PERIOD ANALYSIS OF THE ECLIPSING BINARY U PEGASI

THESIS

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ABSTRACT

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Observations of the W Ursae Majoris type binary U Pegasi were taken over 5 nights in October/November 1995. Numerical techniques were used to generate a period and an epoch of primary minimum. The method and results are compared to previous studies of U Pegasi for verification. The methods used generate results within observational error limits of previous observations. These current computer techniques invite consideration as a new paradigm for standard period determination for eclipsing binary systems.

CHAPTER 1

INTRODUCTION

Photometry is the art and science of measuring the light received from a star and determining the characteristics of the star. Binary stars are important to the development of stellar theory because they provide a direct means to determine the mass ratio of the stars. This supports the size/temperature/luminosity relationship for individual stars. The photometric analysis of eclipsing systems falls into three areas:[1]

a) Given the elements of an eclipsing system, predict the light curve;

b) Given a light curve, derive the orbital elements;

c) Given a set of real, error-prone observations, determine a set of orbital elements, or parameters, which give the best representation of these.

Older methodologies, before electronic computers, attempt to remove any effects, other than those of the mutual eclipse, from the light curve. (Limb darkening of the photosphere is one such example.) The computer, however, allows simultaneous solution of several parameters at once through iterative techniques and there is much current research in the attempt to provide better theories and models for computer simulation.[2]

This paper compares the linear regression technique for determining the ephemeris of eclipsing binaries with computer methods. It is based on 62 new v and b observations of U Pegasi taken by the author in October and November 1995, and the effort to determine the ephemeris and time of primary minimum from those observations.

U PEGASI. S. C. Chandler discovered the variability of U Pegasi in 1894.[3] Although Chandler determined the period at 5^h 31.15^m (roughly ½ the current value) he noted the unique characteristics of the system compared to Algol-type "variables" that define the W Ursae Majoris class of close contact, eclipsing binaries.

Shaply (1915) derived the first orbital elements based on Wendell's (1909) observations. Struve provided the first spectroscopic and radial velocity data in 1950 and classified the star as F3.[4] Binnendijk's 1958 observations have provided the standard epoch for most of the later observations of U Pegasi.[5] Lu reclassified the system as spectral type G2 in 1988.[6] The absolute dimensions of U Pegasi are listed in Table 1. The standard ephemeris (an eclipse minimum and the period, E) is

Hel. J. D. (Min. 1) = 2436511.66856 + 0.37478133E.[7]

The system has also been observed by Yendell (1895), Schilt (1924), Adams, Joy and Sanford (1924), Jordan (1929), Recillas and Woodward (1945), LaFara (1951),[8] Huruhata, Kitamura, and Nakamura (1952, 1957), Kwee (1958), Hinderer (1953) and (1960), Hogg (1964),[9] Saito (1971), Rigterink (1970),[10] Gordon (1975), Patkos (1976)[11] and (1978),[12] Krobusek (1976),[13] Ahnert (1976), Aslan (1977)[14] and (1981), Gülmen (1977),[15] Mallama *et* al (1977), Rovithis (1980),[16] Kreiner (1980), Aslan *et al* (1981), Zhai (1983)[17] and (1984),[18] and Lafta and Granger (1984).[19]

A (separation)	= 2.5325 ± 0.0077 R_{sun}
R_1	= 0.754 ± 0.007 R_{sun}
R_2	= 1.236 ± 0.004 R_{sun}
M_1	= 0.387 ± 0.004 M_{sun}
M_2	= 1.167 ± 0.015 M_{sun}
R_1 (main sequence)	= 0.55 R_{sun}
R_2 (main sequence)	= 1.20 R_{sun}

Table 1: Absolute dimensions of U Pegasi

CHAPTER 2

PHOTOMETRY

Properties of Stars

MAGNITUDE. The magnitude system for measuring stellar brightness goes back to the oldest known systematic efforts to catalog the stars. Claudius Ptolemy's *Megali Syntaxis tis Astronomias* chronicled the magnitudes of Hipparchos' work from 130 BC. which are essentially similar to today's values for the brightest stars. Hipparchos divided the stars into 6 classes called magnitudes. These were arranged ordinally so the brightest stars were called 1st magnitude. Astronomers have retained the historical magnitude system even though it can cause some confusion: if star A appears brighter than star B, we receive more light from A, but A's magnitude is smaller.

In the middle of the 19th century, the physiologist Fechner found the human eye has a logarithmic response to light. A light, f_2, perceived as double the brightness of a light, f_1, is actually 10 times greater in intensity. Pogson, in 1856, related this phenomenon to the magnitude scale and found that a magnitude difference of 5 corresponds to a factor of 100 in transmitted energy flux. Pogson quantified a continuous magnitude scale and set out the standard relation:[20]

$$m_1 - m_2 = -2.5 \log (f_1 / f_2). \tag{2.1}$$

where f_x is the energy flux or energy/unit area/unit time. Or, if star 2 is a reference star of magnitude zero:

$$m_\lambda = q_\lambda - 2.5 \log f_\lambda \tag{2.2}$$

where q is a constant and the subscript λ is a reminder that the magnitude depends on the wavelength of the observation. H. L. Johnson (1965) determined the q_λ values from the directly measured flux of a zero magnitude star as $q_V = -38.52$, $q_U = -38.40$, and $q_B = -37.86$.[21] This m is the apparent, or instrumental, magnitude of a star and is a measure of the star's brightness at a specific telescope and associated devices.

Natural or extra-atmospheric magnitude, m_0, denotes a magnitude corrected for atmospheric extinction:

$$m_0 = m - (k' - k''c)X \tag{2.3}$$

where k′ is the principal coefficient of extinction, k′′ is the second-order extinction coefficient (often small enough to ignore), c is the color index (b – v, see below), and *X* is the air mass. Standard magnitudes, *M*, are derived by comparison to sets of standard stars. The transformation equations for *M* are:

$$M_0 = m_0 + \beta C_0 + \gamma \tag{2.4}$$

$$C_0 = \delta c + \gamma_c . \tag{2.5}$$

C_0 is the standard color index of the star and c_0 is the instrumental color index. β, γ, δ, and γ_c are corrective constants for the telescope system determined from the standard star's values for M_0 and C_0 versus the observed m_0 and c. All of these values are wavelength dependent when determined through broadband filters.

There are also other types of magnitude used in the literature. The absolute magnitude, M, factors out the distance dependence of the brightness and is defined as the apparent brightness of the source at a distance of 10 parsecs:

$$M_0 - \mathrm{M} = 5 \log \mathrm{d} - 5 \qquad (2.6)$$

where d is the distance to the source in parsecs. (M is also used to represent mass and the magnitude usually includes a wavelength subscript to avoid confusion.) The bolometric magnitude, M_{bol}, refers to the total power of the source integrated over all wavelengths. A bolometric correction, BC, is an additive constant (usually a negative magnitude) applied to the apparent magnitude based on the stars spectral type. Alternatively, one can remember the M_{bol} of the sun is 4.75 and apply

$$\mathrm{M_{bol}(star)} - \mathrm{M_{bol}(sun)} = -2.5 \log \mathrm{(L(star)/L(sun))} \qquad (2.7)$$

When wide band filters are used, the wavelength dependent magnitude, M_λ, is often replaced by the filter designation. Examples are u, b, v, *U, B, V*, u_0, b_0, and v_0 instead of $m_{v,b,u}$, $M_{v,b,u}$ and $M_{v0,b0,u0}$ for the instrumental, standard and extra-atmospheric, absolute magnitudes respectively.

LUMINOSITY. Luminosity, L, is the entire radiative output of a star. Stars are very nearly ideal point sources of light and the blackbody approximation is used to determine several characteristics of stars. Applying the Stephen-Boltzman law for blackbody radiation over the surface of a star yields:

$$L = 4\pi R^2 \sigma T^4 = \text{Energy (total) /second.} \qquad (2.8)$$

While Planck's law describes the intensity of light at a given wavelength:

$$I_\lambda = \frac{2hc^2}{\lambda^5\left(e^{hc/\lambda kT} - 1\right)} \qquad (2.9)$$

The mass-luminosity relationship is simple: bigger (more massive) stars are brighter. A plot of Log $(L/L_\odot)$ vs Log $(M/M_\odot)$ is linear with minor deviations for extremely large and small masses. (The subscript $\odot$ designates solar values for L and M.) Therefore, different bodies with the same temperature can have vastly different total luminosities because of their size.

Luminosity Class	Type
I	Supergiants
II	Bright giants
III	Giants
IV	Subgiants
V	Dwarfs (Main Sequence)
VI	Subdwarfs

Table 2: Luminosity Classes

The Yerkes system, developed by Morgan and Keenan (MK), adds luminosity class to the spectral type to provide additional discrimination of stars based on size. The luminosity classes are given in Table 2.

COLOR INDEX: Using the intensity equation 2.9 above, one can derive Wien's displacement law:

$$\lambda_{max}\, T = 2.9 \times 10^7 \text{ Å K} \qquad (2.10)$$

which relates a specific color to a given temperature. If stars were to radiate like blackbodies, we could determine their temperatures by determining λ_{max}. The difficulty of comparing stars to ideal blackbodies makes it much more intrinsically accurate to compare stars with stars. The color indices, B – V and U – B, quantify the difference in intensity between three wavelength regions, $\Delta\lambda_{V,B,U}$ (see wide band photometry below), and are used in lieu of λ_{max} to define the color of a star. Hotter stars are more blue and B – V is more negative. (This follows with the convention for magnitude above.)

TEMPERATURE. The temperature of a star, T, usually refers to the effective temperature. The effective temperature is the equivalent temperature of a blackbody which produces the same energy flux, F ≡ energy/second/cm^2, as the star. F is derived from the Stephen-Boltzmann law:

$$F = \sigma T_{eff}^4 . \qquad (2.11)$$

As a function of wavelength,

$$F_\lambda = \frac{2\pi hc^2}{\lambda^5\left[\exp\left(hc/_{k\lambda T}\right)-1\right]} \tag{2.11a}$$

where *h, c,* and *k* are Planck's constant, the speed of light, and Boltzmann's constant respectively. Astronomers can determine F directly if they can measure the stellar radius, R, through interferometry or occultation and the distance, d, through parallax or other means. Then

$$F = f\frac{d^2}{R^2} \tag{2.12}$$

where f is the flux measured above the earth's atmosphere. Otherwise, it is derived from eq. 2.2 with the wavelength dependency:

$$m_{\lambda 0} = q_\lambda - 2.5 \log F_\lambda \tag{2.2}$$

thus:

$$F_\lambda = 10^{-0.4(m_{\lambda 0} - q_\lambda)} \tag{2.13}$$

The measured flux is a function of the fractional transmission of the interstellar medium (usually ignored), the Earth's atmosphere, the telescope, the filter and the efficiency of the detector with respect to wavelength. The complications of the integral equation make accurate stellar fluxes difficult to measure. However, because the magnitude system is defined by the received flux from certain stars, other stars' magnitudes and thus fluxes can be comparatively determined with corrections only for atmospheric extinction.

SPECTRAL TYPE. Spectral classification is based primarily on the Fraunhofer lines and line strengths seen in the stellar spectrum. The original Harvard system organized the spectra alphabetically from A-S based only on the strength of the Hydrogen lines. Later, the sequence was adjusted and reordered to align with decreasing temperature, so the sequence is now O, B, A, F, G, K, M, N, S. (Hottest to coolest.) Each spectral type is also divided into subclasses such as A0, A1, ...A9, F0, to provide finer distinction among the spectra. For example, a B0 type star has (among others) a H_I line at λ4340 that is 3.5 Å wide, a He_I line at λ4471 1.0 Å wide, and has N_{III}, O_{II}, Si_{III}, and Si_{IV} lines in the region λ3500-4800. Whereas a B8 type star has (among others) a H_I line at λ4340 that is 10 Å wide, a He_I line at λ4471 0.3 Å wide, and has Mg_{II} and Si_{II} lines in the region λ3500-4800.[22]

SUMMARY: The properties of stars listed above are strongly interrelated. For stars on the main sequence (Class V), the B – V color index can define the star's effective temperature, luminosity, mass, radius, and it's absolute magnitude.[23] General relationships are listed below.

Stefan-Boltzman Law: $L = 4\pi R^2 \sigma T^4 = 7.1258 \times 10^{-4} R^2 T^4$ erg/s (2.8)

Magnitude/Luminosity: $\log(L_1/L_2) = 0.4\,(M_1 - M_2)$ (2.14)

$\log(F_1/F_2) = 0.4\,(m_1 - m_2)$ (2.15)

Mass/Luminosity $\log(M/M_\odot) = 0.48 - 0.10\,M_{bol} \quad -8 < M_{bol} < 10.5$ (2.16)

$\log(L/L_\odot) = 3.8 \log(M/M_\odot) + 0.08 \quad M > 0.2\,M_\odot$ (2.17)

Mass/Radius $\log(R/R_\odot) = 0.640 \log(M/M_\odot) + 0.011$ (2.18)

for $0.12 < \log(M/M_\odot) < 1.3$; for $-1.0 < \log(M/M_\odot) < 0.12$

$\log(R/R_\odot) = 0.917 \log(M/M_\odot) - 0.020$ (2.19)

Radius/Luminosity $\log(R/R_\odot) = -0.2M_V - 2F_V + 8.451$ (2.20)

$$\log (R/R_{\odot}) = -0.2M_{bol} - 2\log(T_{eff}) + 8.451 \qquad (2.21)$$

with $F_V = \log T_{eff} + 0.1BC$.

Table 3 summarizes some of the properties of main sequence stars by spectral class. Mass and radius relations are given when direct data is available. Similar relationships for the other classes are only slightly more complicated. Table 4 presents a small sample comparing values between Class I (Supergiants), III (Giants), and V (Main Sequence).

Sp	T_{eff} (°K)	CI_o (mag)	M_V (mag)	BC (mag)	M_{bol} (mag)	L ($L_\odot$)	M ($M_\odot$)	R ($R_\odot$)
		$(U-B)_o$						
O3	52500	– 1.22	– 6.0	– 4.75	– 10.7	1.4×10^6	120	15
4	48000	–1.20	–5.9	–4.45	–10.3	9.9×10^5		
5	44500	–1.19	–5.7	–4.40	–10.1	7.9×10^5	60	12
6	41000	–1.17	–5.5	–3.93	–9.4	4.2×10^5	37	10
7	38000	–1.15	–5.2	–3.68	–8.9	2.6×10^5		
8	35800	–1.14	–4.9	–3.54	–8.4	1.7×10^5	23	8.5
9	33000	–1.12	–4.5	–3.33	–7.8	9.7×10^4		
B0	30000	–1.08	–4.0	–3.16	–7.1	5.2×10^4	17.5	7.4
1	25400	–0.95	–3.2	–2.70	–5.9	1.6×10^4		
2	22000	–0.84	–2.4	–2.35	–4.7	5.7×10^3		
3	18700	–0.71	–1.6	–1.94	–3.5	1.9×10^3	7.6	4.8
B5	15400	–0.58	–1.2	–1.46	–2.7	8.3×10^2	5.9	3.9
6	14000	–0.50	–0.9	–1.21	–2.1	500		
7	13000	–0.43	–0.6	–1.02	–1.6	320		
8	11900	–0.34	–0.2	–0.80	–1.0	180	3.8	3.0
9	10500	–0.20	0.2	–0.51	–0.3	95		
		$(B-V)_0$						
A0	9520	–0.02	0.6	–0.30	0.3	54	2.9	2.4
1	9230	0.01	1.0	–0.23	0.8	35		
3	8720	0.08	1.5	–0.17	1.3	21		
5	8200	0.15	1.9	–0.15	1.7	14	2.0	1.7

Table 3: Some Properties of Class V (Main Sequence) Stars[24]

Sp	T_{eff} (°K)	CI_o (mag)	M_V (mag)	BC (mag)	M_{bol} (mag)	L ($L_\odot$)	M ($M_\odot$)	R ($R_\odot$)
F0	7200	0.30	2.7	–0.09	2.6	6.5	1.6	1.5
2	6890	0.35	3.6	–0.11	3.5	2.9		
5	6440	0.44	3.5	–0.14	3.4	3.2	1.3	1.3
8	6200	0.52	4.0	–0.16	3.8	2.1		
G0	6030	0.58	4.4	–0.18	4.2	1.5	1.05	1.1
2	5860	0.63	4.7	–0.20	4.5	1.1		
5	5770	0.68	5.1	–0.21	4.9	0.79	.92	.92
8	5570	0.74	5.5	–0.40	5.1	0.66		
K0	5250	0.81	5.9	–0.31	5.6	0.42	.79	.85
1	5080	0.86	6.1	–0.37	5.7	0.37		
2	4900	0.91	6.4	–0.42	6.0	0.29		
3	4730	0.96	6.6	–0.50	6.1	0.26		
4	4590	1.05	7.0	–0.55	6.4	0.19		
5	4350	1.15	7.4	–0.72	6.7	0.15	.67	.72
7	4060	1.33	8.1	–1.01	7.1	0.10		
		$(R–I)_0$						
M0	3850	0.92	8.8	–1.38	7.4	7.7 x10^{-2}	.51	.60
1	3720	1.03	9.3	–1.62	7.7	6.1 x10^{-2}		
2	3580	1.17	9.9	–1.89	8.0	4.5 x10^{-2}		
3	3470	1.30	10.4	–2.15	8.2	3.6 x10^{-2}		
4	3370	1.43	11.3	–2.38	8.9	1.9 x10^{-2}		
5	3240	1.61	12.3	–2.73	9.6	1.1 x10^{-2}	.21	.27
6	3050	1.93	13.5	–3.21	10.3	5.3 x10^{-3}		
7	2940	2.1	14.3	–3.46	10.8	3.4 x10^{-3}		
8	2640	2.4	16.0	–4.1	11.9	1.2 x10^{-3}		

Table 3: (Cont.)

Sp	T_{eff} (°K)	CI_o (mag)	M_V (mag)	BC (mag)	M_{bol} (mag)	L ($L_\odot$)	M ($M_\odot$)	R ($R_\odot$)
		$(U-B)_o$						
B0 (V)	30000	–1.08	–4.0	–3.16	–7.1	5.2 x10^4	17.5	7.4
B0 (III)	29000	–1.08	–5.1	–2.88	–8.0	1.1 x10^5	20	15
B0 (I)	26000	–1.06	–6.4	–2.49	–8.9	2.6 x10^5	25	30
		$(B–V)_0$						
G0 (V)	6030	0.58	4.4	–0.18	4.2	1.5	1.05	1.1
G0 (III)	5850	0.65	1.0	–0.20	0.8	34	1	6
G0 (I)	5550	0.76	–6.4	–0.15	–6.6	3.0 x10^4	10	120
		$(R–I)_0$						
M0 (V)	3850	0.92	8.8	–1.38	7.4	7.7 x10^{-2}	.51	.60
M0(III)	3800	0.90	–0.4	–1.25	–1.6	330	1.2	40
M0 (I)	3650	0.96	–5.6	–1.29	–6.9	4.1 x10^4	13	500

Table 4: Comparison of Class V, III, I Properties

Optical Photometry

Photometry is the continuation of ancient, human eye observations replaced by a more accurate and sensitive detector element. These observations determine the brightness of a star and are centered around a transparent atmospheric "window" for electromagnetic radiation from about 4000 Å to 6500 Å (violet to red.) This includes the maximum output at 5000 Å of our Sun. Recent detectors have extended this to the 3000 Å to 10,000Å range (ultraviolet to infrared.) Astronomers also use wide and narrow band filters to measure the brightness of a star at a specific wavelength range.[25]

In the late 19th century, photographic plates were used to create a more independent (from eyesight variations) system for magnitude determination. For a variety of reasons, photographic determination of standard magnitudes and colors was problematic and each astronomer tended to use his own system. Photography did allow astronomers to view fainter stars and despite the difficulties, achieve greater consistency between observations.

The electromagnetic nature of light and the quantization of energy derived from the photoelectric effect both advanced methods for receiving and analyzing the light received from stars. The first photoelectric photometer, a selenium cell device, developed by Minchin in 1892, allowed Stebbins to establish the existence of the secondary minimum of Algol for the first time in 1910. Technical difficulties with photometers prevented their wide–spread use until Radio Corporation of America introduced the photomultiplier in the late 1940s. The photomutiplier is a series of alkaline photocathodes which amplify the output signal generated by each incoming photon. This allowed Johnson and Morgan to set up the now standard UBV photoelectric system based on accurate, empirical measurements of standard stars.[26]

The Charge Coupled Device (CCD) developed at Bell Laboratories in 1970 has again provided a more efficient detector with a larger response range over all previous detectors. Figure 1 shows a comparison of the 4 general detector types' efficiency versus wavelength, frequency, and energy. The high quantum efficiency and ability to record the program star, sky background and the comparison star at the same time make the CCD a nearly perfect detector. Its disadvantage lies in surface nonuniformity which requires dark mapping of the CCD.

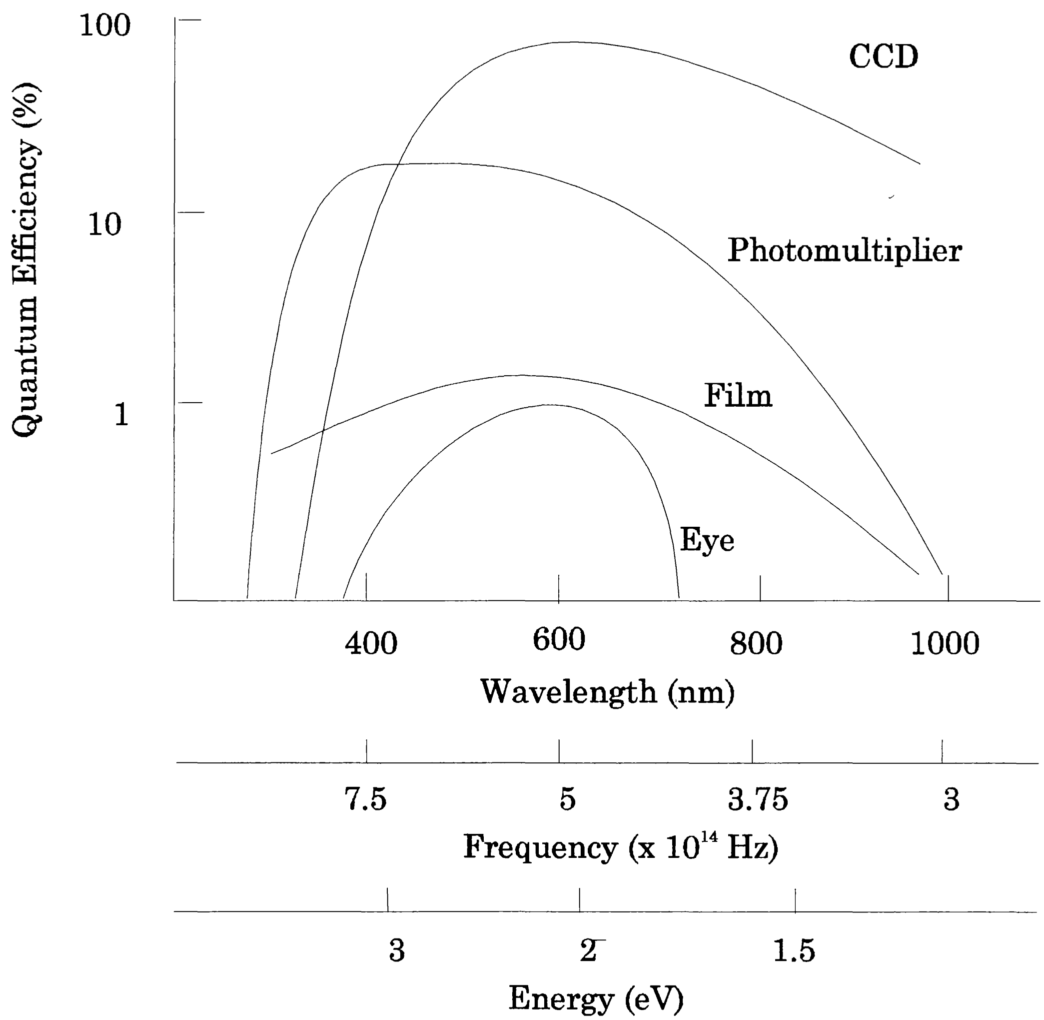


Figure 1: Efficiency of Various Detectors[27]

Wide Band Photometry

Johnson and Morgan developed the UBV photometric system (mentioned earlier) to better discriminate between stellar attributes and tie them to the Morgan–Keenan (MK) spectral classifications. This system uses wide band filters to limit the transmission of light to the approximate wavelength regions shown in figure 2. The filters are thin pieces (~ 2mm) of colored glass with the desired transmission properties made primarily by Corning glassworks or Schott Optical Glass. The filters add clear glass to obtain a uniform thickness in order to avoid changing the telescope focus with each filter.

The V filter is yellow (peak transmission ~ 5500Å) and is designed to match the photovisual magnitudes of the International System. The B (Blue)

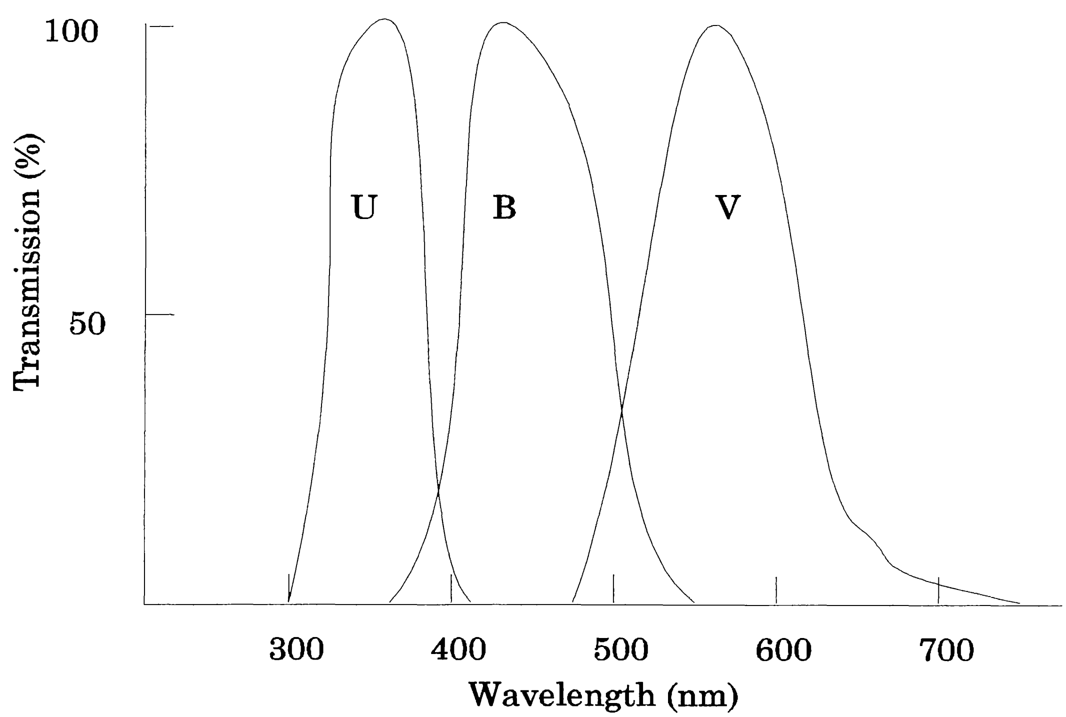


Figure 2: Filter transmission bands for the standard UBV system

filter is centered around 4300Å and includes an ultraviolet blocking filter to prevent any effects of the Balmer discontinuity. (Photons with wavelength less than 3647 Å ionize some of the hydrogen atoms in stars with temperatures less than ~12,000 ° K; absorbing some of the light.) However, stars later than type A0 have increasing metal absorption lines in the range λ4000-4500Å. This effect is called "line blanketing" and prevents the measurement of the total light emitted in the B region. The U filter is centered around 3500Å but has two significant problems. First, the filter transmits some light in the red/near infrared known as "red leak". Second, the earth's atmosphere is not transparent at the shorter wavelengths of the filter, and measurements are greatly affected by the altitude of the observatory and atmospheric conditions.[28]

The color indices derived from wide band measurements, (B–V) and (U–B), are directly related to the temperature and MK spectral type. Plotting B–V against M_V generates the sequence of the well-known Hertzsprung–Russell (H-R) diagram. (See figure 3.)

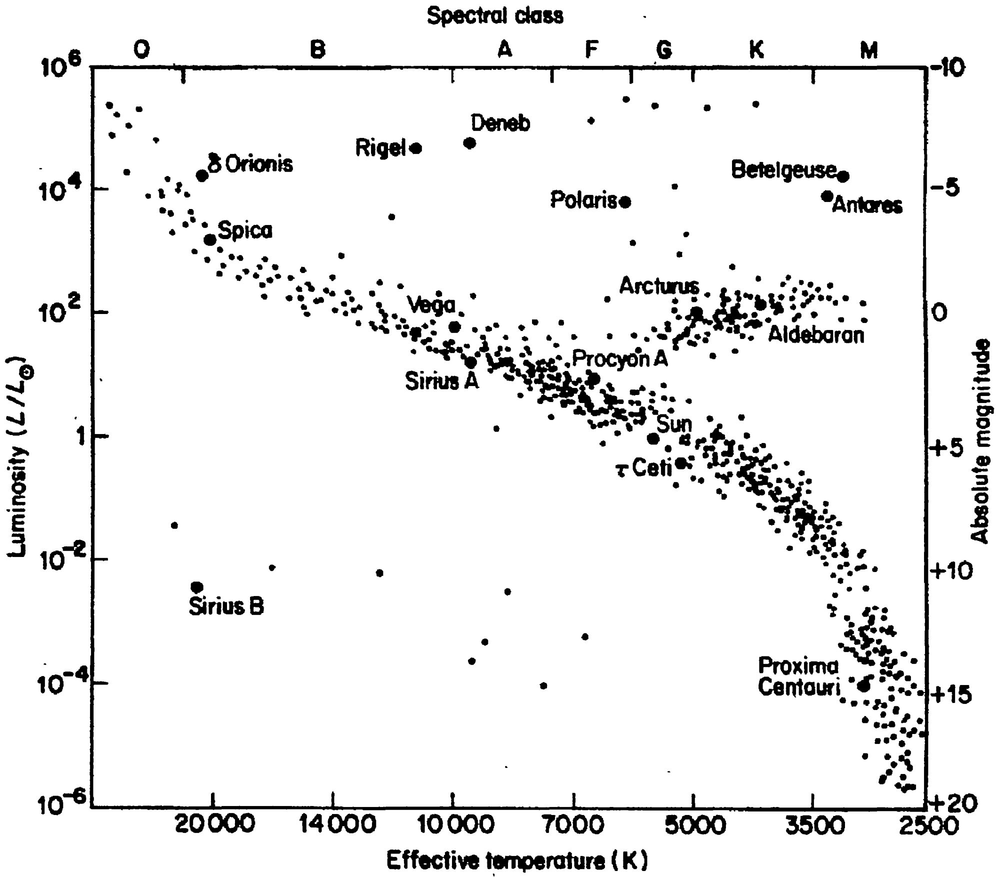


Figure 3: H-R diagram of Absolute Magnitude vs Color Index[29]

Six spectral class A0 stars define the zero points of the UBV system. The stars are α Lyr, γ UMa, 109 Vir, α CrB, γ Oph, and HR 3314; and their average color index is defined to be zero.[30] In order to facilitate UBV calibration at any observatory, there are more extensive lists of secondary standards including lists within three different open clusters. The clusters are especially valuable calibration lists because the problems with interstellar extinction are minimal.[31]

The UBV photometric system has been extended into longer wavelengths to aid in the classification of cool stars. The UBVRI system uses an S-20 photomultiplier, photodiode, or CCD to measure the flux in the red and infrared.

The Strömgren ubvy (v for violet, y for yellow) system is an intermediate-band width system which overcomes several shortcomings of the UBV system and provides astrohphysically important information.[32] The y filter is centered at 5500Å like the V filter in UBV but it is only 200Å wide. The width eliminates strong spectral effects from early type stars and the red cutoff is filter dependent not detector limited. The b filter is offset from B to 4700Å to eliminate the effects of line blanketing while the v filter is centered at 4100Å directly in the region of line blanketing yet away from the Balmer discontinuity. Finally, the u filter is positioned at 3500Å and is 400Å wide. This avoids the atmospheric limit at 3000Å and the Balmer discontinuity.

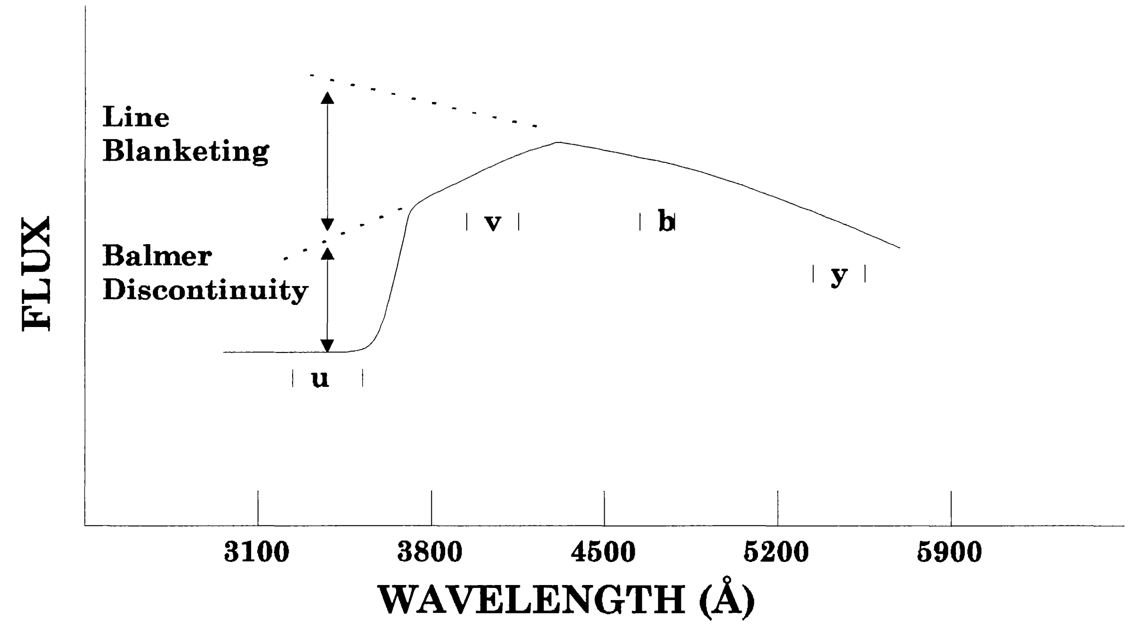


Figure 4: Placement of the Strömgren Filters[33]

Although the UBV system has some drawbacks compared to the Strömgren system, its use has been so widespread for so long that more than twice as many stars have been measured in UBV than in all other systems combined and it is still considered the primary photometric system.

Narrow Band Photometry

Narrow band photometry involves a comparison between the flux measured in a narrow region centered on a spectral line and the surrounding continuum. A common example is H_β or β photometry of the Hydrogen line at 4861Å. The narrow filter typically has a halfwidth of 20-30Å while the wide filter is ~ 150Å. The index is then given by:

$$\beta = -2.5\log\left(f_n / f_w\right) \qquad (2.22)$$

since the two filters have the same effective wavelength and because of the differential nature of the index, β is independent of the effects of both atmospheric and interstellar extinction. For early type stars (< A_0) β has a strong correlation to absolute magnitude. Also, since it is an inherently "reddening free" parameter, β is often used in the Strömgren system to estimate color excesses produced by interstellar absorption. Other lines often selected for narrow band study are CH at 4300Å, CaI at 4227Å and CN at 4200Å.

CHAPTER 3

CLOSE BINARY SYSTEMS

Geometry and Dynamics

ELLIPTICAL ORBITS: Binary systems are composed of two stars orbiting each other about a common center of gravity. The orbit is generally an ellipse and for simplification, the primary (more massive) star is centered at one focus of the ellipse, and the secondary star is considered to orbit the primary. Six parameters define an elliptical orbit. (See Fig. 5) These are:

$a \equiv$ the semi-major axis of the ellipse

$e \equiv$ the eccentricity of the ellipse

$i \equiv$ the inclination of the orbit measured down from the plane of the sky towards the observer

$\Omega \equiv$ the longitude (from the observer) to the ascending node

$\omega \equiv$ the argument of periastron (the angle from the ascending node to the periastron point) and

$T \equiv$ the epoch at which the body is at periastron.

A seventh parameter, $\nu \equiv$ the true anomaly, defines the position of the secondary star with respect to the periastron point at an arbitrary epoch.[34]

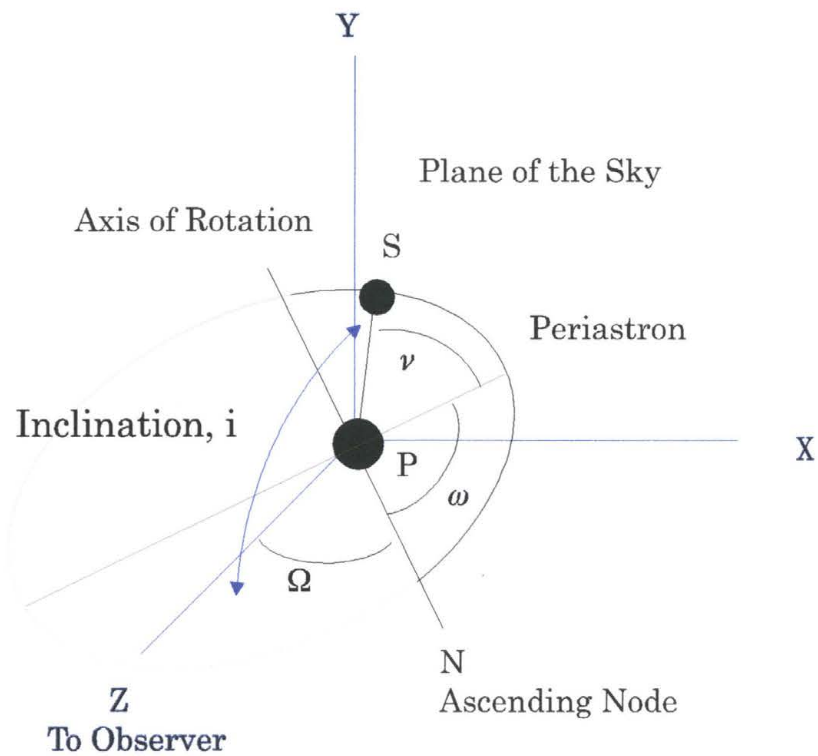


Figure 5: Elliptical Orbit Parameters[35]

DYNAMICS: The system is first defined in a coordinate system with the origin at the center of mass. Then the positions, velocities and masses are related by

$$\frac{r_p}{r_s} = \frac{v_p}{v_s} = \frac{m_s}{m_p}. \quad (3.1)$$

The distance between the two stars is then

$$\vec{r} = \vec{r}_p - \vec{r}_s = (1 + \frac{m_p}{m_s})\vec{r}_p. \quad (3.2)$$

Geometrically, $\vec{r} = \dfrac{a(1-e^2)}{1+e\cos\nu}$. The equation of motion for the system in polar coordinates from the center of mass is

$$\ddot{\vec{r}} = -\frac{GM}{r^2}\hat{r} \quad (3.3)$$

where $M = (m_P + m_S)$

and G is Newton's gravitational constant. This is equivalent to the orbit of a mass $\mu \equiv \frac{m_p m_s}{m_p + m_s}$ about a fixed mass *M*, which simplifies the application of Newton's laws and Kepler's equations and allows the standard notation given in the preceding paragraph.[36] Substituting for the individual orbits, equation 3.3 can be rewritten (for the primary) as

$$\ddot{\vec{r}}_p = -\frac{GM}{\left(1 + {m_p}/{m_s}\right)^2} \frac{\hat{r}_p}{r_p^2} \tag{3.4}$$

The other important relationships (per unit mass) of the system are:

Angular momentum $$l = r^2\dot{\theta} \tag{3.5}$$

Total Energy $$E = \frac{l^2}{2r_{min}^2} - \frac{MG}{r_{min}} = -\frac{MG}{2a} = \frac{v^2}{2} - \frac{MG}{r} \tag{3.6}$$

Orbital Speed $$v^2 = MG\left(\frac{2}{r} - \frac{1}{a}\right) = \left(\dot{r}^2 + r^2\dot{\phi}^2\right) \tag{3.7}$$

$$v_p = r_p\omega \ , \qquad v_s = r_s\omega \ , \text{ and } \quad \omega = \frac{d\theta}{dt}$$

and Period $$P = \frac{2\pi a^{3/2}}{\sqrt{MG}} . \tag{3.8}$$ [37]

The energy of the system per unit mass is also equal to

$$E = \left(e^2 - 1\right)\frac{M^2G^2}{2l^2} \tag{3.9}$$

and the angular momentum is related to the area swept out by the orbit by

Kepler's 2nd law as

$$\frac{dS}{dt}=\frac{1}{2}r^2\omega=\frac{1}{2}l\,. \qquad (3.10)$$

VISUAL BINARIES: When two stars are resolved separately in the telescope and can be seen to orbit each other over time, they are called visual binaries. For visual binaries, one measures the angular separation and position angle as a function of time. The data can be plotted to give the apparent orbit which is the actual orbit projected on the plane of the sky. If the distance to the stars is also known, then the angular separation can be converted to an actual distance.

The sum of the masses can be determined from the relative orbit of the binary. This is done by placing the primary star at one focus of the ellipse and calculating the orbital inclination. To find the ratio of the masses it is necessary to observe the binary astrometrically, i.e. measure the absolute positions against the background stars. With these measurements, the center of mass is determined and the absolute orbit.[38]

SPECTROSCOPIC BINARIES: Unresolved double stars may still show their binary nature under spectrographic analysis. The spectrum of a binary system will exhibit periodic line doubling due to Doppler shift of the various spectral lines as the stars alternately move towards and away from the observer. The spectral shift shows opposite signs because one star is moving away when the other moves towards the observer. The two lines coincide when the stars are in line of sight to the observer and any Doppler shift away from the laboratory values is due to the motion of the center of mass of the system.

Measuring the Doppler shifts as a function of time yields the line-of – sight velocity. The variations are sine curves and the amplitude of the radial velocity curve is related to the radius of the orbit. For a circular orbit the relationship is $v_j = \omega r_j \sin i$ where the subscript $j = p,s$ (primary, secondary) and the radius r_j is relative to the center of mass. (The eccentricity for elliptical orbits can be determined by the distortion generated in the radial velocity curves.) When the orbital velocity of both stars is measured, then from equation 3.1 one can determine the ratio of the masses since the sin *i* term cancels. Because there is no way to determine the inclination, we cannot find the sum of the masses. One can only determine a lower limit to the sum by noting

$$v_p + v_s = \omega(r_p + r_s)\sin i = 2\pi r \sin i / P \qquad (3.11)$$

and using (3.8) to find

$$(m_p + m_s)\sin^3 i = \frac{P(v_p + v_s)^3}{2\pi G} \qquad (3.12)$$ [39]

ECLIPSING BINARIES: Binary systems whose inclination approaches 90° will eclipse each other once their radii overlap. (see figure 6.)

$$r \cos i < r_g + r_s \qquad (3.13)$$

A large distance between the center of masses, D, also increases the period and makes observing the eclipse unlikely. Thus most eclipsing binary systems are in relatively close orbits, usually less than ten times the radius of a component star.

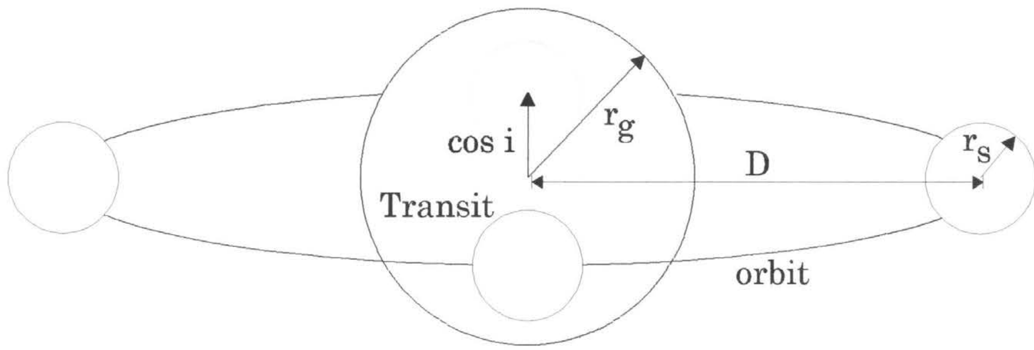


Figure 6: Idealized Eclipsing Binary System

Measuring the flux from the eclipsing binary produces a characteristic light curve shown in figure 7. The various points on the light curve yield the information required to determine the characteristics of the orbit and the stars. For stars with approximately the same brightness, two minima will occur with the deeper minimum corresponding to the eclipse of the hotter star. With stars of different radii, there is a period of totality demonstrated by the flat minima and it is proportional to the difference in radii. For circular motion, the relationship is

$$t_{tot} = \frac{2(R_p - R_s)}{(v_p - v_s)} = \frac{(R_p - R_s)P}{\pi r} \qquad (3.14)$$

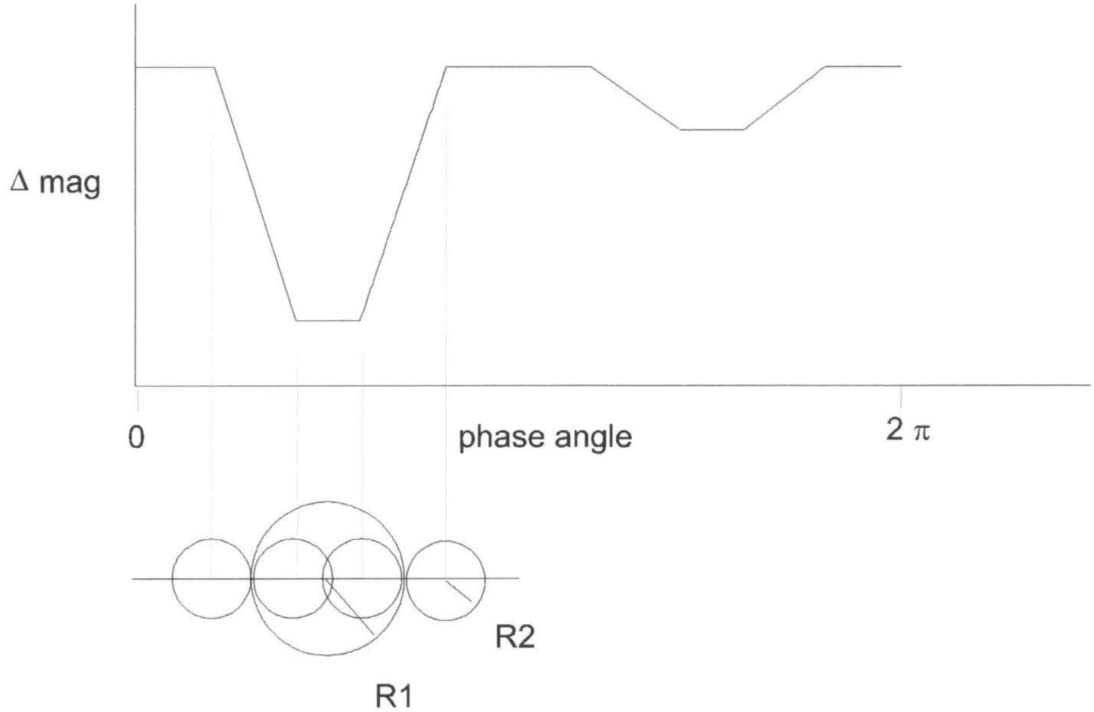


Figure 7: Idealized Light Curve for an Eclipsing Binary with 90° Inclination[40]

and the time from first contact at maximum to eclipse at minimum is

$$t_{drop} = \frac{R_s P}{\pi r}. \tag{3.15}$$

If we also have spectrographically determined the radial velocities, then we can independently determine the separations using equation 3.3

$$v_p = \frac{2\pi r_p}{P} \qquad v_s = \frac{2\pi r_s}{P} \qquad r = r_p + r_s.$$

More realistic, inclined elliptical geometries can be determined by examining the eclipse timings and curvatures of the drop lines.

After evaluating the above relationships, the equations of motion for the system allow us to directly calculate the masses in a binary system. The eclipse allows an evaluation of the relative luminosities; and, when the observed quantities are compared to the Mass/Luminosity relationships, they provide confirmation of the theory.[41]

CLOSE BINARY SYSTEMS: There are three types of close binary systems: detached, semi-detached, and contact systems. The type is determined by whether neither, one, or both stars fill their Roche lobes. As mentioned before, eclipsing binaries are necessarily in fairly close orbits. When the gravitational field around and between the two stars is mapped, it generates equipotential surfaces like those shown in figure 8. The idea is

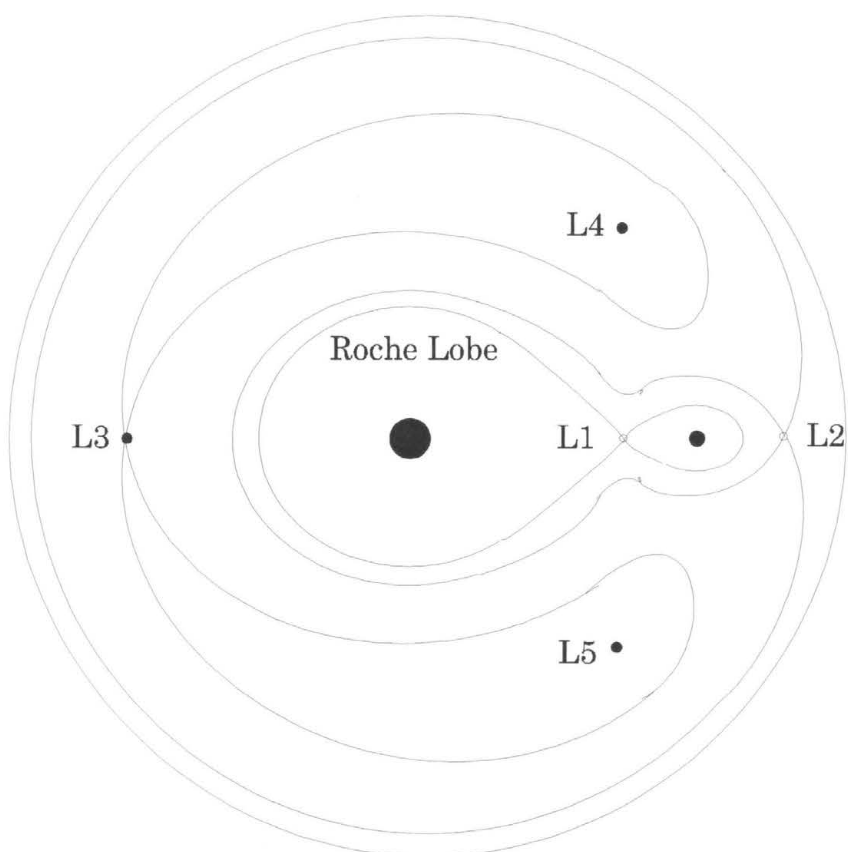


Figure 8: Key Equipotentials and LaGrange Points in the Equatorial Plane of an Idealized Binary Star

common to classical mechanics and the point labeled L1 is called the inner LaGrange point after the French mathematician who developed the idea. The equipotential surface of zero potential is called the Roche surface.

Detached systems occur when the material of both stars is contained within its tear-drop shaped Roche lobe. These systems are classified as EA systems after the Algol system. If the distortion of its photosphere due to gravity and stellar evolution causes the material of one star to fill its Roche lobe, then system is called semi-detached. Some of the stellar material may actually cross the boundary between the stars and "fall" into the other star creating streaming effects and mass transfer. Also, the detached star heats the distorted surface unevenly. This creates a constantly varying light curve, usually with minima of unequal depth and is classified as EB. Beta Lyrae is an example of a semi-detached system with an EB light curve.

In contact systems both stars fill their Roche lobes and there is a common exchange of matter which is not uniquely attached to either star called the convective envelope. The stars are nearly equal in mass and luminosity and show nearly equal minima. Because of the extreme distortion and equal size, these systems also vary continuously. W Ursae Majoris is the prototypical example of this EW type light curve.

W Ursae Majoris Type

Previously, we noted that W Ursae Majoris (W UMa) systems are contact systems with proximity effects that cause the eclipse minima to merge together. Strictly speaking, these are a class of light curve. To study systems of the type W UMa we confine ourselves to systems with periods of less than one day and spectral types of F, G, or K. These systems are of special interest for several reasons. Their spatial density is perhaps the highest of any type of binary and the spectral class of the stars tend to be similar. Also, the continuous curvature indicates large interaction effects. Even though the stars are usually main sequence and similar in size and spectral class the primaries are slightly underluminous and the secondaries are slightly overluminous for their respective masses in terms of the standard mass luminosity relationship. The typical mass ratio is about 2:1 and combined masses are generally 0.8 $M_{\odot}$ to 2.8 $M_{\odot}$. There is also a trend for redder (older) systems to have shorter periods.

Light Curve Modeling

BASIC SOLUTION OF A LIGHT CURVE:

Astronomers have spent much of their time generating better ways to solve the third area of photometric analysis mentioned in the introduction; *Given a set of real, error-prone observations, determine a set of orbital* *elements, or parameters, which give the best representation of these.* The results are new theories and computational methods to account for the variations identified in the reduced light curves. Some of these effects are discussed in the following paragraphs.

GRAVITY DARKENING: An interesting development from the theory of stellar atmospheres is Von Zeipel's theorem. When a star rotates, the equations of state for the radiative pressure, flux, and temperature experience an additional force due to the centrifugal potential. The result is an increase in temperature and flux at the poles compared to the equator.[42]

For extremely distorted stars, the effect is even more pronounced. In practice, the gravity darkening terms for close binary systems depend upon the distortions generated by the two stars. Budding lists the gravity coefficient as

$$\tau_{p,s} = \frac{c_2}{4\lambda T_{p,s}\left[1-\exp\left(-c_2 / \lambda T_{p,s}\right)\right]} . \qquad (3.16)^{43}$$

M. Kitamura and Y. Nakamura studied several W. Ursae Majoris systems in order to evaluate better coefficients for the gravity darkening. They found that the gravity darkening coefficients are relatively independent of reflection effects.[44] They determined a visual wavelength coefficient for U Pegasi as 0.75 if the Roche lobe is assumed to be half filled in. The value of the coefficient is then used back in the expanded equations for the light curve to determine other values of the system more precisely.

LIMB DARKENING: Limb darkening is an effect introduced to account for the variation in intensity of light that is released normal to the surface of the star yet observed at an angle θ to the observer. Light Curve modeling uses analytical approximations of the intensity in order to filter out deviations due to the real 3-dimensional surface of the star. The obvious choice to use is a linear function of $\mu = \cos\theta$ normalized to the specific intensity at the star's center. The linear limb darkening law is then:

$$D_\lambda(\mu) = \frac{I_\lambda(\mu)}{I_\lambda(1)} = 1 - x_\lambda(1-\mu) \qquad (3.17)^{45}$$

in which x_λ is called the linear limb-darkening coefficient. These coefficients are based on stellar atmosphere models. Several studies have proposed other limb darkening laws which are non-linear. These are usually quadratic in both x and y.

The limb darkening coefficients are calculated from the atmospheric model for the various stellar types. Later computational methods impose the restriction of conserved stellar flux such that:

$$F_\lambda = \int_0^1 D_\lambda(\mu)\mu d\mu . \qquad (3.18)^{46}$$

Here the flux on the left is observed, while the function on the right is calculated from the atmospheric model. Van Hamme proposed in 1993 the use of a logarithmic law for stars below 8500 K:

$$D_\lambda(\mu) = 1 - x_\lambda(1-\mu) - y_\lambda \mu \ln \mu \qquad (3.19)$$

and a square root law for stars greater than 8500 K:

$$D_\lambda(\mu) = 1 - x_\lambda(1-\mu) - y_\lambda\left(1-\sqrt{\mu}\right) \qquad (3.20)$$ [47]

REFLECTION: Two stars in a close binary orbit illuminate each other. The incident flux from the companion causes a local increase in temperature on the photosphere of the primary and vice-versa. The bolometric emission of the stars is increased due to the increase in temperature. The new temperature is equal to the sum of the original temperature plus a fraction of the received flux. The amount of increase is related to the distance between the stars, the albedo (reflectivity) of the photosphere, the orbital position, and the limb darkening factors associated with a normal line of sight to the companion.

Obviously, the process is iterative through multiple reflections. When the primary heats the companion, the companion generates more flux towards the primary, which is again heated to generate more flux towards the companion. R. E. Wilson presents a good iterative model to eliminate the refection effect from binary light curves in his article "Accuracy and Efficiency in the Binary Star Reflection Effect".[48]

It is important to note that W Ursae Majoris systems have relatively small reflection coefficients due to the common connective envelope. The envelope partially blocks direct line of sight between the surface regions and the albedo is less than half that of normal radiative photospheres.

CHAPTER 4

PHOTOMETRIC REDUCTION

Instrumentation and Observations

The author used the 24" Schmidt-Cassegrain telescope built by Boller and Chevins at the United States Air Force Academy Observatory. It uses a homebuilt UBV photometer based on the Lowell Observatory design using a 1P21 photomultiplier. The color filters are Johnson UBV standard. The Observatory coordinates are 39° 00.39' N Latitude and 104° 52.89' W Longitude at an elevation of 7160 feet. The motorized mount has automatic diurnal motion compensation and a handheld control for telescope and dome positioning. A DOS based telescope control computer maintains local sidereal time based on a standard, civil time, internal clock and automatically positions the telescope and tracks the dome to designated coordinates. A second Windows based computer runs *The Sky* planetarium software and transfers selected coordinates from the sky maps to the telescope control system (TCS). The TCS program provides continuous readout of the telescope Right Ascension (RA), Declination (DEC), and

Universal Time (UT) and calculated local sidereal time (LST), hour angle (HA), and airmass (X).

The photometer attaches to the base of the telescope and includes a flip mirror to a 10mm eyepiece for correct centering of the star. Diaphragm aperture was selected at .062" or 1.575mm. The photometer electronics are contained in a frame stack near the TCS monitors. The photon count sequence has an automatic timer and a manual start button. Photon counts for the observing sequence were 10 seconds duration. The author was unable to obtain dry ice for the cooling jacket and subsequent "dark" counts of the photometer were consistently on the order of 100 counts per 10 second interval.

Pertinent data for the program star, U Pegasi (U Peg), Comparison (Comp) and Check Stars are listed in Table 5. Observations were taken on 27, 28 and 29 October 1995 and 23, 24, and 26 November 1995.

Star	SAO #	J2000 RA	J2000 DEC	Motion in RA s/yr	Motion in DEC arcsec/yr
U Peg	108933	23h 57m 58.4s	N15° 57' 08"	– 0.0025	– 0.062
Comp	108930	23h 57m 45.6s	N15° 28' 22"	+ 0.0018	– 0.036
Check	108949	23h 59m 50.7s	N15° 46' 59"	+ 0.0003	– 0.005

Table 5: Astrometric Data for Program Observations

The standard observing run began with a power up checklist for the dome, TCS and then the telescope. With both computers running, the telescope was checked at Zenith position with a level against local HA and Latitude. Then the TCS was initialized by centering a bright guide star in the eyepiece and transferring coordinates from *The Sky* program to the TCS. Initial time was set to the US Naval Observatory on both the TCS (manual input) and a wristwatch. The telescope was then centered on the program star, and the coordinates entered into the TCS for autoslaving. The Comparison and Check stars were also entered into the TCS. The autoslave feature of the TCS allows the observer to reposition the telescope to the preset coordinates with two keystrokes.

Once the TCS repositioned the telescope, the author would manually verify the target star (either U Peg, Comp, or Check) and center the star in the aperture. Then the V filter was selected. Back at the console, the author would start the photon count on a second and note the start time of the count. At the end of the 10 second measurement, the photon count was logged and a second count initiated. After the second count was logged, the filter wheel was changed to B, and two more counts logged for the B filter, then two more for the U filter. The author then manually slewed the telescope off the target star to get single counts for V, B, and U of the sky background. In this way, every photon count used is the average of two measurements. Target counts are adjacent to each other and the sky counts bracket each target measurement. Universal Time for the start of each count and the photometer count were logged manually by the author.

To illustrate the observing sequence, let A designate the program star, B designate the Comparison star, C the background sky, and D the Check Star. Designate the V, B, and U filters by the numbers 1, 2, and 3. Then the observing sequence was: C1, C2, C3, D1, D1, D2, D2, D3, D3, C1, C2, C3, B1, B1, B2, B2, B3, B3, C1, C2, C3, A1, A1, A2, A2, A3, A3, C1, C2, C3, B1, ... The Check Star was measured approximately each hour. In addition, the author updated the autoslave coordinates to the current telescope position every third time a target was centered (every time for the Check Star). This compensated for a known drift error in the TCS due to the computer clock.

Notes from the observations follow:

UT 27 Oct 95, JD 2450017.725. Observatory check out with Cpt. Alsing, Dept of Physics, USAFA and initial data runs. Sky is partly cloudy with scattered alto-cumulus moving to the west. Temperature is approximately 38°F. Relative humidity is 30%. Moon is 3 days past new and has set prior to observations. U Peg is due south at 66° altitude. U Peg clears for observation by 2320 local (0620 UT). There is still sufficient cloudiness to make the data suspect. Using the computer clock for UT time of observation, stars become increasingly more difficult to locate. Clouded over at 0050 (0750 UT). There is an obvious time error in the computer clock. Determine the *computer clock gains 8 seconds per hour. This affects the telescope coordinates, HA, LST, and airmass numbers presented. All data determined suspect and discarded from reduction.*

UT 28 Oct 95, JD 2450018.725. Sky is clear. Temperature is approximately 35° F. Relative humidity is 15%. Moon phase is 4 days past new. Observation run begins at 1930 (0230 UT). Initiate changes to procedure to overcome computer clock error. Continue observation until 0130 (0830 UT). U Peg ends at SW azimuth and about 60° altitude. There are no significant problems.

UT 29 Oct 95, JD 2450019.725. Sky is clear. Temperature is approximately 40° F. Relative humidity is 25%. Moon is 5 days past new. Observation run begins at 2030 (0330 UT) due to problems with the dome tracking system. Discontinue at 2230 (0530 UT) for high cirrus clouds obscuring the program stars.

UT 30 Oct 95, JD 2450020.725. Overcast with light rain and snow. Observation cancelled.

UT 23 Nov 95, JD 2450044.725. Sky has widely scattered, thin cirrus, mostly to the east. Temperature is approximately 28° F. Relative humidity is 20%. Moon phase is new. Observation run begins at 1930 (0230 UT).

Discontinue at 2215 (0515 UT) for low cumulus clouds obscuring the program stars. Weather forecaster confirms continued cloudiness through the night.

UT 24 Nov 95, JD 2450045.725. Sky is clear. Temperature is approximately 18° F. Relative humidity is 10%. Moon is 1 day past new. Observation run begins at 1830 (0130 UT). Observation run ends at 2320 (0620 UT). Observation run starts with U Peg in the SE at 61° altitude and ends due west at 36°. Observation run ends due to interference with the Front Range mountains.

UT 25 Nov 95, JD 2450046.725. Overcast with heavy snow. Observation cancelled.

UT 26 Nov 95, JD 2450047.725. Sky is clear with high cirrus to the north. Temperature is approximately 25° F, relative humidity is 20%. Moon is 3 day past new. Observation run begins at 1800 (0100 UT). Observation run ends at 2135 (0435 UT). There is slight trouble with high thin cirrus all night. Observation run ends due to weather.

Data Reduction

The data output from the observing runs are a sequence of UT events and photometer counts for the program stars and background sky. These counts must be converted to a standard format in heliocentric Julian Day and delta magnitude. The *precision* of the UT events is 1 second ± .2s.

Calculations will maintain maximum available accuracy and will display answers within the bounds of precision. For example, the decimal day corresponding to 0349:50 hours 29 Oct 95 is 29.159519705555 repeating. However, since 1 second is equal to 1/86400 = 0.000011574074 of a day, calculations will be rounded to the significant digit corresponding to tenths of a second. In this case, the decimal day is 29.159520, but calculations will include the full computer accuracy. The precision of the photometer counts will be discussed below.

Reduction of Coordinates

In order to use the TCS accurately and continue with further data reduction, the standard stellar coordinates listed in Table 5 must be corrected to the apparent position at the time of the observation. To do this, one applies successive corrections for: proper motion, precession, and nutation.

PROPER MOTION is the apparent movement of the star with respect to the "fixed" background stars. The International Astronomical Union (IAU) has established a set of very distant stars and quasars to use as the defining reference for stellar position and proper motion. The correction for Proper Motion is simply a linear function of the astrometric data:

$$\alpha = \alpha_0 + \Delta\alpha_0 t \qquad (4.1)$$

where α_0 and $\Delta\alpha_0$ are given in Table 5 and t is the number of years from J2000 to the date of observation.

PRECESSION is the long period variation in the position of the equinox and ecliptic due to the gravitational torque of the Sun, Moon, and planets on the Earth's axis. This should be familiar as the "wobbling top" described in many science books. Precession has a period of about 26,000 years. Precession corrections are based on Newcomb's 1895 theory of the Earth's orbital motion about the Sun.

Newcomb's transformation precesses the coordinates from any fixed date to a new date based on the standard J2000 references. The transformation starts with a rectangular coordinate system defined by setting the x-axis through the equinox (where the celestial equator and ecliptic meet), the z-axis through the celestial north pole, and the y-axis to the east in the plane of the equator. The coordinate system is then rotated through three Euler angles: -ζ about the Z-axis, +θ about the new y-axis, and finally $-z$ about the new z-axis to realign the x-axis with the equinox of the date. The transformation is accomplished via the precession matrix:

$$\hat{r}_d = \mathrm{P}\hat{\mathrm{r}}_f \qquad (4.2)$$

where the unit position vector $\hat{r}_x$ uses cartesian coordinates for the fixed reference and the date of observation. The matrix, P, is

$$P = \begin{bmatrix} \cos z\cos\theta\cos\zeta - \sin z\sin\zeta & -\cos z\cos\theta\sin\zeta - \sin z\cos\zeta & -\cos z\sin\theta \\ \sin z\cos\theta\cos\zeta + \cos z\sin\zeta & -\sin z\cos\theta\sin\zeta + \cos z\cos\zeta & -\sin z\sin\theta \\ \sin\theta\cos\zeta & -\sin\theta\cos\zeta & \cos\theta \end{bmatrix} \qquad (4.3)$$

The IAU has adopted rates for the precession angles based on observed quantities. The base epoch for the calculations, e_0, is J2000.0 or JD(e_0) = 2451545.0. The time arguments used in the calculations are:

$$T = (JD(e_f) - JD(e_0)) / 36525$$

$$\text{and} \quad t = (JD(e_d) - JD(e_f)) / 36525. \qquad (4.4)$$

(For the initial calculation of JD, or Julian Day, see "Reduction of Time" below.) The Euler angles are:

$$\zeta = (2306.2181'' + 1.39656''T - 0.000139''T^2)t + (0.30188'' - 0.000344''T)t^2 + 0.017998''t^3$$

$$z = (2306.2181'' + 1.39656''T - 0.000139''T^2)t + (1.09468'' + 0.000066''T)t^2 + 0.018203''t^3$$

$$\theta = (2004.3109'' - 0.85330''T - 0.000217''T^2)t + (-0.42665'' - 0.000217''T)t^2 - 0.041833''t^3. \qquad (4.5)$$ [49]

The basic program "Rigorous Precession of Coordinates" by Krzeminski at Appendix B corrects the star positions for both proper motion and precession using the method described above. For further explanation, see the program listing. Output from the basic program is entered in the EXCEL worksheet "Calculations" in Appendix C for each observing day.

Alternatively, one could perform a straight calculation for precession. Because these observations reference J2000.0 coordinates, eqs. 4.5 reduce to

$$\zeta_0 = 2306.2181''t + 0.30188''t^2 + 0.017998''t^3$$

$$z_0 = 2306.2181''t + 1.09468t^2 + 0.018203''t^3$$

$$\theta_0 = 2004.3109''t - 0.42665''t^2 - 0.041833''t^3. \qquad (4.5a)$$

Meeus, in chapter 20, further reduces eqs. 4.5 by substituting

$$\hat{r}_x = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} \cos\delta\cos\alpha \\ \cos\delta\sin\alpha \\ \sin\delta \end{bmatrix} \qquad (4.6)$$

and completing the transformation. The final result yields the new RA and DEC directly (checking for the correct quadrant with arctan).

$$\alpha - z_0 = \arctan\frac{\cos\delta\ \sin(\alpha_0 + \zeta_0)}{\cos\theta_0\cos\delta_0\cos(\alpha_0 + \zeta_0) - \sin\theta_0\sin\delta_0}$$
$$\delta = \arcsin(\sin\theta_0\cos\delta_0\cos(\alpha_0 + \zeta_0) + \cos\theta_0\sin\delta_0) \qquad (4.7)^{50}$$

NUTATION is the short-period oscillation (primarily 18.6 years) of the Earth's axis about the mean position accounted for by precession. The components of nutation are the nutation in longitude, $\Delta\psi$, and the nutation in obliquity, $\Delta\varepsilon$. These corrections affect both the position of the star and the local hour angle. The mean axis (precessed above) is called the Celestial Ephemeris Pole and represents the primary axis of a deformable, rotating, ellipsoid whose instantaneous moment of inertia tensor is a diagonal matrix.[51] The Celestial Ephemeris Pole is affected primarily by the Moon, and also by the tides, tectonic motion, the fluid core, the Sun, and the planets.

As with precession, nutation involves three separate rotations about a cartesian coordinate system. The first rotation moves the mean equator through the mean obliquity, ε_0, about the x-axis to the ecliptic. Then, it rotates about the z-axis through $-\Delta\psi$ so the x-axis points at the true equinox of the date. Finally, it rotates back through the angle $-\varepsilon$ ($\varepsilon = \varepsilon_0 + \Delta\varepsilon$) to the true equator of the date. The nutation matrix is

$$N = \begin{bmatrix} \cos\Delta\psi & -\sin\Delta\psi\cos\varepsilon_0 & -\sin\Delta\psi\sin\varepsilon_0 \\ \sin\Delta\psi\cos\varepsilon & \cos\Delta\psi\cos\varepsilon\cos\varepsilon_0 + \sin\varepsilon\sin\varepsilon_0 & \cos\Delta\psi\cos\varepsilon\sin\varepsilon_0 - \sin\varepsilon\cos\varepsilon_0 \\ \sin\Delta\psi\sin\varepsilon & \cos\Delta\psi\sin\varepsilon\cos\varepsilon_0 - \cos\varepsilon\sin\varepsilon_0 & \cos\Delta\psi\sin\varepsilon\sin\varepsilon_0 + \cos\varepsilon\cos\varepsilon_0 \end{bmatrix} \quad (4.8)$$

The nutation angles $\Delta\psi$ and $\Delta\varepsilon$ are evaluated from:

$$\Delta\psi = \sum_{i=1}^{n} S_i \sin A_i \qquad \text{and} \qquad \Delta\varepsilon = \sum_{i=1}^{n} C_i \cos A_i \qquad (4.9)$$

where $A_i = a_i l + b_i l' + c_i F + d_i D + e_i \Omega$.. The fundamental arguments for A_i are (to 0.1" accuracy):

l = $134°.96298 + (1325r + 198°.86739)t + 0.00869t^2 + 0.00001t^3$

≡ The mean longitude of the Moon minus the longitude of the Moon's perigee

l' = $357°.52772 + (99r + 359°.05034)t - 0°.00016t^2 - 0°.000003t^3$

≡ The mean longitude of the Sun minus the longitude of the Sun's perigee

F = $93°.27191 + (1342r + 82°.01753)t - 0°.00368t^2 + 0°.000003t^3$

≡ The mean longitude of the Moon minus the longitude of the Moon's node

D = $297°.85036 + (1236r + 307°.11148)t - 0°.00191t^2 + 0°.000005t^3$

≡ The mean elongation of the Moon from the Sun

Ω = $135°.04452 - (5r + 134°.13626)t + 0°.00207t^2 + 0°.000002t^3$

≡ The longitude of the mean ascending node of the lunar orbit on the ecliptic measured from the mean equinox of date.

r = 360°

t = (JD – 2451545.0)/36525 ≡ *Julian Centuries* (4.10)

The multipliers a_i, b_i, c_i, d_i, e_i, and the coefficients S_i and C_i are tabulated in the "Explanatory Supplement to the Astronomical Almanac". The tables have 106 terms in the IAU (1980) series and 85 planetary terms.[52]

Appendix C shows the calculation of nutation using the 13 terms in the series whose coefficients are greater than 0.01 arcseconds. (Of the remaining terms, the maximum change to $\Delta\psi$ is on the order of 0.01 arcseconds and the change to $\Delta\varepsilon$ is even less.) This accuracy is sufficient for the observations conducted. Neglecting the 2nd order terms, eq. 4.8 can be rewritten as

$$N = \begin{bmatrix} 1 & -\Delta\psi\cos\varepsilon & -\Delta\psi\sin\varepsilon \\ \Delta\psi\cos\varepsilon & 1 & -\Delta\varepsilon \\ \Delta\psi\sin\varepsilon & \Delta\varepsilon & 1 \end{bmatrix}. \qquad (4.8a)$$

This provides the first-order corrections ($\Delta\alpha$, $\Delta\delta$) to RA and Dec as

$$\Delta\alpha = (\cos\varepsilon + \sin\varepsilon\sin\alpha\tan\delta)\Delta\psi - \cos\alpha\tan\delta\Delta\varepsilon$$

$$\Delta\delta = \sin\varepsilon\cos\alpha\Delta\psi + \sin\alpha\Delta\varepsilon. \qquad (4.11)$$[53]

The values of $\Delta\psi$ and $\Delta\varepsilon$ calculated on the worksheet "Nutation" are then used in the "Calculations" worksheet to compute ε, $\Delta\alpha$, and $\Delta\delta$ for the precessed coordinates.

Other factors which affect the coordinates are Aberration, Refraction, and Parallax. These factors cause less than 0.01" change to RA and Dec and are therefore not used here. They are primarily of concern for the exact calculations of position necessary for astrometry. The coordinates for the stars are computed for the middle observation on a given night's observing run. The total error generated using this technique is on the order of 0.005" per hour away from the central time and can be neglected from further computation.

Reduction of Time

CONVERT UT TO JULIAN DAY EPHEMERIS (JDE): The standard timeframe for astronomical observations is the Julian Day (JD). "JD is a continuous count of the days and fractions thereof from the beginning of the year –4712."[54] For arithmetic purposes, astronomers count with a year "0" placed before the year +1 A.D. The JD timescale includes all known observations and allows them all to have the same time reference.

To change a UT observation to JD, one first converts the time into a decimal day.

$$D = Day + \frac{Hours}{24} + \frac{Minutes}{60 \times 24} + \frac{Seconds}{60 \times 60 \times 24} \tag{4.12}$$

Then,

$$JD = INT(365.25(Y + 4716)) + INT(30.6001(M + 1)) + D + B - 1524.5 . \tag{4.13}$$

Here, Y is the year, M is the month, and B is the Gregorian calendar correction:

$$B = 2 - A + INT\left(\frac{A}{4}\right) \quad \text{with} \quad A = INT\left(\frac{Y}{100}\right) \tag{4.14}$$

If $M \leq 2$ (i.e. January or February), then substitute M = M+12 and Y = Y-1 in the above equations. For Julian calendar dates, B = 0. The INT function above is the integer part of a decimal number.[55] Care must be used with negative years that the INT function does not round down to the nearest whole number. Microsoft EXCEL does not define the INT function this way, therefore calculations in EXCEL will use the TRUNCate function.

The next item to calculate is the Julian Century, T from eq. 4.4. This is used in several algorithms which will be discussed below. The Julian Century is

$$T = \frac{JD - 2451545.0}{36525}. \tag{4.4}$$

The equations of motion for the solar system require time to be an independent variable. Unfortunately, the Earth's rotation varies irregularly, thus Geocentric Civil time (and Sidereal time) is irregular with respect to International Atomic Time (TAI). Dynamical Time (TDT) is related to Ephemeris Time and corrects the problems with rotation.[56] The exact difference can only be determined by direct observation of the ephemerides. Using table 9.A in *Meeus, pg 72,* and extrapolating to 1995

$$\Delta T = TD - UT = 61.4 \text{ seconds} = 0.00071065 JD. \tag{4.15}$$

The correction for TDT is then applied to the JD to get the Julian Day

Ephemeris, or

$$\text{JDE} = \text{JD} + \Delta\text{T}. \qquad (4.15a)$$

HELIOCENTRIC CORRECTION OF TIME: When making a photometric observation, the timing of the data is necessarily geocentric. In order to quantify the data independent of earth's orbit (and thus time of year) the JDE of the observation is converted to a heliocentric JDE (HJD). The HJD accounts for the time for light to travel from the star to the sun instead of the earth. This correction can be as large as 8 minutes and is significant when determining the eclipse minimum to within a few seconds accuracy. The simplest calculation involves a heliocentric correction such that

$$\text{HJD} = \text{JD} + \Delta\text{t}. \qquad (4.16)$$

Since most observations occur at night, away from the sun, a positive Δt is standard convention.

Figure 8 depicts the problem in 2 dimensions. In 3 dimensions, the problem is solved through standard spherical trigonometric relations using the Longitude of the Sun (L), the Radius vector (R), the Right Ascension (α) and Declination (δ) of the star, and the obliquity of the ecliptic (ε). The solution of the spherical triangle for Δt is

$$\Delta t = -0.0057755R\{\sin L(\sin\varepsilon\sin\delta + \cos\varepsilon\cos\delta\sin\alpha) + \cos L\cos\alpha\cos\delta\} \qquad (4.17)$$ [57]

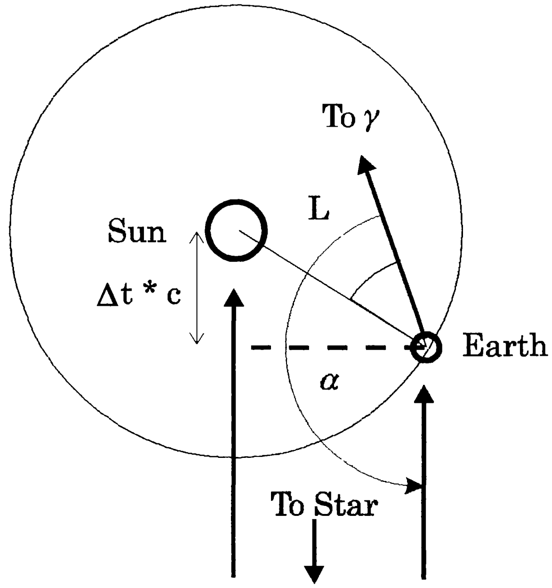


Figure 9: 2-Dimensional Geometry of the Heliocentric Correction

The scaling factor, 0.0057755, is the time for light to travel 1 AU in Julian days. The radius vector of the sun is given from elliptical orbit theory;

$$R = \frac{a\left(1-e^2\right)}{1+e\cos\nu} = a\left(1-e\cos E\right) \tag{4.18}$$

Where a is the semi-major axis of earth's orbit in AU, ν is the true anomaly, E is the eccentric anomaly, and *e* is the eccentricity of Earth's orbit. In order to determine E or ν, one can iterate Kepler's equation (cf. Appendix A) as done in the program "Anomaly of the Sun for an Observing Day" listed in Appendix B. E and R are calculated for the time of mid-observation for each observing day. The error induced in HJD by this method is < 1 second between the first and last observation.

The longitude and mean anomaly of the Sun, the mean obliquity of the ecliptic, and the eccentricity of the Earth's orbit are calculated from P.

Bretagnon's VSOP82 theory.[58]

$$a = 1.000001018$$

$$L_s = 280^\circ.466449 + 36000^\circ.76983T + 0^\circ.0003032T^2 \quad (4.19)$$

$$M_s = 357^\circ.52910 + 35999^\circ.05030T - 0^\circ.0001559T^2 \quad (4.20)$$

$$\varepsilon_0 = 23^\circ.439291 - 0^\circ.01300417T - 0^\circ.00000016T^2 \quad (4.21)$$

$$e = 0.016708617 - 0.000042037T - 0.0000001236T^2 \quad (4.22)$$

Where T is the time in Julian centuries from J2000.0 and terms with T^3 have been dropped because the correction is much smaller than the precision of the observations. The heliocentric correction is determined once for the mid-point observation each day. Error induced by using the mid-point is less than 0.6 seconds for any given observation.

Each individual observation is reduced from the Universal Time logged at the telescope to a heliocentric Julian Day through combined application of equations 4.12, 4.13, 4.15a, and 4.16.

DETERMINATION OF SIDEREAL TIME, HOUR ANGLE and AIRMASS: In order to compare data from several nights' observations, one must use natural magnitudes for the differential measurement. Recall from Chapter 1 that natural, or extra-atmospheric, magnitudes correct the instrumental readings for atmospheric extinction. The equations for the extinction corrections require the airmass, X. In order to determine X, one must first find the local Sidereal Time.

The Universal Time scale (UT) is based on the motion of the mean sun as it passes through the prime meridian at Greenwich observatory in England. Due to the orbit of the earth, the mean sun has a constantly changing right ascension with respect to the background stars. Sidereal Time is a measure of time based on passage of the vernal equinox through the prime meridian. The sidereal day is about 4 minutes shorter than a solar day. Local sidereal time (LST) is the actual angle, measured in hours, from the local meridian to the vernal equinox. The mean sidereal time at Greenwich can be calculated for any JDE by

$$ST = 280.46061837 + 360.98564736629 \times (JDE - 2451545.0) + 0.000387933 \times T^2 - T^3 / 38710000. \qquad (4.23)$$[59]

Equation 4.23 calculates the mean sidereal time in degrees. To obtain LST, one must subtract the observer's longitude and add the correction for the true position of the vernal equinox. (In this case, "West" longitudes are positive numbers and "East" longitudes are negative. The result is the similar to correcting UT to local time.) The correction for the vernal equinox is

$$\Delta ST = \Delta\psi \cos \varepsilon \qquad (4.24)$$

where $\Delta\psi$ and ε are the nutation in longitude and true ecliptic calculated in Appendix C. Care must always be used to maintain the consistent units between seconds and arcseconds when calculating LST. For the final determination of airmass, it is simplest to maintain LST in decimal degrees.

LST must be determined for each observation, but ΔST can be calculated once for each night.

The Hour Angle, H, is the angle measured westward from the observer's meridian to the star. Thus, observable hour angles are 270° through 0° to 90° (horizon to horizon). Normally, the hour angle is expressed in units of time similar to right ascension and has negative value east of the meridian (horizon to horizon is –6 hours to +6 hours). The hour angle is defined as

$$H = LST - RA. \qquad (4.25)$$

Finally, the Airmass is the amount of atmosphere starlight must pass through to the telescope. (See Figure 10) For the curved atmosphere,

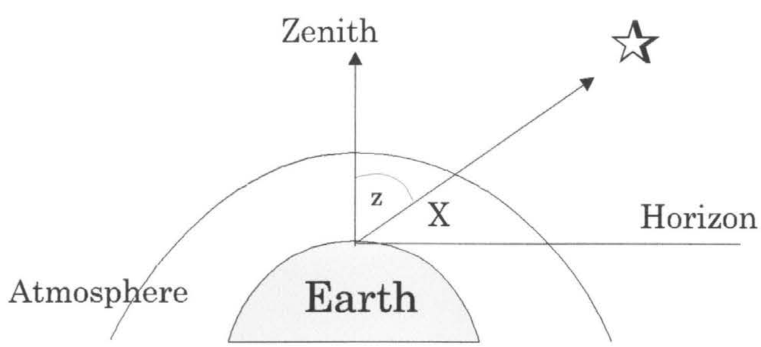


Figure 10: Illustration of Airmass

Bemporad's polynomial (1904) gives the airmass as

$$X = \text{Sec } z - 0.0018167(\text{Sec } z - 1) - 0.002875(\text{Sec } z - 1)^2 - 0.0008083(\text{Sec } z - 1)^3 \qquad (4.26)$$[60]

where

$$\text{Sec } z = (\text{Sin}\varphi \ \text{Sin}\delta + \text{Cos}\varphi \ \text{Cos}\delta \ \text{CosH})^{-1} \quad (4.27)$$

where φ is the observer's latitude, δ is the declination of the star and H is the hour angle in degrees. One can use a simple, plane parallel approximation for zenith angles less than 60°. This approximation gives

$$X = \text{Sec } z \quad (4.28)$$ [61]

Test calculations for airmass using both methods at H = 60° gives a difference of 0.2% which is within the tolerance of the observations. The maximum observed hour angle is 58.9° and the approximation is valid for all data.

Reduction of Photon Counts

DEAD TIME CORRECTION: The first reduction to the raw photon counts is to correct for the response of the photomultiplier tube. The standard 1P21 photomultiplier produces an electronic pulse of approximately 150 nanoseconds for each incoming photon. If a second photon arrives while the first is still being counted the photomultiplier will not count that second photon. This correction is called the "Dead Time", or pulse-pair, correction. Let N be the actual number of photons arriving in the photomultiplier, n the observed (counted) number of pulses, t the integration or count duration time, and d the dead time of the instrument. Then

$$n = N(1 - Nd/t).$$

Solving for N;

$$N = n / (1 - Nd/t) \approx n / (1 - nd/t) \qquad (4.29)^{62}$$

Each star and background sky measurement is corrected to yield an actual count using the observed count as an approximation for N.

The response time for this system was determined using the stars α Eridanus (bright) and HR 875 (faint) and the method described by Schmidtke and Hopkins. An aperture mask blocked 75% of the telescope's aperture. Define the following terms:

F_a = Average count rate of the faint star without the mask

B_a = Average count rate of the bright star without the mask

F_b = Average count rate of the faint star with the mask

B_b = Average count rate of the bright star with the mask.

Then we assume that the photomultiplier is able to count all the photons from the faint star both with and without the mask and let $R = F_a / F_b$ define the effective attenuation of the mask. Then substituting $B_a = n/t$ and $B_bR = N/t$ in equation 4.29 (using the approximation), one can solve for d:

$$d = (N - n)t / Nn$$

$$d = (B_bR - B_a) / B_aB_bR. \qquad (4.30)$$

The results yield a response time of $d = 194$ nanoseconds for the system.

The error inherent in the pulse counting system is due to random events and can be evaluated with Poisson statistics. Using this method, the approximate error is represented as $\varepsilon_n = \sqrt{n}$. The integration time is chosen such that n is large enough to keep ε_n less than 1% of n ($n \sim 10^4$).

BACKGROUND SKY and DARK NOISE: The telescope system uses an aperture at the eyepiece to limit the field of view to a single star for the photon counts. Because the aperture has a finite size ($1.575 mm^2$), it admits some background light from the sky surrounding the star. The sky measurements taken between each target observation are averaged and corrected for response time. Then, the sky count is subtracted from the star count. This procedure yields the photon count of the star alone and also compensates for "dark noise" in the 1P21 photomultiplier. The dark noise is the random or spurious count rate generated in the photomultiplier with a closed shutter. It is present at the same level in both star and sky observations at about 100 counts/second. The subtraction removes this count.

DIFFERENTIAL MAGNITUDES: Using the true counts generated above, one next determines the instrumental, differential magnitude by equation 2.1. To restate:

$$\Delta m = m_1 - m_2 = -2.5 \log (f_1 / f_2) \qquad (2.1)$$

where f_x is the measured flux, or count rate. To determine the color measurement of a given star, the flux refers to the different filter measurements. The measured flux from each star is affected by the extinction coefficient acting through a slightly different airmass. One must reduce the instrumental magnitudes above to a natural magnitude in order to compare observations taken over the course of several nights.

To reduce to natural magnitudes, substitute v for m in equation 2.3 to simplify all discussion to just the visual filter measurements. Then let $V = v_0$

$$V = v - k'X - k''(b\text{-}v)X \qquad (2.3)$$

$$V_{UPeg} - V_{Co} = (v - k' X_{UPeg} - k''(b\text{-}v)X_{UPeg}) - (v - k' X_{Co} - k''(b\text{-}v)X_{Co})$$

or,

$$\Delta V = \Delta v - \Delta(k'X) + \Delta(k''(b - v)X) \qquad (4.31)$$

expanding

$$\Delta V = \Delta v - k'\Delta X - k''X_{Avg}\Delta(b - v) \qquad (4.32)$$

where X_{Avg} is the mean airmass for the observations used.[63] First determine k" by using data from two stars, in this work we use the Comparison and Check stars, in equation 2.3:

$$V_{Co} = v_{Co} - k'X_{Co} - k''(b\text{-}v)_{Co}X_{Co}$$

$$V_{Ck} = v_{Ck} - k'X_{Ck} - k''(b\text{-}v)_{Ck}X_{Ck}$$

and subtracting:

$$\Delta V = \Delta v - k'\Delta X - k''X_{Avg}\Delta(b - v).$$

Since $X_{Co} \approx X_{Ck}$, set $\Delta X = 0$ and rearrange to get the linear equation

$$\Delta v = k''X_{Avg}\Delta(b - v) + \Delta V. \qquad (4.33)$$

Then a plot of Δv versus $X_{Avg}\Delta(b - v)$ (Figure 11) will yield k" as the slope of the linear interpolation. The 2nd order extinction coefficient is relatively

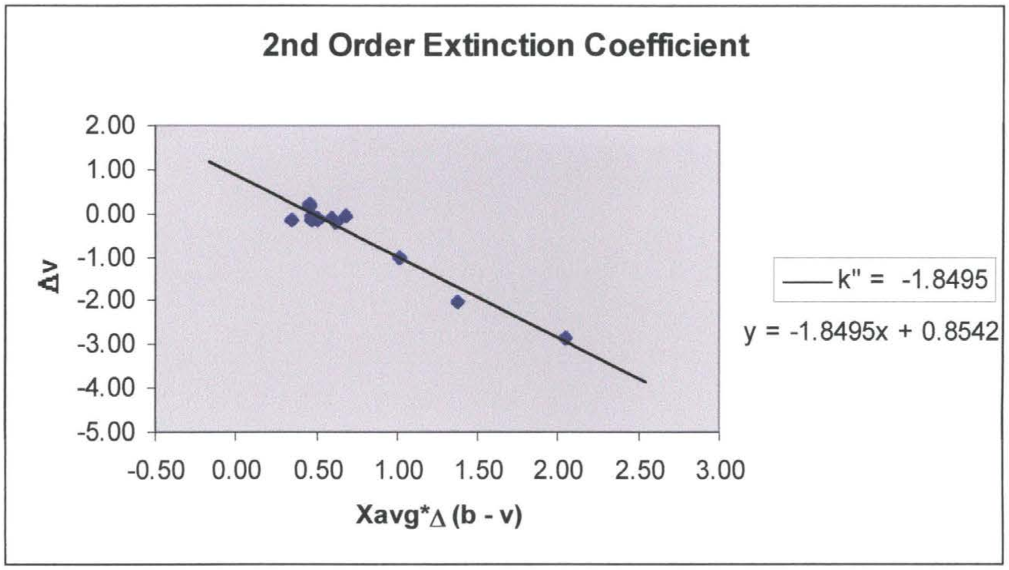


Figure 11: Plot to determine k"

constant and the correction term is small so an average value for all observations is used for further calculations.

Then, using the k" value obtained with both stars, determine k' using equation 2.3 for a single star. Using the Comp star values and rearranging

$$v_{Co} - k''(b\text{-}v)_{Co}X_{Co} = k'X_{Co} + V_{Co} \qquad (4.34)$$

is a linear equation with k' as the slope of the plot. The primary extinction coefficient is determined using the plot of the Comparison star values for each night of observation. The values for k' are listed in Table 6. The plots generating the coefficients are in the "Extinction" worksheet in Appendix C.

	28 Oct	29 Oct	23 Nov	24 Nov	26 Nov
k'	0.2186	-1.9702	6.4081	0.0094	1.4292

Table 6: Values of Primary Extinction Coefficient for the Date

Using the calculated values for k' and k" in equation 4.32 the corresponding values of ΔV are reduced from the instrumental magnitudes. Each value for U Pegasi uses the average of the Comparison star magnitudes which bracket the U Pegasi observation. ΔV is presented in the sense of U Pegasi minus the Comparison. Output is presented in Table 7. The Comparison star is also evaluated against the Check star in Appendix C.

HJD	DV	Phase	HJD	DV	Phase
2450018.634705	0.075	0.0000	2450045.630388	0.123	0.0356
2450018.656476	-0.151	0.0581	2450045.639040	0.053	0.0586
2450018.692257	-0.054	0.1536	2450045.649179	0.077	0.0857
2450018.708750	0.702	0.1976	2450045.657443	0.152	0.1077
2450018.721169	1.232	0.2307	2450045.671621	0.110	0.1456
2450018.730712	0.874	0.2562	2450045.689549	0.360	0.1934
2450018.797205	0.122	0.4336	2450045.700059	0.491	0.2215
2450018.824288	0.872	0.5059	2450045.710226	0.349	0.2486
2450018.835255	0.001	0.5351	2450045.719717	0.538	0.2739
2450018.845151	-0.225	0.5616	2450045.731737	0.842	0.3060
2450019.669871	0.672	0.7622	2450045.746274	0.772	0.3448
2450019.680722	0.515	0.7912	2450045.757946	0.006	0.3759
2450019.690357	0.399	0.8169	2450047.555035	0.352	0.1713
2450019.699646	0.274	0.8417	2450047.562060	0.374	0.1900
2450019.710786	0.081	0.8714	2450047.568374	0.318	0.2069
2450019.726874	-0.378	0.9144	2450047.576985	0.790	0.2299
2450044.622684	0.234	0.3466	2450047.583582	0.610	0.2475
2450044.631481	0.225	0.3701	2450047.590463	0.759	0.2658
2450044.647829	0.355	0.4137	2450047.597407	0.681	0.2844
2450044.655254	0.176	0.4335	2450047.608113	0.491	0.3129
2450044.664652	0.912	0.4586	2450047.614728	0.396	0.3306
2450044.676909	0.276	0.4913	2450047.621233	0.322	0.3479
2450044.688448	0.207	0.5221	2450047.627836	0.260	0.3656
2450044.700497	0.358	0.5542	2450047.634305	0.241	0.3828
2450044.707979	-0.179	0.5742	2450047.640208	0.210	0.3986
2450044.715682	-0.088	0.5947	2450047.646395	0.170	0.4151
2450045.585035	0.172	0.9145	2450047.660417	0.090	0.4525
2450045.594561	0.113	0.9400	2450047.667106	0.025	0.4704
2450045.602350	0.096	0.9607	2450047.673802	0.081	0.4882
2450045.610076	0.040	0.9814	2450047.679664	0.089	0.5039
2450045.617269	0.058	0.0005	2450047.686875	-0.094	0.5231

Table 7: Reduced Heliocentric Julian Day and Δ V magnitudes.

CHAPTER 5

PERIOD AND MINIMUM DETERMINATION

Polygonal Line Method

Given a set of paired, periodic measurements such as time and differential magnitude, the first step in analyzing the data is to determine the period of the data set. The polygonal line method of period determination starts with a range for the period from P_1 to P_2 which contains the actual period P_0. This method scans through the range of periods in incremental steps appropriate to values needed for P_0. For each assumed period, the data points are ordered according to that period and the line segments between each successive point is summed. The true period will have the minimum total path length.

The Basic program "PER&MIN3.BAS" in Appendix B executes the polygonal line method to determine the period of this data. The program requires data input as an ASCII file containing "Julian date, Delta mag"....The Julian date can be a modified Julian date (HJD minus a constant such as 2450000). The data points are input into an array and counted.

Data is loaded into a second array which is converted from Julian day to phase based on an assumed period.

The phase array is then folded into a single phase plot and sorted ordinally. The line segments between successive points are calculated and summed. The assumed period and the total path length are stored in another array while the program steps to the next assumed period. Once all the program has tested all the assumed periods, the path lengths are compared to find the minimum path length. Two tests are used to compare a set of estimated periods where individual data points are not reordered in the phased array. Line 640 in the program selects the minimum value of this set while line 645 uses the method of Bopp, Evans and Laing (1970) and does not discriminate past the 1st value of the set. Both methods are used to find the bounds for the estimated period. The average is used as the actual period, P_0.

Data is plotted on screen based on the best period found with the value of the period and an error estimation based on the bound values.

Method of Kwee and Van Woerden

Once the correct period has been determined using the polygonal line method, the eclipse minimum can be found using the Kwee and Van Woerden method. The Kwee and Van Woerden method is probably the most widely used method of minimum determination.[64] A preliminary rough estimate of the time of minimum, T_1 is chosen among 2n + 1 equidistant points on the light curve. Since the actual observation probably does not have equidistant points, a linear interpolation of the points on each slope of the curve is used to generate the equidistant points. T_1 then defines a reflection axis for the interpolated magnitudes.

Let Δm_k be the difference between the initial branch and the reflected branch magnitudes at the stepped values $k\Delta T$ away from T_1. Then the sum

$$S(T_1) = \sum_{k=1}^{n} (\Delta m_k)^2 \qquad (5.1)$$

is an estimate of the degree of the branches superimposition for the axis T_1. Then the rough axis is shifted and the sum is recalculated to $S(T_1 + \frac{1}{2}\Delta T)$ and $S(T_1 - \frac{1}{2}\Delta T)$. If $S(T_1) < S(T_1 + \frac{1}{2}\Delta T)$ and $> S(T_1 - \frac{1}{2}\Delta T)$ then T_1 has been properly chosen. If not then a new T_1 is selected and the process attempted again. Once the correct reflection axis is found, the function

$$S(T) = aT^2 + bT + c \qquad (5.2)$$

is solved for a, b, and c using the three equations with values $S(T_1)$, $S(T_1 + \frac{1}{2}\Delta T)$, and $S(T_1 - \frac{1}{2}\Delta T)$. The resulting parabola has a minimum value

$$S(T_0) = c - (b^2/4a) \qquad (5.3)$$

at the epoch of minimum $T_0 = -b/2a$. The mean error of the epoch T_0 is

$$\sigma_{T_0}^2 = \frac{4ac - b^2}{4a^2\left(n/2 - 1\right)}. \qquad (5.4)$$

The program PER&MIN3.BAS at Appendix B continues after determining the period by asking the user to input a rough estimate for the reflection axis and the Julian Date modifier for the data and proceeds with a determination of the minimum as described above. There is an error algorithm for estimates that do not have enough points on both sides of the chosen axis to adequately determine the sums.

The known values for the three equations 5.2 are then loaded into a matrix and the constants are found using matrix algebra

$$a = \frac{\left[\left(S_1\left(T_{+\frac{1}{2}} - T_{-\frac{1}{2}}\right) - T_1\left(S_{+\frac{1}{2}} - S_{-\frac{1}{2}}\right)\right) + \left(S_{+\frac{1}{2}}T_{-\frac{1}{2}} - T_{+\frac{1}{2}}S_{-\frac{1}{2}}\right)\right]}{\begin{vmatrix} T_1^2 & T_1 & 1 \\ T_{+\frac{1}{2}}^2 & T_{+\frac{1}{2}} & 1 \\ T_{-\frac{1}{2}}^2 & T_{-\frac{1}{2}} & 1 \end{vmatrix}} \qquad (5.5)$$

with similar equations for b and c. The program then plots $S(T_0)$ and prints the epoch of minimum.

CHAPTER 6

ANALYSIS AND CONCLUSION

Basic Program Per&Min3.bas

The basic program was evaluated using data from previous observations of U Pegasi. Data sets of previously published results were run through the program to generate an epoch of minimum and a period, then compared to the published results. This test method established the accuracy of the computer program. The results of the comparison are listed in table 12.

Author	**Date**	**HJD of Minimum**	**Period**
Program	## Points	Computer Minimum	Computer Period
Binnendijk	Oct 1958	2436511.66878	0.37478192
Per&Min3	130	2436511.668906	0.3747760
Rigterink	Oct 1970	2440826.9010	0.37478133
Per&Min3	203	2440826.901343	0.3747710
Rovithis	Sep 1980	2444500.4922	*Not listed*
Per&Min3	235	2444500.494481	0.3747680
Zhai	Oct 1978	2443785.04296	0.37478048
Per&Min3	45	2443785.043095	0.3747990

Table 8: Minimum Comparison of BASIC Program

The current observations for U Peg generate a Period of

$$\text{HJD Min (I)} = 2450018.730859 + 0.374802E \pm .00009 \qquad (6.1)$$

However, the reduced light curve shows significant deviations between two sequential phase points. Several factors caused these errors.

1) The author's inexperience at the telescope resulted in several occasions of misidentified stars. Comparison star counts on 28 Oct jump from 250,000 to 950,000 in 40 minutes.

2) Poor technique in choosing stars to monitor extinction coefficient resulted in skewed calculations and extinction coefficients that are not physically sensible. (29 Oct generated a negative k').

3) Inconsistent sky conditions coupled with a slow, manual reposition of the telescope resulted in possible non-uniform atmospheric transparency.

Previous observations of U Peg show a ΔV range of 0.5 to 0.6 magnitudes. The current observations have a range almost twice that from minimum magnitude to maximum. In addition the extinction coefficients provided by Lafta (1985) are

$$k' = 0.408 \qquad k'' = -0.03.$$[65]

Large deviations from these values in the current observations resulted in several severely skewed points.

The polygonal line method is extremely susceptible to scatter and error and can choose an isolated "harmonic" as the correct period when data has wide errors in it. In an attempt to minimize this problem, the data was recalculated using

1) k" = -0.6. Second order extinction coefficients are small and can usually be ignored. Because the calculated value was so high, k" was kept in the reduction equations but reduced to one third its original value.

2) k' (29 Oct/23 Nov) = 1.5. These extinction coefficients are –1.5 and 6.5 respectfully. The average extinction coefficient is 1.5. Therefore, k' = 1.5 was used as a more intrinsically correct value for the coefficient.

3) V_{Comp} = -11.415 on the last seven calculations on 28 Oct 95. This represents the average extra-atmospheric magnitude of the first four observations on that night. ΔV was then calculated using the extra-atmospheric magnitudes.

4) Finally, after a trial run the phase plot was inspected qualitatively, and 20 individual points were determined to be greater than 0.1 magnitude in error and discarded. The resulting period and epoch determined by Per&Min3 for these points is:

$$HJD = 2450018.7260407 + .3747740E \pm .000014 \quad (6.2)$$

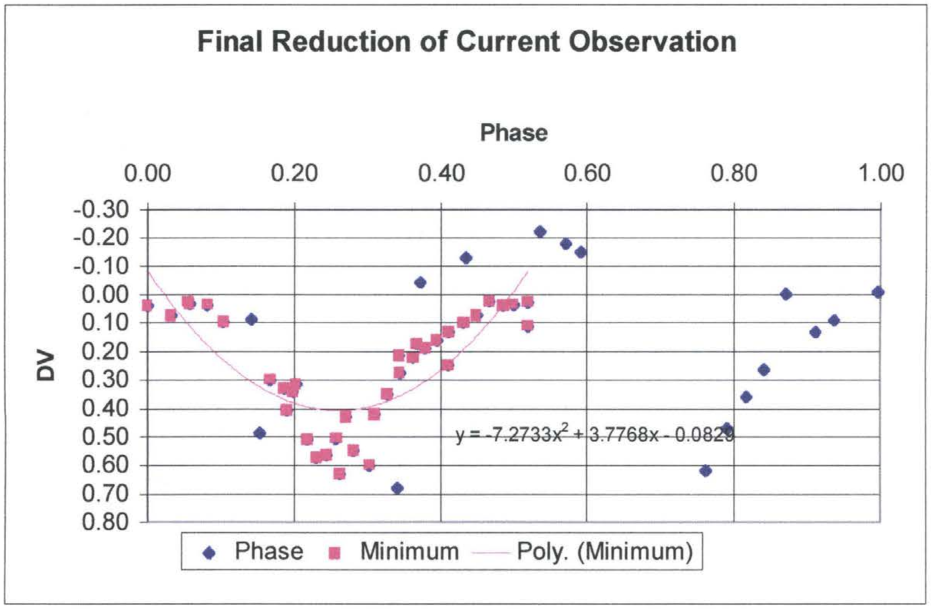


Figure 12: Plot of Final Points

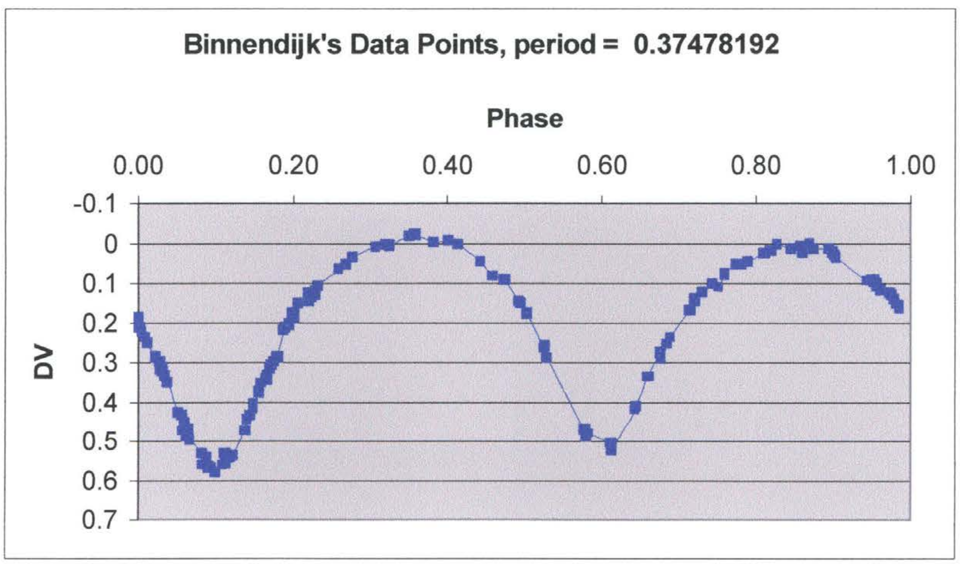


Figure 13: Binnendijk's Data Plot

CONCLUSION: Using Rigterink's data for the primary minimum and period, the calculated value for this epoch is:

$$HJD = 2450018.787900 + .37478133E \qquad (6.3)$$

The residual of 0.061859 days over 24526 periods confirms the indicated decrease in the period. Using the previously published minima listed in Table 9, the observed versus calculated (O-C) plot is derived in Figure 14. The O-C plot shows the decreasing period of U Pegasi after 1950.

HJD of Primary Minimum	Reference
2413094.1229	Chandler (1895)
2430260.6790	Struve (1950)
2433182.8561	LaFara (1951)
2433558.7624	LaFara (1951)
2436511.66878	Binnendijk (1960)
2438691.7693	Gordon (1975)
2440826.9010	Rigterink (1972)
2442347.3879	Patkos (1976)
2442741.2810	Patkos (1976)
2443021.6134	Krobusek (1977)
2443785.04296	Zhai (1984)
2443789.353	Gulmen (1981)
2444185.3093	Patkos (1980)
2444469.3859	Aslan (1981)
2444490.3789	Aslan (1981)
2444500.4922	Rovithis (1982)
2444504.6165	Rovithis (1982)
2450018.7260407	This Paper

Table 9: Times of the Minima of U Pegasi

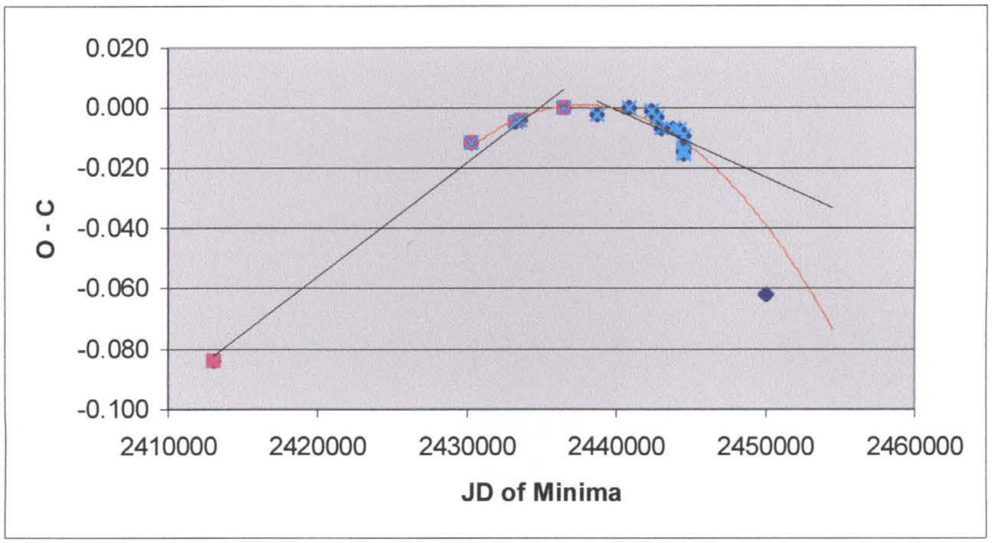


Figure 14: Observed – Calculated Diagram

Computer analysis does generate correct results of an independent set of data points when compared to linear regression techniques based on earlier observations. If the trend indicated by the O – C diagram represents a period changing based on a second order polynomial (red line) as suggested by Zhai *et al.*, then the current data is not far from actual even with the errors present. However, further quantitative discussion is inappropriate given the poor quality of the current data and the small sample size.

APPENDIX A

KEPLER'S EQUATION

Kepler's equation relates the geometry of elliptical orbits to kinematics through relationships between the true anomaly, ν, the mean anomaly, M, and the eccentric anomaly, E. To derive Kepler's equation, one begins by integrating, with respect to time, the angular momentum, $l = r^2\dot{\phi}$, to obtain:

$$\int_{\phi_0}^{\phi} r^2 d\phi = l(t - t_0) \tag{A.1}$$

and substituting the radial distance between the bodies

$$r = \frac{1}{u} = \frac{l^2/\mu}{1 + e\cos(\phi - \phi_0)} \tag{A.2}$$

where t_0 is connected with ϕ_0 at $\nu = 0$ and $\nu = \phi - \phi_0$. One can evaluate this based on Kepler's second and third laws:

2nd. *The radius vector connecting the sun and a planet sweeps through equal areas in equal times.*

3rd. *The squares of the periods of the planets are proportional to the cubes of their semi-major axes.*

Letting $n = (\frac{Gm}{r^3})^{\frac{1}{2}}$ be the mean motion of the body gives the period

$T = 2\pi/n$ and the area of the ellipse $A = ab\pi$ gives $\frac{dA}{dt} = \frac{A}{T} = \frac{abn}{2}$ or, since

$b = a\sqrt{1-e^2}$ and $l = r^2\dot{\phi} = 2\frac{dA}{dt}$,

$$l = na^2\sqrt{1-e^2}\,. \tag{A.3}$$

With some manipulation, the third law can be expressed as

$$n^2a^3 = \mu\,. \tag{A.4}$$

Evaluating 3.5 with 3.6, A.1, and A.2 yields:

$$n(t-t_0) = (1-e^2)^{\frac{3}{2}}\int_0^{v}\frac{dv}{(1+e\cos v)^2}\,. \tag{A.5}$$

Using the substitution $u = \tan(v/2)$, and integrating A.5 becomes:

$$n(t-t_0) = -\frac{e\sqrt{1-e^2}\sin v}{1+e\cos v} + 2\arctan\left[\left(\frac{1-e}{1+e}\right)^{\frac{1}{2}}\tan(v/2)\right]. \tag{A.6}$$

Equation A.6 relates the mean anomaly, $M = n(t - t_0)$, to the true anomaly. Equation 4.18 relates the true and eccentric anomalies. With the trigonometric relations

$$\cos v = \frac{\cos E - e}{1 - e\cos E} \text{ and } \tan\frac{v}{2} = \left[\frac{1+e}{1-e}\right]^{\frac{1}{2}}\tan\frac{E}{2} \tag{A.7}$$

one can transform equation A.6 into Kepler's equation:[66]

$$E = M + e\sin E \tag{A.8}$$

The geometry relating the anomalies is shown in Figure 14. For the elliptical orbit with period T and semi-major axis a, we draw 2 circles. The auxiliary circle has it's center coincident with the center of the ellipse and radius a. While another circle is centered at the focus containing the primary body and has a radius such that the secondary body would have the same period, T, in a circular orbit as it does in the elliptical orbit.

The points C, S, P, and P' create the line defining ϕ_0. The true anomaly measures ϕ about the primary, S, to the secondary, S'. The mean anomaly measures ϕ about S to S"; the position of the secondary in the circular orbit after the same time, t. The eccentric anomaly is the angle about the center of the ellipse (and the auxiliary circle) from periastron to a point, Q, on the auxiliary circle found by drawing QS' perpendicular to the line CP.[67]

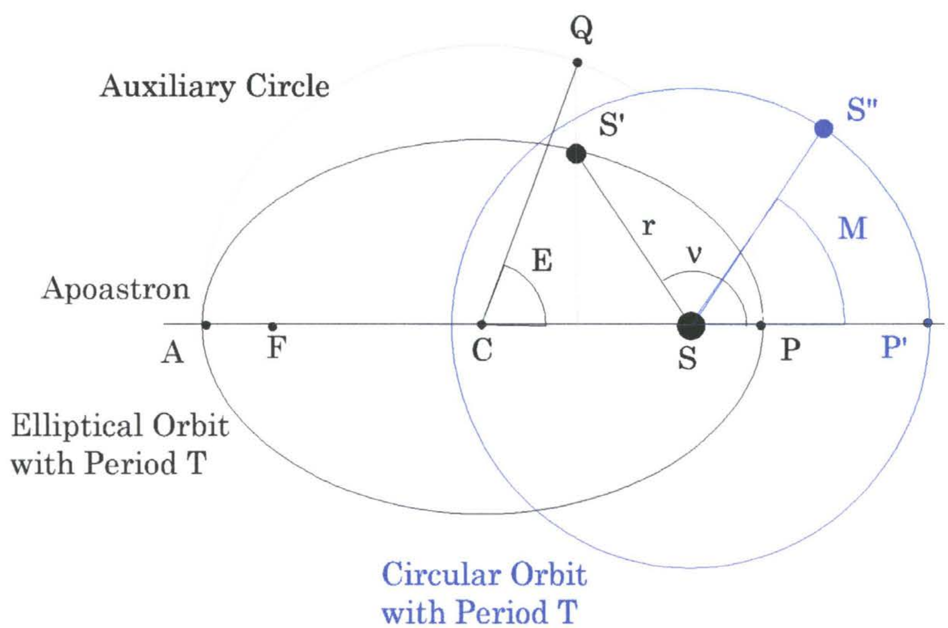


Figure 15: Elliptical Geometry for the Equation of Kepler

Since Kepler's equation is a transcendental equation, it cannot be solved directly. However, one can start with an approximate value for E and the equation will give a better approximation. This is repeated until one obtains the desired precision. One can easily create a computer program which iterates this solution. (cf. Appendix B: "Anomaly of the Sun for an Observing Day".) A good first approximation for E is the mean anomaly, M.

APPENDIX B

BASIC PROGRAMS

Rigorous Precession of Coordinates[68]

The following Basic program calculates the Right Ascension (RA) and Declination (DEC) for the date of any star given a known RA and DEC on any fixed date. The program references the standard tabulated data for precession adopted for J2000.0 and follows the method outlined in the "Explanatory Supplement to the Astronomical Almanac" (1992).

The program first takes input for the fixed epoch and the epoch of the date. Using this, the program calculates the Euler angles and the terms in the transformation matrix P. The terms Hx, Kx, and Lx are the constants listed in Eq 4.5 for the Euler angles. The XX – ZZ variables are the matrix terms. Then, the program accepts input for RA in Hour Angle form and converts it to decimal degrees. DEC is also converted from sexagesimal to decimal degrees. Proper Motion input is in seconds/arcseconds per year. The transformation subroutine at #970 does seven calculations; Proper Motion correction, conversion of RA and DEC to radians, a Spherical to Rectangular coordinate transformation, the Precession transformation with matrix P, a return to Spherical coordinates, a quadrant check for the Arctangent function, and a return to decimal degrees. The program crosschecks itself by running the transformation subroutine both before and after the Proper Motion input, then recalculating the Proper Motion for output. Output is in standard formats for RA, DEC and Motions, but it is left to the operator to determine if there is a difference.

Program Listing:

```
10   REM   Rigorous Precession
20   REM     (J2000.0)
30   DEFDBL A–Z
40   Q1$="## ## ##.###"
50   Q2$="## ## ##.##"
60   Q3$="##.####": Q4$="##.###"
70   P1=4#*ATN(1#): R1=P1/180#
80   E0=2000#: A$="A"
90   CLS
100  INPUT "Initial epoch (yr)";IE
110  INPUT "Final epoch (yr)  ";FE
120  IF ABS(IE–FE)<=500 THEN 150
130  PRINT "Time span too long"
140  GOTO 110
150  CLS: GOSUB 660
155  IF A$="n" OR A$="N" THEN 210
160  PRINT "Initial epoch ";IE
170  PRINT "  R.A. (h,m,s)";
180  GOSUB 530: A=V
190  PRINT "  Dec. (d,m,s)";
200  GOSUB 530: D=V
210  MA=0: MD=0: GOSUB 970
220  A2=A1: D2=D1
225  IF A$="n" OR A$="N" THEN 270
230  PRINT "Proper motion in"
240  INPUT "  R.A. (sec/yr)   ";M1
250  INPUT "  Dec. (arcsec/yr)";M2
260  PRINT
270  MA=M1: MD=M2: GOSUB 970
280  V=A1: GOSUB 590
290  PRINT "Final epoch ";FE
300  PRINT "  R.A. (h,m,s): ";
310  PRINT USING Q1$;V1;V2;V3
320  V=D1: GOSUB 590
330  PRINT "  Dec. (d,m,s): ";S$;
340  PRINT USING Q2$;V1;V2;V3
350  A3=(A1–A2)*3600/NY
360  D3=(D1–D2)*3600/NY
370  PRINT "Proper motion in"
380  PRINT "  R.A. (sec/yr):    ";
390  PRINT USING Q3$;A3
400  PRINT "  Dec. (arcsec/yr):";
410  PRINT USING Q4$;D3
420  PRINT
430  PRINT "Select one:"
440  PRINT "  (A)nother star"
450  PRINT "  (N)ew final epoch"
460  PRINT "  (Q)uit"
470  INPUT A$
480  IF A$="a" OR A$="A" THEN 150
490  IF A$="n" OR A$="N" THEN 110
500  IF A$="q" OR A$="Q" THEN 520
510  GOTO 470
520  END
530  REM  INPUT SEXAGESIMAL
540  S=1: INPUT V$,V2,V3
550  IF LEFT$(V$,1)="–" THEN S=–1
560  V1=ABS(VAL(V$))
570  V=S*(V1+V2/60+V3/3600)
580  RETURN
590  REM  OUTPUT SEXAGESIMAL
600  S$="+": IF V<0 THEN S$="–"
```

```
610  V=ABS(V): V1=INT(V)
620  VM=60*(V–V1): V2=INT(VM)
```

Program Listing (Cont):

```
630  V3=60*(VM–V2)
640  RETURN
650  REM
660  REM  Precession parameters
670  NY=FE–IE
680  T0=(IE–E0)/100: T1=NY/100
690  T2=T1*T1:      T3=T1*T1*T1
700  H1=2306.2181#:  H2=1.39656
710  H3=–0.000139:   H4=0.30188
720  H5=–0.000345:   H6=0.017998
730  K1=1.09468:     K2=0.000066
740  K3=0.018203
750  L1=2004.3109#:  L2=–0.8533
760  L3=–0.000217:   L4=–0.42665
770  L5=–0.000217:   L6=–0.041833
780  W= (H1 +H2*T0 +H3*T0*T0)*T1
790  ZT= W +(H4 +H5*T0)*T2+H6*T3
800  ZD= W +(K1 +K2*T0)*T2 +K3*T3
810  TH= (L1 +L2*T0 +L3*T0*T0)*T1
820  TH= TH+(L4 +L5*T0)*T2 +L6*T3
830  ZT=ZT*R1/3600: ZD=ZD*R1/3600
840  TH=TH*R1/3600
850  REM  ZT,ZD,TH = Euler angles
860  REM
870  REM  Rotation matrix
880  S1=SIN(ZT): C1=COS(ZT)
890  S2=SIN(ZD): C2=COS(ZD)
900  S3=SIN(TH): C3=COS(TH)
910  XX=C1*C3*C2–S1*S2
920  YX=–S1*C3*C2–C1*S2: ZX=–S3*C2
930  XY=C1*C3*S2+S1*C2
940  YY=–S1*C3*S2+C1*C2: ZY=–S3*S2
950  XZ=C1*S3: YZ=–S1*S3: ZZ=C3
960  RETURN
970  REM  Proper–motion correction
980  A0=(A+MA*NY/3600)*15*R1
990  D0=(D+MD*NY/3600)*R1
1000 REM
1010 REM  Spherical—> rectangular
1020 SA=SIN(A0): CA=COS(A0)
1030 SD=SIN(D0): CD=COS(D0)
1040 X0=CA*CD: Y0=SA*CD: Z0=SD
1050 REM   3–D transformation
1060 X1=X0*XX+Y0*YX+Z0*ZX
1070 Y1=X0*XY+Y0*YY+Z0*ZY
1080 Z1=X0*XZ+Y0*YZ+Z0*ZZ
1090 REM  Rectangular—> spherical
1100 A1=ATN(Y1/X1)
1110 IF X1<0 THEN A1=A1+P1
1120 IF A1<0 THEN A1=A1+2*P1
1130 A1=A1/(R1*15): REM Final R.A.
1140 D1=ATN(Z1/SQR(X1*X1+Y1*Y1))
1150 D1=D1/R1: REM  Final Dec.
1160 RETURN
2000 REM
2010 REM   This program for precessing a star's coordinates is described in
Sky & Telescope for October, 1991, page 408.  It was written by Zbigniew S.
Krzeminski.
```

Anomaly of the Sun for an Observing Day

Written by David E. Grilley, 6 Oct 97; based on Table 30.B, page 203, in Meeus (1991). The tabulated data for Earth's orbit is itself based on P. Bretagnon's 1982 work on planetary theory "Variations Séculaires des Orbites Planétaires" or VSOP82. Figure 15 shows the angular relationships described in VSOP82 and discussed in Meeus' work in chapter 30, "Elements of the Planetary Orbits."

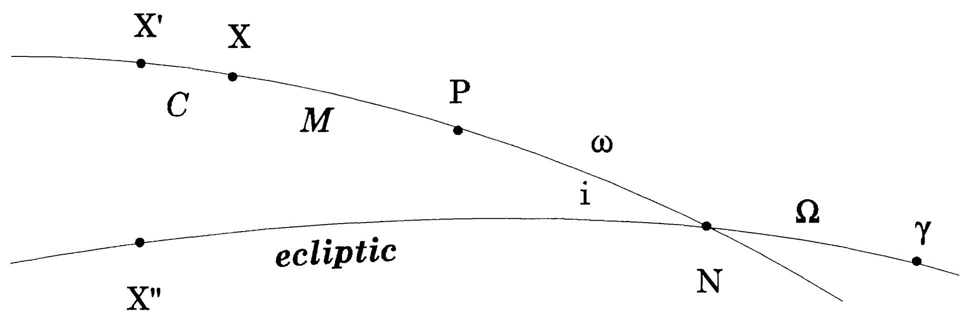


Figure 16: Angle Relationships used in VSOP82[69]

The arc $\gamma NX''$ is a part of the ecliptic as seen from the Sun, and $NPXX'$ is a part of the orbit of the planet (earth in this case) (the intersection of the planet's orbital plane with the celestial sphere). γ is the vernal equinox (longitude 0°), N the ascending node of the orbit, P the planet's perihelion. At a given instant, the mean planet is at X, the true planet at X'. Then we have:

Ω = arc γN = longitude of the ascending node,

ω = arc NP = argument of the perihelion,

$\pi = arc\ \gamma N + arc\ NP = \Omega + \omega =$ *longitude of the perihelion,*

$L = arc\ \gamma N + arc\ NX = \Omega + \omega + M =$ *mean longitude of the planet,*

$M = arc\ PX =$ *planet's mean anomaly,*

$C = arc\ XX' =$ *equation of the center,*

$\nu = arc\ PX' = M + C =$ *planet's true anomaly,*

$i =$ *inclination of the orbit = angle between arcs NP and NX".*[70]

The tabulated data provides a means to calculate M, and *e* (eccentricity). Then, the program iterates Kepler's equation for the Earth's orbit to provide the eccentric anomaly of the Earth's position. This value is used in the Excel spreadsheet (Appendix 3) to determine the Sun longitude and radius vector and the heliocentric correction of time for the observations. Because the change in heliocentric correction is less than the timing precision of the observations through a full night, the program uses an average value of the time for each night of observation. Kepler's equation is discussed in Appendix A.

The baseline values of the Earth's orbit are for January 1.5, 2000. The variables used in the program are:

JD0 = 2451545; the Julian day (JD) for 1.5 Jan 2000.

JD1 is the average JD of the observations

T is the Julian Century from JD0.

ECC is *e*, the eccentricity of the Earth's orbit

M is the Mean anomaly

E is the eccentric anomaly = M + ECC * SIN(E)

Although strictly unnecessary, each value is reduced to an angle between 0 and 360 before further use.

Program Listing:

```
'    Anomaly of the Sun for an Observing day
'     Based on techniques and tables found in
'     "Astronomical Algorithms" by Meeus.
'
10   DEFDBL A-Z
20   JD0 = 2451545#
25   CLS
'
' Enter an average value of JD
'
30   INPUT " Enter the average Julian Date of the observation: ", JD1
40   T = (JD1 - JD0) / 36525 ' Calculate the Julian Century from J2000.0
50   CONST PI = 3.1415926536#
'
'   Calculate the Mean anomaly, convert to radians
'
60   M = 357.5291# + 35999.0503# * T - .0001559# * T ^ 2
61   IF M > 0 THEN
62     DO UNTIL M < 360!
63       M = M - 360
64     LOOP
```

Program Listing (Cont):

```
65   ELSEIF M < 0 THEN
66     DO UNTIL M >= 0!
67       M = M + 360
68     LOOP
69   END IF
70   M = M * PI / 180
'
'    Calculate the Earth's eccentricity
80   ECC = .016708617# - .000042037# * T - .0000001236# * T ^ 2
'
'    Iterate Kepler's equation to find the eccentric anomaly
100  E = M        ' First approximation
110  CHECK = 0: I = 0
120  DO UNTIL (ABS(CHECK - E) < .0000001)
130    CHECK = E
140    E = M + ECC * SIN(E)
150    I = I + 1
160    IF I = 200 GOTO 180
170  LOOP
180  E = E * 180 / PI        ' Convert to degrees
181   IF E > 0 THEN
182     DO UNTIL E < 360!
183       E = E - 360
184     LOOP
185   ELSEIF E < 0 THEN
186     DO UNTIL E >= 0!
187       E = E + 360
188     LOOP
189   END IF
200  PRINT USING "The eccentric anomaly is: ######.########"; E
210  END
```

Period determination program

"PER&MIN3.BAS"
Written by David E. Grilley, and Michael H. Grilley, 28 Oct 96

```
REM %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
REM
REM         Period and minimum determination program
REM         David E. Grilley, 5 Oct 96
REM %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
REM
'   First get the data
'   Data must be in an ascii file as Julian date, Delta mag, ....
'
10  CLS : DEFDBL A-Z
20  SCREEN 12: COLOR 11
30  LOCATE 10, 1: INPUT "Enter Path and Filename:"; DATA$
37  LOCATE 13, 1: PRINT "Chose limits bounding any previously published
period."
40  LOCATE 14, 1: INPUT "Enter a lower limit for the Period:(decimal days)
"; LOWER#
50  LOCATE 15, 1: INPUT "Enter an upper limit for the Period:(decimal
days) "; EPH#
55  LOCATE 17, 1: PRINT USING "Recommended stepsize is ##.#######";
(EPH# - LOWER#) / 50
60  LOCATE 18, 1: INPUT "Enter the desired stepsize: "; INC#
70  LOCATE 23, 10: PRINT "... Standby ..."
75  LT = 60: RT = 564: BT = 360: TP = 40  ' Graph boundaries
'   LT minimum is 60, TP min is 32 to allow labels.
110 OPEN DATA$ FOR INPUT AS #1
'      How big is the file
111 COUNT = 0
112 DO
```

```
113   INPUT #1, TEMP$
114   COUNT = COUNT + 1
115 LOOP UNTIL (EOF(1))
116 COUNT = COUNT / 2
117 CLOSE #1
118 OPEN DATA$ FOR INPUT AS #2
120 DIM SHARED POINTS(COUNT, 2) AS DOUBLE
'             FILL IN THE ARRAY WITH FILE
130 SIZE = 0
140 DO
150   FOR J = 0 TO 1
160     INPUT #2, TEMP$
165     POINTS(SIZE, J) = VAL(TEMP$)
170   NEXT J
175   SIZE = SIZE + 1
180 LOOP UNTIL (EOF(2))
185 CLOSE #2
'     SIZE COUNTED THE DATA ARRAY ROWS ENTERED
210 DIM SHARED PHASE(COUNT, 2) AS DOUBLE
250 NUM = (EPH# - LOWER#) / INC#
270 DIM SHARED PERIOD(NUM, 3) AS DOUBLE
280 N = 0: EST# = LOWER#
290 DO WHILE EST# < EPH#
'     This sets up the loop to try stepped periods.
'     300-550 Convert and sort the data based on assumed period, EST#.
300   I = 0
305   DO WHILE I < SIZE
310     PHASE(I, 0) = POINTS(I, 0)
315     PHASE(I, 1) = POINTS(I, 1)
320     I = I + 1
325   LOOP
'         Fold the data into a single phase.
```

```
330  I = 0
340  DO WHILE I < SIZE
350    HOLD = (PHASE(I, 0) - POINTS(0, 0)) / EST#
360    PHASE(I, 0) = HOLD - INT(HOLD)
380    I = I + 1
390  LOOP
'         Sort the Phase array
450  FOR I = 0 TO (SIZE - 2)
460    P = PHASE(I, 0): M = PHASE(I, 1) ' Keep both elements of the array
470    K = I
480    FOR J = I + 1 TO (SIZE - 1)
490       IF PHASE(J, 0) < P THEN
495          P = PHASE(J, 0): M = PHASE(J, 1)
500          K = J
505       END IF
510    NEXT J
520    A = PHASE(I, 0): B = PHASE(I, 1)
530    PHASE(I, 0) = P: PHASE(I, 1) = M
540    PHASE(K, 0) = A: PHASE(K, 1) = B
550  NEXT I
'   Phase angle conversion and sorting end here.
'   The next procedure sets the assumed period, and sums the line segments.
600  PERIOD(N, 0) = EST#: LENGTH1 = 0#: LENGTH2 = 0#
610  FOR J = 0 TO SIZE - 2
620    C = PHASE(J, 0): D = PHASE(J + 1, 0)
630    E = PHASE(J, 1): F = PHASE(J + 1, 1)
640    S1 = SQR((C - D) ^ 2 + (E - F) ^ 2)
'
'        The two tests used may generate a set of estimated periods where
'      individual data points are not reordered in the array.  640 selects
'      the minimum value of this set.
'        645 Uses the method of Bopp, Evans and Laing (1970) and does
```

```
'       not discriminate past the 1st value of the set.
'       Use both methods to find the bounds for the estimated period.
'       Some data may hit the minimum 1st and not generate a range..
'
645      S2 = ABS(E - F)
650      LENGTH1 = LENGTH1 + S1
655      LENGTH2 = LENGTH2 + S2
660    NEXT J
670    PERIOD(N, 1) = LENGTH1: PERIOD(N, 2) = LENGTH2
'      PRINT N, PERIOD(N, 0), PERIOD(N, 1), PERIOD(N, 2)
680    EST# = EST# + INC#
690    N = N + 1
700  LOOP               ' Goes back to 290
'
'       Search the array for the min/max value of LENGTH 1/2
'
710  K1 = 0: K3 = 0: PER1 = PERIOD(0, 1): UL = PERIOD(0, 1)
715  K2 = 0: PER2 = PERIOD(0, 2)
720  FOR I = 0 TO NUM
730    IF PERIOD(I, 1) < PER1 AND PERIOD(I, 1) > 0 THEN
735      PER1 = PERIOD(I, 1): K1 = I
740    END IF
745    IF PERIOD(I, 2) < PER2 AND PERIOD(I, 2) > 0 THEN
750      PER2 = PERIOD(I, 2): K2 = I
755    END IF
760    IF PERIOD(I, 1) > UL THEN
770      UL = PERIOD(I, 1): K3 = I
780    END IF
790  NEXT I
800  CLS  '        Print a graph of Length vs Period to screen
805  XSCALE = (EPH# - LOWER#) / (RT - LT): LL = LOWER#
810  YSCALE = (UL - PER1) / (.9 * (BT - TP))
```

```
820  LINE (LT, TP)-(RT, BT), 9, B: COLOR 11
825  CALC1 = ((BT - (.05 * BT)) - CINT((PERIOD(K1, 1) - PER1) / YSCALE))
827  CALC3 = ((BT - (.05 * BT)) - CINT((PERIOD(K3, 1) - PER1) / YSCALE))
830  LOCATE (INT(TP / 16) - 1), 20: PRINT "Polygonal Length vs Period Test
Value"
831  LOCATE (INT((TP + BT) / 32) + 1), 1: PRINT "Length"
835  INC1 = (CALC1 - CALC3) / 4: INC2 = (RT - LT) / 4: LT1 = LT: CC =
CALC3
840  DO WHILE CC < BT
845       LINE (LT - 4, CC)-(LT + 4, CC), 9
847       LINE (LT1, BT - 4)-(LT1, BT + 4), 9
850       CC = CC + INC1:  LT1 = LT1 + INC2
855  LOOP
860  LOCATE (INT(BT / 16) + 2), (INT(LT / 8) - 4)
865    PRINT USING "##.#####"; LOWER#
870  LOCATE (INT(BT / 16) + 2), (INT(RT / 8) - 4)
875    PRINT USING "##.#####"; EPH#
876  LOCATE (INT(BT / 16) + 3), (INT((LT + RT) / 16) - 7)
877    PRINT "Assumed Period"
880  LOCATE (INT(CALC1 / 16) + 1), 1
881    PRINT USING "#.#####"; PERIOD(K1, 1)
890  LOCATE (INT(CALC3 / 16) + 1), 1
891    PRINT USING "#.#####"; PERIOD(K3, 1)
910  FOR I = 0 TO NUM - 1
920   XP1 = LT + CINT((PERIOD(I, 0) - LL) / XSCALE)
930   YP1 = ((BT - (.05 * BT)) - CINT((PERIOD(I, 1) - PER1) / YSCALE))
935   YP2 = ((BT - (.05 * BT) + 1) - CINT((PERIOD(I, 2) - PER2) / YSCALE))
940   PSET (XP1, YP1), 15: PSET (XP1, YP2), 14
950  NEXT I
980  LOCATE (INT(BT / 16) + 5), 5: COLOR 12
985  EPHEMERIS# = (PERIOD(K1, 0) + PERIOD(K2, 0)) / 2
987  VAR# = (PERIOD(K1, 0) - PERIOD(K2, 0)) / 2
```

```
990 PRINT USING "The estimated period is: ##.#######, +/- #.########";
EPHEMERIS#; VAR#
1000 LOCATE (INT(BT / 16) + 6), 5: PRINT "Press any key to continue..."
1010 WHILE INKEY$ = "": WEND
'
'       The next sequence plots the data based on the best period.
'
1300  I = 0
1305  DO WHILE I < SIZE
1310    PHASE(I, 0) = POINTS(I, 0)
1315    PHASE(I, 1) = POINTS(I, 1)
1320    I = I + 1
1325  LOOP
'         Fold the data into a single phase.
1330  I = 0
1340  DO WHILE I < SIZE
1350    HOLD = (PHASE(I, 0) - POINTS(0, 0)) / EPHEMERIS#
1360    PHASE(I, 0) = HOLD - INT(HOLD)
1380    I = I + 1
1390  LOOP
'           Sort the Phase array, and find min/max mags
1440  MINMAG = PHASE(0, 1): MAXMAG = PHASE(0, 1)
'      Note: 'MINMAG' is the lowest value of Delta Magnitude
'          and is the brightest luminosity....
1450  FOR I = 0 TO (SIZE - 2)
1460    P = PHASE(I, 0): M = PHASE(I, 1) ' Keep both elements of the array
1470    K = I
1480    FOR J = I + 1 TO (SIZE - 1)
1490       IF PHASE(J, 0) < P THEN
1495          P = PHASE(J, 0): M = PHASE(J, 1)
1500          K = J
1505       END IF
```

```
1510     NEXT J
1520     A = PHASE(I, 0): B = PHASE(I, 1)
1530     PHASE(I, 0) = P: PHASE(I, 1) = M
1540     PHASE(K, 0) = A: PHASE(K, 1) = B
1545     IF PHASE(I, 1) < MINMAG THEN
1550        MINMAG = PHASE(I, 1): K4 = I
1560     END IF
1565     IF PHASE(I, 1) > MAXMAG THEN
1570        MAXMAG = PHASE(I, 1): K5 = I
1575     END IF
1580   NEXT I
'
'        Set the graphics
1700 XSCALE1 = 1 / (RT - LT): LL = 0
1705 IF MINMAG > 0 THEN
1710     MIN = (FIX(10 * MINMAG) + 1) / 10
1715     MAX = (FIX(10 * MAXMAG) + 1) / 10
1720   ELSEIF MAXMAG < 0 THEN
1725     MIN = (FIX(10 * MINMAG) - 1) / 10
1730     MAX = (FIX(10 * MAXMAG) - 1) / 10
1735   ELSE
1740     MIN = (FIX(10 * MINMAG) - 1) / 10
1745     MAX = (FIX(10 * MAXMAG) + 1) / 10
1750   END IF
1755 RANGE = ABS(MIN) + ABS(MAX)
1760 YSCALE1 = RANGE / (BT - TP)
1800 CLS : LINE (LT, TP)-(RT, BT), 9, B: COLOR 11
1805 LOCATE (INT(TP / 16) - 1), 26: PRINT "Lightcurve for this Data"
1810 ZERO = TP + ABS(MIN) / YSCALE1
1815 LINE (LT, ZERO)-(RT, ZERO), 1
1820 LOCATE (INT(ZERO / 16) + 1), 1: PRINT USING "#.###"; 0
1835 INC1 = (BT - TP) / 4: INC2 = (RT - LT) / 4
```

```
1837 LT1 = LT: CC = ZERO - INC1: PP = 0!
1840 DO UNTIL CC > BT
1845      LINE (LT - 4, CC)-(LT + 4, CC), 9
1847      LINE (LT1, BT - 4)-(LT1, BT + 4), 9
1848      LOCATE (INT(BT / 16) + 2), (INT(LT1 / 8) - 1)
1849      PRINT USING "#.##"; PP
1850      CC = CC + INC1:  LT1 = LT1 + INC2: PP = PP + .25
1855 LOOP
1870 LOCATE (INT(BT / 16) + 2), (INT(RT / 8) - 1)
1875   PRINT USING "#.##"; 1
1876 LOCATE (INT((TP + BT) / 32) + 1), 1: PRINT "Delta m"
1877 LOCATE (INT(BT / 16) + 3), (INT((LT + RT) / 16) - 5)
1878   PRINT "Phase Angle"
1880 LOCATE (INT(TP / 16) + 1), 1
1881   PRINT USING "#.###"; MIN
1890 LOCATE (INT(BT / 16) + 1), 1
1891   PRINT USING "#.###"; MAX
'         Plot the points
1900 FOR I = 0 TO SIZE
1910   XP1 = CINT((PHASE(I, 0)) / XSCALE1) + LT
1920   YP1 = CINT((PHASE(I, 1)) / YSCALE1) + ZERO
1930   PSET (XP1, YP1), 15
1940 NEXT I
1945 STARTTIME = TIMER
'
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'%% Begin Kwee and Van Woerden method for minimum determination  %%
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'
2000 WHILE (TIMER - STARTTIME) < 5: WEND
```

```
DEF FNB (L AS INTEGER, U AS DOUBLE) = (PHASE(L - 1, 1) *
(PHASE((L), 0) - U) + PHASE((L), 1) * (U - PHASE(L - 1, 0))) / (PHASE((L),
0) - PHASE(L - 1, 0))
2010  LOCATE (INT(BT / 16) + 5), 1
     INPUT "Enter an approximate phase for the minimum: "; TT#
    LOCATE (INT(BT / 16) + 6), 1
     INPUT "Enter the Julian date modifier for this data: "; HJD0
    IF TT# < .06 OR TT# > .94 THEN
      LOCATE (INT(BT / 16) + 5), 1: PRINT "The first data point is too close
to a minimum"
      END
    END IF
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'%%  Count the points near the reflection axis.  %%
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
2100  N1 = 0
    IF TT# < .5 THEN
      R1 = 2 * TT# / 3
    ELSE R1 = 2 * (1 - TT#) / 3
    END IF
    IF R1 > .11 THEN R1 = .11
    FOR I = 0 TO (SIZE - 2)
      IF PHASE(I, 0) > (TT# - R1) AND PHASE(I, 0) < (TT#) THEN
        NL = NL + 1
      END IF
      IF PHASE(I, 0) > (TT#) AND PHASE(I, 0) < (TT# + R1) THEN
        NU = NU + 1
      END IF
    NEXT I
      IF NL < NU THEN
        N1 = 2 * NL + 1
      ELSE
```

```
        N1 = 2 * NU + 1
      END IF
'
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'%%  Set the reflection axis, and stepsize for the minimum search.%%
'%%  Need 2n+1 values for N1                                    %%
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'
2200  I = 0
    DO UNTIL PHASE(I, 0) > (TT# - R1)
      I = I + 1
    LOOP: I1 = I - 1           'I1 is the start point
    IF I1 + N1 > SIZE - 1 THEN N1 = SIZE - I1 - 1
    IF N1 MOD 2 = 0 THEN N1 = N1 - 1
    N2 = (N1 - 1) / 2
    D = 2 * R1 / (N1 + 1)       ' D is the stepsize
    J3 = 0: J4 = 0: J5 = 0
'
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'%%  Starts the delta m interpolations  %%
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'
2300  J = -1 / 2: J2 = 0
    DO UNTIL J > (1 / 2)
      S = 0: T1 = TT# + J * D
      FOR J1 = 1 TO N2
        T2 = T1 - J1 * D: T3 = T1 + J1 * D: K1 = I1
        DO UNTIL PHASE(K1, 0) >= T2
          K1 = K1 + 1
        LOOP
        IF PHASE(K1, 0) = T2 THEN
          M2 = PHASE(K1, 1)
```

```
            ELSE
               M2 = FNB(K1, T2)
            END IF
            DO UNTIL PHASE(K1, 0) >= T3
               K1 = K1 + 1
            LOOP
            IF PHASE(K1, 0) = T3 THEN
                M3 = PHASE(K1, 1)
            ELSE
                M3 = FNB(K1, T3)
            END IF
            S = S + (M2 - M3) ^ 2
         NEXT J1
         SUM(J2, 0) = T1: SUM(J2, 1) = S
         J = J + (1 / 2): J2 = J2 + 1
      LOOP
      J3 = J3 + 1
      IF J3 > 8 THEN
         PRINT "Cannot isolate a reflection axis. Try a different initial value."
         GOTO 2010
      END IF
'
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'%%  Test the reflection axis.  %%
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'
2400  IF SUM(1, 1) > SUM(0, 1) THEN
         TT# = TT# - (D / (J5 + 1)): J4 = J4 + 1: GOTO 2300
      ELSEIF SUM(1, 1) > SUM(2, 1) THEN
         TT# = TT# + (D / (J4 + 1)): J5 = J5 + 1: GOTO 2300
      END IF
'
```

```
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'%%  Found a good reflection axis. Now load a matrix to solve  %%
'%%  S(T)= A*T^2 + B*T + C; T= TT#, TT#+D/2, TT#-D/2          %%
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'
2500  FOR I = 0 TO 3
        D1(I, 0) = SUM(I, 0) ^ 2: D1(I, 1) = SUM(I, 0)
        D1(I, 2) = 1: D1(I, 3) = SUM(I, 1)
      NEXT I
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'%%  Find the determinant FOR D1(3x3).  %%
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
2600  D9 = D1(0, 0) * (D1(1, 1) * D1(2, 2) - D1(1, 2) * D1(2, 1))
      D8 = D1(0, 1) * (D1(1, 0) * D1(2, 2) - D1(1, 2) * D1(2, 0))
      D7 = D1(0, 2) * (D1(1, 0) * D1(2, 1) - D1(1, 1) * D1(2, 0))
      D9 = D9 - D8 + D7
      IF D9 = 0 THEN
        LOCATE 22, 1: PRINT "No solutions for this method."
        END
      END IF
2700  A1 = D1(0, 1) * (D1(1, 2) * D1(2, 3) - D1(1, 3) * D1(2, 2))
      A2 = D1(0, 2) * (D1(1, 1) * D1(2, 3) - D1(1, 3) * D1(2, 1))
      A3 = D1(0, 3) * (D1(1, 1) * D1(2, 2) - D1(1, 2) * D1(2, 1))
      A = (A1 - A2 + A3) / D9
      B1 = D1(0, 0) * (D1(1, 3) * D1(2, 2) - D1(1, 2) * D1(2, 3))
      B2 = D1(0, 2) * (D1(1, 0) * D1(2, 3) - D1(1, 3) * D1(2, 0))
      B3 = D1(0, 3) * (D1(1, 0) * D1(2, 2) - D1(1, 2) * D1(2, 0))
      B = (B1 + B2 - B3) / D9
      C1 = D1(0, 0) * (D1(1, 1) * D1(2, 3) - D1(1, 3) * D1(2, 1))
      C2 = D1(0, 1) * (D1(1, 0) * D1(2, 3) - D1(1, 3) * D1(2, 0))
      C3 = D1(0, 3) * (D1(1, 0) * D1(2, 1) - D1(1, 1) * D1(2, 0))
      C = (C1 - C2 + C3) / D9
```

```
    S0 = C - (B ^ 2) / (4 * A)  ' The parabolic minimum.
    T0 = -(B / (2 * A))          ' Value of Phase at S0.
    Z = N1 / 4
    E = SQR(ABS((4 * A * C - (B ^ 2)) / (4 * (A ^ 2) * (Z - 1))))
'      E is the mean error in epoch T0.
'
'    %%%%%%%%%%%%%%%%%%%%%%%%%%
'    %%  Set the graphics  %%
'    %%%%%%%%%%%%%%%%%%%%%%%%%%
'
2800  LOCATE (INT(BT / 16) + 5), 1
    PRINT USING "The Kwee and Van Woerden method minimum occurs at
#.##### phase angle"; T0
    LOCATE (INT(BT / 16) + 6), 1
    HJD0 = HJD0 + POINTS(0, 0) + T0 * EPHEMERIS#
    PRINT USING "This is Heliocentric Julian Day #######.#########";
HJD0
2900  X0 = T0 / XSCALE1 + LT
    Y0 = S0 / YSCALE1 + ZERO
    XP2 = ((T0 - R1) / XSCALE1) + LT
    YP2 = Y0 - ((A * ((T0 - R1) ^ 2)) + (B * (T0 - R1)) + C)
    CIRCLE (X0, Y0), 3, 4
    FOR I = (T0 - R1) TO (T0 + R1) STEP .01
      XP3 = (I / XSCALE1) + LT
      YP3 = Y0 - ((A * (I ^ 2)) + (B * I) + C)
      LINE (XP2, YP2)-(XP3, YP3), 4
      XP2 = XP3
      YP2 = YP3
    NEXT I
3000  END
```

APPENDIX C

DATA OUTPUT

I. Output Screens from Period Determination

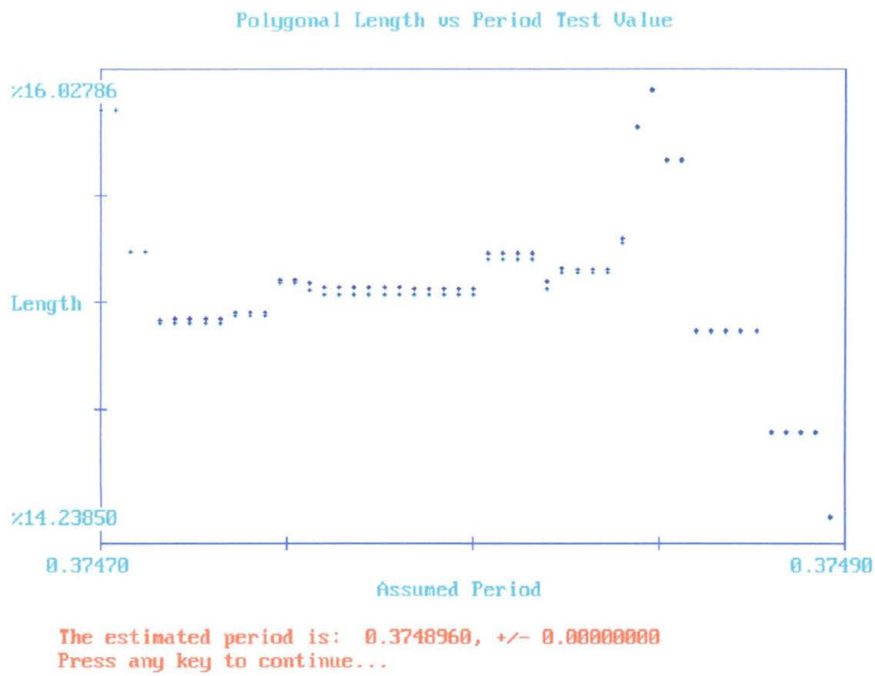
Screens 1-4 contain original uncorrected data points.

Screens 5-6 show the 62 data points corrected for k' and k".

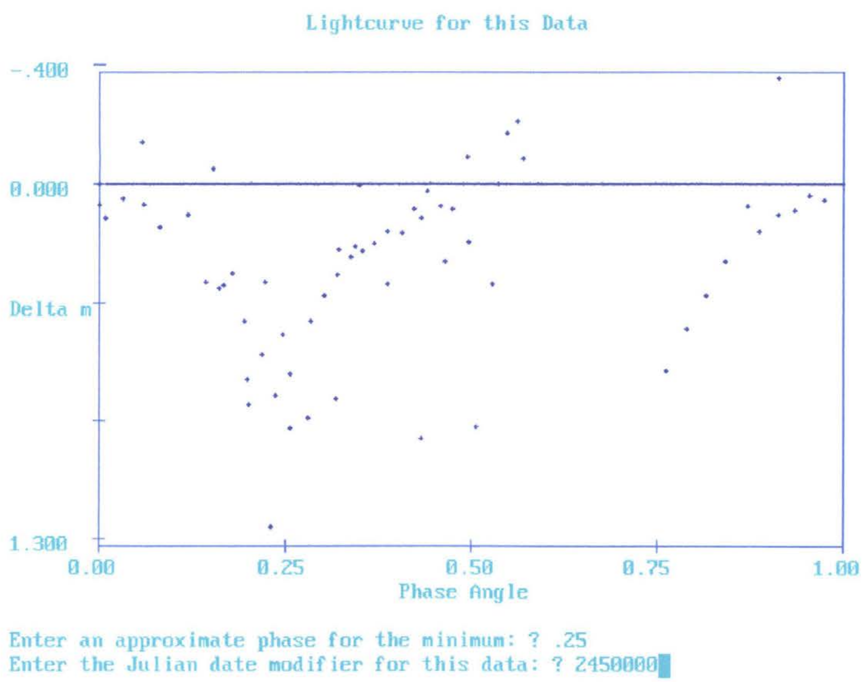
Screens 7-8 show the 42 data points with the least error.

```
Enter Path and Filename:? C:\MYDOCU~1\THESIS\GRIZZV1.DAT


Chose limits bounding any previously published period.
Enter a lower limit for the Period:(decimal days) ? .3747
Enter an upper limit for the Period:(decimal days) ? .3749

Recommended stepsize is  0.0000040
Enter the desired stepsize: ? .000004
```

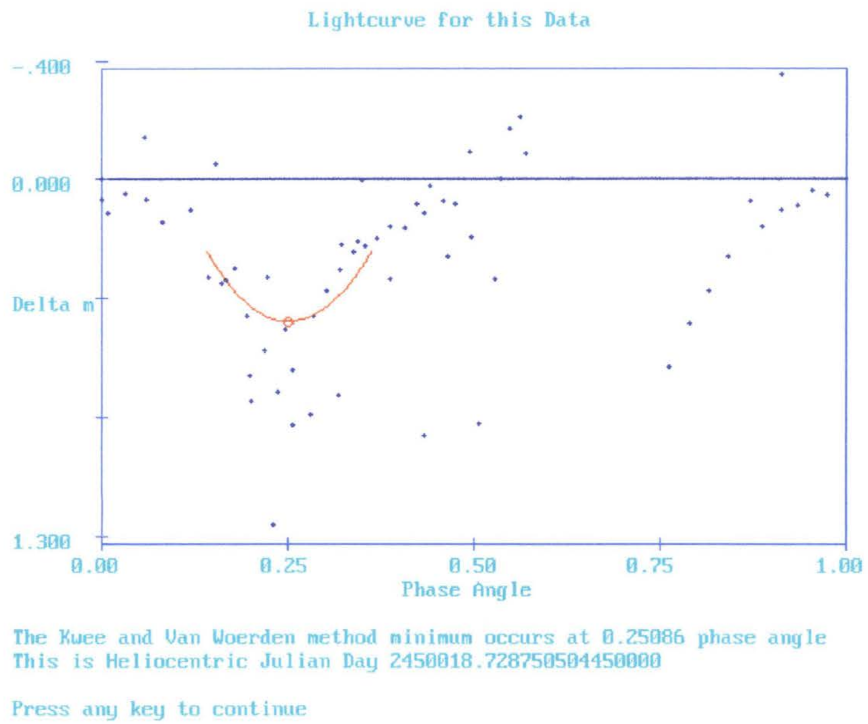
Screen 1.



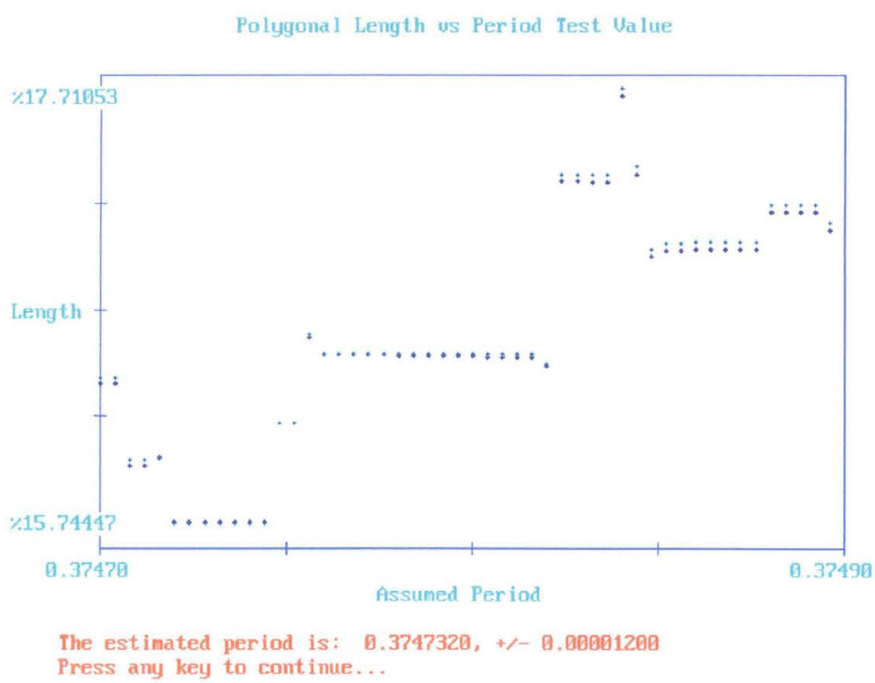
Screen 2.



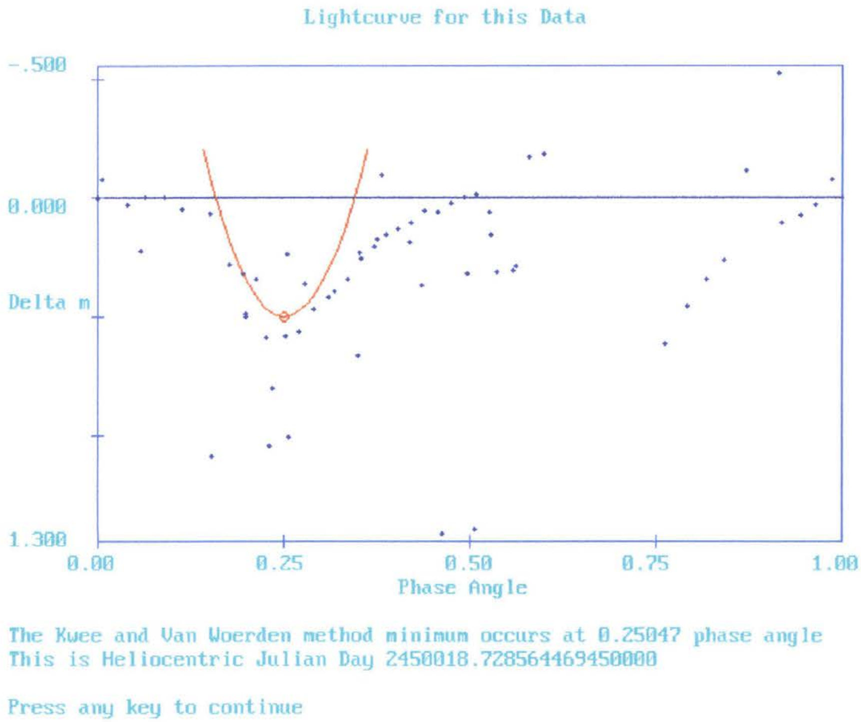
Screen 3.



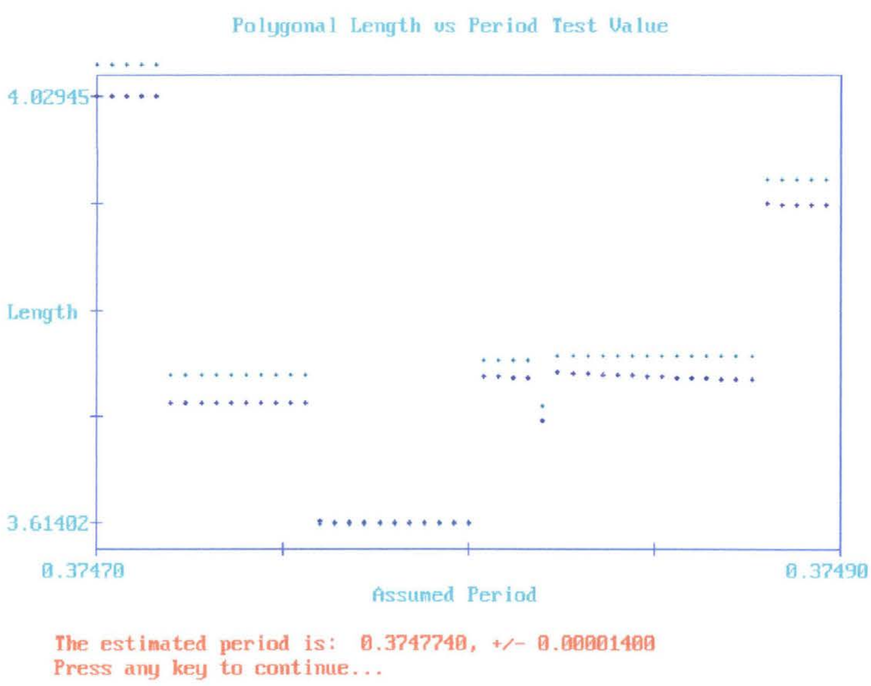
Screen 4.



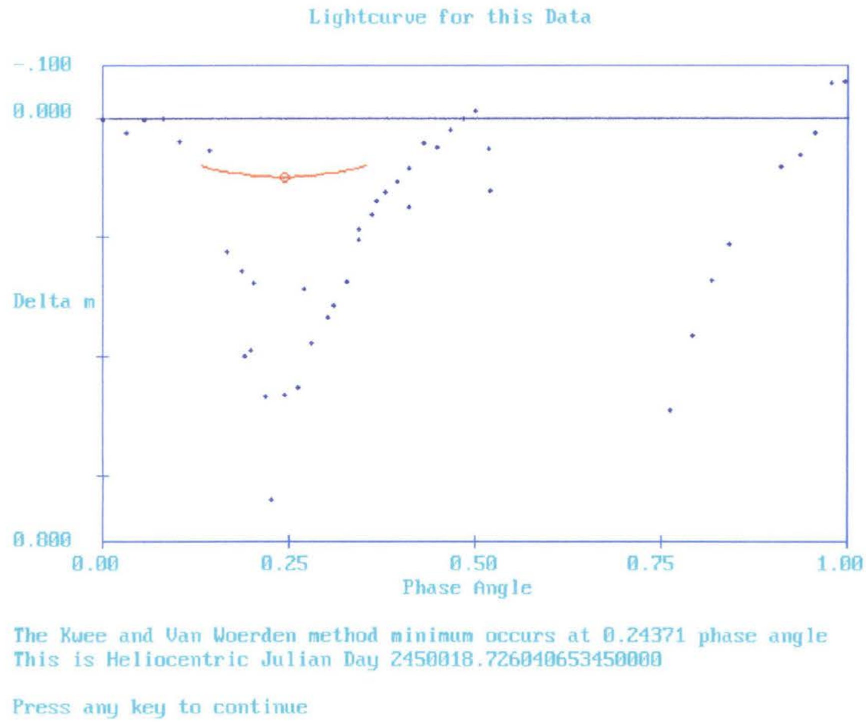
Screen 5.



Screen 6.



Screen 7.


Lightcurve for this Data
-.100
0.000
Delta m
0.800
0.00
0.25
0.50
0.75
1.00
Phase Angle
The Kwee and Van Woerden method minimum occurs at 0.24371 phase angle
This is Heliocentric Julian Day 2450018.726040653450000
Press any key to continue

Screen 8.

II. Constants, Equations and Variables

Constants, Daily Variables, and Day Calculations

Constants and Variables valid for the entire period of observation.

Julian Year, Y =	1995		A ≡	INT(Y/100) =	19
Epoch of Observations, JY =	1995.87		B ≡	2 - A + INT(A/4) =	-13
Avg JD for all Obs, JD =	2450033.151		1 sec/JDay=	0.000011574074	
Avg Julian Century, T =	-0.041392172		T ≡	(JD - 2451545.0)/36525	
Dynamical Time Corr, ΔT =	61.4	s	=	0.000710648 JD	
Earth's Semi-Major Axis a =	1.000001018	a.u.			
Observatory Latitude (N) Lat =	39.006500	degrees		0.680791855 radians	
Obs Longitude (W) Long =	104.881500	degrees		1.830527499 radians	

Star	SAO #	J2000 RA	J2000 DEC	Δ RA s/yr	Δ DEC arcsec/yr
U Peg	108933	23h 57m 58.4s	N15° 57' 08"	-0.0025	-0.06200
Comp	108930	23h 57m 45.6s	N15° 28' 22"	0.0018	-0.03600
Check	108949	23h 59m 50.7s	N15° 46' 59"	0.0003	-0.00500

Dead Time Calculations	Fa	Fb	Ba	Bb	R
	67560	2841	1846037	120776	23.78047636
	d =	1.93526E-07			

2nd Order Extinction k" = -0.6

Formulas for the Elements for the Standard Equinox J2000.0

Mean Longitude of Sun, Ls	= 280°.466449 + 36000°.76983*T + 0°.0003032*T^2
The mean longitude of the Sun minus the longitude of the Sun's perigee *l'*	= 357°.52772 + 35999°.05034*T - 0°.00016*T^2 - 0°.000003*T^3
Mean Anomaly of Sun, Ms	= 357°.52910 + 35999°.05030*T – 0°.0001559*T^2
Mean Longitude of Moon, L'	= 218°.3165 + 481267°.8813*T
The mean longitude of the Moon minus the longitude of the Moon's perigee *l*	= 134°.96298 + 477198°.86739*T + 0.00869*T^2 + 0.00001*T^3
The mean longitude of the Moon minus the longitude of the Moon's node F	= 93°.27191 + 483202°.01753*T - 0°.00368*T^2 + 0°.000003*T^3
The mean elongation of the Moon from the Sun D	= 297°.85036 + 445267°.11148*T - 0°.00191*T^2 + 0°.000005*T^3

Constants, Equations and Variables

Long. Of Ascending Node of the Moon's Orbit, Ω	= 135°.04452 – 1934°.136261*T + 0°.0020708*T^2 + 0.000002*T^3
Mean Obliquity of the Ecliptic εo	= 23°.439291 – 0°.01300417*T – 0°.00000016*T^2 +.0000005*T^3
Nutation in Obliquity, Δε	= SUM of Ci*CosAi (Worksheet "Nutation")
Nutation in Longitude, Δψ	= SUM of Si*SinAi (Worksheet "Nutation")
Eccentricity of Earth, e	= 0.016708617 – 0.000042037*T – 0.0000001236*T^2
Eccentric Anomaly of the Sun E	= E = Ms + e*SinE (Basic Program Output)
Radius of the Sun, Rs	= a*(1-ecosE)
Heliocentric Correction, Δt	= -0.0057755*Rs*(Cos(Ls)*Cos(RA)*Cos(Dec) + Sin(Ls)*(Sin(e)*Sin(Dec) + Cos(e)*Cos(Dec)*Sin(RA)))
Apparent Sidereal Time Correction Δst	= Δψ * Cosε Degrees
Sidereal Time (degrees) LST	= 280.46061837 + 360.98564736629 x (JDE – 2451545.0) + 0.000387933 x T^2 – T^3 / 38710000 – Long + Δstx

Constants valid for each Day

Gregorian Date:	28-Oct-95	29-Oct-95	23-Nov-95	24-Nov-95	26-Nov-95
Month:	10	10	11	11	11
Day:	28	29	23	24	26
Mid-Obs UT:	5:30:00	4:30:00	4:00:00	4:00:00	2:45:00
Mid-Obs JD:	2450018.729167	2450019.687500	2450044.666667	2450045.666667	2450047.614583
Mid-Obs JDE:	2450018.729877	2450019.688211	2450044.667377	2450045.667377	2450047.615294
Julian Century Tx	-0.041786999	-0.041760761	-0.041076869	-0.04104949	-0.040996159
Processed Coordinates:					
Upeg RA	23h 57m 45.587s	23h 57m 45.594s	23h 57m 45.805s	23h 57m 45.815s	23h 57m 45.830s
Upeg Dec	15° 55' 44.58"	15° 55' 44.62"	15° 55' 46.00"	15° 55' 46.06"	15° 55' 46.16"
Comparison RA	23h 57m 32.771s	23h 57m 32.777s	23h 57m 32.989s	23h 57m 32.998s	23h 57m 33.013s
Comparison Dec	15° 26' 58.47"	15° 26' 58.51"	15° 26' 59.89"	15° 26' 59.95"	15° 27' 0.05"
Check RA	23h 59m 37.863s	23h 59m 37.869s	23h 59m 38.081s	23h 59m 38.090s	23h 59m 38.106s
Check Dec	15° 45' 35.34"	15° 45' 35.38"	15° 45' 36.76"	15° 45' 36.82"	15° 45' 36.92"
Convert Coordinates to Decimal Degrees (0.003" precision):					
Upeg RA	359.439946	359.439975	359.440854	359.440896	359.440958
Upeg Dec	15.929050	15.929061	15.929444	15.929461	15.929489
Comparison RA	359.386546	359.386571	359.387454	359.387492	359.387554
Comparison Dec	15.449575	15.449586	15.449969	15.449986	15.450014
Check RA	359.907763	359.907788	359.908671	359.908708	359.908775

Check Dec	15.759817	15.759828	15.760211	15.760228	15.760256
Error / Hour	-0.000001 RA		-4.830918E-07 Dec		

Other Values for the Date (Degrees)

$\varepsilon = (\varepsilon o + \Delta\varepsilon)$ =	23.43773535	23.43773507	23.43756014	23.43755358	23.4375579
$\Delta\varepsilon$ =	-0.002099054	-0.002098997	-0.002265026	-0.002271238	-0.002266224
$\Delta\psi$ =	0.002466691	0.002491214	0.002469566	0.002510641	0.0025804
Error / Hour	1.23367E-08 ε		-2.49811E-09 $\Delta\varepsilon$	$\Delta\psi$=	-1.0662E-06

Corrections to Coordinates (Degrees):

Nutation $\Delta\alpha$ =	0.002859488	0.002881944	0.002909514	0.002948929	0.003011425
Nutation $\Delta\delta$ =	0.001001603	0.001011354	0.001004326	0.001020721	0.001048415
Error / Hour	-9.76361E-07 $\Delta\alpha$		-4.23992E-07 $\Delta\delta$		

Nutated Coordinates (Degrees):

Upeg RA	359.442805	359.442857	359.443764	359.443845	359.443970
Upeg Dec	15.930052	15.930072	15.930449	15.930482	15.930537
Comparison RA	359.389405	359.389453	359.390364	359.390441	359.390566
Comparison Dec	15.450577	15.450597	15.450974	15.451007	15.451062
Check RA	359.910622	359.910669	359.911580	359.911657	359.911786
Check Dec	15.760818	15.760839	15.761215	15.761248	15.761304
Error / Hour	-2.24448E-06 RA		-9.07084E-07 Dec		

Heliocentric Correction to JDE Calculations:

E (From Basic Program) =	292.3513348	293.3020322	318.1622132	319.1603363	321.1051463
ε =	0.0167104	0.0167104	0.0167103	0.0167103	0.0167103
Rs =	0.993646308	0.993390754	0.987551194	0.98735892	0.986995355
Ls =	216.1023322	217.0469109	241.6675606	242.653208	244.5731669
Δt =	0.004798622	0.004750838	0.003107851	0.003028453	0.002871361
Error / Hour	1.99099E-06 JD	or	0.172021708 seconds		

Apparent Sidereal Time Correction (Degrees):

Δst =	0.002263171	0.002285671	0.002265812	0.002303499	0.002367502

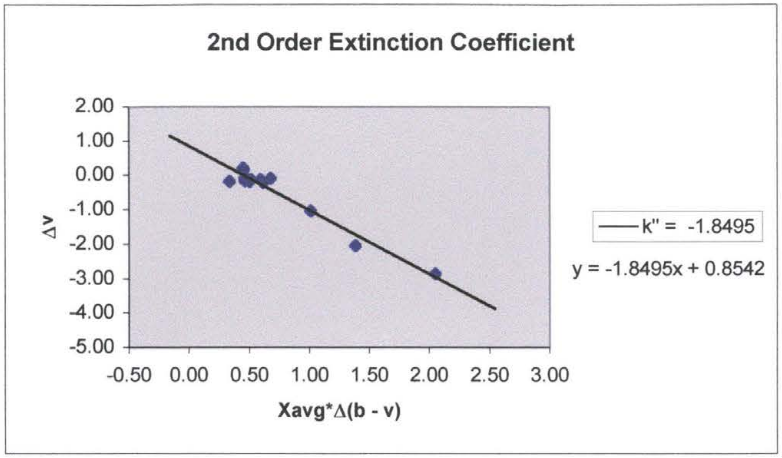
Primary Extinction Coefficient:

k' =	0.2186	-1.9702	6.4081	0.0094	1.4292

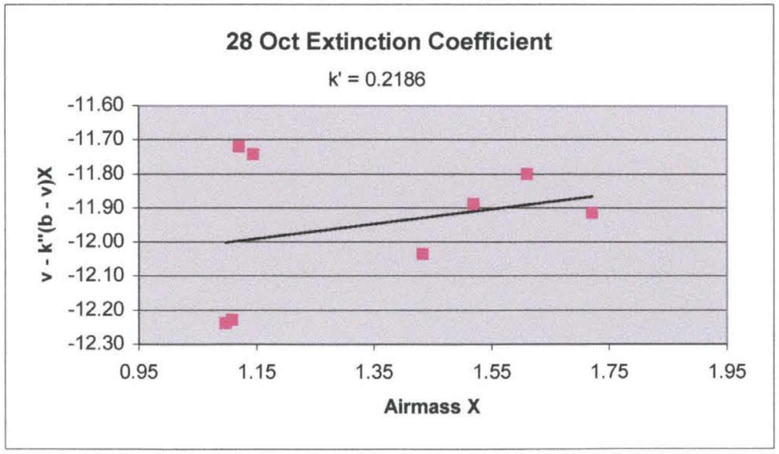
III. Extinction Coefficients

Extinction Coefficients

Date	Δv	Xavg*Δ(b-v)
28-Oct	-0.0714	0.6798
	-0.1668	0.3378
	-2.0280	1.3803
	-2.8372	2.0464
29-Oct	-0.1328	0.4674
	0.2256	0.4514
23-Nov	-0.0972	0.5908
	-0.1051	0.5940
	-1.0224	1.0101
24-Nov	-0.1075	0.5108
	-0.0806	0.4717
	-0.1561	0.5036
	0.1694	0.4542
26-Nov	-0.1944	0.6148
	-0.0478	0.4629
	-0.1646	0.4998

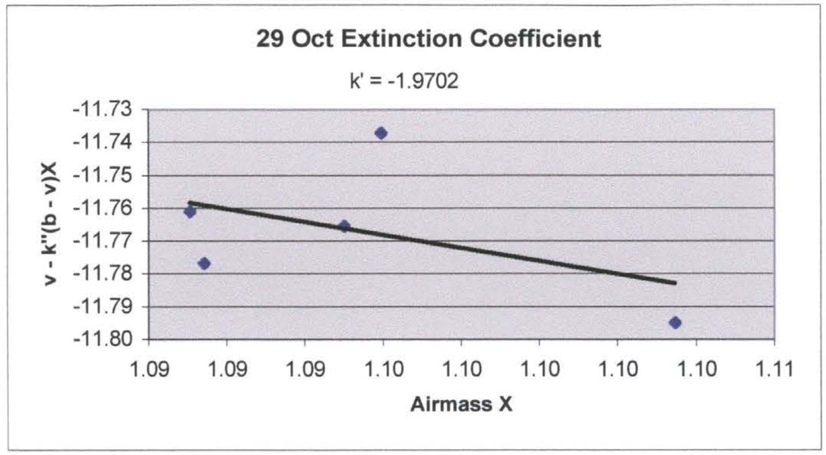


	X	v - k''(b - v)X
28-Oct Comp	1.1451	-11.7429
	1.0984	-12.2386
	1.1087	-12.2290
	1.1207	-11.7194
	1.4329	-12.0355
	1.5197	-11.8894
	1.6105	-11.8009
	1.7213	-11.9146
k' =	0.2186	

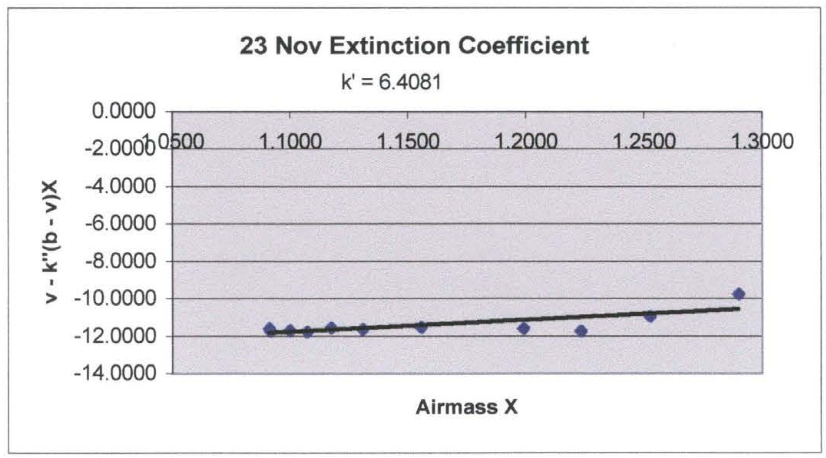


Extinction Coefficients

29-Oct	X	v - k"(b - v)X
Comp	1.1035	-11.7948
	1.0959	-11.7369
	1.0914	-11.7766
	1.0911	-11.7607
	1.0950	-11.7652
k' =	1.5000	

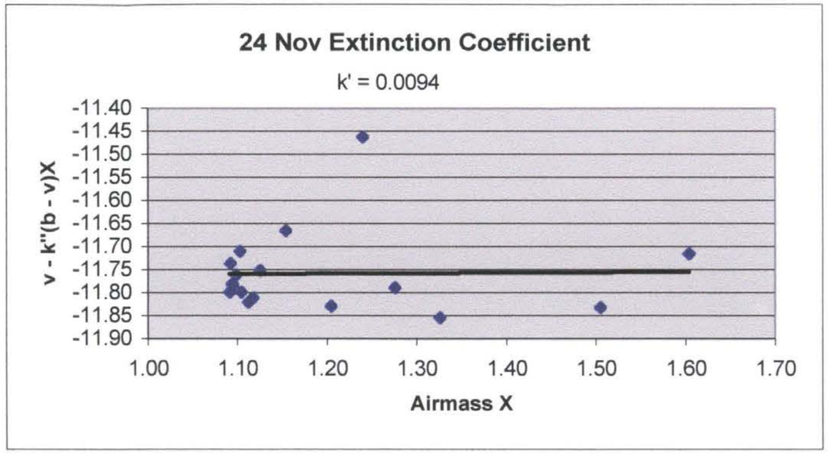


23-Nov	X	v - k"(b - v)X
Comp	1.0911	-11.5593
	1.0915	-11.7089
	1.0998	-11.6564
	1.1071	-11.7459
	1.1172	-11.5414
	1.1306	-11.6049
	1.1554	-11.4993
	1.1988	-11.5547
	1.2232	-11.6980
	1.2523	-10.9200
	1.2898	-9.7132
k' =	1.5000	

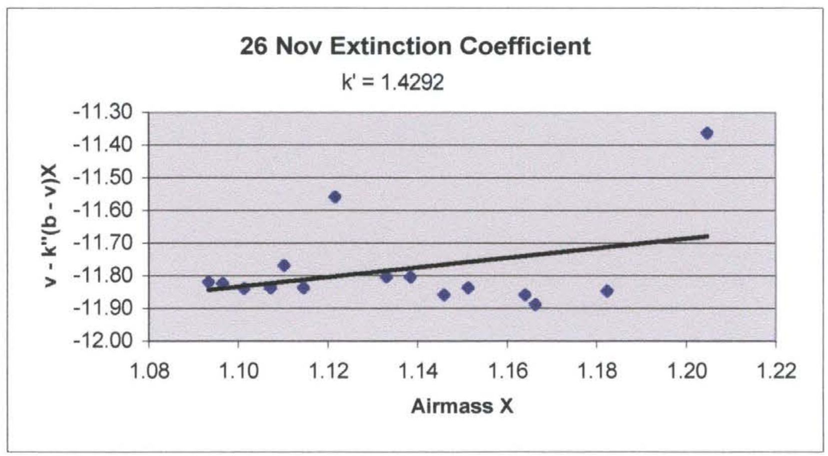


Extinction Coefficients

24-Nov	X	v - k"(b - v)X
Comp	1.1169	-11.8099
	1.1042	-11.7968
	1.0984	-11.7597
	1.0936	-11.7792
	1.0914	-11.7349
	1.0911	-11.7970
	1.0948	-11.7825
	1.1027	-11.7080
	1.1119	-11.8190
	1.1253	-11.7501
	1.1542	-11.6636
	1.2042	-11.8283
	1.2401	-11.4609
	1.2752	-11.7880
	1.3256	-11.8525
	1.5047	-11.8310
	1.6039	-11.7137
k' =	0.0094	



24-Nov	X	v - k"(b - v)X
Comp	1.1640	-11.8573
	1.1459	-11.8560
	1.1330	-11.8020
	1.1216	-11.5568
	1.1103	-11.7664
	1.0933	-11.8177
	1.0965	-11.8217
	1.1012	-11.8380
	1.1072	-11.8357
	1.1145	-11.8357
	1.1384	-11.8024
	1.1513	-11.8351
	1.1662	-11.8854
	1.1823	-11.8448
	1.2047	-11.3617
k' =	1.4292	



IV. Nutation Correction

Nutation Correction

				NUTATION CALCULATIONS						
				From Explanatory Supp to Astronomical Almanac						
J2000.0	2451545									
Date	35000	29-Oct-95	23-Nov-95	24-Nov-95	26-Nov-95					
JDE	2450018 73	2450019.688	2450044.667	2450045.667	2450047.615		Conversion of fundamental arguments from sexagesimal to decimal degrees			
t of the date	-0.041786999	-0 041760761	-0 041076869	-0.04104949	-0.040996159					
l	-19805.74539	-19793.22477	-19466.87214	-19453.80714	-19428.35763		134 962981	198 867398	0.008697	0.000018
l'	-1146.764542	-1145 820008	-1121 200535	-1120 214934	-1118.295067		357.527723	359.050340	0.000160	0.000003
F	-20098.29011	-20085.61198	-19755.15384	-19741.92449	-19716.15482		93.271910	82.017538	0.003683	0.000003
D	-18308.52579	-18296.84299	-17992 32823	-17980.13749	-17956.39092		297.850363	307.111480	0.001914	0.000005
Om	215.866275	215 8155276	214 4927866	214.4398328	214 3366833		135.044522	134.136261	0.002071	0.000002
Term #		a	b	c	d	e	S (0.0001")	C (0.0001")		
1	The multipliers for the	0	0	0	0	1	-171988.7207	92024.6281		
2	argument Al and the	0	0	2	-2	2	-13186.93314	5736.12954		
3	Sin/Cos Coefficients.	0	0	2	0	2	-2273.991643	977.0208935		
4	All terms with	0	0	0	0	2	2061.991643	-895.0208935		
5	coefficients > 0.01"	0	1	0	0	0	1426.142076	54.00041787		
6	included.	0	1	2	-2	2	-517.0501444	224.0250722		
7		0	-1	2	-2	2	217 0208935	-95.0125361		
8		0	0	2	-2	1	128.9958213	-70		
9		1	0	0	0	0	711.9958213	-7		
10		0	0	2	0	1	-385.9832852	200		
11		1	0	2	0	2	-301	129.0041787		
12		1	0	0	-2	0	-158	-1		
13		-1	0	2	0	2	123	-53		

Nutation Correction

		28-Oct-95		29-Oct-95		23-Nov-95		24-Nov-95		26-Nov-95
	A --degrees	A -- Radians	A --degrees	A -- Radians	A --degrees	A -- Radians	A --degrees	A -- Radians	A --degrees	A -- Radians
1	215.866275	3.767577243	215.8155276	3.766691534	214.4927866	3.743605348	214.4398328	3.74268113	214.3366833	3.740880831
2	-3147.796092	-54.93940599	-3145.906935	-54.90643397	-3096.665635	-54.04701117	-3094.694341	-54.01260558	-3090.854423	-53.94558638
3	-39764.84767	-694.0275184	-39739.59291	-693.5867397	-39081.3221	-682.0977468	-39054.96931	-681.6378038	-39003.63627	-680.7418731
4	431.73255	7.535154486	431.6310553	7.533383068	428.9855732	7.487210696	428.8796657	7.485362261	428.6733666	7.481761663
5	-1146.764542	-20.014817	-1145.820008	-19.99833178	-1121.200535	-19.5686409	-1120.214934	-19.55143893	-1118.295067	-19.51793093
6	-4294.560634	-74.95422299	-4291.726943	-74.90476575	-4217.86617	-73.61565207	-4214.909275	-73.56404452	-4209.14949	-73.46351731
7	-2001.03155	-34.92458898	-2000.086926	-34.90810219	-1975.465101	-34.47837026	-1974.479406	-34.46116665	-1972.559356	-34.42765545
8	-3363.662367	-58.70698323	-3361.722462	-58.6731255	-3311.158422	-57.79061652	-3309.134173	-57.75528672	-3305.191106	-57.68646721
9	-19805.74539	-345.6754679	-19793.22477	-345.4569419	-19466.87214	-339.7610139	-19453.80714	-339.5329867	-19428.35763	-339.0888089
10	-39980.71395	-697.7950957	-39955.40844	-697.3534312	-39295.81489	-685.8413521	-39269.40914	-685.3804849	-39217.97295	-684.4827539
11	-59570.59306	-1039.702986	-59532.81769	-1039.043682	-58548.19424	-1021.858761	-58508.77646	-1021.17079	-58431.99389	-1019.830682
12	16811.30619	293.4126445	16800.4612	293.2233639	16517.78433	288.2897217	16506.46783	288.0922114	16484.42422	287.7074779
13	-19959.10228	-348.3520505	-19946.36814	-348.1297978	-19614.44997	-342.3367329	-19601.16217	-342.104817	-19575.27864	-341.6530643
	Del psi	Del Eps	Del psi	Del Eps	Del psi	Del Eps	Del psi	Del Eps	Del psi	Del Eps
1	100767.4097	-74575.52972	100643.9225	-74623.25504	97397.63855	-75846.46761	97266.58665	-75894.59968	97011.07003	-75988.17077
2	-13177.17871	-220.5884076	-13153.29893	-409.426131	-7874.500006	-4601.144203	-7505.980085	-4716.247248	-6763.031028	-4924.313155
3	594.3899535	-943.0540879	1474.03346	-743.9604954	-826.8475708	-910.1448073	199.404751	-973.2572852	1893.259018	-541.1901024
4	1958.074903	-280.547013	1956.926899	-282.0521264	1924.848912	-320.9571857	1923.478824	-322.5009916	1920.791142	-325.5050283
5	-1310.469644	21.30373996	-1301.016948	22.11881341	-939.3947659	40.63038761	-920.7982597	41.23621826	-883.7965933	42.38113326
6	-222.1018289	202.3036846	-244.9132719	197.2989241	-505.4988809	-47.08914191	-499.2195604	-58.32452837	-483.1896998	-79.73745418
7	77.8848864	88.68308114	74.53482803	89.23317477	-17.15904171	94.71508593	-20.87817409	94.57183796	-28.10399618	94.2124876
8	-107.3655925	38.80085043	-109.7244956	36.80636131	-122.0835996	-22.60667996	-120.5358987	-24.93265189	-117.0911009	-29.37150941
9	-71.27650575	-6.96483601	83.99743407	-6.951116277	-321.8228138	-6.244122059	-169.9210483	-6.797731687	143.6823957	-6.855983935
10	136.5232675	187.0715922	-30.8987724	199.3581362	319.2956526	112.3736804	189.5343102	174.2270904	-144.7608243	185.4013793
11	49.19706412	-127.2693798	220.7895516	-87.67998037	-224.3681138	-85.99513757	-45.92650412	-127.4936896	279.0943544	-48.31306948
12	149.664694	0.320510689	137.4634863	0.493012785	106.1638578	-0.740620874	127.0621387	-0.594371295	153.0195181	-0.249099249
13	-43.87420141	49.51358947	-68.1241213	44.12850888	-11.89593791	52.75154246	-39.71555778	50.16112158	-86.55013673	37.65847111
seconds	**8.880087801**	**-7.55659564**	**8.968369161**	**-7.556388796**	**8.890437624**	**-8.154091881**	**9.038309158**	**-8.176455191**	**9.289439308**	**-8.15840527**
degrees	0.002466691	-0.002099054	0.002491214	-0.002098997	0.002469566	-0.002265026	0.002510641	-0.002271238	0.0025804	-0.002266224

V. Observation Reductions

28 Oct 95

			28	10	1995	JD =	2450018.50				
Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
Sky	V	2:37:40	10344								
	B	2:38:25	13863								
	U	2:41:15	6544								
Check	V	2:44:05	135409								
	V	2:44:40	135947	V	135678	10407	2:44:28	2450018.614918	2450018.619716	-0.041790	332.474373
	B	2:45:30	362477								
	B	2:46:05	361726	B	362102	13580	2:45:53	2450018.615902	2450018.620700	-0.041790	332.829510
	U	2:46:40	125285								
	U	2:47:05	125469	U	125377	6601	2:46:58	2450018.616654	2450018.621453	-0.041790	333.101085
sky	V	2:48:20	10469								
	B	2:49:15	13297								
	U	2:49:45	6657								
Comparison	V	2:57:45	146261								
	V	2:58:15	142465	V	144363	10598	2:58:05	2450018.624380	2450018.629178	-0.041790	335.889949
	B	2:59:00	244330								
	B	2:59:30	223294	B	233812	14040	2:59:20	2450018.625248	2450018.630046	-0.041790	336.203305
	U	3:00:07	72972								
	U	3:00:35	65653	U	69313	7141	3:00:26	2450018.626012	2450018.630810	-0.041790	336.479058
Sky	V	3:01:40	10726								
	B	3:02:25	14782								
	U	3:02:55	7625								
UPeg	V	3:05:45	152716								
	V	3:06:10	150529	V	151623	10456	3:06:03	2450018.629906	2450018.634705	-0.041790	337.884980
	B	3:07:00	252484								
	B	3:07:30	241289	B	246887	14181	3:07:20	2450018.630803	2450018.635602	-0.041790	338.208781
	U	3:08:00	83805								
	U	3:08:25	82417	U	83111	7109	3:08:18	2450018.631469	2450018.636267	-0.041790	338.449020
Sky	V	3:09:15	10186								
	B	3:09:50	13580								
	U	3:10:25	6593								
Comp	V	3:13:20	150055								
	V	3:13:50	151634	V	150845	10009	3:13:40	2450018.635201	2450018.640000	-0.041790	339.796449
	B	3:14:40	269041								

28 Oct 95

Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V	
		Degrees	Airmass	True Count of	Instrumental	Instrumental			
Sky	V			Star - Sky	Magnitude	Color			
	B					and			
	U					v - k"(b - v)X			
Check	V								
	V	-27.436249	1.198028	125627	-10.248			-11.312	
	B					-1.116			
	B	-27.081112	1.194989	351073	-11.363				
	U								
	U	-26.809537	1.192700	119081	-10.190				
sky	V								
	B								
	U								
Comparison	V								
	V	-23.499456	1.170204	134168	-10.319		0.309	-10.955	
	B					-0.541			
	B	-23.186100	1.167985	220831	-10.860				
	U					-10.699			
	U	-22.910347	1.166063	62264	-9.486				
Sky	V								
	B								
	U								
UPeg	V								
	V	-21.557825	1.152457	141611	-10.378		0.004	-11.006	
	B					-0.545			
	B	-21.234025	1.150414	233887	-10.923		-0.001		
	U						0.033		
	U	-20.993785	1.148922	76135	-9.704				
Sky	V								
	B								
	U								
Comp	V								
	V	-19.592956	1.145078	141275	-10.375		0.063	-11.069	
	B					-0.646			

28 Oct 95

Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	B	3:15:05	265799	B	267420	12718	3:14:58	2450018.636098	2450018.640897	-0.041790	340.120250
	U	3:15:35	97759								
	U	3:16:00	95600	U	96680	6277	3:15:53	2450018.636735	2450018.641534	-0.041790	340.350044
Sky	V	3:16:45	9832								
	B	3:18:10	11856								
	U	3:18:45	5961								
Check	V	3:27:45	130556								
	V	3:28:15	130188	V	130372	9544	3:28:05	2450018.645213	2450018.650012	-0.041789	343.410484
	B	3:28:45	312170								
	B	3:29:05	285531	B	298851	11699	3:29:00	2450018.645850	2450018.650648	-0.041789	343.640278
	U	3:29:35	92420								
	U	3:30:15	95449	U	93935	5871	3:30:00	2450018.646544	2450018.651343	-0.041789	343.890962
Sky	V	3:31:10	9255								
	B	3:31:35	11541								
	U	3:32:05	5781								
UPeg	V	3:37:05	146030								
	V	3:37:32	148251	V	147141	9182	3:37:24	2450018.651677	2450018.656476	-0.041789	345.743938
	B	3:38:05	254979								
	B	3:38:32	250656	B	252818	11463	3:38:24	2450018.652372	2450018.657170	-0.041789	345.994623
	U	3:39:05	88270								
	U	3:39:25	87686	U	87978	5696	3:39:20	2450018.653025	2450018.657824	-0.041789	346.230684
Sky	V	3:40:55	9109								
	B	3:41:25	11385								
	U	3:41:55	5610								
Comp	V	3:56:50	261115								
	V	3:57:20	287590	V	274353	9387	3:57:10	2450018.665410	2450018.670208	-0.041789	350.701224
	B	3:57:55	254197								
	B	3:58:22	333413	B	293805	11193	3:58:14	2450018.666145	2450018.670943	-0.041789	350.966532
	U	3:59:05	45542								
	U	3:59:30	53612	U	49577	5371	3:59:23	2450018.666943	2450018.671742	-0.041789	351.254819
Sky	V	4:00:30	9664								
	B	4:01:00	11001								
	U	4:01:25	5131								
Sky	V	4:23:25	8576								
	B	4:24:10	10036								

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V	
		Degrees	Airmass	True Count of	Instrumental	Instrumental			
	B	-19.269155	1.143235	256090	-11.021				
	U					-10.819			
	U	-19.039361	1.141948	90583	-9.893				
Sky	V								
	B								
	U								
Check	V								
	V	-16.500138	1.126096	121157	-10.208			-11.092	
	B					-0.943			
	B	-16.270344	1.125025	288888	-11.152				
	U								
	U	-16.019660	1.123874	88234	-9.864				
Sky	V								
	B								
	U								
UPeg	V								
	V	-13.698867	1.112685	138377	-10.353		0.200	-11.003	
	B					-0.610			
	B	-13.448182	1.111736	242595	-10.962				
	U								
	U	-13.212121	1.110859	82432	-9.790				
Sky	V								
	B								
	U								
Comp	V								
	V	-8.688181	1.101230	266429	-11.064			-11.351	
	B					-0.070			
	B	-8.422874	1.100604	284290	-11.134				
	U					-11.111			
	U	-8.134587	1.099947	44254	-9.115				
Sky	V								
	B								
	U								
Sky	V								
	B								

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	U	4:24:45	5145								
UPeg	V	4:27:00	131000								
	V	4:30:40	131696	V	131348	8463	4:28:55	2450018.687458	2450018.692257	-0.041788	358.660456
	B	4:31:20	230691								
	B	4:31:45	227433	B	229062	10130	4:31:38	2450018.689339	2450018.694138	-0.041788	359.339393
	U	4:32:15	82139								
	U	4:32:35	82795	U	82467	5084	4:32:30	2450018.689947	2450018.694745	-0.041788	359.558742
Sky	V	4:34:45	8350								
	B	4:35:20	10224								
	U	4:35:50	5022								
Comp	V	4:39:30	939560								
	V	4:41:45	775854	V	857707	8452	4:40:43	2450018.695647	2450018.700446	-0.041788	1.616444
	B	4:43:45	622629								
	B	4:44:10	659526	B	641078	10137	4:44:03	2450018.697962	2450018.702760	-0.041788	2.452059
	U	4:44:45	64103								
	U	4:45:08	58612	U	61358	4974	4:45:02	2450018.698645	2450018.703443	-0 041788	2.698565
Sky	V	4:46:15	8554								
	B	4:47:00	10050								
	U	4:47:30	4925								
UPeg	V	4:52:20	113414								
	V	4:52:50	113809	V	113612	8380	4:52:40	2450018.703951	2450018.708750	-0.041788	4.614212
	B	4:53:22	191776								
	B	4:53:45	191021	B	191399	9912	4:53:39	2450018.704629	2450018.709427	-0.041788	4.858630
	U	4:54:20	66848								
	U	4:54:45	67216	U	67032	4853	4:54:38	2450018.705311	2450018.710110	-0.041788	5.105136
Sky	V	4:55:55	8205								
	B	4:56:25	9773								
	U	4:56:55	4781								
Comp	V	5:00:55	962383								
	V	5:01:30	958144	V	960264	8516	5:01:18	2450018.709941	2450018.714740	-0.041788	6.776366
	B	5:02:08	879274								
	B	5:02:30	859744	B	869509	9803	5:02:24	2450018.710711	2450018.715509	-0.041788	7.054208
	U	5:03:05	86584								
	U	5:03:25	86584	U	86584	4756	5:03:20	2450018.711359	2450018.716157	-0.041788	7.288180
Sky	V	5:04:20	8827								

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V	
		Degrees	Airmass	True Count of	Instrumental	Instrumental			
	U								
UPeg	V								
	V	-0.782349	1.087059	123218	-10.227		0.981	-10.875	
	B					-0.629			
	B	-0.103412	1.086978	219950	-10.856				
	U								
	U	0.115937	1.086979	77515	-9.723				
Sky	V			Note the extreme change in the True count of the Comp star. All					
	B			mags after this use an average magnitude based on the correct					
	U			observations					
Comp	V								
	V	2.227039	1.091578	863731	-12.341			-11.125	
	B					0.327			
	B	3.062653	1.092179	638992	-12.014				
	U					-12.127			
	U	3.309160	1.092393	56456	-9.379				
Sky	V								
	B								
	U								
UPeg	V								
	V	5.171407	1.090583	105481	-10.058		1.813	-10.685	
	B					-0.593			
	B	5.415824	1.090933	182197	-10.651		Corrected		
	U						0.440		
	U	5.662331	1.091302	62266	-9.486				
Sky	V								
	B								
	U								
Comp	V								
	V	7.386961	1.098353	969929	-12.467			-11.415	
	B					0.112			
	B	7.664803	1.098927	874587	-12.355				
	U					-12.393			
	U	7.898775	1.099427	81973	-9.784				
Sky	V								

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	B	5:05:30	9832								
	U	5:06:00	4731								
UPeg	V	5:10:15	96077								
	V	5:10:41	97012	V	96545	8519	5:10:33	2450018.716370	2450018.721169	-0.041787	9.097287
	B	5:11:15	160463								
	B	5:11:35	152986	B	156725	9605	5:11:30	2450018.717030	2450018.721829	-0.041787	9.335437
	U	5:12:01	54817								
	U	5:12:25	55929	U	55373	4701	5:12:18	2450018.717586	2450018.722384	-0.041787	9.535984
Sky	V	5:13:50	8211								
	B	5:14:20	9378								
	U	5:14:45	4671								
Comp	V	5:16:55	935322								
	V	5:17:23	956829	V	946076	8414	5:17:14	2450018.721012	2450018.725810	-0.041787	10.772694
	B	5:18:00	861693								
	B	5:18:25	857798	B	859746	9407	5:18:18	2450018.721747	2450018.726545	-0.041787	11.038002
	U	5:18:55	81876								
	U	5:19:15	79628	U	80752	4515	5:19:10	2450018.722354	2450018.727153	-0.041787	11.257351
Sky	V	5:20:15	8616								
	B	5:20:45	9436								
	U	5:21:15	4358								
UPeg	V	5:24:00	96839								
	V	5:24:25	96834	V	96837	8356	5:24:18	2450018.725913	2450018.730712	-0.041787	12.542109
	B	5:25:00	162736								
	B	5:25:20	161455	B	162096	8766	5:25:15	2450018.726579	2450018.731377	-0.041787	12.782348
	U	5:25:50	56572								
	U	5:26:10	58177	U	57375	4427	5:26:05	2450018.727157	2450018.731956	-0.041787	12.991252
Sky	V	5:27:00	8096								
	B	5:27:27	8096								
	U	5:27:55	4495								
Comp	V	5:30:00	665915								
	V	5:30:25	659440	V	662678	8573	5:30:18	2450018.730080	2450018.734879	-0.041787	14.046216
	B	5:31:00	567148								
	B	5:31:20	580299	B	573724	8838	5:31:15	2450018.730745	2450018.735544	-0.041787	14.286455
	U	5:31:50	58509								
	U	5:32:15	62652	U	60581	4452	5:32:08	2450018.731353	2450018.736152	-0.041787	14.505804

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V	
		Degrees	Airmass	True Count of	Instrumental	Instrumental			
	B								
	U								
UPeg	V								
	V	9.654481	1.099627	88205	-9.864		2.153	-10.473	
	B					-0.559			
	B	9.892631	1.100264	147595	-10.423		Corrected		
	U						0.942		
	U	10.093179	1.100814	50731	-9.263				
Sky	V								
	B								
	U								
Comp	V								
	V	11.383289	1.108725	955305	-12.450			-11.415	
	B					0.108			
	B	11.648597	1.109577	864884	-12.342				
	U					-12.379			
	U	11.867946	1.110297	76363	-9.707				
Sky	V								
	B								
	U								
UPeg	V								
	V	13.099304	1.110446	88661	-9.869		1.894	-10.511	
	B					-0.598			
	B	13.339543	1.111331	153838	-10.468		Corrected		
	U						0.904		
	U	13.548447	1.112113	53011	-9.311				
Sky	V								
	B								
	U								
Comp	V								
	V	14.656811	1.120703	662713	-12.053		-1.199	-11.415	
	B					0.161			
	B	14.897050	1.121710	571326	-11.892				
	U					-11.945			
	U	15.116399	1.122645	56200	-9.374				

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
Sky	V	5:33:30	9049								
	B	5:34:00	9580								
	U	5:34:30	4408								
Check	V	5:38:55	107548								
	V	5:39:20	113868	V	110708	8590	5:39:13	2450018.736272	2450018.741071	-0.041787	16.281486
	B	5:39:50	298094								
	B	5:40:10	264536	B	281315	9300	5:40:05	2450018.736880	2450018.741678	-0.041787	16.500835
	U	5:40:40	94499								
	U	5:41:00	106469	U	100484	4447	5:40:55	2450018.737458	2450018.742257	-0.041787	16.709738
Sky	V	5:44:50	8130								
	B	5:45:50	9020								
	U	5:46:25	4485								
Sky	V	6:56:00	8887								
	B	6:56:42	9321								
	U	6:57:20	4780								
UPeg	V	6:59:40	144324								
	V	7:00:15	145373	V	144849	8912	7:00:03	2450018.792406	2450018.797205	-0.041785	36.545148
	B	7:00:55	244947								
	B	7:01:20	241885	B	243416	9325	7:01:13	2450018.793216	2450018.798015	-0.041785	36.837613
	U	7:01:50	82052								
	U	7:02:15	82468	U	82260	4619	7:02:08	2450018.793853	2450018.798652	-0.041785	37.067407
Sky	V	7:03:40	8937								
	B	7:04:15	9329								
	U	7:05:02	4457								
Comp	V	7:30:45	910706								
	V	7:31:15	893601	V	902154	9955	7:31:05	2450018.813963	2450018.818762	-0.041785	44.326812
	B	7:31:45	793799								
	B	7:32:10	803892	B	798846	9969	7:32:03	2450018.814629	2450018.819427	-0.041785	44.567051
	U	7:32:45	71459								
	U	7:33:10	72934	U	72197	4644	7:33:03	2450018.815323	2450018.820122	-0.041785	44.817735
Sky	V	7:34:40	10973								
	B	7:35:10	10608								
	U	7:35:40	4831								
UPeg	V	7:38:40	60279								
	V	7:39:15	60244	V	60262	10554	7:39:03	2450018.819490	2450018.824288	-0.041785	46.321842

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V	
		Degrees	Airmass	True Count of	Instrumental	Instrumental			
Sky	V								
	B								
	U								
Check	V								
	V	16.370864	1.125491	102355	-10.025			-10.992	
	B					-1.067			
	B	16.590213	1.126521	273553	-11.093				
	U								
	U	16.799116	1.127516	96233	-9.958				
Sky	V								
	B								
	U								
Sky	V								
	B								
	U								
UPeg	V								
	V	37.102342	1.300877	136342	-10.337		1.312	-11.083	
	B					-0.592			
	B	37.394808	1.304795	235241	-10.929		Corrected		
	U						0.332		
	U	37.624602	1.307910	77772	-9.727				
Sky	V								
	B								
	U								
Comp	V								
	V	44.937406	1.432923	908227	-12.395			-11.415	
	B					0.136			
	B	45.177646	1.437502	801419	-12.260				
	U					-12.279			
	U	45.428330	1.442332	67653	-9.576				
Sky	V								
	B								
	U								
UPeg	V								
	V	46.879037	1.463028	49776	-9.243		2.383	-10.160	

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	B	7:40:35	104025								
	B	7:41:00	102654	B	103340	10396	7:40:53	2450018.820763	2450018.825561	-0.041785	46.781430
	U	7:41:30	37563								
	U	7:41:55	37049	U	37306	4800	7:41:48	2450018.821399	2450018.826198	-0.041784	47.011225
Sky	V	7:43:10	10135								
	B	7:43:55	10184								
	U	7:44:25	4769								
Comp	V	7:47:25	829642								
	V	7:47:50	826990	V	828316	10548	7:47:43	2450018.825508	2450018.830307	-0.041784	48.494441
	B	7:48:25	725407								
	B	7:48:45	728328	B	726868	10470	7:48:40	2450018.826174	2450018.830972	-0.041784	48.734680
	U	7:49:15	63665								
	U	7:49:35	59363	U	61514	4884	7:49:30	2450018.826752	2450018.831551	-0.041784	48.943584
Sky	V	7:50:40	10961								
	B	7:51:20	10756								
	U	7:51:45	4998								
UPeg	V	7:54:35	140083								
	V	7:54:55	143402	V	141743	10703	7:54:50	2450018.830456	2450018.835255	-0.041784	50.280568
	B	7:55:30	229274								
	B	7:55:50	221140	B	225207	10600	7:55:45	2450018.831093	2450018.835891	-0.041784	50.510362
	U	7:56:20	70483								
	U	7:56:40	66050	U	68267	4911	7:56:35	2450018.831671	2450018.836470	-0.041784	50.719266
Sky	V	7:58:10	10445								
	B	7:58:35	10443								
	U	7:59:05	4824								
Comp	V	8:02:00	740545								
	V	8:02:25	761251	V	750898	10990	8:02:18	2450018.835635	2450018.840434	-0.041784	52.150256
	B	8:02:55	666398								
	B	8:03:15	669615	B	668007	10719	8:03:10	2450018.836243	2450018.841042	-0.041784	52.369605
	U	8:03:45	56259								
	U	8:04:10	58126	U	57193	4886	8:04:03	2450018.836851	2450018.841649	-0.041784	52.588954
Sky	V	8:05:10	11535								
	B	8:05:36	10994								
	U	8:06:00	4948								
UPeg	V	8:08:45	126230								

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V	
		Degrees	Airmass	True Count of	Instrumental	Instrumental			
	B					-0.680			
	B	47.338625	1.472488	93148	-9.923		Corrected		
	U						1.255		
	U	47.568419	1.477291	32533	-8.781				
Sky	V								
	B								
	U								
Comp	V								
	V	49.105036	1.519700	831260	-12.299			-11.415	
	B					0.146			
	B	49.345275	1.525213	726766	-12.153				
	U					-12.166			
	U	49.554179	1.530055	56703	-9.384				
Sky	V								
	B								
	U								
UPeg	V								
	V	50.837763	1.551251	131427	-10.297		1.318	-11.136	
	B					-0.537			
	B	51.067557	1.556872	215591	-10.834		Corrected		
	U						0.279		
	U	51.276461	1.562033	63445	-9.506				
Sky	V								
	B								
	U								
Comp	V								
	V	52.760851	1.610498	750978	-12.189			-11.415	
	B					0.130			
	B	52.980200	1.616449	666035	-12.059				
	U					-12.063			
	U	53.199549	1.622462	52369	-9.298				
Sky	V								
	B								
	U								
UPeg	V								

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	V	8:09:15	132352	V	129291	11369	8:09:05	2450018.840352	2450018.845151	-0.041784	53.852822
	B	8:09:55	220740								
	B	8:10:20	218371	B	219556	10928	8:10:13	2450018.841133	2450018.845932	-0.041784	54.134842
	U	8:11:15	65638								
	U	8:11:35	62533	U	64086	4960	8:11:30	2450018.842030	2450018.846829	-0.041784	54.458643
Sky	V	8:12:55	11202								
	B	8:13:30	10862								
	U	8:14:00	4971								
Comp	V	8:16:55	839990								
	V	8:17:25	881219	V	860605	11499	8:17:15	2450018.846023	2450018.850822	-0.041784	55.900078
	B	8:18:00	763564								
	B	8:18:22	762819	B	763192	11155	8:18:16	2450018.846729	2450018.851528	-0.041784	56.154941
	U	8:18:50	65263								
	U	8:19:15	64470	U	64867	5048	8:19:08	2450018.847325	2450018.852124	-0.041784	56.370112
Sky	V	8:20:30	11795								
	B	8:21:00	11448								
	U	8:21:25	5124								
Check	V	8:26:50	70244								
	V	8:27:15	79660	V	74952	11749	8:27:08	2450018.852881	2450018.857679	-0.041784	58.375588
	B	8:27:45	171933								
	B	8:28:10	177394	B	174664	11372	8:28:03	2450018.853517	2450018.858316	-0.041784	58.605382
	U	8:28:41	53317								
	U	8:29:00	51208	U	52263	5071	8:28:56	2450018.854131	2450018.858929	-0.041784	58.826820
Sky	V	8:30:20	11702								
	B	8:30:45	11296								
	U	8:31:15	5018								

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V	
		Degrees	Airmass	True Count of	Instrumental	Instrumental			
	V	54.410017	1.645752	118244	-10.182		1.337	-11.155	
	B					-0.621			
	B	54.692036	1.653907	209562	-10.803		Corrected		
	U						0.260		
	U	55.015837	1.663407	59205	-9.431				
Sky	V								
	B								
	U								
Comp	V								
	V	56.510673	1.721293	863680	-12.341		-1.600	-11.415	
	B					0.134			
	B	56.765536	1.729577	763475	-12.207				
	U					-12.203			
	U	56.980706	1.736653	59900	-9.444				
Sky	V								
	B								
	U								
Check	V								
	V	58.464966	1.779022	63310	-9.504			-10.995	
	B					-1.033			
	B	58.694760	1.787160	163881	-10.536				
	U								
	U	58.916198	1.795091	47244	-9.186				
Sky	V								
	B								
	U								

29 Oct 95

			29	10	1995	JD =	2450019.50				
Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
		(Dec Hours UT)			Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
Sky	V	3:34:45	9485								
	B	3:37:30	13135								
	U	3:38:00	6164								
Check	V	3:43:00	137886								
	V	3:43:25	136447	V	137167	9088	3:43:18	2450019.655774	2450019.660525	-0.041762	348.208647
	B	3:44:05	365405								
	B	3:44:30	365327	B	365366	12841	3:44:23	2450019.656527	2450019.661277	-0.041762	348.480221
	U	3:45:25	123755								
	U	3:45:50	114897	U	119326	6128	3:45:43	2450019.657453	2450019.662203	-0.041762	348.814467
sky	V	3:46:45	8690								
	B	3:47:15	12547								
	U	3:47:40	6091								
Comparison	V	3:49:25	153267								
	V	3:49:50	153314	V	153291	8586	3:49:43	2450019.660230	2450019.664981	-0.041762	349.817205
	B	3:50:20	282040								
	B	3:50:40	282999	B	282520	12226	3:50:35	2450019.660838	2450019.665589	-0.041762	350.036554
	U	3:51:06	102959								
	U	3:51:25	99997	U	101478	6058	3:51:21	2450019.661365	2450019.666115	-0.041761	350.226657
Sky	V	3:52:10	8481								
	B	3:52:35	11905								
	U	3:53:05	6024								
UPeg	V	3:56:25	101474								
	V	3:56:55	101827	V	101651	8520	3:56:45	2450019.665120	2450019.669871	-0.041761	351.582442
	B	3:57:25	169464								
	B	3:57:45	168841	B	169153	11928	3:57:40	2450019.665757	2450019.670508	-0.041761	351.812236
	U	3:58:10	57976								
	U	3:58:30	58148	U	58062	5801	3:58:25	2450019.666278	2450019.671029	-0.041761	352.000249
Sky	V	3:59:35	8559								
	B	4:00:05	11950								
	U	4:00:35	5578								
Comp	V	4:03:20	153995								
	V	4:03:45	152554	V	153275	8425	4:03:38	2450019.669895	2450019.674646	-0.041761	353.305898
	B	4:04:15	277449								

29 Oct 95

Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V	
		Degrees	Airmass	True Count of	Instrumental	Instrumental			
Sky	V			Star - Sky	Magnitude	Color			
	B					and			
	U					v - k"(b - v)X			
Check	V								
	V	-11.702023	1.107080	128442	-10.272			-12.666	
	B					-1.104			
	B	-11.430448	1.106209	355124	-11.376				
	U								
	U	-11.096202	1.105168	113474	-10.137				
sky	V								
	B								
	U								
Comparison	V								
	V	-9.572247	1.103458	145160	-10.405		0.153	-12.511	
	B					-0.681			
	B	-9.352898	1.102884	271844	-11.086				
	U					-10.856			
	U	-9.162796	1.102398	95619	-9.951				
Sky	V								
	B								
	U								
UPeg	V								
	V	-7.860415	1.095336	93329	-9.925		0.552	-11.943	
	B					-0.570			
	B	-7.630621	1.094852	157778	-10.495				
	U						-0.007		
	U	-7.442608	1.094466	52326	-9.297		0.059		
Sky	V								
	B								
	U								
Comp	V								
	V	-6.083555	1.095947	145305	-10.406			-12.481	
	B					-0.657			

29 Oct 95

Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
		(Dec Hours UT)			Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	B	4:04:35	274622	B	276036	11453	4:04:30	2450019.670502	2450019.675253	-0.041761	353.525247
	U	4:05:00	102149								
	U	4:05:20	101301	U	101725	5481	4:05:15	2450019.671023	2450019.675774	-0.041761	353.713260
Sky	V	4:06:05	8290								
	B	4:06:35	10955								
	U	4:07:00	5383								
UPeg	V	4:12:00	104374								
	V	4:12:35	105279	V	104827	8173	4:12:23	2450019.675971	2450019.680722	-0.041761	355.499387
	B	4:13:10	180547								
	B	4:13:30	184890	B	182719	10862	4:13:25	2450019.676694	2450019.681445	-0.041761	355.760516
	U	4:14:00	66478								
	U	4:14:20	66115	U	66297	5274	4:14:15	2450019.677273	2450019.682024	-0.041761	355.969420
Sky	V	4:15:15	8055								
	B	4:15:45	10769								
	U	4:16:10	5165								
Comp	V	4:19:50	126693								
	V	4:20:10	133893	V	130293	7935	4:20:05	2450019.681324	2450019.686075	-0.041761	357.431746
	B	4:20:36	262708								
	B	4:20:55	254484	B	258596	10514	4:20:51	2450019.681851	2450019.686602	-0.041761	357.621849
	U	4:21:25	99260								
	U	4:21:45	100535	U	99898	5075	4:21:40	2450019.682424	2450019.687174	-0.041761	357.828663
Sky	V	4:22:40	7815								
	B	4:23:15	10258								
	U	4:23:45	4985								
UPeg	V	4:25:55	109315								
	V	4:26:25	110786	V	110051	7838	4:26:15	2450019.685607	2450019.690357	-0.041761	358.977634
	B	4:27:00	195658								
	B	4:27:20	200021	B	197840	10204	4:27:15	2450019.686301	2450019.691052	-0.041761	359.228318
	U	4:27:45	72782								
	U	4:28:05	73295	U	73039	5067	4:28:00	2450019.686822	2450019.691573	-0.041761	359.416332
Sky	V	4:29:00	7861								
	B	4:29:30	10150								
	U	4:29:55	5149								
Comp	V	4:31:50	143076								
	V	4:32:15	143094	V	143085	7951	4:32:08	2450019.689686	2450019.694437	-0.041761	0.450405

29 Oct 95

Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V	
		Degrees	Airmass	True Count of	Instrumental	Instrumental			
	B	-5.864206	1.095589	266063	-11.062				
	U					-10.838			
	U	-5.676193	1.095293	96445	-9.961				
Sky	V								
	B								
	U								
UPeg	V								
	V	-3.943470	1.089071	96866	-9.965		0.412	-12.008	
	B					-0.627			
	B	-3.682341	1.088803	172503	-10.592				
	U								
	U	-3.473437	1.088601	61107	-9.465				
Sky	V								
	B								
	U								
Comp	V								
	V	-1.957706	1.091425	122686	-10.222			-12.363	
	B					-0.770			
	B	-1.767604	1.091329	249381	-10.992				
	U					-10.726			
	U	-1.560789	1.091235	95016	-9.944				
Sky	V								
	B								
	U								
UPeg	V								
	V	-0.465223	1.087006	102446	-10.026		0.307	-12.088	
	B					-0.661			
	B	-0.214539	1.086983	188394	-10.688				
	U								
	U	-0.026525	1.086977	68074	-9.582				
Sky	V								
	B								
	U								
Comp	V								
	V	1.060952	1.091057	135530	-10.330			-12.431	

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
		(Dec Hours UT)			Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	B	4:32:50	269381								
	B	4:33:10	268947	B	269164	10180	4:33:05	2450019.690352	2450019.695103	-0.041761	0.690645
	U	4:33:35	101377								
	U	4:33:55	100871	U	101124	5111	4:33:50	2450019.690873	2450019.695624	-0.041761	0.878658
Sky	V	4:35:30	8041								
	B	4:36:00	10210								
	U	4:36:25	5073								
UPeg	V	4:39:20	120269								
	V	4:39:45	124551	V	122410	7983	4:39:38	2450019.694895	2450019.699646	-0.041761	2.330539
	B	4:40:15	218864								
	B	4:40:35	220032	B	219448	10095	4:40:30	2450019.695502	2450019.700253	-0.041761	2.549888
	U	4:41:05	78944								
	U	4:41:25	78546	U	78745	5067	4:41:20	2450019.696081	2450019.700832	-0.041761	2.758791
Sky	V	4:42:10	7925								
	B	4:42:35	9979								
	U	4:43:00	5060								
Comp	V	4:49:25	149041								
	V	4:49:55	148862	V	148952	7823	4:49:45	2450019.701926	2450019.706677	-0.041760	4.868719
	B	4:50:30	274353								
	B	4:50:50	275051	B	274702	10058	4:50:45	2450019.702620	2450019.707371	-0.041760	5.119404
	U	4:51:15	102841								
	U	4:51:35	102597	U	102719	5154	4:51:30	2450019.703141	2450019.707892	-0.041760	5.307417
Sky	V	4:52:35	7721								
	B	4:53:05	10137								
	U	4:53:30	5247								
UPeg	V	4:55:20	131394								
	V	4:55:50	132045	V	131720	8507	4:55:40	2450019.706035	2450019.710786	-0.041760	6.351936
	B	4:56:20	222472								
	B	4:56:40	226065	B	224269	10470	4:56:35	2450019.706671	2450019.711422	-0.041760	6.581730
	U	4:57:10	82596								
	U	4:57:30	83420	U	83008	5312	4:57:25	2450019.707250	2450019.712001	-0.041760	6.790633
Sky	V	4:58:15	9292								
	B	4:58:45	10803								
	U	4:59:15	5377								
Comp	V	5:02:50	81538								

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V	
		Degrees	Airmass	True Count of	Instrumental	Instrumental			
	B					-0.709			
	B	1.301192	1.091134	260391	-11.039				
	U					-10.794			
	U	1.489205	1.091206	96211	-9.958				
Sky	V								
	B								
	U								
UPeg	V								
	V	2.887682	1.088099	114716	-10.149		0.238	-12.211	
	B					-0.658			
	B	3.107031	1.088276	210287	-10.807				
	U								
	U	3.315935	1.088457	73798	-9.670				
Sky	V								
	B								
	U								
Comp	V								
	V	5.479266	1.094992	141558	-10.377			-12.470	
	B					-0.685			
	B	5.729951	1.095376	266110	-11.063				
	U					-10.828			
	U	5.917964	1.095676	97770	-9.976				
Sky	V								
	B								
	U								
UPeg	V								
	V	6.909079	1.093426	123548	-10.230		-0.099	-12.264	
	B					-0.600			
	B	7.138873	1.093864	214774	-10.830				
	U								
	U	7.347776	1.094275	77829	-9.728				
Sky	V								
	B								
	U								
Comp	V								

29 Oct 95

Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
		(Dec Hours UT)			Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	V	5:03:25	90528	V	86033	11703	5:03:13	2450019.711272	2450019.716023	-0.041760	8.242514
	B	5:04:30	174122								
	B	5:04:50	160433	B	167278	11863	5:04:45	2450019.712343	2450019.717093	-0.041760	8.628986
	U	5:05:20	62460								
	U	5:05:40	58025	U	60243	5409	5:05:35	2450019.712921	2450019.717672	-0.041760	8.837890
Sky	V	5:06:35	14113								
	B	5:07:05	12922								
	U	5:07:55	5440								
Check	V	5:11:05	103896								
	V	5:11:25	107441	V	105669	14214	5:11:20	2450019.716914	2450019.721665	-0.041760	10.279326
	B	5:11:55	296439								
	B	5:12:15	289230	B	292835	14629	5:12:10	2450019.717493	2450019.722244	-0.041760	10.488230
	U	5:13:20	92776								
	U	5:13:45	91092	U	91934	6204	5:13:38	2450019.718506	2450019.723257	-0.041760	10.853811
Sky	V	5:14:40	14315								
	B	5:15:15	16336								
	U	5:15:50	6968								
UPeg	V	5:18:30	122338								
	V	5:19:00	133417	V	127878	11044	5:18:50	2450019.722123	2450019.726874	-0.041760	12.159459
	B	5:19:30	244034								
	B	5:19:50	248775	B	246405	12940	5:19:45	2450019.722759	2450019.727510	-0.041760	12.389253
	U	5:20:25	91389								
	U	5:20:50	91181	U	91285	5926	5:20:43	2450019.723425	2450019.728176	-0.041760	12.629493
Sky	V	5:21:40	7772								
	B	5:22:10	9544								
	U	5:22:40	4884								

29 Oct 95

Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V	
		Degrees	Airmass	True Count of	Instrumental	Instrumental			
	V	8.853062	1.101628	74471	-9.680		0.498	-11.863	
	B					-0.803			
	B	9.239534	1.102593	155956	-10.483				
	U					-10.210			
	U	9.448437	1.103132	54904	-9.349				
Sky	V								
	B								
	U								
Check	V								
	V	10.368656	1.103012	91667	-9.906			-12.362	
	B					-1.212			
	B	10.577560	1.103615	279870	-11.117				
	U								
	U	10.943142	1.104701	85893	-9.835				
Sky	V								
	B								
	U								
UPeg	V								
	V	12.716603	1.109073	117149	-10.172		-0.471	-12.337	
	B					-0.754			
	B	12.946397	1.109892	234642	-10.926				
	U								
	U	13.186636	1.110766	85520	-9.830				
Sky	V								
	B								
	U								

23 Nov 95

			23	11	1995	JD =	2450044.50					
Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST	H
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees	Degrees
Sky	V	2:33:00	8817									
	B	2:33:35	10231									
	U	2:34:00	4746									
Check	V	2:36:30	136341									
	V	2:36:55	136241	V	136291	8733	2:36:48	2450044.609594	2450044.612702	-0.041078	356.179293	-3.732287
	B	2:37:45	372650									
	B	2:38:05	369574	B	371112	10347	2:38:00	2450044.610433	2450044.613541	-0.041078	356.482204	-3.429377
	U	2:38:40	127707									
	U	2:39:00	128719	U	128213	4769	2:38:55	2450044.611069	2450044.614177	-0.041078	356.711998	-3.199583
sky	V	2:40:20	8649									
	B	2:40:45	10462									
	U	2:41:10	4791									
Comparison	V	2:44:30	149687									
	V	2:44:48	146663	V	148175	8709	2:44:44	2450044.615109	2450044.618217	-0.041078	358.170146	-1.220218
	B	2:45:15	259885									
	B	2:45:35	241107	B	250496	10378	2:45:30	2450044.615641	2450044.618749	-0.041078	358.362337	-1.028027
	U	2:46:05	86411									
	U	2:46:25	87038	U	86725	4759	2:46:20	2450044.616220	2450044.619328	-0.041078	358.571241	-0.819123
Sky	V	2:48:00	8768									
	B	2:48:25	10294									
	U	2:48:50	4726									
UPeg	V	2:50:55	124662									
	V	2:51:15	125429	V	125046	8675	2:51:10	2450044.619576	2450044.622684	-0.041078	359.782882	0.339119
	B	2:51:40	216602									
	B	2:52:00	217115	B	216859	10412	2:51:55	2450044.620097	2450044.623205	-0.041078	359.970896	0.527132
	U	2:52:25	76671									
	U	2:52:44	75892	U	76282	4723	2:52:40	2450044.620612	2450044.623720	-0.041078	0.156820	0.713057
Sky	V	2:54:10	8581									
	B	2:54:40	10530									
	U	2:55:05	4720									
Comp	V	2:57:55	149530									
	V	2:58:15	149243	V	149387	8719	2:58:10	2450044.624438	2450044.627545	-0.041078	1.537674	2.147310
	B	2:58:45	269274									
	B	2:59:05	267556	B	268415	10363	2:59:00	2450044.625016	2450044.628124	-0.041078	1.746578	2.356214
	U	2:59:35	96682									
	U	2:59:55	96052	U	96367	4635	2:59:50	2450044.625595	2450044.628703	-0.041078	1.955481	2.565118

23 Nov 95

Observable	Filter	X	N	v, b, u	(b-v)	ΔV	V
		Airmass	True Count of	Instrumental	Instrumental		
Sky	V		Star - Sky	Magnitude	Color		
	B				and		
	U				v - k"(b - v)X		
Check	V						
	V	1.090230	127917	-10.267			-12.644
	B				-1.134		
	B	1.089937	363448	-11.401			
	U						
	U	1.089731	123763	-10.231			
sky	V						
	B						
	U						
Comparison	V						
	V	1.091103	139891	-10.364		0.256	-12.389
	B				-0.592		
	B	1.091045	241336	-10.957			
	U				-10.752		
	U	1.090992	82111	-9.786			
Sky	V						
	B						
	U						
UPeg	V						
	V	1.086989	116673	-10.167		0.210	-12.205
	B				-0.624		
	B	1.087011	207358	-10.792		-0.006	
	U					-0.005	
	U	1.087042	71671	-9.638			
Sky	V						
	B						
	U						
Comp	V						
	V	1.091528	141100	-10.374			-12.444
	B				-0.661		
	B	1.091655	259452	-11.035			
	U				-10.807		
	U	1.091795	91912	-9.908			

23 Nov 95

Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST	H
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees	Degrees
Sky	V	3:00:35	8856									
	B	3:01:00	10195									
	U	3:01:25	4550									
UPeg	V	3:03:35	129899									
	V	3:03:55	129584	V	129742	8792	3:03:50	2450044.628373	2450044.631481	-0.041078	2.958219	3.514456
	B	3:04:25	226887									
	B	3:04:45	227916	B	227402	10168	3:04:40	2450044.628951	2450044.632059	-0.041078	3.167123	3.723359
	U	3:05:10	81516									
	U	3:05:30	81488	U	81502	4487	3:05:25	2450044.629472	2450044.632580	-0.041078	3.355136	3.911373
Sky	V	3:06:10	8728									
	B	3:06:40	10141									
	U	3:07:00	4424									
Comp	V	3:21:30	139878									
	V	3:21:50	142840	V	141359	8863	3:21:45	2450044.640815	2450044.643923	-0.041078	7.449650	8.059286
	B	3:22:20	253601									
	B	3:22:33	253551	B	253576	10199	3:22:32	2450044.641353	2450044.644461	-0.041078	7.643930	8.253566
	U	3:23:00	84705									
	U	3:23:15	86270	U	85488	4438	3:23:13	2450044.641828	2450044.644935	-0.041078	7.815231	8.424867
Sky	V	3:23:55	8997									
	B	3:24:15	10257									
	U	3:24:40	4452									
UPeg	V	3:27:10	133851									
	V	3:27:25	135359	V	134605	8785	3:27:23	2450044.644721	2450044.647829	-0.041077	8.859750	9.415986
	B	3:27:55	220093									
	B	3:28:08	217029	B	218561	10139	3:28:07	2450044.645230	2450044.648338	-0.041077	9.043585	9.599821
	U	3:28:40	76715									
	U	3:28:55	74411	U	75563	4437	3:28:53	2450044.645763	2450044.648871	-0.041077	9.235776	9.792013
Sky	V	3:29:32	8573									
	B	3:29:56	10020									
	U	3:30:22	4421									
Comp	V	3:32:38	147562									
	V	3:32:58	147323	V	147443	8643	3:32:53	2450044.648546	2450044.651654	-0.041077	10.240603	10.850240
	B	3:33:24	269097									
	B	3:33:43	267567	B	268332	9963	3:33:39	2450044.649073	2450044.652181	-0.041077	10.430706	11.040342
	U	3:34:10	96438									
	U	3:34:28	95766	U	96102	4415	3:34:24	2450044.649600	2450044.652707	-0.041077	10.620808	11.230444
Sky	V	3:35:30	8712									
	B	3:35:55	9905									

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Observable	Filter	X	N	v, b, u	(b-v)	ΔV	V
		Airmass	True Count of	Instrumental	Instrumental		
Sky	V						
	B						
	U						
UPeg	V						
	V	1.088637	121275	-10.209		0.158	-12.259
	B				-0.638		
	B	1.088840	218237	-10.847			
	U						
	U	1.089034	77143	-9.718			
Sky	V						
	B						
	U						
Comp	V						
	V	1.099776	132883	-10.309			-12.396
	B				-0.663		
	B	1.100212	244626	-10.971			
	U				-10.746		
	U	1.100606	81191	-9.774			
Sky	V						
	B						
	U						
UPeg	V						
	V	1.099001	126170	-10.252		0.168	-12.263
	B				-0.550		
	B	1.099479	209349	-10.802			
	U						
	U	1.099990	71237	-9.632			
Sky	V						
	B						
	U						
Comp	V						
	V	1.107073	139220	-10.359			-12.470
	B				-0.677		
	B	1.107651	259768	-11.036			
	U				-10.809		
	U	1.108240	91866	-9.908			
Sky	V						
	B						

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST	H
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees	Degrees
	U	3:36:19	4408									
UPeg	V	3:37:44	116188									
	V	3:38:14	119421	V	117805	8741	3:38:04	2450044.652146	2450044.655254	-0.041077	11.539985	12.096221
	B	3:38:40	207034									
	B	3:38:58	220912	B	213973	9938	3:38:54	2450044.652725	2450044.655832	-0.041077	11.748888	12.305125
	U	3:39:23	81365									
	U	3:39:40	83596	U	82481	4366	3:39:37	2450044.653216	2450044.656324	-0.041077	11.926456	12.482693
Sky	V	3:40:33	8770									
	B	3:40:56	9970									
	U	3:41:21	4324									
Comp	V	3:44:17	89058									
	V	3:44:43	97019	V	93039	8806	3:44:35	2450044.656671	2450044.659779	-0.041077	13.173612	13.783248
	B	3:45:14	186819									
	B	3:45:34	195966	B	191393	9970	3:45:29	2450044.657296	2450044.660404	-0.041077	13.399228	14.008864
	U	3:46:04	71202									
	U	3:46:21	74968	U	73085	4394	3:46:18	2450044.657858	2450044.660966	-0.041077	13.601864	14.211501
Sky	V	3:47:04	8841									
	B	3:47:30	9970									
	U	3:47:55	4464									
UPeg	V	3:51:20	33758									
	V	3:51:42	37852	V	35805	8692	3:51:36	2450044.661544	2450044.664652	-0.041077	14.932581	15.488817
	B	3:52:10	75804									
	B	3:52:29	81621	B	78713	9913	3:52:25	2450044.662105	2450044.665213	-0.041077	15.135218	15.691454
	U	3:52:56	30575									
	U	3:53:14	31631	U	31103	4427	3:53:10	2450044.662632	2450044.665740	-0.041077	15.325320	15.881556
Sky	V	3:53:58	8543									
	B	3:54:26	9855									
	U	3:54:22	4390									
Comp	V	3:56:35	136038									
	V	3:56:55	130081	V	133060	8666	3:56:50	2450044.665178	2450044.668286	-0.041077	16.244496	16.854133
	B	3:57:21	234230									
	B	3:57:39	238577	B	236404	9933	3:57:35	2450044.665699	2450044.668807	-0.041077	16.432510	17.042146
	U	3:58:07	73925									
	U	3:58:26	78527	U	76226	4390	3:58:22	2450044.666237	2450044.669345	-0.041077	16.626790	17.236427
Sky	V	3:59:09	8788									
	B	3:59:39	10011									
	U	4:00:04	4389									
Check	V	4:03:08	118251									

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Observable	Filter	X	N	v, b, u	(b-v)	ΔV	V
		Airmass	True Count of	Instrumental	Instrumental		
	U						
UPeg	V						
	V	1.106936	109331	-10.097		0.048	-12.210
	B				-0.682		
	B	1.107642	204923	-10.779			
	U						
	U	1.108252	78246	-9.734			
Sky	V						
	B						
	U						
Comp	V						
	V	1.117187	84399	-9.816			-12.051
	B				-0.835		
	B	1.118072	182132	-10.651			
	U				-10.376		
	U	1.118880	68794	-9.594			
Sky	V						
	B						
	U						
UPeg	V						
	V	1.120012	27136	-8.584		1.269	-10.944
	B				-1.012		
	B	1.120903	68918	-9.596			
	U						
	U	1.121751	26694	-8.566			
Sky	V						
	B						
	U						
Comp	V						
	V	1.130581	124736	-10.240		0.255	-12.379
	B				-0.653		
	B	1.131497	227555	-10.893			
	U				-10.683		
	U	1.132456	71949	-9.643			
Sky	V						
	B						
	U						
Check	V						

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST	H
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees	Degrees
	V	4:03:28	125176	V	121714	8777	4:03:23	2450044.669727	2450044.672835	-0.041077	17.886480	17.974899
	B	4:03:55	341497									
	B	4:04:14	343660	B	342579	10033	4:04:10	2450044.670265	2450044.673373	-0.041077	18.080760	18.169180
	U	4:04:40	123115									
	U	4:04:58	122432	U	122774	4480	4:04:54	2450044.670780	2450044.673888	-0.041077	18.266685	18.355104
Sky	V	4:05:34	8766									
	B	4:05:57	10054									
	U	4:06:25	4570									
UPeg	V	4:09:01	89902									
	V	4:09:19	87952	V	88927	8818	4:09:15	2450044.673801	2450044.676909	-0.041077	19.357162	19.913398
	B	4:09:46	158483									
	B	4:10:05	171473	B	164978	10054	4:10:01	2450044.674328	2450044.677435	-0.041077	19.547264	20.103501
	U	4:10:33	61581									
	U	4:10:53	61044	U	61313	4399	4:10:48	2450044.674877	2450044.677985	-0.041077	19.745723	20.301959
Sky	V	4:11:39	8869									
	B	4:12:05	10054									
	U	4:12:29	4228									
Comp	V	4:14:19	97969									
	V	4:14:37	98213	V	98091	9310	4:14:33	2450044.677482	2450044.680589	-0.041077	20.685790	21.295426
	B	4:15:02	195615									
	B	4:15:20	182288	B	188952	10317	4:15:16	2450044.677979	2450044.681087	-0.041077	20.865447	21.475083
	U	4:15:47	60119									
	U	4:16:05	63740	U	61930	4201	4:16:01	2450044.678500	2450044.681608	-0.041077	21.053461	21.663097
Sky	V	4:17:04	9750									
	B	4:17:28	10580									
	U	4:17:53	4174									
UPeg	V	4:25:38	94099									
	V	4:25:56	96061	V	95080	9292	4:25:52	2450044.685340	2450044.688448	-0.041076	23.522702	24.078939
	B	4:26:21	168871									
	B	4:26:39	178966	B	173919	10218	4:26:35	2450044.685838	2450044.688946	-0.041076	23.702360	24.258596
	U	4:27:08	64455									
	U	4:27:27	58859	U	61657	4214	4:27:23	2450044.686388	2450044.689496	-0.041076	23.900818	24.457055
Sky	V	4:28:10	8833									
	B	4:28:36	9856									
	U	4:29:04	4253									
Comp	V	4:37:39	89802									
	V	4:37:59	92276	V	91039	9203	4:37:54	2450044.693697	2450044.696805	-0.041076	26.539272	27.148909
	B	4:38:25	168772									

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Observable	Filter	X	N	v, b, u	(b-v)	ΔV	V
		Airmass	True Count of	Instrumental	Instrumental		
	V	1.133373	113222	-10.135			-12.635
	B				-1.177		
	B	1.134384	334830	-11.312			
	U						
	U	1.135364	118586	-10.185			
Sky	V						
	B						
	U						
UPeg	V						
	V	1.142456	80261	-9.761		0.289	-11.967
	B				-0.718		
	B	1.143564	155450	-10.479			
	U						
	U	1.144734	56986	-9.389			
Sky	V						
	B						
	U						
Comp	V						
	V	1.155358	88966	-9.873			-12.134
	B				-0.761		
	B	1.156503	179326	-10.634			
	U				-10.401		
	U	1.157712	57802	-9.405			
Sky	V						
	B						
	U						
UPeg	V						
	V	1.169639	85962	-9.836		0.058	-12.084
	B				-0.703		
	B	1.170953	164286	-10.539			
	U						
	U	1.172419	57517	-9.399			
Sky	V						
	B						
	U						
Comp	V						
	V	1.198822	81995	-9.784			-12.157
	B				-0.798		

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST	H
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees	Degrees
	B	4:38:44	192614	B	180693	10267	4:38:40	2450044.694223	2450044.697331	-0.041076	26.729375	27.339011
	U	4:39:10	71013									
	U	4:39:28	75451	U	73232	4292	4:39:24	2450044.694738	2450044.697846	-0.041076	26.915299	27.524935
Sky	V	4:40:12	9573									
	B	4:40:39	10678									
	U	4:41:04	4330									
UPeg	V	4:42:46	83583									
	V	4:43:30	95067	V	89325	9294	4:43:13	2450044.697389	2450044.700497	-0.041076	27.872078	28.428315
	B	4:43:57	159587									
	B	4:44:18	163072	B	161330	10296	4:44:13	2450044.698078	2450044.701185	-0.041076	28.120674	28.676910
	U	4:44:45	55827									
	U	4:45:03	57240	U	56534	4256	4:44:59	2450044.698616	2450044.701724	-0.041076	28.314954	28.871190
Sky	V	4:45:57	9014									
	B	4:46:22	9914									
	U	4:46:46	4181									
Comp	V	4:48:18	130306									
	V	4:48:36	134128	V	132217	9833	4:48:32	2450044.701081	2450044.704189	-0.041076	29.204884	29.814520
	B	4:49:02	238192									
	B	4:49:21	227871	B	233032	10298	4:49:17	2450044.701596	2450044.704704	-0.041076	29.390808	30.000445
	U	4:49:46	77597									
	U	4:50:04	78442	U	78020	4272	4:50:00	2450044.702100	2450044.705207	-0.041076	29.572555	30.182191
Sky	V	4:50:54	10651									
	B	4:51:26	10682									
	U	4:51:53	4363									
UPeg	V	4:53:45	121881									
	V	4:54:04	118491	V	120186	10750	4:54:00	2450044.704872	2450044.707979	-0.041076	30.573203	31.129440
	B	4:54:32	202625									
	B	4:54:51	207960	B	205293	10842	4:54:47	2450044.705416	2450044.708523	-0.041076	30.769573	31.325809
	U	4:55:17	71105									
	U	4:55:34	71385	U	71245	4300	4:55:31	2450044.705925	2450044.709033	-0.041076	30.953408	31.509644
Sky	V	4:56:36	10848									
	B	4:57:05	11001									
	U	4:57:29	4237									
Comp	V	4:59:30	86095									
	V	4:59:48	89720	V	87908	11461	4:59:44	2450044.708859	2450044.711967	-0.041076	32.012550	32.622186
	B	5:00:15	137369									
	B	5:00:34	132263	B	134816	11263	5:00:30	2450044.709385	2450044.712493	-0.041076	32.202653	32.812289
	U	5:01:00	44076									

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Observable	Filter	X	N	v, b, u	(b-v)	ΔV	V
		Airmass	True Count of	Instrumental	Instrumental		
	B	1.200459	171058	-10.583			
	U				-10.359		
	U	1.202075	69044	-9.598			
Sky	V						
	B						
	U						
UPeg	V						
	V	1.204994	80185	-9.760		0.277	-12.067
	B				-0.691		
	B	1.207249	151537	-10.451			
	U						
	U	1.209029	52340	-9.297			
Sky	V						
	B						
	U						
Comp	V						
	V	1.223187	122722	-10.222			-12.536
	B				-0.652		
	B	1.225003	223787	-10.875			
	U				-10.701		
	U	1.226793	73865	-9.671			
Sky	V						
	B						
	U						
UPeg	V						
	V	1.230943	109714	-10.101		-0.153	-12.409
	B				-0.626		
	B	1.232958	195268	-10.727			
	U						
	U	1.234861	67043	-9.566			
Sky	V						
	B						
	U						
Comp	V						
	V	1.252324	76594	-9.710			-11.981
	B				-0.522		
	B	1.254434	123904	-10.233			
	U				-10.103		

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST	H
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees	Degrees
	U	5:01:17	44183	U	44130	4243	5:01:14	2450044.709895	2450044.713003	-0.041076	32.386488	32.996124
Sky	V	5:02:00	12073									
	B	5:02:28	11524									
	U	5:02:53	4249									
UPeg	V	5:04:48	70383									
	V	5:05:12	75167	V	72775	12963	5:05:05	2450044.712574	2450044.715682	-0.041076	33.353712	33.909948
	B	5:05:38	102817									
	B	5:05:55	100993	B	101905	12541	5:05:52	2450044.713112	2450044.716220	-0.041076	33.547993	34.104229
	U	5:06:23	41506									
	U	5:06:40	31656	U	36581	4354	5:06:37	2450044.713633	2450044.716741	-0.041076	33.736006	34.292242
Sky	V	5:07:28	13852									
	B	5:07:57	13557									
	U	5:08:21	4458									
Comp	V	5:12:04	48080									
	V	5:12:24	47564	V	47822	14817	5:12:19	2450044.717597	2450044.720705	-0.041075	35.166997	35.776633
	B	5:12:54	61820									
	B	5:13:11	59568	B	60694	13707	5:13:08	2450044.718159	2450044.721266	-0.041075	35.369633	35.979269
	U	5:13:44	26658									
	U	5:14:03	28428	U	27543	4548	5:13:59	2450044.718749	2450044.721857	-0.041075	35.582715	36.192351
Sky	V	5:15:13	15781									
	B	5:15:46	13856									
	U	5:16:13	4637									
Check	V	5:18:56	28268									
	V	5:19:16	29046	V	28657	15781	5:19:11	2450044.722366	2450044.725474	-0.041075	36.888363	36.976783
	B	5:19:42	54423									
	B	5:20:01	48395	B	51409	13856	5:19:57	2450044.722892	2450044.726000	-0.041075	37.078466	37.166885
	U	5:20:30	14805									
	U	5:20:49	18656	U	16731	4637	5:20:45	2450044.723448	2450044.726556	-0.041075	37.279013	37.367433

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Observable	Filter	X	N	v, b, u	(b-v)	ΔV	V
		Airmass	True Count of	Instrumental	Instrumental		
	U	1.256492	39924	-9.003			
Sky	V						
	B						
	U						
UPeg	V						
	V	1.261204	59912	-9.444		-0.162	-11.666
	B				-0.437		
	B	1.263463	89563	-9.880			
	U						
	U	1.265666	32253	-8.771			
Sky	V						
	B						
	U						
Comp	V						
	V	1.289756	33046	-8.798		-0.400	-11.029
	B				-0.384		
	B	1.292344	47055	-9.182			
	U				-9.095		
	U	1.295089	23010	-8.405			
Sky	V						
	B						
	U						
Check	V						
	V	1.301382	12887	-7.775			-10.635
	B				-1.163		
	B	1.303920	37600	-8.938			
	U						
	U	1.306621	12099	-7.707			

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			24	11	1995	JD =	2450045.50			
Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T
					Average of 2	Average of 2	Avg + 5 secs			Julian Century
Sky	V	1:41:30	8402							
	B	1:41:58	10723							
	U	1:42:24	4309							
Check	V	1:44:24	133814							
	V	1:44:42	135254	V	134534	8328	1:44:38	2450045.573373	2450045.576401	-0.041052
	B	1:46:10	374151							
	B	1:46:28	376187	B	375169	10647	1:46:24	2450045.574600	2450045.577628	-0.041052
	U	1:46:54	130713							
	U	1:47:11	131654	U	131184	4356	1:47:08	2450045.575103	2450045.578131	-0.041052
sky	V	1:48:06	8254							
	B	1:48:30	10571							
	U	1:48:53	4403							
Comparison	V	1:50:46	146013							
	V	1:51:04	149089	V	147551	8248	1:51:00	2450045.577794	2450045.580822	-0.041052
	B	1:51:30	277281							
	B	1:51:48	273356	B	275319	10458	1:51:44	2450045.578303	2450045.581332	-0.041052
	U	1:52:14	100462							
	U	1:52:31	98816	U	99639	4251	1:52:28	2450045.578807	2450045.581835	-0.041052
Sky	V	1:53:12	8242							
	B	1:53:34	10345							
	U	1:53:57	4099							
UPeg	V	1:56:50	141548							
	V	1:57:08	141836	V	141692	8222	1:57:04	2450045.582007	2450045.585035	-0.041052
	B	1:57:33	249204							
	B	1:57:52	251909	B	250557	10397	1:57:48	2450045.582510	2450045.585539	-0.041052
	U	1:58:16	87851							
	U	1:58:35	86689	U	87270	4138	1:58:31	2450045.583008	2450045.586037	-0.041052
Sky	V	1:59:24	8202							
	B	1:59:49	10448							
	U	2:00:16	4176							
Comp	V	2:06:06	150829							

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Observable	Filter	LST	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Degrees	Airmass	True Count of	Instrumental	Instrumental		
Sky	V				Star - Sky	Magnitude	Color		
	B						and		
	U						v - k"(b - v)X		
Check	V								
	V	344.089694	-15.821964	1.122977	126556	-10.256			-11.046
	B						-1.157		
	B	344.532570	-15.379088	1.121020	367264	-11.412			
	U								
	U	344.714316	-15.197341	1.120234	127161	-10.261			
sky	V								
	B								
	U								
Comparison	V								
	V	345.685718	-13.704722	1.116882	139724	-10.363		0.199	-10.843
	B						-0.700		
	B	345.869553	-13.520887	1.116177	266333	-11.064			
	U						-10.833		
	U	346.051300	-13.339141	1.115490	95580	-9.951			
Sky	V								
	B								
	U								
UPeg	V								
	V	347.206537	-12.237307	1.107411	133858	-10.317		0.094	-10.752
	B						-0.640		
	B	347.388284	-12.055561	1.106800	241379	-10.957		0.000	
	U							0.037	
	U	347.567941	-11.875904	1.106205	83280	-9.801			
Sky	V								
	B								
	U								
Comp	V								

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T
					Average of 2	Average of 2	Avg + 5 secs			Julian Century
	V	2:06:28	149440	V	150135	8145	2:06:22	2450045.588465	2450045.591494	-0.041052
	B	2:05:20	279745							
	B	2:05:39	276555	B	278150	10305	2:05:35	2450045.587916	2450045.590944	-0.041052
	U	2:04:25	101916							
	U	2:04:46	100868	U	101392	4110	2:04:41	2450045.587291	2450045.590319	-0.041052
Sky	V	2:07:20	8087							
	B	2:07:44	10162							
	U	2:08:10	4044							
UPeg	V	2:10:32	145536							
	V	2:10:52	144511	V	145024	8169	2:10:47	2450045.591532	2450045.594561	-0.041052
	B	2:11:17	256727							
	B	2:11:35	259959	B	258343	10226	2:11:31	2450045.592042	2450045.595070	-0.041052
	U	2:11:58	91949							
	U	2:12:17	91806	U	91878	3999	2:12:13	2450045.592522	2450045.595550	-0.041052
Sky	V	2:12:58	8250							
	B	2:13:21	10289							
	U	2:13:44	3954							
Comp	V	2:15:50	151994							
	V	2:16:07	152646	V	152320	8137	2:16:04	2450045.595196	2450045.598224	-0.041051
	B	2:16:32	276192							
	B	2:16:49	277000	B	276596	10262	2:16:46	2450045.595682	2450045.598710	-0.041051
	U	2:17:12	93701							
	U	2:17:28	94539	U	94120	3946	2:17:25	2450045.596139	2450045.599167	-0.041051
Sky	V	2:18:10	8023							
	B	2:18:35	10234							
	U	2:19:00	3937							
UPeg	V	2:21:46	145910							
	V	2:22:04	145679	V	145795	8078	2:22:00	2450045.599322	2450045.602350	-0.041051
	B	2:22:30	260424							
	B	2:22:48	261231	B	260828	10154	2:22:44	2450045.599831	2450045.602860	-0.041051
	U	2:23:11	94659							
	U	2:23:28	94563	U	94611	3943	2:23:25	2450045.600300	2450045.603328	-0.041051
Sky	V	2:24:060	8132							

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Observable	Filter	LST	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Degrees	Airmass	True Count of	Instrumental	Instrumental		
	V	349.537903	-9.852538	1.104207	142426	-10.384			-10.853
	B						-0.692		
	B	349.339444	-10.050996	1.104754	269348	-11.076			
	U						-10.842		
	U	349.113828	-10.276612	1.105390	97481	-9.972			
Sky	V								
	B								
	U								
UPeg	V								
	V	350.645093	-8.798752	1.097464	137262	-10.344		0.070	-10.781
	B						-0.648		
	B	350.828928	-8.614917	1.097027	249414	-10.992			
	U								
	U	351.002318	-8.441527	1.096623	88042	-9.862			
Sky	V								
	B								
	U								
Comp	V								
	V	351.967453	-7.422987	1.098423	144633	-10.401			-10.852
	B						-0.669		
	B	352.142932	-7.247508	1.098069	267821	-11.070			
	U						-10.842		
	U	352.307966	-7.082474	1.097745	90346	-9.890			
Sky	V								
	B								
	U								
UPeg	V								
	V	353.456937	-5.986908	1.091810	138128	-10.351		0.029	-10.789
	B						-0.653		
	B	353.640772	-5.803073	1.091517	251995	-11.003			
	U								
	U	353.809984	-5.633860	1.091255	90842	-9.896			
Sky	V								

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T
					Average of 2	Average of 2	Avg + 5 secs			Julian Century
	B	2:24:29	10074							
	U	2:24:51	3948							
Comp	V	2:27:32	135048							
	V	2:27:51	142510	V	138779	8105	2:27:47	2450045.603332	2450045.606361	-0.041051
	B	2:28:14	265899							
	B	2:28:32	266987	B	266443	10055	2:28:28	2450045.603813	2450045.606841	-0.041051
	U	2:28:56	100902							
	U	2:29:13	100406	U	100654	3889	2:29:10	2450045.604293	2450045.607321	-0.041051
Sky	V	2:29:51	8077							
	B	2:30:14	10035							
	U	2:30:38	3830							
UPeg	V	2:32:52	146338							
	V	2:33:13	148042	V	147190	8027	2:33:08	2450045.607047	2450045.610076	-0.041051
	B	2:33:37	266171							
	B	2:34:11	268764	B	267468	10062	2:33:59	2450045.607644	2450045.610672	-0.041051
	U	2:34:35	95758							
	U	2:34:53	96222	U	95990	3866	2:34:49	2450045.608222	2450045.611251	-0.041051
Sky	V	2:35:28	7977							
	B	2:35:53	10089							
	U	2:36:16	3901							
Comp	V	2:37:42	127822							
	V	2:38:00	126407	V	127115	7939	2:37:56	2450045.610387	2450045.613415	-0.041051
	B	2:38:26	246484							
	B	2:38:44	253929	B	250207	9988	2:38:40	2450045.610896	2450045.613924	-0.041051
	U	2:39:09	91539							
	U	2:39:26	93320	U	92430	3884	2:39:23	2450045.611388	2450045.614416	-0.041051
Sky	V	2:40:06	7900							
	B	2:40:31	9887							
	U	2:40:55	3866							
UPeg	V	2:43:14	151688							
	V	2:43:34	152765	V	152227	7891	2:43:29	2450045.614241	2450045.617269	-0.041051
	B	2:44:00	269929							
	B	2:44:33	272133	B	271031	9727	2:44:22	2450045.614848	2450045.617877	-0.041051

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Observable	Filter	LST	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Degrees	Airmass	True Count of	Instrumental	Instrumental		
	B								
	U								
Comp	V								
	V	354.904640	-4.485801	1.093638	131047	-10.294			-10.786
	B						-0.735		
	B	355.078030	-4.312411	1.093430	257768	-11.028			
	U						-10.776		
	U	355.251420	-4.139021	1.093231	96961	-9.966			
Sky	V								
	B								
	U								
UPeg	V								
	V	356.245802	-3.198043	1.088350	139582	-10.362		-0.067	-10.810
	B						-0.670		
	B	356.460973	-2.982872	1.088171	258795	-11.032			
	U								
	U	356.669876	-2.773968	1.088009	92303	-9.913			
Sky	V								
	B								
	U								
Comp	V								
	V	357.451176	-1.939264	1.091412	119488	-10.193			-10.704
	B						-0.764		
	B	357.635012	-1.755429	1.091320	241434	-10.957			
	U						-10.693		
	U	357.812580	-1.577861	1.091239	88711	-9.870			
Sky	V								
	B								
	U								
UPeg	V								
	V	358.842475	-0.601370	1.087022	144785	-10.402		-0.070	-10.834
	B						-0.647		
	B	359.061824	-0.382021	1.086993	262731	-11.049			

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T
					Average of 2	Average of 2	Avg + 5 secs			Julian Century
	U	2:44:58	96132							
	U	2:45:15	96668	U	96400	3757	2:45:12	2450045.615427	2450045.618456	-0.041051
Sky	V	2:45:52	7881							
	B	2:46:16	9567							
	U	2:46:40	3647							
Comp	V	2:51:07	146335							
	V	2:50:48	144187	V	145261	7861	2:51:03	2450045.619490	2450045.622518	-0.041051
	B	2:51:35	274398							
	B	2:51:55	275745	B	275072	9578	2:51:50	2450045.620039	2450045.623068	-0.041051
	U	2:52:32	101147							
	U	2:52:50	101316	U	101232	3723	2:52:46	2450045.620688	2450045.623716	-0.041051
Sky	V	2:53:32	7840							
	B	2:53:58	9589							
	U	2:54:21	3798							
Check	V	2:56:43	134514							
	V	2:57:01	136401	V	135458	7867	2:56:57	2450045.623593	2450045.626621	-0.041051
	B	2:57:26	376210							
	B	2:57:43	376073	B	376142	9690	2:57:40	2450045.624085	2450045.627113	-0.041051
	U	2:58:09	133767							
	U	2:58:27	132463	U	133115	3745	2:58:23	2450045.624588	2450045.627616	-0.041051
Sky	V	2:59:07	7894							
	B	2:59:33	9790							
	U	2:59:55	3692							
UPeg	V	3:02:08	147965							
	V	3:02:27	149001	V	148483	7875	3:02:23	2450045.627360	2450045.630388	-0.041051
	B	3:02:53	260453							
	B	3:03:12	264754	B	262604	9654	3:03:08	2450045.627881	2450045.630909	-0.041051
	U	3:03:39	94883							
	U	3:03:56	92449	U	93666	3674	3:03:53	2450045.628402	2450045.631430	-0.041051
Sky	V	3:04:50	7855							
	B	3:05:15	9517							
	U	3:05:39	3655							
Comp	V	3:06:52	147045							

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Observable	Filter	LST	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Degrees	Airmass	True Count of	Instrumental	Instrumental		
	U								
	U	359.270728	-0.173117	1.086978	92823	-9.919			
Sky	V								
	B								
	U								
Comp	V								
	V	0.737232	1.346791	1.091147	137809	-10.348		0.202	-10.828
	B						-0.718		
	B	0.935691	1.545250	1.091225	266964	-11.066			
	U						-10.818		
	U	1.169663	1.779222	1.091331	97707	-9.975			
Sky	V								
	B								
	U								
Check	V								
	V	2.218359	2.306702	1.089066	127945	-10.268			-11.030
	B						-1.151		
	B	2.395928	2.484270	1.089181	369208	-11.418			
	U								
	U	2.577674	2.666017	1.089307	129714	-10.282			
Sky	V								
	B								
	U								
UPeg	V								
	V	3.578323	4.134478	1.089276	141035	-10.373		0.027	-10.802
	B						-0.640		
	B	3.766336	4.322491	1.089491	254290	-11.013			
	U								
	U	3.954349	4.510505	1.089715	90162	-9.888			
Sky	V								
	B								
	U								
Comp	V								

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T
					Average of 2	Average of 2	Avg + 5 secs			Julian Century
	V	3:07:09	146576	V	146811	7839	3:07:06	2450045.630635	2450045.633664	-0.041050
	B	3:07:34	273430							
	B	3:07:52	274824	B	274127	9446	3:07:48	2450045.631127	2450045.634156	-0.041050
	U	3:08:17	99740							
	U	3:08:33	99246	U	99493	3687	3:08:30	2450045.631613	2450045.634642	-0.041050
Sky	V	3:09:16	7823							
	B	3:09:41	9375							
	U	3:10:05	3719							
UPeg	V	3:14:54	145008							
	V	3:14:36	143379	V	144194	7817	3:14:50	2450045.636012	2450045.639040	-0.041050
	B	3:15:22	260191							
	B	3:15:39	260978	B	260585	9425	3:15:36	2450045.636538	2450045.639567	-0.041050
	U	3:16:05	91249							
	U	3:16:22	90514	U	90882	3678	3:16:19	2450045.637036	2450045.640064	-0.041050
Sky	V	3:17:03	7810							
	B	3:17:29	9475							
	U	3:17:53	3636							
Comp	V	3:22:27	133529							
	V	3:22:46	139220	V	136375	7812	3:22:42	2450045.641469	2450045.644497	-0.041050
	B	3:23:11	251584							
	B	3:23:29	257062	B	254323	9417	3:23:25	2450045.641972	2450045.645001	-0.041050
	U	3:23:53	94806							
	U	3:24:10	96327	U	95567	3653	3:24:07	2450045.642453	2450045.645481	-0.041050
Sky	V	3:25:19	7814							
	B	3:25:45	9358							
	U	3:26:16	3669							
UPeg	V	3:29:12	136966							
	V	3:29:30	139149	V	138058	7787	3:29:26	2450045.646150	2450045.649179	-0.041050
	B	3:29:57	249753							
	B	3:30:16	255948	B	252851	9308	3:30:12	2450045.646677	2450045.649706	-0.041050
	U	3:30:43	90245							
	U	3:31:00	88973	U	89609	3603	3:30:57	2450045.647198	2450045.650226	-0.041050
Sky	V	3:31:40	7759							

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Observable	Filter	LST	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Degrees	Airmass	True Count of	Instrumental	Instrumental		
	V	4.760718	5.370277	1.094828	139389	-10.361			-10.832
	B						-0.702		
	B	4.938286	5.547845	1.095092	266141	-11.063			
	U						-10.822		
	U	5.113765	5.723325	1.095363	95998	-9.956			
Sky	V								
	B								
	U								
UPeg	V								
	V	6.701434	7.257589	1.094093	136779	-10.340		0.002	-10.787
	B						-0.666		
	B	6.891536	7.447691	1.094473	252479	-11.006			
	U								
	U	7.071193	7.627348	1.094841	87364	-9.853			
Sky	V								
	B								
	U								
Comp	V								
	V	8.671396	9.280955	1.102695	128922	-10.276			-10.751
	B						-0.702		
	B	8.853142	9.462701	1.103166	246163	-10.978			
	U						-10.740		
	U	9.026532	9.636091	1.103624	92091	-9.911			
Sky	V								
	B								
	U								
UPeg	V								
	V	10.361427	10.917582	1.103191	130640	-10.290		-0.001	-10.752
	B						-0.682		
	B	10.551529	11.107684	1.103768	244784	-10.972			
	U								
	U	10.739543	11.295698	1.104348	86162	-9.838			
Sky	V								

24 Nov 95

Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T
					Average of 2	Average of 2	Avg + 5 secs			Julian Century
	B	3:32:06	9258							
	U	3:32:29	3536							
Comp	V	3:34:36	127962							
	V	3:34:59	133667	V	130815	7764	3:34:53	2450045.649929	2450045.652958	-0.041050
	B	3:35:26	257039							
	B	3:35:44	262201	B	259620	9339	3:35:40	2450045.650479	2450045.653508	-0.041050
	U	3:36:09	96129							
	U	3:36:29	95827	U	95978	3523	3:36:24	2450045.650988	2450045.654017	-0.041050
Sky	V	3:38:01	7768							
	B	3:38:26	9419							
	U	3:38:48	3509							
UPeg	V	3:41:06	127239							
	V	3:41:24	126931	V	127085	7855	3:41:20	2450045.654414	2450045.657443	-0.041050
	B	3:41:49	234193							
	B	3:42:04	236220	B	235207	9466	3:42:02	2450045.654895	2450045.657923	-0.041050
	U	3:42:31	83312							
	U	3:42:50	79122	U	81217	3576	3:42:46	2450045.655404	2450045.658432	-0.041050
Sky	V	3:43:39	7942							
	B	3:44:02	9512							
	U	3:44:26	3643							
Comp	V	3:48:10	120612							
	V	3:48:28	123423	V	122018	7990	3:48:24	2450045.659322	2450045.662350	-0.041050
	B	3:48:54	235634							
	B	3:49:10	246347	B	240991	9559	3:49:07	2450045.659819	2450045.662848	-0.041050
	U	3:49:36	87333							
	U	3:49:54	88227	U	87780	3571	3:49:50	2450045.660317	2450045.663346	-0.041050
Sky	V	3:51:37	8038							
	B	3:51:56	9606							
	U	3:52:20	3498							
UPeg	V	4:01:31	123133							
	V	4:01:49	129146	V	126140	7870	4:01:45	2450045.668593	2450045.671621	-0.041049
	B	4:02:17	226790							
	B	4:02:35	229965	B	228378	9496	4:02:31	2450045.669125	2450045.672153	-0.041049

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Observable	Filter	LST	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Degrees	Airmass	True Count of	Instrumental	Instrumental		
	B								
	U								
Comp	V								
	V	11.725568	12.335128	1.111874	123382	-10.228			-10.755
	B						-0.774		
	B	11.924027	12.533586	1.112565	251591	-11.002			
	U						-10.744		
	U	12.107862	12.717421	1.113215	92634	-9.917			
Sky	V								
	B								
	U								
UPeg	V								
	V	13.344572	13.900727	1.113460	119542	-10.194		0.045	-10.669
	B						-0.695		
	B	13.517962	14.074118	1.114138	226815	-10.889			
	U								
	U	13.701798	14.257953	1.114866	77769	-9.727			
Sky	V								
	B								
	U								
Comp	V								
	V	15.116076	15.725635	1.125316	114315	-10.145			-10.676
	B						-0.771		
	B	15.295733	15.905292	1.126127	232559	-10.916			
	U						-10.666		
	U	15.475390	16.084950	1.126949	84359	-9.815			
Sky	V								
	B								
	U								
UPeg	V								
	V	18.462714	19.018869	1.137404	118577	-10.185		0.063	-10.653
	B						-0.671		
	B	18.654905	19.211060	1.138467	219894	-10.856			

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T
					Average of 2	Average of 2	Avg + 5 secs			Julian Century
	U	4:03:01	80384							
	U	4:03:20	81622	U	81003	3490	4:03:16	2450045.669640	2450045.672669	-0.041049
Sky	V	4:04:07	7702							
	B	4:04:31	9386							
	U	4:04:56	3482							
Comp	V	4:09:56	141402							
	V	4:09:38	138441	V	139922	7756	4:09:52	2450045.674229	2450045.677258	-0.041049
	B	4:10:24	253354							
	B	4:10:42	239135	B	246245	9312	4:10:38	2450045.674762	2450045.677790	-0.041049
	U	4:11:08	85297							
	U	4:11:25	90058	U	87678	3470	4:11:22	2450045.675265	2450045.678294	-0.041049
Sky	V	4:12:14	7810							
	B	4:12:39	9238							
	U	4:13:02	3458							
Check	V	4:21:05	122208							
	V	4:21:24	122520	V	122364	7861	4:21:20	2450045.682186	2450045.685215	-0.041049
	B	4:19:30	304988							
	B	4:19:51	324992	B	314990	9345	4:19:46	2450045.681098	2450045.684127	-0.041049
	U	4:20:18	106147							
	U	4:20:36	107781	U	106964	3547	4:20:32	2450045.681637	2450045.684665	-0.041049
Sky	V	4:22:43	7912							
	B	4:23:07	9452							
	U	4:23:32	3635							
UPeg	V	4:26:11	98412							
	V	4:28:47	81331	V	89872	8070	4:27:34	2450045.686521	2450045.689549	-0.041049
	B	4:30:27	170066							
	B	4:30:46	170149	B	170108	9599	4:30:42	2450045.688691	2450045.691719	-0.041049
	U	4:31:12	60766							
	U	4:31:29	58365	U	59566	3662	4:31:26	2450045.689200	2450045.692229	-0.041049
Sky	V	4:32:57	8227							
	B	4:33:23	9745							
	U	4:33:49	3688							
Comp	V	4:36:12	133747							

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Observable	Filter	LST	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Degrees	Airmass	True Count of	Instrumental	Instrumental		
	U								
	U	18.840829	19.396985	1.139506	77640	-9.725			
Sky	V								
	B								
	U								
Comp	V								
	V	20.497436	21.106995	1.154170	132544	-10.306		0.146	-10.757
	B						-0.636		
	B	20.689627	21.299187	1.155382	238110	-10.942			
	U						-10.746		
	U	20.871374	21.480933	1.156540	84356	-9.815			
Sky	V								
	B								
	U								
Check	V								
	V	23.369862	23.458205	1.166842	114792	-10.150			-10.910
	B						-1.070		
	B	22.977123	23.065466	1.164092	307575	-11.220			
	U								
	U	23.171404	23.259746	1.165445	103639	-10.039			
Sky	V								
	B								
	U								
UPeg	V								
	V	24.934551	25.490706	1.180294	81957	-9.784		0.450	-10.315
	B						-0.734		
	B	25.717940	26.274095	1.186540	161069	-10.518			
	U								
	U	25.901776	26.457931	1.188041	55972	-9.370			
Sky	V								
	B								
	U								
Comp	V								

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T
					Average of 2	Average of 2	Avg + 5 secs			Julian Century
	V	4:36:30	133995	V	133871	8431	4:36:26	2450045.692678	2450045.695707	-0.041049
	B	4:36:56	250776							
	B	4:37:13	249870	B	250323	9848	4:37:10	2450045.693182	2450045.696210	-0.041049
	U	4:37:38	87819							
	U	4:37:56	87187	U	87503	3673	4:37:52	2450045.693674	2450045.696702	-0.041049
Sky	V	4:38:39	8635							
	B	4:39:05	9950							
	U	4:39:29	3658							
UPeg	V	4:42:27	76728							
	V	4:42:47	74186	V	75457	8530	4:42:42	2450045.697030	2450045.700059	-0.041049
	B	4:43:16	135972							
	B	4:43:34	139479	B	137726	10008	4:43:30	2450045.697586	2450045.700614	-0.041049
	U	4:44:02	48488							
	U	4:44:21	49851	U	49170	3758	4:44:17	2450045.698124	2450045.701152	-0.041049
Sky	V	4:46:45	8425							
	B	4:47:09	10066							
	U	4:47:33	3857							
Comp	V	4:50:58	105457							
	V	4:51:27	104826	V	105142	8343	4:51:18	2450045.702997	2450045.706025	-0.041049
	B	4:51:55	181248							
	B	4:52:14	190971	B	186110	10038	4:52:10	2450045.703598	2450045.706627	-0.041048
	U	4:52:39	64898							
	U	4:52:58	60441	U	62670	3838	4:52:54	2450045.704108	2450045.707136	-0.041048
Sky	V	4:53:53	8260							
	B	4:54:16	10009							
	U	4:54:39	3819							
UPeg	V	4:57:07	91201							
	V	4:57:24	90995	V	91098	8963	4:57:21	2450045.707198	2450045.710226	-0.041048
	B	4:57:49	155736							
	B	4:58:07	160311	B	158024	10381	4:58:03	2450045.707690	2450045.710718	-0.041048
	U	4:58:32	53553							
	U	4:58:50	51705	U	52629	4021	4:58:46	2450045.708188	2450045.711216	-0.041048
Sky	V	4:59:44	9666							

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Observable	Filter	LST	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Degrees	Airmass	True Count of	Instrumental	Instrumental		
	V	27.157287	27.766846	1.204199	125786	-10.249			-10.773
	B						-0.709		
	B	27.339033	27.948593	1.205811	241692	-10.958			
	U						-10.761		
	U	27.516601	28.126161	1.207399	83978	-9.810			
Sky	V								
	B								
	U								
UPeg	V								
	V	28.728243	29.284398	1.212869	67036	-9.566		0.526	-10.089
	B						-0.703		
	B	28.928791	29.484946	1.214760	128084	-10.269			
	U								
	U	29.123071	29.679226	1.216608	45459	-9.144			
Sky	V								
	B								
	U								
Comp	V								
	V	30.882040	31.491600	1.240141	97012	-9.967			-10.463
	B						-0.651		
	B	31.099300	31.708860	1.242434	176743	-10.618			
	U						-10.452		
	U	31.283136	31.892695	1.244392	58907	-9.425			
Sky	V								
	B								
	U								
UPeg	V								
	V	32.398681	32.954837	1.250382	82294	-9.788		0.211	-10.279
	B						-0.638		
	B	32.576250	33.132405	1.252359	148125	-10.427			
	U								
	U	32.755907	33.312062	1.254376	48661	-9.218			
Sky	V								

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Observable	Filter	UT Start Time	Count		Star/filter count Average of 2	Sky/filter count Average of 2	UT Time Avg + 5 secs	JDE	HJD	T Julian Century
	B	5:00:08	10753							
	U	5:00:32	4223							
Comp	V	5:03:27	94781							
	V	5:03:47	105105	V	99943	8970	5:03:42	2450045.711613	2450045.714642	-0.041048
	B	5:04:40	192120							
	B	5:04:58	208000	B	200060	10247	5:04:54	2450045.712447	2450045.715475	-0.041048
	U	5:05:28	66292							
	U	5:05:45	70792	U	68542	3938	5:05:42	2450045.712997	2450045.716025	-0.041048
Sky	V	5:08:07	8274							
	B	5:07:37	9740							
	U	5:08:34	3652							
UPeg	V	5:10:47	72396							
	V	5:11:04	84122	V	78259	8118	5:11:01	2450045.716689	2450045.719717	-0.041048
	B	5:11:33	142860							
	B	5:11:50	141373	B	142117	9669	5:11:47	2450045.717221	2450045.720250	-0.041048
	U	5:12:16	46139							
	U	5:12:33	45573	U	45856	3631	5:12:30	2450045.717719	2450045.720747	-0.041048
Sky	V	5:13:28	7961							
	B	5:14:37	9598							
	U	5:15:03	3610							
Comp	V	5:18:45	84019							
	V	5:19:05	94767	V	89393	8124	5:19:00	2450045.722238	2450045.725267	-0.041048
	B	5:19:36	178456							
	B	5:19:54	194597	B	186527	9626	5:19:50	2450045.722817	2450045.725846	-0.041048
	U	5:20:24	66762							
	U	5:20:41	75358	U	71060	3701	5:20:38	2450045.723367	2450045.726395	-0.041048
Sky	V	5:22:17	8286							
	B	5:22:42	9653							
	U	5:23:08	3792							
UPeg	V	5:28:23	82660							
	V	5:28:05	92323	V	87492	8355	5:28:19	2450045.728708	2450045.731737	-0.041048
	B	5:28:54	138860							
	B	5:29:15	143545	B	141203	9721	5:29:10	2450045.729293	2450045.732321	-0.041048

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Observable	Filter	LST	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Degrees	Airmass	True Count of	Instrumental	Instrumental		
	B								
	U								
Comp	V								
	V	33.992617	34.602176	1.275204	91165	-9.900			-10.524
	B						-0.801		
	B	34.293438	34.902998	1.278860	190589	-10.700			
	U						-10.512		
	U	34.491897	35.101456	1.281298	64695	-9.527			
Sky	V								
	B								
	U								
UPeg	V								
	V	35.824703	36.380858	1.291415	70259	-9.617		0.324	-10.165
	B						-0.692		
	B	36.016894	36.573049	1.293905	132838	-10.308			
	U								
	U	36.196551	36.752707	1.296252	42265	-9.065			
Sky	V								
	B								
	U								
Comp	V								
	V	37.828089	38.437649	1.325634	81423	-9.777			-10.463
	B						-0.847		
	B	38.036993	38.646553	1.328631	177575	-10.623			
	U						-10.450		
	U	38.235452	38.845011	1.331503	67457	-9.573			
Sky	V								
	B								
	U								
UPeg	V								
	V	40.163633	40.719788	1.353019	79284	-9.748		0.376	-10.209
	B						-0.552		
	B	40.374626	40.930781	1.356321	131867	-10.300			

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T
					Average of 2	Average of 2	Avg + 5 secs			Julian Century
	U	5:29:43	46025							
	U	5:30:02	42161	U	44093	3797	5:29:58	2450045.729848	2450045.732877	-0.041048
Sky	V	5:31:39	8424							
	B	5:32:05	9789							
	U	5:32:31	3801							
Comp	V	5:36:19	110133							
	V	5:36:37	110848	V	110491	8601	5:36:33	2450045.734426	2450045.737454	-0.041048
	B	5:37:06	227914							
	B	5:37:24	220654	B	224284	10341	5:37:20	2450045.734970	2450045.737998	-0.041048
	U	5:37:56	80871							
	U	5:38:14	82022	U	81447	3824	5:38:10	2450045.735549	2450045.738577	-0.041048
Sky	V	5:39:26	8778							
	B	5:39:52	10893							
	U	5:40:17	3847							
Check	V	5:42:23	130449							
	V	5:42:41	125777	V	128113	9058	5:42:37	2450045.738639	2450045.741667	-0.041048
	B	5:43:10	351615							
	B	5:43:28	341616	B	346616	10467	5:43:24	2450045.739183	2450045.742211	-0.041048
	U	5:43:56	111443							
	U	5:44:14	111923	U	111683	3789	5:44:10	2450045.739715	2450045.742744	-0.041048
Sky	V	5:45:25	9338							
	B	5:45:53	10041							
	U	5:46:20	3731							
UPeg	V	5:49:00	76858							
	V	5:49:20	79480	V	78169	8894	5:49:15	2450045.743245	2450045.746274	-0.041047
	B	5:49:48	128196							
	B	5:50:05	132037	B	130117	10039	5:50:02	2450045.743784	2450045.746812	-0.041047
	U	5:50:32	44905							
	U	5:50:50	45972	U	45439	3782	5:50:46	2450045.744299	2450045.747327	-0.041047
Sky	V	5:51:52	8449							
	B	5:52:18	10037							
	U	5:52:44	3833							
Comp	V	5:58:58	126354							

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Observable	Filter	LST	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Degrees	Airmass	True Count of	Instrumental	Instrumental		
	U								
	U	40.575174	41.131329	1.359487	40334	-9.014			
Sky	V								
	B								
	U								
Comp	V								
	V	42.227602	42.837161	1.394876	102125	-10.023		0.442	-10.712
	B						-0.808		
	B	42.423972	43.033531	1.398287	214919	-10.831			
	U						-10.699		
	U	42.632875	43.242435	1.401947	77751	-9.727			
Sky	V								
	B								
	U								
Check	V								
	V	43.748421	43.836764	1.407642	119372	-10.192			-11.161
	B						-1.132		
	B	43.944791	44.033133	1.411175	338487	-11.324			
	U								
	U	44.136982	44.225325	1.414662	108136	-10.085			
Sky	V								
	B								
	U								
UPeg	V								
	V	45.411295	45.967450	1.444815	69392	-9.603		0.594	-10.136
	B						-0.598		
	B	45.605575	46.161731	1.448634	120404	-10.202			
	U								
	U	45.791500	46.347655	1.452319	41696	-9.050			
Sky	V								
	B								
	U								
Comp	V								

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T
					Average of 2	Average of 2	Avg + 5 secs			Julian Century
	V	5:58:40	130579	V	128467	8654	5:58:54	2450045.749947	2450045.752975	-0.041047
	B	5:59:28	213928							
	B	5:59:45	217028	B	215478	10222	5:59:42	2450045.750497	2450045.753525	-0.041047
	U	6:00:14	62067							
	U	6:00:32	57661	U	59864	3853	6:00:28	2450045.751035	2450045.754063	-0.041047
Sky	V	6:01:59	8859							
	B	6:02:26	10406							
	U	6:02:56	3873							
UPeg	V	6:05:44	116069							
	V	6:06:13	122317	V	119193	8937	6:06:04	2450045.754918	2450045.757946	-0.041047
	B	6:06:46	190326							
	B	6:07:04	204900	B	197613	10601	6:07:00	2450045.755572	2450045.758600	-0.041047
	U	6:07:33	65098							
	U	6:07:52	64958	U	65028	3894	6:07:48	2450045.756122	2450045.759150	-0.041047
Sky	V	6:08:46	9015							
	B	6:09:13	10795							
	U	6:09:38	3915							
Comp	V	6:15:15	90726							
	V	6:14:53	87931	V	89329	9075	6:15:09	2450045.761232	2450045.764260	-0.041047
	B	6:15:50	147892							
	B	6:16:08	167341	B	157617	10760	6:16:04	2450045.761868	2450045.764897	-0.041047
	U	6:16:42	55011							
	U	6:16:58	60798	U	57905	3959	6:16:55	2450045.762458	2450045.765487	-0.041047
Sky	V	6:17:56	9134							
	B	6:18:22	10724							
	U	6:18:48	4003							

24 Nov 95

Observable	Filter	LST	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Degrees	Airmass	True Count of	Instrumental	Instrumental		
	V	47.830400	48.439960	1.504740	120131	-10.199			-10.743
	B						-0.586		
	B	48.028859	48.638418	1.509155	206157	-10.785			
	U						-10.729		
	U	48.223139	48.832698	1.513515	56080	-9.372			
Sky	V								
	B								
	U								
UPeg	V								
	V	49.624883	50.181038	1.535499	110530	-10.109		-0.084	-10.653
	B						-0.575		
	B	49.860944	50.417100	1.541104	187769	-10.684			
	U								
	U	50.059403	50.615558	1.545863	61216	-9.467			
Sky	V								
	B								
	U								
Comp	V								
	V	51.904023	52.513582	1.603852	80407	-9.763			-10.411
	B						-0.658		
	B	52.133817	52.743376	1.610017	147337	-10.421			
	U						-10.396		
	U	52.346899	52.956458	1.615793	54010	-9.331			
Sky	V								
	B								
	U								

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			26	11	1995	JD =	2450047.50					
Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST	
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees	
Sky	V	0:56:50	10179									
	B	0:57:40	16013									
	U	0:58:08	7453									
Check	V	1:01:22	123443									
	V	1:01:40	129054	V	126249	9865	1:01:36	2450047.543488	2450047.546360	-0.040998	335.273264	
	B	1:02:05	369930									
	B	1:02:22	372976	B	371453	15018	1:02:19	2450047.543980	2450047.546852	-0.040998	335.450832	
	U	1:02:45	131909									
	U	1:03:02	131680	U	131795	7024	1:02:59	2450047.544443	2450047.547315	-0.040998	335.617955	
sky	V	1:03:47	9550									
	B	1:04:09	14023									
	U	1:04:33	6594									
Comparison	V	1:07:23	148982									
	V	1:07:42	148604	V	148793	9648	1:07:38	2450047.547672	2450047.550544	-0.040998	336.783638	
	B	1:08:06	276354									
	B	1:08:22	277082	B	276718	13572	1:08:19	2450047.548153	2450047.551024	-0.040998	336 957028	
	U	1:08:45	99635									
	U	1:09:01	98602	U	99119	6323	1:08:58	2450047.548604	2450047.551476	-0.040998	337.119973	
Sky	V	1:10:00	9746									
	B	1:10:25	13121									
	U	1:10:47	6052									
UPeg	V	1:13:51	123710									
	V	1:14:10	124659	V	124185	9492	1:14:06	2450047.552163	2450047.555035	-0.040998	338.404731	
	B	1:14:36	219012									
	B	1:14:53	218496	B	218754	12852	1:14:50	2450047.552672	2450047.555544	-0.040998	338.588566	
	U	1:15:19	77118									
	U	1:15:36	76648	U	76883	5941	1:15:33	2450047.553170	2450047.556042	-0.040998	338.768223	
Sky	V	1:16:19	9238									
	B	1:16:47	12582									
	U	1:17:12	5829									
Comp	V	1:18:52	143468									
	V	1:19:10	146439	V	144954	9485	1:19:06	2450047.555641	2450047.558513	-0.040998	339.660242	
	B	1:19:34	274841									

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Airmass	True Count of	Instrumental	Instrumental		
Sky	V			Star - Sky	Magnitude	Color		
	B					and		
	U					v - k"(b - v)X		
Check	V							
	V	-24.638523	1.175452	116691	-10.168			-12.708
	B					-1.221		
	B	-24.460955	1.174123	359120	-11.388			
	U							
	U	-24.293831	1.172883	125107	-10.243			
sky	V							
	B							
	U							
Comparison	V							
	V	-22.606928	1.163976	139573	-10.362		0.191	-12.511
	B					-0.695		
	B	-22.433538	1.162801	264632	-11.057			
	U					-10.847		
	U	-22.270593	1.161707	92985	-9.921			
Sky	V							
	B							
	U							
UPeg	V							
	V	-21.039239	1.149199	114990	-10.152		0.252	-12.234
	B					-0.637		
	B	-20.855404	1.148068	206829	-10.789		-0.008	
	U						0.040	
	U	-20.675747	1.146974	71056	-9.629			
Sky	V							
	B							
	U							
Comp	V							
	V	-19.730324	1.145866	135875	-10.333			-12.465
	B					-0.719		

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	B	1:19:51	274637	B	274739	12798	1:19:48	2450047.556122	2450047.558993	-0.040998	339.833632
	U	1:20:16	98663								
	U	1:20:33	99077	U	98870	5866	1:20:30	2450047.556608	2450047.559479	-0.040998	340.009111
Sky	V	1:21:14	9731								
	B	1:21:39	13014								
	U	1:22:03	5903								
UPeg	V	1:23:58	119398								
	V	1:24:17	119185	V	119292	9538	1:24:13	2450047.559189	2450047.562060	-0.040998	340.940822
	B	1:24:40	210421								
	B	1:24:56	211609	B	211015	12723	1:24:53	2450047.559657	2450047.562529	-0.040998	341.110034
	U	1:25:19	74204								
	U	1:25:36	73782	U	73993	5832	1:25:33	2450047.560115	2450047.562986	-0.040998	341.275068
Sky	V	1:26:15	9345								
	B	1:26:37	12432								
	U	1:27:00	5761								
Comp	V	1:28:25	148336								
	V	1:28:43	147969	V	148153	9477	1:28:39	2450047.562273	2450047.565145	-0.040998	342.054279
	B	1:29:07	274673								
	B	1:29:24	272783	B	273728	12806	1:29:21	2450047.562754	2450047.565625	-0.040998	342.227669
	U	1:29:48	99049								
	U	1:30:05	99211	U	99130	5882	1:30:02	2450047.563228	2450047.566099	-0.040998	342.398970
Sky	V	1:30:44	9608								
	B	1:31:06	13180								
	U	1:31:29	6002								
UPeg	V	1:33:03	107646								
	V	1:33:23	108747	V	108197	9796	1:33:18	2450047.565502	2450047.568374	-0.040998	343.219962
	B	1:33:58	193874								
	B	1:34:15	194367	B	194121	13242	1:34:12	2450047.566122	2450047.568993	-0.040998	343.443489
	U	1:34:40	67444								
	U	1:34:57	67962	U	67703	6001	1:34:54	2450047.566608	2450047.569479	-0.040997	343.618968
Sky	V	1:35:37	9984								
	B	1:36:01	13304								
	U	1:36:24	5999								
Comp	V	1:38:11	135784								
	V	1:38:31	130245	V	133015	11256	1:38:26	2450047.569067	2450047.571939	-0.040997	344.506809

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Airmass	True Count of	Instrumental	Instrumental		
	B	-19.556933	1.144867	263406	-11.052			
	U					-10.827		
	U	-19.381454	1.143865	93193	-9.923			
Sky	V							
	B							
	U							
UPeg	V							
	V	-18.503148	1.134612	110028	-10.104		0.289	-12.164
	B					-0.644		
	B	-18.333936	1.133715	199154	-10.748			
	U							
	U	-18.168902	1.132849	68266	-9.586			
Sky	V							
	B							
	U							
Comp	V							
	V	-17.336287	1.132953	139100	-10.358			-12.446
	B					-0.689		
	B	-17.162897	1.132091	262377	-11.047			
	U					-10.827		
	U	-16.991596	1.131249	93438	-9.926			
Sky	V							
	B							
	U							
UPeg	V							
	V	-16.224008	1.123307	98626	-9.985		0.311	-12.037
	B					-0.663		
	B	-16.000481	1.122287	181607	-10.648			
	U							
	U	-15.825002	1.121497	61791	-9.477			
Sky	V							
	B							
	U							
Comp	V							
	V	-14.883757	1.121649	122099	-10.217			-12.255

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	B	1:39:08	237167								
	B	1:39:26	231607	B	234387	14091	1:39:22	2450047.569715	2450047.572587	-0.040997	344.740781
	U	1:39:50	83763								
	U	1:40:08	81902	U	82833	6132	1:40:04	2450047.570201	2450047.573073	-0.040997	344.916260
Sky	V	1:41:28	12528								
	B	1:41:56	14878								
	U	1:42:24	6264								
UPeg	V	1:45:28	75227								
	V	1:45:46	76207	V	75717	12818	1:45:42	2450047.574113	2450047.576985	-0.040997	346.328449
	B	1:46:12	131156								
	B	1:46:34	130765	B	130961	14589	1:46:28	2450047.574646	2450047.577517	-0.040997	346.520641
	U	1:46:59	46321								
	U	1:47:17	46574	U	46448	6089	1:47:13	2450047.575167	2450047.578038	-0.040997	346.708654
Sky	V	1:47:53	13108								
	B	1:48:18	14300								
	U	1:48:41	5914								
Comp	V	1:50:17	123922								
	V	1:50:34	125336	V	124629	11742	1:50:31	2450047.577453	2450047.580324	-0.040997	347.533824
	B	1:51:01	247478								
	B	1:51:18	248368	B	247923	13783	1:51:15	2450047.577962	2450047.580833	-0.040997	347.717659
	U	1:51:43	89780								
	U	1:52:00	92135	U	90958	5870	1:51:57	2450047.578448	2450047.581319	-0.040997	347.893138
Sky	V	1:52:43	10375								
	B	1:53:07	13266								
	U	1:53:32	5825								
UPeg	V	1:54:57	90730								
	V	1:55:17	92236	V	91483	9547	1:55:12	2450047.580711	2450047.583582	-0.040997	348.709952
	B	1:55:41	164868								
	B	1:55:58	166671	B	165770	12577	1:55:55	2450047.581203	2450047.584074	-0.040997	348.887520
	U	1:56:22	62244								
	U	1:56:38	62064	U	62154	5753	1:56:35	2450047.581671	2450047.584543	-0.040997	349.056732
Sky	V	1:57:19	8719								
	B	1:57.44	11887								
	U	1:58:07	5680								
Comp	V	1:59:54	150107								

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Airmass	True Count of	Instrumental	Instrumental		
	B					-0.646		
	B	-14.649785	1.120669	221360	-10.863			
	U					-10.652		
	U	-14.474306	1.119945	76833	-9.714			
Sky	V							
	B							
	U							
UPeg	V							
	V	-13.115521	1.110501	63007	-9.498		0.719	-11.531
	B					-0.669		
	B	-12.923329	1.109805	116700	-10.168			
	U							
	U	-12.735316	1.109135	40400	-9.016			
Sky	V							
	B							
	U							
Comp	V							
	V	-11.856742	1.110255	113186	-10.134			-12.251
	B					-0.795		
	B	-11.672907	1.109652	235332	-10.929			
	U					-10.664		
	U	-11.497427	1.109085	85248	-9.827			
Sky	V							
	B							
	U							
UPeg	V							
	V	-10.734018	1.102644	82096	-9.786		0.522	-11.812
	B					-0.681		
	B	-10.556450	1.102124	153723	-10.467			
	U							
	U	-10.387238	1.101637	56476	-9.380			
Sky	V							
	B							
	U							
Comp	V							

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	V	2:00:10	151574	V	150841	8686	2:00:07	2450047.584125	2450047.586996	-0.040997	349.942484
	B	2:00:35	281062								
	B	2:00:50	280705	B	280884	11988	2:00:48	2450047.584594	2450047.587465	-0.040997	350.111696
	U	2:01:15	104520								
	U	2:01:32	104475	U	104498	5686	2:01:29	2450047.585068	2450047.587940	-0.040997	350.282997
Sky	V	2:02:14	8653								
	B	2:02:37	12089								
	U	2:03:00	5692								
UPeg	V	2:04:53	94850								
	V	2:05:10	95075	V	94963	9196	2:05:07	2450047.587591	2450047.590463	-0.040997	351.193817
	B	2:05:35	165531								
	B	2:05:54	164120	B	164826	12520	2:05:50	2450047.588089	2450047.590961	-0.040997	351.373474
	U	2:06:17	58846								
	U	2:06:33	58357	U	58602	5698	2:06:30	2450047.588558	2450047.591429	-0.040997	351.542686
Sky	V	2:07:23	9738								
	B	2:07:48	12950								
	U	2:08:11	5703								
Comp	V	2:09:42	105585								
	V	2:10:44	122645	V	114115	9807	2:10:18	2450047.591197	2450047.594068	-0.040997	352.495287
	B	2:11:11	256013								
	B	2:11:27	255367	B	255690	12823	2:11:24	2450047.591961	2450047.594832	-0.040997	352.771040
	U	2:11:50	95875								
	U	2:12:07	97319	U	96597	5701	2:12:04	2450047.592418	2450047.595289	-0.040997	352.936074
Sky	V	2:12:42	9875								
	B	2:13:05	12695								
	U	2:13:28	5699								
UPeg	V	2:14:53	99430								
	V	2:15:10	100021	V	99726	9851	2:15:07	2450047.594536	2450047.597407	-0.040997	353.700662
	B	2:15:34	174285								
	B	2:15:51	176382	B	175334	12703	2:15:48	2450047.595010	2450047.597882	-0.040997	353.871963
	U	2:16:14	62969								
	U	2:16:31	63994	U	63482	5777	2:16:28	2450047.595473	2450047.598345	-0.040997	354.039086
Sky	V	2:17:09	9826								
	B	2:17:34	12711								
	U	2:17:55	5855								

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Airmass	True Count of	Instrumental	Instrumental		
	V	-9.448082	1.103127	142595	-10.385			-12.422
	B					-0.695		
	B	-9.278870	1.102690	270428	-11.080			
	U					-10.845		
	U	-9.107569	1.102255	99023	-9.989			
Sky	V							
	B							
	U							
UPeg	V							
	V	-8.250153	1.096187	85940	-9.835		0.508	-11.813
	B					-0.625		
	B	-8.070495	1.095788	152830	-10.461			
	U							
	U	-7.901283	1.095420	52970	-9.310			
Sky	V							
	B							
	U							
Comp	V							
	V	-6.895278	1.097386	104559	-10.048			-12.223
	B					-0.921		
	B	-6.619525	1.096875	244136	-10.969			
	U					-10.655		
	U	-6.454491	1.096580	91076	-9.899			
Sky	V							
	B							
	U							
UPeg	V							
	V	-5.743308	1.091423	90066	-9.886		0.424	-11.869
	B					-0.646		
	B	-5.572007	1.091161	163224	-10.532			
	U							
	U	-5.404884	1.090913	57782	-9.404			
Sky	V							
	B							
	U							

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
Comp	V	2:19:05	142800								
	V	2:19:22	142710	V	142755	9549	2:19:19	2450047.597453	2450047.600324	-0.040997	354.753537
	B	2:19:48	275834								
	B	2:20:05	277498	B	276666	12531	2:20:02	2450047.597950	2450047.600822	-0.040997	354.933194
	U	2:20:31	103303								
	U	2:20:48	104250	U	103777	5767	2:20:45	2450047.598448	2450047.601319	-0.040997	355.112851
Sky	V	2:21:24	9272								
	B	2:21:47	12350								
	U	2:22:09	5679								
Check	V	2:23:38	136273								
	V	2:23:55	136644	V	136459	8972	2:23:52	2450047.600612	2450047.603484	-0.040997	355.894151
	B	2:24:20	384426								
	B	2:24:37	384840	B	384633	11946	2:24:34	2450047.601098	2450047.603970	-0.040997	356.069630
	U	2:25:03	137791								
	U	2:25:18	138099	U	137945	5554	2:25:16	2450047.601585	2450047.604456	-0.040997	356.245109
Sky	V	2:26:11	8671								
	B	2:26:36	11542								
	U	2:26:58	5429								
UPeg	V	2:30:13	114531								
	V	2:30:40	114054	V	114293	8603	2:30:32	2450047.605242	2450047.608113	-0.040996	357.565381
	B	2:31:05	198979								
	B	2:31:22	200374	B	199677	11402	2:31:19	2450047.605786	2450047.608657	-0.040996	357.761750
	U	2:31:48	71879								
	U	2:32:05	72011	U	71945	5419	2:32:02	2450047.606284	2450047.609155	-0.040996	357.941408
Sky	V	2:32:48	8535								
	B	2:33:11	11261								
	U	2:33:33	5408								
Comp	V	2:35:08	149536								
	V	2:35:25	150352	V	149944	8836	2:35:22	2450047.608598	2450047.611470	-0.040996	358.777023
	B	2:35:50	282920								
	B	2:36:06	281633	B	282277	11583	2:36:03	2450047.609079	2450047.611950	-0.040996	358.950413
	U	2:36:30	105477								
	U	2:36:47	105130	U	105304	5354	2:36:44	2450047.609547	2450047.612419	-0.040996	359.119625
Sky	V	2:37:22	9136								
	B	2:37:46	11904								

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Airmass	True Count of	Instrumental	Instrumental		
Comp	V							
	V	-4.637029	1.093826	133600	-10.315		0.225	-12.368
	B					-0.746		
	B	-4.457372	1.093603	265622	-11.061			
	U					-10.804		
	U	-4.277714	1.093389	98218	-9.980			
Sky	V							
	B							
	U							
Check	V							
	V	-4.017635	1.090529	127847	-10.267			-12.591
	B					-1.170		
	B	-3.842156	1.090342	375569	-11.437			
	U							
	U	-3.666677	1.090164	132760	-10.308			
Sky	V							
	B							
	U							
UPeg	V							
	V	-1.878589	1.087448	105941	-10.063		0.355	-12.027
	B					-0.629		
	B	-1.682219	1.087354	189047	-10.691			
	U							
	U	-1.502562	1.087277	66626	-9.559			
Sky	V							
	B							
	U							
Comp	V							
	V	-0.613543	1.090952	141543	-10.377			-12.401
	B					-0.710		
	B	-0.440153	1.090927	272242	-11.087			
	U					-10.842		
	U	-0.270941	1.090911	100164	-10.002			
Sky	V							
	B							

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	U	2:38:10	5299								
UPeg	V	2:39:50	119489								
	V	2:40:06	119998	V	119744	8871	2:40:03	2450047.611857	2450047.614728	-0.040996	359.953150
	B	2:40:31	211672								
	B	2:40:48	213617	B	212645	11645	2:40:45	2450047.612337	2450047.615208	-0.040996	0.126541
	U	2:41:11	76951								
	U	2:41:27	75944	U	76448	5294	2:41:24	2450047.612794	2450047.615665	-0.040996	0.291575
Sky	V	2:42:05	8605								
	B	2:42:28	11385								
	U	2:42:51	5289								
Comp	V	2:44:33	148417								
	V	2:44:49	149167	V	148792	8508	2:44:46	2450047.615132	2450047.618003	-0.040996	1.135546
	B	2:45:13	282413								
	B	2:45:29	280930	B	281672	11271	2:45:26	2450047.615595	2450047.618466	-0.040996	1.302669
	U	2:45:53	103323								
	U	2:46:09	104930	U	104127	5295	2:46:06	2450047.616058	2450047.618929	-0.040996	1.469792
Sky	V	2:46:44	8411								
	B	2:47:08	11156								
	U	2:47:31	5301								
UPeg	V	2:49:12	127651								
	V	2:49:28	129019	V	128335	8321	2:49:25	2450047.618361	2450047.621233	-0.040996	2.301228
	B	2:49:51	226903								
	B	2:50:08	228380	B	227642	11028	2:50:05	2450047.618818	2450047.621690	-0.040996	2.466262
	U	2:50:33	81776								
	U	2:50:49	82216	U	81996	5181	2:50:46	2450047.619299	2450047.622170	-0.040996	2.639653
Sky	V	2:51:56	8231								
	B	2:52:18	10899								
	U	2:52:41	5060								
Comp	V	2:54:11	151860								
	V	2:54:28	152161	V	152011	8353	2:54:25	2450047.621828	2450047.624699	-0.040996	3.552562
	B	2:54:52	284446								
	B	2:55:09	284567	B	284507	10790	2:55:06	2450047.622302	2450047.625173	-0.040996	3.723863
	U	2:55:33	104211								
	U	2:55:48	104160	U	104186	5055	2:55:46	2450047.622765	2450047.625636	-0.040996	3.890986
Sky	V	2:56:36	8475								

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Airmass	True Count of	Instrumental	Instrumental		
	U							
UPeg	V							
	V	0.509181	1.087008	111150	-10.115		0.308	-12.091
	B					-0.648		
	B	0.682571	1.087036	201876	-10.763			
	U							
	U	0.847605	1.087070	71266	-9.632			
Sky	V							
	B							
	U							
Comp	V							
	V	1.744980	1.091314	140712	-10.371			-12.399
	B					-0.715		
	B	1.912103	1.091397	271942	-11.086			
	U					-10.839		
	U	2.079226	1.091488	99041	-9.990			
Sky	V							
	B							
	U							
UPeg	V							
	V	2.857259	1.088072	120332	-10.201		0.232	-12.176
	B					-0.643		
	B	3.022293	1.088202	217619	-10.844			
	U							
	U	3.195683	1.088348	76945	-9.715			
Sky	V							
	B							
	U							
Comp	V							
	V	4.161996	1.093256	144105	-10.397			-12.420
	B					-0.703		
	B	4.333297	1.093455	275289	-11.099			
	U					-10.858		
	U	4.500420	1.093656	99340	-9.993			
Sky	V							

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	B	2:57:00	10681								
	U	2:57:22	5050								
UPeg	V	2:58:42	134650								
	V	2:58:59	134105	V	134378	8353	2:58:56	2450047.624964	2450047.627836	-0.040996	4.684820
	B	2:59:23	238797								
	B	2:59:39	239204	B	239001	10600	2:59:36	2450047.625433	2450047.628304	-0.040996	4.854032
	U	3:00:03	86414								
	U	3:00:19	86842	U	86628	4936	3:00:16	2450047.625896	2450047.628767	-0.040996	5.021155
Sky	V	3:00:58	8230								
	B	3:01:21	10518								
	U	3:01:46	4821								
Comp	V	3:03:10	151691								
	V	3:03:27	152041	V	151866	8265	3:03:24	2450047.628066	2450047.630937	-0.040996	5.804544
	B	3:03:51	284486								
	B	3:04:07	284068	B	284277	10637	3:04:04	2450047.628535	2450047.631406	-0.040996	5.973756
	U	3:04:32	103806								
	U	3:04:47	103951	U	103879	4880	3:04:45	2450047.629004	2450047.631875	-0.040996	6.142968
Sky	V	3:05:23	8299								
	B	3:05:45	10756								
	U	3:06:07	4938								
UPeg	V	3:08:02	139101								
	V	3:08:17	139670	V	139386	8260	3:08:15	2450047.631434	2450047.634305	-0.040996	7.020364
	B	3:08:44	246378								
	B	3:09:01	246094	B	246236	10658	3:08:58	2450047.631932	2450047.634803	-0.040996	7.200021
	U	3:09:25	89042								
	U	3:09:41	89030	U	89036	4828	3:09:38	2450047.632400	2450047.635272	-0.040996	7.369233
Sky	V	3:10:17	8220								
	B	3:10:39	10560								
	U	3:11:00	4718								
Comp	V	3:12:15	149248								
	V	3:12:34	149353	V	149301	8264	3:12:30	2450047.634385	2450047.637257	-0.040996	8.085773
	B	3:12:58	282418								
	B	3:13:14	283414	B	282916	10534	3:13:11	2450047.634866	2450047.637737	-0.040996	8.259163
	U	3:13:37	104695								
	U	3:13:52	105075	U	104885	4721	3:13:50	2450047.635311	2450047.638183	-0.040996	8.420019

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Airmass	True Count of	Instrumental	Instrumental		
	B							
	U							
UPeg	V							
	V	5.240850	1.090676	126374	-10.254		0.184	-12.237
	B					-0.648		
	B	5.410062	1.090920	229509	-10.902			
	U							
	U	5.577185	1.091168	81838	-9.782			
Sky	V							
	B							
	U							
Comp	V							
	V	6.413979	1.096508	144048	-10.396			-12.426
	B					-0.703		
	B	6.583191	1.096810	275210	-11.099			
	U					-10.859		
	U	6.752402	1.097119	99208	-9.991			
Sky	V							
	B							
	U							
UPeg	V							
	V	7.576394	1.094736	131502	-10.297		0.142	-12.281
	B					-0.638		
	B	7.756051	1.095110	236755	-10.936			
	U							
	U	7.925263	1.095471	84361	-9.815			
Sky	V							
	B							
	U							
Comp	V							
	V	8.695207	1.101242	141468	-10.377			-12.425
	B					-0.717		
	B	8.868597	1.101662	273938	-11.094			
	U					-10.851		
	U	9.029453	1.102059	100377	-10.004			

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
Sky	V	3:14:26	8308								
	B	3:14:49	10507								
	U	3:15:14	4723								
UPeg	V	3:16:30	140851								
	V	3:16:49	140642	V	140747	8094	3:16:45	2450047.637337	2450047.640208	-0.040996	9.151182
	B	3:17:11	250840								
	B	3:17:27	250718	B	250779	10358	3:17:24	2450047.637794	2450047.640665	-0.040996	9.316216
	U	3:17:50	89617								
	U	3:18:07	90336	U	89977	4739	3:18:04	2450047.638251	2450047.641123	-0.040996	9.481250
Sky	V	3:18:43	7879								
	B	3:19:06	10208								
	U	3:19:29	4754								
Comp	V	3:21:02	148912								
	V	3:21:18	150845	V	149879	7981	3:21:15	2450047.640468	2450047.643339	-0.040995	10.281351
	B	3:21:43	281588								
	B	3:21:59	282890	B	282239	10253	3:21:56	2450047.640942	2450047.643814	-0.040995	10.452652
	U	3:22:23	103471								
	U	3:22:39	103718	U	103595	4738	3:22:36	2450047.641405	2450047.644276	-0.040995	10.619775
Sky	V	3:23:13	8082								
	B	3:23:35	10298								
	U	3:23:56	4722								
UPeg	V	3:25:26	142725								
	V	3:25:42	142020	V	142373	8031	3:25:39	2450047.643523	2450047.646395	-0.040995	11.384363
	B	3:26:05	255376								
	B	3:26:21	255695	B	255536	10219	3:26:18	2450047.643975	2450047.646846	-0.040995	11.547308
	U	3:26:43	91964								
	U	3:27:00	92092	U	92028	4710	3:26:57	2450047.644420	2450047.647292	-0.040995	11.708163
Sky	V	3:27:37	7979								
	B	3:27:59	10140								
	U	3:28:20	4698								
Comp	V	3:29:43	148725								
	V	3:30:00	148546	V	148636	8040	3:29:57	2450047.646504	2450047.649375	-0.040995	12.460217
	B	3:30:24	279317								
	B	3:30:39	280348	B	279833	10277	3:30:37	2450047.646966	2450047.649838	-0.040995	12.627340
	U	3:31:01	102655								

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Airmass	True Count of	Instrumental	Instrumental		
Sky	V							
	B							
	U							
UPeg	V							
	V	9.707212	1.099762	133036	-10.310		0.120	-12.309
	B					-0.648		
	B	9.872246	1.100205	241642	-10.958			
	U							
	U	10.037280	1.100656	85395	-9.829			
Sky	V							
	B							
	U							
Comp	V							
	V	10.890785	1.107194	142333	-10.383			-12.437
	B					-0.709		
	B	11.062086	1.107717	273534	-11.093			
	U					-10.854		
	U	11.229209	1.108236	99064	-9.990			
Sky	V							
	B							
	U							
UPeg	V							
	V	11.940393	1.106417	134734	-10.324		0.096	-12.341
	B					-0.656		
	B	12.103338	1.106959	246584	-10.980			
	U							
	U	12.264194	1.107502	87482	-9.855			
Sky	V							
	B							
	U							
Comp	V							
	V	13.069651	1.114489	141023	-10.373		0.135	-12.440
	B					-0.710		
	B	13.236774	1.115107	271078	-11.083			
	U					-10.848		

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	U	3:31:18	101028	U	101842	4680	3:31:15	2450047.647406	2450047.650278	-0.040995	12.786107
Sky	V	3:32:04	8101								
	B	3:32:26	10413								
	U	3:32:50	4662								
Check	V	3:34:23	129836								
	V	3:35:08	129189	V	129513	8651	3:34:51	2450047.649906	2450047.652778	-0.040995	13.688571
	B	3:35:32	362711								
	B	3:35:48	357715	B	360213	10701	3:35:45	2450047.650537	2450047.653408	-0.040995	13.916276
	U	3:36:12	124894								
	U	3:36:28	124890	U	124892	4726	3:36:25	2450047.651000	2450047.653871	-0.040995	14.083399
Sky	V	3:37:20	9200								
	B	3:37:43	10989								
	U	3:38:06	4789								
UPeg	V	3:45:36	136456								
	V	3:45:55	138753	V	137605	8807	3:45:51	2450047.657545	2450047.660417	-0.040995	16.446100
	B	3:46:20	256082								
	B	3:46:39	253732	B	254907	10900	3:46:35	2450047.658054	2450047.660926	-0.040995	16.629935
	U	3:47:19	90538								
	U	3:47:36	91276	U	90907	4731	3:47:33	2450047.658726	2450047.661597	-0.040995	16.872264
Sky	V	3:48:20	8414								
	B	3:48:44	10810								
	U	3:49:05	4672								
Comp	V	3:50:57	133583								
	V	3:51:14	137899	V	135741	8434	3:51:11	2450047.661249	2450047.664120	-0.040995	17.783084
	B	3:51:41	257168								
	B	3:51:57	261459	B	259314	10519	3:51:54	2450047.661752	2450047.664624	-0.040995	17.964830
	U	3:52:22	94766								
	U	3:52:38	95855	U	95311	4666	3:52:35	2450047.662227	2450047.665098	-0.040995	18.136131
Sky	V	3:53:14	8454								
	B	3:53:38	10228								
	U	3:54:00	4659								
UPeg	V	3:55:15	137642								
	V	3:55:32	138616	V	138129	8401	3:55:29	2450047.664235	2450047.667106	-0.040995	18.861027
	B	3:55:56	258977								
	B	3:56:13	261884	B	260431	10243	3:56:10	2450047.664710	2450047.667581	-0.040995	19.032328

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Airmass	True Count of	Instrumental	Instrumental		
	U	13.395541	1.115702	97362	-9.971			
Sky	V							
	B							
	U							
Check	V							
	V	13.776784	1.114443	121186	-10.209			-12.576
	B					-1.158		
	B	14.004490	1.115330	352038	-11.366			
	U							
	U	14.171612	1.115991	120469	-10.202			
Sky	V							
	B							
	U							
UPeg	V							
	V	17.002130	1.126980	129163	-10.278		0.057	-12.359
	B					-0.696		
	B	17.185966	1.127875	245269	-10.974			
	U							
	U	17.428294	1.129073	86336	-9.840			
Sky	V							
	B							
	U							
Comp	V							
	V	18.392518	1.138416	127663	-10.265			-12.391
	B					-0.730		
	B	18.574265	1.139393	250100	-10.995			
	U					-10.764		
	U	18.745566	1.140324	90821	-9.895			
Sky	V							
	B							
	U							
UPeg	V							
	V	19.417058	1.139619	130097	-10.286		0.023	-12.404
	B					-0.716		
	B	19.588358	1.140588	251505	-11.001			

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Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	U	3:56:38	94411								
	U	3:56:53	94285	U	94348	4603	3:56:51	2450047.665184	2450047.668055	-0.040995	19.203629
Sky	V	3:57:28	8348								
	B	3:57:52	10257								
	U	3:58:16	4546								
Comp	V	3:59:55	144312								
	V	4:00:10	143909	V	144111	8373	4:00:08	2450047.667464	2450047.670336	-0.040995	20.026710
	B	4:00:35	273270								
	B	4:00:51	265820	B	269545	10458	4:00:48	2450047.667933	2450047.670804	-0.040995	20.195922
	U	4:01:16	97308								
	U	4:01:31	99960	U	98634	4733	4:01:29	2450047.668402	2450047.671273	-0.040995	20.365134
Sky	V	4:02:15	8398								
	B	4:02:39	10659								
	U	4:03:03	4920								
UPeg	V	4:04:53	151034								
	V	4:05:11	153272	V	152153	8225	4:05:07	2450047.670931	2450047.673802	-0.040995	21.278043
	B	4:05:34	269742								
	B	4:05:49	272363	B	271053	10509	4:05:47	2450047.671388	2450047.674259	-0.040995	21.443077
	U	4:06:13	95634								
	U	4:06:29	96514	U	96074	4880	4:06:26	2450047.671845	2450047.674716	-0.040995	21.608111
Sky	V	4:07:04	8052								
	B	4:07:37	10358								
	U	4:08:01	4839								
Comp	V	4:09:02	148843								
	V	4:09:22	149030	V	148937	8095	4:09:17	2450047.673824	2450047.676695	-0.040995	22.322562
	B	4:09:45	277822								
	B	4:10:00	278299	B	278061	10330	4:09:58	2450047.674293	2450047.677164	-0.040995	22.491774
	U	4:10:25	98935								
	U	4:10:41	99608	U	99272	4812	4:10:38	2450047.674762	2450047.677633	-0.040995	22.660986
Sky	V	4:11:17	8138								
	B	4:11:40	10301								
	U	4:12:04	4785								
UPeg	V	4:13:20	152730								
	V	4:13:37	152699	V	152715	8160	4:13:34	2450047.676793	2450047.679664	-0.040994	23.394238
	B	4:14:00	271185								

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Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Airmass	True Count of	Instrumental	Instrumental		
	U							
	U	19.759660	1.141568	89918	-9.885			
Sky	V							
	B							
	U							
Comp	V							
	V	20.636144	1.151256	136139	-10.335			-12.467
	B					-0.705		
	B	20.805356	1.152294	260498	-11.040			
	U					-10.822		
	U	20.974568	1.153342	94089	-9.934			
Sky	V							
	B							
	U							
UPeg	V							
	V	21.834074	1.154224	144376	-10.399		0.001	-12.496
	B					-0.647		
	B	21.999108	1.155295	261971	-11.046			
	U							
	U	22.164142	1.156376	91373	-9.902			
Sky	V							
	B							
	U							
Comp	V							
	V	22.931996	1.166208	141271	-10.375			-12.532
	B					-0.700		
	B	23.101208	1.167386	269233	-11.075			
	U					-10.865		
	U	23.270421	1.168574	94650	-9.940			
Sky	V							
	B							
	U							
UPeg	V							
	V	23.950268	1.168705	145006	-10.403		-0.014	-12.519
	B					-0.635		

26 Nov 95

Observable	Filter	UT Start Time	Count		Star/filter count	Sky/filter count	UT Time	JDE	HJD	T	LST
					Average of 2	Average of 2	Avg + 5 secs			Julian Century	Degrees
	B	4:14:15	267274	B	269230	10290	4:14:13	2450047.677244	2450047.680116	-0.040994	23.557183
	U	4:14:39	95092								
	U	4:14:55	96049	U	95571	4694	4:14:52	2450047.677701	2450047.680573	-0.040994	23.722217
Sky	V	4:15:28	8182								
	B	4:15:50	10278								
	U	4:16:15	4603								
Comp	V	4:17:48	136265								
	V	4:18:05	142283	V	139274	9096	4:18:02	2450047.679895	2450047.682766	-0.040994	24.513962
	B	4:18:28	263246								
	B	4:18:44	258306	B	260776	10733	4:18:41	2450047.680352	2450047.683223	-0.040994	24.678996
	U	4:19:09	87462								
	U	4:19:25	84157	U	85810	4670	4:19:22	2450047.680826	2450047.683698	-0.040994	24.850297
Sky	V	4:20:00	10009								
	B	4:20:25	11188								
	U	4:20:48	4736								
UPeg	V	4:24:05	109199								
	V	4:23:38	97268	V	103234	10320	4:23:57	2450047.684004	2450047.686875	-0.040994	25.997179
	B	4:24:39	207425								
	B	4:24:57	206694	B	207060	11932	4:24:53	2450047.684657	2450047.687529	-0.040994	26.233240
	U	4:25:23	74579								
	U	4:25:42	74751	U	74665	4826	4:25:38	2450047.685172	2450047.688044	-0.040994	26.419164
Sky	V	4:26:26	10630								
	B	4:26:49	12676								
	U	4:27:12	4915								
Comp	V	4:28:34	113778								
	V	4:28:52	118774	V	116276	12541	4:28:48	2450047.687377	2450047.690249	-0.040994	27.215087
	B	4:29:17	195068								
	B	4:29:33	189160	B	192114	13425	4:29:30	2450047.687863	2450047.690735	-0.040994	27.390567
	U	4:29:57	67207								
	U	4:30:13	64715	U	65961	5022	4:30:10	2450047.688326	2450047.691198	-0.040994	27.557690
Sky	V	4:30:48	14451								
	B	4:32:04	14174								
	U	4:32:28	5128								

26 Nov 95

Observable	Filter	H	X	N	v, b, u	(b-v)	ΔV	V
		Degrees	Airmass	True Count of	Instrumental	Instrumental		
	B	24.113213	1.169888	260348	-11.039			
	U							
	U	24.278247	1.171097	91053	-9.898			
Sky	V							
	B							
	U							
Comp	V							
	V	25.123397	1.182290	130553	-10.289			-12.484
	B					-0.711		
	B	25.288431	1.183576	251364	-11.001			
	U					-10.794		
	U	25.459732	1.184922	81282	-9.775			
Sky	V							
	B							
	U							
UPeg	V							
	V	26.553209	1.188823	93119	-9.923		0.138	-12.198
	B					-0.808		
	B	26.789270	1.190780	195958	-10.730			
	U							
	U	26.975195	1.192336	69947	-9.612			
Sky	V							
	B							
	U							
Comp	V							
	V	27.824522	1.204708	103995	-10.043			-12.192
	B					-0.592		
	B	28.000001	1.206269	179402	-10.635			
	U					-10.470		
	U	28.167124	1.207767	61023	-9.464			
Sky	V							
	B							
	U							

VI. Data Output

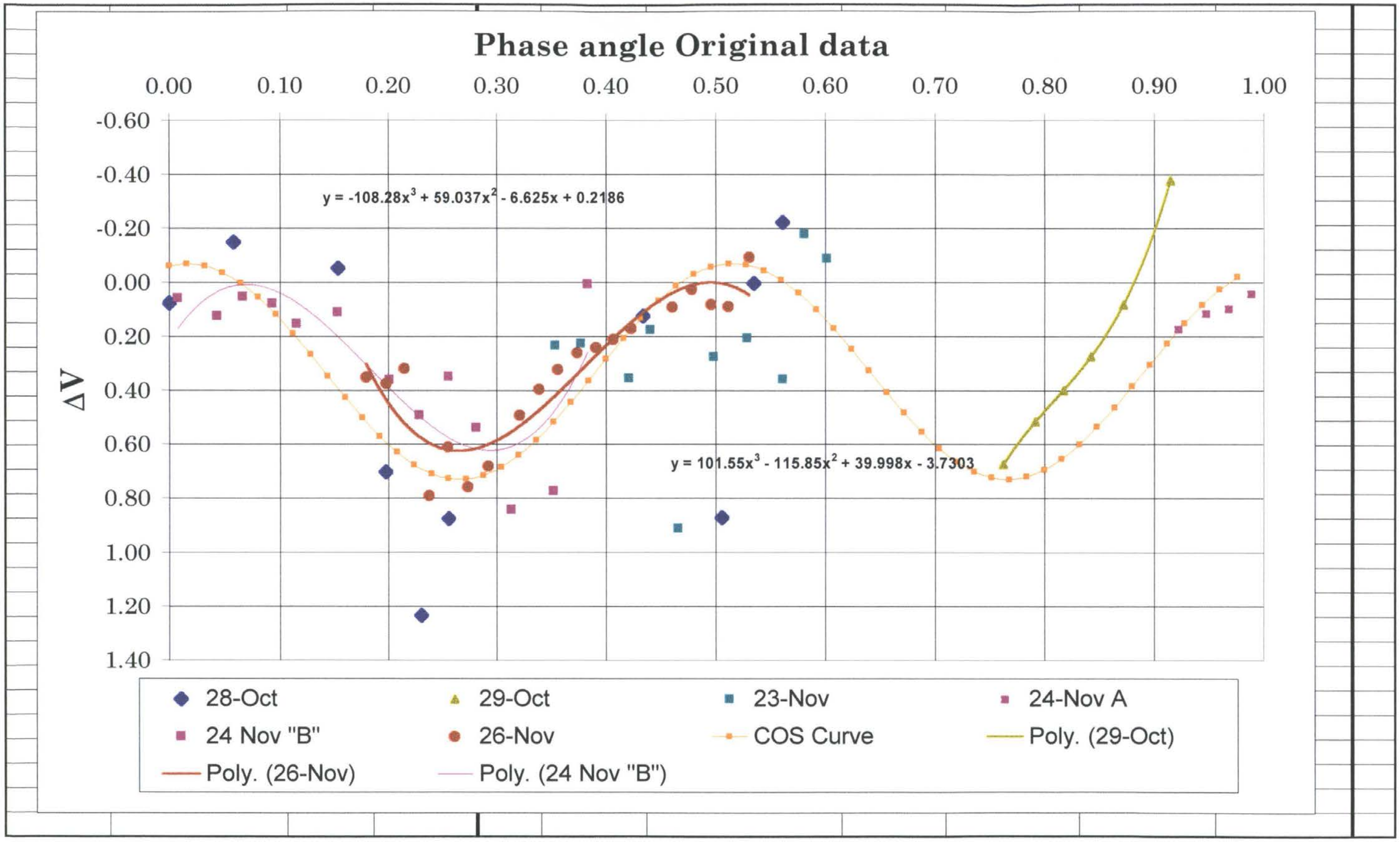
Data Output

Comparison						U Pegasi	P =	0.3747170	Min	.2683?	
	HJD	ΔV	V		V	HJD	ΔV	Phase	Phase	Cos Curve	
28-Oct	2450018.629178	1.145	-11.746		-11.791	2450018.634705	0.075	0.0000	0.0000	-0.062141553	
	2450018.640000	0.493	-11.993		-11.850	2450018.656476	-0.151	0.0581	0.0160	-0.069998737	
	2450018.734879	0.525	-11.448		-11.729	2450018.692257	-0.054	0.1536	0.0320	-0.061740013	
	2450018.850822	0.951	-11.919		-11.493	2450018.708750	0.702	0.1976	0.0480	-0.037698125	
			-12.479		-11.241	2450018.721169	1.232	0.2307	0.0640	0.001158282	
			-12.471		-11.341	2450018.730712	0.874	0.2562	0.0800	0.053263687	
			-11.964		-12.046	2450018.797205	0.122	0.4337	0.0960	0.116518769	
			-12.349		-11.403	2450018.824288	0.872	0.5059	0.1120	0.188374988	
			-12.222		-12.178	2450018.835255	0.001	0.5352	0.1280	0.265937263	
			-12.153		-12.433	2450018.845151	-0.225	0.5616	0.1440	0.34608062	
29-Oct	2450019.664981	0.725	-12.291		-8.922	2450019.669871	0.672	0.7625	0.1600	0.42557609	
	2450019.716023	1.057	-9.621		-9.082	2450019.680722	0.515	0.7915	0.1760	0.501220809	
			-9.578		-9.214	2450019.690357	0.399	0.8172	0.1920	0.56996706	
			-9.626		-9.329	2450019.699646	0.274	0.8420	0.2080	0.629045063	
			-9.611		-9.289	2450019.710786	0.081	0.8717	0.2240	0.676074572	
			-9.608		-9.534	2450019.726874	-0.378	0.9146	0.2400	0.709160773	
23-Nov	2450044.618217	0.990	-9.145		-18.388	2450044.622684	0.234	0.3536	0.2560	0.726970626	
	2450044.668286	1.011	-18.551		-18.470	2450044.631481	0.225	0.3771	0.2720	0.728786574	
	2450044.720705	0.918	-18.704		-18.412	2450044.647829	0.355	0.4207	0.2880	0.714535452	
			-18.704		-18.587	2450044.655254	0.176	0.4405	0.3040	0.684791438	
			-18.840		-17.857	2450044.664652	0.912	0.4656	0.3200	0.640752914	
			-18.700		-18.599	2450044.676909	0.276	0.4983	0.3360	0.584194187	
			-18.850		-18.852	2450044.688448	0.207	0.5291	0.3520	0.517394003	
			-18.903		-19.022	2450044.700497	0.358	0.5613	0.3680	0.443043735	
			-19.237		-19.414	2450044.707979	-0.179	0.5812	0.3840	0.364138946	
			-19.536		-18.544	2450044.715682	-0.088	0.6018	0.4000	0.283858703	
24-Nov	2450045.580822	0.838	-18.945		-11.638	2450045.585035	0.172	0.9218	0.4160	0.205437487	
	2450045.622518	0.792	-17.978		-11.670	2450045.594561	0.113	0.9472	0.4320	0.132034883	
	2450045.677258	0.776	-11.820		-11.679	2450045.602350	0.096	0.9680	0.4480	0.066608272	
	2450045.737454	1.009	-11.807		-11.722	2450045.610076	0.040	0.9887	0.4640	0.011793686	
			-11.770		-11.713	2450045.617269	0.058	0.0078	0.4800	-0.030200401	
			-11.790		-11.673	2450045.630388	0.123	0.0429	0.4960	-0.057682051	

Data Output

			-11.745		-11.697	2450045.639040	0.053	0.0659	0.5120	-0.069544032	
			-11.807		-11.692	2450045.649179	0.077	0.0930	0.5280	-0.065308426	
			-11.793		-11.636	2450045.657443	0.152	0.1151	0.5440	-0.045145885	
			-11.718		-11.606	2450045.671621	0.110	0.1529	0.5600	-0.009868755	
			-11.829		-11.396	2450045.689549	0.360	0.2007	0.5760	0.039101651	
			-11.761		-11.154	2450045.700059	0.491	0.2288	0.5920	0.099792321	
			-11.674		-11.276	2450045.710226	0.349	0.2559	0.6080	0.169758035	
			-11.840		-11.281	2450045.719717	0.538	0.2812	0.6240	0.24617988	
			-11.473		-11.143	2450045.731737	0.842	0.3133	0.6400	0.325978829	
			-11.800		-11.216	2450045.746274	0.772	0.3521	0.6560	0.405939791	
			-11.865		-11.757	2450045.757946	0.006	0.3833	0.6720	0.482841146	
26-Nov	2450047.550544	0.960	-12.120		-13.149	2450047.555035	0.352	0.1791	0.6880	0.553584548	
	2450047.600324	0.804	-11.845		-13.077	2450047.562060	0.374	0.1979	0.7040	0.615319752	
	2450047.649375	0.759	-11.729		-12.968	2450047.568374	0.318	0.2147	0.7200	0.665559453	
			-13.521		-12.460	2450047.576985	0.790	0.2377	0.7360	0.702279499	
	Average	0.860	-13.494		-12.751	2450047.583582	0.610	0.2553	0.7520	0.724000442	
	Std Dev	0.182	-13.421		-12.669	2450047.590463	0.759	0.2737	0.7680	0.729847149	
			-13.160		-12.749	2450047.597407	0.681	0.2922	0.7840	0.719584057	
			-13.353		-12.881	2450047.608113	0.491	0.3208	0.8000	0.693624663	
			-13.380		-12.971	2450047.614728	0.396	0.3384	0.8160	0.65301487	
			-13.485		-13.051	2450047.621233	0.322	0.3558	0.8320	0.599390842	
			-13.387		-13.120	2450047.627836	0.260	0.3734	0.8480	0.534913085	
			-13.369		-13.155	2450047.634305	0.241	0.3907	0.8640	0.462179401	
			-13.374		-13.200	2450047.640208	0.210	0.4064	0.8800	0.384120223	
			-13.380		-13.248	2450047.646395	0.170	0.4229	0.8960	0.303880547	
			-13.389		-13.340	2450047.660417	0.090	0.4604	0.9120	0.224693221	
			-13.412		-13.423	2450047.667106	0.025	0.4782	0.9280	0.149748694	
			-13.418		-13.429	2450047.673802	0.081	0.4961	0.9440	0.082066473	
			-13.429		-13.447	2450047.679664	0.089	0.5117	0.9600	0.024373468	
			-13.429		-13.398	2450047.686875	-0.094	0.5310	0.9760	-0.021005876	
			-13.481								
			-13.552								
			-13.535		0.016						
			-13.083								

Data Output



Phase angle Original data
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
-0.60
-0.40
-0.20
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
ΔV
y = -108.28x³ + 59.037x² - 6.625x + 0.2186
y = 101.55x³ - 115.85x² + 39.998x - 3.7303
28-Oct
29-Oct
23-Nov
24-Nov A
24 Nov "B"
26-Nov
COS Curve
Poly. (29-Oct)
Poly. (26-Nov)
Poly. (24 Nov "B")

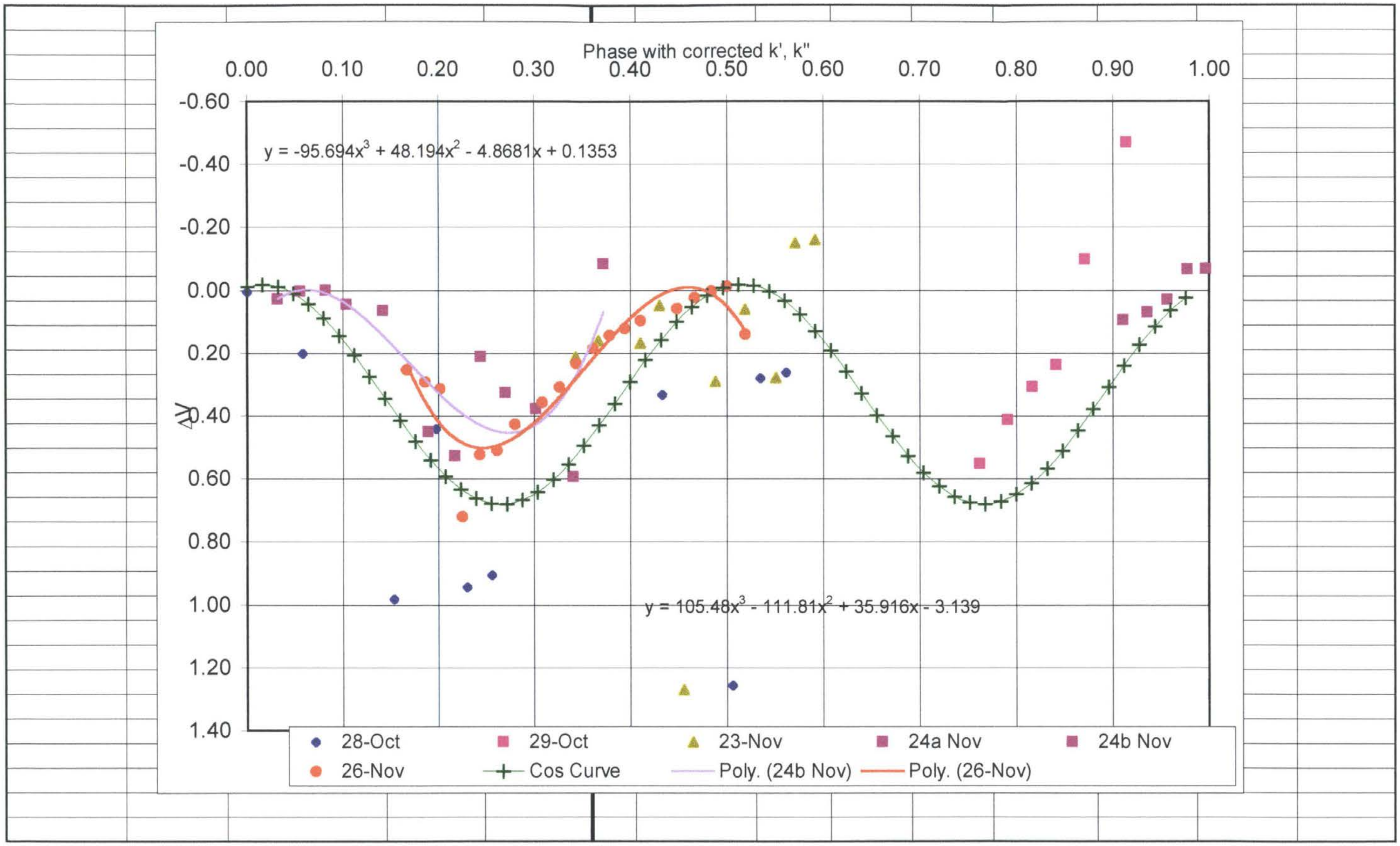
Data Output

k2 = -.6	k'2 = k'3 = 1.5		P =	0.3747740		Data set: k corrected, minus spurious points...							
HJD	**ΔV**	**Phase**	**Phase**	Cos Curve		**HJD**	**ΔV**	**Phase**		Δς	**Phase**		
18.634705	0.004	0.0000	0.0000	-0.013124		18.634705	0.004	0.0000		0.004	0.0000		
18.656476	0.200	0.0581	0.0160	-0.019999		18.708750	0.440	0.1976		0.027	0.0319		
18.692257	0.981	0.1536	0.0320	-0.012773		18.835255	0.279	0.5351		0.002	0.0550		
18.708750	0.440	0.1976	0.0480	0.0082641		18.845151	0.260	0.5615		-0.001	0.0820		
18.721169	0.942	0.2307	0.0640	0.0422635		19.669871	0.552	0.7621		0.045	0.1041		
18.730712	0.904	0.2562	0.0800	0.0878557		19.680722	0.412	0.7911		0.063	0.1419		
18.797205	0.332	0.4336	0.0960	0.1432039		19.690357	0.307	0.8168		0.252	0.1674		
18.824288	1.255	0.5059	0.1120	0.2060781		19.699646	0.238	0.8416		0.289	0.1861		
18.835255	0.279	0.5351	0.1280	0.2739451		44.622684	0.210	0.3431		0.450	0.1898		
18.845151	0.260	0.5615	0.1440	0.3440705		44.631481	0.158	0.3665		0.440	0.1976		
19.669871	0.552	0.7621	0.1600	0.4136291		44.647829	0.168	0.4102		0.311	0.2030		
19.680722	0.412	0.7911	0.1760	0.4798182		44.655254	0.048	0.4300		0.526	0.2178		
19.690357	0.307	0.8168	0.1920	0.5399712		44.688448	0.058	0.5185		0.522	0.2436		
19.699646	0.238	0.8416	0.2080	0.5916644		44.700497	0.277	0.5507		0.508	0.2619		
19.710786	-0.099	0.8713	0.2240	0.6328153		45.585035	0.094	0.9109		0.424	0.2804		
19.726874	-0.471	0.9142	0.2400	0.6617657		45.594561	0.070	0.9363		0.376	0.3023		
44.622684	0.210	0.3431	0.2560	0.6773493		45.602350	0.029	0.9571		0.355	0.3090		
44.631481	0.158	0.3665	0.2720	0.6789383		45.610076	-0.067	0.9777		0.308	0.3267		
44.647829	0.168	0.4102	0.2880	0.6664685		45.617269	-0.070	0.9969		0.210	0.3431		
44.655254	0.048	0.4300	0.3040	0.6404425		45.630388	0.027	0.0319		0.232	0.3440		
44.664652	1.269	0.4551	0.3200	0.6019088		45.639040	0.002	0.0550		0.184	0.3616		
44.676909	0.289	0.4878	0.3360	0.5524199		45.649179	-0.001	0.0820		0.158	0.3665		
44.688448	0.058	0.5185	0.3520	0.4939698		45.657443	0.045	0.1041		0.142	0.3789		
44.700497	0.277	0.5507	0.3680	0.4289133		45.671621	0.063	0.1419		0.120	0.3947		
44.707979	-0.153	0.5707	0.3840	0.3598716		45.689549	0.450	0.1898		0.168	0.4102		
44.715682	-0.162	0.5912	0.4000	0.2896264		45.700059	0.526	0.2178		0.096	0.4112		
45.585035	0.094	0.9109	0.4160	0.2210078		45.731737	0.376	0.3023		0.048	0.4300		
45.594561	0.070	0.9363	0.4320	0.1567805		47.555035	0.252	0.1674		0.057	0.4486		
45.602350	0.029	0.9571	0.4480	0.0995322		47.562060	0.289	0.1861		0.023	0.4664		
45.610076	-0.067	0.9777	0.4640	0.0515695		47.568374	0.311	0.2030		0.001	0.4843		
45.617269	-0.070	0.9969	0.4800	0.0148246		47.583582	0.522	0.2436		-0.013776	0.499931		
45.630388	0.027	0.0319	0.4960	-0.009222		47.590463	0.508	0.2619		0.058	0.5185		

Data Output

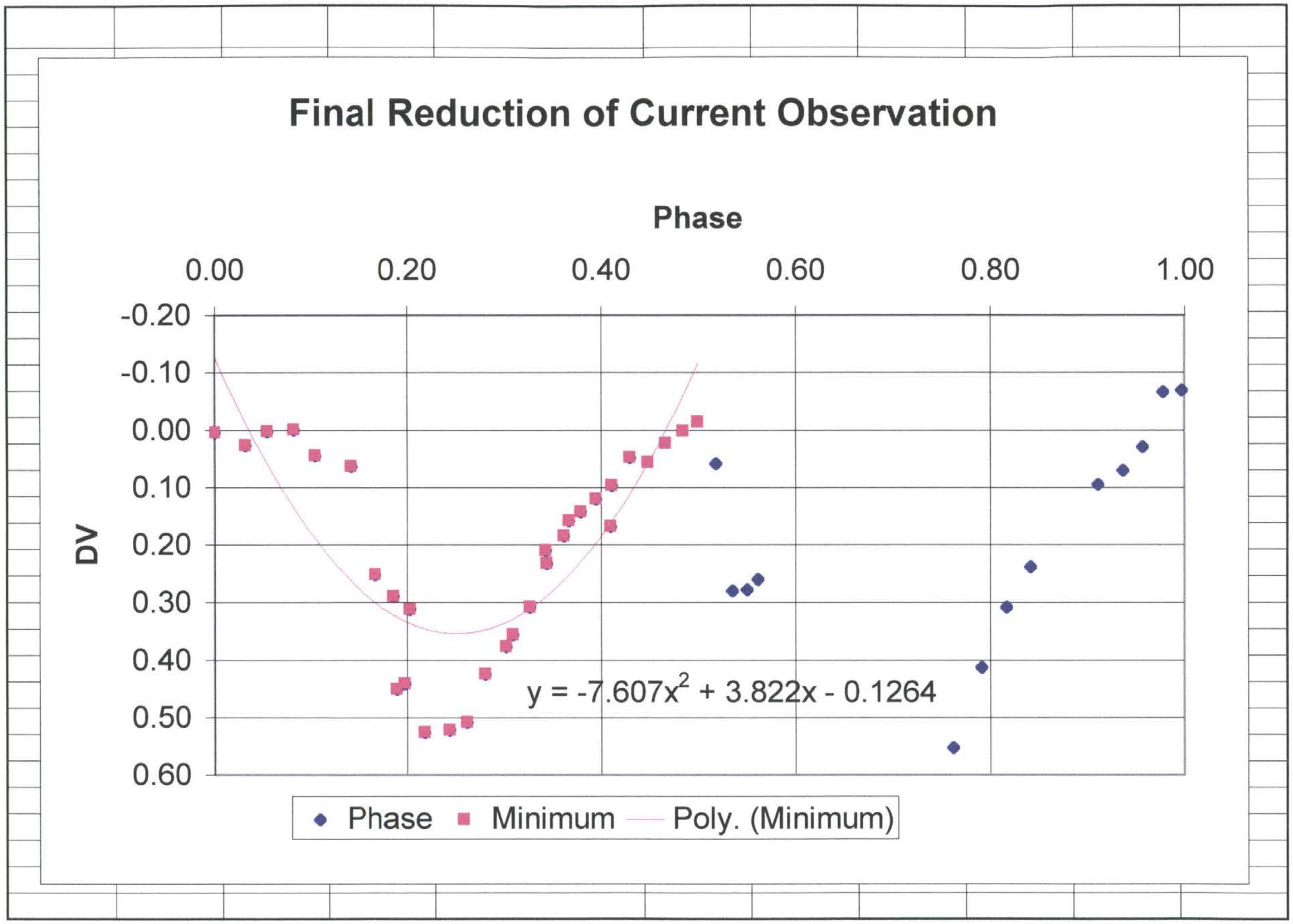
45.639040	0.002	0.0550	0.5120	-0.019601		47.597407	0.424	0.2804		0.138417	0.519171		
45.649179	-0.001	0.0820	0.5280	-0.015895		47.608113	0.355	0.3090		0.279	0.5351		
45.657443	0.045	0.1041	0.5440	0.0017474		47.614728	0.308	0.3267		0.277	0.5507		
45.671621	0.063	0.1419	0.5600	0.0326148		47.621233	0.232	0.3440		0.260	0.5615		
45.689549	0.450	0.1898	0.5760	0.0754639		47.627836	0.184	0.3616		0.552	0.7621		
45.700059	0.526	0.2178	0.5920	0.1285683		47.634305	0.142	0.3789		0.412	0.7911		
45.710226	0.211	0.2449	0.6080	0.1897883		47.640208	0.120	0.3947		0.307	0.8168		
45.719717	0.324	0.2703	0.6240	0.2566574		47.646395	0.096	0.4112		0.238	0.8416		
45.731737	0.376	0.3023	0.6400	0.3264815		47.660417	0.057	0.4486		0.094	0.9109		
45.746274	0.594	0.3411	0.6560	0.3964473		47.667106	0.023	0.4664		0.070	0.9363		
45.757946	-0.084	0.3723	0.6720	0.463736		47.673802	0.001	0.4843		0.029	0.9571		
47.555035	0.252	0.1674	0.6880	0.5256365		47.679664	-0.014	0.4999		-0.067	0.9777		
47.562060	0.289	0.1861	0.7040	0.5796548		47.686875	0.138	0.5192		-0.070	0.9969		
47.568374	0.311	0.2030	0.7200	0.6236145									
47.576985	0.719	0.2260	0.7360	0.6557446									
47.583582	0.522	0.2436	0.7520	0.6747504									
47.590463	0.508	0.2619	0.7680	0.6798663									
47.597407	0.424	0.2804	0.7840	0.670886									
47.608113	0.355	0.3090	0.8000	0.6481716									
47.614728	0.308	0.3267	0.8160	0.612638									
47.621233	0.232	0.3440	0.8320	0.565717									
47.627836	0.184	0.3616	0.8480	0.5092989									
47.634305	0.142	0.3789	0.8640	0.445657									
47.640208	0.120	0.3947	0.8800	0.3773552									
47.646395	0.096	0.4112	0.8960	0.3071455									
47.660417	0.057	0.4486	0.9120	0.2378566									
47.667106	0.023	0.4664	0.9280	0.1722801									
47.673802	0.001	0.4843	0.9440	0.1130582									
47.679664	-0.014	0.4999	0.9600	0.0625768									
47.686875	0.138	0.5192	0.9760	0.0228699									

Data Output



Phase with corrected k', k"
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
-0.60
-0.40
-0.20
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
ΔV
y = -95.694x3 + 48.194x2 - 4.8681x + 0.1353
y = 105.48x3 - 111.81x2 + 35.916x - 3.139
28-Oct
29-Oct
23-Nov
24a Nov
24b Nov
26-Nov
Cos Curve
Poly. (24b Nov)
Poly. (26-Nov)

Data Output



Final Reduction of Current Observation
Phase
0.00
0.20
0.40
0.60
0.80
1.00
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
0.50
0.60
DV
y = -7.607x2 + 3.822x - 0.1264
Phase
Minimum
Poly. (Minimum)

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VITA

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During his career Dave has attended or completed: Parachute Jumpmaster/Instructor Training, Undergraduate Navigator Training, Undergraduate Pilot Training, RF–4 and F–16 Replacement Training, T-38 Pilot Instructor Training, Squadron Officer School, Air Command and Staff College, Cross–Cultural Communications Course, Security Assistance Orientation Course, and the Quality Awareness Course. With Jonathon Gallmeier and Donald Olson, he co–authored the paper "How Old Is the Universe?", published in Sky & Telescope, January 1996. His permanent address is:

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ENDNOTES

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