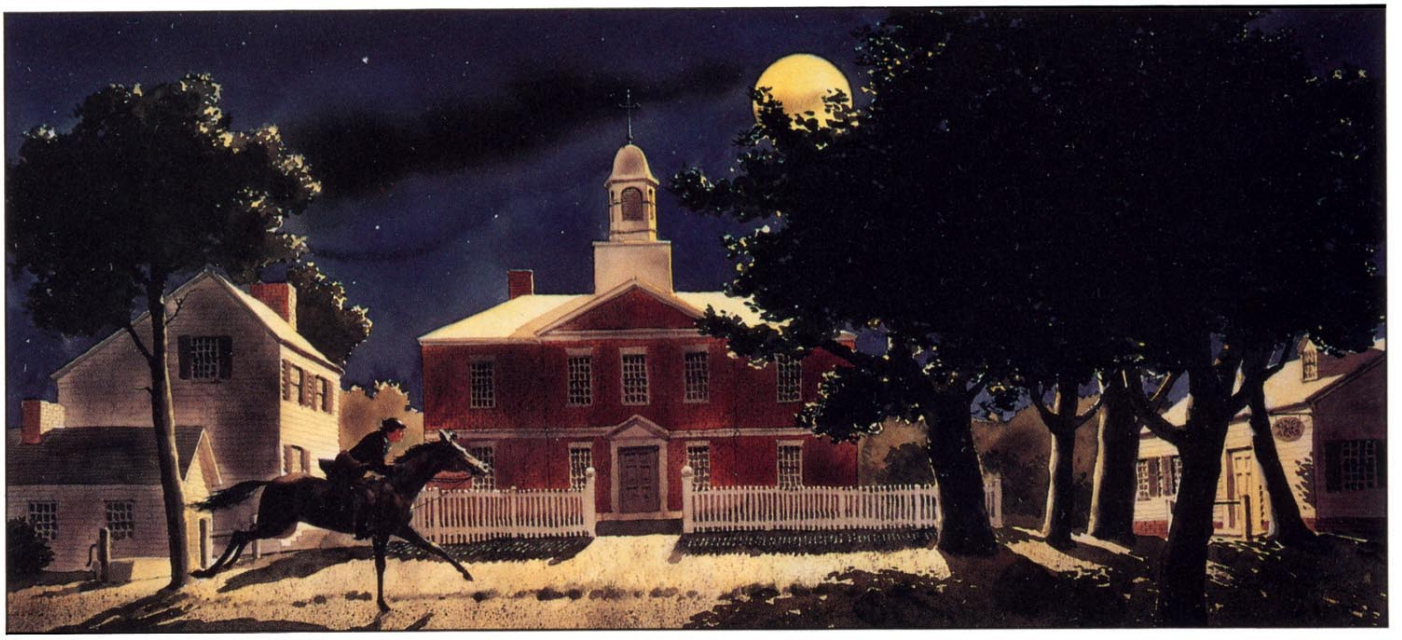
Astronomical Computing

Conducted by Roger W. Sinnott



On April 18, 1775, a bright Moon rose shortly before 10 p.m. and remained in the sky throughout the famous midnight ride. This painting and that on page 363 are from *Paul Revere's Ride* (Dutton, 1990), an illustrated edition of Longfellow's poem. Courtesy artist Ted Rand.

PAUL REVERE'S MIDNIGHT RIDE

IN HIS *Tales of a Wayside Inn* (1863), Henry Wadsworth Longfellow began the landlord's tale with these stirring lines:

Listen, my children, and you shall hear
Of the midnight ride of Paul Revere,
On the eighteenth of April, in Seventy-five;
Hardly a man is now alive
Who remembers that famous day and year.

The poem refers to the spring of 1775, when General Thomas Gage, British commander in Boston, received information that a considerable quantity of provincial military stores was concealed in Concord, a town about 18 miles west of Boston. On the night of April 18th, Gage ordered a detachment of grenadiers and light infantry to proceed to Concord and destroy the depot. Boats began ferrying the troops from Boston to Cambridge across the tidal backwash of the Charles River.

Anticipating such a move, the patriots had wondered if the British might go to Concord by the land route instead, marching south and then west. Gage's choice to cross the water led to the famous two-lantern signal ("two if by sea") from the belfry of the Old North Church. Paul Revere himself, according to the times given in his own later statements, crossed the harbor sometime between 10 p.m. and 11 p.m. in a rowboat from Boston to Charlestown. There he began his famous midnight ride toward Lexington and Concord — passing through "every Middlesex village and farm" to warn of the British advance.

Longfellow's poem contains a number of astronomical allusions. For example, he mentions the Moon five times:

he . . .
Silently rowed to the Charlestown shore,
Just as the moon rose over the bay . . .

The Somerset, British man-of-war;
A phantom ship, with each mast and spar
Across the moon like a prison bar . . .

Where he paused to listen and look down
A moment on the roofs of the town,
And the moonlight flowing over all . . .

A hurry of hoofs in a village street,
A shape in the moonlight, a bulk in the dark . . .

He saw the gilded weathercock
Swim in the moonlight as he passed.

But are these statements really accurate? Does Longfellow merely invoke the Moon through poetic license? There is every reason to ask such questions, in view of other well-known historical errors in the account. For example, the poem puts Revere on the wrong side of the harbor. Actually, he was involved in *sending* the two-lantern signal and did not receive it. Also, the poem has Revere reach Concord, but in reality he and his friend William Dawes were stopped just past Lexington, and it was a third rider, Samuel Prescott, who got to Concord.

Was the Moon, in fact, rising as Revere crossed the river? Was there bright moonlight throughout the midnight ride?

THE MOON ON APRIL 18-19, 1775

Following the methods of Jean Meeus' *Astronomical Formulae for Calculators* (Willmann-Bell, 1982), we have calculated the following dates and Universal times of lunar phases in 1775:

Full Moon . . . . . April 15, 22^h UT
Last Quarter . . . . . April 22, 20^h UT

So there was indeed a bright waning-gibbous Moon, 87 percent sunlit, in Boston on the night of April 18, 1775. Moonrise occurred at about 9:37 p.m. Eastern standard time, which is 9:52 p.m. local mean time at the meridian of Boston, 71° 03′ west longitude, or $4^h\ 44^m$ west of Greenwich. (The United States did not adopt standard time zones until 1883.) It also corresponds to 9:53 p.m. local apparent solar time. Regardless of how the time is expressed, it's clear that a bright Moon was rising when Paul Revere crossed the harbor between 10 p.m. and 11 p.m.

To explore the matter further, we have

A popular tourist stop on Boston's Freedom Trail is this statue of Paul Revere, erected in 1944 only about 100 yards from Old North Church (also known as Christ Church) in the background. Two lanterns were hung high in its steeple on April 18, 1775, the night before the start of the Revolutionary War. *Sky & Telescope* photograph by Roger Sinnott.

located several colonial almanacs for 1775 published in Boston, including those of Nathaniel Low, Isaac Bickerstaff, Isaiah Thomas, and Nathaniel Ames. Moonrise on April 18th is given as 9:45 p.m. (Low, Ames), 9:46 p.m. (Thomas), and 9:53 p.m. (Bickerstaff). A separate comparison, using sunrise times for all 365 days of 1775, shows that the colonial almanacs did use apparent solar time ("sundial time") rather than mean time in their predictions.

REVERE'S OWN RECOLLECTIONS

Paul Revere left three first-person accounts of the famous night. Two are in the Revere family papers, and both describe how "the Moon shone bright." His third account, a letter sent in 1798 to Jeremy Belknap of the Massachusetts Historical Society, contains the following often-quoted lines:

> Went to the north part of the town, where I had kept a boat; two friends rowed me across Charles River, a little to the eastward where the *Somerset* man-of-war lay. It was then young flood, the ship was winding, and the moon was rising.

It may seem hard to understand how Revere could have passed HMS *Somerset* without being detected. If he was to the east of the ship, why didn't the British see his rowboat silhouetted against the rising Moon?

Our computer simulations provide the answer. The Moon that night had a southern declination (−18°) which, combined with Boston's latitude of 42° 22′ north, caused the Moon to rise considerably south of east. When Revere crossed the harbor, roughly 45 minutes after moonrise, the Moon was low in the southeast (altitude 6°, azimuth 121°).

As shown on the accompanying map, a sentinel on the *Somerset* would have seen the Moon rising over the city of Boston, not over the open water of the bay, and therefore he would not have seen the rowboat against the rising Moon. This calculation helps to explain why Revere was successful in reaching his horse on the opposite shore!

TIDES

Apart from Revere's recollection of a "young flood" as he was crossing the harbor, Longfellow's poem mentions tides three times and even includes a description of soldiers being ferried on "the rising tide, like a bridge of boats." We can check these statements with computer programs based on harmonic analysis of the tides. Our program calculates the tide curve as the sum of 37 periodic constituents, with amplitudes and phases tabulated as the "station constants" for the port (*S&T:* November, 1987, page 526).

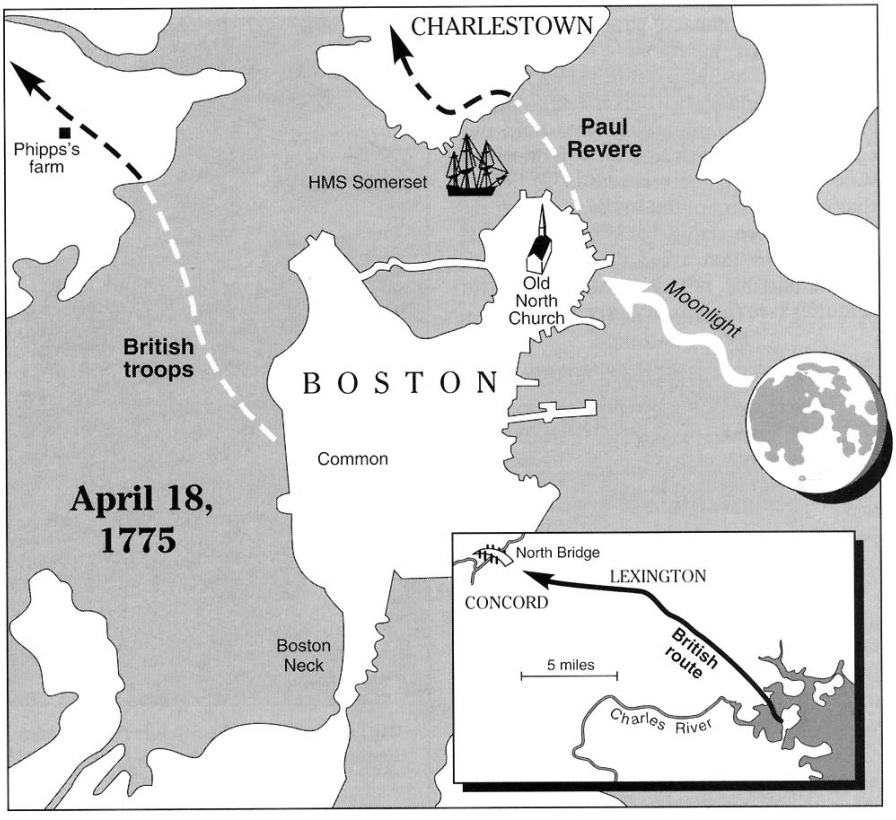
Our results, listed overleaf, show that Revere's letter and Longfellow's poem are again both correct — there was a rising tide between 10 p.m. and 11 p.m. as Revere passed the *Somerset*.

Contemporary accounts also recorded the effects of the following high water that occurred early on April 19th and flooded the marshes on the Cambridge side of the river. A report by an anonymous British officer, recorded by Lieutenant Frederick Mackenzie of the Royal Welch Fusiliers, describes the events:

> The Grenadier & Light Companies of the Regiments in Boston were ordered to assemble on the Beach near the Magazine at 10 o'Clock last night . . . embarked, and landed at Phipps's farm. The boats then returned for the remainder, and it was near One oClock in the Morning before the whole were landed on the opposite shore . . . . it was 2 oClock before they marched off. Their march across the marshes into the high road, was hasty and fatiguing, and they were obliged to wade, halfway up their thighs, through two Inlets, the tide being by that time, up. This should have been avoided if possible, as the troops had a long march to perform. . . .

Lieutenant William Sutherland of the 38th Regiment described how he

> . . . embarked at the Magazine Guard & landed near Cambridge. . . . here we remained for two long hours, partly waiting for the rest of the Detachment & for provisions, About 2 in the Morning on the 19th we marched. . . . the Tide being in we were up to our Middles before we got into the road. . . .



Sentinels on the man-of-war would not have seen Revere's rowboat silhouetted against the rising Moon or its reflection, since the Moon rose considerably south of east.

Colonial almanacs gave the time of morning high water, or "full sea," on April 19th as 2:34 a.m. (Low), 2:36 (Thomas), and 2:39 (Bickerstaff, Ames). All of these are somewhat later than our computed time of 1:26 a.m. for that high water. However, there is reason to believe that our tide computations are fairly accurate, even projecting back to 1775, since we can show that a certain time constant for the port has not changed much in two centuries (see the box at lower right).

BOSTON HARBOR TIDES

(Times are local apparent solar time)

April 18, 1775	1:14 p.m.	high water
April 18, 1775	7:19 p.m.	low water
April 19, 1775	1:26 a.m.	high water

RELATION TO APRIL 18, 1992

On April 18, 1775, the Moon rose at about 9:37 p.m. EST, and 45 minutes later it stood 6° above the southeastern horizon at azimuth 121°. The Moon was in the waning-gibbous phase and 87 percent sunlit.

On April 18, 1992, the Moon will rise at about 9:38 p.m. EDT, and 45 minutes later it will stand 6° above the southeastern horizon at azimuth 128°. The Moon will be waning gibbous and 96 percent sunlit. While the Moon in 1992 is somewhat closer to full, the expected difference in rise time is almost exactly canceled by our use of daylight time.

If the sky is clear, the bright moonlight in 1992 will angle across Boston harbor, shine down the country roads, and illuminate Lexington Green and Concord Bridge, just as it did more than two centuries ago, on the night before the first day of the American Revolution.

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This engraving of the famous ride is based on a drawing by Felix Darley and appeared in Benson Lossing's *Our Country* (New York, 1888).

IV. APRIL hath 30 Days. 1775

BUT when the rage of winter's night is paſt,
(Kind heav'ns indulgences forever laſt.)
The vernal dawn of blooming ſpring appears,
And Sol's kind influence all nature chears:
Refreſhing ſhowers prepare the earth for ſeed,
While pleaſing verdure cloathes the fertile mead.

Firſt Quart. 7 Day 6½ Aft. | Laſt Quart 22 Day 2 Aftern
Full Moon 15 Day 5 Aft. | New Moon 29 Day 3 Aftern

M	W.	Courts, Asp Weath &c.	r. ☉		s.	F sea		☽ pl.	r. ● s.		O.S
1	7	St Philip & James. ☍ ☽ ♀	5	43	7	12	20	head	7	45	21
2	A	Pleasant. ☌ ♃ ☽	5	42	7	1	8	neck	8	56	22
3	2	Sup. C. South Kingston	5	40	7	1	55	25	9	56	23
4	3	I.C. Barnst. N Hav. Amher	5	39	7	2	42	arms	10	56	24
5	4	pleasant ☊ 2 ♍	5	38	7	3	29	20	11	52	25
6	5	weather, for	5	37	7	4	16	breaſt	Morn.		26
7	6	P.N. 9 41 ſeveral	5	35	7	5	3	15	0	46	27
8	7	days together.	5	34	7	5	49	26	1	35	28
9	A	● Apogee Palm Sunday	5	33	7	6	35	heart	2	20	29
10	2	S. C. Briſtol. warm,	5	31	7	7	21	20	2	57	30
11	3	S.C. Charleſt. I.C. Plim	5	30	7	8	6	belly	3	30	31
12	4	(Hartf & Charleſt N.H.	5	28	7	8	51	14	4	1	Ap
13	5	pleaſant,	5	27	7	9	36	27	4	31	2
14	6	Good Friday ☌ ☽ ♄	5	26	7	10	21	reins	5	1	3
15	7	△ ☉ ♂ thunder, ☌ ♃ ♀	5	24	7	11	6	23	☾ riſe		4
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21	6	weather, ☍ ♄ ☿	5	16	7	4	19	16	Morn.		10
22	7	then ● Per	5	15	7	5	12	legs	0	52	11
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24	2	Tides	5	12	7	6	55	29	2	23	13
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26	4	7*'s ſet 9 4 perhaps a	5	10	7	8	37	27	3	25	15
27	5	△ ♄ ♀ cold ☍ ☽ ♄	5	9	7	9	28	head	3	50	16
28	6	Yard L ſets 9h. rain,	5	7	7	10	19	24	4	23	17
29	7	then pleaſant	5	6	7	11	10	neck	☽ ſets		18
30	A	weather. ☌ ☽ ♃	5	4	7	11	56	20	7	46	19

This page for April is from *An Astronomical Diary; Or, Almanack For the Year of Christian Era, 1775*, written by Nathaniel Low and published in Boston by John Kneeland.

Tide Computations

The "high water lunitidal interval" is defined as the timespan between the Moon's transit across the meridian of the place and the following high water. A related quantity, called High Water Full & Change, is the average value of the high water lunitidal interval on the days of full Moon or new Moon ("change"). We have located two series of navigation guides from the late 1700's, and both state that HWF&C equals $11^h\ 30^m$ for Boston harbor.

For comparison, we computed the times of high waters and then subtracted the times of the preceding lunar transits on the days of the 25 new and full Moons in 1992. The average difference, or HWF&C, is $11^h\ 24^m$ in 1992, in good agreement with the colonial value. This indicates that the harbor has not changed significantly, at least in how it affects the times of high tide, despite the shoreline and depth changes through dredging and landfill.

For the day of full Moon on April 15, 1775, our computer program gives high water at 11:06 a.m., exactly the time listed in Nathaniel Low's almanac. However, Low appears to have computed tide times in detail on only a few days each month, obtaining other times by "uniform differencing," equivalent to the fairly crude method of linear interpolation.

Our program for computing ocean tides by harmonic analysis is too long to give here. However, a shareware program called TIDES is available from Ed Wallner, 32 Barney Hill Rd., Wayland, Mass. 01778. He described an earlier version of it in Astronomical Computing for February, 1988, page 195. Running on IBM PC or compatible computers, the program finds times of high and low waters and displays tide height versus time in either tabular or graphical form. Interested readers should send Wallner either the requested $15 shareware contribution or a formatted 5¼-inch disk, mailer, and return postage.