The Indian Luni-Solar Calendar and the Concept of Adhik-Maas (Extra-Month)

Introduction:

The Hindu calendar is basically a lunar calendar and is based on the cycles of the Moon. In a purely lunar calendar - like the Islamic calendar - months move forward by about 11 days every solar year. But the Hindu calendar, which is actually luni-solar, tries to fit together the cycle of lunar months and the solar year in a single framework, by adding adhik-maas every 2-3 years. The concept of Adhik-Maas is unique to the traditional Hindu lunar calendars. For example, in 2012 calendar, there were 13 months with an Adhik-Maas falling between August 18th and September 16th.

The Hindu Calendar still shifts slowly with respect to seasons due to the precession of the Earth's axis. As a result Uttrayan (Makar-Sankranti or Pongal, marking the day of the year when Sun starts moving towards Uttar (North) which is usually celebrated around January 14th, actually falls on 22nd of December as it is on this date that the Sun is at the southernmost point, as seen from Earth. If it continued in the same way, after about 11,000 years, Pongal will occur in June, Diwali will then be celebrated around April and Sawan-Bhadon will no longer imply torrential rains.

Added to all this is the slowing down of the Earth's rotation due to tides, and the recession of the Moon from Earth. Extrapolated backwards, Earth's day length was perhaps very short (5-6 hours!) during its first billion years, and in a distant future the day will become much longer (if everything else remained the same, it could become a month long). Moon was much nearer, with many more days in a lunar month. Eventually the day and night cycle should stop with one side of Earth always facing Sun and the opposite side of Earth in a perpetual dark, with no further need of any calendar.

Three natural clocks:

From almost the dawn of civilization, man noticed that many phenomena in nature were repetitive. The most basic cycle was the alternation of day and night. This is due to our most basic natural clock, viz. the rotation of the Earth, causing the rising and setting of the Sun, giving rise to alternative periods of light and darkness. All human and animal life has evolved accordingly, keeping awake during the day-light but sleeping through the dark nights. Even plants follow a daily rhythm. Of course some crafty beings have turned nocturnal to take advantage of the darkness, e.g., the beasts of prey, blood–sucker mosquitoes, thieves and burglars, and of course astronomers.

The next natural clock in terms of importance is the revolution of the Earth around the Sun. Early humans noticed that over a certain period of time, the seasons changed, following a fixed pattern. Near the tropics - for instance, over most of India - the hot summer gives way to rain, which in turn is followed by a cool winter. Further away from the equator, there were four distinct seasons - spring, summer, autumn, winter. This period defined a year.

The third clock is the revolution of the Moon around the Earth. The phases of the Moon were a curious phenomenon, which repeated over a period, called month. Though many religious and social customs became tied to the cycle of the seasons, but often their timings got fixed with respect to phases of the Moon.

Unlike the day, month and the year, the week is a completely artificial unit of time. The week probably first came into existence when man began trading regularly, it perhaps marked the interval of working days followed by a holiday in repetitive manner. The week varied in length in different parts of the world. Some African tribes used a 4 day week, the Central American week was 5 days long and the ancient Romans used 8 day intervals. Most societies eventually settled on a 7 day week.

Different types of calendars:

To keep track of the days, months and years, the need of a calendar arose. There are many different types of calendars in use. The calendar which we follow for most of our daily activities developed mostly in Europe. This so called Western or Gregorian calendar is purely solar – it ignores Moon completely and relates important days (for example, birth-days, festivals etc.) only to the time of the year. There is a widely used calendar which is purely lunar - the Islamic calendar. It ignores Sun completely.

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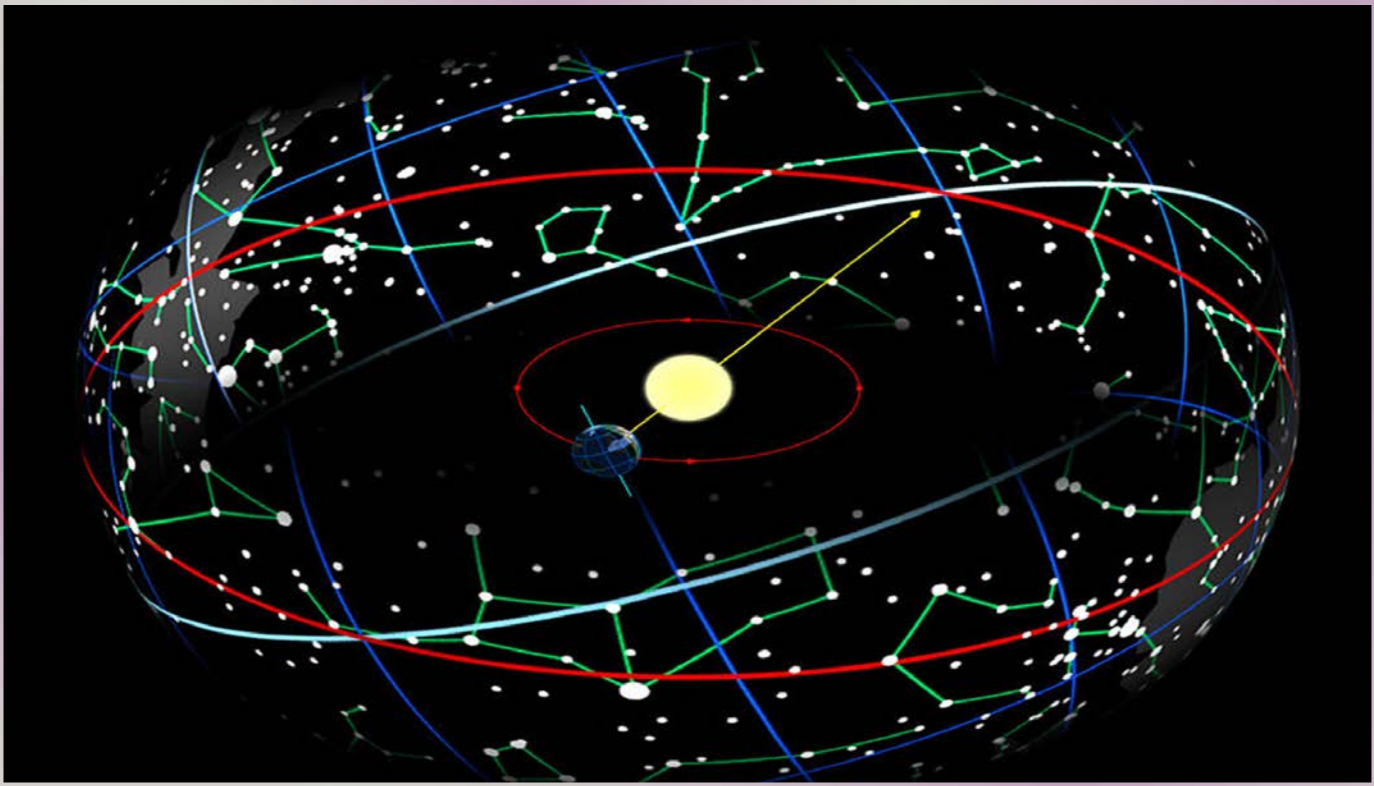

Figure 1: The Zodiac constellations

The most common Indian calendar is luni-solar, taking both the Sun and Moon into account. It tries to fit together the cycle of lunar months and the solar year in a single framework. There are some calendars that appear to be synchronized to the motion of Venus, such as some of the ancient Egyptian calendars.

Mismatch between different time units:

The problem with designing an accurate calendar is that the three natural units of time - the day, the month and the year - are based on different movements - the Earth's rotation about its axis, the Moon's revolution around the Earth and the Earth's revolution around the Sun. Their periods are not integer multiples of each other.

There is no convenient way to relate these three concepts of time. A solar year is about 365.25 days long, while a lunar month is about 29.53 days long. Twelve lunar months add up to 354 days and thus fall a little short of a year. On the other hand, thirteen lunar months are 18 days more than those (365.25 days) in a year.

More precisely the solar and the lunar years have gaps of 11 days, 1 hour, 31 minutes and 12 seconds. As this gap accumulates every year, in three years it approximates to one month. The Moon takes about 27.3 days to make one complete orbit around the Earth. The Earth orbits around the sun, equinox to equinox, once every 365.2422 days. The Earth and the Moon in 27.3 days have moved as a system about 1/12 of the ways around the sun. This means that from one full Moon to the next full Moon, the Moon must travel 2.2 extra days before it appears full. Thus to line up with the Earth and Sun to become a full Moon it takes 29.531 days. With 29.531 day per lunar months implies 354.372 days per lunar year. Thus we arrive at a difference of 10.87 days a year between a lunar year and a solar year of 365.2422 days per year.

Sun's path in Sky – Zodiac:

As Earth moves around the Sun, as seen from Earth, the Sun changes its position with respect to the background stars. The path that Sun takes on the celestial sphere is called the *Ecliptic*.

Of course we cannot directly observe which star the Sun is passing in front of, since we cannot see the stars when the Sun is shining. However, we can indirectly infer the position of the Sun by observing which stars on the ecliptic are visible near the horizon just before Sunrise or just after Sunset.

The familiar Zodiac constellations (Fig. 1) are just divisions of the ecliptic into twelve parts. There are a total of 88 constellations in the sky, but Sun's path passes through only 12 of them, one for each month. Actually there are 13 of them in the Zodiac but one of them has somehow been ignored. In fact a better system could be with 13 months in a year, one for each of the 13 Zodiac constellations, each month four weeks long, and a leap day at the end of the year (two consecutive Sundays at the year end!). Then there would be no need of the Gregorian calendar as each day of the year will always fall on the same day of the week. Of course one would still need to track Moon's phases over the year and the mismatch with the lunar calendar over the year, and in particular, the need for the adhik-maas in the Hindu calendar will still persist.

Seasons:

The celestial equator is inclined to the ecliptic by 23.5°. The points of intersections of these two circles on the celestial sphere are called the "Vernal Equinox" and the "Autumnal Equinox". The Vernal Equinox is the point on the celestial sphere that the Sun passes through around 22nd of March every year.

The seasons arise because of the tilt of the Earth's axis. As the Earth goes around the Sun, the Earth alternately tilts towards and away from the Sun.

At the summer solstice (June 21), the northern hemisphere is tilted towards the Sun while at the winter solstice (December 22), it is the southern hemisphere that is tilted towards the Sun. Between the solstices fall the equinoxes, when the axis is not tilted with respect to the Sun. The vernal equinox is on March 22 and the autumnal equinox on September 23.

A solar month is the time taken for the Sun to pass through one of the twelve segments of the Zodiac. The time when the Sun crosses from one segment to the next is called a Sankranti and marks the beginning of the solar month.

Two well known Sankrantis are Makara Sankranti around January 14 and Mesh Sankranti on April 14. Mesha Sankranti marks the beginning of the new year in Assam, Bengal, Kerala, Orissa, Punjab and Tamil Nadu - these states follow a purely solar calendar for fixing the length of the year.

Why an adhikmaas (extra month)?

As mentioned earlier, 12 lunar months add up to less than a full year whereas 13 lunar months are more than a year. To solve this problem, the Indian calendar defines a normal year to have 12 lunar months. Every few years, an extra lunar month is added to keep in step with the solar year. Adding 7 extra lunar months over a period of 19 years gives a remarkably close approximation of 19 solar years. But how exactly does the Indian luni-solar calendar work? How does one decide when to add the extra lunar months?

Lunar months:

The lunar months are defined with respect to the solar months – in fact, they have the same names as the solar months.

The first lunar month of the year is Chaitra. In Andhra Pradesh, Karnataka, Maharashtra and Gujarat, Chaitra begins with the last Amavasya (new Moon) before Mesha Sankranti (April 14). In North India, the lunar month begins and ends with Purnima (full Moon).

The next lunar month is Vaisakha, beginning with the first Amavasya during the solar month Vaisakha. Similarly each Amavasya falling between two Sankrantis marks the beginning of the lunar month. The lunar month inherits the same name as the solar month during which Amavasya falls.

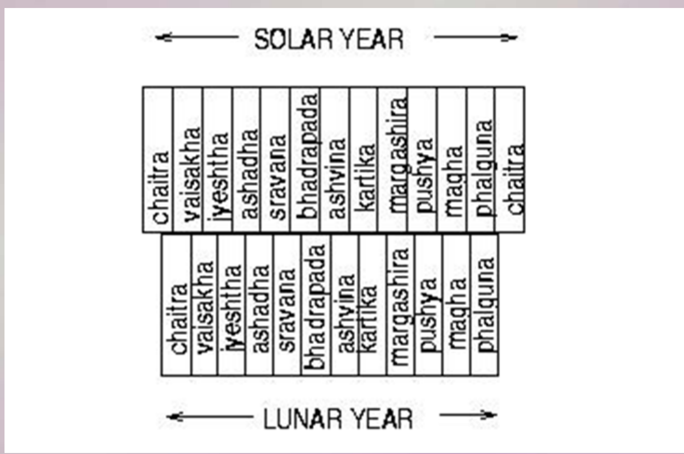

Figure 2: Mismatch in the solar and lunar

In Fig. 2 the upper row denotes the solar months, with the vertical lines denoting Sankrantis. The lower row denotes lunar months, with vertical lines denoting Amavasyas.

A solar month is normally 30 to 31 days in length whereas the lunar month is only 29.5 days long. Thus, as the year goes by, each lunar month starts a little earlier within the corresponding solar month.

Eventually, an entire lunar month will lie within a solar month – in other words, there will be two Amavasyas between a pair of Sankrantis. In such a case we get an extra intercalated month, called an adhik-maas.

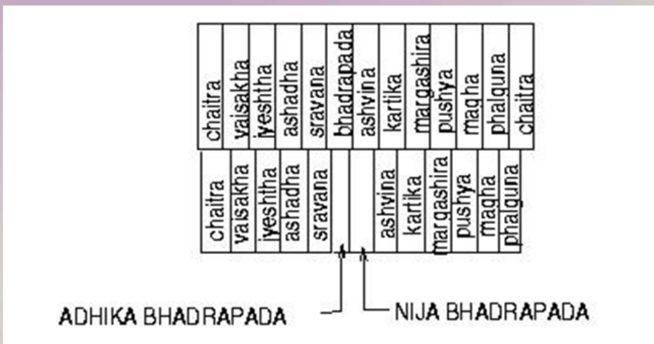

Figure 3: Matching the solar and lunar years by introducing an adhik-mass

For instance, consider a year like the following when there are two Amavasyas within the solar month of Bhadrapada (Fig. 3). The first Amavasya begins an extra month called Adhika Bhadrapada while the second one begins the "real" month Nija Bhadrapada.

A year with an adhikmaas occurs around 7 times in 19 years. The adhikmaas could come at almost any time during the year, depending on which solar month happens to have a double Amavasya.

Occasionally, a very peculiar situation occurs - a lunar month spans two Sankrantis. This, for example, is what happened in 1982-83. There was no Amavasya during the solar month Magha. As a result, the lunar month Magha was "lost" and became a kshayamaas.

How can this happen? Isn't a lunar month always shorter than a solar month?

It so happens that a solar month is normally 30 to 31 days long. However, since the Earth moves at varying speeds around the Sun, the Sun's apparent motion through the ecliptic is not uniform. If the Earth is moving exceptionally fast, the Sun may pass through a sign of the zodiac in less than a lunar month.

Note that in 1982-83, there were two adhikmaas - Ashvina and Phalguna. This is always the case - a year with a kshayamaas will have two adhikmaas.

A purely lunar calendar:

The Islamic calendar consists of twelve lunar months, with no correction for the extra days in a solar year. As a result, the Islamic months move forward by about 11 days every solar year. For instance, the month of Ramzan keeps shifting. It used to occur in mid-summer during the 1980s but moved to mid-winter around 2000. It was in November in 2005 and is in September in 2010.

Even in a luni-solar Calendar, festivals shift slowly with respect to the seasons.

Precession of the Earth's axis:

The Earth's axis is not pointed at a constant spot in the sky. Instead, it describes a large circle in the sky around the ecliptic axis with a time period of ~ 25800 years. Due to this, the equinoxes shift westwards on the ecliptic by an amount 360/258 ~ 1.4° per century.

To keep track of the cycle of the seasons accurately, we need to measure the time between corresponding equinoxes (or solstices). This is known as the tropical year which is 365.2422 days long.

The tropical year is shorter than the true revolution period of the Earth of 365.2564 days. As a result, a calendar based on the Zodiac boundaries fixed on the sky will gradually begin to err with respect to the seasons - the "real" equinoxes and solstices will shift away from the original dates specified by the calendar.

Shifting of the seasons:

We see this in the two prominent Sankrantis – Makara Sankranti (Pongal - January 14) and Mesha Sankranti (Baisakhi - April 14). These two dates are supposed to denote the winter solstice and the vernal equinox respectively. However, since the time these dates were fixed, the equinoxes have shifted back by about 23 days due to precession.

Gradually the point corresponding to the vernal equinox shifts further and further back along the trajectory of the Earth. After about 11,000 years, Pongal will be in June and the Baisakhi will be in September. Diwali will then be celebrated around April. The summer will be in Marghshira-Posha while the winter will fall in Jyestha-Assada and the Holi will be celebrated around August. Sawan-Bhadon will no longer imply torrential rains. To avoid these ever increasing shifts, all Sankrantis and dates of the festivals need to be periodically moved backwards by a day about every 70 years (average life-span of a person!). Of course, to start with it will have to be a big backward shift of about 23 days.

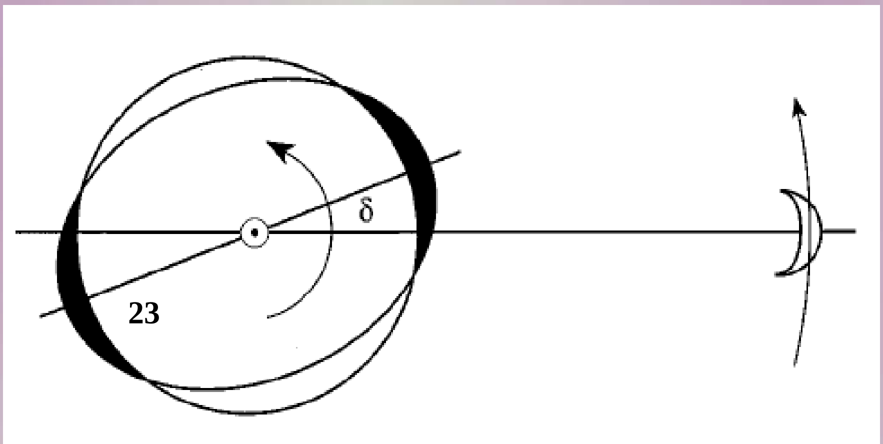

Figure 4: Tides caused by the Moon

Unlike the Indian calendars, the Western calendar directly measures the tropical year. So the goal of the Western calendar is to keep the dates of the solstices and equinoxes fixed - the vernal equinox always falls on March 21-22 and the winter solstice always falls on 21-22nd December. The calendar is thus designed to ensure that it never shifts from these date. Then there is no shift of seasons with respect to the Western calendar due to precession of Earth's axis.

The slowing down of Earth rotation:

However on timescales of thousands of years, the Gregorian calendar also falls behind the seasons drastically because the slowing down of the Earth's rotation . This makes each day slightly longer over time while the year maintains a more uniform duration. The equinox will occur earlier than now by a number of days approximately equal to (years into future / 5000)^2. This is a problem that the Gregorian calendar shares with all other calendars.

Moon keeps the same face turned toward the Earth at all times. This is the effect of the tides that might have been caused on the lunar surface due to the gravity of the Earth. Now Moon's rotation period has become synchronized with its period of revolution around the Earth. Similar effect is slowing down the Earth too and the day is lengthening, and in a distant future the day will become much longer.

The gravitational force of the Moon raises a tidal bulge in the oceans on Earth. Because of friction there is a delay in Earth's response, causing the tidal bulge to lead the Earth-Moon axis by a small angle (Fig. 4). The Moon exerts a torque on the tidal bulge that retards Earth's rotation, thereby increasing the length of day. The torque that Earth's tidal bulge exerts on the Moon leads to an acceleration of the Moon's orbital motion, causing the Moon to recede from Earth at an average rate of about 2 cm/year. Not infrequently, a *leap* second has to be added in the standard time keeping, based on atomic clocks, to keep in synchronism with the slowing down of Earth's rotation(Fig. 5).

Evidence for the slowing down of Earth's rotation came from an apparent discrepancy between the paths of totality in eclipse of the Sun on Jan. 14, 484 A.D., as predicted theoretically and from the ancient Greek and

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Time suspended for a second

Time will stand still throughout the world for one second at midnight, June 30. All radio time signals will insert a "leap second" to bring Greenwich Mean Time into line with the earth's loss of three thousandths of a second a day.

The signal from the Royal Greenwich Observatory to Broadcasting House at midnight GMT (1 am BST July 1) will be six short pips marking the seconds 55 to 60 inclusive, followed by a lengthened signal at the following second to mark the new minute.

Figure 5: A leap second makes a news

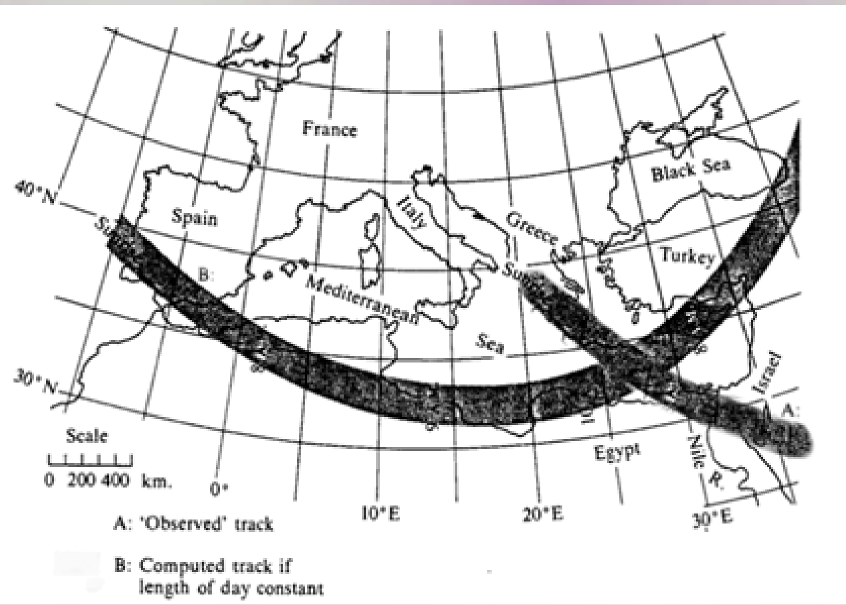

Figure 6: ***The predicted and actual paths of totality of the solar eclipse of Jan. 14, 484 A.D.***

Roman records (Fig. 6). The Earth had to be rotating faster in past to match the two results. The angular speed change being proportional to time, the angular correction is proportional to square of the elapsed time, which turns out to be ~30º for a period of about 1500 years, explaining the discrepancy quite neatly.

Other historical evidence:

This slowing down mechanism has been working for 4.5 billion years, since oceans first formed on the Earth. There is geological and paleontological evidence that the Earth rotated faster and that the Moon was closer to the Earth in the remote past. *Tidal rhythmites* are alternating layers of sand and silt laid down offshore from estuaries having great tidal flows. Daily, monthly and seasonal cycles can be found in the deposits. This geological record is consistent with these conditions 620 million years ago: the day was 21.9±0.4 hours and there were 400±7 solar days/year.

Extrapolated backwards, the day was much shorter (perhaps 5-6 hours long only!) during its first billion years (Was that called "Satyug – the golden era" with the school/office timings lasting only a couple of hours including the lunch and tea breaks – though we humans were not there to enjoy these benefits!).

The future:

We have leap second once or twice a year (on 30th June or 31st December). The year is already about a second longer since 1920s, when it was first realized that the universe extended even beyond our Milky Way galaxy and Hubble discovered the expansion of the universe. The day loses a second every 40,000 years. It may not seem much, but when linearly extrapolated it becomes substantial. The slowing rotation of the Earth results in a longer day as well as a longer month. Once the length of a day equals the length of a month, the lunar tidal friction mechanism will cease. That's been projected to happen once the day and month both equal about 47 (current) days, billions of years in the future, with no need of any lunar calendars then. If the Earth and Moon still exist, the Moon's distance will have increased to about 1.35 times its current value. (It may result in long working hours but then monthly salaries would be getting distributed every evening!!). Tides due to Sun will be still there and eventually the rotation period of Earth should become equal to its revolution period around the Sun, and the day and night cycle having ceased, with one side of Earth always facing the Sun and the opposite side of Earth in a perpetual dark, then there would be no need of a solar calendar too.

Further Reading:

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