Babylonian puzzle

In unguarded moments, most of us think of the Solar System as a model of clock-like periodic dynamical motion. From the human perspective, certainly, the motion of the planets, the Moon's orbit and Earth's rotation appear purely repetitive and unchanging. Indeed, only in the 1860s did astronomers come to appreciate that tidal effects between the two bodies introduce a dissipative element into the picture, decorating the perfect cyclic repetition with a slow secular evolution.

As undergraduates learn today, the attraction of the Moon, in driving vast tidal fluid flows and land-mass deformations on Earth, slowly saps angular momentum from the spinning Earth. The orbiting Moon gains angular momentum and moves away at an average of about 38 mm each year, a quantity we can now measure directly with modern laser ranging technology. As a result of the loss of angular momentum, the Earth spins ever slower, leading to a gradual lengthening of the day. Geological evidence from sediments of tidal flows from 600 million years ago suggests that the year back then included some 400 days, with each day roughly 22 hours long.

With this tidal correction, the picture is still one of cyclic motion modulated by gradual, steady change. Yet even today our quantitative understanding still appears to be missing something important. That's clear from a new analysis by Richard Stephenson, Leslie Morrison and Catherine Hohenkerk (*Proc. R. Soc. A* **472,** 20160404; 2016), which suggests that the Earth's rotation appears to be slowing less quickly than we'd expect from tides alone — and is also fluctuating fairly erratically over time. Somewhat surprisingly, the compelling evidence for this view comes not from the application of new and more sophisticated technology — as we've come to expect in these times — but from an analysis of astronomical observations recorded by the Babylonians, dating back to as early as 700 BC.

As the team notes, the straightforward theory of tidal frictions — if combined with modern satellite and laser-ranging data — predicts that the angular speed of the Earth's rotation should decrease over time in a steady, linear way. Over geological times, in principle, big changes in sea level — by changing the torque on the planet provided during tides — could alter

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the linear trend. Yet there's good evidence to suggest that the basic forces driving tidal friction have not changed significantly over the past few millennia. Hence, it seems that a steady linear increase in the length of the day due to tides should hold across this period.

The historical evidence, however, doesn't quite agree. Two decades ago, Stephenson and Morrison put together a number of data sources to make an early test of this expectation over the period from 700 BC to 1990. They used high-precision data collected using modern techniques from 1950 to 1990. But the estimate of the long-term change also required the use of ancient historical data, beginning with thousands of observations recorded by Western scientists since the invention of the telescope in the early 1600s. They also used dozens of Arab observations of eclipse times in treatises by medieval astronomers Ibn Yunus, al-Battani and al-Biruni, and observations from the time of ancient Greece preserved by Ptolemy in his book the *Almagest*. Still further back they used Chinese astronomical observations from official dynastic histories, as well as details of eclipses going back to the eighth century BC, written by Babylonian astronomers in cuneiform on clay tablets that still exist today, largely in the British Museum.

Analysis of all this data indicated, over a period of around 2,690 years, a gradual increase in the average length of day of about 1.7 ms per century, which differs from the 2.3 ms per century expected from lunar tidal braking alone. Something appears to be driving an acceleration in the Earth's rotation that acts against the prevailing tidal trend.

Now, some twenty years later, Stephenson and colleagues have returned to the matter, primarily because further research in the intervening period has increased the number of useful Babylonian eclipse observations by 25%. Exploiting significant improvements also in the Chinese, medieval and modern data, they now provide an improved estimate of trends in the Earth's rotation over the period 720 BC to AD 2015. The results don't eliminate the discrepancy, but indicate the length of solar day increasing at an average rate of 1.8 ms per century, still much less than the predicted 2.3 ms per century from tidal friction alone. Even more interesting, the data also shows significant fluctuation about this trend — a spectrum of variation on timescales ranging from years to centuries, with hints of a peak at a period of about six years.

The discrepancy from the tidal expectation alone presents a puzzle, as it suggests that the action of an unknown torque is spinning the Earth forward. If not linked to variation in sea level above current values, what are the other possibilities? One idea invokes changes in the Earth's shape — and therefore its inertial properties — over the past few thousand years. The Earth is an oblate spheroid, with equatorial radius roughly 20 km larger than its polar radius — a distortion mostly caused by the Earth's rotation pushing mass away from the polar axis. But the degree of distortion is also influenced by geological processes, and the Earth's oblateness may be decreasing due to viscous rebound of the solid Earth from the decrease in load on the polar caps following the last deglaciation.

Evidently, however, geophysicists doubt that this effect alone would be sufficient to account for the full discrepancy in acceleration. Another mechanism currently under investigation involves transfers of mass and angular momentum between the Earth's solid core and liquid mantle. Some recent computational simulations of flows at the core–mantle boundary, including the effects of historical magnetic field reversals, suggest this as at least a plausible explanation.

It's not surprising that we'll probably need advanced computational modelling of complex internal Earth processes to get to the bottom of the puzzle. It may be surprising that deep puzzles of this sort can still arise in part from observations made by Babylonian astronomers nearly 3,000 years ago. ❐

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