USES OF ANCIENT DATA IN MODERN ASTRONOMY

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Abstract. Ancient astronomical data are a limited resource that can fill unique needs in modern research. Records from the Orient are of particular value because they were taken more or less continuously, as parts of dynastic and local histories --- often for astrological purposes. We review three problems in modern astronomy that lean heavily on ancient records from the Middle East and Orient: the study of solar variability; studies of the variable rotation of the earth; and studies of the occurrence and physics of novae, supernovae and comets.

INTRODUCTION

What I shall review here are some of the uses that modern astronomy makes of ancient data, and particularly the early records from the Orient.

I think of this as the applied history of astronomy, as opposed to the study of history for its own sake. In this endeavor we attempt to wring useful data from ancient observations --- to rework old mines, with more modern methods, for answers that contemporary data cannot yield. Owen Gingerich has described these activities best as "history in the service of astronomy."

No one has ever thought seriously of starting a journal devoted to the applied history of astronomy, and in today's world that says that the field is very small indeed. The reason it is small is that the corpus of ancient data that is absolutely reliable and adequately documented to be of use is very limited. What is more, all of it has been worked and reworked many times. Practitioners in this field operate much like antique dealers, knowing that the stock of material that makes their trade possible is forever fixed, and that there is nothing one can do to improve either the quality or the quantity of it, regardless of demand. The appearance of anything "new," like the provincial histories, or fang chi, that were unearthed in China by our colleagues there a few years ago, send ripples of excitement through the field (Xu & Jiang 1982).

Like archaeoastronomy, applied history is also a dangerous field, for the temptation is always there, born of hunger or desperation, or national pride, to read more into dusty records than they were ever meant to tell, or to lose sight of the context in which they were made. Nonetheless, there are classes of problems in modern astronomy that lean heavily on old and even ancient records (Stephenson & Clark 1978). The three best known are the study of solar variablitity, resting on naked-eye observations of sunspots and the aurora; studies of the earth's rotation, based on recorded circumstances of solar eclipses; and studies of the physics of novae and supernovae and the mechanics of comets,

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based on surviving records of these rare phenomena of the sky. I shall briefly review each of these, to point out their promise and some of the present problems involved.

In each of these cases, our need is for continuous and systematic records. At no time and in no place has either criterion been rigorously met for very long; even today. But at times in dynastic China, later in Korea and Japan and much earlier in Babylon, astronomers came close to this ideal. In each of these places these unique, quasi-continuous records were written not as a natural history but as elements of a political one, from naked-eye observations that were made almost exclusively in the name of astrology, and then recorded as a rationalization of what had happened to kings. This unquestionably colors and even edits what was written down. But these accounts, whatever their faults, hold a hundred times more than any early records from the Occident. And it is on these unlikely sources, built on the shaky ground of pseudo-science, that the applied history of astronomy almost wholly leans.

THE SUN

Solar variability is most readily observed through the appearance of sunspots, the largest of which can be seen, by careful observers, with the naked eye (Eddy 1980). Only a handful of these were noted in Europe before the time of the telescope; in the Orient, by comparison, more than 150 are recorded. These naked-eye sunspot reports were accumulated over a span of 17 centuries, yielding an average of about one sunspot per decade, although the number is far from uniform. So small a sample has proven a surprisingly consistent index of the level of solar activity in the past, when tested against contemporaneous indirect and proxy records: the first from historical records of the occurrence of aurorae and the second from measurements of carbon-14 abundance in dated tree-rings, which tell of the solar modulation of galactic cosmic rays (Eddy 1977). The thin record of naked-eye sunspot reports from the Orient can also be used to bolster the case for significant lapses in solar activity in the early telescopic era (Eddy 1976, 1977). For example, a significant drop in naked-eye reports is found to accompany the Maunder Minimum of 1645-1715 (Eddy 1983). It has also been of value in demonstrating the persistence of the 11-year sunspot cycle in pre-telescopic times, through statistical analysis of these naked-eye reports in historical periods when reports of sunspots were sufficiently numerous to withstand the rigors of statistical tests (Clark & Stephenson 1978; Stephenson & Clark 1978; Yunnan Obs. 1979).

Philosophy and even religion have been used to explain why so many more naked-eye sunspots were recorded in the Orient than in the Occident (Needham, 1959). Indeed, the Chinese, unfettered by Christian ideals of divine perfection in the universe may well have been more ready to accept a blemished sun. Meteorological differences have similarly been invoked to explain why these elusive features were most apparent to observers in China, where persistent dust from the Gobi desert may have systematically attenuated the burning brightness of the sun (Willis *et al.* 1980). The hazy landscapes and dim pastels that characterize Chinese paintings are a tempting confirmation of this convenient conjecture. Moreover, the only records of sunspots from the West --- from Russia in early medieval times --- were made through the haze of forest fires (Bray & Loughhead 1965).

Needham (1959), among others, has suggested that the Oriental astrologers looked at the sun by clever technique: attenuated by reflection in a darkened pool, or perhaps through optical filters. I think this unlikely, given the severe requirements of stability and visual acuity that are needed. It is more likely that most of the 150 Oriental naked-eye sunspot reports come from direct looks stolen from the sun when it was near the horizon, and sufficiently reddened to be viewed without optical aid.

Two enigmas still wrap the Oriental naked-eye sunspot record in something of a mystery: the question of why so few were seen, if an astrological patrol was really maintained, and the riddle of why so small a sample is of any value at all. Stephenson and Clark (1978; Clark & Stephenson 1978) have maintained that sunspots were watched for systematically over the centuries by court astrologers in China, much as these astronomers also patrolled the sky at night. Yet, if we accept the canonical value for the limit of angular resolution of the eye, which is one arc minute, or the experience of modern, naked-eye sunspot observers, then 10,000 times the number that were reported should have been seen in the span of 17 centuries of Chinese dynastic accounts (Eddy 1983).

The vast discrepancy suggests that the 150 sunspots that are recorded come not from a patrol but from occasional or accidental sampling: that large sunspots were there to be seen in all but a few years of each 11-year sunspot cycle but they were only sporadically sampled or noted. Data from this random sampling process --- if that is what it was --- should tell us much more of the observing habits of the Chinese astrologers than of the sun, and this leads to the second enigma: namely that the 150 sunspots seem to be a remarkably good record of the overall level of solar activity on time scales of centuries.

A more trivial unknown is the basis for the curious angular scale that was used by the Chinese and later adopted by Korean court astronomers. Sunspots were reported as dark features on the sun, with sizes described by a variety of mundane objects: "as big as a plum", a date, a peach, a pear,a walnut, or a hen's egg (Stephenson & Clark 1978; Yunnan Obs. 1979). The same comparison objects are used over and over and almost all are edible objects. One is tempted to surmise that the sunspot sightings were made systematically at sunrise, before breakfast, when the astronomers were understandably hungry and thinking about such things. But that is too easy an answer.

What is certain is that these objects were not used as a literal rule-of-thumb, each held at arm's length for comparison against the sun. Any of the objects used for scale would at arm's length cover the half-degree disk of the sun many times over: the seed of an apple would more than suffice to cover the largest sunspot. There may be a clue in the distribution of sizes of the objects used: their dimensions --- the smallest a nut, the largest a pear or a goose's egg -- are in reasonable proportion to the range of relative sizes of visible sunspot groups. If one assumes, as Kevin Yau and I have recently done, that the disk of the sun was thought of as the size of a common, round Chinese washbasin, about a meter in diameter, then nuts and eggs and pears and plums make reasonable, relative measures of large sunspots. If that is so, we may have evidence for the existence of a megalithic washbowl.

THE ROTATION OF THE EARTH

One of the classic problems of celestial mechanics is the determination of the earth's rate of rotation, which is neither constant nor at present wholly predictable. Any astronomer who makes use of the modern Astronomical Almanac is reminded of this fundamental irregularity by the requirement to use Ephemeris Time, which his watch, however expensive, does not exactly keep.

The length of the day is gradually increasing, at a rate of about 2 1/2 seconds per century. The loss of inertial energy is principally through the friction of water against the ocean floor, chiefly on the continental shelves, in the course of tidal motions. Other, non-tidal mechanisms also contribute: one is change in the intrinsic moment of inertia of the planet, brought about by the waxing and waning of polar ice, by the subtle swelling and shrinking of the atmosphere through changes in solar heating, and by shifts of mass in the earth's interior. Another mechanism is that of presumed changes in electromagnetic coupling between the turbulent core of the earth and the mantle above it.

These varying effects on the rate of rotation are noted in accumulated observations made by astronomers with transit telescopes. The long-term, or secular changes of these parameters in the past can be recovered from historical fiducial points that arise from the geometry of solar and lunar eclipses (Stephenson 1982a).

Through such analyses Halley in 1695 noted that the moon's rate of revolution is also decreasing. The associated retreat in distance from the earth is about 5 cm per year which can today be measured directly. The effect is now ascribed to a transfer of the angular momentum lost by the earth, through tidal friction, to the orbit of the moon.

The precise placement and timing of the umbral shadows cast by eclipses is a convolved and sensitive measure of the changing angular momenta of both the earth and the moon. Recovering these circumstances from as many times and as far into the past as possible has been the stock and trade of applied historians (Stephenson & Morrison 1984). Here we profit from the traditional obsession of astronomers and astrologers of all ages with the dramatic phenomena of eclipses. But is has also been the fuel for heated debates, particularly in the more ancient data, where the exact places where recorded eclipses were seen must often be inferred and where times and even dates of occurrence are often vague. Often the crucial distinction between a total and a partial eclipse hangs on the thread of inexact semantics and on the debated translations of ideograms. In the more exact languages of classic or medieval sources, these important distinctions are all too often lost in the mists of allegory.

The best of the older data come from records of solar and lunar eclipses that were compiled by Arab astronomers between the 9th and 11th centuries, A.D. Although clocks were not that accurate, accompanying measurements of the angular altitudes of the moon and sun above the horizon may be used to establish time-of-day with a precision of about 5 minutes in time. These early data were first employed for this purpose by Newcomb in 1878 (Stephenson & Morrison 1984).

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More ancient data are found in untimed sightings of total eclipses, mainly from Chinese dynastic histories, and in Babylonian, cuneiform records of the circumstances of lunar eclipses. The Chinese data useful for this purpose are derived from five total and near-total eclipses that were recorded in sufficient detail between 198 B.C. and A.D. 120. The most useful Babylonian records describe about 40 accurately-timed contacts of lunar eclipses between roughly 700 B.C. and 50 B.C. As in the case of sunspots, the useful data describe a minute fraction of the total number of eclipse opportunities that nature provided in this long span.

TRANSIENT PHENOMENA

The third of the major areas of applied history makes use of recorded observations of novae and supernovae and comets.

Bright supernovae were observed by Tycho Brahe and Kepler in 1572, in Cassiopeia, and again in 1604, in Ophiuchus. The first and brighter of these became as bright as Venus and was observed by the famous astronomers for five months; the second for nearly a year. An earlier, more poorly observed event of the same kind was later found in European records from 1006, in Lupus. There have been none since and that is all we would know of these cataclysmic eruptions were it not for early Oriental astronomy and the detailed records kept of the sky in Chinese, Japanese, Korean and Middle Eastern annals.

Chinese and Korean astronomers had observed the same three supernovae that were noted in Europe; in doing so they recorded far more of the course of the earlier two than did their European counterparts. But they also recorded detailed histories of five earlier supernovae, which they called "guest stars": in A.D. 1181, 1054, 393, 386 and 185. In the net that they cast in the sky are also found 67 guest stars of shorter duration, which we now ascribe to galactic novae (Clark & Stephenson 1977).

These Oriental records of galactic novae and supernovae allow a meaningful statistic of the frequency of occurrence of such events; they also provide a basis for deriving their development and expansion with time, which for supernovae are seen today as expanding optical shells and radio sources.

We can only be impressed by the positional detail that was routinely provided in the early Oriental accounts. Tycho's supernova of 1604, for example, is recorded in the following way in the Korean Sillok, in the diary of a single day in a specified month and year:

> "In the first watch of the night a guest star was seen above the stars of T'ien-chiang. It was 11 degrees in Wei lunar mansion and distant 109 degrees from the (celestial) pole. Its form was as large as Venus and its ray emanations were very resplendent. Its color was orange and it was scintillating" (Stephenson & Clark 1978).

The events were scrupulously followed, allowing one to determine, for example, that the supernova seen by the Chinese in Centaurus in A.D. 185 persisted for 20 months.

Comets were no less fixed and followed through the sky, allowing us today to identify every return of Halley's comet since 12 B.C. (Stephenson & Yau 1985). Early positional data secured in this way are especially valuable in studying the long-term motion of the comet. Halley's comet has made several close approaches to the earth during the past two millennia, as in A.D. 837, when it approached within the orbit of the moon. These close encounters of a real kind severely perturb the comet's orbit, and it is impractical to numerically integrate the orbit over the historical period without making use of the early, Oriental accounts.

In some cases the detail given in the Chinese records rivals that of today; as with supernova accounts, it far surpasses what was preserved in the Western world. For the apparition of A.D. 1066, for example, Europe left us the Bayeaux tapestry. The chroniclers of the Sung dynasty, in contrast, gave us this record:

> "On a chi-wei day in the third month of the third year of the Chih-p'ing reign period a comet appeared at the thirteenth lunar mansion. In the morning it was seen at the east measuring about 7 ft., pointing south-west towards the twelfth lunar mansion and reaching Fen-mu. It gradually moved faster towards the east and became concealed when it approached the Sun. Until the evening on a hsin-szu day it appeared at the north-west but without its rays. The comet moved further eastward. Then there was a white vapor about 3 ft. in width penetrating the Tzu-wei and the Pole Star, joining the fourth lunar mansion and with both its head and its tail getting below the horizon.
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> The comet moved further eastward, passed Wen-ch'ang and Pei-tou and penetrated the sixth lunar mansion. On a jen-wu day the comet retained its rays and measured over 10 ft. in length and 3 ft. in breadth. It was pointing north-east and then it passed Wu-ch'e. The white vapor became branched, stretching horizontally across the heavens, and penetrated Pei-ho, Wu-chu-hou, Hsien-yuan and Wu-ti-tso and Nei-wu-chu-hou with the T'ai-wei.
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> It reached the first, second, third, and fourth lunar mansions. On a kuei-wei day the comet measured 15 ft. It had a broom-like vapor and resembled a ten-peck measure. From the thirteenth lunar mansion it moved to the 26th lunar mansion passing altogether 14 lunar mansions. The comet and vapor went out of sight after a total of 67 days" (Stephenson & Clark 1978).

For the apparition of 1066 to whom do we owe the greater debt? Is a picture worth a thousand words?

Much of what I have reported on here is based on the work of my British colleague Richard Stephenson. It is also he, with Kevin Yau and Prof. H. Hunger, who has recently sent ripples through the pond of applied history by turning up two very early records of Halley's comet, both of them predating the earliest accepted Chinese account (Stephenson _et al._ 1985).

The new-found descriptions come from Babylon, where they were incised by an unknown hand on tablets of wet clay in 87 and in 164 B.C. These clay tablets were discovered about a century ago in excavations at Babylon, most of them broken, and were later sold to private collectors. About 2000 of the tablets were later repurchased by the British Museum in London. Some 1200 of these are fragments of astronomical records, mostly datable from about 380 and 40 B.C. (Walker 1985). A number of people have labored long on their translation --- most notably the late A.J. Sachs.

These cuneiform diaries give scattered, day-by-day accounts of lunar and planetary observations and weather conditions in Babylon, with occasional references to comets and other transient phenomena (Stephenson 1982b). Stephenson and his colleagues found three that tell of comets in years when Halley's comet might be expected. There is no question that it is comets that are described; the issue is whether it was Halley's or another. The accomplishment of Stephenson et al. was in deducing the precise positions and dates of inscription, from ancillary information on the double-sided tablets, from the ephemerides of planets and phases of the moon and from a knowledge of Babylonian astronomy. Their paper leaves little doubt that in each case what was described "in the area of Pleiades and Taurus," "one cubit in front of Jupiter," with a "tail 4 cubits long," was the same Halley's comet that we can see, by happenstance, tonight --- from Dehli --- once again near the shining swarm of the Pleiades.

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