THE NEED FOR MORE ACCURATE 4000-YEAR EPHEMERIDES, BASED ON LUNAR AND SPACECRAFT RANGING, ANCIENT ECLIPSE AND PLANETARY DATA

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1. Introduction

Long planetary and lunar ephemerides like the JPL DE102 and LE51 (Newhall *et al.*, 1983) and the Bureau des Longitudes VSOP (Bretagnon, 1982) and ELP (Chapront-Touze and Chapront, 1983) have enabled more positive ancient eclipse, planetary and cometary identifications, which have in turn refined ephemerides, *e.g.*, the reconstruction of the orbit of comets Halley and Swift-Tuttle (Yeomans and Kiang, 1981; and Yau *et al.*, 1994). The data used to initialize DE102 are pre-1977. Much more observational data have been collected since. The lunar ephemeris has also been improved. The secular lunar acceleration, $\dot{n}_{moon}$, from laser ranging, is $-25.9\pm 0.5''/\mathrm{cen}^2$ (Williams *et al.*, 1992). We can now uniquely solve for ΔT, the clock error, from ancient eclipse records. The lack of ΔT values before 700 B.C. has left the early timescale of the ephemerides unconstrained (Morrison, 1992). Our solution of this problem is outlined here.

2. Earth's Rotation Rate Deduced From Ancient Eclipse Records

Since $\Delta T = ct^2$ (t = centuries before 1800), the oldest data have the most weight. Sunrise and sunset eclipses are most valuable, as they can be retrospectively timed. The *Bamboo Annals*, entombed in 299 B.C. and unearthed in A.D. 281, states that "in the first year of King Yi of the W. Zhou dynasty (1100-771 B.C.) the day dawned twice at Zheng (34.5°N,

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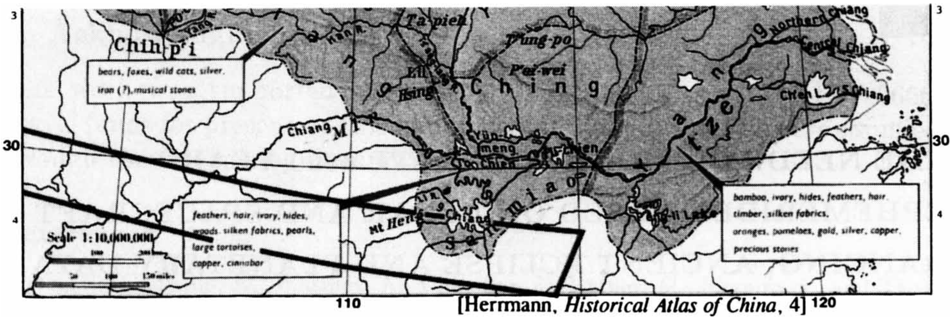

Figure 1. The path of annularity of the September 24, 1912 B.C. solar eclipse. The "double sunset" eclipse was seen in the land of the *san* Miao during the reign of King Yu, founder of the first dynasty Xia. Map from Herrmann (1966).

109.8°E)." *Kaiyuan zhanjing* (Siddhartha, A.D. 724) cites this record and adds that "in the 2nd (*actually 12th*) year of Sheng Ping reign period of King Shang (*actually King Xi*) the day began twice at Zheng." Matching these records with the April 21, 899 B.C. and April 4, A.D. 368 sunrise eclipses gives ΔT values of 5.8 ± 0.15 and 1.7 ± 0.1 hr, respectively (Pang *et al.*, 1988; Pang and Yau, 1992; Pang *et al.*, 1996).

The brightness changes for the magnitudes 0.95–0.97 and 0.991–0.998 annular eclipses were greater than for the January 4, 1992 "double sunset" annular eclipse over S. California (magnitude 0.91–0.92). Levy (1992), *e.g.*, noted that "...as annularity ended. Sunset had come and gone, but the sky began to brighten not darken. For almost 15 minutes it continued to brighten until the onrushing shadow of Earth took over and darkness fell again." A "double sunset" eclipse will occur at Zheng on August 1, 2008.

Analysis of our data gives $\Delta T = (30 \pm 2.5)t^2$. Results from analyzing 14–12th century B.C. Shang dynasty oracle bone eclipse records are included, but not discussed, here (Pang *et al.*, 1989 and 1996). Recent astronomical dating of these unique records has converged to a set of common matching dates with only minor differences (Xu *et al.*, 1995). From these results, we get an $\dot{\omega}/\omega$ of $-(19 \pm 1.6) \times 10^{-11}$/yr. Subtracting a tidal $\dot{\omega}/\omega$ of -27.8×10^{-11}/yr (Lambeck, 1980) gives a nontidal $\dot{\omega}/\omega$ of $(9 \pm 1.6) \times 10^{-11}$/yr ($\equiv \dot{J}_2$ of $-(4.5 \pm 0.8) \times 10^{-11}$/yr). The historical $\dot{J}_2$ and the present $\dot{J}_2$ from satellite laser ranging, -3×10^{-11}/yr (Cheng *et al.*, 1989), are consistent with postglacial rebound from an upper mantle of viscosity 10^{21} Pa s, and lower mantle of $(2\text{–}4) \times 10^{21}$ Pa s, deformed by Pleistocene ice sheet loading (Peltier, 1985). The bounceback to its less oblate interglacial shape makes the Earth spin faster, overcoming a third of the tidal braking. The net effect has been lengthening the day by 1.64 ± 0.14 msec/cen. We now test our model with still earlier records.

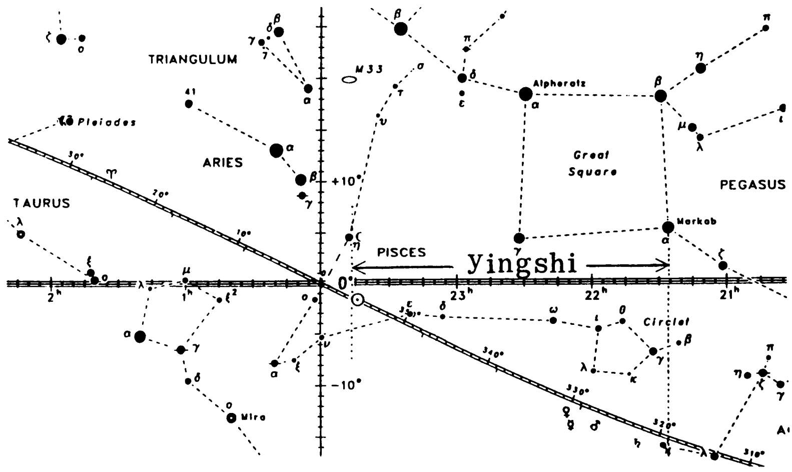

Figure 2. The March 5, 1953 B.C. conjunction of the Sun, Moon and five planets in Yingshi (the equatorial space 35 arc degrees east of α Pegasus, within the two vertical dotted lines). The Moon is just west of η Pisces. The Sun is on and the planets just below, the ecliptic. The reference frame is 1 B.C., close to Liu Xiang's lifetime (77 to 9 B.C.). From *Sky and Telescope* chart SC004

3. Results Obtained From Still Earlier Observations

Philosopher Mozi (*ca.* 468-382 B.C.) wrote: "In ancient times, the *san* (three) Miao tribes were in disarray. Heaven ordered their destruction. The Sun rose in the evening ... King Yu, founder of Xia, first dynasty, vanquished them..." The *Bamboo Annals* adds: "When the *san* Miao perished ... the Sun disappeared by day and reappeared at night ..." Astronomically verified *Bamboo Annals* Xia chronology puts Yu's official reign in 1914-1907 B.C. (Nivison and Pang, 1990). We have found that a "double sunset" eclipse did occur over south-central China on September 24, 1912 B.C. (year 3 of Yu's reign). The *san* Miao domain was south of the Yangzi River, east of Mount Heng and west of Lake Pengli (Herrmann, 1966). A ΔT of 12.2 hr or c of 32 sec/cen^2 would put the sunset eclipse (magnitude 0.97-0.99) right there (28°N, 115°E) (Fig. 1), consistent with results from analyzing third millennium B.C. Mesopotamian lunar eclipse records (Huber, 1987; Pang and Yau, 1995). We conclude that our model holds back to at least 2300 B.C. Analysis of an even earlier planetary record follows.

Sirius' heliacal rise (with Nile floods) in the summer "dog days" regulated the ancient Egyptian Sothic calendar. Yingshi's (Pegasus') heliacal rise initiated spring in the ancient Zhuanxu calendar, *e.g.*, The *Book of Rites* (1000 B.C.) states that "in the first lunar month, the Sun is in Yingshi." The lunisolar calendar was invented in Mesopotamia in mid-third millennium B.C. and has been used by the Chinese since about 2000 B.C.

Liu Xiang's (77–9 B.C.) *Hong Fan Zhuan, e.g.*, states that "the original Zhuanxu calendar began on cyclic day 6, month 51, year 51 (modulo 60) at the start of spring when the Sun, Moon and five planets met in Yingshi, 5°." Liu's interpolated date is wrong, and its errors can be reproduced mathematically. Some even consider it an imaginary epoch when the day, lunation, year and planetary cycles last came together. Using VSOP85 and ELP2000-85, with the new $\dot{n}_{moon}$ and $\Delta T(t)$ values, we have uniquely matched Liu's record with circumstances of the sky computed for early 1953 B.C. (Fig. 2). On February 26, the five planets were visible before dawn like "a pearl necklace," spanning $< 5°$. On March 5, the Sun, new Moon and five planets were all in Yingshi (= lunar mansions 13+14, with an old width of 35° in RA, east of α Peg). From time immemorial, the Chinese have been using the Xia dynasty calendar, which starts the year with the second new moon after winter solstice. In 1953 B.C., winter solstice fell on January 5, so spring began on March 5. All of Liu's conditions are thus satisfied.

4. Conclusions

Whereas the initial conditions of the current planetary ephemerides are better known, the Moon's secular acceleration rate improved by laser ranging, and the history of the Earth's rotation determined for 4300 years, it is timely to produce more accurate 4000-year ephemerides, valuable for analyzing ancient astronomical records. We hope to stimulate such production, and the discussion of old astronomical records. We thank J. Bangert.

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