

Earth Orientation: Does Solar System Motion Matter?

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Abstract Long term predictions of changes in the Earth's orientation to Very Long Baseline Interferometry (VLBI) sources have been historically unreliable. The International Astronomical Union (IAU) has found that current methods are "not consistent with dynamical theory." Part of the problem appears to be that measurements of the precession observable are made to points outside the moving frame of the solar system yet do not account for motion of the solar system relative to those reference points.

We have found that by separating the motions of the Earth within the local frame (of the solar system), from the motion of the frame relative to external reference points (outside the moving frame), long term measurements of the Earth's changing orientation may be simplified and predicted with a higher degree of accuracy.

The main point of this paper is to show that changes in the Earth's orientation to stellar reference points can be better predicted by including solar system motion as a component in the precession nutation model.

Keywords earth orientation · precession · solar system motion · nutation · lunisolar · reference frame

1 Overview

One of the exercises herein was to show that a moving solar system model, without any local dynamical inputs, was able to predict the annual rate of change in the precession observable better than Simon Newcomb's model over

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the last 100 years, we are not suggesting that local dynamical inputs are unnecessary. Short period polar motions such as Nutation and Chandler wobble appear to be directly related to lunar motions and terrestrial dynamics, and thus all efforts to understand local gravitational inputs and the local dynamics of the Earth are acknowledged. It is only the very long period precession portion of the precession nutation calculation that would appear to require consideration of solar system motion. This appears consistent with the findings of the 26th Annual IAU General Assembly that determined:

1. the need for a precession theory consistent with dynamical theory,
2. that, while the precession portion of the IAU 2000A precession-nutation model, recommended for use beginning on 1 January 2003 by resolution B1.6 of the XXIVth IAU General Assembly, is based on improved precession rates with respect to the IAU 1976 precession, it is not consistent with dynamical theory, and
3. that resolution B1.6 of the XXIVth General Assembly also encourages the development of new expressions for precession consistent with the IAU 2000A precession nutation model (IAU 2006).

2 A Static Solar System Model

Changes in the Earth's orientation are measured to VLBI reference points far outside the moving frame of the solar system (SS) - yet do not account for any motion of that frame.

When the lunisolar theory of precession was first developed astronomers were unaware the SS moved. SS motion is now accepted, and while its magnitude is still unknown, its range of motion is artificially constrained by lunisolar theory that requires all changes in earth orientation to be attributed to local dynamical effects - thereby leaving no allocation for SS motion.

“Changes in the Earth's orientation in inertial space have two causes: the gravitational forces of the Sun and Moon and the redistribution of the total angular momentum among the solid Earth, ocean and atmosphere. VLBI makes a direct measurement of the Earth's orientation in space from which geoscientists then model such phenomena as atmospheric angular momentum, ocean tides and currents, and the elastic response of the solid Earth” (NASA VLBI 2009).

Essentially, VLBI makes the measurements and geoscientists build the model. The problem with this methodology is that no one is asking if the measurements to points outside the SS need to be adjusted for the motion of the frame (relative to the reference points) before these measurements are handed off to the geoscientists. Current practices assume that the Earth's changing orientation to points “inside” the SS (local measurements) must be the same as changes in the Earth's orientation to points “outside” the moving SS—but there is no evidence of this (see “Separating the Components” below). In a circular argument the static SS model constrains geoscientists to explain all changes in earth orientation through local dynamics, and because

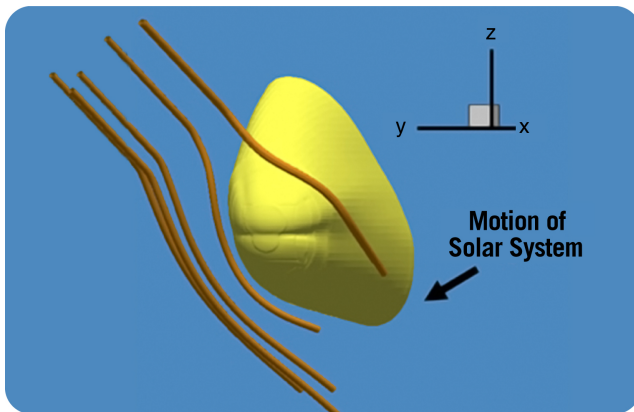


Fig. 1 3-D rendition of the SS as seen from the outside. In 2007 Voyager 2 unexpectedly reached the edge of the heliosphere at a distance approximately 1.5 billion km less than the distance traveled by Voyager 1, indicating the SS is bullet shaped in the direction of the interstellar magnetic field. The field lines are shown wrapping around the SS. Image credit: Opher et al. 2007/Science

all changes in earth orientation are explained through local dynamics, the SS is constrained to zero motion (for EOP purposes).

A lot of effort has gone into perfecting our VLBI capabilities. The IAU recently adopted a new reference frame that uses a set of 295 quasars to define celestial positions (IAU News Jan. 2010), meaning astronomers can now very accurately determine the positions and motions of objects in the sky. But no amount of interferometry can tell us how much the SS curves through space unless measurements from “inside” the moving frame (where our radio telescopes are located) to points “outside” the moving frame (where the reference points are located) account for the motion of the SS. That is exceedingly hard to do if we have already allocated 100 percent of all changes in orientation to motions of the earth.

Recent data from the edge of our solar system by Voyager 1 and 2, show the heliosphere is not a sphere but rather appears to be “bullet shaped,” providing some indication of its motion (Fig. 1).

3 What Are We Observing: Precession or Parallax/Stellar Aberration?

The observable of the stars moving across the sky at approximately 30 degrees per month is obviously due to orbital motion – the Earth’s orbit around the sun. The purpose of this paper is to ask if the observable of the stars moving retrograde across the sky at the rate of about 30 degrees per 2000 years, (a.k.a. the precession observable) might also be due in part to orbital motion; the orbit of our SS around another mass (be it the galactic center, local cluster, nearby

star or any other body that might gravitationally influence the path of the SS).

If this is the case then the observable of the stars moving across the sky at $50''$ /y (a.k.a. precession) may actually contain some component of geometric effect such as parallax or aberration of light. This type of geometric effect would be apparent to an observer on a planet that is part of a binary or multiple star system (Sablinski 2009). The motion of any stellar system around its common center of mass would cause a change in orientation to reference points outside the moving frame of that system commensurate with the periodicity of the orbit, plus or minus local effects. In short, motion of a stellar frame (including our own SS) can produce a change in orientation relative to distant reference points yet this observable is indistinguishable from the precession observable (as both are experienced as a change in orientation).

If the only motion of the SS is around the galactic center then the amount of stellar reorientation effect (within the total precession observable) would be very small, on the order of $.005''$ /y ($1,296,000''/240,000,000\text{y}=.005$). However, if the SS has any other short or intermediate motion, such as up and down the galactic plane or around the local cluster or around a nearby star, the component for SS motion would need to be adjusted upward, and the amount allocated to local dynamical effects would need to be adjusted downward. This is because the total observable change in orientation, about $50.3''$ /y, is all-inclusive, not affected by changes in allocation.

The fact that there is some SS motion in the total precession observable has been acknowledged by Goddard Space Flight Center (GSFC) NASA and has been termed “geometric effect” (MacMillan 2005). However, the current assumption is that the only motion of the SS is around the galactic center in a period of about 240,000,000 years and therefore the effect is considered inconsequential and not separately identified or accounted for.

“The motion of the barycenter of the solar system is not linear in its orbit about the center of the Galaxy. There is therefore a Coriolis-like acceleration, which gives rise to a galactic geodesic precession. It is not included in the definition of the International Celestial Reference System (ICRS)” (Kovalevsky 2002).

Because the specific motion of our SS, and its exact angular velocity is unknown (yet constrained by current precession theory to zero) it is possible the contribution from SS motion could be larger than expected. This is what is implied by the 100 Year Test, Sec.10, that compares Newcomb’s precession model to a moving SS model.

4 Problems With Current Theory

The history of the lunisolar precession model is one of problems, revisions, and the continuous addition of new inputs, infact, Newtons’ original equations did not work. Jean le Rond d’Alembert, recognizing the earth was not a rigid body, made the first major changes, and many others since have added and changed

dynamical inputs until the values have come very close to fitting the observable of approximately 50.3"p/y. However, while current models are designed to closely approximate a fixed precession observable on a fixed date, the observed rate has been increasing at an increasing rate over the long term (at least since modern records have been kept), something the original theory neither anticipated nor predicted. Consequently, the lunisolar theory is undergoing increased scrutiny.

In recent decades precession nutation models have been revised more frequently, and in the process, grown quite complex. The 2000A version now includes almost 1400 terms (Bangert 2002) yet it still does not accurately predict changes in the precession rate trend, and it has failed a key test: dynamic equivalence. In 2006 the IAU noted the precession nutation model is "not consistent with dynamical theory" (IAU Resolution P03). This same resolution recognized that the planets must make a "significant contribution to the motion of the Earth's equator making the terms lunisolar precession and planetary precession misleading."

This is no trivial matter. For over 250 years it was assumed the force of the moon and the sun acting on the oblate earth caused the stars to appear to move across the sky at the rate of about 50"p/y (lunisolar precession observable) and the planets had an insignificant role. After modifying this theory with an array of new inputs, and making an increasingly wide number of assumptions about the inner earth, it has now been decided that the moon and the sun must have so little to do with "changes" in the precession rate that the term lunisolar precession be eliminated (P03 recommendation) and the planets really do make a "significant contribution." Since none of the local masses (sun, moon or planets) have changed meaningfully since the adoption of lunisolar theory, we must conclude the causes of the precession observable are not as well understood as once believed.

Noticing the lack of predictability and or consistency with dynamical theory a number of scientists have commented on the problem or written papers trying to identify some of the issues, some suggesting it might be due to problems with the Earth's rotation or with the motion of the solar system:

"Presently used models for observing techniques (VLBI etc.) are practically in agreement with the IAU2000 resolutions. Presently used theories of Earth's rotation, however, are not." (Soffel 2002)

"This situation was particularly inconvenient for the definition of the equinox J2000.0, which had to be placed despite an erroneous constant of precession and an insufficient nutation/precession theory. The result is that there were three different equinoxes (the FK5 equinox and two different dynamical)." (Kovalevsky 2002)

"Another thing in common between the Pioneer and these flybys is what you would call an unbound orbit around a central body. For instance, the Pioneers are flying out of the solar system – they're not bound to their central body, the sun. For the other flybys, the Earth is the central body. These kinds of orbits just don't occur very often in nature – it could be when you get into an unbound orbit around a central body, something goes on that's not in our

standard models. The fact this effect seems most evident with flybys most asymmetrical with respect to Earth's equator suggests that the anomaly is related to Earth's rotation. (John Anderson, Choi 2008)

5 Separating the Components

Nutation is obviously driven by local dynamics as its 18.6 year signature neatly reflects the timing of the moon's orbit parameters. And Chandler wobble and other short term polar motions would also appear to have their basis in local dynamics but none of these affect our present system of time like the much larger, long term motion of precession that results in a difference of approximately 20 minutes between the tropical year (non-precessing frame) and the sidereal year (precessing frame). Nonetheless, both the short term and long term motions are often lumped together and or superimposed on one another as in the classic diagram (Fig. 2), making the problems with precession more

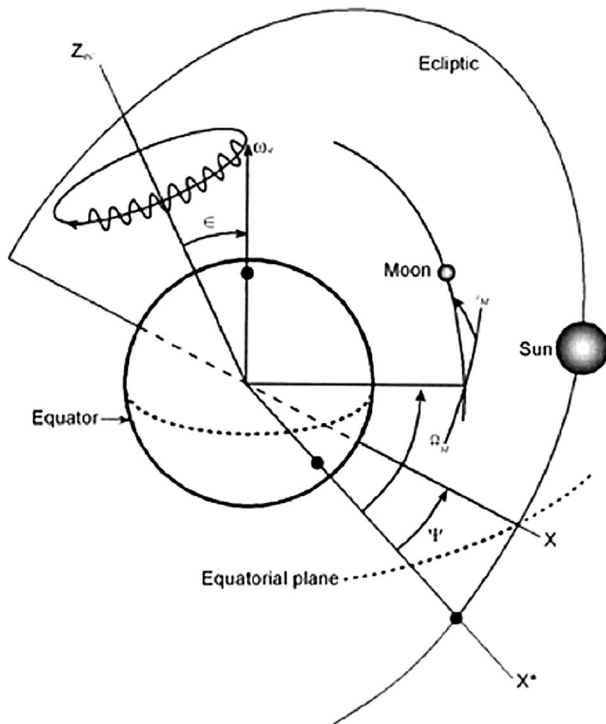


Fig. 2 Short period motions like nutation are local - long period motions like precession may have a non-local component.

difficult to understand. Fortunately, the IAU has recognized that only the precession part of the 2000A precession nutation model needs revision.

From a modeling standpoint the larger motion of precession, which causes the 20 minute time difference between the tropical year and the sidereal year, is comparable to the 4 minute time difference we see between the tropical day and sidereal day. We know the “daily” difference is caused by the orbital motion of the earth around the sun, but because we do not presently associate precession with any SS motion we do not recognize the time delta between the tropical and sidereal “years” as having a cause similar to the “daily” delta. However as seen in the similarity of the two models below, the time delta between the tropical and sidereal years (precession) can be easily replicated with an orbital model, indicating the precession observable may contain some artifact of orbital motion, a.k.a. angular velocity. In other words, we suspect that part of the precession observable may be attributed to the angular velocity of the SS as it curves through space (relative to the reference points) rather than 100 percent to local dynamics.

In further support of the above is the fact that changes in Earth’s orientation relative to objects “inside” the SS (i.e. Sun, Moon, etc.) appear to be very small, whereas changes in the Earth’s orientation relative to objects “outside” the moving frame of the SS (fixed stars, quasars, etc.) are greater

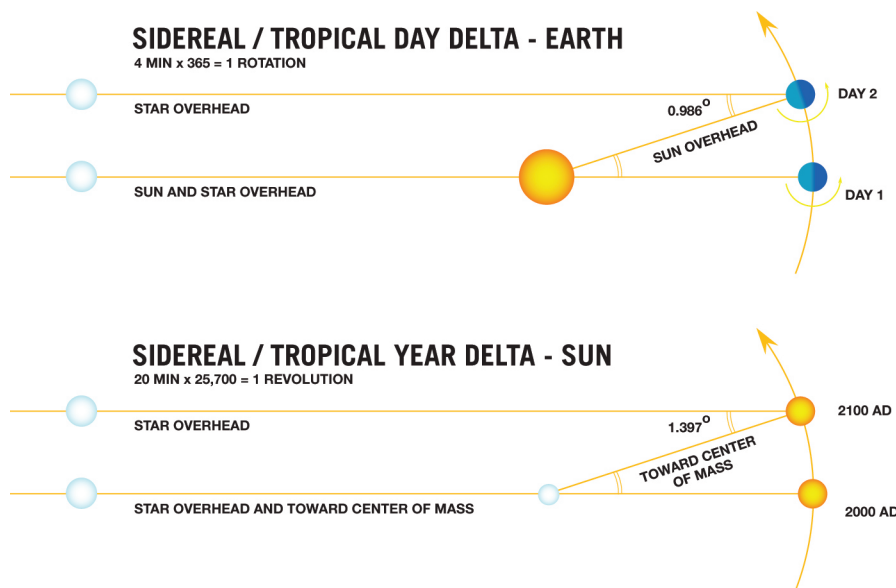


Fig. 3 The fact that both daily and yearly time deltas can be produced by orbital models suggests that the precession nutation model may require an orbital component to fully explain the precession observable.

than 50" p/y. In fact, rotation time equivalence calculations show the earth hardly "precesses" at all relative to objects within the SS:

$$365.24219878 \times 86,400s = 366.24219878x$$

$$8,6164.0905382s = 31,556,925.97s$$

This equation describes Earth's complete 360 degree period of revolution of 31,556,925.97s relative to a fixed frame of reference, implying that the position of the vernal equinox remains fixed with respect to the orientation of Earth's axis in local space. The total number of rotations of Earth in such a complete orbit is expressed by the equations:

$$1 \div (1 - (86164.0905382 \text{ s} \div 86400 \text{ s})) = 366.24219878$$

$$86,400s \div 235.9094618 \text{ s} = 366.24219878$$

It is a geometric principle that the delta of "one" between the two orbits takes place only at the point that the earth has gone 360 degrees around the sun. This equation shows that this occurs in the time period known as a tropical year. Yet, if we use the stars as a reference point, it appears the earth is still 50" short of a 360 degree orbit around the sun in this time period. Thus, the mathematical calculation of the motion of the earth around the sun in a tropical year (= 360 degrees relative to local objects) differs from observations of the earth's motion relative to the fixed stars "outside" the moving frame of the solar system. The only way to solve this seeming paradox is to understand that both are correct: the earth moves around the sun 360 degrees (relative to local objects) in a tropical year, but measures 50" less than this amount (relative to the stars) because the frame of the SS has curved through space.

Lunar calculations, comparing the delta of the moon's revolutions around the earth in a tropical year, 13.386266, to the number of new moons in a tropical year, 12.368266, apply the same principle and confirm the same thing; the delta of "one" (lunar orbits in this case) occurs in the time frame of the tropical year. In other words, the moon confirms the earth does not appear to precess relative to local objects "inside" the solar system but does apparently precess at least 50"p/y relative to objects "outside" the solar system. Most astronomers acknowledge this in practice by using a non-precessing tropical frame to locate objects "inside" the SS, whereas they adopt a precessing sidereal frame (add precession, or T[J2000] +P×Y) to find objects "outside" the moving SS.

This paradox of conflicting measurements only exists in a static SS model where the frame of the SS cannot move relative to reference points outside the SS. The paradox goes away if we allow the solar system to move. In a dynamic SS model, the earth can have one motion relative to objects within the solar system (hardly precessing at all) and another motion relative to objects outside the SS frame (where we find the change in orientation we call "precession") because the entire frame of the SS has moved relative to VLBI reference points. All of this suggests that much of what we call "precession" in actuality may be "angular velocity" - the motion of our SS around another

mass. The following is an explanation that shows how the precession observable might be better-predicted using elliptical orbit dynamics.

6 Elliptical Orbit Dynamics: Angular Velocity and Orbit Parameters

6.1 Angular Velocity

Departing from the classic two-body central force problem and letting the central force be that of gravity, a formula for the angular velocity is derived.

The two-body central force problem is a classic problem in orbital dynamics. Regardless of the nature of the force (whether it's due to gravity, electrostatics, etc.) the problem can be simplified as one where a single object moves around a fixed center of mass.

In this context, the mass of the single object, m , is related to the masses of the two orbiting bodies (m_1, m_2) as follows,

$$\frac{1}{m} = \frac{1}{m_1} + \frac{1}{m_2}, \quad (1)$$

and is referred to as the reduced mass. The distance between the two objects is r , and the angular displacement measured from the center of mass is θ . The equations of motion can be derived from the following Lagrangian (in polar coordinates),

$$L = \frac{1}{2}m(\dot{r}^2 + r^2\dot{\theta}^2) - V(r), \quad (2)$$

where the dotted variables are the linear and angular velocities, respectively, and $V(r)$ is the potential energy of the system. (The Lagrangian is a mathematical construct used in physics to derive the equations of motion of any system; it is the difference between the kinetic energy and the potential energy of the system).

For this Lagrangian, one can show that the angular momentum of the system, $l = mr^2\dot{\theta}$, is conserved. (This leads to Kepler's second law—equal areas in equal times). Introducing the potential corresponding to an attractive inverse squared law of force (i.e. gravity) yields the Keplerian solution,

$$r = \frac{p}{1 - \epsilon \cos \theta} \quad (3)$$

which is the equation of an ellipse in polar coordinates. ϵ is the eccentricity of the orbit and p is the semi-latus rectum of the ellipse which depends on the eccentricity and the semi-major axis of the orbit, a ($p = a(1 - \epsilon^2)$). Solving the angular momentum equation for $\dot{\theta}$, and plugging in for r yields the expression for the angular velocity with respect to the center of mass of the system,

$$\begin{aligned}
\dot{\theta} &= \frac{l}{mr^2}, \\
\dot{\theta} &= \frac{l}{mp^2}(1 - \epsilon \cos \theta)^2, \\
\dot{\theta} &= \frac{l}{ma^2} \frac{(1 - \epsilon \cos \theta)^2}{(1 - \epsilon^2)}. \tag{4}
\end{aligned}$$

Note that if the eccentricity is zero, one obtains the expression for the angular velocity of an object in uniform circular motion with radius a ,

$$\dot{\theta} = \frac{l}{ma^2} = \omega. \tag{5}$$

In terms of this quantity our expression becomes

$$\dot{\theta} = \omega \frac{(1 - \epsilon \cos \theta)^2}{(1 - \epsilon^2)}. \tag{6}$$

From this equation, it is easy to see that at apoapsis, when $\theta = 0$, the angular speed is a minimum, and that at periapsis, when $\theta = 180$, the angular speed is a maximum (the values of $\cos\theta$ are 1 and -1, respectively).

6.2 Angular Velocity and Period

To relate the angular velocity to the period, the average angular velocity needs to be calculated. The following integral yields the desired result,

$$\dot{\theta}_{avg} = \frac{1}{2\pi} \int_0^{2\pi} \omega \frac{(1 - \epsilon \cos \theta)^2}{(1 - \epsilon^2)} d\theta, \tag{7}$$

which is,

$$\dot{\theta}_{avg} = \omega \frac{1 + \epsilon^2}{(1 - \epsilon^2)^2}. \tag{8}$$

Finally, we relate the period of the orbit, T , to the average angular velocity by dividing the number of radians in one revolution by the average angular velocity,

$$T = \frac{2\pi}{\dot{\theta}_{avg}}. \tag{9}$$

7 Eccentricity

From the above equations, one can see that the eccentricity of an elliptical orbit can be obtained from various quantities; most readily from the location of the object (r, θ) and the semi-major axis, a . Here, an expression is derived for eccentricity which depends on two angular positions and their corresponding angular velocities.

Via conservation of angular momentum, one can write it in terms of two different radii and angular velocities,

$$l = mr_1^2\dot{\theta}_1 = mr_2^2\dot{\theta}_2. \quad (10)$$

Cancelling the reduced mass and solving for the ratio of the radii leads to

$$\frac{r_1}{r_2} = \sqrt{\frac{\dot{\theta}_2}{\dot{\theta}_1}}. \quad (11)$$

Calling this ratio R and substituting for the radii via Equation 3 leads to

$$\sqrt{\frac{\dot{\theta}_2}{\dot{\theta}_1}} = R = \frac{1 - \epsilon \cos \theta_2}{1 - \epsilon \cos \theta_1}. \quad (12)$$

To simplify this equation further, let position one be apoapsis, so that $\cos \theta_1 = \cos \theta_{ap} = 1$, then

$$\sqrt{\frac{\dot{\theta}_2}{\dot{\theta}_{ap}}} = R = \frac{1 - \epsilon \cos \theta_2}{1 - \epsilon}. \quad (13)$$

Thus, the eccentricity of the orbit can be related to the angular velocities at apoapsis and any other time as long as the angular position at the other time is also known. Letting θ_2 and $\dot{\theta}_2$ refer to the position and angular velocity now we have

$$\begin{aligned} R &= \sqrt{\frac{\dot{\theta}_{now}}{\dot{\theta}_{ap}}}, \\ R &= \frac{1 - \epsilon \cos \theta_{now}}{1 - \epsilon}, \end{aligned} \quad (14)$$

which yields an expression for the eccentricity,

$$\epsilon = \frac{R - 1}{R - \cos \theta_{now}}. \quad (15)$$

Hence, for an orbit for which the angular displacement from apoapsis is known, as well as the angular speed at apoapsis and at any other time, the eccentricity of the orbit can be calculated.

8 Binary Precession Exercise

Consider the case where one of the orbiting bodies is observed from the center of mass. The goal is to find the eccentricity of the orbit and its period from angular velocity observations. These observations would consist of the change in position of the object across the background stars, a number measured in hours/minutes/seconds of arc per year.

Let the sun be the object of interest (assuming that it is in a binary orbit) and assume that its angular velocity as measured from the center of mass corresponds to the precession measurements done from the Earth.

Equation 15 shows the need to obtain three parameters: θ_{now} , $\dot{\theta}_{now}$, $\dot{\theta}_{ap}$. Setting apoapsis for the sun in its assumed binary orbit near the year 500AD yields an angular displacement near 21° . Using Newcomb's precession formula (1900), one can estimate the precession rate in the year 500AD to be $49.9456''/\text{year}$. Finally, the precession observed now (2000, Astronomical Almanac) is $50.2910''/\text{year}$.

Allowing a 10% error in Newcomb's linear coefficient ($.222''/\text{century}$) yields precession estimates in the range from $49.9145''/\text{year}$ to $49.9767''/\text{year}$. Using these numbers, allowing a 1° change from the 21° estimate for θ_{now} , and letting $\dot{\theta}_{now}=50.2910''/\text{year}$ yields an average eccentricity of $0.0495 \pm .0041$, where the standard deviation is about 8% of the average value.

Using Equation 6, one can invert it to solve for ω , and then use ω to solve for the average angular velocity, $\dot{\theta}_{avg}$. The average value obtained for this number is $(55.4170 \pm 0.4894)''/\text{year}$, which corresponds to a period of $23,388 \pm 206$ years. Note that the standard deviation for these values (0.8%) is much smaller than for the eccentricity: a small change in eccentricity does not affect the average angular velocity (or the period) of the orbit significantly when the eccentricity is small.

Figure 4 below plots Equation 6 using the average values for our parameters. The dark circles are the precession data from Newcomb's approximation (1900-1980) and the last three (1991.5, 2000, 2002.5) are from the Astronomical Almanac. Although the analysis done here was not a formal fit, it is interesting to note that the estimates used for $\dot{\theta}_{ap}$ and θ_{now} yield such good agreement. Trial and error shows that neither the eccentricity of the orbit nor the period (or the average angular velocity) will change much (less than 3%) if a formal fit to the data is performed.

Orbit Parameter	Average	Standard Deviation
Eccentricity	0.0495	0.0041
Average Angular Speed ("/year)	55.4170	0.4894
Period (years)	23388	208

Table 1 Summary of orbit parameters calculated for the values of θ_{now} , $\dot{\theta}_{ap}$, and $\dot{\theta}_{now}$ described in the text.

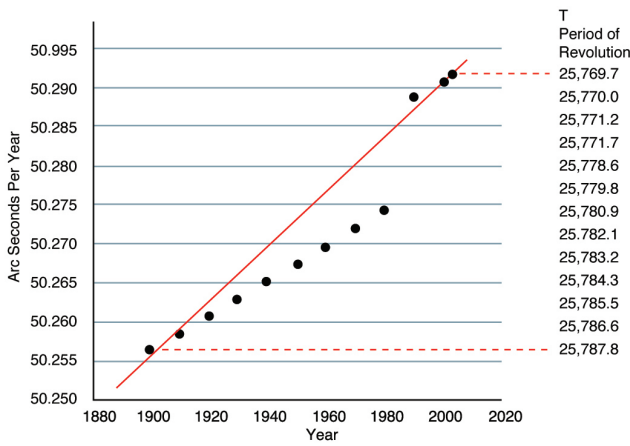


Fig. 4 Angular Velocity ("/year) vs Time (years)

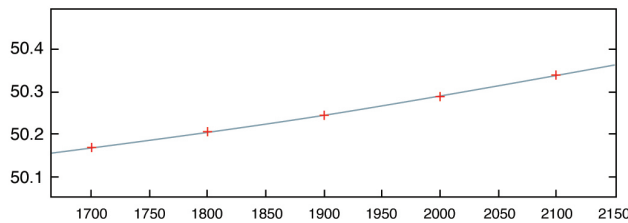


Fig. 5 Change in arc length travelled p/y by a body in 24,000 year elliptical orbit from 1700 AD to 2100 AD.

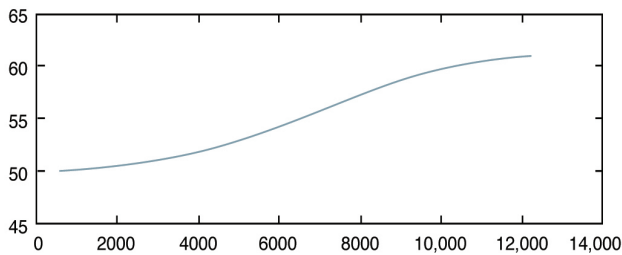


Fig. 6 Change in arc length travelled p/y by a body in a 24,000 year elliptical orbit from apoapsis, 500 AD, to periapsis, 12,500 AD.

9 Binary Model Simplified

In 1894, about the same time that the great astronomer Simon Newcomb gave us a precession formula with a fixed constant of .000222"/p/y (designed to predict changes in the precession rate), an Indian astronomer, Sri Yukteswar, explained that the moving equinox (precession) was a result of a our solar

system moving around another star and he gave us a binary orbit periodicity of 24,000 years, with apoapsis at 500A.D (Yuktswar 1894). This effectively implies a variable constant. To understand the simplicity of predicting the precession observable using such a model consider that with minor local effects, and no eccentricity, an observer on a planet in a binary system that sees the stars moving across the sky at 50"p/y would find that it takes 25,920 years to complete one orbit.

$$1,296,000"/50" = 25,920 \text{ years}$$

If the angular velocity were 54"p/y, again with no eccentricity, the orbit period would be 24,000 years.

$$1,296,000"/54" = 24,000 \text{ years}$$

If we add in eccentricity, then in accordance with Kepler's laws, the angular velocity would increase as the two stars move from apoapsis to periapsis and decrease when they move away from periapsis. Thus, if the observable known as the precession of the equinox is largely the geometric effect of a SS in motion (around another mass), then the precession rate (angular velocity) would increase or decrease according to Kepler's laws. History shows that the precession rate has been steadily increasing, at least as long as modern records have been kept, but there has never been a proven explanation for this phenomenon.

To provide some indication of which method of predicting the changing rate of precession might be more accurate we have compared Simon Newcomb's precession model to a model based on Sri Yuktswar's orbit parameters. It is effectively a test of a strictly local dynamics based model (current theory) versus a moving SS model, over the last 100 years, the period of the most accurate modern records.

10 One Hundred Year Test

From Yuktswar's orbit parameters, and utilizing the same data that Newcomb had available to him for the period before 1900 we can apply Kepler's laws to Yuktswar's orbit data (constrained by a ~24,000 year orbit period with apoapsis at around ~500A.D.) to come up with a forced eccentricity range and expected rate of change for the 100 year period between 1900 and 2000 of .000349"p/y (best fit). Thus we have two different predictions for the rate of change between 1900 and 2000.

$$\text{Yuktswar} = .000349"p/y$$

$$\text{Newcomb} = .000222"p/y$$

The actual rate of change for the precession observable (or change in angular velocity of the solar system along its binary orbit path in the dynamic SS model) was .000346"p/y (derived by subtracting the year 1900 precession rate from the 2000 precession rate, according to the Astronomical Almanac).

Thus to find which model proved to be the most accurate over the test period we take .000346 and subtract Yukteswar's and Newcomb's number:

$$.000346 - .000349 = .000003" \text{ Yukteswar error}$$

$$.000346 - .000222 = .000124" \text{ Newcomb error}$$

As you can see Yukteswar was off by .000003" and Newcomb was off by .000124" equating to a difference of 41x.

$$.000124 \div .000003 = 41x \text{ Difference}$$

The conclusion is that Yukteswar's dynamic SS model has proven to be 41 times more accurate than the lunisolar precession model put forth by Simon Newcomb, as tested over the period 1900 to 2000. Of course there have been numerous revisions to the precession nutation model since Newcomb's time, and as expected the newer models claim greater accuracy, but none of the newer models have yet withstood the test of time. Given that predictability is the hallmark of science we think the binary model should be given due consideration as a replacement for the precession component of the precession nutation model.

An important feature of the binary model is that it gives a solid reason for the specific amount of increase in the rate of precession (change in angular velocity of our sun) noticed over the last few hundred years, whereas the current lunisolar precession model is weak on its theoretical assumptions concerning the increase in the precession rate. In fact, if the moon is the primary force tugging on the earth (as computed in lunisolar theory), and the moon is slowly receding in distance from the earth, the current precession rate should be slowing down as local gravitational forces weaken.

The binary model also puts constraints on the overall precession rate. If the approximate 24,000 year orbit period is correct, and if apoapsis did occur around 500AD (give or take a few hundred years) then the rate should never go much below 49.5"p/y and never go much beyond 62"p/y.

11 Precession Nutation – Model Issues

The fact that the binary model is so accurate in predicting small changes in the rate of precession means that something is wrong with the current lunisolar model. If a dynamic solar system accounts for a large portion of the precession observable then it implies the gravity of the sun and moon acting upon the oblate earth either:

1. Produces less force than heretofore believed (highly unlikely given our present knowledge of gravity), or
2. The effect of that force manifests in ways other than the precessional motion of the axis (perhaps the distribution and uniformity of the oblateness cancels or diminishes the angle of the gravitational effects), and or
3. There is another body at work that has been ignored in the calculations. Or some combination of the above.

When lunisolar theory was first employed to explain the precession observable, Chandler wobble, Nutation, the Bradley effect, and even some of the planets were still unknown—and the SS was assumed to be static. Nutation, which is a relatively large effect (+ or – 9"), was not discovered until long after Newton proposed his theory of lunisolar precession. Yet when nutation was discovered it required the same forces that Newton had already attributed to the precession observable. What happened was none of the moon's gravitational forces were allocated away from the precession observable to nutation. People just assumed that the moon must cause the earth to nod up and down in an 18.6 year cycle, as well as cause the earth to lose one rotation and one revolution (precession observable relative to the stars) every 25,850 years. Thus the newly discovered nutation was "superimposed" on the precession model, and this has been the case ever since. But according to Hilton this should not be the case:

"As the precession and nutation angles are referred to the ecliptic of date, the resulting matrix mixes the precession and nutation of the equator and the motion of the ecliptic whereas the two phenomena are of different physical origins and have to be considered in different celestial reference systems." (Hilton 2002)

Under the original lunisolar theory the sun and moon were deemed to be the only forces acting upon the oblate earth. Since then many other inputs have been added to the precession nutation model but it should be noted the combined gravitational effect of the sun and moon is still many thousands of times stronger than the next significant object acting upon the Earth (Jupiter). While it is now widely recognized that the moon is receding in distance from the earth each year (thus slightly lessening its force) and the earth is slowly receding in distance from the sun (again slightly lessening its force with time) the precession rate is increasing with time, suggesting an unknown force may be at work.

Those aware of the problem have assumed that the collective effect of the planets must somehow be exerting more force upon the oblate earth, yet we see no waxing and waning of the precession rate in synch with the 12 year orbit period of the next largest gravitational input, massive Jupiter. The precession rate just keeps increasing decade after decade ignoring the diminishing force of the sun and moon, and showing no signature for the largest planet in the solar system. The signature we do see is the moon's 18.6 year nutation cycle moving in perfect synchronicity with the revolution of the moon's nodes around the ecliptic—while somehow never showing up in the precession rate. Thus we can only surmise that the moon causes nutation but probably only plays a minor role in producing the precession observable.

It is not the purpose of this paper to examine every possible problem with lunisolar precession theory but a cursory look at the theoretical dynamics will show that there should be no force exerted on the oblate earth by the sun at the time of the equinoxes when the uneven distribution of mass is effectively equalized (relative to the sun). There should be a slight tug on the earth at the time of the solstices (when the distribution of mass is most uneven) but this

appears to be almost inconsequential compared to the distance to the sun. If there is a third body, such as an unknown companion to the sun, that plays a role in the dynamics of the solar system, and this force is not being considered, then that might explain the lunisolar miscalculation.

An unknown companion has been suggested in numerous papers over the years (Brown, Muller, Whitmire 2010) but none have explored the effect it would have on the position of our sun, with the exception of Lammerzahl, Preuss and Dittus in their paper “Is the Physics within the Solar System Really Understood,” wherein they suggested that an “Accelerated Sun” might explain the Pioneer 10 and 11 acceleration anomalies. Antreasian and Guinn, investigating anomalies in the flybys of Galileo and NEAR also suggested there might be an “unknown perturbing force” affecting the solar system.

12 Conclusion

The lunisolar theory was put forth to explain the observable of precession (well before the discovery of nutation) in the absence of any knowledge that the solar system moved. In hindsight, the theory of lunisolar precession should have been revisited with the discovery of nutation, and then revisited again with the discovery that the solar system moved. It is hoped that with the recent recognition by the IAU that the precession nutation model is “inconsistent with dynamical theory,” and the recent knowledge that the solar system may be more dynamic than heretofore believed (Voyager 1 and 2, and IBEX data), that precession theory will finally be seen as ripe for reconsideration.

At a minimum we hope that motion of the moving frame of the solar system will be accounted for when measuring changes in the Earth’s orientation to points outside that moving frame.

Given the great accuracy of the moving solar system model over the last 100 years, and its ability to explain the difference in local versus non-local precession measurements, we question the static SS model with the same vigor as a certain 16th century astronomer that once said:

“E pur si muove”

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