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JOVIMAGNETIC SECULAR VARIATION

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Long term variations of a planetary magnetic field are one of the few observables available in the study of planetary interiors and dynamo theory. While variations of the geomagnetic field have been accessible to direct measurement for centuries, knowledge of the secular variations of other planetary dynamos is limited. New limits on Jovimagnetic secular variations are found by comparison of a Jovian internal field model (1) obtained from the Voyager 1 magnetic field observations at epoch 1979.2 with the epoch 1974.9 Pioneer 11 O_4 model (2). No significant secular variation of either the magnitude or position of the Jovidipole is found for the years 1974.9 through 1979.2 although a small earth-like variation cannot be ruled out.

Long term (secular) variations of the earth's magnetic field have been documented for several hundred years, dating to observations of magnetic declination in London by Edmund Gunter in 1622 and Henry Gellibrand shortly thereafter. A gradual decrease in the earth's dipole moment at a rate of approximately 5% per hundred years has been established from observations of the geomagnetic field over the last 150 years (3). Less well established but still generally accepted is the slow westward drift of certain features of the geomagnetic field at a rate of about 0.1° or 0.2° longitude per year. And from the paleomagnetic records it is well known that the earth's dipole field has a rich history of wanderings and polarity reversals. The irregular and unpredictable switching of the geodipole occurs with varying frequency, a rate of several reversals per million years being typical of the last 200 million years.

Geomagnetic secular variations are an important source of information about the earth's deep interior and the dynamo presumed responsible for the geomagnetic field (4,5,6). Within the context of modern dynamo theory, secular variations can provide constraints on material properties deep within the planet's otherwise inaccessible interior. Comparative studies of planetary dynamos may prove invaluable in unraveling the complexities of the self-sustaining dynamo. Thus the time history of Jupiter's planetary magnetic field is of great interest, especially since it represents the first real opportunity to observe secular variations of a planetary dynamo other than the earth's.

The first indirect observations of the Jovian magnetic field began with the discovery of non-thermal radio emissions by Burke and Franklin (7) in 1955 and have continued to the present (8). Continued observations of Jovian radio emissions have precisely established the rotation rate of the planet and have suggested the possibility of secular variations of the Jovimagnetic field. Berge (9) has suggested that the 30% decrease in Jupiter's integrated flux density occurring from 1961 through 1973 may possibly be a result of a decrease in the Jovian magnetic dipole moment. An upper limit on the variation of magnetic field strength between epochs 1967 to 1970 of about 5%/year was obtained from observations of the circular polarization of decimetric radiation (10). From observations of the maximum frequency of Jovian decametric radiation, Alexander (J. K. Alexander, private communications) concludes that the magnetic field magnitude at high northern latitudes has changed by less than 0.1% per year. Observations relating to the inclination of the Jovidipole with respect to the planet's rotation axis have been interpreted as evidence of a secular decrease of the inclination angle by .07 ± .05 degrees per year (10) but have not been confirmed (11).

In situ observations of the Jovian planetary magnetic field are limited to the Pioneer 10 and 11 flybys at epochs 1973.9 and 1974.9 and the Voyager 1 and 2 flyby encounters at epochs 1979.2 and 1979.5. Comparison of spherical harmonic models of the Jovimagnetic field obtained from the Pioneer observations (12) suggested a decrease in the dipole moment of ~6% during the intervening year. The decrease was, however, attributed to other effects although the possibility of a secular change as large as 6% per year was explicitly not excluded (13). A preliminary Jovimagnetic field model based on Voyager 1 observations (14) yielded a similarly reduced dipole moment attributed not to a secular decrease of the Jovian field but rather the presence of a large scale current system in the Jovian magnetosphere. This azimuthally directed 'magnetodisc' current is confined to an equatorial annular disc extending from ~5 R_J (Jovian radii) to > 50 R_J (15) and appears to be a permanent feature of the voluminous Jovian magnetosphere. The relative contribution of this ~ 3×10^8 A current system to the magnetic field observed by Voyager 1 near closest approach is greater than that of previous flybys by virtue of the larger periapsis of the Voyager 1 encounter (4.9 R_J) relative to those of Pioneer 10 and 11 (2.8 and 1.6 R_J).

A more recent estimate of the Jovimagnetic field has been obtained from the Voyager 1 observations (1) through the use of new modeling and inversion techniques (16) which facilitate the separation of externally generated fields from those generated within Jupiter's core. The Schmidt normalized spherical harmonic coefficients of this recent Voyager 1 internal field model are listed in Table 1 along with some previous estimates obtained from the Pioneer 11 vector helium (12) and fluxgate magnetometer observations (2). The parameters which have no corresponding entry in the V1 list are not determinable from the Voyager 1 magnetic field observations alone and are therefore not available at epoch 1979.2. A general agreement among the Pioneer 11 and V1 models is evident, and the correspondence between the dipole terms of the V1 and O_4 models is particularly good. In what follows we will restrict our discussion to a comparison of the V1 and Pioneer 11 O_4 model parameter estimates and the associated estimated parameter uncertainties (in parentheses in Table 1). [Davis and Smith (13) estimate that uncertainties in the dipole terms of the SHA 23 model quoted in Table 1 are as large as 5% of the g_1^0 term, i.e., ~0.2 G. They estimate that uncertainties in the quadrupole and octupole terms range from 0.2 G to 0.8 G. Since these uncertainties are approximately an order of magnitude greater than those estimated for the O_4 and VI models we do not consider the SHA 23 model.]

In Figure 1 we compare the time dependence of the magnitude of the g_1^0 coefficient for both the earth (17) and Jupiter, scaled such that a major division represents ~ .33% of the field magnitude. A linear fit to the Jovian g_1^0 estimates shown in Figure 1 is

$$g_1^0(t) = 4.218(\pm .015) - .0023 (\pm .0050)t \tag{1}$$

where g_1^0 is given in gauss, and t is the time difference in years from 1974.9. No significant secular variation of the magnitude of the g_1^0 term is found. The observations are consistent with a modest secular increase of ~ .06% per year (at 1 standard deviation in the rate) or a decrease of as much as ~ .17% per year. For comparison, the observed secular decrease of the magnitude of the earth's g_1^0 term is about .075%/year. The dashed lines in Figure 1 correspond to a 1 standard deviation error in an estimate of g_1^0

calculated using Eq. 1, illustrating the deterioration in predictive capability for epochs far removed from the 1977 median epoch.

A comparison of the two remaining dipole terms g_1^1 and h_1^1 leads to a negligible inferred drift of the magnetic dipole axis of 0.025° (± .22)/year in longitude. The estimated uncertainty in the drift rate is comparable to the uncertainties in Jupiter's rotation rate (18). The inclination of Jupiter's dipole axis has decreased by an insignificant ~ .01°(± .03)/year. These conclusions are not substantially altered if an alternate model (16) derived from the Pioneer 11 fluxgate magnetometer observations is used in place of the O_4 model. The uncertainties quoted here are largely the result of uncertainties in the position of the dipole axis at epoch 1974.9. Some of the V1 quadrupole and octupole parameters (in particular the g_2^0, h_2^1, g_3^2 and h_3^2 terms) depend on the details of the model used to represent the Jovian magnetodisc currents (1, 15) and therefore we will forego a discussion of higher order terms at this time.

The in situ magnetic field observations are consistent with no secular variation of the Jovimagnetic dipole field from 1974.9 to 1979.2. They are also consistent with a modest earth-like secular variation in both the magnitude of the main dipole g_1^0 term and the drift of the dipole axis in longitude. Earlier suggestions of relatively large secular variations in the dipole moment and inclination (10) are thus not substantiated. Current theoretical estimates of Jovimagnetic secular variations based on free hydromagnetic oscillations of the liquid core (19) range from days to centuries. Assuming the Voyager 1 and O_4 models do not represent a chance agreement of 2 samples of an aliased time sequence, Jovimagnetic secular variations must have a time scale of centuries and not decades. It is also clear that the differences in the Pioneer 10 and 11 internal field models reflects more the influence of unmodeled current systems than a real secular variation of the Jovimagnetic field. Estimates of the size of Jupiter's conducting core (20) based on Hide's method (21) and the large secular variations inferred from the Pioneer models need to be critically reassessed.

Finally, the methods used to obtain an estimate of the Jovian internal field from the Voyager 1 observations (1) should be equally applicable to flybys planned for the near future with similarly large periapses. A similar determination of Jupiter's internal field from either the International Solar Polar Mission (to $\sim 6\ R_J$) in 1984 or the Galileo encounter ($\sim 5\ R_J$) presently scheduled for $\sim$ 1990 could in principle distinguish between an earth-like and no secular variation of Jupiter's main field.

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JOVIAN MAGNETIC FIELD MODELS

		(1979.2)			(1974.9)		
		V1		P11		P11	P11
		17 ev[A]		0^4(GSFC)[B]		15 evs[C]	SHA 23[D]
			(ε)		(2σ)[C]		
1	g_1^0	4.208	(.032)	4.218	(.030)	4.068	4.092
2	g_1^1	-.660	(.004)	-.664	(.019)	-.668	-.705
3	h_1^1	.261	(.005)	.264	(.024)	.243	.231
4	g_2^0	-.034	(.028)	-.203	(.023)	-.093	-.033
5	g_2^1	-.759	(.030)	-.735	(.039)	-.672	-.699
6	g_2^2	.483	(.018)	.513	(.048)	.502	.537
7	h_2^1	-.294	(.058)	-.469	(.037)	-.498	-.531
8	h_2^2	.107	(.018)	.088	(.037)	.119	.074
9	g_3^0	—	(—)	-.233	(.060)	-.111	-.113
10	g_3^1	—	(--)	-.076	(.083)	-.316	-.585
11	g_3^2	.263	(.114)	.168	(.080)	.220	.283
12	g_3^3	-.069	(.054)	-.231	(.082)	-.250	.067
13	h_3^1	—	(—)	-.580	(.104)	-.476	-.423
14	h_3^2	.695	(.108)	.487	(.108)	.380	.120
15	h_3^3	-.247	(.054)	-.294	(.068)	-.228	-.171

1965 System III ϕ Positive East unless noted

Schmidt normalized spherical harmonic coefficients, Gauss

A. Connerney et al. (1982)

B. Acuña and Ness (1976): Rotated to 1965 System III

C. Connerney (1981)

D. Smith et al. (1976): Rotated to 1965 System III

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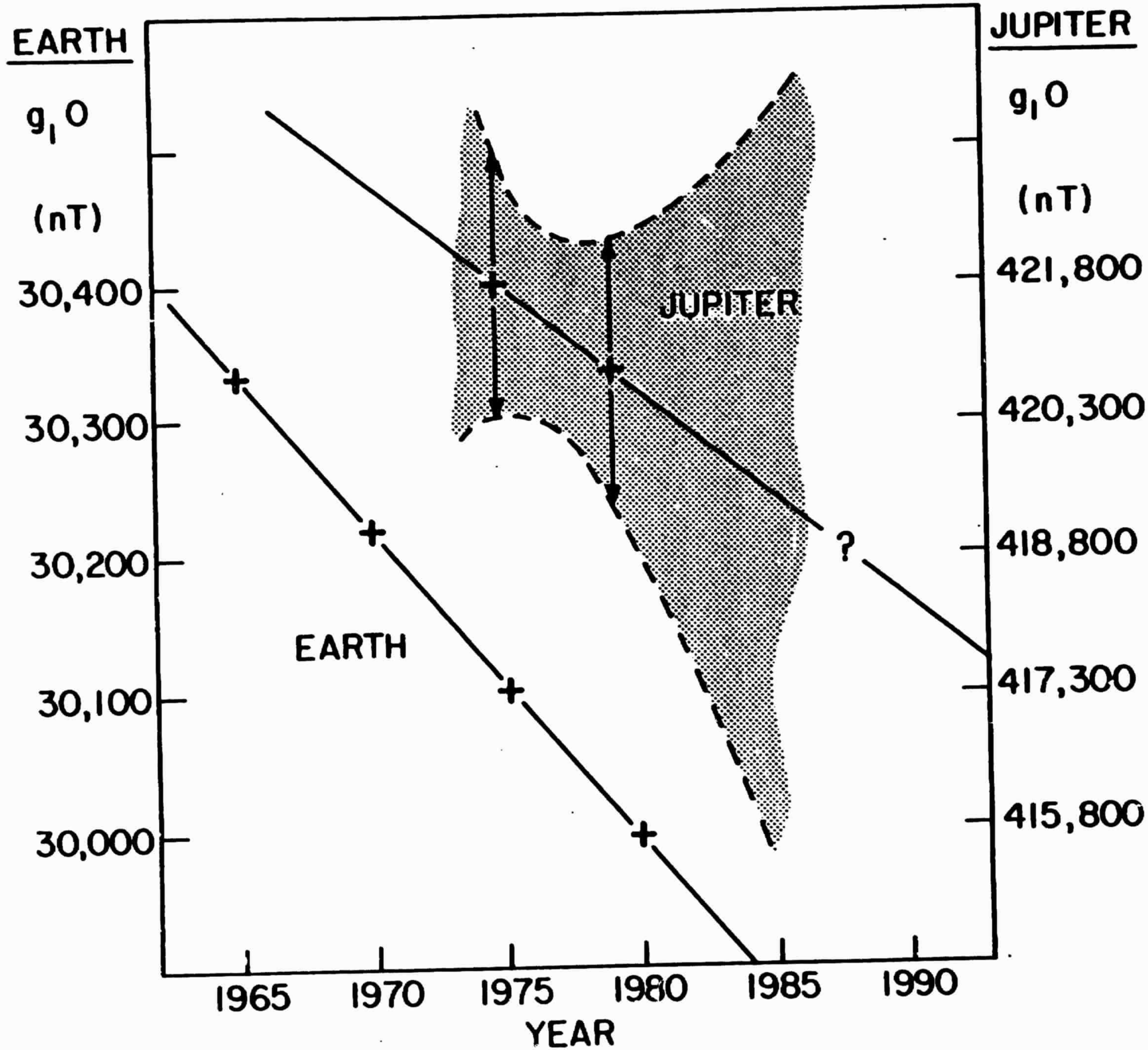
FIGURE CAPTIONS

Figure 1. Secular decrease of the Earth's main dipole g_1^0 term (left scale) compared with estimates of Jupiter's main dipole term (right scale). One vertical division represents ~.33% of the main dipole term in each case.


EARTH
g_1^0
(nT)
30,400
30,300
30,200
30,100
30,000
JUPITER
g_1^0
(nT)
421,800
420,300
418,800
417,300
415,800
JUPITER
EARTH
?
1965
1970
1975
1980
1985
1990
YEAR