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The Intrinsic Magnetic Fields of Saturn and Jupiter: How different are they from the geomagnetic field?

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The nature of its intrinsic magnetic field is one of the most fundamental characteristics of a planet. Certain properties of the interior structure of the planet can be extracted by analyzing the magnetic field measured in the magnetosphere. Jupiter and Saturn, the two gas giant planets in our solar system, both carry strong dipole-dominant intrinsic magnetic fields when viewing at the surface of the planets. The magnetic field of these two planets, as well as other properties such as bulk composition, element abundance in the atmosphere, and heat flux share similarities and distinctions.

The Cassini mission is providing an excellent opportunity to characterize the intrinsic magnetic field of Saturn. The axisymmetry of the field, the high degree and order moments of the field, as well as the secular variation rate of the field can be carefully examined with the continuously growing data set and improving understanding of the magnetospheric dynamics. In this study, we model the contributions to the measured magnetic field from various sources in the magnetosphere: the ring current, the mysterious ~11h periodic perturbations, the magnetopause current and tail current, etc. The displacement of the magnetodisk from the magnetic equator by the oblique incidence of the solar wind is also taken into account. Modeling the external contributions is conducted on measurements outside L-shell = 3.8 Rs orbit by orbit. The parameters extracted are then used to calculate the external field inside L-shell = 3.8 Rs for the corresponding orbit. After removing the external contributions orbit by orbit, we search for the non-axisymmetric components and result in tighter upper bounds. The secular variation rate of the field is investigated based on yearly grouped observations: no secular variation is found. The upper limits on the secular variation rate are more constrained. A parameter search based on the SOI measurements of Cassini which went into 1.3 Rs reveals that the high degree moments of the field are unexpectedly small and the total field spectrum shows a zig-zag pattern at the planet surface up to degree 5. More surprisingly, the spatial spectrum of the odd terms becomes flat at ~0.4 Rs which implies a much deeper dynamo than previously estimated based on pressure ionization argument. This deeply seated dynamo is also consistent with the energy flux scaling laws. The electromagnetic shielding mechanism is also favored to some extent. This mechanism implies that the Saturnian magnetic field observed is averaged over ~ 100,000 years. However, the depression of the even terms points toward another possibility that the Saturnian dynamo is a special dynamo solution different from the geodynamo. These possibilities have to be further examined by numerical dynamo modeling.

Better characterization the magnetic field of Jupiter is possible with current better understanding of the magnetospheric current systems in the Jovian magnetosphere. Both Pioneer 11 and Galileo measured the field inside Io's orbit; these measurements placed important constraints on the main intrinsic field. Galileo magnetometer measured the field continuously over 7 years (Dec 1995 – Sep 2003); these measurements are the most important dataset for studying the secular variation rate of the field. As in our Saturn study, the contributions to the measured magnetic field from various sources in the magnetosphere are modeled and removed orbit by orbit. A more realistic shape of the magnetodisk is taken into account. The secular variation rate of the dipole term is then investigated based on yearly grouped observations. No clear secular variation trend is found, and tighter upper limits on the secular variation rate are placed. Possible uncertainties in the IAU definition of the rotation rate of the planet are investigated as well. Constraints on the interior and evolution models of Jupiter and Saturn are placed from the various characteristics of the intrinsic magnetic fields extracted in this study.