

Magnetar-type bursting evolution of Jupiter global magnetoactivity since 1996

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Abstract. The decade-scale evolution profile of short-burst pulses, observed previously in 4U 0142+61, emerges from mean spectra of mission-integrated Galileo–Cassini–Juno 1996–2020 annual orbiting samplings of Jupiter $\approx 8\text{nT}$ global magnetic field. The profile is obtained by temporally mapping hyperlow-frequency ($<1\mu\text{Hz}$) dynamics of the magnetospheric signature of solar wind’s Rieger-resonance perturbations in $\sim 0.2\text{--}2\text{ zeV}$, here used as a proxy of magnetoactivity. The 1–6 month ($385.8\text{--}64.3\text{ nHz}$) mechanical resonance of solar wind is impressed onto the Jovian magnetosphere entirely and encompassed the Rieger period $P_{\text{Rg}} = 154\text{ days}$ and first six harmonics: $5/6 P_{\text{Rg}}$, $2/3 P_{\text{Rg}}$, $1/2 P_{\text{Rg}}$, $1/3 P_{\text{Rg}}$, $1/4 P_{\text{Rg}}$, $1/5 P_{\text{Rg}}$. Statistical fidelity of spectral peaks stayed well within a very high ($\Phi \gg 12$) range, $10^7\text{--}10^5$, reflecting the imprint’s completeness and incessantness. The magnetoactivity upsurge from the means that reach a high $\sim 20\%$ field variance began reformatting the signature around 1999, gradually transforming it into an anomalous state by 2002, also indicated from the anisotropic splitting of spectral peaks. In contrast, a comparison against 2005–2016 Cassini global samplings of Saturn revealed a calm Saturnian magnetoactivity, at a low $\lesssim 1\%$ field variance except for every $\sim 7.3\text{ yr}$ when it is $\lesssim 5\%$ due to orbital-tidal forcing. Because the change in annual magnetoactivity is becoming more sinusoidal with time, resembling a magnetar bursts evolution profile, the Jupiter upsurge is the greatest possible. This conclusive confirmation of the ongoing Jupiter upsurge and its pulsar-type supports my earlier proposal that an increasing Jovian magnetoactivity facilitates seismicity on magnetically exposed Mars via magnetotail reconnecting. A global pulsation profile of magnetar type in a planet demands beacon orbiter missions to monitor Jupiter magnetoactivity permanently for deciphering the disruption capacity of possible Jovian magnetodipole-discharge jets to electrical grids and communication systems.

Jupiter magnetosphere; Saturn magnetosphere; solar wind; Rieger resonance; Jovian pulsar bursts; seismogenesis.

1. Introduction

It has been recently shown with 99% confidence that presently, in the absence of an inherent magnetic field and plate tectonics, seismicity on Mars gets generated externally by the unstable Rieger resonant process in the solar wind, as facilitated by Jupiter magnetotail reconnecting (Omerbashich, 2021b). The process is characterized by the $P_{\text{Rg}} = 154\text{-day}$ *Rieger period* (Rieger et al., 1984) and its $5/6 P_{\text{Rg}}$, $2/3 P_{\text{Rg}}$, $1/2 P_{\text{Rg}}$, $1/3 P_{\text{Rg}}$, etc. harmonics, i.e., ~ 128 , ~ 102 , ~ 78 , $\sim 51\text{-day}$, etc. periods, called Rieger-type periodicities (Dimitropoulou et al., 2008). A damped, periodically forced nonlinear oscillator, which exhibits both periodic and chaotic behavior, successfully simulates the Rieger process (Bai and Cliver, 1990). The process has been reported previously in the interplanetary magnetic field (IMF) (Cane et al., 1998) and most heliophysics data types: solar flares, photospheric magnetic flux, group sunspot numbers, proton speed, etc.

To examine the criticality of the Rieger process for planetary dynamics and seismicity, I use all available data from Space missions that flew by Jupiter for at least six months. Then, in an integrative study, I temporally map the annual effect of the Jovian magnetosphere on the surrounding solar wind represented by its inherent Rieger resonant process, here used a proxy of planetary magnetoactivity. To measure the change of magnetic activity, I employ a method for measuring field dynamics by Omerbashich (2003, 2007, 2009). In that method, unlike classical approaches where ratios of Fourier spectral amplitudes of some dynamic are compared in between to learn about relative field activity, the average variance-spectral magnitude over the entire band of interest is, thanks primarily to linear background representation of spectral noise, taken to represent field dynamics during the epoch of data analyzed. In the present study, one Earth year is the epoch of choice.

2. Data and methodology

To temporally map hyperlow-frequency ($<1\mu\text{Hz}$) dynamics in the solar wind near Jupiter, I spectrally analyze magnetometer recordings collected between 1996–2020 in the Jupiter and, for a check, Saturn vicinity,

in the 1–6-month band of the overall most energetic dynamics (interplanetary dynamics as normalized to the Earth case). Since the Sun-outward direction is critical to mapping dynamics of any solar system-wide process correctly, the Sun RTN (Radial–Tangential–Normal) is the optimal Space coordinate frame for the present study. The RTN coordinate system, also called Spacecraft-Solar equatorial (SE) system, consists of the Normal component roughly normal to the solar equatorial plane, the Tangential component parallel to the solar equatorial plane, the Radial component that points in the Sun-spacecraft direction outwards from the Sun, and the Total (average) field obtained from the field components in the usual way. This choice preserves the relative orientation of the magnetopause–wind collision interface to always point towards the Sun. In that context, the Rieger mechanical resonant process in the interplanetary magnetic field is understood for simplicity as the solar wind’s particles blanketing and flapping resonantly about the ecliptic. Galileo data included full-year magnetometer readings of Jupiter from 1996–2002 inclusively, Juno data included full-year data for Jupiter from 2017–2020 inclusively, while full-year Cassini measurements spanned 2005–2016 inclusively for Saturn and the 1 September 2000–31 April 2001 comprising the October 2000–March 2001 Jupiter flyby.

The Cassini data used were the updated and calibrated 1-minute averages v2.0 of Cassini magnetometer recordings spanning 2000.01.20:18:28:30–2017.09.12:15:14:31, where the part preceding 2001.01.01 used an older calibration (Dougherty et al., 2006). The Galileo and Juno data were provided to me concatenated and rotated to RTN (Sun) coordinate frame (see Acknowledgments). To expedite the computation, and since it is the band of highest planetary energies that are examined here, I take 100-minute averages of magnetometer readings to represent the field realistically.

For simplicity, I assume that Jupiter magnetosphere acted alone on the nearby solar wind that, in turn, is the sole and constant dynamic impressed onto the magnetosphere. At the same time, and owing to Jupiter lacking significant density variations akin to rocky planets, yearlong data sampling makes the variation in spacecraft distance to observed field features like central plasma sheet irrelevant. Moreover, effects from all magnetospheric components cancel out under planetary rotation, especially in the context of the highest interplanetary energies (~ 0.2 – 2 zeV), making the sampled magnetoactivity variation virtually radial. This scenario is also the optimal way to properly account for variability features in Jupiter’s predominantly radial field; see Moore et al. (2018). Besides, I remove maneuvers and flybys of other celestial bodies from the data to constrain the maximum field strengths used to the ~ 4 to ~ 8 nT interval as the Jupiter natural range of highest field strengths; see, e.g., Yao et al. (2021).

The magnetometer data show occasional inexplicable swellings (Steven Joy, personal communication, 2021; ref. Acknowledgments) that exceed the declared data precision in the product-delivered values of total magnetic field values, as obtained from theoretical vs. complete observed component values. I confirmed the same on random samples supplied to me (see Acknowledgments) for 2009, 2011, and 2014. Therefore, to retain strictness and uniformity in an analysis that relies on mission integration, I use commonly used theoretical (average) total magnetic field values obtained from the product field components throughout and for all missions.

Spectra were computed in var% and dB against linear background noise levels using the rigorous Gauss–Vaniček method of spectral analysis (GVSA) by Vaniček (1969, 1971), which comes integrated with statistical analysis in a scientific software package LSSA that provides periodicity estimates in the strictly least-squares sense, unlike the more popular Lomb–Scargle variation. Using GVSA has many benefits, including benefits over Fourier methods (Omerbashich, 2021a, 2007, 2006; Press et al., 2007; Pagiatakis, 1999; Wells et al., 1985; Taylor, 1972). By discarding variations that maneuver and flyby events left in the record, I also take advantage of the blindness to data gaps as a feature exclusive to the least-squares class of spectral analysis techniques.

3. Results

That Jupiter magnetosphere was in the above way indeed sampled largely radially, and data treatment and processing approach were correct, can be seen from Fig. 1a (radial field component) v. Fig. 1d–e (total-field) that yielded practically the same result. The same follows from the statistical fidelity that stayed well

within a very high ($\Phi \gg 12$, as indicative of a physical process) range, of 10^7 – 10^5 going from lowest- to shortest-frequency spectral peaks, respectively. Thus, the imprint of Rieger resonance via solar wind onto the magnetopause and below was both total and incessant for all practical purposes itself. Note that, while the 99%-significance level in all cases was very close to the 67% level, the latter is considered sufficient for validating physical period ensembles reported broadly, as is the case here.

As seen in Fig. 1e, variation in the (upsurge's) mean-spectral amplitude from annual-epoch magnetometer records is becoming more sinusoidal with time, thus resembling the evolution of short-burst pulses seen in 4U 0142+61 magnetar whose own decade-long profile obtained from the highest-resolution data available (Gonzalez et al., 2010) is comparable to the Jupiter's. Note that incomplete (closer to half-year) epochs for Cassini-2001/2002 and Juno-2016 data, while sufficient for estimating average spectral amplitude per epoch, still lacked information for a detailed depiction of anisotropy. Ironing out the field, i.e., discarding measurements taken during maneuvers and flybys of other celestial bodies, resulted in band-wide-mean variance-spectral magnitudes exposing the relative magnetoactivity more successfully in terms of detailed features than can be achieved classically, e.g., by looking at the variation in the anisotropic splitting of spectral peaks. The staggering overall level attained by the mean spectra, of $\sim 20\%$ field variance, shows that a systematic signal dominates the band of interest, which, in turn, justifies the initial assumptions on the solar wind being the sole actor in Jovian ~ 0.2 – 2 zeV domain.

The main result of this study, Fig. 1, was compared against the same type of analysis, just of the Saturn magnetic field, from the 2005–2016 Cassini samplings of that planet's $\lesssim 8$ nT global magnetic field. In contrast to the Jovian magnetoactivity increase, the analysis of the Saturnian magnetic field shows no activity above very low (weak) $\sim 1\%$ field variance, other than an orbital-tidal forcing of ~ 7.3 years ($\frac{1}{4}T_{\text{orbit}}$, $T_{\text{orbit}} \approx 29.4$ years) when Saturnian magnetoactivity climbs to a low $\sim 5\%$ field variance, Fig. 2.

4. Discussion

The Rieger process involves the heliosphere proper (and thus the IMF too) and possibly other planets in addition to Mars — of which Jupiters probably are most significant due to vast magnetospheres. Due to a lack of inherent magnetism, external magnetic fields could be facilitating sustained electrical and magneto-hydrodynamic couplings that result in planetary seismic fracturing response as found for marsquakes by Omerbashich (2021b) and for moonquakes and earthquakes by Omerbashich (2021c). Thus, since only the Jupiter magnetosphere extends to Mars, the seismogenic property of the solar-wind Rieger process on Mars likely is facilitated by magnetotail reconnecting as the Jovian magnetic field is currently undergoing a polarity reversal or a transition between different dynamo states, as implied from Juno mission (Moore et al., 2018). Before the Juno mission, Pap et al. (1990) had offered an intuitive yet analogous explanation suggesting that the transient existence of a 154 ± 13 -days period was related to an emerging strong magnetic field.

Jupiter magnetoactivity is both internally and solar-wind driven (Vogt et al., 2019). Because interaction between the solar wind's highly variable external conditions and the (wind-impacted) magnetospheres is essential for understanding energy flow within a planetary system, the nature of the solar wind-Jupiter magnetosphere interaction has been widely debated but remains poorly understood (Masters, 2017). However, such an interaction has been established between the solar wind and Jupiter inner magnetosphere by the Hisaki satellite (Murakami et al., 2017), and the solar wind can produce compressional mode waves in the magnetosphere (Cho et al., 2017). Therefore, and since Jupiter magnetosphere is the most powerful planetary particle accelerator in our solar system (Saur et al., 2017), the present study attempts to fill the gap by establishing such interaction for the highest energies, too. Moreover, if such an interaction is showed to apply in the frequency space, its dominant periodicities likely drive numerous unexplained (but likely resonant) subdiurnal and periodicities down to very low frequencies or periods of a few days in duration. Namely, a clear ~ 26 -day solar periodicity is seen in the Cassini data (Stallard et al., 2019), while solar wind-induced periodicities in the magnetosphere are ~ 13 or ~ 26 days (Roussos et al., 2018) as well as the Rieger-type and longer periodicities (Lou et al., 2003). In addition, Chancia et al. (2019) have noticed certain resonant features in the Saturn magnetosphere, with expected pattern speeds much slower than the magnetospheric periodicities.

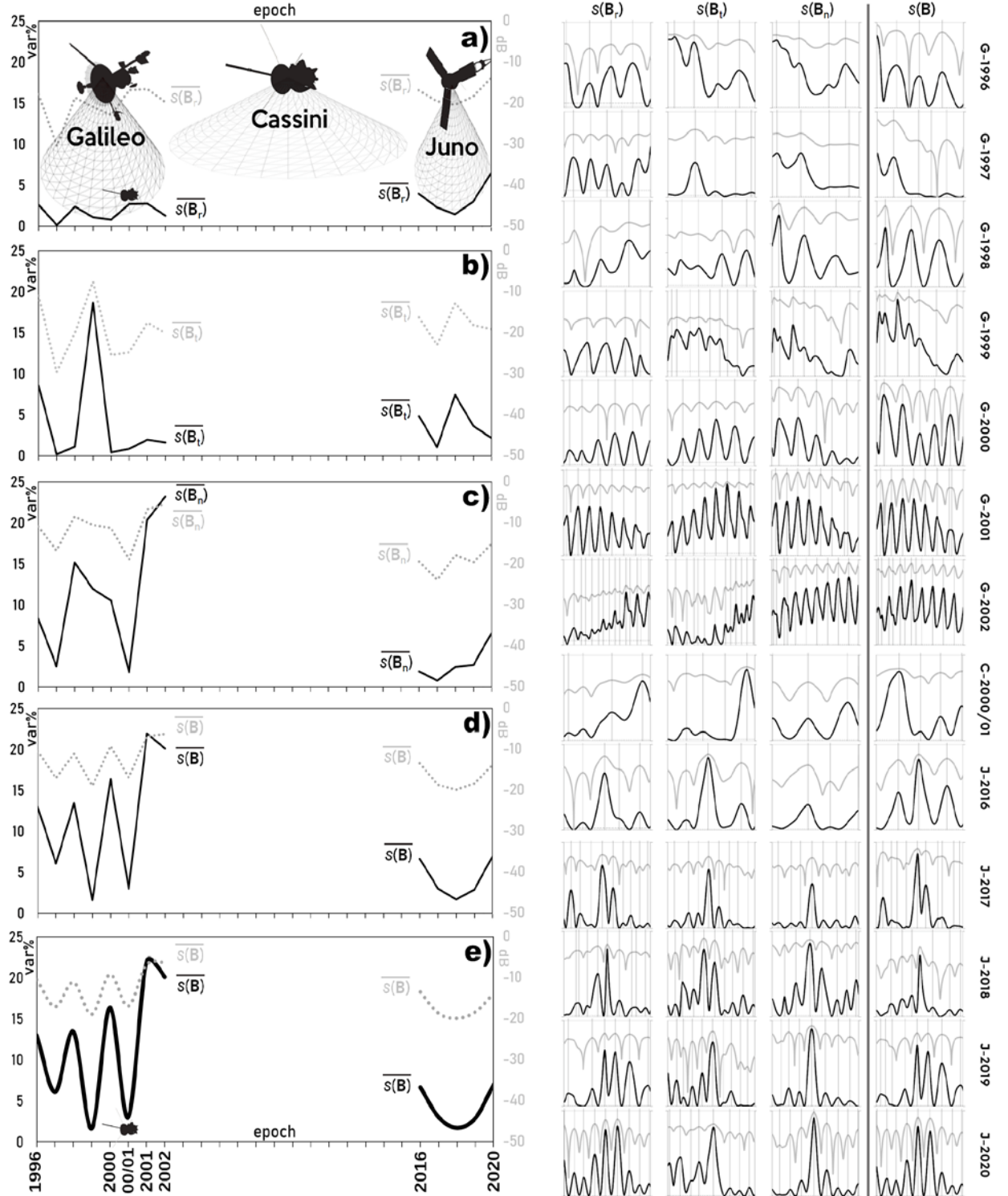


Figure 1. *Left composite:* Relative change of Jupiter magnetosphere activity with time, as the mean Gauss-Vaniček spectral magnitude in var% (solid black line) and dB (dotted gray) of annual Jovian ≈ 8 nT magnetic field, per field component (panels a–c) and the total-field (panel d and the same but smoothed in panel e). Note that results from the radial field component (panel a) and total field (panels d–e) are virtually the same, as expected due to a lack of significant density variation in Jupiter, and the heads-on (Sun-outward v. Jupiter-outward) collision between the planetary magnetic field and the solar wind. One epoch spans one Earth year as an arbitrary and convenient field sampling size, except for the Cassini (C) case where the data extended over an eight-month interval including an extra month respectively prepended and appended to the October 2000–March 2001 flyby and spanning 1 September 2000–30 April 2001 for that case. *Right composite:* a blind-plots stack of spectral peak splitting due to anisotropy under magnetoactivity upsurge since 1996. Amplitudes not to scale. Note the 2001/2002 Cassini flyby case, with average spectra seen as dominated by a single Rieger period, is due to a remote tangential flyby and its duration of half a year, so locking to one preferential frequency, which gave the impression of power absorption, was to be expected. The same preferential locking is in Juno (J) v. Galileo (G) spectra due to Juno’s highly varying altitude, including regular crossings of the magnetopause. Cassini data included an extra month to the October 2000–March 2001 flyby and thus spanned 1 September 2000–30 April 2001. Short-dashed line marks confidence at 67%, with the 99% level always nearby (long-dashed on radial-component plots for illustration). The Galileo and Juno data were magnetometer recordings provided by the UCLA–NASA data team, in batches as concatenated and rotated to RTN (Sun) coordinate frame (see Acknowledgments). See Supplement for the complete data set.

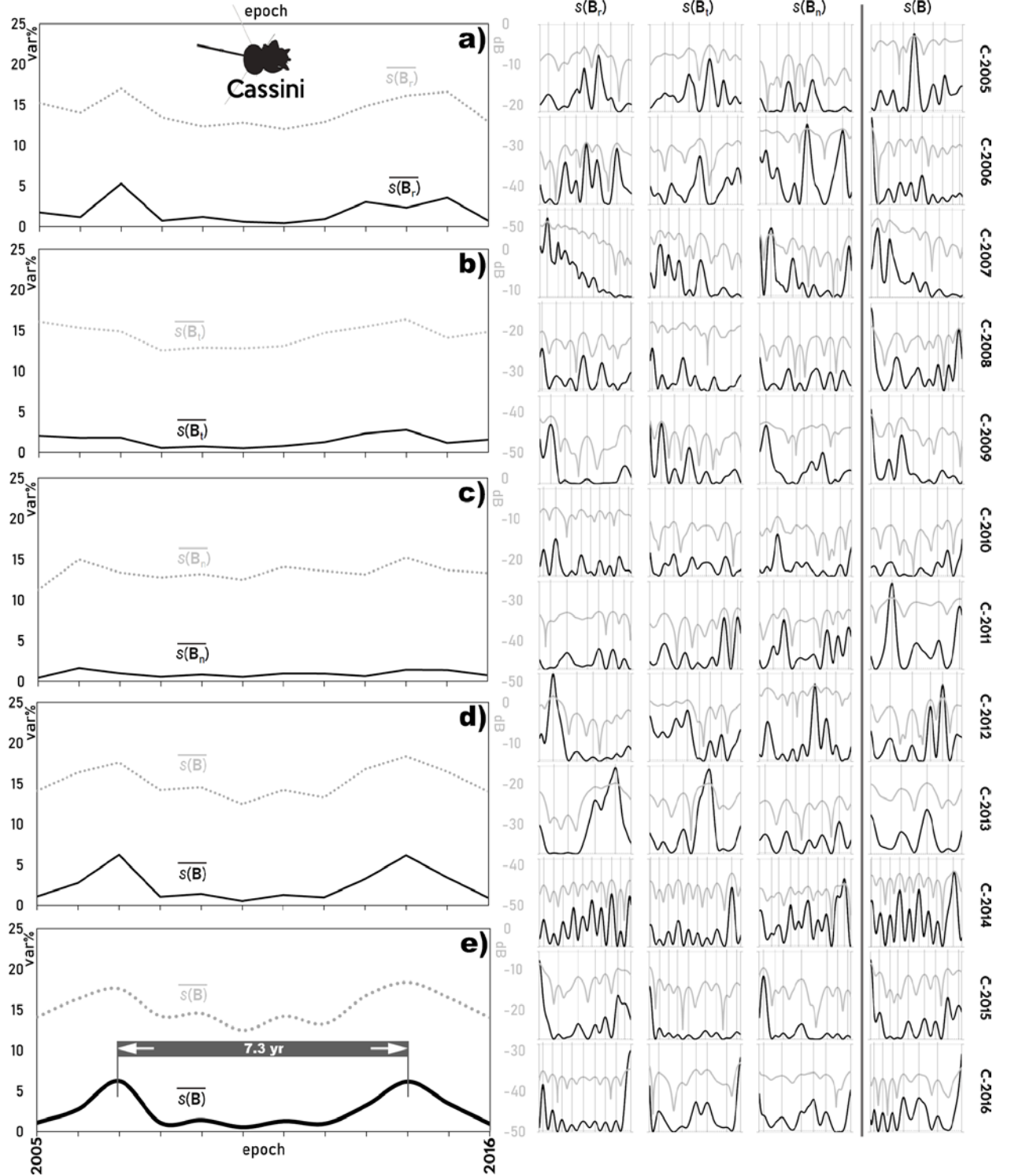


Figure 2. *Left composite:* Relative change of Saturn magnetosphere activity with time, as the mean Gauss-Vaniček spectral magnitude in var% (solid black line) and dB (dotted gray) of annual Saturnian ≈ 8 nT magnetic field, per field component (panels a–c) and the total-field (panel d and the same but smoothed in panel e). As in the Jupiter case (Fig. 1), results from the radial field component (panel a) and total field (panels d–e) are virtually the same, as expected due to a lack of significant density variation in Saturn, and the heads-on (Sun-outward v. Saturn-outward) collision between the planetary magnetic field and the solar wind. Here Saturn’s global magnetic field is seen as forced by a ~ 7.3 -year period, or its $1/4 T_{\text{orbit}}$, $T_{\text{orbit}} \approx 29.4$ years, orbital tide only as transpired via the solar wind. One epoch spans one Earth year as an arbitrary and convenient field sampling size. *Right composite:* a blind-plots stack of spectral peak splitting as due to anisotropy. Unlike for Jupiter, anisotropy in the Saturn magnetosphere shows no clear temporal trending, revealing random and very weak upsurges as seen from the number of split peaks rarely exceeding eight (a degree of freedom beyond the set of seven Rieger periodicities). Amplitudes not to scale. Short-dashed line marks confidence at 67% and practically coincides with the abscissa in all panels, with the 99% level always nearby to within a few var% (shown long-dashed on radial-component plots for illustration). The data used were 2005–2016 Cassini magnetometer recordings (Dougherty et al., 2006). See Supplement for the complete data set.

In many ways, Jupiter behaves like a pulsar (Dowden, 1968), so that Jupiter is a very weak pulsar itself since both the Jupiter magnetic moment and angular momentum are only slightly less than in pulsars (Michel, 1982). Similarly, as indicators of planetary magnetoactivity, ion aurorae share common mechanisms across planetary systems, despite temporal, spatial, and energetic scales varying by orders of magnitude (Yao et al., 2021). Since we can expect all macroscale (and especially astrophysical) magnetic fields to behave in similar ways regardless of those scales, the above conclusions probably hold for magnetars as well. Magnetars are young isolated neutron stars characterized by exceptionally high X-ray luminosity and are extremely rare, so only about 20 active such objects in the known universe are known presently. They are discovered either by analyzing their steady X-ray emission or in outburst events and in both scenarios supplied most energy from the decay and instabilities of very intense magnetic fields of $\geq 10^{14}$ G (Pizzocaro et al., 2019). As such, magnetars act overwhelmingly on all other forces in their vicinity, making them natural laboratories for observing and learning about general processes and mechanisms of astrophysical magnetic fields under most extreme conditions that can create nearly perfect isolation.

To study high-energy bursts from magnetars as remote astronomical objects for which detailed magnetic field measurements are therefore unavailable, astronomers rely on observations of proxies such as X-ray emissions, changes in persistent emissions, and spectra of surface or internal processes and instabilities. On the other hand, the Jupiter magnetosphere is within our reach and has been sampled directly in nearly a dozen Space missions. Thus the main result of the present study - the evolution profile of the planetary magnetoactivity shown in Fig. 1 - has been obtained from all available *in situ* measurements of the Jovian global magnetic field's decade-scale activity. Given that the energy scales involved are the highest possible for that planet, the result shows conclusively that the current magnetoactivity of Jupiter is the highest possible as well, and that much of that activity naturally is relayed via magnetotail reconnecting onto the surrounding environment and thus Mars too during its regular traversals of the Jovian magnetotail. This result lends the highest credence to the claim on marsquakes mainly arising in a planetary fracturing response to a current increase in Jovian magnetoactivity (Omerbashich, 2021b).

While the primary source of magnetospheric power for Jupiter is the spin of the planet, the present study has also shown that plasma in solar wind's lowermost frequencies (as the most significant alternative plasma source to the Jovian moon Io) interacts with a spinning planetary magnetic field. This interaction could provide energy for global (dipole-side) bursts by creating a torque that slows the Jupiter rotation, providing power for a whole variety of magnetospheric phenomena to occur (Dessler, 1987). One such event could be a global outburst in the form of dipolar beam ejecta of pulsar type.

5. Conclusions

The 4U 0142+61 magnetar evolution profile of short-burst high-energy pulsations, whose decadal-scale preparation phase had been obtained from highest-resolution data, is comparable to Jupiter evolution profile of its own (as-of-yet unobserved) high-energy global outbursts of pulsar type. The Jupiter magnetoactivity increase, revealed by the decadal-scale global activity profile from mean spectra of annual records obtained by integrating magnetometer measurements from Galileo, Cassini, and Juno missions, is the highest possible in a planetary magnetosphere. So constrained (to the upper end of the planetary energy band), the Jovian magnetoactivity upsurge is likely responsible for the Martian seismicity via magnetotail reconnecting, as sampled independently by the InSight mission.

The conclusive evidence presented here on a magnetar-pulsar nature of Jupiter and its outburst capacity demands broadest efforts towards learning more about the threats that global high-energy outbursts (all-bursts, which dissipate up to $\sim 20\%$ of the magnetic field energy) in the form of magnetopolar beams along the dipole under the 10° tilt (up to 13° to the ecliptic with obliquity) pose for electrical grids and communication systems. This likely scenario demands deploying permanent multi-vessel missions for constantly monitoring the magnetoactivity of pulsar Jupiter.

Acknowledgments and Data & Code Statements

The Cassini RTN data source was https://pds-atmospheres.nmsu.edu/data_and_services/atmospheres_data/Cassini. Dr. Steven P. Joy (UCLA & NASA Planetary Data System/Planetary Plasma Interactions Node) provided outstanding support, and the Galileo and Juno MAG data concatenated and rotated to the RTN frame. Joe Mafi (UCLA & NASA PDS/PPI) provided valuable additional support and random samples of field swelling. Dr. Raymond J. Walker (UCLA & NASA PPI) provided valuable additional support, advice, and data management supervision. The least-squares spectral analysis scientific software LSSA, based on the rigorous method by Vaniček (1969, 1971), was used to compute spectra. Dr. Spiros Pagiatakis (York University) provided LSSA v.5.0, which is now available as an open-source version from <http://www2.unb.ca/gge/Research/GRL/LSSA/sourceCode.html>. All data analyzed in this study are enclosed in a Supplement accompanying this manuscript.

Declarations

The author reports no competing interests.

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