JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, A10203, doi:10.1029/2012JA018134, 2012

Comment on "Jovian slow-drift shadow events" by T. Koshida et al.

P. Zarka,[1] S. L. G. Hess,[2] and F. Mottez[3]

Received 17 July 2012; revised 27 August 2012; accepted 27 August 2012; published 3 October 2012.

Citation: Zarka, P., S. L. G. Hess, and F. Mottez (2012), Comment on "Jovian slow-drift shadow events" by T. Koshida et al., *J. Geophys. Res.*, *117*, A10203, doi:10.1029/2012JA018134.

1. Introduction

[1] *Koshida et al.* [2010a] describe specific unusual features of the Jovian decametric (DAM) radiation, called "slow-drift shadow" (SDS) events. These events consist of brief (a few tens of milliseconds long) extinctions of the slowly varying Io-induced Jovian decametric emission (so-called«L-burst») in the 21–23 MHz range. SDS drifts from high to low frequencies across the observed 21–23 MHz range in a few hundred milliseconds.

2. Tentative Interpretation of SDS: CMI and Alfvén Velocity Hypotheses

[2] In an attempt to give a physical interpretation for SDS, the authors made the commonly accepted assumption that the background emission is produced via the Cyclotron Maser Instability (CMI) [see, e.g., *Galopeau et al.*, 2004, and references therein]. In addition, they assumed that SDS are related in some way (not precised) to Alfvén waves. The first assumption implies that radio emission occurs at the local electron cyclotron frequency ($f_{ce} = eB/2\pi m_e$ with B the local magnetic field amplitude and e and m_e the electron charge and mass), and permits to make a correspondence between frequency and altitude via a magnetic field model. As a consequence, SDS drift can be converted into a motion along the Io-Jupiter magnetic flux tube. The second assumption allows the authors to deduce a background plasma density from the speed of this motion by identifying it with the local Alfvén velocity ($V_A = B/(\rho\mu_o)^{1/2}$ with $\rho \approx Nm_p$ the background mass density, N the number density, and m_p the proton mass).

[3] The conclusion of *Koshida et al.*'s [2010a, paragraph 16] paper includes the following discussion: "We have attempted to quantitatively estimate the background plasma densities by assuming that the background L burst emissions were generated by CMI and that the SDS events were related to the Alfvén wave. The estimated background plasma densities were in the range of 5×10^6–2×10^7 cm^{-3}. Since $f_p/f_c \approx 0.87$–1.7, the CMI must be quenched. This give rises to the question of what induced the SDS events" with $f_{pe} = (Ne^2/4\pi^2\epsilon_o m_e)^{1/2}$ the local plasma frequency. This statement is repeated 3 times throughout the paper (in the Abstract and Conclusions) without any additional comment. It may lead the reader to think that CMI is questioned as the source of the SDS, or even of the background DAM radiation, as SDS are extinctions of the underlying L-burst emission.

[4] Further discussion with the lead author suggests that he indeed implied to question the relevance of the CMI on the basis of the high densities found: "*Millward et al.* [2002] assumed that the plasma density in the polar region of Jupiter became greater than 10^7 cm^{-3} along with the incoming flux density of 1000 ergs cm^{-2} s^{-1}. Therefore, I thought the estimated electron density was not unusual" (T. Koshida, personal communication, 2010).

[5] We believe that this implication on the CMI inferred by *Koshida et al.* [2010a] is not justified, and that the methodology leading to it is not correct. The proper way to confront the results with the hypotheses should be (1) Is the plasma density deduced from the two hypotheses (CMI radio emission + SDS at Alfvén velocity) compatible with these two hypotheses and is it realistic? (2) If it is, the proposed interpretation of SDS is valid; if not, at least one of the hypotheses is incorrect: which one should be rejected? (3) Are there alternative hypotheses? Let us examine these 3 points.

3. Background Plasma Densities

[6] The plasma densities found by *Koshida et al.* [2010a] are extremely high ($N = 0.4$–1.8×10^7 cm^{-3}), larger than those measured or predicted at the Jovian ionospheric peak. The electron density profiles from Pioneer and Voyager occultation measurements reported by *Strobel and Atreya* [1983], which were performed at various latitudes (between 58°N and 79°S), do not exceed 10^6 cm^{-3} at the ionospheric peak, even taking into account the low-altitude high density peaks likely of meteoritic origin. Jupiter's high altitude ionospheric electron density was well described and modeled by *Hinson et al.* [1998], from a reanalysis of Voyager 2 occultation measurements, by a topside scale height ~900 km above a maximum density layer of 3.5×10^5 cm^{-3}

---

[1] LESIA, Observatoire de Paris, CNRS, UPMC Université Paris 6, Université Paris Diderot, Meudon, France.

[2] LATMOS, IPSL-CNRS, Université de Versailles Saint Quentin, Versailles, France.

[3] LUTH, Observatoire de Paris, CNRS, Université Paris Diderot, Meudon, France.

Corresponding author: P. Zarka, LESIA, Observatoire de Paris, CNRS, UPMC Université Paris 6, Université Paris Diderot, Place J. Janssen, Meudon FR-92190, France. (philippe.zarka@obspm.fr)

0148-0227/12/2012JA018134

located 1600 km above the 1 bar level. By including magnetospheric precipitations of 10 keV electrons in the polar Jovian ionosphere with a very large incoming flux density of 1000 ergs cm^{-2} s^{-1} (mW m^{-2}), *Millward et al.* [2002] obtained a sharp peak of electron density reaching 3×10^7 cm^{-3} at the 10^{-7} bar level, ~700 km > 1 bar level. But apart from being restricted to the auroral ionosphere, this peak is very limited in altitude, the electron density having already decreased by one order of magnitude 200 km above the peak.

[7] The source of Jovian DAM at 21–23 MHz lies at an altitude of ~0.05 to 0.1 Jovian radius, i.e., ~3000 to 7000 km above the 1 bar level (consistent with *Koshida et al.* [2010a, Table 2]), whatever the magnetic field model used for the internal field: dipole, O6, VIP4, VIPAL [see, e.g., *Zarka et al.*, 1996, 2001; *Hess et al.*, 2011]. This altitude range corresponds to 2 to 4 scale heights above the ionospheric peak, implying a reduction by 1 to 2 orders of magnitude of the electron density. All electron density models, from simple extrapolations of a topside ionosphere [*Hinson et al.*, 1998] to more sophisticated models including the Io plasma torus source [*Bagenal*, 1994; *Su et al.*, 2003] predict an electron density much lower than that inferred by *Koshida et al.* [2010a].

[8] In his paper subsequent about the so-called wave modulations (WMs) of L-burst emission [*Koshida et al.*, 2010b], Koshida himself contradicts his first (above) conclusion about the electron density in DAM sources. Comparing observed WM frequencies to predicted frequencies of the ionospheric Alfvén resonator, they infer ionospheric densities of 2×10^4 to 2×10^5 cm−3 and scale heights of 1650–1750 km. In spite of the fact that these numbers are not very robust because WM frequencies depend on several parameters including the density and the scale height, it remains that these density values are much below those of *Koshida et al.* [2010a] and more in agreement with our knowledge of the Jovian plasma in DAM sources.

4. Questioning the CMI Hypothesis?

[9] *Koshida et al.* [2010a] correctly conclude that the plasma densities deduced from their two hypotheses, and the corresponding local f_{pe}/f_{ce} ratio, are incompatible with generation of radio emission by the CMI. With $f_{pe}/f_{ce} = 0.87$–1.7, no CMI emission would be possible. The highest theoretical limit, derived in an inhomogeneous magnetoplasma, is $f_{pe}/f_{ce} = 0.385$ [*Le Quéau et al.*, 1985], whereas the observed maximum value, within the terrestrial sources of Auroral Kilometric Radiation, is $f_{pe}/f_{ce} \approx 0.14$ [*Hilgers*, 1992; *Louarn and Le Quéau*, 1996].

[10] As the Alfvén waves invoked by *Koshida et al.* [2010a], from which they infer the constraint $f_{pe}/f_{ce} = 0.87$–1.7, are mere perturbations of the background plasma, this constraint should apply to the whole plasma within which these Alfvén Waves propagate. Thus the L-burst emission surrounding the SDS events, and not only the SDS events themselves, could not be produced either by the CMI. However, a broad literature exists that confirms that all Jovian DAM emission characteristics are in good agreement with the CMI theory [*Zarka*, 1998; *Treumann*, 2006; *Hess et al.*, 2008, and references therein]. Moreover, characteristic properties of the CMI (emission near f_{ce}, $f_{pe} \ll f_{ce}$) invoked by the authors for determining the background plasma densities, are contradicted by their results. Hence, one cannot simply question the CMI origin of the Jovian L-bursts based on plasma densities determined using the assumption that CMI produces the emission. Finally, as discussed above, the plasma densities found and invoked for questioning the CMI are not realistic.

5. Questioning the Alfvén Velocity Hypothesis

[11] By contrast, the hypothesis of SDS drifting rates matching the local Alfvén velocity via electron motion along the Io flux tube is very fragile and carries internal contradictions. Drifting radio emission fine structures in the time-frequency plane have been consistently attributed to the motion of upgoing electrons along magnetic field lines locally generating emission at $f \approx f_{ce}$, by many authors and with various supporting arguments [*Ellis*, 1965; *Zarka et al.*, 1996; *Hess et al.*, 2007a]. While Jovian (short) S-bursts, drifting at some −20 to −25 MHz s^{-1}, imply electron energies about 5 keV [*Zarka et al.*, 1996; *Hess et al.*, 2007a, and references therein], SDS drifts at -5 ± 2 MHz would correspond to electron energies ~100 eV (~50 to ~200 eV). Note that energies of the order of 175 eV are precisely those inferred for the warm core of electron distributions in the Io flux tube [*Bagenal*, 1994].

[12] Alfvén waves have been convincingly proposed for the energization of these electrons [*Su et al.*, 2004; *Hess et al.*, 2007b, and references therein], but not for the direct production of radio emission. The interaction between Alfvén waves and the electrons is not resonant, and thus the Alfvén velocity has no reason to be equal to the electrons velocity [*Hess et al.*, 2007b; *Mottez and Génot*, 2011]. Furthermore, following *Hess et al.* [2007a], *Koshida et al.* [2010a] suggest that SDS slope changes in dynamic spectra could be due to potential drops (strong double layers) along the Io flux tube. We support this interpretation, further noting that the amplitude of these potential drops should be a few 10 s eV (as compared to a few 100 s eV in the S-bursts case [*Hess et al.*, 2009]), but it excludes Alfvén waves at the origin of SDS drifts because double layers affect the motion of (upgoing) electrons, not of Alfvén waves.

6. Conclusion

[13] Thus, after concluding (1) that the plasma density deduced from the two hypotheses (CMI + Alfvén waves) is neither compatible with these two hypotheses nor realistic, we must conclude (2) that the proposed interpretation of SDS is not valid. But, because the inferred plasma densities are not realistic, nothing here permits to question the well-established CMI as the source of the background DAM L-burst emission. The only reasonable conclusion is thus to reject the other hypothesis, i.e., the SDS drifts cannot be due to a perturbation at the local Alfvén velocity, and are not the direct signature of Alfvén waves in DAM sources. Contrary to the rejection of the CMI, the rejection of the direct relationship between SDS frequency drifts and the Alfvén velocity is not polemic, because this hypothesis led to internal contradictions (about slope and slope change interpretations) in *Koshida et al.*, [2010a], and because upgoing electron bunches with 100 s eV energy have already been invoked in the previous literature for producing drifting radio emissions.

Therefore, (3) the absorption mechanism proposed by *Gopalswamy* [1986], i.e., absorption of background CMI-generated decameter emission by weakly energetic (∼100 eV) upgoing electron beams with a velocity distribution stable relative to the CMI, remains the most probable scenario for SDS extinctions. Other phenomena may be invoked, e.g., acoustic waves (instead of Alfvén waves or electrons beams) with a velocity more in agreement with SDS drifts, but they seem less likely to us and would anyway deserve a specific study. Note that this does not rule out any role for Alfvén waves, as those could generate the electron beams in a manner similar to what has been proposed to explain S-bursts [*Hess et al.*, 2007b].

[14] **Acknowledgment.** Robert Lysak thanks the reviewer for his or her assistance in evaluating the manuscript.

References

Bagenal, F. (1994), Empirical model of the Io plasma torus: Voyager measurements, *J. Geophys. Res.*, *99*, 11,043–11,062, doi:10.1029/93JA02908.

Ellis, G. R. A. (1965), The decametric radio emission of Jupiter, *J. Res. Natl. Bur. Stand., Sect. D*, *69*, 1513–1530.

Galopeau, P. H. M., M. Y. Boudjada, and H. O. Rucker (2004), Evidence of Jovian active longitude: 1. Efficiency of cyclotron maser instability, *J. Geophys. Res.*, *109*, A12217, doi:10.1029/2004JA010459.

Gopalswamy, N. (1986), A theory of Jovian shadow bursts, *Earth Moon Planets*, *35*, 93–115, doi:10.1007/BF00117270.

Hess, S., P. Zarka, and F. Mottez (2007a), Io-Jupiter interaction, millisecond bursts and field aligned potentials, *Planet. Space Sci.*, *55*, 89–99, doi:10.1016/j.pss.2006.05.016.

Hess, S., F. Mottez, and P. Zarka (2007b), Jovian S burst generation by Alfvén waves, *J. Geophys. Res.*, *112*, A11212, doi:10.1029/2006JA012191.

Hess, S., F. Mottez, P. Zarka, and T. Chust (2008), Generation of the Jovian radio decametric arcs from the Io flux tube, *J. Geophys. Res.*, *113*, A03209, doi:10.1029/2007JA012745.

Hess, S., P. Zarka, F. Mottez, and V. B. Ryabov (2009), Electric potential jumps in the Io-Jupiter flux tube, *Planet. Space Sci.*, *57*, 23–33, doi:10.1016/j.pss.2008.10.006.

Hess, S. L. G., B. Bonfond, P. Zarka, and D. Grodent (2011), Model of the Jovian magnetic field topology constrained by the Io auroral emissions, *J. Geophys. Res.*, *116*, A05217, doi:10.1029/2010JA016262.

Hilgers, A. (1992), The auroral radiating plasma cavities, *Geophys. Res. Lett.*, *19*, 237–240, doi:10.1029/91GL02938.

Hinson, D. P., J. D. Twicken, and E. T. Karayel (1998), Jupiter's ionosphere: New results from Voyager 2 radio occultation measurements, *J. Geophys. Res.*, *103*, 9505–9520, doi:10.1029/97JA03689.

Koshida, T., T. Ono, M. Iizima, and A. Kumamoto (2010a), Jovian slow-drift shadow events, *J. Geophys. Res.*, *115*, A01202, doi:10.1029/2009JA014608.

Koshida, T., T. F. Shibata, S. Taguchi, and H. Misawa (2010b), Characteristics of Jovian ionospheric Alfvén resonator observed by using wave modulations of L-burst emissions, *J. Geophys. Res.*, *115*, A12213, doi:10.1029/2010JA016065.

Le Quéau, D., R. Pellat, and A. Roux (1985), The Maser synchrotron instability in an inhomogeneous medium: Application to the generation of auroral kilometric radiation, *Ann. Geophys.*, *3*, 273–292.

Louarn, P., and D. Le Quéau (1996), Generation of the auroral kilometric radiation in plasma cavities–I. Experimental study, *Planet. Space Sci.*, *44*, 199–210, doi:10.1016/0032-0633(95)00121-2.

Millward, G., S. Miller, T. Stallard, and A. D. Aylward (2002), On the dynamics of the Jovian ionosphere and thermosphere: III. The modelling of auroral conductivity, *Icarus*, *160*, 95–107, doi:10.1006/icar.2002.6951.

Mottez, F., and V. Génot (2011), Electron acceleration by an Alfvénic pulse propagating in an auroral plasma cavity, *J. Geophys. Res.*, *116*, A00K15, doi:10.1029/2010JA016367.

Strobel, D. F., and S. K. Atreya (1983), Ionosphere, in *Physics of the Jovian Magnetosphere*, edited by A. J. Dessler, pp. 51–67, Cambridge Univ. Press, Cambridge, U. K., doi:10.1017/CBO9780511564574.004.

Su, Y., R. E. Ergun, F. Bagenal, and P. A. Delamere (2003), Io-related Jovian auroral arcs: Modeling parallel electric fields, *J. Geophys. Res.*, *108*(A2), 1094, doi:10.1029/2002JA009247.

Su, Y.-J., S. T. Jones, R. E. Ergun, and S. E. Parker (2004), Modeling of field-aligned electron bursts by dispersive Alfvén waves in the dayside auroral region, *J. Geophys. Res.*, *109*, A11201, doi:10.1029/2003JA010344.

Treumann, R. A. (2006), The electron cyclotron maser for astrophysical application, *Astron. Astrophys. Rev.*, *13*, 229–315, doi:10.1007/s00159-006-0001-y.

Zarka, P. (1998), Auroral radio emissions at the outer planets: Observations and theories, *J. Geophys. Res.*, *103*, 20,159–20,194, doi:10.1029/98JE01323.

Zarka, P., T. Farges, B. P. Ryabov, M. Abada-Simon, and L. Denis (1996), A scenario for Jovian S-bursts, *Geophys. Res. Lett.*, *23*, 125–128, doi:10.1029/95GL03780.

Zarka, P., J. Queinnec, and F. Crary (2001), Low-frequency limit of Jovian radio emissions and implications on source locations and Io plasma wake, *Planet. Space Sci.*, *49*, 1137–1149, doi:10.1016/S0032-0633(01)00021-6.