Enhanced radial diffusion in Jupiter's Radiation Belt induced by solar wind: a simulation study

Sooman Han[1], Go Murakami[2], Atsushi Yamazaki[2], Masato Nakamura[2]

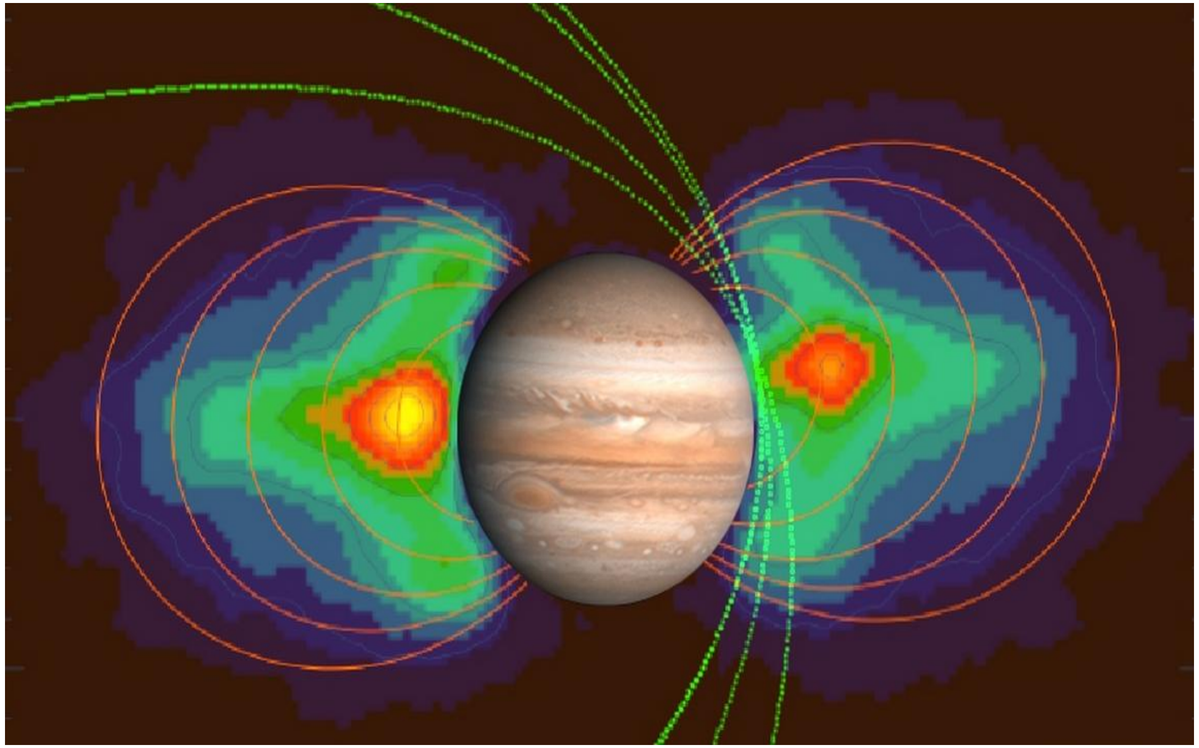
Feb. 21/2017, Symposium on Planetary Science in Sendai

1. Department of Earth and Planetary Science, the University of Tokyo

2. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency

What is Radiation Belt?

- A layer of energetic charged particles that is held in place around the Earth and Outer planets like Jupiter.
- ~ Several tens of MeV electrons can be found in Jovian radiation belt (JRB) ($1R_J$~$4R_J$; R_J: Jovian radii).



Comparison of Earth and Jupiter Magnetosphere

Electric field

Earth

$\boldsymbol{E_{corotational}}$ $\mathbf{0.4[mV/m]}$ **at** $\mathbf{6R_E}$

$\sim\boldsymbol{E_{convection, solar\ wind}}$ $\mathbf{0.4[mV/m]}$

->Combined environment

VS

Jupiter

$\boldsymbol{E_{corotational}}$ $\mathbf{150[mV/m]}$ **at** $\mathbf{6R_J}$

$\gg$ $\boldsymbol{E_{convection, solar\ wind}}$ $\mathbf{0.4[mV/m]}$

->Rotational dominated environment

Predominant electric field for radial diffusion

Earth

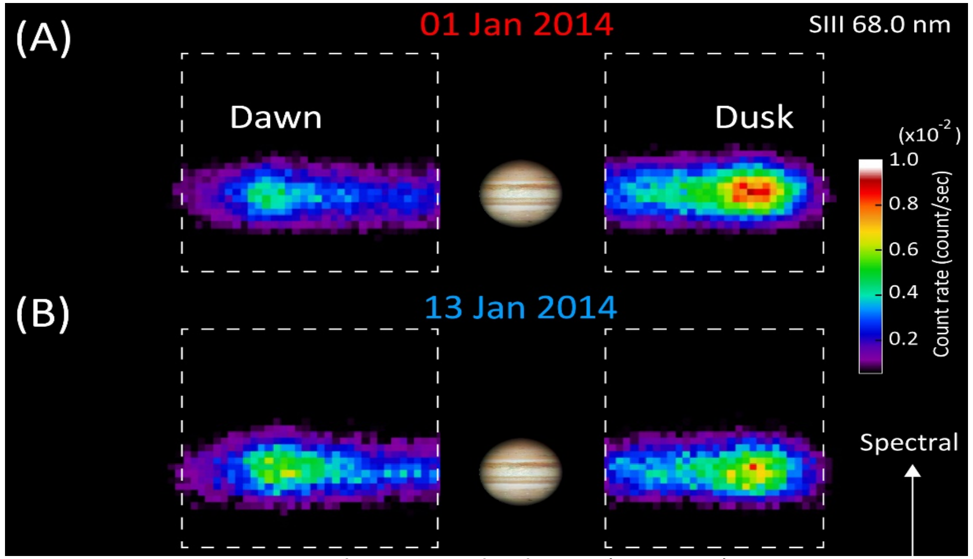
Convection electric field perturbation by solar wind [Cornwall 1972]

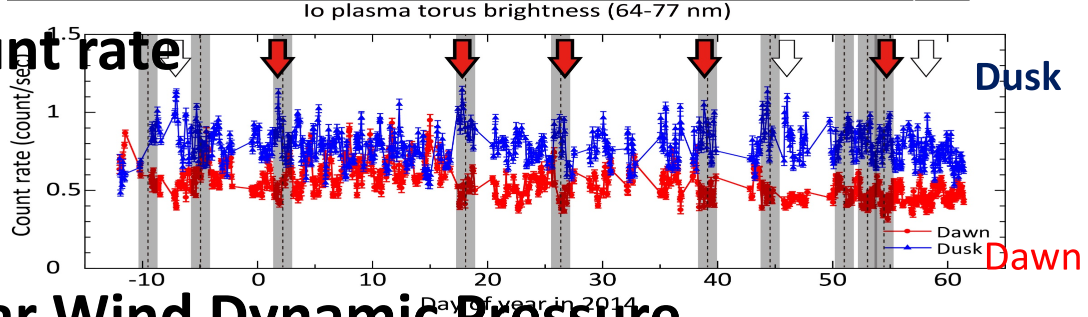
VS

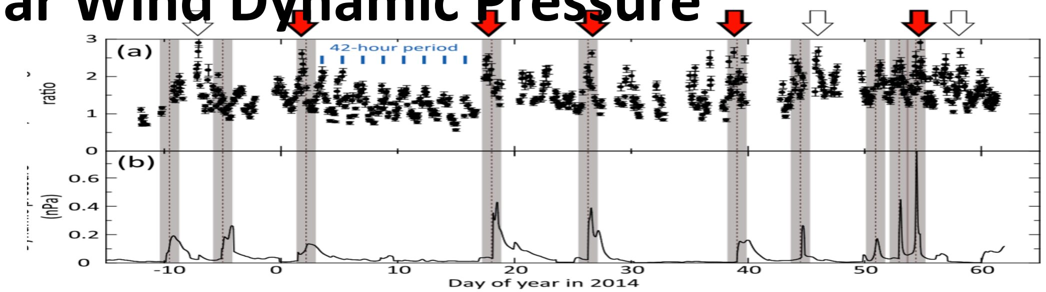
Jupiter

Dynamo electric field perturbation [Brice et al. 1972]

A new finding by HISAKI – Io Plasma Torus (IPT) response to solar wind [Murakami et al. 2016]







Drift paths of IPT plasmas shifted toward dawn side by dawn-to-dusk electric field ?(so that plasmas become hotter at dusk)

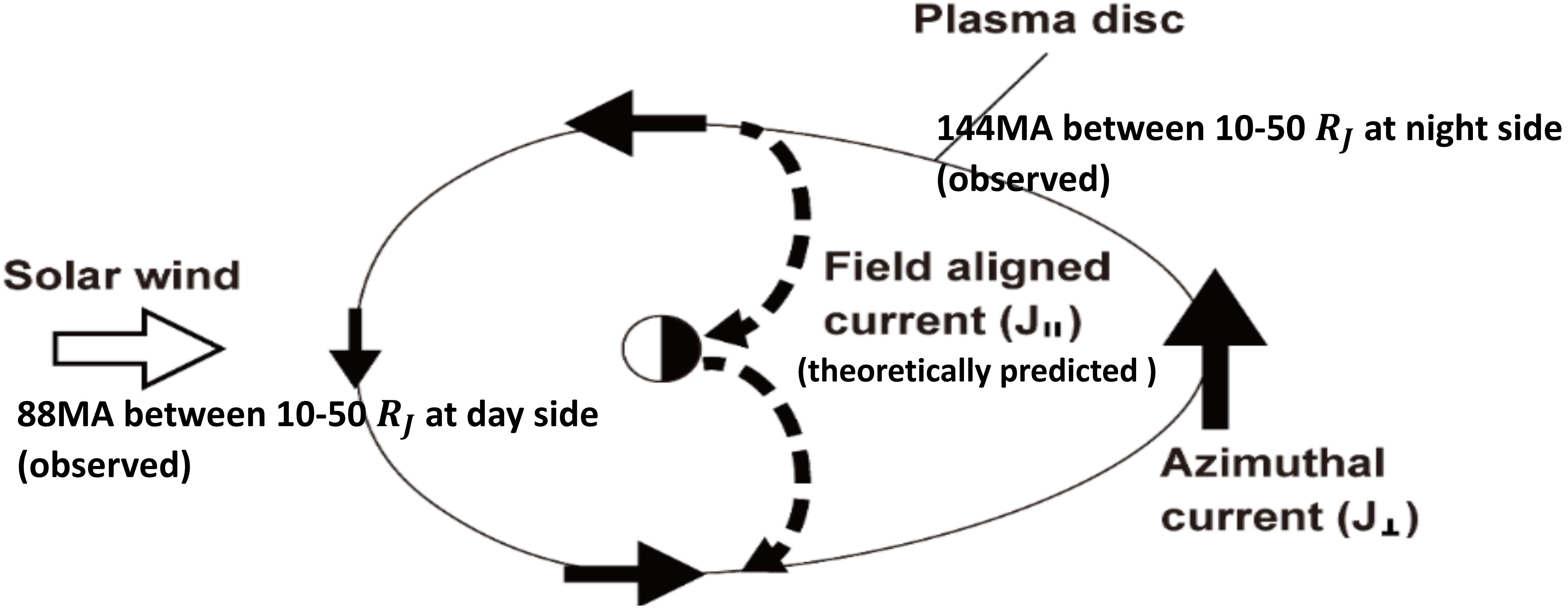
-> If true, its amplitude **4-9[mV/m]** can be deduced from brightness ratio.

->If true, what is the source of the electric field? (Electric field of solar wind itself ($\mathbf{0.4[mV/m]}$)is not supposed to be it.)

HISAKI has discovered solar wind influence reaches deep into the heart of Jupiter`s magnetosphere!

From G. Murakami et al. 2016

The origin of convection electric field –induced by Field Aligned Current [Khurana et al. 2001]



Khurana et al. theoretically predicted that **FAC (thus convection electric field) increases with higher dynamic pressure**

Purpose of my study

- HISAKI hinted at the fluctuating convection electric field with short temporal scale (days) related with solar wind.
- According to the dynamo electric field theory from [Brice et al. 1972], enhanced solar UV/EUV Flux is responsible for short-term JSR variation (a few % total flux density variation over days to weeks in several hundreds MHz to a few GHz) [Miyoshi et al. 1999; Santos-costa et al. 2008; Tsuchiya et al. 2011; Kita et al. 2015].
- **I would want to see whether the convection electric field (4-9[mV/m]) deduced from HISAKI could possibly bring about JSR variations of the same magnitude observed in the past?**

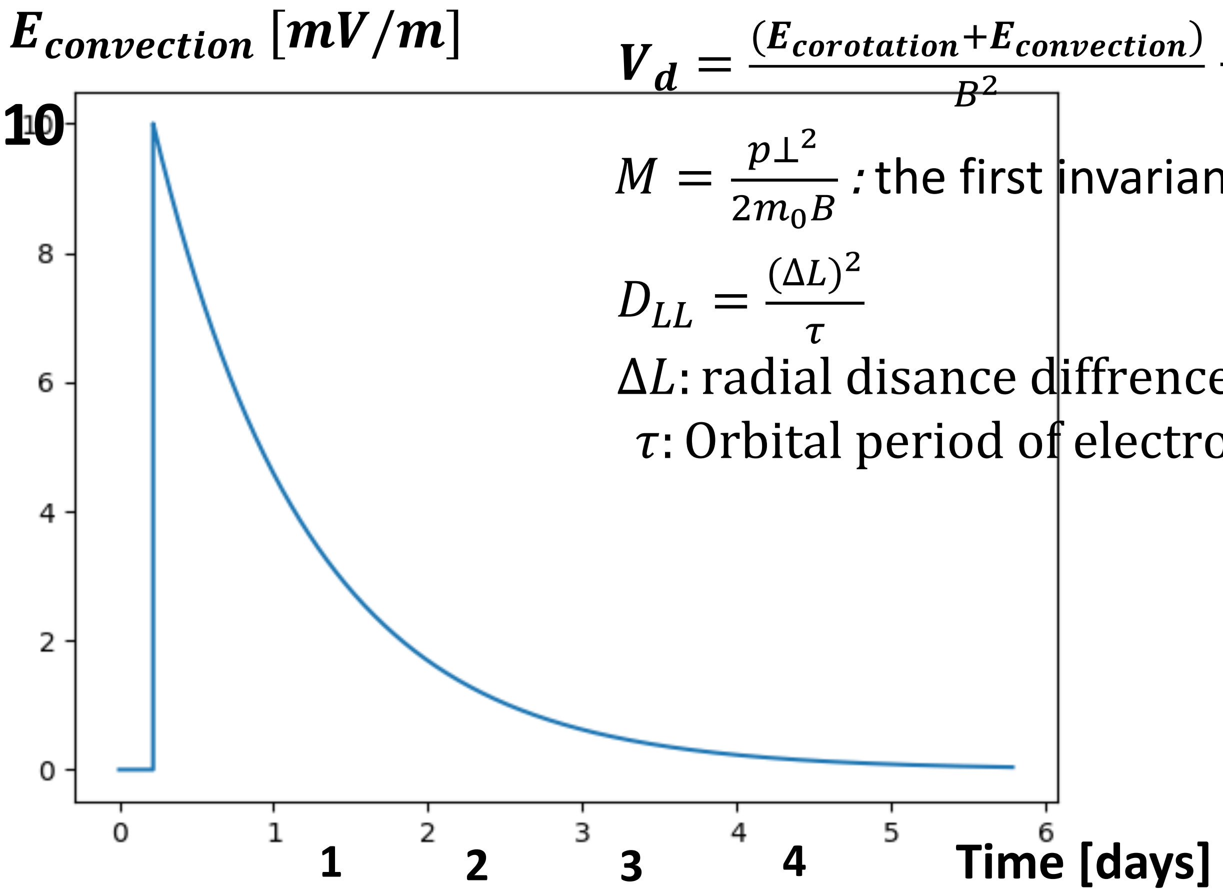
Method

1. I determined $\boldsymbol{D_{LL}(E_{convection})}$ (diffusion coefficient) from a numerical calculation, assuming the dipole magnetic field for various energy range (0.1~50MeV) electrons in equatorial plane $(p_{\parallel} = 0)$

2. I solved Planck-fokker equation (diffusion equation) to achieve a steady profile of electron distribution and confirmed that it is consistent with the empirical model from [Divine and Garrett, 1983]).

3. I solved time-dependent Planck-fokker equation with the $\boldsymbol{D_{LL}(E_{convection})}$, and calculated JSR variation at 2290MHz resulted therefrom, and compared the result from Miyoshi et al. 1999, where about 10% JSR variation at 2290MHz associated with enhanced UV/EUV solar flux ($\boldsymbol{D_{LL}\left(E_{enhanced\ dynamo}\right)}$) was reported.

Method 1 – Numerical calculation on drift path



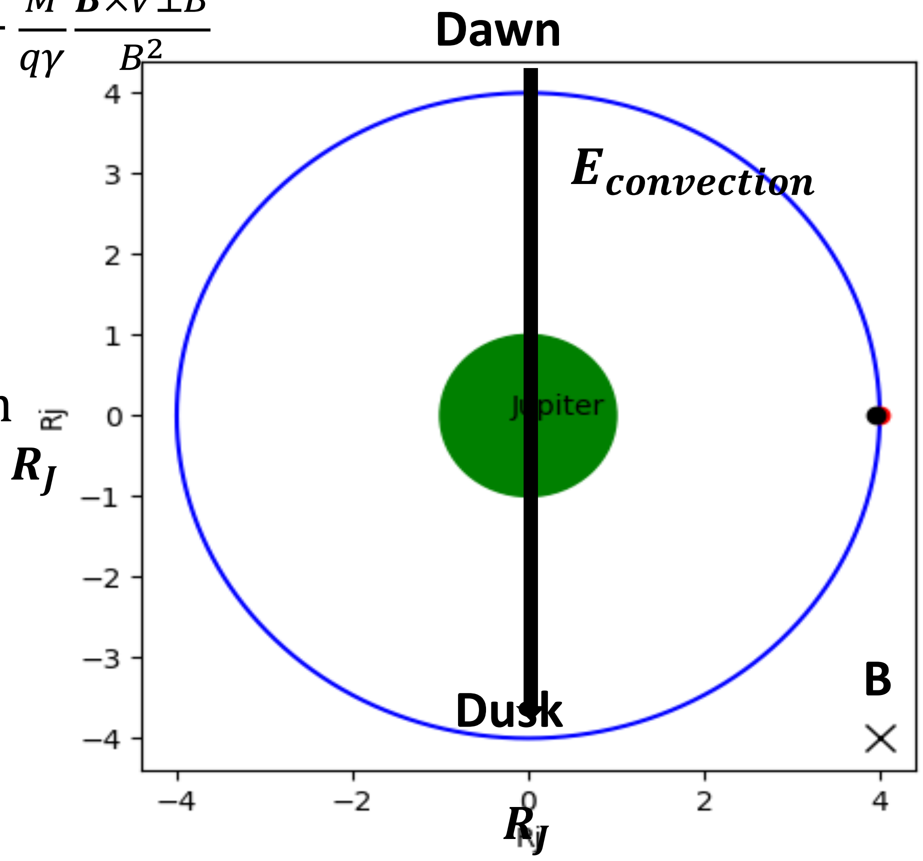
$$V_d = \frac{(E_{corotation} + E_{convection})}{B^2} + \frac{M}{q\gamma}\frac{B \times \nabla \perp B}{B^2}$$

$$M = \frac{p\perp^2}{2m_0 B}$$: the first invariant

$$D_{LL} = \frac{(\Delta L)^2}{\tau}$$

ΔL: radial disance diffrence

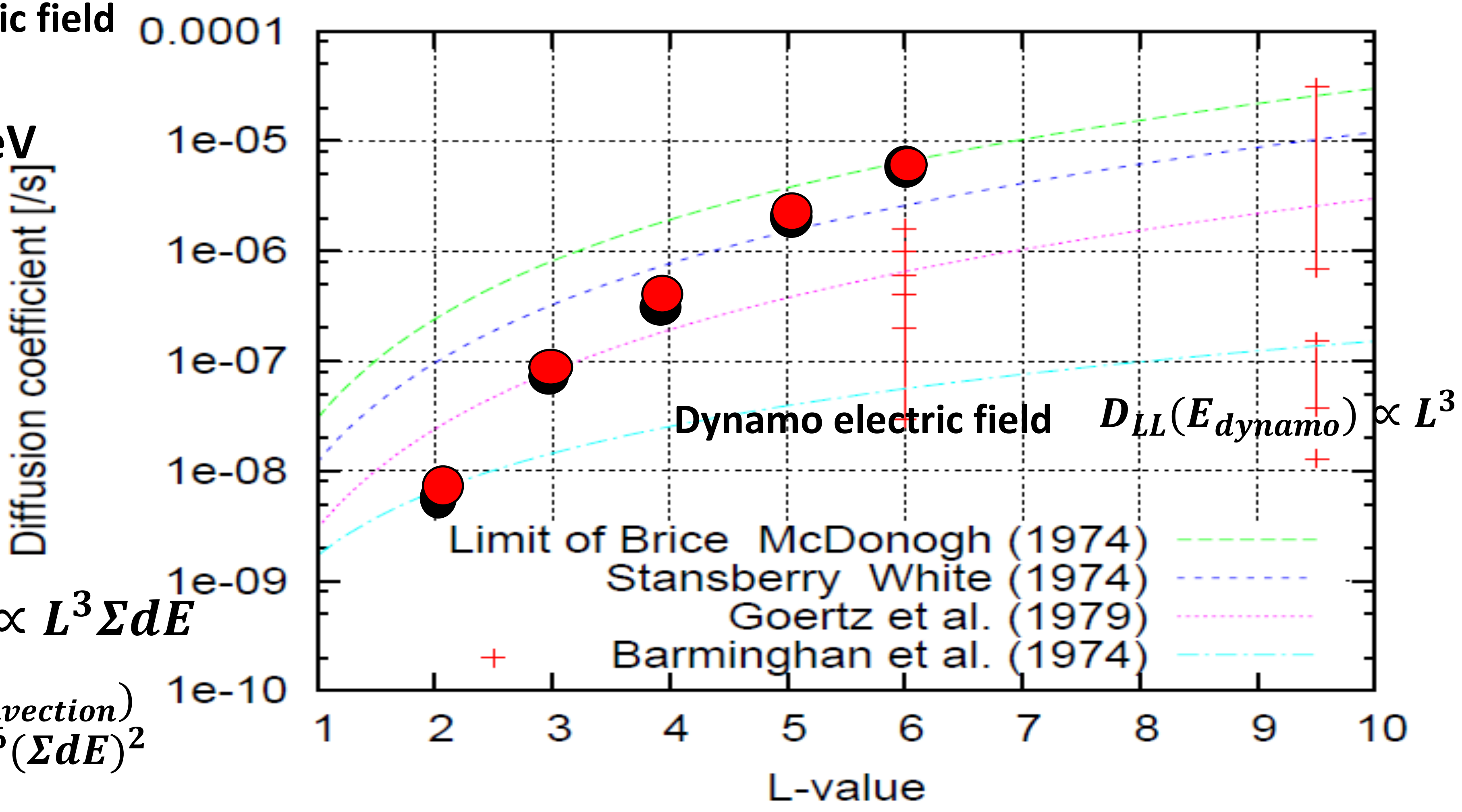
τ: Orbital period of electron



Method 1 - DLL result

Convection electric field

1MeV **20MeV**



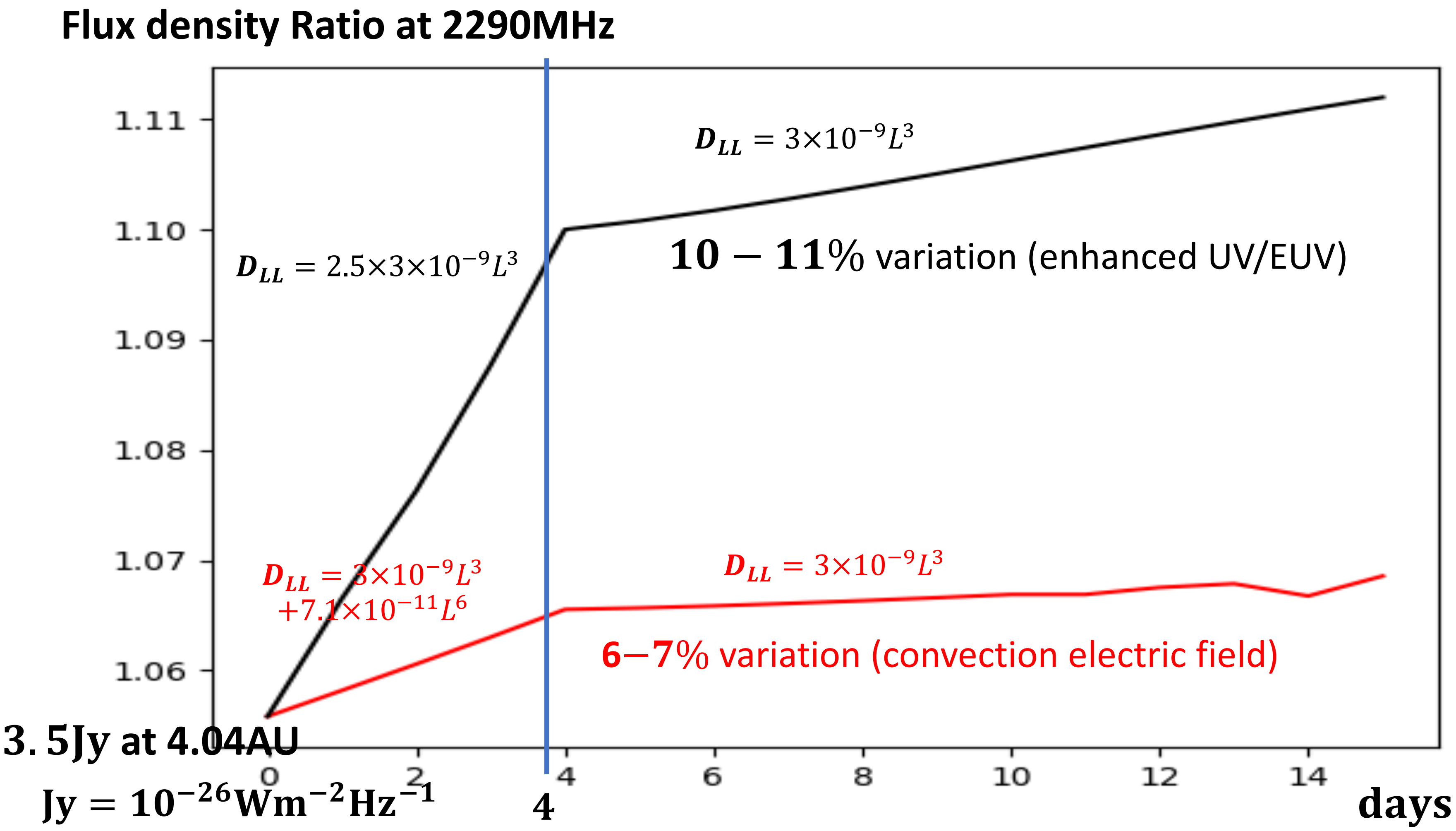
$$\frac{dL}{dt} = \frac{\Sigma dE}{B} \propto L^3 \Sigma dE$$

$$\therefore D_{LL}(E_{convection}) \propto dL^2 \propto L^6 (\Sigma dE)^2$$

Method 2 and 3- Fokker-Planck equation

- $\frac{\partial f}{\partial t} = L^2 \frac{\partial}{\partial L}\left(\frac{D_{LL}}{L^2}\frac{\partial f}{\partial L}\right) - \sum_{j=1}^{4}\frac{f}{\tau_j}$
- $D_{LL}(E_{dynamo}) = 3\times10^{-9}L^3$[Goertz et al. 1979] to achieve a steady state, and then $D_{LL}(E_{dynamo+convection}) = 3\times10^{-9}L^3 + 7.1\times10^{-11}L^6$, $D_{LL}(E_{enhanced\ dynamo}) = 2.5\times3\times10^{-9}L^3$ for 4 days to see the effects of the applied convection field and enhanced dynamo electric field respectively.
- $\tau_1, \tau_2, \tau_3, \tau_4$: the sweeping effects by the Jovian Ring (L=1.7-1.8) , by the moon Amalthea (L=2.4-2.7) (Hood [1993]), the energy degradation by synchrotron radiation (Hood [1993]) , pitch angle scattering (De Pater and Goertz [1990])
- Boundary condition at L=1.3 and L=6: [Baker and Van Allen 1976]
- W$(2290MHz)[WHz^{-1}m^{-2}] = \int_{W=0.1}^{W=50MeV}\int_{L=1.3}^{L=4} N\times\frac{P(2290MHz)}{A}dv$ after assuming longitudinal homogeneity and $1R_J$ thickness distribution [Tsuchiya et al. 2011; Kita et al. 2013]

Method 2 and 3 – JSR variation Result



Summary

- $D_{LL}(E_{convection})$ calculated from the convection electric field estimated from HISAKI has a comparable magnitude to the theoretical estimates of D_{LL} based on dynamo electric field theory.
- With the above $D_{LL}(E_{ctonvection})$, I achieved 6-7% JSR variation over a few days (c.f. 10-11 % JSR variation from $D_{LL}(E_{enhanced\ dynamo})$)
- Convection electric field can be a good source of radial diffusion and can also be responsible for short-term variation of JSR alongside with fluctuating dynamo electric field, if it ever really exists.

References

- Brice, N., and T. R. McDonough (1973), Jupiter’s radiation belts, Icarus, 18, 206–219, doi:10.1016/0019-1035(73)90204-2.
- Miyoshi, Y., H. Misawa, A. Morioka, T. Kondo, Y. Koyama, and J. Nakajima (1999), Observation of short-term variation of Jupiter’s synchrotron radiation, Geophys. Res. Lett., 26, 9–12, doi:10.1029/1998GL900244.
- Tsuchiya, F., H. Misawa, K. Imai, and A. Morioka (2011), Short-term changes in Jupiter’s synchrotron radiation at 325 MHz: Enhanced radial diffusion in Jupiter’s radiation belt driven by solar UV/EUV heating, J. Geophys. Res., 116, A09202, doi:10.1029/2010JA016303.
- Kita, H., H. Misawa, F. Tsuchiya, C. Tao, and A. Morioka (2013), Effect of solar UV/EUV heating on the intensity and spatial distribution of Jupiter’s synchrotron radiation, J. Geophys. Res. Space Physics, 118, 6106–6115, doi:10.1002/jgra.50568.
- Murakami, G., et al. (2016), Response of Jupiter’s inner magnetosphere to the solar wind derived from extreme ultraviolet monitoring of the Io plasma torus, Geophys. Res. Lett., 43, 12,308–12,316, doi:10.1002/ 2016GL071675.