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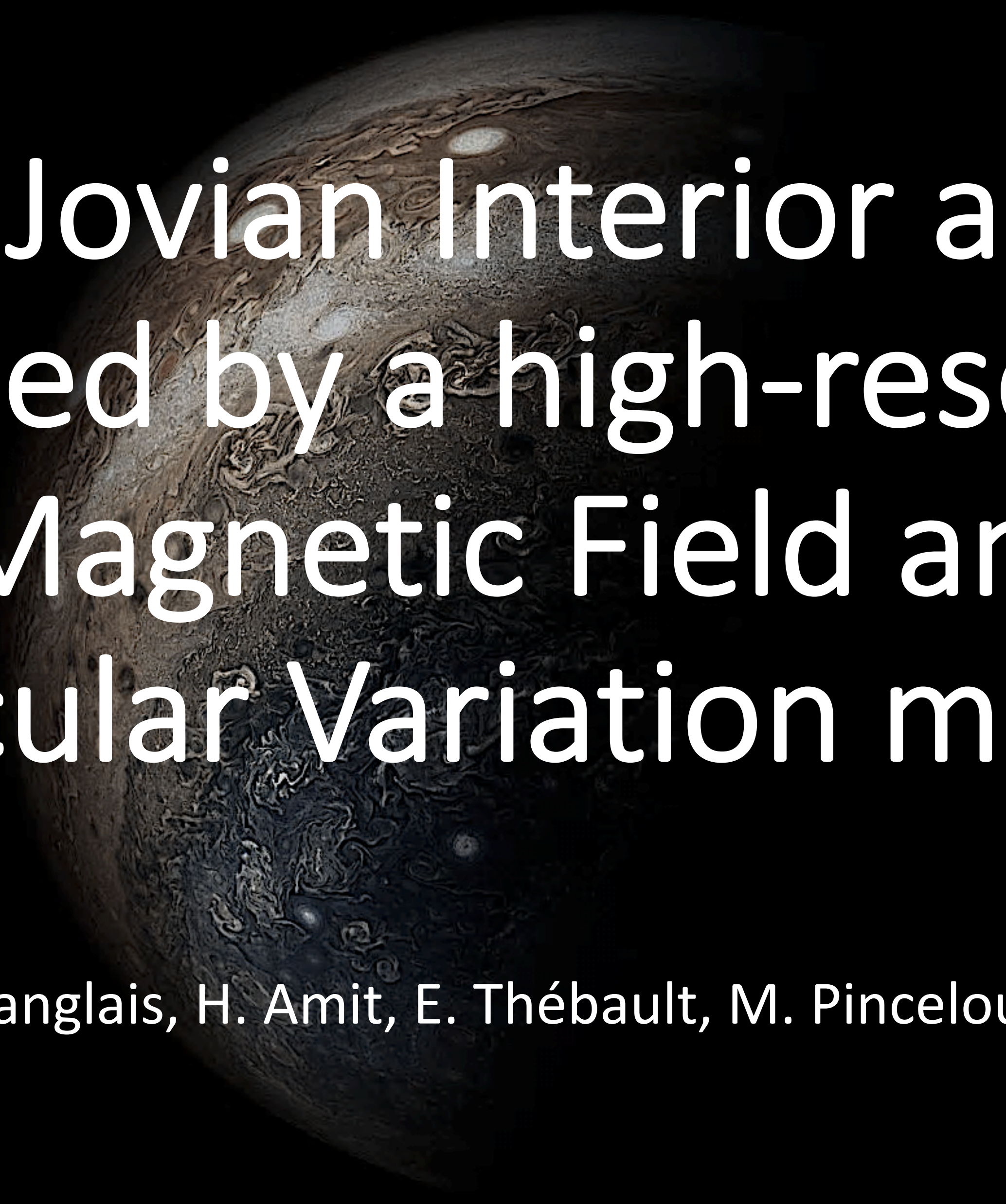
Outstanding Student & PhD candidate Presentation contest



Jovian Interior as unveiled by a high-resolution Magnetic Field and Secular Variation model

S. Sharan, B. Langlais, H. Amit, E. Thébault, M. Pinceloup, O. Verhoeven

CONTENT

- Background
- Our results
  - Model
  - Dynamo radius
  - Correlation times
  - Secular variation
- Future work

JUPITER

- Largest planet of the Solar System
  Equatorial Radius (R_J) – 71,492 km
- Distance from Sun – 5.2 AU
  Fifth planet
- Gaseous Giant
- Over 70 moons

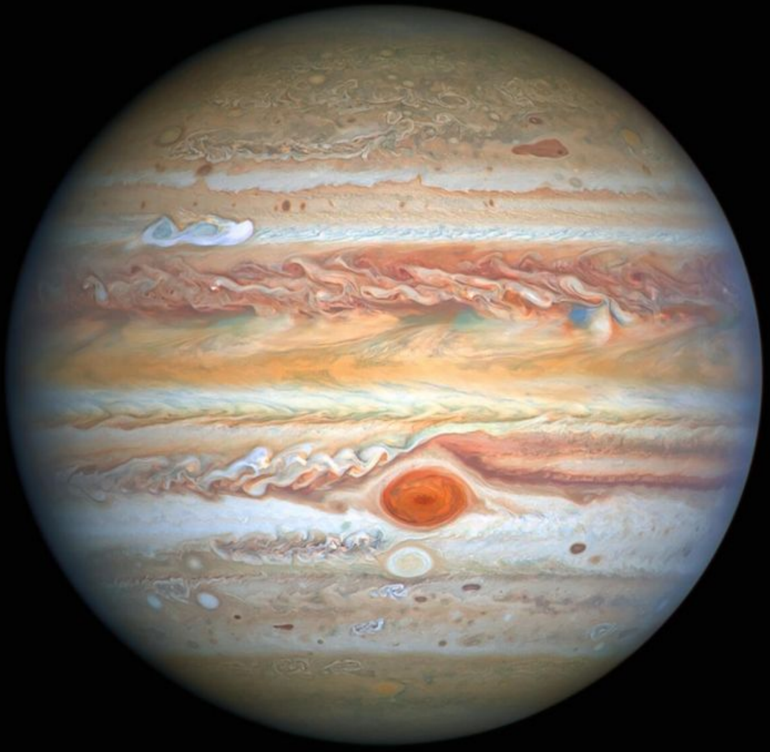


Image from NASA

INTERIOR OF JUPITER

- Core

  solid: heavy metals (0.2 R_J)

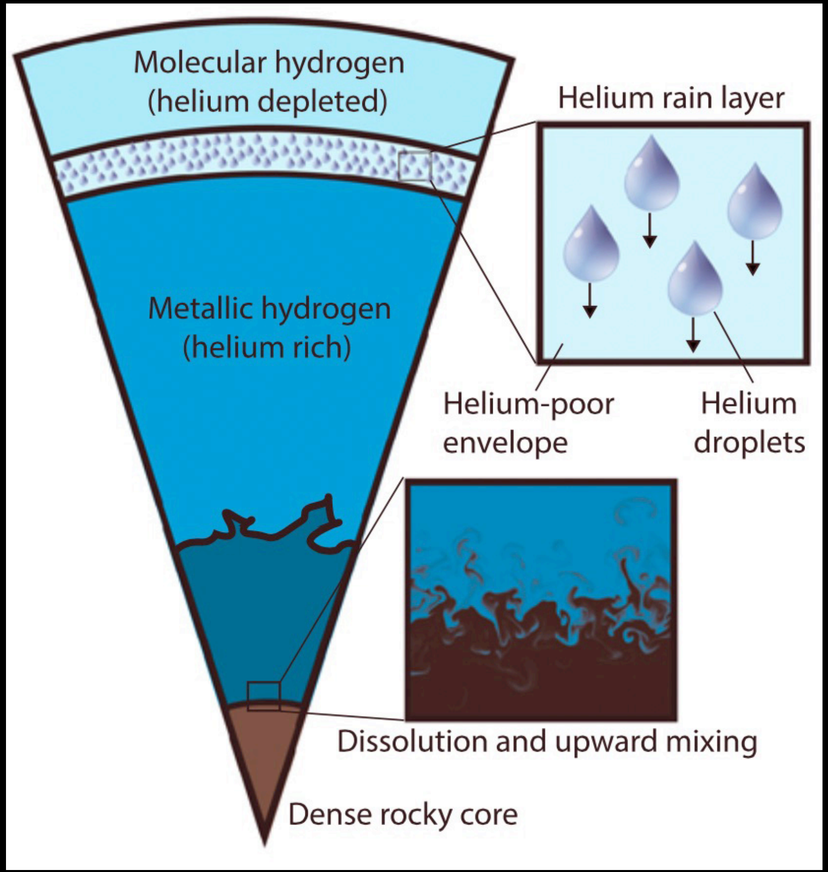
  possibly dilute (0.2 R_J – ??)

- Envelopes

  liquid metallic H + He (?? – 0.68 R_J)

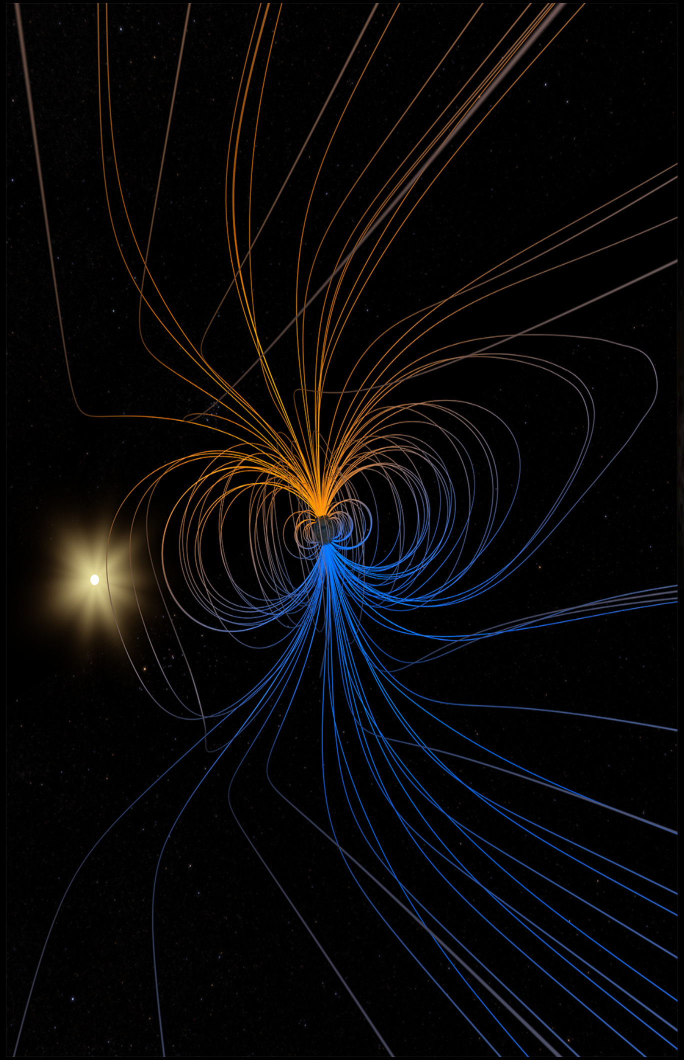
  transition layer: H-He phase separated layer (0.68 – 0.84 R_J)

  gaseous molecular H + He (0.84 – 1 R_J)



Wahl et al. 2017

MAGNETIC FIELDS



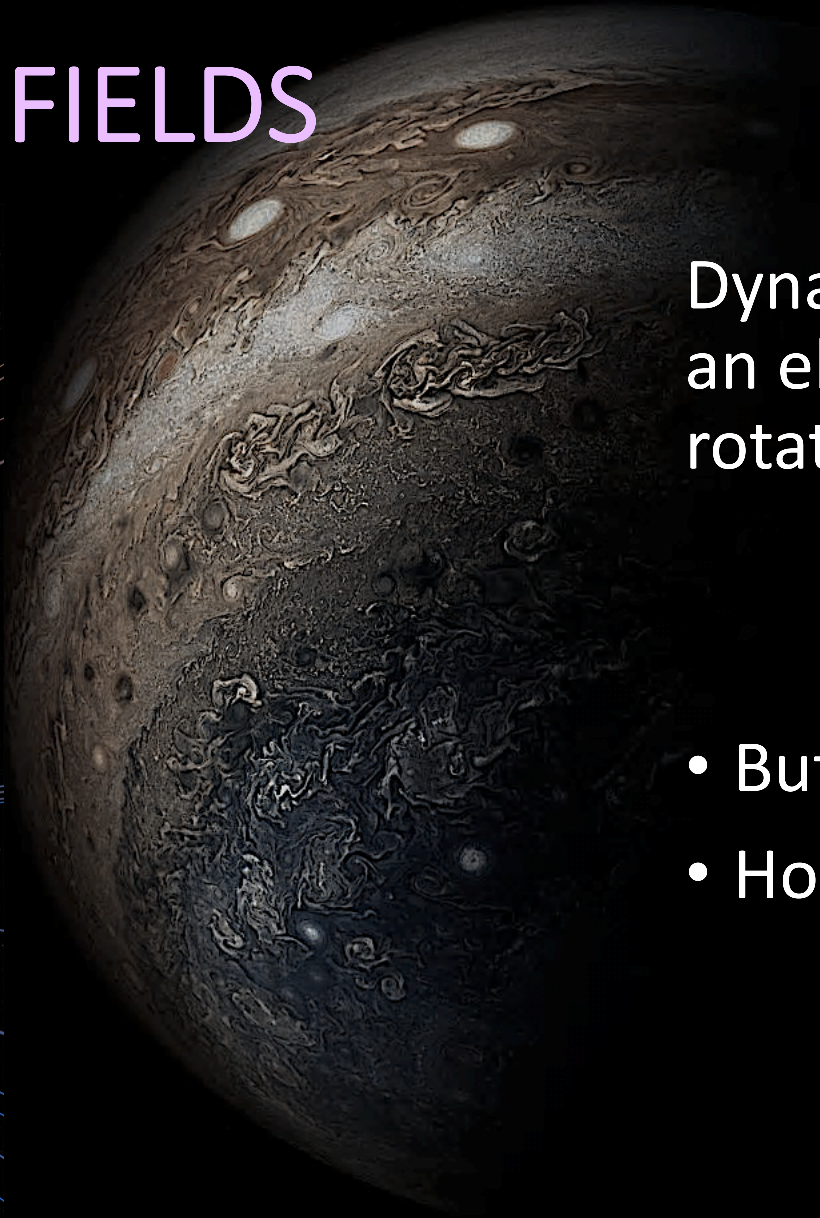


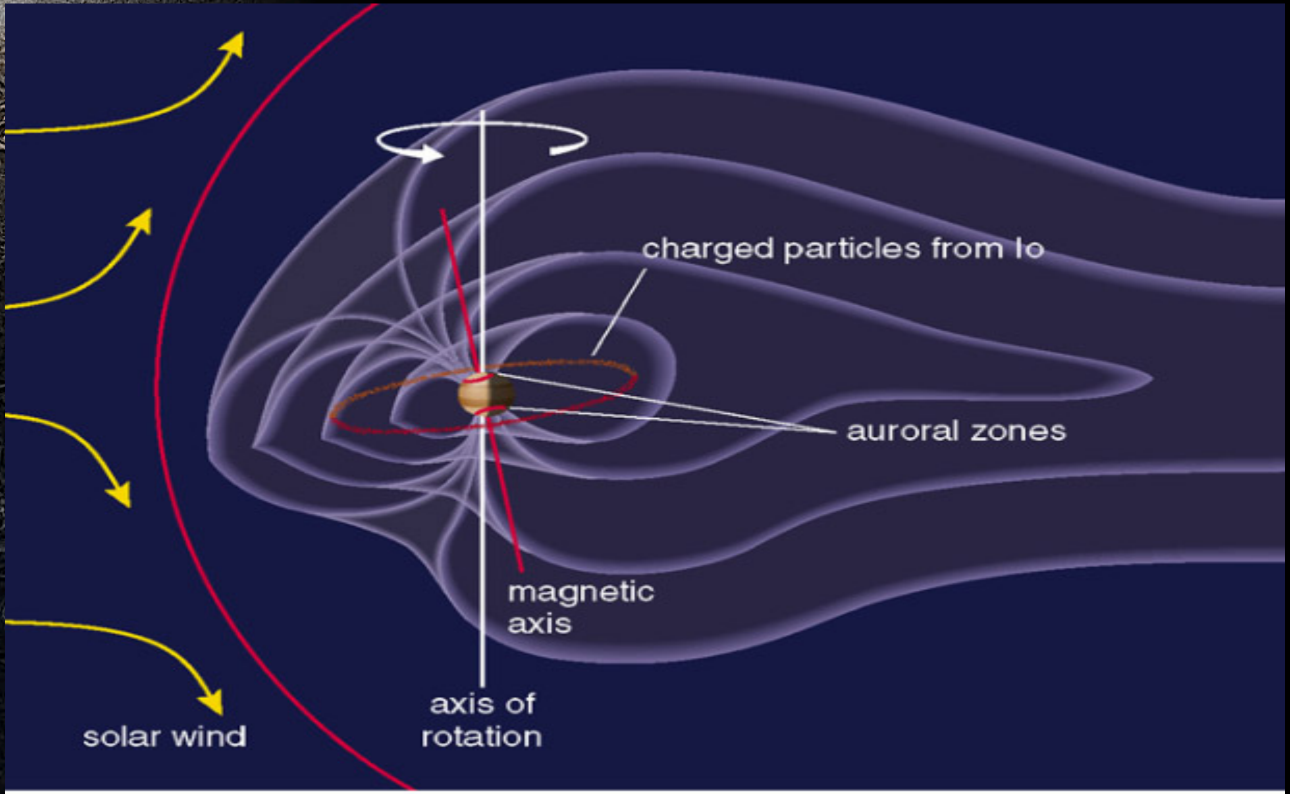
Image from NASA

Dynamo action due to convection of an electrically conductive fluid in rotating deep planetary envelops

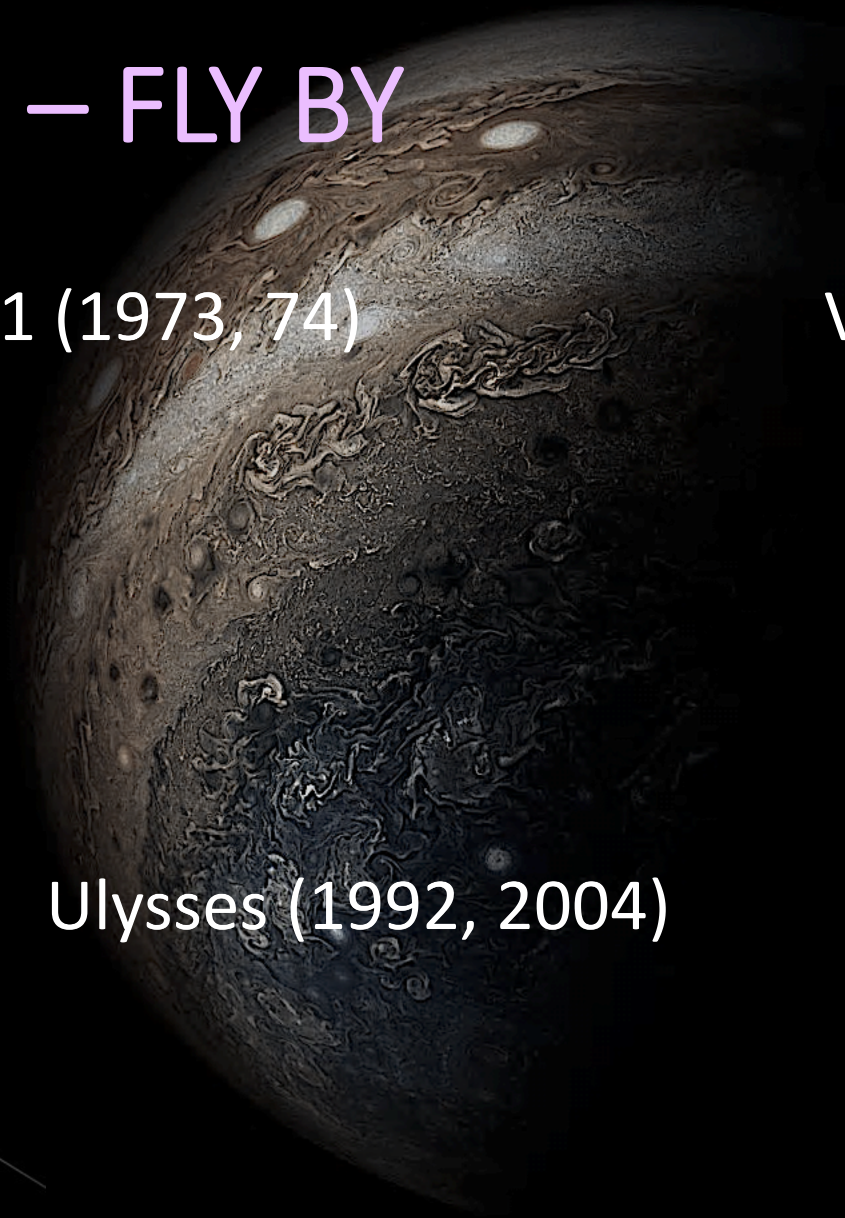
- But at what depth ??
- How does it change with time ??

MAGNETIC FIELD OF JUPITER

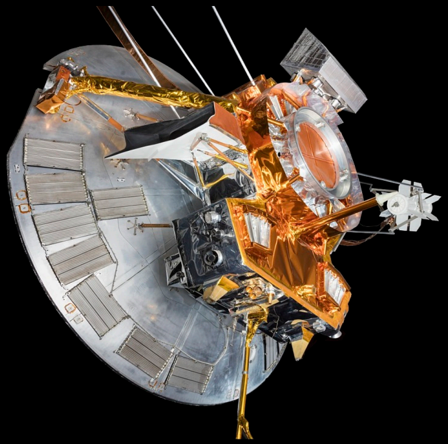
- $MF_{Jupiter}$ ~ 30 MF_{Earth}
- Internal field – metallic hydrogen
- External field – current systems surrounding the planet (e.g., plasma produced by Io)



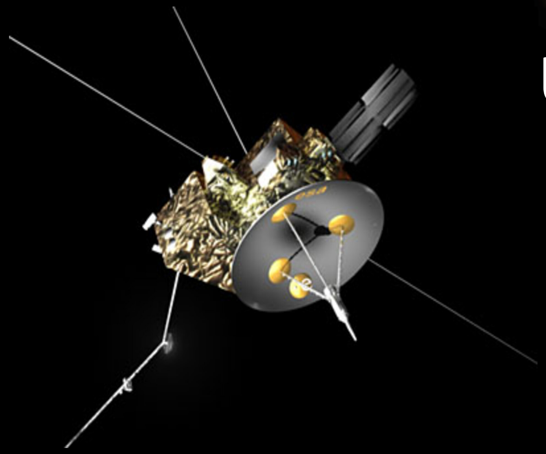
SATELLITES – FLY BY



Pioneer 10 and 11 (1973, 74)



Voyager 1 and 2 (1979)



Ulysses (1992, 2004)

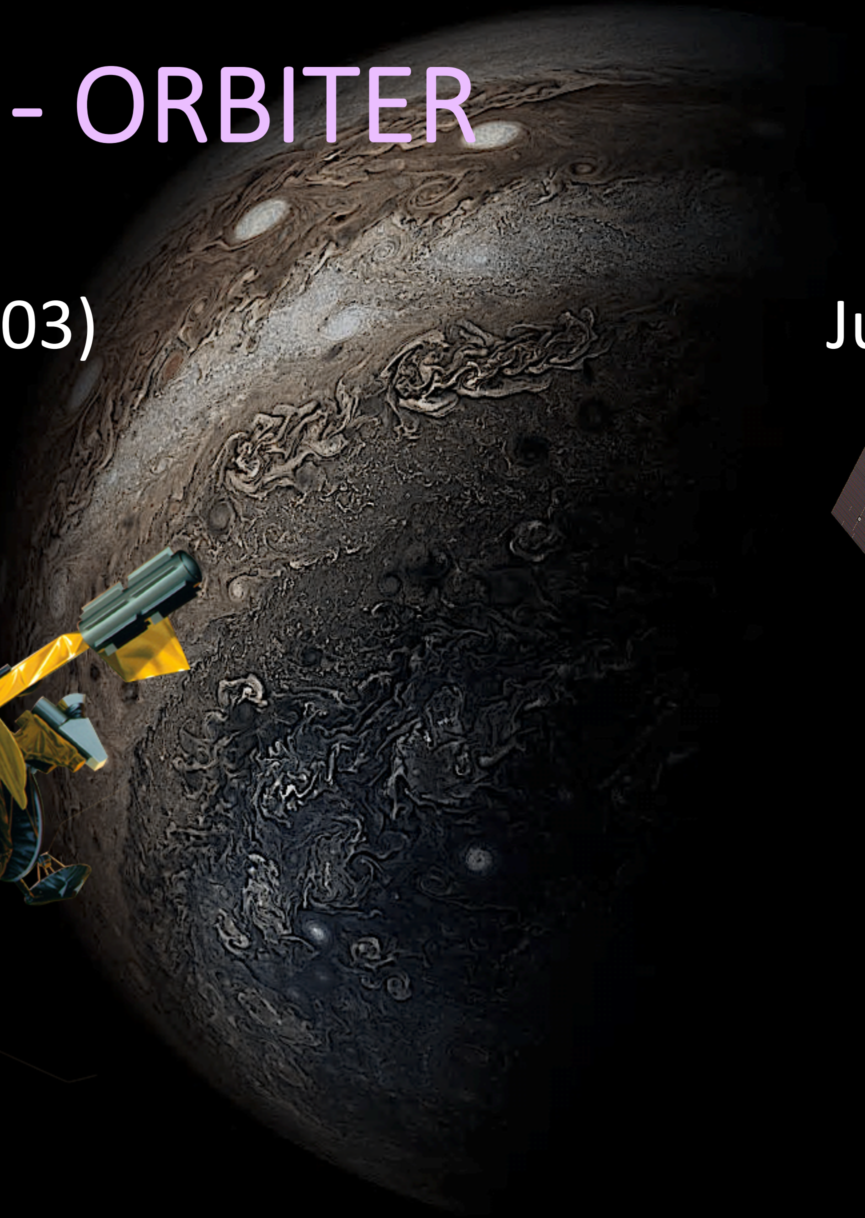
without magnetometers-

Cassini (2000)

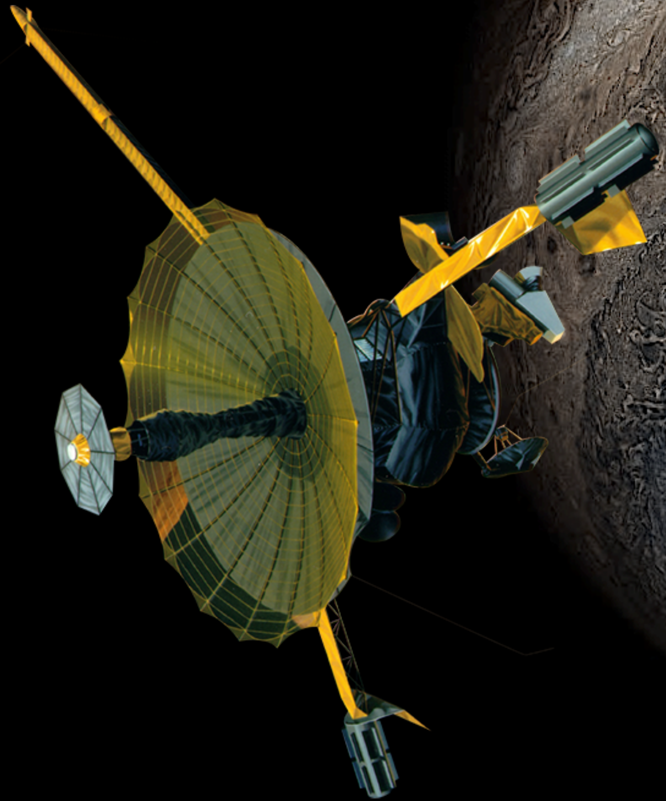
New Horizons (2007)

Images from NASA and ESA

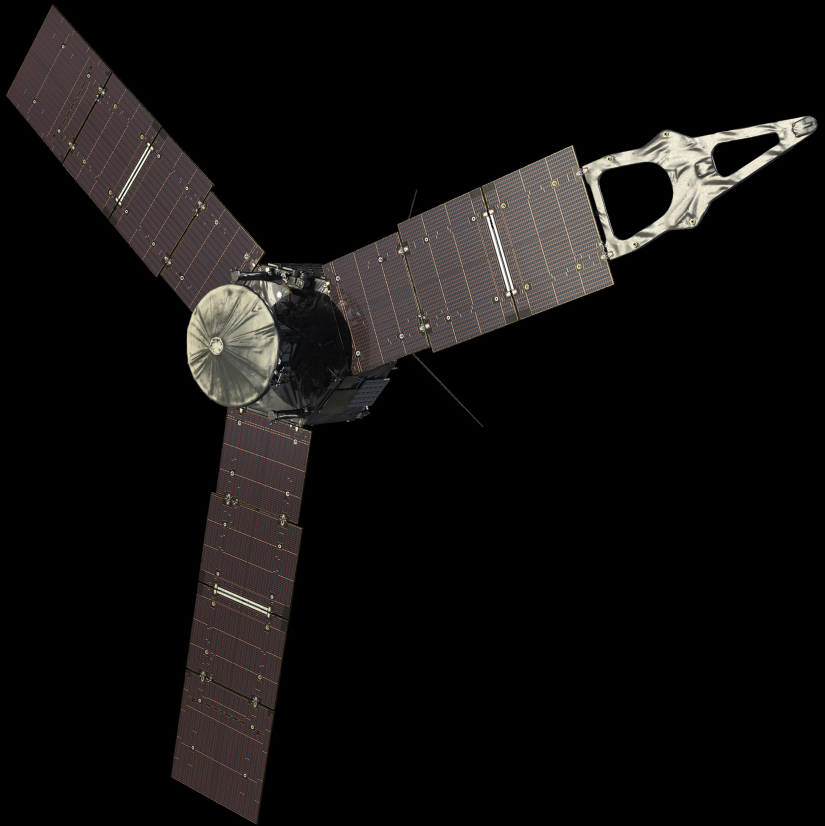
SATELLITES - ORBITER



Galileo (1995 - 2003)



Juno (2016 – present)



Images from NASA

JUNO

- Launch – August 5th, 2011
- Jupiter Orbit Insertion – July 4th, 2016
- Two Fluxgate Magnetometers
- Elliptical orbit (~53 days)

Bolton et al. 2017

JUNO

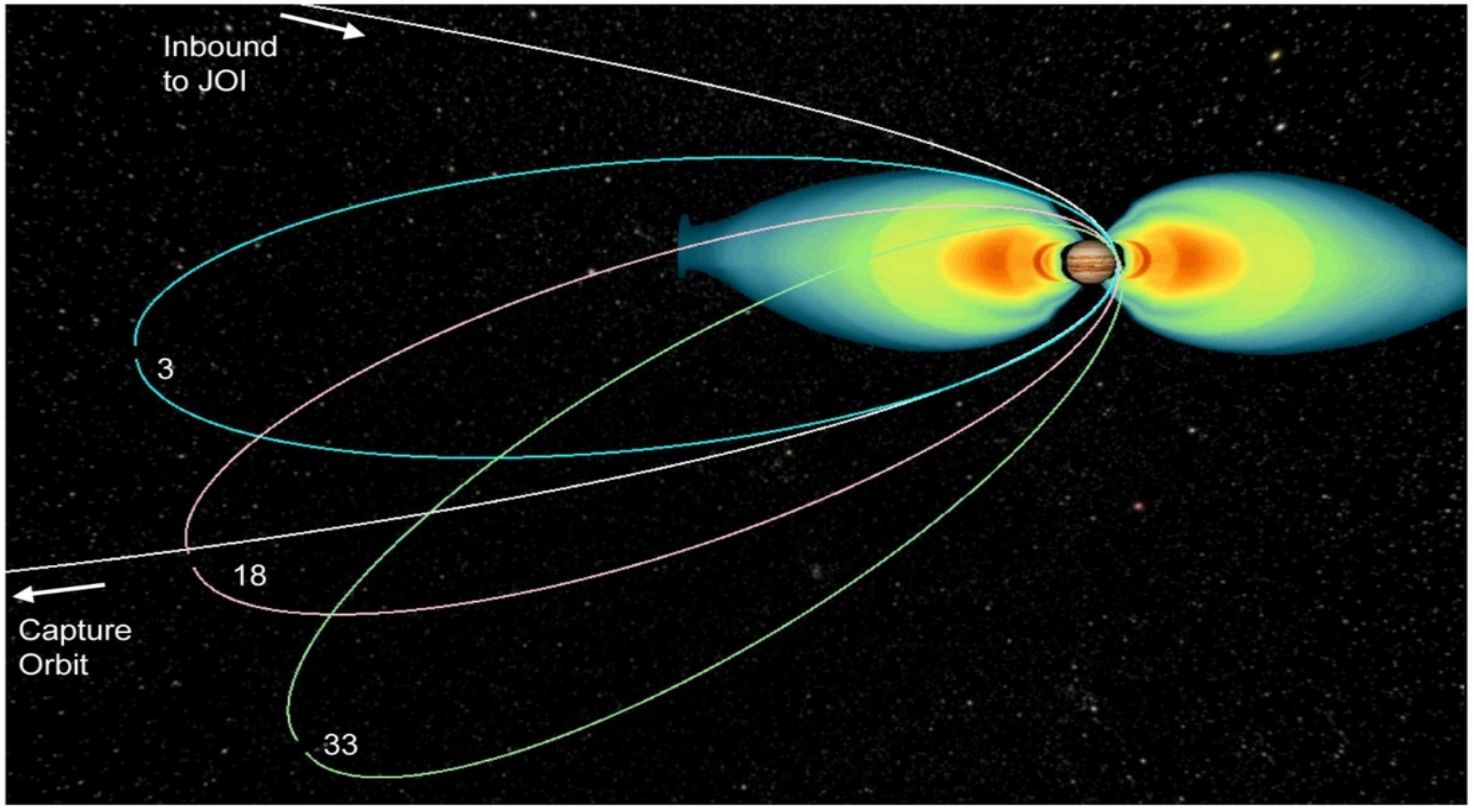


Image from NASA

Periapsis:

~2600 km near equator

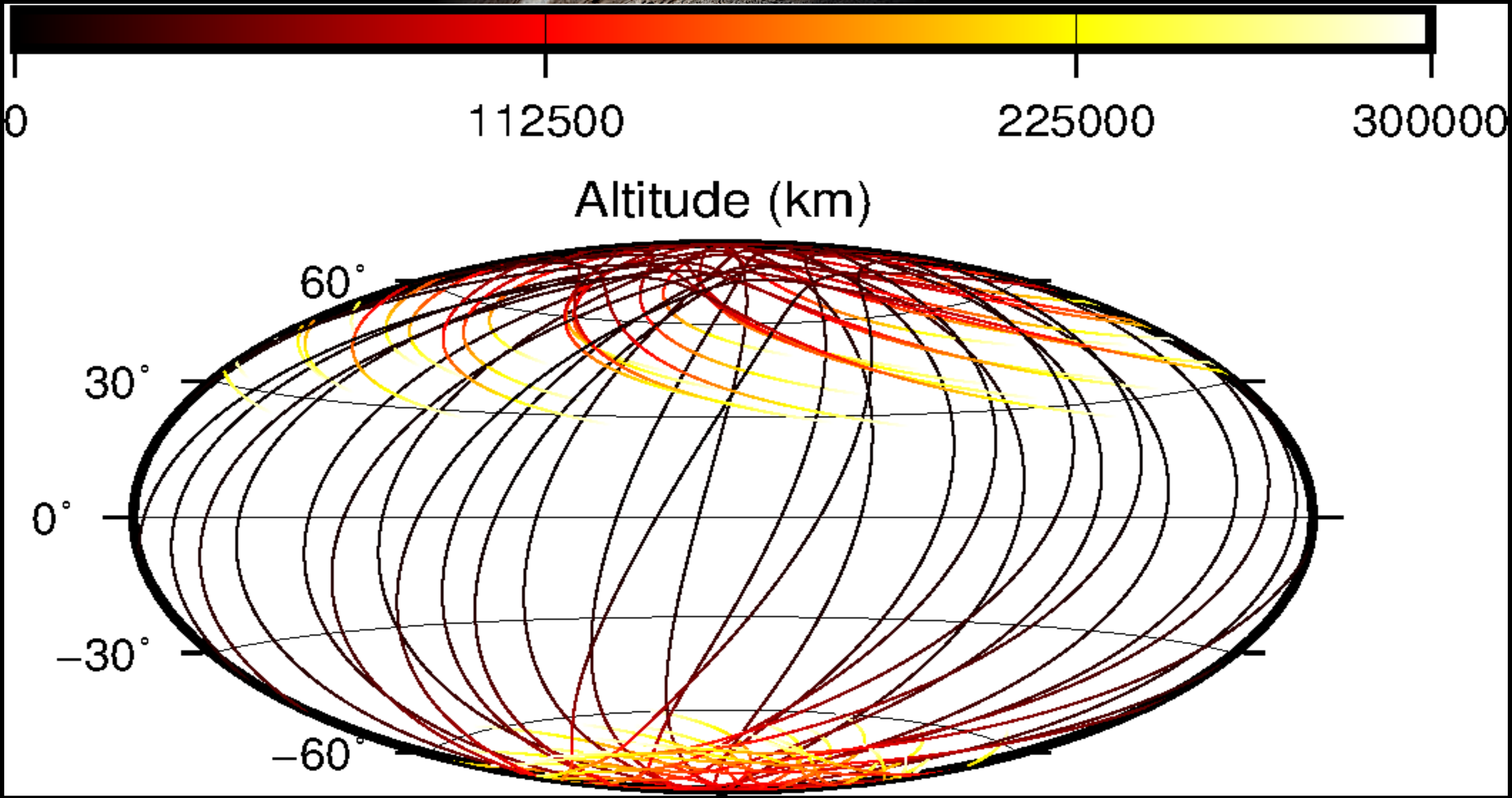
Precesses one degree northward in periapsis after every orbit.

Apoapsis:

> 100 Jupiter radius

Mission extended to 75 orbits

JUNO



SPHERICAL HARMONIC (SH) MODEL

JUNO DATA-

- Polar orbit
- 1 second data
- Below 300,000 km (~5.2 R_J)
- First 28 perijoves (w/o 2,19)
- Data span – Aug ‘16 to July ‘20
- 628,828 vector data

METHOD-

- SH main field (n=16) and SV (n=8)
- Least-square inversion
- Instrument error as weights
- Secular variation (SV) using B-Splines
- Synthetic tests on CHAOS-7.8

MODEL POWER SPECTRA

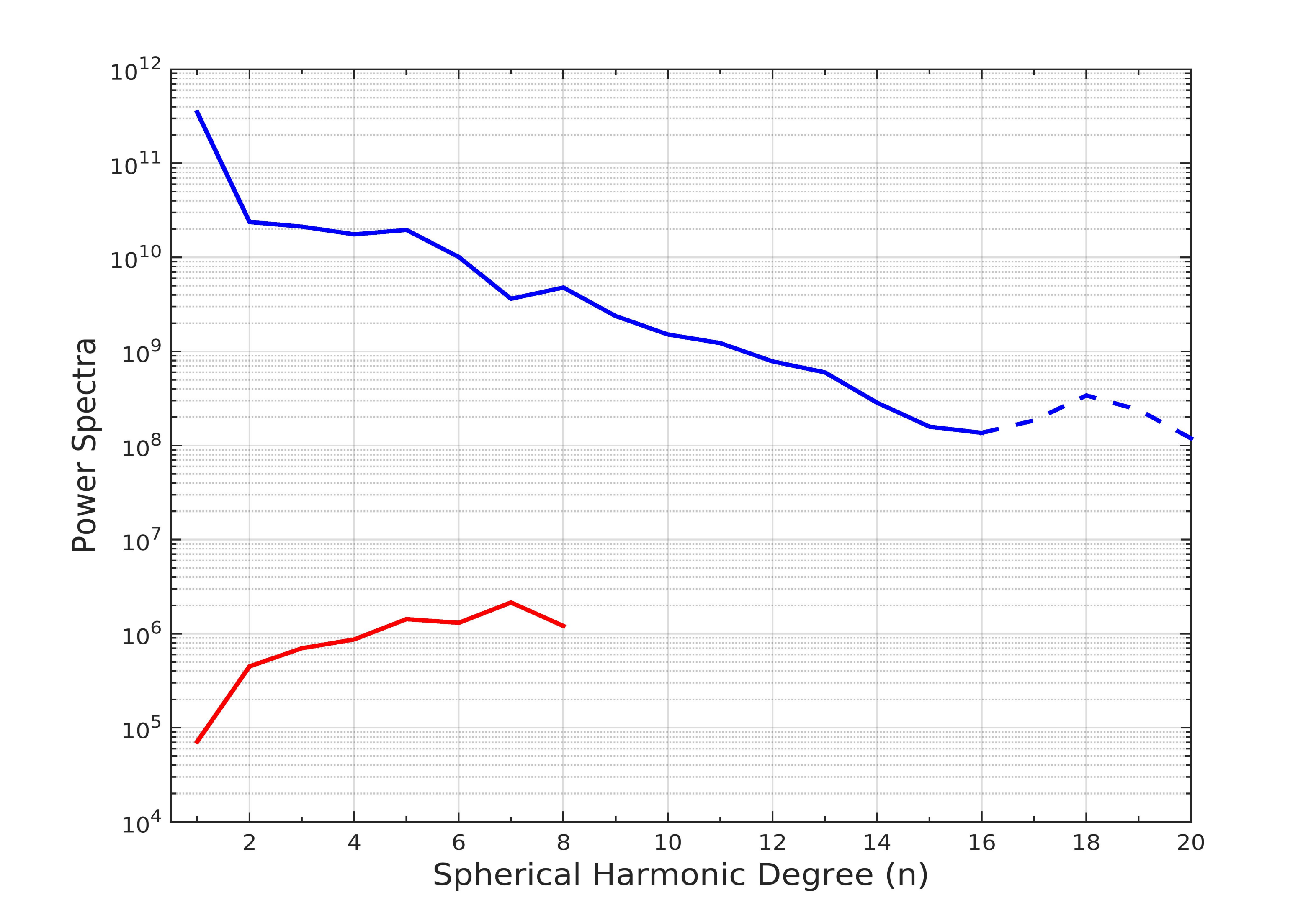
MAIN FIELD POWER SPECTRUM

$$R_n = (n+1)\left(\frac{a}{r}\right)^{(2n+4)} \sum_{m=0}^{n} \left[(g_n^m)^2 + (h_n^m)^2\right]$$

SECULAR VARIATION POWER SPECTRUM

$$S_n = (n+1)\left(\frac{a}{r}\right)^{(2n+4)} \sum_{m=0}^{n} \left[(\dot{g}_n^m)^2 + (\dot{h}_n^m)^2\right]$$

POWER SPECTRA AT SURFACE



Units –

Main field - $(nT)^2$

SV - $(nT/year)^2$

DYNAMO RADIUS

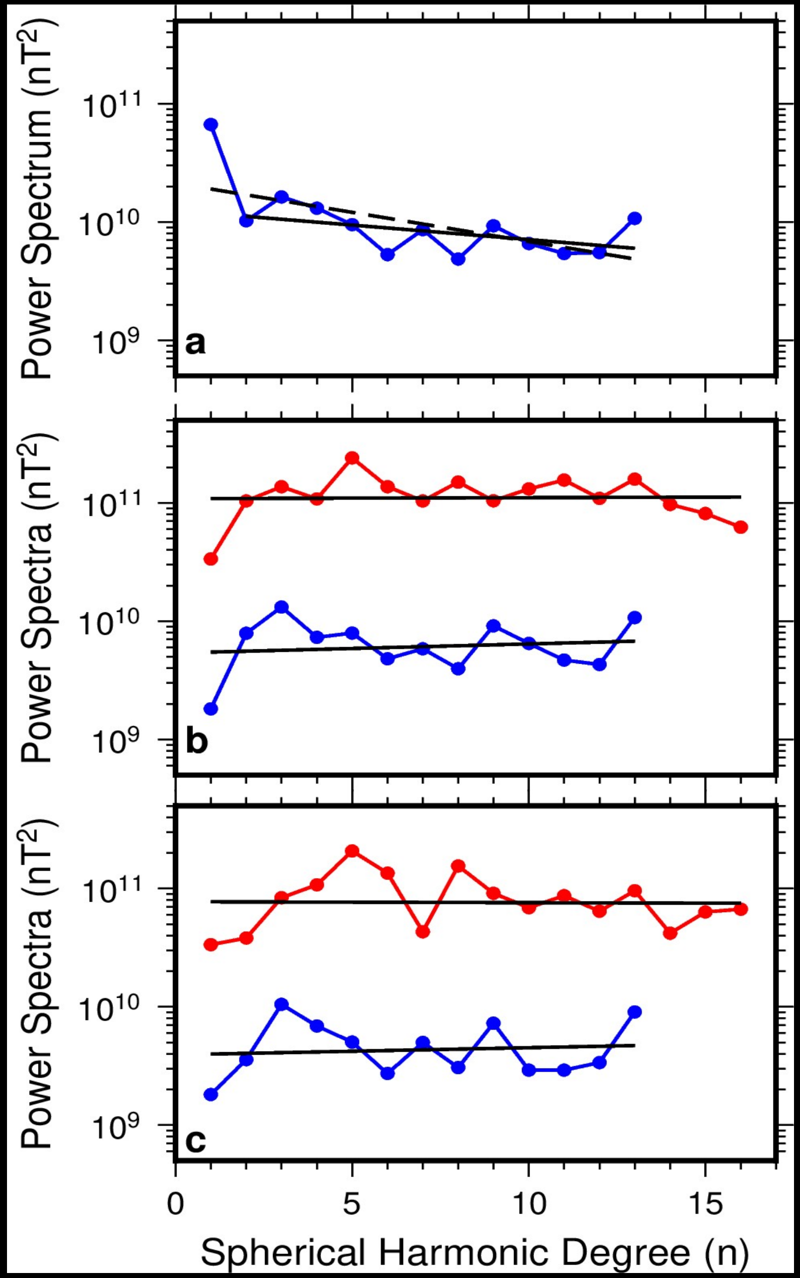
(a) White noise hypothesis :

Radius ‘r’ where parts of the spectrum are independent of degree ‘n’ (Langlais et al. 2014) –

top of source region, or bottom of source-free region = $\mathbf{R_{sf}}$

(b) Non-zonal terms (m ≠ 0)

(c) Quadrupole terms (n + m even)



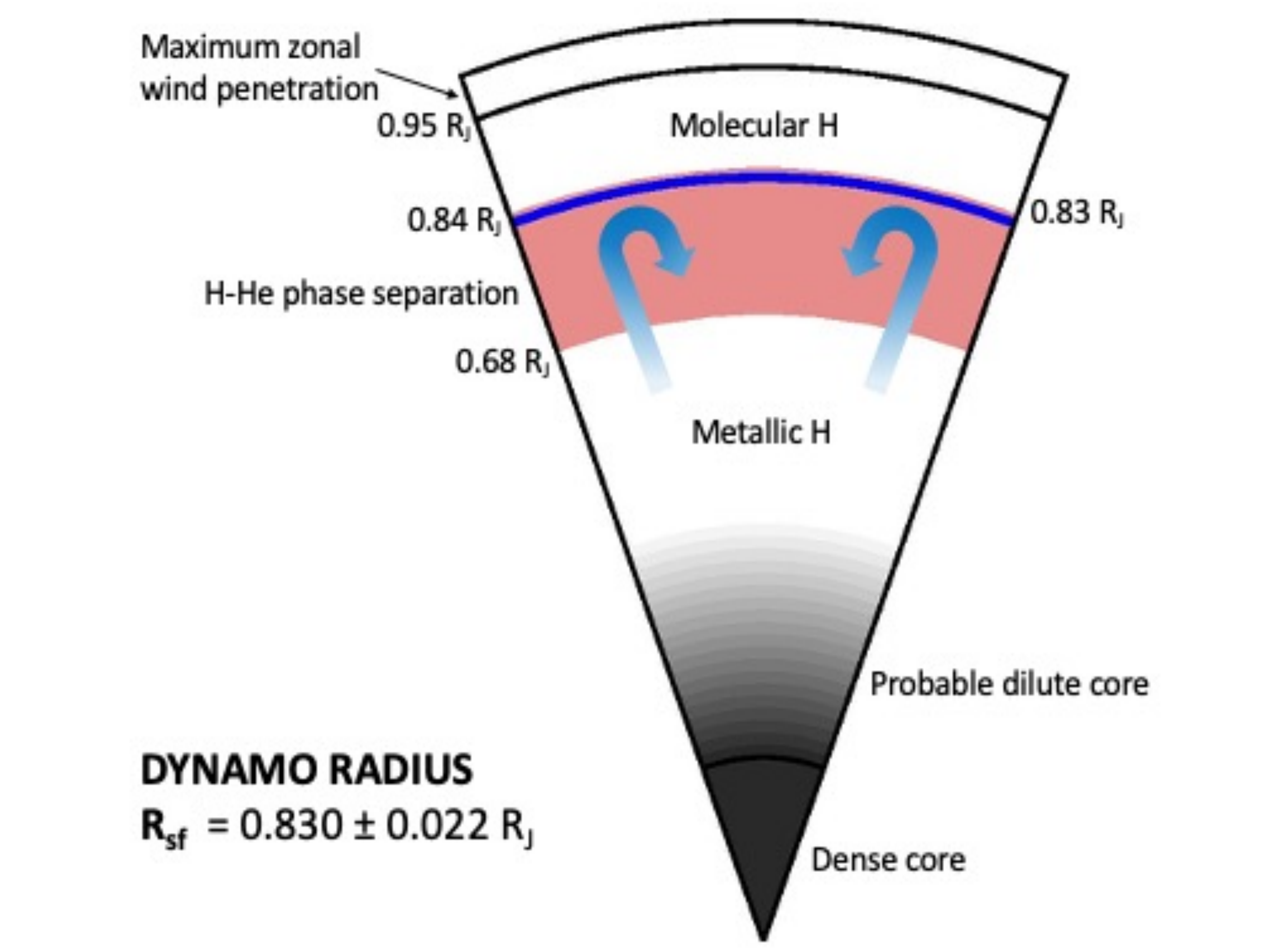
Blue for Earth (CHAOS model) and Red for Jupiter (this model)

INTERIOR STRUCTURE

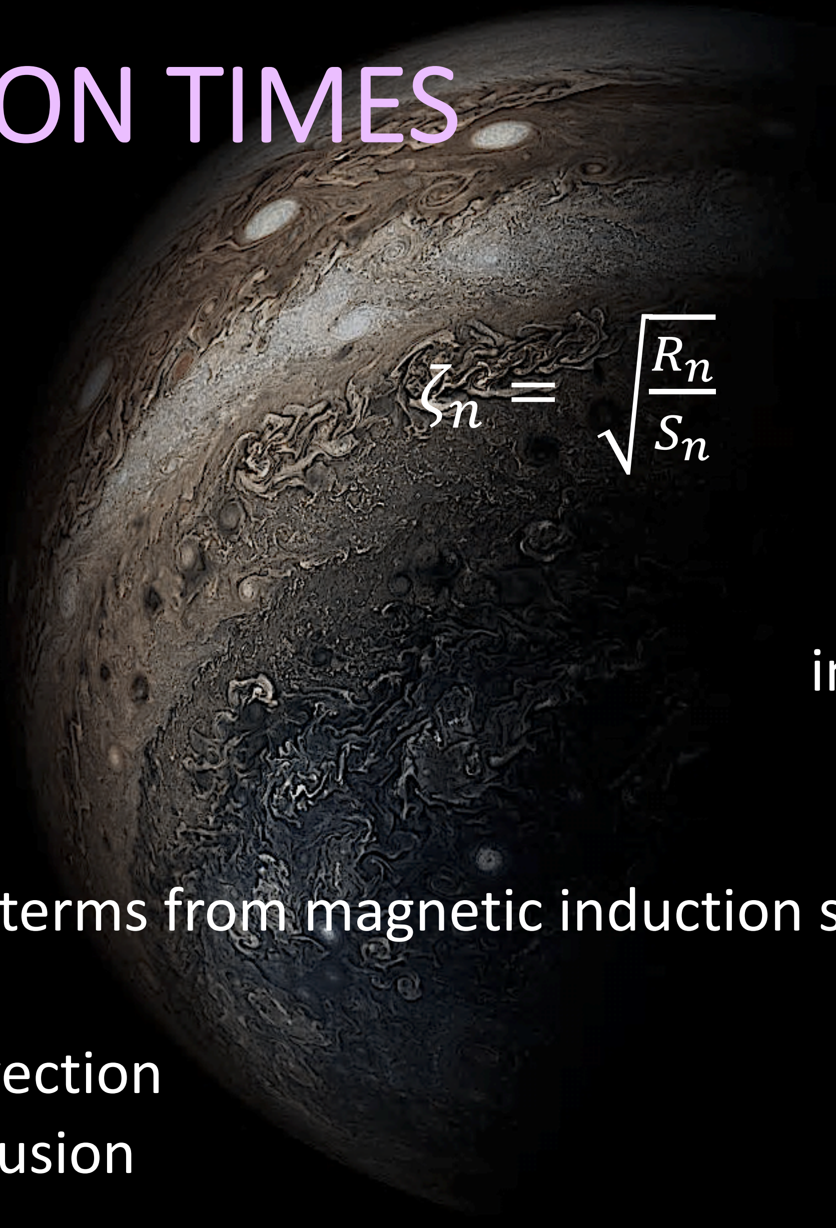
$R_{nz} = 0.831 \pm 0.021\ R_J$

$R_{qf} = 0.829 \pm 0.024\ R_J$

R_{sf} $= 0.830 \pm 0.022\ R_J$



CORRELATION TIMES



Or, SV timescales

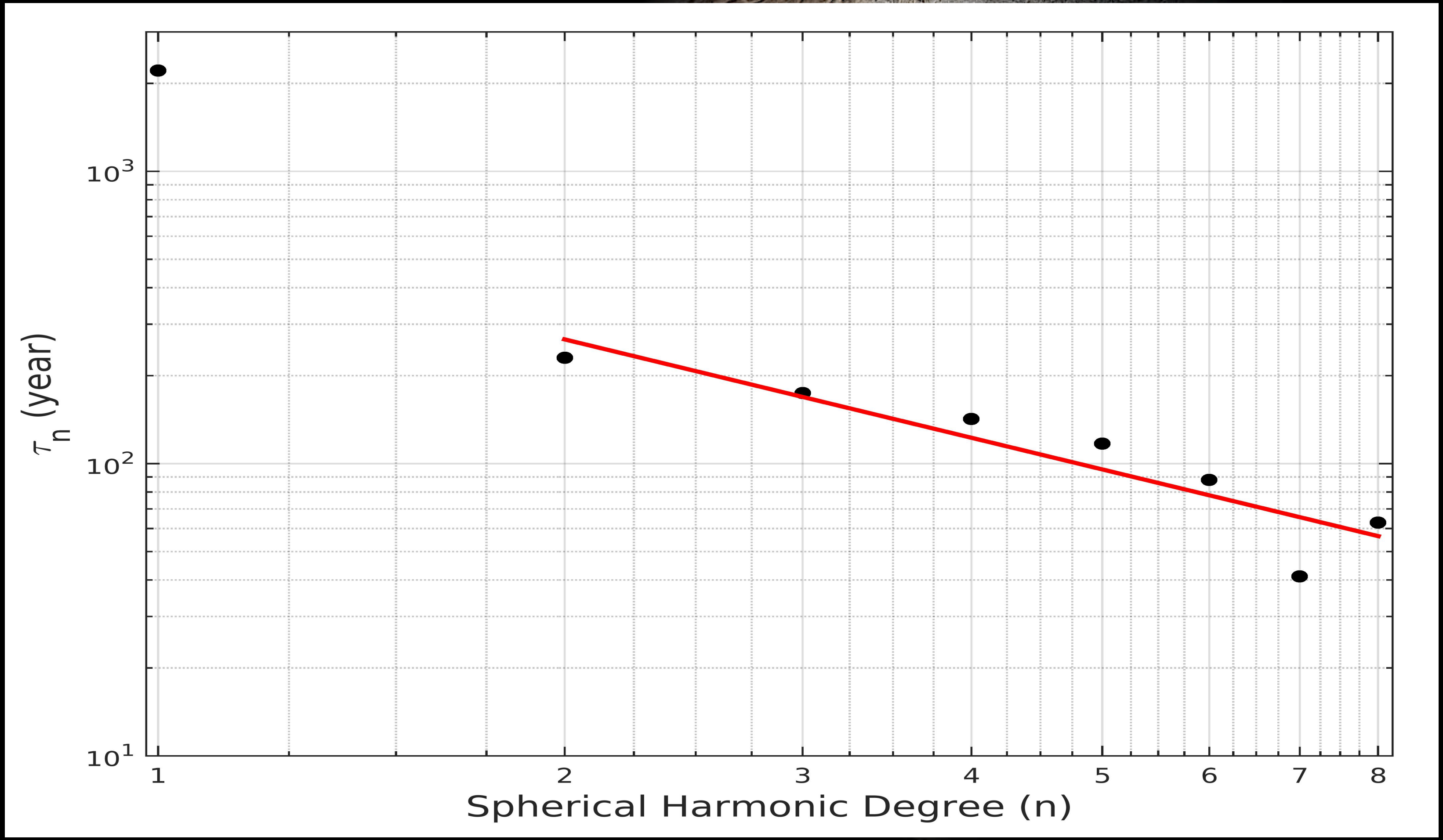
$$\zeta_n = \sqrt{\frac{R_n}{S_n}}$$

non-dipole terms
inversely proportional to degree
(Christensen and Tilgner 2004)

Slope of non-dipole terms from magnetic induction scaling laws-

-1 : SV driven by advection
-2 : SV driven by diffusion

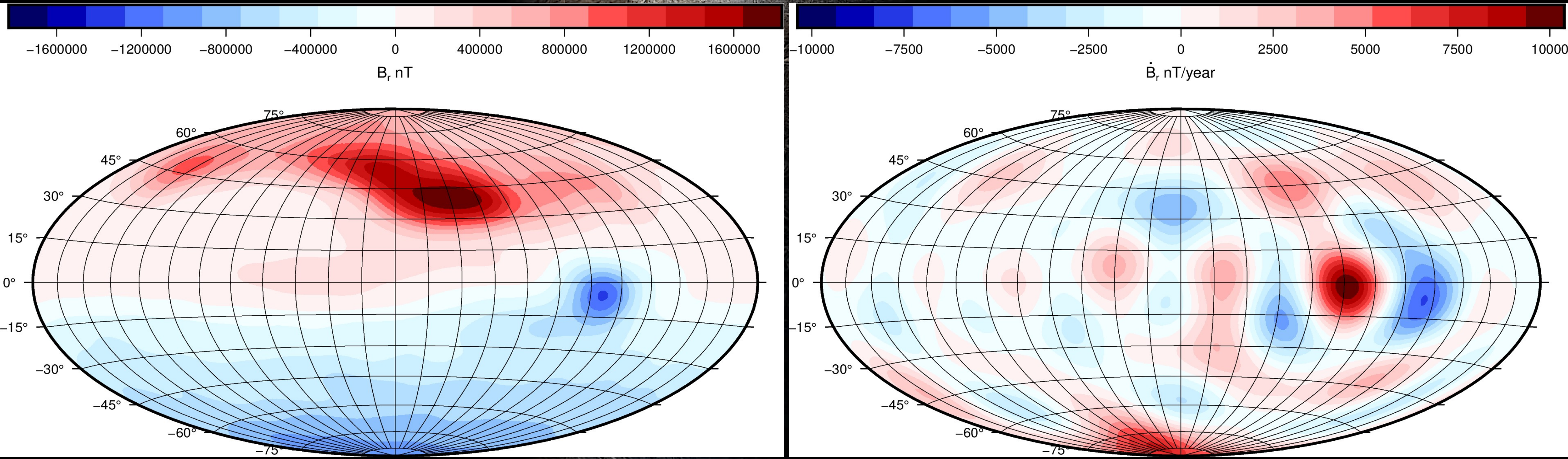
CORRELATION TIMES



Slope = -1.12 ± 0.21

Advection

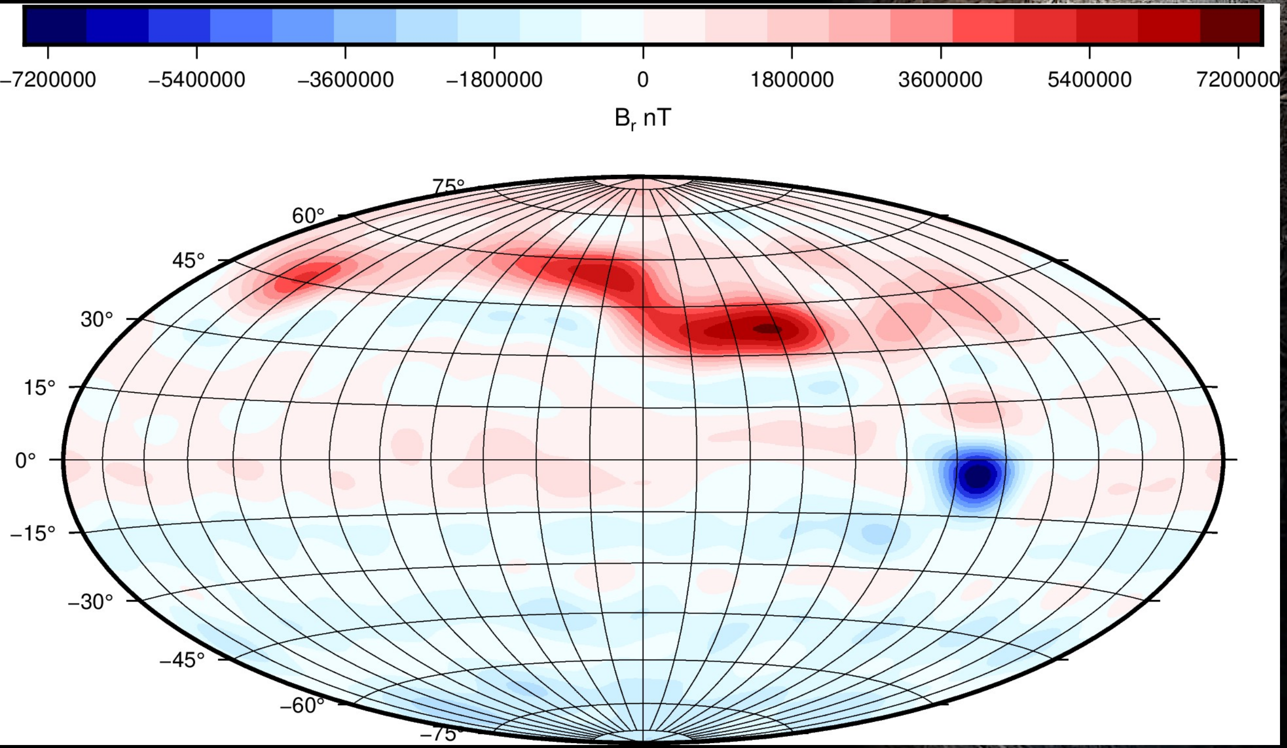
RADIAL FIELD AND ITS SV AT SURFACE

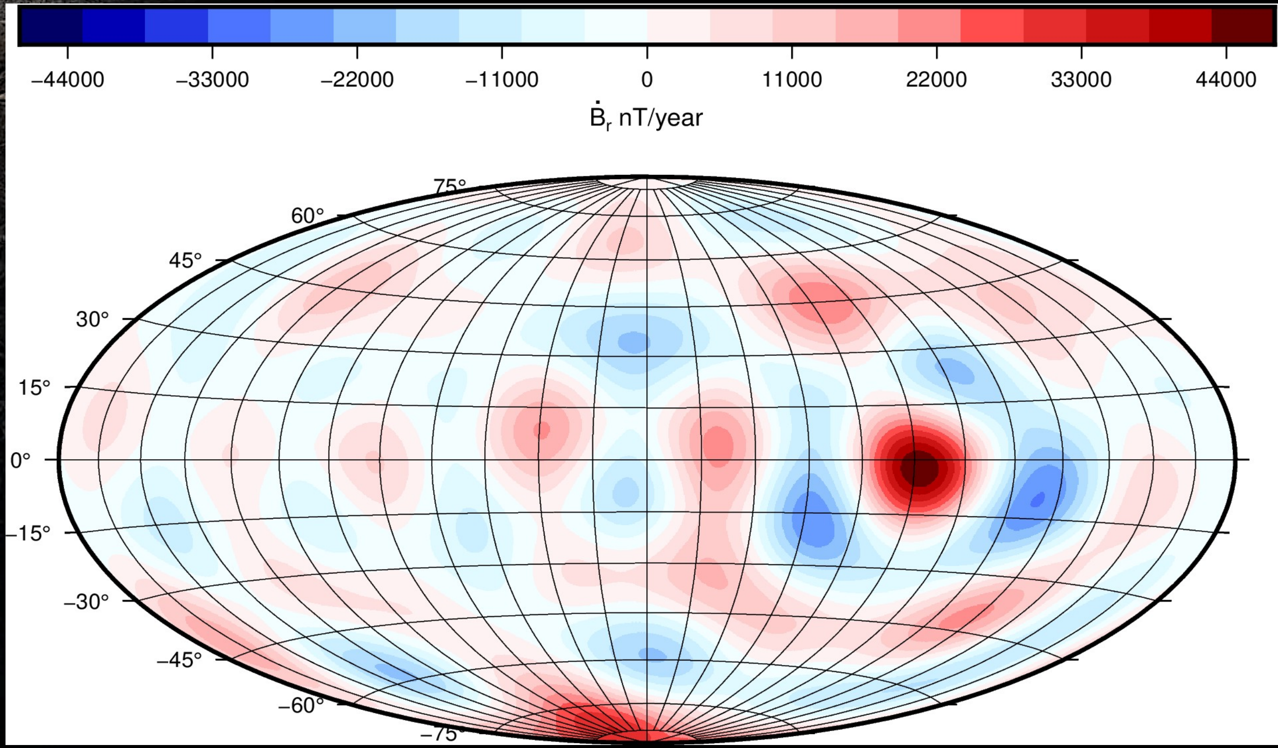


Two prominent features –

- large positive field in northern hemisphere
- intense negative field near equator – Great Blue Spot

RADIAL FIELD AND ITS SV AT R_{sf} (0.83 R_J)





Two prominent features –
- large positive field in northern hemisphere
- intense negative field near equator – Great Blue Spot

Corresponding to –
- weak eastward drift + field aligned flow
- eastward drift – zonal winds

SECULAR VARIATION

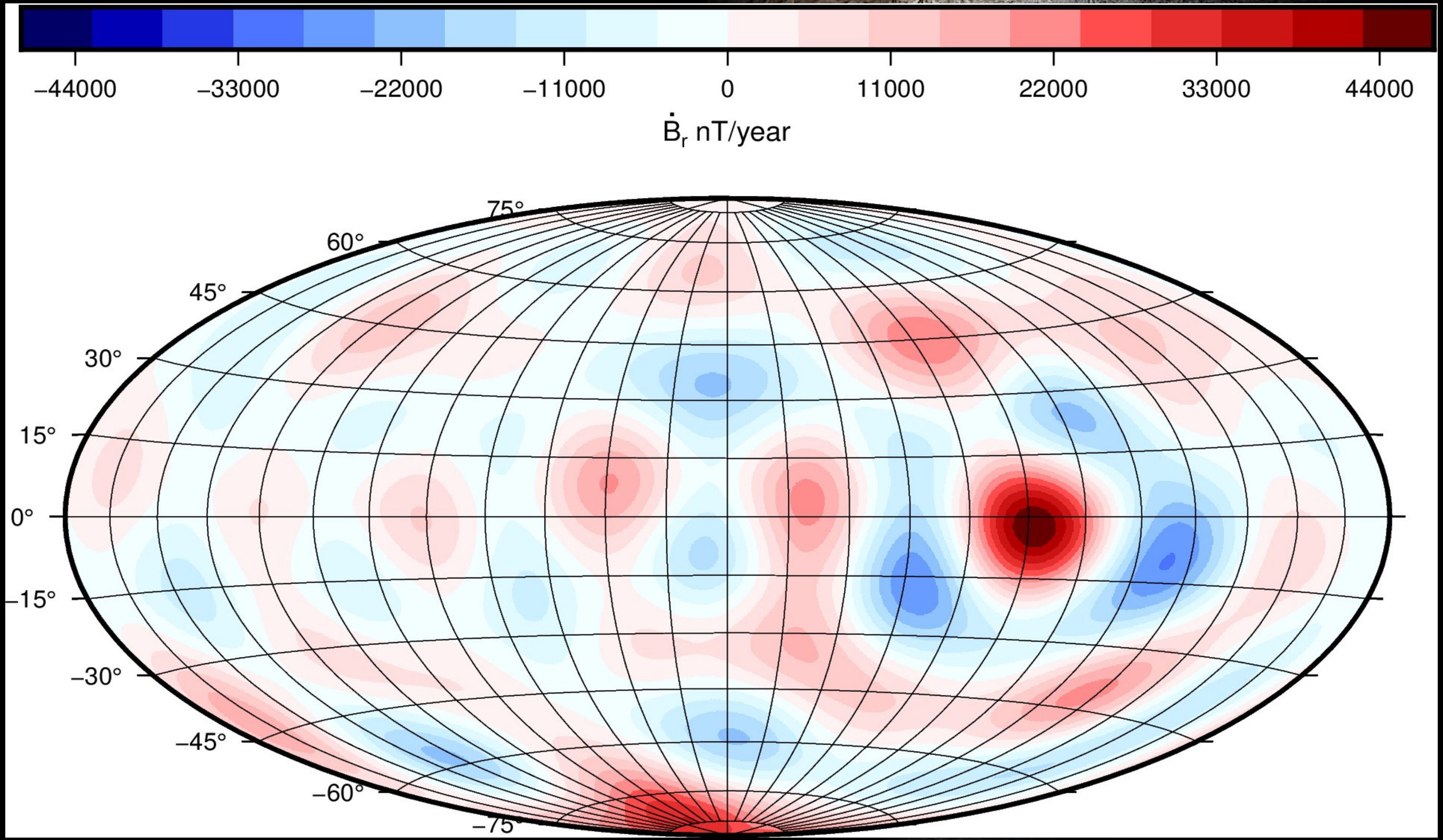


Figure at R_{sf} (0.83 R_J)

Strength ~ 10^4 nT/year

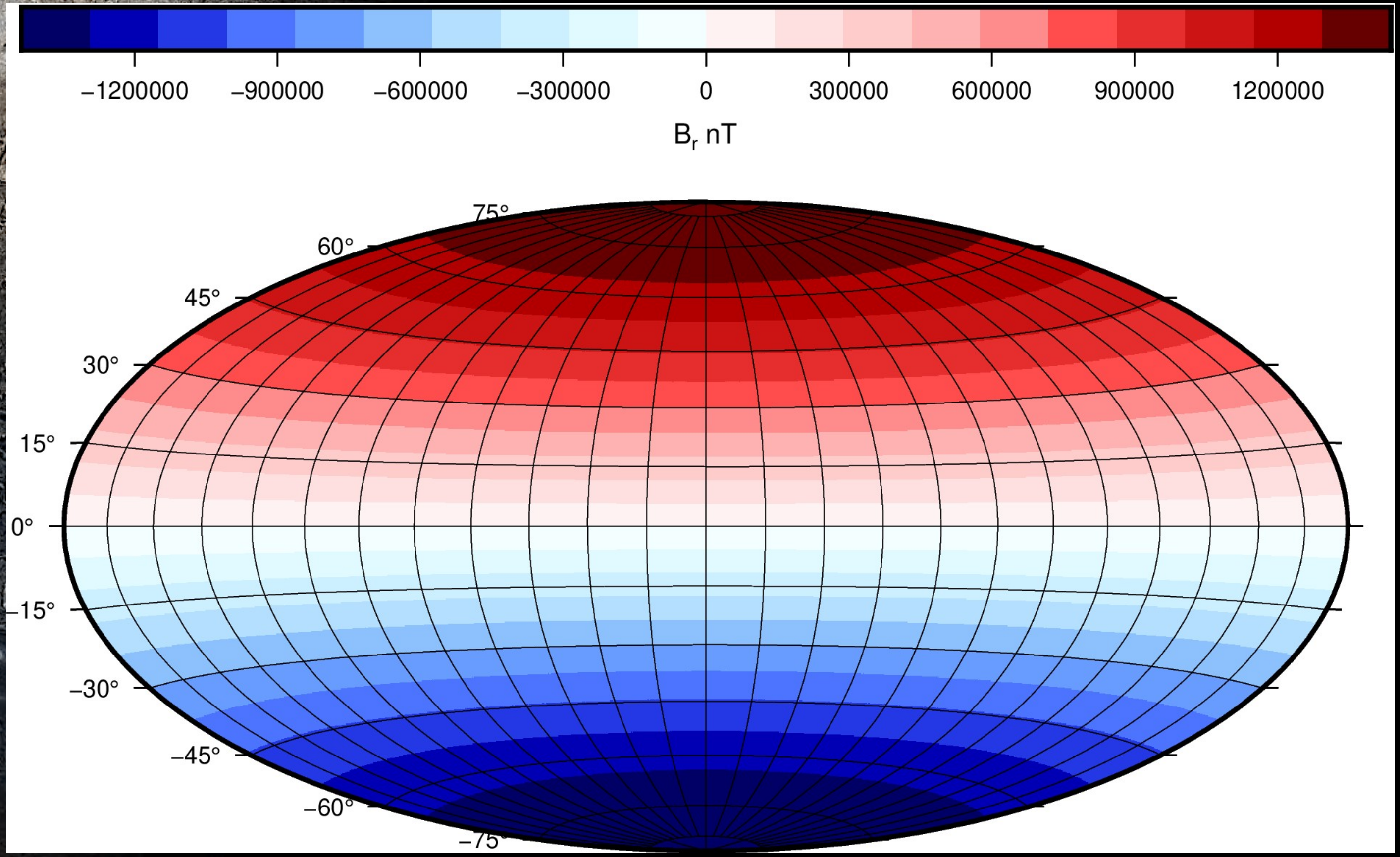
Variation ~ 2.3% over 4 years

Zonal and non-zonal features

Advection driven

COMPARISON WITH THE GEODYNAMO

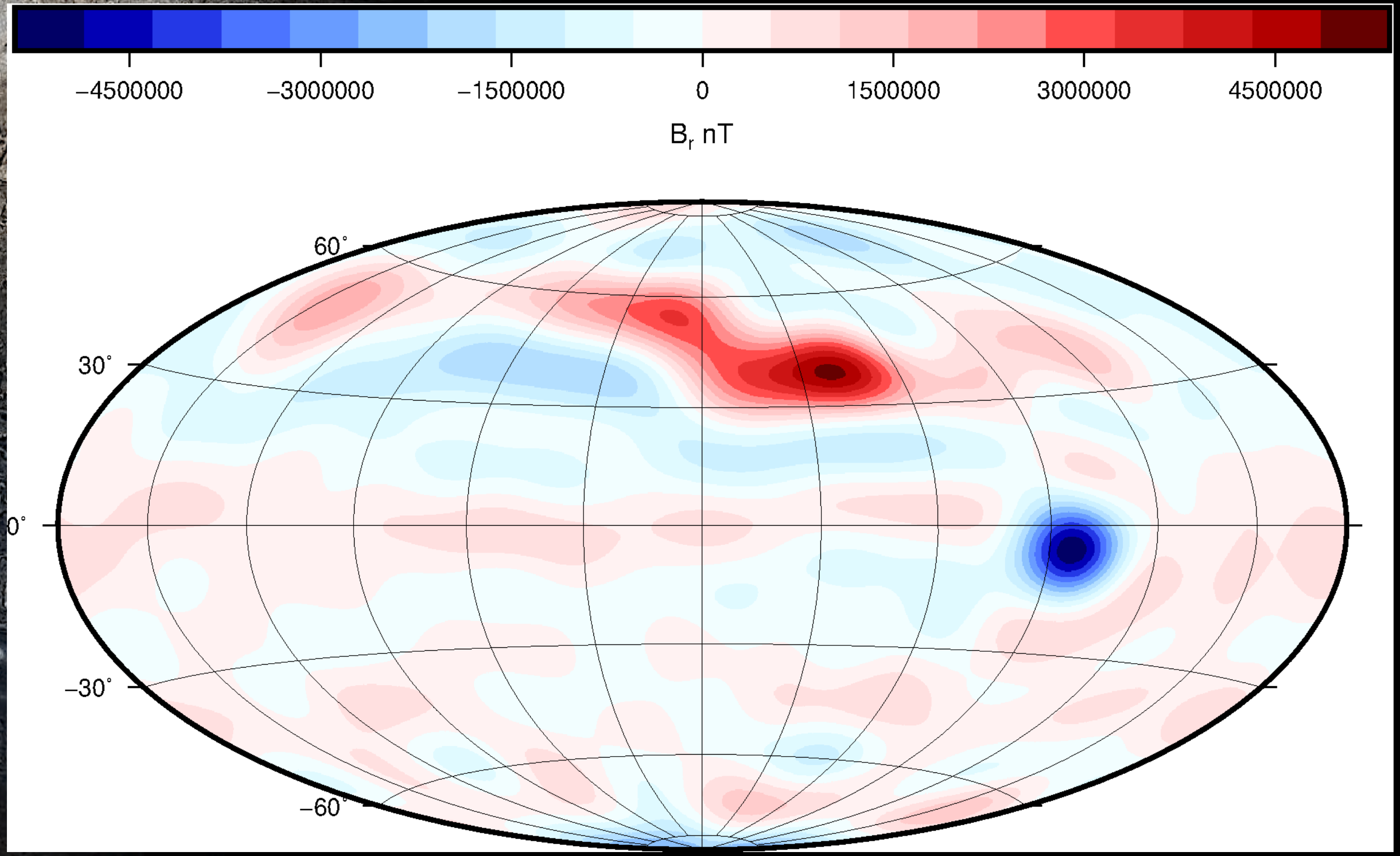
- Dynamo dipolarity - similar



Axial dipole radial field at R_{sf} (0.83 R_J)

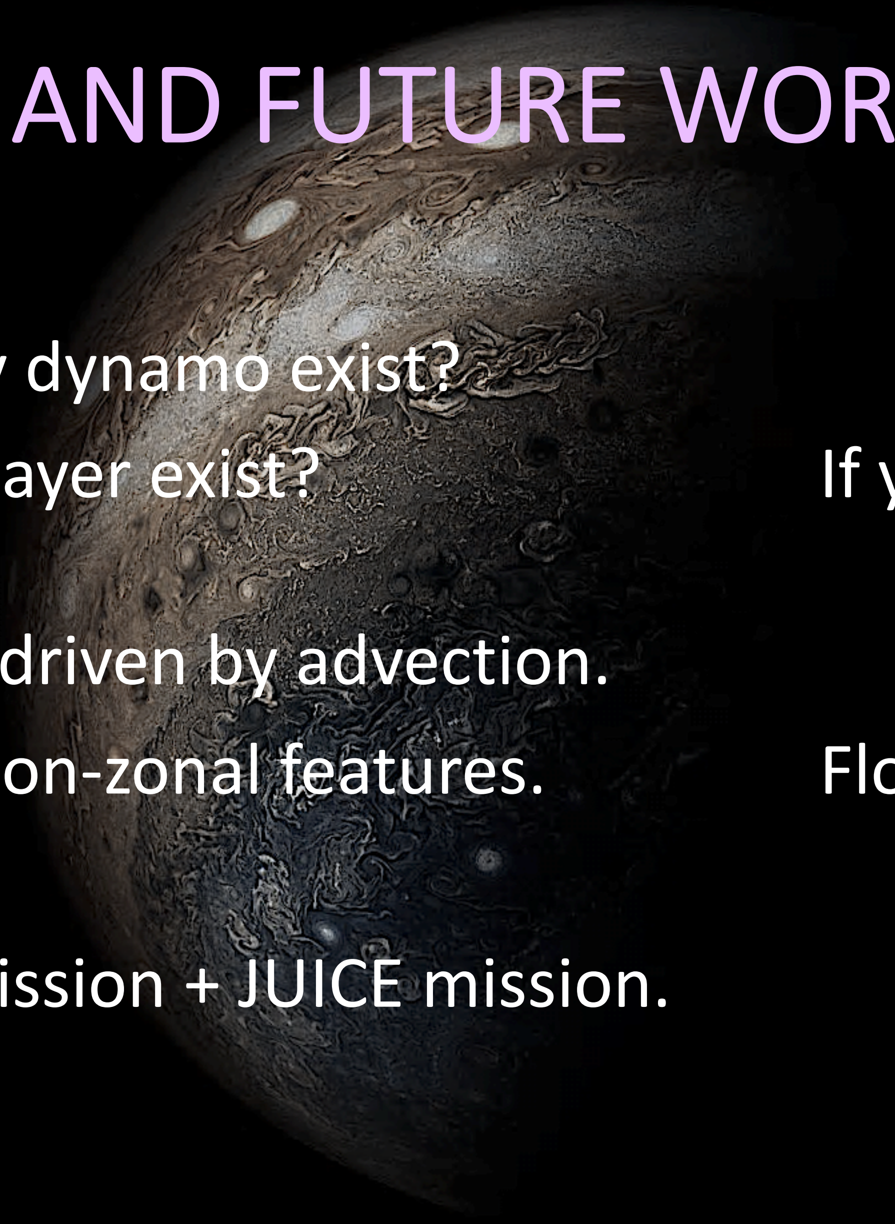
COMPARISON WITH THE GEODYNAMO

- Dynamo dipolarity - similar
- Non-dipole field more symmetric wrt equator
- Zonality of non-dipole field comparable (zonal preference)



Non axial dipole radial field at R_{sf} (0.83 R_J)

SUMMARY AND FUTURE WORK



Does a secondary dynamo exist?

Does a stratified layer exist? If yes, below 0.830 R_J

Secular variation driven by advection.

Zonal as well as non-zonal features. Flow patterns at R_{sf}

Juno extended mission + JUICE mission.


THANK YOU!