Explaining Jupiter's internal dynamics

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planetary magnetism

MPS

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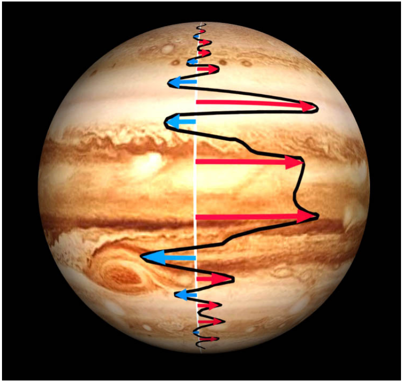
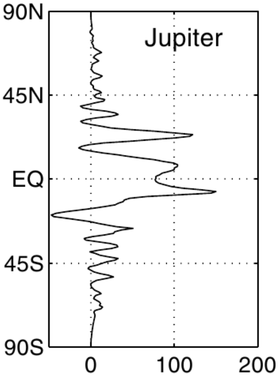
Internal dynamics: zonal flows

Zonal winds

Jupiter and Saturn: banded structures associated with prograde and retrograde **zonal flows** = east-west flows independent of the longitude ϕ



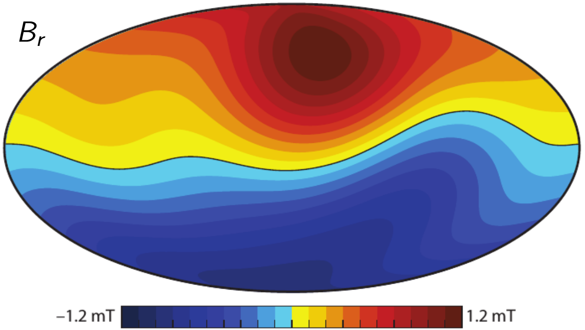
Jupiter's zonal flows



Cassini and Porco *et al.* (2003)

- Large amplitude **prograde equatorial jet** (~ 150 m.s^{-1})
- Flanked by **multiple alternating zonal winds** (~ 10 m.s^{-1})
- Alternating pattern up to the polar regions
- **How deep they are?**

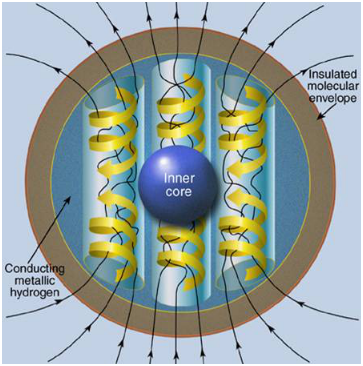
Internal dynamics: magnetic field



Connerney *et al.* 1998

- Flybys by Voyager, Pioneer + Galileo: **magnetic field up to $\ell_{\mathbf{max}} = 4$**
- Tilted dipole with $\Theta_d \sim 10^\circ$
- **Similar to the geodynamo?**

Is the geodynamo suitable to describe the Jovian field?



- Rapidly-rotating planet: **columnar convection**
- Curvature, density contrast: **helical flow= dynamo-capable**
- **Earth-like if zonal winds don't couple**
- Is it the correct picture of the Jovian dynamo?

Goals of this work

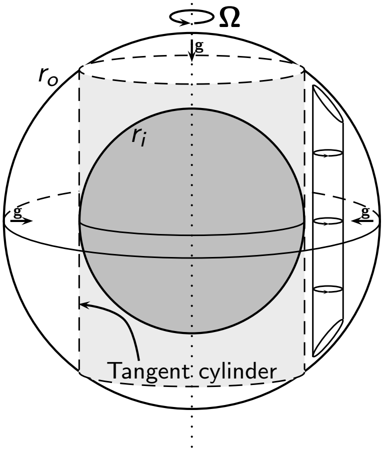
Open questions

- Zonal flows: **how deep they are?**
- "Decoupled dynamics": **is it the correct picture of the jovian dynamo?**
- So far, geodynamo-based models (Boussinesq): **is it applicable to giant planets (variable transport properties)?**

Goal: towards more realistic models of giant planets

1. Integrated **coupled global models** as realistic as possible (Juno mission) = variable electrical conductivity
2. **New generation of global models is required!**

Developing a new generation of planetary dynamo models



Numerical developments

1. Transformation of a Boussinesq code into an **anelastic code**: fast acoustic waves are filtered out but **density stratification effects** are allowed
2. Validation of the numerical devs by an international Benchmark (Jones *et al.* 2011)

Numerical method

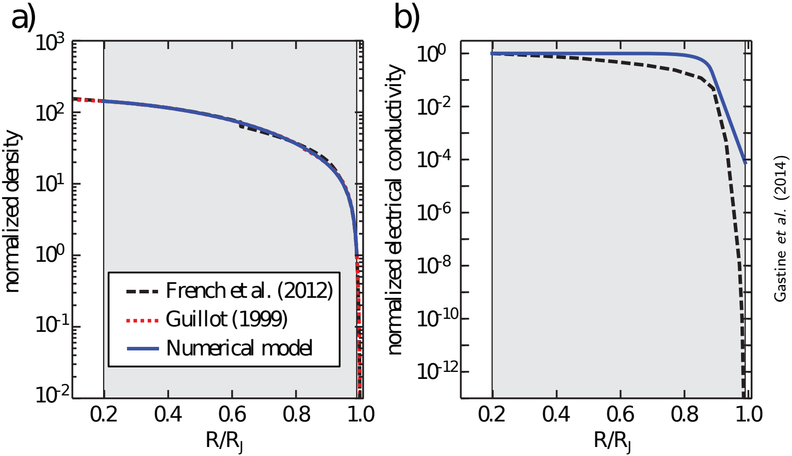
- Anelastic approximation: $\boldsymbol{\nabla} \cdot \tilde{\rho}\mathbf{u} = 0$
- 3-D numerical simulations in rotating spherical shells: hydro and MHD
- Pseudo-spectral code: spherical harmonic decomposition

Observations vs numerical models?

Parameter	Earth	Giant planets	Numerical model
E (Visc./Coriolis)	10^{-15}	10^{-18}	10^{-5}
Ra (Buoyancy/Diff.)	10^{27}	10^{30}	5×10^{9}
Pr	0.1	$0.1 - 1$	1
Pm (visc/magn diff.)	10^{-6}	10^{-7}	0.6
N_ρ	0.2	8	5
Λ (Lorentz/Coriolis)	1	1	1
Rm (ind./diff.)	1000	$10^{5} - 10^{6}$	200

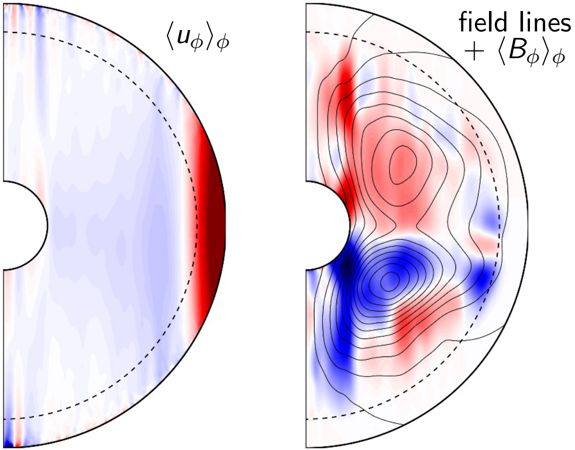
- Most of the control parameters are under/over-estimated by many orders of magnitude
- Parameter studies (e.g. Duarte *et al.* 2013)

Realistic interior model

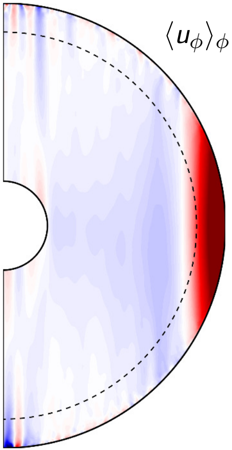


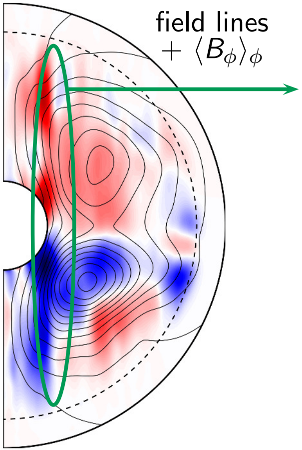
- $\tilde{\rho} \rightarrow$ from $r = 0.2\,R_J$ to $r = 0.99\,R_J$
- $\tilde{\sigma} \rightarrow$ constant in the metallic region + exponential decay

Analyzing dynamo action

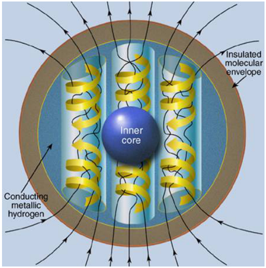


Analyzing dynamo action

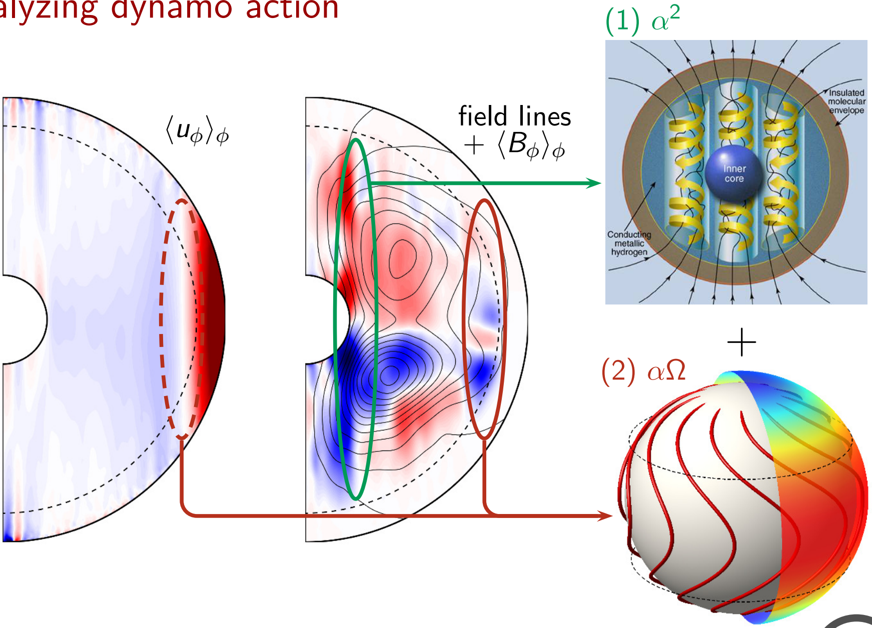




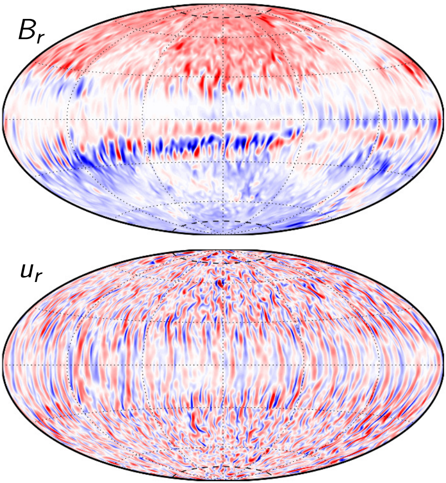
(1) α^2



Analyzing dynamo action



Interface dynamics ($r = 0.87\,R_J$) $\rightarrow$ magnetic banding

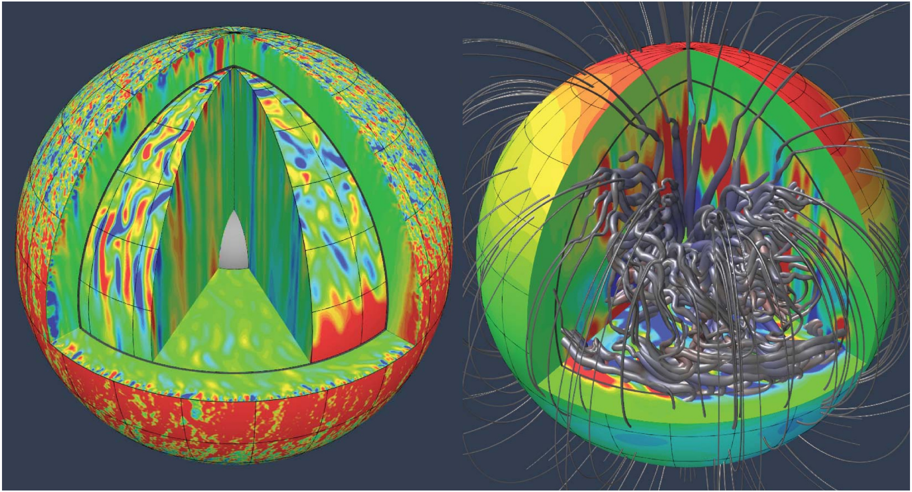


Deep-seated columns $\rightarrow$ dipolar component of the field

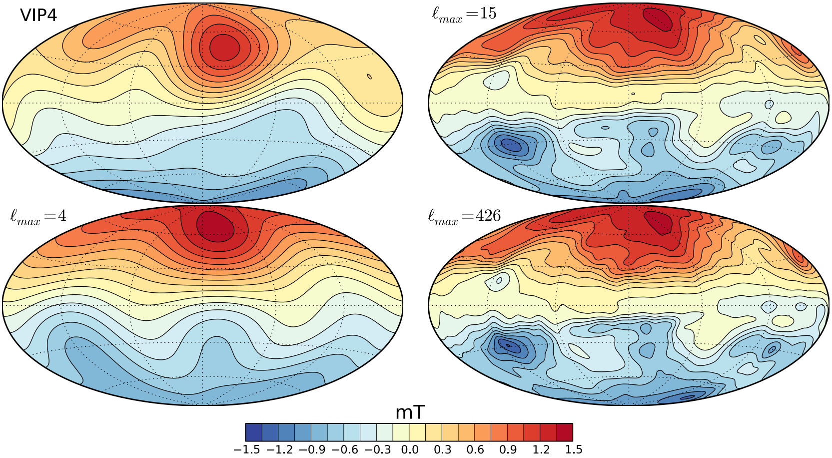
Interface shear $\rightarrow$ Ω-effect $\rightarrow$ equatorial magnetic bands

Global dynamics

u_r, u_ϕ B_r, B_ϕ, $\mathbf{B}$

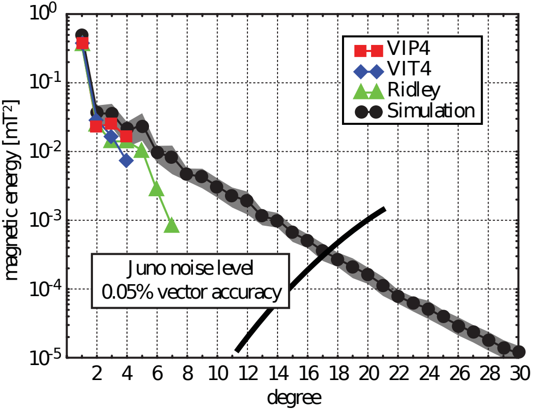


Surface magnetic field



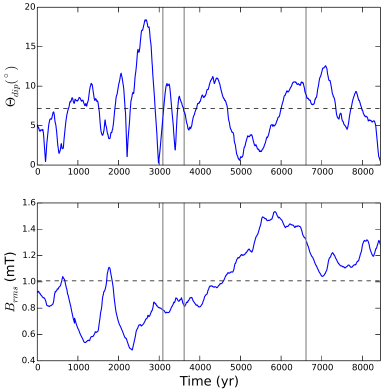
- Good agreement with VIP4 ($\ell \leq 4$)
- All the morphology is essentially captured for $\ell \leq 15$

Spectra and Juno mission



- Match the known spectra
- Prediction for Juno: possible detection threshold at $\ell_{\textbf{max}} = 16$

Time variation of the surface field



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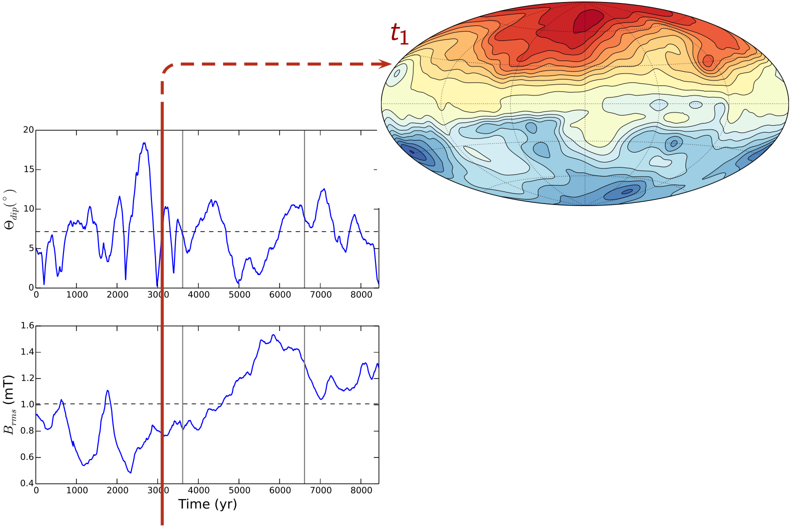

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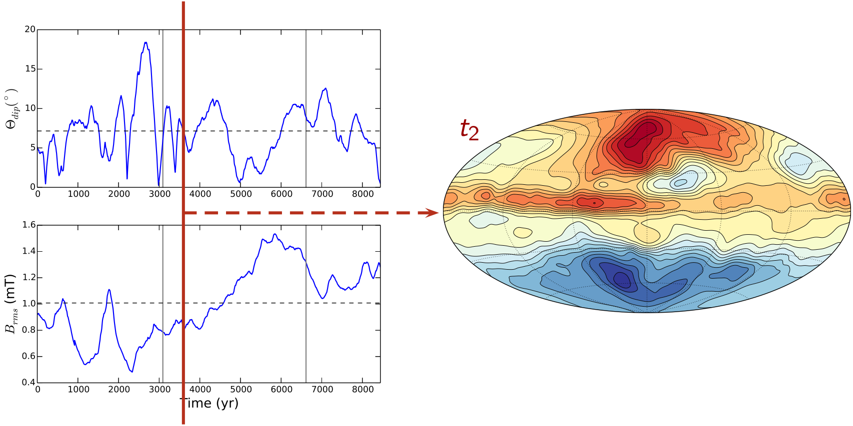

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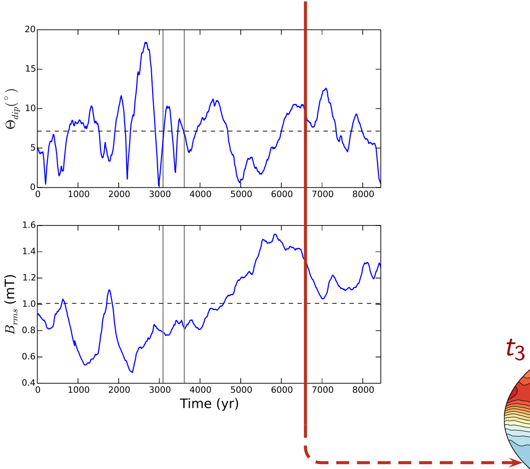
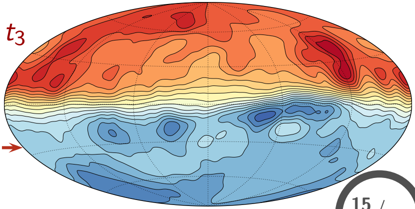
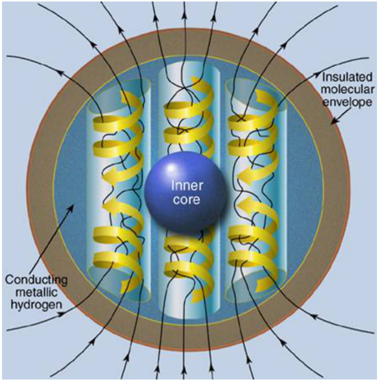




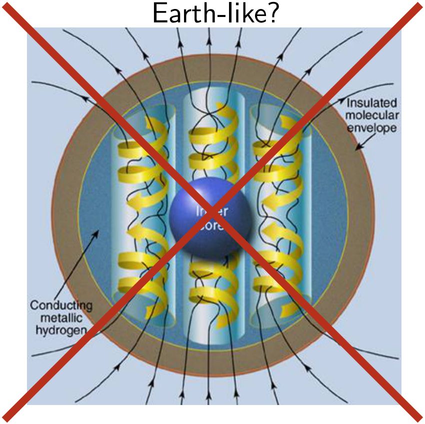
Conclusion

Earth-like?

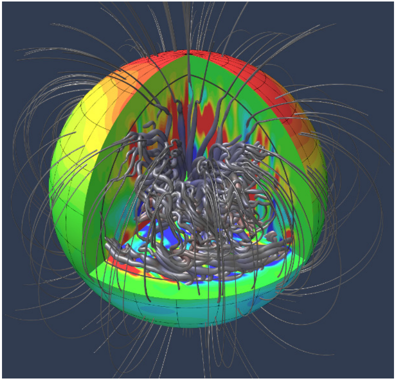


Conclusion

Earth-like?



Coupled dynamics




Thank you for your attention