Anelastic dynamo models with variable electrical conductivity: an application to gas giants

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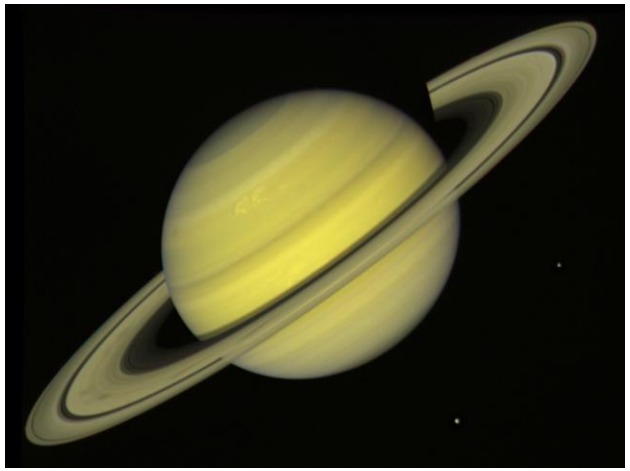
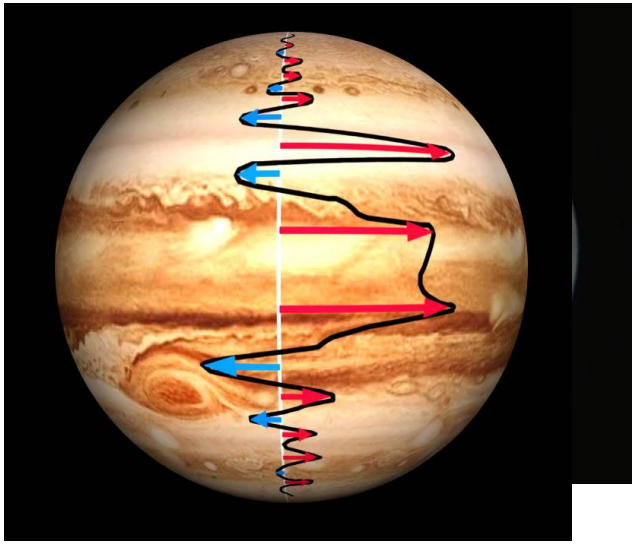
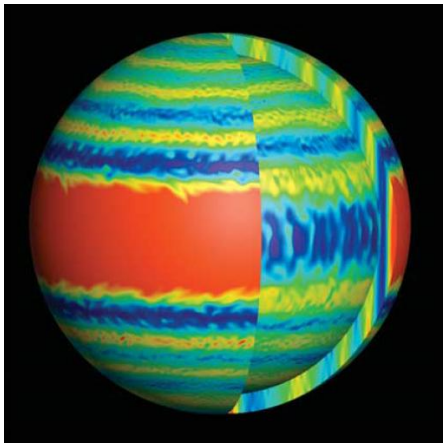
1. Introduction – giant planets' atmospheres

- We observe bands at the surface of the gas giants that we know, from cloud tracking, to be zonal flows.
- Both planets radiate more energy than what they receive from the Sun, which is either due to an internal heat source or residual heat from their formation.
  - An internal source suggests strong convection in the interior.
  - Is an internal source the main responsible for these surface patterns? (In the Earth, the weather is driven by heat coming from the Sun.)

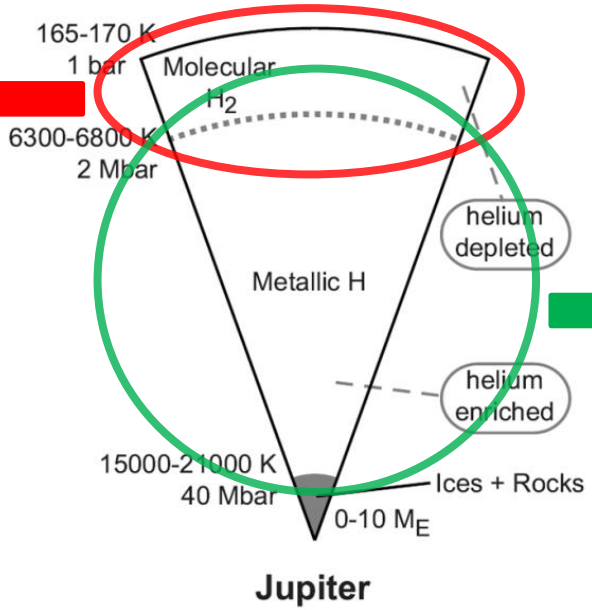


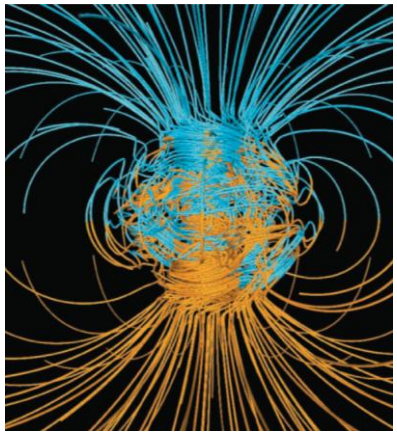


1. Introduction – interior structure



Heimpel et al. (2005)

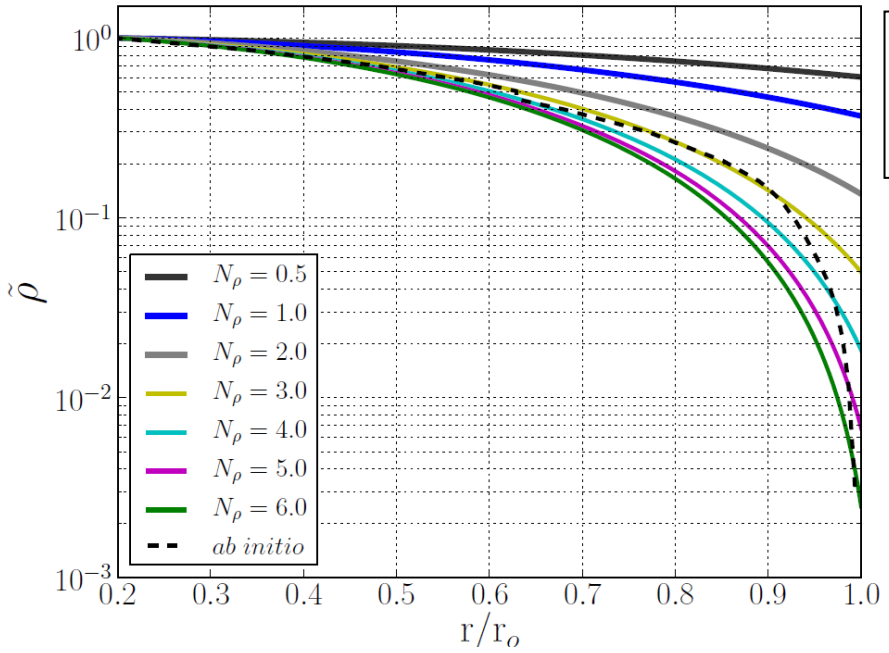




Glatzmaier et al. (2006)

Our model...

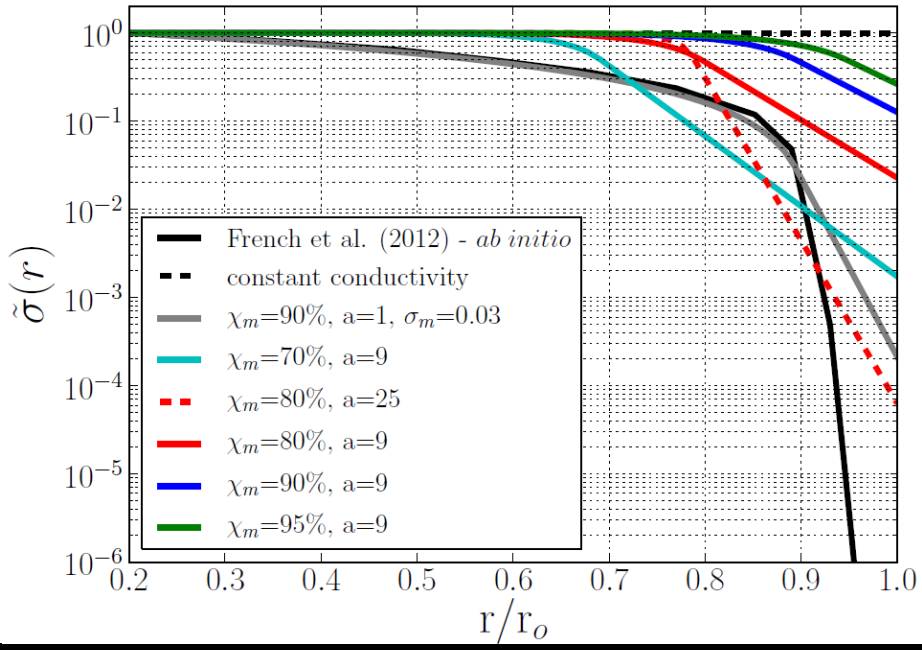
1. Introduction – our model



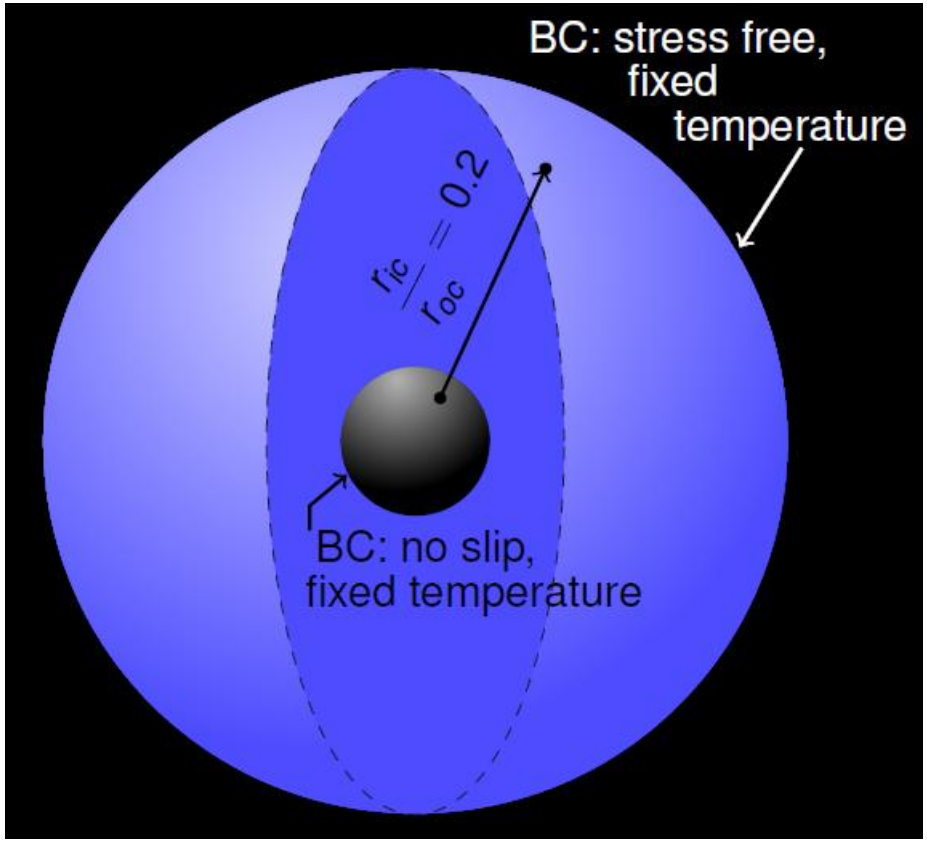
$$N_\rho = \ln\left(\frac{\rho_i}{\rho_o}\right)$$

→ we assume a polytropic ideal gas

we assume constant electrical conductivity and an exponential decay in the outer layer ←



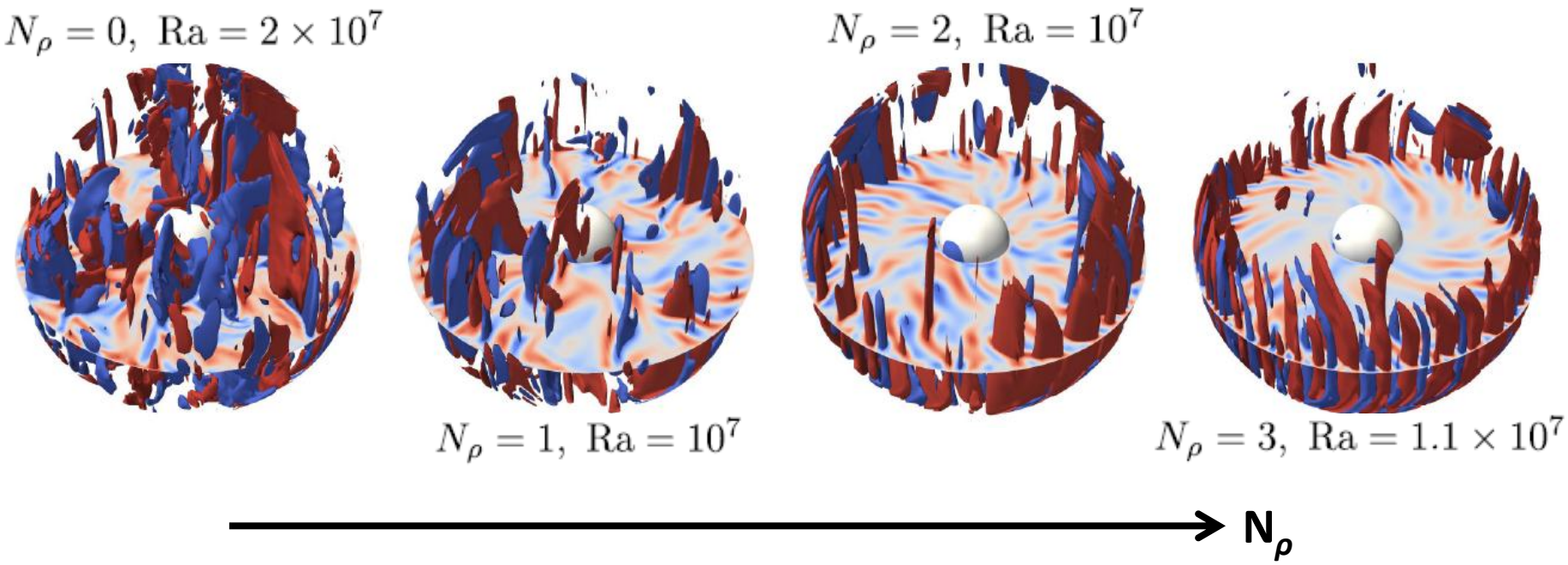
1. Introduction – our model's set-up

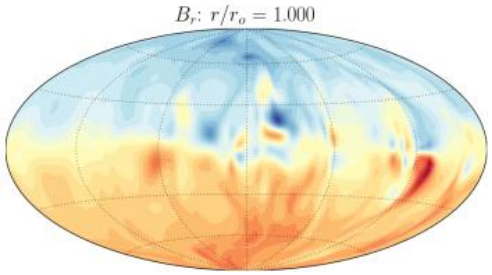


Input parameters:

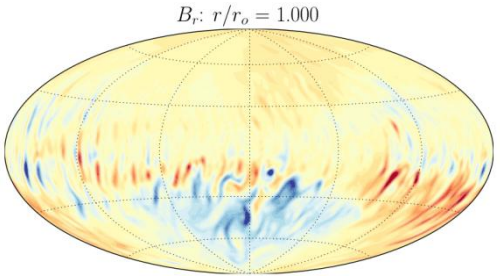
- Rayleigh number: $3 – 46\ Ra_{cr}$
- Ekman number: $3x10^{-4} – 10^{-5}$
- r_{IC}/r_{OC}: 0.2
- fixed temperature at both limits
- no slip at the bottom and stress-free at the top
- Prandtl number: 1
- magnetic Prandtl number at IC: 2
- density scale heights N_ρ: 0.0 – 5.5
- transition radius χ_m: $70 – 95\%\ r_{OC}$

2. Effects of density stratification – z-vorticity

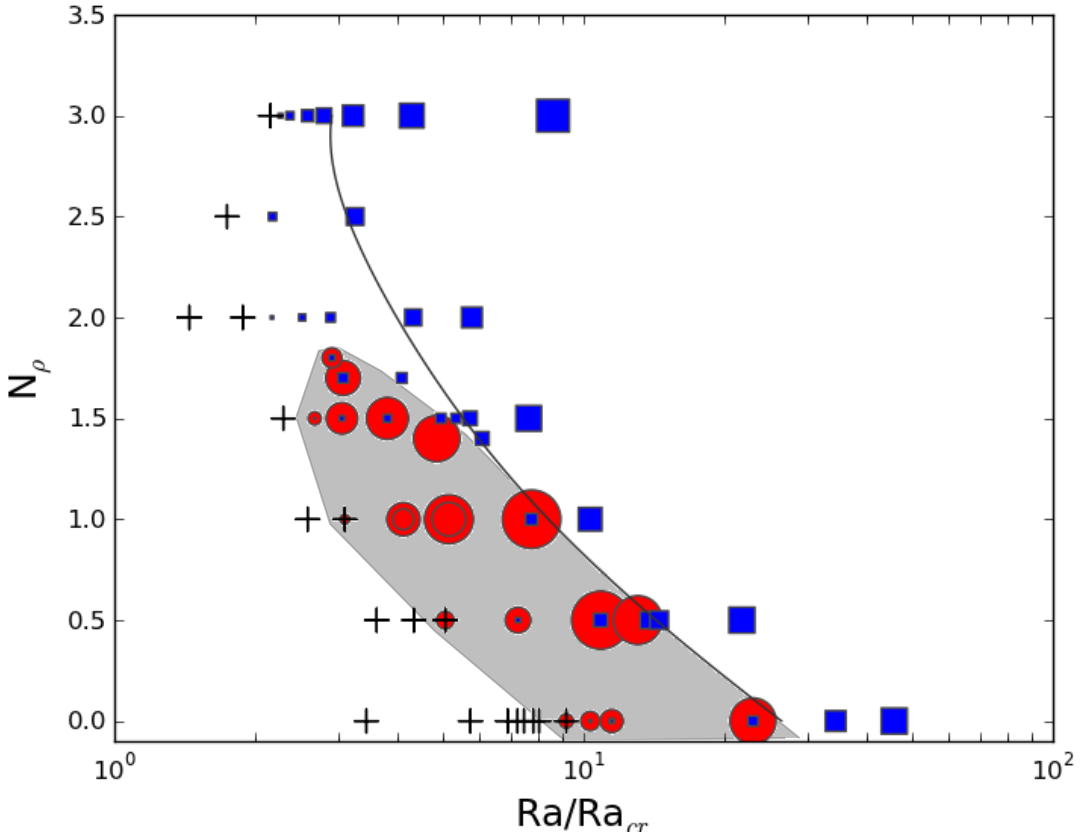




radial magnetic field at
the outer boundary



2. Effects of density stratification – regime diagrams

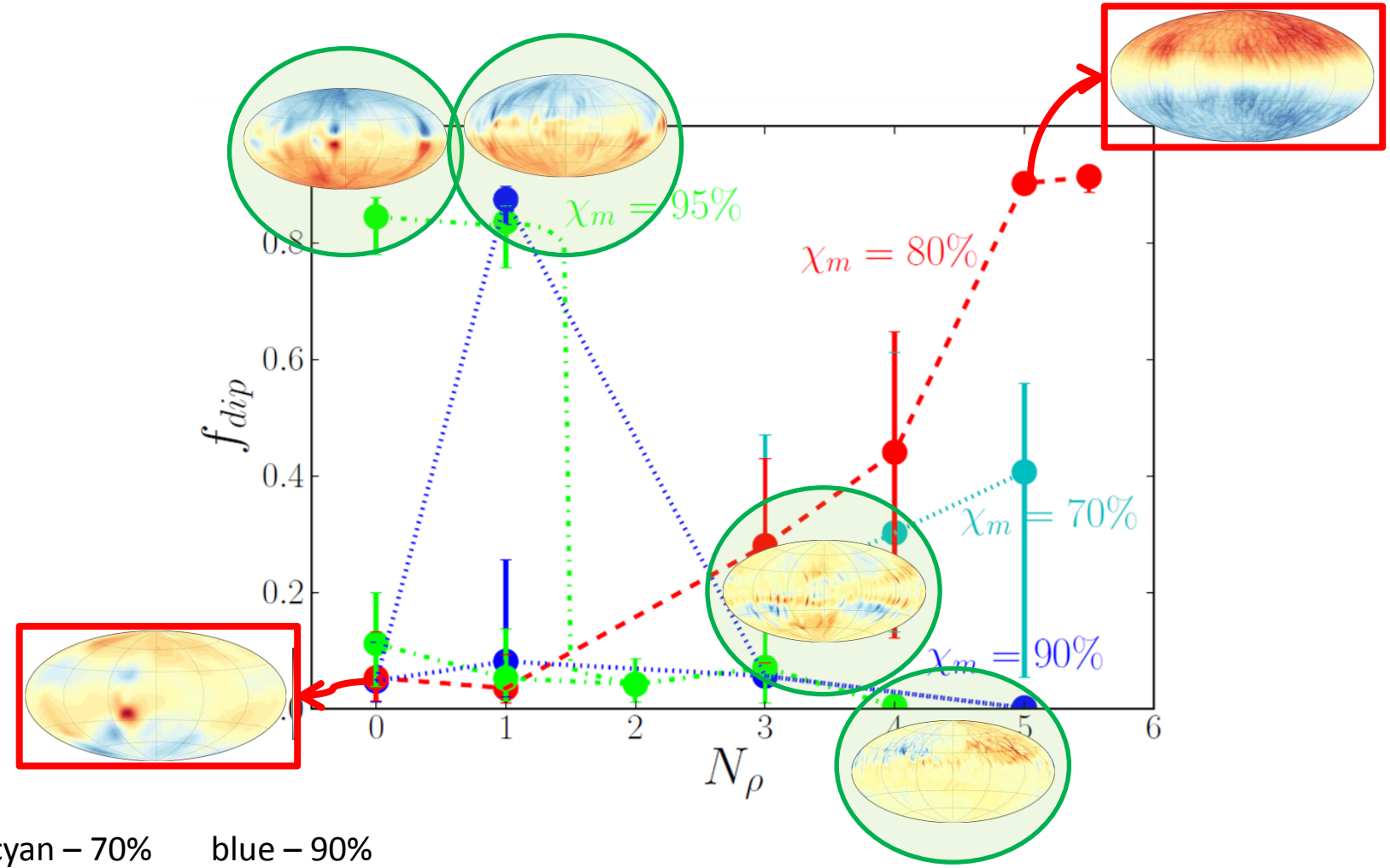


Dipole

Multipole

Non-magnetic

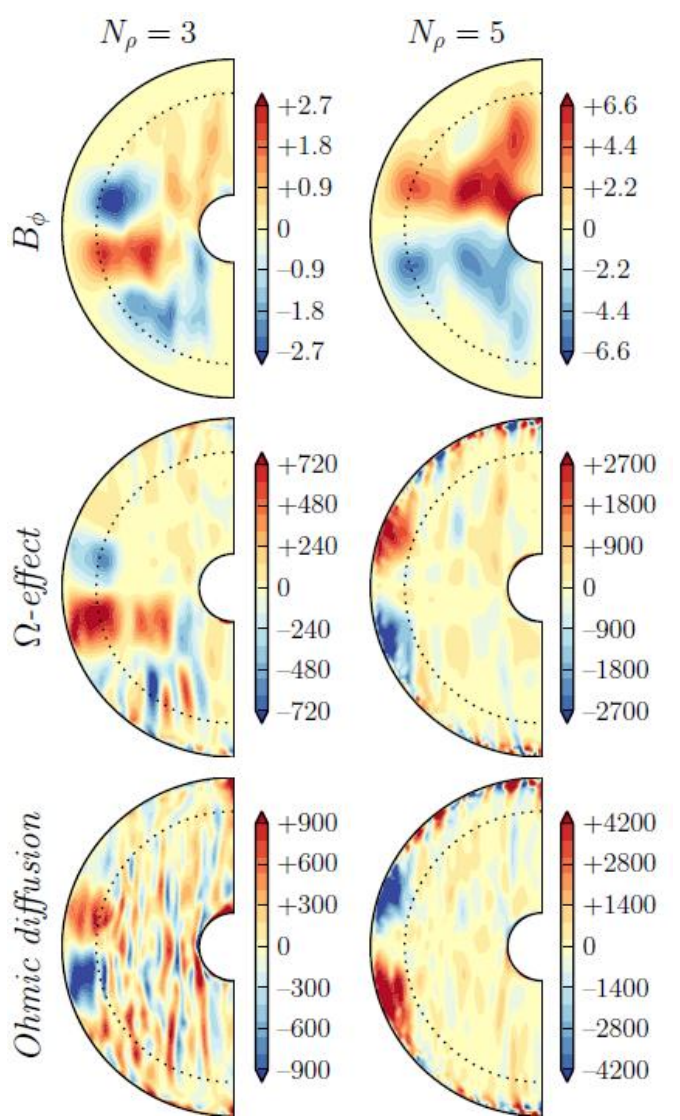
3. Variable conductivity – critical Rossby number

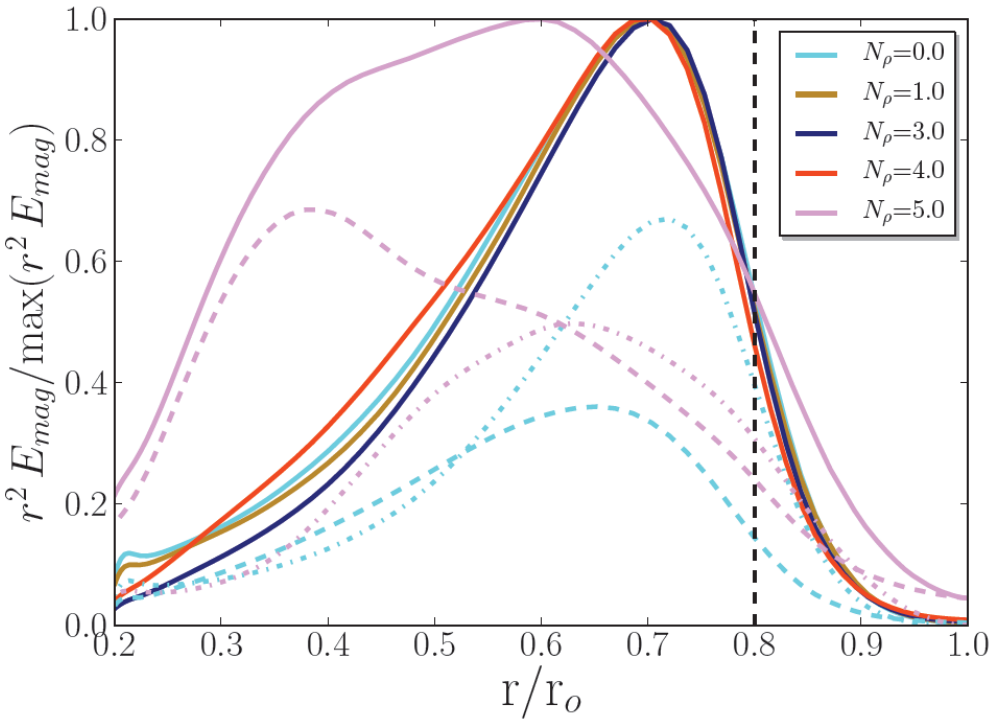


cyan – 70% blue – 90%

red – 80% green – 95%

3. Variable conductivity – different dynamo mechanisms

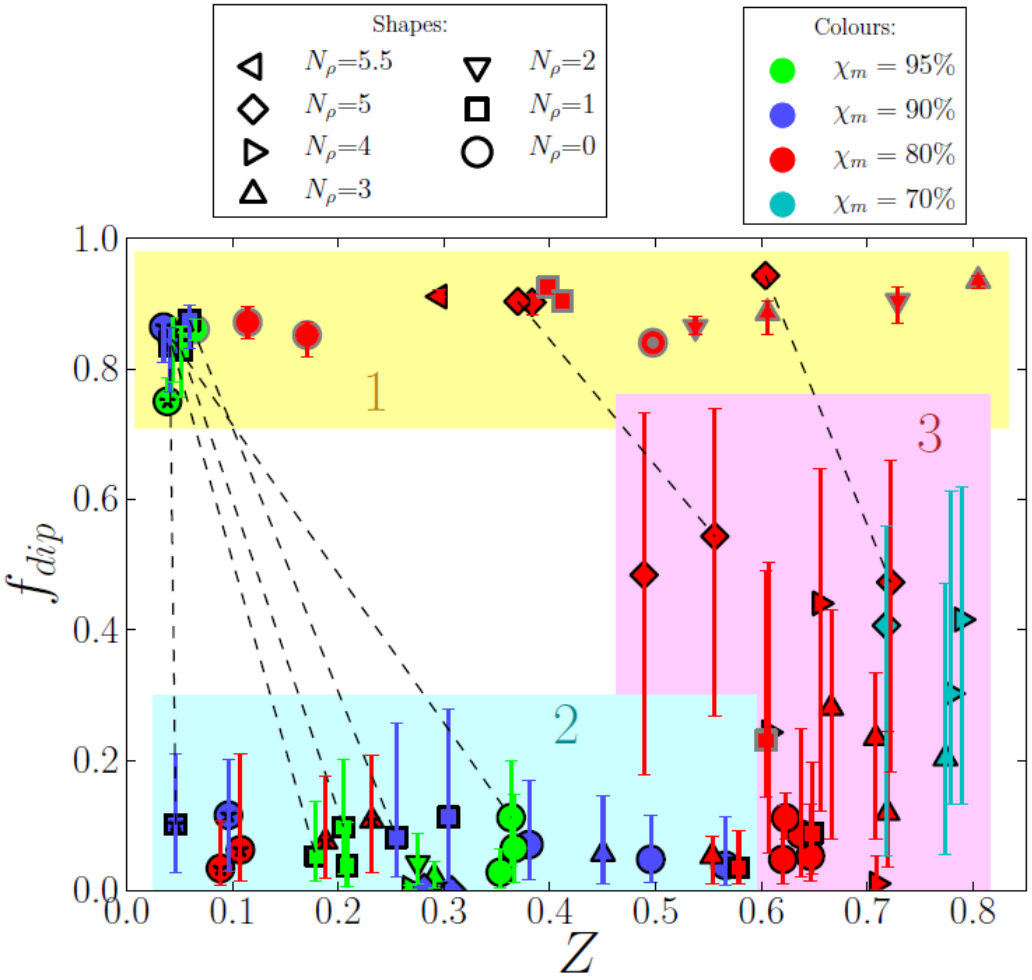




dashed line: poloidal
dash-dotted line: toroidal

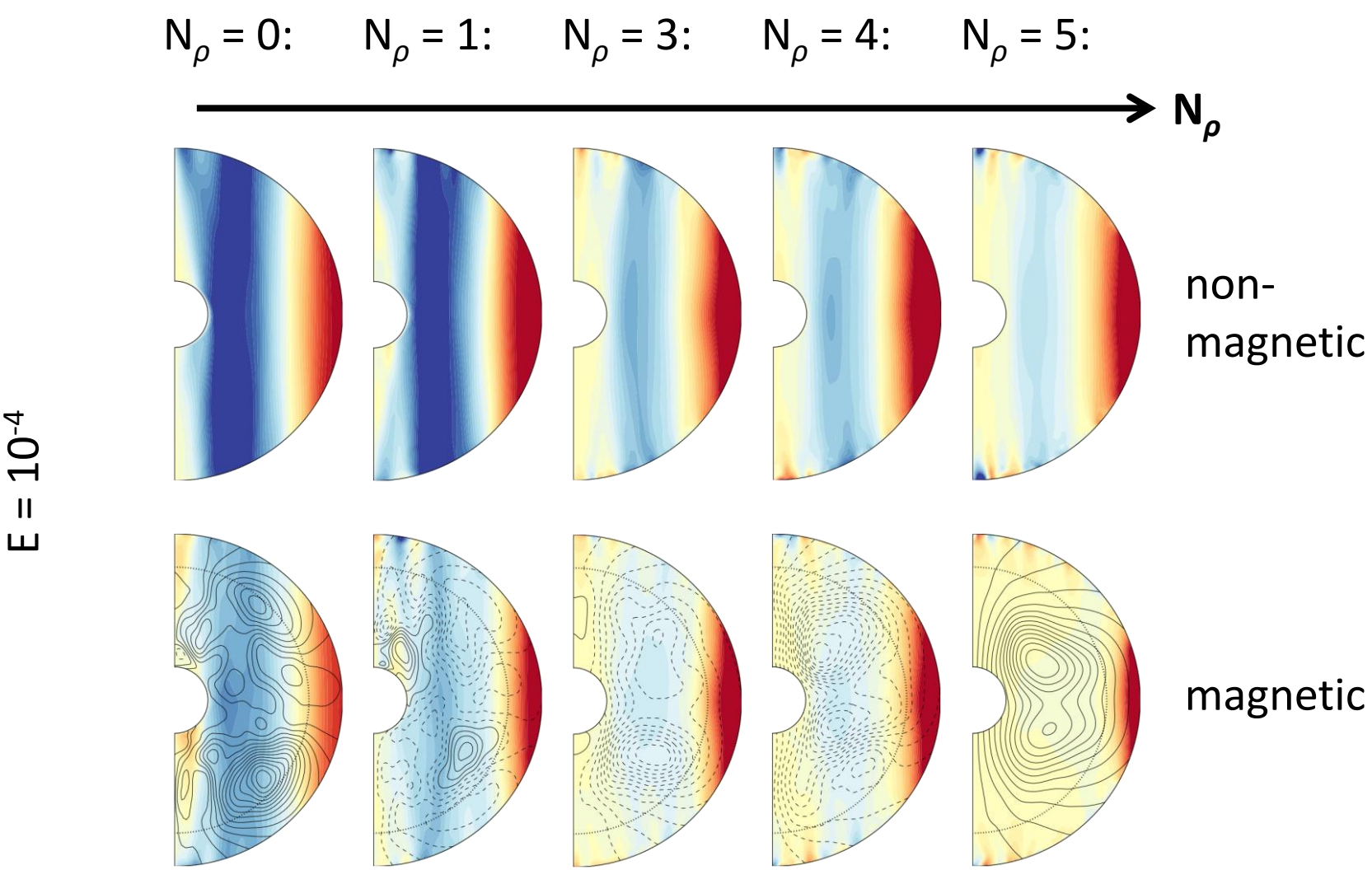
3. Variable conductivity – zonal flow

black– lower Ekman number
grey – higher Ekman number



$$Z = \frac{Ro_{zon}^2}{Ro^2}$$

3. Variable conductivity – zonal flow

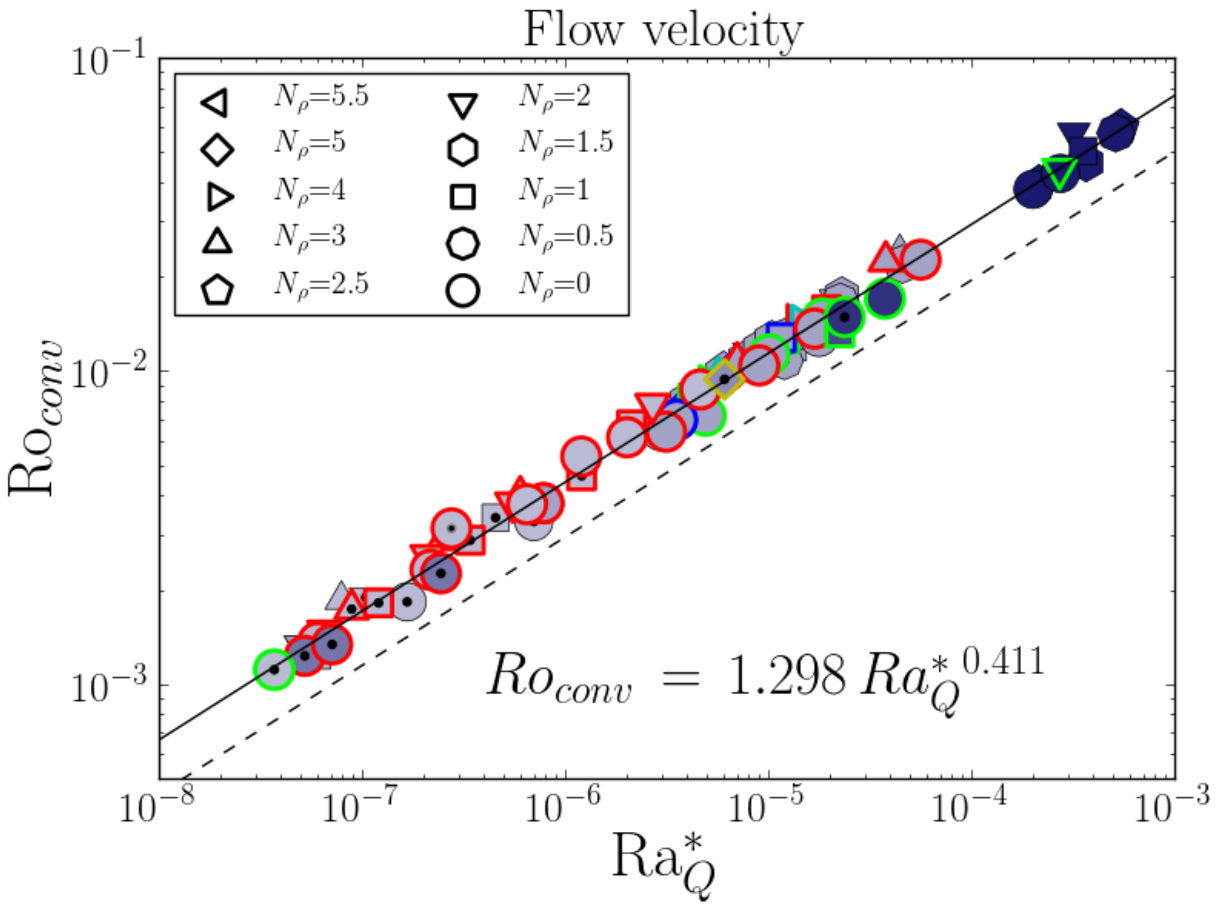


4. Scaling Laws – convective flow

Jupiter:
convective flow velocity
1 – 5 cm/s

$$Ra_Q^* = Ra(Nu-1)\frac{E^3}{Pr^2}$$

$$Ro_{conv} = \frac{u_{conv}}{\Omega\, d_{shell}}$$



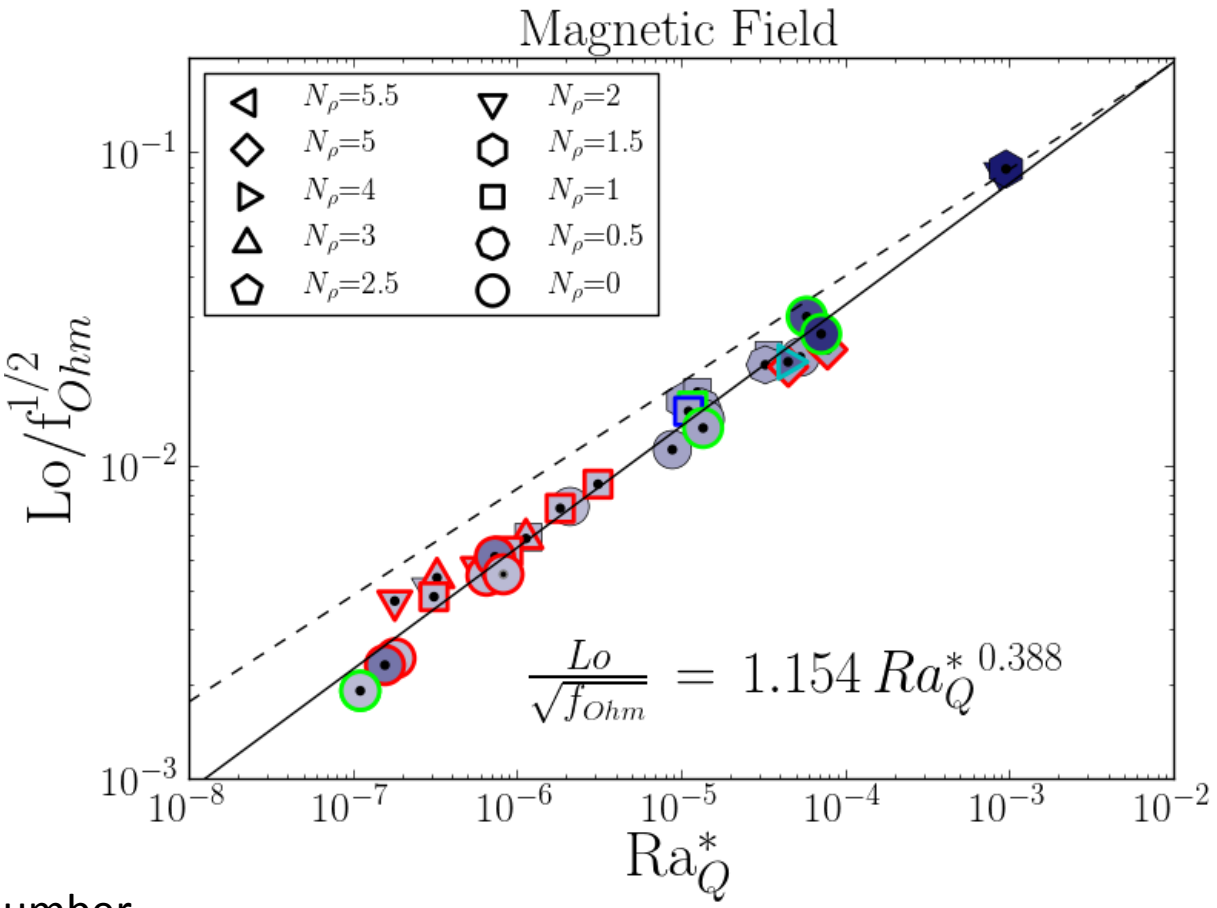
4. Scaling Laws – magnetic field

Jupiter:
magnetic field strength
1 – 5 mT

$$Ra_Q^* = Ra(Nu-1)\frac{E^3}{Pr^2}$$

$$\frac{Lo}{\sqrt{f_{Ohm}}} = \frac{\sqrt{2E_{mag}/volume}}{\sqrt{OhmicDiss\ /BuoPower}}$$

$$Lo = \frac{B_{rms}}{\Omega d\sqrt{\mu_0 \rho}}$$ → Lorentz number



5. Conclusions

- Our anelastic model is still a simple model for Jupiter, but it is a step in the right direction.
- From our variable electrical conductivity simulations, we find that a stable dipole doesn't coexist with strong zonal flow.
- Our simulations point to the fact that we cannot have a stable dipole if Ω-effect is present inside the main conducting region.
- A model with density stratification appears to only be successful in generating a dipolar dynamo when:
  - we are able to confine the steeper part of the density gradient outside of the metallic hydrogen envelope;
  - the magnetic field generated deeper is strong enough to push the jets outside (for example, lower Ekman number).

MPS

planetary magnetism

Technische Universität Braunschweig

Thank you.

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SOLAR SYSTEM SCHOOL