Simulations of the gravity and magnetic fields to be measured by *Juno* at Jupiter

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NASA *Juno* Mission to Jupiter

launched in August 2011

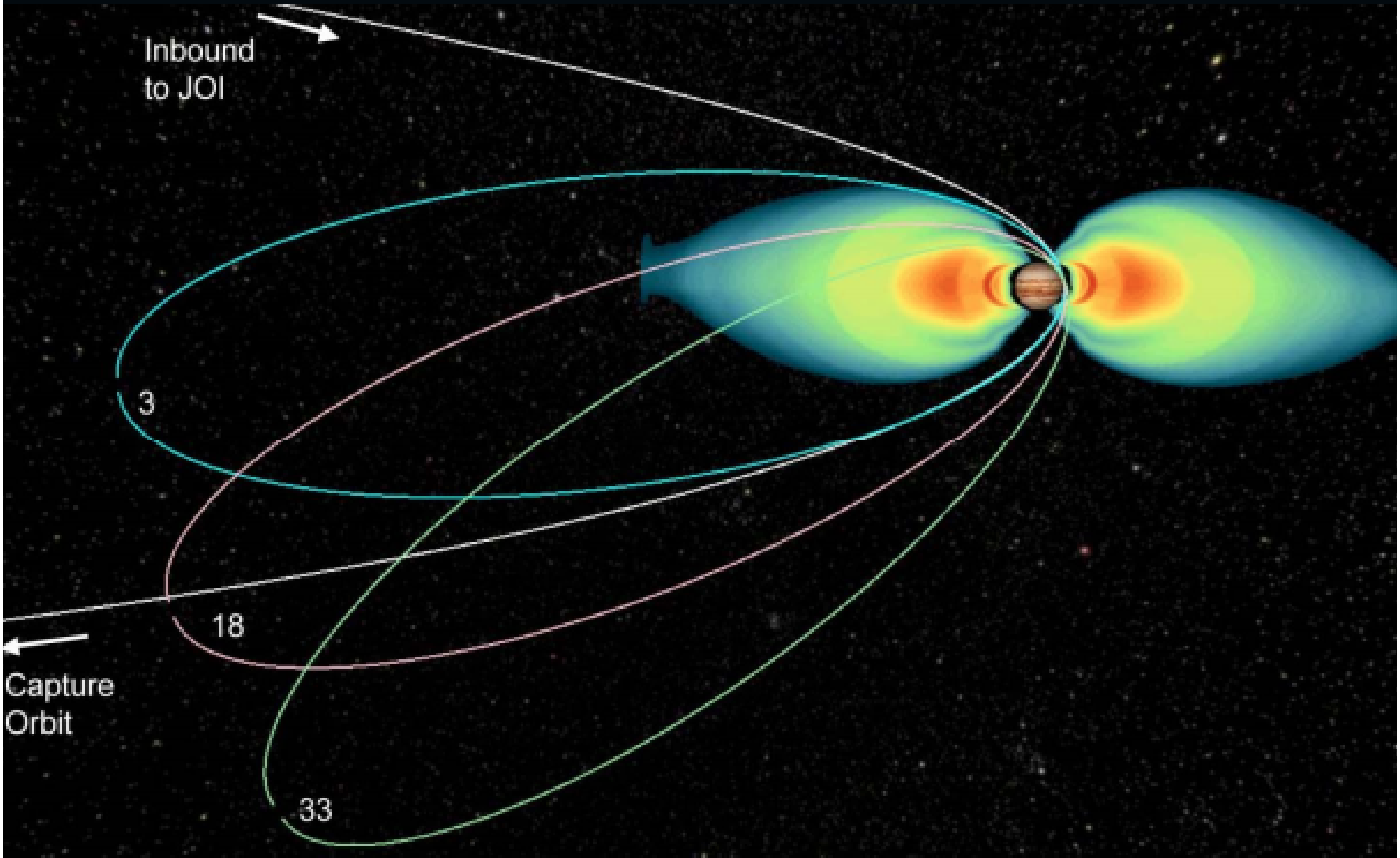
arriving in July 2016

one year orbiting Jupiter
11-day, eccentric, polar orbit
with closest approach of 5000 km

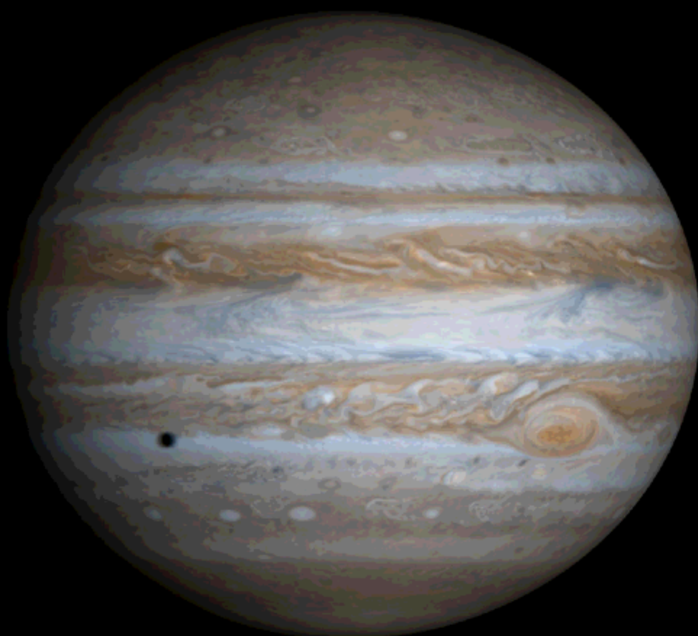
magnetosphere, atmosphere, <u>interior</u>

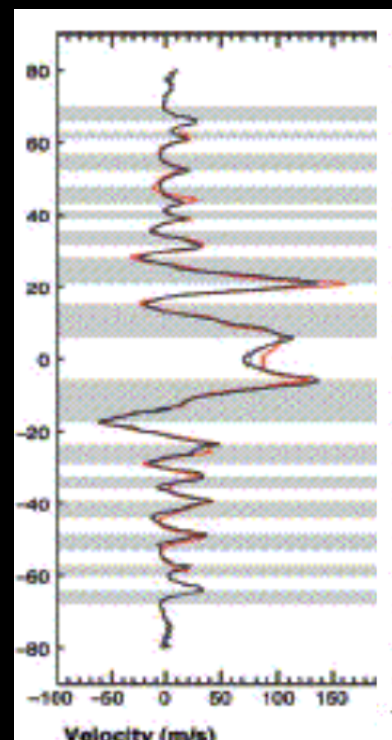
NASA *Cassini Soltice* Mission to at Saturn

NASA *Juno* Mission to Jupiter



What is the structure of the banded zonal winds deep below the surface and how is it maintained?





Spherical harmonic expansions of the gravitational and magnetic fields

$$\Phi'_G(r,\theta,\phi,t) = \sum_{l,m} \Phi_l^m(r) Y_l^m(\theta,\phi)$$

For $m = 0$ and $r \geq r_{top}$,

$$\Phi_G(r,\theta,t) = -\frac{GM}{r}\left(1 - \sum_l J_l \left(\frac{r_{top}}{r}\right)^l P_l(\cos\theta)\right)$$

and

$$\Delta J_l \equiv J_l - \overline{J}_l = \left(\frac{2l+1}{4\pi}\right)^{1/2} \frac{r_{top}}{GM}\, \Phi_l^0(r_{top})\,.$$

Using all l and m, we can plot the three components of

$$\mathrm{g}'(r,\theta,\phi,t) = -\nabla\Phi'_G$$

for $r \geq r_{top}$.

Similarly, for the external potential magnetic field (i.e., for $r \geq r_{top}$, $\nabla \times \mathrm{B} = 0$),

$$\mathrm{B} = -\nabla \Phi_B$$

where

$$\Phi_B = r_{top} \sum_{l,m} \left(\frac{r_{top}}{r} \right)^{l+1} \left(g_l^m \cos m\phi + h_l^m \sin m\phi \right) P_l^m \, .$$

For $m = 0$ and $r \geq r_{top}$, we can plot g_l^0 vs l.

Using all l and m, we can plot the three components of B for $r \geq r_{top}$.

Numerical method and resolution

Spherical harmonic and Chebyshev polynomial expansions:

$l_{max} = m_{max} = 511$, $n_{max} = 241$

grid space: 1536 x 768 x 241

$\Delta t \approx 100$ s, 1 million time steps

Polytropic reference state fitted to models of Nettelmann et al. 2008 and French et al. 2012, using a polytropic index of 0.96.

$$\bar{p} \propto \bar{\rho}^{2.04}$$

$$\overline{T} \propto \bar{\rho}^{0.515}$$

$r_{top} = 0.98 R_J \qquad r_{bot} = 0.10 R_J \qquad D = r_{top} - r_{bot} = 6.15 \times 10^9 \mathrm{cm}$

$\bar{\rho}_{bot}/\bar{\rho}_{top} = 52$ **(4 density scale heights, 8 pressure scale heights)**

$\Omega = 1.77 \times 10^{-4}$ **radians/s**

$\nu = 10^{10}$ $\mathrm{cm^2/s}$ **(constant)**

$\kappa = 10^{12}$ $\mathrm{cm^2/s}$ **(constant)**

$\eta_{top} = 10^{14}\ \mathrm{cm^2/s} \qquad \eta_{0.86 R_J} = \eta_{bot} = 10^{10}\ \mathrm{cm^2/s}$

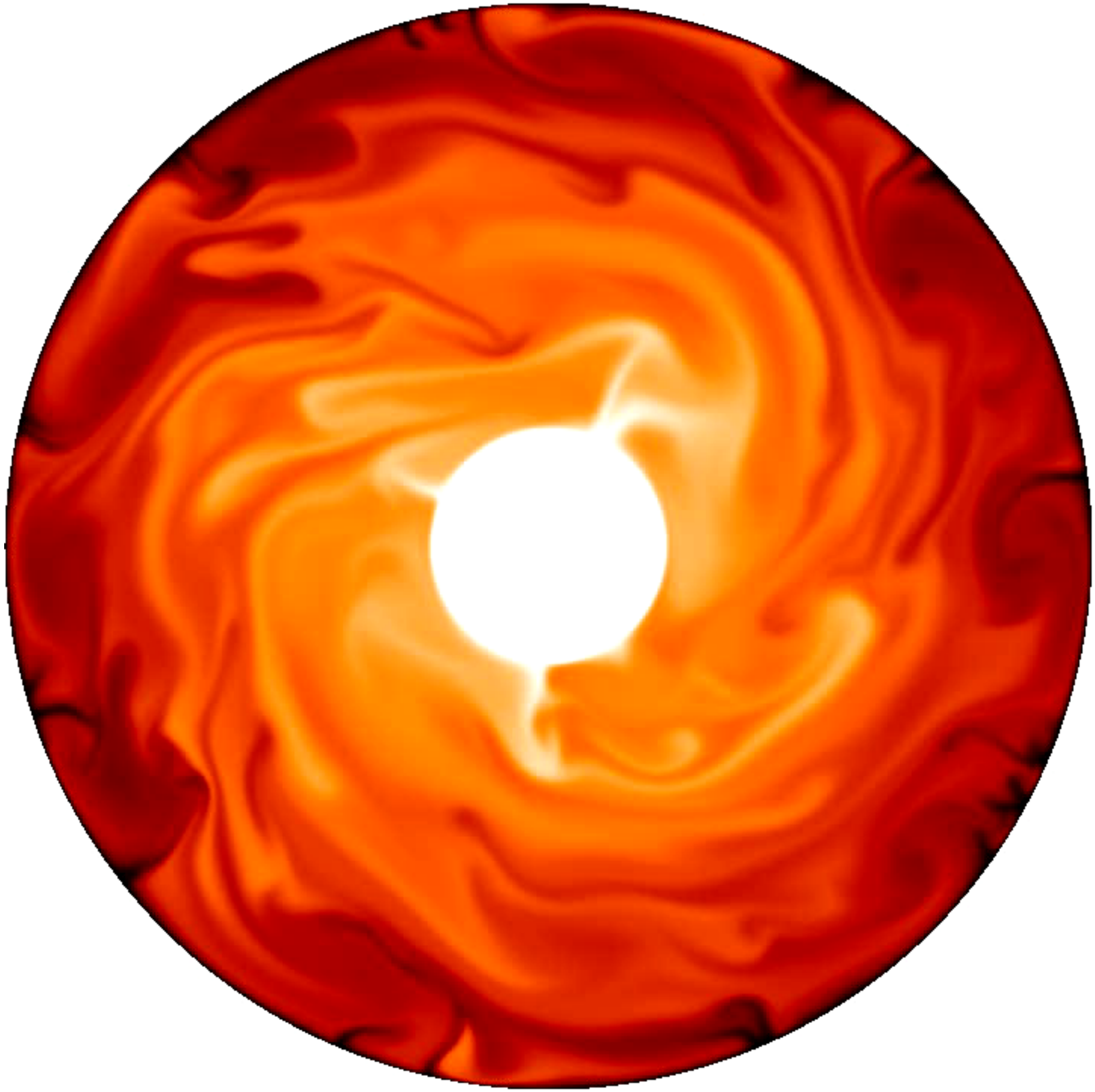
$\mathrm{Pr} = \frac{\nu}{\kappa} = 10^{-2}$

$\mathrm{Ek} = \frac{\nu}{\Omega D^2} = 10^{-6}$

$\mathrm{Re} = \left(\frac{UD}{\nu}\right) = 10^4$

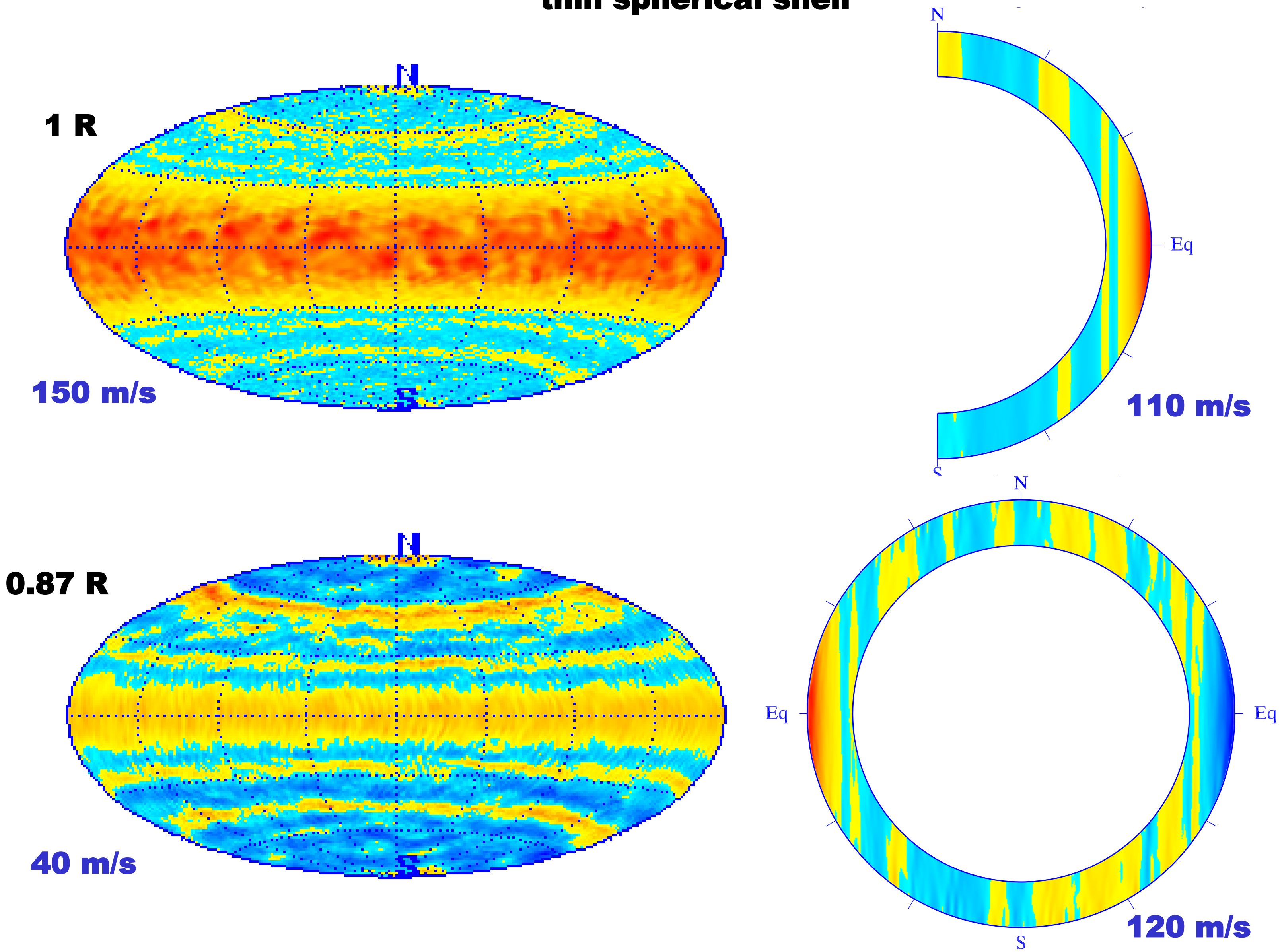
$\mathrm{Rm} = \left(\frac{UD}{\eta}\right) = 10^3$

$\mathrm{Ro} = \left(\frac{U}{\Omega D}\right) = 10^{-2}$



Zonal winds (differential rotation)

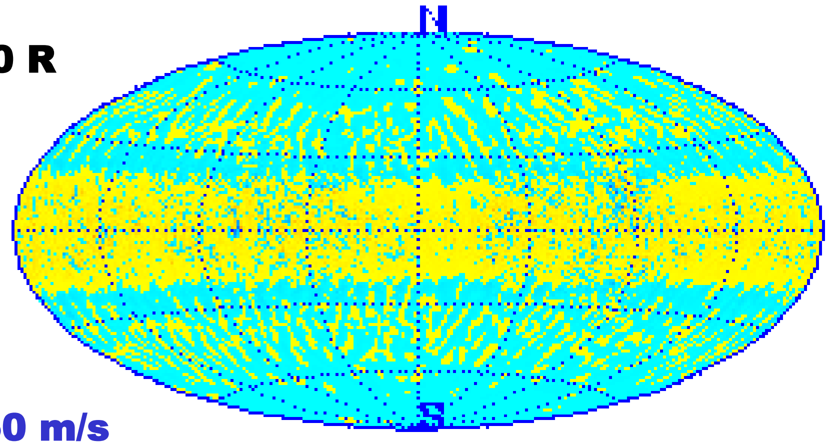
thin spherical shell



Zonal winds (differential rotation)

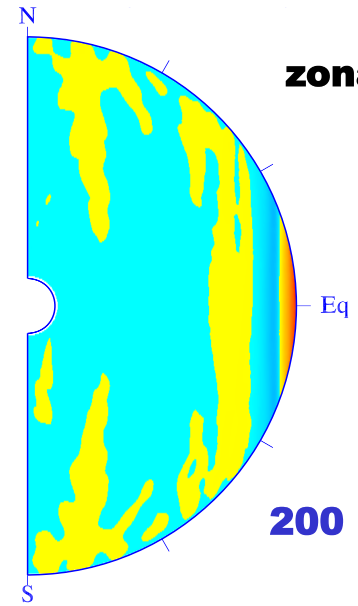
deep spherical shell

1.0 R



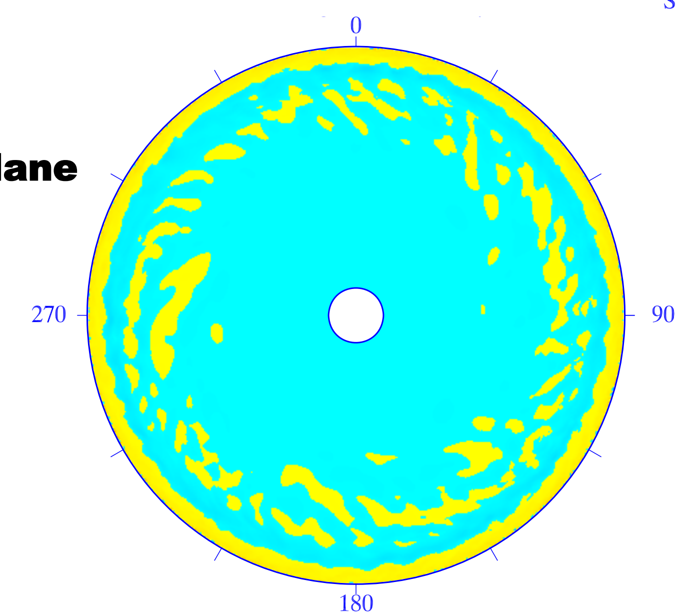
250 m/s

zonal ave



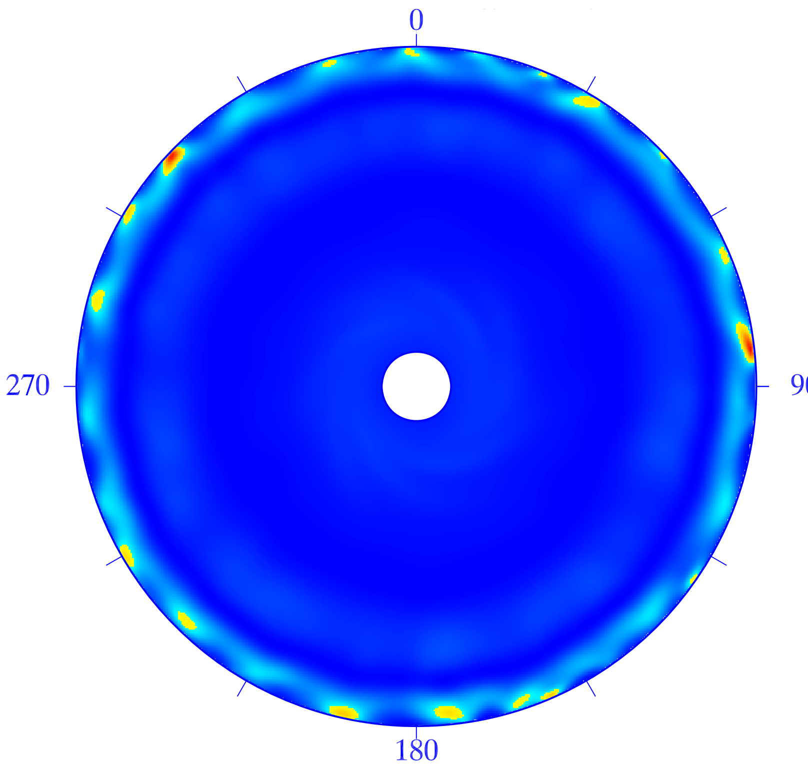
200 m/s

eq plane

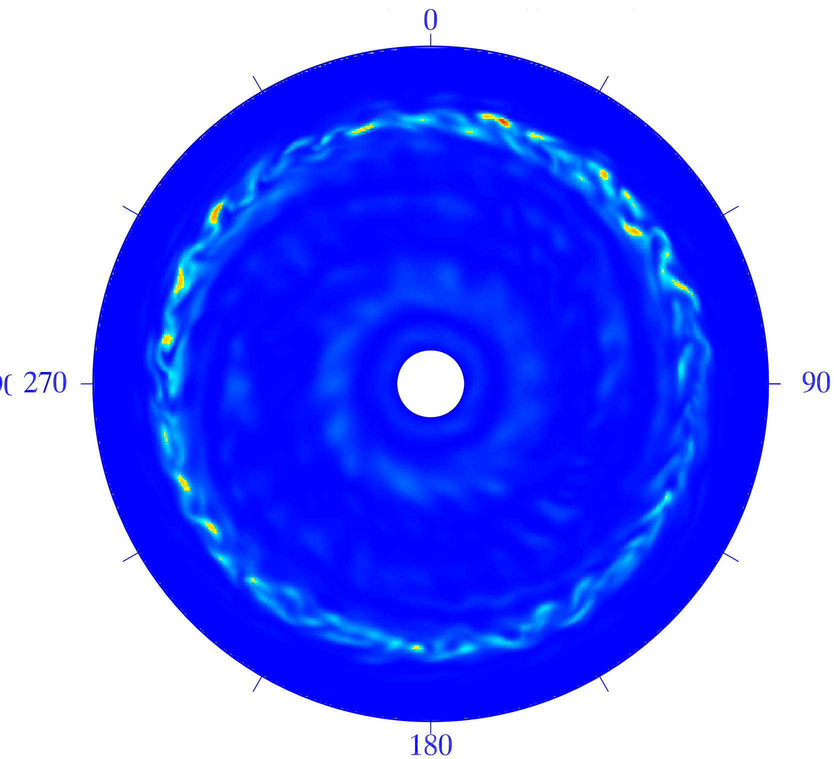


equatorial plane

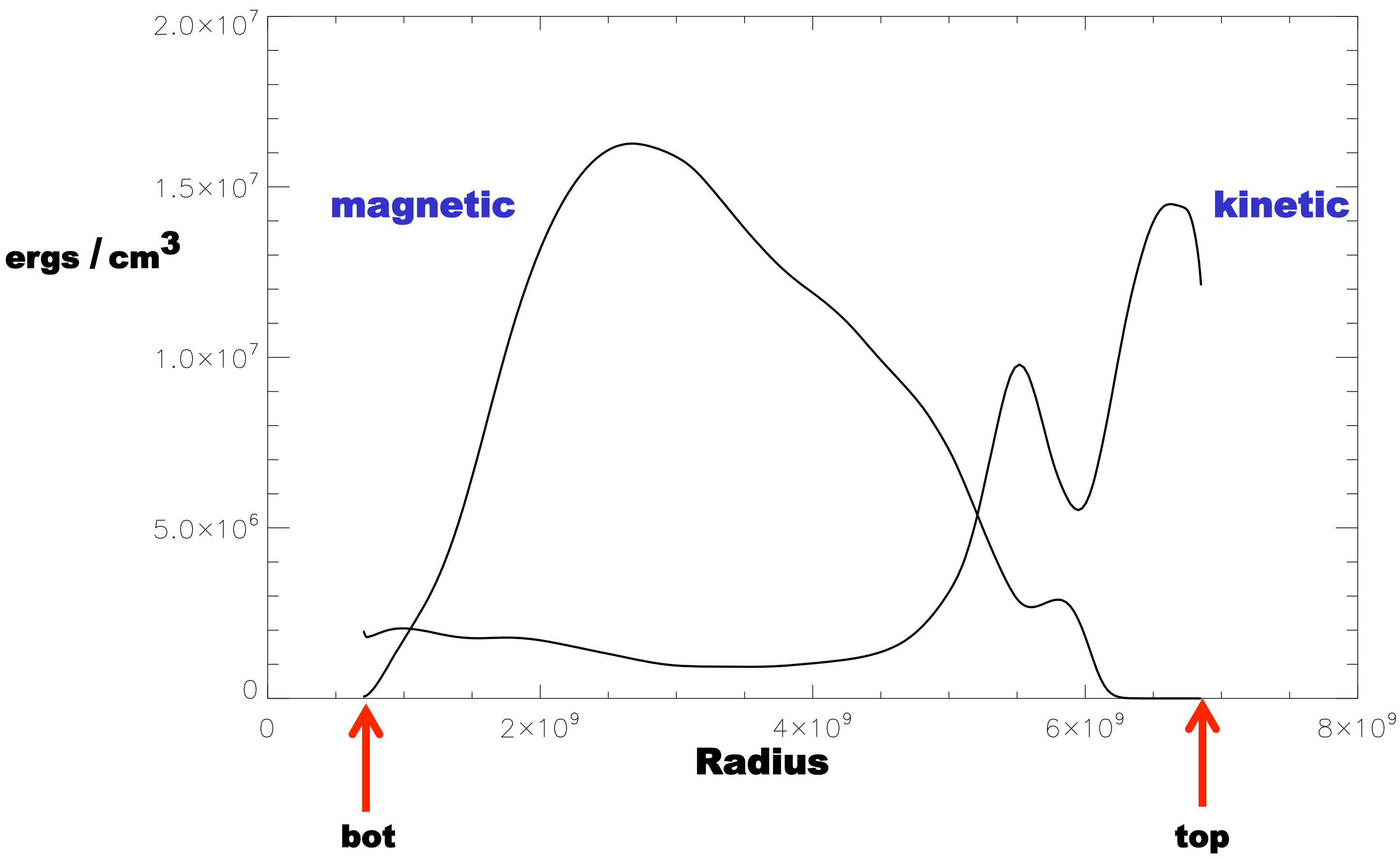
kinetic energy density



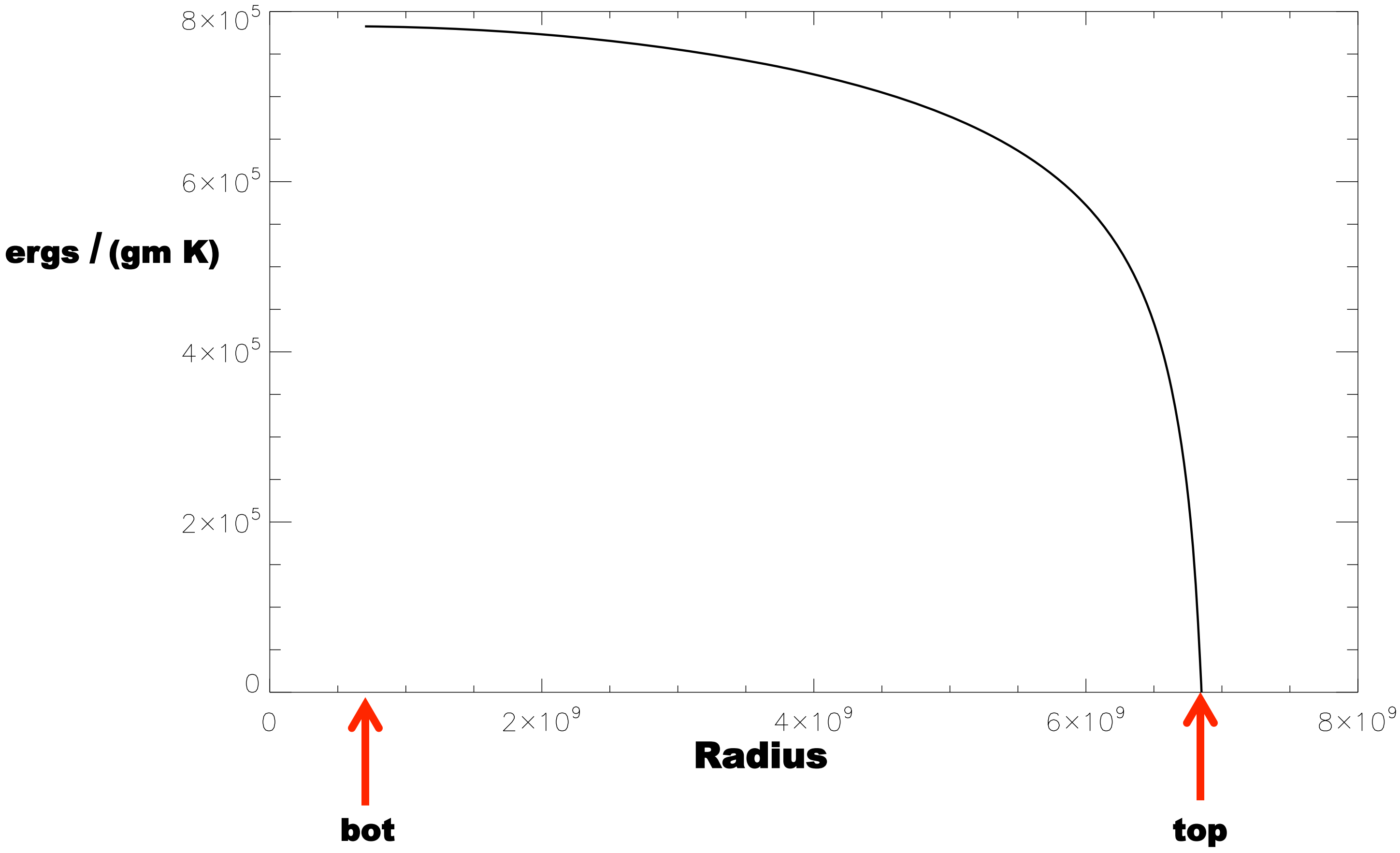
magnetic energy density



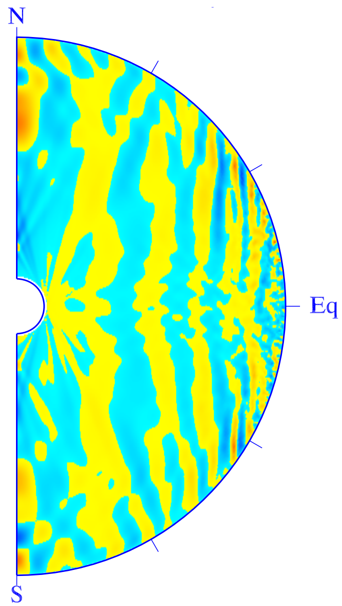
Magnetic energy density



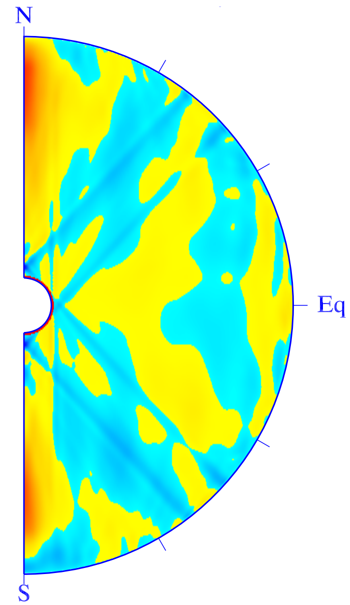
entropy perturbation vs radius



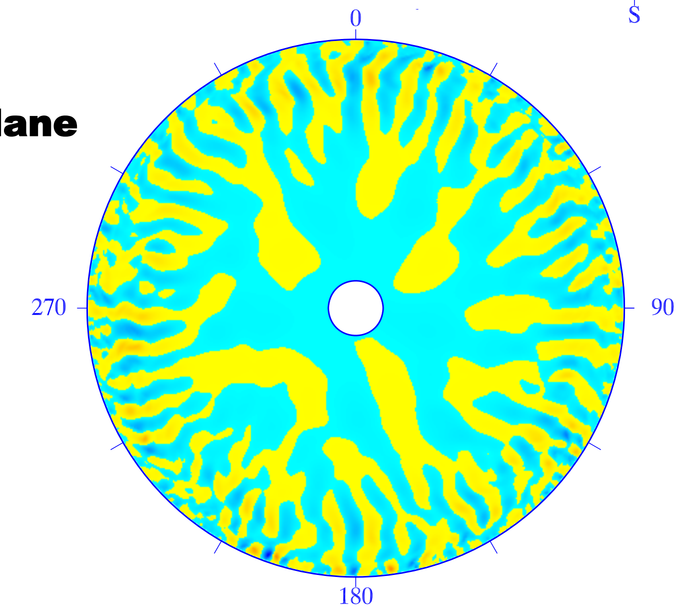
Radial velocity



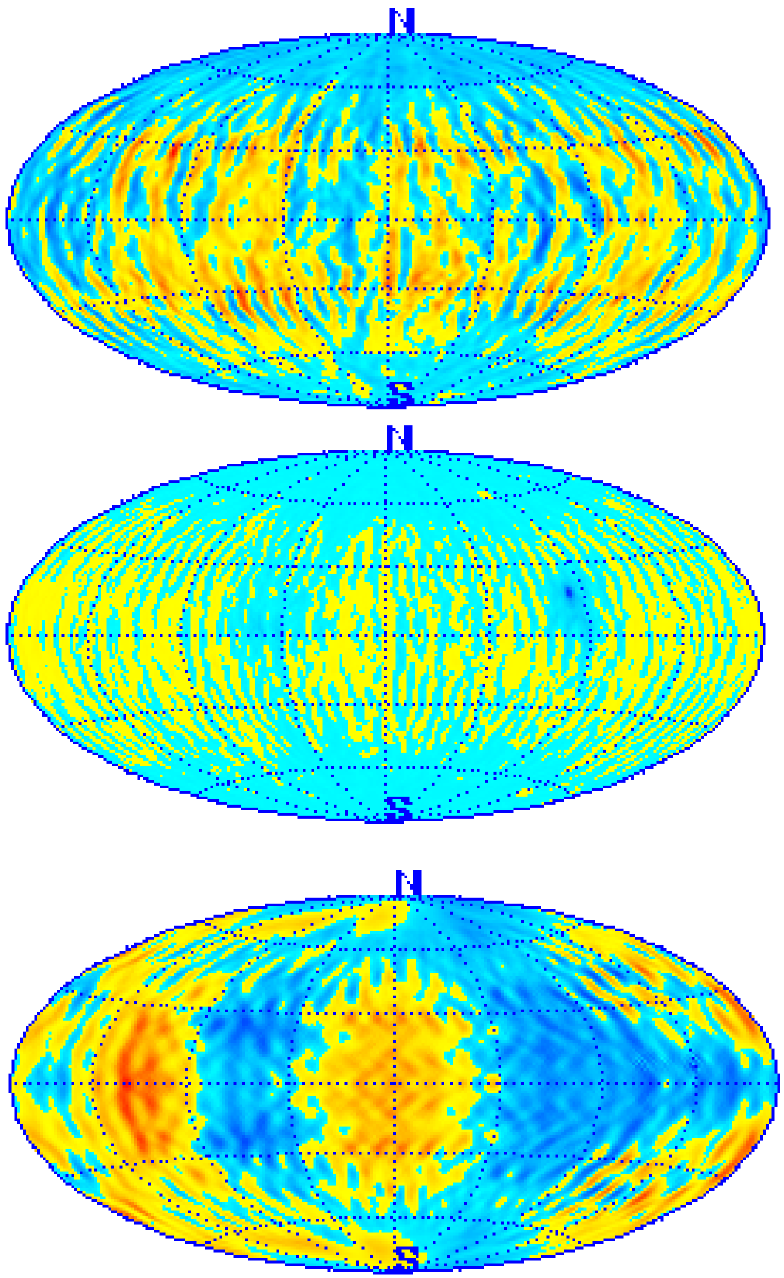
zonal ave



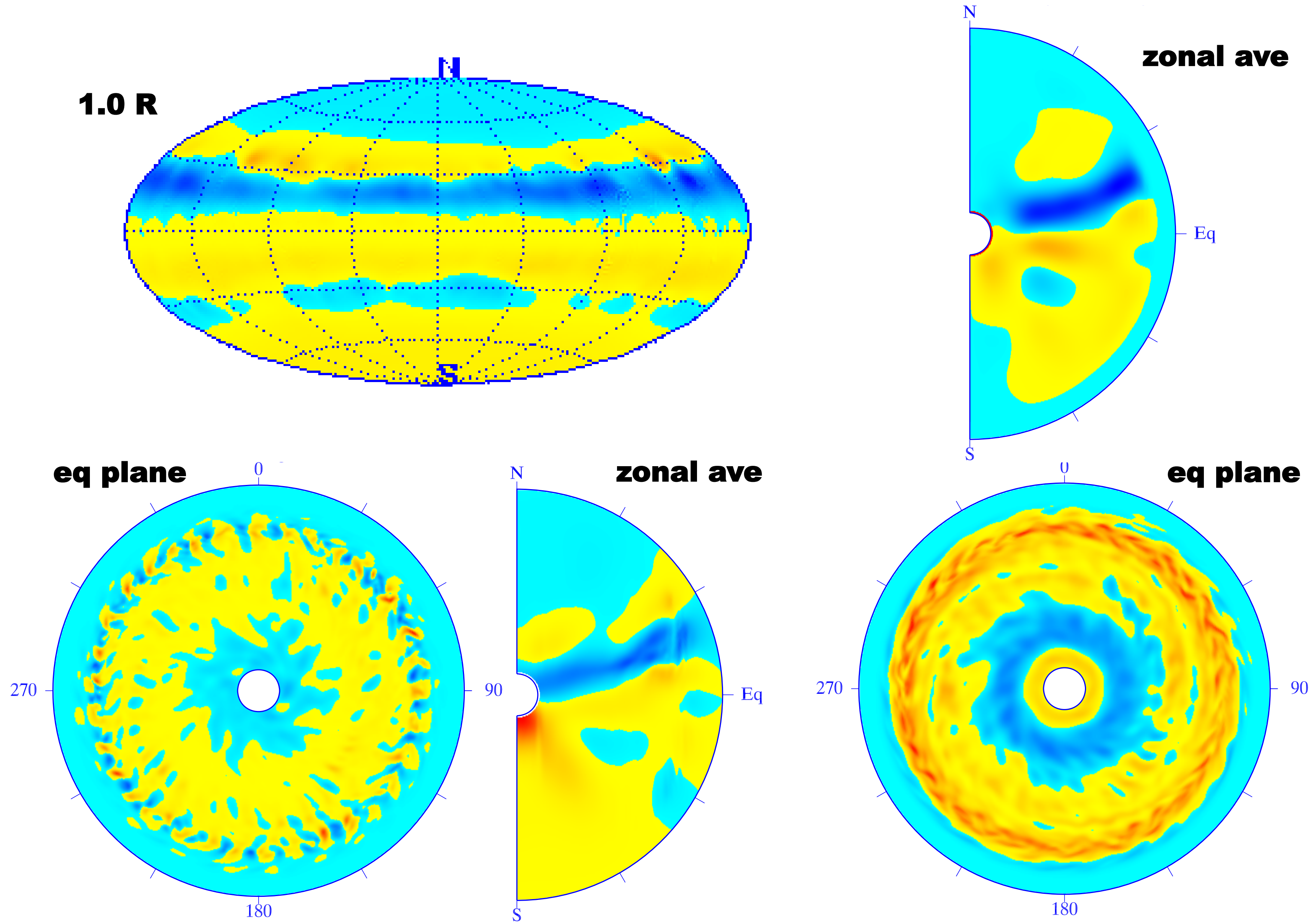
eq plane



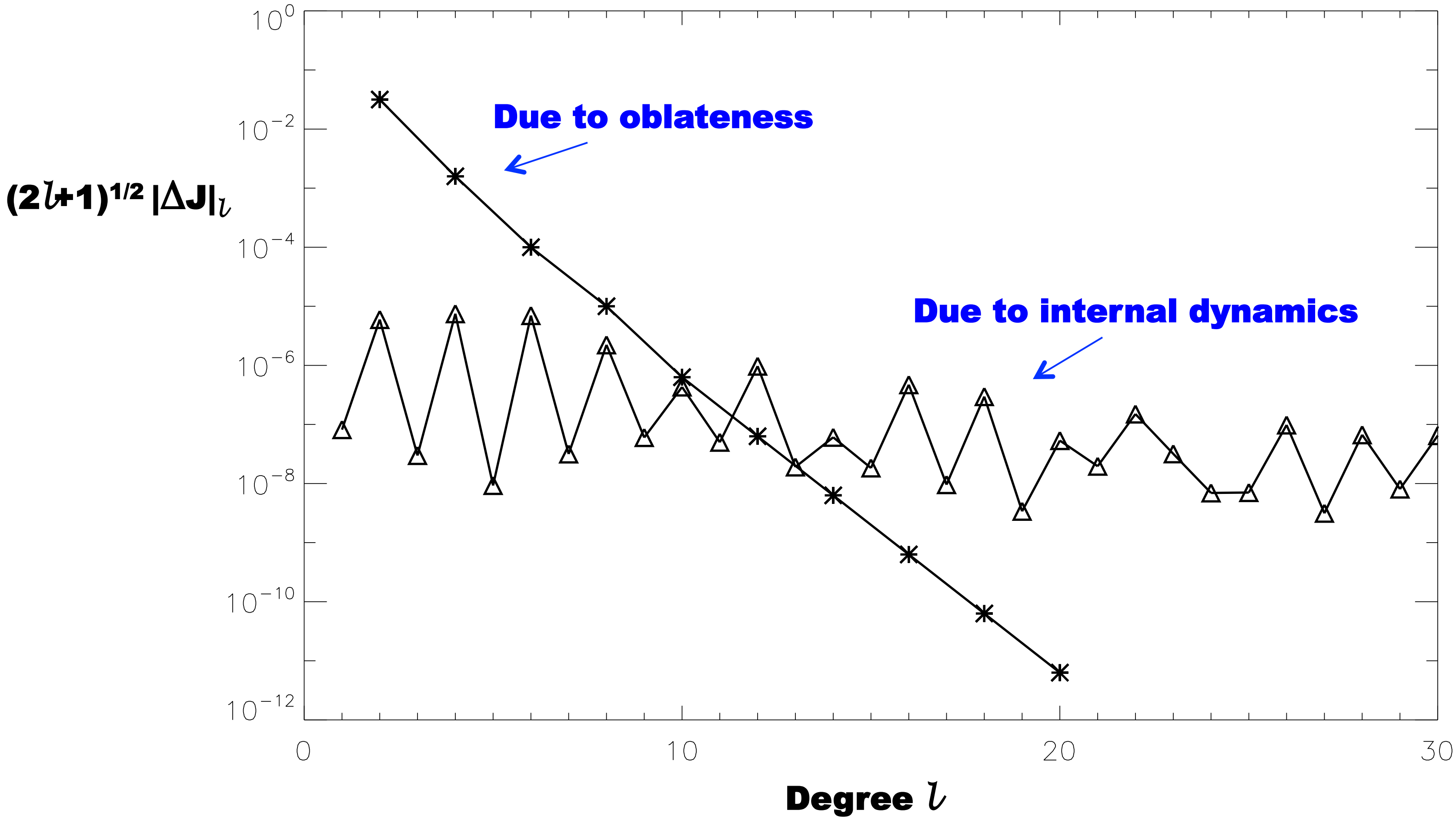
Entropy at surface

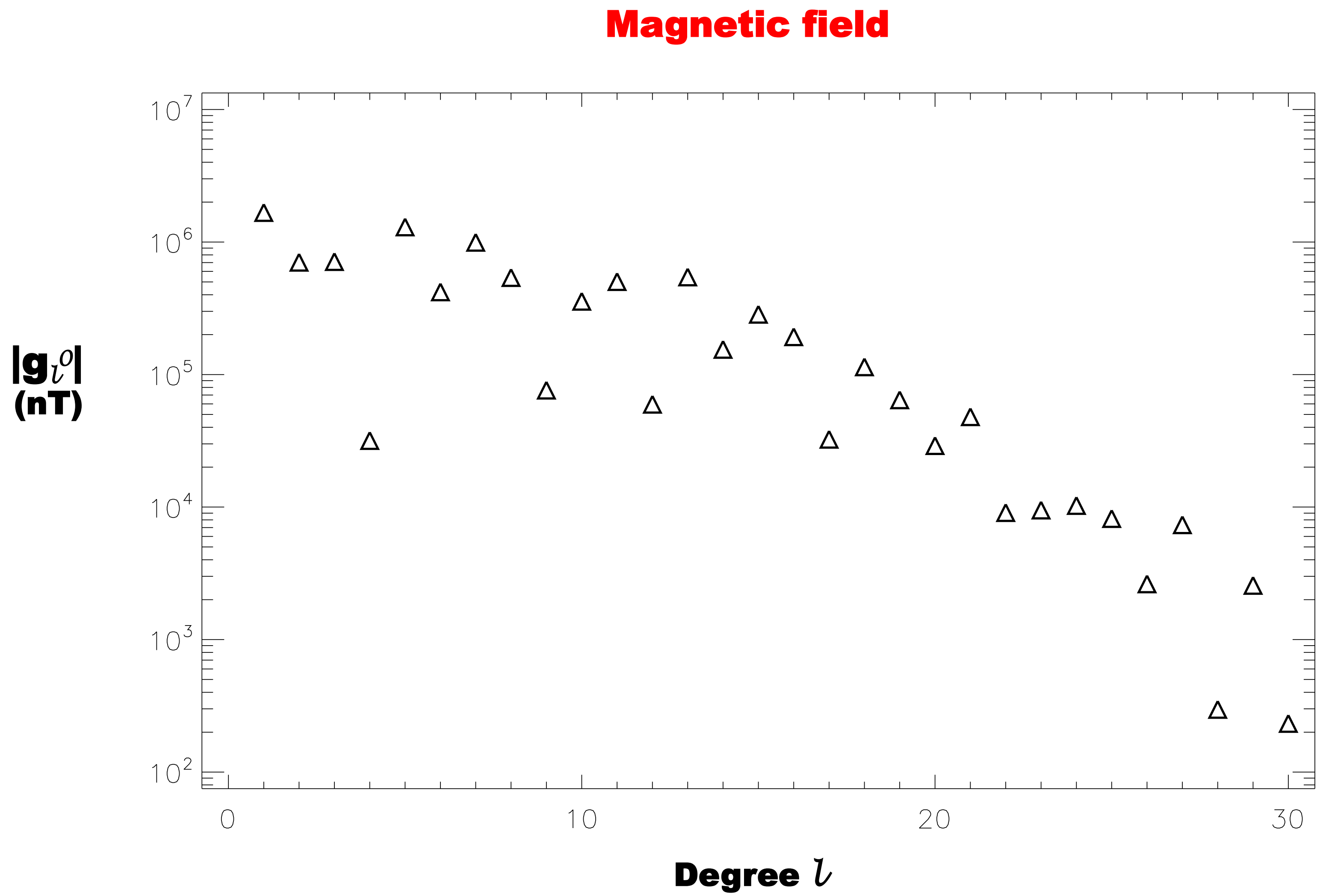


Radial magnetic field   Longitudinal magnetic field



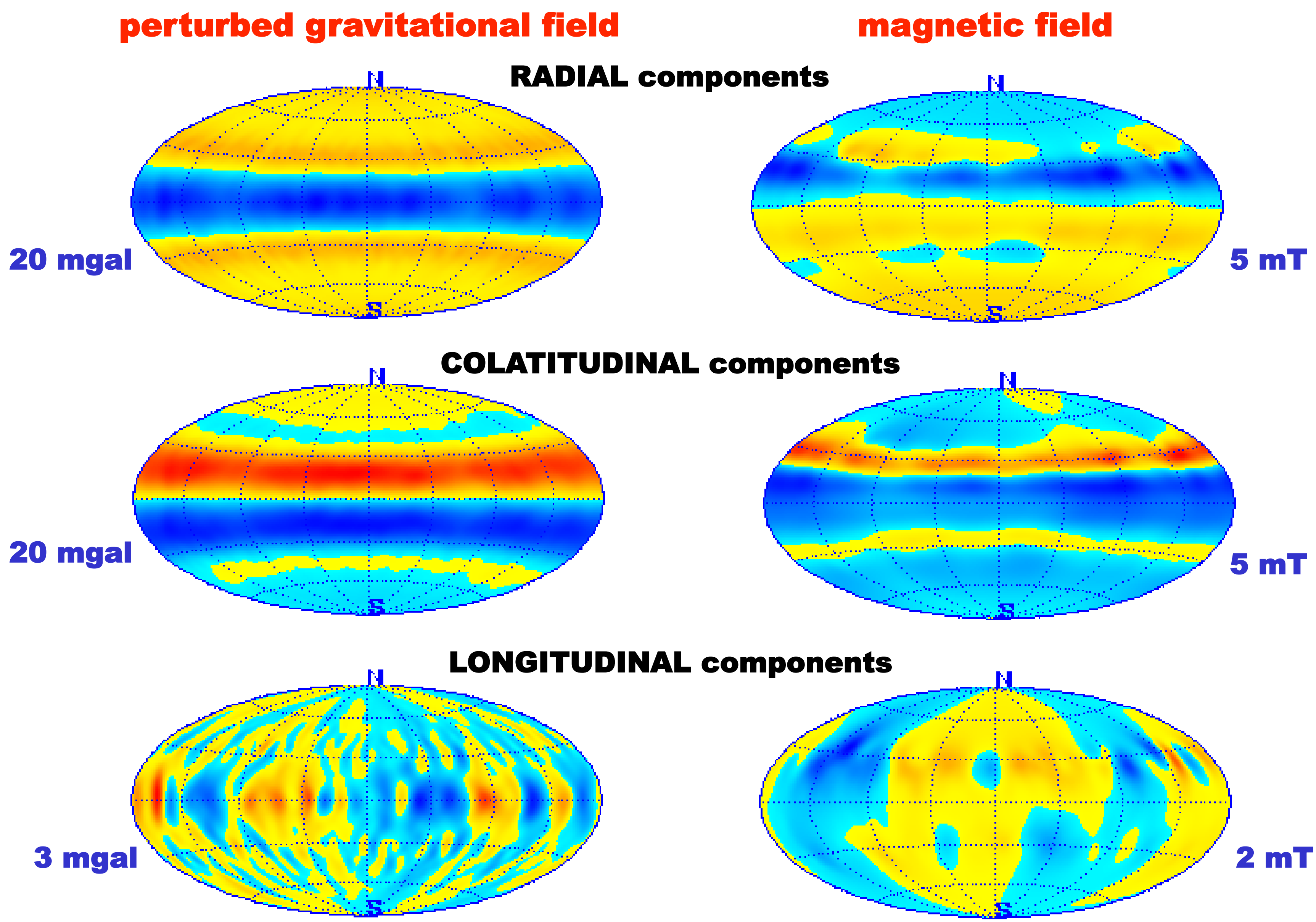
Gravitational field





Magnetic field
$|g_l^0|$ (nT)
10^7
10^6
10^5
10^4
10^3
10^2
0
10
20
30
Degree l

Perijove (1.07 R_J)



To gain the most from the *Juno* mission, we will need to analyze the gravity and magnetic data together and in conjunction with what is predicted by 3D computer simulations that self-consistently solve for thermal convection, differential rotation, and the resulting gravitational and magnetic fields.

Latitudinally-banded structures observed in the gravity and magnetic data would indicate that the zonal winds extend deep below the surface.

Observing no banded structures in the data would suggest that the zonal winds are shallow atmospheric features.