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

Gary A Glatzmaier
University of California Santa Cruz
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, *interior*

NASA *Cassini Solstice* Mission to 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

\[ \Phi'_G(r, \theta, \phi, t) = \sum_{l,m} \Phi^m_l(r) Y^m_l(\theta, \phi) \]

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

\[ \Delta J_l \equiv J_l - J_l = \left( \frac{2l + 1}{4\pi} \right)^{1/2} \frac{r_{top}}{GM} \Phi^0_l(r_{top}). \]

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

\[ g'(r, \theta, \phi, t) = -\nabla \Phi'_G \]

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

$$B = -\nabla \Phi_B$$

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: $1536 \times 768 \times 241$

$\Delta t \approx 100$ 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.

\[ \tilde{\rho} \propto \tilde{\rho}^{2.04} \]
\[ \overline{T} \propto \tilde{\rho}^{0.515} \]

\[ r_{top} = 0.98R_J \quad r_{bot} = 0.10R_J \quad D = r_{top} - r_{bot} = 6.15 \times 10^9 \text{cm} \]

\[ \tilde{\rho}_{bot}/\tilde{\rho}_{top} = 52 \quad (4 \text{ density scale heights, 8 pressure scale heights}) \]

\[ \Omega = 1.77 \times 10^{-4} \text{ radians/s} \]

\[ \nu = 10^{10} \text{ cm}^2/\text{s} \text{ (constant)} \]

\[ \kappa = 10^{12} \text{ cm}^2/\text{s} \text{ (constant)} \]

\[ \eta_{top} = 10^{14} \text{ cm}^2/\text{s} \quad \eta_{0.86R_J} = \eta_{bot} = 10^{10} \text{ cm}^2/\text{s} \]

\[ \text{Pr} = \frac{\nu}{\kappa} = 10^{-2} \]

\[ \text{Ek} = \frac{\nu}{\Omega D^2} = 10^{-6} \]

\[ \text{Re} = \left( \frac{U D}{\nu} \right) = 10^4 \]

\[ \text{Rm} = \left( \frac{U D}{\eta} \right) = 10^3 \]

\[ \text{Ro} = \left( \frac{U}{\Omega D} \right) = 10^{-2} \]
Zonal winds (differential rotation)

thin spherical shell

1 R
150 m/s

0.87 R
40 m/s

110 m/s

120 m/s
Zonal winds (differential rotation)

deep spherical shell

1.0 R

250 m/s

eq plane

zonal ave

200 m/s

eq plane
equatorial plane

kinetic energy density

magnetic energy density
Magnetic energy density

ergs / cm$^3$

Radius

magnetic

kinetic

bot

top
entropy perturbation vs radius

```
    8x10^5
    6x10^5
    4x10^5
    2x10^5
    0
    0
   2x10^9
   4x10^9
   6x10^9
   8x10^9

ergs / (gm K)
```

Radius

bottom:

```
bot
```

top:

```
top
```
Radial velocity

zonal ave

eq plane
Entropy at surface
Gravitational field

Due to oblateness

Due to internal dynamics

$(2l+1)^{1/2} |\Delta J|_l$
Magnetic field

\[ |g_{i}^\circ| \quad \text{(nT)} \]

Degree \( l \)
Perijove (1.07 R\textsubscript{J})

perturbed gravitational field

RADIAL components

20 mgal

magnetic field

RADIAL components

5 mT

20 mgal

COLATITUDINAL components

5 mT

20 mgal

LONGITUDINAL components

3 mgal

2 mT
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.