Does Saturn have a solid core? Evidence from its intrinsic magnetic field

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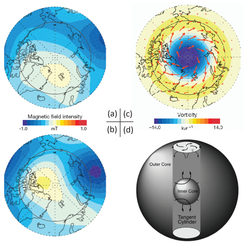
Planetary Magnetism: An Overview

Field strength	Driving power (Energy budget)
Power spectrum	Dynamo surface (Material phase transition)
Field geometry Secular variation	Dynamo mechanism Flow structure (Energy Source Distribution)
History of the field (Paleomagnetism)	Evolution of the host planet

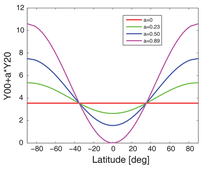
What Causes the Polar Field Minima at the Earth

- Anticyclonic polar vortex and upwelling flow inside the tangent cylinder (TC) expel magnetic flux away from the polar region



(a,b) Geomagnetic field at the outer core surface at epochs 1870 and 1990, northern hemisphere; (c) Inferred axisymmetric surface flow structure; (d) A thermal wind inside the tangent cylinder: upwelling near the spin axis, prograde above the inner core surface, retrograde below the outer core surface [Adapted from Olson & Aurnou, 1999]

Model Set-up

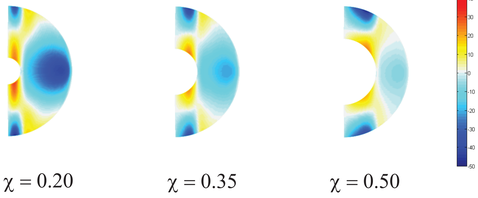


- Community dynamo code MagIC
- Driven purely by secular cooling, inner core is not a buoyancy source
- Prescribed heat flow at the outer boundary
- Proportional heat flow at the inner boundary
- Varying the inner core size, χ = 0.20, 0.35, 0.50

Inner Core Size Effects: Flow Structure

- With uniform outer boundary heat flux, a thermal wind with upwelling near the spin axis, prograde above the inner core surface, retrograde below the outer core surface is developed and well confined within the tangent cylinder

[Uφ]

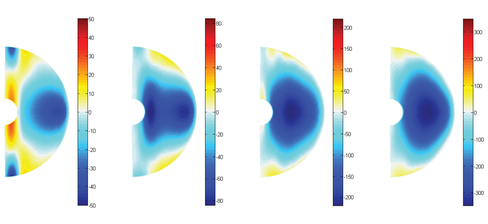


χ = 0.20 χ = 0.35 χ = 0.50

Boundary Heat Flow Effects: Flow Structure

- Zonal flow velocity increases with increasing Y20 amplitude
- Strong zonal flow in the equatorial region removes the radial magnetic field to minimize the magnetic shear
- These strong zonal flows are of thermal wind origin, driven by the non-uniform boundary heat flow ($\frac{\partial U_\varphi}{\partial z} = \frac{Ra}{r_0}\frac{\partial T}{\partial \theta}$)

[Uφ]



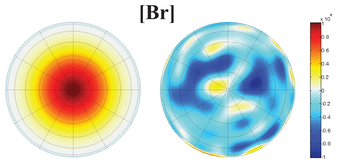
a=0.00 a=0.23 a=0.50 a=0.89

Saturn's Intrinsic Magnetic Field: Some Recent Discoveries

- Study of Cassini magnetometer measurements (Cao et al., 2011, 2012)
  - extreme axisymmetry: dipole tilt < 0.06 deg
  - no detectable secular variation
  - high degree moments (n>3) are identified for the first time
  - distinct magnetic field geometries at the dynamo surfaces: polar field maxima (Saturn) VS. polar field minima (Earth)

Cassini 5	
Coeff.	Value [nT]
g10	21191 +/- 24
g20	1586 +/- 7
g30	2374 +/- 47
g40	65 +/- 70
g50	185 +/- 100

[Br]



Saturn - 0.5 Rs Earth Core-mantle boundary

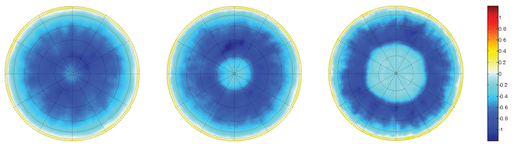
Could the Solid Inner Core Size Play a Role?

- The presence of the solid inner core defines the tangent cylinder (TC)
  - TC divides the fluid dynamo region into three parts: in the north TC,in the south TC, and outside the TC
  - Fluid in the north TC and south TC hardly communicate, could lead to equatorial asymmetry
  - Different flows, such as a thermal wind could develop inside the TC

Inner Core Size Effects: Magnetic Field

- With uniform outer boundary heat flux, the size of the polar field minimum is controlled by the relative size of the inner core

[Br]



χ = 0.20 χ = 0.35 χ = 0.50

Boundary Heat Flow Effects: Magnetic Field

- With χ = 0.20, the magnetic fluxes get more and more concentrated towards the rotation poles as the amplitude of Y20 heat anomaly gets increased (The equatorial region gets emptier in magnetic fluxes)

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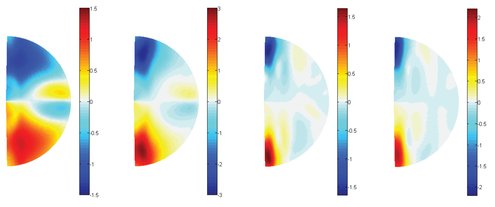
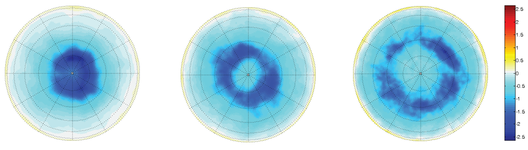


a=0.00 a=0.23 a=0.50 a=0.89

Same Heat Anomaly with Different Inner Core Sizes

- The effects of a moderate heat anamoly, a=0.23, are mediated by the inner core sizes

[Br]



χ = 0.20 χ = 0.35 χ = 0.50

The observed magnetic field of Saturn favors a small (<10 Earth Masses) core inside this planet and some Y20 type heat anomaly at the dynamo surface