CIG INCITE Project
Physical Arguments & Brief Case Descriptions

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Physical Arguments & Brief Case Descriptions

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Observations

- Remote system
  - Requires accurate modeling

- Axial dipolar field
  - High and low latitude large-scale flux patches
  - Fit ~ 6 - 8 patches around TC
    - Patch scale: \( L \sim 1000 \text{ km} \)

Jackson, Nature 2003

\( B_r \) CMB Magnetic flux (\( \mu T \))

\( L_{\text{max}} \sim 13 \)
Observations

- Remote system
  - Requires accurate modeling
  - Great success in recent numerical efforts

- Axial dipolar field
  - High and low latitude large-scale flux patches
  - Fit ~ 6 - 8 patches around TC
    - Patch scale: $L \sim 1000 \text{ km}$
Observations

Jackson, Nature 2003

$B_r$ CMB

Magnetic flux (μT)

0 10 20 30 40 50 60 70 80 90 100

-100 -200 -300 -400 -500 -600 -700 -800 -900

2000

$L_{max} \sim 13$

Models

Christensen, Enc. Solid Earth Geophys. 2011

z-vorticity
**Observations**

Jackson, Nature 2003

**Models**

Christensen, Enc. Solid Earth Geophys. 2011

- **Success**: Aligned flux patches in models & geomagnetic field
- **Extrapolation 1**: columns in models exist in cores
- **Extrapolation 2**: physics in models extrapolates to planetary cores

Extrapolations valid?
Christensen & Aubert '06

- Posit that present-day models —quasilaminar, non-metal dynamos—extrapolate to planets & stars

\[ Rm = Re Pm \]
Possible Problems

- 1) Overly strong viscosity
- 2) Lack of turbulent processes
- 3) Inaccurate material properties
Possible Problems

1) Overly strong viscosity
2) Lack of turbulent processes
3) Inaccurate material properties
\[ E = \frac{T_{\text{rot}}}{T_{\text{visc}}} = \frac{\nu}{\Omega L^2} \]

- Ekman number, $E$
- Scaled viscous force
Rotating Convection

- **Ekman number,** $E$
  - Scaled viscous force

- **Rayleigh number,** $Ra$
  - Scaled buoyancy force
  - Onset Forcing:
    \[ Ra_C \sim E^{-4/3} \]

\[
E = \frac{\tau_{rot}}{\tau_{visc}} = \frac{\nu}{\Omega L^2}
\]
Rotating Convection Columns

- Ekman number, $E$
  - Scaled viscous force

- Rayleigh number, $Ra$
  - Scaled buoyancy force
  - Onset Forcing:
    \[ Ra_C \sim E^{-4/3} \]

- Onset column width:
  \[ l_C \sim E^{1/3} \]

\[ E = \frac{\tau_{rot}}{\tau_{visc}} = \frac{\nu}{\Omega L^2} \]

Image: J. Cheng
Rotating Convection Columns

\[ \ell / D \]

\[ \ell \sim E^{1/3} \]

Ekman number, \( E \)

King & Buffett EPSL 2013
Rotating Convection Columns

Christensen, Enc. Solid Earth Geophys. 2011
Soderlund et al. EPSL 2012

\[ E = \frac{T_{rot}}{T_{visc}} = \frac{\nu}{\Omega L^2} \]

- Models:
  \[ E \approx 1e-4; l_c \approx 0.1 \]
\[ \frac{T_{rot}}{T_{visc}} = \frac{\nu}{\Omega L^2} \]

Models:

\[ E \sim 1 \times 10^{-4}; l_c \sim 0.1 \]
Rotating Convection Columns

\[ E = \frac{T_{\text{rot}}}{T_{\text{visc}}} = \frac{\nu}{\Omega L^2} \]

Models:

- Earth’s Core:
  \[ E \sim 1e^{-15}; l_c \sim 1e^{-5} \]
  (i.e., \(10^4\) x smaller than scale of flux patches)

Soderlund et al. *EPSL* 2012

10^3 too wide
Columnar Arguments

- **Model** $E^{1/3}$ columns: large-scale, $Rm_l > 1$

- **Planetary Cores** $E^{1/3}$ columns: ~10 - $10^2$ m wide; magnetically diffusive

\[
Rm_l = \frac{\tau_{\text{diff}}}{\tau_{\text{ind}}} = \frac{U_\ell \ell}{\eta} \ll 1
\]

- If they exist, model-style columns unlikely to play same part in planetary core dynamo processes

**HPC Dynamo Model**
$E = 3e^{-7}, Pm=0.05$; $Rm = 3e3, Re \sim 5e4, Ro \sim 0.02$

Andrey Sheyko, Ph.D. Thesis (2014)

HPC Dynamo Model
HPC Dynamo Model

Andrey Sheyko, Ph.D. Thesis (2014)

$(E = 3e-7, Pm=0.05); \ (Rm = 3e3, Re \sim 5e4, Ro \sim 0.02)$
\( Br \) Slice

\( (E = 3 \times 10^{-7}, Pm = 0.05); [Rm = 3 \times 10^3, Re \sim 5 \times 10^4, Ro \sim 0.02] \)

Andrey Sheyko, Ph.D. Thesis (2014)

HPC Dynamo Model
Sheyko's HPC Dynamo

Andrey Sheyko, Ph.D. Thesis (2014)

\( E = 3 \times 10^{-7}, \ Pm = 0.05 \); \( Rm = 3 \times 10^{3}, \ Re \sim 5 \times 10^{4}, \ Ro \sim 0.02 \)
- Small-scale columns:
  - Rarely extend across fluid shell
  - No obvious magnetic signatures
- Starting to enter new scale-separated regime
- But how does this further scale down natural dynamos?
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INCITE Award at ALCF
Year 1: Geodynamo:

- If Y1, Year 2: Jovian interior; 170M hrs.
- If Y2, Year 3: Solar Convection; 66M hrs.
Goal: \( Pm \sim 1e^{-3}; \ E \sim 1e^{-8} \)

- Step down from “moderate” cases to as close to the goal as possible
- Test Christensen scalings
  - In turn, testing the need for turbulence, metals, scale separation, scale-separated balances,…
- Given success, extreme “differencing” tests
- Outreach Visualizations (Goal: beyond G&R 95)
- Open Community Data

Year 2: Jupiter
Goal: $Pm \sim 0 - 1e-3; \ E \sim 1e-8; \ N_{\rho} \sim 5$

- Multiple jet solutions **AND** dynamo
- Juno Mission enters orbit August 2016
- Magnetic, heat flux, gravity measurements
- Deep jets reaching down to the dynamo?
- Open Community Data

**Year 3: Solar Convection**
Goal: \( Re \sim 10^5, E \sim 1e^{-7}; N_{\rho \phi} \sim 5 \)

- Heat transport by scale-separated convection
- If low Rossby convection (Hanasoge et al. 2012), then how is solar luminosity being transported across the convection zone?

Open Community Data