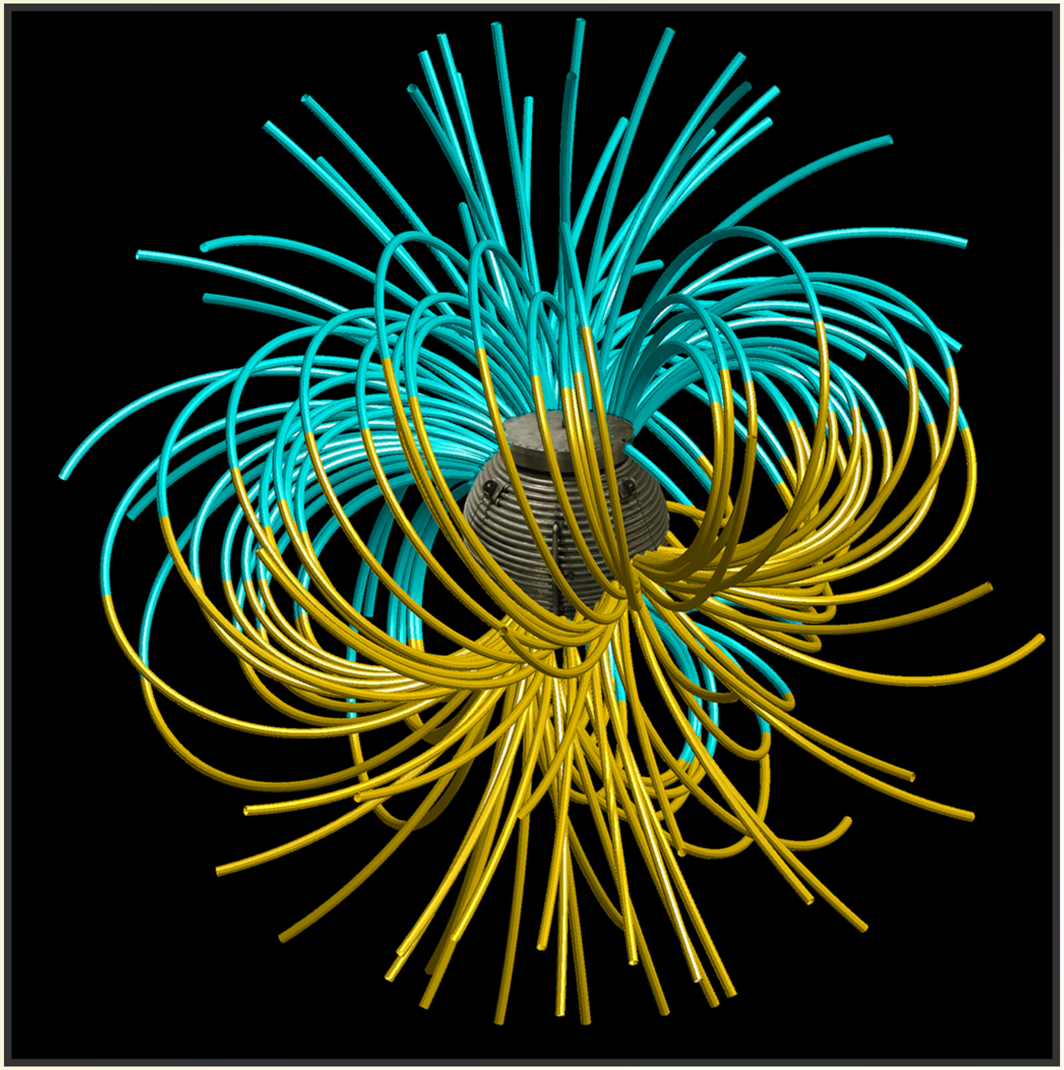

PLANETARY FLUID MECHANICS IN THE LAB

TRANSPORT, WAVES, AND MAGNETIC FIELDS IN HIGH RE SPHERICAL COUETTE FLOW

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Santiago A. Triana
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NSF/MRI EAR-0116129
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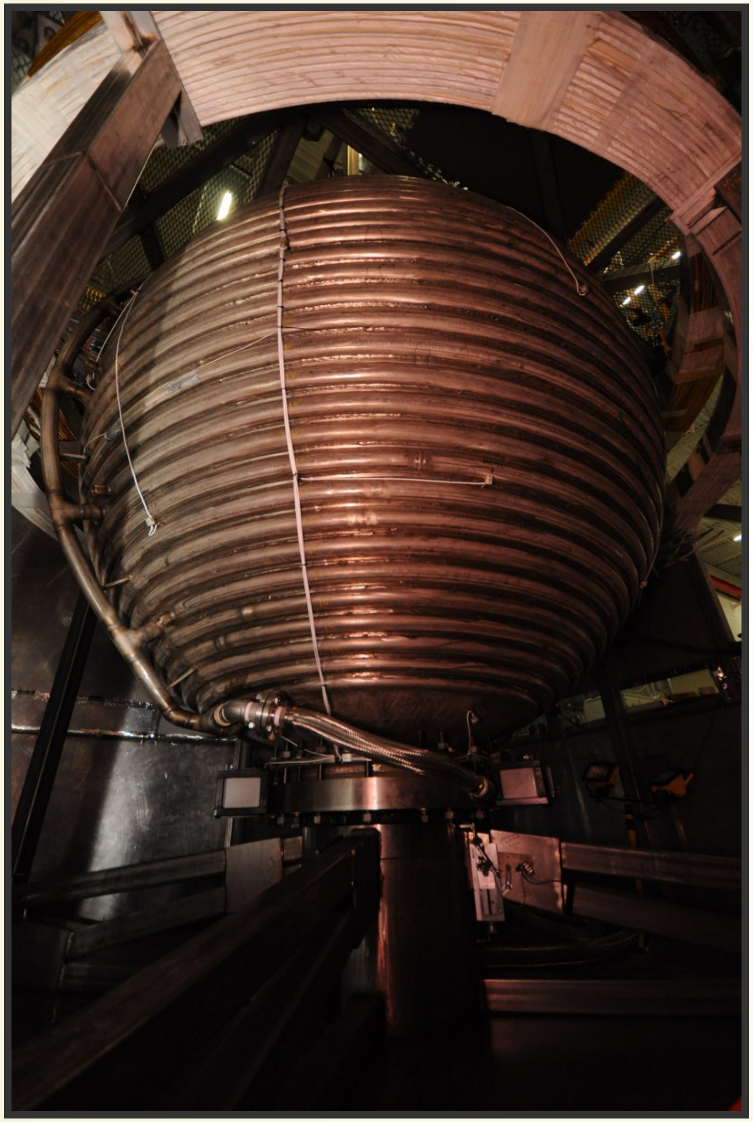
University of Maryland
Physics/IREAP/Geology

THE EXPERIMENT



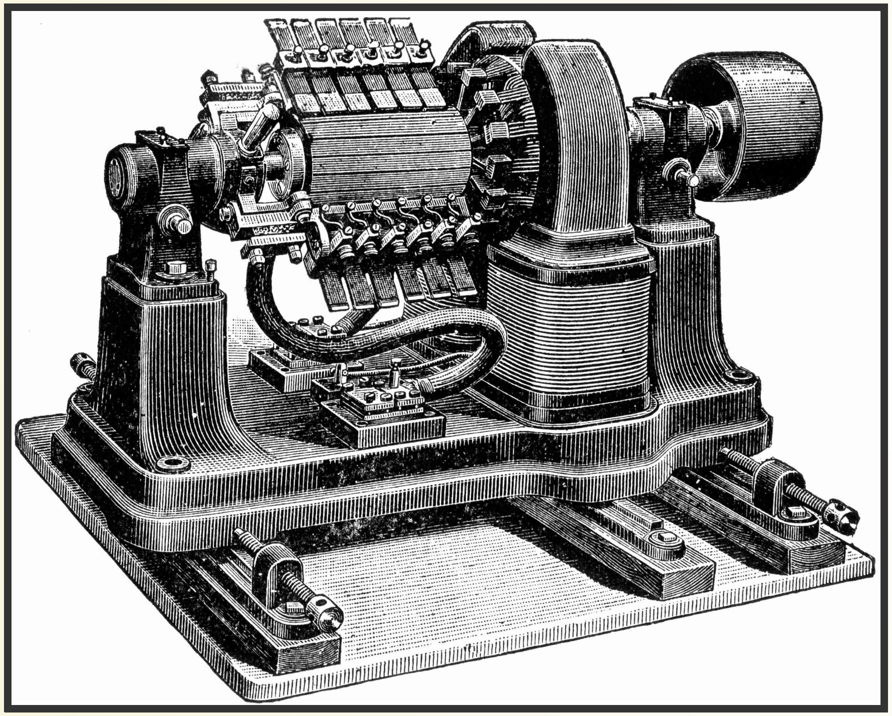
STATS:

- Outer sphere maximum speed
  $$\Omega/2\pi = 4\mathrm{Hz}$$
- Inner sphere maximum speed
  $$\Omega_\mathrm{i}/2\pi = \pm 20\mathrm{Hz}$$
- Total rotating mass: 20 tons
  - 7 ton, 3m diameter shell
  - 13 tons fluid (water, sodium metal)
- Two 250kW (350HP) motors
- Hot oil system: 120kW heating + 500kW cooling

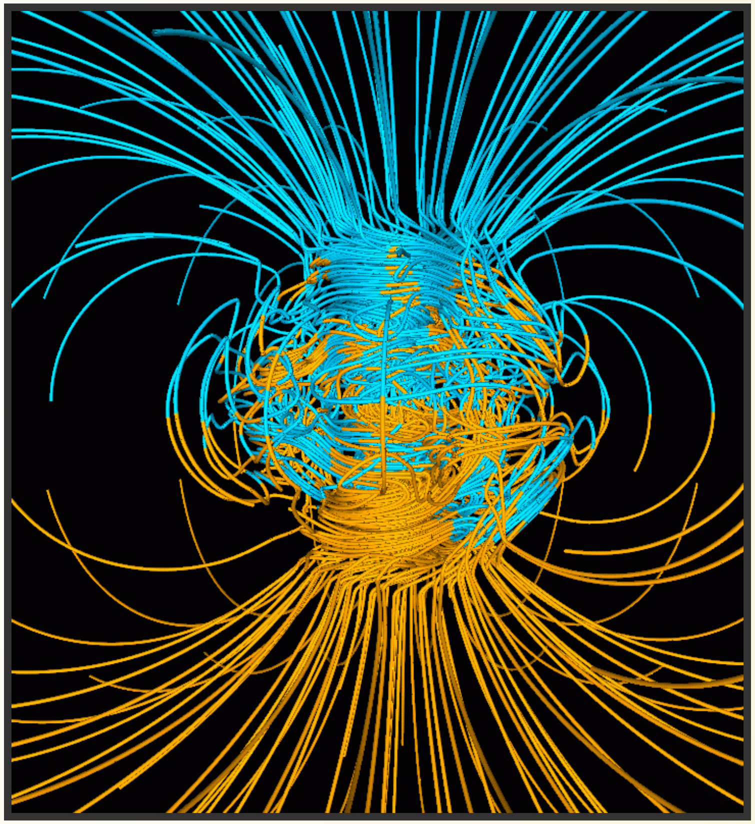
OUTER SPHERE AT TWO REVOLUTIONS/SECOND

DYNAMOS

WESTINGHOUSE

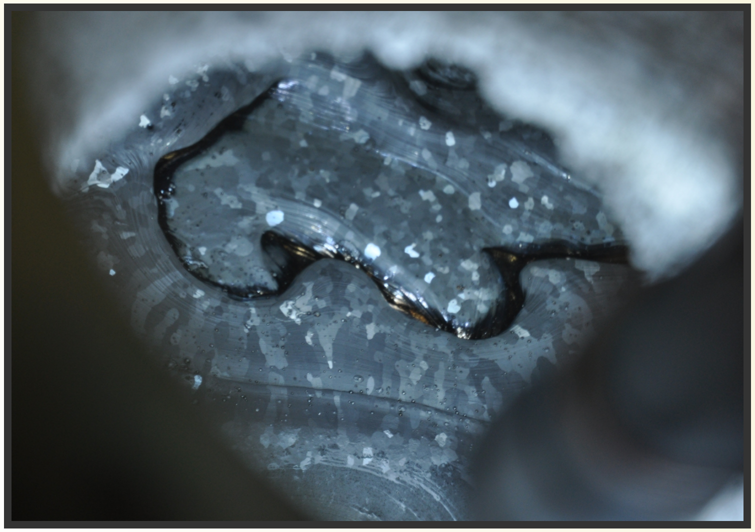


HOMOGENEOUS



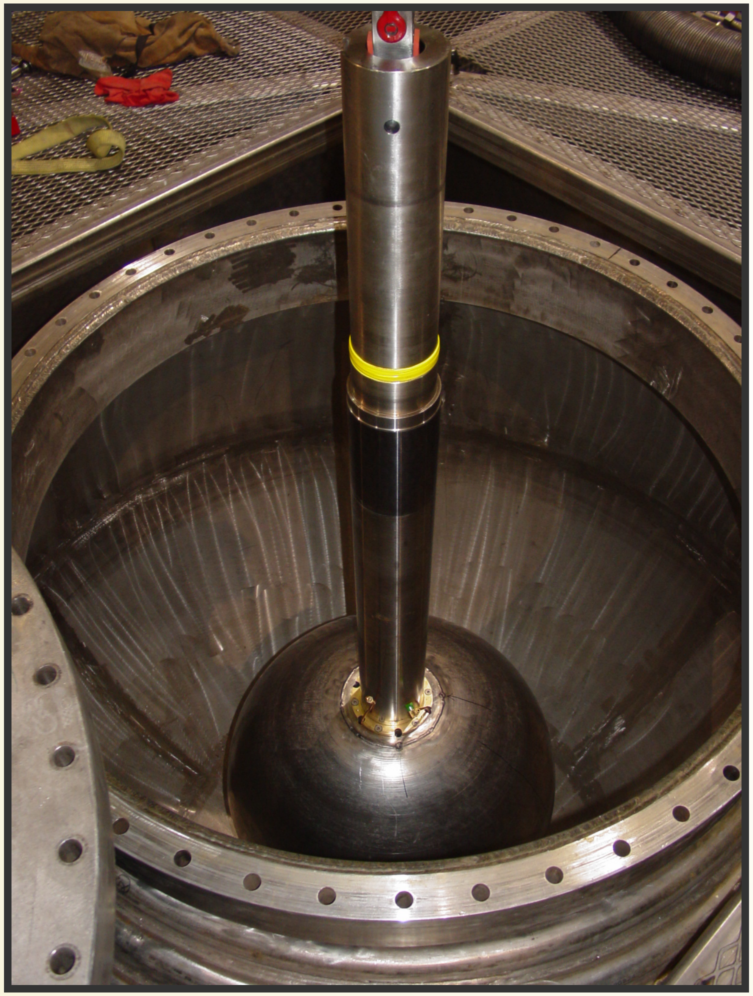
Glatzmaier and Roberts Reversing Dynamo Simulation 1995

WHY 13 TONS OF SPINNING SODIUM?



- Sodium best chance for liquid metal dynamo.
- Fast rotation is very important in planetary dynamo.

GEOMETRY & FORCING



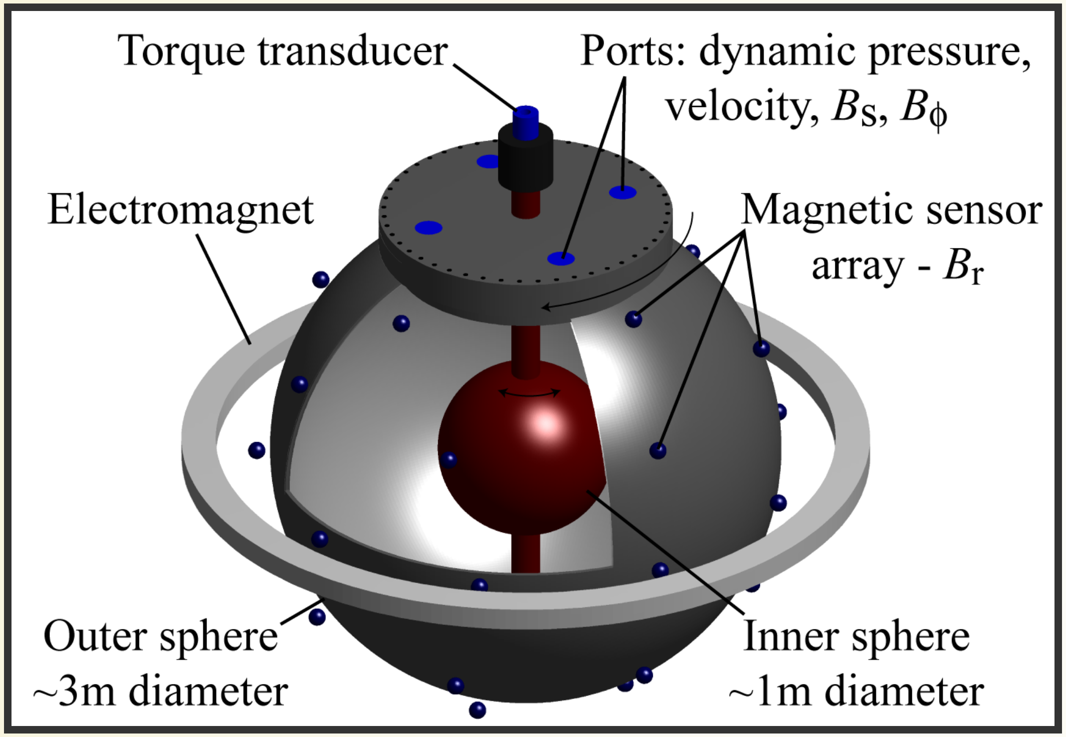
DESIGN:

- Geometrically similar to Earth's core:

$$\Gamma = r_\mathrm{i}/r_\mathrm{o} = 0.35$$

- Differential rotation to provide stirring in rotating frame.
- Simple geometry amenable to simulation
- Common features with planetary core, not a scale model.

INSTRUMENTATION



DIMENSIONLESS NUMBERS

$$Ro = \frac{\Delta\Omega}{\Omega}\,,\, |Ro| < 100$$

$$Re = \frac{\Delta\Omega(r_o - r_i)^2}{\nu}\,,\, Re \sim 10^8$$

$$Rm = \frac{\Delta\Omega(r_o - r_i)^2}{\eta}\,,\, Rm \sim 10^3$$

$$Pm = \frac{\nu}{\eta} = \frac{Rm}{Re} \sim 10^{-5}$$

$$S = \frac{B_0 L}{\eta\sqrt{\rho\mu_0}}\,,\, S \sim 6$$

$$\Lambda = \frac{B_0^2}{\rho\mu_0\eta\Omega}\,,\, \Lambda \sim 15$$

$$Ha = \frac{B_0 L}{\sqrt{\rho\mu_0\eta\nu}}\,,\, Ha \sim 2 \times 10^3$$

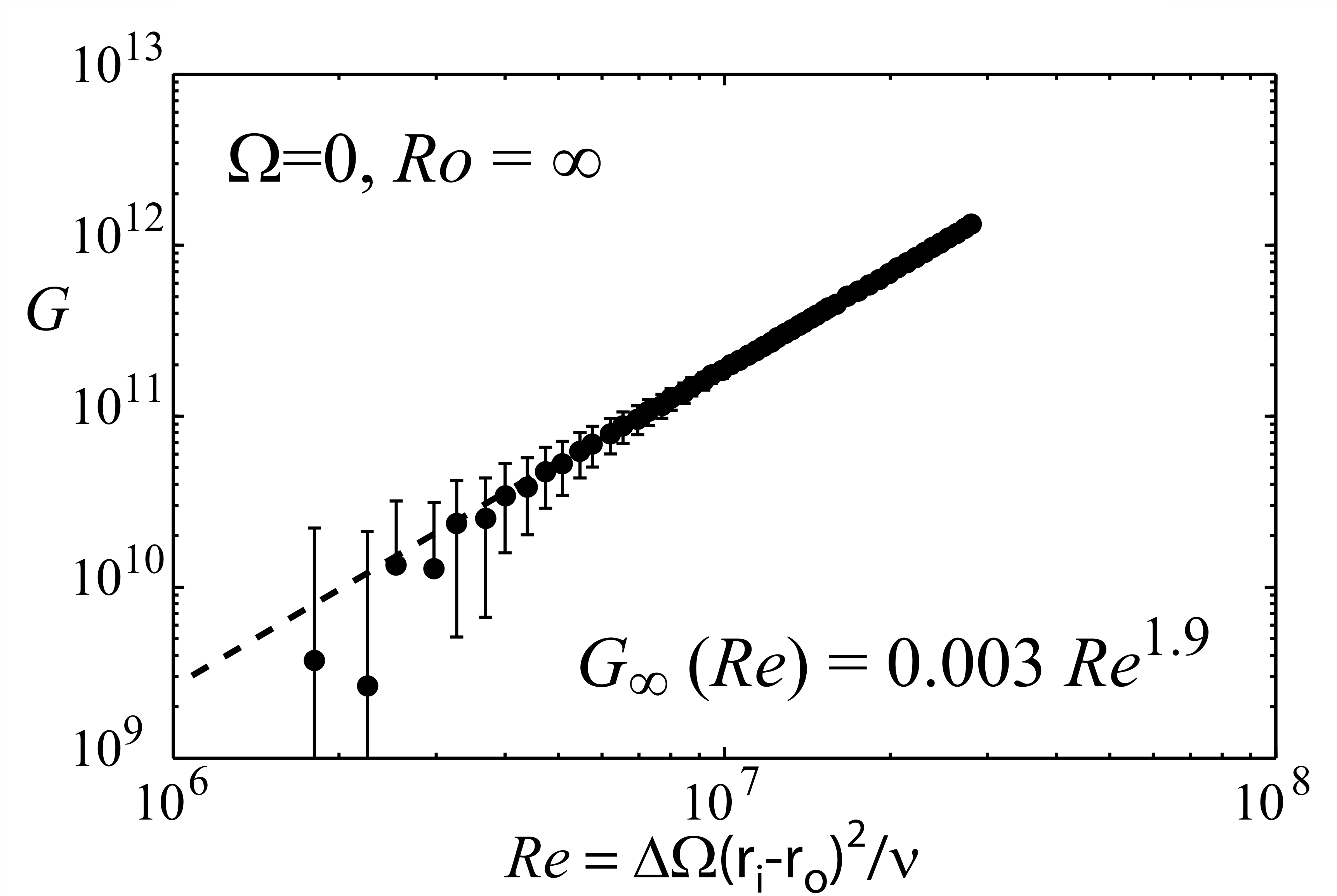
HYDRODYNAMIC PREVIEW

- Torque, *G*: common turbulent scaling with *Re*
- State changes: dozens of states depending on *Ro*
- Turbulent rotating shear flow torque:

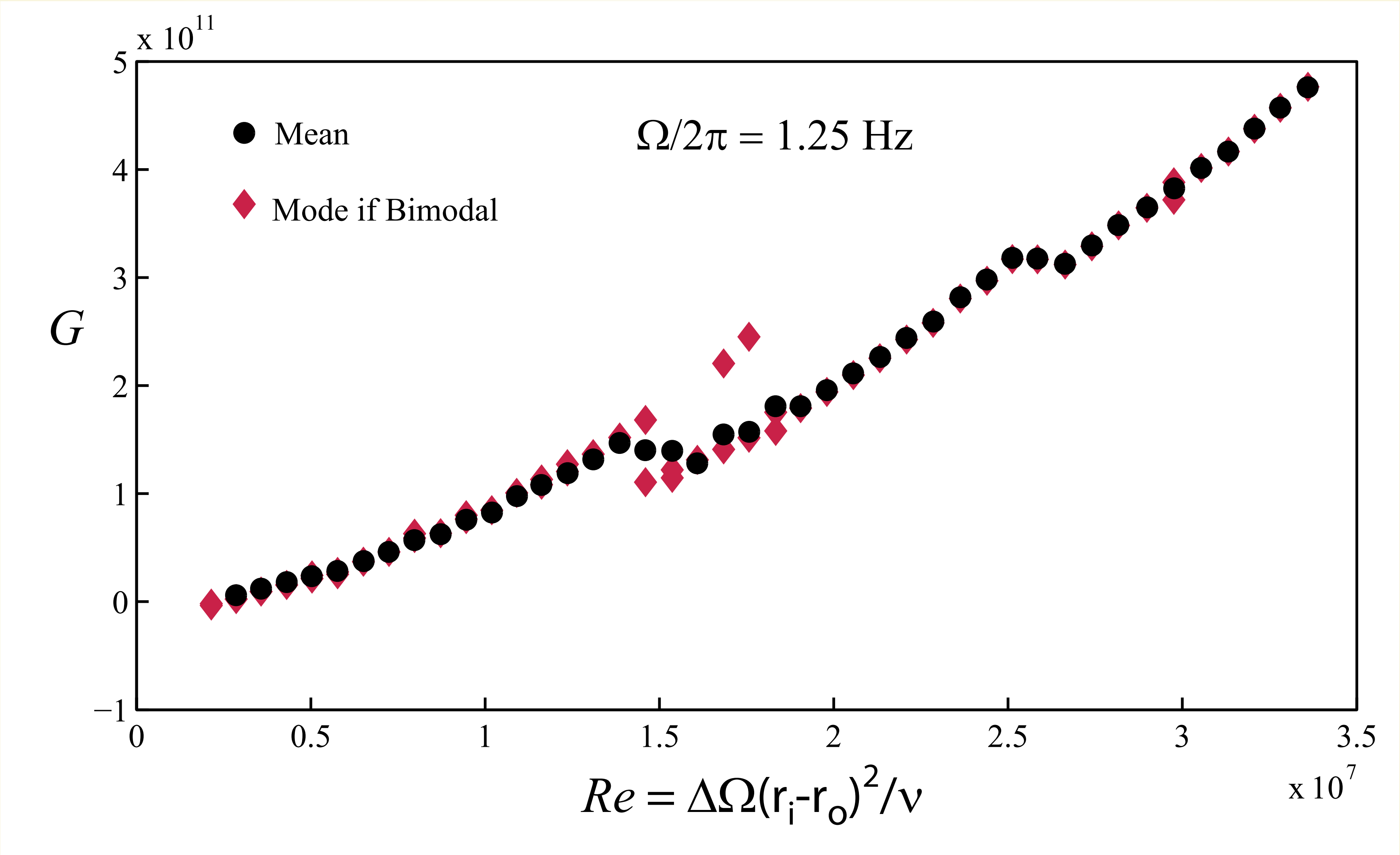
$$G(Re, Ro) = f(Ro)g(Re)$$

$$g(Re) = C_f Re^2, Re \to \infty$$

TORQUE VS. REYNOLDS NUMBER, OUTER STATIONARY



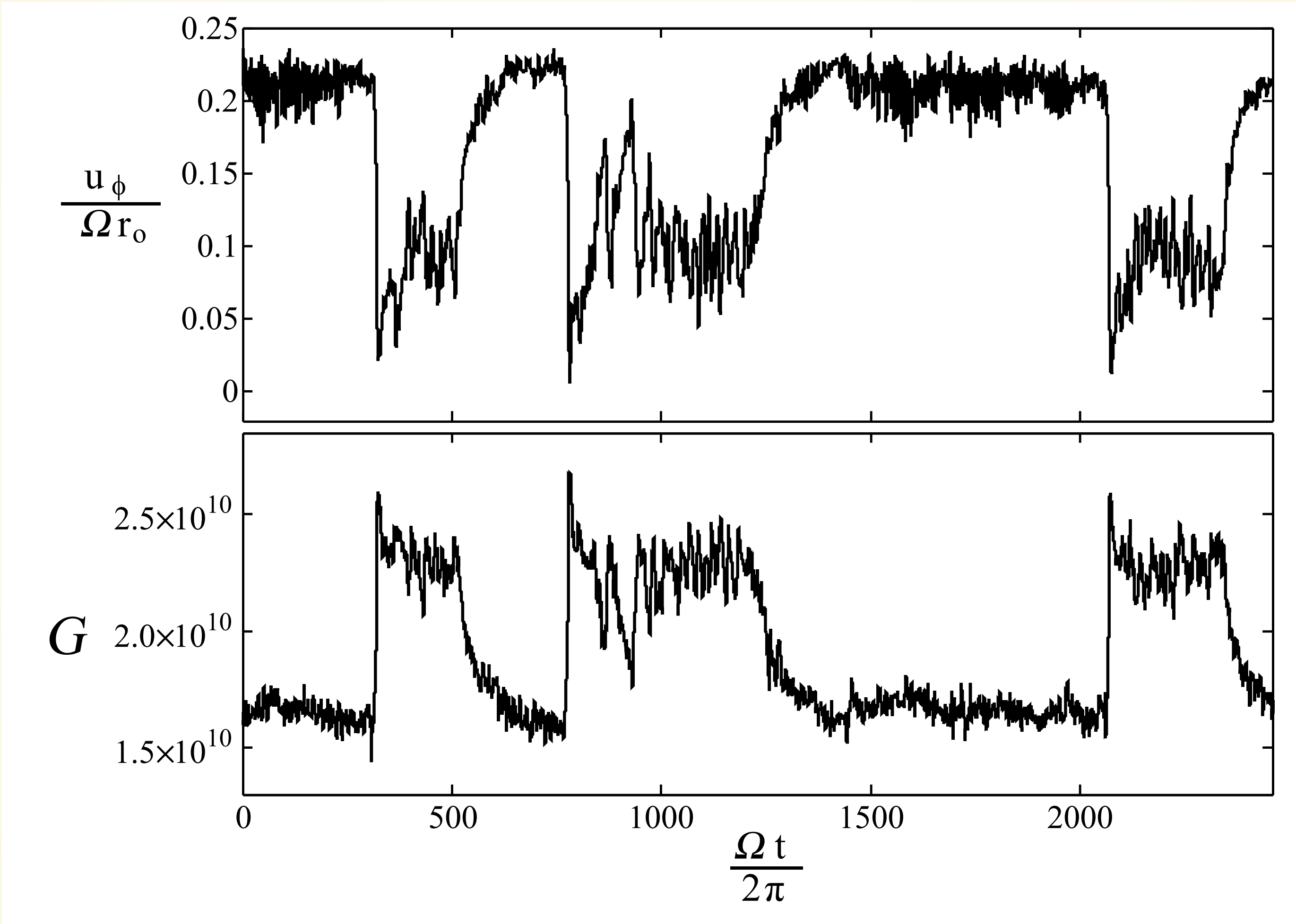
TORQUE VS. REYNOLDS NUMBER, OUTER 1.25HZ



- $Ro = \Delta\Omega/\Omega$

TORQUE AND AZIMUTHAL VELOCITY - STATE CHANGES

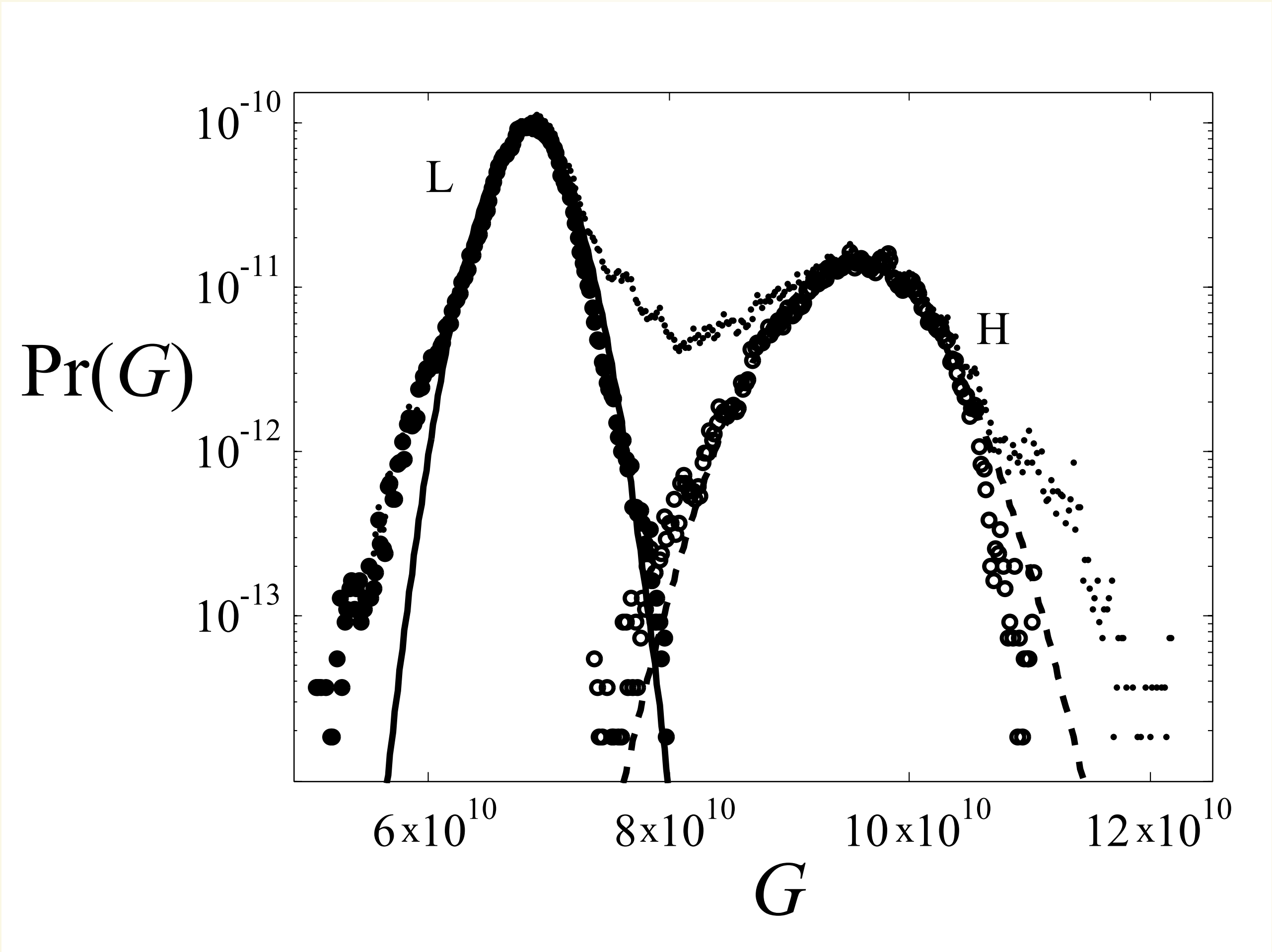
$Ro = 2.33$



Phys. Fluids **23**, 065104 (2011) - http://arxiv.org/abs/1107.5082

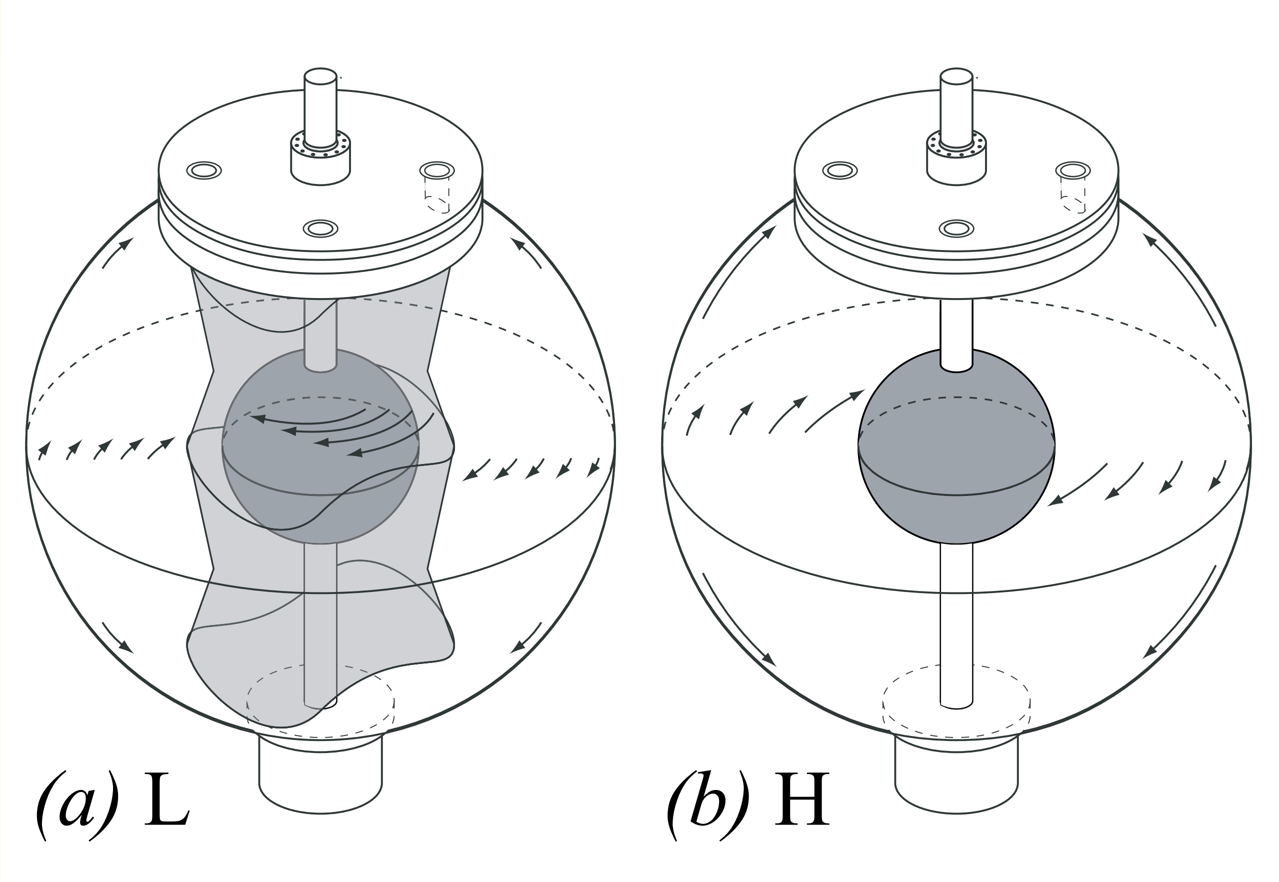
PROBABILITY DISTRIBUTION OF TORQUE

$Ro = 2.13$



Phys. Fluids **23**, 065104 (2011) - http://arxiv.org/abs/1107.5082

DIFFERENT LARGE-SCALE FLOW STATES



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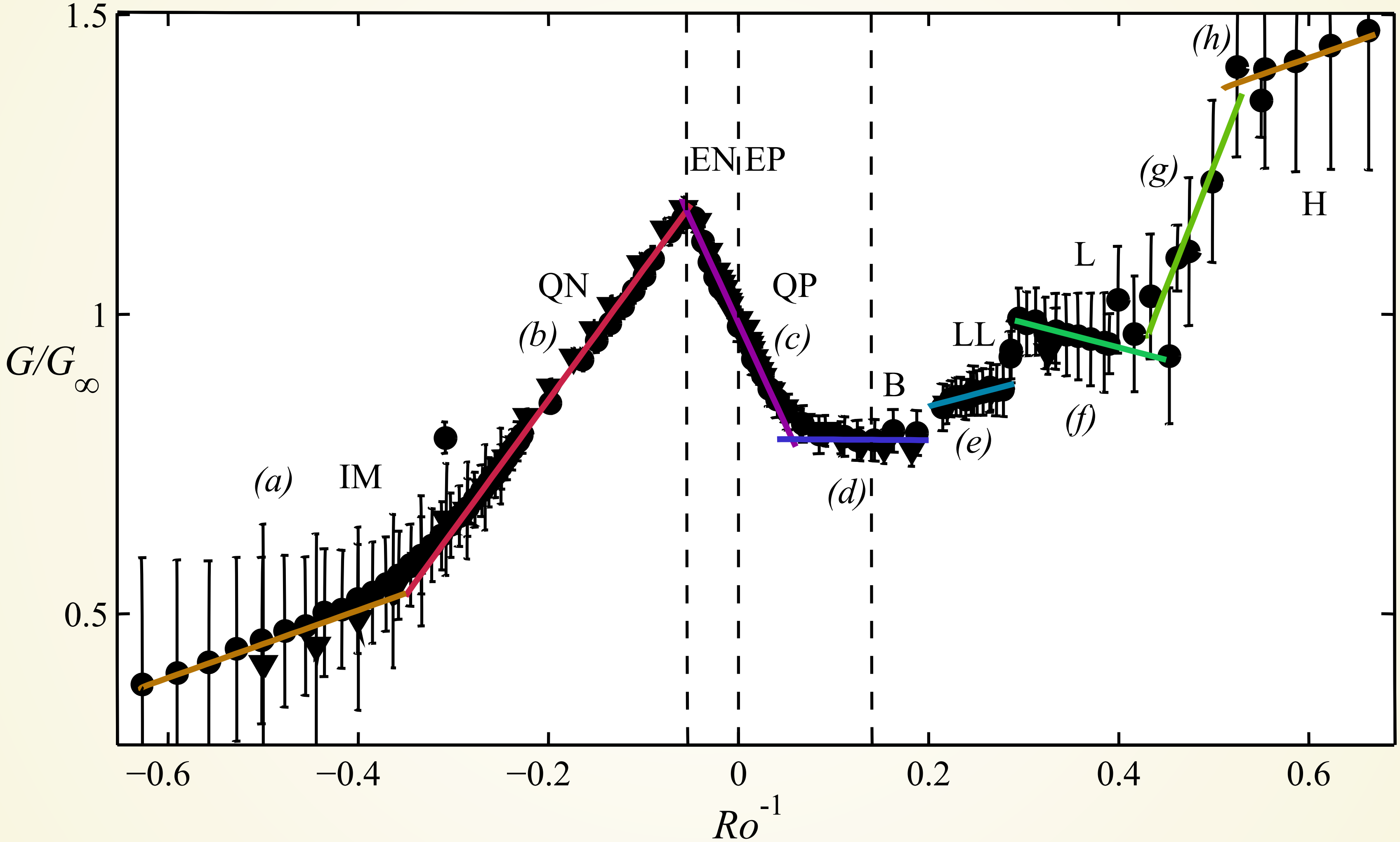
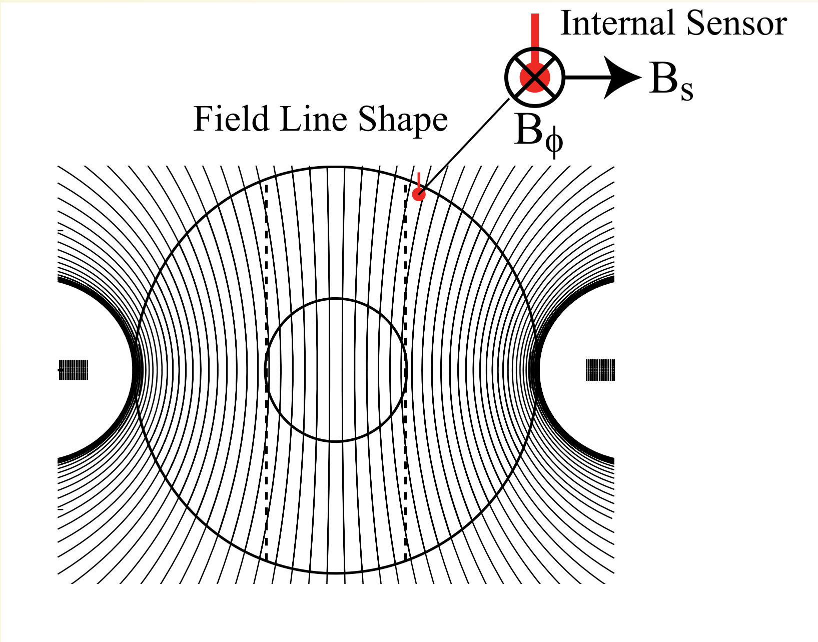
TURBULENT TORQUE ROSSBY DEPENDENCE

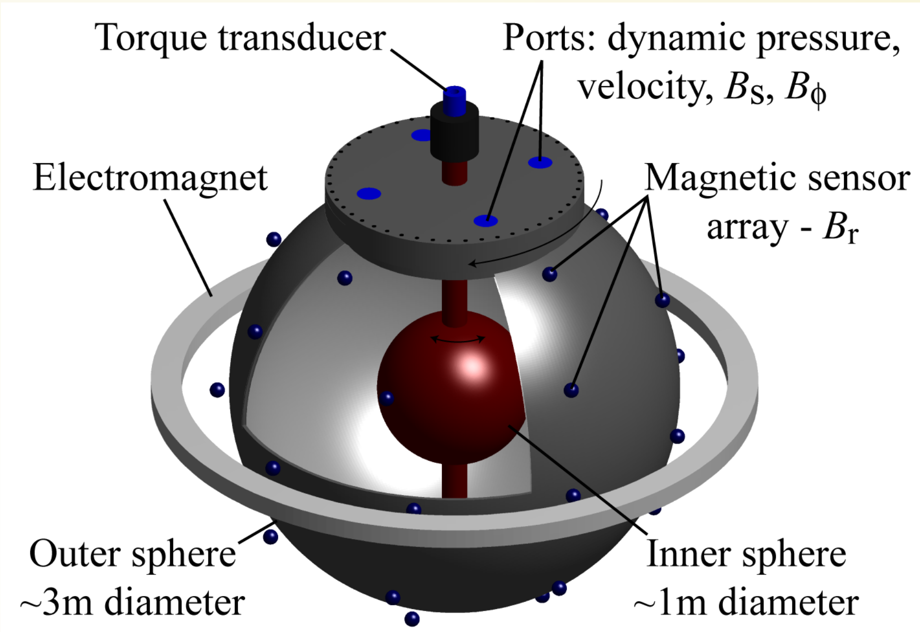


MAGNETOHYDRODYNAMIC PREVIEW

- Differential rotation generates strong internal azimuthal field (strong ω-effect)- important for dynamo.
- Large *Ro*-dependence from hydrodynamic state changes: ω-effect peaks at *Ro*=+6.
- Strong applied field: new states, reduced ω-effect, field bursting with a "dynamo-like" feedback loop.

INTERNAL FIELD AND EXTERNAL GAUSS COEFFICIENTS



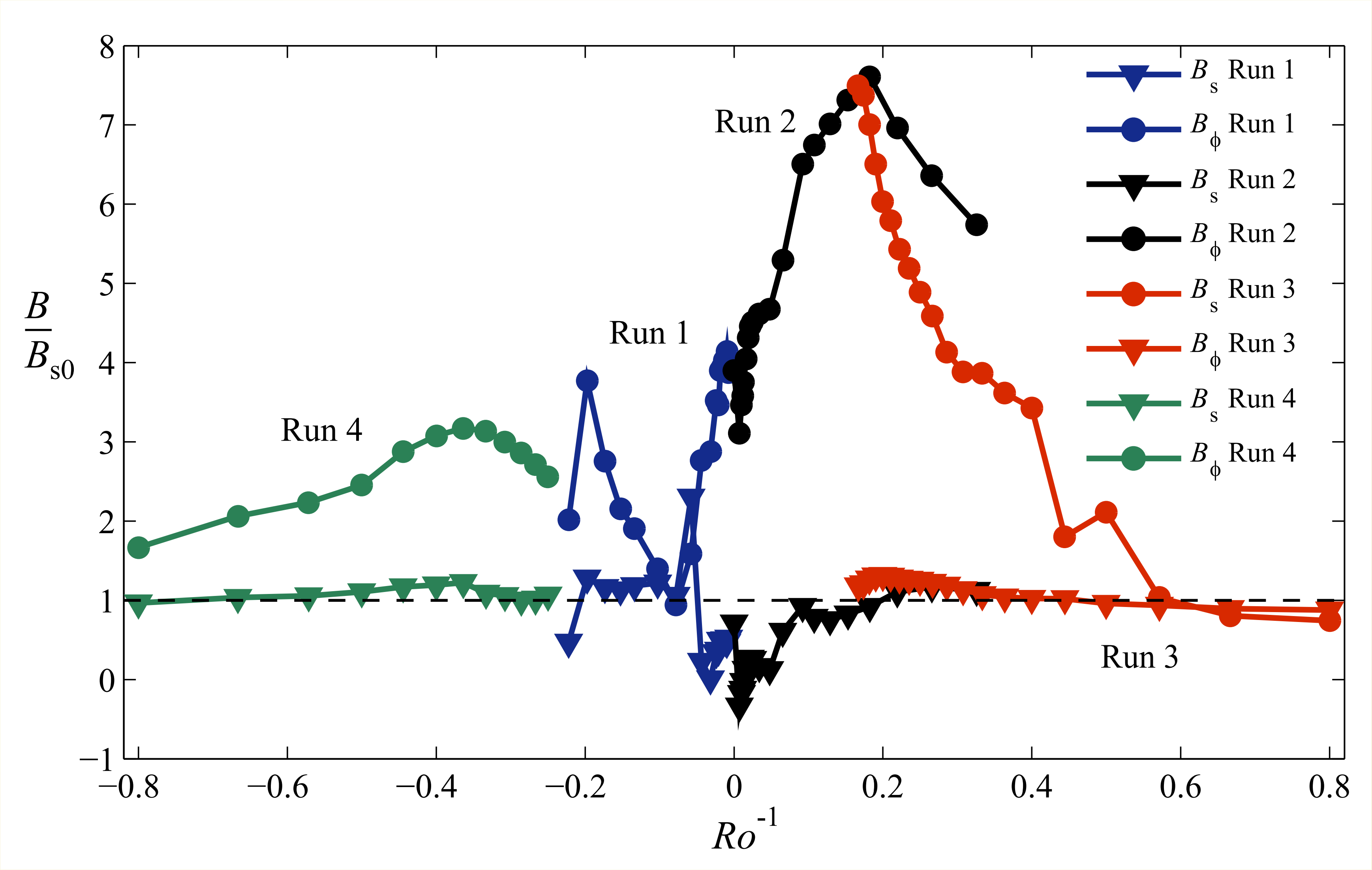


$$B_r(r,\theta,\phi) = \sum_{l=0}^{l=4}\sum_{m=0}^{m=4} l(l+1)\left(\frac{r_o}{r}\right)^{l+2} P_l^m(\cos\theta)(g_l^{m,s}\sin\phi + g_l^{m,c}\cos\phi)$$

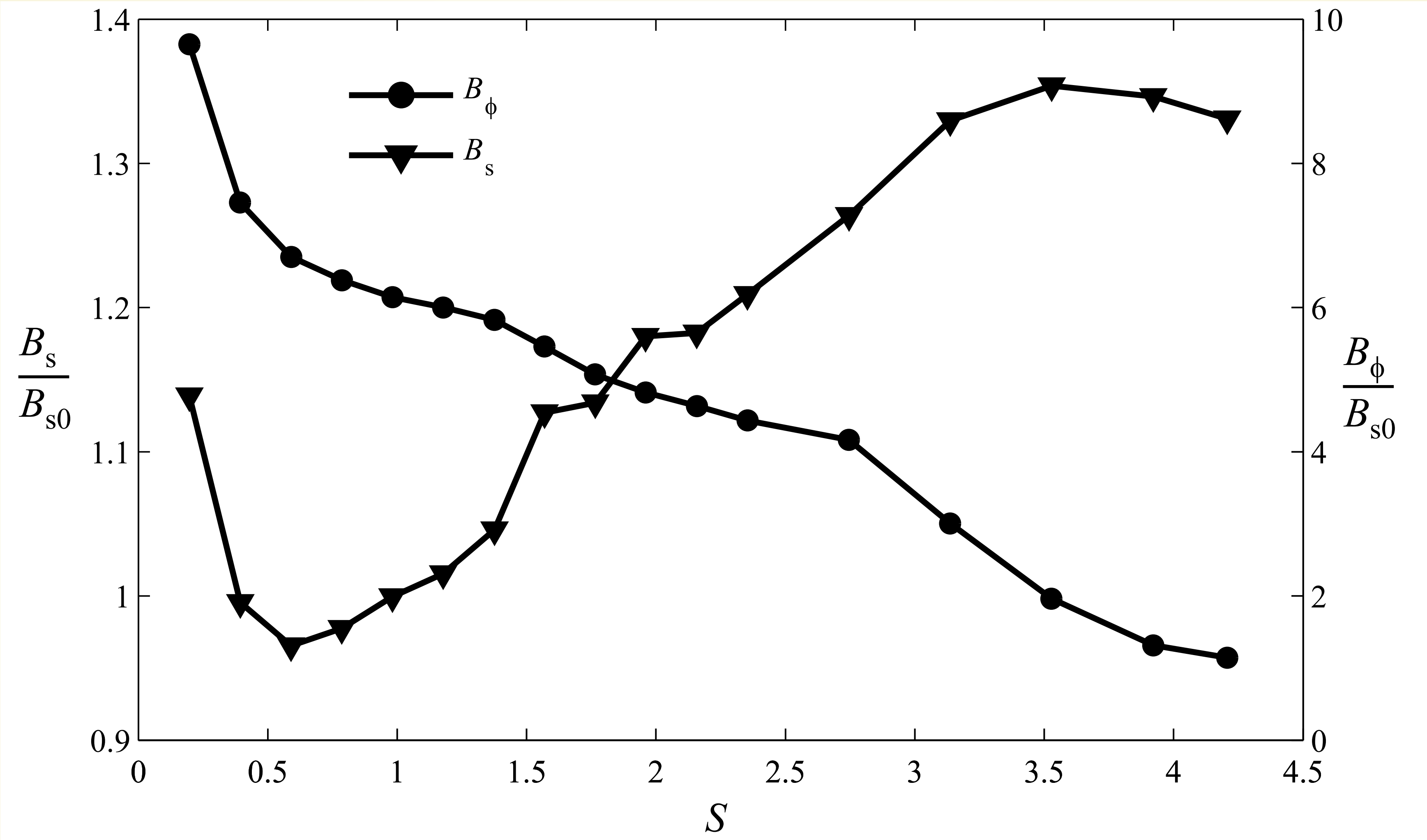
$$B_l^m = l(l+1)g_l^m$$

INTERNAL MAGNETIC FIELD, 'WEAK' APPLIED FIELD

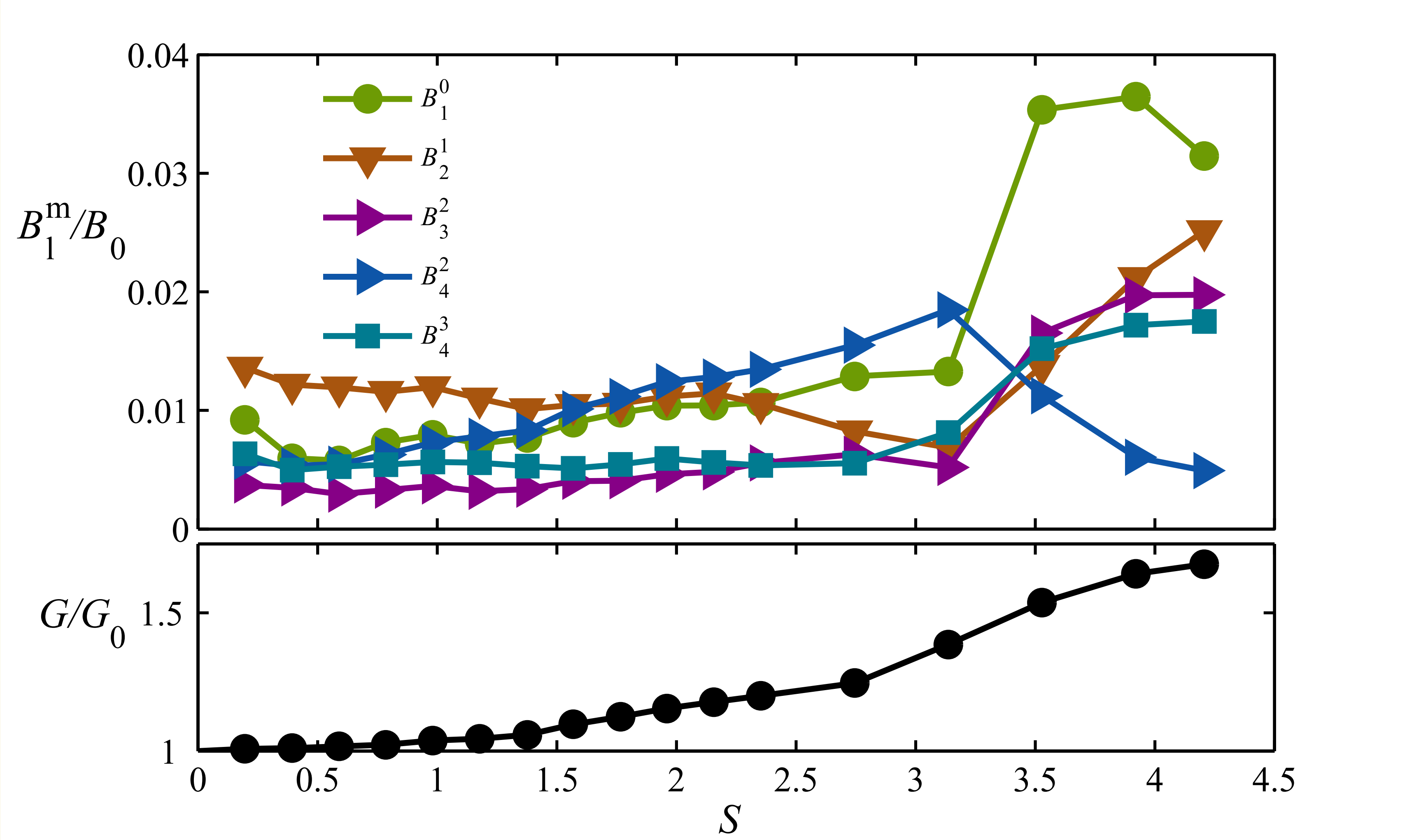
$S = 0.39$



INTERNAL MAGNETIC FIELD VS. APPLIED FIELD

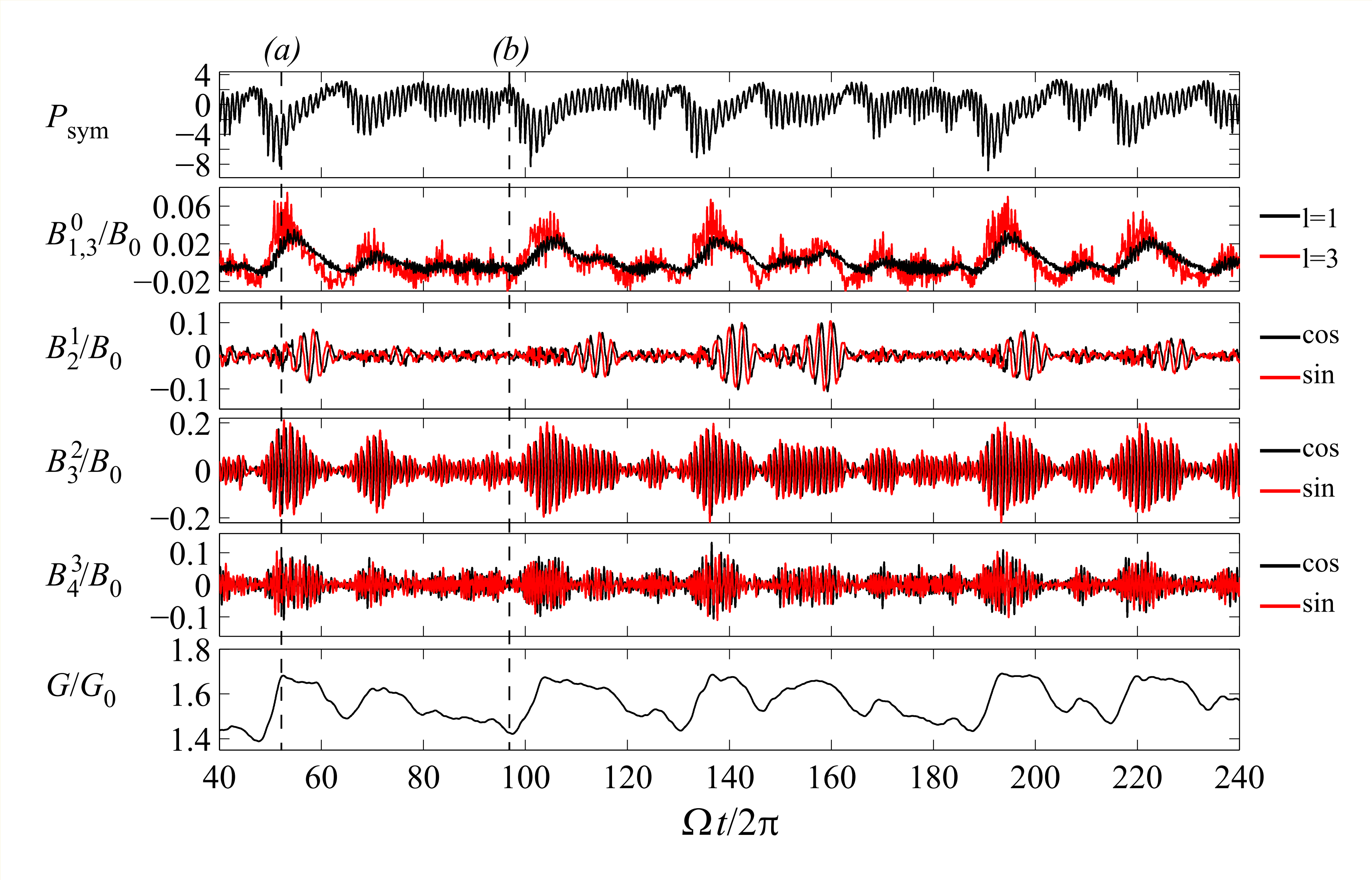


STATE CHANGES AT STRONG FIELD

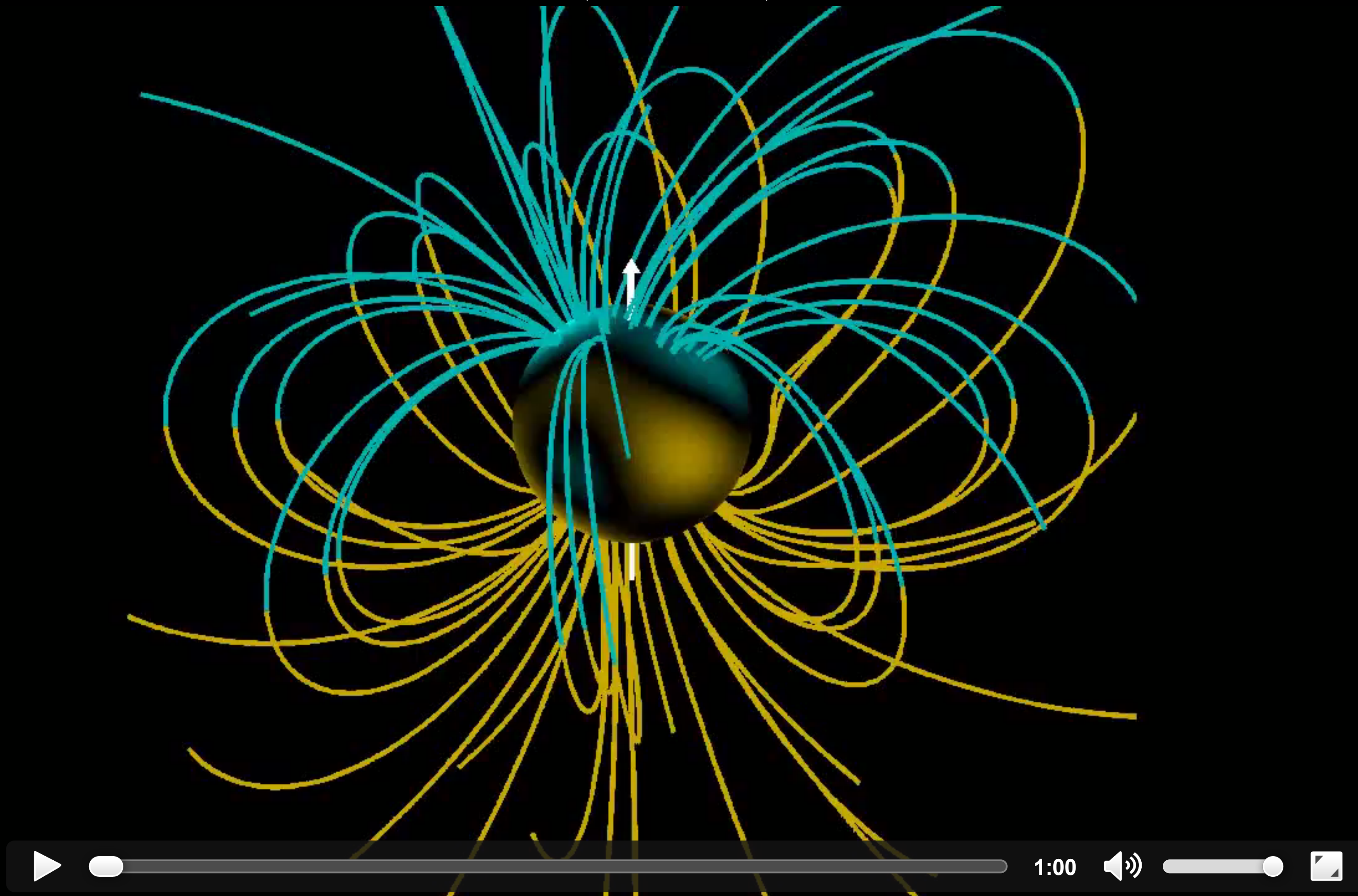


FIELD BURSTS

$S = 3.5, Ro = +6, Rm = 477$



$Ro=+6.0$, $S=3.5$, $Rm=477$



SUMMARY

- Torque, *G*: common turbulent scaling with *Re*
- Dozens of turbulent flow states depending on *Ro*
- Turbulent rotating shear flow torque:

$$G(Re, Ro) = f(Ro)g(Re)$$

$$g(Re) = C_f Re^2, Re \to \infty$$

- Differential rotation gives strong ω-effect- important for dynamo.
- Large *Ro*-dependence of ω-effect due to hydrodynamic state changes.
- Strong applied field: new states, reduced ω-effect, field bursting (*Ro*=+6) with a "dynamo-like" feedback loop.
- Opportunities for good quantitative tests for spherical turbulent codes (fluid Rossby relatively small!)