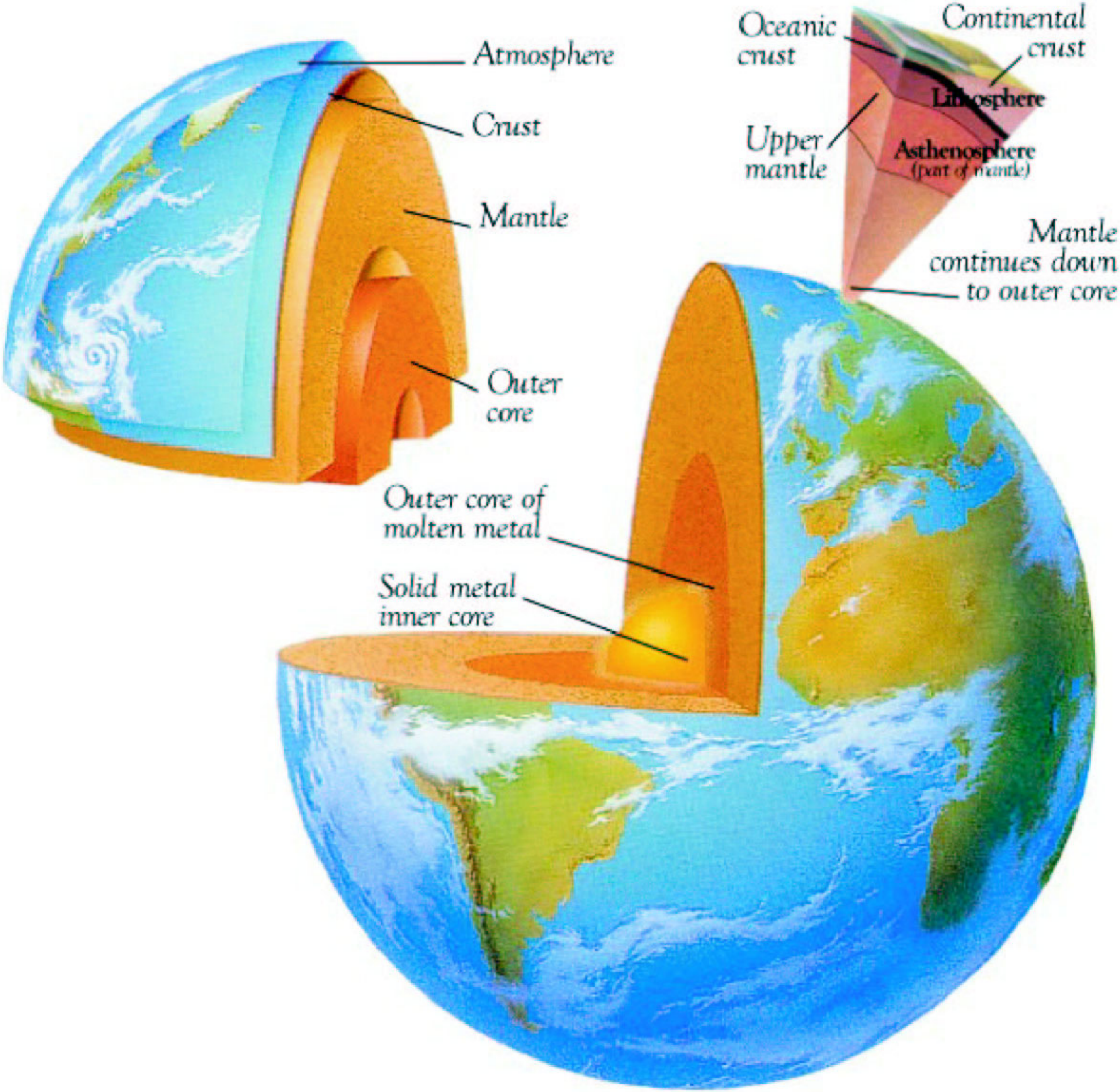
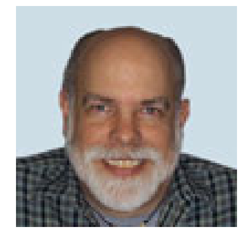

Atmosphere
Crust
Mantle
Outer core
Oceanic crust
Continental crust
Lithosphere
Upper mantle
Asthenosphere (part of mantle)
Mantle continues down to outer core
Outer core of molten metal
Solid metal inner core

Instabilities in liquid sodium, nitrogen, water or helium

Matt Paoletti

Santiago Triana

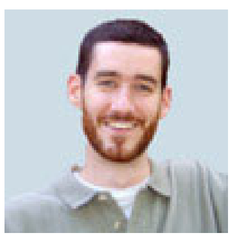
Greg Bewley



Don Martin

Dan Sisan

Dan Zimmerman



Doug Kelley

Dan Lathrop
雷丹

University of Maryland
National Science Foundation

VOLUME 93, NUMBER 11 PHYSICAL REVIEW LETTERS week ending 10 SEPTEMBER 2004

Experimental Observation and Characterization of the Magnetorotational Instability

Daniel R. Sisan, Nicolás Mujica, W. Andrew Tillotson, Yi-Min Huang, William Dorland, Adil B. Hassam, Thomas M. Antonsen, and Daniel P. Lathrop*

PHYSICS OF FLUIDS 19, 071701 (2007)

Inertial waves in rotating grid turbulence

Gregory P. Bewley
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NATURE|Vol 441|1 June 2006

SUPERFLUID HELIUM

Visualization of quantized vortices

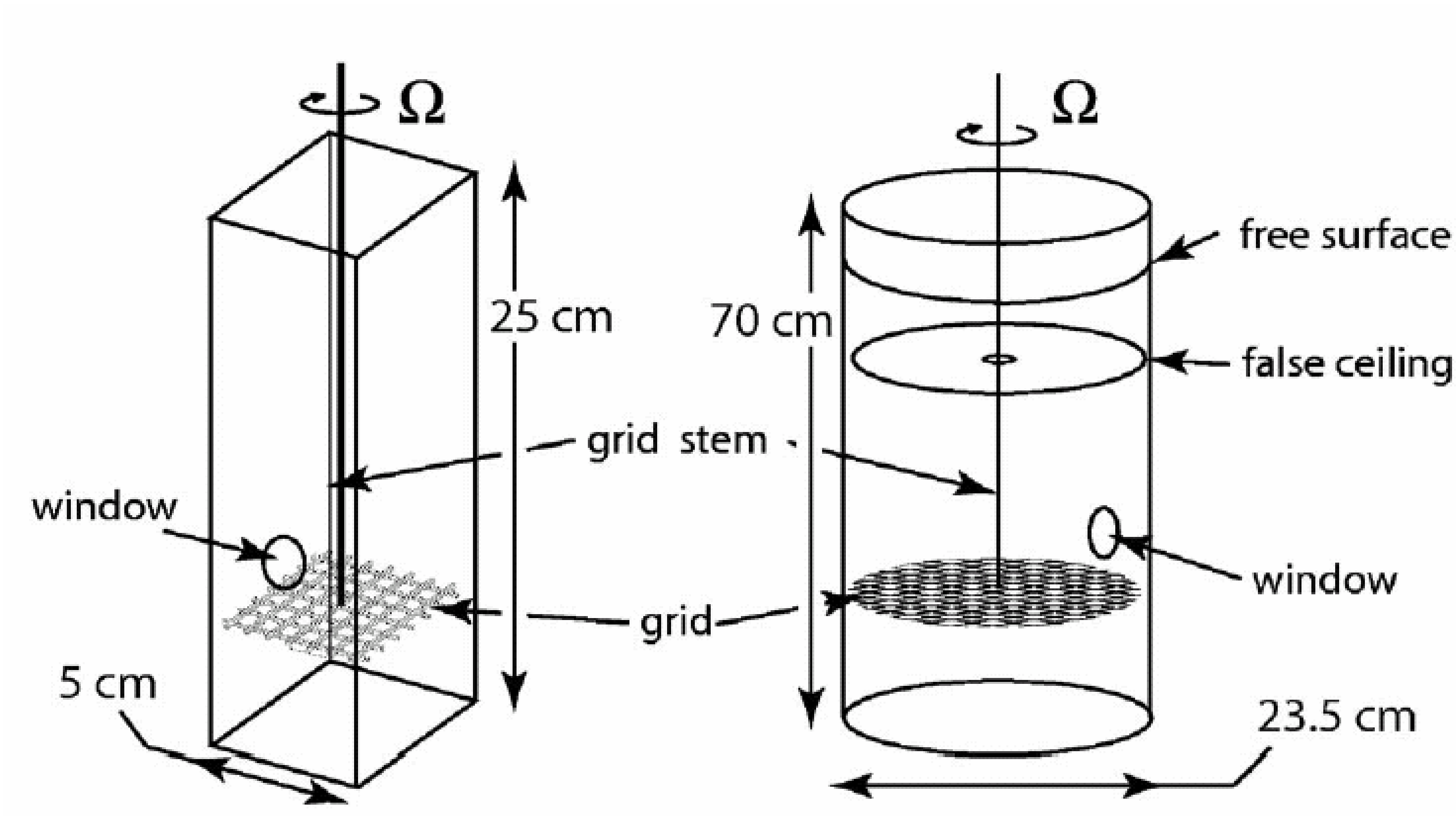
Gregory P. Bewley*†, Daniel P. Lathrop*, Katepalli R. Sreenivasan*‡

Geophysical and Astrophysical Fluid Dynamics,
Vol. 101, Nos. 5–6, October–December 2007, 469–487

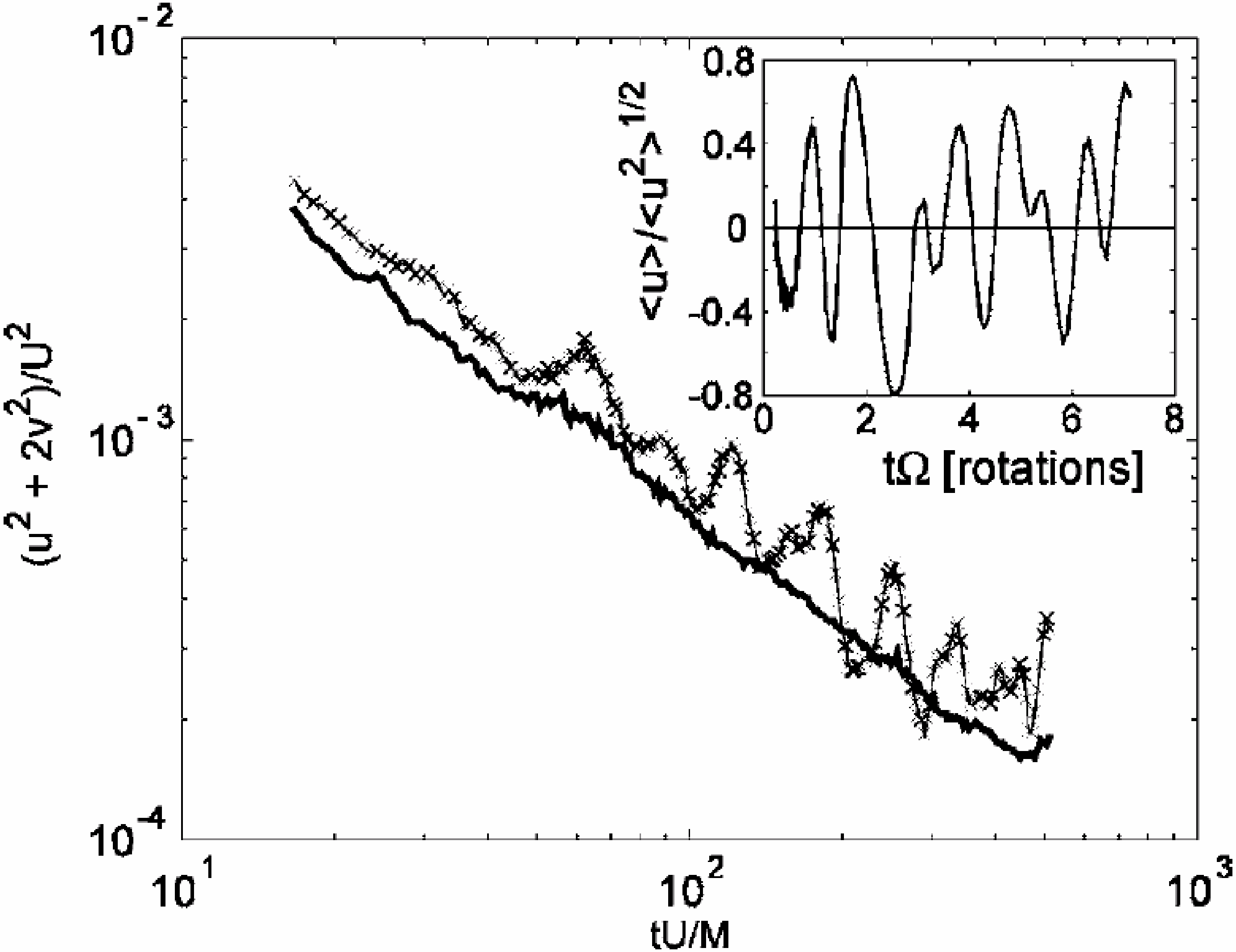
Inertial waves driven by differential rotation in a planetary geometry

DOUGLAS H. KELLEY†, SANTIAGO ANDRÉS TRIANA†, DANIEL S. ZIMMERMAN†, ANDREAS TILGNER‡ and DANIEL P. LATHROP*§

Rotating grid turbulence



Decay of local kinetic energy



Rapidly Rotating -- Coriolis Large

$$\partial_t \vec{v} + (\vec{v} \bullet \vec{\nabla}) \vec{v} + 2\vec{\Omega} \times \vec{v} = -\frac{1}{\rho}\vec{\nabla} P + \nu \nabla^2 \vec{v}$$

$$\vec{\nabla} \bullet \vec{v} = 0$$

$$\partial_t \vec{v} + 2\vec{\Omega} \times \vec{v} = -\frac{1}{\rho}\vec{\nabla} P$$

$$2\vec{\Omega} \times \vec{v} = -\frac{1}{\rho}\vec{\nabla} P$$

$$(\vec{\Omega} \bullet \vec{\nabla}) \vec{v} = 0$$

Taylor-Proudman theorem

$$\partial_t \vec{v} + 2\vec{\Omega} \times \vec{v} = -\frac{1}{\rho}\vec{\nabla} P$$

$$\partial_t \vec{\omega} = 2(\vec{\Omega} \cdot \vec{\nabla}) \vec{v} = 2\Omega_o \partial_z \vec{v}$$

Plane wave solutions

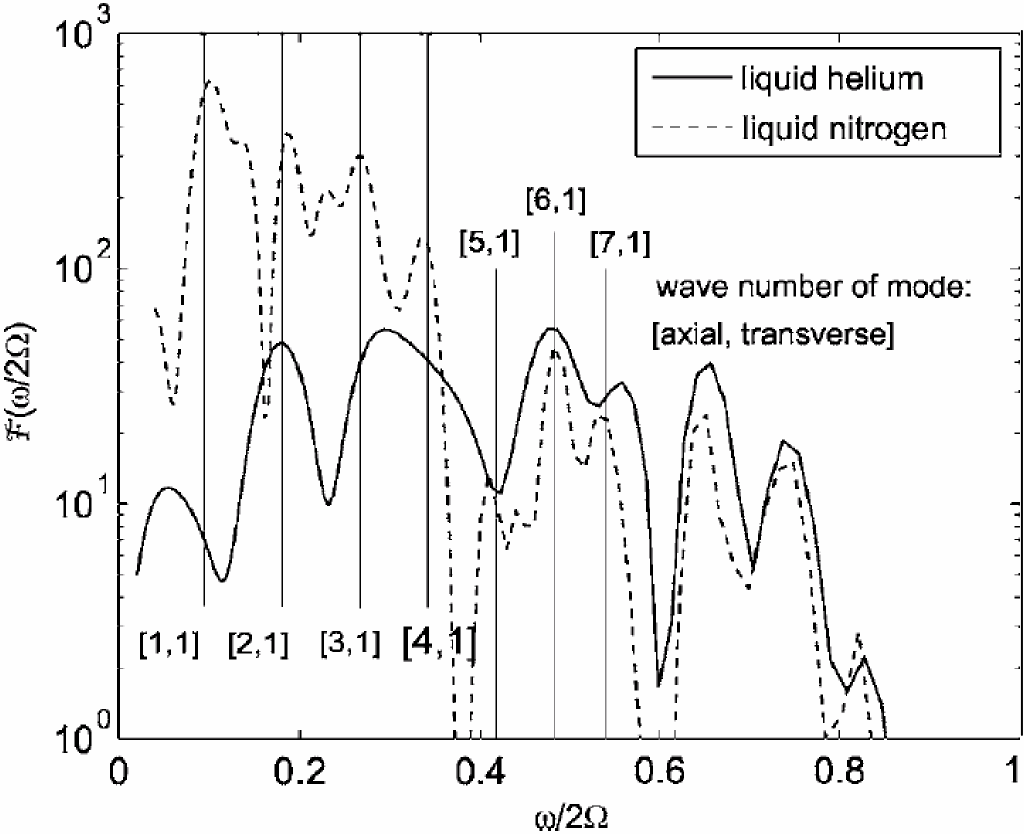
$$\vec{v} = \vec{v}_o e^{i(\vec{k}\cdot\vec{r} - \omega t)}$$

$$\omega = \pm 2\Omega_o \frac{k_z}{k}$$

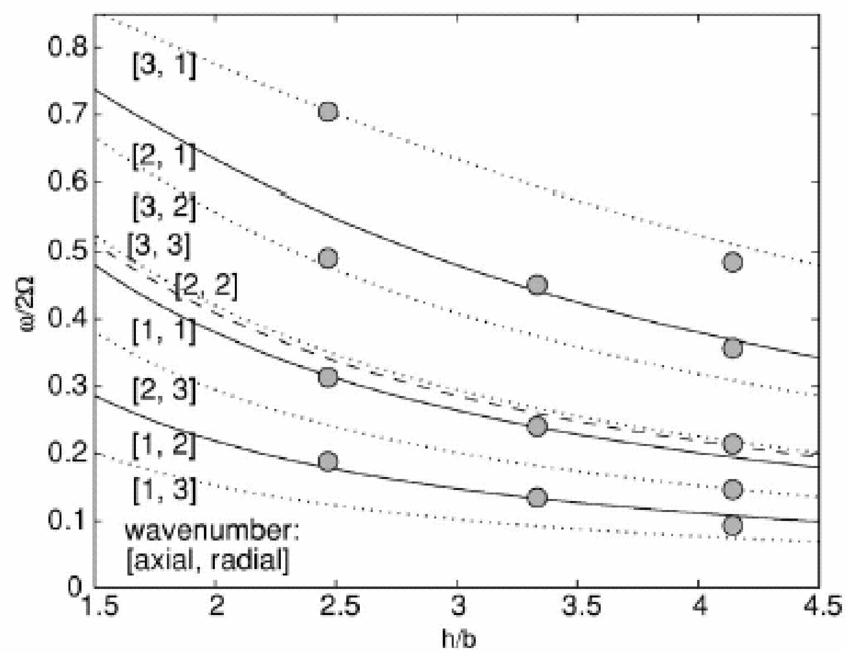
$$0 < |\omega| < 2\Omega_o$$

Modes of Containers

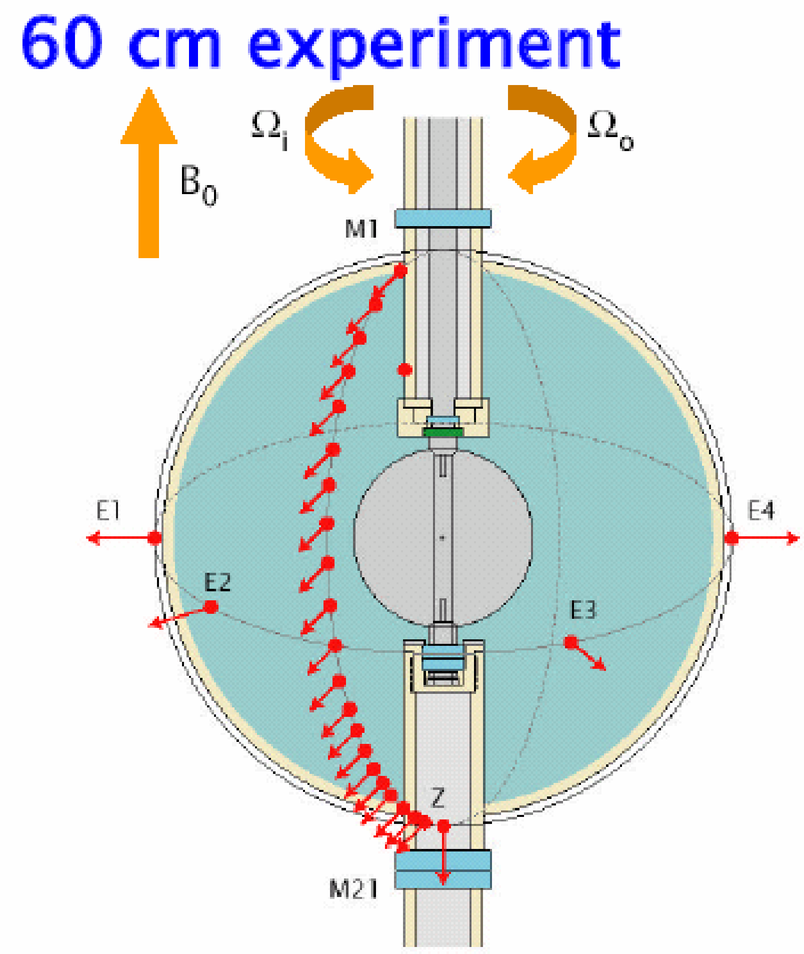
$$Q \sim E^{-1/2} = (\nu/2\Omega l^2)^{-1/2}$$



(theory L. Maas)

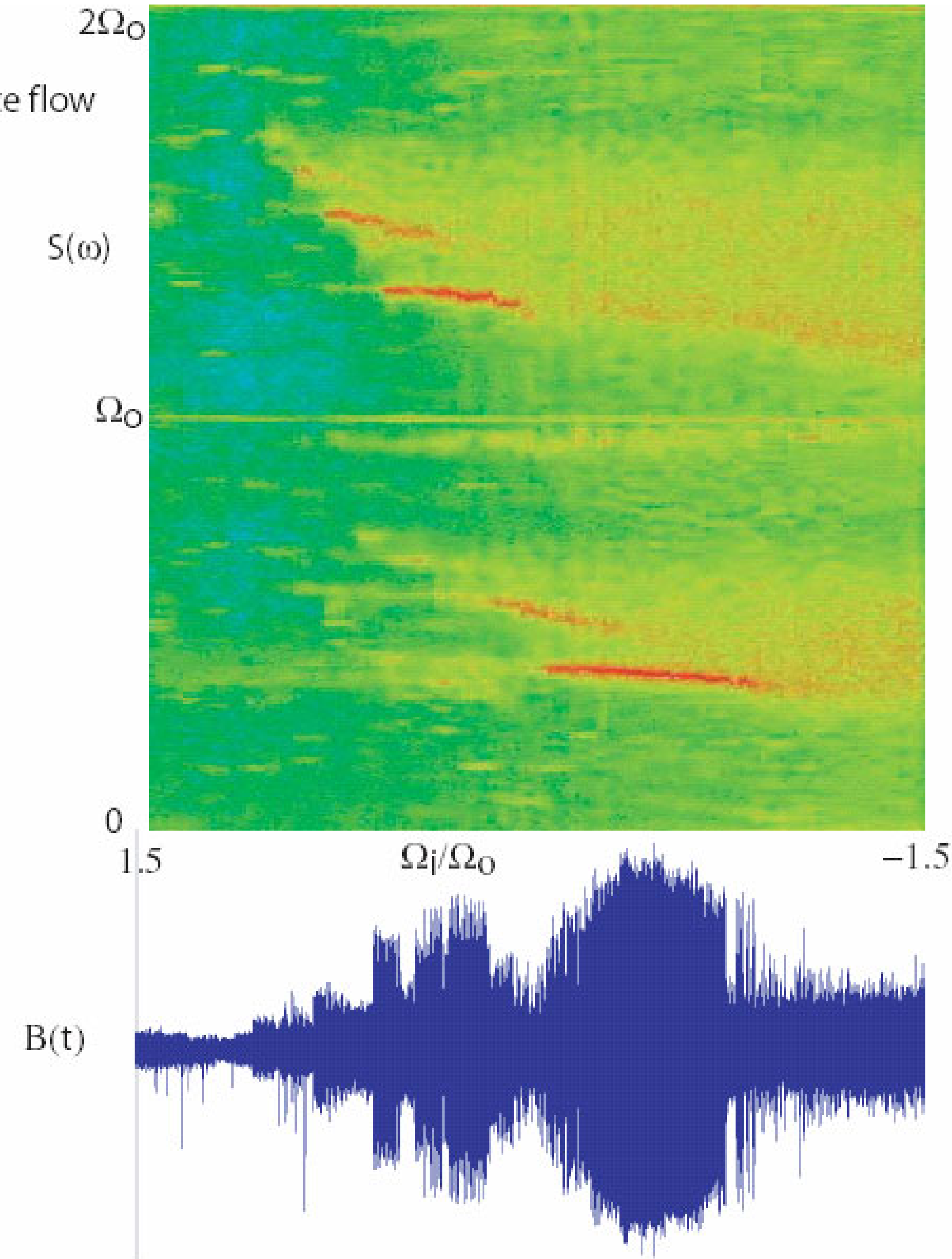


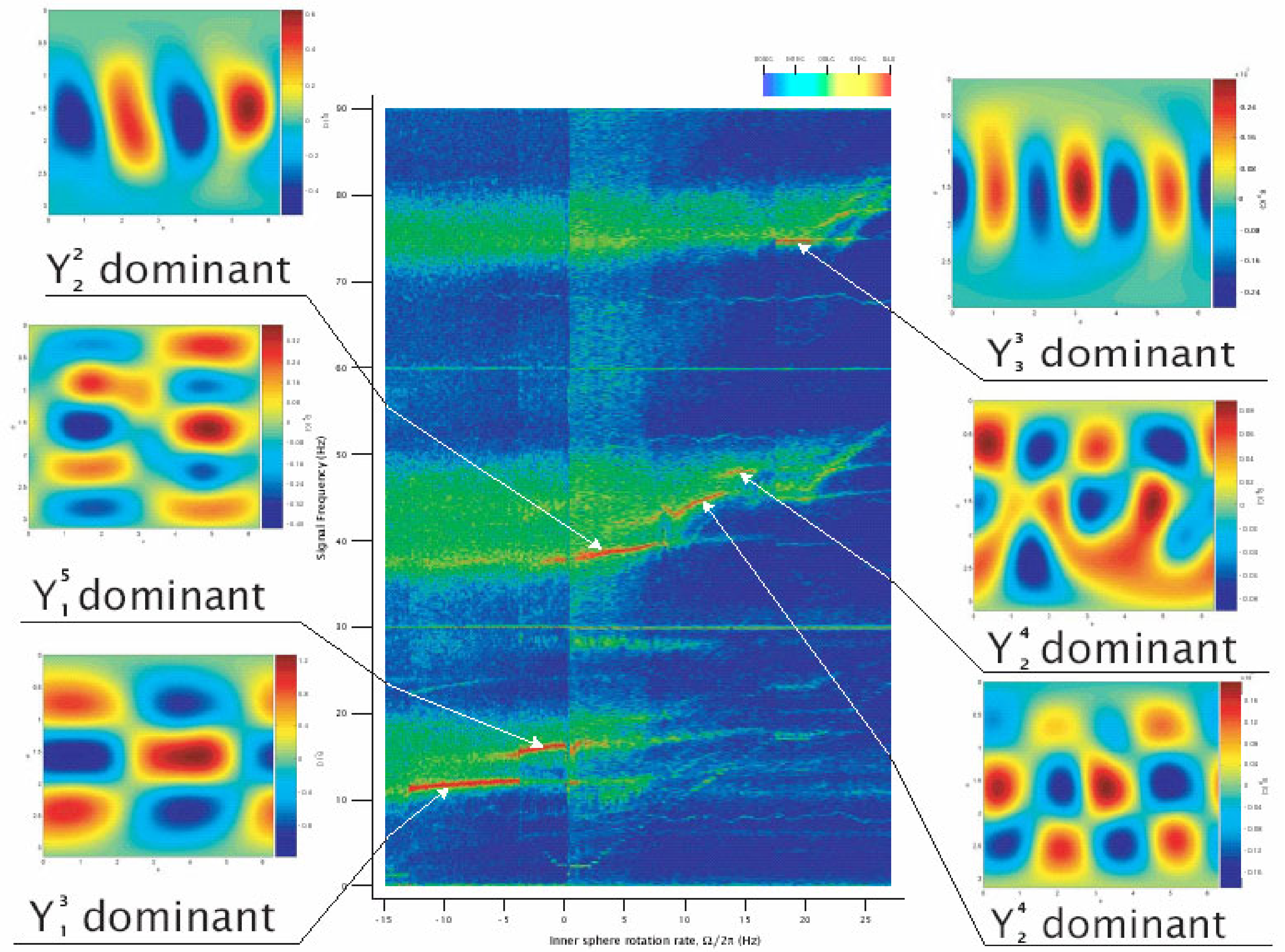
Na spherical Couette flow



Modes in spherical Couette flow

$\Omega_O = 30$ Hz

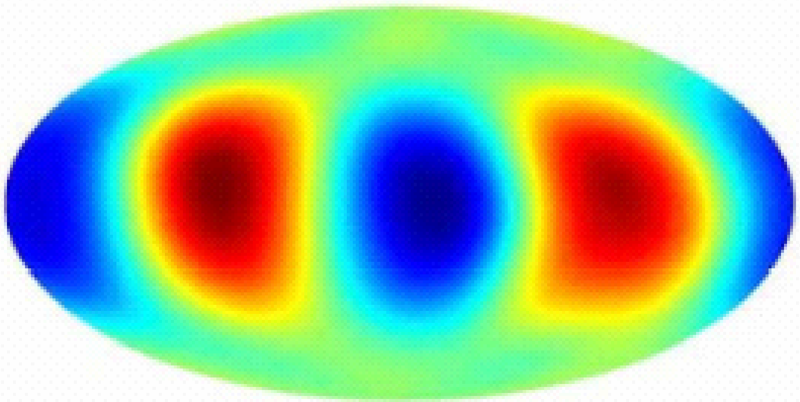




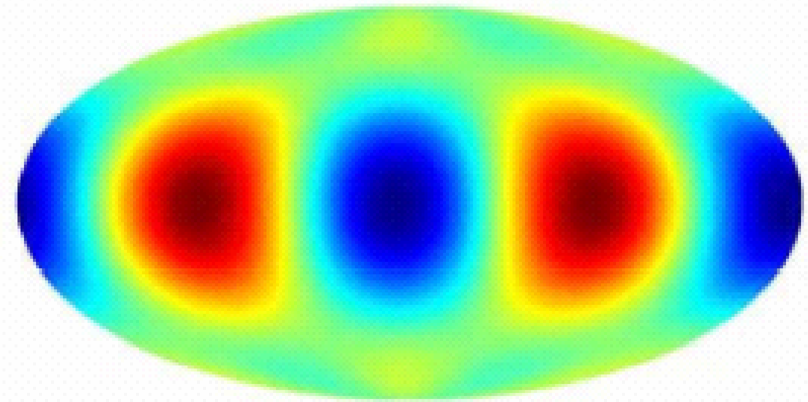
Y_2^2 dominant
Y_1^5 dominant
Y_1^3 dominant
Y_3^3 dominant
Y_2^4 dominant
Y_2^4 dominant
Signal Frequency (Hz)
Inner sphere rotation rate, Ω/2π (Hz)

Induced magnetic field

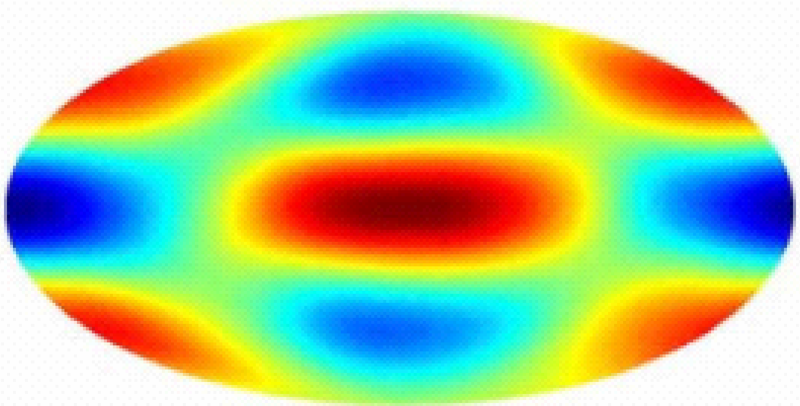
Experiment | Theory **(Tilgner)**



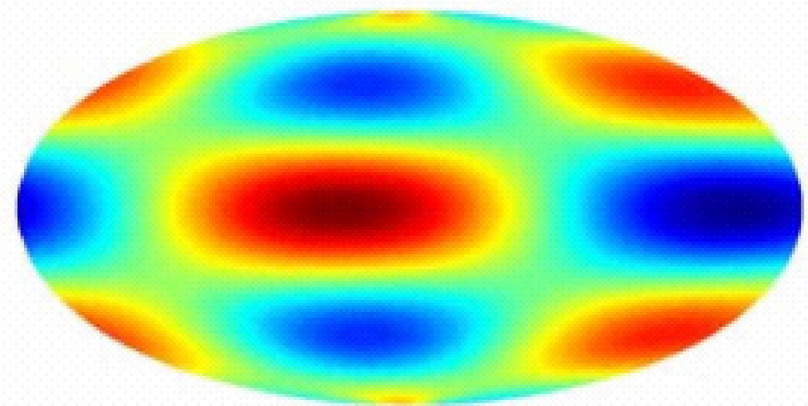
(a) $\omega_{lab}/\Omega_o = 1.30$, $\Omega_i = 5.7$ Hz



(b) $l_{mag} = 2$, $l = 3$, $m = 2$, $\omega/\Omega = 0.667$



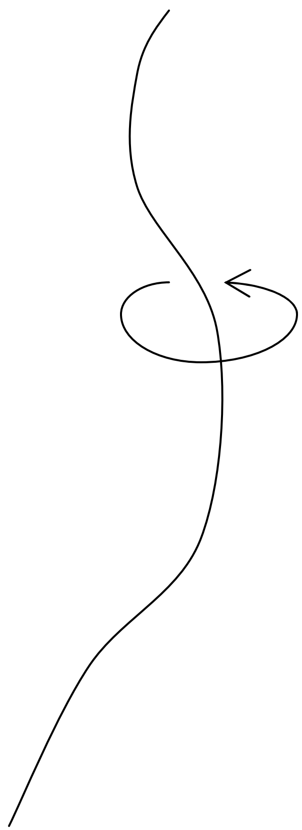
(c) $\omega_{lab}/\Omega_o = 0.39$, $\Omega_i = -12.2$ Hz



(d) $l_{mag} = 3$, $l = 4$, $m = 1$, $\omega/\Omega = 0.612$

Superfluid ^{4}He as model system for high R_m dynamics:

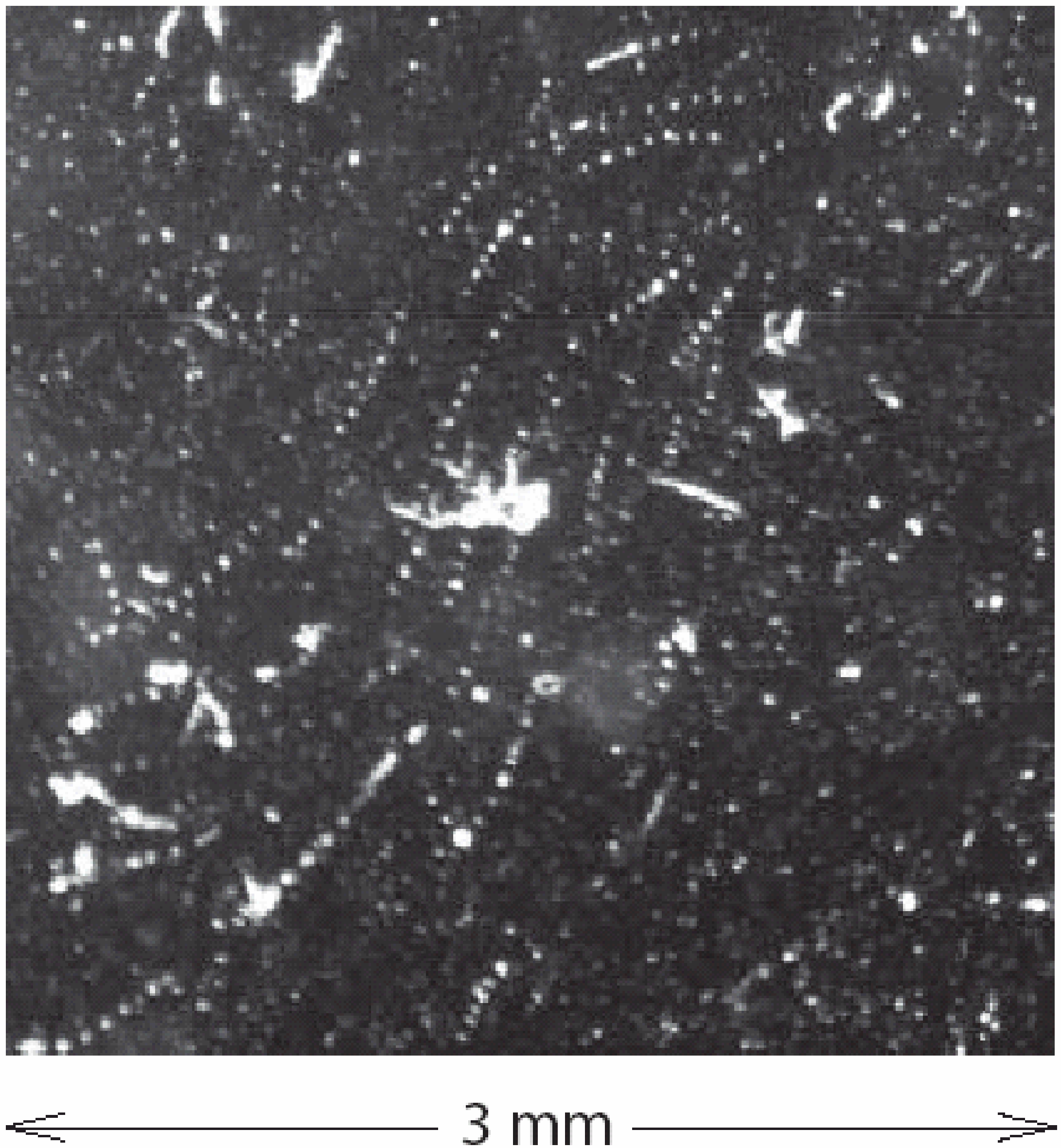
Quantum vortices ←→ Magnetic field lines
Normal fluid flow ←→ Conducting fluid or plasma flow
Q. vortex stretching ←→ Induction



$$\Psi = f e^{i\phi}$$

visualize by decorating with hydrogen ice particles

Spaced particles, "dotted lines"



$\langle \ell \rangle \sim 130\ \mu\text{m}$

$d \sim 10\ \mu\text{m}$

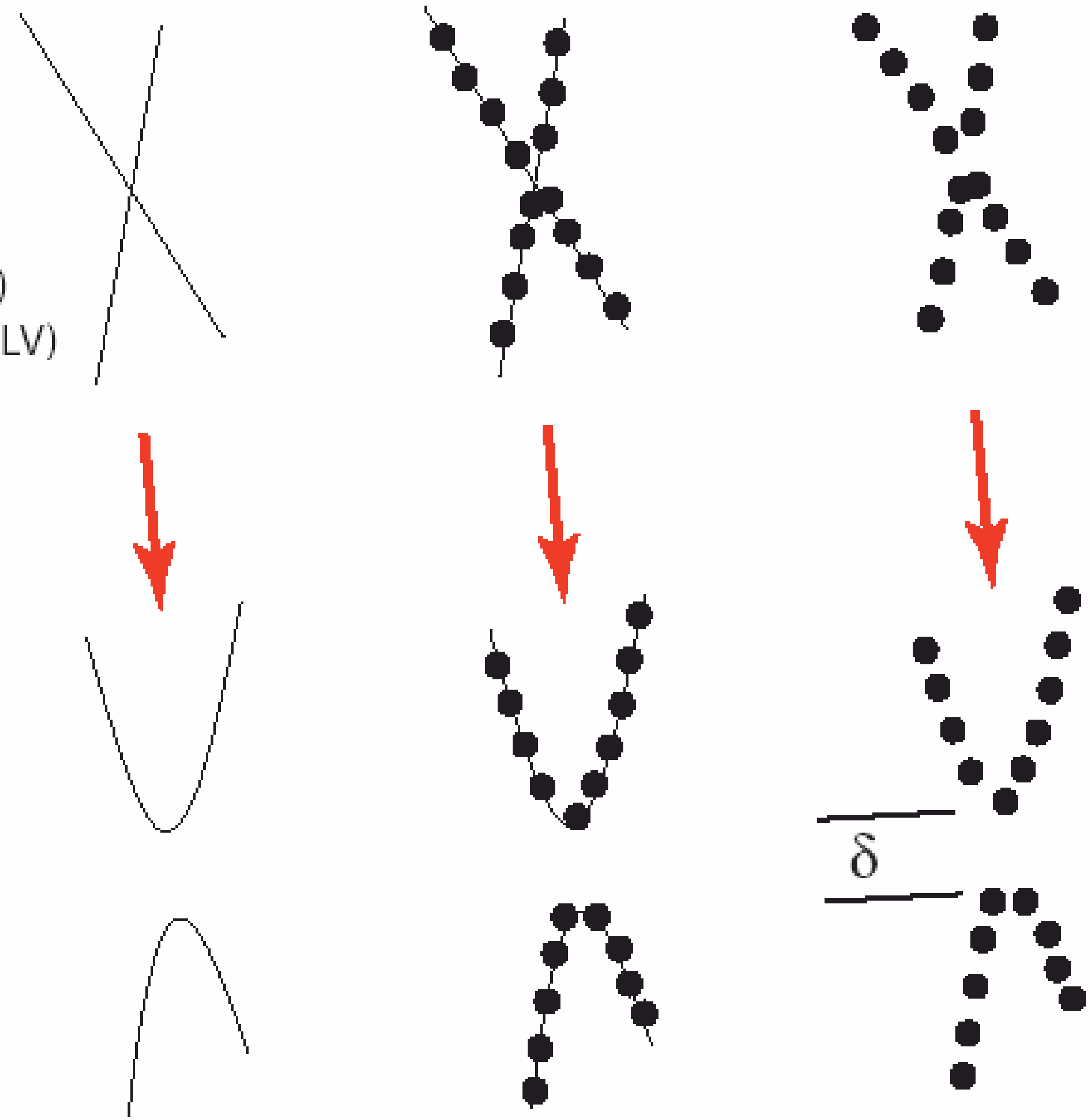
vortex reconnection

Theoretical work

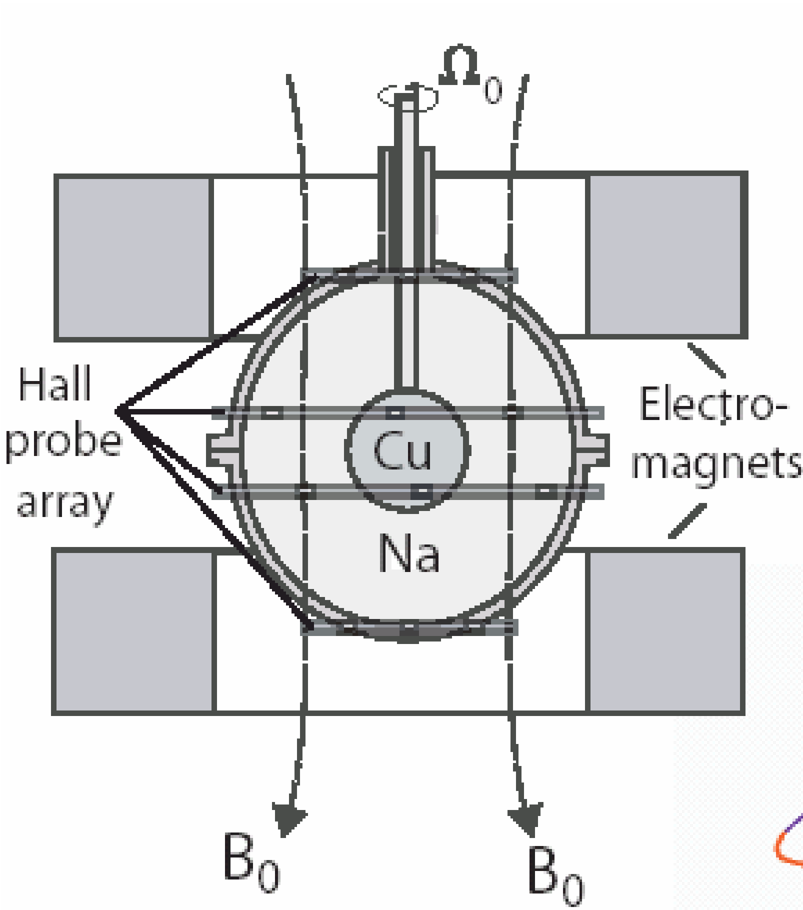
Schwarz, PRB 1985 (LV)
de Waele and Aarts, PRL 1994 (LV)
Koplik and Levine, PRL 1993 (NLSE)
Tsubota and Maekawa, JPSJ 1992 (LV)
Nazarenko and West 2003 (NLSE)

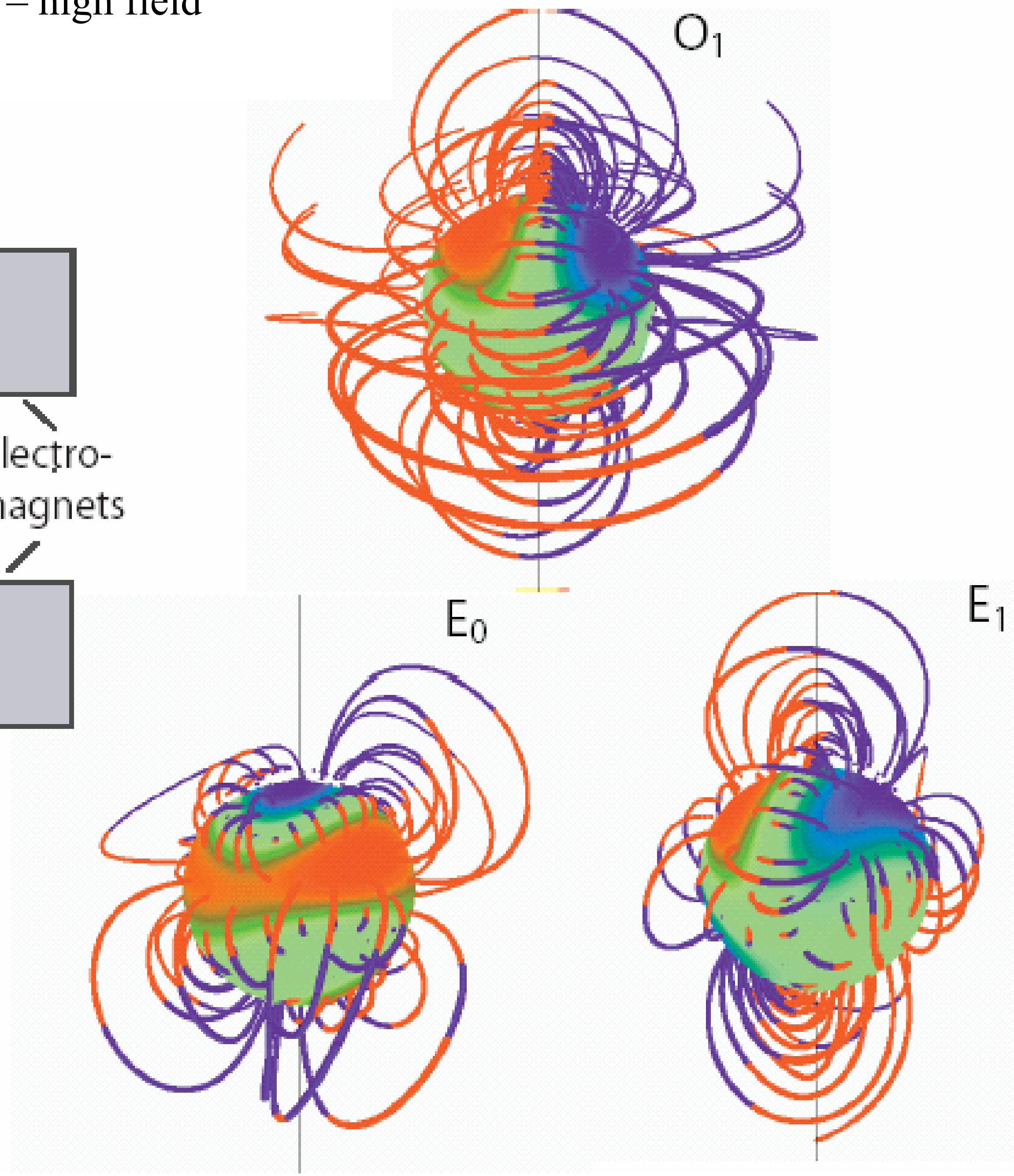
$$\delta \sim \kappa^{1/2}(t_0-t)^{1/2}$$

$$\delta \sim \kappa^{1/2}(t-t_0)^{1/2}$$



Spherical Couette flow in Na – high field





Velikhov (magnetorotational) instability

Sisan et al., Phys. Rev. Lett. 93, 114502 (2004).

Similarities with linear theory

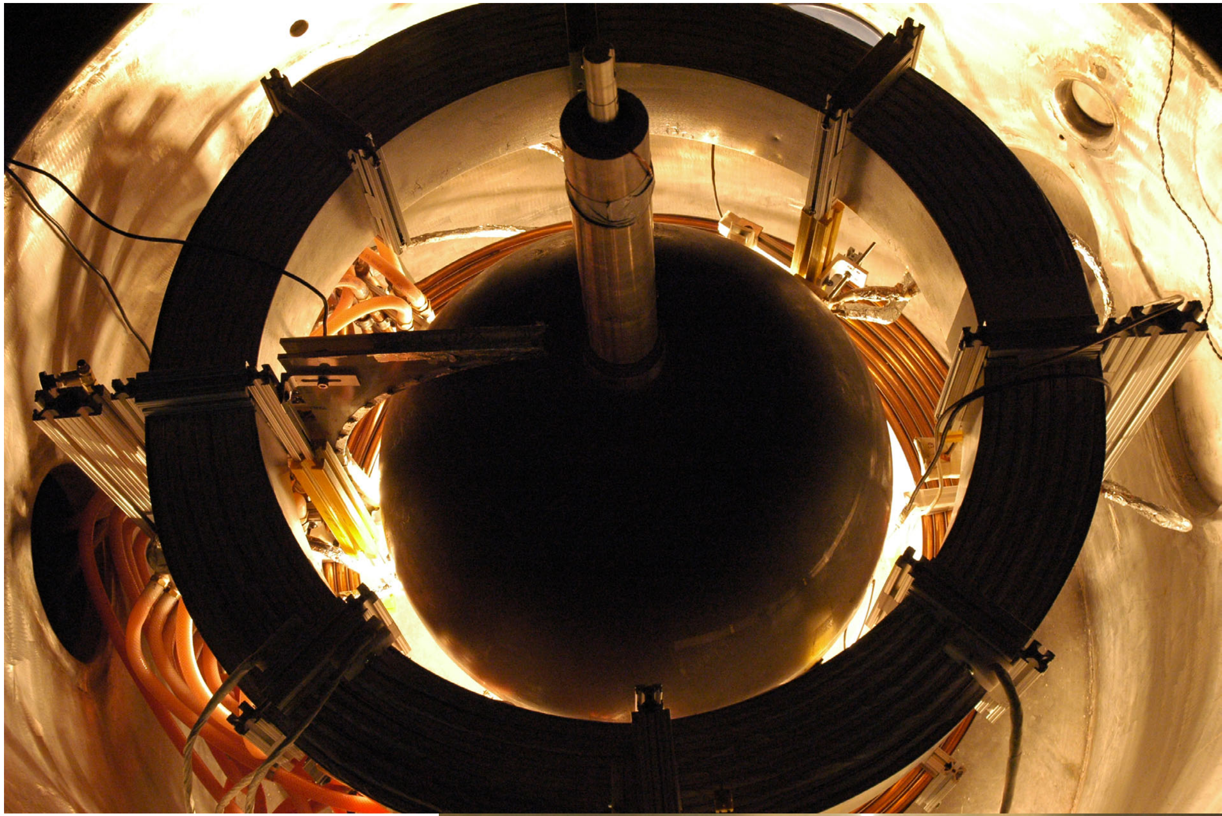
- Stability boundary
- Angular velocity profile (of mean field)
- Centrifugal and Lorentz forces relevant
- Increased angular momentum

Differences with linear theory

- Base state turbulent (15-25% fluctuations)
- First instability nonaxisymmetric
- Most (but not all) linear theories done in cylindrical geometries

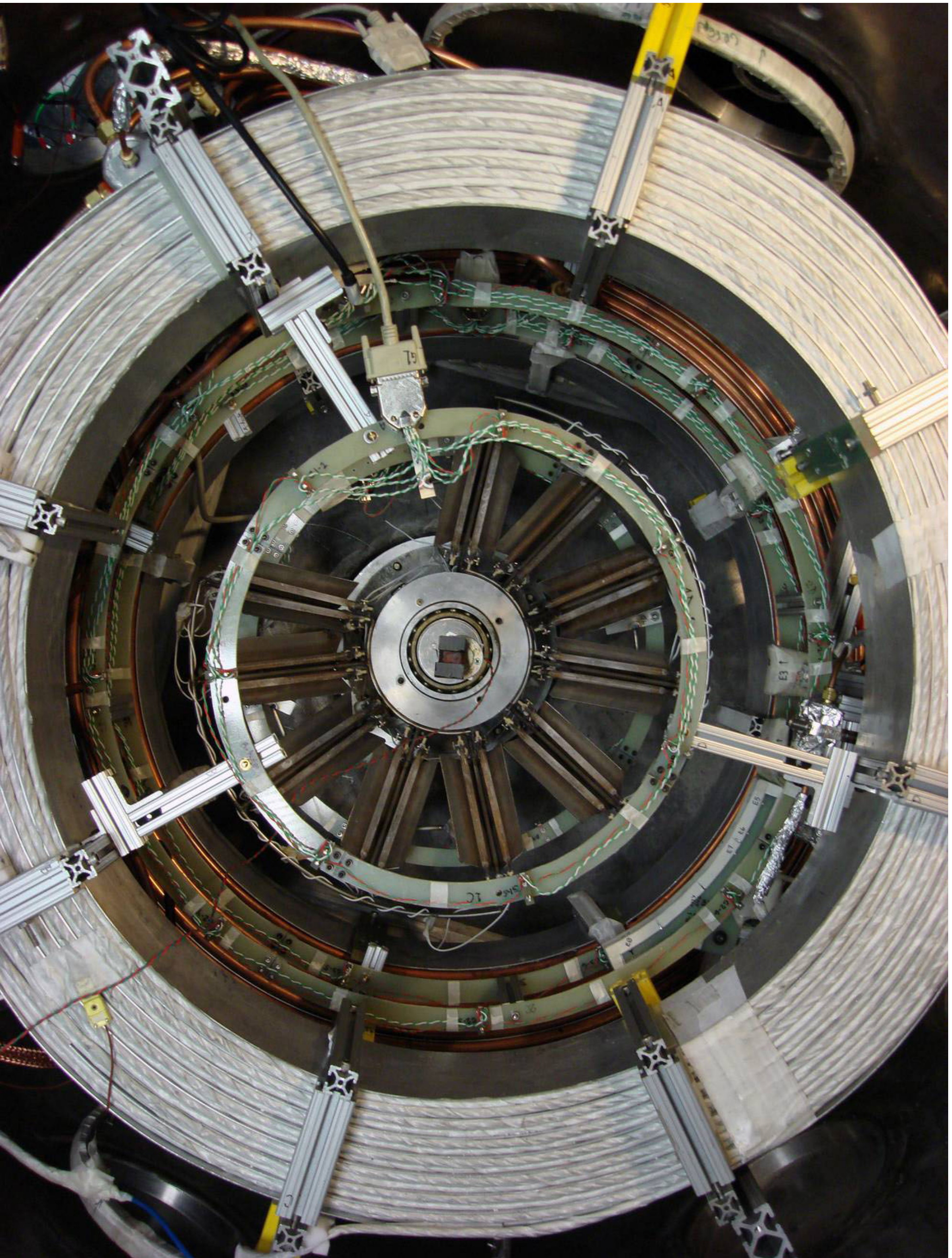
60 cm diameter system – high field

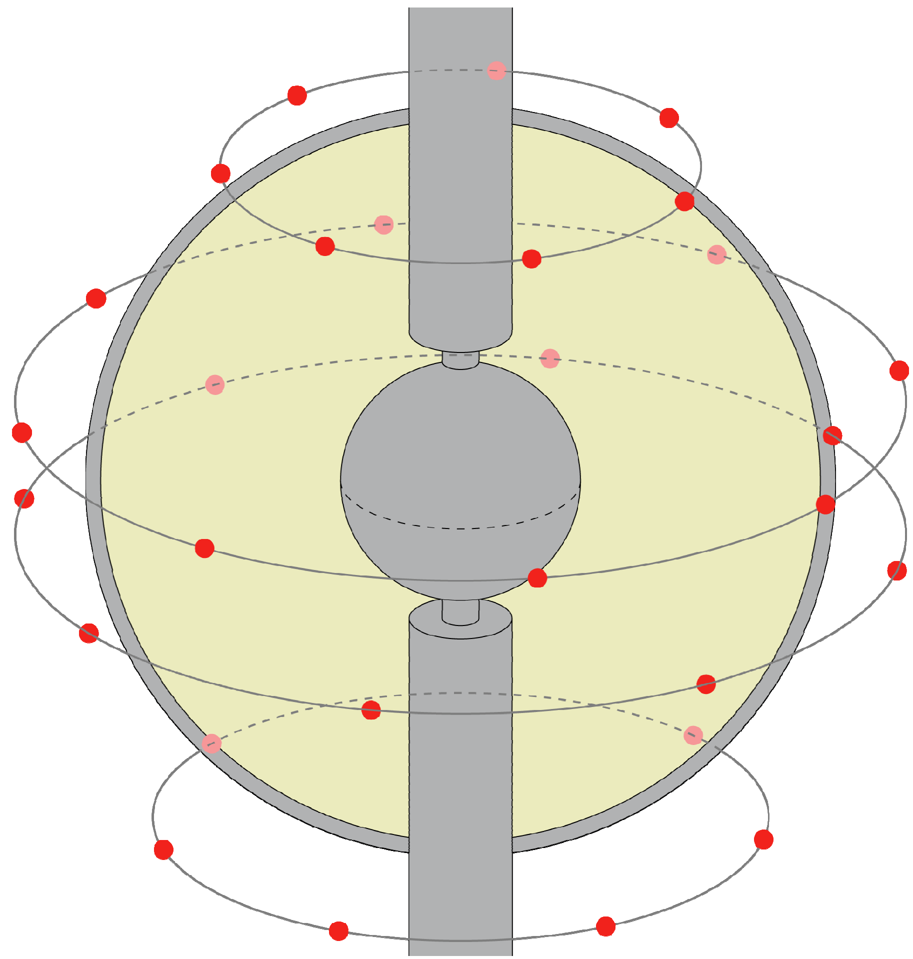
Outer sphere

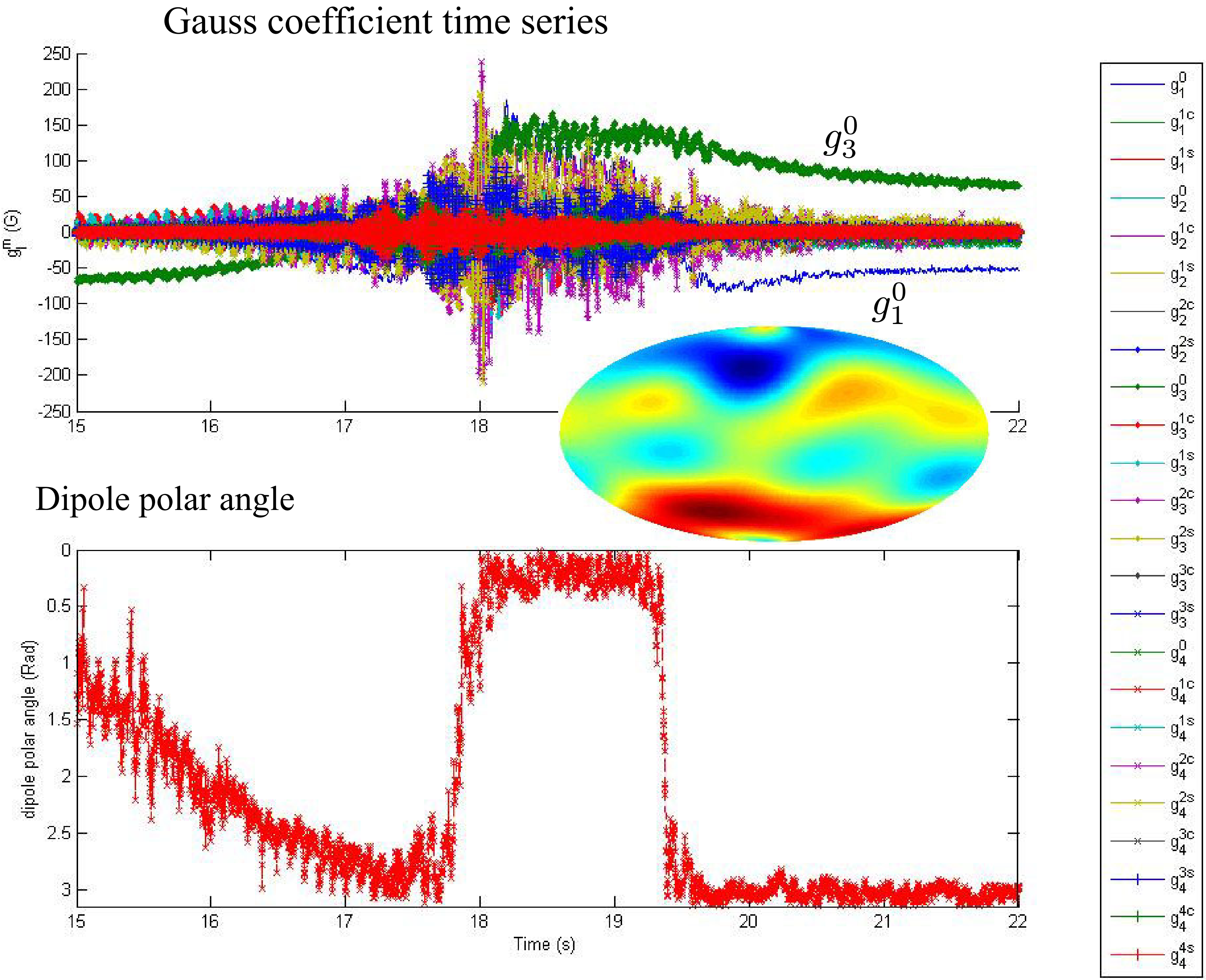


Inner sphere
Cu or Fe

60 cm system Gauss array (to ℓ=4)







Gauss coefficient time series
g_l^m (G)
g_3^0
g_1^0
Dipole polar angle
dipole polar angle (Rad)
Time (s)
g_1^0
g_1^{1c}
g_1^{1s}
g_2^0
g_2^{1c}
g_2^{1s}
g_2^{2c}
g_2^{2s}
g_3^0
g_3^{1c}
g_3^{1s}
g_3^{2c}
g_3^{2s}
g_3^{3c}
g_3^{3s}
g_4^0
g_4^{1c}
g_4^{1s}
g_4^{2c}
g_4^{2s}
g_4^{3c}
g_4^{3s}
g_4^{4c}
g_4^{4s}

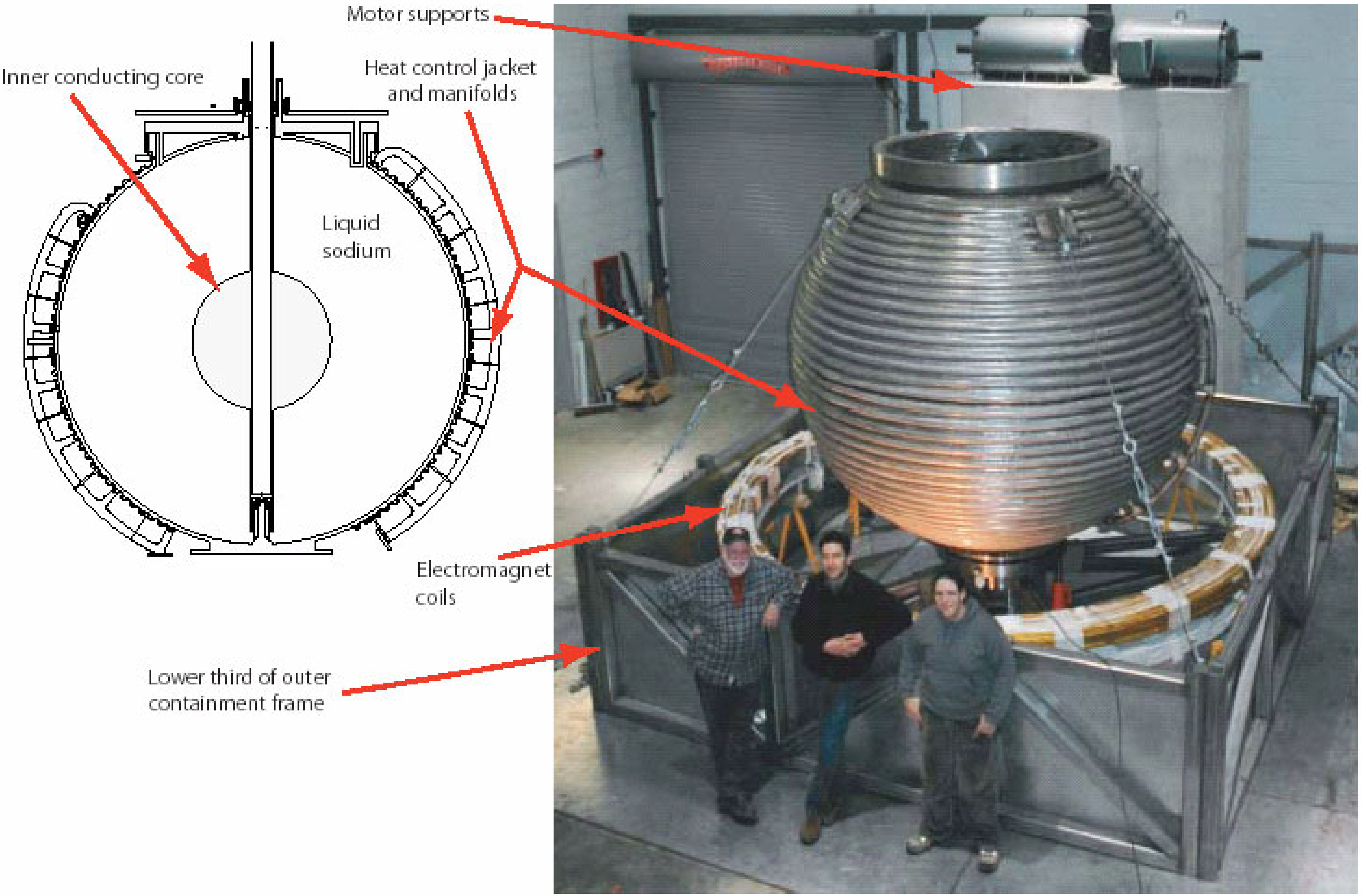
Summary hypotheses

1 Systems with $E < 10^{-6}$ are oscillatory
- power law scalings gone – structured wave spectra instead
- consequences to dynamos

2 high R_m limit states determined by competition of
- generation and reconnection

3 Velikhov and shear instabilities are <u>not</u> exclusive
- MRI instability can be finite onset (hysteretic)

http://complex.umd.edu



Motor supports
Inner conducting core
Heat control jacket
and manifolds
Liquid
sodium
Electromagnet
coils
Lower third of outer
containment frame


MARYLAND
Geodynamo Lab