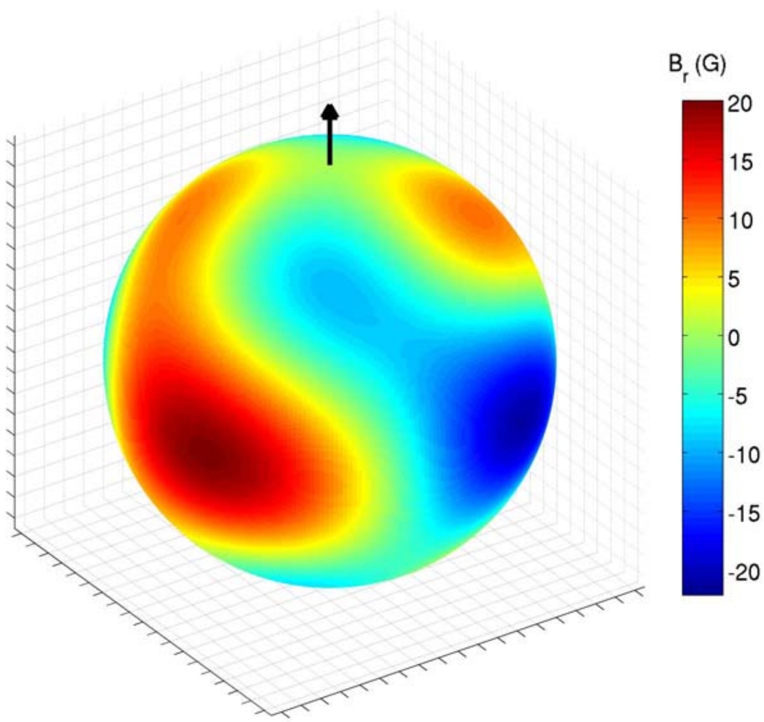
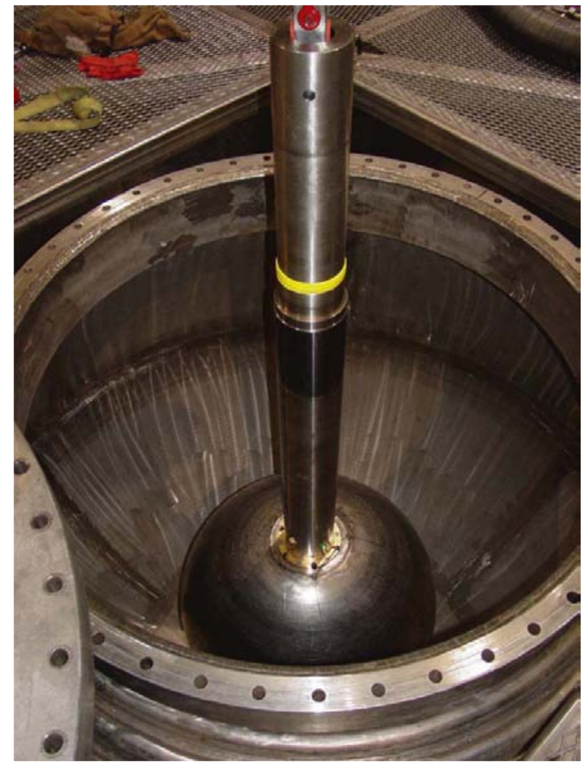
UNIVERSITY OF MARYLAND

Journey to the Center of the ERF: Planetary Cores, Accretion Disks, and "Helioseismology" in the Lab



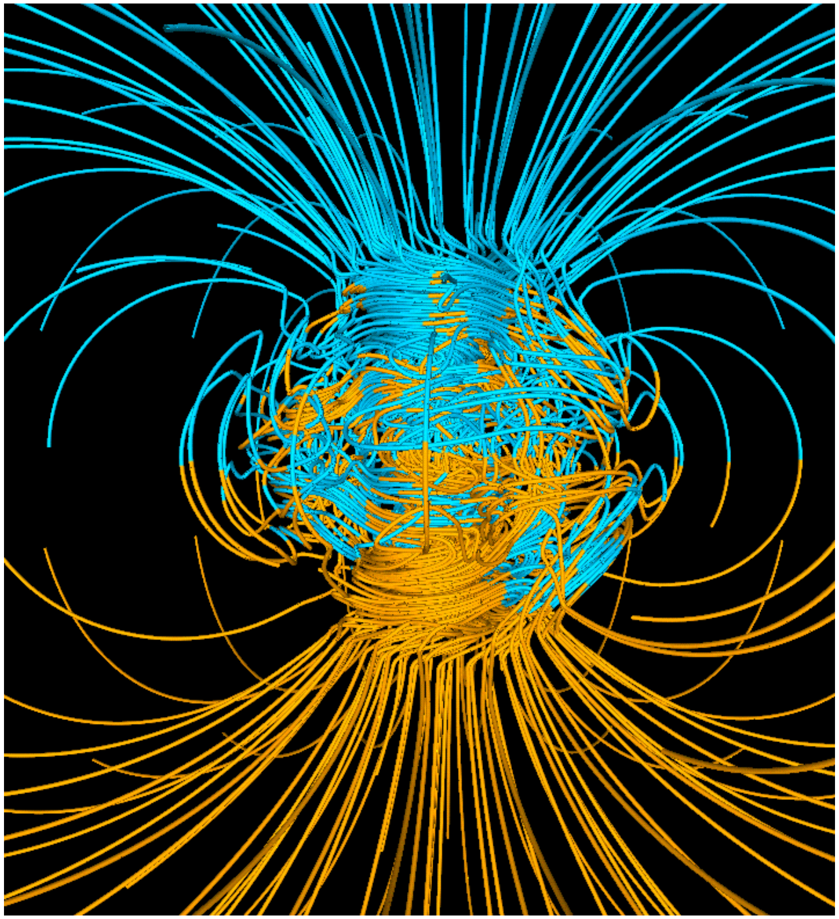


Daniel S. Zimmerman

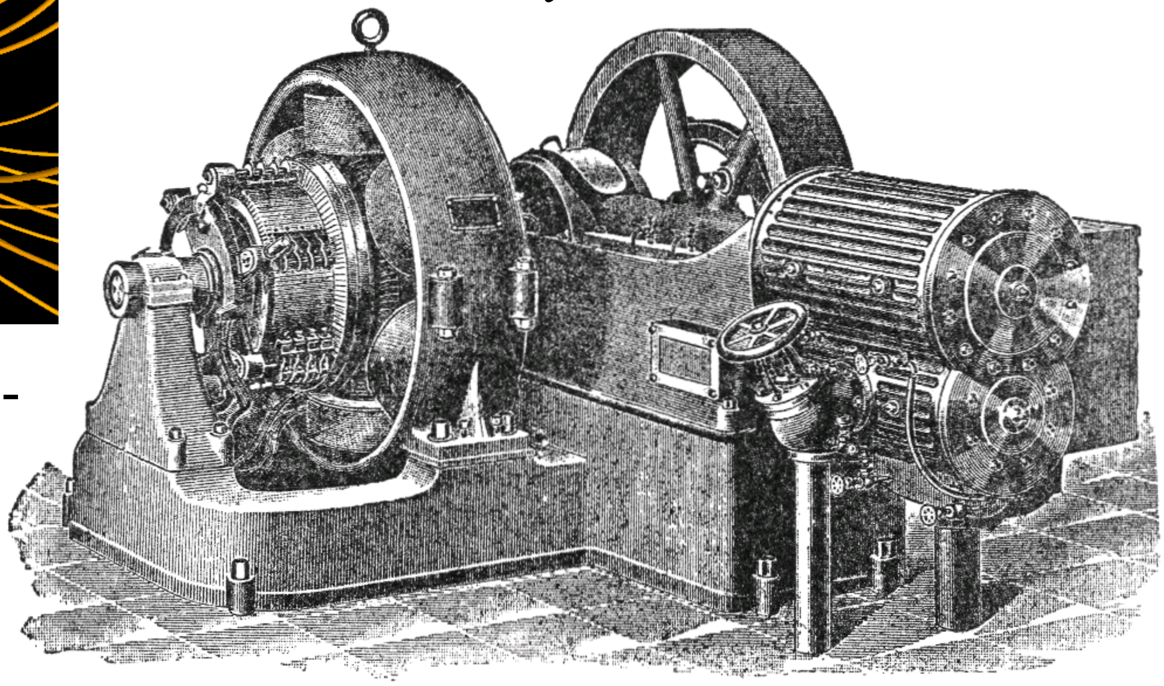
Funding:
NSF EAR/Geophysics
University of Maryland

Dynamos

Solar Dynamics - NASA



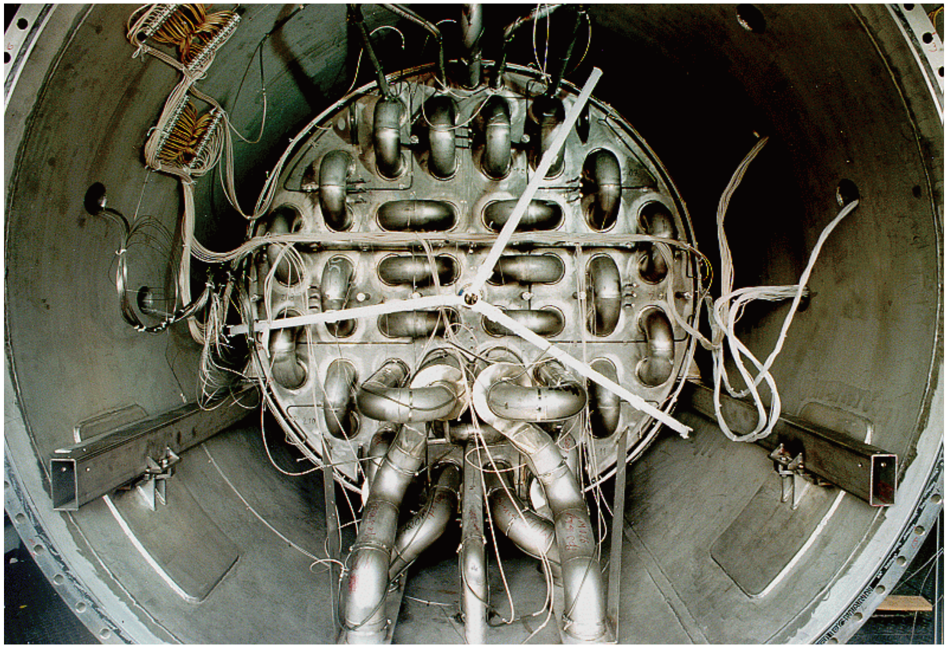
Reversing Dynamo Simulation - Glatzmeier and Roberts



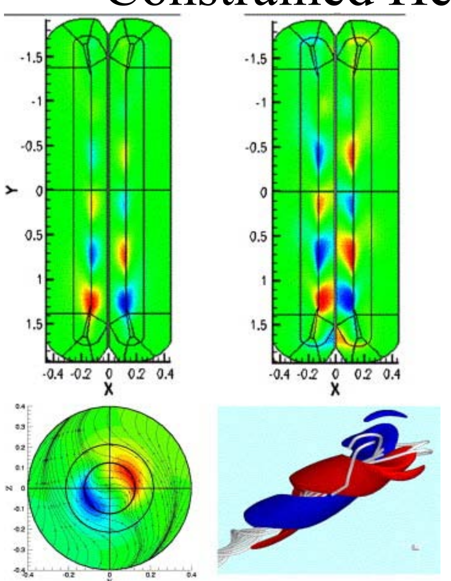
Looks Like The Plan, But Not The Plan.

Dynamos

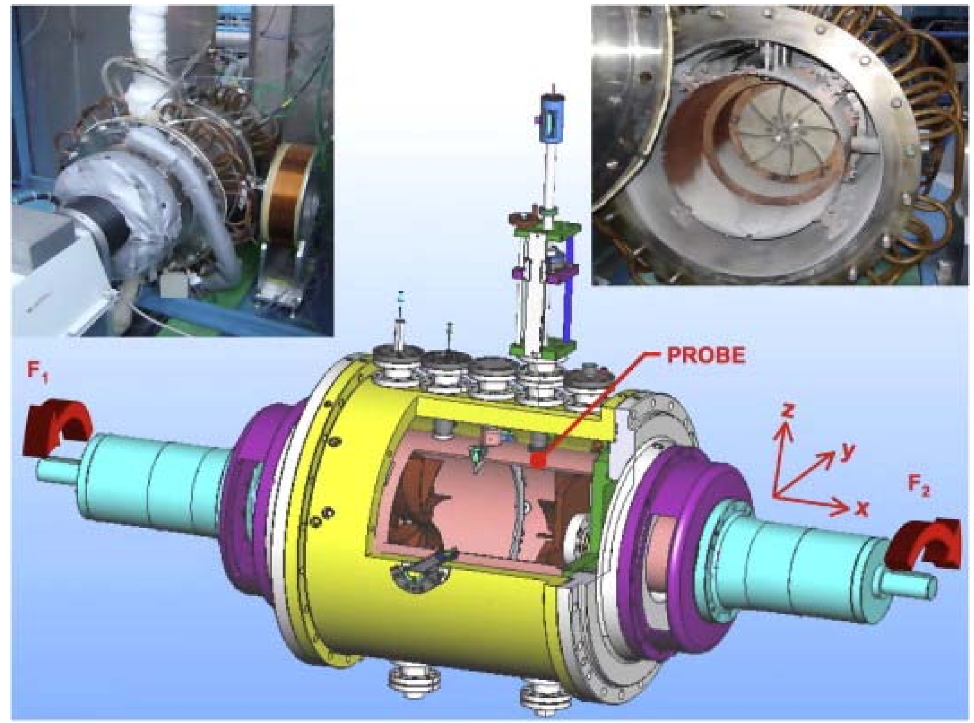
Important proof that you can build a 'homogeneous' dynamos, or nearly so: No electrical insulation, at least! Interesting MHD States.



Karlsruhe Dynamo
Constrained Helical Flow Paths



Riga Dynamo-
Fairly Constrained



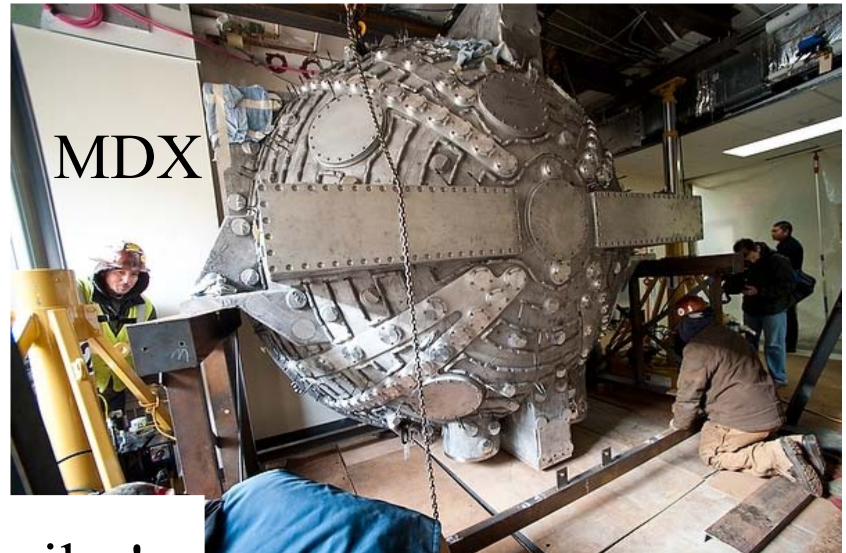
Von Karman Sodium II
Open Geometry but has
Ferromagnetic Impellers!
Shows Reversals

Why experiments? - Computer models even further from realistic.

Dynamos

Planetary and Astrophysically Inspired
Dynamo Attempts: 3m, Madison Plasma

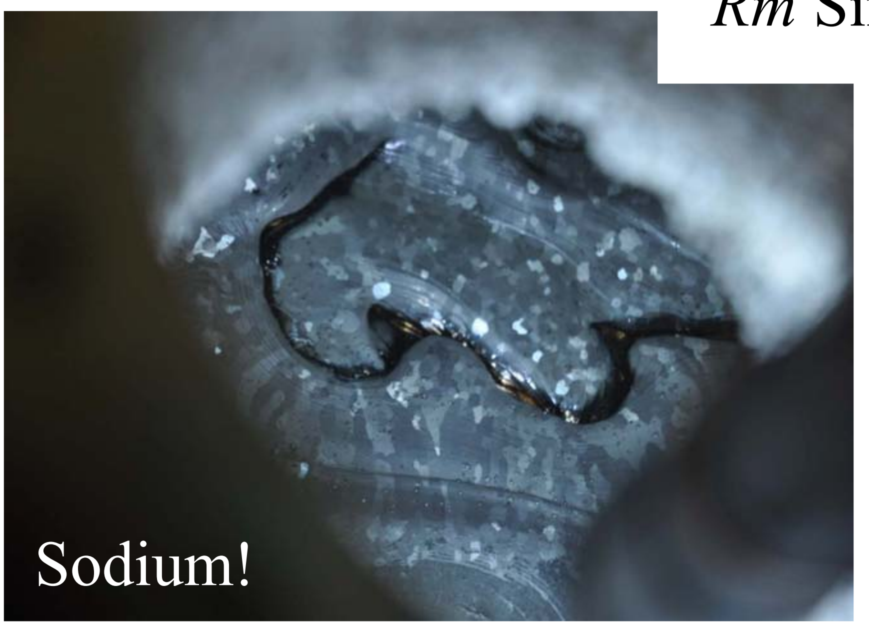
Re Large

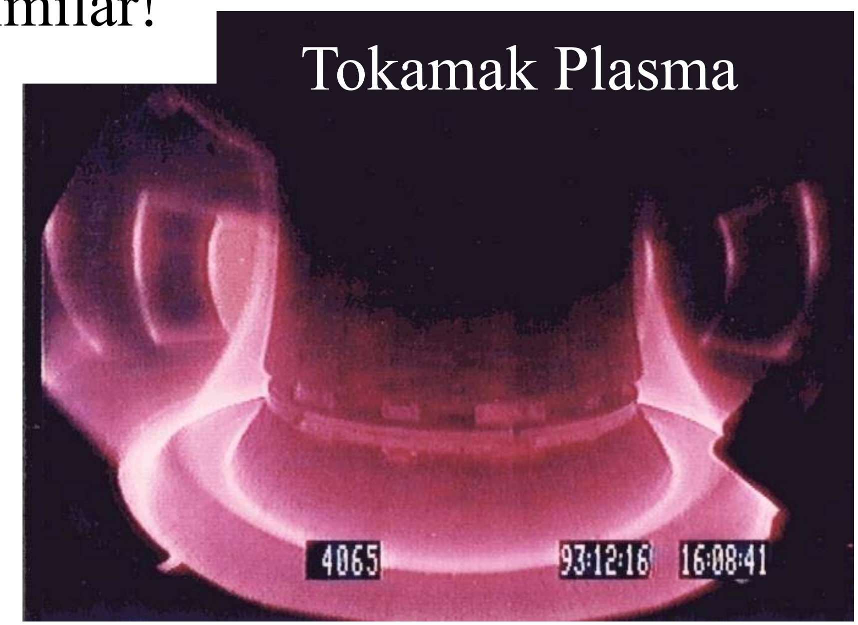


Re Small

Rm Similar!

Pm Small





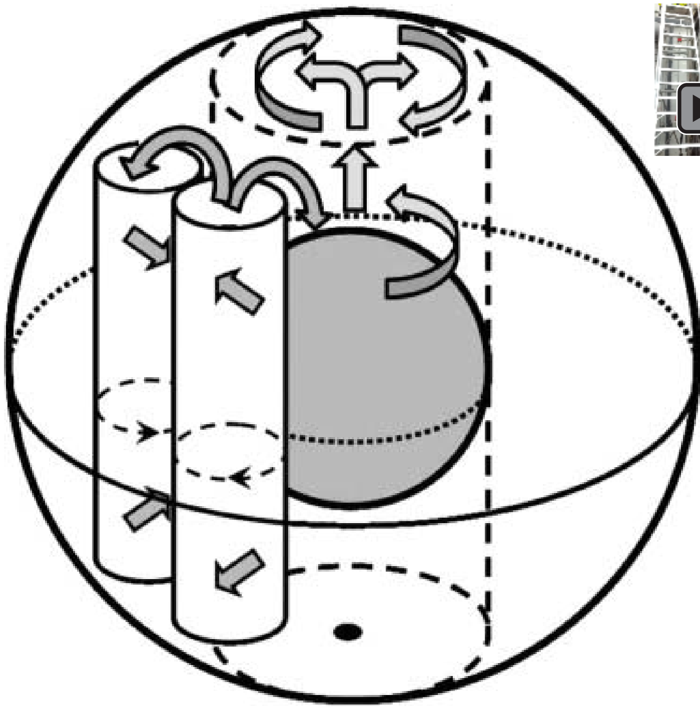
Pm Large

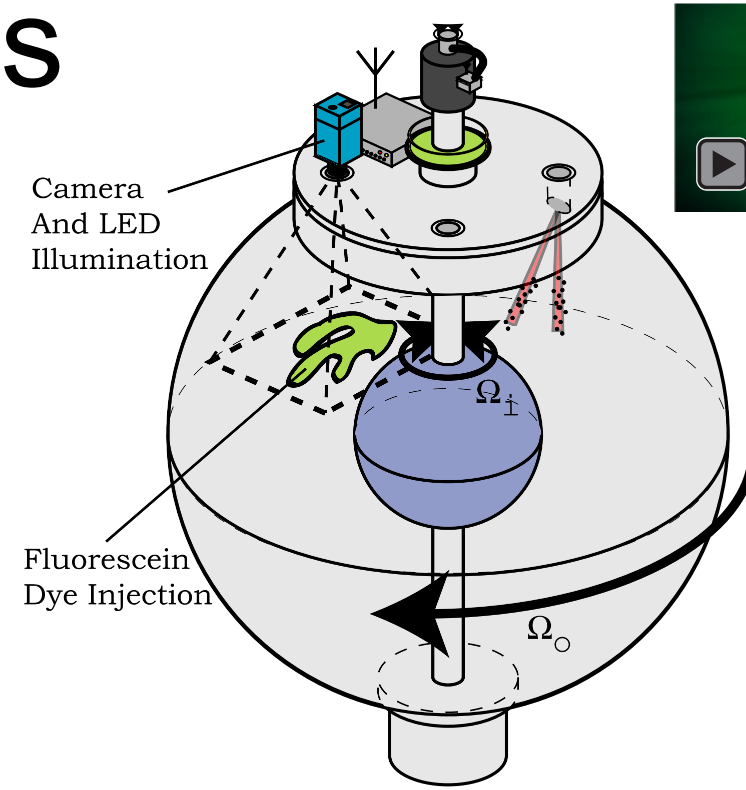
Large *Re* = Turbulent!   Large *Rm* = Good For Dynamos

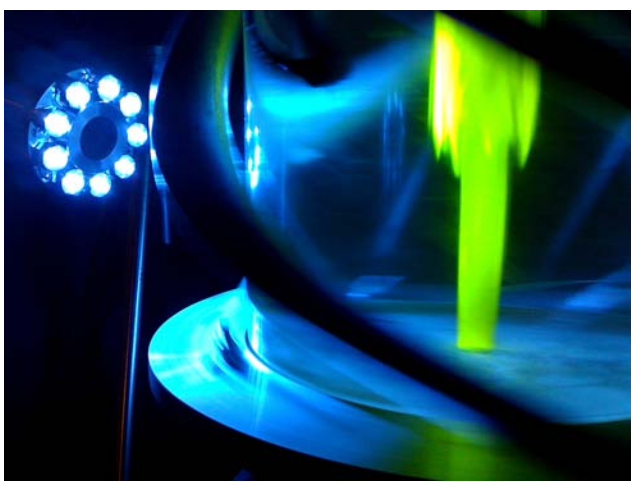
$$Re = \frac{\text{Velocity x Size}}{\text{Viscosity}} \quad Rm = \frac{\text{Velocity x Size}}{\text{Magnetic Diffusivity}} \quad Pm = Rm/Re = \frac{\text{Viscosity}}{\text{Magnetic Diffusivity}}$$

Dynamo Ingredients

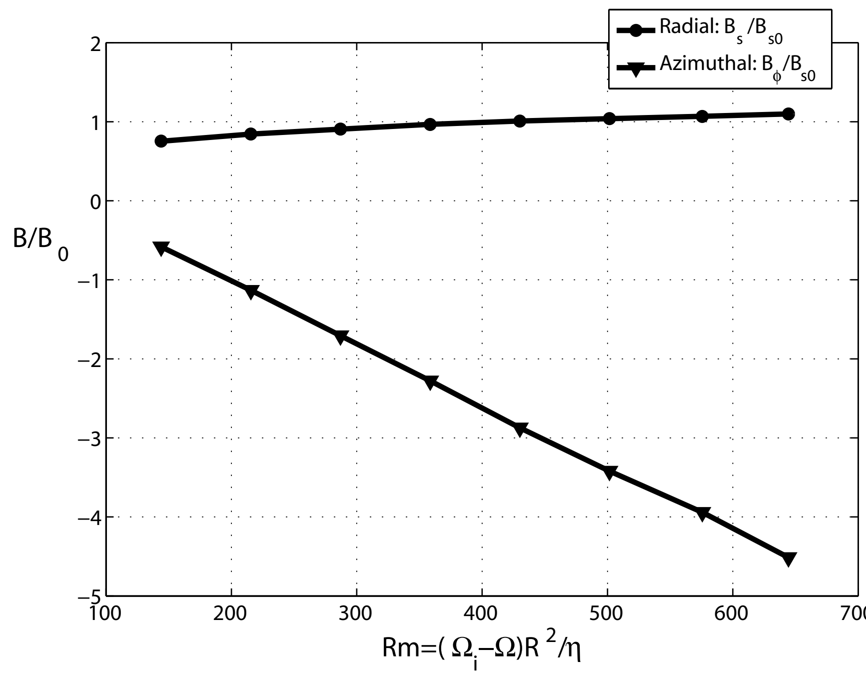
Flow Organization From Rotation

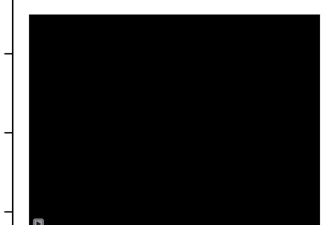




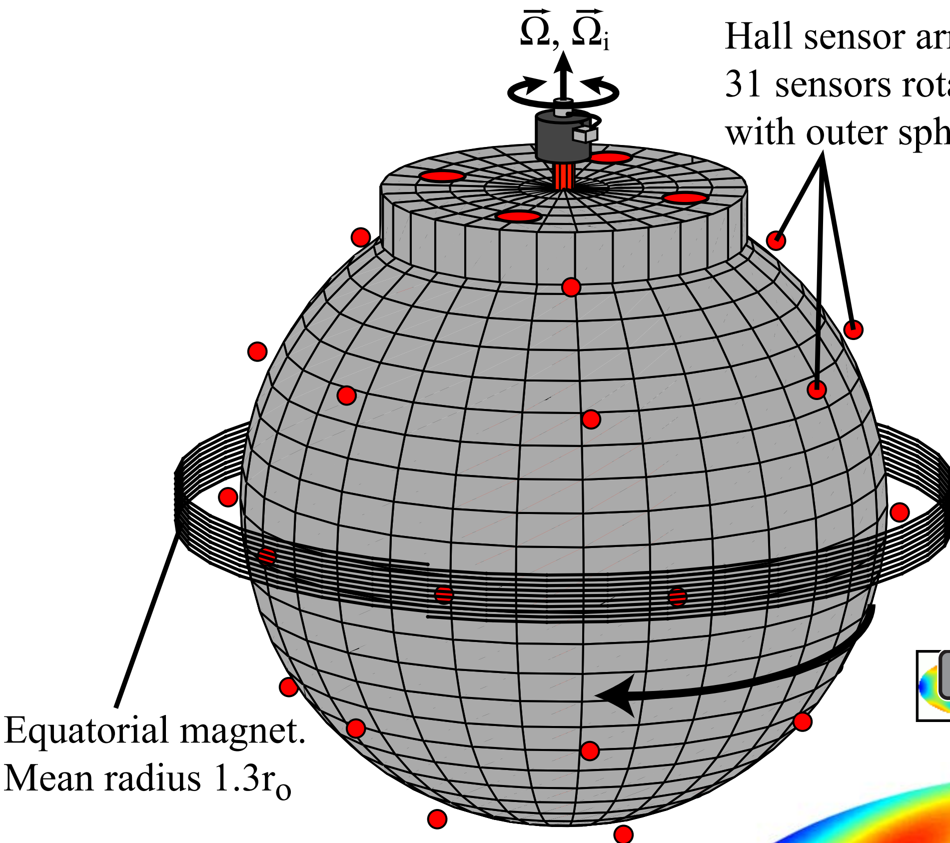


Winding Up Field Lines: Azimuthal Field vs *Rm*

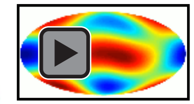


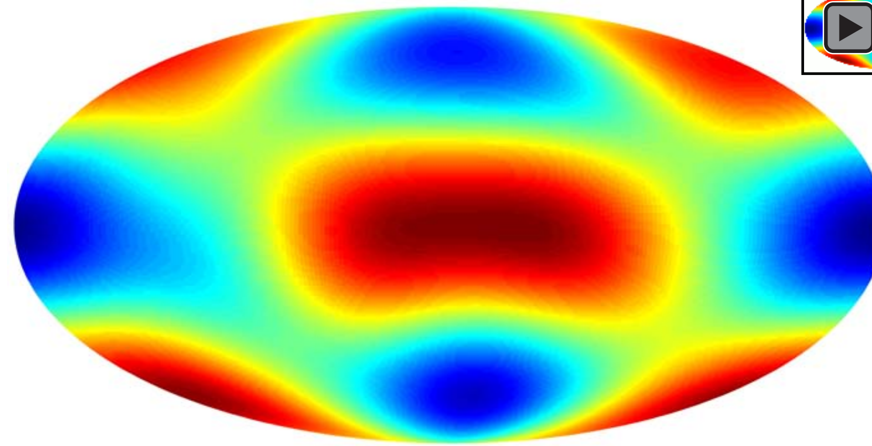


No Dynamo, But Core-Like Flows!

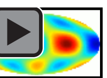


Weak Magnetic Field - Inertial Mode
Coriolis Restoring Force

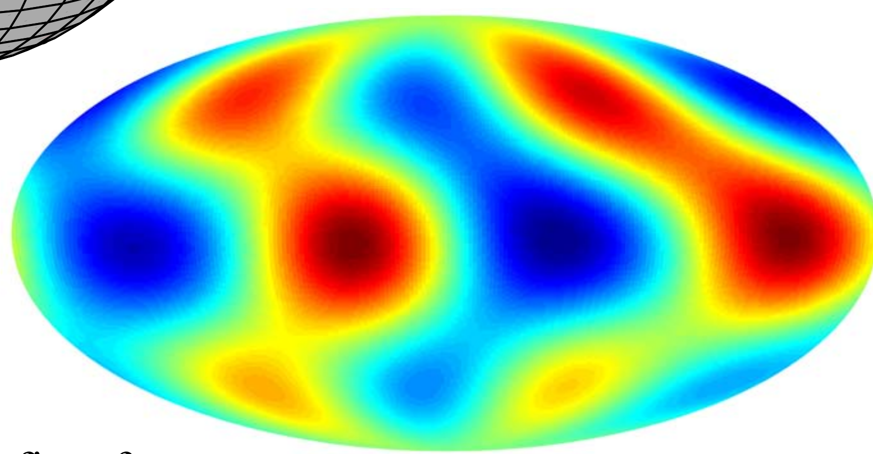


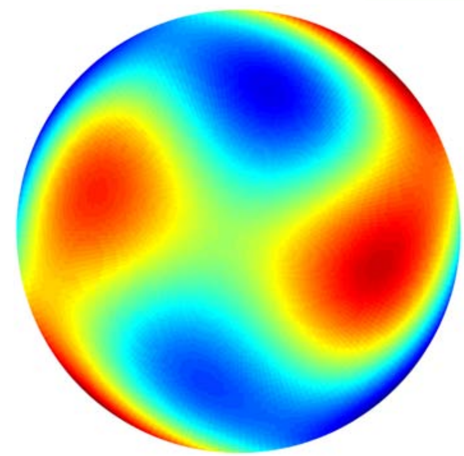


Weak magnetic field - imaging technique!
Inertial Waves RESPONSIBLE
for Columnar Flow!



Mollweide: Whole
Sphere Surface Flattened -->



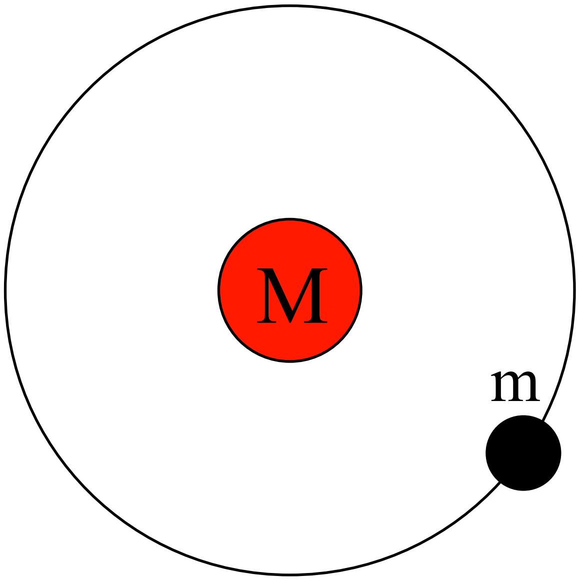


These pictures are least-squares fits of spherical harmonic functions to probe data.

Strong Applied Magnetic Field - MAYBE a MagnetoCoriolis (MC) Mode

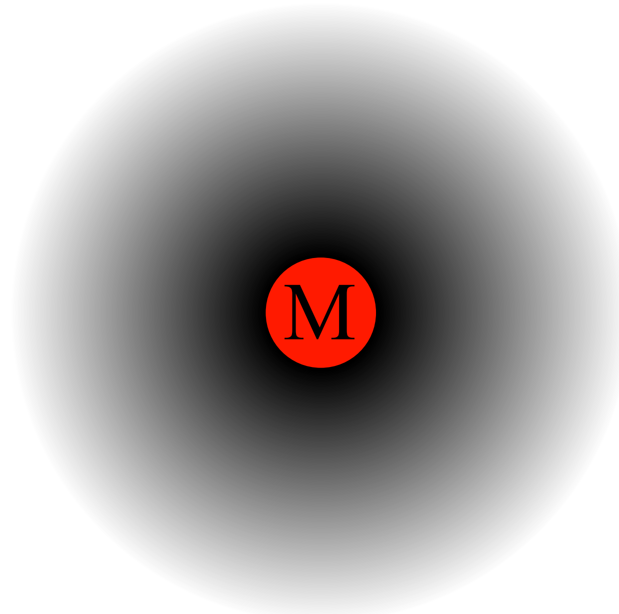
Accretion Disks

Circular orbit,
angular speed $\Omega(r)$ in radians/sec



$$m\Omega^2 r = GmM/r^2$$

Orbiting gas and dust
density ρ
(when orbiting stuff is colliding)



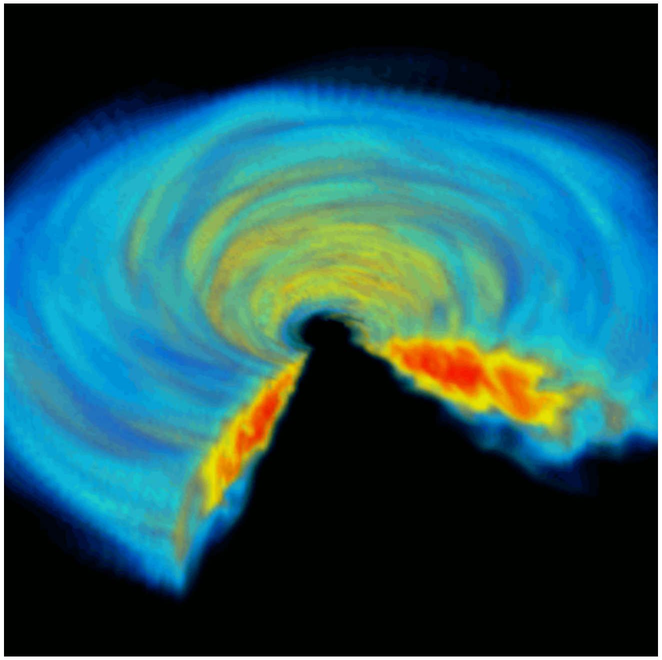
$$\rho\Omega^2 r = G\rho M/r^2$$

$$\Omega(r) = \frac{GM}{r^{3/2}}$$

This angular velocity profile may be very STABLE even for enormous Reynolds number (an open question, IMO!)

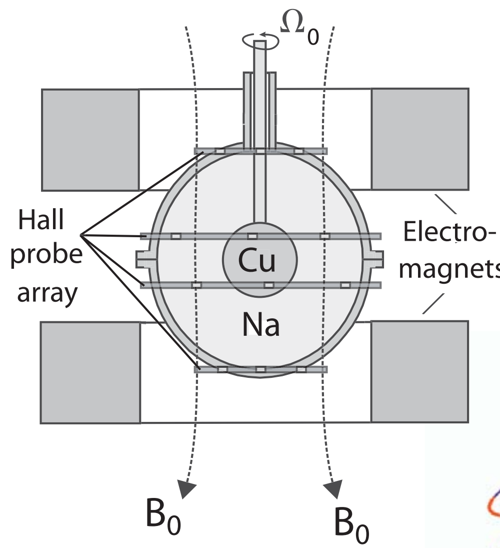
Why stable? - Inertial Waves!
Why NOT stable? High *Re* (10^{15}!!), Magnetic Field.
Why does it matter? - Accretion Rate, Angular Momentum Shedding

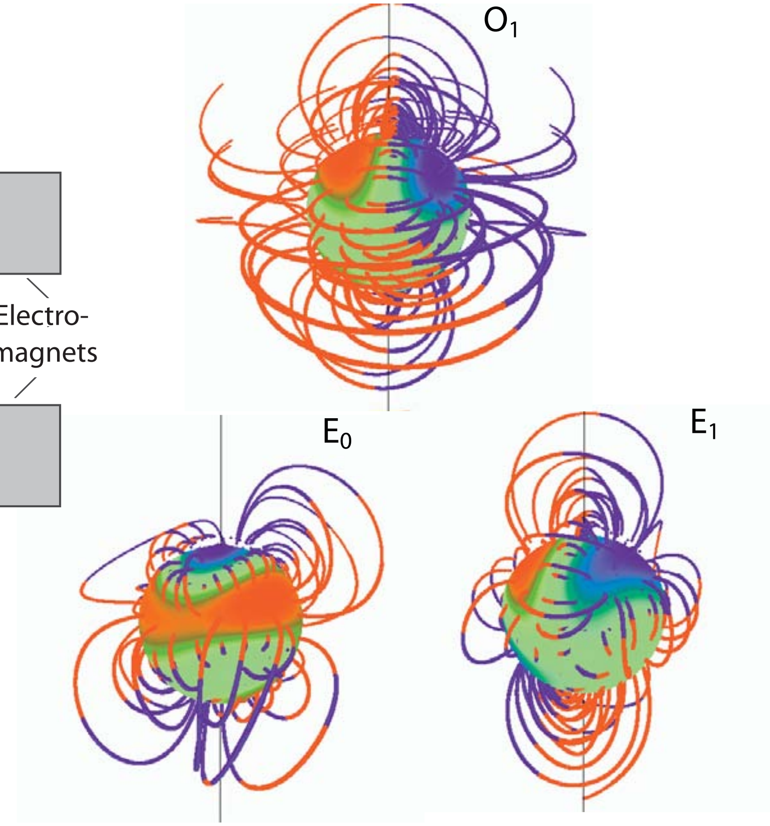
Accretion Disks - MRI



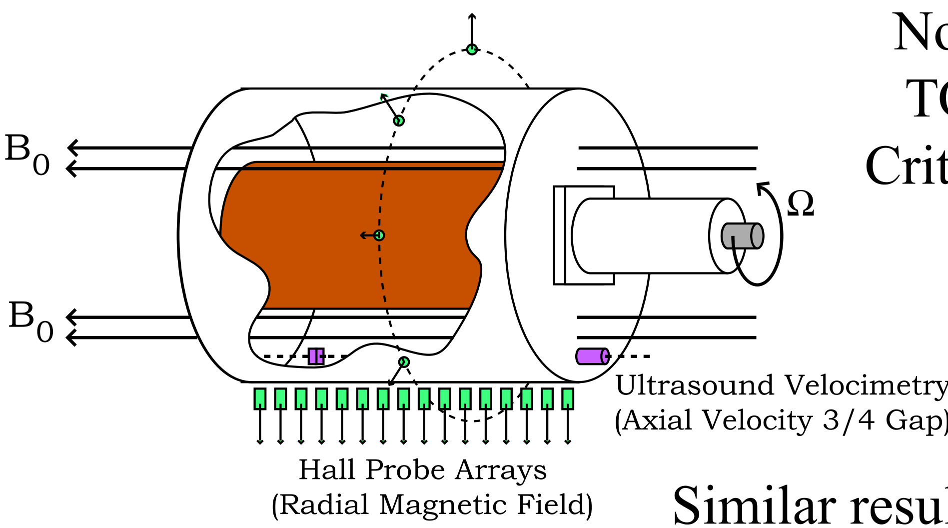
Magnetic Field Changes Stability

Allows Overturning Motions,
Then Turbulence



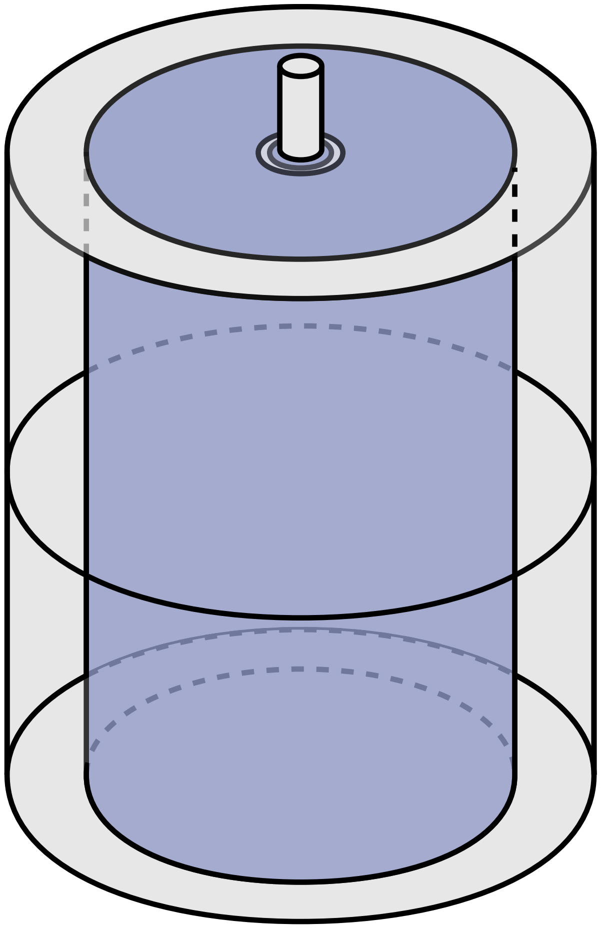


Strong Applied Field - 30cm Experiment,
No applied field: flow happens to be $\Omega \sim r^{3/2}$!!
TORQUE increases -> Angular Momentum.
Criticism: Already Turbulent. Active research!



Similar results in cylinder.

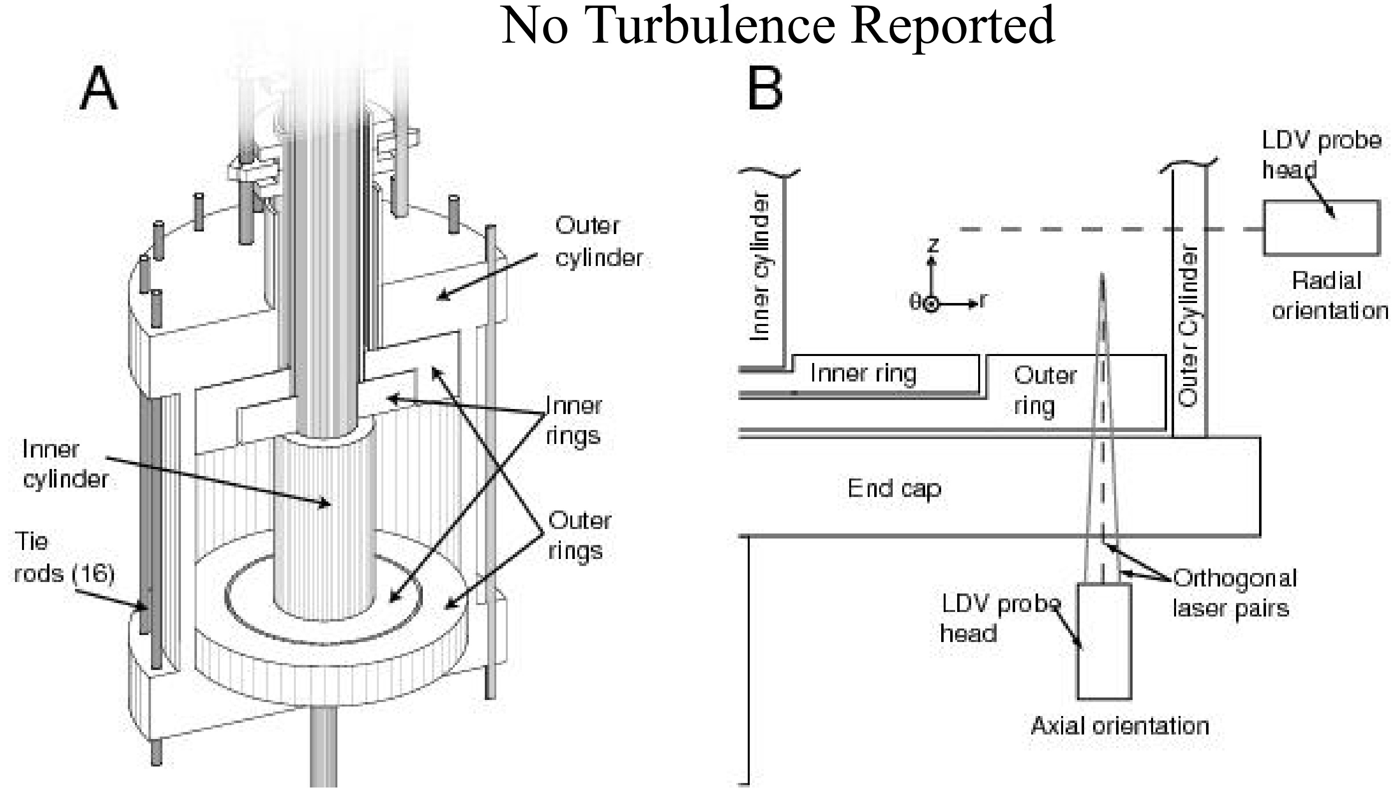
Accretion Disks - Hydrodynamics??



Taylor-Couette
With BOTH Rotating
$\Omega \sim r^{3/2}$ Possible
Our Experiment is
Turbulent

Larger *Re*
Turbulence from End Effects?

Princeton Apparatus - > Independent
Inner, Outer, and Two Endwall Rings!
No Turbulence Reported

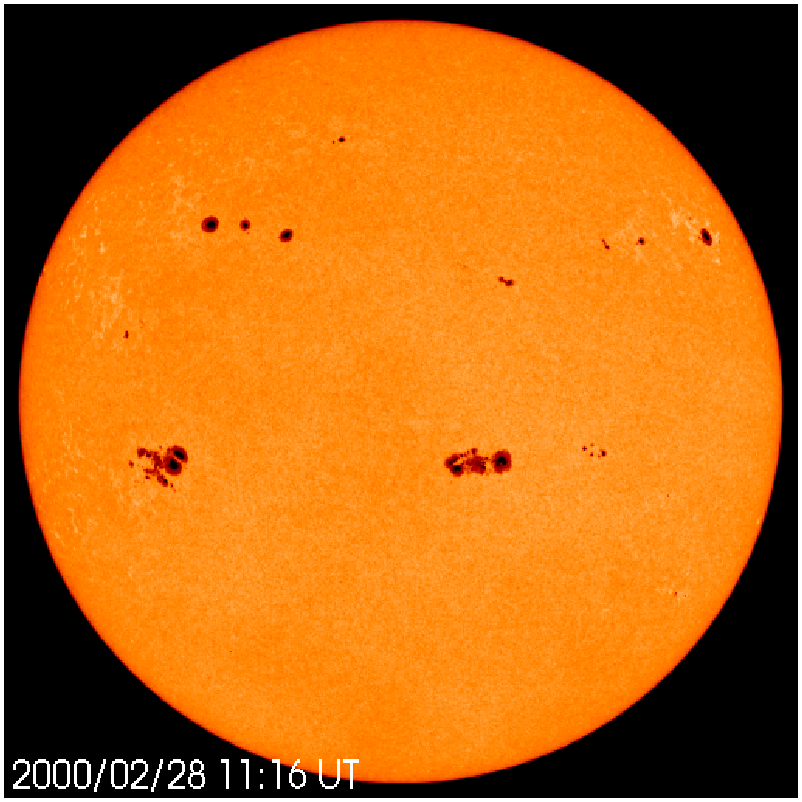


Somewhat Smaller *Re*
Rotating ends ≠ No ends
Measurement Noise 1-2%

Can NEVER be idealized: Need to try many things and find common ground.

"Helioseismology"

Can't see INSIDE the Sun... Can't see INSIDE sodium, either.

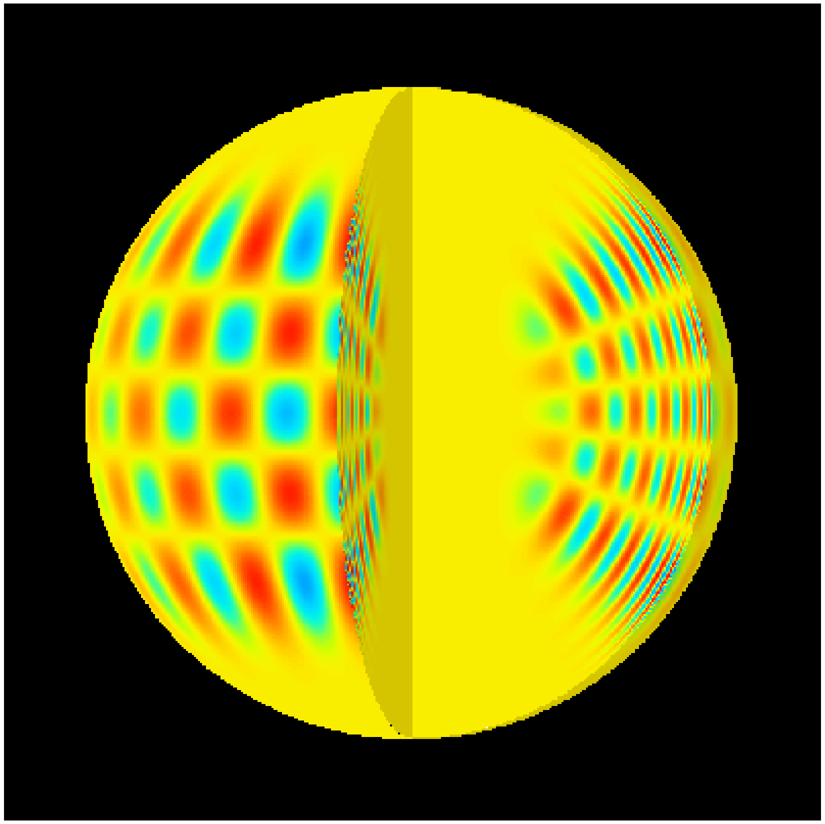


What's the internal flow like??

Ultrasound, but limited to a single pencil beam ... OR...

Thanks to Santiago Triana for some slides...

"Helioseismology"

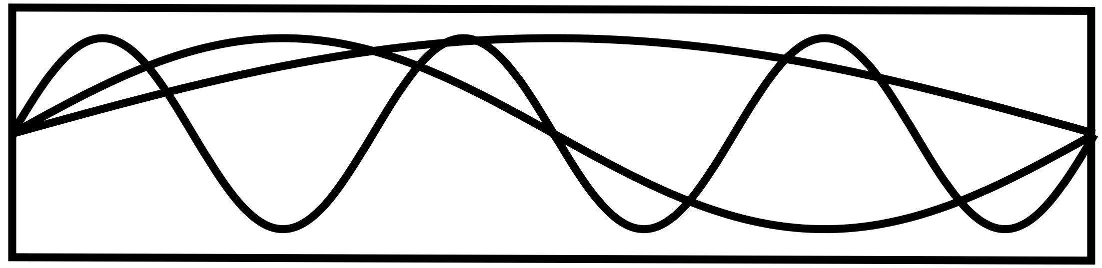


Solar Acoustic Mode

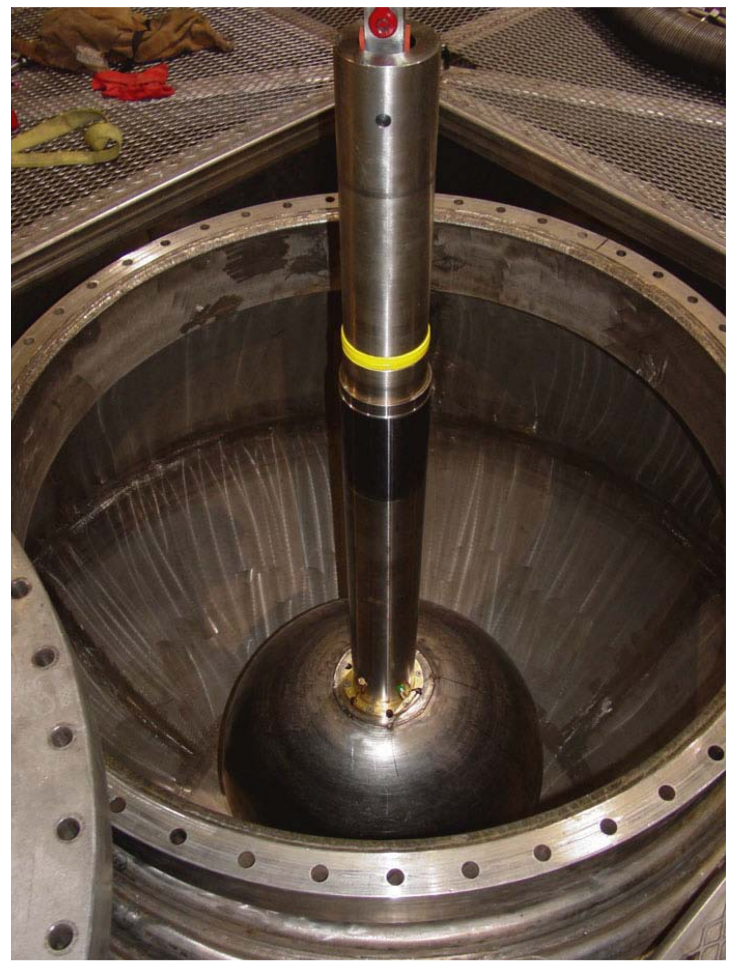
$$\delta\omega = \omega_0 \pm f(\Omega(r,\theta,\phi),\text{mode stuff})$$

System of equations with MANY $\delta\omega$ for
all identifiable modes gives
a good guess for rotation profile Ω

Modes in a Pipe

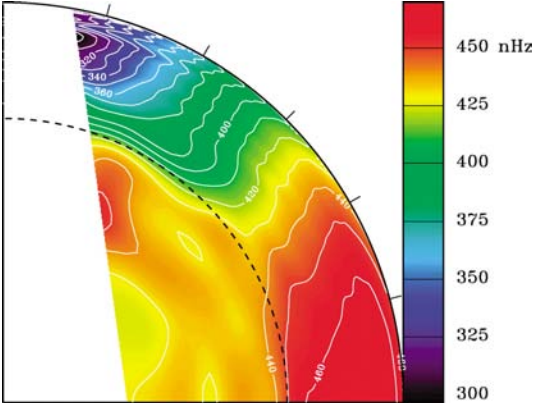


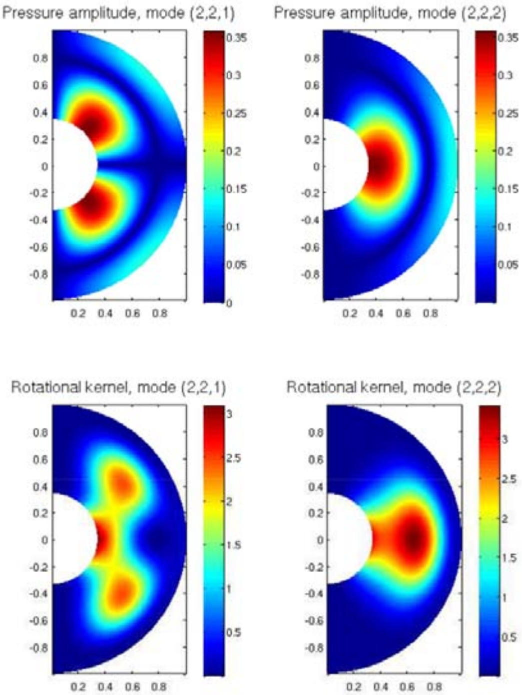
Modes In Here!



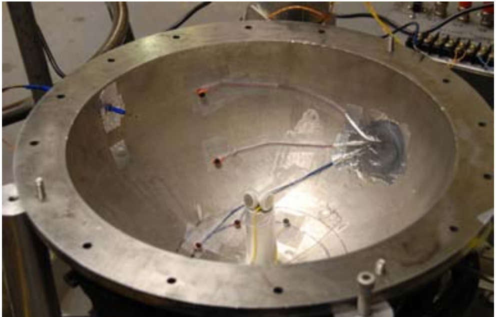
Acoustic (p-Mode) splitting caused by rotation in the Sun

$$\delta\omega_{nlm} = m \int_0^R \int_0^{2\pi} K_{nlm}(r,\theta)\Omega(r,\theta) r \, dr \, d\theta$$

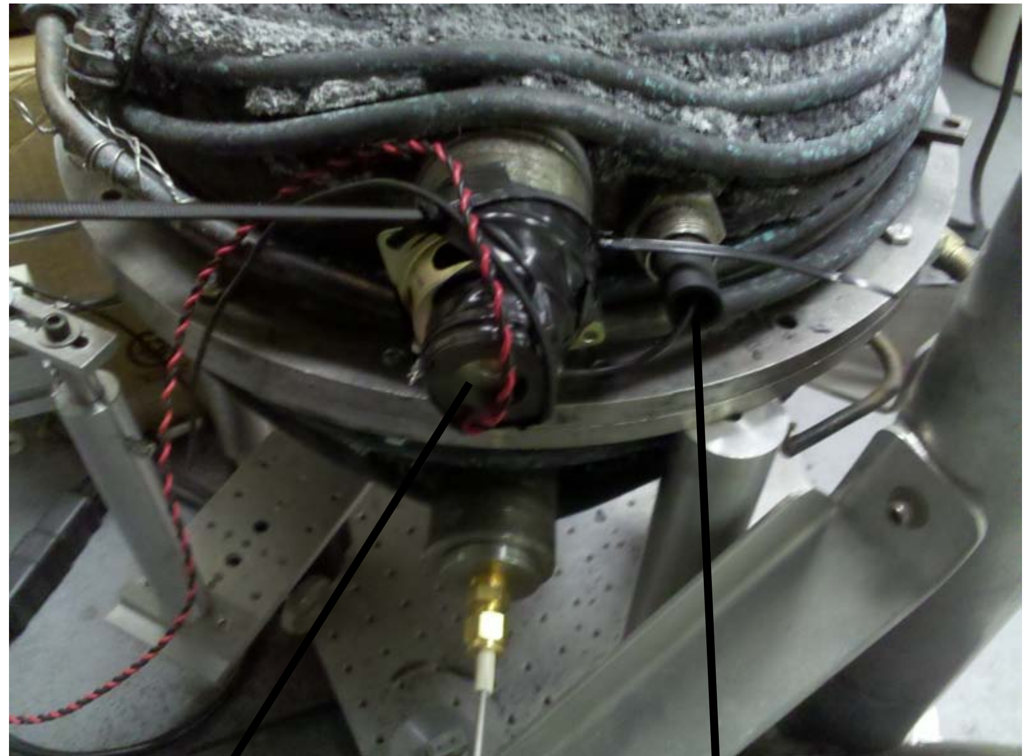



Pressure amplitude, mode (2,2,1)
Pressure amplitude, mode (2,2,2)
Rotational kernel, mode (2,2,1)
Rotational kernel, mode (2,2,2)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0.2 0.4 0.6 0.8
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
3
2.5
2
1.5
1
0.5

30 cm air proof of concept experiment - acoustics easy!



DC motor ~ 5-37Hz: $12000<Re<94000$



TSI Air Velocity Meter

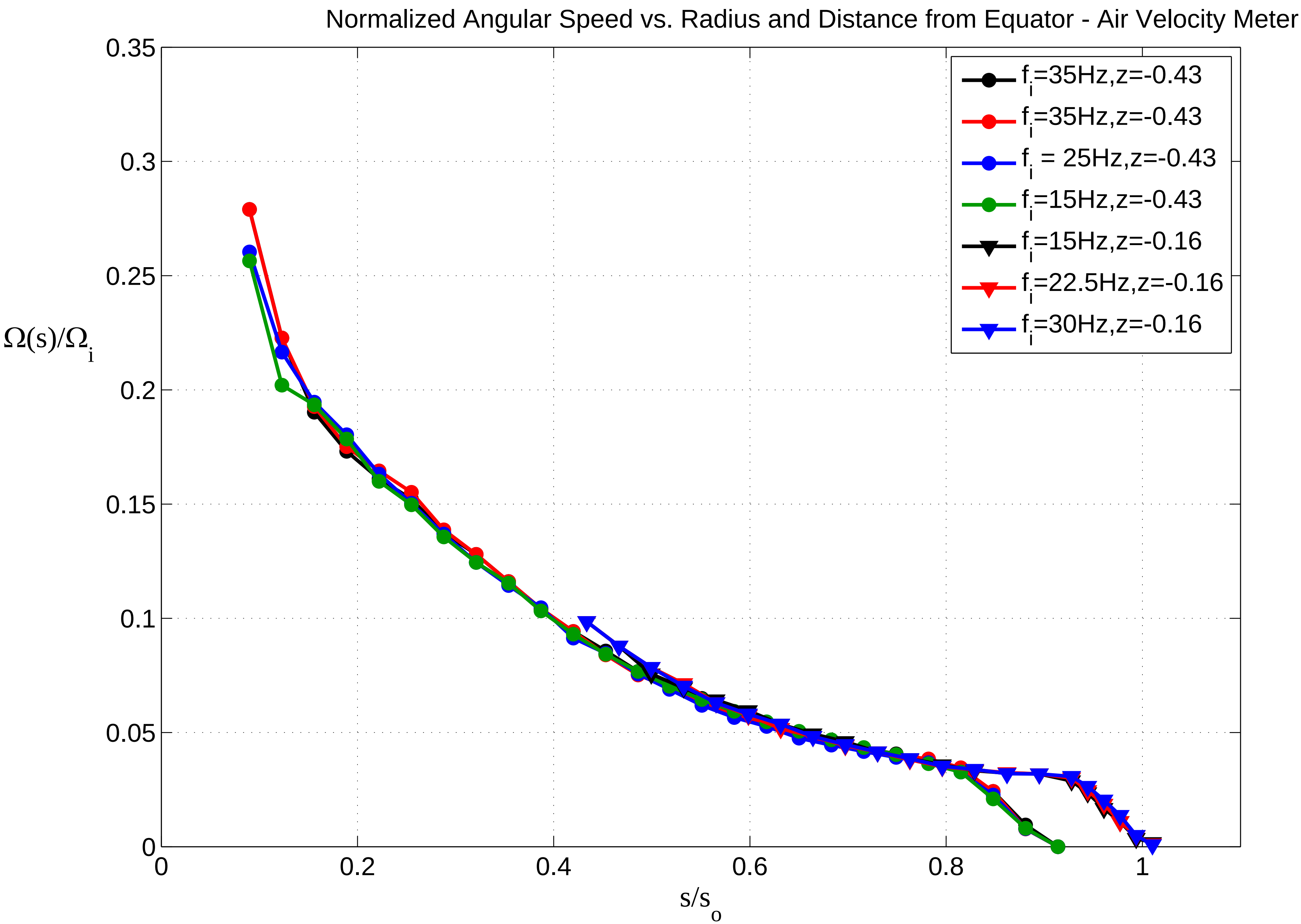
Velocity Probe on Transit
~2.5cm down from equator
moves in cylindrical radius

30cm spherical
couette $\eta = 0.33$

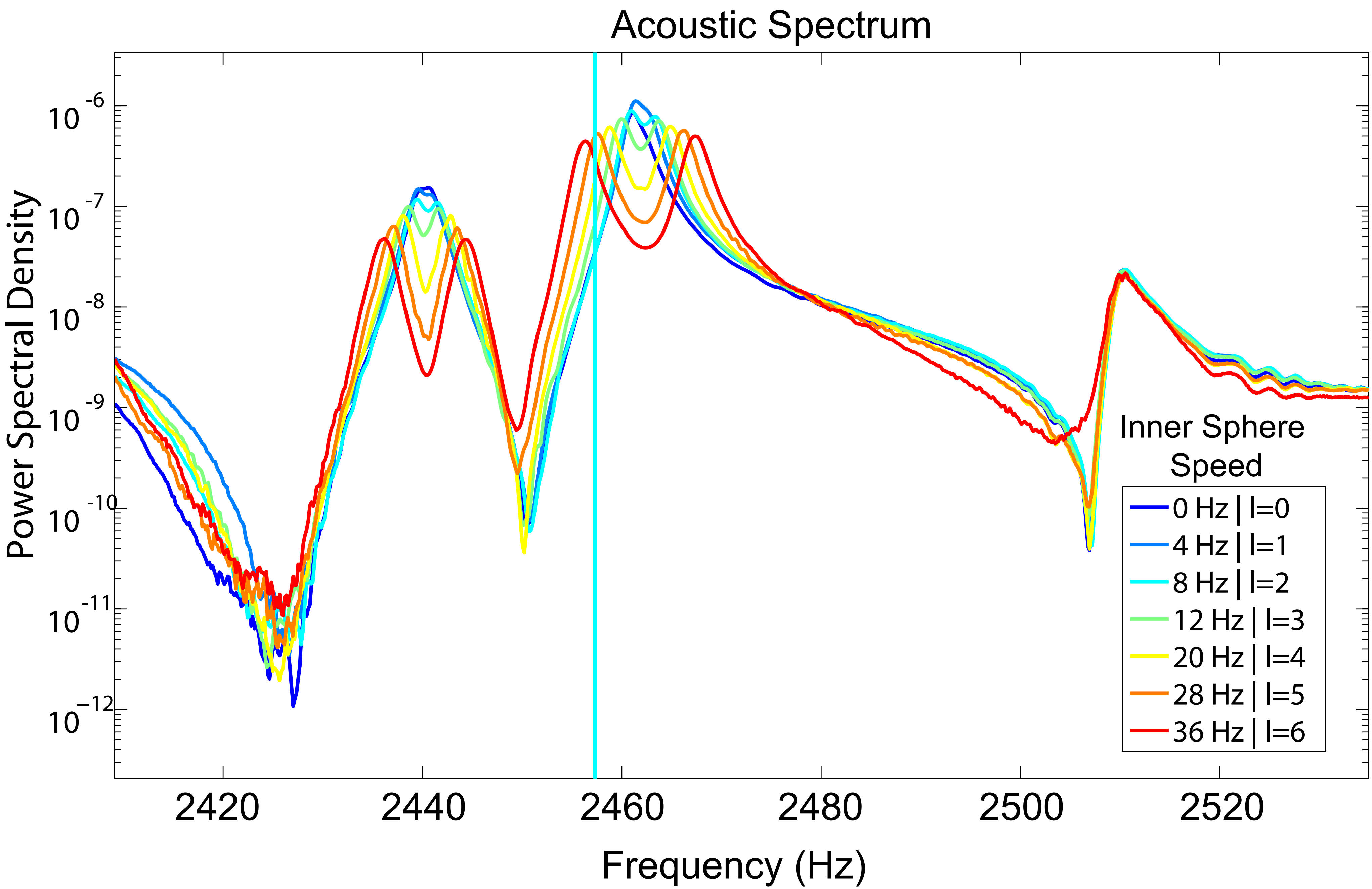
Speaker driven with
10kHz band limited
white noise.

Electret microphone

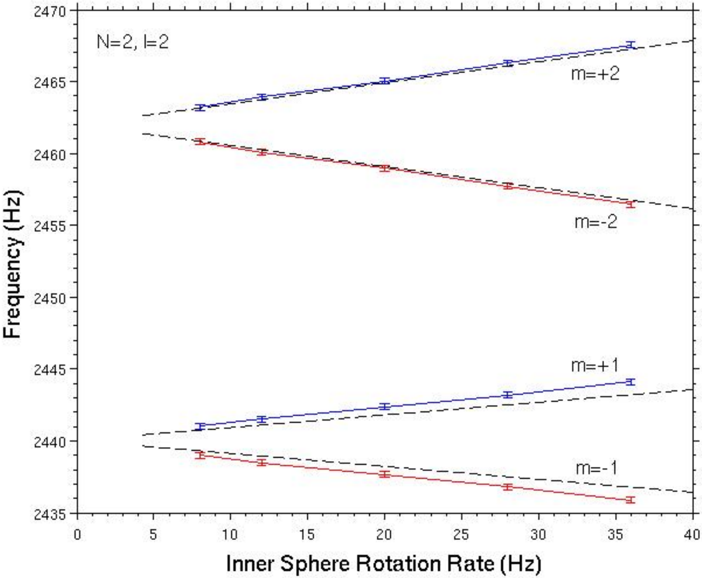
Very lucky find
hidden in an
old box:


Normalized Angular Speed vs. Radius and Distance from Equator - Air Velocity Meter
$\Omega(s)/\Omega_i$
s/s_o
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.2
0.4
0.6
0.8
1
f_i=35Hz,z=-0.43
f_i=35Hz,z=-0.43
f_i = 25Hz,z=-0.43
f_i=15Hz,z=-0.43
f_i=15Hz,z=-0.16
f_i=22.5Hz,z=-0.16
f_i=30Hz,z=-0.16

“Helioseismology”



Forward problem, splitting is linear with rotation



“Helioseismology” To-Do

-Need to do the *inverse* problem: that’s the useful part.

- -Infer rotation profile from frequency shifts, see if it’s right.

-We have microphones but need a sodium speaker!

-Some promise in “asteroseismology” of distant stars.

- -Instead of full disk measurements, just a point.
- -Inertial modes may be useful here too.
- -Santiago Triana turning into an astronomer (hopefully)