NG43B-1492: Angular Momentum Transport in Turbulent Spherical Couette Flow

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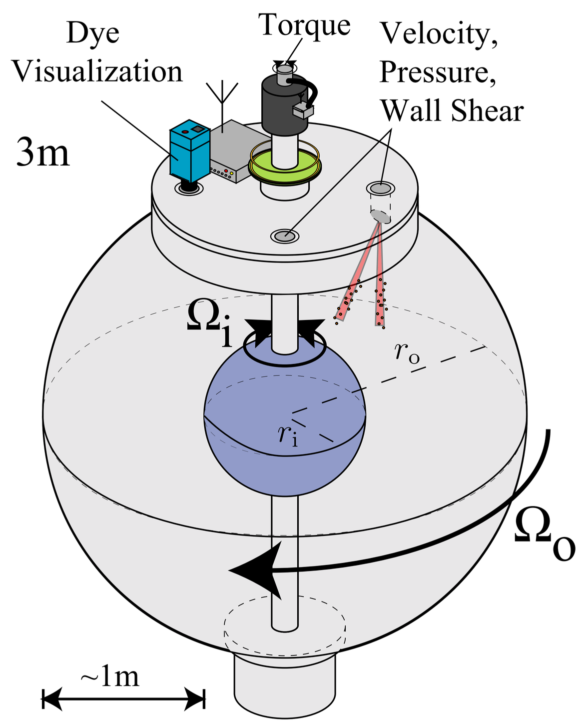
Three Meter Experiment & Parameters



YouTube Spin Test

$$\ell = r_o - r_i$$

$$\eta = \frac{r_i}{r_o} = 0.35$$

Ekman Number

$$E = \frac{\nu}{\Omega_o \ell^2}$$

$$9\times10^{-8} < E < 5\times10^{-6}$$

Rossby Number

$$Ro = \frac{\Omega_i - \Omega_o}{\Omega_o}$$

$$-5 < Ro < 100$$

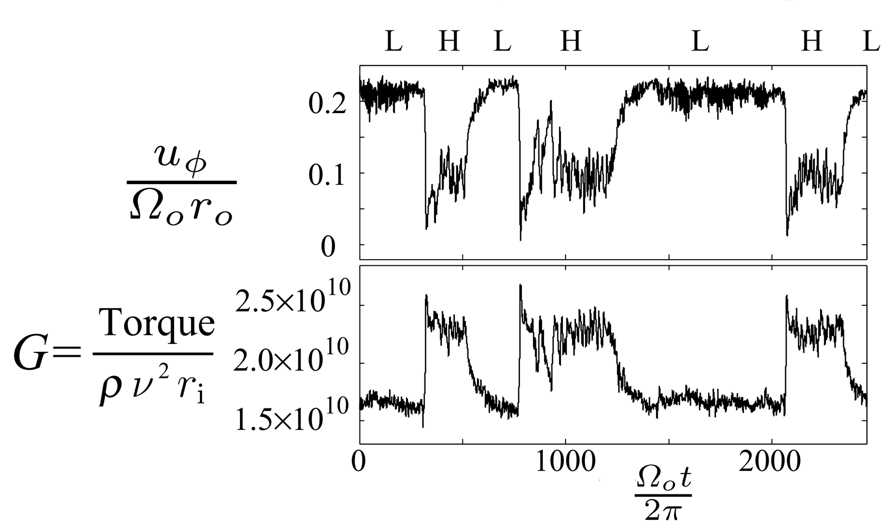
Reynolds Number

$$Re = \frac{Ro}{E} = \frac{(\Omega_i - \Omega_o)\ell^2}{\nu}$$

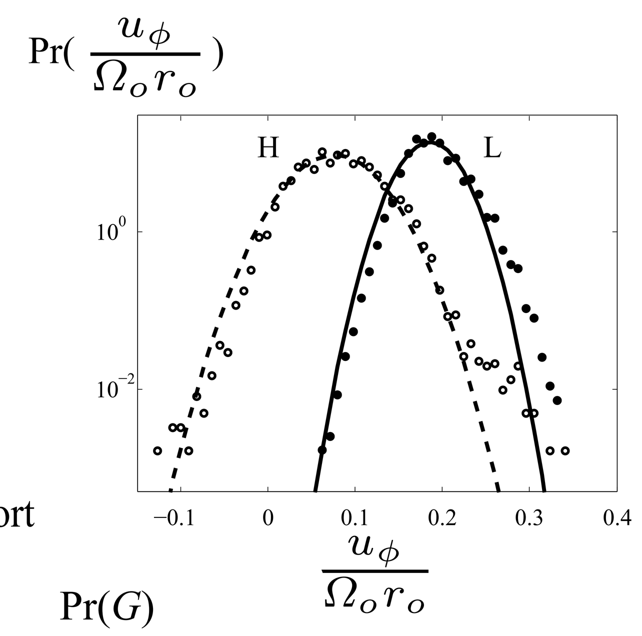
$$2.5\times10^5 < Re < 5\times10^7$$

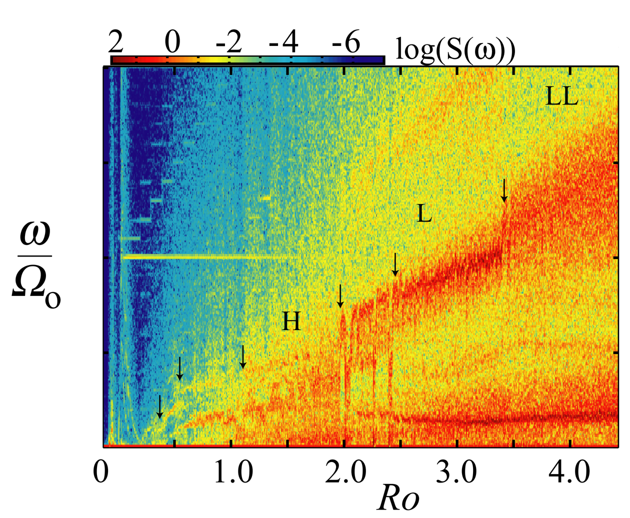
The experiment is an approximately 2.92m diameter spherical tank of water mounted on bearings with an independently rotating 1.02m diameter inner sphere. Maximum possible rotation rates are 4Hz for the outer sphere and about 12Hz for the inner sphere, driven by a pair of 250kW electric motors with variable frequency drives. The torques on the boundaries provide a global measurement of angular momentum flux Four ports in the lid allow measurements of pressure and wall shear stress 60cm distant from the axis and ultrasound velocimetry is possible 10-30cm from these ports.

Turbulent Multiple Stability

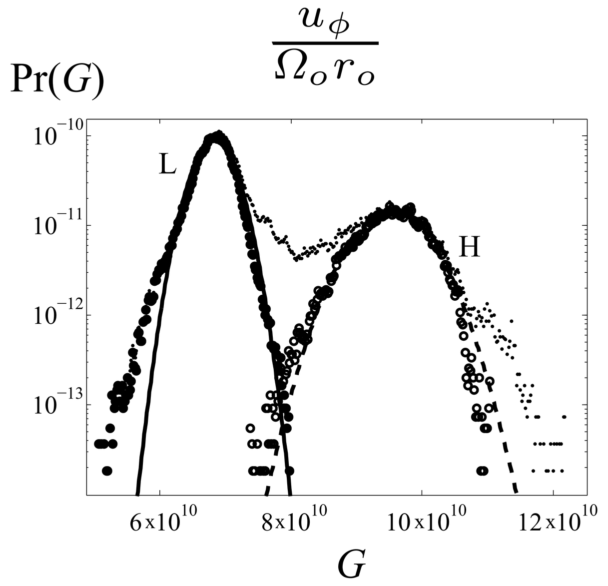


Time series of azimuthal velocity near port (top) and inner sphere torque (bottom) Ro = 2.33 E = 5e-7.





Pressure power spectral density vs. *Ro*, *E* = 1.6e-7 showing changes in large scale wave motions.

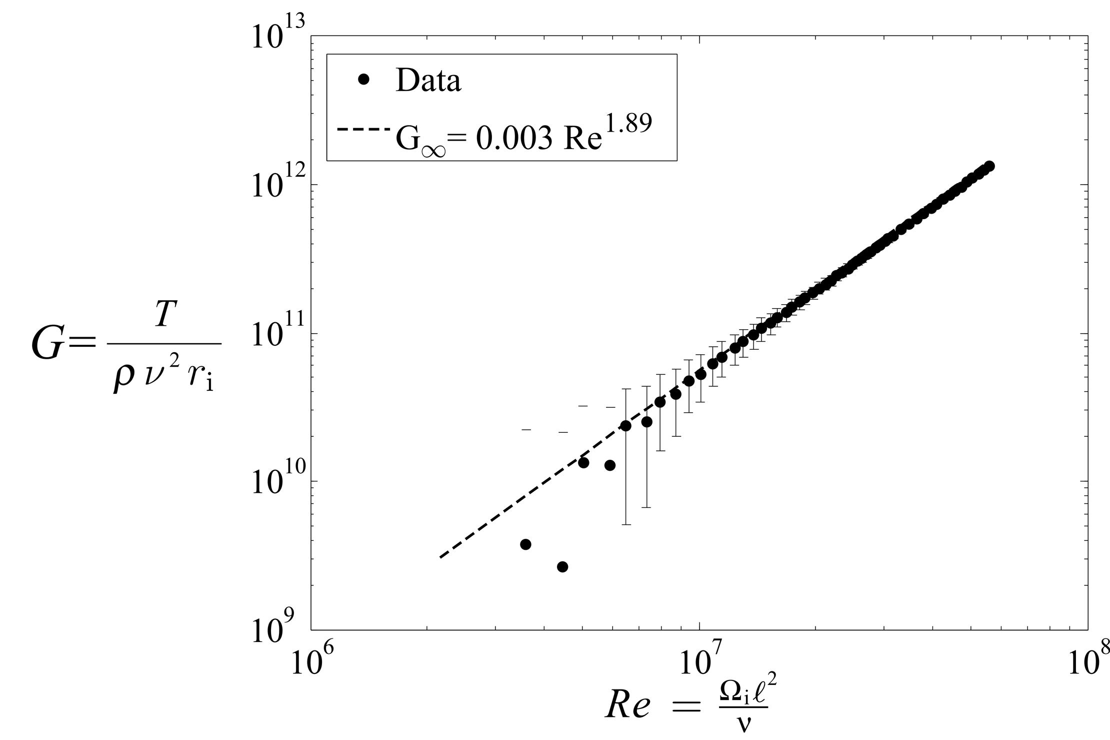


Bimodal probability distributions of azimuthal velocity (top) and torque (bottom) *Ro* = 2.13, *E* = 2.1e-7

As the Rossby number *Ro* is varied, we observe many different turbulent flow states that are characterized by different torque demand and mean velocity profiles, and different large scale (m=1 and m=2 for *Ro*>2) coherent wave motions. In certain ranges of *Ro* the flow undergoes spontaneous transitions between adjacent states, leading to the bimodal distributions of torque and azimuthal velocity velocity shown on the right. One transition is analyzed in detail here:

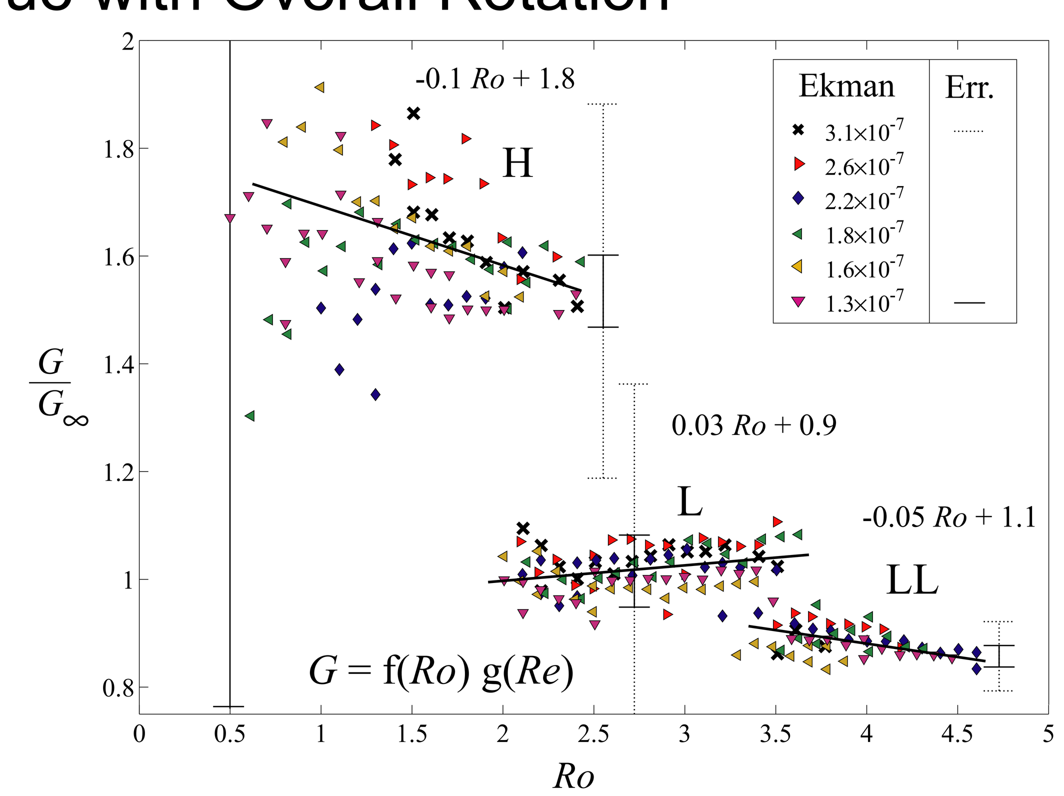
Phys. Fluids **23**, 065104 (2011) arxiv.org/abs/1107.5082

Torque with Outer Stationary



The torque with the outer sphere stationary depends on Reynolds number in a way that is typical of turbulent drag, torque nearly proportional to the square of Reynolds number. We use the fit to this data to normalize the torque when the outer sphere revolves as well.

Torque with Overall Rotation

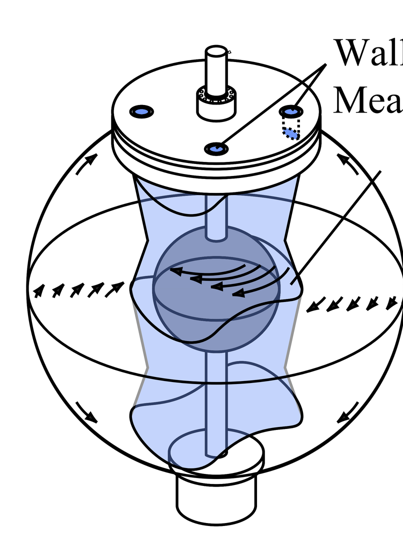


More information: Ph.D. Thesis complex.umd.edu/papers /zimmerman_thesis.pdf

Taylor-Couette: Paoletti and Lathrop (2011) arxiv.org/abs/1011.3475

Normalizing measured torque by the torque predicted same Reynolds number without rotation nearly collapses the torque data for all measured parameters. Here the torque has been conditioned on flow state in those ranges of *Ro* where the torque is bimodal. The large scatter at low Rossby number is likely due to shaft seal drag dominating the torque. The implication of the collapse presented here is that the angular momentum transport factorizes, with a Rossby dependent prefactor unique to the geometry and a typical turbulent scaling with *Re*. The same behavior with a different Rossby dependence has been observed in Taylor-Couette flow, see: Paoletti and Lathrop, Phys. Rev. Lett. , **106** 024501a (2011) and van Gils et al., Phys. Rev. Lett. **106**, 024502 (2011).

Angular Momentum Transport Barrier?



Wall shear & Velocity Measurement Location

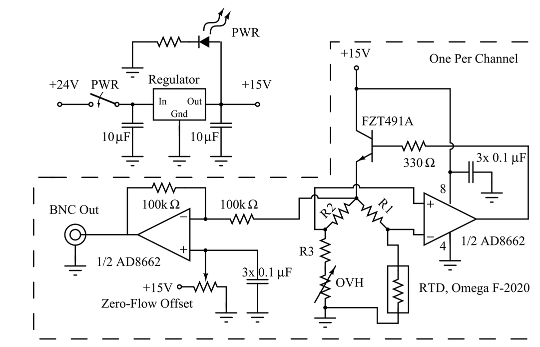
Fast zonal transport barrier with waves?

Dye Movie QR Links *Ro* = 2.33

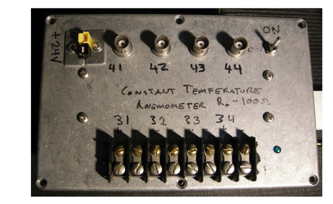
High Torque Low Torque

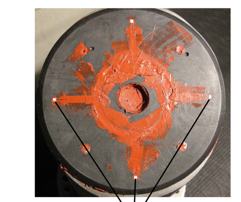
The data for the H/L state transition are consistent with the formation of an angular momentum transport barrier near the inner sphere. Fast fluid trapped at, above, and below the inner sphere lowers the drag. The further transitions may be related to intensification of the transport barrier. Dye visualization along with the torque and measurements far above the inner sphere corroborates faster flow at all vertical distances above the inner sphere in the L state, strongly reduced in the H state, but global velocimetry is needed to measure angular velocity profiles.

Shear Stress Concentration - Transport Inhomogeneity



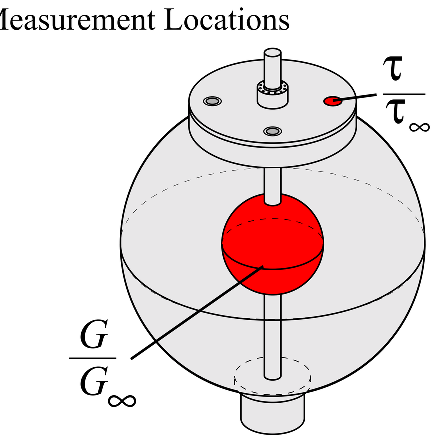
Low Cost CTA Schematic

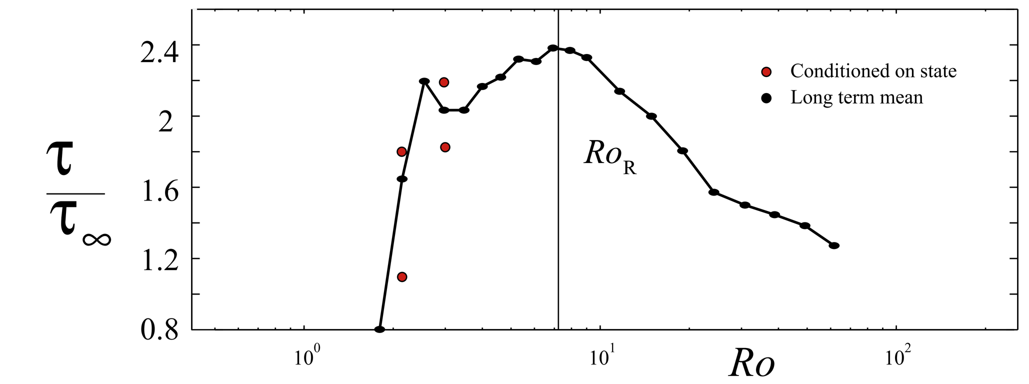


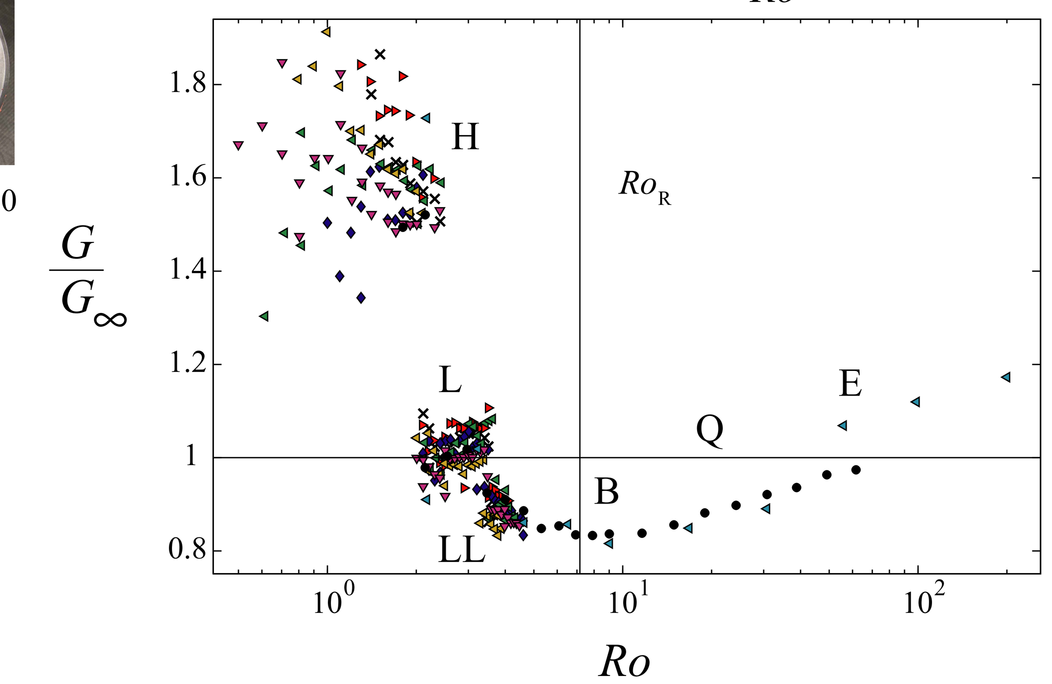


Omega F-2020 RTD Array

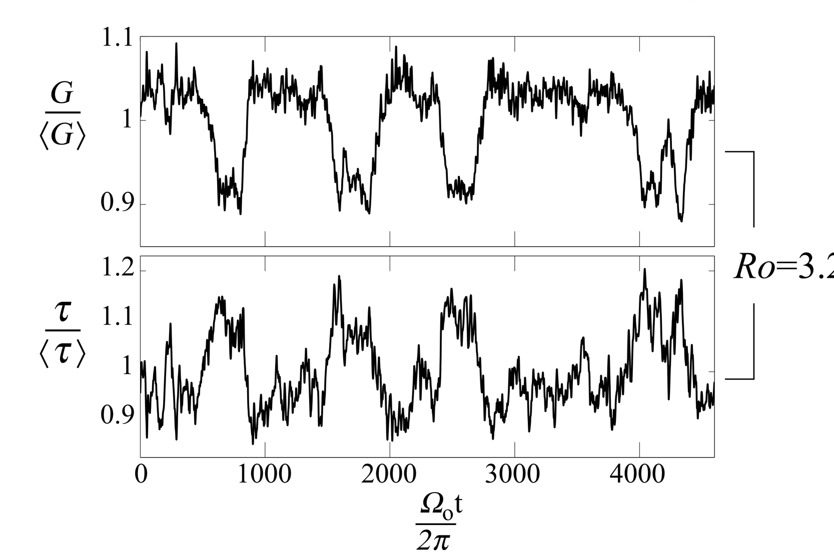
Measurement Locations

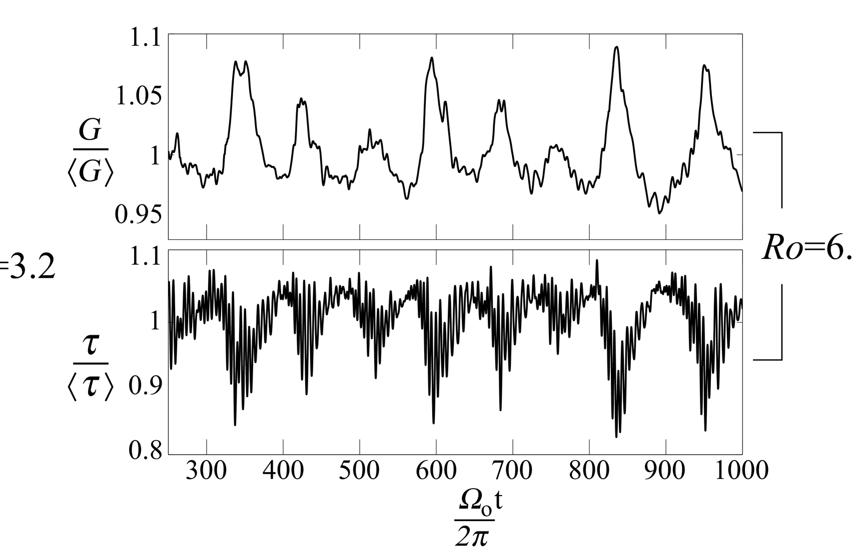






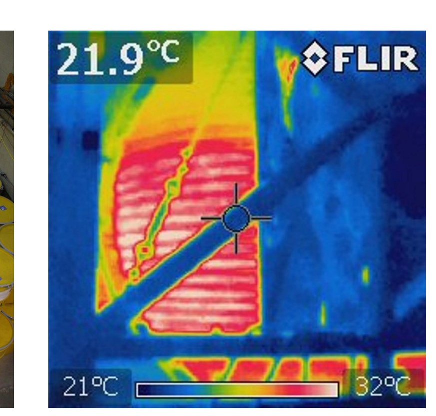
We make measurements of the wall shear stress 60cm from the axis using a homemade constant temperature anemometry system with low cost RTD sensors. Using the wall shear stress in-situ calibration, we normalize the wall shear stress by that expected at the same Reynolds number with the outer sphere stationary. The normalized wall shear stress peaks at the same *Ro* where the normalized torque is minimized.





The same anti-correlation between the long term mean wall shear stress on the outer sphere and the torque on the inner sphere is observed in shorter term fluctuations in those quantities at transition Rossby numbers, two of which are shown here. Torque (top) and wall shear stress (bottom) are normalized by their mean values. In all cases, the lower torque is concurrent with higher shear stress, implying a different pattern of wall shear stress on the outer sphere as *Ro* is varied. At about Ro = 7, there seems to be a peak in “upward” transport of angular momentum but an overall reduction in transport.

Future Work - Hydromagnetic Experiments



YouTube Sodium Fill Time Lapse

The hydrodynamic phase of this experiment using water has finished as we work to prepare for experiments with liquid sodium metal. As of this meeting the experiment is 73% full of sodium and we await shipment of the remaining material. Above left are the original drums that we have used, in the center is a thermal image of the sphere 66% full of warm sodium, and on the right is a drum with heaters and insulating mantle. We will recieve the remaining sodium this month and hope that the three meter experiment will soon show self-excited dynamo action in a laboratory experiment geometrically similar to Earth’s core.