Turntable GFD Experiments

Explore Your Universe 11/12/2011
Prof. Jon Aurnou

All Planets and Stars Rotate!

Cassini image

J. Aubert 2008

19nm EIT SOHO
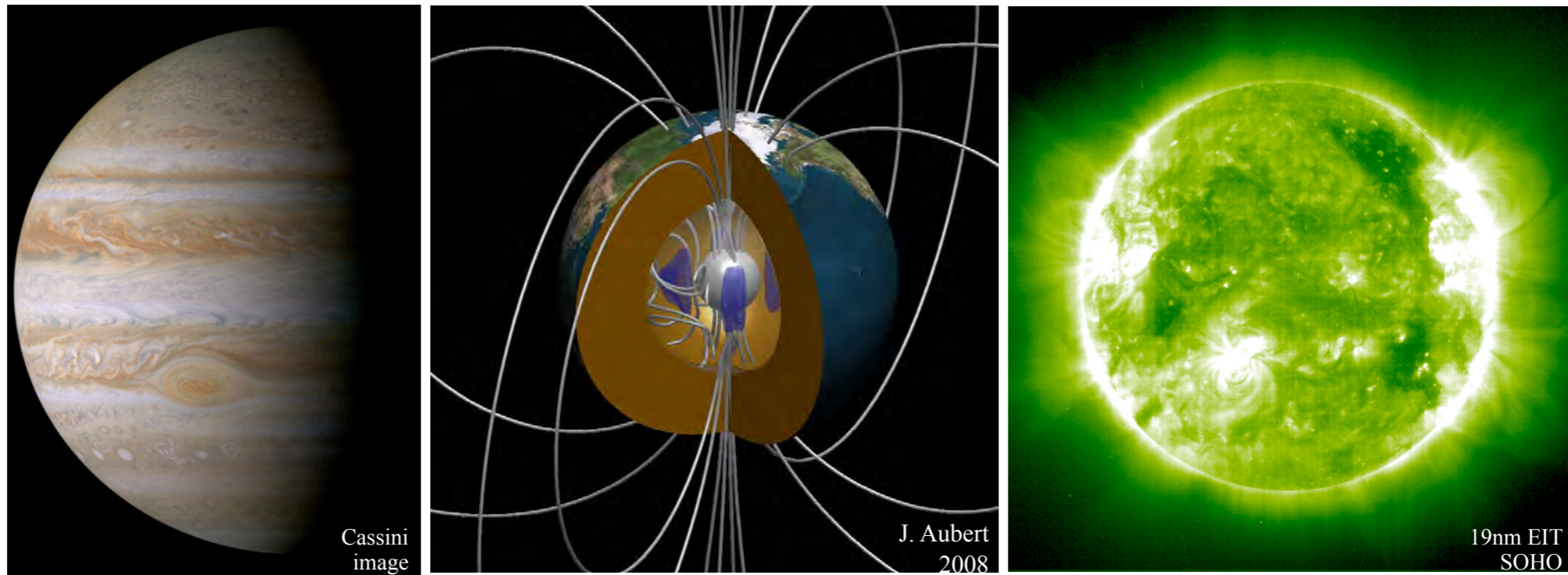
- Atmospheric circulations and magnetic fields are due to fluid dynamical processes on rotating planets and stars
- **Goal**: Understand basic interplay between rotation and fluid motions

Possible Experiments EYU 2011

1. The Spiraling Dye Curtain

2. Spinning Up to a Parabolic Free Surface

3. Creamer Plumes in Rotating and Non-Rotating Systems

4. Evaporative Convection in Rotating and Non-Rotating Systems

5. Formation of "Taylor Columns"
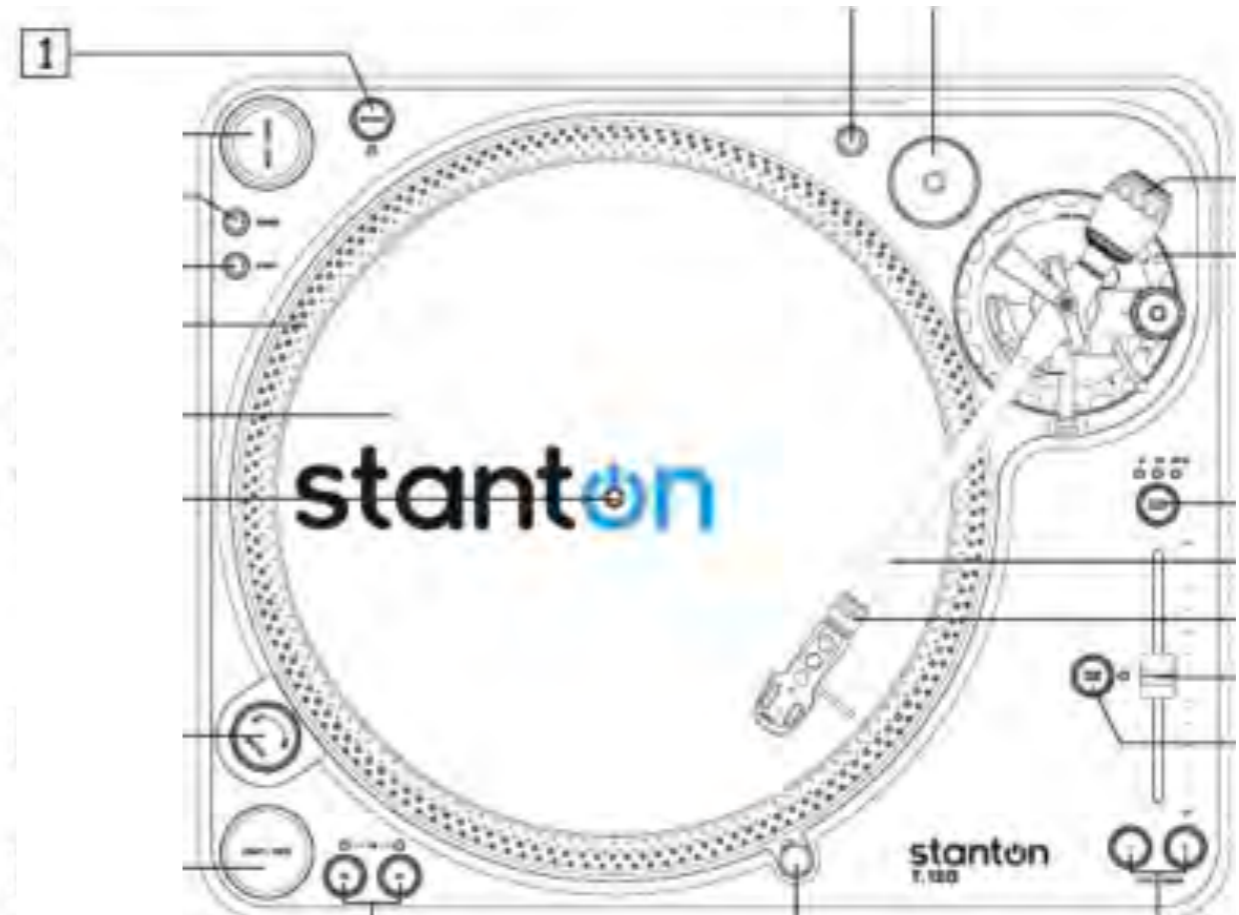
6. Building a Jovian-Like Vortex

Base State

1. **Set all turntables to rotate CCW**

   1. e.g., hit reverse button, denoted by #1, on the Stanton turntables
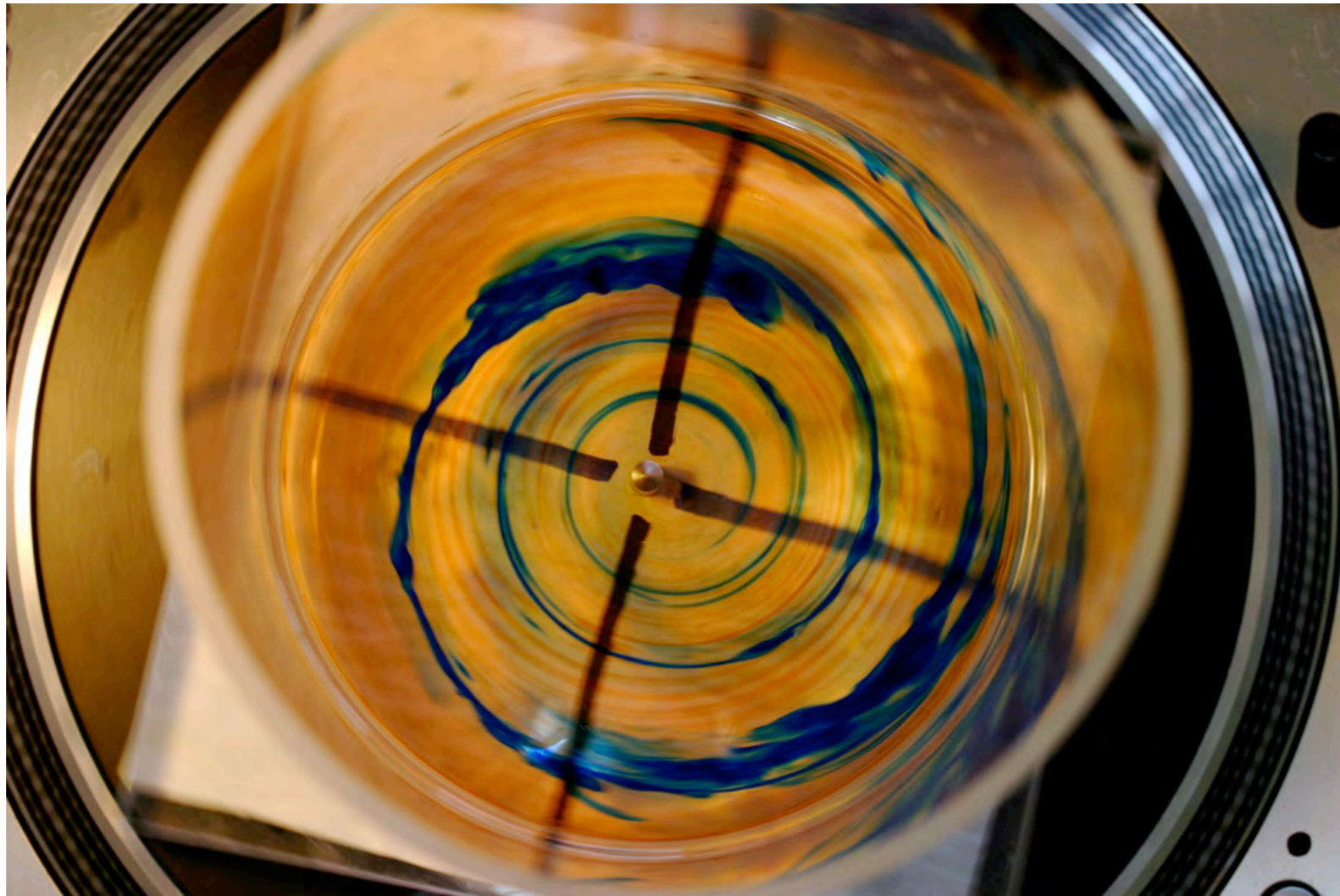
2. **WHY?**

   1. Because left-handed systems seem upside down at best, that is why.

Spin Up 1: Spiralling Dye Curtain

1. Start spinning a tank of 5 - 10 cm deep water, at 16 - 33 rpm.

    1. Spin up should complete in a few minutes (~ 3 - 5).

2. After only 1 minute or so, drop in a blob or, if possible, a radial sheet of dye (~0.25 - 0.5 mL dye volume).

Typical Top View

Spin Up 1: Spiralling Dye Curtain

3. Dye will get sheared out because fluid near the tank sidewall has been spun up by being centrifuged through the bottom boundary layer (the Ekman boundary layer, EBL). The fluid in the top-middle of the tank is centrifuged last, as it gets slowly sucked down into the EBL. So it is rotating slower then the outer fluid.
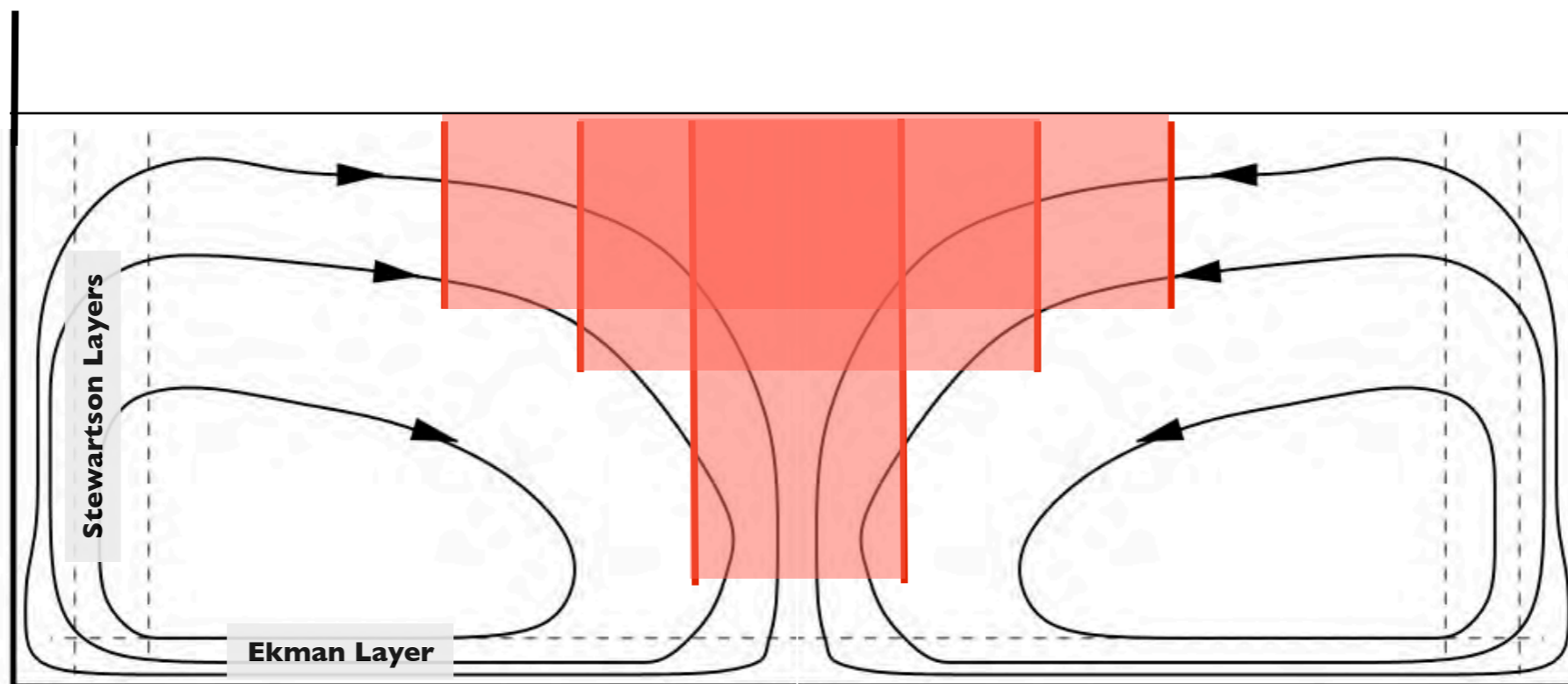
Figure 1 Schematic of meridional-plane streamlines for homogenous spin-up. ~~The left hand boundary is the container centerline.~~ The dashed lines indicate Ekman layers and sidewall Stewartson layers, all of which transport mass.

Adapted from Duck and Foster, ARFM 2001

Spin Up 1: Spiralling Dye Curtain

4. End result: Spin up shears out the dye patch into a clockwise spiral (viewing down onto the right-handed rotation axis). The dye is also stretched down in the tank center and is pushed up at the periphery by the meridional circulation.

Reflection off parabolic free surface

**Mediocre
Side View
Image**
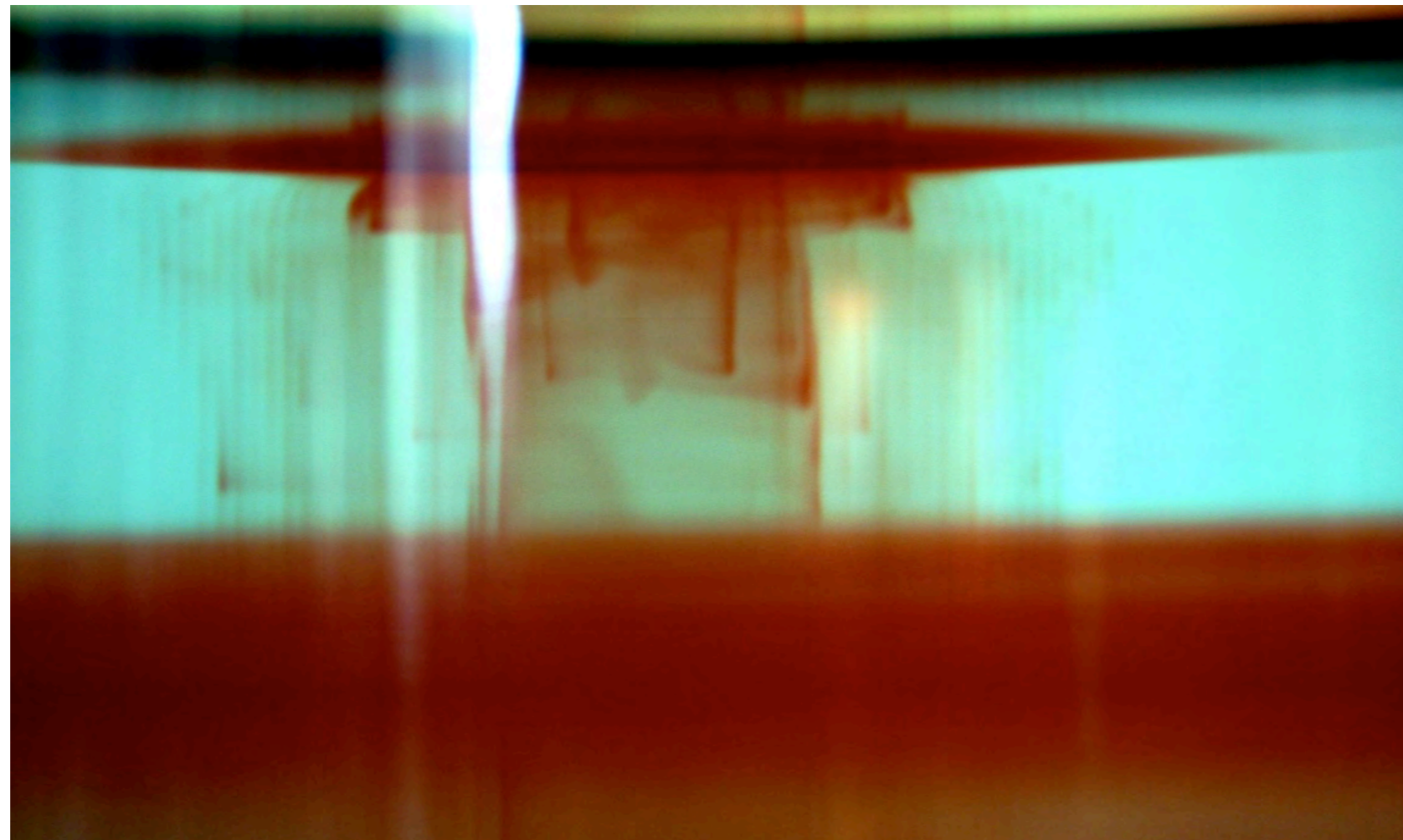
Spun-up dyed
fluid in
Stewartson Layer
(i.e. coating the
sidewall)

Spin Up 2: Parabolic Free Surface

1. Spin up tank of 5 - 10 cm deep water from rest to anywhere from 45 - 100 rpm

    1. Don't centrifuge the water out of the tank, so no short tanks for this

2. RESULT: Rotate a tank of water: Initially flat surface gets centrifuged into parabola

3. *IMPLICATION: Rotate a planet or star: Initially spherical body gets centrifuged as well, forming oblate spheroid with equatorial bulge (e.g., Saturn!).*

Side View at ~60rpm;

Parabolic surface shape is distorted here by cylindrical tank surface;

Far easier to see in the lab.
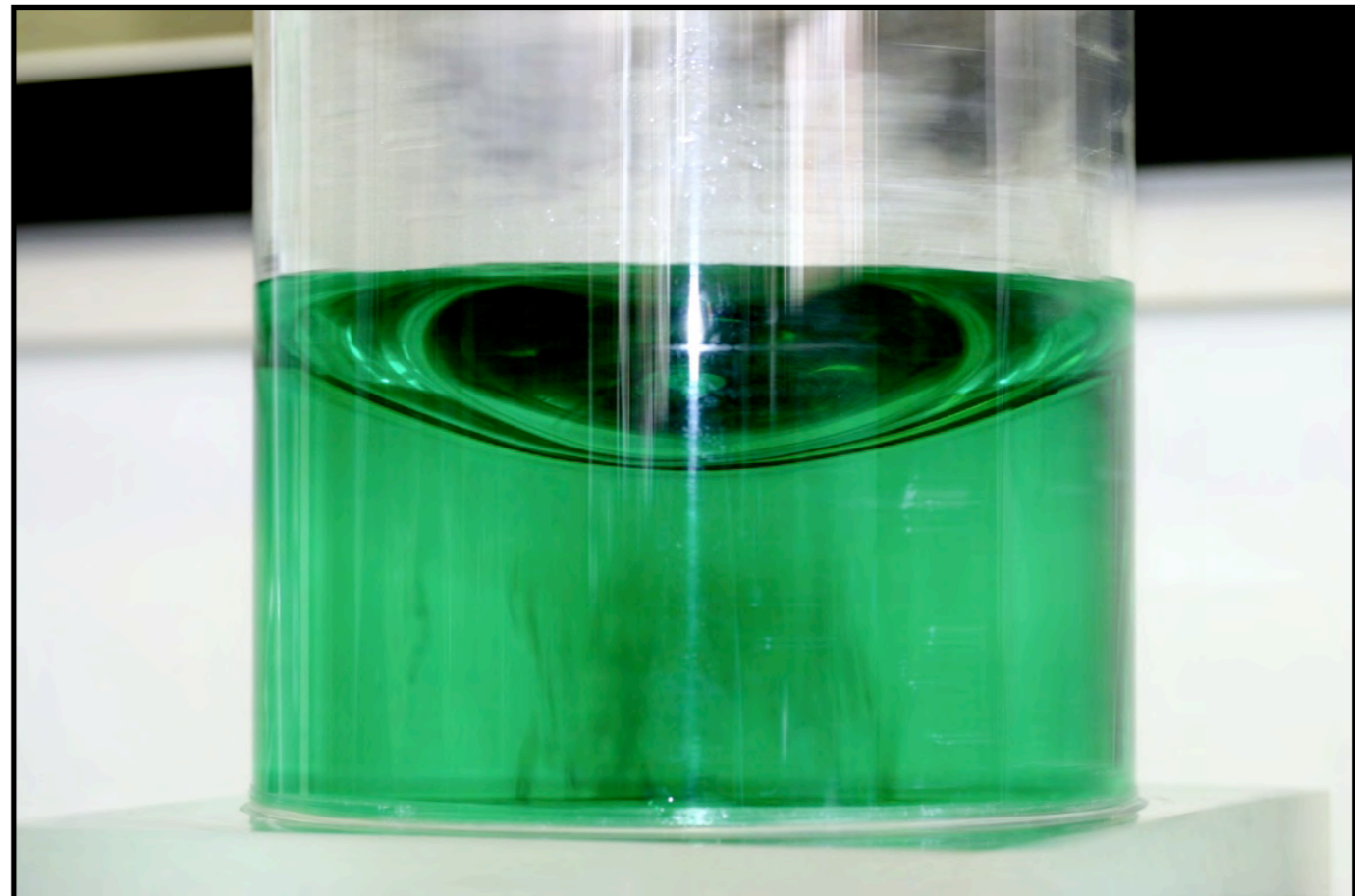
Gyroscopic Flow 1: Creamer Plumes

1. NON-ROTATING DYNAMICS
   1. Solids: Release non-rotating top and observe.
   2. Fluids: Drop 1/2 n 1/2 packet into non-rotating tank filled with 10 - 30 cm depth and observe
2. ROTATING DYNAMICS
   1. Solids: Spin a top and observe.
   2. Fluids: drop 1/2 n 1/2 into spun up tank of fluid (10 - 20 cm depth) and observe
      1. Compare response at 16 rpm vs. 45 rpm
   2. *Axially-alignment: relevant to patterns of planetary flows and magnetic fields*
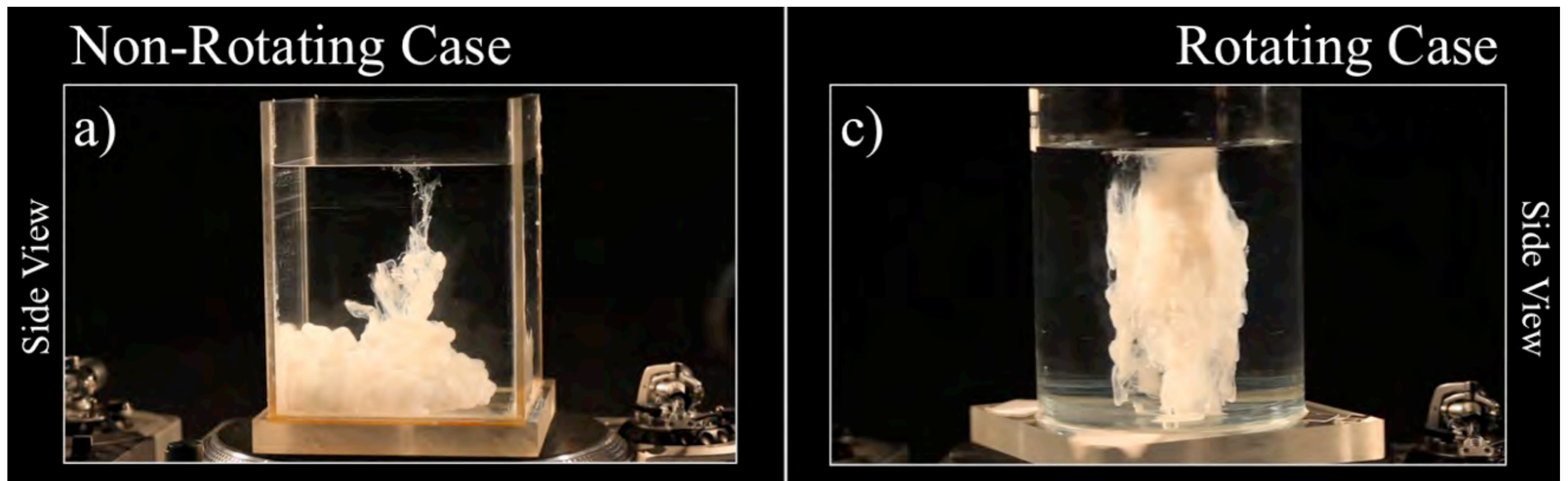
**See vimeo.com/29120537 about minute 15 or so**

Gyro. Flow 2: Columnar Convection

1. Fill bucket with warm to hot (but not scalding!) tap water.

2. Fill two tanks each to ~5, 10, 20 cm deep

3. Start one tank rotating at 16, 33 or even 45 rpm. Then wait ~ a spin-up time

4. Spray in fine dye patches (2 colors) with spray bottles

5. Note massive difference in scales, patterns, organization (e.g., symmetry properties) of flow field, etc.

6. *Alignment of motions in planetary cores argued to explain why compasses work: magnet field generated by flow structures that tends to line up along rotation axis. So field lines up along rotation axis as well.*

Typical Rotating Convection Top View
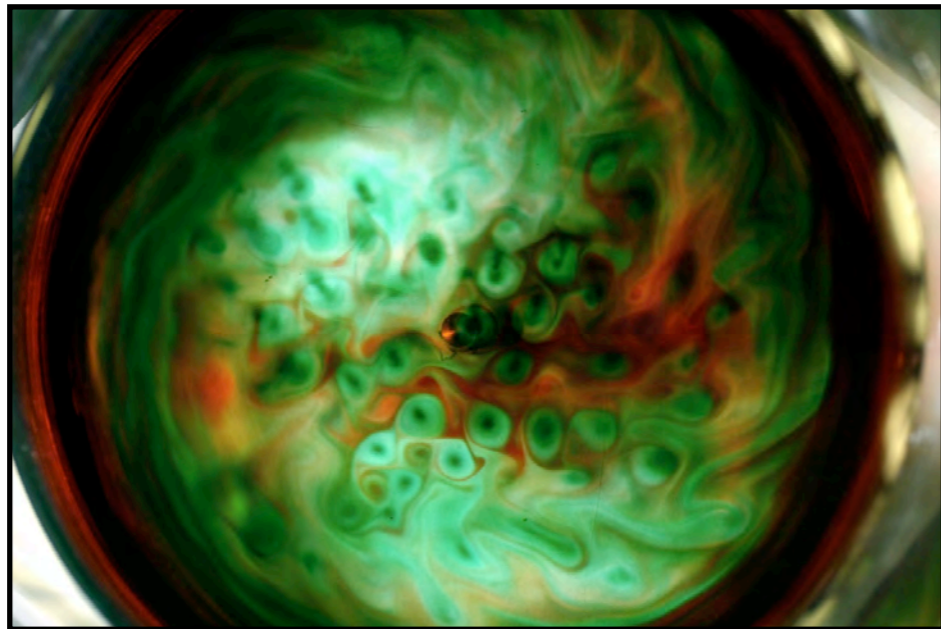
Typical Rotating Convection Side View
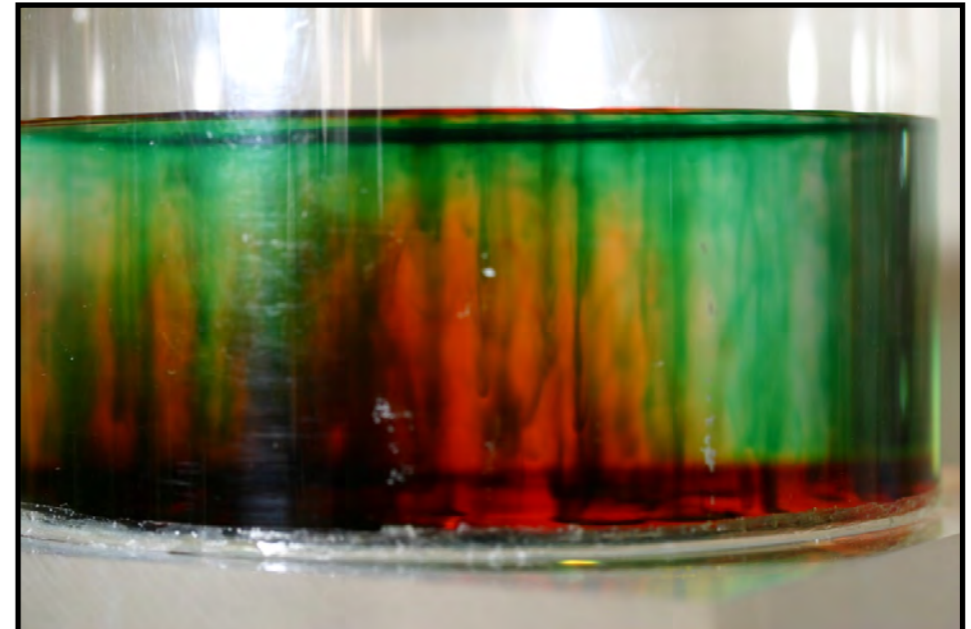
Gyro. Flow 2: Columnar Convection

1. If all that works, you can try 16 vs. 33 vs. 45 rpm. Convection columns should get (slightly) narrower with rotation rate; Column diameter D ~ (Ekman number)^1/3 ~ (Angular rotation rate)^-1/3

2. If that works, you can try different fluid layer heights, H, at fixed rpm. Column diameter D ~ (Ekman number)^1/3 ~ H^-2/3. You might try 5 cm vs. 20 or 30 cm (in one of the new taller tanks John C just made).

Close-up Top View of Rotating Convection
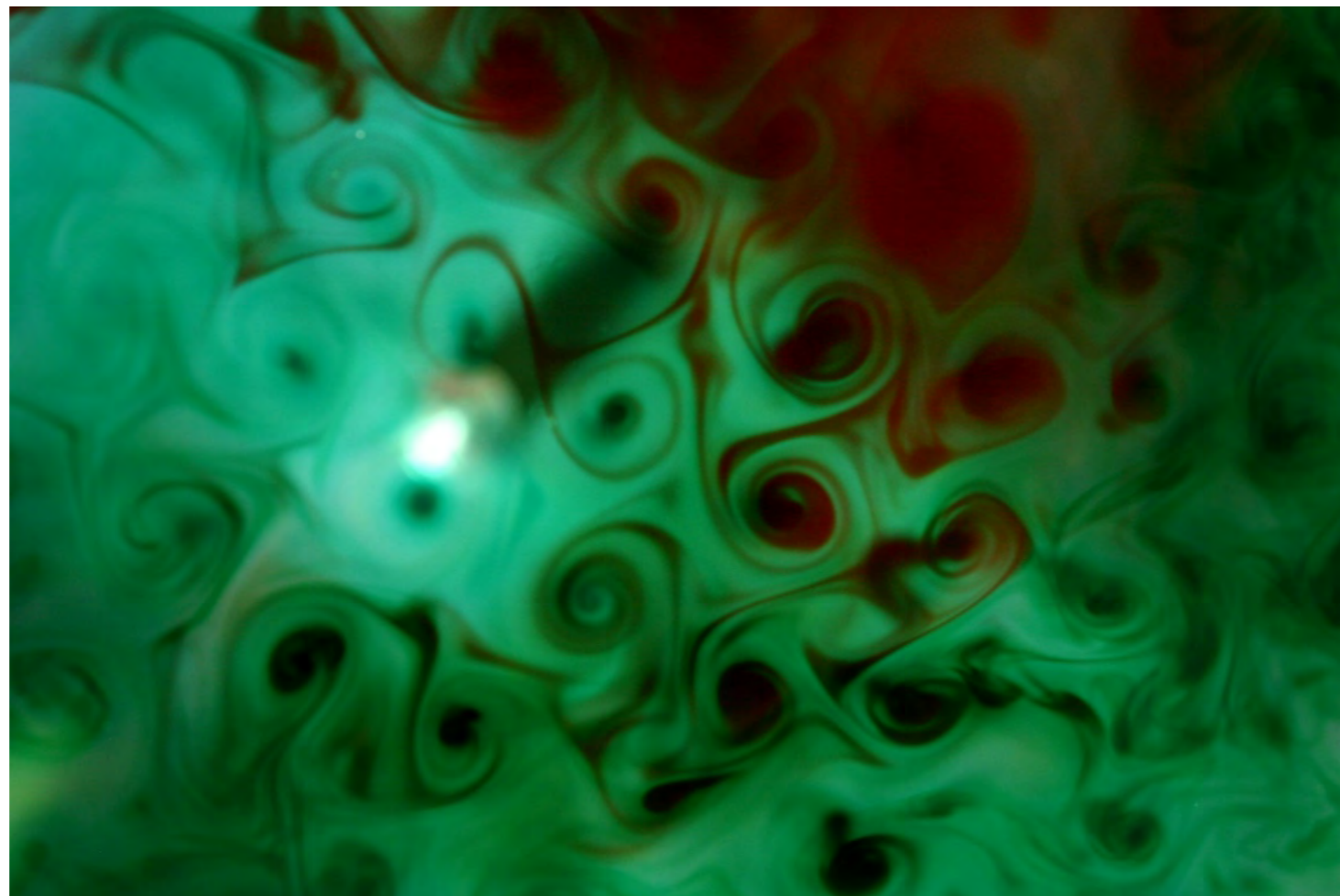
Gyroscopic Flow 3: Taylor Columns

I. NON-ROTATING DYNAMICS

1. Grease obstacle onto bottom of 5-10 cm deep tank of water

2. Inject two food coloring patches "upstream" of obstacle (white paper bottom, white background if possible; external light source on stand helps too)

3. let dye plume reach bottom of tank (note 3D flow; estimate Re)

4. Slowly rotate turntable so that obstacle slowly rotates through dye patch; observe massive 3D mixing

I. ROTATING DYNAMICS

1. Grease obstacle onto bottom of 5-10 cm deep tank of water

2. Spin up fluid at 16 - 33 rpm

3. Inject two food coloring patches "upstream" of obstacle

4. Let dye plume just reach bottom of tank (note quasi-2D flow)

5. Form "Taylor column" by changing rotation rate using pitch control (by +/- 5% max)

Gyroscopic Flow 3: Taylor Columns

I. **ROTATING DYNAMICS, Take 2**

1. If above works swimmingly, you might try an "end-member" case.

2. Use one of our new tall tanks (~ 40cm high). Put small obstacle on the bottom. Fill up with ~30 - 35cm of water. Spin up at 33 rpm. (This spin up will take a while; at least 15 minutes.) Inject one or two dye patches. Let settle ~1/4 of the way down tank. Now spin up by a few percent (e.g., +2%). Does a Taylor column form around basal obstacle that extends all the way to the dye patch near the surface of the fluid layer? If so, very impressive.

3. I have never tried this before, as we just made these taller tanks to play with. Depending on how well aligned they are with the rotation axis, this experiment will or will not work. If these taller tanks are tipped off vertical by too much, instabilities will likely swamp the system.

Gyroscopic Flow 4: Building a Jovian-Style Vortex

I. NON-ROTATING DYNAMICS

1. Non-rotating tank, 5-10 cm water.

2. Add in three different dye patches, let settle to just hit tank bottom

3. Using spoon or paddle, give fluid one moderate stir

4. Note that fully 3D turbulence = rapid mixing of colors

5. *Vortex forms, but with little internal structure (e.g. dye all mixed), a bit like a massively turbulent hurricane on Earth*

See "Geophysical Vortices" experiments during last five minutes of "Untitled" on vimeo.com/29120537

Gyroscopic Flow 4: Building a Jovian-Style Vortex

I. **ROTATING DYNAMICS**

1. Spun up rotating tank at 16 - 33 rpm, 5 -10 cm of water

2. Add in three different dye patches, let settle to just hit tank bottom

3. Using spoon or paddle, give fluid one moderate stir

4. Initial 3D turbulence quickly gives way to gyroscopic 2D turbulence. Axialized, 2D motions do not stir dye well; instead, stretches horizontally until dye filaments reach chemical diffusive lengthscale

5. Formation of large-scale vortices with fine structure

6. *Gas Giants: Formation of large-scale vortices with filamentary structure as well as some mixing*

Experiments for Future Years

1. Thermal Wind (16 rpm, what density fluid is needed for Ro>1)
2. Baroclinic Instability (Balu experiment)
3. Raymond Hide Rossby Wave Experiment (Shylo a tank bottom)
4. Ekman layer with (K MnO4)
5. Resonant Instability with tilted tank
6. Gallium vortex on hot plate with spinning magnet
7. VitaMixer: Apple-Carrot-Celery Juice Planetary Differentiation experiment
8. **Other experiments?**