

Simulation of Spiral Density Waves with Rotating, Shallow water

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Abstract

We report progress on the creation of an apparatus for simulating galaxy spiral density waves using rotating containers of water. A popular explanation for the spiral arms of galaxies are spiral density waves (the Lin-Shu hypothesis). Here, the arms are density waves which rotate at a global pattern speed which differs from the speed of the gas and stars. It is uncertain what begins or sustains these density enhancements in Galaxies, and it is hoped that our apparatus, "Swirly", may shed light on this. Swirly will simulate the fluid-like stars and gas in a galaxy using a liquid (water). It will reproduce the differential rotation of spiral galaxies by using two concentric vessels with different rotation periods. Using a similar apparatus, Nezlin et al. have succeeded in reproducing multi-armed spiral patterns, presumably due to a centrifugal force instability. Swirly will be used in an advanced undergraduate lab at Ohio Northern University.

Theories and Problems

Theory: Differential rotation theory: since galaxies have a greater angular frequency, Ω , at small radii than large, any extended region of dust or young stars should be sheared into an arm-like segment.

Problem: "the winding problem" - since the universe is 13.7* Gyr old, and a typical rotation period is ~ 200 Myr, galaxies have made ~ 50 revolutions since they formed. All spirals would have many, tight windings. Nearby (old) spirals should have more windings than distant (young) spirals..

T: Stochastic star formation: supernovae of young, massive stars is likely to trigger new star formation in neighboring regions. So star formation regions can spread and be sheared by differential rotation (see above).

P: This can't reproduce grand-design spirals. Works fairly well for flocculent spirals.

* Thanks WMAP!

Theories and Problems (II).

T: Density wave theory (Lin and Shu 1964): the spiral pattern is a quasi-stationary wave (fixed with respect to some rotating frame). A small perturbation can grow into a large wave via gravitational instability.

P:

- 1) It is difficult to measure the fixed pattern speed of the spiral structure, Ω_p .
- 2) What sustains the waves? (damping in 1-2Gyr expected)
- 3) This theory doesn't reproduce flocculent spirals well.

T: Driven density waves: instead of requiring an instability, create the waves with a rotating structure - a bar, or a passing galaxy.

P:

Not all spirals have obvious interacting companions (like M51) and not all spirals have a bar.

Spiral Galaxies

M100 (Sc):
Two-arm, "grand-
design" spiral.



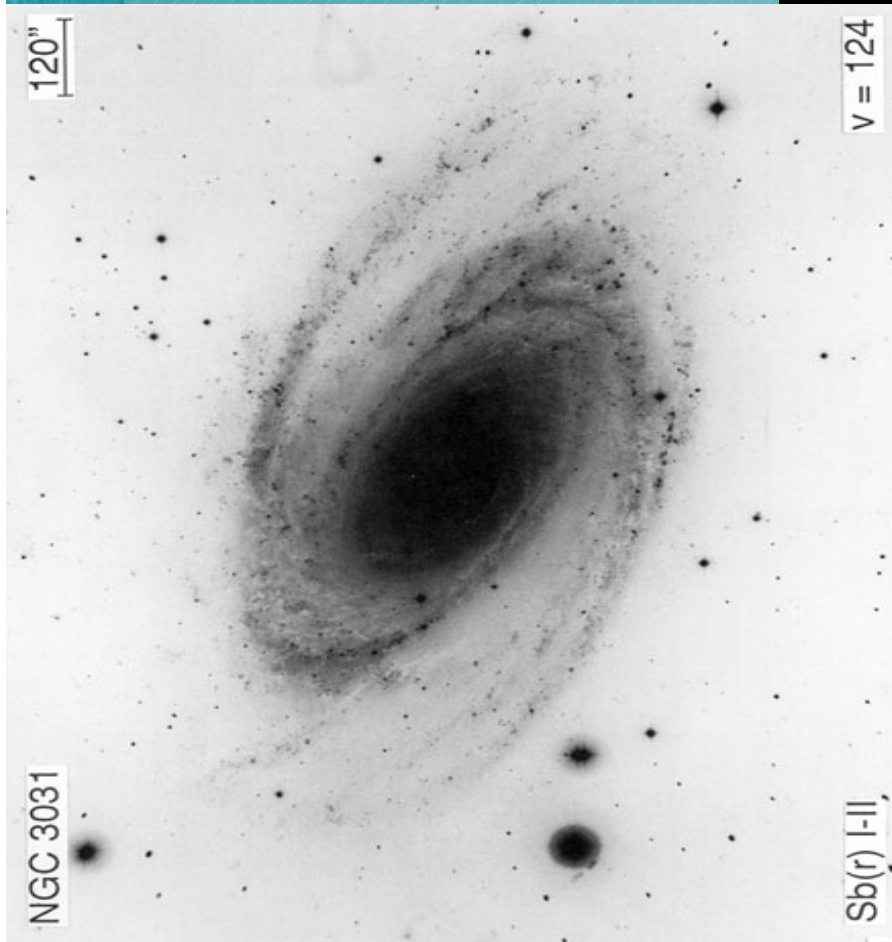
NGC 4565 (Sb): Typical edge-on
spiral galaxy.

Spiral arms reside in disks!

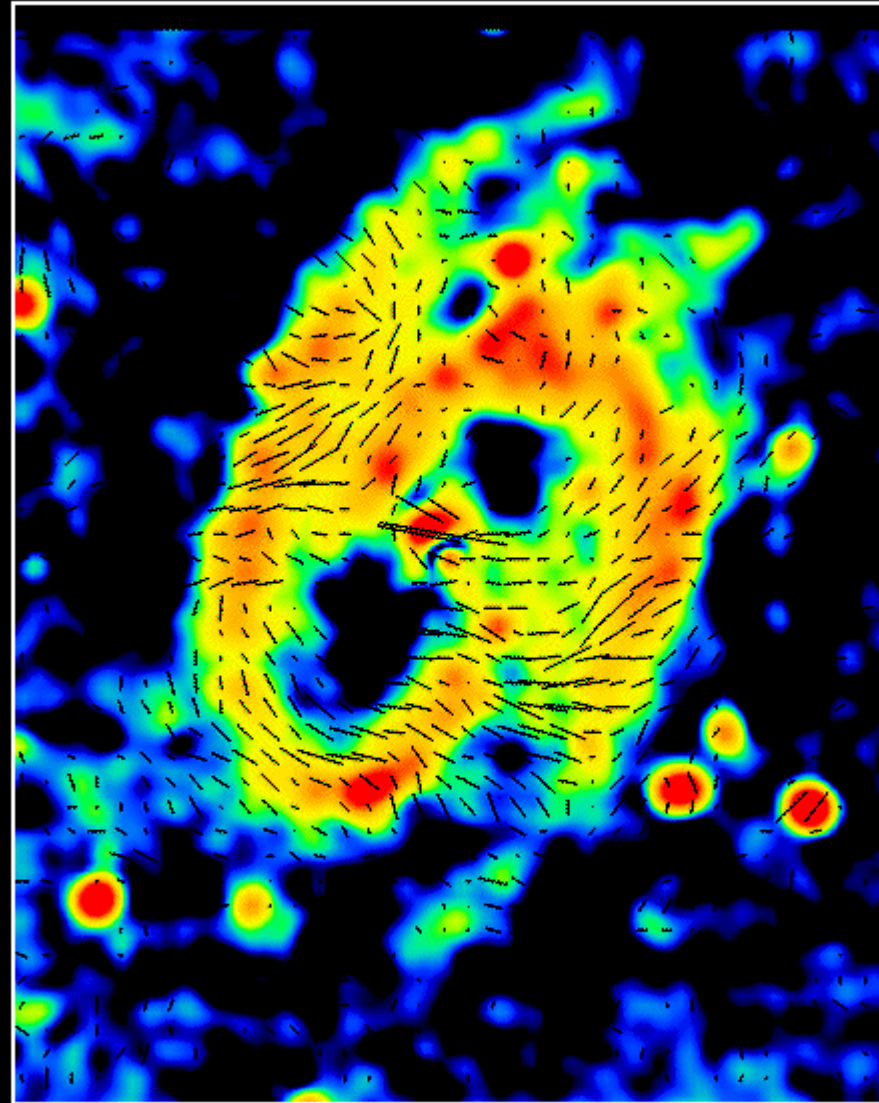
Spirals in stars and gas

Radio (20 cm)

Optical



M81 20cm Total Intensity + (E+90)-Vectors (VLA)



M81(Sb): a two-arm, spiral.

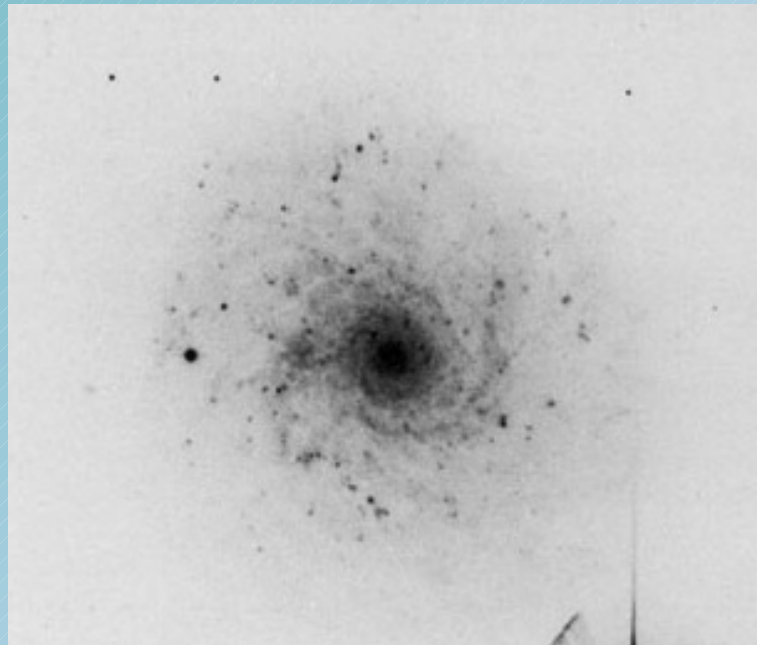
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More Spirals

NGC 1300 (Sb):
barred spiral.

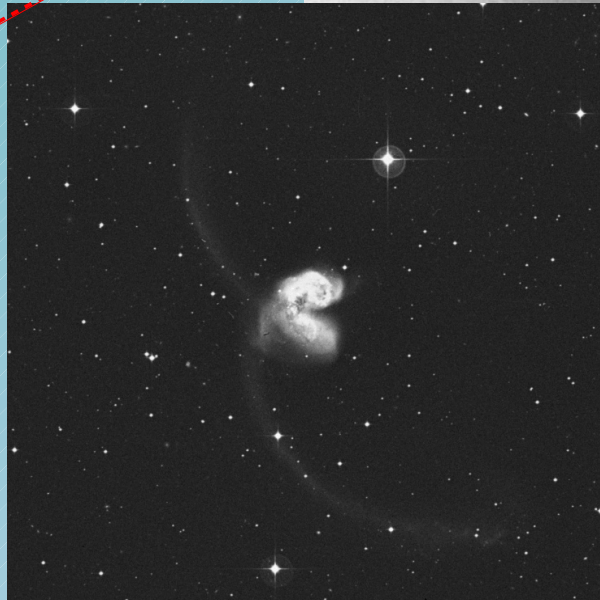
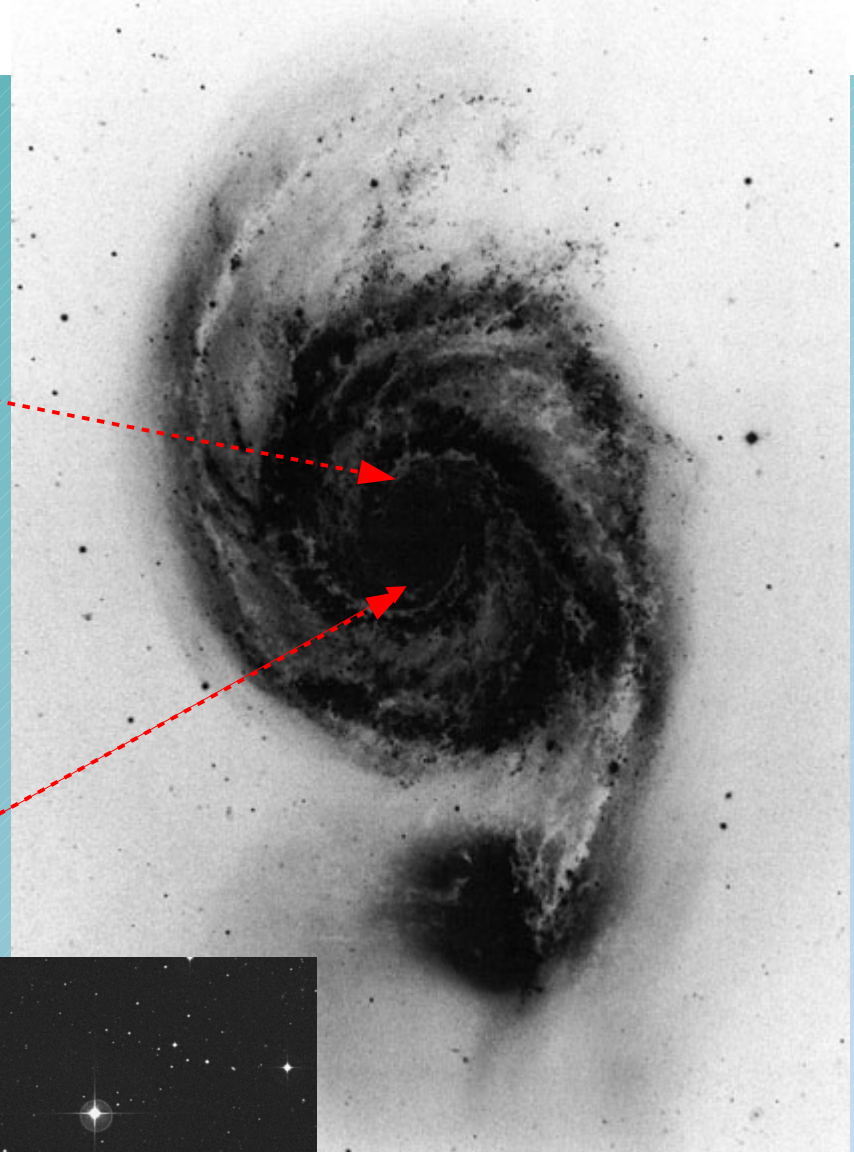


NGC 4571 (Sc):
flocculent spiral.



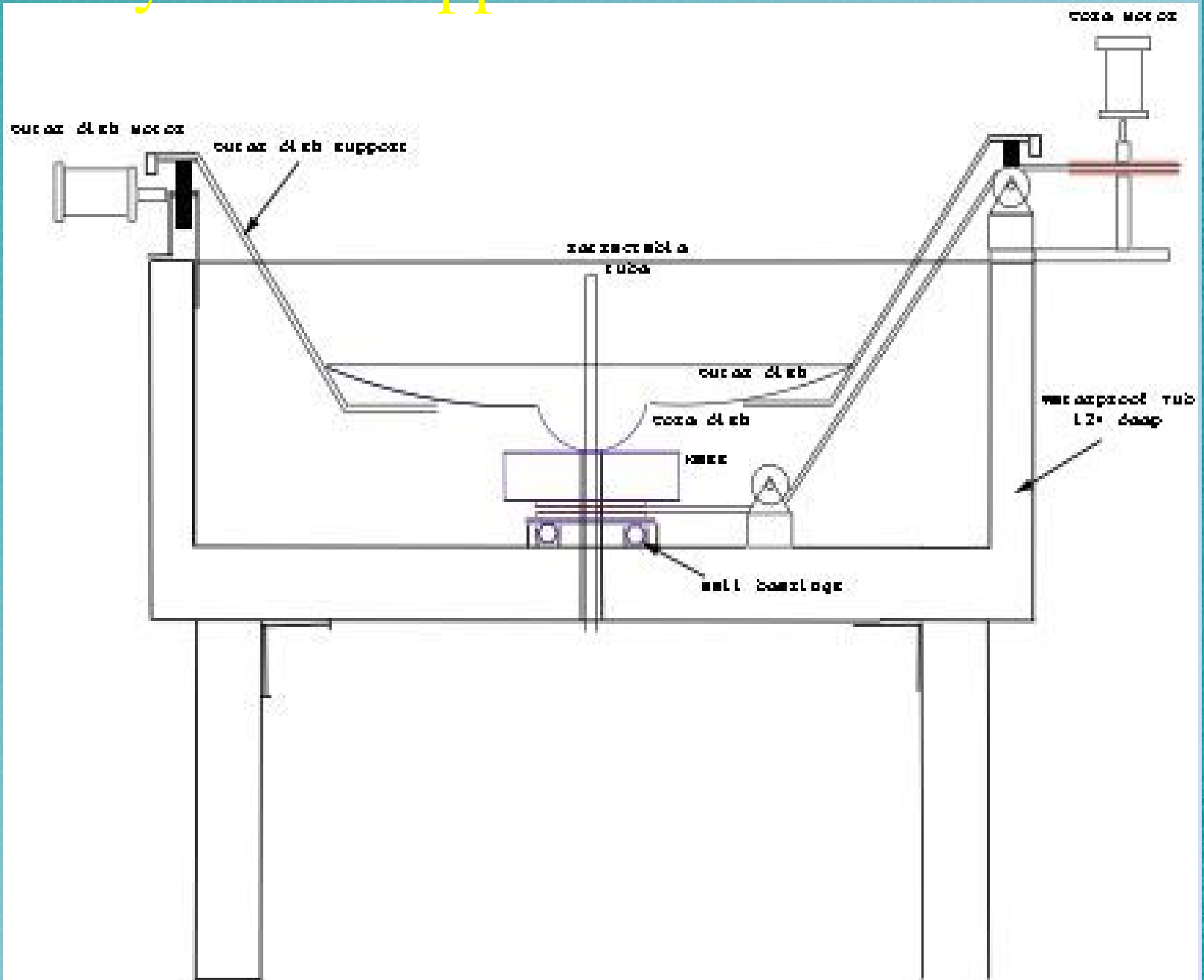
Interacting Spirals

M51: Grand design spiral.



The Antennae

"Swirly" - The Apparatus



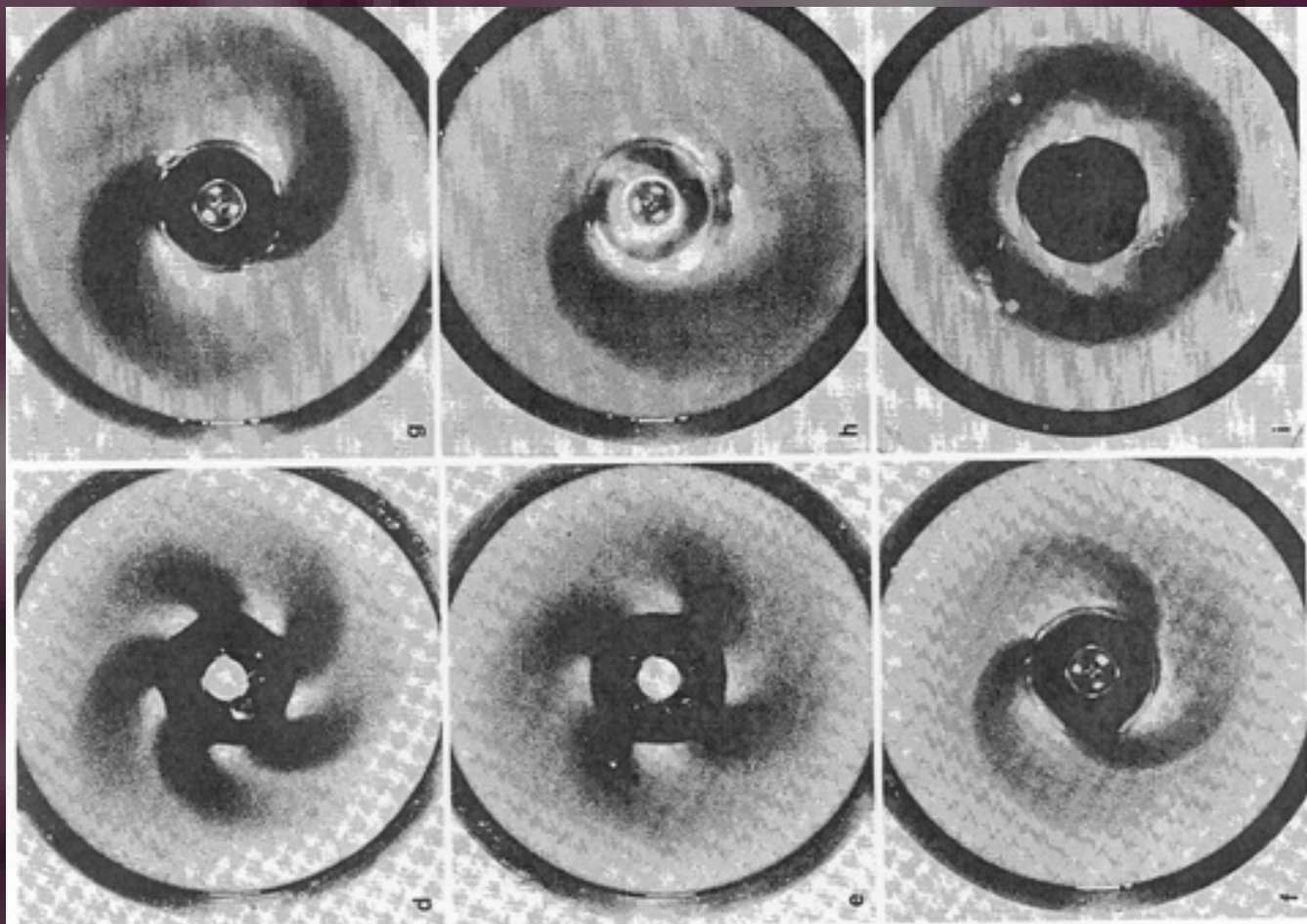
"Swirly" - Capabilities

This apparatus is intended to test theories #3 and 4 (above). It is based upon a schematic created by a Russian team (Nezlin et al.)

- Spins two, concentric vessels independently.
- Both motors provide a continuum of angular speeds from 0 to 170 rad/sec (1600 RPM).
- Can accommodate many different vessel shapes, from flat to parabolic. (Other phenomena can be studied.)
- Cameras (not shown) will be suspended above the apparatus and used to record data.
- Camera can be attached to outer dish support for a rotating frame of reference.

Results by Others

The Russian team (Nezlin et al.) successfully reproduced spiral density waves with between 1 and 8 arms in their shallow water spinner.

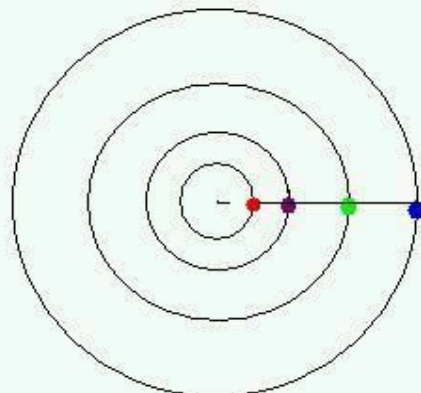


References

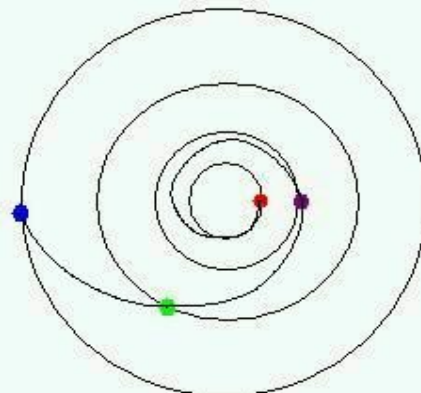
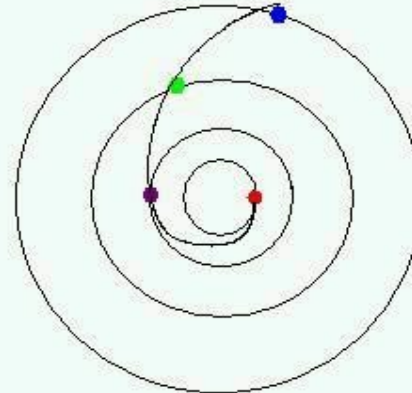
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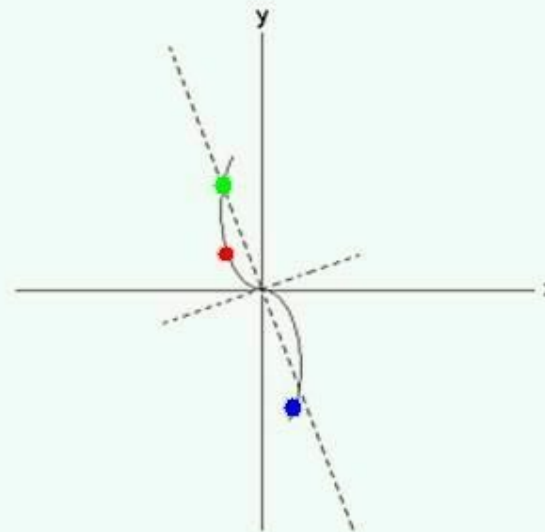
The Winding Problem



Start



Finish



Motions of stars in an inertial reference frame