Laboratory Astrophysics

Jim Stone
Department of Astrophysical Sciences and PACM
Princeton University

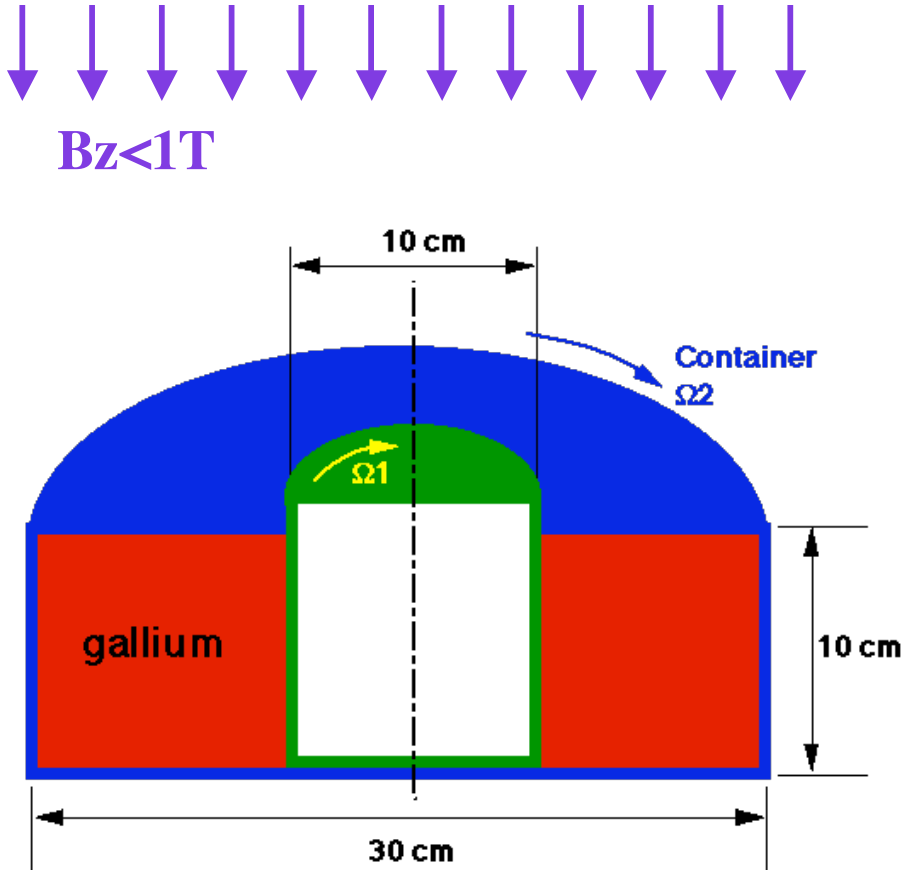
1. What is laboratory astrophysics?
   - Laboratory experiments that are motivated primarily by problems in astrophysics.

2. What defines the field, and what are some examples?
   - See #1.
   - Measurement of opacities.
   - Measurement of astrophysically relevant chemical and nuclear reaction rates.
   - Formation and spectral properties of dust grains.
   - Laboratory fluid dynamic experiments of, e.g., dynamos, Couette flow, magneto-rotational instability.
   - HEDP experiments involving, e.g., shock dynamics, EOS measurements, radiation transfer, kinetic plasmas, etc.

3. How does laboratory astrophysics relate to other fields of science?
   - It is traditional experimental physics and chemistry.
   - However, very few (if any) astrophysics departments at universities support laboratory astrophysics. Needs close collaboration between astrophysics and experimentalists.

PPPL MRI Experiment: The Basic Idea

- **Liquid gallium Couette flow**
- **Centrifugal force balanced by pressure force from the outer wall**
- **MRI destabilized with appropriate Ω_1, Ω_2 and Bz in a table-top size.**
- **Identical dispersion relation as in accretion disks in incompressible limit**

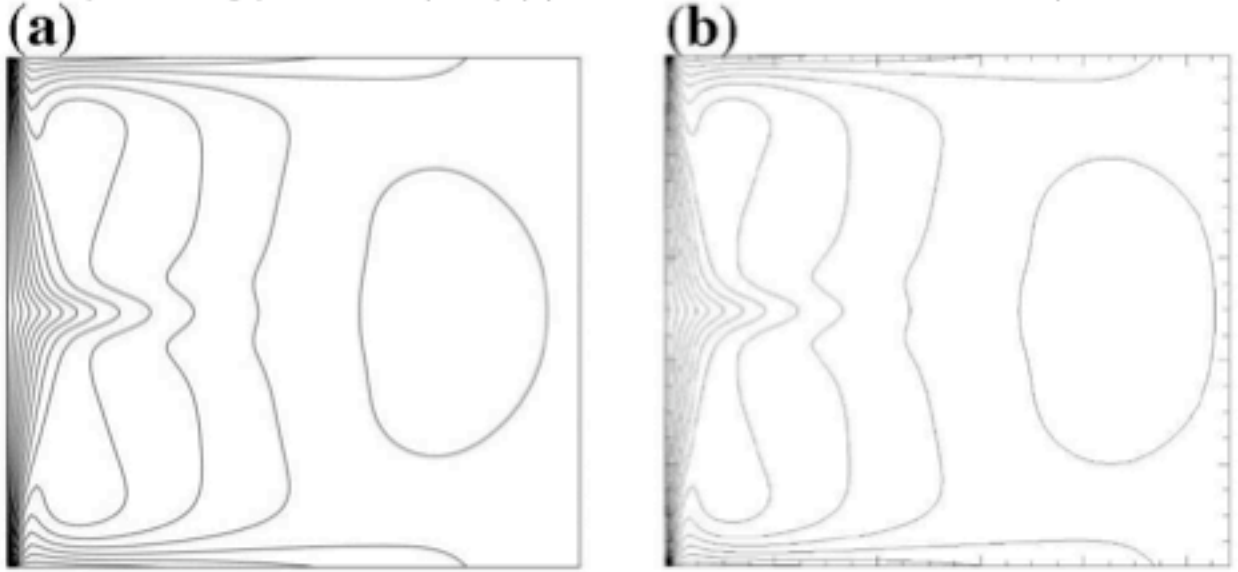


- Ji et al (2006) report no nonlinear hydrodynamic instability for Re ~ 10^6 in water
- MHD (gallium) experiment in progress…

These experiments are used to verify the MHD code ZEUS.

The ZEUS simulations provide more diagnostics of the flow, and can be used to predict and refine the experiments.

Fig. 3.— Comparison with incompressible code at $Re = 1600$: (a) Contours of toroidal velocity from Kageyama et al. (2004) (b) Results from ZEUS-2D with $M = 1/4$



Liu, Goodman, & Ji (2006)

Some lessons from this experiment.

1. The experiment is motivated by astrophysical accretion disks. But it is not an accretion disk. It focuses on physics important in an accretion disk. Trying to model "XX in the lab" is not feasible.

2. Often important physics in the experiment is not present in the astrophysical system (boundary layers, conduction, viscosity, resistivity, non-ideal EOS, kinetic effects). This complicates numerical modeling, and limits verification efforts.

3. It is really important to have *both* experimental and computational results to understand what is happening.

Verification and validation.

- Laboratory experiments have traditionally been the source of test problems for computational algorithms (*verification*)
  - Shocktubes
  - Double Mach reflection
- . Most *verification* tests are now abstractions of experiments based on analytic solutions or previous numerical results.
- Nowadays, more complicated experiments are used for *validation* of the mathematical models:
  - MRI and dynamo experiments
  - RT instability (Dimonte et al. 2004)
- In multi-dimensions, even simple problems in new regimes (compressible MHD, radiation hydrodynamics) may not be solvable analytically. Experiments could provide *verification* tests in this regime provided they are simple (no kinetic effects, no line transport, etc.), as they did 40 years ago for hydrodynamics.

Summary

Laboratory astrophysics encompasses an extremely broad range of investigation with a long history. HED plasma physics experiments are only the latest examples.

Trying to model entire astrophysical systems is challenging. Focusing on fundamental physical processes is productive.

It is critical that the experiment be in the appropriate regime (MHD versus collisionless; line versus continuum radiation transport, etc.)

Experiments might define new verification tests, and can validate mathematical models. Equally important is the use of computation to predict, diagnose, and refine the experiment.

Example: radiative jets formed by HE lasers.