Interface & Shear Flow Instabilities in Astronomy

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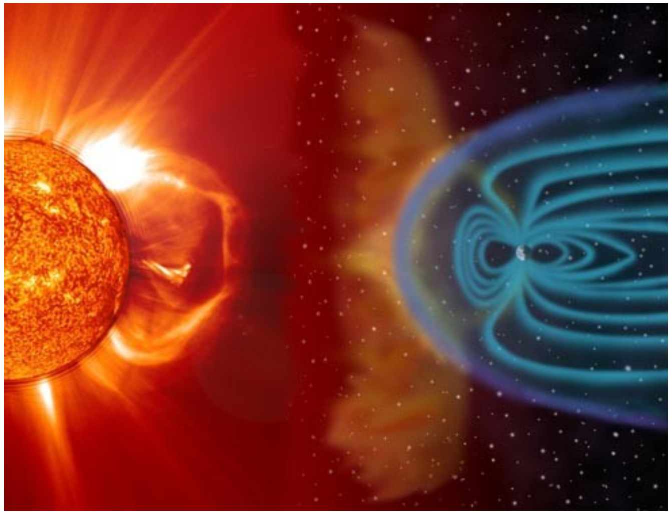
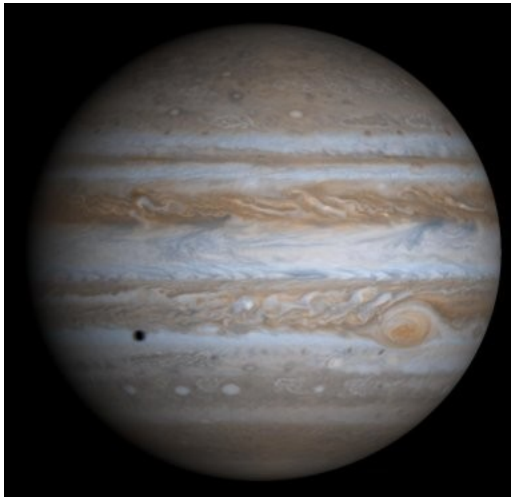
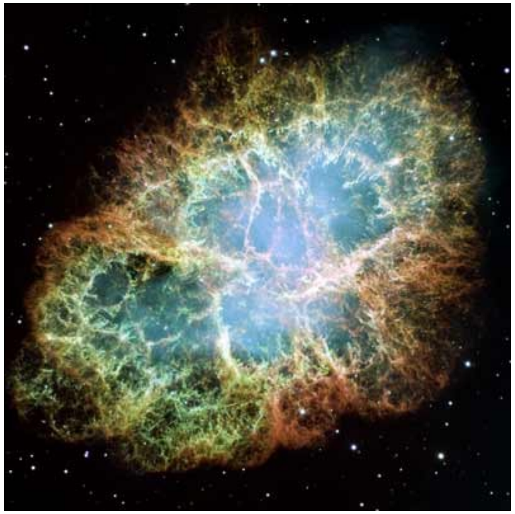
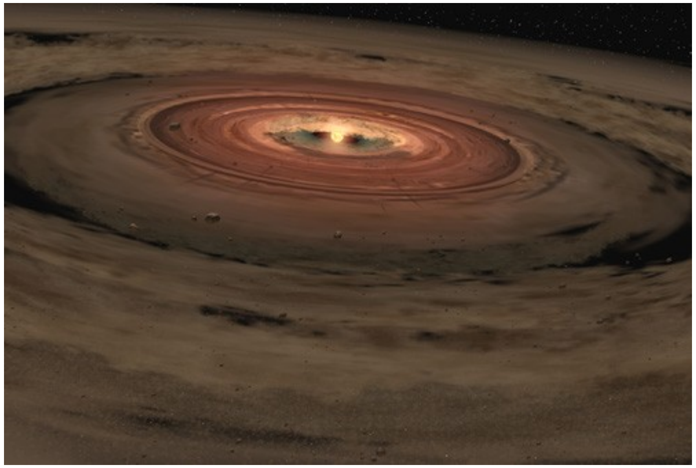
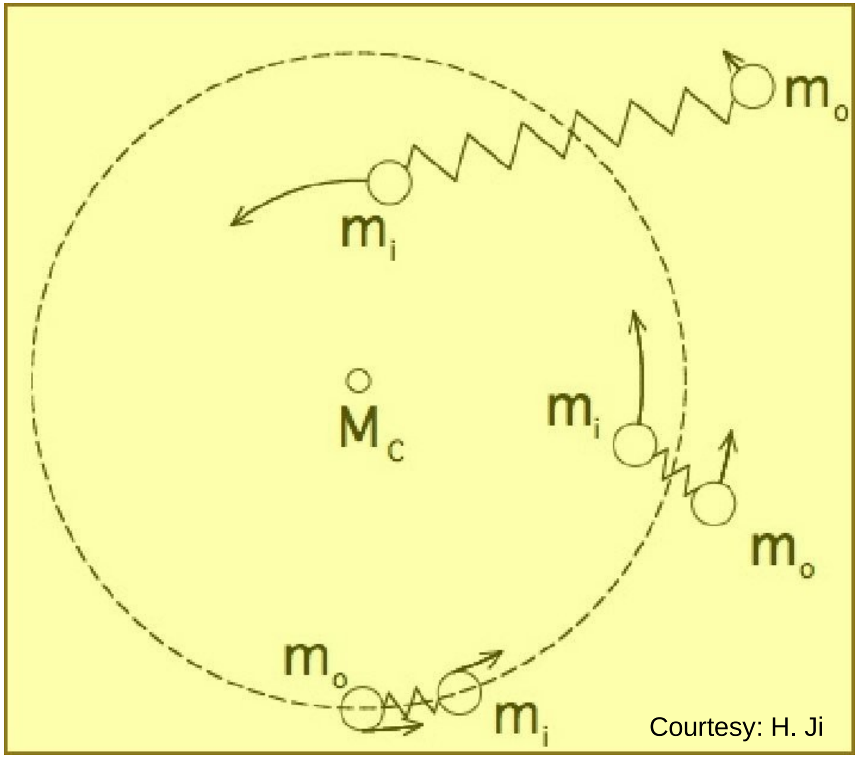







Accretion Disks: Magneto-Rotation Instability

In differentially rotating disks, an axial magnetic field acts like a weak spring to transport angular momentum radially outward and mass inward.
Balbus & Hawley 1991, 1998 (See Momentum Transfer session)



Courtesy: H. Ji

Instability occurs as long as

$$\frac{d\,\Omega^2}{d\ln R} < 0$$

which is virtually always true for astrophysical disks (Ω is the angular speed).

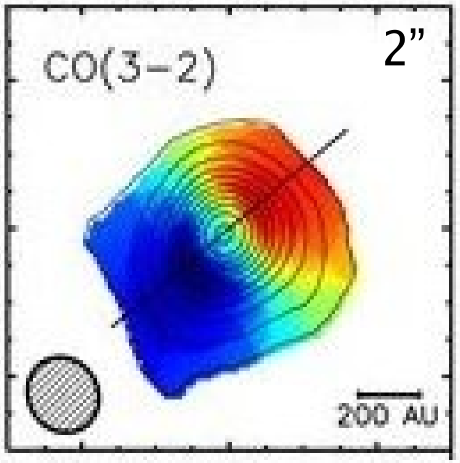
In the last decade or so, most of our understanding of accretion disk (M)HD has come from advances in theory and numerical simulations (Balbus, Hawley, Stone, Shu, and others). Astronomical observations are only now catching up.

Accretion Disks: Observational Status

Protostellar disks

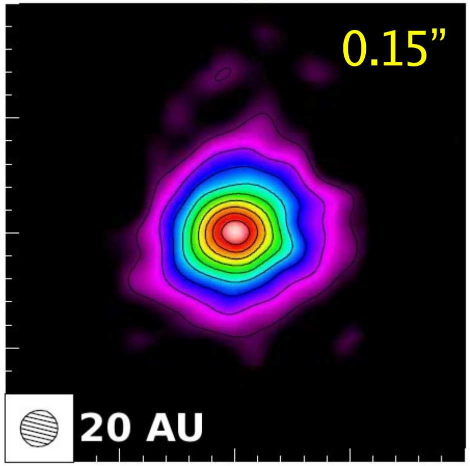
- Imaging on the scale of 10s of AU

HD 163296 (SMA)



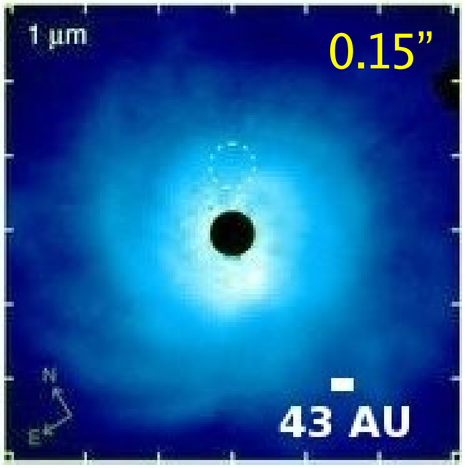
Hughes et al 2009

DG Tau (CARMA)



Isella et al. 2010

AB Aur (HST)



Perrin et al 2009

- Direct detection of B field in FU Ori (Donati et al. 2005)
  - 32G LOS, implies 1kG at the inner surface.
- Polarized dust emission with SMA (upper limits only?)

Black hole (supermassive and regular size) disks

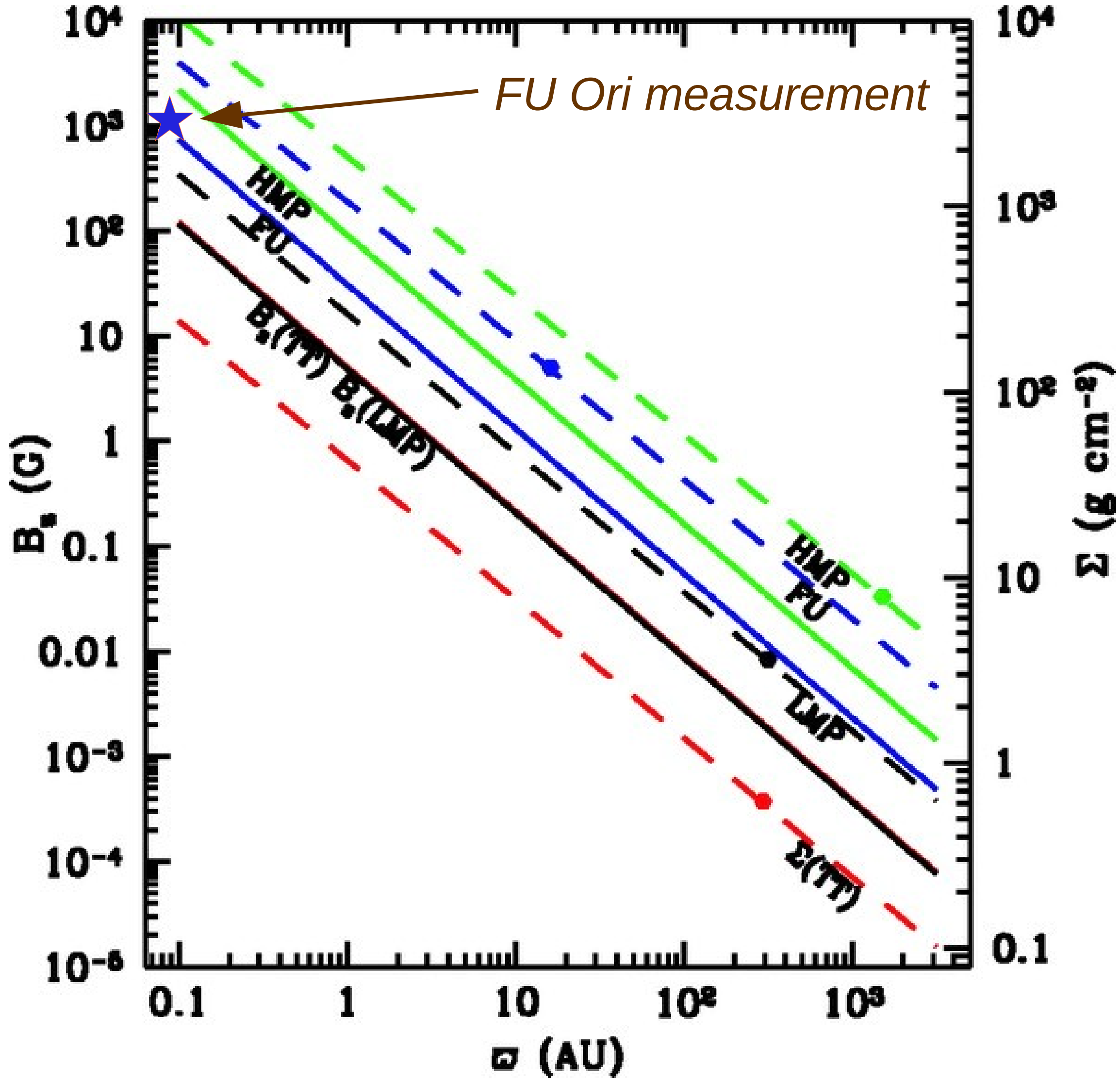
- No direct observations. Gross properties inferred from, e.g. X-ray variability and microlensing observations

Protostellar Disks: Magnetic fields

Predicted axial B field strength for various disk types [solid lines].
(Shu et al 2007)

FU Ori is the prototype of a class of variable stars that undergo outbursts due to accretion events

B ≥ 10^{-4} G amenable to observations at 10-100 AU scale



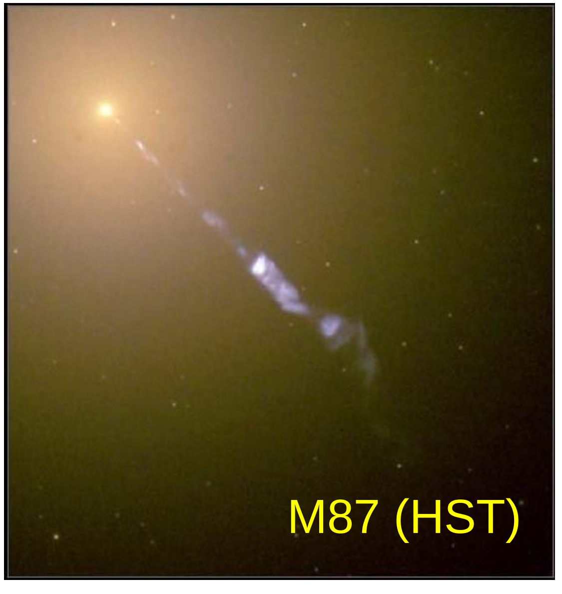
Astrophysical Jets

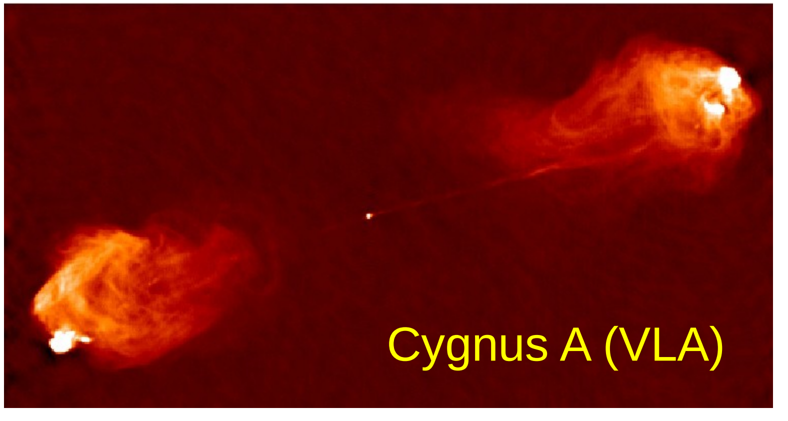
• What keeps galactic jets collimated for ~Mpc? What role does shear flow play?

• Can the jet/lobe interaction with ISM/IGM (working surfaces) be characterized by Rayleigh-Taylor and Richter-Meshkov instabilities?

• Are knots formed by instabilities such as Kelvin-Helmholtz or source modulation?

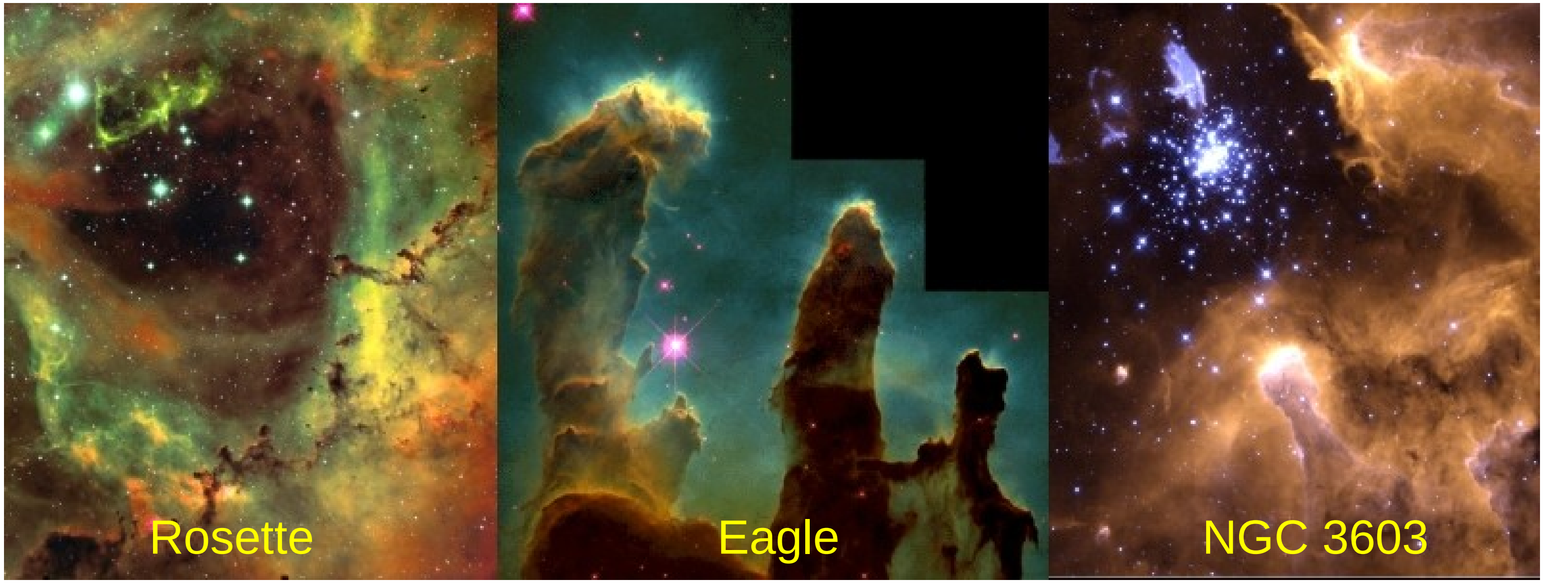
See Uri's talk and the session on Jets.





Molecular Pillars: Ablative RT Instability

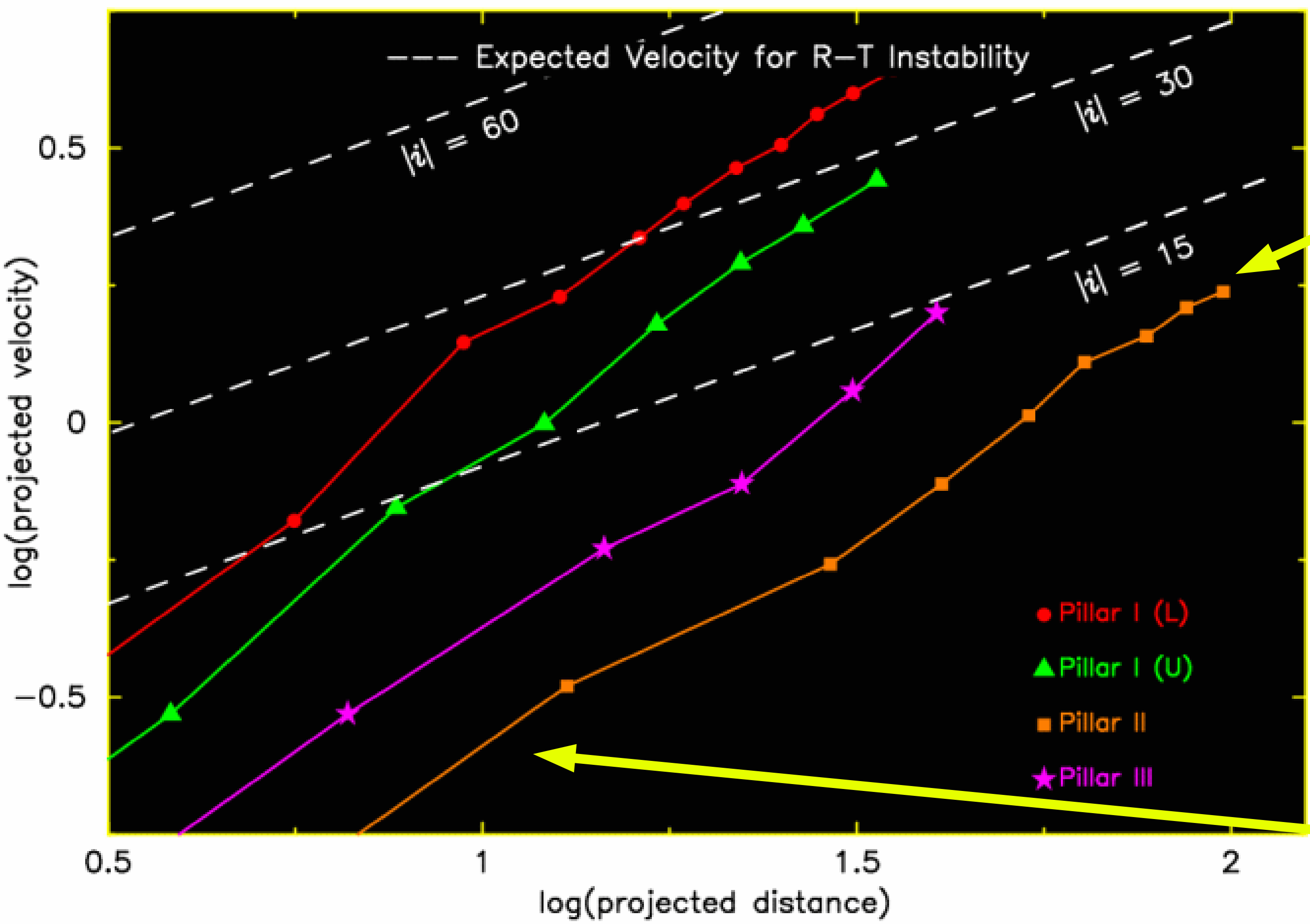
When OB stars form, they disrupt the parent molecular cloud through photoionization and photodissocation.   The result is pillars of molecular material, which always point back towards the disruptive stars.



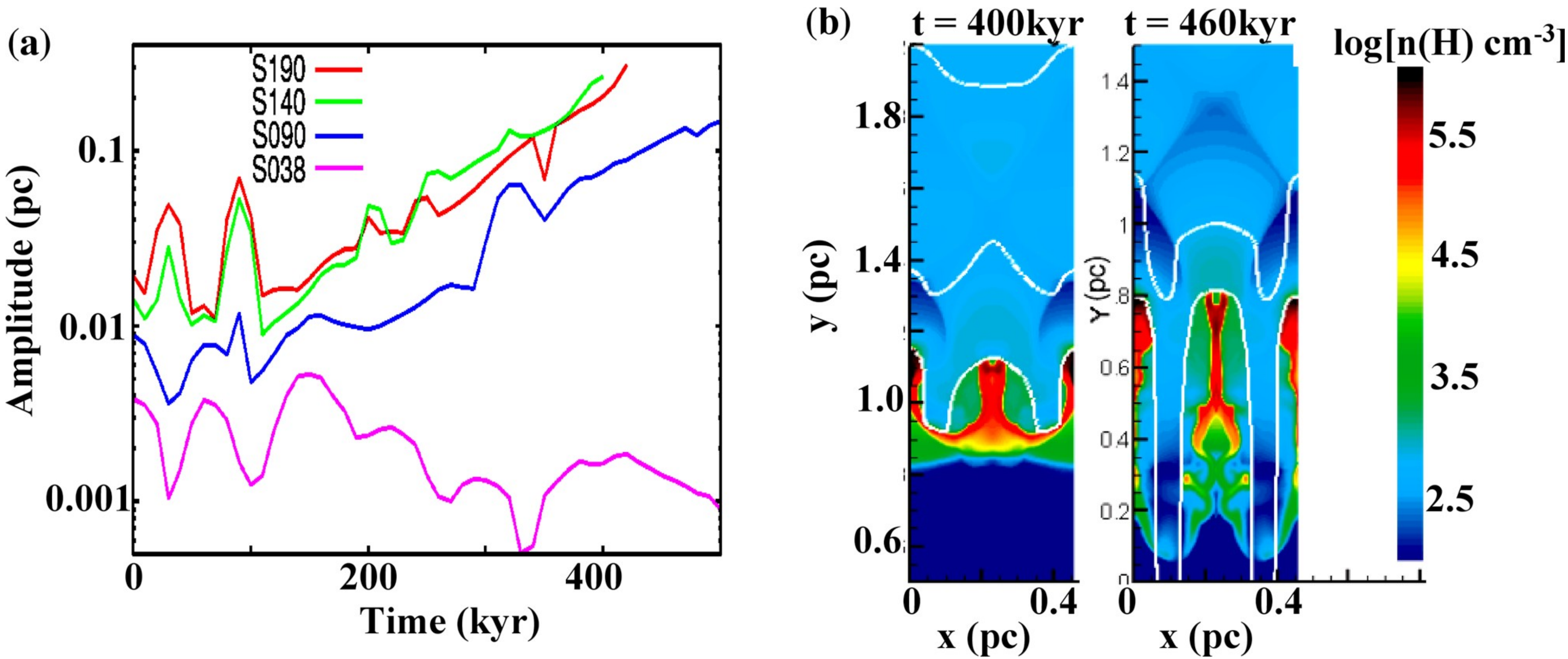
One possible formation mechanism is through an ablative RT instability (via the rocket effect) at the surface between the ionized HII region and the neutral molecular cloud (Spitzer 1954; Frieman 1954)

The Case of the Eagle Nebula

Mm-wave observations showed that the gas velocity field in the Eagle Pillars was inconsistent with constant acceleration RT instability theory (Pound 1998).



The Case of the Eagle Nebula



This has prompted 2-D radiative hydrodynamical simulations which show pillar growth in the non-linear regime that reproduces observed features: velocity gradient, density profile, dynamical timescale (Mizuta et al 2005, 2007).

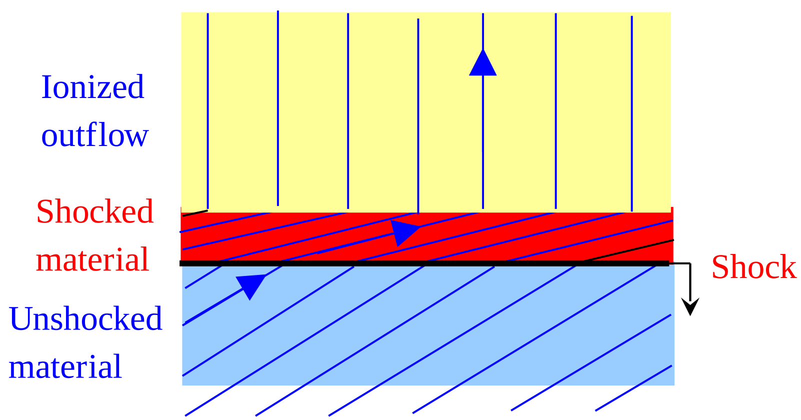
Above case is for amplitude perturbations from 3.8E-3 pc to 1.9E-2 pc. Perturbations are stable in the linear regime due to "plasma self-annealing."

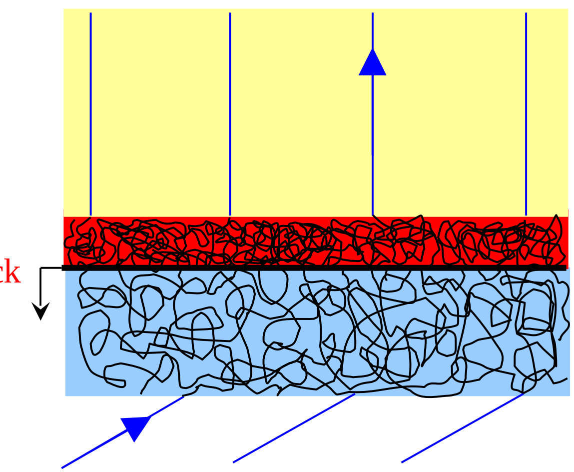
Eagle Nebula: Two models of magnetic support

quasi-homogeneous; compressed by ablative pressure

tangled, force-free ("magnetostatic"); acts like a gas pressure

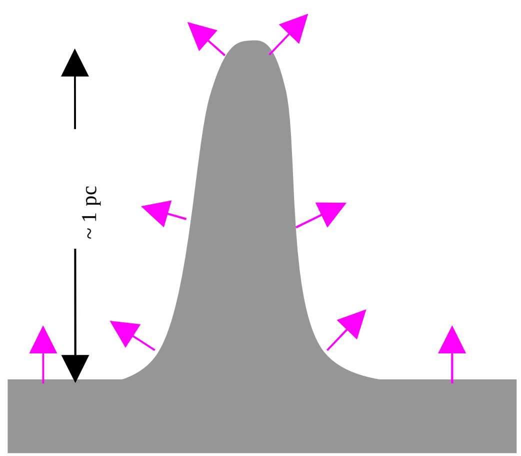
predicted $B_{obs} \sim 200\ \mu G$





predicted $B_{obs} \sim 0$

Field in ionized flow will be normal everywhere to pillar surface



Field in ionized flow will be very weak.

(Ryutov & Remington 2002; Ryutov et al 2006)

Supernova Remnants: RM/RT Instabilities

There is a large amount of observational, theoretical, and numerical work characterizing the ejecta in SNRs.

• Richter-Meshkov may dominate at early times

• Contact surface between ejecta and circumstellar medium is subject to RT instability.

• Observed fingers are usually attributed to RT, *but such conclusions should rely on more than morphological similarity*; e.g. synthetic observations.

• Not every finger is RT, in fact some may not even be fingers.

See Aaron Miles talk.

Tycho SNR (Chandra/Spitzer/Calar Alto)

Red: 25 μm
Blue: 4.1-6.1 keV
Green: 0.95-2.26 keV

Prospect for Observation Breakthroughs

Any observations that characterize the velocity and magnetic fields in these systems, at high spatial and spectral resolution, can help us understand the influence of these instabilities.

Accretion disks (MRI): **Are B and V fields consistent with predictions**?
The leading-edge and next generation radio interferometers are key:
- CARMA/SMA - CO Zeeman, dust polarimetry, velocity fields -- all on ~20 AU scale
- EVLA/VLBI - OH masers to provide Zeeman and rotation curve
- ALMA/SKA - 2012+; potential for sub-AU measurements.

Molecular pillars (RT): **Solve the puzzle of magnetic support**
- Measurement of B field in molecular gas is possible at mm/submm wavelengths
- *How do we measure the B field orientation in the ionized flow?*

Jets/SNRs (RT/RM/KH): **Follow time evolution**
Could the highest resolution telescopes produce time-lapse images & spectra on shorter timescales than currently? Including polarization/Zeeman?
- HH47 jet - dT = 4.9 yr with HST (Hartigan et al 2005)
- SN 1993J - dT = 50 days with VLBI (Beitenholz et al 2003)

Possibly limited by available sources (especially for SNRs)

Prospect For Lab Astro Experiments

The combination of lab astrophysics, observations, theory, and numerical simulations is extraordinarily powerful.

The increased interest by astronomers in lab astro is an **opportunity** that should not be squandered.

- Accretion disks
  - MRI observed in liquid sodium experiment (Sisan et al. 2004) [Bill Dorland].
  - Also work by Hantao Ji and collaborators in MRI Experiment lab.
  - *What is prospect for doing this with plasma?*
- Molecular Pillars
  - Eagle experiment has been proposed for the National Ignition Facililty [Remington, Ryutov, Pound].
- Jets
  - Probably the most successful lab astro experiments to date have been related to jets, more should be pursued.
  - You et al 2005 [Paul Bellan]; Ciardi et al 2009 [Sergey Lebedev]; Hartigan et al 2009
- SNe and SNRs - see Carolyn Kuranz's talk

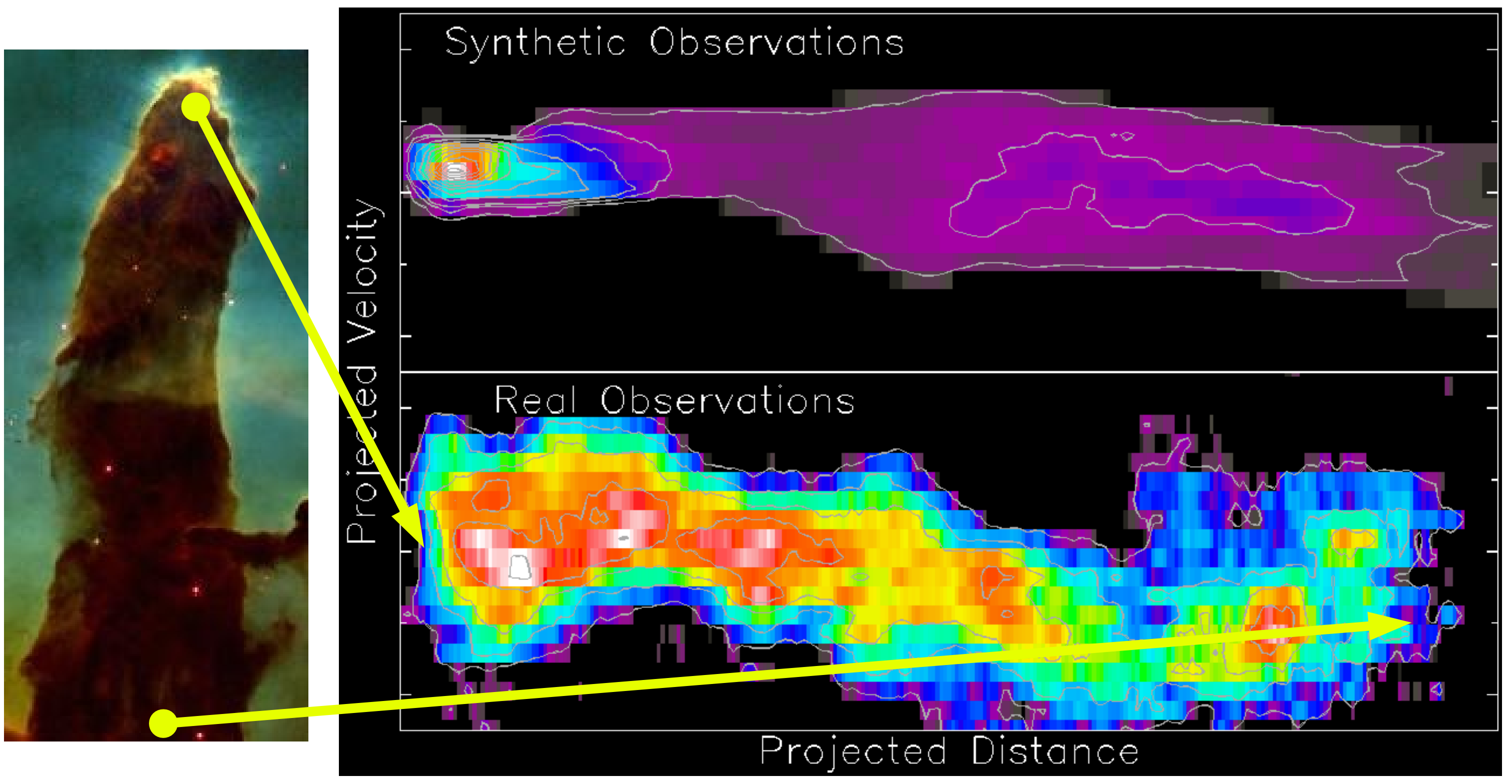
Lab diagnostic need:

When am I going to be able to measure velocities in the lab with the same ease and accuracy with which I can measure them at the telescope?

Tying Simulations and Observations Together

More collaboration needed between observers and numericists to create multidimensional *synthetic observations* that can be directly compared to real observations. This can feedback to suggest new observations.

Telescopes are filters. Apply filter to simulations => synthetic observations. *This is another form of code validation.*



Example: Position-velocity diagrams of gas flow in Eagle Nebula "cometary" simulation and in real data.