Protostellar jets from SPMHD simulations of star formation

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Outline

- Performing ideal MHD simulations of star formation
- Small scale:
  - Collapse of a single prestellar core to form First Hydrostatic Core
- Large scale:
  - Supersonic MHD turbulence in the interstellar medium
- Using SPH MHD with new method enhancements:
  - Constrained hyperbolic divergence cleaning
  - New artificial resistivity switch for magnetic shocks
Discretize fluid into set of particles which simulate fluid motion

Well suited for star formation:
  - Couples well with N-body methods
  - Strong conservation properties, very stable
  - Inherently adaptive, resolution traces mass
Star formation: first hydrostatic core

- Prestellar core:
  - Dense clump of molecular gas, but no central object yet

- Protostellar core:
  - A formed star

- First hydrostatic core:
  - Before H$_2$ disassociates
  - ~2000K, short life time ~1000-10k years, few AU in radius
  - Predicted in theory from as early as Larson, 1969
  - Observational candidates only in recent years, prime target of ALMA
• 1 solar mass core, mass-to-flux ratio 5 (edge on view)
• Divergence errors in the magnetic field cause the disc to become unstable
Constrained divergence cleaning

- Hamiltonian formulation of hyperbolic divergence cleaning
  - Retains conservation and stability properties of SPH
  - Accounts for Lagrangian motion of particles
  - Ensures strict energy conservation, guaranteed to always decrease divergence of the field
  - Provides approx. 10x decrease in divergence error
• 1 solar mass core, mass-to-flux ratio 5 (edge on view)
• Well collimated magnetically propelled jet during first hydrostatic core
First core Jet

- ~2-8 km/s, roughly equal to escape velocity
- ~<10° opening angle for jet
- ~40% of material is ejected
Supersonic MHD turbulence

- Isothermal, driven Mach 10 turbulence
  - Initially weak magnetic field, $E_{\text{magnetic}}$ 10 orders of magnitude smaller than $E_{\text{kinetic}}$
  - Using new artificial resistivity switch that captures shocks for this wide range of field strengths
  - Results compared against grid based code Flash
- Extends the pure Hydro turbulence comparison by Price, Federrath 2010
log column density

log $|B|$
Dynamo amplification
Summary

- First hydrostatic core:
  - Slow, well collimated (<10°) jet

- Supersonic MHD turbulence:
  - Dynamo amplification grows magnetic energy $\times 10^{10}$
  - Similar results to grid based code Flash

- New method enhancements for SPH MHD
  - Constrained divergence cleaning, reduces divergence error approx. 10x
  - Artificial resistivity switch for better treatment of magnetic shocks