Protostellar jets from SPMHD simulations of star formation

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Outline

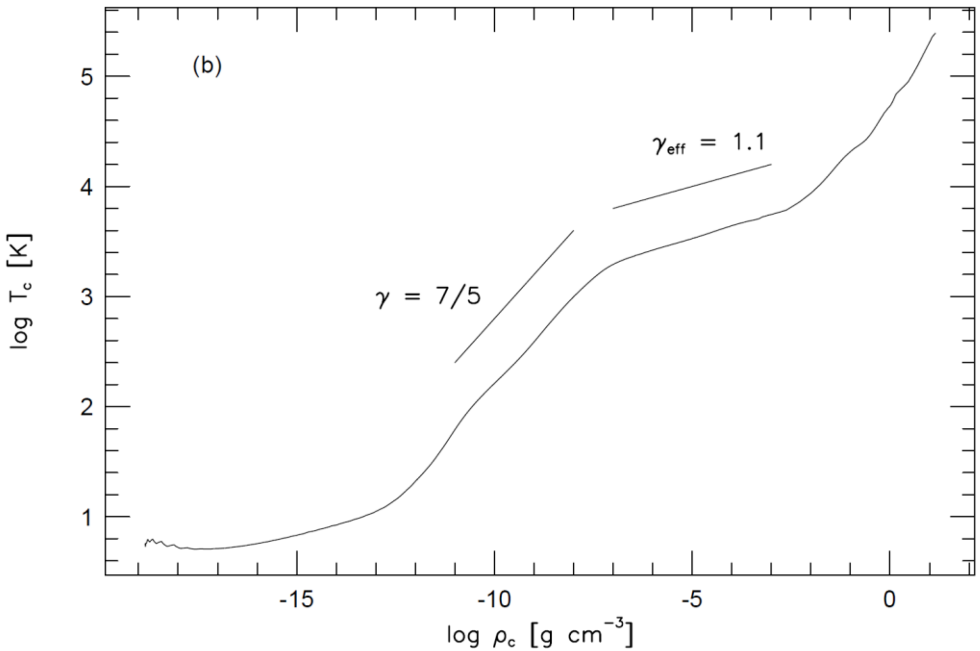
- Performing ideal MHD simulations of star formation
- Small scale:
  - Collapse of a single prestellar core to form First Hydrostatic Core
- Large scale:
  - Supersonic MHD turbulence in the interstellar medium
- Using SPH MHD with new method enhancements:
  - Constrained hyperbolic divergence cleaning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

SPMHD

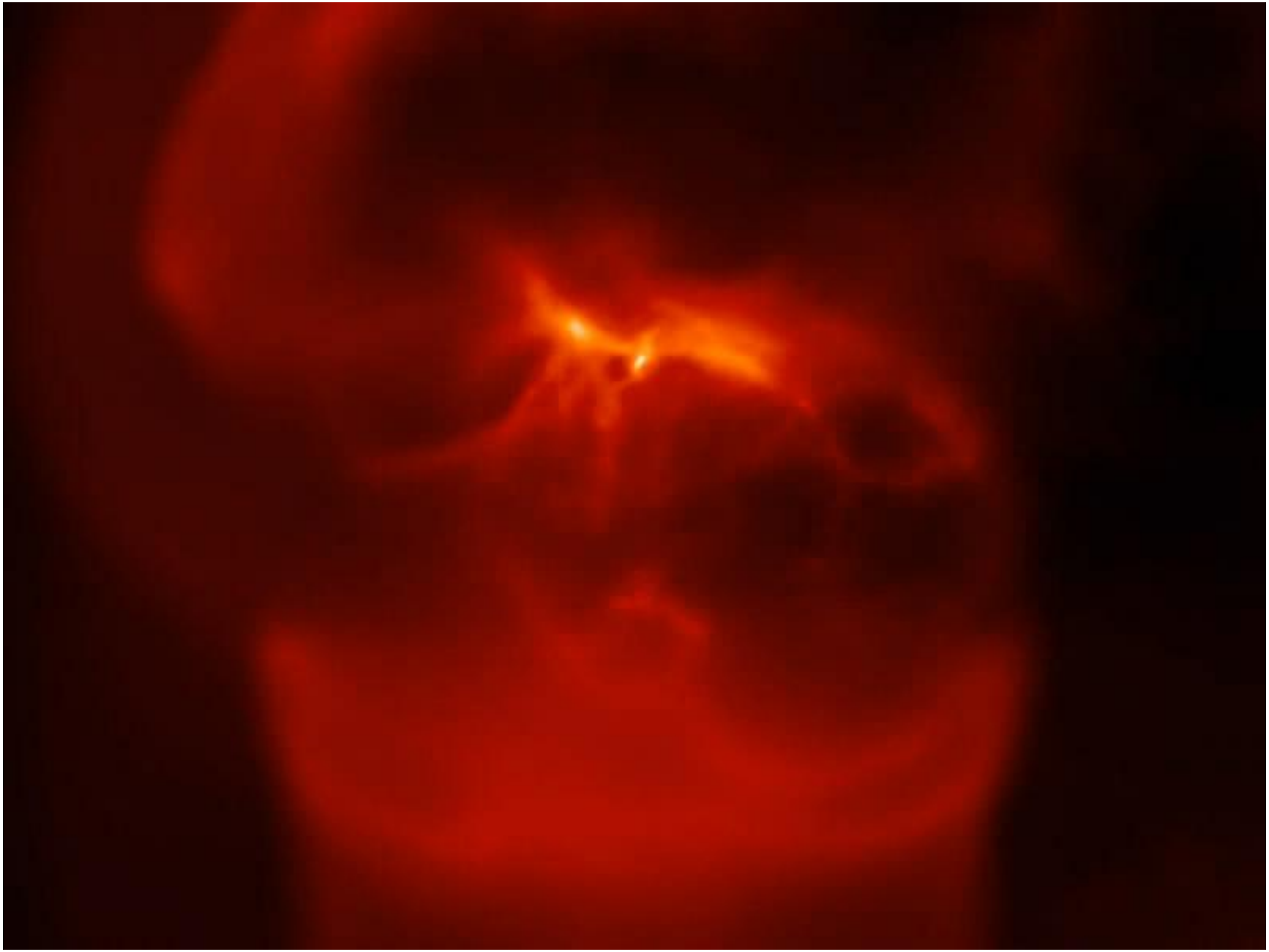
- Discretize fluid into set of particles which simulate fluid motion
- Well suited for star formation:
  - Couples well with N-body methods
  - Strong conservation properties, very stable
  - Inherently adaptive, resolution traces mass

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



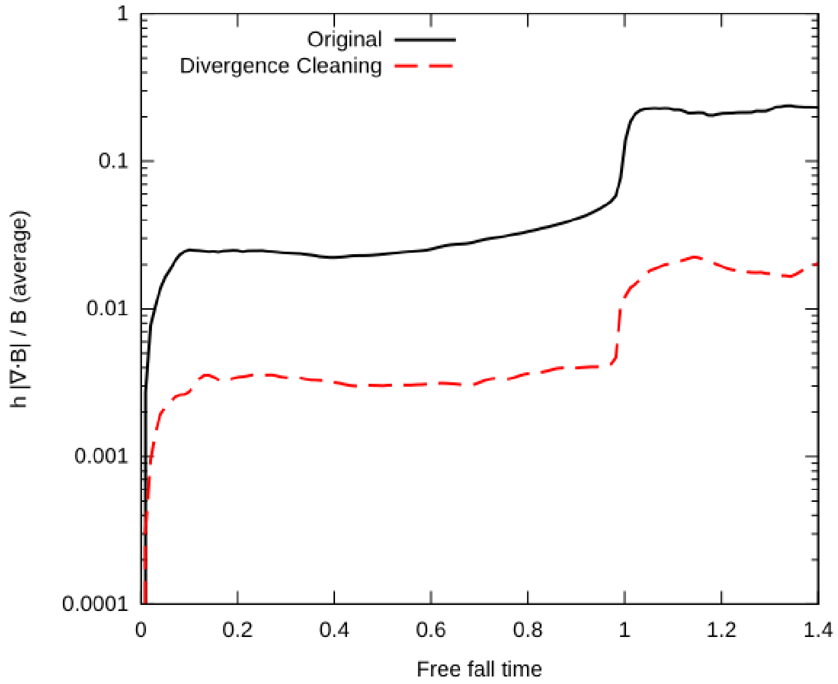
Masunaga, Inutsuka, 2000

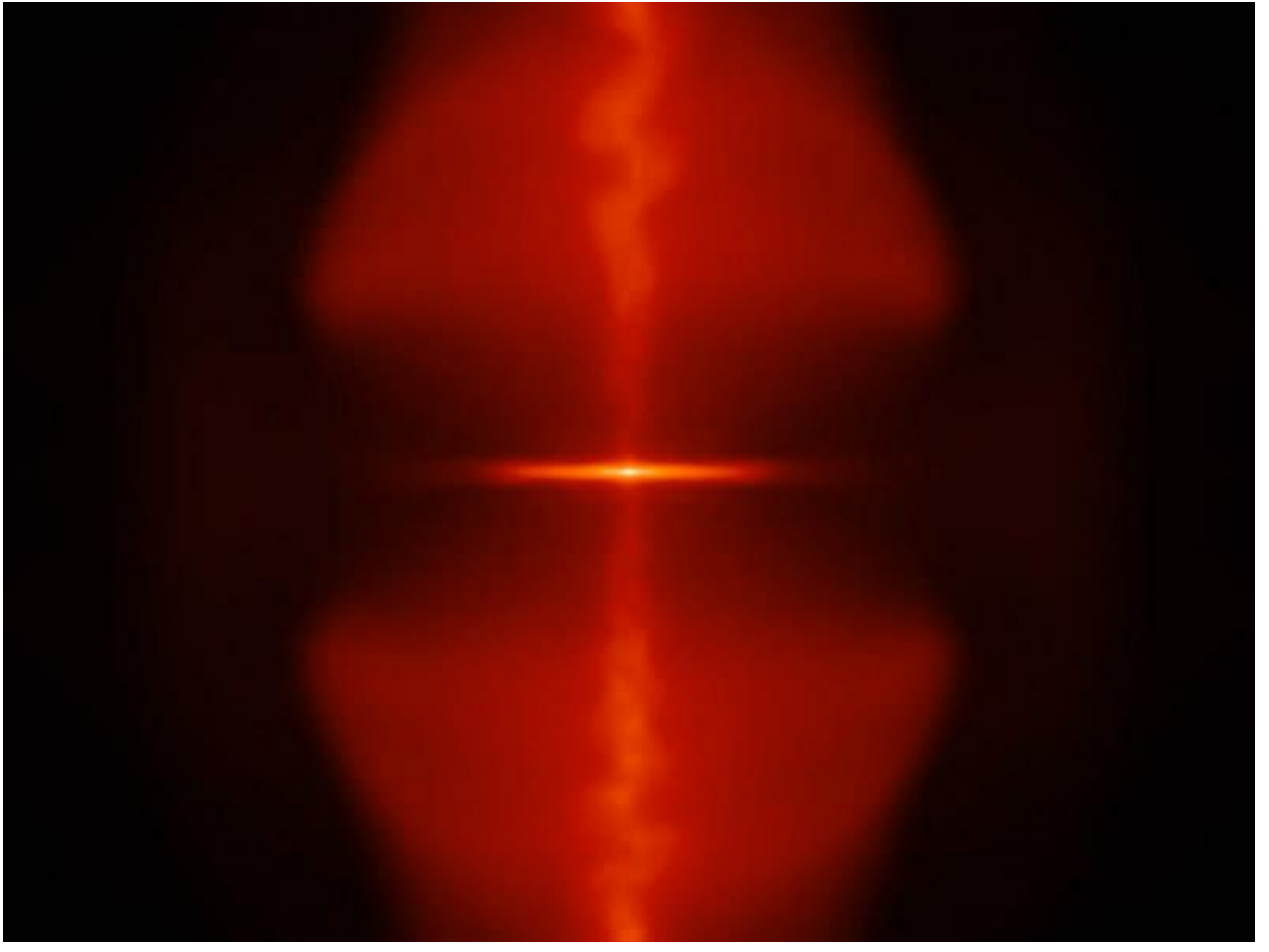


- 1 solar mass core, mass-to-flux ratio 5 (edge on view)
- Divergence errors in the magnetic field cause the disc to become unstable

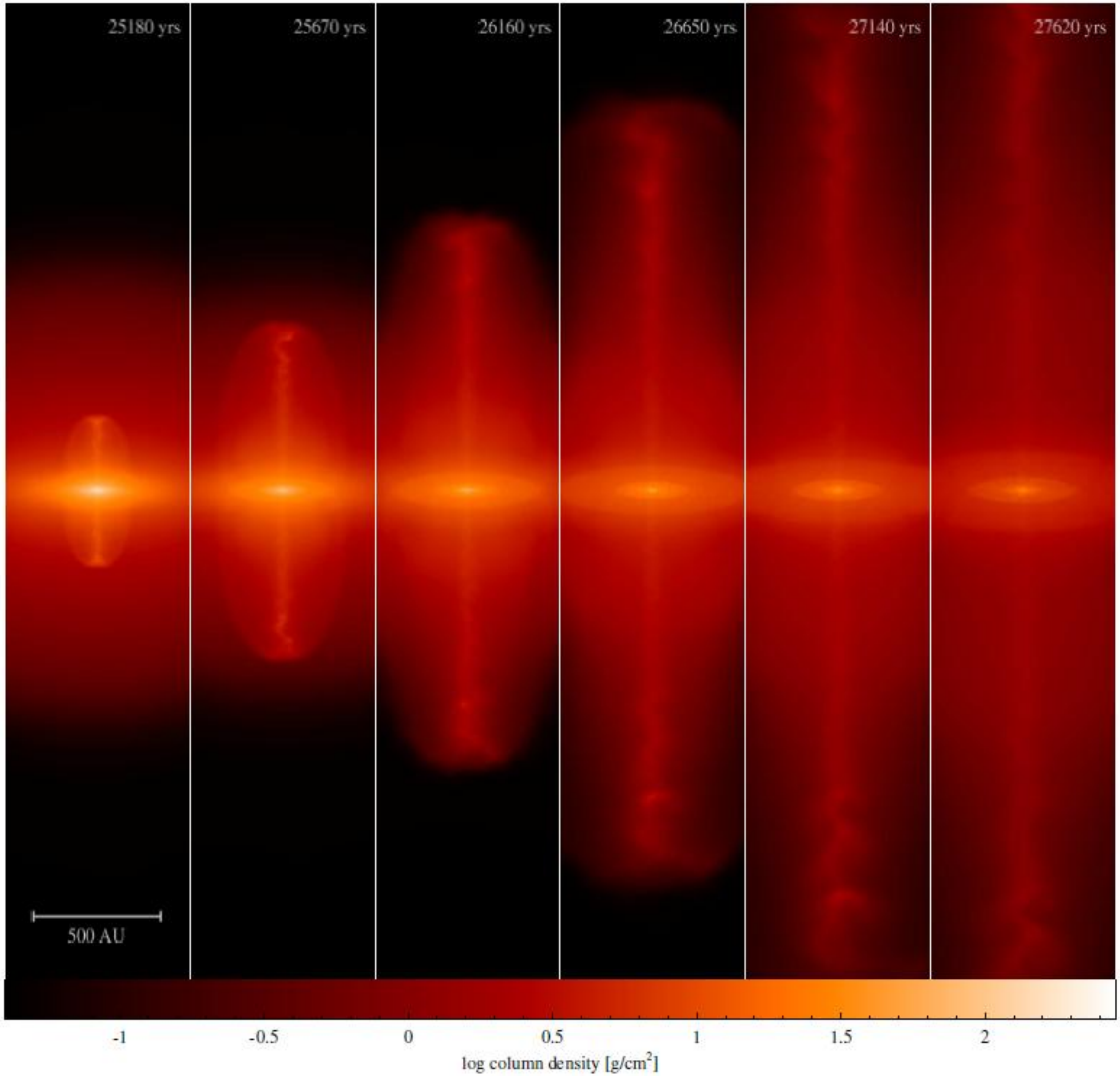
Constrained divergence cleaning

- 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

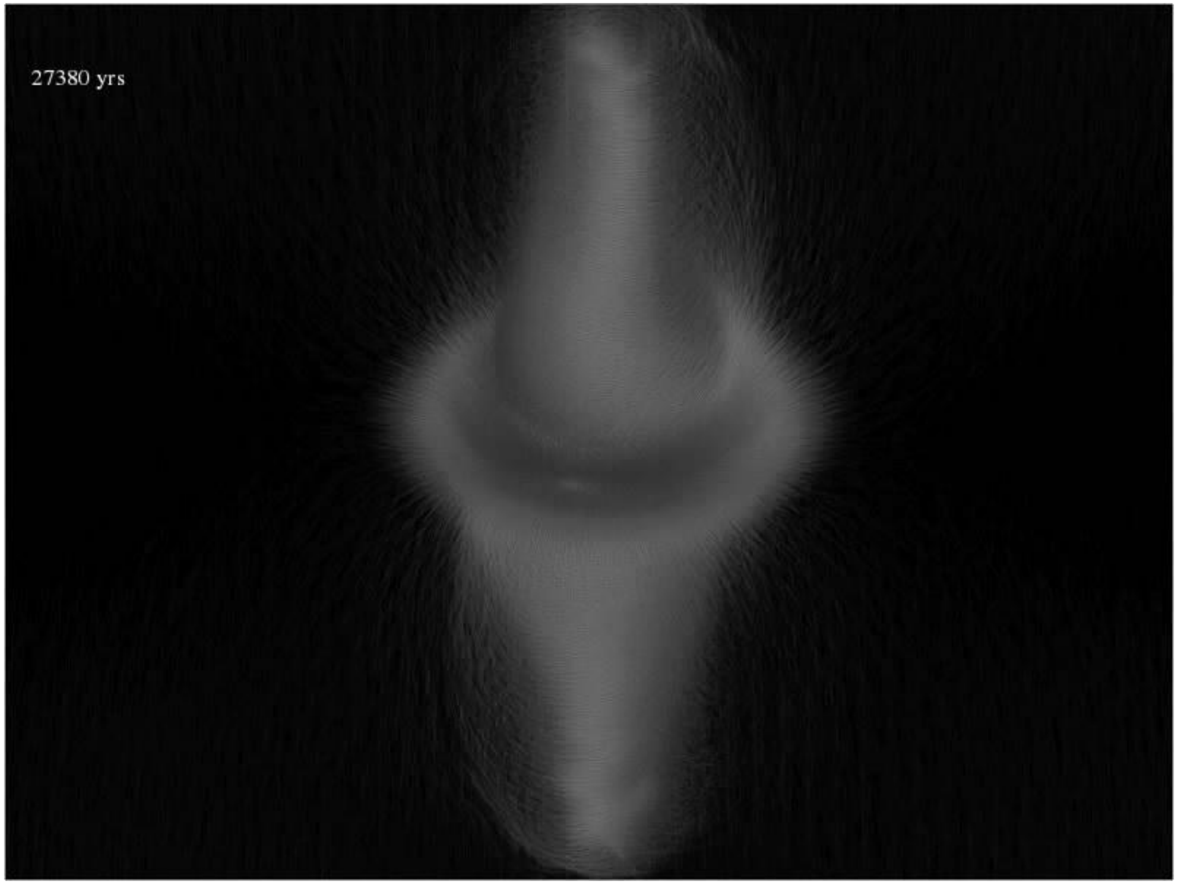


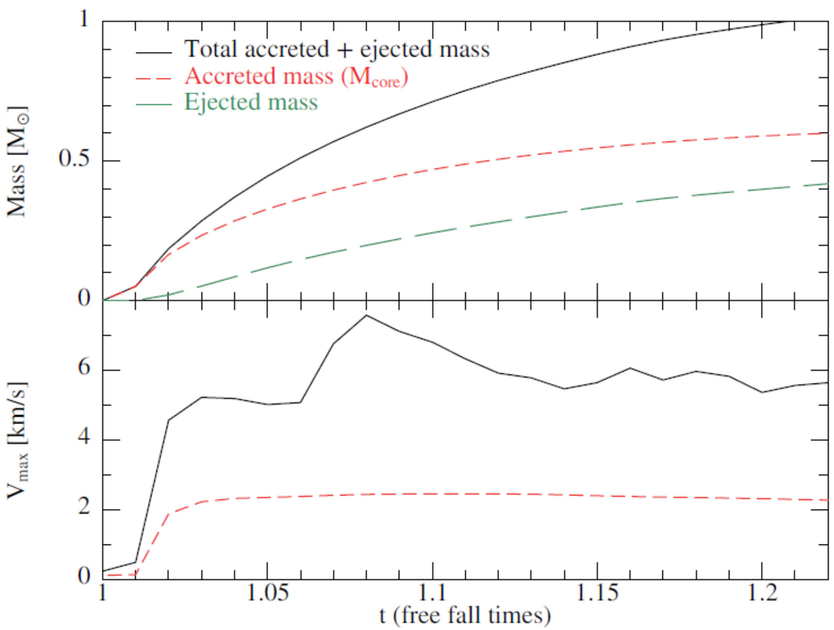


- 1 solar mass core, mass-to-flux ratio 5 (edge on view)
- Well collimated magnetically propelled jet during first hydrostatic core


25180 yrs
25670 yrs
26160 yrs
26650 yrs
27140 yrs
27620 yrs
500 AU
-1
-0.5
0
0.5
1
1.5
2
log column density [g/cm^2]

First core Jet

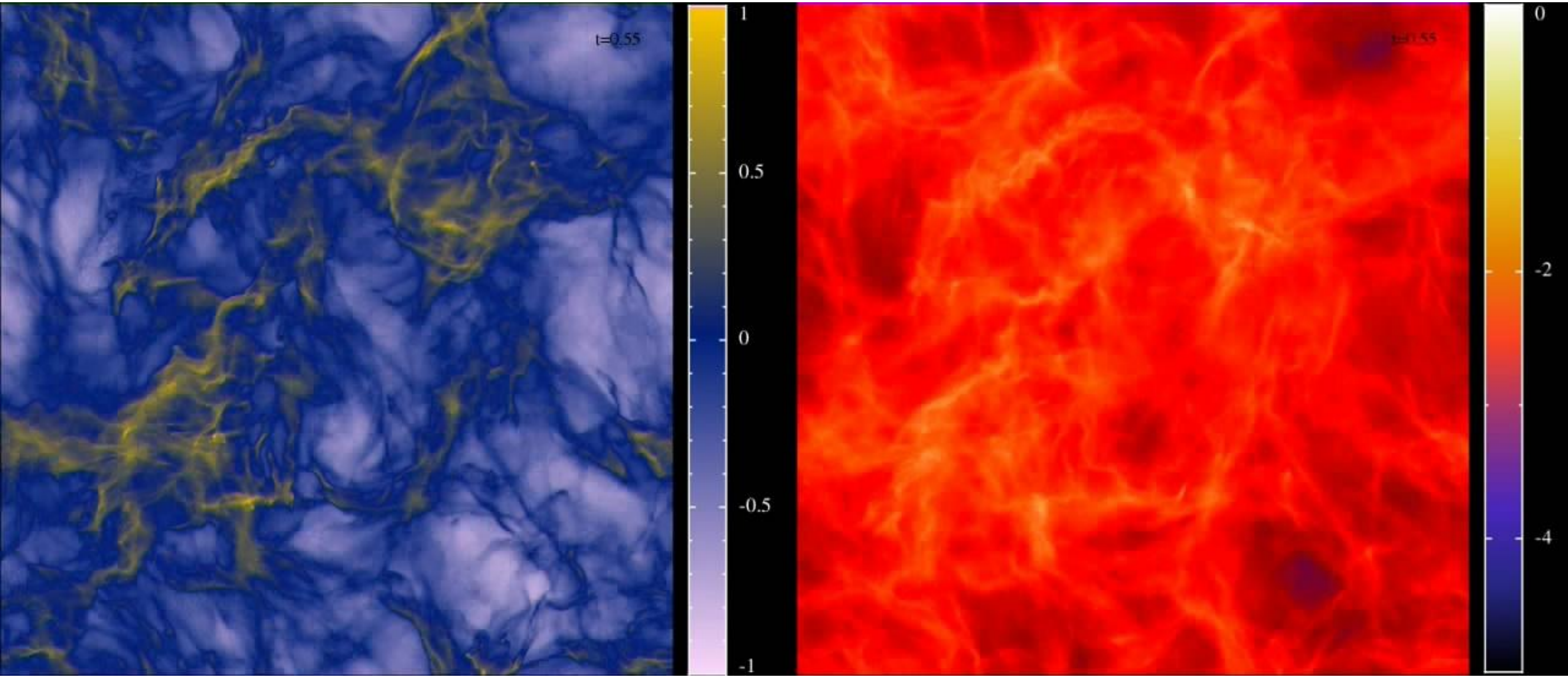




- ~2-8km/s, roughly equal to escape velocity
- ~<10° opening angle for jet
- ~40% of material is ejected

Supersonic MHD turbulence

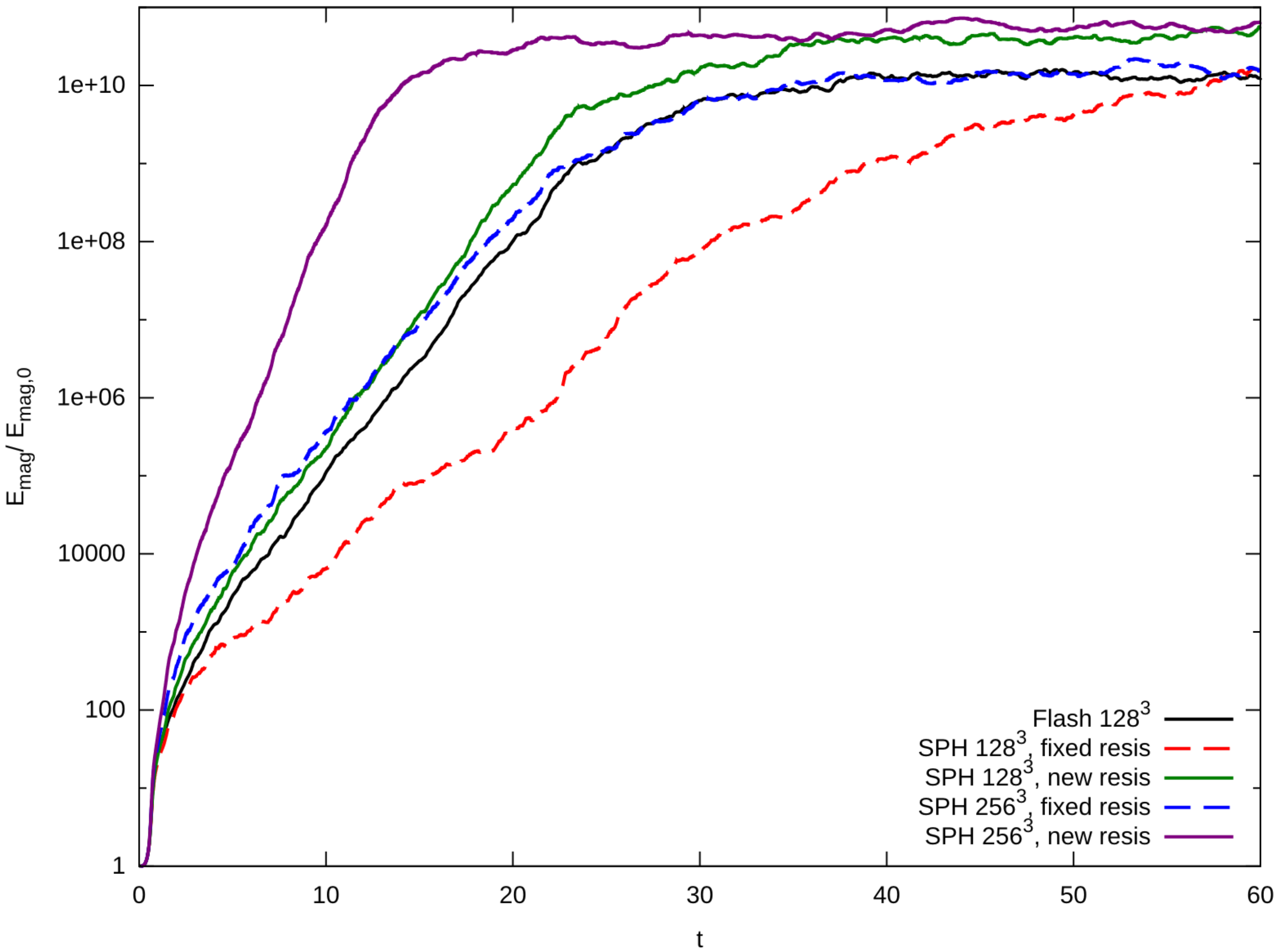
- Isothermal, driven Mach 10 turbulence
  - Initially weak magnetic field, $E_{magnetic}$ 10 orders of magnitude smaller than $E_{kinetic}$
  - Using new artificial resistivity switch that captures shocks for this wide range of field strengths
  - Results compared against grid based code Flash
- Extends 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 x10^{10}
  - Similar results to grid based code Flash
- New method enhancements for SPH MHD
  - Constrained divergence cleaning, reduces divergence error aprrox. 10x
  - Artificial resistivity switch for better treatment of magnetic shocks