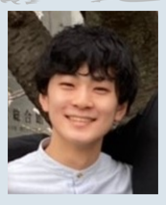
星形成理論構築に向けたフィラメント状分子雲の進化過程の研究



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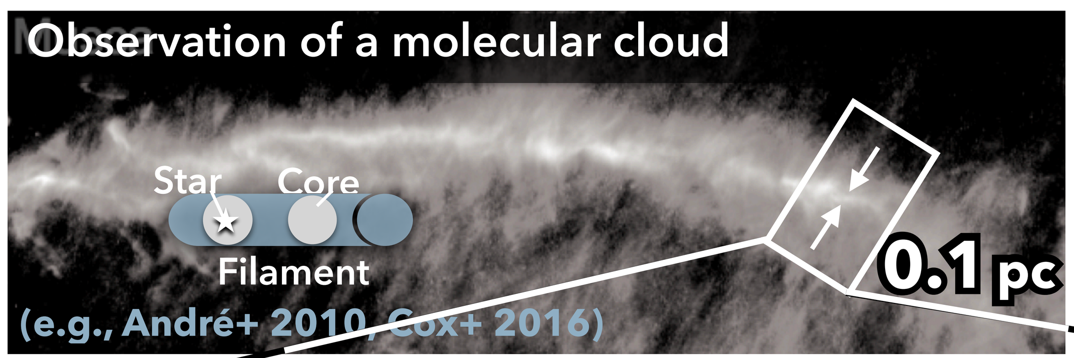
#EX24506

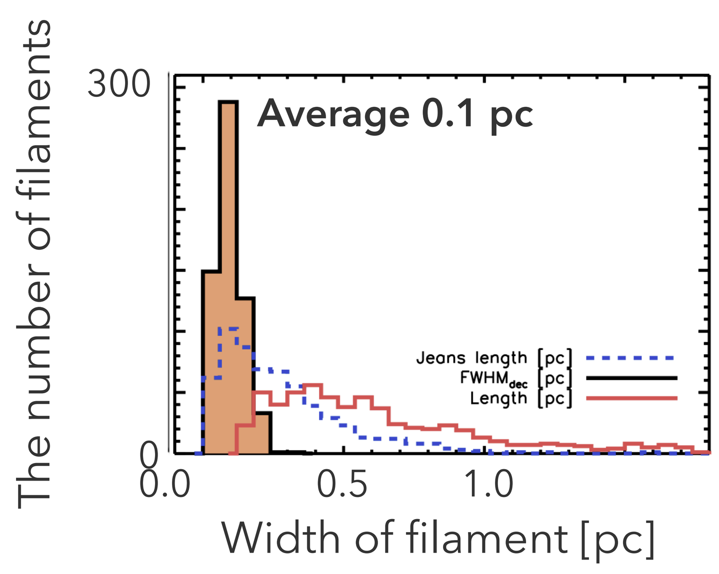
1. Introduction

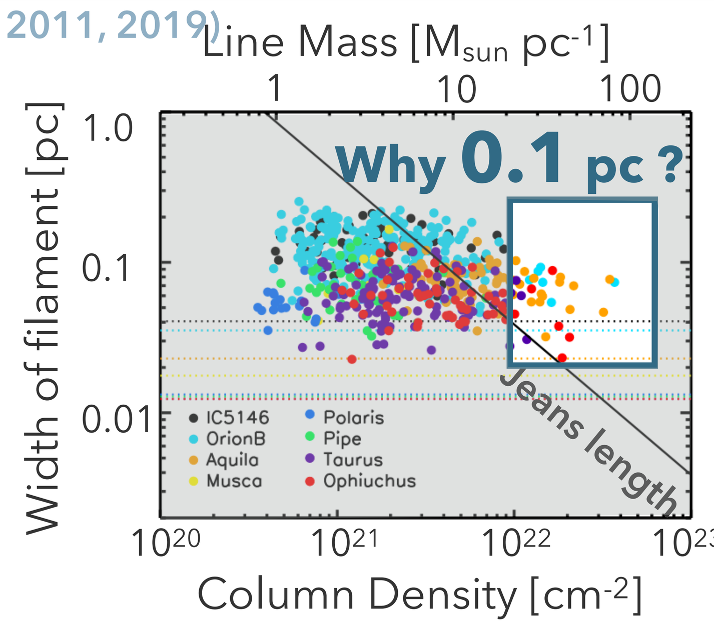
Stars are formed in dense filamentary molecular clouds.

The filament evolution process is important to understand **the initial conditions of star formation.**



The width of filaments (Arzoumanian+ 2011, 2019)





Filaments have a width of ~ **0.1 pc**

0.1 pc problem:

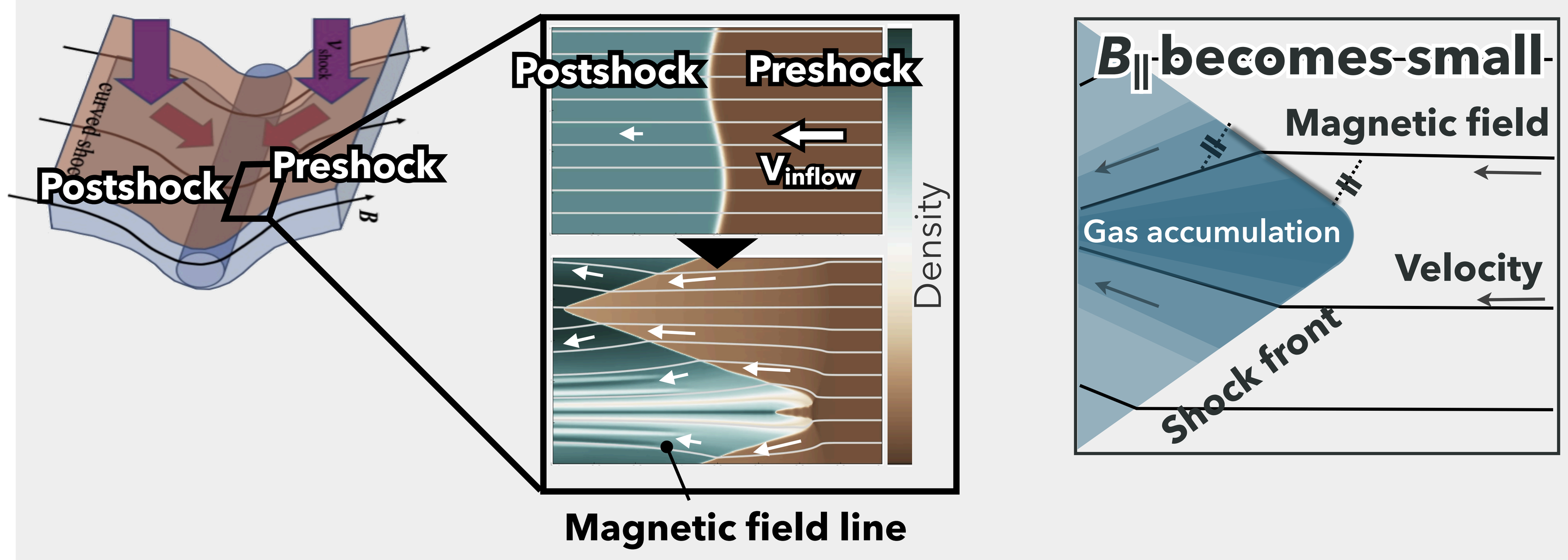
Most simulations show much narrower width due to strong gravity.

MHD Slow Mode Shock Instability at Filament Boundaries

Massive filaments are always bound by slow shocks that is known to be unstable.

Condition: Supersonic & Sub-Alfvénic

The front of Slow shock is unstable (SSI)
(e.g., Lesson & Deshpande 1967, Stone & Edelman 1995)



The maximum growth wavelength of the SSI is ~ 5 x (the length scale of **ambipolar diffusion**). (**Abe+ 2023 submitted to ApJ**)

Can instability-driven turbulence create ram pressure to sustain the 0.1 pc width?

2. Method: Non-ideal MHD Simulations

Simulations using Athena++ code (Stone+ 2020, Tomida & Stone 2023)

Isothermal MHD including **ambipolar diffusion (AD)** w, w/o self-gravity

$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho \boldsymbol{v}) = 0$$

$$\frac{\partial \rho \boldsymbol{v}}{\partial t} + \nabla\cdot(\rho \boldsymbol{v}\boldsymbol{v} - \boldsymbol{B}\boldsymbol{B} + P + B^2/2) = 0$$

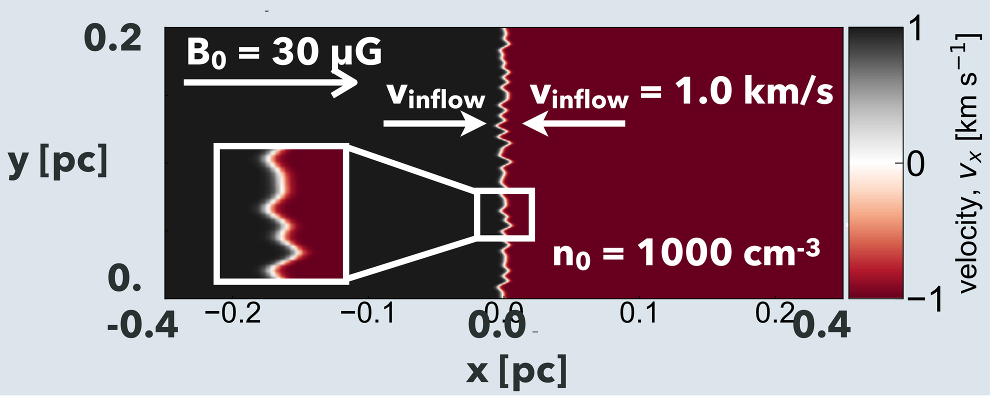
$$\frac{\partial E}{\partial t} + \nabla\cdot\left[(E + P + B^2/2)\boldsymbol{v} - \boldsymbol{B}(\boldsymbol{B}\cdot\boldsymbol{v}) + \underbrace{\frac{\eta_{\rm AD}}{|\boldsymbol{B}|^2}(\boldsymbol{B}\times(\boldsymbol{J}\times\boldsymbol{B}))\times\boldsymbol{B}}_{\rm AD}\right] = 0$$

$$E = e + \frac{1}{2}\rho v^2 + \frac{B^2}{2} \qquad P = (\gamma - 1)e \qquad \gamma = 1.01$$

$$\frac{\partial \boldsymbol{B}}{\partial t} - \nabla\times\left[(\boldsymbol{v}\times\boldsymbol{B}) - \underbrace{\frac{\eta_{\rm AD}}{|\boldsymbol{B}|^2}\boldsymbol{B}\times((\nabla\times\boldsymbol{B})\times\boldsymbol{B})}_{\rm AD}\right] = 0$$

$$\eta_{\rm AD} = \frac{B^2}{4\pi\gamma_{\rm in}\rho_{\rm n}\rho_{\rm i}}$$ (Shu 1992)

Initial Condition: Gas inflows along the B field –> filament formation



Boundary Condition
- x–> gas continue to flow in
- y–> Periodic

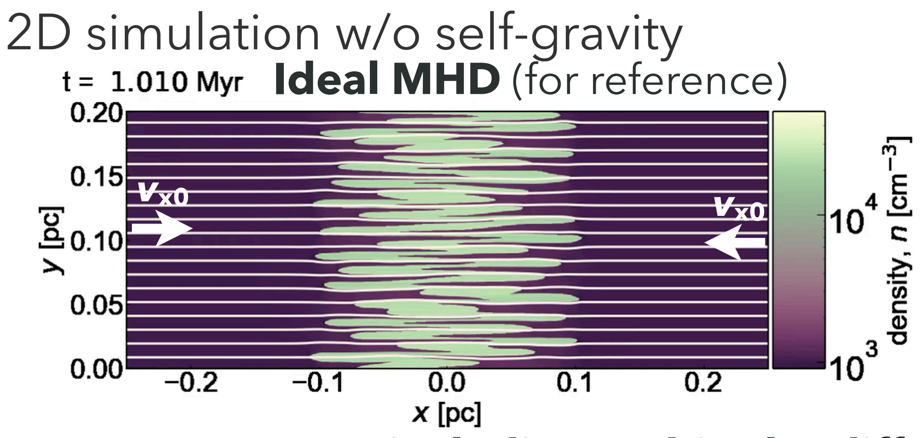
$c_s = 0.2$ km/s

Resolution : 3.9 x 10^{-4} pc

3. Results

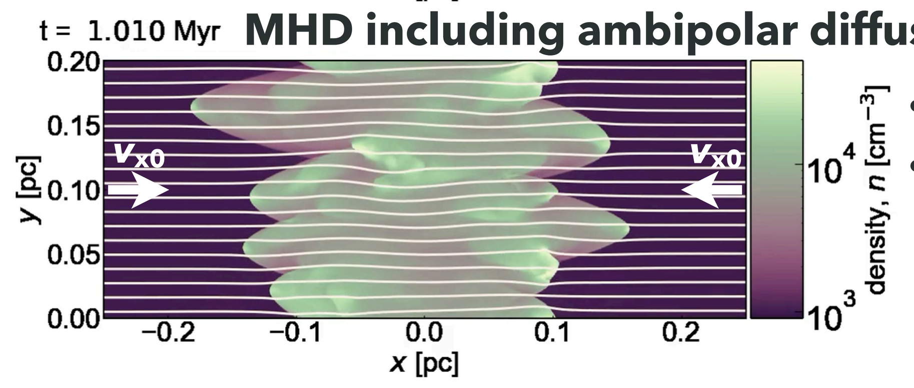
2D simulation w/o self-gravity

Ideal MHD (for reference)



- SSI causes shock front corrugation.
- **No turbulence**

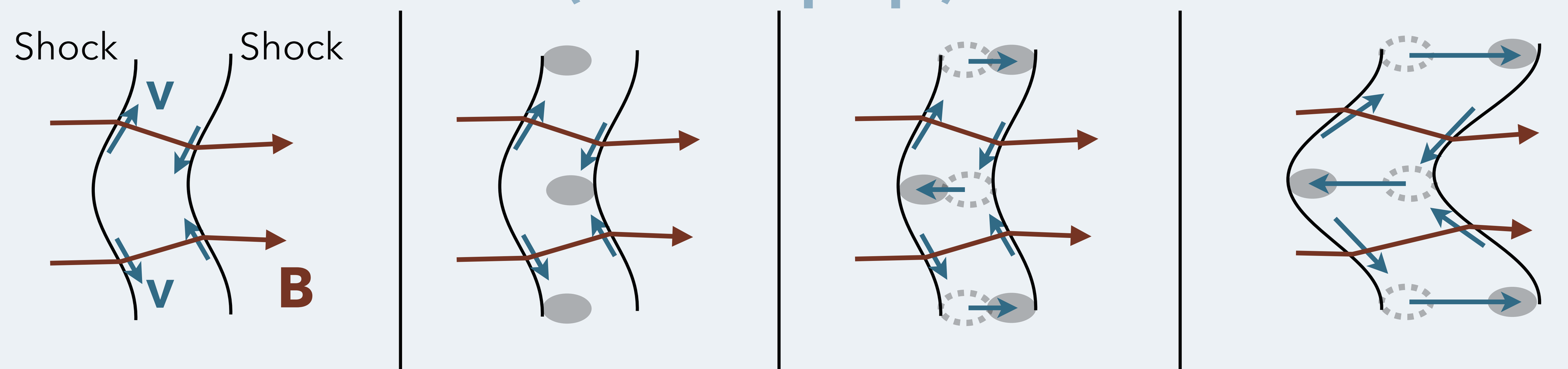
MHD including ambipolar diffusion



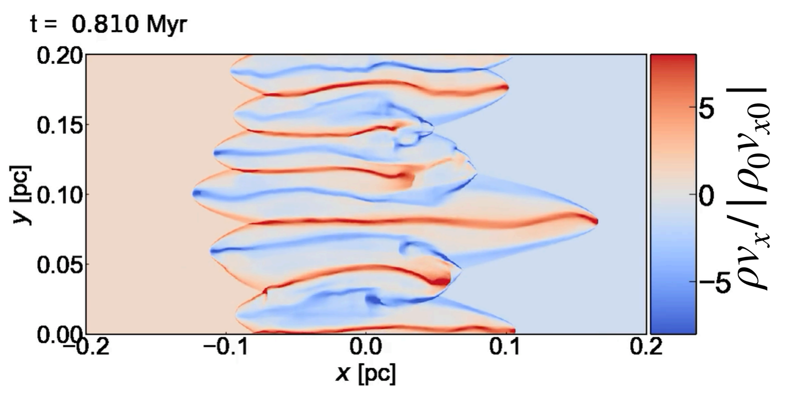
- **More turbulent** than ideal MHD case
- Turbulent pressure makes **wider** shock bound region.
  –> **Generation of Additional pressure**

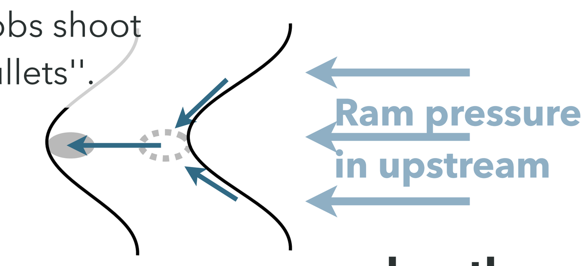
What's going on in at the shock in the AD case?

New filament width maintaining mechanism
"Bullet Mechanism" (Abe+ in prep.)



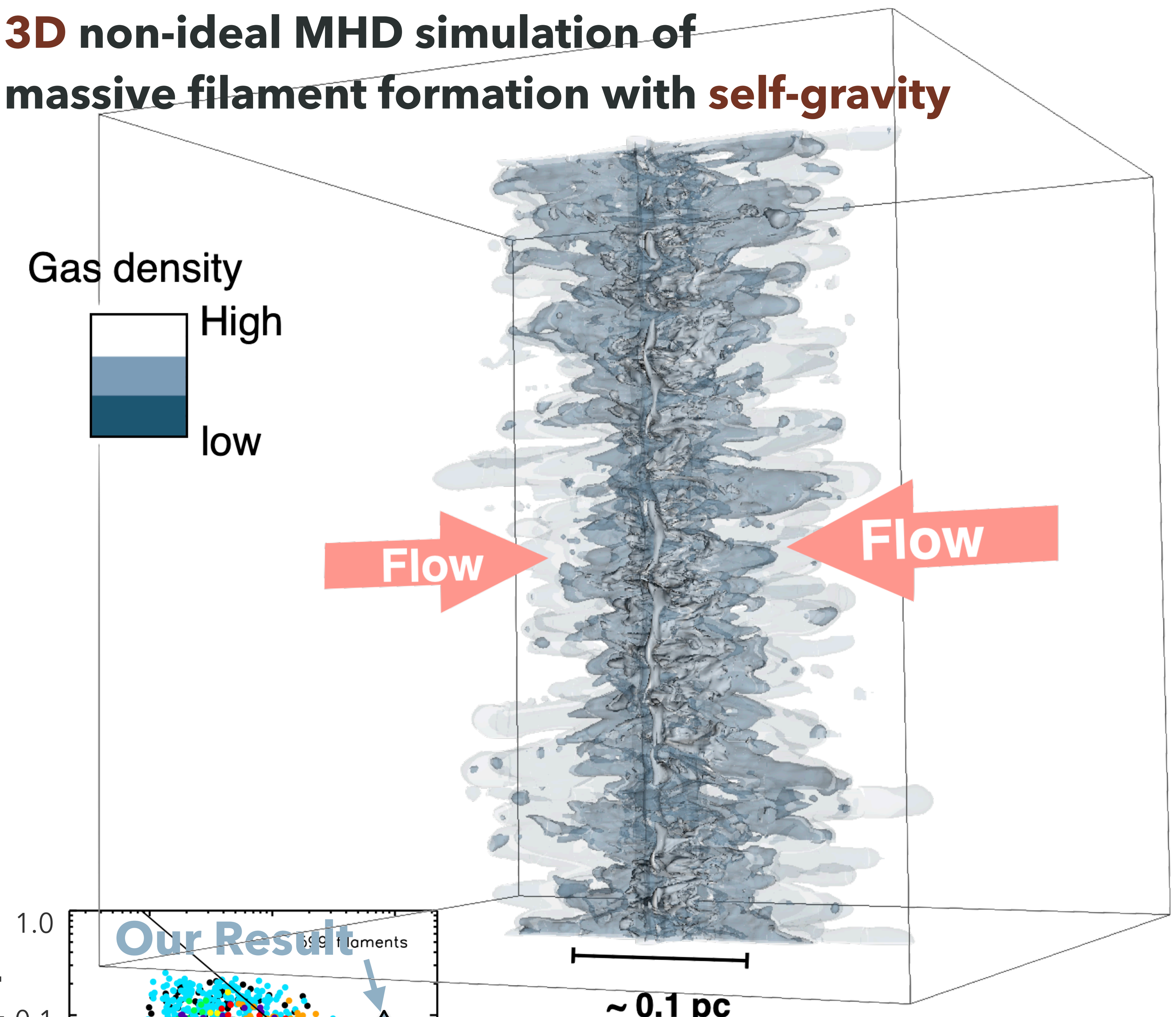
1. **AD** permits the flow along the shock fronts
2. Gas accumulates in valleys.
3. Momentum transport
4. Magnitude of corrugation grows

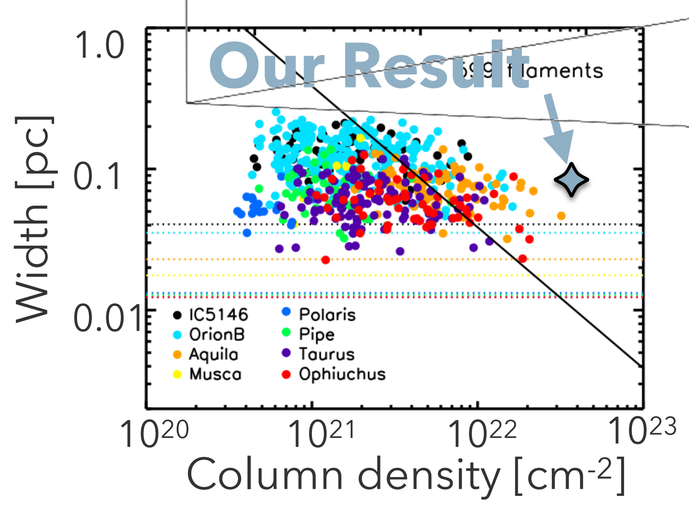




Upstream ram pressure pushes the opposite shock wave

3D non-ideal MHD simulation of massive filament formation with self-gravity





Width is consistent with observations

Ambipolar diffusion mediate SSI drives anisotropic turbulence in massive filament!

Summary

We perform non-ideal MHD simulations and investigate filament evolution to understand the origin of 0.1 pc filament width.

"Anisotropic turbulence driven by the Bullet mechanism (SSI with ambipolar diffusion)" can maintain the width of massive filaments.