Formation Of Massive Stars

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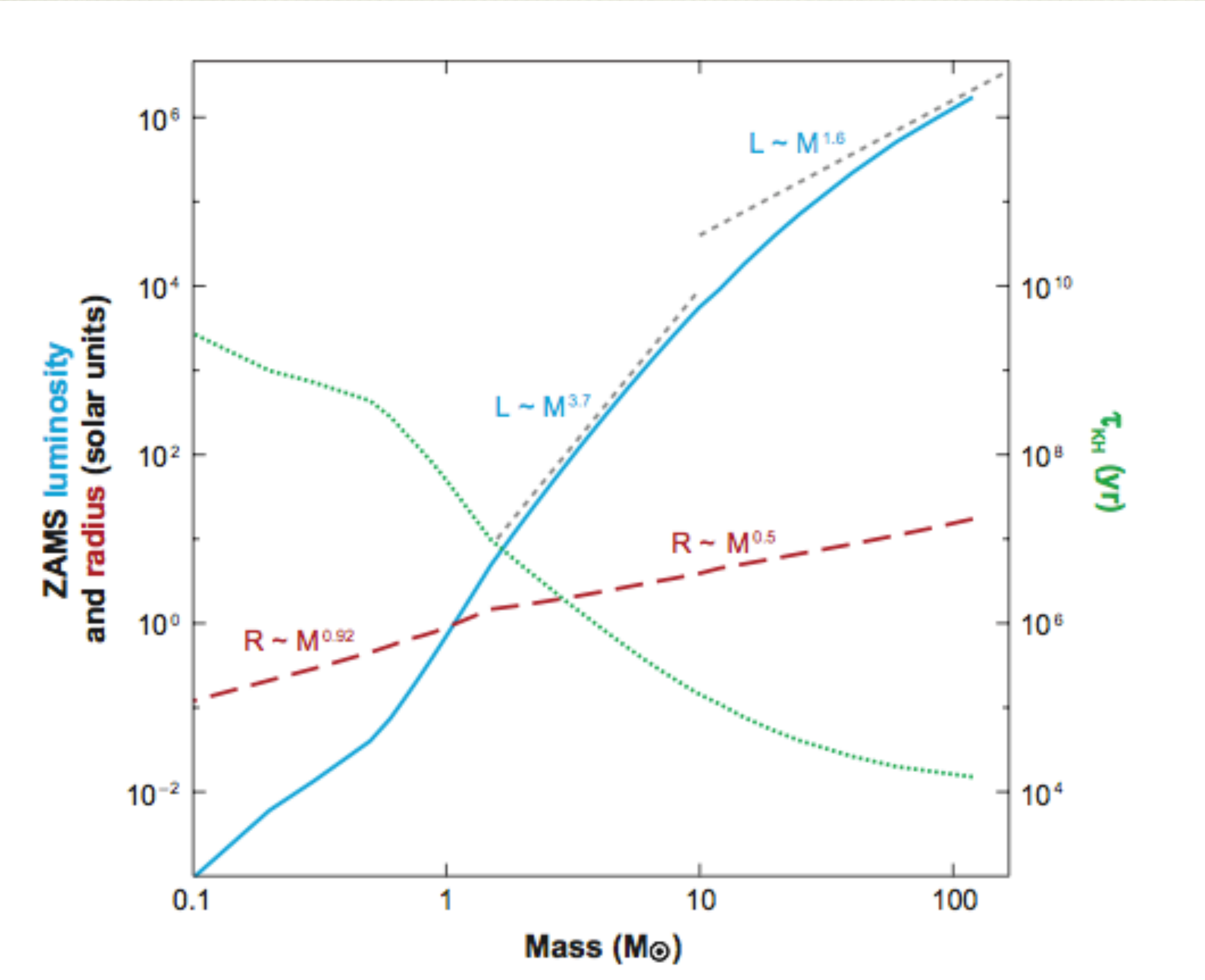
Outline

- Why massive stars are interesting?
- The issue with radiation pressure
- How does the accretion happen?
- The issue with fragmentation

Importance of Massive Stars

- Here massive stars mean stars with mass larger than 10 solar mass.
- Sources of strong ionization UV photons.
- Source of strong kinetic energy to affect the ISM.
- Source of heavy elements.

Properties of Massive Stars



- Large luminosity
- Short KH time scale.

Zinnecker & Yorke (2007)

Why radiation matters?

- Massive stars are radiation supported
  - Eddington model

$$\frac{M}{M_\odot} = \frac{18.1}{\mu^2}\,\frac{(1-\beta)^{1/2}}{\beta^2}.$$

$$\beta \equiv \frac{P_g}{P}$$

- Eddington limit for the 1D spherical case

$$L_*/M_* = 4\pi c G/\bar{\kappa}$$

  - For dust opacity, the critical mass is ~15 solar mass
  - For electron scattering opacity, the critical mass is over 200 solar mass.

Bodenheimer (2011)

Mass limit based on 1D modeling

Larson & Starrfield (1971)
Kahn (1974)

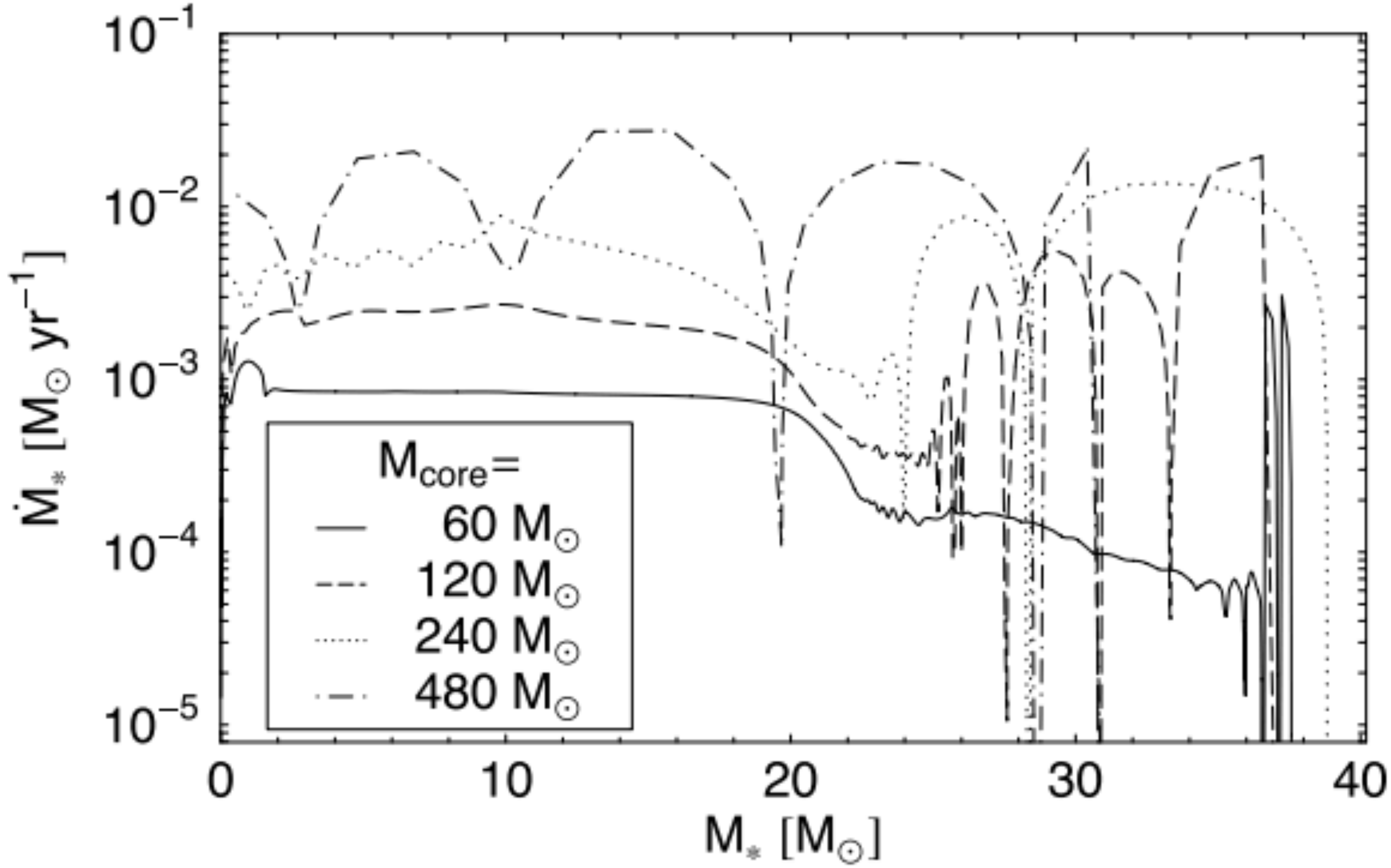
- Radiation versus ram pressure

$$\frac{L/4\pi r^2 c}{\rho u^2} \approx 1.3\times10^{-11}\frac{L/L_S}{(M/M_S)^{1/2}}r^{1/2}$$

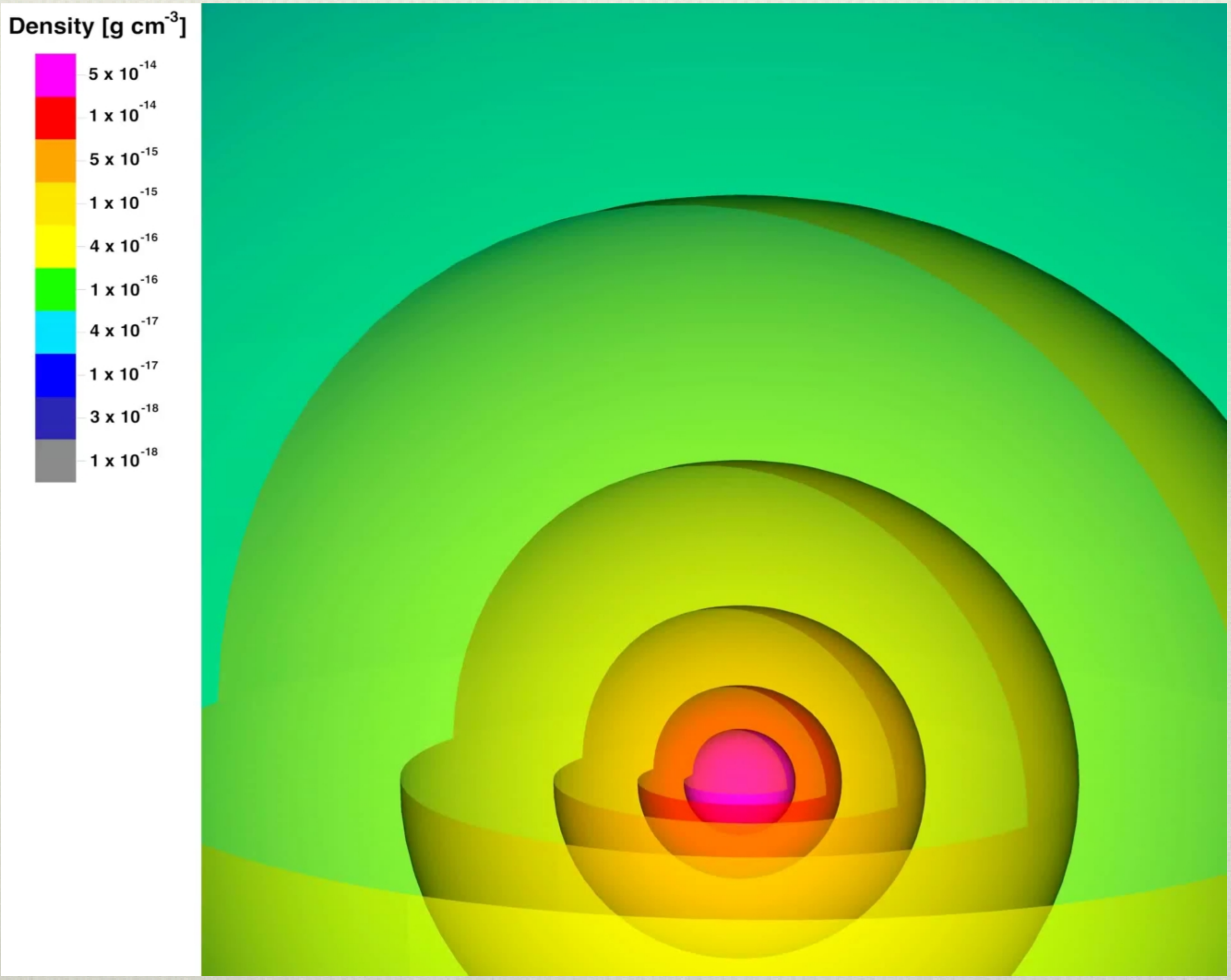
  - The radius is taken to be the shell where grains evaporate at temperature ~1500 K
  - The mass limit is calculated to be ~20 - 40 solar mass
- This is confirmed by recent 1D simulations (Kuiper et al. 2010)

Episodic Accretion in 1D

Kuiper et al. (2010)



Solution for Accretion: Flashlight effect

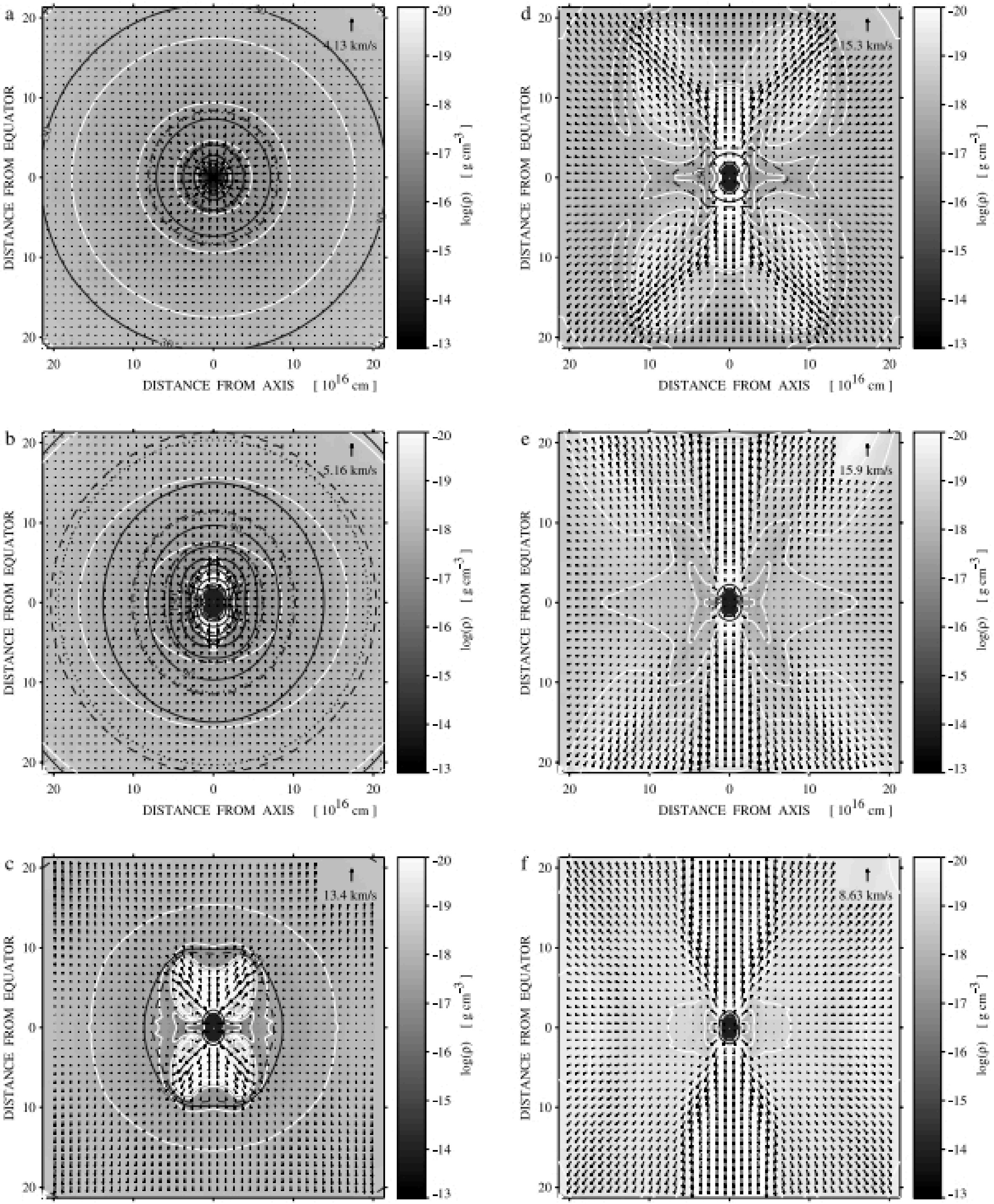


Kuiper et al. (2012)

Anisotropy of the Disk

Yorke & Bodenheimer (1999)

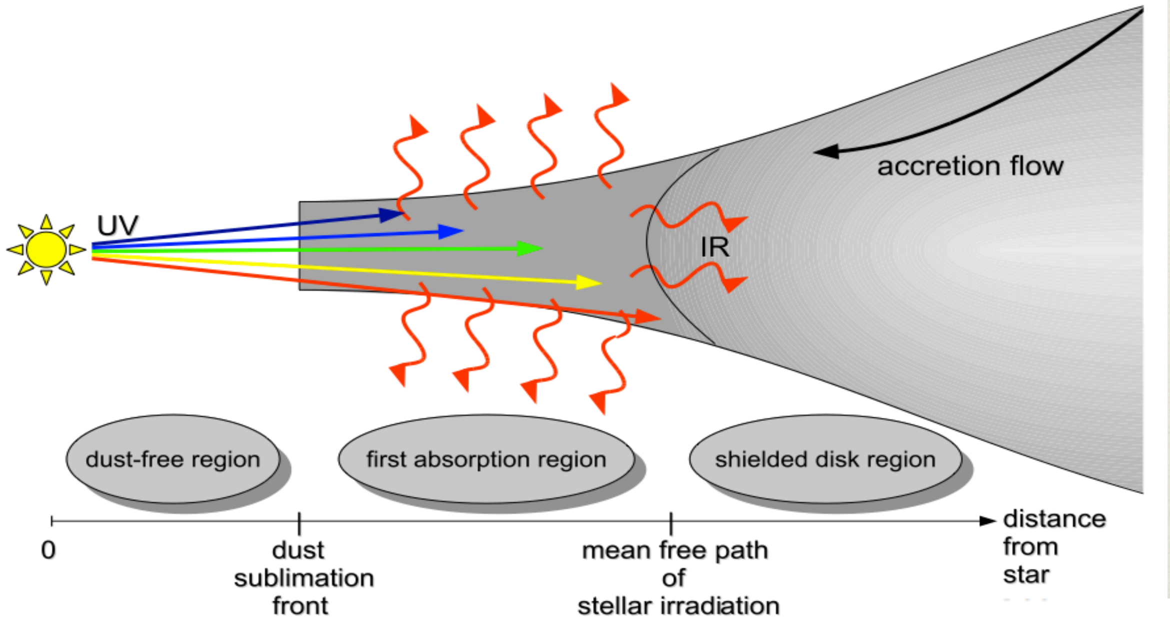
- First, collapse nearly spherically
- Then, matter piles up in the equatorial plan due to centrifugal force
- Optical depth is larger in the equatorial plane than alone the pole
- Photons escape alone the pole and radiation pressure is reduced.



Yorke & Sonnhalter (2002)

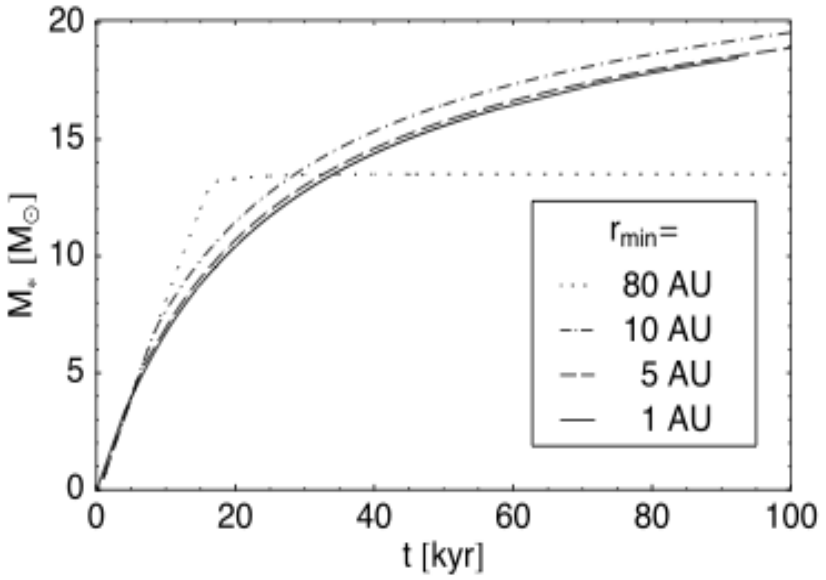
- 2D, frequency dependent
- Formation of outflow alone the pole
- Final mass is 33 solar mass.

Resolve Dust Free Region



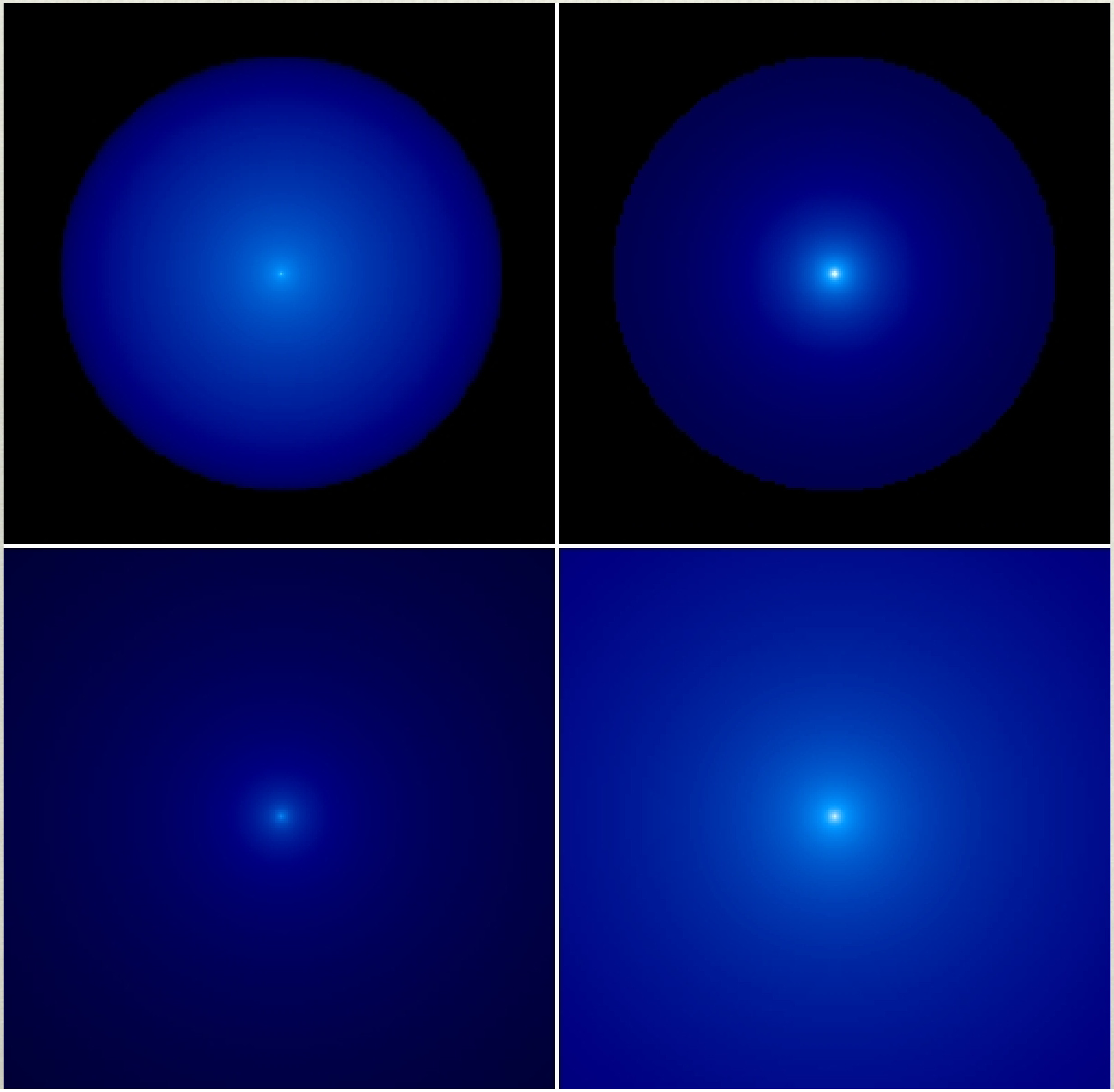
Kuiper et al. (2010)

- When the size of the sink cell is too large, anisotropy of the radiation field is under-estimated, which stops the accretion.



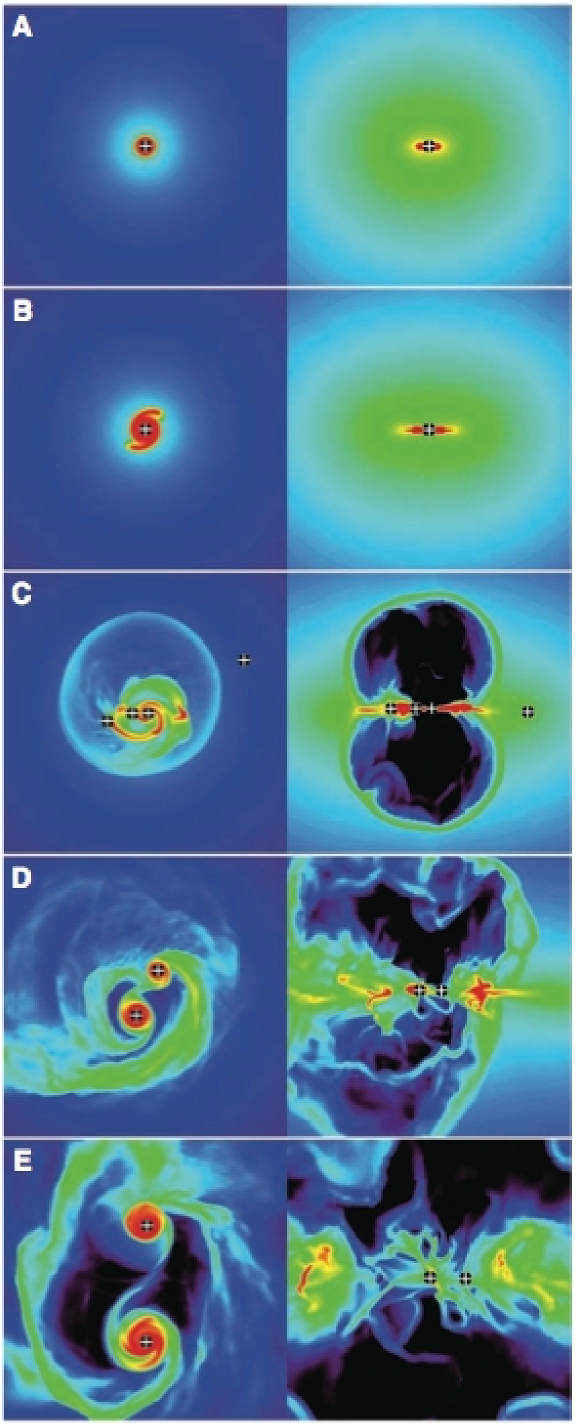
Accretion Due to Rayleigh-Taylor Instability?

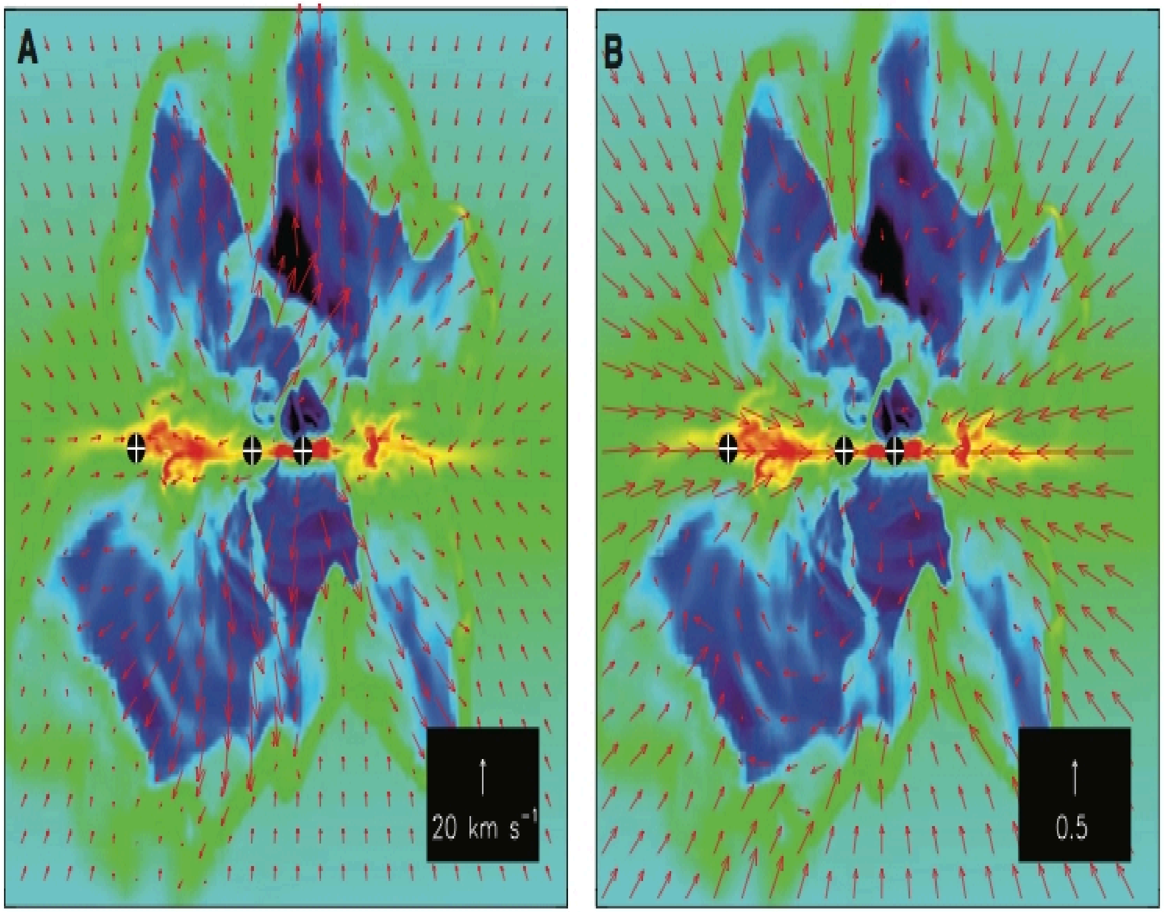
Krumholz et al. (2009)



0.25 pc by 0.25 pc

4000 AU by 4000 AU



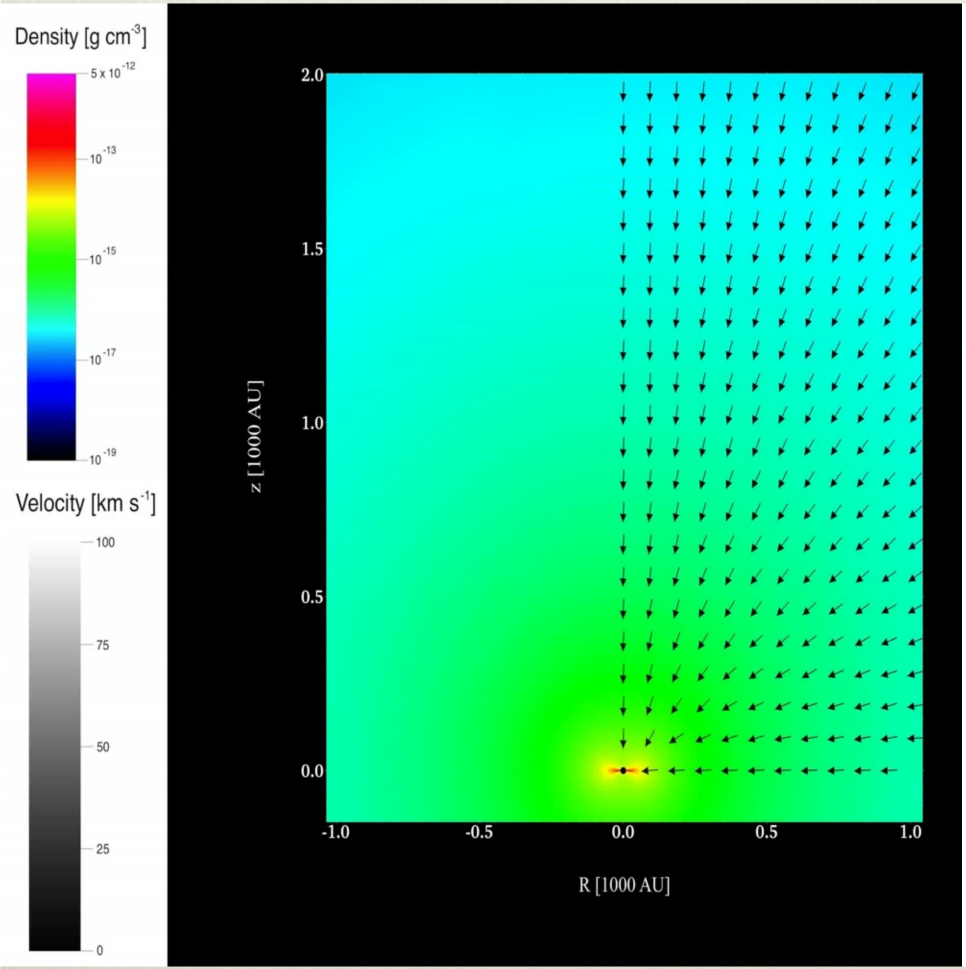


Velocity Field

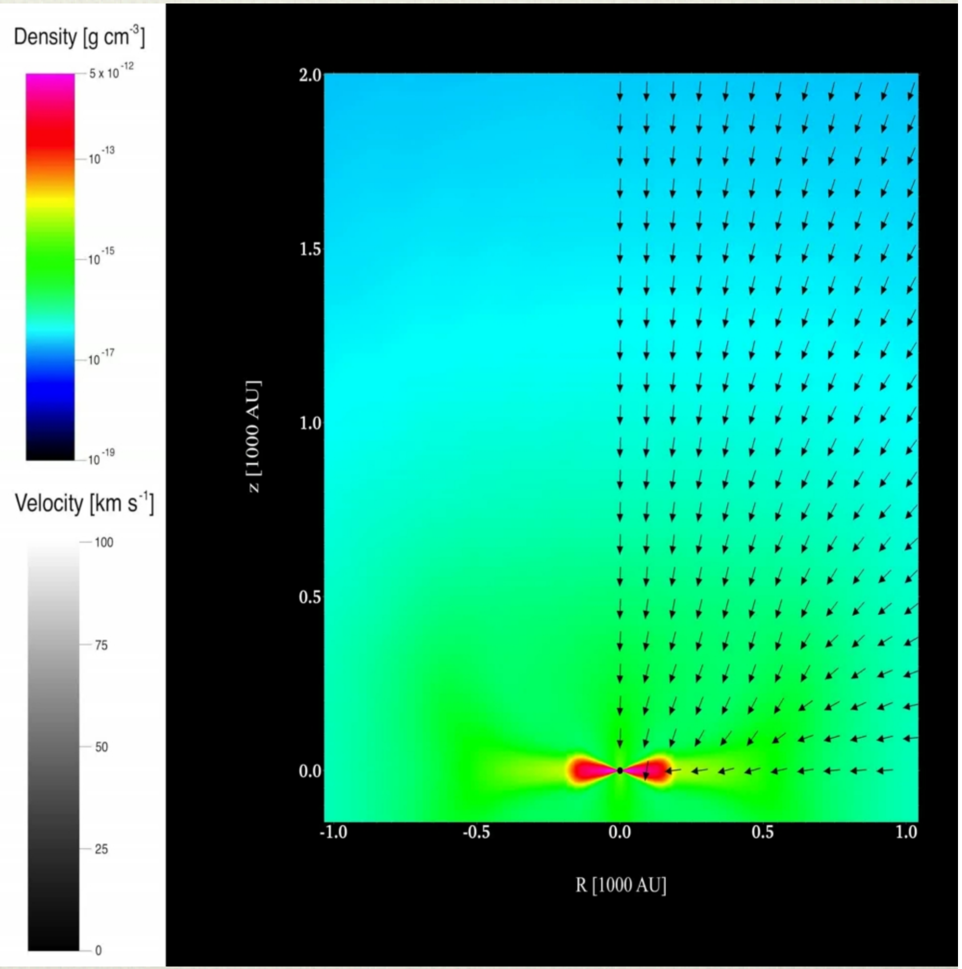
Net force

Results Depends on the Numerical Algorithm

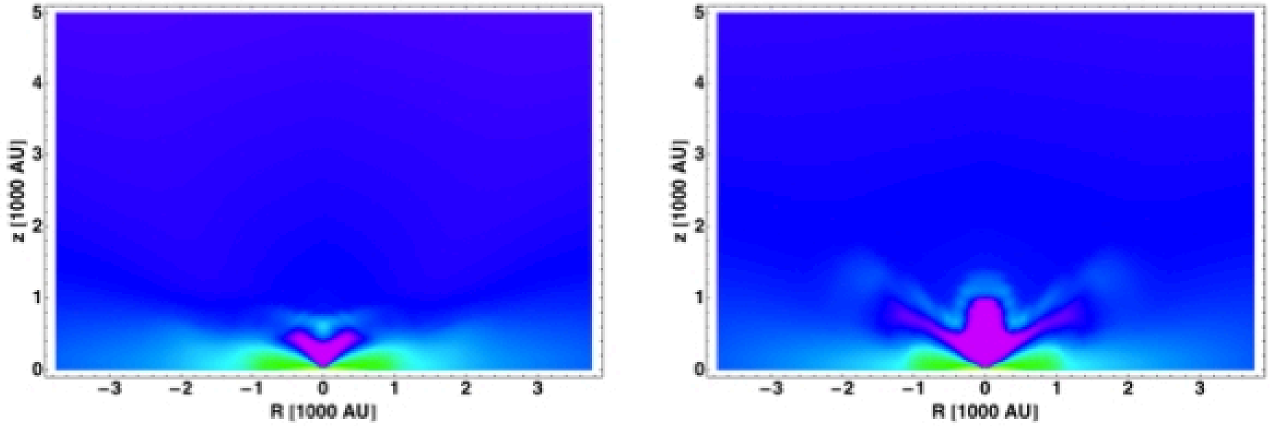
Kuiper et al. (2012)



FLD

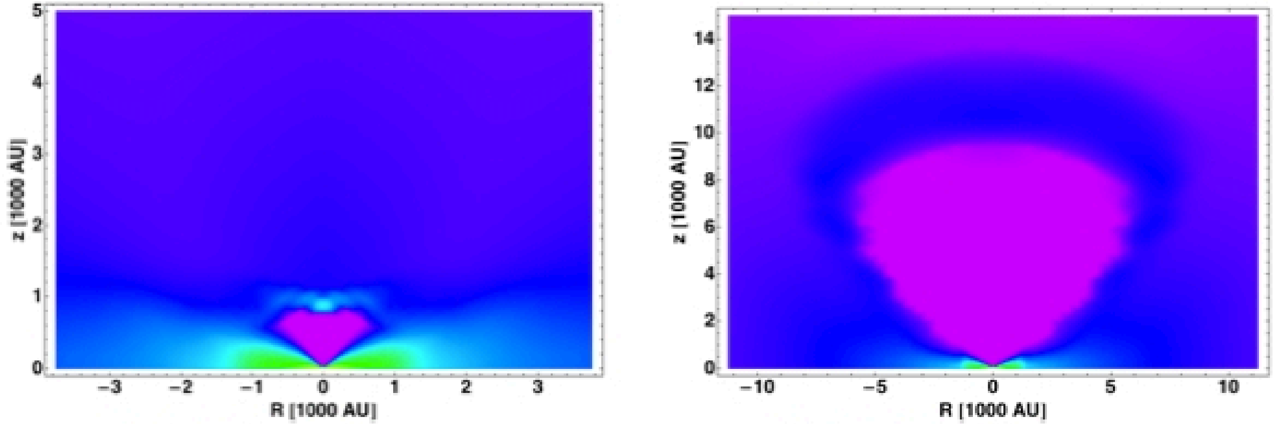


Hybrid method



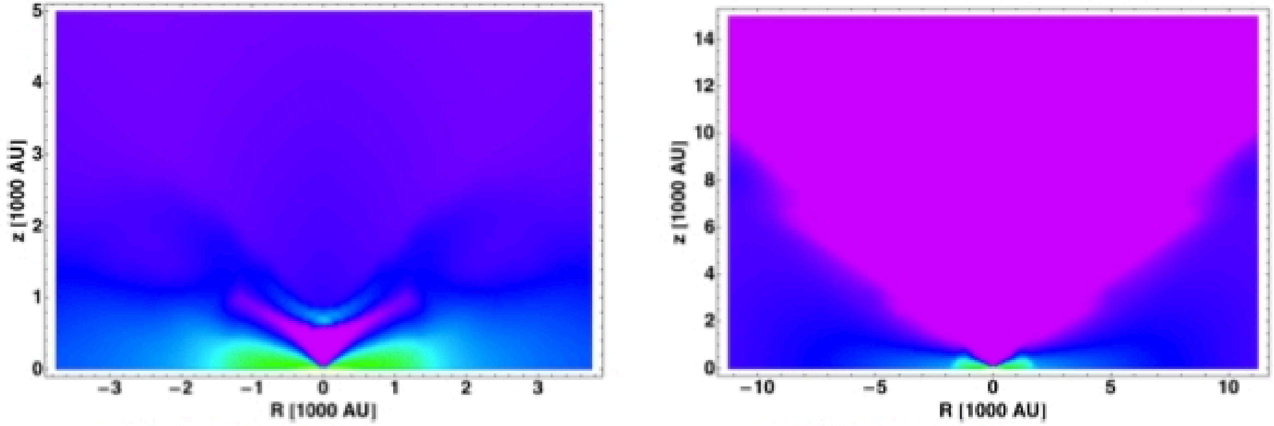
(a) FLD run at $t = 44$ kyr

(b) RT+FLD run at $t = 39$ kyr



(c) FLD run at $t = 49$ kyr

(d) RT+FLD run at $t = 44$ kyr



(e) FLD run at $t = 54$ kyr

(f) RT+FLD run at $t = 49$ kyr

FLD, grey approximation under estimate the opacity,
And thus the acceleration
Due to stellar irradiation.

Core Fragmentation

Also see Wendy's talk

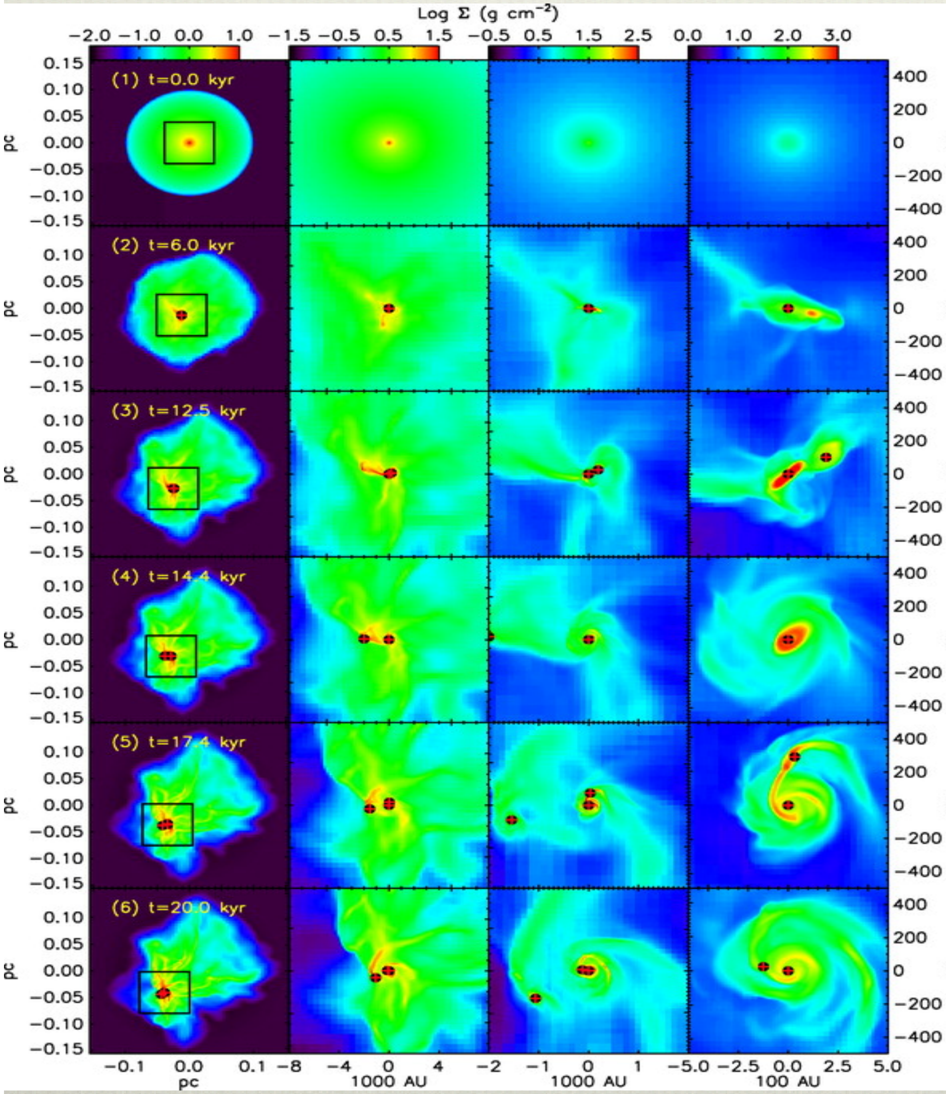
$$Q \equiv \frac{c_s \Omega}{\pi G \Sigma} < Q_{\mathrm{crit}} \simeq 1$$

- Massive cores can fragment:
  - Binary stars can be formed
  - Limit the mass of the massive stars
- The effects of radiation/magnetic field on the fragmentation.
- All the studies on the fragmentation will assume a dense, high mass core to start with.

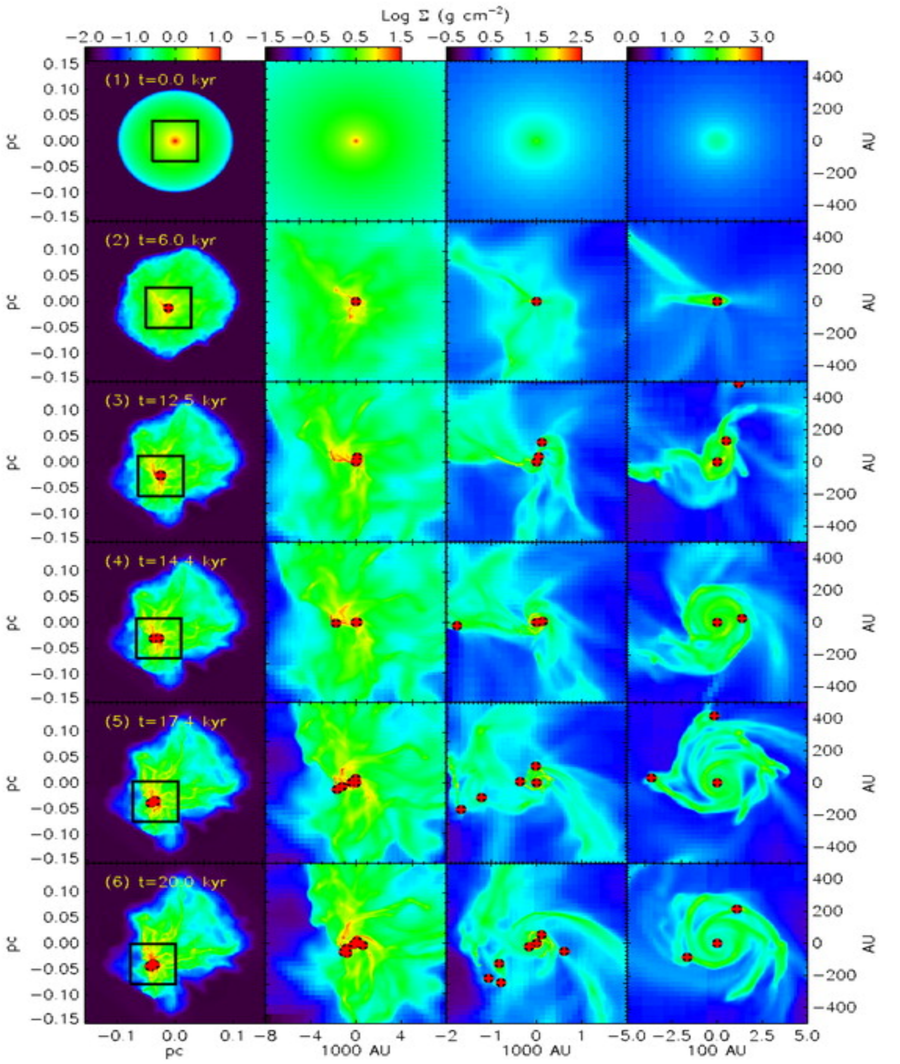
Radiation Feedback Reduces Fragmentation

Krumholz et al. (2007)

Also see Simone’s talk



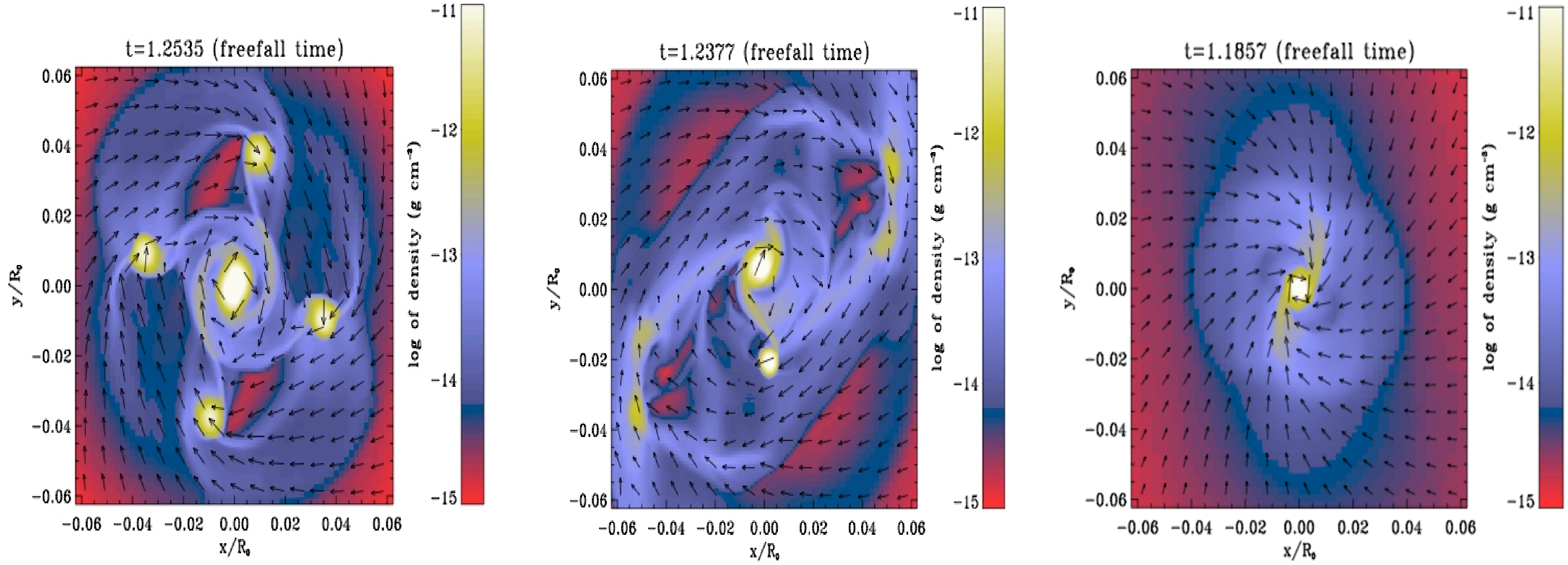
Radiation Transfer



Isothermal

Effects of Magnetic Field

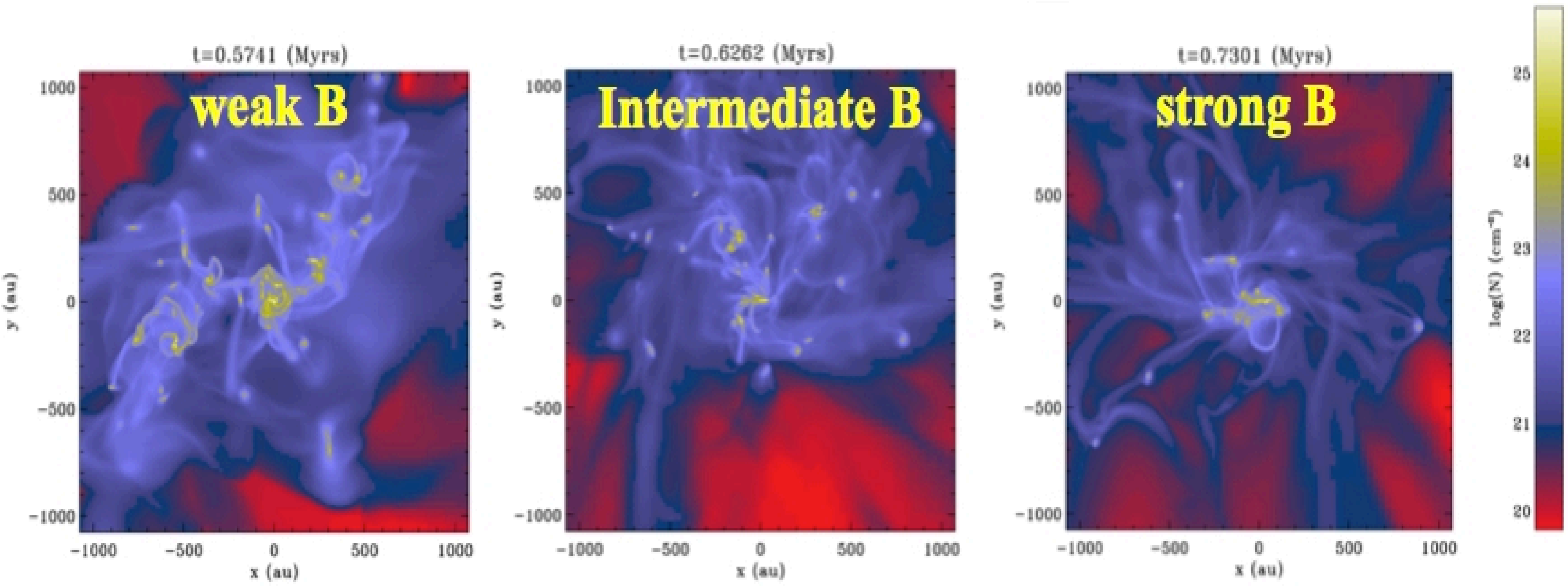
Hennebelle & Teyssie (2008)



Hydro Weak Strong

When the turbulence is weak, strong magnetic field can prevent fragmentation.

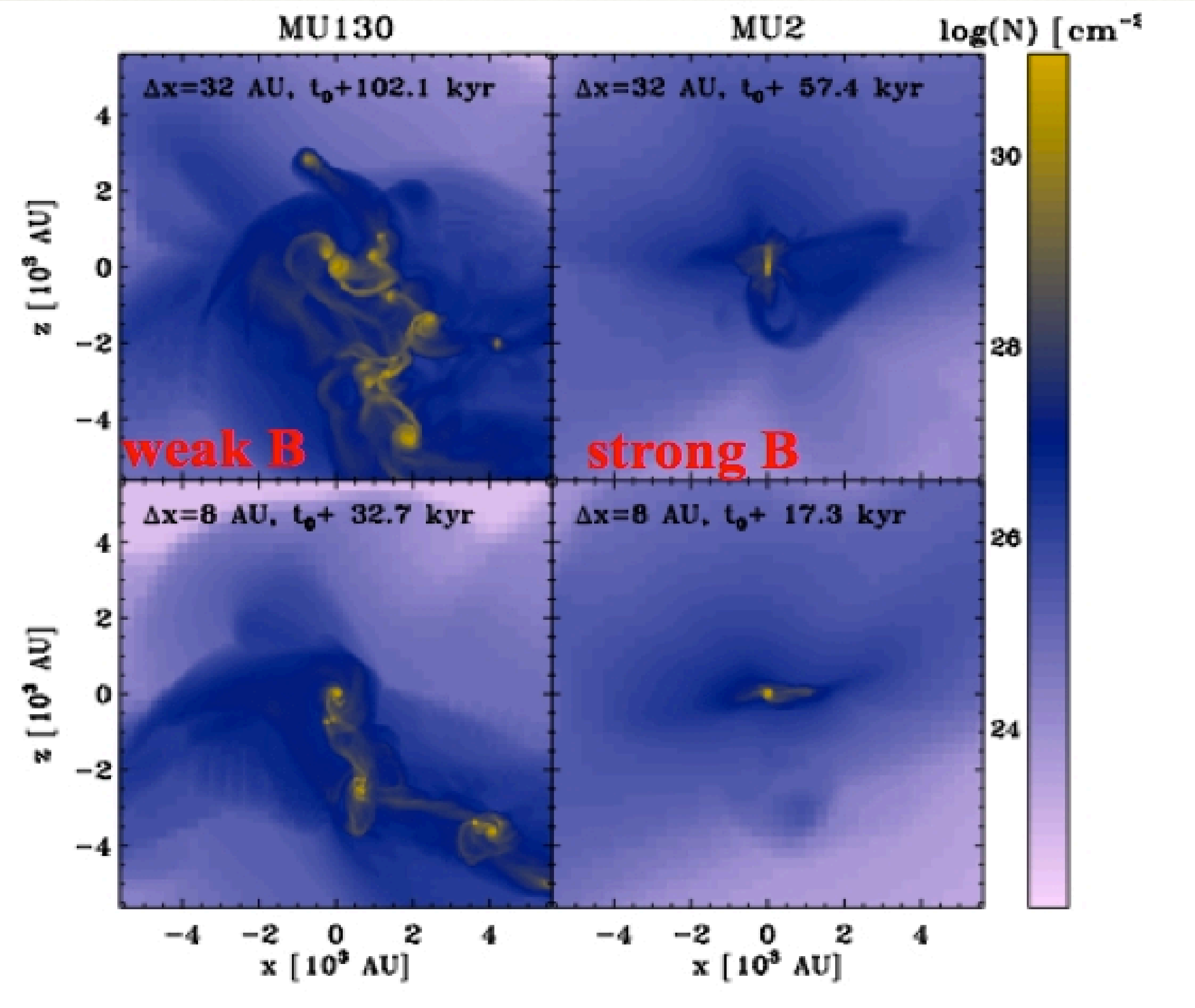
With turbulence, strong magnetic field affects, but not prevent, fragmentation.



μ=120 μ=5 μ=2

Hennebelle et al. (2011)

Effects of Radiation + magnetic field



Commercon et al. (2011)

- Magnetic fields increase the effect of radiation
- Strong magnetic field plus radiation can suppress fragmentation.

Summary

- Flashlight effects can get around the radiation barrier to form massive stars.
- Whether Radiation Rayleigh-Taylor instability play a major role during the formation of massive stars is still under debate.
- Radiation feedback or strong magnetic field can reduce fragmentation.
- Radiation feedback and magnetic field can amplify the effects of each other and suppress fragmentation.

References

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