Feedback in star-forming regions

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Motivation

Current paradigm: star formation regulated by supersonic turbulence (Mordecai's talk)

- What drives the turbulence?
  (driven inside star forming regions
  → self-regulated star formation?)
- What determines the **low** star formation efficiency?
- What **stops** star formation?

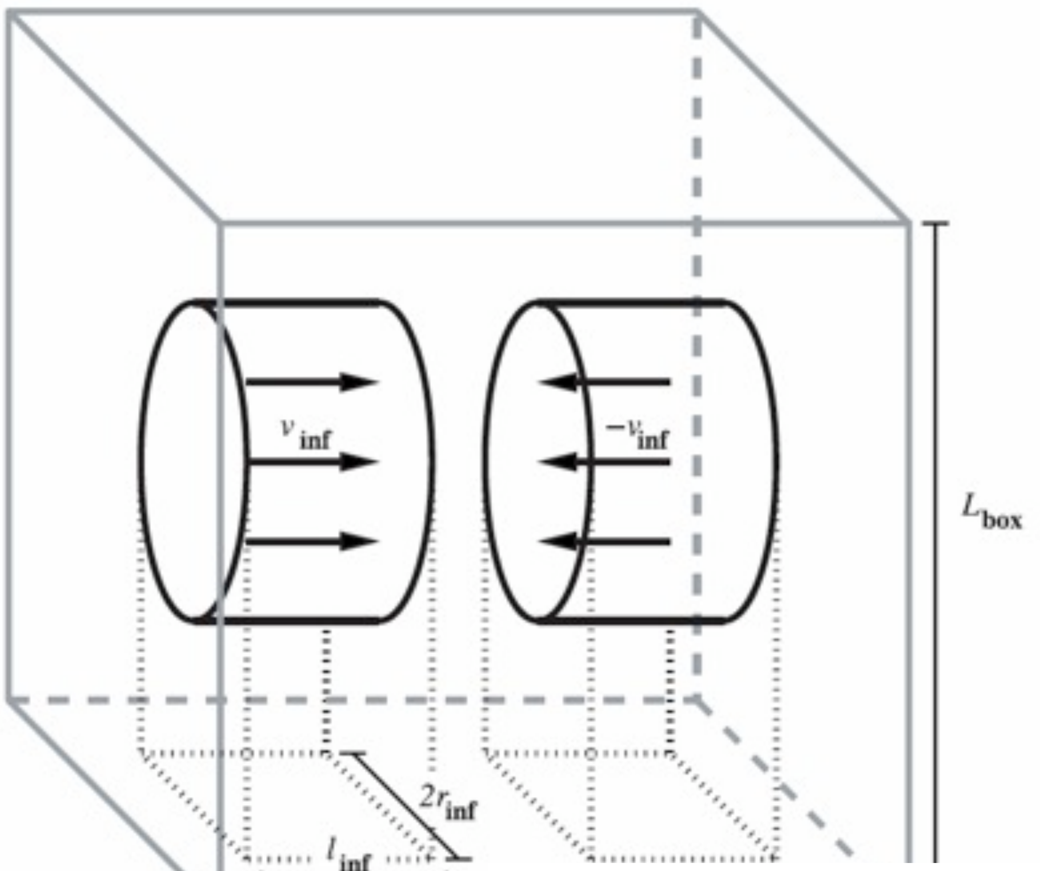
FEEDBACK?

Magnetic Fields

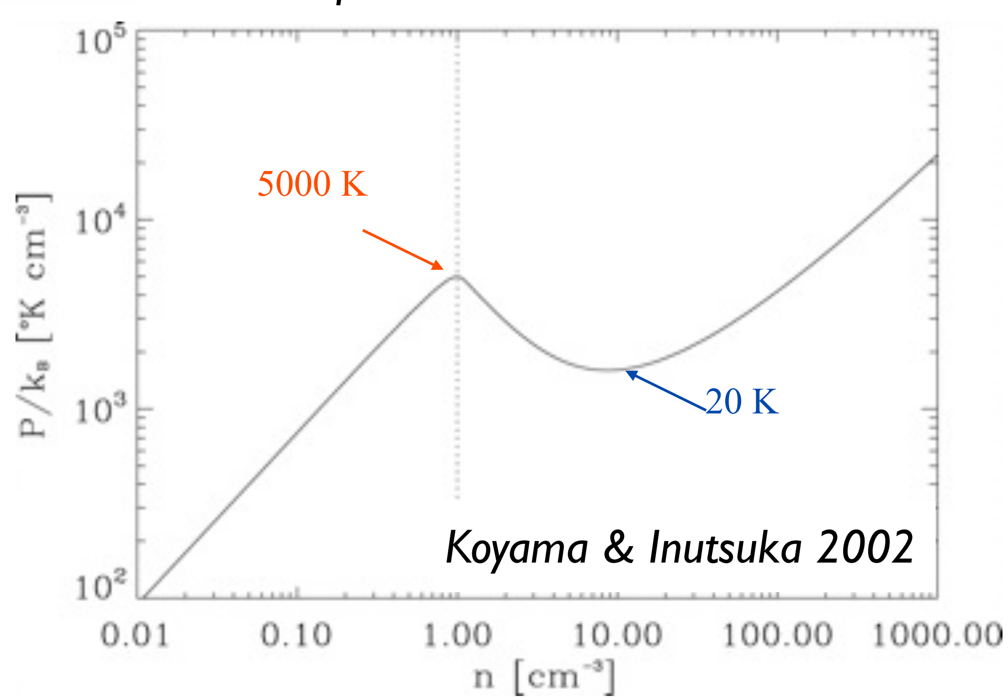
- What is the influence of magnetic fields on the star formation efficiency?
- Is star formation initiated by **ambipolar diffusion**?

Molecular Cloud Evolution

3D simulations with AMR code FLASH



from *Vazquez-Semadeni et al. 2007*



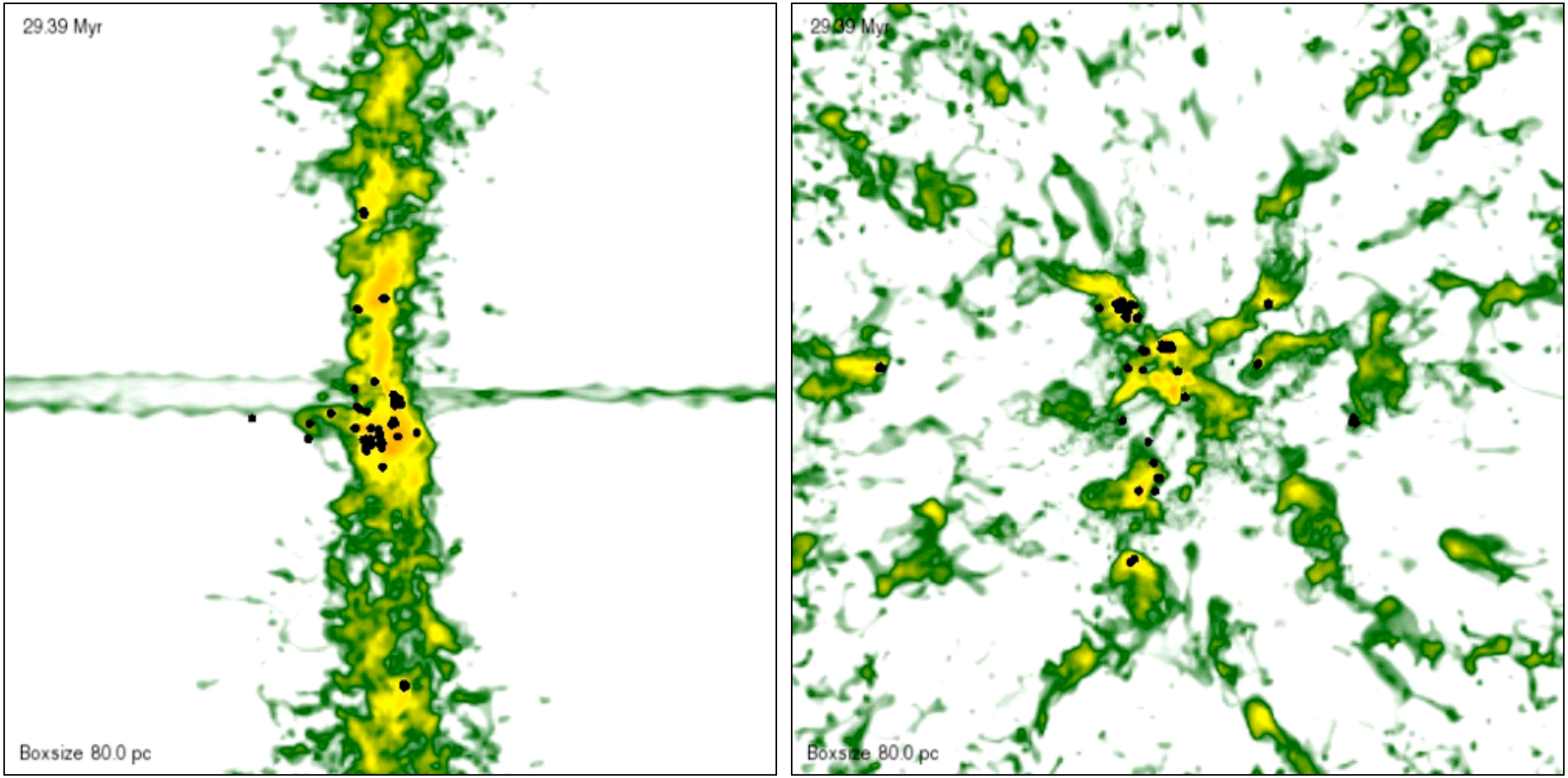
Large scale converging flows

Model parameter:

- $L_{box} = 256$ pc, $\Delta x_{min} = 0.03$ pc
- $l_{inf} = 112$ pc, $r_{inf} = 32$ pc
- $v_{inf} = 13.9$ km/sec $= 2.44\ M_a$
- density: $n = 1\ cm^{-3}$
- $M_{inf} = 2.3 \times 10^4\ M_{sol}$
- $T = 5000$ K
- $M_J = 10^7\ M_{sol}$
- $B_x = 1\text{-}4\mu G$ aligned with the flow
- $\beta = 17.3\ (B/1\mu G)^{-2}$
- $\mu = 2.7\ (B/1\mu G)^{-1}\ \mu_{crit}$
- $t_{crit} = 5.4$ Myr $(B/1\mu G)$

Molecular Cloud Evolution

the non-magnetic case



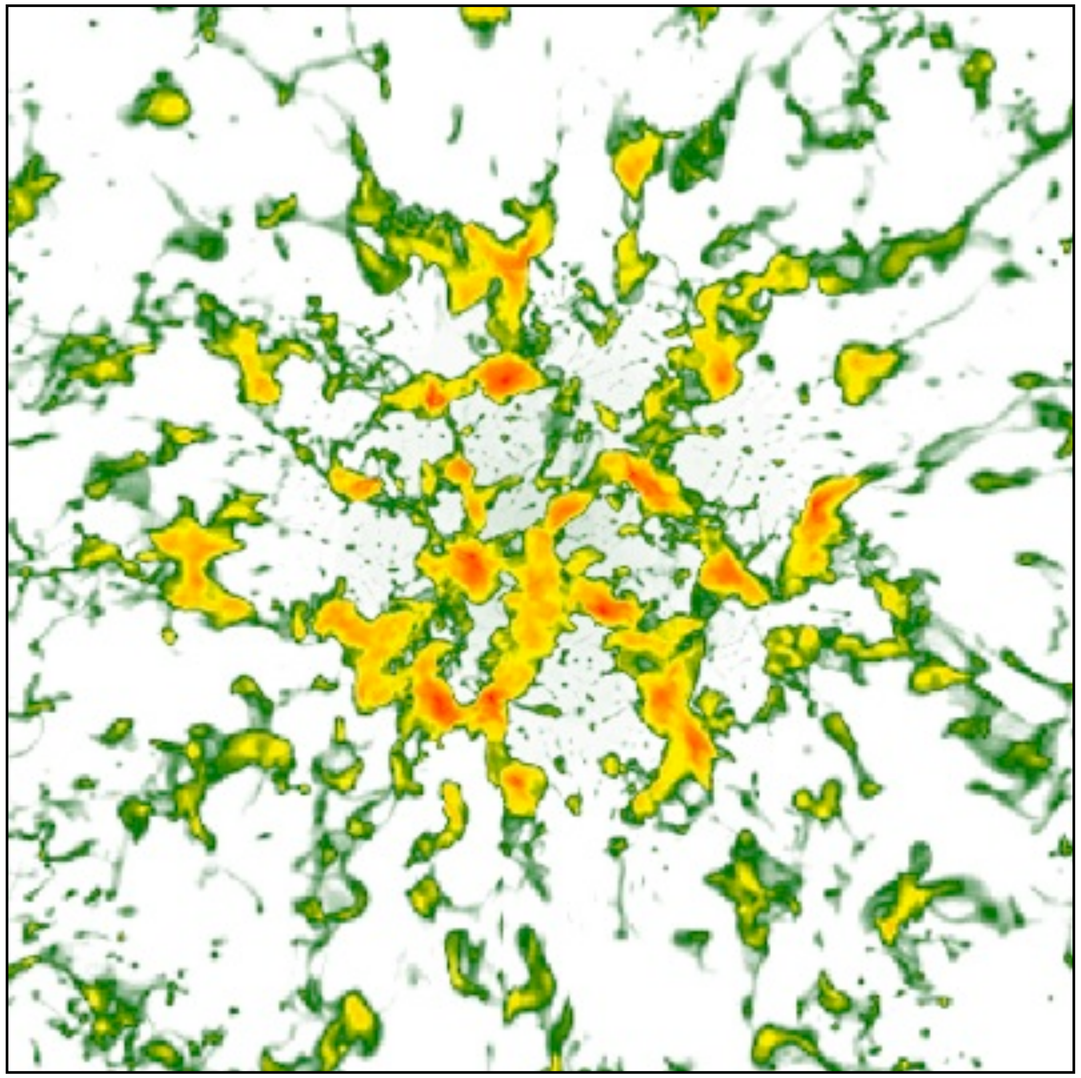
edge-on view

face-on view

Molecular Cloud Evolution

main properties of MCs:

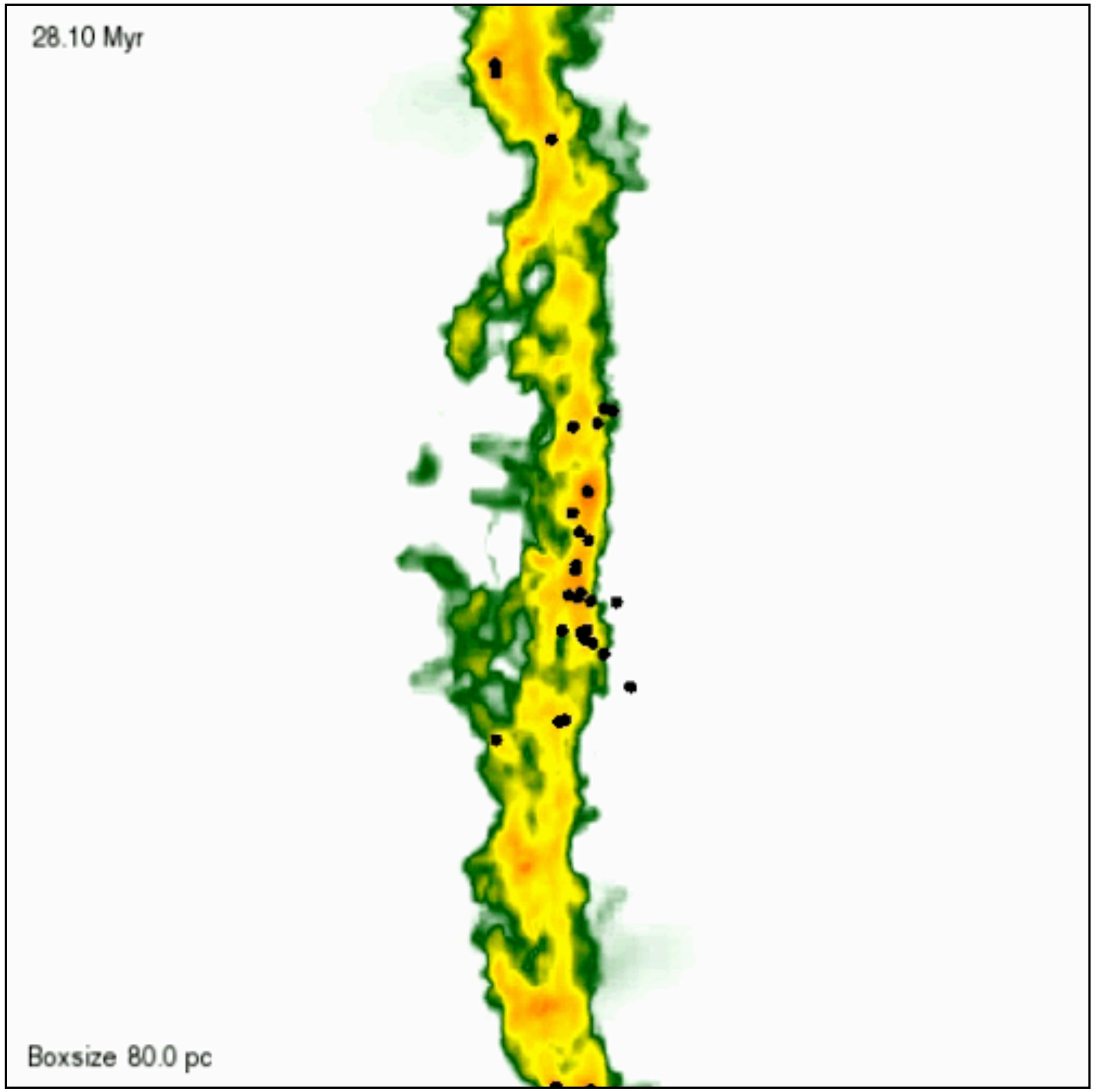
- highly patchy and clumpy
- high fraction of substructure
- cold dense molecular clumps coexist with warm atomic gas
- not a well bounded entity
- dynamical evolution (different star formation modes: from low mass to high mass SF?)



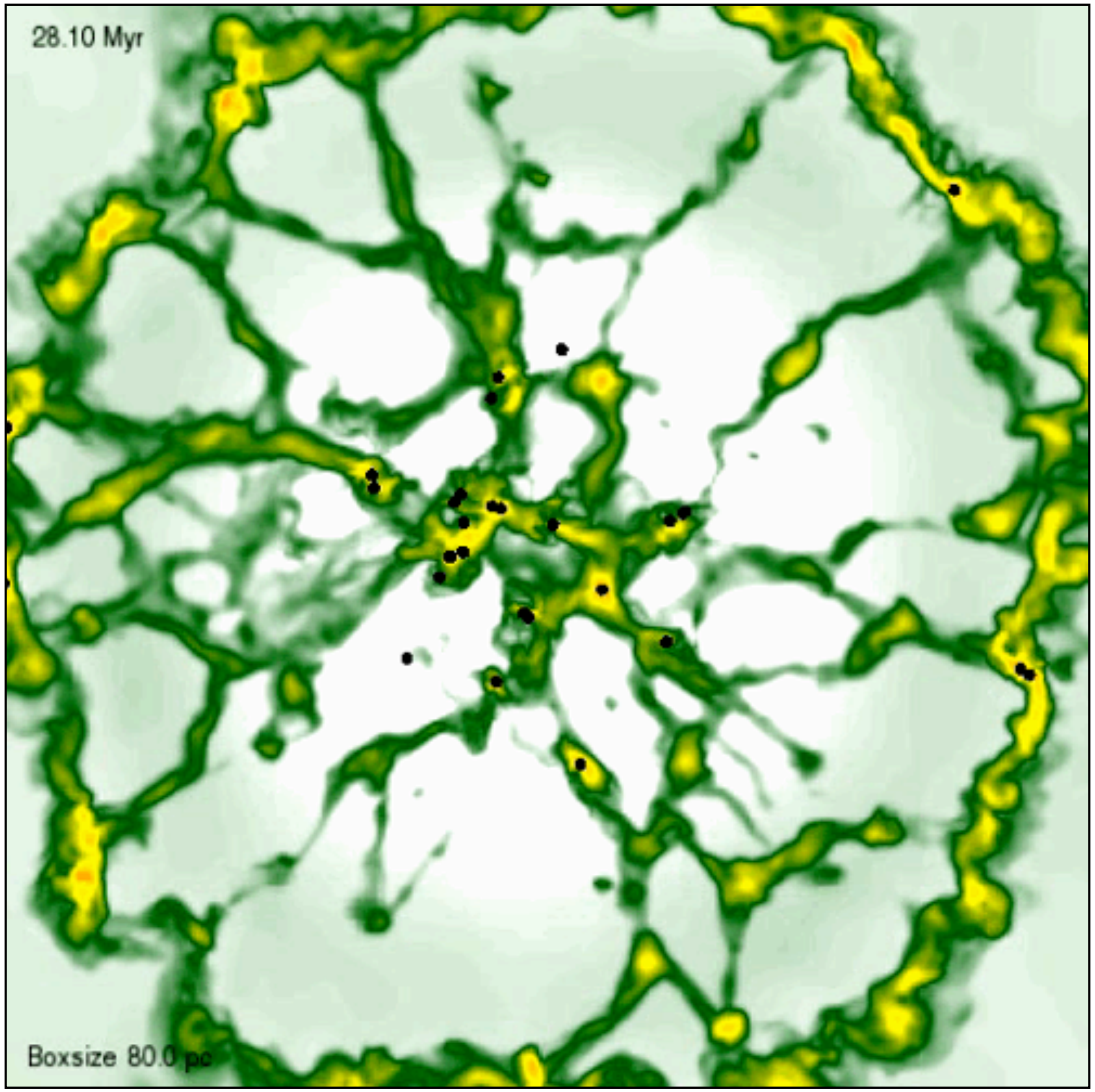
(see also e.g., *Hennebelle et al. 2008, Heitsch&Hartmann 2008*)

Molecular Cloud Evolution

the weakly magnetized ($B_x = 1\mu G$) case

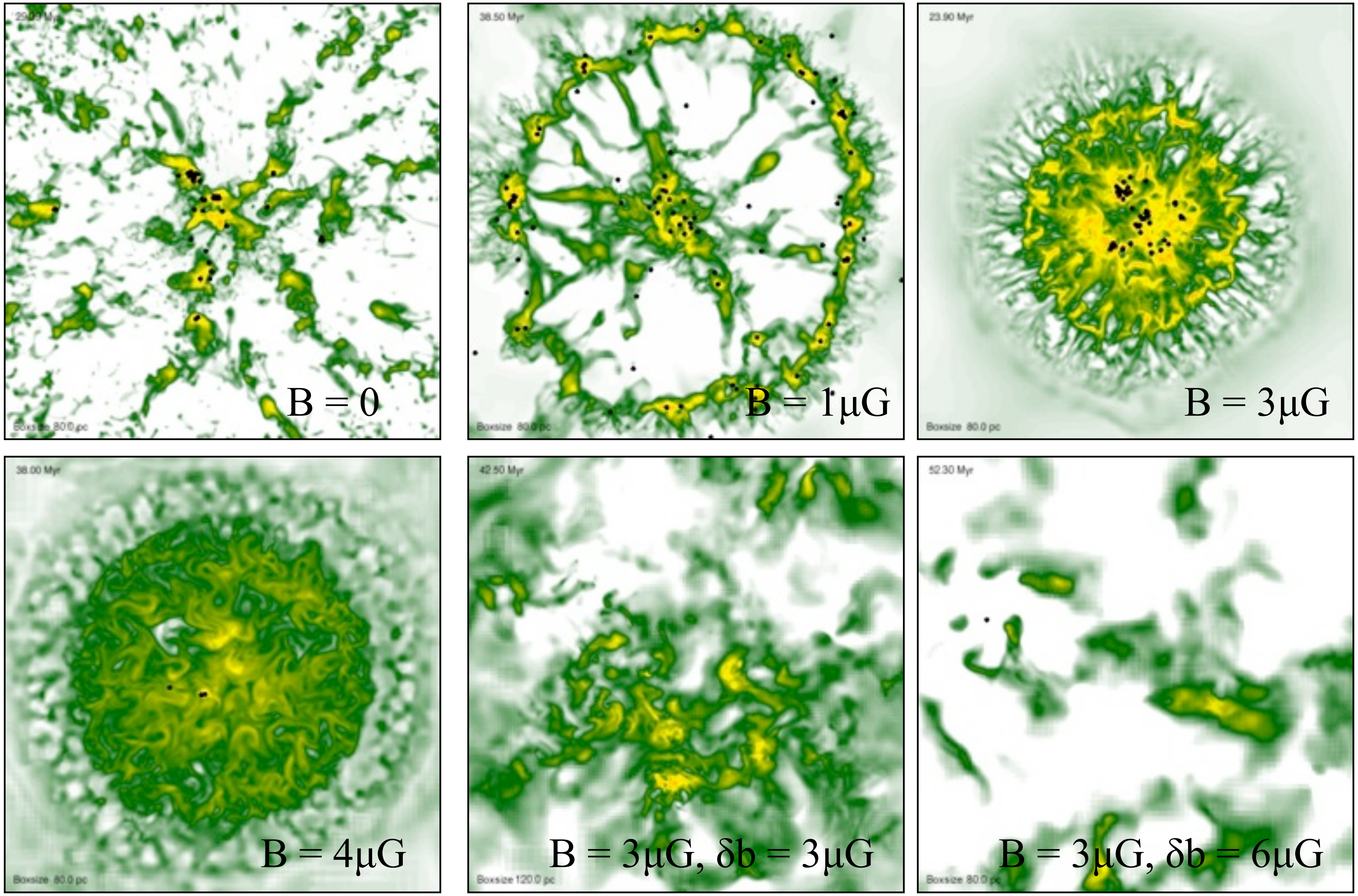


edge-on view



face-on view

Molecular Cloud Evolution



Morphology of the molecular cloud and star formation efficiency depends on the strength of the magnetic field

Molecular Cloud Evolution

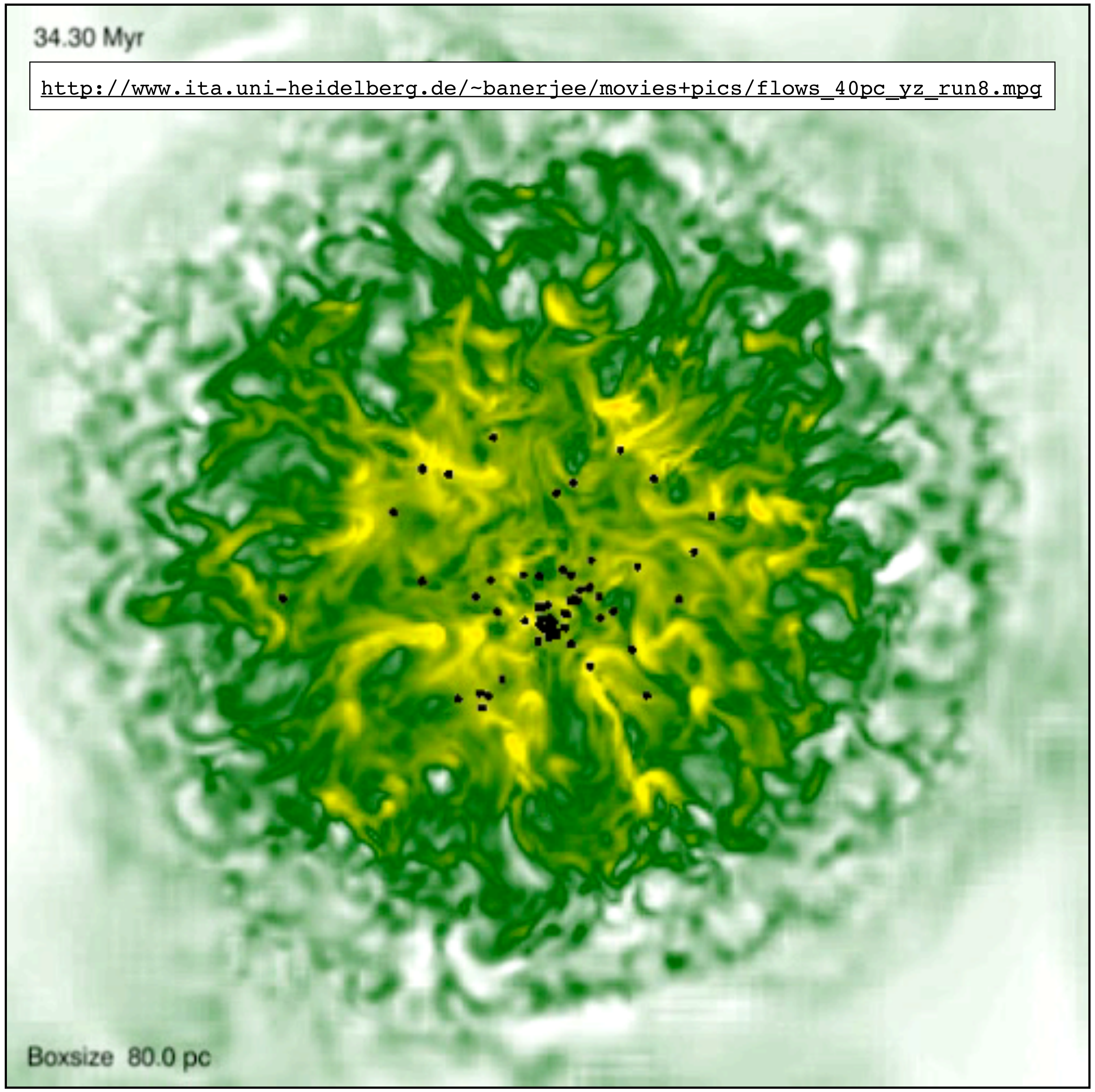
influence of magnetic fields

- B = **3**μG
- μ/μ_{crit} = **0.9**
  with $\mu_{crit} = 0.13/\sqrt{G}$
  (Nakano & Namkamura 1978)
- μ/μ_{crit} = **1.11**
  with $\mu_{crit} = 0.13/\sqrt{G}$
  (Mouschovias & Spitzer 1976)

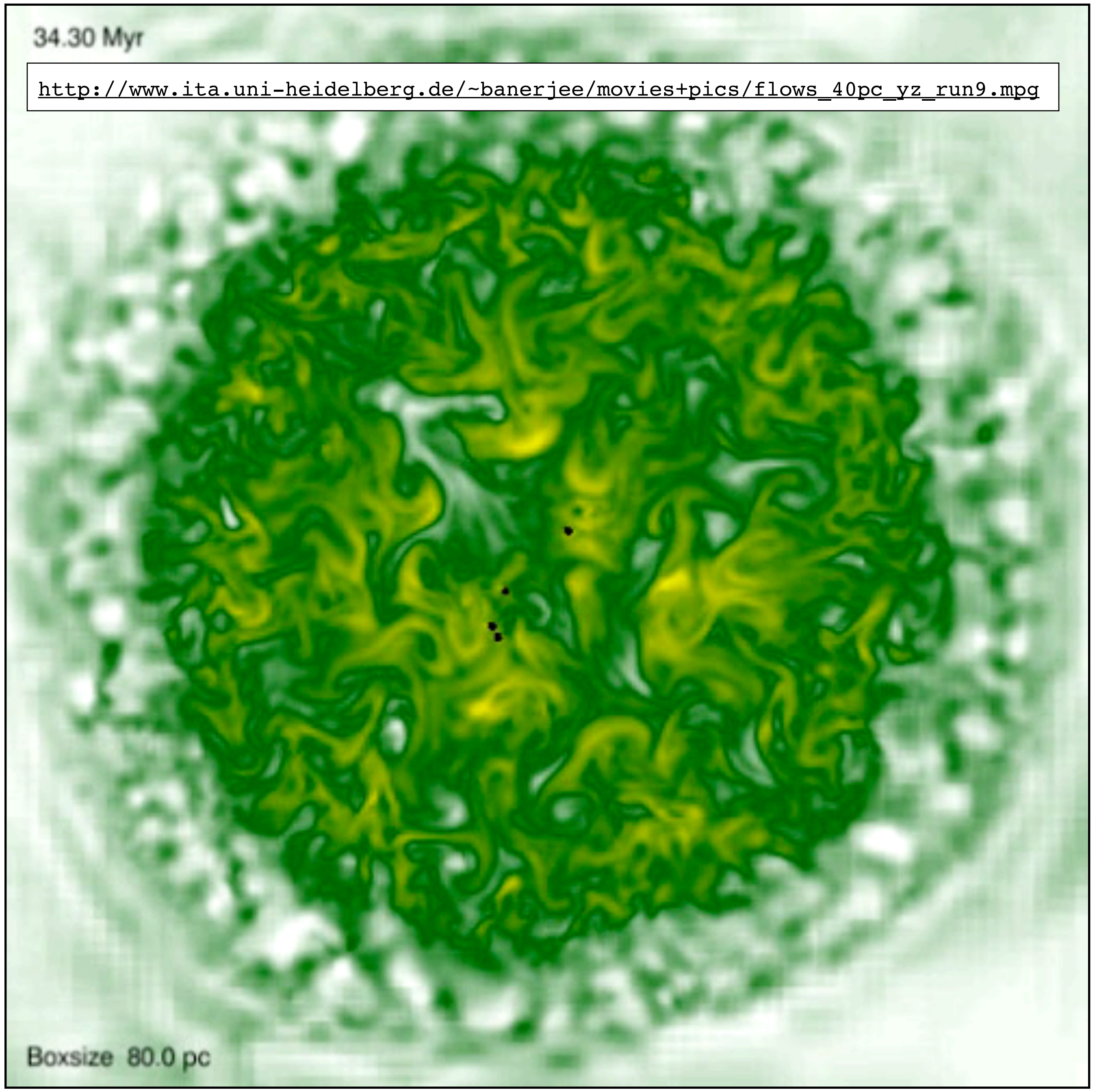
- B = **4**μG
- μ/μ_{crit} = **0.7**
- μ/μ_{crit} = **0.8**

Molecular Cloud Evolution

influence of magnetic fields



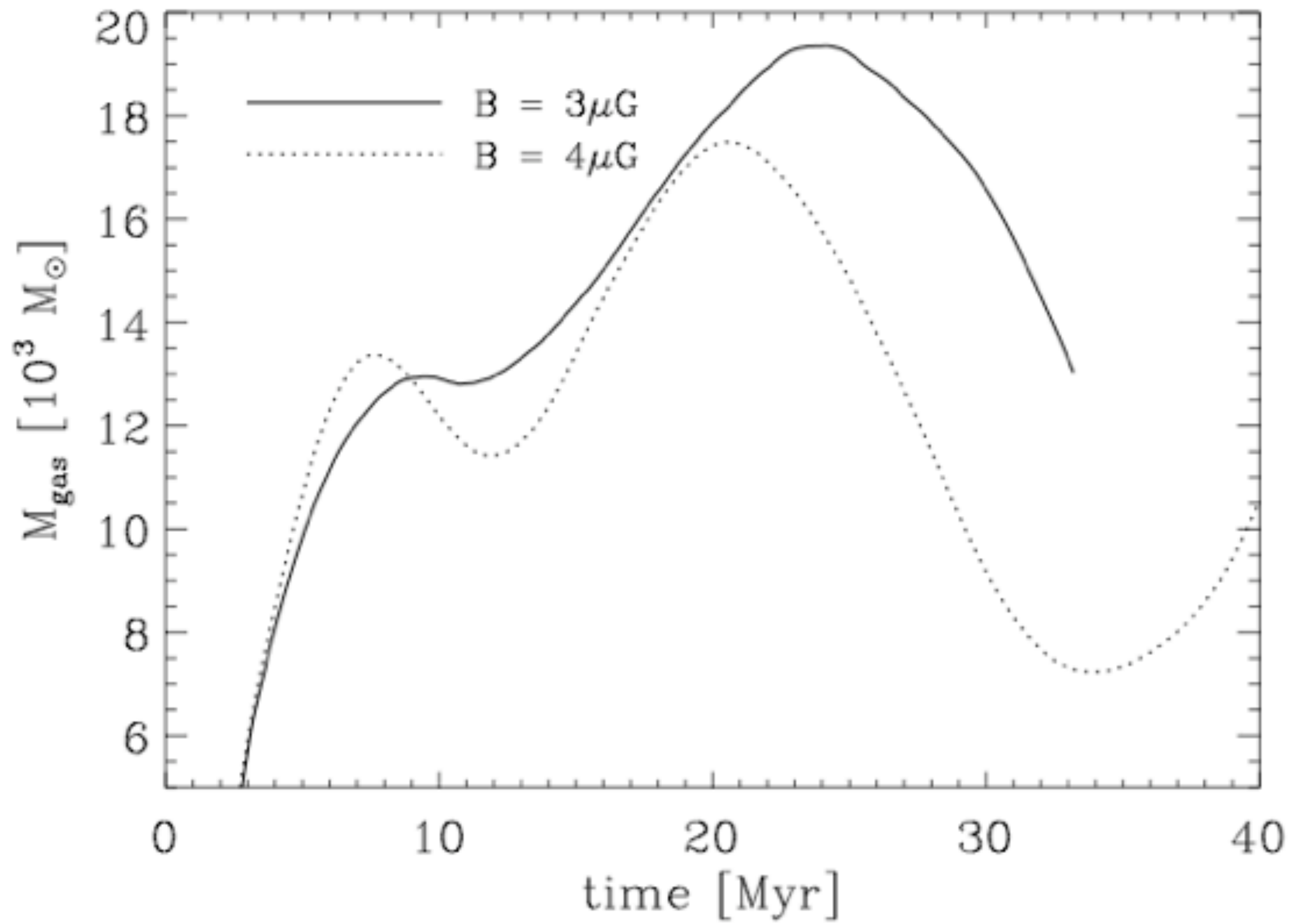
$B = 3\mu G;\ \mu/\mu_{crit} = 1.11$



$B = 4\mu G;\ \mu/\mu_{crit} = 0.83$

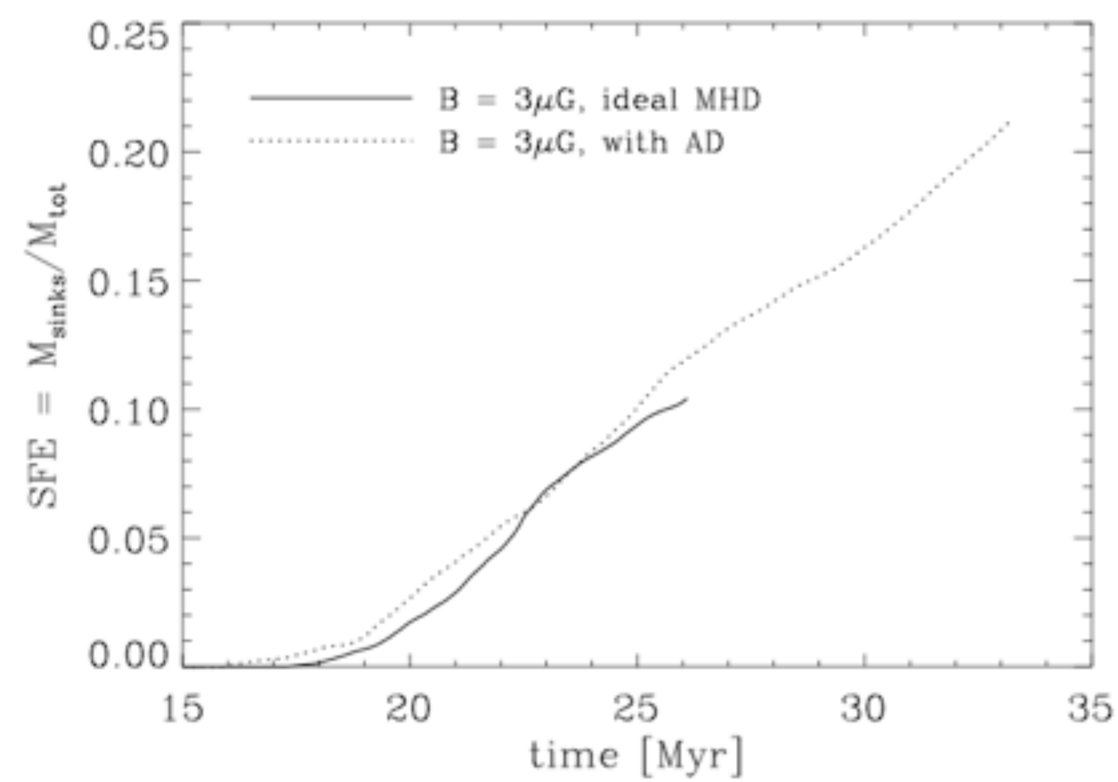
Molecular Cloud Evolution

influence of magnetic fields



Vazquez-Semadeni, RB, Gomez, Duffin, Klessen, Hennebelle in prep.

star formation efficiency
(B = **3**μG case)



Molecular Cloud Evolution

influence of **Ambipolar Diffusion**

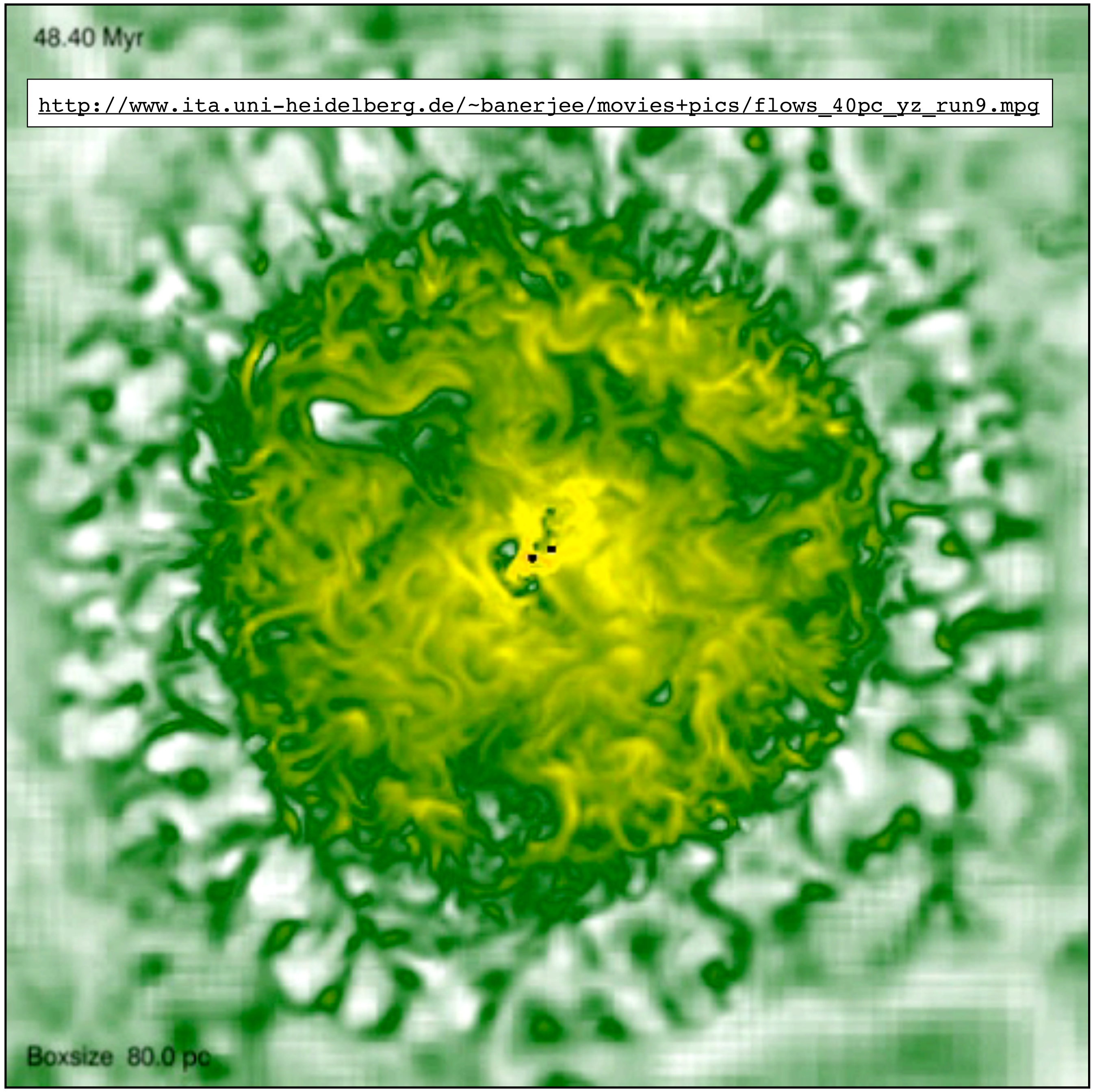
(star formation is initiated by AD?
Shu et al. 1987, Mouschovias 1991)

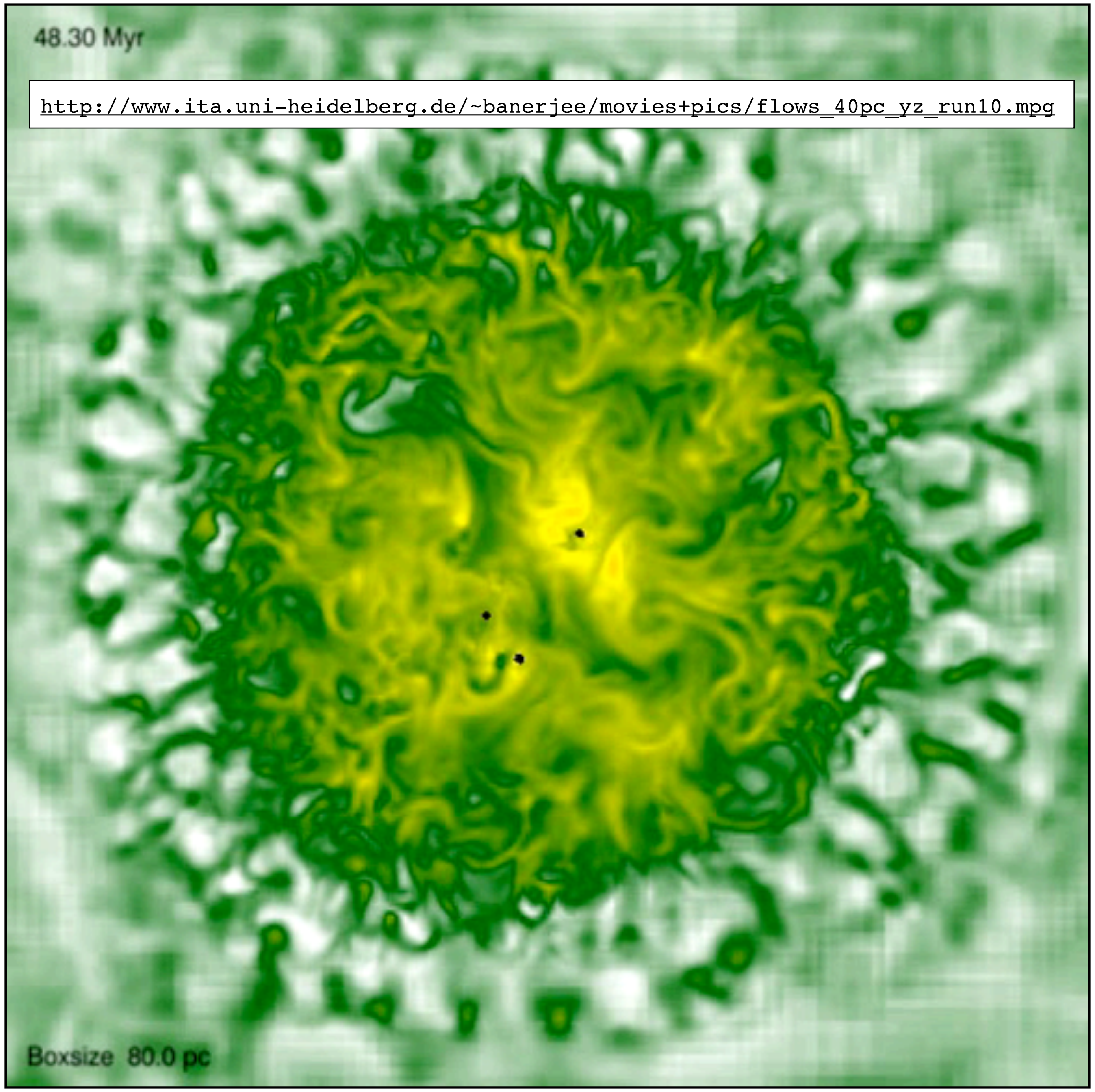
subcritical case:

- B = **4**μG
- μ/μ_{crit} = **0.7 / 0.8**

Molecular Cloud Evolution

influence of ambipolar diffusion





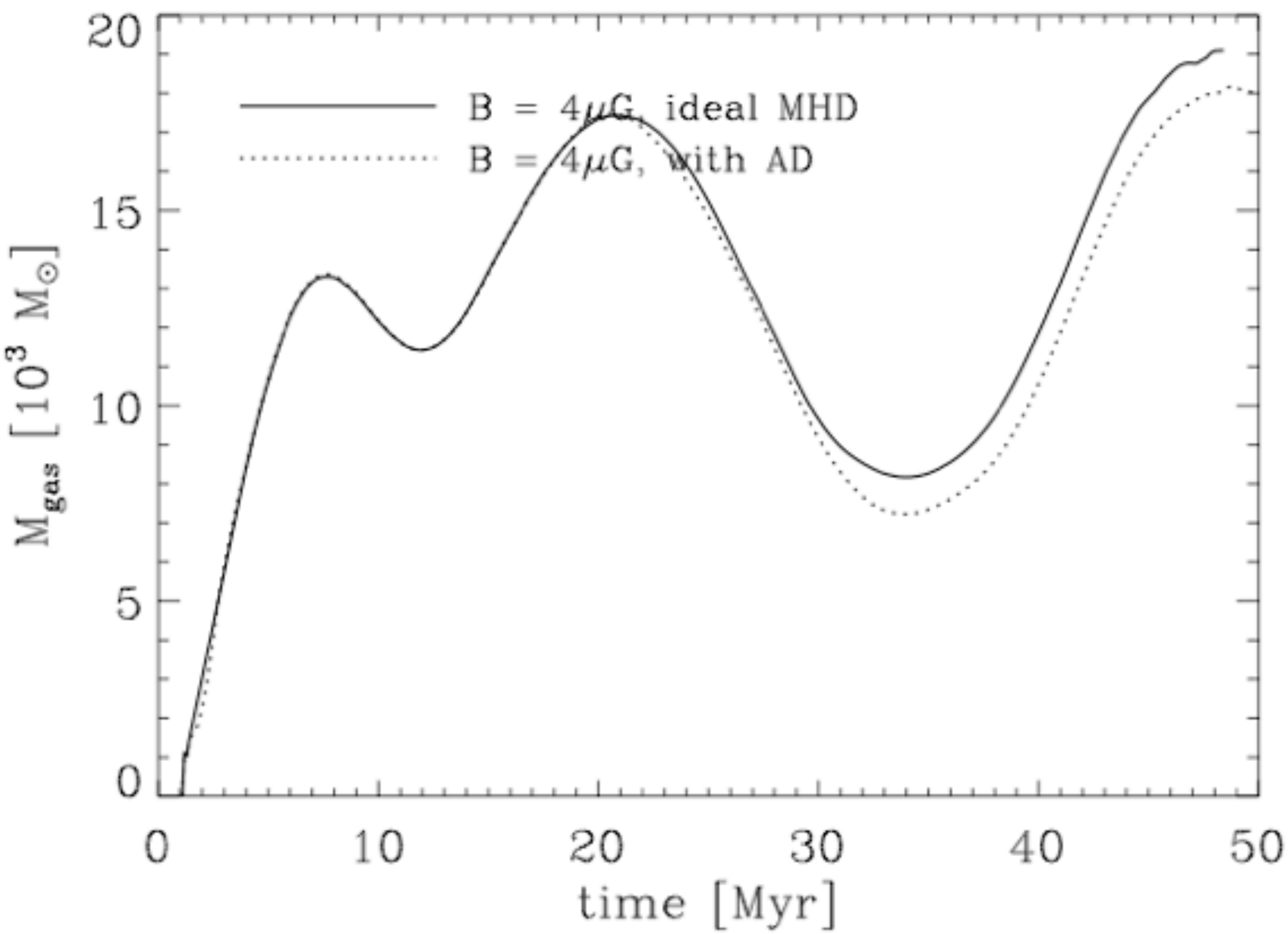
ideal case

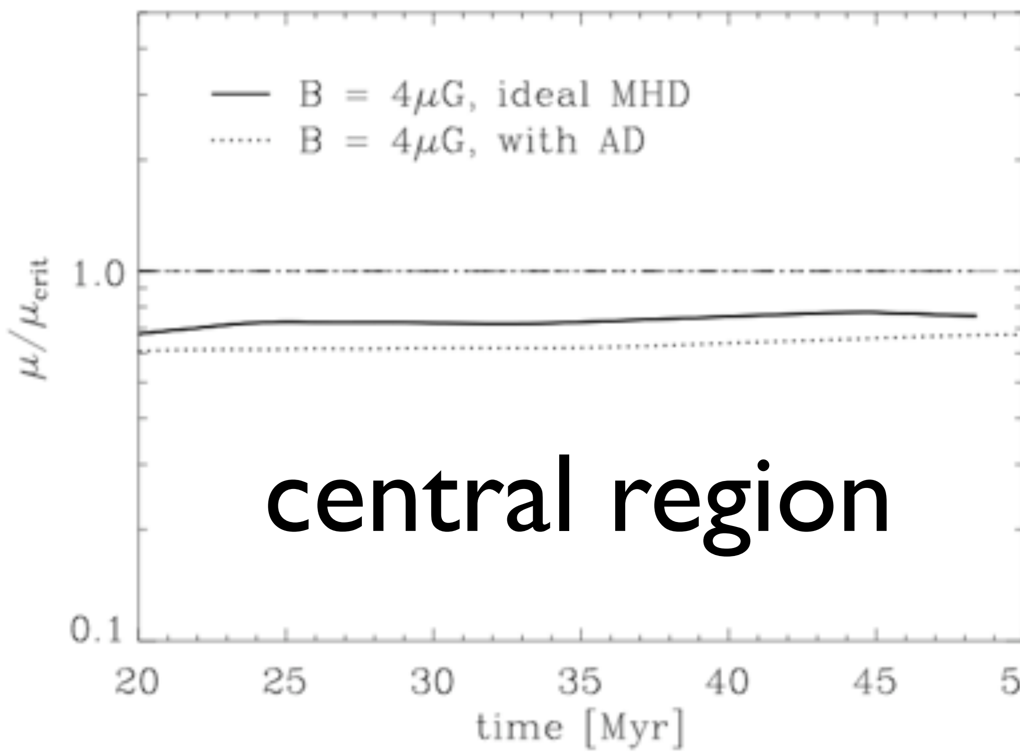
$B = 4\mu G$

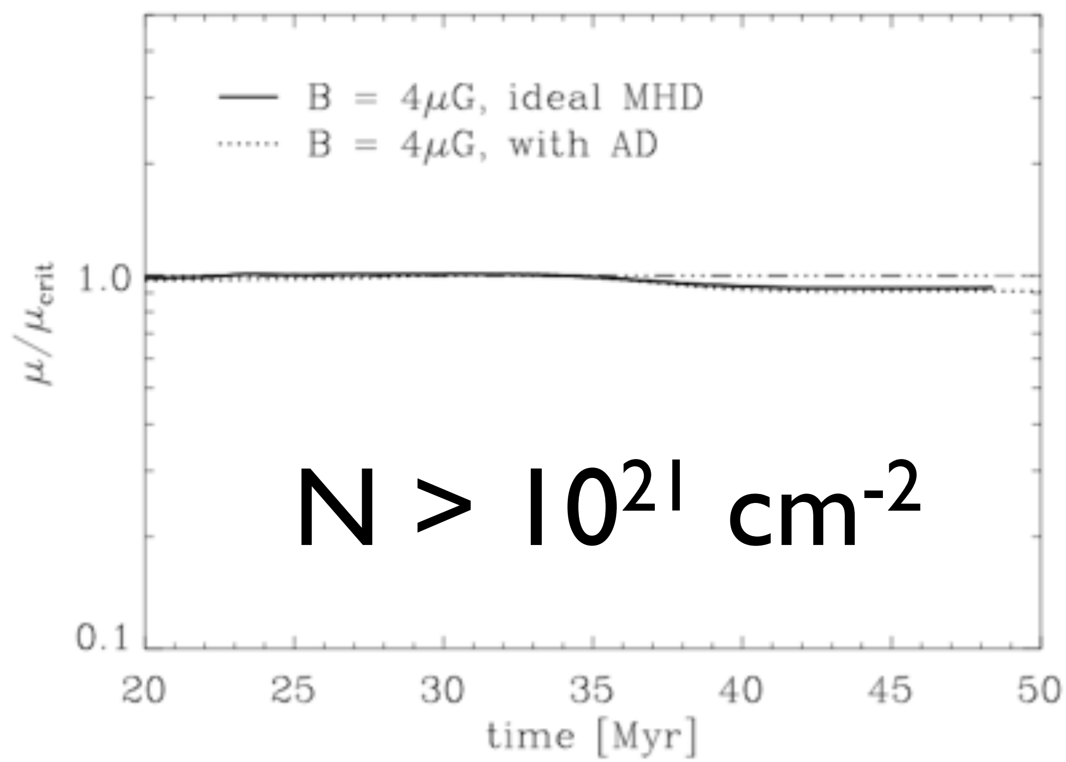
with ambipolar diffusion

Molecular Cloud Evolution

Ambipolar Diffusion: the sub-critical case

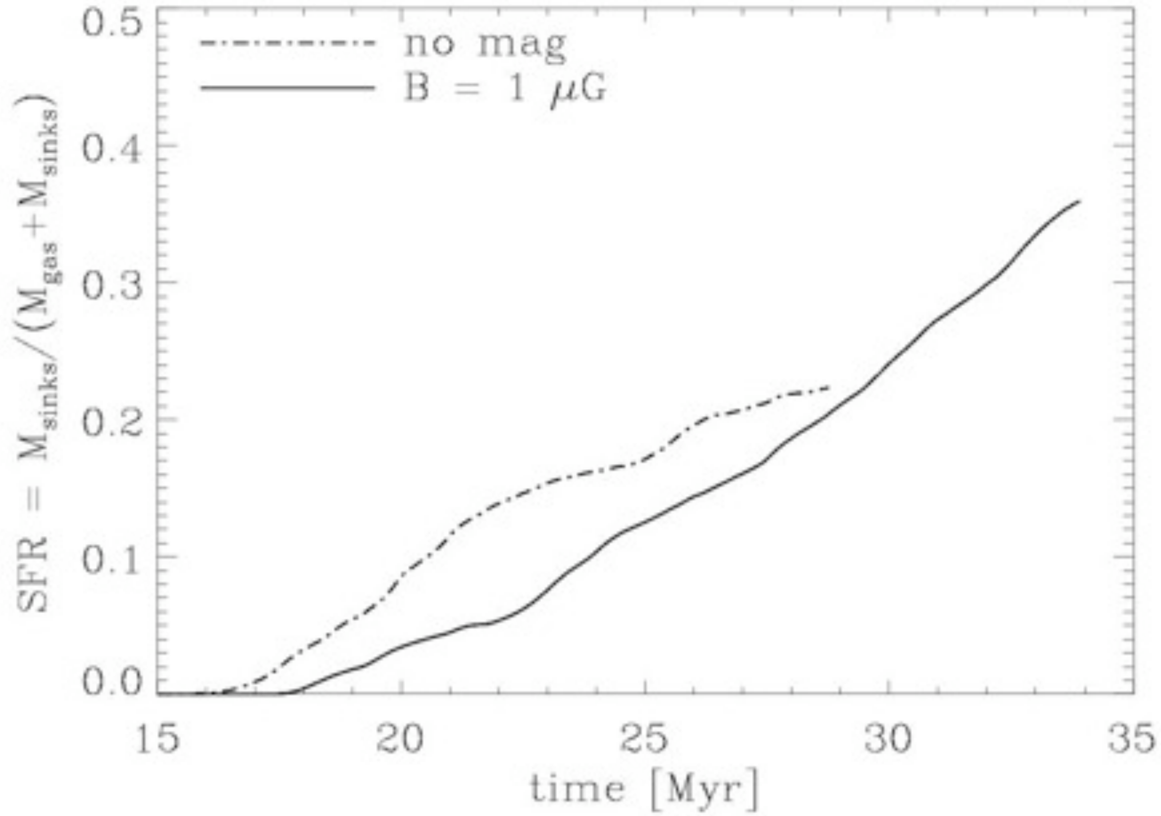


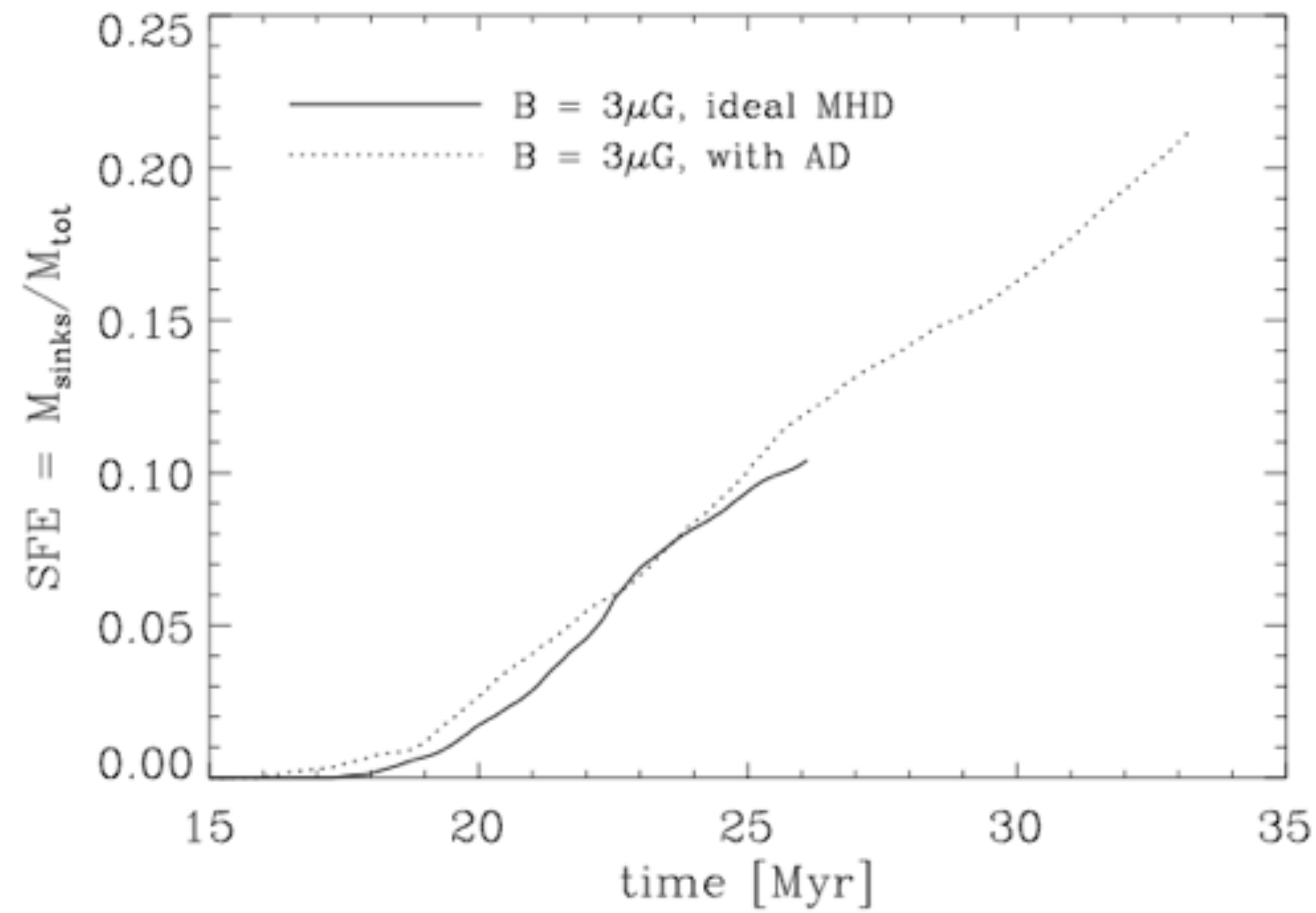


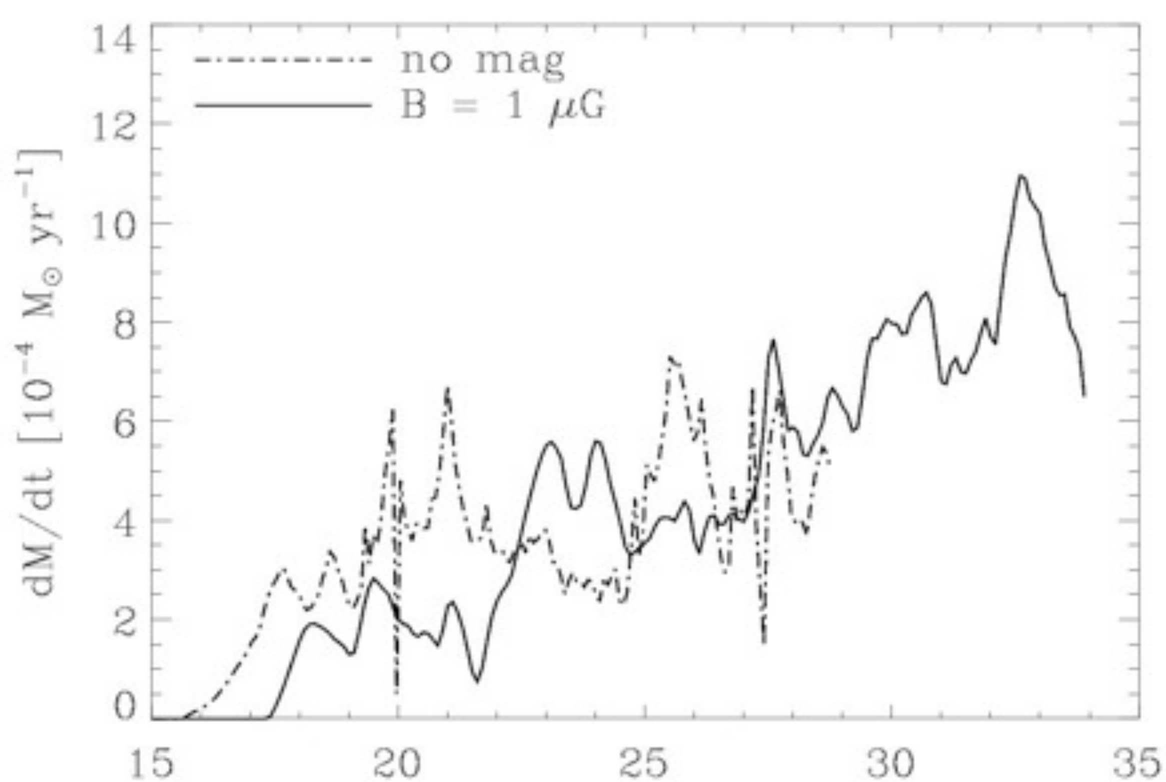


Molecular Cloud Evolution

Star formation efficiency

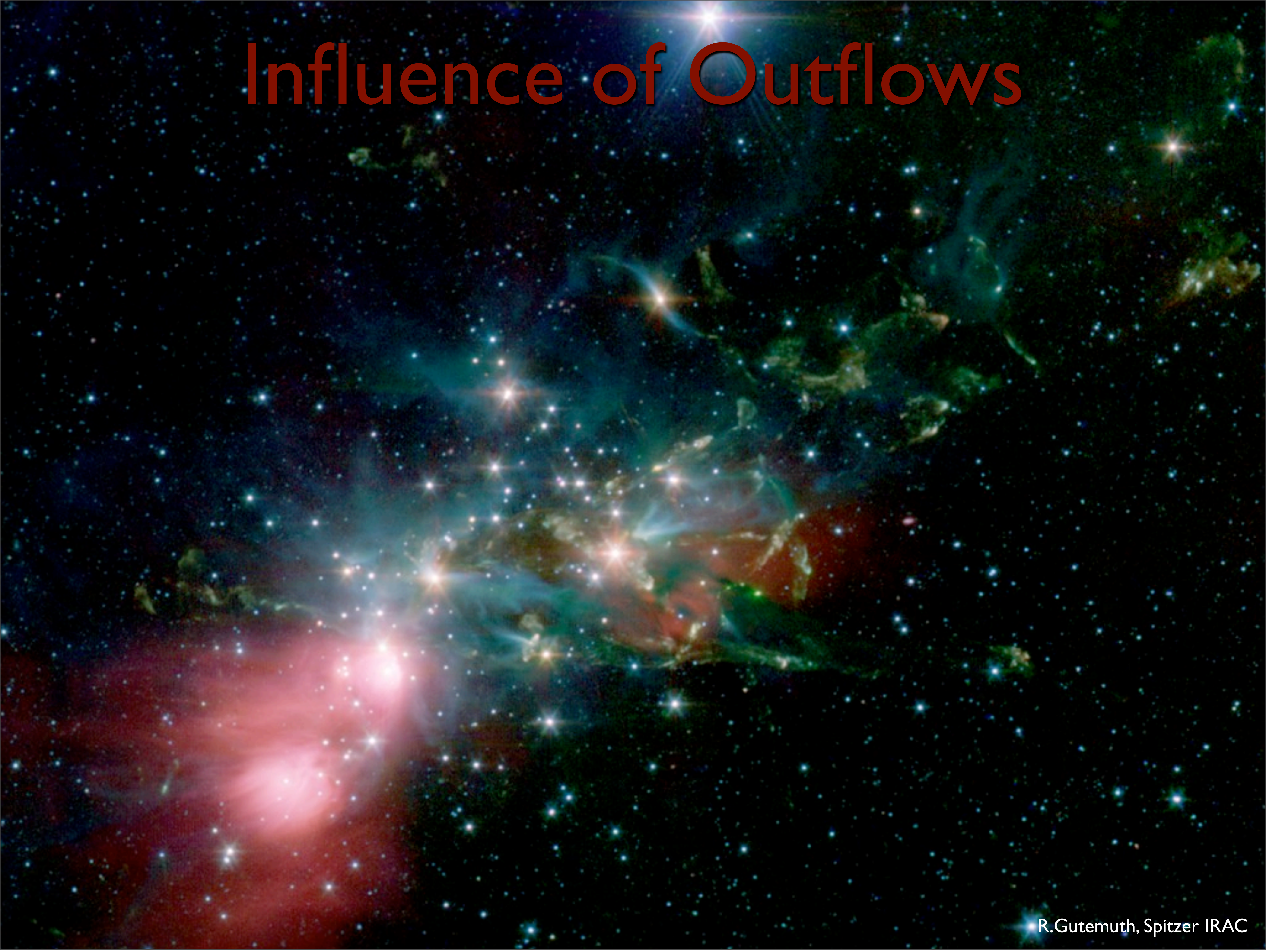






without **feedback**:
continous star formation
with no limit on the SFE

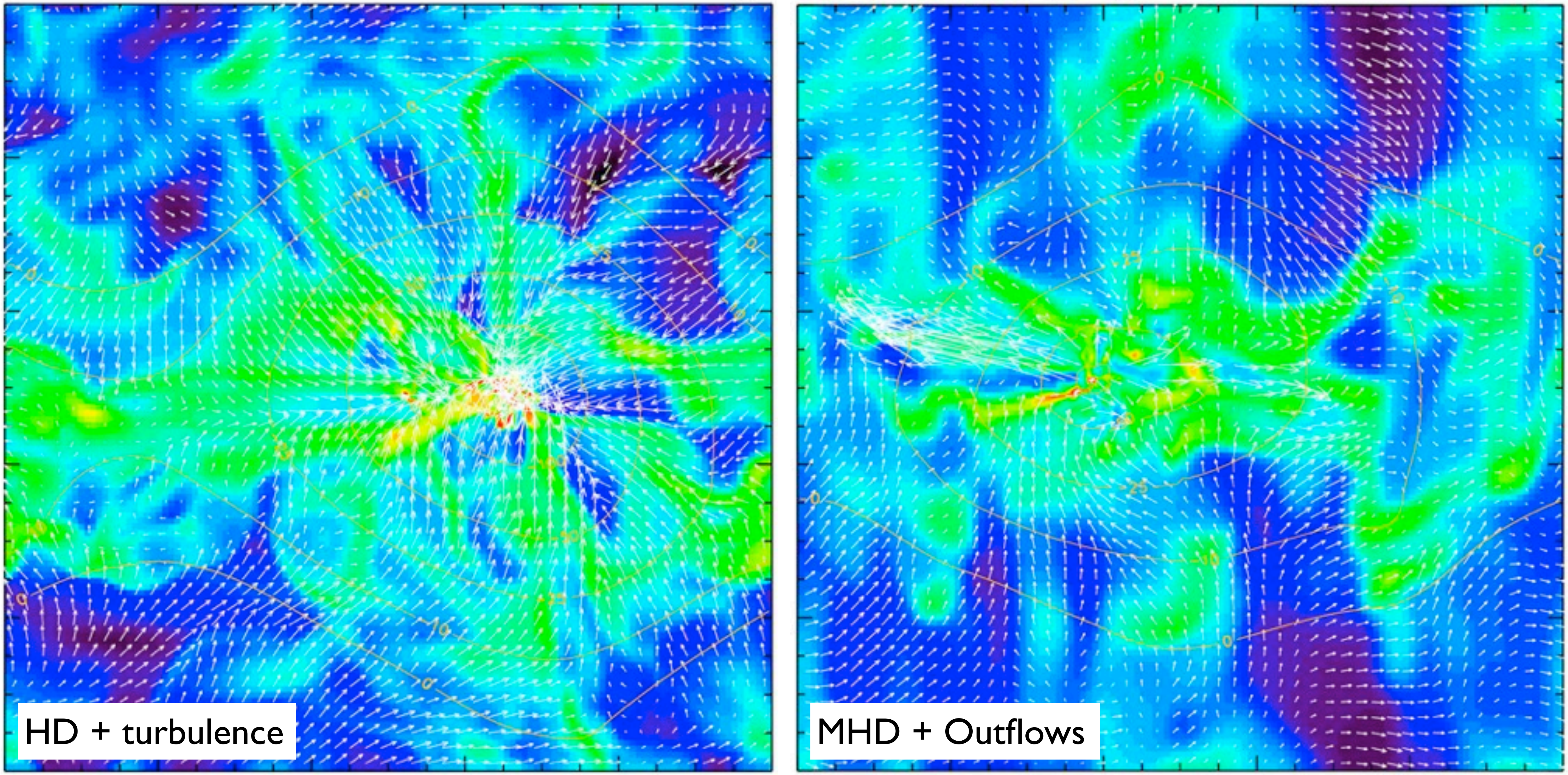
Influence of Outflows



R.Gutemuth, Spitzer IRAC

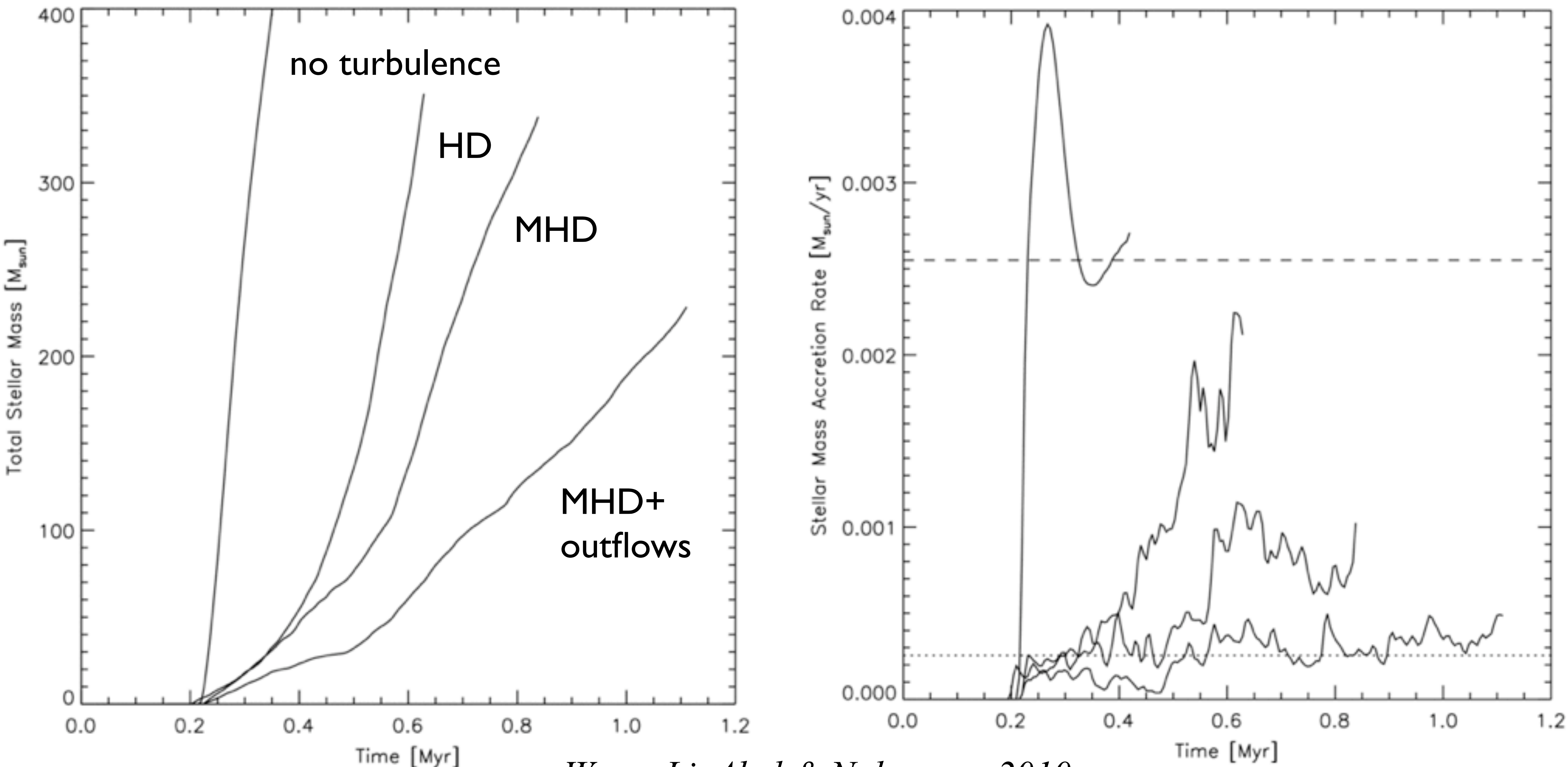
Outflows

Collapse of a massive, turublent cloud core (M_{core} = 1600 M_{sol}) + feedback from jets & outflows



Wang, Li, Abel & Nakamura 2010

Outflows



Wang, Li, Abel & Nakamura 2010

Outflows & Jets do not halt star formation

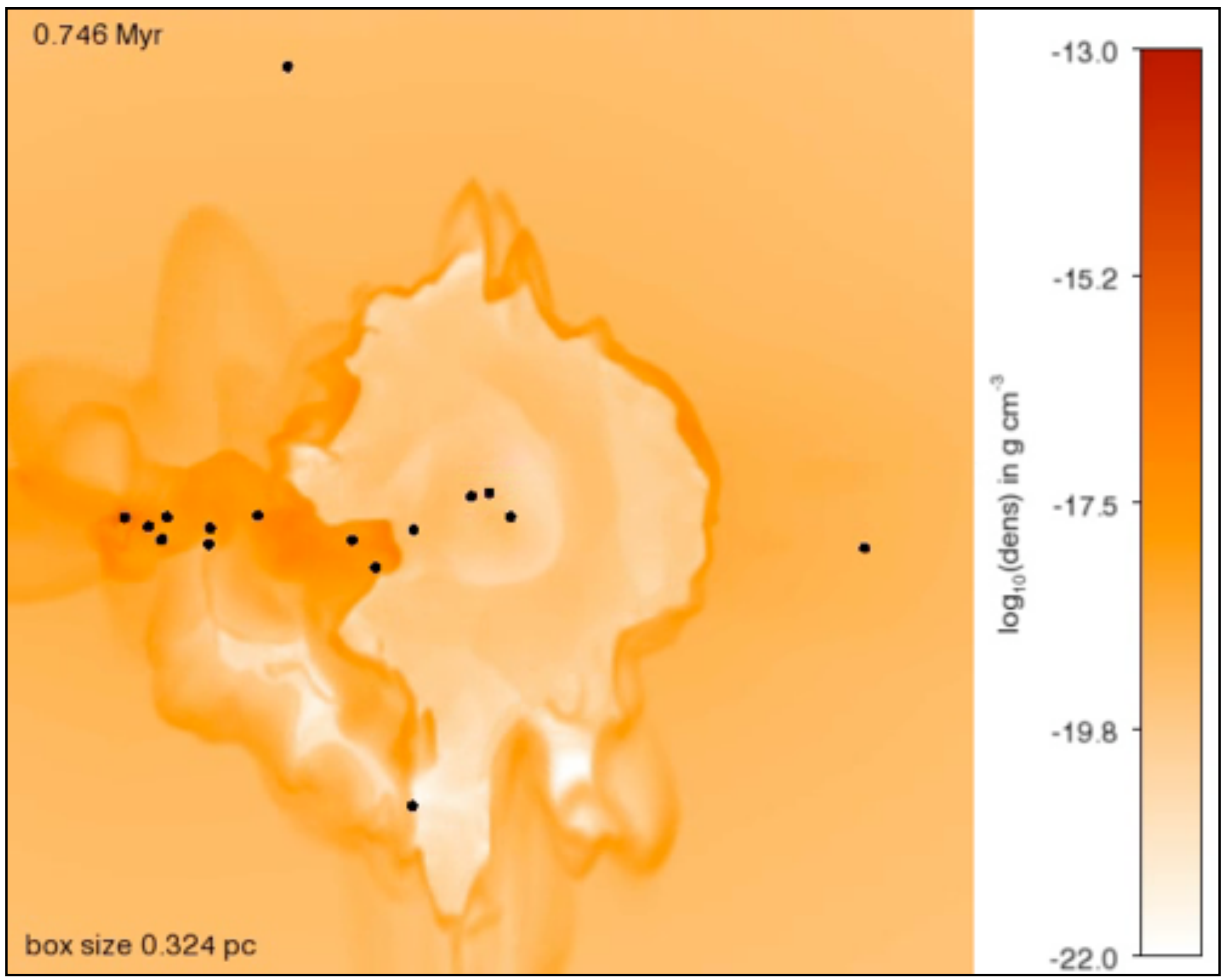
Ionization feedback from massive stars

Herschel Obs.: RCW 120

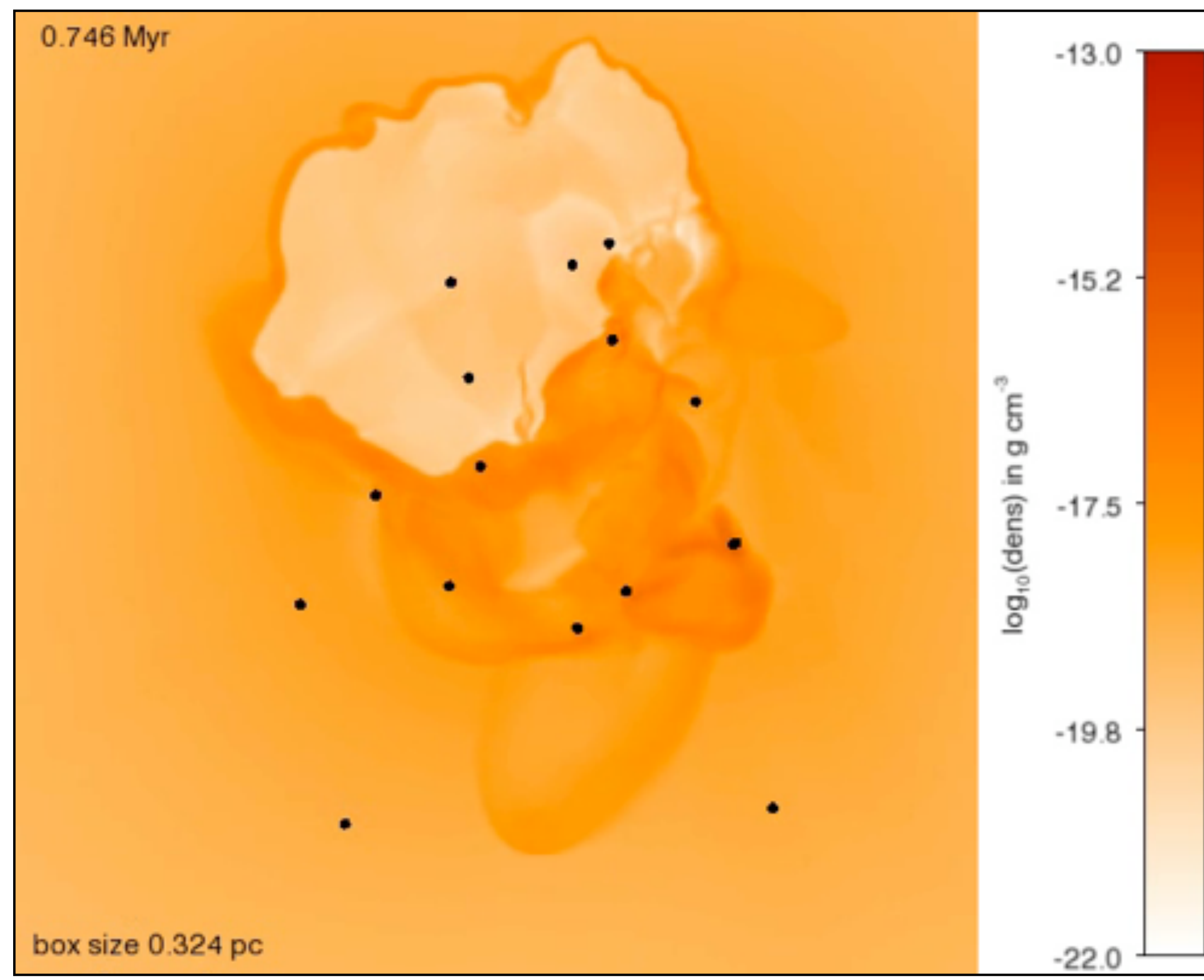
Ionization feedback from massive stars

Collapse of a massive, rotating cloud core
(M_{core} = 1000 M_{sol}) + ionization feedback

Simulations by Thomas Peters (ITA)

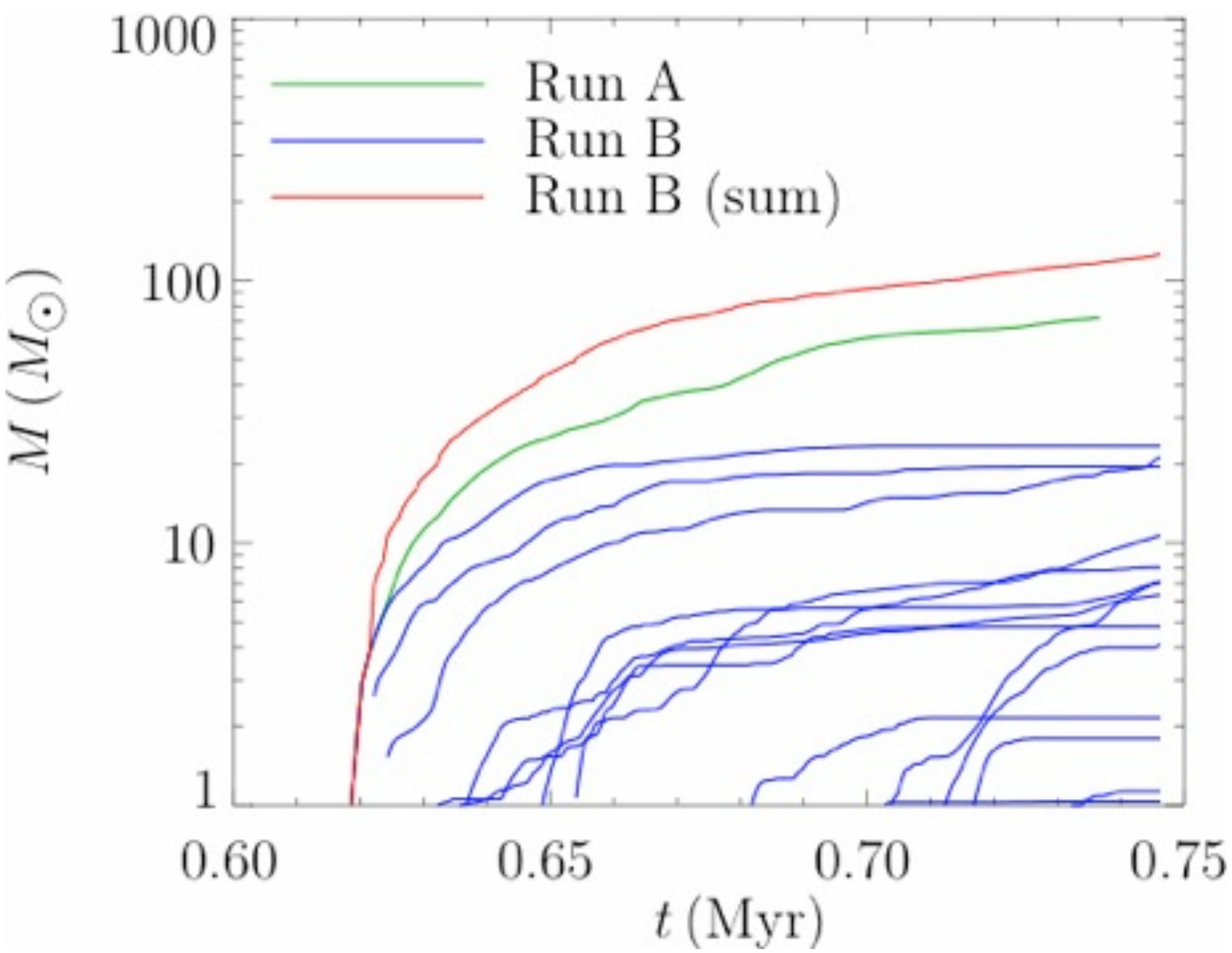


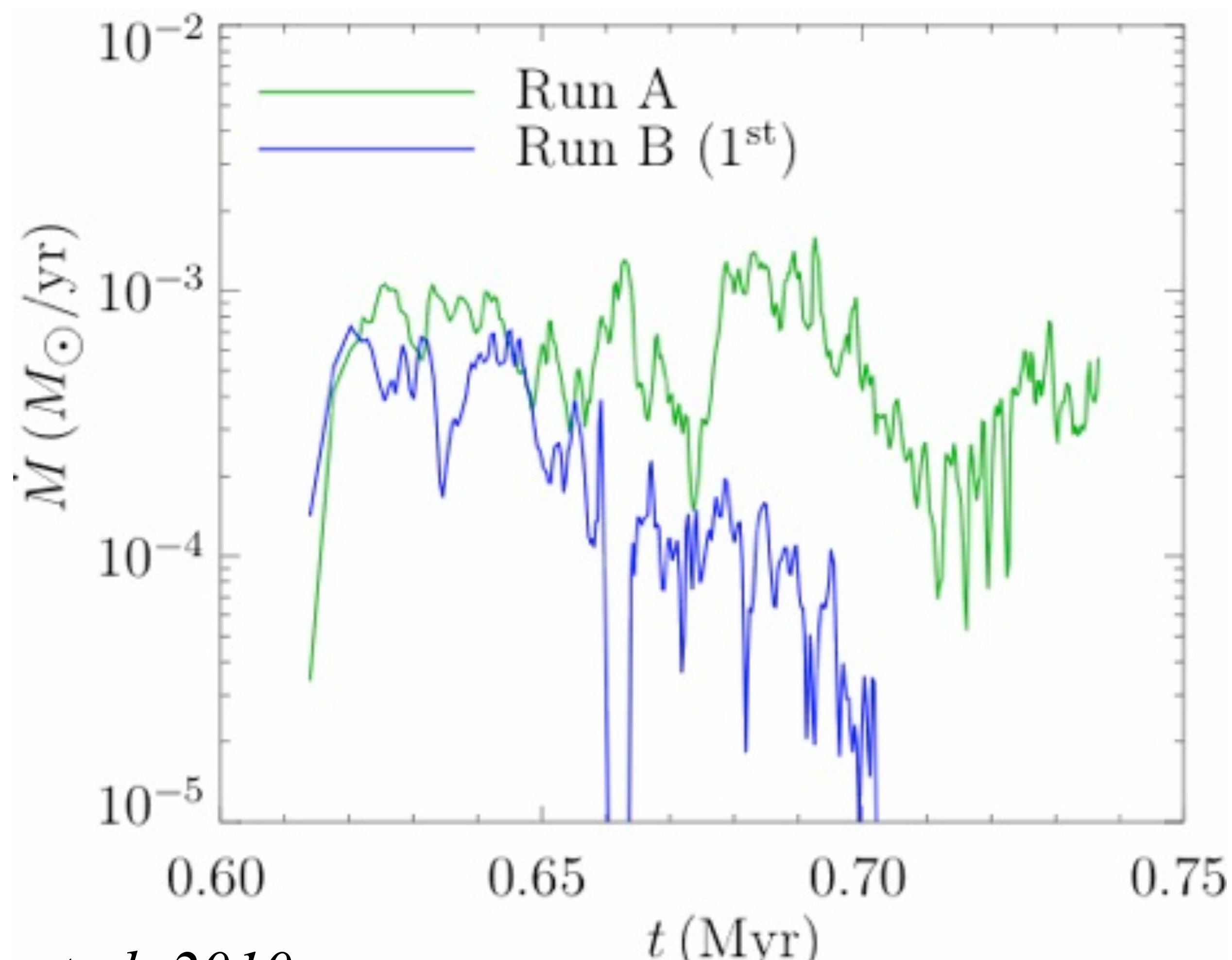
Disk edge on



Disk plane

Ionization feedback from massive stars

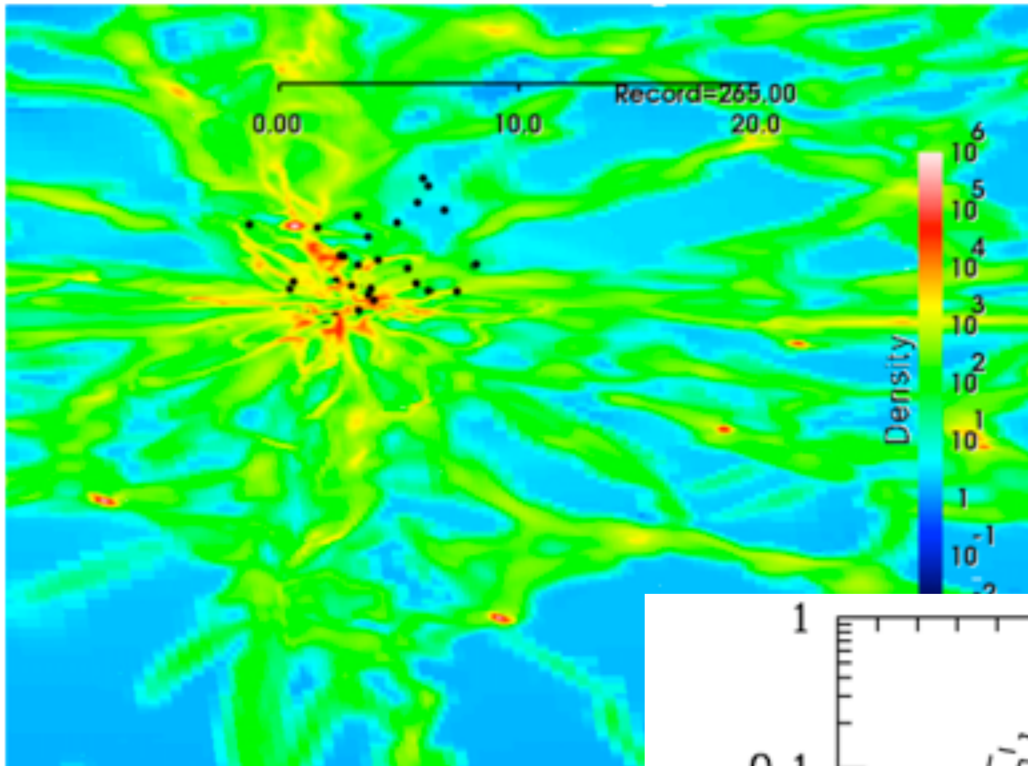




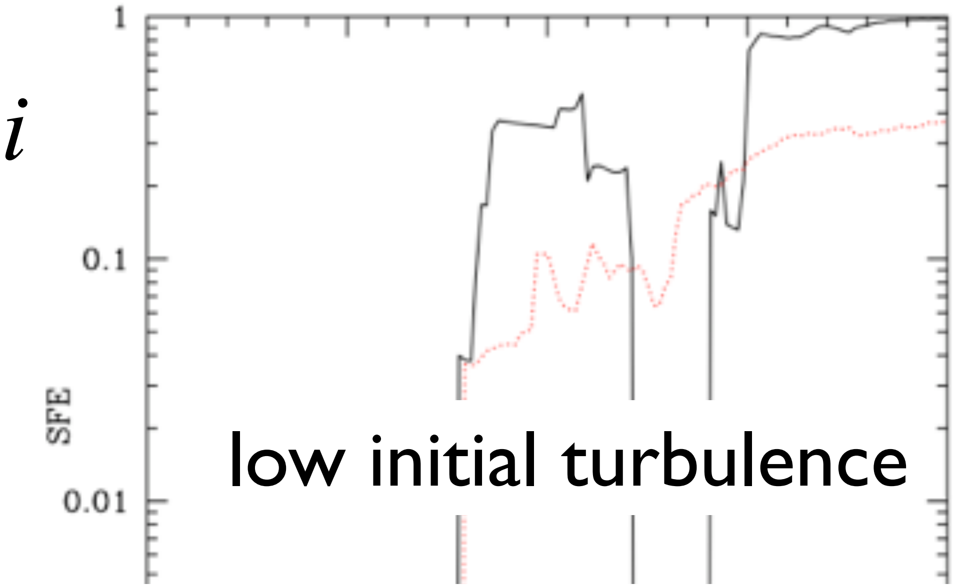
Peters et al. 2010

- Ionisation feedback does not shut off star formation
- accretion onto the most massive star is cut off by ***fragmention induced starvation*** *(Peters et al. 2010)*

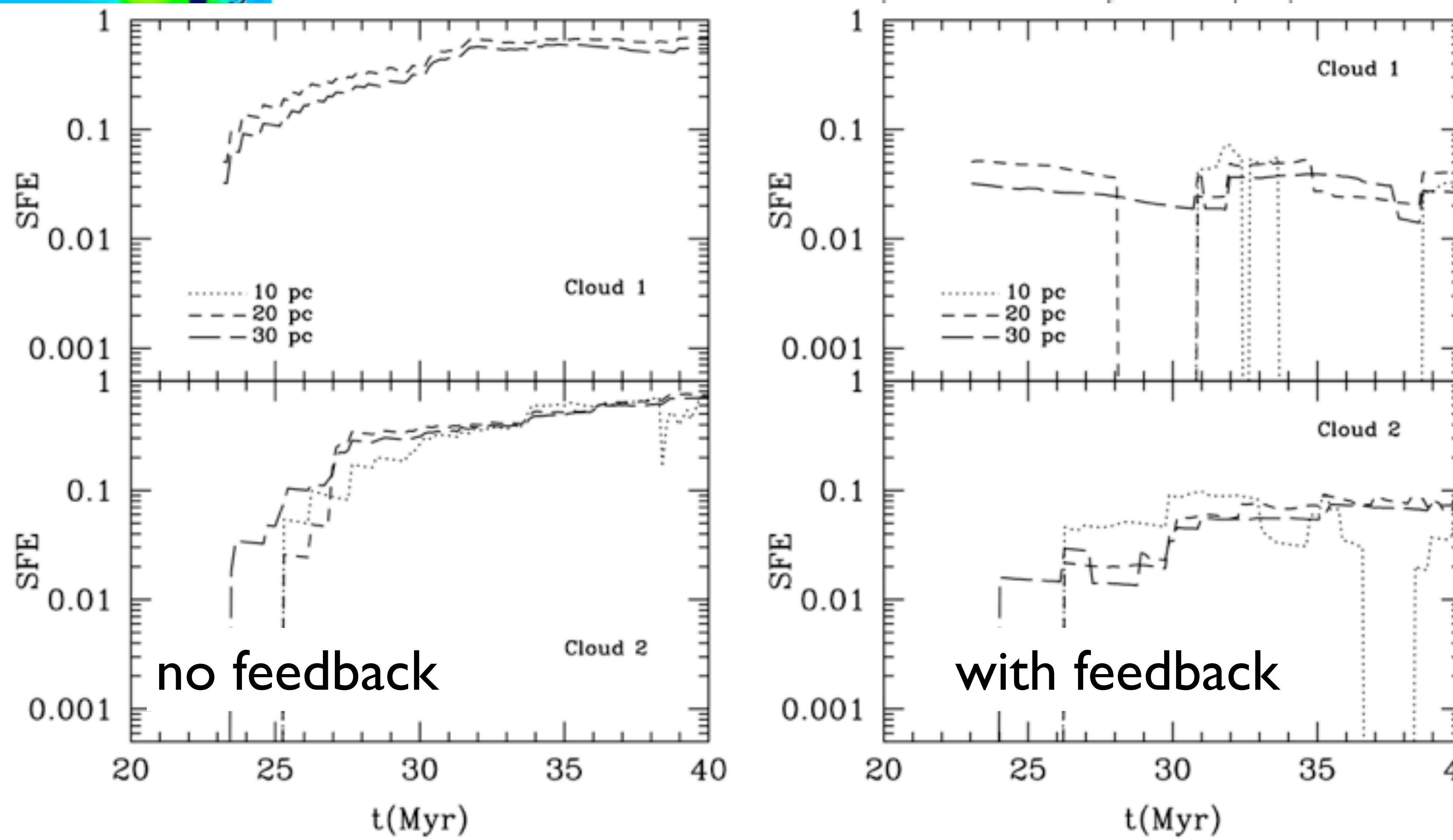
Ionization feedback from massive stars



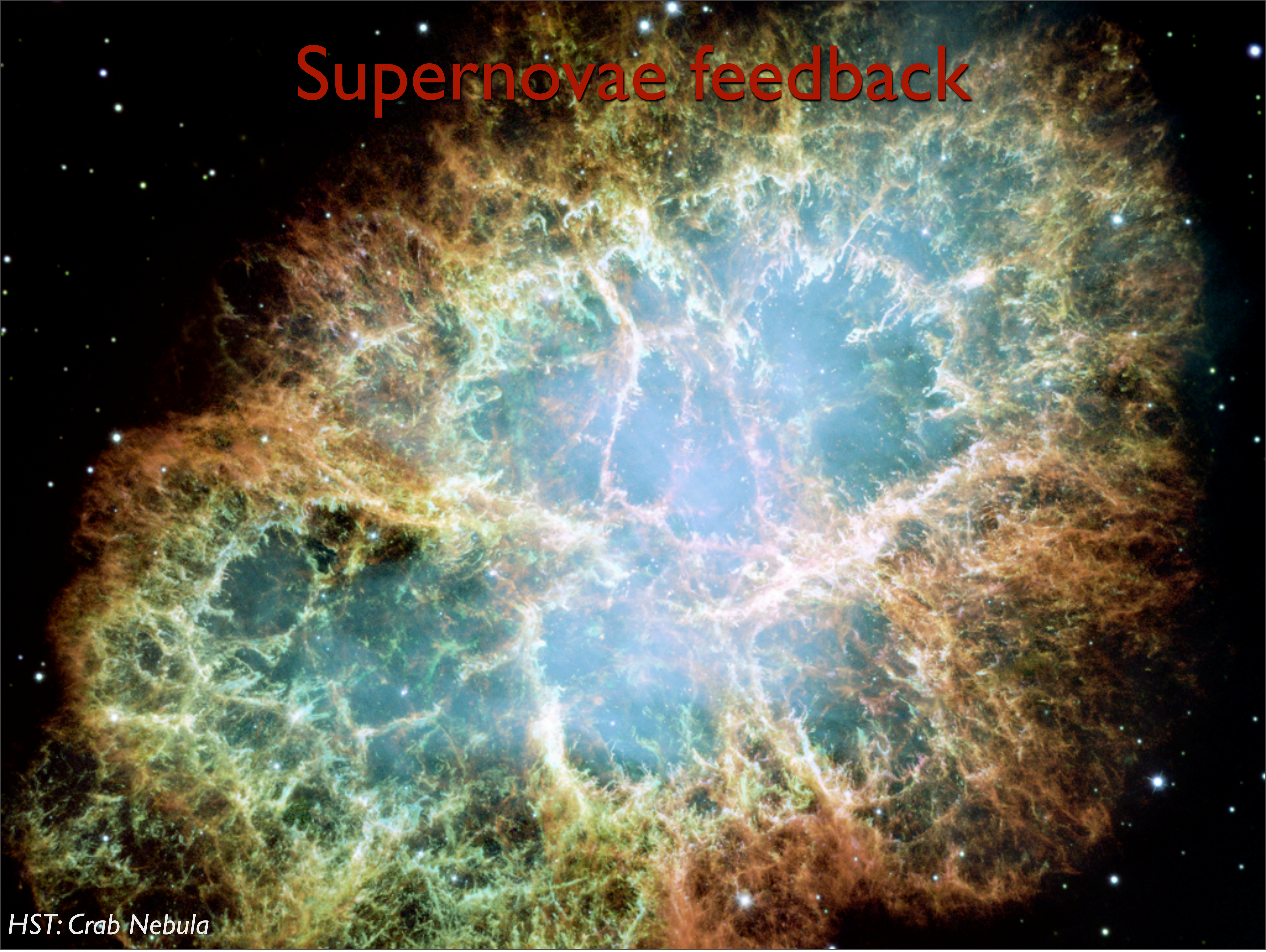
Vazquez-Semadini et al. 2010:



Feedback:
injection of E_{therm}
with properties
of HII regions

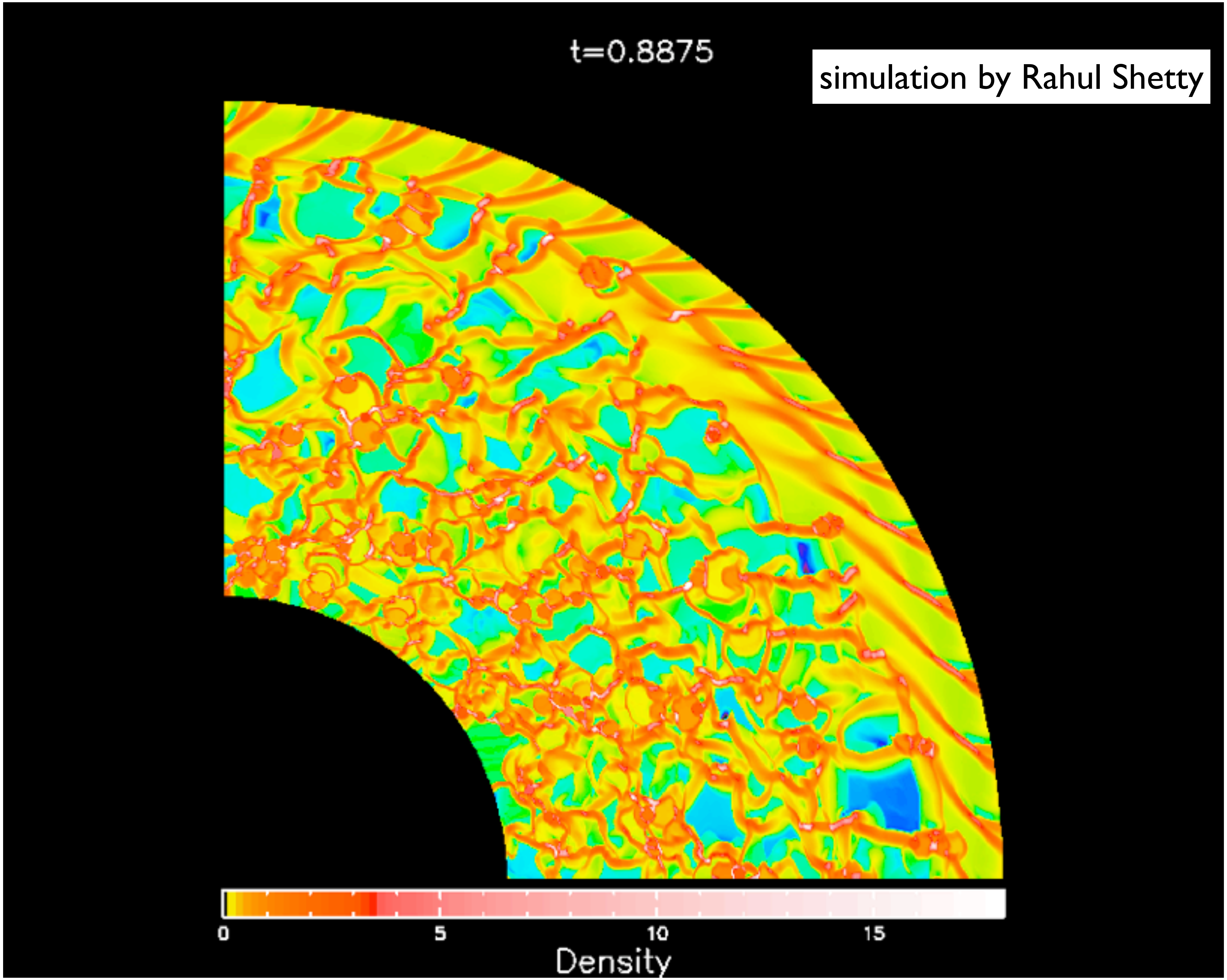


Supernovae feedback



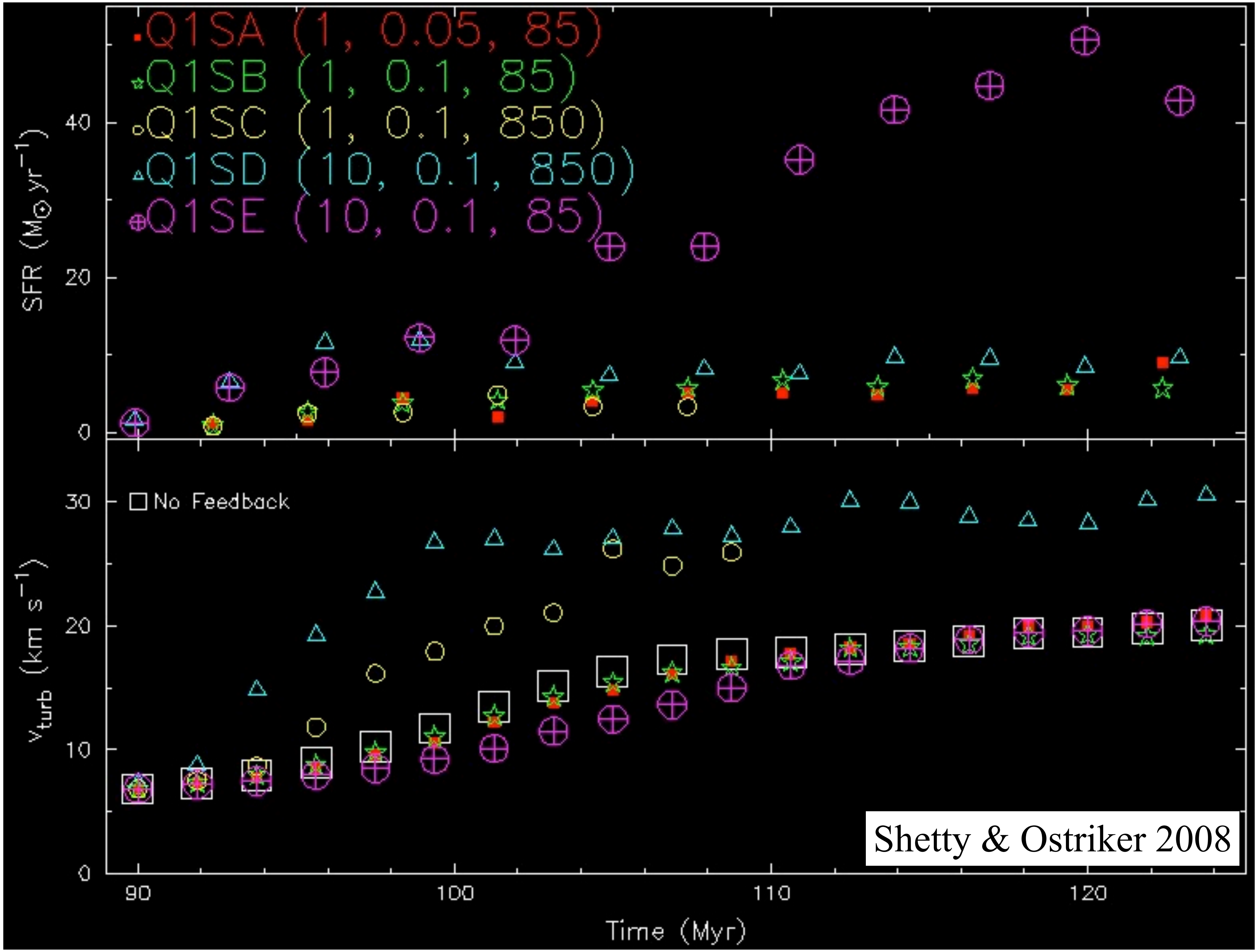
HST: Crab Nebula

Supernovae feedback



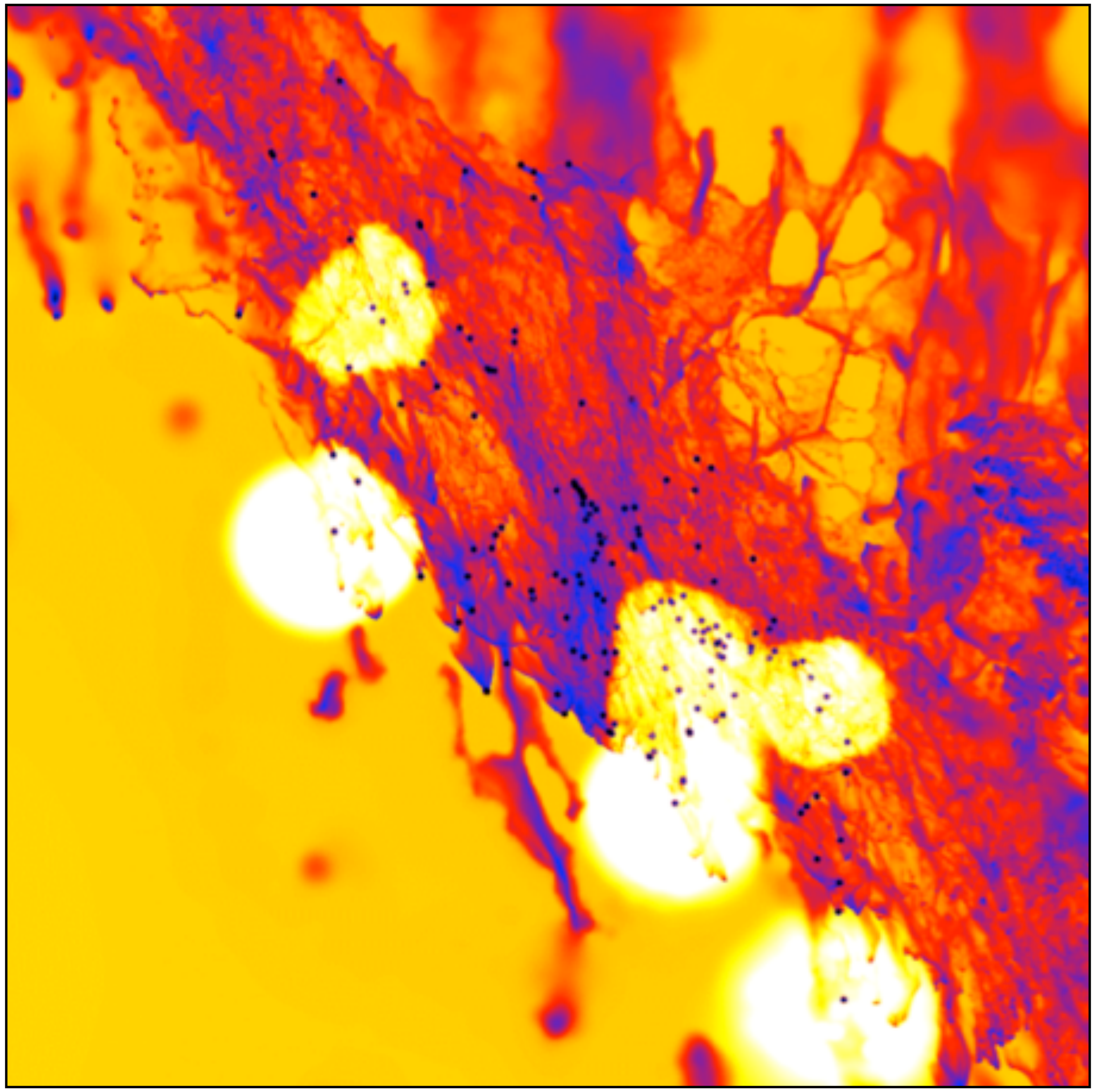
Supernovae feedback

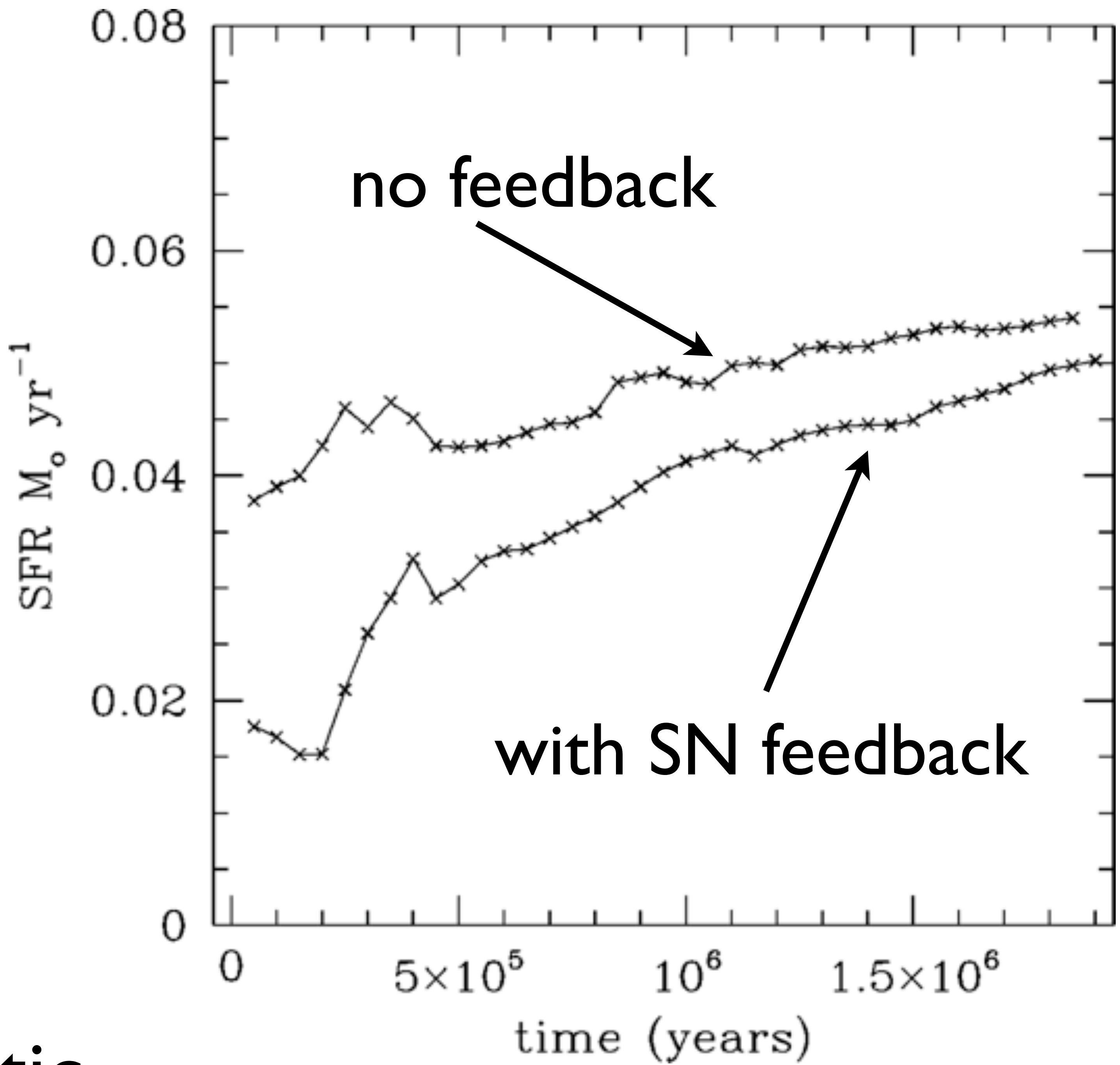
effect on star formation



Supernovae feedback

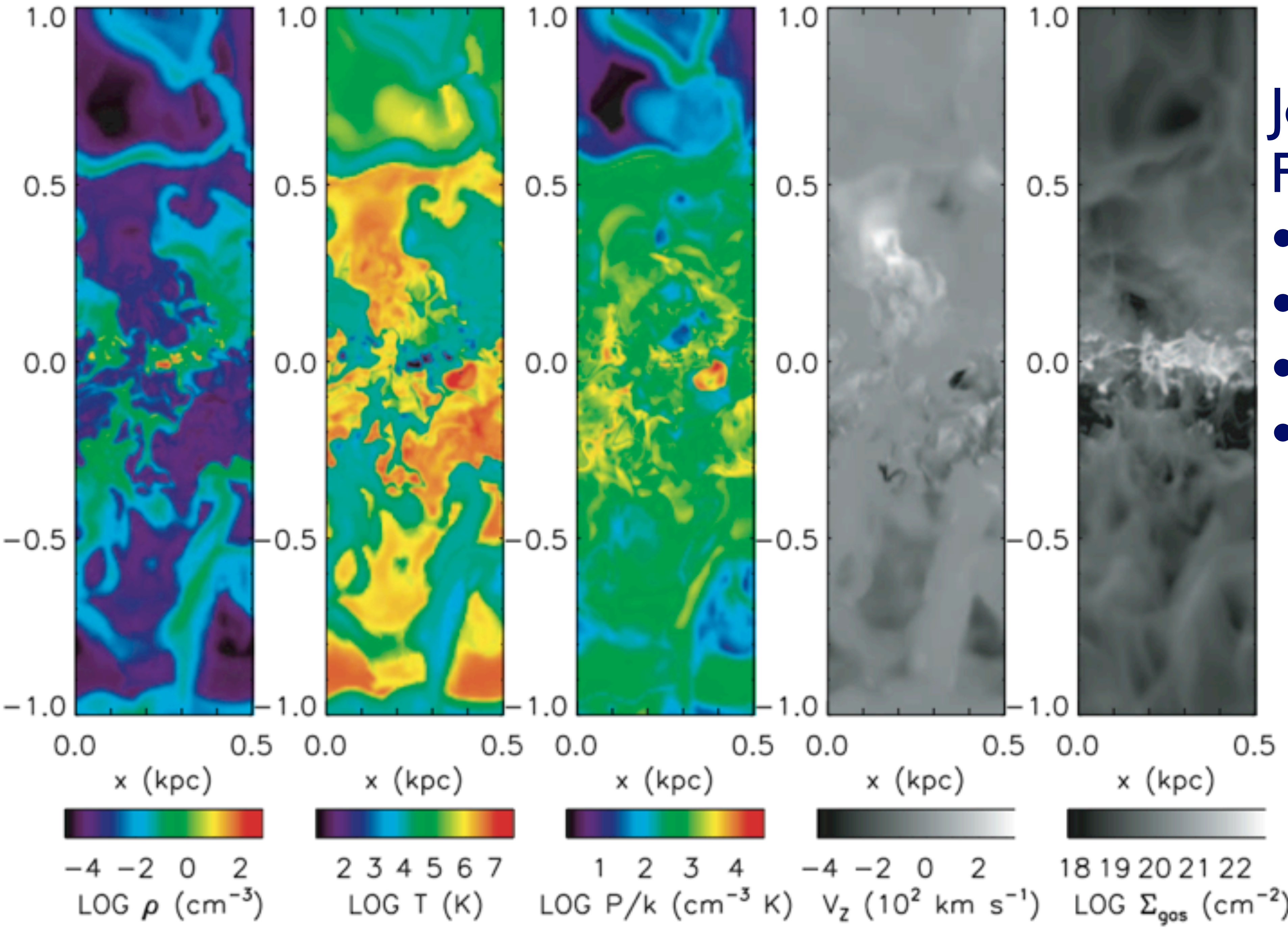
effect on star formation





simulation by Ian Bonnell: zoom-in form a global galactic disc simulation 250x250 pc^2

Supernovae feedback



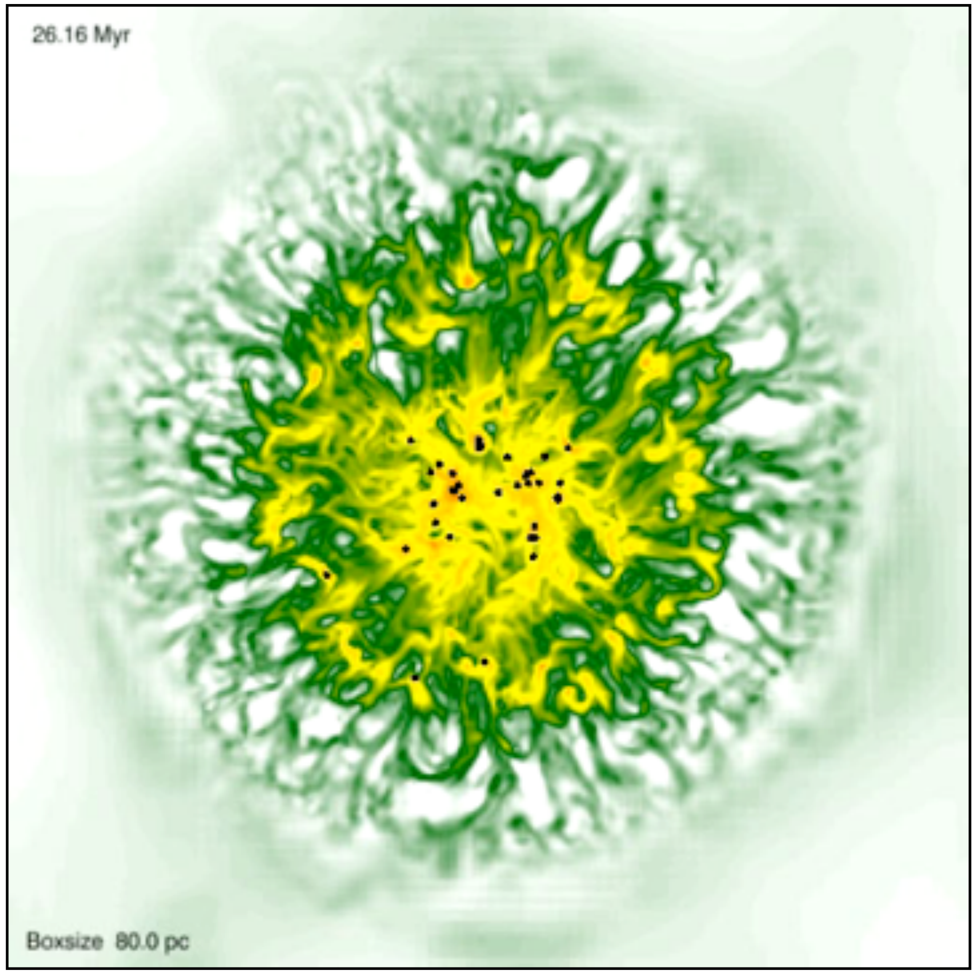
Joung & Mac Low 2006:
FLASH simulations

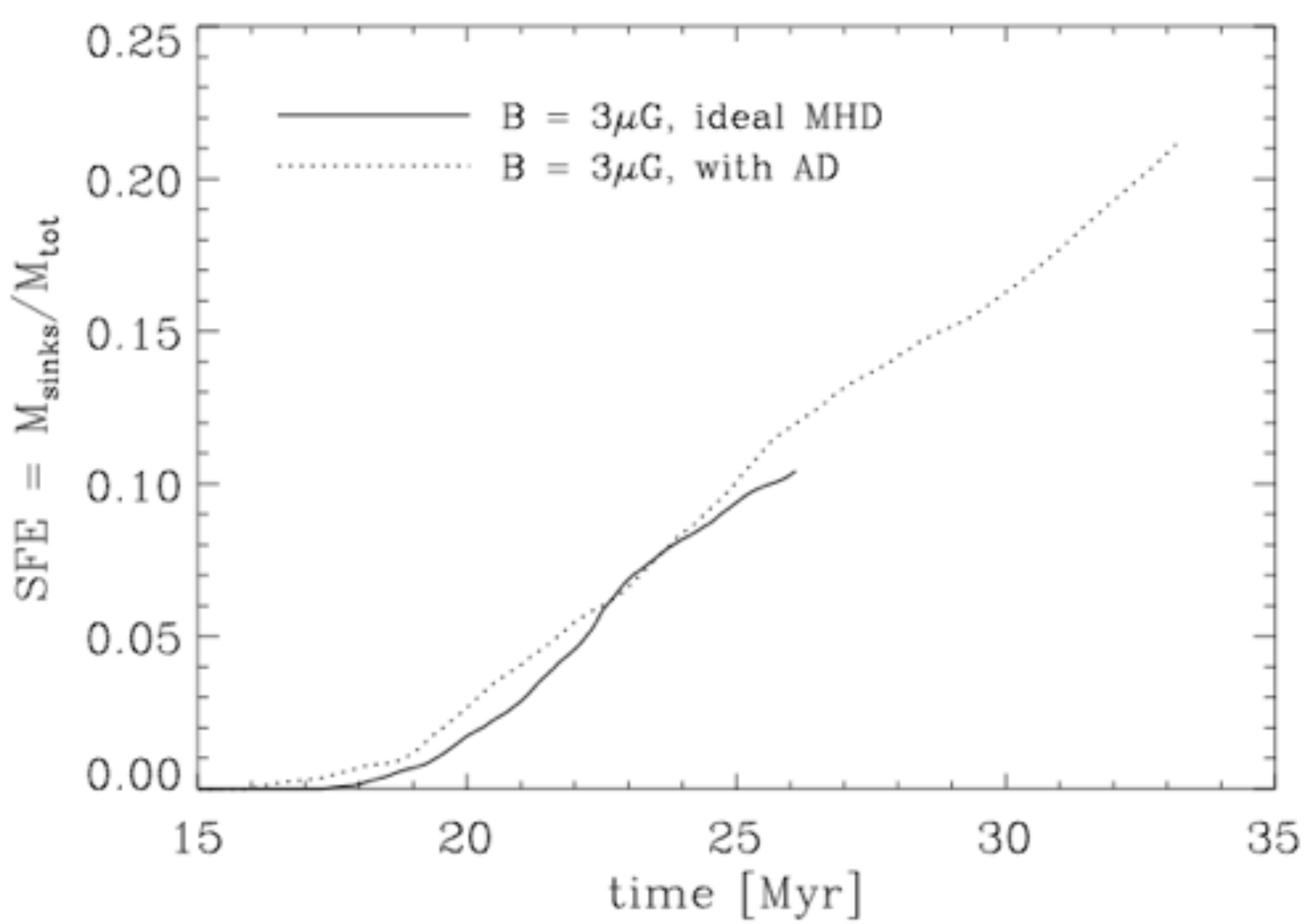
- stratified medium
- no self-gravity
- injection of E_{therm}
- random positions

→ SN inhibits star formation

sufficently to halt star formation in individual MC?

Supernovae feedback



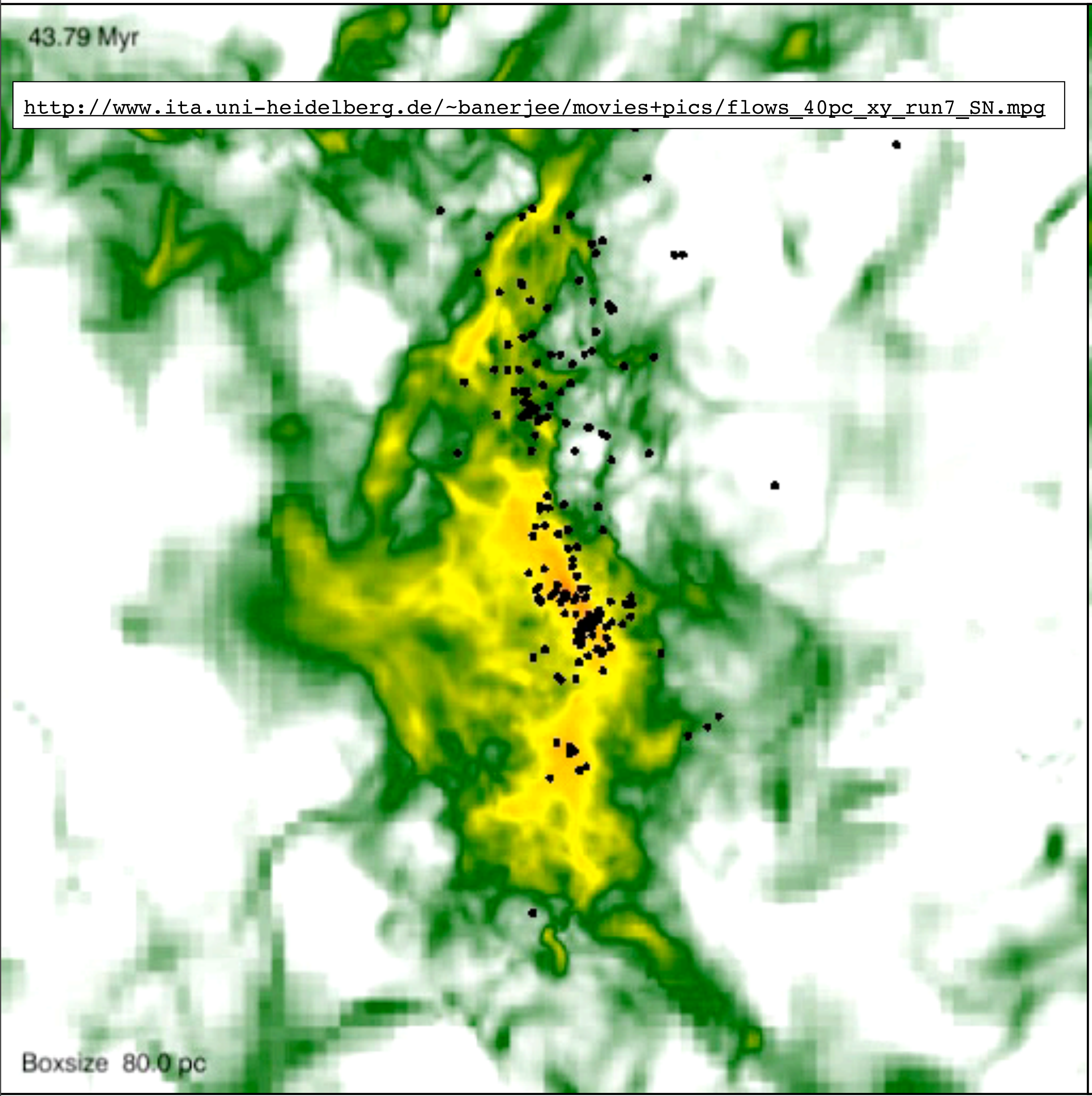


Modeling of SN using sink particle properties:

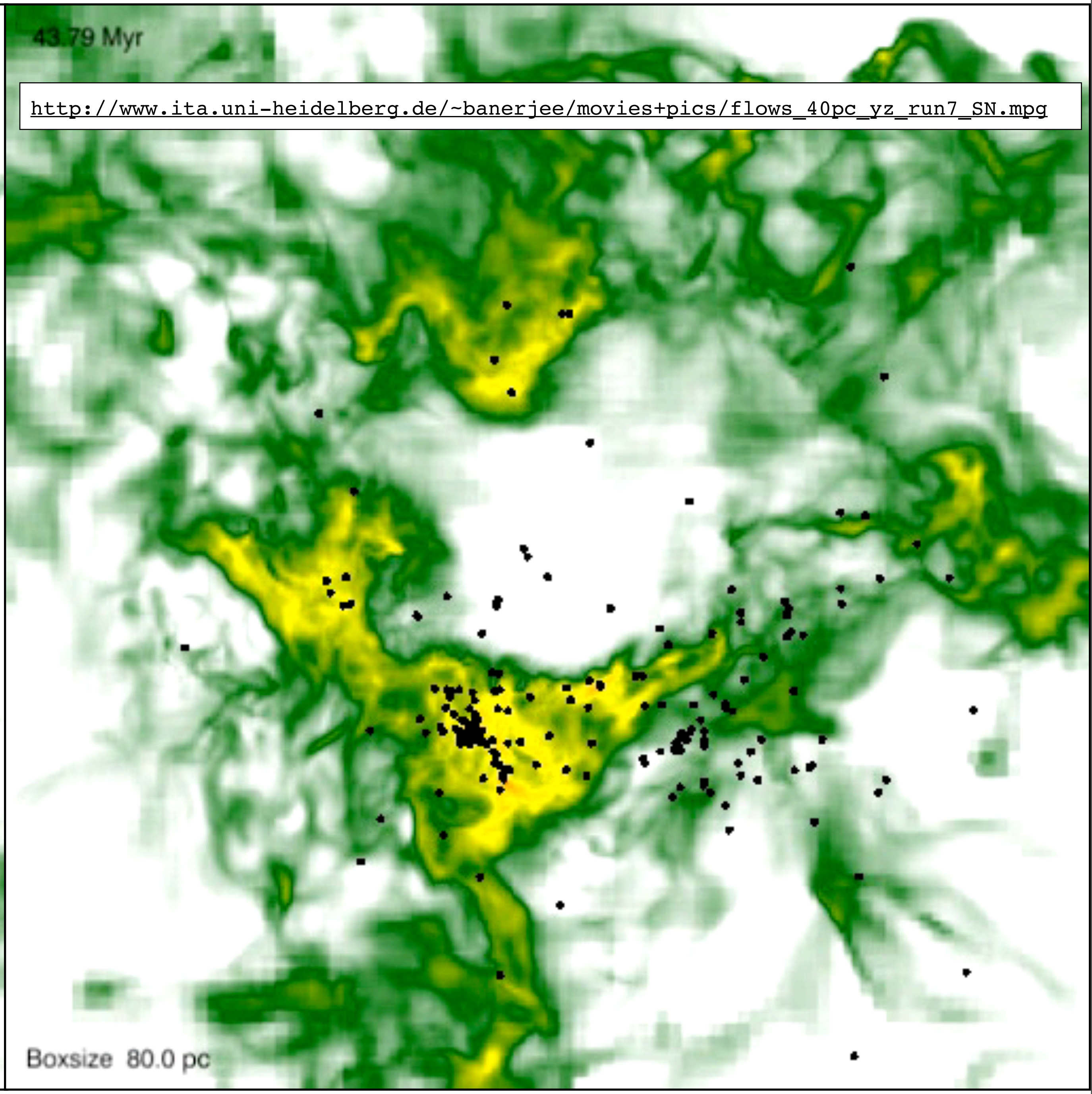
- $M_{sink} > 100\ M_{sol}$
- sink age > 6 Myr

→ kinetic energy injection 10^{51} erg @ $r_{SN} = 1$pc

Supernovae feedback

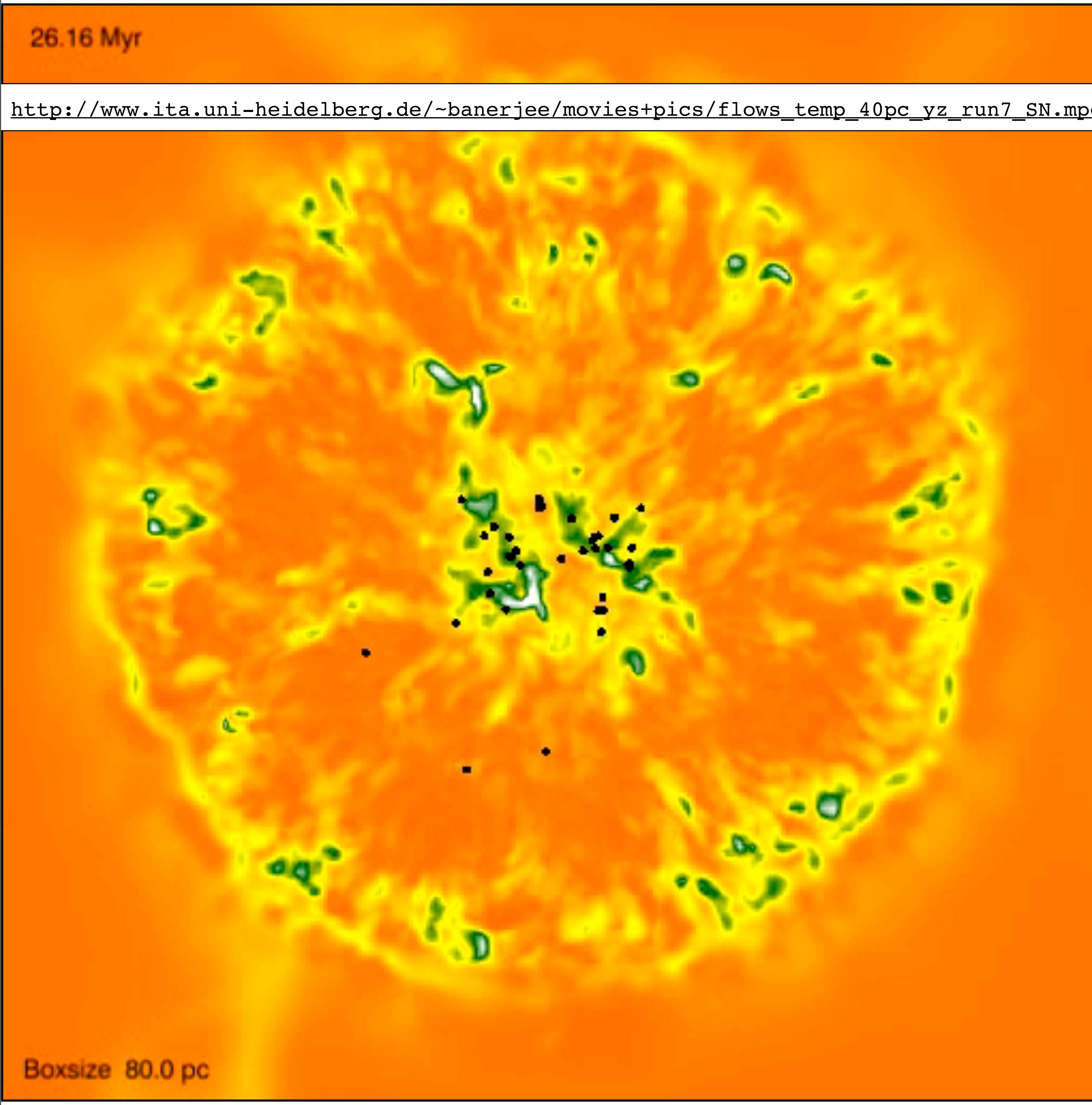


edge-on view



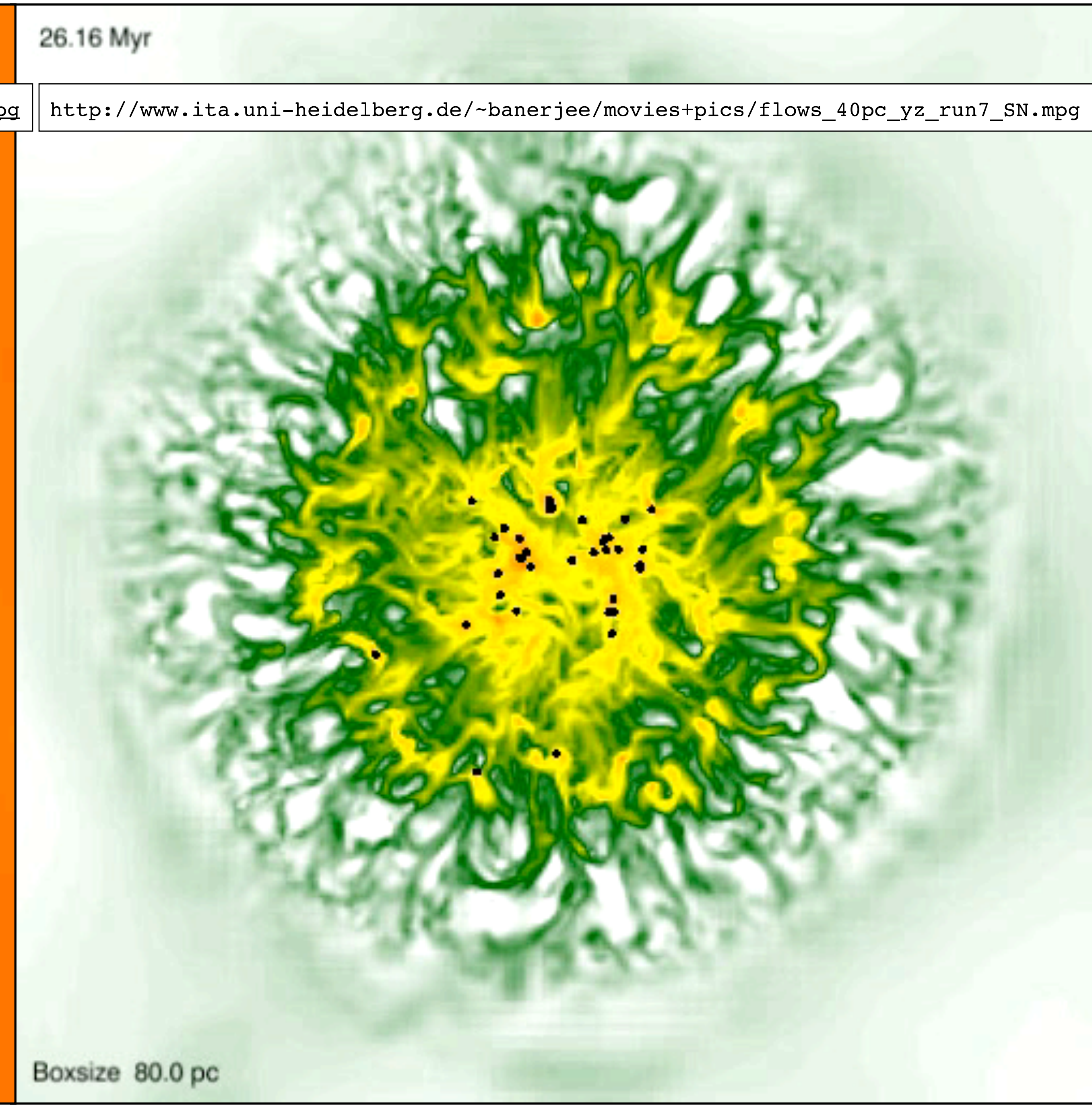
face-on view

Supernovae feedback



http://www.ita.uni-heidelberg.de/~banerjee/movies+pics/flows_temp_40pc_yz_run7_SN.mpg

temperature

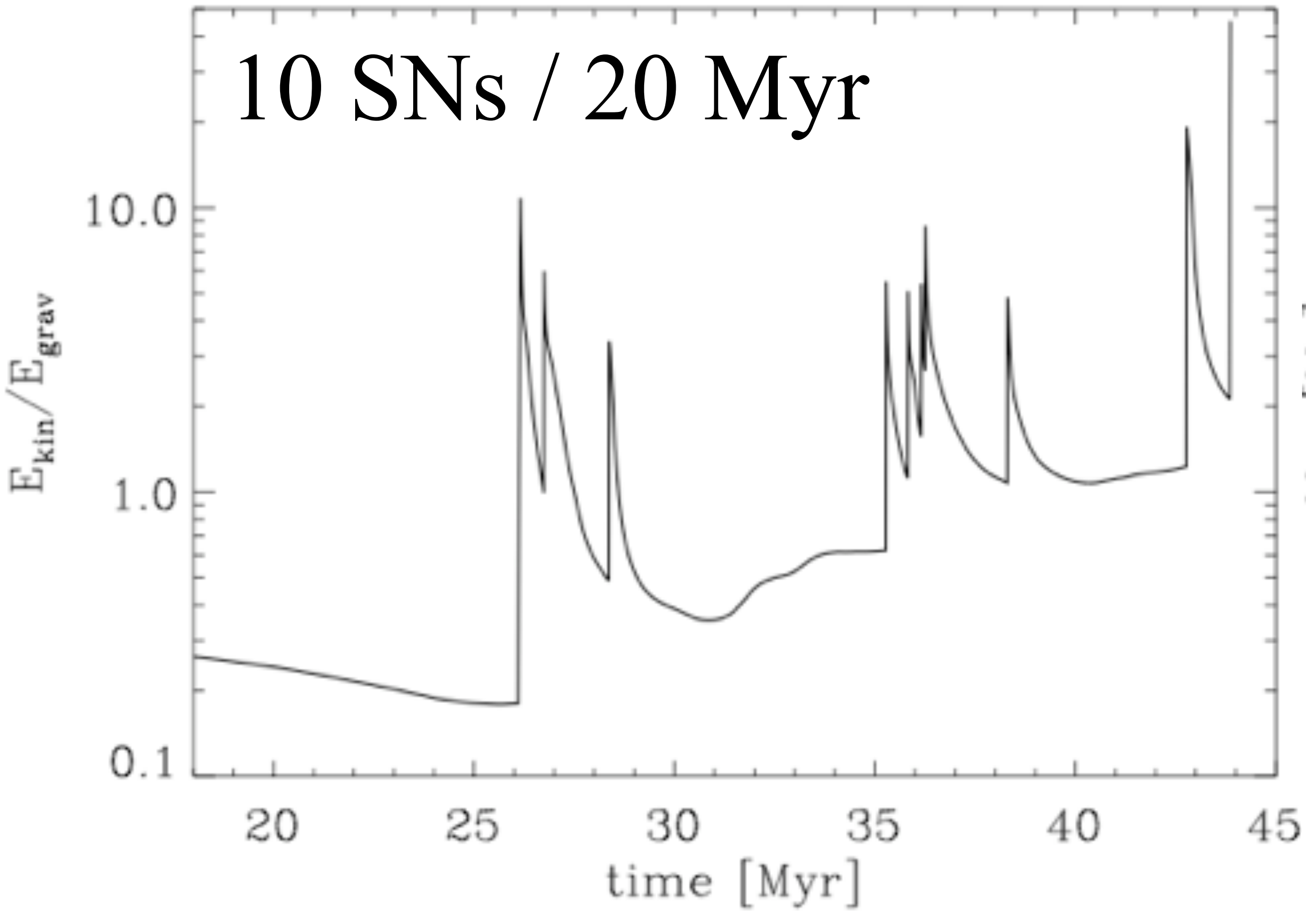


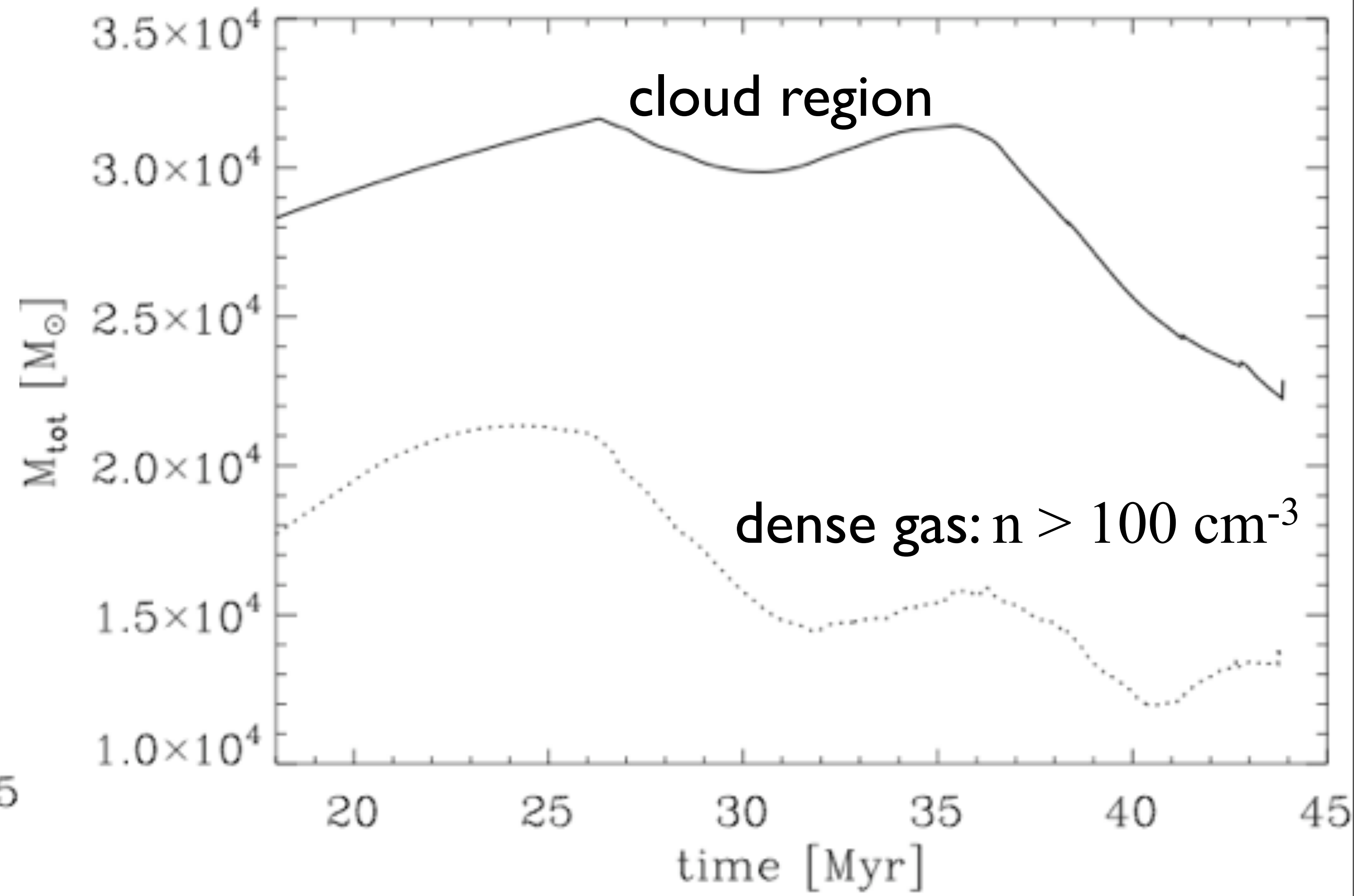
http://www.ita.uni-heidelberg.de/~banerjee/movies+pics/flows_40pc_yz_run7_SN.mpg

column density

Supernovae feedback

cloud disruption?



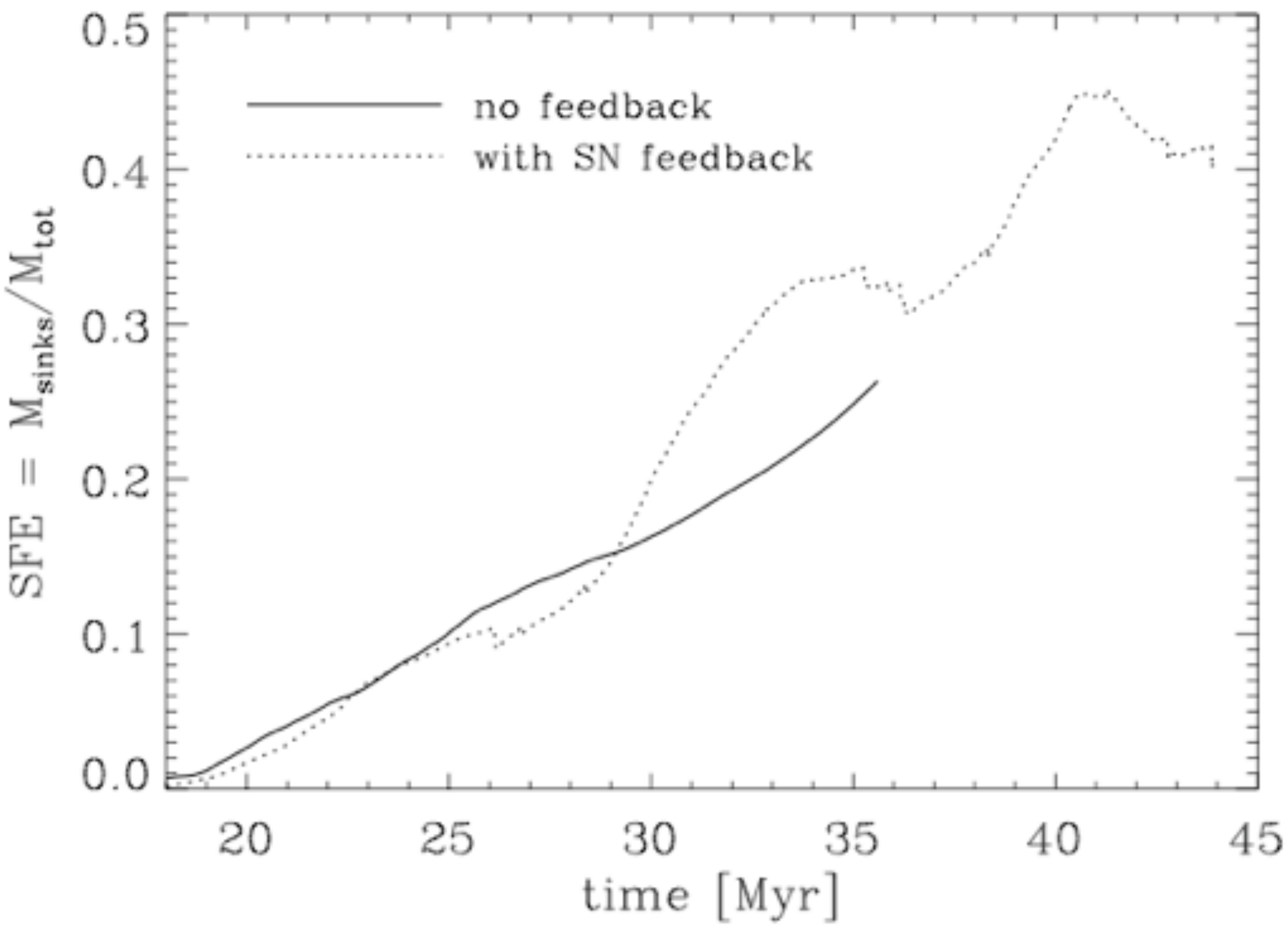


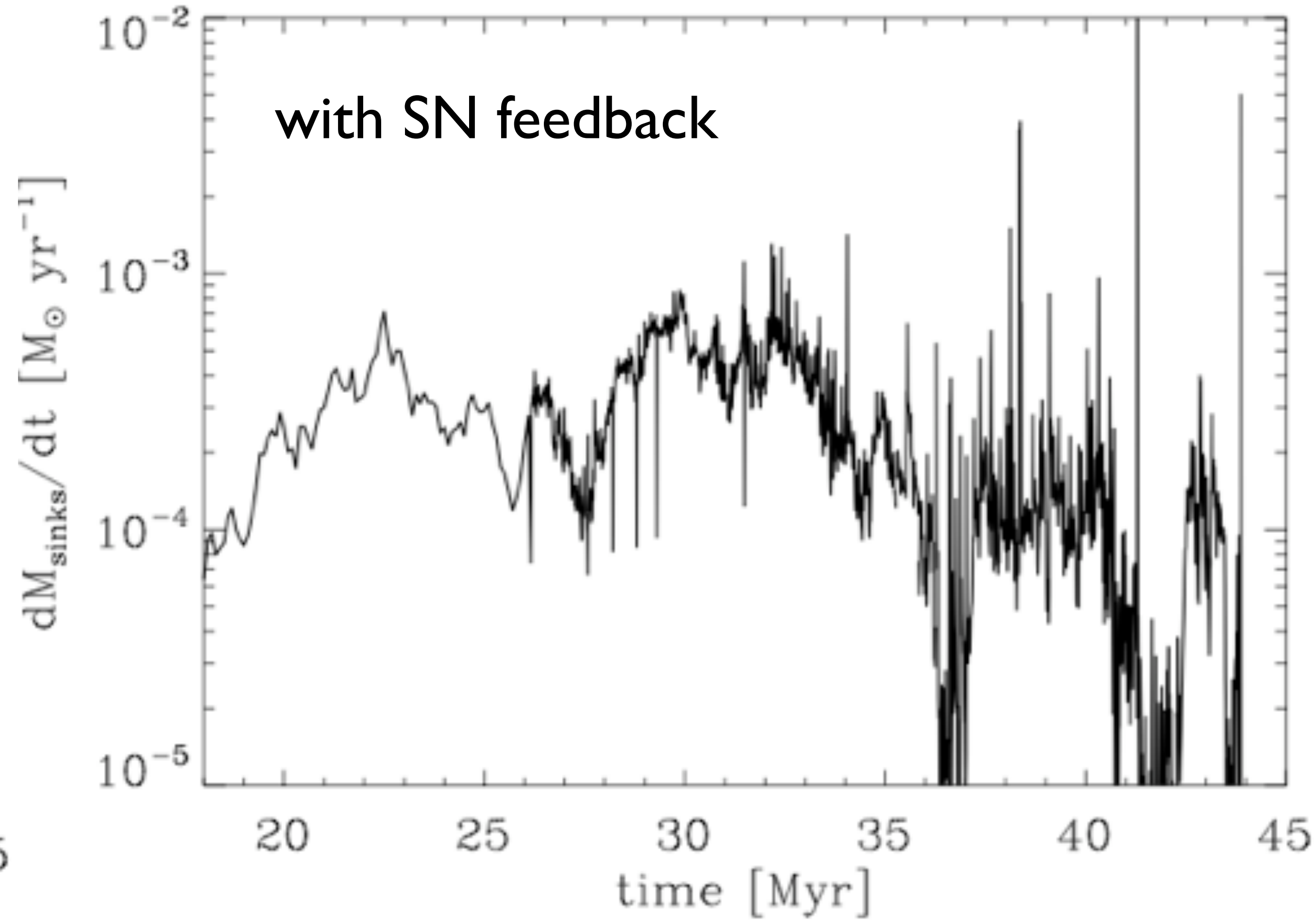
RB et al. in prep.

- cloud looks unbound
- looses ~ 30% of its peak mass, but ...

Supernovae feedback

effect on star formation

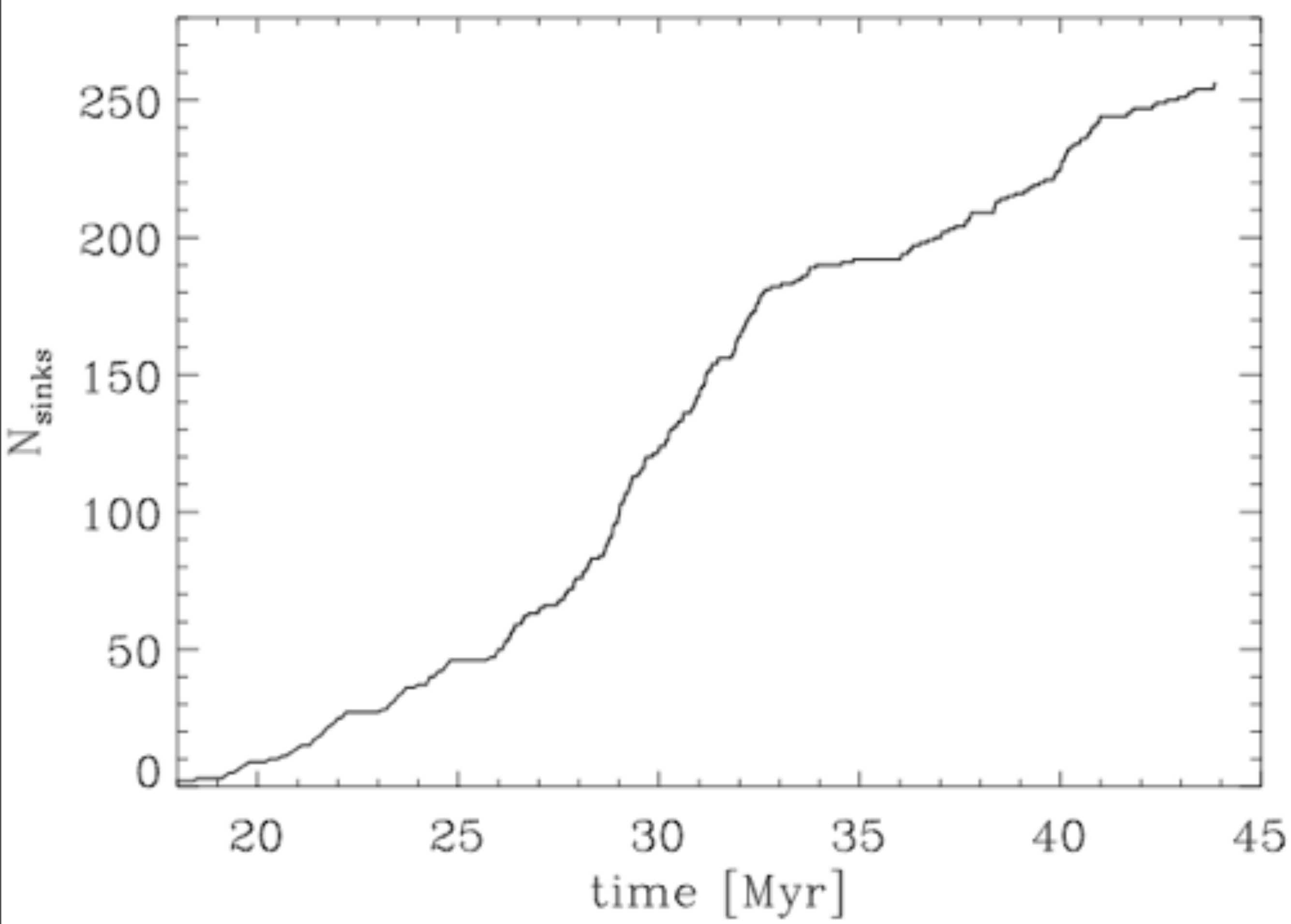


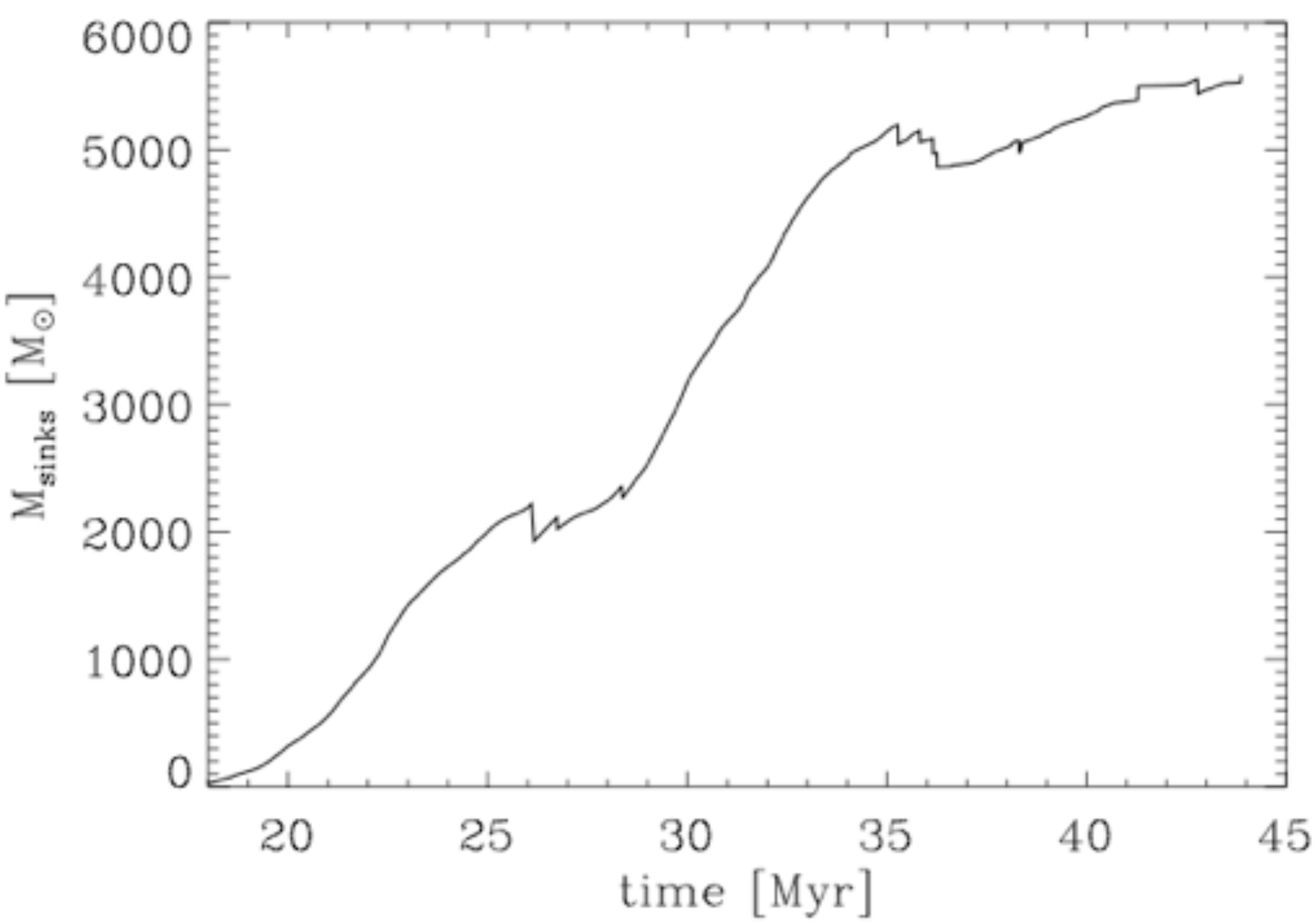


- star formation continues

Supernovae feedback

effect on star formation





- star formation continues

Summary

- What determines the low star formation efficiency? (combination of turbulence, magnetic fields and feedback?)
- What stops star formation?