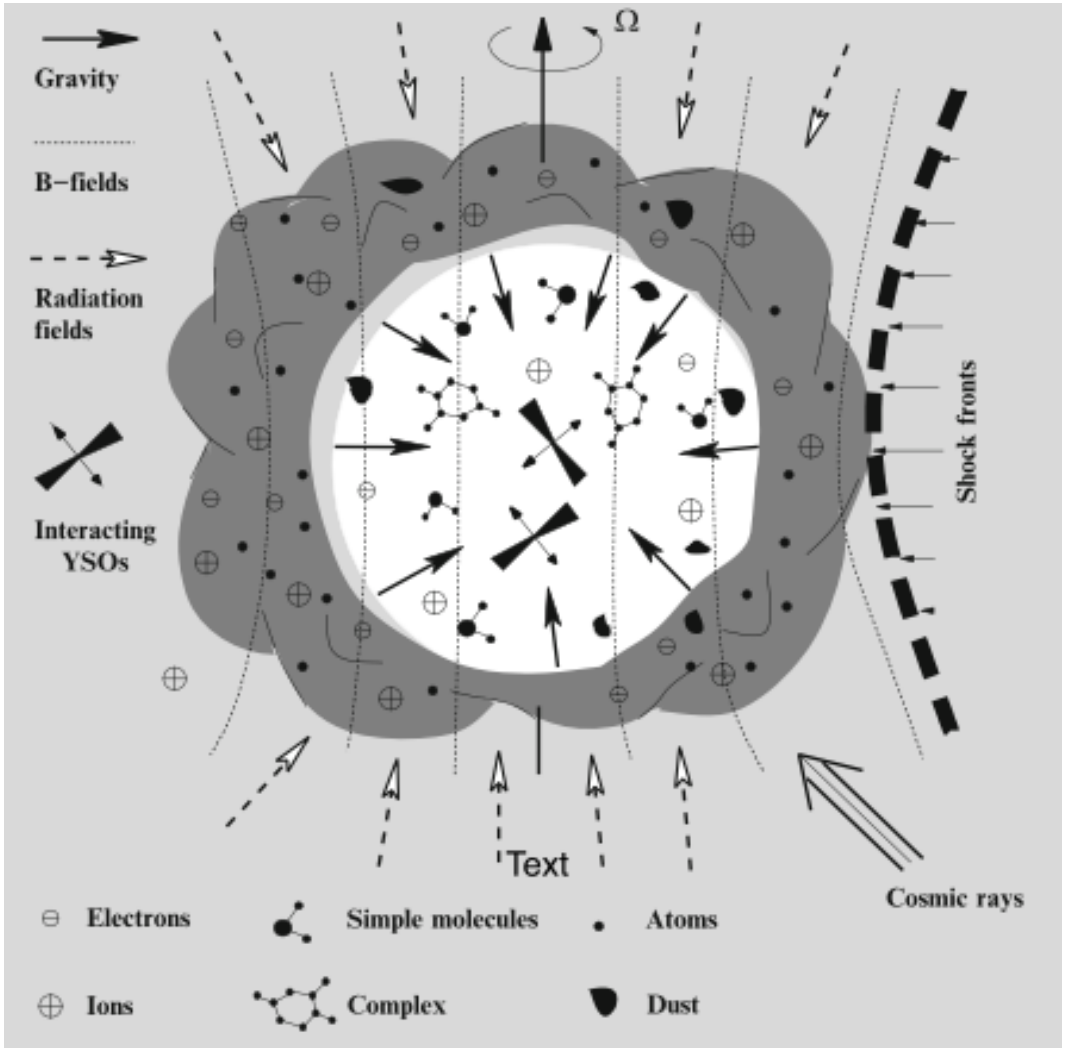
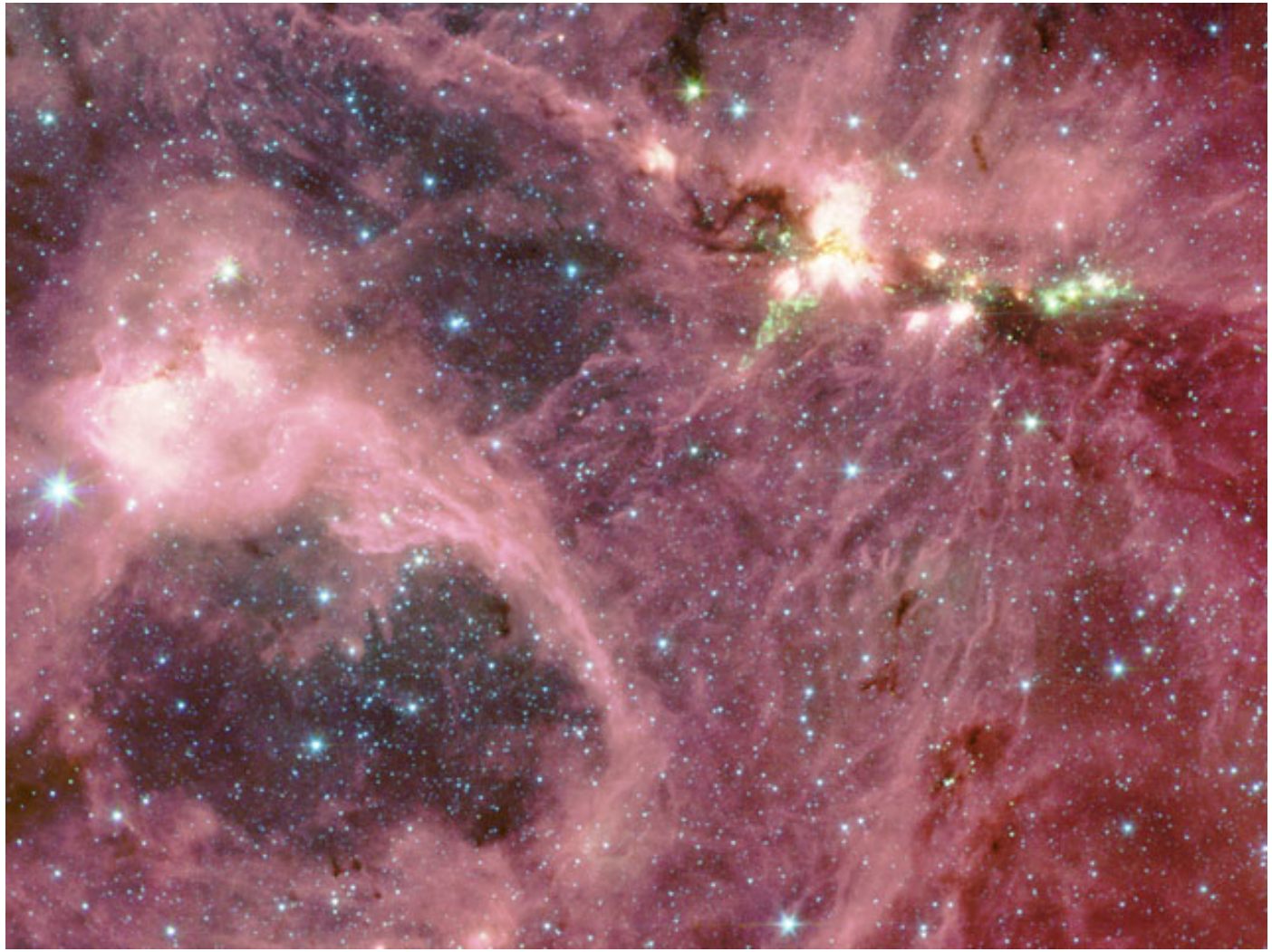
Feedback in Star Forming Regions





Feedback in Star Forming Regions

Only a small percentage of gas turns in to stars over a free-fall time. Star formation is inefficient. This is because of feedback and self-regulation.

- Star forming regions are harboured in giant molecular clouds
  - What drives the super-sonic turbulence in GMCs?
  - Where is the driving scale?
  - Is feedback scale-dependent; does it differ in different environments?

- What dominates feedback (and maintains turbulence)
  - Is it internal or external to a star forming region?
  - On what scale does it operate?
  - How tightly correlated in time is it?

- Where are we now?

Star forming regions and giant molecular clouds

- **What drives the super-sonic turbulence in GMCs?**
- **Where is the driving scale?**
- Is feedback scale-dependent; does it differ in different environments?

What drives the turbulence and where is the driving scale ?

- Galactic shear ?
- Spiral waves ?
- Gravity ?
- Supernovae ?
- Ionizing radiation ?
- Stellar winds ?
- Outflows / jets ?

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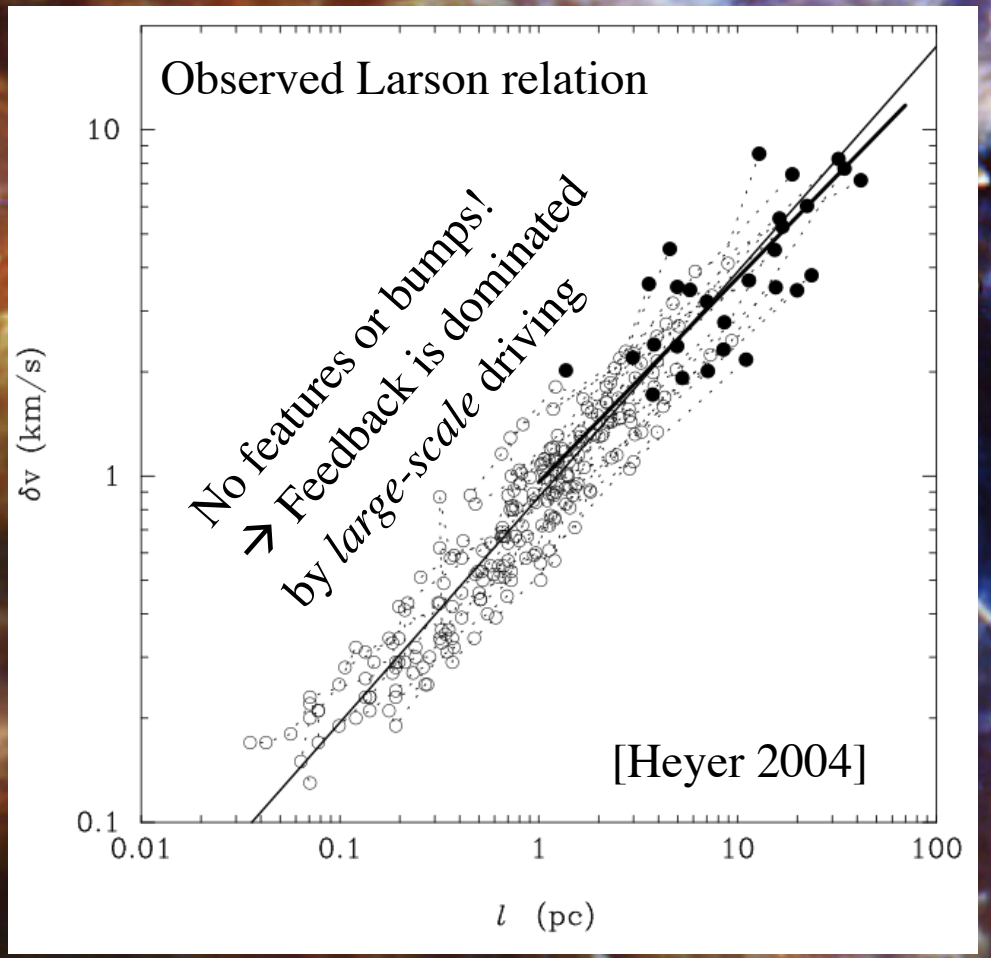

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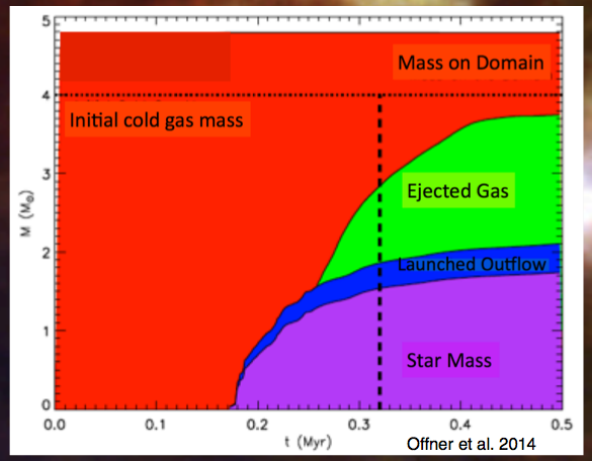
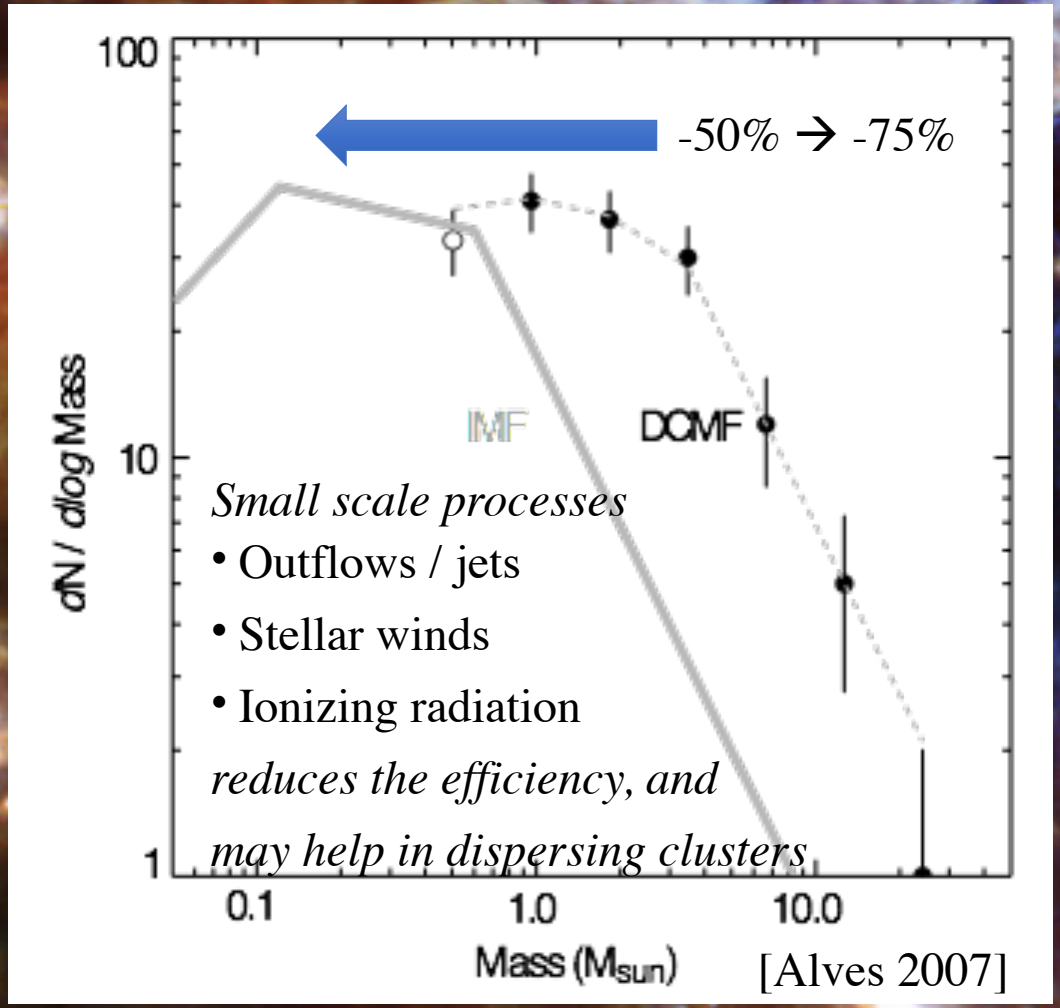




Small scale processes

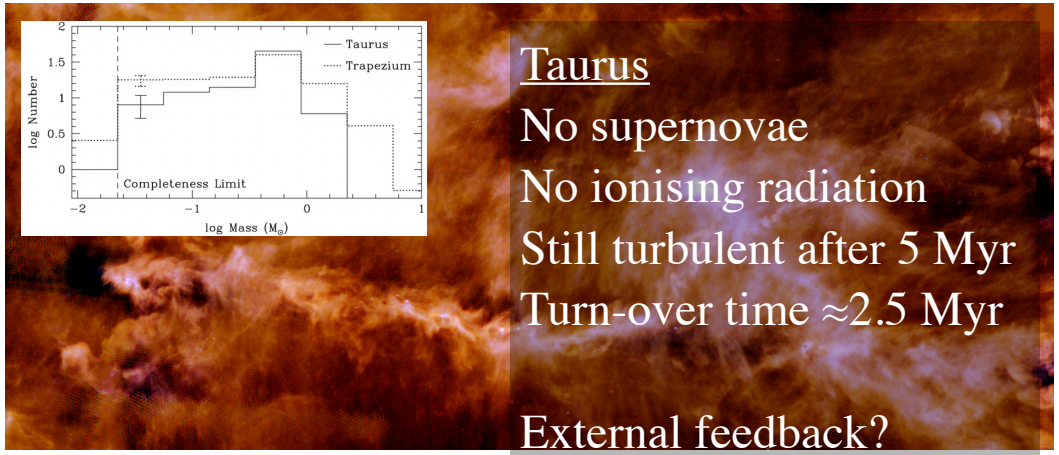
- Outflows / jets
- Stellar winds
- Ionizing radiation

reduces the efficiency, and

may help in dispersing clusters

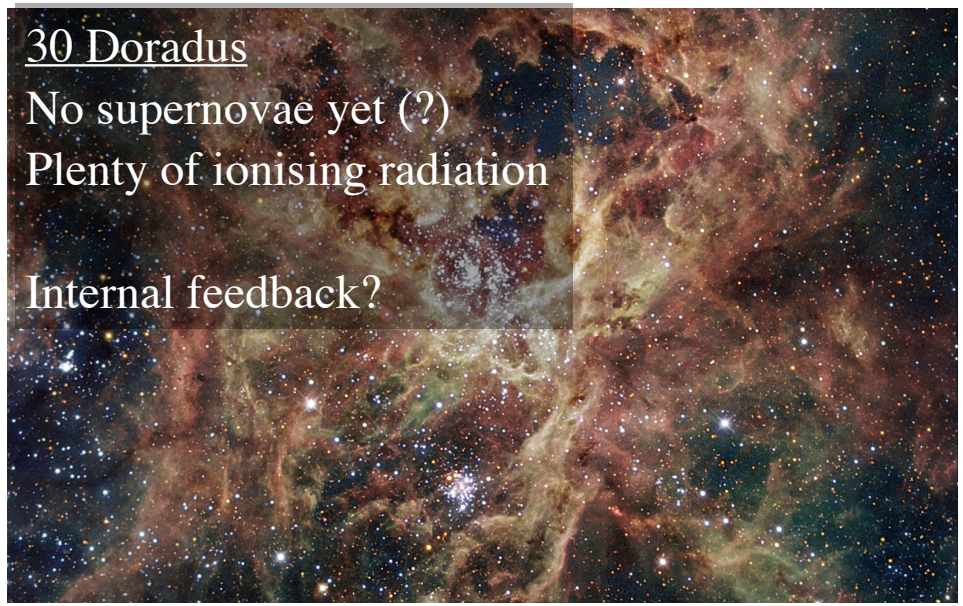
Star forming regions and giant molecular clouds

- **Is feedback scale-dependent; does it differ in different environments?**



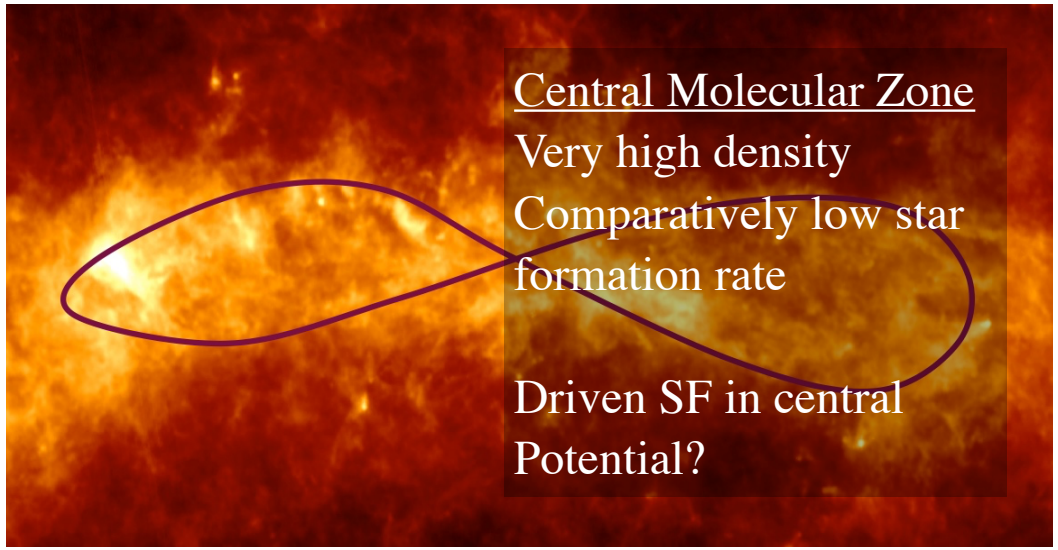
Taurus
No supernovae
No ionising radiation
Still turbulent after 5 Myr
Turn-over time ≈2.5 Myr

External feedback?



30 Doradus
No supernovae yet (?)
Plenty of ionising radiation

Internal feedback?



Central Molecular Zone
Very high density
Comparatively low star formation rate

Driven SF in central Potential?

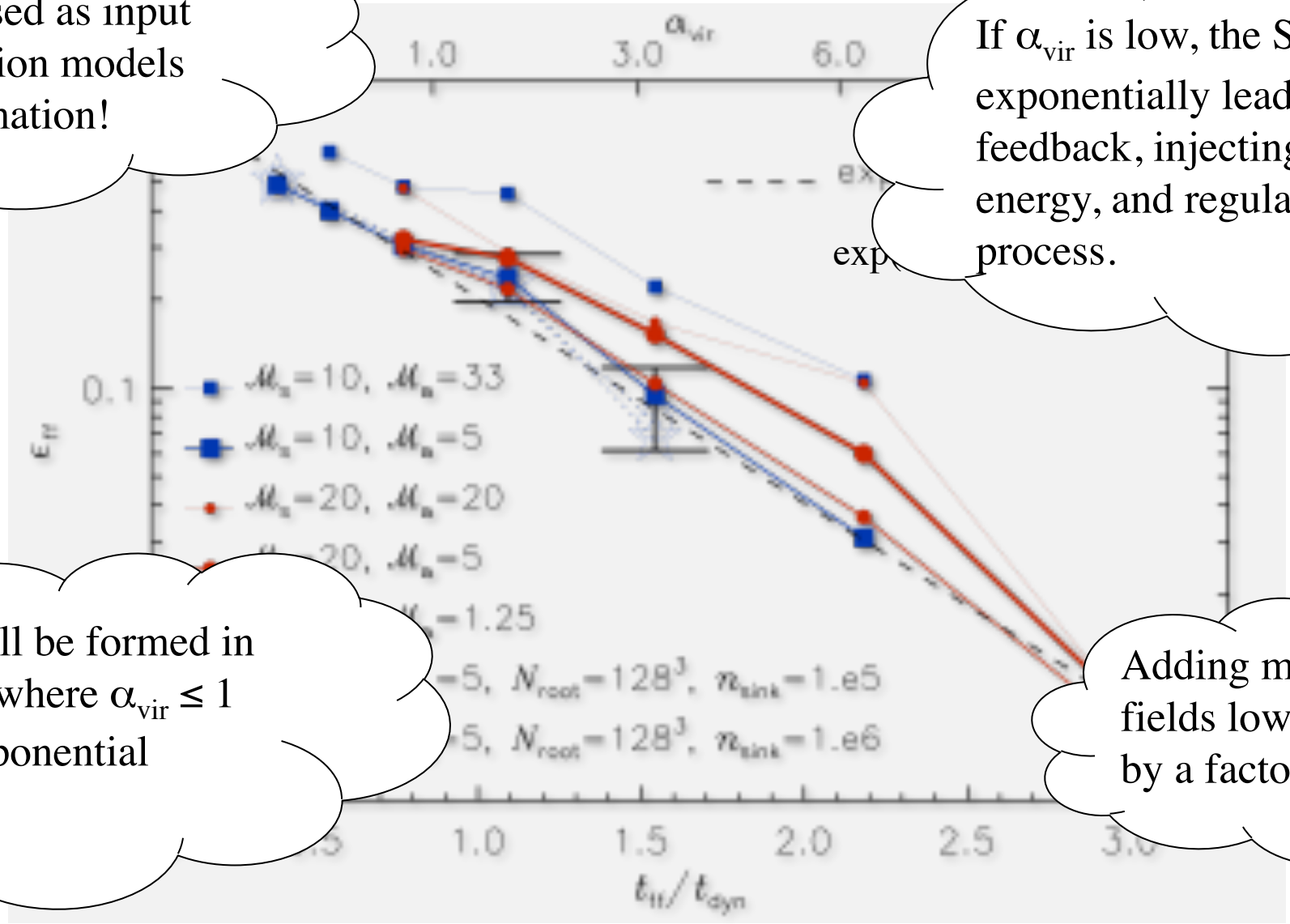
What dominates feedback (and maintains turbulence)

- Is it internal or external to a star forming region?
- On what scale does it operate?
- How tightly correlated in time is it?

The Star Formation rate in simple boxes

This can be used as input for starformation models in galaxy formation!

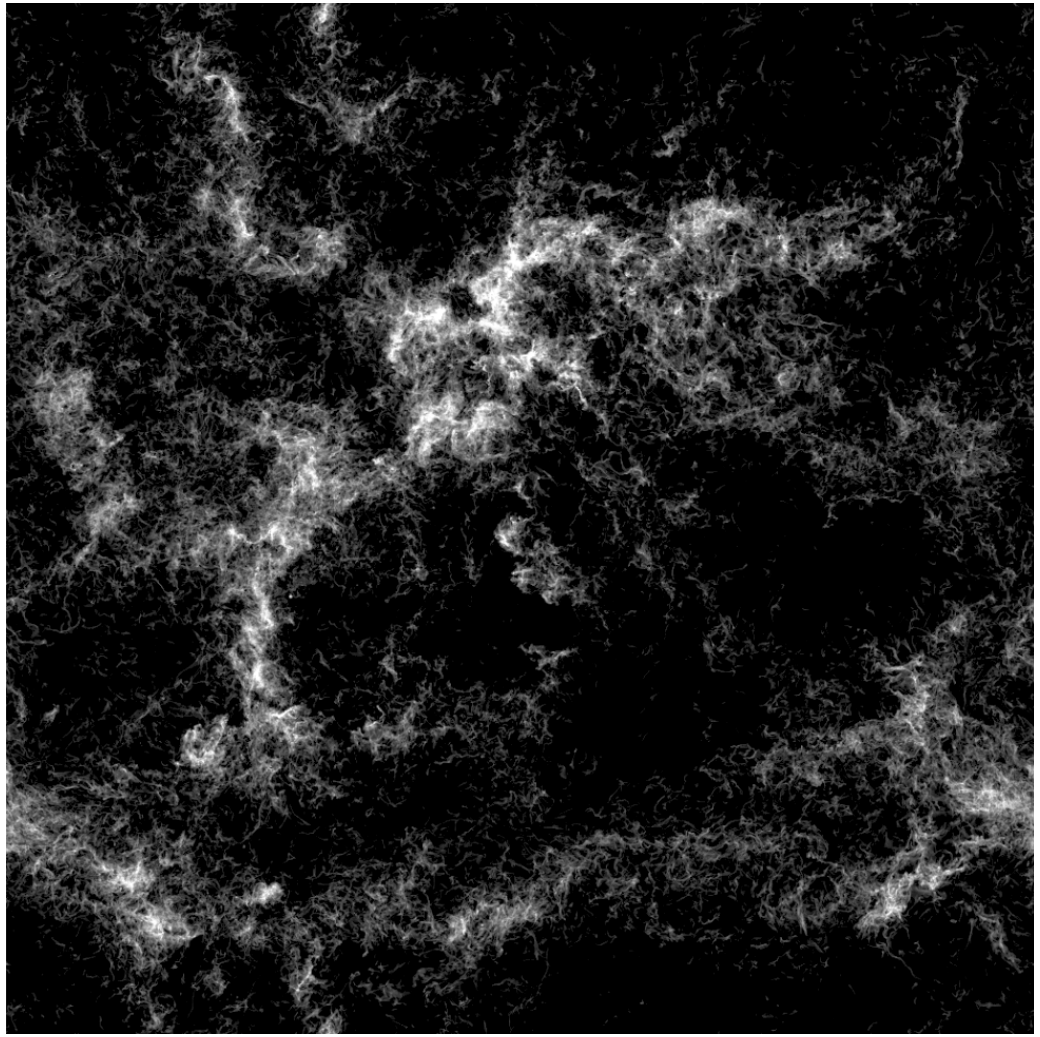
If α_{vir} is low, the SFE rises exponentially leading to feedback, injecting more energy, and regulating the process.

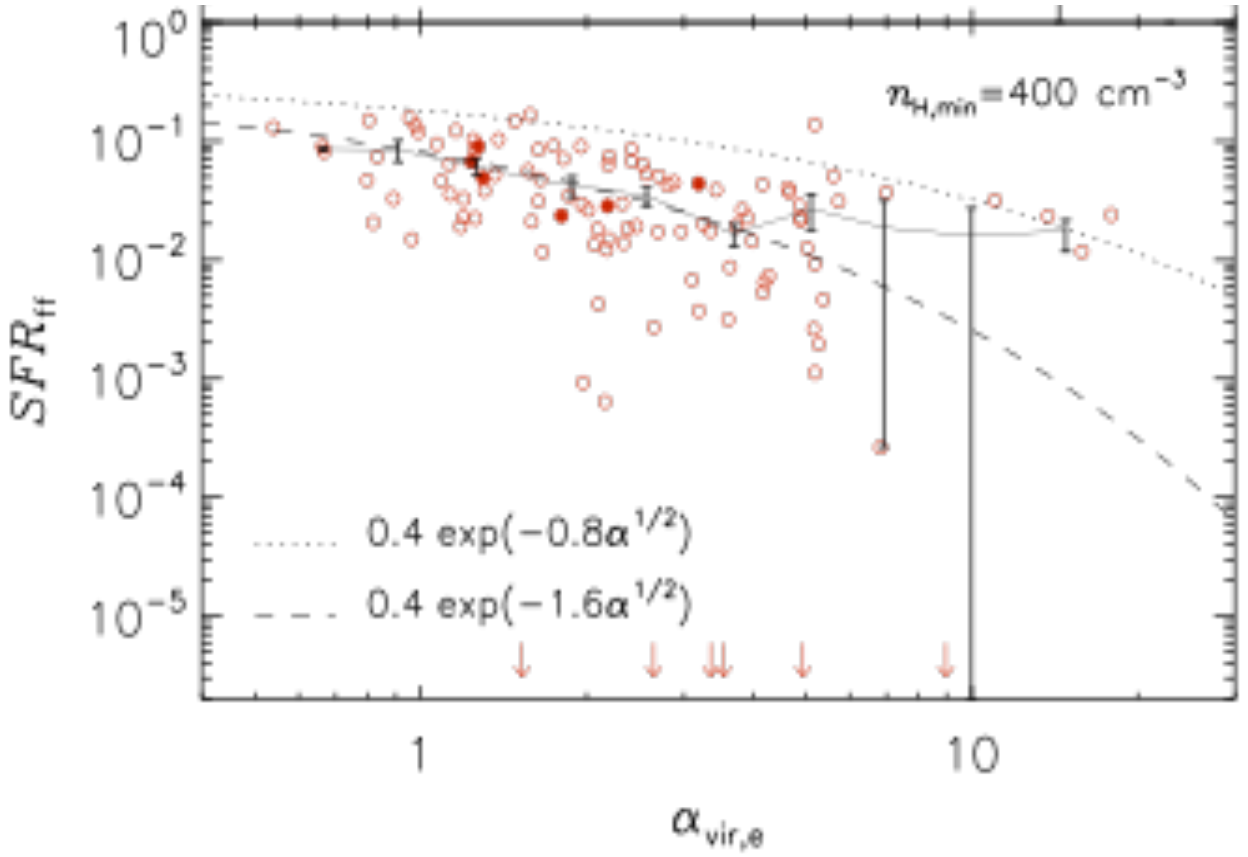


Most stars will be formed in (sub)-clouds where $\alpha_{vir} \leq 1$ due to the exponential dependence

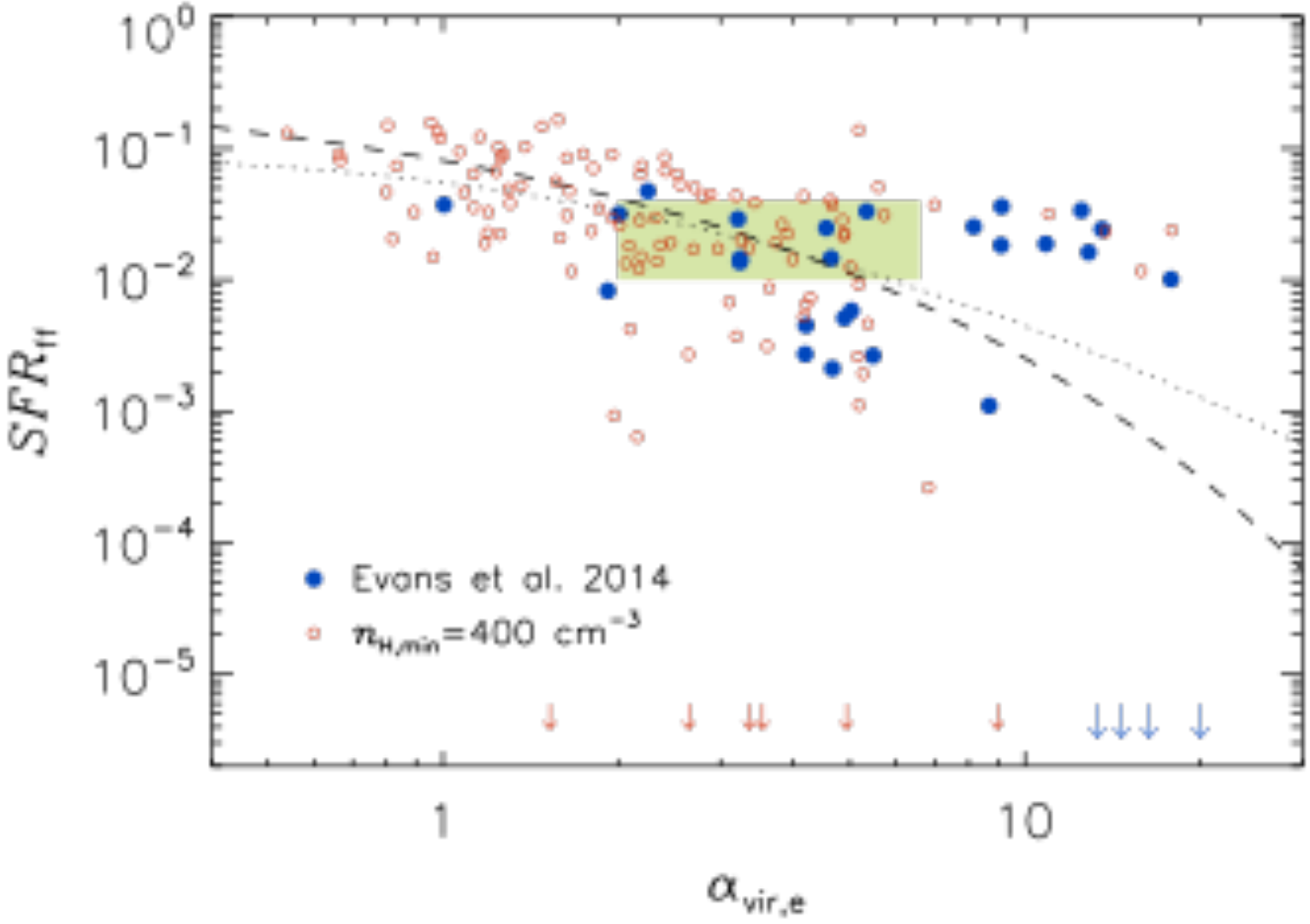
Adding magnetic fields lowers SFR by a factor of ≈3

The Star Formation Rate with realistic feedback





Simulation versus observations of nearby clouds and CMZ in center of MW



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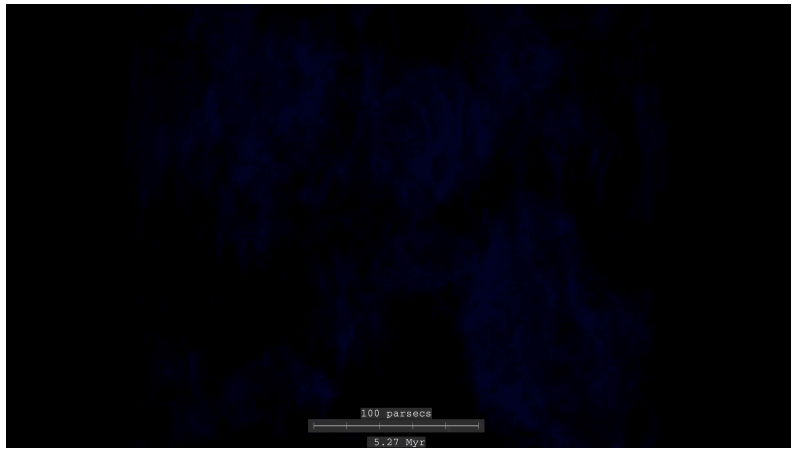
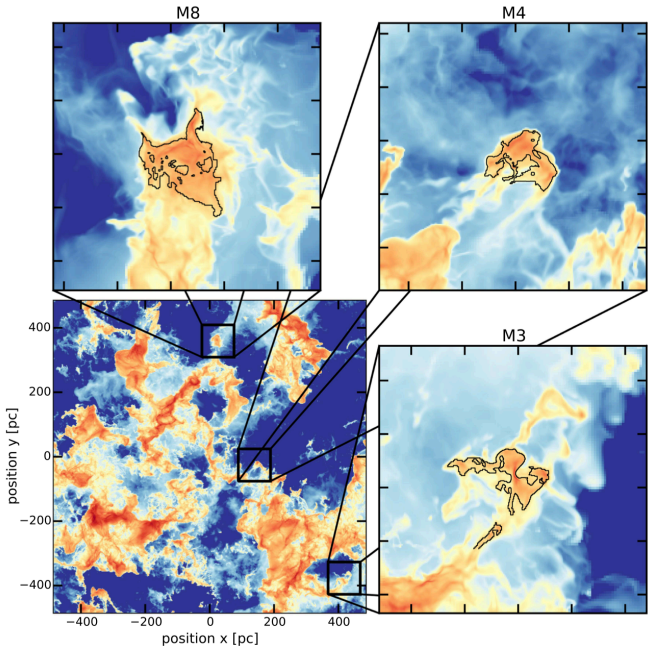
”External / delayed SN feedback”



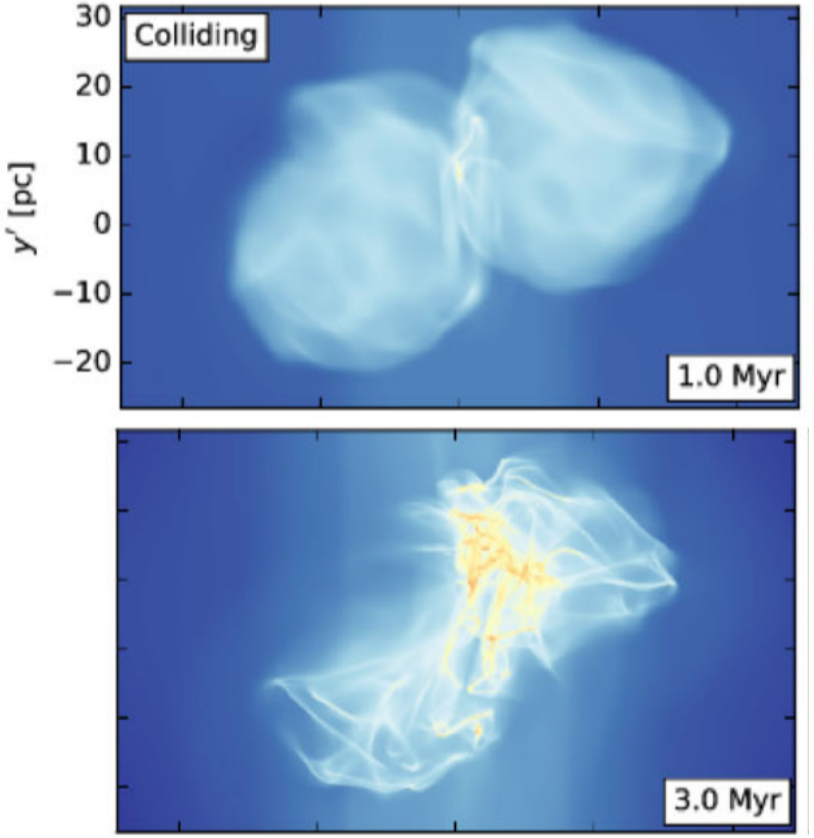
- % Only Supernovae
- + Very high resolution
- + Tracking single stars
- + Reproduce observations

”External: Gravity ?”



- + maintain cascade through collapse
- % needs alpha-virial < 1

”External: Cloud-cloud collisions”



- + explain high SFR in arms
- % not self regulating

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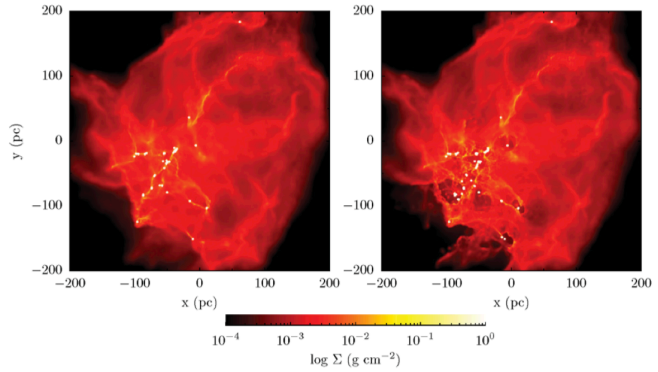
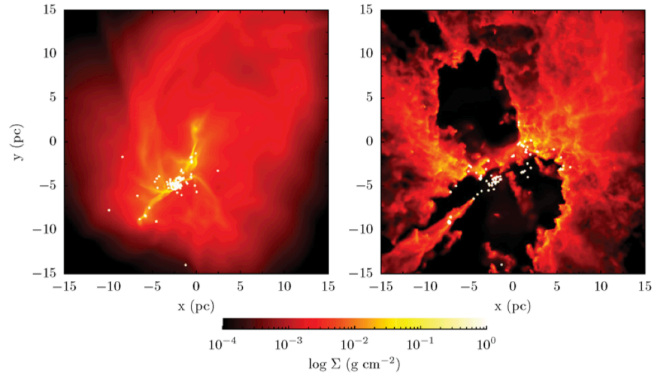
”Internal Feedback: Photo-Ionization”



(a) Run A



- Superficially large impact
- Largest impact on dense, small clusters
- Smaller impact on large clusters. Gravitational potential probably too deep

- Triggering not effective
- Radiation decrease SFE / SFR

”Internal Feedback: Rad Pressure”

- Only able to do something for extremely dense environments
- Maybe limit density of stars

”Internal Feedback: Stellar Winds”

- Subdominant compared to RT and SN
- May help in starving accretion flow
- Result in lower cluster life-times

Where are we now?

- Low efficiency of SF can be explained if stellar feedback is regulating the energy input.
- Shear / spiral arms / cloud collisions play a role; but maybe do not *regulate* SF
- In exceptional places (e.g. centres of galaxies) external drivers may overpower feedback loop. In particular if forcing time-scale is lower than the SF time-scale

- <u>Feedback mechanisms</u>
  - Many contenders. Supernovae and ionizing radiation most important (?)
  - Magnetic fields, cosmic rays, outflows give additional suppression of SFR_{ff}
  - Different effects may dominate in different settings. Is Larson non-universal?
  - Community has suffered from using the hammer we have: *"my code / IC can do XX"*.

- <u>What is needed:</u>
  - Large boxes with high enough spatial and temporal resolution (>100 pc boxes, <0,05pc)
  - Sufficient physics (SN, Rad, Chemistry, CRs(?), Stellar models, single stars,…)
  - Forward modelling for comparison with observations

- What about Extreme Star Formation?

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