How to kill a Giant Molecular Cloud

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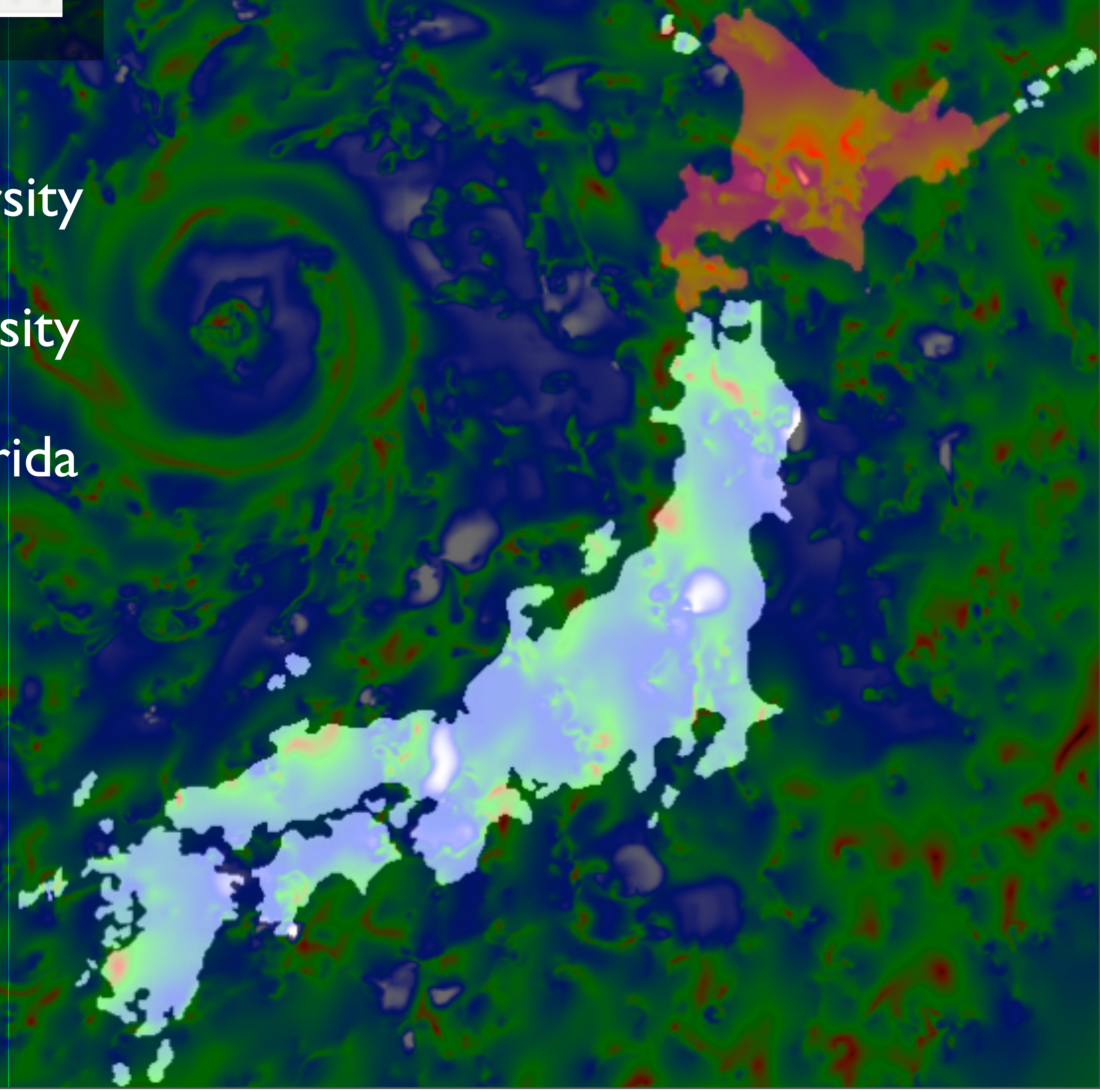


The hand that rocks the cradle

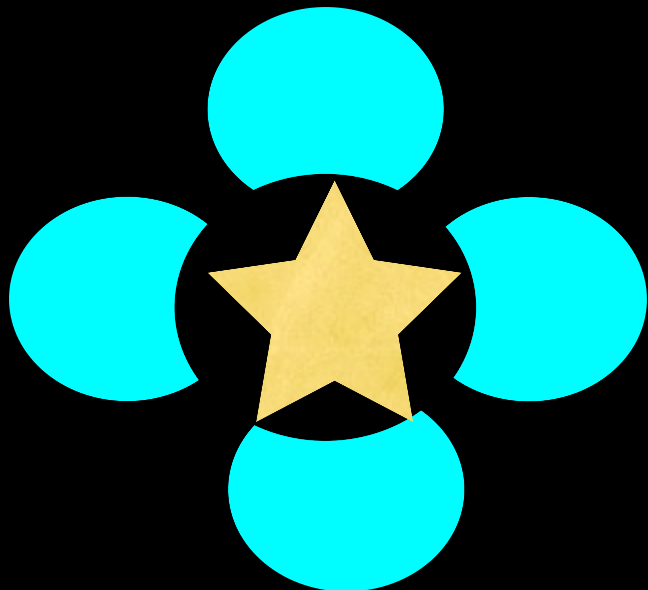
The cold gas in a disc galaxy is organised into the giant molecular clouds.

These clouds are the nurseries for the majority of the stellar population

Their properties and evolution govern the galaxy's star formation rate.

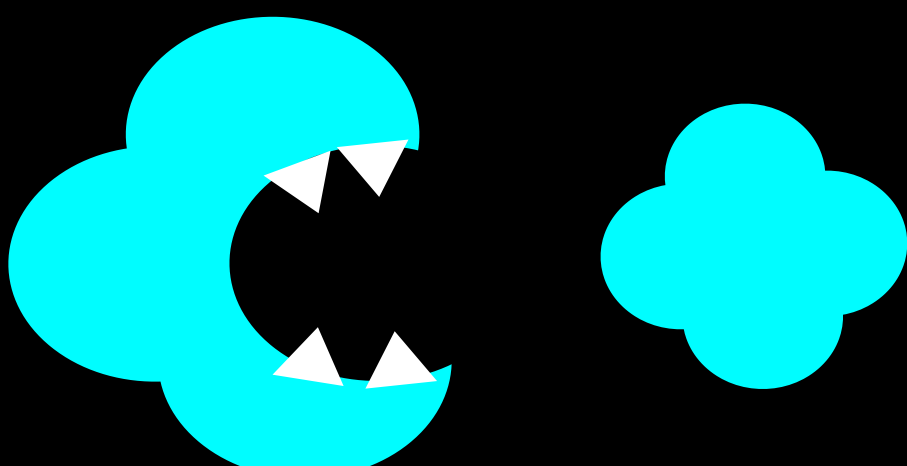
But does the stellar child they produce also cause their death?

The hand that rocks the cradle



One way to kill a GMC is via the local effect of an internal energy injection

e.g. supernovae explosion, ionising winds



Alternatively, global cloud-cloud interactions may merge clouds or trigger star formation that destroys them

What we did....

Compared the properties of GMCs formed in galaxy disc simulations with different star formation properties

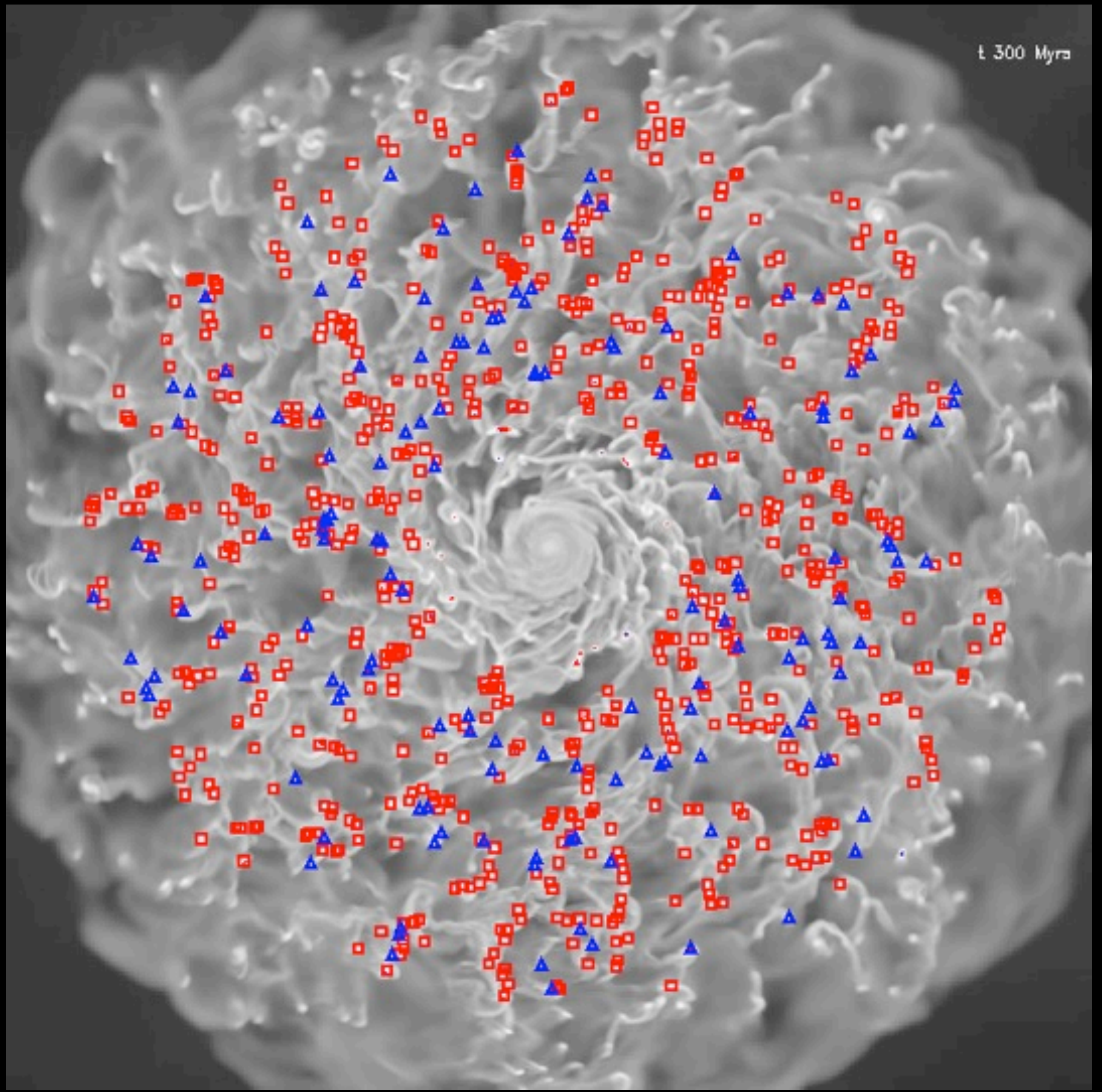
	Self gravity + radiative cooling	Star formation	Diffuse heating	Localised energy injection
No SF	Yes	No	No	No
SF only	Yes	Yes	No	No
PE heat	Yes	Yes	Yes	No
SNe	Yes	Yes	Yes	Yes

What we did....

3D isolated disc simulation, performed with the AMR code, Enzo. Limiting resolution 7.8 pc.

Disc is initially smooth and sits in a static background potential that gives a Milky Way-like flat rotation curve.

Gravitational instabilities occur as the disc cools (> 300 K), forming dense knots of gas that we recognise as the GMCs



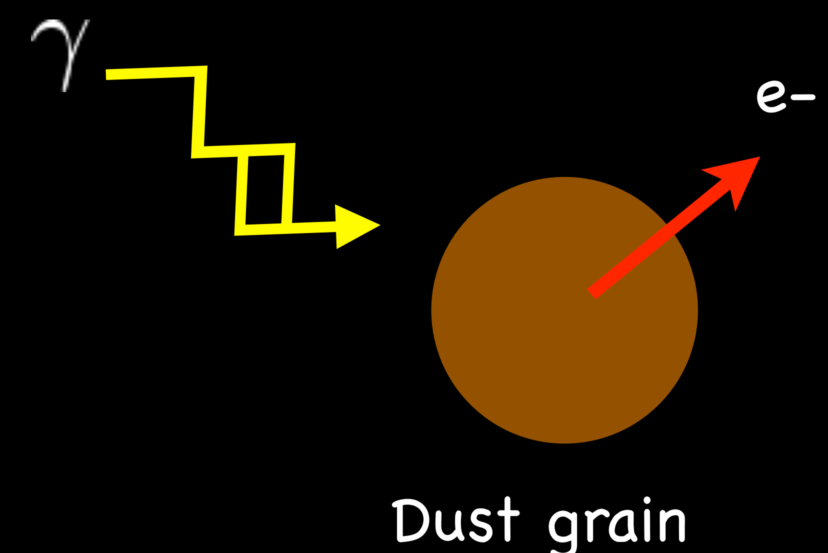
20 kpc

What we did....

Star formation at a constant efficiency per free-fall time of 2%. Star particles are created with 1000 solar masses

Feedback type I: diffuse heating from dust grains

Heating term proportional to the gas density, with a radial dependence suggested by Wolfire et al. (2003)

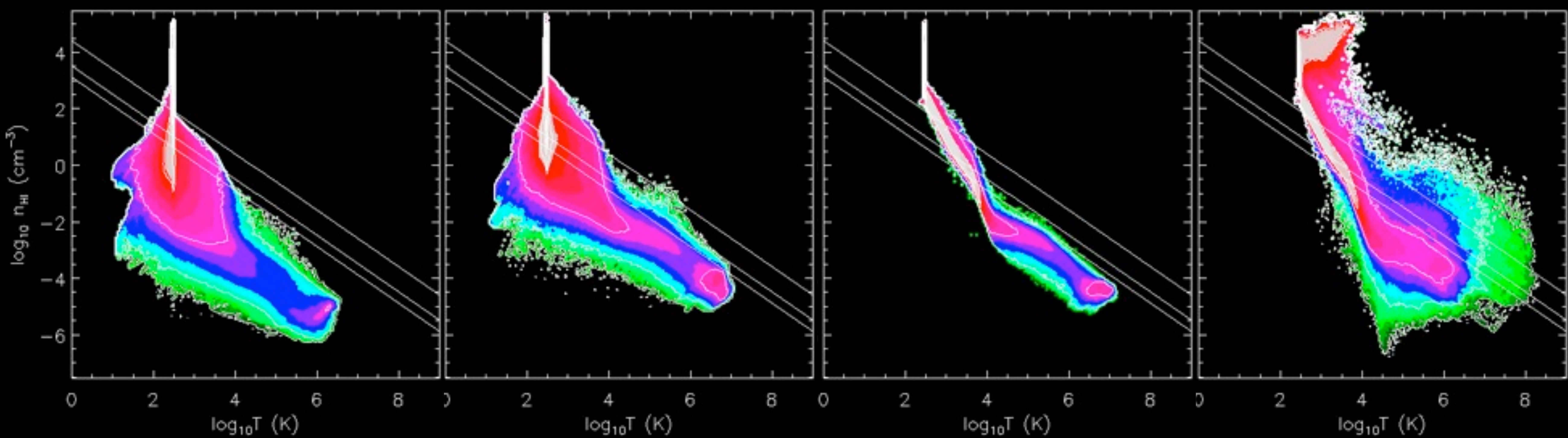


Feedback type II: localised heating from SNe

Thermal energy is deposited into the cell the star particle is in over a dynamical time

10^{51} ergs per $55\,\mathrm{M}_{\odot}$ of star particles formed

What we did....



No SF

SF only

PE heat

SNe

Continuous range of densities and temperatures, largely in pressure equilibrium

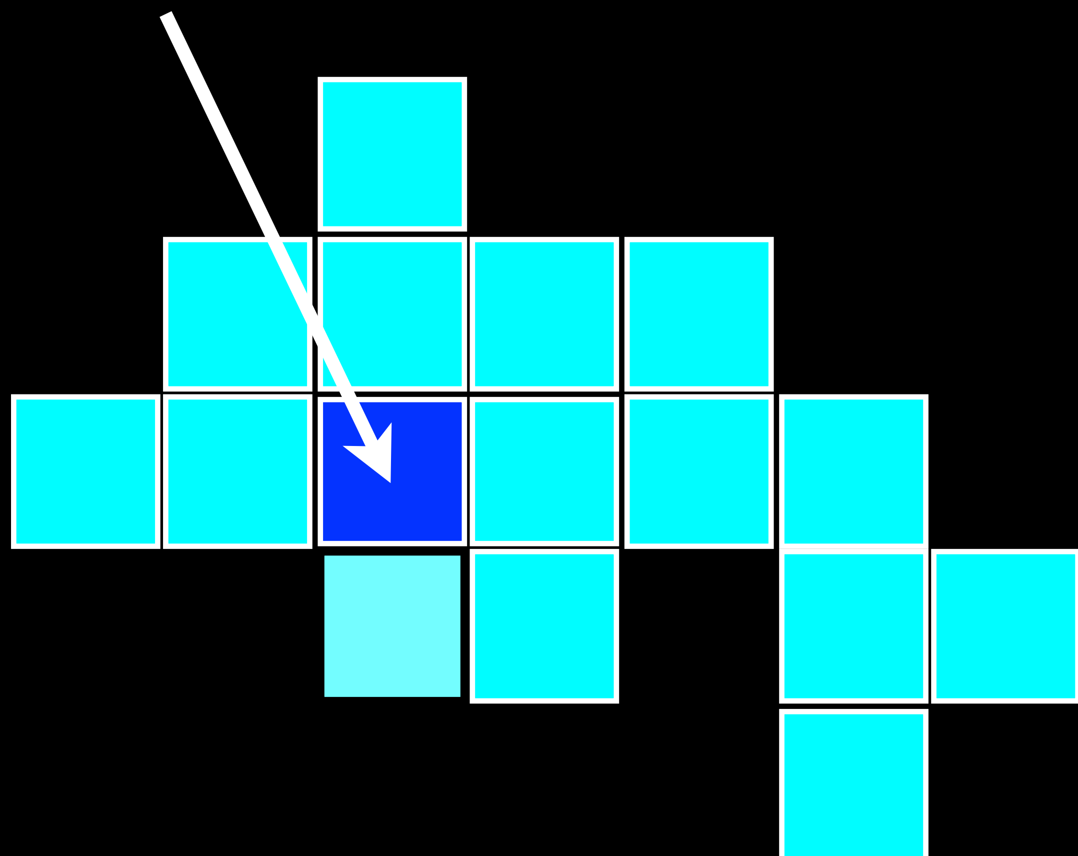
Star formation reduces the amount of mass at the cooling floor over time

Diffuse heating warms cooler gas to increase its pressure. Smaller range in T and rho reflects a more coherent structure

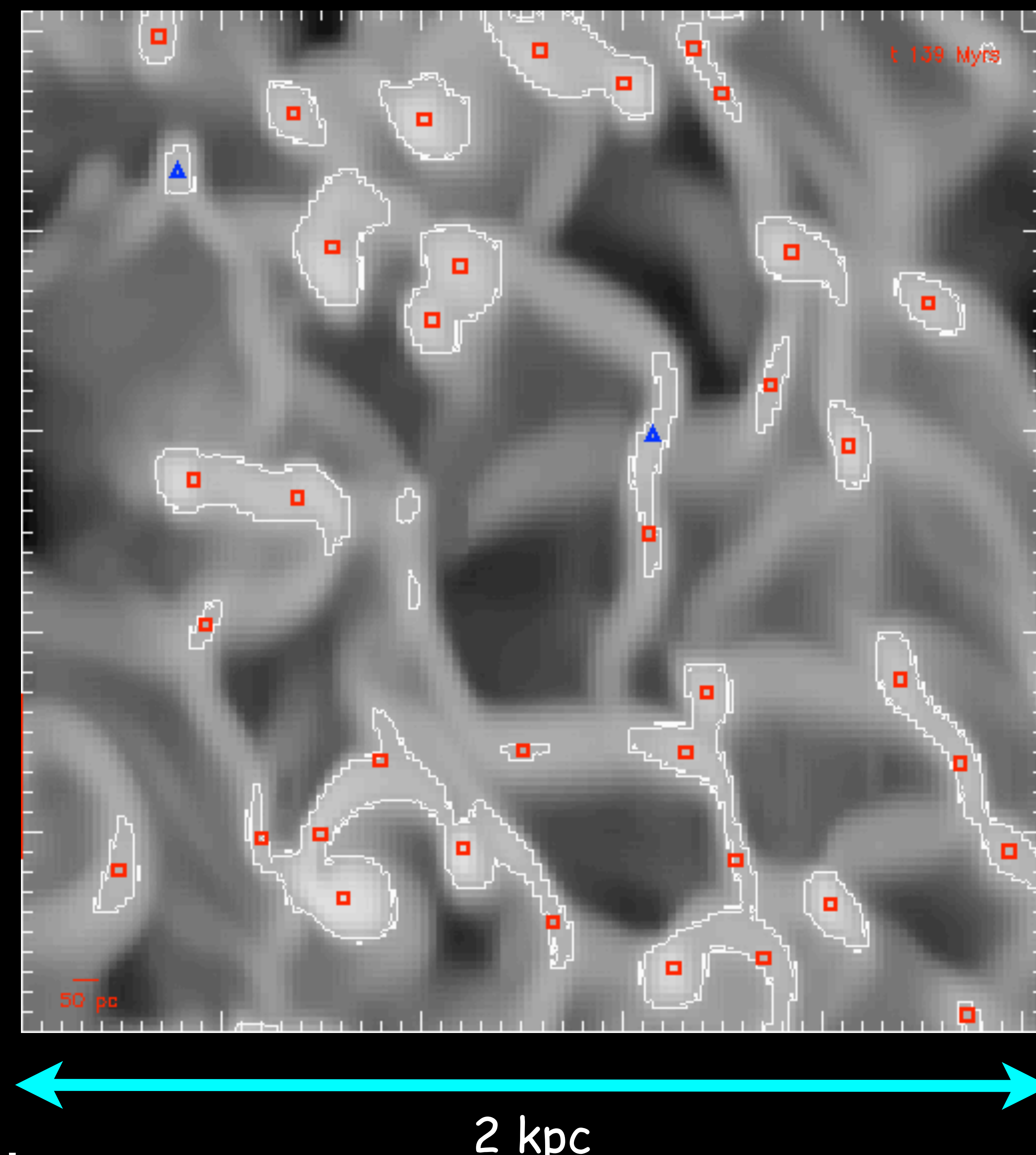
Gas is ejected out of the cold dense region by the SNe, expanding to produce hot, lower density bubbles of gas

What we did....

Find peaks in the gas density field with $n_{HI} > 100 cm^{-3}$



Recursively search peak neighbours for cells also $n_{HI} > 100 cm^{-3}$



Clouds are tracked through the simulation

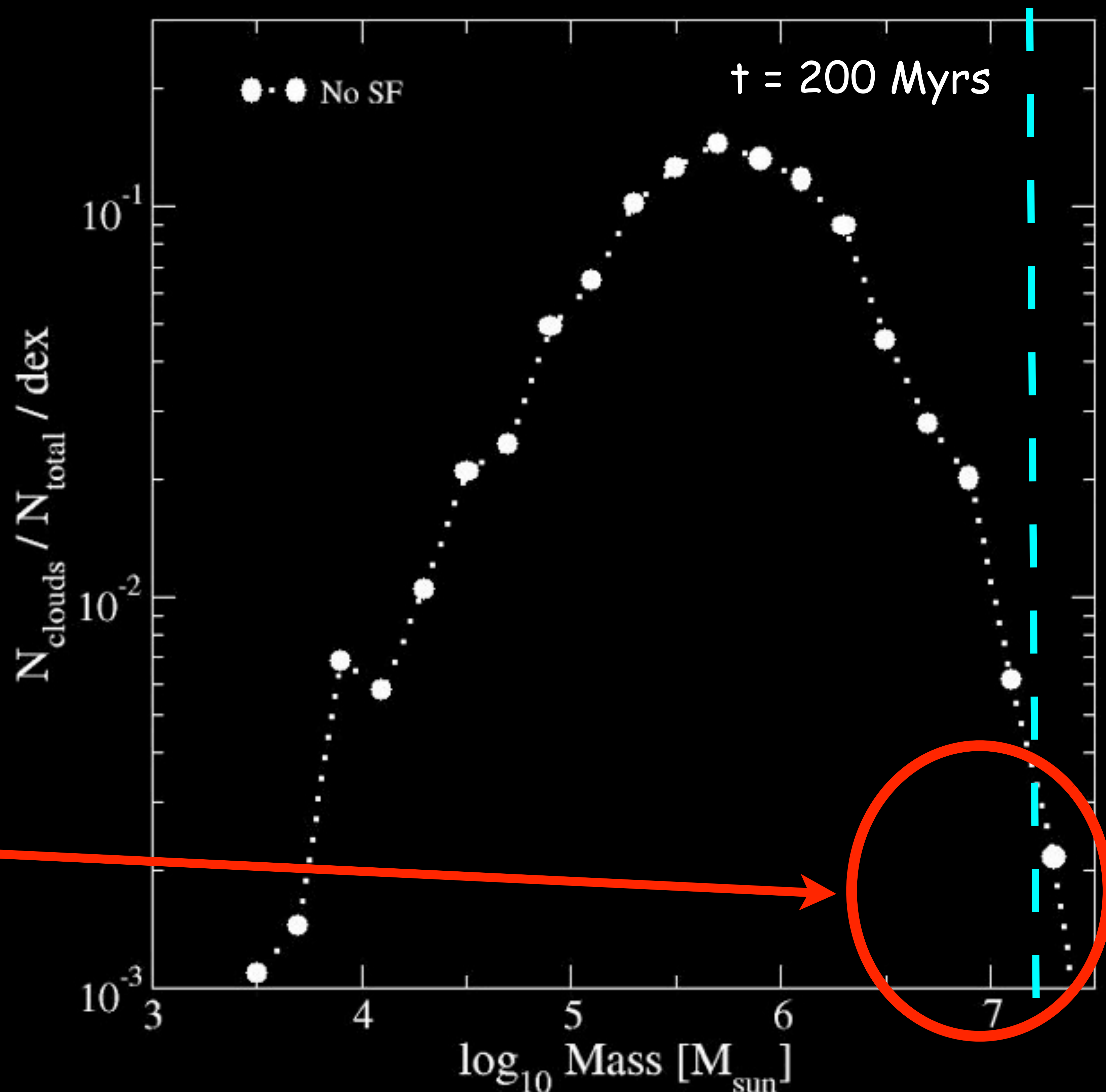
Cloud mass distribution

Simplest model
(no star formation or feedback)

Observed clouds (including atomic envelopes) have max masses < $1.2 \times 10^7 M_\odot$

(Williams & McKee, 1997)

Not a bad match, although we do have a high mass tail due to repeated cloud collisions and agglomerations without anything to destroy the cloud.



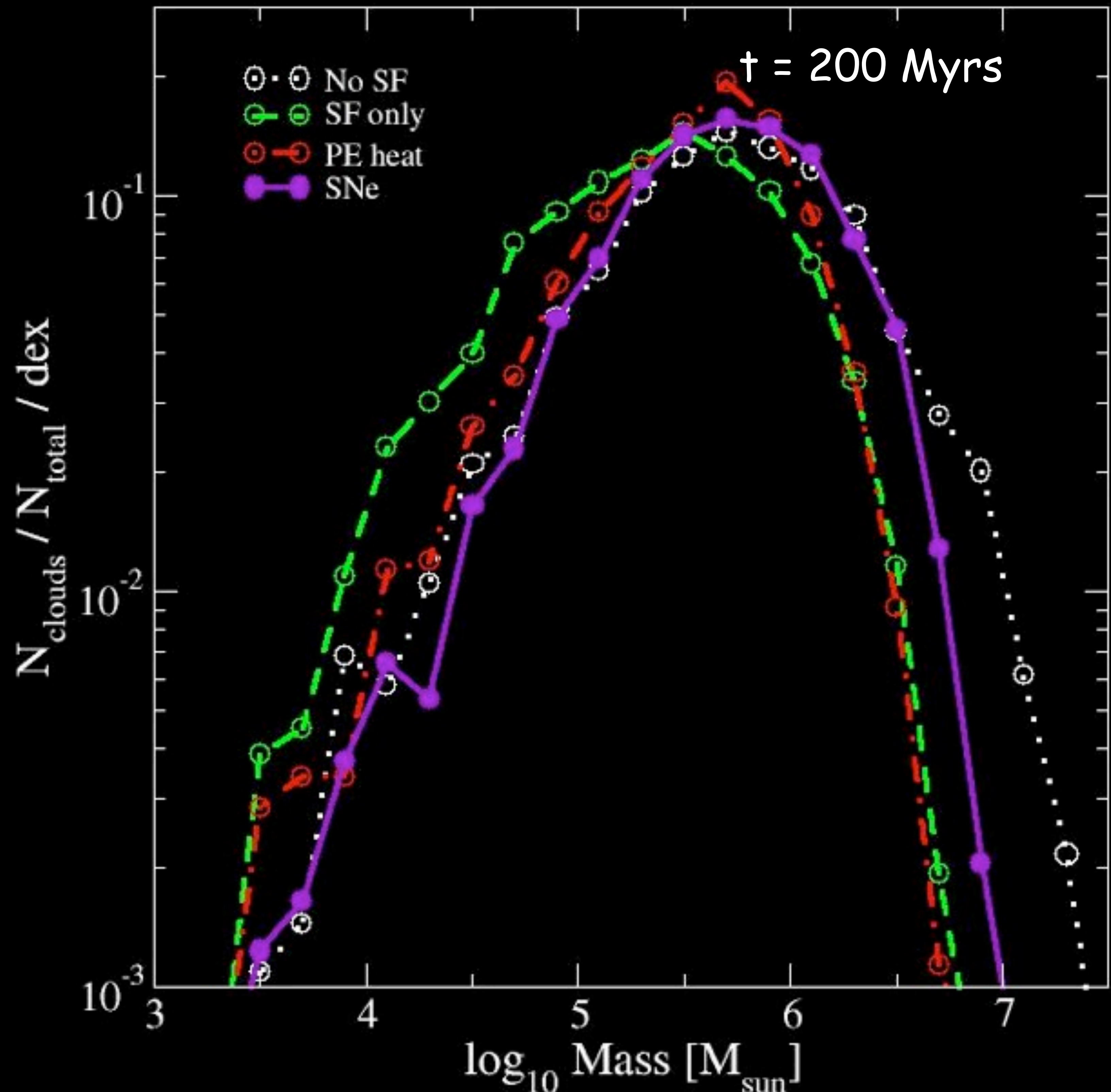
Cloud mass distribution

Star formation models

Star formation converts gas into star particles, preventing the clouds from becoming excessively large

Diffuse heating reduces the conversion of gas into stars, allowing clouds of a higher mass to persist longer.

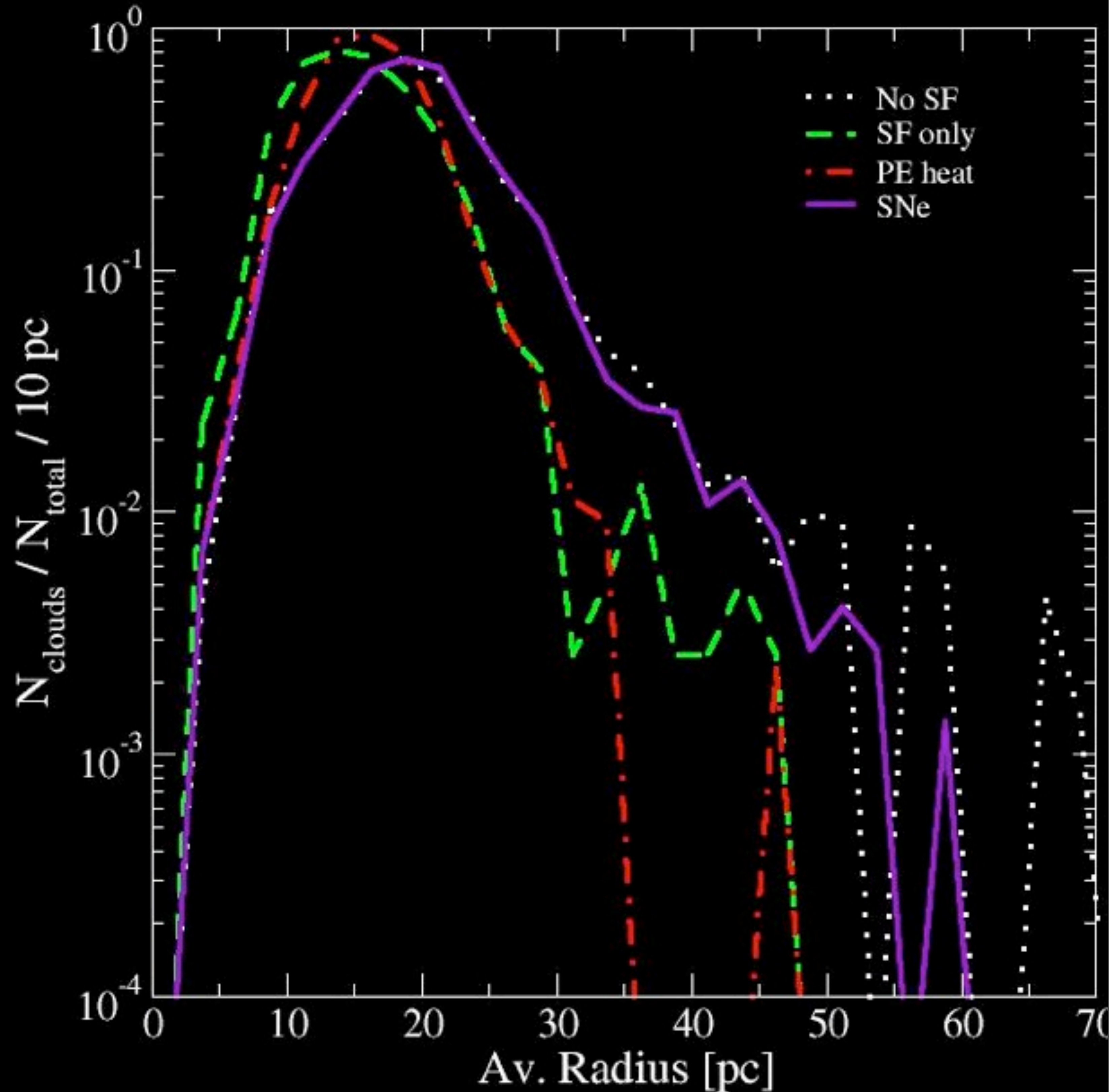
SNe inhibit star formation still more, allowing the mass profile to approach that for the simulation without star formation



Cloud radius distribution

Similarly, star formation and PE heat remove the extended tail in the other cloud properties....

... and SNe undoes all that work.



Cloud radius distribution

Similarly, sta
and PE heat
extended tai
cloud proper

... and SNe
that work.

SNe revert the properties of clouds to those with no star formation.

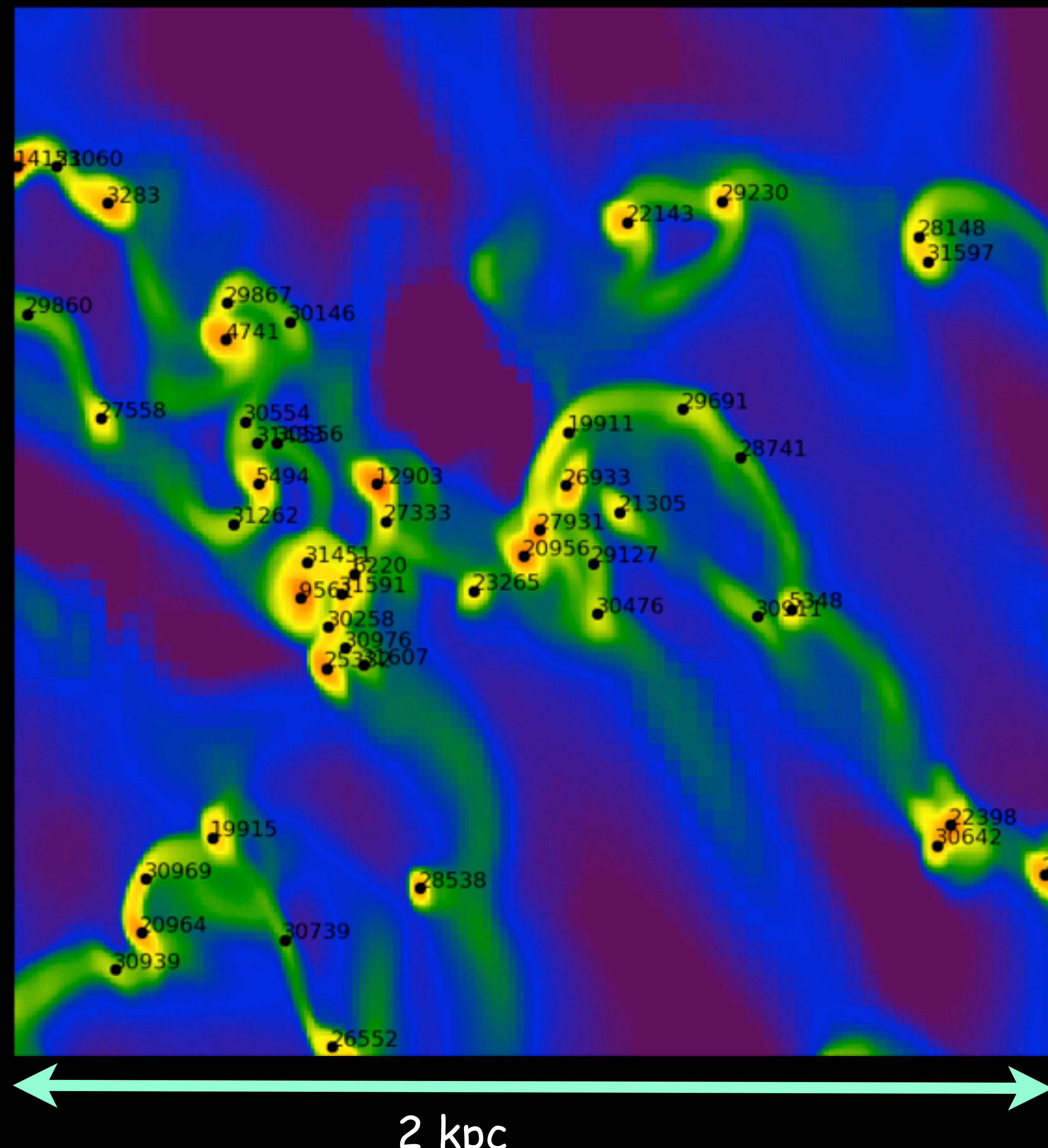
SNe don't destroy clouds....

... they make them live longer?!

Cloud identification: does it work?

Density peak identification is a simple approach, similar to observational identification.

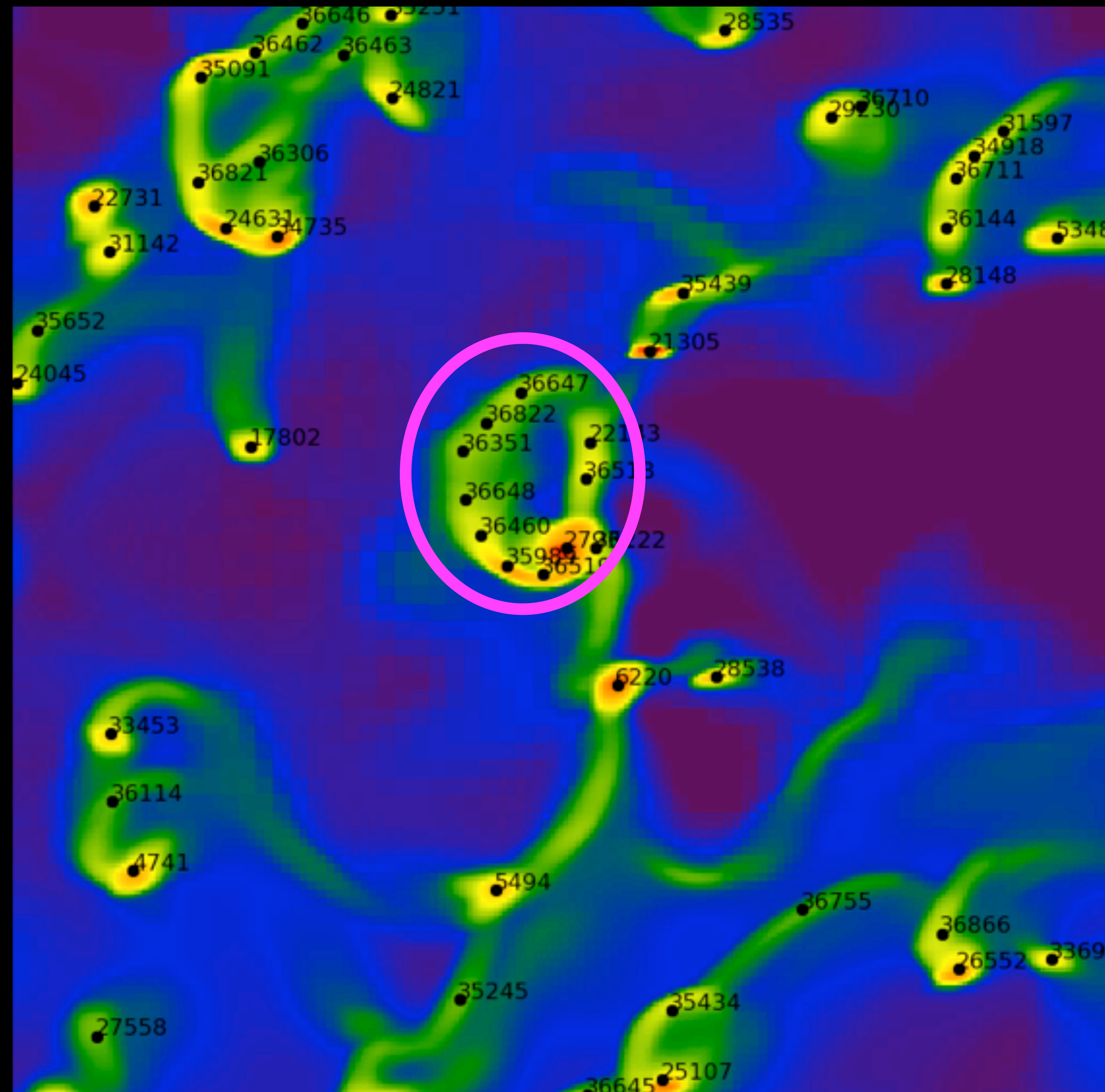
But it produces a large number of small clouds within the same gravitationally bound structure.



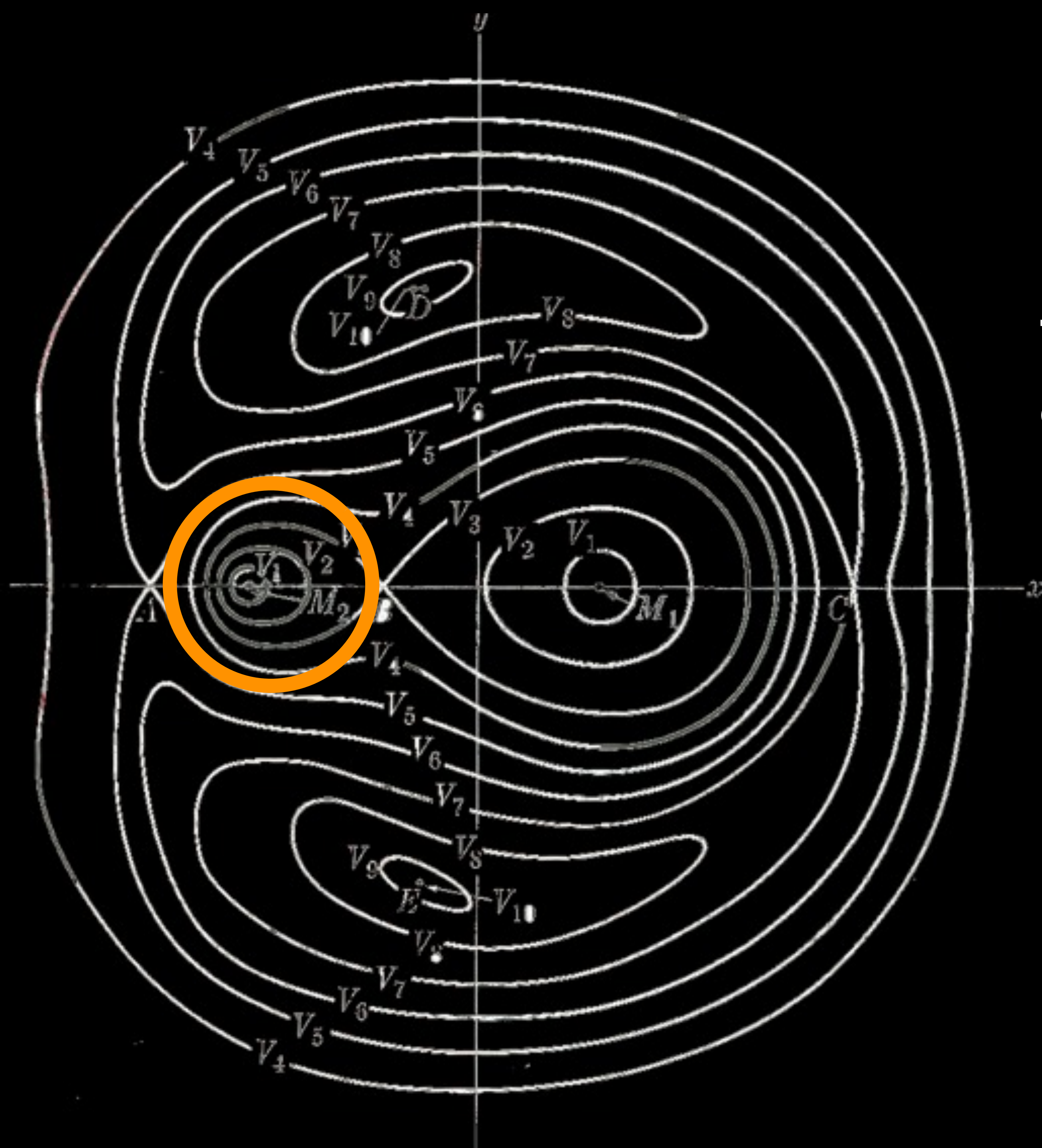
Cloud identification: does it work?

When a SNe explodes, a wave of short-lived clouds are formed.

Are these truly separate entities, or should they be part of the main cloud's evolution?



What we did next....



$$E_J = \Phi_{\rm eff}$$

New cloud definition scheme!

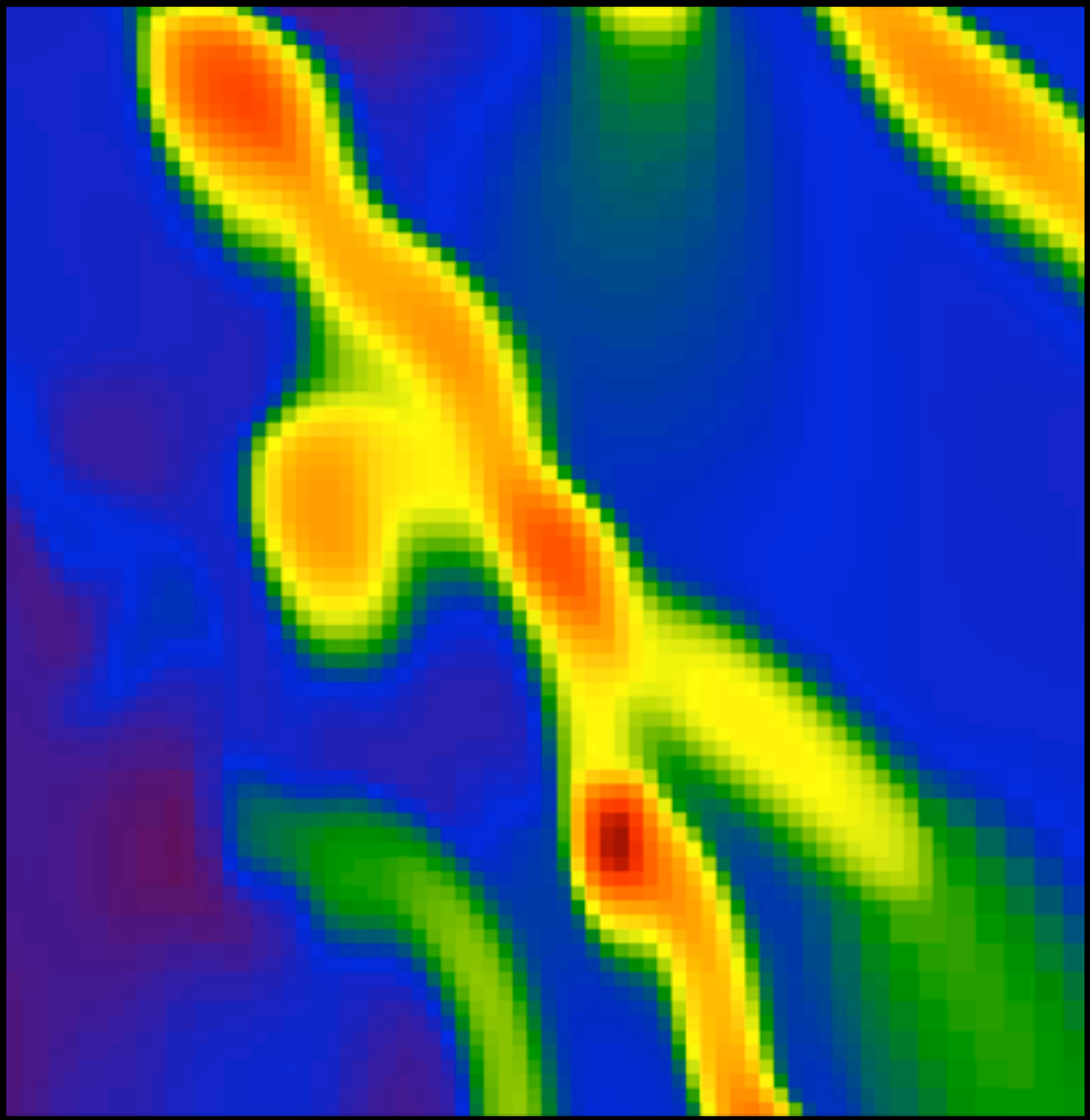
Using the restricted 3-body solution for the gravitational potential of cloud and galaxy

Gas within the contours should be trapped and bound to the cloud

Cloud cells with velocity high enough to escape are removed

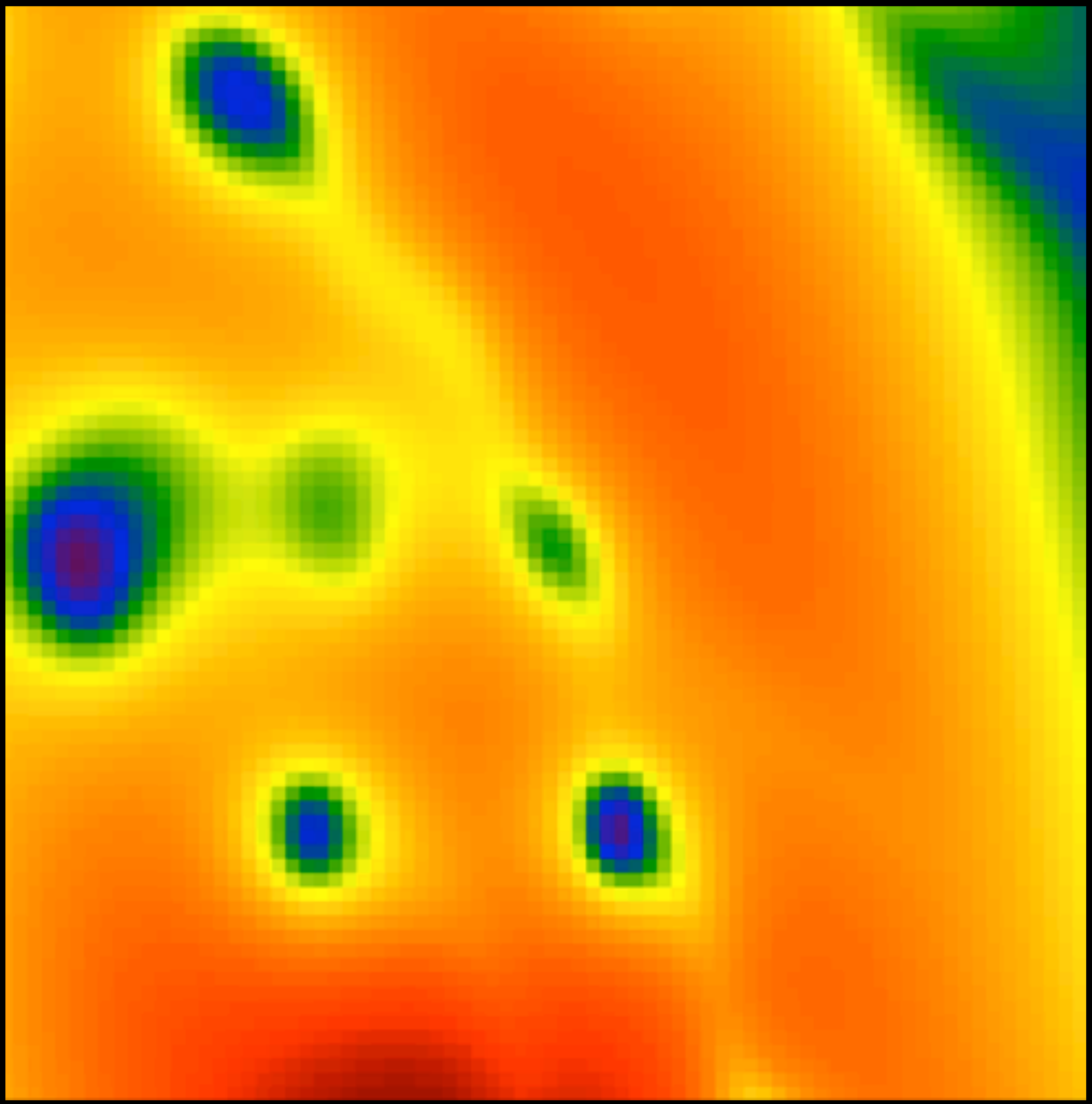
What we did next....

Does it work?



Density

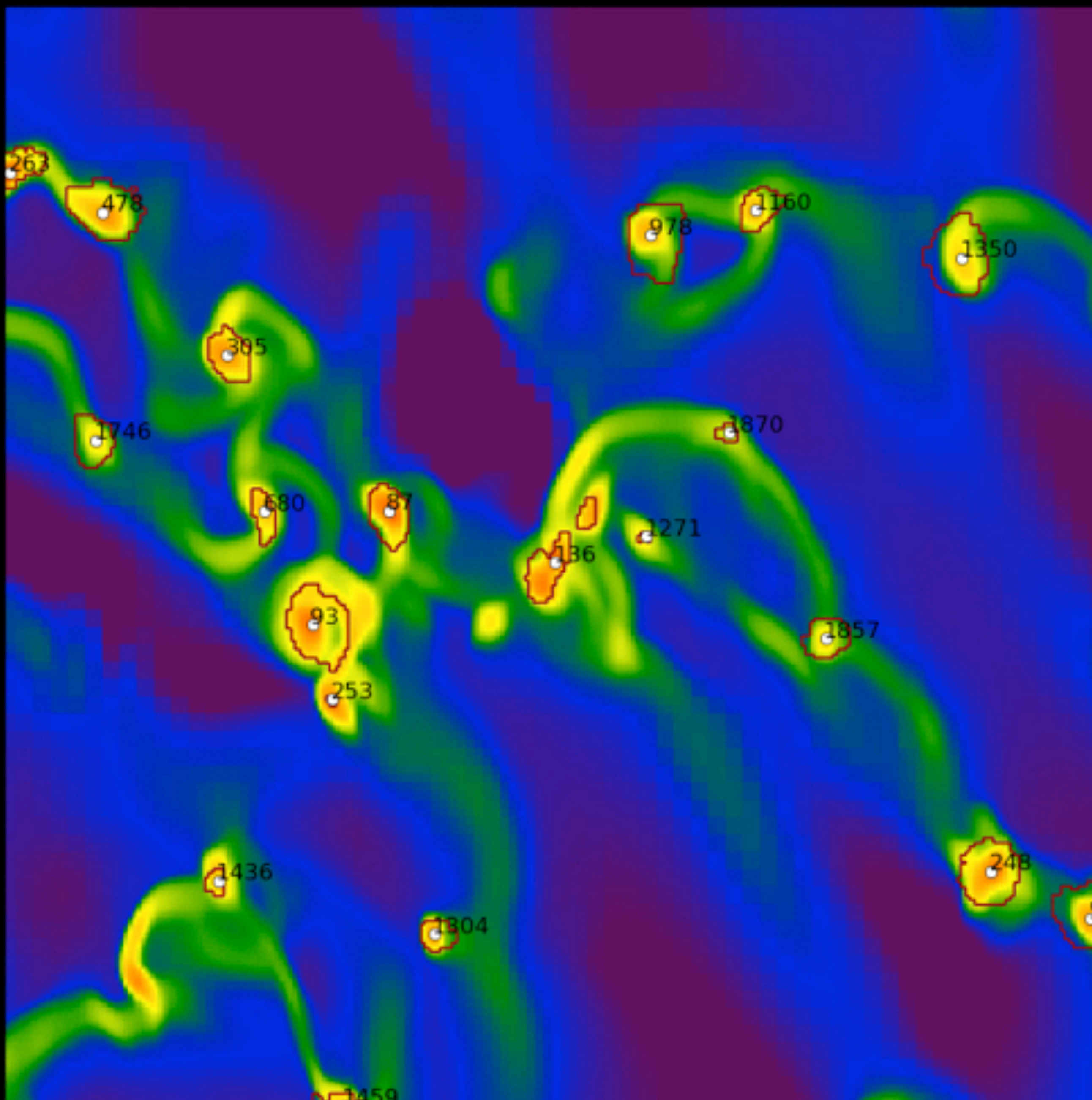
Cloud boundaries unclear



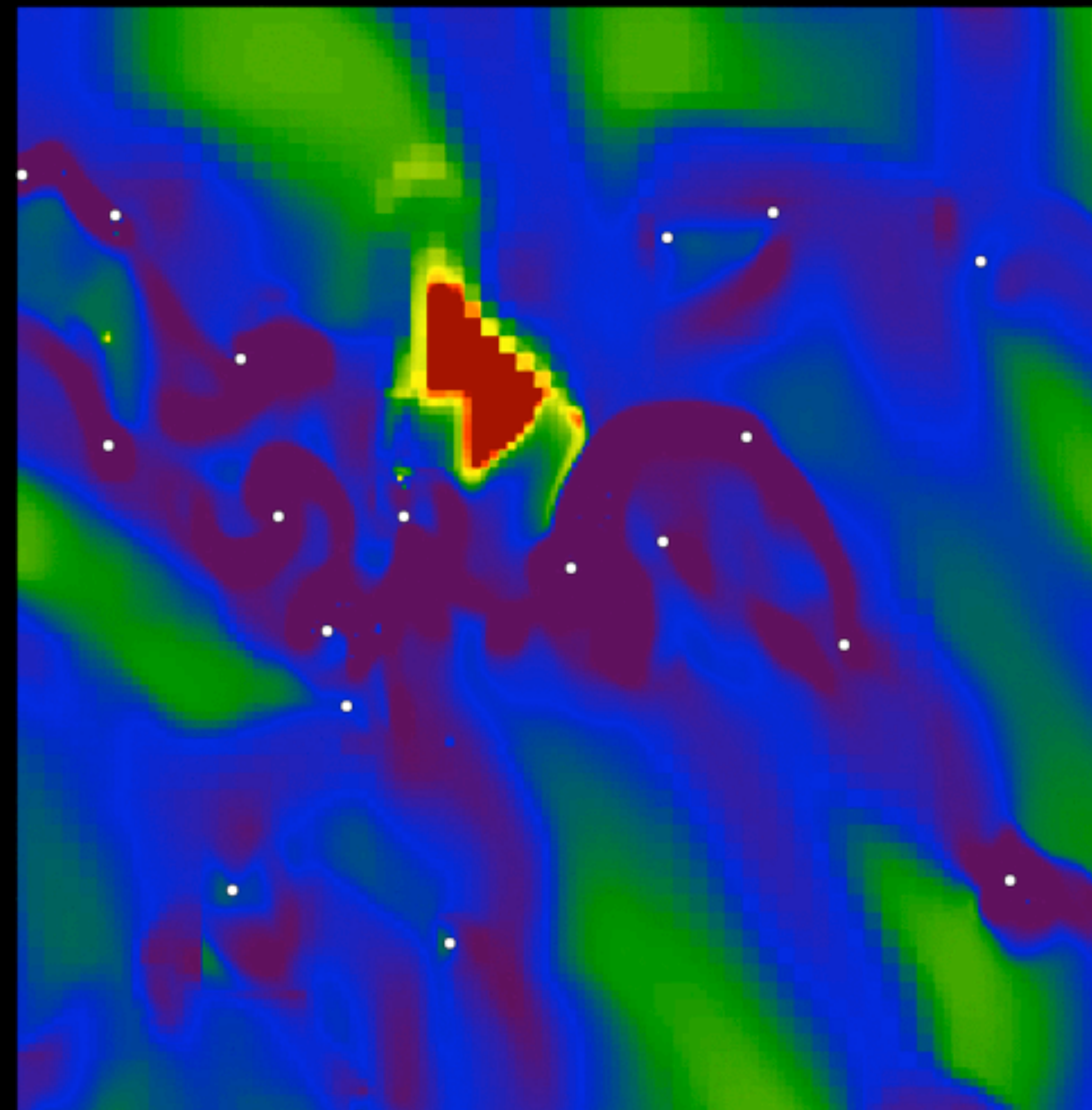
Effective Potential

Clouds clearly distinct

What we did next....



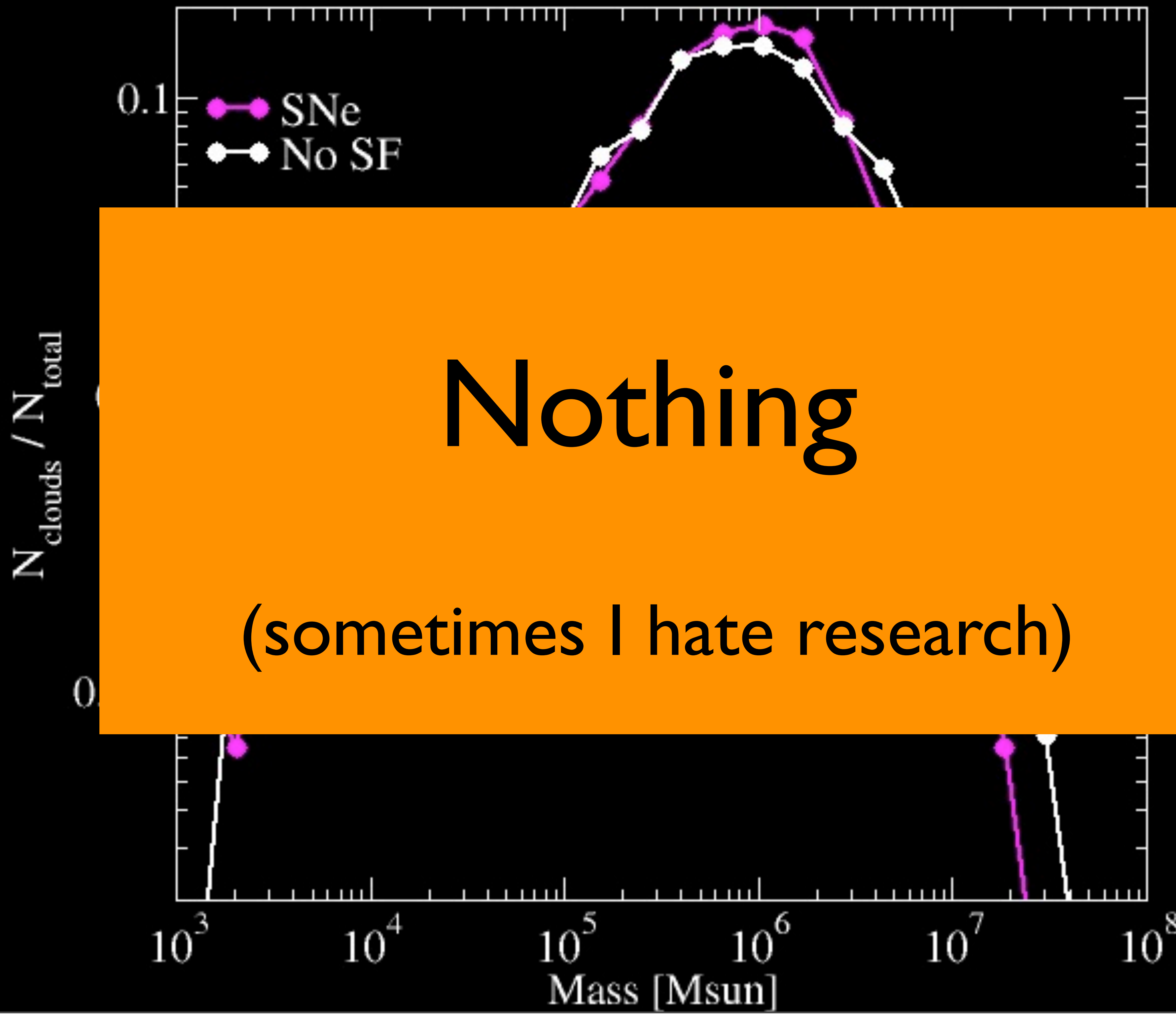
Surface density



Temperature

What we did next....

After all of that... the difference in the mass plot between no-star formation and SNe simulations is now....



Nothing

(sometimes I hate research)

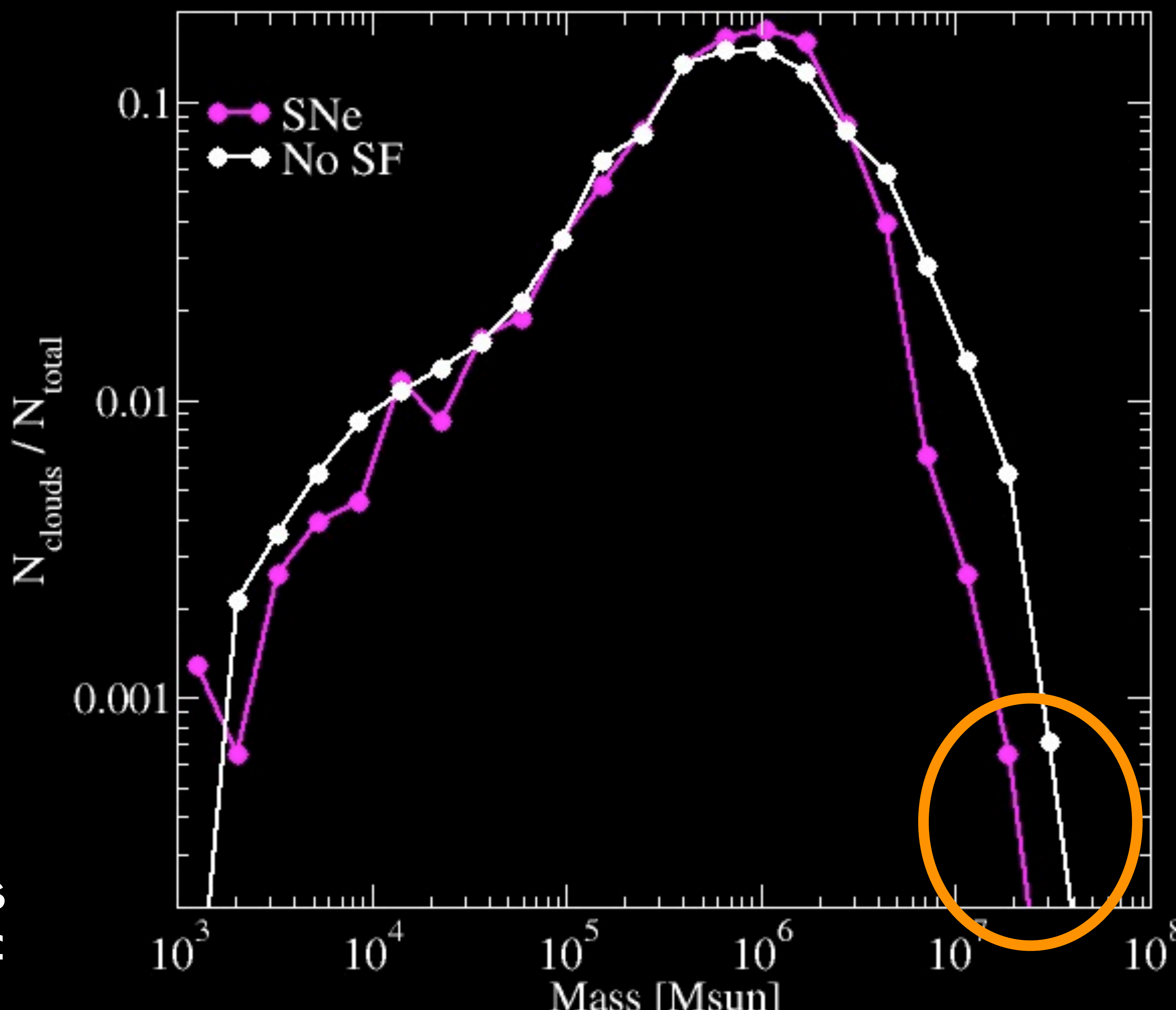
What we did next....

Gravitationally bound structures, not individual clouds.

Supernovae appear to suppress star formation, but do not destroy the cloud.

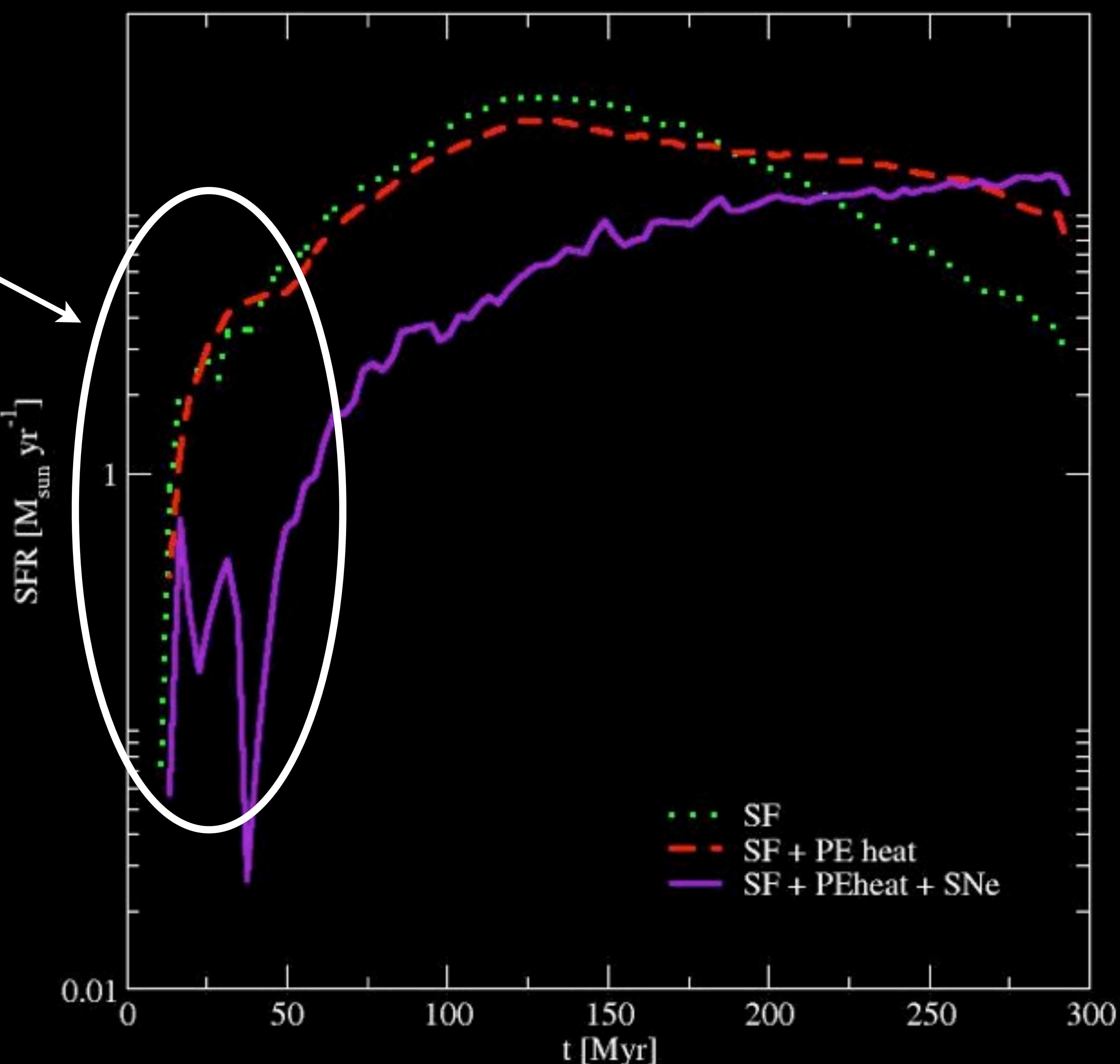
This allows the cloud evolution to tend back towards the non-star formation simulation.

Gravitational interactions are the dominate form of cloud evolution.



Star formation history

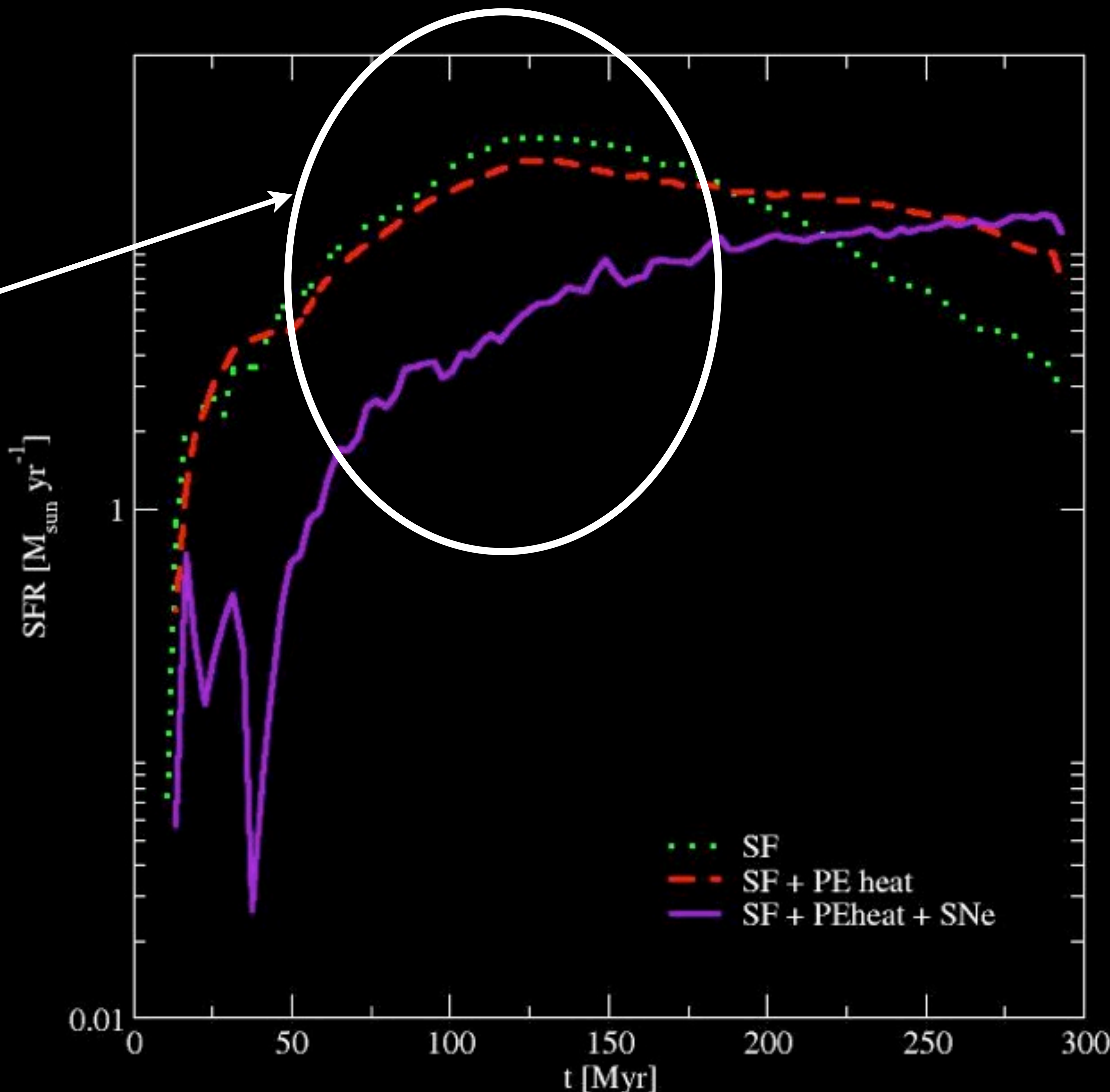
Initial fragmentation of disc. SNe at this stage totally suppress the SF



Star formation history

Initial fragmentation of disc. SNe at this stage totally suppress the SF

Simulation without any feedback has a greater SFR over the first 200 Myr of the simulation

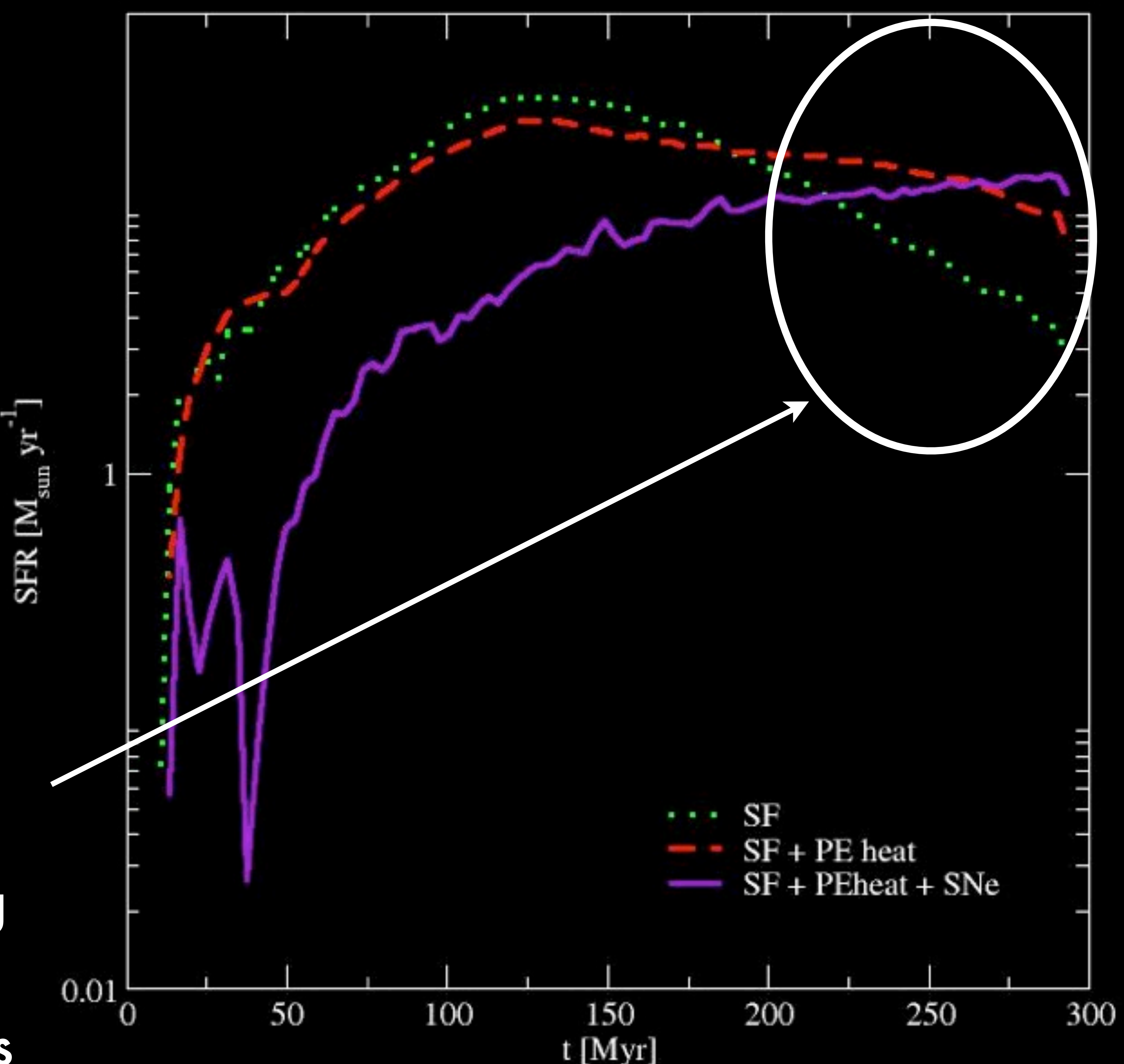


Star formation history

Initial fragmentation of disc. SNe at this stage totally suppress the SF

Simulation without any feedback has a greater SFR over the first 200 Myr of the simulation

In the last 100 Myr, both the simulations with only star formation and diffuse heating start to suffer from gas depletion and their SFR drops



Conclusions

- SNe explosions carry mass away from the cloud, suppressing its star formation rate.
- However, the asymmetric outflow means the clouds typically survive this explosion.
- In the simulations here, gravitational interactions are the most important process in determining cloud evolution
- However, different types of feedback (e.g. earlier or RT) might change this result.