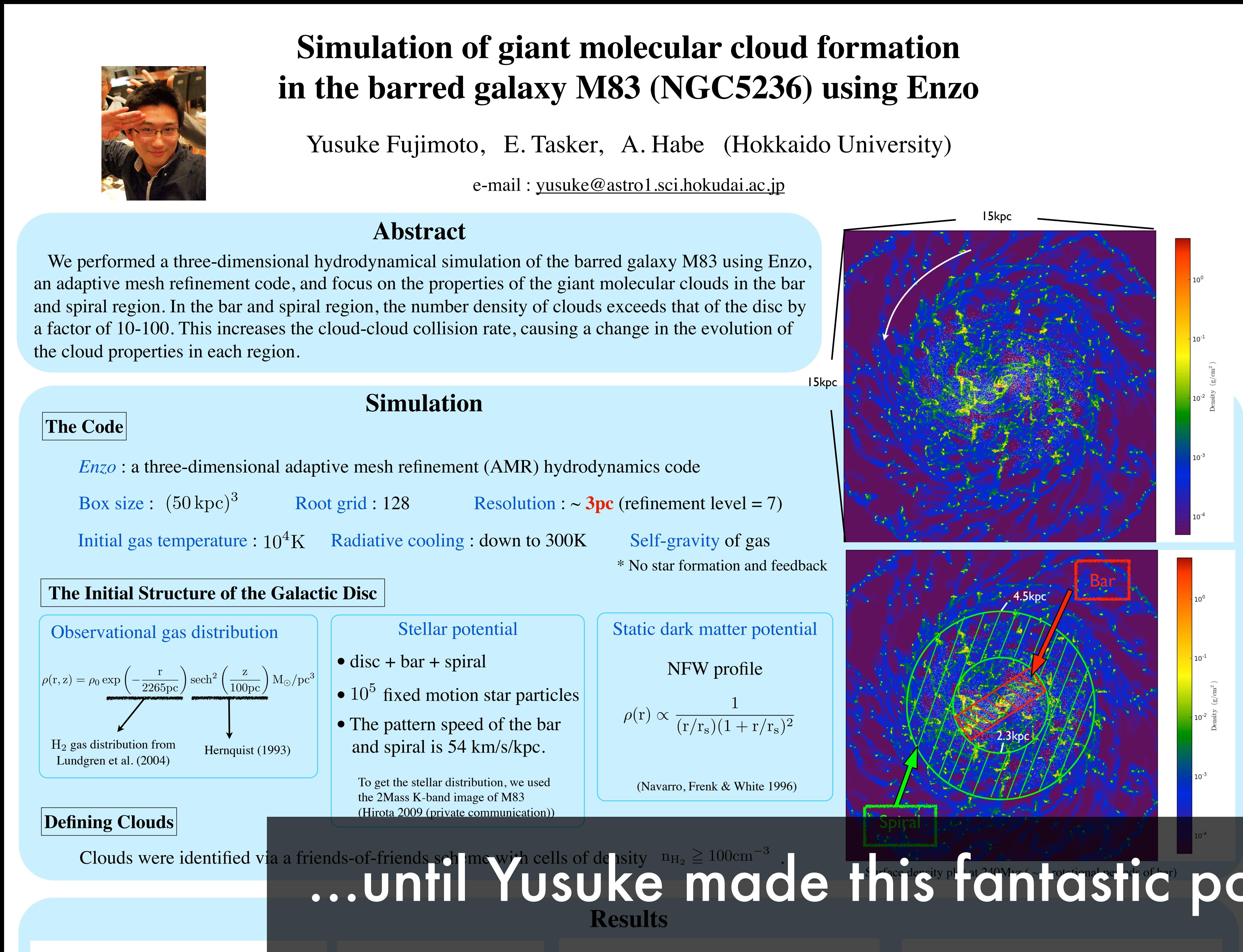
What I was going to talk about...



Simulation of giant molecular cloud formation in the barred galaxy M83 (NGC5236) using Enzo

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Abstract

We performed a three-dimensional hydrodynamical simulation of the barred galaxy M83 using Enzo, an adaptive mesh refinement code, and focus on the properties of the giant molecular clouds in the bar and spiral region. In the bar and spiral region, the number density of clouds exceeds that of the disc by a factor of 10-100. This increases the cloud-cloud collision rate, causing a change in the evolution of the cloud properties in each region.

Simulation

The Code

Enzo : a three-dimensional adaptive mesh refinement (AMR) hydrodynamics code

Box size : $(50\,\mathrm{kpc})^3$ Root grid : 128 Resolution : ~ **3pc** (refinement level = 7)

Initial gas temperature : 10^4K Radiative cooling : down to 300K Self-gravity of gas

* No star formation and feedback

The Initial Structure of the Galactic Disc

Observational gas distribution

$$\rho(r,z) = \rho_0 \exp\left(-\frac{r}{2265\mathrm{pc}}\right) \mathrm{sech}^2\left(\frac{z}{100\mathrm{pc}}\right) \mathrm{M_\odot/pc^3}$$

H_2 gas distribution from Lundgren et al. (2004)

Hernquist (1993)

Stellar potential

- disc + bar + spiral
- 10^5 fixed motion star particles
- The pattern speed of the bar and spiral is 54 km/s/kpc.

To get the stellar distribution, we used the 2Mass K-band image of M83 (Hirota 2009 (private communication))

Static dark matter potential

NFW profile

$$\rho(r) \propto \frac{1}{(r/r_s)(1+r/r_s)^2}$$

(Navarro, Frenk & White 1996)

Defining Clouds

Clouds were identified via a friends-of-friends scheme with cells of density $n_{H_2} \gtrsim 100\mathrm{cm}^{-3}$.

Results

...until Yusuke made this fantastic poster

What Kills a Giant Molecular Cloud?

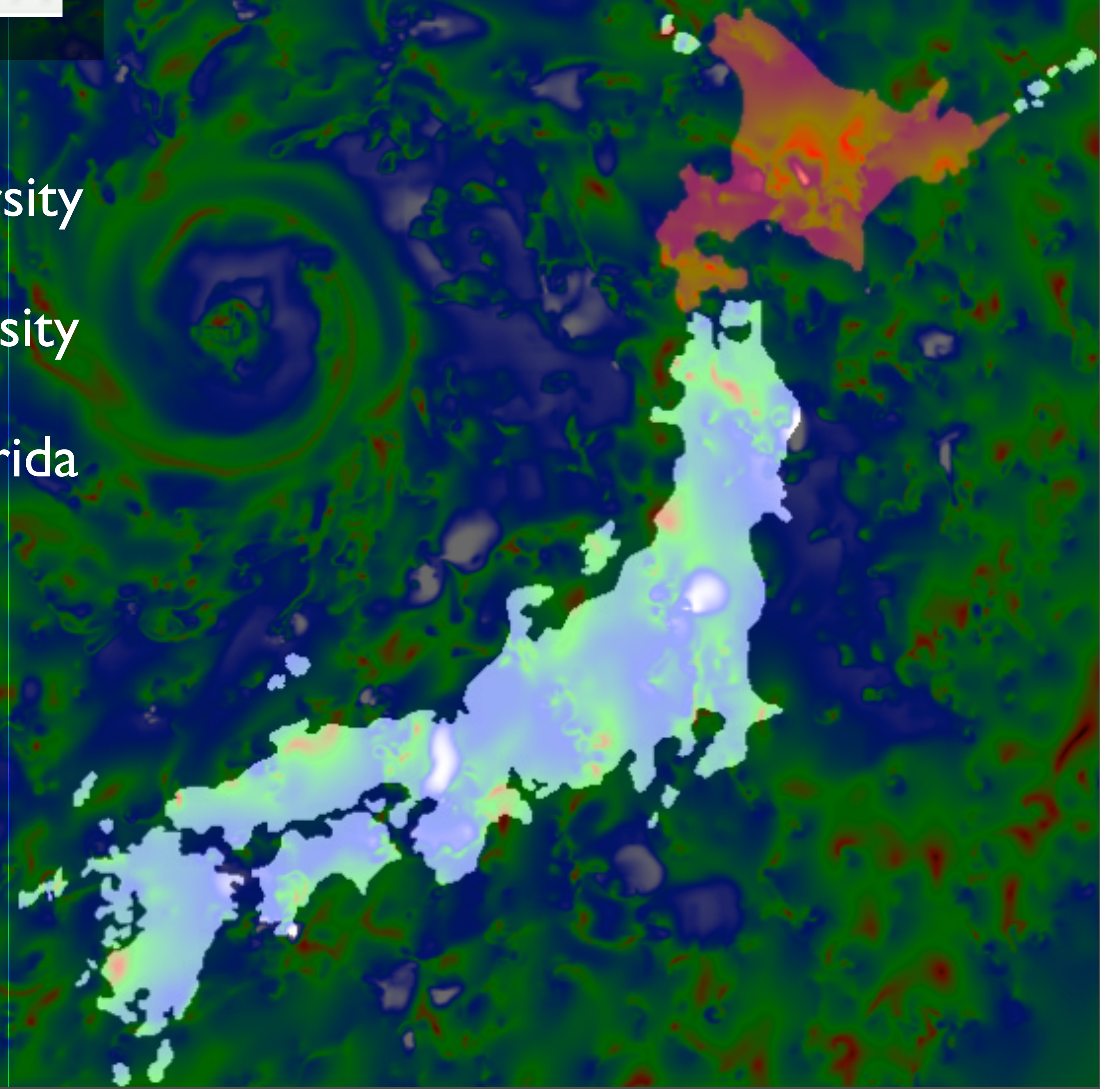
Elizabeth Tasker HOKKAIDO UNIVERSITY

James Wadsley McMaster University

Ralph Pudritz McMaster University

Jonathan Tan University of Florida

yt development team



The hand that rocks the cradle

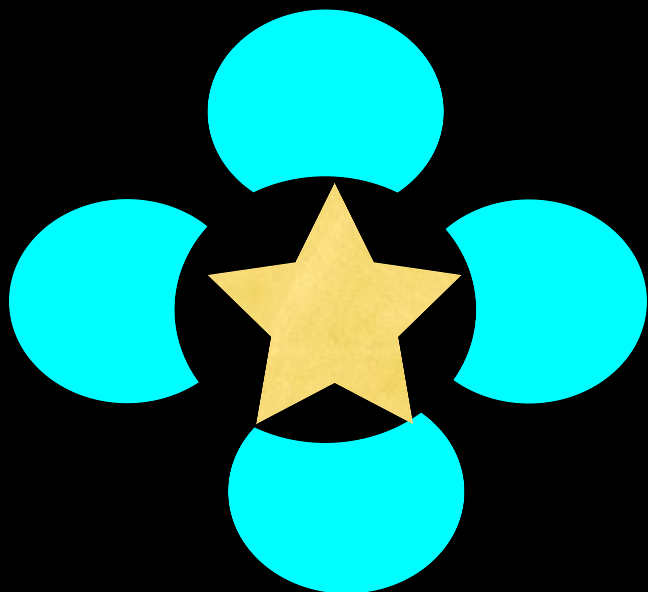
The cold gas in a disc galaxy is organised into the giant molecular clouds.

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

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

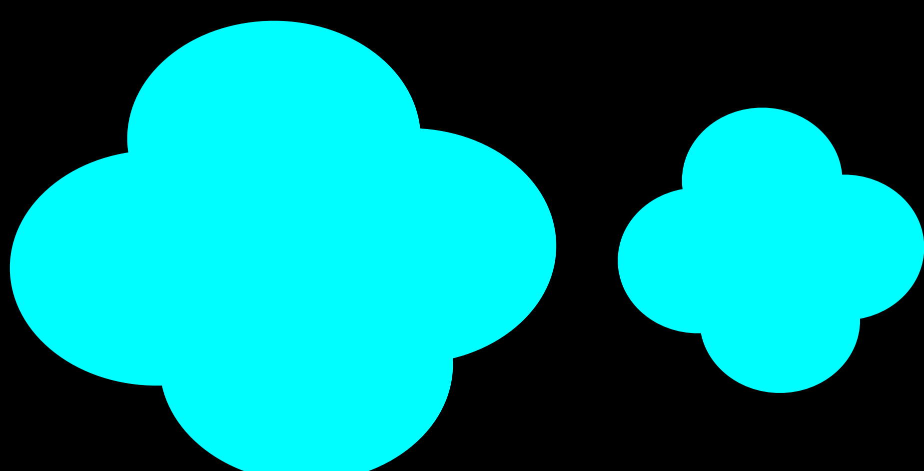
But does the stellar child they produce also cause their death?

The hand that rocks the cradle

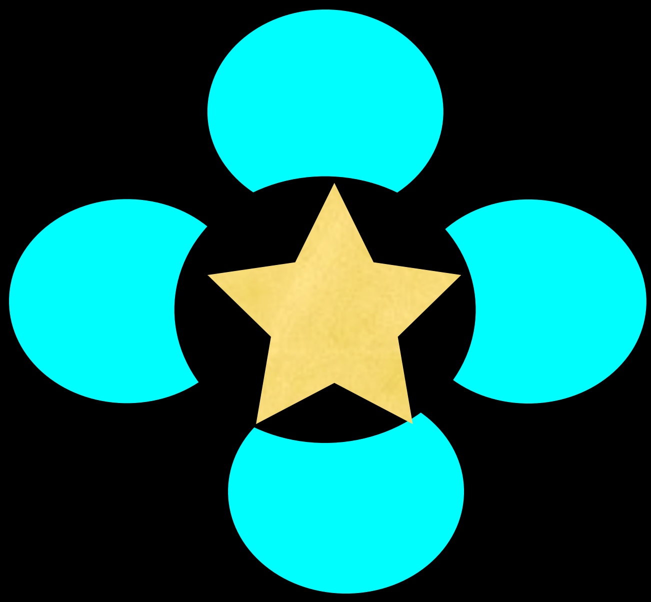


One way to kill a GMC is via the local effect of an internal energy injection

e.g. supernovae explosion, ionising winds



The hand that rocks the cradle



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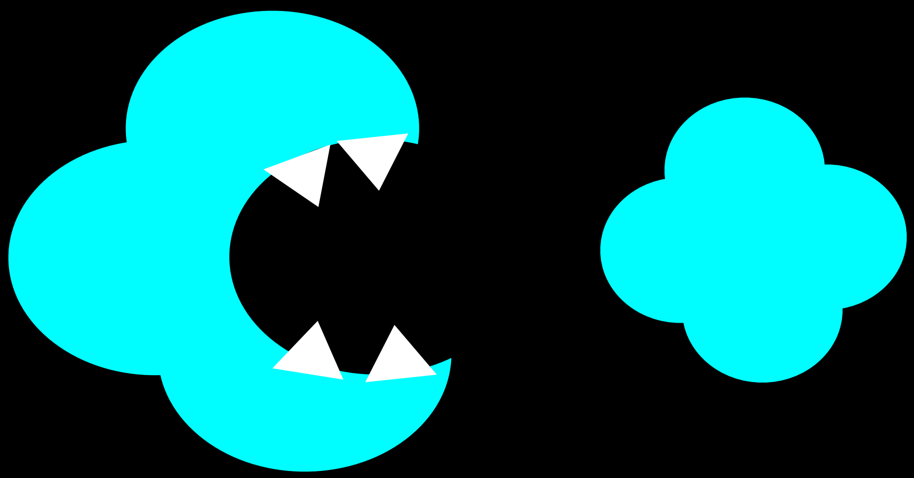


Alternatively, global cloud-cloud interactions may merge clouds or trigger star formation that destroys them

What we did....

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

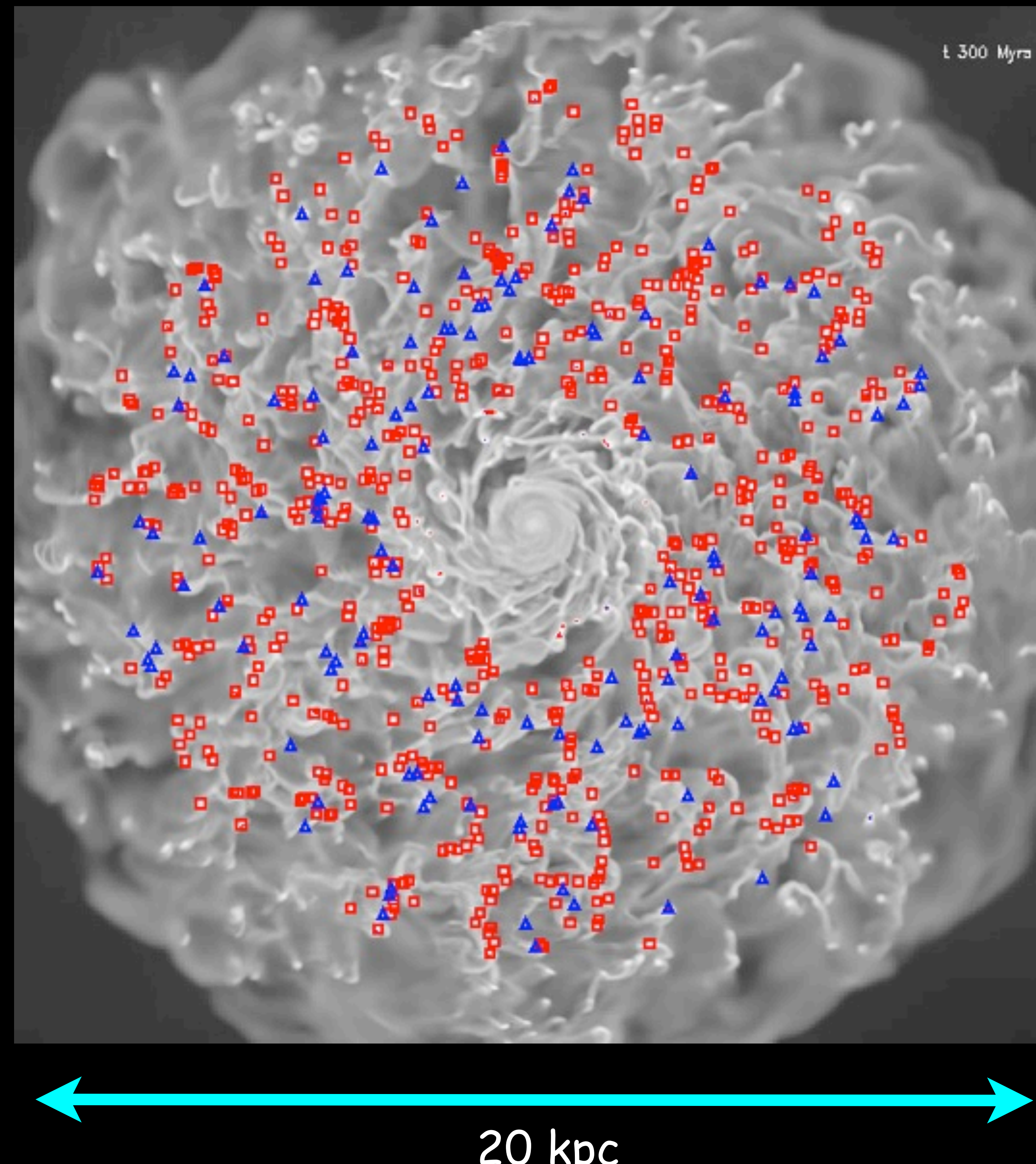
	Self gravity + radiative cooling	Star formation	Diffuse heating	Localised energy injection
No SF	Yes	No	No	No
SF only	Yes	Yes	No	No
PE heat	Yes	Yes	Yes	No
SNe	Yes	Yes	Yes	Yes

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

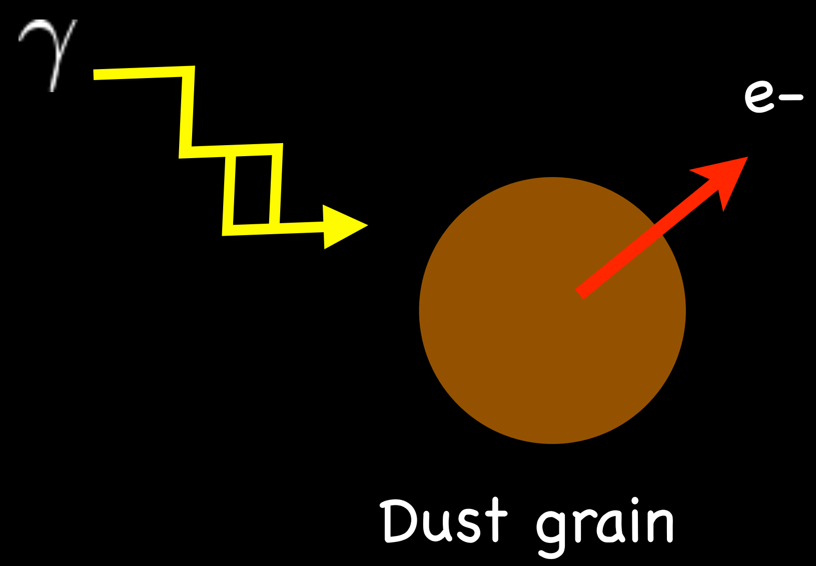


What we did....

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)



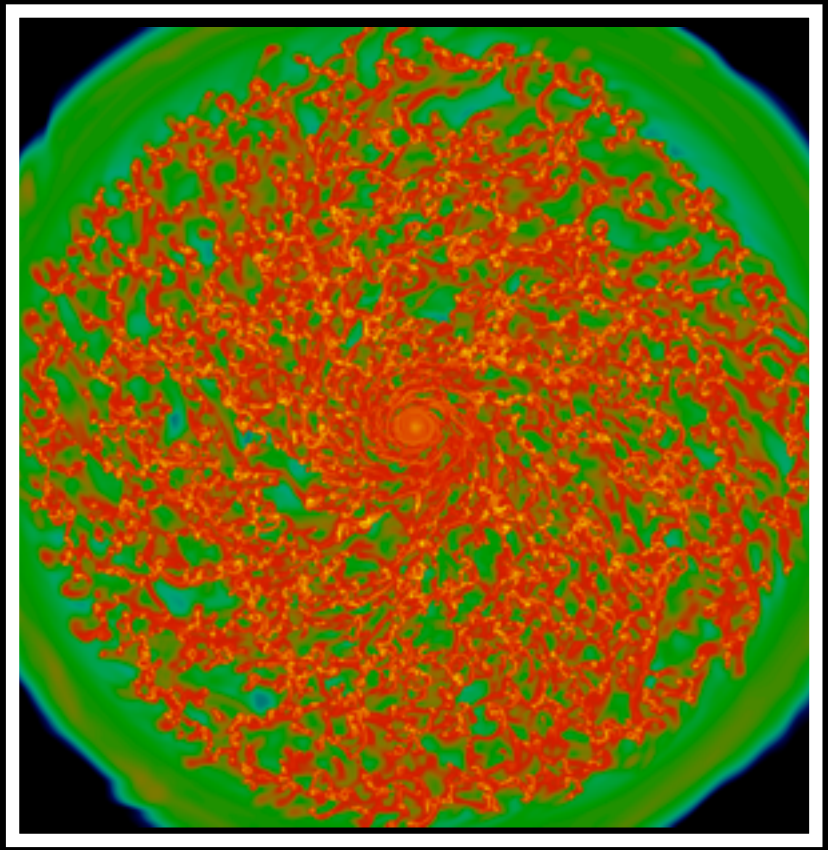
Feedback type II: localised heating from SNe

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....

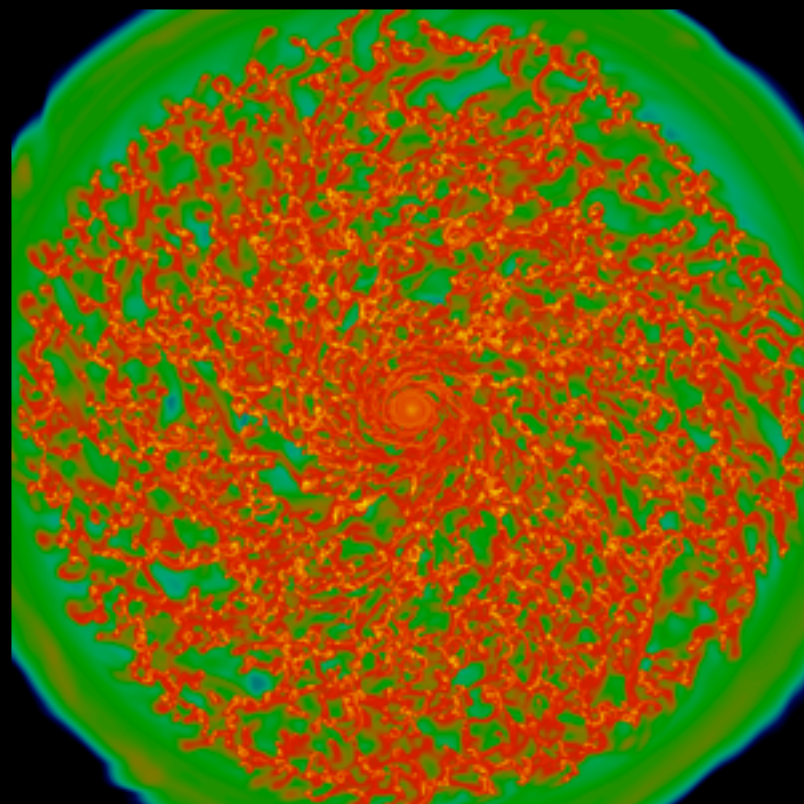
No SF

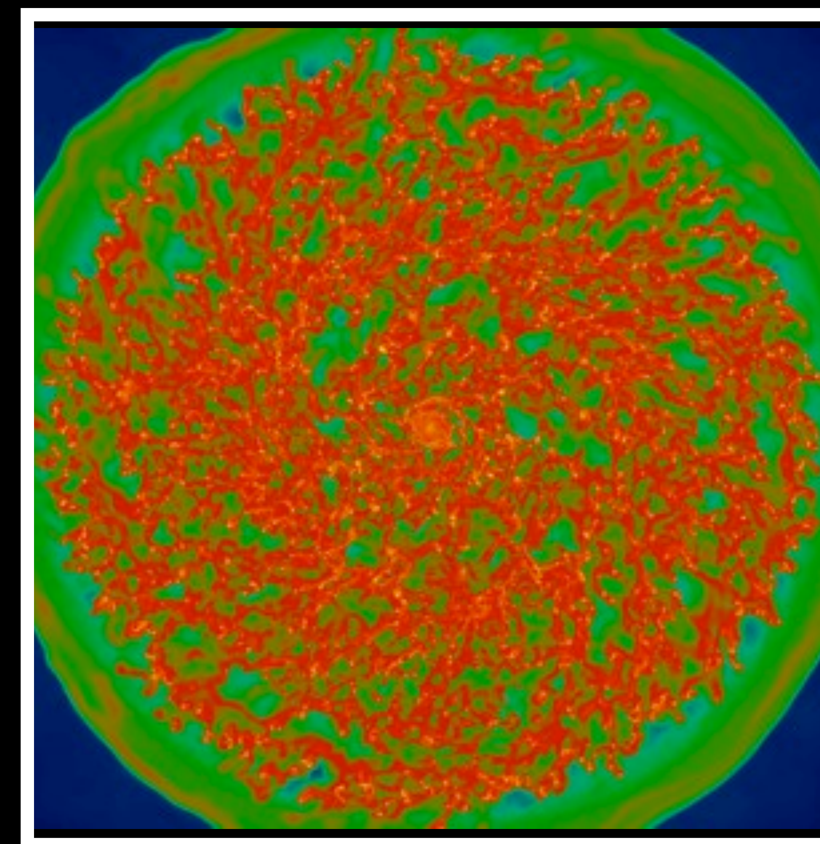


Flocculent,
fragmented structure:
no grand design
spiral due to lack of
satellite companions

What we did....

No SF



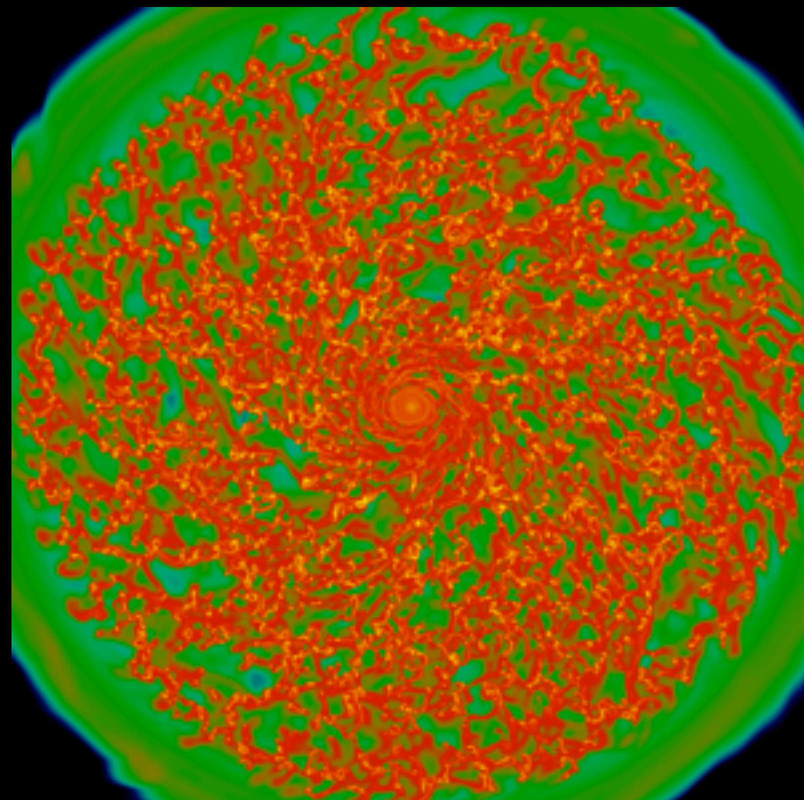


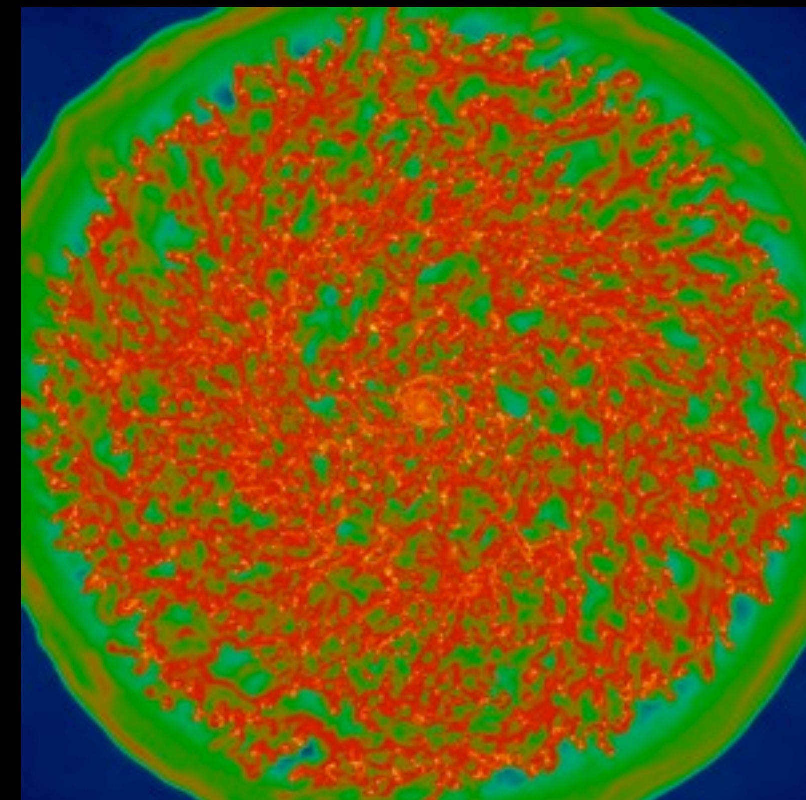
SF only

Similar structure to simulation "No SF" but the densest clumps have been eroded by the star formation

What we did....

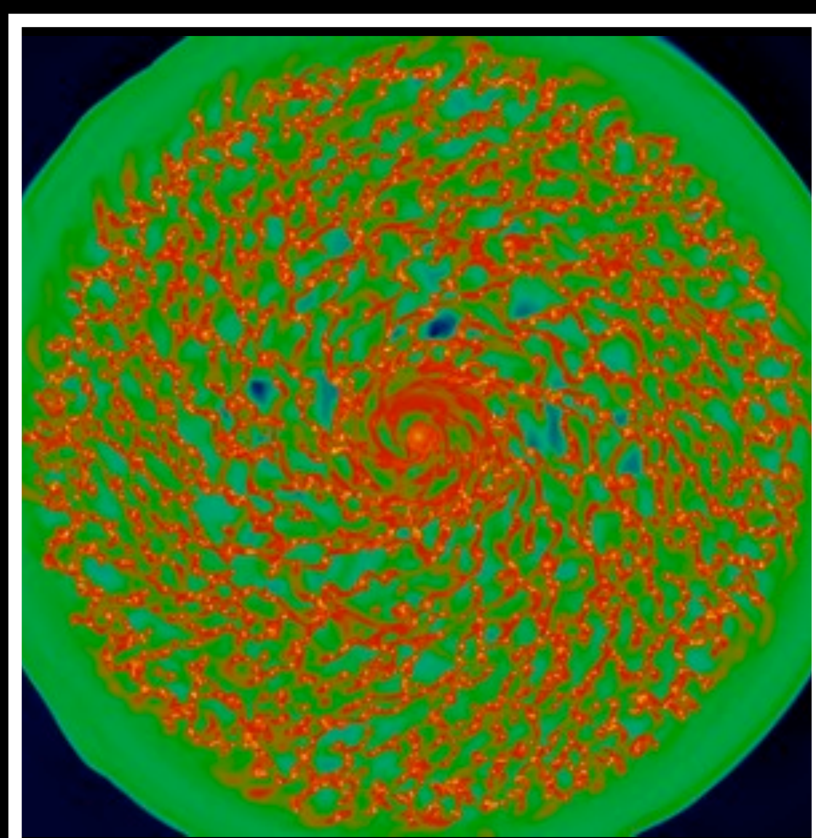
No SF





SF only

PE heat



The diffuse heating inhibits the gravitational collapse, producing a more ordered filament structure. This reducing the gravitational scattering between the clouds, causing the disc velocity dispersion to be lower.

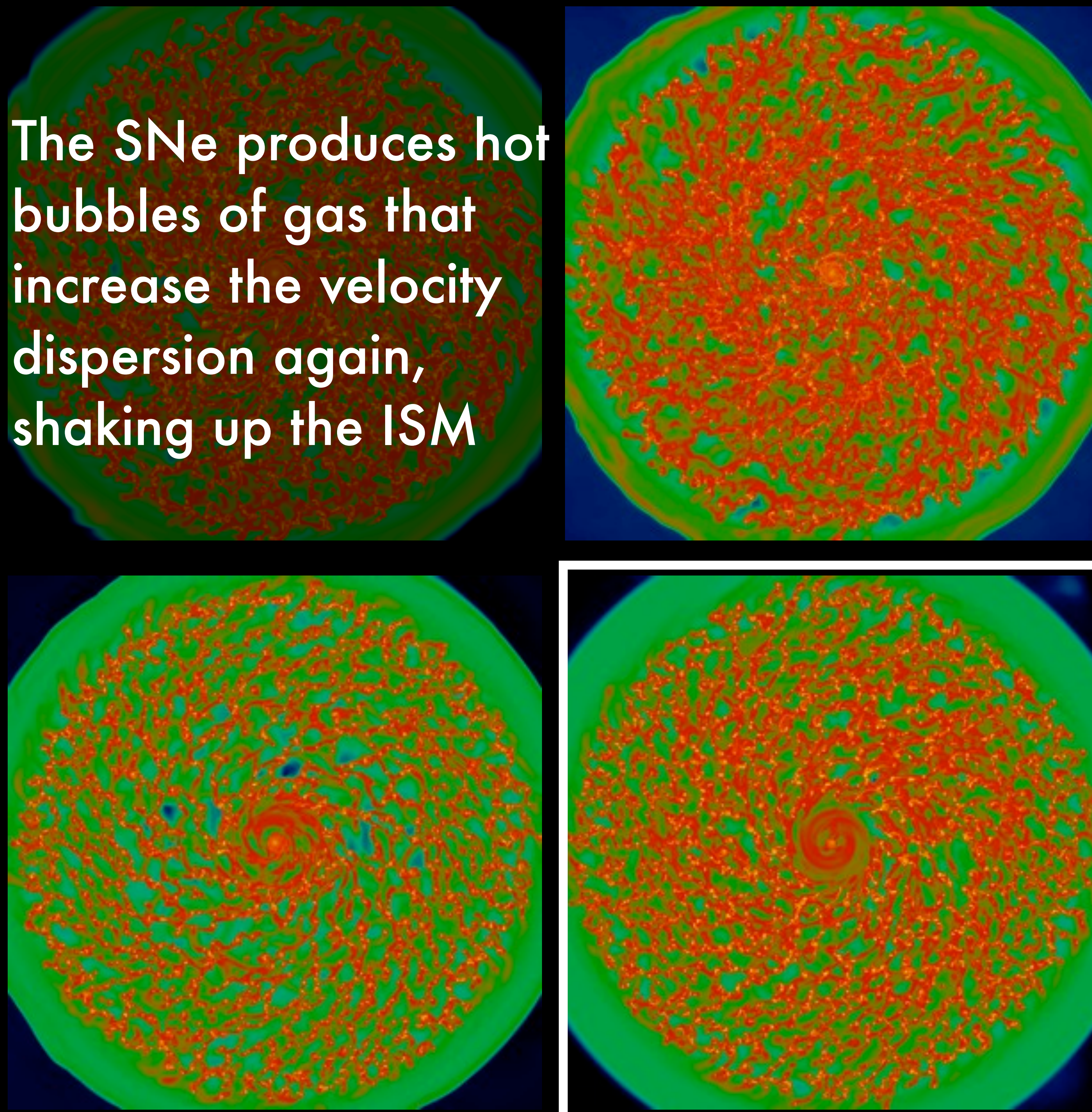
What we did....

No SF

SF only

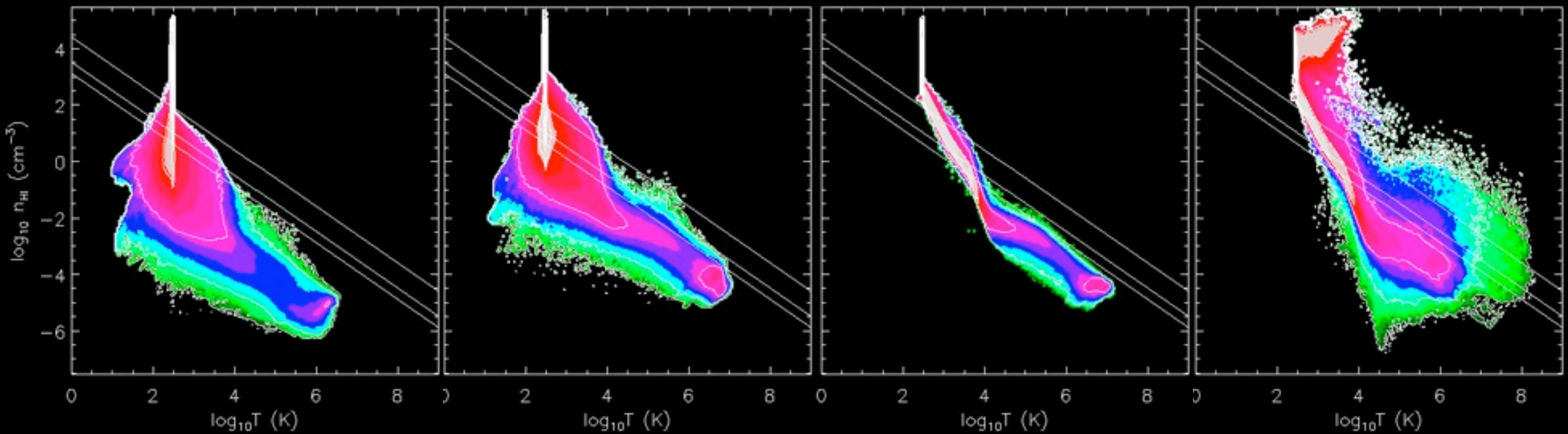
PE heat

SNe



The SNe produces hot bubbles of gas that increase the velocity dispersion again, shaking up the ISM

What we did....



No SF | SF only | PE heat | SNe

Continuous range of densities and temperatures, largely in pressure equilibrium

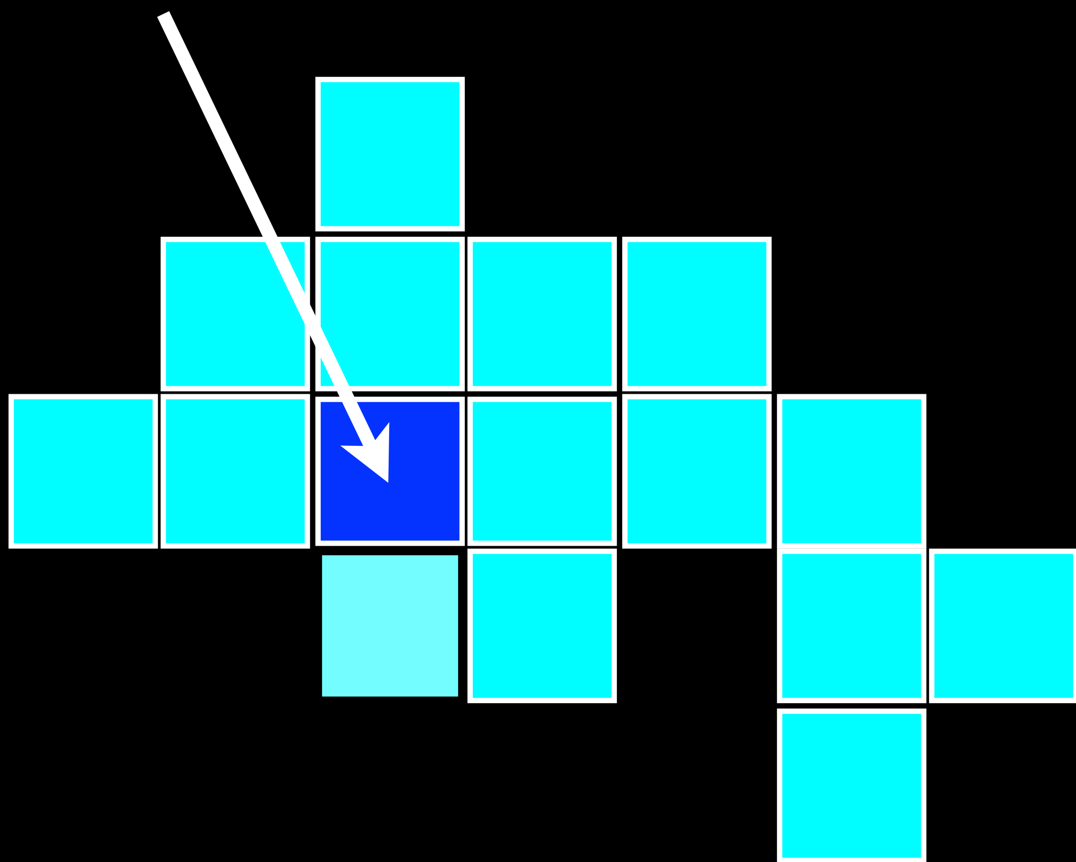
Star formation reduces the amount of mass at the cooling floor over time

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

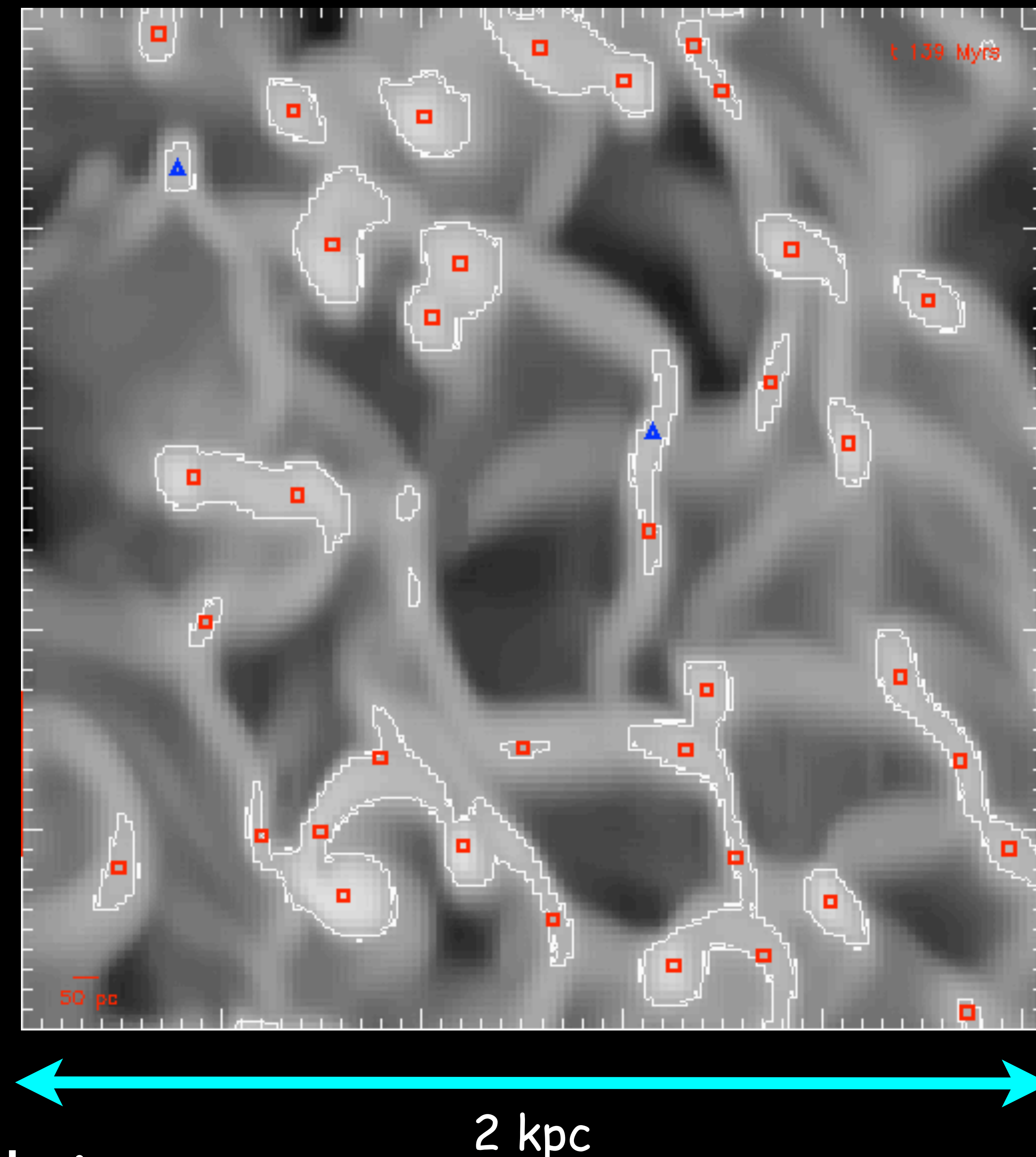
Gas is ejected out of the cold dense region by the SNe, expanding to produce hot, lower density bubbles of gas

What we did....

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



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



Clouds are tracked through the simulation

Cloud mass distribution

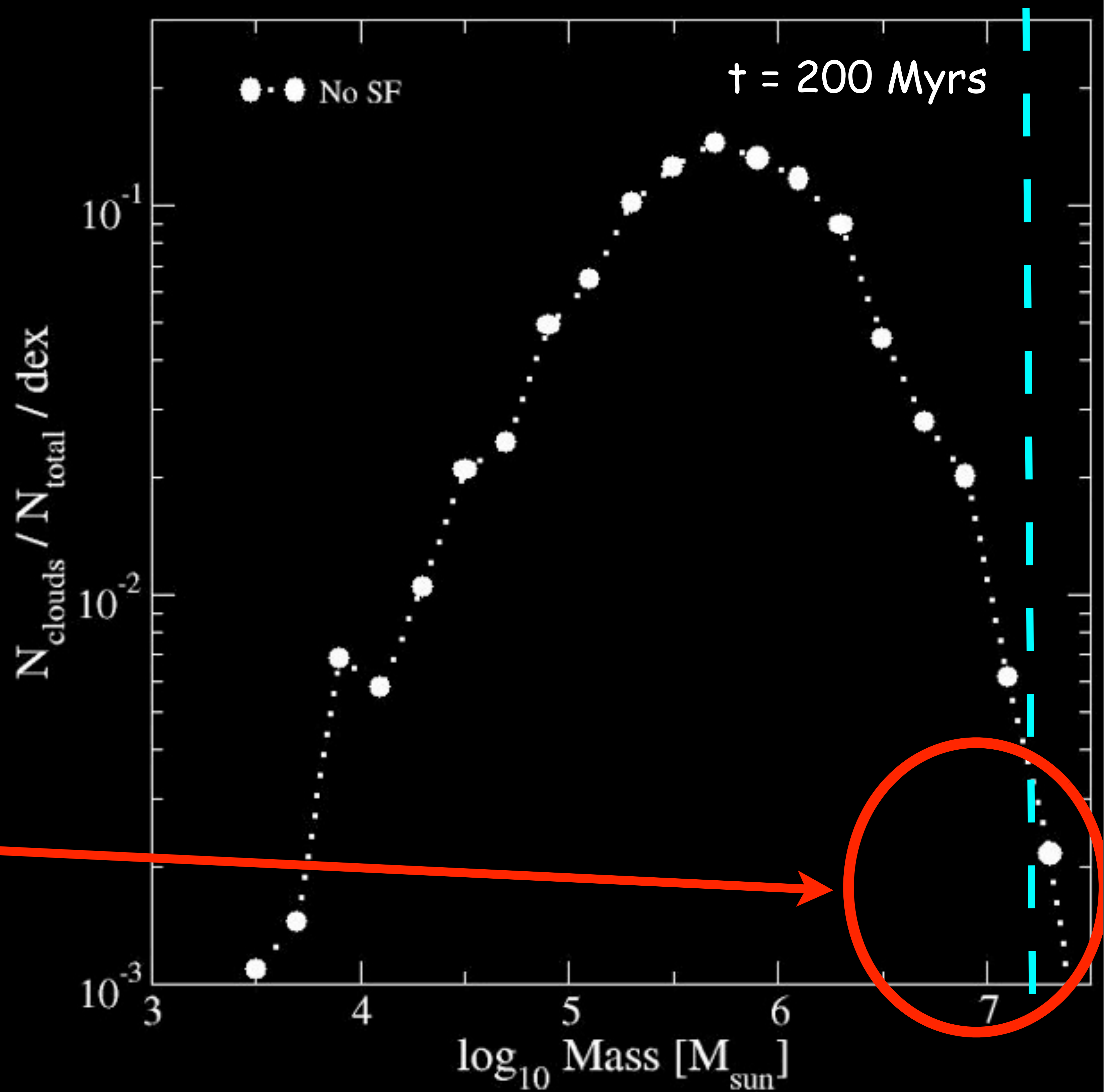
Simplest model

(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.



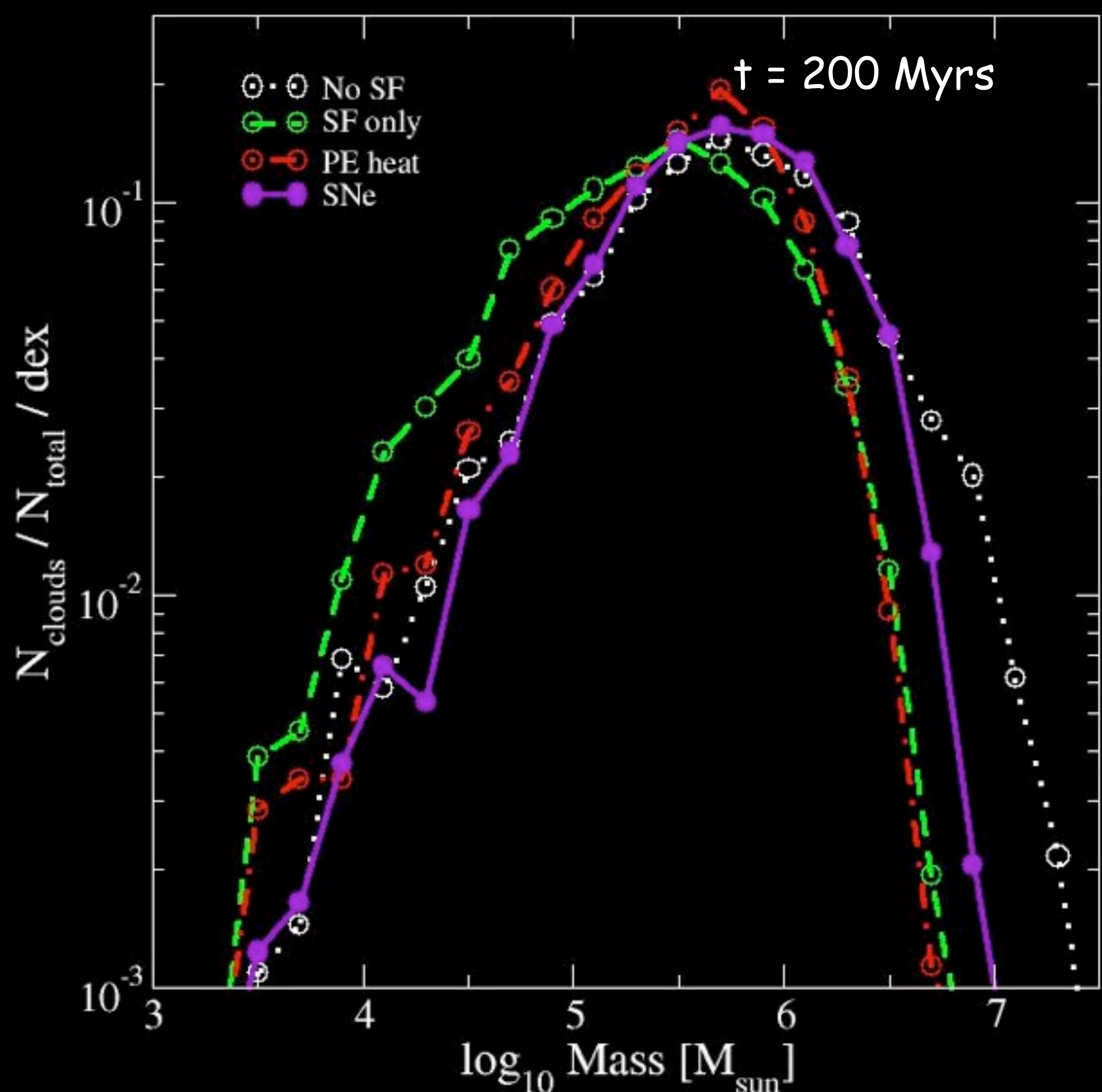
Cloud mass distribution

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.

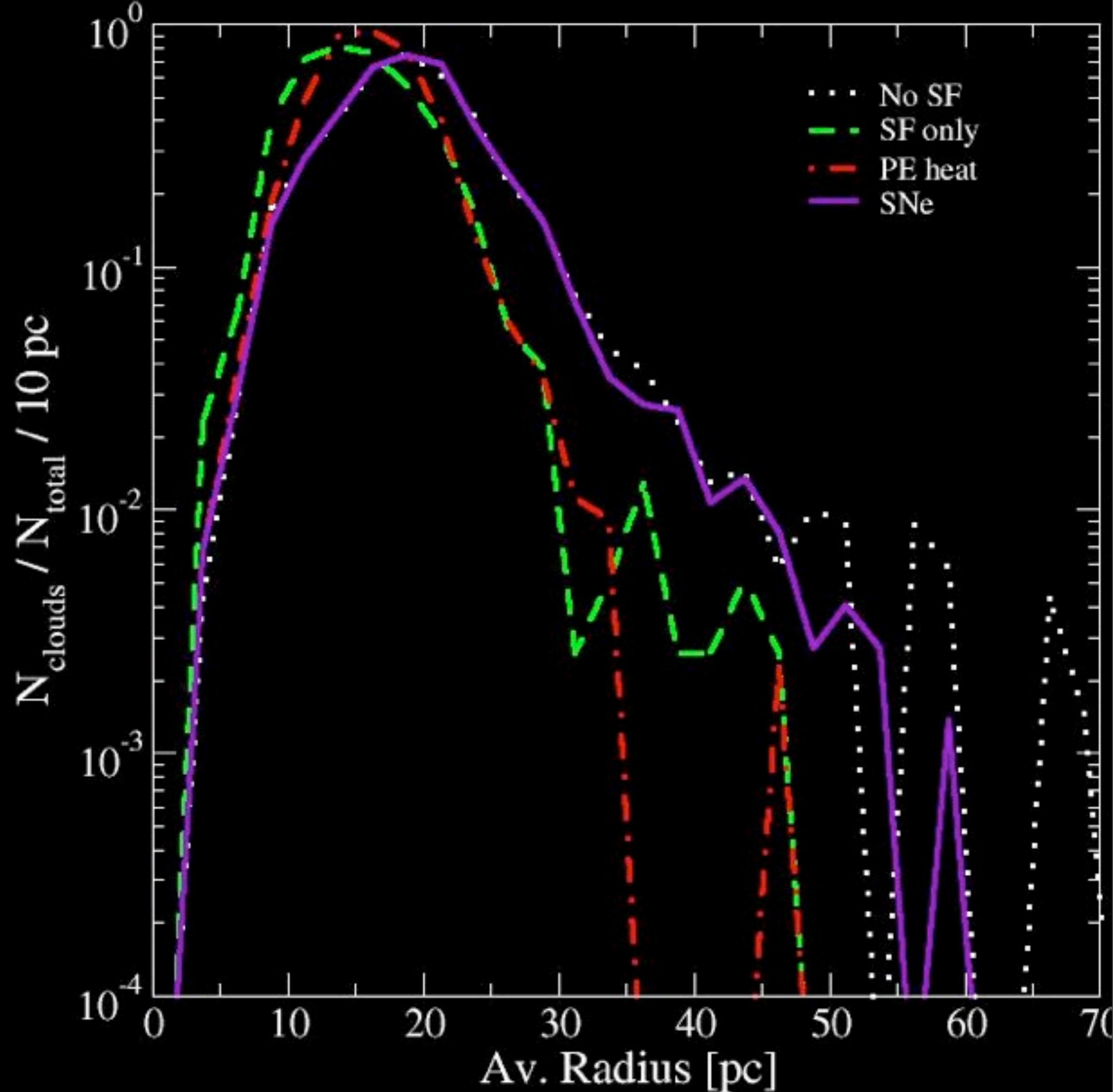
SNe inhibit star formation still more, allowing the mass profile to approach that for the simulation without star formation



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.

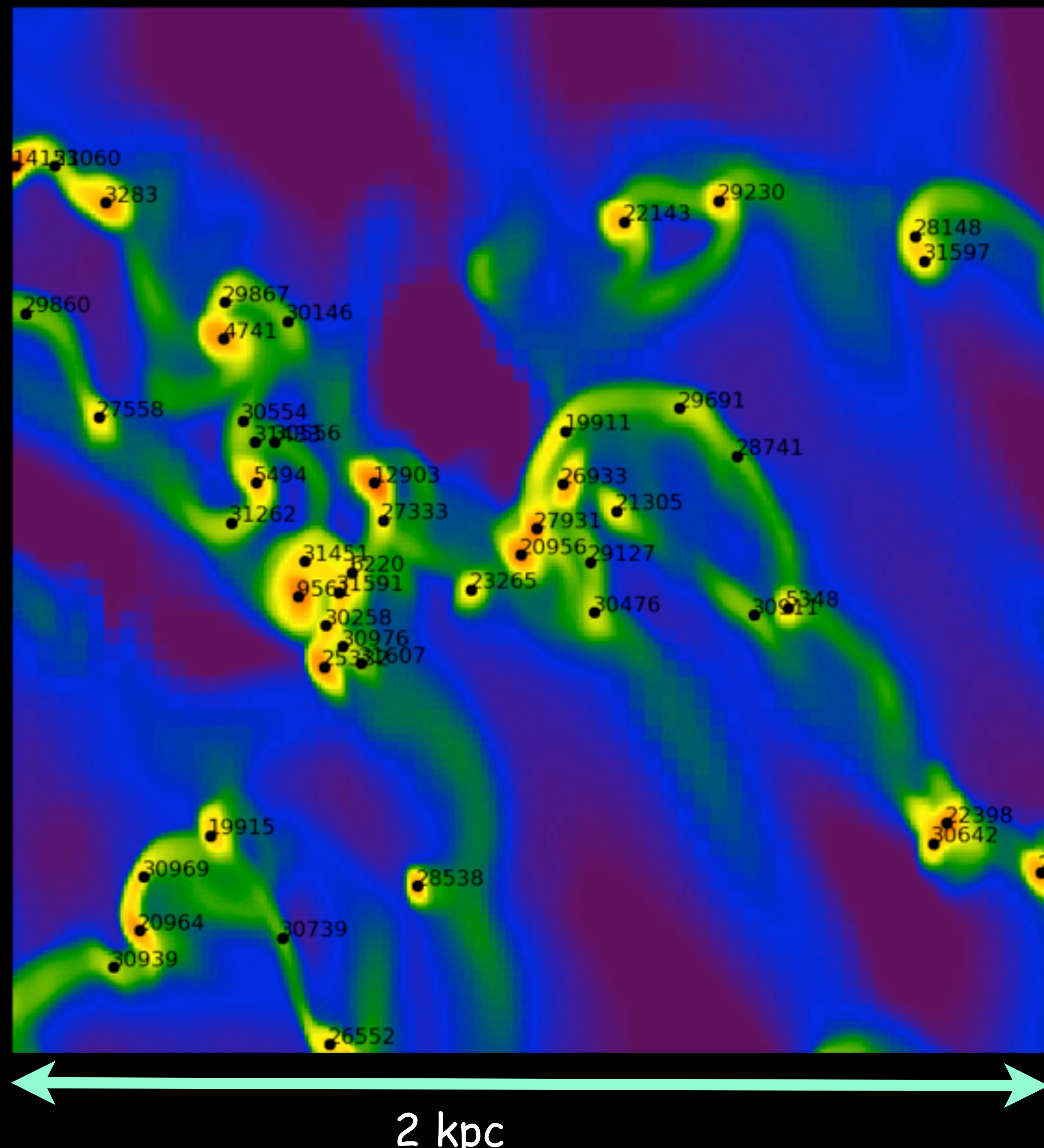
SNe don't destroy clouds....

... they make them live longer?!

Cloud identification: does it work?

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

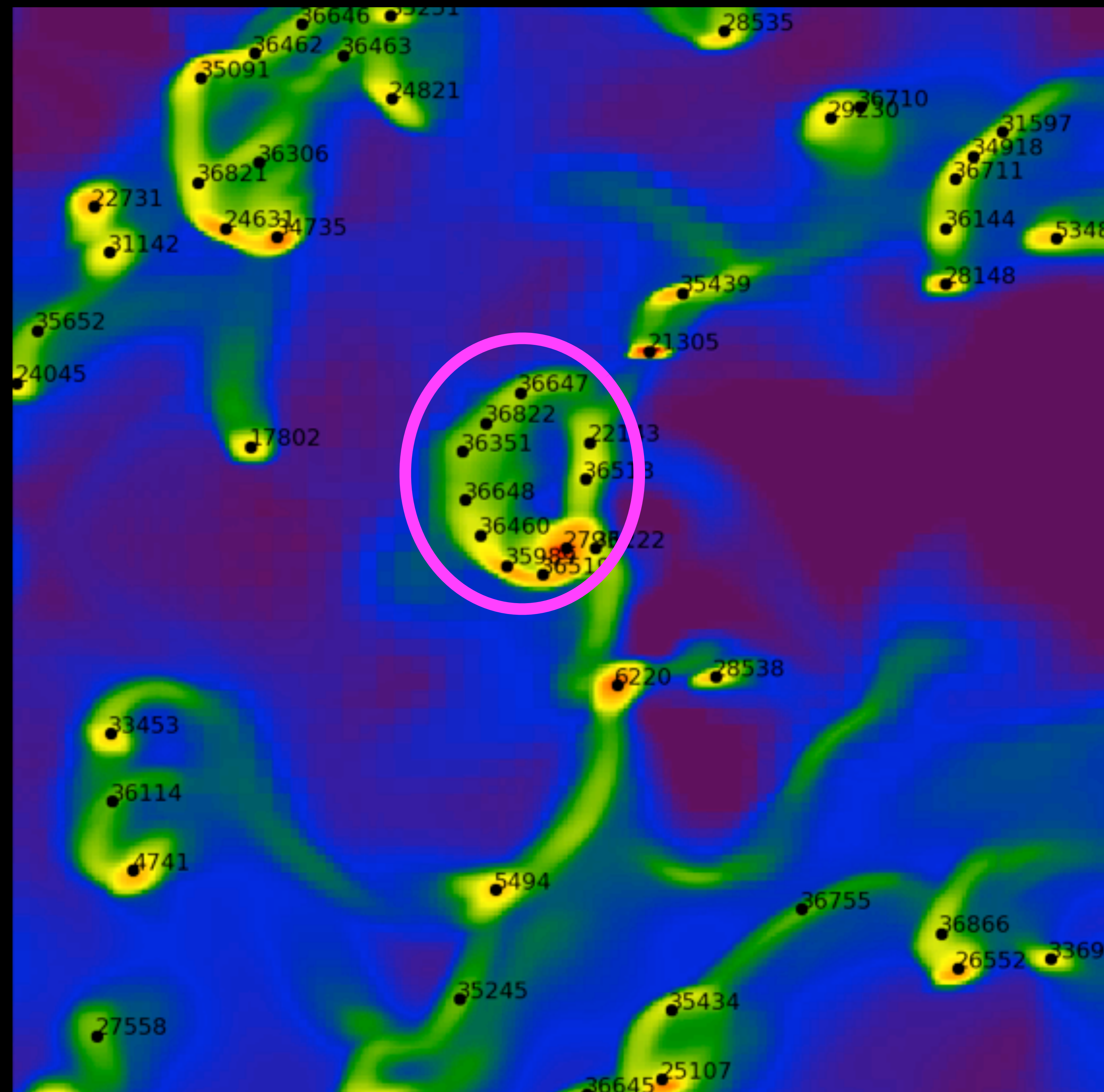
But it produces a large number of small clouds within the same gravitationally bound structure.



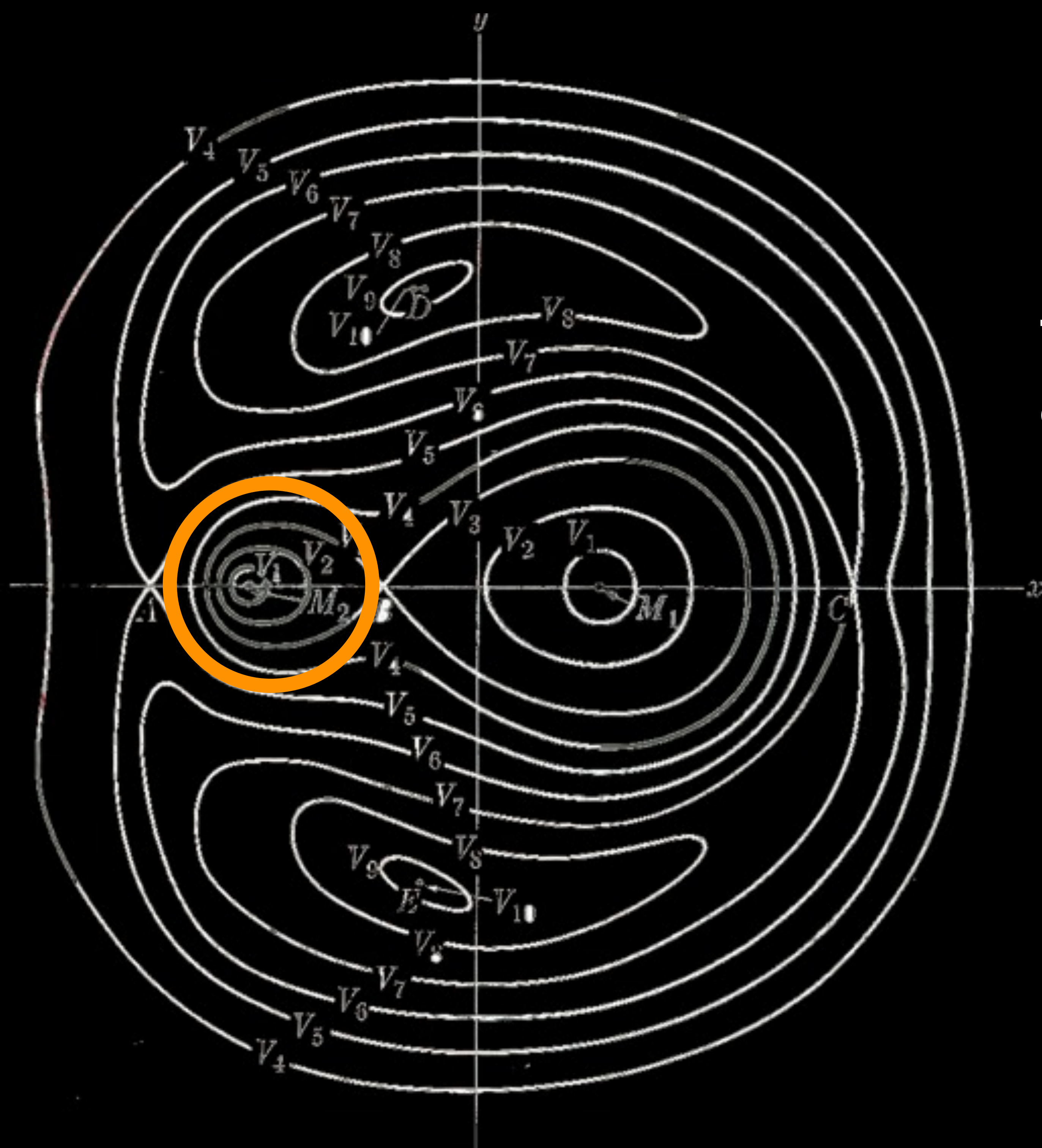
Cloud identification: does it work?

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!

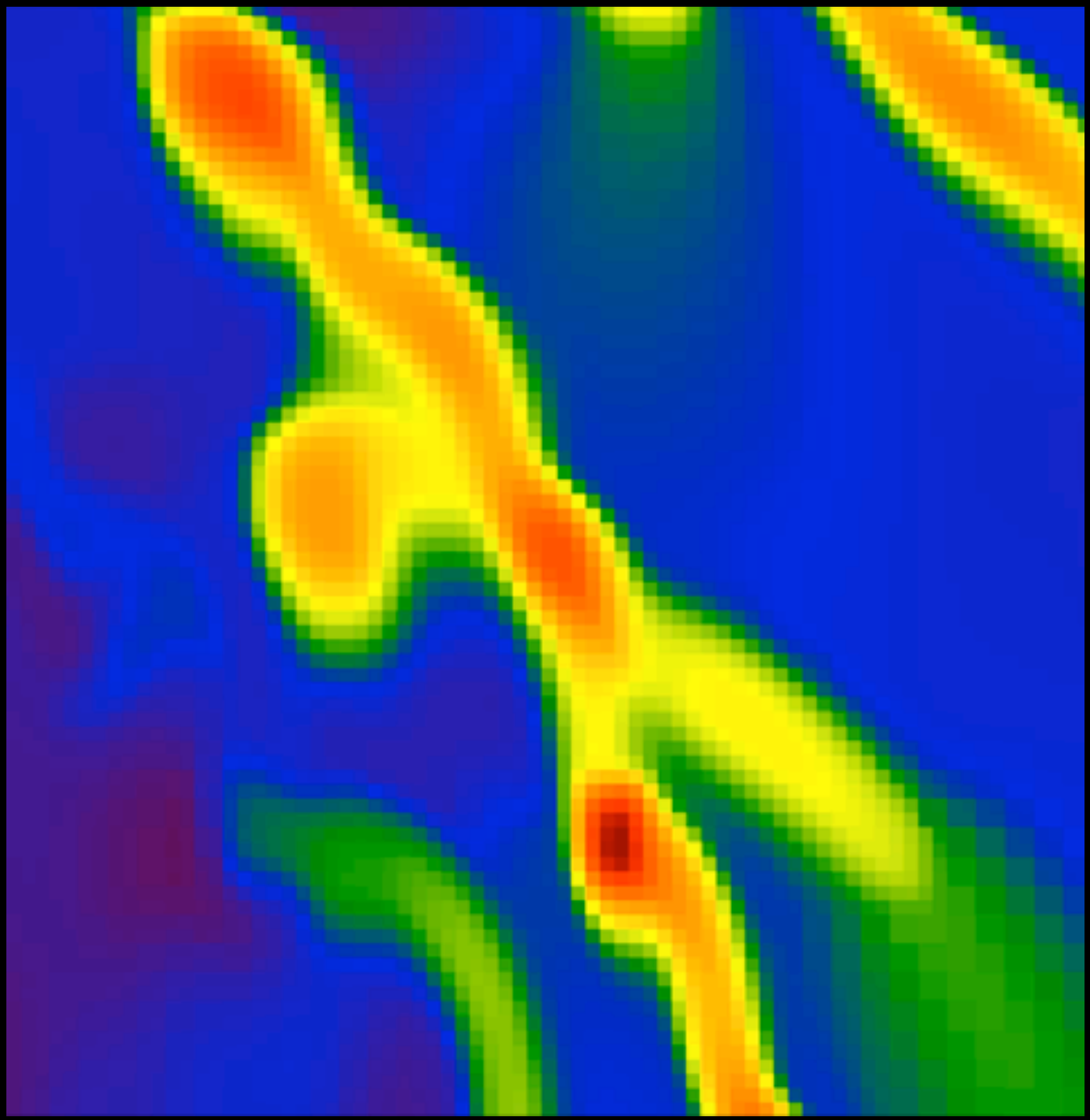
Using the restricted 3-body solution for the gravitational potential of cloud and galaxy

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

Cloud cells with velocity high enough to escape are removed

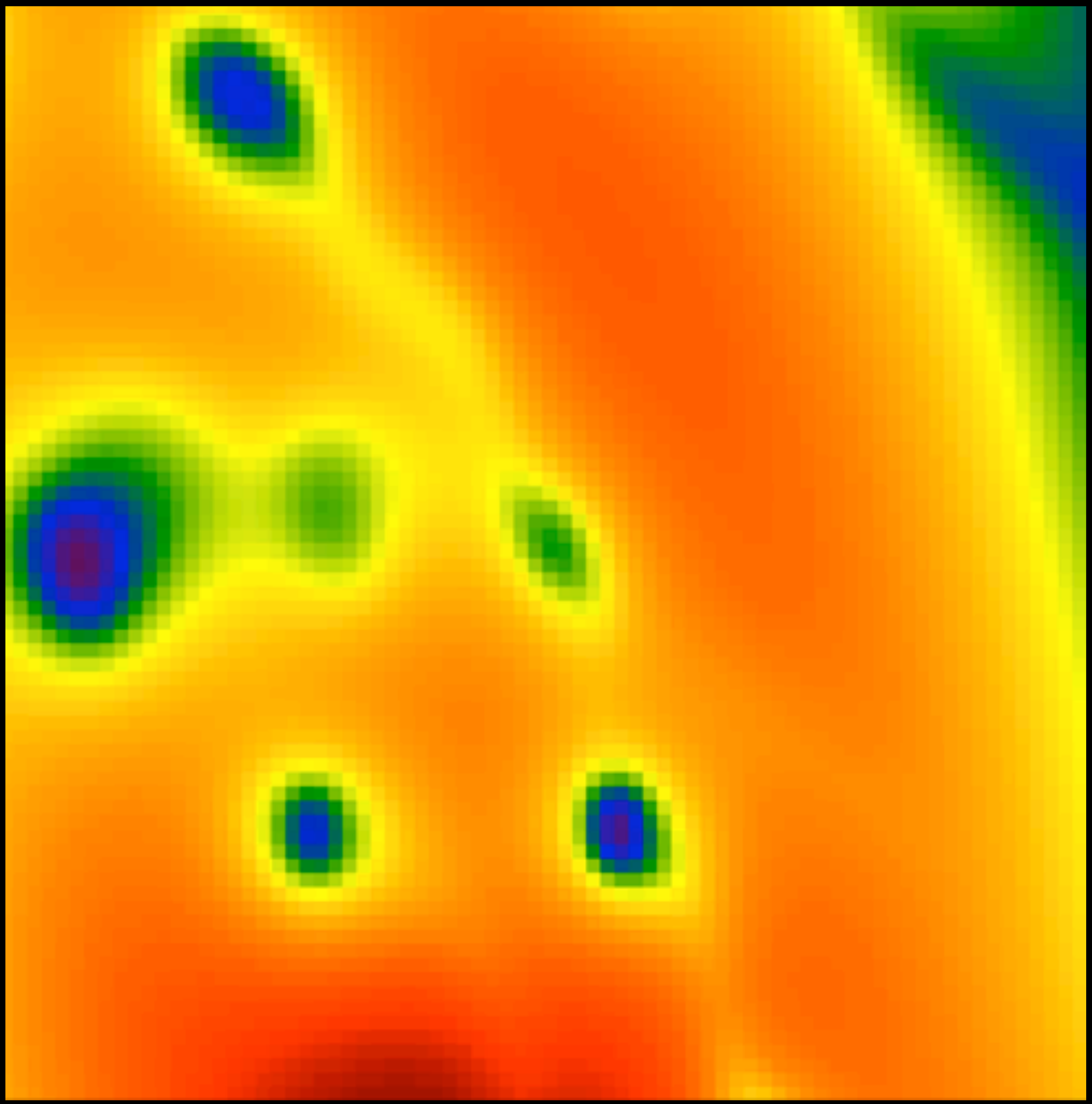
What we did next....

Does it work?



Density

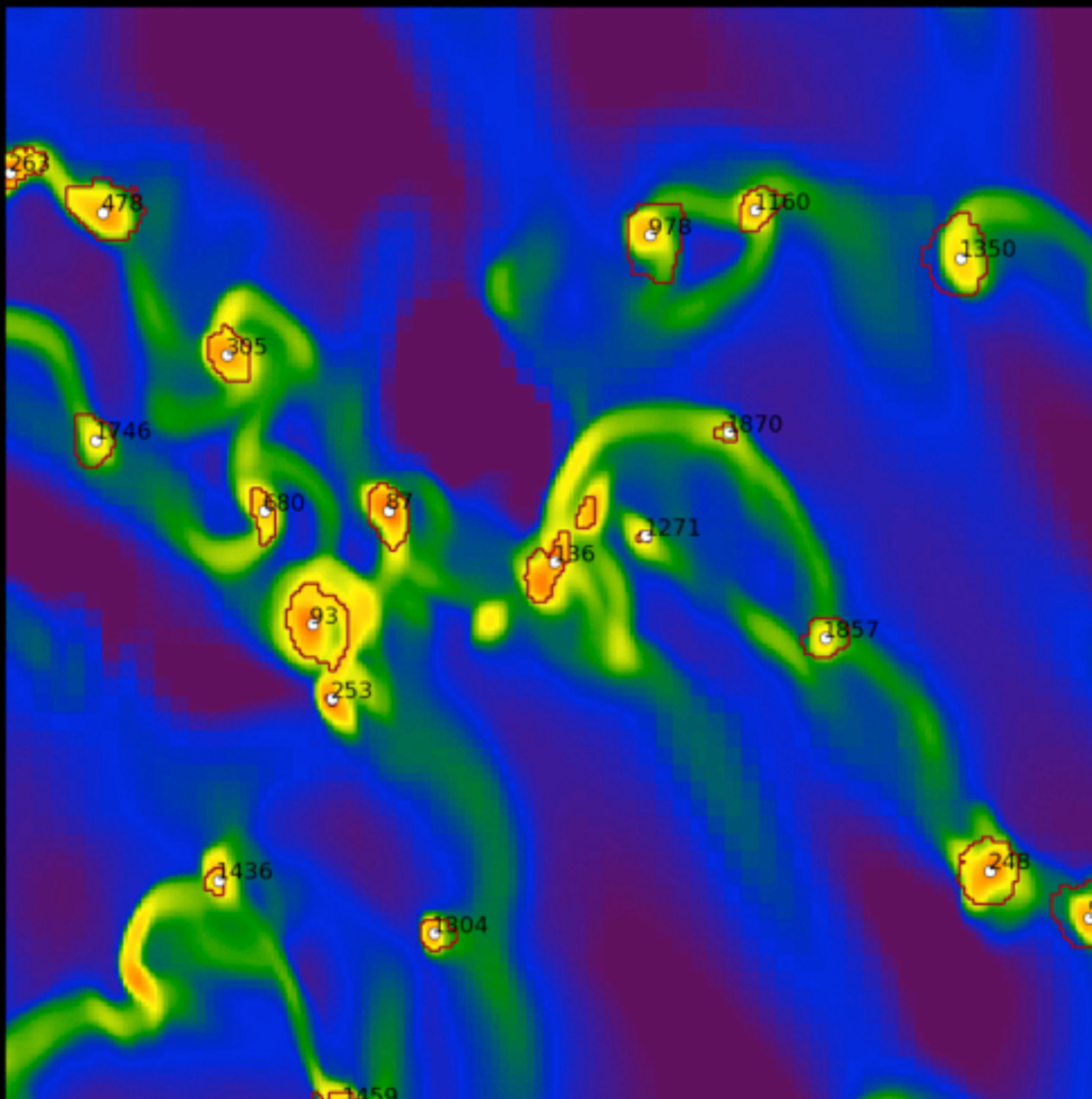
Cloud boundaries unclear



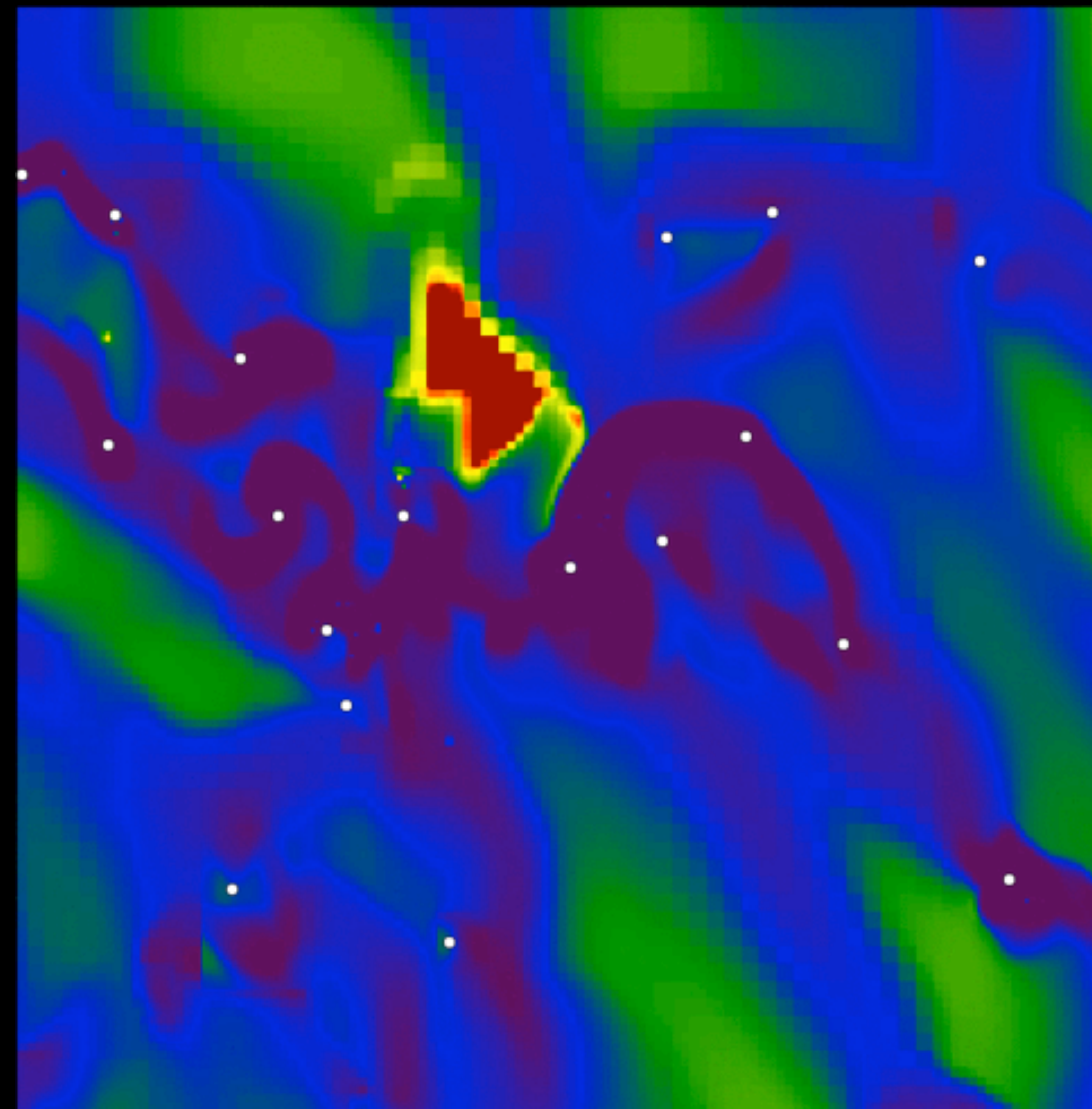
Effective Potential

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)

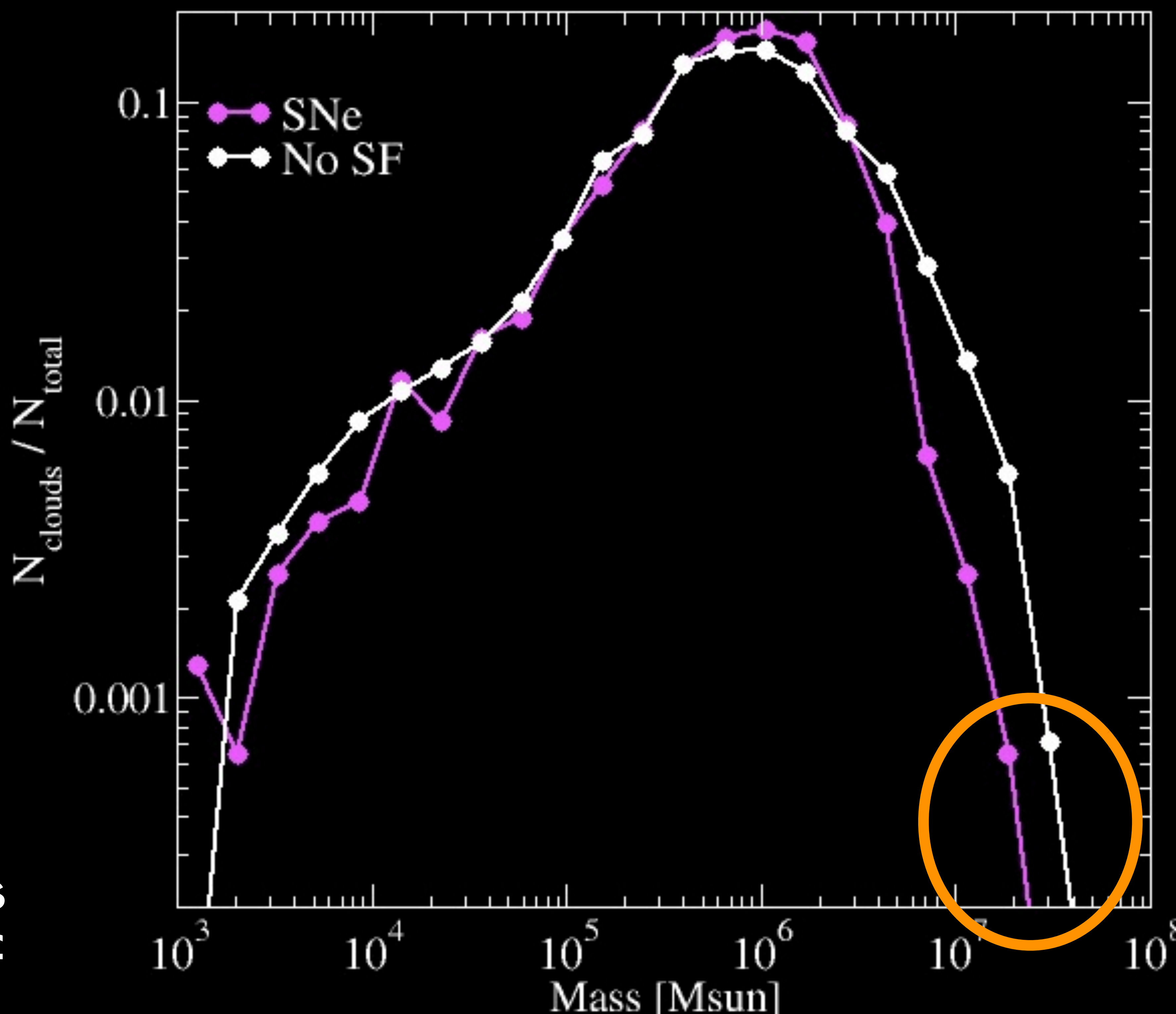
What we did next....

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.

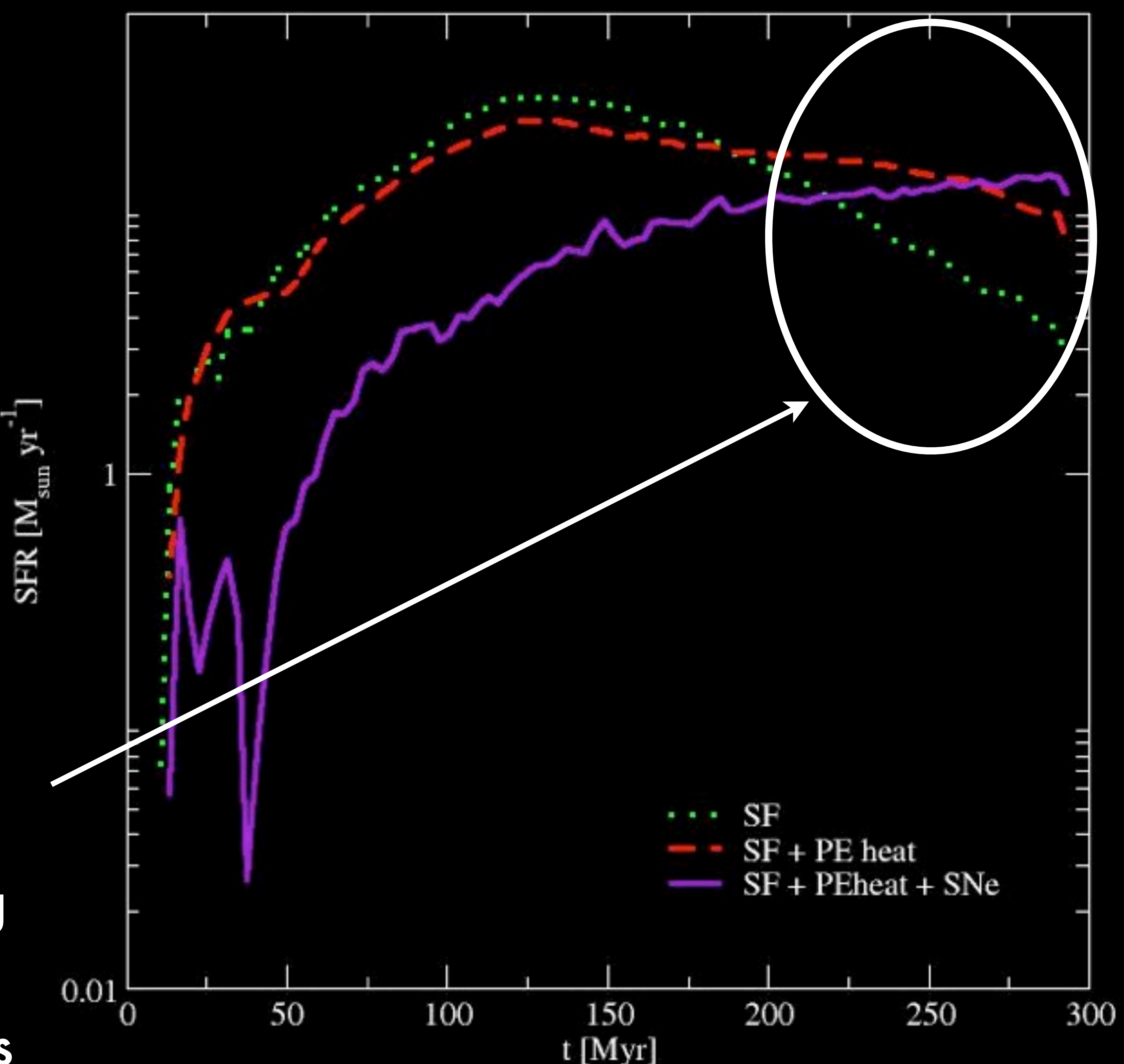


Star formation history

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

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 (also, Oscar Agertz's poster)