Combined effects of HII regions and stellar winds

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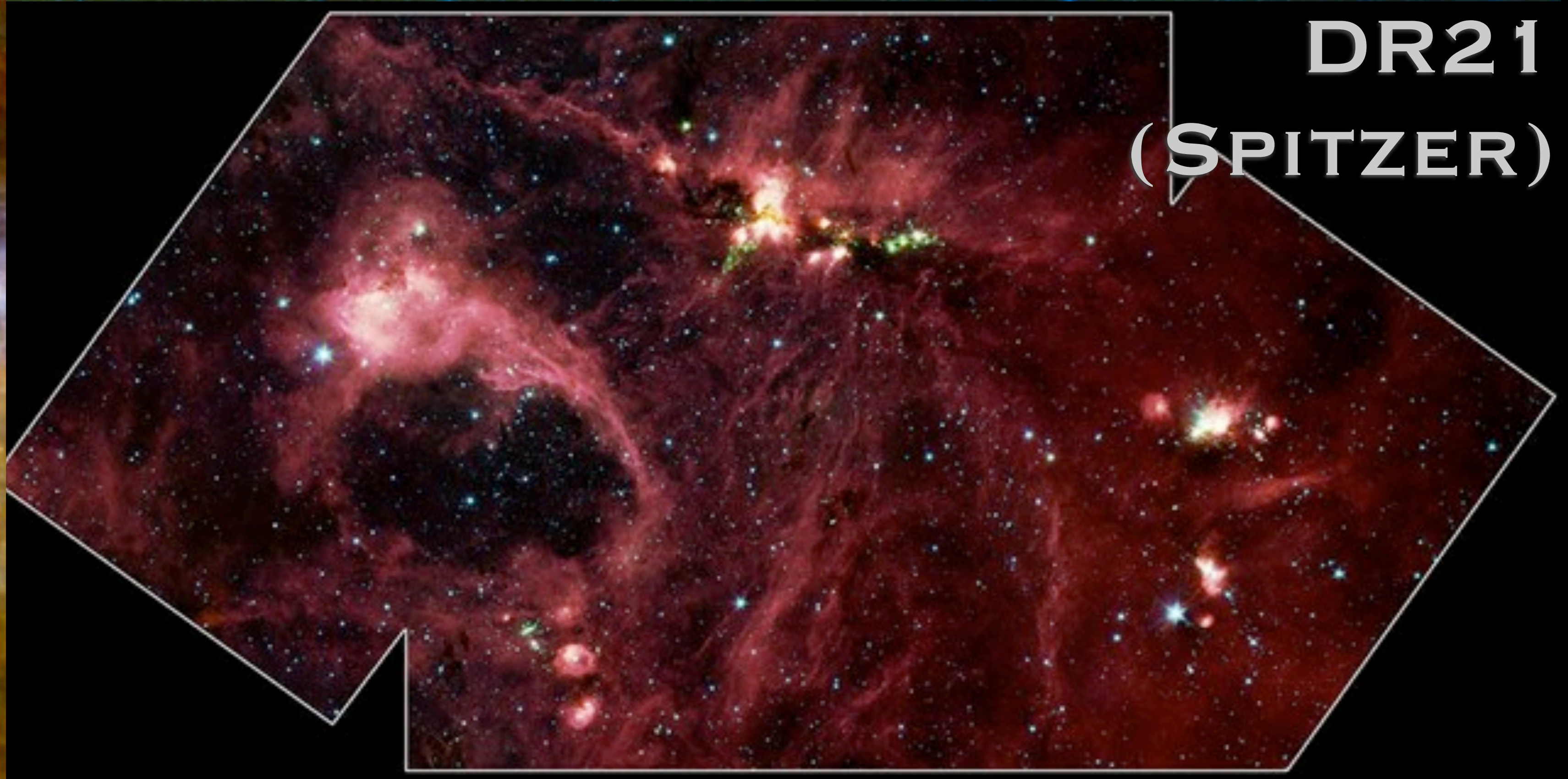
CYGNUS X
(HERSCHEL)

W3/4/5
(WISE)

DR21
(SPITZER)

PREVIOUS WORK...

champagne flows: tenorio-tagle+ 79, whitworth 79, yorke+ 89, williams & mckee 97

cluster/cloud destruction: hills 80, goodwin 97, boilly & kroupa 03a,b, lada & lada 03, goodwin & bastian 06

hii regions/accretion flows: walmsley 95, keto 03, 07, dale+05, 11, 12a,b, 13a,b, peters+ 10, vazquez-semadeni+ 10

winds: weaver+77, koo & mckee 92a,b, pittard 05, dale & bonnell 08, fierlinger+12, rogers & pittard 13

winds vs hii regions: mckee 84, matzner 02, freyer 03,06, harper-clark & murray 09

What I actually do:

SPH simulations of GMCs

including:

photoionization from O-stars

winds from O-stars

both types of feedback

(M,R) parameter space of clouds based on Heyer et al 2009, seeded with turbulent velocity fields

velocity dispersion chosen so that clouds have initial virial ratios of either 0.7 or 2.3

LET'S DO SOME EXPERIMENTS:

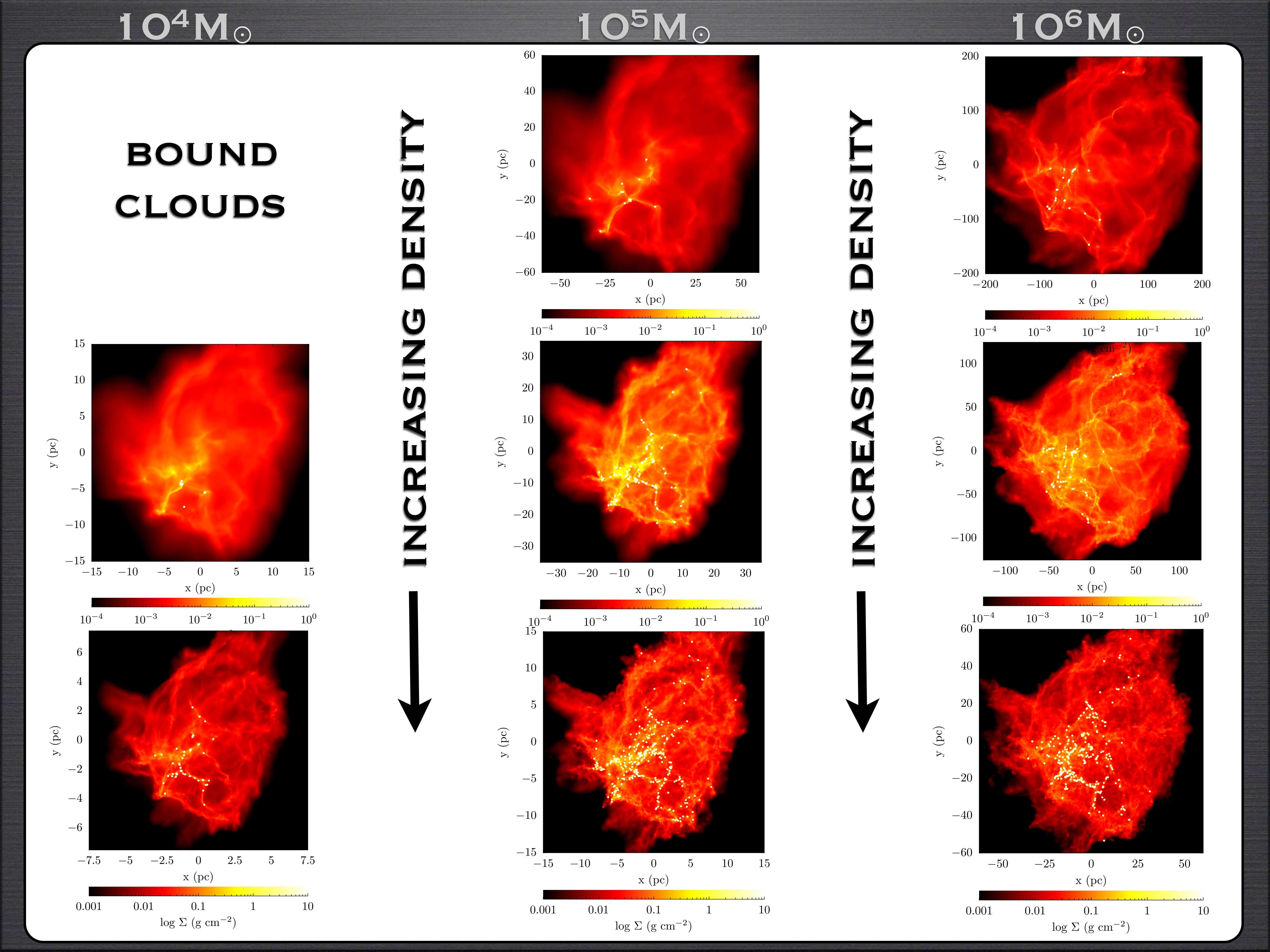
(1) LET CLOUDS FORM STARS

(2) EXPOSE THEM TO IONIZATION

(3) EXPOSE THEM TO WINDS

(4) EXPOSE THEM TO BOTH

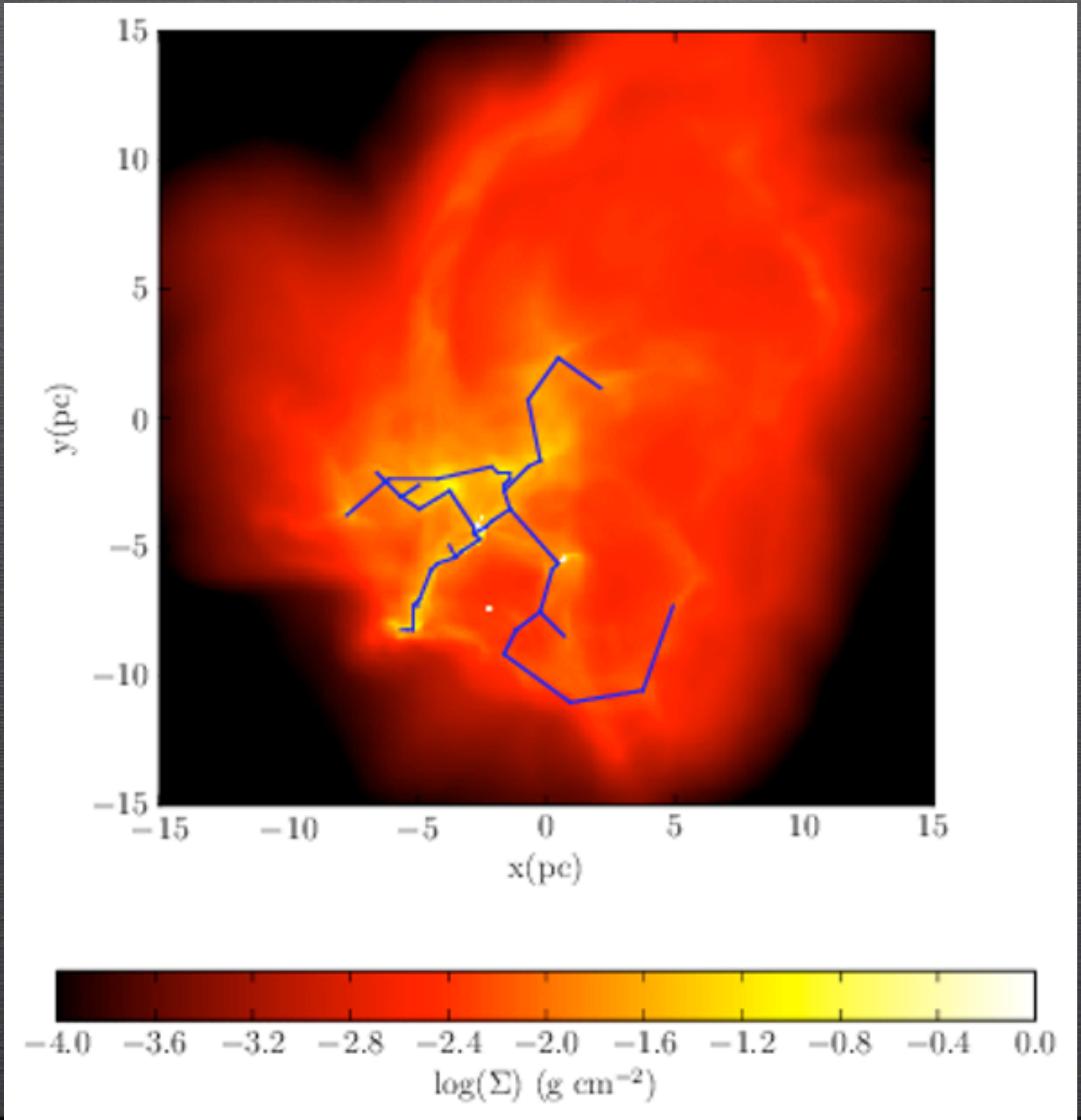
FOR 3MYR (NO SNE YET)



$10^4 M_\odot$
$10^5 M_\odot$
$10^6 M_\odot$
BOUND CLOUDS
INCREASING DENSITY
INCREASING DENSITY
x (pc)
y (pc)
log Σ (g cm^{-2})

CLOUD STRUCTURE

- TURBULENCE GOOD AT MAKING FILAMENTS
- RICHEST CLUSTERS FORM AT JUNCTIONS



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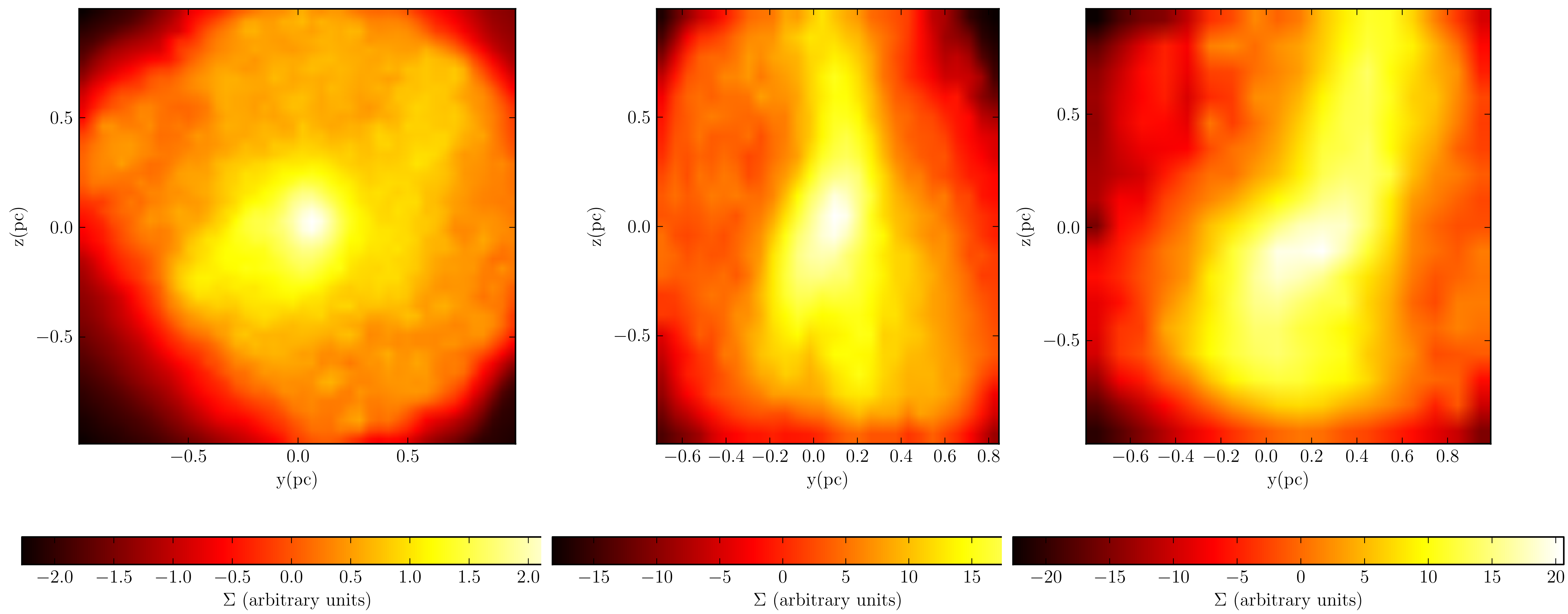
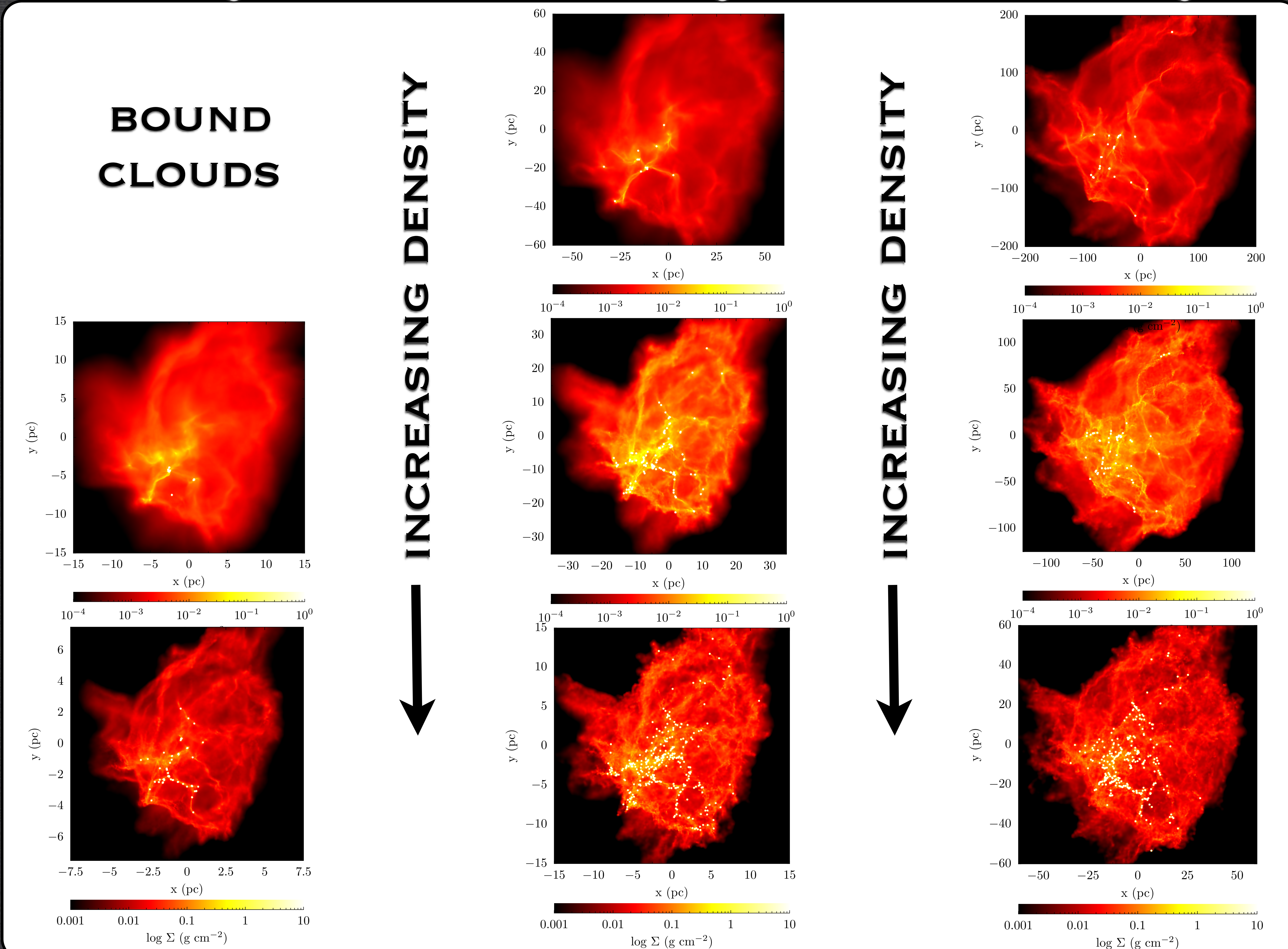
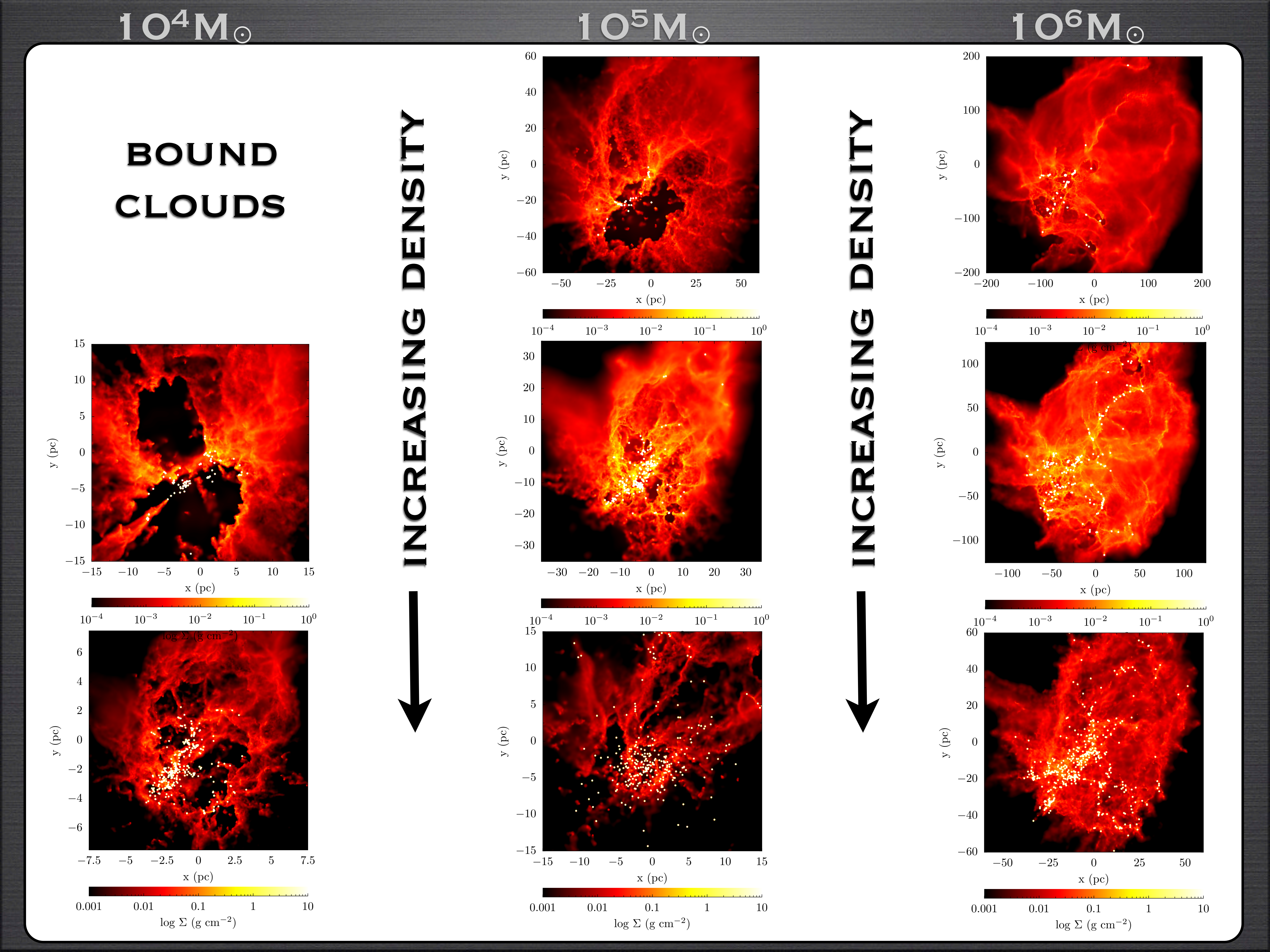


...BUT MOST ARE NOT CYLINDRICAL

...AND DO NOT HAVE CONSTANT WIDTHS

$10^4 M_\odot$ $10^5 M_\odot$ $10^6 M_\odot$





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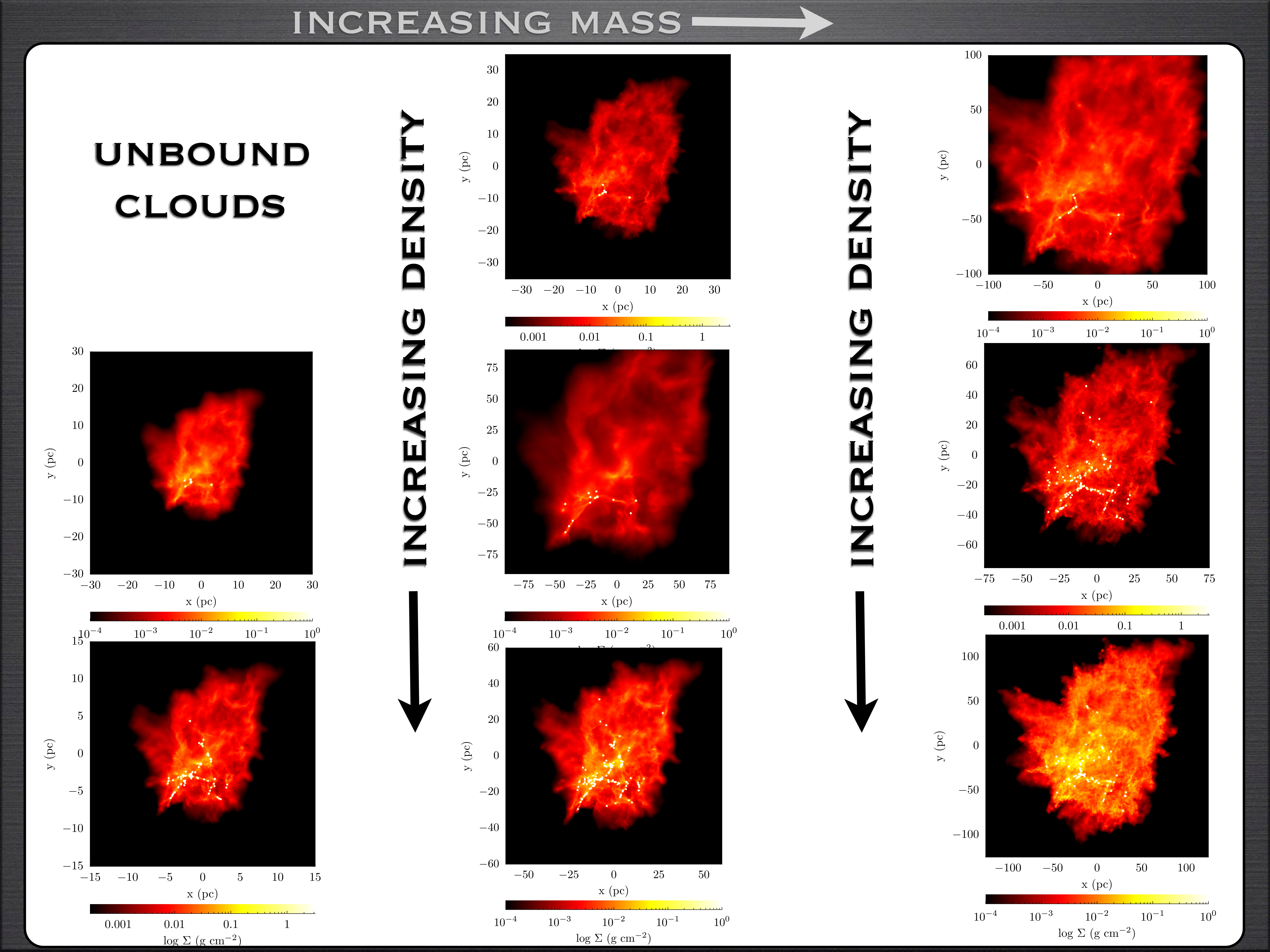
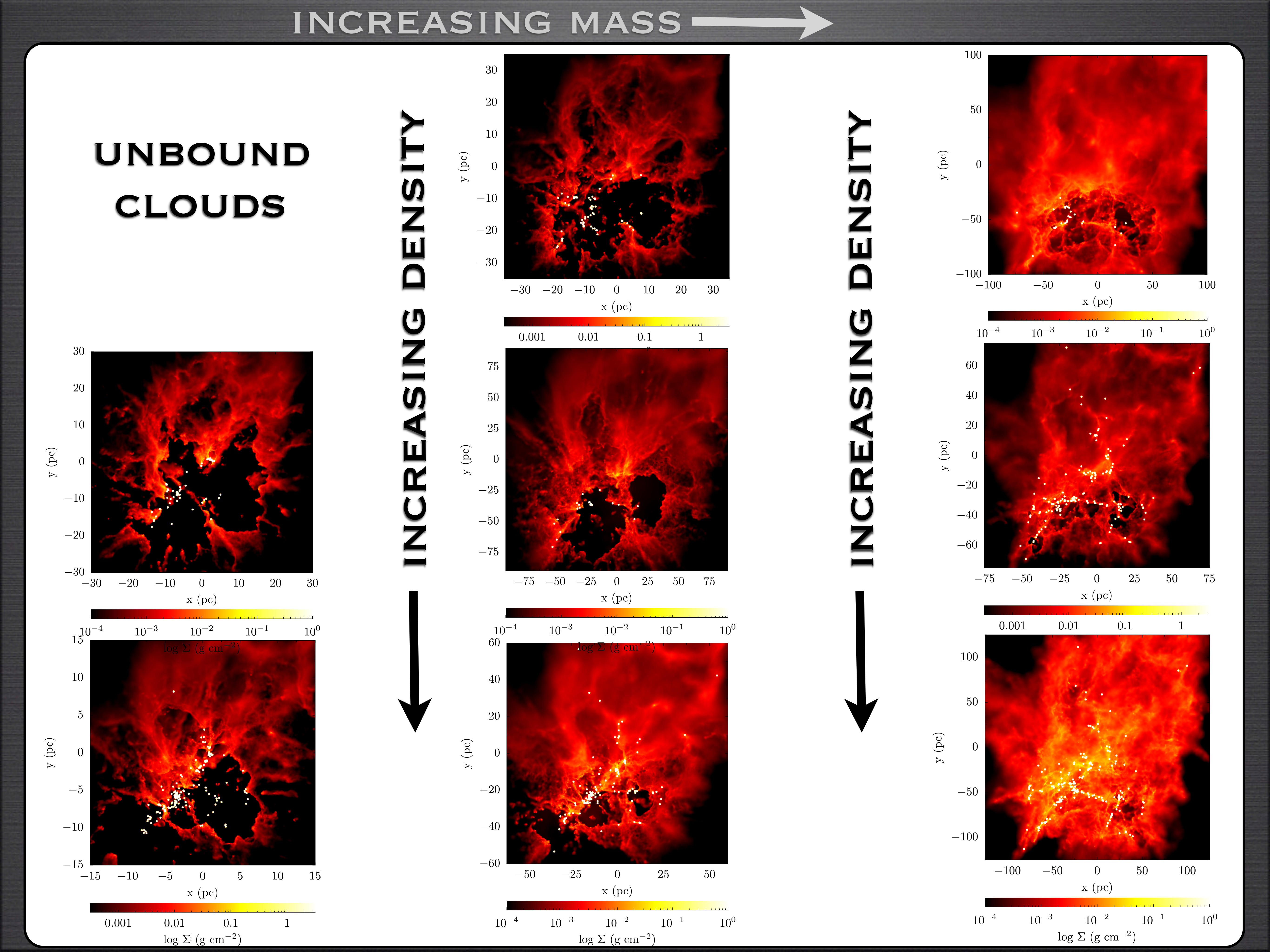
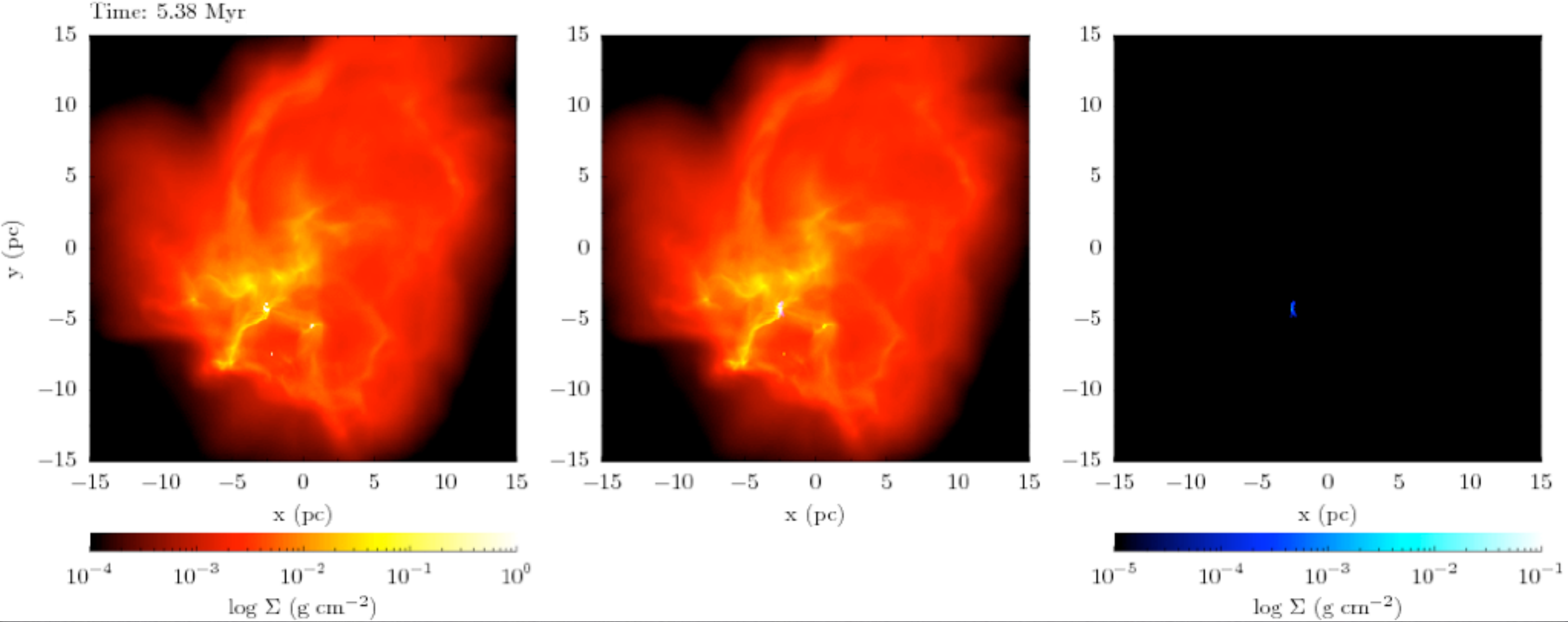

INCREASING MASS
UNBOUND CLOUDS
INCREASING DENSITY
INCREASING DENSITY
x (pc)
y (pc)
log Σ (g cm−2)



INCREASING MASS
UNBOUND CLOUDS
INCREASING DENSITY
INCREASING DENSITY
x (pc)
y (pc)
log Σ (g cm^{-2})

$10^4 M_\odot$ unbound cloud

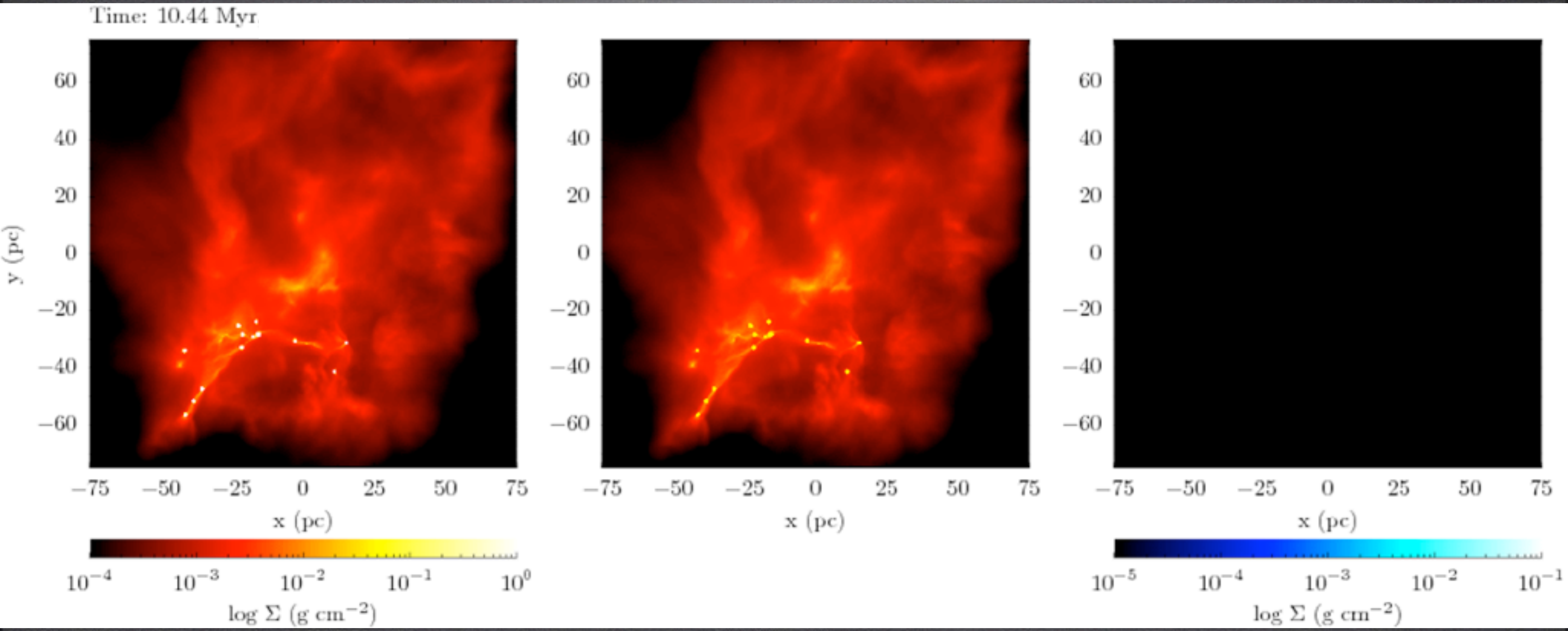
v_{esc}=2.9km/s



Dale et al 2012a

$10^5 M_\odot$ unbound cloud

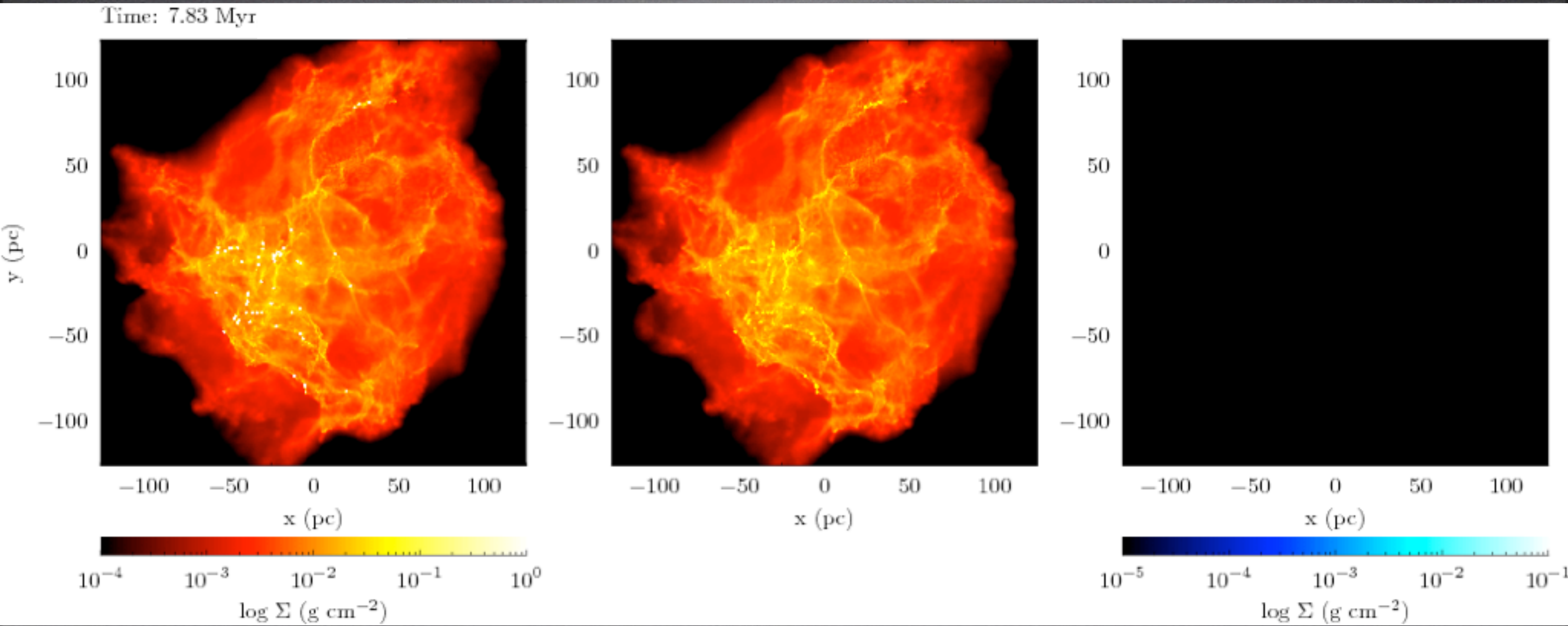
v_{esc}=6.4km/s



dale et al 2013a

$10^6 M_\odot$ bound cloud

v_{esc}=9.5km/s



Dale et al 2012a

(1) clouds appear to be filamentary

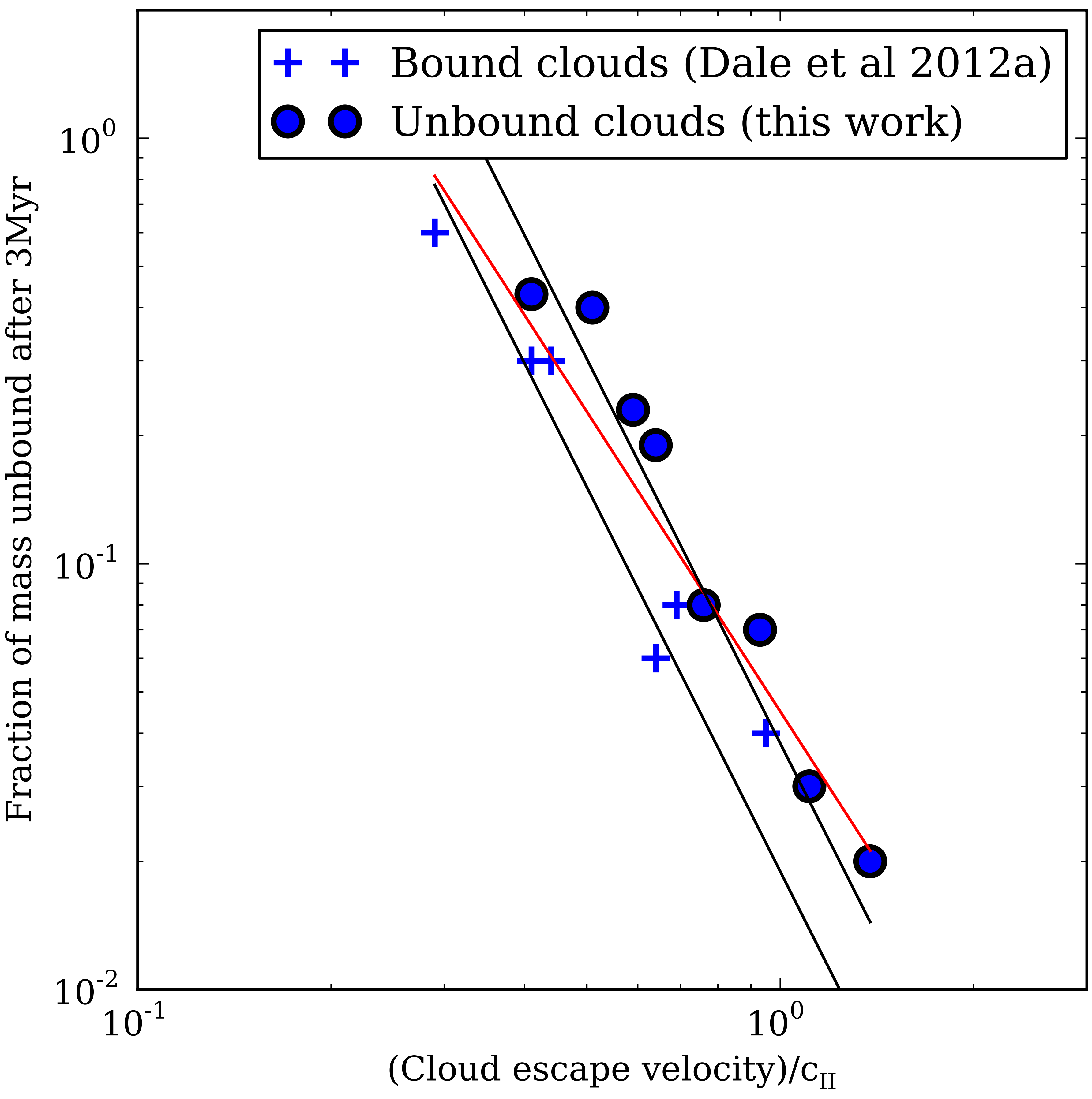
(2) massive stars born inside filaments (often at junctions)

(3) first thing feedback does, if it does anything, is destroy filaments

(4) dense gas near sources initially limits the growth of HII regions

(5) mass expelled depends strongly on cloud escape velocity - ranges from ~1-~60%

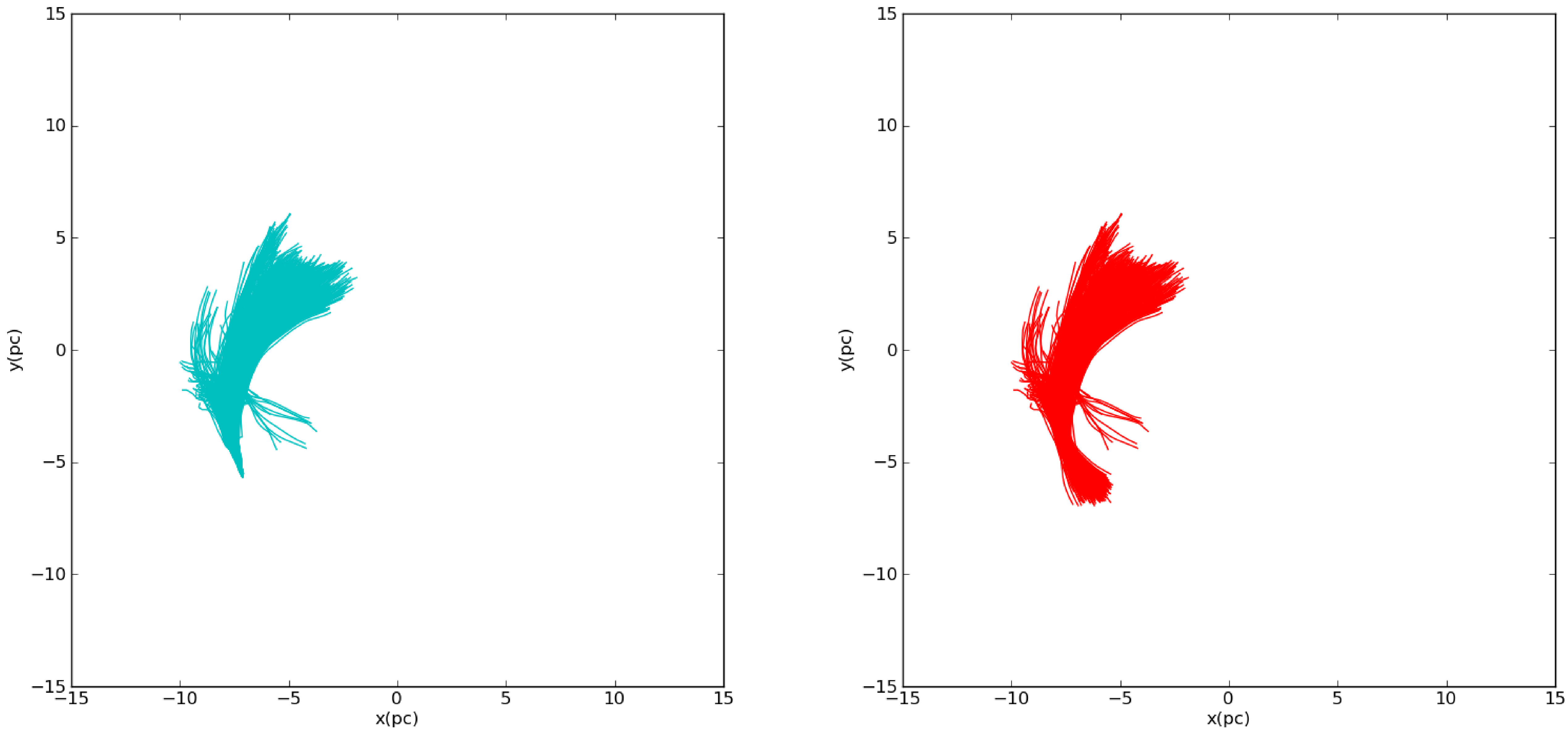
(6) SFE reduced by, <u>at most</u>, 50% - often still goes to >10%



Bound clouds (Dale et al 2012a)
Unbound clouds (this work)
Fraction of mass unbound after 3Myr
(Cloud escape velocity)/c_{II}
10^0
10^{-1}
10^{-2}
10^{-1}
10^0

WHAT ABOUT TRIGGERING?

HOW CAN WE TELL IF THE FORMATION OF A GIVEN STAR IS TRIGGERED OR NOT? (DALE ET AL 2007)

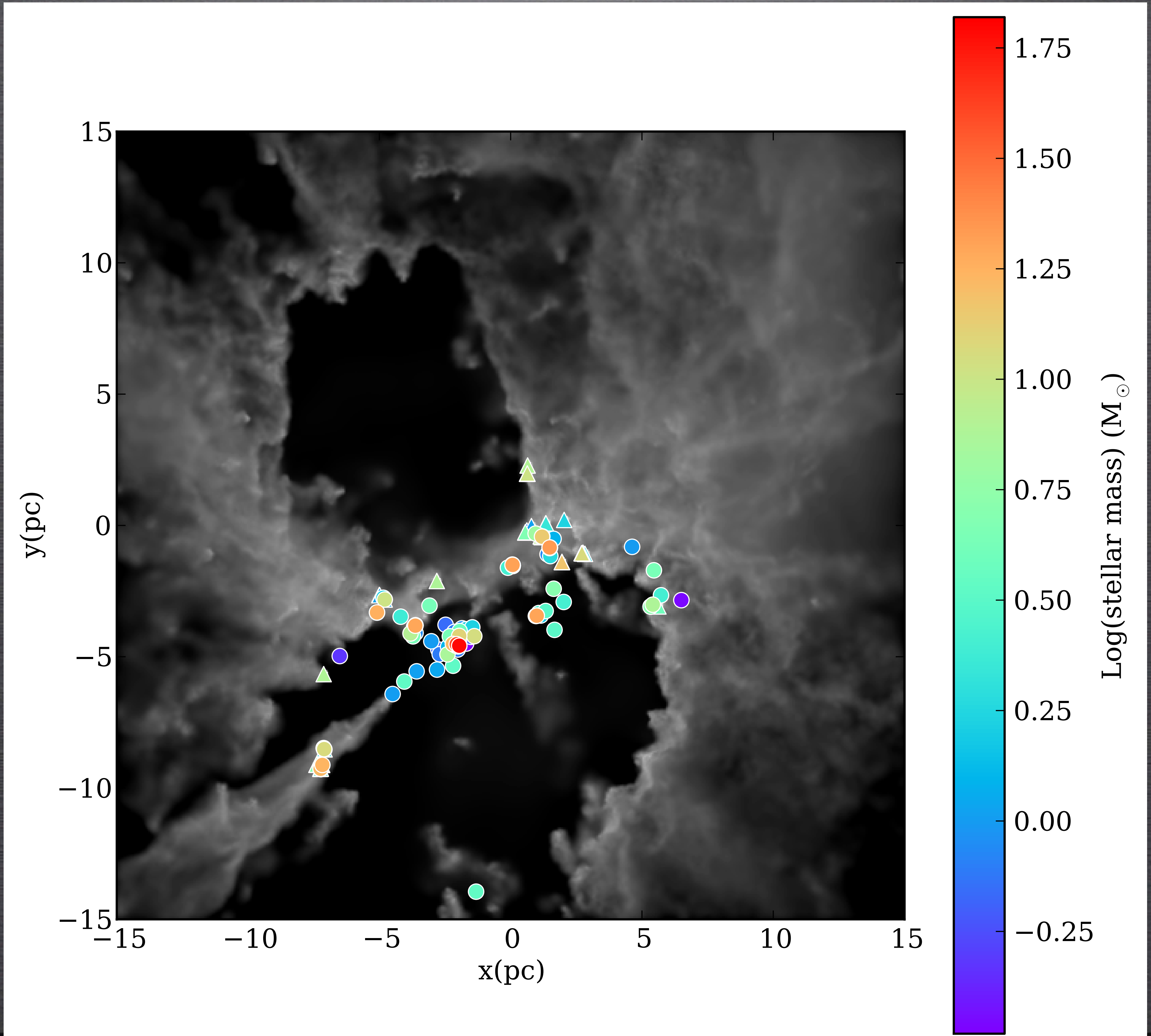


IONIZED RUN

CONTROL RUN

TRIGGERED STAR FORMATION

DALE ET AL., 2012B, 2013B - TRIGGERED AND SPONTANEOUSLY-FORMED STARS GEOMETRICALLY MIXED



(1) triggering does occur

(2) it's local and a second-order effect on the SFE

(3) also lots of aborted/ displaced star formation

(4) very hard to tell from a single snapshot which stars are triggered

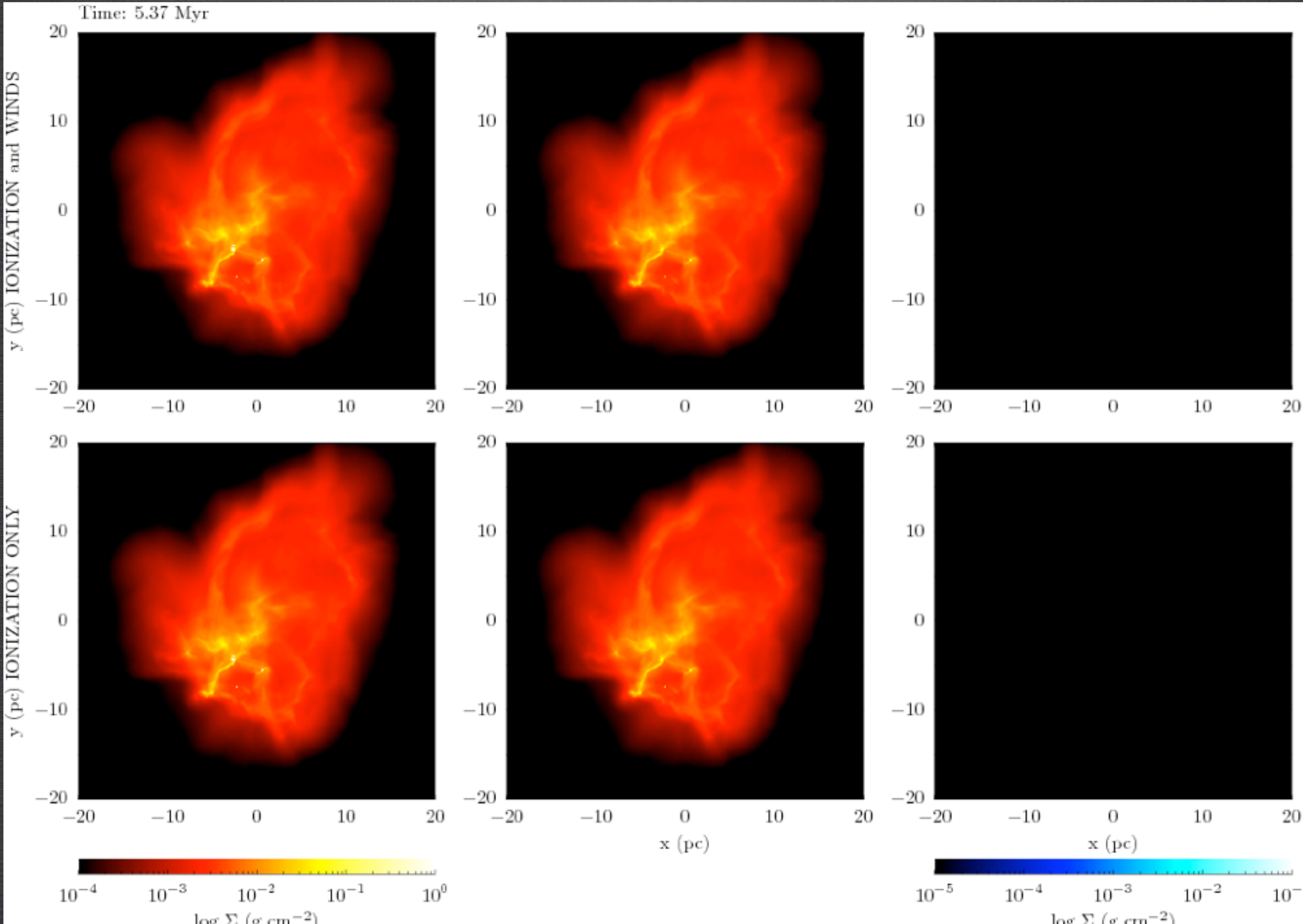
WHAT IF YOU TURN ON WINDS TOO?

- MODEL WINDS AS SPHERICAL MOMENTUM FLUXES - NO HOT GAS INJECTED

- SETS LOWER LIMIT TO WHAT WINDS WILL DO

- HOT WIND GAS WOULD ALMOST CERTAINLY QUICKLY LEAK FROM CLOUDS - THE HII DOES!

WHAT IF YOU TURN ON WINDS TOO?



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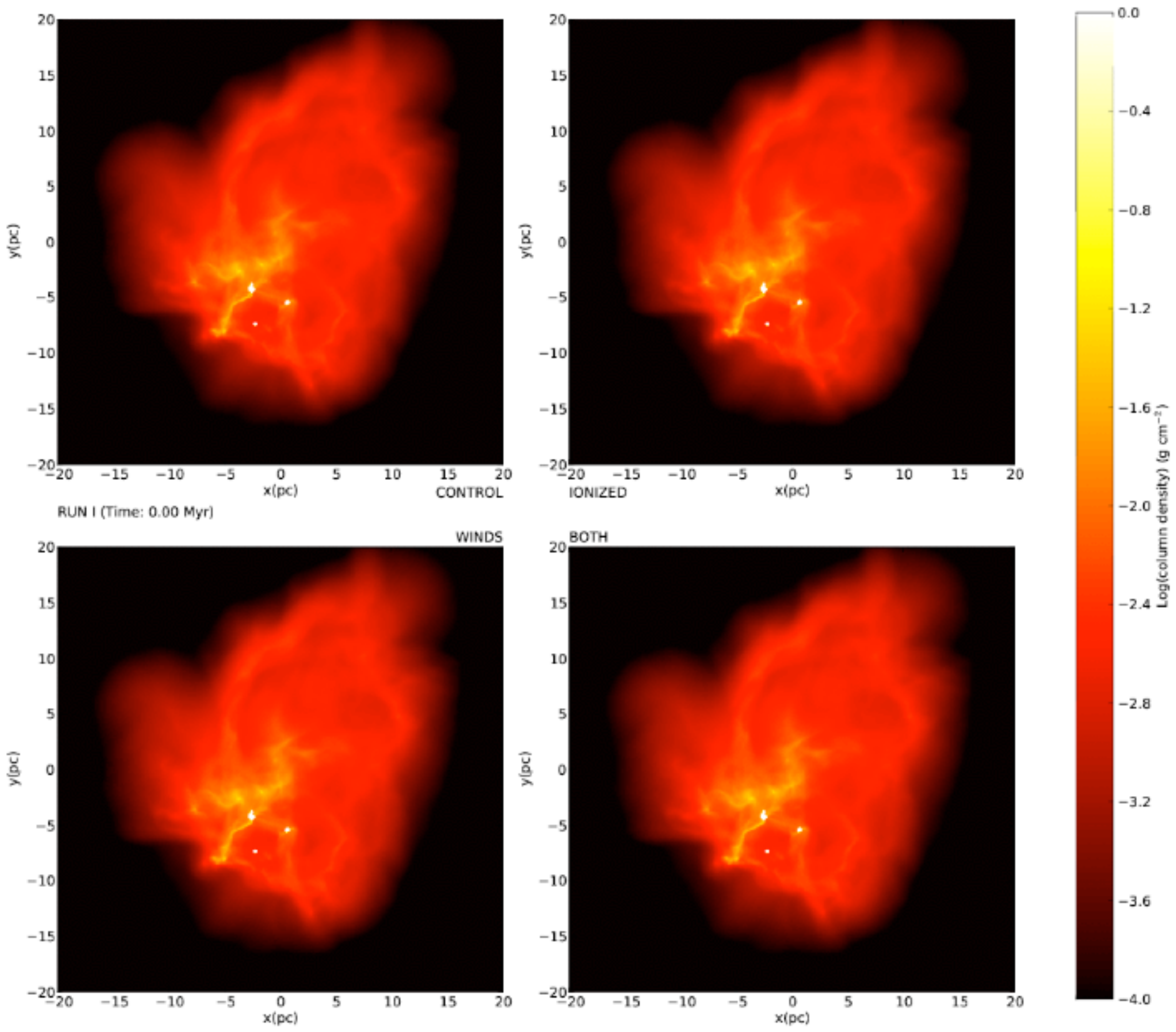


(1) winds help the HII regions a bit in unbinding clouds

(2) winds make cavities in HII regions (more realistic)

(3) ionization/winds can do 'substantial' damage to 10^4-$10^5 M_{\odot}$ clouds before SNe

(4) reduce SFE by <u>at most</u> 50%

SUMMARY - IN THESE MODELS:

- IONIZATION MORE IMPORTANT THAN WINDS

- IONIZATION/WINDS CAN DO 'SUBSTANTIAL' DAMAGE TO 10^4-$10^5 M_\odot$ CLOUDS BEFORE SNE

- THEY DON'T DO MUCH TO $10^6 M_\odot$ CLOUDS

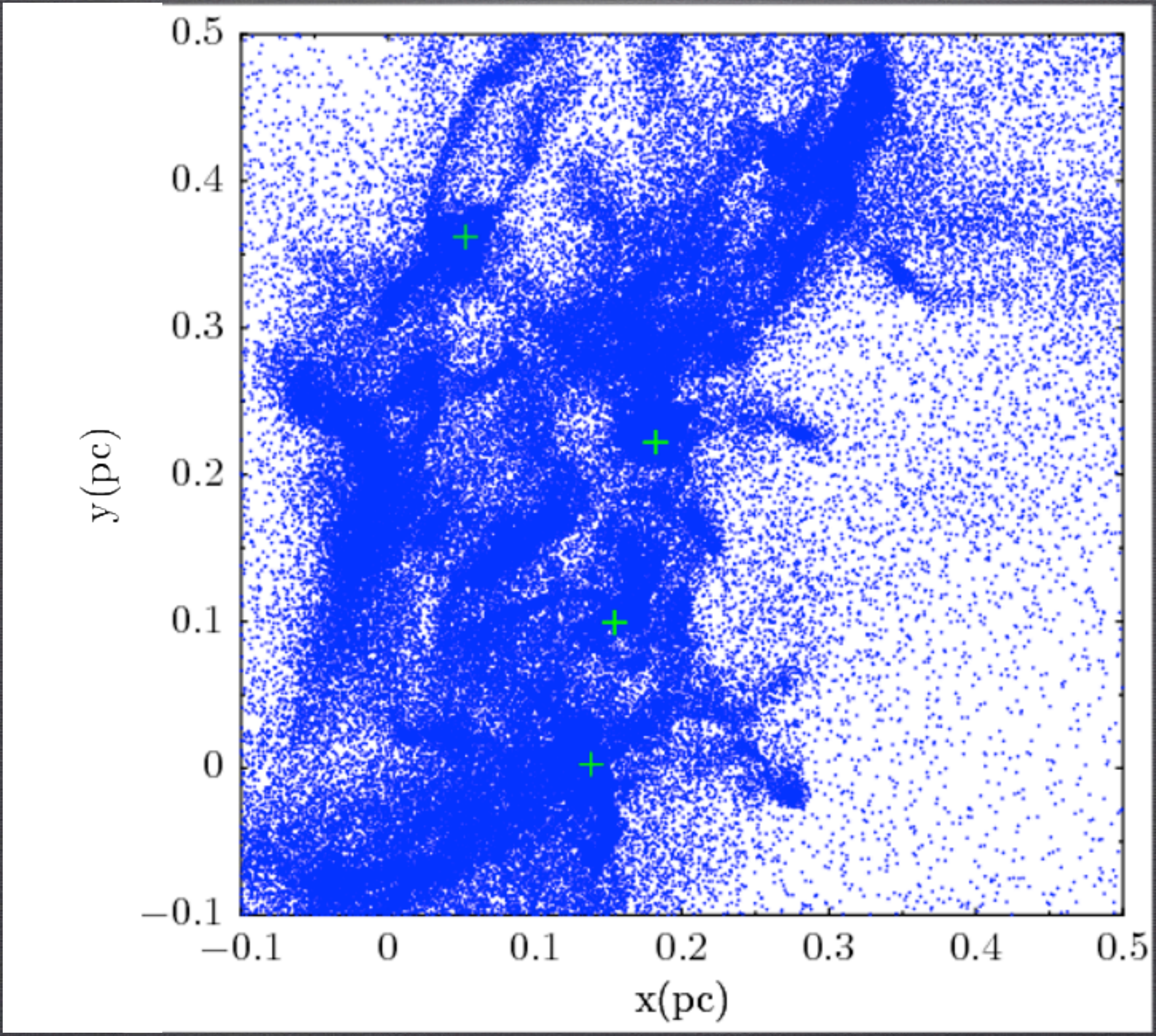
- THEY REDUCE SFE BY AT MOST 50% - SFES IN BOUND CLOUDS OFTEN >10% AFTER 3MYR

- TRIGGERING DOES OCCUR, BUT: LOCAL, SECOND-ORDER EFFECT, HARD TO CONFIRM

What next?

SNe - have now modelled how the clouds have been sculpted by other two types of feedback

This has drastically changed the environments in which the SNe explode



0.5
0.4
0.3
0.2
0.1
0
−0.1
y(pc)
−0.1
0
0.1
0.2
0.3
0.4
0.5
x(pc)