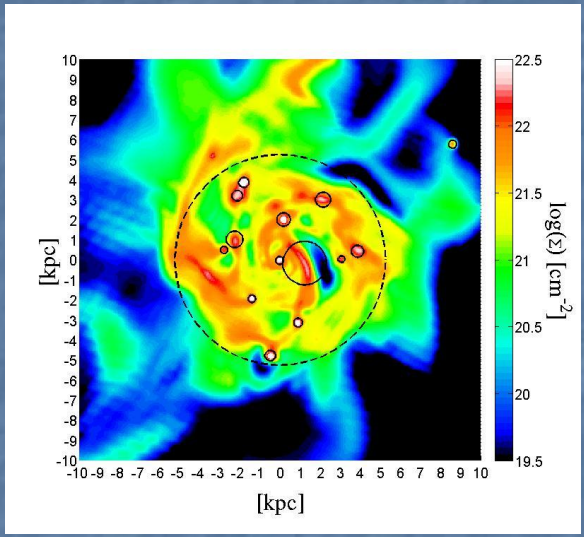
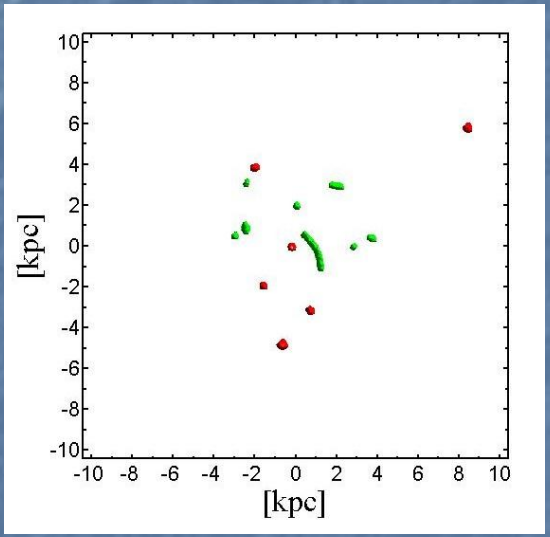
Clumps in the HART Simulations: Identification, Classification and Statistics





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Collaborators: Avishai Dekel, Daniel Ceverino, Dylan Tweed, Joel Primack

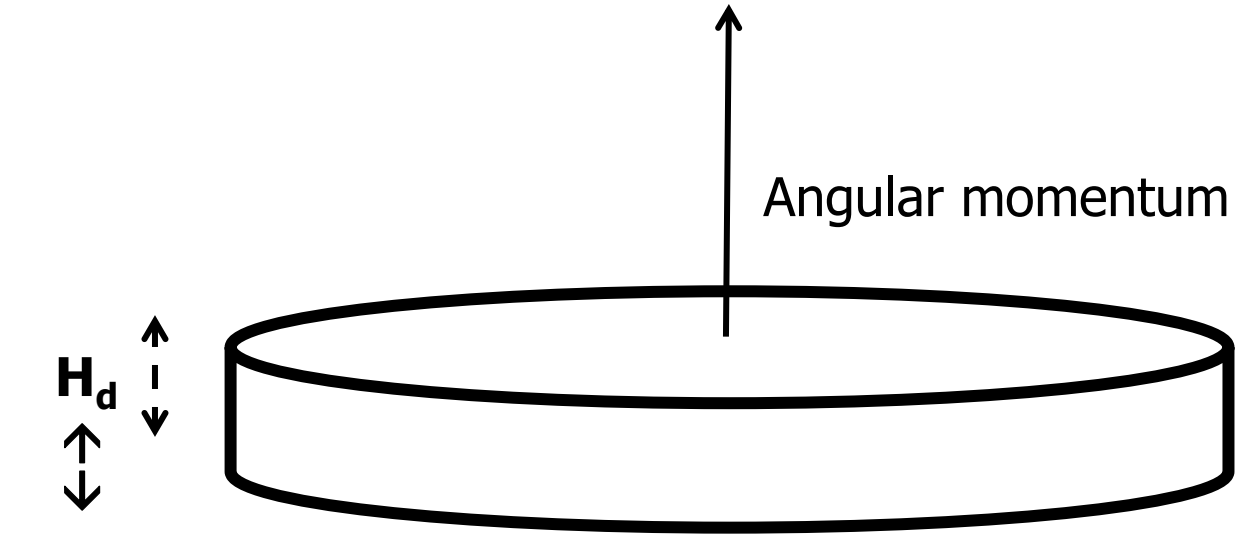
Introduction – What We Did and Why We Did It

- >750 snapshots from ~30 galaxies simulated with HART in the redshift range $1 \leq z \leq 4$
- We aim to identify clumps in **the 3-d gas distribution** and study their properties.
- Note: No attempt made (yet) to properly observe the images. (No dust!)

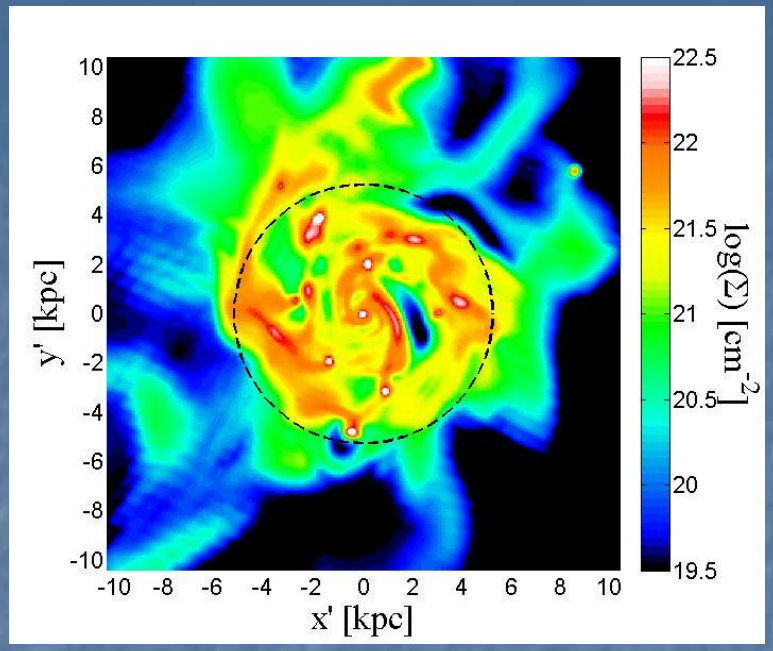
Why Bother?

- Can gain insight into the nature of instabilities in the theory plane
- Comparison of different populations of clumps found in gas / stars / H_α , in 3-d / 2-d, with / without dust
- First, simple step towards making observable predictions

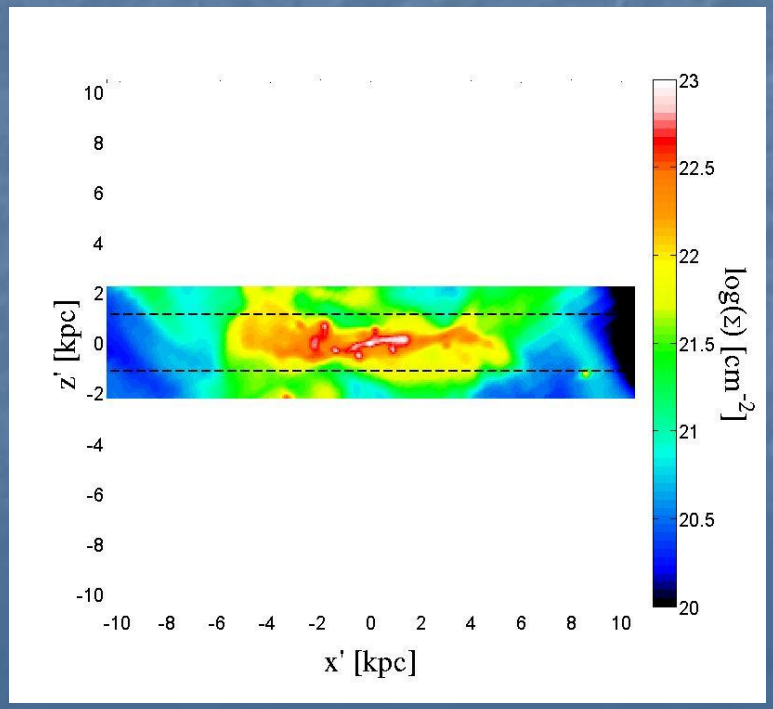
3d disc model

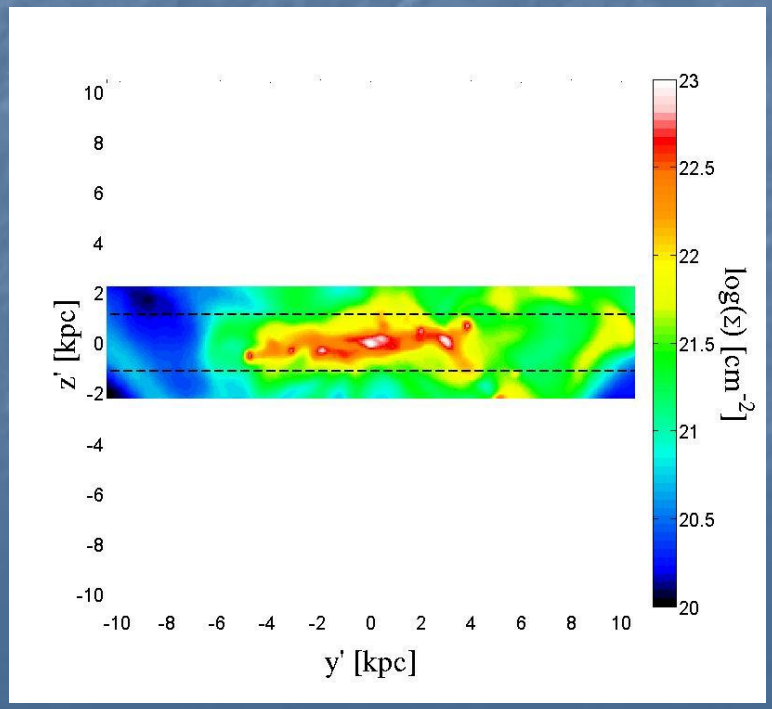


MW3
at z=2.3



We search for clumps in a box twice as large as the disc



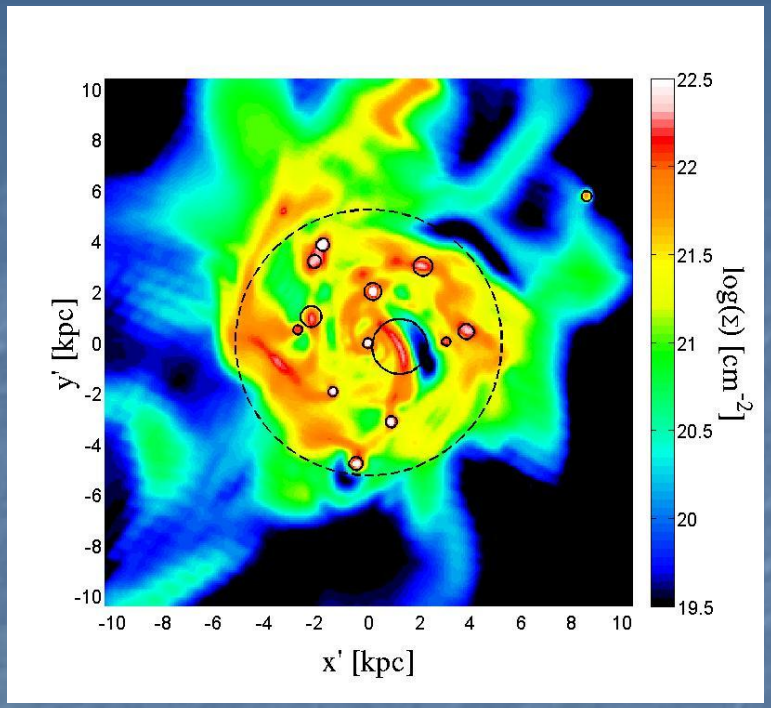


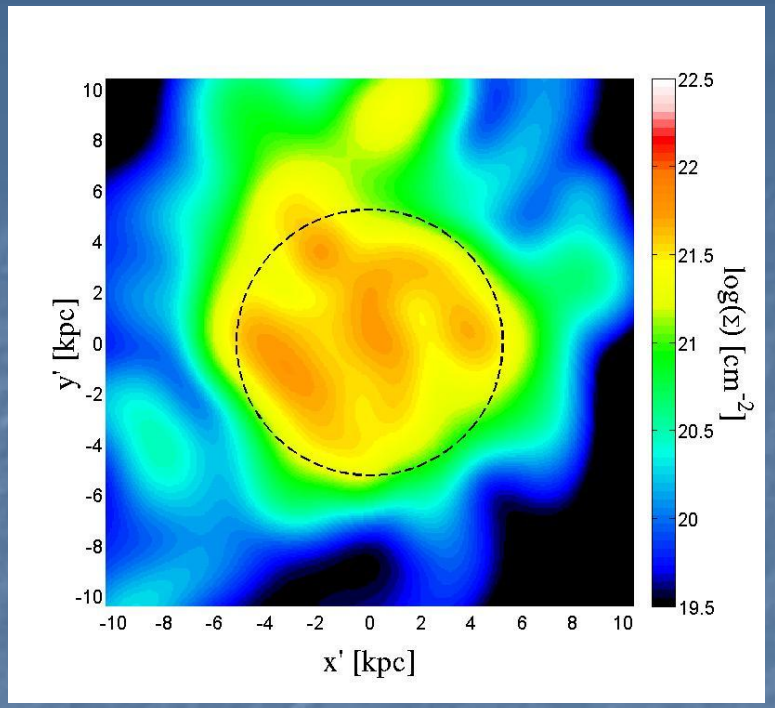
High Pass Filter

Smooth the density field on two different scales and calculate the residuals.

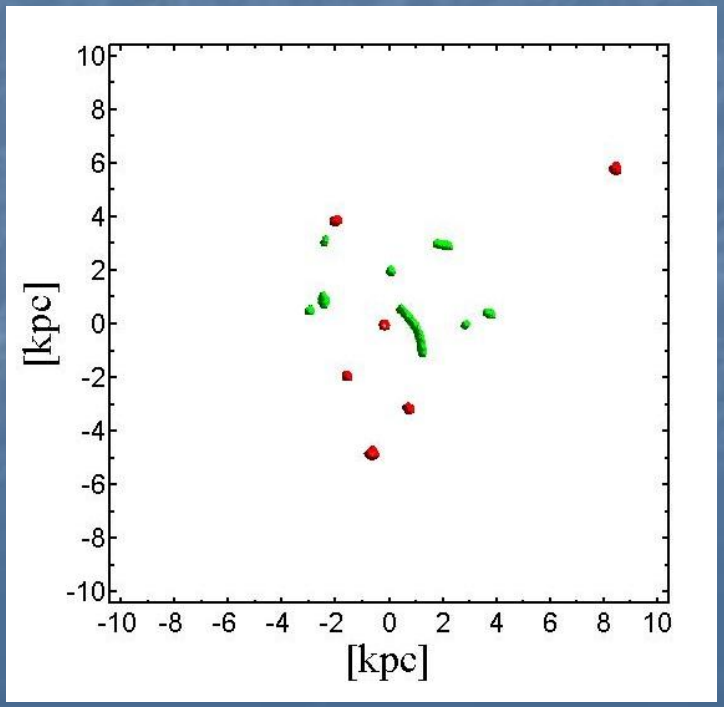
$$\delta_\rho = \frac{\rho_N - \rho_W}{\rho_W}$$

Locate regions above a threshold residual and above a minimum size.





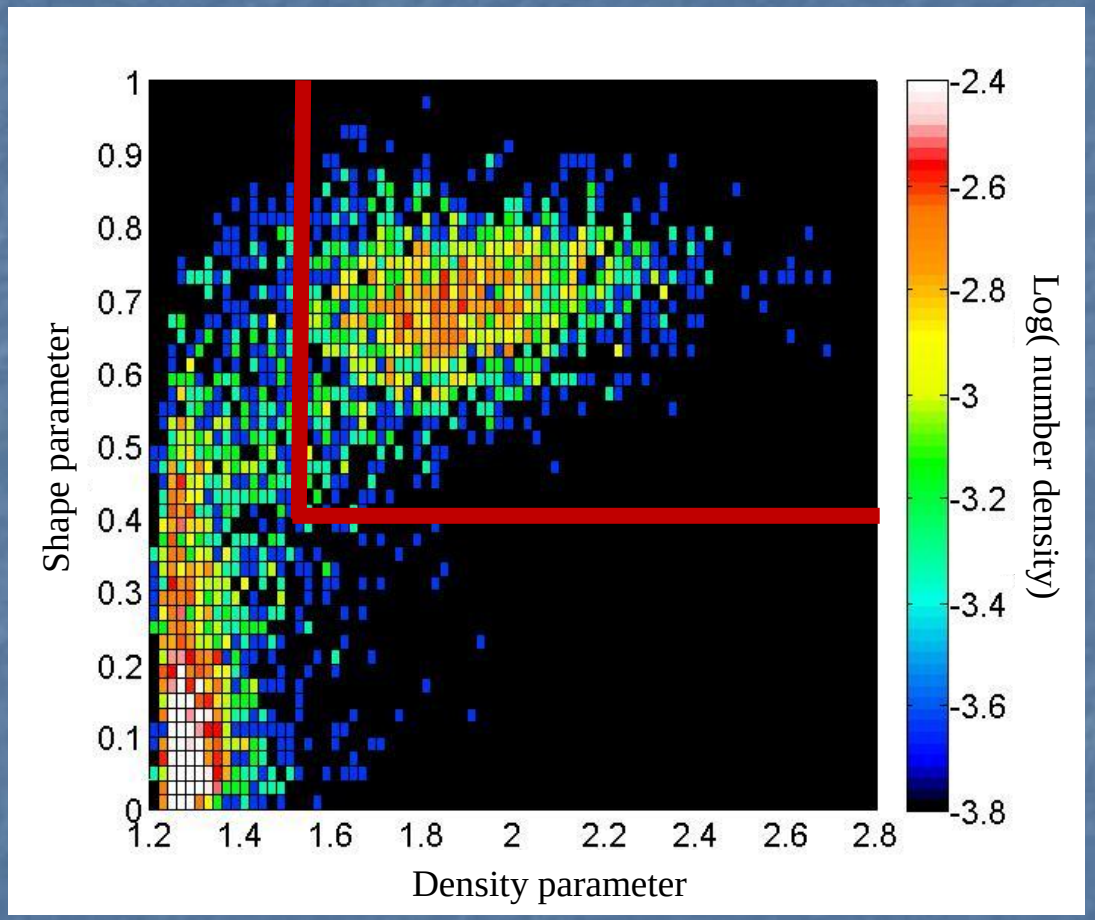
MW3
at z=2.3



Clumps Come in All Shapes and Sizes!

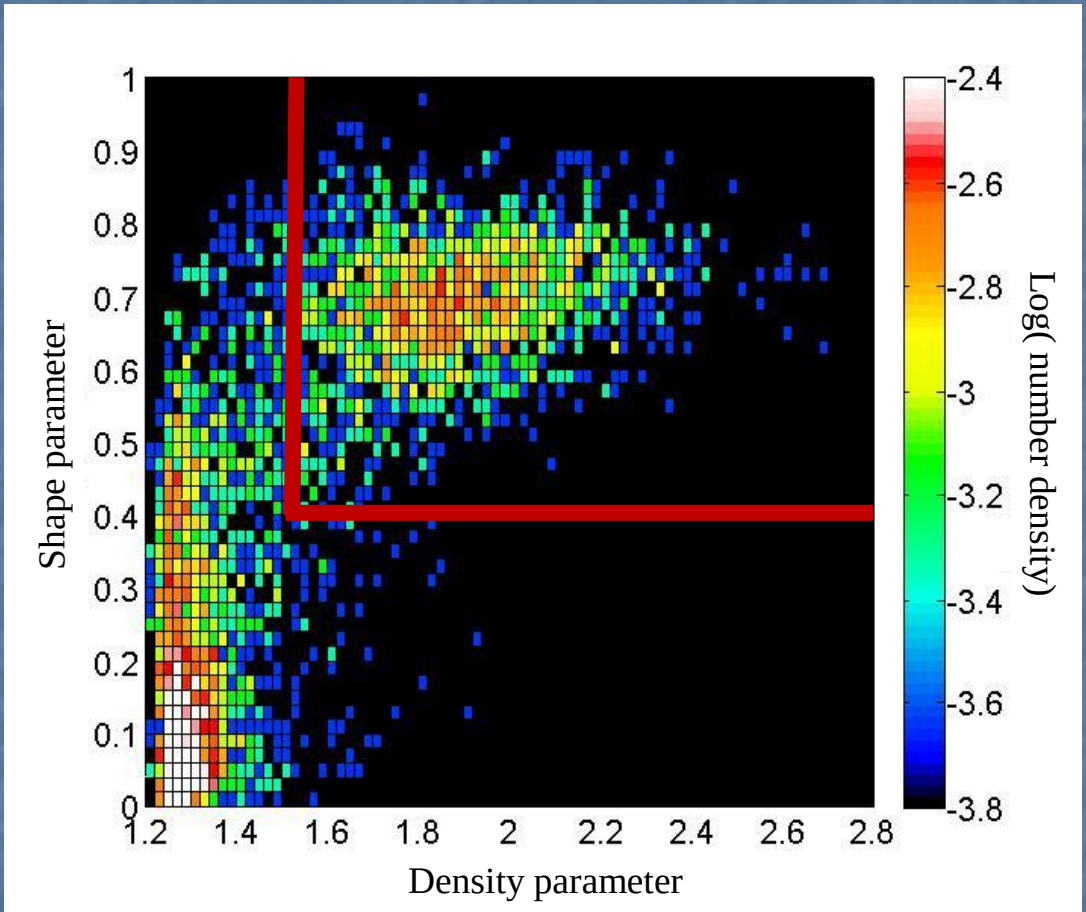
SPHERICAL

FILAMENTARY



HIGHER CONTRAST

Clumps Come in All Shapes and Sizes!



Diffuse or Elongated

Compact & Spherical

~ 45 % in number

> 90 % in mass

> 80 % in SFR

~ 2000 clumps

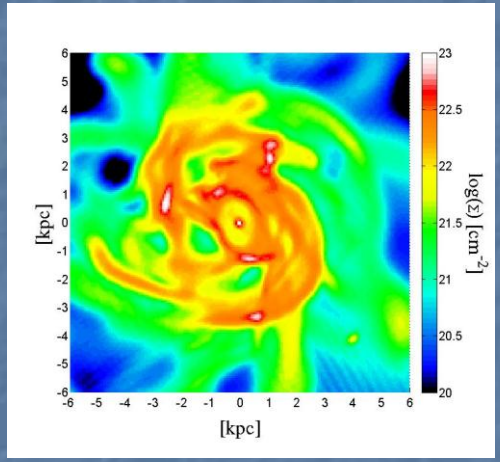
Bulge Clumps

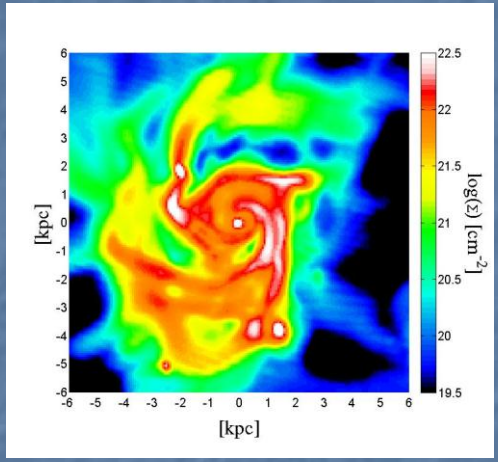
Nearly every galaxy has a clump at its center

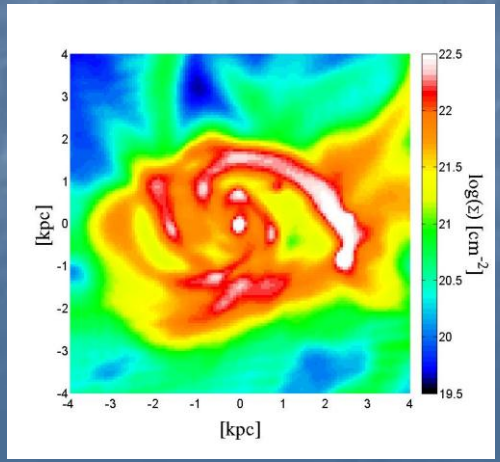
Peak of gas density distribution at galactic center

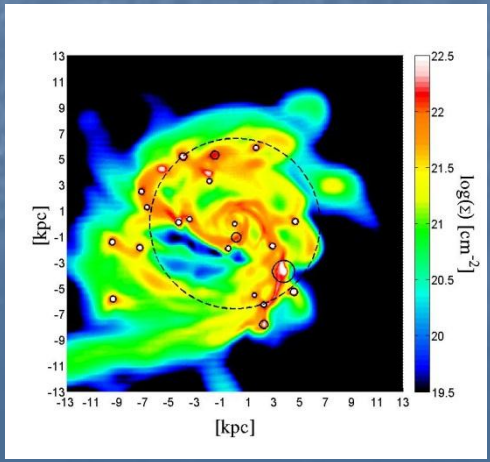
We denote these objects "*bulge clumps*"

NOTE: This is *not* the stellar bulge. It is a gas clump associated with and smaller than the bulge.









Off Center Clumps

~ 60% of our discs have off center clumps

Two possible origins for off center clumps:

- *In-Situ:* Clumps which formed internally through disc instability.
- *Ex-Situ:* Clumps which joined the disc as external minor mergers.

How Can We Distinguish Between Them?

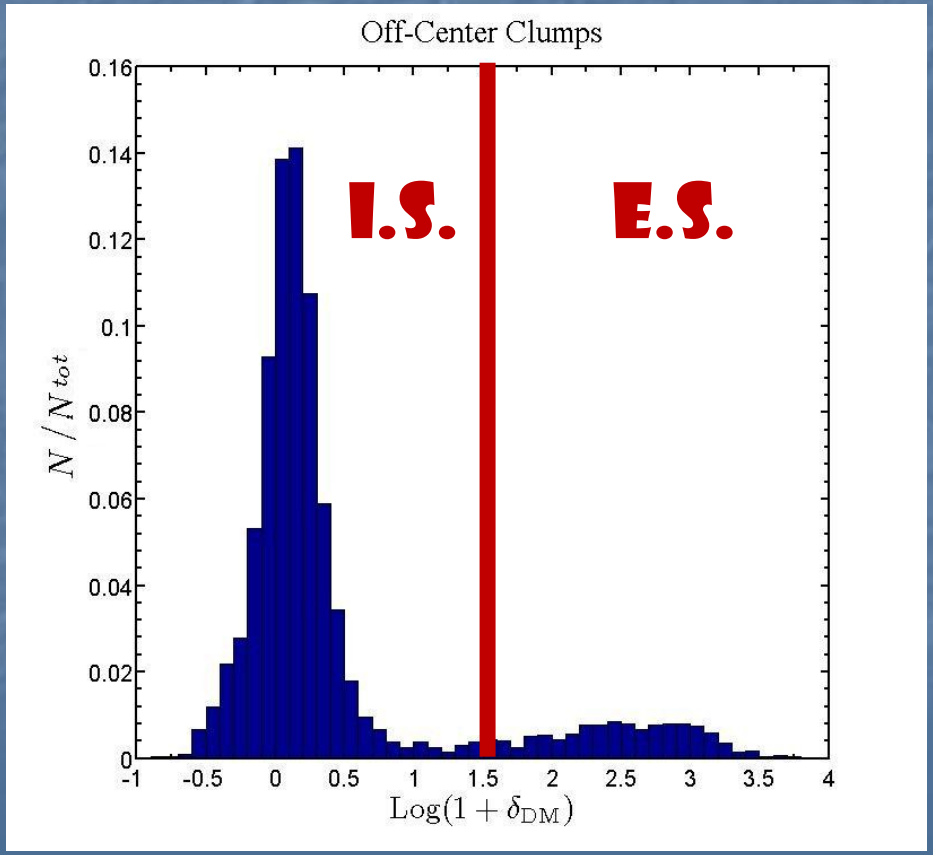
Ex-Situ (Es) Clumps

We examined 3 possible definitions for *Ex-Situ* clumps:

1. Dark Matter Contrast

2. Stellar population
Most of the mass is in stars which formed outside the disc

3. Kinematics
Clump velocity deviates from mean motion of local disc.

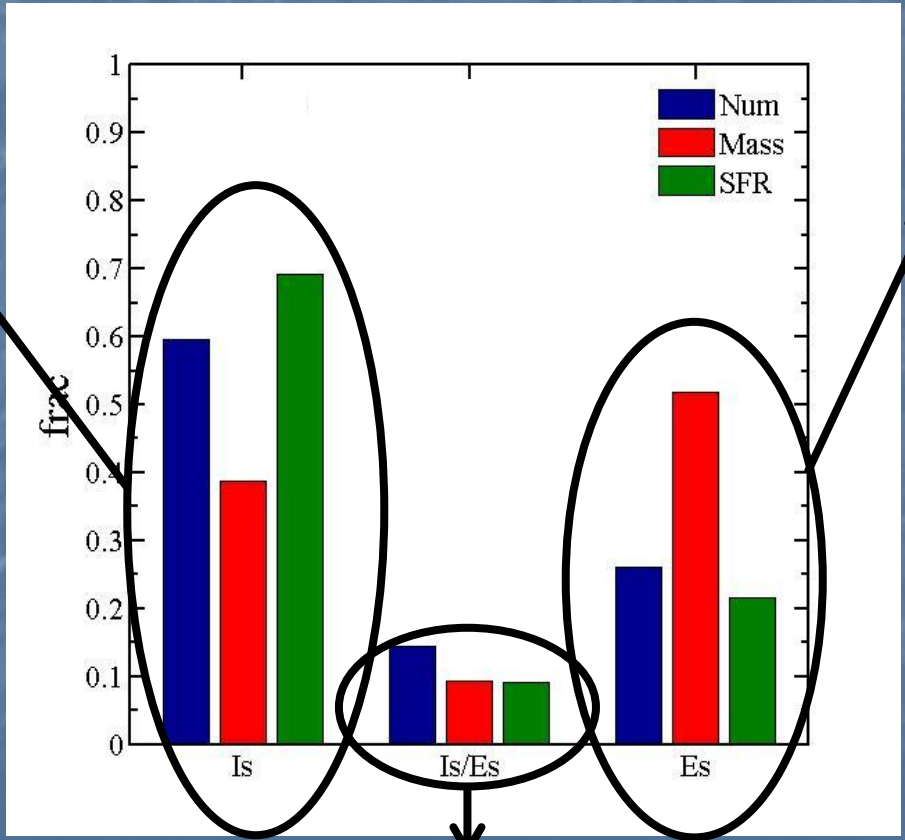


Census of Compact, Off Center Clumps

"Kosher" *in-situ* clumps, not obeying any *ex-situ* criterion

~ 2/3 in number and SFR

~ 40% of the mass



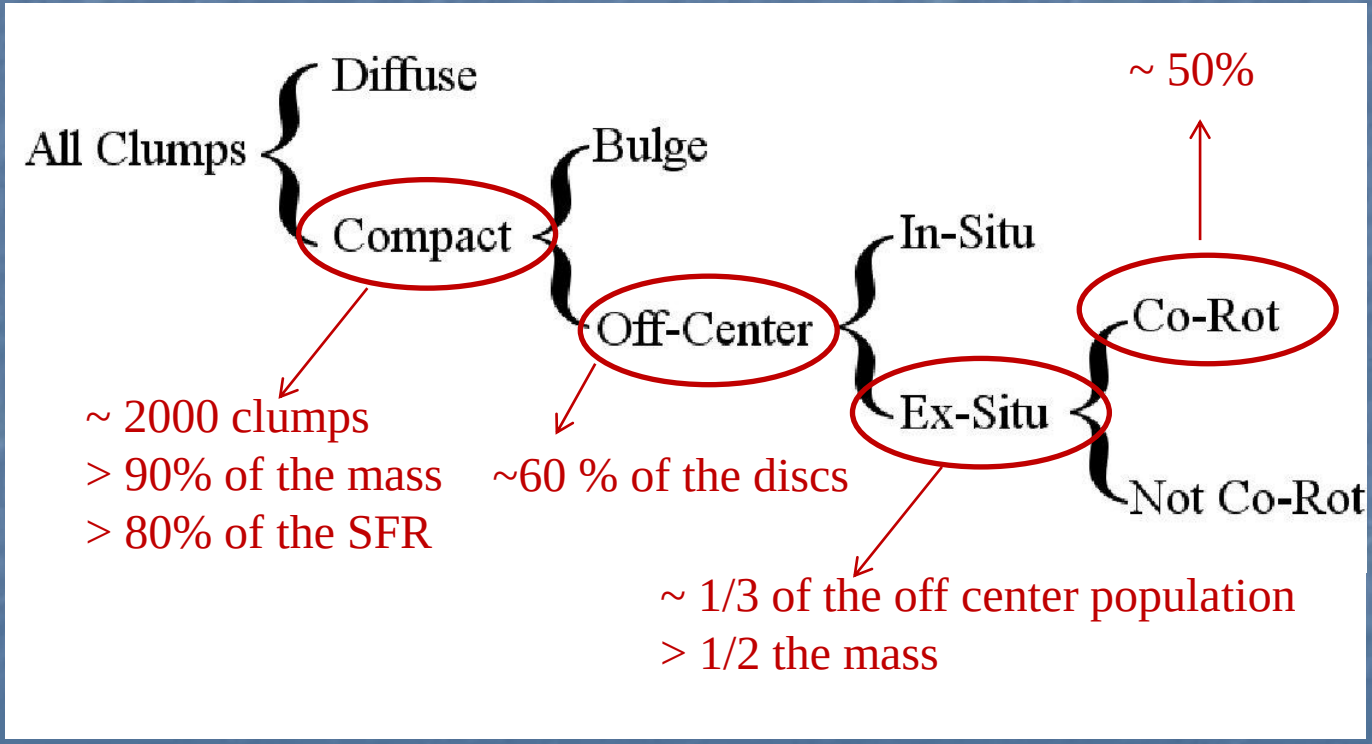
Ex-situ clumps with excess dark matter

~ 1/3 in number and SFR

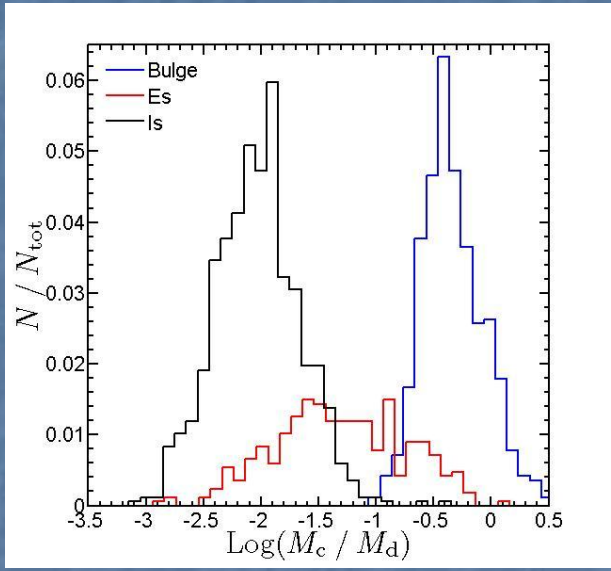
>1/2 the mass

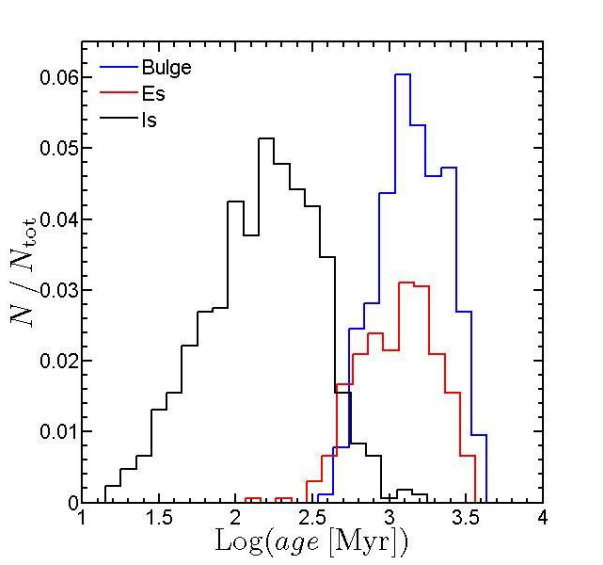
Without excess dark matter, but with external stars or kinematic deviations

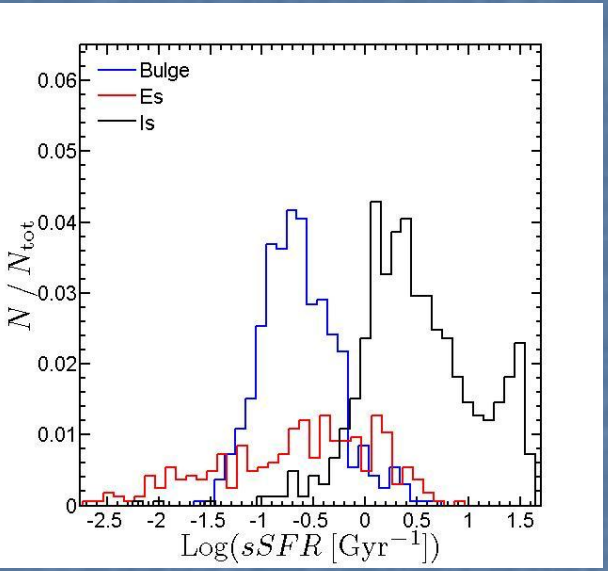
Clump Classification Summary



Distributions

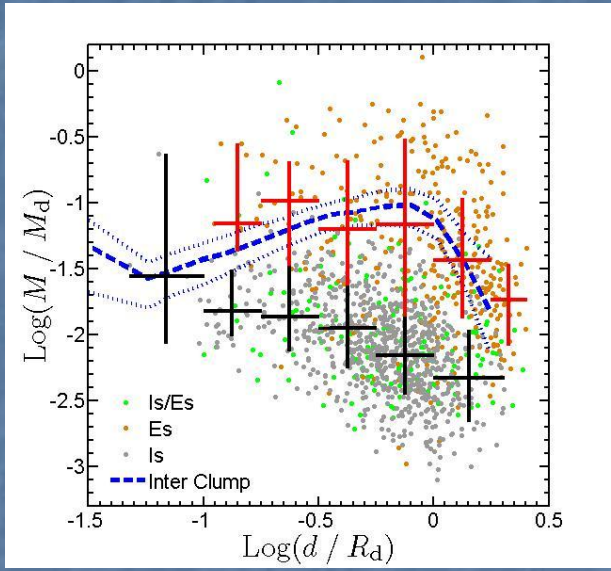


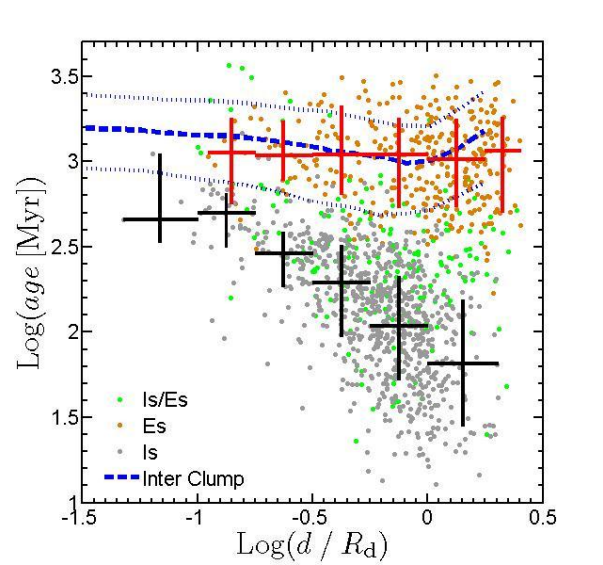


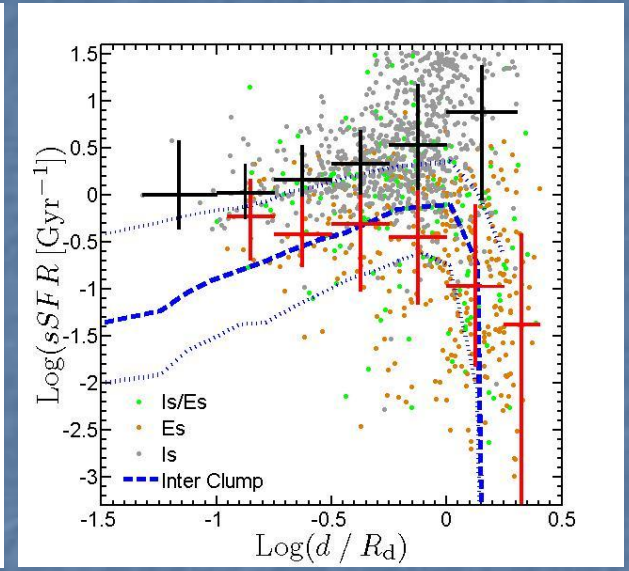


IN-SITU **CLUMPS ~ 1 - 2% OF THE DISC MASS**	**~ 150 - 300 MYR OLD (MIGRATION TIME)**	**HIGH SSFR (BLUE)**
EX-SITU **CLUMPS FACTOR ~ 2 - 4 MORE MASSIVE**	**AS OLD AS THE DISC ~ 1 GYR**	**CAN HAVE MUCH LOWER SSFR (REDDER)**
BULGE **CLUMPS FACTOR ~ 10 MORE MASSIVE**	**>1 GYR OLD**	**LOW SSFR (REDDER)**

Gradients







IN-SITU: **Closer to the disc center, clumps are more massive, older and with lower sSFR (i.e. redder).**
Age gradient much steeper than the background disc. Consistent with clump survival and migration.

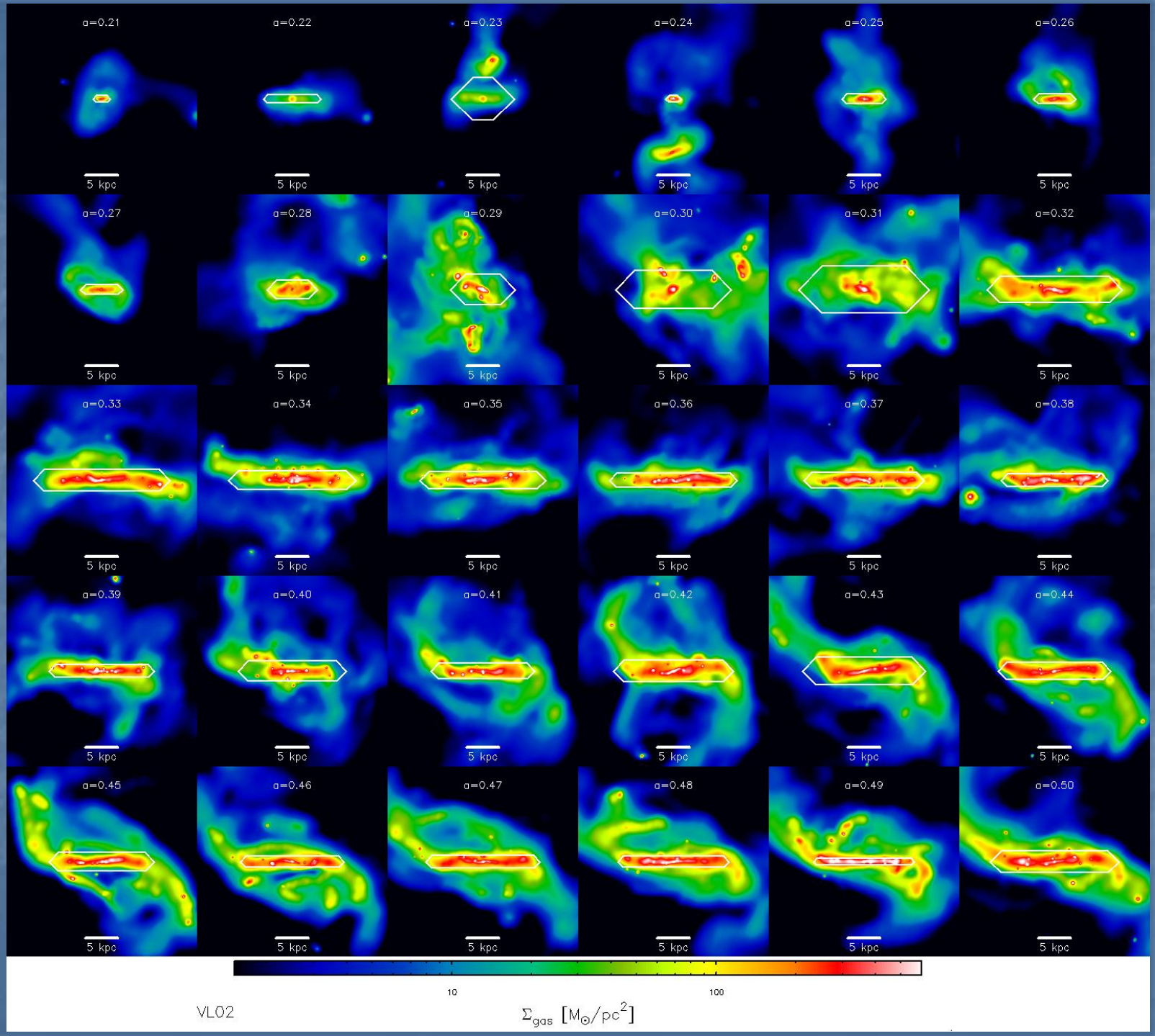
EX-SITU: **Gradients much weaker. Age and sSFR simillar to local disc → May hide overall clump gradient.**
Old clumps with low sSFR in the outer disc → *Ex-Situ*.

Summary and Conclusions

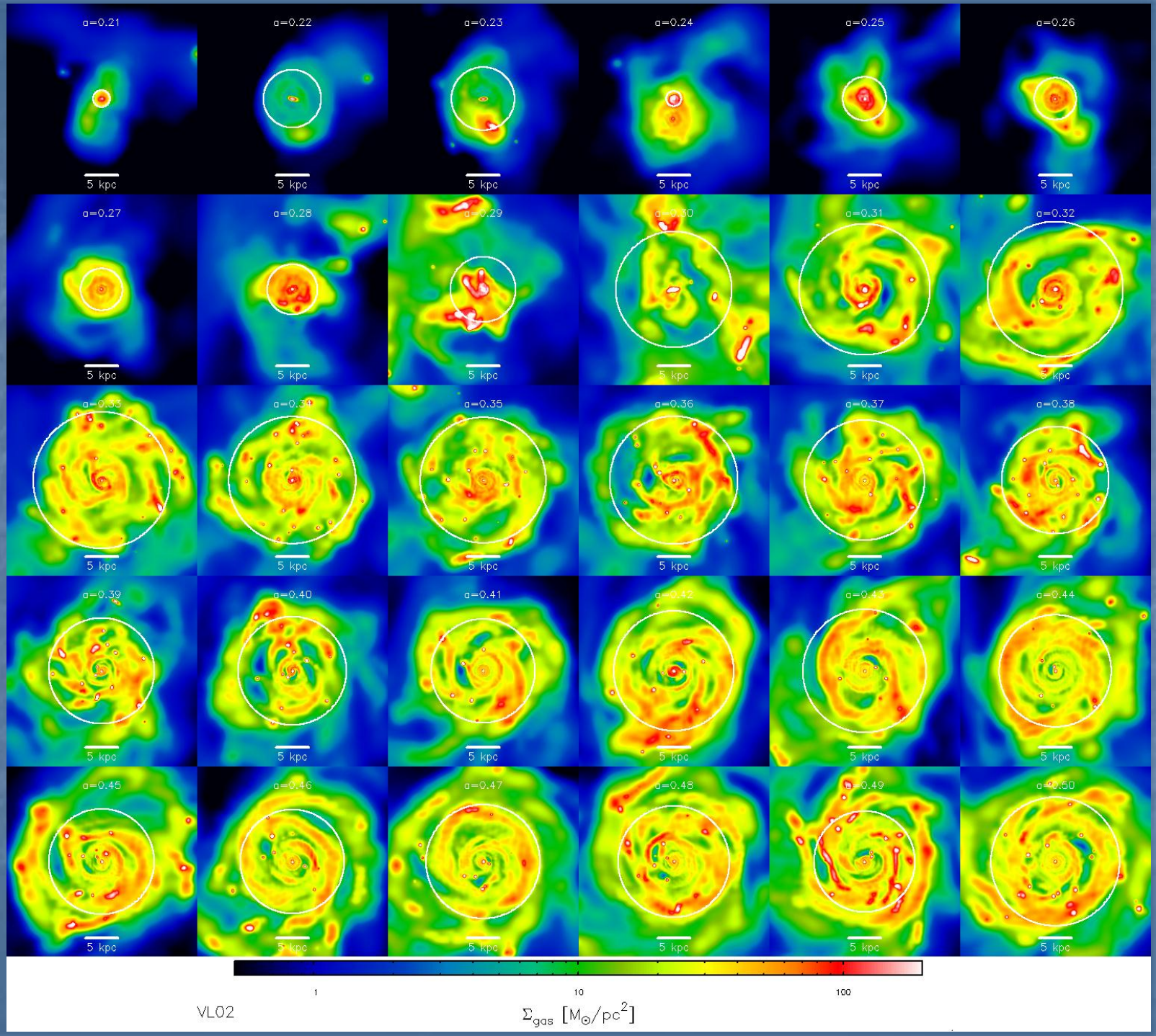
- > 750 snapshots, ~ 30 galaxies, $1 \leq z \leq 4$
- ~ 2000 compact, spherical clumps in the 3-d gas distribution
- ~ 60% of discs have off center clumps
- ~ 2/3 of the off center clumps formed *in-situ* while the remaining ~ 1/3 joined as mergers
- *In-situ* clumps are less massive, much younger and have higher sSFR (bluer), especially near the outer disc
- Gradients of *in-situ* clump age, mass, gas fraction consistent with clump survival and migration
- **Next Step:** Repeating the analysis in 2-d, after the images have been "CANDLE-ized"

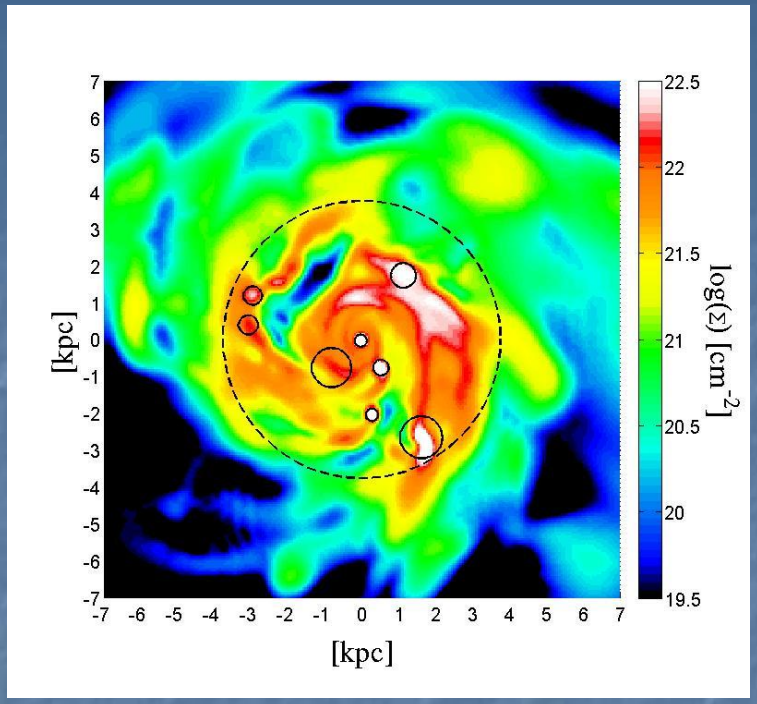
THANK YOU!!

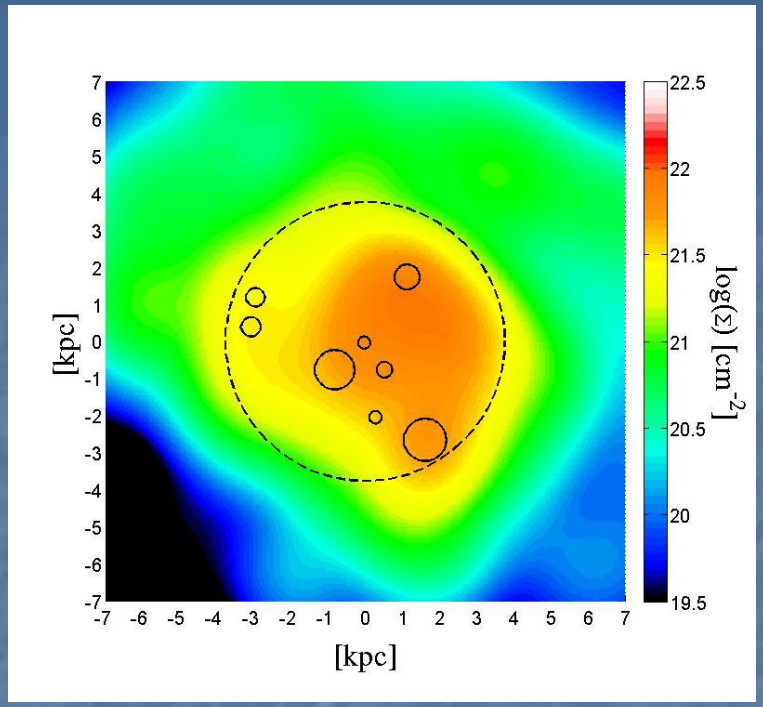
VL02 from z=3.8 to z=1



VL02 from z=3.8 to z=1




[kpc]
[kpc]
log(Σ) [cm^{-2}]
22.5
22
21.5
21
20.5
20
19.5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22.5
22
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21
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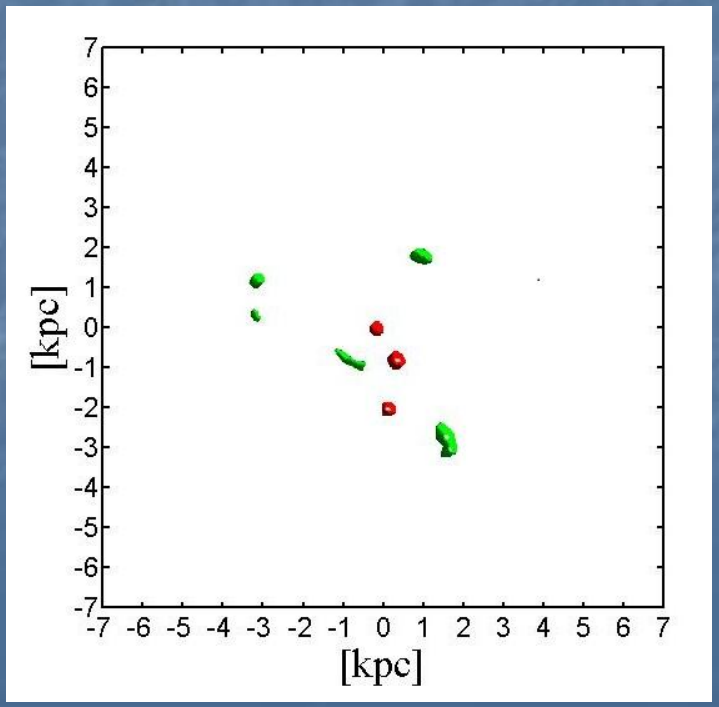
19.5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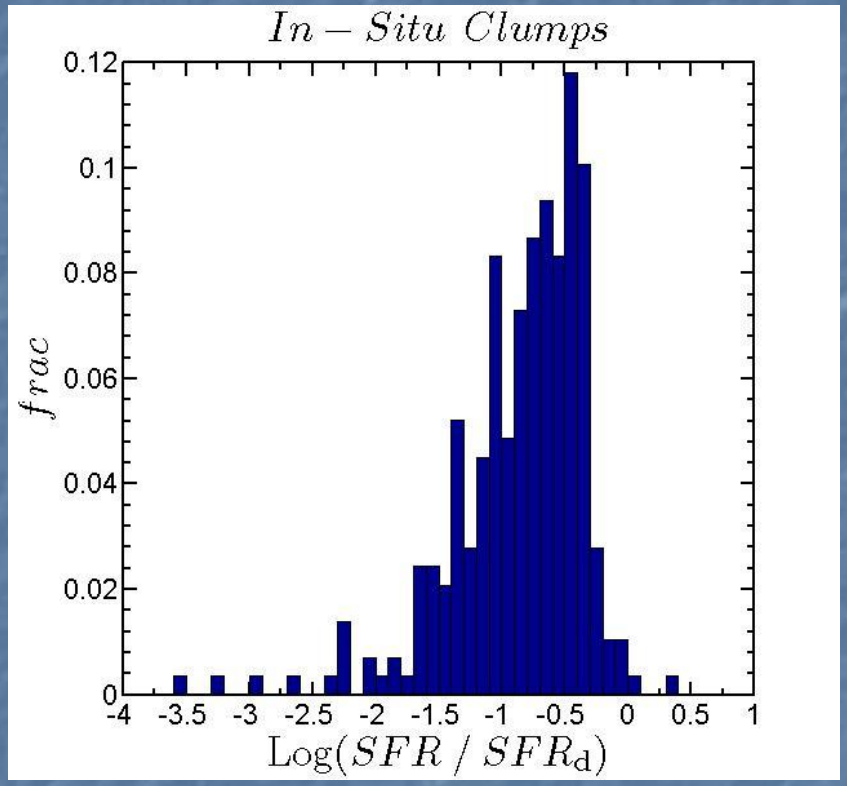
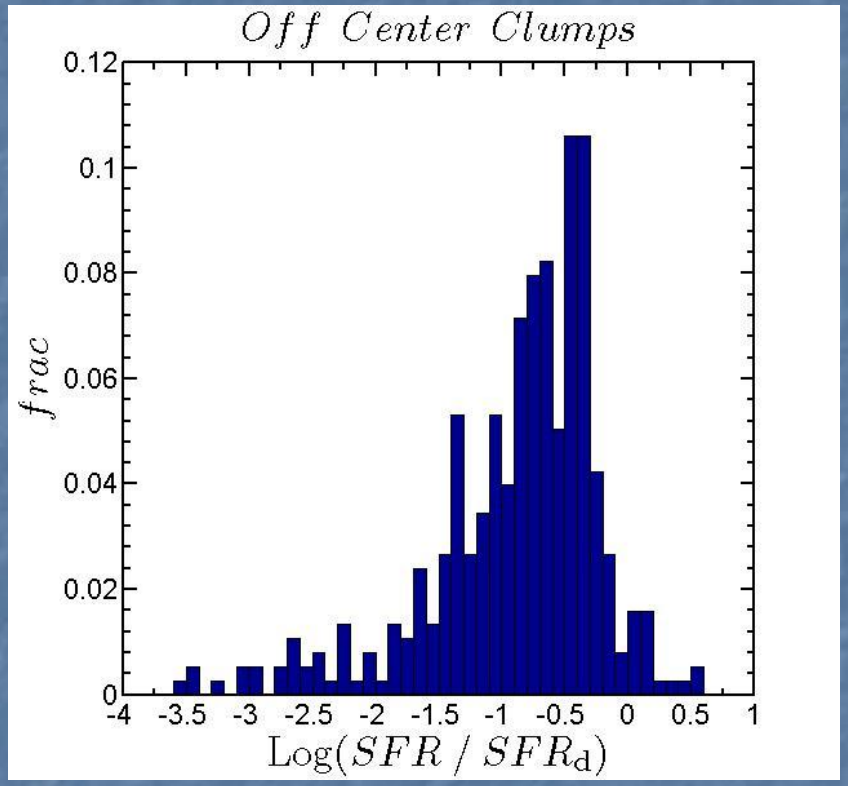
How Much SFR in Clumps?

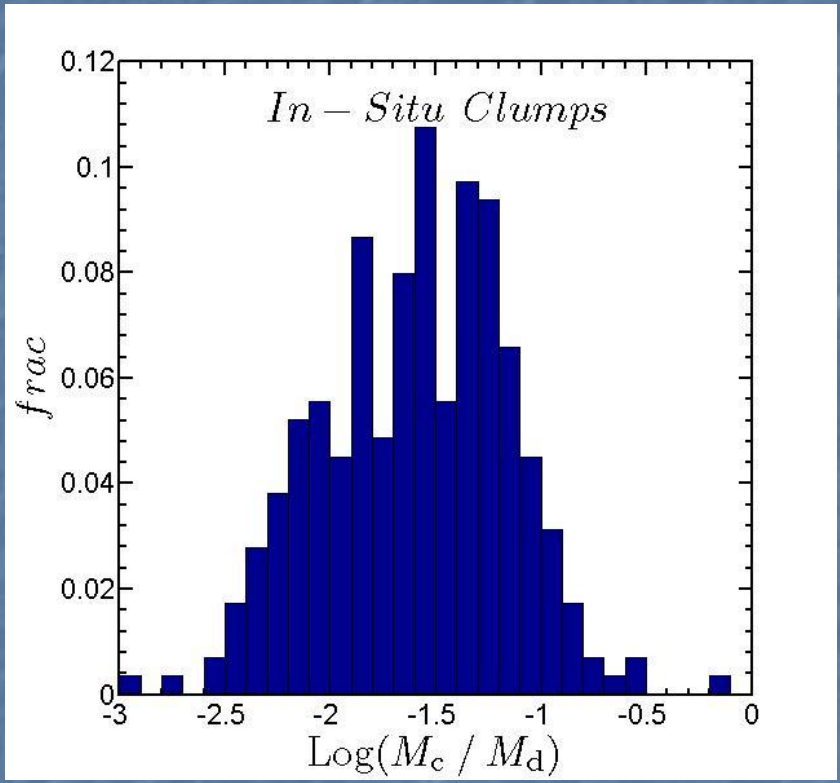


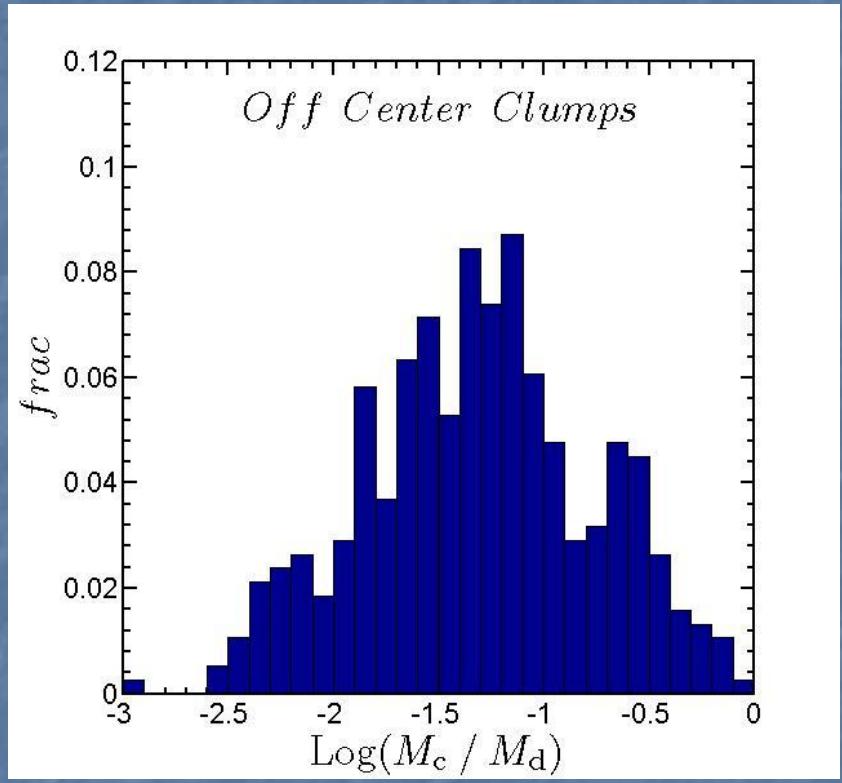


~ 30%

But observations would likely show higher values!

How Much mass in Clumps?

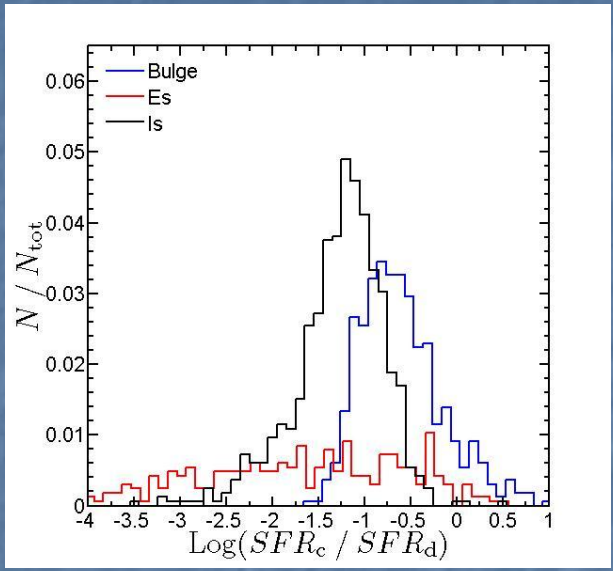


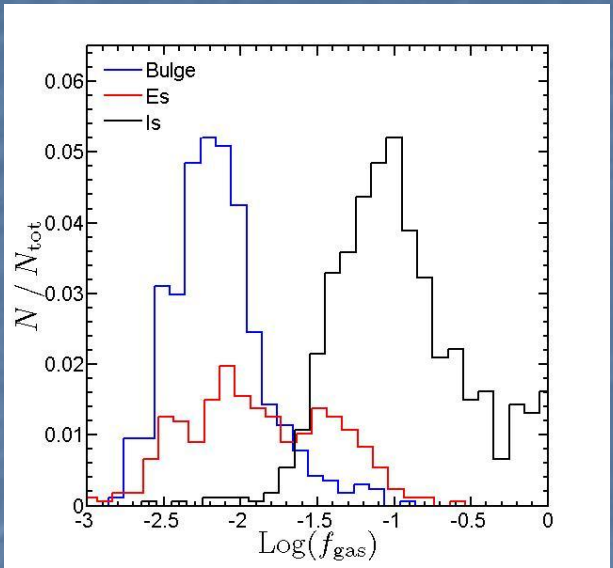


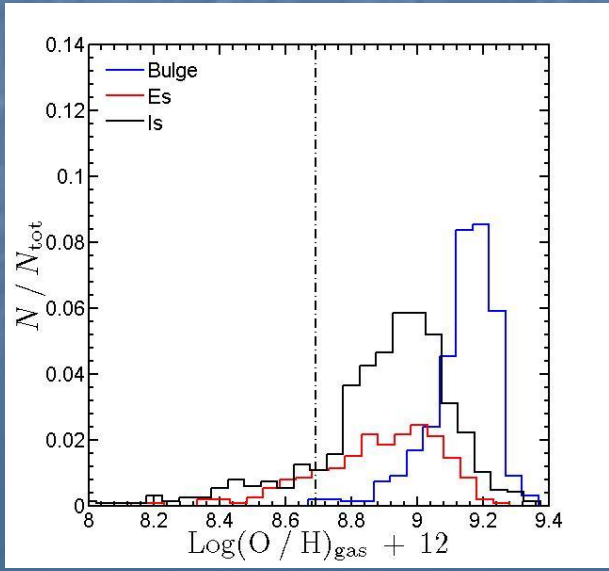
~ 5%

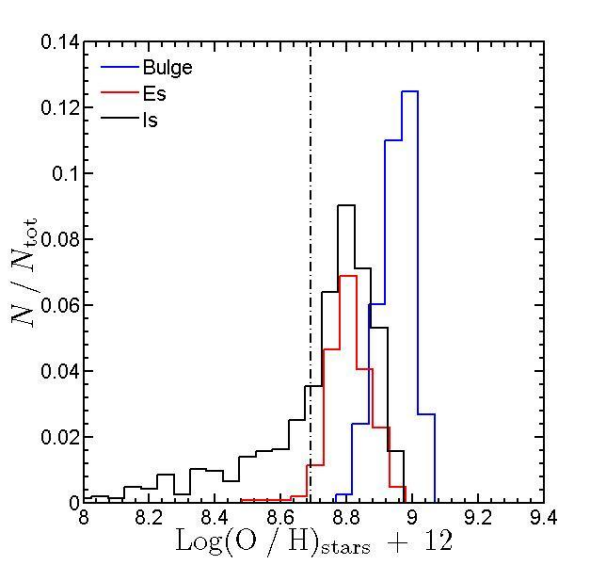
But observations would likely show higher values!

More Histograms









More Gradients