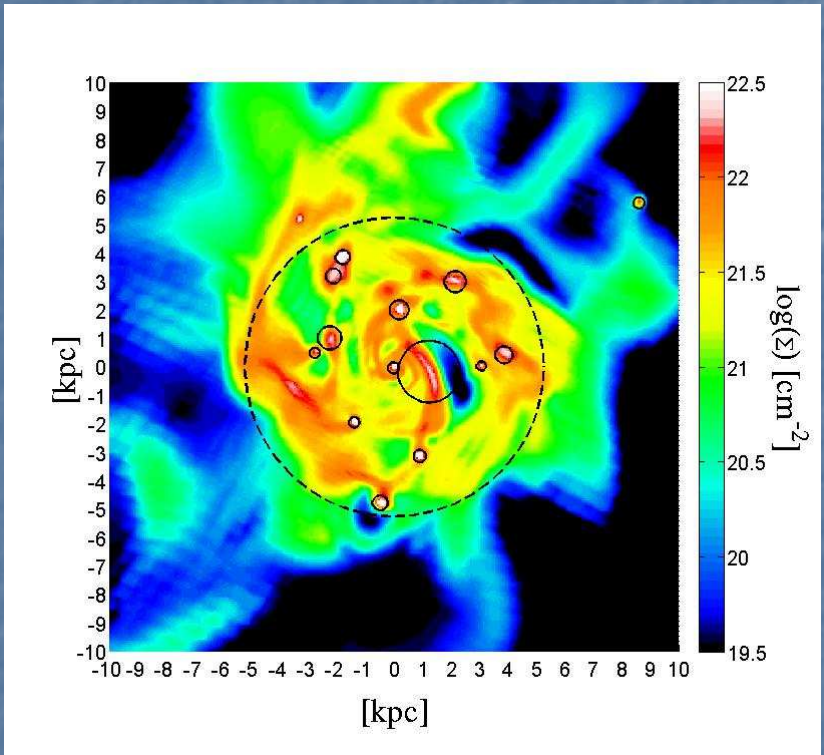
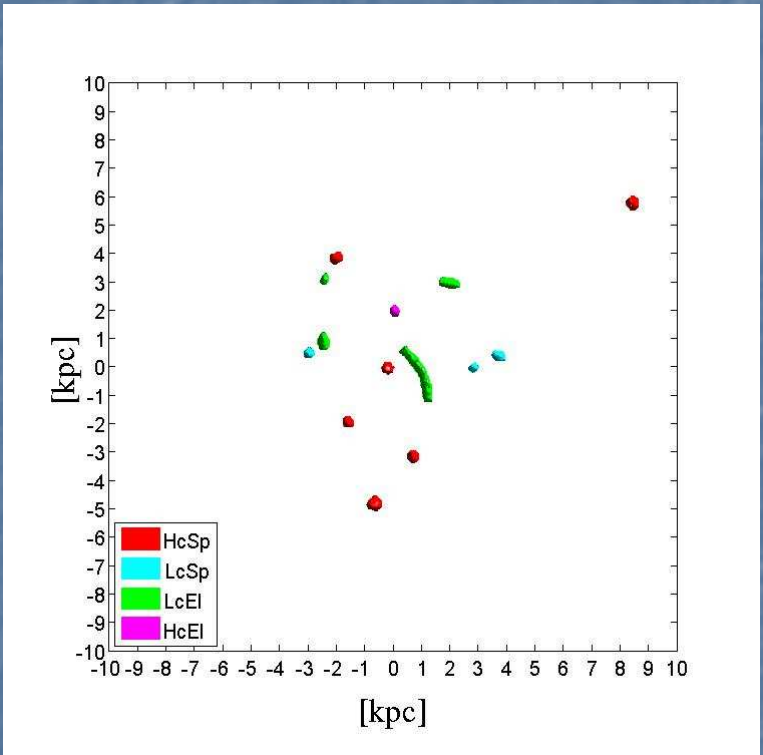
Clumps in the HART Simulations: Identification, Classification and Statistics





Nir Mandelker, H.U.J.I.

CANDLES Theory Workshop, 08.08.12

Collaborators

Avishai Dekel

Daniel Ceverino

Dylan Tweed

Joel Primack

Outline

- **Introduction:** What did we do and why did we do it?
- **Method:** How did we do it?
  - Identifying clumps in the simulations
  - Classification of clump types
- **A Few Results:** Statistics of clumps in the simulations (Stay tuned for next week's workshop!)

Introduction

- >750 snapshots from ~30 galaxies simulated with HART in the redshift range $4 \geq z \geq 1$

- We aim to identify clumps in **the 3-d gas distribution** and study their properties.

IMPORTANT!

- NO attempt made (yet) to "CANDLE-ize" the images and observe them. (No dust!)

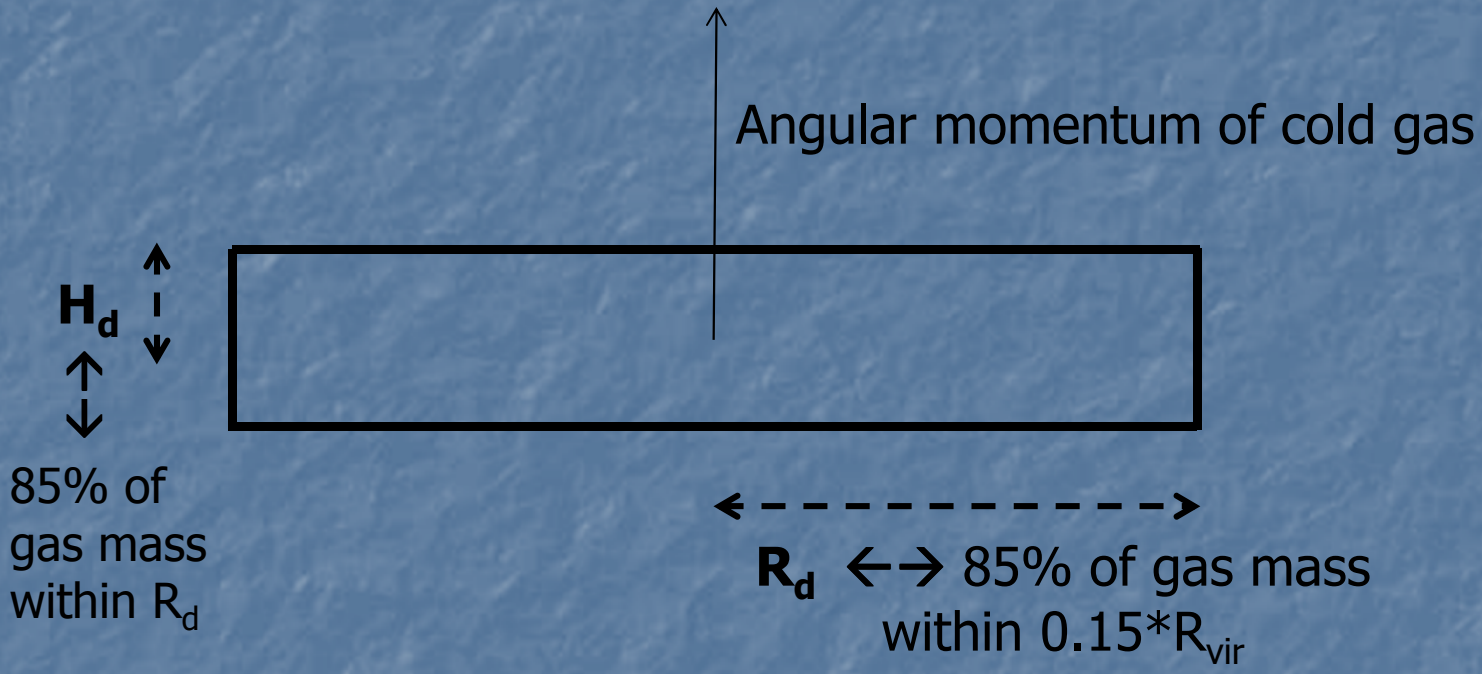
- The study is preformed entirely on the *raw, 3-d* data.

FIRST STEP!

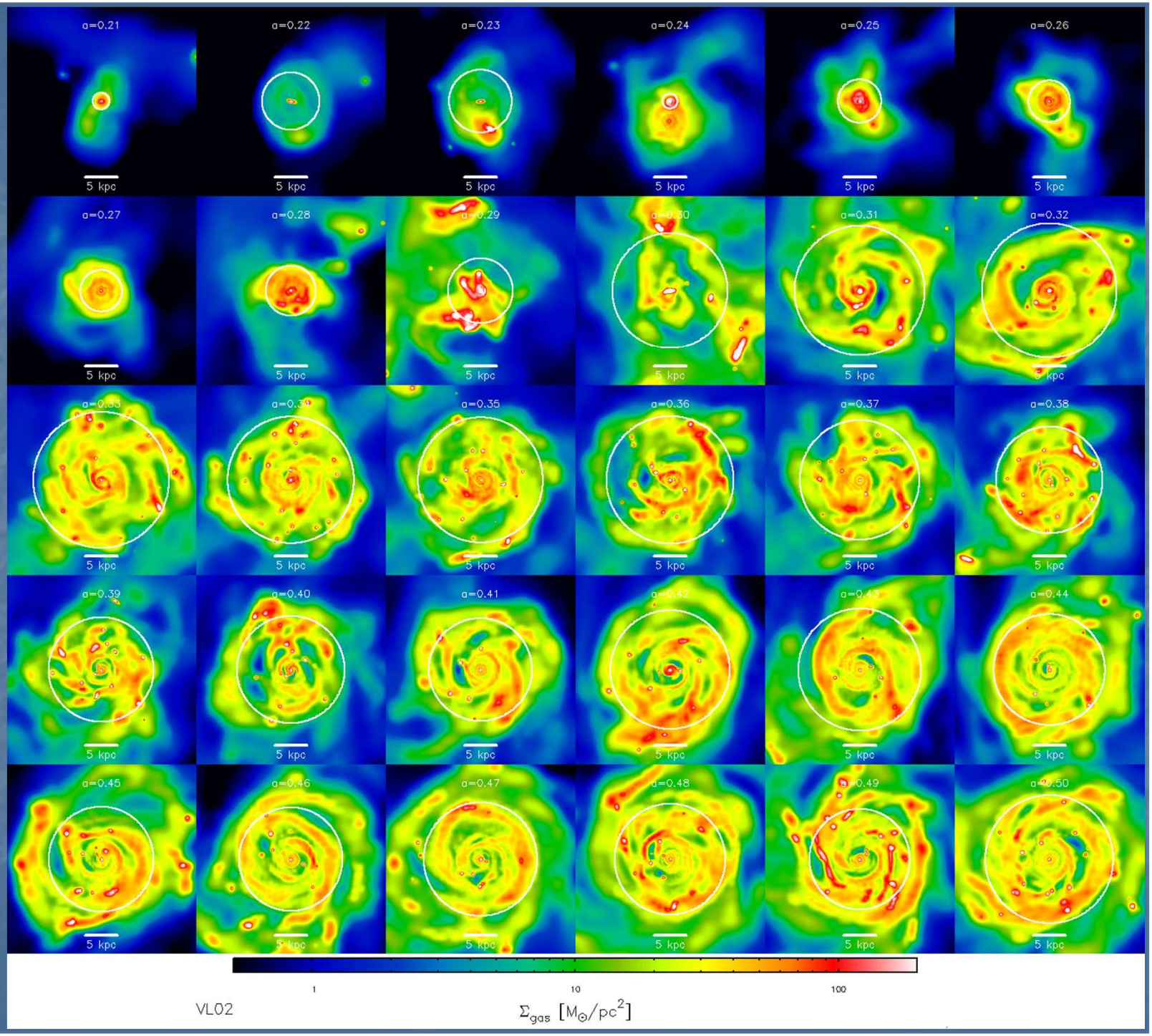
Why Bother?

- 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

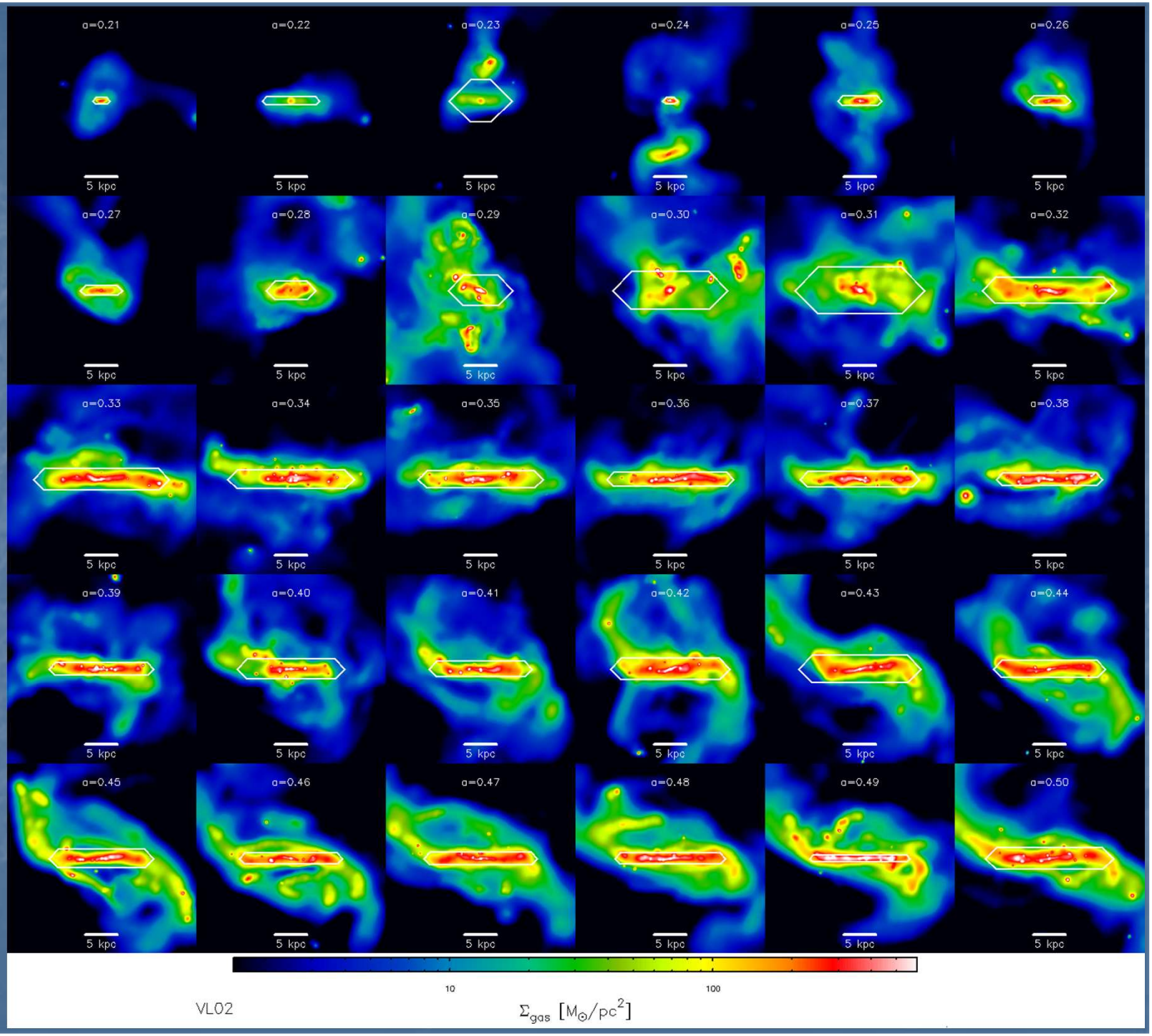
Step I – Define the disc



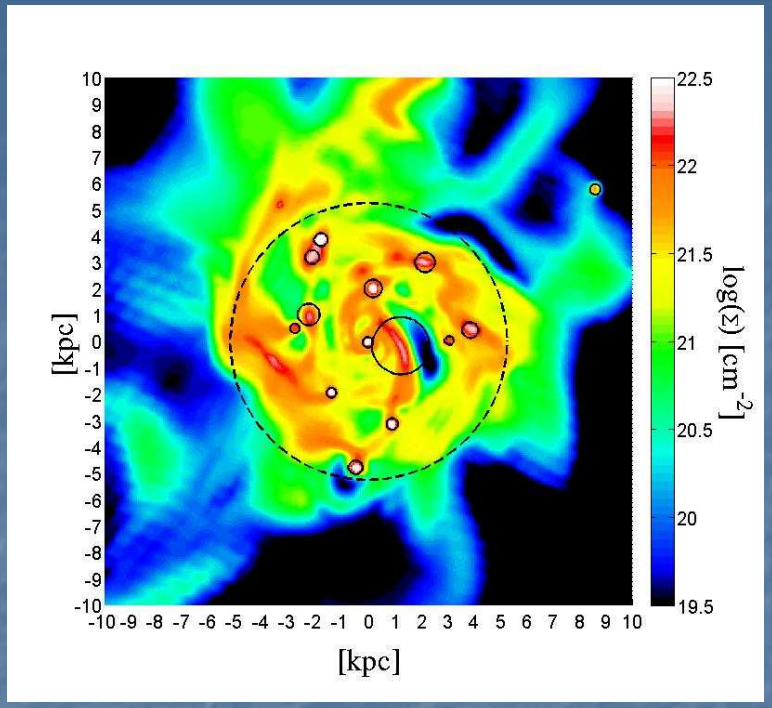
VL02 from z=3.8 to z=1



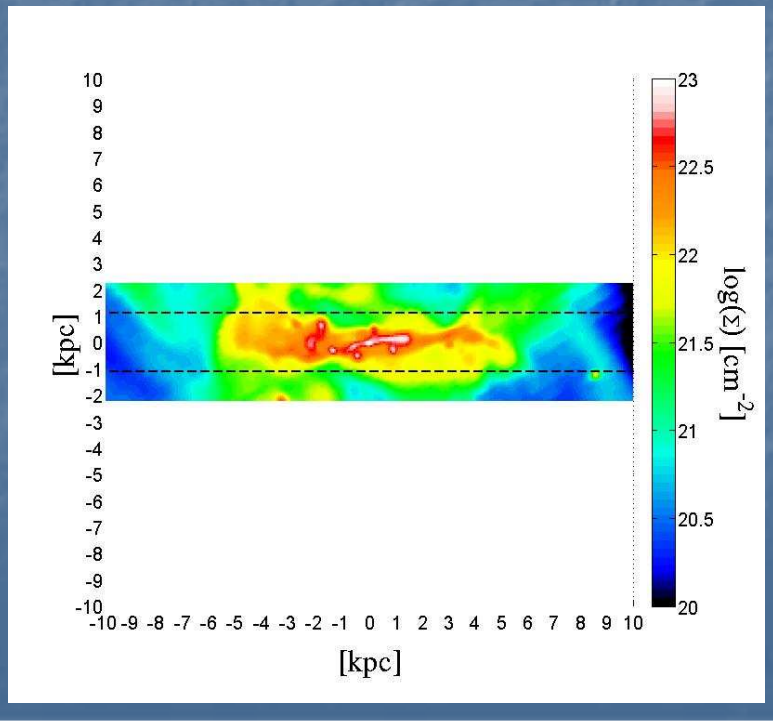
VL02 from z=3.8 to z=1

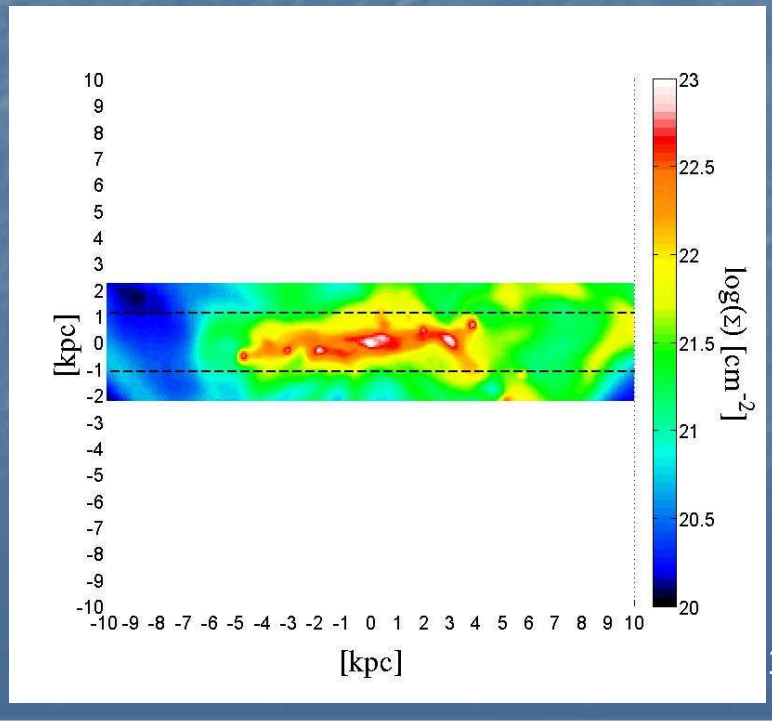


MW3
at z=2.3



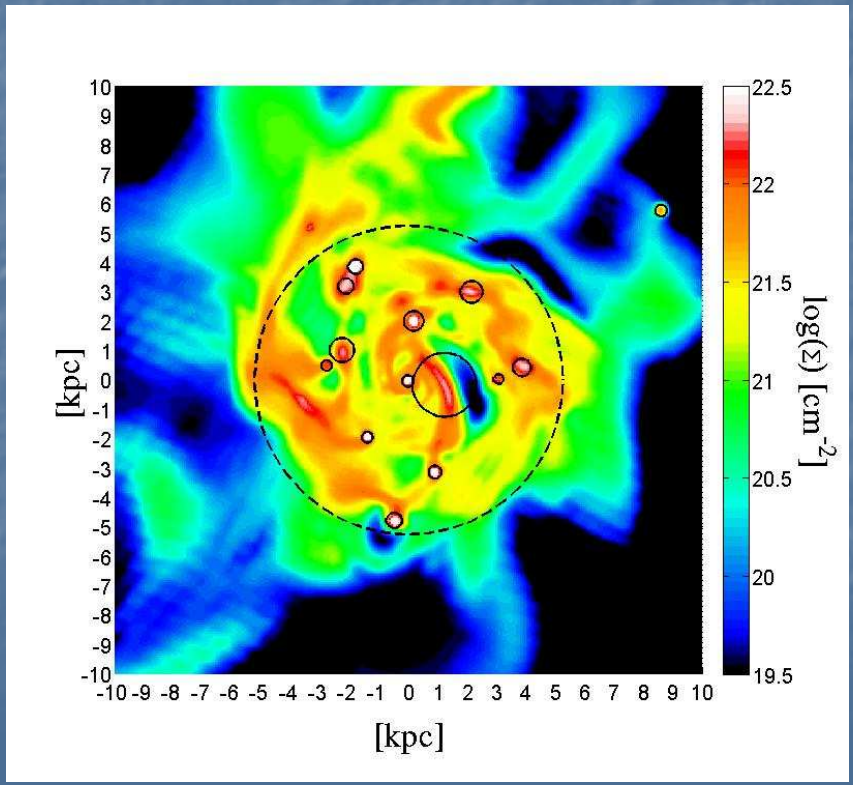
We search for clumps in a box twice as large as the measured disc

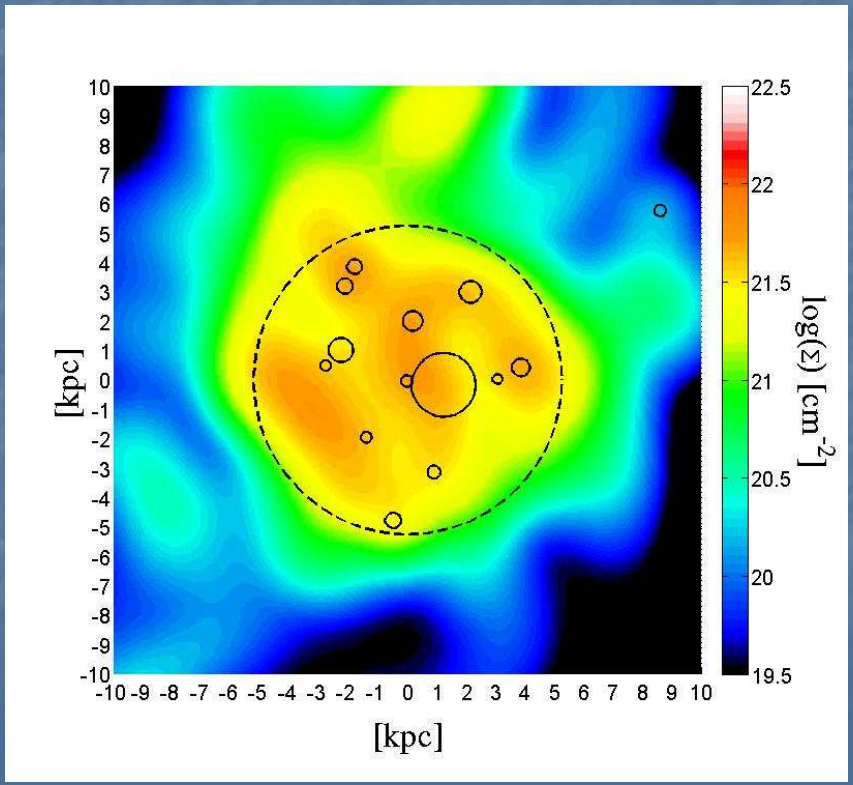




Step II – High Pass Filter

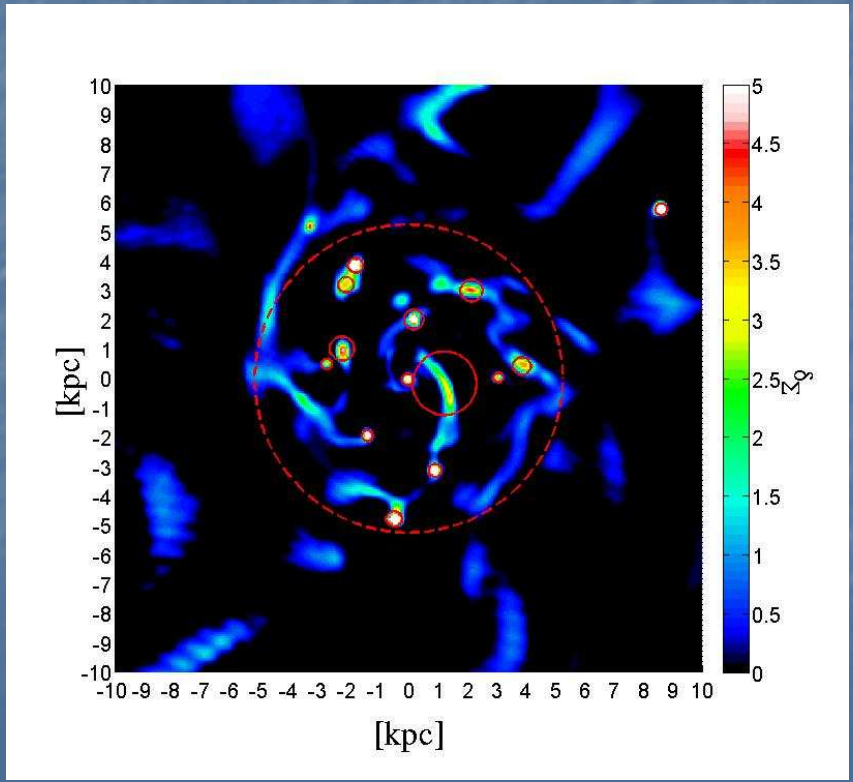
Smooth the density field on two different scales and calculate the residuals

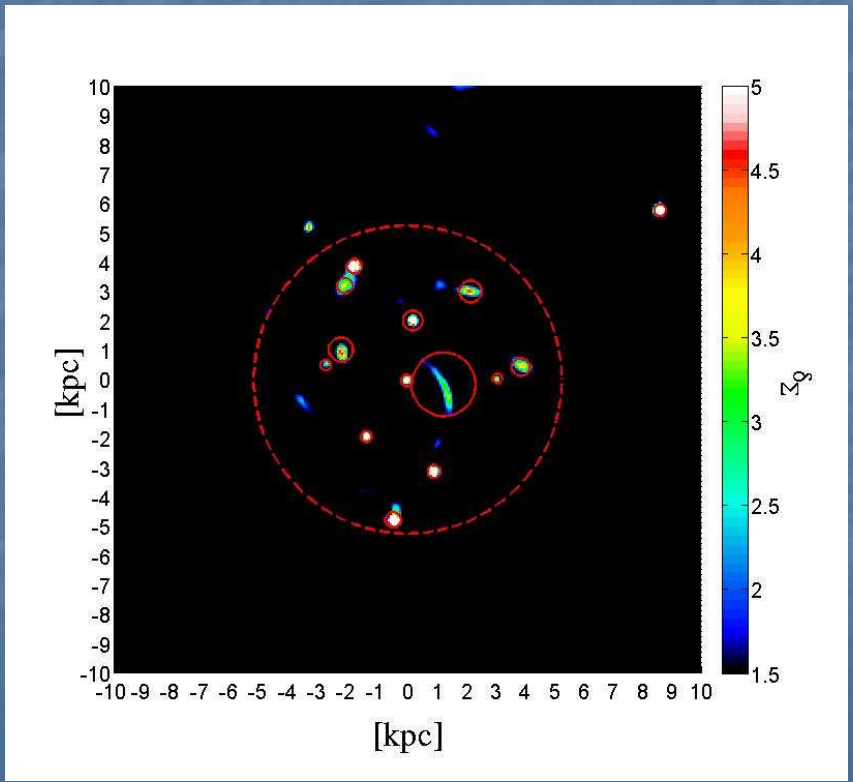




If we were working in 2-d:

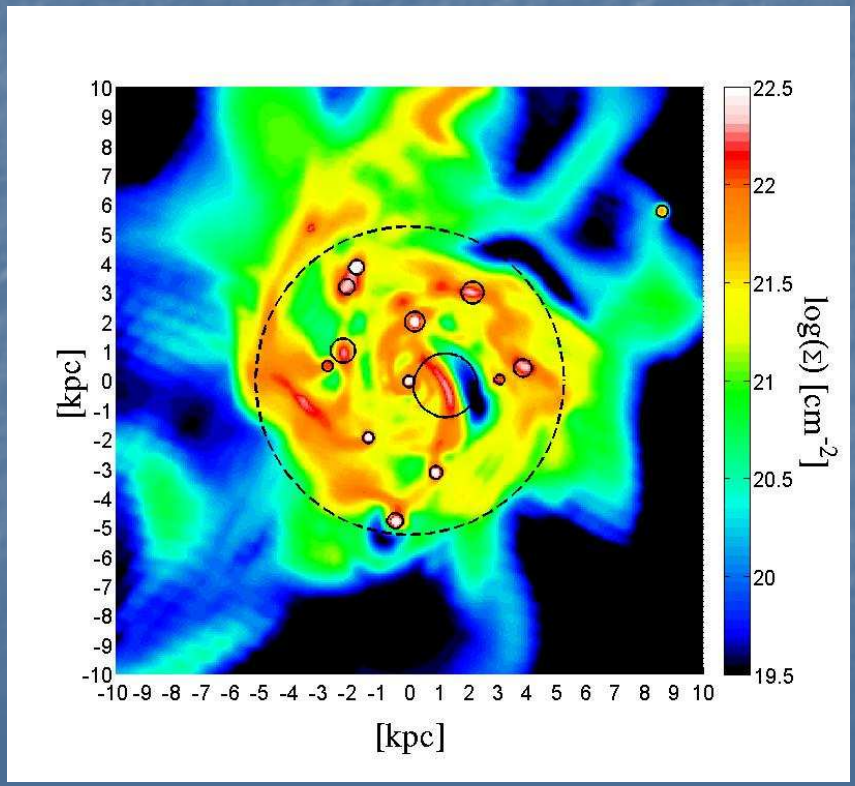
$$\delta_{\Sigma} = \frac{\Sigma_N - \Sigma_W}{\Sigma_N}$$

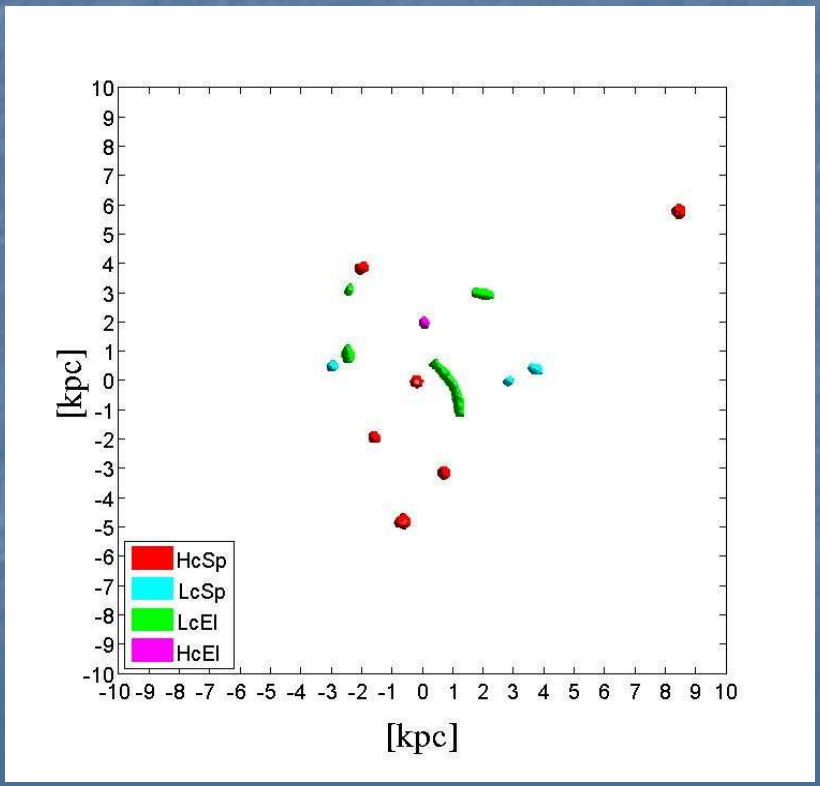




In 3-d

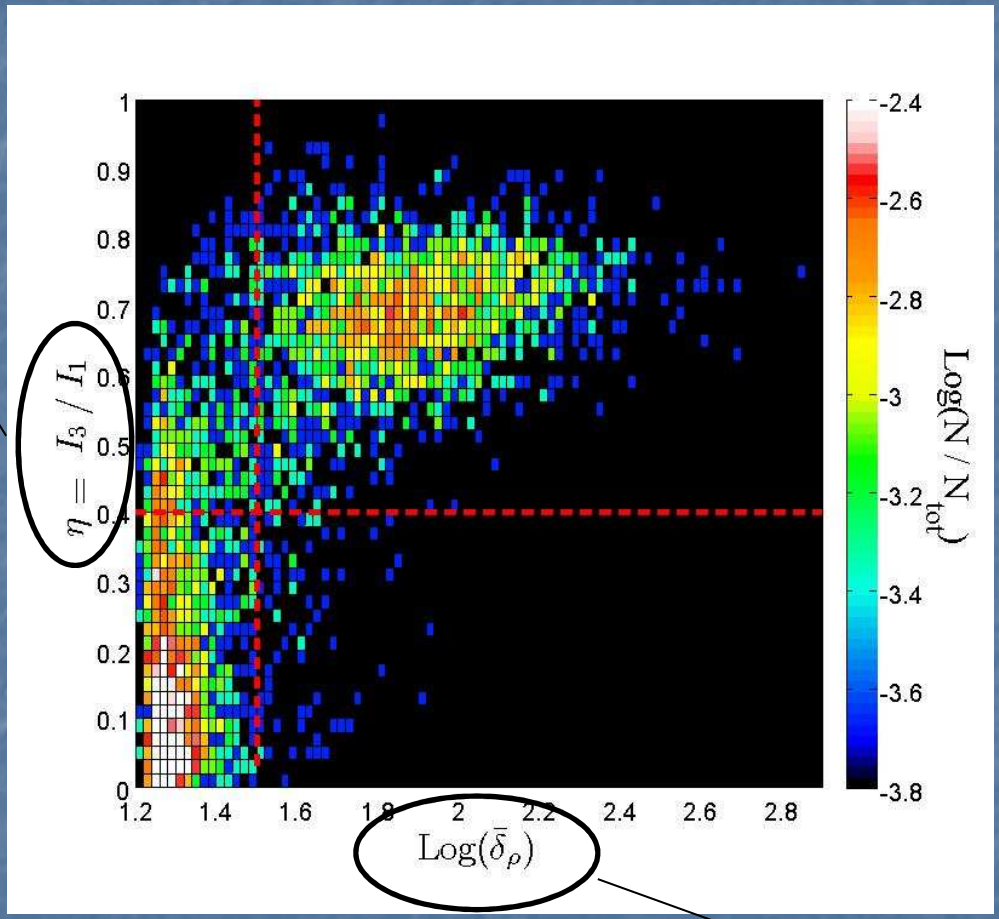
$$\delta_\rho = \frac{\rho_N - \rho_W}{\rho_W}$$





Clumps Come in All Shapes and Sizes!

Shape Parameter
(Inertia Tensor)



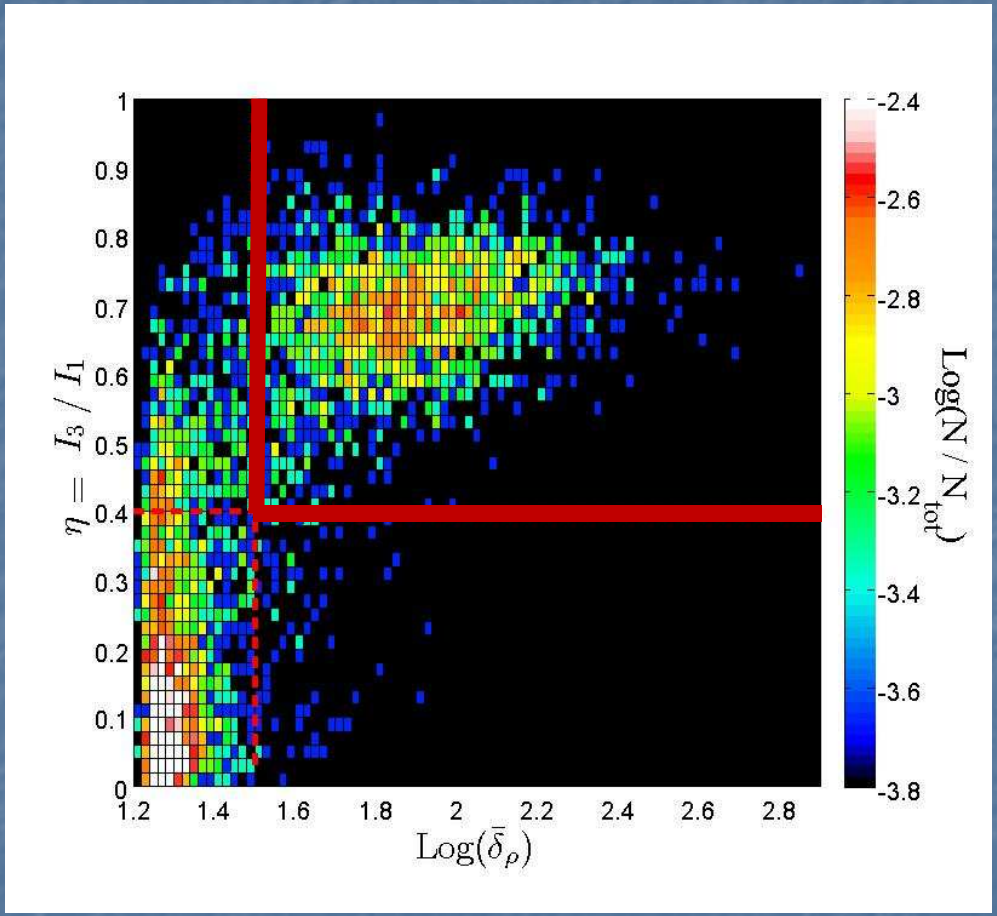
SPHERICAL

FILAMENTARY

Mean Residual

HIGHER CONTRAST

Bimodality



Compact & Spherical

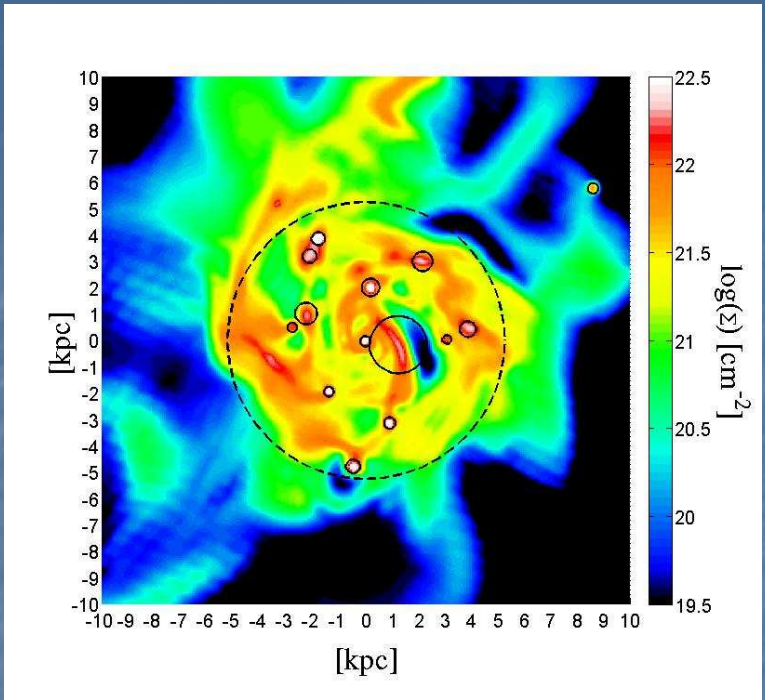
~ 45 % in number

> 90 % in mass

> 80 % in SFR

~ 2000 clumps

Diffuse or Elongated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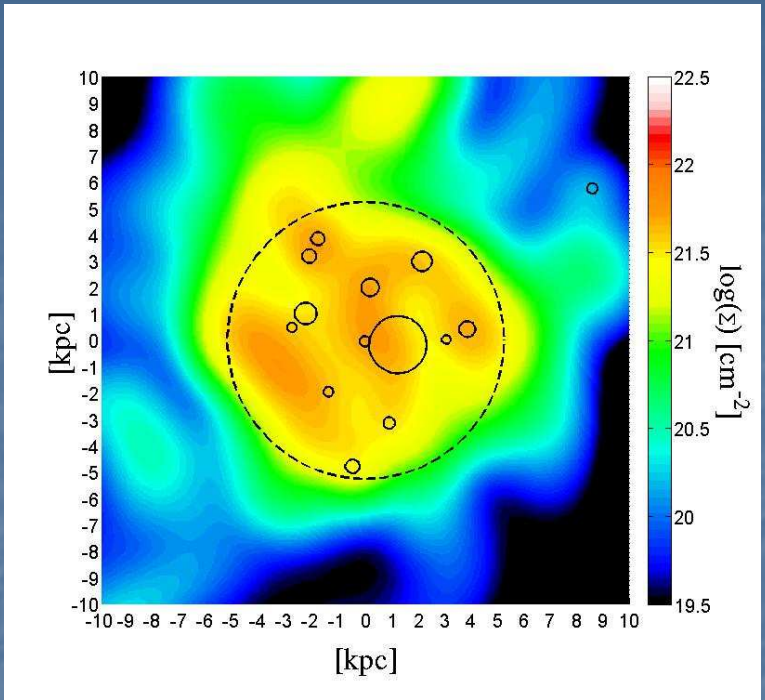
[kpc]
log(Σ) [cm^{-2}]
22.5
22
21.5
21
20.5
20
19.5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22.5
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21.5
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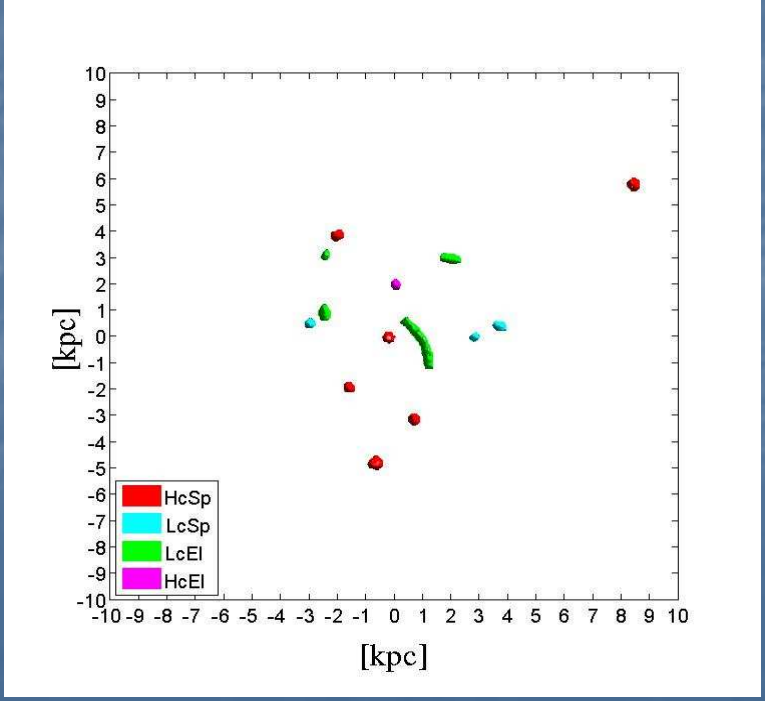
19.5


[kpc]
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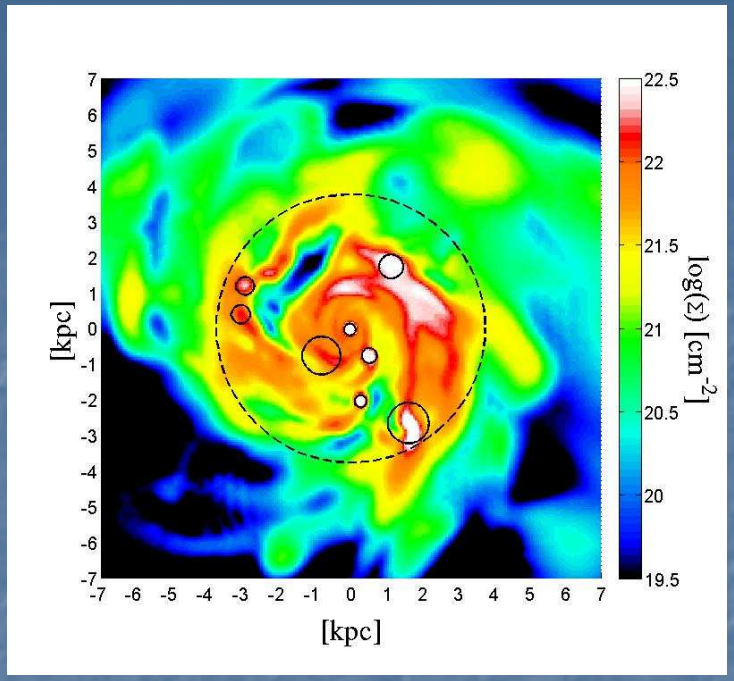
HcSp
LcSp
LcEl
HcEl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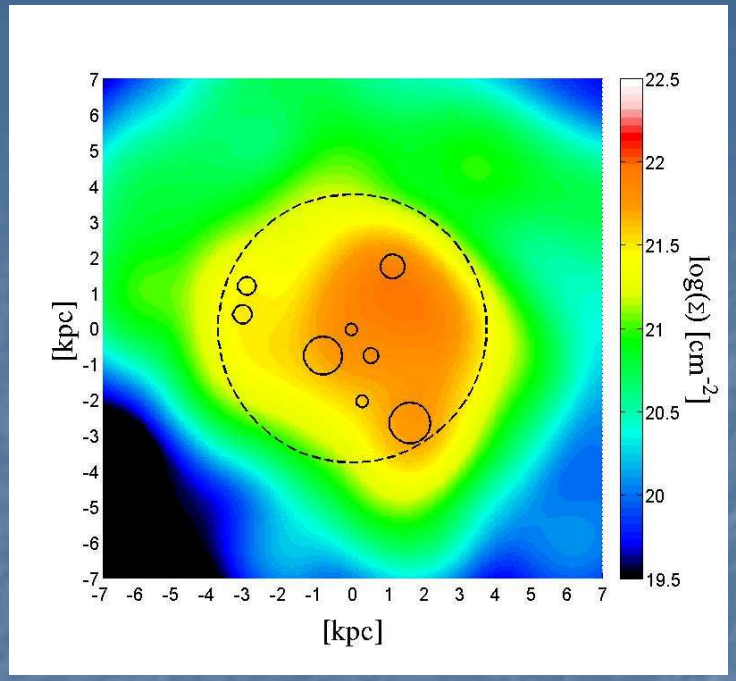
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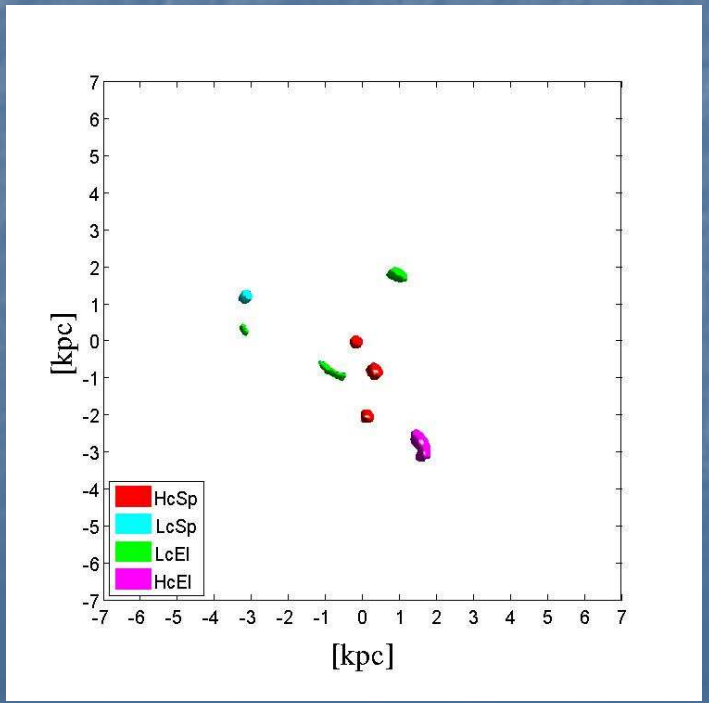
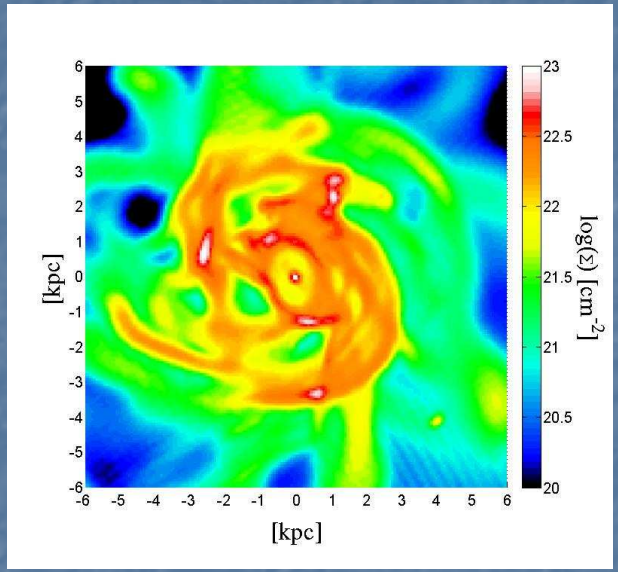

HcSp
LcSp
LcEl
HcEl
[kpc]
[kpc]

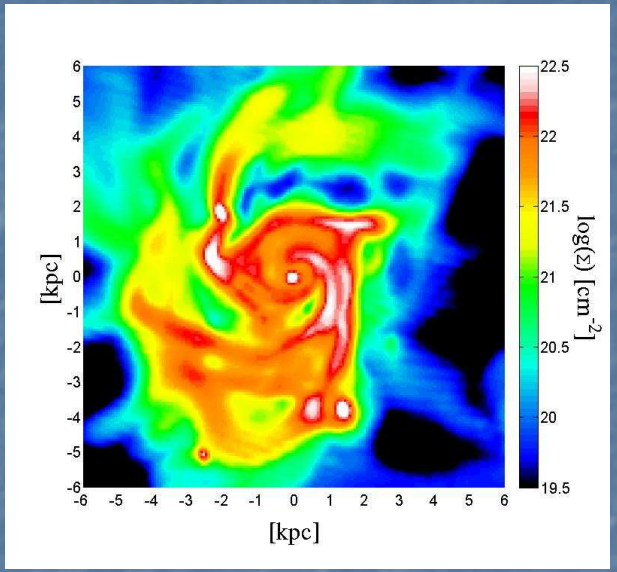
Bulge Clumps

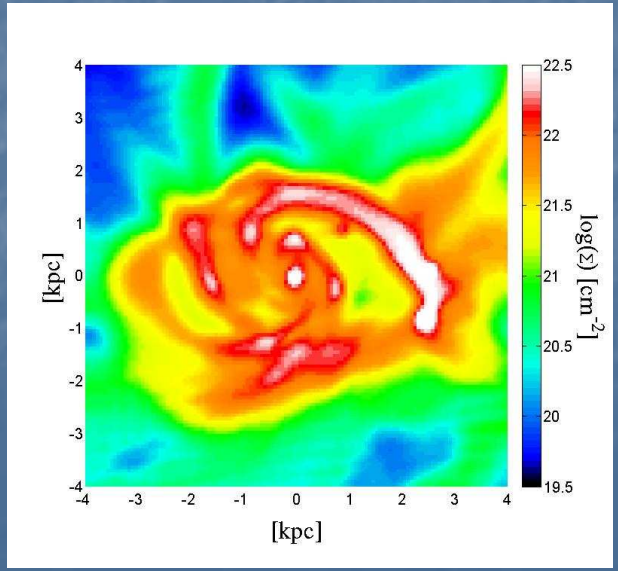
Nearly every galaxy has a clump located at its center.

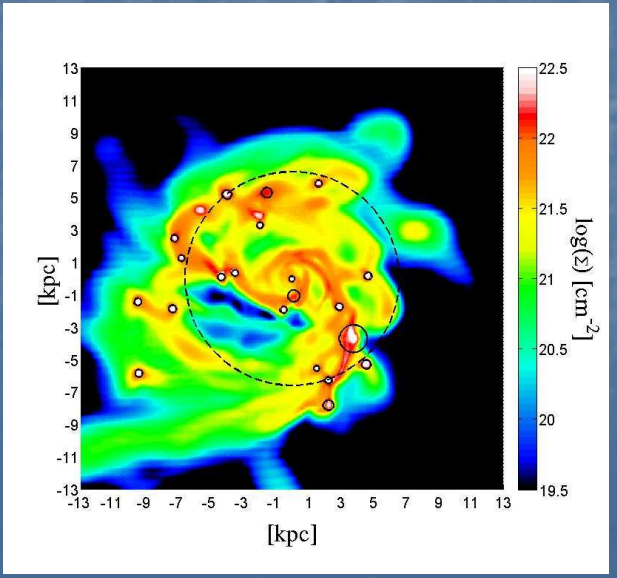
We denote these objects "bulge clumps"

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









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:

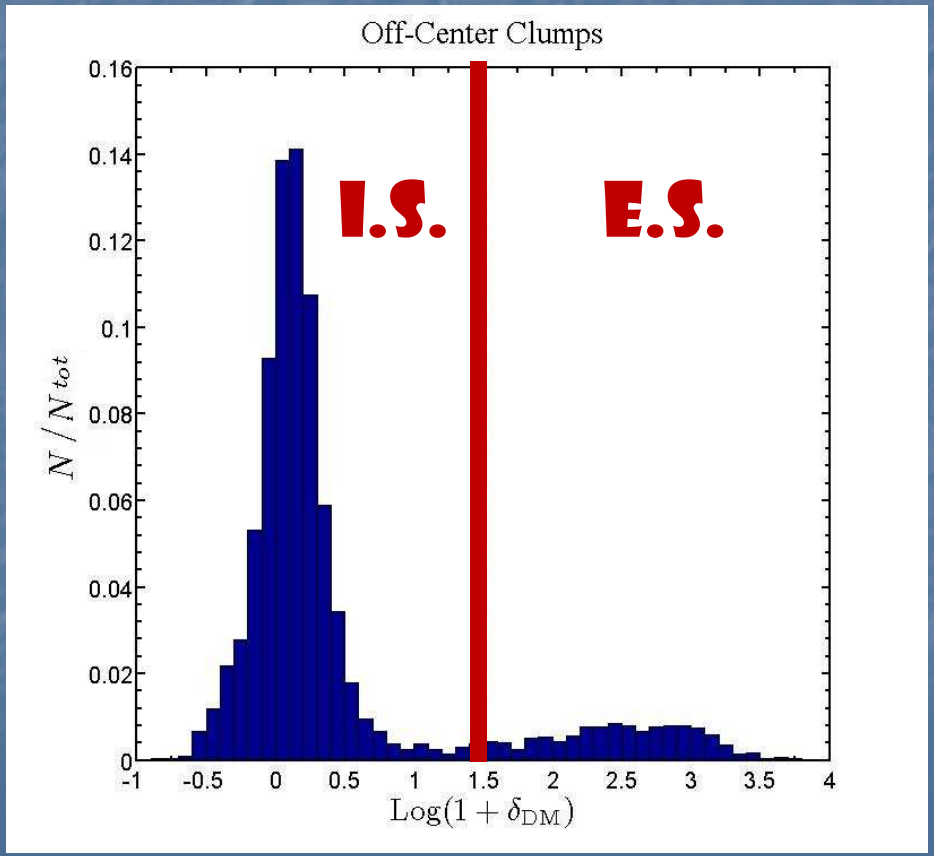
1. Dark Matter Contrast

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.

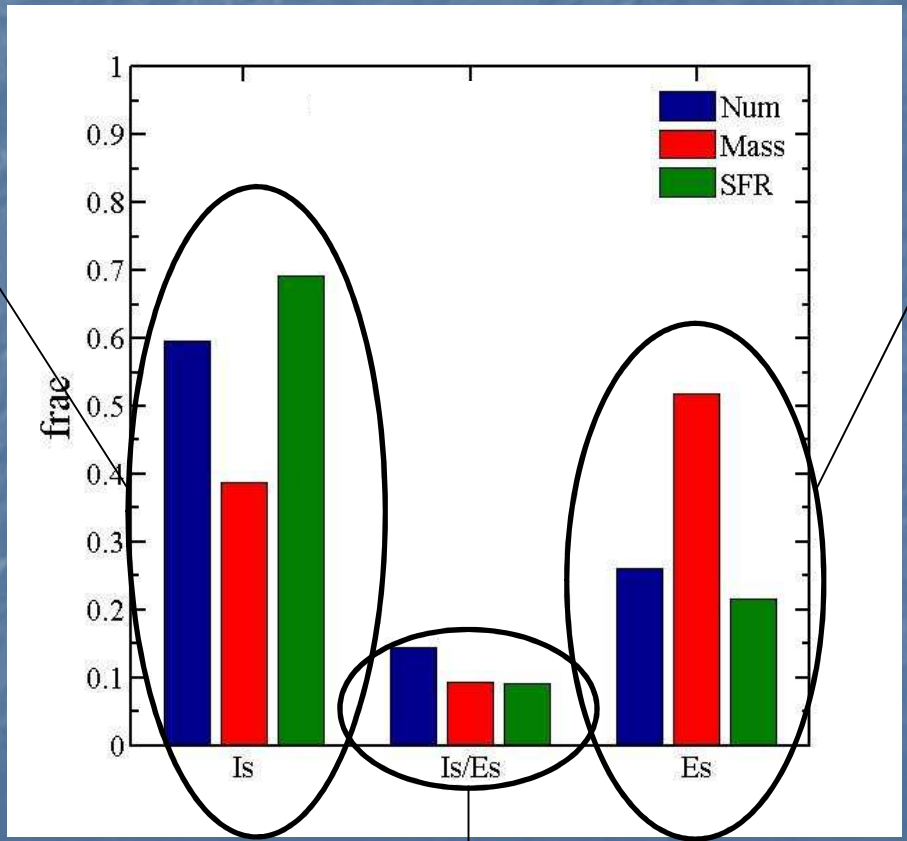


Census of Compact, Off Center Clumps

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

~ 2/3 in number and SFR

~40% of the mass



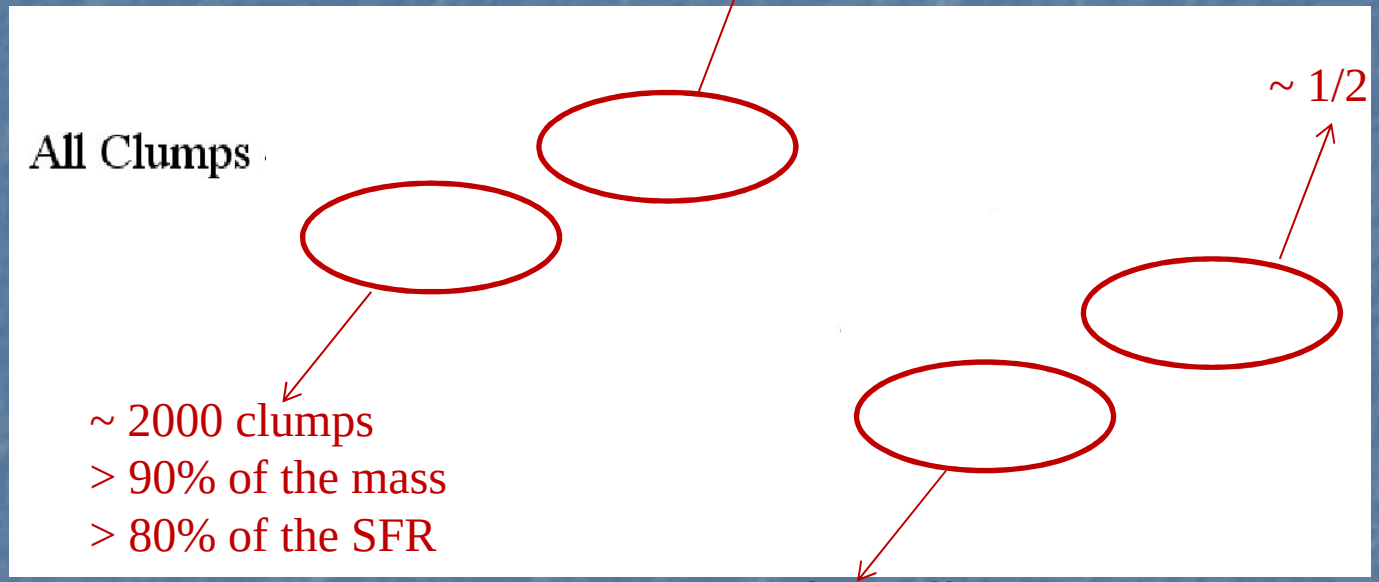
Ex-situ clumps with excess dark matter

~ 1/3 in number and SFR

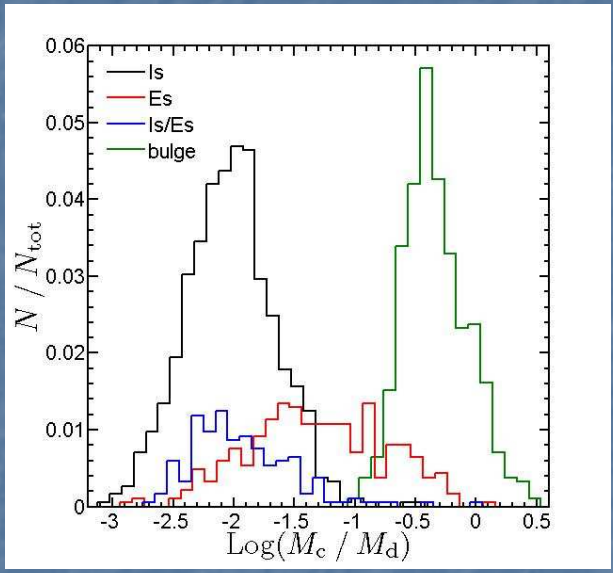
>1/2 the mass

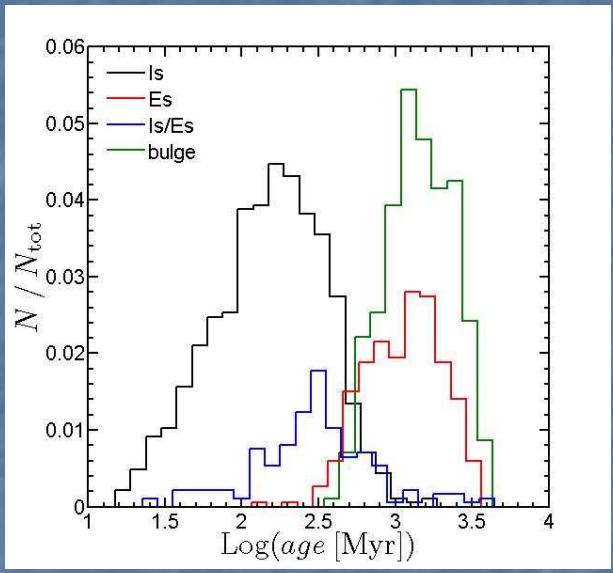
Without excess dark matter, but with external stars or kinematic deviations

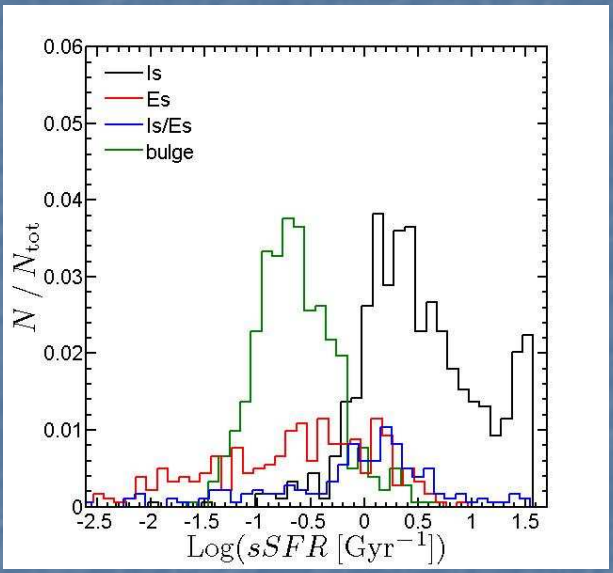
Clump Classification Summary



Distributions







***IN-SITU* CLUMPS ~ 1 - 2% OF THE DISC MASS**

***EX-SITU* CLUMPS FACTOR ~ 2 - 4 MORE MASSIVE**

***BULGE* CLUMPS FACTOR ~ 10 MORE MASSIVE**

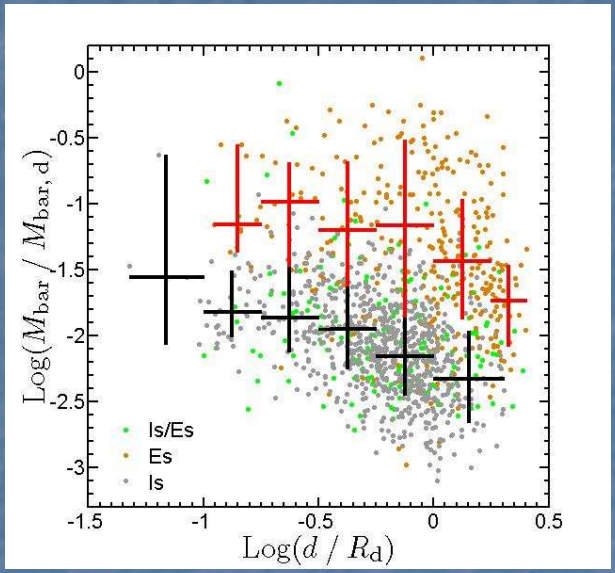
***IN-SITU* CLUMPS ~ 150 - 300 MYR OLD (MIGRATION TIME)**

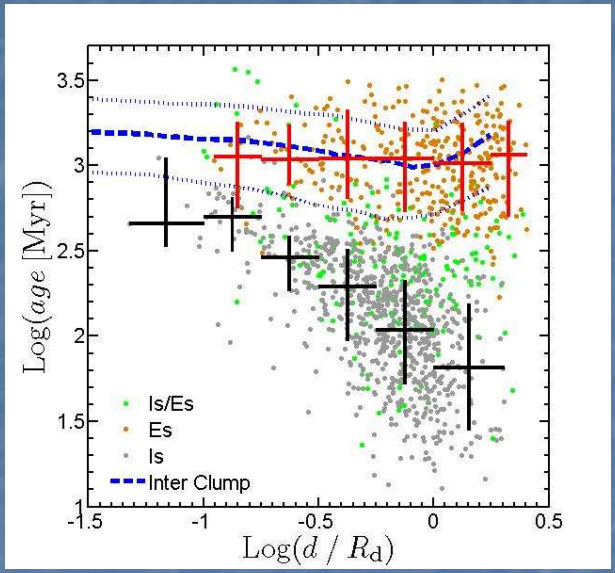
***EX-SITU* CLUMPS AS OLD AS THE DISC ~ 1 GYR**

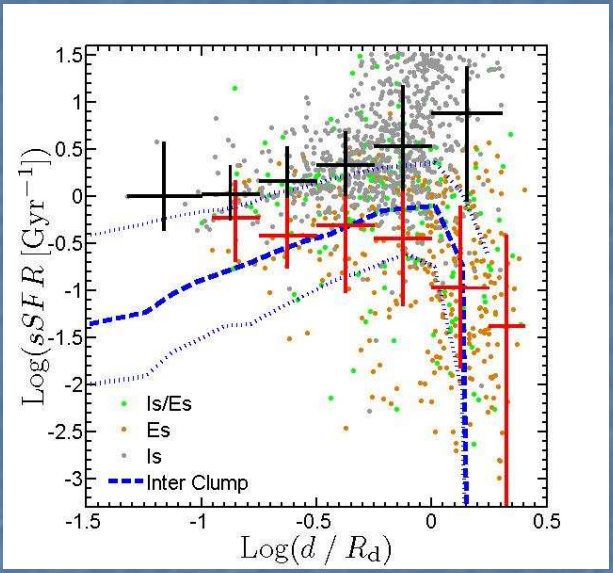
***IN-SITU* CLUMPS HAVE HIGH SSFR**

***EX-SITU* CLUMPS CAN BE MUCH LOWER**

Gradients







IN-SITU: **Closer to the disc center, clumps are more massive, older and with lower sSFR.**
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.**
Old clumps with low sSFR in the outer disc → *Ex-Situ*.

Summary and Conclusions

- > 750 snapshots, ~ 30 galaxies, $4 \geq z \geq 1$
- ~ 2000 compact spherical clumps in the 3-d gas distribution
- Nearly every galaxy has a *bulge* clump at the center
- ~ 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, especially near the outer disc.
- All the properties of the clumps and their host galaxies will soon be made available in an extensive catalogue.
- **Next Step:** Repeating the analysis in 2-d, after the images have been "CANDLE-ized"

THANK YOU!!