Towards a New Understanding of Giant Clumps in Clumpy Disks at z~1-3

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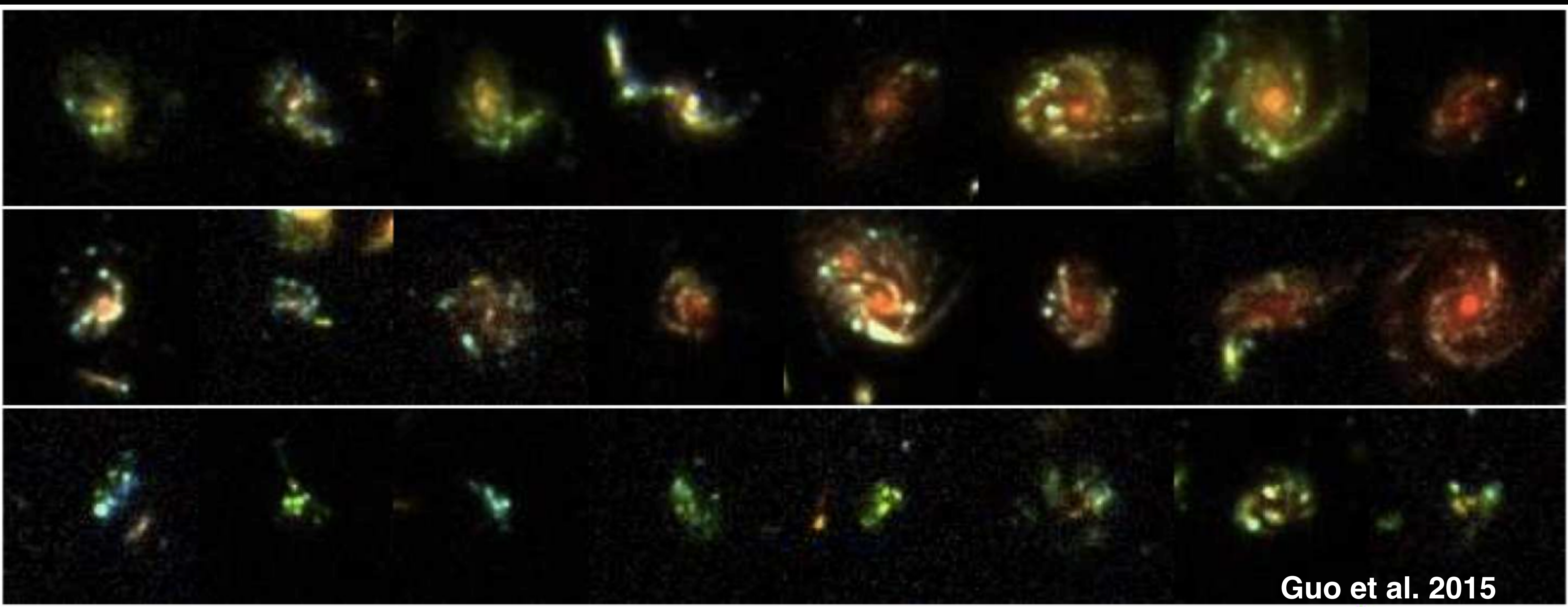
OPINAS Seminar, MPE, 27.04.2015

Typical **Morphology** of clumpy galaxies

SFGs in the CANDELS/Goods-S and UDS field



z = 0.5-3 composite RGB images spatial resolution ~kpc

z=1-3

galaxies - irregular structure - relatively thick

~kpc sized clumps **10^8-10^9** M_{sol}

high gas fractions ~50%

high velocity dispersion ~50 km/s

high sfr, relatively young stars ~10^8 yrs

minority display signatures from mergers

minority origin outside

Generally:

higher z → lower z

- gas fractions
- gas densities

cause gravitational instabilities

- clumpiness
- clump sizes

Local Axisymmetric Instability

stabilizing

(Toomre 1964) $$\boxed{Q \propto \frac{\sigma_R V_{rot}}{\boldsymbol{R}\,\Sigma}}$$

destabilizing

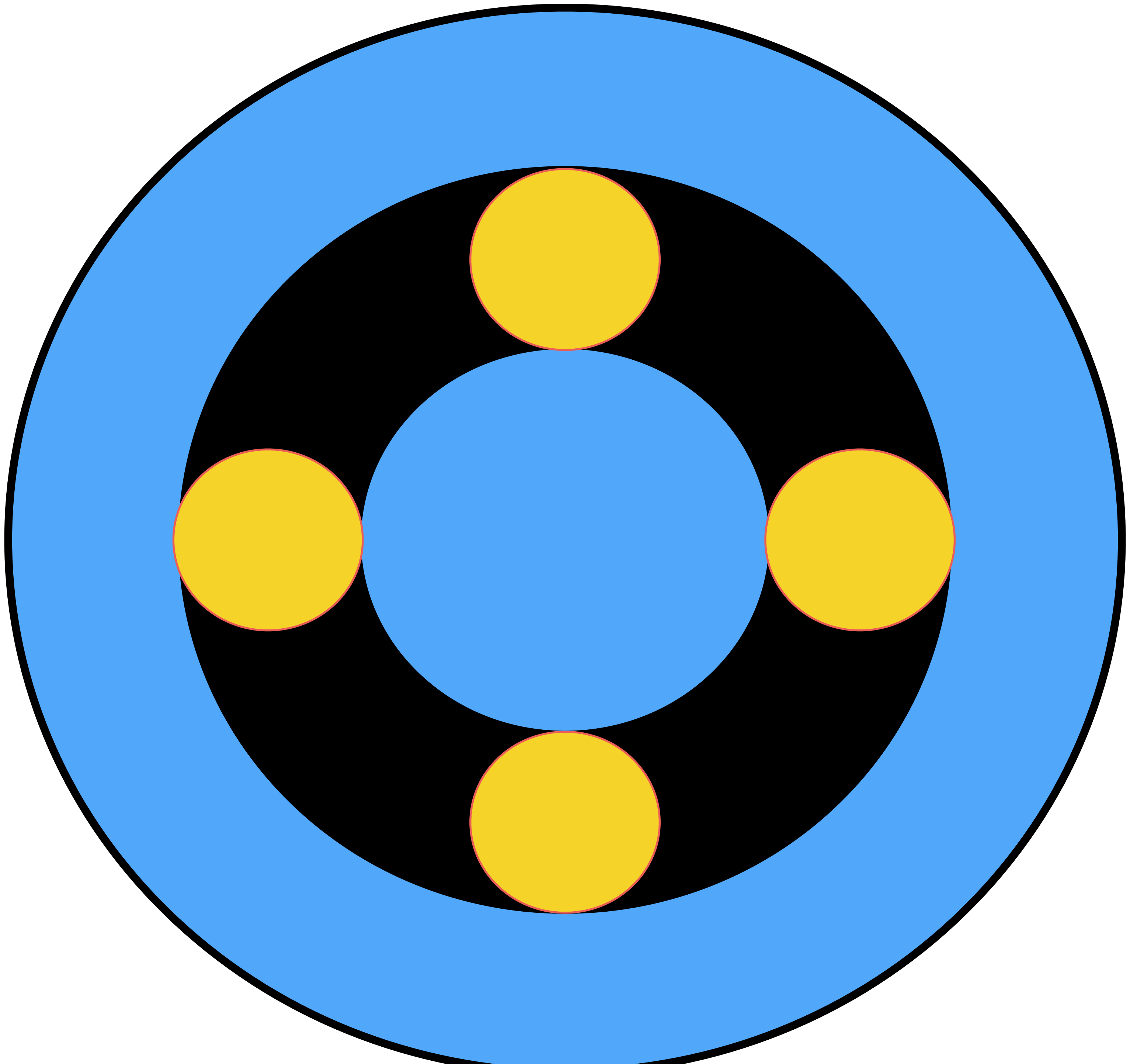
$$\begin{cases} Q < Q_{crit} & \text{unstable} \\ Q > Q_{crit} & \text{stable} \end{cases}$$

$Q_{crit} = 1 \quad (razor\ thin\ disk)$

$Q_{crit} \sim 0.7 \quad (disk\ with\ thickness)$

-> unstable to non axisymmetric modes
(local spirals)

Fragmentation in an axisymmetric disk



$Q < Q_{crit}$ unstable

↓

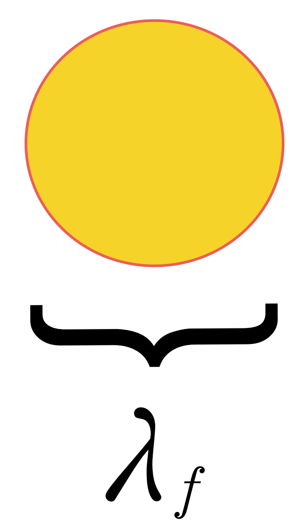
range of perturbations can grow

↓

ring-like structures

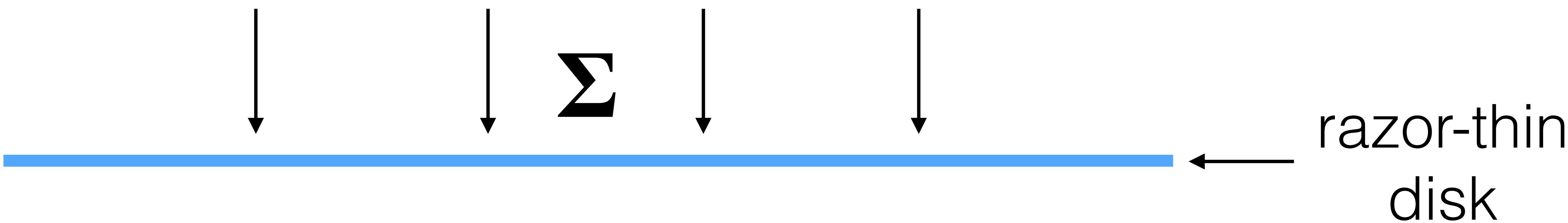
↓

break-up into clumps



$$M_{cl} = \Sigma \frac{\pi \lambda_f^2}{4}$$

Thickness Effects



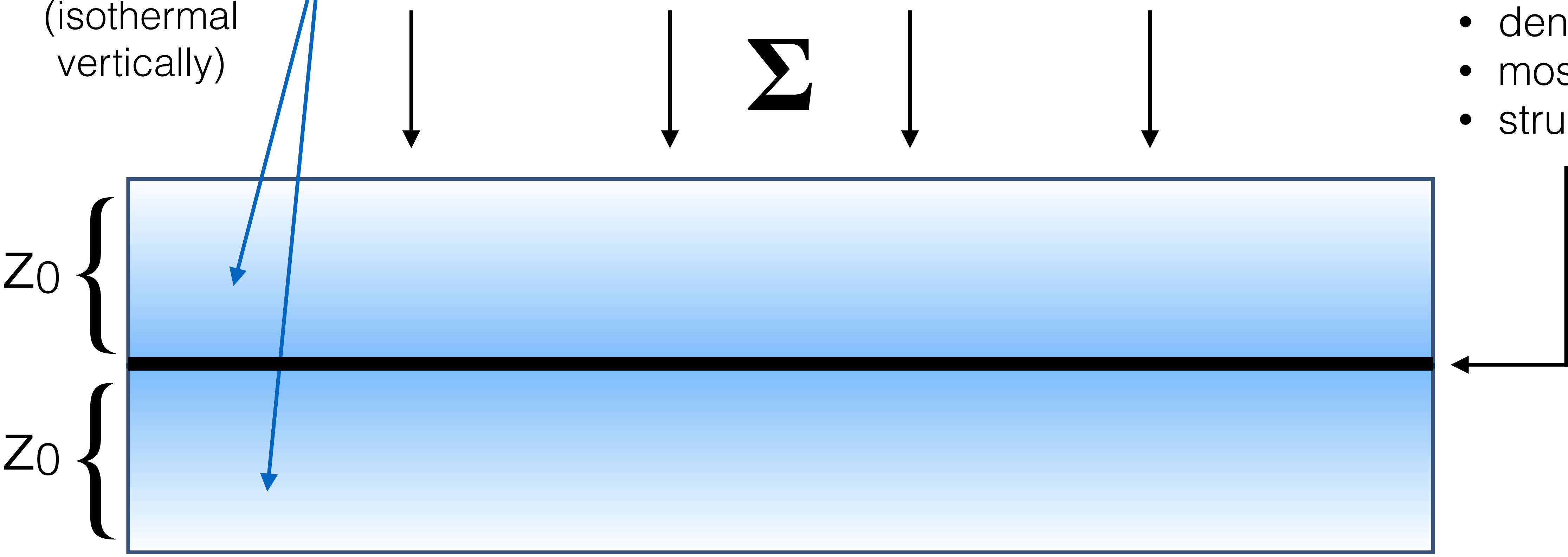
Behrendt et al. 2015

Thickness Effects

Vertical Distribution

$$\rho(z) = \rho_0 \cdot \sec h^2(\tfrac{z}{z_0})$$

(isothermal vertically)



Midplane

- density peaks
- most unstable part
- structures form first

Potential: $\Phi_{\mathrm{tot}}(\lambda, x, z=0) = \Phi_0(\lambda, x)\, F(\lambda, z=0)$

for an infinitesimally thin-disk

Reduction Factor

F=(0,1)

Behrendt et al. 2015

Thickness Effects

for a gas disk in vertical equilibrium

fastest growing wavelength

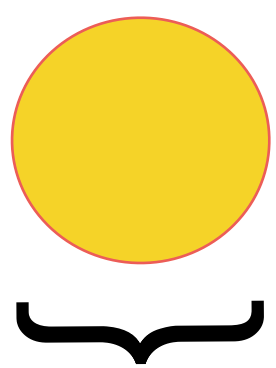
$$\lambda_f = A\,\lambda_0 = A\,\frac{2c_s^2}{G\Sigma}$$

(independent of the galactic rotation !)

scale height independent constant factor

$$A \sim 1.9 \;\left(\mathrm{sec}\,h^2\right)$$

profile



λ_f

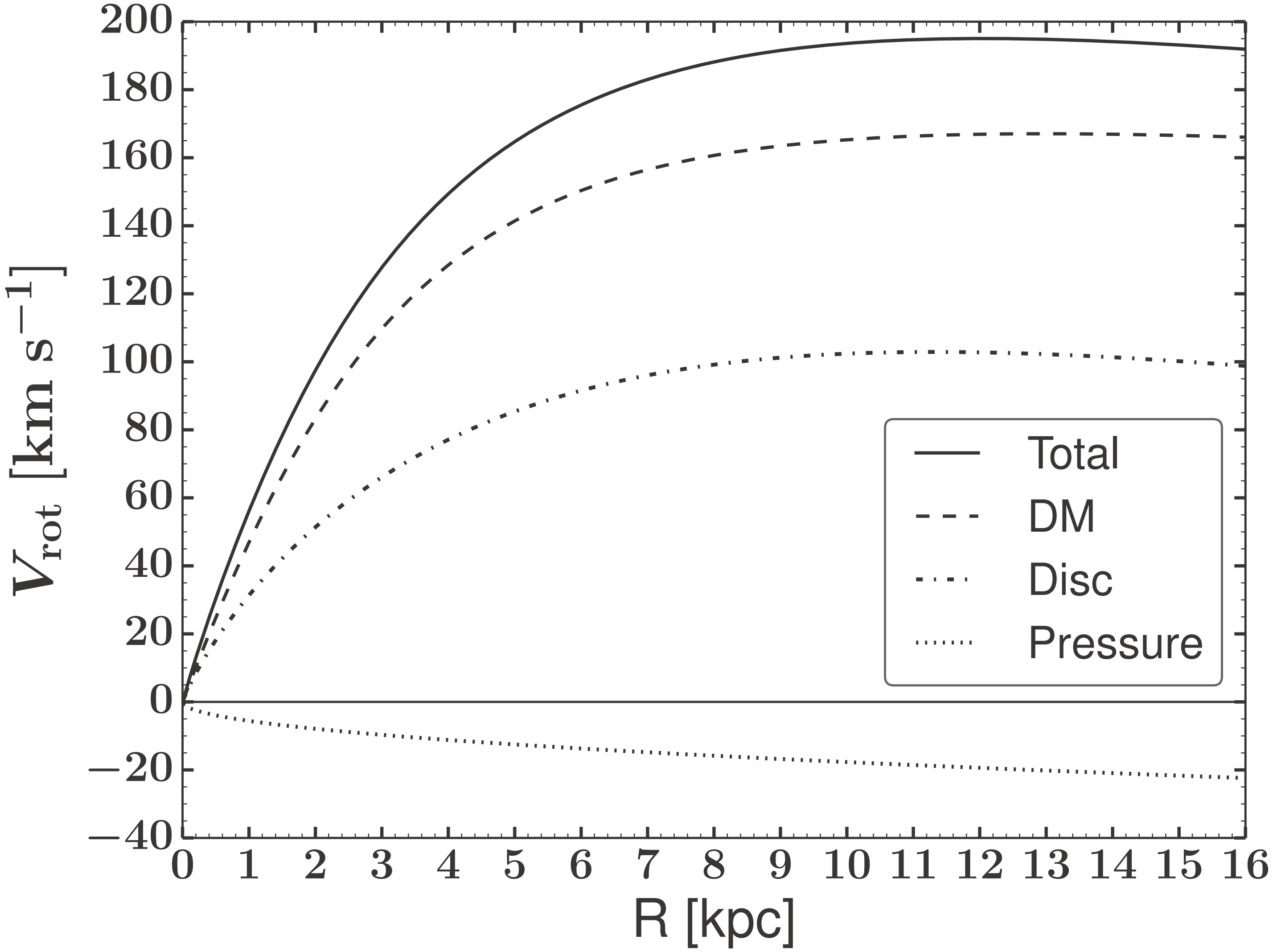
$$M_{cl} = \Sigma\frac{\pi\lambda_f^2}{4} = A^2\,\Sigma\frac{\pi\lambda_0^2}{4}$$

-> size: ~2 x
-> mass: ~4 x

!

Behrendt et al. 2015

Simulation



Main Properties:
exponential surface density

$R_{disc} = 16\,kpc$

$h = 5.26\,kpc$

$T = 10^4 K$

$M_{disc} = 2.7 \times 10^{10} M_\odot$

$M_{DM} = 1.03 \times 10^{11} M_\odot$

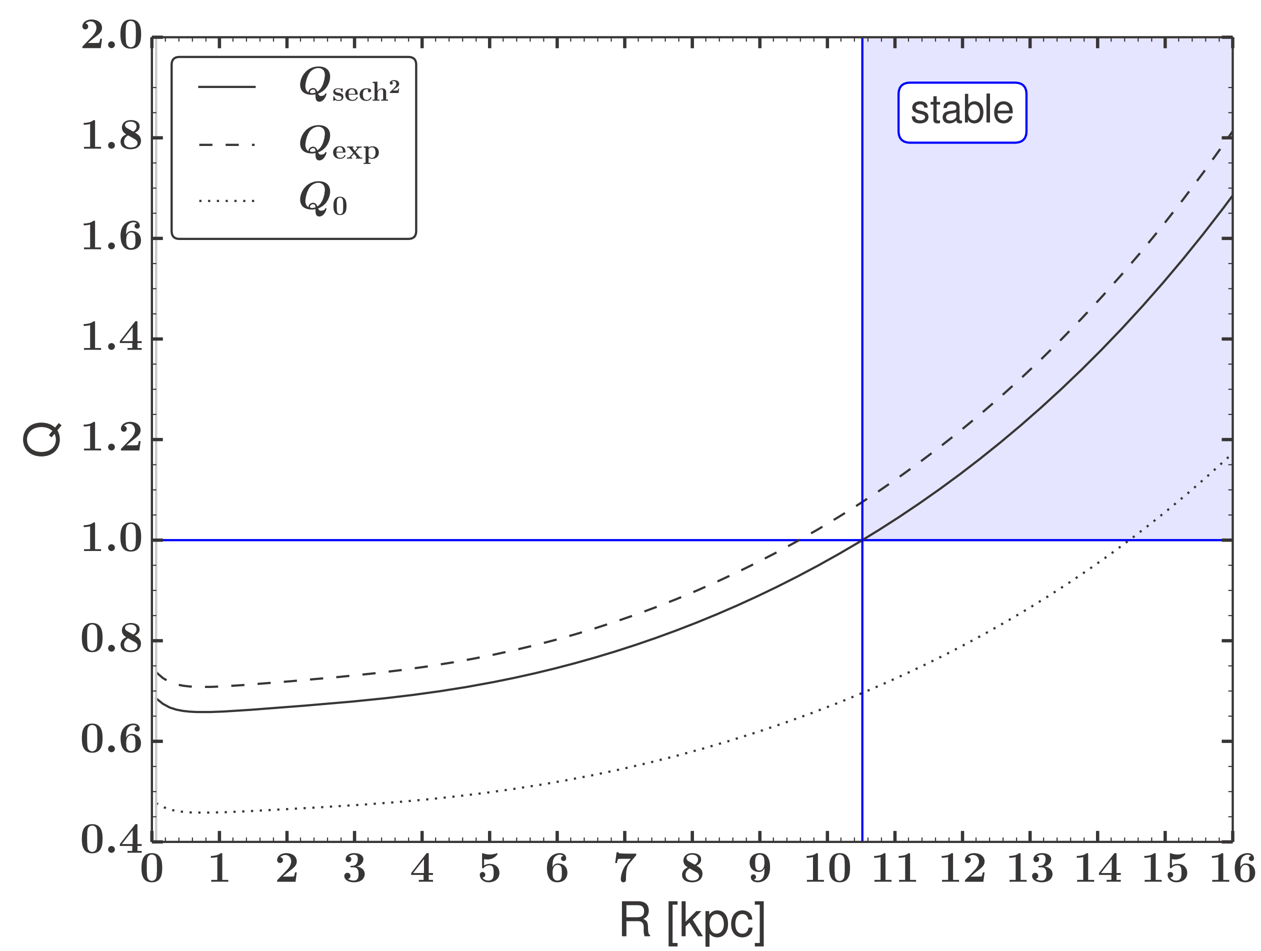
AMR Refinement:
RAMSES

$N_J = 18$

$\Delta_{\max} = 187.5\,pc$

$\Delta_{\min} = 5.86\,pc$

$\approx z_0, 5 \times resolved$



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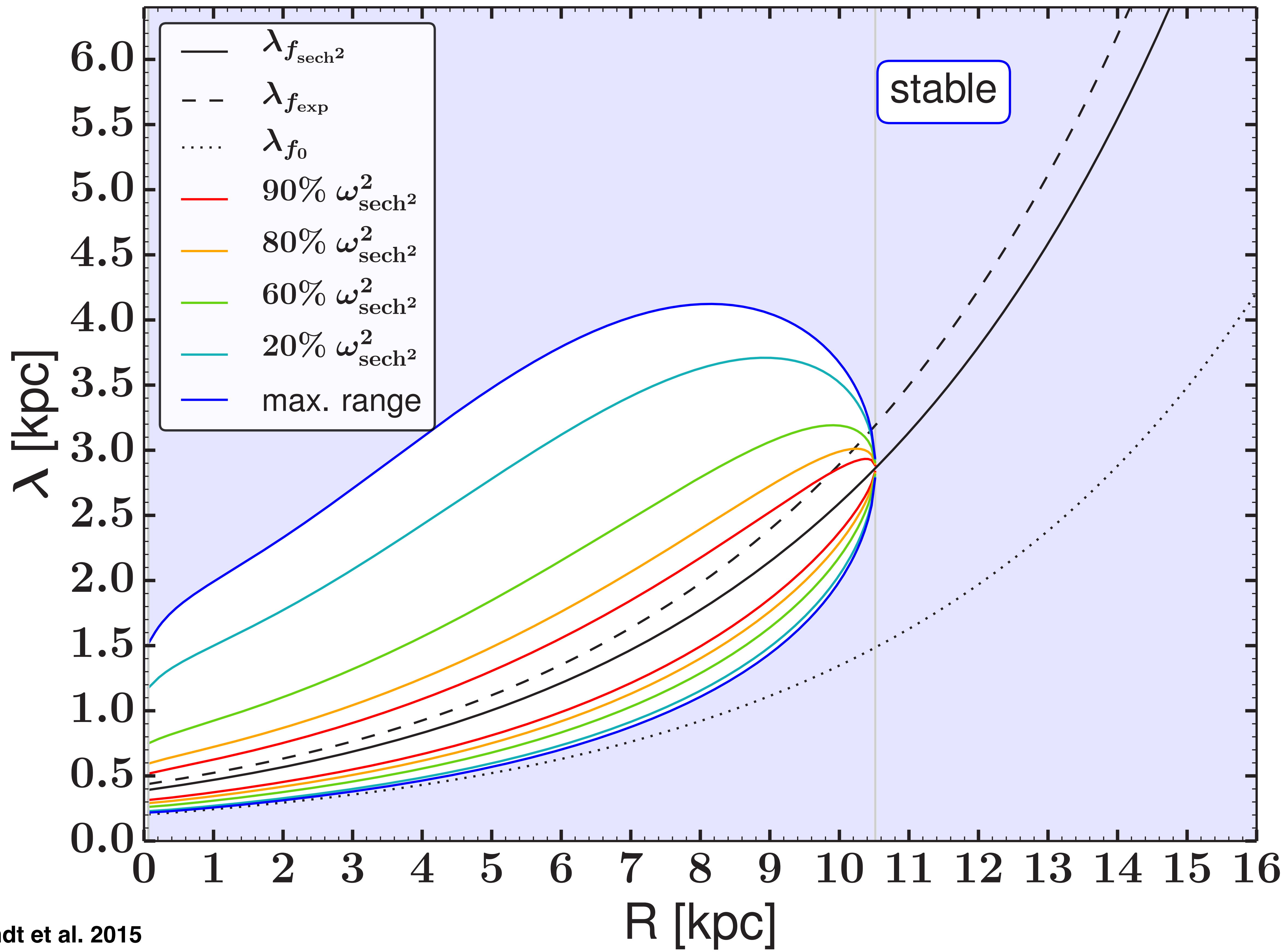
Growing Wavelengths



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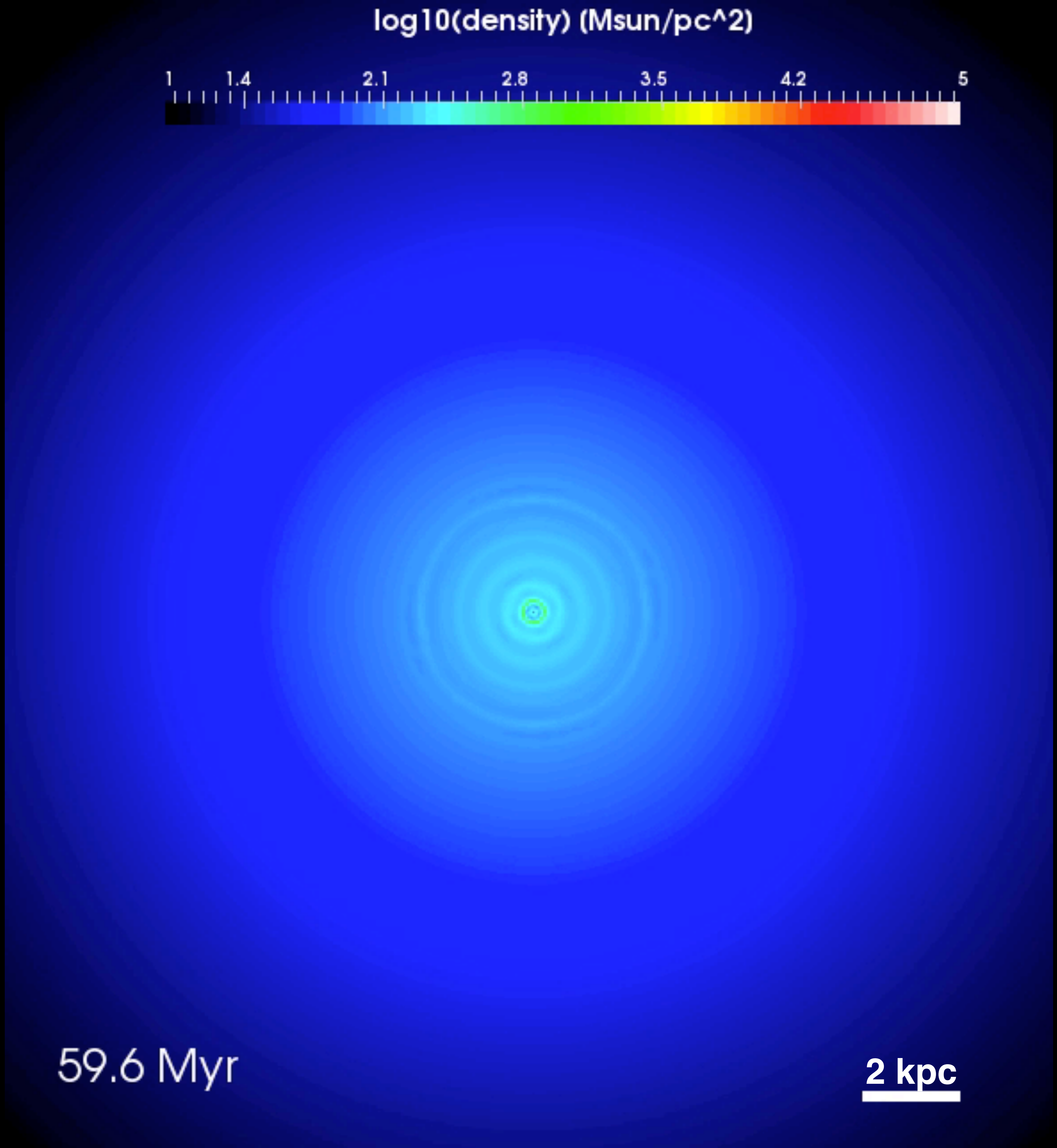
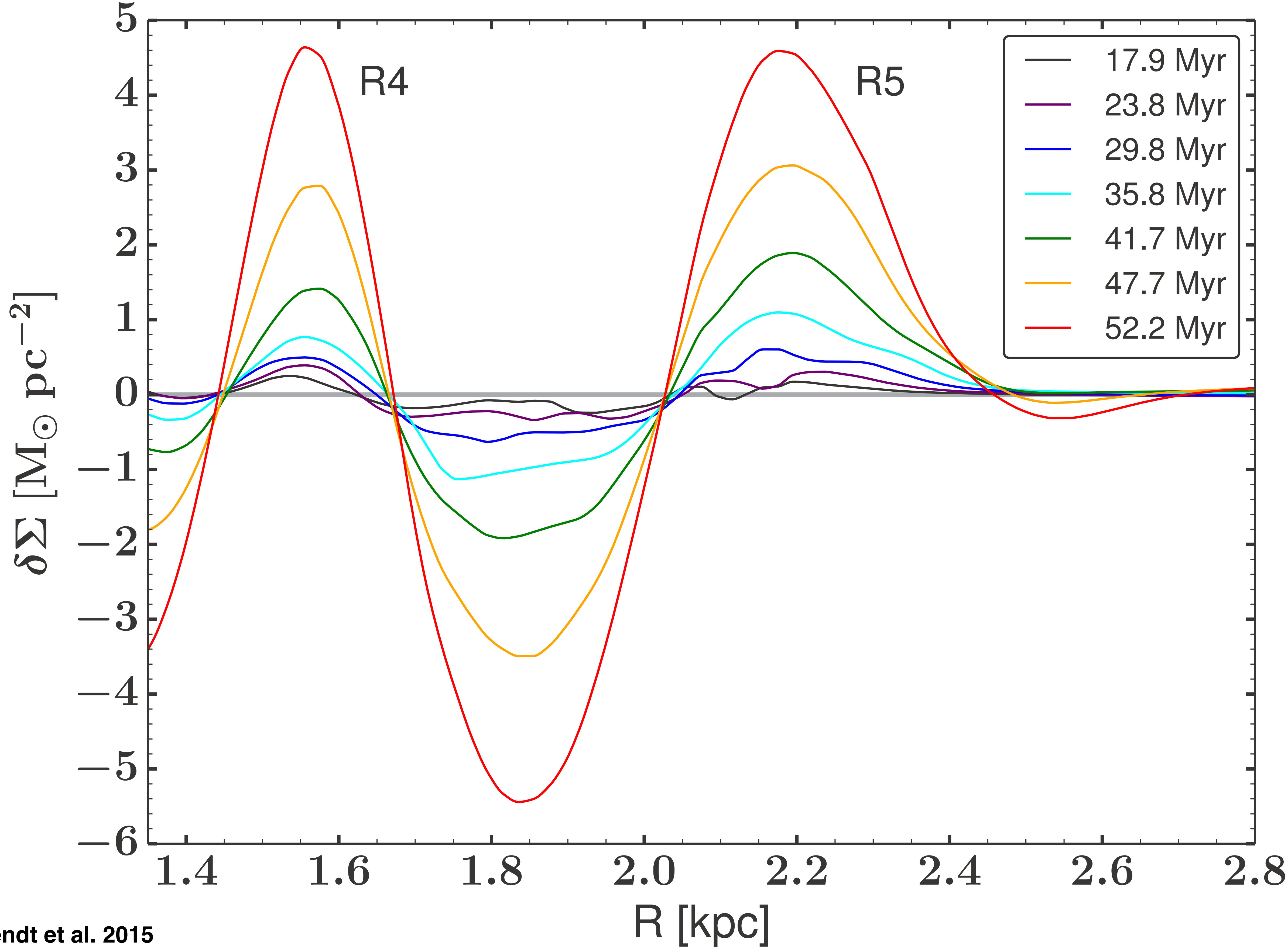
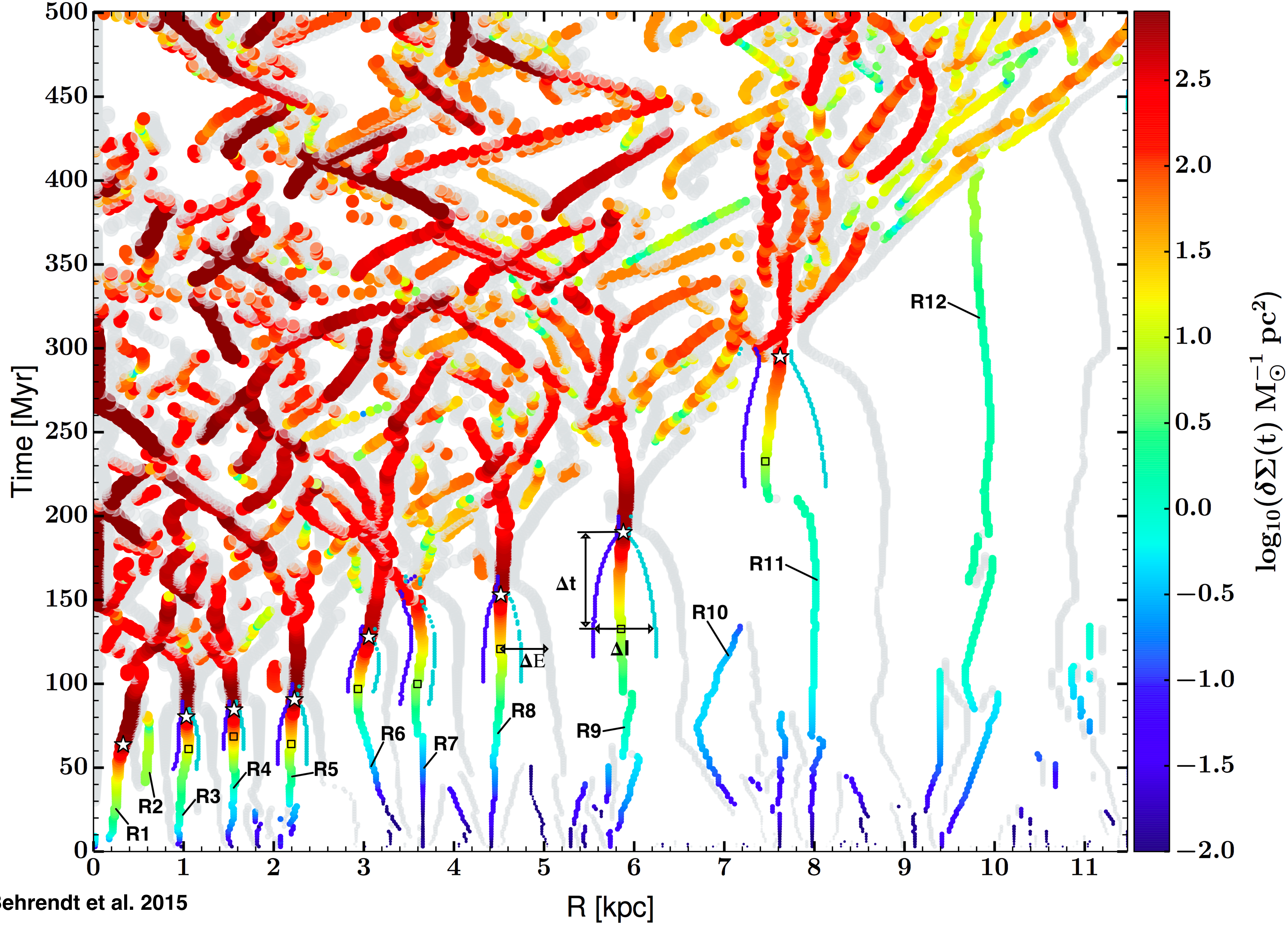

log10(density) (Msun/pc^2)
1
1.4
2.1
2.8
3.5
4.2
5
59.6 Myr
2 kpc

Overdensities



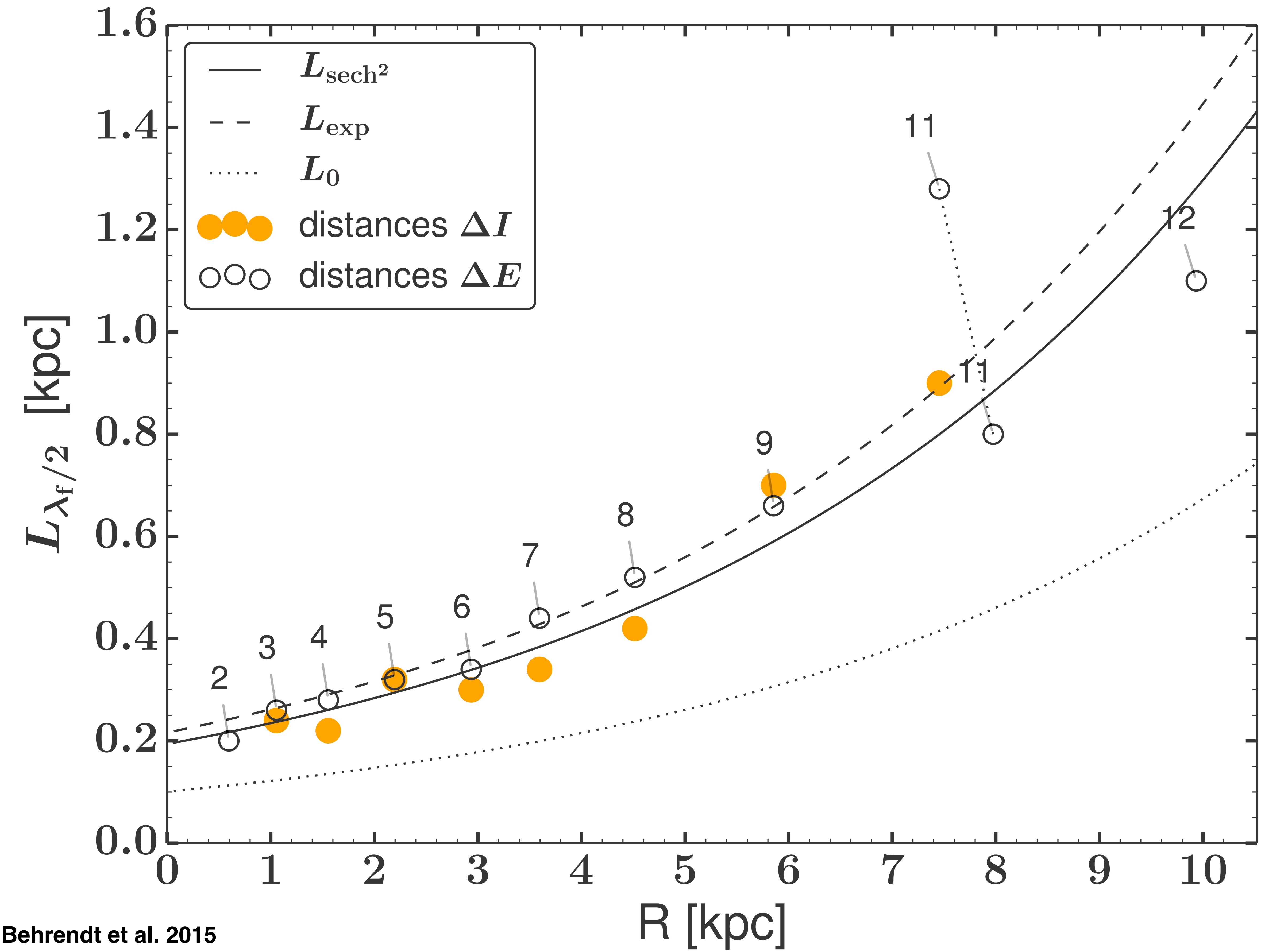
Behrendt et al. 2015

Relative Extrema



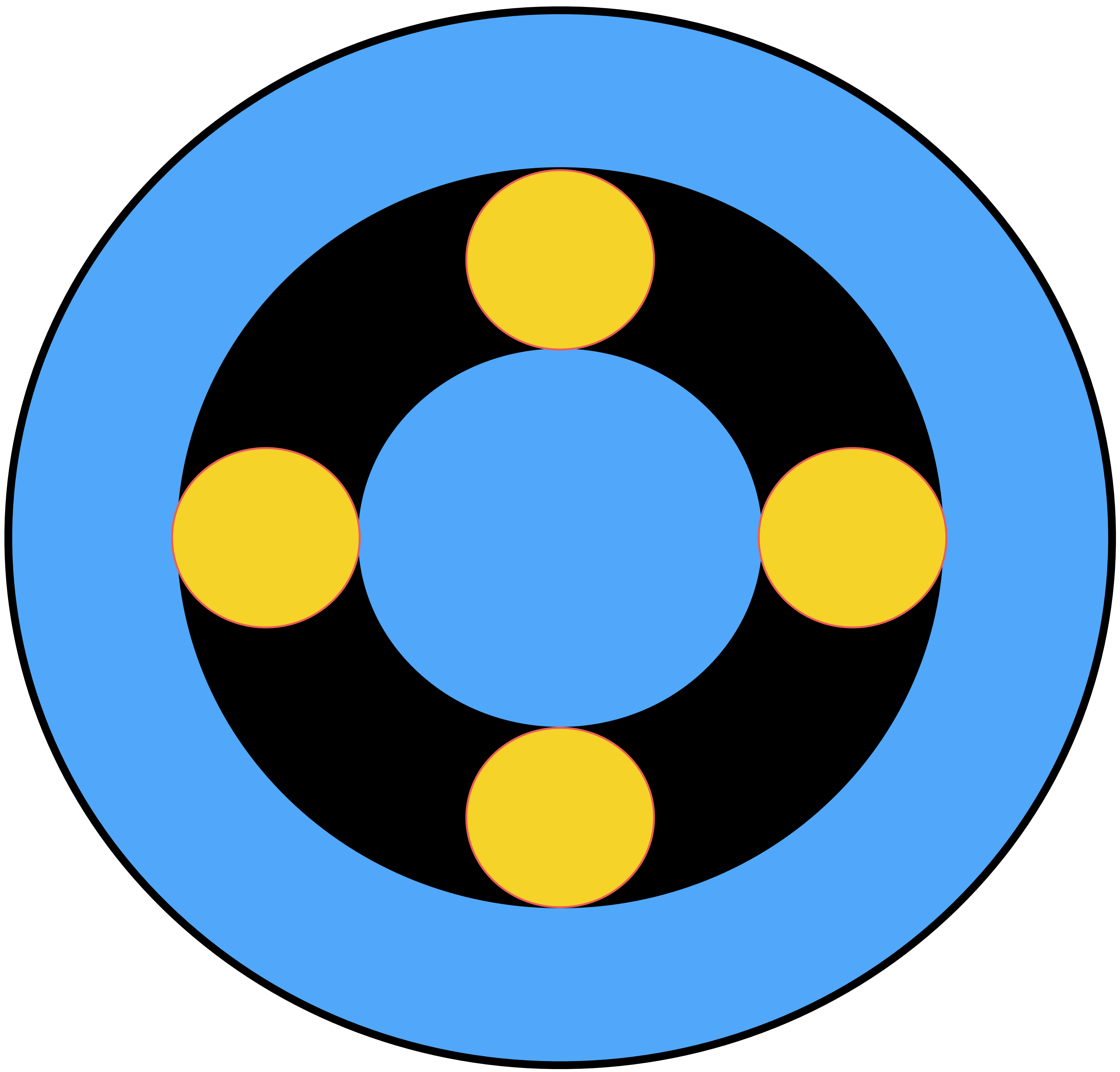
Behrendt et al. 2015

Ring Sizes



Behrendt et al. 2015

**Rings collapse first,
then clumps fragment on smaller scales** **!**



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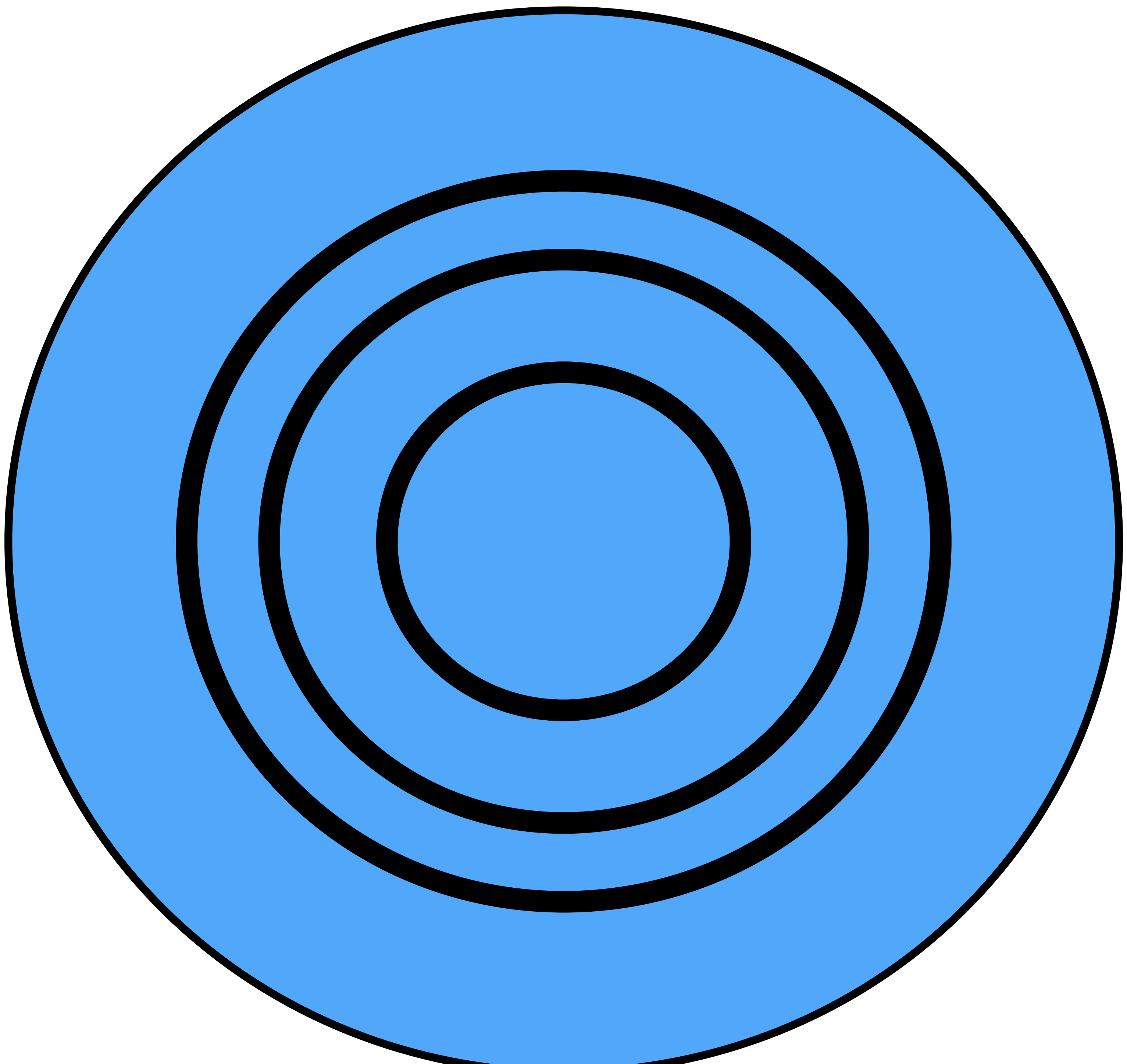


Clump Finding

Clump Finder RAMSES:

- density ≥ 100 H/cc
- distinguish substructures with sattel point criterium
- gravitationally bound

-> Clump positions
-> Clump area

Postprocessing:

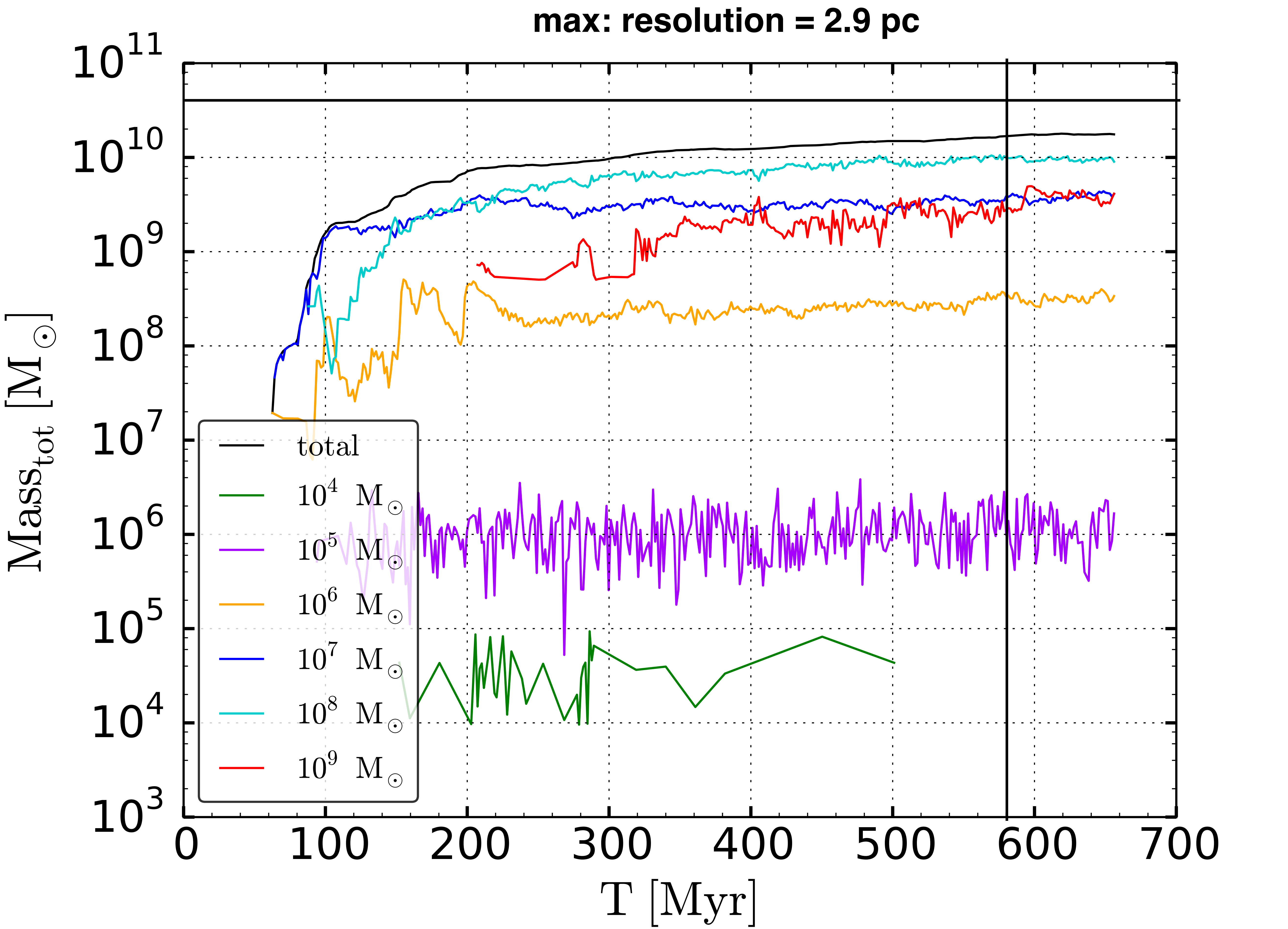
- V_i - V_{cm} (substract center of mass velocity)
- angular momentum vector

-> go into clump restframe
-> calculate profiles

Radius definition:

- density profile ~ <100 H/cc
- else: M_cum ~ const.

Behrendt et al. (in prep.)



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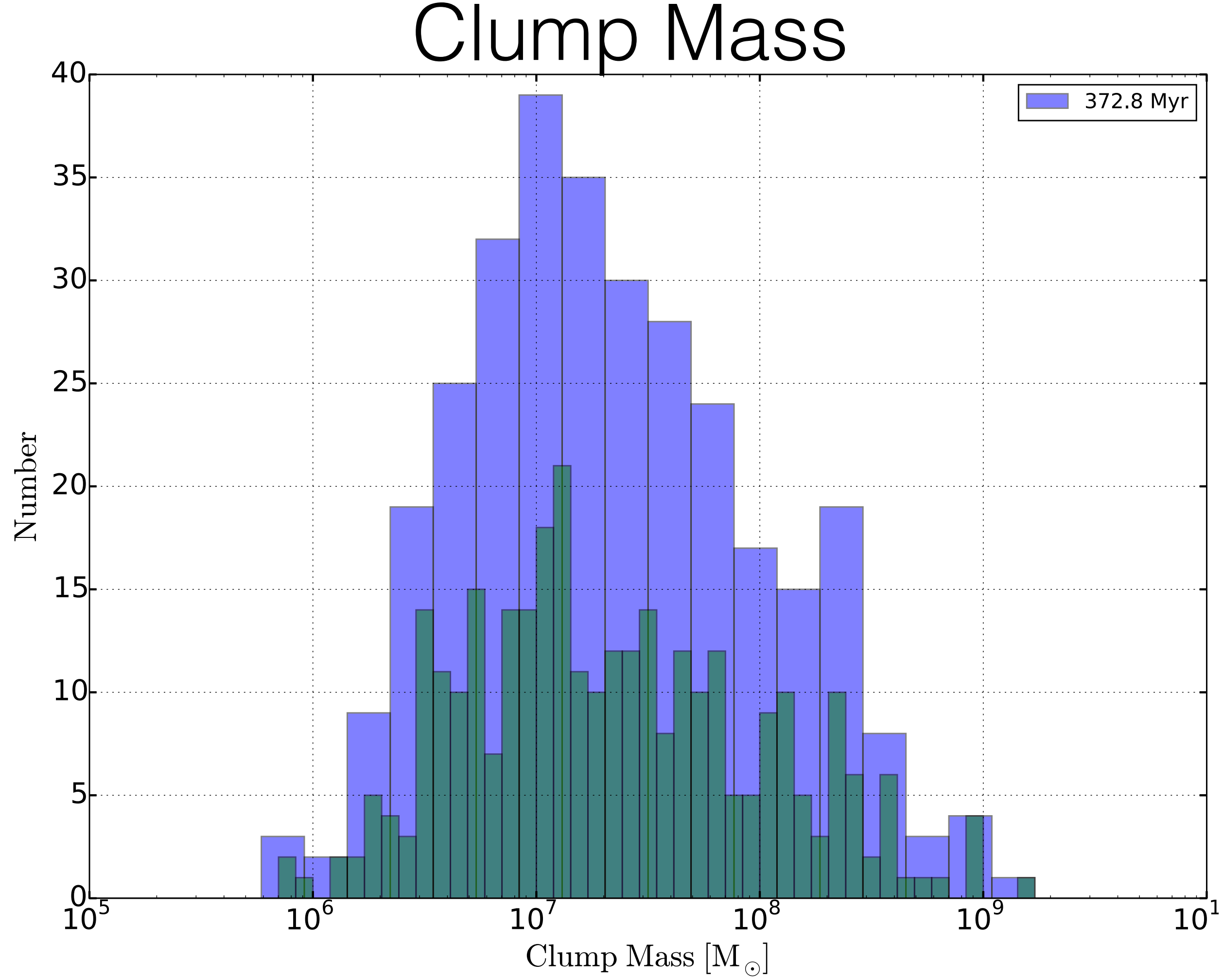
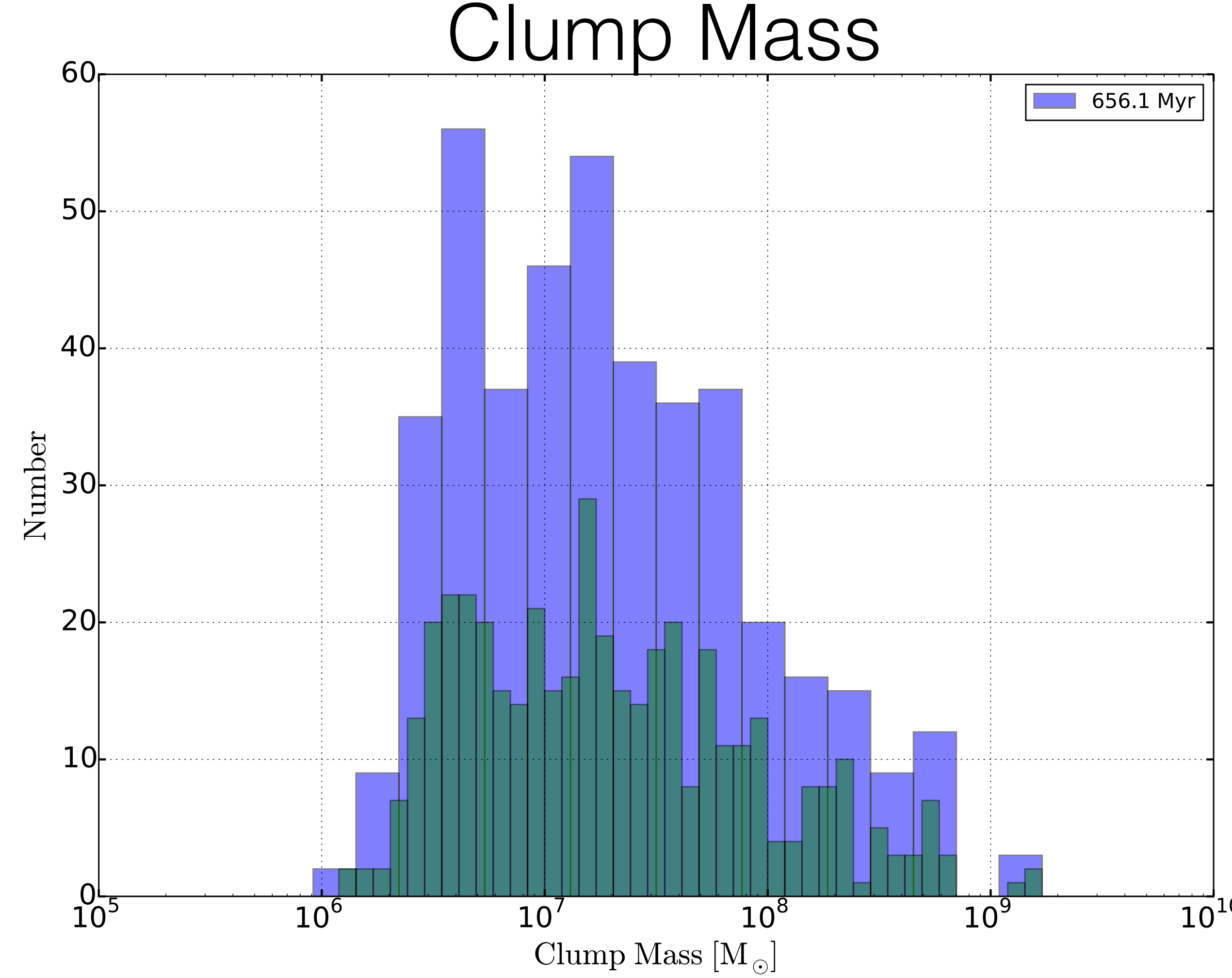
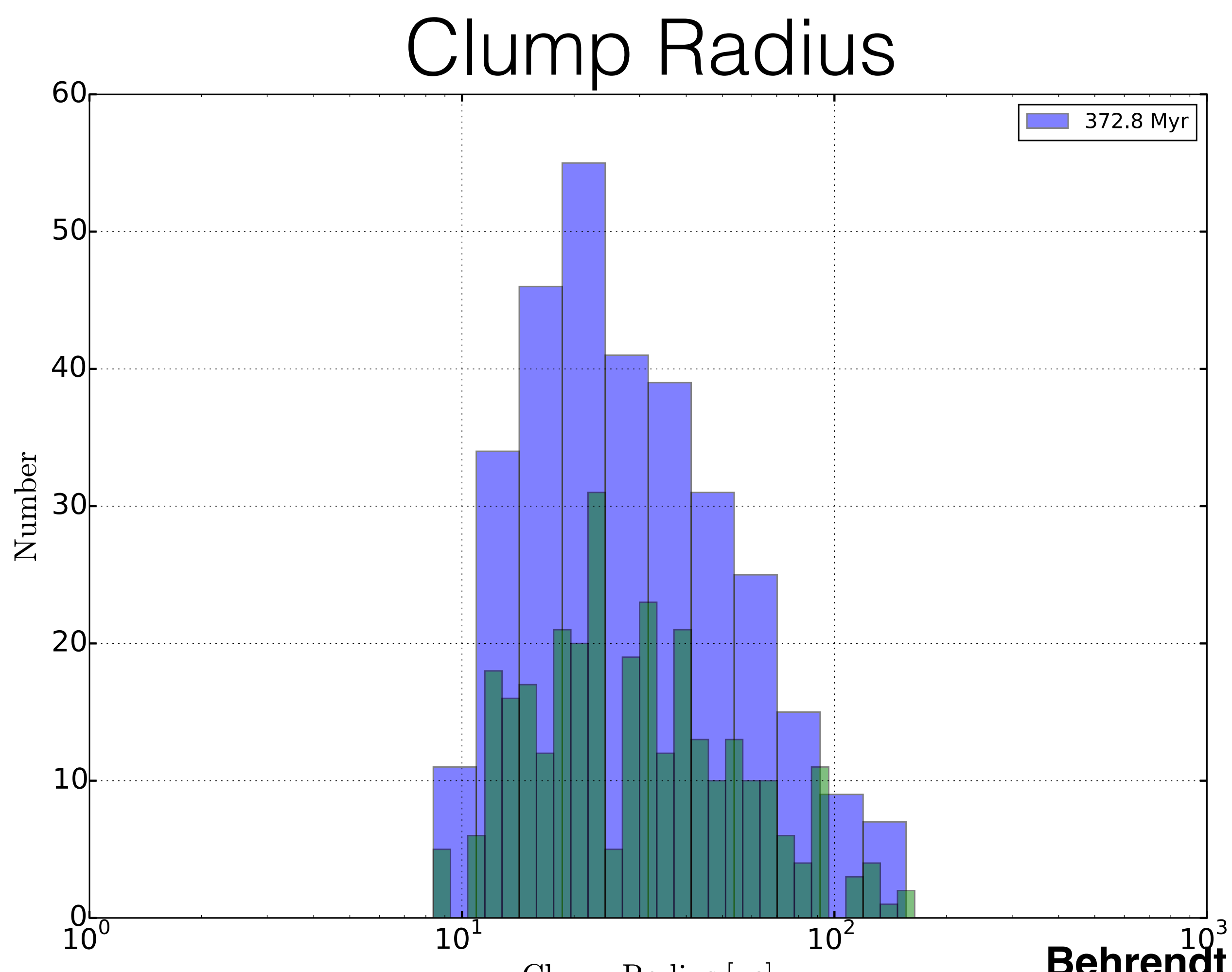
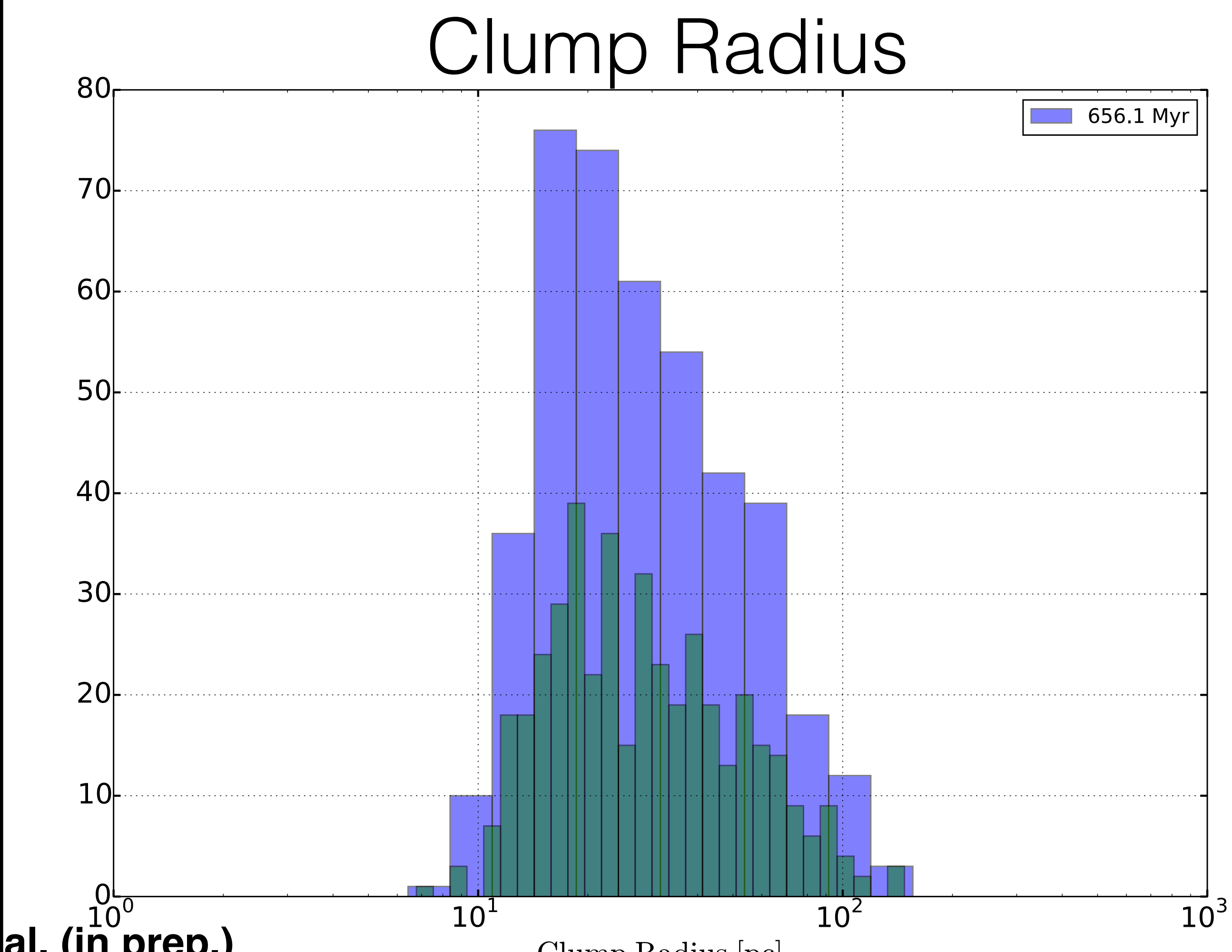


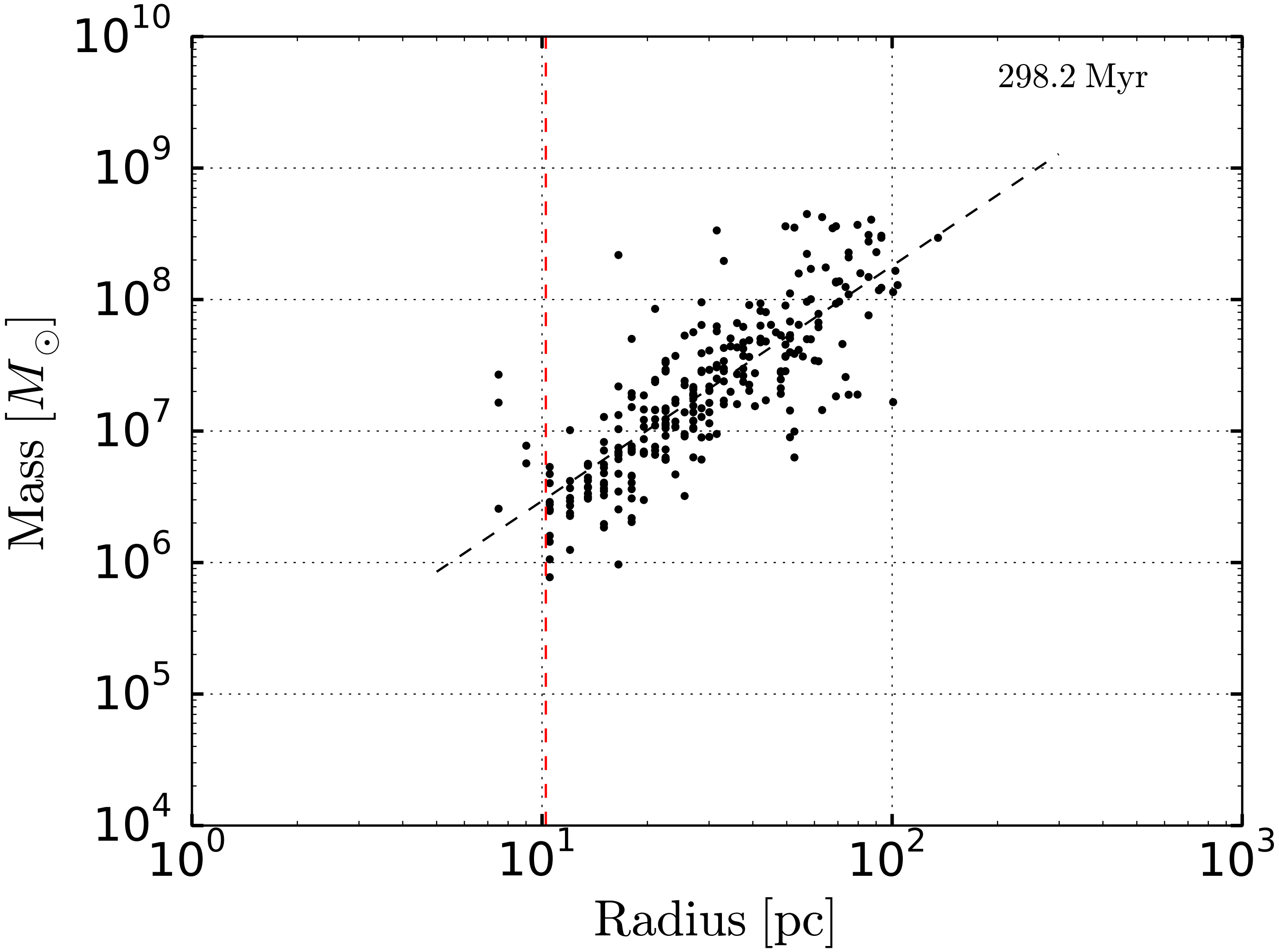


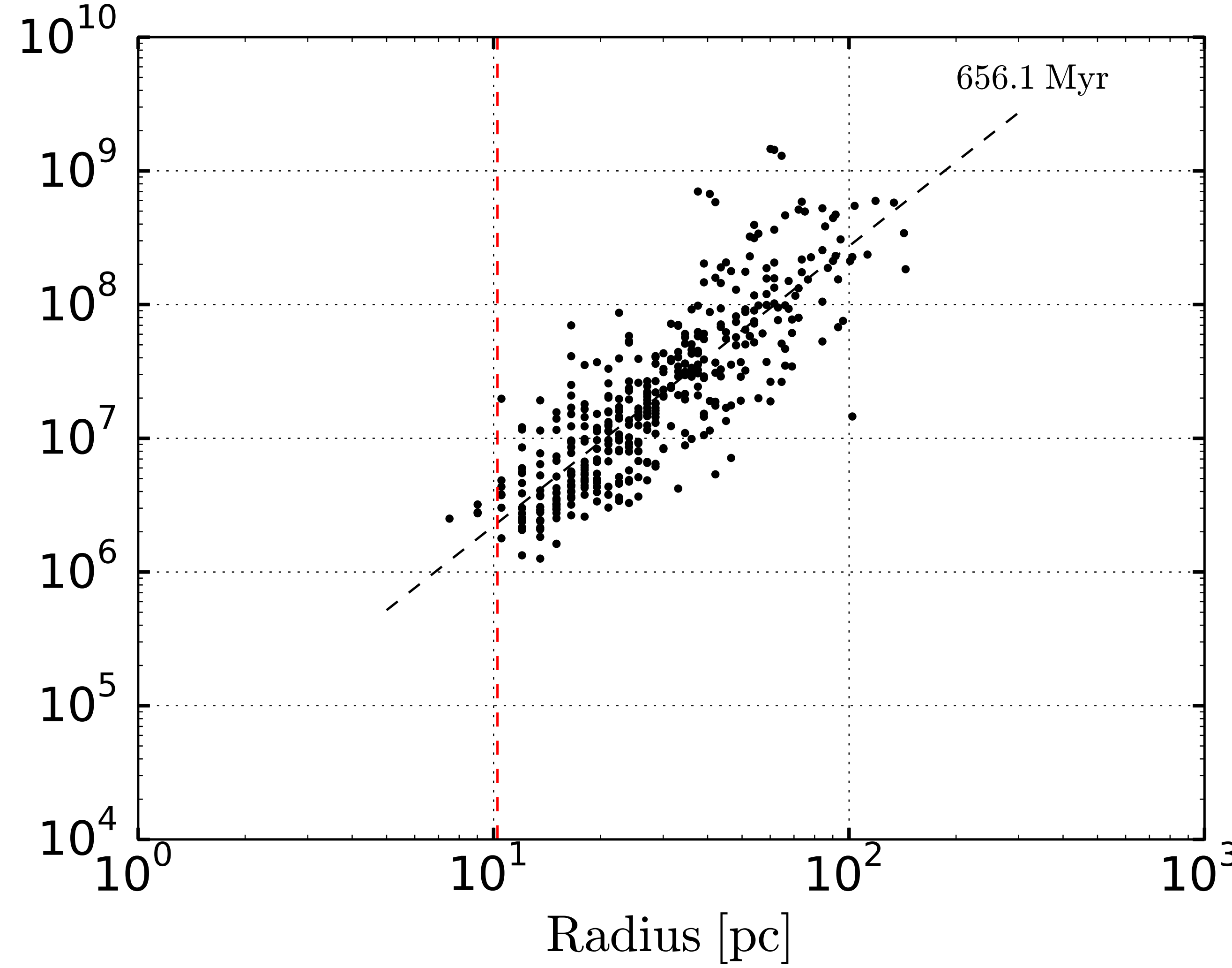




Behrendt et al. (in prep.)

Mass ∝ Radius$^{2\pm0.2}$





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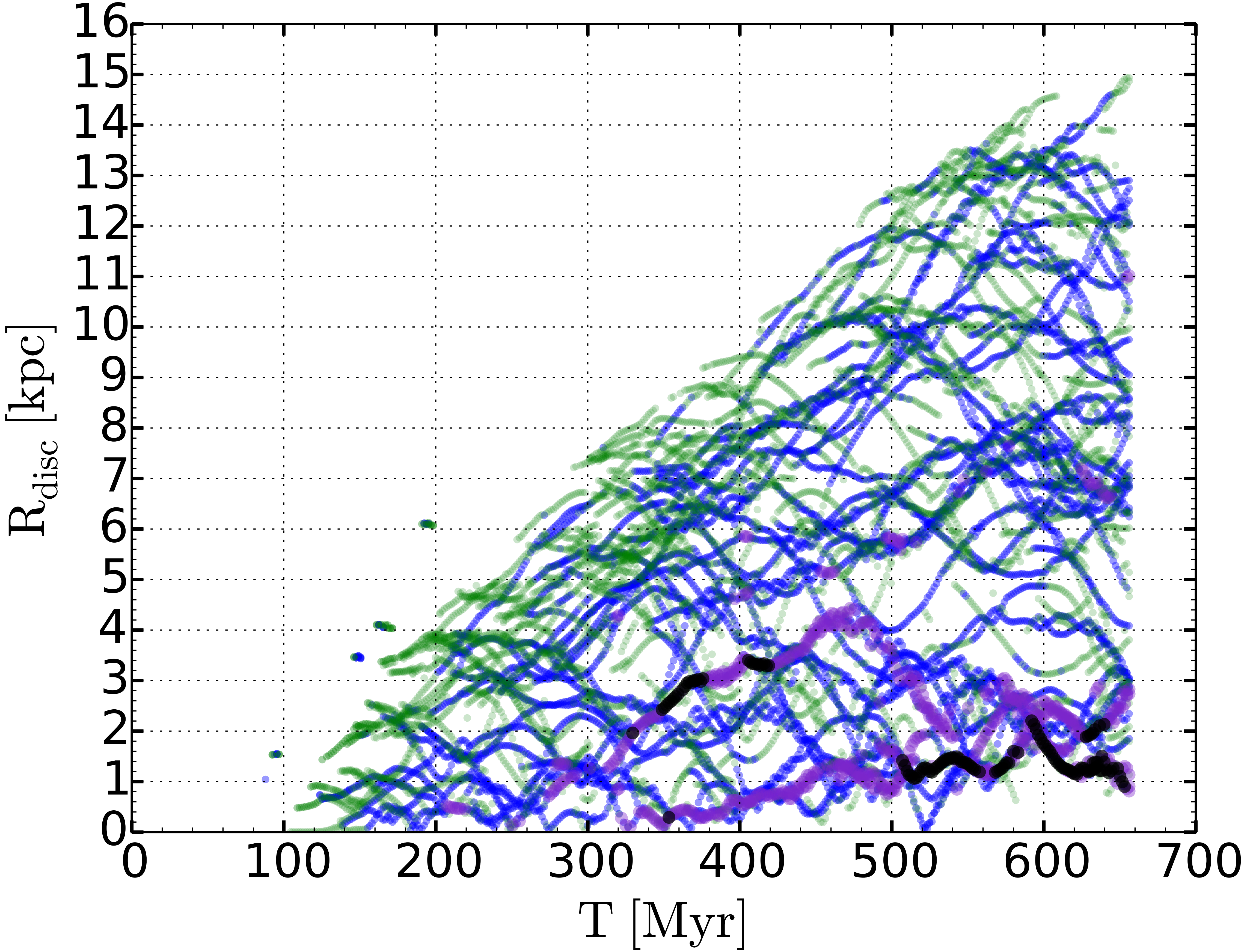
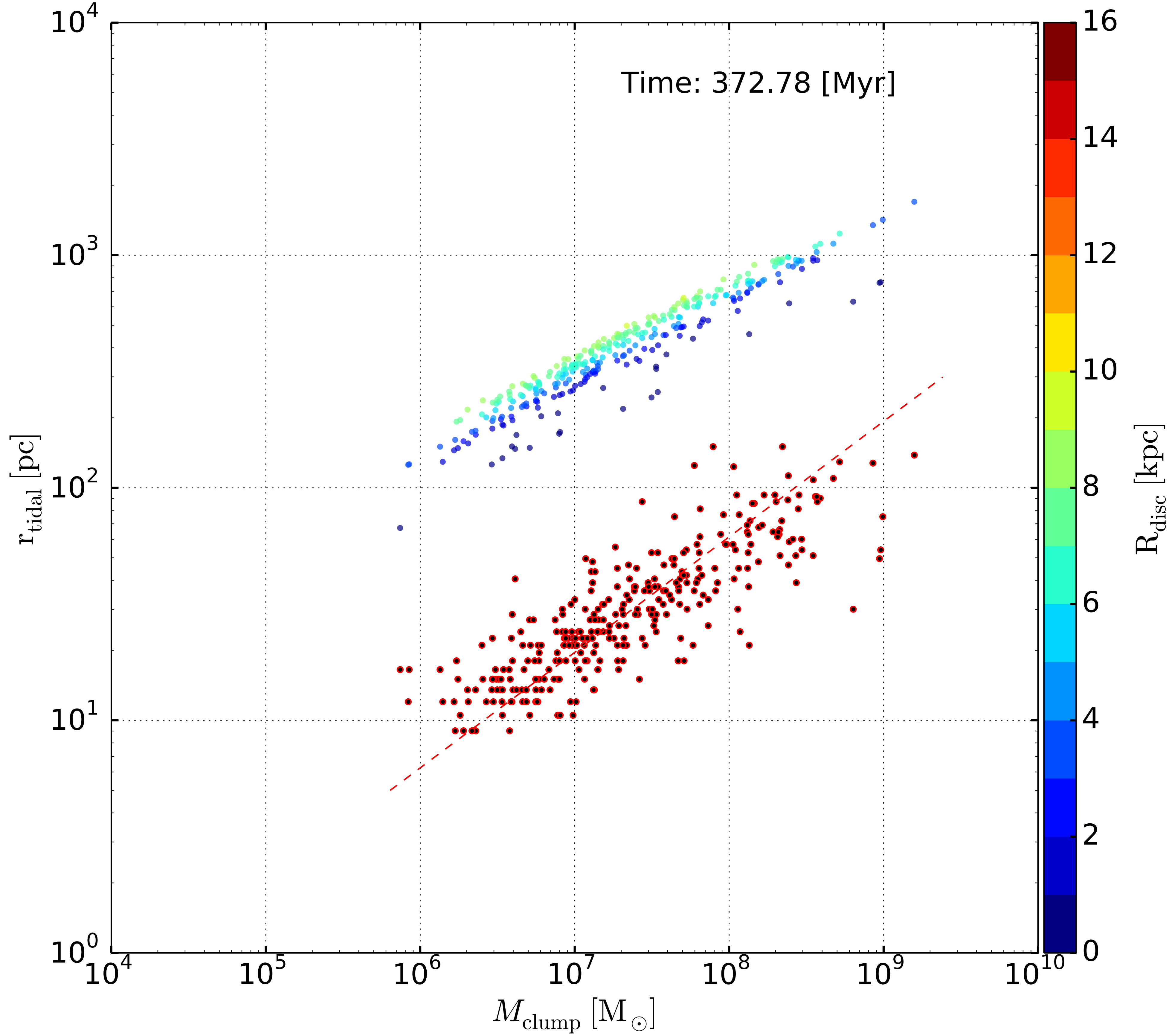
Time Evolution



Mass-bins: green [5e7:1e8[; **blue** [1e8:5e8[; **purple** [5e8:1e9[; **black** [1e9:5e9[

Behrendt et al. (in prep.)

Tidal Stripping?



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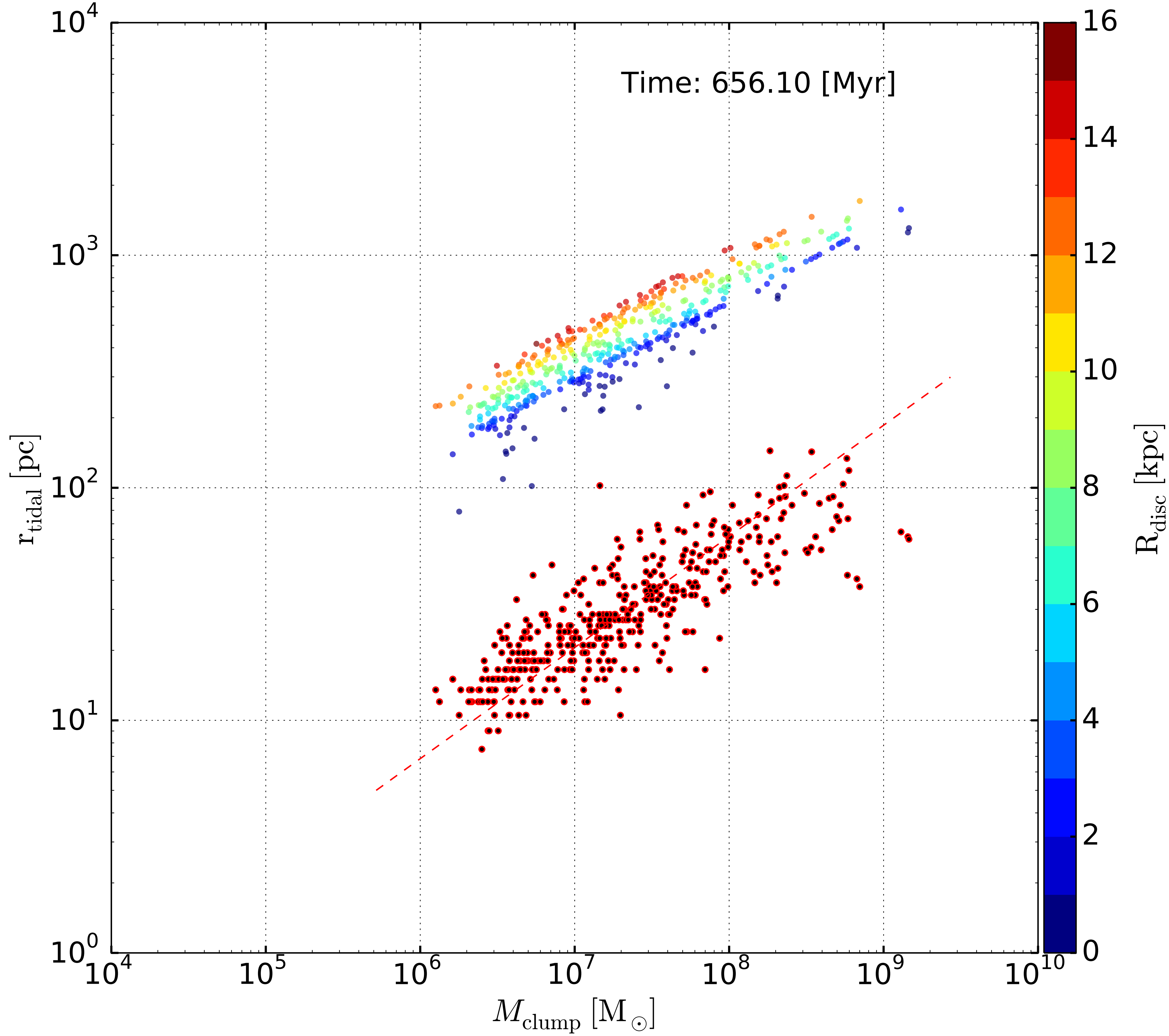

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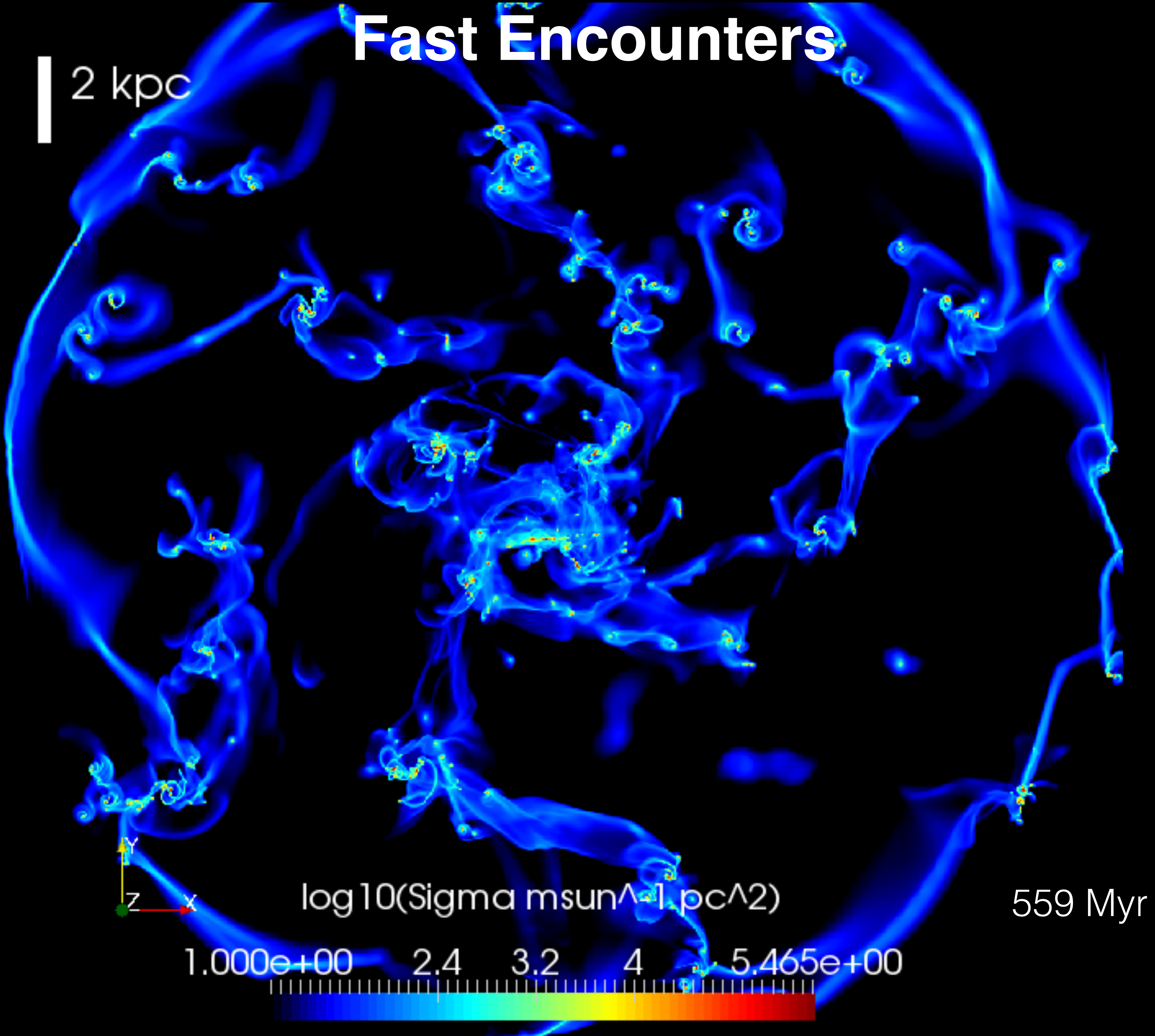
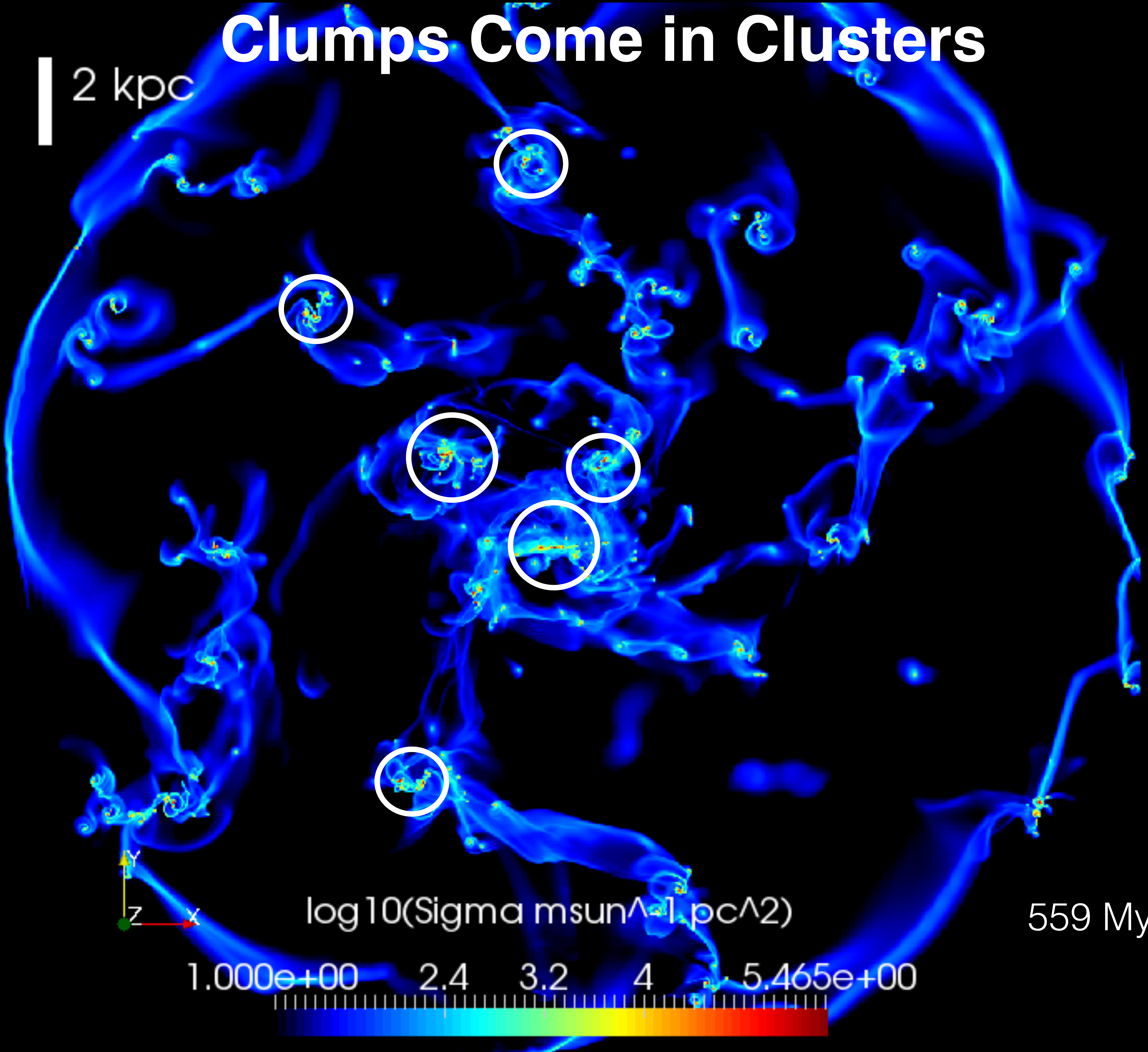
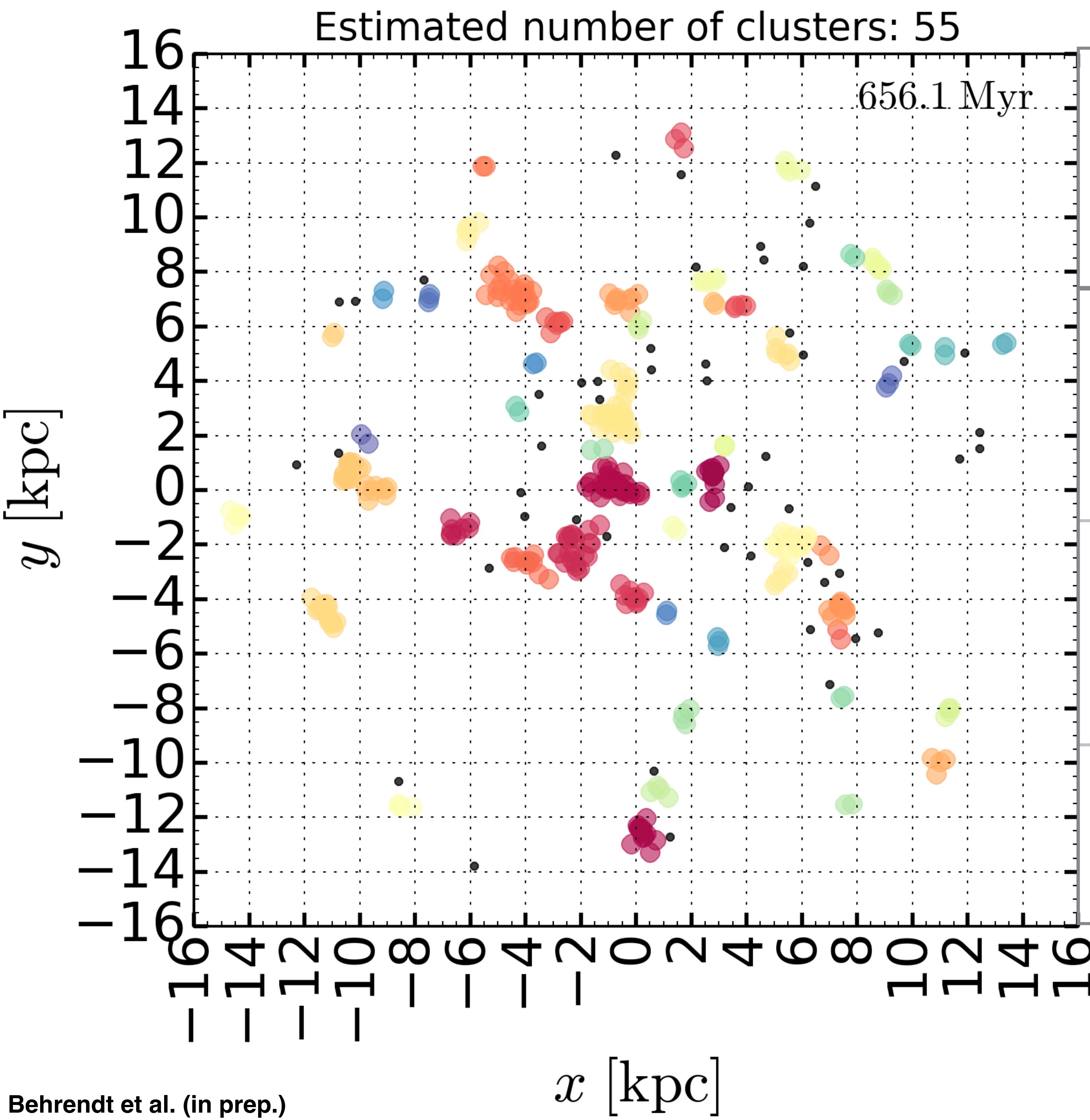
Fast Encounters



Clumps Come in Clusters



> 250 Myr interesting



color = cluster
(double assignment in color possible)
black = outliers

Density-Based Algorithm for Discovering Clusters in Large Spatial Databases with Noise. Finds core samples of high density and expands clusters from them.

Conditions:

The maximum distance between two samples for them to be considered as in the same neighborhood = **500 pc**

The number of samples in a neighborhood for a point to be considered as a core point. = min. **2**

Behrendt et al. (in prep.)

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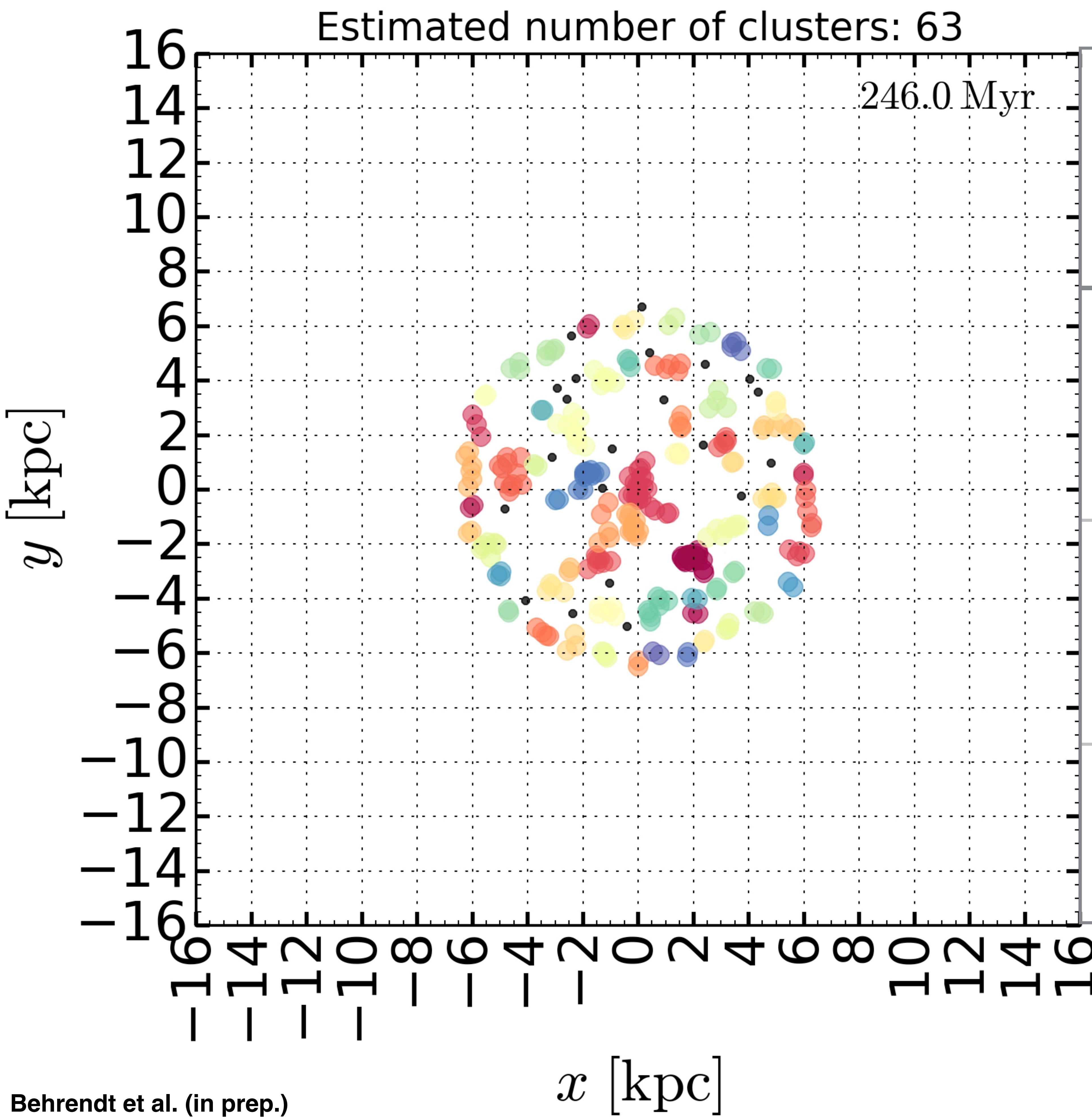

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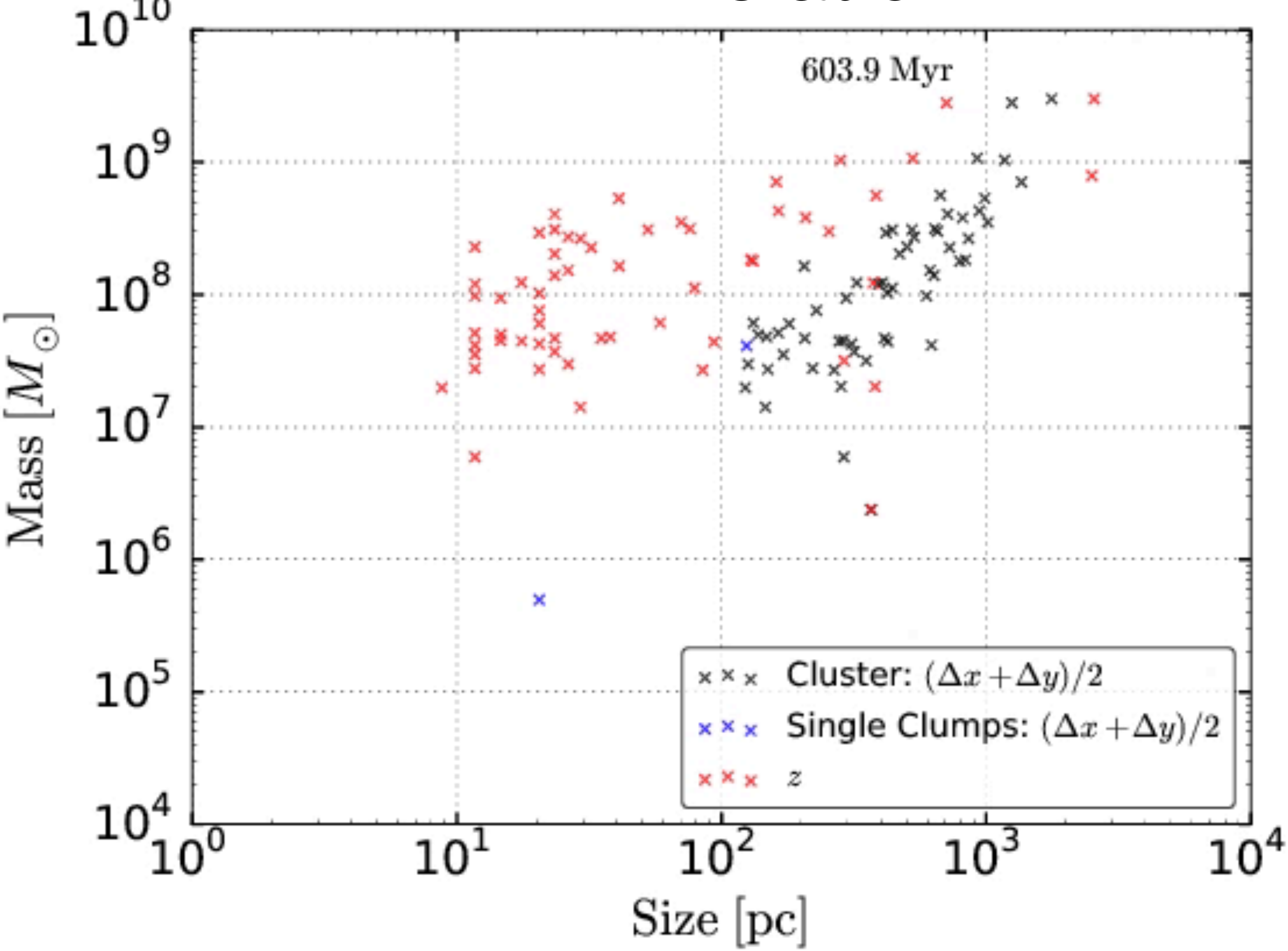
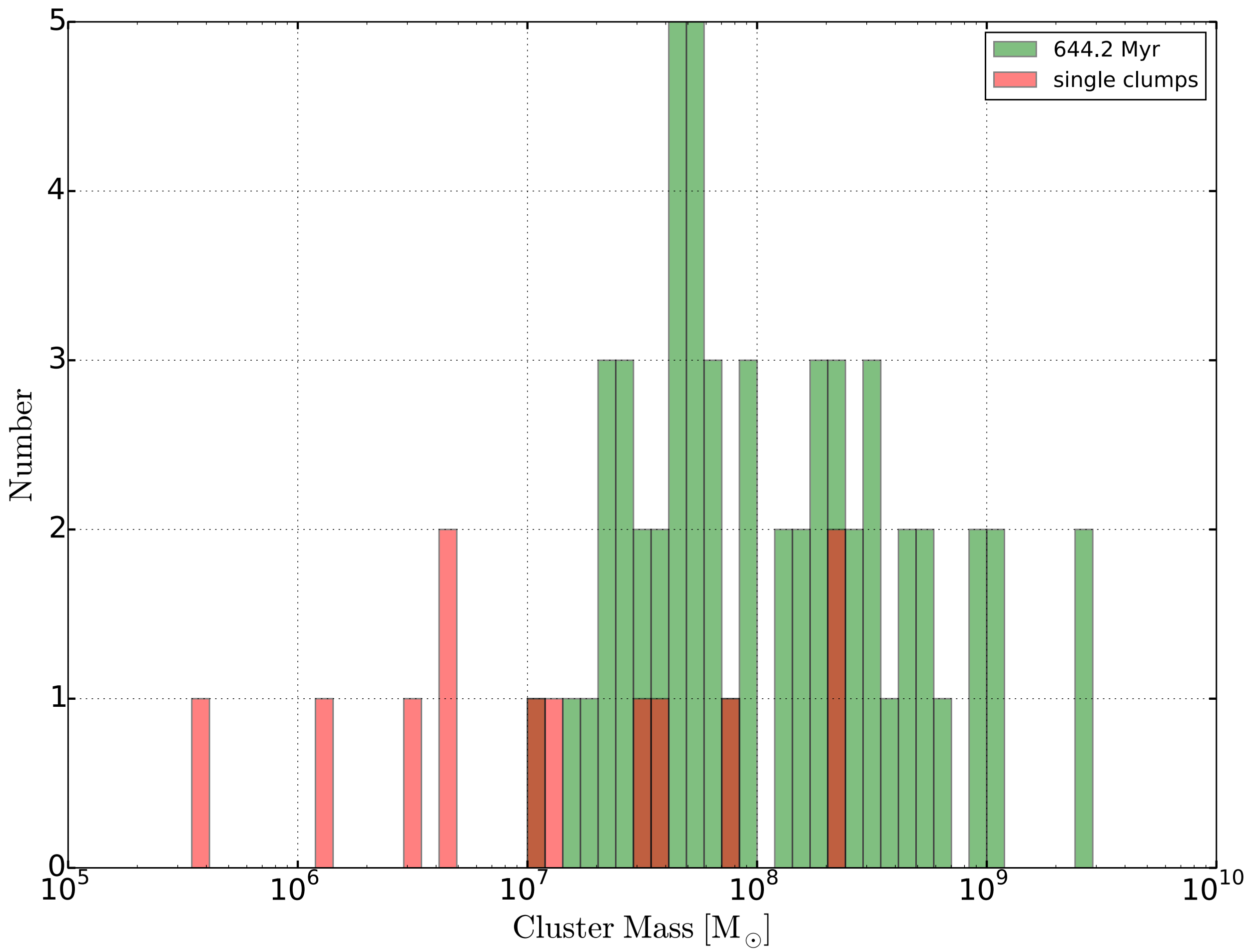
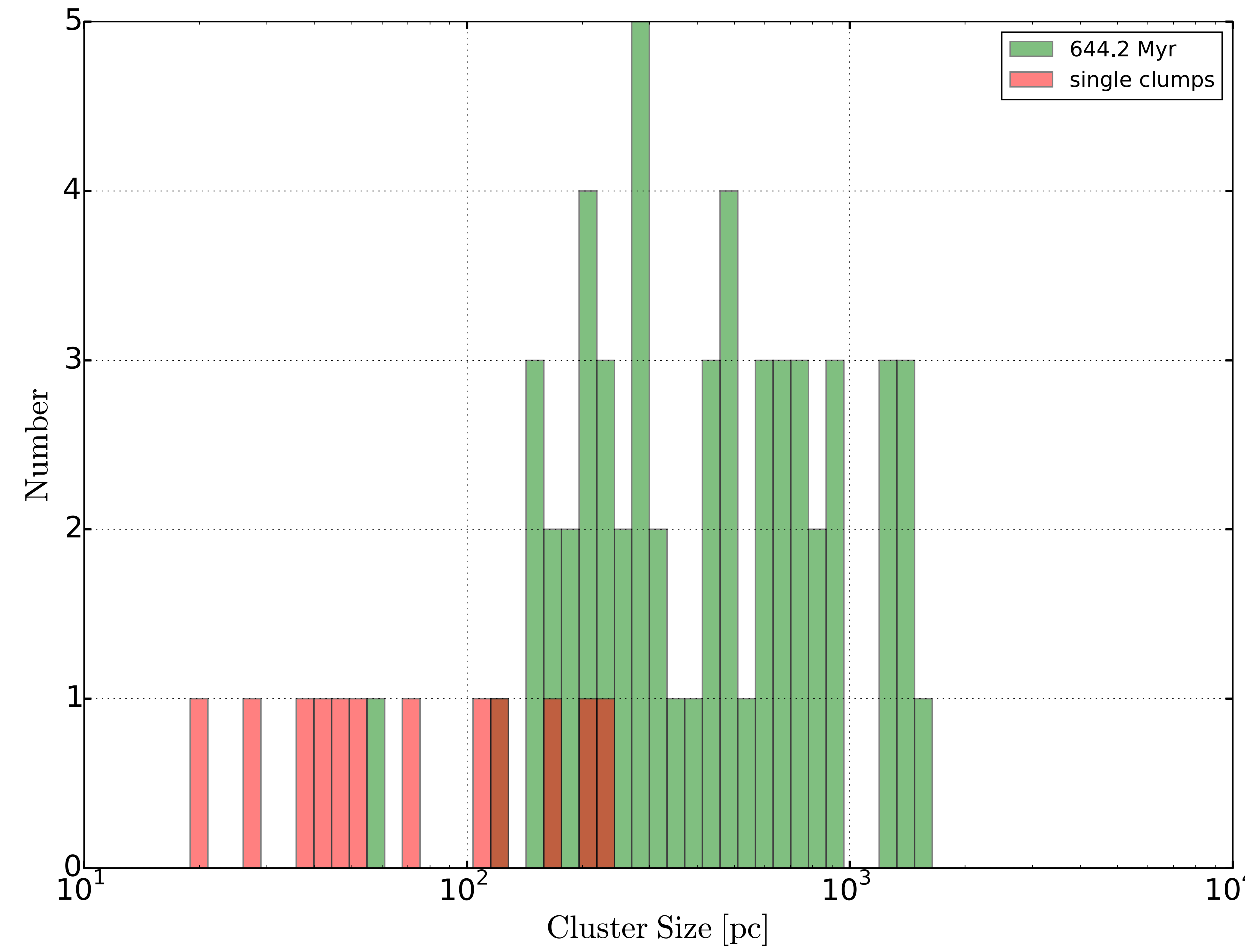
M-R Relation



Behrendt et al. (in prep.)

Cluster Histograms

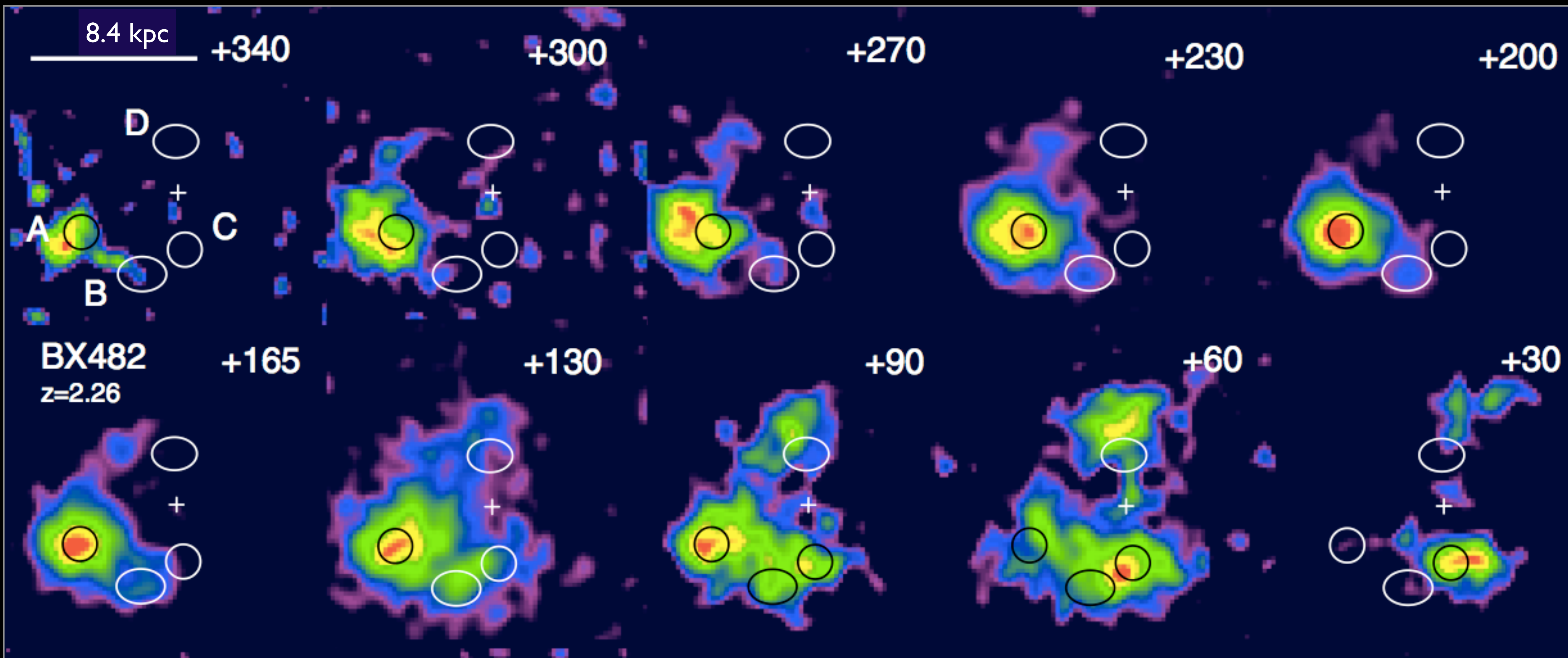




Behrendt et al. (in prep.)

Observations: Genzel et al. 2011

-Clumpy substructure below the current resolution-



Velocity "channels" in the Hα-line of width ~34 km/s

Summary

- Clumpiness is very common at high z
  -> can be explained by gravitational disk instability

- Fastest growing wavelength is ~2x larger for disks with thickness
- -> for $Q < Q_{crit}$ -> Rings form (in an axisymmetric disk)
- It is very import to resolve the disk scale height several times
- -> rings collapse first, before they break-up
  into a large number of clumps (according to local conditions)
  -> wavelength is not directly correlated to clump size anymore
  -> giant clumps cannot form initially

- Clumps merge to upper limit of $<10^9\ M_{sol}$
- Clumps build ~kpc sized groups and re-group all the time
  -> indication: observed giant clumps have substructure