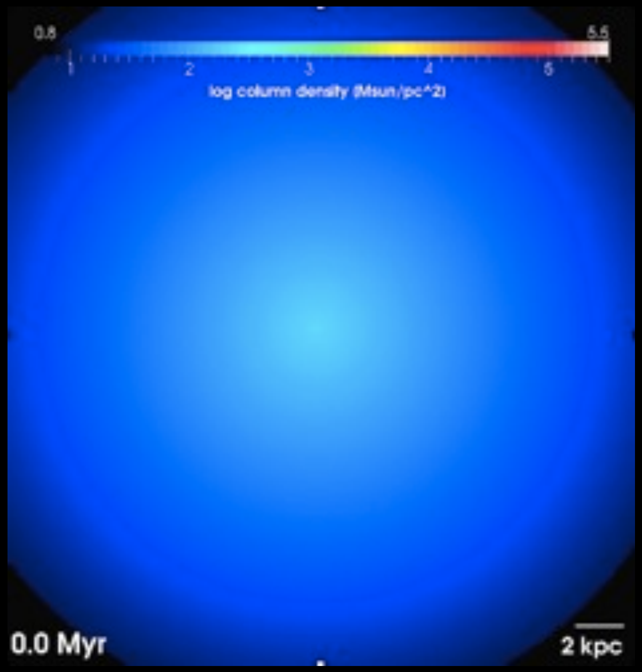
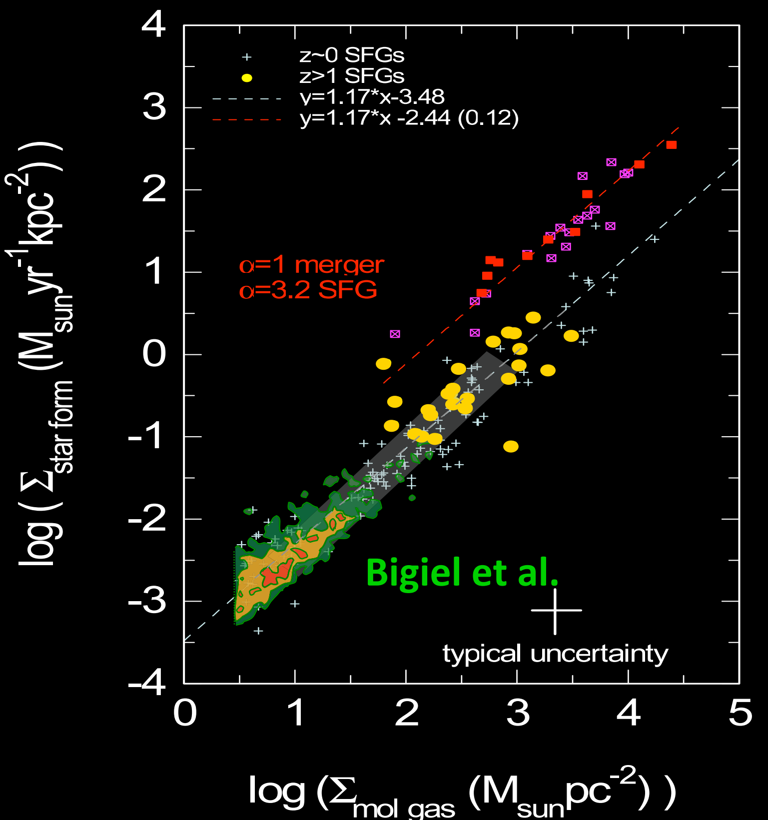
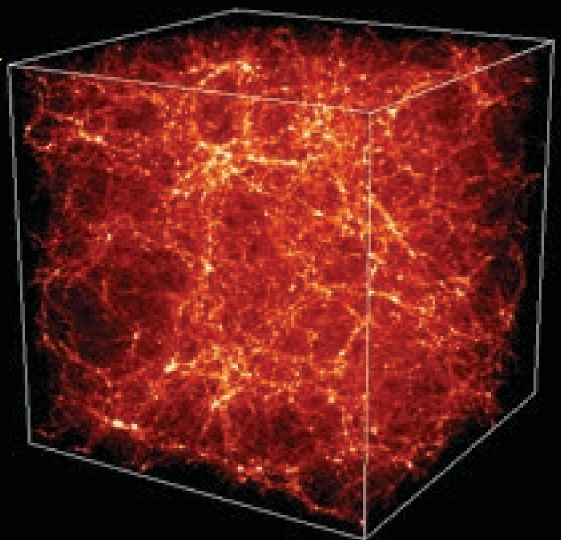
Violent disk instabilities and high-z disk galaxies

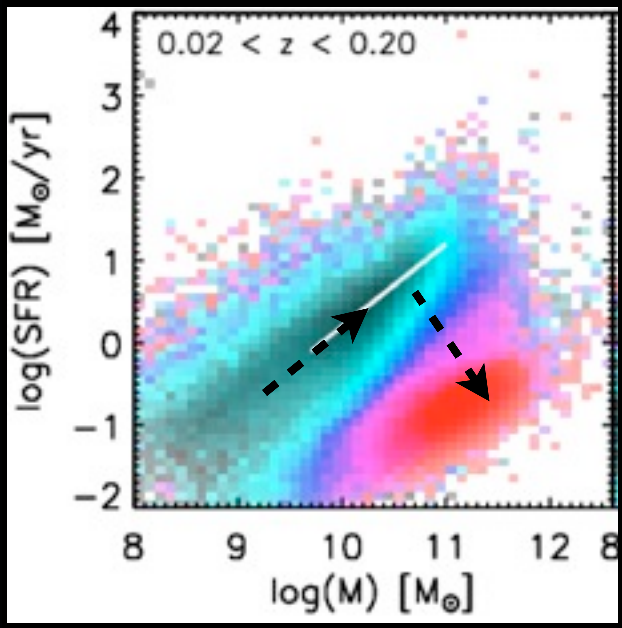


Andreas Burkert
USM & MPE

R.Genzel, L. Tacconi, N. Förster-Schreiber + SINS
C. Dobbs, K. Fierlinger, M. Gritschneder
J. Ngoumou, C. Alig, L. Hartmann, N. Möckel,
S. Heigl, M. Krause, M. Brunner, M. Schartmann

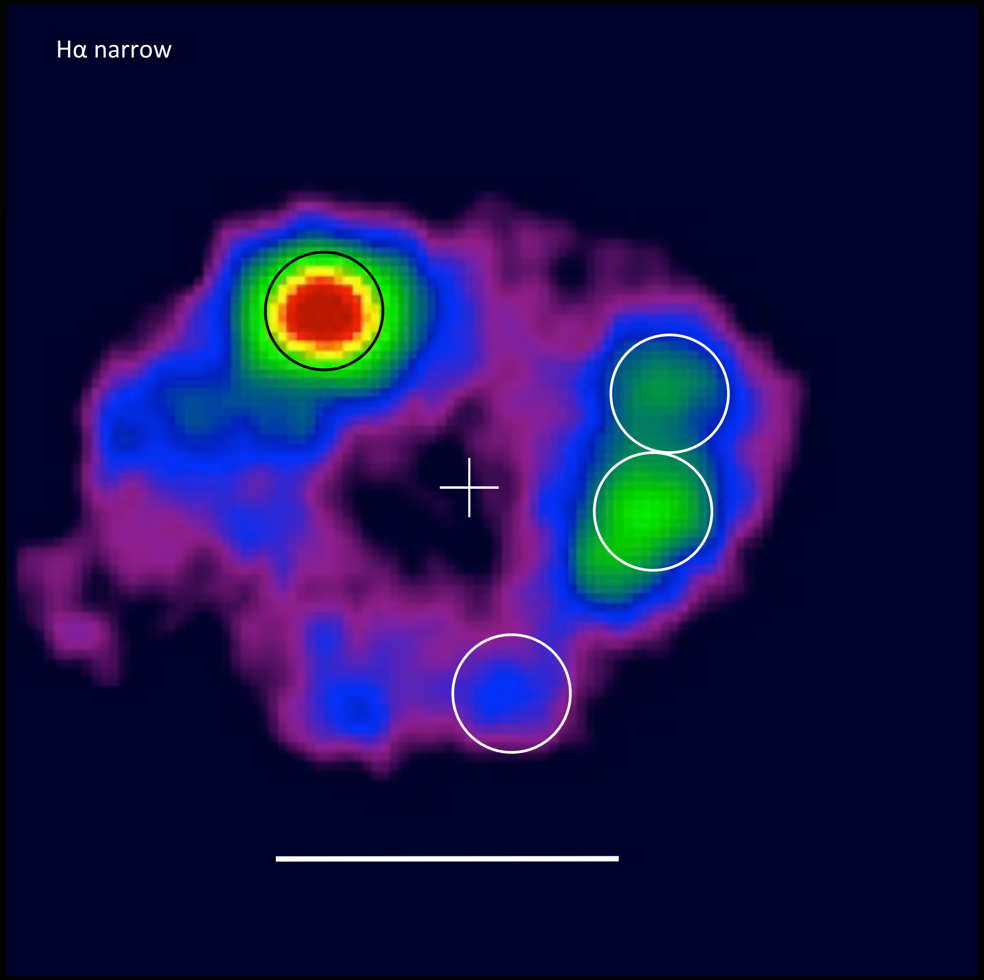


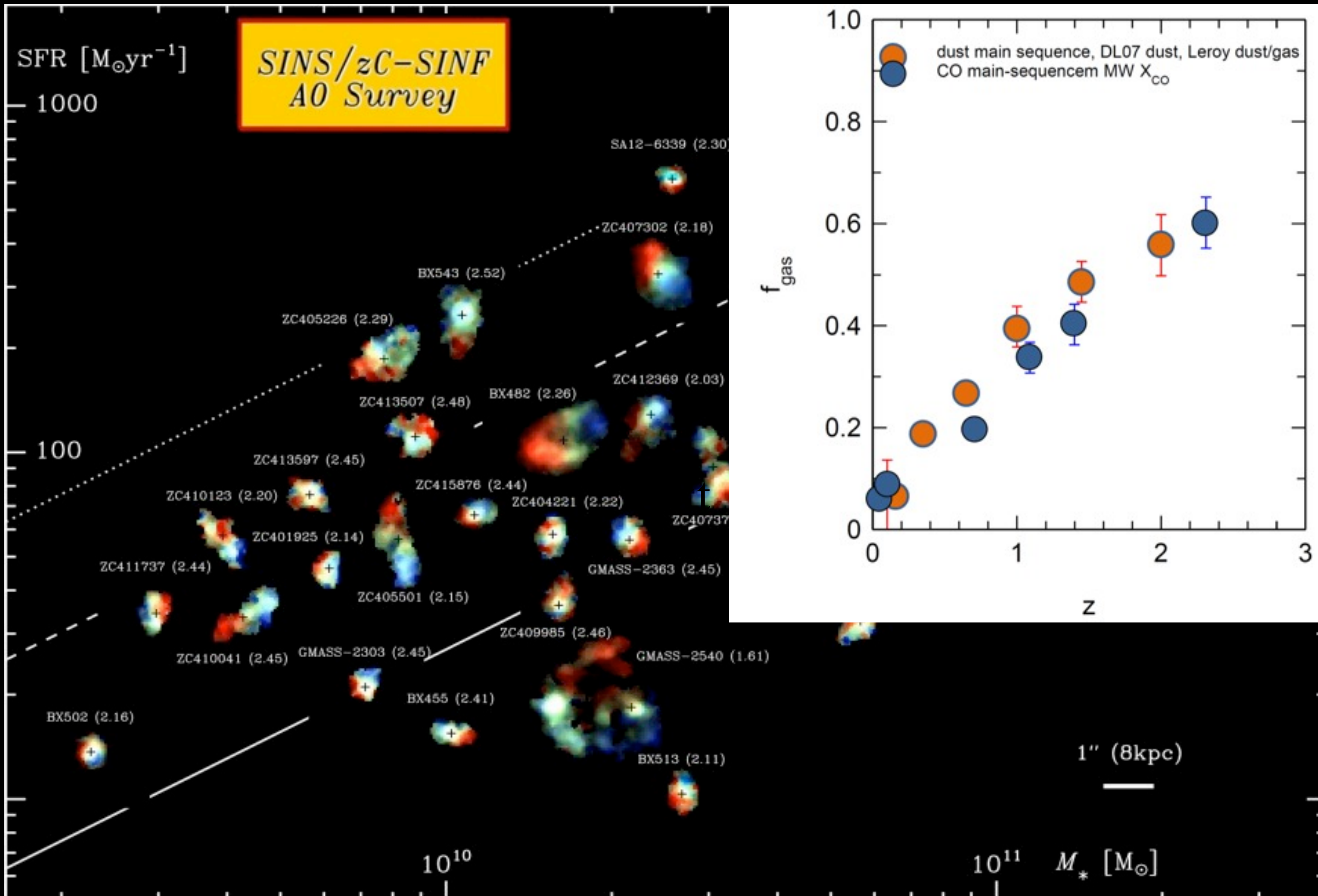




A Nearby, Normal
Star Forming Disk Galaxy

A Normal
Star Forming Disk Galaxy
Far, Far Away



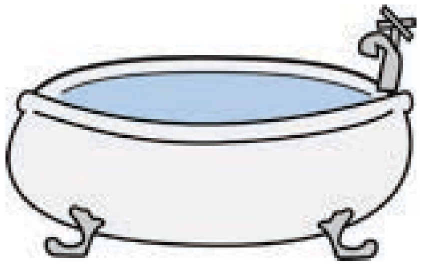


Förster-Schreiber+ 09,11, Genzel+ 08,11, Cresci+09, Mancini+11, Newman+13

What determines the SFR and gas fraction of a galaxy?

(Bouche+10; Davé+11a,b; Forbes+12,13, Lilly+13)

$$\left(\frac{dM_g}{dt}\right)_{acc} = SFR \cdot \left(1 - R + \alpha_{wind}\right)$$



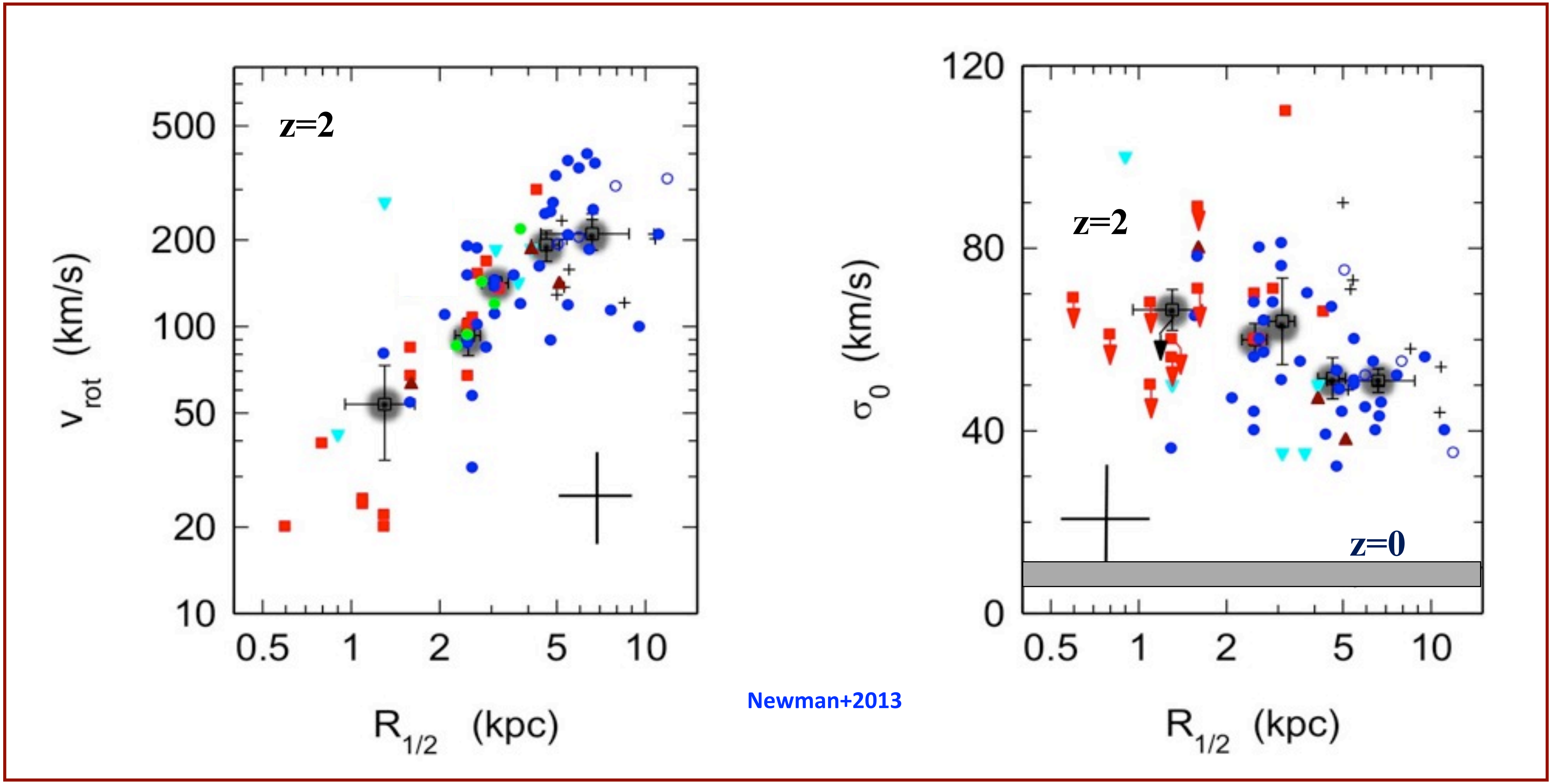
$$SFR = \frac{1}{1 - R + \alpha_{wind}} \left(\frac{dM_g}{dt}\right)_{acc} \equiv \dot{M}_{acc,eff} = \frac{M_g}{\tau_{sf}}$$

$$f_g = \frac{M_g}{M_*} = \frac{\dot{M}_{acc,eff} \cdot \tau_{sf}}{M_*}$$

$$\tau_{sf} \overset{?}{\approx} 5 \cdot 10^8 - 10^9 \, yrs$$

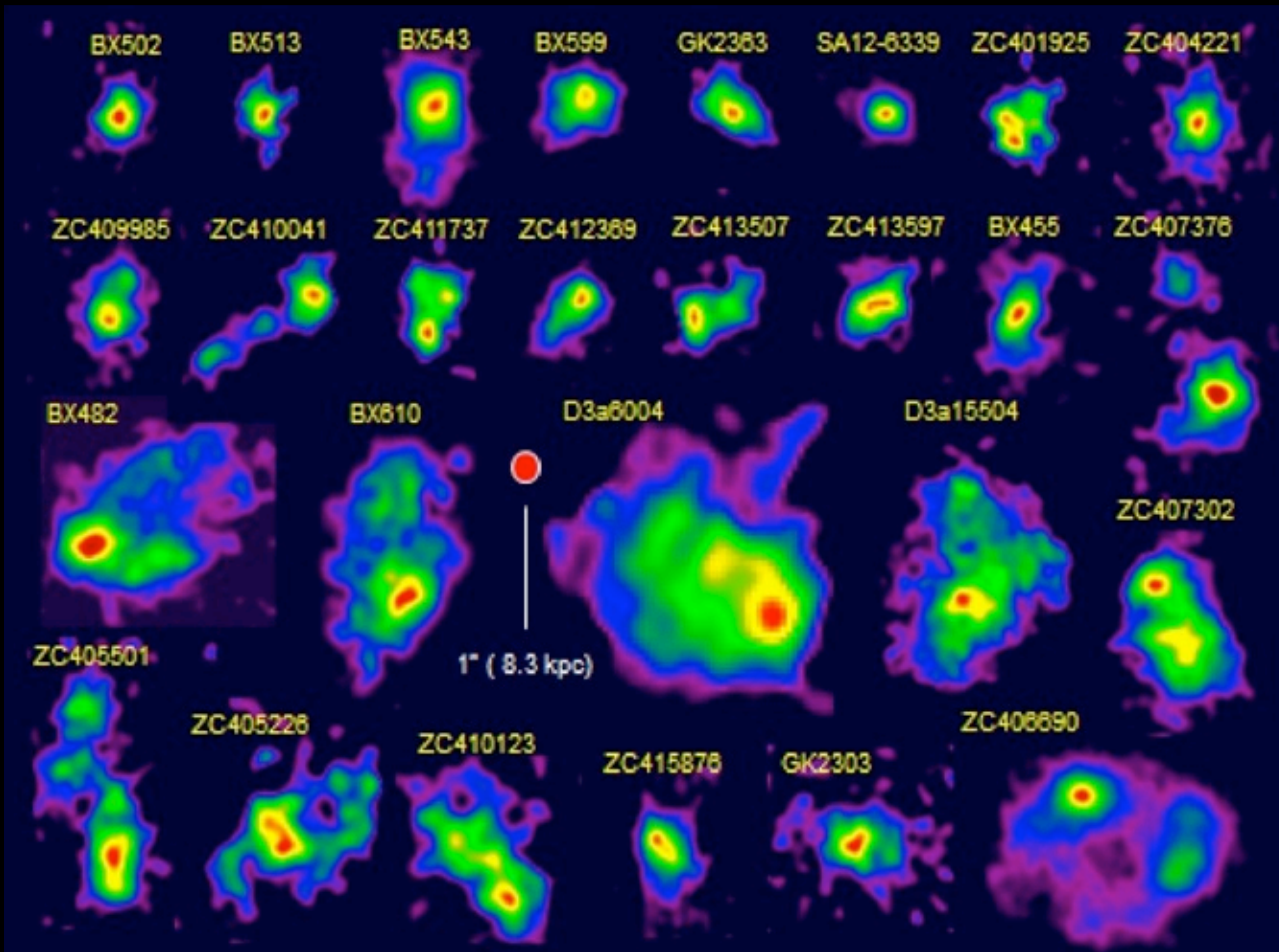
(Everett+ 8,10, Brook+ 11, Hopkins+ 12, Dalla Vecchia+ 12, Bolatto+ 13, Hirschmann+13, von Glasow+ 13, Hanasz+ 13, Agertz+ 13)

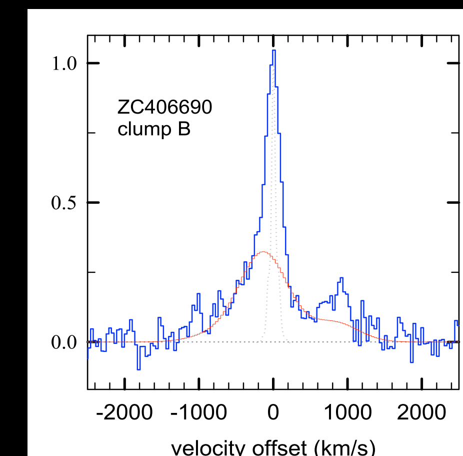
High irregular gas velocities

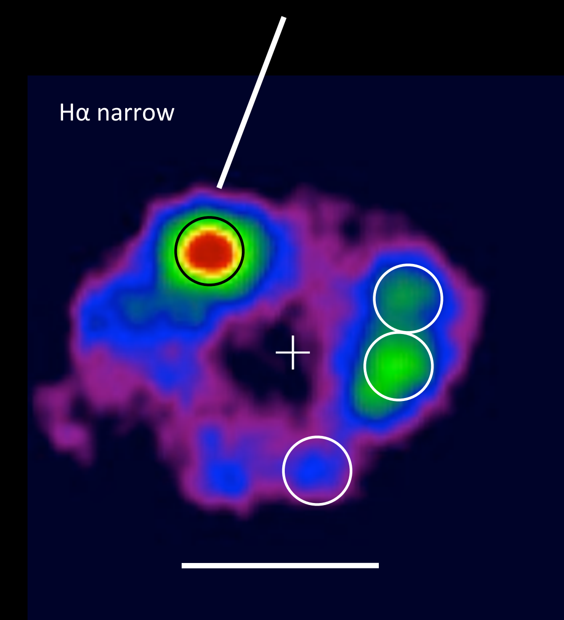


Newman+2013

kpc sized star-forming clumps
with strong winds launched from clumps







$$M_{clump} \approx 10^{7.5} - 10^{9.5} M_{\odot}$$

$$R_{clump} \approx 0.5 \text{ kpc - } 2 \text{ kpc}$$

Local Axisymmetric Instability

sound speed → pressure

epicyclic frequency → $\propto \frac{V_{rot}}{R}$

$$Q_0 = \frac{c_s \varkappa}{\pi G \Sigma}$$

Toomre 1964

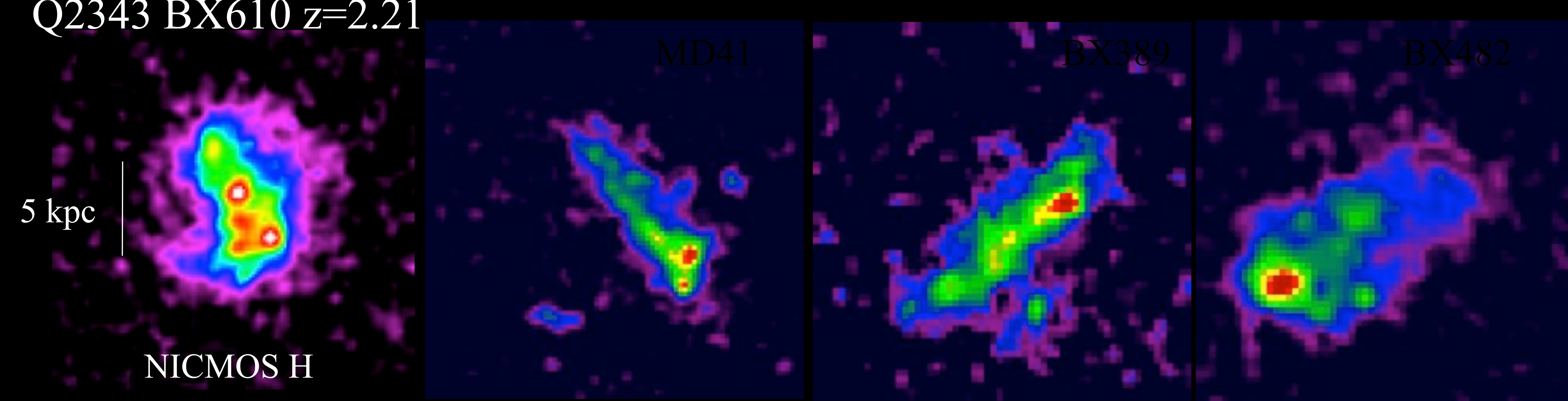
$$\begin{cases} Q_0 < 1 & \text{unstable} \\ Q_0 > 1 & \text{stable} \end{cases}$$

self-gravity → destabilizing

$$\delta \equiv M_{gas} / M_{dyn}$$

$$Q = \frac{\sqrt{2}}{\delta} \frac{\sigma}{v_{rot}}$$

(e.g. Dekel+ 10,12,13,14)



Problems

- Linear theory does not apply
- Galaxies are not axisymmetric
- Do disks really stabilize for Q>1?
- σ does not depend on v_{rot}
- Most of the molecular mass is not in massive clumps
- Clumps should be fast rotating which is not observed.

Violent disk instability

$$\delta \equiv M_{gas} / M_{dyn} \approx 0.3 - 0.7$$

$$Q = \frac{\sqrt{2}}{\delta}\left(\frac{\sigma}{v_{rot}}\right) \approx 1 \quad \downarrow$$

$$\frac{\sigma}{v_{rot}} = \frac{\delta}{\sqrt{2}} \qquad \frac{\lambda}{R} = \delta$$

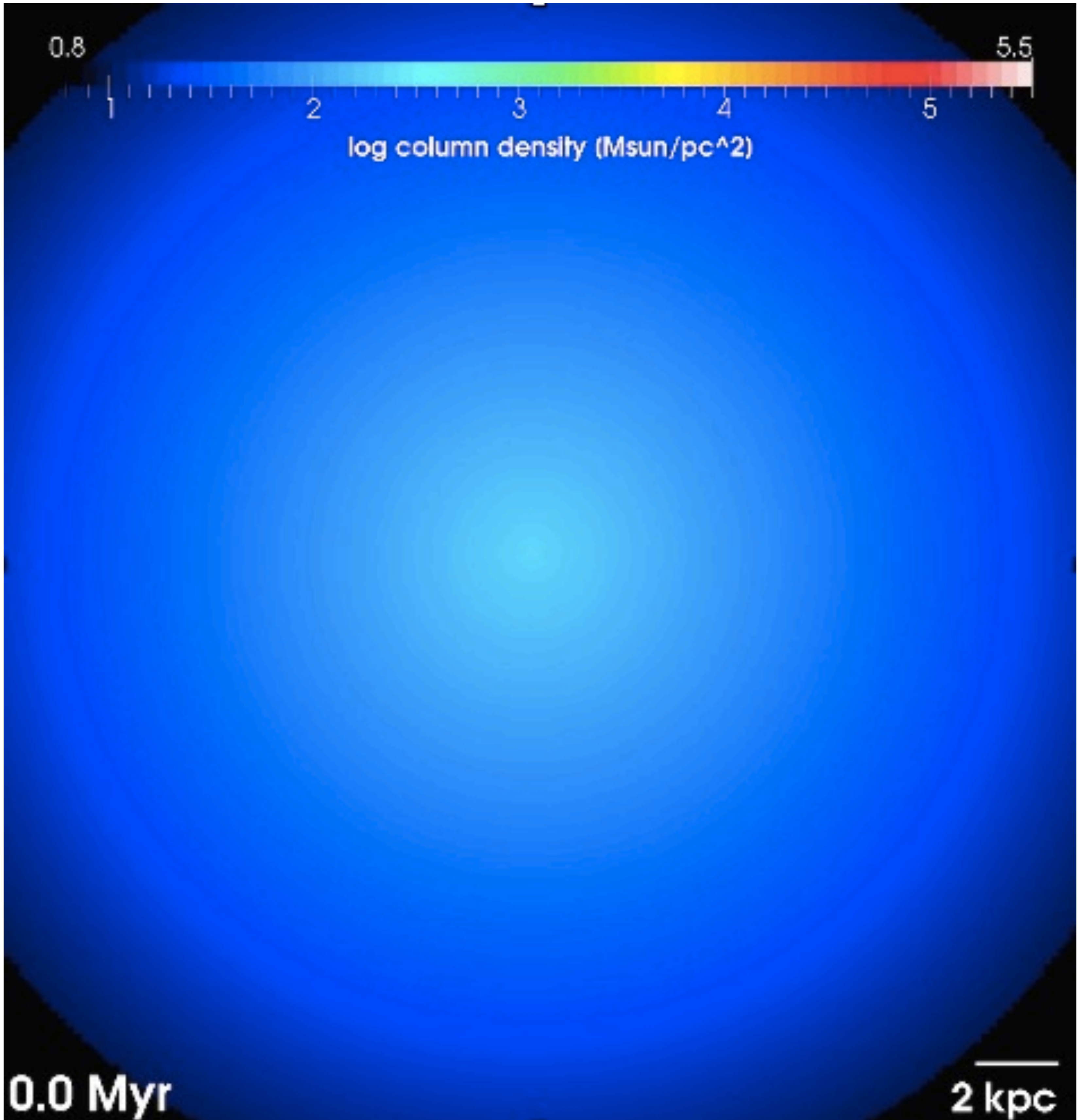
$$\frac{M_{clump}}{M_{disk}} \approx \delta^2$$

Toomre 1964, Giavalisco et al. 1996, Förster Schreiber et al. 2009b, Elmegreen et al. 2005, 2007, 2009

Structure Formation in High-Redshift Disk Galaxies

Manuel Behrendt, Andreas Burkert, Marc Schartmann

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

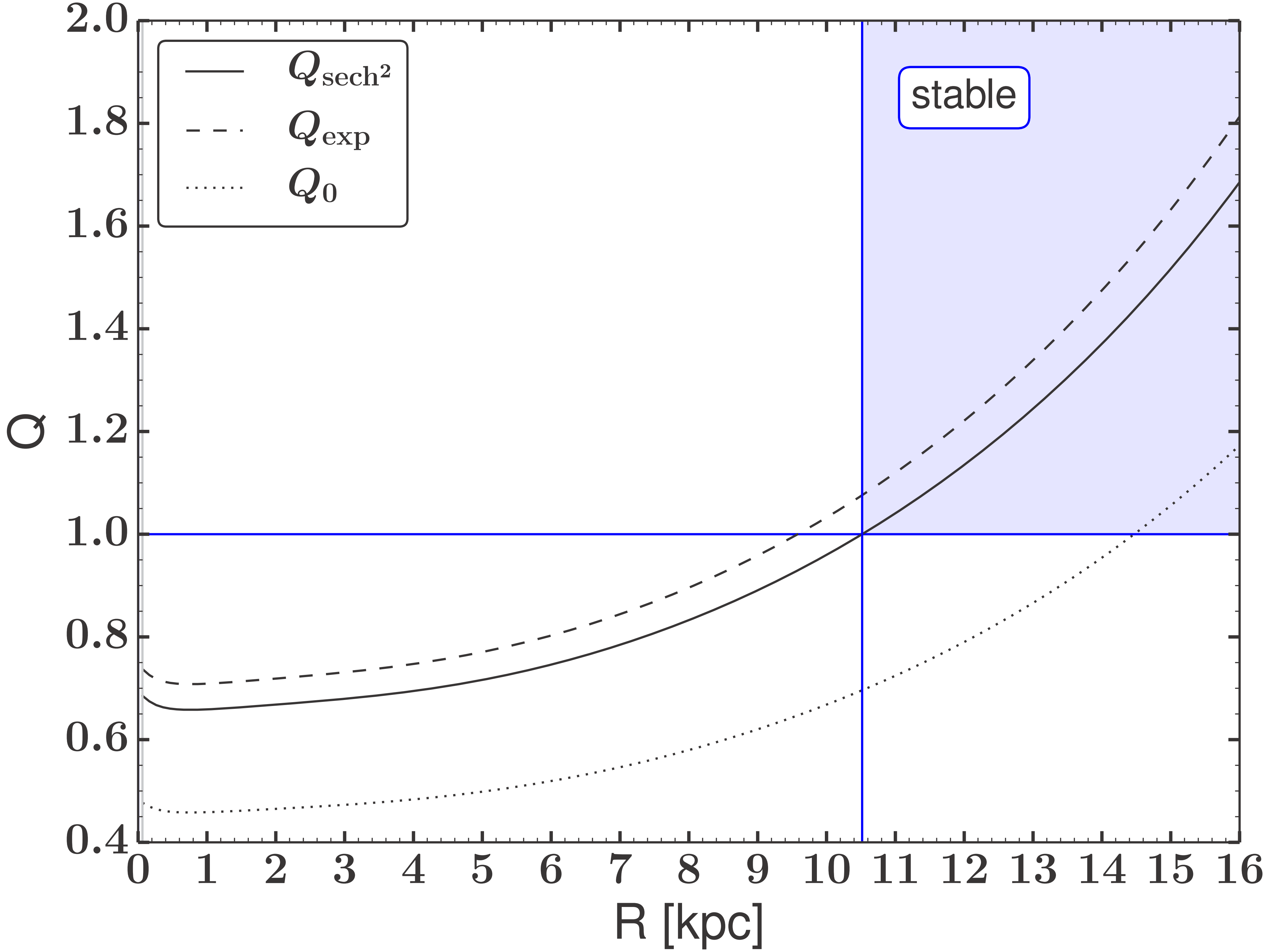
$N_J = 19$

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

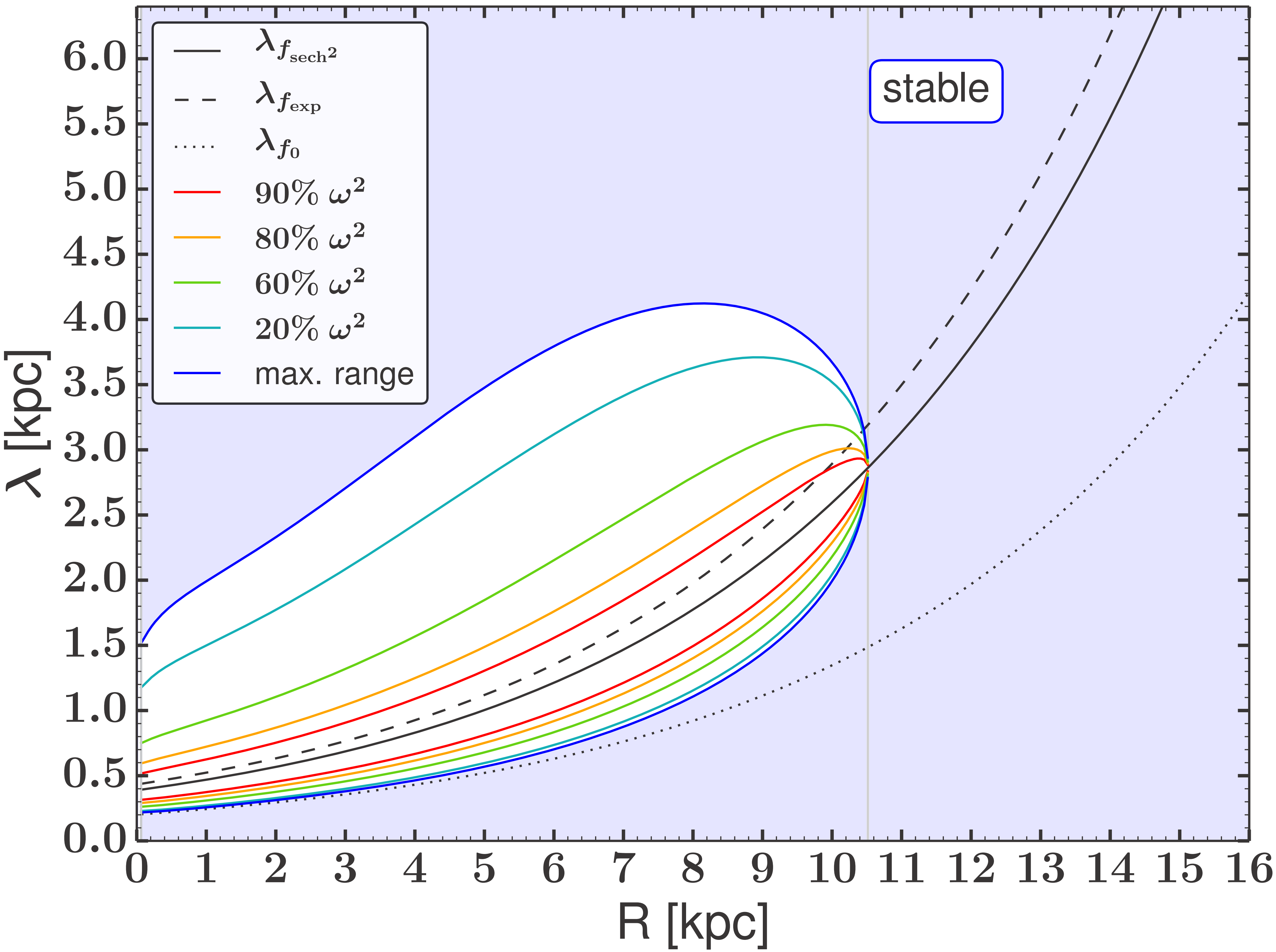
$\Delta_{\min} = 2.9\ pc$

$\approx z_0, 5 \times resolved$

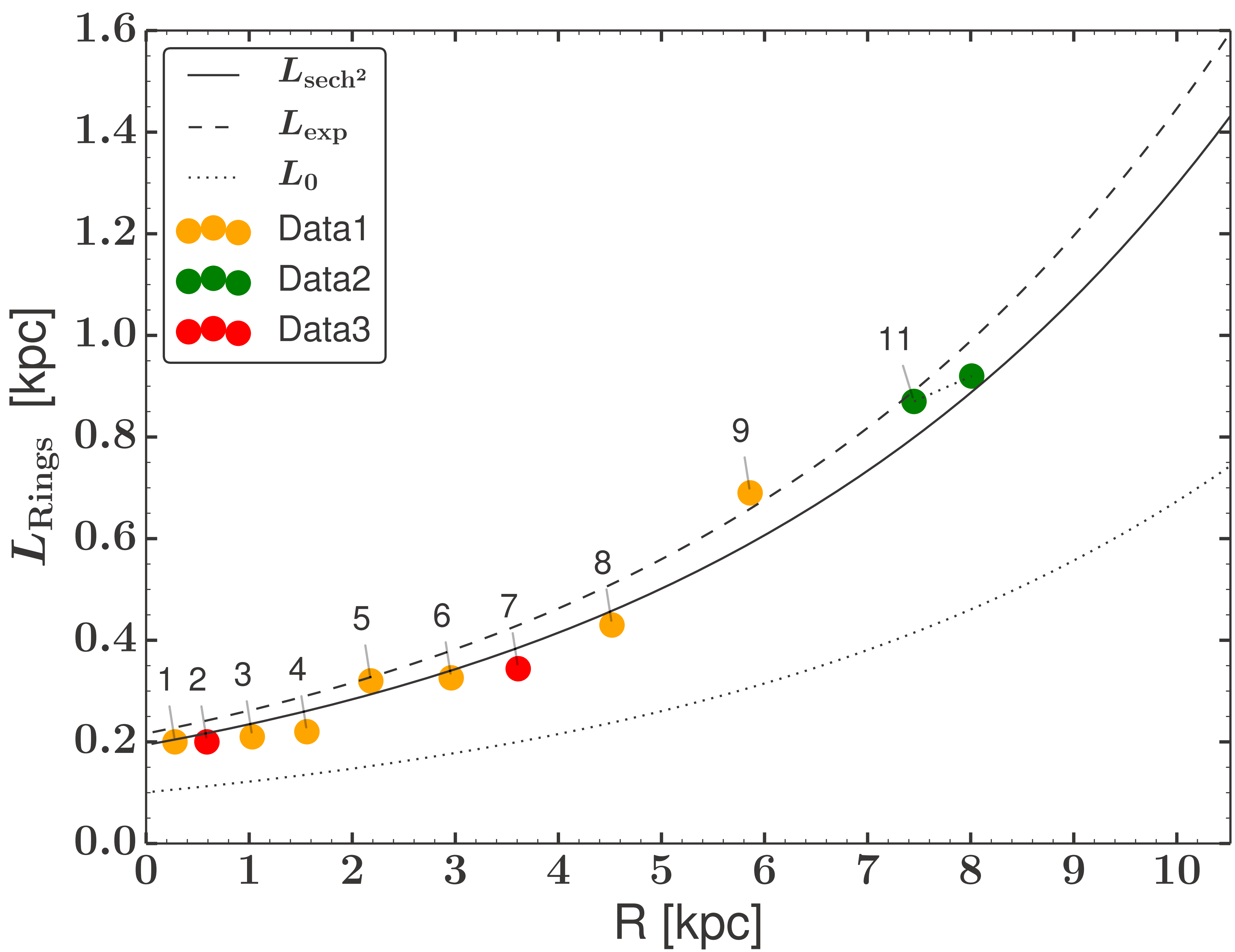
Instability Parameter

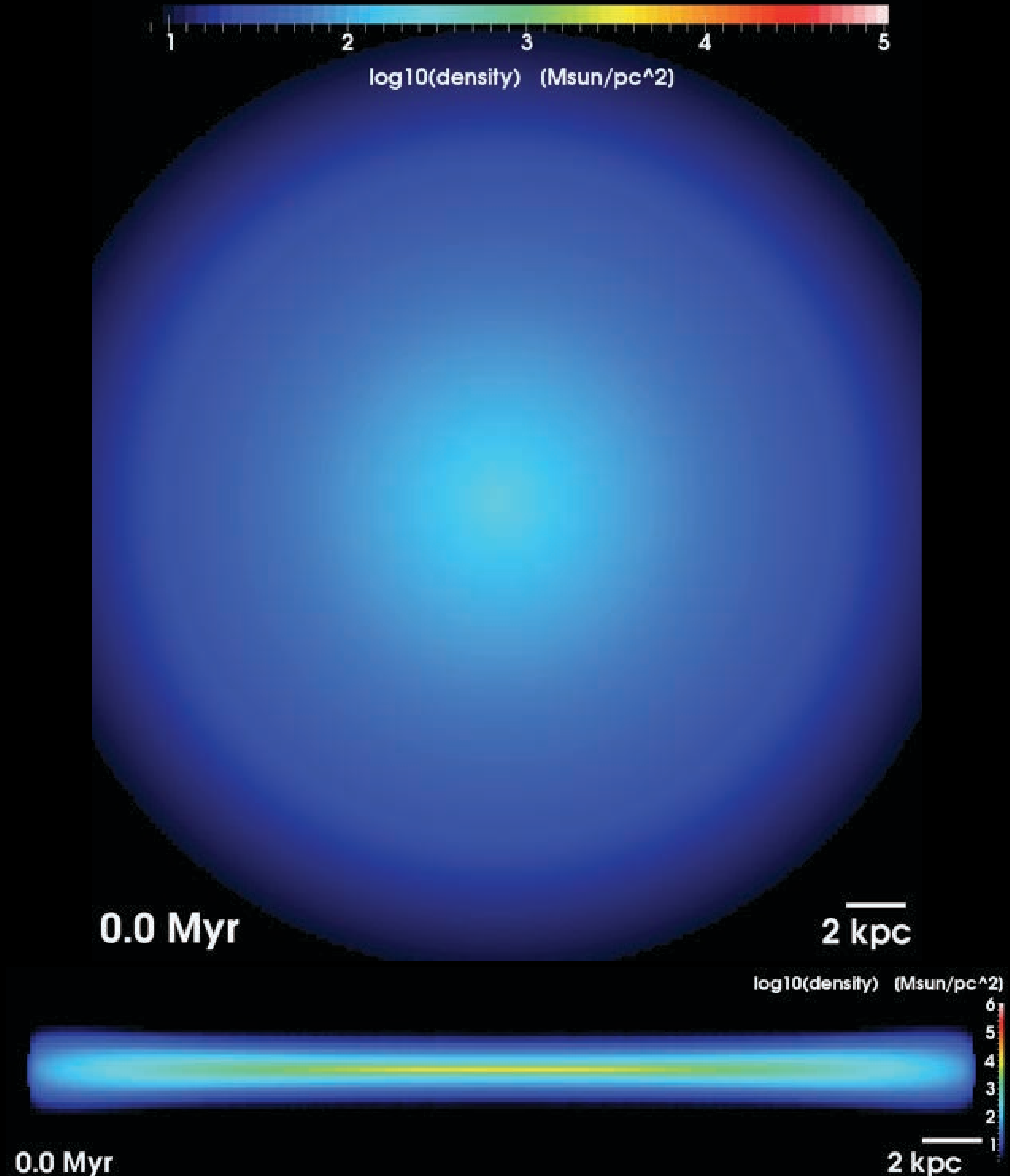


Perturbation Wavelengths



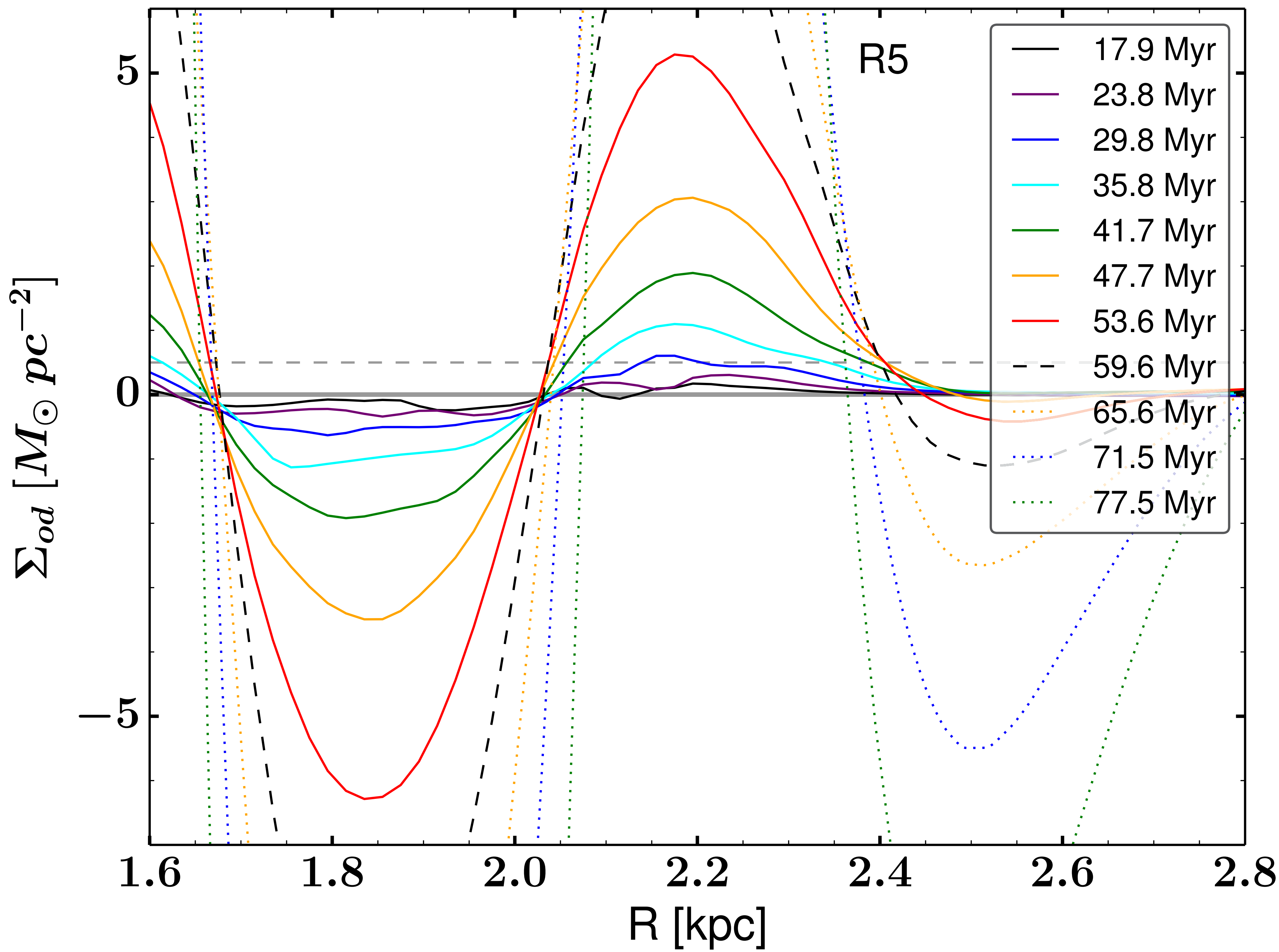
Ring Dimensions




1 2 3 4 5
log10(density) (Msun/pc^2)
0.0 Myr
2 kpc
log10(density) (Msun/pc^2)
6 5 4 3 2 1
0.0 Myr
2 kpc

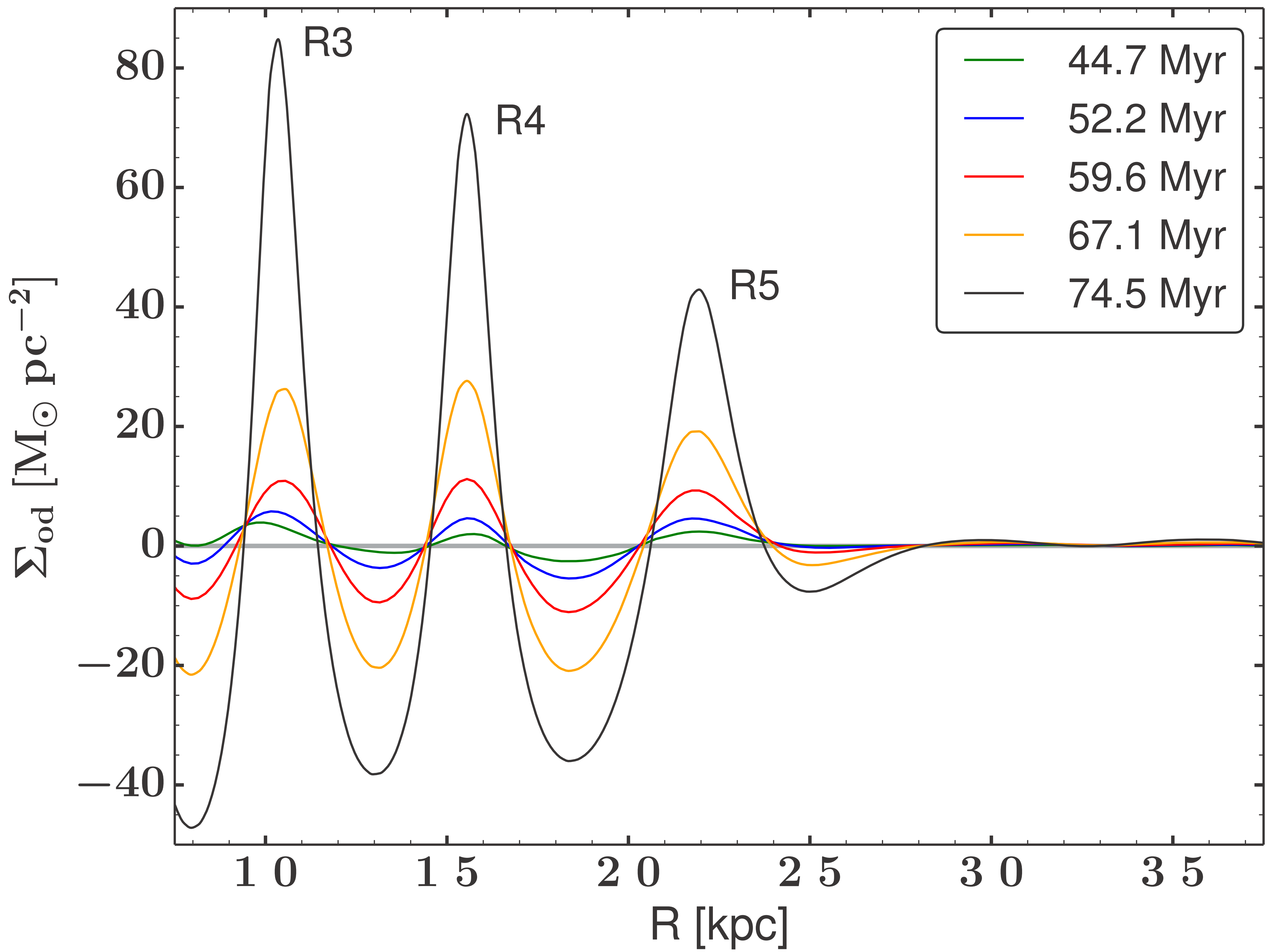
Radial Overdensity - Zoom

$$\Sigma_{od} = \Sigma_t - \Sigma_0$$



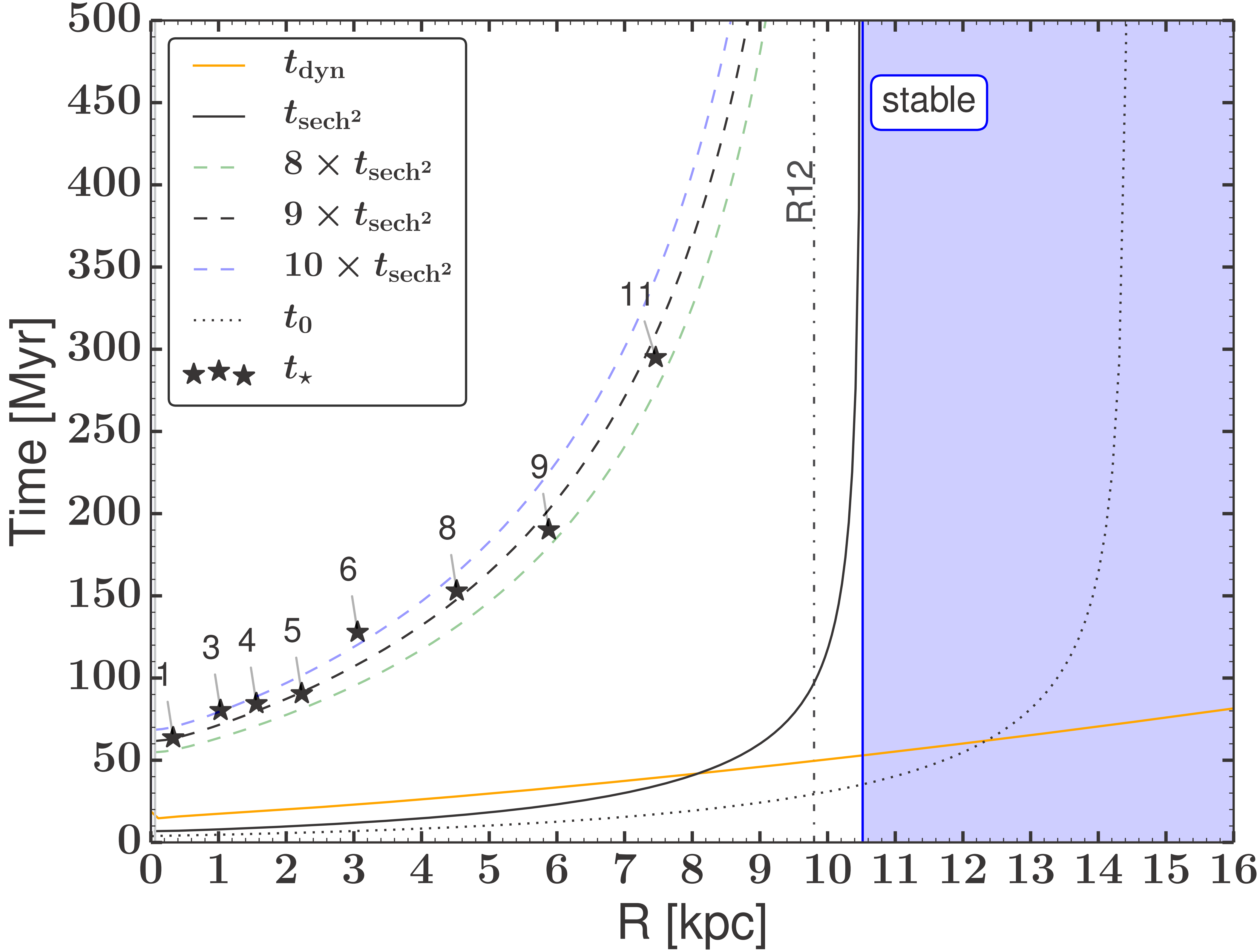
Radial Overdensity

$$\Sigma_{od} = \Sigma_t - \Sigma_0$$

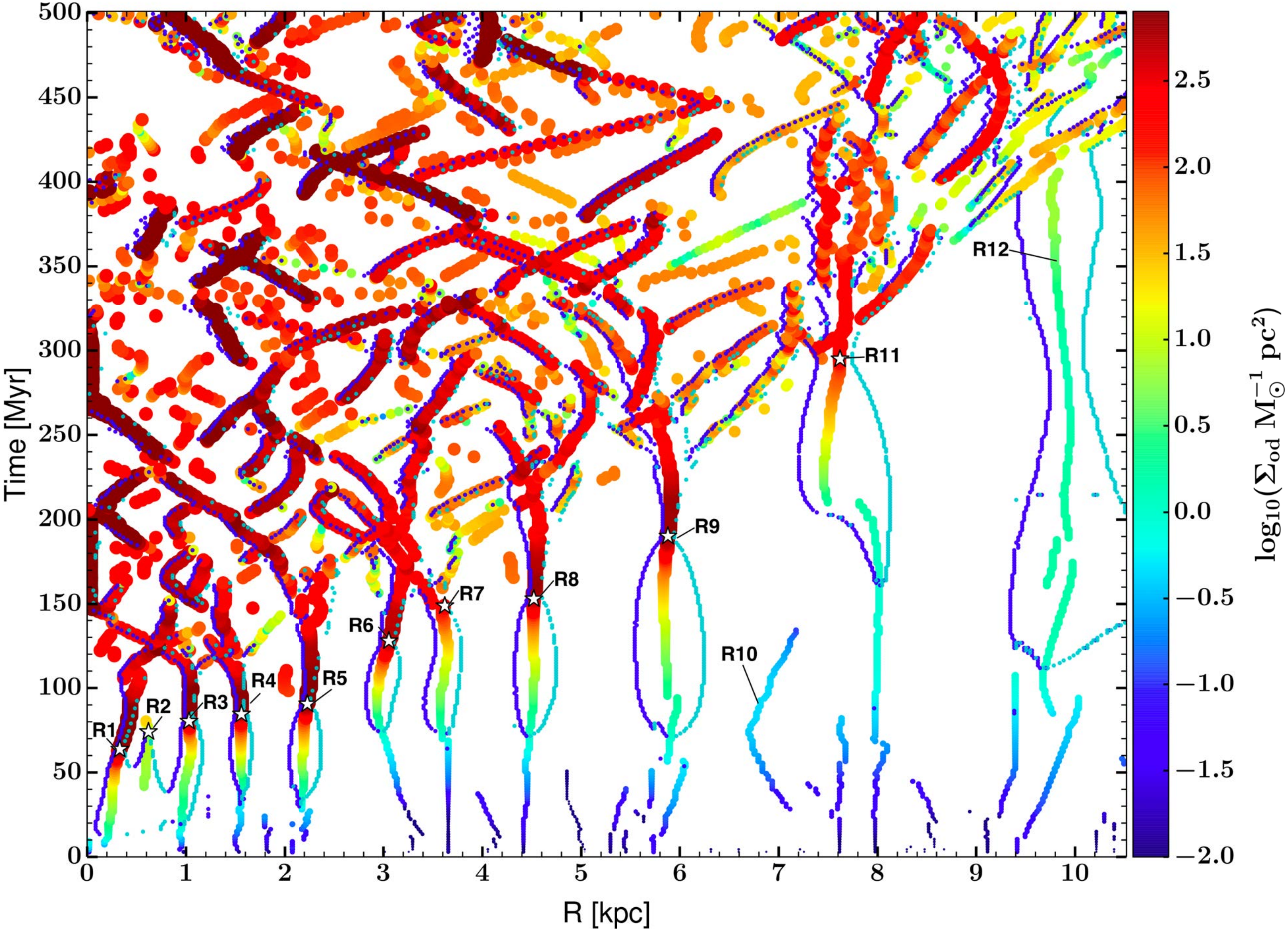


Ring Collapse Time Scale

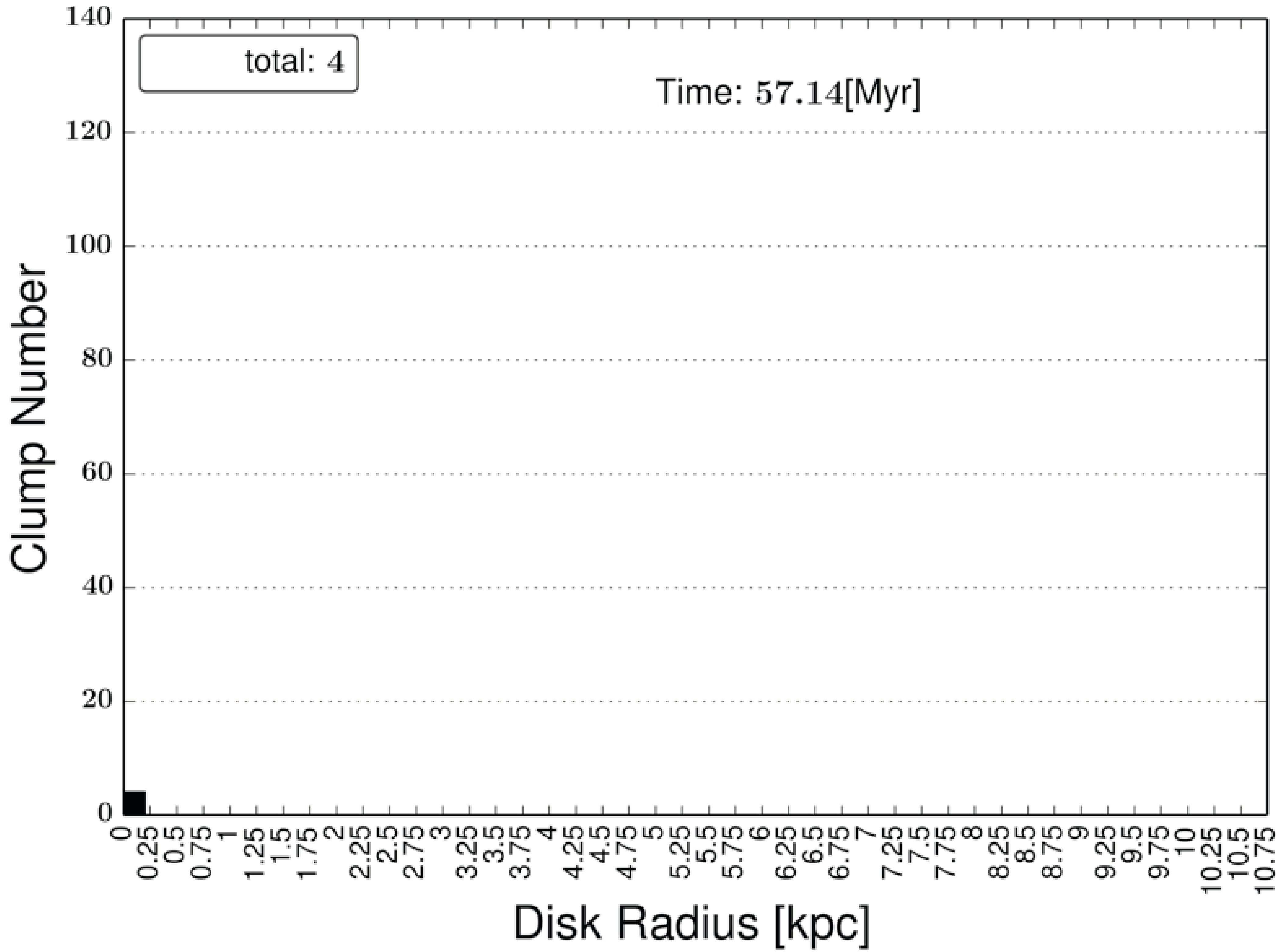
t_{sech^2} = time where perturbations are grown by factor of e

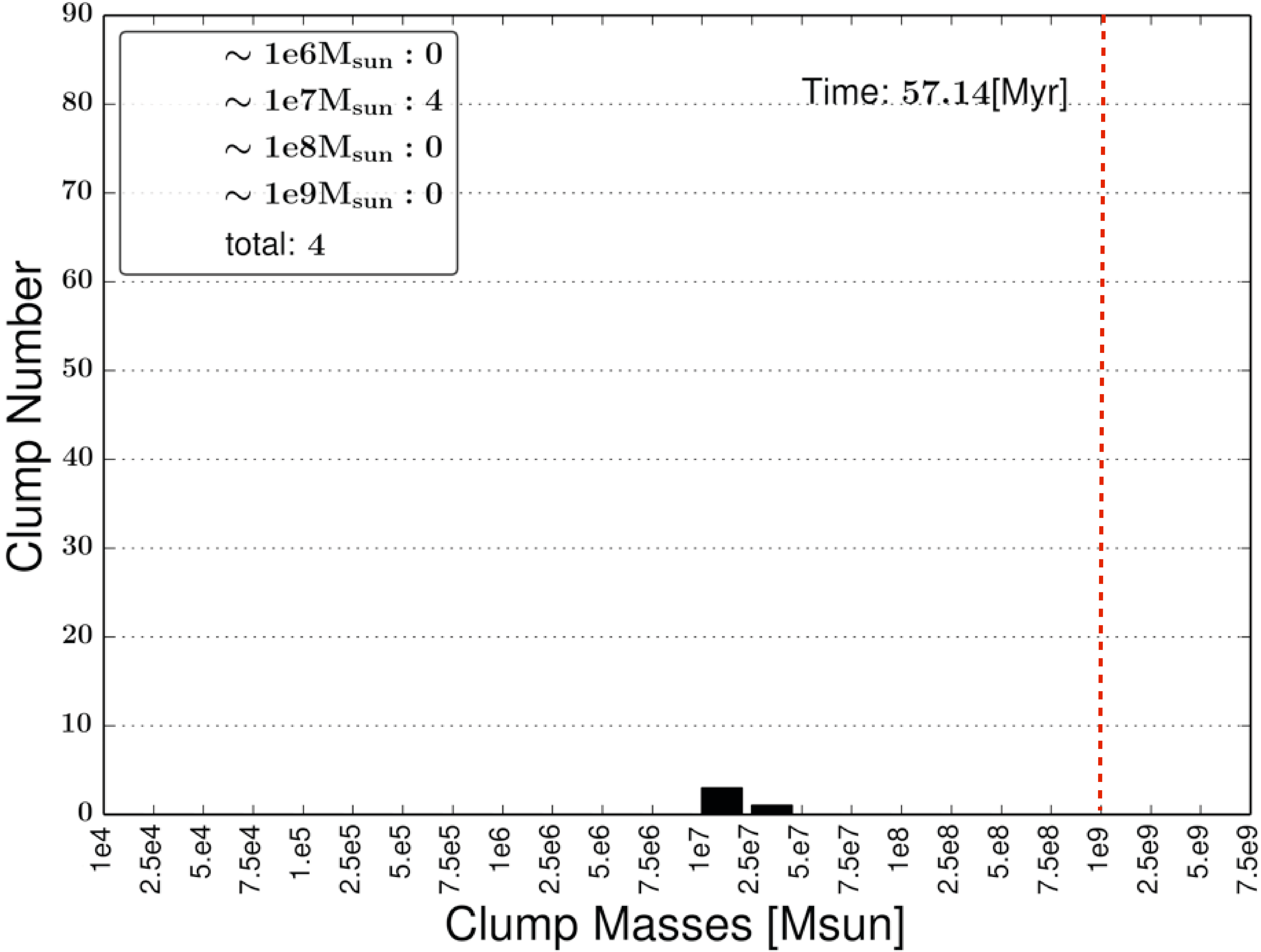


Relative Maxima

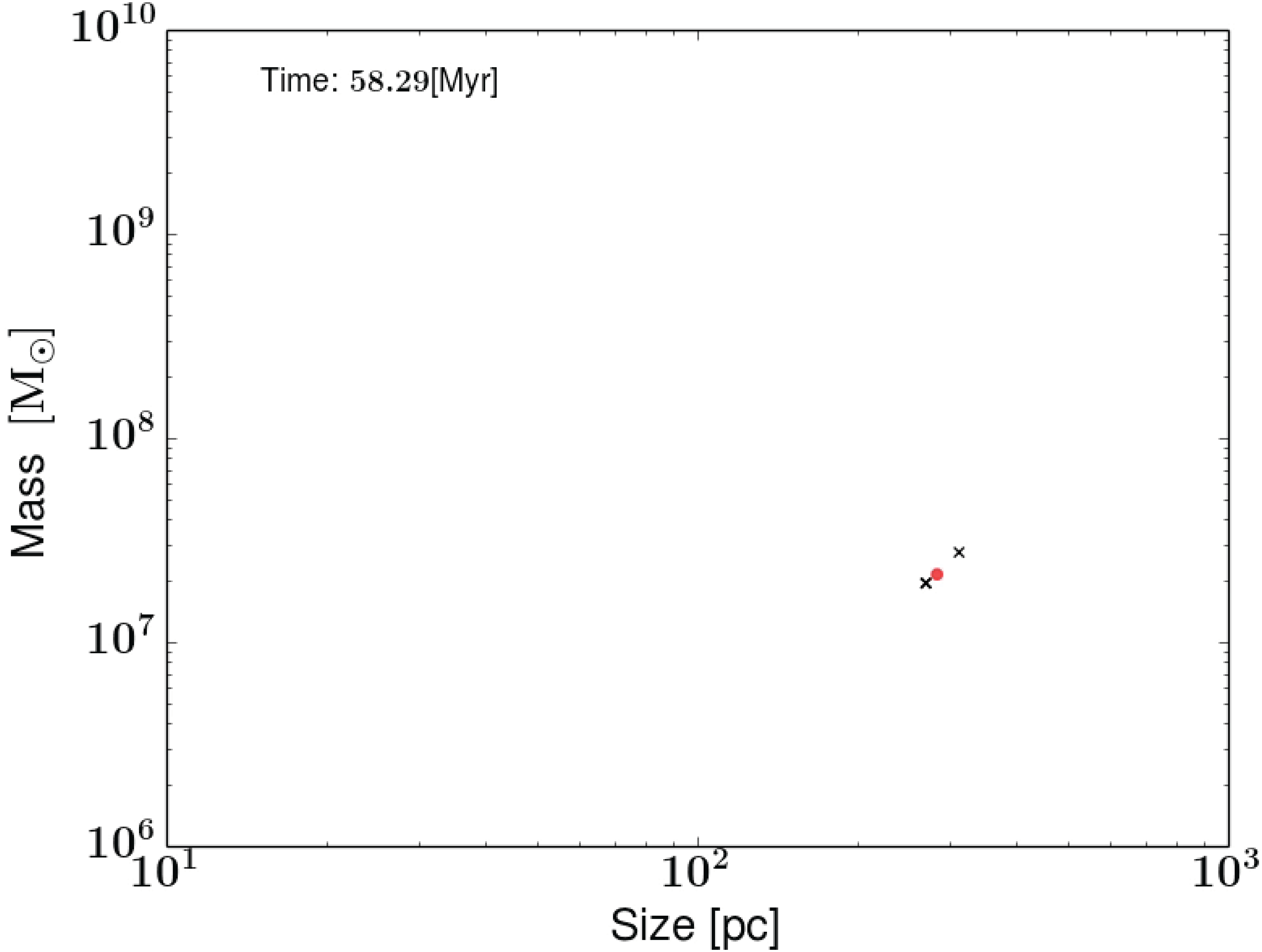


Physics of clump formation



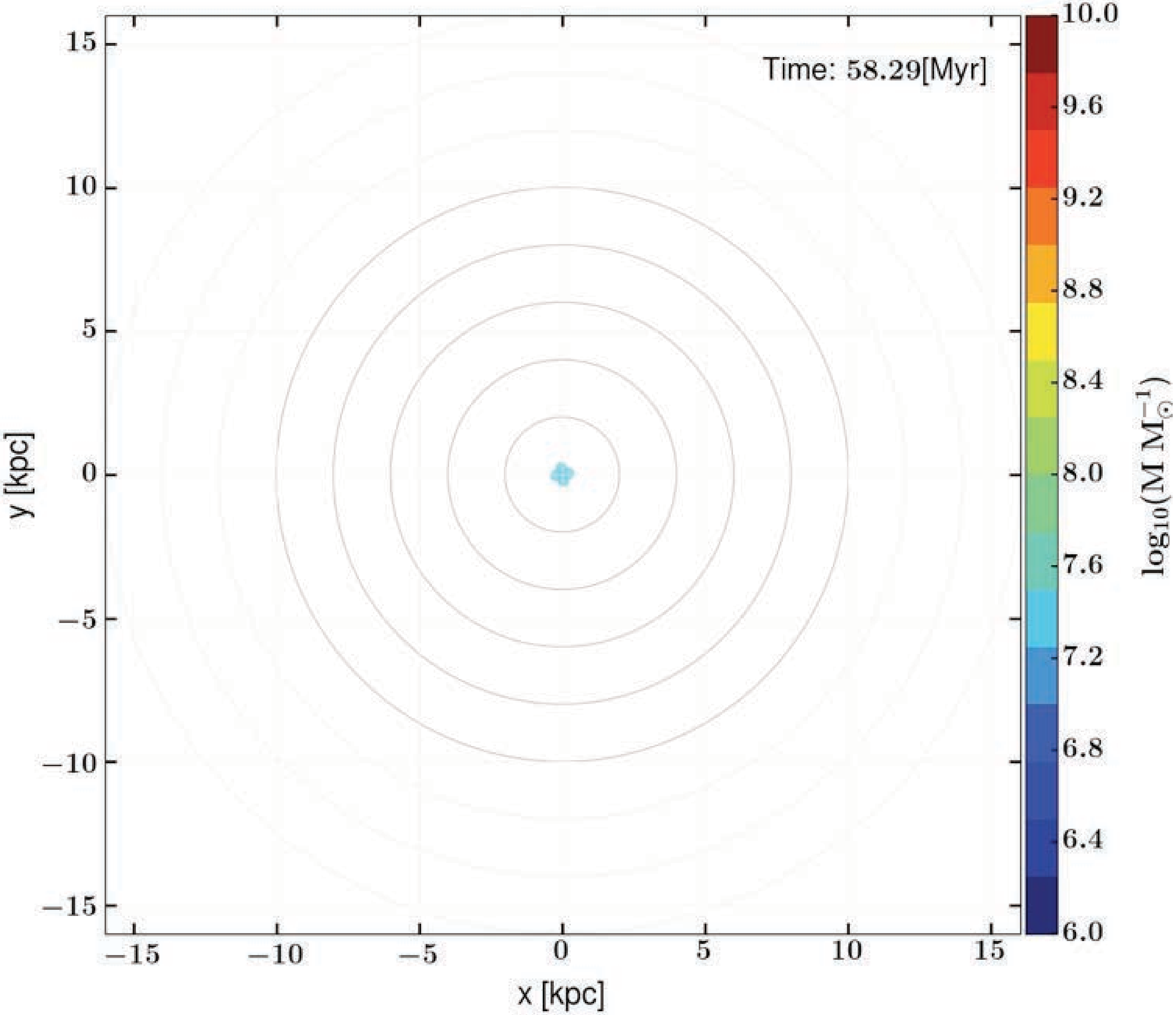


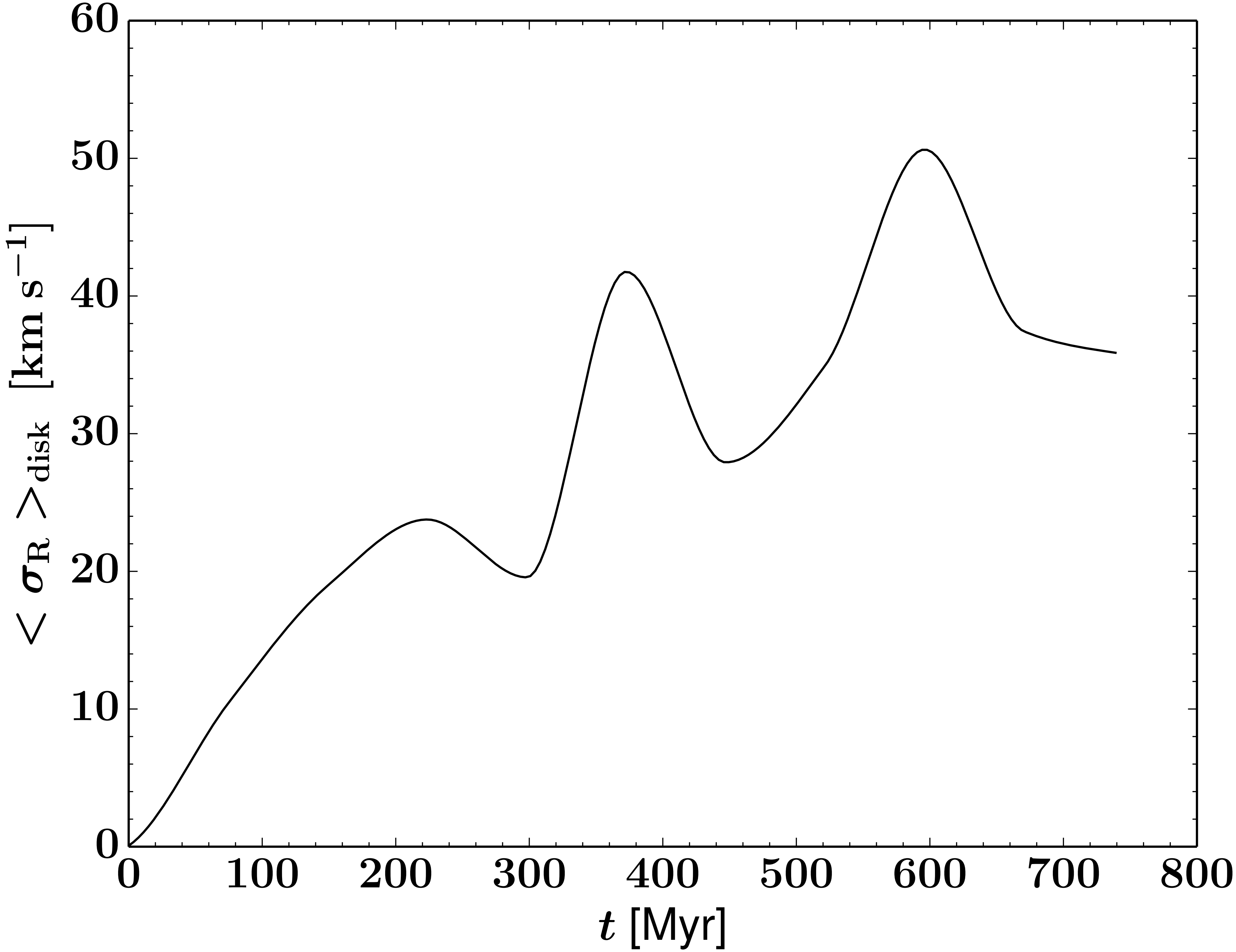
~ 1e6Msun : 0
~ 1e7Msun : 4
~ 1e8Msun : 0
~ 1e9Msun : 0
total: 4
Time: 57.14[Myr]
Clump Number
0
10
20
30
40
50
60
70
80
90
1e4
2.5e4
5.e4
7.5e4
1.e5
2.5e5
5.e5
7.5e5
1e6
2.5e6
5.e6
7.5e6
1e7
2.5e7
5.e7
7.5e7
1e8
2.5e8
5.e8
7.5e8
1e9
2.5e9
5.e9
7.5e9
Clump Masses [Msun]



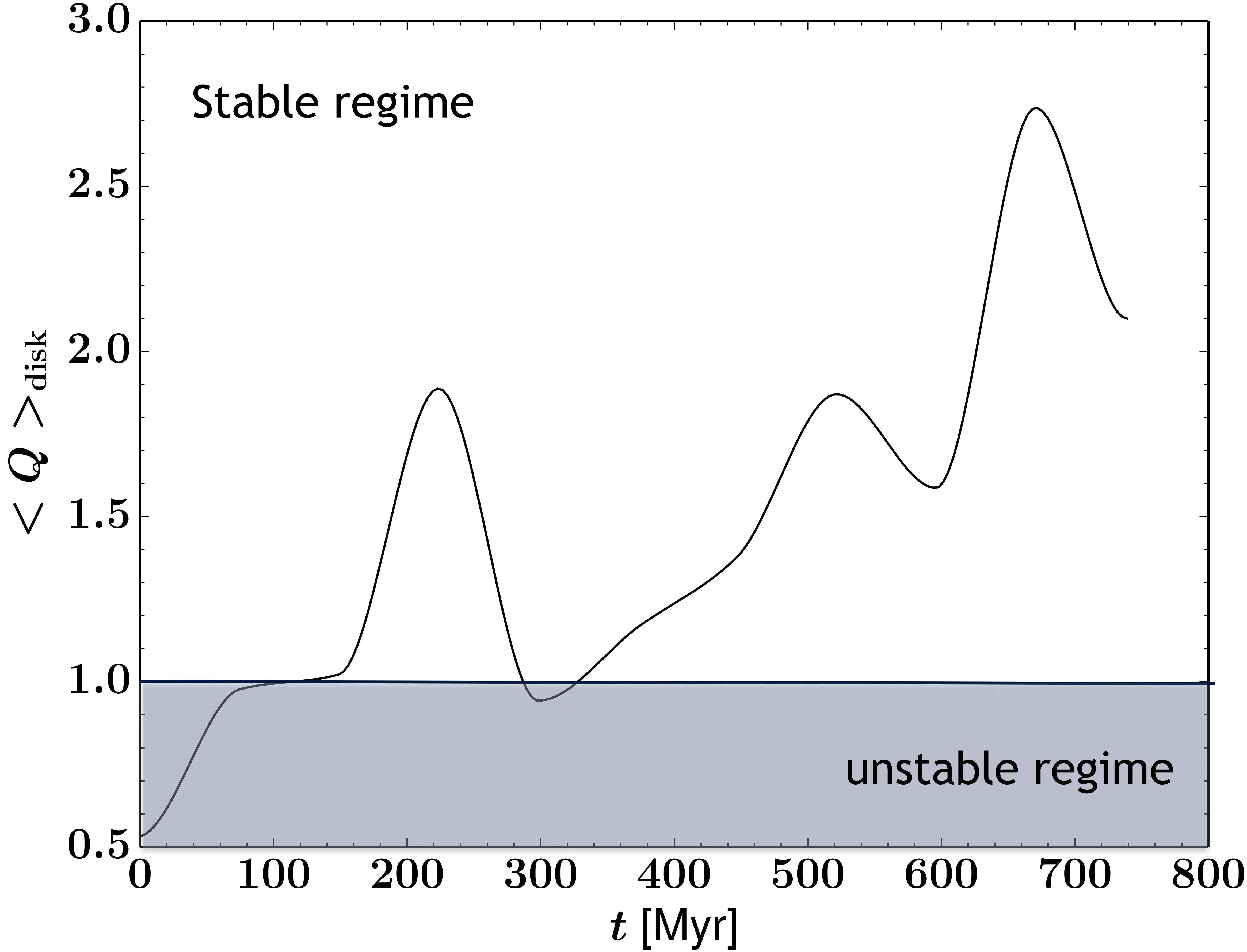
Time: 58.29[Myr]
Mass [M$_\odot$]
Size [pc]
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{1}
10^{2}
10^{3}

Physics of clump formation

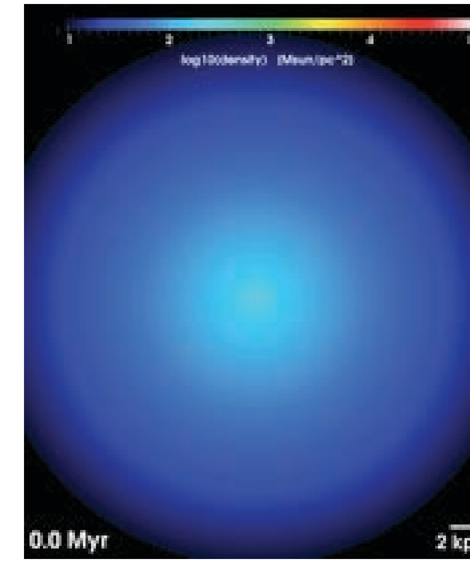




$< \sigma_{\rm R} >_{\rm disk}$ [km s^{-1}]
t [Myr]
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700
800


Stable regime
unstable regime
3.0
2.5
2.0
1.5
1.0
0.5
0
100
200
300
400
500
600
700
800
$< Q >_{\rm disk}$
t [Myr]

Conclusions



Toomre theory correctly predicts the growth of ring-like structures in unstable disks. Even with many initial perturbations present, the **fastest growing wavelength** wins.

The **collapse timescales** of the rings are 9 times the Toomre timescale.

The fragmentation of the rings into **clumps** and the initial clump properties **cannot be determined** using the Toomre theory.

Fragments initially are **small** despite Q=0.5 however they lateron grow by **merging** and are **disrupted** by violent encounters when clumps become larger than the Toomre length scale or Toomre mass for Q=1.

Eventually a **self-regulated** time-independent **clump mass** and size **spectrum** is established.

The massive clumps are only the **tip of the iceberg.**

Toomre theory does not apply to the observed non-linear phase of high-z disks