Self-Consistent Isolated Galaxy Models

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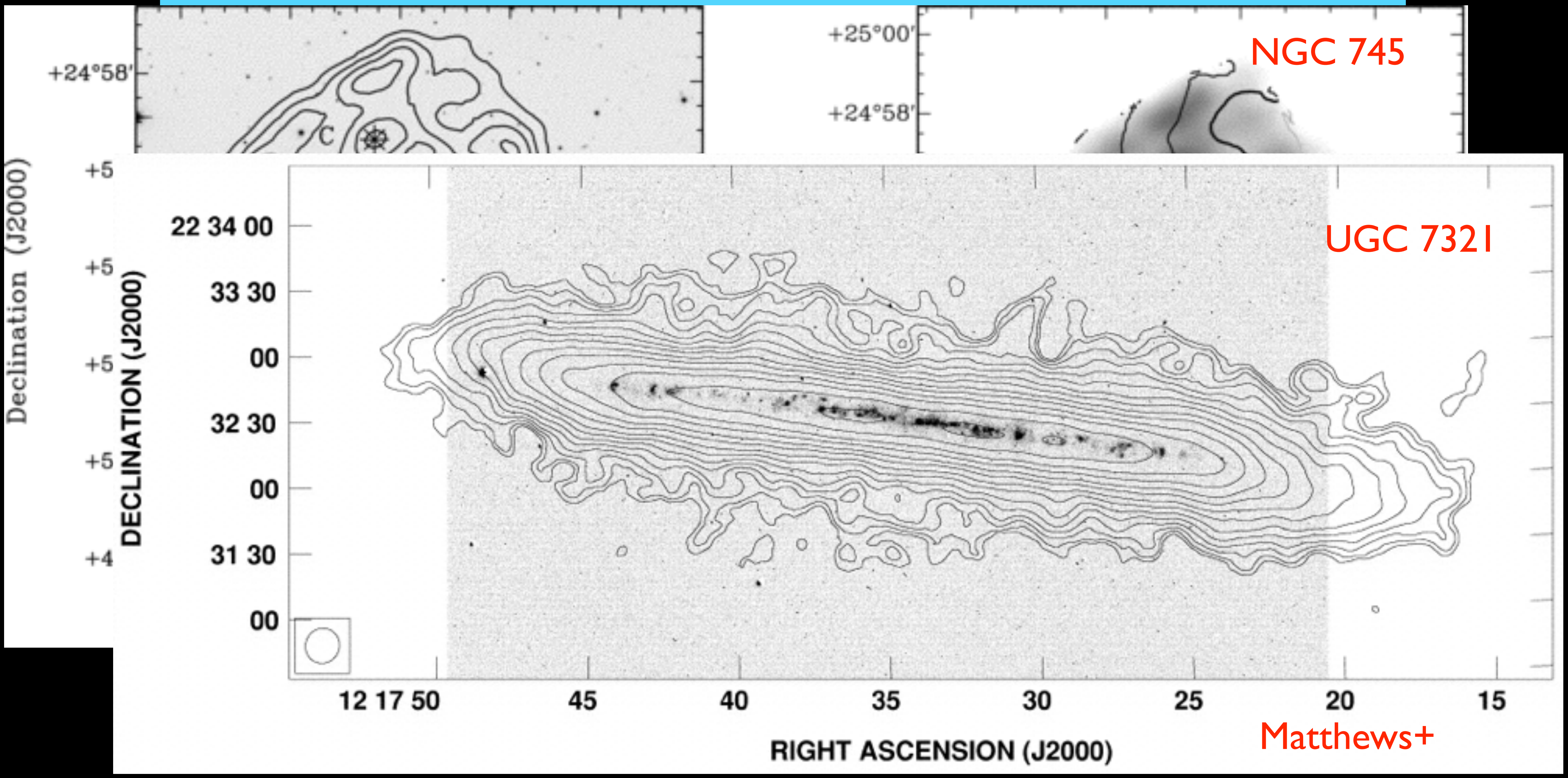


➡ Origin of ‘Superthin’ spirals

A POWERFUL METHOD

[Wang et al. 2010]

- 3D rotating gas disc in equilibrium (self-gravity, w/o external static potential), and arbitrary surface density profile
- Assumptions:
  - isothermal
  - vertical HSE; rotational support in R
- Self-consistent potential-density pair via iterative solution of Poisson's equation [see also Springel+05]
- Velocity field from (composite) potential

➡ fully characterized by R_d (extension), Σ_0 (mass) and T (thickness)

Spitzer-Freeman Disc

[Spitzer 1942; Freeman 1970]

- Full analytic solution known; excellent test for:
  - ✓ ICs generator
  - ✓ simulation setup / numerical method

- Features:
  - flaring, sech^2 vertical density profile [Spitzer 1942]
  - velocity (self-gravity) in terms of Bessel functions [Freeman 1970]
  - vertical structure and total velocity given by the balance between self-gravity and pressure

Spitzer-Freeman Disc

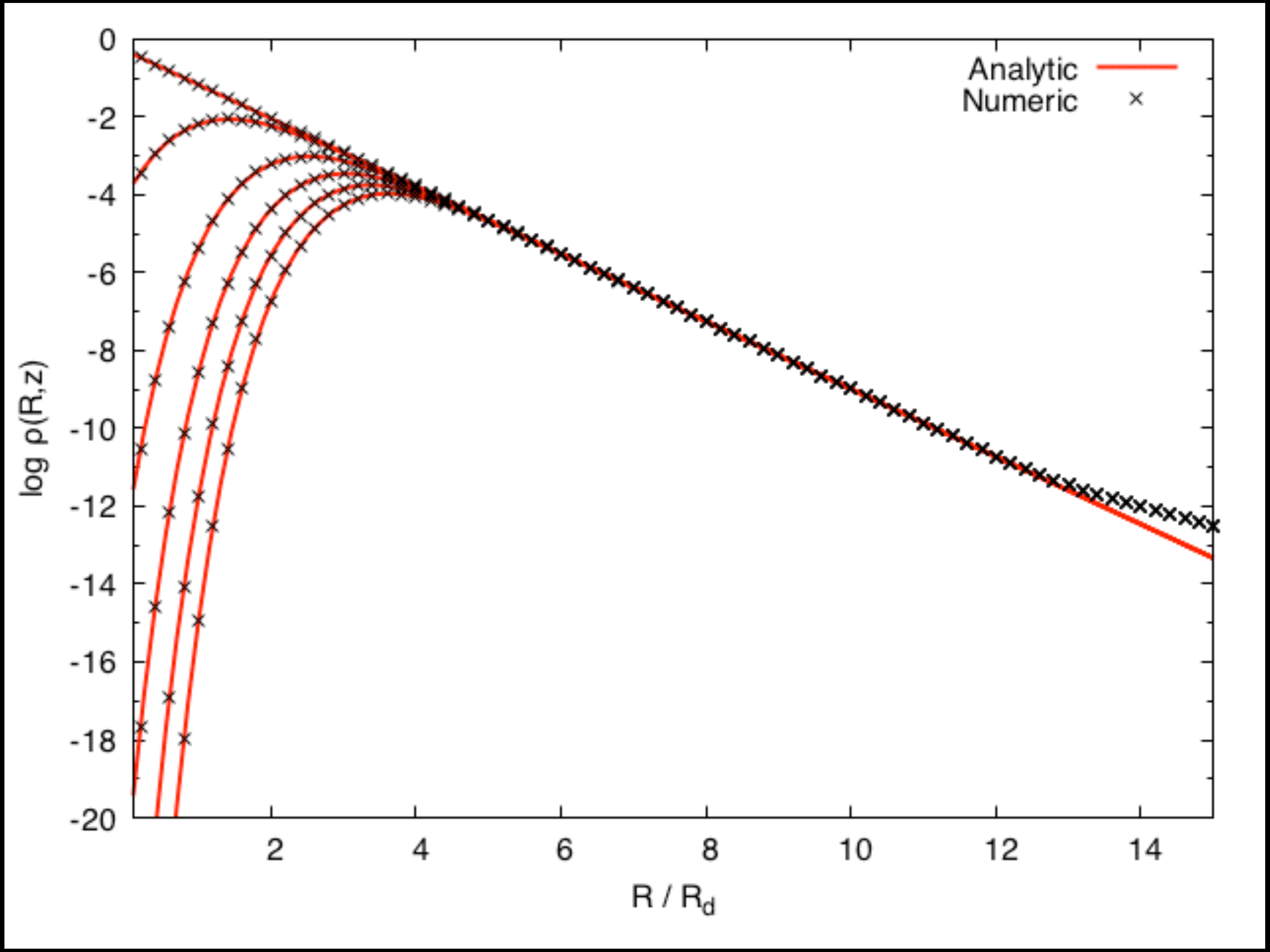
[Spitzer 1942; Freeman 1970]

R_d [kpc]	3,5
T [K]	5×10^3

Physical parameters

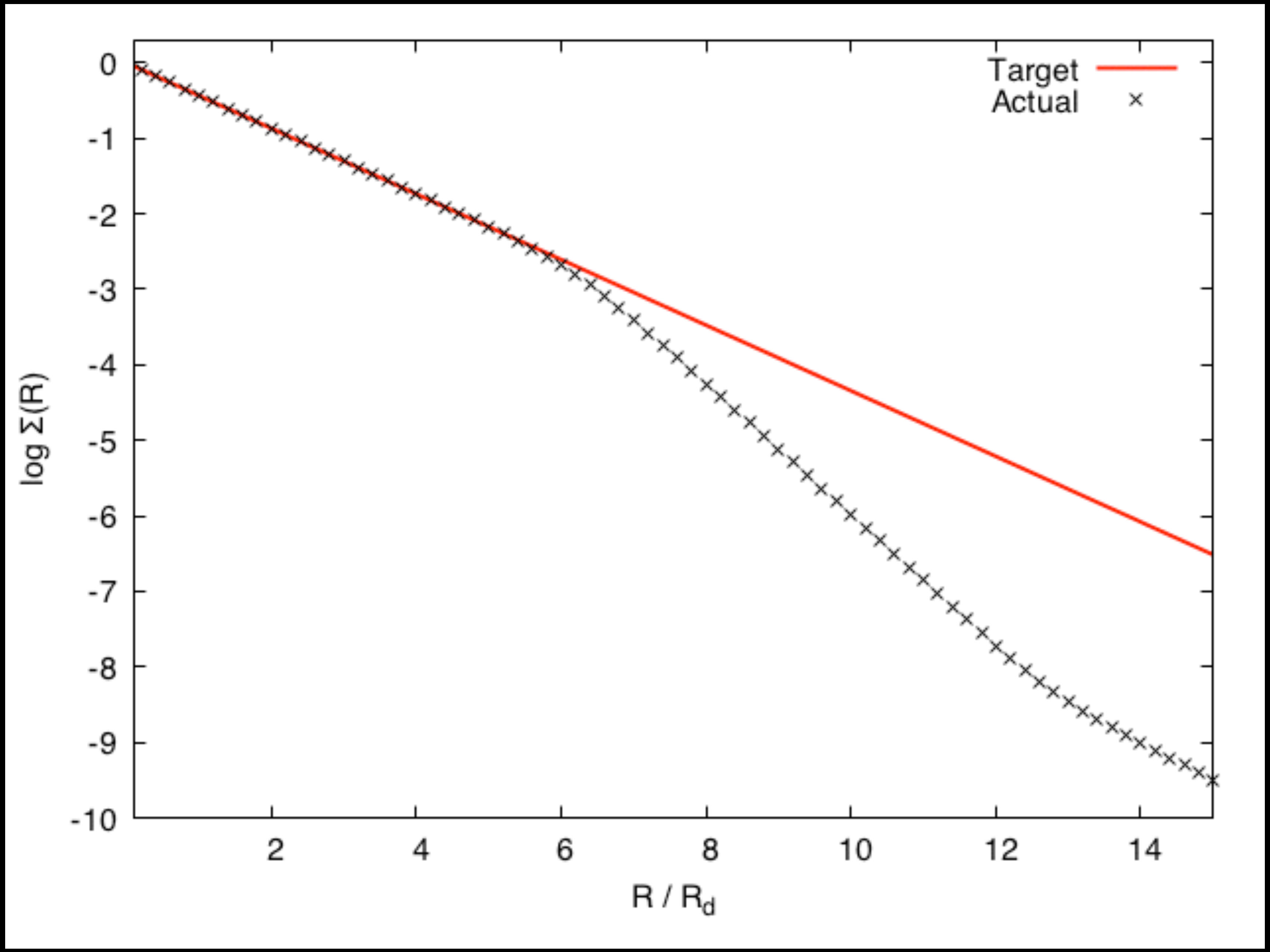
Spitzer-Freeman Disc

[Spitzer 1942; Freeman 1970]



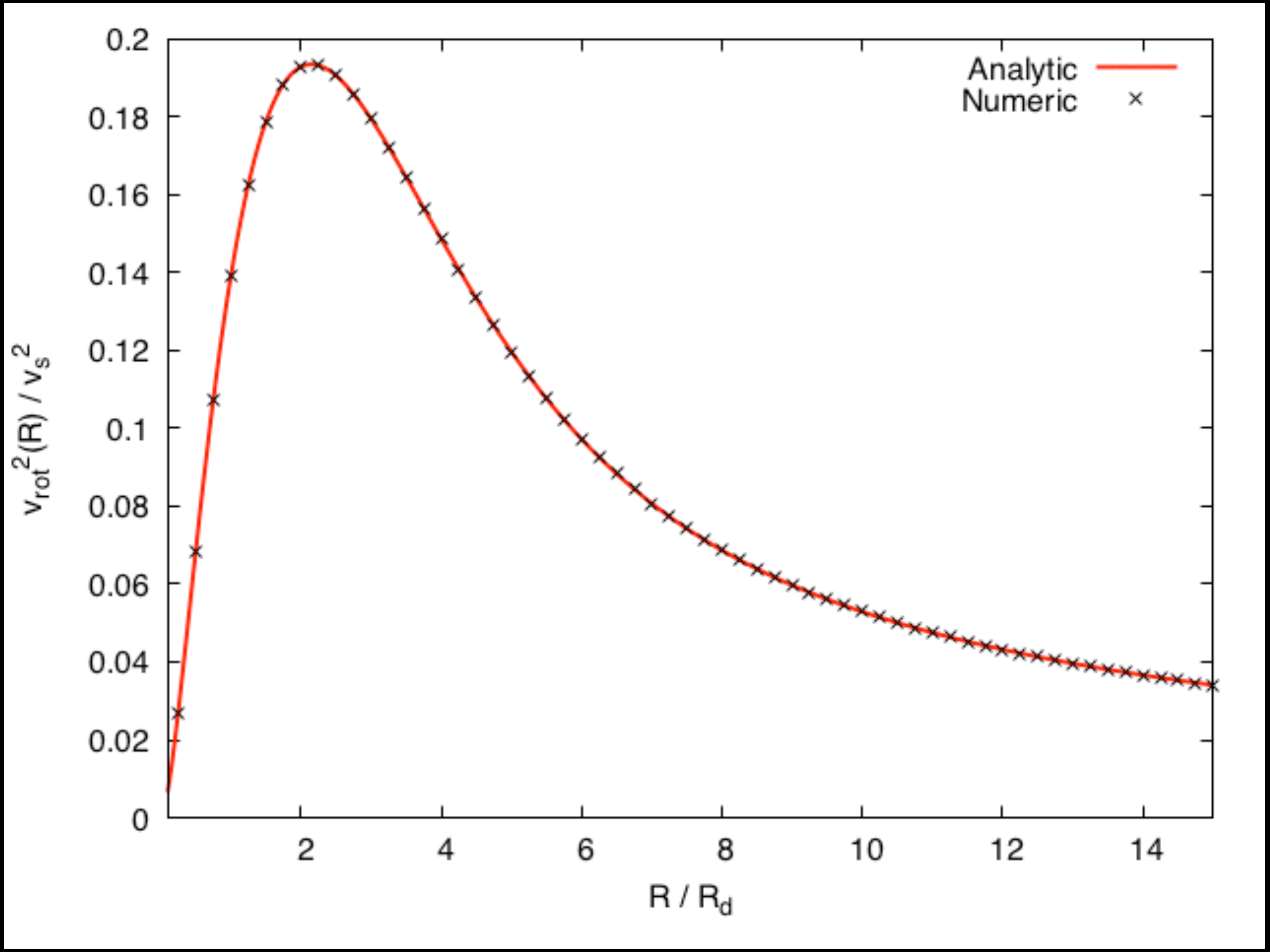
Spitzer-Freeman Disc

[Spitzer 1942; Freeman 1970]



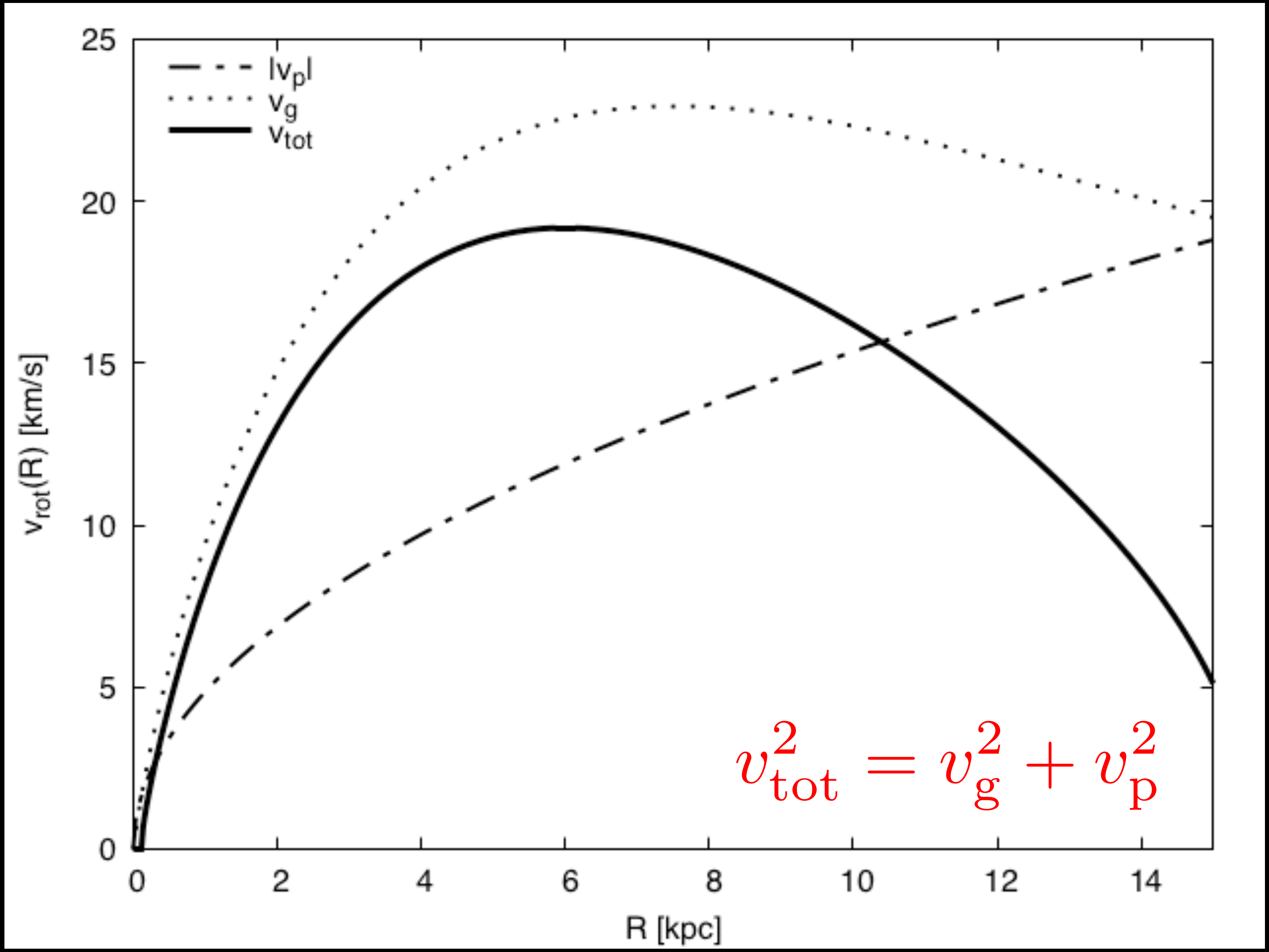
Spitzer-Freeman Disc

[Spitzer 1942; Freeman 1970]



Spitzer-Freeman Disc

[Spitzer 1942; Freeman 1970]

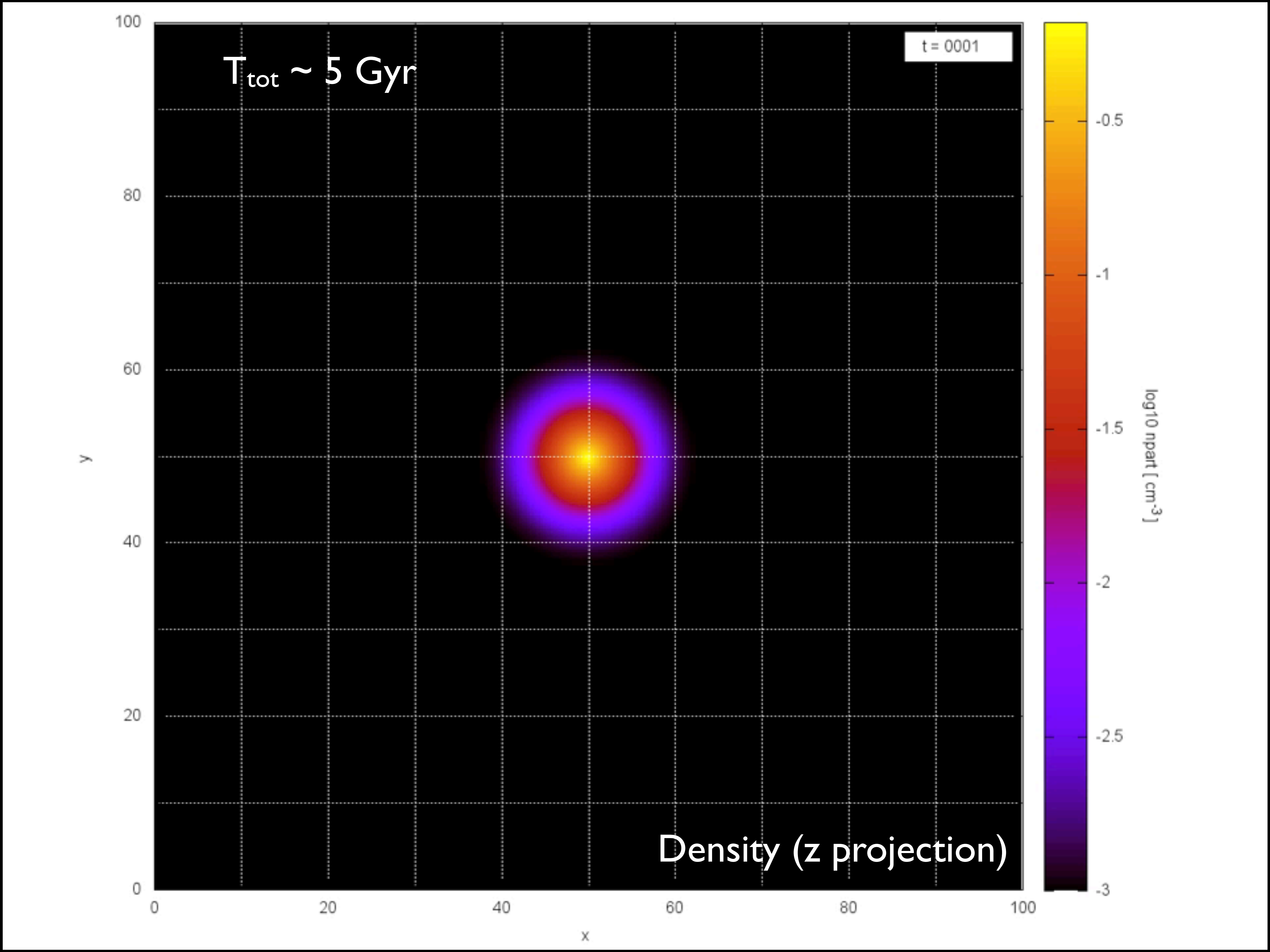


Spitzer-Freeman Disc

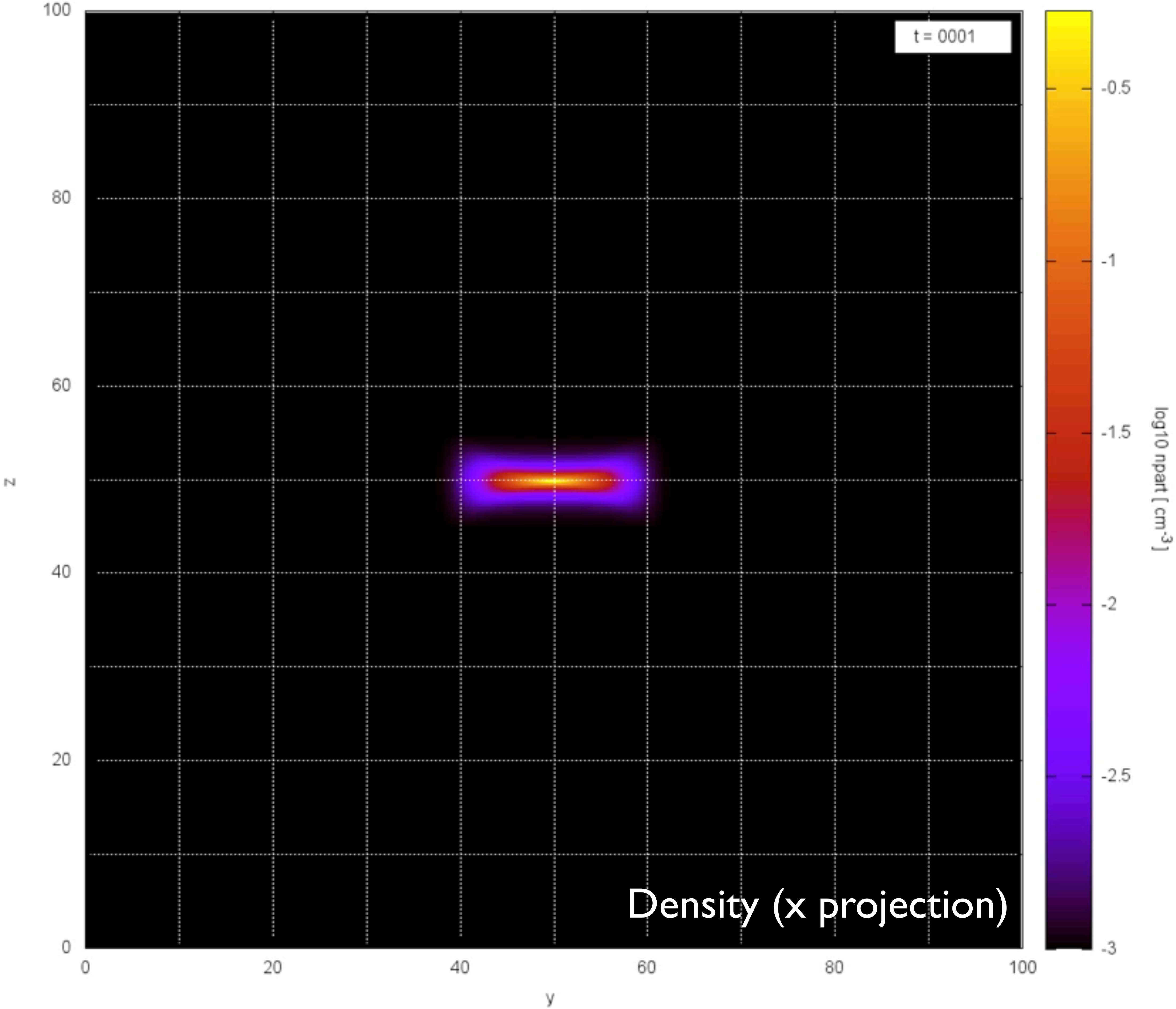
[Spitzer 1942; Freeman 1970]

EoS	Isothermal
Riemann	LLF
Refinement	Quasi-Lagrangian

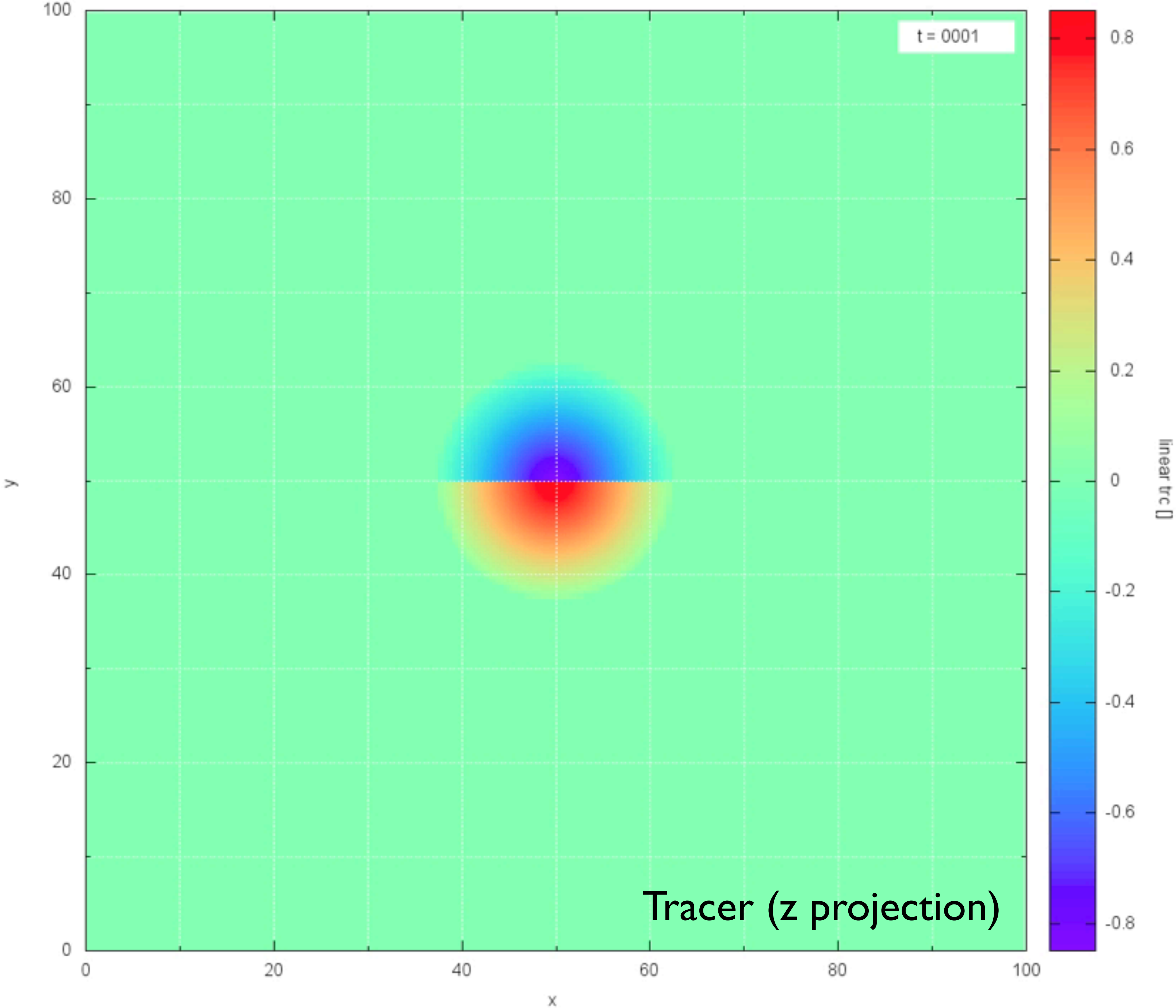
RAMSES setup



T$_{tot}$ ~ 5 Gyr
t = 0001
Density (z projection)
x
y
log10 npart [cm^{-3}]
0
20
40
60
80
100
-0.5
-1
-1.5
-2
-2.5
-3



t = 0001
Density (x projection)
z
y
log10 npart [cm-3]

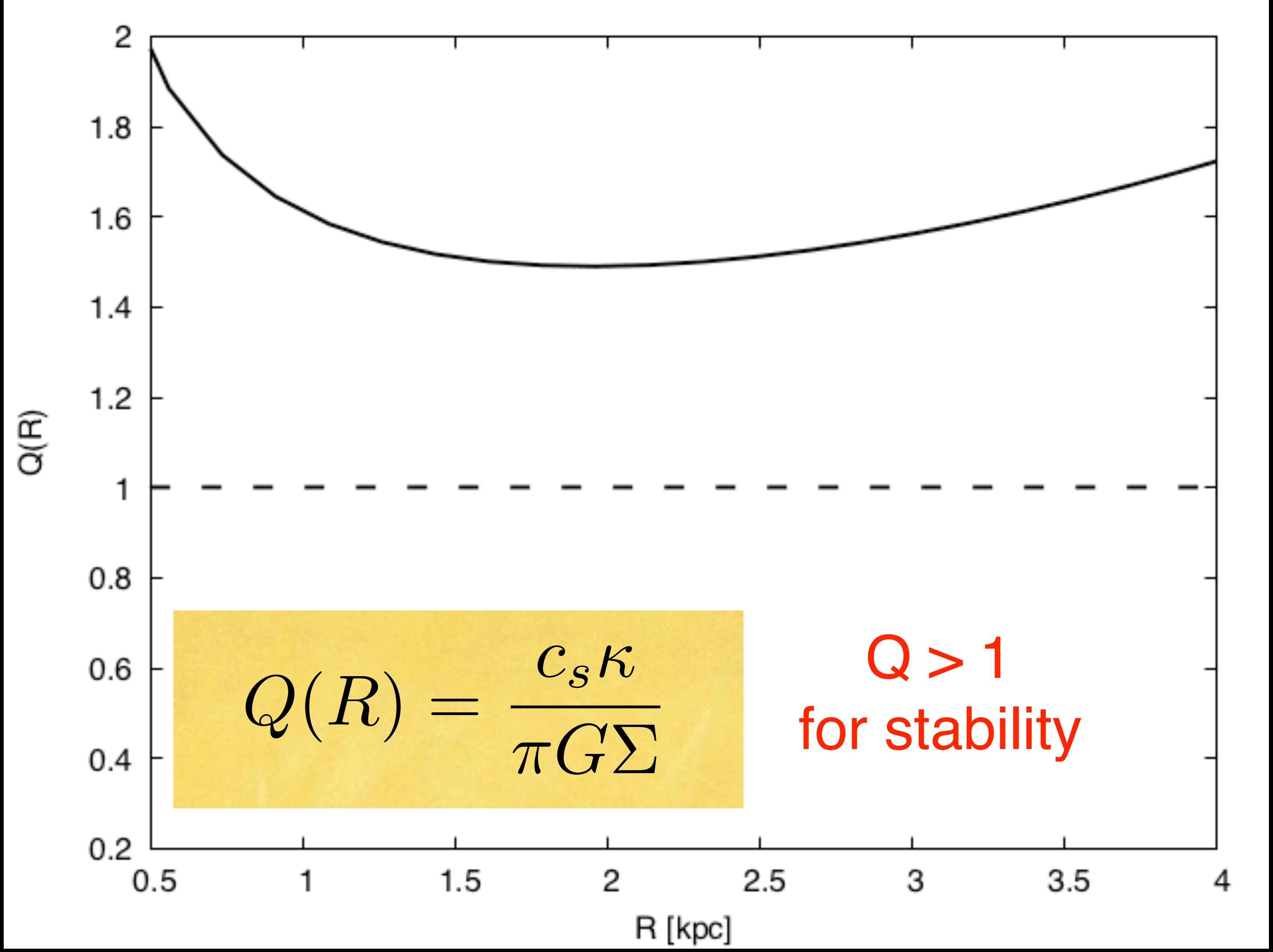

t = 0001
Tracer (z projection)
linear trc []
x
y
0
20
40
60
80
100
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8

Disc in an external, static potential I: DM halo

R_d [kpc]	3,5
T [K]	4×10^4

[cf. model Gas0 of Wang+10]

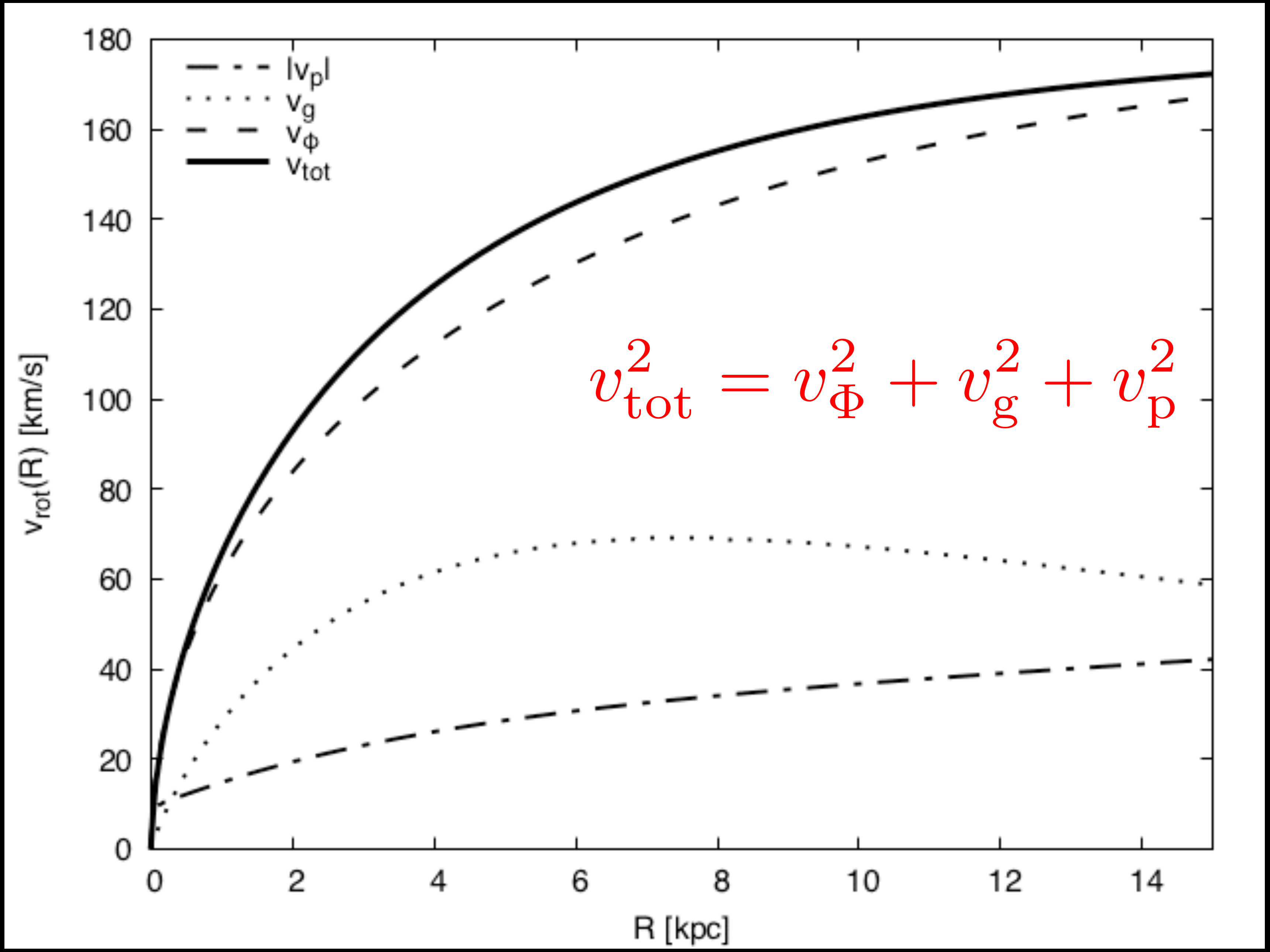
Disc in an external, static potential I:
DM halo only

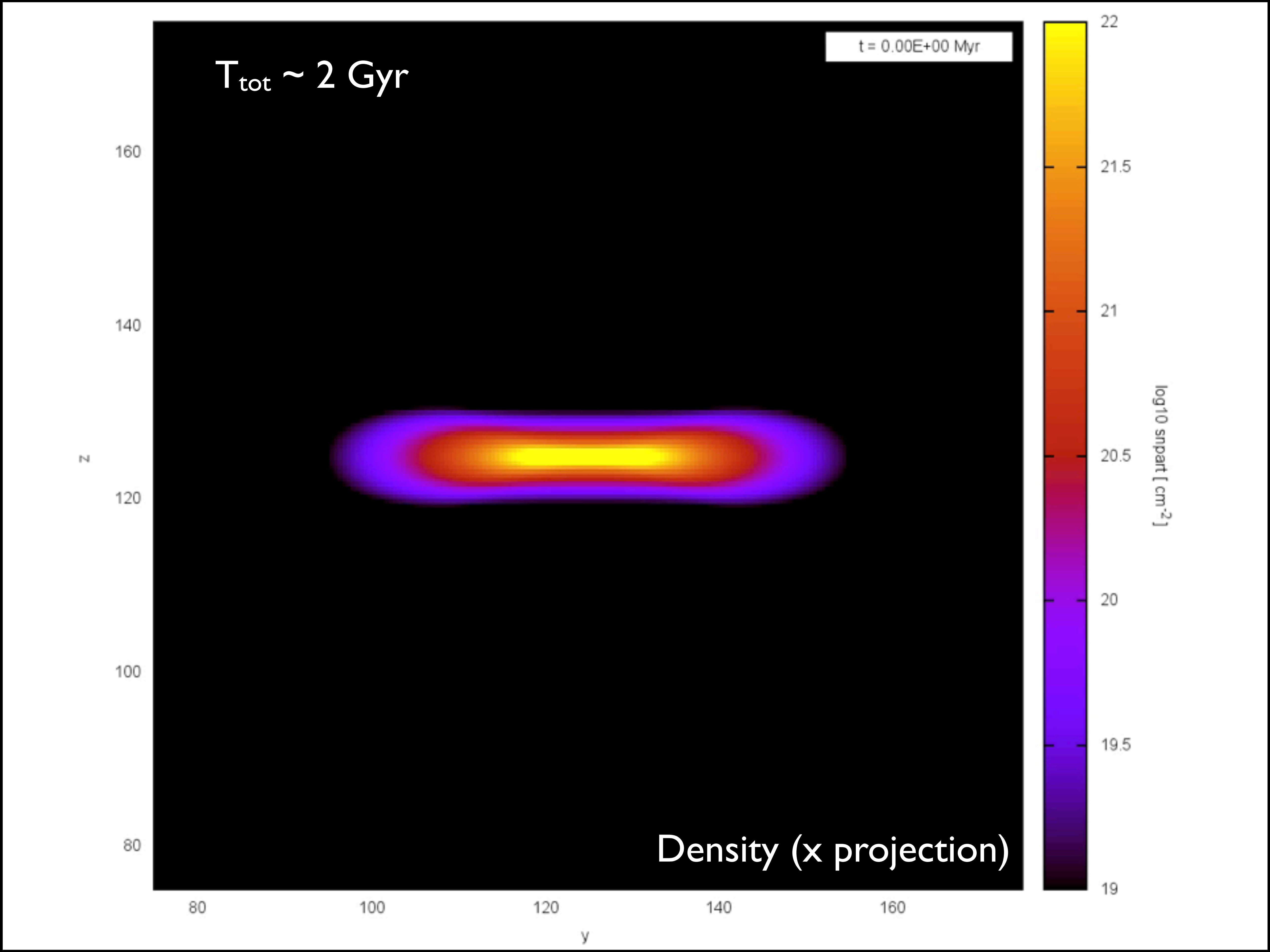


$$Q(R) = \frac{c_s \kappa}{\pi G \Sigma}$$

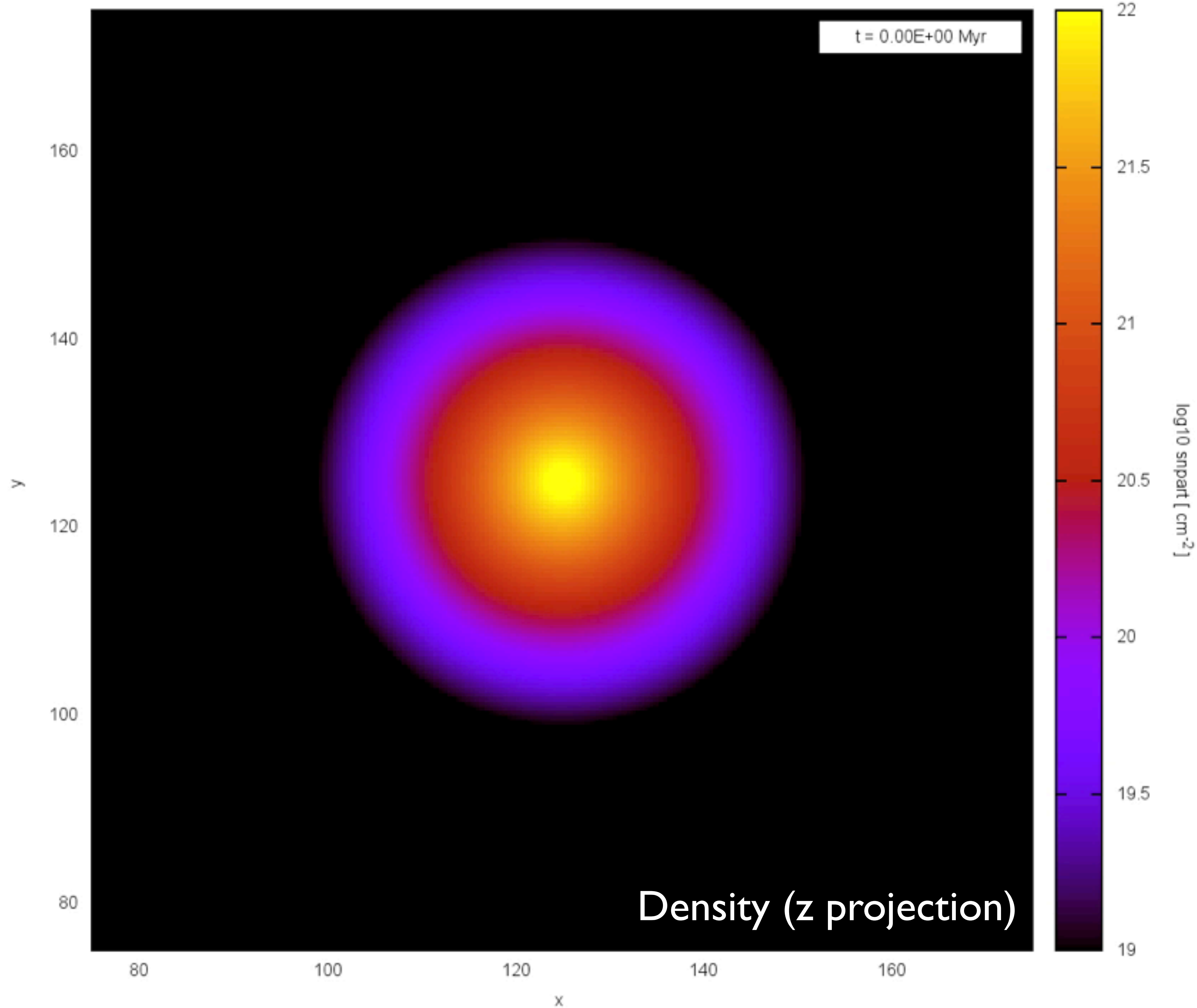
Q > 1
for stability

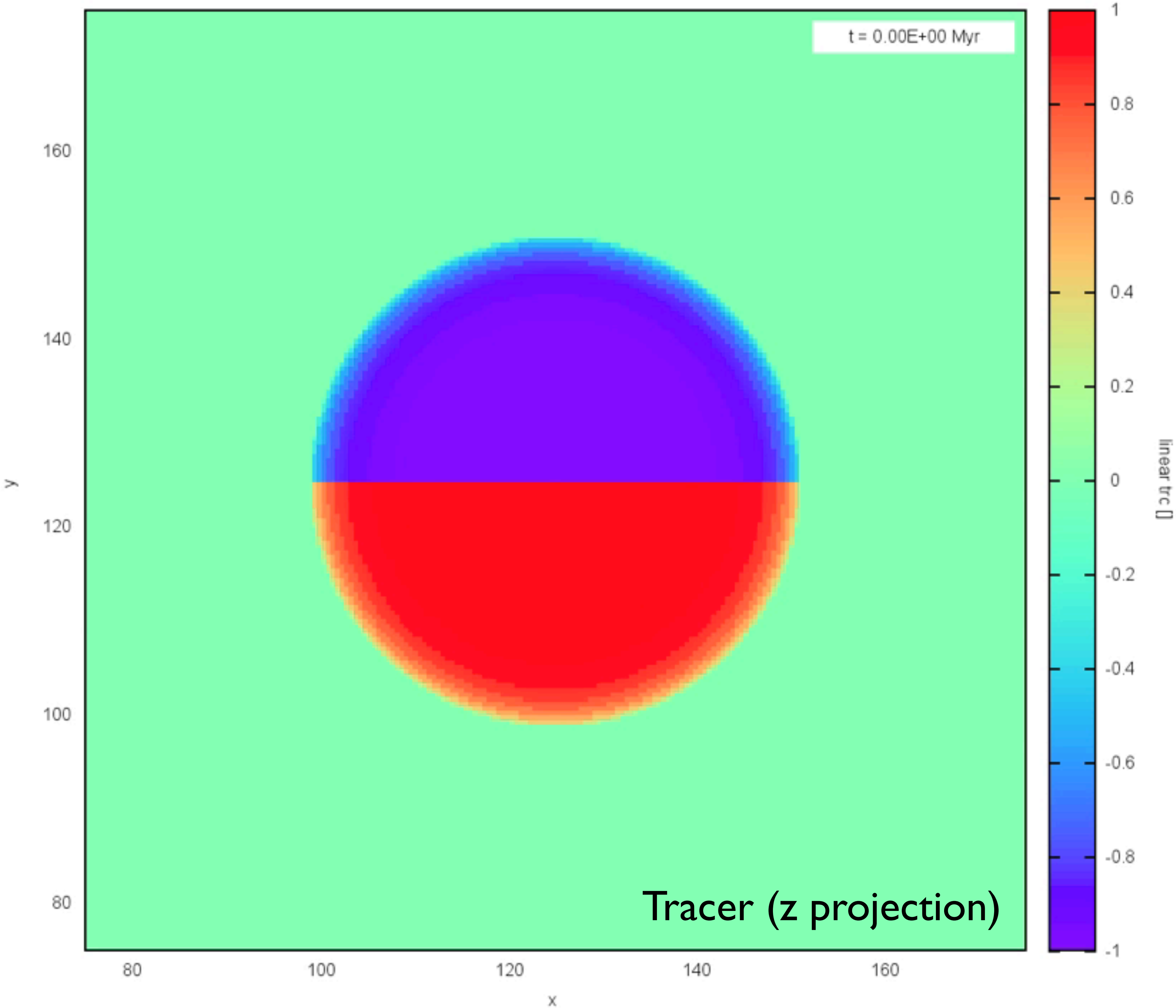
Disc in an external, static potential I: DM halo only



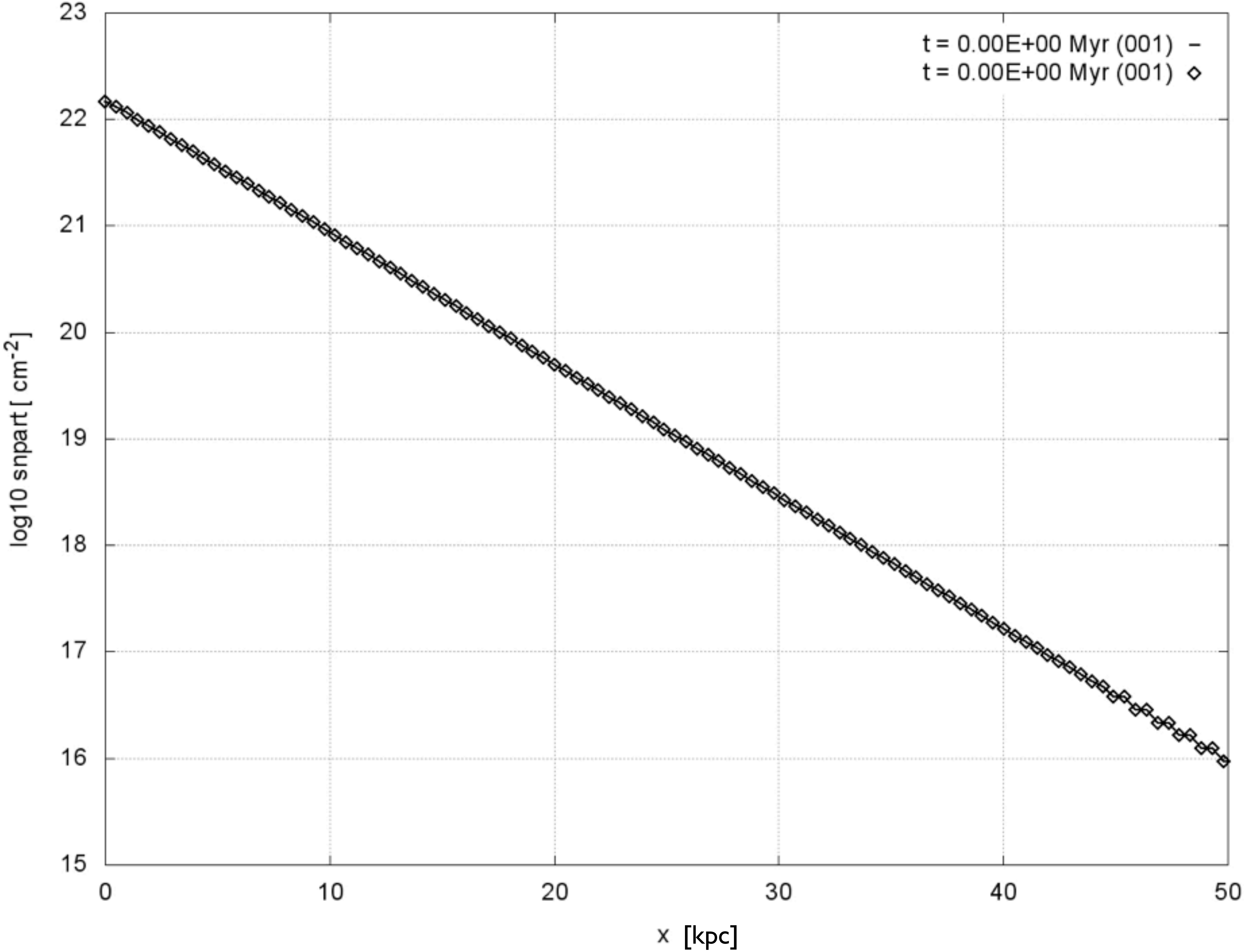


T_tot ~ 2 Gyr
t = 0.00E+00 Myr
Density (x projection)
160
140
120
100
80
z
80
100
120
140
160
y
22
21.5
21
20.5
20
19.5
19
log10 snpart [cm-2]

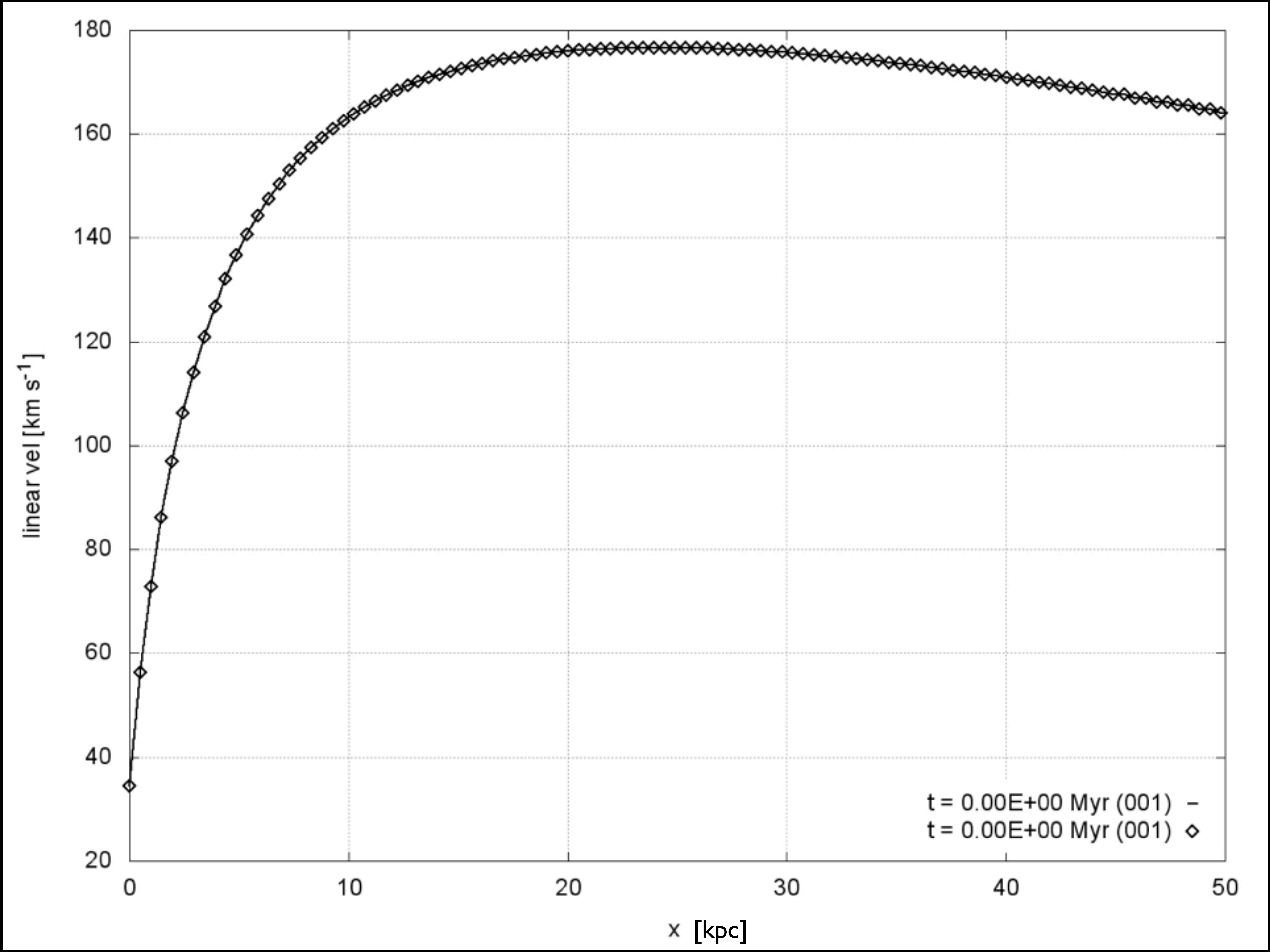

t = 0.00E+00 Myr
Density (z projection)
160
140
120
100
80
y
80
100
120
140
160
x
22
21.5
21
20.5
20
19.5
19
log10 snpart [cm-2]



t = 0.00E+00 Myr
Tracer (z projection)
160
140
120
100
80
y
80
100
120
140
160
x
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
linear trc []



t = 0.00E+00 Myr (001)
t = 0.00E+00 Myr (001)
log10 snpart [cm^{-2}]
x [kpc]
23
22
21
20
19
18
17
16
15
0
10
20
30
40
50

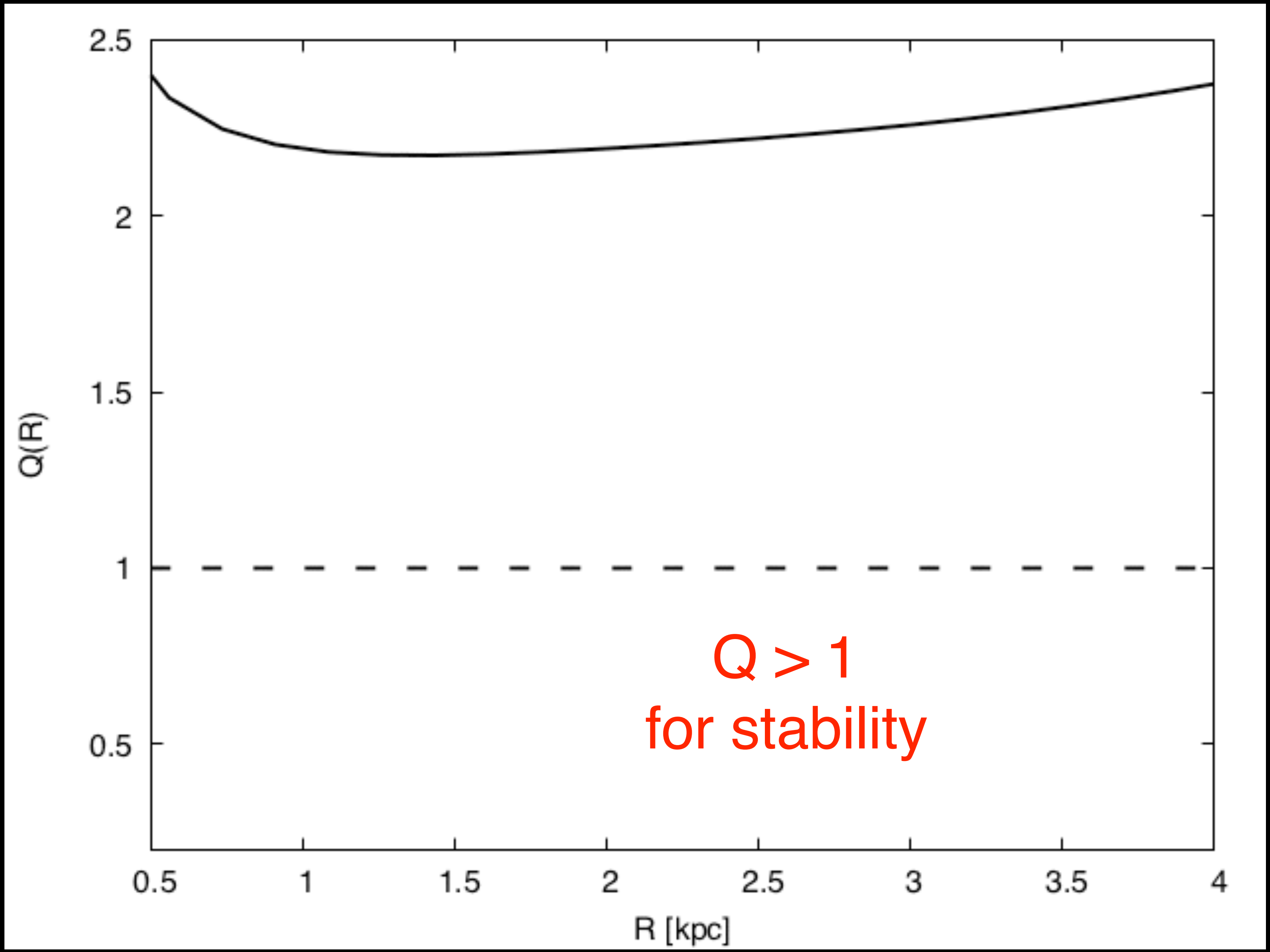

linear vel [km s^{-1}]
x [kpc]
t = 0.00E+00 Myr (001)
t = 0.00E+00 Myr (001)
180
160
140
120
100
80
60
40
20
0
10
20
30
40
50

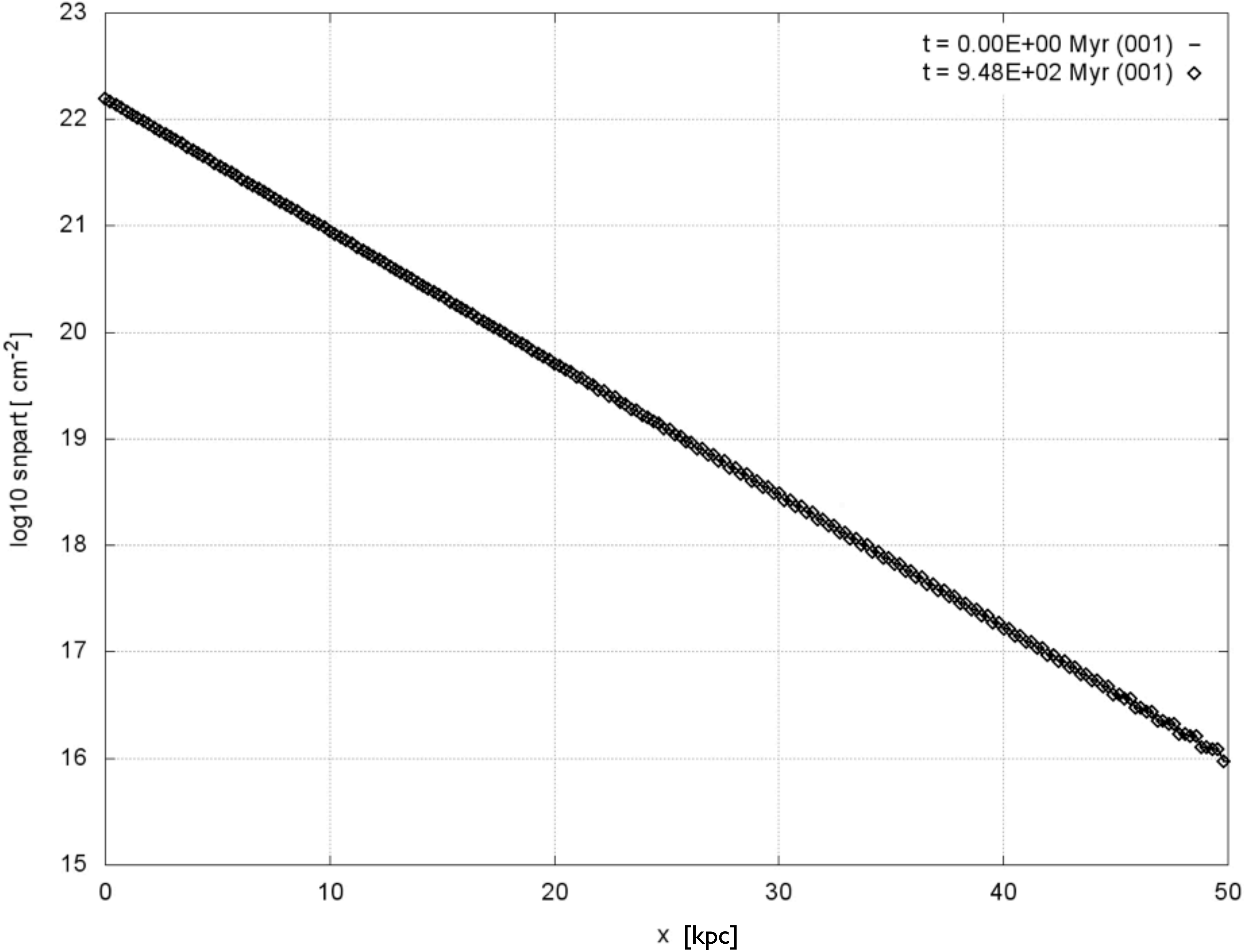
Disc in an external, static potential II:
DM halo + stellar potential

R_d [kpc]	3,5
M_{DM} [$M_\odot$]	10^{12}
T [K]	4×10^4

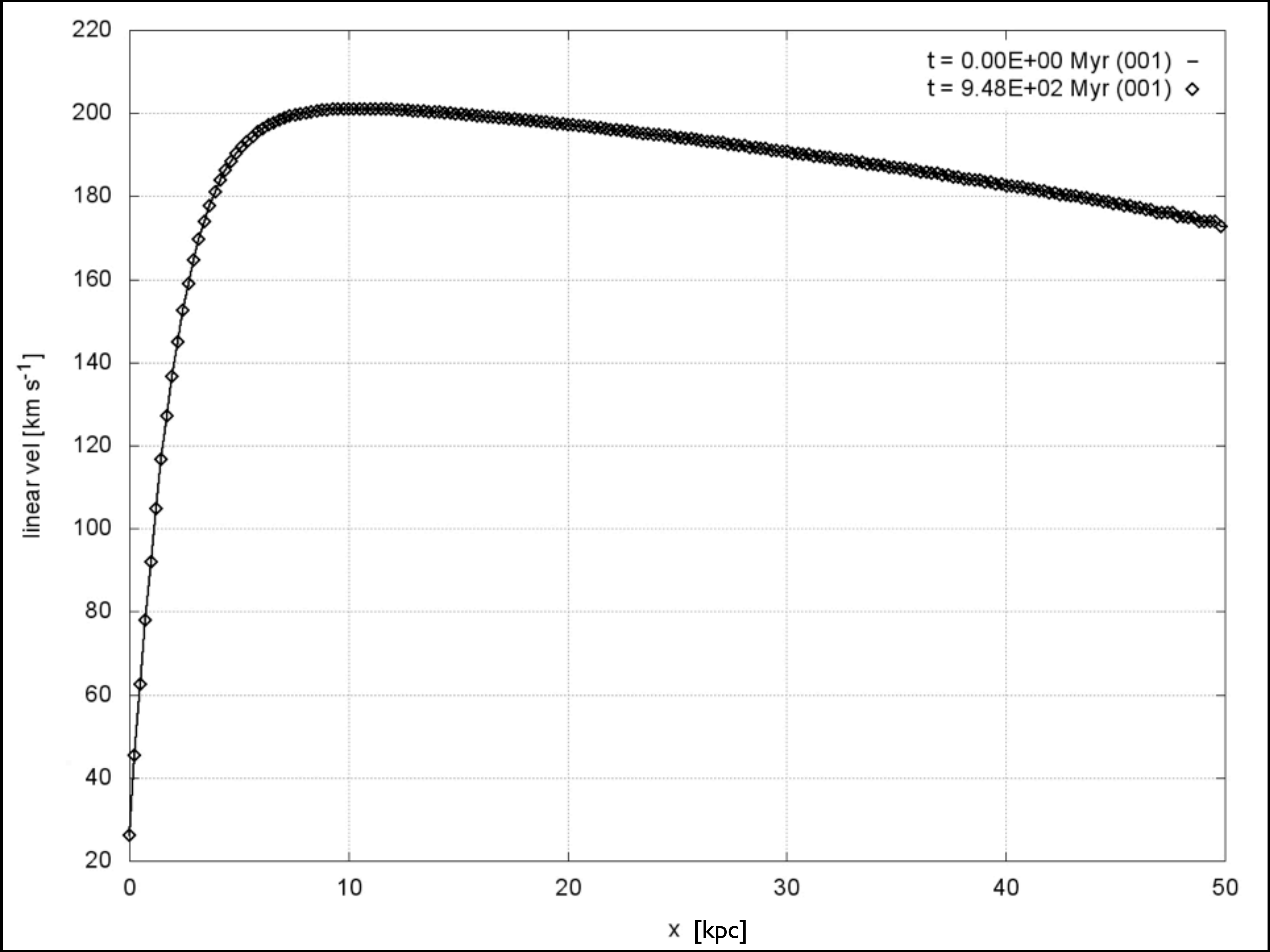
[cf. model GasStar of Wang+10]

STABLE CASE



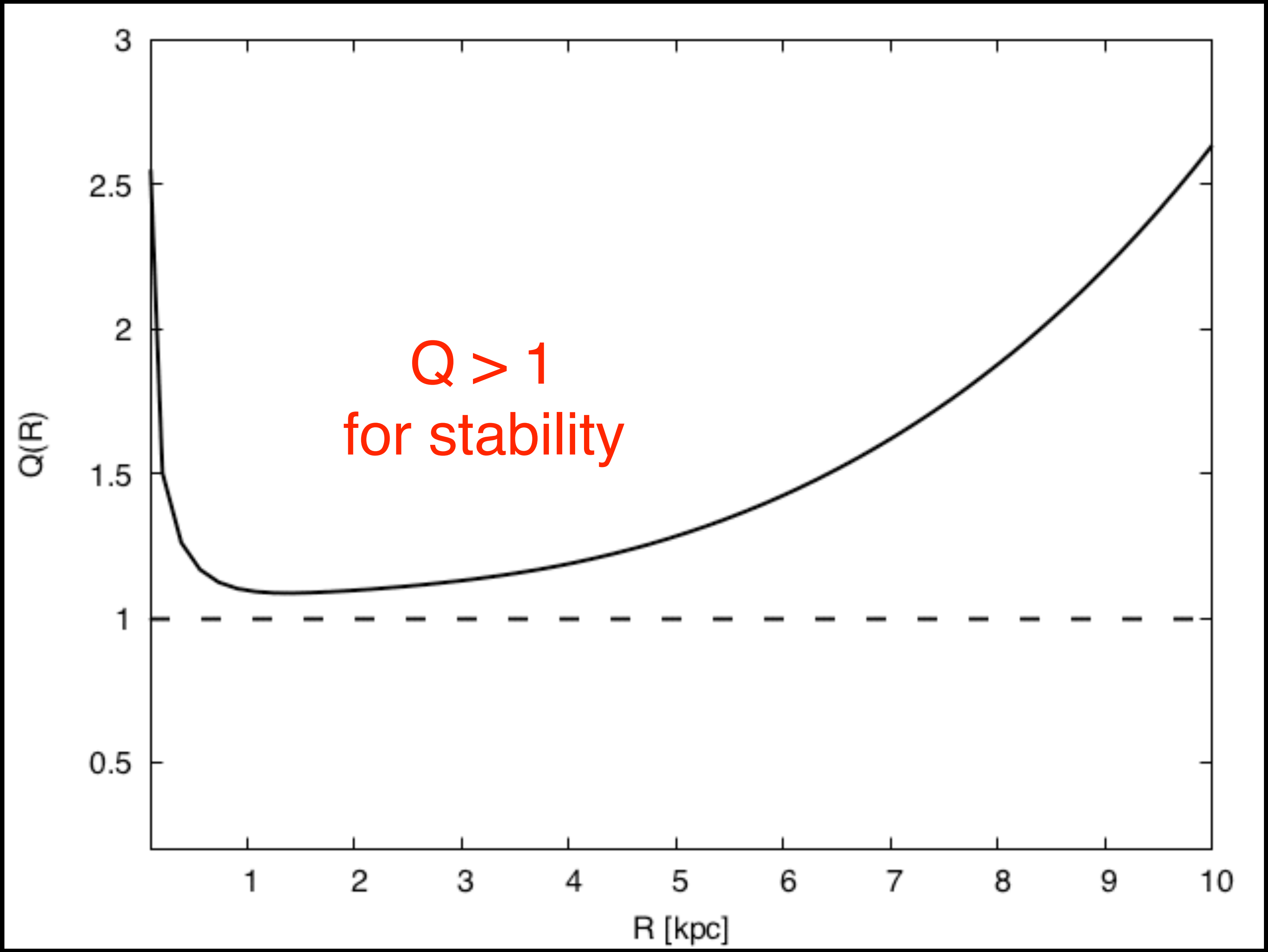


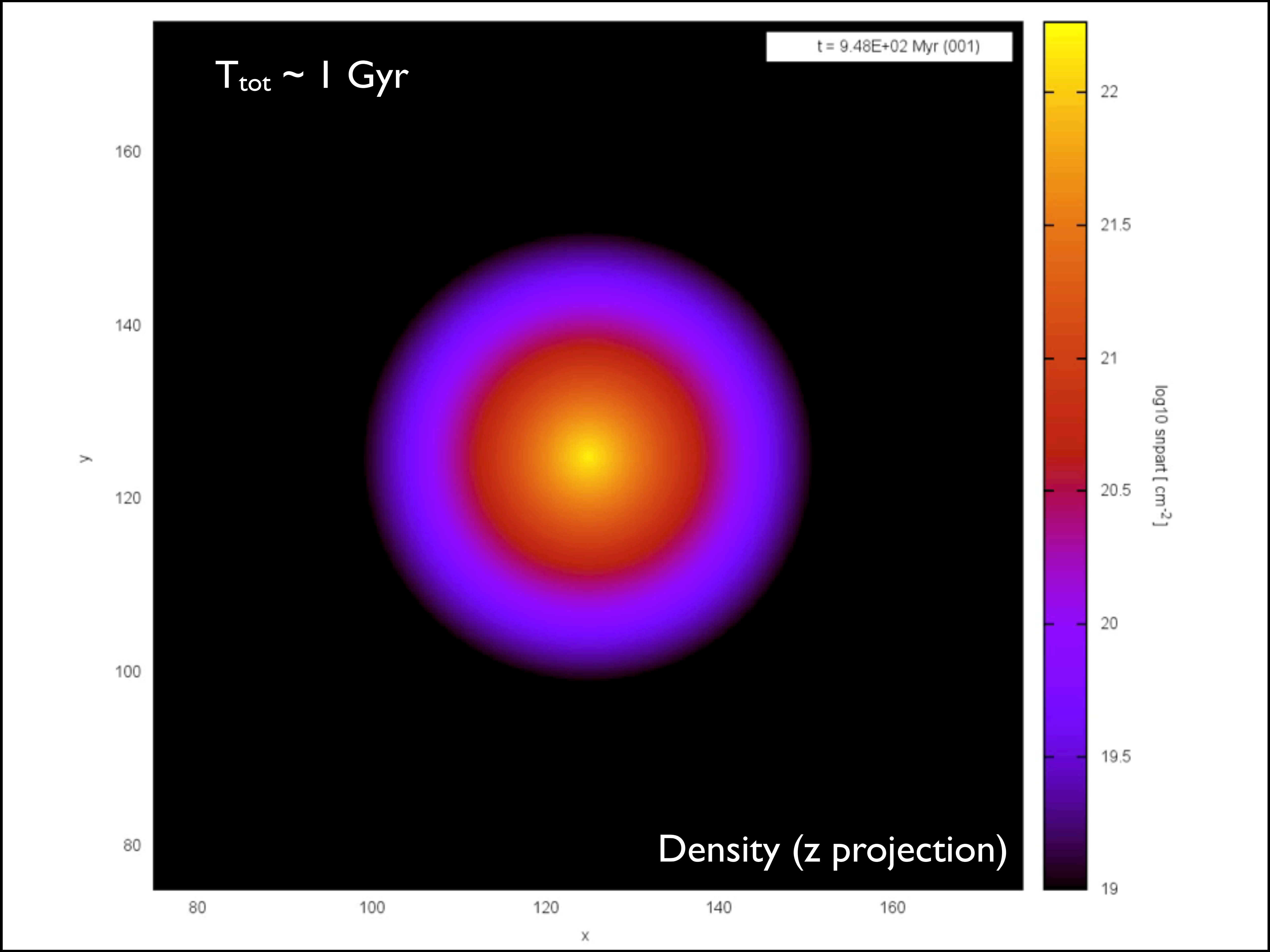
t = 0.00E+00 Myr (001)
t = 9.48E+02 Myr (001)
log10 snpart [cm^-2]
x [kpc]



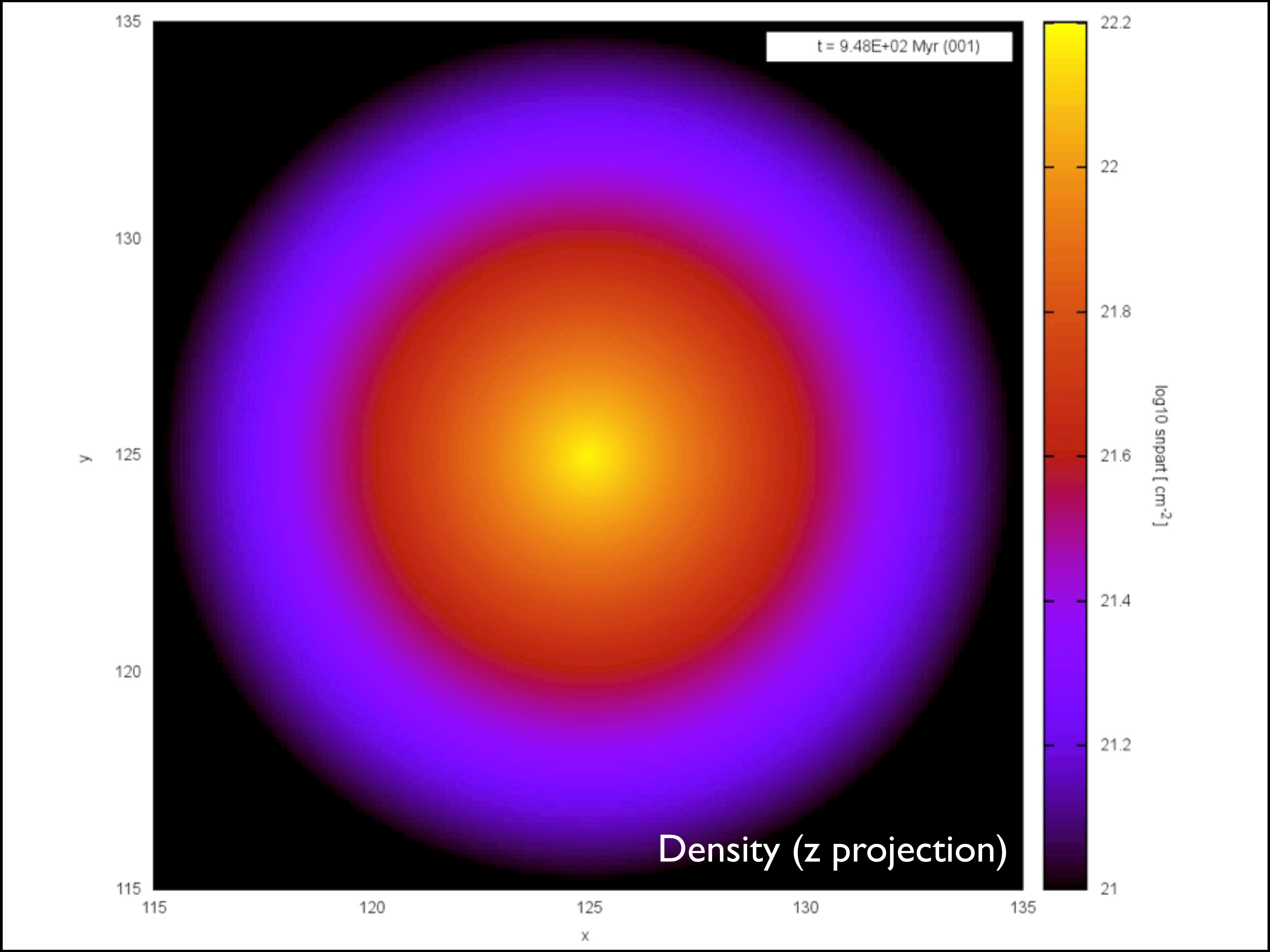
t = 0.00E+00 Myr (001)
t = 9.48E+02 Myr (001)
linear vel [km s-1]
x [kpc]
220
200
180
160
140
120
100
80
60
40
20
0
10
20
30
40
50

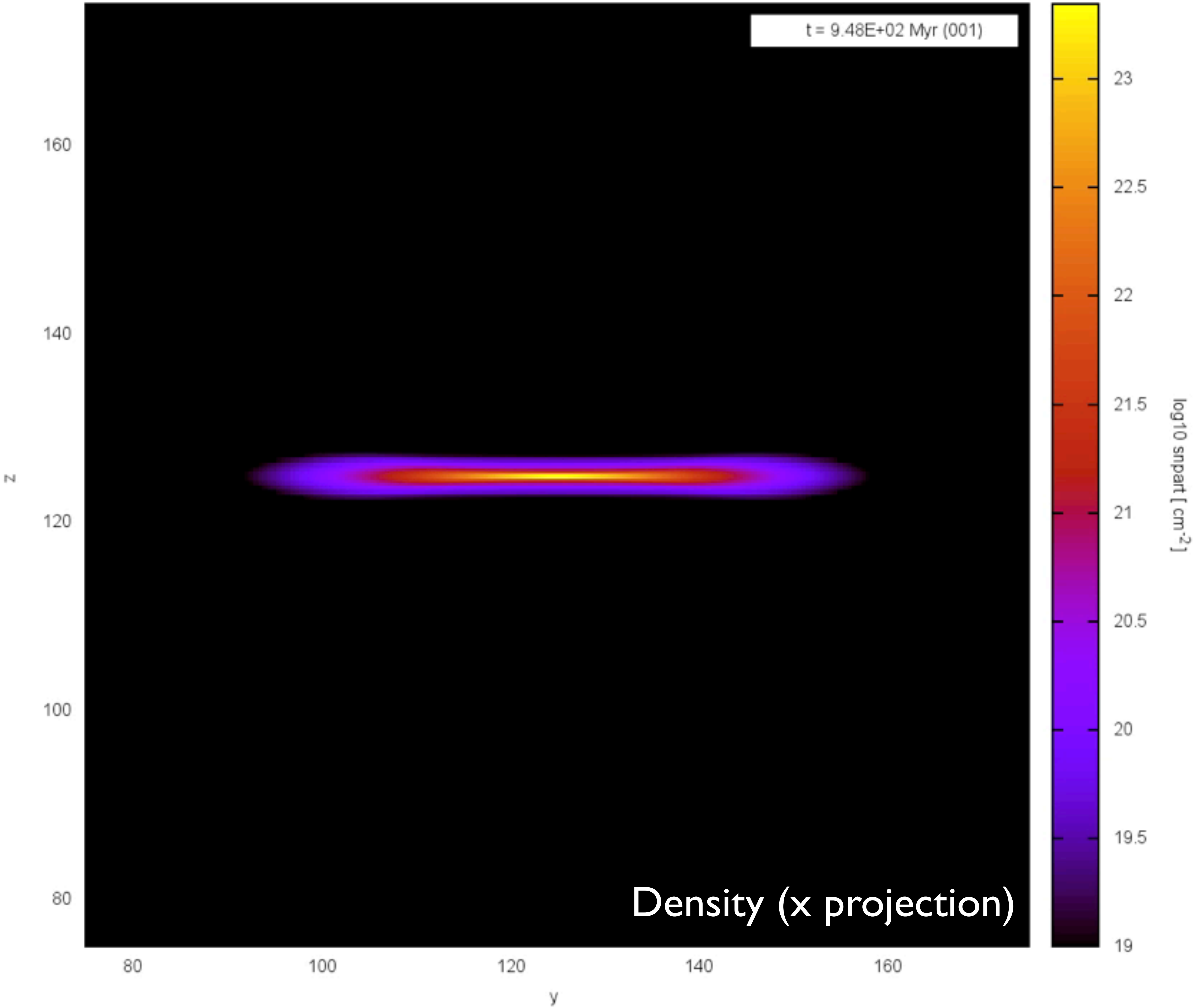
CRITICALLY STABLE CASE





t = 9.48E+02 Myr (001)
T_tot ~ 1 Gyr
Density (z projection)
160
140
120
100
80
y
80
100
120
140
160
x
22
21.5
21
20.5
20
19.5
19
log10 snpart [cm-2]


t = 9.48E+02 Myr (001)
Density (z projection)
135
130
125
120
115
y
115
120
125
130
135
x
22.2
22
21.8
21.6
21.4
21.2
21
log10 snpart [cm-2]


t = 9.48E+02 Myr (001)
160
140
120
100
80
z
80
100
120
140
160
y
23
22.5
22
21.5
21
20.5
20
19.5
19
log10 snpart [cm-2]
Density (x projection)

SUMMARY

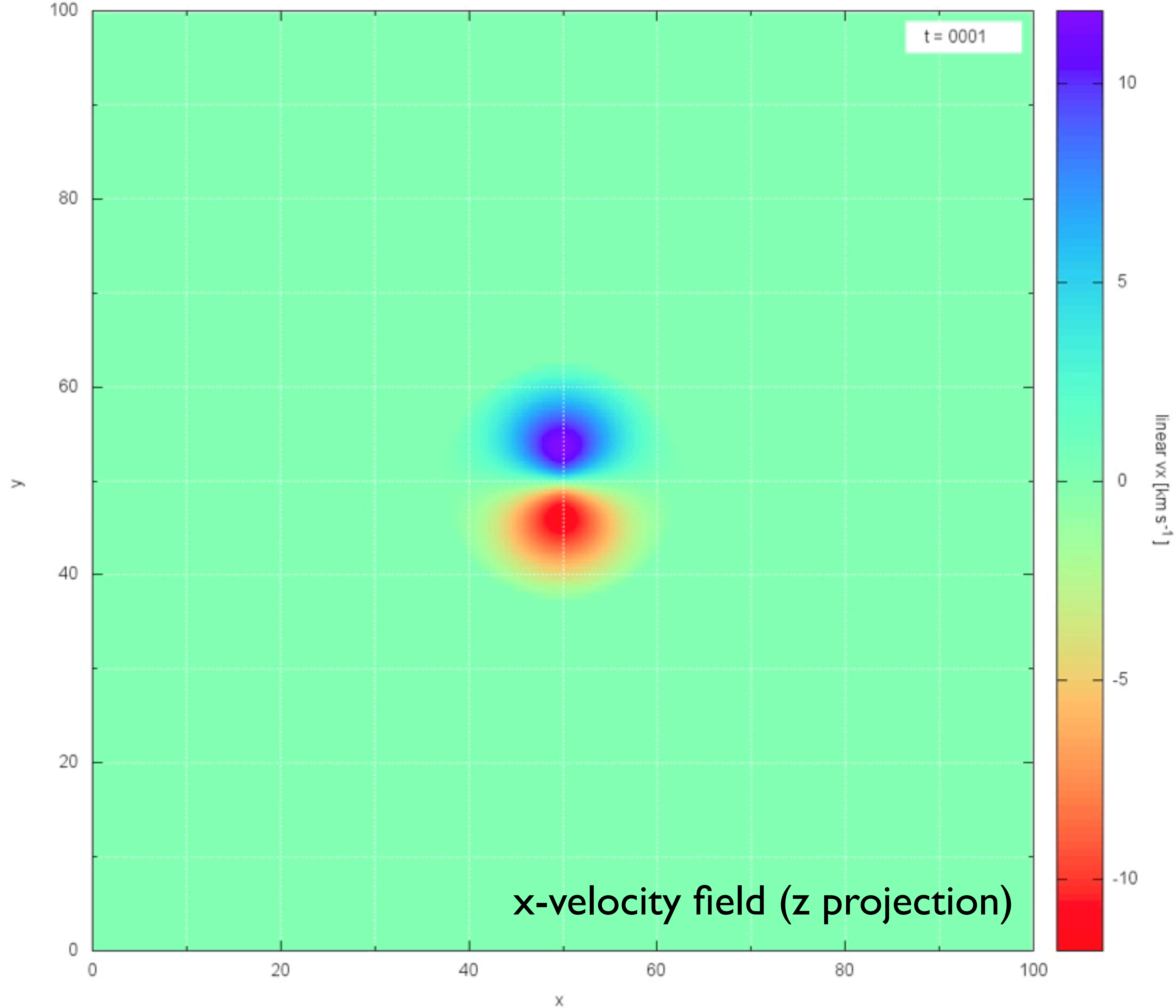
- Powerful method to create equilibrium ICs for isolated galaxies [Wang+2010]
- Three examples of increasing complexity:
  - self-gravitating, isothermal gas disc (a.k.a. Spitzer-Freeman disc)
    - particulary useful to check for the correctness of ICs and numerical setup
  - gas disc in external potential (DM halo [+ stellar disc])
- RAMSES demonstrate that the models are in equilibrium and obey standard stability criteria
  - What about the solver?
- Next step: perturb models out of equilibrium

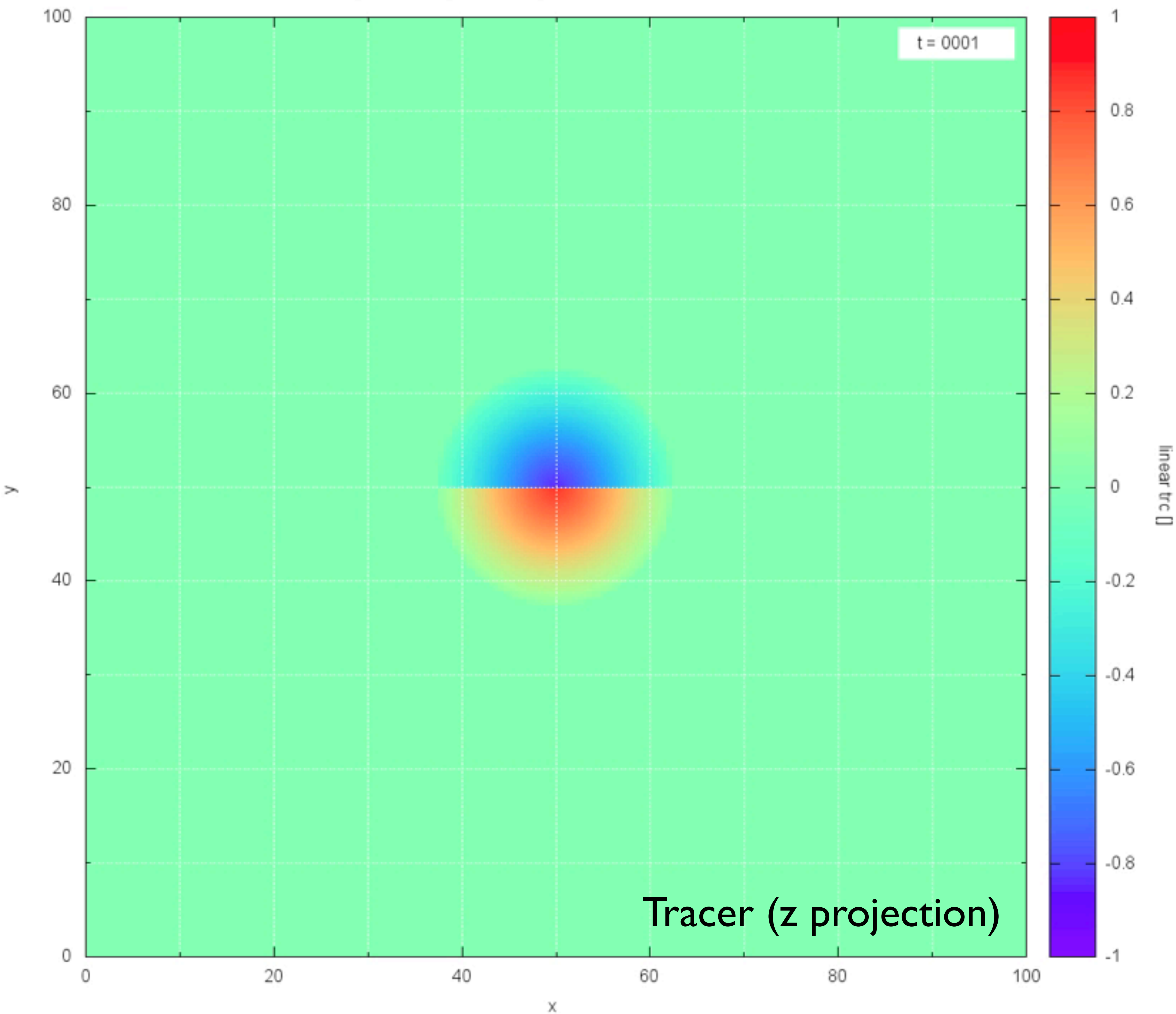
Force: $$\frac{1}{\rho}\frac{\partial p}{\partial R} + \frac{\partial \Phi}{\partial R} = \frac{V_{\mathrm{rot}}^2}{R}$$

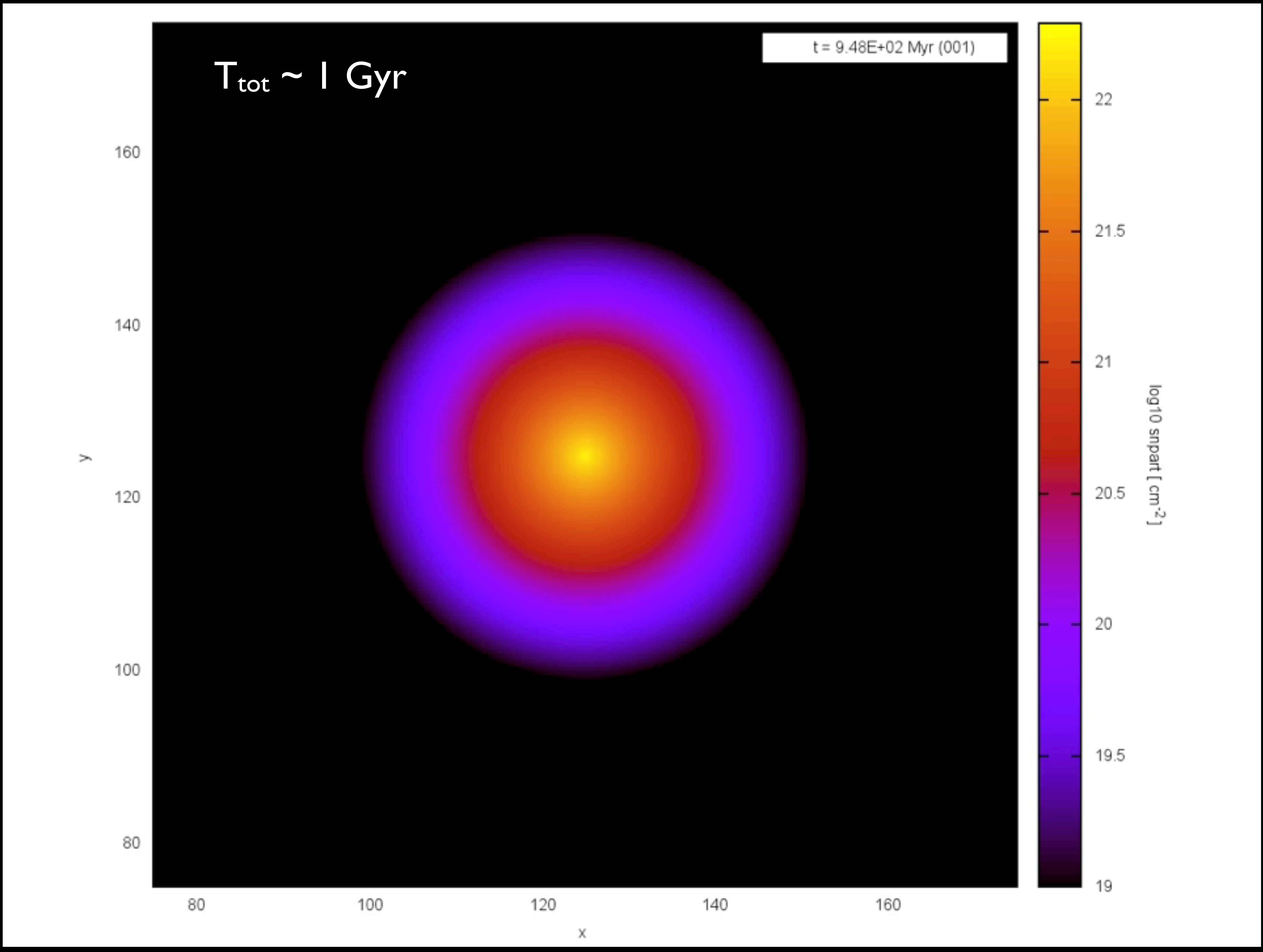
HSE: $$\frac{1}{\rho}\frac{\partial p}{\partial z} + \frac{\partial \Phi}{\partial z} = 0$$

Poisson: $$\nabla^2 \Phi = 4\pi G \rho_{\mathrm{tot}}$$

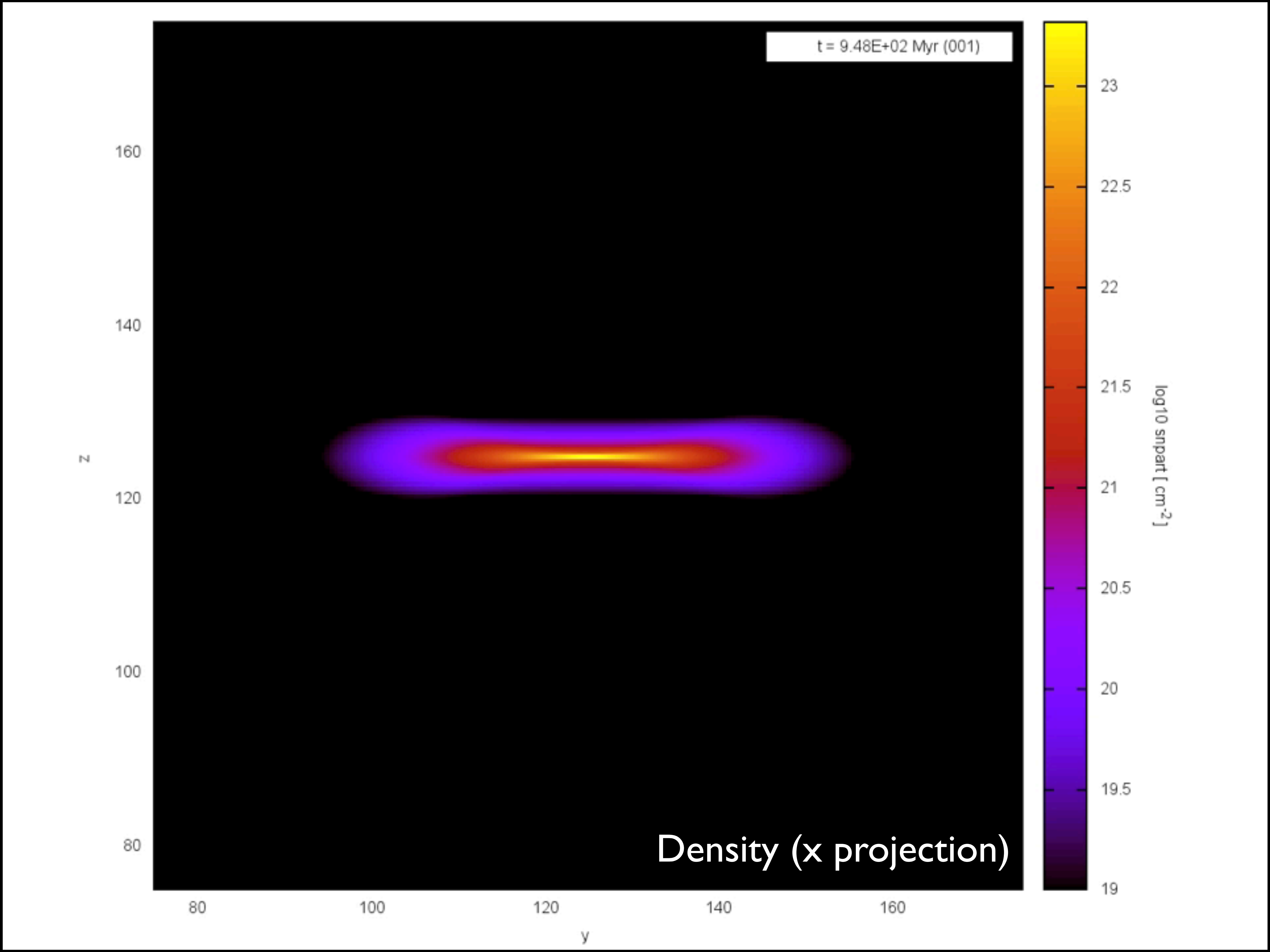
EOS: $$p = p(\rho)$$

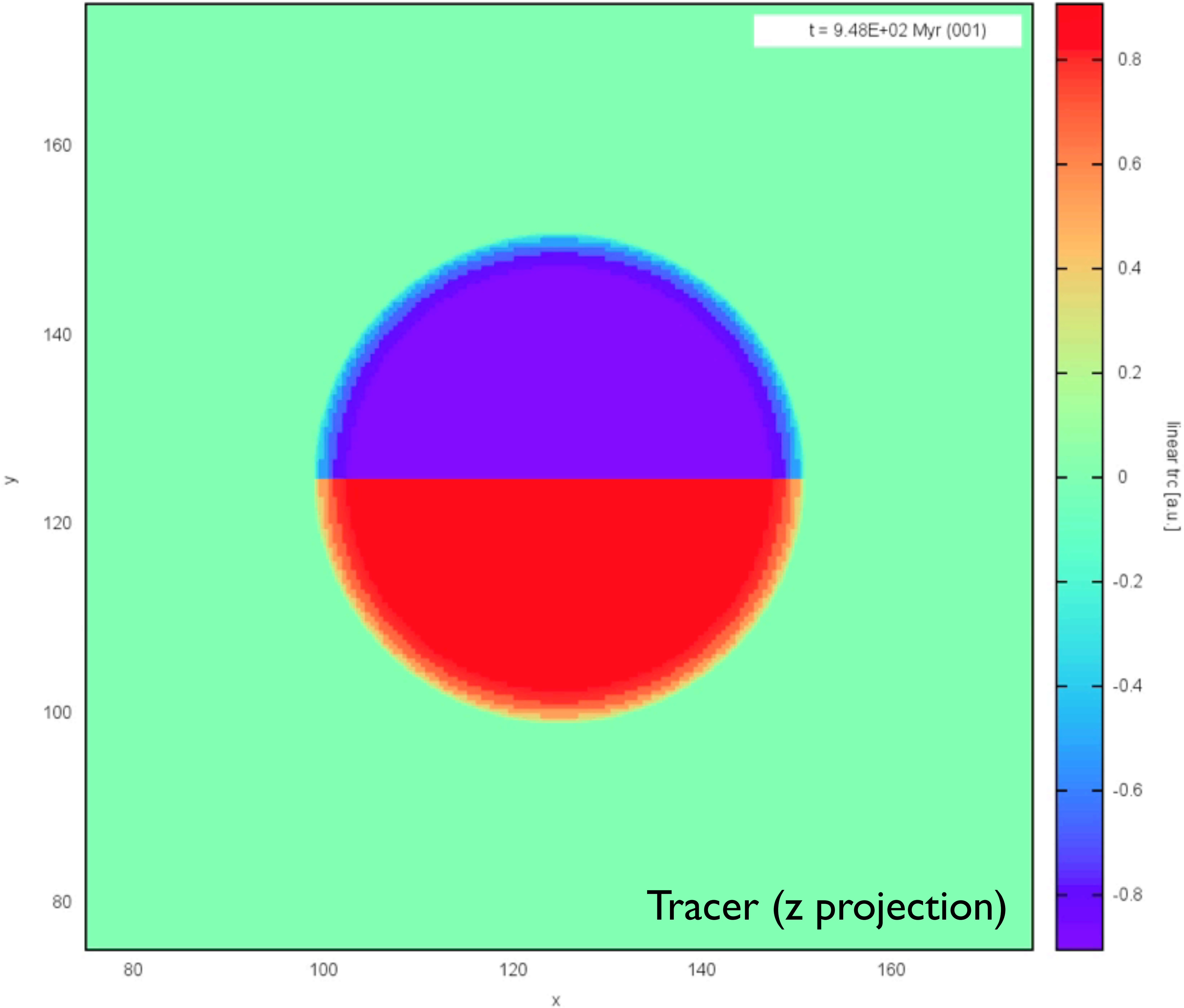

t = 0001
x-velocity field (z projection)
linear vx [km s-1]
x
y
0
20
40
60
80
100
10
5
0
-5
-10


t = 0001
y
x
linear trc []
Tracer (z projection)



T_{tot} ~ 1 Gyr
t = 9.48E+02 Myr (001)
160
140
120
100
80
y
80
100
120
140
160
x
22
21.5
21
20.5
20
19.5
19
log10 snpart [cm^{-2}]

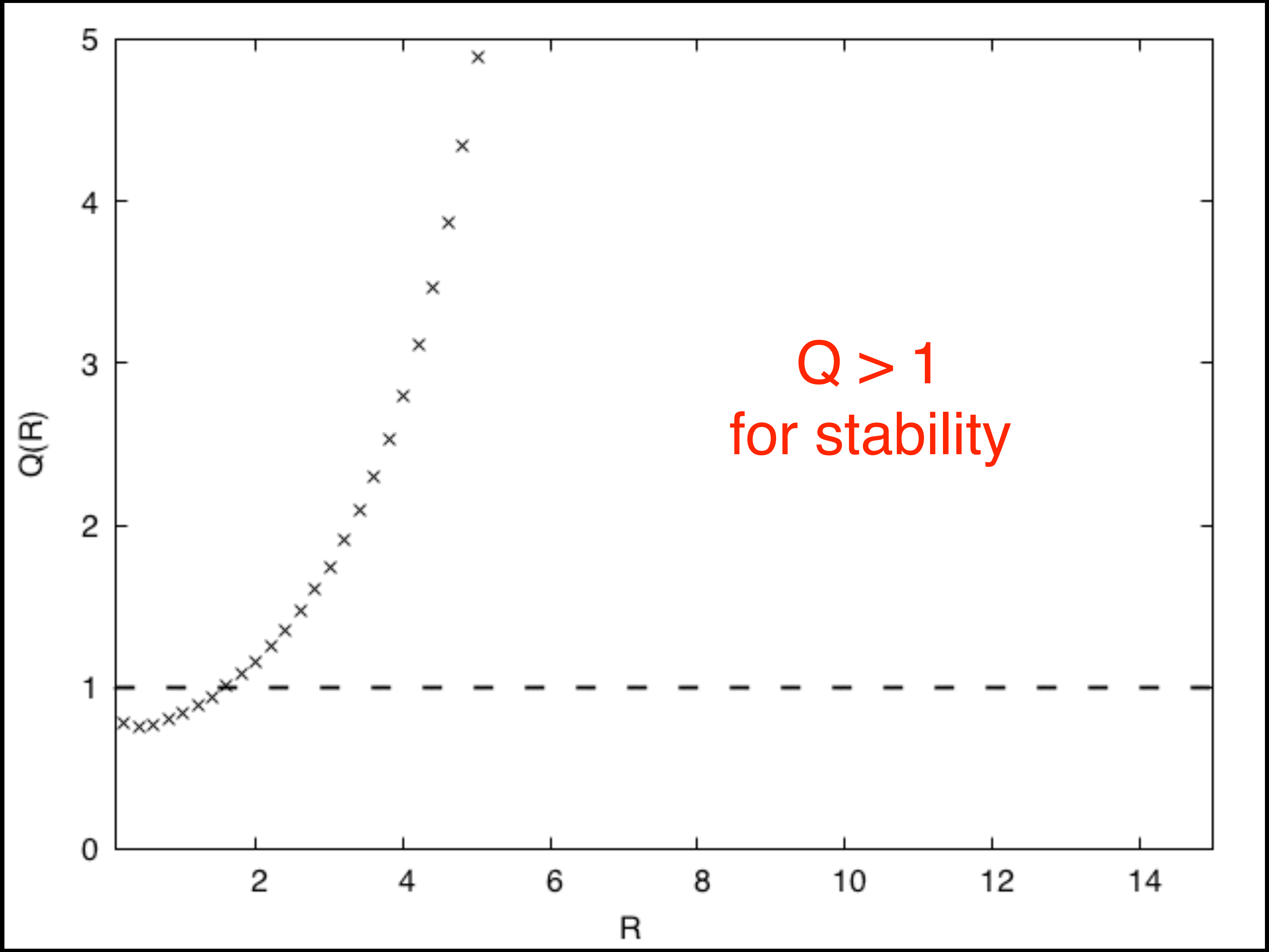

t = 9.48E+02 Myr (001)
Density (x projection)
z
y
80
100
120
140
160
log10 snpart [cm^{-2}]
19
19.5
20
20.5
21
21.5
22
22.5
23



t = 9.48E+02 Myr (001)
Tracer (z projection)
y
160
140
120
100
80
x
80
100
120
140
160
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
linear trc [a.u.]

Spitzer-Freeman Disc

[Spitzer 1942; Freeman 1970]



OUTLINE

- What are we doing?
- Why?
- Three test cases (increasing complexity)
  - Spitzer-Freeman Gas Disc
  - Gas Disc in DM halo
  - Gas Disc in DM halo + stellar potential
    - stable / crtitically stable
- Summary
  - Issues / tricks
  - Lessons learned / Improvements