The Stability of Dwarf Elliptical Galaxies in MOND

Xufen Wu, HongSheng Zhao (University of St Andrews)

In collaboration with Y.G. Wang, C. Llinares, A. Knebe


Tully-Fisher relation and Rotation Curves of galaxies
(Milgrom 1983a,b,c; Bekenstein & Milgrom 1984; Sanders & McGaugh 2002)
Tidal Dwarf Galaxies
(Gentile et al. 2008)
Cosmic Microwave Background Anisotropic Spectrum
(Skordis et al. 2006)
$g>>a_0$: $\mu=1$, Newton
$g<<a_0$: $\mu=x$, dMOND
$a_0 = 1.2x10^{-10}$ m/s^2
Bullet Cluster
(Angus et al. 2007; Llinares et al. 2009)
Structure Formation
(Halle et al. 2007; Skordis et al. 2008; Llinares et al. 2008)
Strong gravitational lenses
(Zhao et al 2006; Chen & Zhao 2006, Shan et al. 2008)
Weak Lensing
(Angus et al. 2007; Famaey et al. 2007)

MOdified Newtonian Dynamics

Basic idea of MOND:

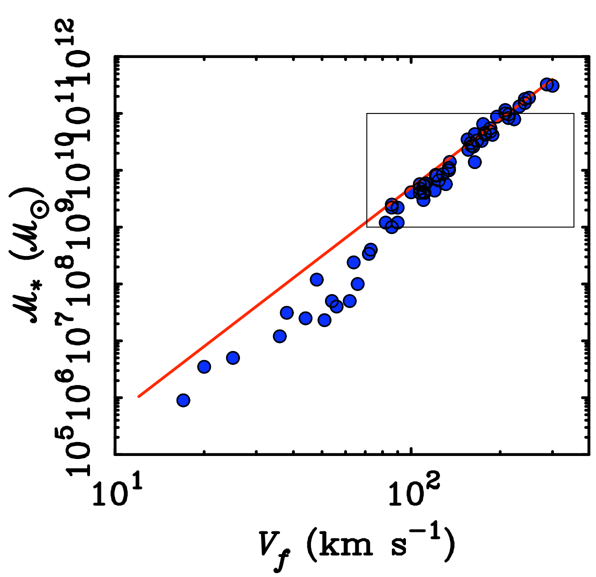
$$\nabla \cdot [\mu(x)\nabla\Phi] = 4\pi G\rho$$

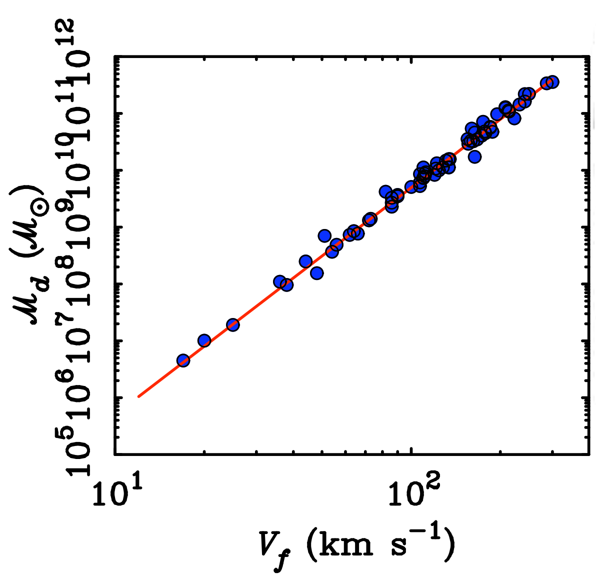
(Bekenstein & Milgrom 1984)

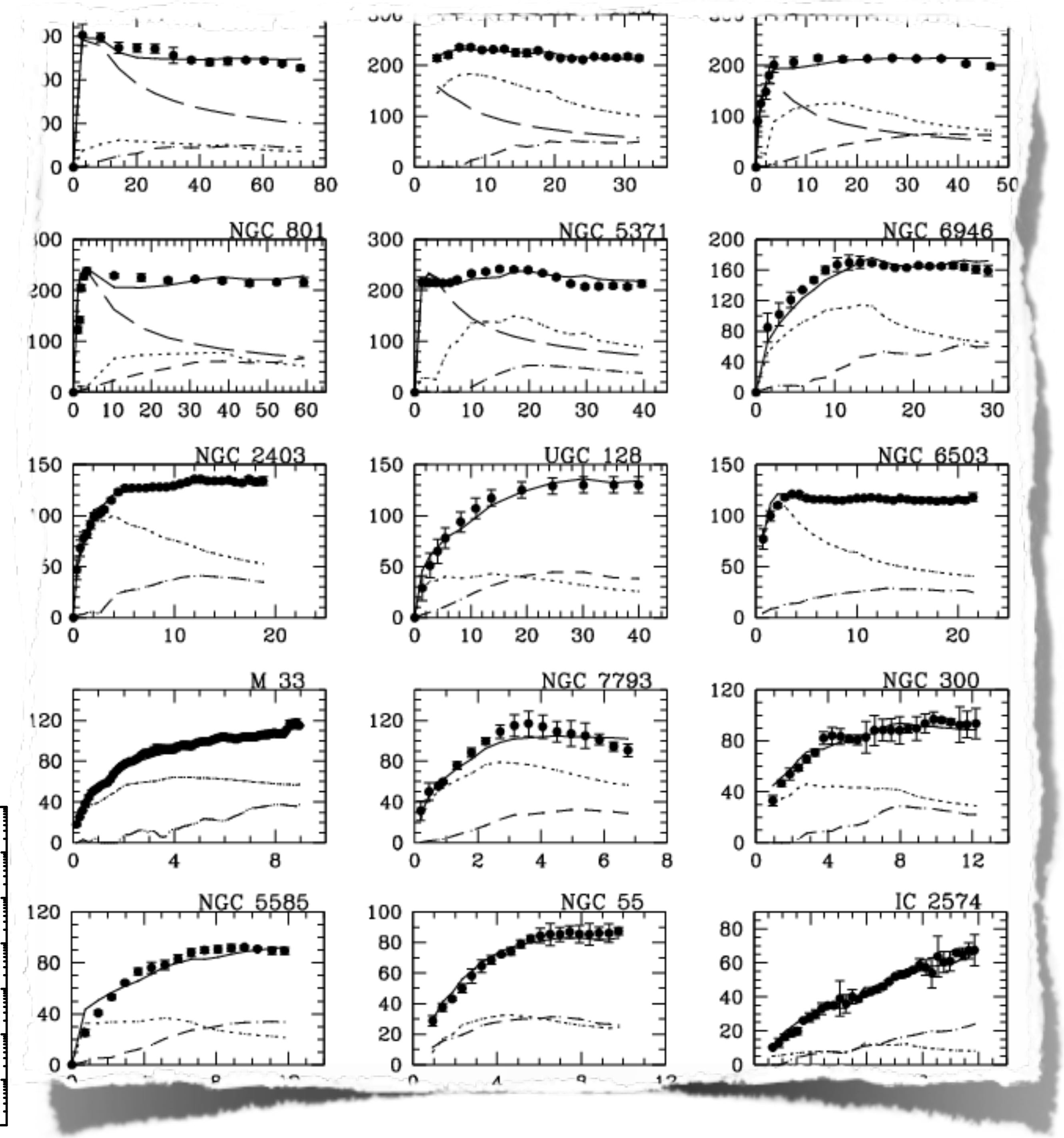
g>> a_0 : μ=1, Newton
g<< a_0 : μ=x, dMOND

$$x = \frac{|\nabla\Phi|}{a_0} = \frac{g}{a_0}$$

$$a_0 = 1.2 \times 10^{-10} m \cdot s^{-2}$$







In Newtonian Gravity, there exists instability on some models for galaxies

Can we find stable models for galaxies in MOND?

Triaxial Cuspy Galaxy Stability

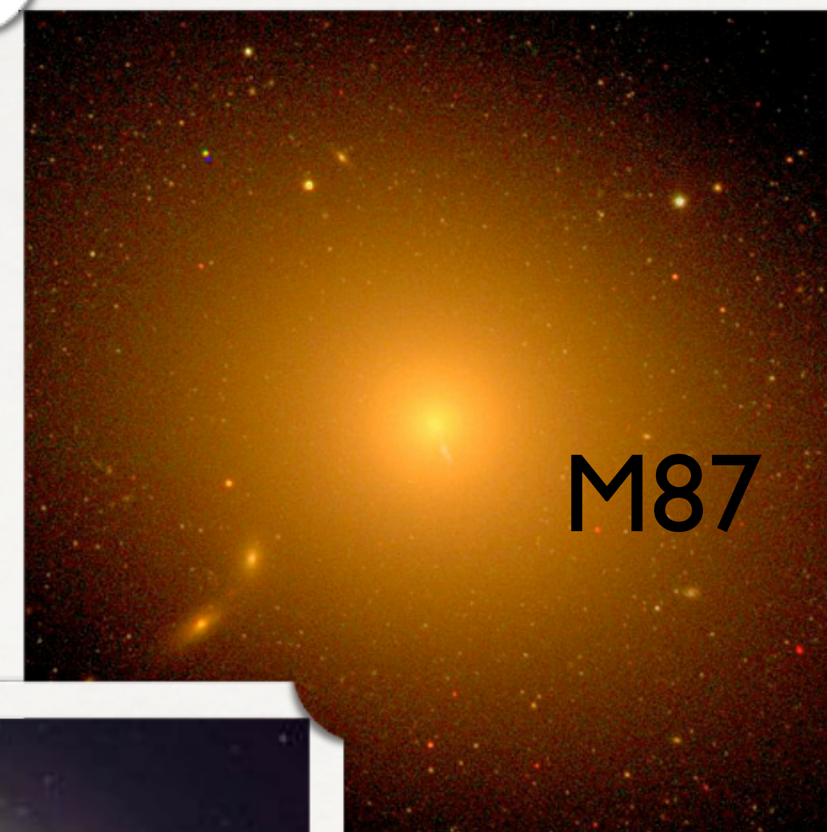
- Nbody Simulations: Constructing galaxies with Hernquist profile , i.e. 1/r cusp centre

$$\rho = \frac{M}{2\pi abc}\frac{1}{r(r+1)^3}$$

$$r = \sqrt{\left(\frac{x}{a}\right)^2 + \left(\frac{y}{b}\right)^2 + \left(\frac{z}{c}\right)^2}$$

density axis ratio
a:b:c=1: 0.86 : 0.7 kpc

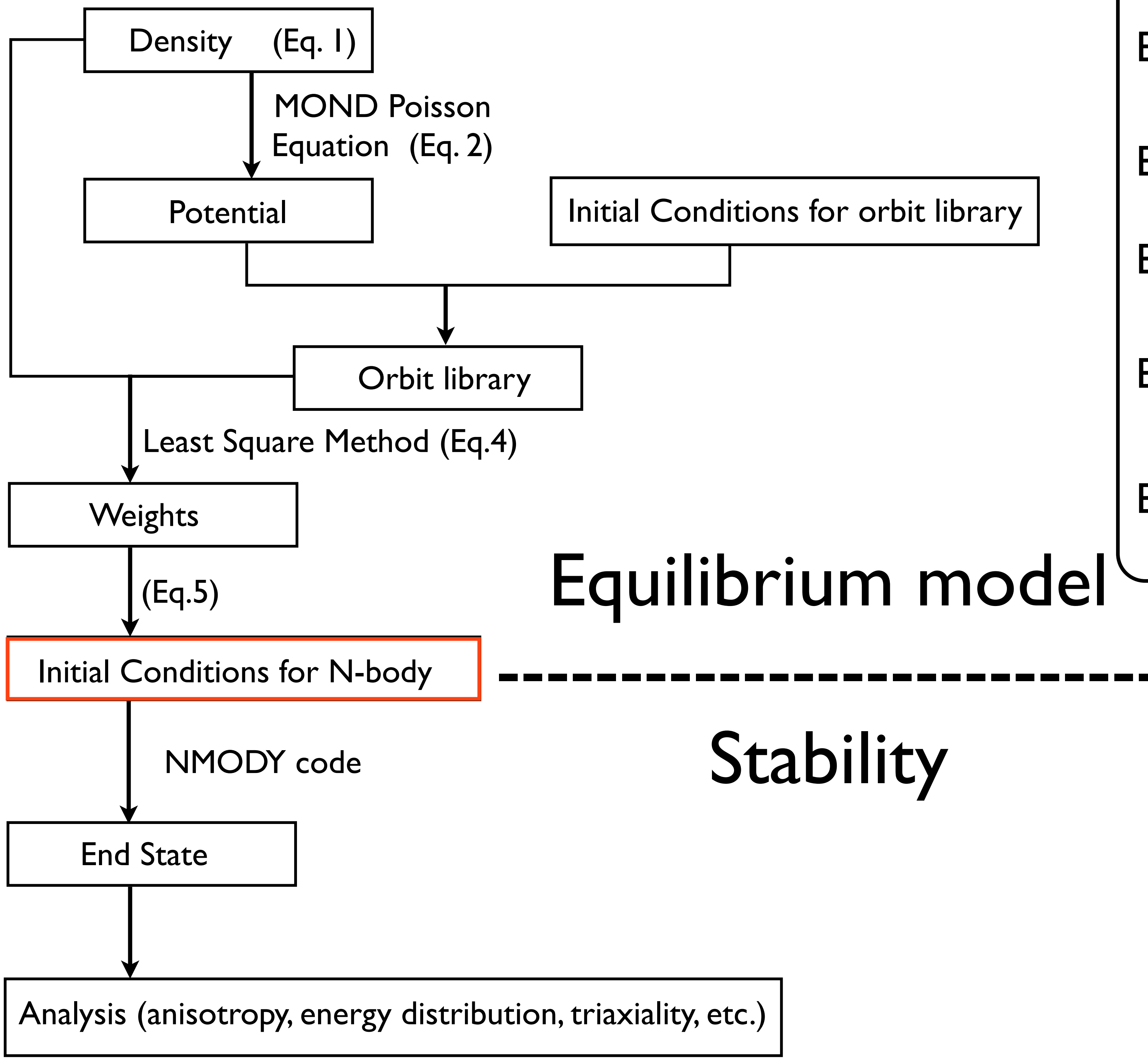
(Wang et al. 2008, ApJ, 677, 1033;
Wu et al. 2009, MNRAS, in press)



NGC1316

Schwarzschild Technique+NMODY

Schwarzschild (1979,1982); Zhao (1996); Merritt & Fridman (1996); Rix (1997)



Eq.1 $$\rho = \frac{M}{2\pi abc}\frac{1}{r(r+1)^3}$$

Eq.2 $$\nabla \cdot [\mu(x)\nabla\Phi] = 4\pi G\rho$$

Eq.3 $$\mu(x) = \frac{x}{1+x}$$

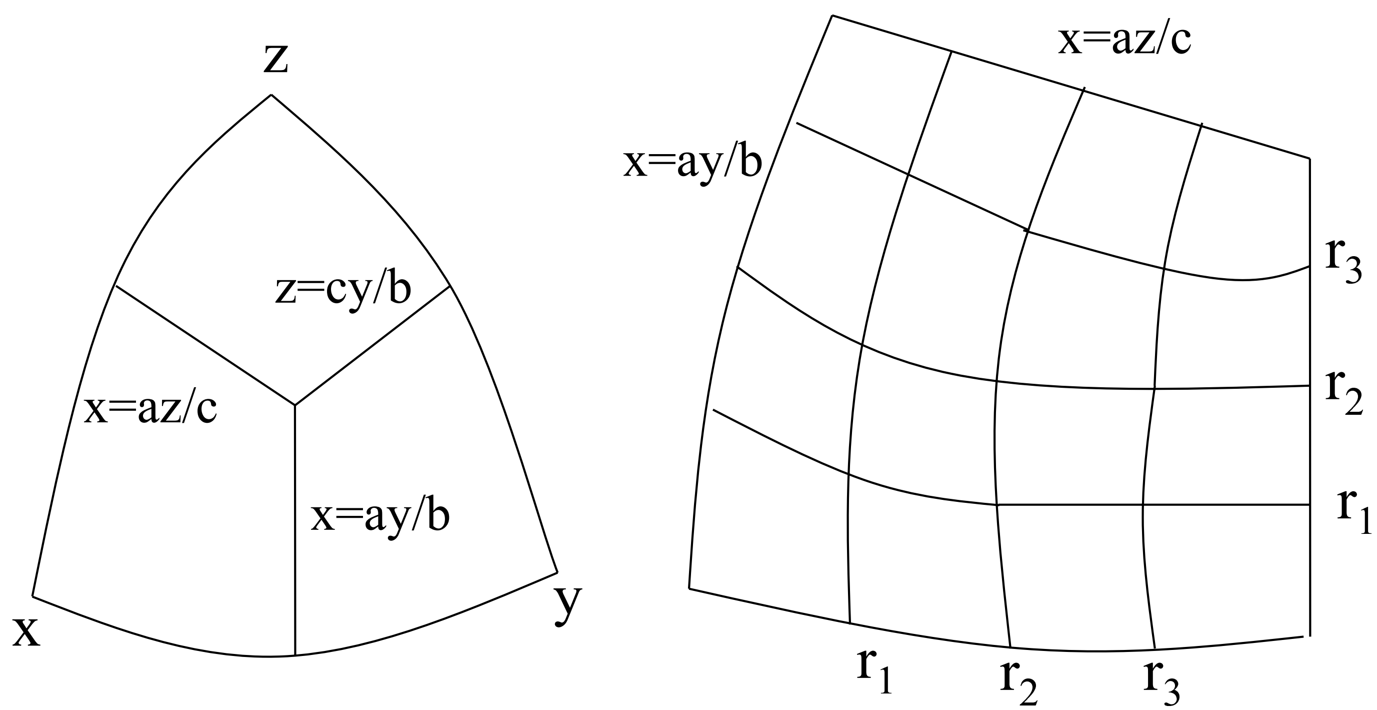
Eq.4 $$\chi^2 = \frac{1}{N_{cells}}\sum_{i=1}^{N_{cells}}\left(\sum_{j=1}^{Norbits} W_j O_{ij} - M_i\right)^2$$

Eq.5 $$n_j = W_j N_{total}$$

Launch Orbits

(Merritt & Fridman 1996)

1. Stationary Orbits:

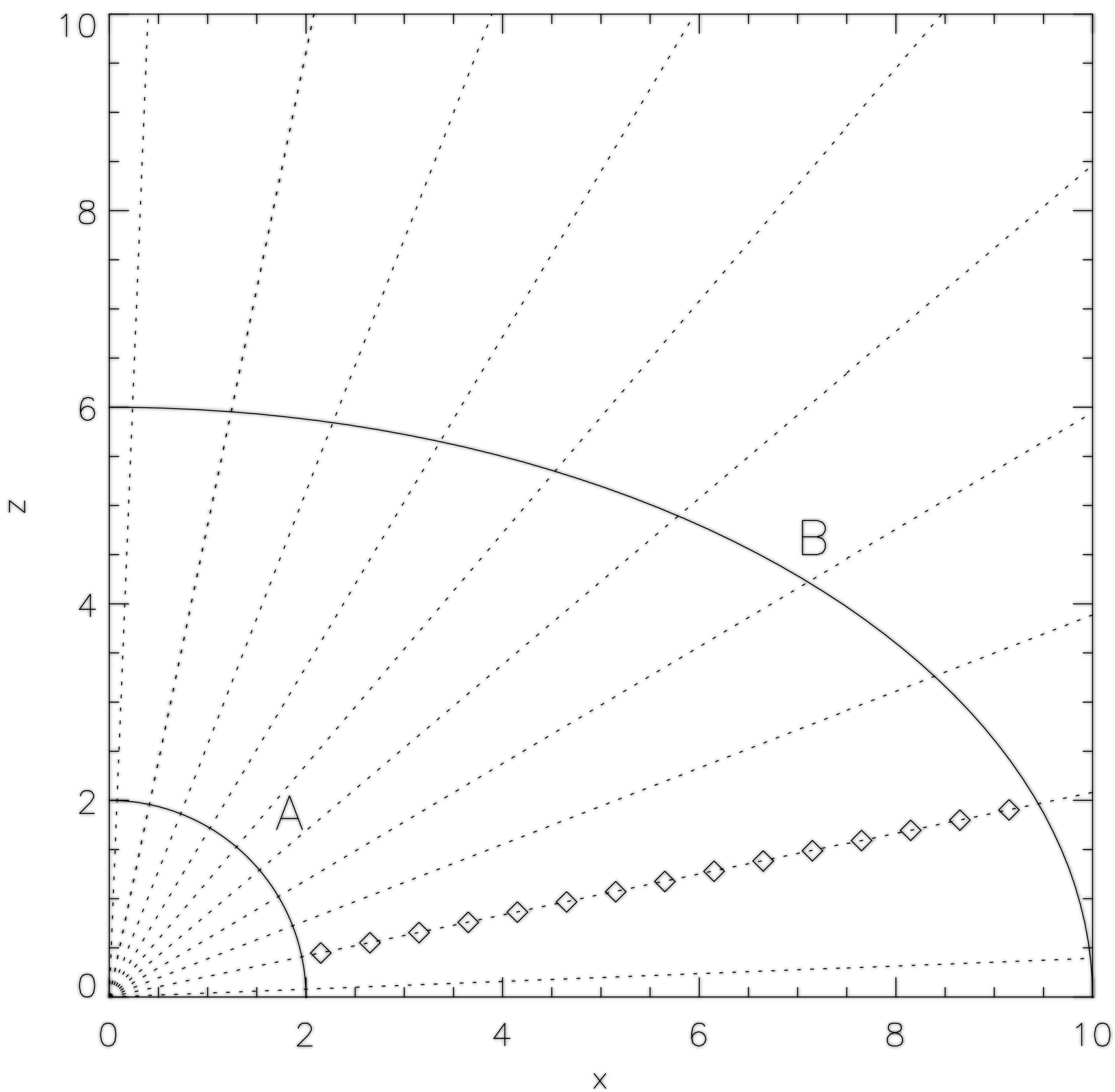


The first octant is divided into 21 equal mass sectors by 20 shells.
The first octant is further divided by planes z = cx/a, y = bx/a and z = cy/b (left panel) into 3 parts.
Each part is subdivided by planes ay/bx = 1/5, 2/5, 2/3 and az /cx = 1/5, 2/5, 2/3 into 16 cells (right panel).
we sub-divide the cells by the mid-planes of the cells once again.

Stationary orbits are launched from the central points of the outer shell surfaces of the sub-cells.
4 x 16 x (21-2) =192 orbits for each shell

Launch Orbits

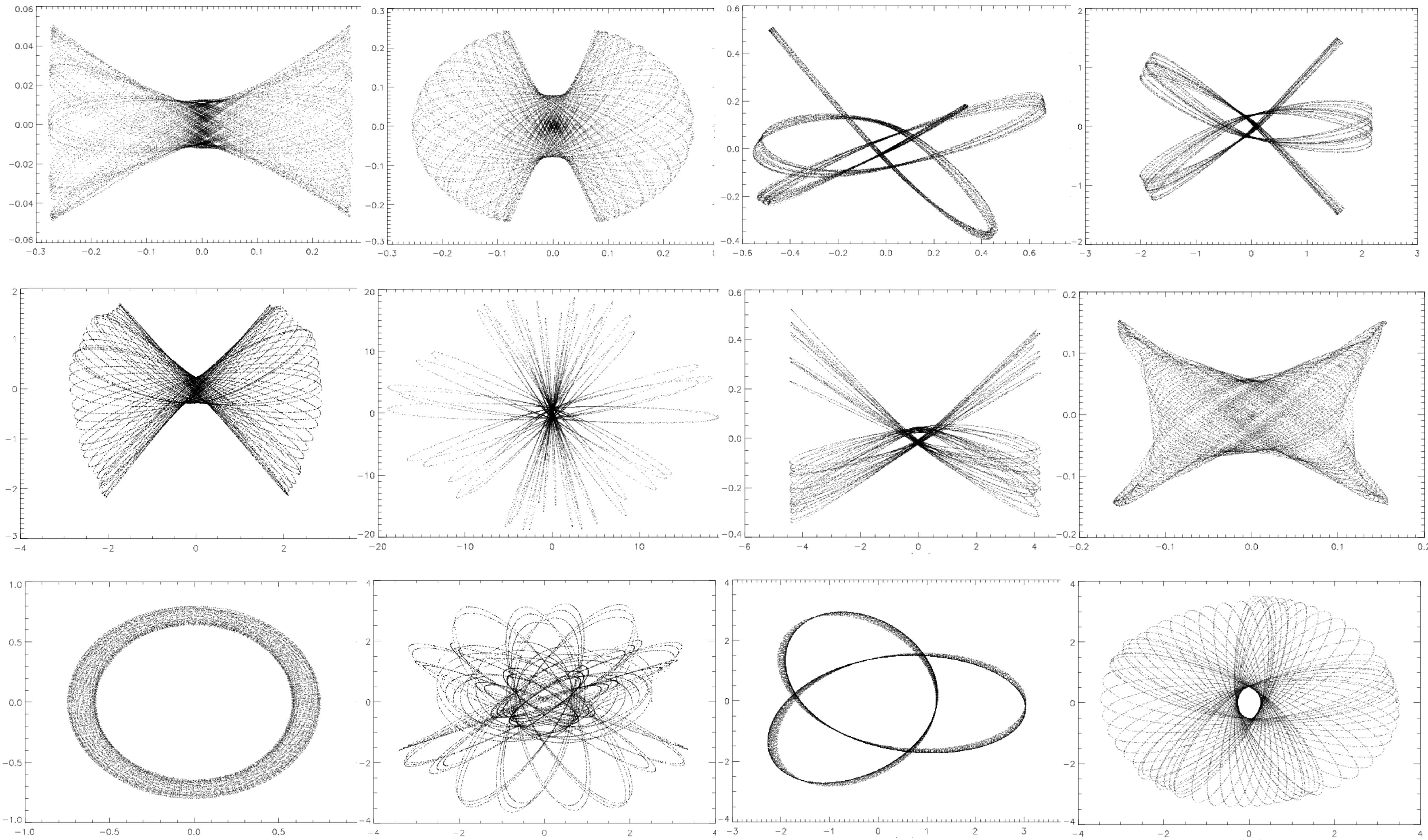
2. x-z plane launched orbits:



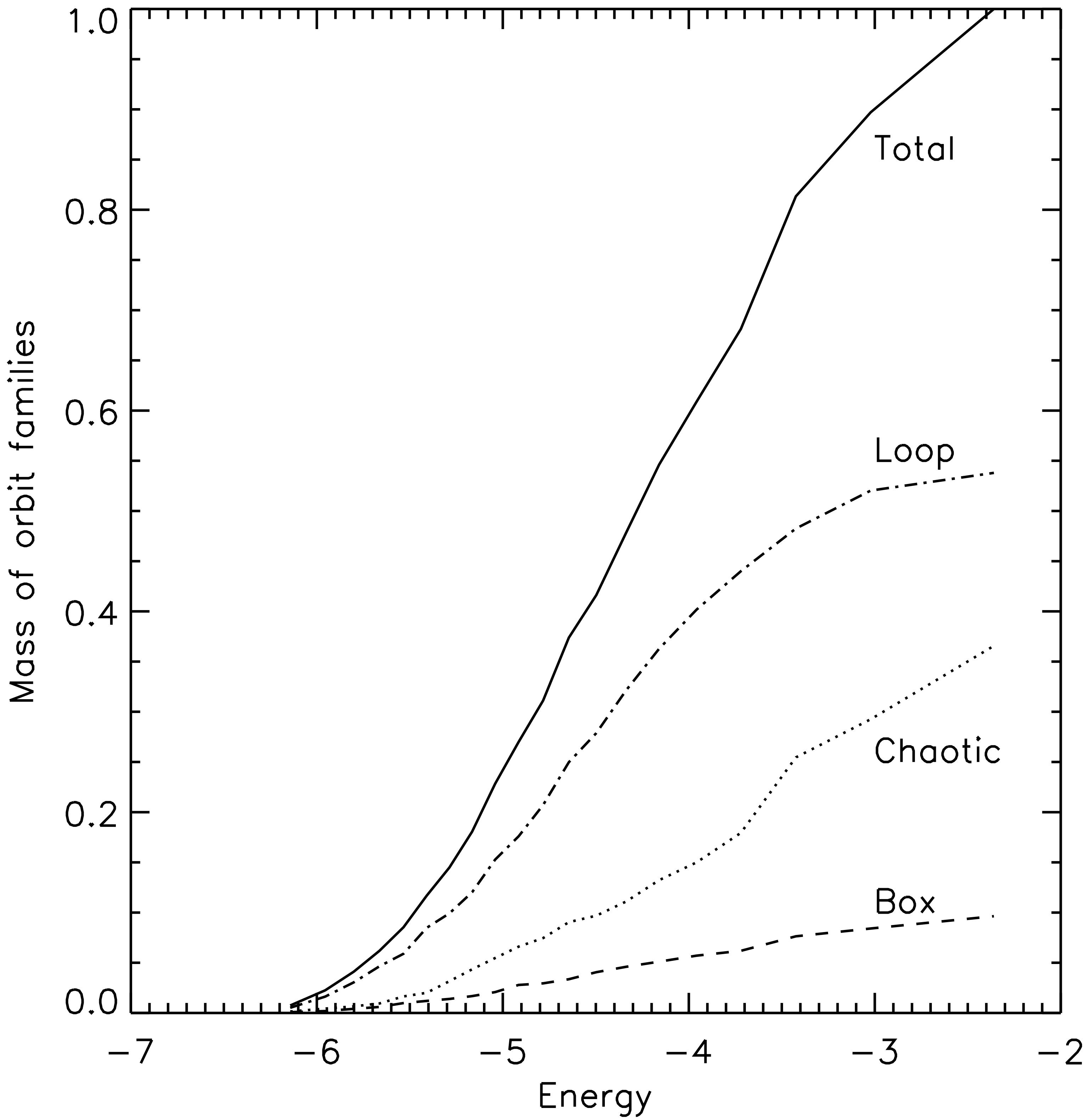
Give a certain energy $E_k = \Phi(x, 0, z)$ on K^{th} sector, Curve A is the minimal radius of 1:1 resonant orbits (x:y), and Curve B is the zero velocity surface. We define 10 lines satisfying $x = z \tan\theta$, where θ lies within the range 2.25° to 87.75°. Along the radial direction, we equally divide the radius between two boundaries into 16 parts with 15 points, where those 15 points are the initial positions for the orbits launched from the x – z plane.

There are 150 x – z plane starting orbits for each sector.

Orbits Example



Weights of Orbits

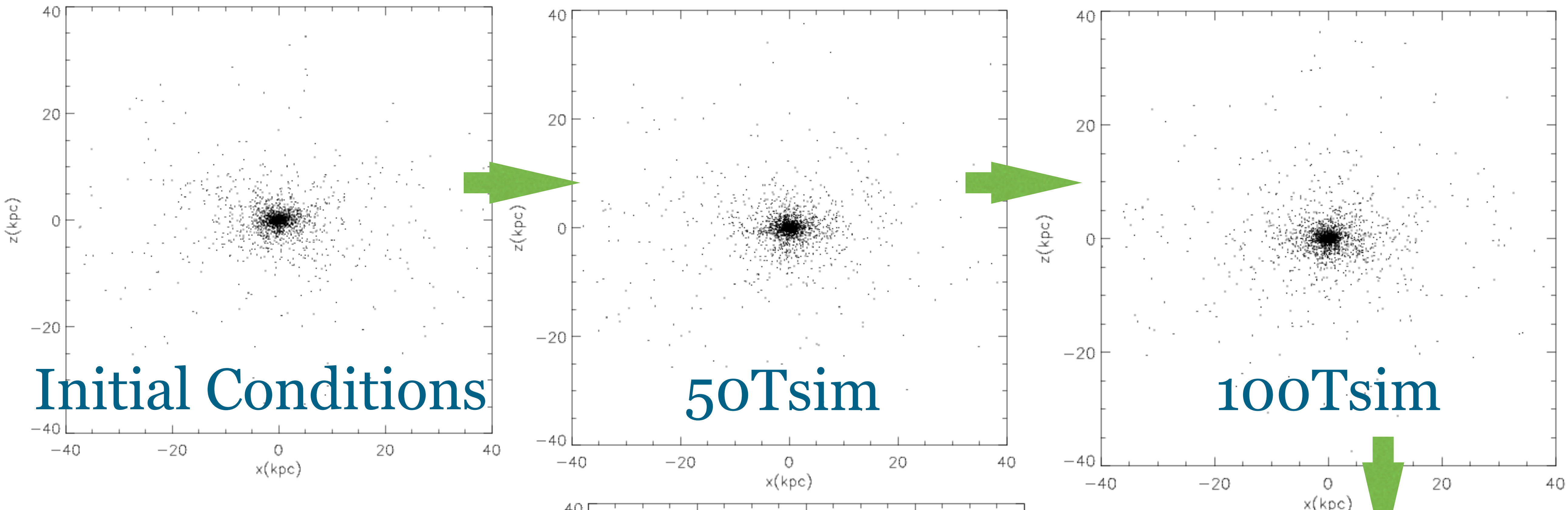


Accumulated energy distribution of different orbit families

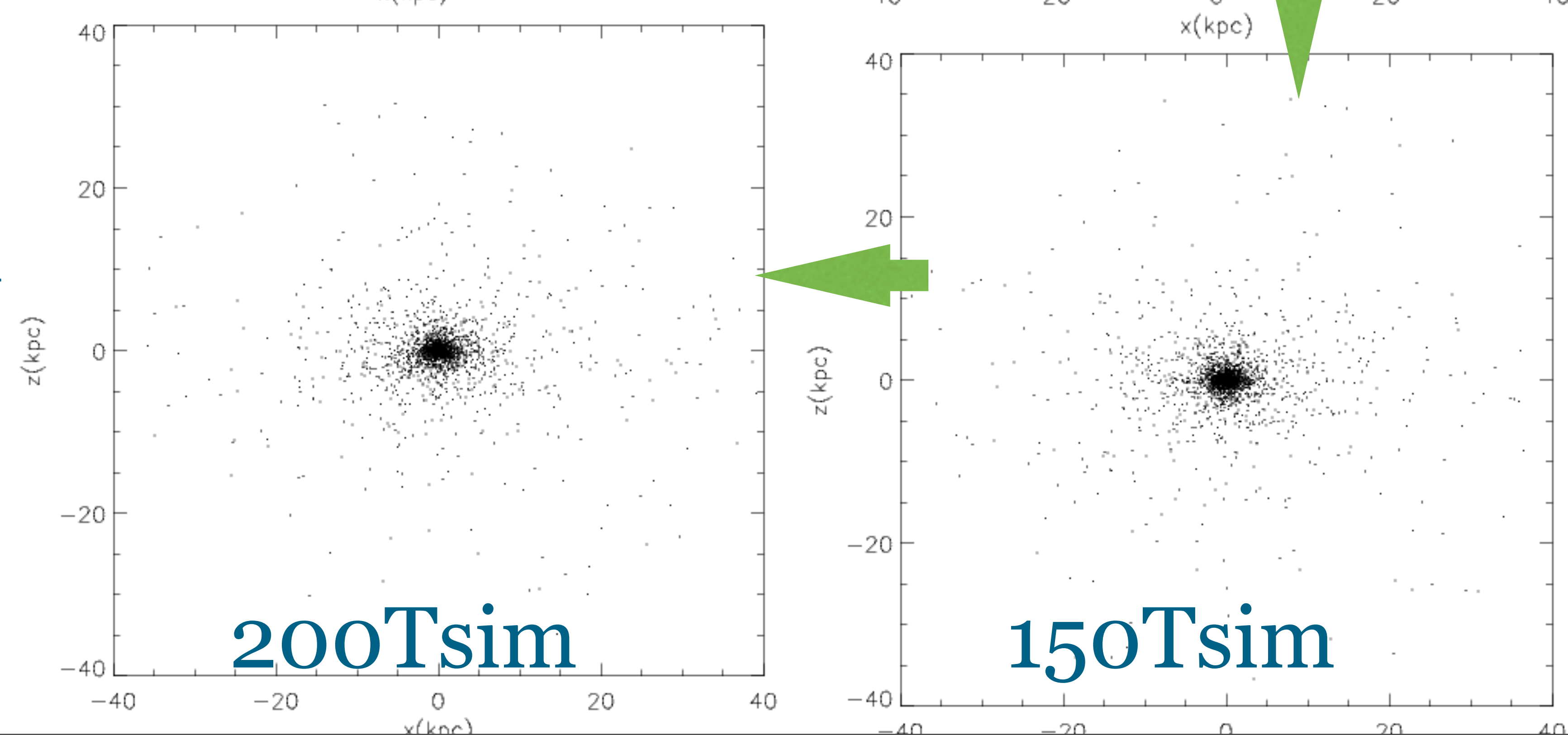
Mass model: 10^9 Msun

Wu et al. (2009)

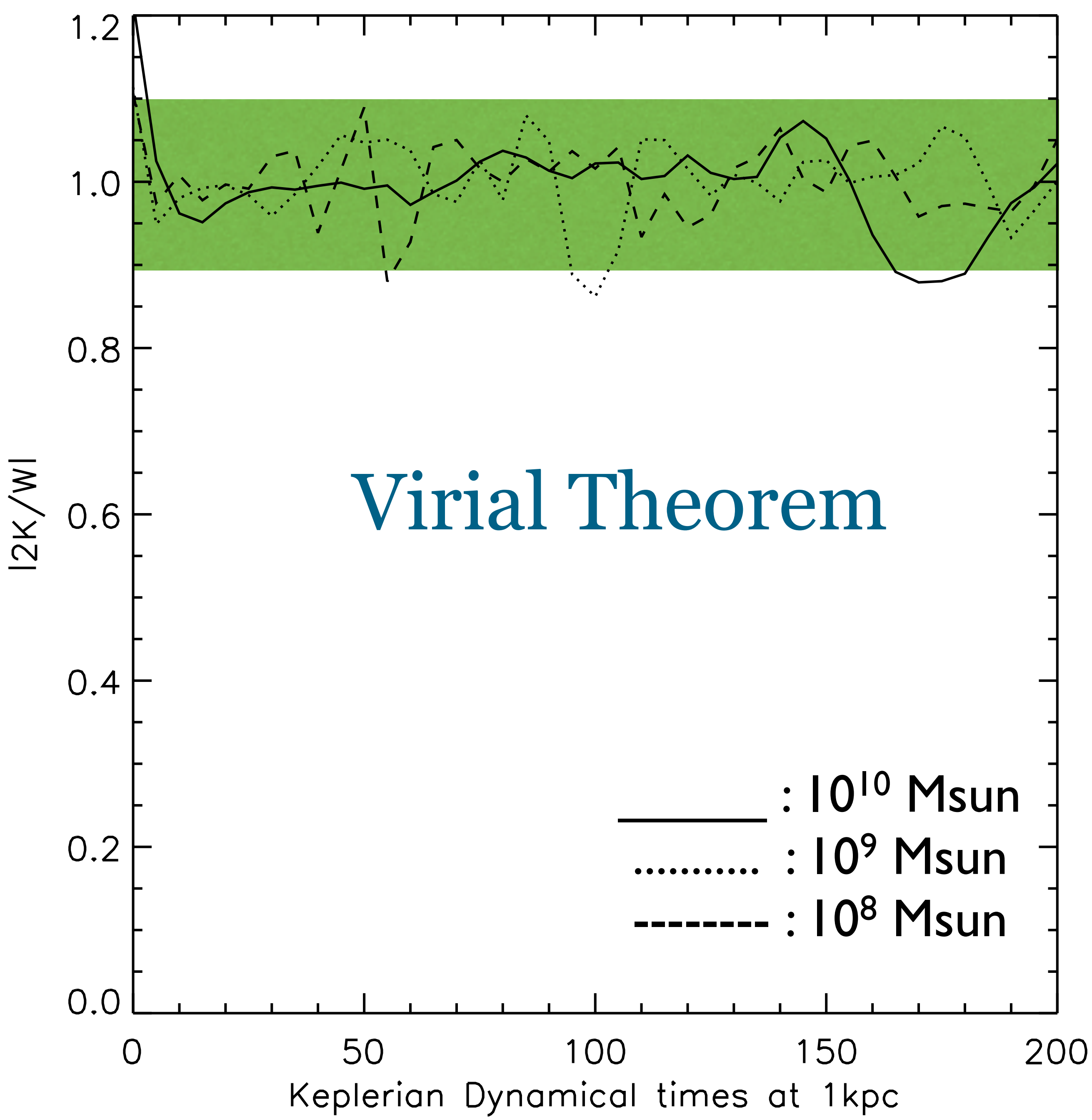
Snapshots



1 Tsim = 1 Keplerian orbit time (1.0 kpc)

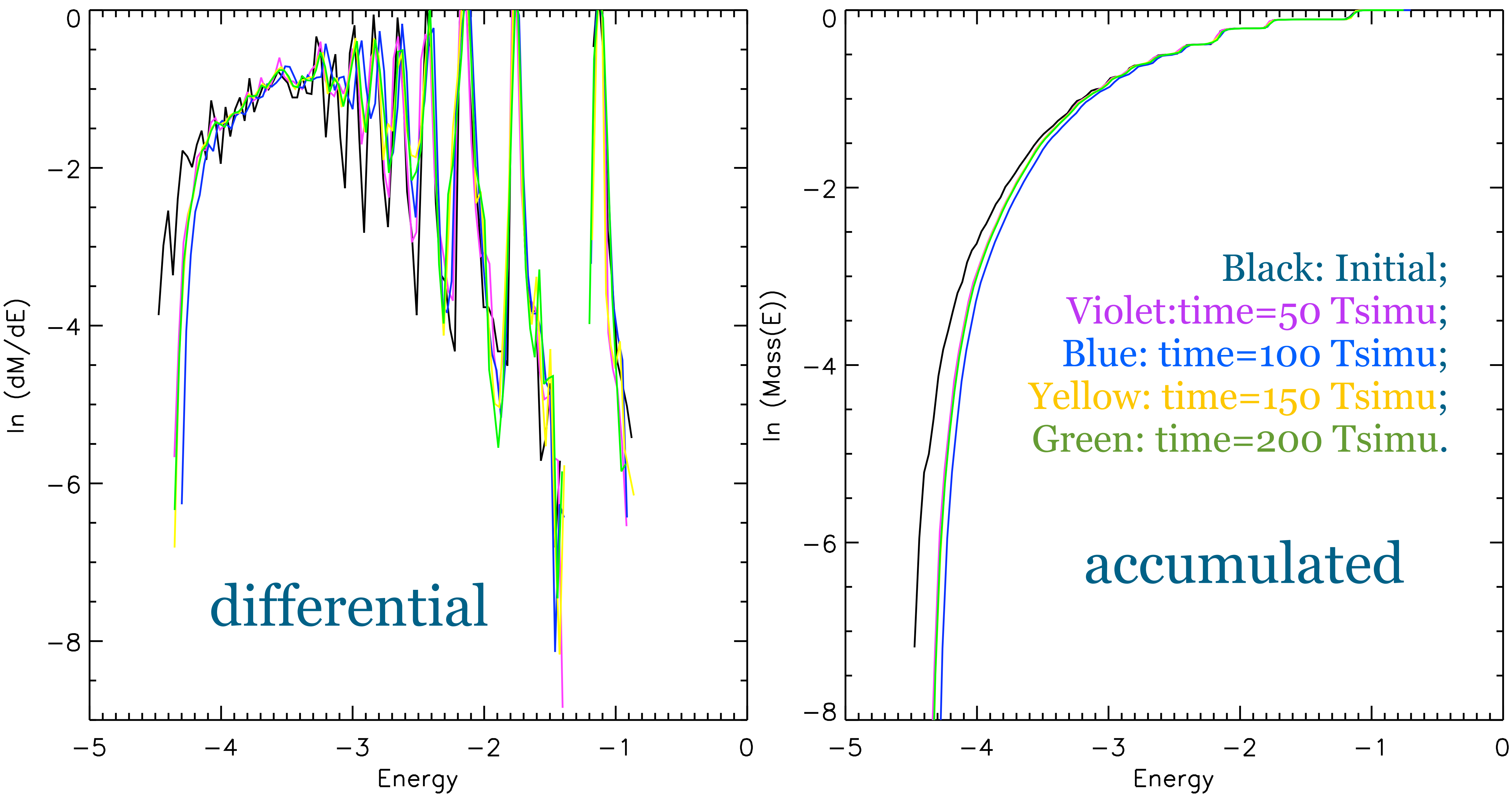


Virial Theorem



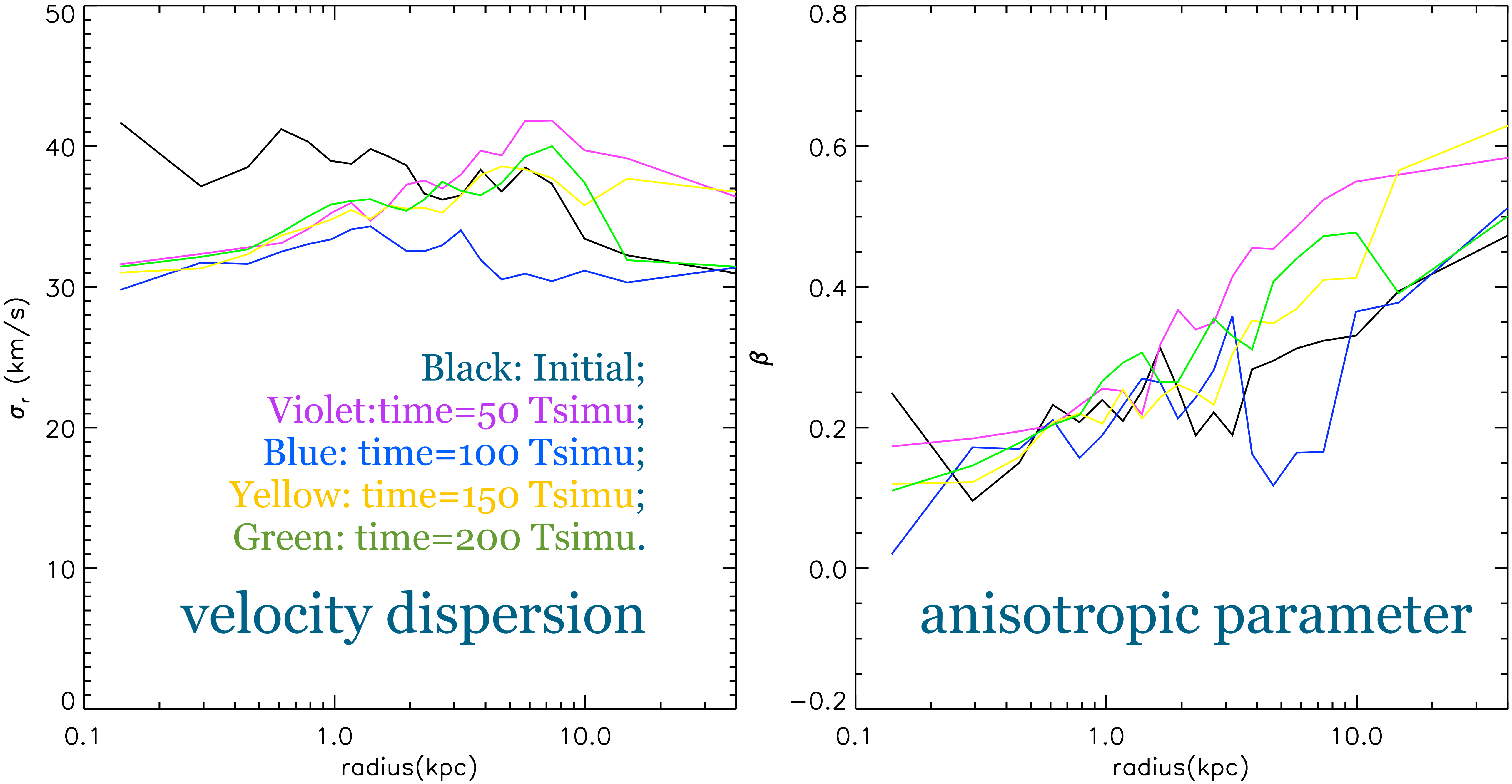
$|2K/W| = 1 \pm 0.1$

Galaxies Stability



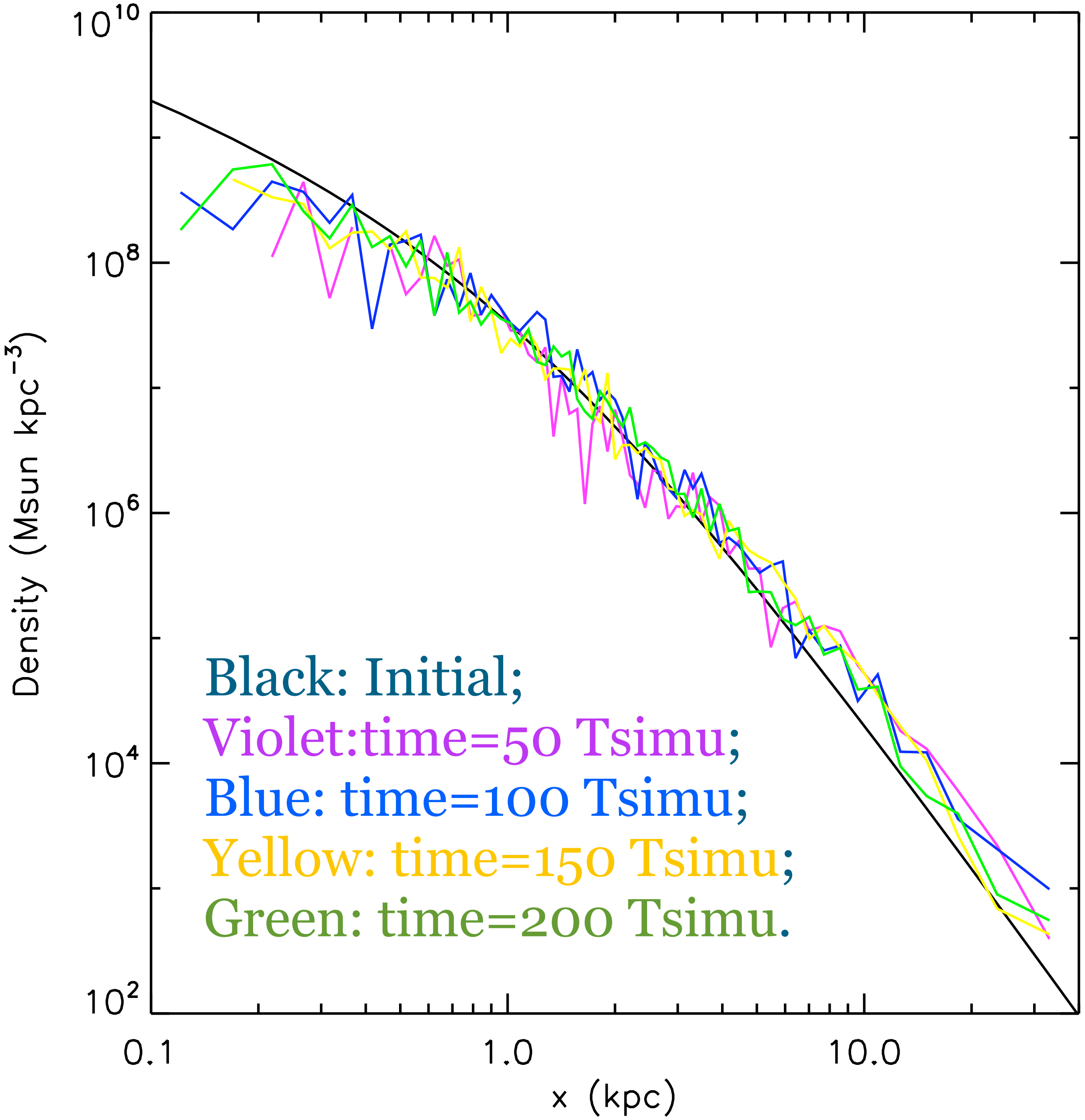
Energy distribution

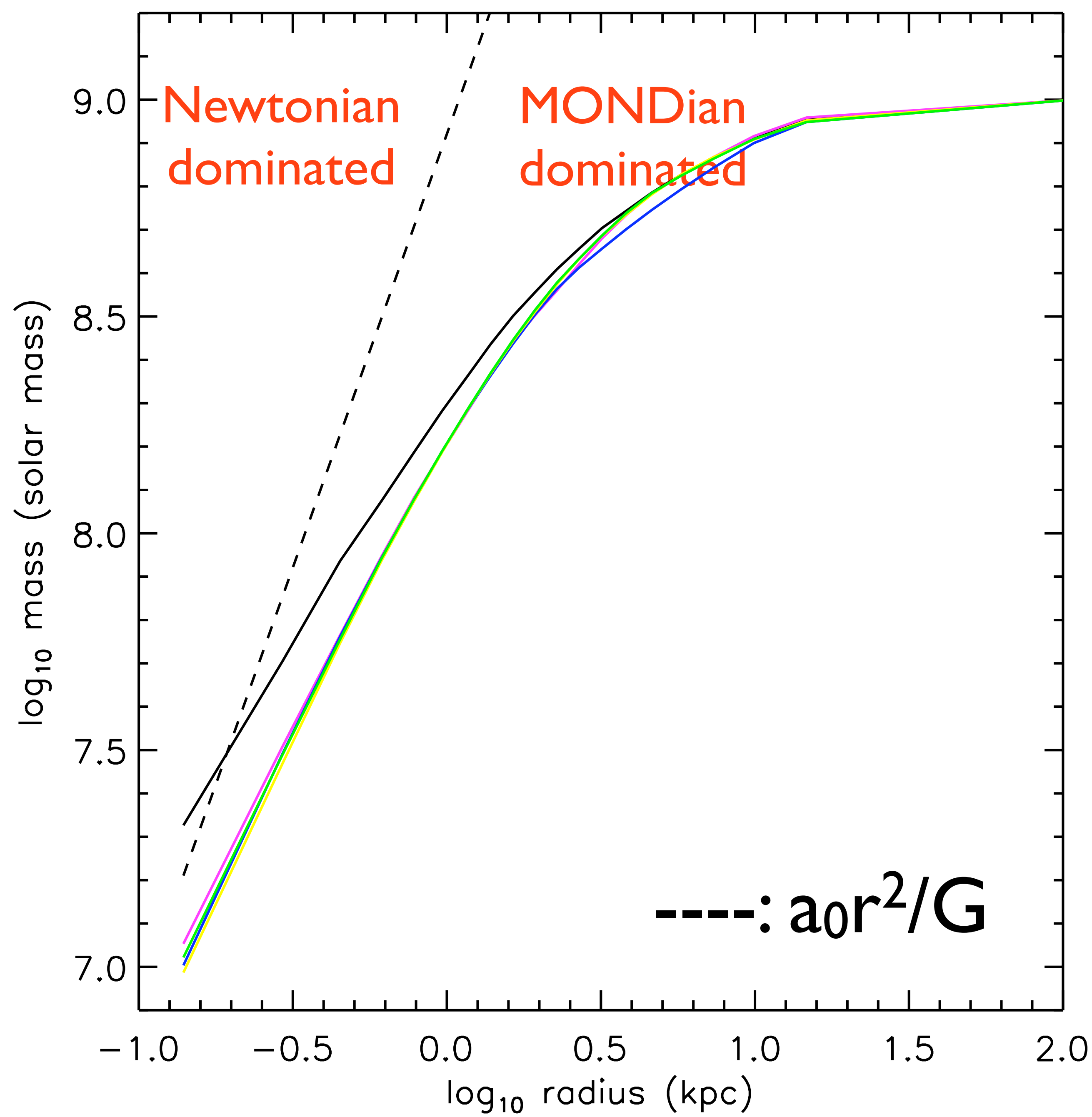
Galaxies Stability



1 Tsimu= 4.7 Myrs

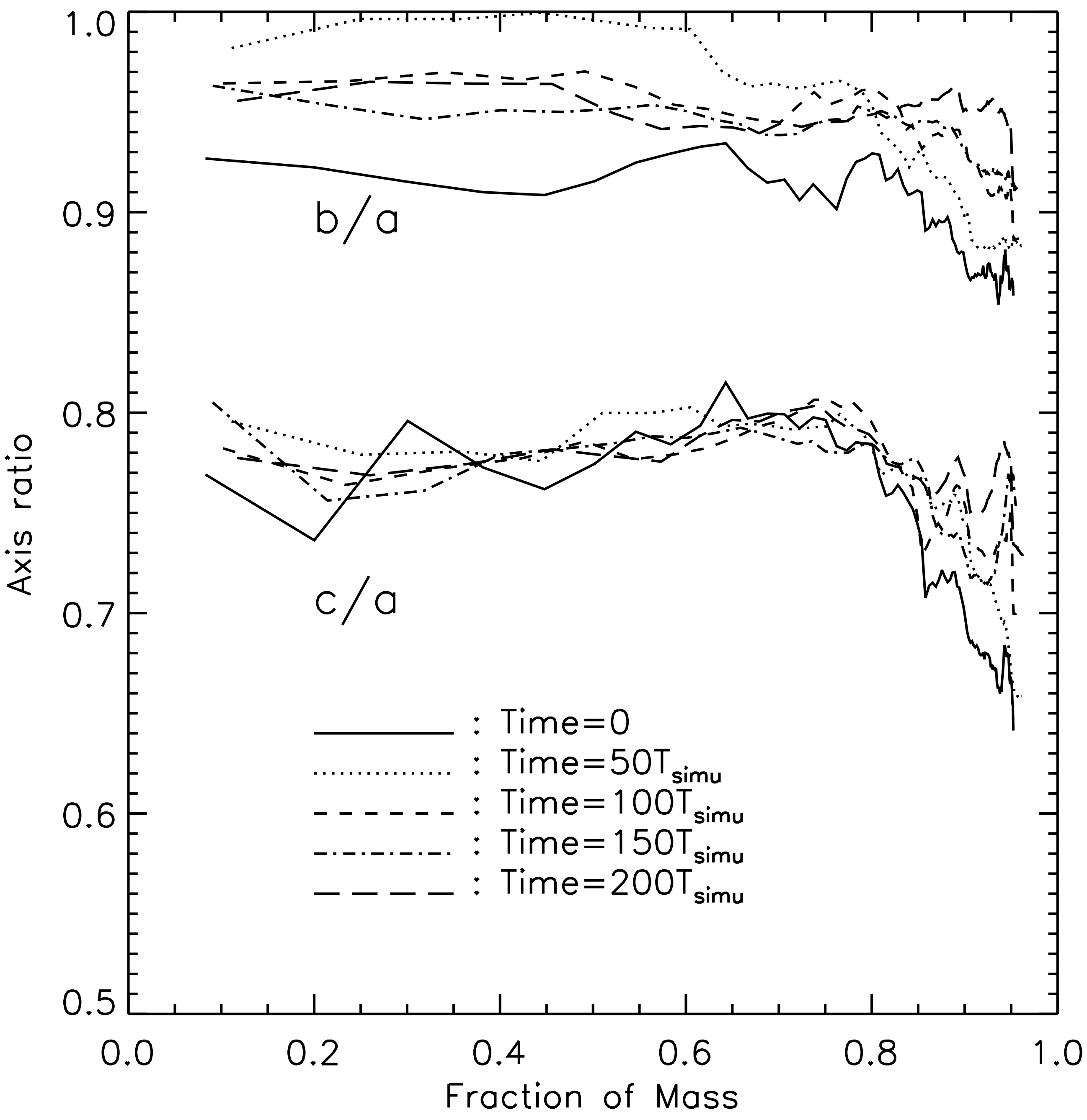
Galaxies Stability





Mass distribution

Galaxies Stability



Axis ratios evolution: ~ 10% in 200 simulation time

Conclusion: model is quasi-equilibrium and stable.

Coming back to the question ...

Can we find stable models for galaxies in MOND?

Yes we found it ^_^

On Going (Schwarzschild model in MOND)

Systems embedded in External Field:

$$\nabla \cdot [\mu(\frac{|\mathbf{g}|}{\mathbf{a_0}})\mathbf{g}] = 4\pi \mathbf{G}\rho$$

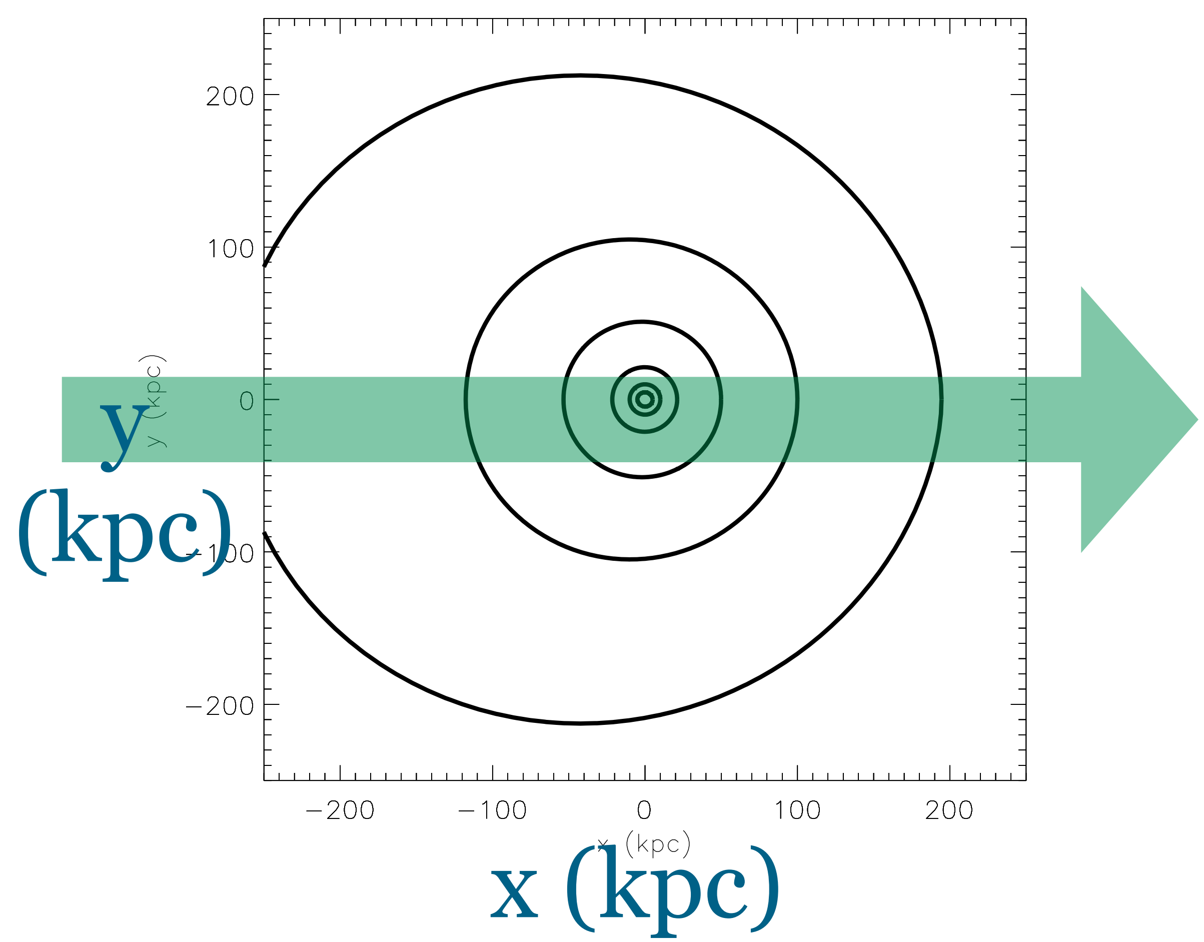
$$\mathbf{g} = \mathbf{g_{ext}} - \nabla \mathbf{\Phi_{int}}$$

Constructing triaxial galaxies

(1) add external field : lopsided galaxies in rich clusters?

(2) fitting the data from observations;

Testing self-consistency and stability (N-body) of the Milky Way bar



Thank You !