Angular momentum – mass relation in dark matter haloes

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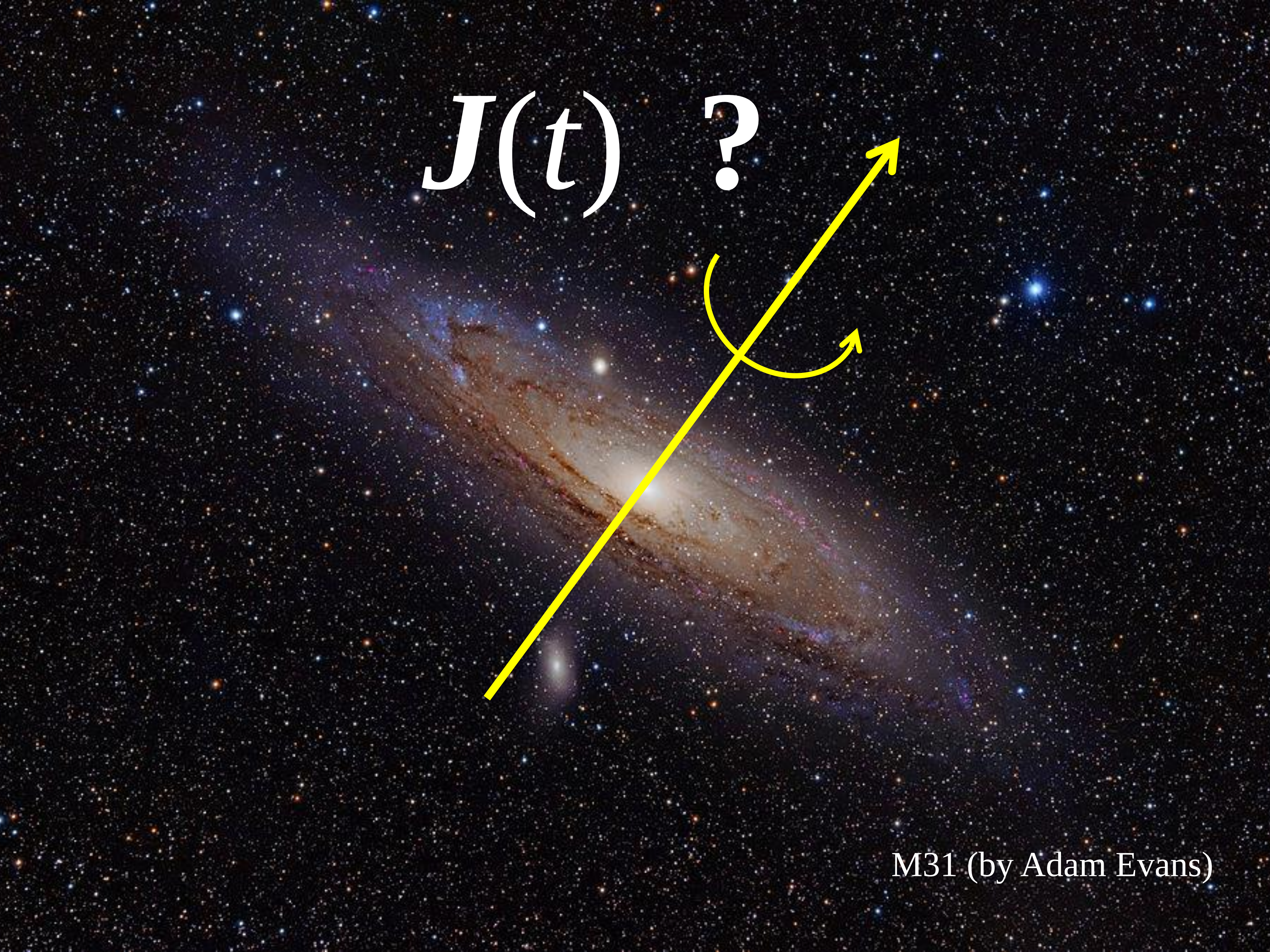


$\boldsymbol{J}(t)$?
M31 (by Adam Evans)

Contents

- Angular momentum – mass relation (*J* – *M* relation)

- Time evolution of *J* – *M* relation

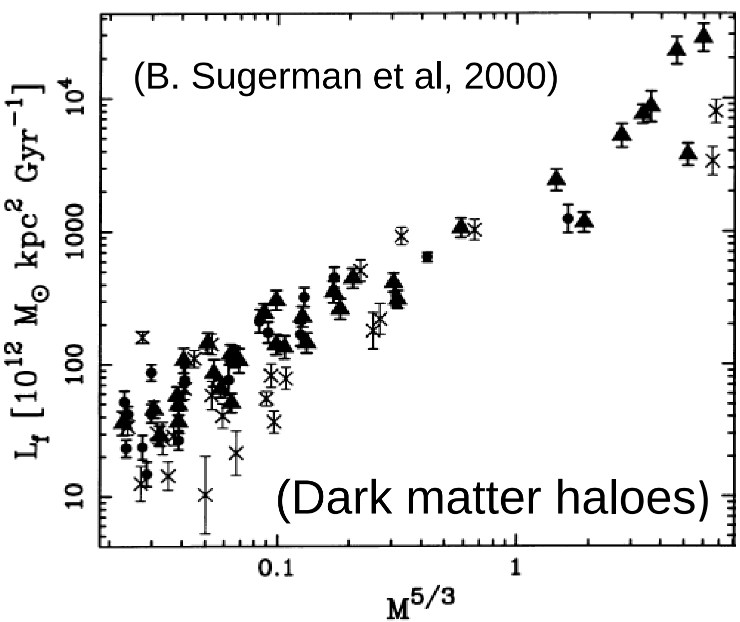
- Summary

J – M relation

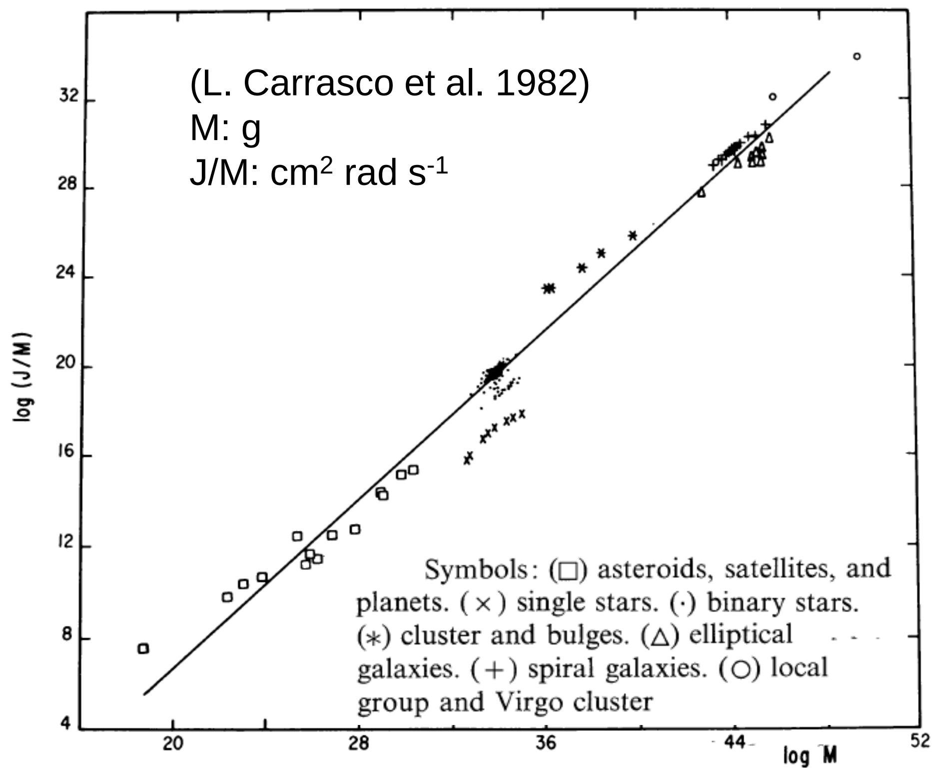
- An empirical and universal power law relation (Brosche, 1963)

$$\boxed{J = \beta M^{\alpha \approx 5/3}}$$

- Many orders of magnitude
- From asteroids to haloes



N-body simulation



Observation

Explanations

- Mechanical equilibrium (Ozernoy, 1967; Carrasco et al, 1982)

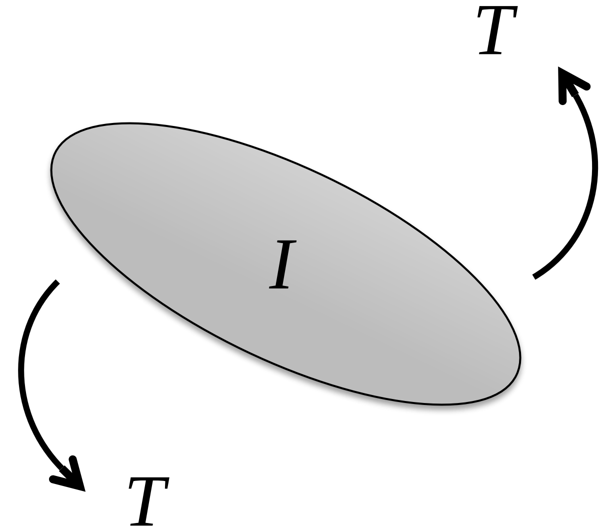
Virial relation $2K + U = 0 \quad \Rightarrow \quad J \propto MRV \propto M^{5/3}$

- Simple argument from **tidal torque theory** (Peebles, 1969; White, 1994; Catelan & Theuns, 1996)

$$J_i = -a^2 \dot{D} \varepsilon_{ijk} T_{jl} I_{lk}$$

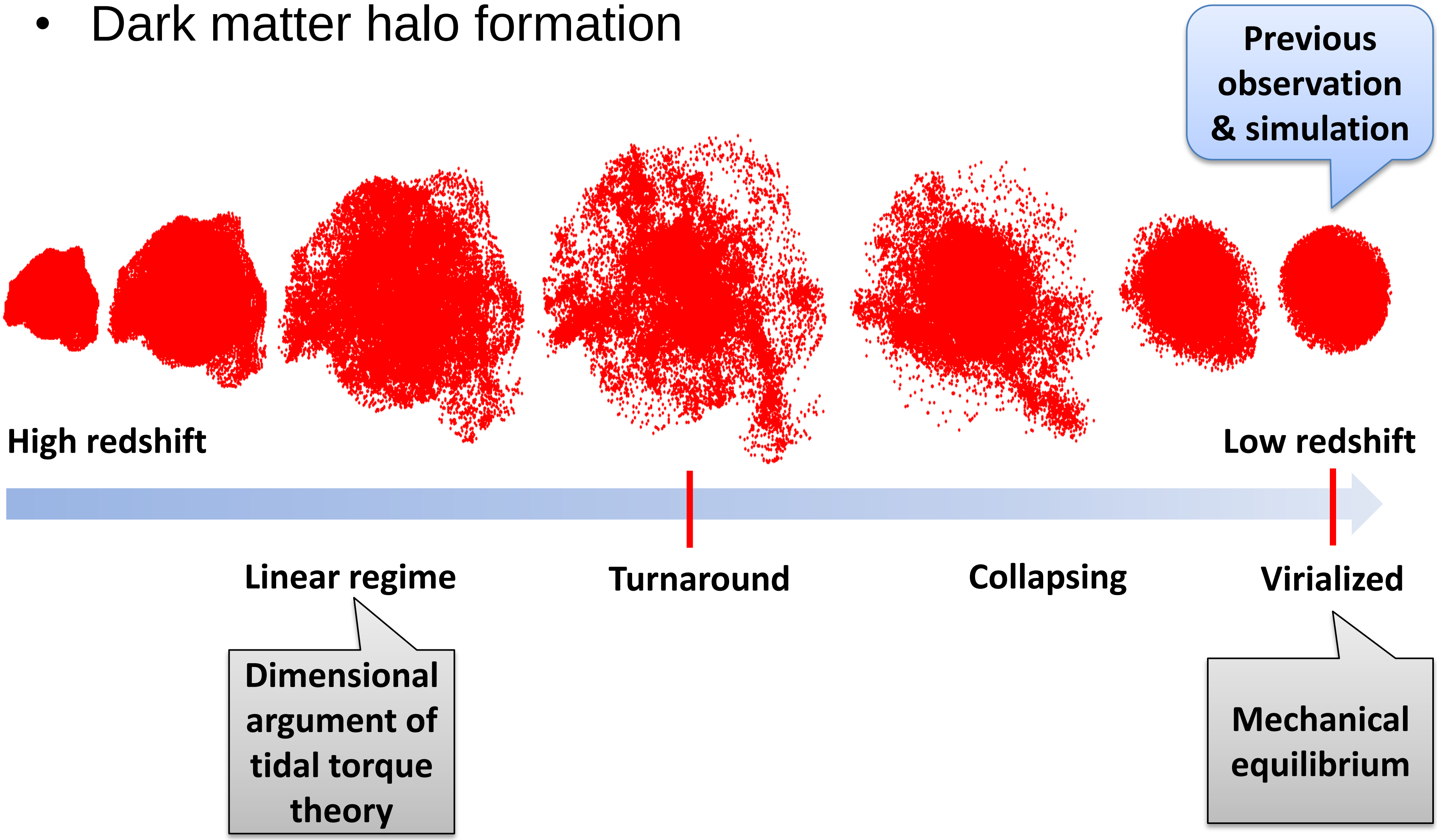
$$J \sim I \text{ and } T \quad \Rightarrow \quad J \propto I \propto MR^2 \propto M^{5/3}$$

$$(M \sim R^3)$$



Explanations

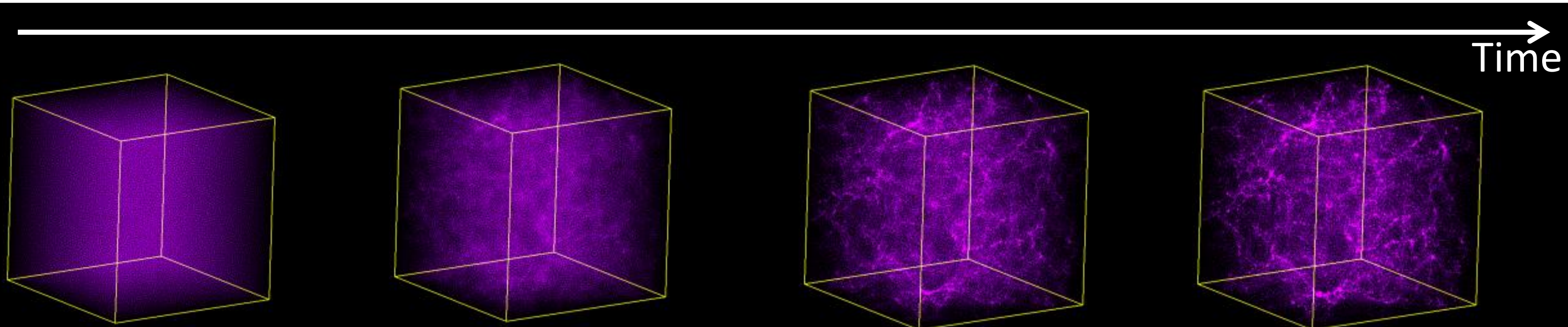
- Dark matter halo formation



Question (motivation)

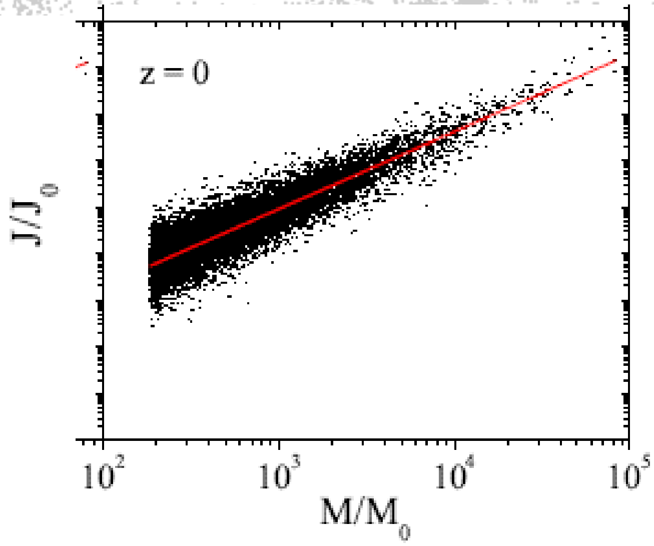
$$\boxed{J(t) = \beta(t) M^{\alpha(t)}}$$

- Time evolution of *J-M* relation?
- To get a more clear picture about the establishment of *J-M* relation
- To see the nonlinear effects in collapse stage on halos' spins



(Acknowledgement: ITSC, CUHK)

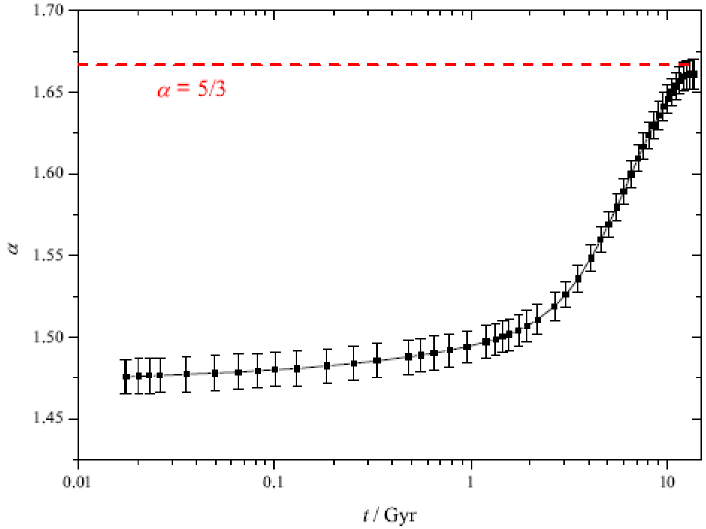
Results from N-body simulation

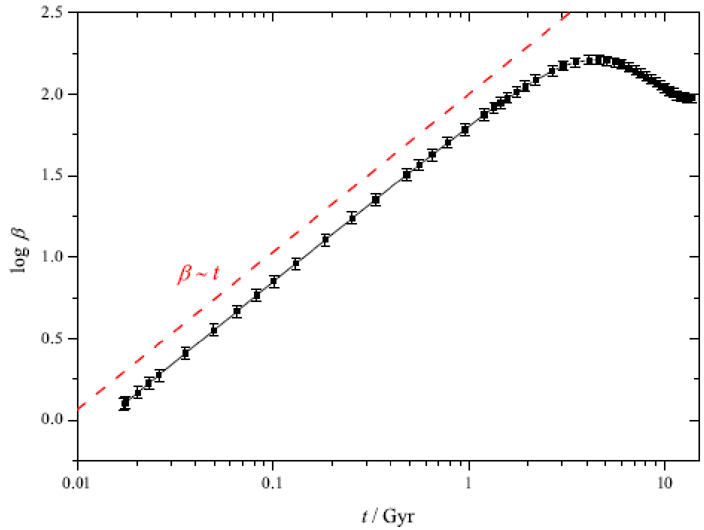


$$J(t) = \beta(t) M^{\alpha(t)}$$

ΛCDM:

- *J-M* relation is hold from high redshift (z=100) to today
- α starts from ~1.5 and reaches 5/3 recently
- β evolves linearly with time in the beginning





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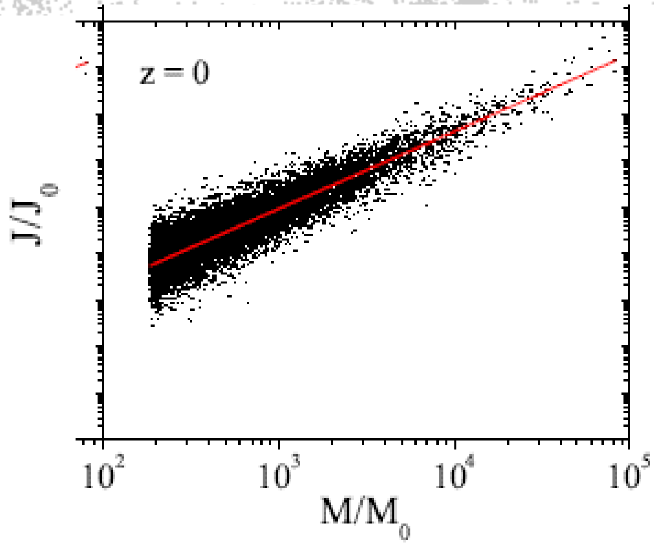
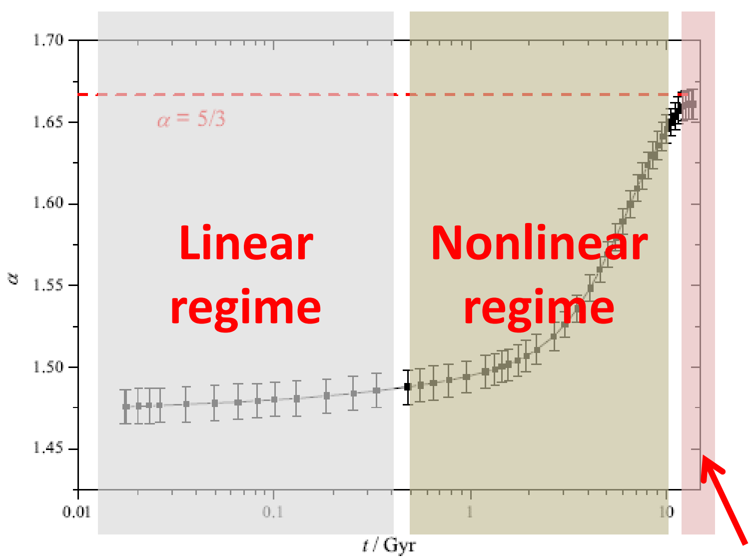
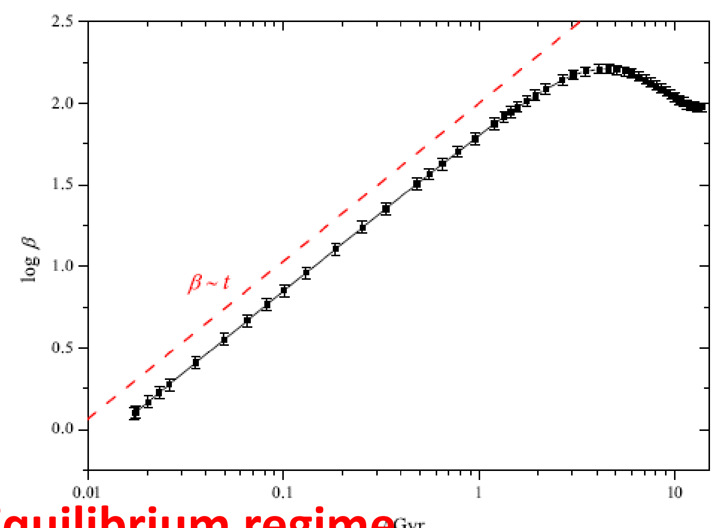






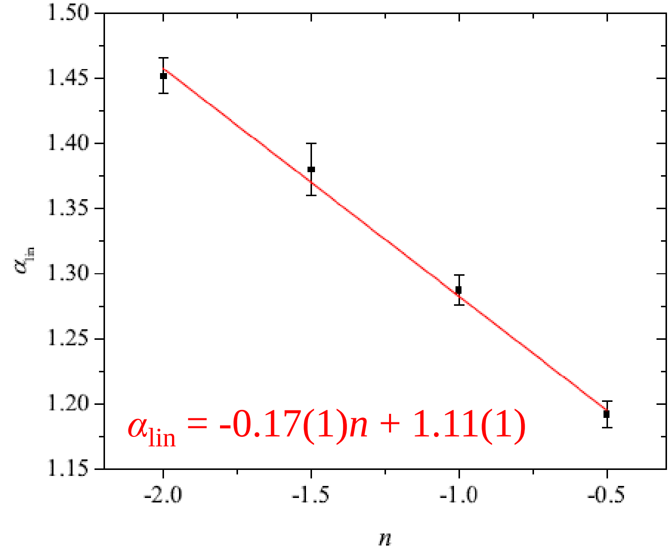
Results from N-body simulation

- Linear regime:

$$\text{if} \quad P(k) = Ak^n,$$

$$\text{TTT} \longrightarrow \quad \alpha_{\text{lin}}(t) = -\frac{n}{6} + \frac{7}{6} \approx -0.167n + 1.167$$

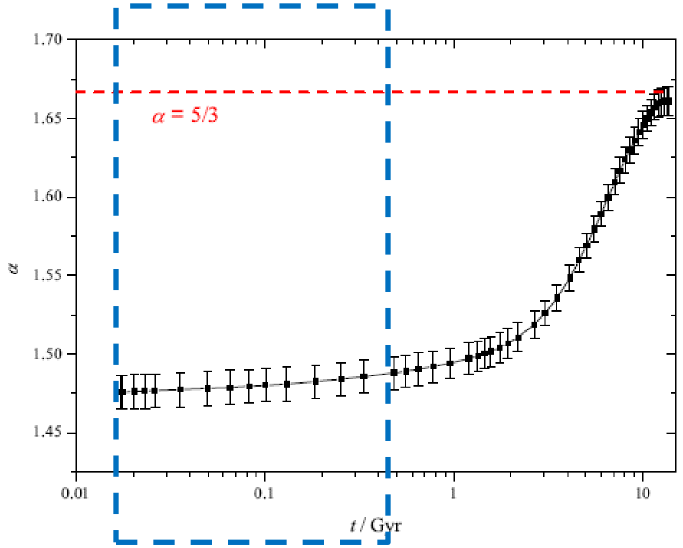
$$\beta(t) \propto t$$

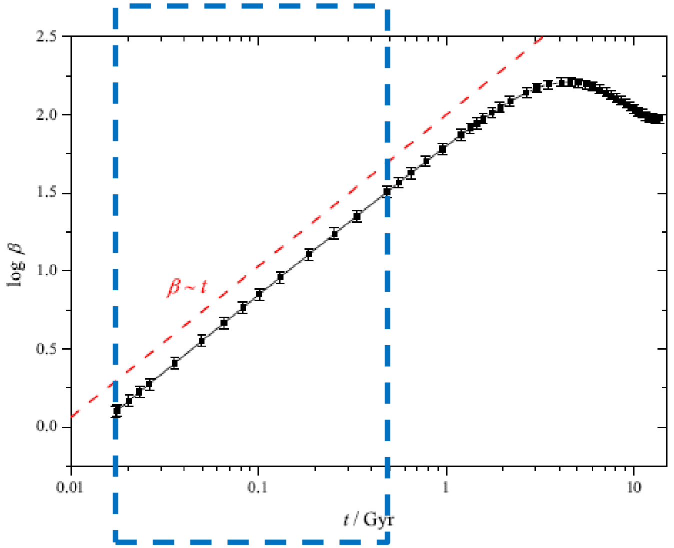


$$n_{\text{eff}}(k) = \frac{d \ln P(k)}{d \ln k}$$

$$n_{\text{eff}} \approx -2$$

$$\alpha_{\text{lin}} \approx 1.5$$



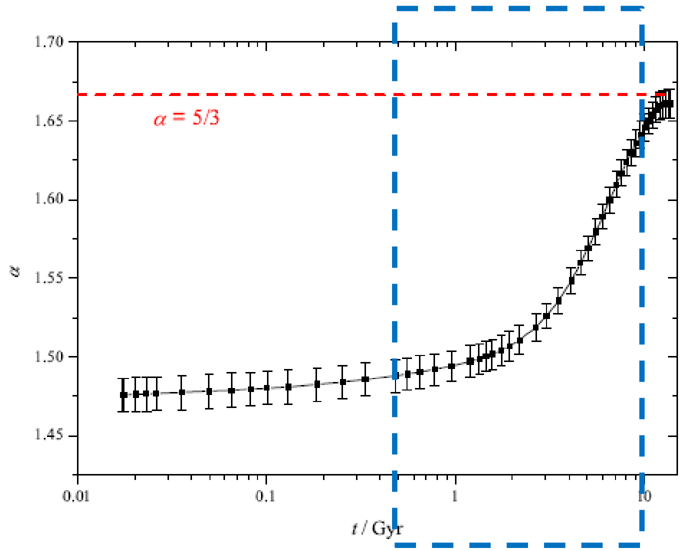


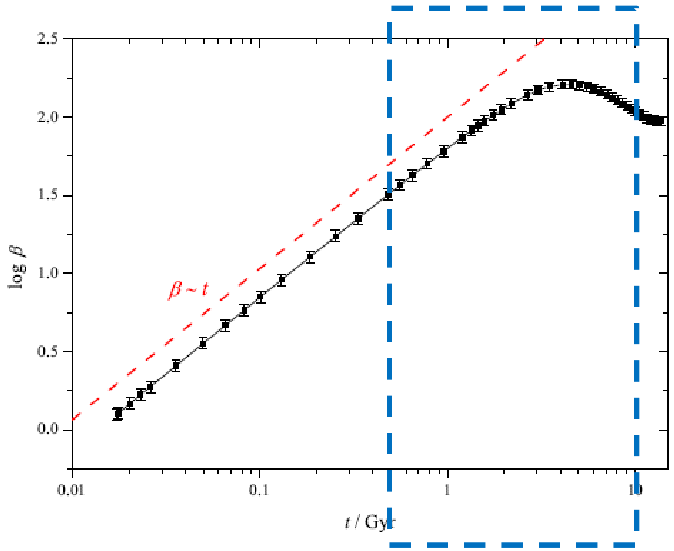
Results from N-body simulation

- Nonlinear regime:

  Nonlinear effects affect *J*-*M* relation significantly.

  Drive α to 5/3.





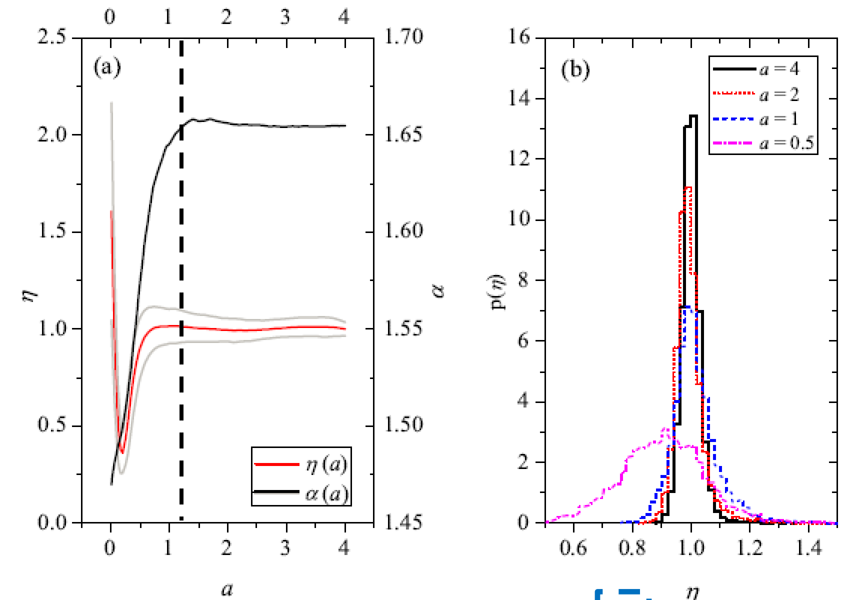
Results from N-body simulation

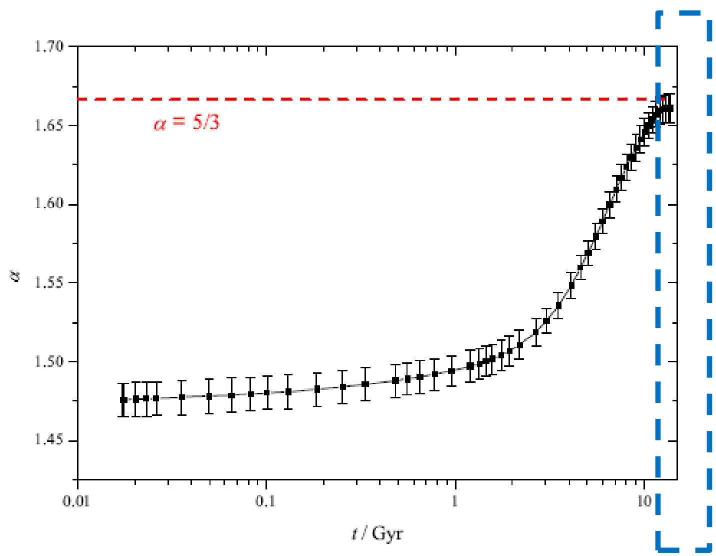
- Equilibrium regime:

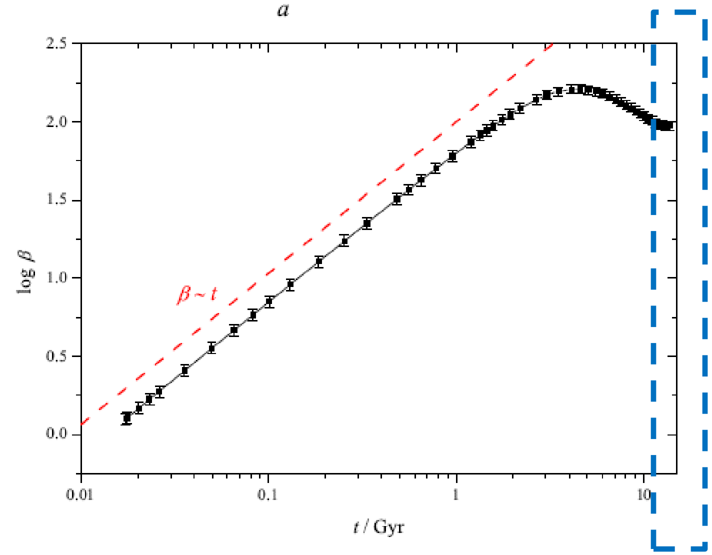
virial equilibrium $2K + U = 0$

virial parameter $\eta = \frac{2K}{|U|}$

$\eta = 1 \rightarrow \alpha = 5/3$







Summary

$$J(t) = \beta(t) M^{\alpha(t)}$$

- A new, detailed picture of evolution and establishment for *J-M* relation is given, based on simulation and theoretical calculation.

- Three regimes' scheme: (1) the value of power index in linear regime depends on initial $P(k)$; $\beta(t)$ evolves linearly with time; (2) Nonlinear process has a significant effect on the evolution of *J-M* relation; (3) Virialization makes $\alpha = 5/3$ and leads to a "memory loss" of initial $P(k)$; β also becomes a stable value.

- Detailed calculation of tidal torque theory (TTT) can explain *J-M* relation in linear regime well. This supports the validity of TTT in linear regime.