Dynamical Tidal Locking

A new source of the spin of dark matter halos

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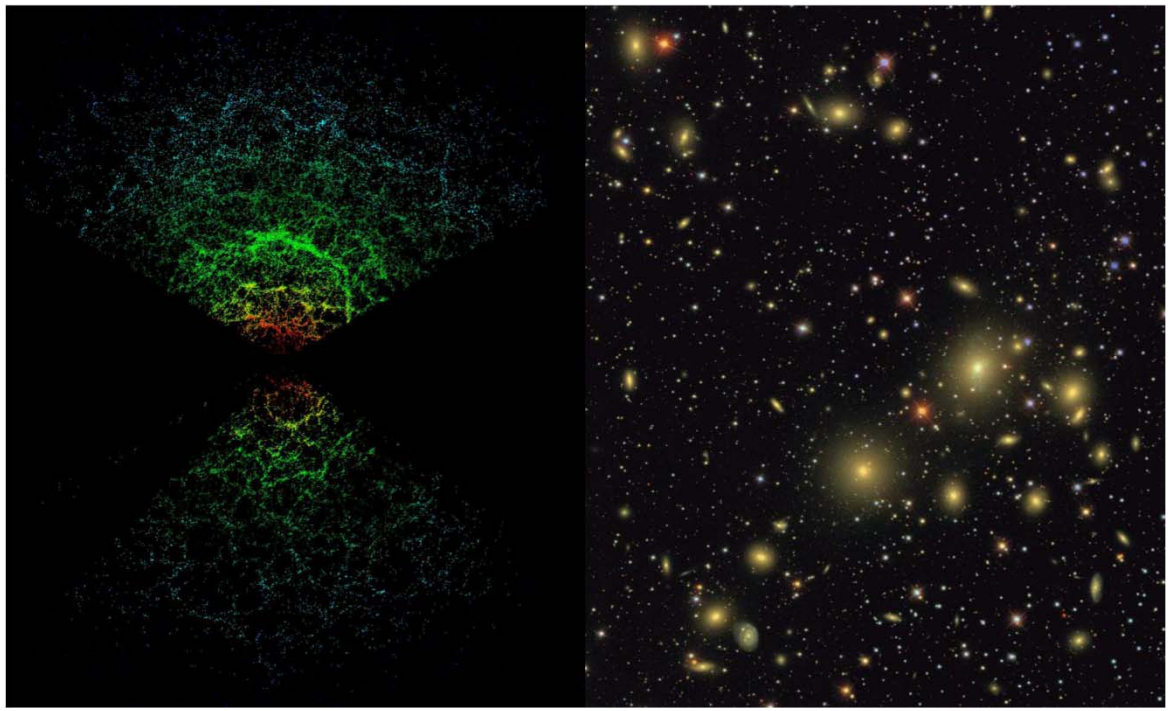
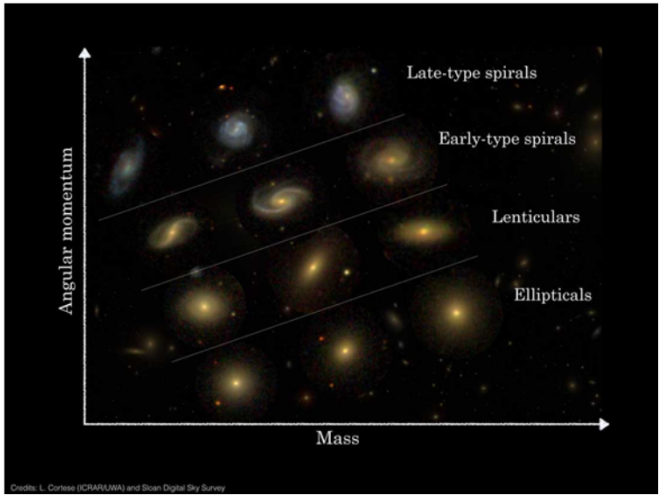
Question

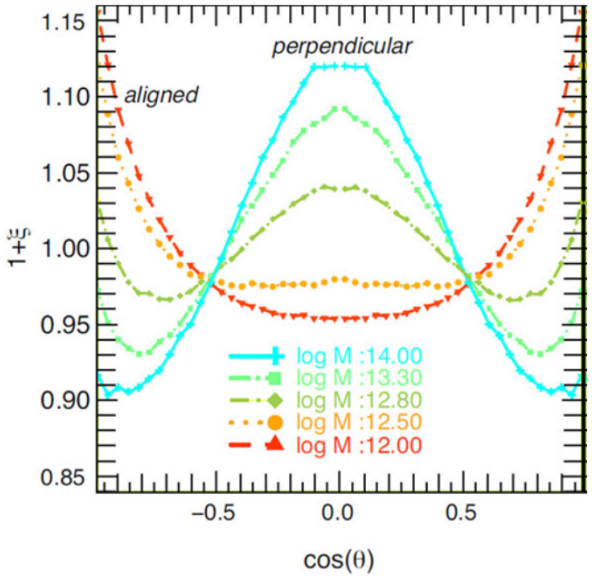
- What is the origin of the angular momentum of galaxies/dark matter halos?
- How it evolves?



Why is it important?

- It is part of the structure formation theory.
- Lensing surveys are sensitive to the alignment of the galaxies.





Codis S., Pichon C., Devriendt J., Slyz A., Pogosyan D., Dubois Y. Sousbie T., Mon. Not. R. Astron. Soc. 427 (2012) 3320.

Tidal Torque Theory (TTT)

- When the matter collapses to form the halos, ambient gravitational field exerts a torque an proto-halo
- Using the Zel'dovich approximation:

$$\mathbf{r} = a(t)[\mathbf{q} + \mathbf{S}(t)] \tag{1}$$

$$d^3\mathbf{r}\bar{\rho}(1+\delta) = d^3\mathbf{q}\bar{\rho}a^3, d^3\mathbf{r} = a^3(1+\nabla.\mathbf{S})d^3\mathbf{q} \tag{2}$$

$$\implies \delta = -\nabla_{\mathbf{q}}.\mathbf{S} = \frac{\nabla^2\phi}{a^2 4\pi G\bar{\rho}} \tag{3}$$

$$\implies \mathbf{S} = -b(t)\nabla_q\phi, b(t) = \frac{1}{4\pi G\bar{\rho}a^2} = \frac{2}{3a^2H^2} \tag{4}$$

Tidal Torque Theory (TTT)

- Angular momentum of the proto-halo, $\vec{L} = \int \vec{r} \times \vec{v}\rho \, d^3r$ in Zel'dovich approximation is

$$\mathbf{L} = -a^2\dot{b}(\bar{\rho}a^3) \int_{V_L} d^3\mathbf{q}(\mathbf{q} - \mathbf{q_{cm}}) \times \nabla\phi \tag{1}$$

$$L_i = -a^2\dot{b}\epsilon_{ijk}\frac{\partial^2\phi}{\partial q^l \partial q^k}\Big|_{cm} \int_{V_L} d^3\mathbf{q}a^3\bar{\rho}\Delta q^j \Delta q^l \tag{2}$$

$$L_i = -a^2\dot{b}\epsilon_{ijk}I_{jl}T_{lk} \tag{3}$$

Predictions of TTT

- During the matter dominated era $a^2\,\dot{b} = t$ so

$$L \propto t \tag{1}$$

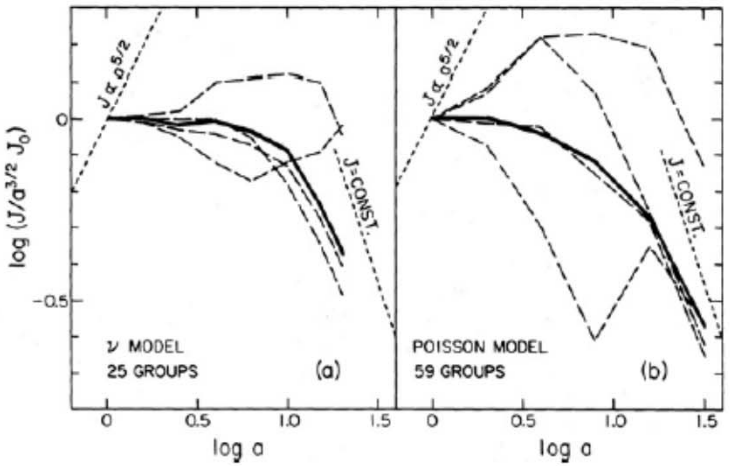


Figure: White 1984

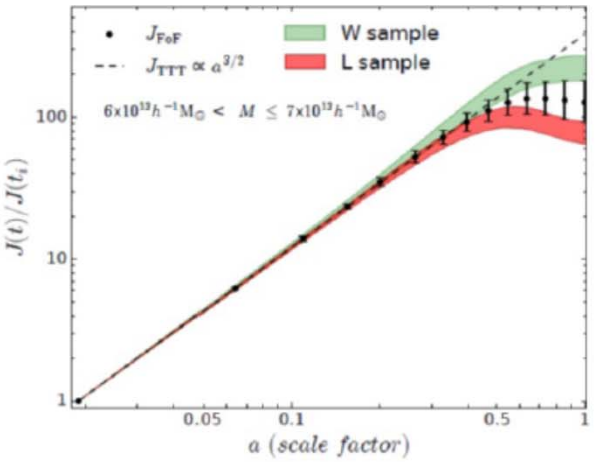


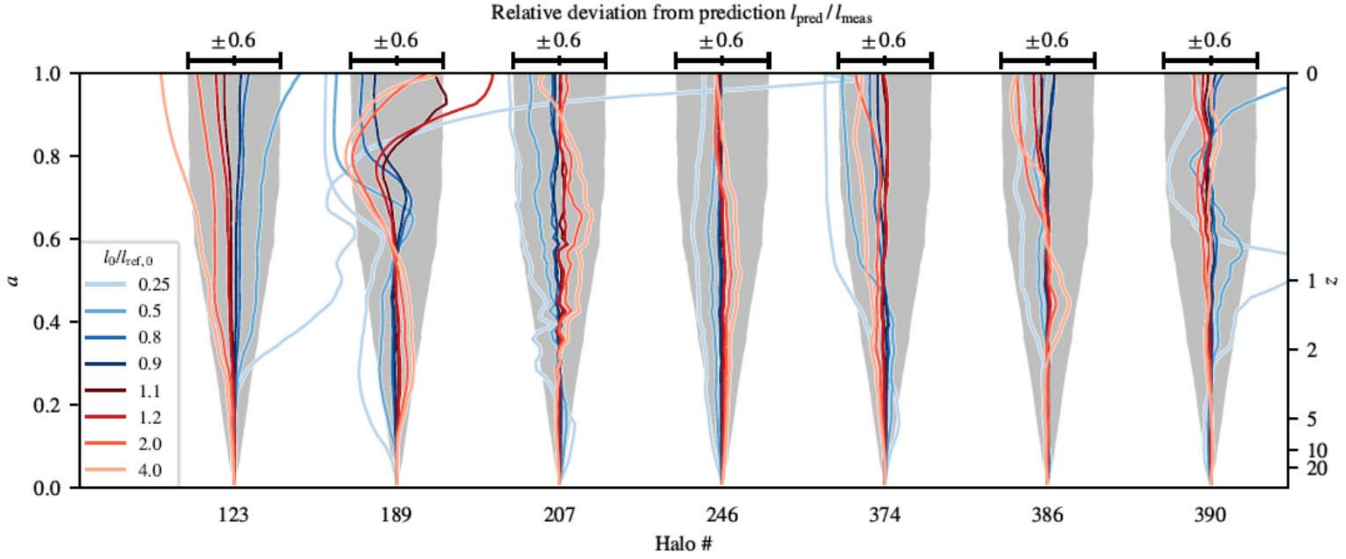
Figure: Lopez 2018

After TTT

- Nothing can compete the TTT in proto-halo time.
- However, TTT says nothing about angular momentum evolution once the halo forms.
- A possible solution is taking mergers into account (Vitvitska 2002)

Evidences

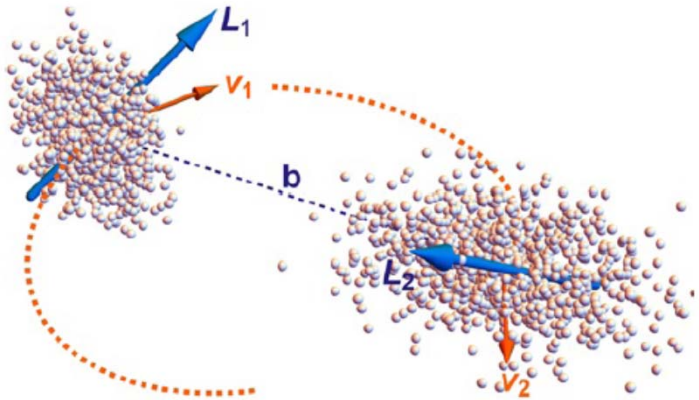
- Spin directions deviate from TTT prediction
  - (Barnes & Efstathiou 1987;Sugerman et al. 2000; Porciani et al. 2002; López et al. 2019; Zjupa & Springel 2017).
- Mergers can be encoded to initial condition
  - Corentin Cadiou, Andrew Pontzen, Hiranya V Peiris *Monthly Notices of the Royal Astronomical Society*, Volume 502, Issue 4



Our proposal: Tidal Locking Theory

- When two halo with mass M_1 and M_2 passes by each other with the relative velocity v and impact parameter b, because of the effect like tidal locking in planets, their angular momentum changes like

$$\Delta L_1 = f\frac{GM_1M_2R_1^2}{b^2v_0} \tag{1}$$

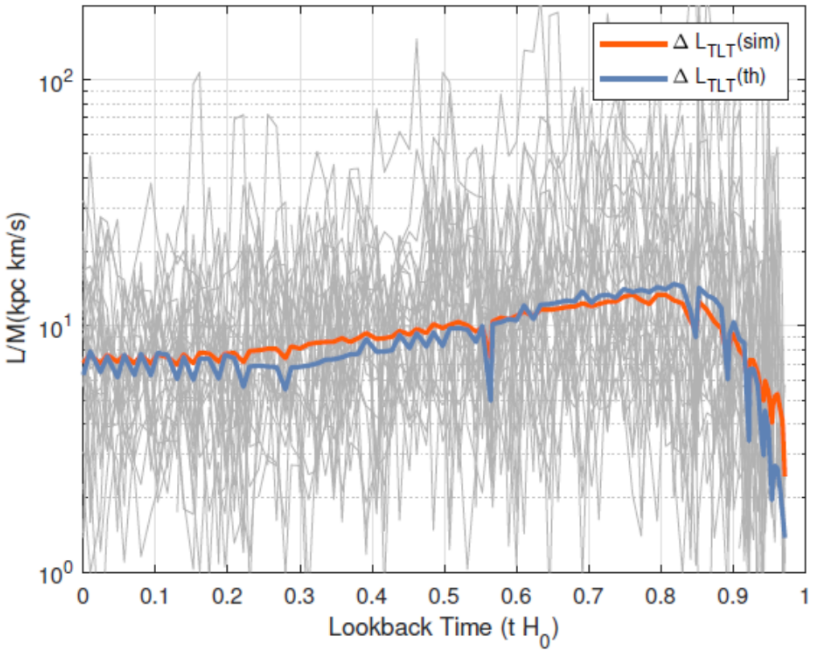


Checking Tidal Locking Theory

- Tracking 3000 halo in the Illustiris simulation from z=0 to z=9 and subtracting the angular momentum change of TTT (due to the mass accretion) from total change

$$\langle \Delta L^2_{\mathrm{TLT}} \rangle_{\mathrm{sim.}} = \langle \Delta L^2 \rangle - \langle \Delta L^2_{\mathrm{TTT}} \rangle \qquad (1)$$

$$\langle \Delta L^2_{TLT} \rangle_{\mathrm{th.}} = f^2 \left\langle \int \left(\frac{G M_1 \bar{M} R_1^2}{b^2 v_0} \right)^2 2\pi b \, \mathrm{d}b \; v_0 n \Delta t \right\rangle \qquad (2)$$



$f \approx 0.25$

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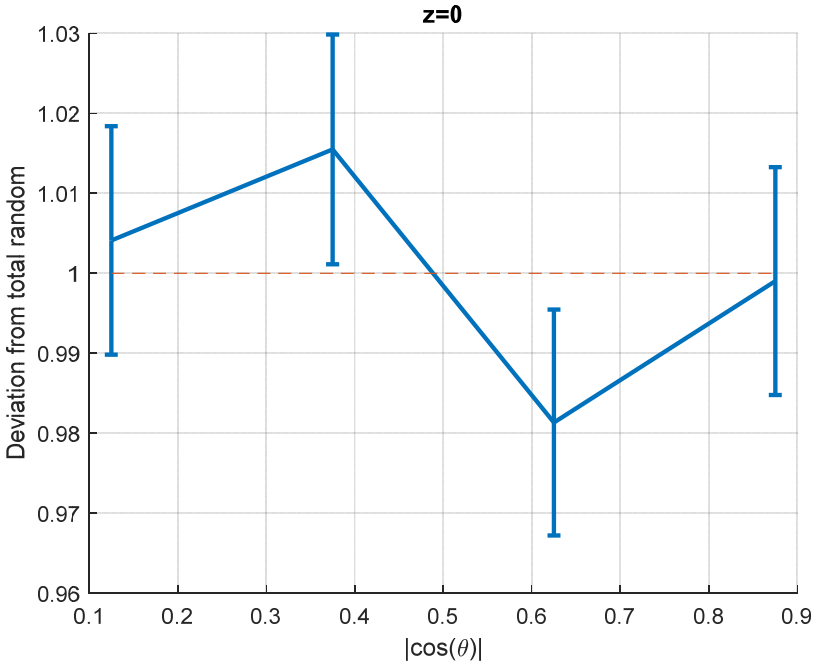
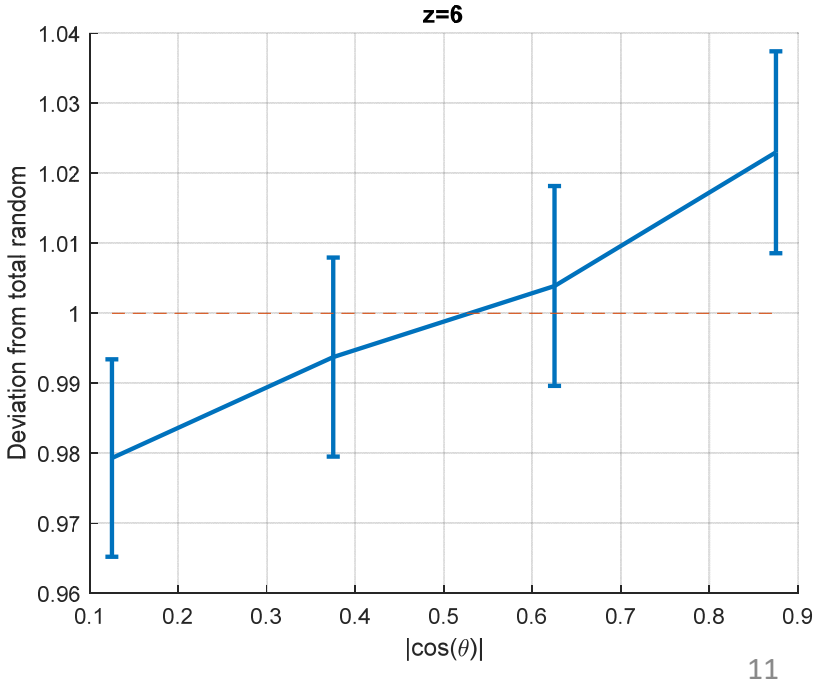
Alignment of TTT and TLT

- It is not hard to show that if the TTT were the only effect then halo spin tends to align with the middle eigenvector of the tidal potential

$$cos(\theta) = \hat{\mathbf{L}}.\hat{\mathbf{P^2}} \quad \partial_i \partial_j \phi P_j^2 = \lambda_2 P_i^2 \qquad (1)$$

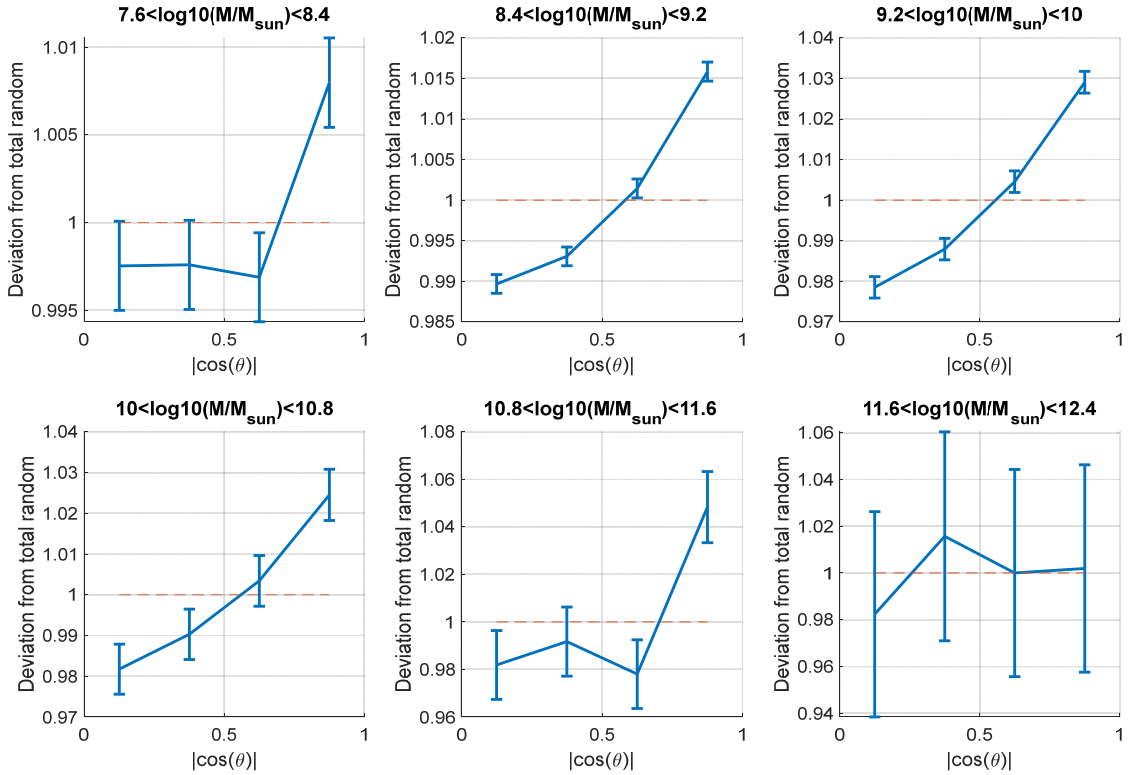




TLT alignment

- Also it is not hard to show that if the TLT were the only effect then the halo spin tends to align with the speed

$$cos\theta = \hat{\mathbf{L}}.\hat{\mathbf{V}} \qquad (1)$$



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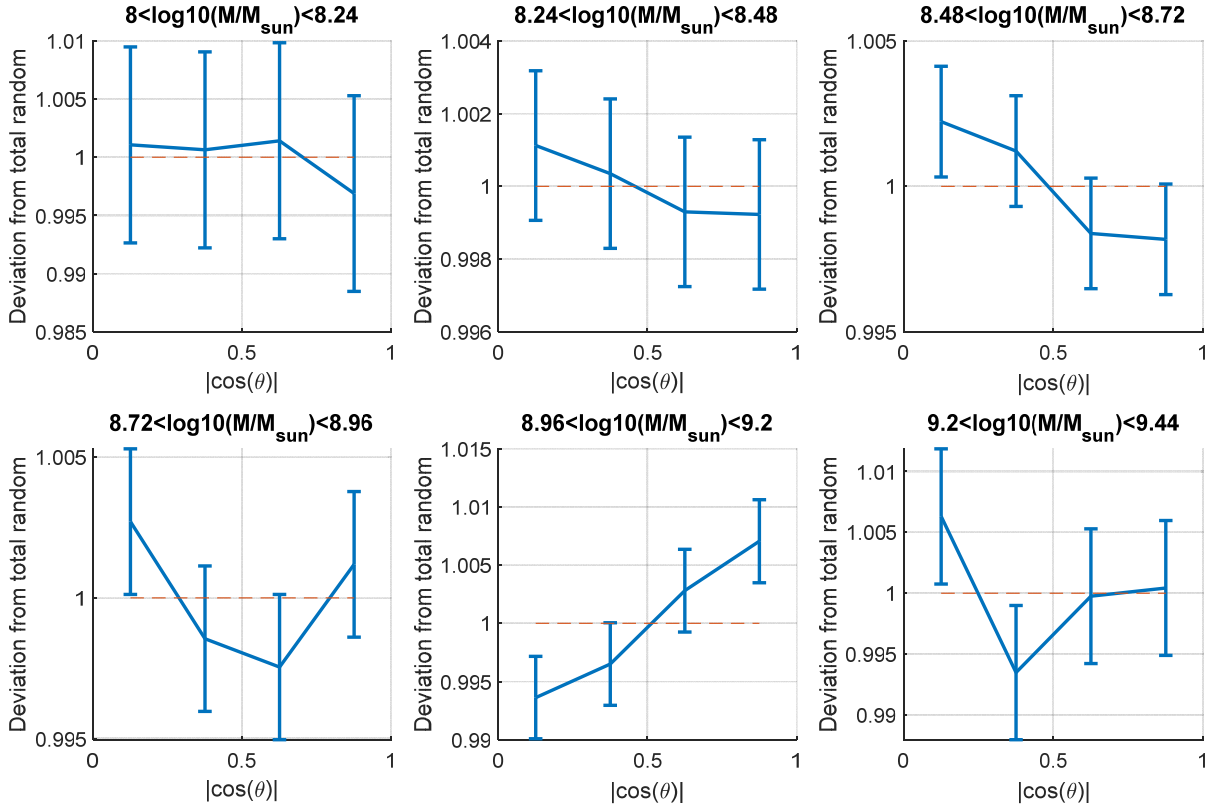
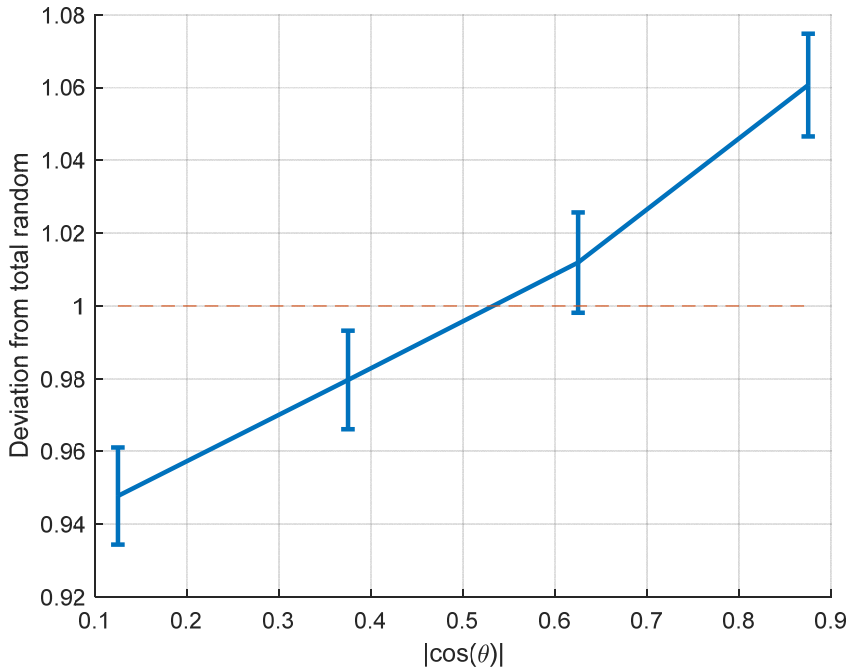


Mad Halos (V>>Vrms)

- High speed halos are most likely to undergone a fly-bye.



Summery and Outlook

- TTT is the only effect responsible for the initial angular momentum
- TLT can predict spin evolution
- TLT can change the spin alignment significantly
- TLT can help to explain the spin-LSS correlation because the anisotropic velocity distributions in the structures

Thank you