Correlations between halo spins and primordial perturbations

暗晕角动量与宇宙原初扰动的相关性




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Summary: Galaxy angular momentum directions (spins) are observable, well described by the Lagrangian tidal torque theory, and proposed to probe the primordial universe. They trace the spins of dark matter halos, and are indicators of protohalos properties in Lagrangian space. We construct: 1) a dimensionless kinematic spin parameter λ_K of protohalos in Lagrangian space. Higher λ_K corresponds to more rotational-supported systems; 2) a dimensionless misalignment parameter β_{IT} to characterize the anisotropies and misalignment of **I** and **T**; 3) a dimensionless tidal torque parameter β_{TT} to measure the anisotropy and twist of tidal tensor **T** on different smoothing scales r, and as a reliable proxy of β_{IT} and λ_K. Our simulation shows that: protohalos in a more misaligned environment between **I** and **T** (high-β_{IT}) are more spin-supported (high-λ_K), and tend to have higher λ_B and better spin conservation at $z=0$. Therefore, a weighted selection of rotation-supported halos by β_{TT} is expected to straightforwardly improve the correlation between galaxy spins and the initial conditions in the study of constraining the primordial universe by spin mode reconstruction.

Introduction

Tidal Torque Theory

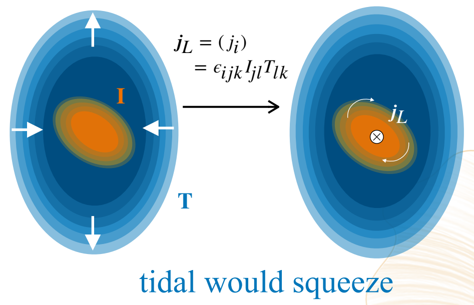
— how does halo spin in the first place?

the moment of inertia

$$\mathbf{I} = (I_{ij}) = \left(\int_{V_L} q_i q_j \mathrm{d}^3 q\right)$$

tidal tensor

$$\mathbf{T} = (T_{ij}) = \left(-\partial_i\partial_j\phi\right)$$

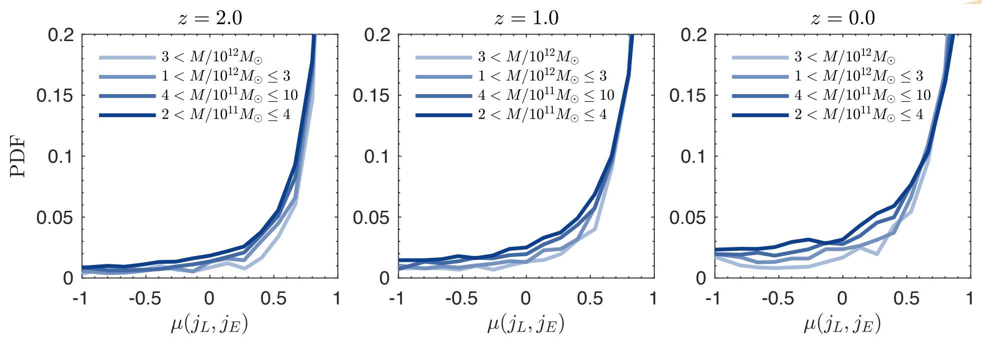


tidal would squeeze and stretch objects

Spin conservation

— the conservation of halo spin through cosmic evolution

$\mu(\boldsymbol{j}_L, \boldsymbol{j}_E) = cos\theta = \hat{j}_L \cdot \hat{j}_E \sim 0.7$



halo spins in Lagrangian space $\boldsymbol{j}_L$ and in Eulerian space $\boldsymbol{j}_E$ are highly correlated

Spin Reconstruction

— the predicted halo spin in Lagrangian space

$$\boldsymbol{j}_R = L_{TT}(r, r_{\rm opt}) = \epsilon_{ijk} T^r_{jl} T^{r_{\rm opt}}_{lk} = \epsilon_{ijk}\phi_{,jl}(r)\delta_{,lk}(r_{\rm opt})$$

the predicted halo spin $\boldsymbol{j}_R$ can be constructed from a tide-tide self-interaction (Yu et al. PRL 2020)

Parameters we defined

Kinematic spin parameter

$$\lambda_K \equiv \frac{\int_{V_q} \hat{j}_i \epsilon_{ijk} q'_j u'_k M}{\int_{V_q} q' u' M} = \frac{\int_{V_q} \sin\theta_1 \cos\theta_2 q' u' M}{\int_{V_q} q' u' M},$$

characterizing magnitudes of halos' angular momenta in Lagrangian space

$\lambda_B \equiv J/(\sqrt{2}MVR)$

characterizing magnitudes of halos' angular momenta in Eulerian space (Bullock et al. APJ 2001)

Misalignment parameter

$$\beta_{IT} \equiv \left.\frac{\left|\int_{V_q}\epsilon_{ijk} q'_j u'_k V\right|}{-\int_{V_q} q'_i u'_i V}\right|_{\rm 1st-order} = \frac{\left|\int_{V_q}\epsilon_{ijk} q'_j(-\phi_{,kl}q'_l)V\right|}{-\int_{V_q} q'_i(-\phi_{,ij}q'_j)V} = \frac{|\epsilon_{ijk}I_{jl}T_{lk}|}{-I_{ij}T_{ij}}$$

measuring the anisotropies and misalignment between moment of inertia **I** and tidal tensor **T**

Tidal torque parameter

$$\beta_{TT}(r) \equiv = \frac{|\epsilon_{ijk}\phi_{,jl}(r)\delta_{,lk}(r)|}{-\phi_{,ij}(r)\delta_{,ij}(r)}$$

measuring the anisotropy and twist of tidal tensor **T** on different smoothing scales r

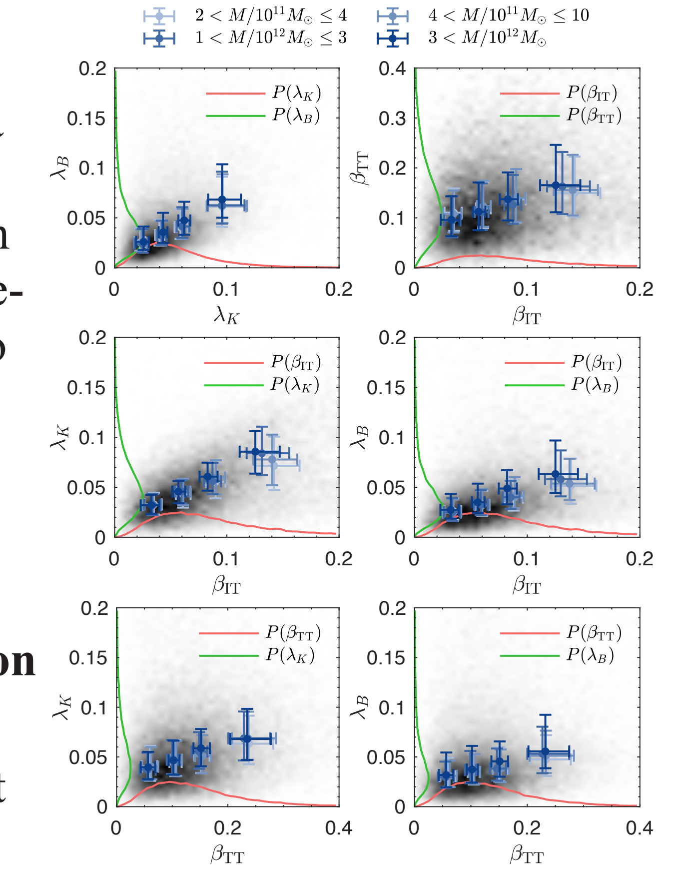
Results

The dependences between λ_K, λ_B, β_{IT} and β_{TT}:

a) a more misalignment between I and T leads to a more spin-supported Lagrangian protohalo;

b) the kinematic spin-supportedness of Lagrangian halos is closely related to the Eulerian spin parameter — a more spin supported Lagrangian protohalo is more likely to result in a spin supported halo at $z=0$;

c) β_{TT} is indeed a reliable proxy of β_{IT} and λ_K.

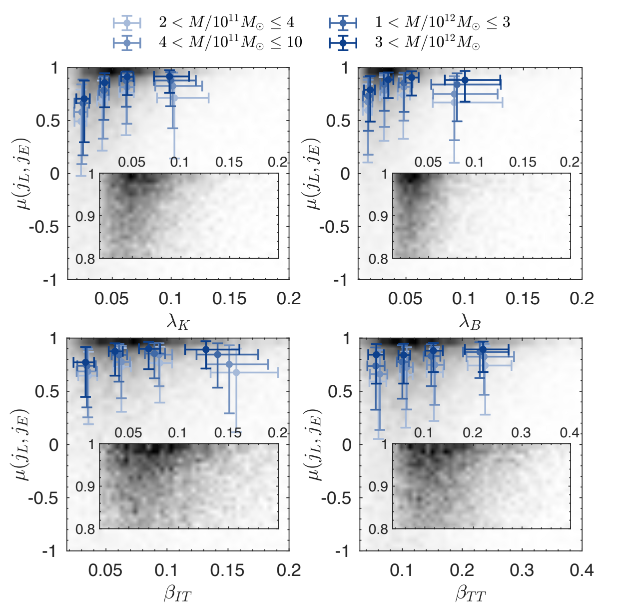


PDFs of λ_K, λ_B, β_{IT}, β_{TT} and the spin conservation quantified by $\mu(\boldsymbol{j}_L, \boldsymbol{j}_E)$:

a) protohalos in a more misaligned environment between **I** and **T** (high-β_{IT}) tend to preserve their spin directions all the way to $z=0$;

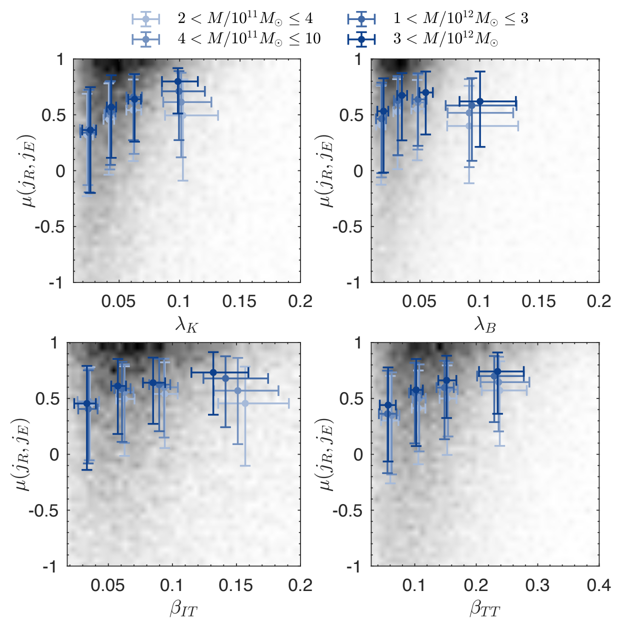
b) spin-supported (high-λ_K) protohalos have better spin conservation during the cosmic evolution;

c) halo-galaxy systems with high β_{TT} values better reflect cosmological information in Lagrangian space.



PDFs of λ_K, λ_B, β_{IT}, β_{TT} and the spin conservation quantified by $\mu(\boldsymbol{j}_R, \boldsymbol{j}_E)$:

a) halos with higher β_{TT} values tend to have more reliable predicted halo spins $\boldsymbol{j}_R$.



N-body simulation CUBE

Box size: 100Mpc/h

Initial condition:

z_{int} = 100 & Zel'dovich Approximation

Particle number: 512^3

Particle mass $\simeq 8.8 \times 10^8 M_\odot$

Halo Finder: Friend of Friend Method ($b = 0.2$)