Alignment of interacting haloes in the Horizon Run 4 simulation

L'Huillier, Park & Kim MNRAS submitted

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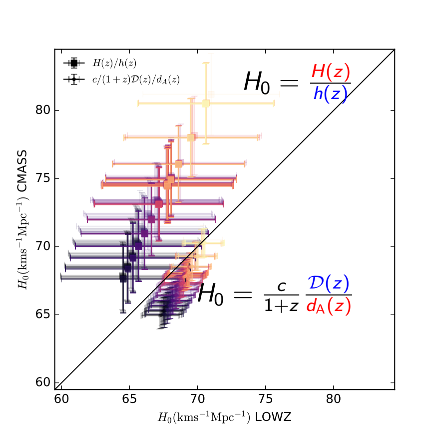
XII$^{\text{th}}$ Rencontres du Vietnam, ICSE, Quy Nhon

Model-independent measurement of H_0

L'Huillier & Shafieloo, arXiv:1606.06832



- $H(z), d_A(z)$ from BAO (BOSS, Cuesta et al 2016)
- $h(z) = 1/\mathcal{D}'(z), \mathcal{D}(z)$: **model-independently** reconstructed from supernovae (JLA, Betoule et al 2014)

Outline

Motivations

- Galaxies form within the cosmic web: properties must be related to their environment
- The study of the alignment of the spins and shapes of haloes can shed light on galaxy formation within their environments
- Alignment as a probe of the large-scale structures
- Intrinsic alignment: source of systematics for weak lensing analysis
- From simulations: spins aligned with the intermediate axis of the tidal tensor Wang et al (2011)
- mass dependence: low-mass (massive) haloes have their spin parallel (orthogonal) to filaments Hahn et al (2007),
- Haloes in sheets have their spin in the plane

The Horizon Run 4 simulation

Horizon Run 4 (J. Kim et al 2015, JKAS)

- N-body: $L = 3.15\, h^{-1}\mathrm{Gpc}$, $N = 6300^3$ ($\bar{d} = 0.5\, h^{-1}\mathrm{Mpc}$), WMAP5 cosmology
- 8000 CPU cores, 2000 timesteps, 50 days at KISTI (Korea).

Catalogues

- Haloes detected with OPFOF, and subhaloes with PSB
- Minimum subhalo mass (20 particles): $1.8 \times 10^{11}\, h^{-1} M_\odot$
- Target ($M_\mathrm{T} > 5 \times 10^{11}\, h^{-1} M_\odot$) and neighbour ($M_\mathrm{N} > 2 \times 10^{11}\, h^{-1} M_\odot$) catalogues
- Hereafter, "haloes" refer to PSB subhaloes ($\leftrightarrow$ galaxies)

Interactions

- A target T is interacting if
  - it is located with the virial radius of its neighbour N
  - $M_\mathrm{N} > 0.4\ M_\mathrm{T}$
- At $z = 0$: $N_\mathrm{Target} = 225\,406\,978$; $N_\mathrm{interactions} = 14\,267\,922$

Large-scale density

B. L'Huillier, C. Park and J. Kim 2015, MNRAS 451, 527

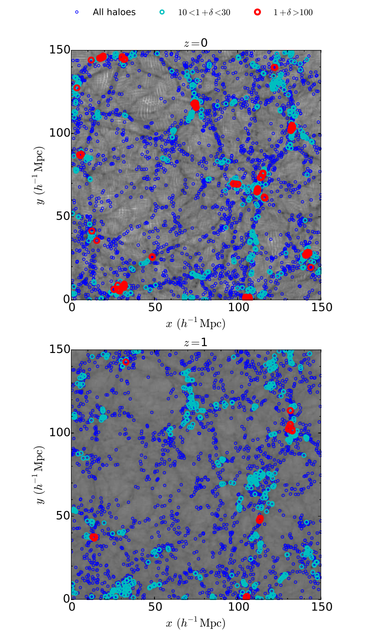
To quantify the environment: ρ_{20}: density over 20 neighbours

$$\rho_{20} = \sum_{i=1}^{20} M_i W(r_i, h),$$

where r_i is the distance to the $i^{\rm th}$ neighbour, M_i its mass, W the SPH spline kernel, and h the smoothing length.

Normalisation by $\bar{\rho} = \sum_{\rm N} M_i$:

$$1 + \delta = \rho_{20}/\bar{\rho}$$



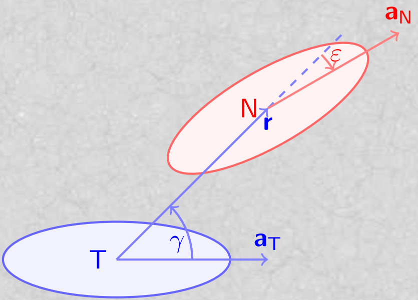
Method

B. L'Huillier, C. Park & J. Kim MNRAS submitted

To detect an alignment signal of an angle $\theta = (\mathbf{u}, \mathbf{v})$, following Yang et al 2006, we used the normalised pair count:

- Count the number of pairs $N(\theta)$ with angle θ
- for $N_{\mathrm{rand}} \simeq 200$, calculate $\left\langle N^{\mathrm{R}}(\theta) \right\rangle$ and σ_θ the mean and std deviation of random permutations of **u**.
- We look at $f(\theta) = N(\theta) / \left\langle N^{\mathrm{R}}(\theta) \right\rangle$
  - If $f \equiv 1$: No alignment (random)
  - If $f(\cos\theta \simeq \pm 1) \gg 1$: Alignment (parallel/anti parallel)
  - If $f(\cos\theta \simeq 0) \gg 1$: Anti-alignment (orthogonal)
- the strength of the signal (error bars) is given by $\sigma_\theta / \left\langle N^{\mathrm{R}}(\theta) \right\rangle$.

Shapes



$\gamma = (\mathbf{a}_\mathsf{T}, \mathbf{r})$: angle between major axis (target) and direction neighbour

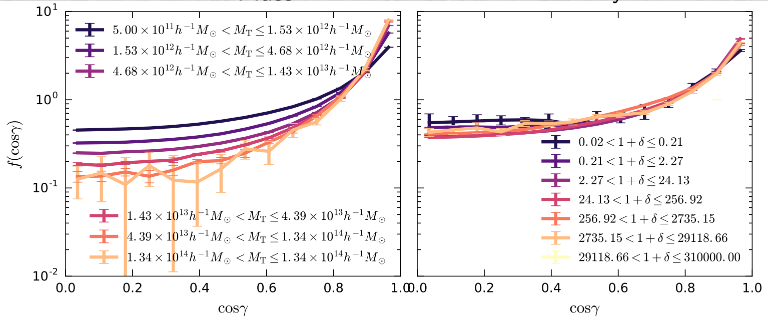
$\varepsilon = (\mathbf{a}_\mathsf{N}, \mathbf{r})$: angle major between the major axis of the neighbour and the direction of the target

Dependence on mass and environment

$z = 0$

Mass

Density

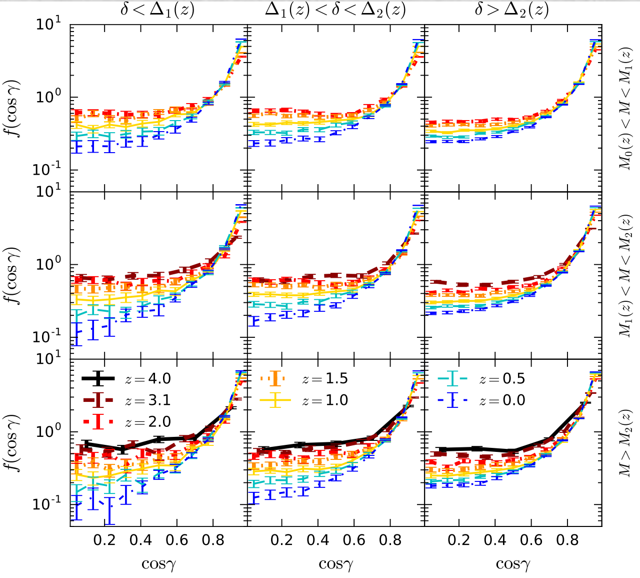


Alignment increase with mass; little density dependence

Major axis aligned with the direction of the neighbour

$\gamma = (\mathbf{a}_\mathrm{T}, \mathbf{r});\ q_\mathrm{T} < 0.8$

Higher densities

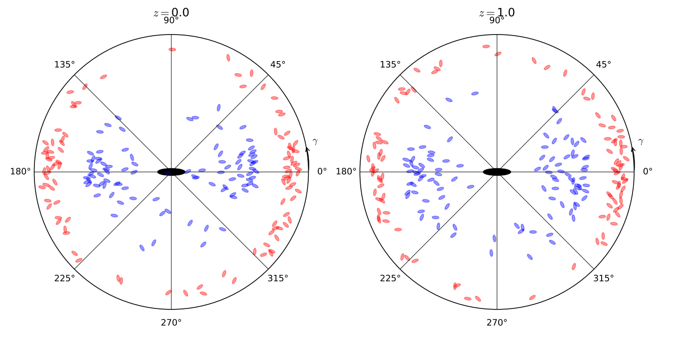


Higher masses

Alignment stronger at low-δ and low-z; little mass dependence

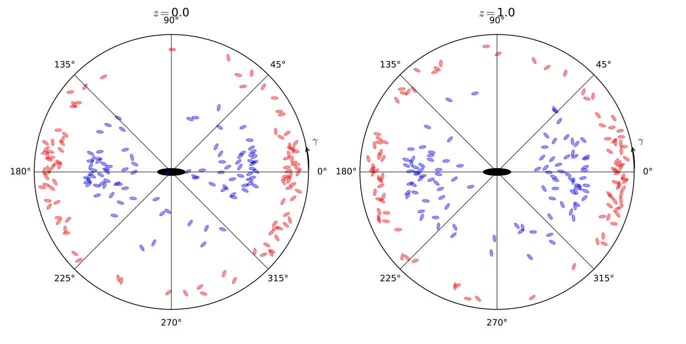
Major axis aligned with the direction of the neighbour

Alignment of prolate pairs



- Neighbours are drawn at their angular position γ proportionaly to $P(\gamma)$.
- Neighbours located in the direction of the major axis
- Neighbours point toward the Target

Alignment of prolate pairs



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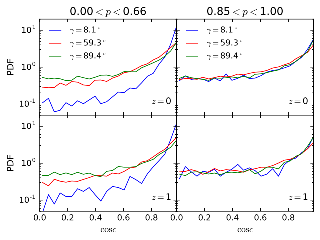
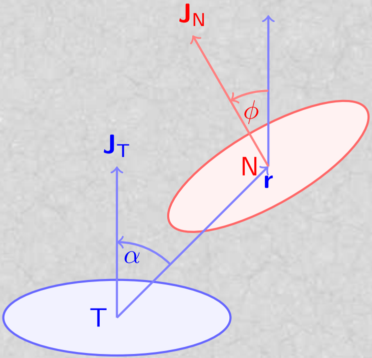


Spins

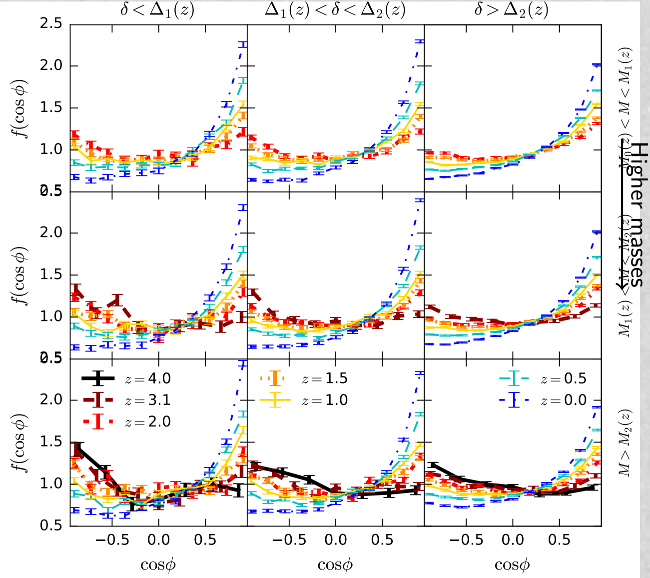


$\alpha = (\mathbf{J}_{\mathsf{T}}, \mathbf{r})$: angle between spin target and direction neighbour

$\phi = (\mathbf{J}_{\mathsf{T}}, \mathbf{J}_{\mathsf{N}})$: angle between target and neighbour neighbour spins

$\phi = (\mathbf{J}_\mathrm{T}, \mathbf{J}_\mathrm{N})$

Higher densities



Higher masses

At high-z: anti-parallel or no alignment

At low-z: aligned

Summary and perspective

- The unprecedented statistics of HR4 enable us to study the alignment as a function of the environment
- The angular position neighbour is aligned with the major axis of the target
- Alignment increases with mass, independent of large-scale density
- Alignment signal stronger at low redshift
- Flip in the spin alignemtn at $z \simeq 2$

- Compare with observations: need for hydro simulations

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Cảm ơn!