# Alignment of interacting haloes in the Horizon Run 4 simulation

Benjamin L'Huillier (KIAS)

with Changbom Park, Juhan Kim (KIAS)

Science survey group meeting

2016-02-02, High One Resort

KOREA INSTITUTE FOR ADVANCED STUDY

# 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 $z = 0$: $N_\mathrm{Target} = 225\,406\,978$; $N_\mathrm{interactions} = 14\,267\,922$

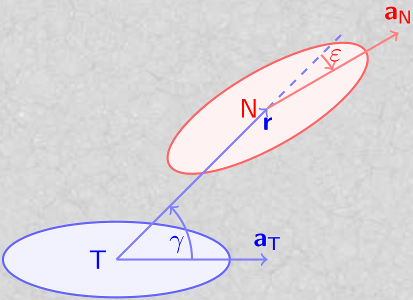
# Method

B. L'Huillier, C. Park & J. Kim in prep.

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 $\theta$
- for $N_{\rm rand} \simeq 200$, calculate $\left\langle N^{\rm R}(\theta) \right\rangle$ and $\sigma_\theta$ the mean and std deviation of random permutations of $\mathbf{u}$.
- We look at $f(\theta) = N(\theta) / \left\langle N^{\rm R}(\theta) \right\rangle$
  - 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 $\sigma_\theta / \left\langle N^{\rm R}(\theta) \right\rangle$.

# Shapes

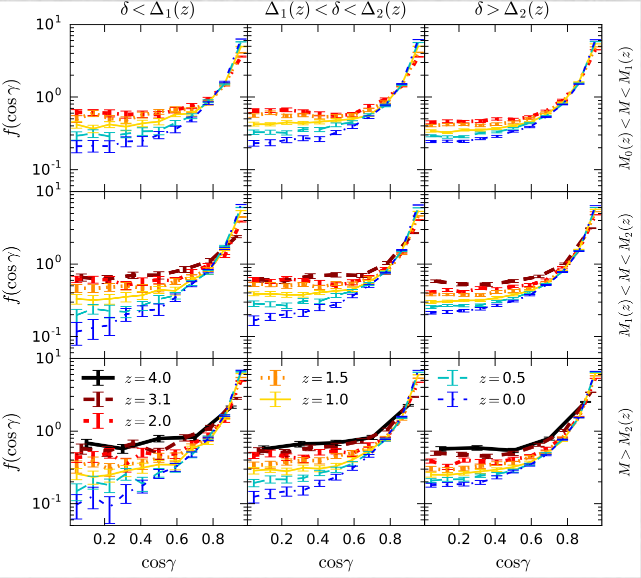



$\gamma = (\mathbf{a}_\mathsf{T}, \mathbf{r})$: angle between major axis (target) and direction neighbour

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

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

Higher densities

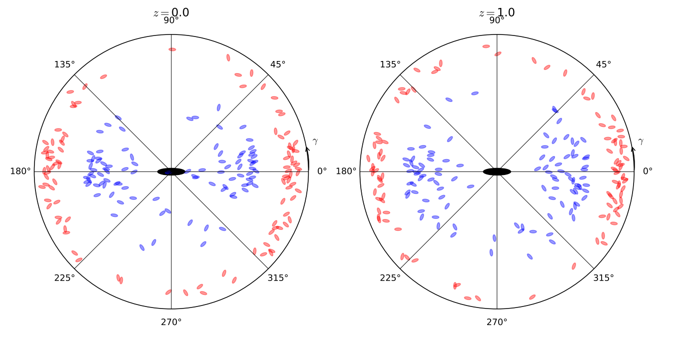



Higher masses

Alignment stronger at low-$\delta$ and low-$z$; little mass dependence

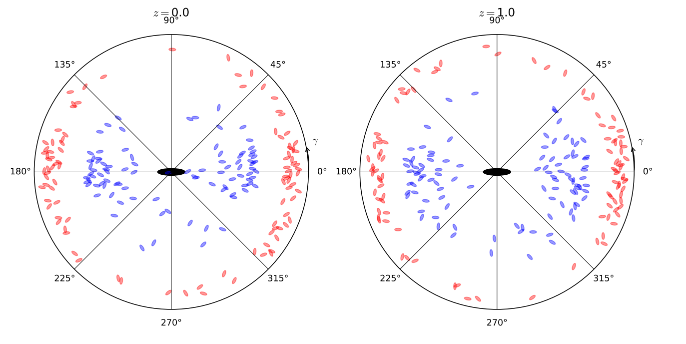
*Major axis aligned with the direction of the neighbour*

# Alignment of prolate pairs

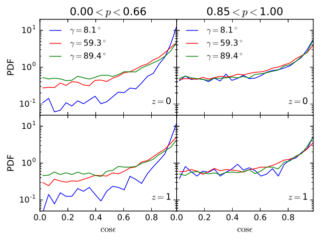



- Neighbours are drawn at their angular position $\gamma$ proportionaly to $P(\gamma)$.
- Neighbours located in the direction of the major axis
- Neighbours point toward the Target

# Alignment of prolate pairs




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



# 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 signal stronger at low redshift, increases with density, independant of mass

- Compare with observations
- Robust characterisation of the LSS (ex: Hessian of the density field)
- Inclusion of hydrodynamics: morphological transformation, star formation, misalignment galaxy/halo
- Strong alignemnt at high redhshift ($\simeq 4$): Study the initial density field and compare with TTT

# 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 signal stronger at low redshift, increases with density, independant of mass

- Compare with observations
- Robust characterisation of the LSS (ex: Hessian of the density field)
- Inclusion of hydrodynamics: morphological transformation, star formation, misalignment galaxy/halo
- Strong alignemnt at high redhshift ($\simeq 4$): Study the initial density field and compare with TTT

감사합니다!