# Halo interactions in the Horizon run 4 simulation

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6th KIAS workshop on

Cosmology and Structure Formation

Seoul, 2014-11-04

KOREA INSTITUTE FOR ADVANCED STUDY

# The rates and types of halo interactions

In a hierarchical ΛCDM Universe, galaxies evolve via secular evolution (formation of bars, bulges, spiral structure, . . . ), interactions with their neighbours (major and minor mergers, flybys, . . . ) and smooth gas accretion

- Major merger have a dramatic impact (morphology transformation, significant mass increase) (Toomre & Toomre 1972)
- Minor mergers also matter: more frequent (Bournaud et al 2007)
- How about flybys? Not much studied (notable exception: Sinha & Holley-Bockelmann 2012)
- Role of the environment: field, groups and cluster

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## Main questions

- What kind of interaction has the most significant impact?
- How does it change with redshift?
- With other properties (mass ratio, impact parameter, environment)?

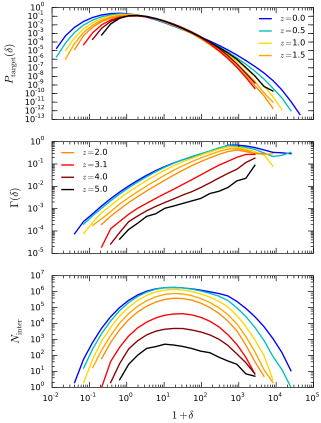
# Horizon Run 4

## Horizon Run 4

- $N$-body simulation using GOTPM, WMAP5 cosmology
- 8000 CPU cores, 50 days at KISTI.
- $L = 3.15\,h^{-1}\mathrm{Gpc}$, $N = 6300^3$ ($\bar{d} = 0.5\,h^{-1}\mathrm{Mpc}$)
- 2LPT, $z_{\mathrm{ini}} = 100$, 2000 timesteps
- 70 outputs, lightcone up to $z = 1.39$
- Applications: Galaxy interactions, clustering, semi-analytic models, lensing, ...

- Haloes detected with OPFOF, and subhaloes with PSB
- Minimum subhalo mass (20 particles): $1.8 \times 10^{11}\,h^{-1}M_\odot$
- Use of a target and neighbour catalogue
- Hereafter, "haloes" refer to PSB subhaloes

# Interaction rate: background density




Background density: smoothed over 20 neighbours:

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

Top: PDF of the density of interacting targets

Bottom: fraction of targets that are interacting

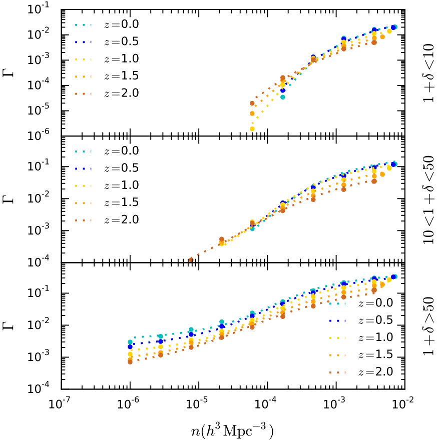
$\Gamma$ increases with $\delta$

The number of interactions peaks at $\delta \simeq 20$

# Interaction rate: $\Gamma(n, \delta|z)$

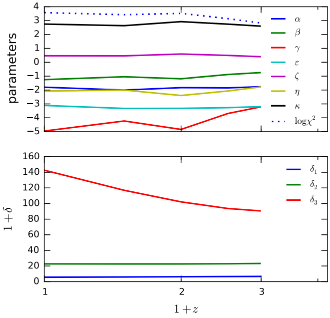
## 7-parameters fit at fixed redshift

### 3 density bins

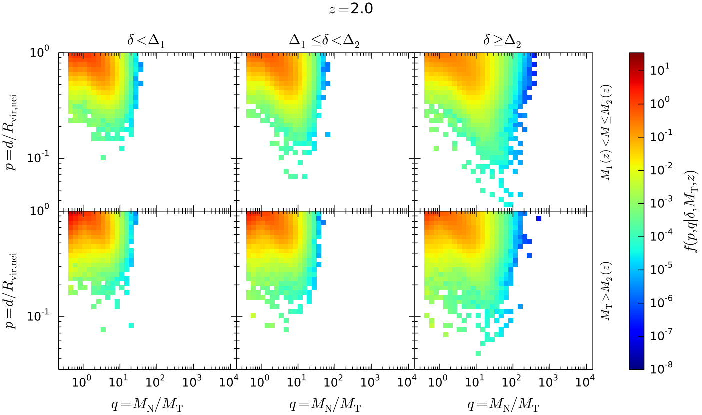



$$\log\Gamma(n,\ \delta|z) = (\alpha\ \arctan(\beta\ \log n + \gamma) + \varepsilon)\ (\zeta\ \log(1+\delta))^2 + \eta\ \log(1+\delta) + \kappa), \quad (1)$$

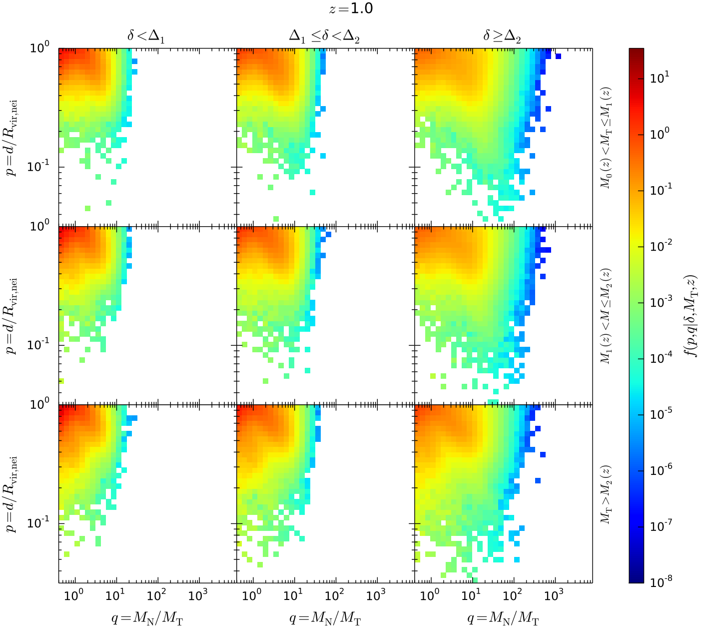
### Time-evolution of the parameters:



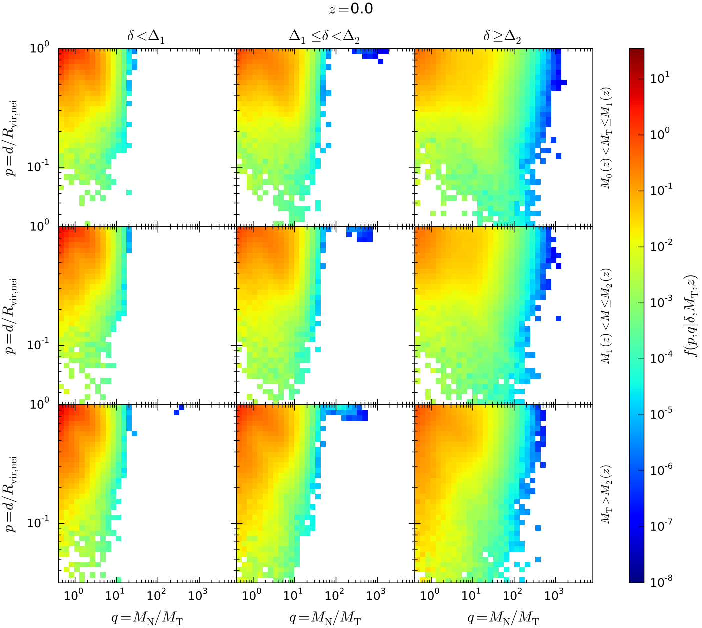
# PDF of interactions: distance and mass ratio




- Two branches in the $p - q$ plane
  - $q \leq 1$: target is a host, or equal mass interaction
  - $q > 1$: target is the satellite, loosing mass through tidal stripping



$z = 1.0$
$\delta < \Delta_1$
$\Delta_1 \leq \delta < \Delta_2$
$\delta \geq \Delta_2$
$p = d/R_{\rm vir,nei}$
$q = M_{\rm N}/M_{\rm T}$
$M_0(z) < M_{\rm T} \leq M_1(z)$
$M_1(z) < M \leq M_2(z)$
$M_{\rm T} > M_2(z)$
$f(p,q|\delta, M_{\rm T}, z)$



$z=0.0$
$\delta < \Delta_1$
$\Delta_1 \leq \delta < \Delta_2$
$\delta \geq \Delta_2$
$p = d/R_{\rm vir,nei}$
$q = M_{\rm N}/M_{\rm T}$
$M_0(z) < M_{\rm T} \leq M_1(z)$
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# Summary

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- We study the interaction rate in the HR4 simulation as a function of target mass, environment, distance to the nearest neighbour, and redshift
  - Large box: environment study and good statistics
  - High resolution: haloes more masive than $2 \times 10^{11}\, h^{-1} M_{\odot}$
- We provide a new fit $f(n, \delta | z)$
- Two branches in the $p - q$ plane: probe different stages of interactions

## Perspective

- Alignment (spin, shape) with the LSS as a function of the environment
- Use of a merger tree to distinguish merger and flybys
- Use of an improved galaxy–subhalo assignment scheme for the catalogue
- Inclusion of hydrodynamics: morphological transformation, star formation, ...

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# Method

## Interactions

We define interactions pairs of targets and neighbours such as

- the target halo lies within the virial radius of its (closest) neighbour
- the neighbour satisfies: $M_{\mathrm{N}} > fM_{\mathrm{T}}$ ($f = 0.4$)

Notes:

- At the moment, we don't consider multiple interactions: only the closest neighbour is considered
- An interaction may counted twice if the neighbour is also in the Target catalogue, and if the target is the closest neighbour of the neighbour satisfying the mass condition

# Catalogue

## Catalogues

- Two catalogues of target and neighbour haloes defined by a mass cut
- Catalogue of target haloes (T): $M > M_0 = 5 \times 10^{11}\, h^{-1} M_\odot$
- Catalogue of neighbour haloes (N): $M > fM_0 = 2 \times 10^{11}\, h^{-1} M_\odot$; $f = 0.4$ sets the minimum mass ratio
- Both catalogues are complete (more massive than the mass resolution)