Marked cross-correlation functions and merger trees: update Geraint Harker

## Marked correlation function: reminder!

•  $\xi(r) = \sum_{\{i, j | r_{ij} = r\}} \frac{m_i m_j}{n(r) \overline{m}^2}$ • Assign a mark  $m_i$  to each halo (formation redshift here) and evaluate the above formula.

ξ=1 indicates noenvironmentaldependence.



# Marked correlation function: disadvantages

- The halo environment as measured by the marked correlation function is only defined by haloes of the same mass as those being measured.
- Averaging over a large mass range to give a less noisy signal introduces problems:
  - Signal tends to be dominated by the more numerous, lower mass haloes in the range.
  - Signal from higher mass haloes only cuts in above some scale determined by halo exclusion.
  - Resulting marked correlation function is hard to interpret.

#### Marked cross-correlation function: definition

- Find the environmental dependence of the mark for some 'marked' population.
- Measure environment using some 'tracer' population.
  - $\xi(r) = \sum_{\{i,j|r_{ij}=r\}} \frac{m_j}{n(r)\overline{m}}$  *i* from tracer population *j* from marked population
- $\xi \neq 1$  still indicates environmental dependence.
- Marked cross-correlation function of a population with itself is not the marked autocorrelation function
- Interchanging marked and tracer populations changes the marked cross-correlation function.

### Marked cross-correlation function: results

- Choose a sufficiently abundant tracer population: ~6x10<sup>13</sup>h<sup>-1</sup>M<sub>sun</sub> here.
- Clearly >1 for low mass marked haloes; less significant signal for high mass haloes.
- Possible sign change for high mass marked population.



# Tracer population less massive than marked population



 Throwing away any subhaloes the centre of which are outside twice the half-mass radius of the parent halo, or which have retained more than 75% of the mass they had at the last time they were independent haloes.



 Treating as separate haloes any subhaloes the centre of which are outside twice the half-mass radius of the parent halo, or which have retained more than 75% of the mass they had at the last time they were independent haloes.



- Dashed line: oldest 10%.
- Dotted line: youngest 10%.
- Haloes with 100-200 particles
- Sign of age dependence changes in most extreme case.





# Not a problem case

Several possible ways to treat this situation, affecting the final halo catalogue and the merger trees: a choice, not a problem!

Time

Substructure

FOF halo

Twice the halfmass radius



# Conclusions

- For haloes with a wide range in mass, the Millennium Simulation enables us to determine well:
  - The marked correlation function;
  - The marked cross-correlation function (easier to interpret, and gives us additional information on good choices for tracers of environment);
  - Halo formation redshift as a function of local overdensity in dark matter.
  - All of these give secure detections of an environmental dependence of halo formation.
- The details of these statistics depend on choices made in merger tree construction. Whatever these choices, care must be taken that de-mergers, which become more important for environmentally weighted statistics are properly accounted for. FOF haloes do especially badly!