Mass loss of galaxies in galaxy clusters

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Gravitational interactions in groups and clusters

- Galaxy-galaxy interactions:
  - Mergers (Toomre & Toomre 1972; Di Matteo et al. 2007; Angulo et al. 2009)
  - Harassment (Moore et al. 1998, 1999; Gnedin et al. 2003)

Gravitational interactions in groups and clusters

- Galaxy-cluster interactions:
  - Truncation of dark matter halos (Limousin et al. 2009; Gao et al. 2004; Warnick et. al. 2008)
  - Induce central starbursts (Byrd & Valtonen, 2001)
  - Trigger bar instabilities, enhanced spiral structure (Lokas et al. 2016; Semczuk et al. 2017)

Tidal mass loss in combined group/cluster environments

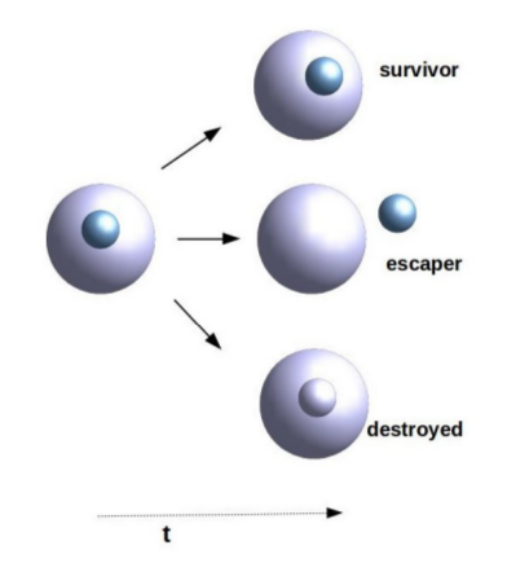
- Approximately 25%-45% of cluster galaxies are accreted within groups. (McGee et. al. 2009, De Lucia et. al. 2012)
- Increasing evidence for *pre-processing* of cluster galaxies (Mihos 2004, Haines et. al. 2015, Jaff et. al. 2016)

- Choque, Smith, Candlish, et al., submitted to MNRAS
- Cosmological simulation (Warnick & Knebe 2006), halos used to analyse group/group-member mass loss.

Nelvy Choque

Tidal mass loss in combined group/cluster environments

- "Group": contains at least one bound halo within $2R_{vir}$
- "Group member": within halo and contains no subhalos.
- Group member halos classified as:
  - Survivor: persists until $z = 0$.
  - Escaper: unbound from host halo.
  - Destroyed: mass drops below resolution limit.



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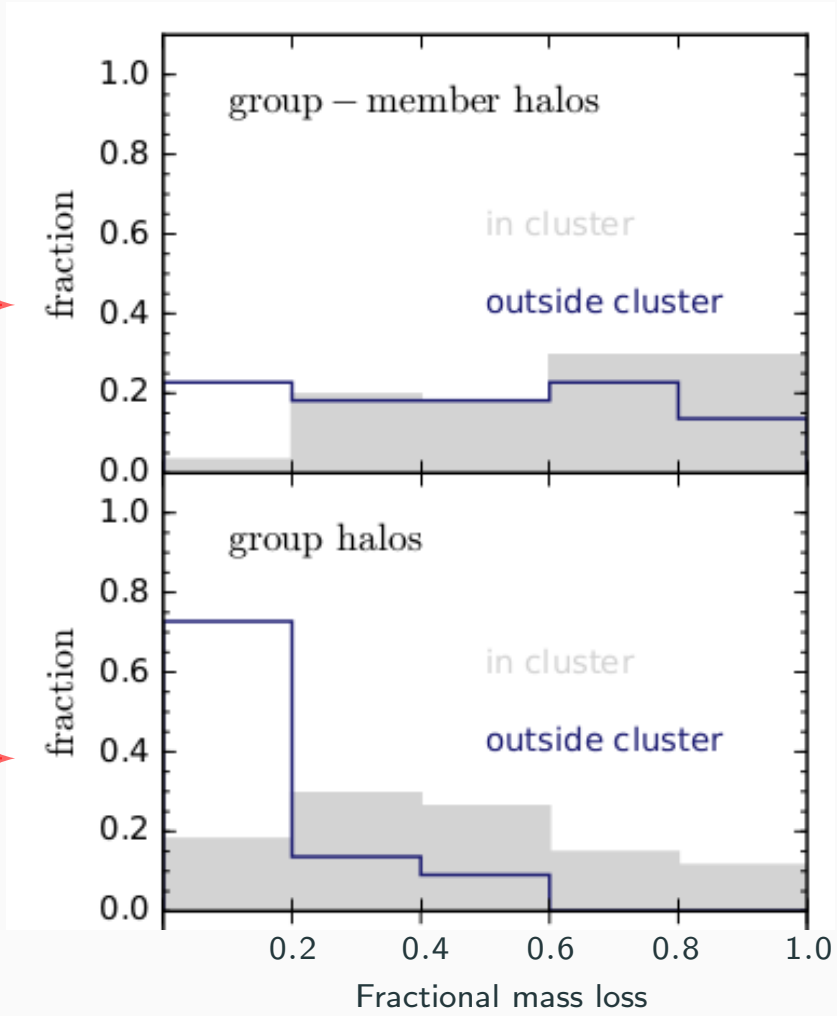
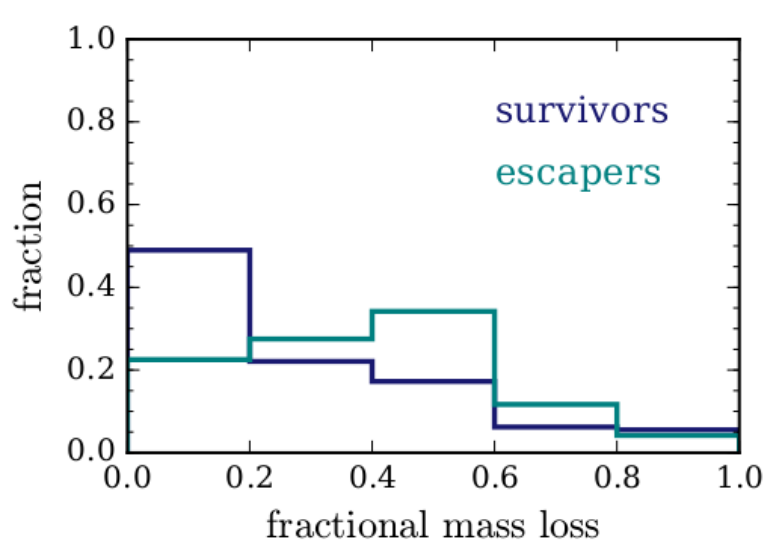
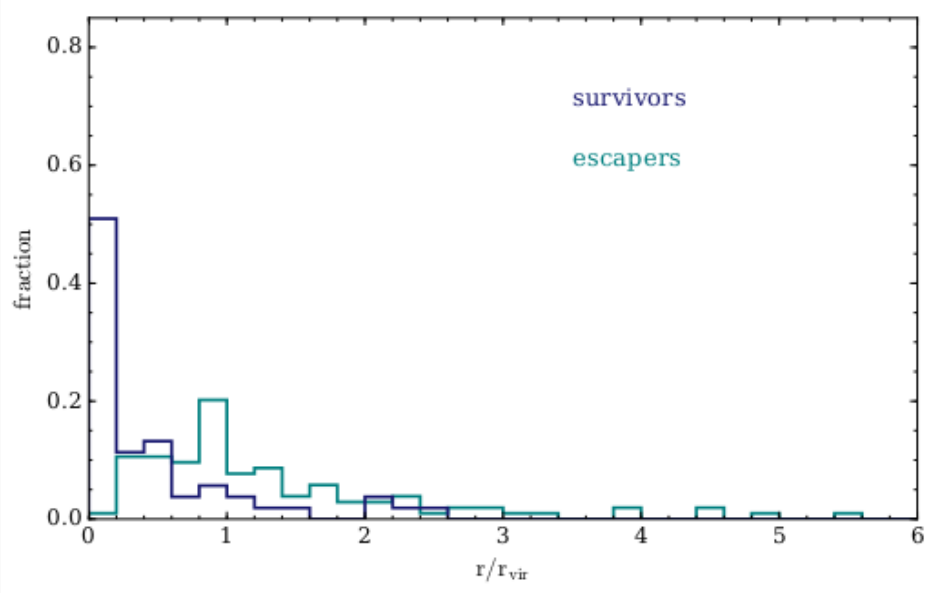
- Group members lose mass due to group tides, inside or outside cluster
- Groups only lose mass inside cluster, not affected by substructure



Tidal mass loss in combined group/cluster environments

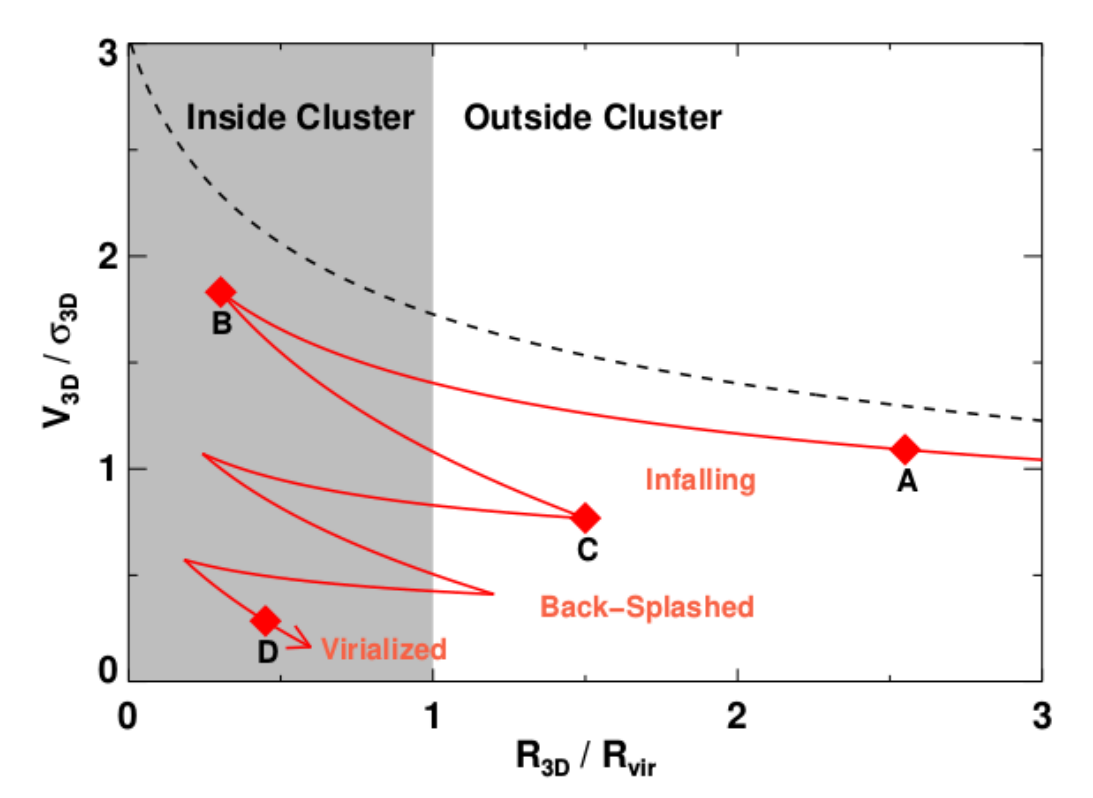


Group mass loss not significantly different between subsamples.



Subhalos close to group virial radius more easily stripped.

Phase-space analysis in the group and cluster environment

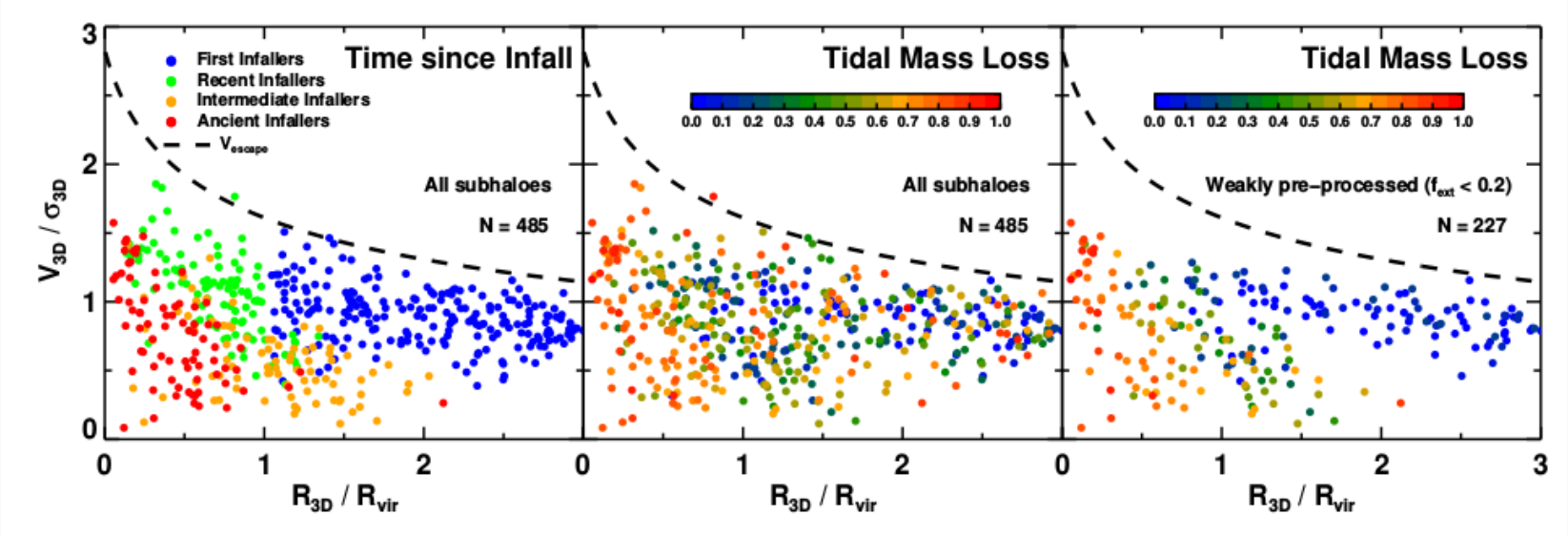


Rhee, Smith, ..., Jaffé, Candlish, et. al., submitted to MNRAS

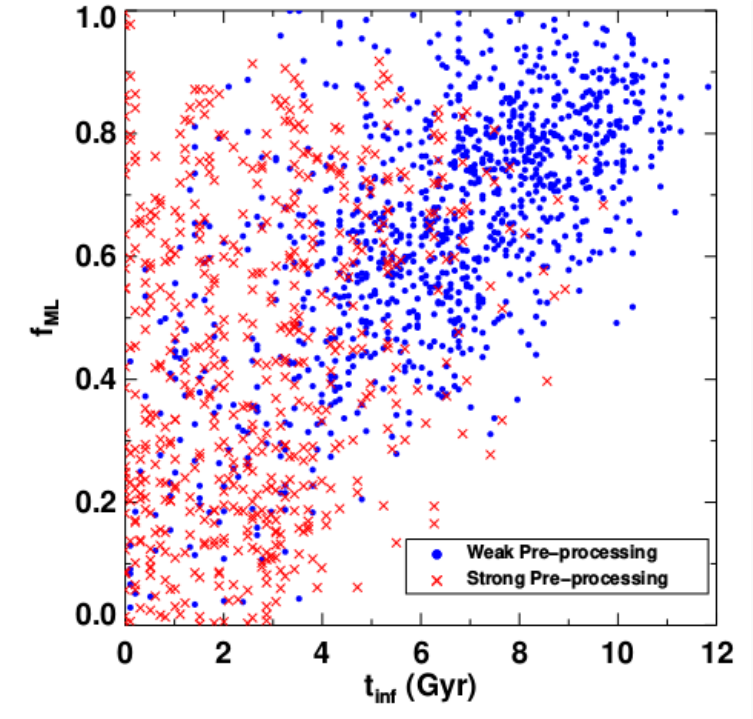
Spatial res 760 pc/h, mass res $8 \times 10^7 M_\odot$ for DM, physics as for Dubois et al. (2012, Horizon-AGN)

See also: Oman et al. (2013), Haines et al. (2015), Oman & Hudson (2016), Jaffé et al. (2015, 2016)

Phase-space analysis in the group and cluster environment



Time grouping	Time bin (Gyr)
First infallers	Not fallen in yet
Recent infallers	$0 < t_{inf} < 3.63$
Intermediate infallers	$3.63 < t_{inf} < 6.45$
Ancient infallers	$6.45 < t_{inf} < 13.7$



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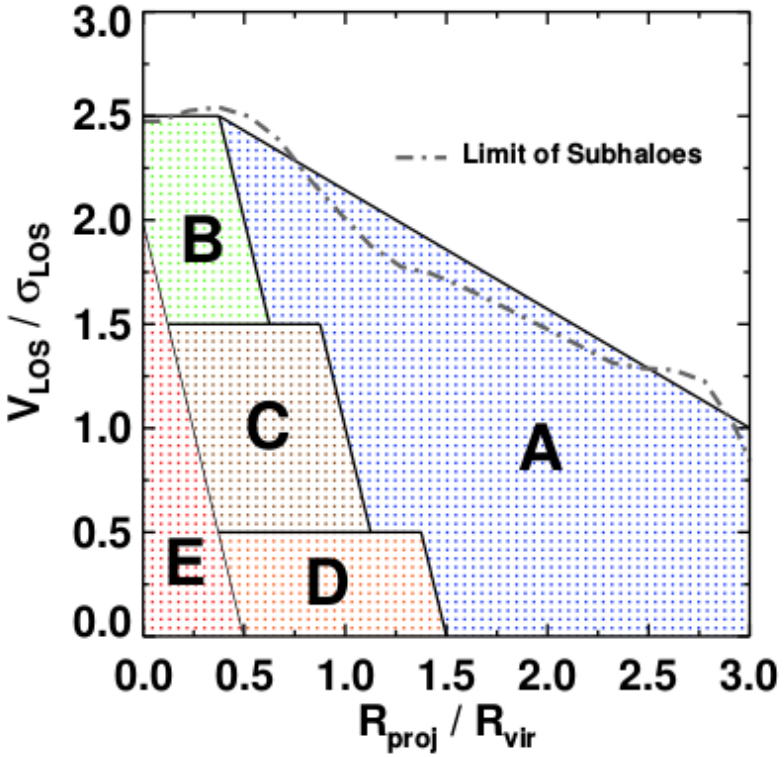

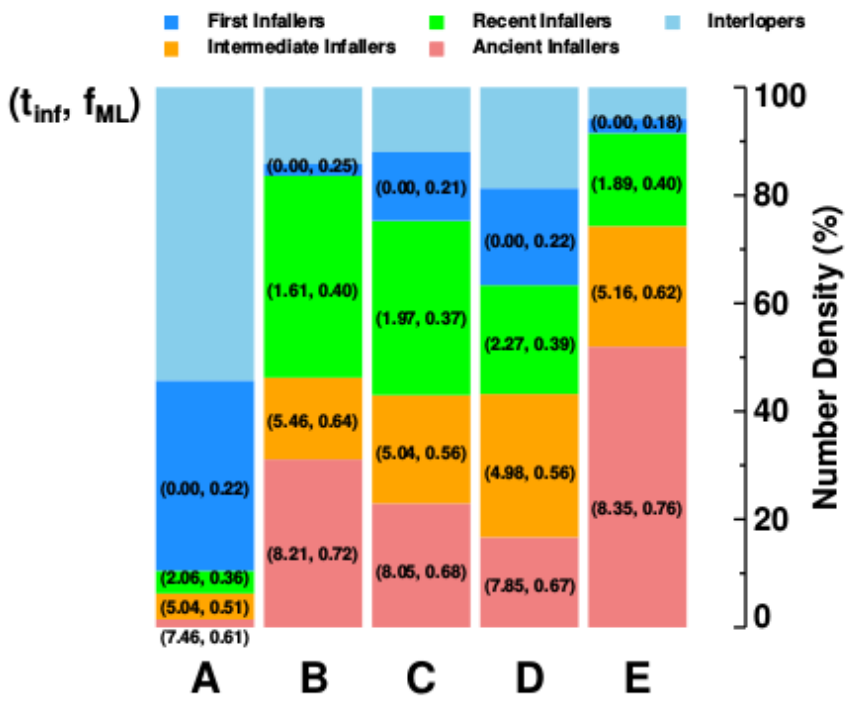

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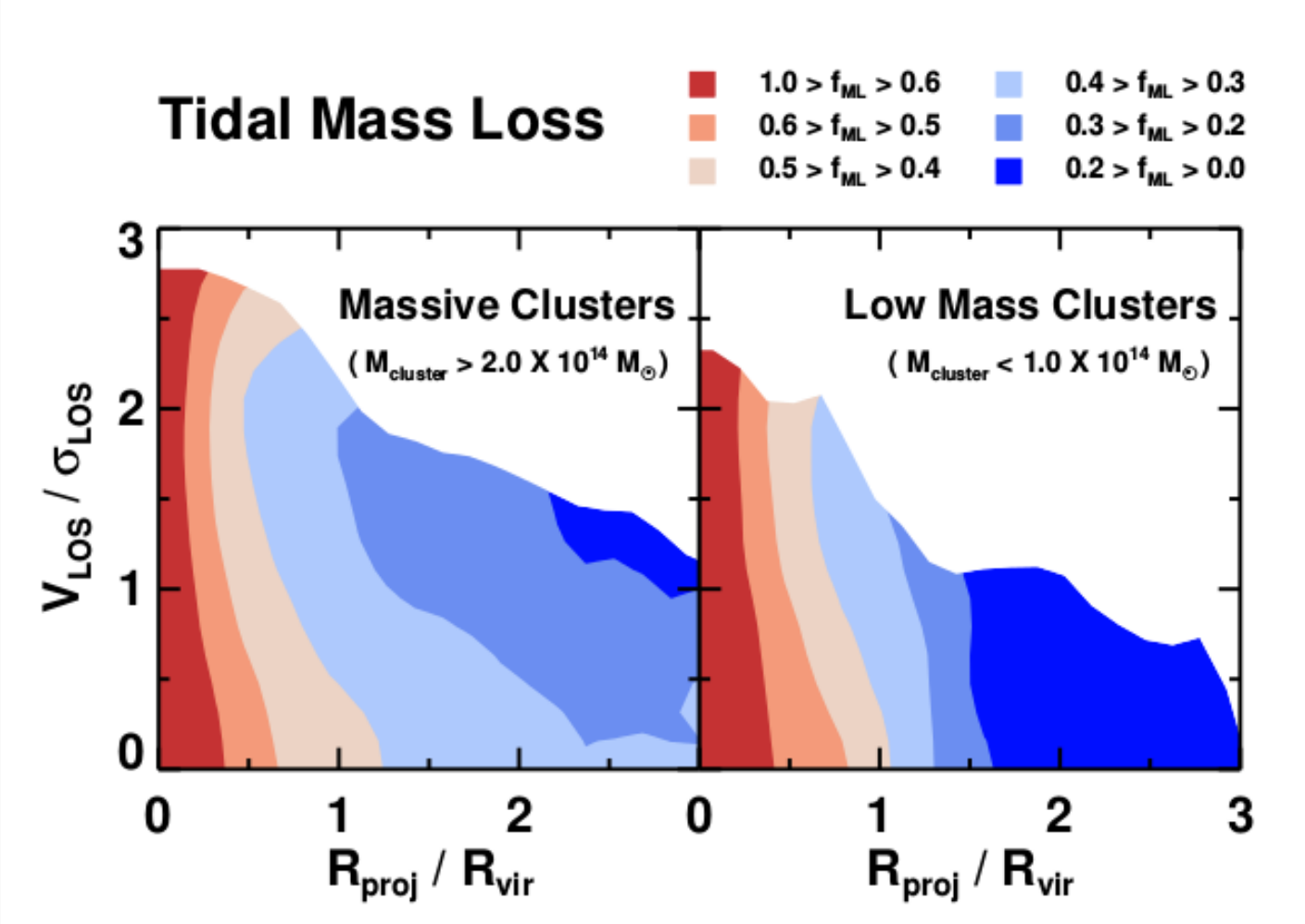


Weak dependence on both cluster mass and galaxy (subhalo) mass.

Summary

- Galaxy groups tend to release more tidally damaged subhalos into the cluster environment.
- Projected phase-space diagrams: reconstruction of galaxy orbital histories thanks to approximate separation of populations.
- Almost linear relationship between tidal mass loss and time in cluster $\Rightarrow$ distinct mass loss regions.

Choque, Smith, Candlish et al., submitted to MNRAS
Rhee, Smith, ..., Candlish et al., submitted to ApJ

Further details: group/cluster analysis

- Data from AHF halo finder applied to zoom cosmological simulations (Warnick & Knebe 2006).
- Eight clusters, roughly Virgo mass ($1 - 3 \times 10^{14} h^{-1} M_{\odot}$).
- Force resolution of ~ 0.2 kpc/h, mass resolution of $\sim 1.6 \times 10^{8} h^{-1} M_{\odot}$.
- Lowest mass of halo considered is $\sim 3 \times 10^{9} M_{\odot}$ (20 particles)

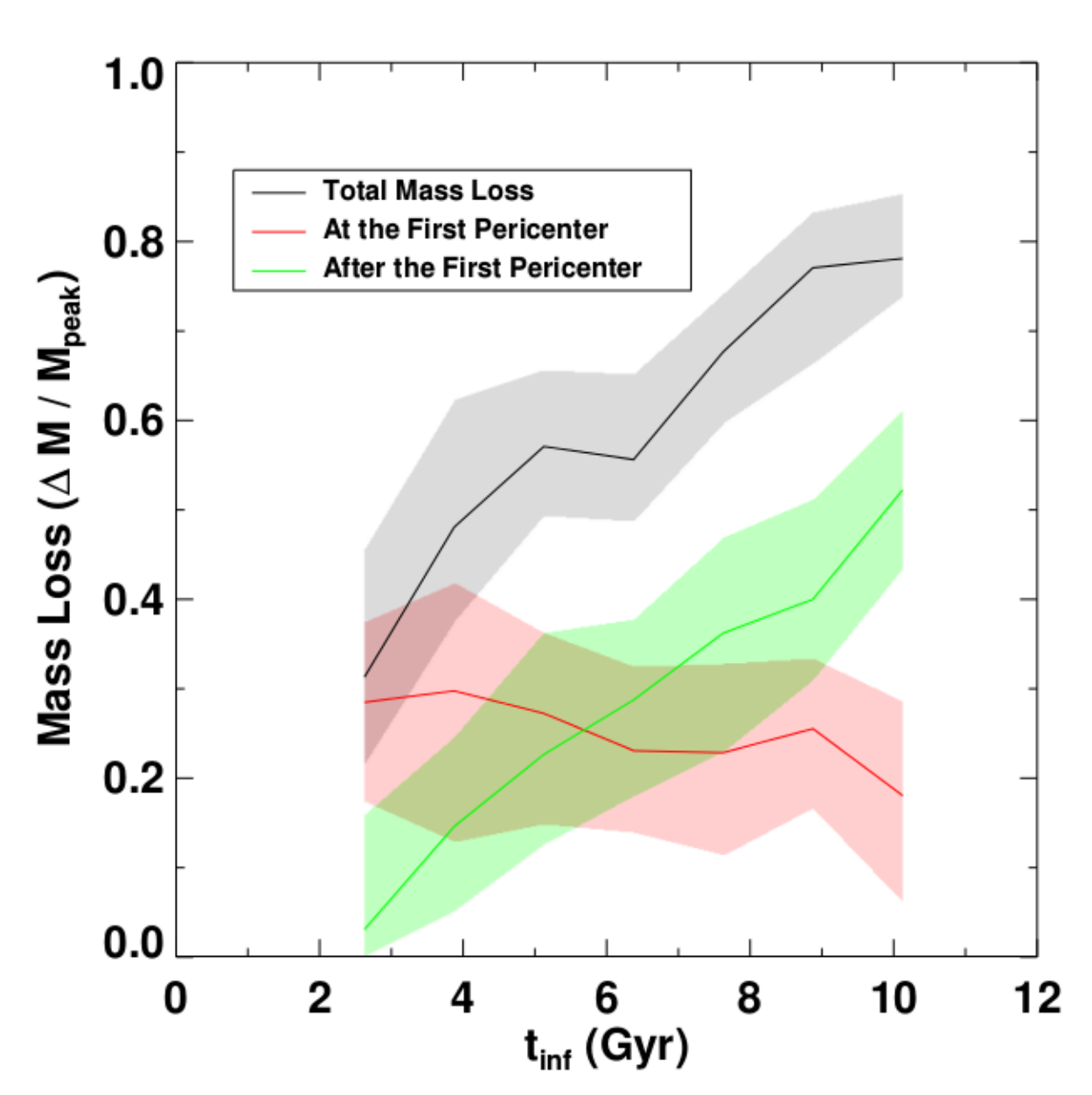
Further details: phase-space analysis

- Cosmological zoom simulations in RAMSES.
- Force resolution of 760 pc/h, mass resolution of $8 \times 10^7 M_\odot$ for DM.
- Hydrodynamics: cooling, star formation, AGN, SN feedback (following Dubois et. al. (2012), Horizon-AGN simulations)

Further details: phase-space analysis

- Minimum halo mass of $3 \times 10^{10} M_{\odot}$ corresponds to stellar mass of $\sim 10^{7} M_{\odot}$ (by halo abundance matching).
- Fractional tidal mass loss: $f_{ML} = 1 - \frac{M_{now}}{M_{peak}}$
- Pre-processing stronger for more recent infallers: median $f_{ext}/f_{ML} = 0.27$ (total sample), median $f_{ext}/f_{ML} = 0.15$ ($t_{inf} > 6$ Gyr).

Further details: phase-space analysis



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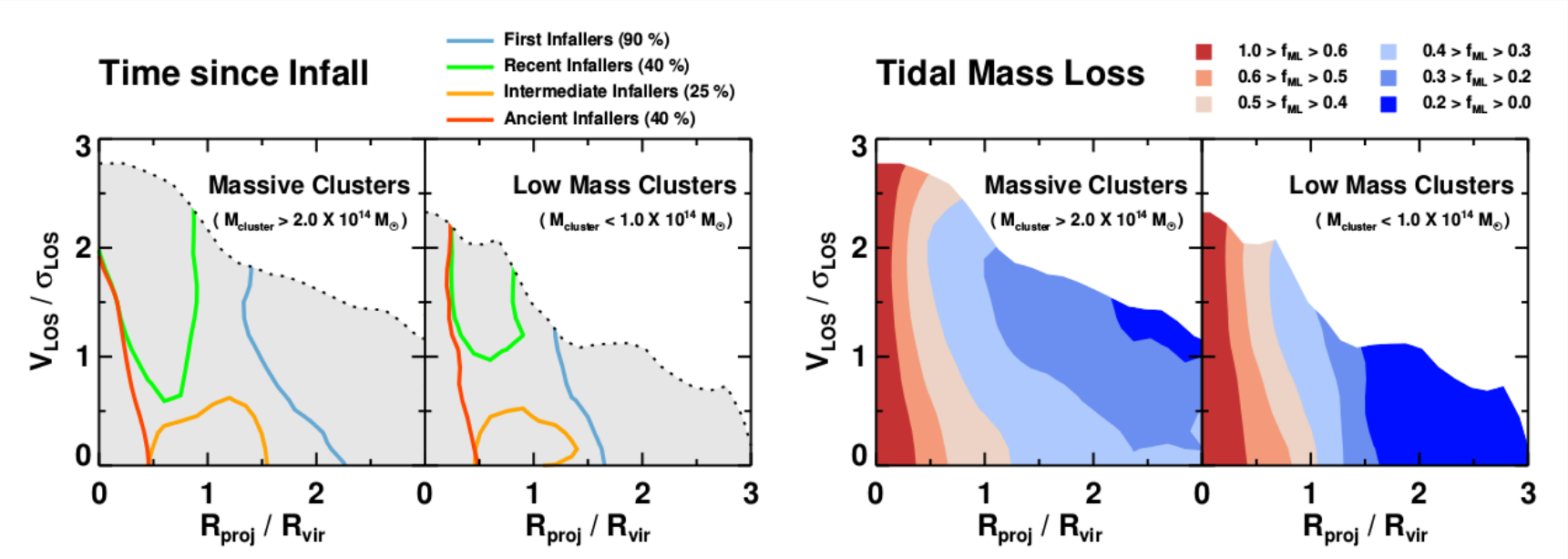

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