# The Measurement of the Mass Accretion Rate of Galaxy Clusters


Michele Pizzardo

University of Turin


Based on *arXiv:2005.11562*


with S. Di Gioia, A. Diaferio, C. De Boni, A. L. Serra, M. J. Geller, J. Sohn, K. Rines, M. Baldi


Cosmology from Home 2020

UNIVERSITÀ DEGLI STUDI DI TORINO

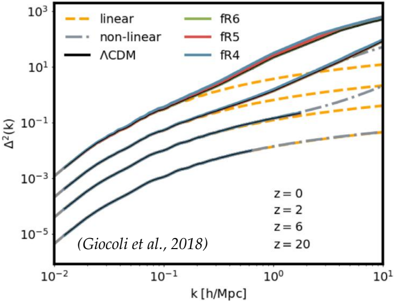
INFN TORINO

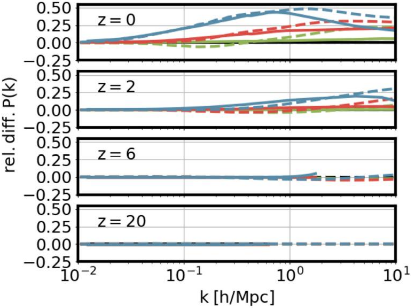
# The Measurement of the Mass Accretion Rate (MAR) of Galaxy Clusters

Outline of the talk

1. **Motivations**
2. **The estimation of the MAR from data**
   - <u>The procedure</u>
     Data, caustic technique, spherical accretion model
   - <u>The validation of the recipe</u>
     N-body simulations and mock catalogues
3. **The MAR in the observable Universe**
   Analysis, robustness and results
4. **Conclusions**

# Large and small scales



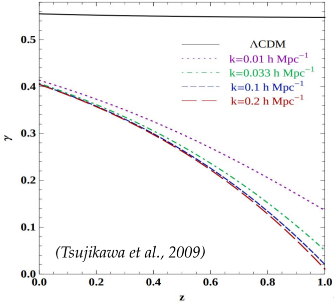

At linear scales

$$\longrightarrow \qquad f_z = \frac{d \log D_+}{d \log a}$$

$D_+ \propto$ growth of perturbations

$f(z,k) \approx \Omega_m(z)^{\gamma(z,k)}$

☛ MAR of clusters suitable for intermediate scales



# The MAR

An estimate of the MAR of real galaxy clusters can provide new tests in a variety of fields:

- it is linked with internal properties of the clusters (concentration, shape, spin, degree of internal relaxation, splashback radius, age);
- it can trace the accretion rate of baryons from the cosmic web onto the dark matter halo;
- it can be a probe of cosmological parameters;
- it could discriminate among different models of gravity.

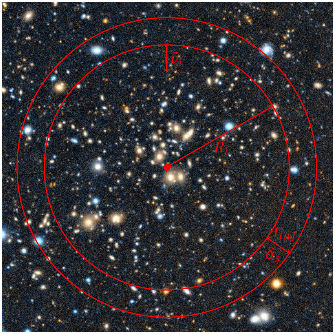
# Previous attempts

1. *Lemze & al. (2013)* investigate the region slightly beyond $R_{200}$ in X-ray and the optical bands;
2. *Tchernin & al. (2016)* detect infalling gas clumps of A2142 in X-ray and SZ out to $\sim 1.3R_{200}$;
3. *Haines & al. (2018)* identify the infalling groups in the range $(0.28; 1.35)R_{200}$.

From simulations: splashback radius at $\sim 2R_{200}$ *(More & al., 2015)*
So... What's the right infalling region? Where's the cluster actually accreting new matter?

⚠ Lack of a recipe to perform measurements!
At present, no "unambiguous" measurement of the MAR in real Universe.

# The ingredients of the measurement




- Dynamical model for the accretion is needed
  $\longrightarrow$ spherical accretion model *(De Boni et al., 2016)*
  - Variables: $M(r)$, $R_i$, $t_{inf}$, $v_i$ $\longrightarrow$ $\delta_s$
- We need a good method for estimating the mass profile of clusters at large radii (up to $\sim 3R_{200}$)
  $\longrightarrow$ caustic technique *(Diaferio & Geller, 1997)*

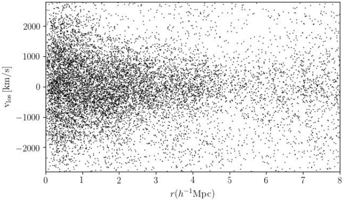
# Pipeline (I)

## 1) Data Retrieval

ABELL 1314

| id | RA [deg] | $\delta$ [deg] | $z$ | g | ... |
|---|---|---|---|---|---|
| 1 | 177.318260 | 49.589084 | 0.47415 | 19.3198 | |
| 2 | 177.379809 | 49.606580 | 0.05509 | 16.9693 | |
| 3 | 177.336652 | 49.615467 | 0.09051 | 17.4208 | |
| 4 | 177.352944 | 49.589621 | 0.05865 | 16.5336 | |
| 5 | 177.383568 | 49.542269 | 0.29258 | 18.8525 | |
| ... | | | | | |

## 2) Caustic Technique



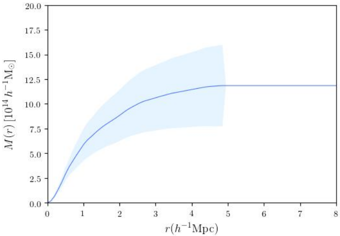

$f_{2D}(r, v)$

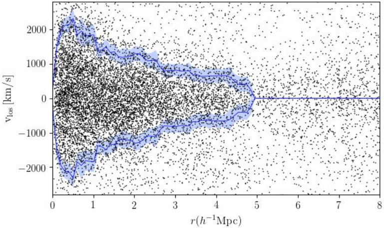
$S(\kappa) = 0$

$f_{2D}(r, v) = \kappa$

$$-2\phi = \langle v_{esc}^2 \rangle, \quad \mathscr{A}^2 = \left\langle v_{esc,los}^2 \right\rangle$$

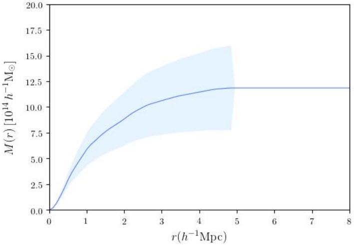
$$-2\phi = \mathscr{A}^2 g(\beta), \quad GM(< r) = \mathscr{F}_\beta \int_0^r \mathscr{A}(r)\mathrm{d}r$$



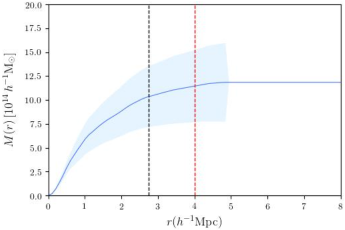



# Pipeline (II)

## 3) Spherical Accretion



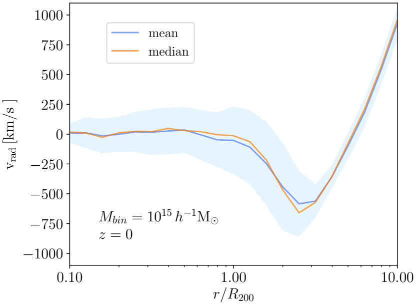

$$t_{\rm inf}^2 GM(<R_i) - t_{\rm inf} 2R_i^2 (1+\delta_s/2)^2 v_i + - R_i^3 \delta_s (1+\delta_s/2)^2 = 0$$




$v_i$ from simulations

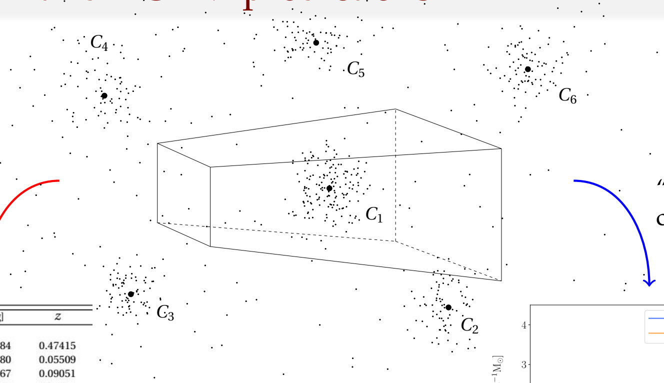
$R_i = 2R_{200}$

$t_{inf} = 1Gyr$




$$\mathbf{MAR} = \frac{M(<R_i+\delta_s) - M(<R_i)}{t_{inf}}$$

# Validation and ΛCDM predictions




emulation of the recipe

| RA [deg] | $\delta$ [deg] | $z$ |
|---|---|---|
| 177.318260 | 49.589084 | 0.47415 |
| 177.379809 | 49.606580 | 0.05509 |
| 177.336652 | 49.615467 | 0.09051 |
| 177.352944 | 49.589621 | 0.05865 |
| 177.383568 | 49.542269 | 0.29258 |

caustic mass profile
+
spherical accretion

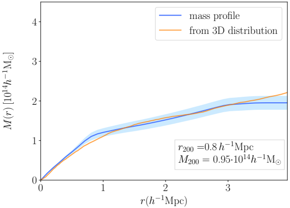
MAR

two mass bins:
$M_{200} \sim 10^{14}; 10^{15} \mathrm{M}_{\odot}/h$

low-mass bin: 6000 mock clusters
high-mass bin: 150 mock clusters

six redshifts: $z \in [0; 0.44]$

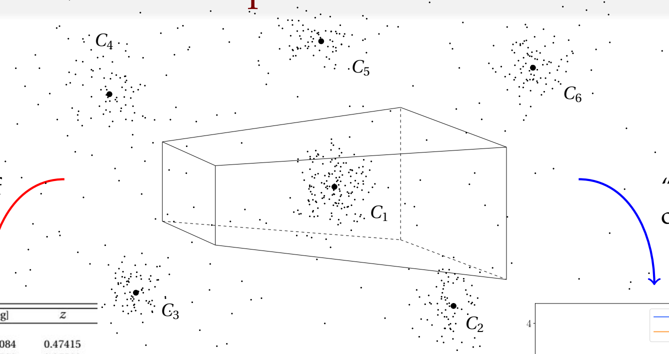
"full" 3-d catalogues




spherical accretion

MAR

# Validation and ΛCDM predictions




emulation of the recipe

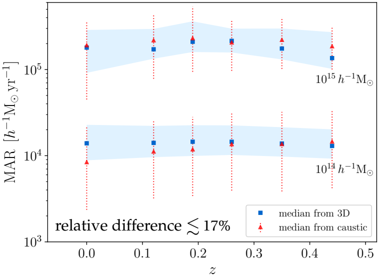
| RA [deg] | $\delta$ [deg] | $z$ |
|---|---|---|
| 177.318260 | 49.589084 | 0.47415 |
| 177.379809 | 49.606580 | 0.05509 |
| 177.336652 | 49.615467 | 0.09051 |
| 177.352944 | 49.589621 | 0.05865 |
| 177.383568 | 49.542269 | 0.29258 |

caustic mass profile

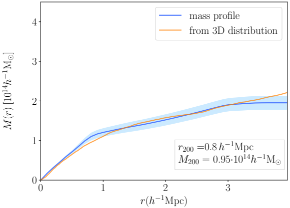
+

spherical accretion

MAR



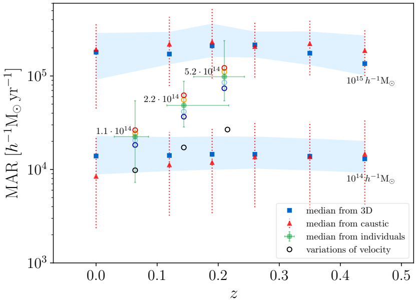

"full" 3-d catalogues




spherical accretion

MAR

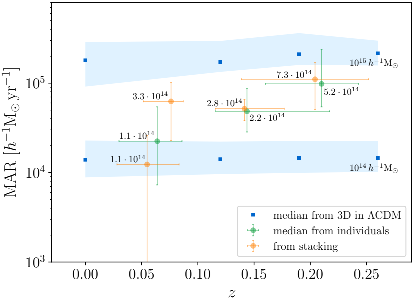
# Results for real clusters (I)



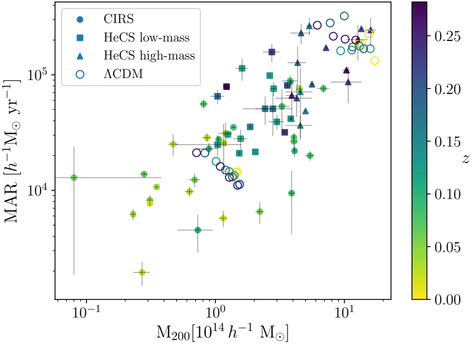

- 129 clusters from CIRS and HeCS *(Rines & Diaferio, 2006; Rines et al., 2013)*;
- No photometric nor spectroscopic bias induced by different selections;
- $\lesssim 25\%$ uncertainties in single MARs;
- Weak dependence on $v_i$.

Robustness ensured by 3 different procedures of stacking:

- all cluster galaxies (figure);
- equally-weighted clusters;
- only individual members.

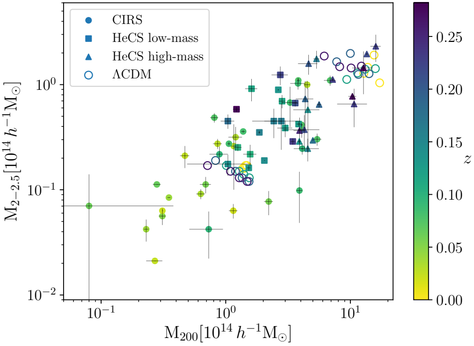


# Results for real clusters (II)




MAR vs $M_{200}$ vs $z$ agree with ΛCDM

$M_{2-2.5}$ good proxy for MAR at low redshifts

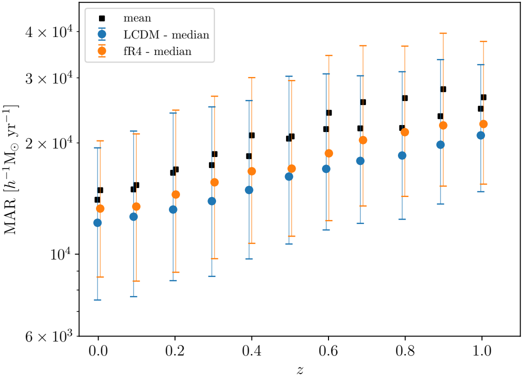


# MAR in Modified Gravity?

- How much does the MAR change in MG?
- Has the MAR got the power to effectively exclude alternative theories?

☛ Theoretically: $f(R)$ simulations with different scalarons.

☞ Observationally: deeper and denser surveys.



# Conclusions and future perspectives

- We developed a pipeline to perform the estimation of the MAR of real clusters based on the caustic technique.
- The recipe allows the estimation of the MAR at unprecedented large distances from the center of the clusters ($\gtrsim 2R_{200}$).
- We validated the recipe with N-body simulations: caustic and 3D MARs agree within $\lesssim 17\%$.
- We estimated the MAR of the CIRS and HeCS clusters. These data agree with $\Lambda$CDM (MAR, mass and $z$ are correlated as expected).
- We are investigating whether the MAR can provide new tests in a large range of phenomena, thanks to its intermediate-scale nature.