Constrain the Milky Way Mass Profile with Phase Space Distribution of Satellite Galaxies[1]

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Context

- The mass profile of the Milky Way (MW) outer halo is important but not well constrained yet
- Dwarf satellite galaxies are the best tracers for the MW outer halo
  - The only tracers for r >100kpc or farther
- Information from simulations can bypass the model dependence in conventional methods.

Method

- Assumptions
  - Spherical **NFW** potential for outer halo
  - **Steady-state** for satellite population
  - **Similarity** of halo dynamics though scaling with NFW characteristic scales r_s, v_s

  Any deviation to above ⇒ systematics <10%
- Build **Empirical Model** for 6D phase-space Distribution Function (DF) of satellites from simulation through scaling relation

$$p(\mathbf{r}, \mathbf{v}|M, c) = \frac{1}{r_s^3 v_s^3} \tilde{f}\left(\frac{E}{v_s^2}, \frac{L}{r_s v_s}\right)$$

M: virial mass M_{200c}
c : concentration

- Infer M & c from observations

$$p(M, c|\{\mathbf{w}\}) \propto \left[\prod_{i=1}^{n_{\rm sat}} p(\mathbf{w}_i|M, c)\right] \times \boxed{p(c|M)p(M)}$$

$\mathbf{w} \equiv (\mathbf{r}, \mathbf{v})$ — *prior information*

- Treat observational errors & selection function rigorously with Bayesian statistics

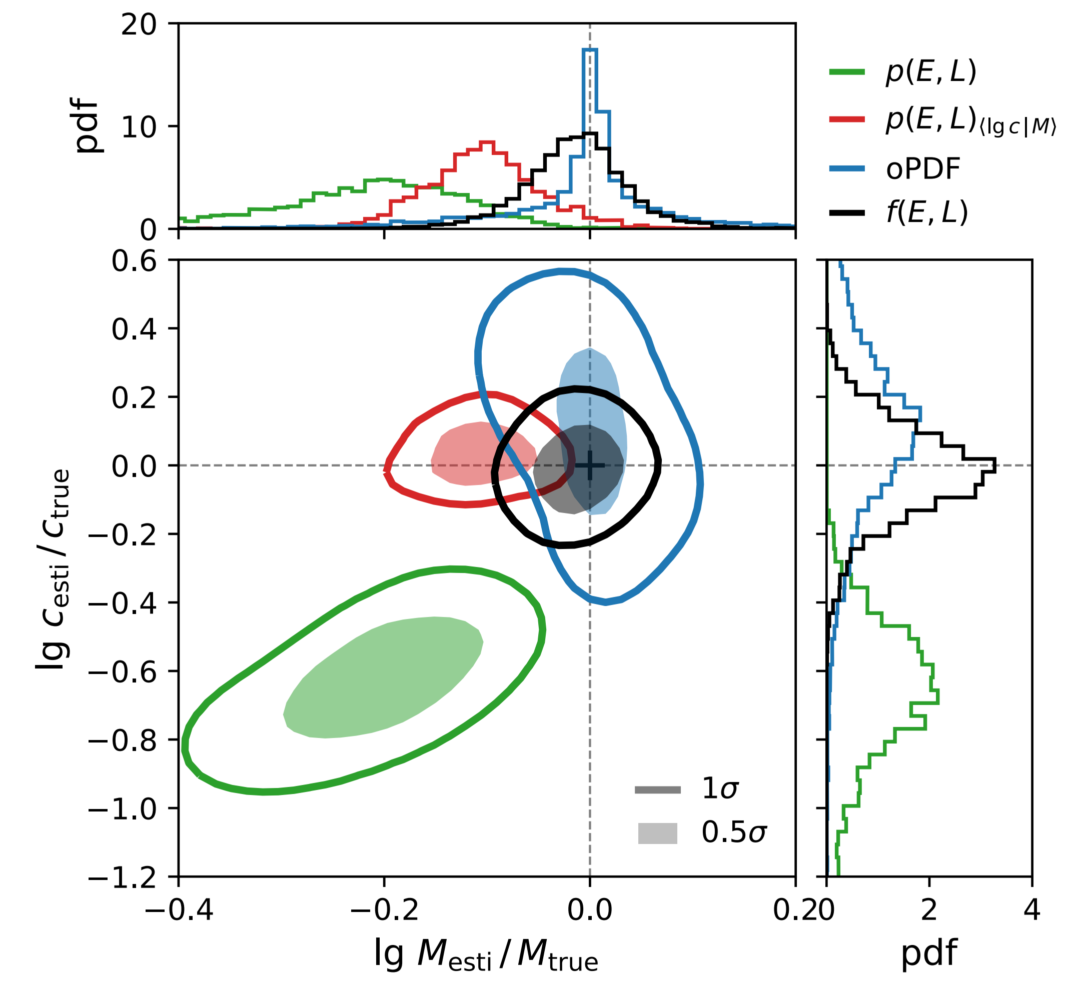

Fig 1. Performance test with mock sample. Our method (***Black***)[1] achieves better precision and accuracy than methods merely based on Jeans theorem (*Blue*)[2] or orbital distribution (*Red*)[3].

Result

- **Data**: 28 MW satellites within 40 to 280 kpc with 6D kinematics[4] measured by Gaia.
- The inferred mass profile is consistent with previous measurements (**Fig 2**), and can be improved with other tracers, e.g. rotation curve of halo stars[5] (**Fig 3**).
- Result is robust against changing sample selection criterion on luminosity or distance.

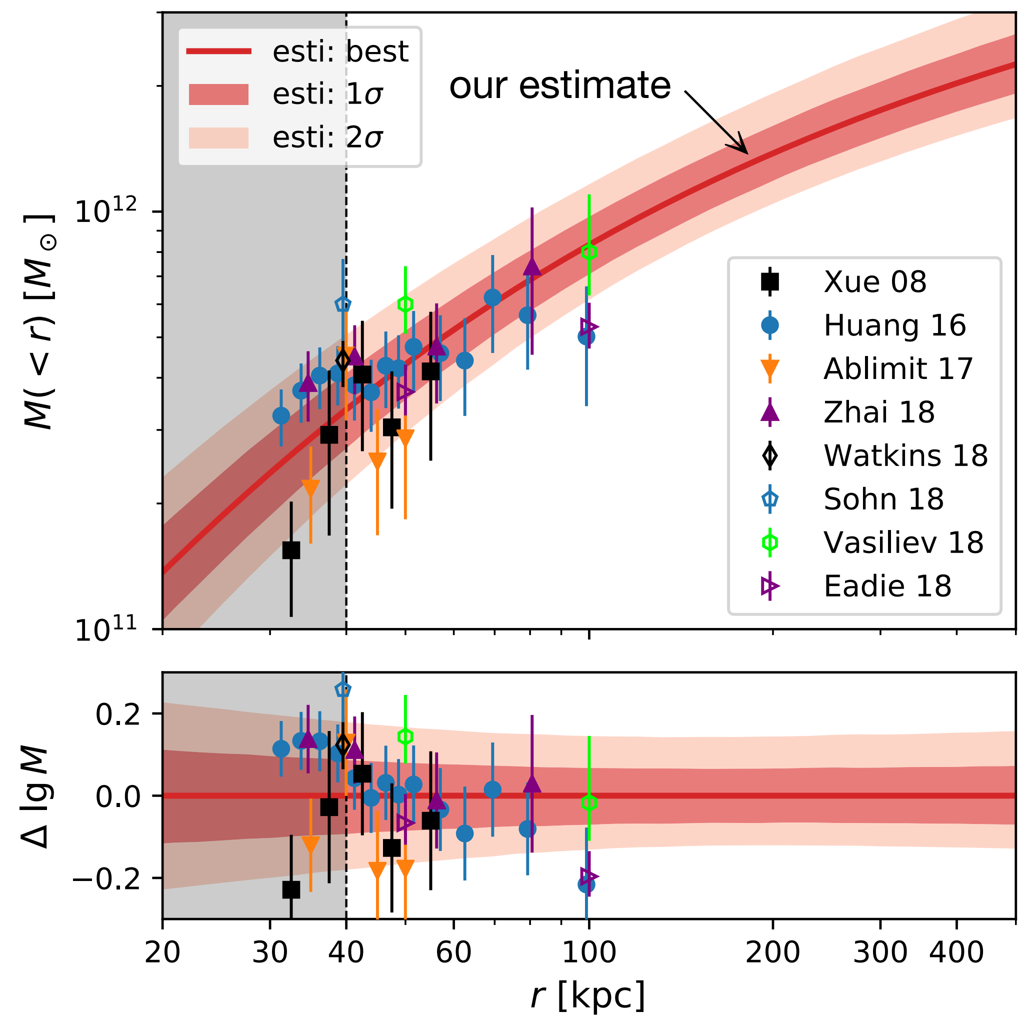

Fig 2. MW mass profile inferred from satellites kinematics (*curve*) is consistent with previous measurements (*symbols*) from halo stars or globular clusters.

	Satellite Only		Satellite + Halo Star	
	flat prior	M-c relation	flat prior	M-c relation
M	$1.49^{+0.35}_{-0.28}$	$1.50^{+0.32}_{-0.26}$	$1.43^{+0.25}_{-0.22}$	$1.44^{+0.24}_{-0.21}$
c	$9.5^{+10.9}_{-5.1}$	$8.1^{+2.7}_{-2.0}$	$8.4^{+4.8}_{-3.1}$	$7.9^{+2.3}_{-1.8}$

Table 1. Mass and concentration estimation with different information used (see Fig 3). Consistent result is reported in each case.

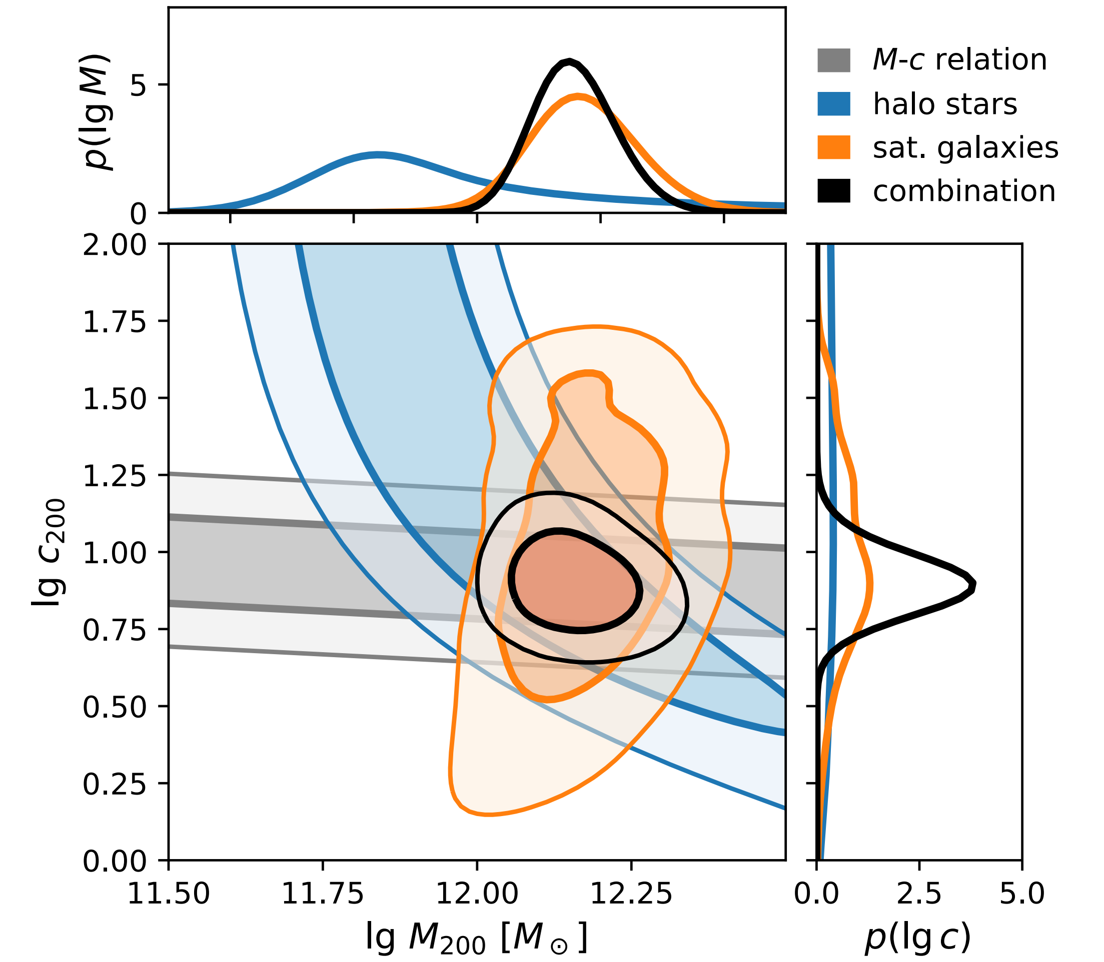

Fig 3. Inferred MW halo parameters from various constraints: *M-c relation*, *halo stars*, *sat. galaxies*, *combination of all above*.

Satellite galaxies ⇨ Halo mass

Satellites + Stars ⇨ Concentration

Conclusion

Current **BEST** estimation to MW halo mass

- ✓ best **tracer** for outer halo: satellite galaxies
- ✓ best **data** available: 28 satellites with Gaia DR2 proper motion
- ✓ realistic **model**: empirical DF model from simulation with wide usage
- ✓ rigorous **statistics**: observational errors & selection function included

This method can also apply to any other galaxy groups/clusters.

References

[1] Li et al. 2019, in preparation
[2] Han et al. 2016, MNRAS, 456, 1003
[3] Li et al. 2017, ApJ, 850, 116
[4] Riley et al. 2018, arXiv:1810.10645
[5] Huang et al. 2016, MNRAS, 463, 2623