Probing mass spectrum of destroyed dwarf galaxies with the metallicity distribution function

Sergey Koposov

University of Edinburgh
University of Cambridge
&
Alis Deason, Azadeh Fattahi, Robert Grand

THE UNIVERSITY of EDINBURGH

Based on Deason, SK+2023
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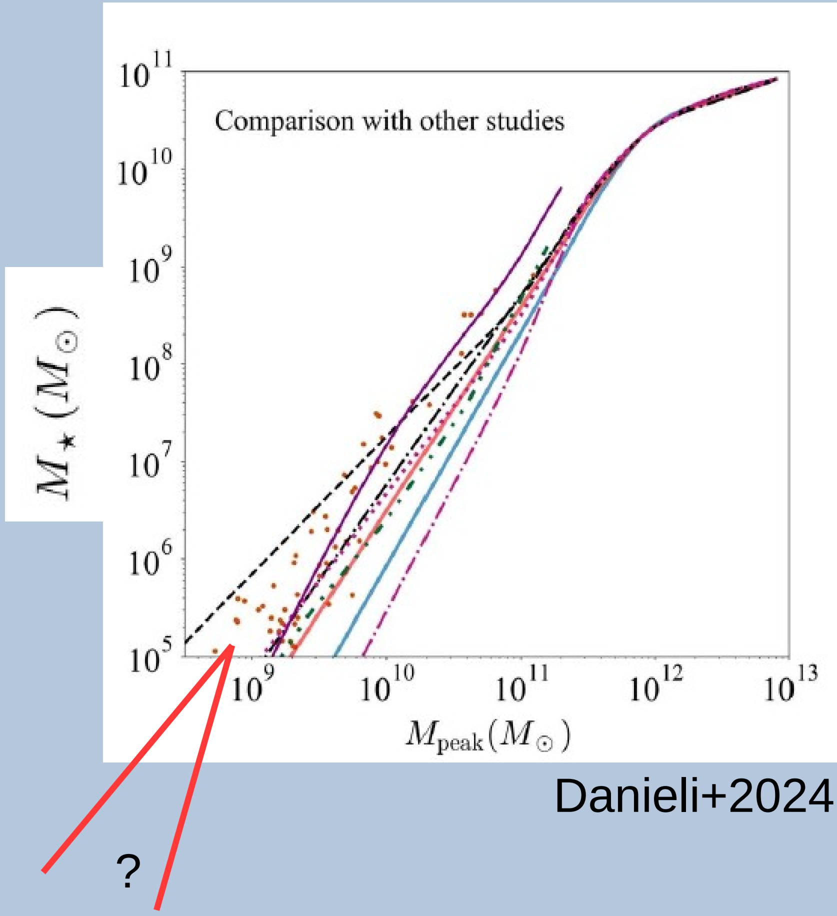
Stellar mass – halo mass relation

- We can probe it with individual objects
- We can probe it with accreted populations: streams/phase mixed debris



Danieli+2024

New generation of spectroscopic surveys

- Spectroscopic counter-parts to the imaging surveys. 4-m class telescopes

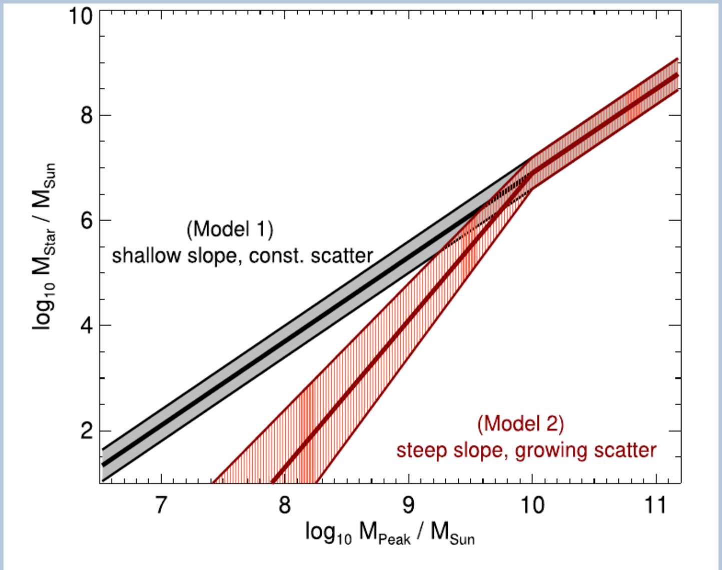
➔ DESI – 5000 spectra over 8 degree field of view.

➔ WEAVE – 1000 spectra over 2 degree field

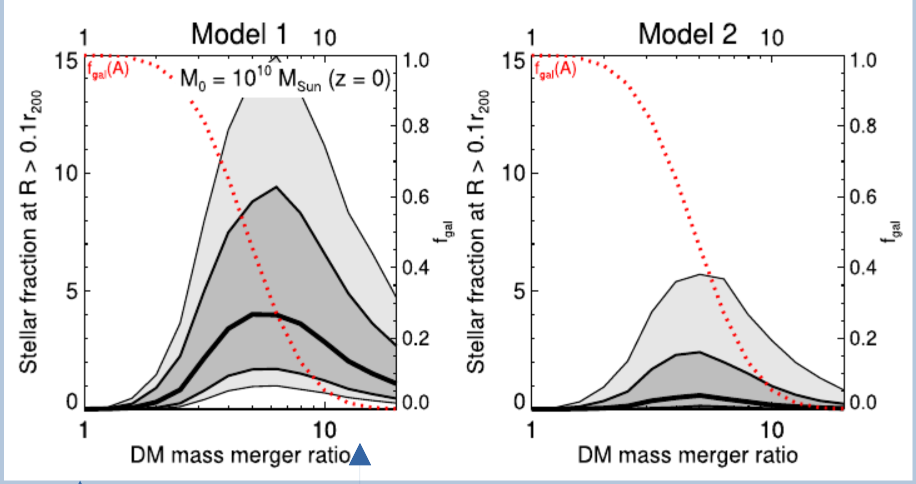
➔ 4MOST – 4000 spectra over 4 degree field of view

➔ They will deliver thousands of spectra in dwarfs, streams, and millions in the MW.

Mergers in dwarfs



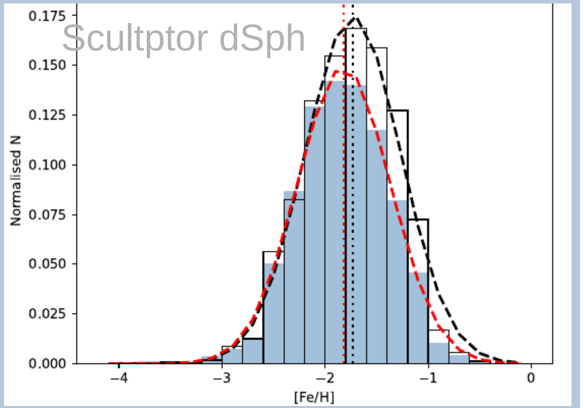
- Accretion events to dwarf galaxies are probing low M_{halo}
- Minor merger debris will be in the outskirts
- Fraction of accreted stars in outskirts is sensitive to DM halo counts & stellar mass-halo mass relation.
- We want to probe accretion events in dwarfs



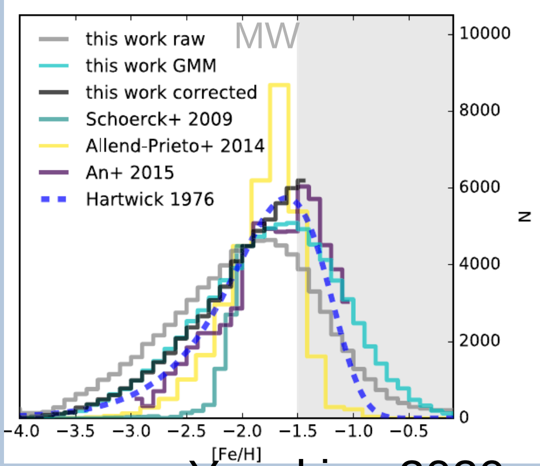
Deason+2022

Metallicity distribution

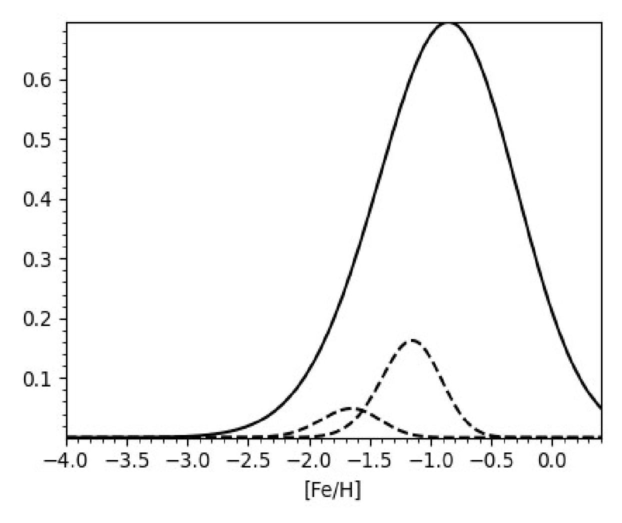
- What determines the metallicity distribution ?
- Metallicity distribution function (MDF) is a linear combination of in-situ formed stars and all accreted galaxies.



Tolstoy+2023



Youakim+2020



MDF mixture

- The metallicity distribution is a mixture of MDFs of parent galaxy and accretions.

$$P(z) = \sum_i \frac{L_i}{L} P(z|i)$$

Metallicity distribution

Metallicity distribution for i-th accreted galaxy

- The mixture is weighted by the Luminosity/stellar mass

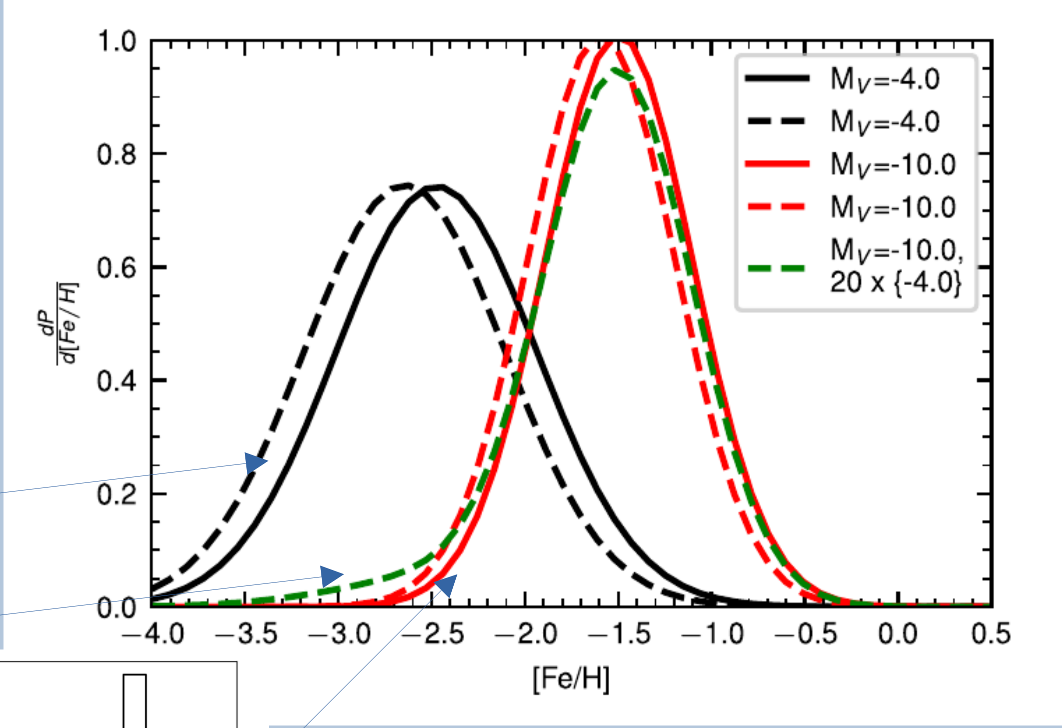
Assumptions

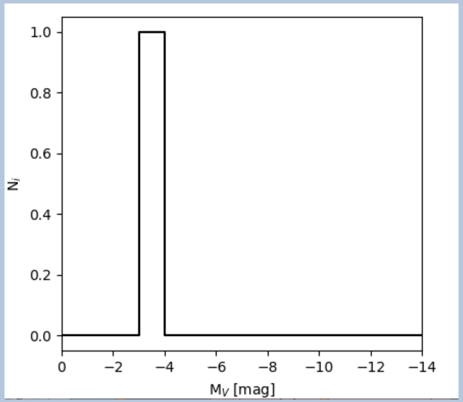
- $$P(z) = \sum_i \frac{L_i}{L} P(z|i)$$
- We assume MDF of individual galaxies are Gaussian
- We assume a mass-metallicity relationship from Kirby+2011 (with scatter)
- We require the luminosities to sum up to to total luminosity of the system.
- Model: $P(z) = P(z|L_1, L_2, L_3, \ldots L_n, \text{random seed})$
- We bin systems in luminosity

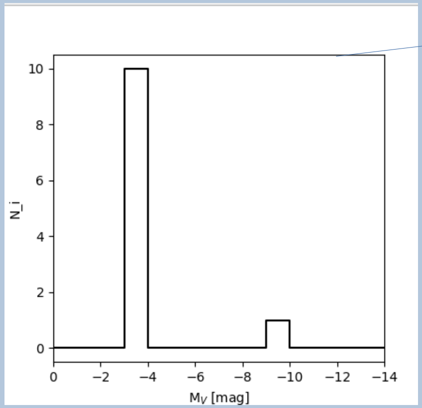
Model

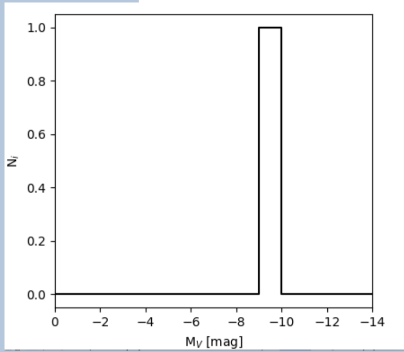
- We fit for the number of systems in bins of luminosity N_i (occupation numbers)

Example MDFs









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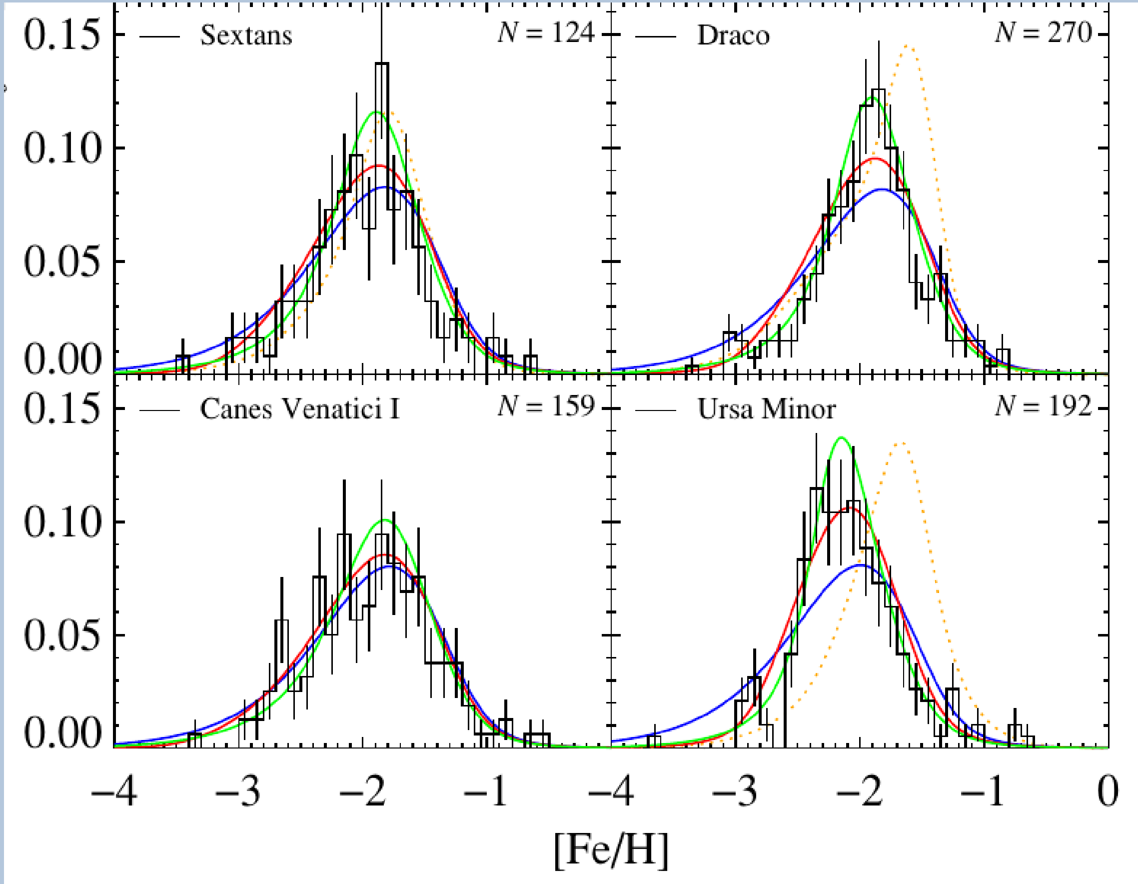
Data

- We start with the sample from Kirby+2011
- We assume the sample is a random/unbiased sample of the whole dwarf galaxy

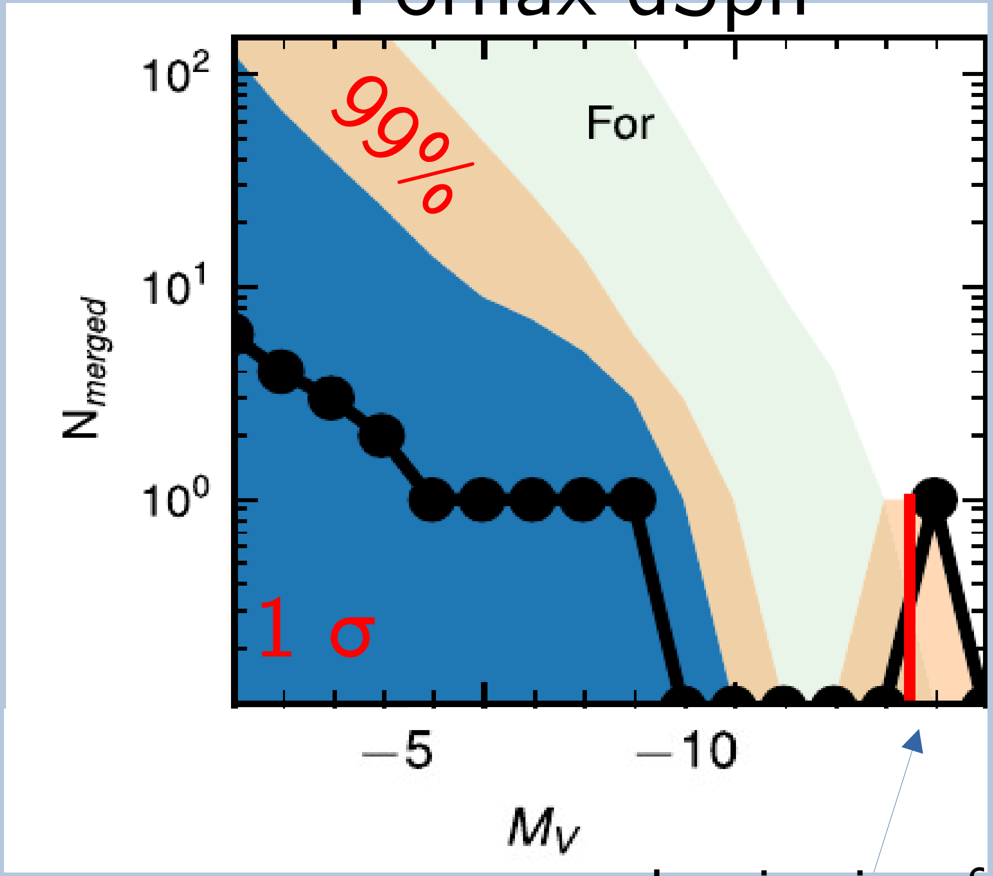


Kirby+2011

Example

- Fornax dSph ~ 700 stars
- We see no evidence of a merger more massive than ~ 1/40 $M_{*,Fornax}$
- Smaller mergers are possible up tens of systems with M_V=-5 (poorly constrained)

Fornax dSph



Luminosity of Fornax

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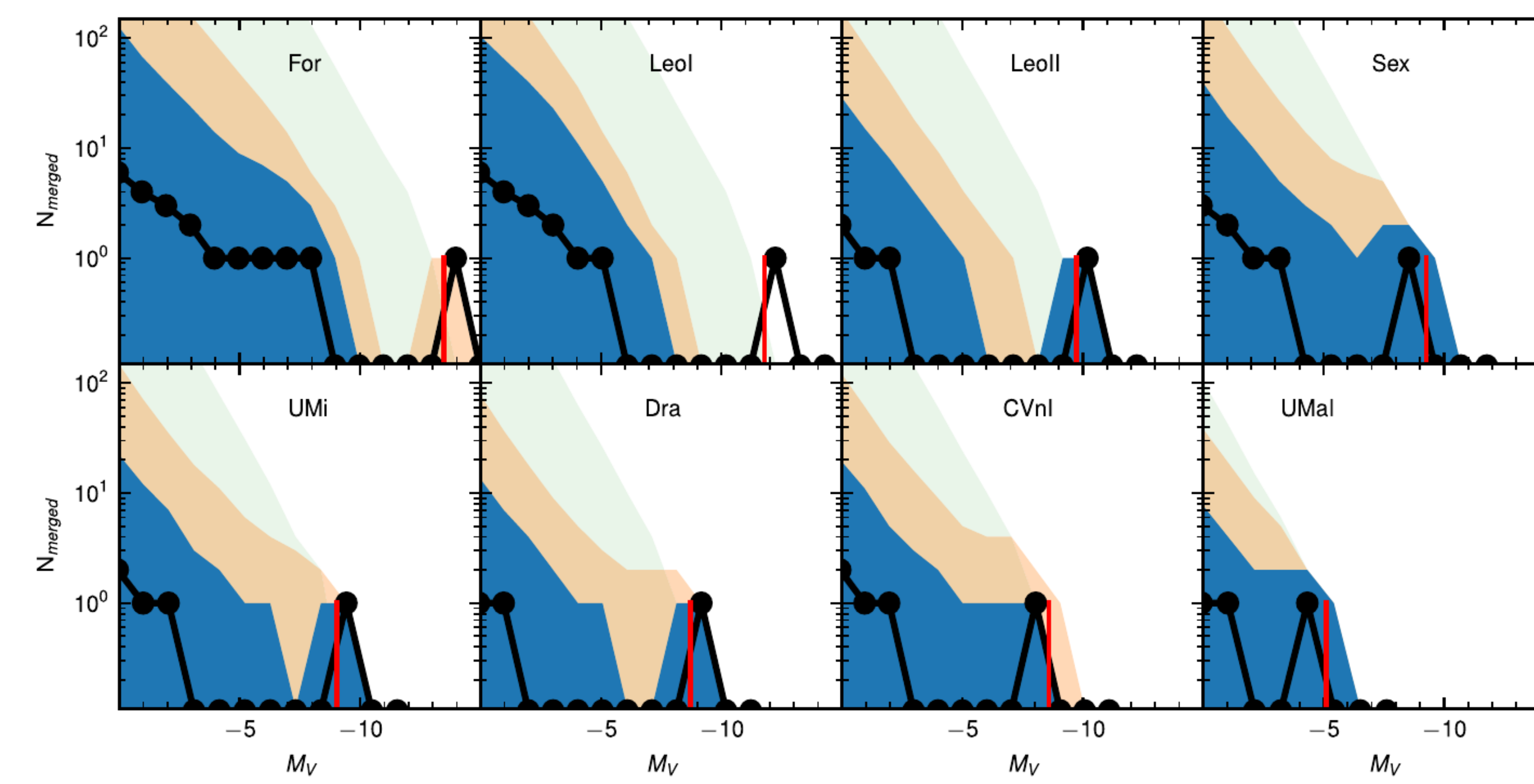
Multiple dwarfs

Only for Leo I, Leo II, Fornax the constraints are significant



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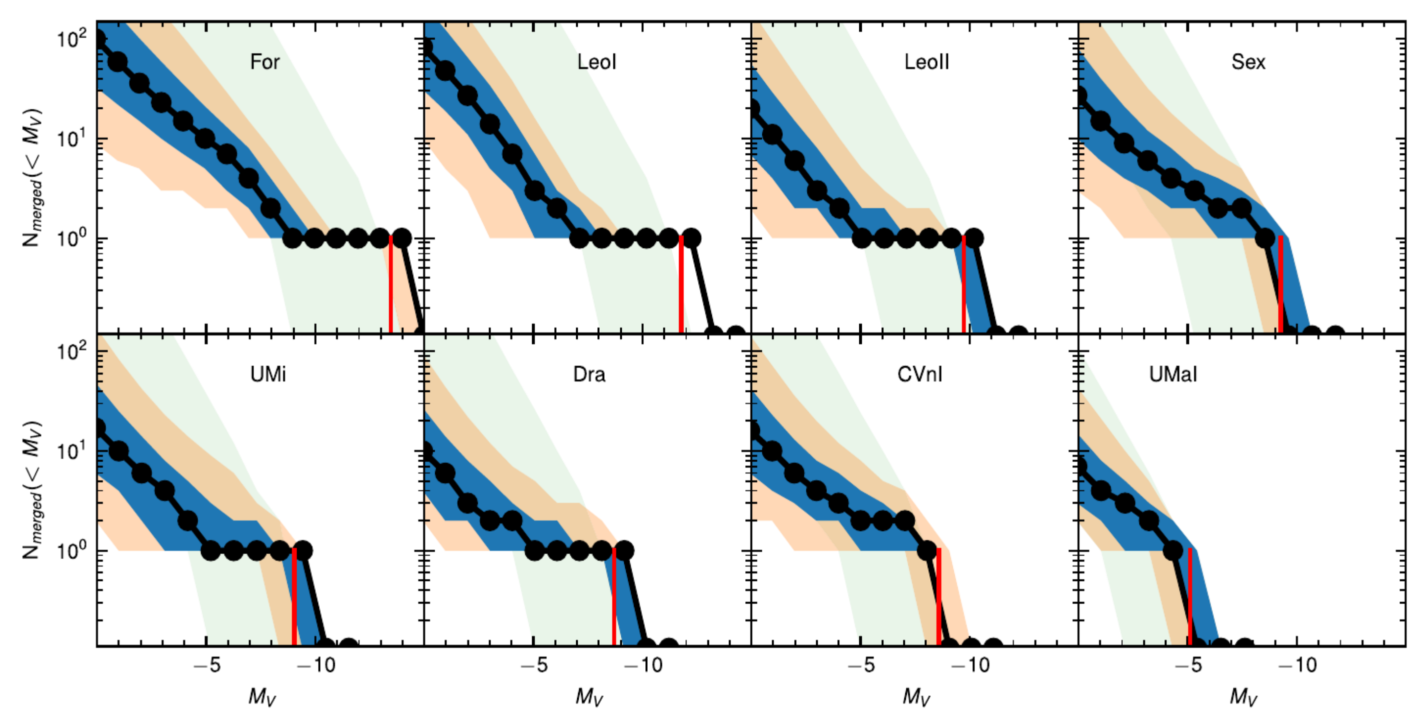
Cumulative distributions

- Similar picture to differential distributions.
- For/Leo I, Leo II, Dra can be constrained

Number of systems contributed to the MDF brighter than M_V



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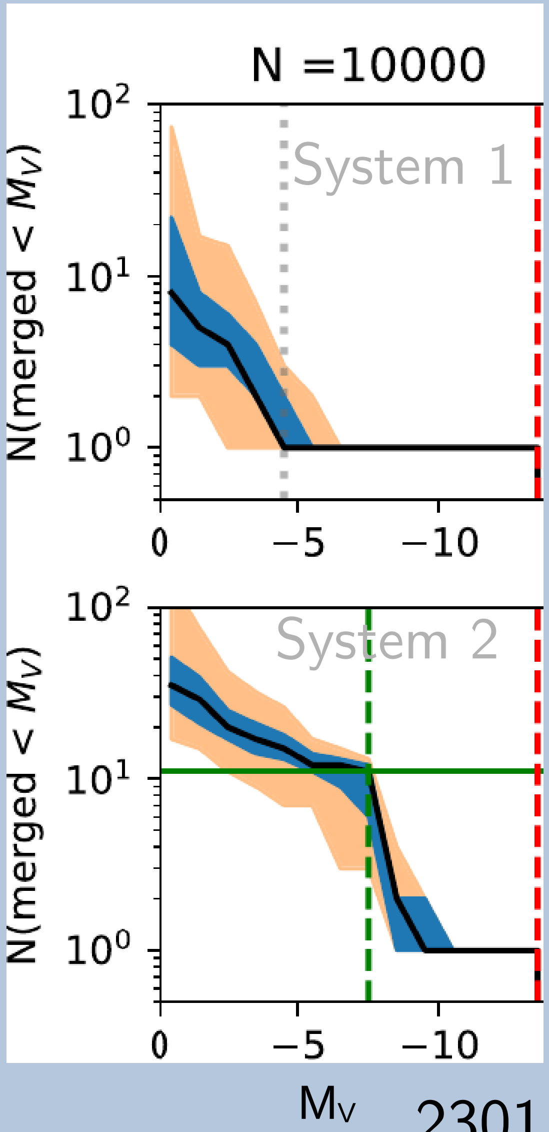
More stars

- What if we had more stars?
- System 1: M_V=-13.5 and had no accretion
- System 2: M_V=-13.5 had 10 M_V=-7 accretions
- With 10000 stars we can recover the accretion events close to 1/10000 mass-ratio.



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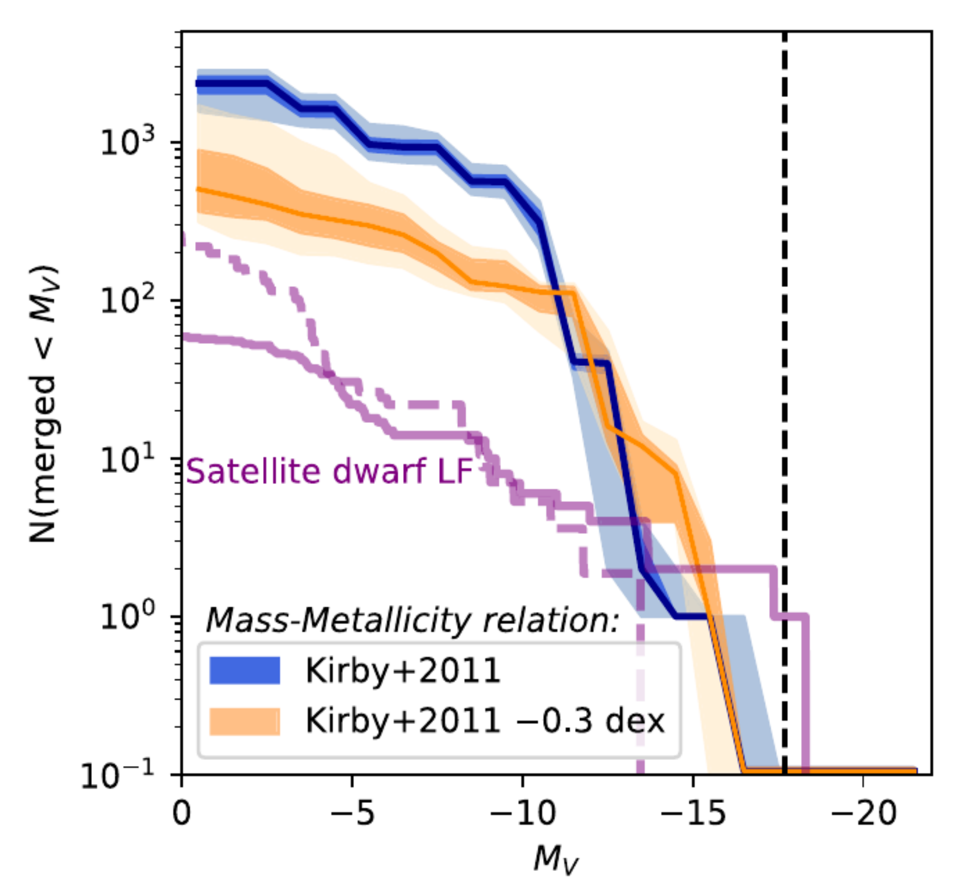
Improvements

- Need more stars (~ 10,000)
- Remove Gaussian assumptions on MDF
- Select stars in the outskirts of galaxies to improve contrast of accreted systems.

MW stellar halo

- Sample of stars with Gaia parallaxes from APOGEE/LAMOST/SEGUE
- Tricky (selection effects + errors)
- Non-Gaussianity of MDFs may be more of an issue
- The results are sensitive to mass-metallicity relation
- We formally predict more systems than intact satellites



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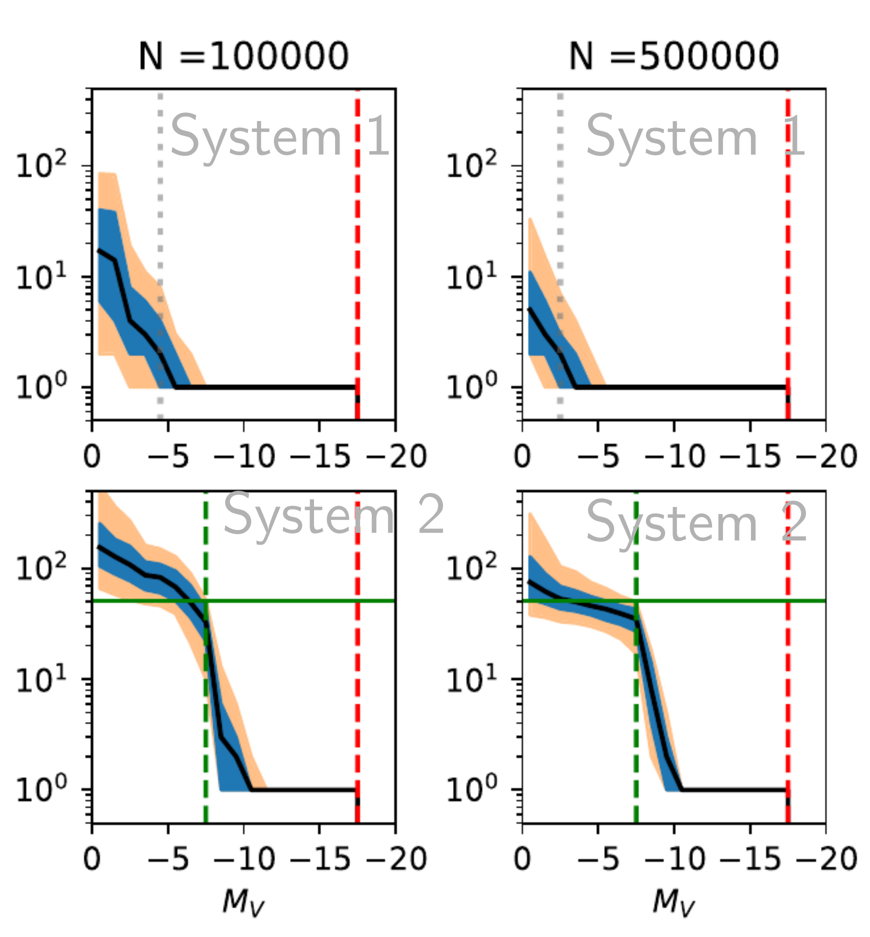
Conclusions

- With MDFs we are capable of constraining the number of small accretion events in dwarfs.
- We need $>$1000 stars.
- We did make strong assumptions on mass-metallicity+MDF shape. More work is needed to understand the impact of the assumptions.

Mock test

- System 1, M_V=-17.5 no accretion
- System 2, M_V=-17.5, 100 M_V=-7 accreted systems



Simulations test

- Auriga stellar halos.
- Mostly successful.
- Few failures:
  1) One massive progenitor of f the Mass-[Fe/H] relation
  2) Not enough mixing in the halo