Dwarf satellite galaxies exist in three different states:

Spheroidals, Streams & Stellar Halo

Vasily Belokurov, Institute of Astronomy
Cambridge, UK

The point of this talk

- Is to convince you that the progress can (only) be made through a simultaneous analysis of both the surviving and the destroyed dwarfs.


ARTICLE IN PRESS

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ELSEVIER

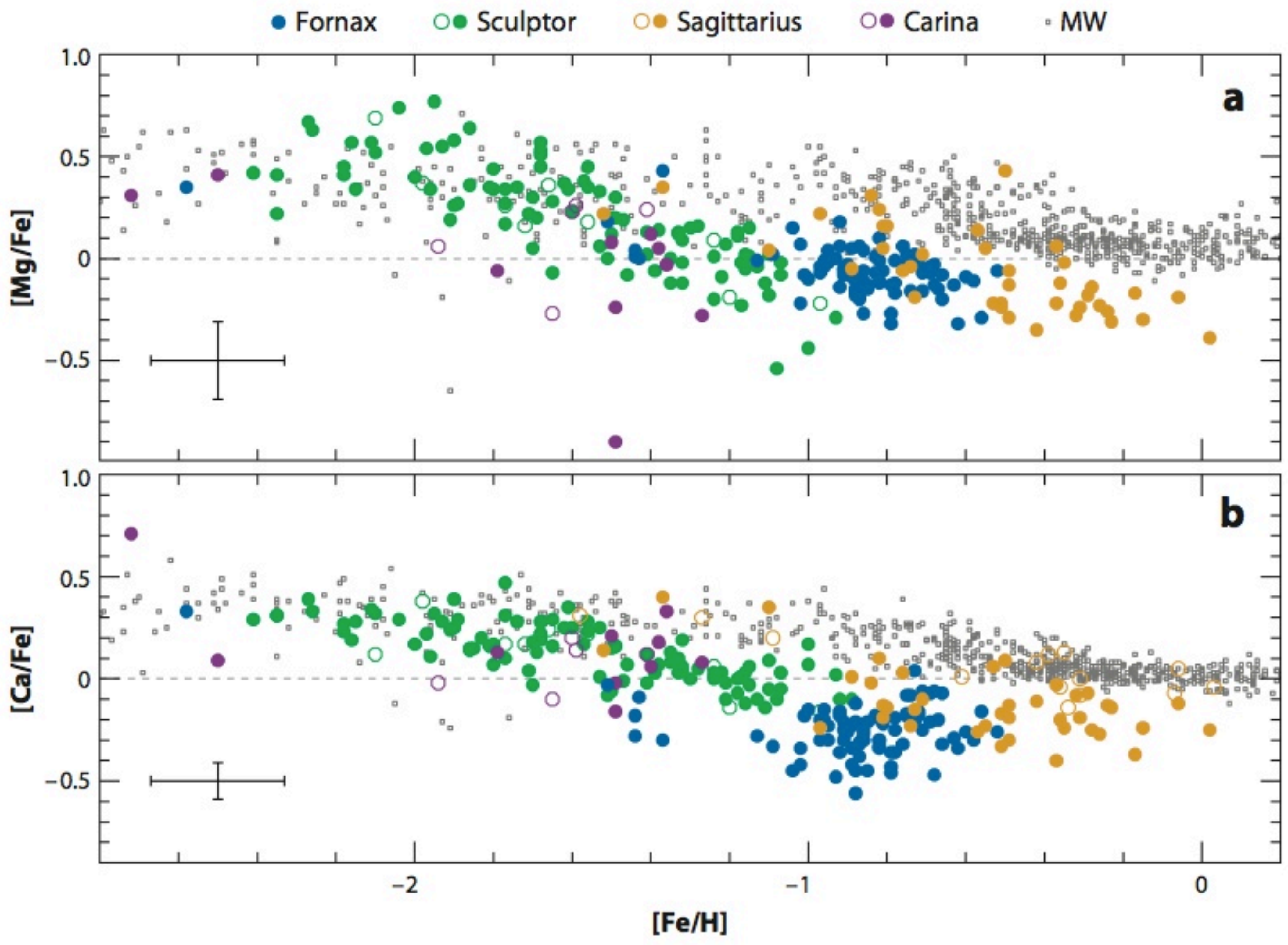
Galactic Archaeology: The dwarfs that survived and perished

Vasily Belokurov *

Institute of Astronomy, Cambridge, United Kingdom

- Star formation in dwarfs
- Dwarf accretion onto MW
- MW mass distribution

Are dwarfs in different states different?



Tolstoy et al, 2009

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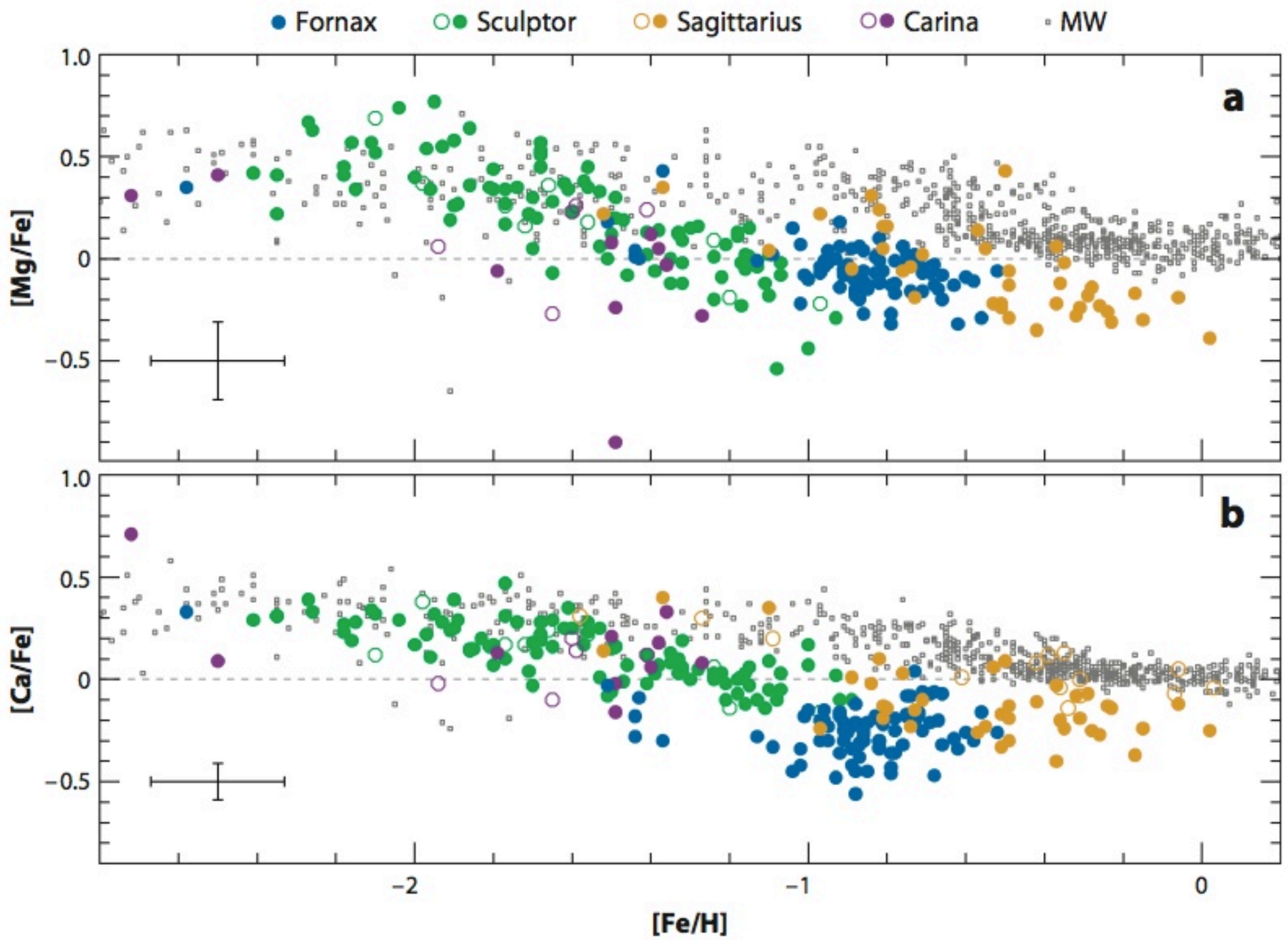

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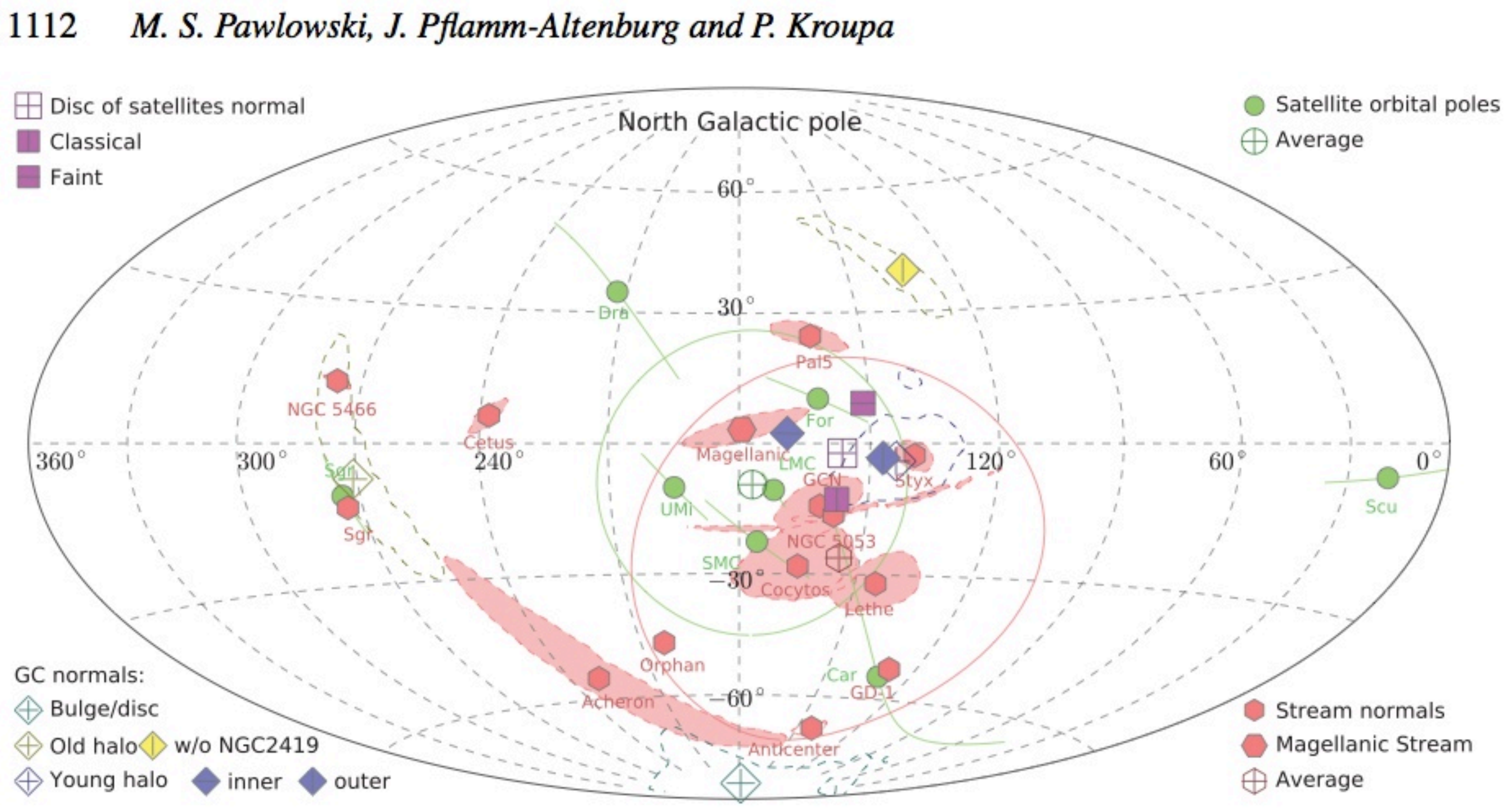

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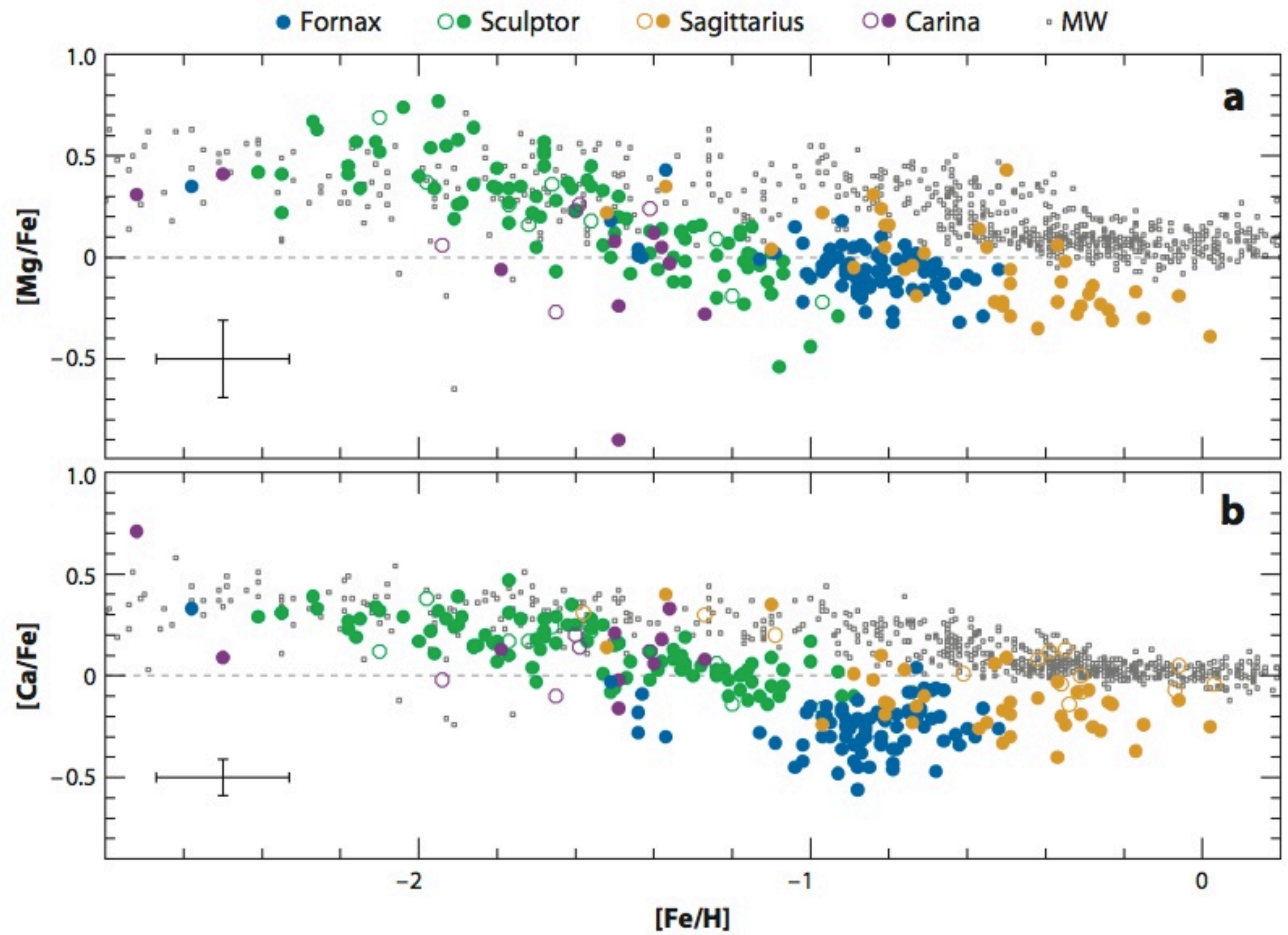

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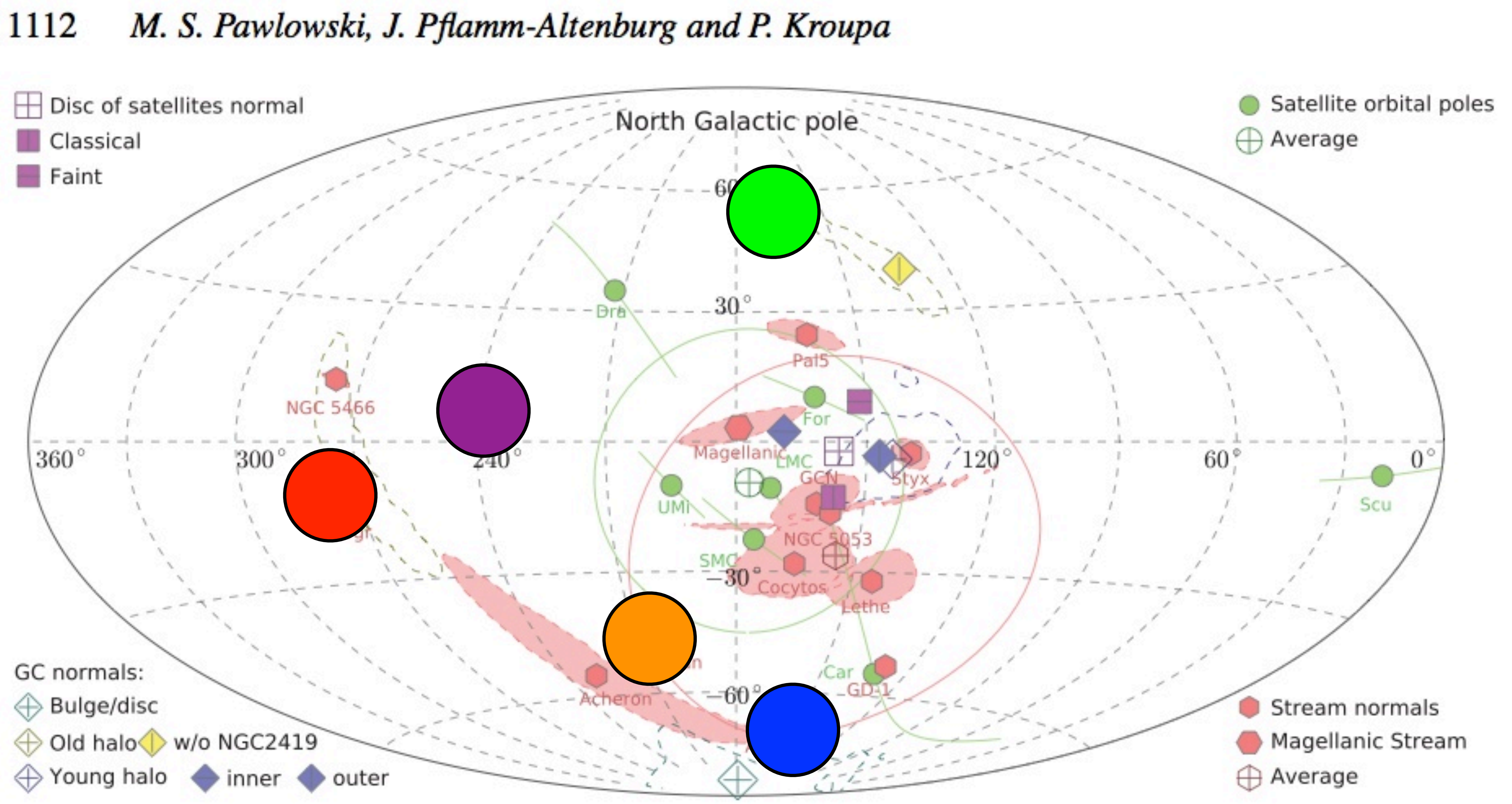


7 known dwarf galaxy stellar streams:

Sagittarius, Tri-And, Monoceros, Her-Aquila, Cetus, Virgo, Orphan

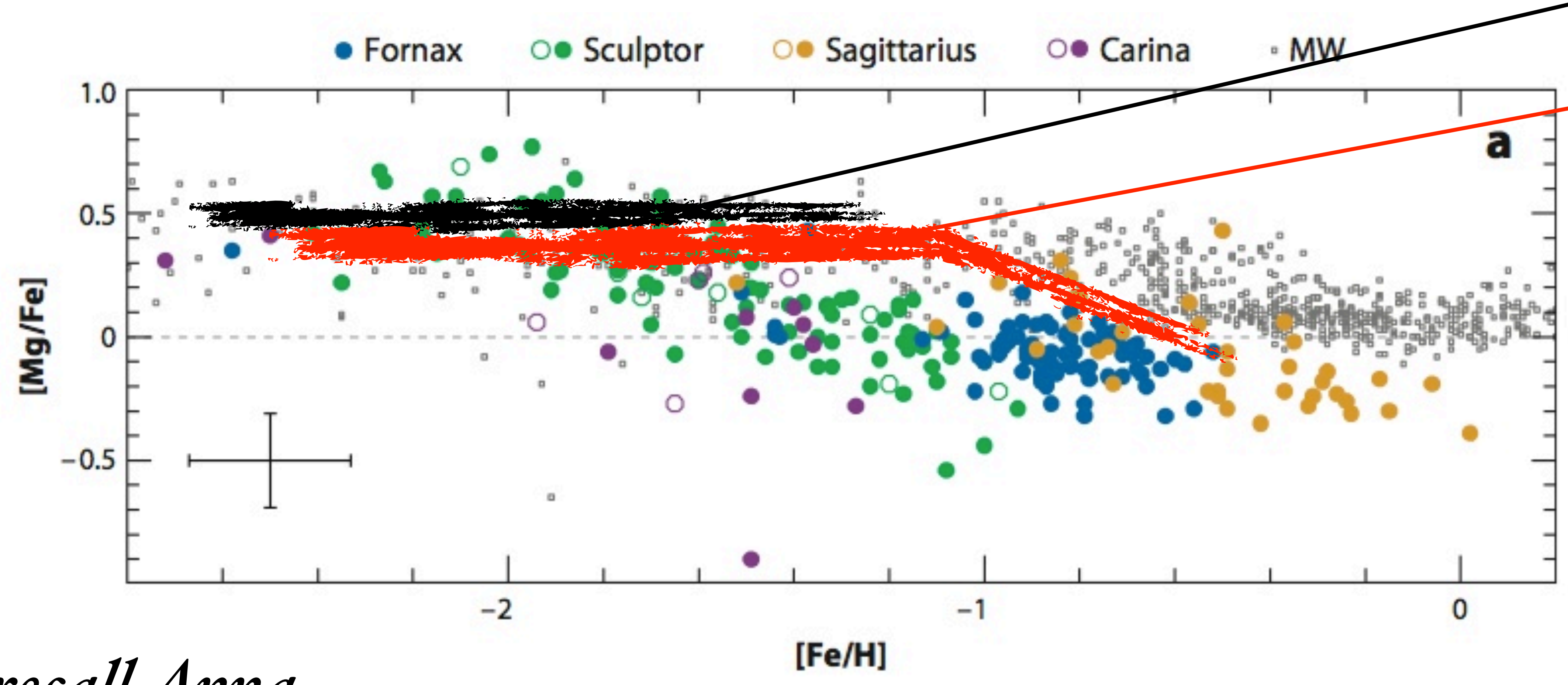
none aligned with the so-called VPOS!

The genesis of the MW stellar halo and the predicted dwarf LF

A tonne of Ultra-faints?

or

One SMC/LMC dwarf?

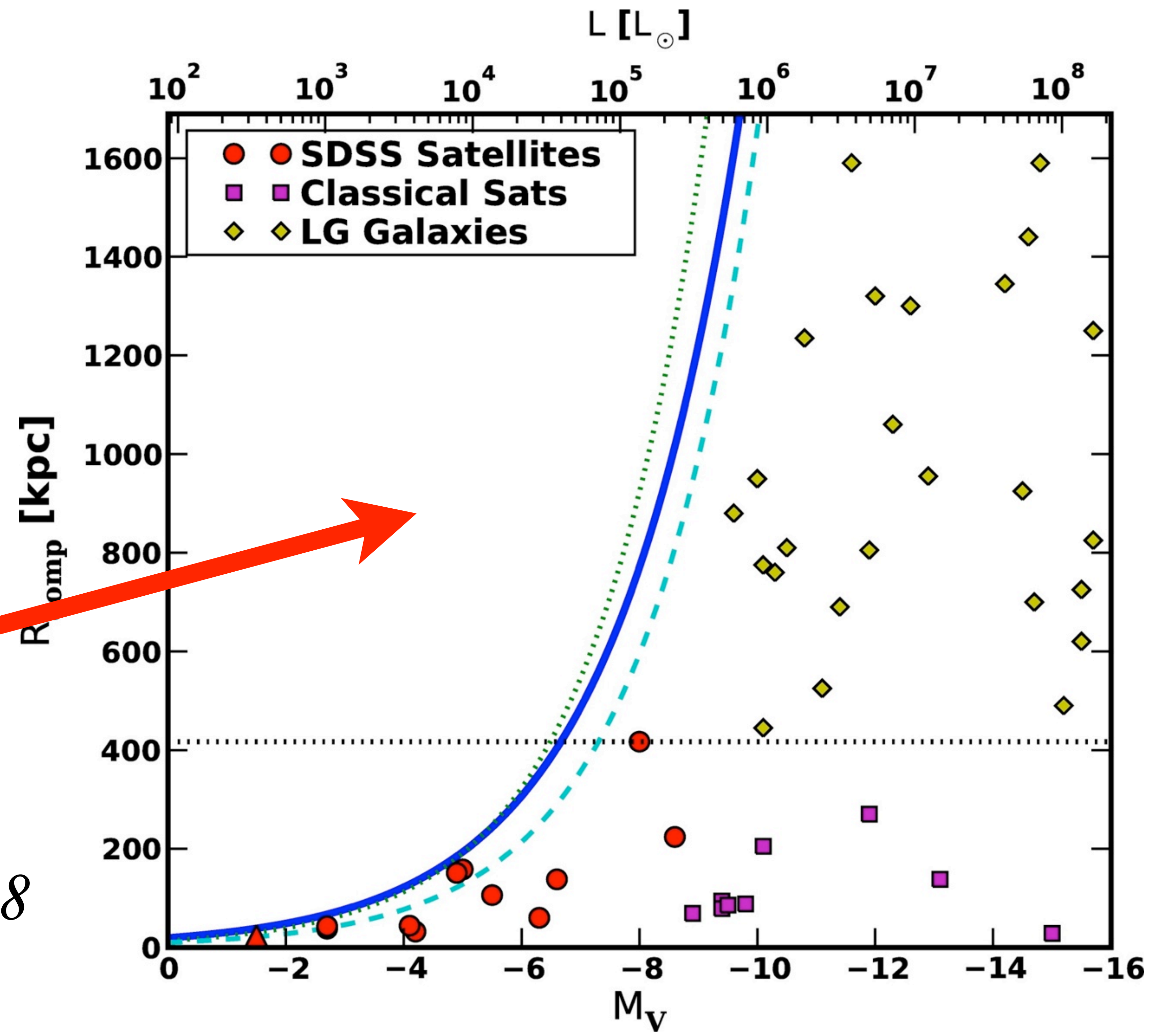


aslo recall Anna Frebel's talk on Tuesday

Hundreds of MW satellites to be discovered?

essentially using 3 to predict 600

Tollerud et al, 2008



The genesis of the MW stellar halo

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
Mon. Not. R. Astron. Soc. **416**, 2903–2915 (2011) doi:10.1111/j.1365-2966.2011.19237.x

The Milky Way stellar halo out to 40 kpc: squashed, broken but smooth

A. J. Deason,★ V. Belokurov★ and N. W. Evans★
Institute of Astronomy, Madingley Road, Cambridge CB3 0HA

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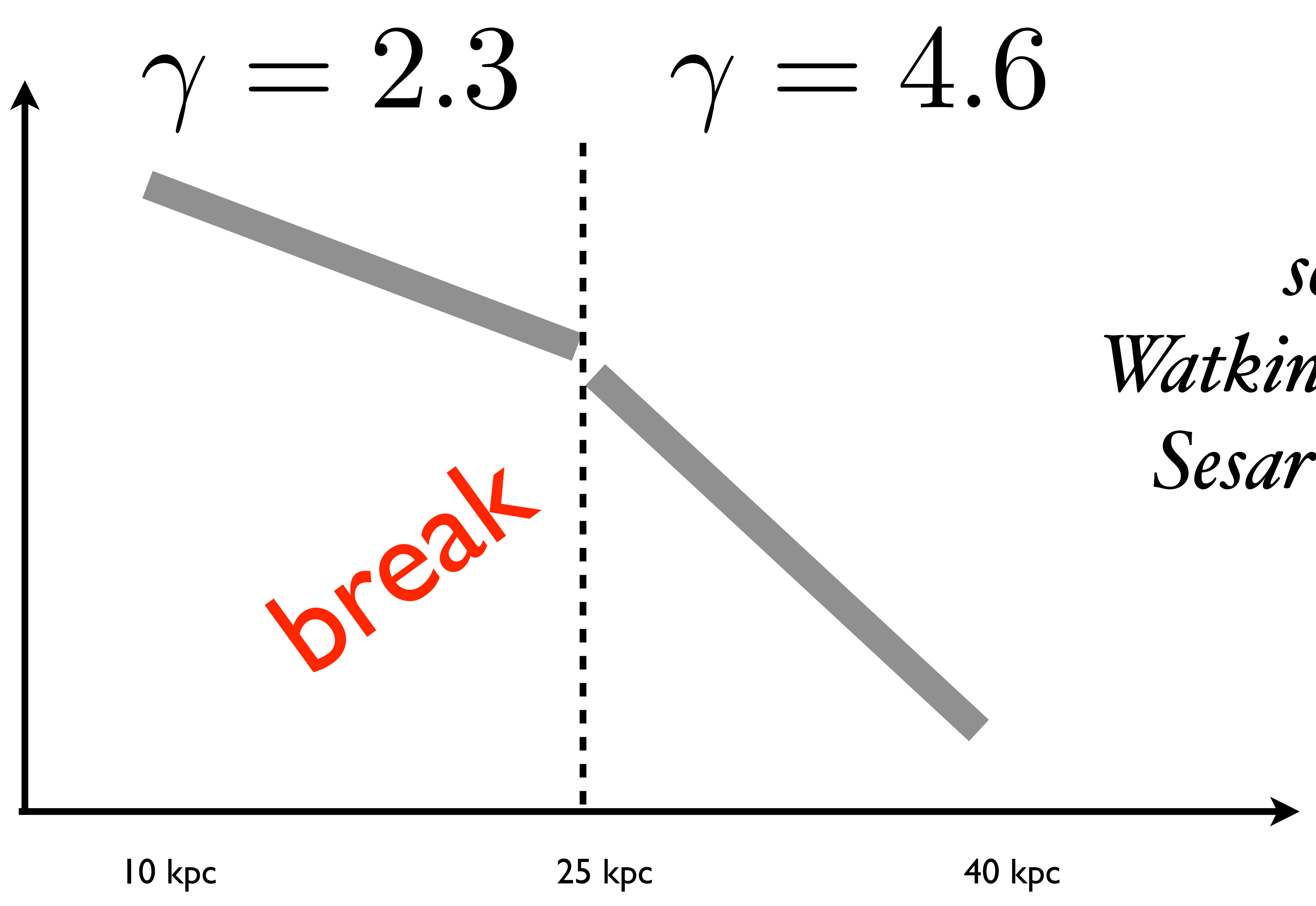
Stellar halo density profile as inferred from
Blue Horizontal Branch & Blue Straggler stars



see also
Watkins et al, 2009
Sesar et al, 2011

for M31, recall the talk by
Raja Guhathakuurta

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The Astrophysical Journal, 763:113 (9pp), 2013 February 1 doi:10.1088/0004-637X/763/2/113

BROKEN AND UNBROKEN: THE MILKY WAY AND M31 STELLAR HALOS

A. J. Deason[1,2,4], V. Belokurov[2], N. W. Evans[2], and K. V. Johnston[3]
[1] Department of Astronomy and Astrophysics, University of California Santa Cruz, Santa Cruz, CA 95064, USA; alis@ucolick.org
[2] Institute of Astronomy, Madingley Road, Cambridge CB3 0HA, UK
[3] Department of Astronomy, Columbia University, New York, NY 10027, USA
Received 2012 October 16; accepted 2012 December 5; published 2013 January 16

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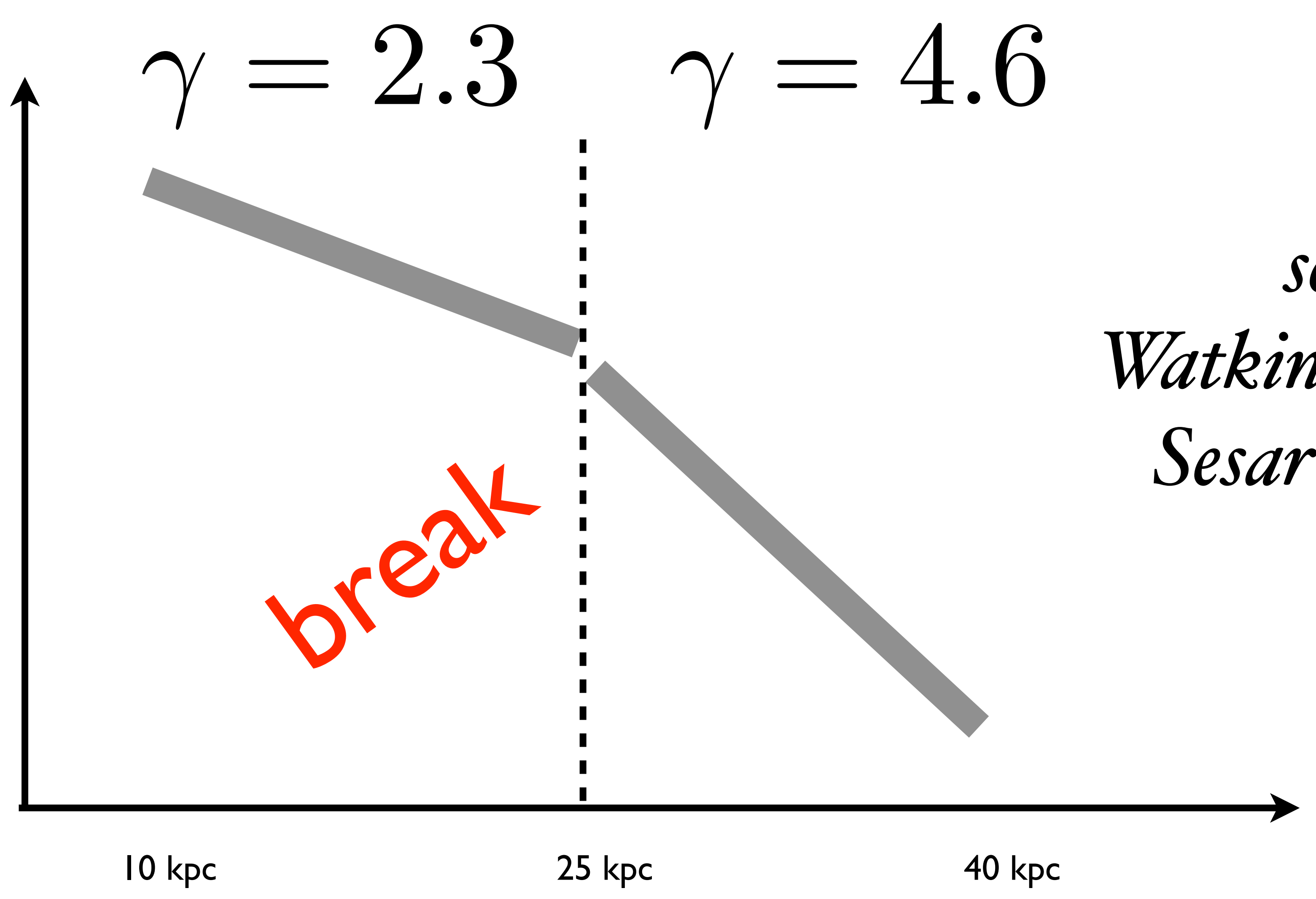

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- Breaks represent apo-centers of accreted satellites
- Breaks are strongest if a massive satellite (or a small group) is accreted early on, followed by a long quiescent period

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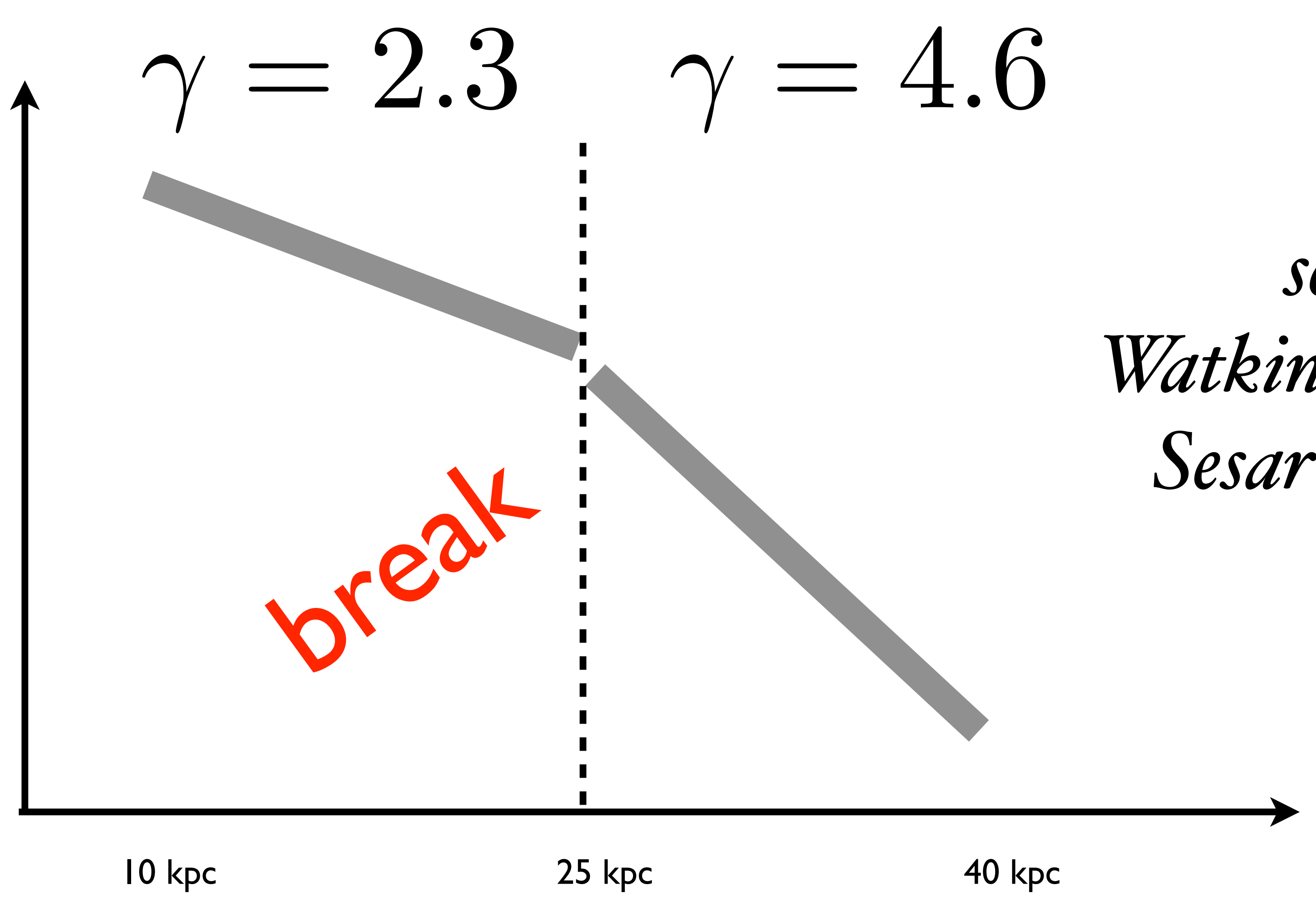

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or
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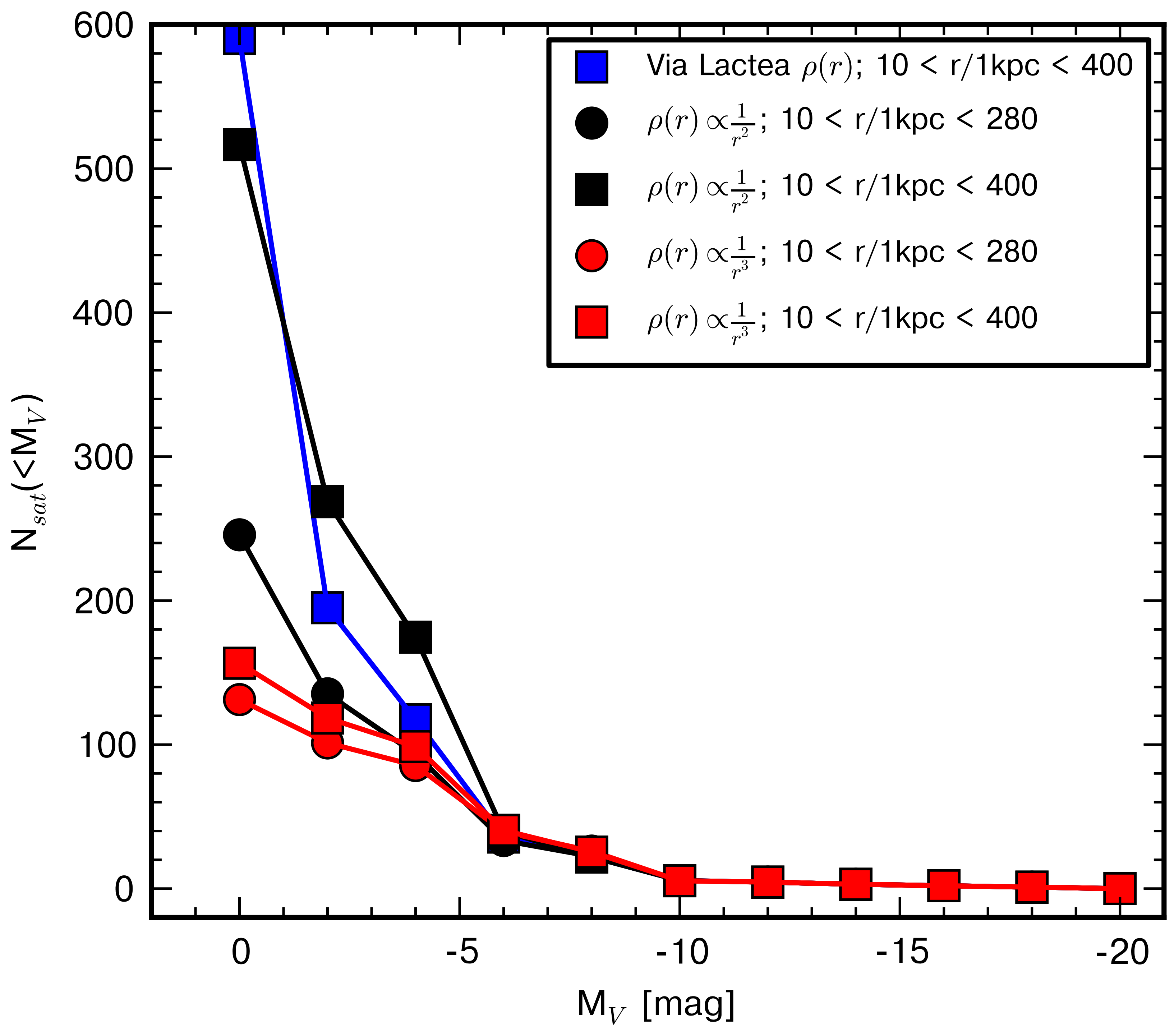
Actually, how many ultra-faints are out there?

Cumulative luminosity function



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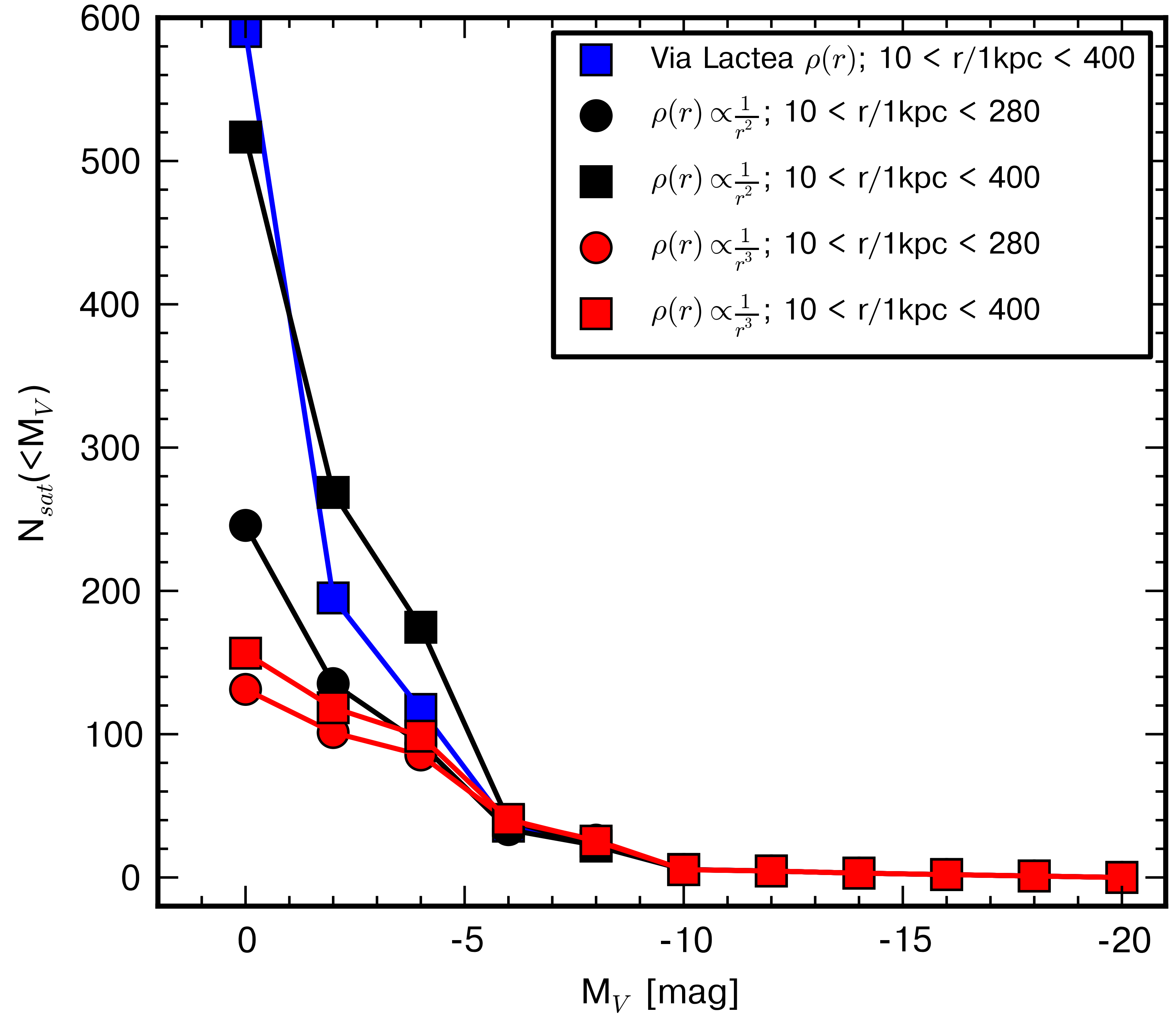
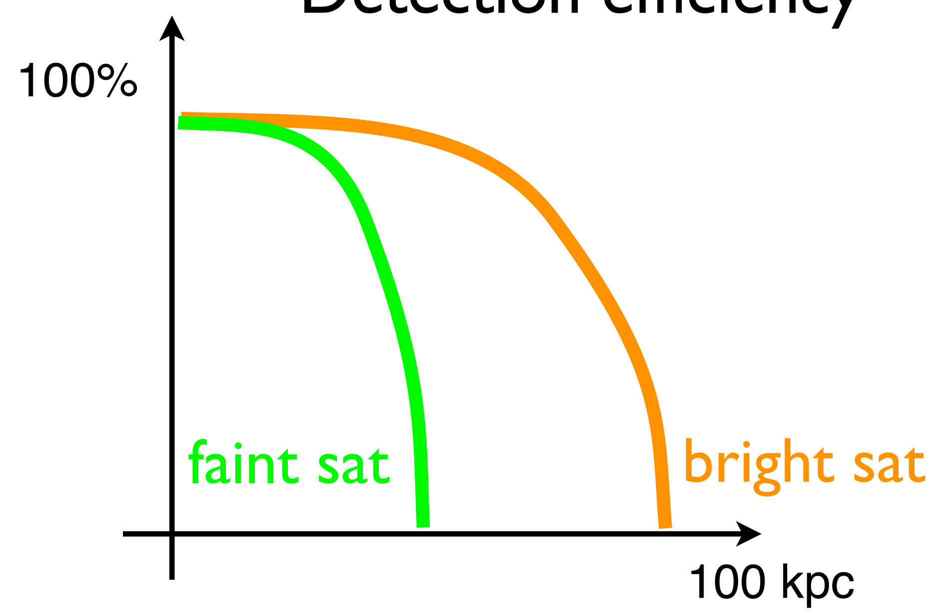
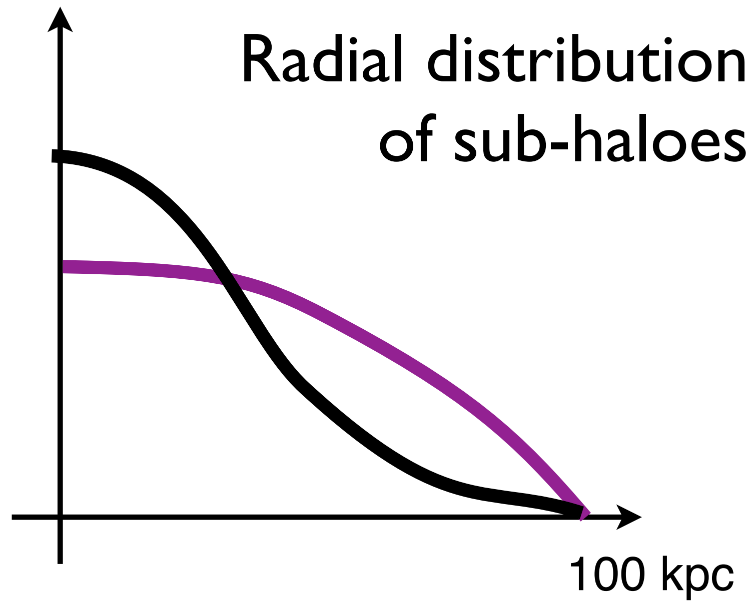


Detection efficiency





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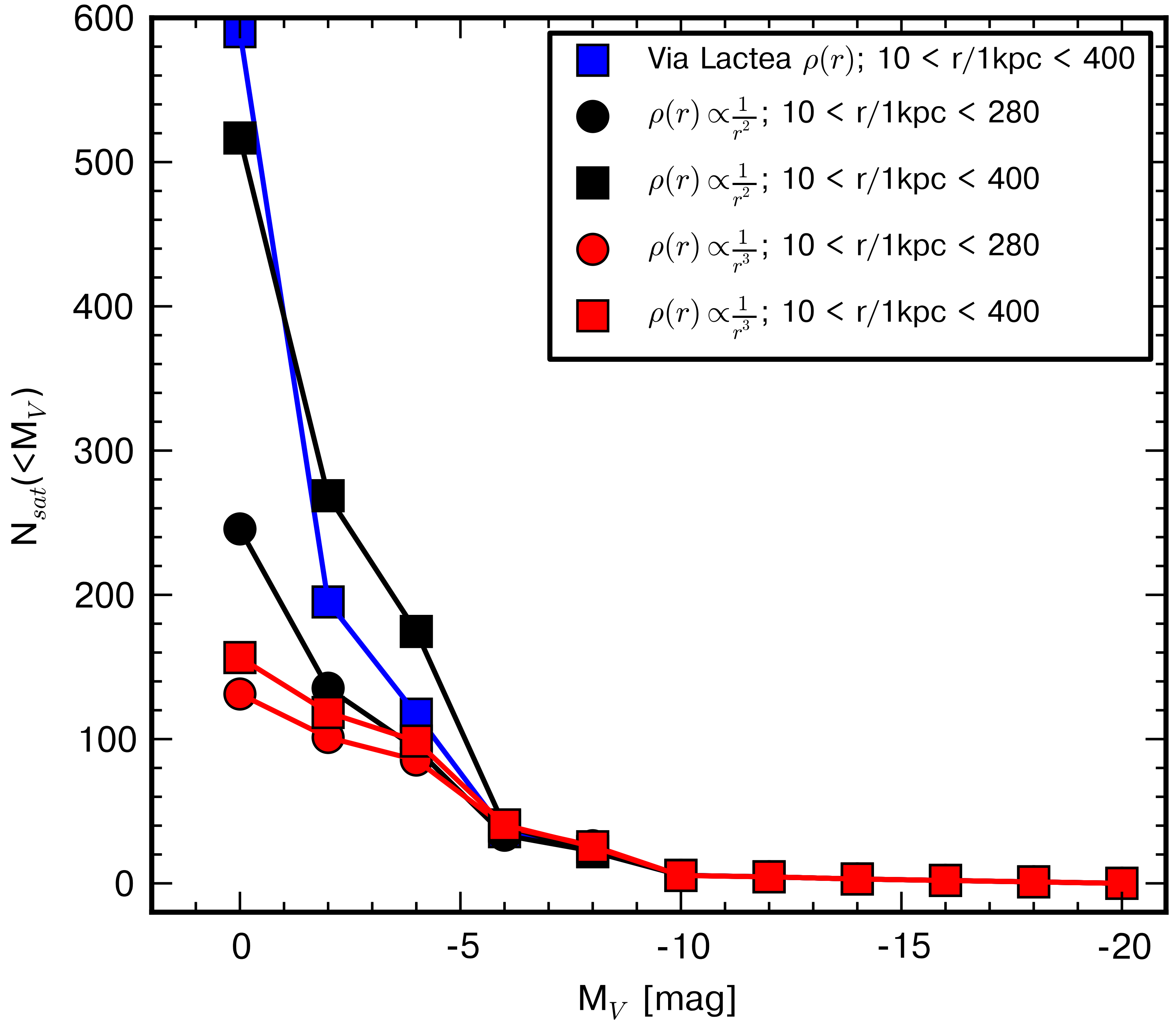

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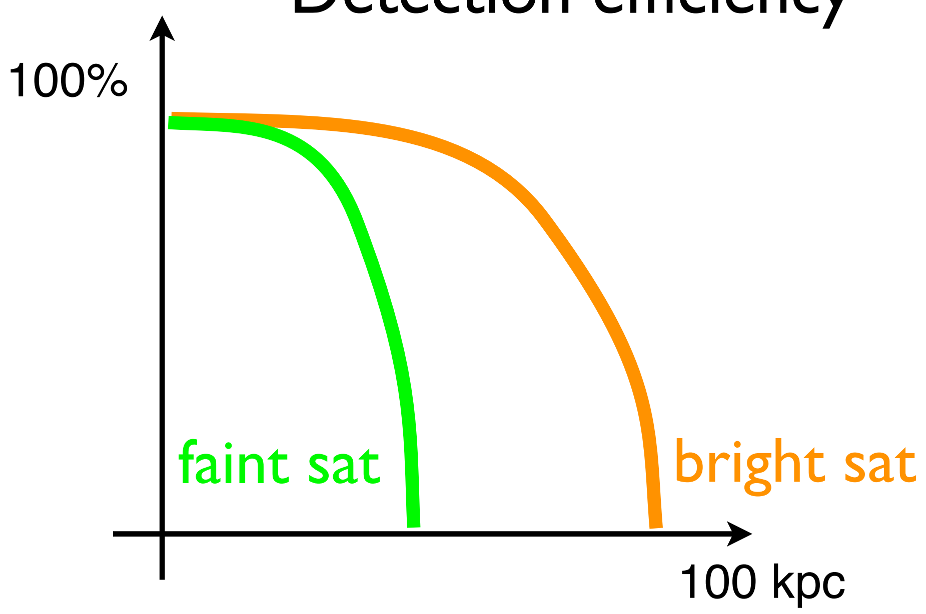
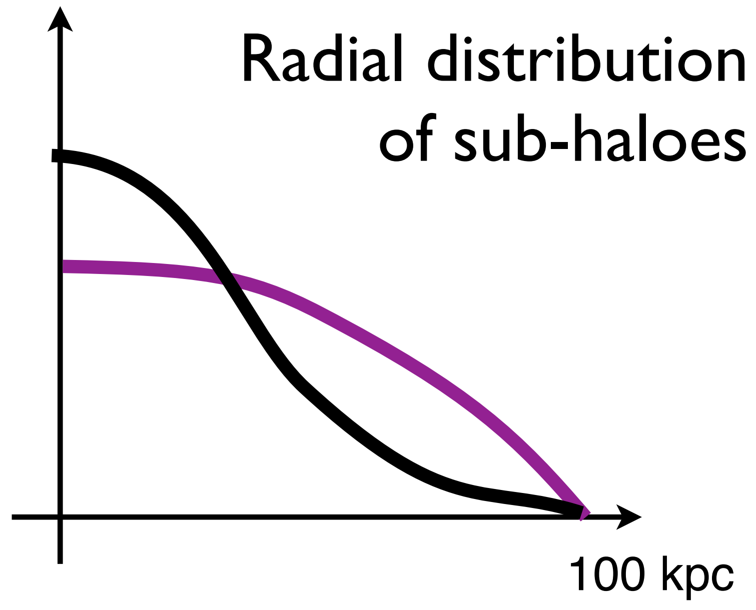


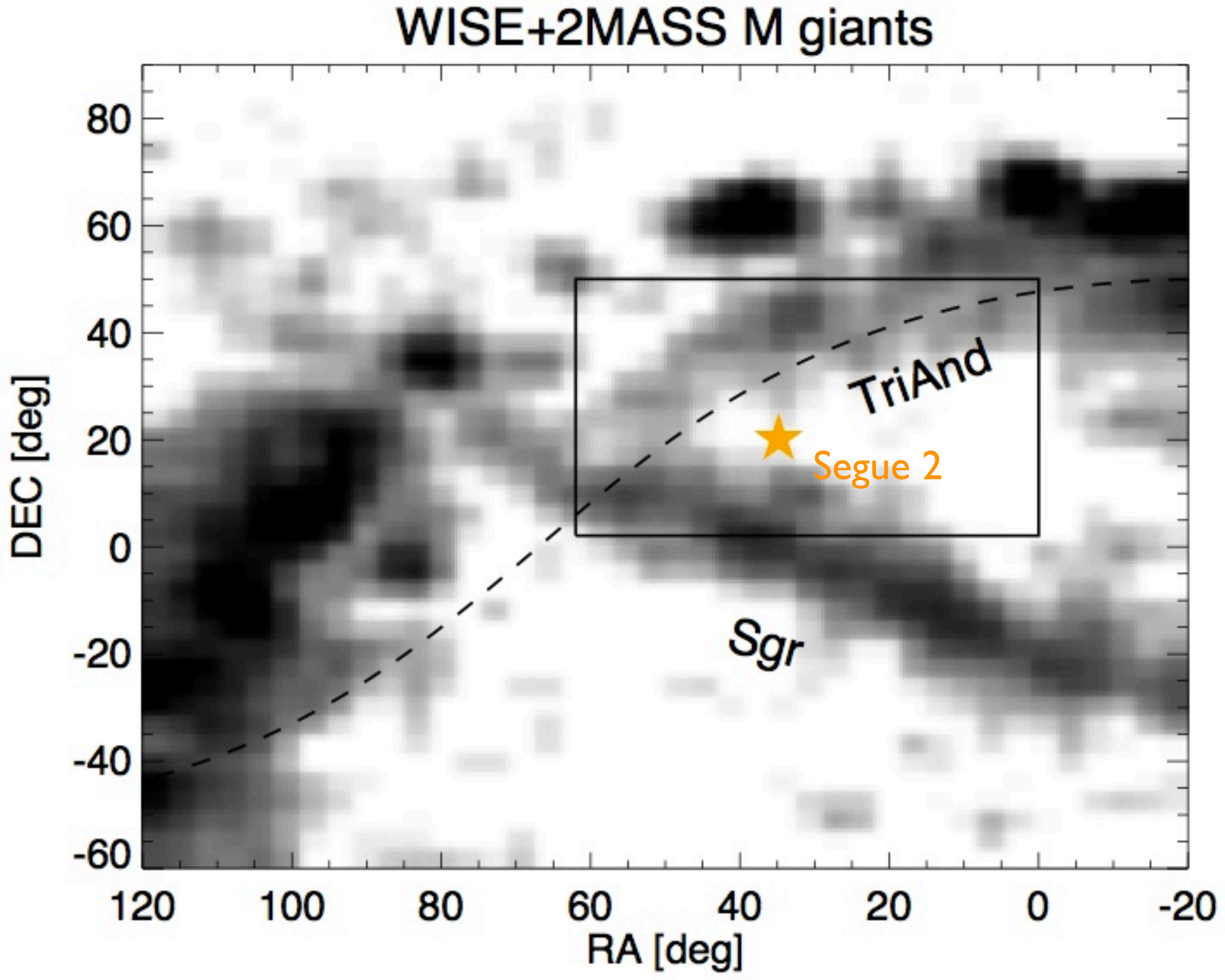
Radial distribution of sub-haloes



By playing with the flatness of the **radial density profile** of the ultra-faint satellites it is possible to predict either a few tens or more than a thousand such objects around MW!

also recall Beth Willman's talk on Tuesday

The radial density profile of the faintest satellites



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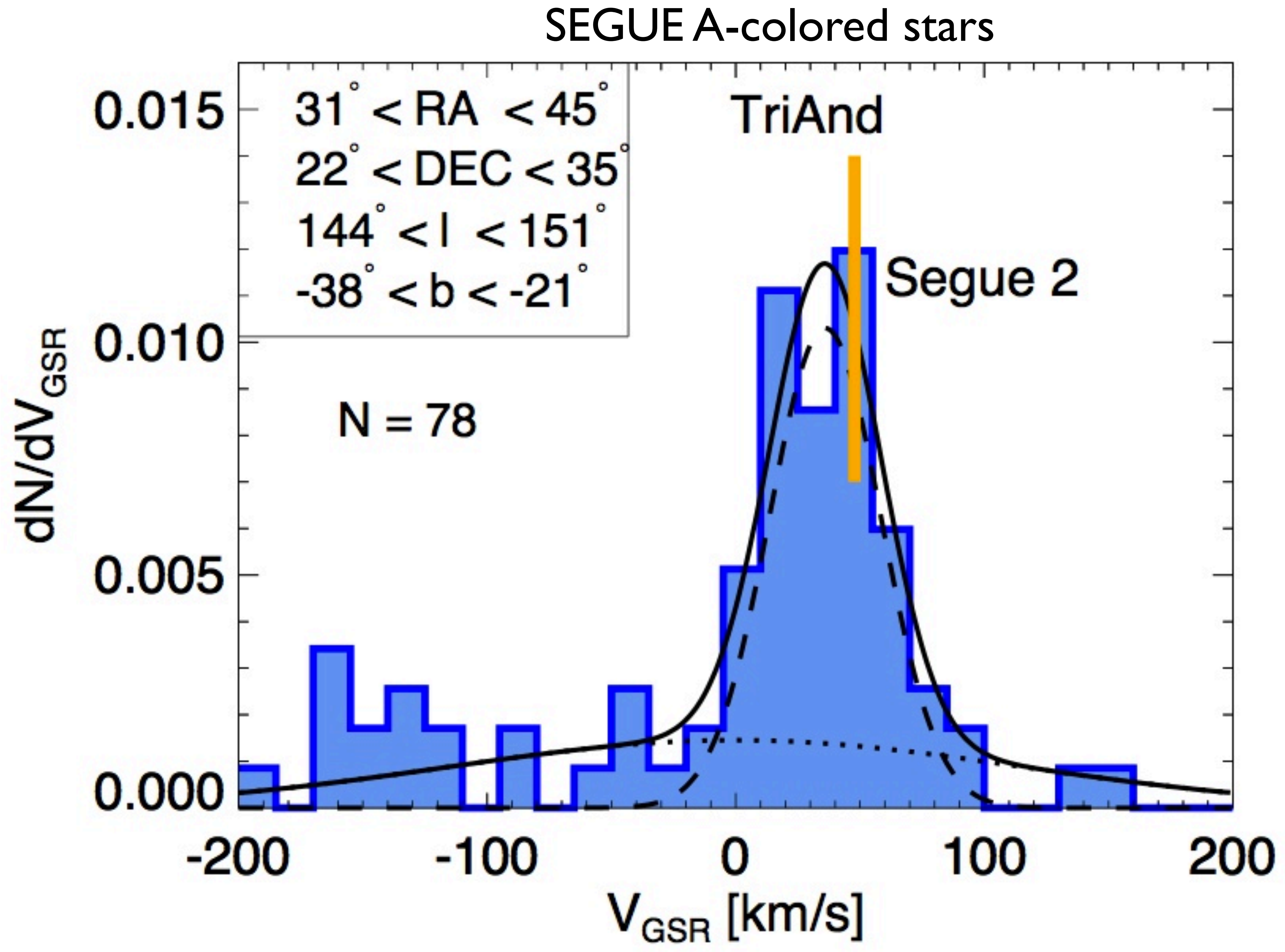
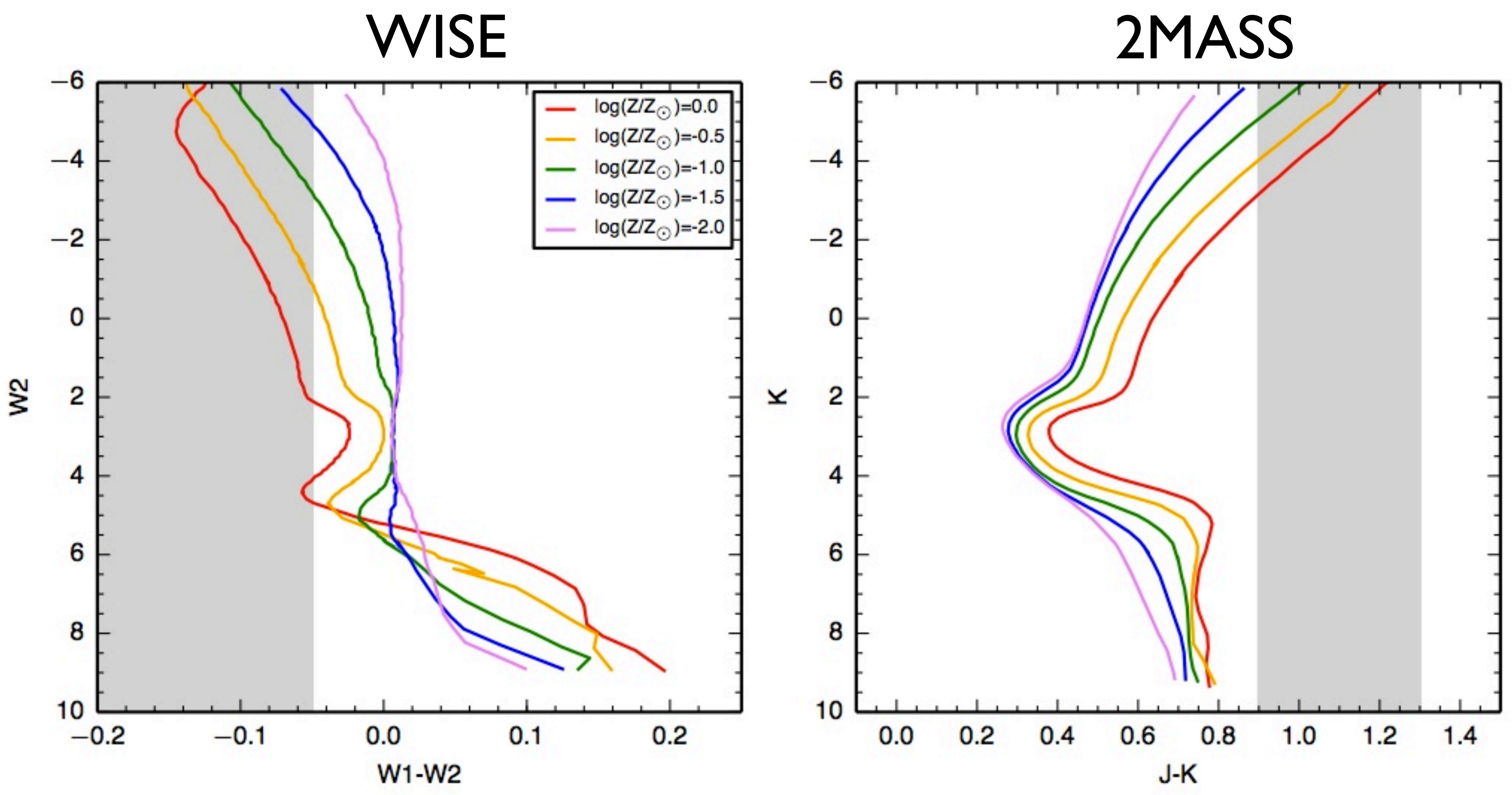


"TriAnd and its Siblings: Satellites of Satellites in the Milky Way Halo"

Deason et al, 2014, accepted to MNRAS

Some WISE magic to reveal stellar halo sub-structure



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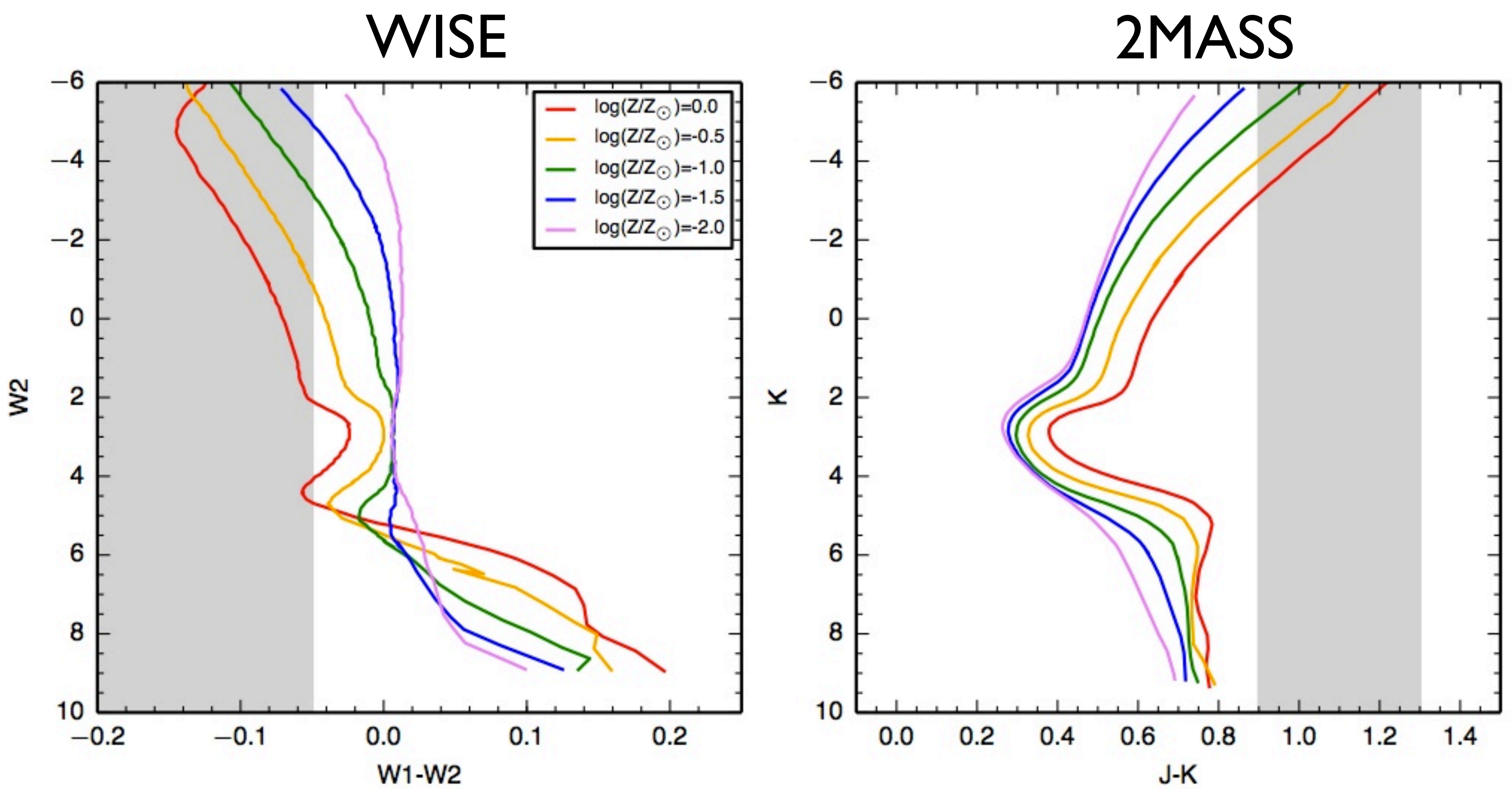
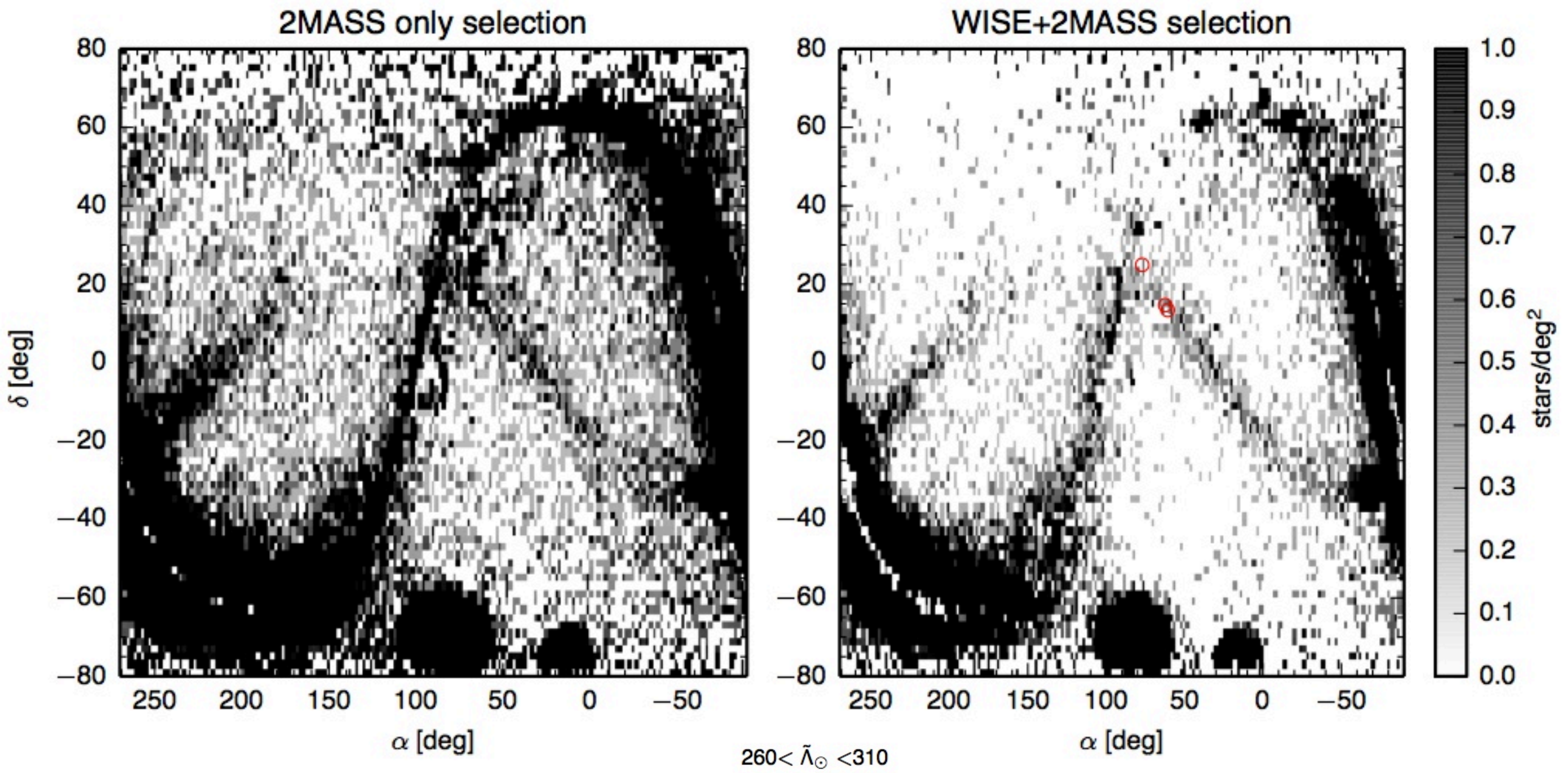
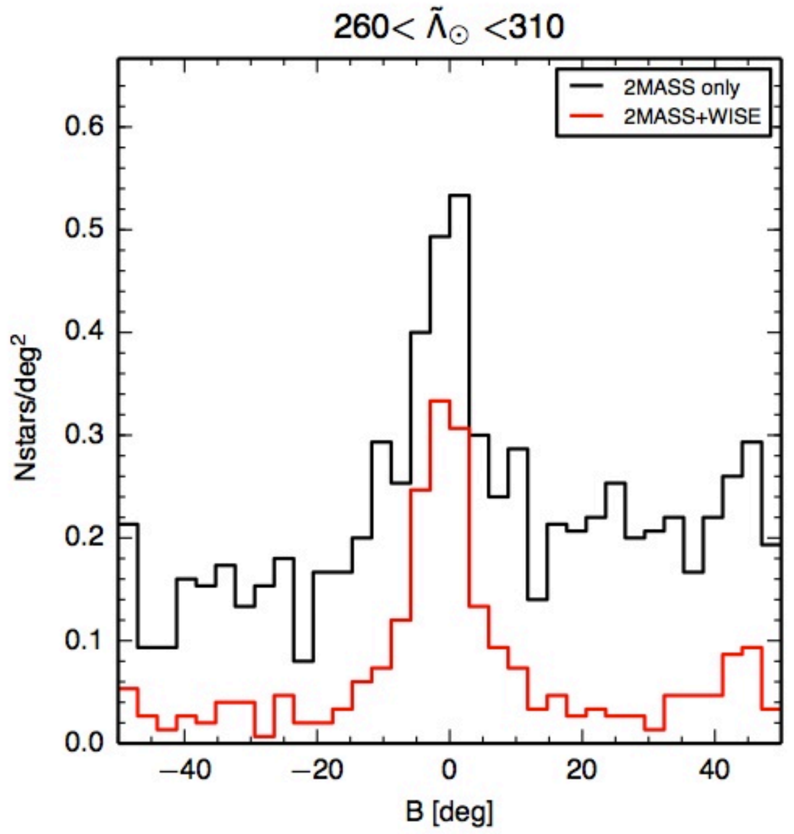






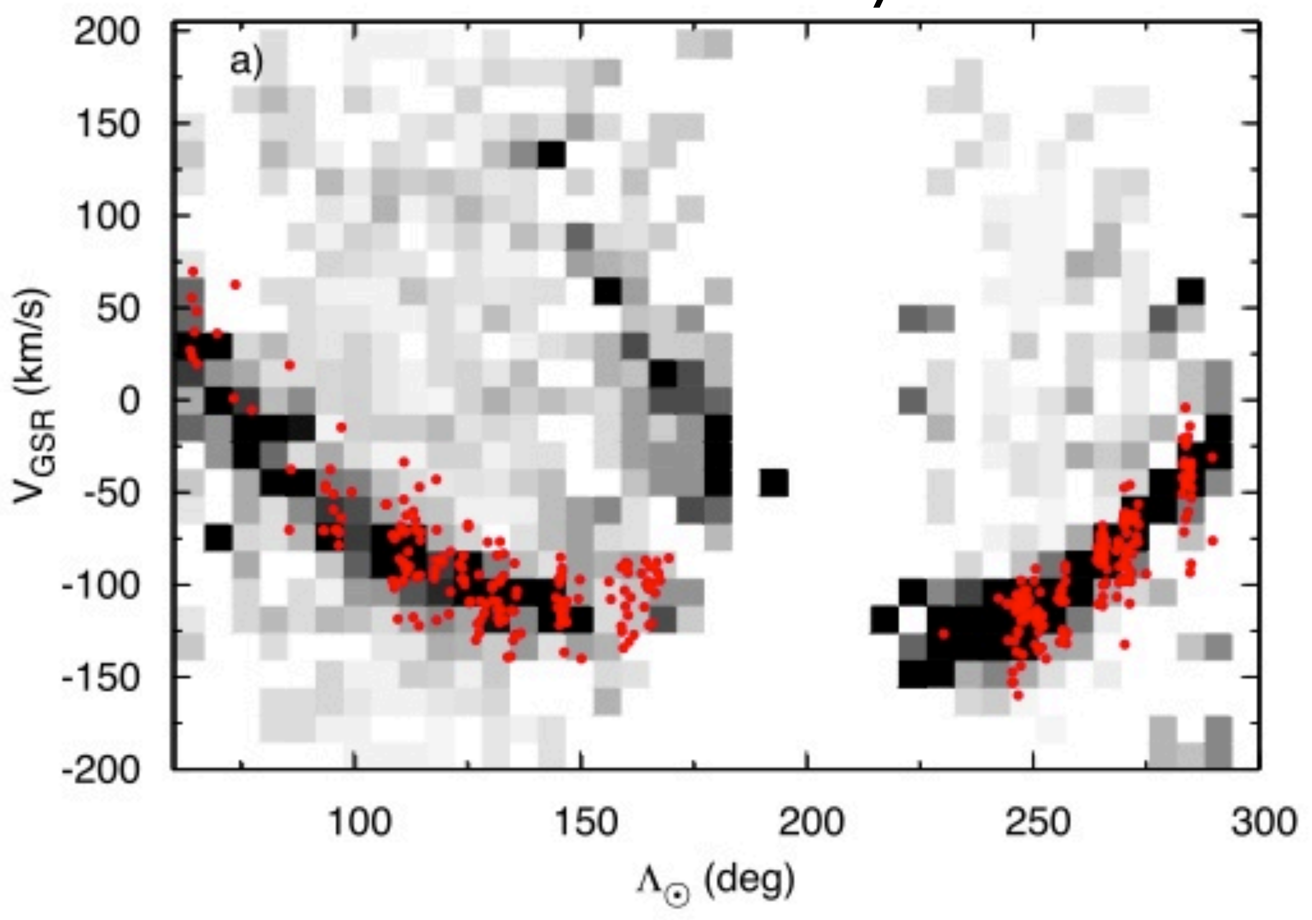
Exposing Sgr tidal debris behind the Galactic disk with M giants selected in WISE∩2MASS

S. E. Koposov[1] ⋆, V. Belokurov[1], D. B. Zucker[2,3,4], G. F. Lewis[5], R. A. Ibata[6], E. W. Olszewski[7], Á. R. López-Sánchez[4,3], E. A. Hyde[2,3]
[1] *Institute of Astronomy, Madingley Rd, Cambridge, CB3 0HA, UK*
[2] *Macquarie University Research Centre in Astronomy, Astrophysics & Astrophotonics, NSW 2109, Australia*
[3] *Department of Physics and Astronomy, Macquarie University, North Ryde, NSW 2109, Australia*
[4] *Australian Astronomical Observatory, PO Box 915, North Ryde, NSW 1670, Australia*
[5] *Sydney Institute for Astronomy, School of Physics, A28, University of Sydney, Sydney NSW 2006, Australia*
[6] *Observatoire Astronomique de Strasbourg, Université de Strasbourg, CNRS, UMR 7550, 11 rue de l'Université, F-67000 Strasbourg, France*

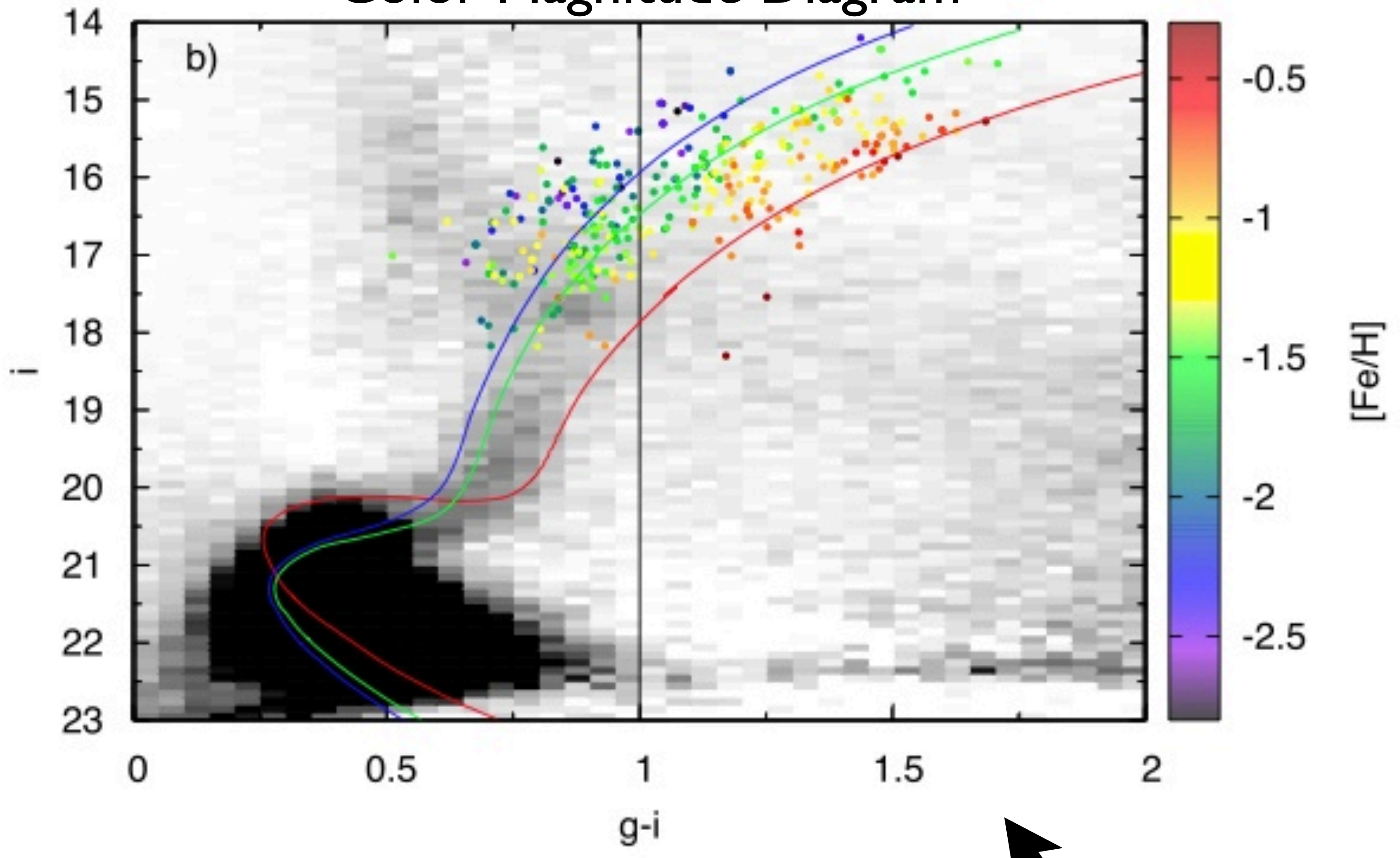
Reconstructing star-formation histories of destroyed dwarfs

Having located sub-structure in the halo, combine different stellar tracers!

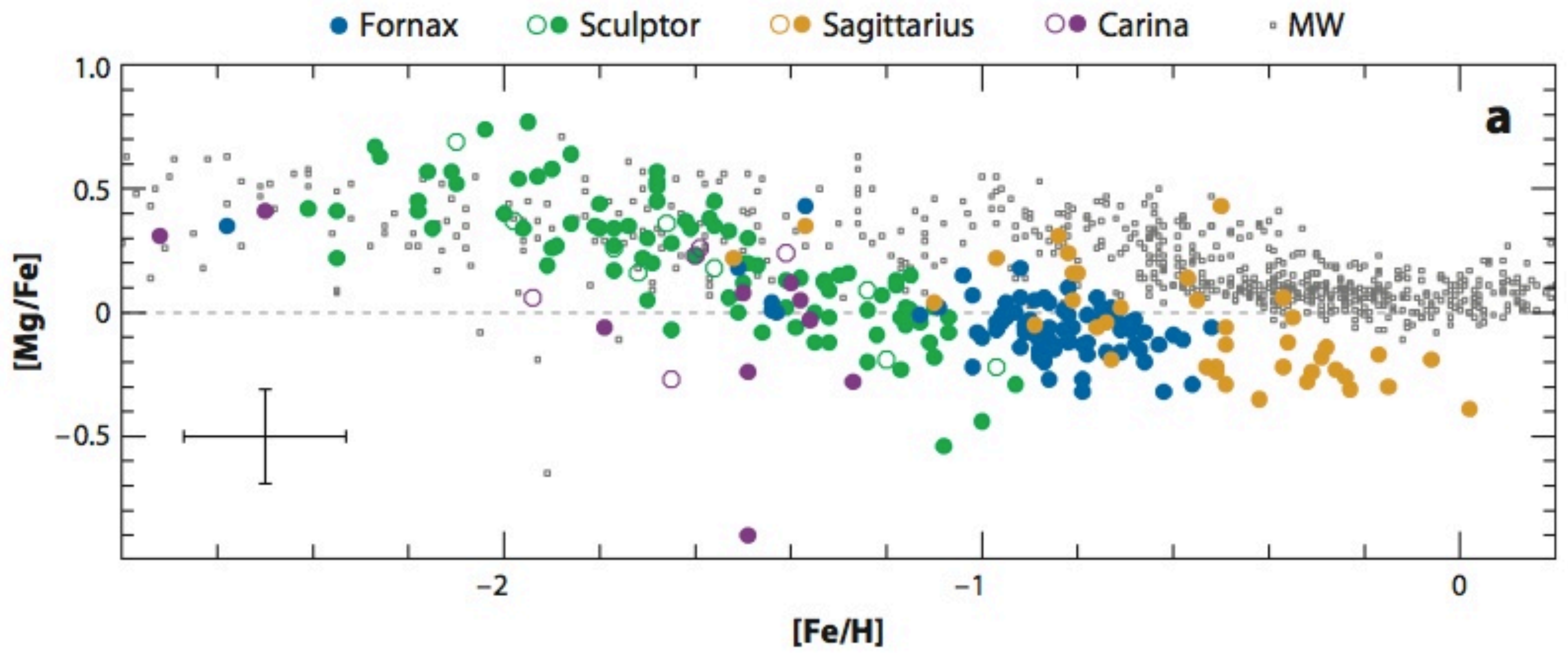
Radial velocity



Color Magnitude Diagram



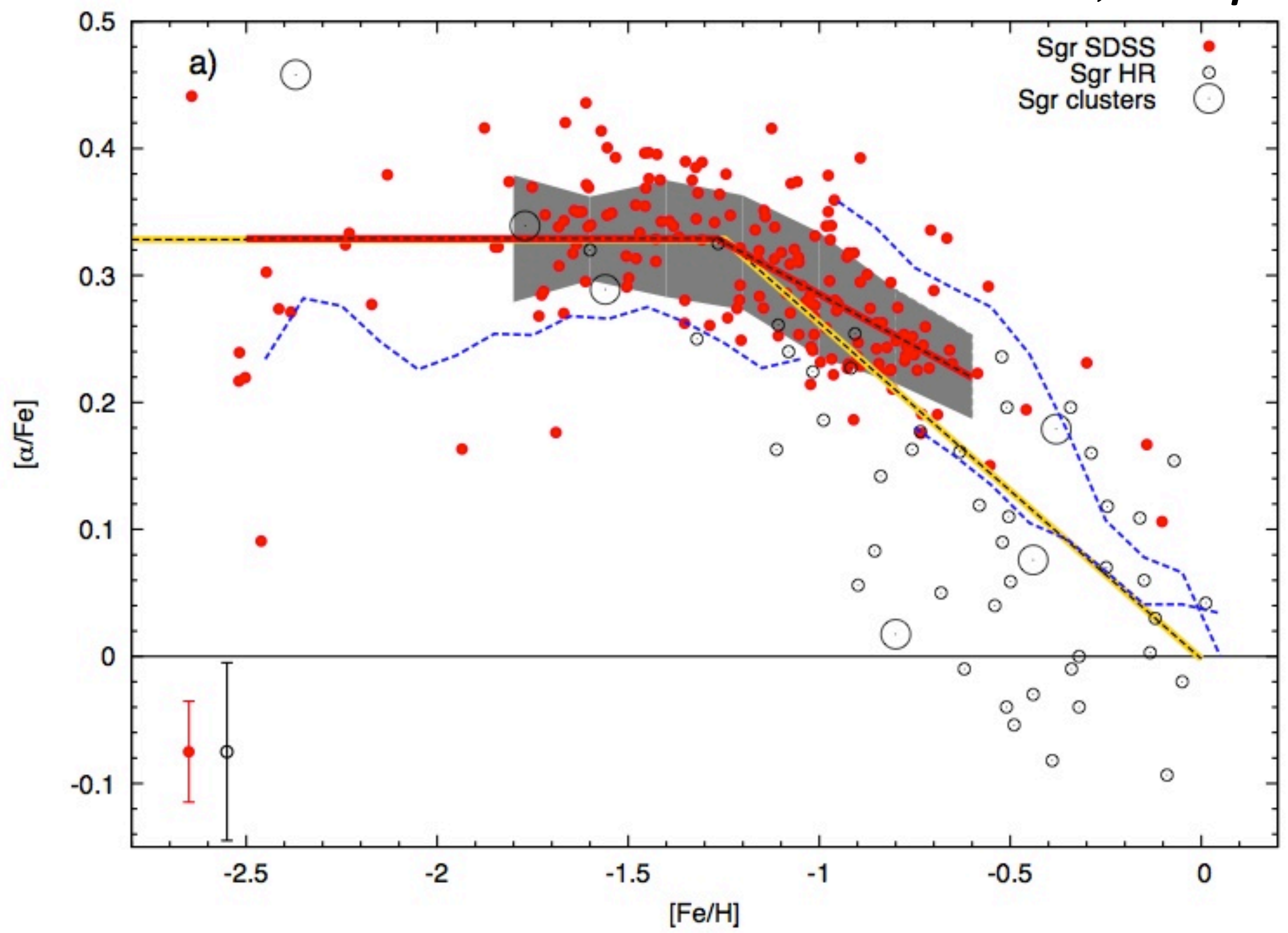
SDSS data



previous HR spectroscopy

stream track: M giants + MSTO
distances: BHBs
velocities: RGB

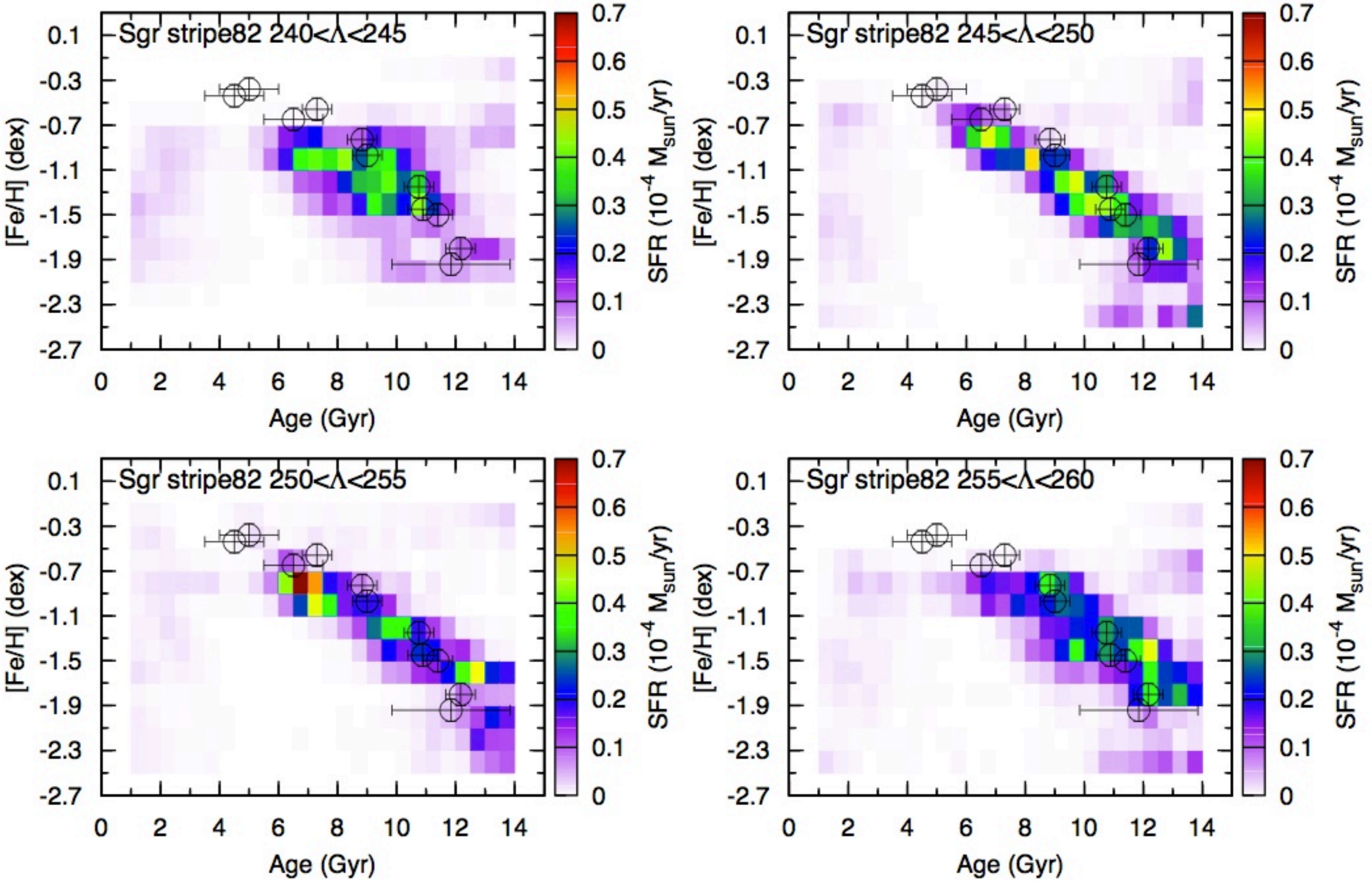
de Boer et al, 2014



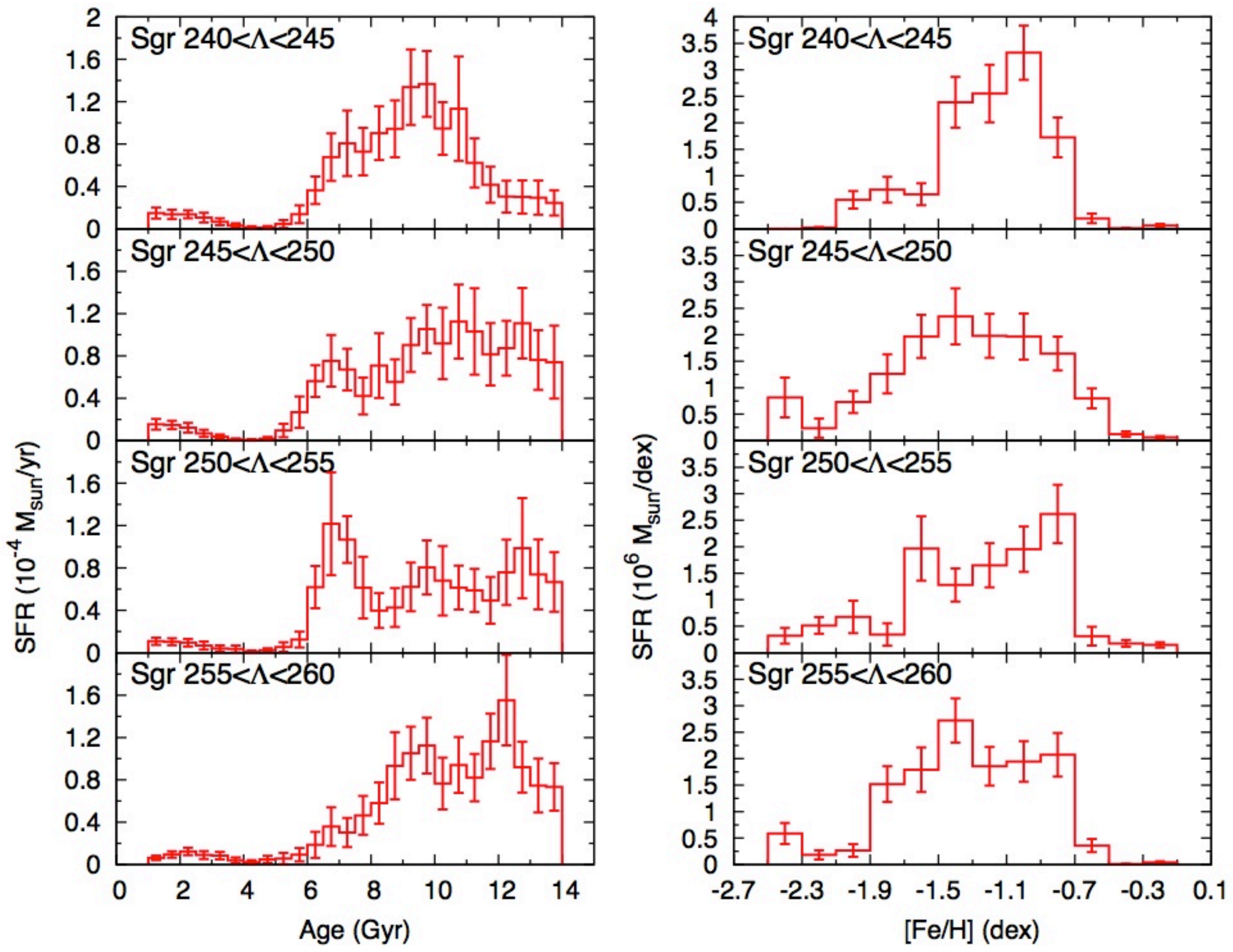
Reconstructing star-formation histories of destroyed dwarfs

de Boer et al, in prep

Metallicity-Age relation for the Sgr debris

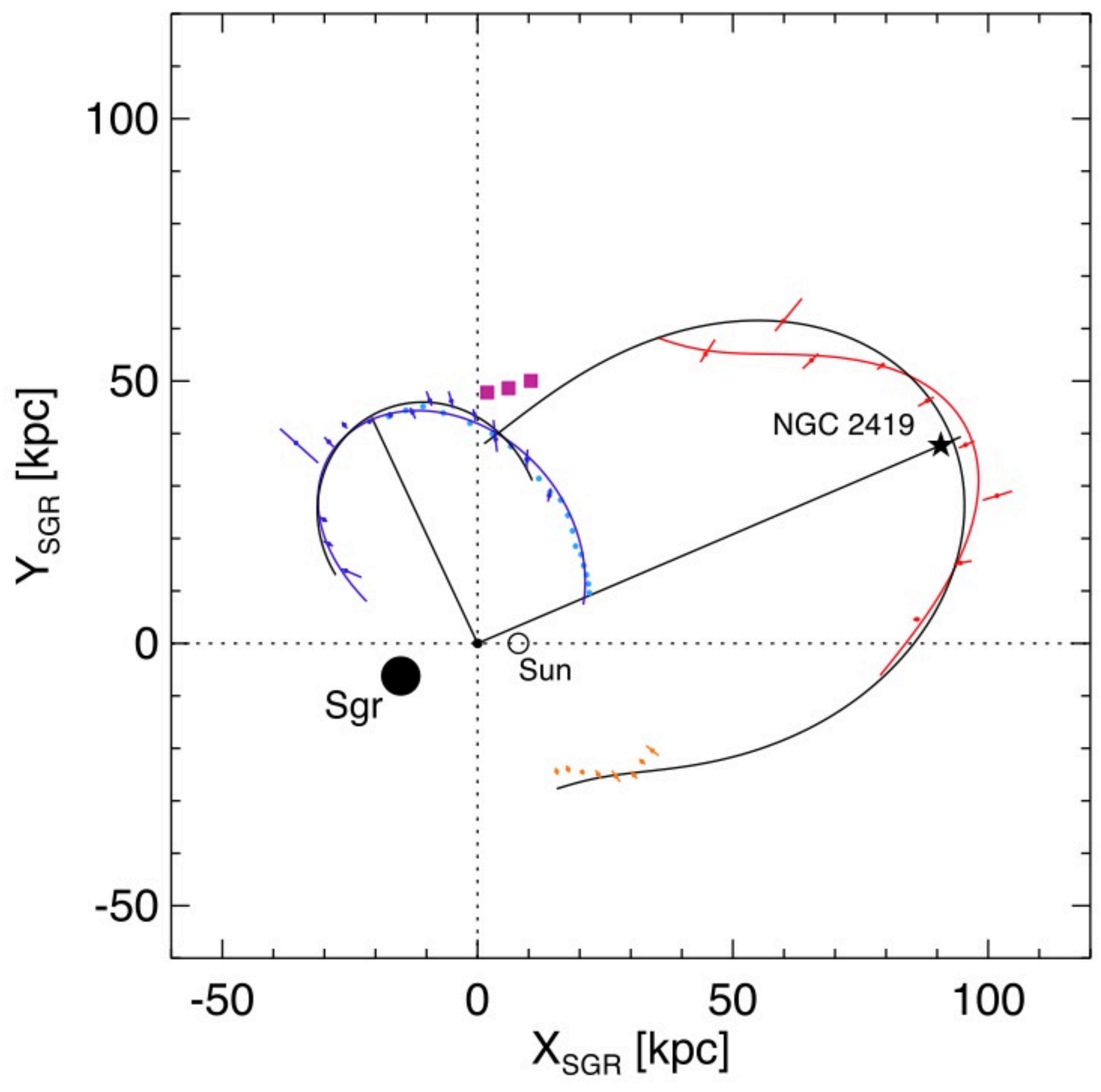


SFH & MDF for the Sgr debris

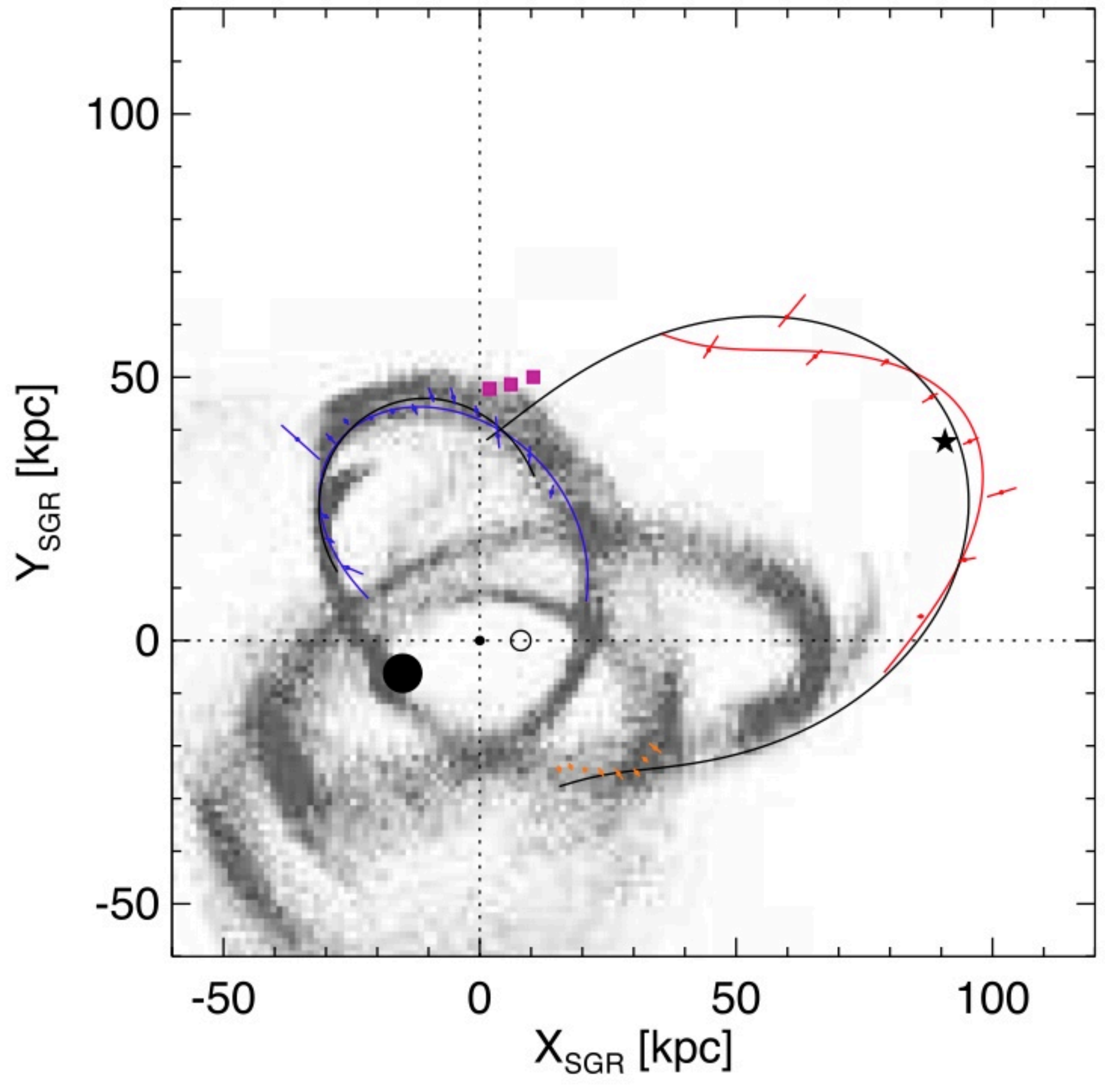


Sgr dwarf disruption and the Galactic DM content

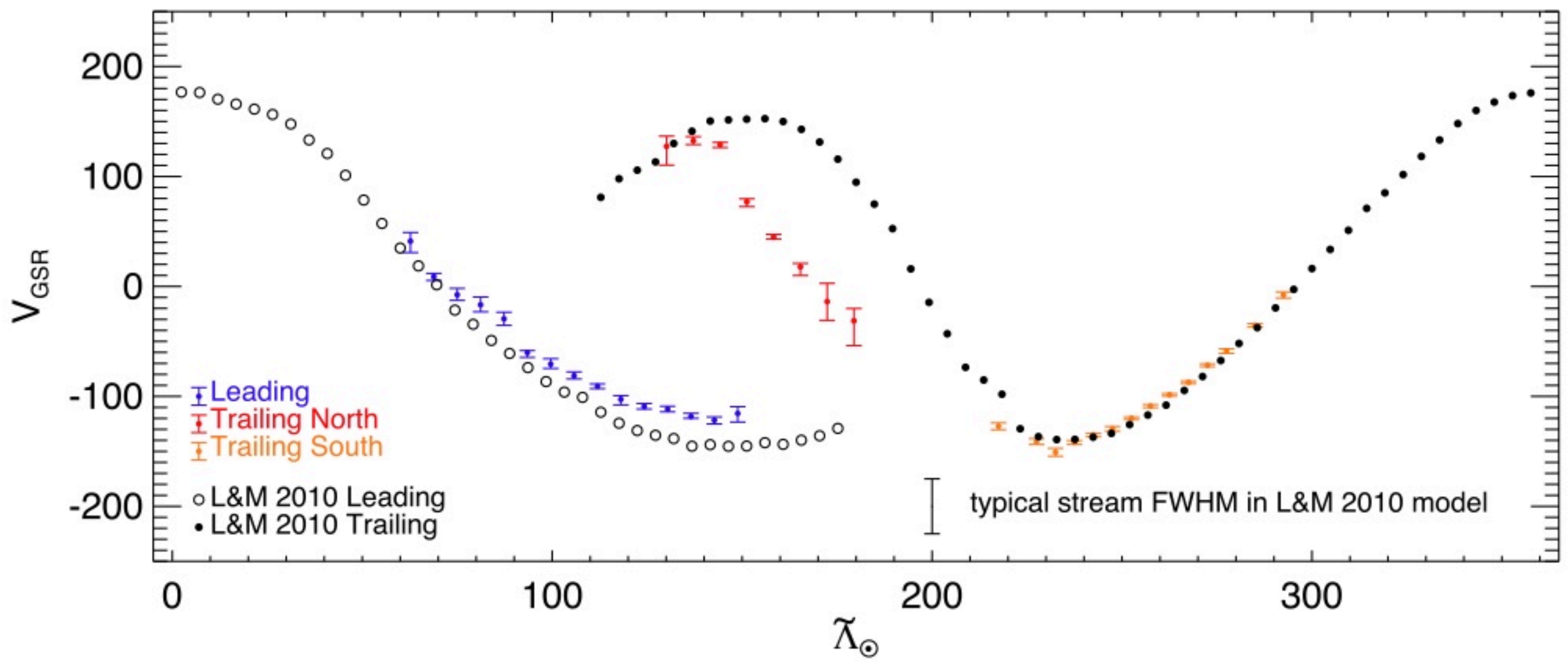
Leading apo ~50 kpc
Trailing apo ~ 100 kpc
Angle ~ 93°



Current state-of-the-art Nbody model



Sgr debris radial velocity: data vs LM2010



Belokurov et al, 2014

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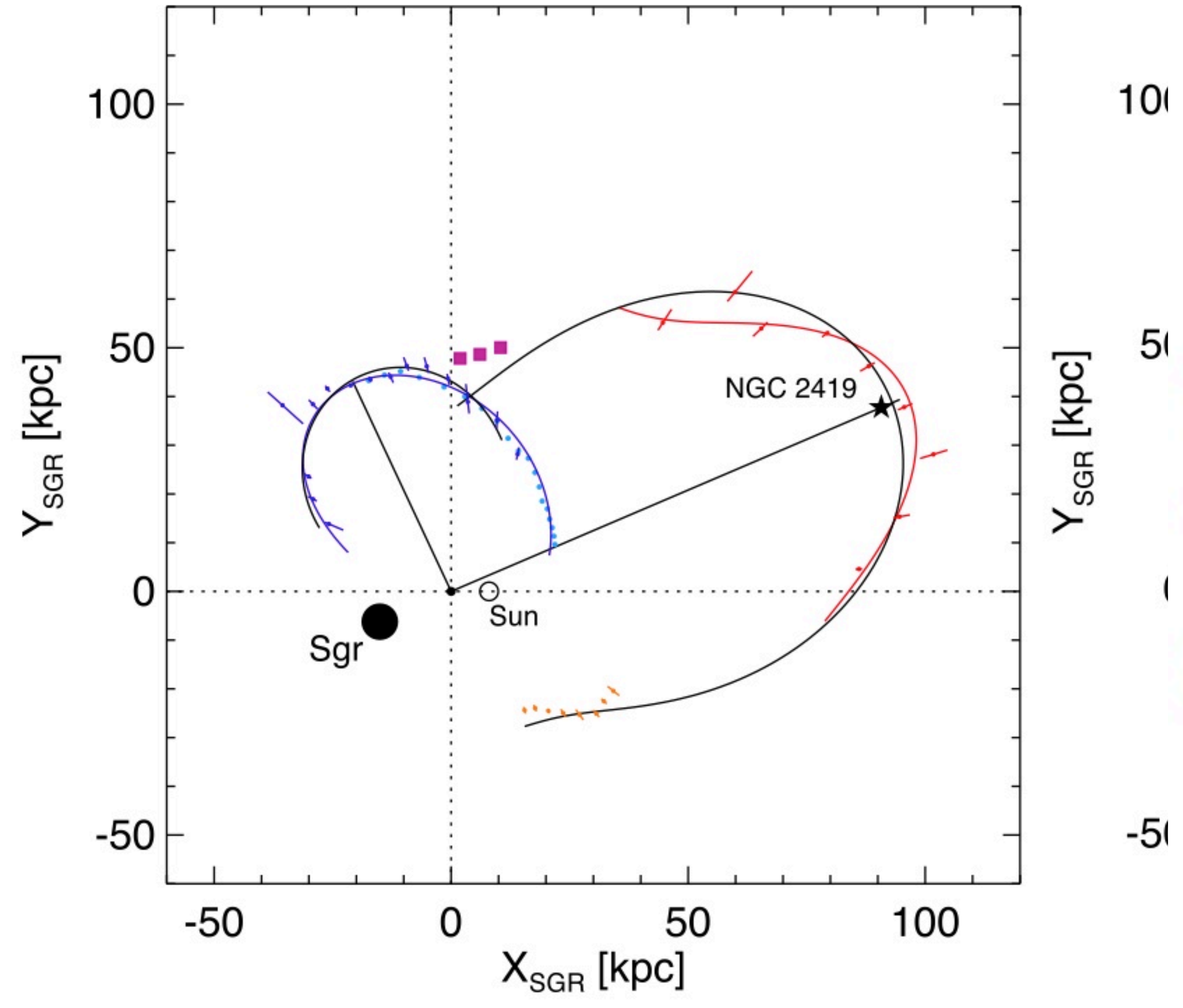
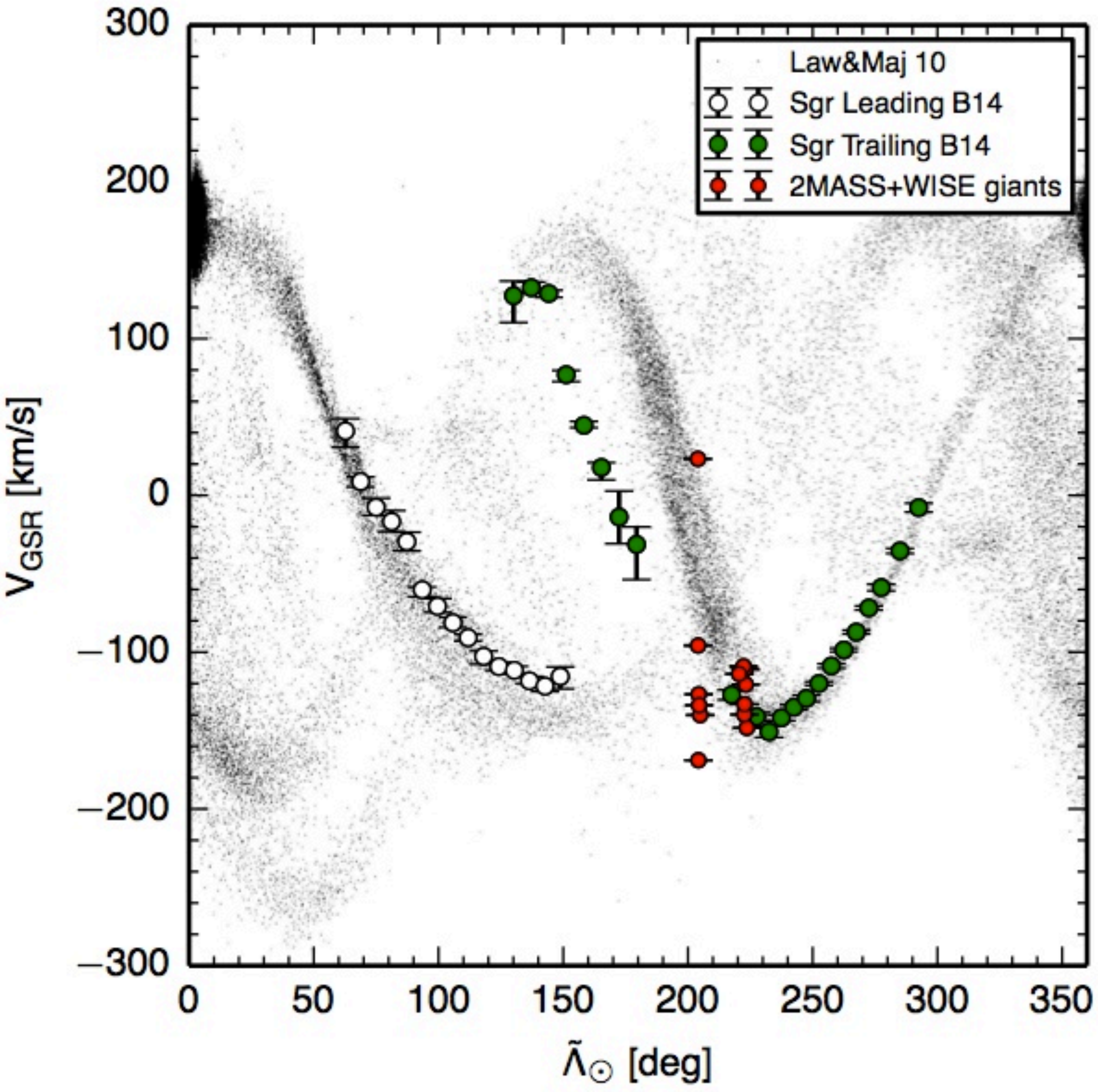
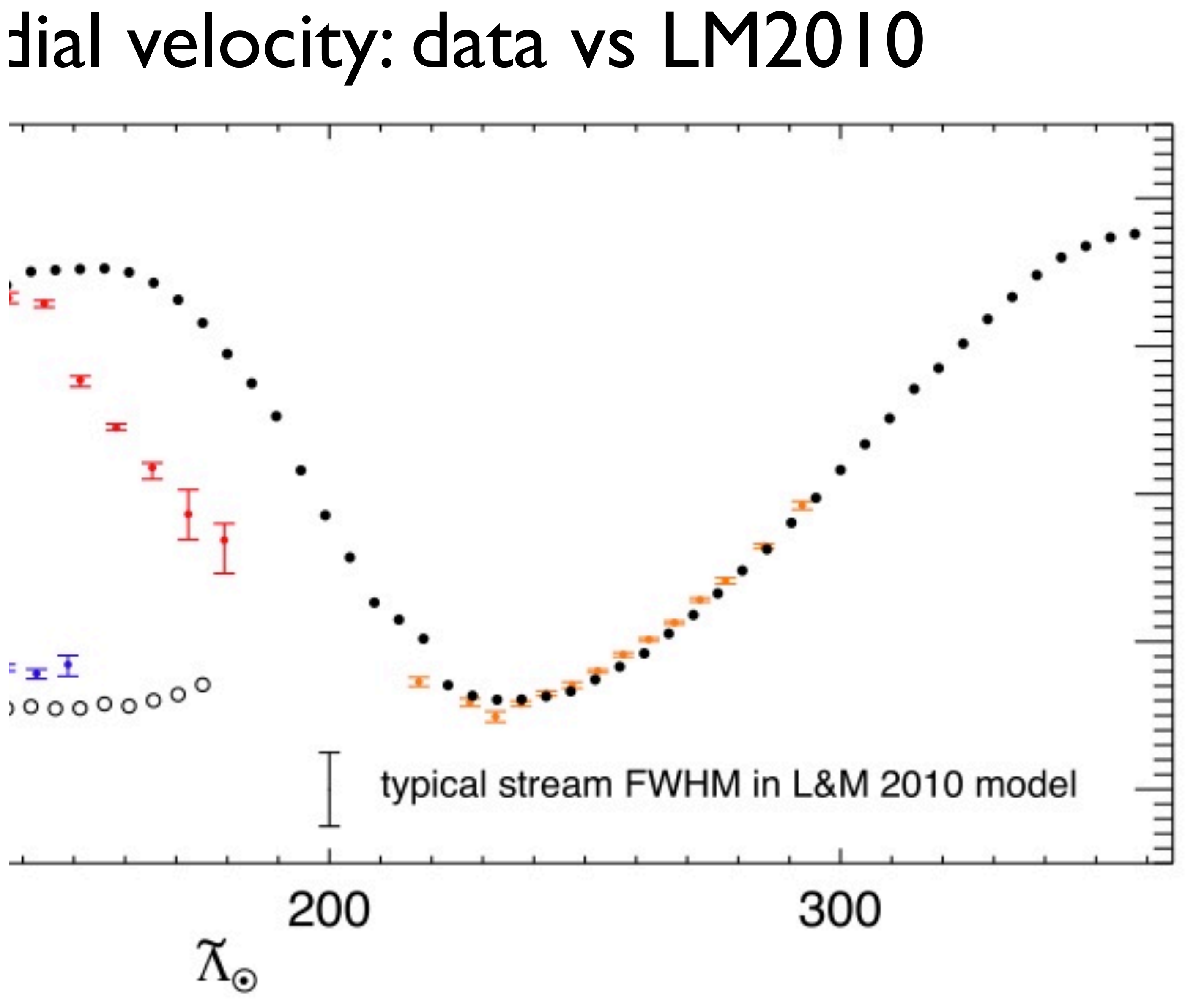


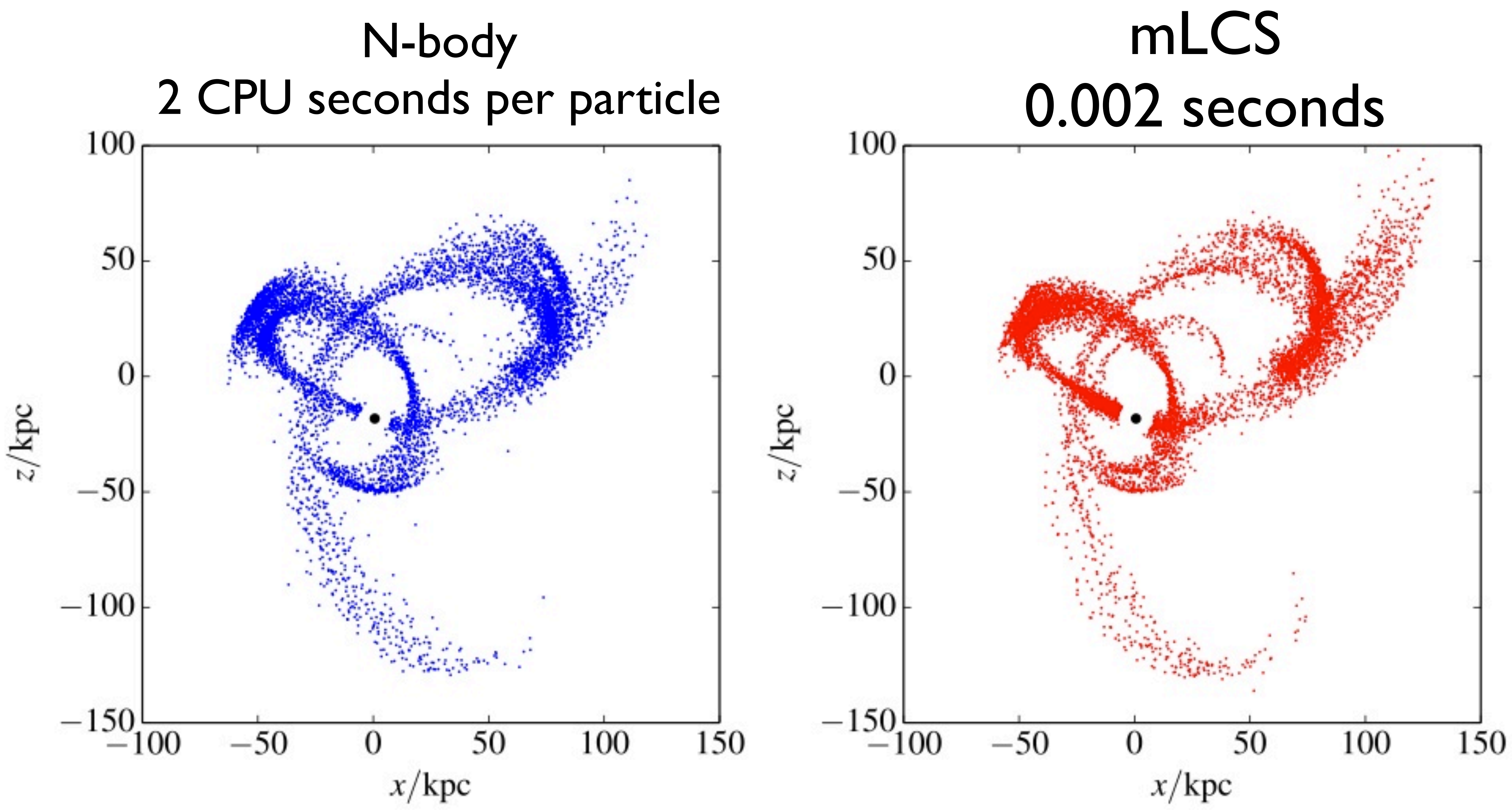
Belokurov et al, 2014





Koposov et al, 2014

Fast stream production
Models of Sgr precession



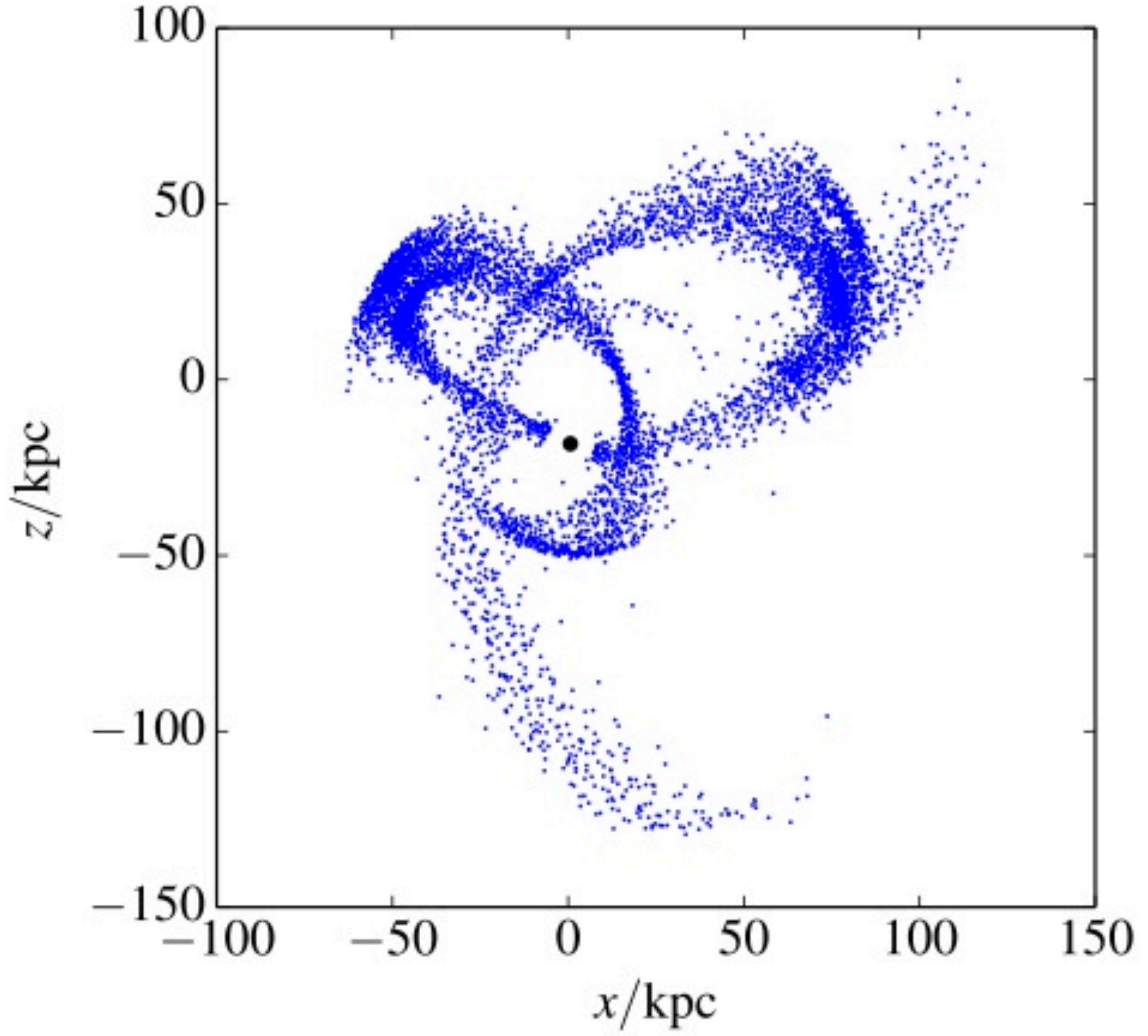
mLCS=**m**odified **L**agrange **C**loud **S**tripping

Gibbons et al, 2014
recall also Adam Bowden's talk yesterday

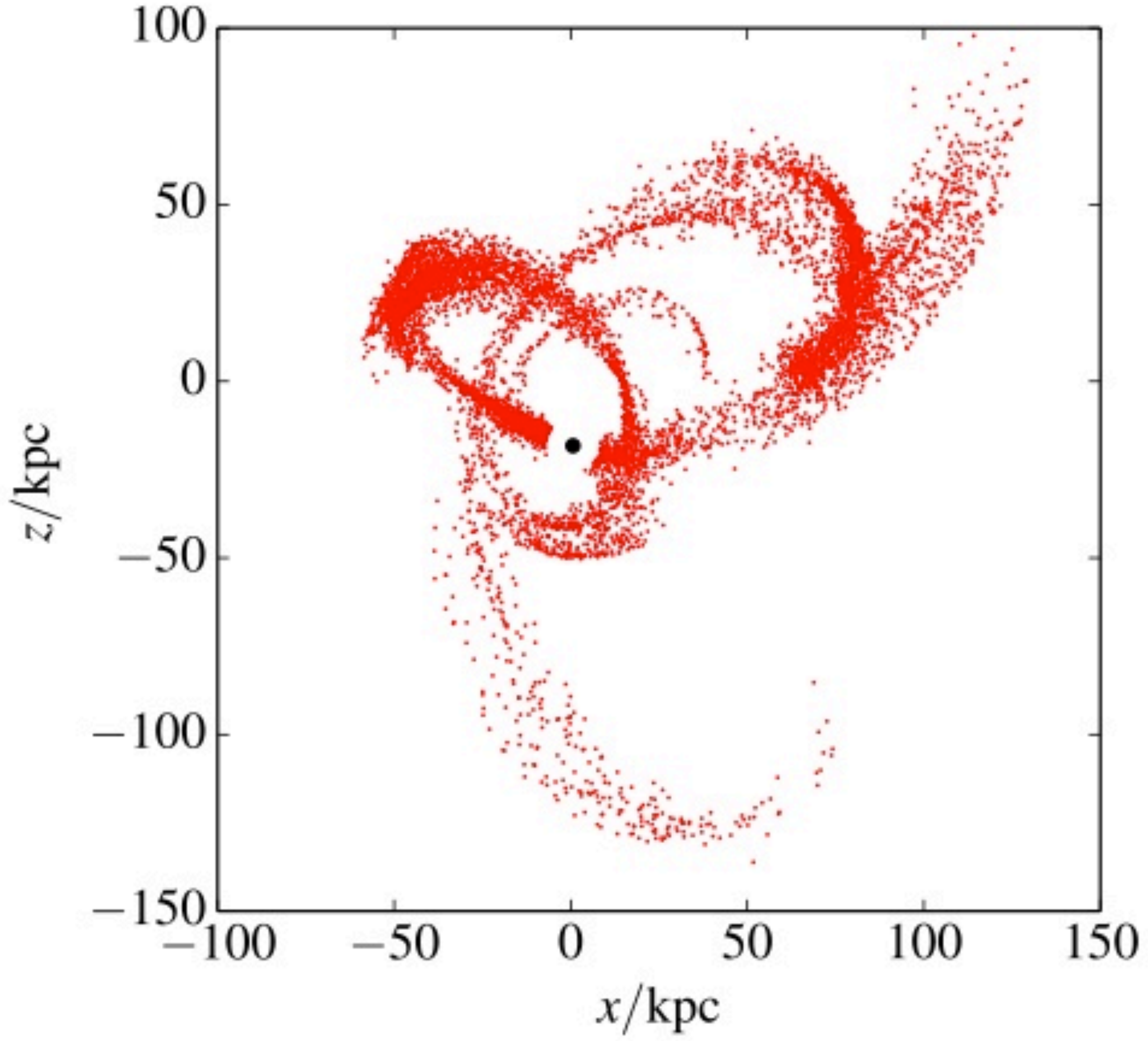
simulation by Victor Debattista

Fast stream production
Models of Sgr precession

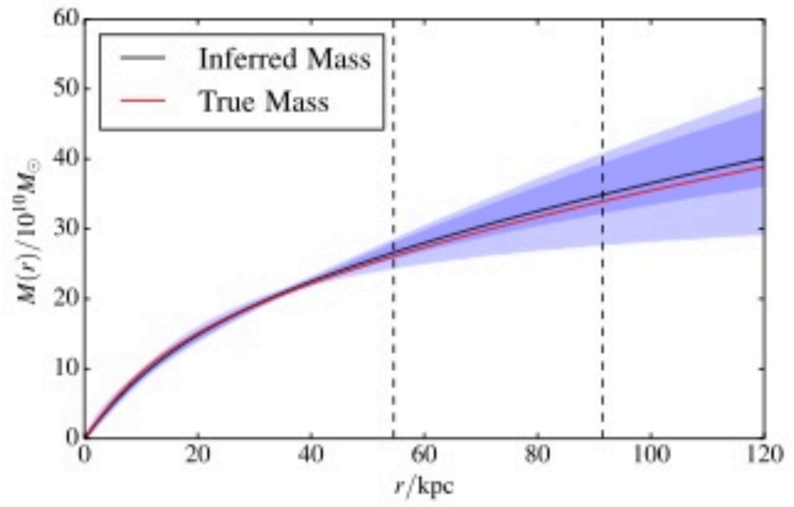
N-body
2 CPU seconds per particle



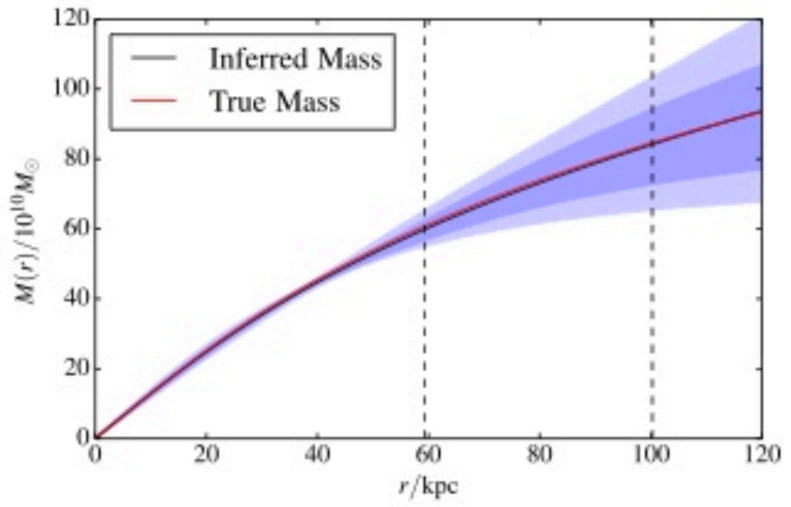
mLCS
0.002 seconds



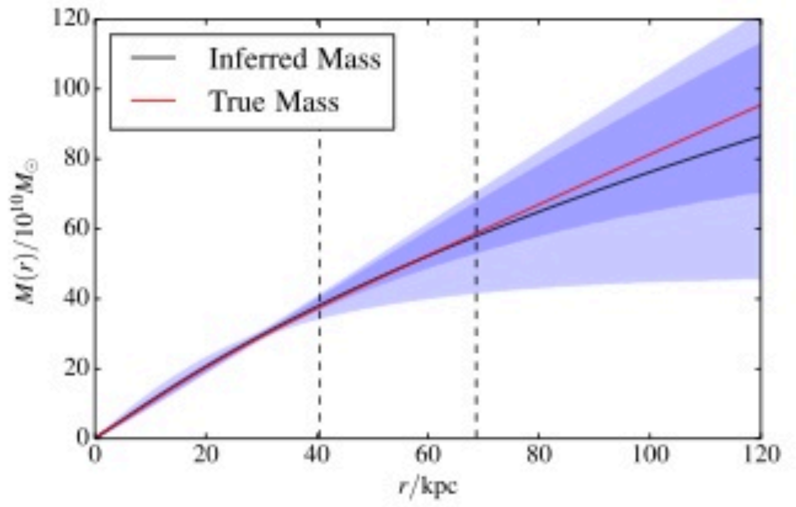
Test. Cumulative mass profiles



Spherical



Disk+Bulge+Halo



LM2010

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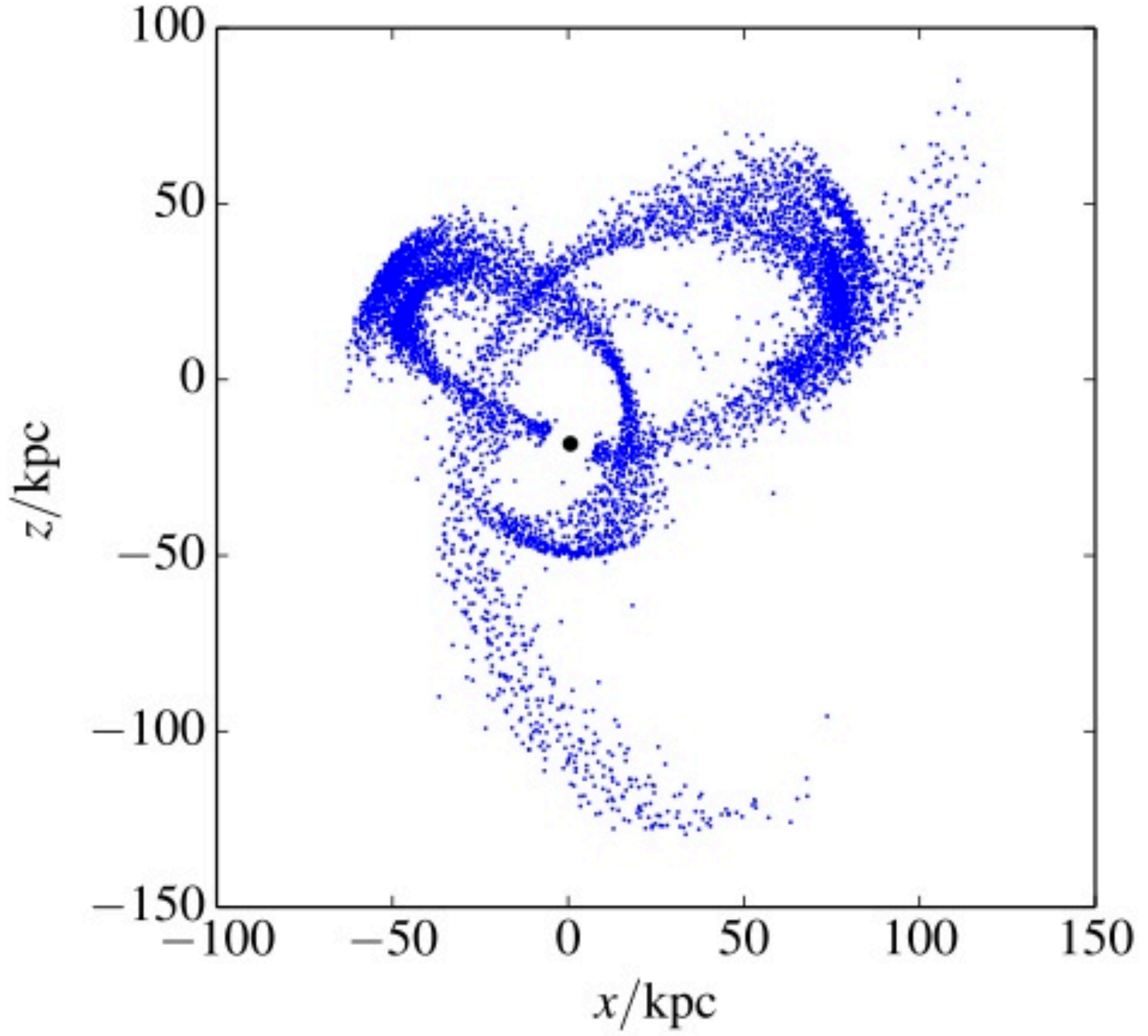

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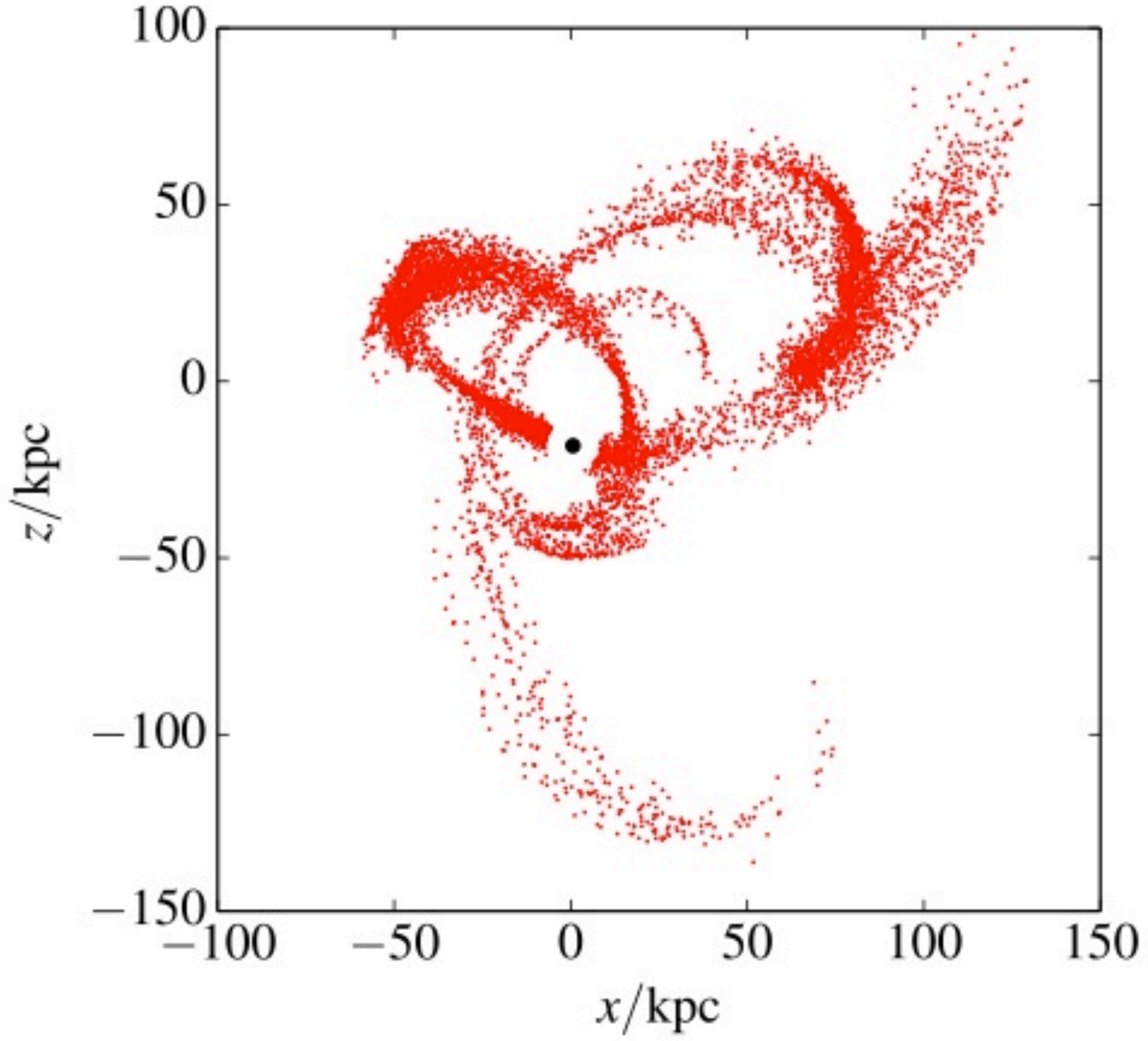

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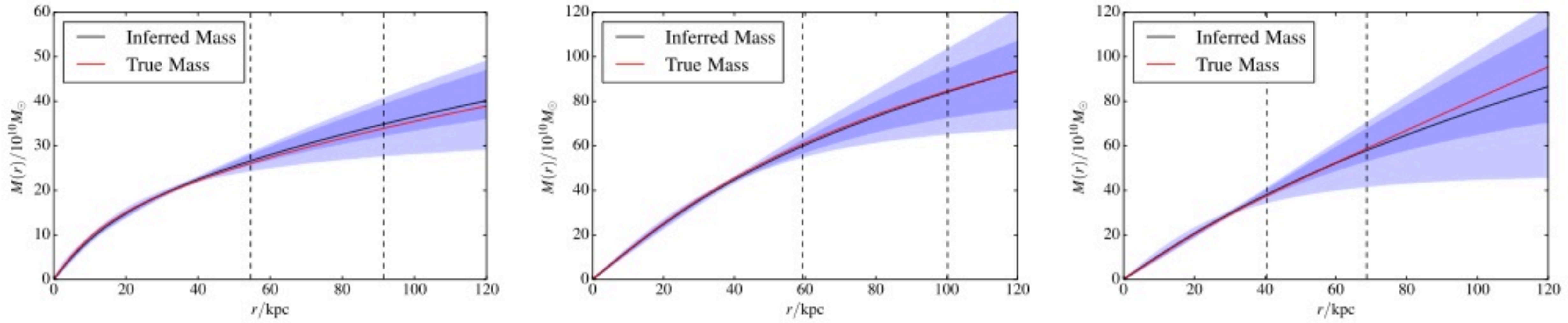
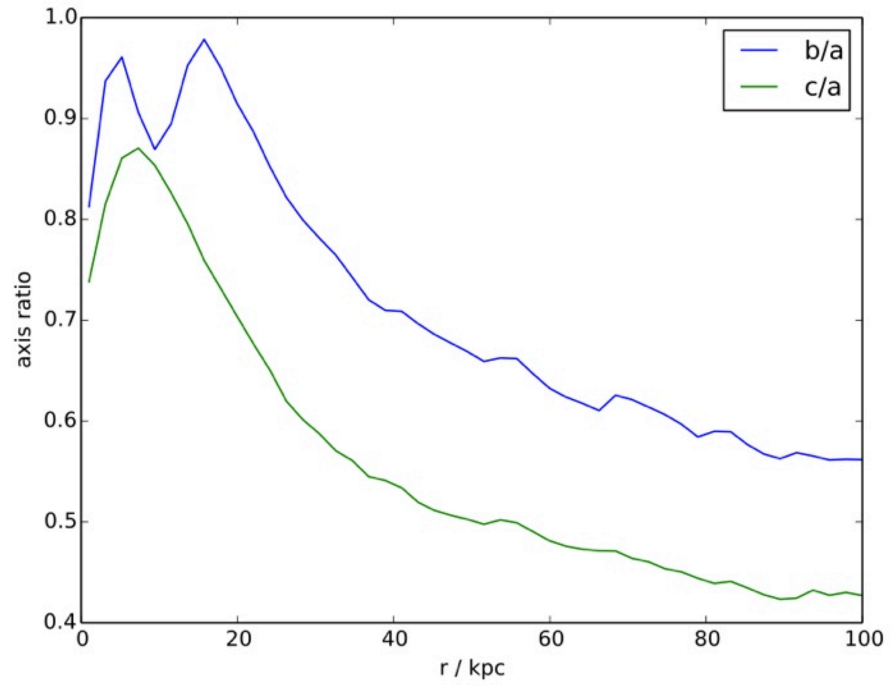


Spherical | Disk+Bulge+Halo | LM2010



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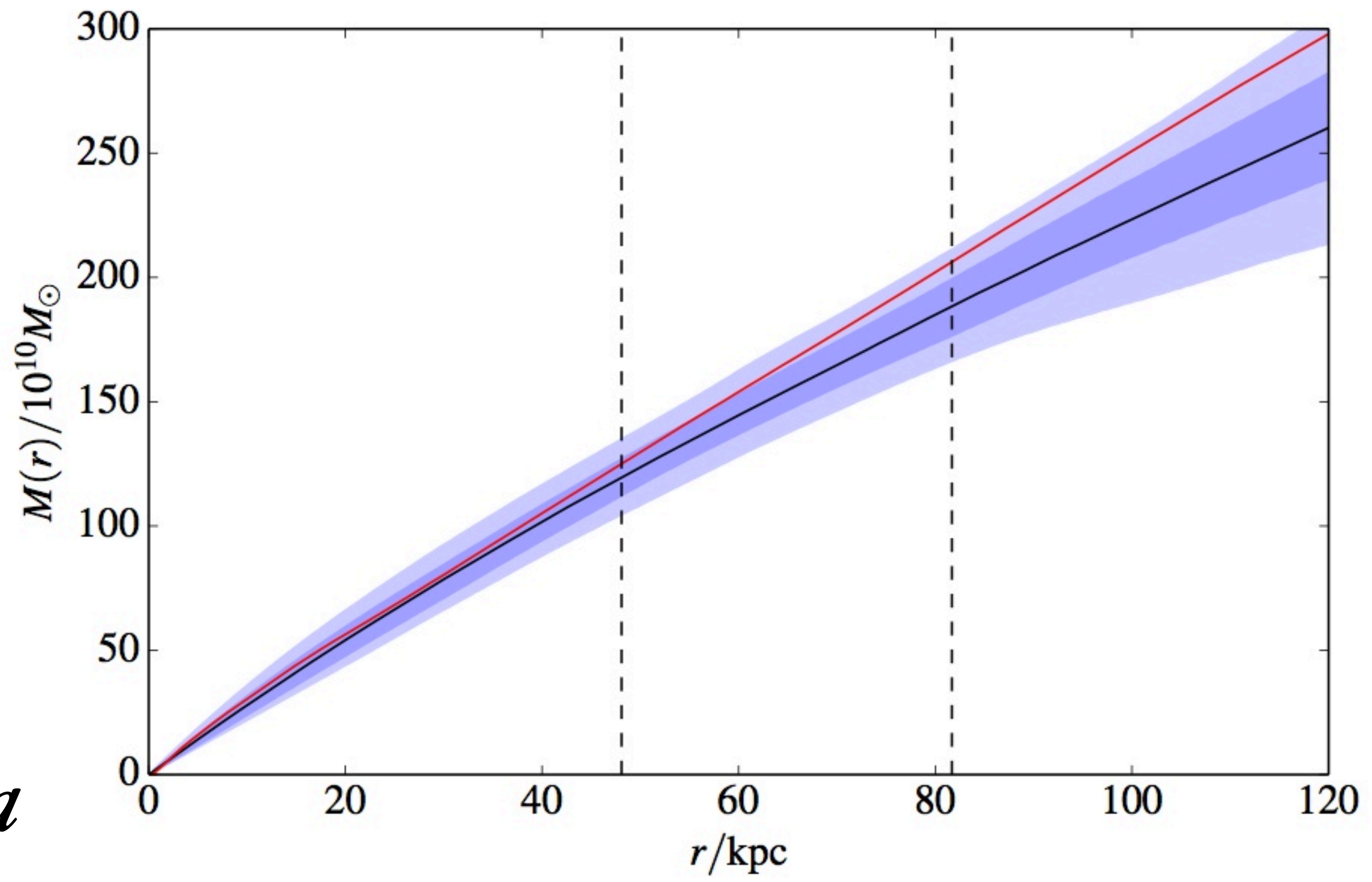
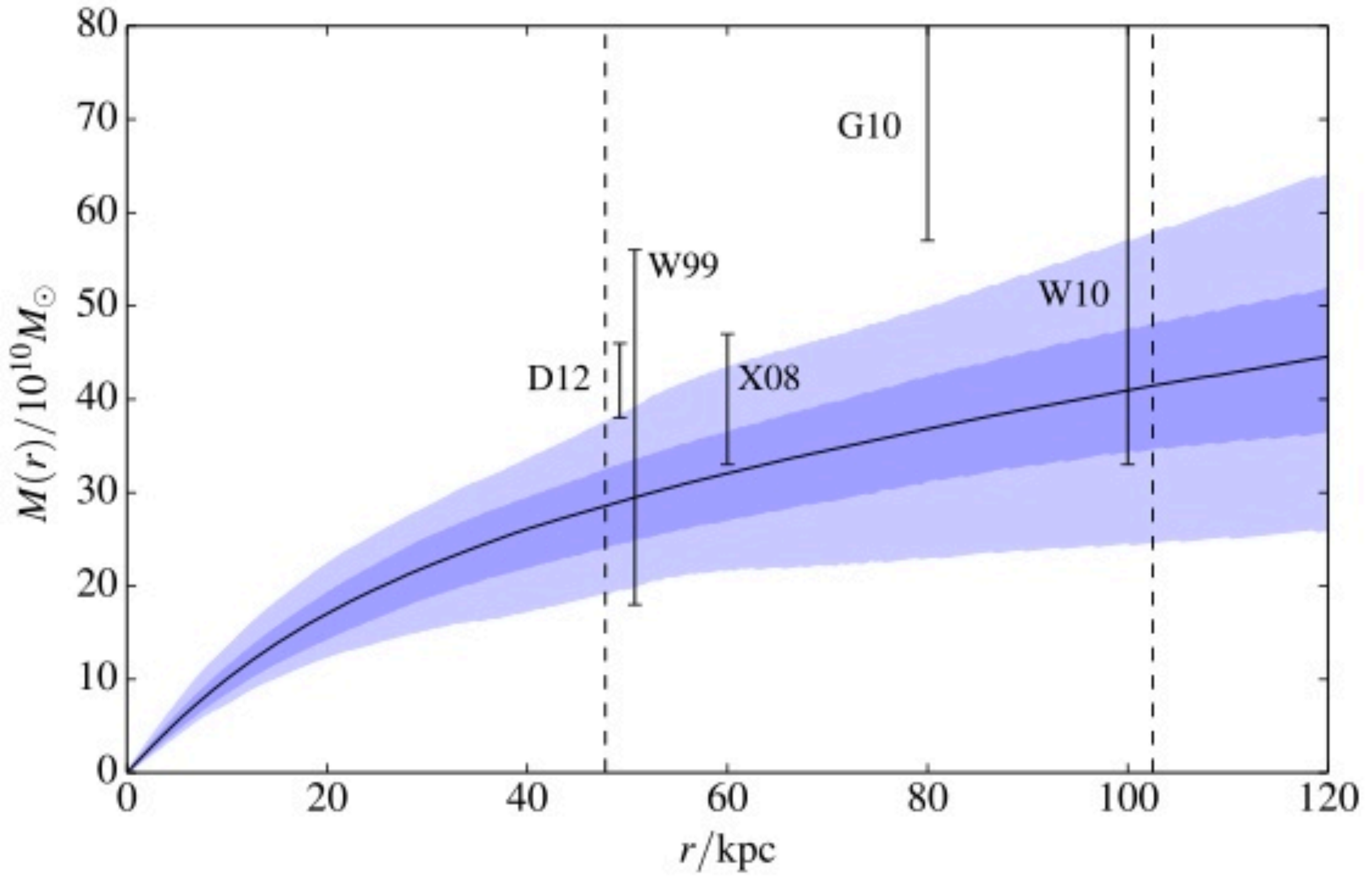


Mass profile of the Galaxy to 100 kpc



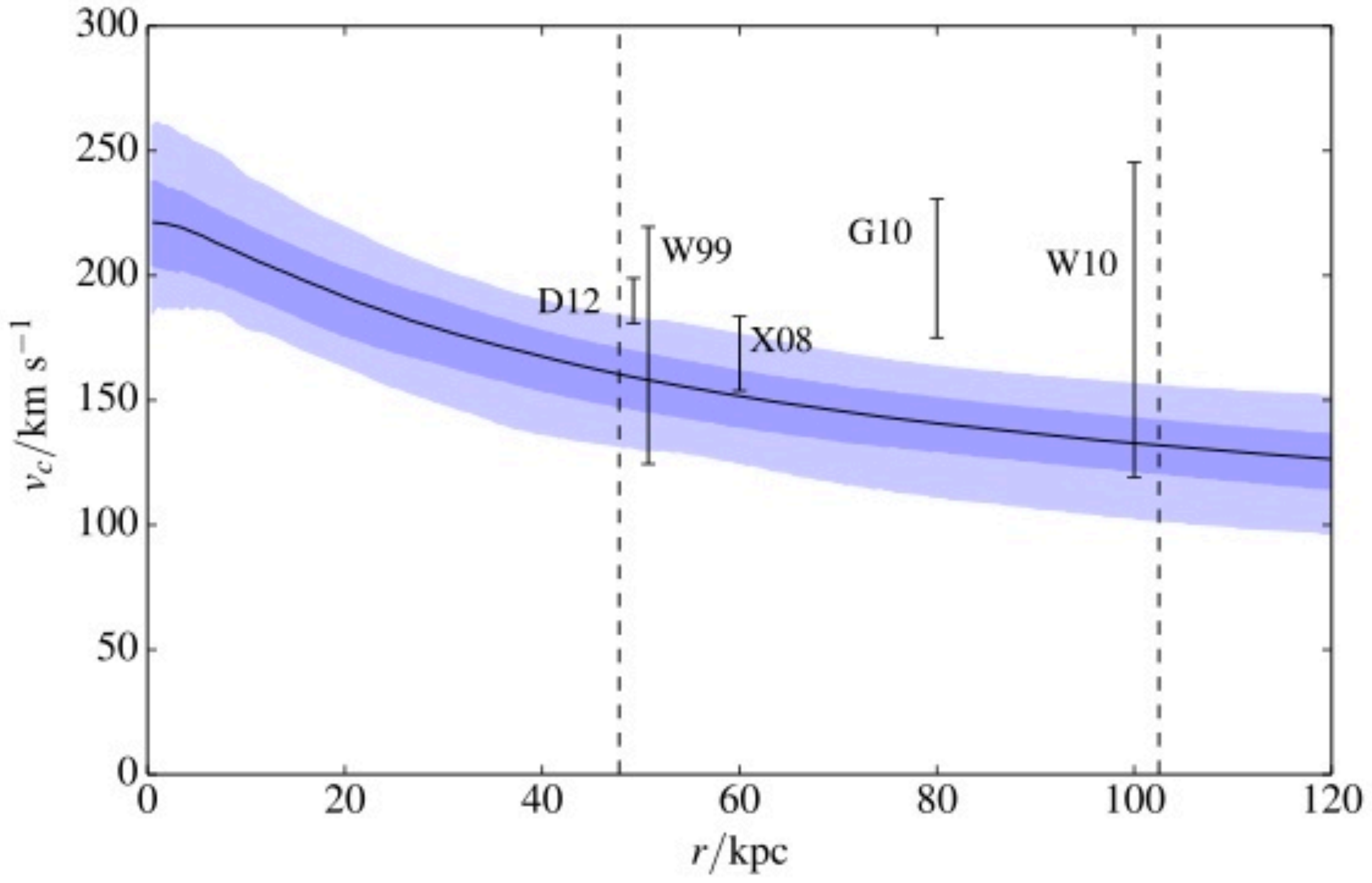


Table 3. The enclosed mass of the Milky Way as inferred from the stream precession modeling. We provide estimates at 50, 100, 150 and 200 kpc. Along with 68% and 95% confidence intervals.

r/kpc	$M(r)/10^{11}M_\odot$	$1\sigma/10^{11}M_\odot$	$2\sigma/10^{11}M_\odot$
50	2.9	0.4	0.9
100	4.1	0.7	1.6
150	4.9	1.0	2.4
200	5.6	1.2	3.0

Conclusions

- Progenitor(s) of the MW stellar halo was (likely) one massive system or a small group
- Accreted (but not fully dissolved) dwarfs are not aligned with the Magellanic family. Or each other.
- First detection of alpha knee in Sgr. First measurement of a SFH of a disrupting dwarf
- The number of expected dwarf satellites around the Galaxy is likely to go down
- First, due to the UFD radial profile assumptions and possible associations of the faintest satellites with big systems
- Second, due to the reduced MW mass
- WISE is magic. TBTF solved.

Caveats

- Why would the faintest satellites only live in bigger systems and not in the field?
- If the accretion was quiescent after the bouts of very early accretion, what about all the dwarf galaxy streams in the MW?
- Our low MW mass starts to disagree strongly with most other estimates
- Can the Sgr disruption model be broken by assuming a rotating progenitor (see Penarrubia et al 2010/2011) or perturbed Milky Way (see Vera-Ciro & Helmi, Gomez et al)