Gaia's view of the Milky Way halo

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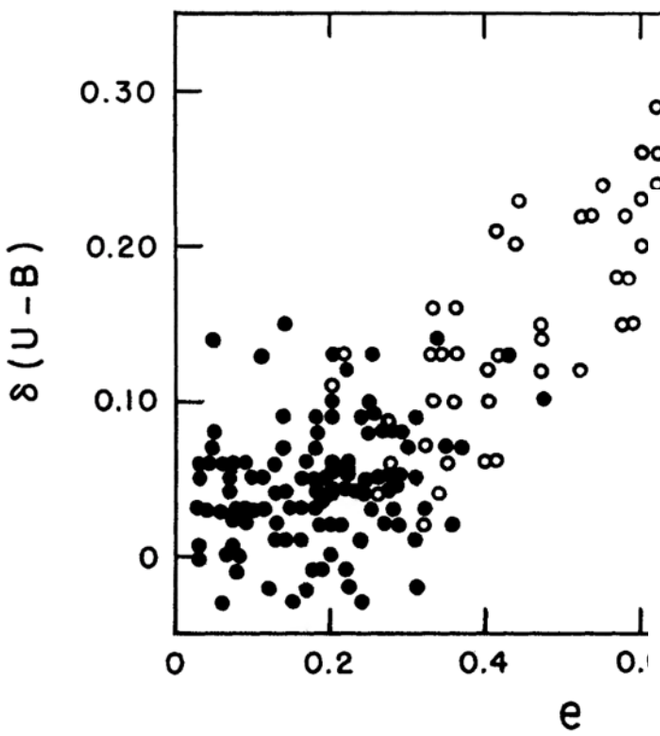
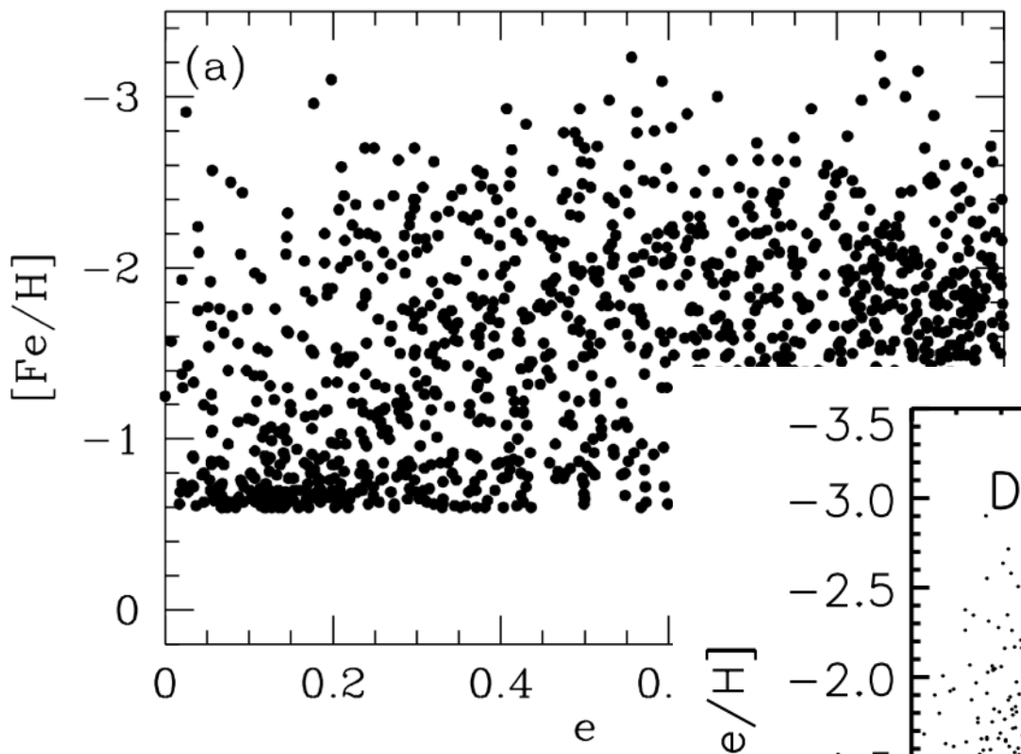
IoA, Cambridge

Previous attempts to understand the chemo-dynamics of the Galaxy

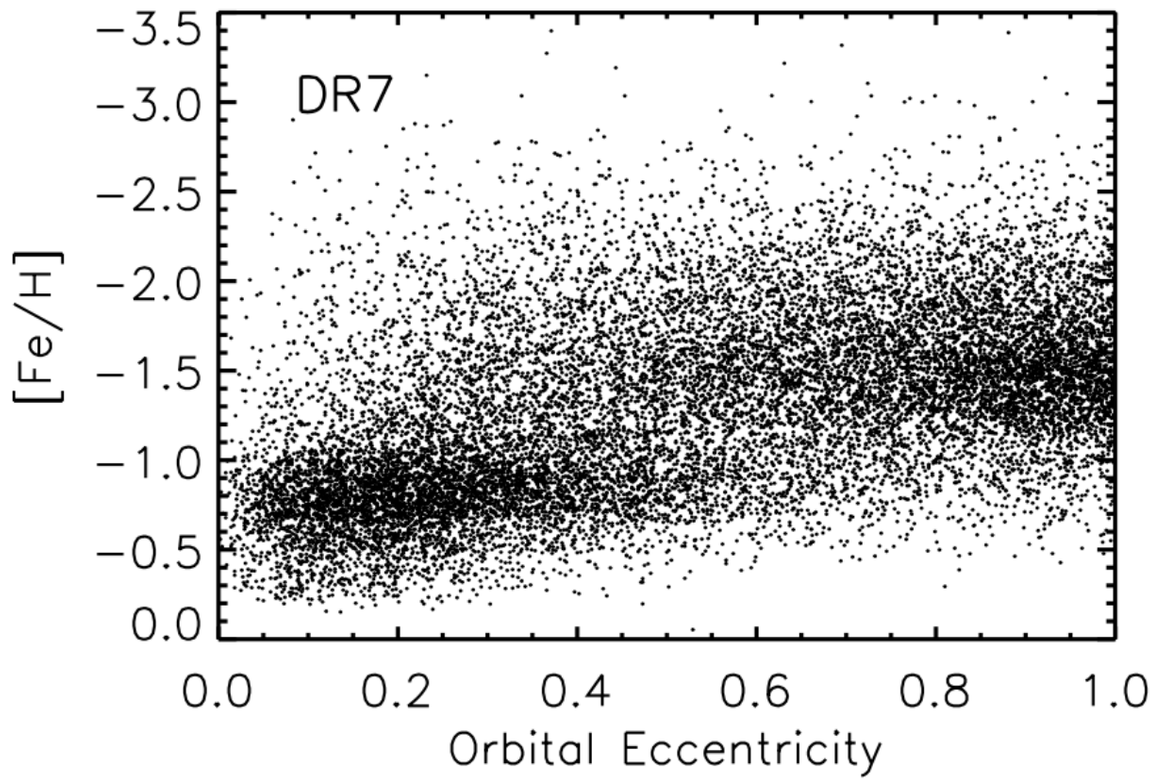
Eggen, Lynden-Bell & Sandage 1962



Chiba & Beers 2000



Carollo et al 2000



A prediction

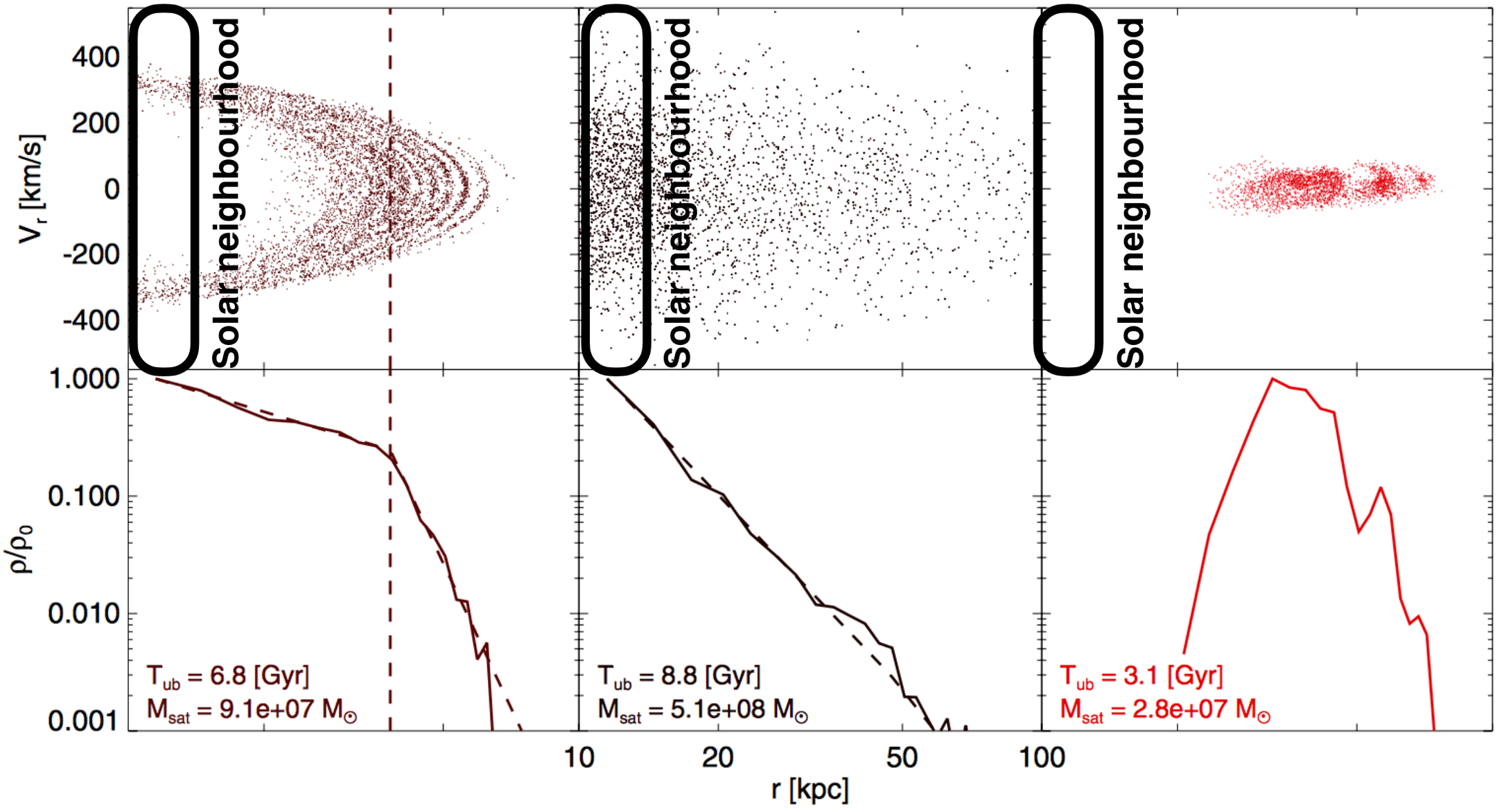
From the Abstract of
"Broken and Unbroken. The Milky Way and M31 stellar halos"

"The presence or absence of a break in the stellar halo profile can be related to the accretion history of the galaxy. We find that a break radius is strongly related to the buildup of stars at apocenters. We relate these findings to observations, and find that the "break" in the Milky Way density profile is likely associated with a **relatively early (~6–9 Gyr ago) and massive accretion event.**"

- *A. Deason et al, 2013*

Link between the stellar halo and the MW accretion history

Individual accretion events in Bullock & Johnston 2005 suite



Deason et al 2013

“Transient fossil”

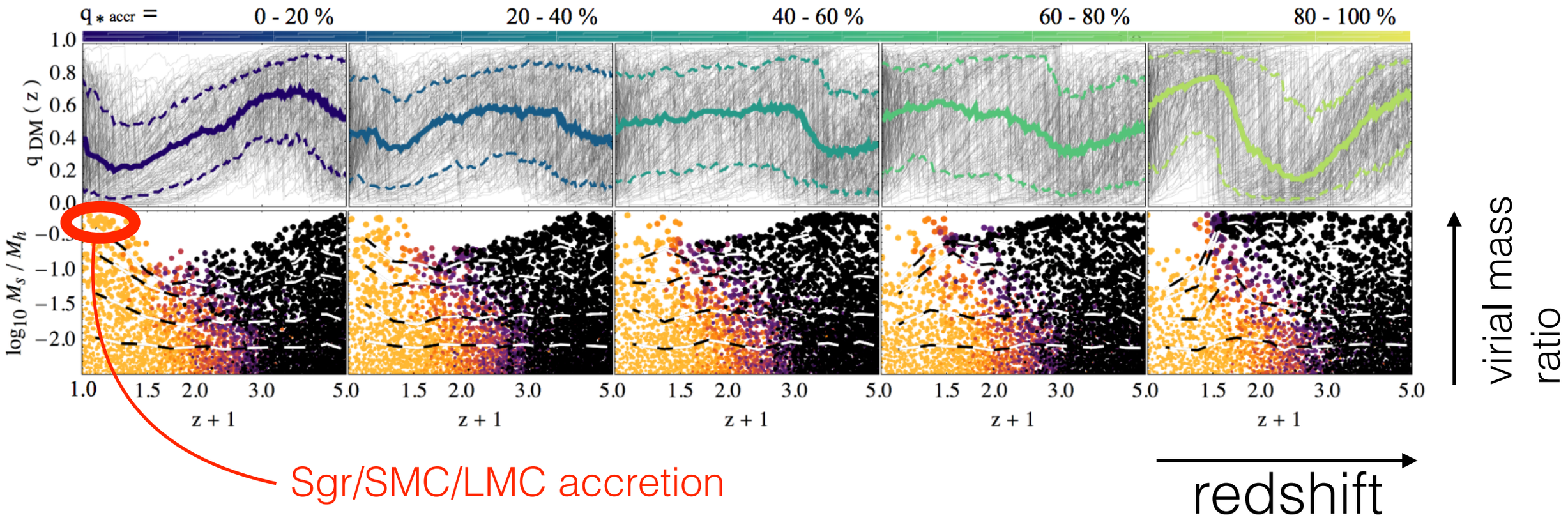
- halo break implies a significant early merger and, subsequently, a quiescent accretion history
- MW may be in a rare class of “transient fossils” with low stellar halo mass **and** massive currently in-falling dwarfs (such as Sgr/SMC/LMC) - Deason et al (2018)

Link between the stellar halo and the MW accretion history

5 quantile ranges in total stellar halo mass at z=0

low stellar halo mass

high stellar halo mass

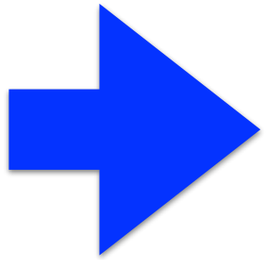


0 — 1 f * = fraction of stellar mass in surviving satellite remnant at z = 0

Amorisco 2017

Local Stellar halo in 7-D

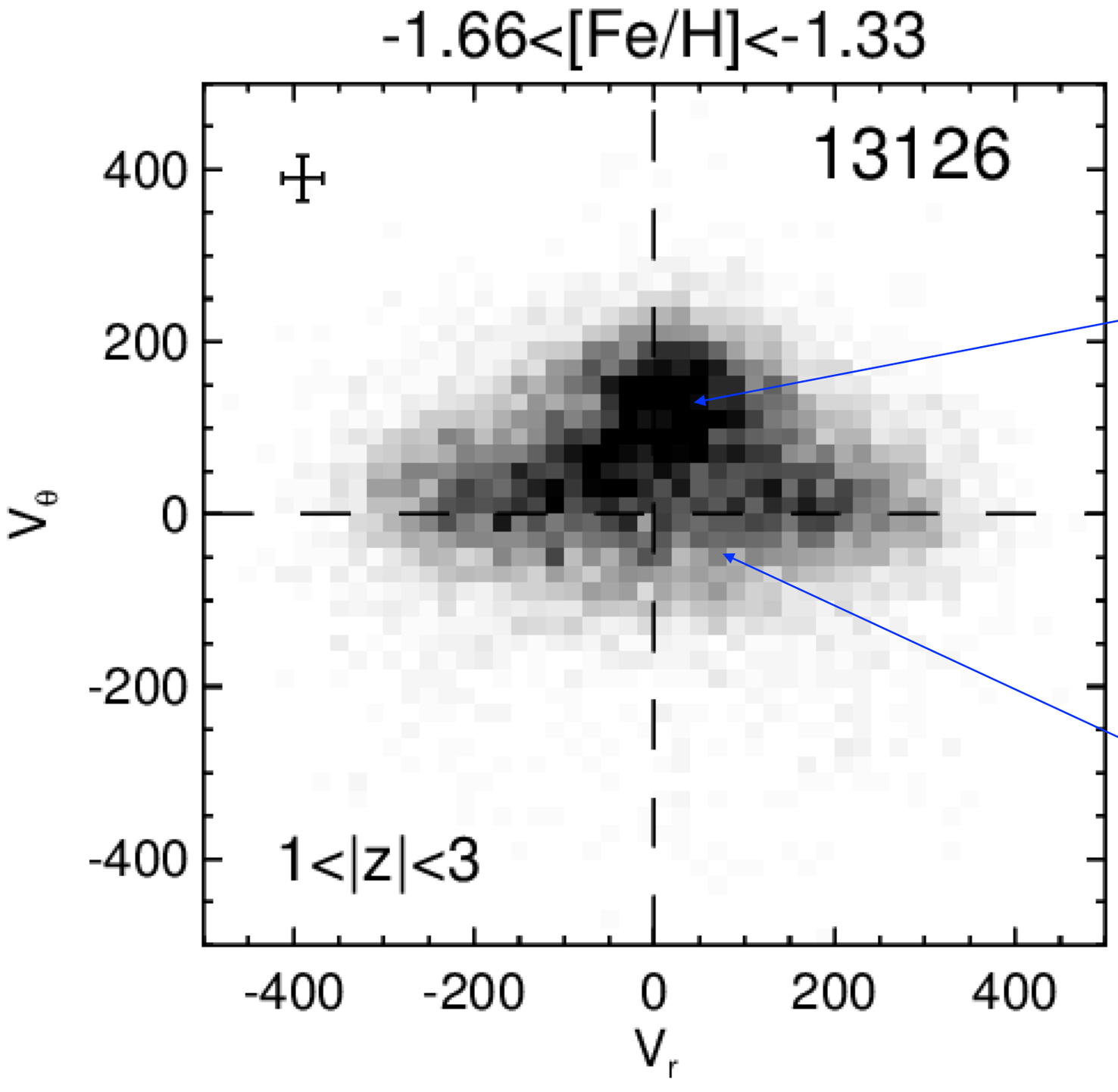
1. Position on the sky
2. Position on the sky
3. Color+magnitude
4. Proper motion RA
5. Proper motion Dec
6. Line-of-sight velocity
7. Metallicity



1. Galactic X
2. Galactic Y
3. Galactic Z
4. Galactic Vx
5. Galactic Vy
6. Galactic Vz
7. Metallicity

SDSS+Gaia DR1: 100,000 Main Sequence stars
in 10x10x10 kpc box centred on the Sun

Local Stellar halo in 7-D

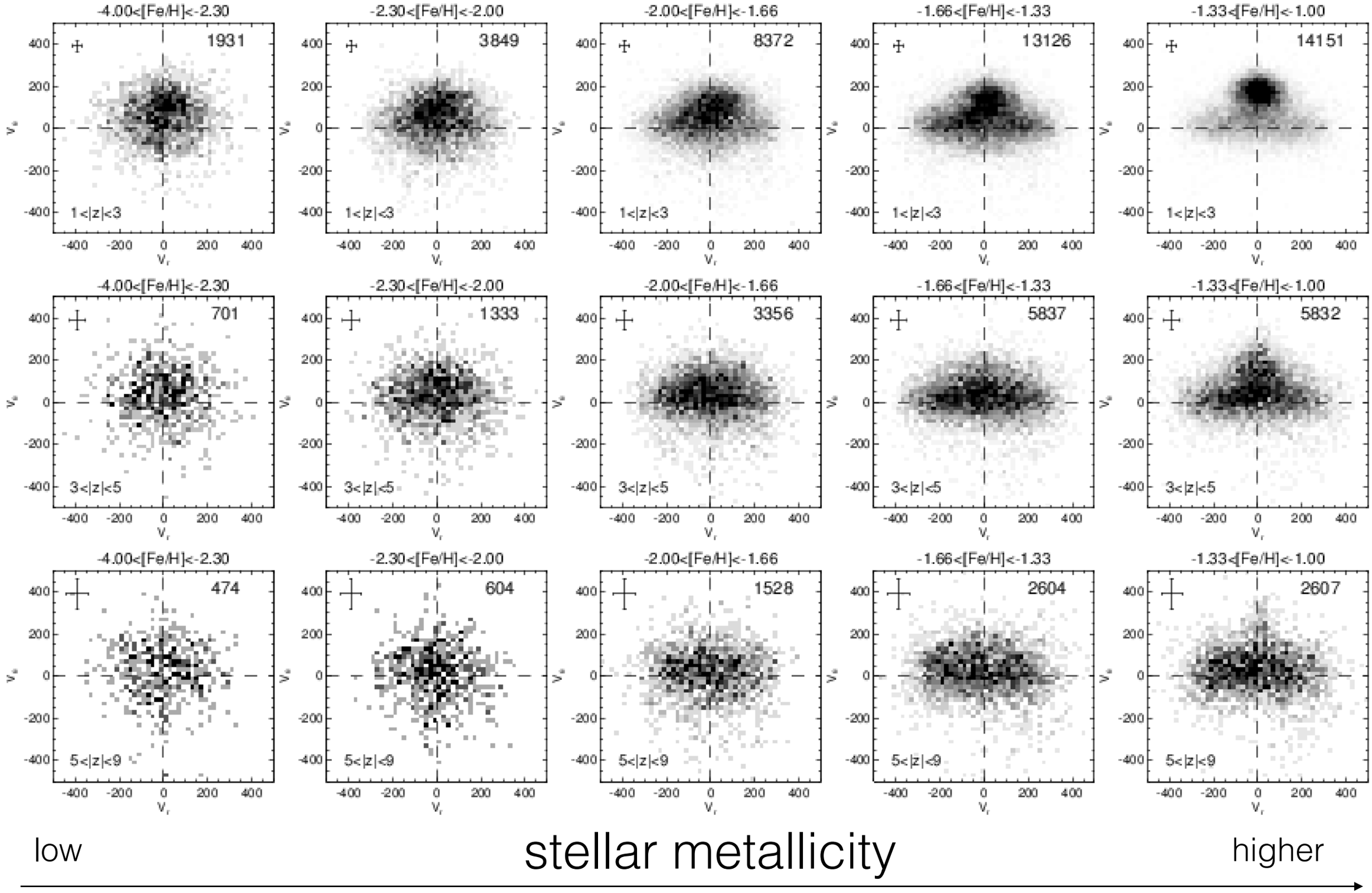


(thick) disc stars

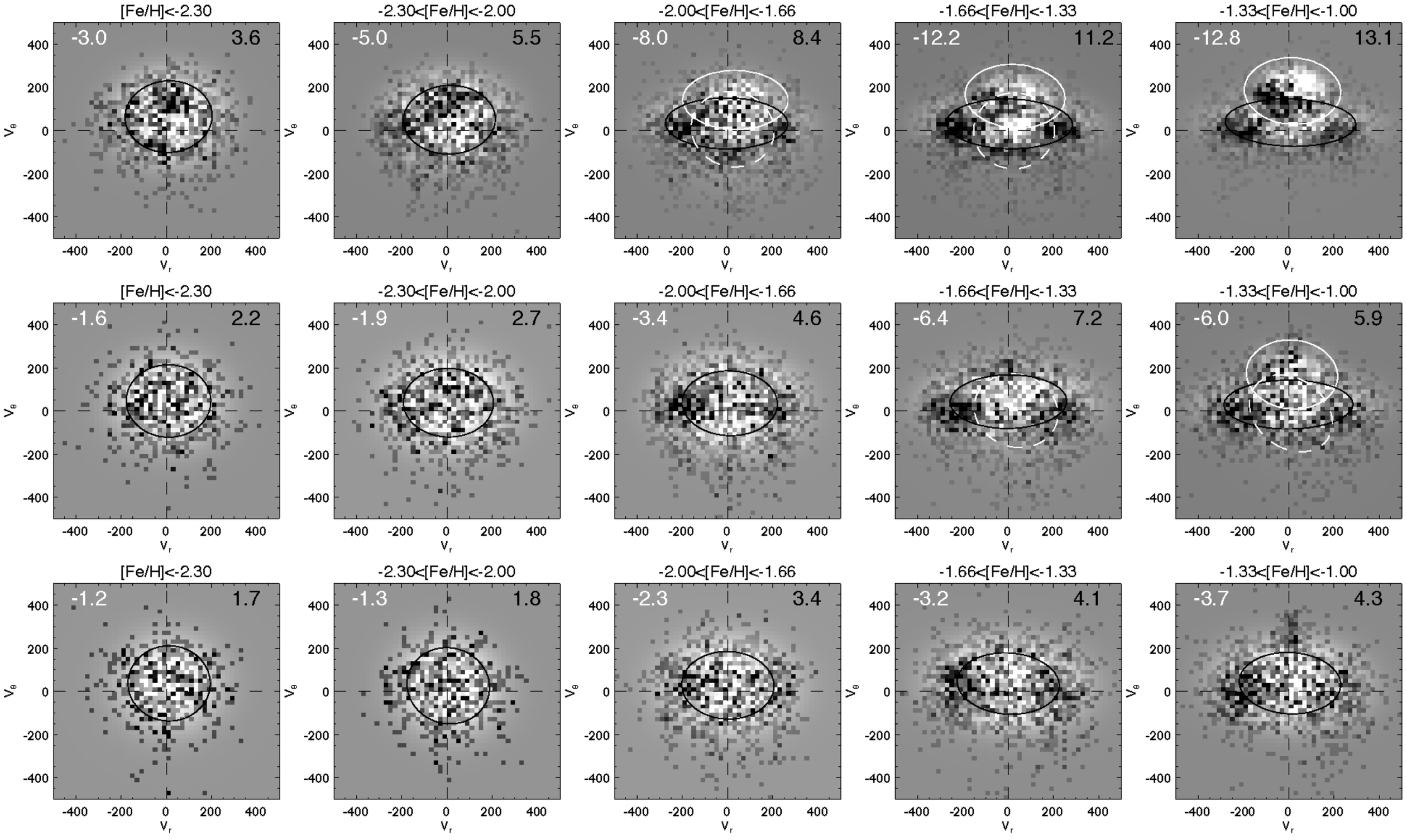
stellar halo

VB et al 2018

Local Stellar halo in 7-D

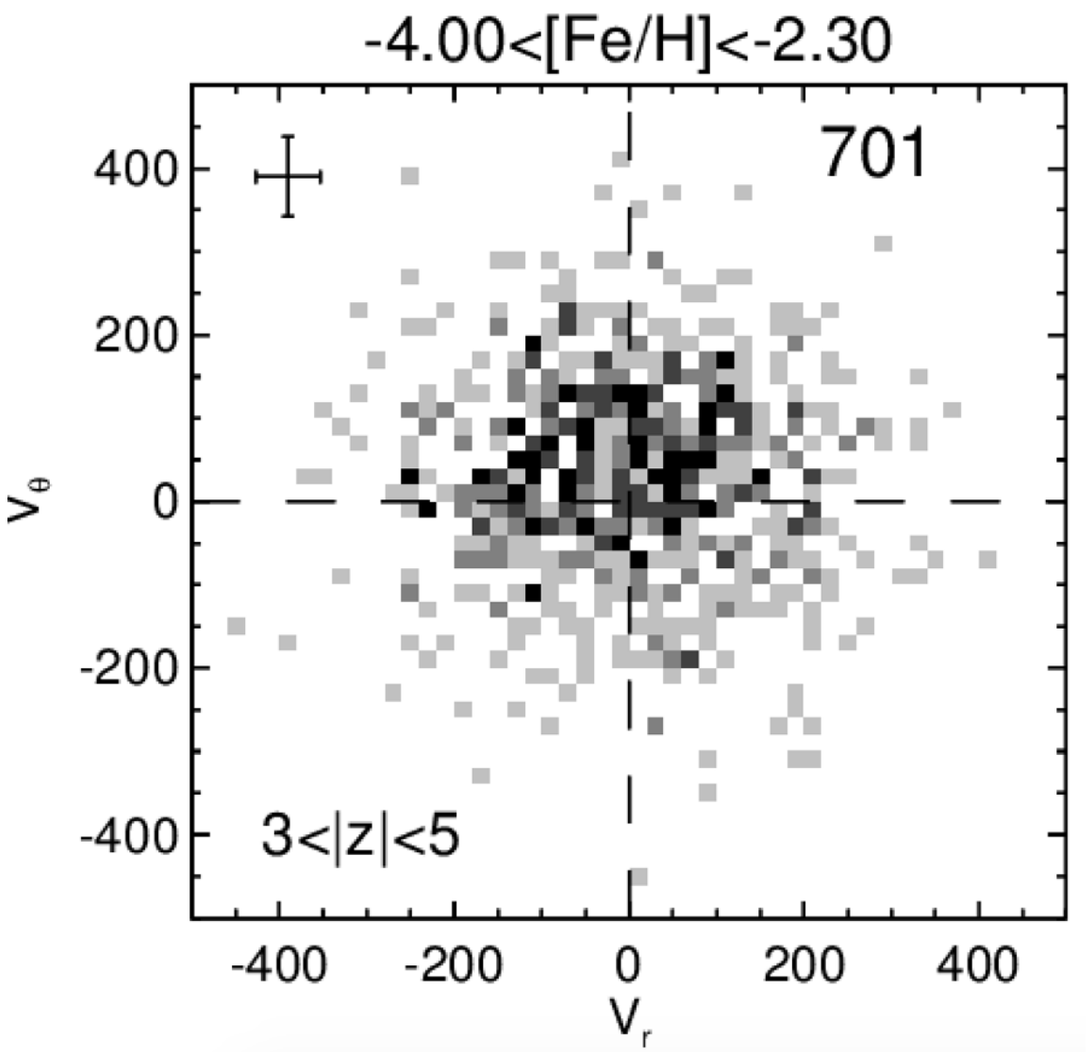


Non-gaussian velocity distribution

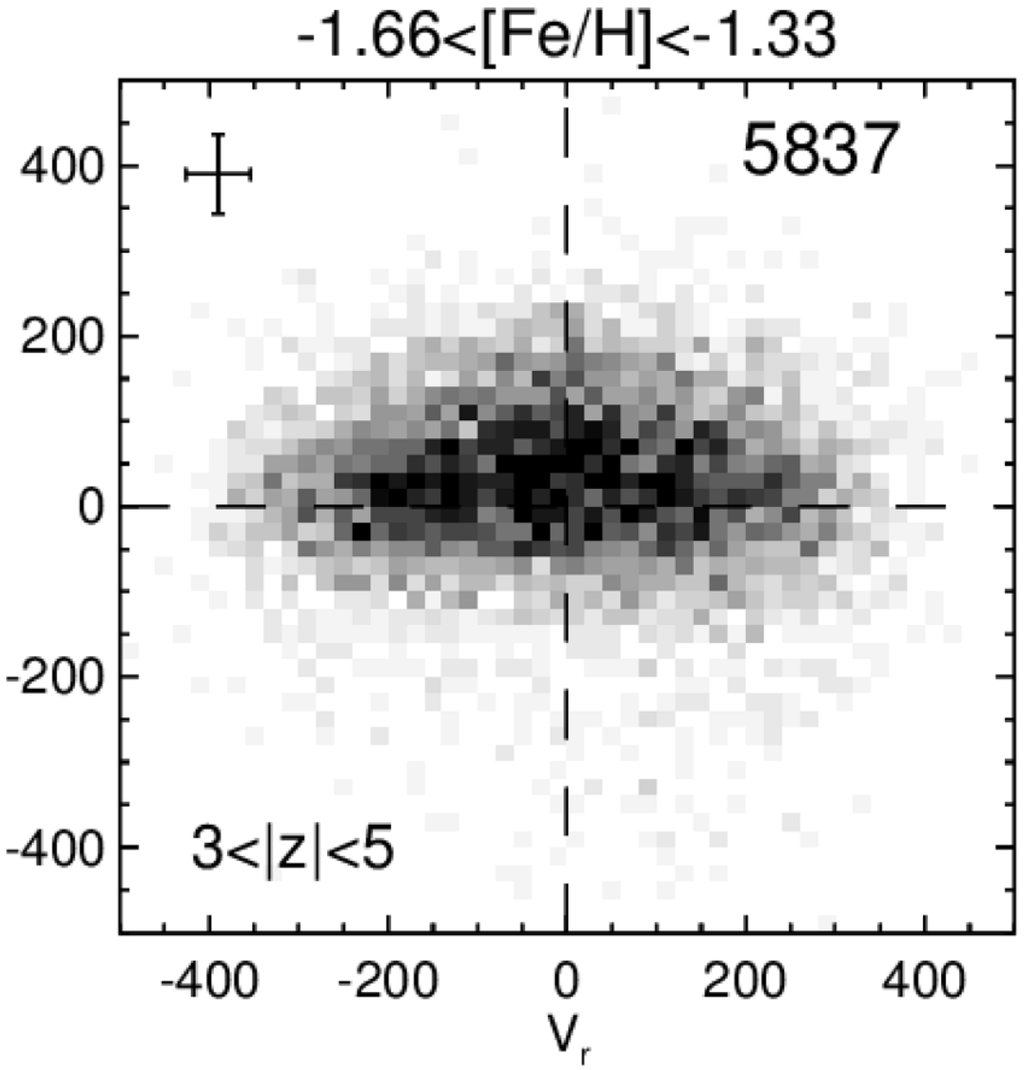


Meatball-sausage dichotomy

"metal-poor"

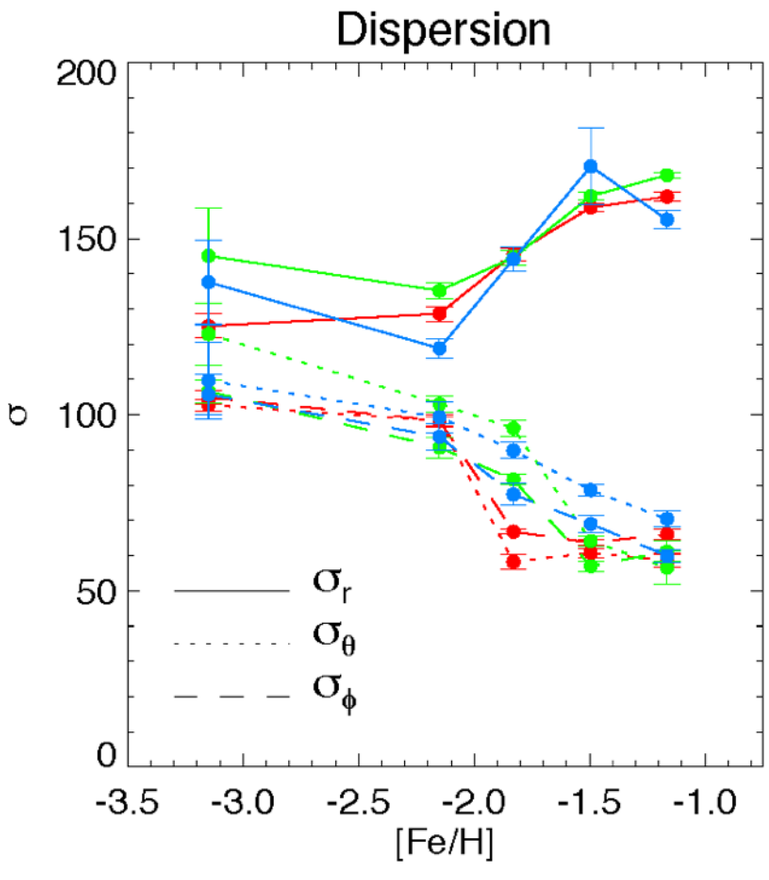


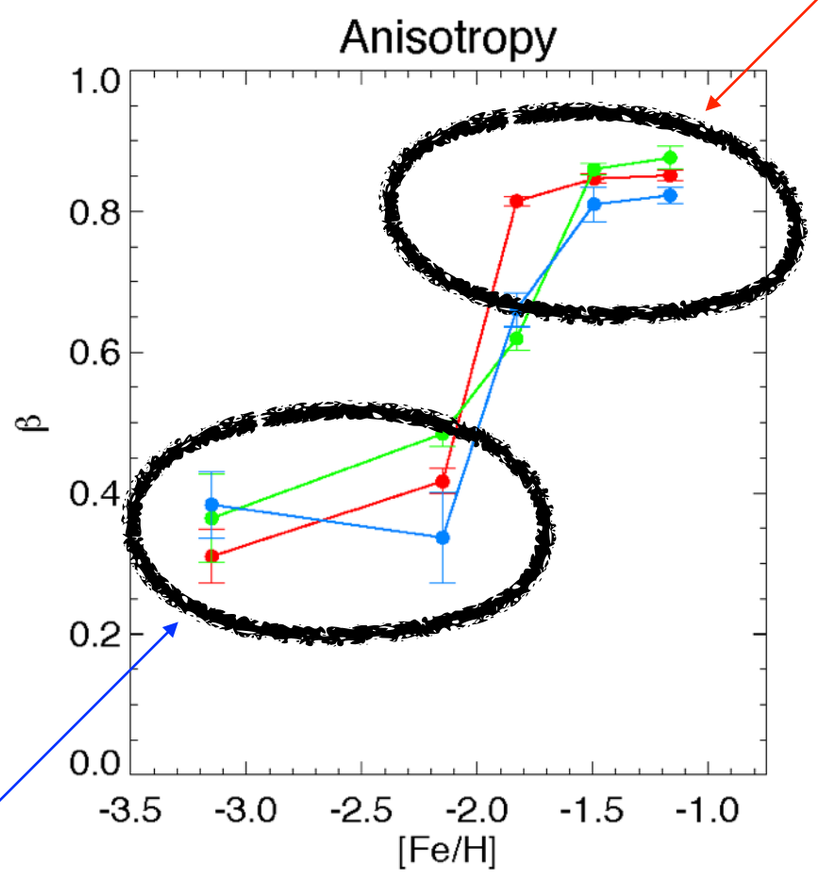
"metal-rich"

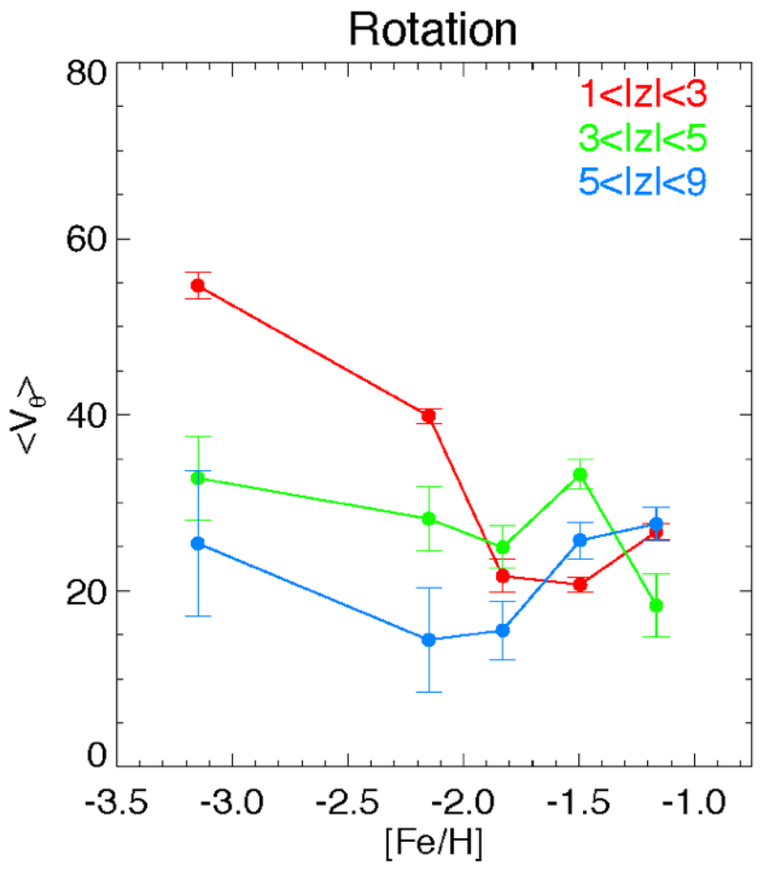


Galactic stellar halo in 7-D

extreme radial anisotropy - preferred direction







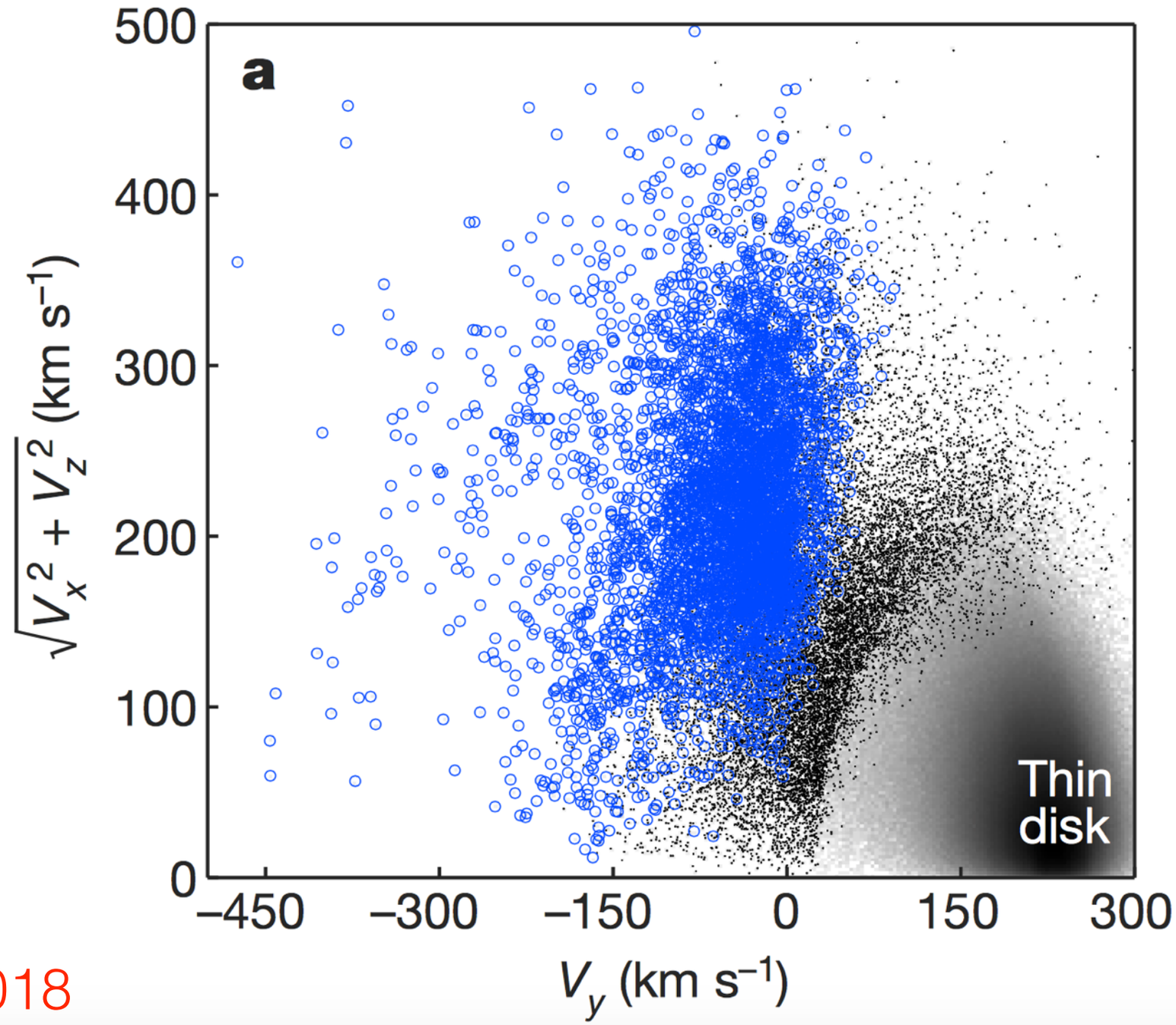
consistent with continuous accretion of small dwarfs

Summary of the discovery in Gaia DR1

- 2/3 of the (local) stellar halo in a single component
- Stars as metal-rich as 1/10 Solar
- Extreme radial anisotropy

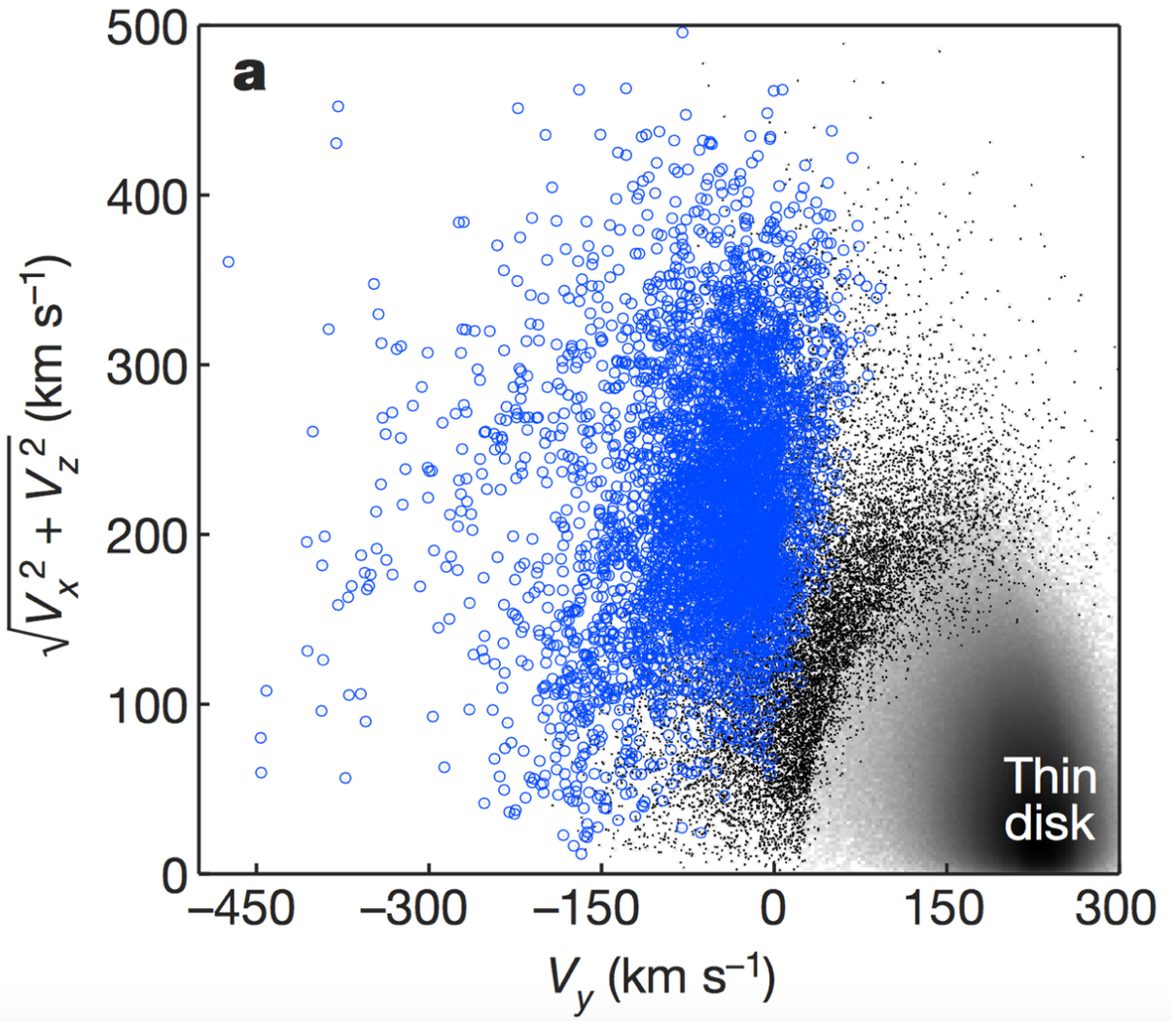
Independent discovery in Gaia DR2

$-1{,}500$ kpc km s^{-1} < Lz < 150 kpc km s^{-1}

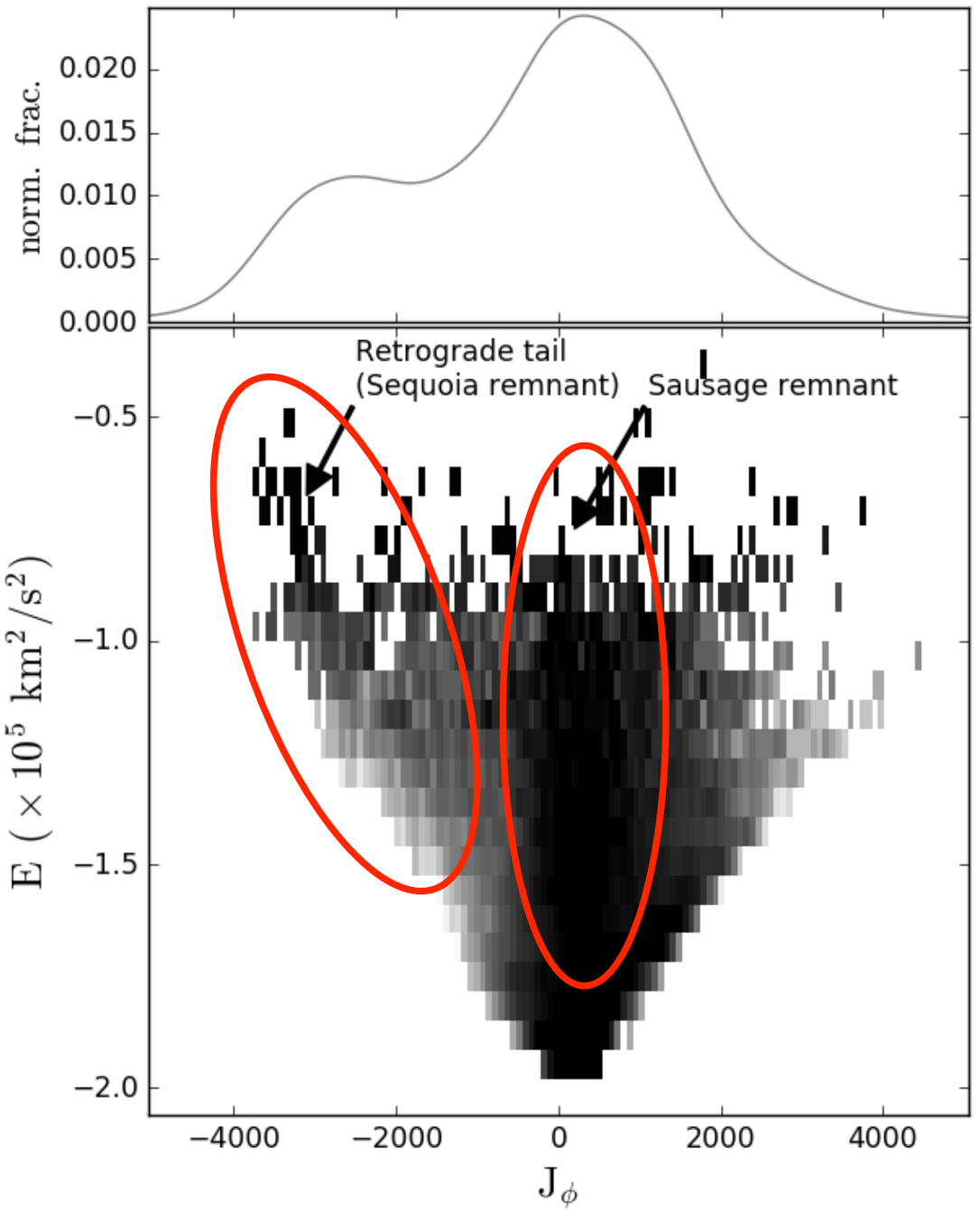


Helmi et al 2018

Enceladus=2/3 Sausage + Sequioa



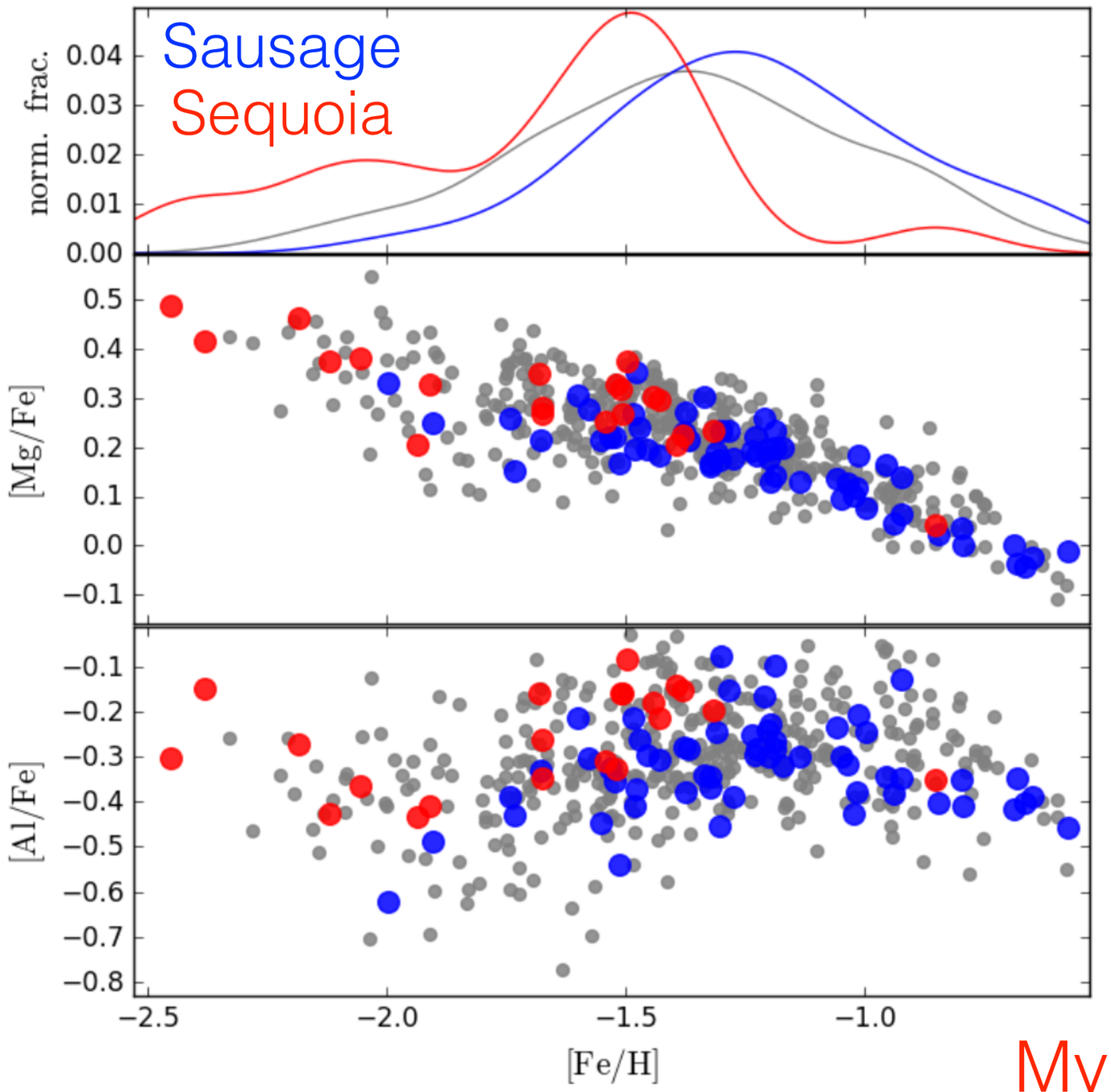
Helmi et al 2018



Myeong et al 2019

The Sequoia Event

APOGEE DR14

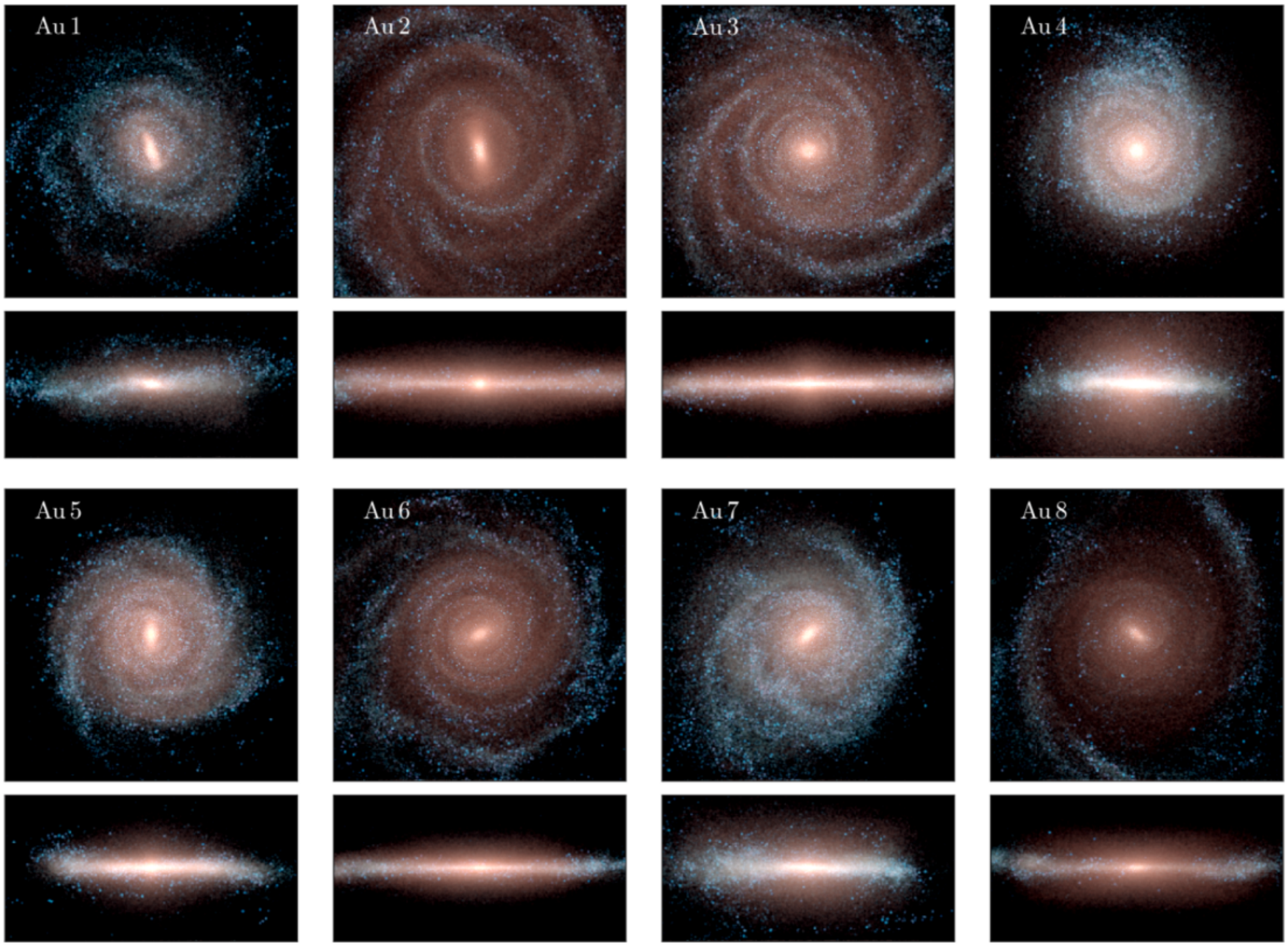


Myeong et al 2019

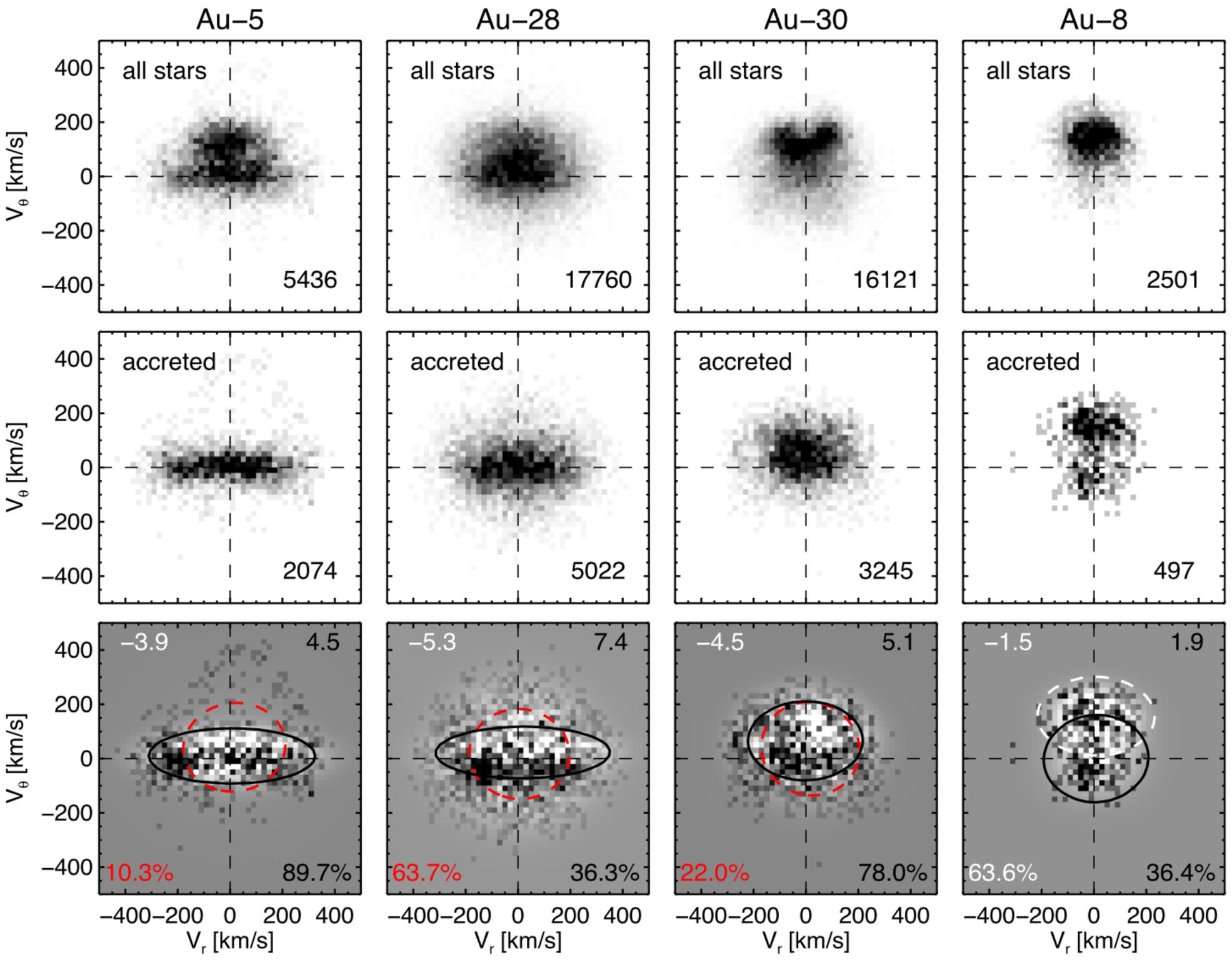
When and What smashed into us?

Numerical simulations

The Auriga suite (Grand et al 2017) - 30 Milky Ways

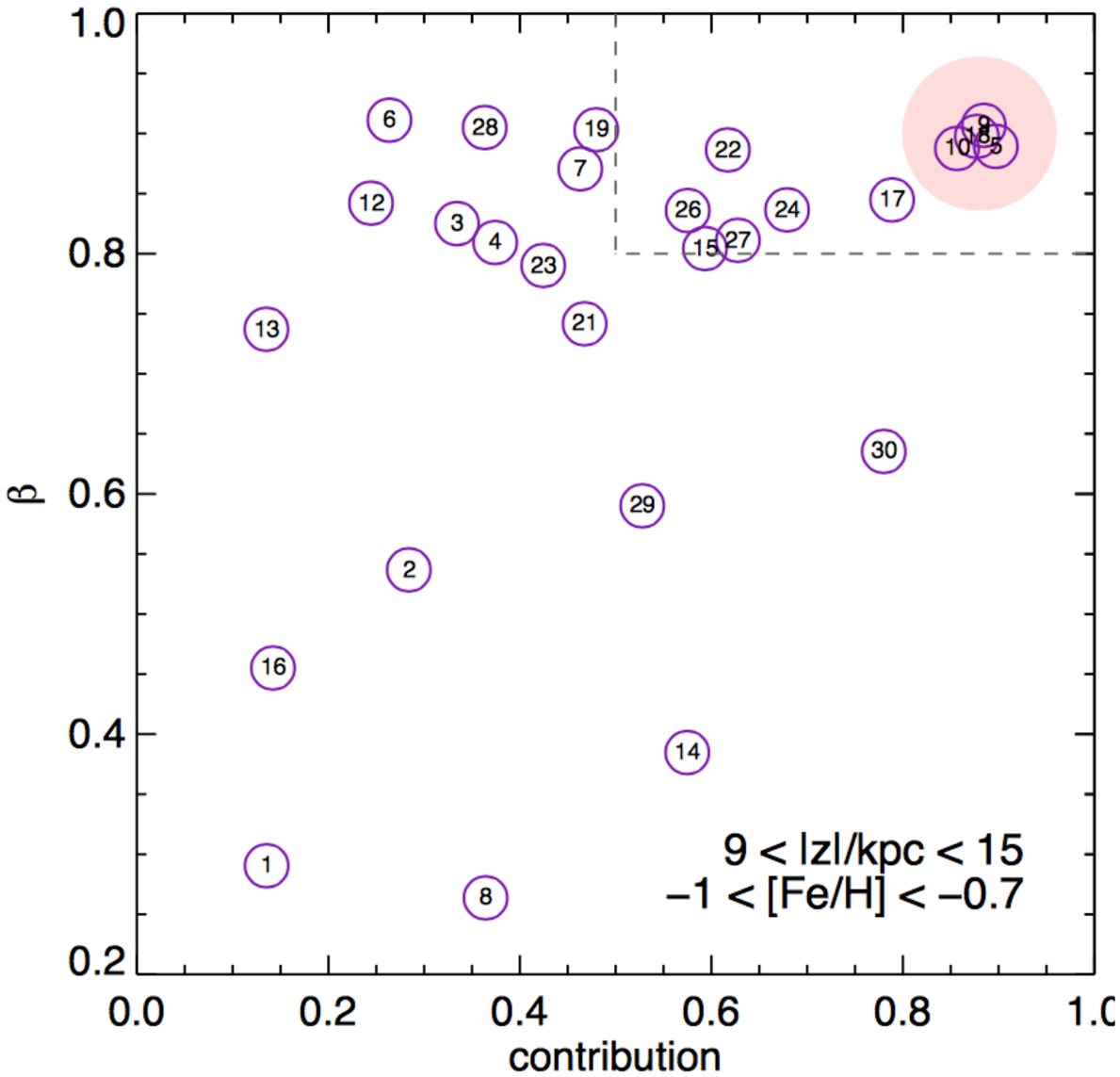


Observing the simulations

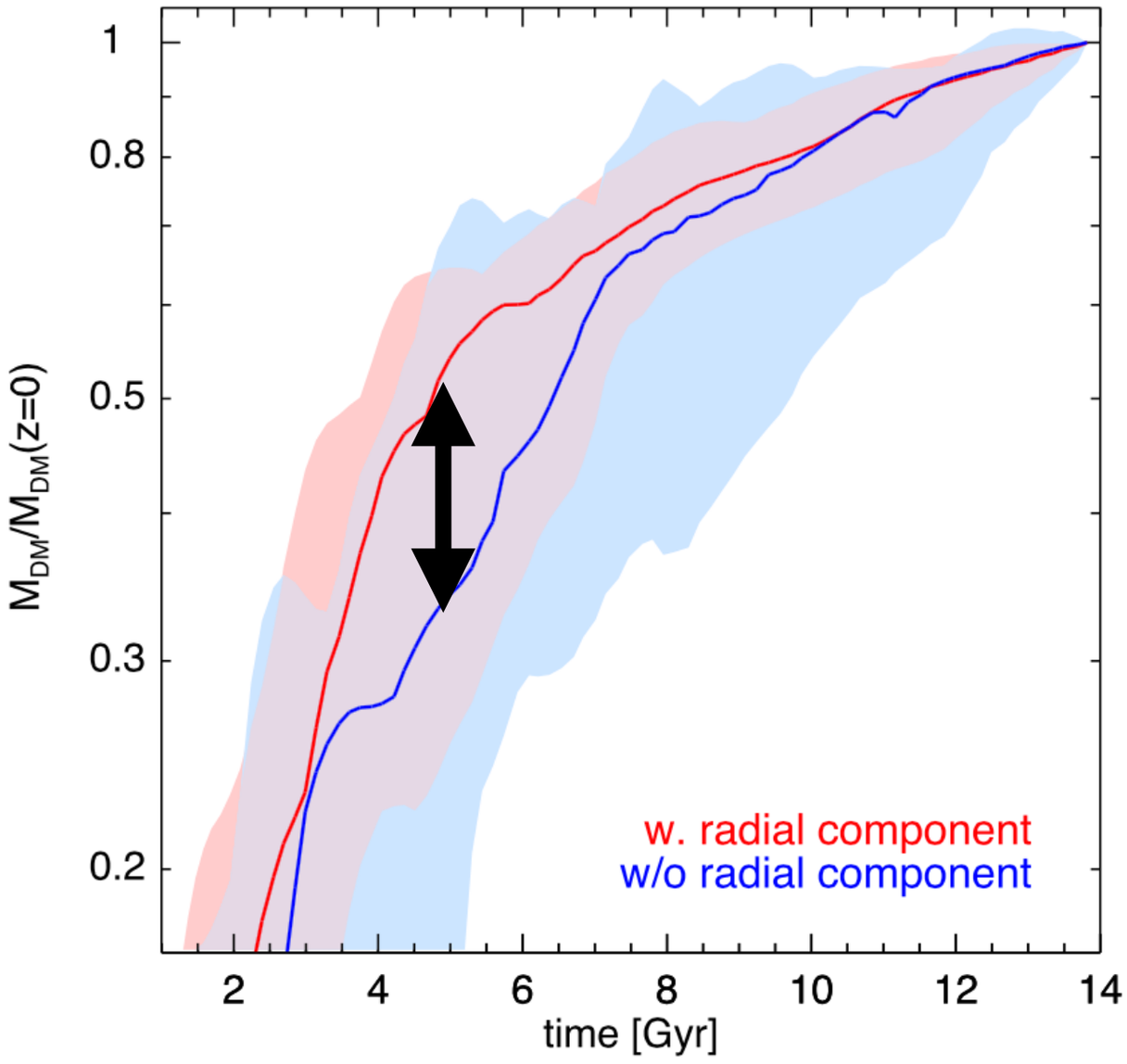


Variety of accretion histories

Orbital anisotropy



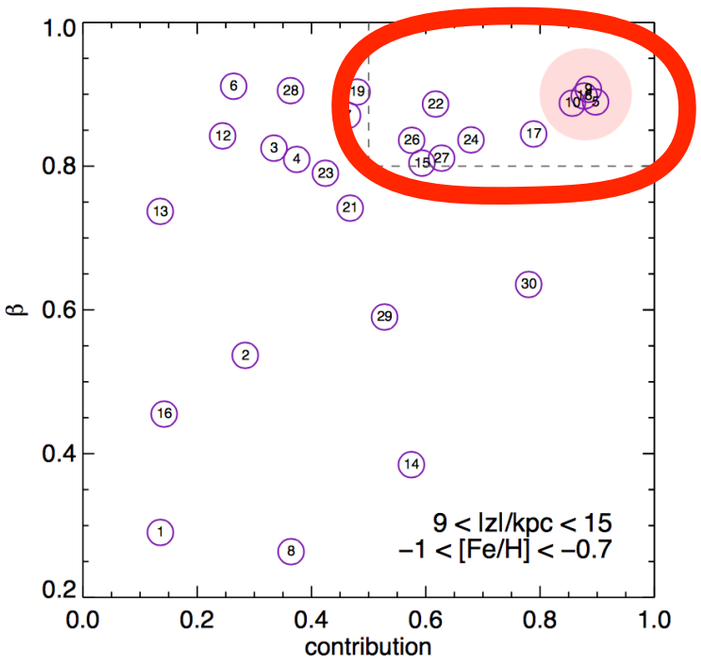
Mass assembly

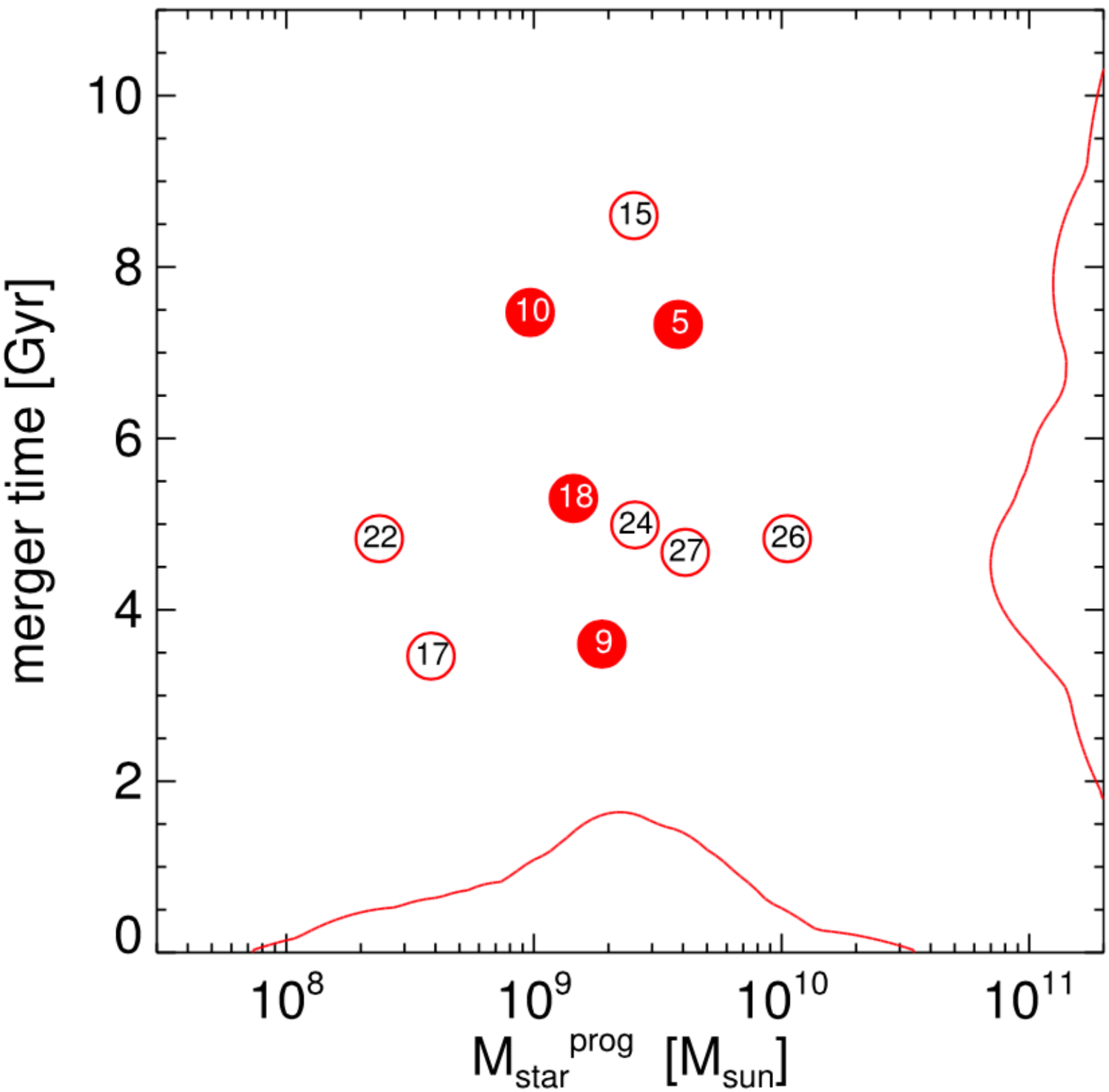


1/3 simulated Milky Ways with a Sausage-like halo

Fattahi et al 2018

When and What smashed into us?



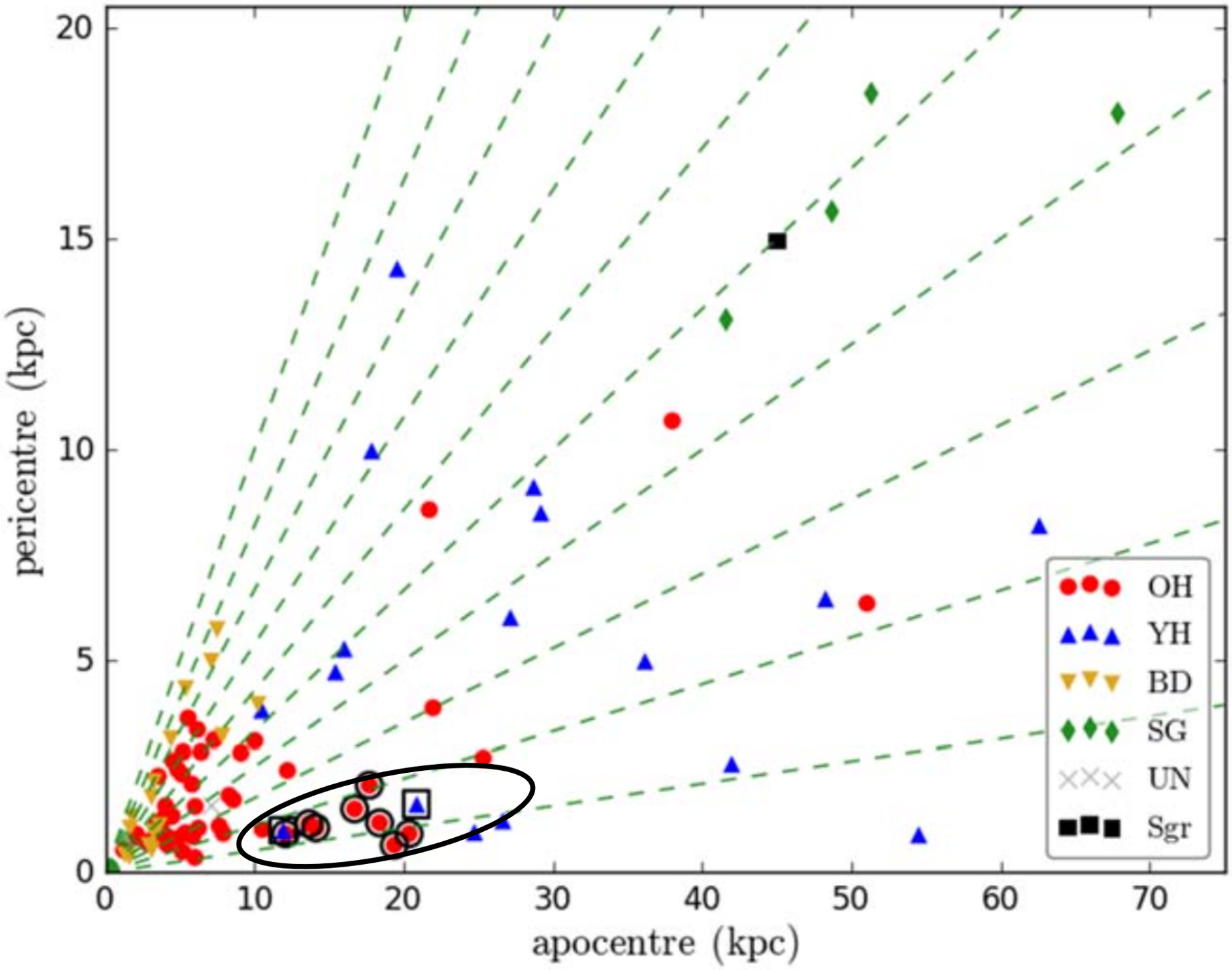


7-11 Gyr ago
as big as the LMC

Fattahi et al 2018

Massive accretion event must bring Globular Clusters

The Sausage globular clusters

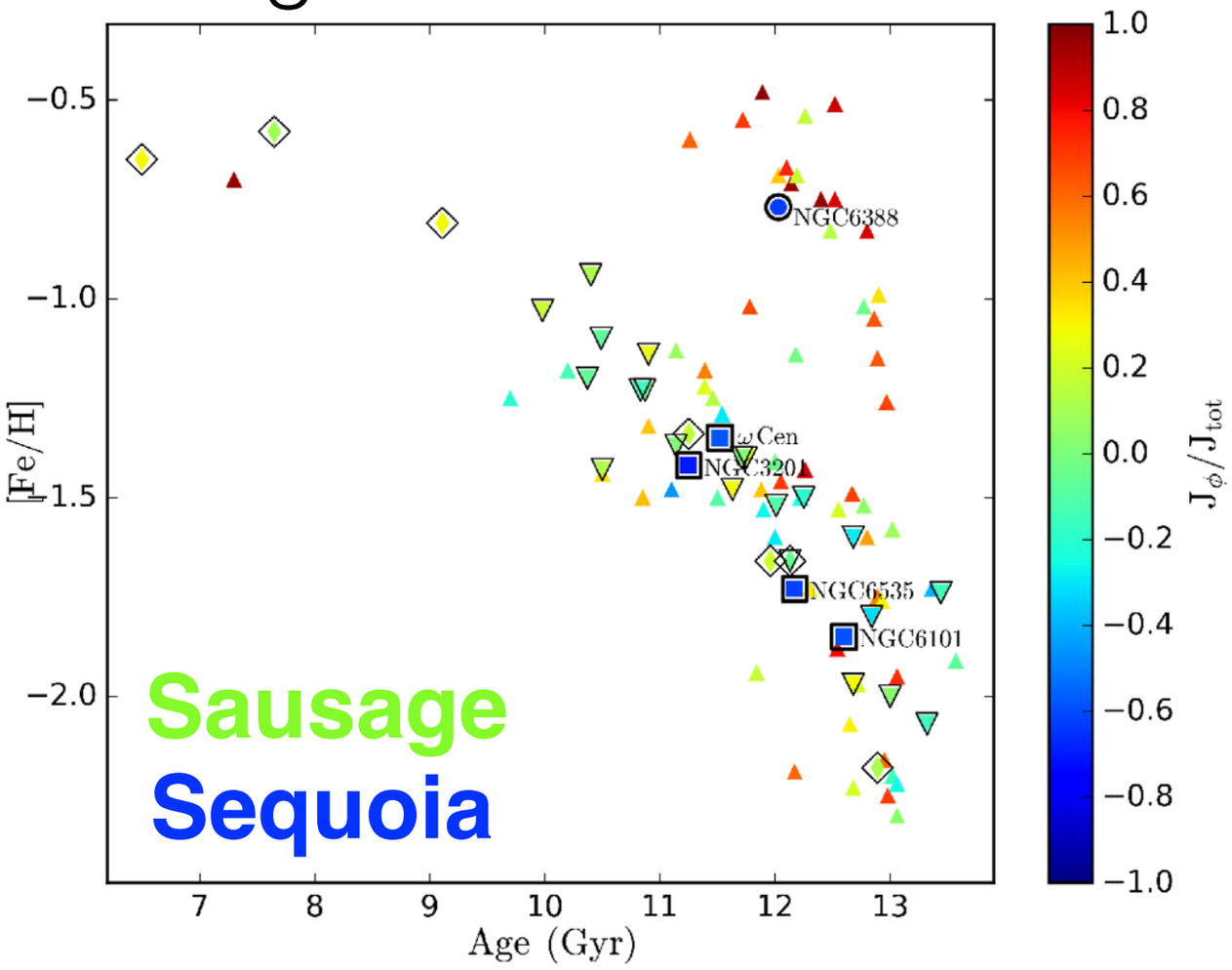


10-20 GCs
depending on the energy cut

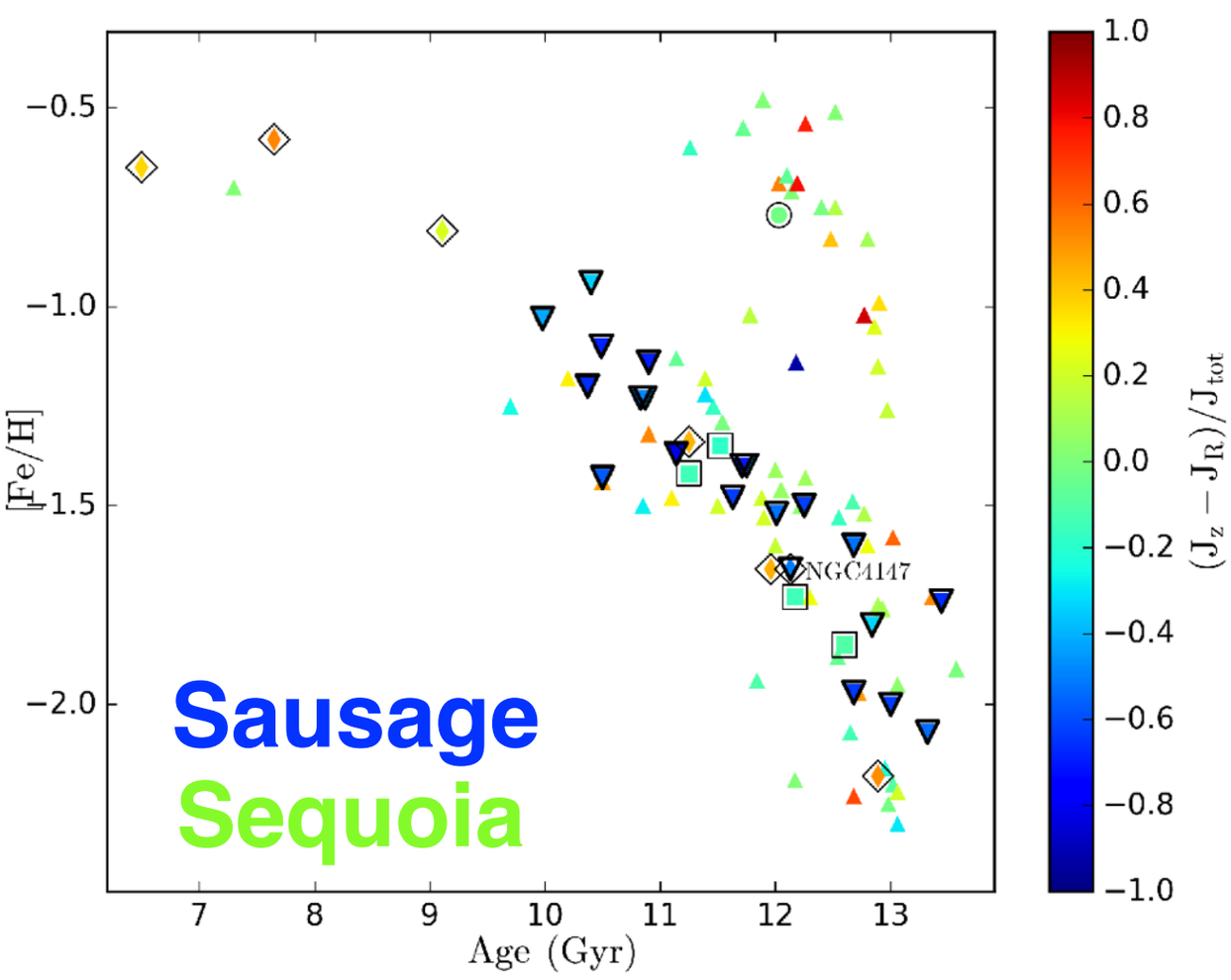
Myeong et al 2018

Sausage and Sequoia globular clusters

Angular momentum

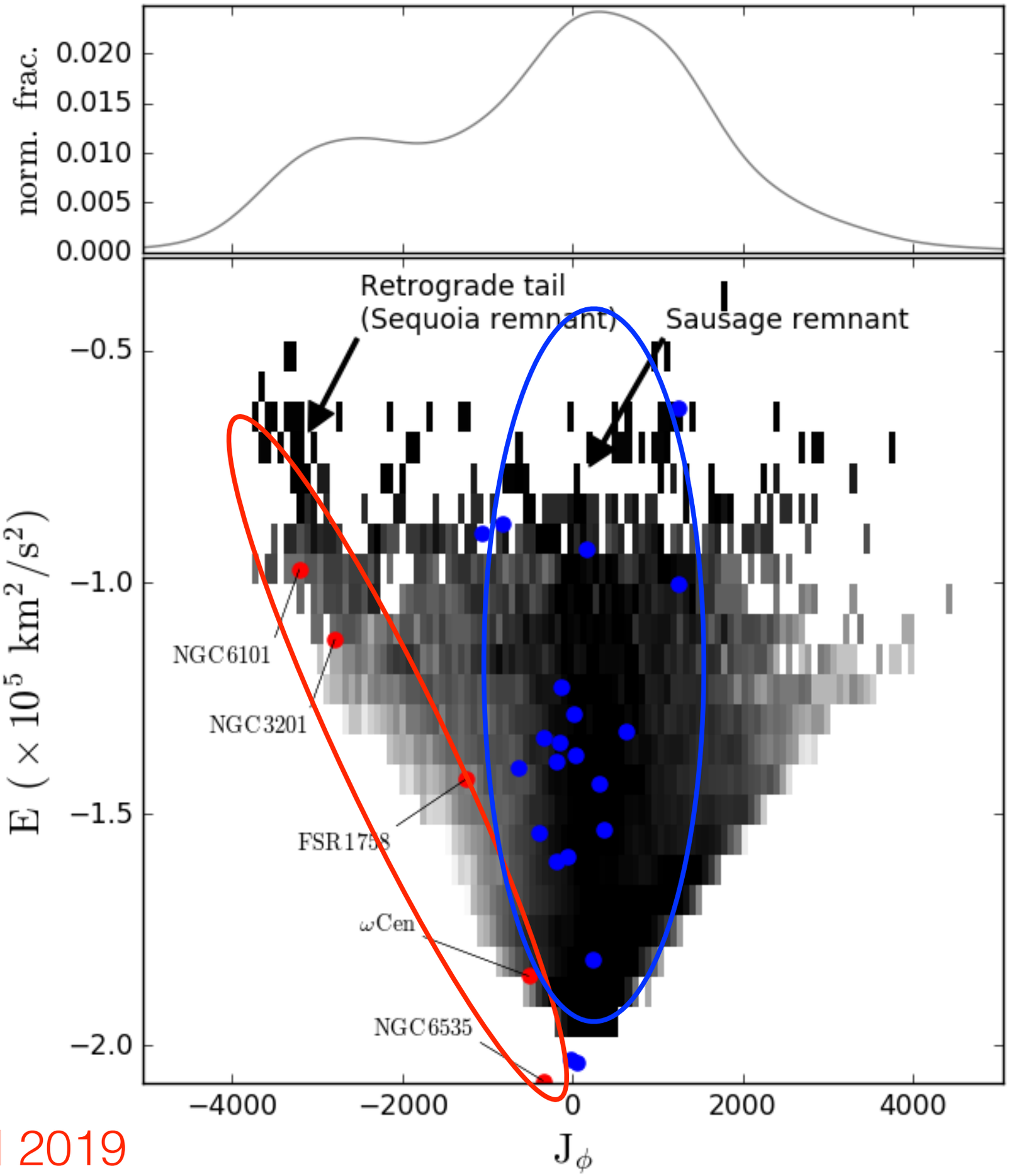


Vertical-Radial Action



age and metallicity from Kruijssen et al. (2019)

Myeong et al 2019



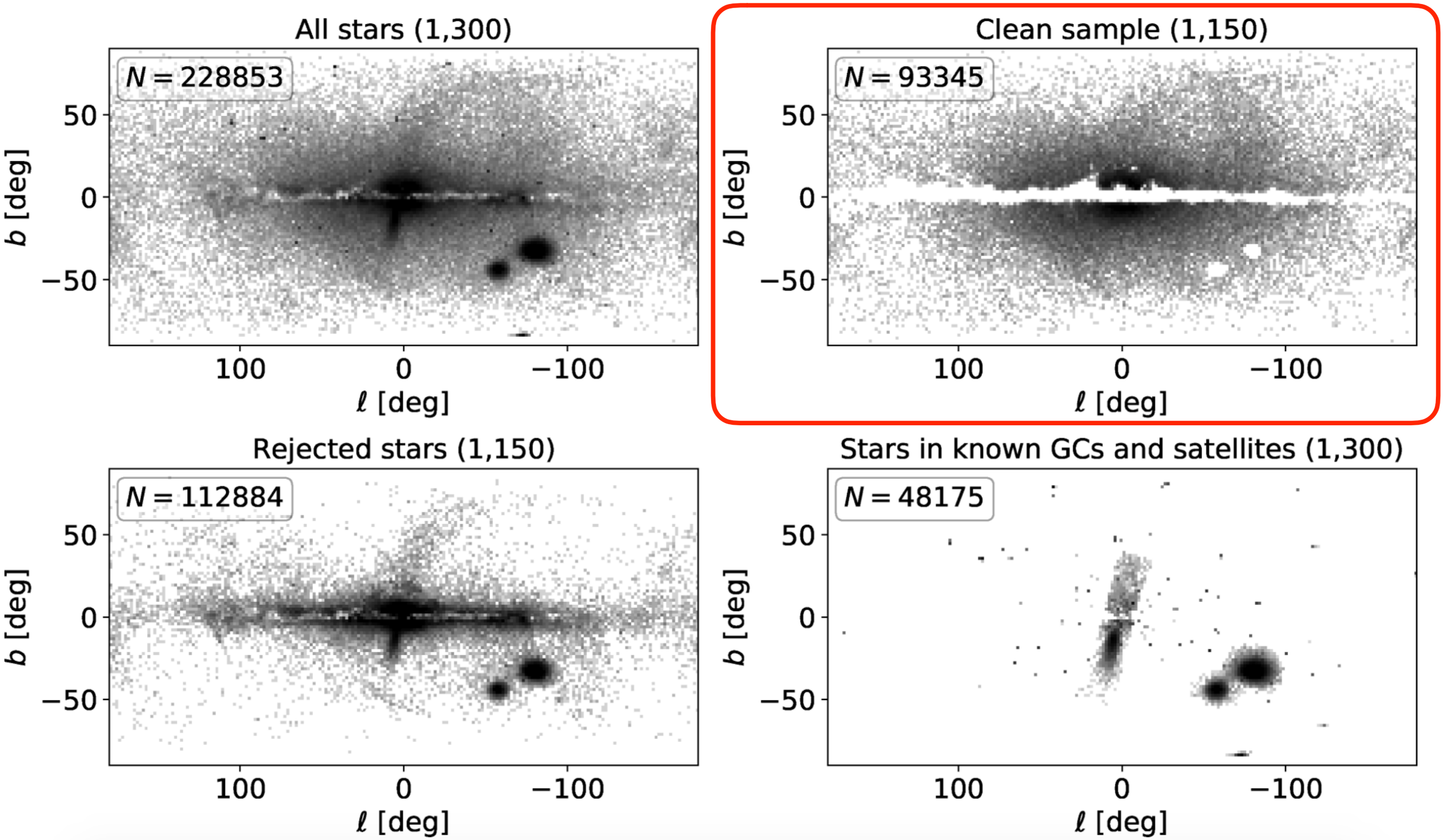
Myeong et al 2019

Anatomy of an ancient major merger

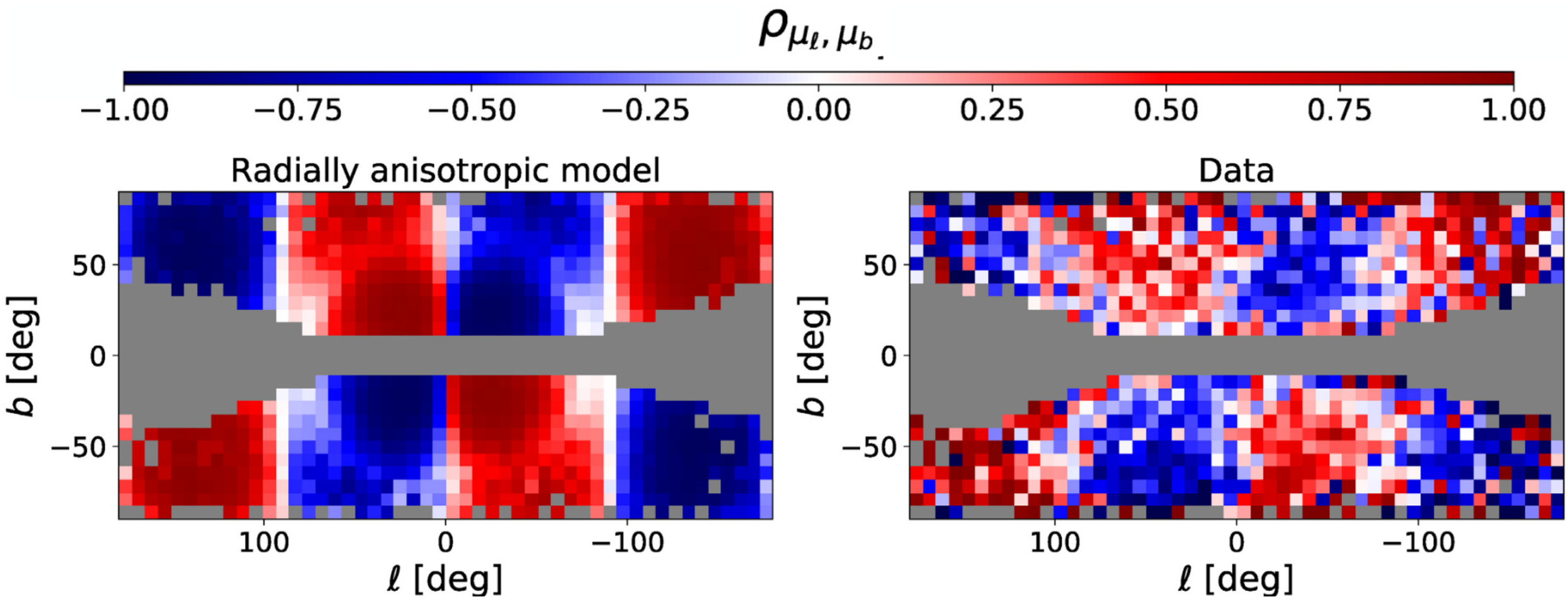
Solar Vicinity → Entire Milky Way

Gaia DR2 RR Lyrae

Gaia DR2 RR Lyrae



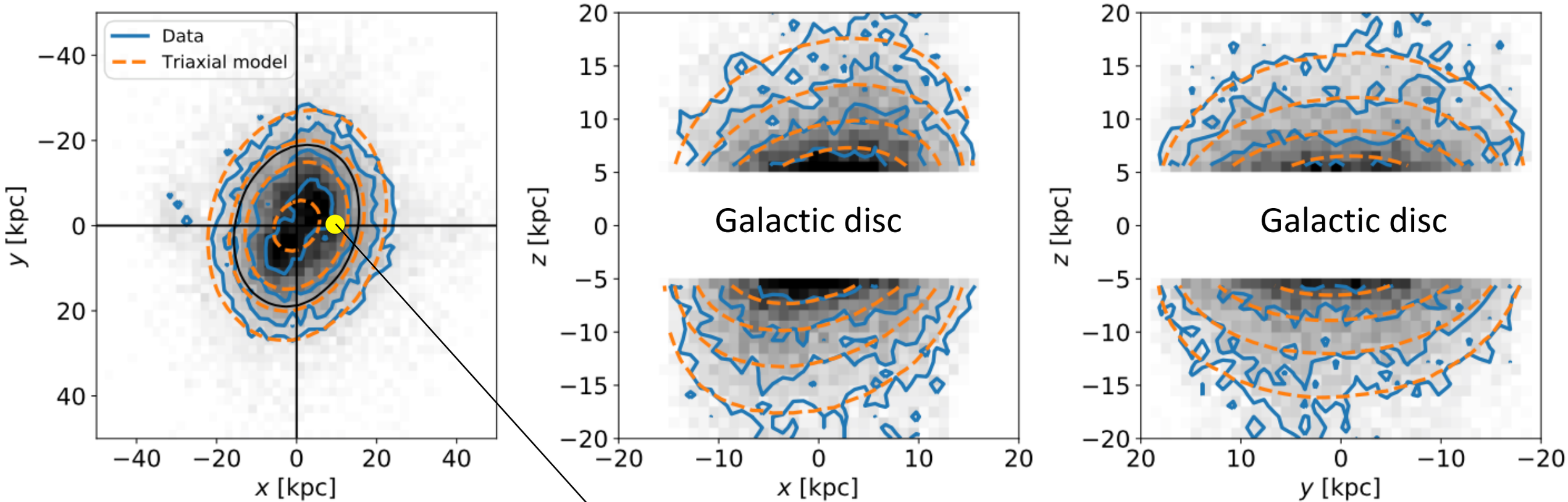
RR Lyrae direction of motion across the whole sky



for a much more thorough analysis, see Wegg & Gerhard 2019

The shape of the debris cloud

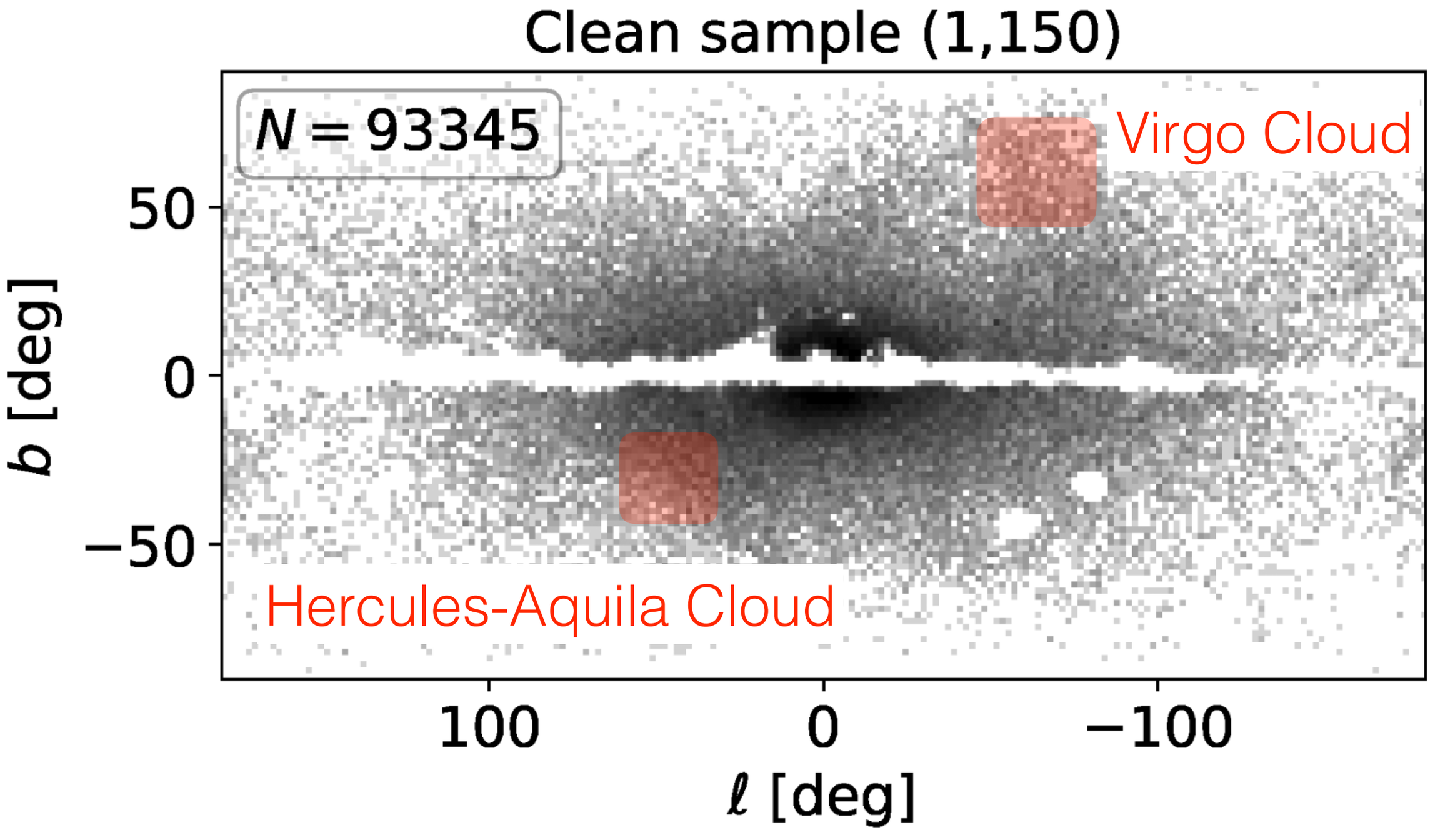
Observed density and model of the Gaia DR2 RR Lyrae



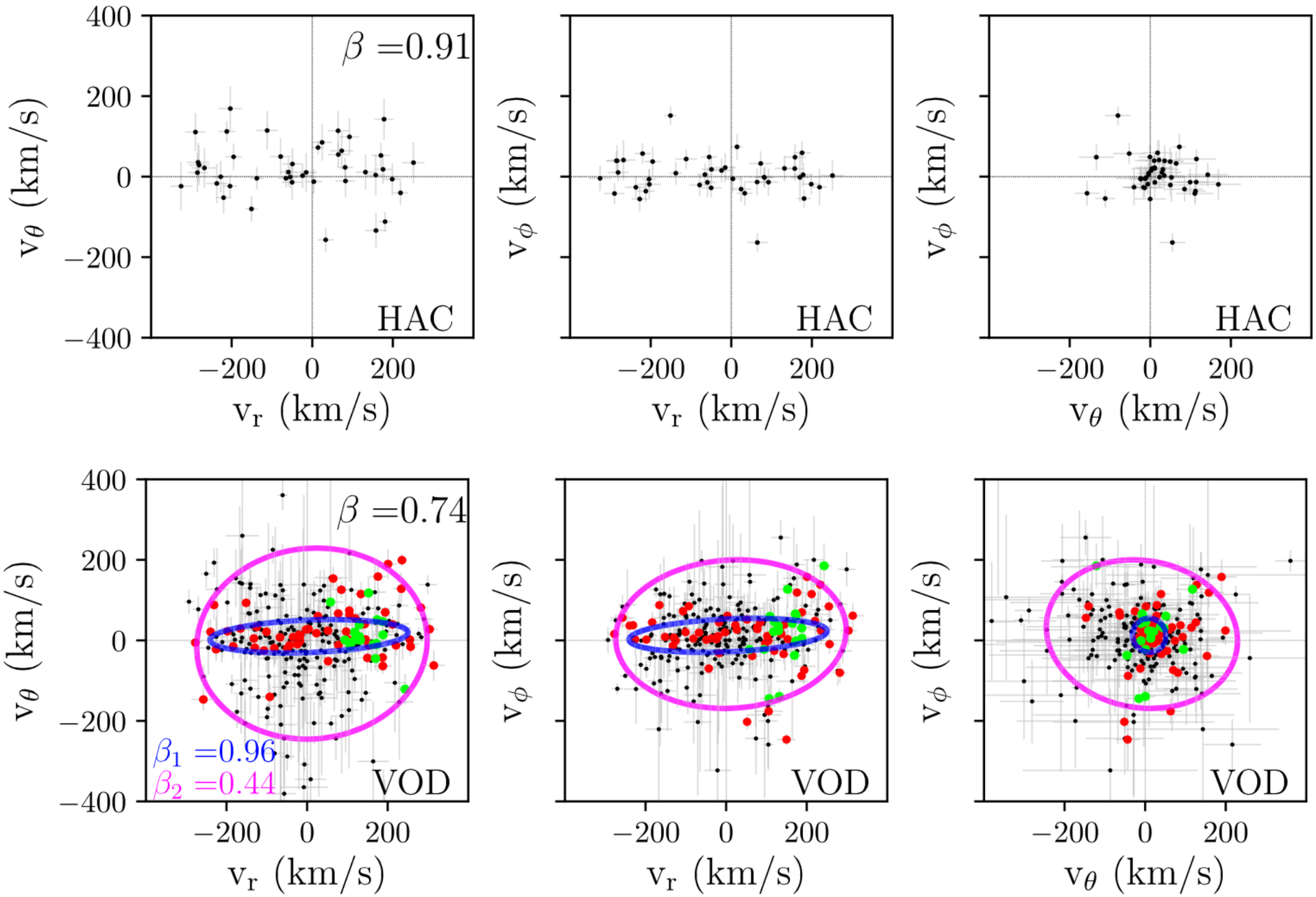
Elongated, triaxial, tilted

Iorio et al 2018

Sausage. Is it well-mixed?

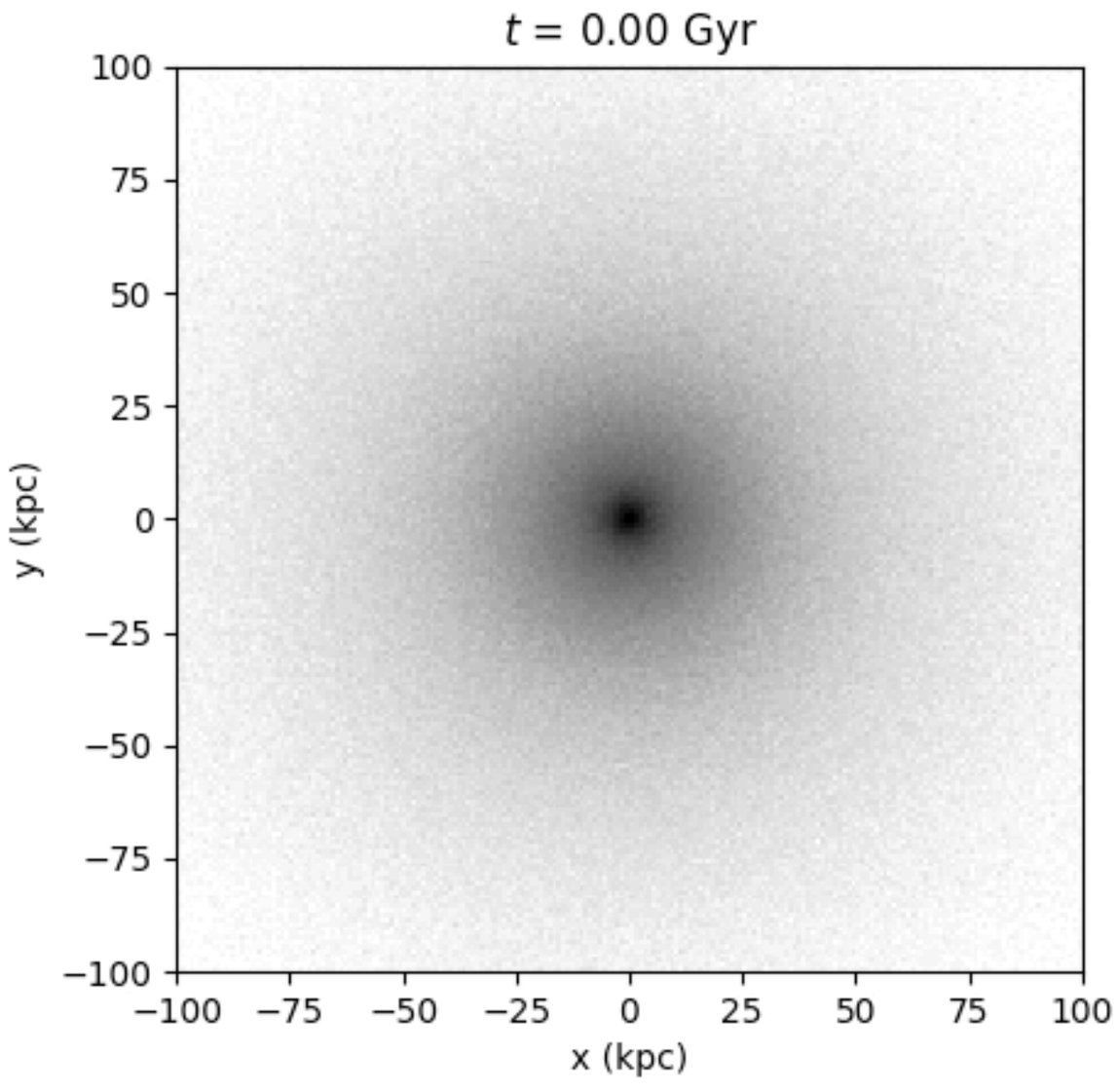


Kinematics of the “Clouds”



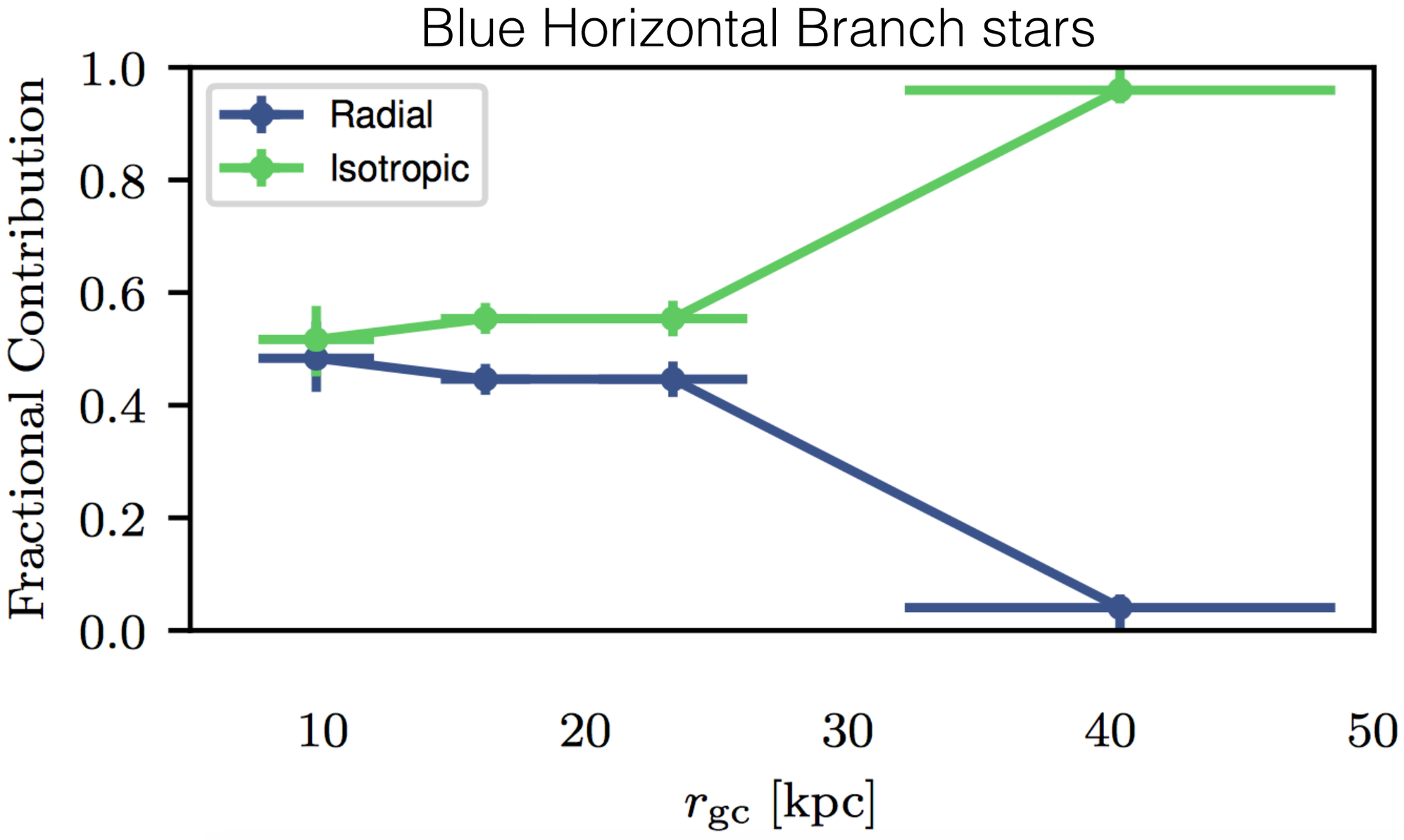
Simion et al 2018

Sausage simulation



Denis Erkal

Evolution of velocity ellipsoid with Galactocentric radius



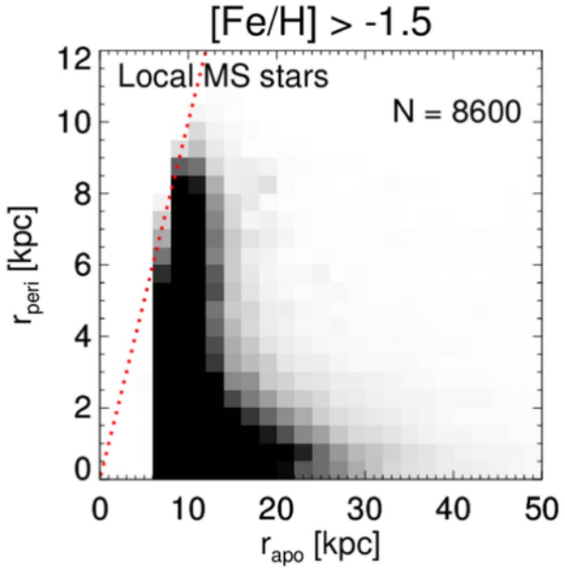
Lancaster et al 2018

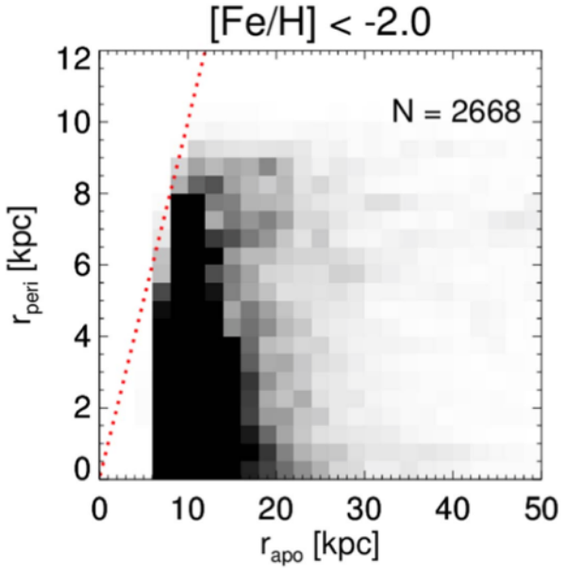
Questions and Implications

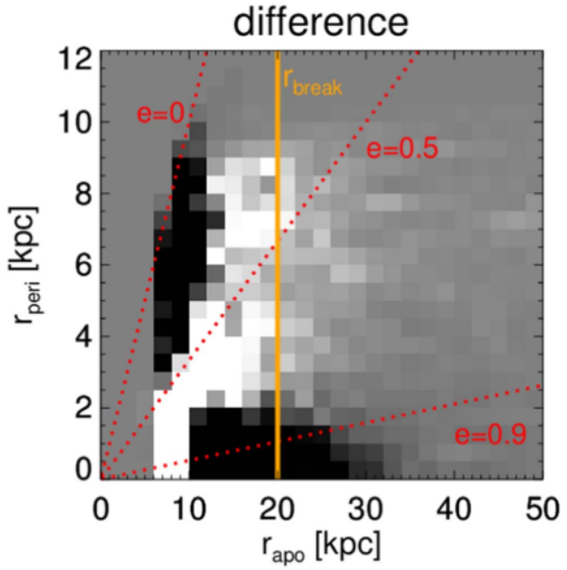
- Major merger debris swamps the accretion signatures of the lower-mass systems
- Ancient massive merger sets the velocity distribution and the shape of the high speed tail (previous talk)
- What does this accretion history imply for the shape of the DM halo and the properties of the DM sub-halo population?
- When exactly did it happen?
- Did the progenitor's core survive?
- Was the existing Galactic disc destroyed?
- Did the Sausage progenitor bring fresh gas and if yes, was it used for the disc re-formation?
- Did the event trigger MW bar formation?
- Did the event flip the MW disc spin?

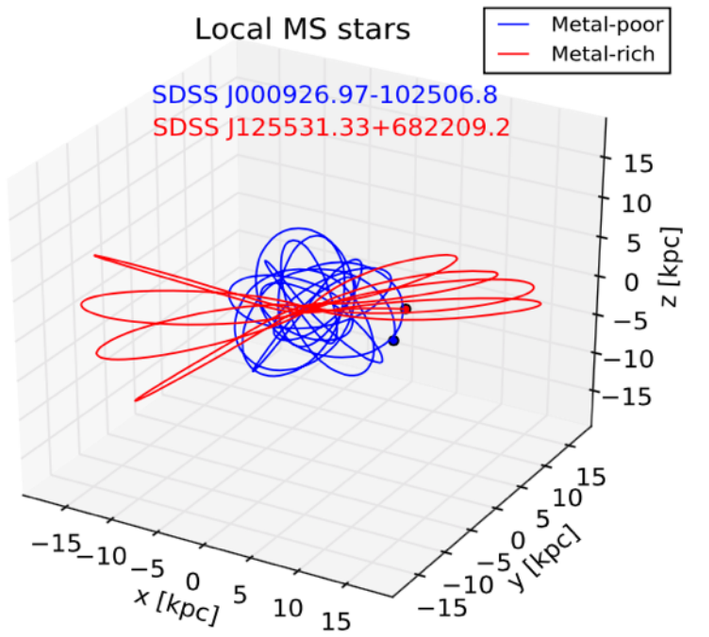
Extra slides

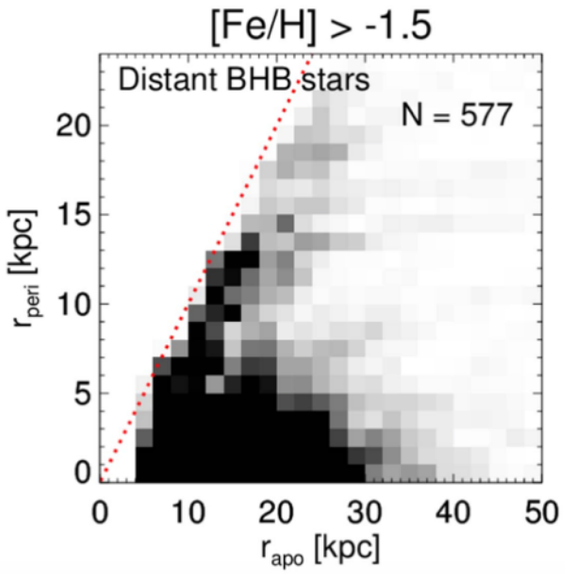
Break in the stellar halo

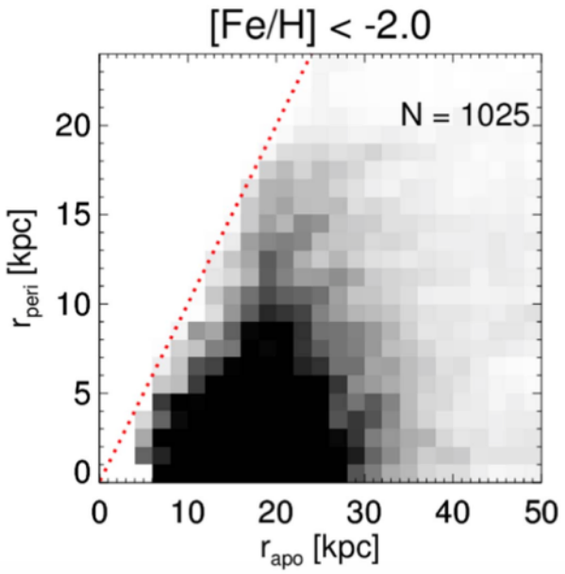


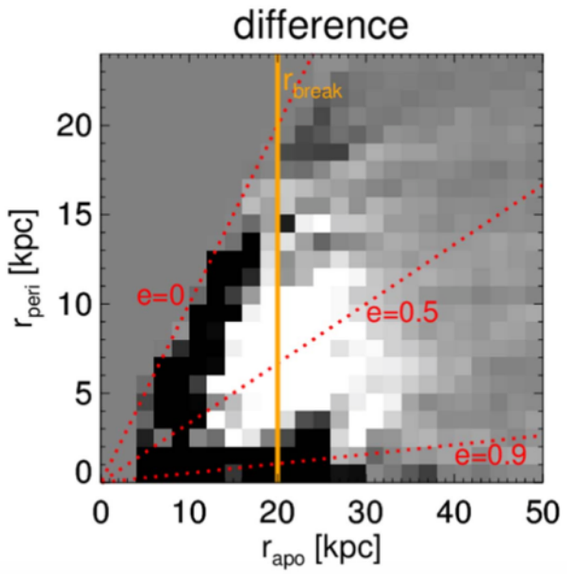


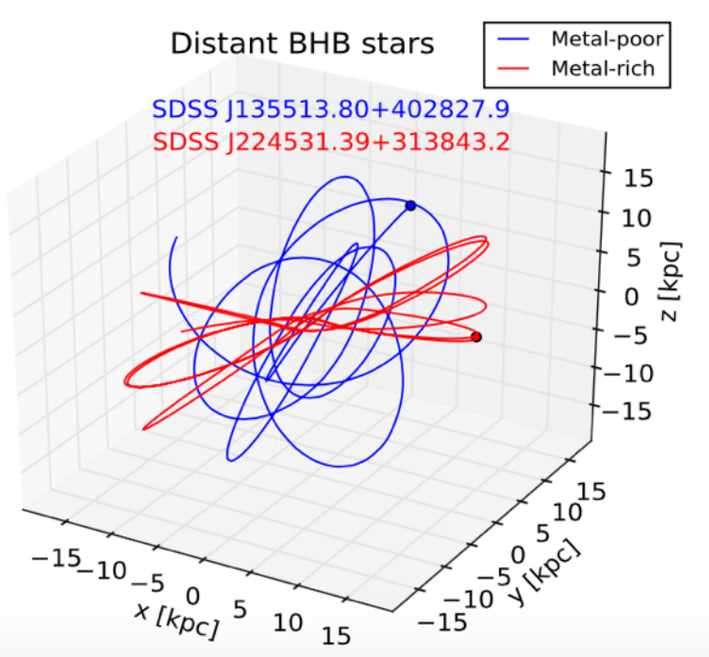










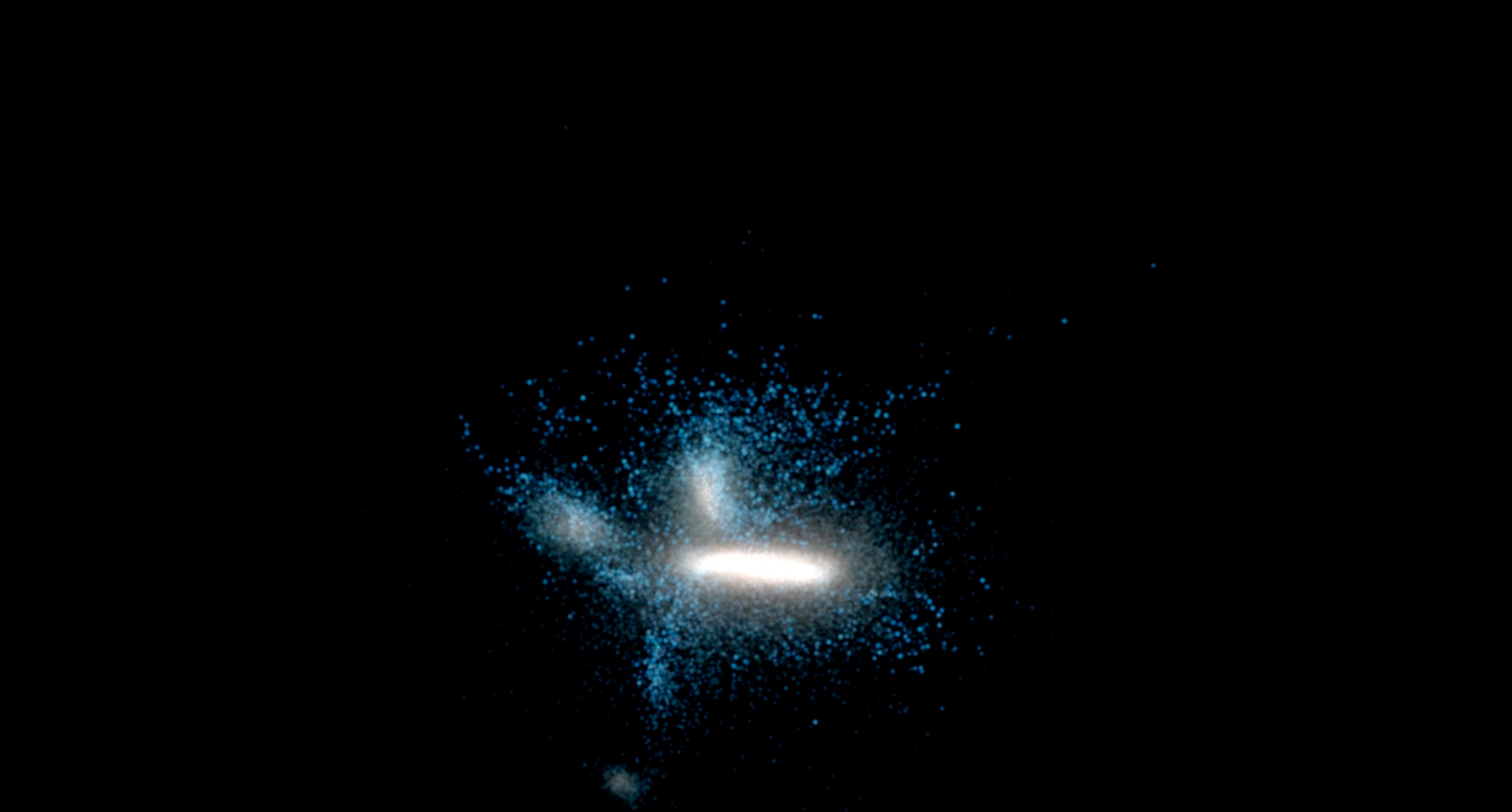


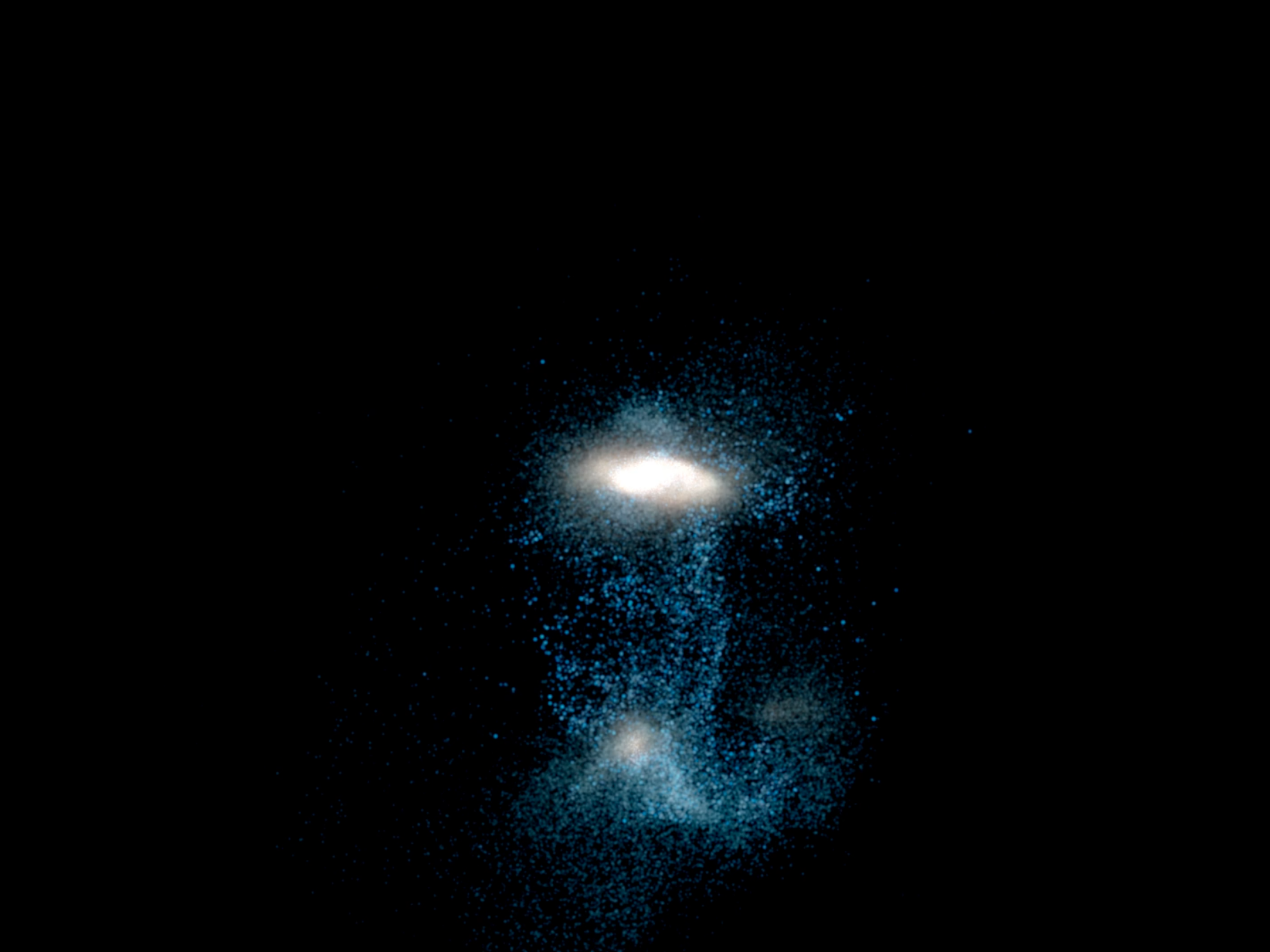
Deason et al 2018

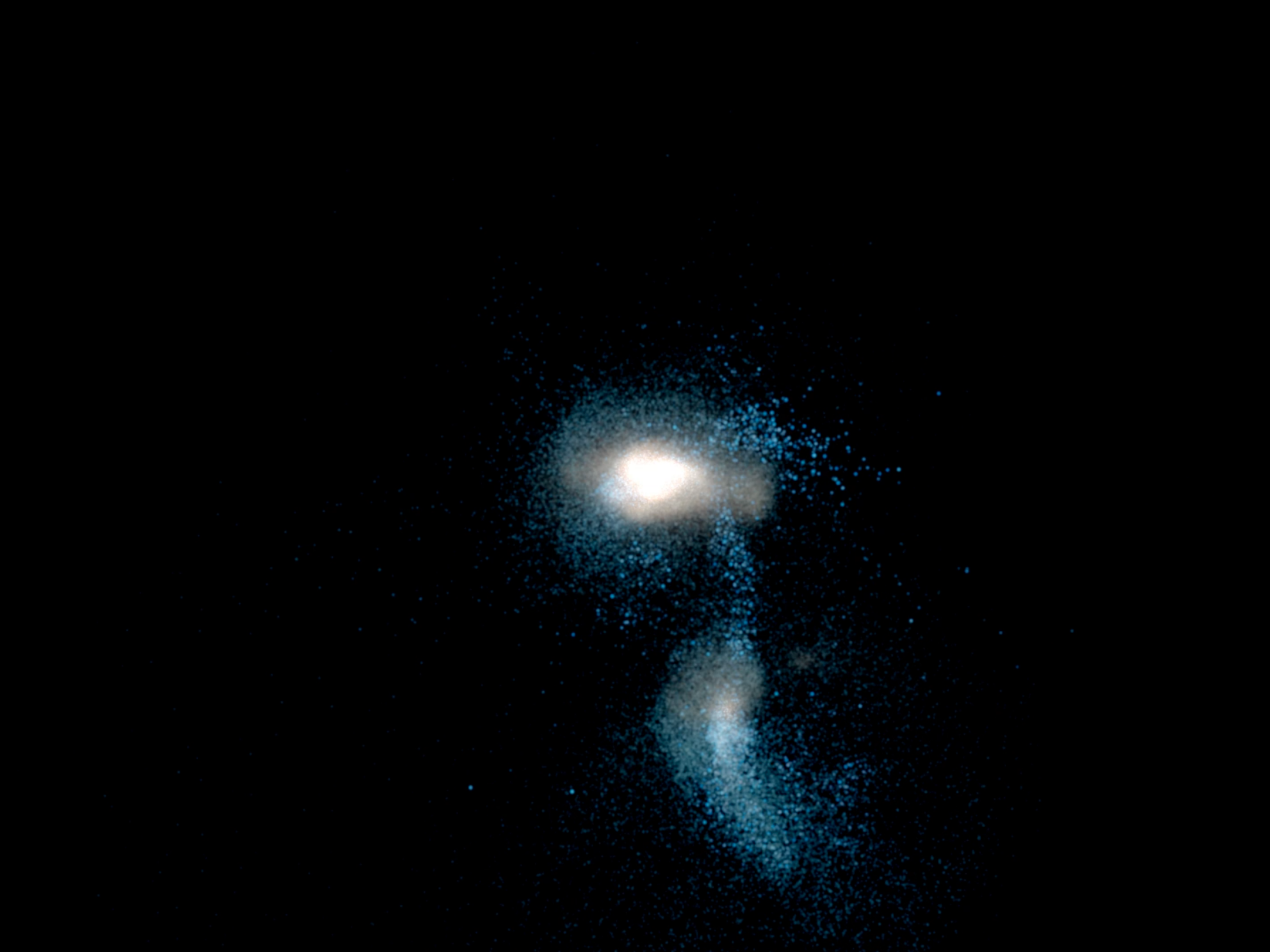
Auriga 18 movie snapshots courtesy of

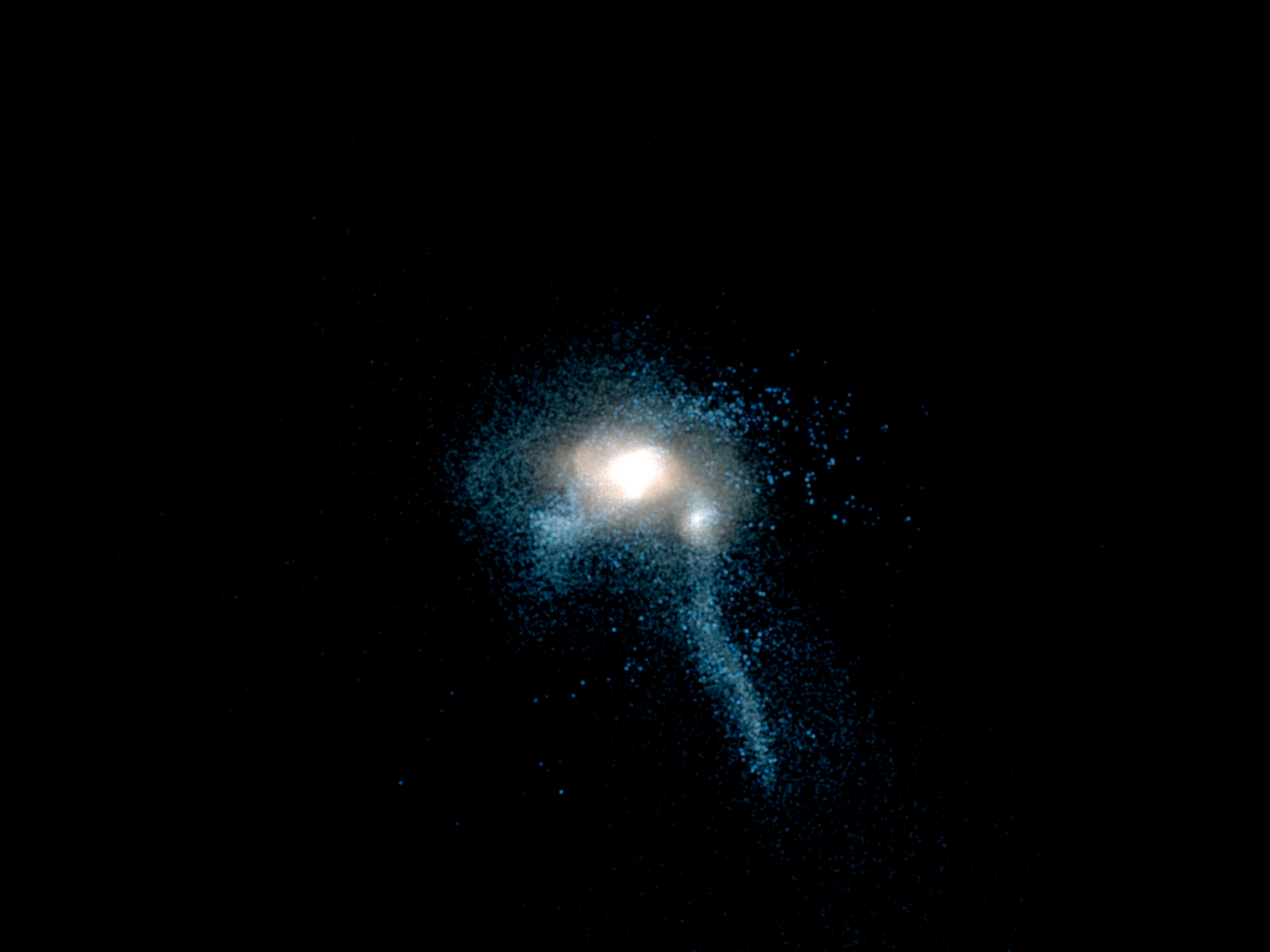
Auriga Collaboration

and Rüdiger Pakmor

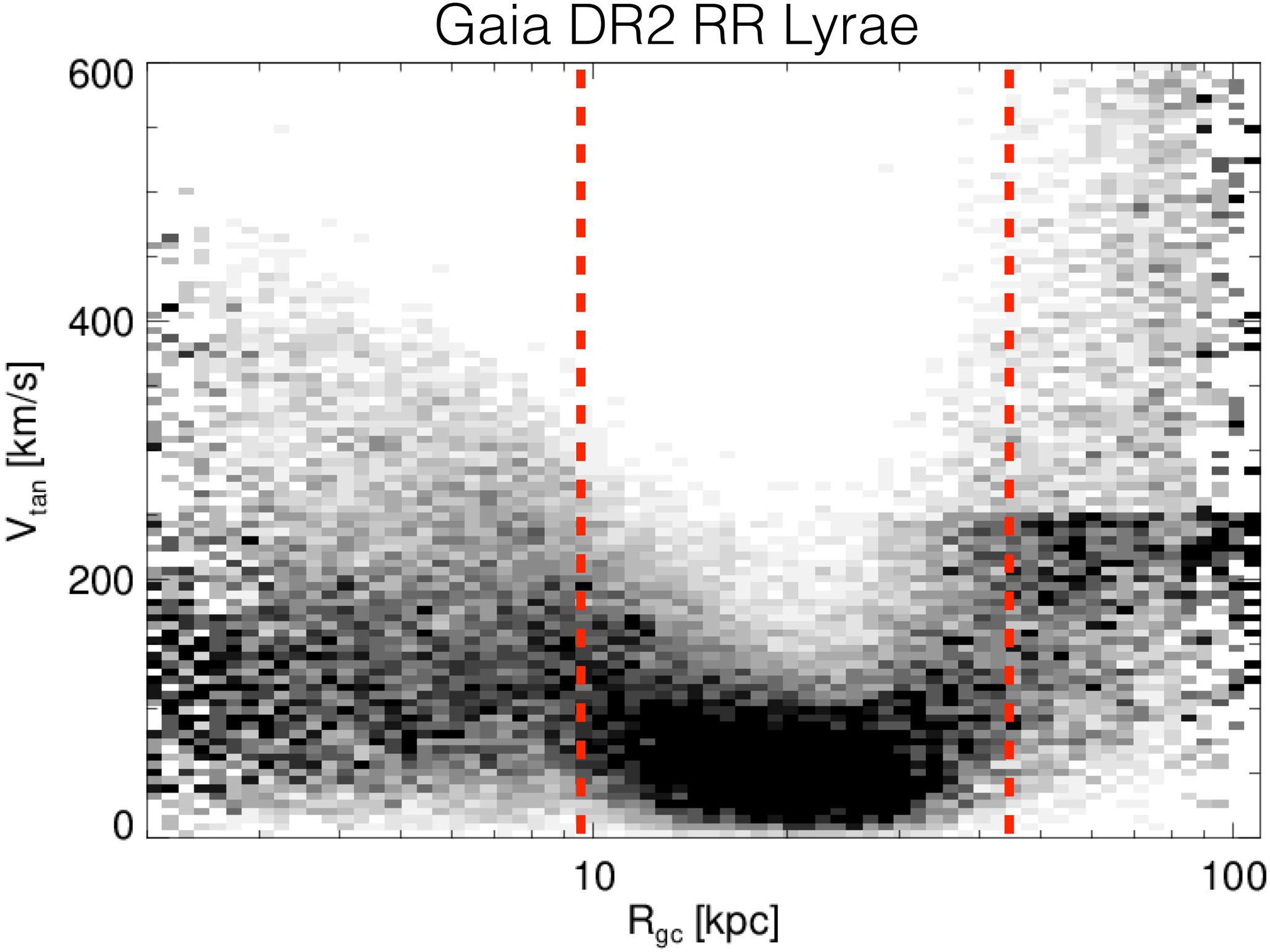






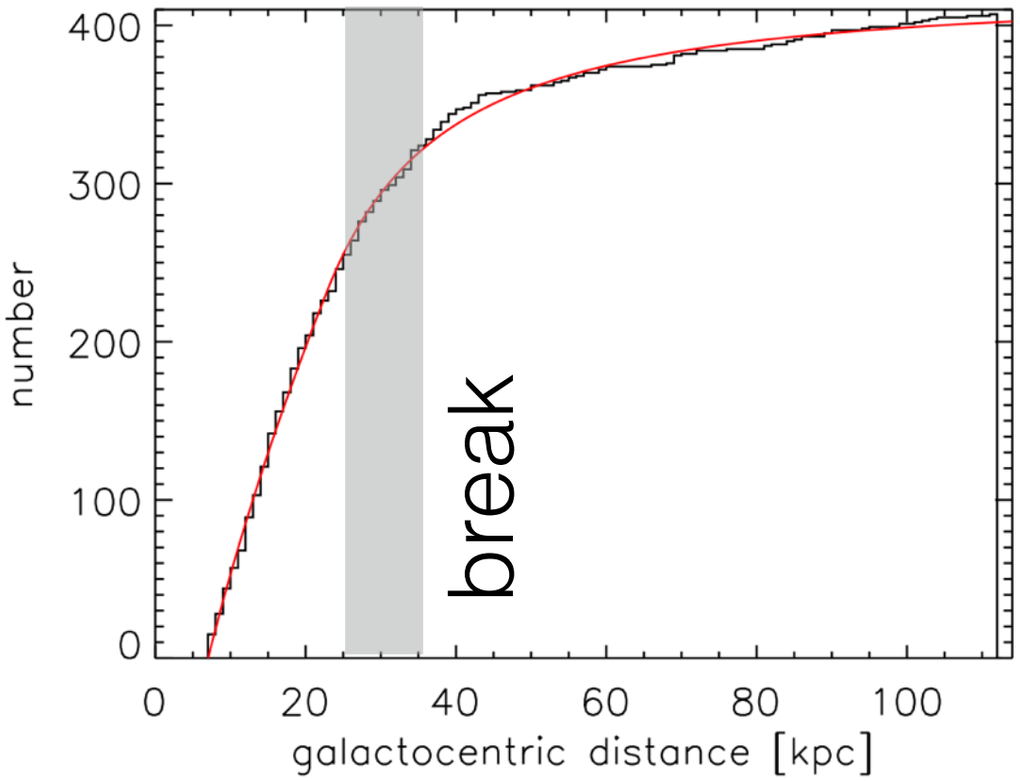


Stellar halo kinematics



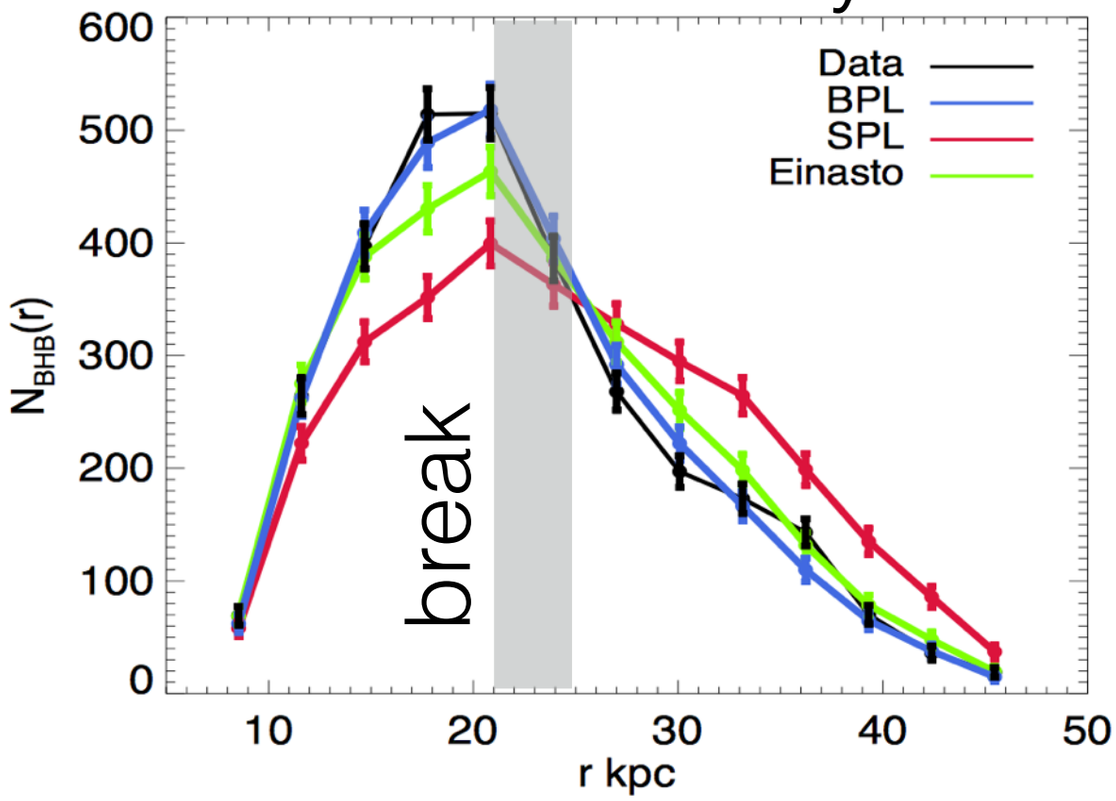
Break in the stellar halo

RR Lyrae density



Watkins et al 2009

BHB density



Deason et al 2011