Empirical Determination of Dark Matter Velocity Distribution

Lina Necib, MIT

Based on 1704.04499 & 1708.XXXX

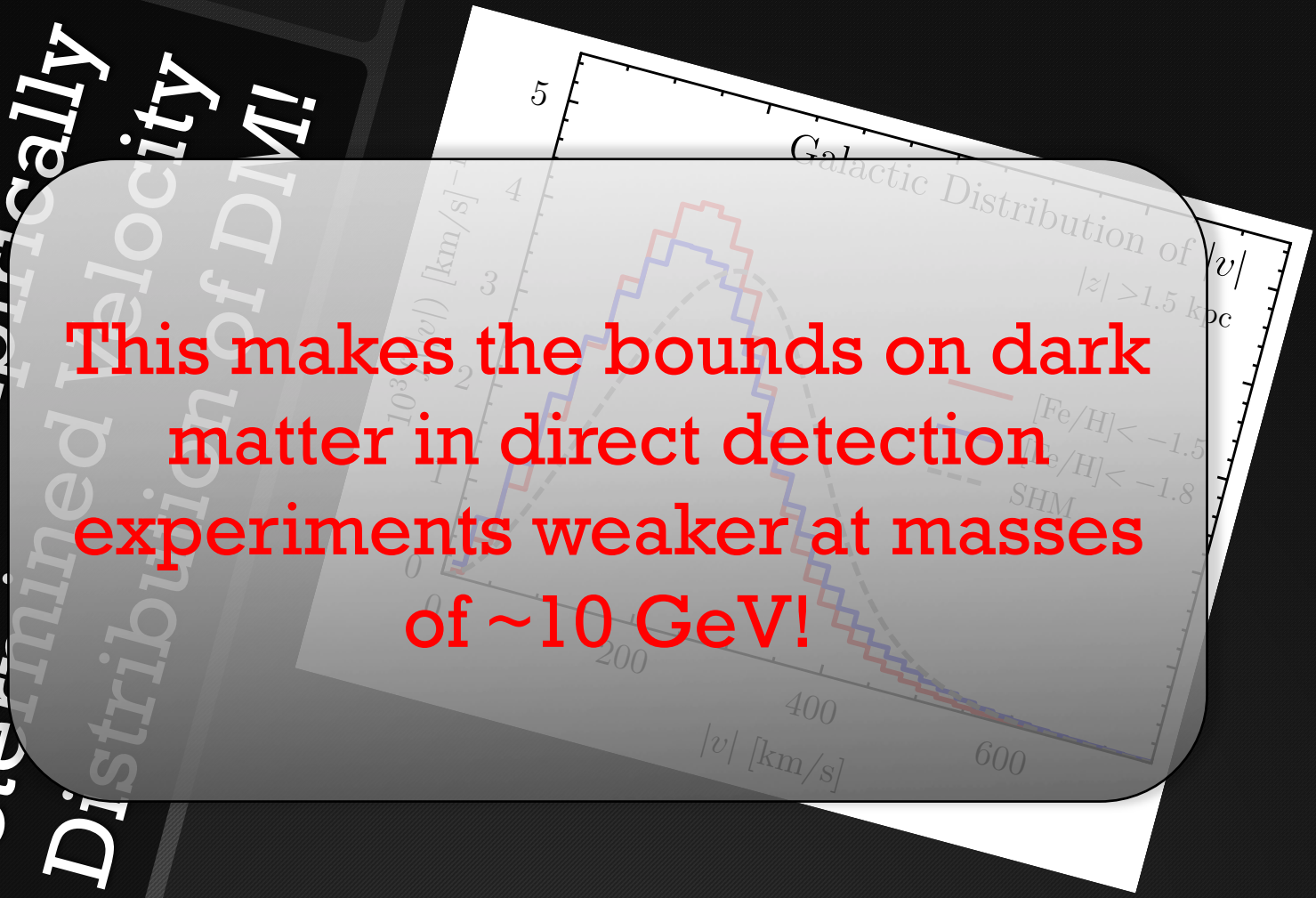
In collaboration with Jonah Herzog-Arbeitman and Mariangela Lisanti

Next week!

Empirically Determined Velocity Distribution of DM!

Lina Necib, MIT

Empirically Determined Velocity Distribution of DM!



This makes the bounds on dark matter in direct detection experiments weaker at masses of ~10 GeV!

From Simulations:

Metal-Poor Stars trace the velocity of Dark Matter.

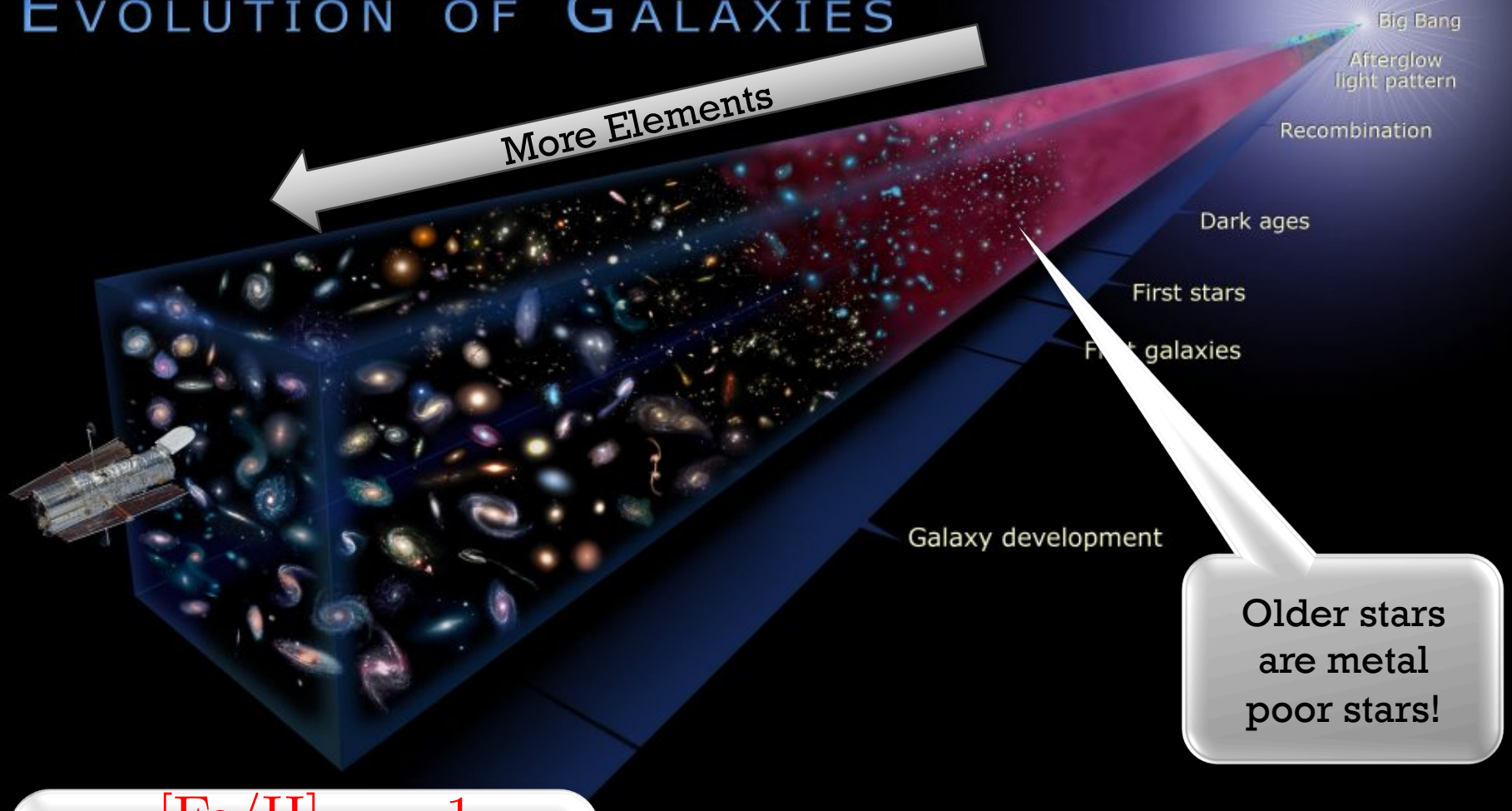
From Gaia DR1:

We get the local velocity distribution of Metal-Poor Stars.

Therefore:

We empirically obtain the Dark Matter velocity distribution.

Evolution of Galaxies

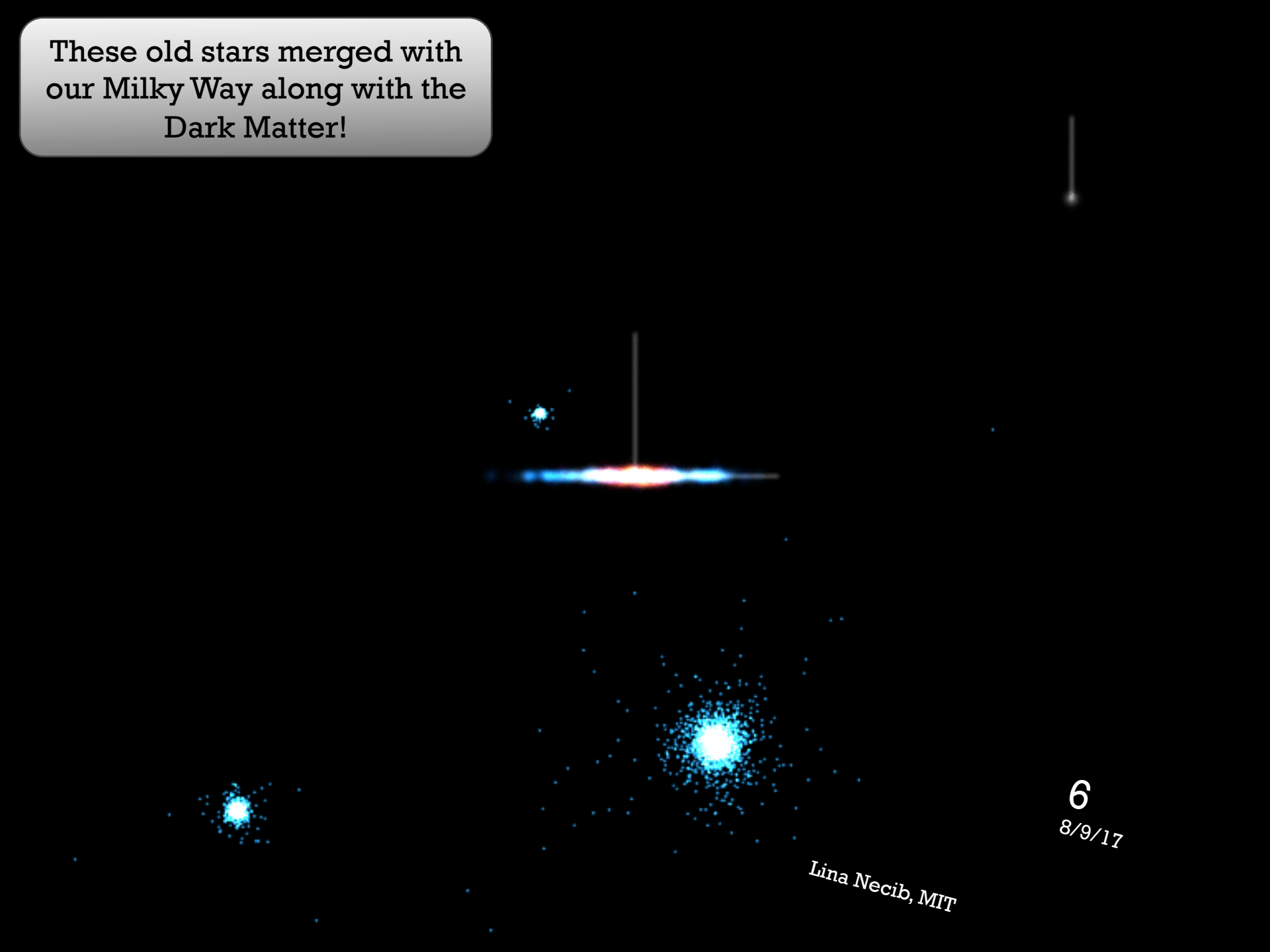


Older stars are metal poor stars!

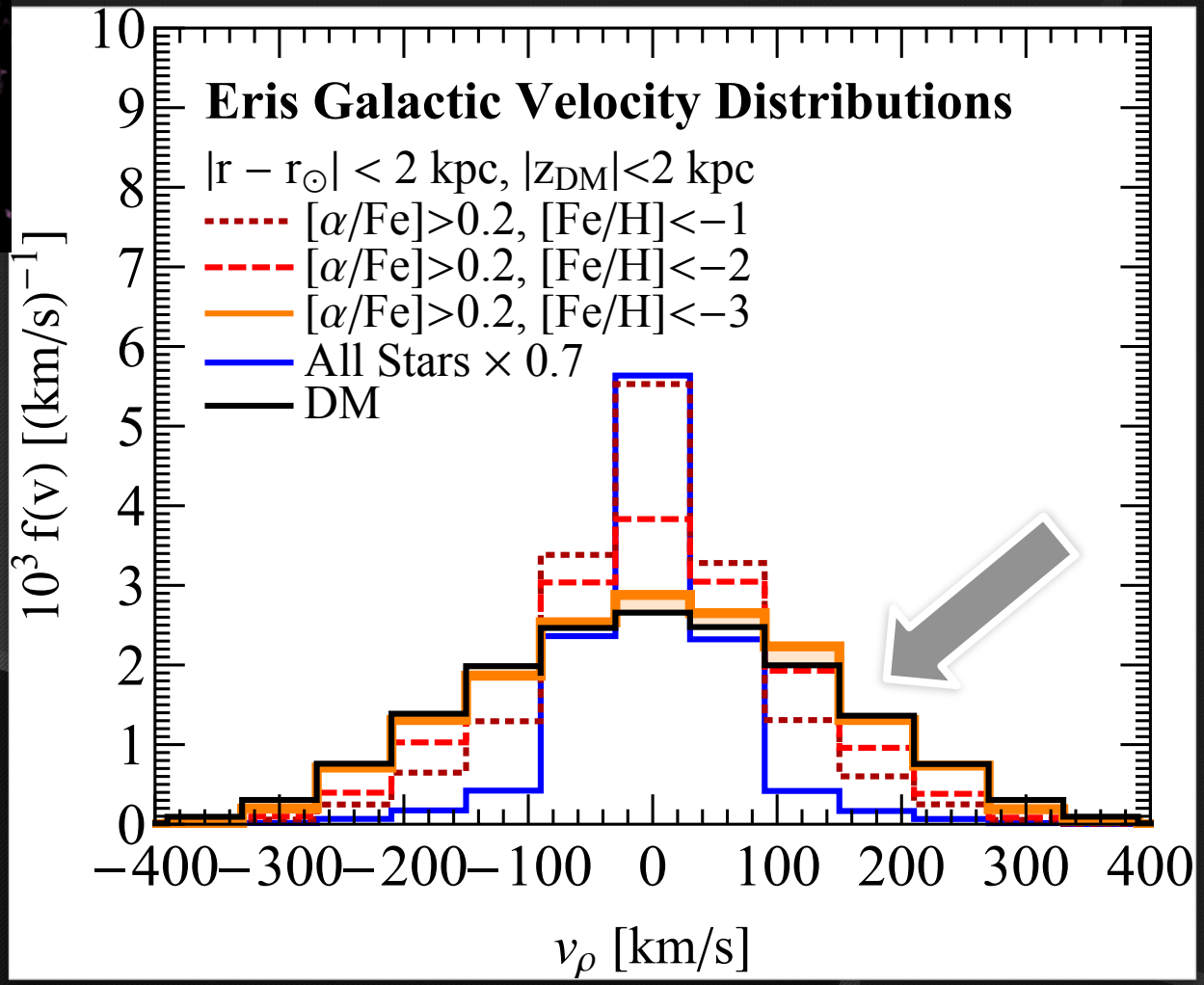
$[\mathrm{Fe/H}] = -1$

Means that this star has 1/10 of the iron fraction of the Sun.

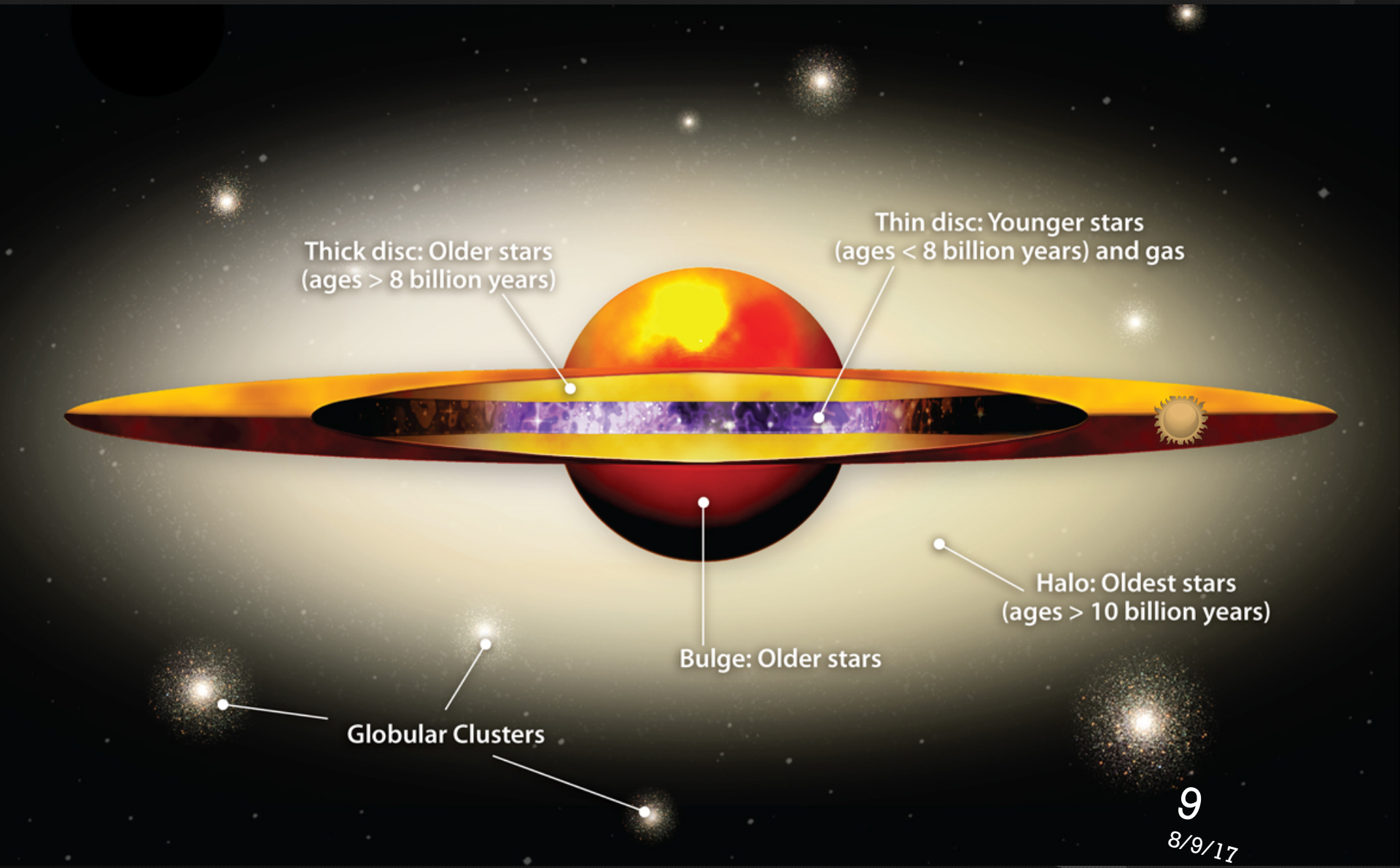
These old stars merged with our Milky Way along with the Dark Matter!

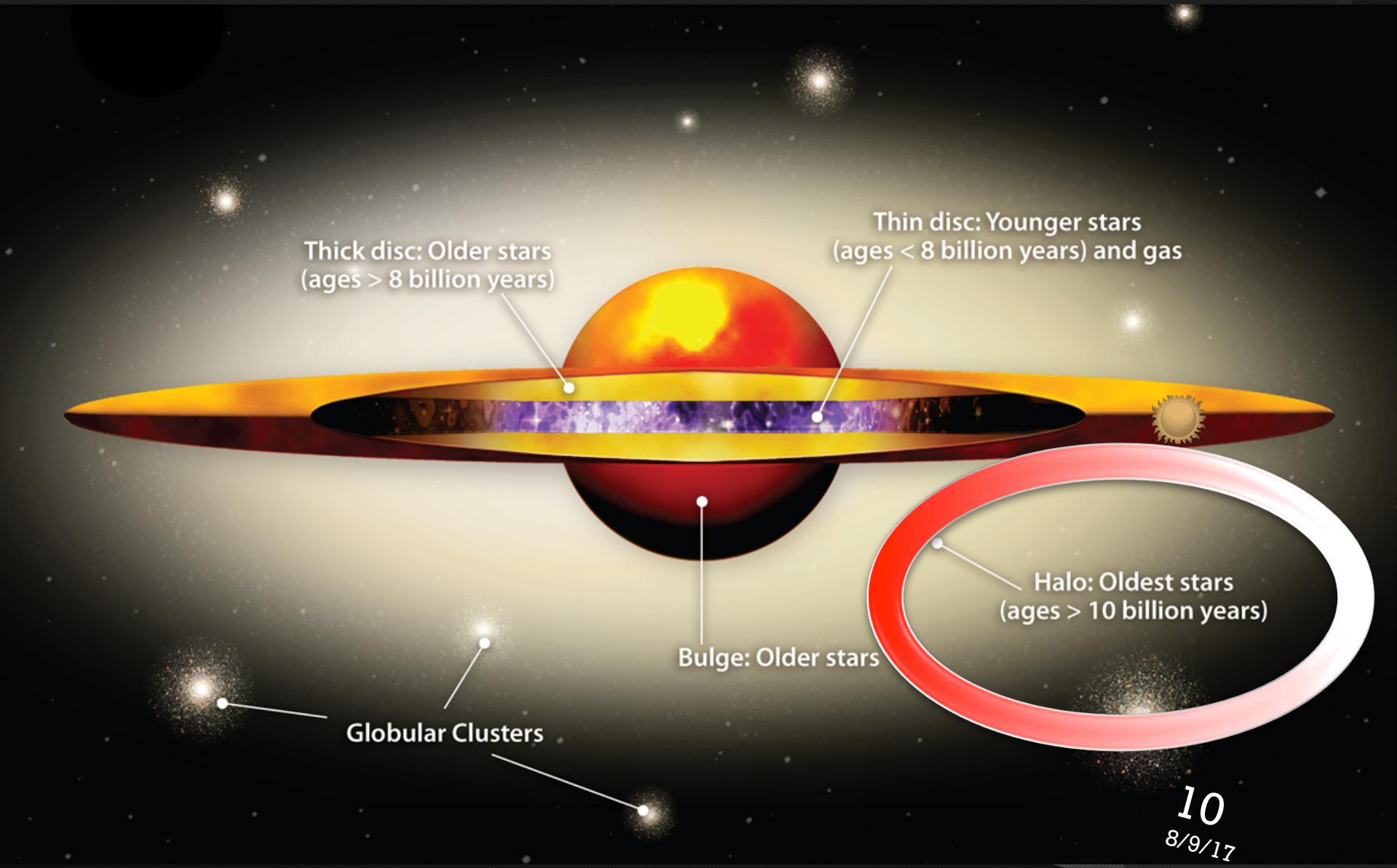


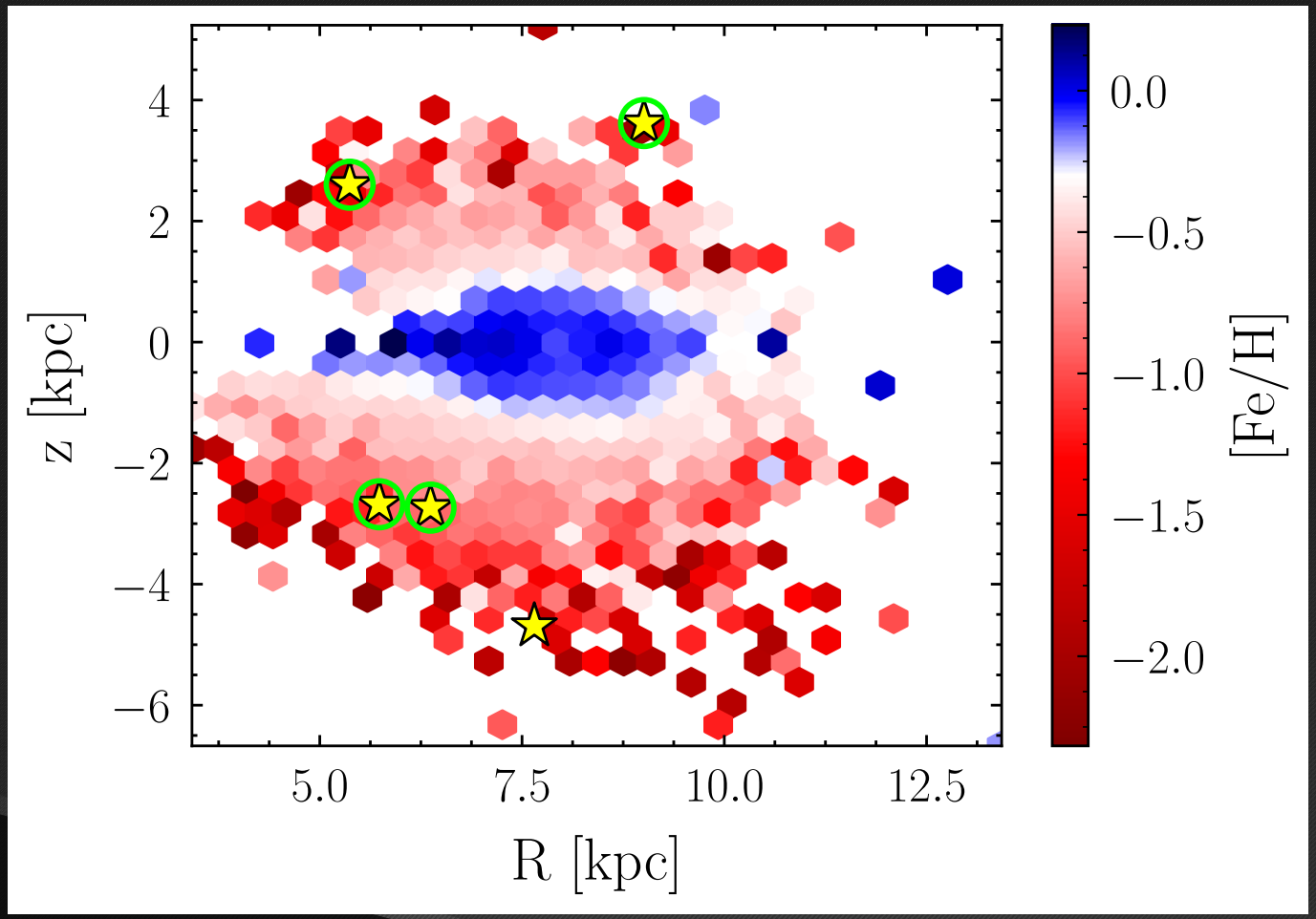
This is being further studied in other simulations.



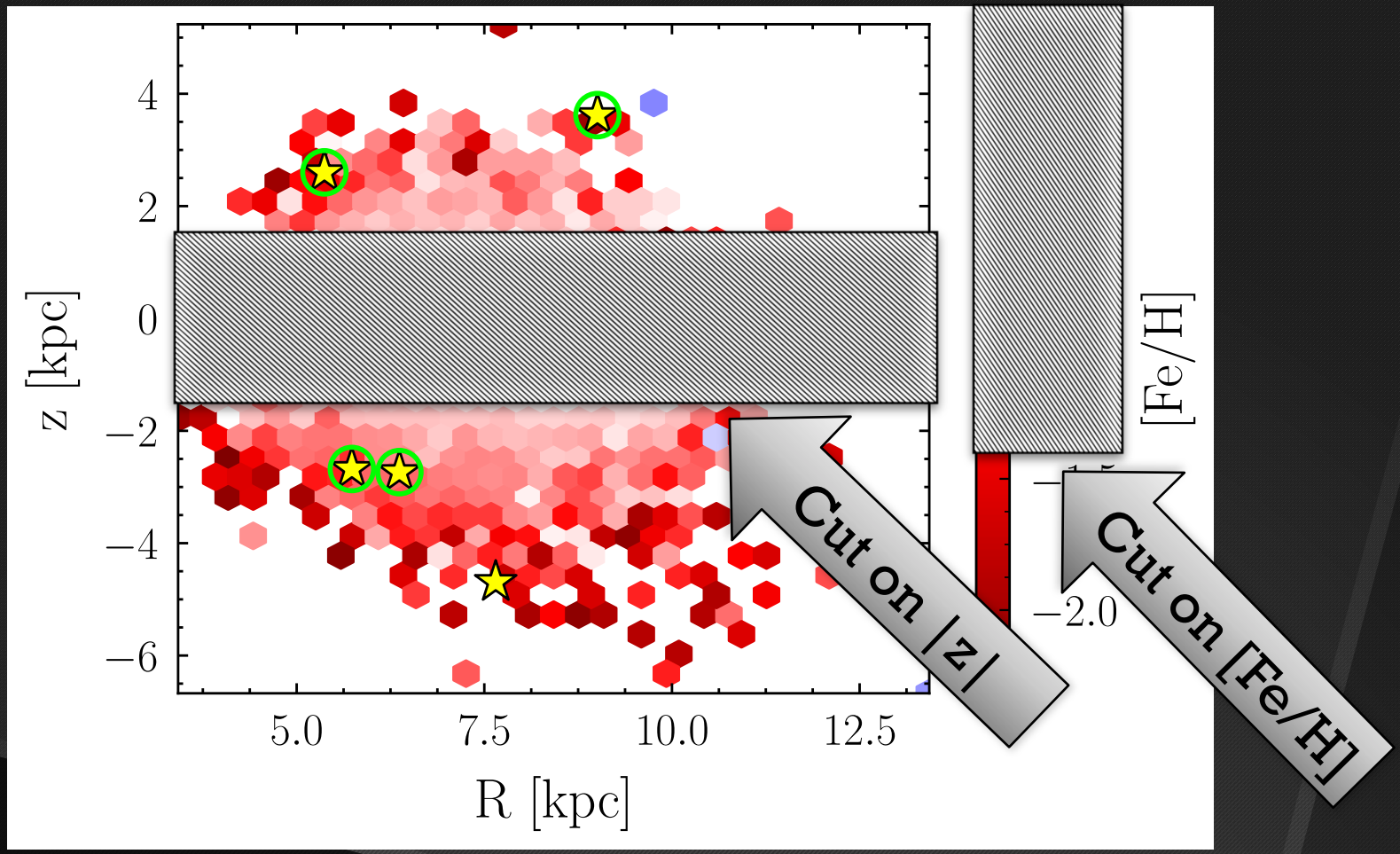
Where do we find these Metal Poor Stars?


Thick disc: Older stars
(ages > 8 billion years)
Thin disc: Younger stars
(ages < 8 billion years) and gas
Halo: Oldest stars
(ages > 10 billion years)
Bulge: Older stars
Globular Clusters

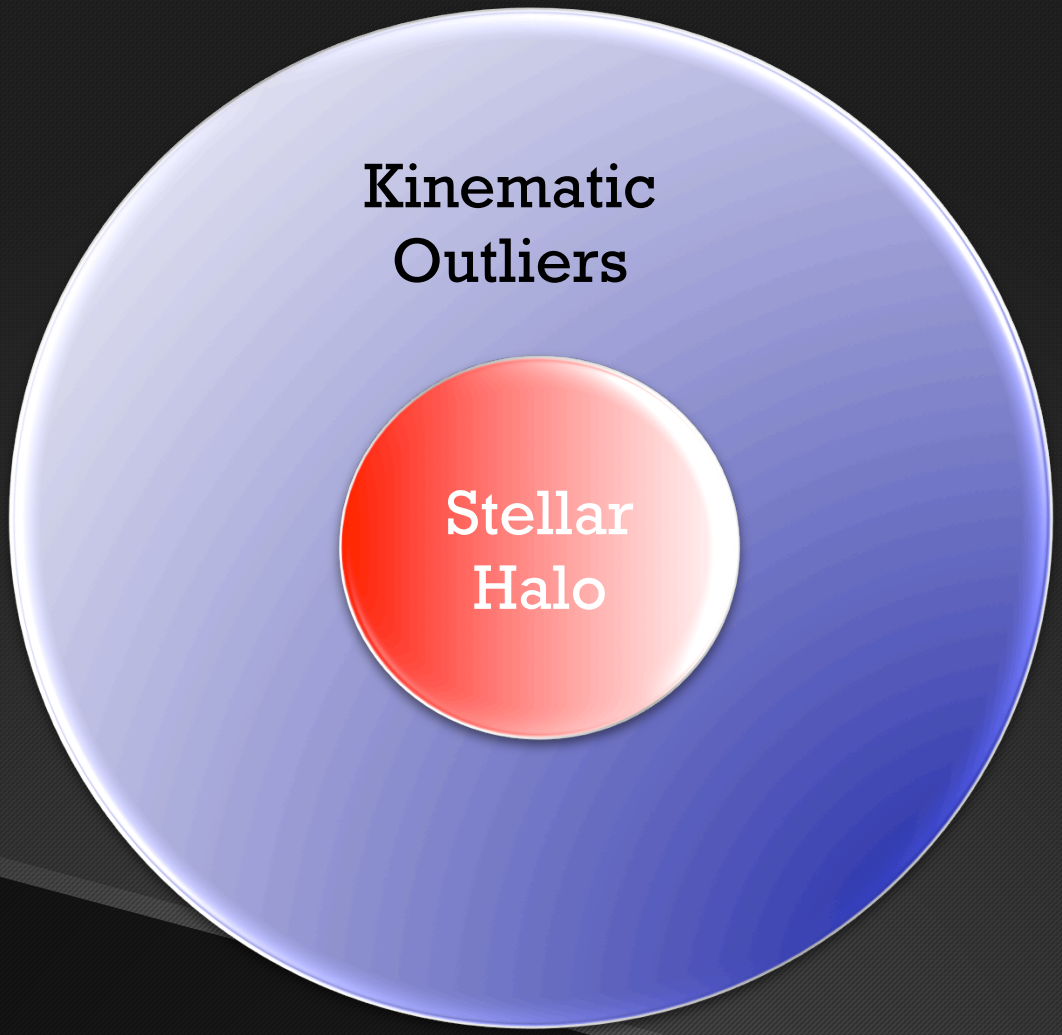

Thick disc: Older stars
(ages > 8 billion years)
Thin disc: Younger stars
(ages < 8 billion years) and gas
Halo: Oldest stars
(ages > 10 billion years)
Bulge: Older stars
Globular Clusters



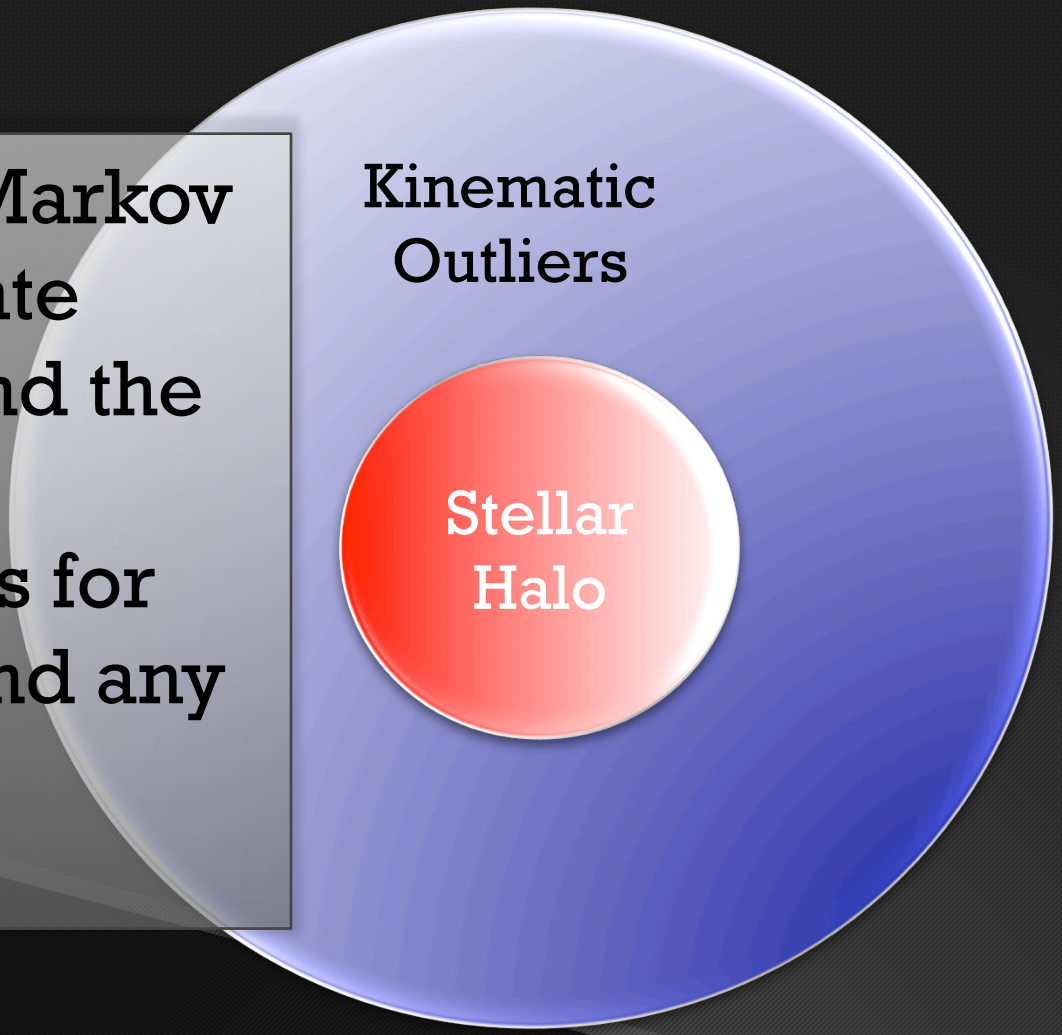
Gaia DR1: Lindergren et al. (2016)
RAVE heliocentric velocities: Kunder et al. (2017)
TGAS (Tycho-Gaia) proper motions: Michalik et al.(2015)
RAVE-on chemical properties: Casey et al. (2016)
Distances: McMillan et al. (2017)

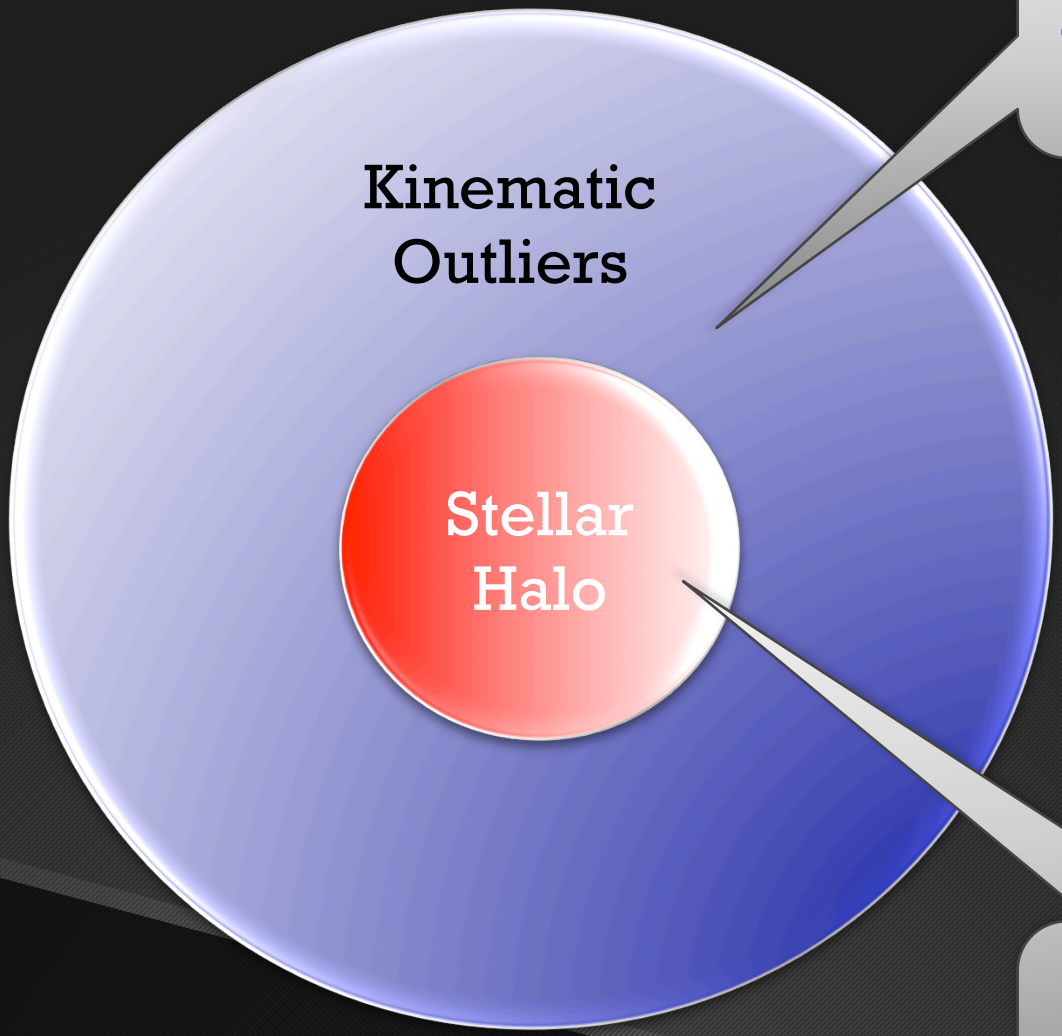


Gaia DR1: Lindergren et al. (2016)
RAVE heliocentric velocities: Kunder et al. (2017)
TGAS (Tycho-Gaia) proper motions: Michalik et al.(2015)
RAVE-on chemical properties: Casey et al. (2016)
Distances: McMillan et al. (2017)


Kinematic
Outliers
Stellar
Halo

We use a Markov Chain Monte Carlo to find the best fit parameters for the halo, and any kinematic outliers.

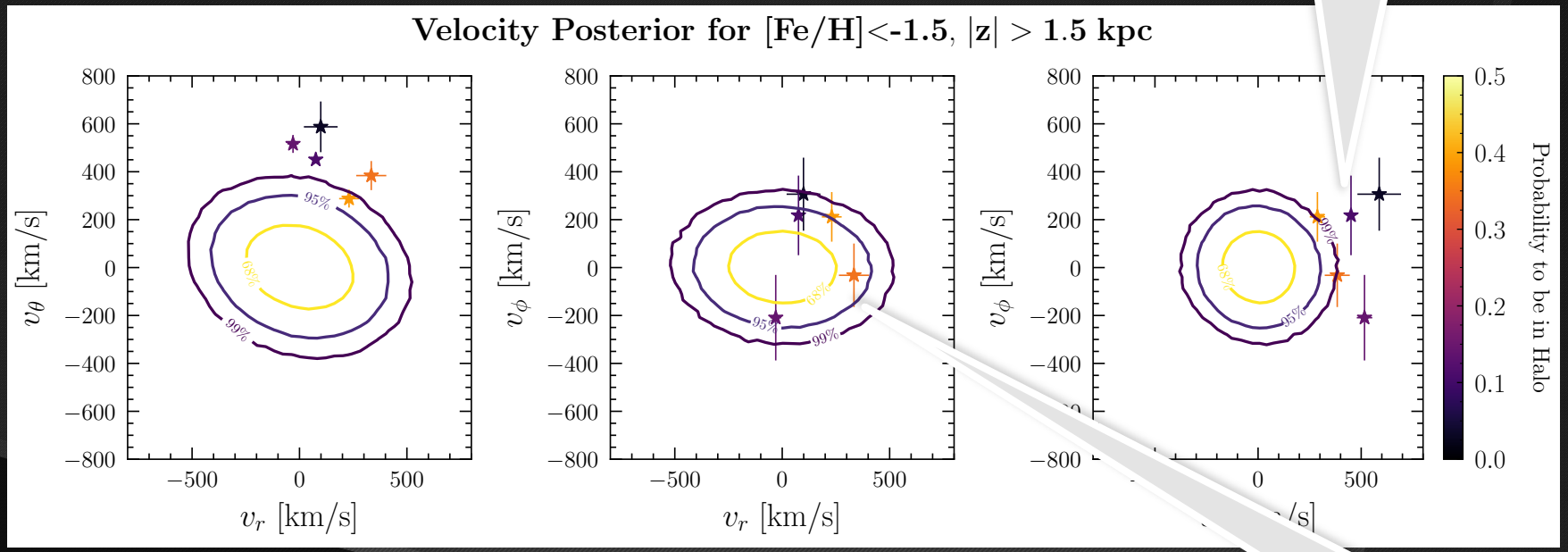




3 Dimensional Gaussian

3 Dimensional Gaussian

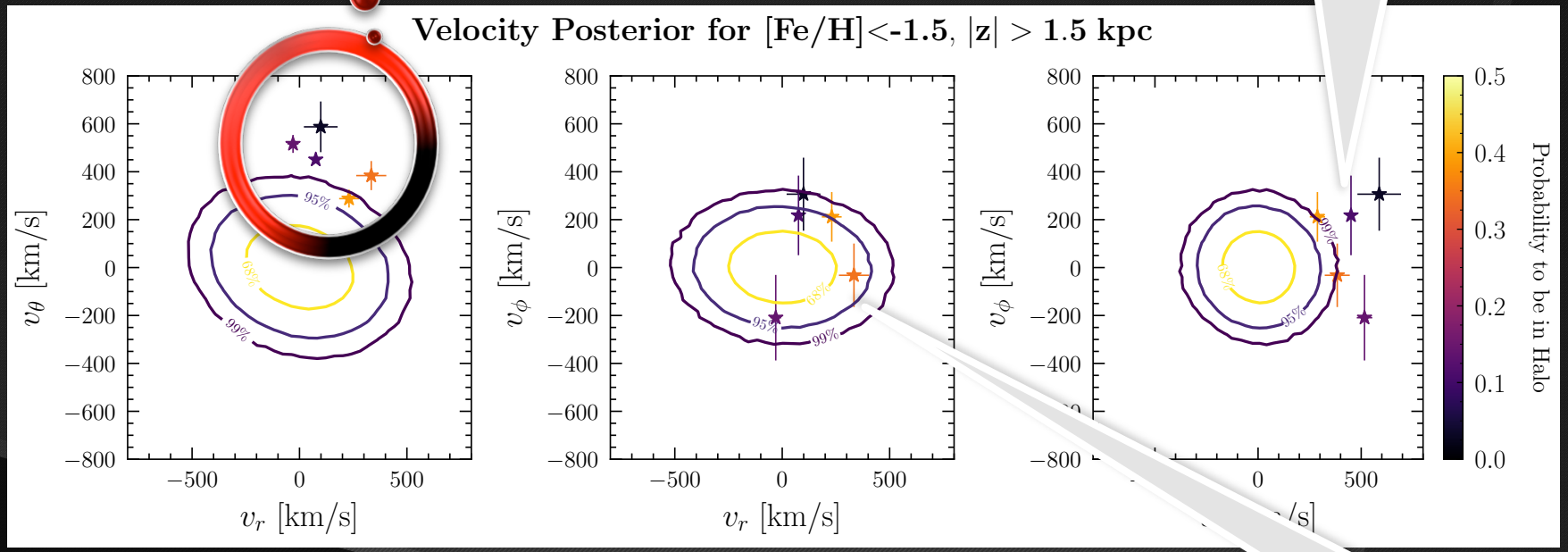
Kinematic Outliers



Best Fit Halo

Hints of dark matter substructure?

Kinematic Outliers



Best Fit Halo

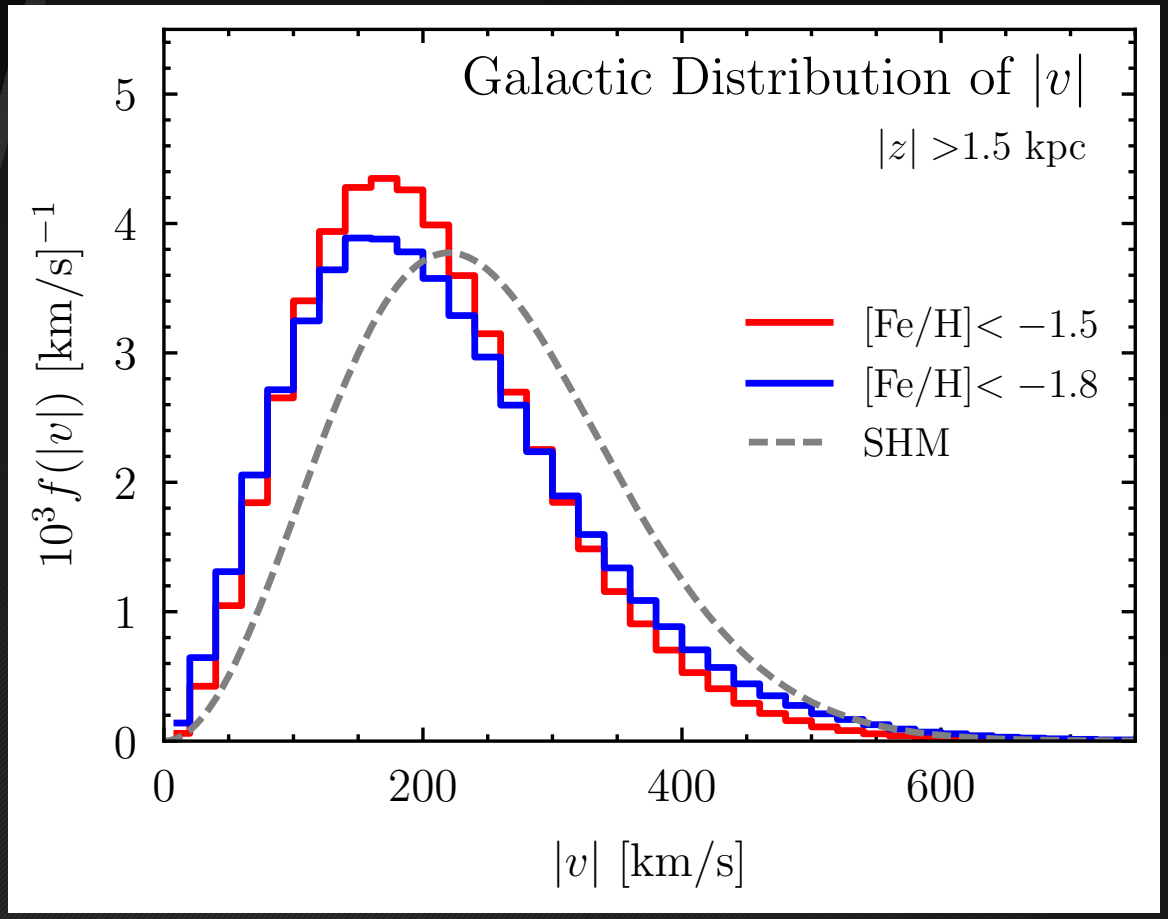
Lina Necib, MIT

Local Velocity Distribution

Drum Roll

Lina Necib, MIT

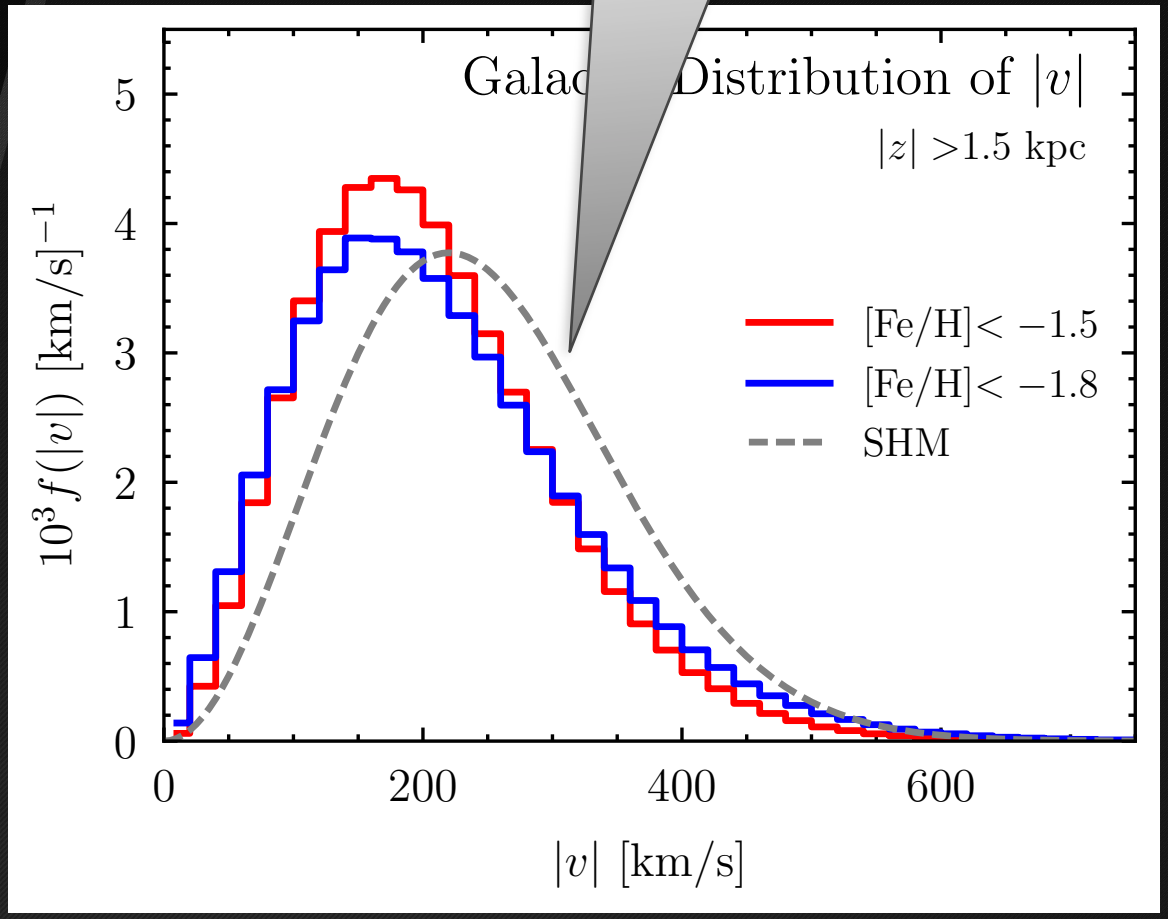
Posterior Distribution of $|v|$



Lina Necib, MIT

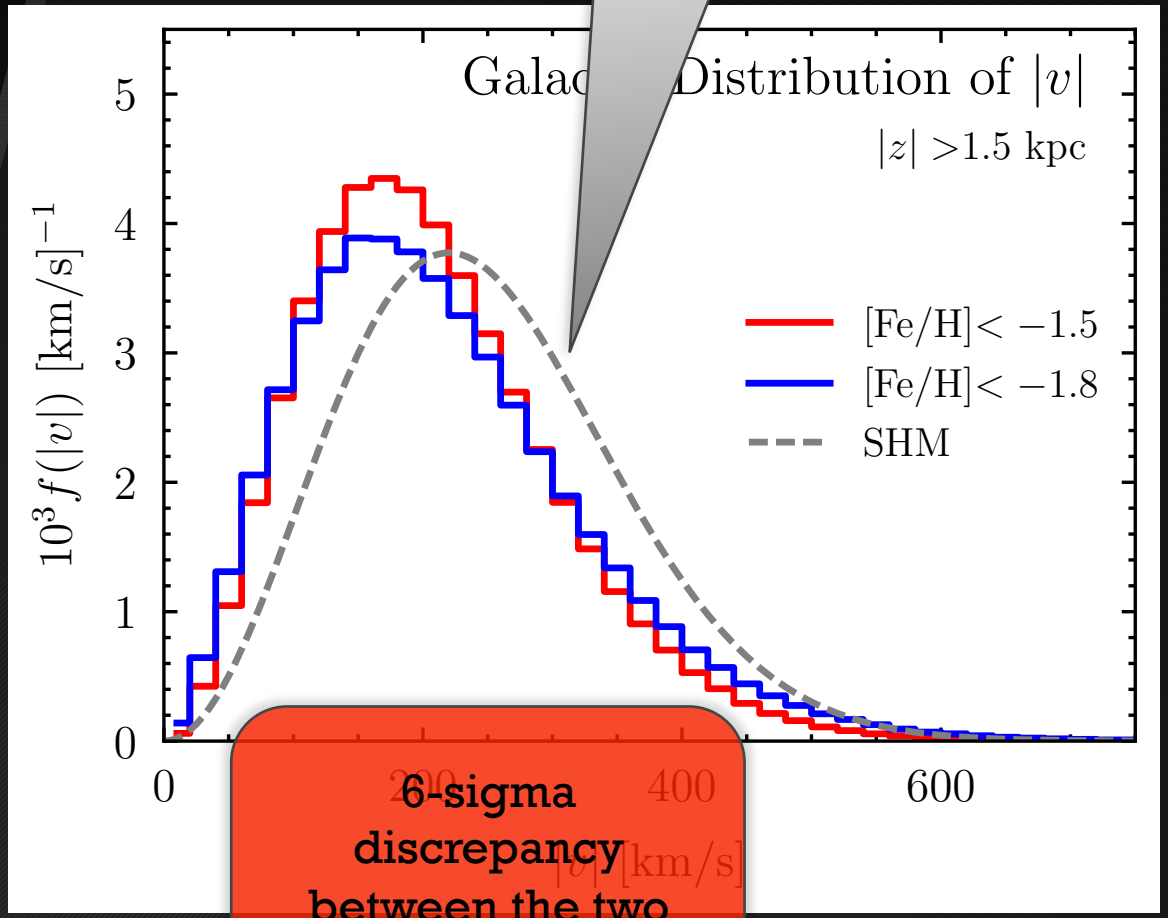
Posterior Distribution of $|v|$

The Maxwell Boltzmann distribution we are taught at school!



Posterior Distribution of $|v|$

The Maxwell Boltzmann distribution we are taught at school!



6-sigma discrepancy between the two distributions!

Direct Detection Rate

The DM velocity distribution is part of the computation of the expected direct detection rate.

$$\frac{dR}{dQ} \propto \frac{\sigma_0 \rho_0}{m_\chi m_r^2} F^2(Q) g(v_{\min})$$

Astrophysical Parameters:
Dark matter density, velocity.

Particle Physics Parameters:
Scattering cross section, mass of the dark matter.

Experimental Parameters:
Form factors, mass of the nucleus (also experimental mass/ exposure should be added)

Direct Detection Rate

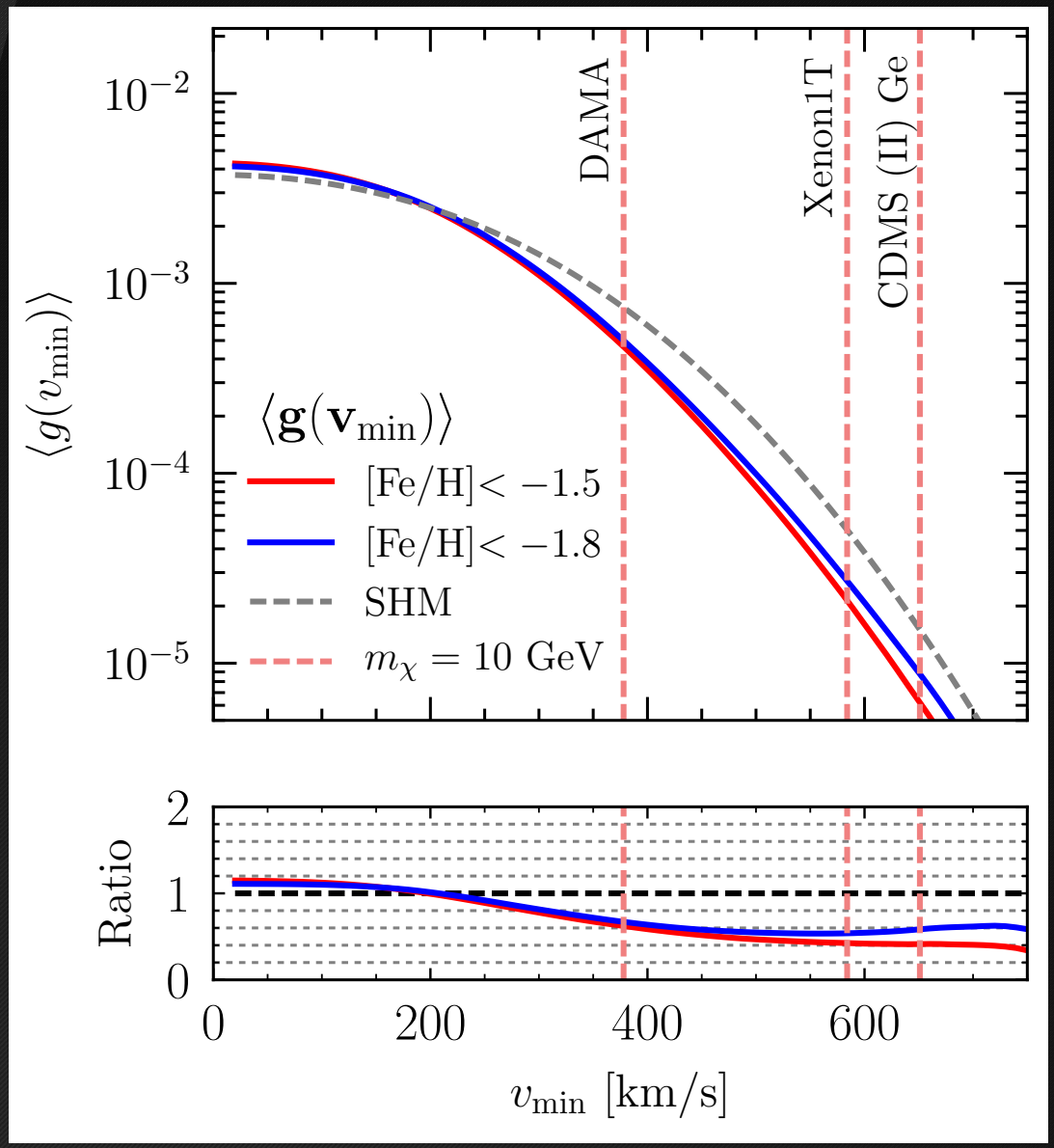
The DM velocity distribution is part of the computation of the expected direct detection rate.

$$\frac{dR}{dQ} \propto \frac{\sigma_0 \rho_0}{m_\chi m_r^2} F^2(Q) g(v_{\min})$$

$$g(v_{\min}) = \int_{v_{\min}}^{\infty} \frac{f(v)}{v} dv$$

v_{min} depends on the experimental threshold, and the dark matter mass.

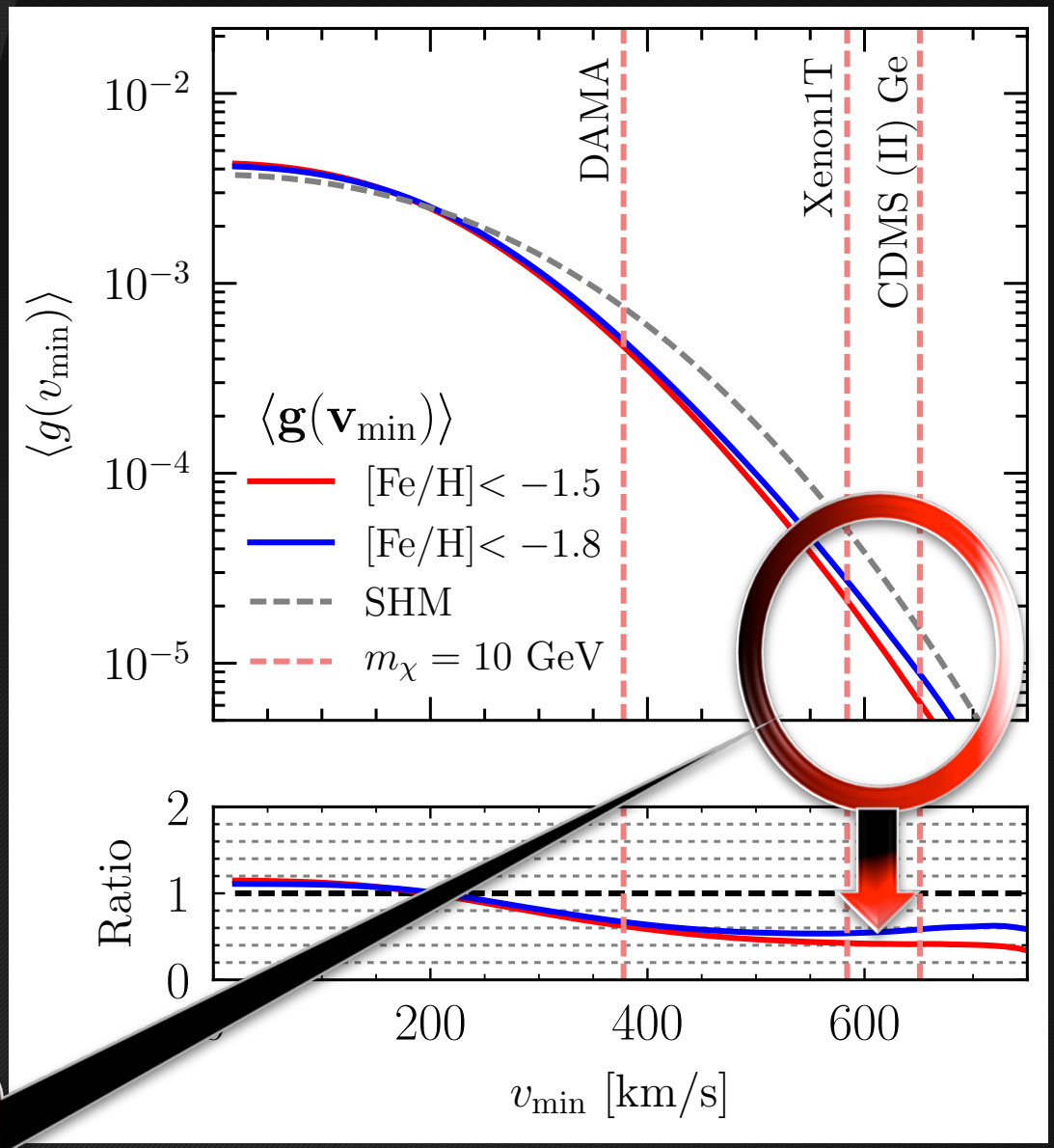
In terms of Direct Detection Experiments



$$g(v_{\rm min}) = \int_{v_{\rm min}}^{\infty} \frac{f(v)}{v} dv$$

Lina Necib, MIT

In terms of Direct Detection Experiments

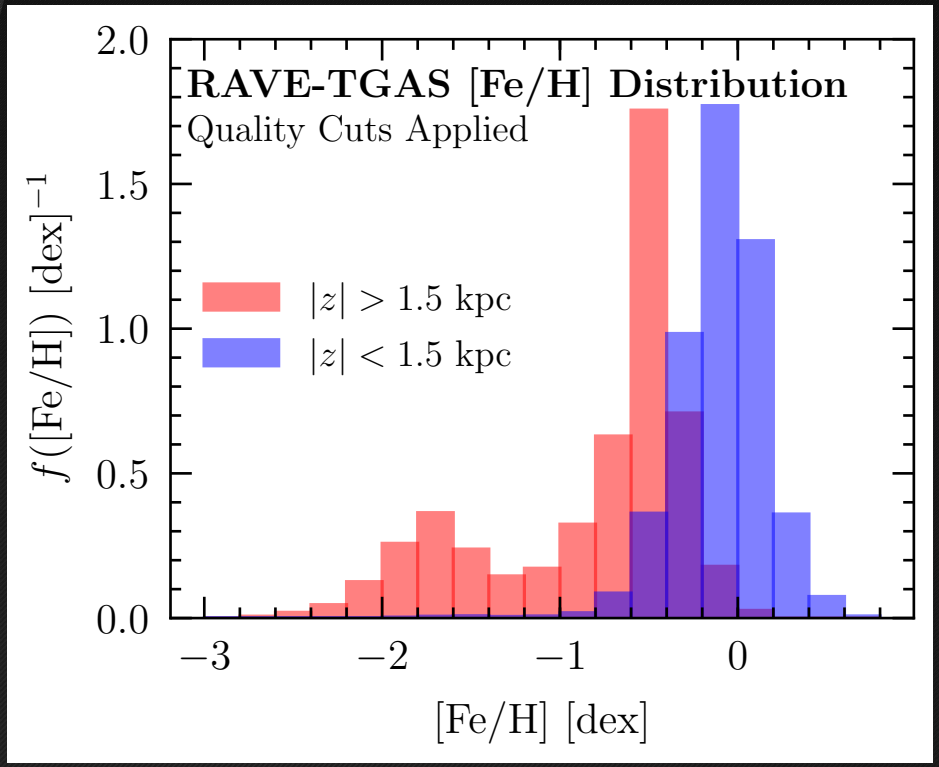


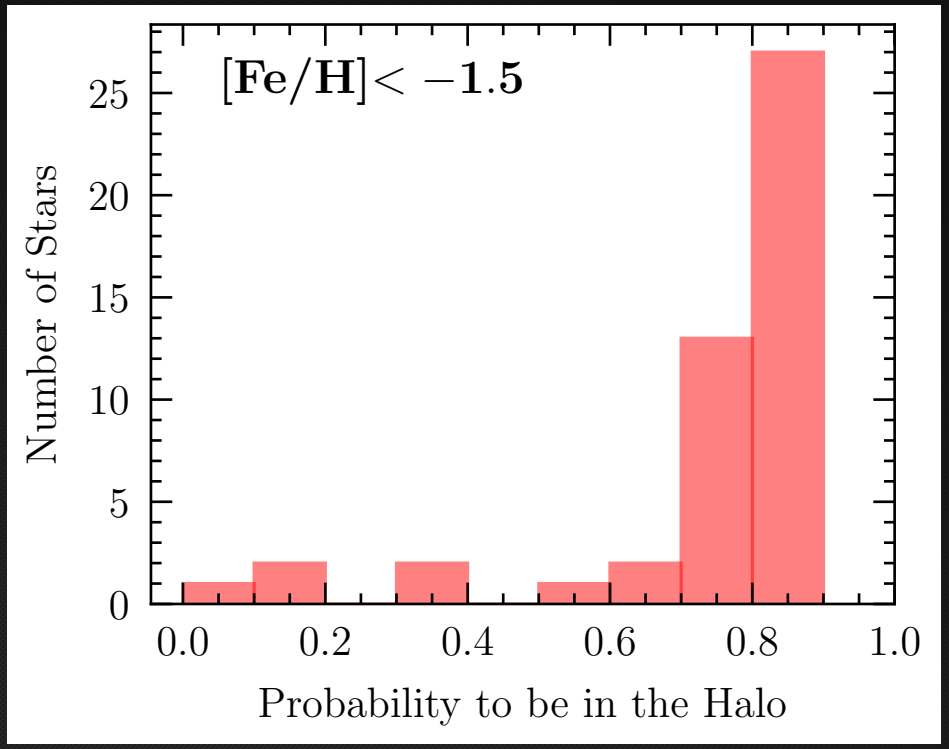
A factor of 2!

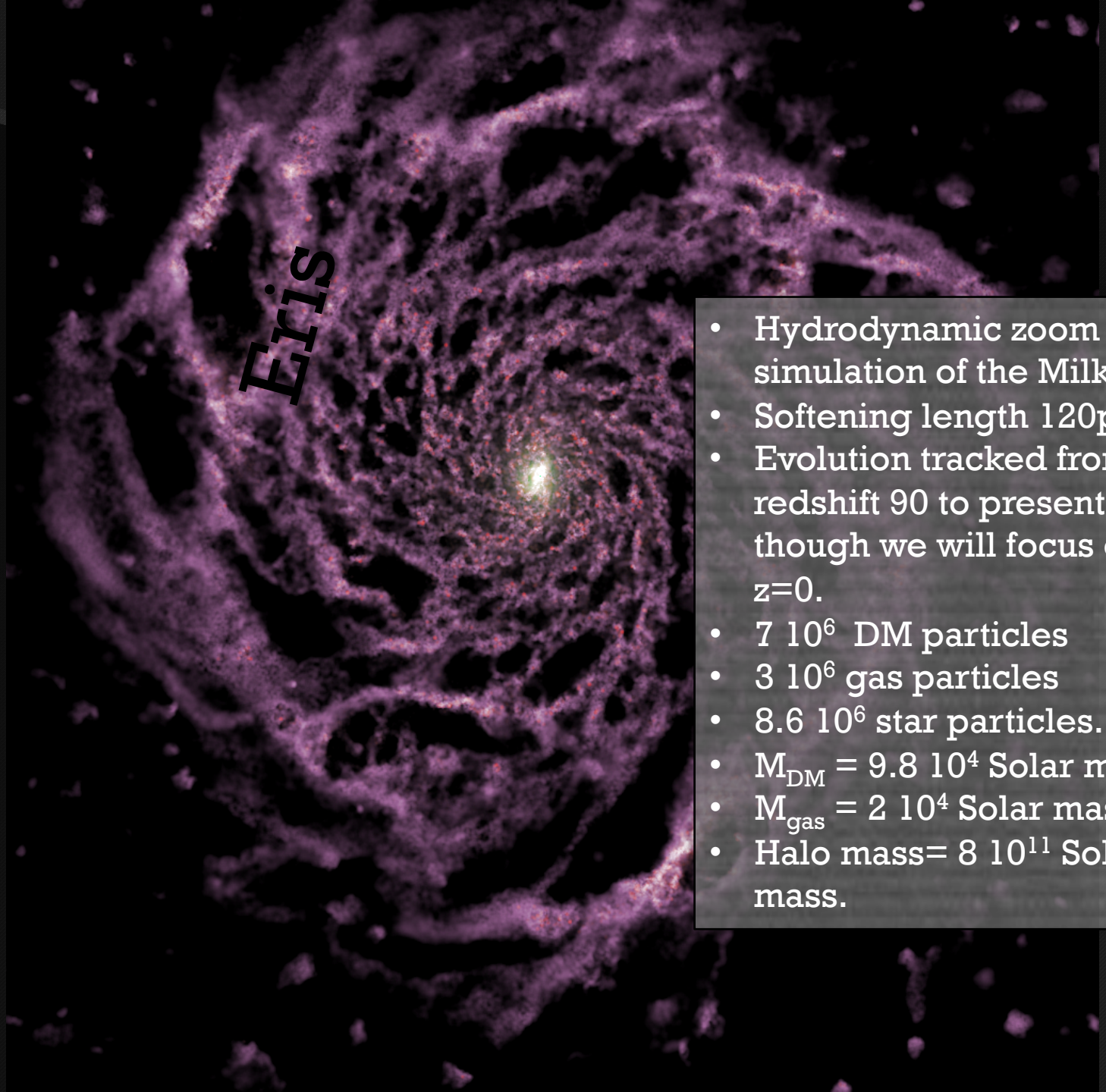
First Empirical Velocity Distribution of Dark Matter

- Error bars will decrease with the next Gaia releases.
- Kinematic outliers sign of DM substructure?

Thank you!

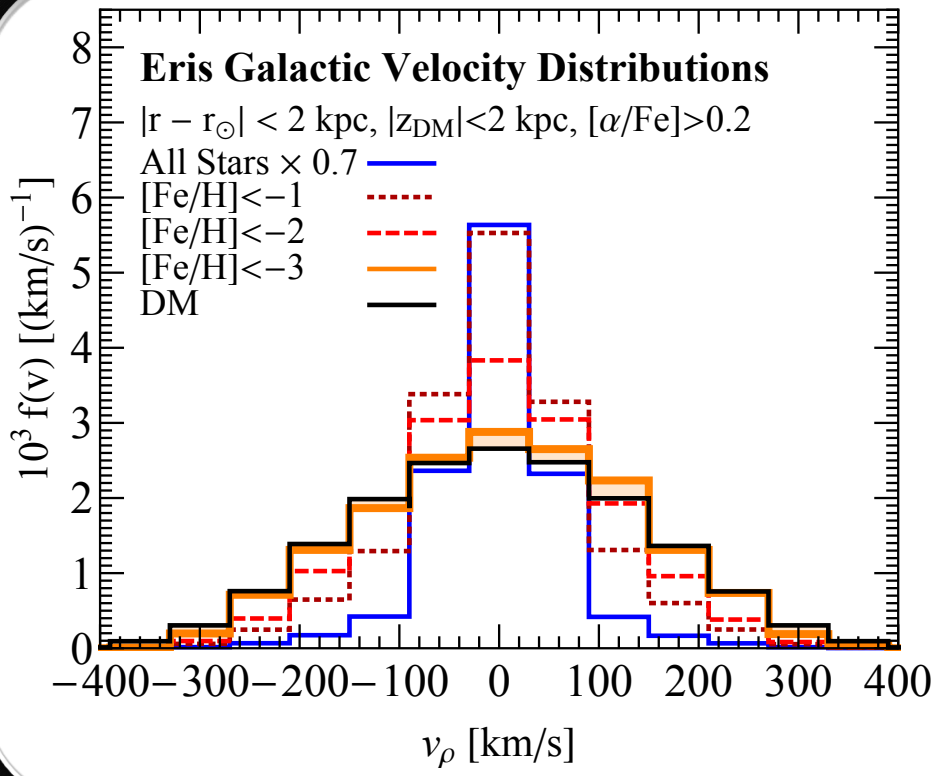

RAVE-TGAS [Fe/H] Distribution
Quality Cuts Applied
$|z| > 1.5$ kpc
$|z| < 1.5$ kpc
$f([\mathrm{Fe/H}])$ [dex]$^{-1}$
[Fe/H] [dex]
2.0
1.5
1.0
0.5
0.0
−3
−2
−1
0

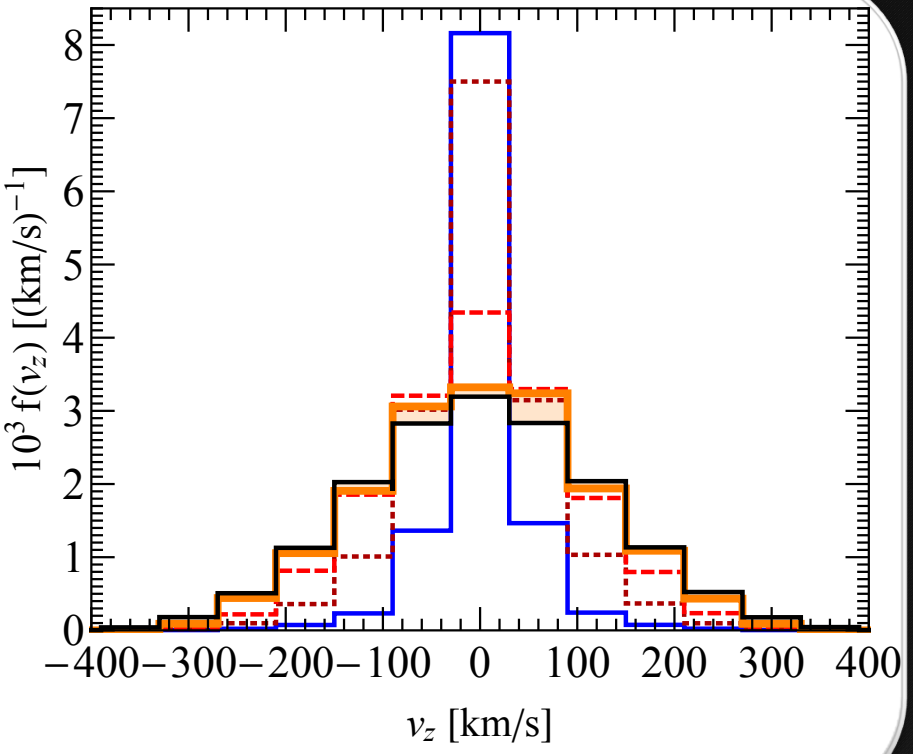

[Fe/H]< −1.5
Number of Stars
0
5
10
15
20
25
0.0
0.2
0.4
0.6
0.8
1.0
Probability to be in the Halo



- Hydrodynamic zoom in simulation of the Milky way.
- Softening length 120pc.
- Evolution tracked from redshift 90 to present day, though we will focus on z=0.
- 7 10^6 DM particles
- 3 10^6 gas particles
- 8.6 10^6 star particles.
- M_{DM} = 9.8 10^4 Solar mass
- M_{gas} = 2 10^4 Solar mass
- Halo mass= 8 10^{11} Solar mass.

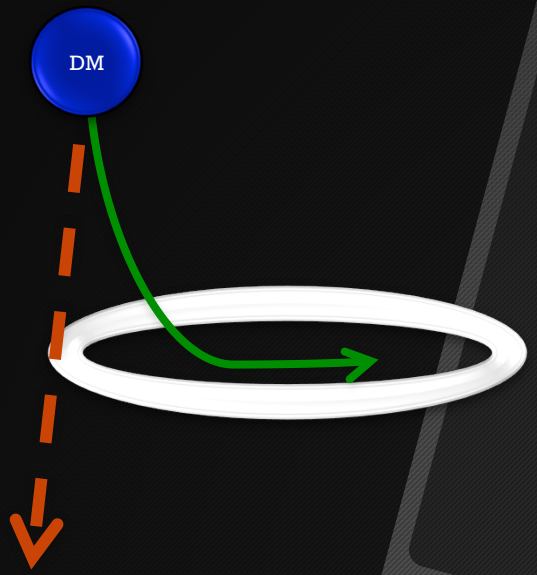
Stellar and Dark Matter Distributions

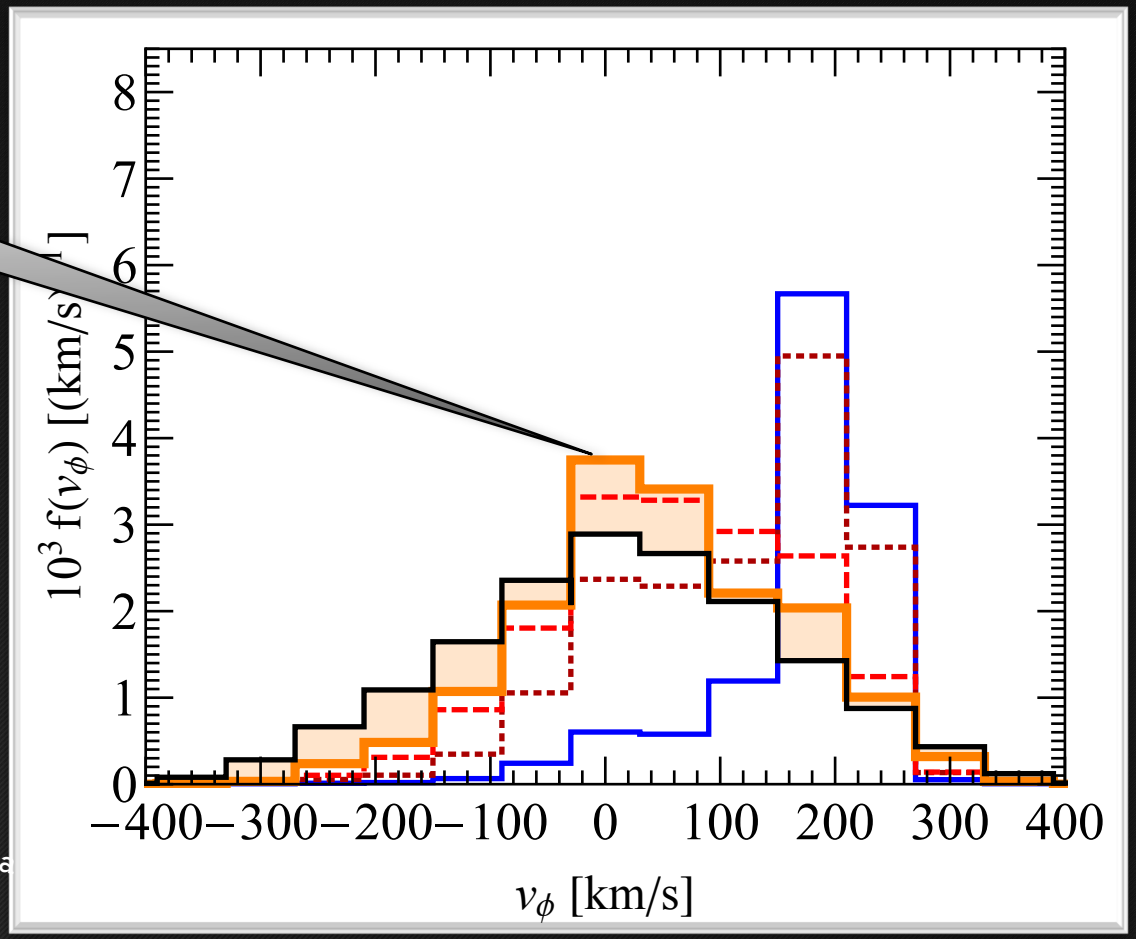




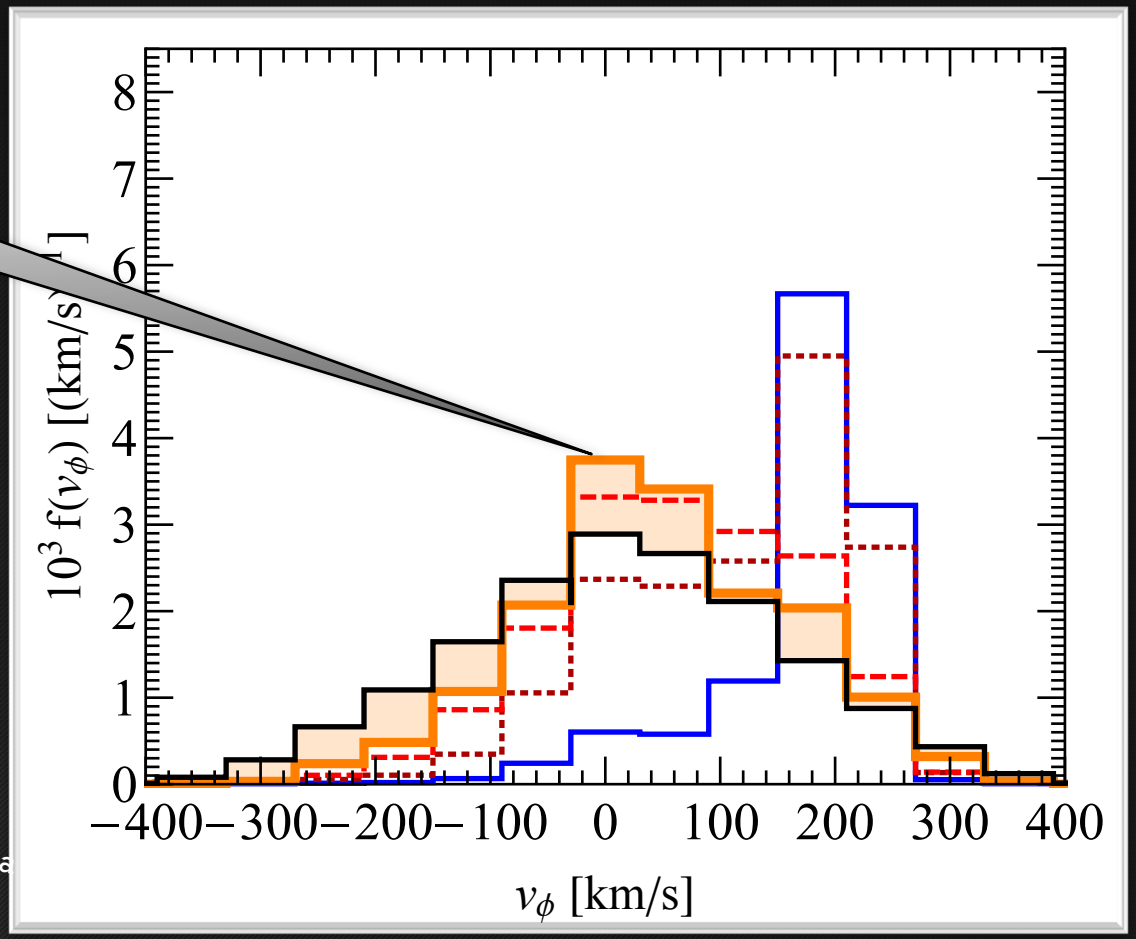
Stellar and Dark Matter Distributions

Prograde rotation found in Eris





Stellar and Dark Matter Distributions

Prograde rotation found in Eris

There is no evidence for significant prograde rotation for metal poor stars in data.