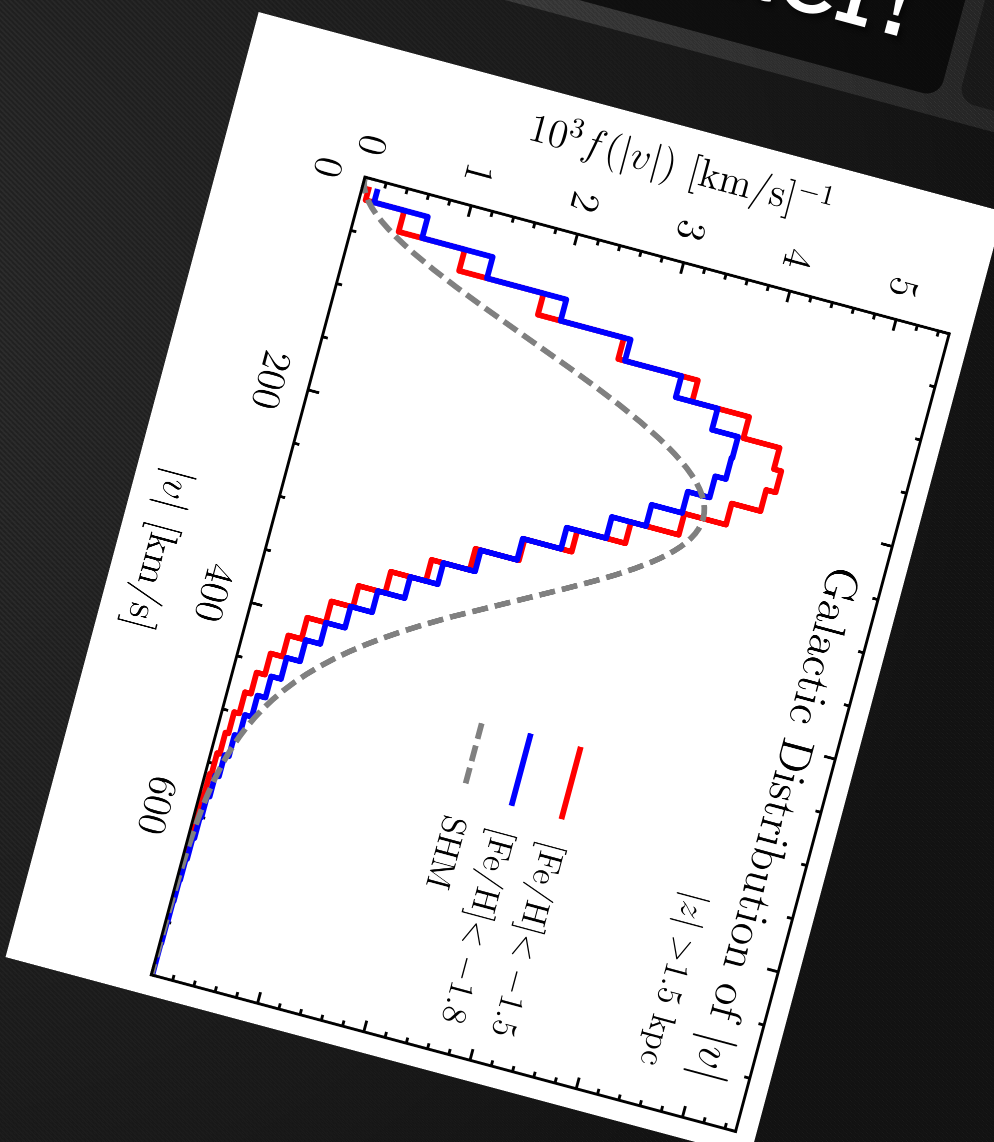
Empirical Determination of Dark Matter Velocity Distribution

Lina Necib, Caltech

Based on 1704.04499 & 1708.03635

In collaboration with Jonah Herzog-Arbeitman and Mariangela Lisanti

Empirically Determined Velocity Distribution of Dark Matter!



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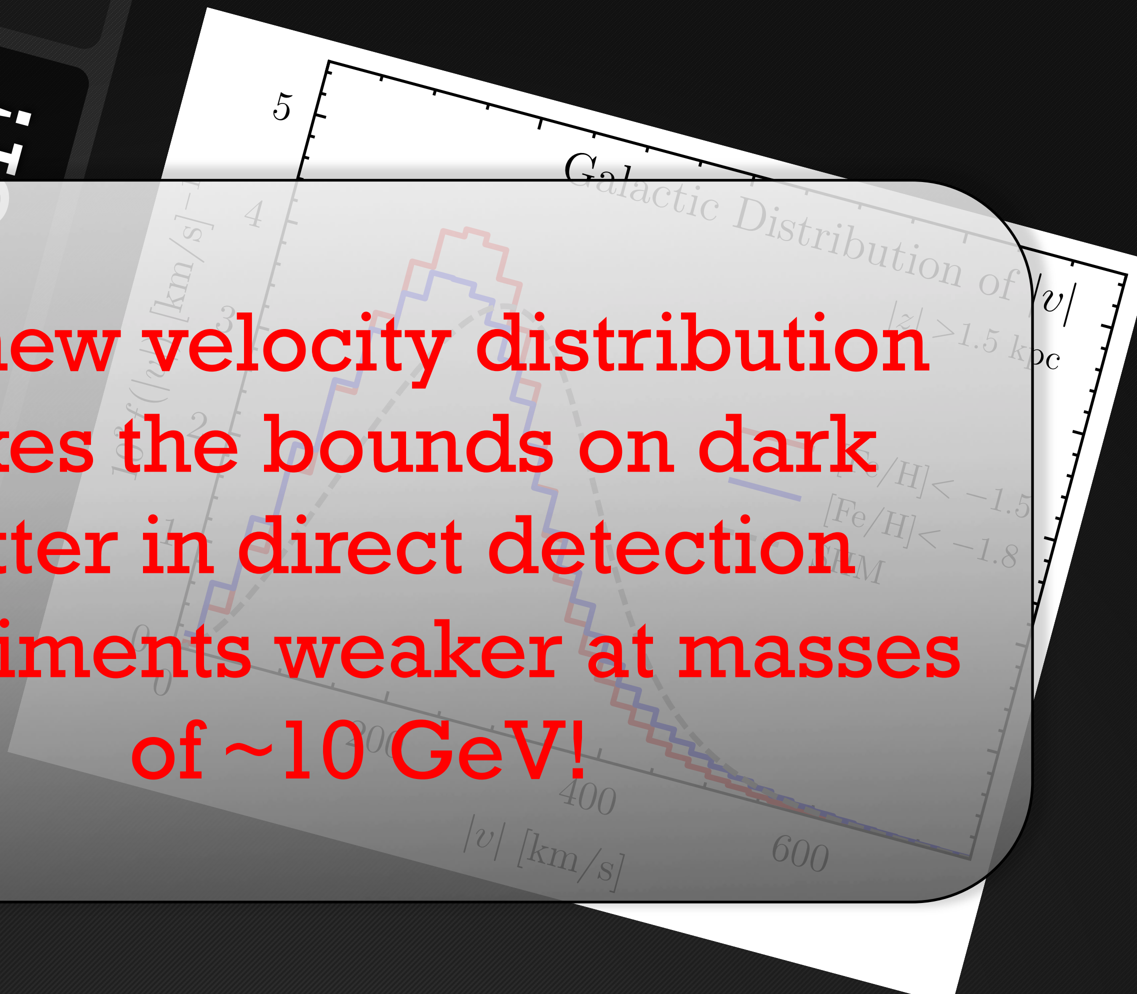
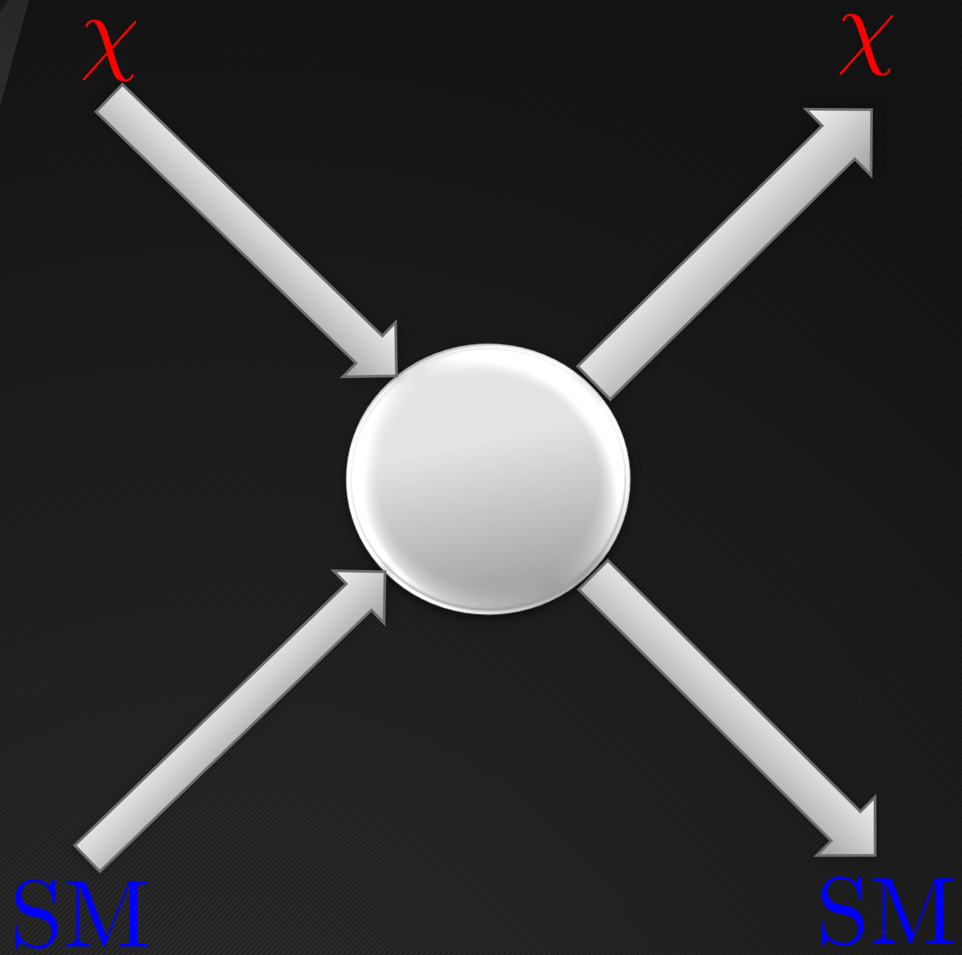


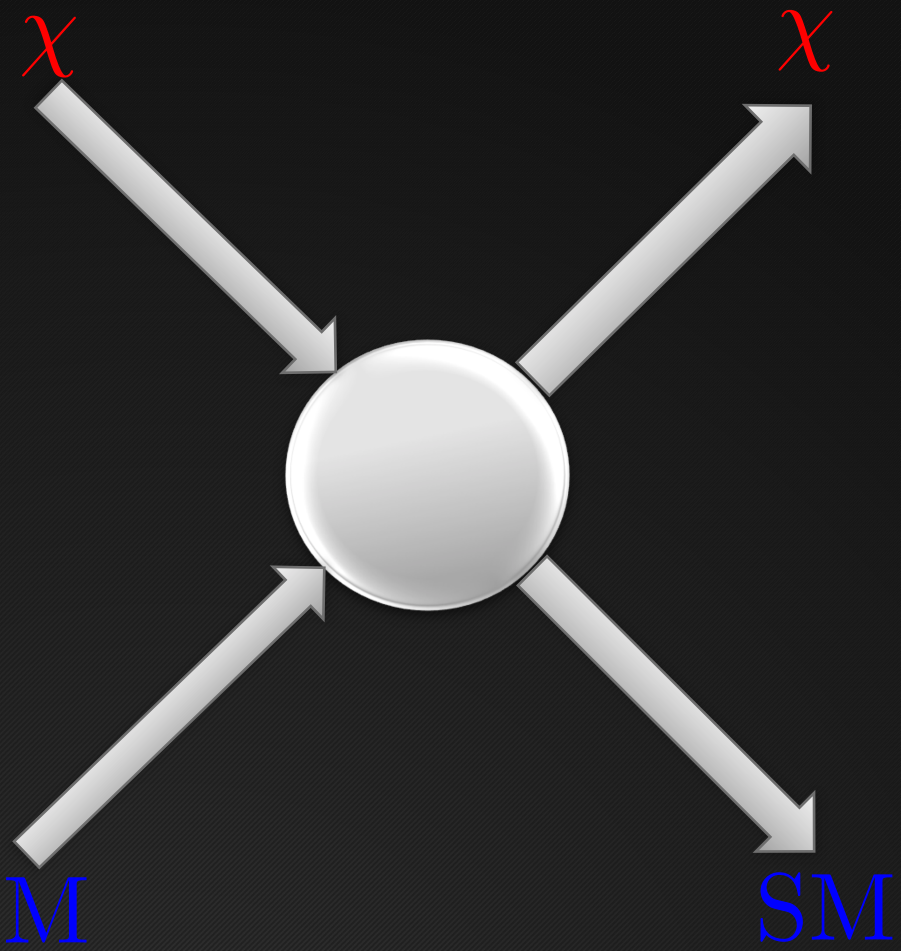
The new velocity distribution makes the bounds on dark matter in direct detection experiments weaker at masses of ~10 GeV!

Direct Detection



Direct Detection

The detection rate depends on the incoming velocity of Dark Matter.



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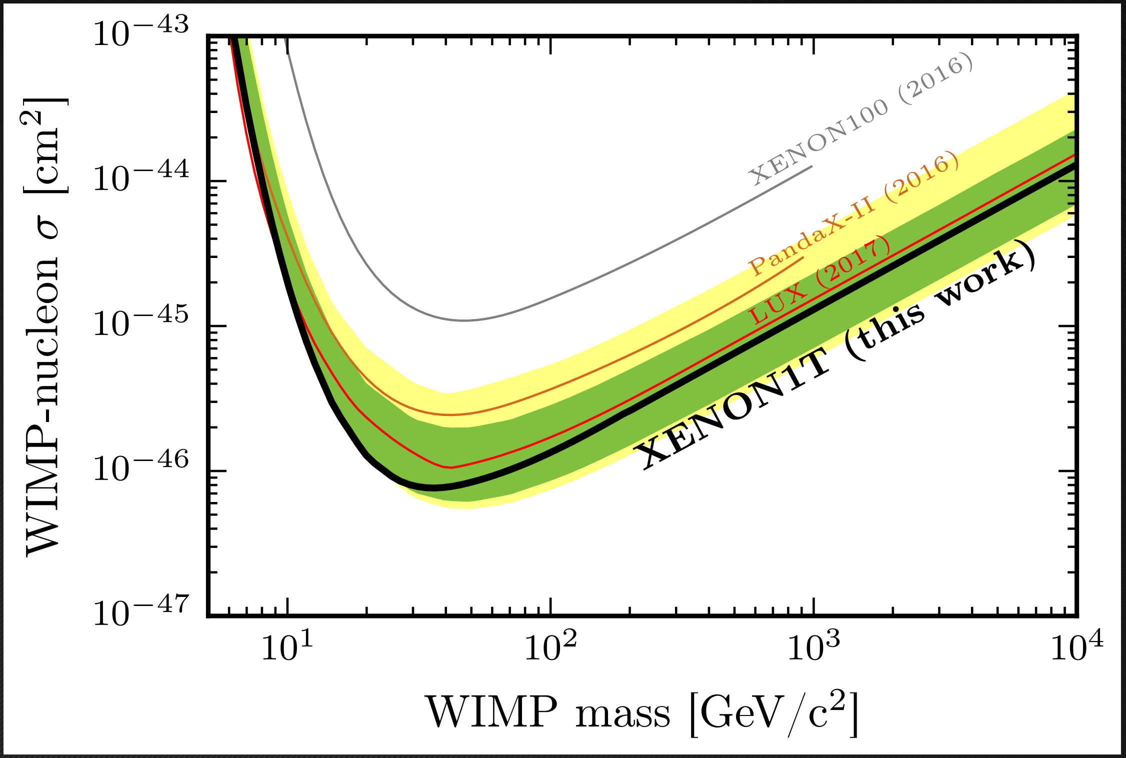

Aprile et al.
arXiv:1705.06655

Direct Detection

The detection rate depends on the incoming velocity of Dark Matter.

These limits might be strong by as much as a faction of 2.

Aprile et al.
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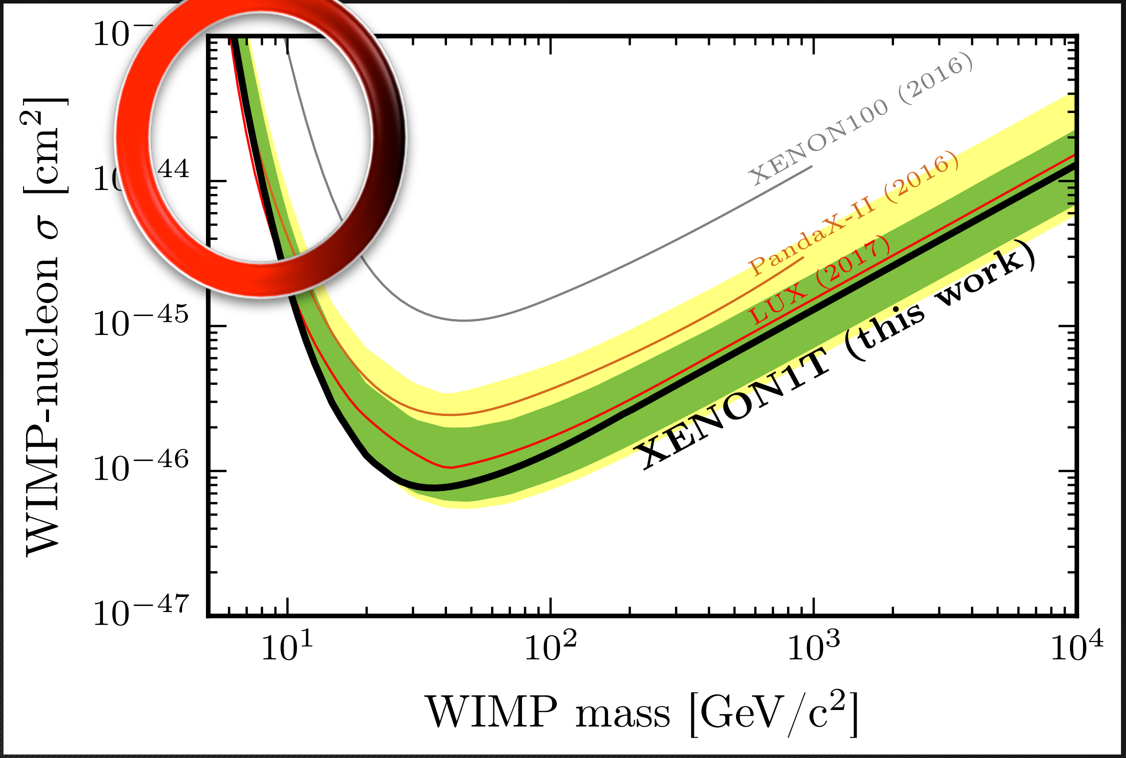

Assumes the standard Maxwell Boltzmann velocity distribution.

Strategy

How to empirically measure the velocity distribution of Dark Matter!

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Find Dark Matter Tracers!

Strategy

How to empirically measure the velocity distribution of Dark Matter!

From Simulations:

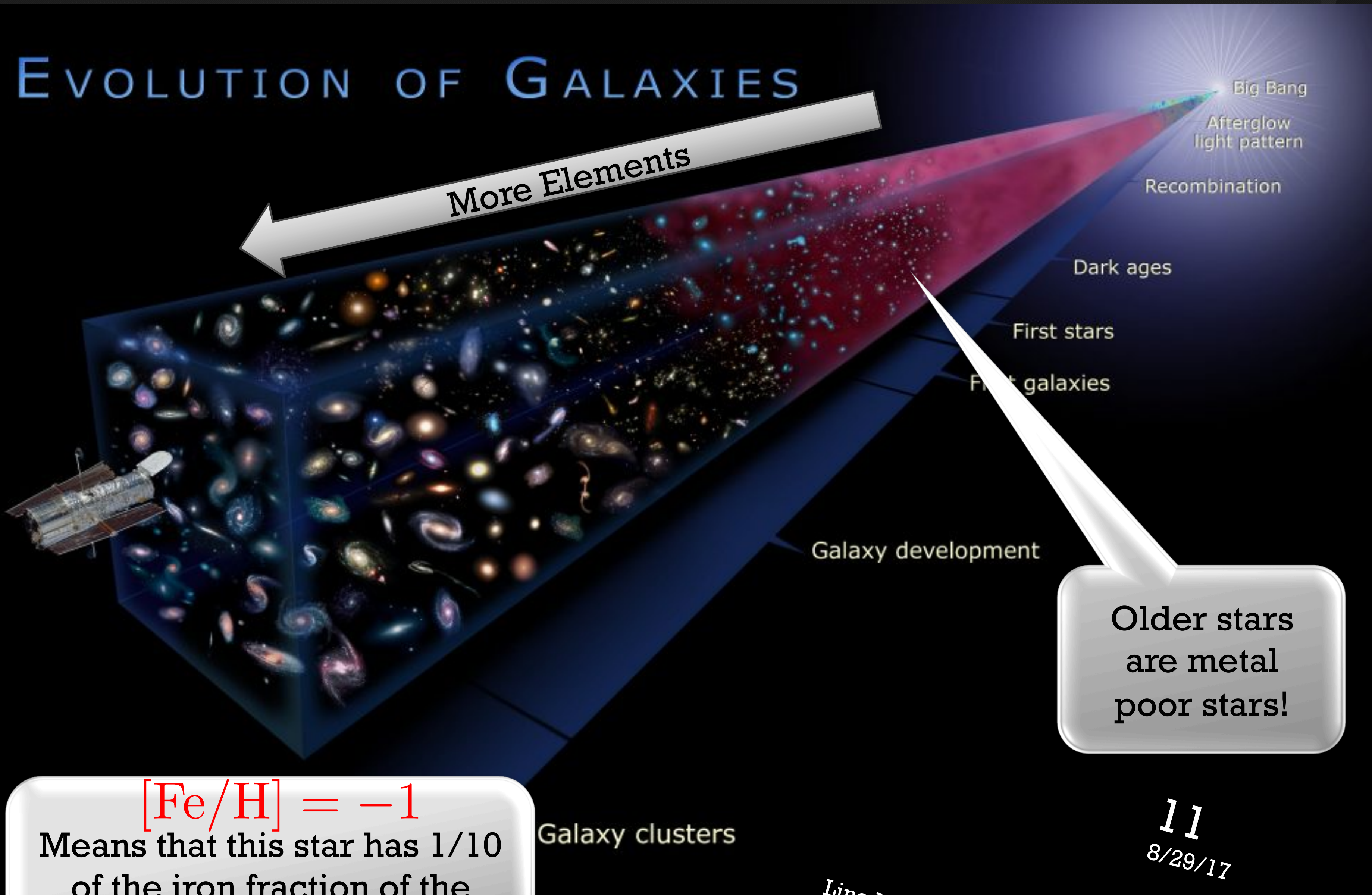
Metal-Poor Stars trace the velocity of Dark Matter.

From Gaia DR1:

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

Therefore:

We empirically obtain the Dark Matter velocity distribution.



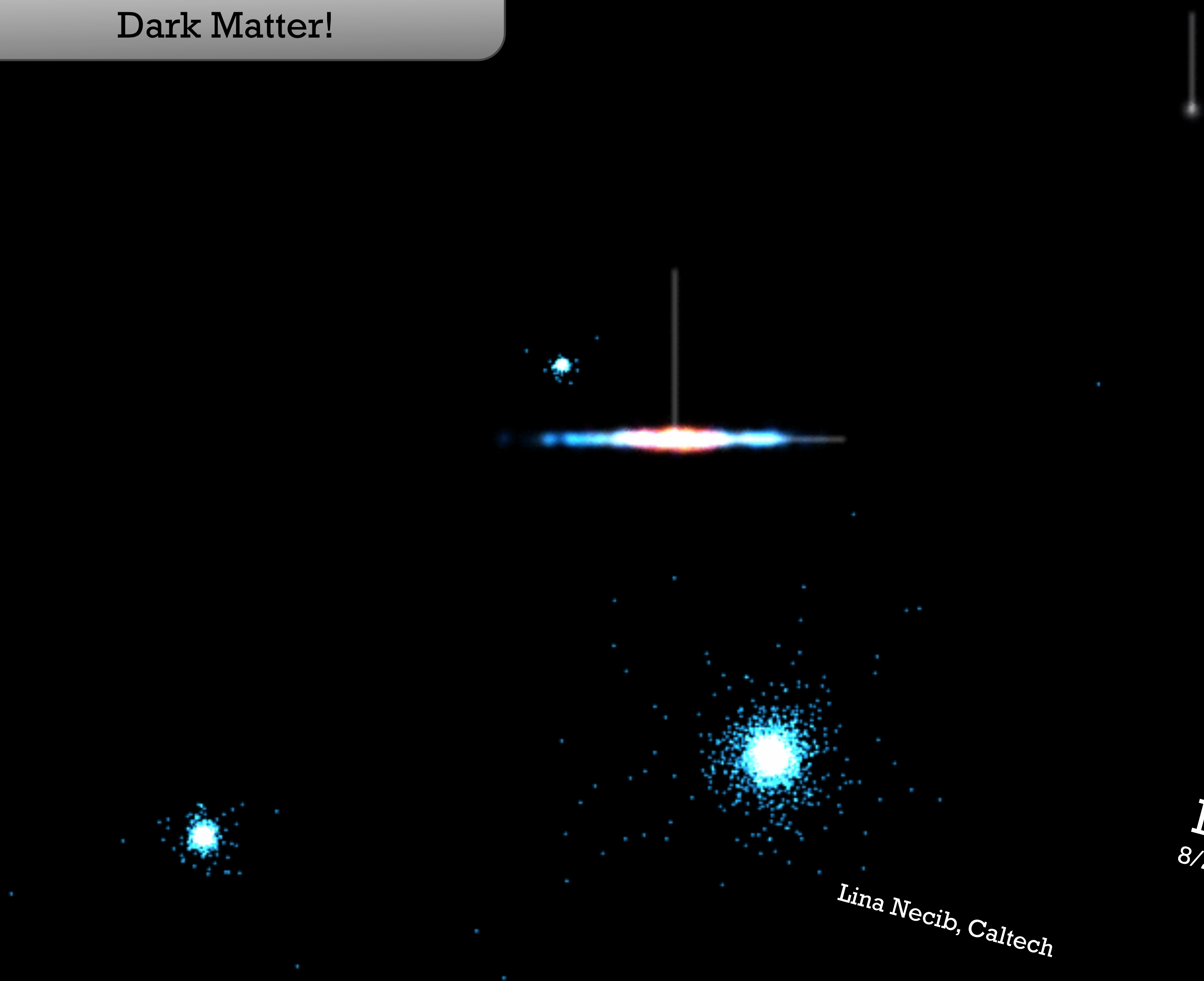
More Elements

Older stars are metal poor stars!

$[Fe/H] = -1$

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!



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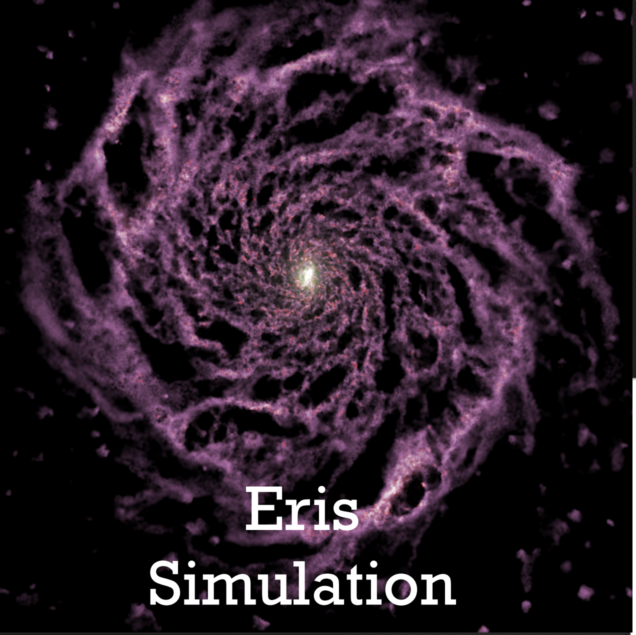
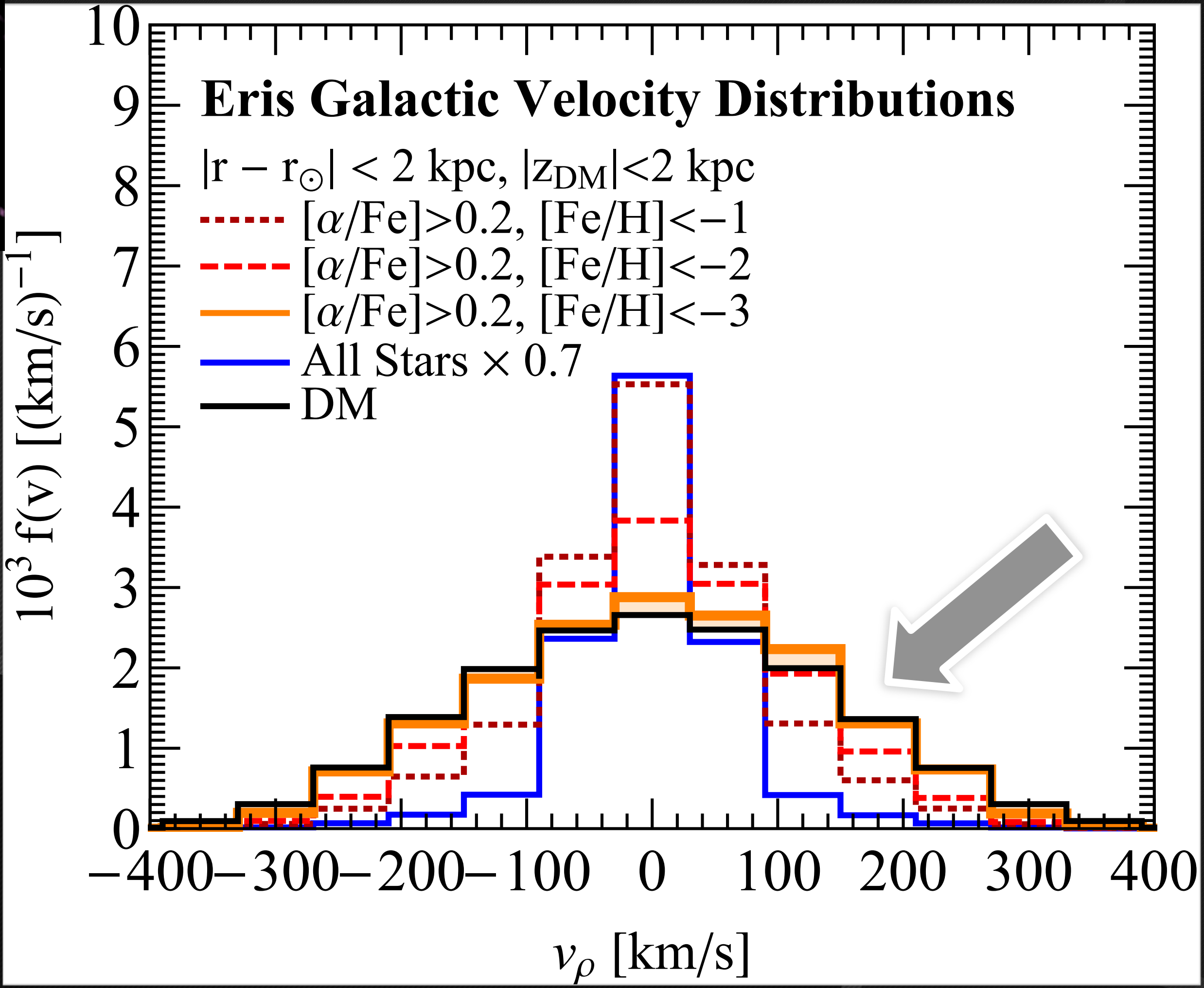
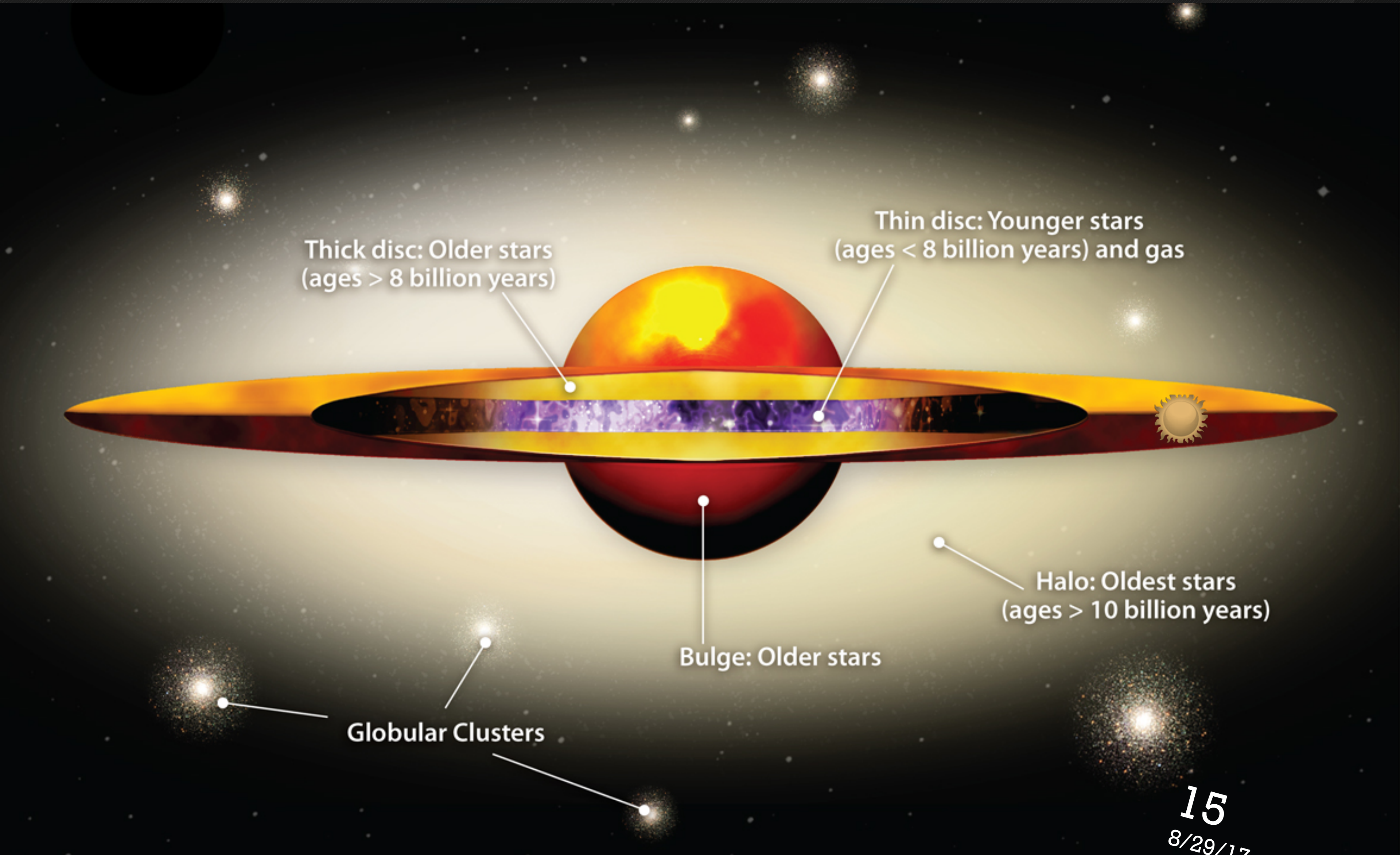
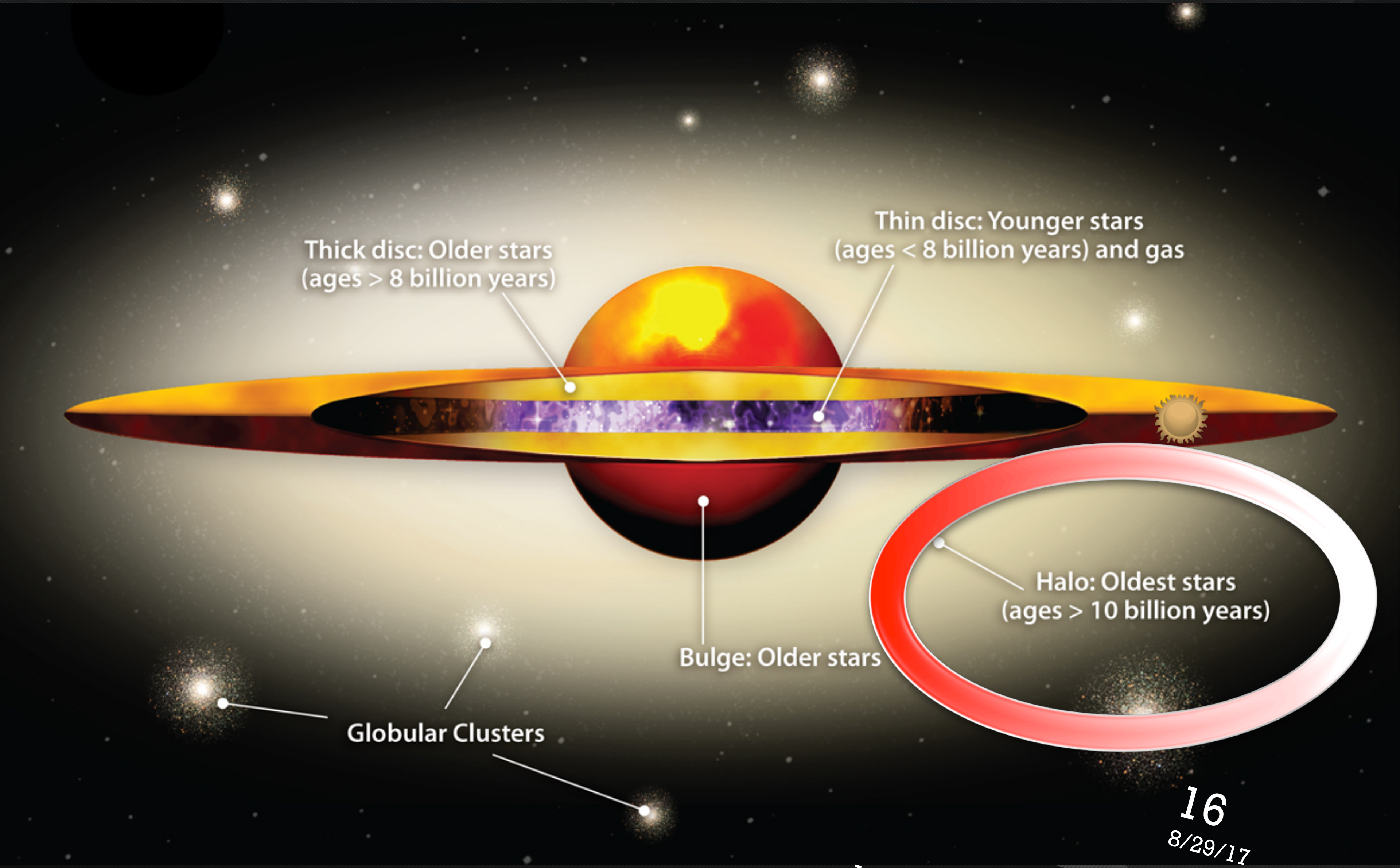




This is being further studied in other simulations.

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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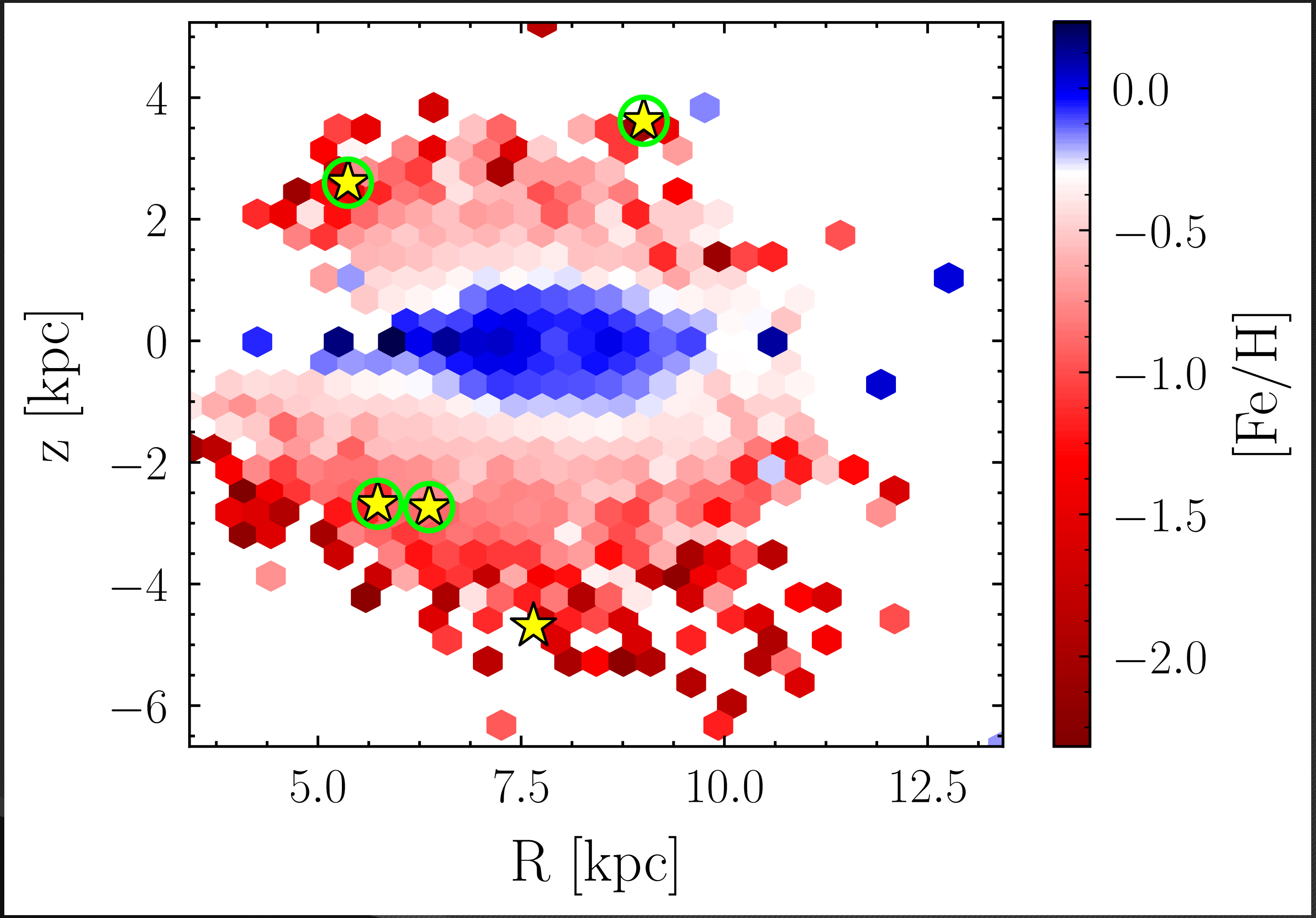
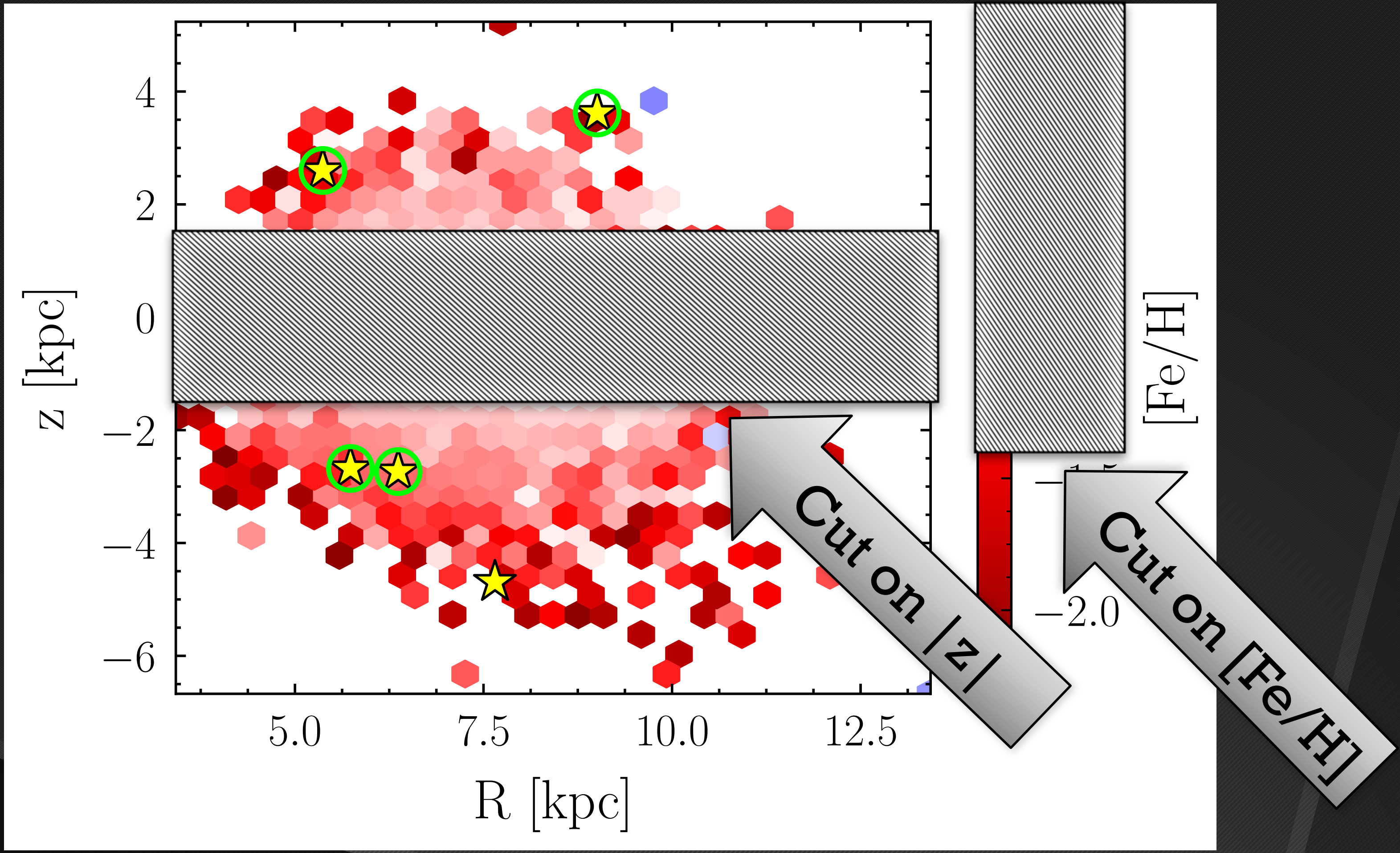


Gaia DR1: Lindergren et al. (2016)
RAVE heliocentric velocities: Kunder et al. (2017)
TGAS (Tycho-Gaia) proper motions: Michalik et al.(2015)
RAVE-on chemical properties: Casey et al. (2016)
Distances: McMillan et al. (2017)



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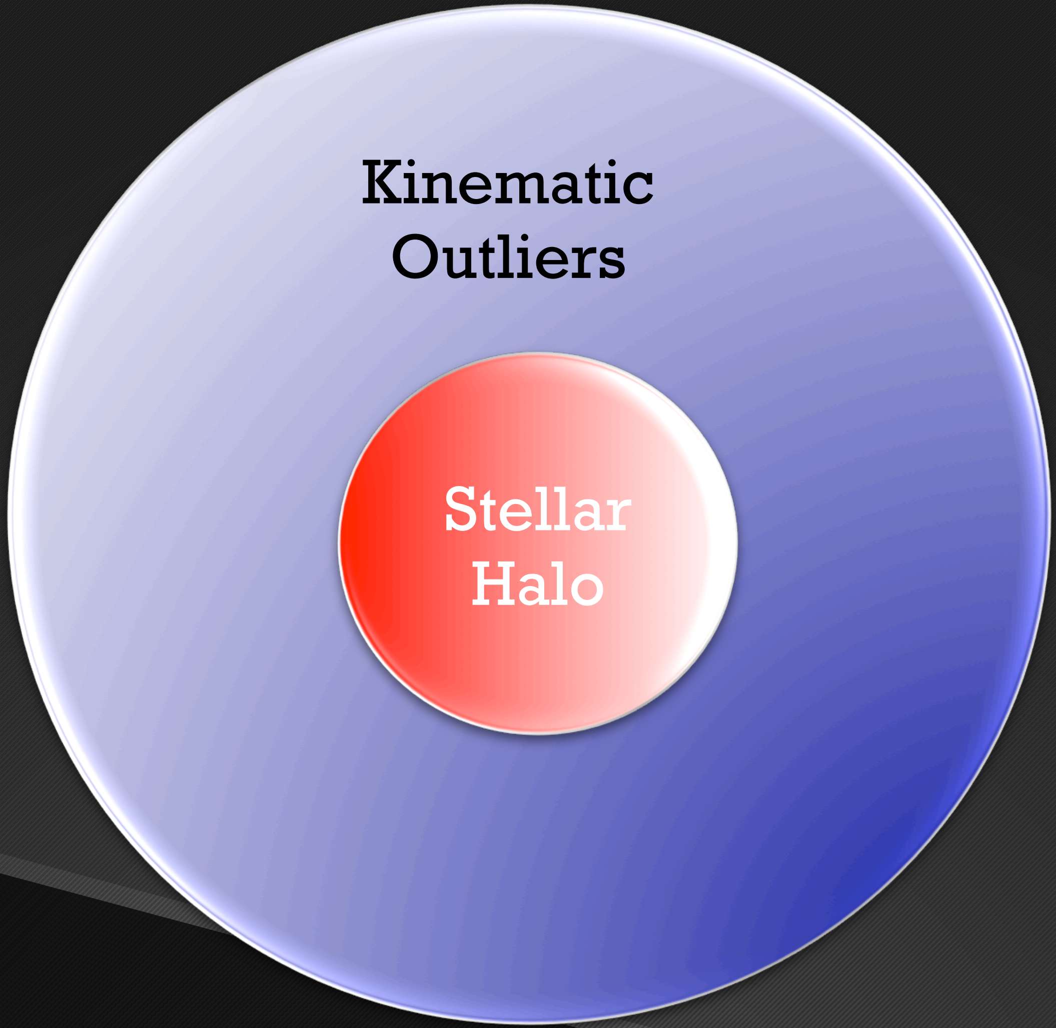
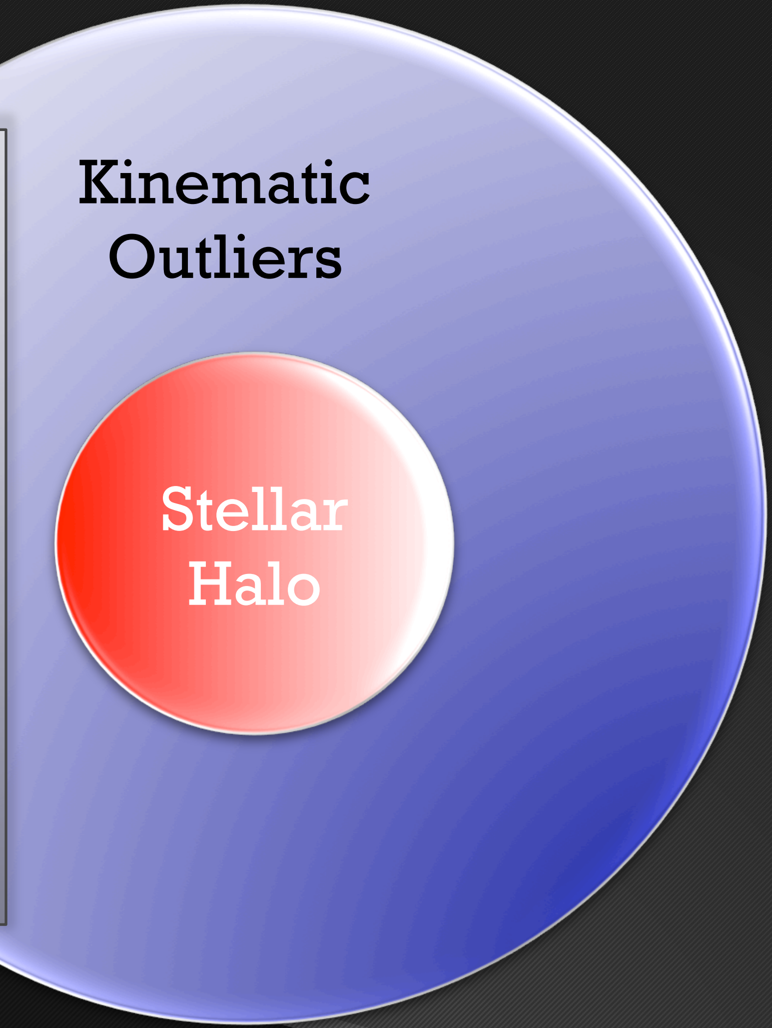
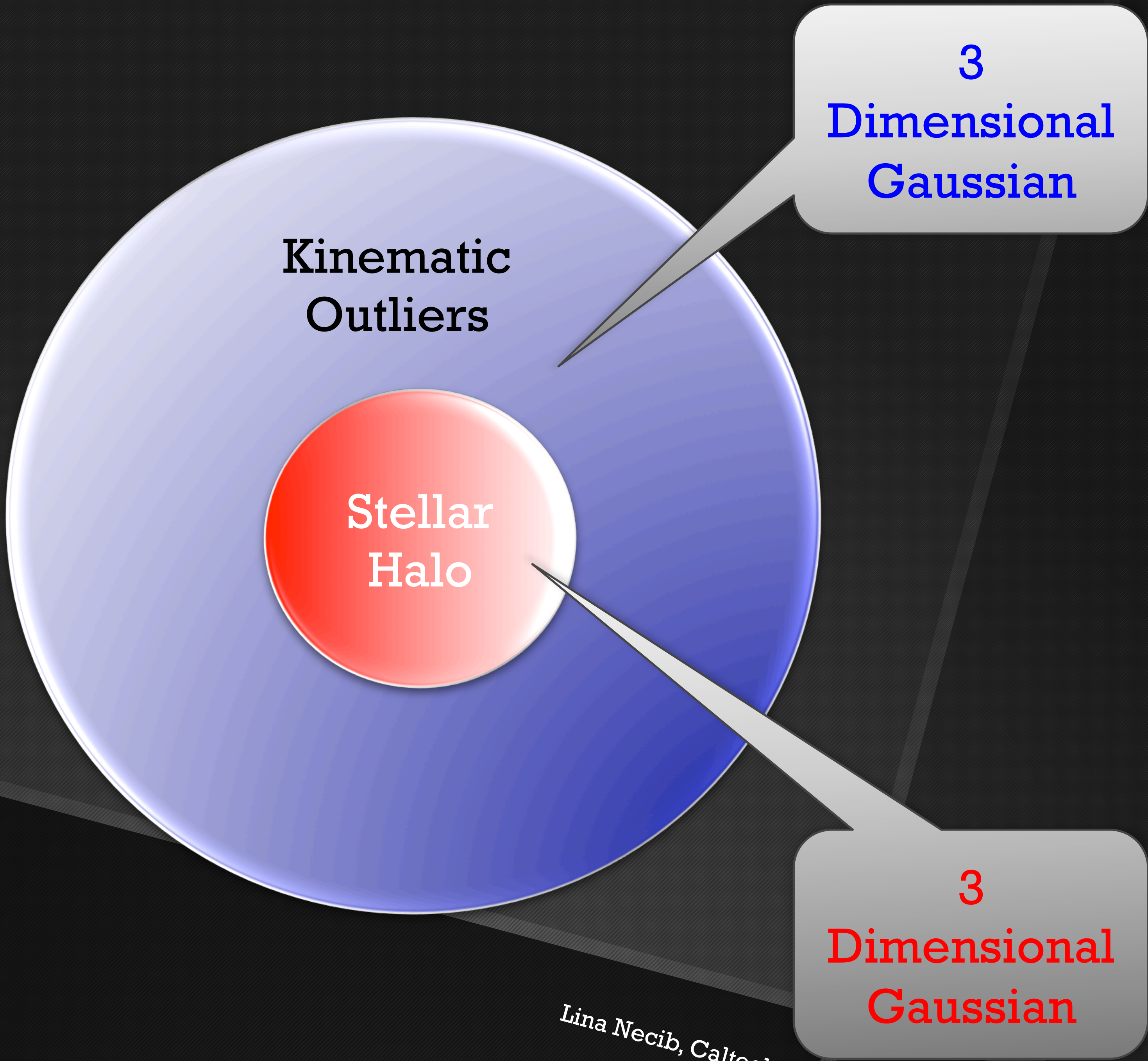
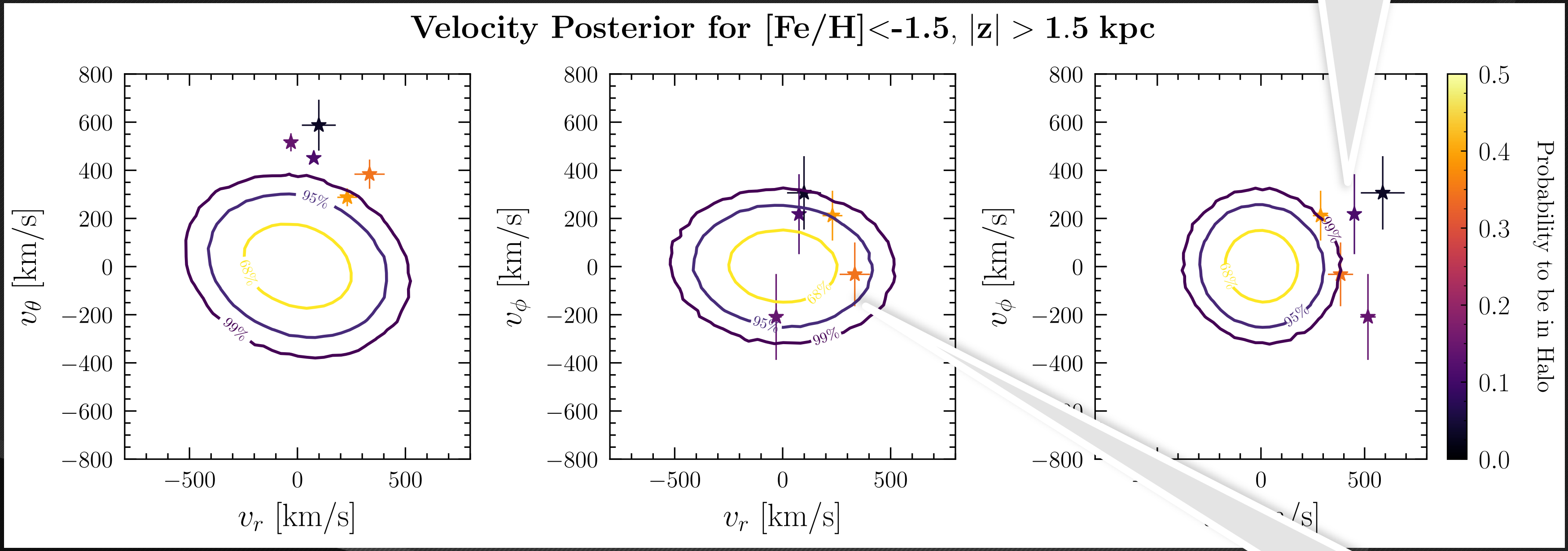

Kinematic
Outliers
Stellar
Halo

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





Kinematic Outliers
Stellar Halo
3 Dimensional Gaussian
3 Dimensional Gaussian

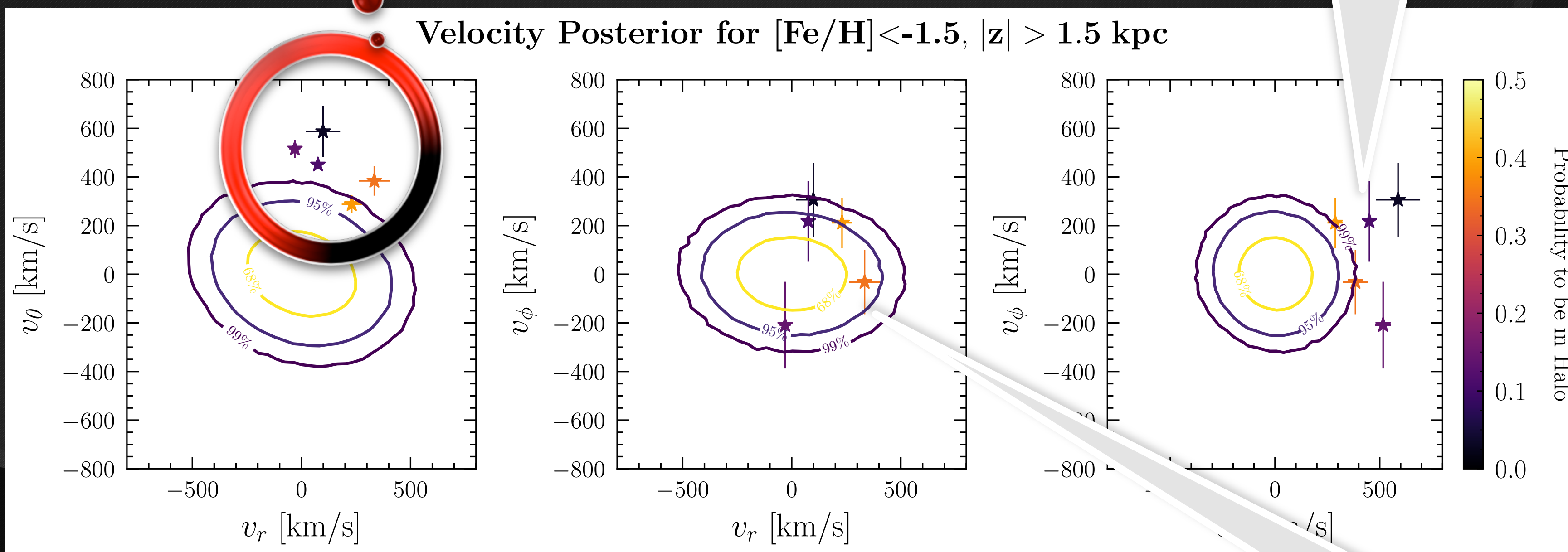


Kinematic Outliers

Best Fit Halo

Hints of dark matter substructure?

Kinematic Outliers



Best Fit Halo

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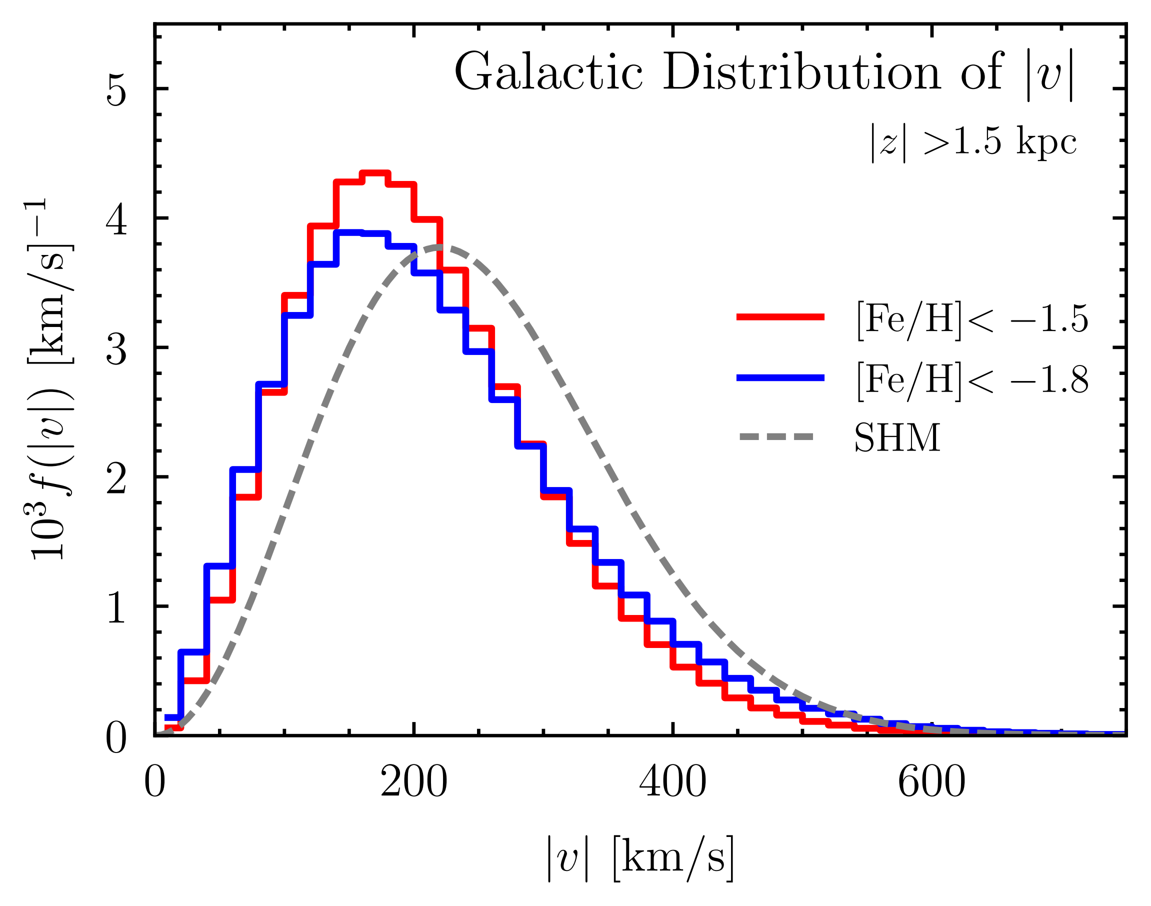
Local Velocity Distribution

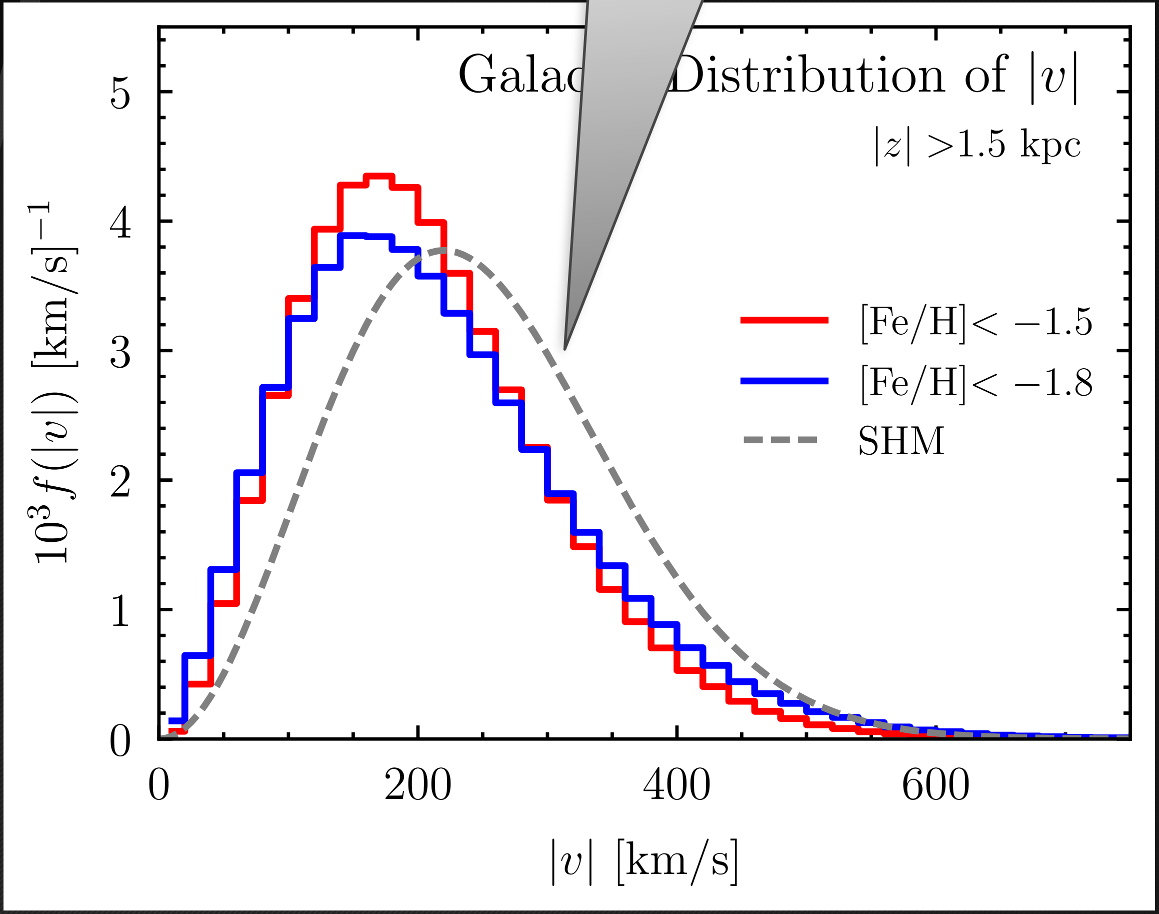
Drum Roll

Posterior Distribution of |v|



Posterior Distribution of |v|

The Maxwell Boltzmann distribution we are taught at school!



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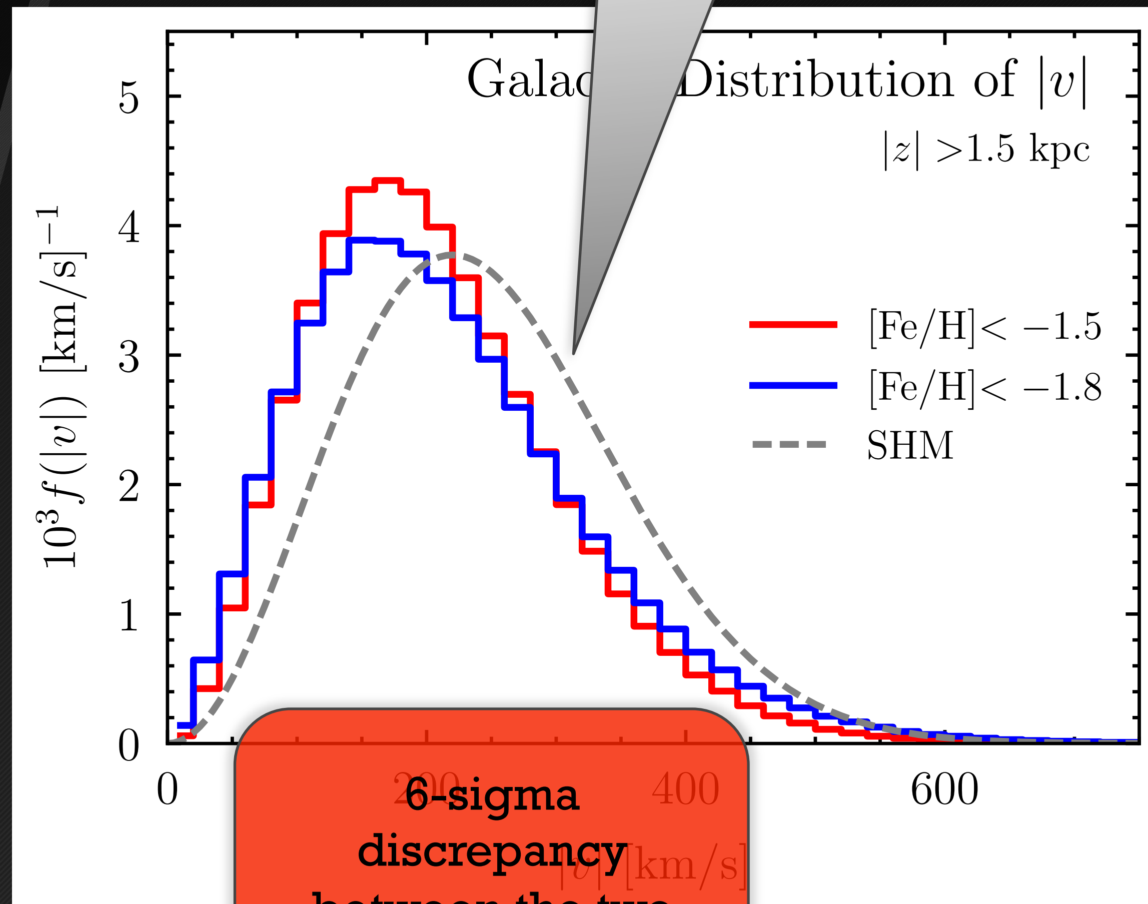

6-sigma discrepancy between the two distributions!

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

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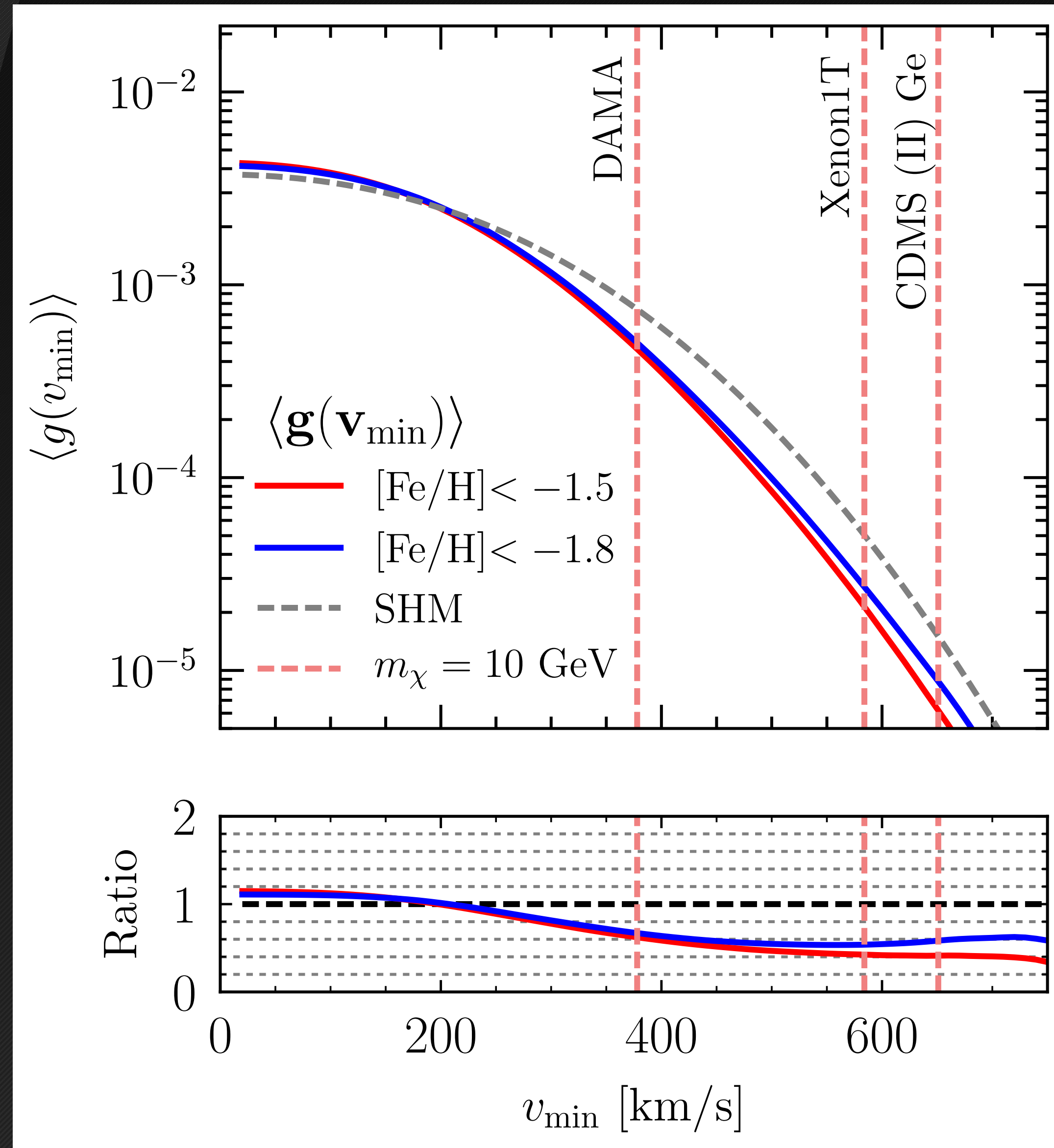
$$\frac{dR}{dQ} \propto \frac{\sigma_0 \rho_0}{m_\chi m_r^2} F^2(Q) g(v_{\min})$$

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

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

In terms of Direct Detection Experiments



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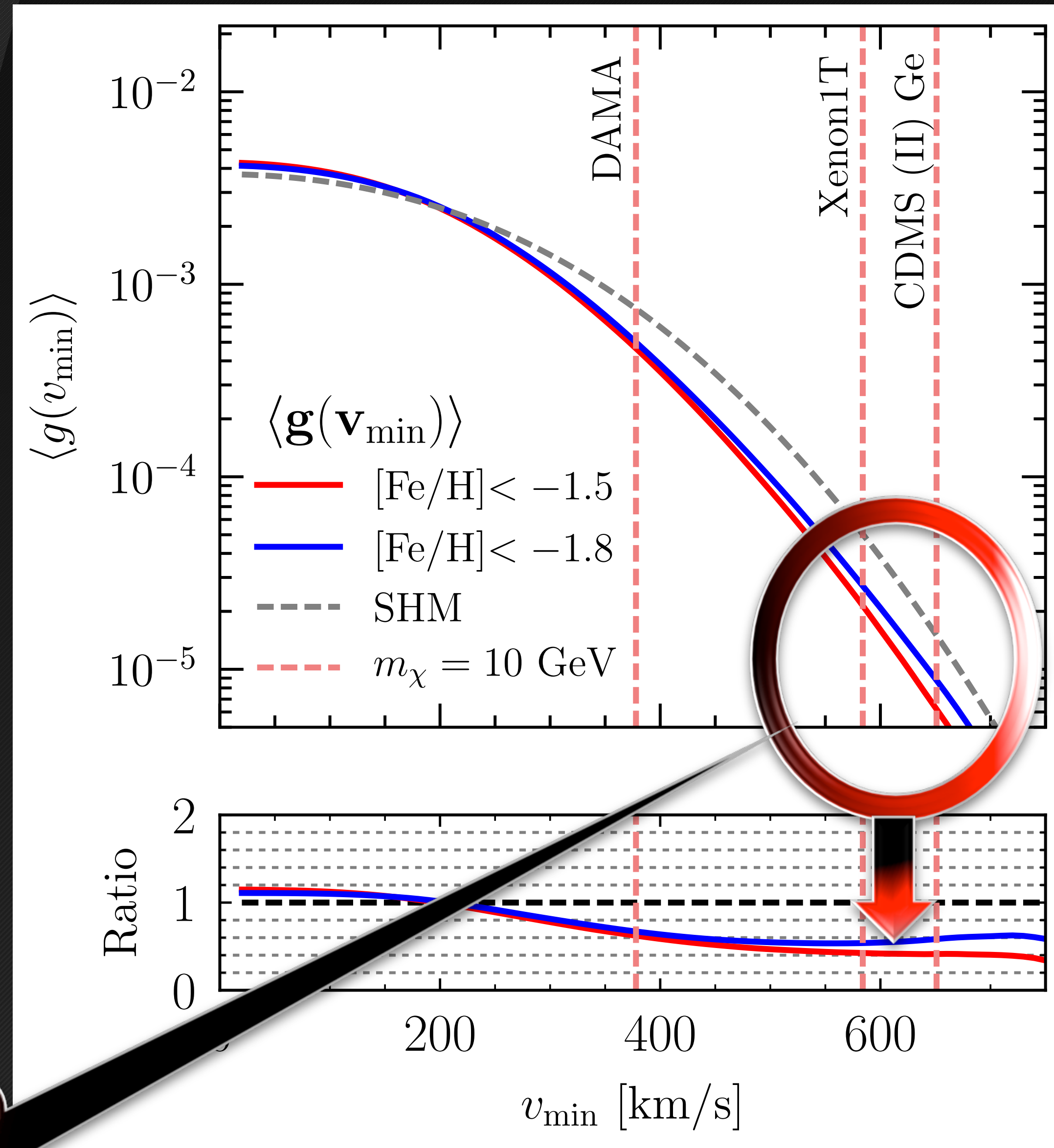
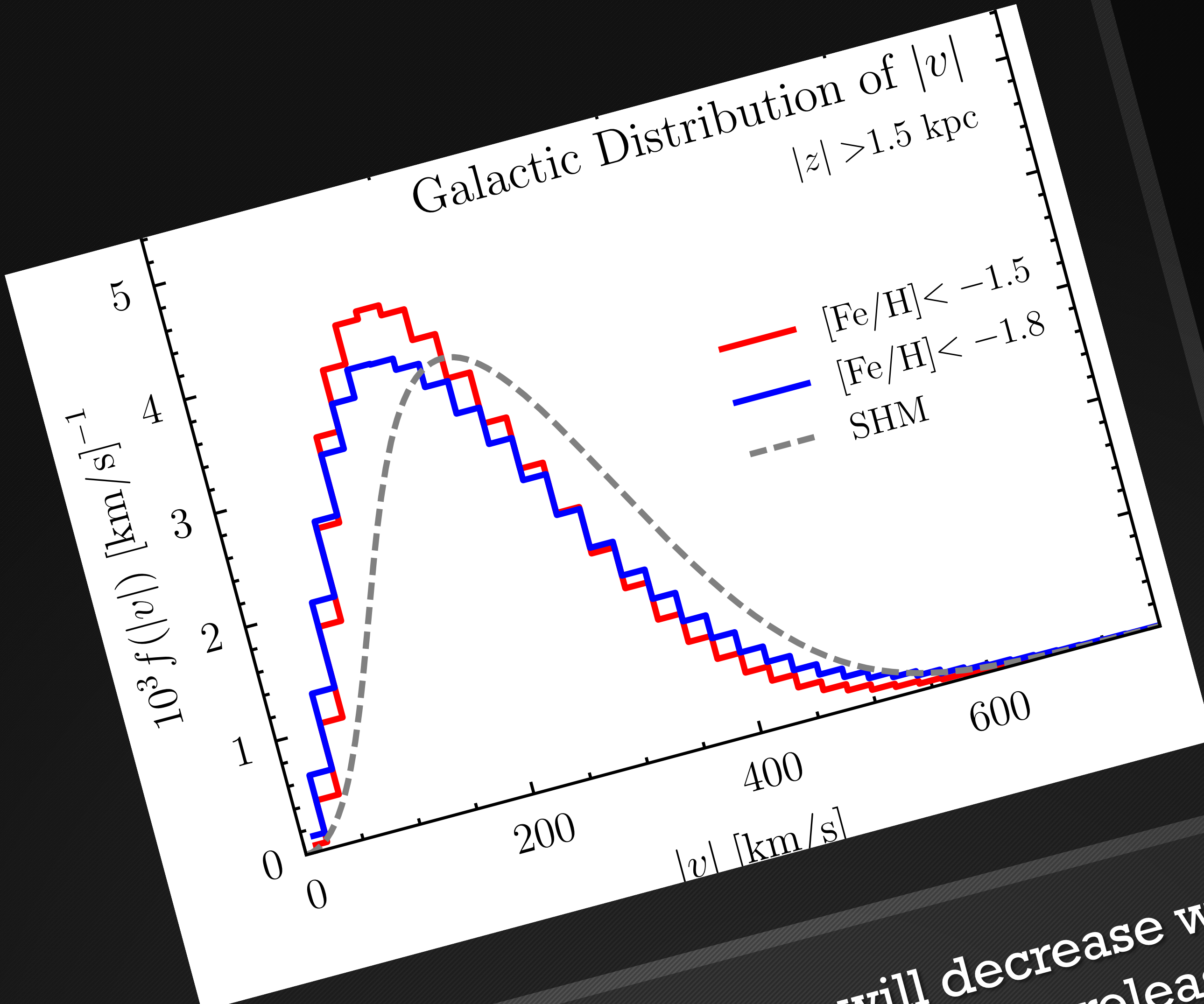
In terms of Direct Detection Experiments



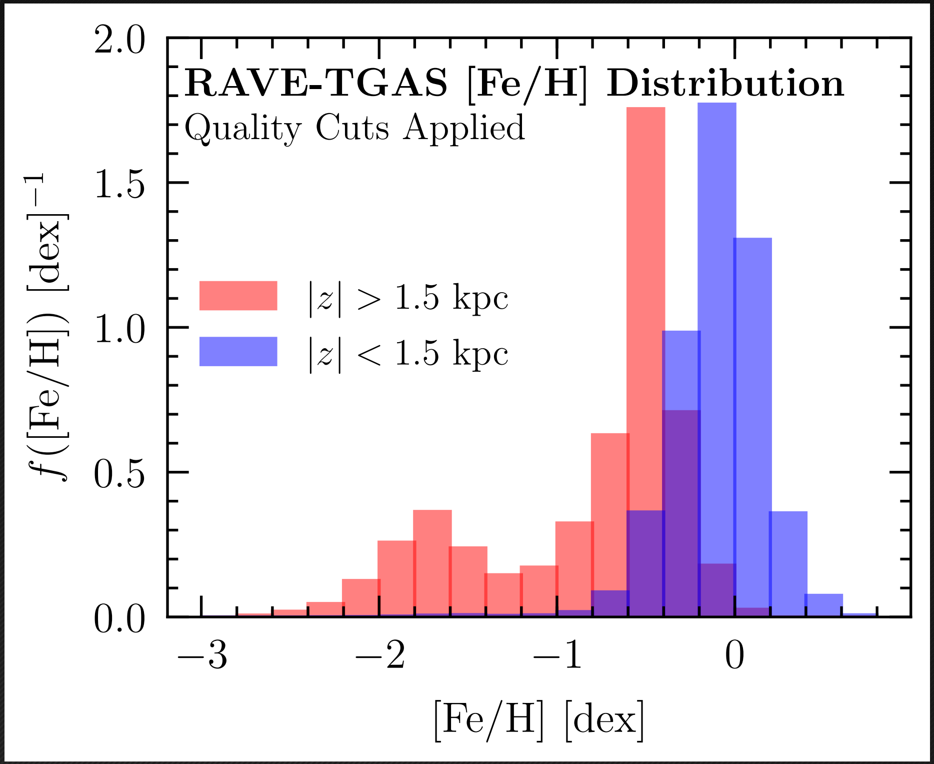
A factor of 2!

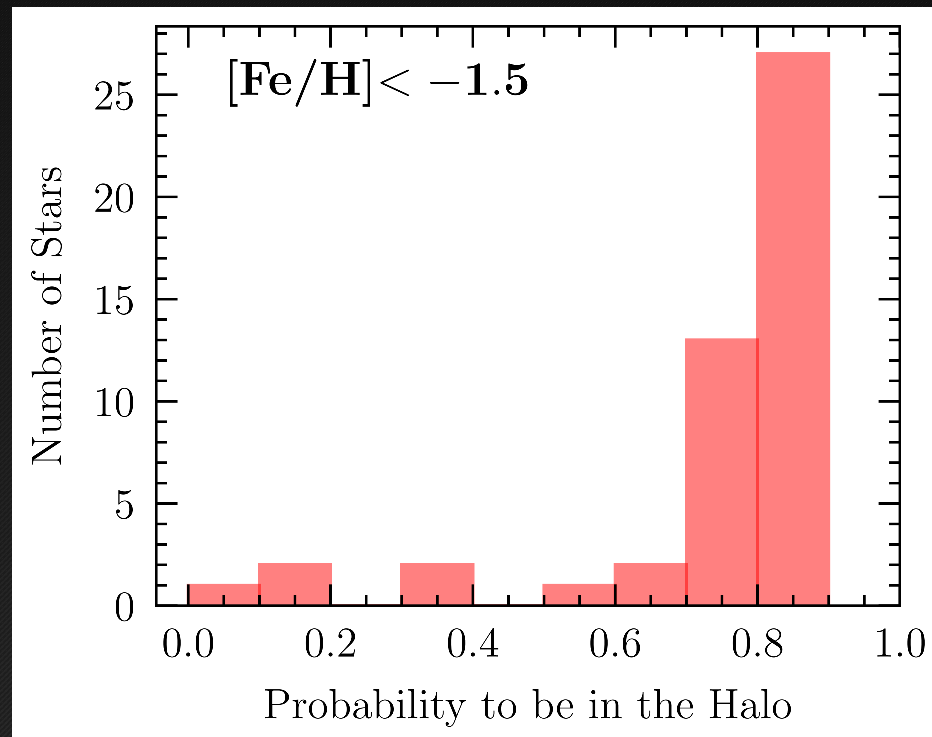
First Empirical Velocity Distribution of Dark Matter

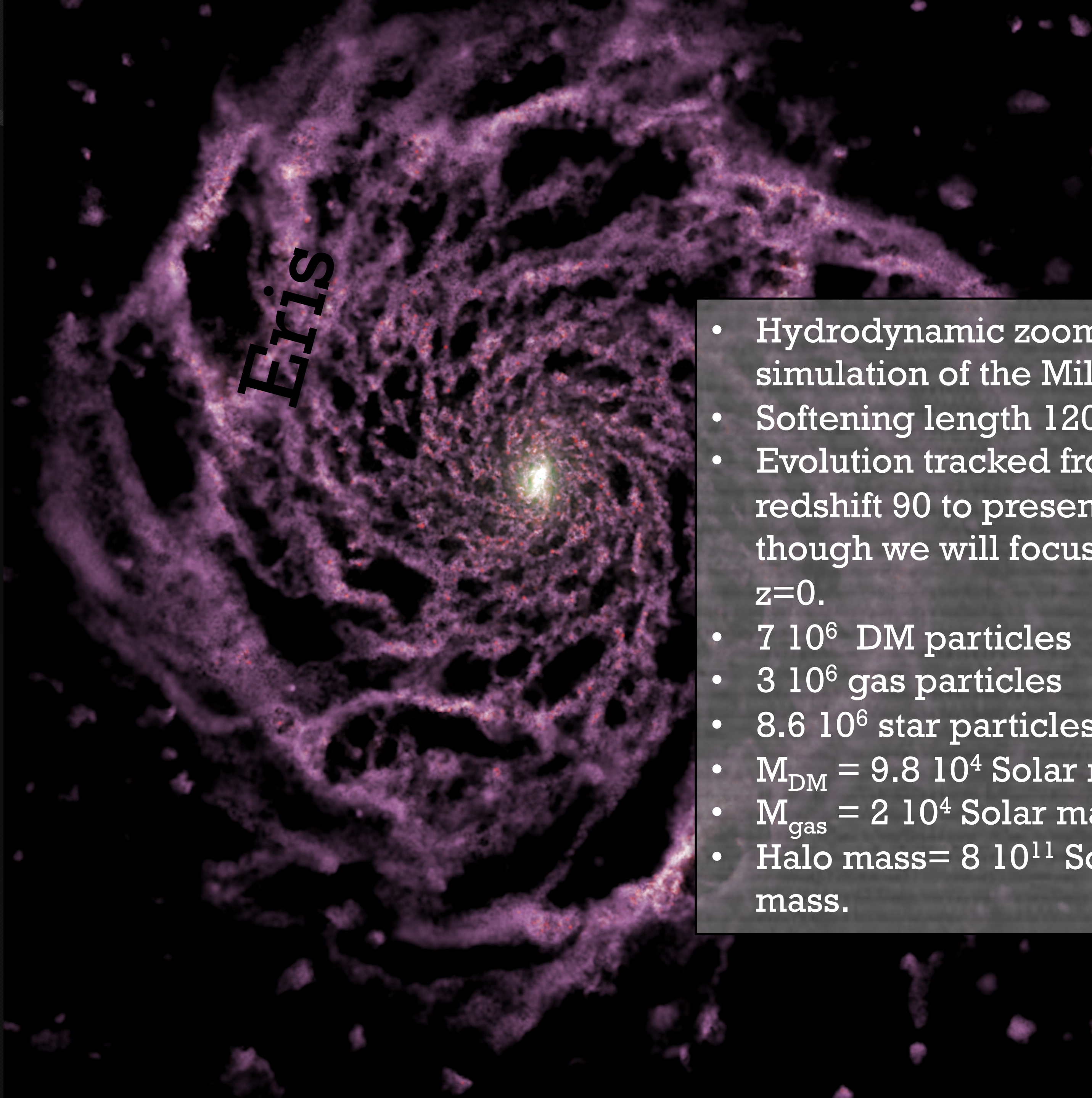


- Error bars will decrease with the next Gaia releases.
- Kinematic outliers sign of DM substructure?

Thank you!

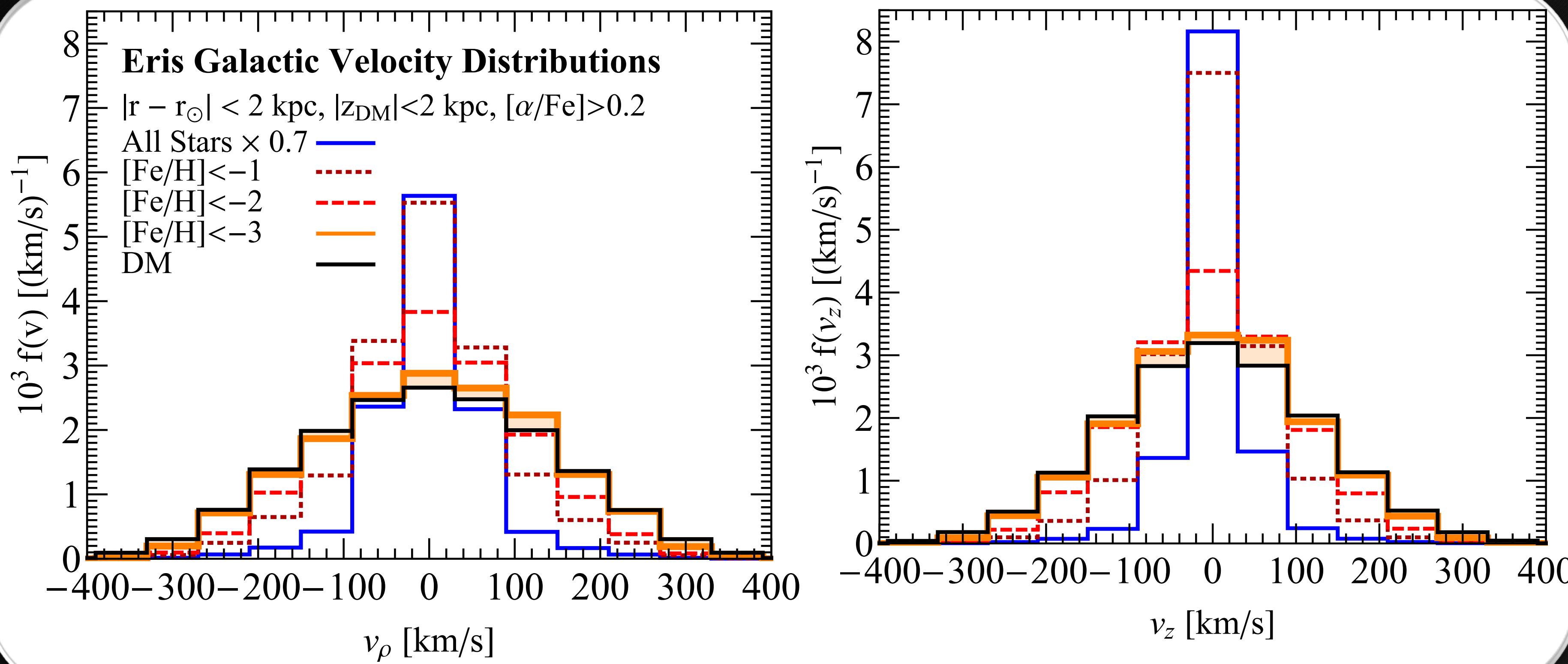

RAVE-TGAS [Fe/H] Distribution
Quality Cuts Applied
|z| > 1.5 kpc
|z| < 1.5 kpc
f([Fe/H]) [dex]^−1
[Fe/H] [dex]
2.0
1.5
1.0
0.5
0.0
−3
−2
−1
0


[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



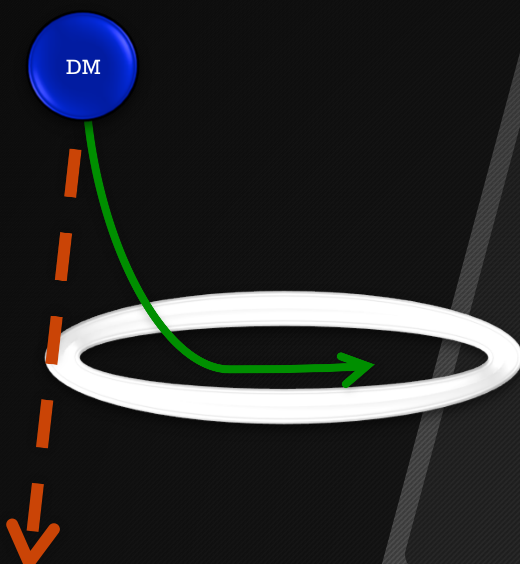
- Hydrodynamic zoom in simulation of the Milky way.
- Softening length 120pc.
- Evolution tracked from redshift 90 to present day, though we will focus on z=0.
- $7\ 10^6$ DM particles
- $3\ 10^6$ gas particles
- $8.6\ 10^6$ star particles.
- $M_{DM} = 9.8\ 10^4$ Solar mass
- $M_{gas} = 2\ 10^4$ Solar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

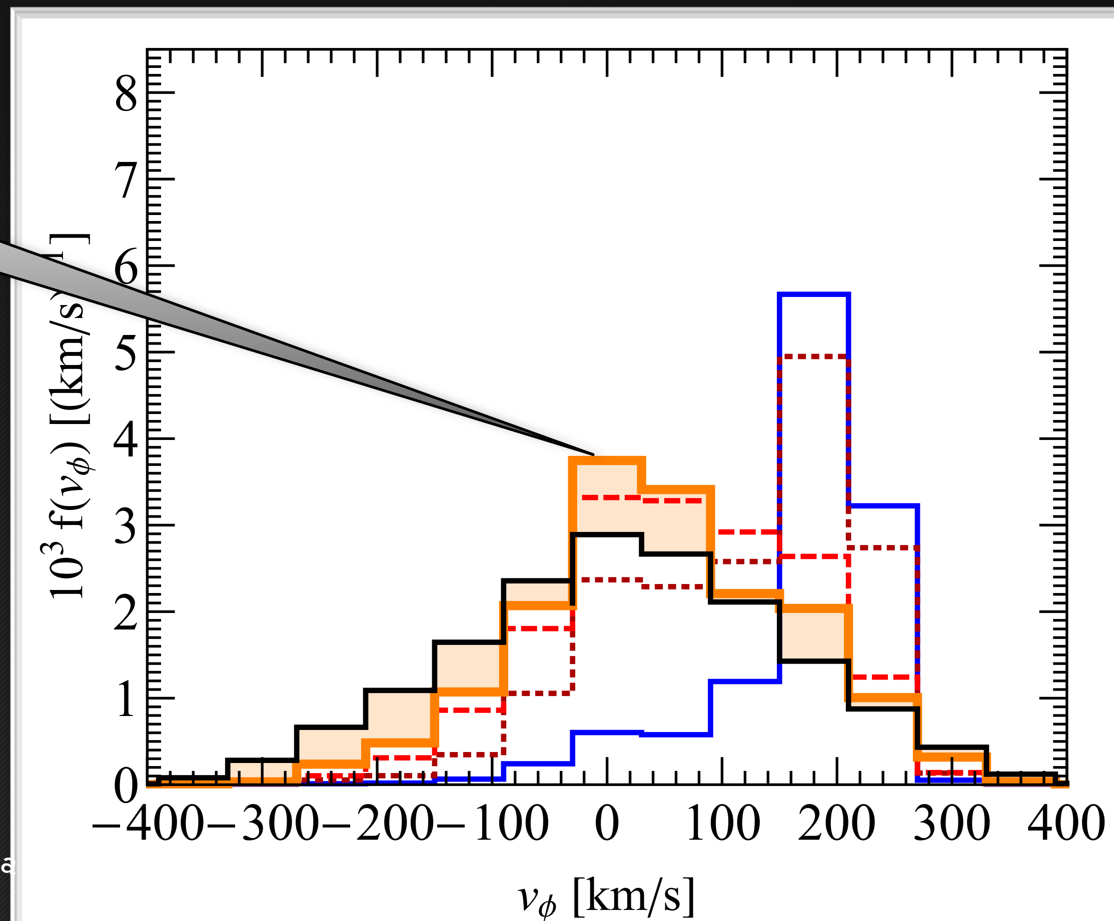
Stellar and Dark Matter Distributions



Stellar and Dark Matter Distributions

Prograde rotation found in Eris





Stellar and Dark Matter Distributions

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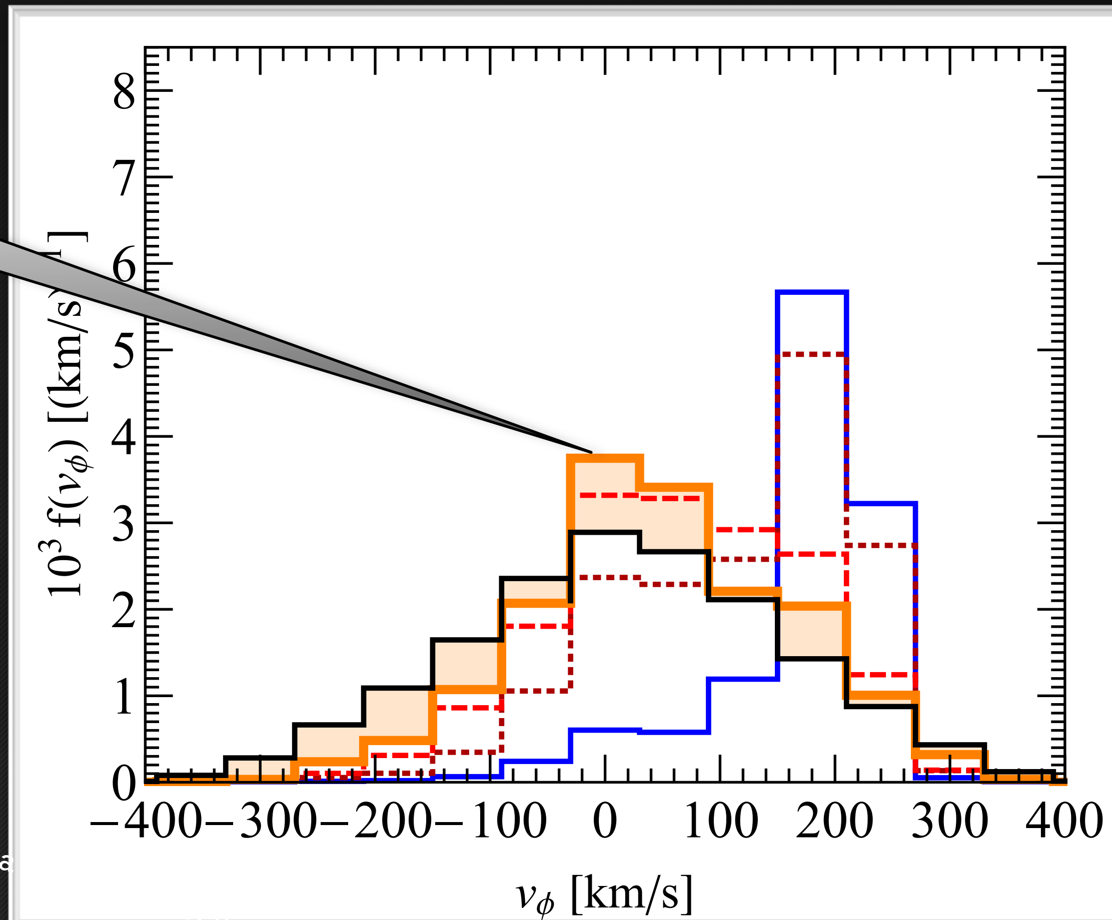

There is no evidence for significant prograde rotation for metal poor stars in data.