Dark Matter in Disequilibrium: The Velocity Distribution

Lina Necib, Caltech

Based on

Herzog-Arbeitman, Lisanti, Madau, Necib PRL 120(2018) no.4, 041102

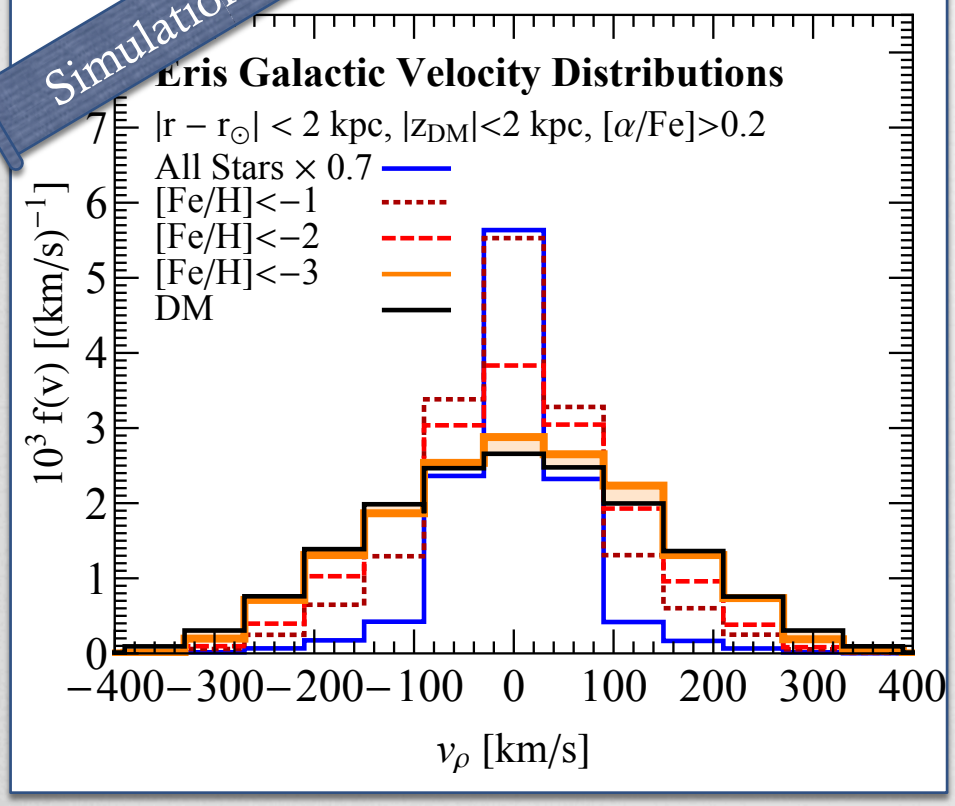
Herzog-Arbeitman, Lisanti, Necib, JCAP 1804 no. 4, 052

Necib, Lisanti, Garisson-Kimmel, Sanderson, Wetzel, Hopkins, arXiv:180X.XXXXX

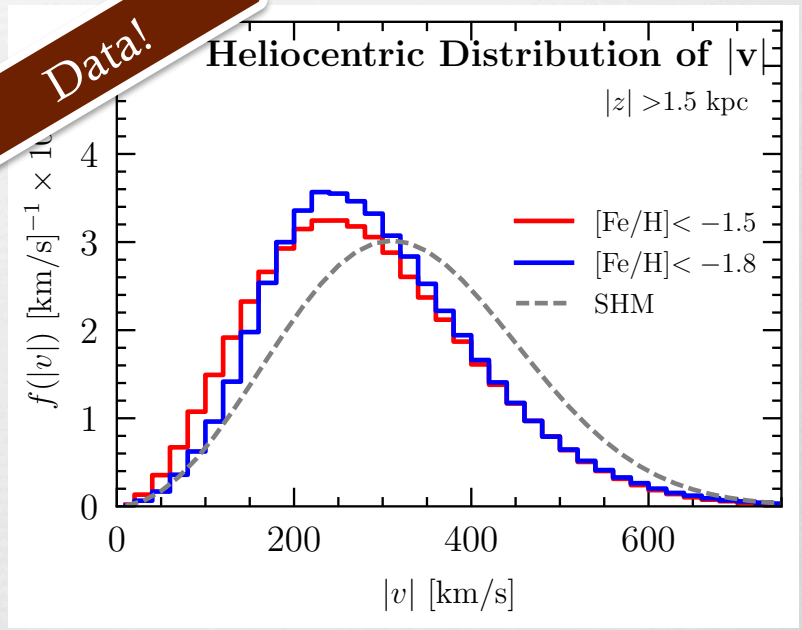
Necib, Lisanti, Belokurov, arXiv:180X.XXXXX

Empirically Determined Velocity Distribution of Dark Matter

Simulation



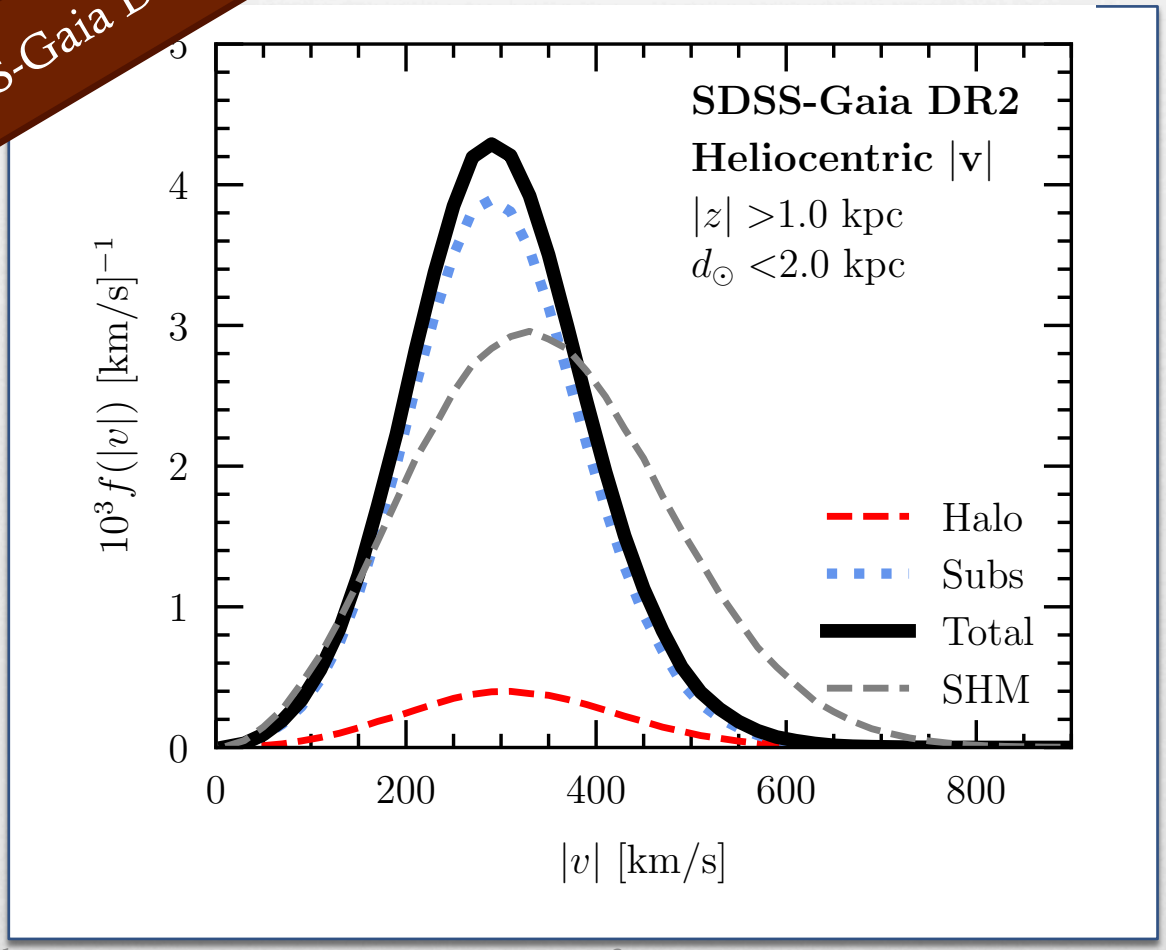
Data!



Herzog-Arbeitman, Lisanti, Madau, **Necib** PRL 120(2018) no.4, 041102
Herzog-Arbeitman, Lisanti, **Necib**, JCAP 1804 no. 4, 052

Empirically Determined Velocity Distribution of Dark Matter

SDSS-Gaia DR2



Necib, Lisanti, Belokurov, 2018

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/DR2:

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

Therefore:

We empirically obtain the Dark Matter velocity distribution.

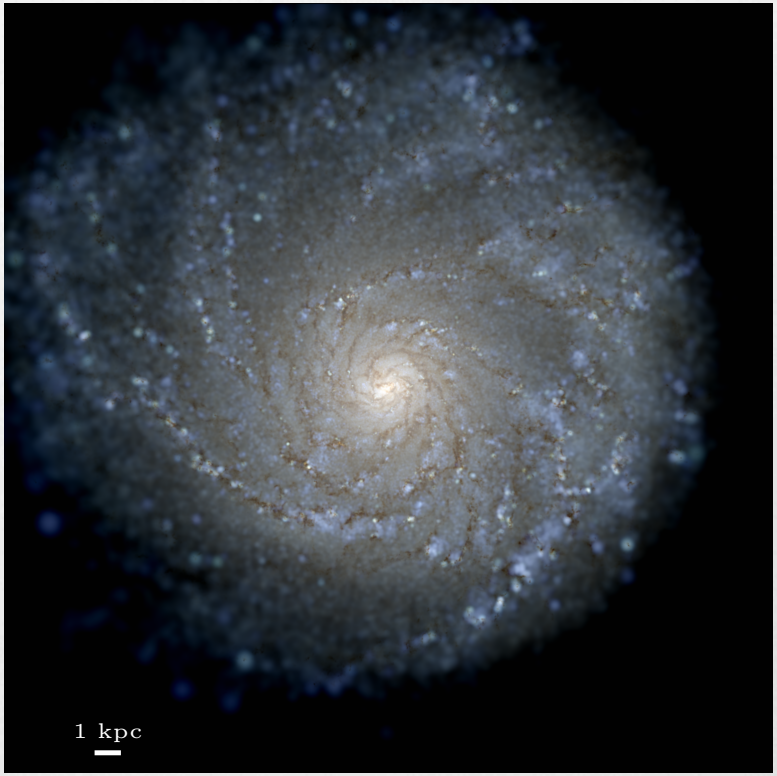
Video by Shea Garisson-Kimmel,
http://www.tapir.caltech.edu/~sheagk/firemovies.html

FIRE: Feedback In Realistic Environments

A suite of high resolution simulations, with different merger histories, and particle physics dynamics.

Focus on Milky Way like simulations:

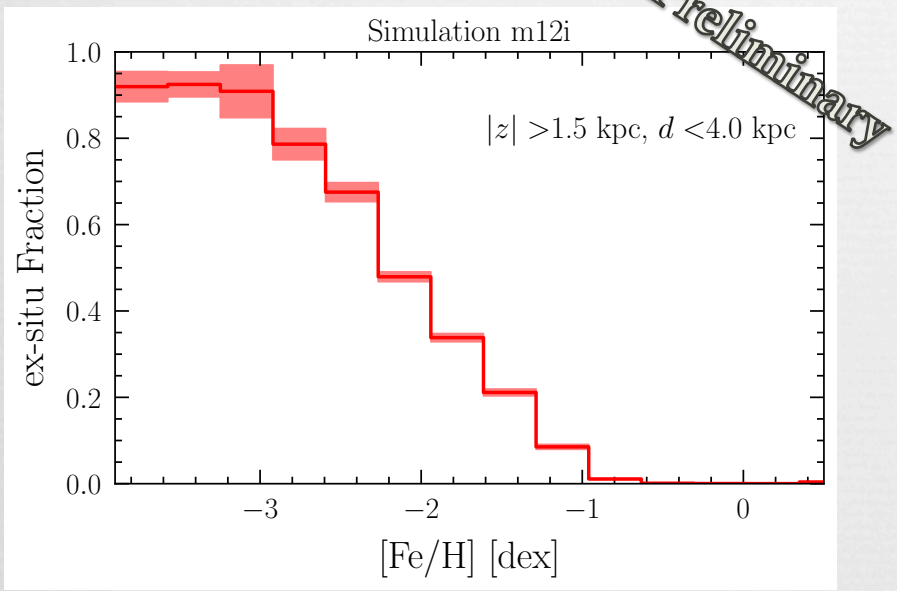
- Total mass: (1.2-1.6) 10^{12} Msun.
- Particle mass: 7000 Msun.
- Dark Matter softening length: 30pc.

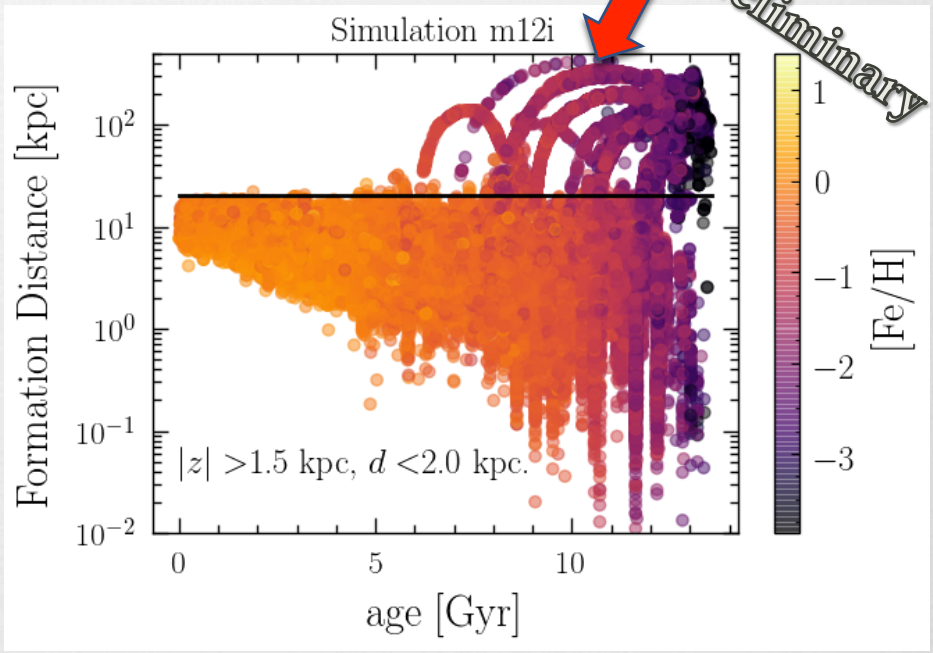


Hopkins et al. (2014) MNRAS 445,581
Wetzel et al. (2016) ApJL, 827, L23
Hopkins et al. (2017) arXiv:1702.06148

Quiet Merger History

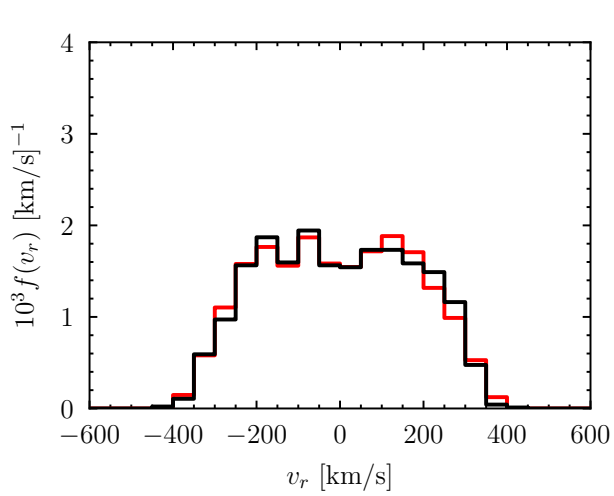
Merging dwarf galaxies!

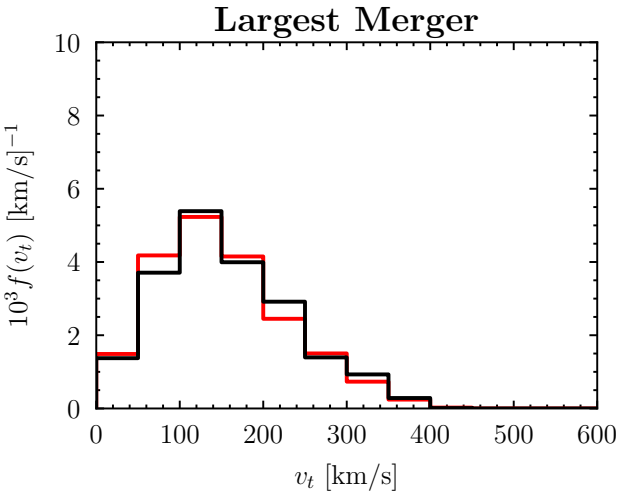


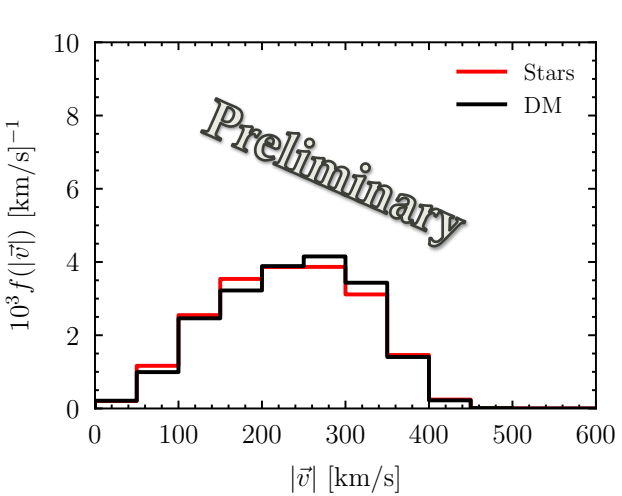


When we cut at low [Fe/H], we are primarily selecting stars that are born in dwarf galaxies.

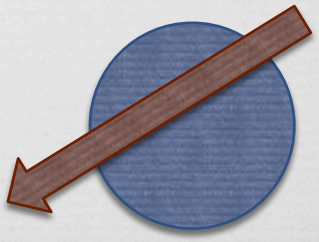
Quiet Merger History





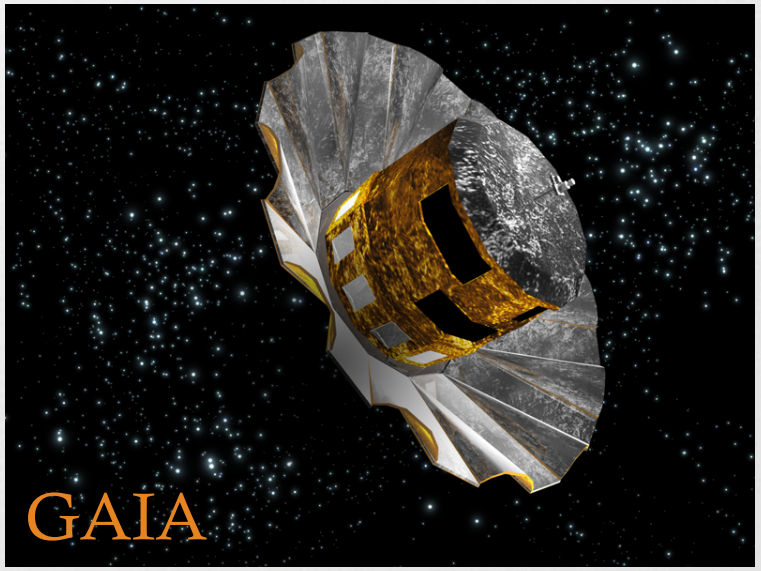


Tracking particles from the same merger back to redshift zero!



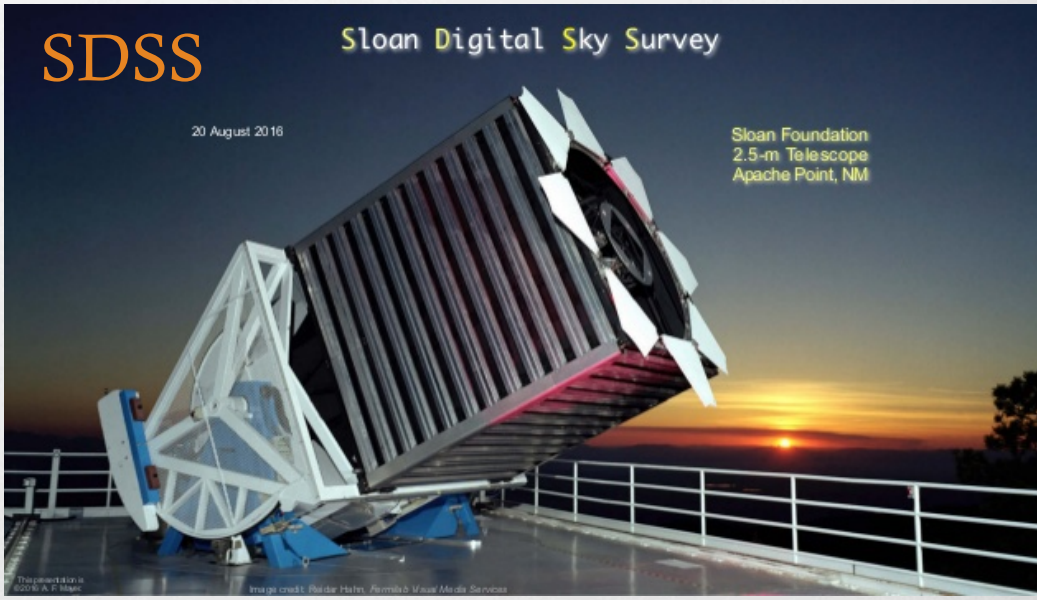
Telescopes

- Launched December 2013
- Goal: Positional measurement of 1 billion stars, radial velocity for the brightest 150 million

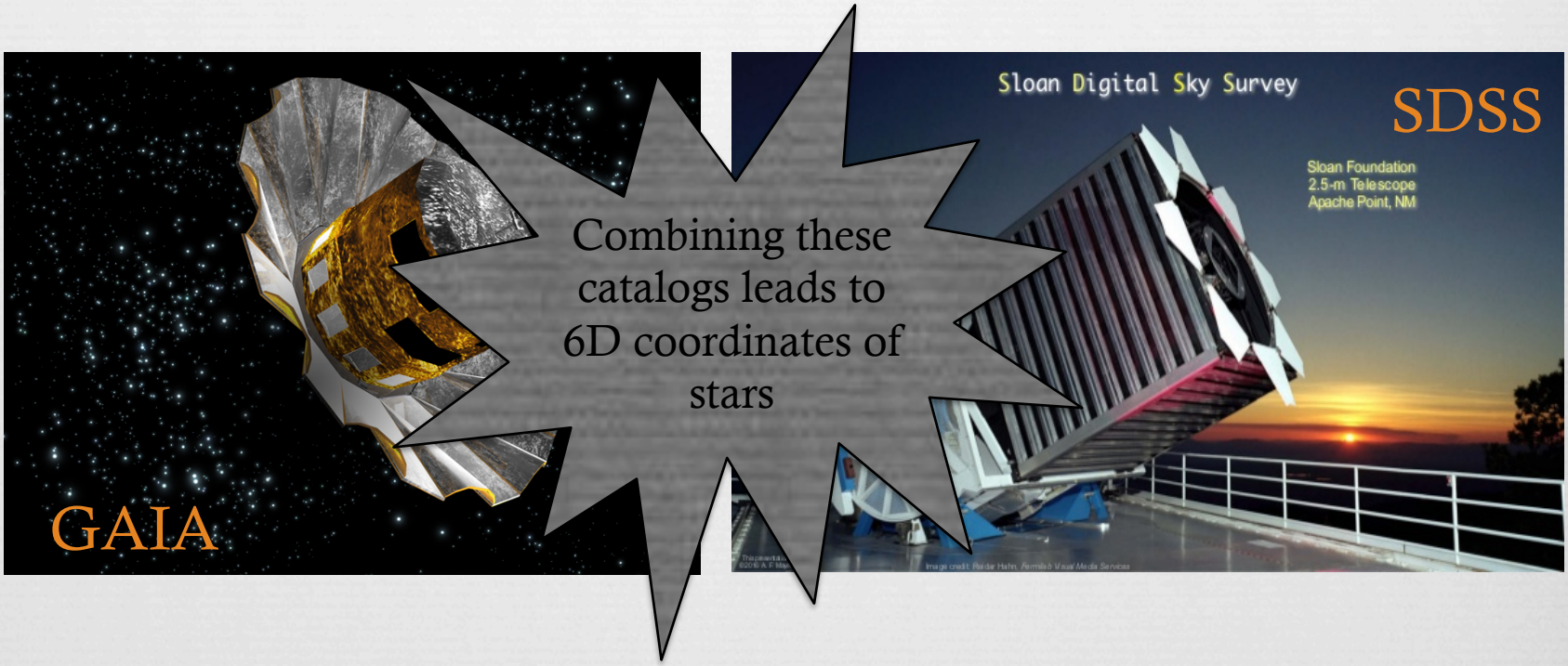


Telescopes

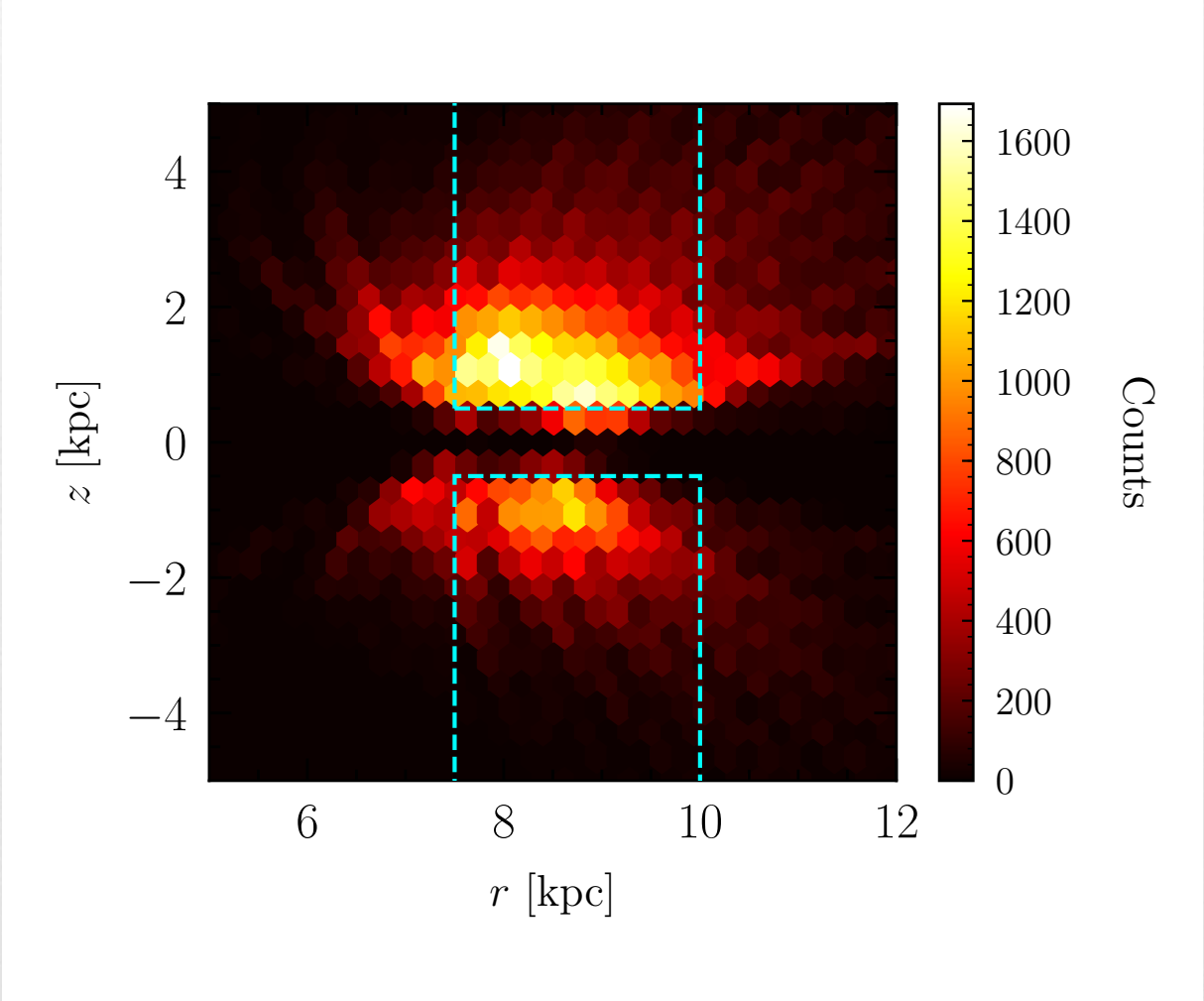
- Sloan Digital Sky Survey: 2.5 meter telescope at the Apache Point Observatory.
- Gathered spectra of more than 1 million objects.
- SDSS: Radial Velocity+ Chemical information

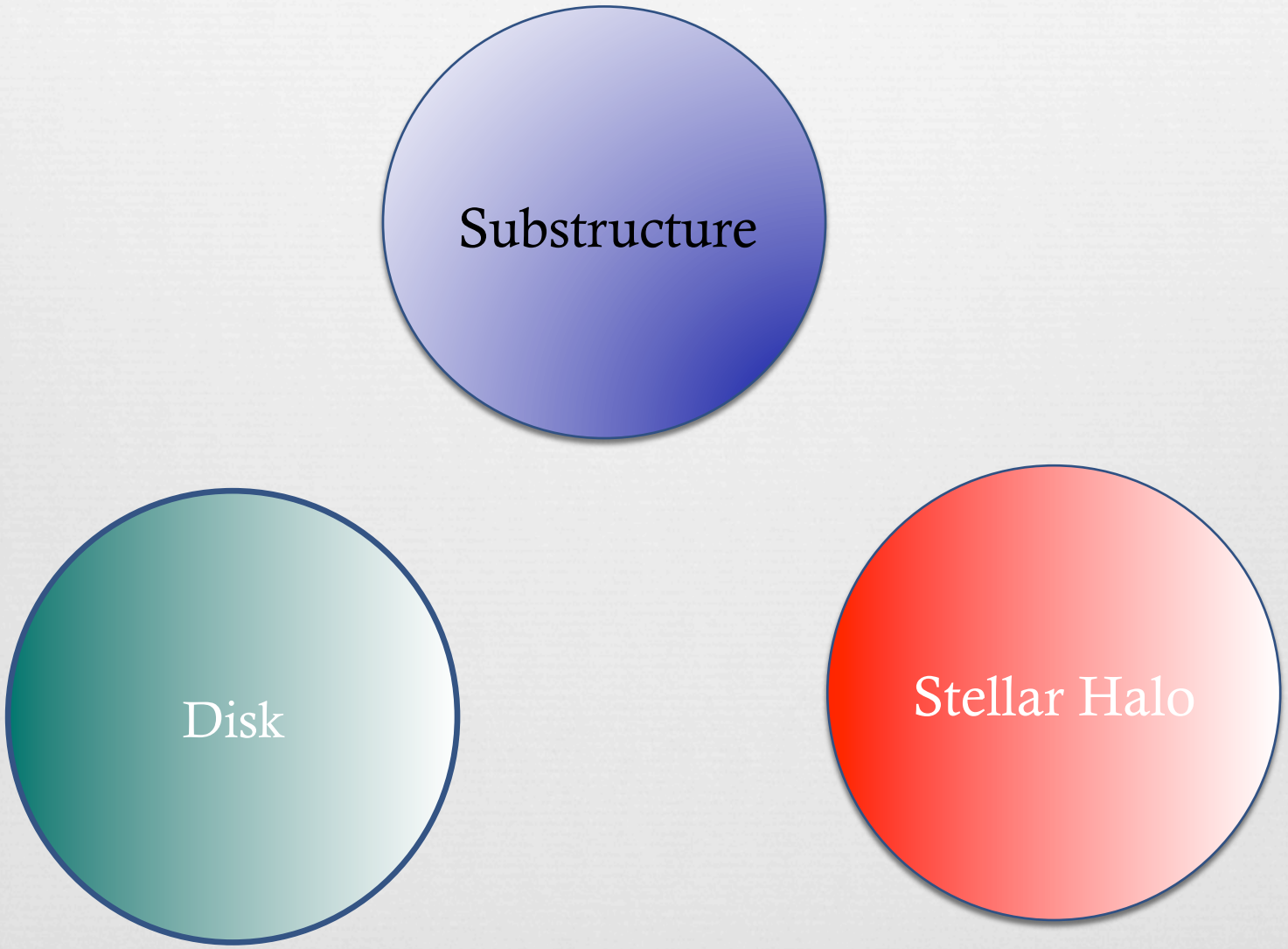


Telescopes

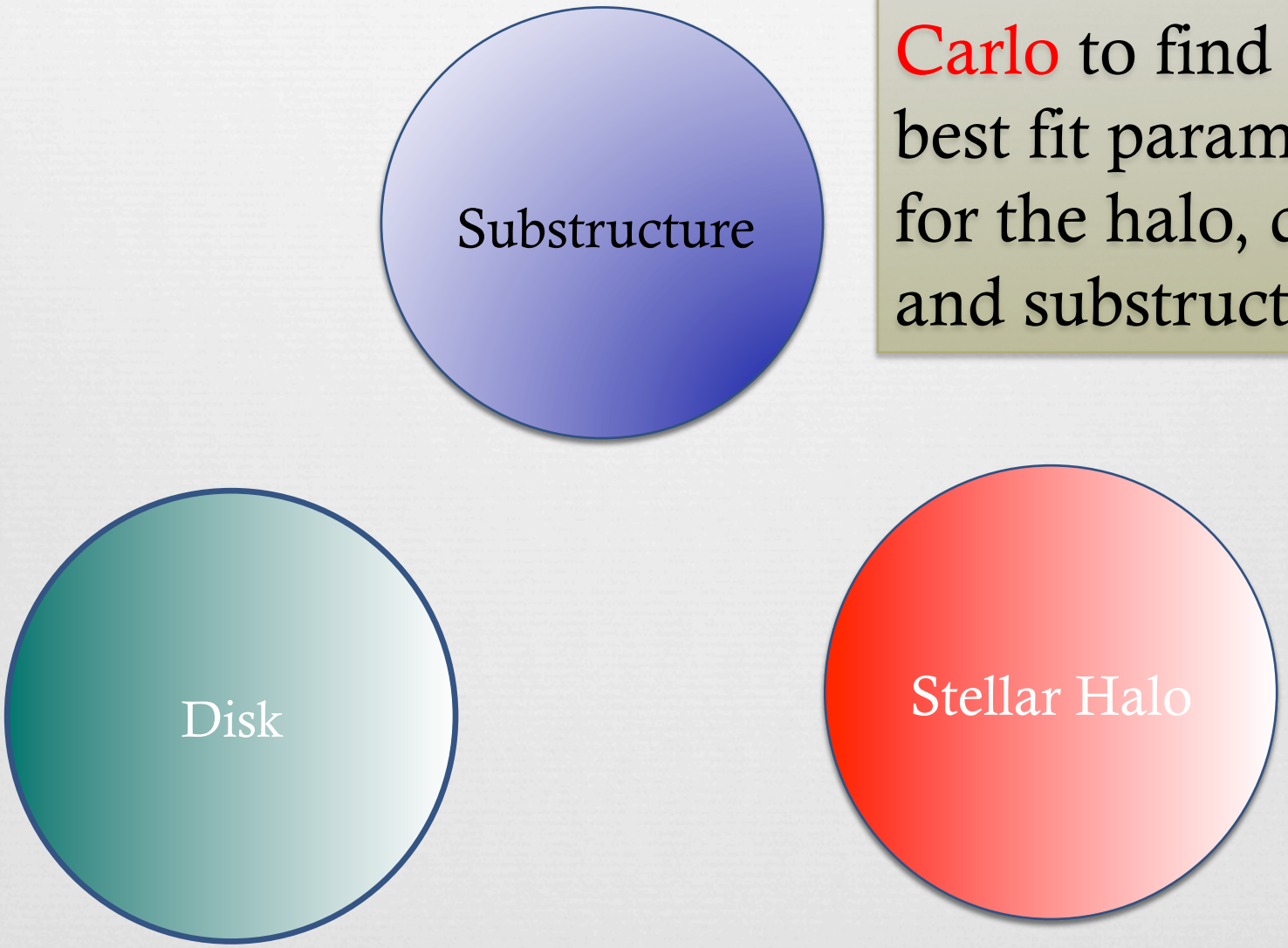

GAIA
Combining these catalogs leads to 6D coordinates of stars
Sloan Digital Sky Survey
SDSS
Sloan Foundation
2.5-m Telescope
Apache Point, NM

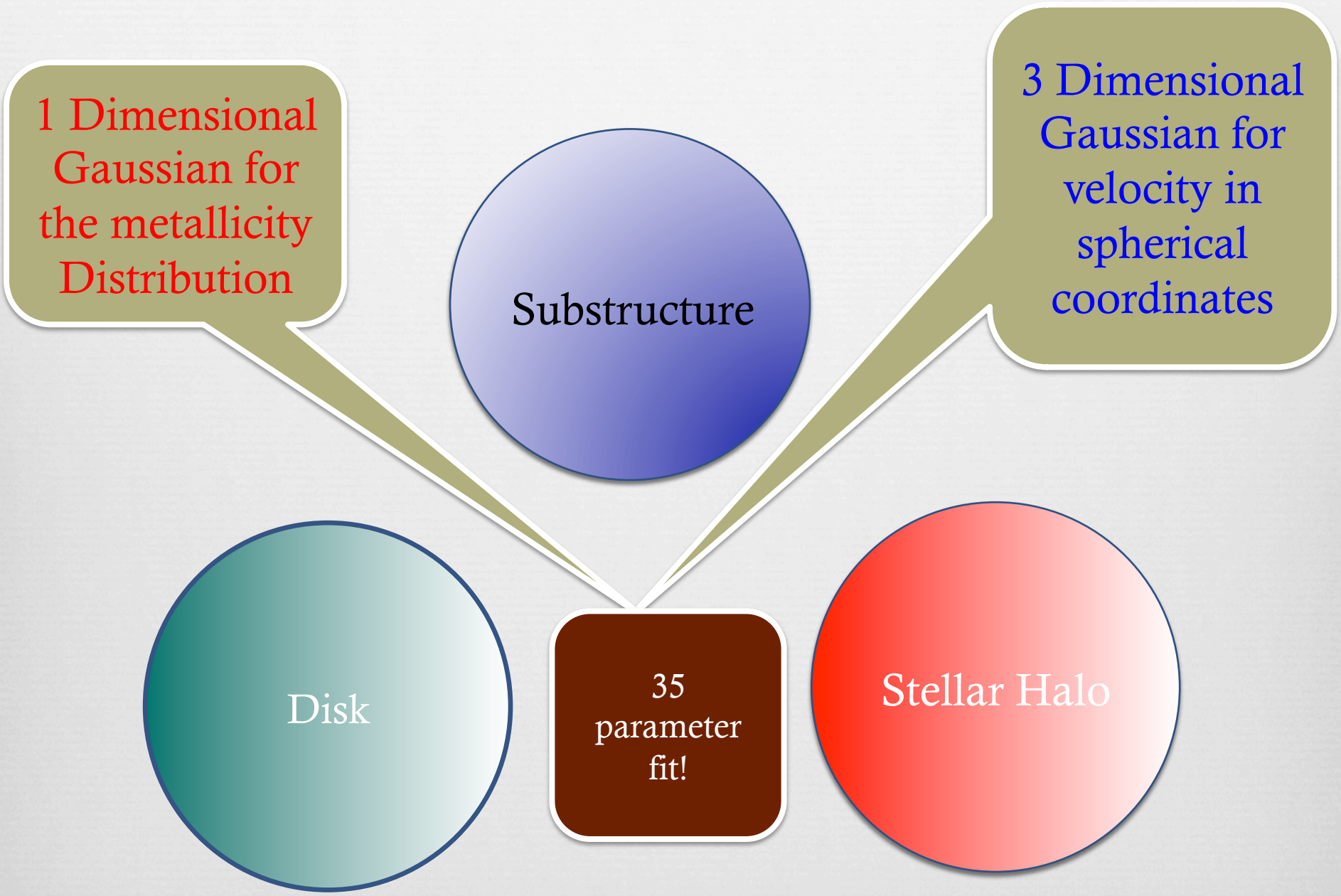
New Analysis:
Using Gaia DR2 + SDSS



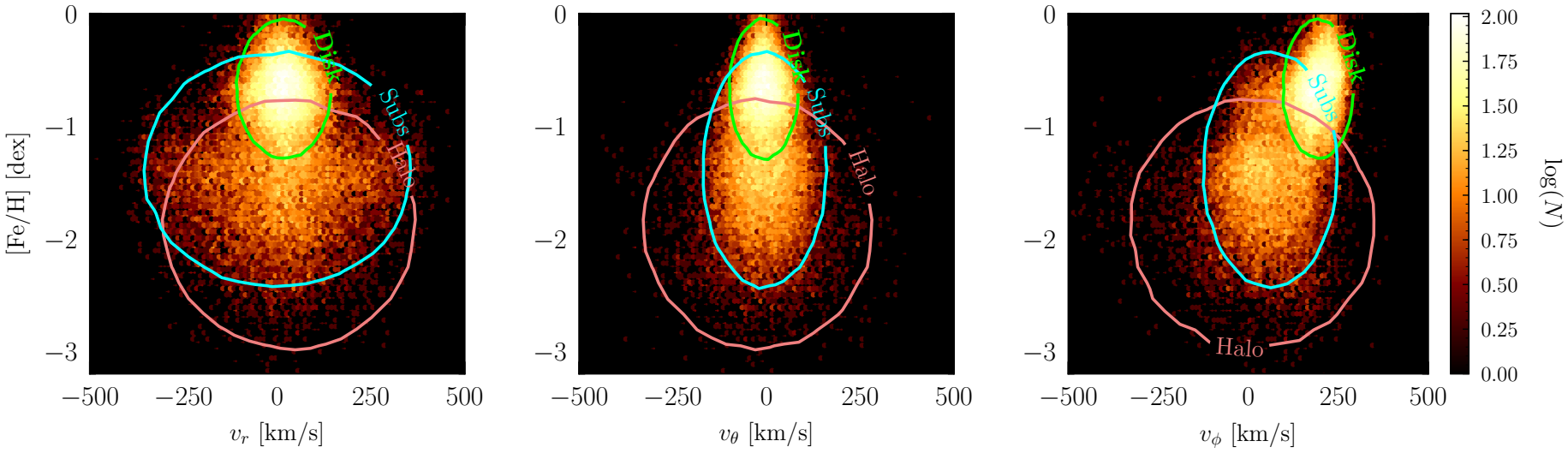

Substructure
Disk
Stellar Halo

We use Markov Chain Monte Carlo to find the best fit parameters for the halo, disk, and substructure.



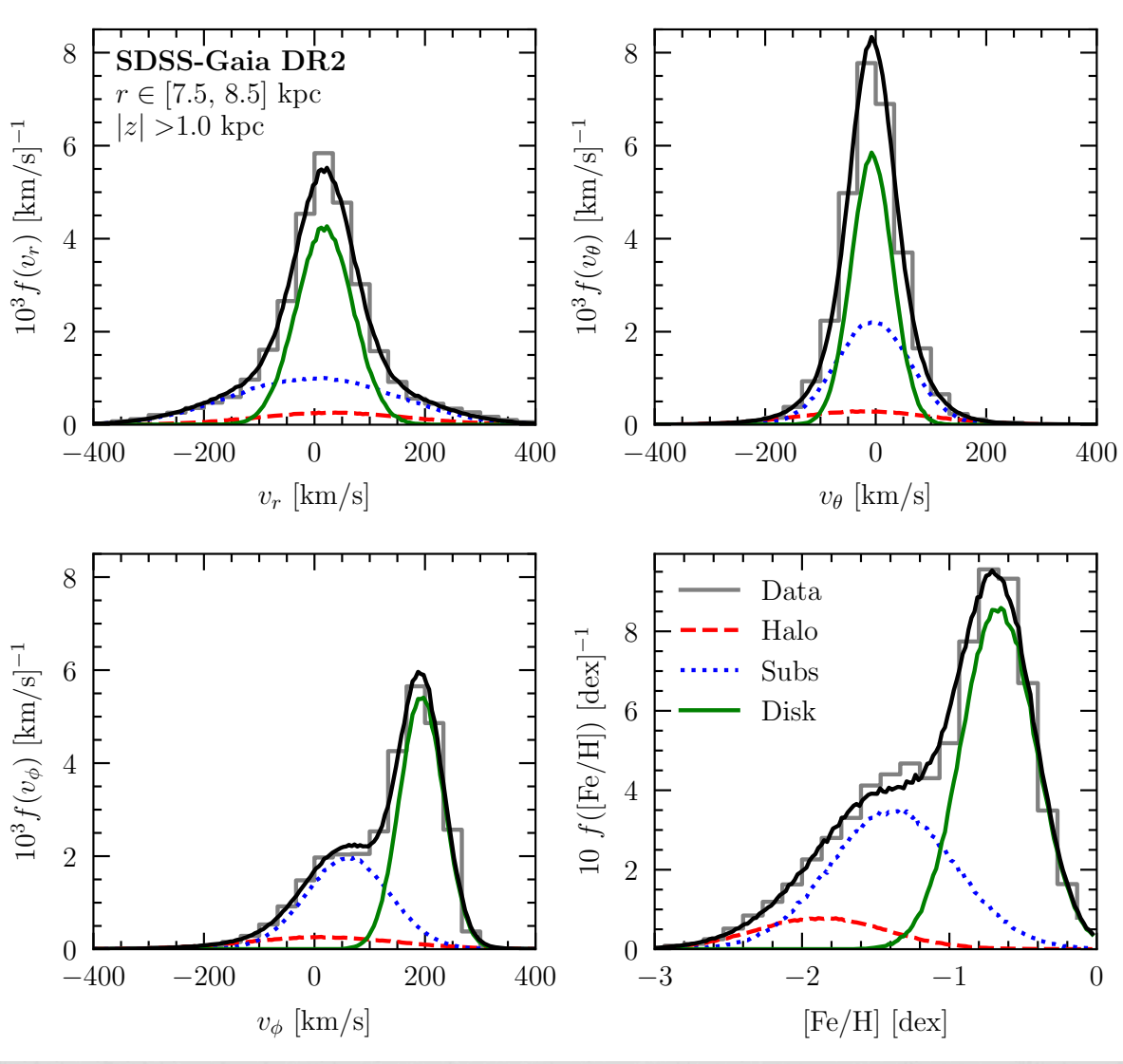

1 Dimensional Gaussian for the metallicity Distribution
Substructure
3 Dimensional Gaussian for velocity in spherical coordinates
Disk
35 parameter fit!
Stellar Halo

Best Fit Velocity/Metallicity



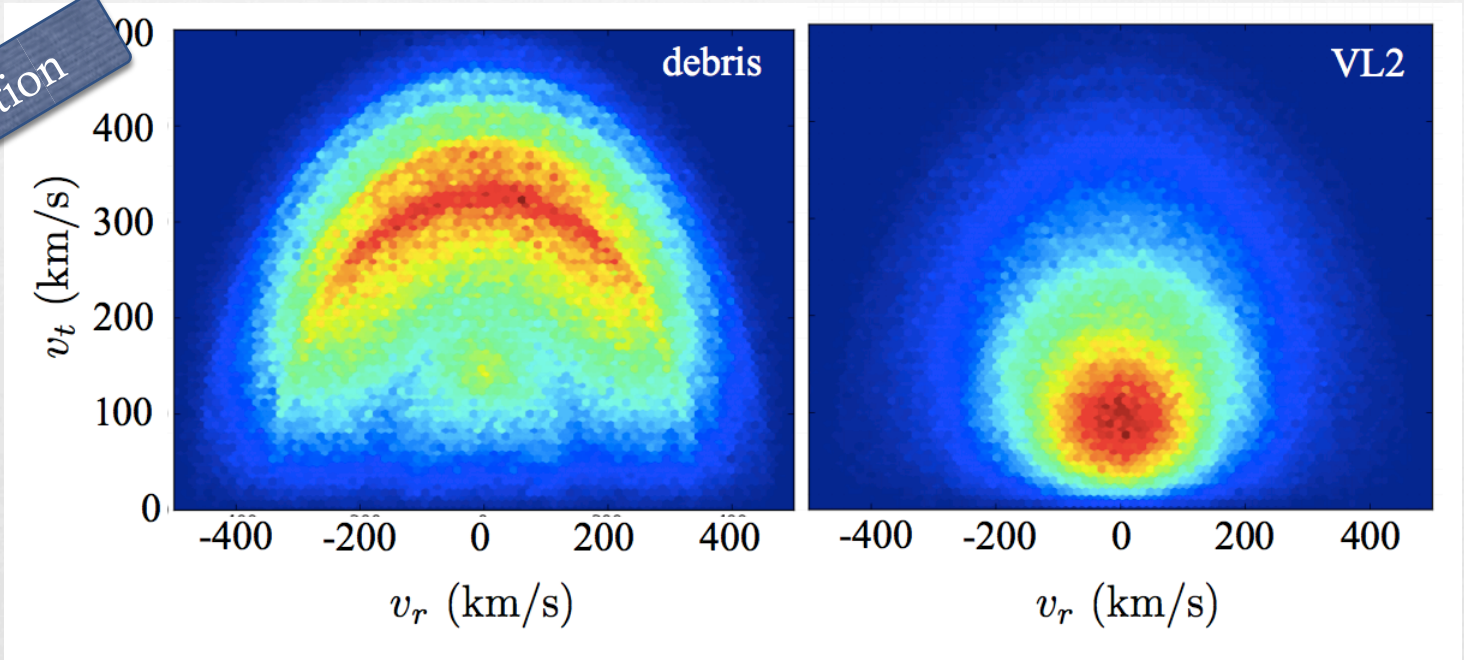
Best Fit Velocity/Metallicity

Data!



Understanding Substructure

Simulation

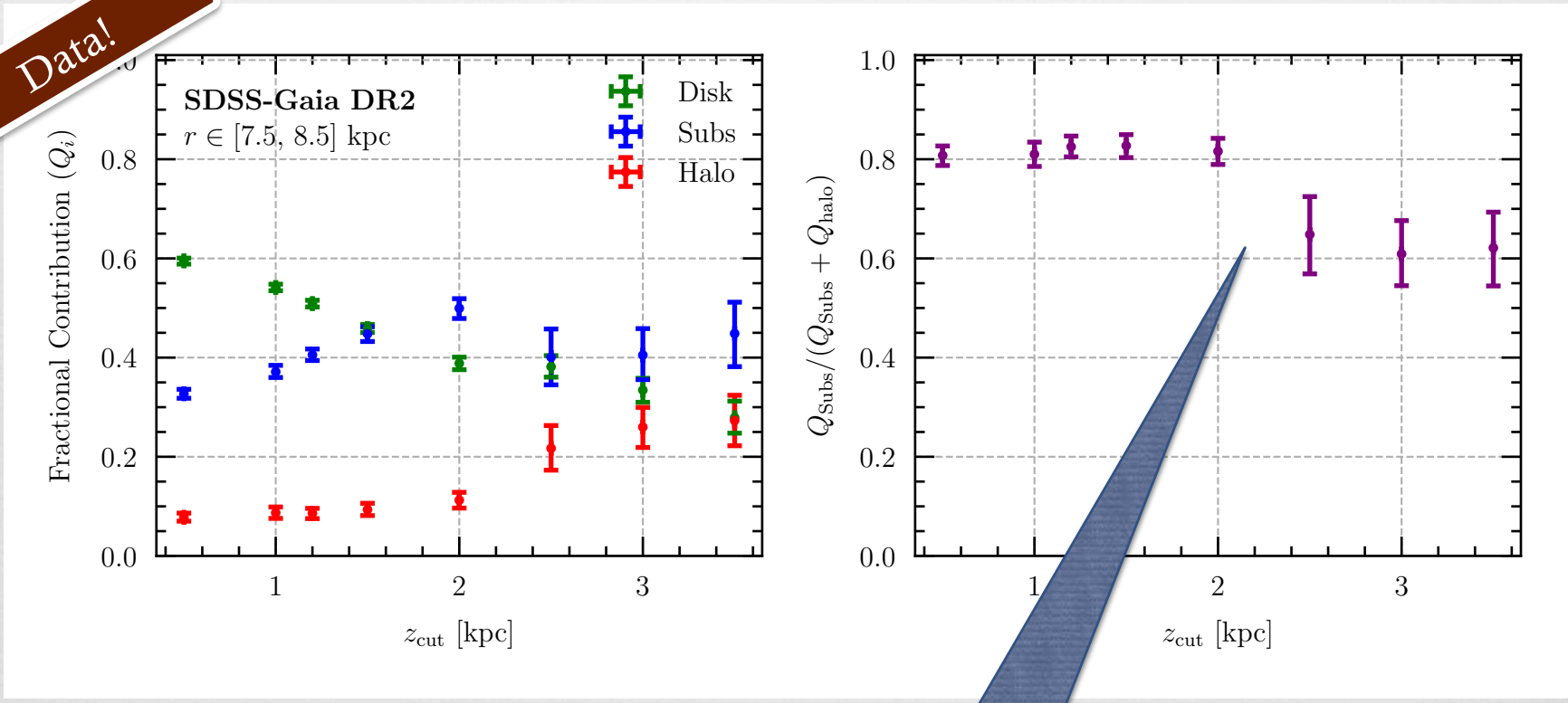


This is debris flow: unlike streams, these stars and dark matter have lost all spatial features but maintain coherence in velocity space.

Lisanti & Spergel (2011)
Kuhlen, Lisanti & Spergel (2012)

Understanding Substructure

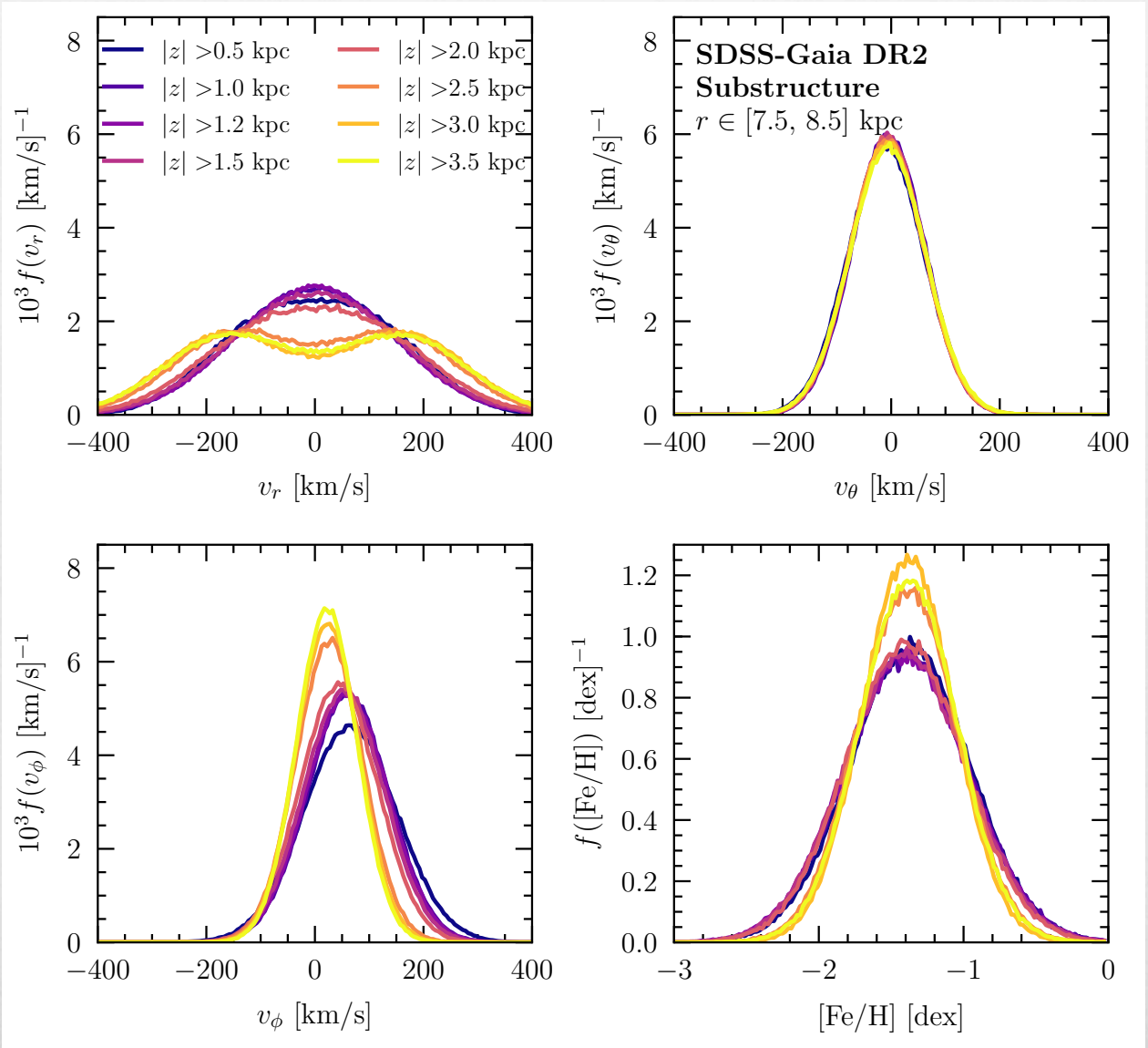
Data!



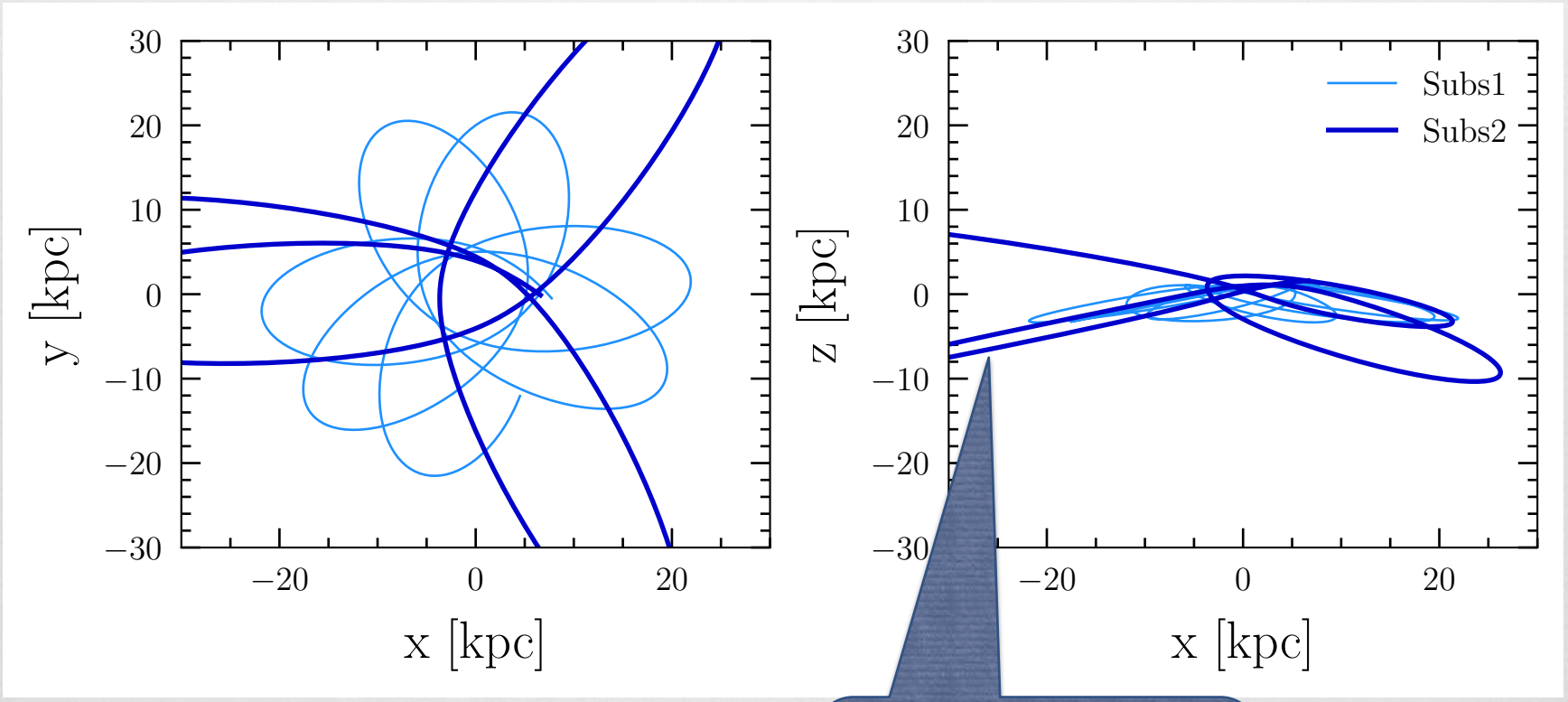
Large fraction!

Understanding Substructure

Data!



Understanding Substructure

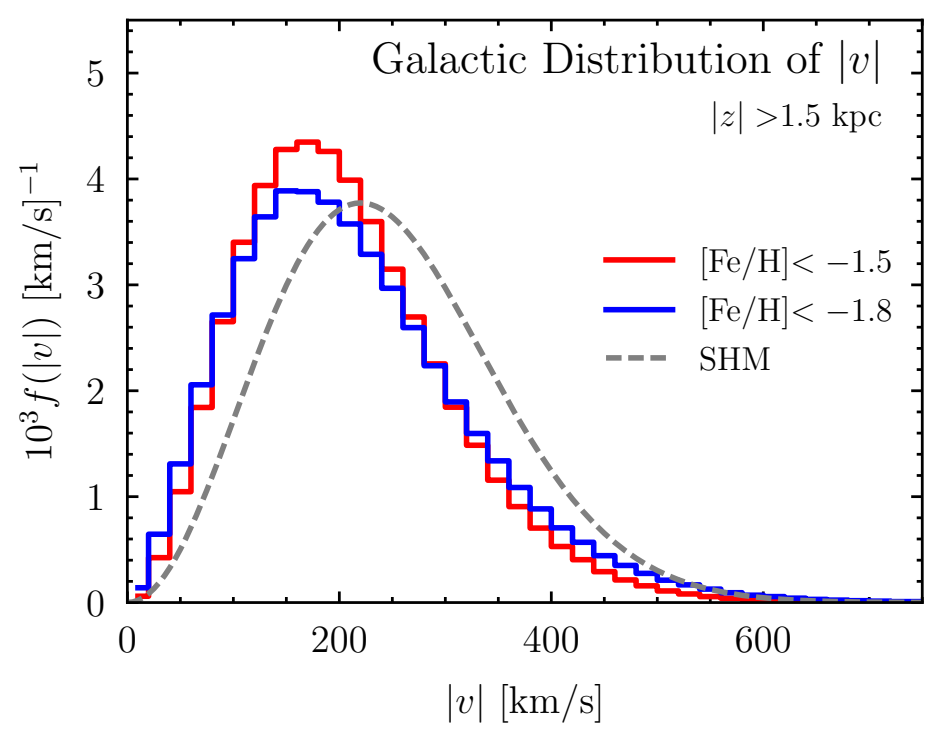


Eccentric orbits at small angles from the disk

Local Velocity Distribution

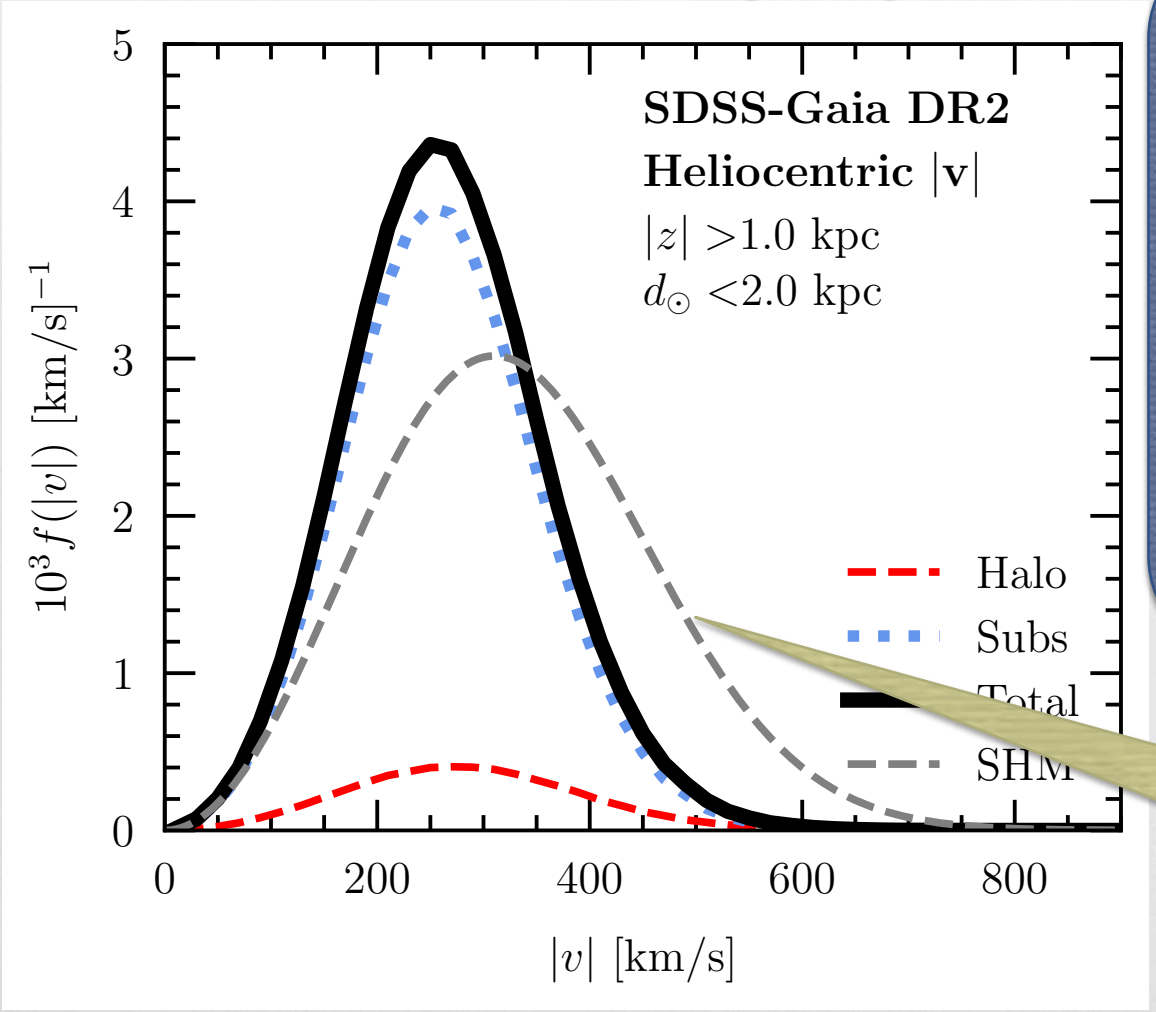
Drum Roll

Posterior Distribution of |v|



Old distribution from Gaia DR1.
High metallicity cut, no fit for substructure!

Posterior Distribution of |v|



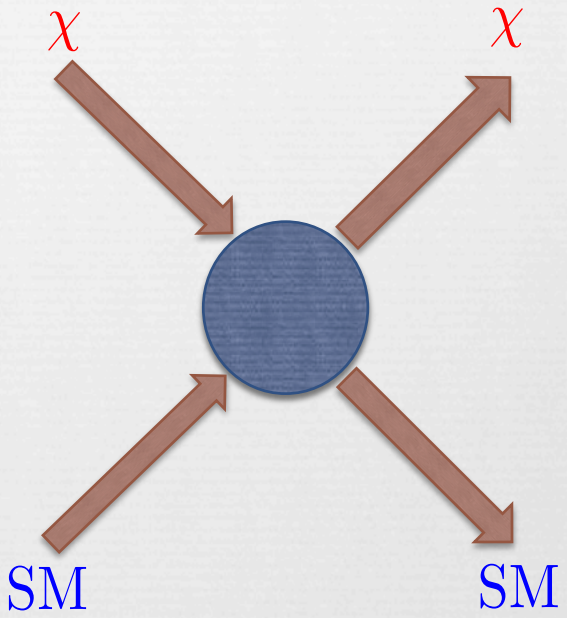
New distribution from Gaia DR2. **Uncovered substructure dominating the distribution!**

The Maxwell Boltzmann distribution we are taught at school!

Direct Detection Rate

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

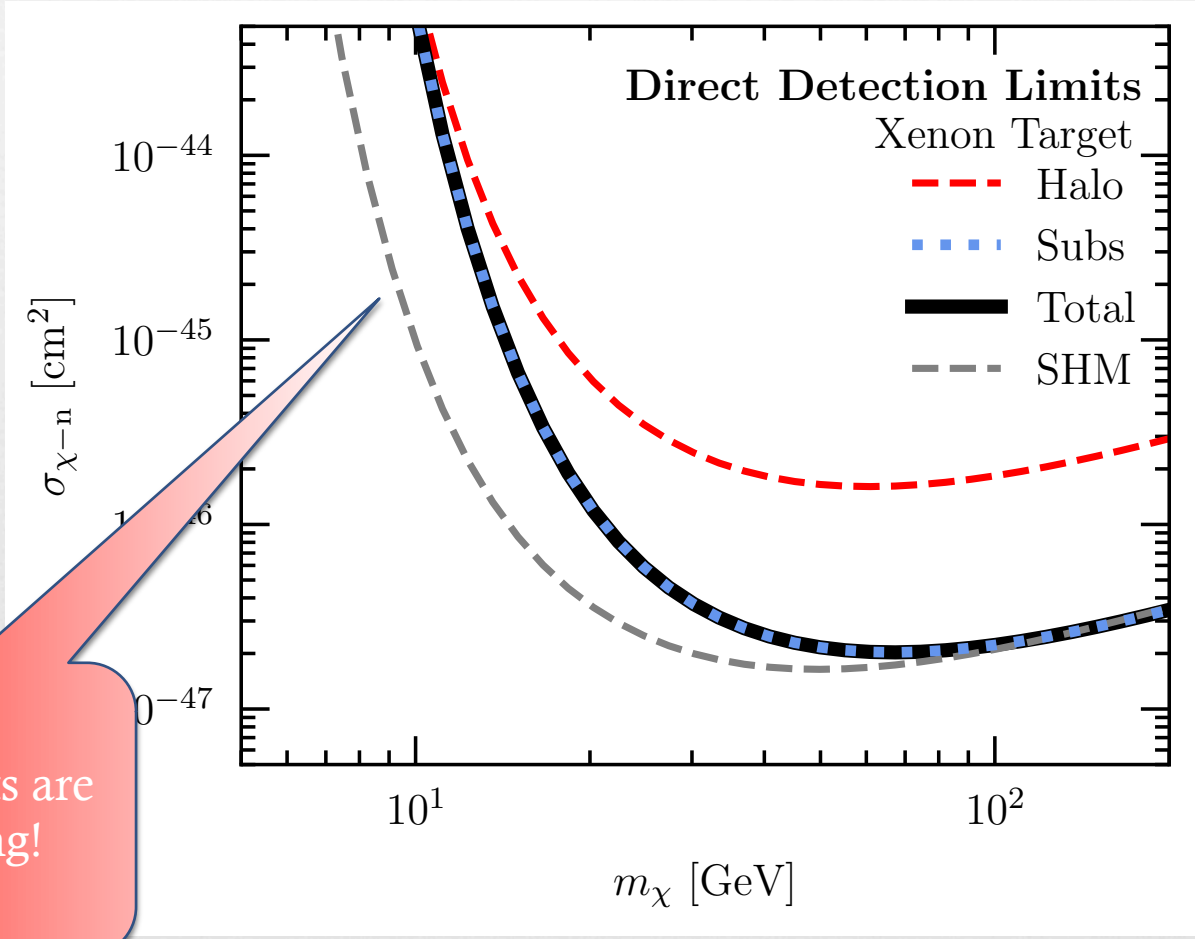
$$\frac{dR}{dQ} \propto \frac{\sigma_0 \rho_0}{m_\chi m_r^2} F^2(Q) g(v_{\rm min})$$



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

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

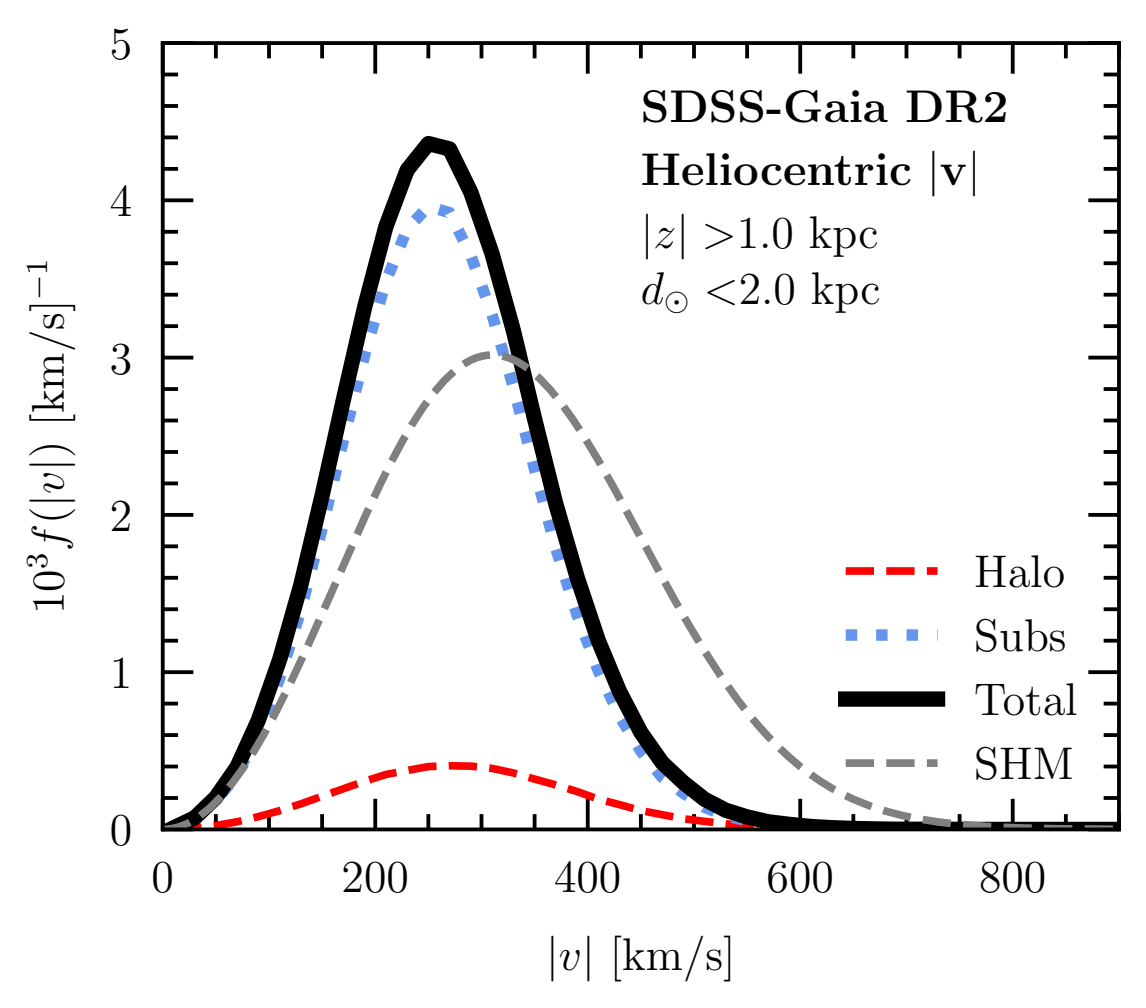
Direct Detection



These limits are too strong!

Assumes the standard Maxwell Boltzmann velocity distribution.

The Velocity Distribution of Dark Matter is FAR from Equilibrium!



We need to stop assuming that the Milky Way is in equilibrium!

The Velocity Distribution of Dark Matter is FAR from Equilibrium!

- Finalizing the study of mergers in the FIRE simulations
- Studying more complex dynamics of Milky Way-like galaxies.
- Looking for a tracer for Self-Interacting Dark Matter.
- Currently running a simulation for Warm Dark Matter.
- Stay tuned for more to come!

The Velocity Distribution of Dark Matter is FAR from Equilibrium!

- Finalizing the study of mergers in the FIRE simulations
- Studying more complex dynamics of Milky Way-like galaxies.
- Looking for a [illegible] Dark Matter.
- Currently [illegible] Dark Matter.
- Stay tuned for more to come!

Exciting times ahead!

Thank you!