Title: Gravitational effects of DM & Cosmology

Speakers: Lina Necib

Collection: School on Table-Top Experiments for Fundamental Physics

Date: September 21, 2022 - 9:15 AM

URL: https://pirsa.org/22090014

Some references for axion dark matter and the local velocity distribution

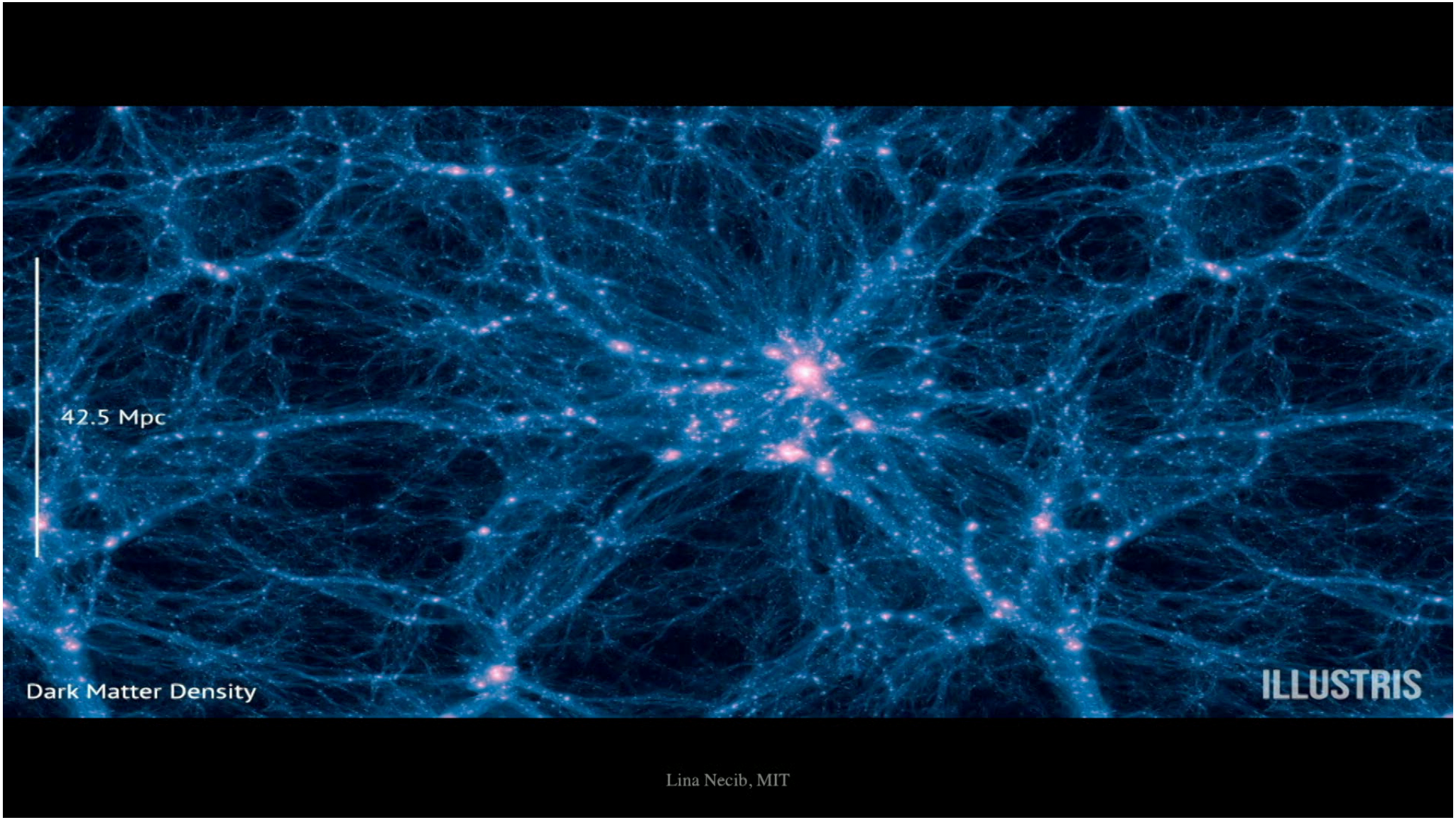
- Knirck et al. 1806.05927
- Foster et al. 1711.10489
- Ohare & Green 1701.03118
- Hoskins et al. 1109.4128
- Ling, Skivie, & Wick (Phys. Rev. D **70**, 123503)

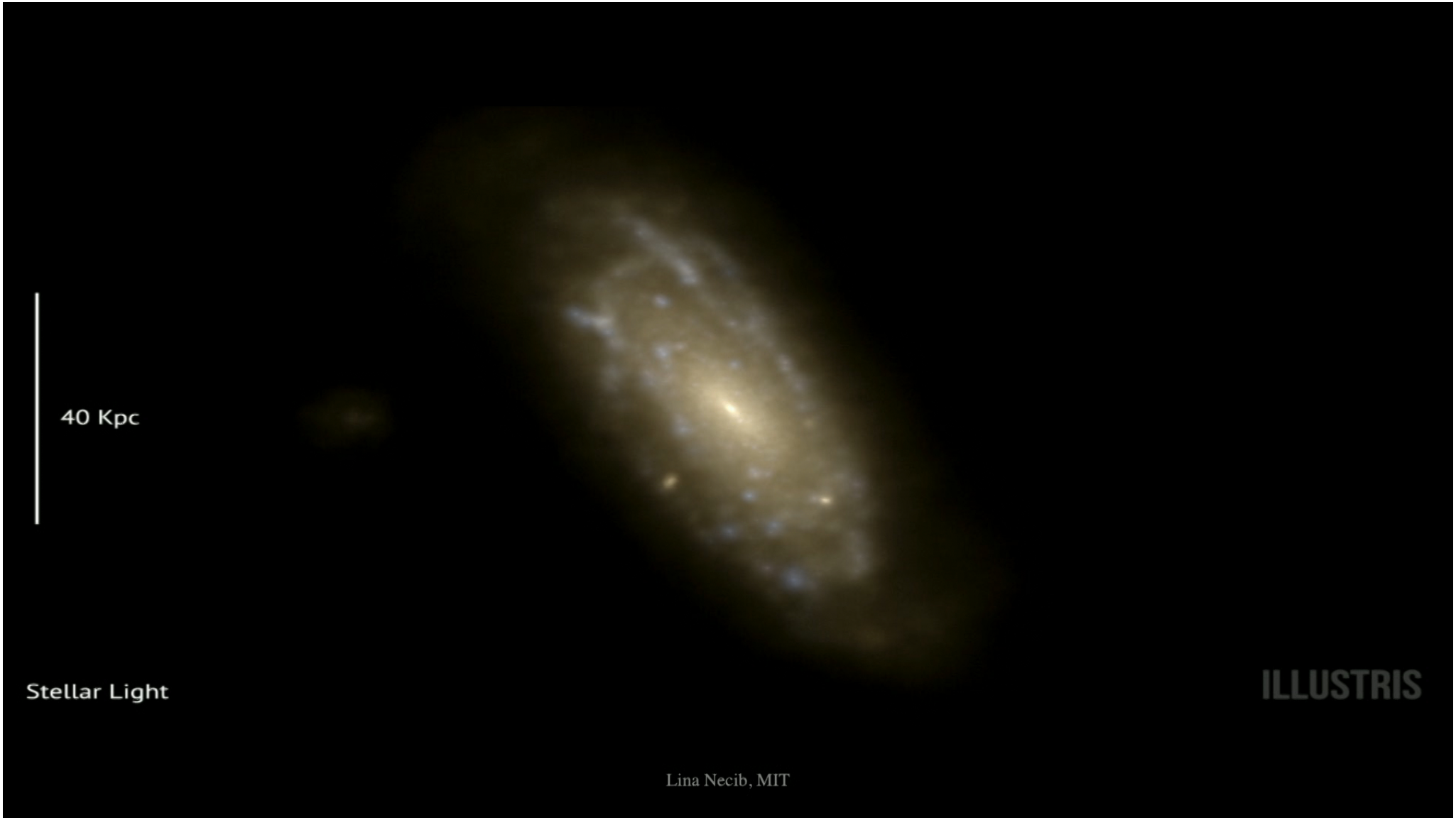
References from Yesterday

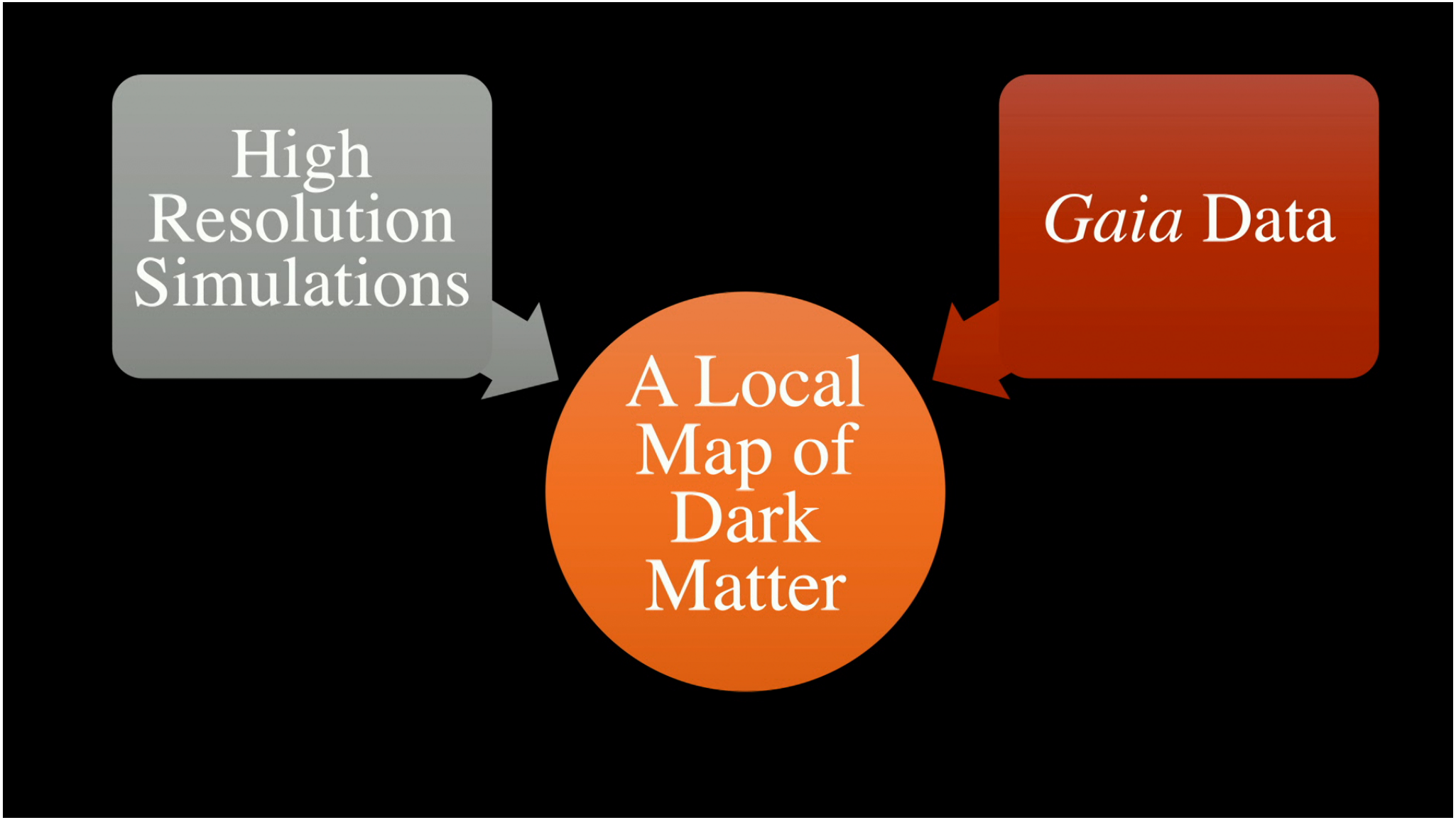
- Read (2014)
- Read et al. (2008)
- Freese, Lisanti, Savage (2013)
- Jungman (1996)
- Bruch et al. (2009)
- Eilers et al. (2019)
- Textbook: Galactic Dynamics, by Binney & Tremaine (2008 edition)

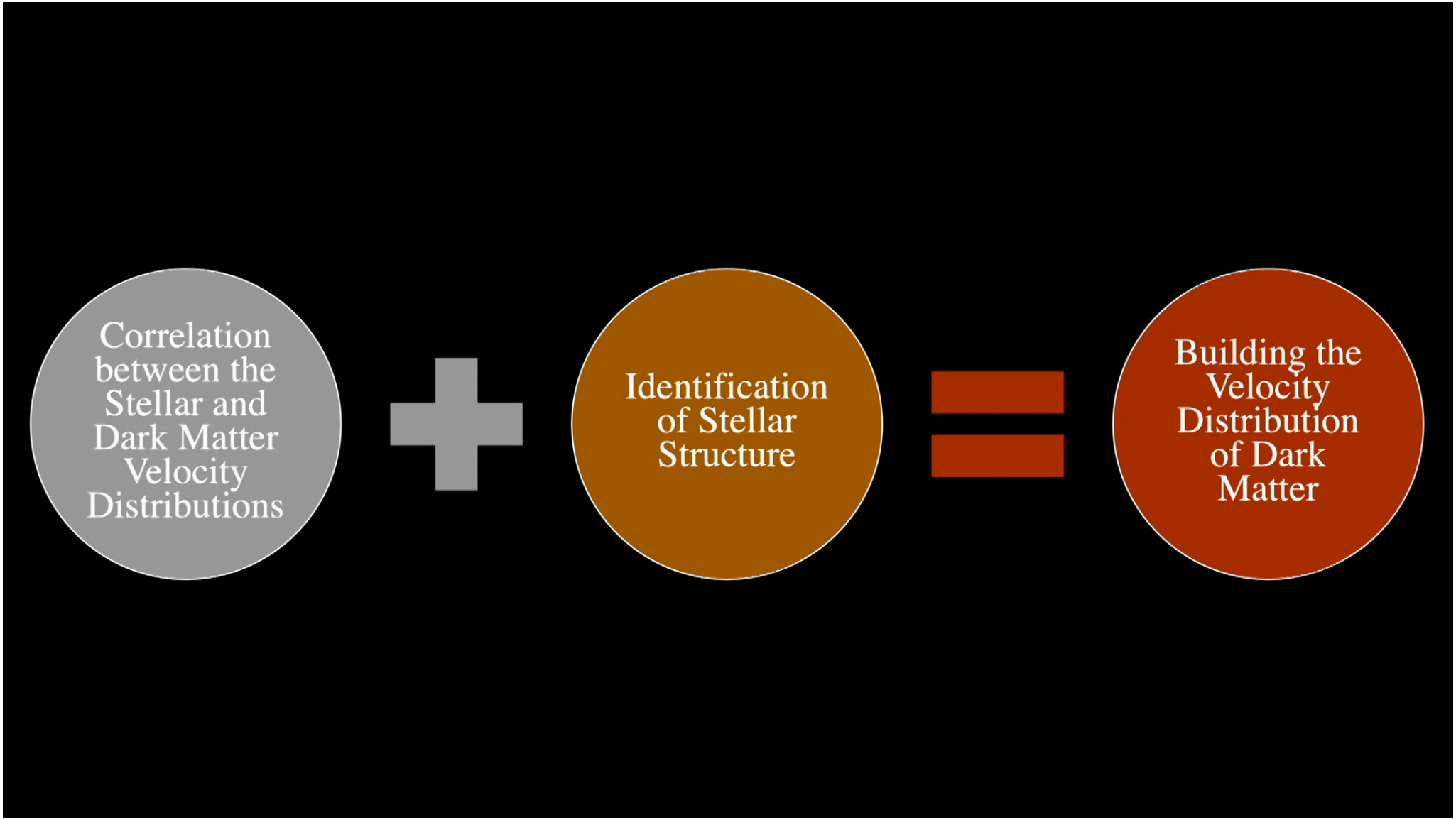
*Underlined are good reviews

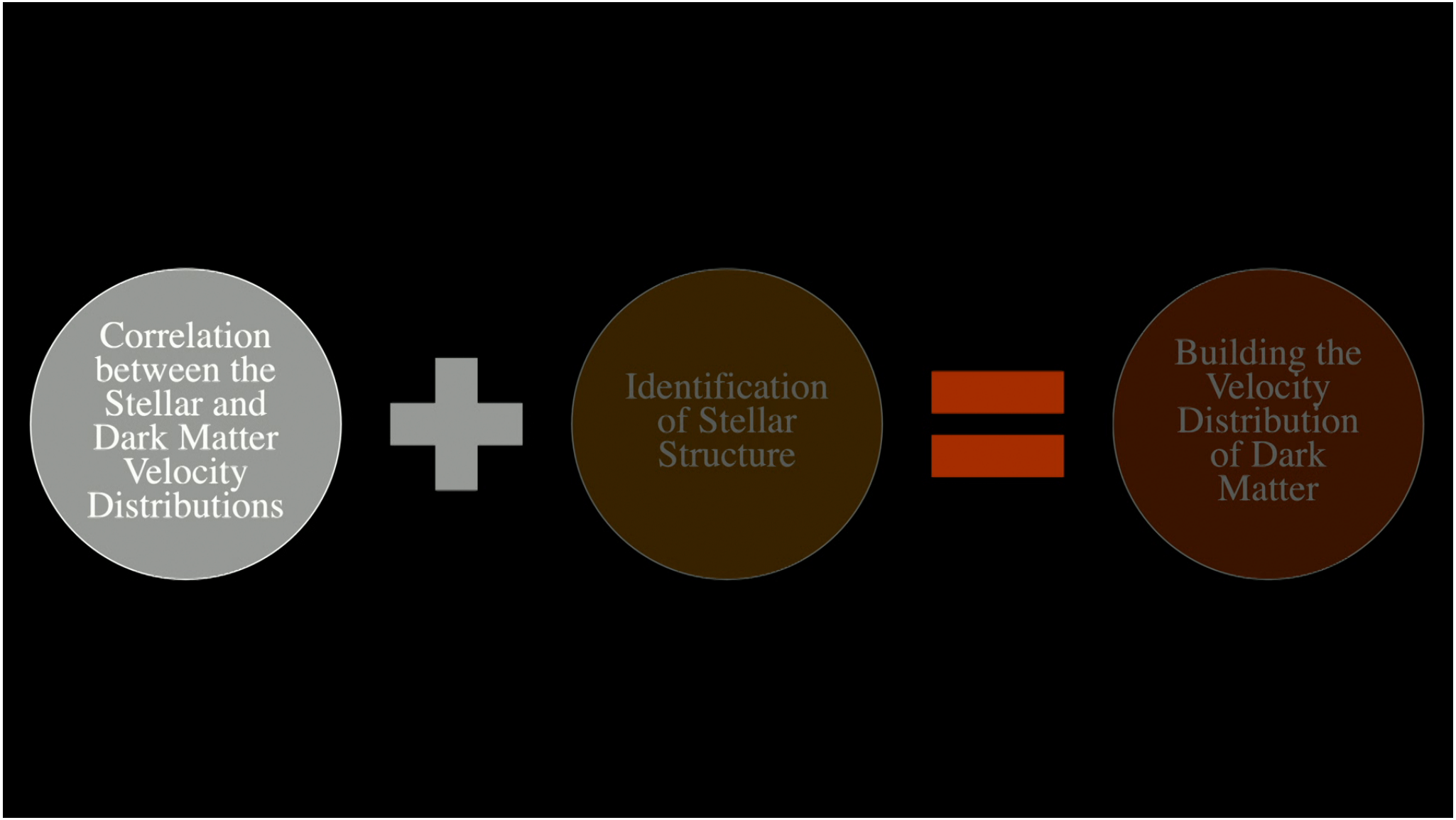
We Need to Understand Dark Matter Substructure


42.5 Mpc
Dark Matter Density
ILLUSTRIS
Lina Necib, MIT


40 Kpc
Stellar Light
ILLUSTRIS
Lina Necib, MIT


High Resolution Simulations
Gaia Data
A Local Map of Dark Matter


Correlation between the Stellar and Dark Matter Velocity Distributions
Identification of Stellar Structure
Building the Velocity Distribution of Dark Matter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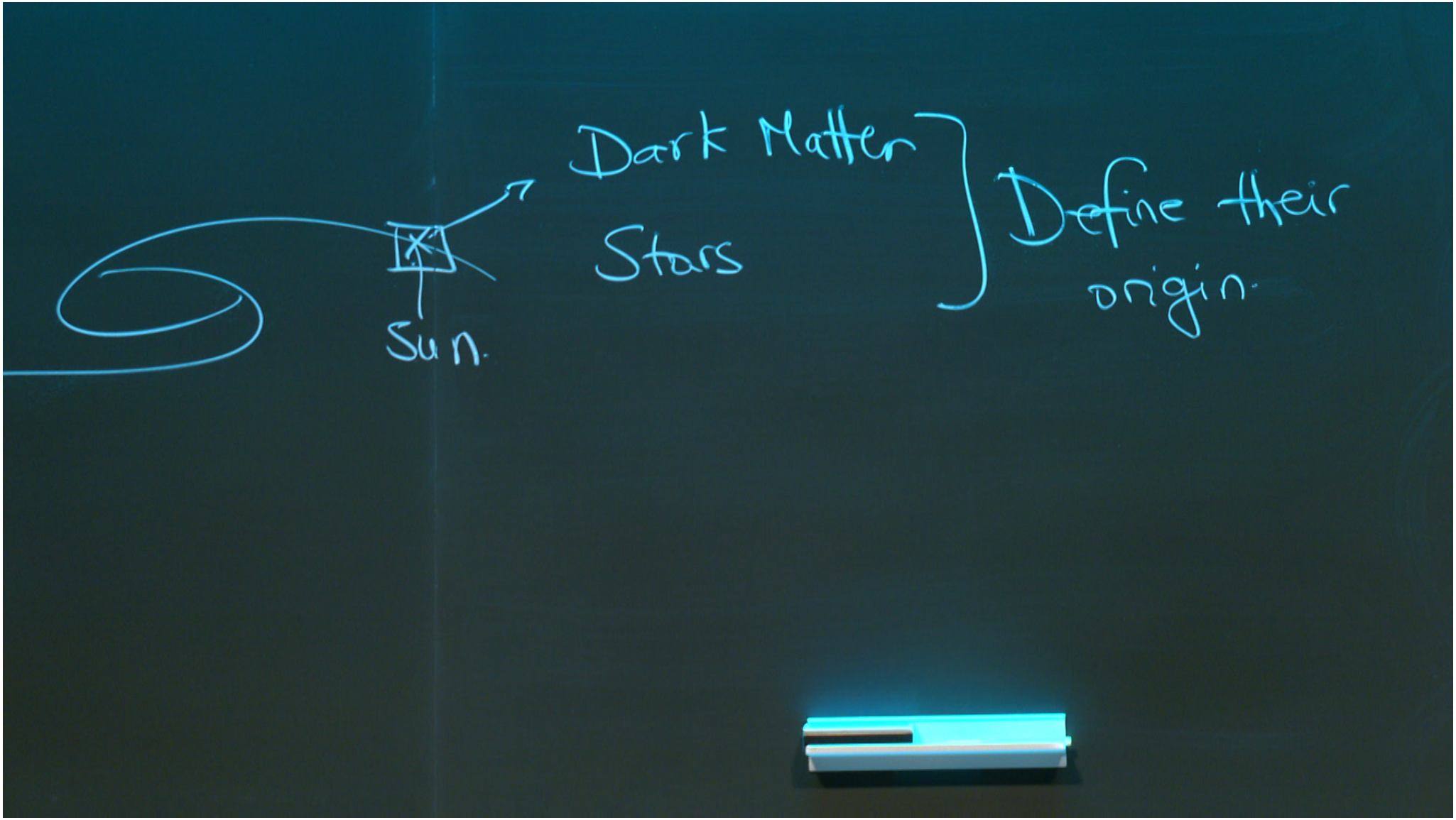
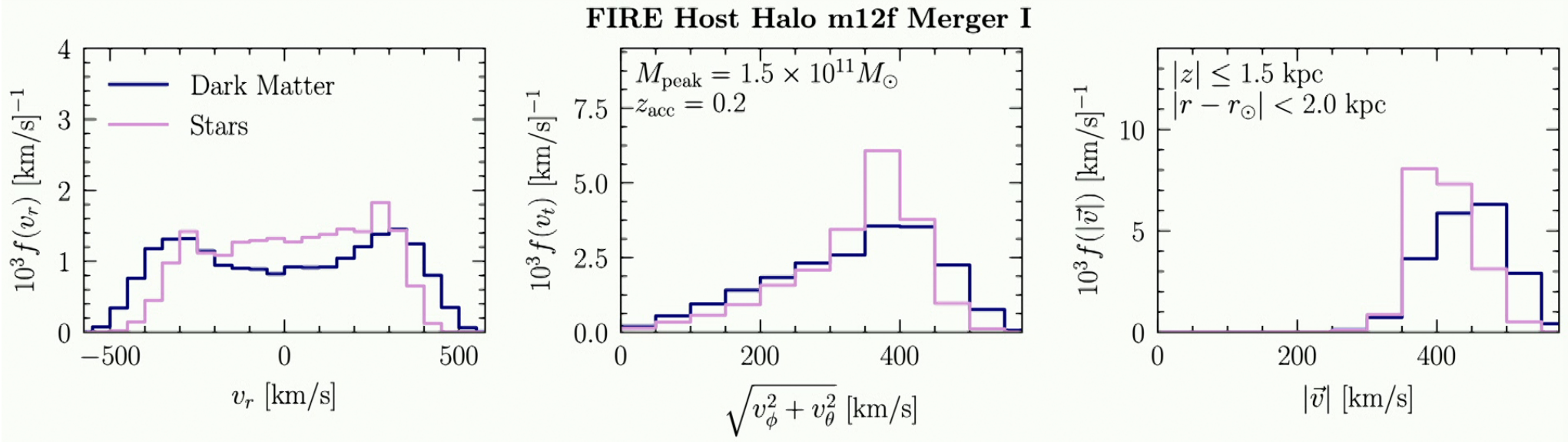
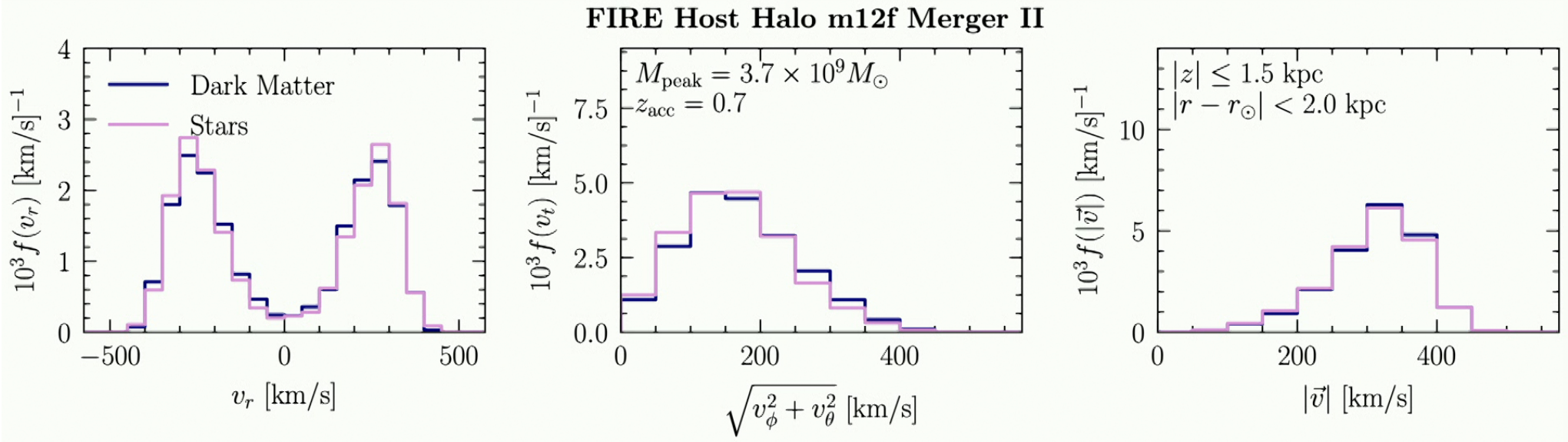

Dark Matter
Stars
Define their origin.
Sun.

Correlation the velocity distributions of Dark Matter and stars merger by merger.



Necib, Lisanti, Garisson Kimmel et al. (2019)

Correlation the velocity distributions of Dark Matter and stars merger by merger.



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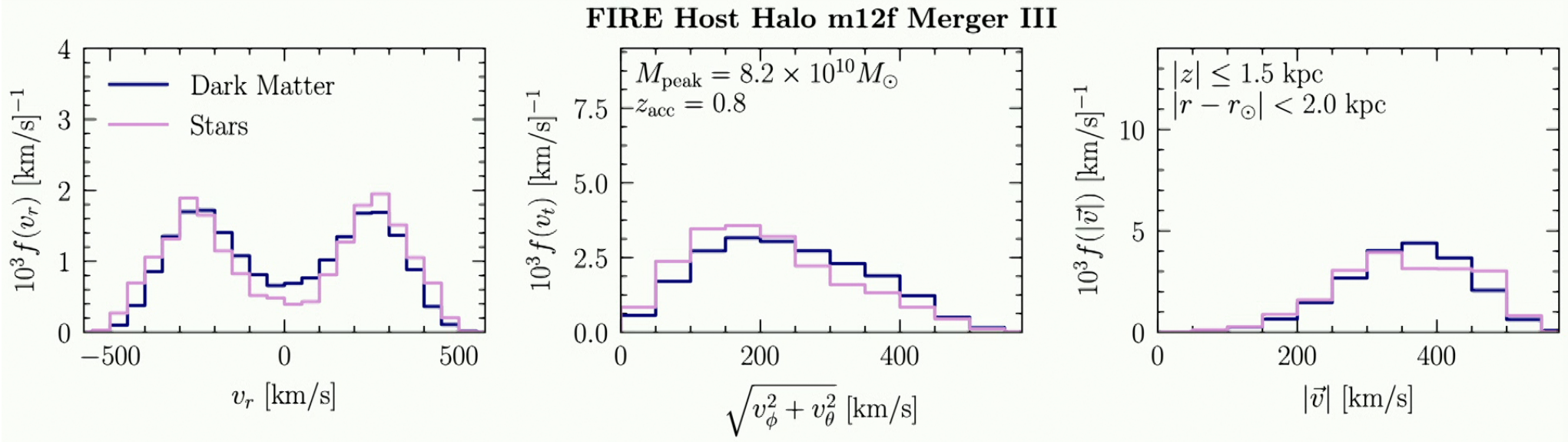
Correlation the velocity distributions of Dark Matter and stars merger by merger.



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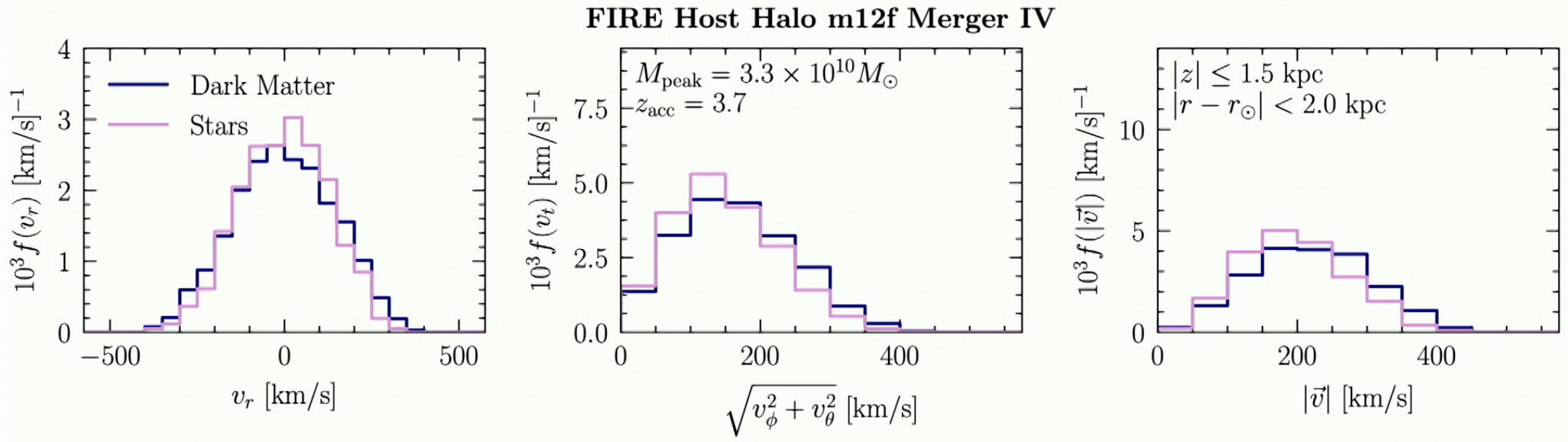
Correlation the velocity distributions of Dark Matter and stars merger by merger.



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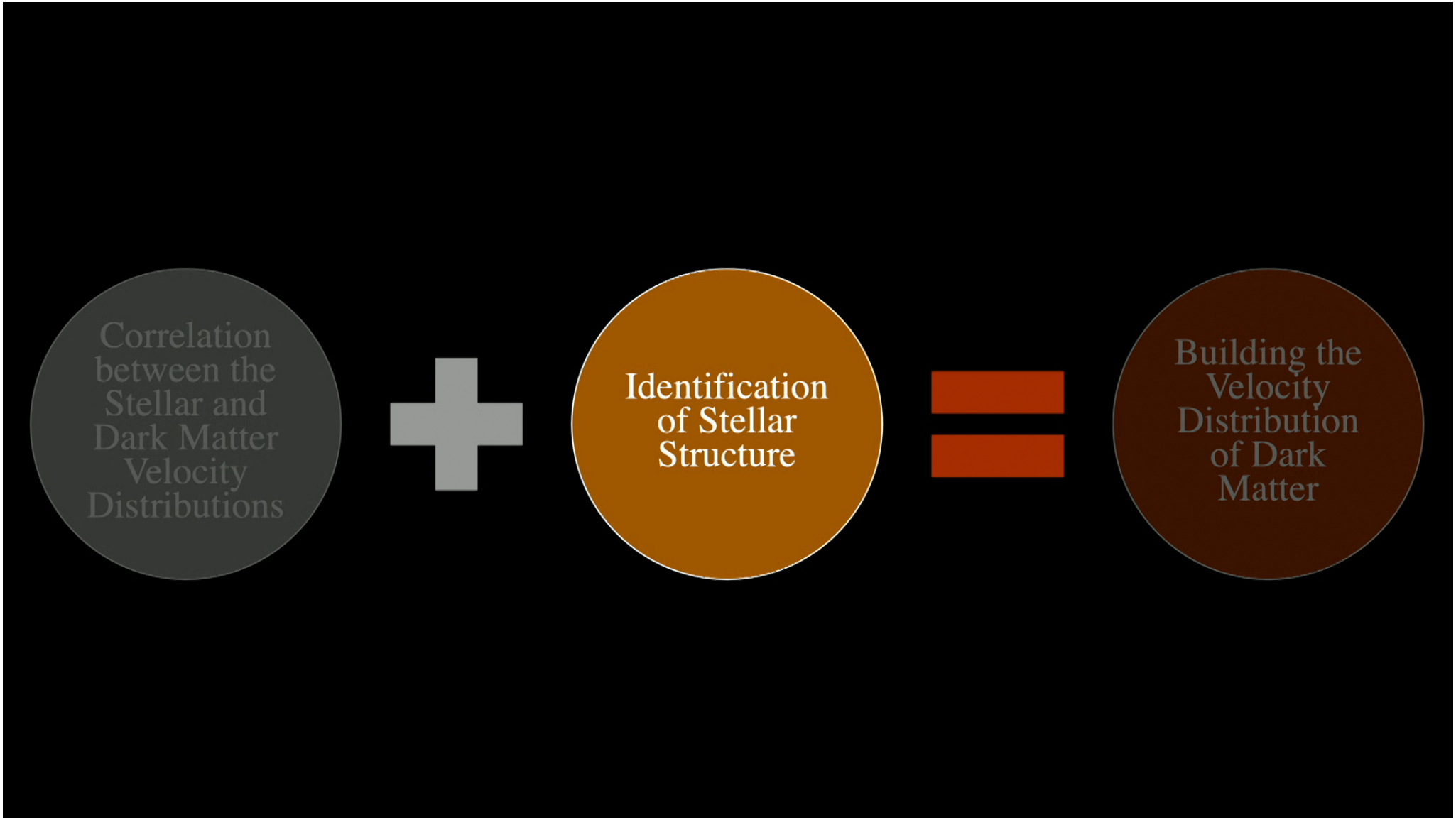
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Identification of Stellar Structure
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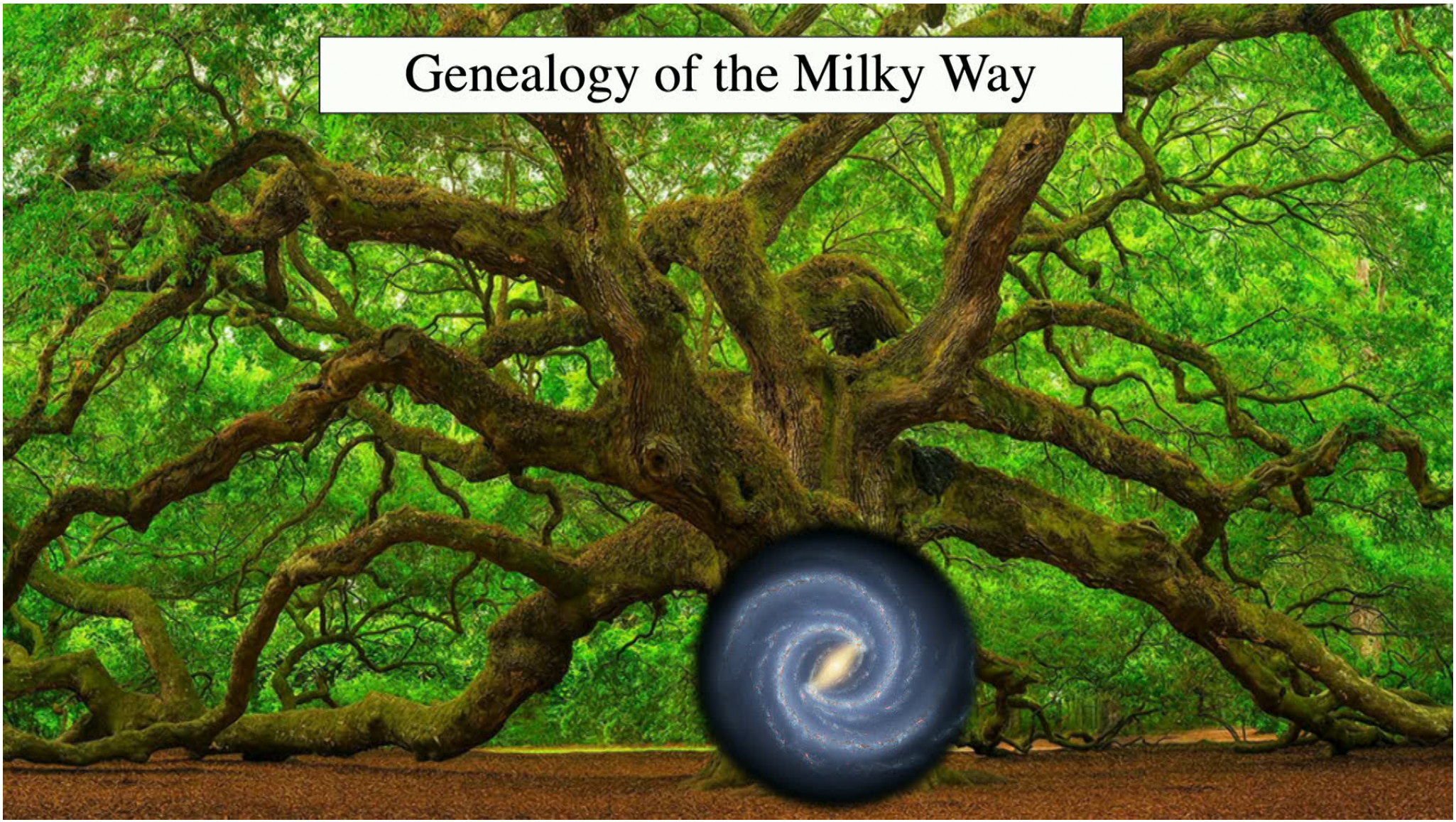
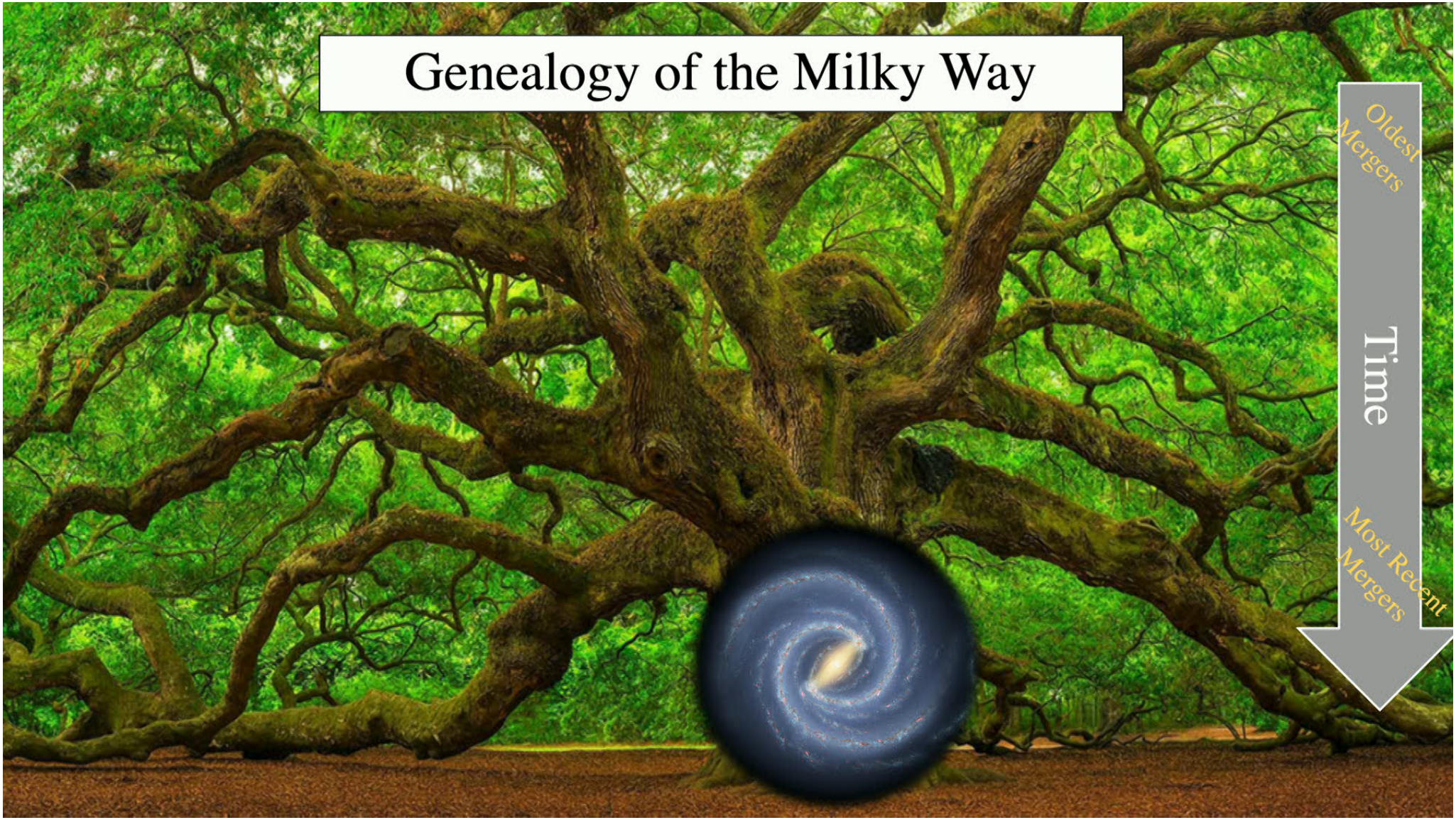
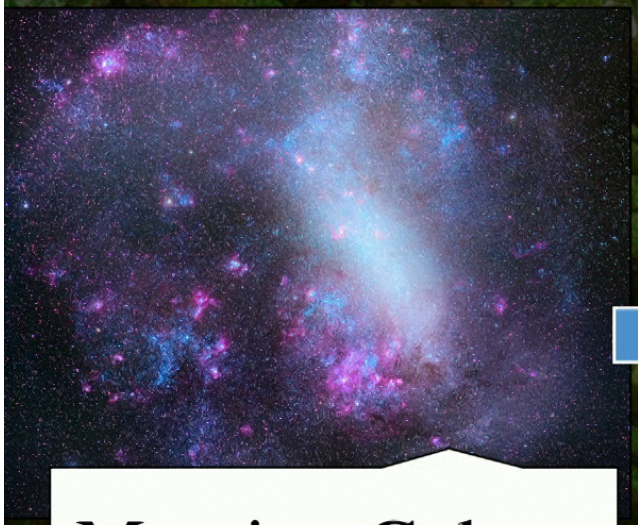

Genealogy of the Milky Way


Genealogy of the Milky Way
Oldest Mergers
Time
Most Recent Mergers

Merging Stages



Merging Galaxy

Stream

Debris Flow

Most Recent Mergers

Time

Oldest Mergers

Genealogy of the Milky Way

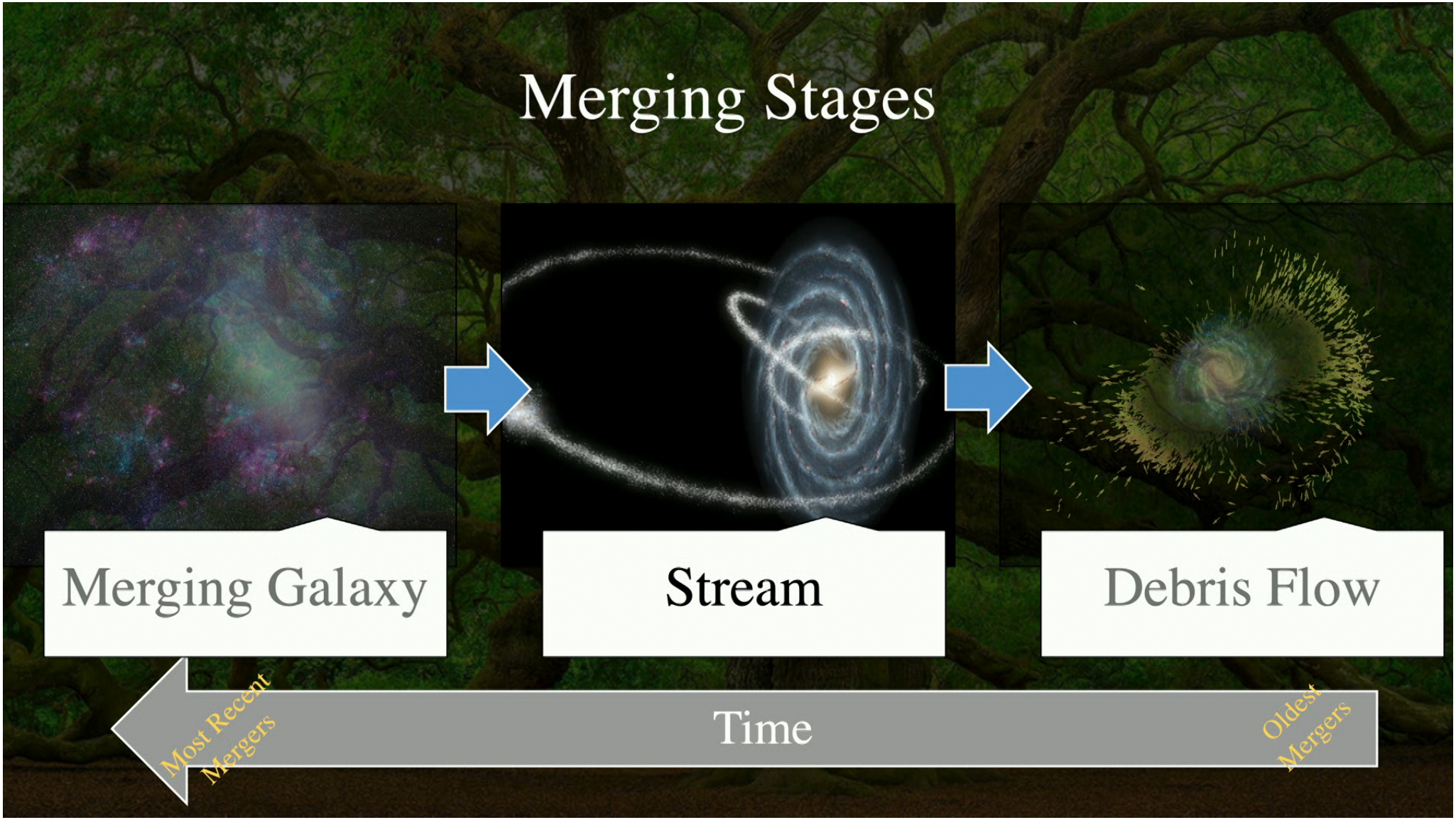
Pawlowski/Bullock/Boylan-Kolchin

Oldest Mergers

Time

Most Recent Mergers

Large Magellanic Cloud


Merging Stages
Merging Galaxy
Stream
Debris Flow
Most Recent Mergers
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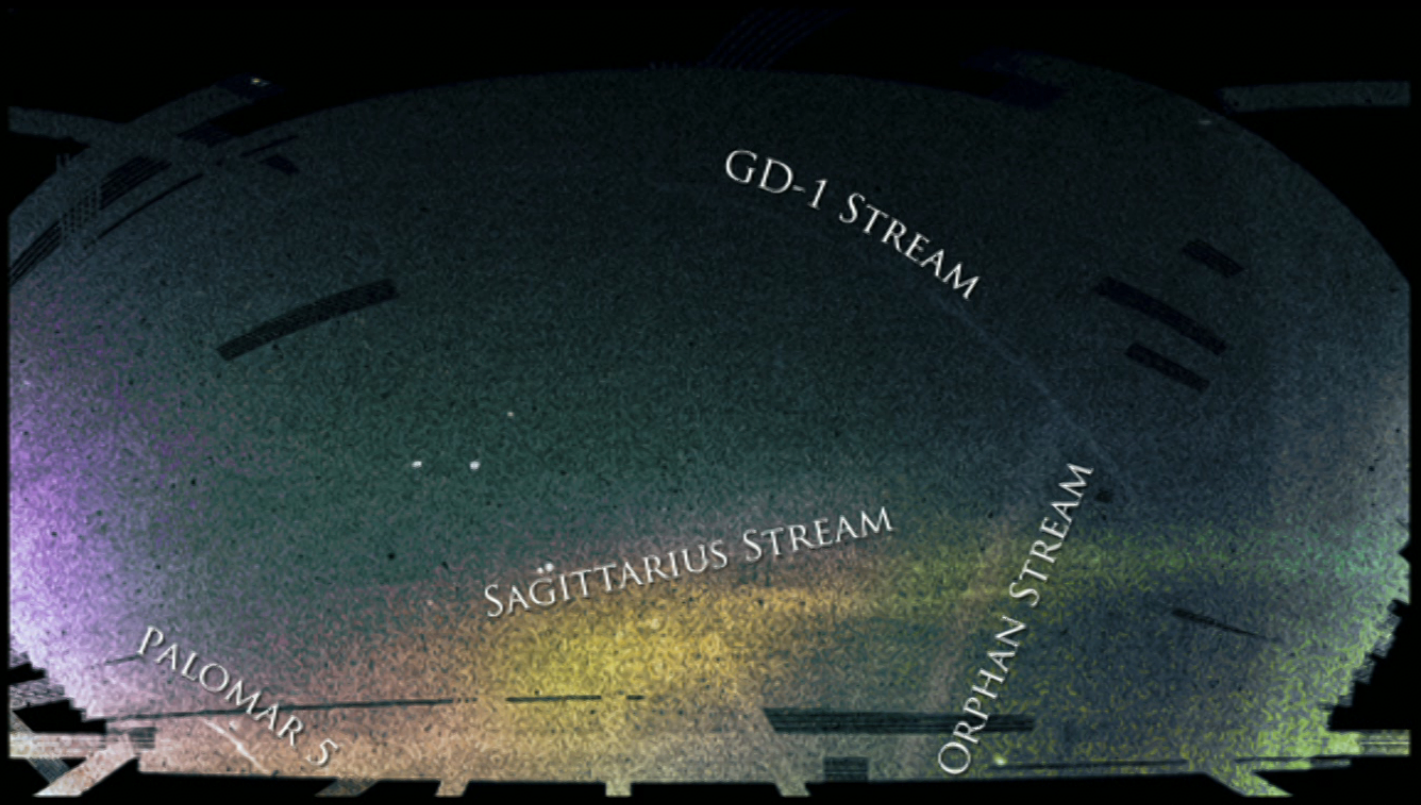
Field of Streams

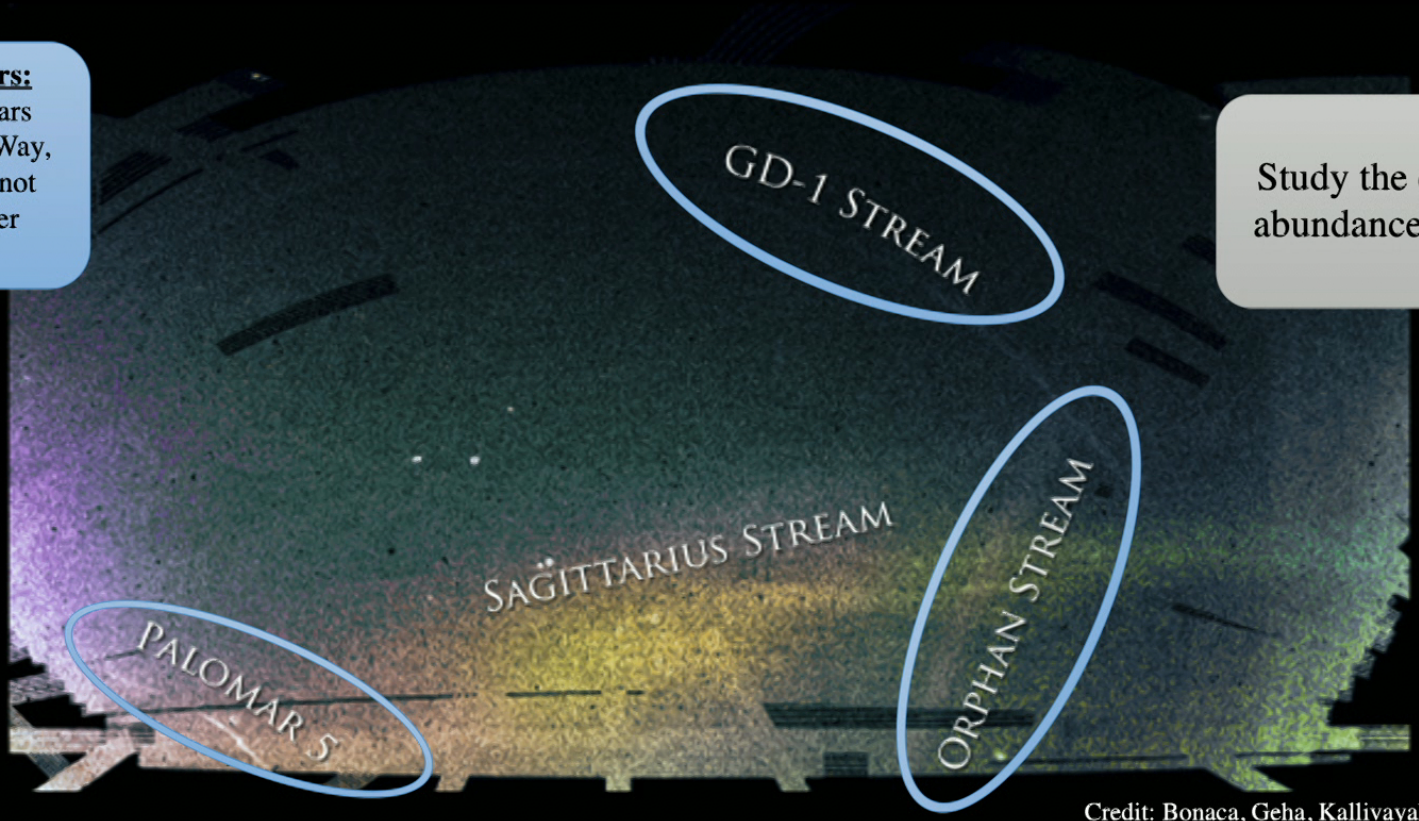


Credit: Bonaca, Geha, Kallivayalil

Belokurov, Zucker, Evans, et al. (2007)

Field of Streams

Globular Clusters:
A collection of stars born in the Milky Way, and therefore are not part of the merger history



Credit: Bonaca, Geha, Kallivayalil

Study the chemical abundances of stars

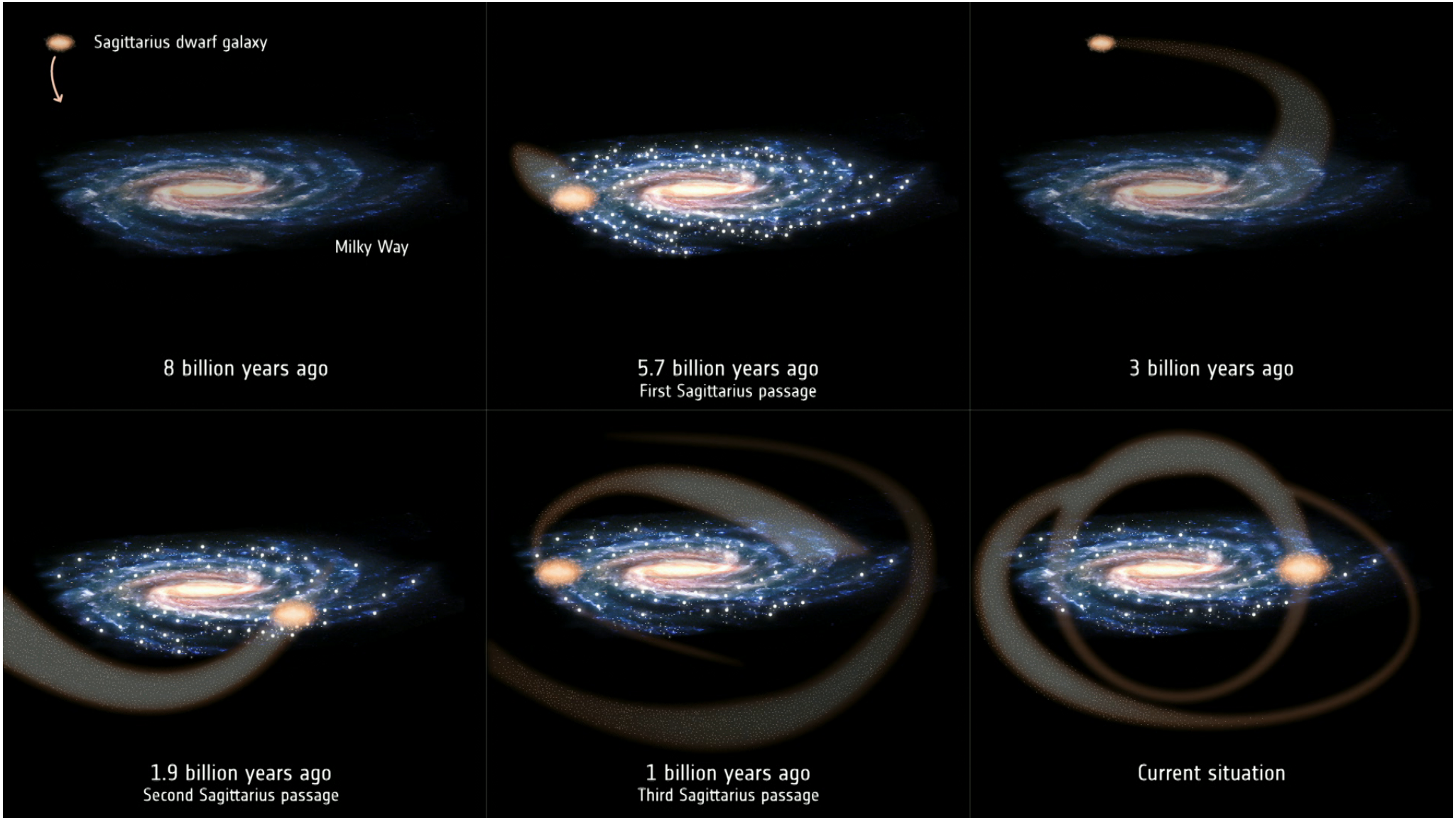
Belokurov, Zucker, Evans, et al. (2007)

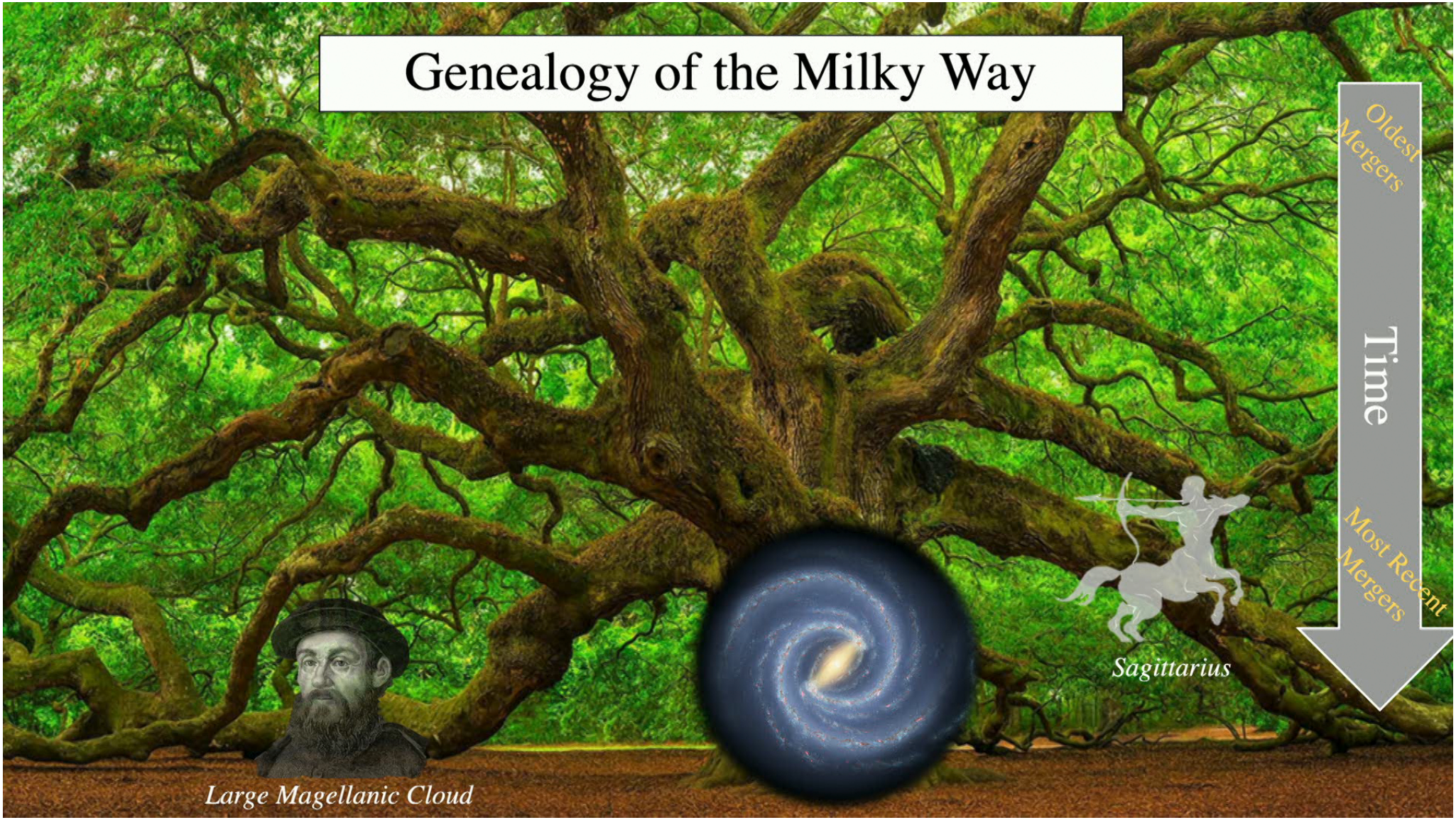
Field of Streams

Dwarf Galaxies:
Galaxies that have formed outside the Milky Way and are currently merging.

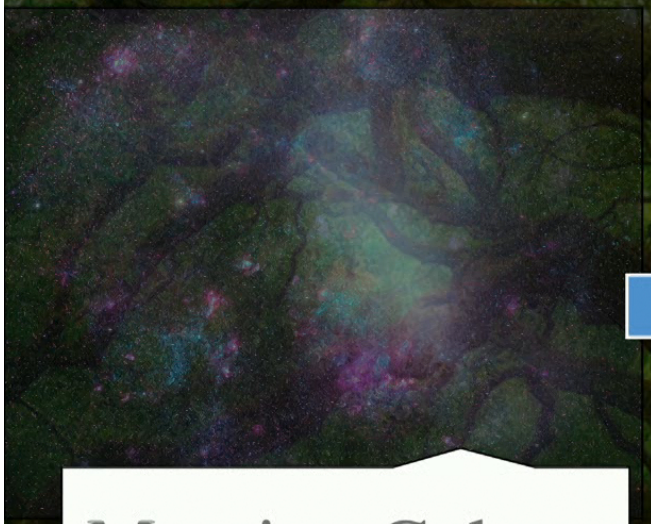
Credit: Bonaca, Geha, Kallivayalil

Belokurov, Zucker, Evans, et al. (2007)

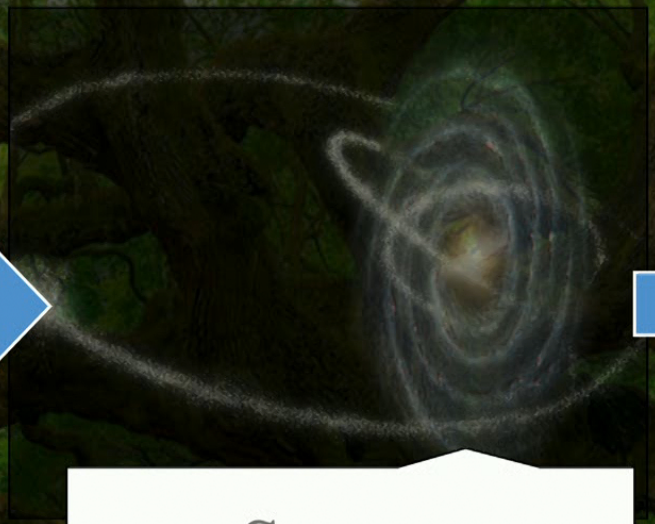

Sagittarius dwarf galaxy
Milky Way
8 billion years ago
5.7 billion years ago
First Sagittarius passage
3 billion years ago
1.9 billion years ago
Second Sagittarius passage
1 billion years ago
Third Sagittarius passage
Current situation


Genealogy of the Milky Way
Oldest Mergers
Time
Most Recent Mergers
Sagittarius
Large Magellanic Cloud

Merging Stages



Merging Galaxy



Stream

Debris Flow

Most Recent Mergers

Time

Oldest Mergers

Gaia Enceladus
Accretion time: 6-10 billion years ago
Mass: 1%-10% of the mass of the Milky Way
Belokurov et al. (2018)
Helmi et al. (2018)

Gaia Enceladus

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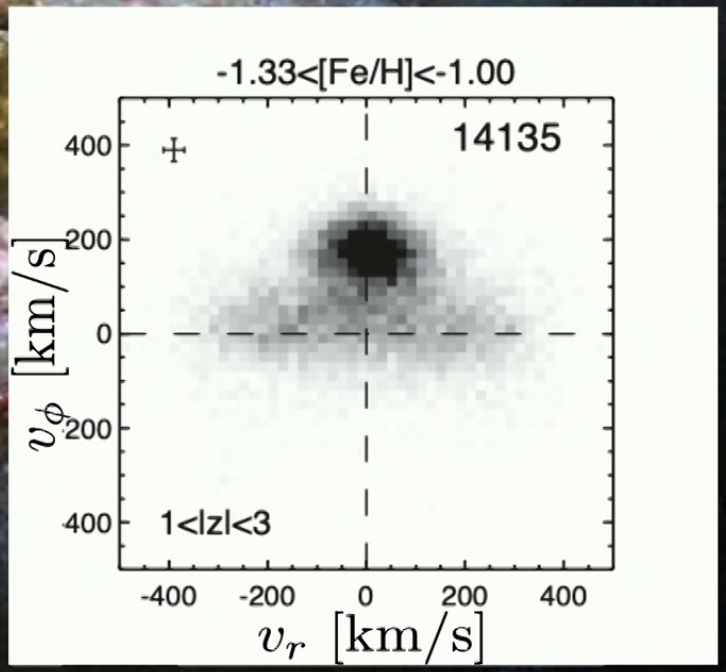
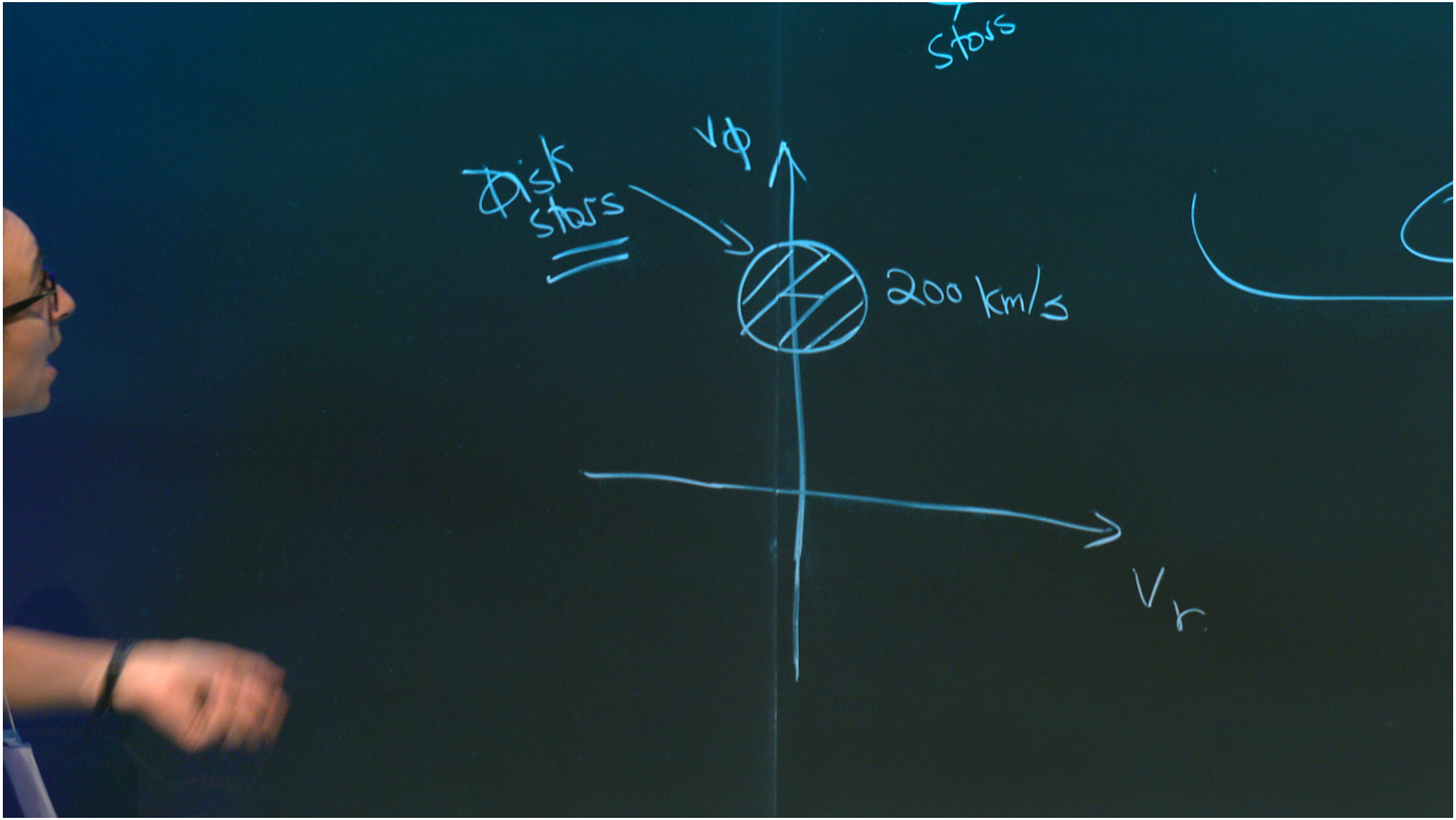
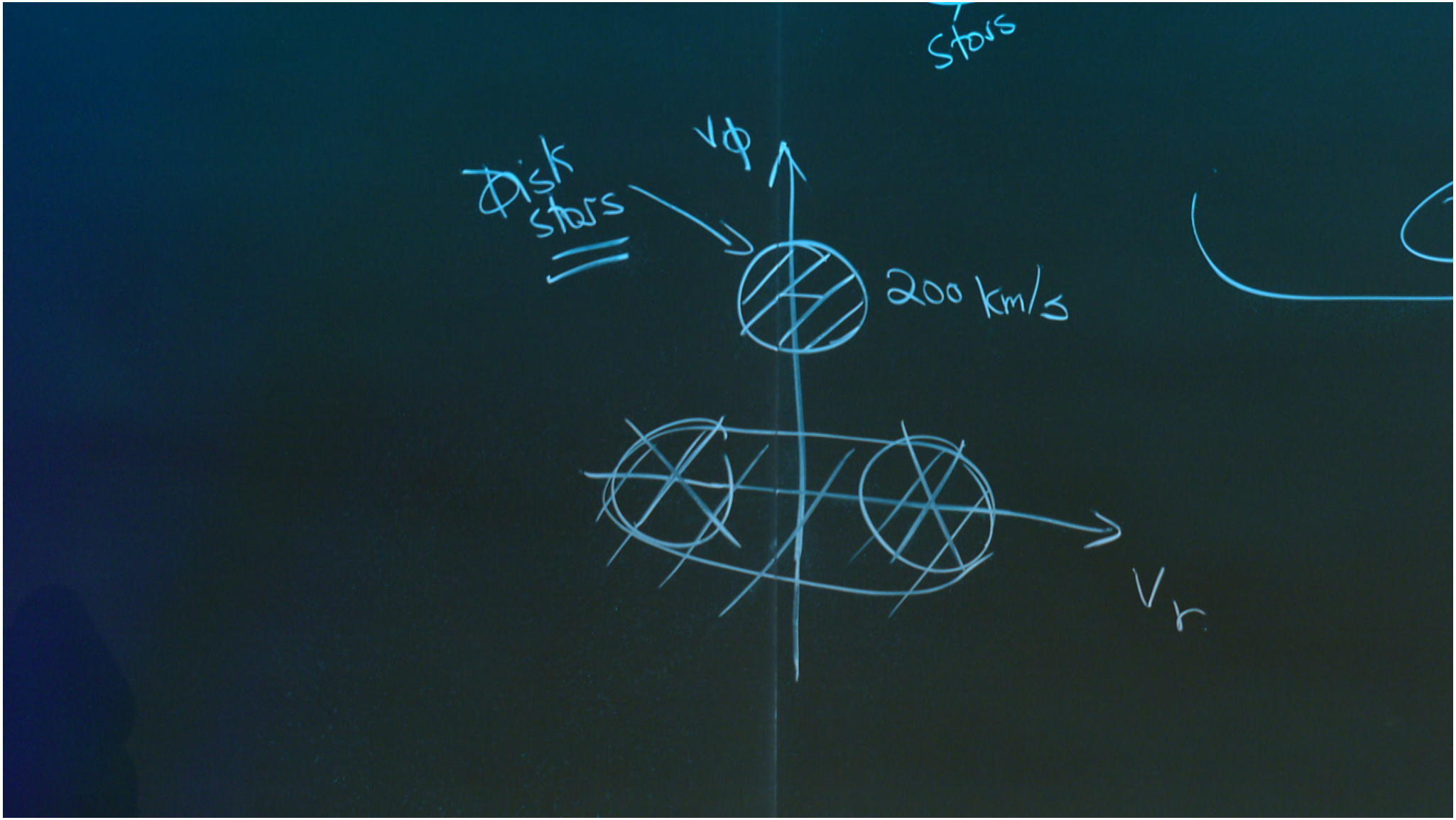


Belokurov et al. (2018)
Helmi et al. (2018)


Stars
Disk stars
v_ϕ
200 km/s
v_r


Stars
Disk stars
v_ϕ
200 km/s
V_r

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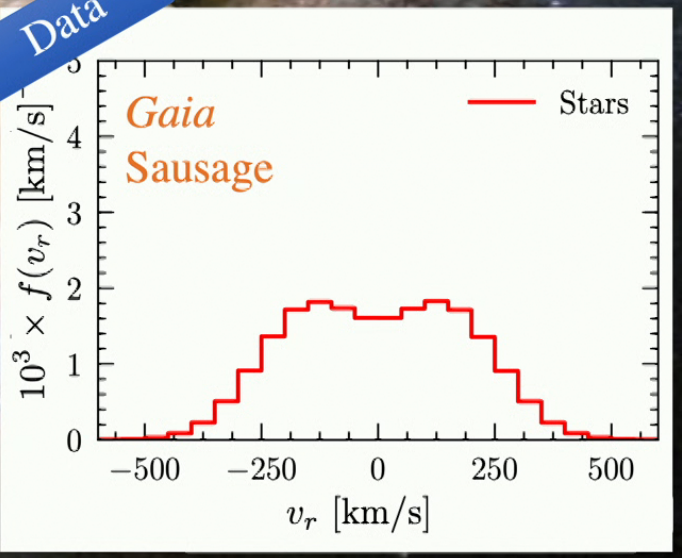
Data

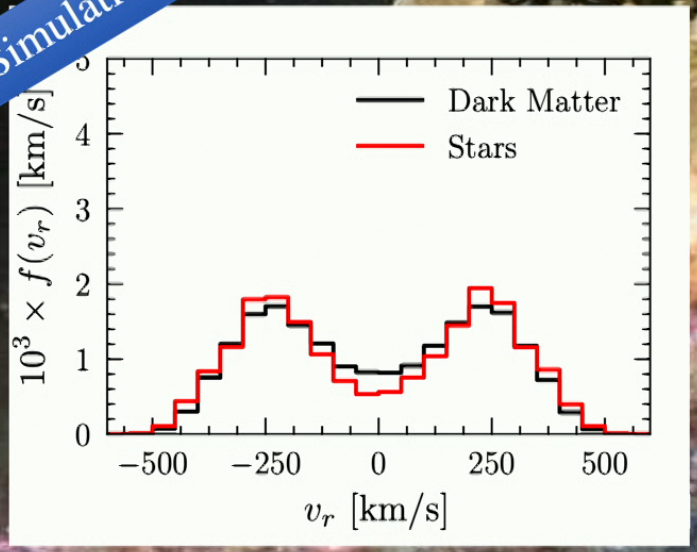


Necib, Lisanti, Belokurov (2019)

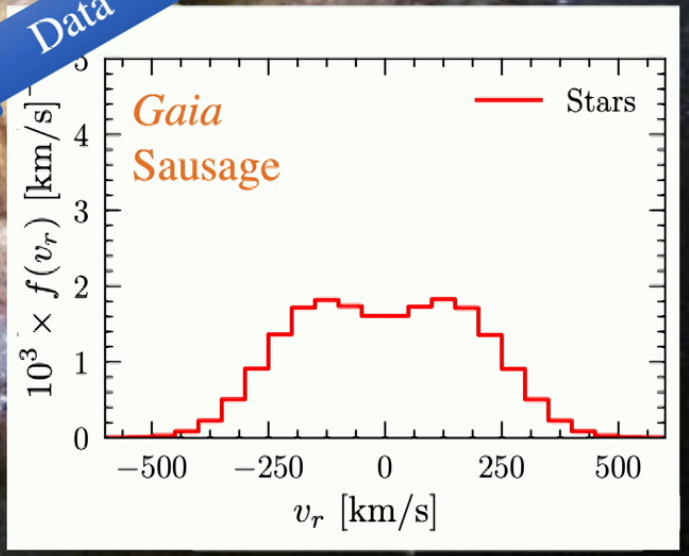
Gaia Enceladus

Accretion time: 6-10 billion years ago
Mass: 1%-10% of the mass of the Milky Way

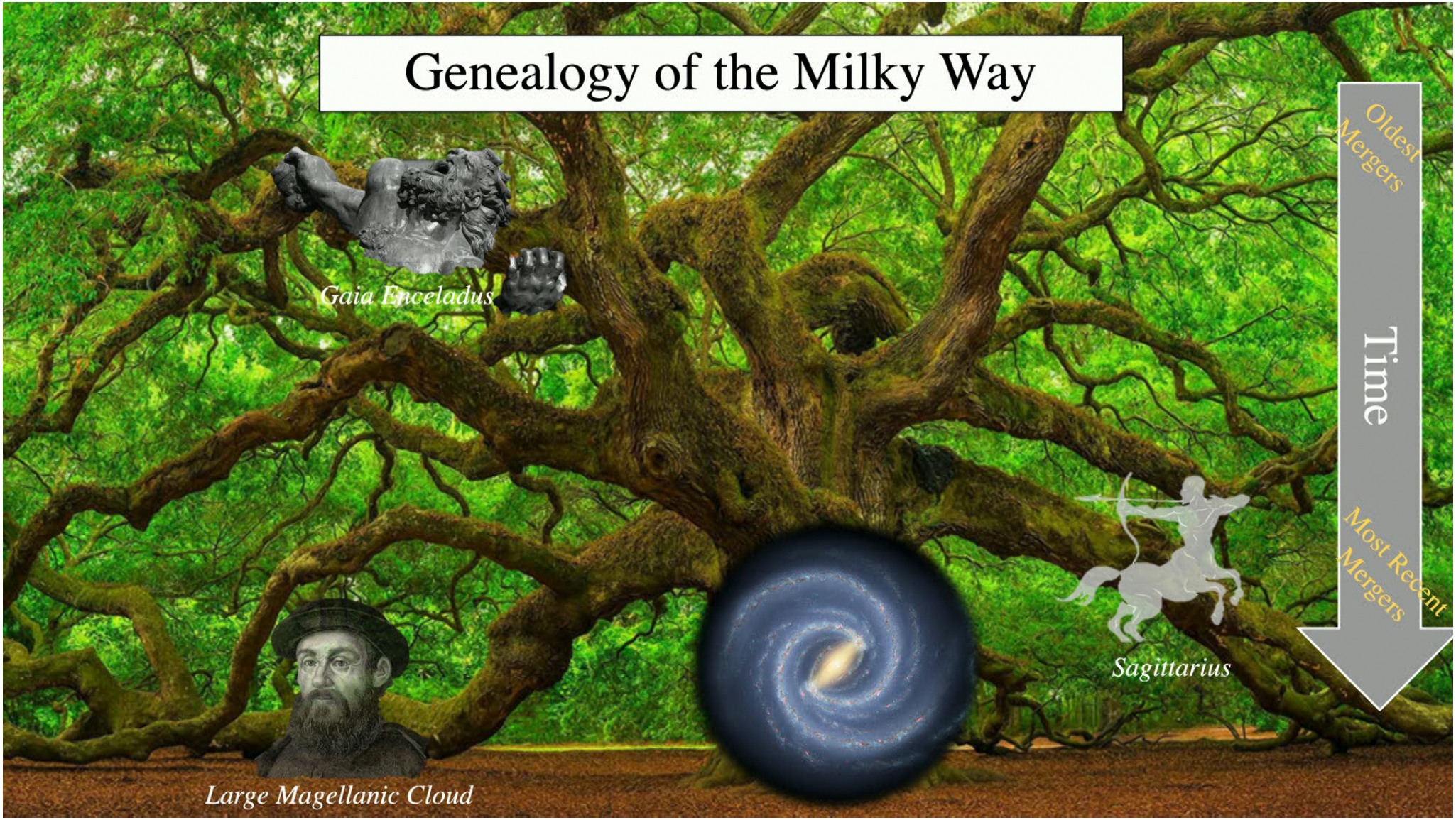
Simulation



Data

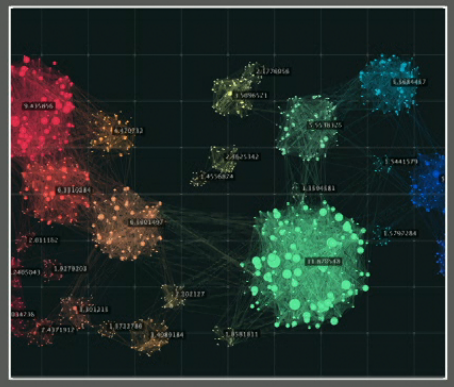


Necib, Lisanti, Belokurov (2019)
Necib, Lisanti, Garrison-Kimmel et al. (2018)

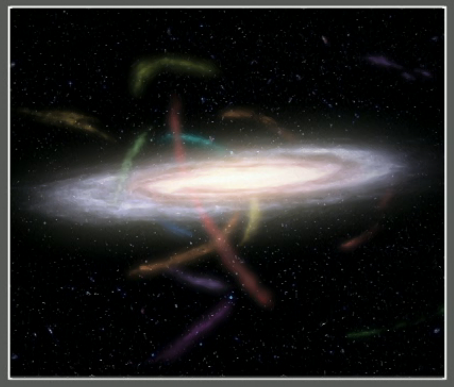

Genealogy of the Milky Way
Oldest Mergers
Time
Most Recent Mergers
Gaia Enceladus
Sagittarius
Large Magellanic Cloud

Automating the Identification of Stellar Substructure

Train on Simulations to Identify Accreted Stars



Cluster Local Stars

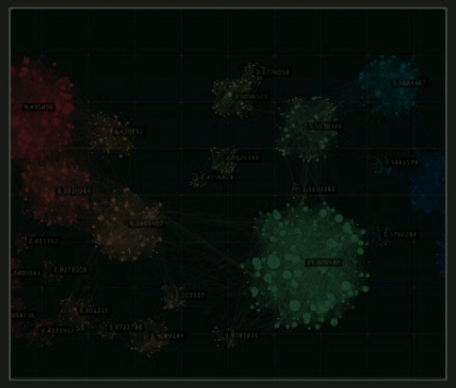


Build a Stream Finder Algorithm

Lina Necib, MIT

Automating the Identification of Stellar Substructure

Train on Simulations to Identify Accreted Stars



Cluster Local Stars

Build a Stream Finder Algorithm

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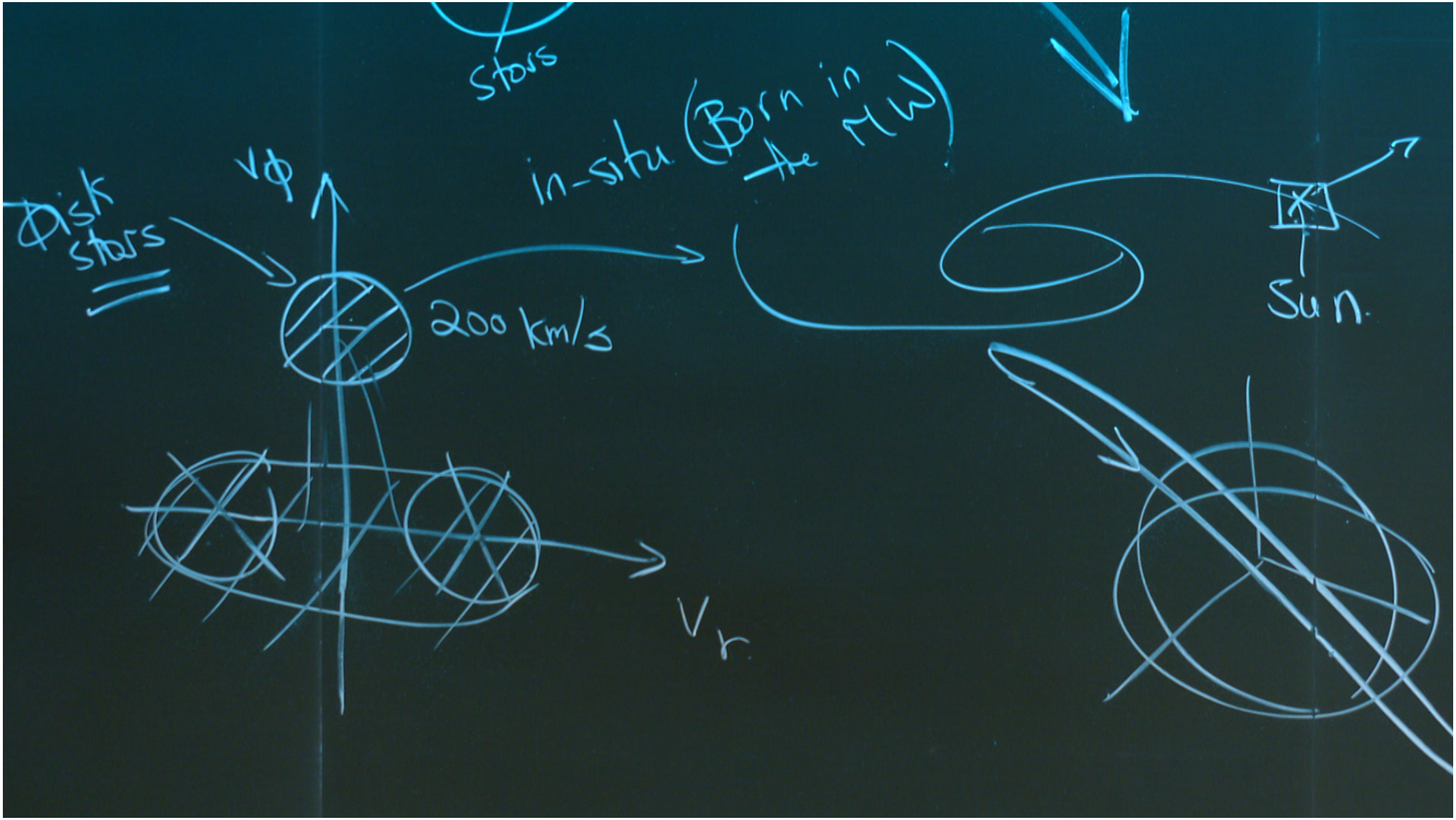
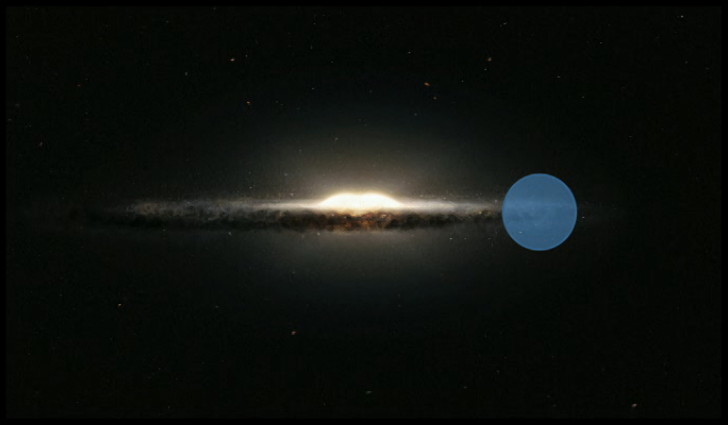

Stars
Disk stars
v_ϕ
200 km/s
in-situ (Born in the MW)
Sun.
v_r

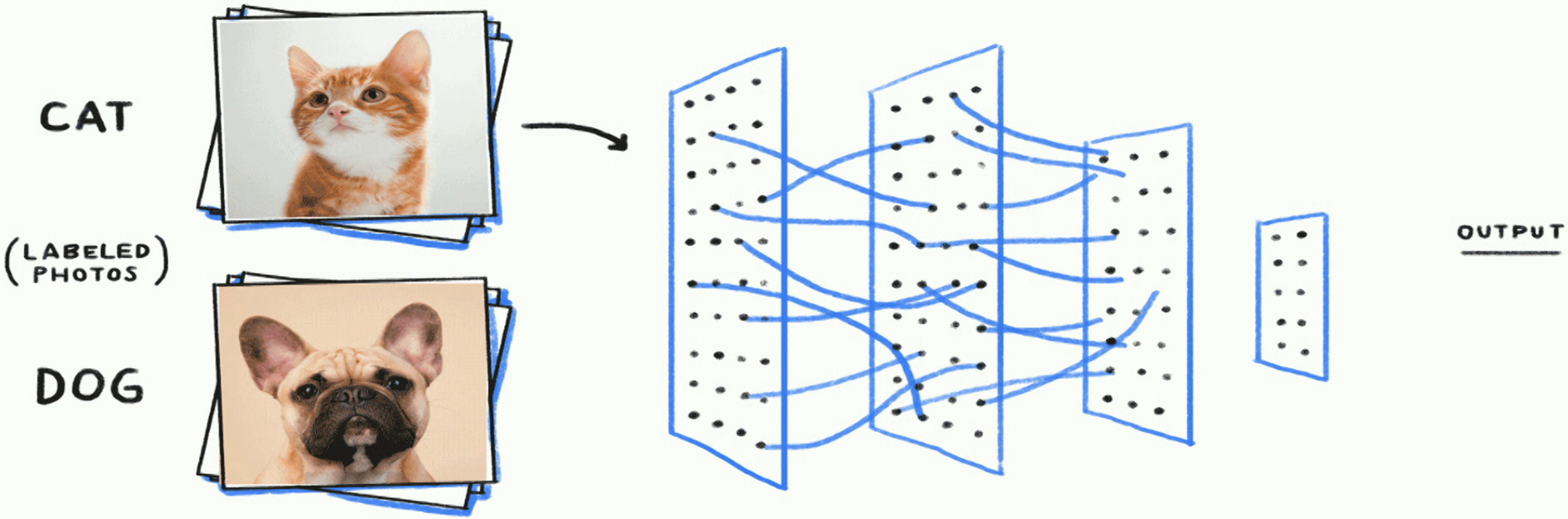
Accreted stars close to the plane?



1% of the stars close to the disk plane are accreted

Lina Necib, MIT

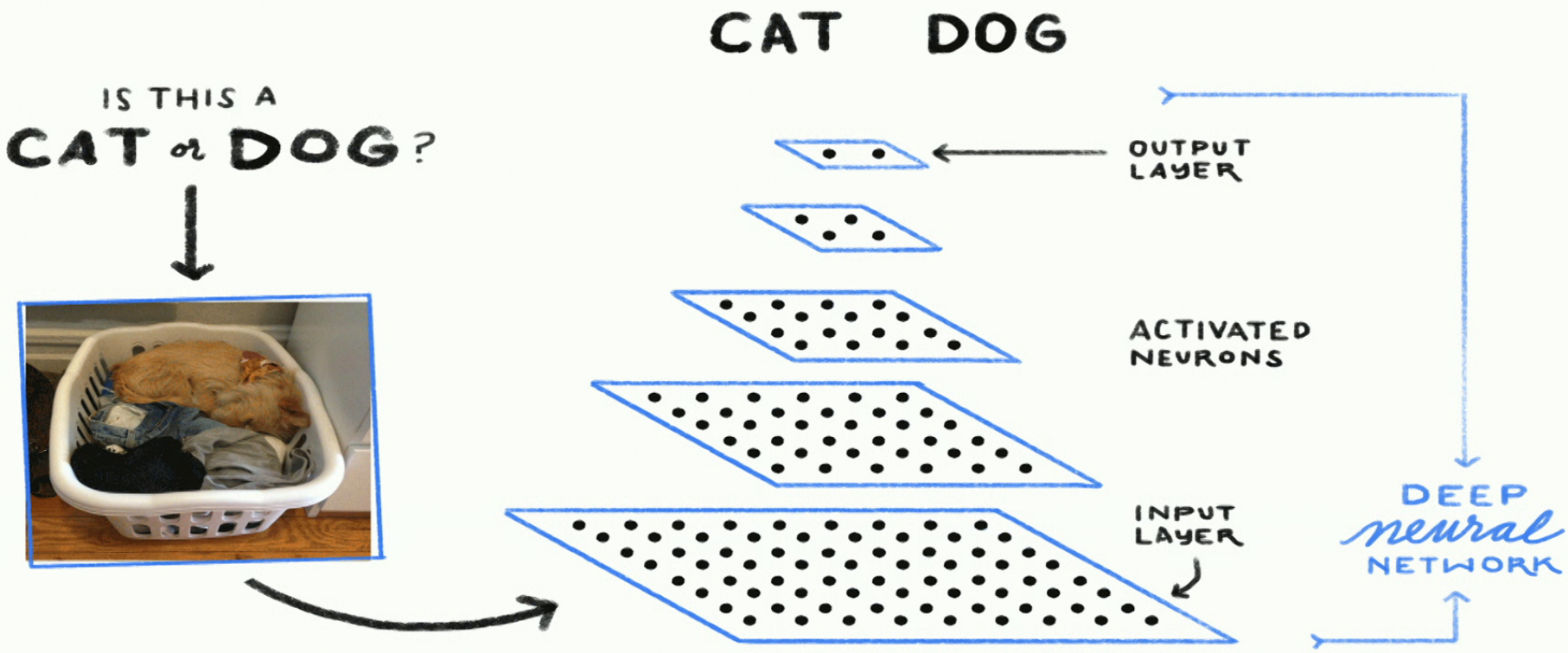
Machine Learning



Lina Necib, MIT

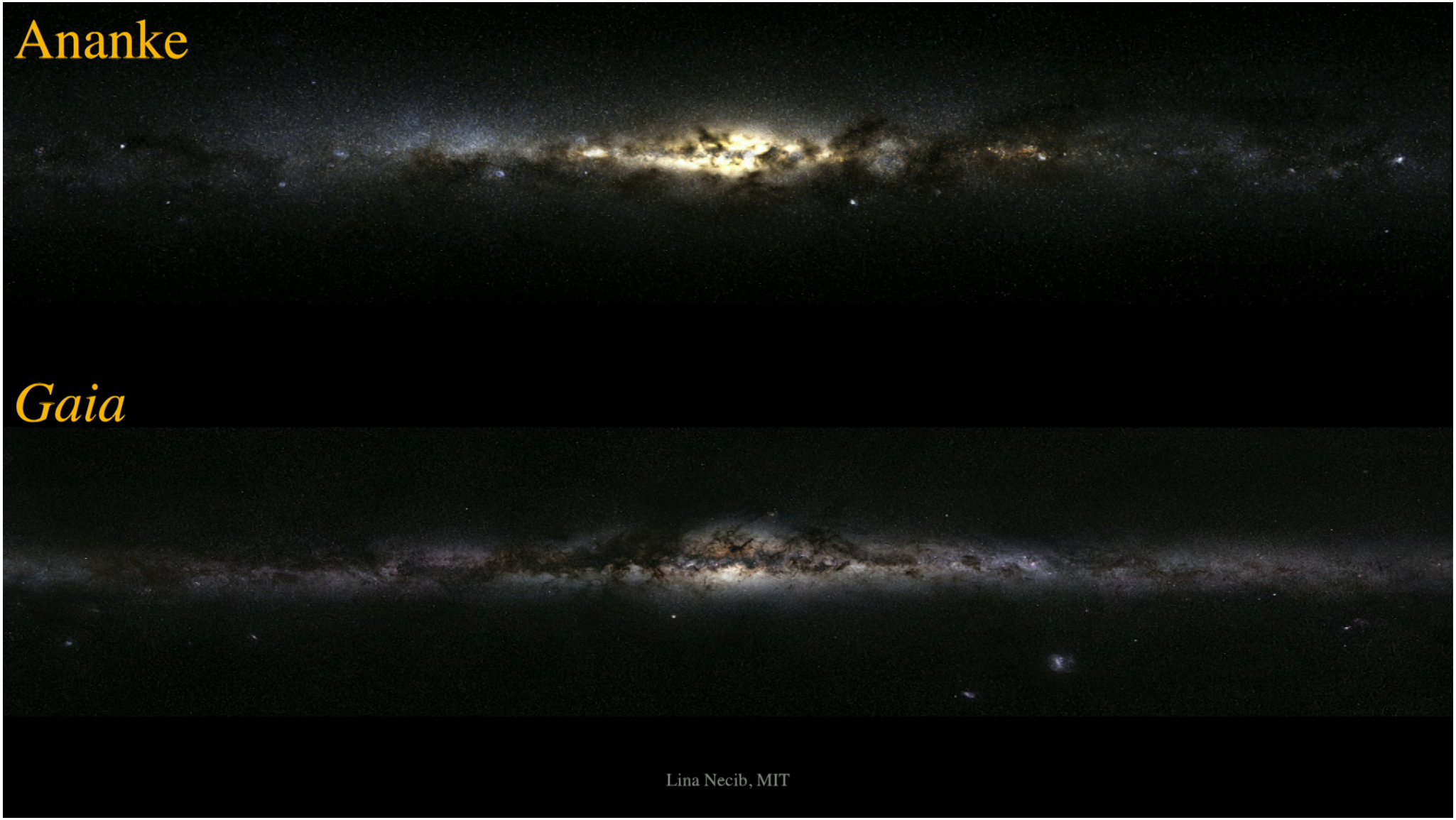
https://becominghuman.ai/building-an-image-classifier-using-deep-learning-in-python-totally-from-a-beginners-perspective-be8dbaf22dd8

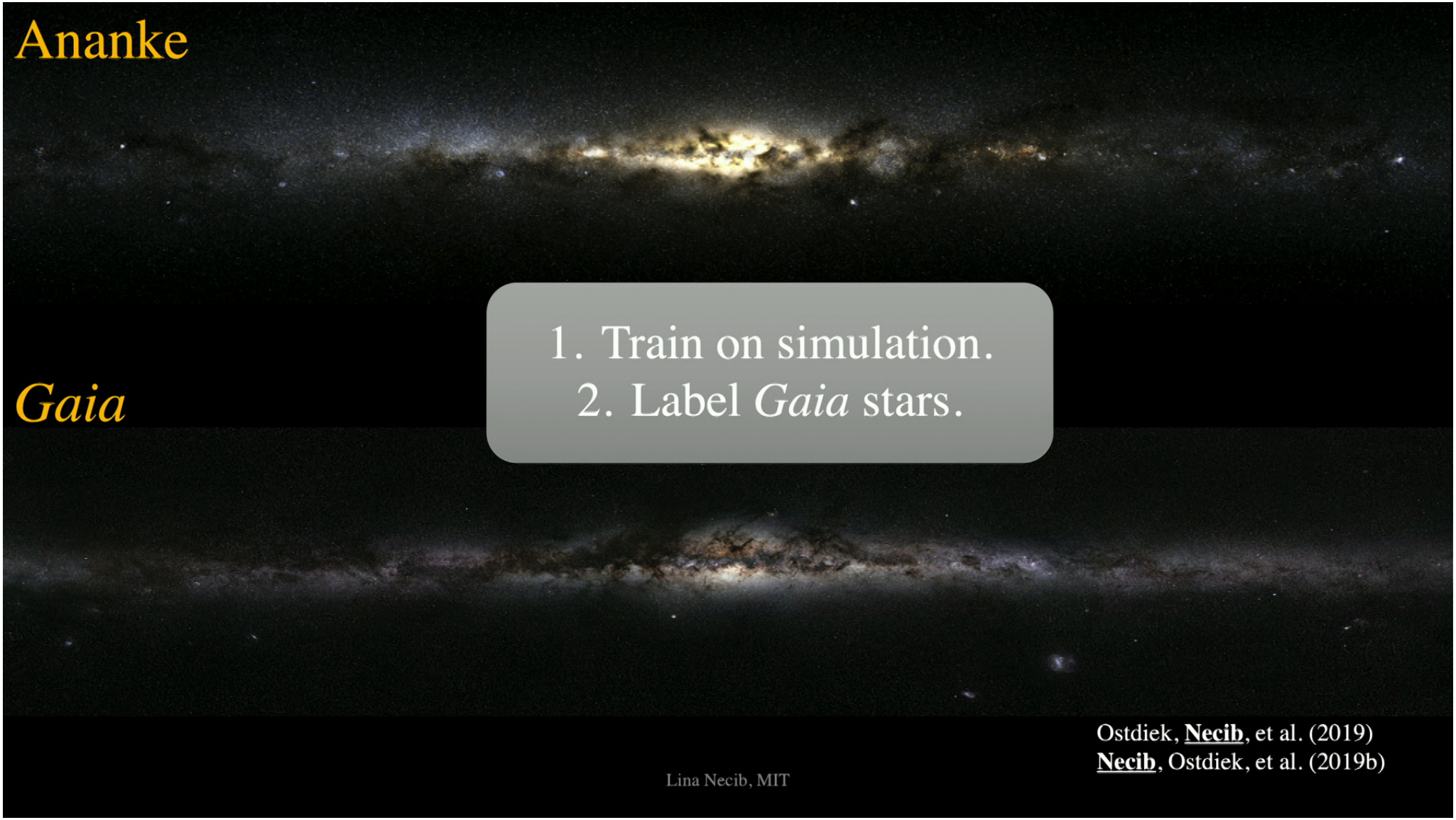
Machine Learning



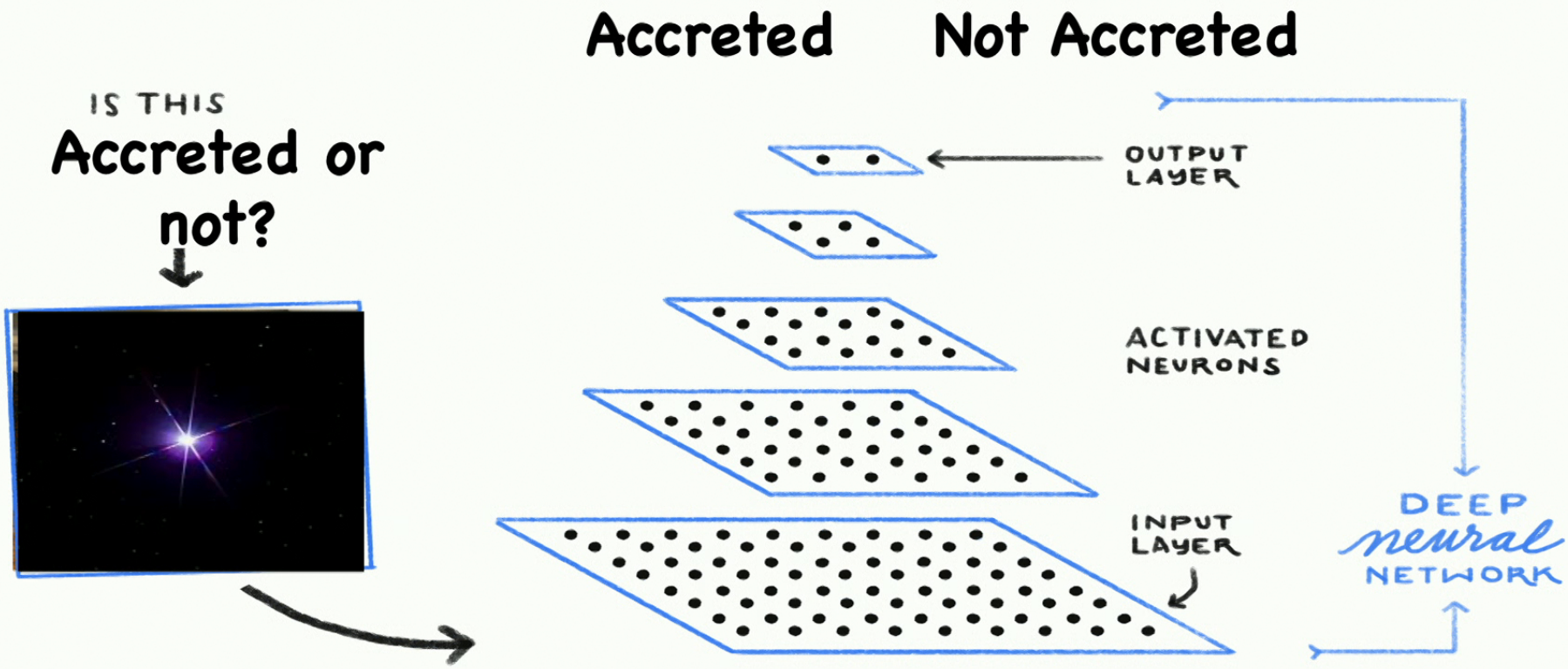
Lina Necib, MIT

https://becominghuman.ai/building-an-image-classifier-using-deep-learning-in-python-totally-from-a-beginners-perspective-be8dbaf22dd8


Ananke
Gaia
Lina Necib, MIT

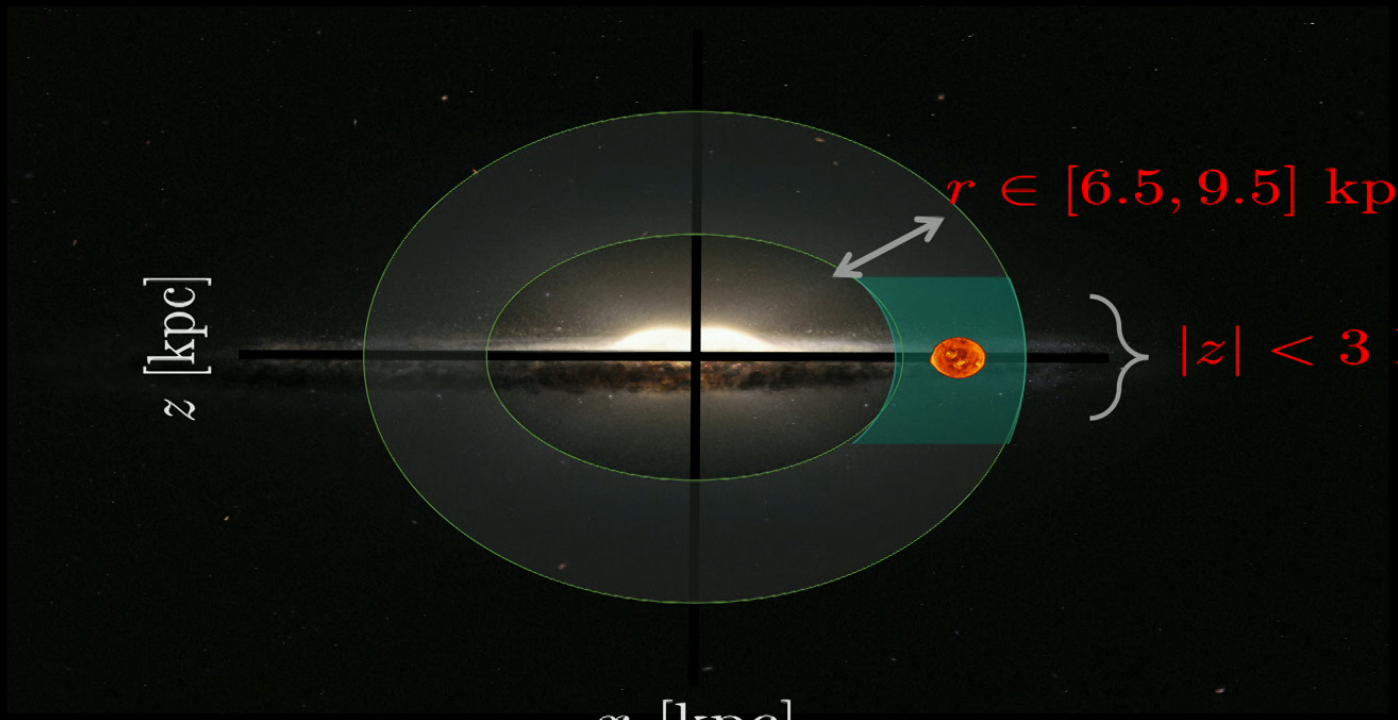

Ananke
Gaia
1. Train on simulation.
2. Label *Gaia* stars.
Ostdiek, **Necib**, et al. (2019)
Necib, Ostdiek, et al. (2019b)
Lina Necib, MIT

Machine Learning

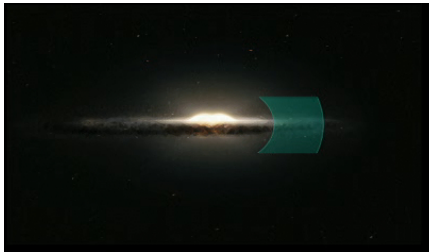


Lina Necib, MIT

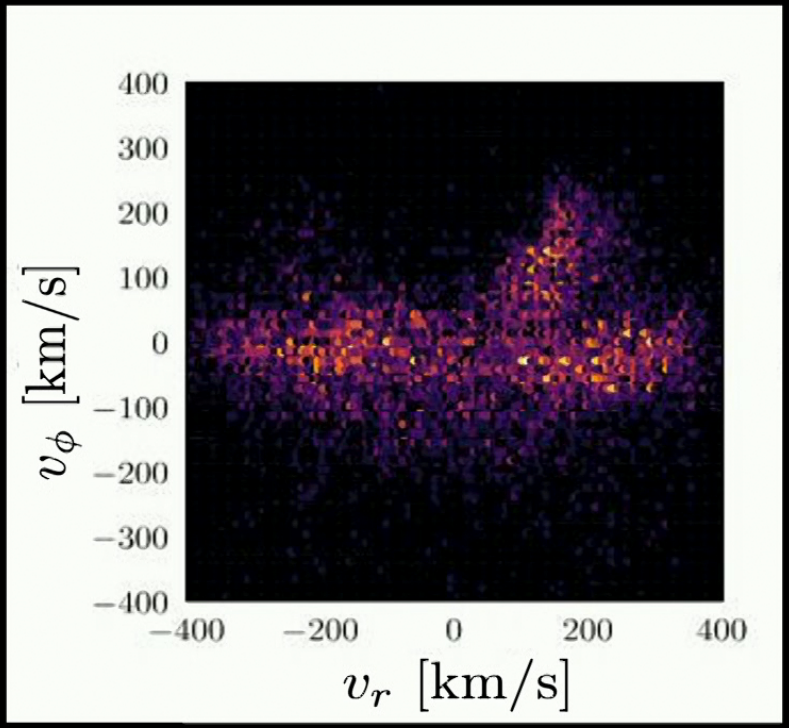
Build the Accreted Catalog of Stars



Lina Necib, MIT

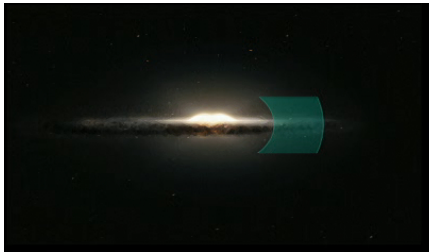


Structures close to the Disk

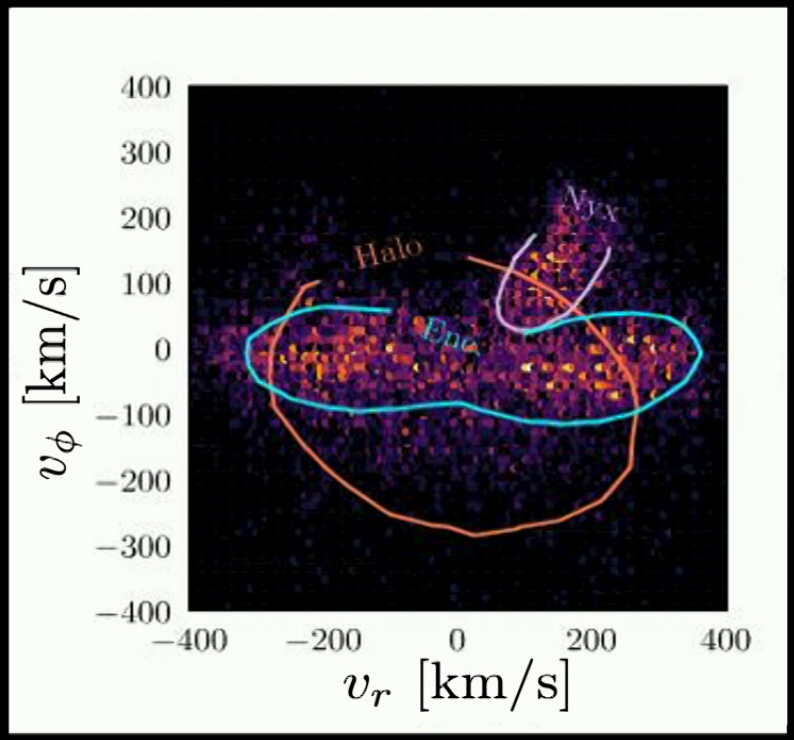


Lina Necib, MIT

Necib, Ostdiek, et al. (2019b)

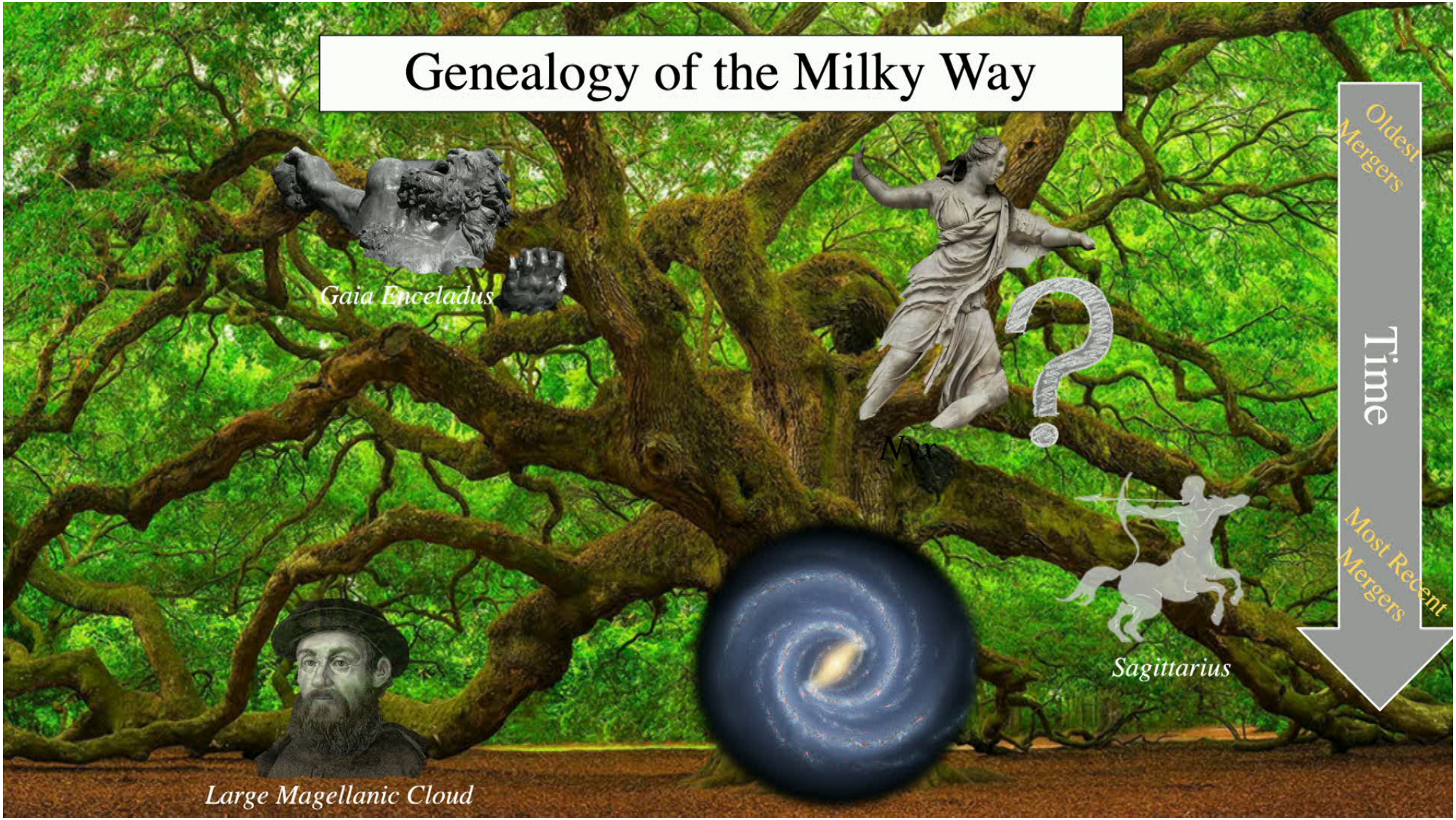


Structures close to the Disk



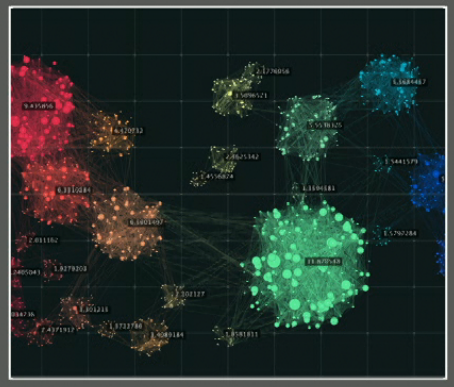
Lina Necib, MIT

Necib, Ostdiek, et al. (2019b)

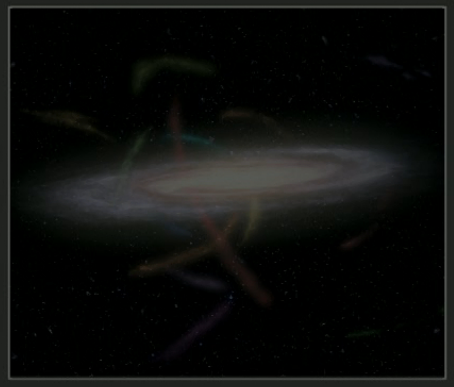

Genealogy of the Milky Way
Oldest Mergers
Time
Most Recent Mergers
Gaia Enceladus
?
Nyx
Sagittarius
Large Magellanic Cloud

How to Automate the Identification of Stellar Substructure?

Train on Simulations to Identify Accreted Stars



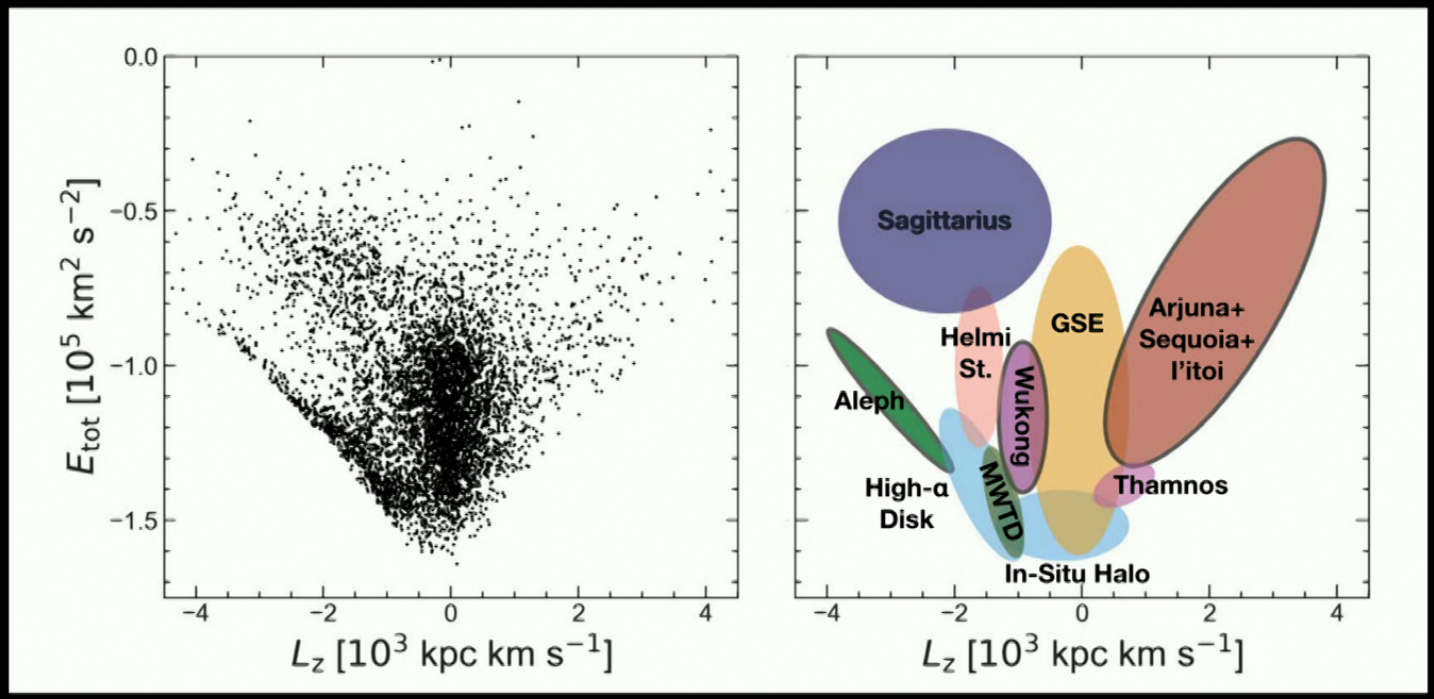
Cluster Local Stars



Build a Stream Finder Algorithm

Lina Necib, MIT

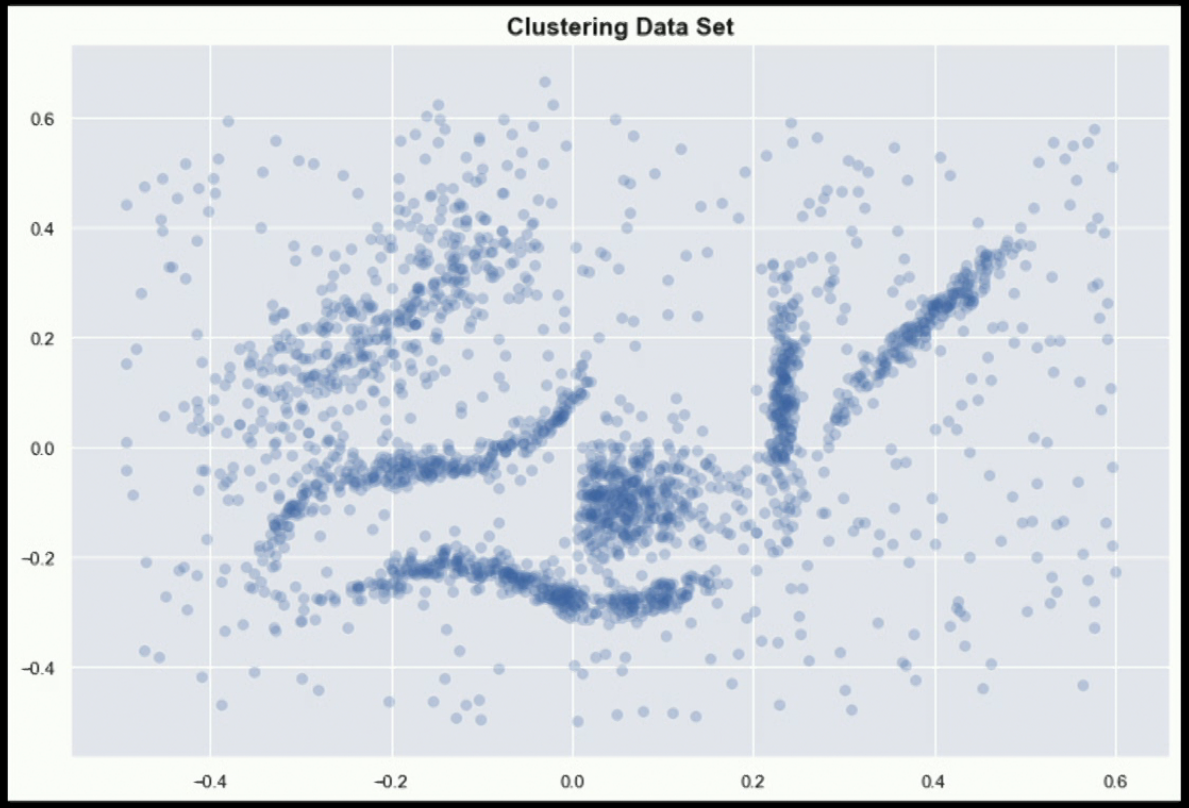
Identification of Stellar Clusters



Naidu et al. (2020)

Alternatively, we can use clustering

- Cluster in action and velocity spaces for kinematic structures



https://pberba.github.io/stats/2020/01/17/hdbscan/

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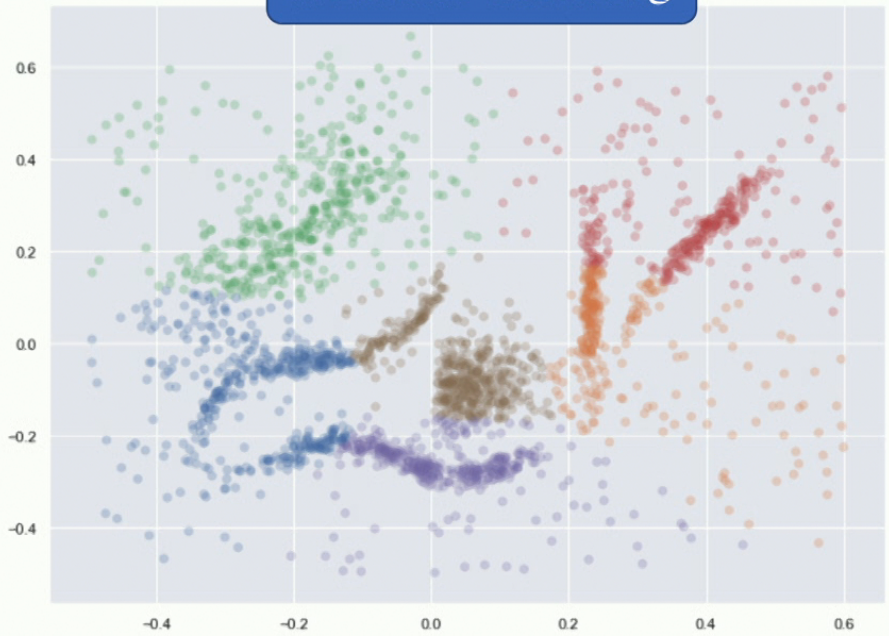
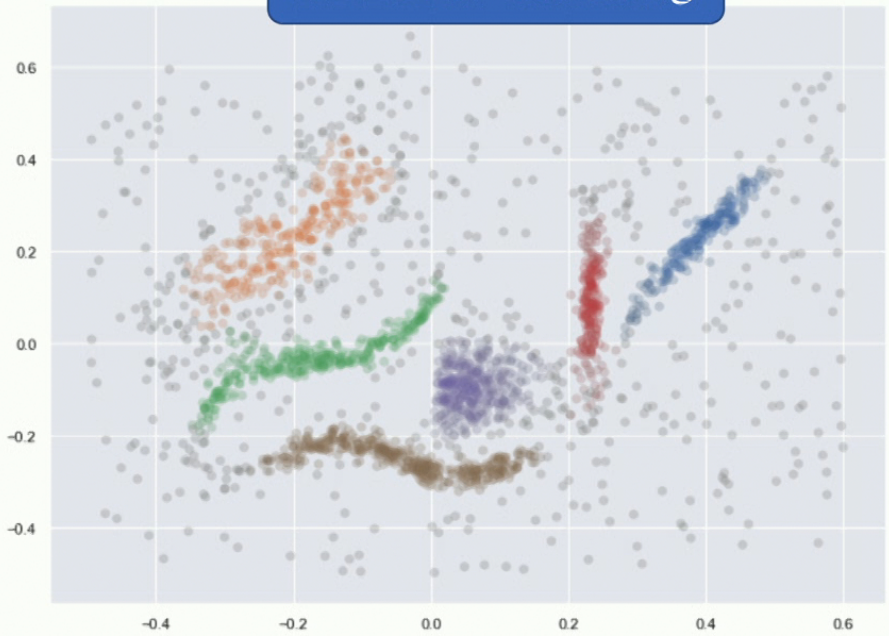
K-Means Clustering



HDBScan Clustering



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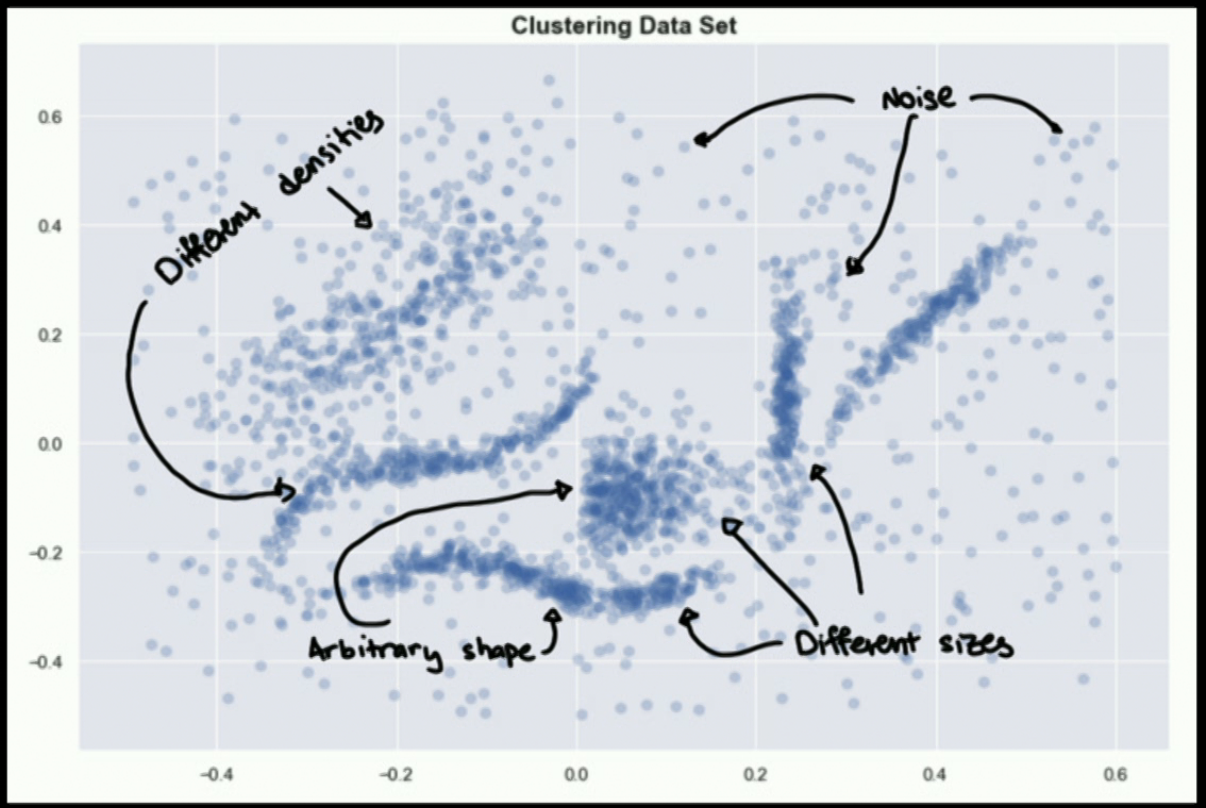

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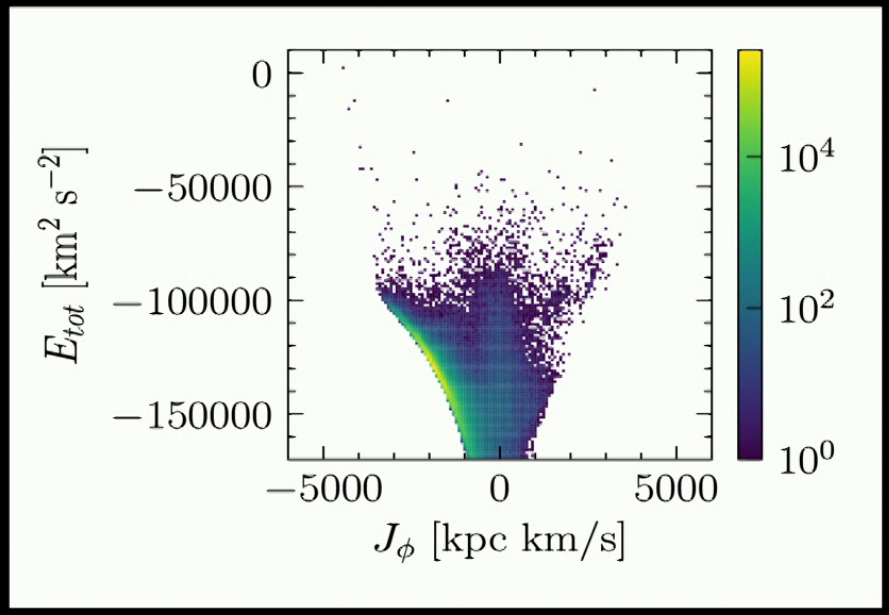
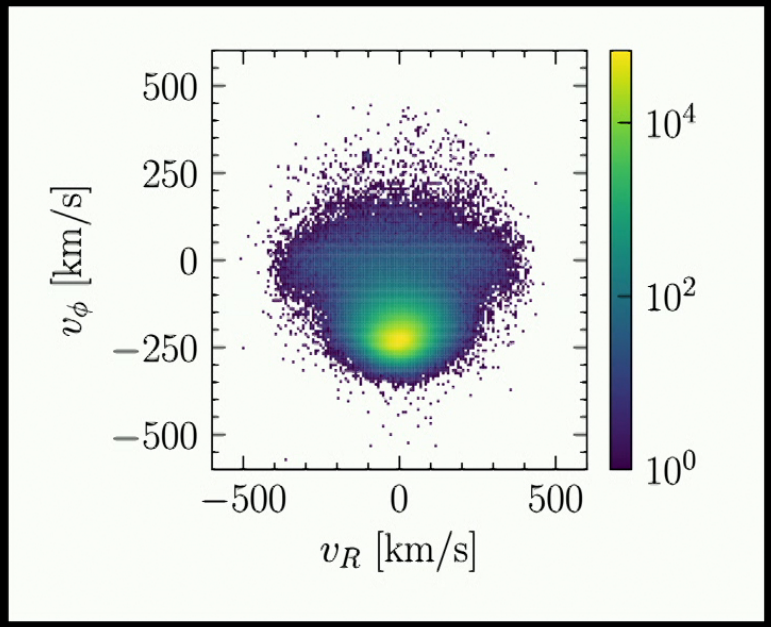
Stability of Clusters

Xiaowei Ou





- Gaia eDR3 proper motions
- Gaia DR2 radial velocities
- Quality cuts

Ou, **Necib** & Frebel (2022)

Stability of Clusters

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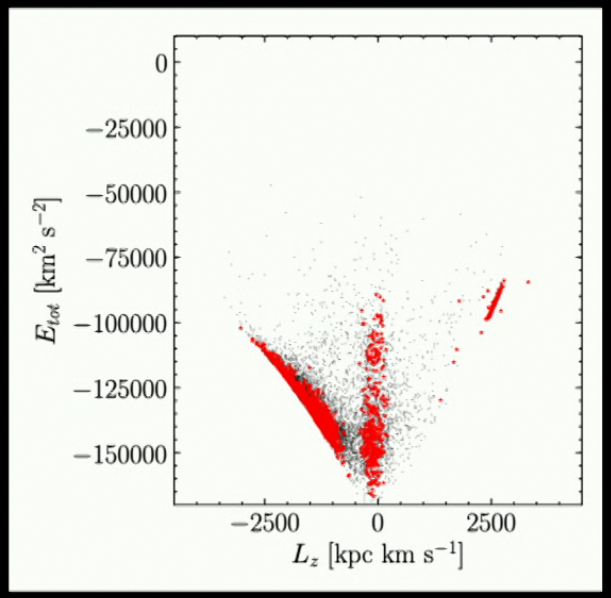

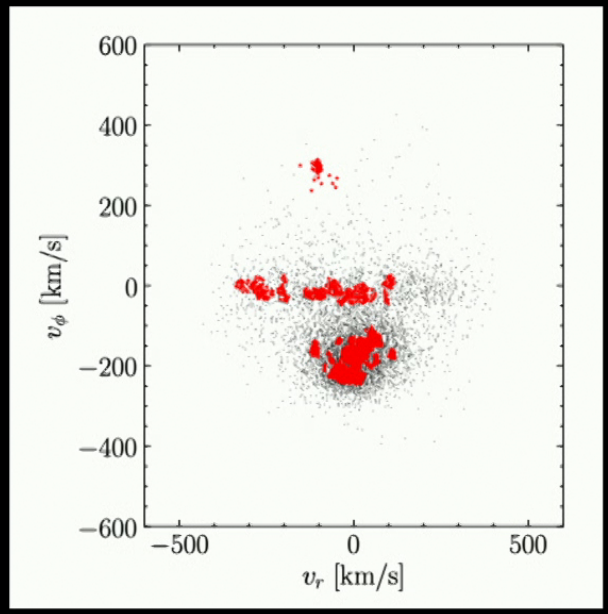

- Prioritized stable clusters.
- Looked at the stars that got clustered at least 40 times through 100 realizations. Dropped the stars always associated as noise.
- These structures are stable, although possibly incomplete.

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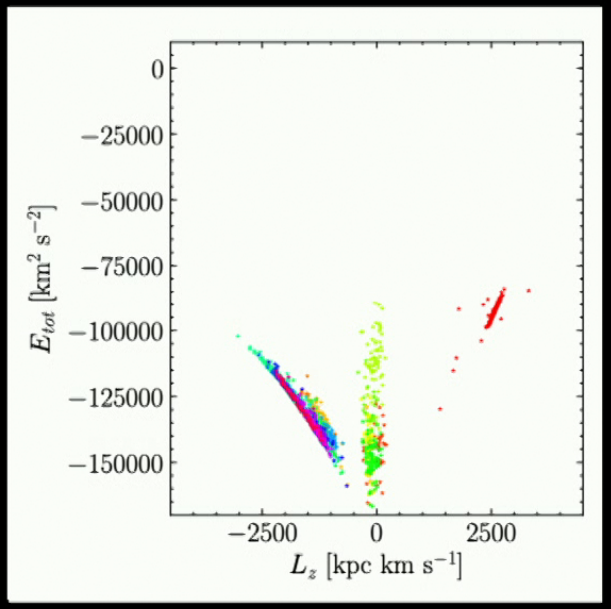
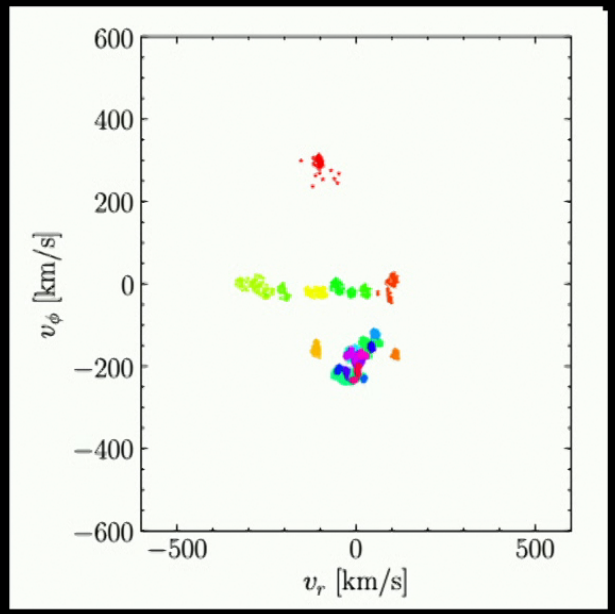
Stability of Clusters

Xiaowei Ou





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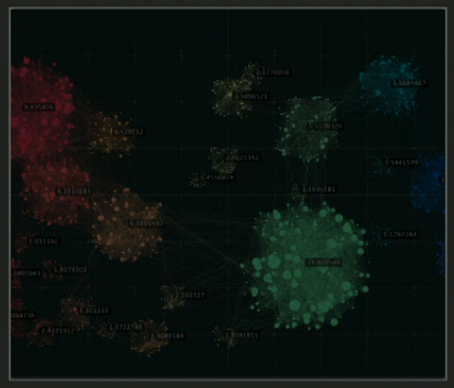
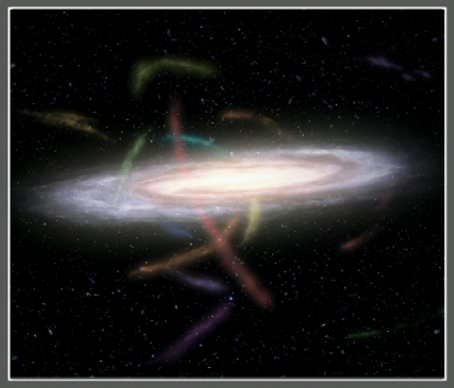


Cluster Local Stars



Build a Stream Finder Algorithm

Lina Necib, MIT

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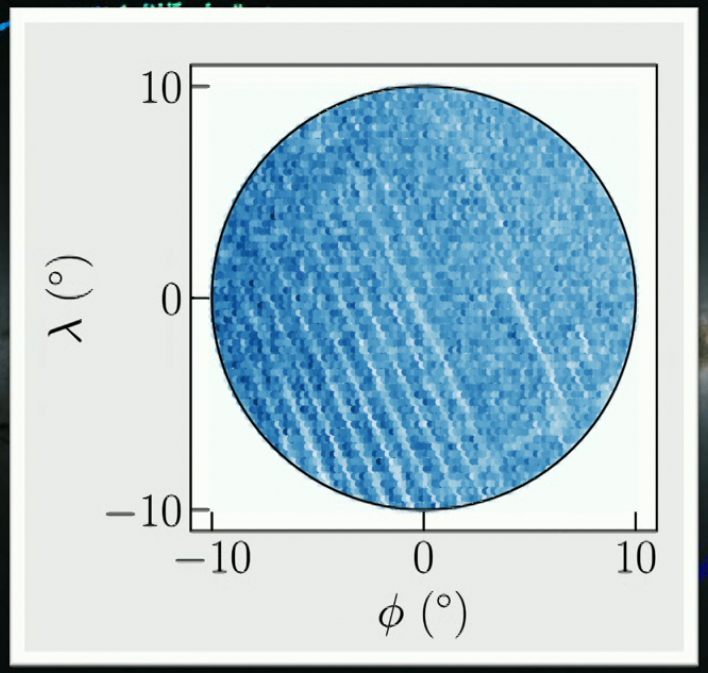
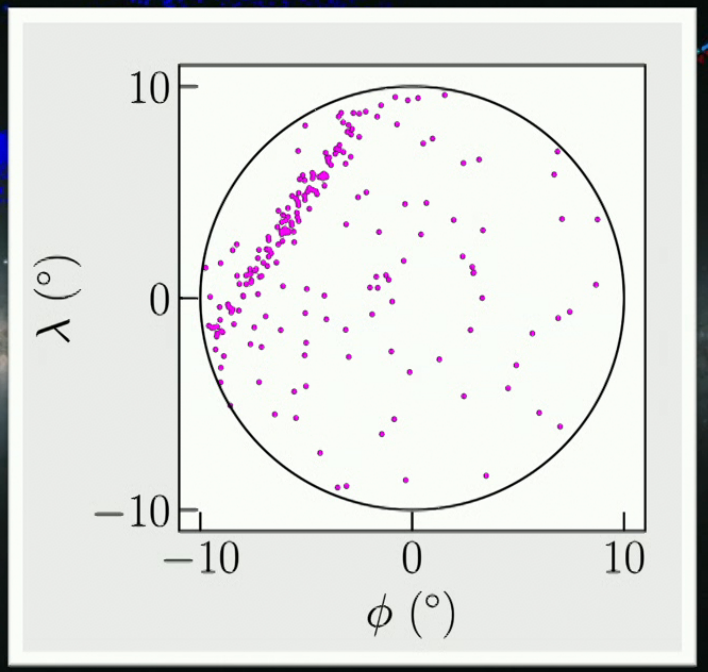


Via Machinae

A machine learning algorithm that searches for anomalies in a multi-dimensional distribution.

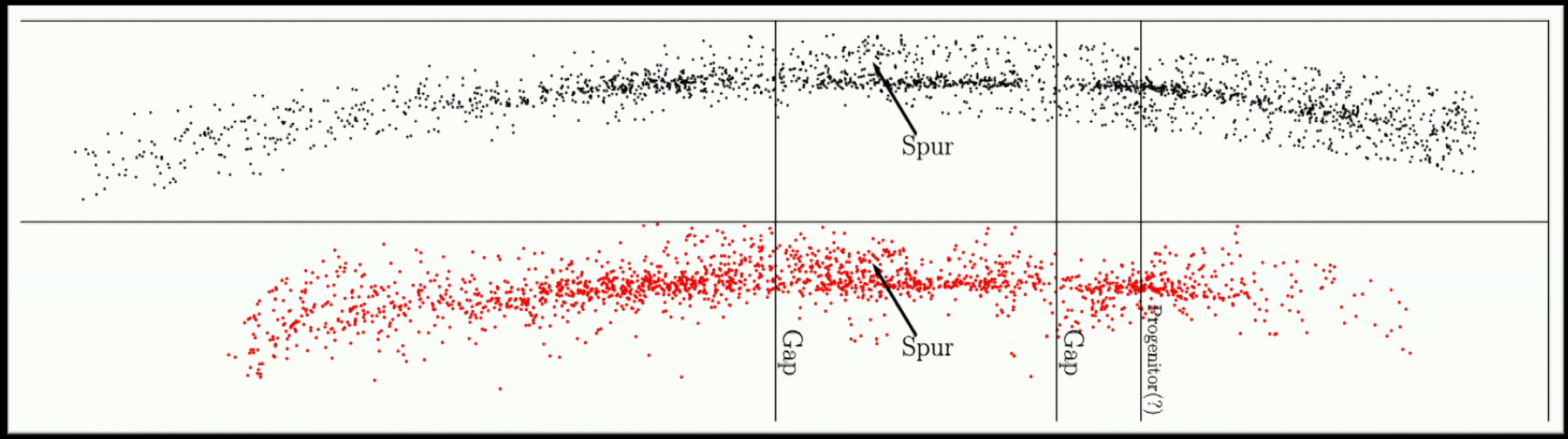


Gaia

Galaxy Picture
Credit : ESA/Gaia/DPAC
Stellar Streams
Malhan et al. (2018), Ibata et al. (2019)

Shih, Buckley, **Necib**, Tamanas (2021)

Apply Via Machinae on GD-1



Lina Necib, MIT

Shih, Buckley, **Necib**, Tamanas (2021)

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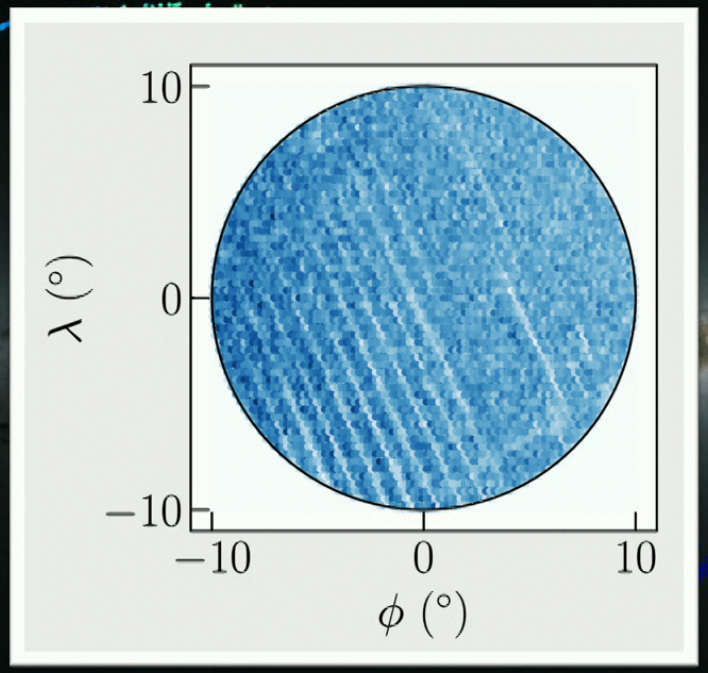

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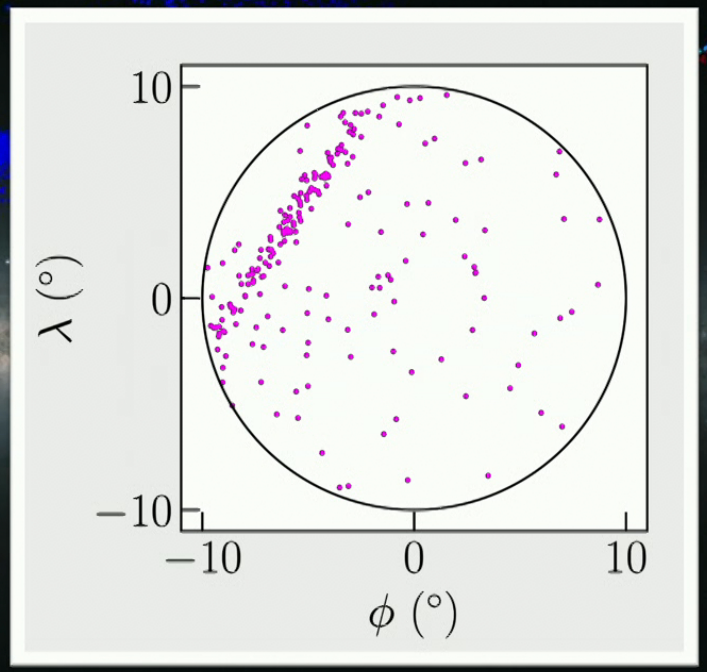

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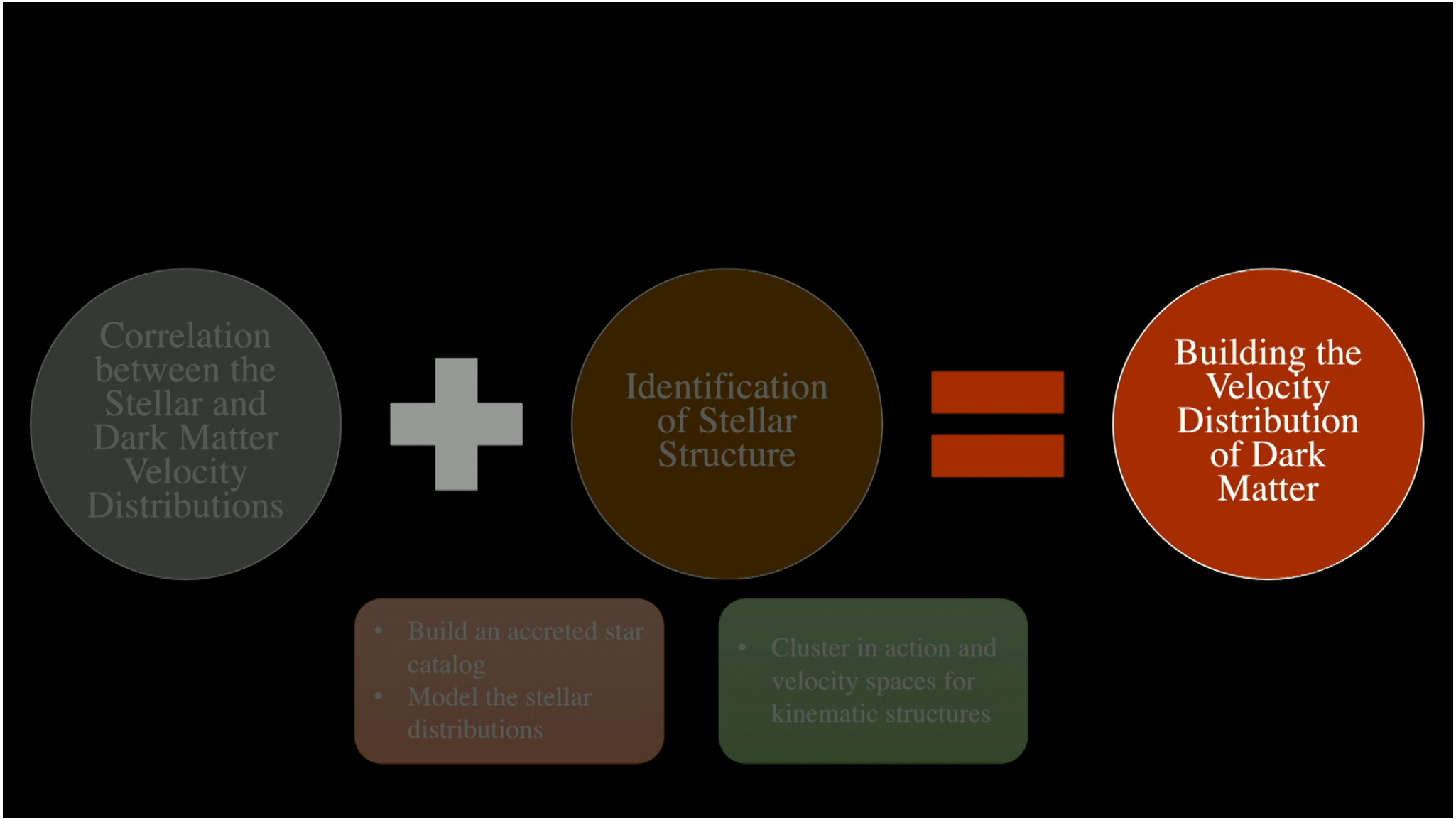
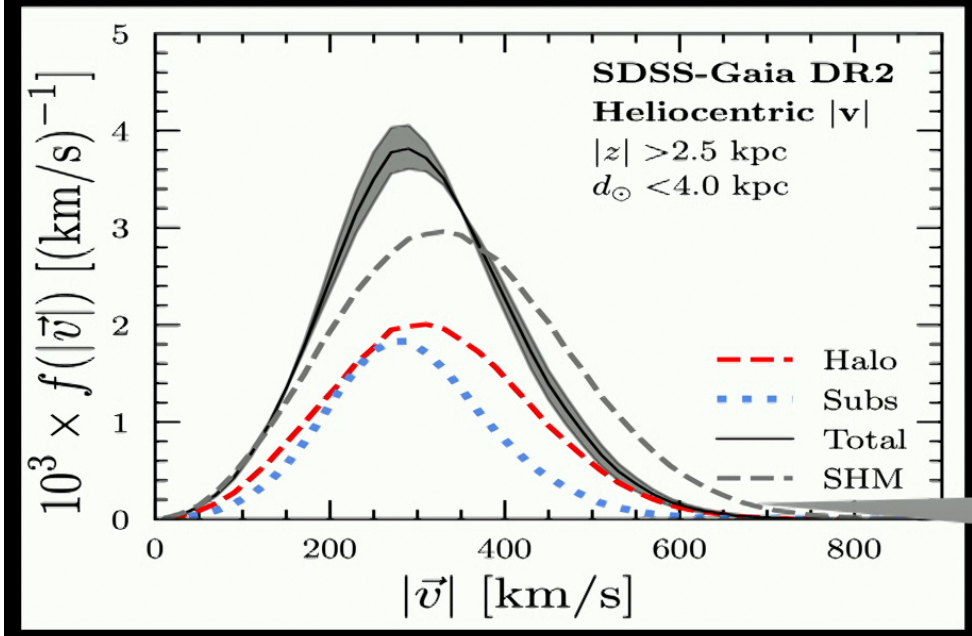

Correlation between the Stellar and Dark Matter Velocity Distributions
Identification of Stellar Structure
Building the Velocity Distribution of Dark Matter
• Build an accreted star catalog
• Model the stellar distributions
• Cluster in action and velocity spaces for kinematic structures

New Dark Matter Velocity Distribution

$$f_{\rm total}(v) = c_{\rm halo} f_{\rm halo}(v) + c_{\rm subs} f_{\rm subs}(v)$$



- Fraction Dark Matter ≠ Fraction Stars.
- Use Mass-Metallicity relation to estimate fractions.

$$c_{\rm subs} = 0.42^{+0.26}_{-0.22}$$

Final distribution different from the assumed Maxwell Boltzmann distribution

Kirby et al. (2013)
Garrison-Kimmel et al. (2015)
Necib, Lisanti, Belokurov (2018)
Necib, Lisanti, Garrison-Kimmel et al. (2018)