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Detecting the Milky Way Halo Structure and Sub-Structure with OPTICS

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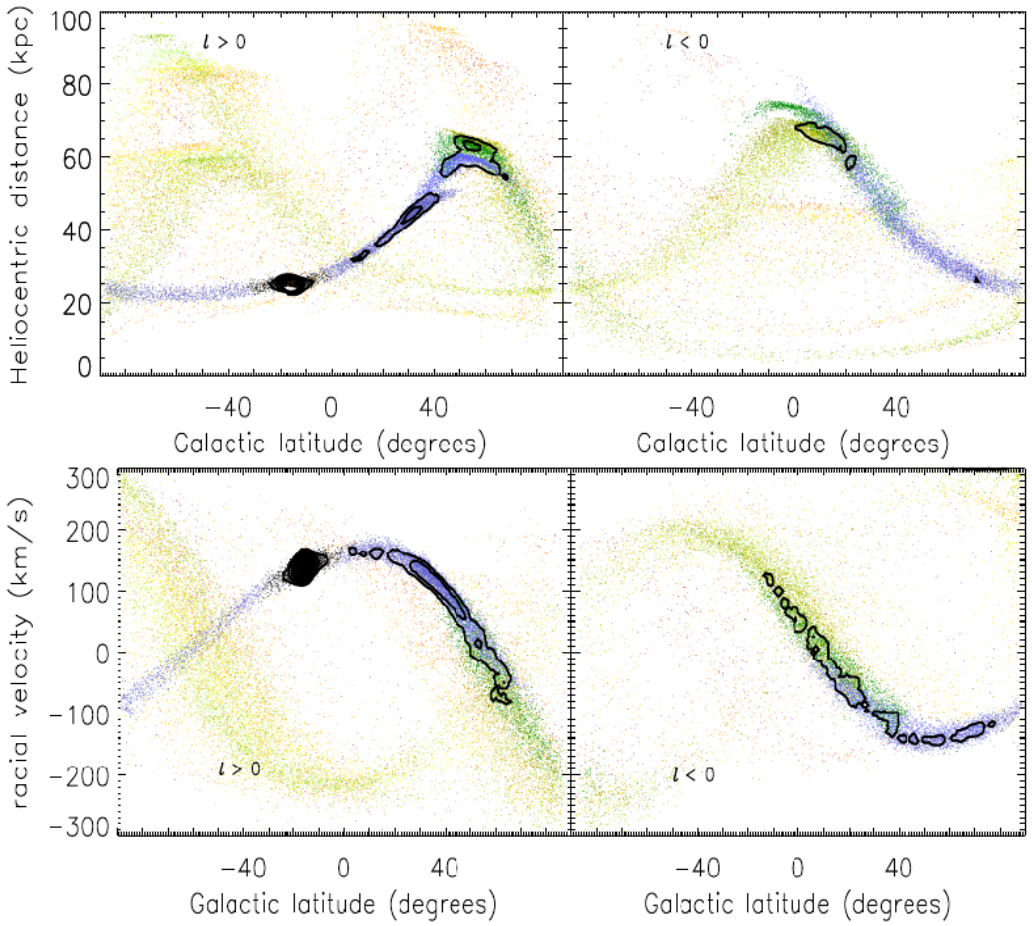
Stellar Halo Overdensities

- Λ-CDM framework indicate a hierarchical assembly of large galaxies.
- Mergers, tidal interactions, and disruptions create stellar streams and clouds
- The Stellar Halo some of the best preserved fossils of galactic formation
- Streams will appear as coherent structures in GAIA phase-space.



Phase-Space Distribution making up the Sagittarius Stream. (Helmi and White 2000)

Known Streams/Over-densities:
Aquarius, Monoceros, Sagittarius ,Magellanic Virgo, Pal 5, Ophiuchus, etc.

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Unsolved Questions

Primary questions:

- When was the Halo formed/ Is it still forming?
- How many objects have helped build up the Milky Way?
- What were the properties of accreted objects?
- What is the dynamical history of the Milky Way?

Gaia will give us the opportunity to:

- Exhaustively identify all tidal debris overdensities
- Quantify the number, size, and morphology of each over-density
- Take into account uncertainty ellipsoids of each star

Clustering algorithms to detect overdensities

- Many clustering algorithms available and applied to detect halo overdensities: e.g. Subfind, ROCKSTAR, and EnLink.

- Each has their own strengths and weaknesses, leading to slightly different results

- Wish list for an optimal algorithm:

    - Ability to detect overdensities against a non-uniform background
    - Ability to detect small-scale substructure in large-scale overdensities
    - Ability to detect non-convex streams and clouds
    - Scale independent
    - Time complexity suitable for large surveys
    - Comprehensive visualization of N-dimensional space

What is OPTICS?

Ordering **P**oints **T**o **I**dentify the **C**lustering **S**tructure (Ankerst et. 1999 ;Kriegel 2003)

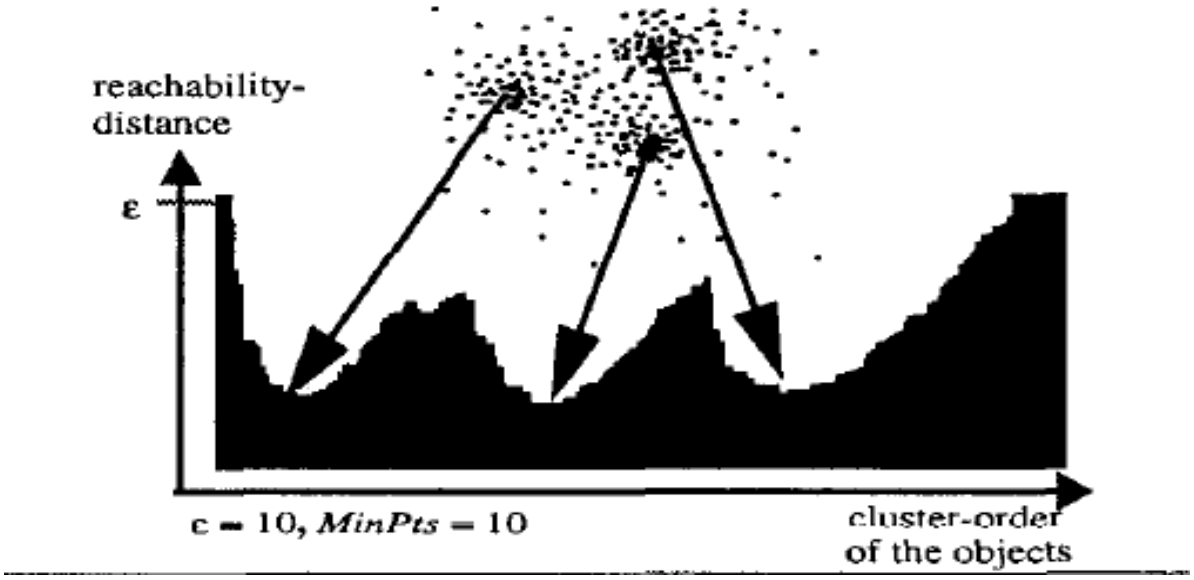
- Density-based clustering algorithm
- Successor to DBSCAN
- Only 1 configuration parameter. Robust results.
- Does not assign each star to an overdensity, but orders the stars: 1-D visualization of N Dimensions
- Optimized for the detection of overdensities and substructure against a non-uniform background

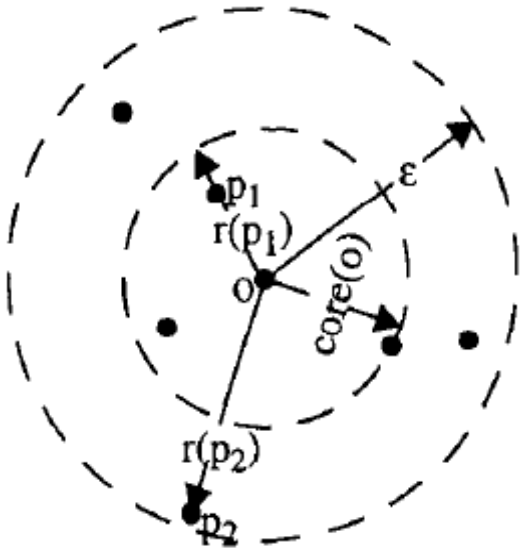
How does OPTICS work?

Min-Points (user-input) → Epsilon → Core Dist. → Reachability

If N* in Epsilon > Min Points:
Collect all “nearby” points and iterate

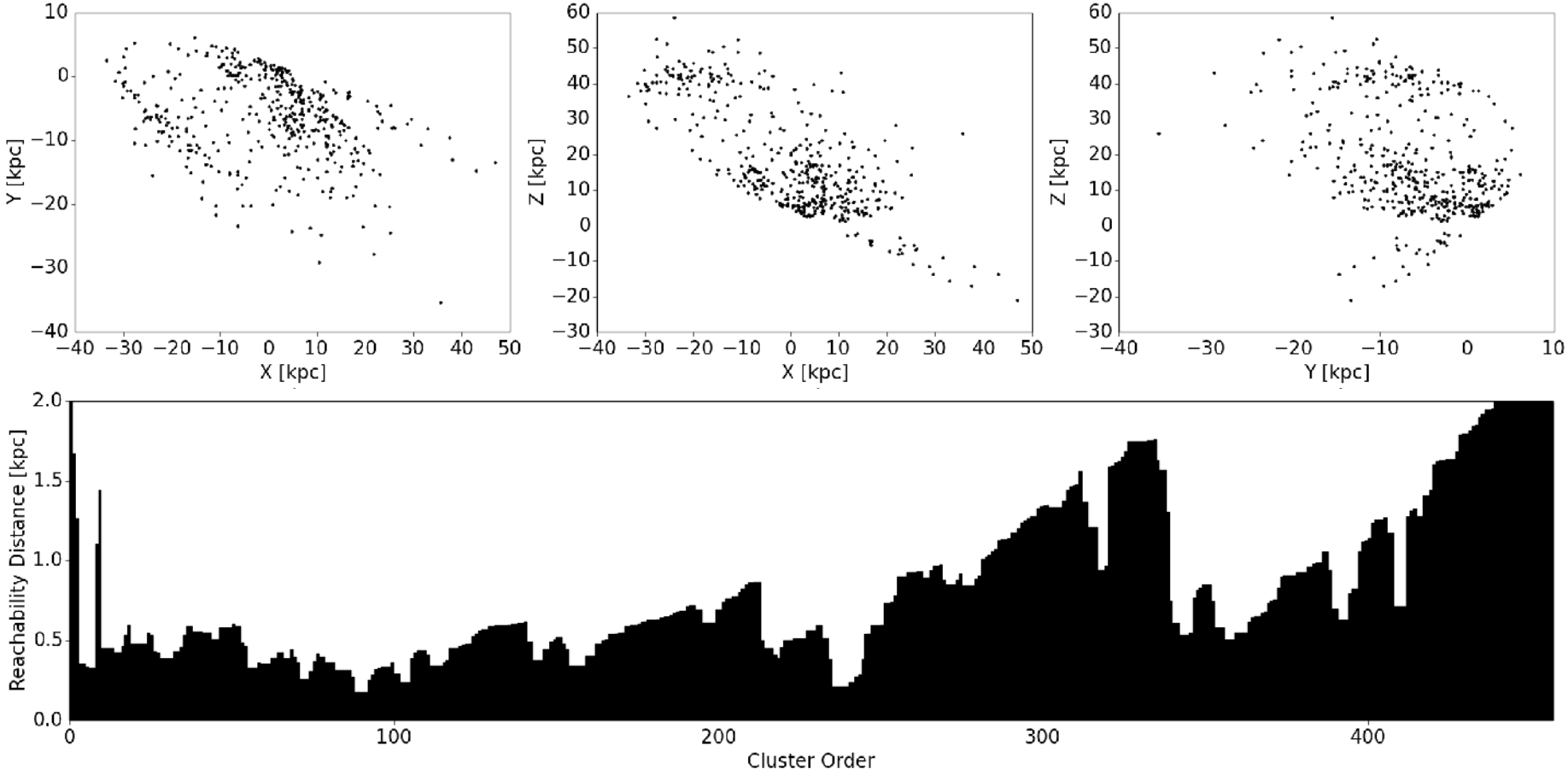
Clusters have high density, low reachability distances





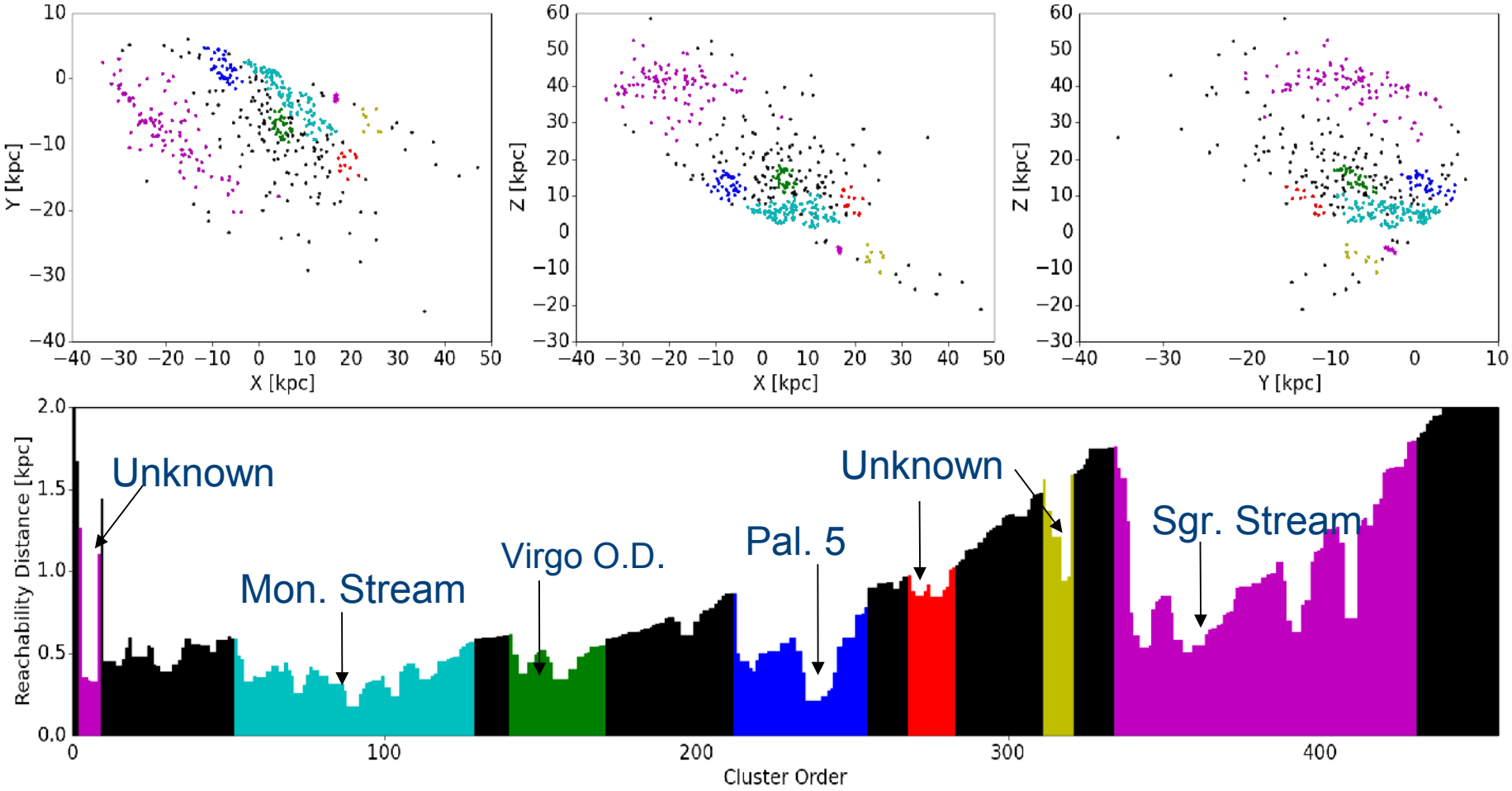
A First Application

QUEST RR Lyrae - Halo Overdensities (Vivas K.A. And Zinn R. 2006)



QUEST RR Lyr Halo Overdensities

Revisiting Vivas K.A. And Zinn R. 2006



Substructure becomes obvious, even in multi-D parameter space

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Future work: research questions

- How to determine the significance of an overdensity?
  or substructure, against a non-uniform background
- How to determine cluster membership significance?
- How to include the uncertainty ellipsoids of the stars?
  particularly relevant for the more distant halo
- How to improve the speed of the algorithm?
  Parallelization, incremetation …

Overall goals:

- Complete picture of number, size, and morphology of the streams and clouds in the inner halo of our Galaxy
- Constrain the gradient and anisotropy of the halo background

THANK YOU

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