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

S.A. Sans Fuentes and J. De Ridder
Institute of Astronomy, KU Leuven
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.

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

Phase-Space Distribution making up the Sagittarius Stream. (Helmi and White 2000)
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 Points To Identify the Clustering Structure (Ankerst et al. 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 → Epsilon → Core Dist. → Reachability

(user-input)

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)
Substructure becomes obvious, even in multi-D parameter space

QUEST RR Lyr Halo Overdensities
Revisiting Vivas K.A. And Zinn R. 2006
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, incrementation …

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