Galactic Archeology: Searching for Tidal Debris Streams with WFIRST

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Why are Stellar Debris Streams Interesting?

- Tidal streams closely follow the progenitor’s orbit.
  - $\Delta E/E < 1\%$ for globular clusters, $< 5\%$ for dwarf galaxies
  - debris streams therefore give us the shape of the progenitor’s orbit.
  - As fossil remnants, debris streams can be used to reconstruct the formation process of galaxies.
- In our own Galaxy, stars in debris streams can be used to accurately measure the exchange of potential and kinetic energy along an orbit.
  - Debris streams therefore provide the most sensitive available probes of the Galactic potential field.
  - Debris streams sample the Galactic halo potential over a range of otherwise inaccessible radii and quadrants
- The morphologies of debris streams tell us about their orbital histories
  - Heating and scattering by dark matter subhaloes
  - Orbital precession in non-spherical potentials
  - Dynamical friction
- Tidal streams may help us to understand gravity at very low accelerations.
Due to their proximity, MW halo streams are too extended and tenuous to be detected in integrated light.

- Surface densities of streams detected to date are of order 10-100 stars per square degree to g ~ 22.

Instead we use color-selected star counts, where signal-to-noise ratio goes roughly as $\frac{N_{\text{stream}}}{\sqrt{N_{\text{foreground}}}}$. This requires that we:

- select on a particular stellar population
- push as far down the stellar luminosity function as possible
- keep the photometric errors small, the color selection envelope narrow, and foreground contamination as low as possible

Advantage is that, once detected, we can measure positions and velocities for stream stars *much* more accurately than for any other galaxy.
# Known Halo Streams

Grillmair 2010

<table>
<thead>
<tr>
<th>Designation</th>
<th>Progenitor</th>
<th>Selected References</th>
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</thead>
<tbody>
<tr>
<td>NGC 5466</td>
<td>NGC 5466</td>
<td>Belokurov et al. 2006a, Grillmair &amp; Johnson 2006, Fellhauer 2007</td>
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<tr>
<td>Orphan Stream</td>
<td>Unknown (dwarf galaxy?)</td>
<td>Grillmair 2006a, Belokurov 2007, Fellhauer et al. 2007, Sales et al. 2008, Newberg et al. 2010</td>
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<tr>
<td>GD-1</td>
<td>Unknown (globular cluster?)</td>
<td>Grillmair &amp; Dionatos 2006b, Willet et al. 2009, Koposov, Rix, &amp; Hogg 2009</td>
</tr>
<tr>
<td>AntiCenter Stream</td>
<td>Unknown (dwarf galaxy?)</td>
<td>Grillmair 2006b, Grillmair, Carlin, &amp; Majewski 2008</td>
</tr>
<tr>
<td>EBS</td>
<td>Unknown (dwarf galaxy?)</td>
<td>Grillmair 2006, Grillmair, Carlin, &amp; Majewski 2008</td>
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<tr>
<td>Acheron</td>
<td>Unknown (globular cluster?)</td>
<td>Grillmair 2009</td>
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<td>Cocytos</td>
<td>Unknown (globular cluster?)</td>
<td>Grillmair 2009</td>
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<tr>
<td>Lethe</td>
<td>Unknown (globular cluster?)</td>
<td>Grillmair 2009</td>
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<tr>
<td>Styx</td>
<td>Bootes III dwarf?</td>
<td>Grillmair 2009</td>
</tr>
<tr>
<td>Cetus Polar Stream</td>
<td>NGC 5824?</td>
<td>Newberg, Yanny, &amp; Willett 2009</td>
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“Oh! what a tangled web we weave…”

(apol. to Sir Walter Scott)
Full 6-d phase space analysis of GD-1 has yielded the tightest constraint yet on $V_c$ (224 +/- 13 km/s) and the mass of the Galaxy.
Halo Lumpiness

Pal 5 – evidence of dark matter subhalos?

Stream morphologies may favor many hundreds of $\sim 10^7$ $M_\odot$ subhalos.
Streams with WFIRST?
Optimal Matched Filtering

- majority of power comes from main sequence turn-off and below.
Isolating Stellar Populations

SDSS

WISE

$g - i$

$W1 - W2$
Euclid Photometry
Euclid Photometry
RR Lyrae

3643 RR Lyrae from single epoch SDSS colors.

With an appropriate observing cadence, WFIRST could detect RR Lyrae out to 2 Mpc using variability signatures.

S/N per stream would necessarily be low, but corresponding distance estimates will be crucial.

Ivezic et al. 2005
Conclusions

- WFIRST will go extremely deep, sampling nearly all stars within 25 kpc, turn-off stars out to 300 kpc, and giant stars throughout the Local Group.

- WFIRST can explore the more highly extincted regions near the Galactic plane, though constrained by limited WFIRST population discrimination and/or the reach of visible light photometry.

- Depending on observing cadence, WFIRST could detect many thousands of remote RR Lyrae.

-- combining WFIRST and LSST photometry would improve S/N of streams and substructures in the Galactic halo by a factor of ~2 compared with LSST alone.
Sagittarius dSph cont’d

All-sky view of 2MASS M giant star distribution

Majewski et al. 2003