The Detailed Substructure of the Milky Way: Stellar Streams: DECam Imaging of the Eastern Banded Structure

Collaborators
Beth Willman (Haverford)
Brian Kimmig (Haverford)
Nelson Caldwell (Harvard/CfA)
Matt Walker (Carnegie Mellon)
Jay Strader (Michigan State)
David Sand (Texas Tech)
Carl Grillmair (Caltech/IPAC)
Joo Heon Yoon (UCSB)
Ross Fadely (NYU)

Jonathan R. Hargis
Haverford College
@jrh_astro

CMD filtered and smoothed surface density map of the EBS region (data from Grillmair 2011)
What can stellar streams tell us about the Milky Way in a cosmological context?

Streams trace the hierarchical nature of galaxy formation and the assembly of the Galactic halo

- Stream orbits probe the Galactic potential out to large galactocentric radii
- Identifying stream progenitors informs our understanding of the relative contribution of various objects to the halo’s formation
- Spatial morphology of streams may contain signatures of the numerous dark subhalos predicted by LCDM

LCDM simulation of a Milky Way-like galaxy showing the stellar streams created from tidal destruction of accreted dwarf galaxies (Bullock & Johnston 2005)
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What are the progenitors of the known stellar streams? How do dwarfs and globular clusters contribute to halo assembly?

At present: Only ~3 stellar streams have known progenitors. Most streams have no identifiable progenitor.

Numerical simulations of subhalo + stream encounters in Pal 5 by Yoon et al. (2011)
The Eastern Banded Structure (EBS)

Filtered and smoothed surface density maps from Grillmair (2011)

Photometry:
DECam gri
1080 s per pointing

Spectroscopy of Hydra I:
MMT + Hectochelle
700 MSTO stars
[selected from SDSS!]
RV errors < 5 km/s

Filtered and smoothed surface density maps from Grillmair (2011)
DECam Data Analysis and Photometric Calibration

NOAO CP Image Reduction
  +
Python/DAOPHOT photometry pipeline

Calibrate each image directly to SDSS using ML analysis:
  → Color terms + ZPs for each image
  → Only (g-r) < 1

Examine residuals as a function of magnitude, color, focal plane position, chip

What We Learned:
  • Reject low S/N SDSS stars
  • Use well-measured DECam point sources
    → Should mitigate brighter/fatter in the calibration...?
DECam Photometric Calibration

1) Quality cut the raw photometry
2) Match these to SDSS
3) Reject outliers to increase robustness of calibration
Color-Magnitude Diagram: **Hydra I region**

**DECam (180 s exposure)**

-0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1

**g - i (mag)**

17 18 19 20 21 22 23

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**SDSS**

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DECam (180 s exposure)  
SDSS
Results: **Chemo-Dynamic Properties**

Histogram of Hectochelle velocities

→ **Minimize thick disk contamination** by removing $g < 19$

→ **N = 187 stars in faint sample**

Velocity versus radius from Hydra I center

→ **Membership probabilities**

determined using EM algorithm
(Walker et al. 2009)
Results: **Chemo-Dynamic Properties**

Histogram of [Fe/H] values from SDSS/SEGUE spectra

→ $[\text{Fe/H}] = -0.93 \pm 0.03$
→ Four stars with $[\text{Fe/H}] < -1.5$ are likely contaminants
Results: Stellar Populations

- **DECam + Hectochelle Members**
  - 5.5 Gyr [Fe/H] = -0.9 [a/Fe] = 0.2
  - 80% Spectroscopic Members

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Observed rotation in Hectochelle sample of stars with $P_m > 50\%$.

→ **Before** removing photometric contaminates: $8 \pm 2$ km/s

→ **After** removing photometric contaminates: $3 \pm 2$ km/s
Results: **Spatial Distribution of MSTO Stars**

Selection of MSTO stars with $g-r$ errors consistent with isochrone

Spatial position of MSTO stars (red) compared to spatial distribution of all point-sources
What is Hydra I?
Three Hypotheses...

Star Cluster
If a globular cluster, we expect:
- Old age (10–13 Gyr)
- $-2 < [\text{Fe/H}] < -0.5$
If an open cluster, we expect
- Young age ($< \sim 2$ Gyr)
- $-0.5 < [\text{Fe/H}] < 0.2$

Dwarf Galaxy
From mass-metallicity relation: progenitor would have been a Fornax-like dwarf
- Implies significant (>99.99%) mass loss

Substructure in the Monoceros Ring
EBS/Hydra could simply be part of the large Monoceros Ring complex

Age-[Fe/H] diagram for Milky Way globular (red, black) and open (green) clusters. Data from Dotter et al. 2011, Dias et al. 2014.
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Stellar mass versus [Fe/H] for Local Group dwarf galaxies (Kirby et al. 2013)
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*Star count map of MSTO stars from Pan-STARRS1 (Slater et al. 2014). In the top panel, color indicates distance. The EBS stream is labeled as feature B in the bottom panel.*
The Milky Way affords us the chance to study halo substructure in great detail. Much remains unknown about stream progenitors!

**The properties of Hydra I:**
- No rotation at the few km/s level
- Stellar pops as young as \(~6\) Gyr
- \([\text{Fe/H}] = -0.93 \pm 0.03\)

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**What To Take Away:**

**Future Work:**
- Attempt CMD foreground subtraction to disentangle Hydra I from MRi region
- Artificial star test to improve star-galaxy separation; quantify completeness
- Detailed analysis of stream substructure using spatial maps
- Simulate observations of stream gaps/clumps to test for statistical significance