Proper Motion Measurements in Dwarf Galaxies of the Milky Way

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Milky Way Satellites

Why Proper Motion?
Orbit
Infall time
MW tidal influence
LMC connection?
Kinematics/Mass Profile

Figure courtesy of Alex Drlica-Wagner
Gaia DR2 - Proper Motions of Satellites

Systemic Proper Motions

Helmi, Gaia Collaboration+ 2018
Gaia DR2 - Proper Motions of Satellites

- Cross match spectroscopic sample to Gaia DR2.
- Derive systemic proper motion from members.
- May be biased due to small sample sizes.

Blue: Members
Red: Non-Members

Simon 2018
see also Fritz+ 2018a, b
Probabilistic Mixture Model

- Goal: Measure proper motion of all (or as many as possible) DES satellites.
- DES photometry + Gaia Astrometry
- Mixture model with satellite and MW foreground components
- Uses position and proper motion data
- Uses all Gaia stars within field-of-view.

\[ \mathcal{L} = (1 - f_{\text{MW}}) \mathcal{L}_{\text{satellite}} + f_{\text{MW}} \mathcal{L}_{\text{MW}} \]

\[ \mathcal{L}_{\text{satellite/MW}} = \mathcal{L}_{\text{spatial}} \mathcal{L}_{\text{PM}} \]

**Positions**

- \( \Delta \delta \) (deg)
- \( \Delta \alpha \) (deg)

**Proper Motion**

- \( \mu_\delta \) (mas yr\(^{-1}\))
- \( \mu_\alpha \cos \delta \) (mas yr\(^{-1}\))

**CMD**

- \( g - r \)
- \( r \)

Pace & Li 2019
Mixture Model Proper Motions

Phoenix II

Tucana IV

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Need radial velocities to confirm association.

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What’s Next in Proper Motions

What is the distribution of dark matter in Dwarf Galaxies?

![Graph showing log-slope vs. log-slope with annotations for Cusp and Core regions.](image)

Projections: Strigari+ 2007

Tangential Dispersions in Sculptor
HST+Gaia DR1 measurement: Massari+ 2017

However, velocities are not precise enough to measure core/cusp (Strigari+ 2018)
What’s Next in Proper Motions

Gaia DR2

Ursa Minor (D=76 kpc)

Spectroscopic Members only
Average proper motion error in km/s in ‘bright’ magnitude bins

\[ \bar{\varepsilon} = 36 \text{ km s}^{-1} \]
\[ \bar{\varepsilon} = 64 \text{ km s}^{-1} \]

Sculptor (D=84 kpc)

\[ \bar{\varepsilon} = 70 \text{ km s}^{-1} \]
\[ \bar{\varepsilon} = 105 \text{ km s}^{-1} \]
Sagittarius dSph

Sagittarius is nearby (D=26.3 kpc)
Close to Galactic plane (b~ -14)
Massive dSph (Mstar > 10^7)
Undergoing tidal disruption

Proper Motion errors are ‘small’

Solid lines are proper motion dispersion measurement
Sgr Tangential Dispersion Profile

Central region (los, pmra, pmdec directions)

Apogee ~ 300 stars in 1 degree

Frinchaboy+ 2012, ~1000 stars within ~ 8 degrees

Extended (corrected for geometry, Sgr x,y,z)
Resolved Tangential Dispersion Profile
MSE and Gaia

![Diagrams showing LOS velocity dispersion and DM density](image-url)
Conclusions

- We constructed a mixture model in spatial positions and proper motion using DES photometry and Gaia astrometry to measure systemic proper motions for MW satellites in the DES footprint.
- Recovered proper motion of 6 satellites with spectroscopic followup and measured the systemic proper motion for 7 additional satellites.
- Two are possible LMC satellites (Eridanus III, Phoenix II) and Eridanus III, Pictor I, and Phoenix II are consistent with membership in the vast polar structure. Confirmation for both requires radial velocity followup.

- The tangential velocity dispersion of the Sagittarius dwarf spheroidal galaxy is measurable in Gaia DR2.
- We have cross matched to several spectroscopic surveys for 3D velocities
- We find $\sigma_{(pmra/pmdec)} \sim 10-20$ km/s (smaller in the center).
Thanks
Metallicity w/ Color-Color Diagram

![Metallicity plots with Color-Color Diagram](image)
Metallicity w/ Color-Color Diagram

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Mixture Model Proper Motions

Columba I

Grus II

Pictor I

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Mixture Model Proper Motions

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