Dynamical Histories of the Crater II and Hercules Dwarf Galaxies

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Overview

Crater II and Hercules are both structurally peculiar galaxies that have been speculated to be tidally stripped by the Milky Way Galaxy. We present a multi-faceted investigation of these hypotheses using **spectroscopic** and **astrometric** data, as well as results from **theoretical** studies of the tidal evolution of dwarf galaxies.

For Crater II, we determine that binary stars do not affect its measured velocity dispersion. We find that **both galaxies may have experienced tidal interactions with the Milky Way**. Using results from theoretical studies on tidal evolution, we infer possible progenitors of each galaxy.

Methods

Calcium-triplet line spectroscopy with Magellan/IMACS

- Target stars within 15' of Cra II to determine whether binary stars affect observed velocity dispersion
- Target stars in extratidal densities around Hercules (Roderick et al. 2015); detection of members would be evidence of tidal stripping

Orbit Modeling Using *Gaia* DR2 proper motions

- Monte Carlo simulation of pericenter distribution

Inference of possible progenitor analogs using tidal evolution tracks for cored and cusped dwarf galaxies (Peñarrubia et al. 2008, Errani et al. 2015)

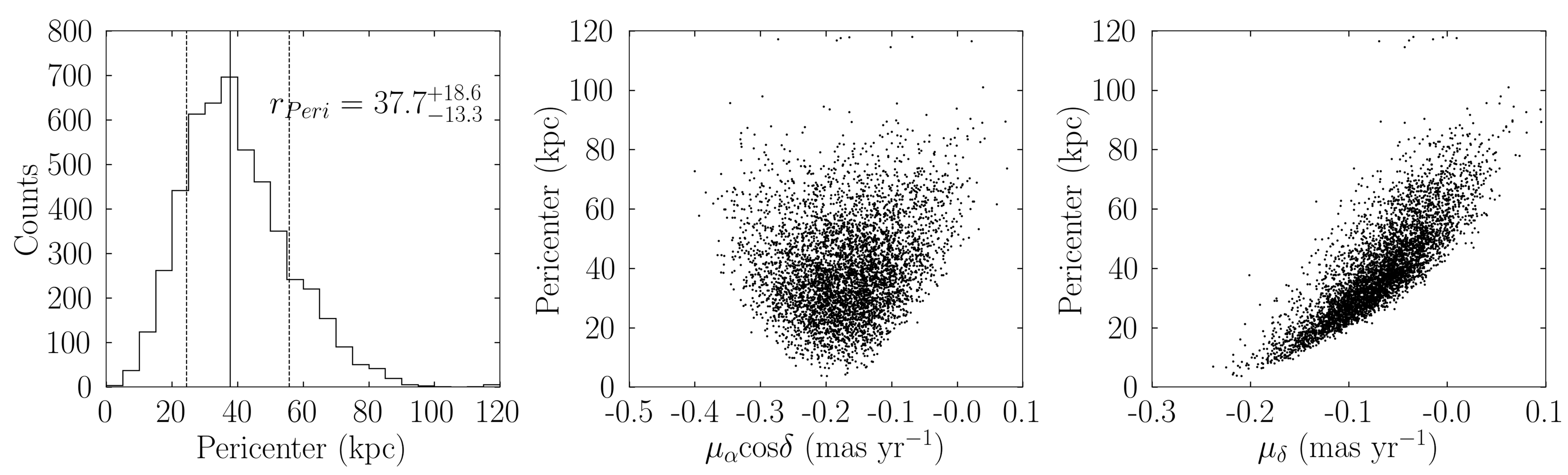
Crater II

Spectroscopic Results:

- Vlos = 87.4 ± 0.6 km/s; σ_{Vlos} = 2.7 ± 0.5 km/s
- [Fe/H] = -1.95 ± 0.6; $\sigma_{[Fe/H]}$ = 0.18 ± 0.6 dex

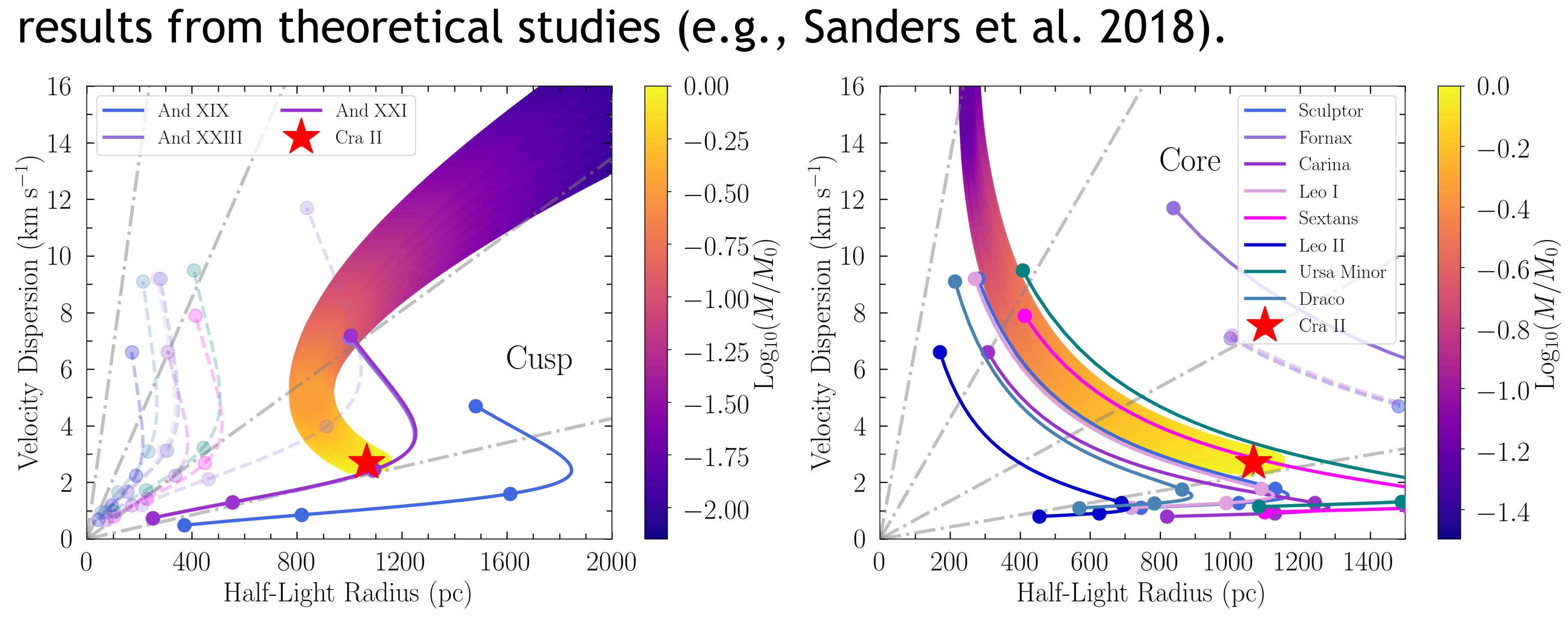
25 of the 37 Cra II members identified in our study overlap with members from Caldwell et al. (2017), providing a binary time baseline of 2 years. We identify 3 binary candidates, and verify that their presence does not change the measured velocity dispersion of Cra II at all. We confirm that Cra II resides in a cold dark matter halo.

Orbital Monte Carlo Results: We calculate that the tidal radius of Cra II even at its present-day position of 118 kpc from the Galactic Center is on the order of the dwarf's half-light radius ($r_{tidal}/r_{h,\text{ Cra II}} \sim 1.5$). Thus, stars could be stripped from Cra II even at its current location.



(Left) Pericenter distribution from Monte Carlo simulation. Lines correspond to the 16th, 50th, and 84th percentiles. (Center, Right) Correlation of pericenter distance with proper motion in RA and Dec directions, respectively.

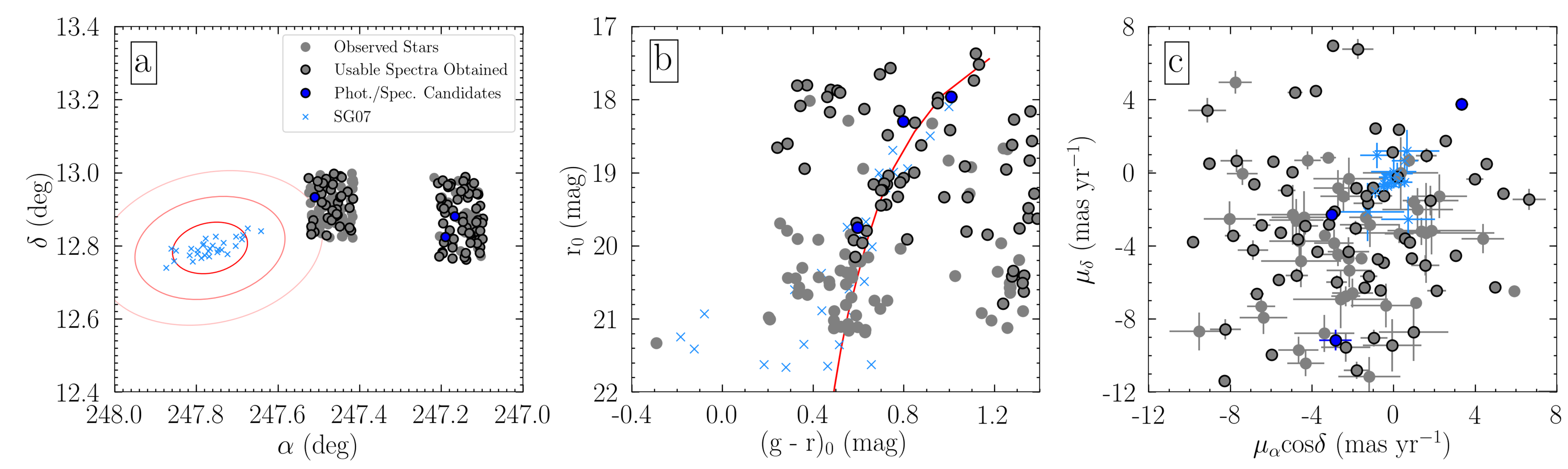
Tidal Evolution Track Results: If the progenitor of Cra II had a cuspy halo, Cra II could have descended from an object similar to the 3 largest M31 satellites. If the progenitor instead had a cored halo, Cra II may have descended from an object similar to MW dSphs, which is consistent with results from RR Lyrae studies of the dwarf (e.g., Joo et al. 2018). All cases are consistent with Cra II having lost >50% of its stellar mass, confirming results from theoretical studies (e.g., Sanders et al. 2018).



Inference of possible Cra II progenitors. Colored swaths show possible progenitor space, where color corresponds to the fraction of initial mass lost Cra II. Dash-dotted lines correspond to lines of constant density. Dots on individual evolution tracks correspond to consecutive 90% mass loss. (Left) Cusped progenitor case. (Right) Cored progenitor case.

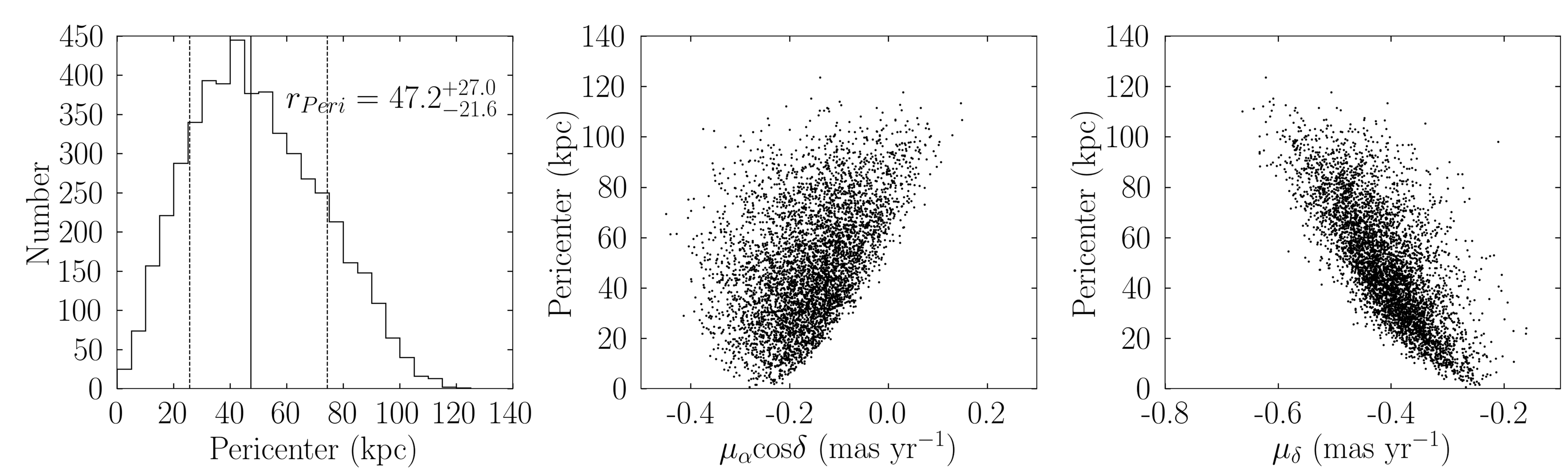
Hercules

Spectroscopic Results: We did not find red giant branch (RGB) stars associated with Hercules. However, we cannot rule out the existence of fainter RGB or main sequence stars in these overdensities.



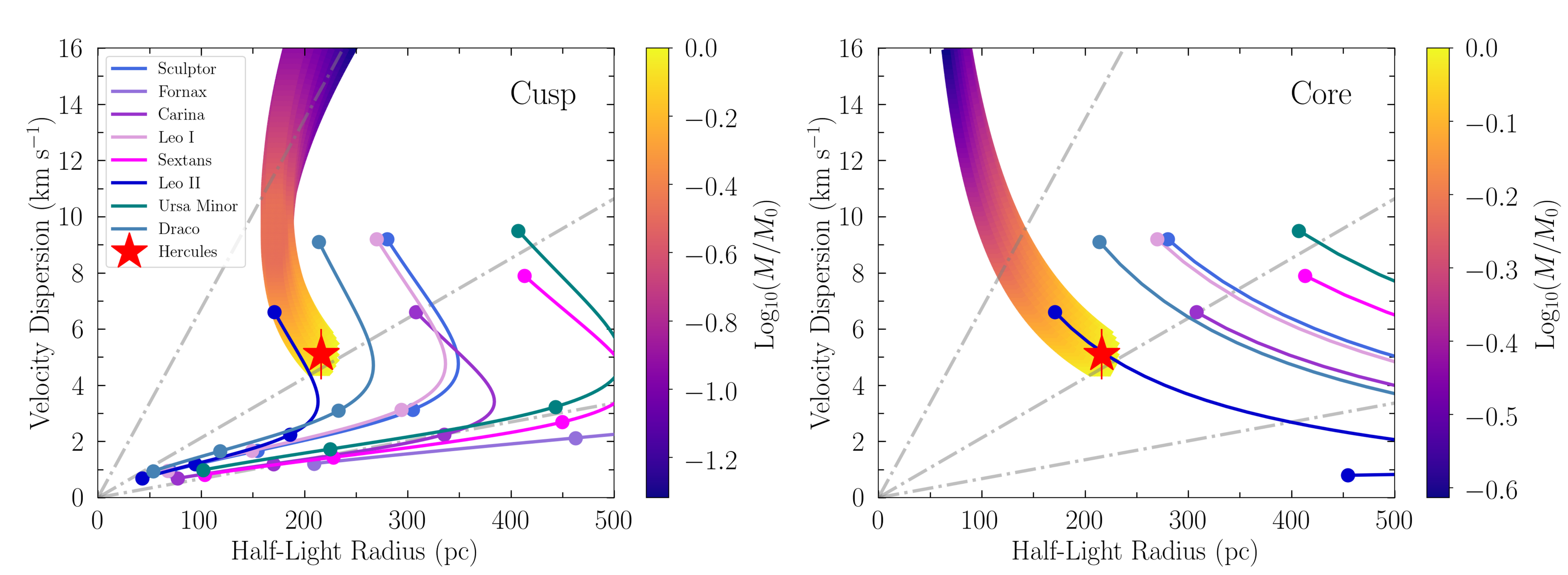
(Left) On-sky plot of our targets. Red ellipses correspond to 1, 2, and 3 times the half-light radius of Hercules. (Center) CMD of our targets. The red line is the M92 fiducial sequence. (Right) Proper motions of spectroscopic targets. We find three RGB stars (dark blue points) in the Roderick et al. (2015) extratidal densities OD13.2 and OD16, whose photometry and velocity are consistent with Hercules membership, but whose proper motions demonstrate them to be Milky Way foreground stars.

Orbital Monte Carlo Results: We determine that Hercules must come within 40 kpc of the Galactic Center to be tidally stripped. 40% of our simulated orbits have pericenter distances less than 40 kpc. Thus, it is possible that Hercules has been tidally stripped by the Milky Way.



(Left) Pericenter distribution from Monte Carlo simulation. Lines correspond to the 16th, 50th, and 84th percentiles. (Center, Right) Correlation of pericenter distance with proper motion in RA and Dec directions, respectively.

Tidal Evolution Track Results: For both the cored and cuspy progenitor cases, Leo II is a possible analog to the progenitor of Hercules.



Inference of possible Hercules progenitors. Colored swaths show possible progenitor space, where color corresponds to the fraction of initial mass lost to reach the position of Hercules. Dash-dotted lines correspond to lines of constant density. Dots on individual evolution tracks correspond to consecutive 90% mass loss. (Left) Cusped progenitor case. (Right) Cored progenitor case.

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