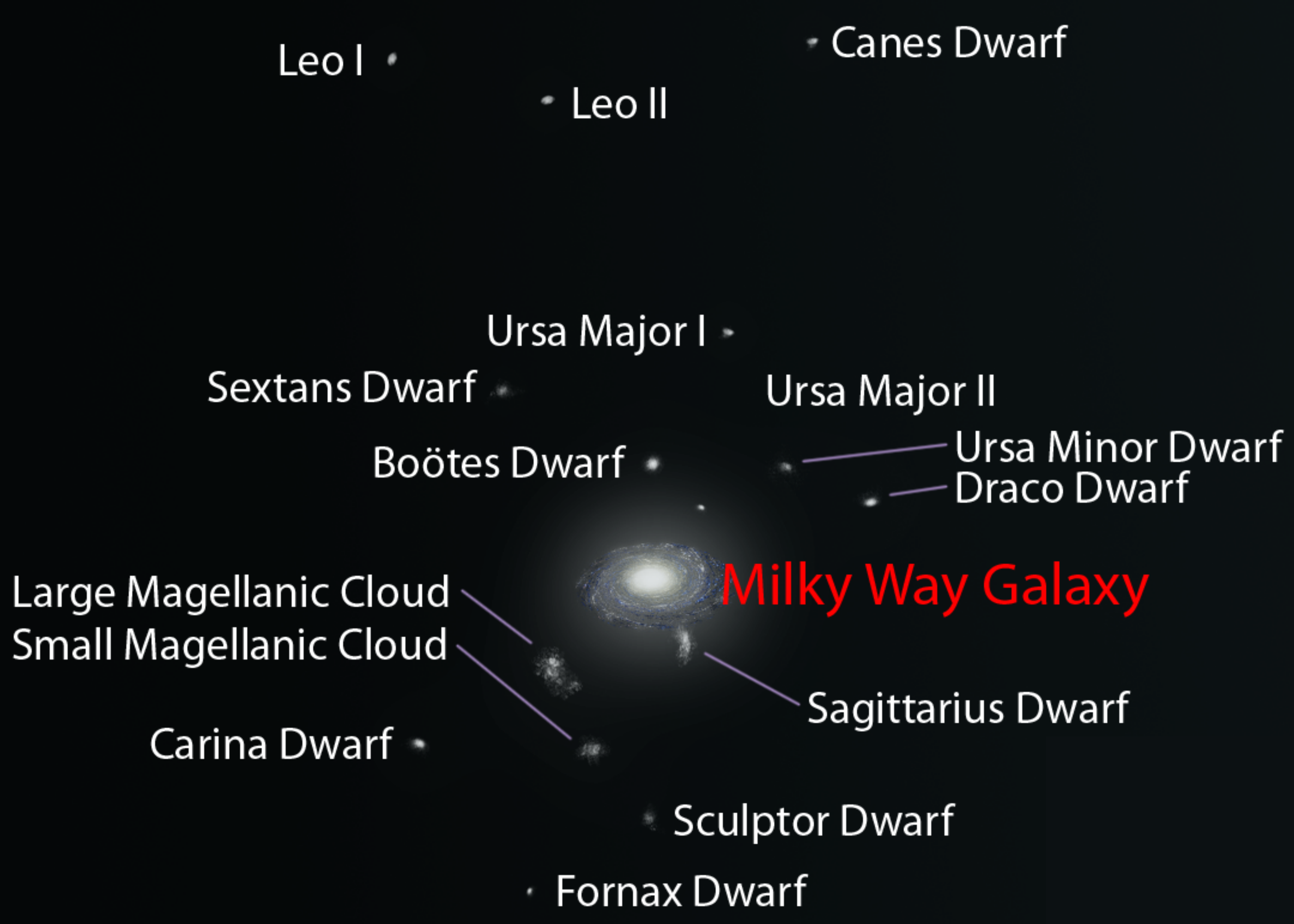
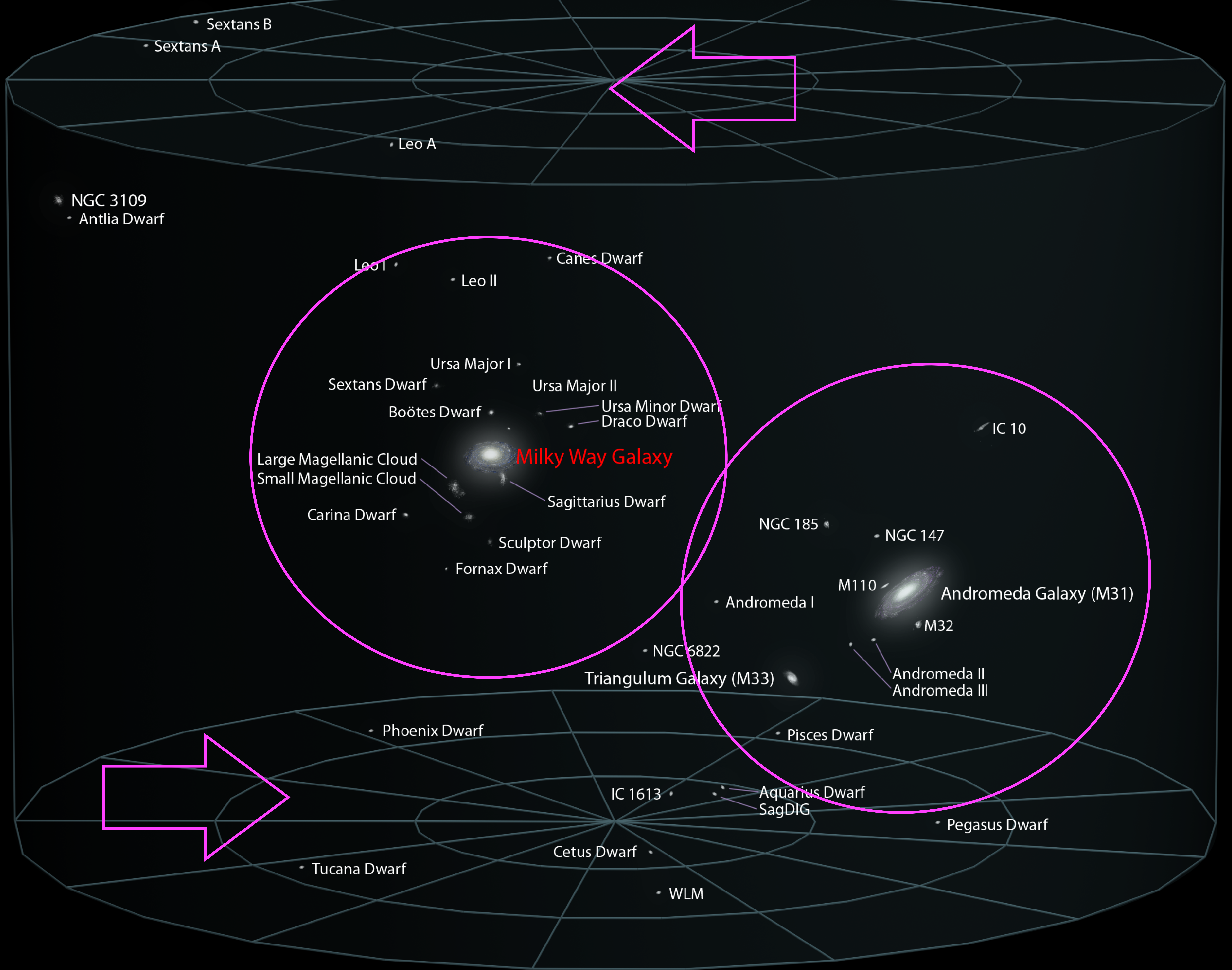
PROPER MOTIONS BEYOND THE MILKY WAY

S. Tony Sohn (STScI) and HSTPROMO Collaboration

The Milky Way



The Local Group



The Local Group

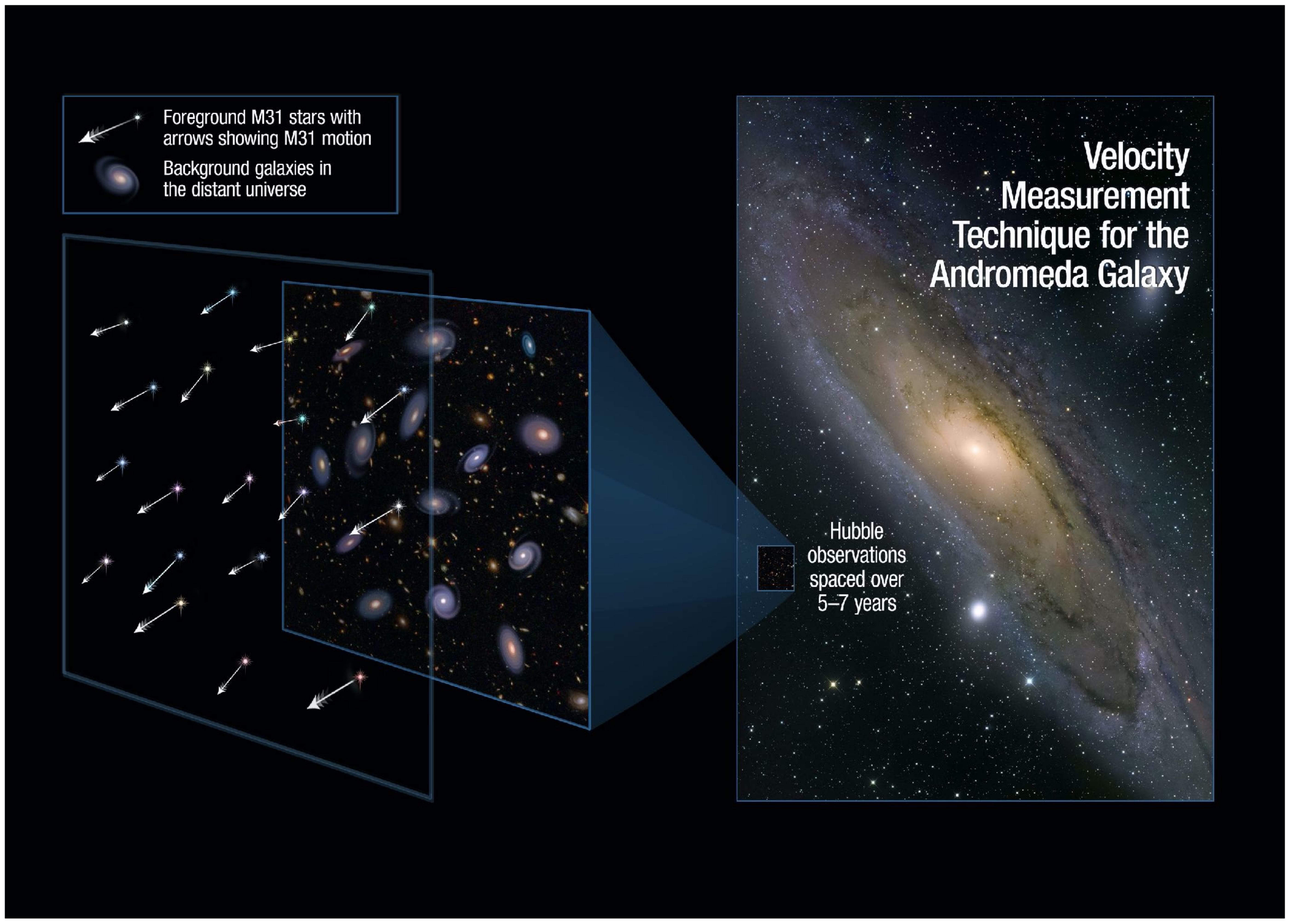
WHY PROPER MOTIONS OF GALAXIES?

- Direct measure of V_{tan} (+V_{rad} = $V_{3\text{-}D}$)
- Important for fundamental properties (e.g., zero-velocity radius, total mass of the Local Group, fate of merger, etc)
- Unavailable for the majority of Local Group galaxies

HOW?

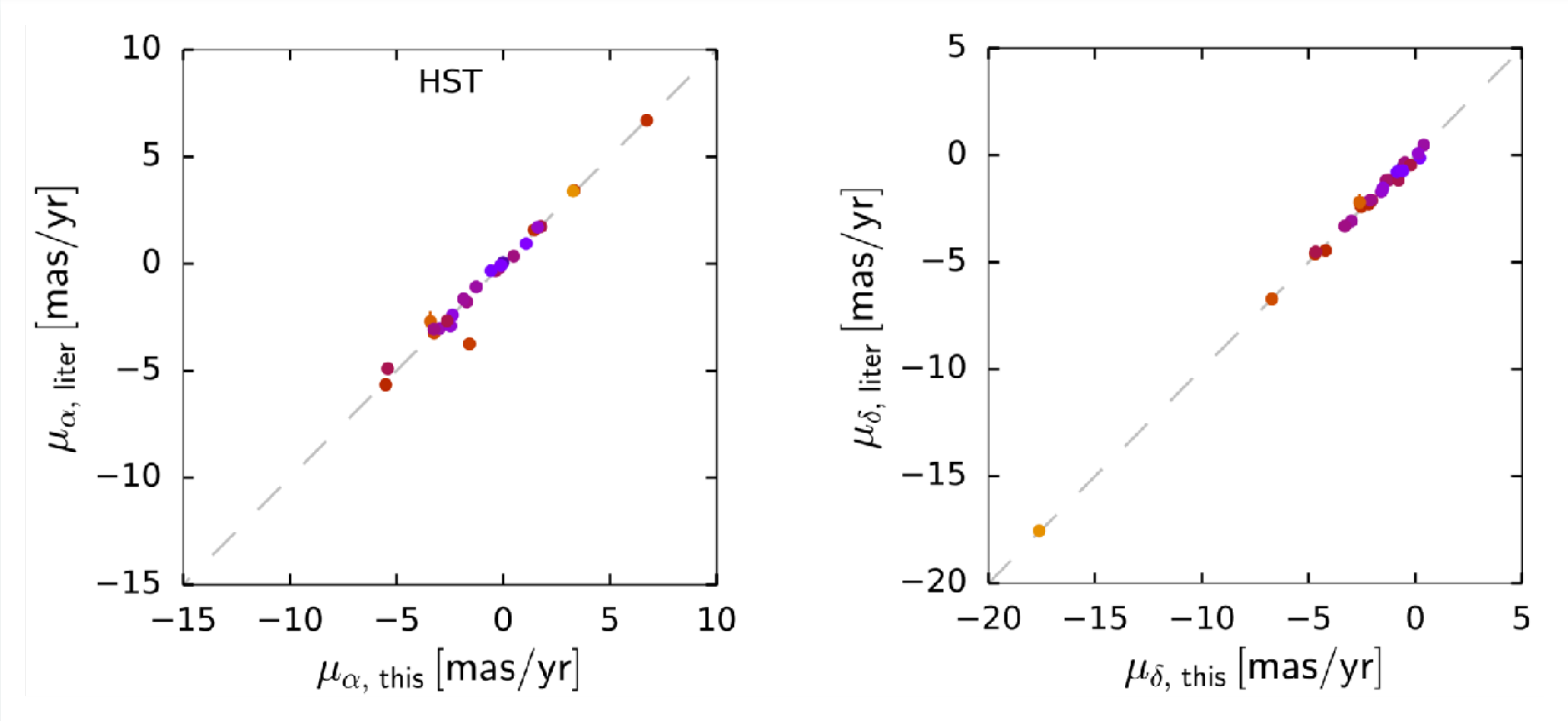
- Difficult to measure due to tiny motions (require μas/yr level accuracies: e.g., at 1 Mpc, 20 km/s ≃ 4 μas/yr)
- Successfully measured with space-based high-resolution telescopes (HST and Gaia)
- Gaia can only measure stars down to V~21 ➔ distances limited mostly to within the MW halo
- HST vs. HST/JWST/NGRST (will) allow PMs for all known LG galaxies

Measurement Techniques



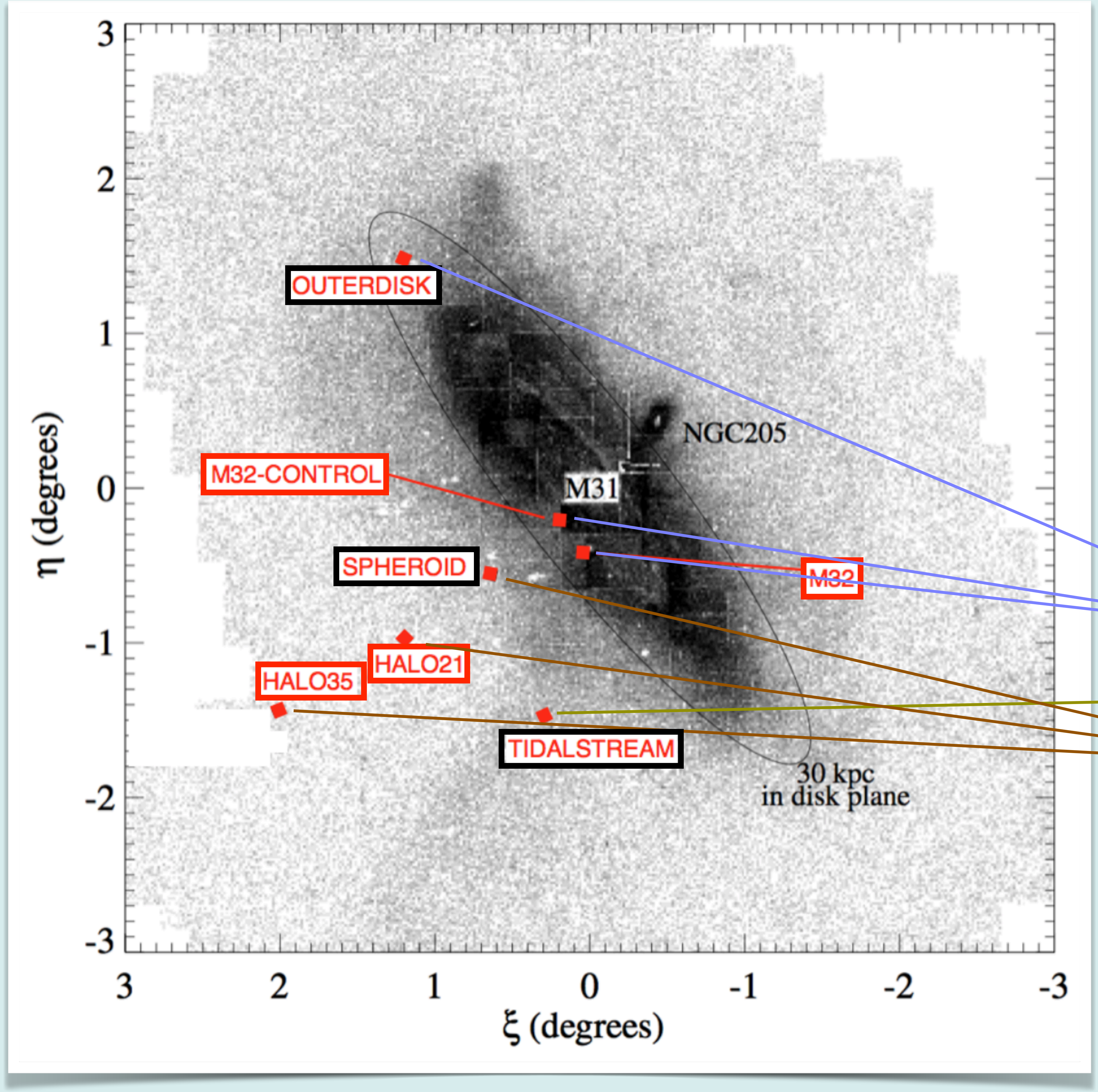
HST PM MEASUREMENTS

- Measure displacements of foreground (M31) stars against background galaxies in distant universe over time
- Established method. Numerous successful measurements:
  - First M31 proper motion (2012)
  - Dwarf galaxies & globular clusters in the MW halo
  - Individual stars in stellar streams
  - Satellites of M31 (Sohn+2020)
- Gaia vs. HST proper motions show excellent agreement



Vasiliev (2019) - 27 MW Globular Clusters

M31 Proper Motion - New HST Program

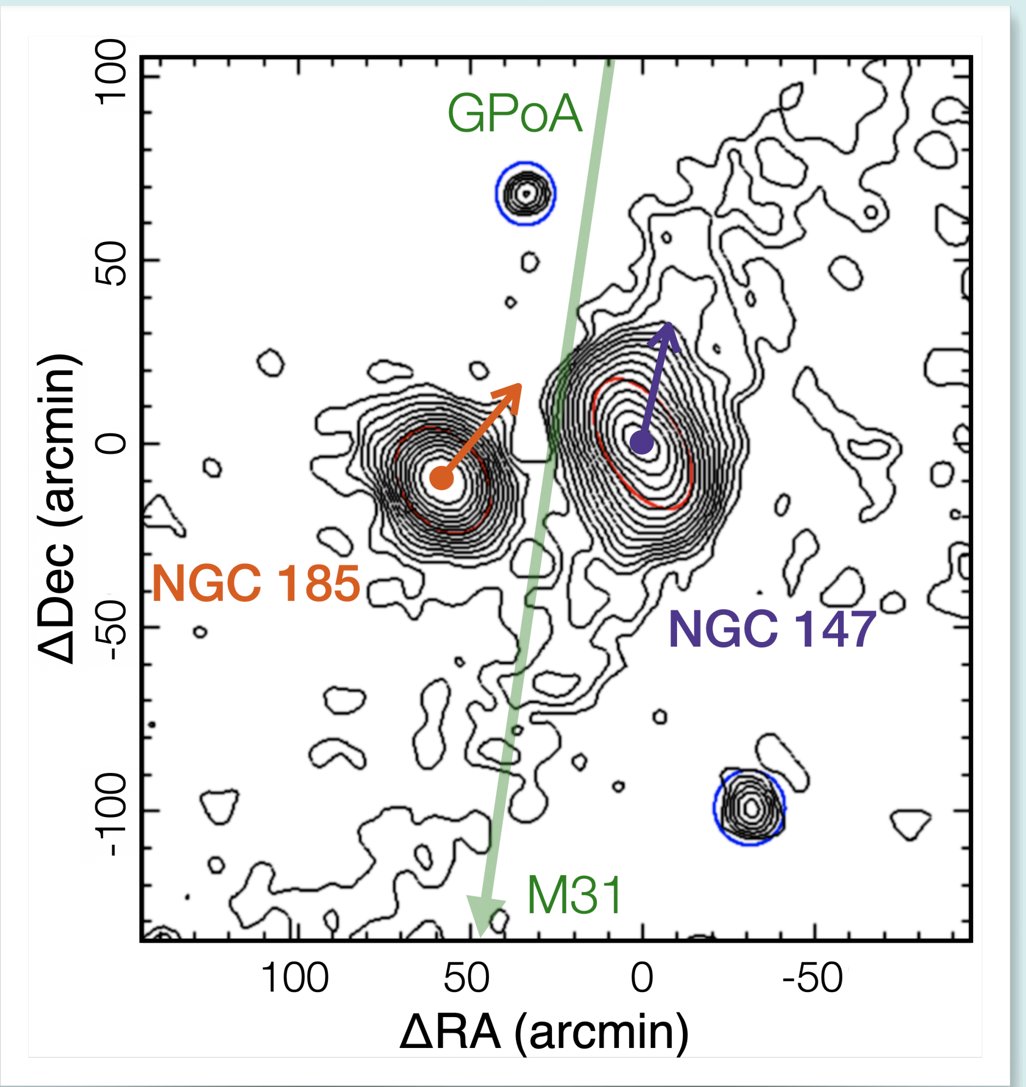


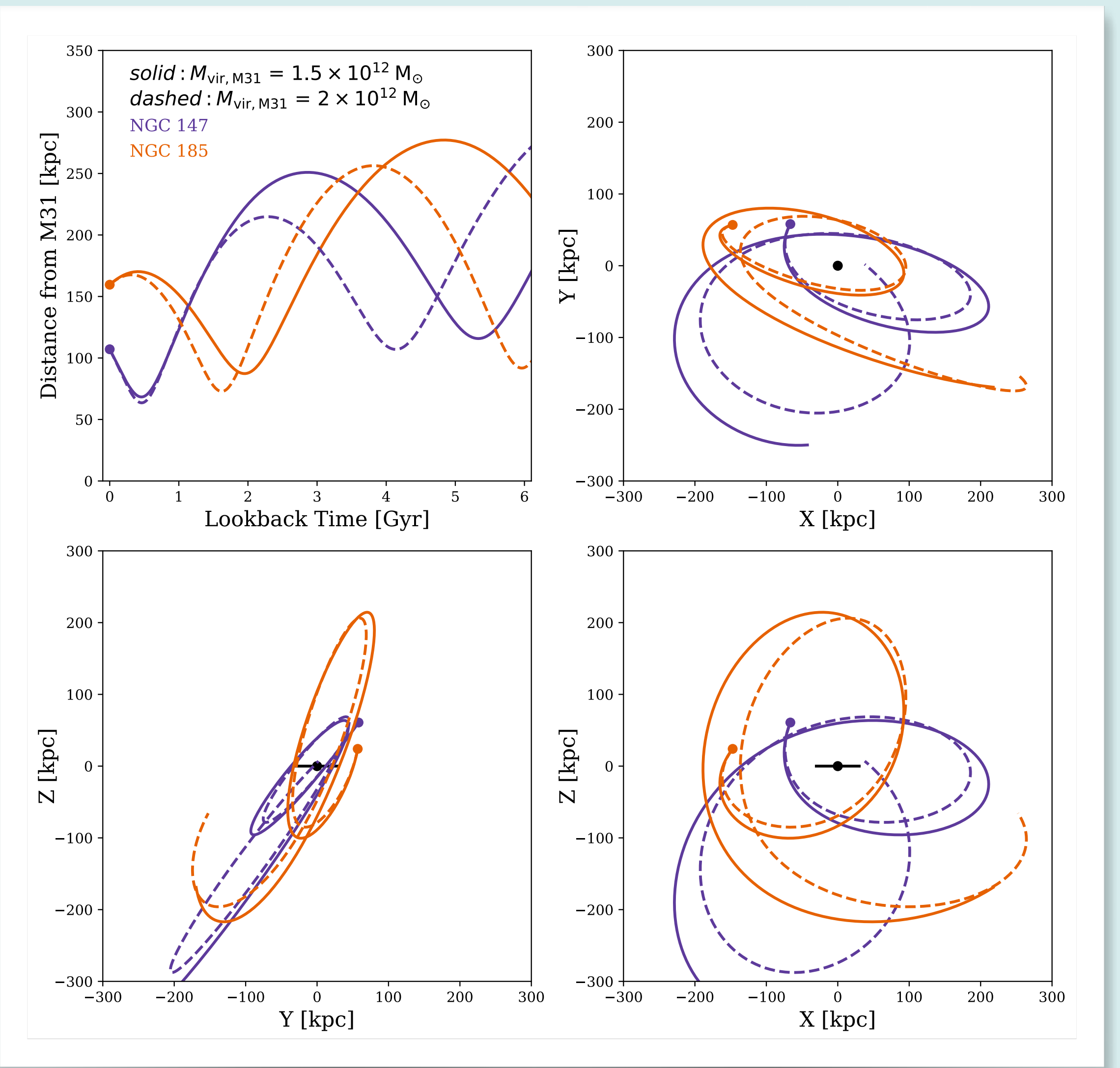
HST PROGRAM GO-15658 (PI: SOHN)

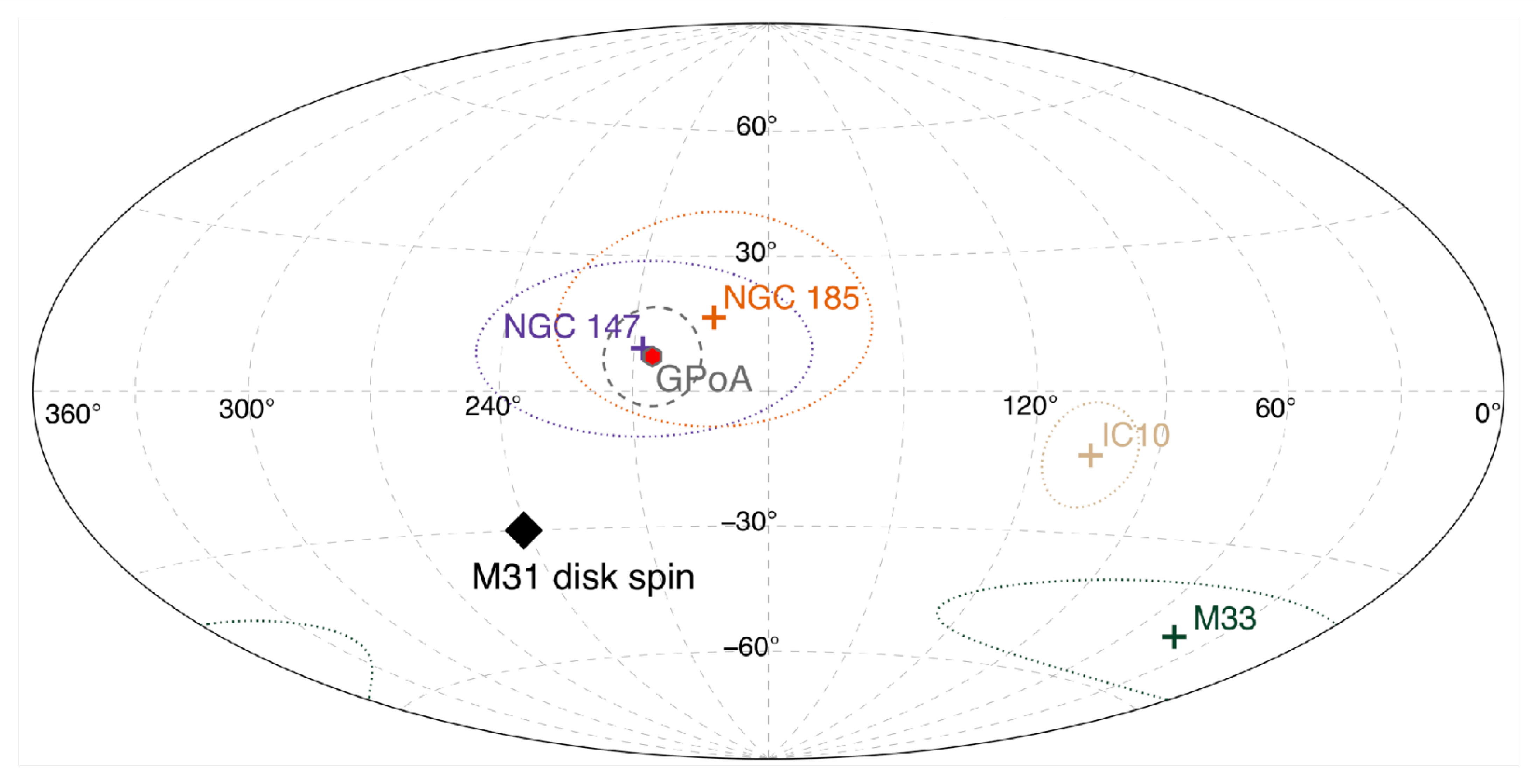
- Target fields = 7
- Time baseline = 13~17 years
- Expected center-of-mass PM uncertainty ≲ 12 km/s (Sohn in prep., 2022)
- "Resolved" proper motions
  - → Disk rotation
  - → Origin of Giant Stellar Stream
  - → Tangential velocity dispersion profile (11, 21, 35 kpc)
- The first proper motion of M32 (Fardal in prep., 2022)
  → M32's role of shaping the M31 halo

PMs of M31 Satellites – NGC 147 & 185

- Sohn, Patel, et al. (2020)
- Proper motions of NGC 147 and 185 with 40-50 km/s uncertainties
- 2-D motions show NGC 147's motion aligned with tidal tails + GPoA
- Orbital integrations:
  - NGC 147 just passed pericenter ~0.3-0.4 Gyr ago → Tidal tails
  - NGC 185 near apocenter → no tails
- Orbital poles imply both consistent with rotating along the plane







PMs of M31 Satellites

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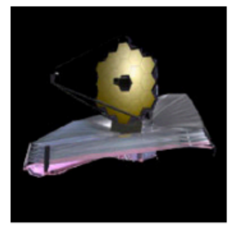
Andromeda and the Seven Dwarfs: M31 Mass, Satellite Orbits, and the Nature of the Satellite Plane

JWST Proposal 1305 (Created: Friday, July 15, 2022 at 12:00:11 PM Eastern Standard Time) - Overview



1305 - Dynamics of the Andromeda Galaxy Satellite System

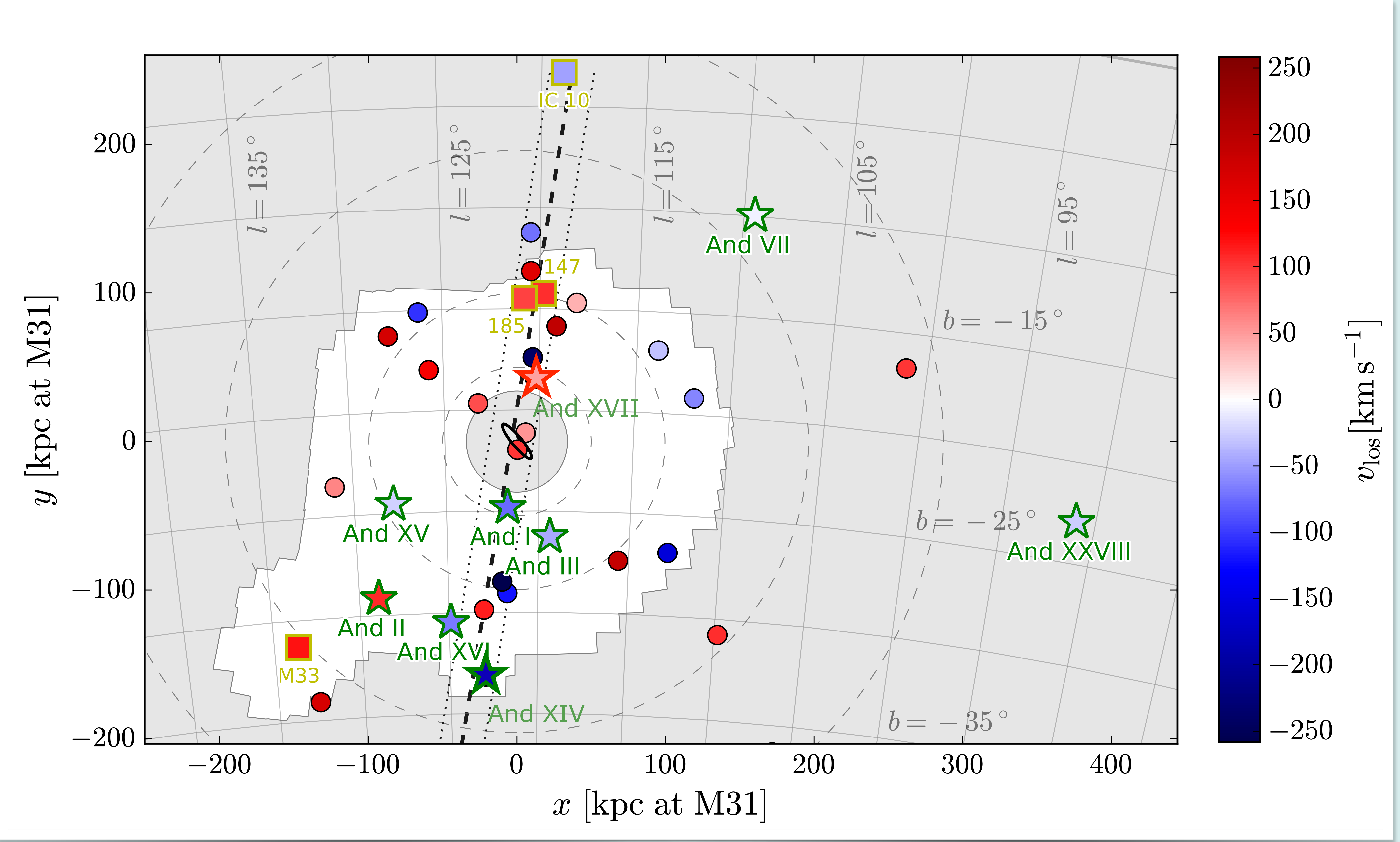
Cycle: 1, Proposal Category: GTO

- Measure PMs of 7 M31 satellites (48 orbits) w/ HST vs. HST
  + PMs of +2 M31 satellites w/ HST vs. JWST

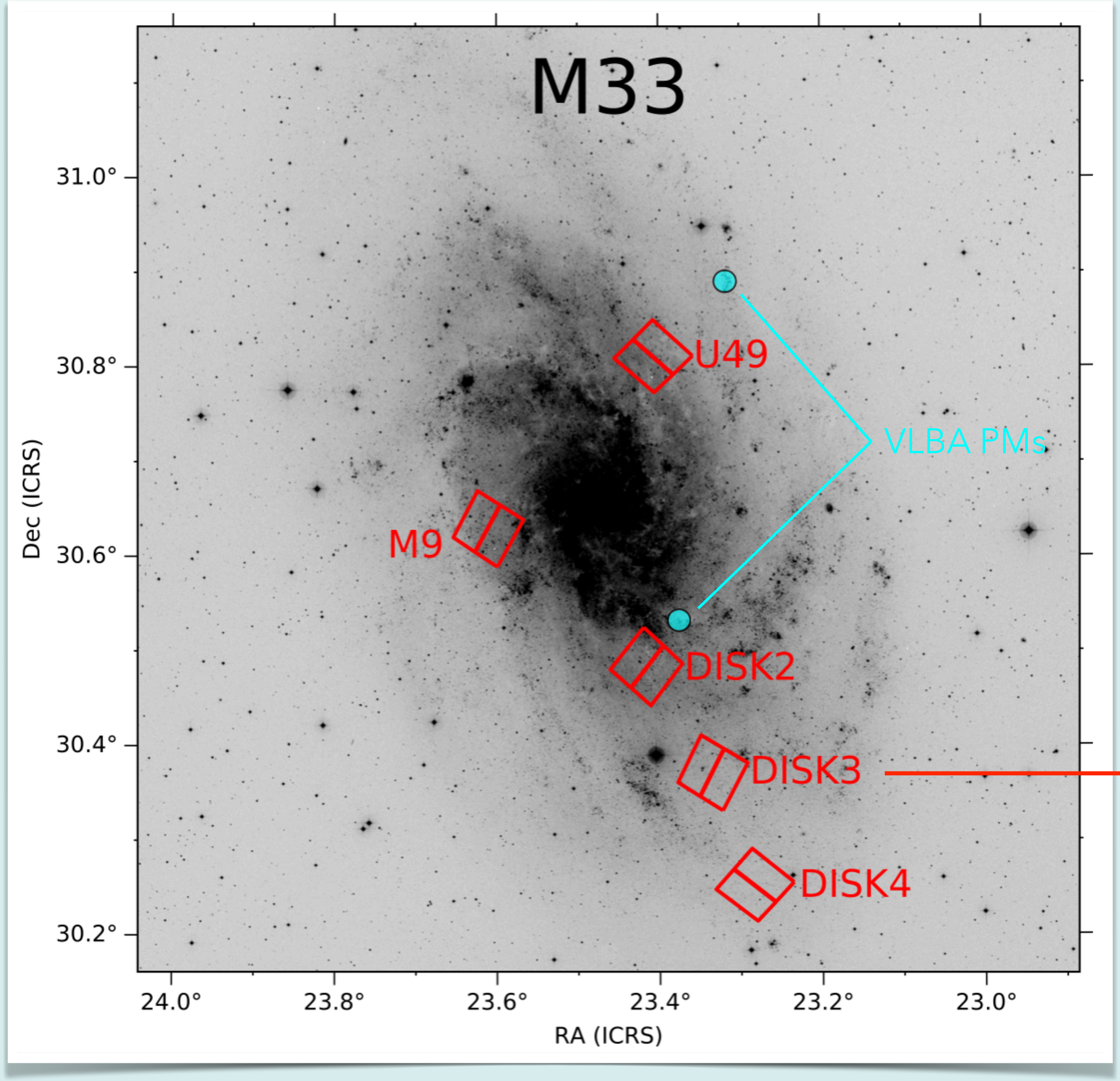
- 40-50 km/s proper motion uncertainty per galaxy

- NGC 147/185 + M33 + IC10 + 9 (from these programs)
  = **13** satellites with 3-D motions

- Main goals:
  - Constrain M_{M31} using 3-D motions ($r_{M31} \lesssim 370$ kpc)
  - Test the dynamical coherence of GPoA members
  - Infall times vs. star formation histories
  - Orbital histories of individual satellites
    (e.g., And I vs. Giant Stellar Stream)



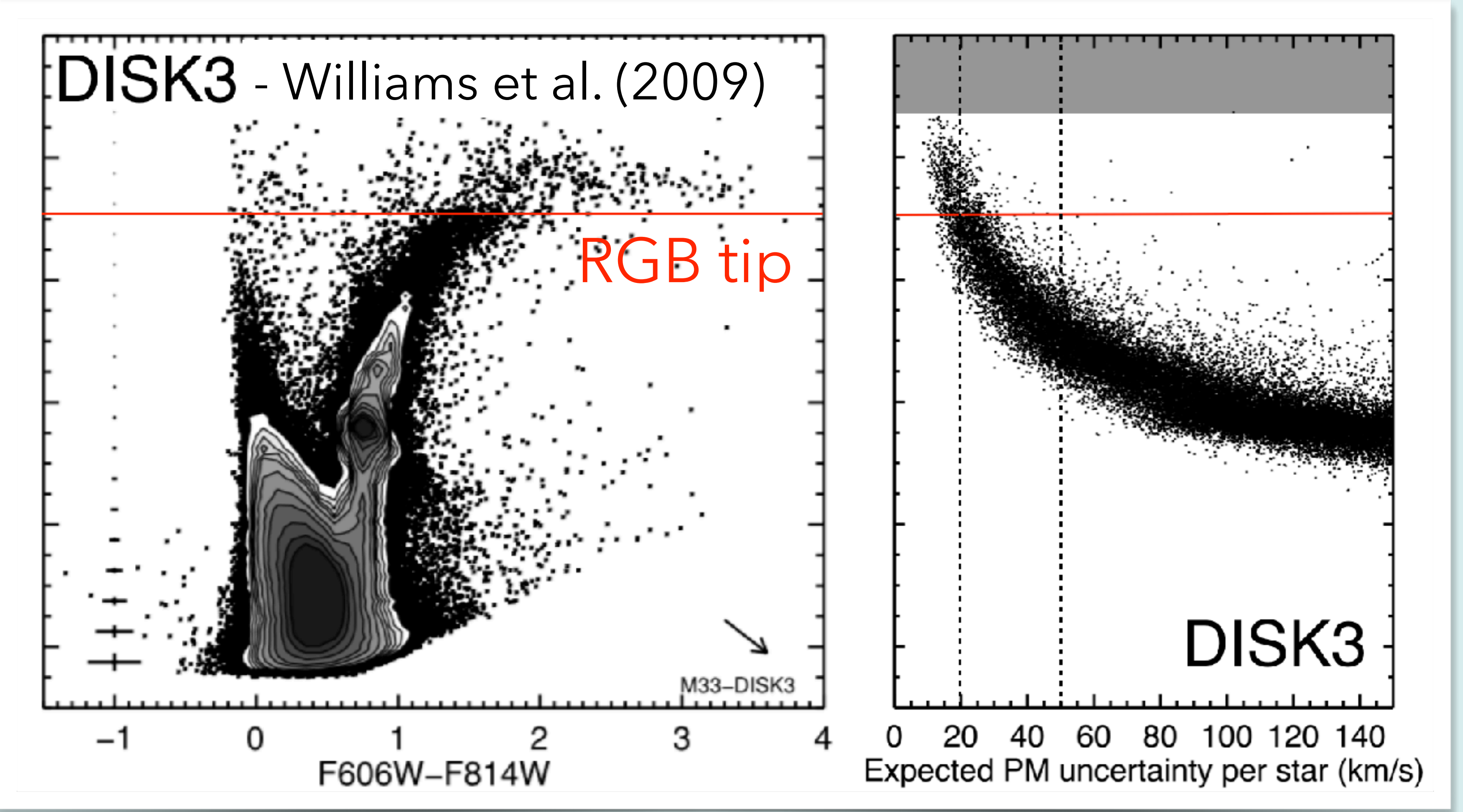
Resolved Proper Motions of M33



Hubble Space Telescope Cycle 28 GO Proposal 947

Resolved Proper Motions of M33

- Proper motions of M33 stars in 5 disk fields (35 orbits)
- Time baseline = 16 years
- Main goals:
  - On-sky rotation of M33's disk
  - Characterize M33's dynamically-hot components
  - (Non-)Detection of hot halo and/or thick disk stars
  - Improved ($\sigma_{1\text{-}D}$~12 km/s) systemic proper motion of M33



PMs of Isolated Local Group Dwarfs

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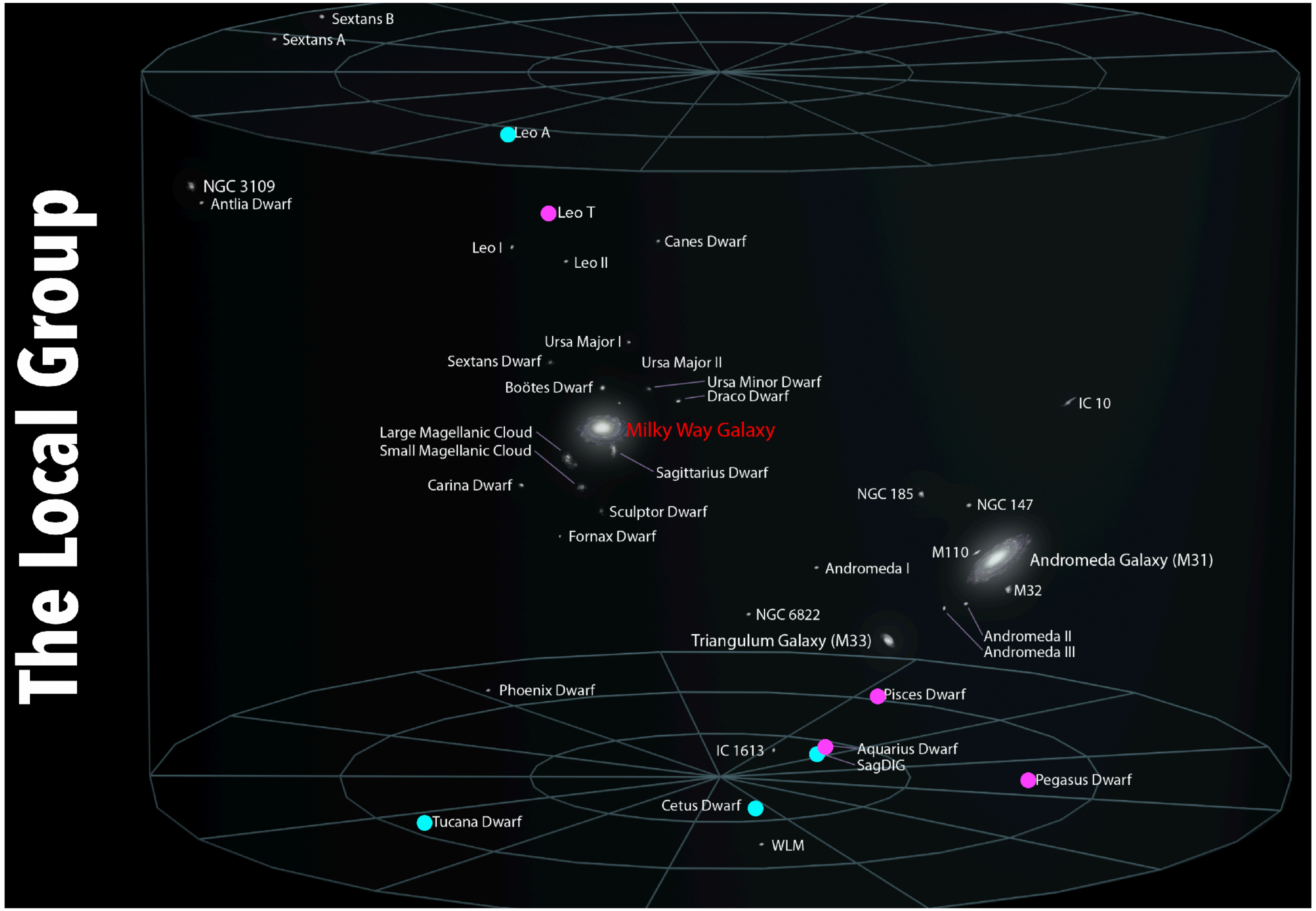
Orbits of Isolated Dwarfs: Local Group Mass and Environmental Quenching

- PMs of 4 isolated dwarfs: Leo A, Cetus, Tucana, Sag DIG
- Time baseline = 9–15 years (ΔPM = 35–50 km/s)

Hubble Space Telescope | Cycle 30 GO Proposal | 3358

New Kids on the Block? Proper Motions of First Infall Galaxies in the Local Group

- PMs of +4 isolated dwarfs: Aquarius, Pegasus, Pisces, Leo T
- Time baseline = 9–17 years (ΔPM = 20–45 km/s)
- Main goals:
  - Bound or unbound? First infall?
  - Mass of the Local Group
  - Orbital history vs. SFH → quenching mechanism?



Dynamical Understanding of the Local Group

RESOLVED PM OF M31

- ✓ Ongoing program to provide accurate velocity zero-point for the M31 satellite system

ANDROMEDA AND ITS SATELLTES

- ✓ Mass of M31, dynamical stability of GPoA, orbital histories of individual dwarfs

RESOLVED PM OF M33

- ✓ Disk rotation, disk/halo separation, absolute proper motion of M33

PMS OF ISOLATED LG DWARFS

- ✓ Origins, mass of the Local Group, quenching mechanism