A DETAILED VIEW OF THE SATELLITE SYSTEM OF A SINGLE L* GALAXY

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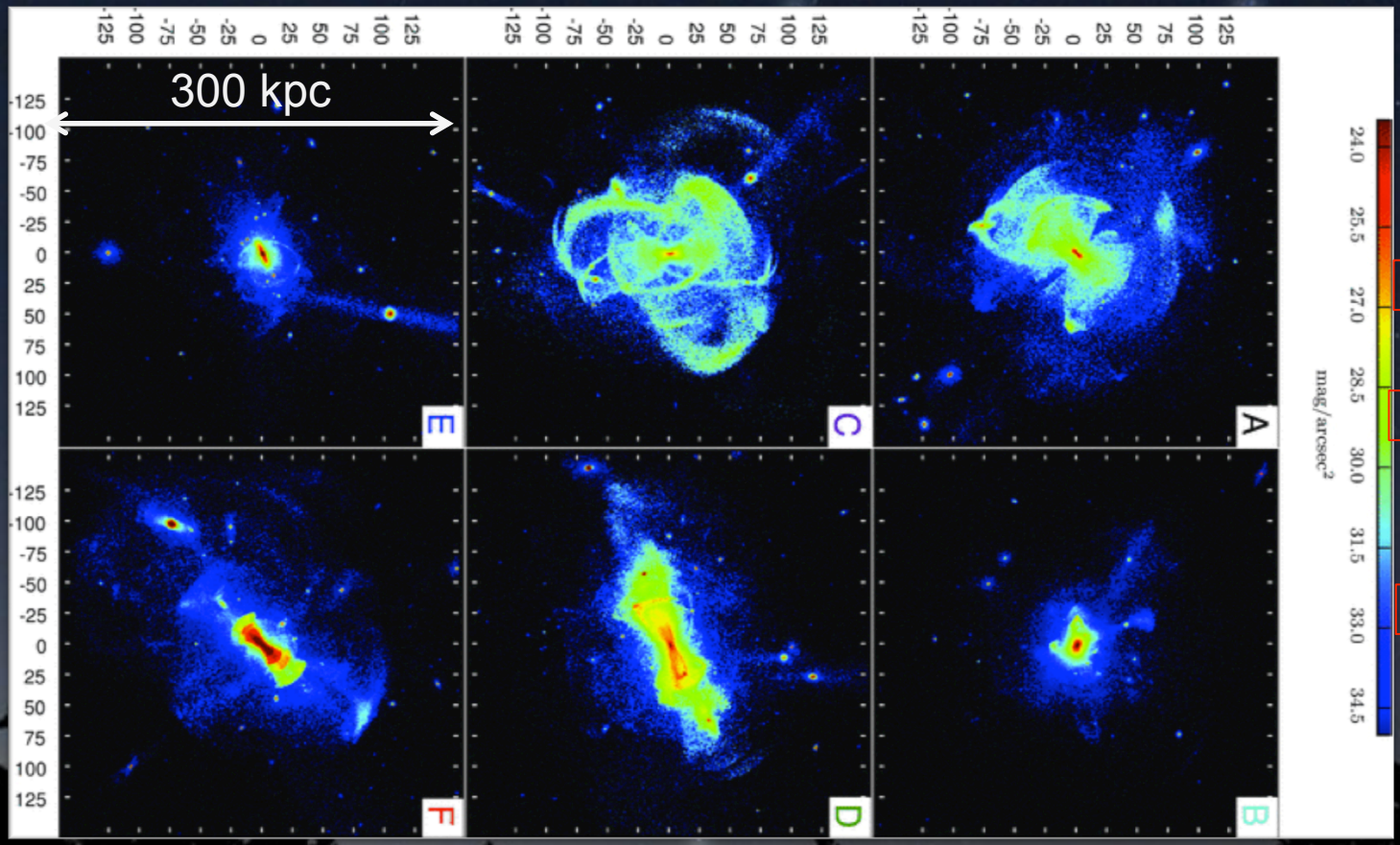
LOCAL GROUP TESTS OF GALAXY FORMATION

- L* systems figure prominently in galaxy redshift surveys and dominate the integrated mass and luminosity density of the low redshift universe
  - → we also happen to live in one and another is very nearby (M31 @ 800 kpc)
- The Milky Way and M31 provide an exquisite view of the detailed internal structure and content of L* galaxies, including their satellite systems
- Such observations constrain the galaxy assembly histories and are essential to confront the predictions of models of cosmological galaxy formation

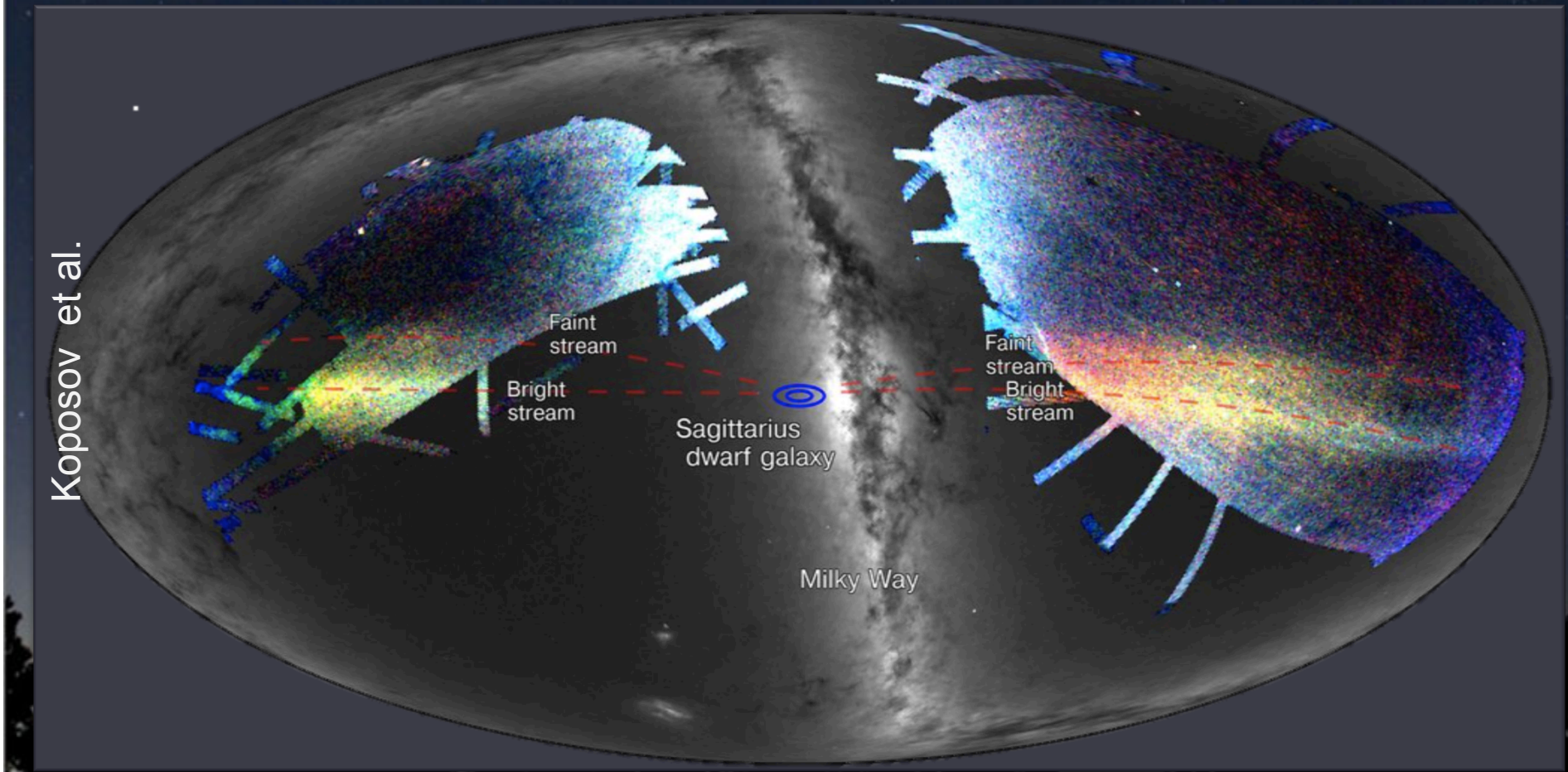
LOCAL GROUP TESTS OF GALAXY FORMATION



Cooper et al. 2010

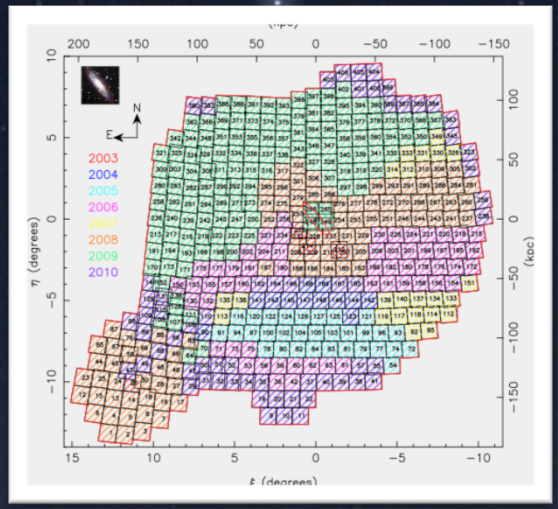
Much low surface brightness substructure predicted around galaxies – both in intact satellites and disrupted ones

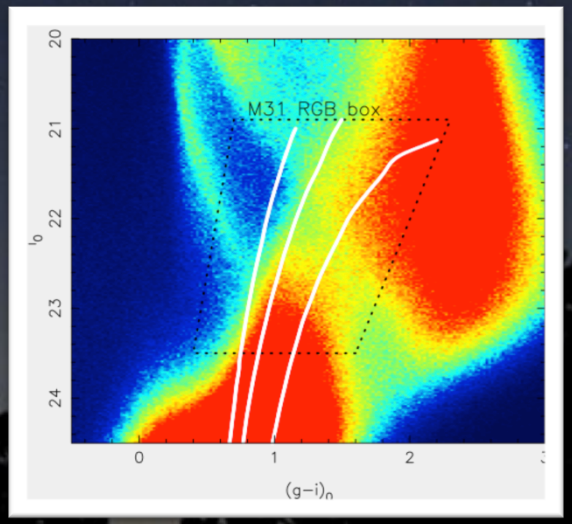
THE MILKY WAY IS NOT ALWAYS THE BEST L* TARGET



THE PAN-ANDROMEDA ARCHAEOLOGICAL SURVEY (PAndAS)

- CFHT Large Program, 220h over 2008-2011
- ~380 deg^2 mapped (to R_{proj}~150 kpc) with MegaCam in to g_{AB}~26.0 and i_{AB}~24.8 (5σ)
- mean seeing ~0.6-0.7”
- 96 million sources, 10 million M31 red giant branch stars

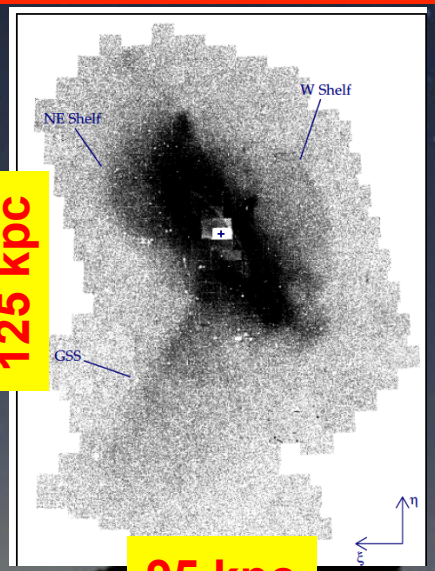




Ibata et al. 2013, Martin et al. 2013a

THE PAN-ANDROMEDA ARCHAEOLOGICAL SURVEY (PAndAS)

The INT/WC Survey (2000-2003)



125 kpc

95 kpc

Ferguson et al. 2002

[Fe/H] ~ –2.3
[Fe/H] ~ –1.4
[Fe/H] ~ –0.7

150 kpc

400 kpc

50 kpc

400 kpc

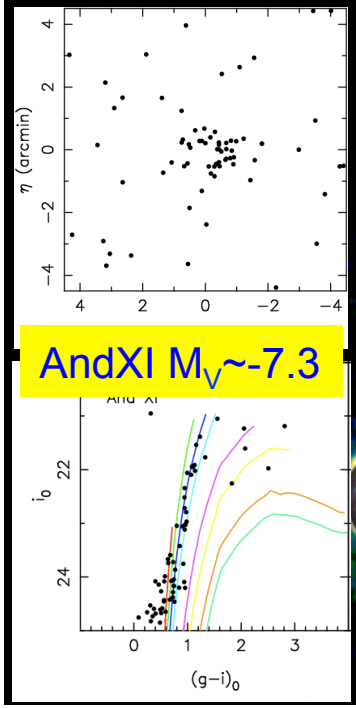
Martin et al. 2013;
McConnachie et al. 2009, Ibata et al. 2013

Martin et al. (2013b)

Dwarf galaxies

Zucker et al. (2004; 1)
Martin et al. (2006; 3)
Majewski et al. (2007; 1)
Ibata, Martin et al. (2007; 2)
Irwin et al. (2008; 1)
Zucker et al. (2007; 1)
McConnachie et al. (2008; 3)
Martin et al. (2009; 2)
Richardson et al. (2011, 5)
Bell, Slater & Martin (2011, 1)
Slater, Bell & Martin (2011, 1)
Martin et al. (2013a, 2)
Irwin et al. (in prep, 1)

PS1

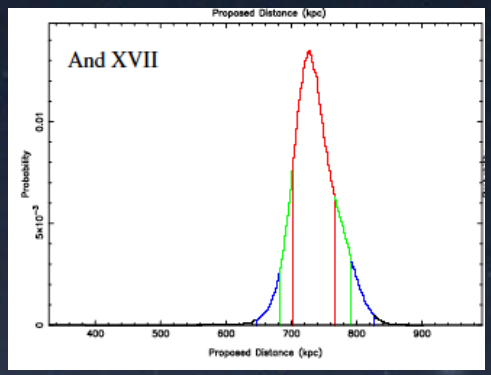


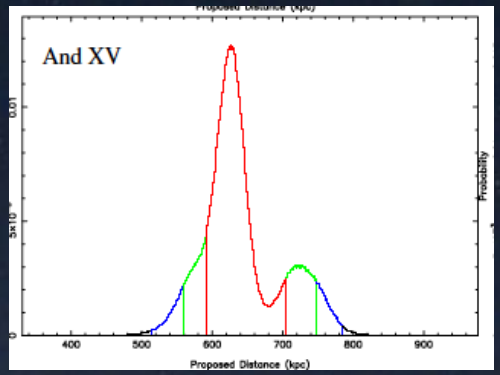
Martin et al. 2013

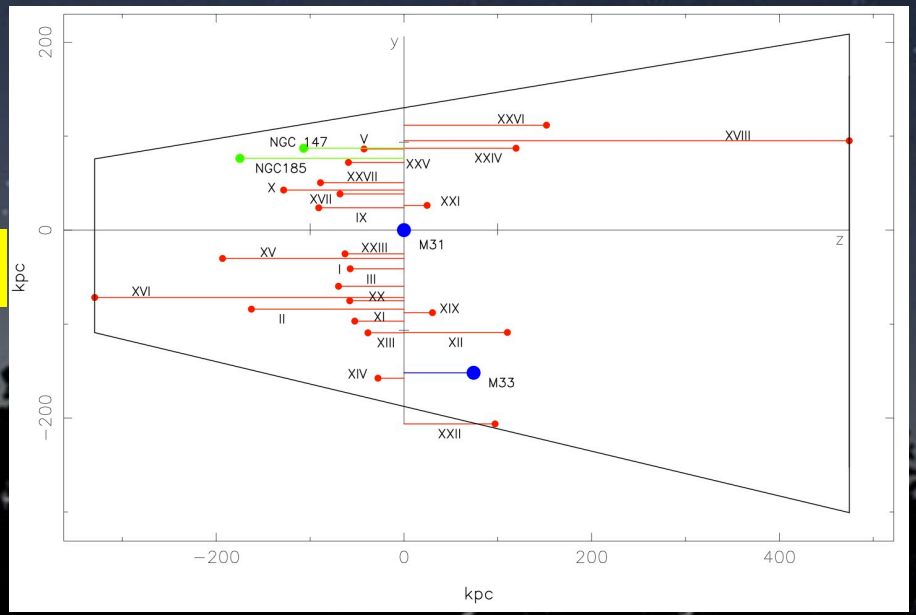
6 dSphs (2004) → 30 dSphs (now;
4 SDSS + 17 PAndAS + 2 PS1 + 2)

THE ASYMMETRIC DWARF SATELLITE SYSTEM OF M31

Conn et al. 2011, 2012







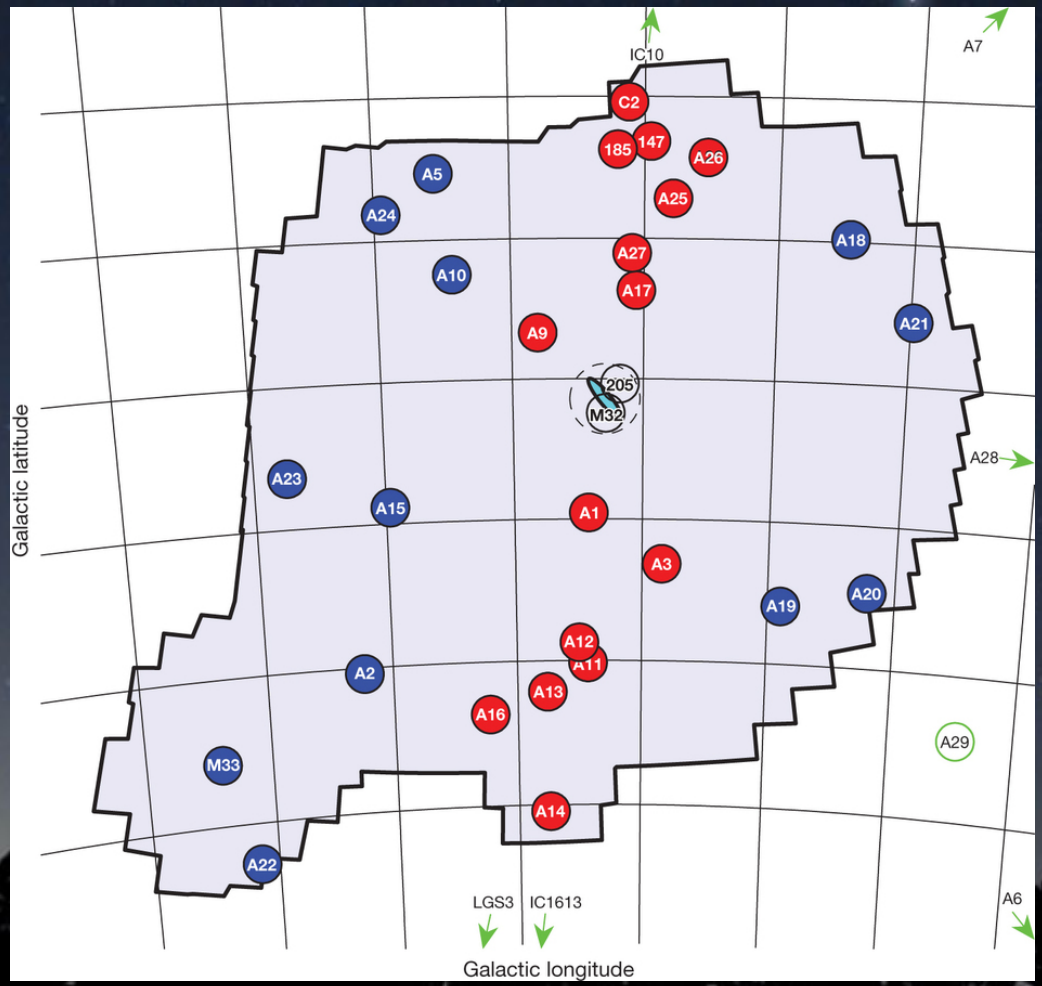
Line-of-sight distances to satellites can be derived from the tip of the red giant branch

Use Bayesian method to derive probability distribution functions for distance to each of the 27 satellites within PAndAS

Typical uncertainty ~20-50 kpc

A VAST PLANE OF DWARF GALAXIES

Ibata et al. 2013, Conn et al 2013

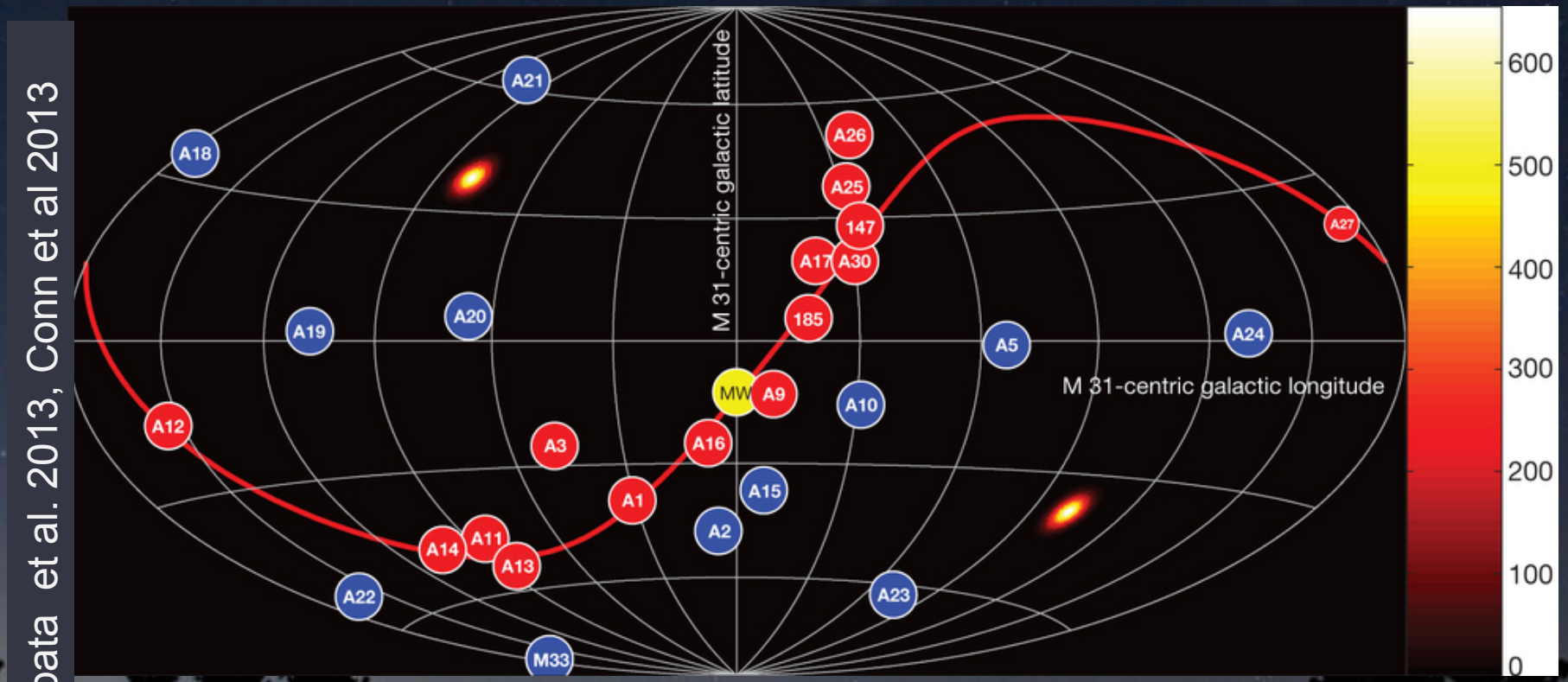


Can identify a significant plane which contains ~½ (13/27) of the known dwarf satellite population

~14 kpc thickness
~400 kpc diameter
P_{random} ~ 0.1%

Roughly perpendicular to MW disk

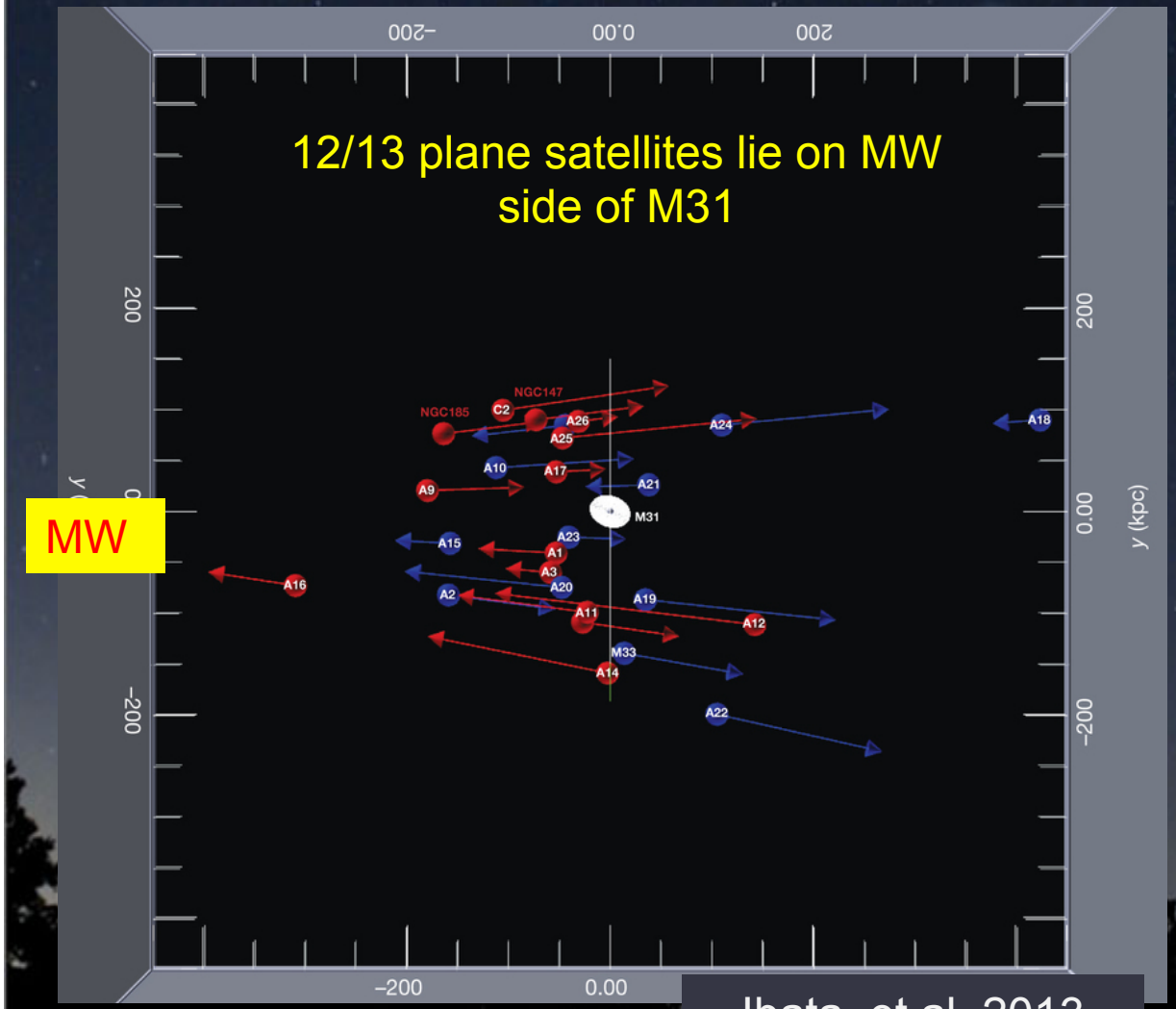
A VAST PLANE OF DWARF GALAXIES



Ibata et al. 2013, Conn et al 2013

PAndAS satellite distribution as viewed from centre of M31;
Poles of plane at l_{M31}~100°, b_{M31}~-38°.

A VAST PLANE OF DWARF GALAXIES



Ibata et al. 2013

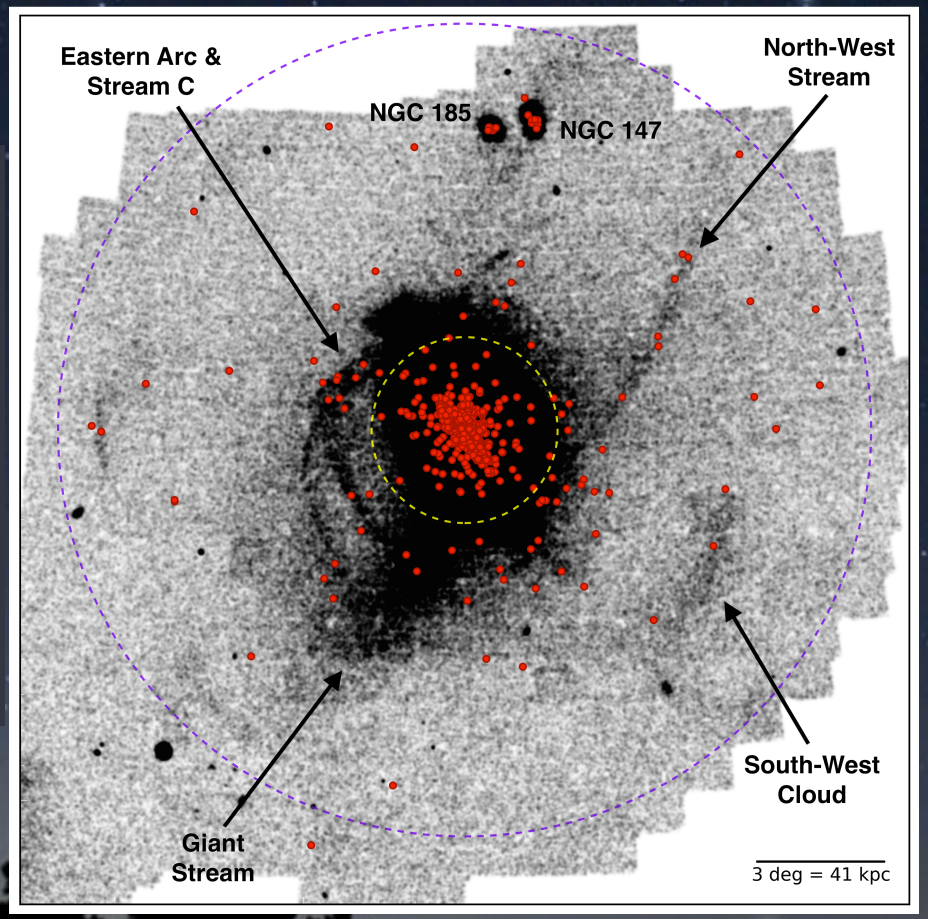
Plane satellites have motion that suggests rotation (P_{random}<0.002%)

Is the existence of a giant thin rotating disk of satellites a problem for models?

Filament Accretion?
Disk Stability within triaxial halo?
Tidal Dwarfs?.

SUBSTRUCTURE IN THE M31 GLOBULAR CLUSTER SYSTEM

Mackey et al 2010, 2013
Huxor et al 2011, 2013

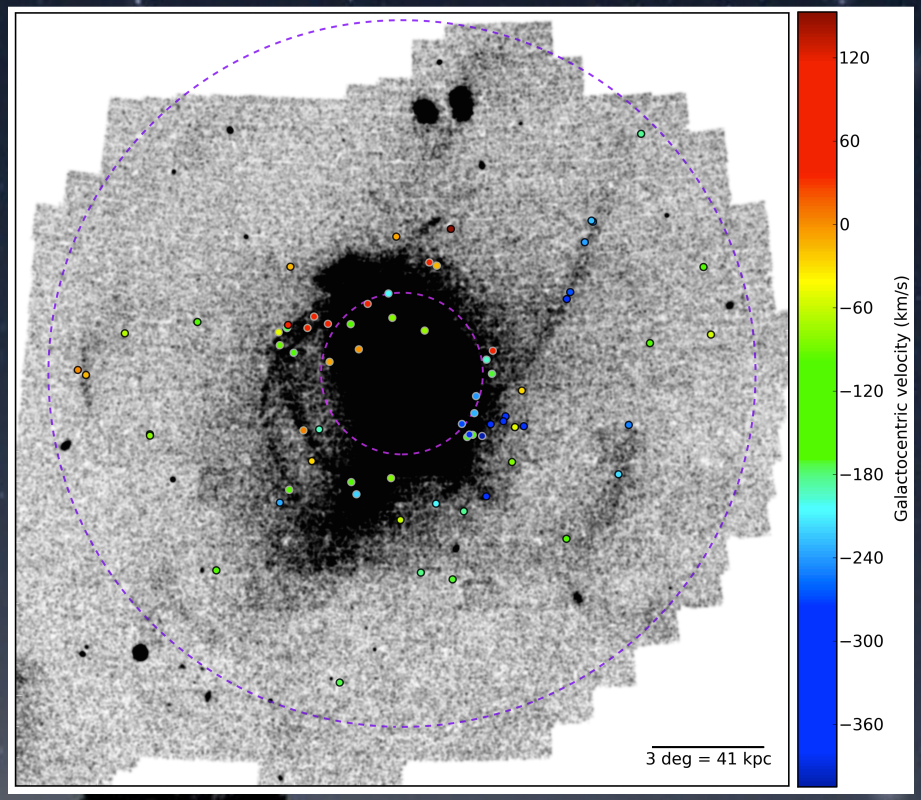


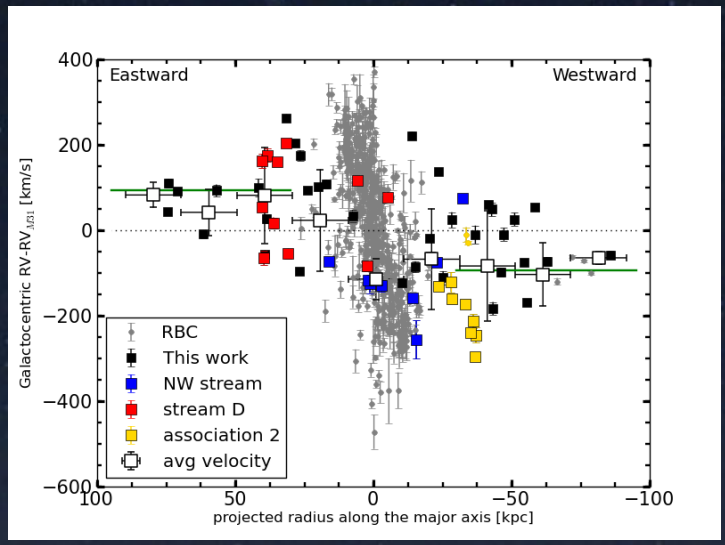
- ~90 new halo globular clusters (R>30 kpc) discovered in PAndAS out to R_{proj}~140 kpc, and R_{3D}≥ 200 kpc (3 known pre-PAndAS)
- Outer halo clusters are highly correlated with underlying halo substructure: P_{random}<0.25%

Most of the M31 outer halo clusters have been accreted with dwarf hosts

SUBSTRUCTURE IN THE M31 GLOBULAR CLUSTER SYSTEM

Veljanoski et al 2013a, 2013b





V/σ~1 to > 100 kpc (20 Reff)?

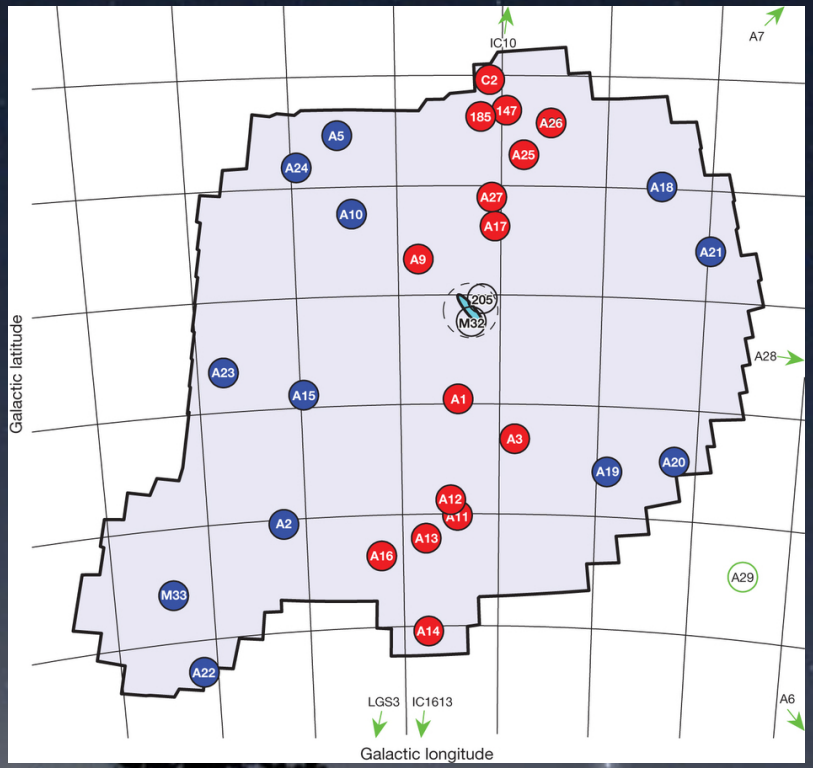
M31 outer halo clusters lie along streams and rotate coherently in the same sense as the main disk?

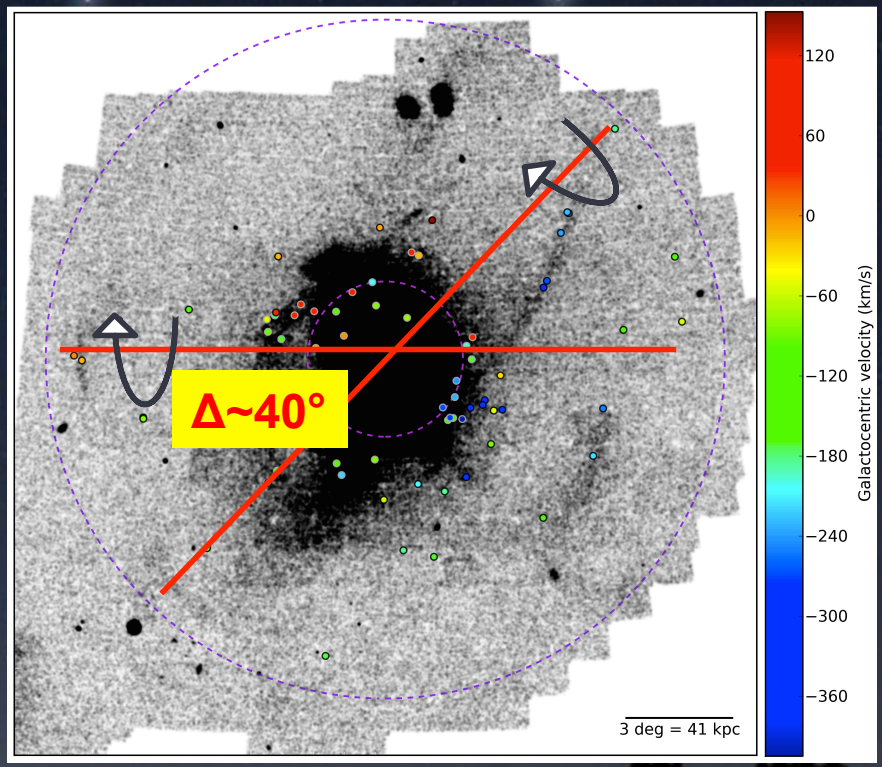
Table 1
Derived Rotational Properties for M31 Halo GCs

	A (km s^{-1})	θ_0 (deg)	Velocity Dispersion (km s^{-1})	N_{GC}
All GCs	133 ± 11	124 ± 4	115 ± 5	595
R_{proj} < 30 kpc	137 ± 10	124 ± 4	114 ± 5	545
R_{proj} > 30 kpc	79 ± 19	123 ± 27	106 ± 12	50

DWARFS AND GLOBULAR CLUSTERS

Ibata et al 2013, Veljanoski et al 2013b





300 kpc

300 kpc

GCs and dwarf plane rotate in same sense but rotation axes misaligned…

Summary

- The PAndAS Survey has allowed us to explore in detail the satellite system of a single L* galaxy. Satellites probed down to M_V~-6 and R_{proj}~150 kpc.
- The dwarf satellite distribution is highly asymmetric with most systems located on the near side of M31 with respect to the Milky Way.
- Approximately 50% of the currently-known satellites lie in a vast planar structure (~400 x14 kpc) that appears to rotate. Note: M33 is not in this plane but the MW is!
- Halo globular clusters are highly-correlated with stellar streams and also exhibit net rotation, but the rotation axis misaligned by ~40% to that of the dwarf plane…