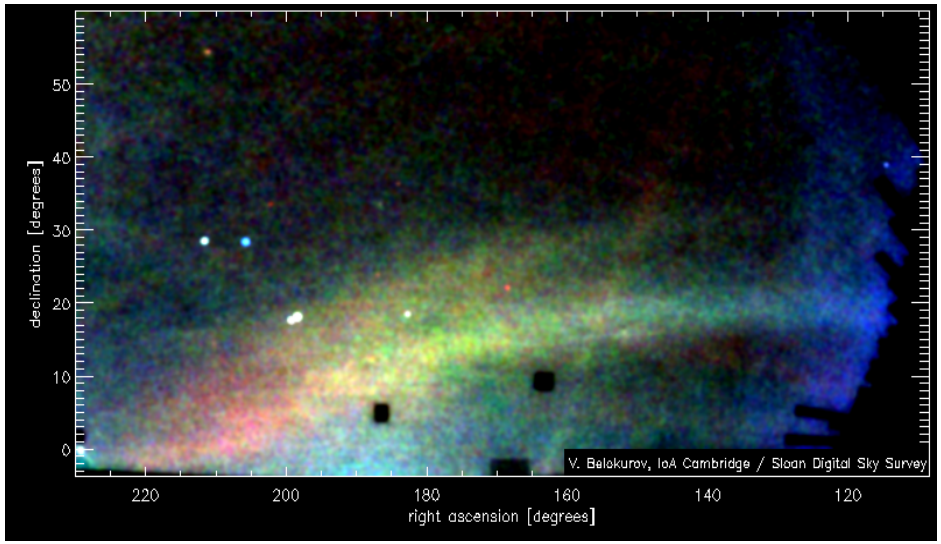
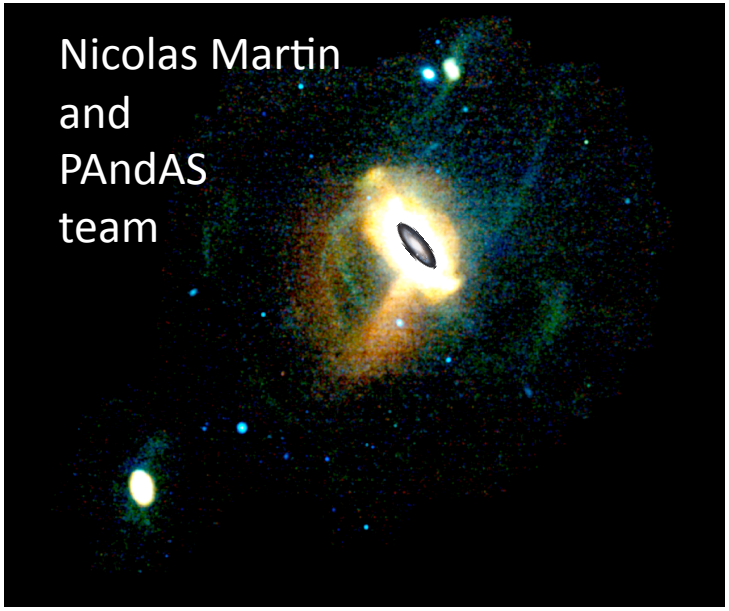


Belokurov et al, 2005



Tidal Interactions Around the M31 and MW Halo's

Tidal Streams in the M31 Halo

Kathryn V Johnston

Supported by the
National Science Foundation

Columbia University
Astronomy Department

Part I:
What IS in the Halo?

Part II:
Substructured Substructure

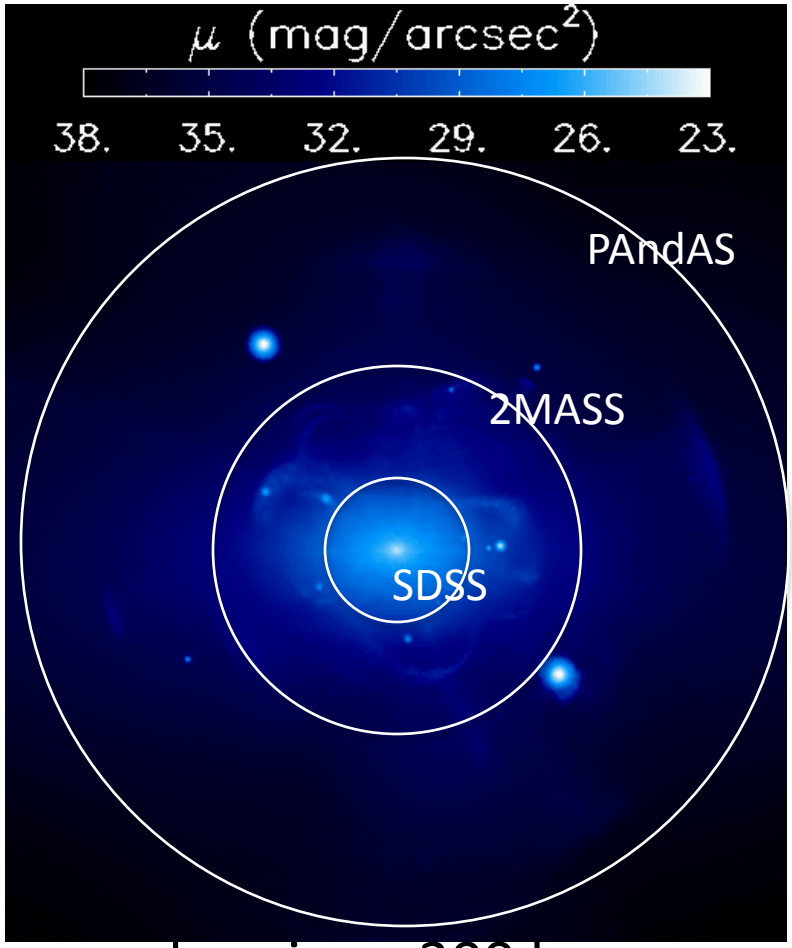
Part III:
What WAS in the Halo?

Part I:
What is in the Halo?
M31-MW Comparison
(Spatial Overdensities)

Nature of Spatial Overdensities

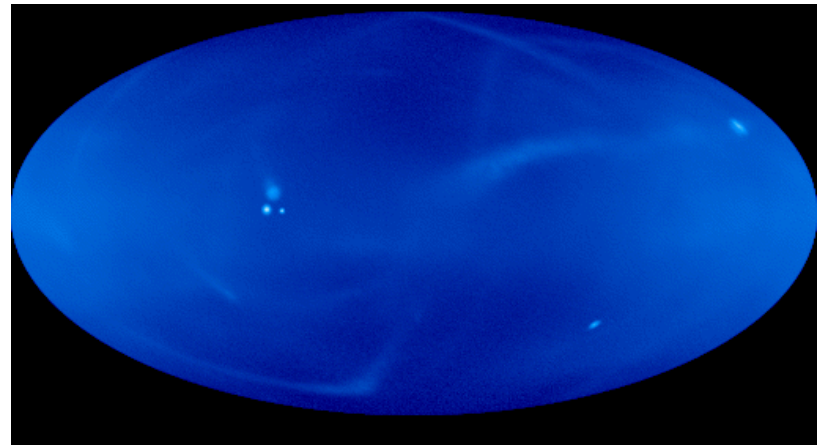
(Bullock & Johnston 2005, Johnston et al, 2008)

"M31" perspective

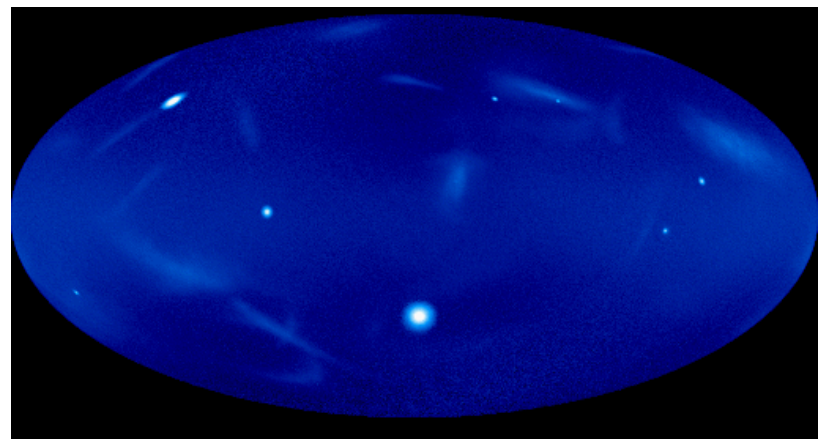


boxsize = 300 kpc

"MW" perspective



25 kpc < r < 63 kpc

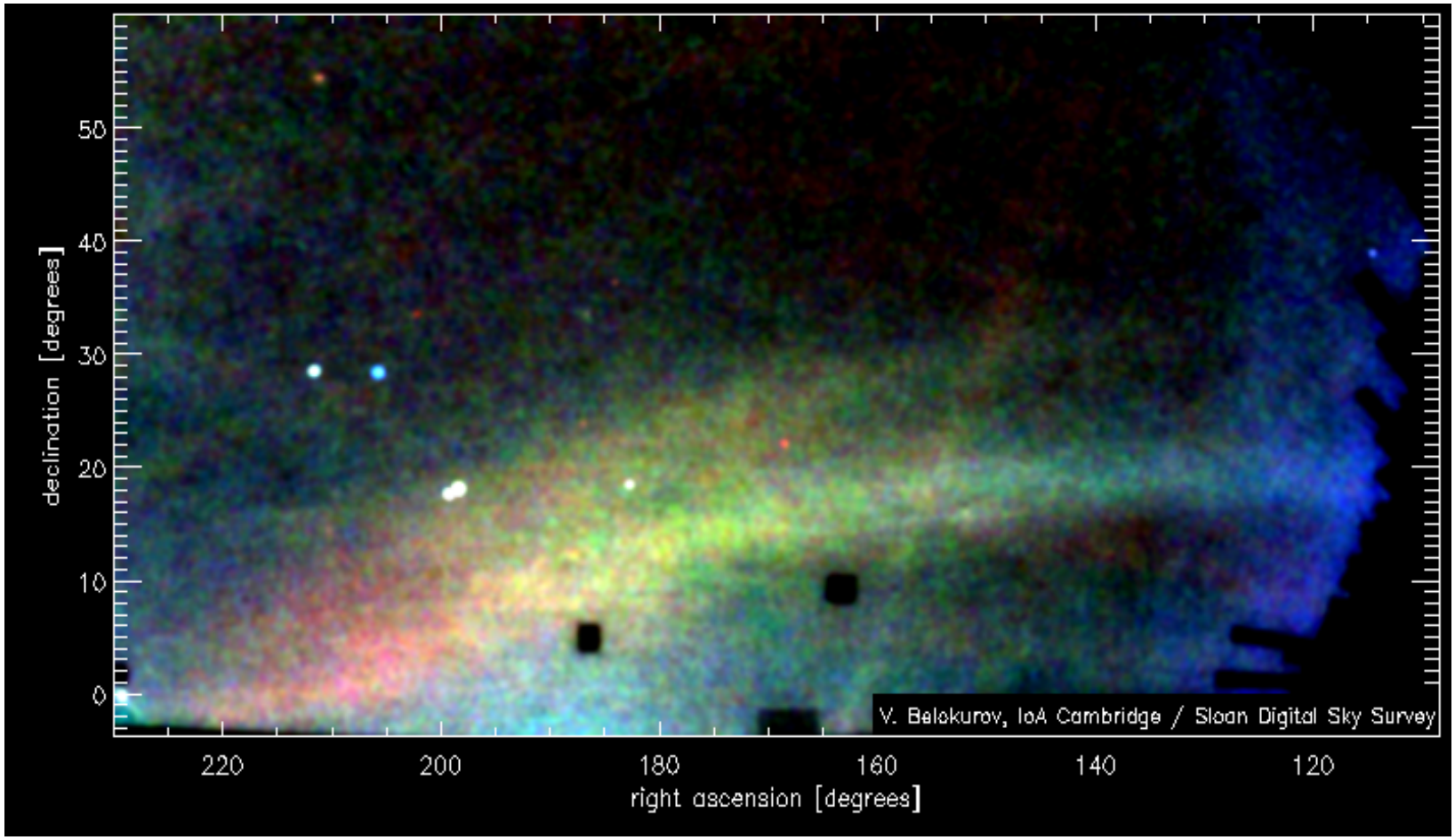


63 kpc < r < 158 kpc

MW substructures

SDSS (e.g. “field of streams” Belokurov et al 2005)

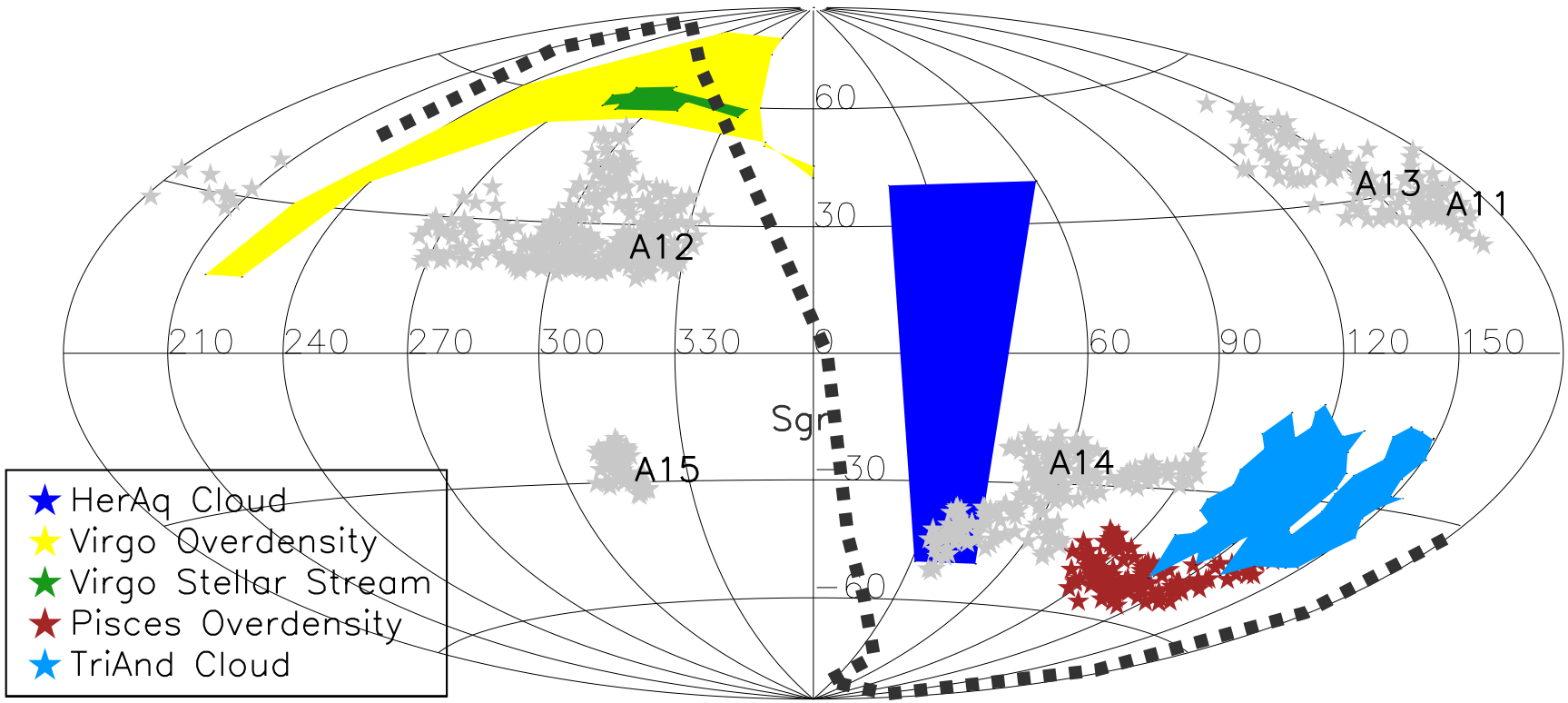
2MASS M-giants (e.g. Majewski et al, 2003)



Milky Way Halo Substructures

Name	L ($L_\odot$)	Extent	Morph-ology	Origin
Monoceros Ring	? 10^8 ?	? × ~100° ? × ~60 kpc	ring	???
Sgr	~ few × 10^7	~10° × ~360° ~15 × 300 kpc	stream	Dwarf, low-ecc orb
Orphan	~ few × 10^5	~2° × ~100° ~3 × 100 kpc	stream	Dwarf, low-ecc orb

MW substructures: clouds

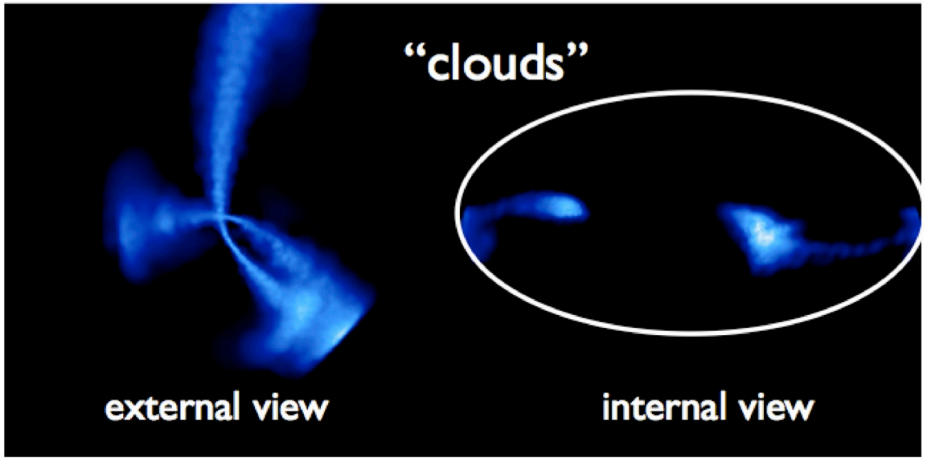


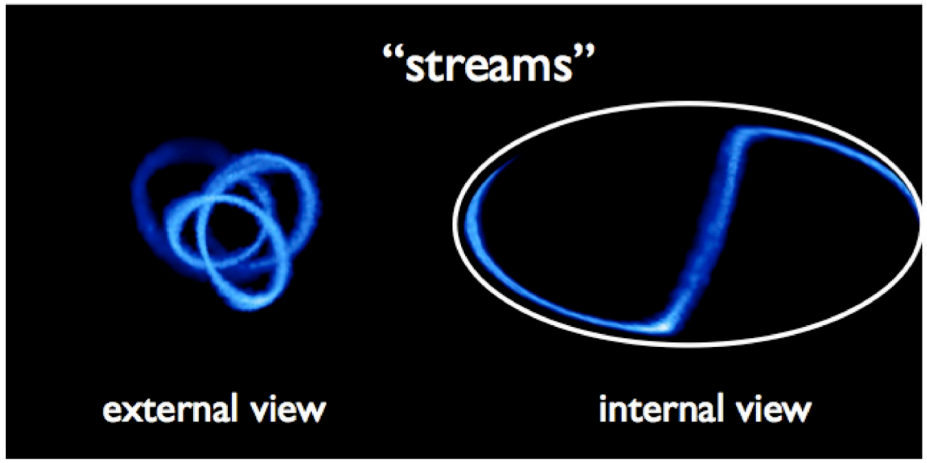
Rocha-Pinto et al 2004, Belokurov et al 2006, Juric et al 2008, Sharma et al 2010

Milky Way Halo Substructures

Name	L ($L_\odot$)	Extent	Morph-ology	Origin
Monoceros Ring	? 10^8 ?	? × ~100° ? × ~60 kpc	ring	???
Sgr	~ few × 10^7	~10° × ~360° ~15 × 300 kpc	stream	Dwarf, low-ecc orb
Orphan	~ few × 10^5	~2° × ~100° ~3 × 100 kpc	stream	Dwarf, low-ecc orb
VOD, POD, HerAq, TriAnd	? 10^5 – 10^6 ?	1000's square degrees	clouds	Dwarf, high-ecc orb

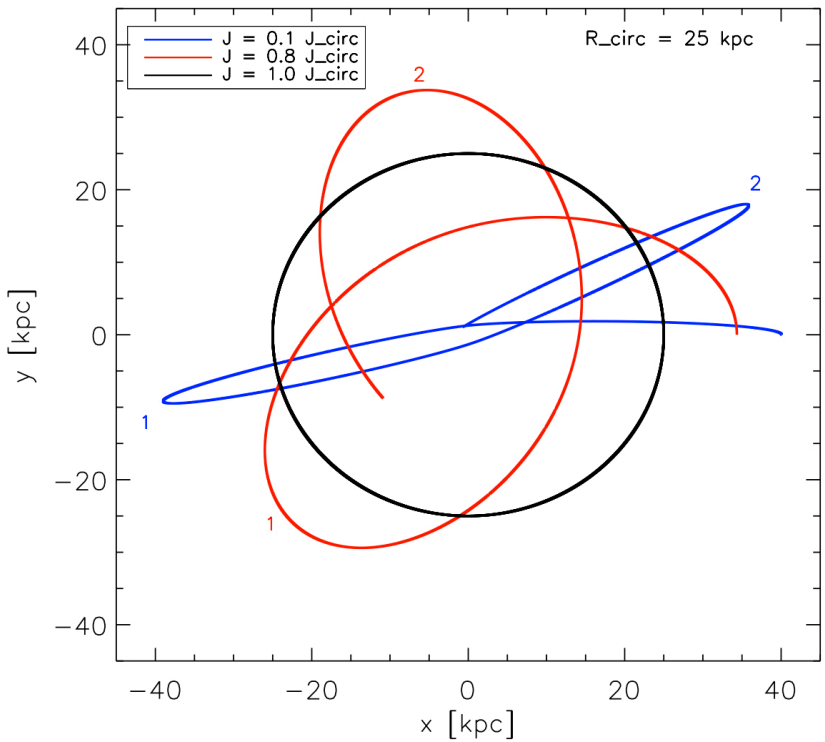
Debris Morphology ⇔ Orbit Type





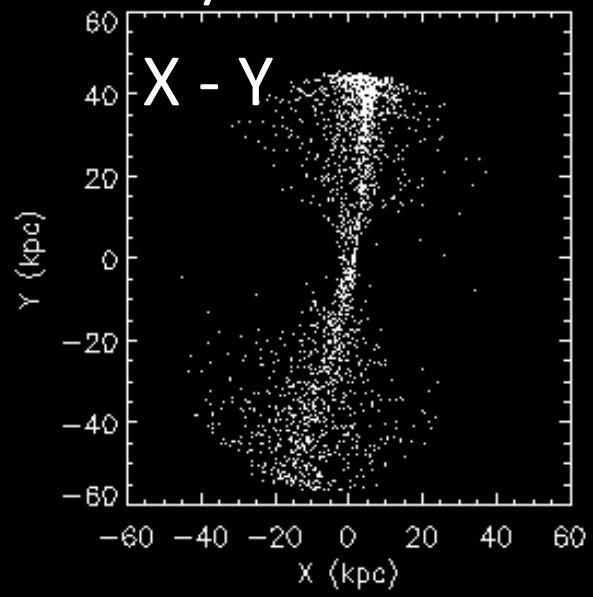
Why clouds? Why streams?

- Contrast orbits with same energy, J/Jcirc=0.1 and J/Jcirc=0.8

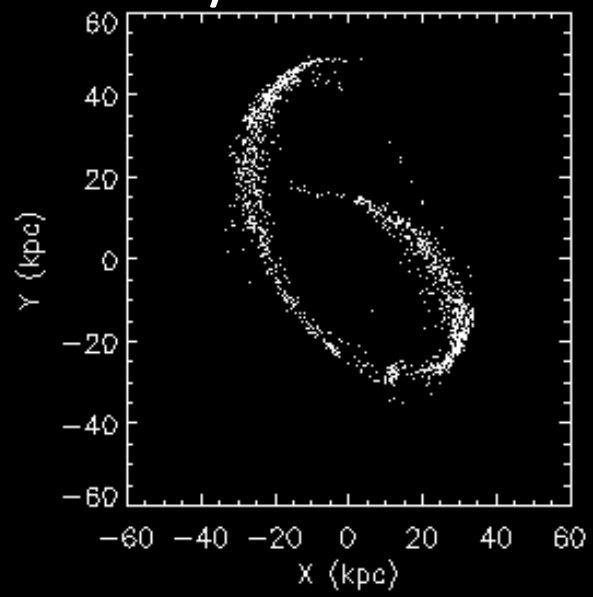


David Hendel
Columbia University

J/Jcirc =0.1

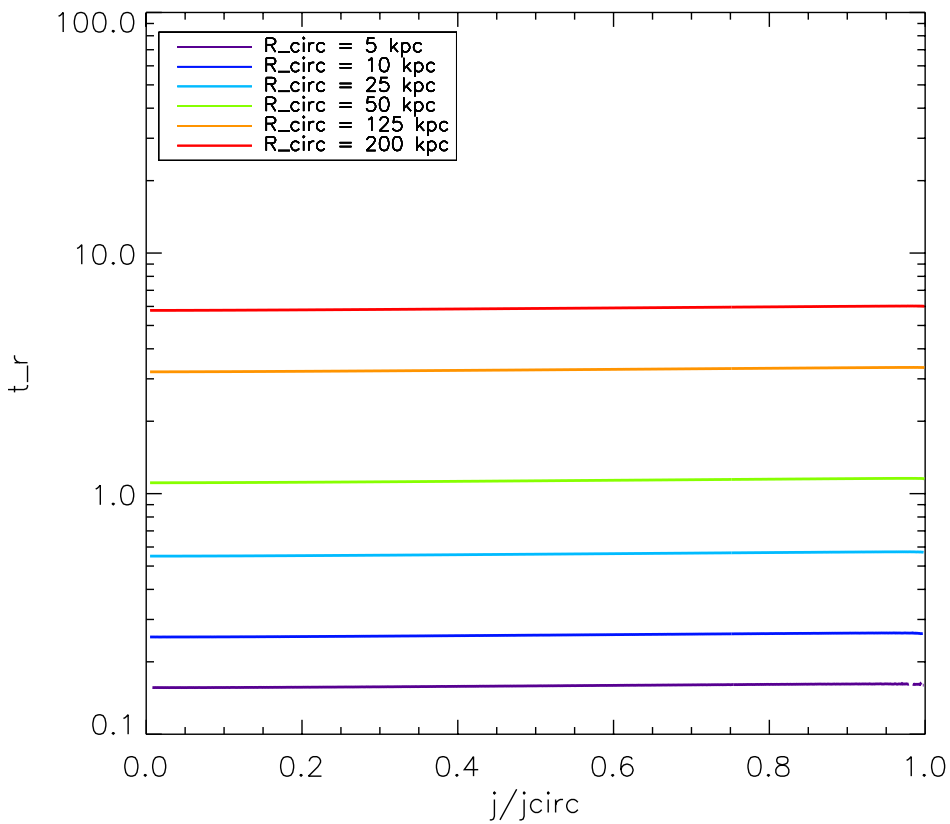


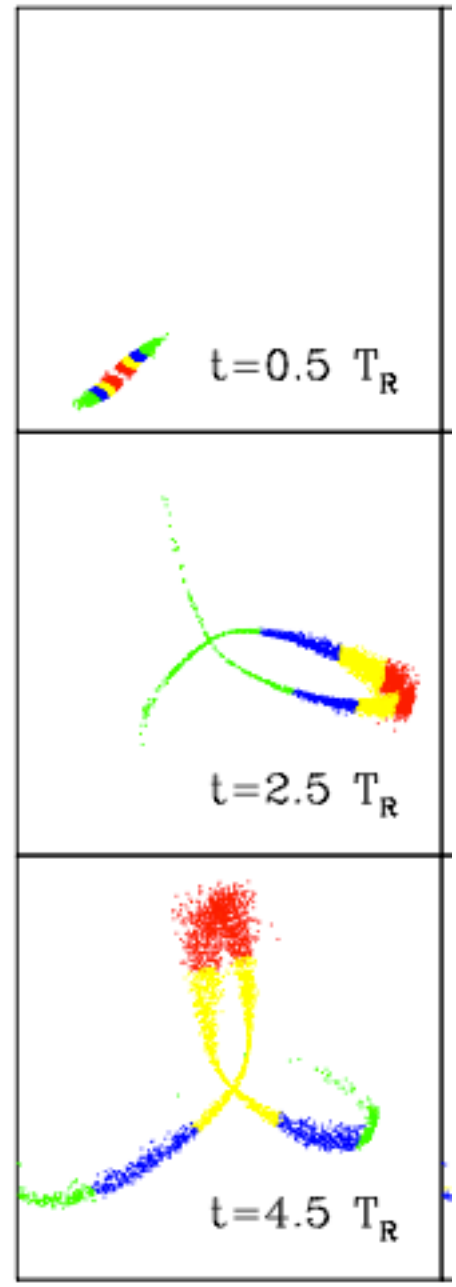
J/Jcirc =0.8



Why clouds? Why streams?

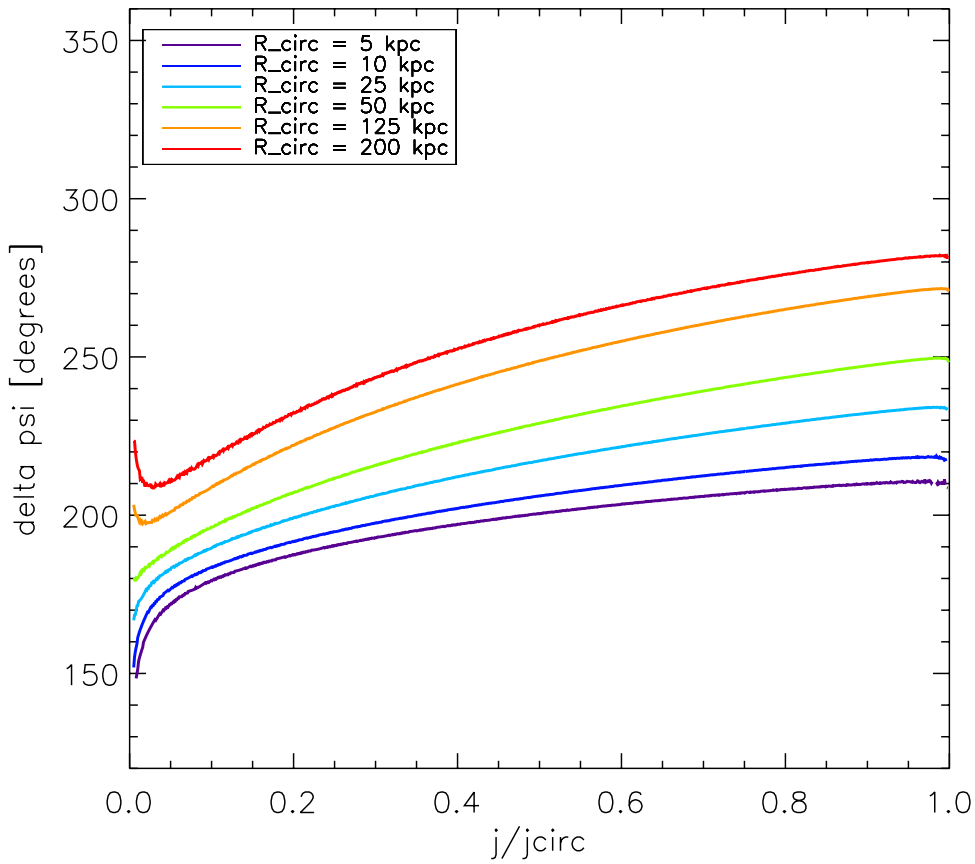
- ΔE ⇔ spread *along* orbit

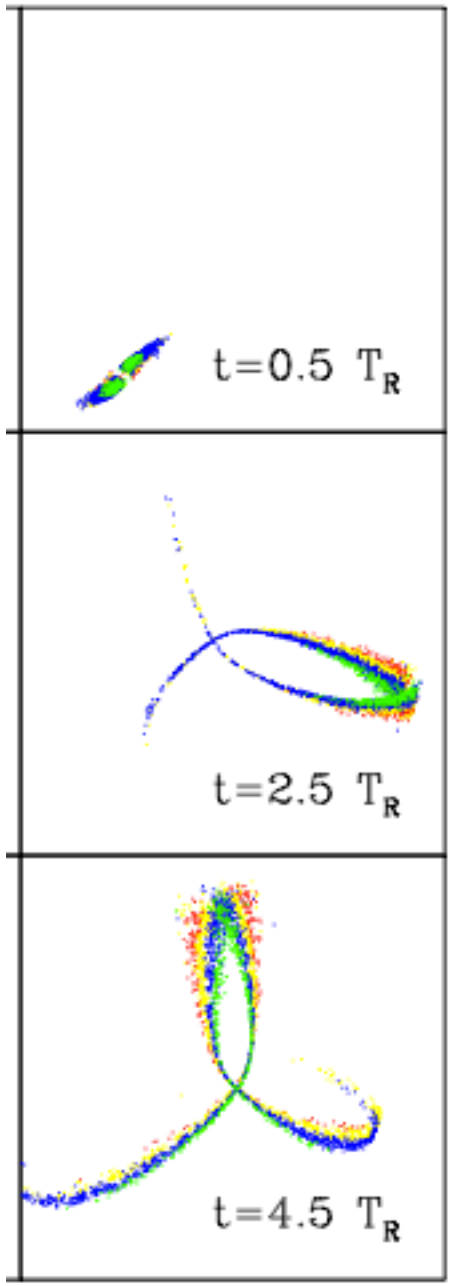


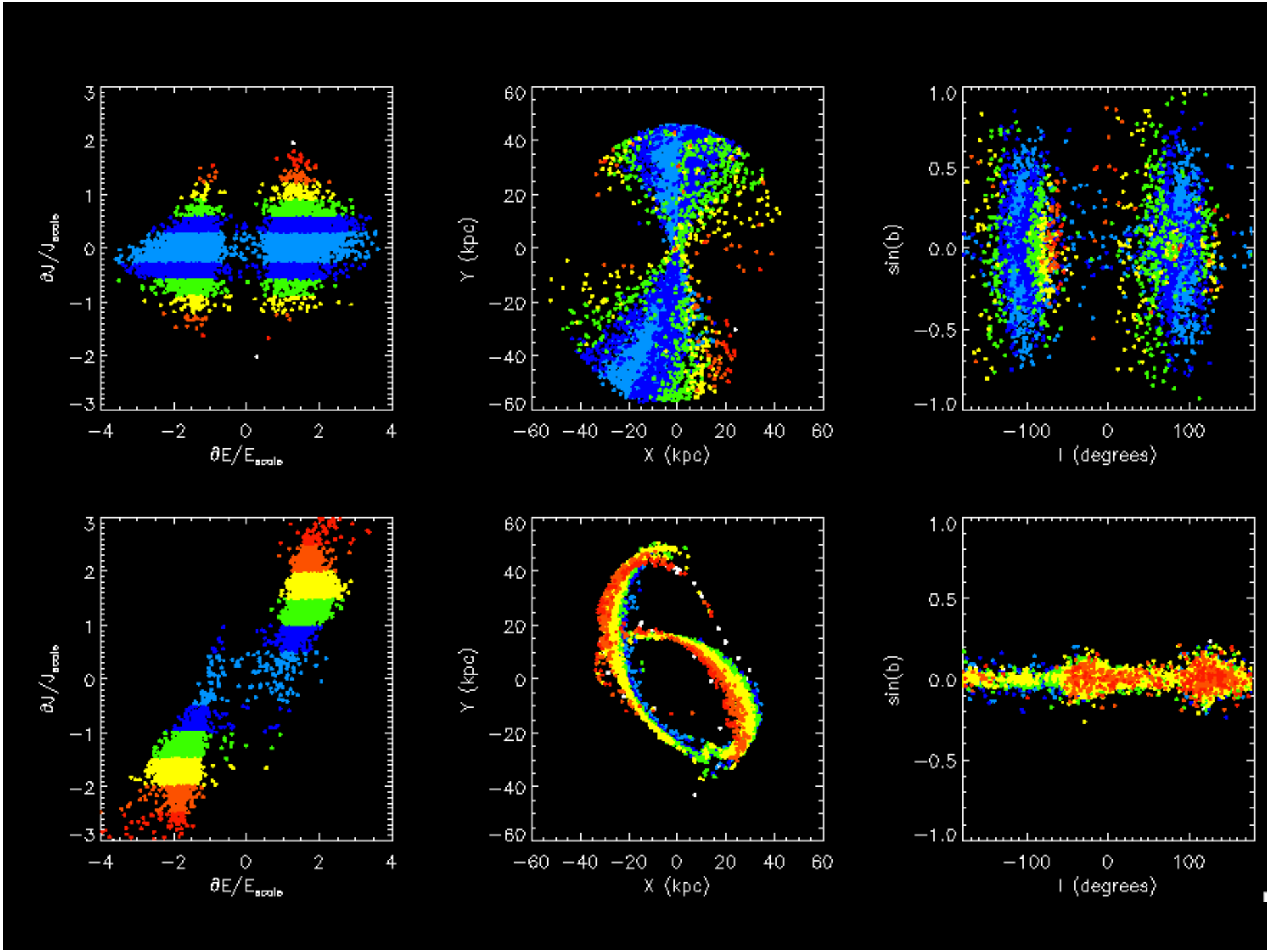


Why clouds? Why streams?

- ΔJ ⇔ spread *about* orbit ⇔ differential precession

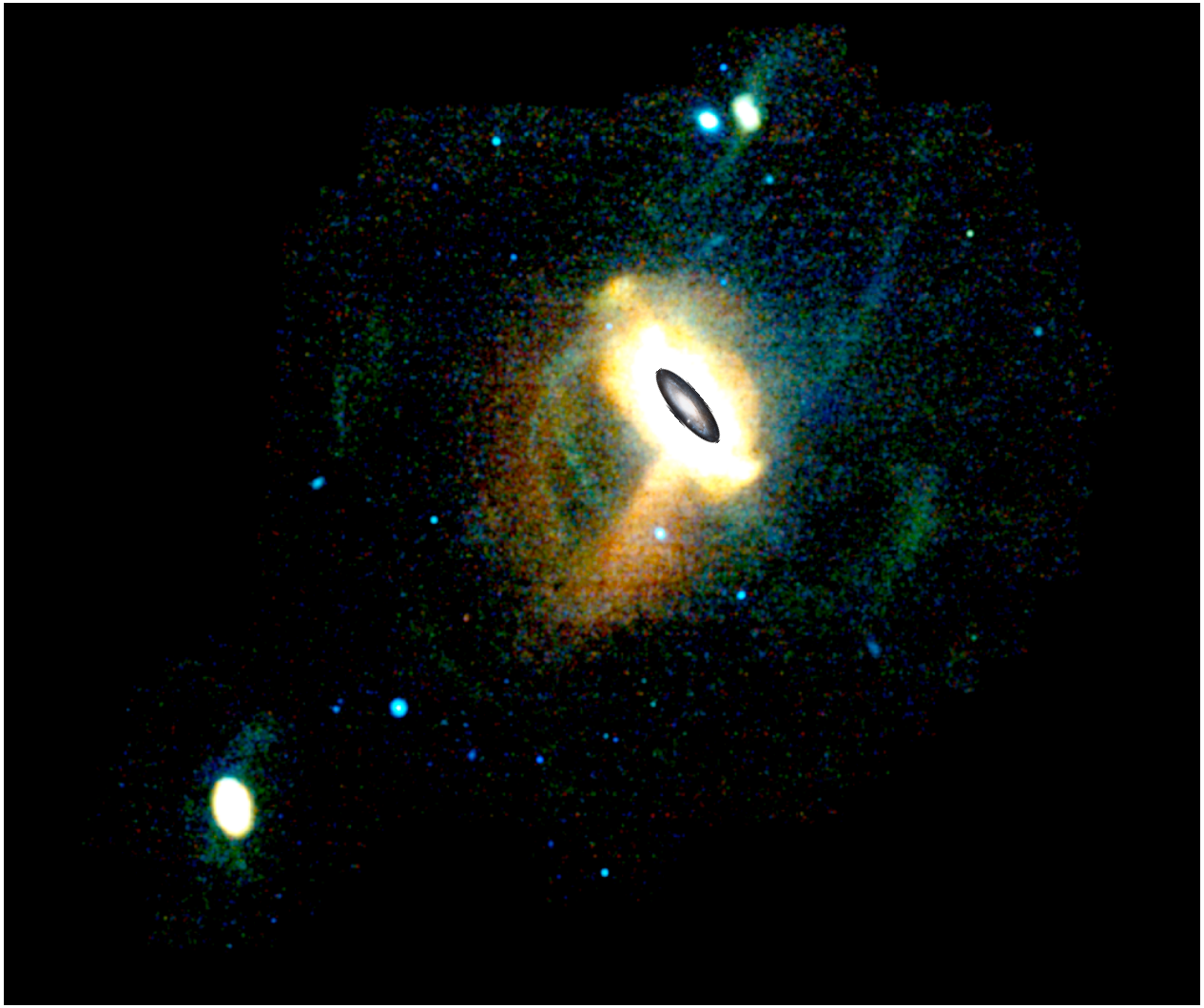





∂J/J_scale
∂E/E_scale
Y (kpc)
X (kpc)
sin(b)
l (degrees)

M31 – PAndAS

(Ibata et al 2002, 2008; McConnachie et al 2010
Richardson et al, 2011)

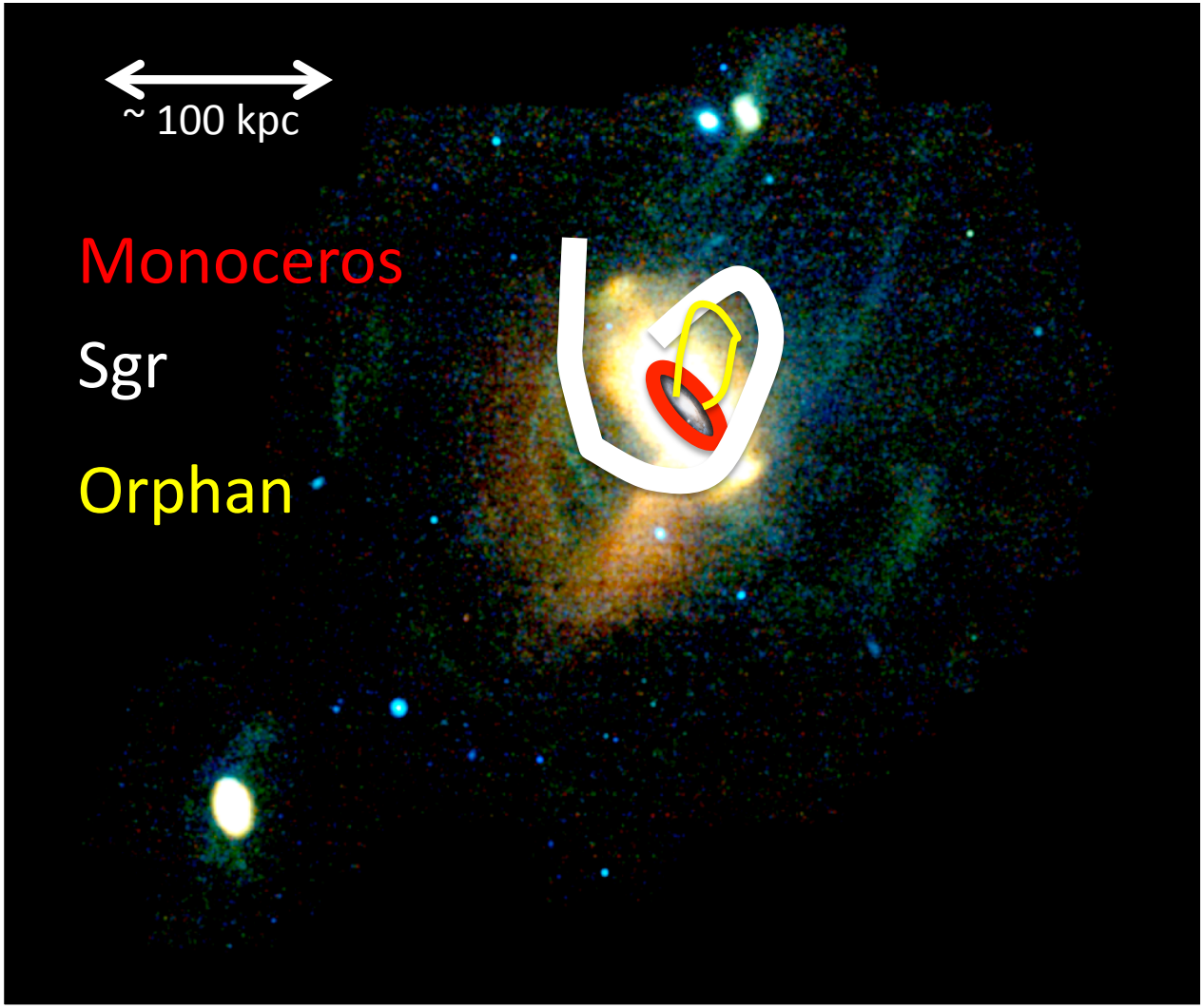


ξ (degrees)

M31 Halo Substructures

Name	L ($L_\odot$)	Extent	Morph-ology	Origin
Giant Stream	~ 5×10^9	20 × 200 kpc	Stream, shelf, shells	Disk disruption, high-ecc orbit
NW stream	~10^6	5 × 150 kpc	stream	Dwarf, low-ecc orbit

M31 *vs* MW



ξ (degrees)

Part I: Conclusion

Recent Histories

MW ⇔ ~ quiet

(but here comes the LMC)

M31 ⇔ ~ exciting

(and here comes M33)

Ancient Histories?

M31: deep CMD's (e.g. Brown et al), spectroscopic studies (e.g. SPLASH)

MW: GAIA, APOGEE, Hermes

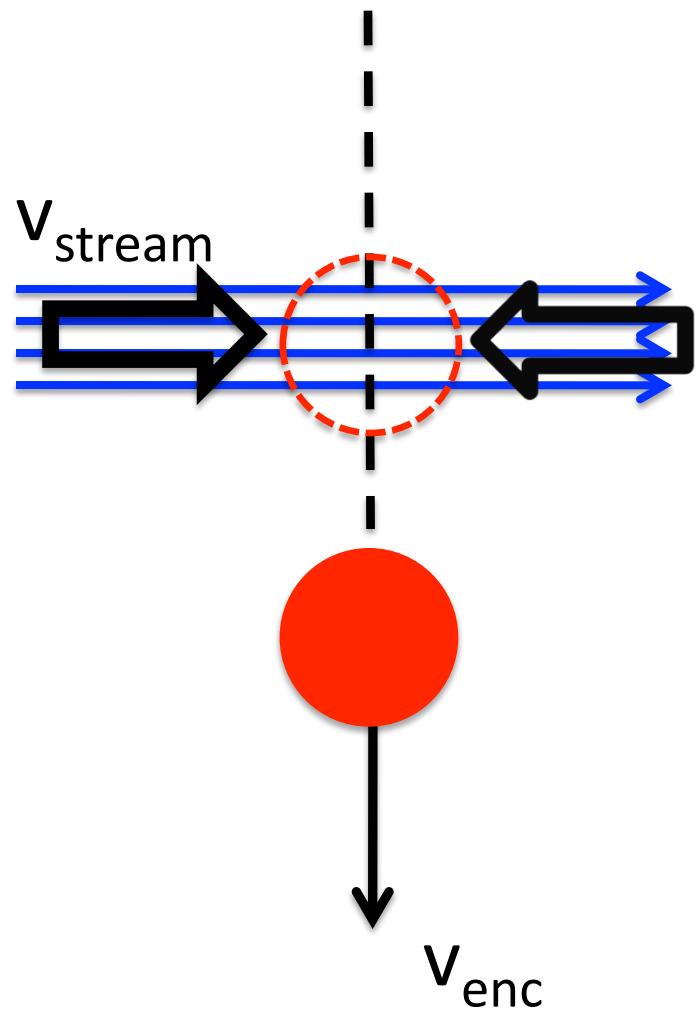
Part II:
Substructured Substucture

Finding what is “missing” from halos?

Dark Matter Subhalos and Streams

Impulsive velocity change

$\Delta v \sim G\, M_{sub} / r_{sub} v_{enc}$



➔ Impulsive energy change

$\Delta E = v_{stream}\, \Delta v + \frac{1}{2} \Delta v^2$

➔ gap in energy

+ time

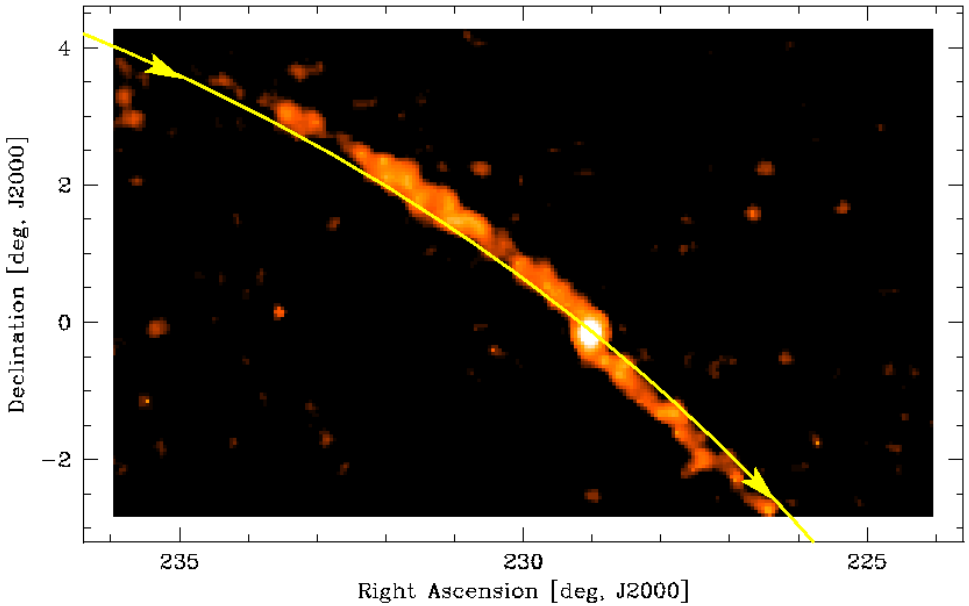
➔ gap in space

Carlberg et al 2011

Part II: Conclusion: Stream density variations ⇔ dark matter subhalos

Carlberg et al, 2011
1000 subhalos needed

Yoon, Johnston & Hogg, 2010
MW globular cluster streams probe "darkest" subhalos



Odenkirchen et al 2002

Breaking News

(from PAndAS infiltration team)

Maureen Teyssier

Kathryn V Johnston

Mike Kuhlen

Part III:
What WAS in the Halo?
Dynamical Histories of Local Group Objects

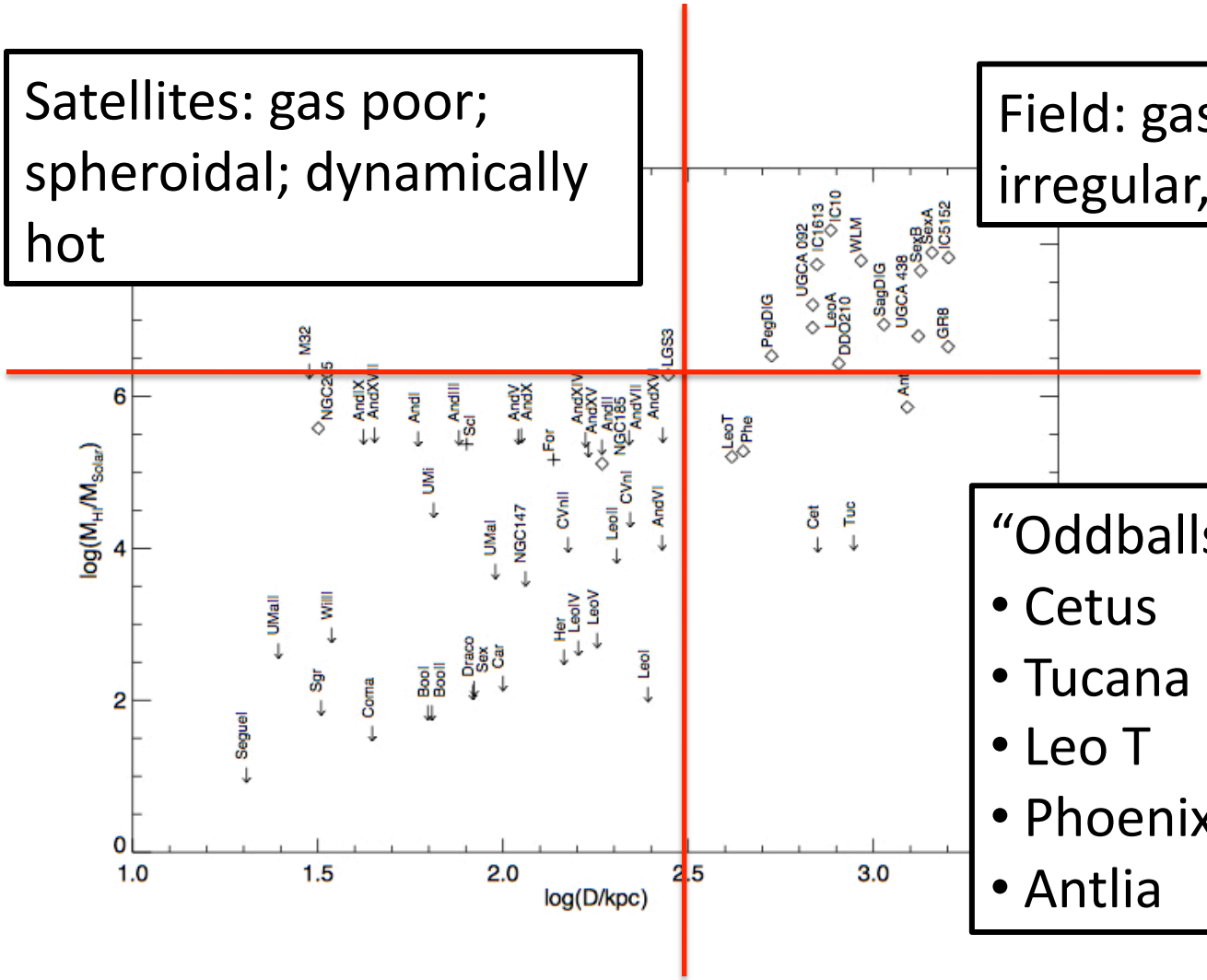
e.g. Local Group Dwarfs

Grcevich & Putman (2010)

(See also Grebel, Gallagher & Harbeck, 2003)

Satellites: gas poor; spheroidal; dynamically hot

Field: gas rich, irregular, rotators



"Oddballs"?:

- Cetus
- Tucana
- Leo T
- Phoenix
- Antlia

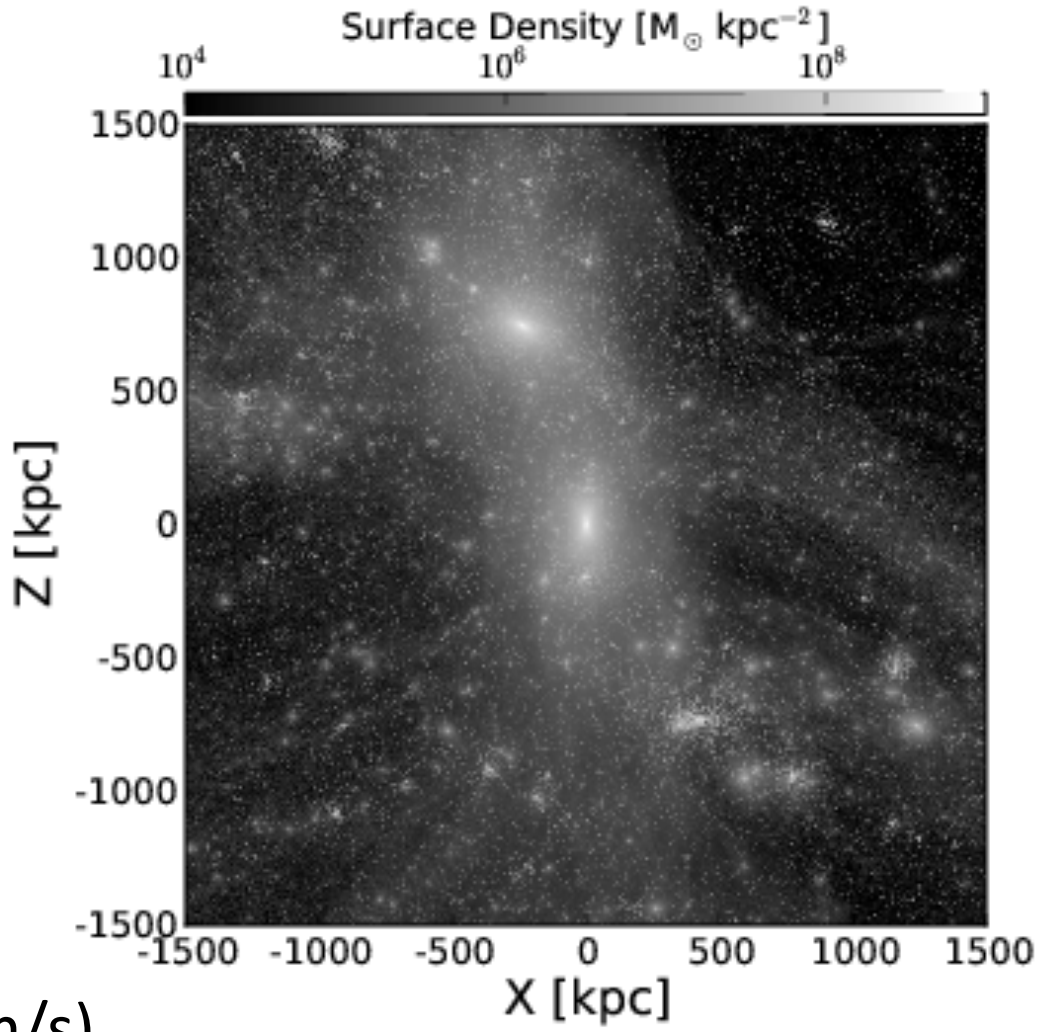
WHY?
Hierarchical Structure Formation

- Field dwarfs ➔ satellites (Mayer et al, Lokas et al, D'Onghia et al)
  - tidal heating
  - gas stripping
  - morphological transformation

- Oddballs ⇔ "backsplash galaxies" (Gill et al, Sales et al, Ludlow et al, Warnick et al, Knebe et al)
  - were within R_{vir} at earlier times

e.g. Via Lactea II

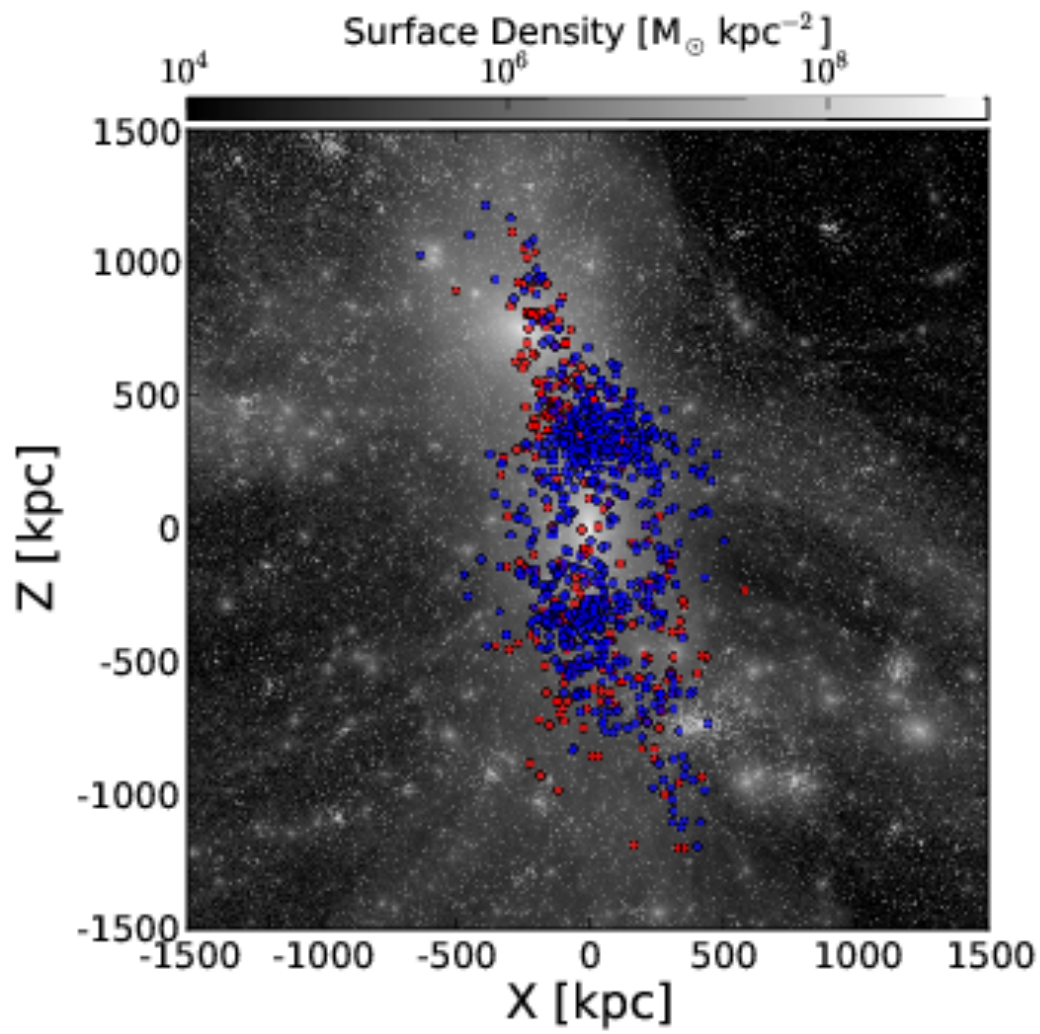
- 13,512 “star-forming” subhalos at z=4.56
- 10,053 survive at z=0
  - 1534 satellites
  - 8519 R > R_{vir}
- Note – M31 analogue
  - Mass = 6.5×10^{11} Msun (1.2×10^{12} Msun)
  - Distance = 833 kpc (785 kpc)
  - v_{los}= -60 km/s (-122 km/s)
  - V_{tan}= 102 km/s (17 km/s)

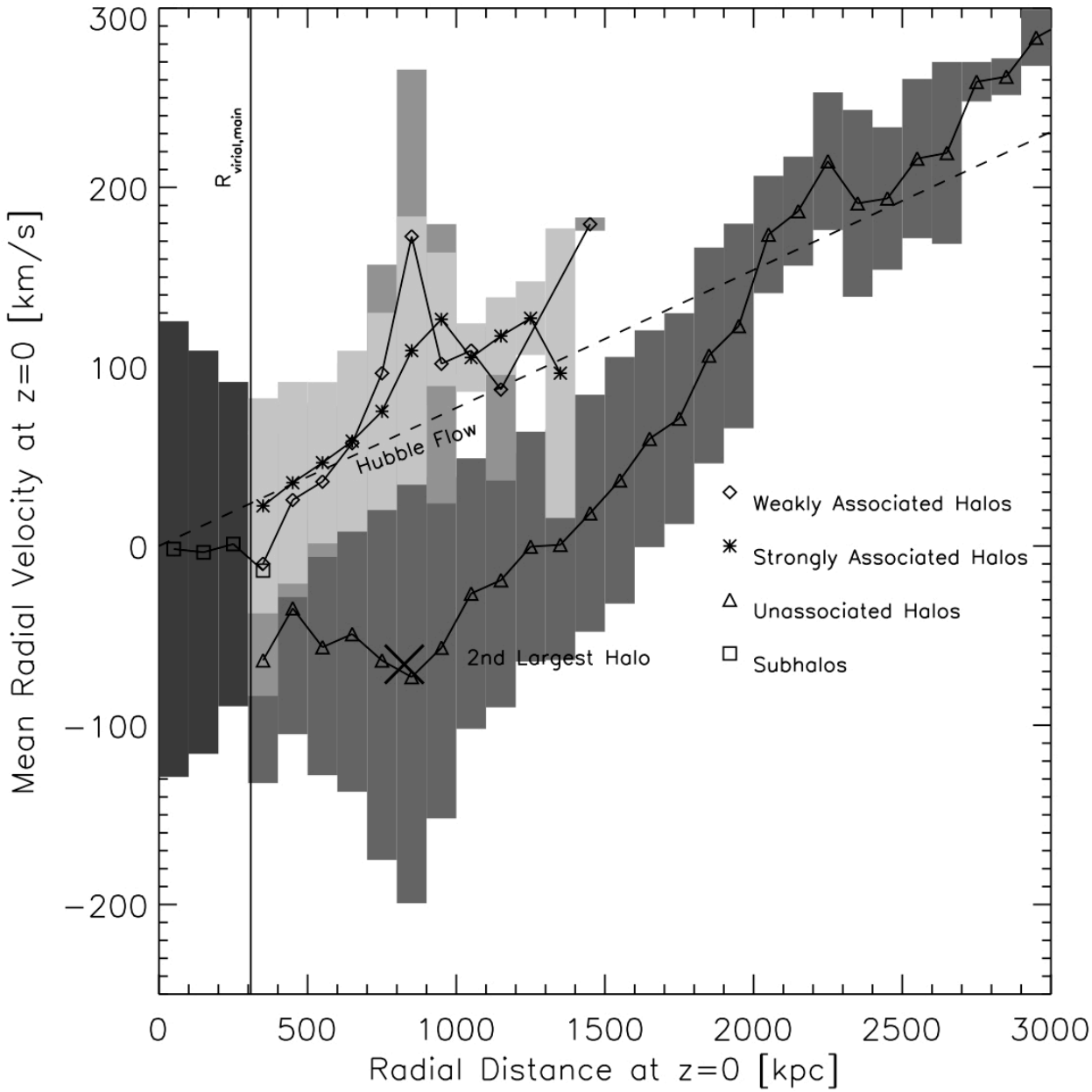


Backsplash Galaxies in Via Lactea II

Backsplash properties at z=0:

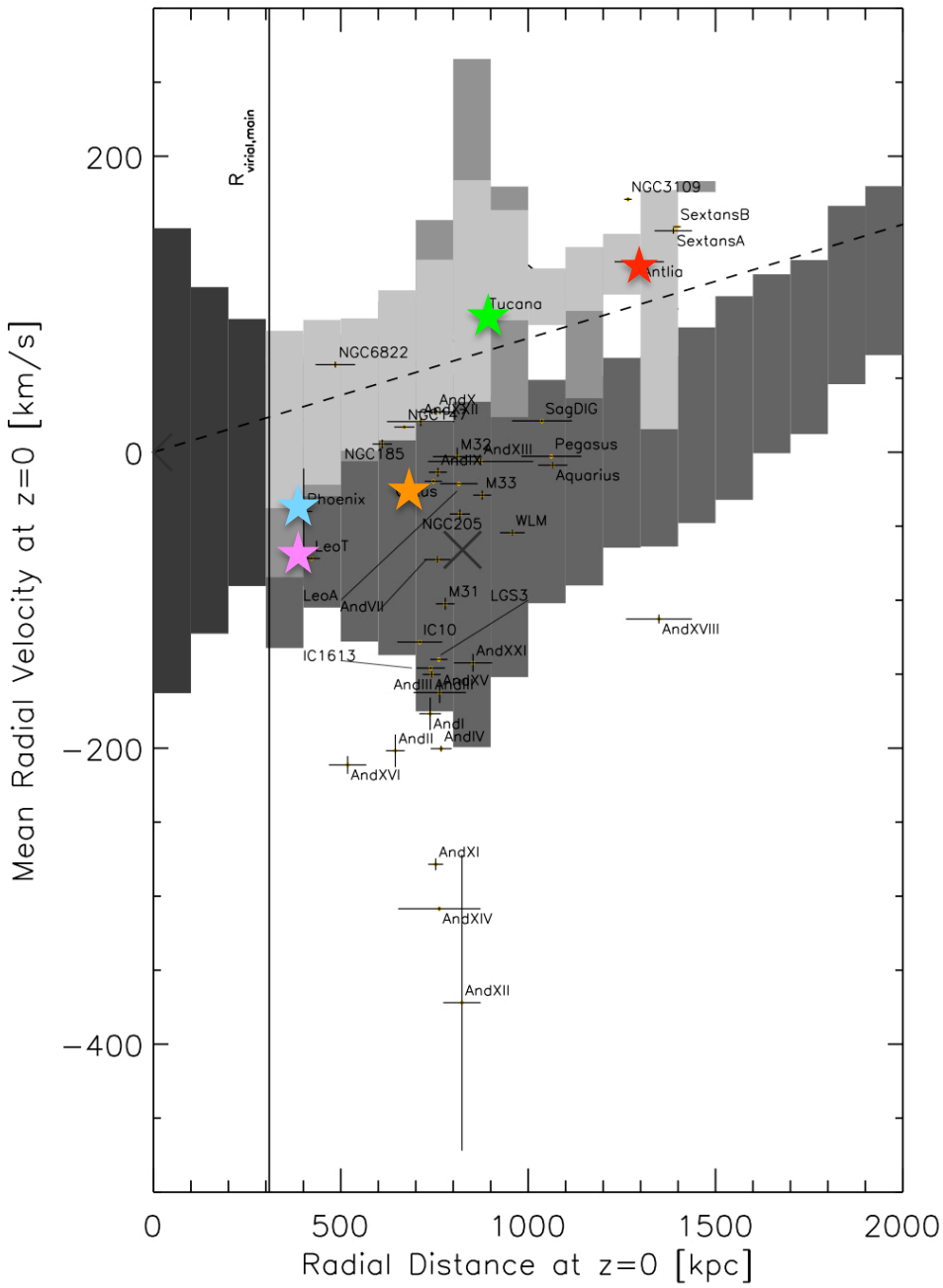
- n≈1000
- d < 5 R_{vir}
- 13% of all field subhalos
- clustered around parent
- no mass dependence
- ~5% "renegades" bound to "M31"





Identifying Backsplash Galaxies

Identifying Backsplash Galaxies



"Oddballs"?:

- Cetus (0.17)
- Tucana (1.0)
- Leo T (0.74)
- Phoenix (0.74)
- Antlia (1.0)

() = simulated fraction backsplash/field in same (d,v) bin

Part III: Conclusion

VL II ⇔ positions and speeds of subhalos provide indication of dynamical history

↓

"Oddballs" in Local Group match properties expected for "backsplash galaxies"

↓

Strong support for scenarios where "oddballs" are due to past interaction with Milky Way