Planes of satellite galaxies: a dynamical study

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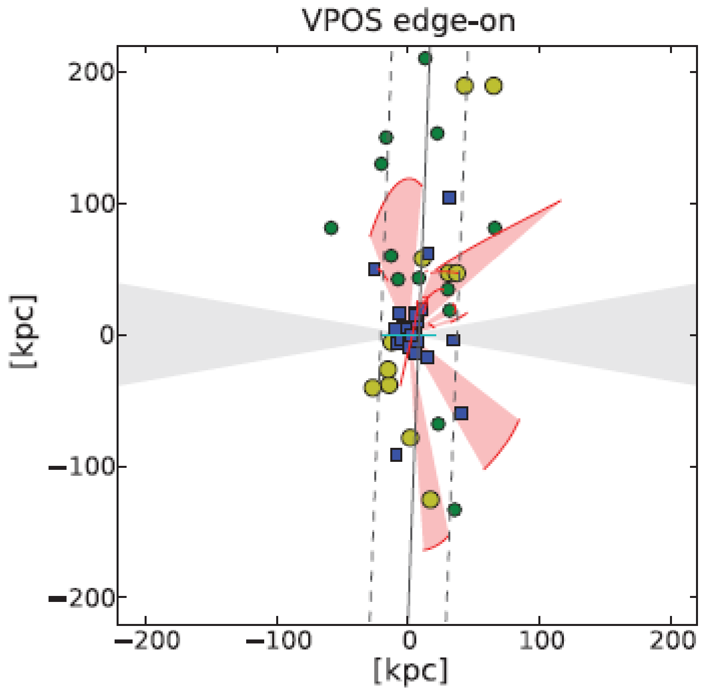
Image: http://www.spacetelescope.org/images/potw1301a/

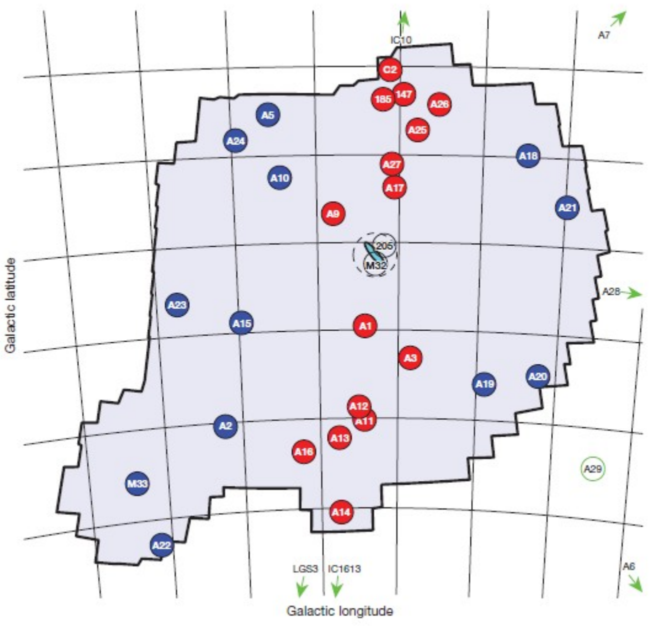
Satellite Galaxies:
Anisothropic distribution

Milky Way



Pawlowski et al. 2012
Linden-Bell 1976

Andromeda

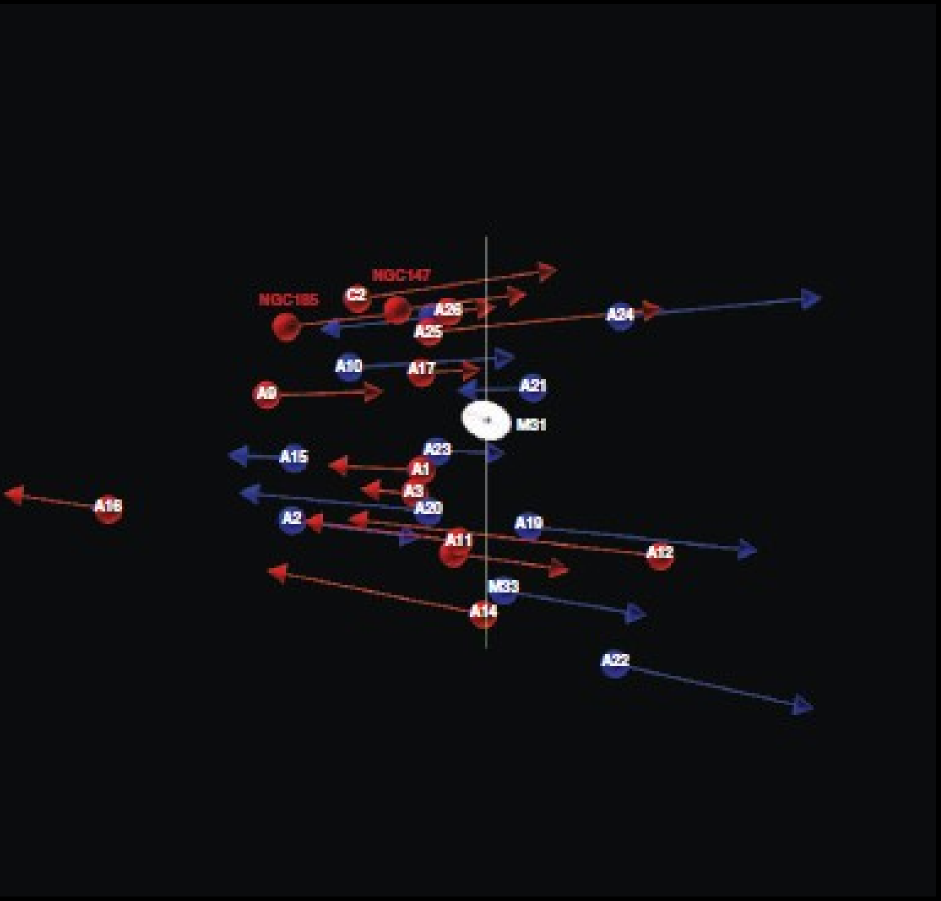


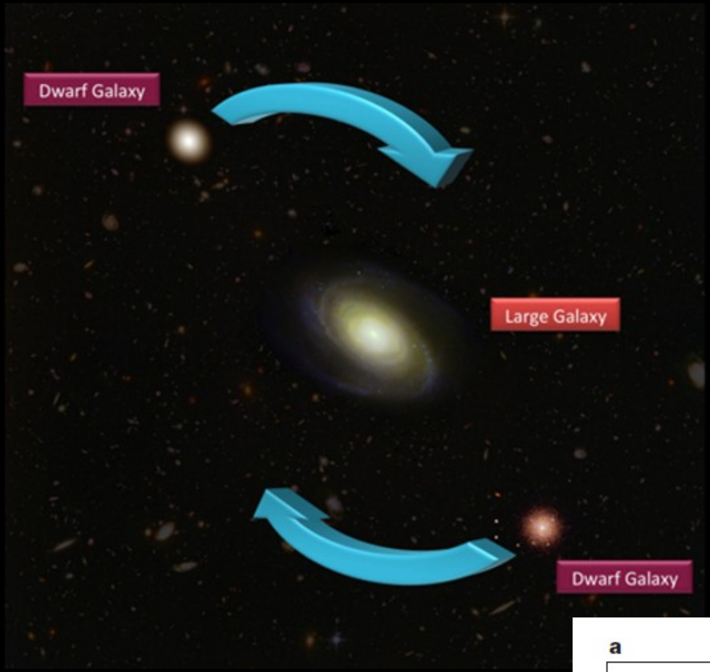
Ibata et al. 2013
Conn et al. 2013

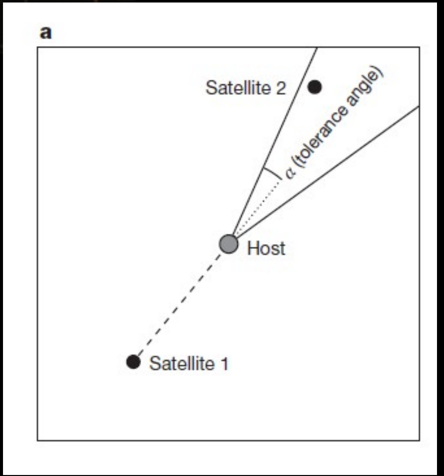
Evidence of corotation:

In Andromeda

In other galaxies







Ibata et al. 2013, Collins et al. 2013

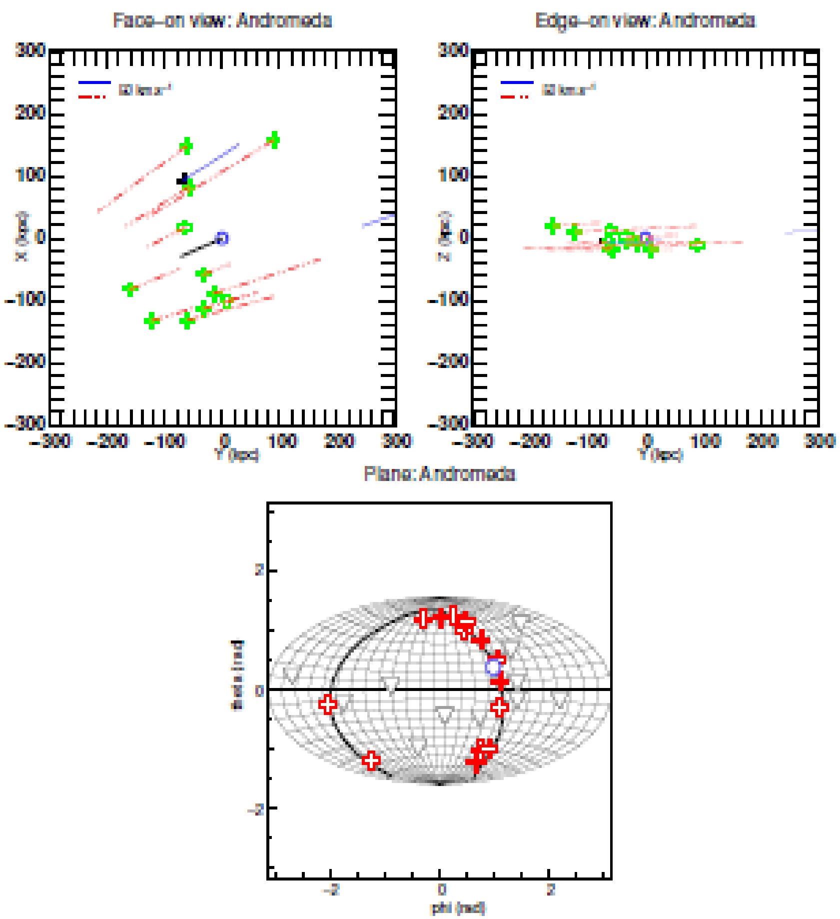
Ibata et al. 2014

Looking for plane in the simulations:

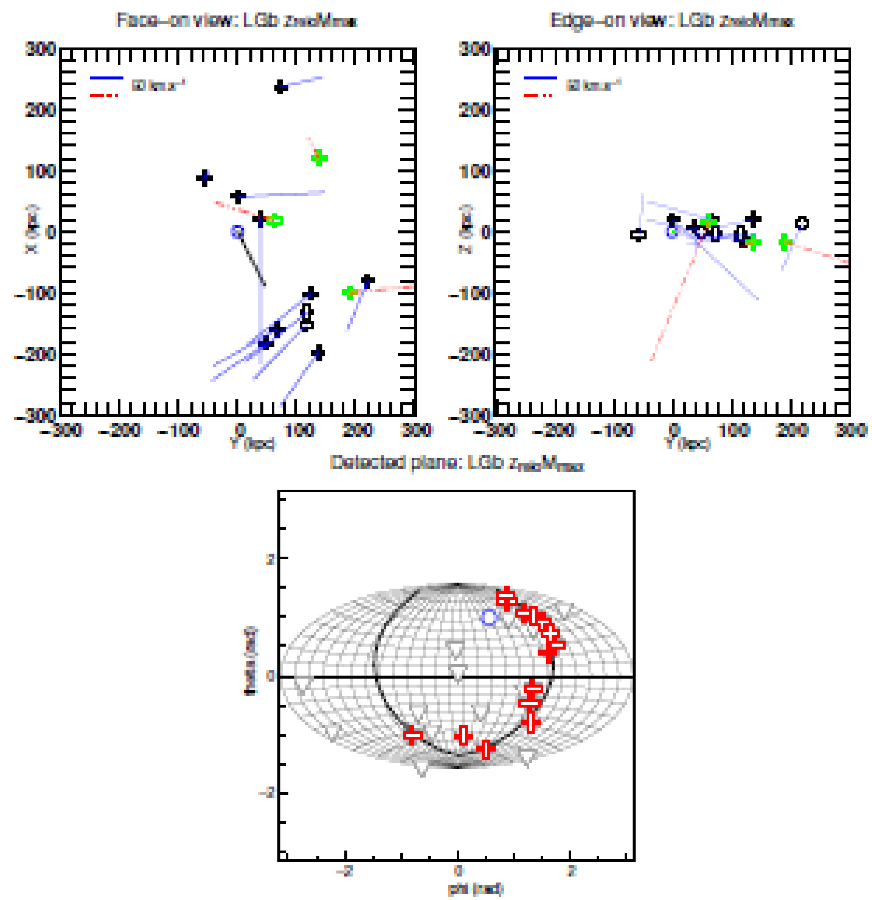
Millenium II, Aquarius. Not really

In CLUES Gillet et al. (2015) found planes (se also Buck et al 2015, Sawalla et al. 2015)

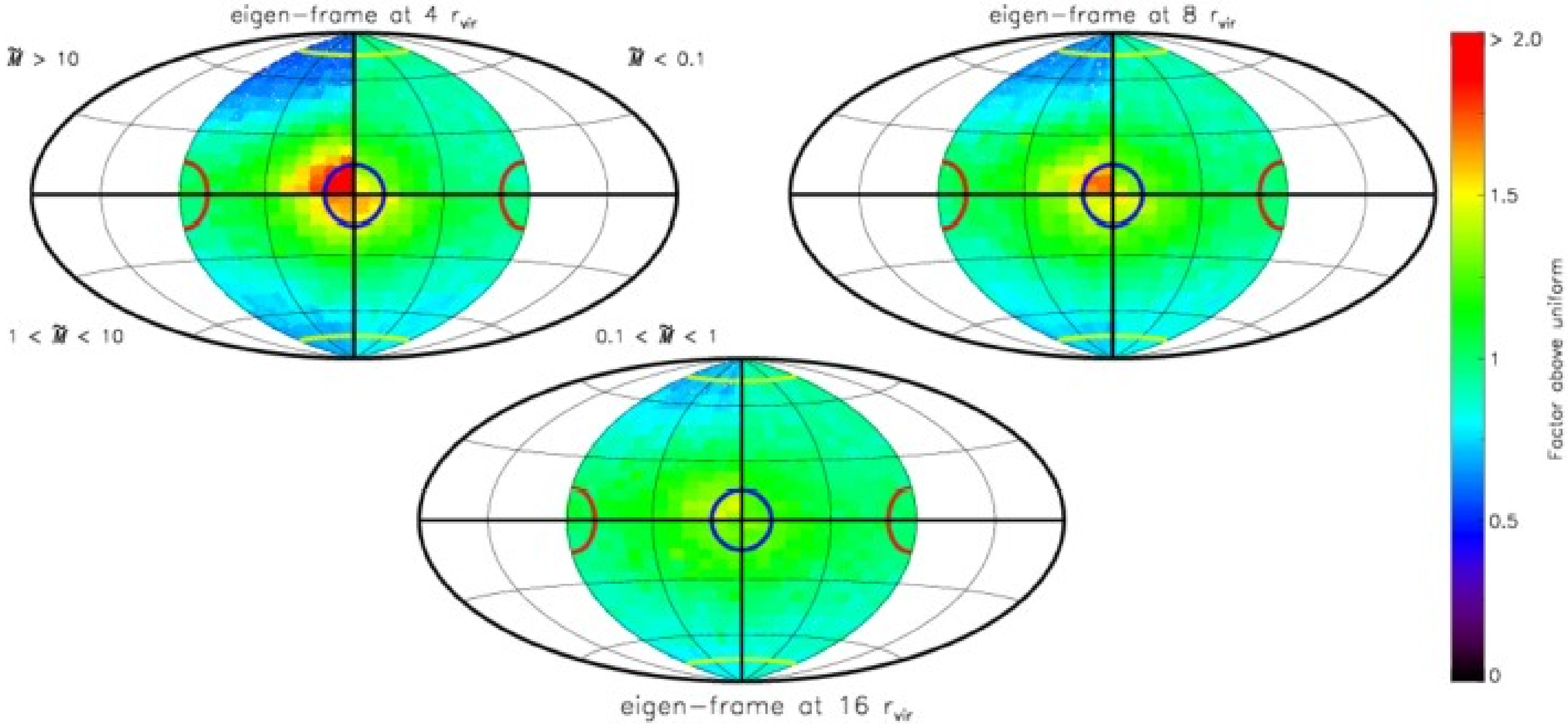
Observationss (Andrómeda)



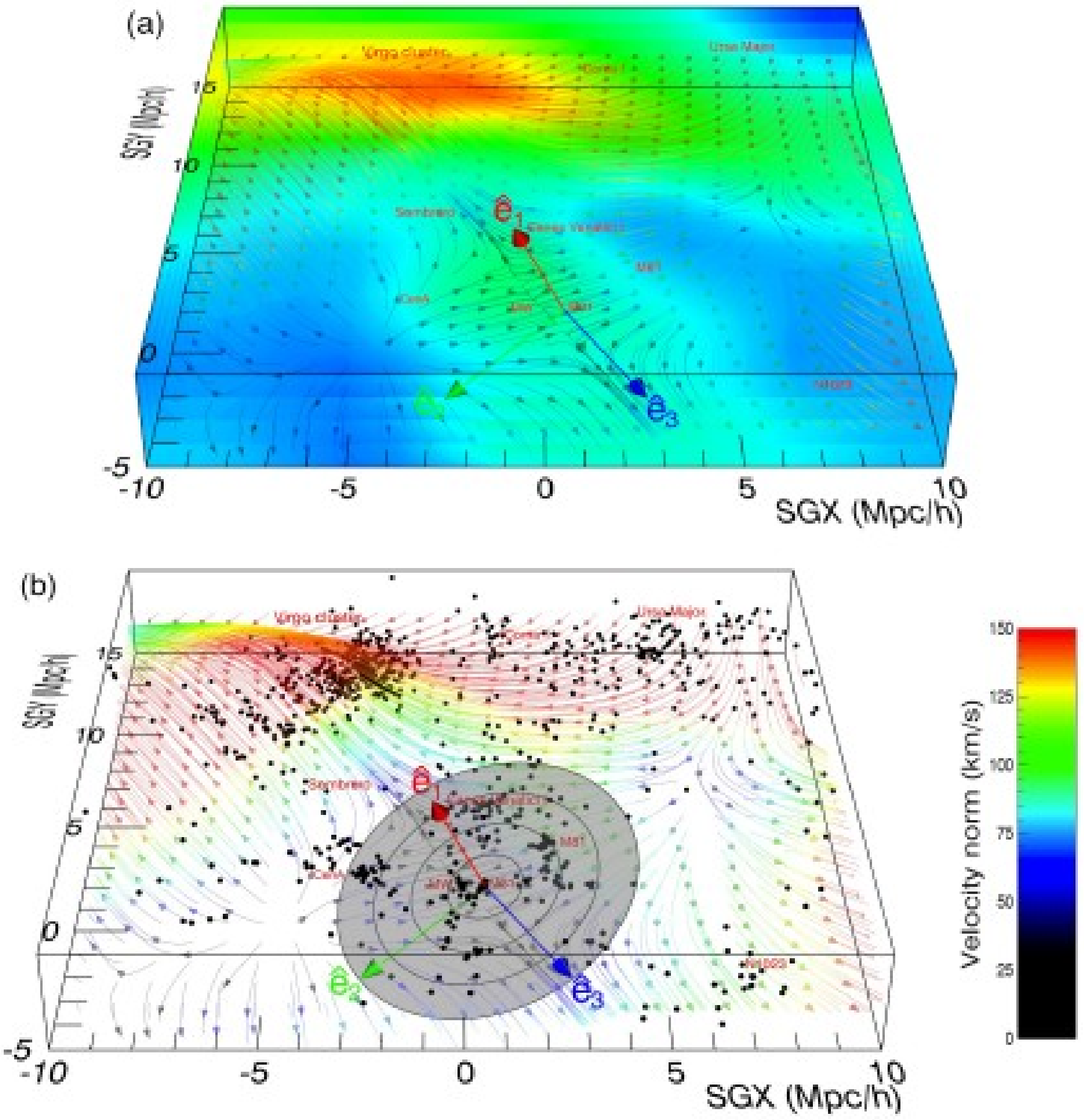
Simulations (CLUES)



Libeskind et al. 2014,
Kubik(in this meeting)



Alignments with the large scale structure (observational)



Liebeskind et al. 2015

My aproach:

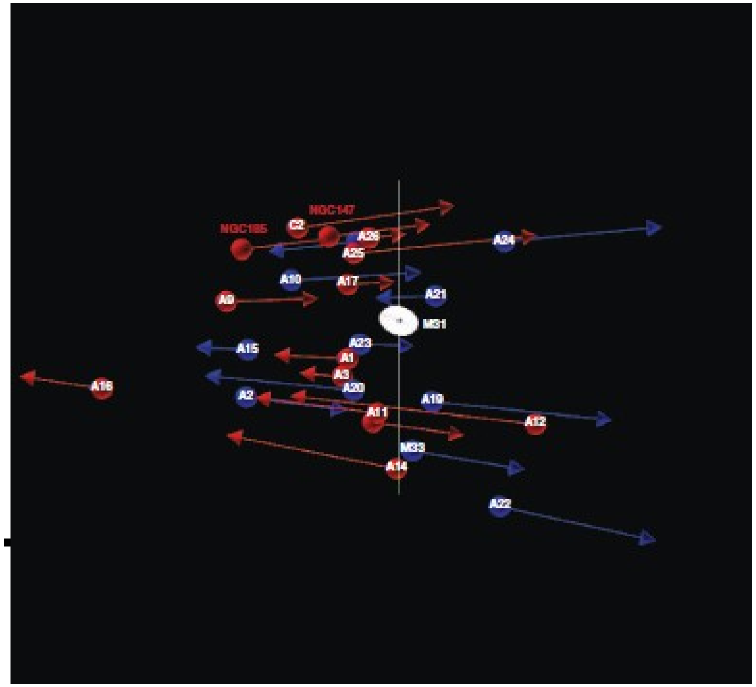
Find the orbits of the Andromeda satellites

We have:

* positions

* radial velocities

Ibata et al. 2013, Conn et al. 2012, Collins et al 2013, Tollerud et al 2012)



Unknown:

* Tangential velocities

Rigid potential for Andromeda
+
Point mass approximation for the satellites
=
Orbit integration

$$\Phi_{\rm halo}(r) = -\frac{\rm GM_{halo}}{r}\log\left(\frac{r}{r_{\rm halo}} + 1\right)$$

$$\Phi_{\rm disk}(r) = -2\pi G\Sigma_0 r_{\rm disk}{}^2\left[\frac{1-\exp^{-r/r_{\rm disk}}}{r}\right]$$

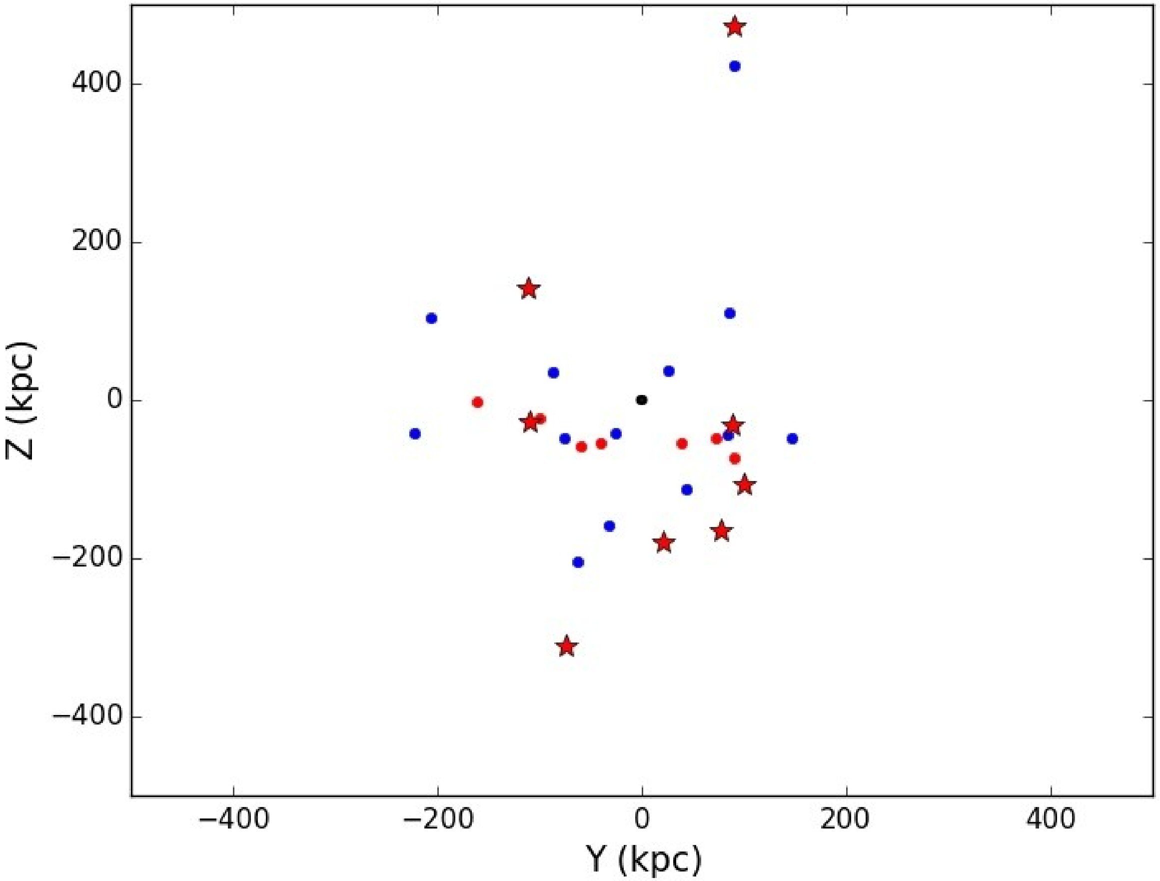
$$\Phi_{\rm bulge}(r) = -\frac{\rm GM_{bulge}}{r_{\rm bulge}+r}$$

	M31
$\rm M_{bulge}$	$2.86 \times 10^{10}\ \rm M_\odot$
$\rm r_{bulge}$	0.61 kpc
$\rm M_{disk}$	$8.4 \times 10^{10}\ \rm M_\odot$
$\rm r_{disk}$	5.4 kpc
Σ_0	$4.6 \times 10^8\ \rm M_\odot kpc^{-2}$
$\rm M_{halo}$	$103.7 \times 10^{10}\ \rm M_\odot$
$\rm r_{halo}$	13.5 kpc

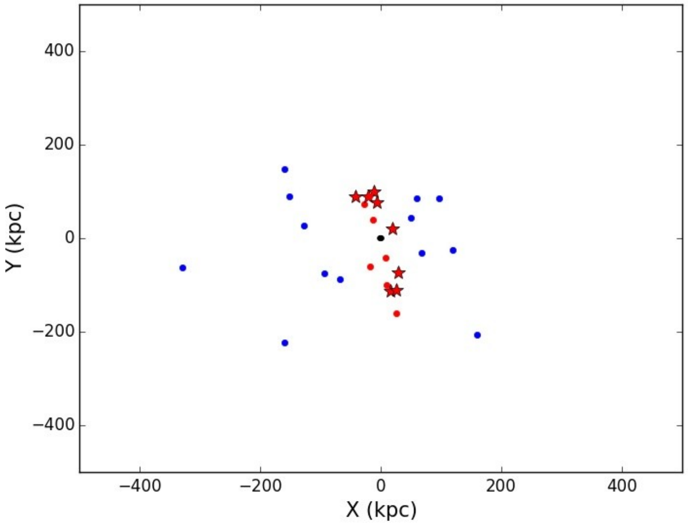
Geehan et al. (2006)

We have the positions

Plane face-on



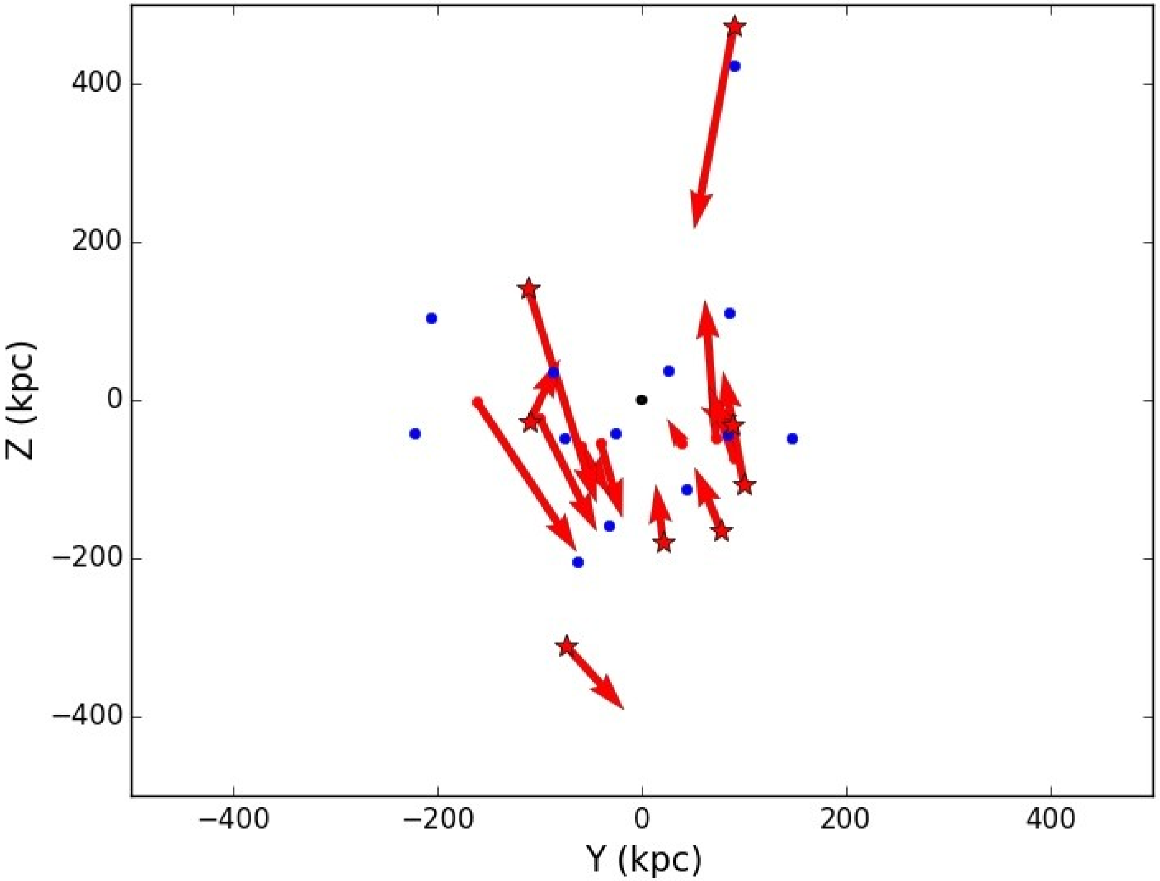
Plane edge-on
(as observed)



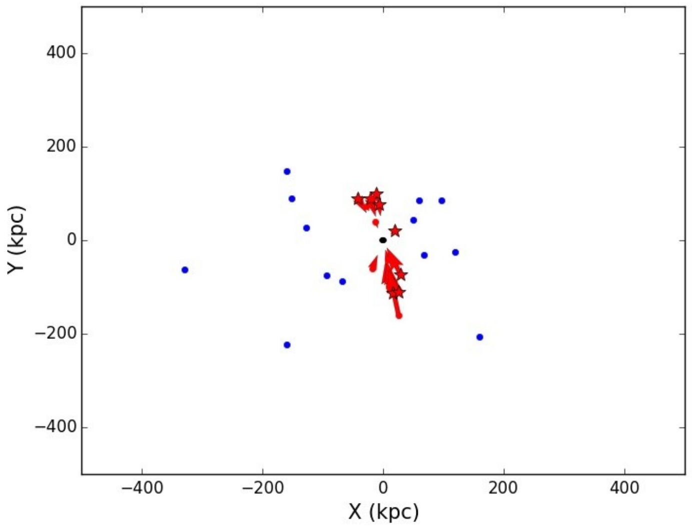
MW

We have the line of sight velocities

Plane face-on



Plane edge-on
(as observed)



MW

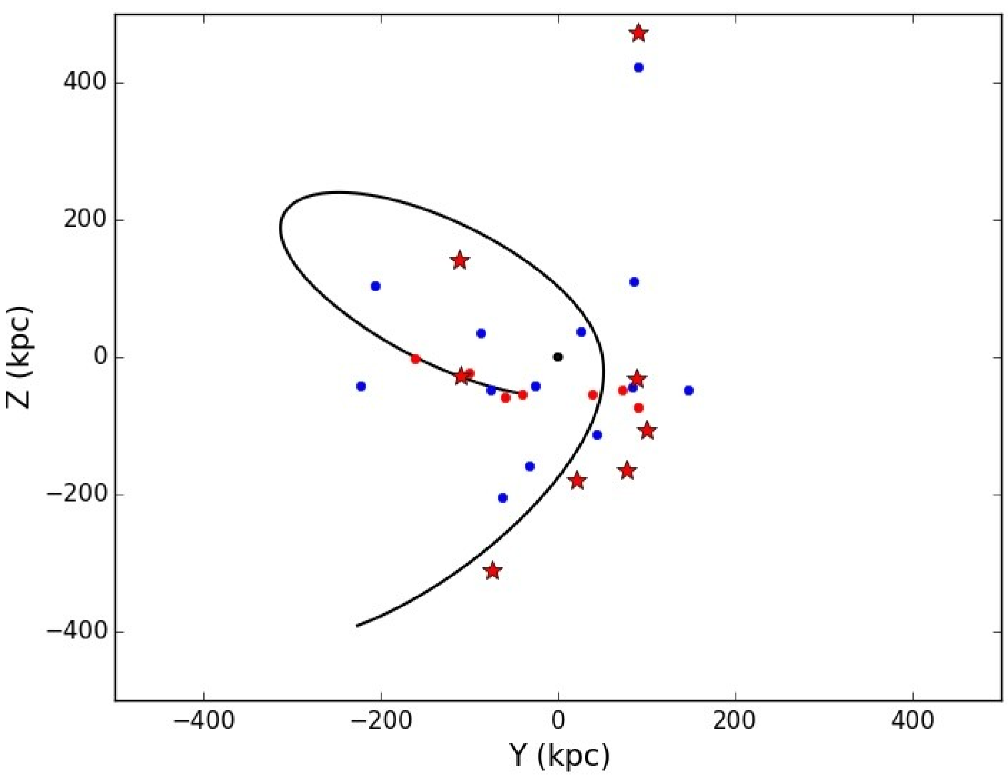
We construct a tangential velocity

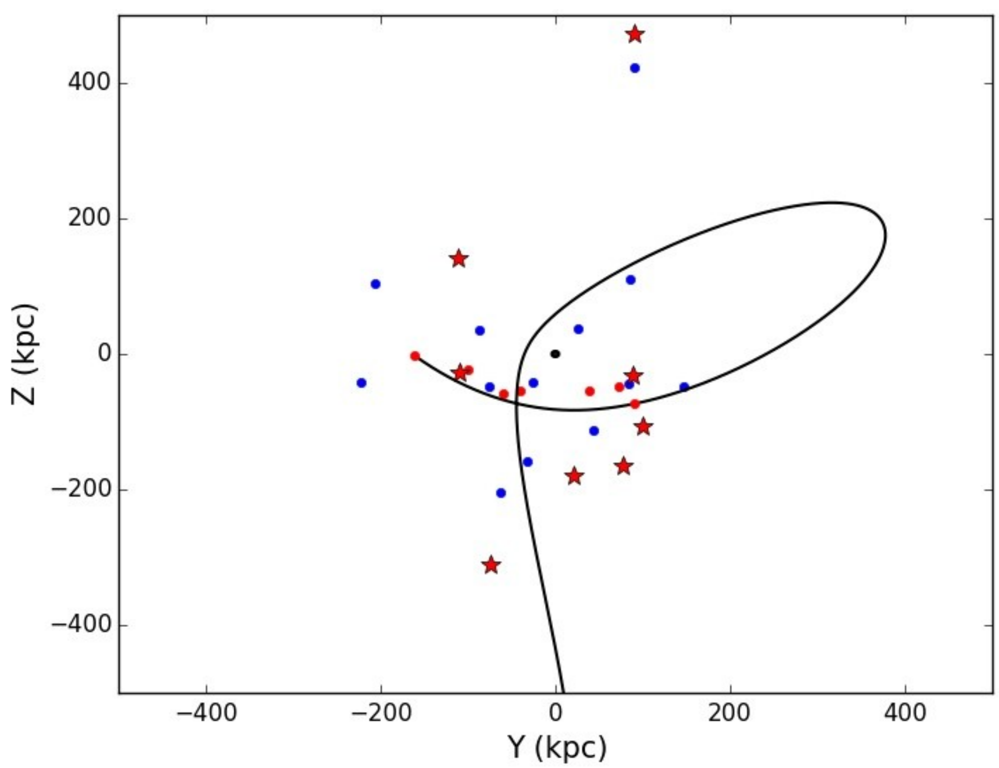
Assuming that the total velocity is on the plane

Magnitude of the tangential velocity is the only free parameter

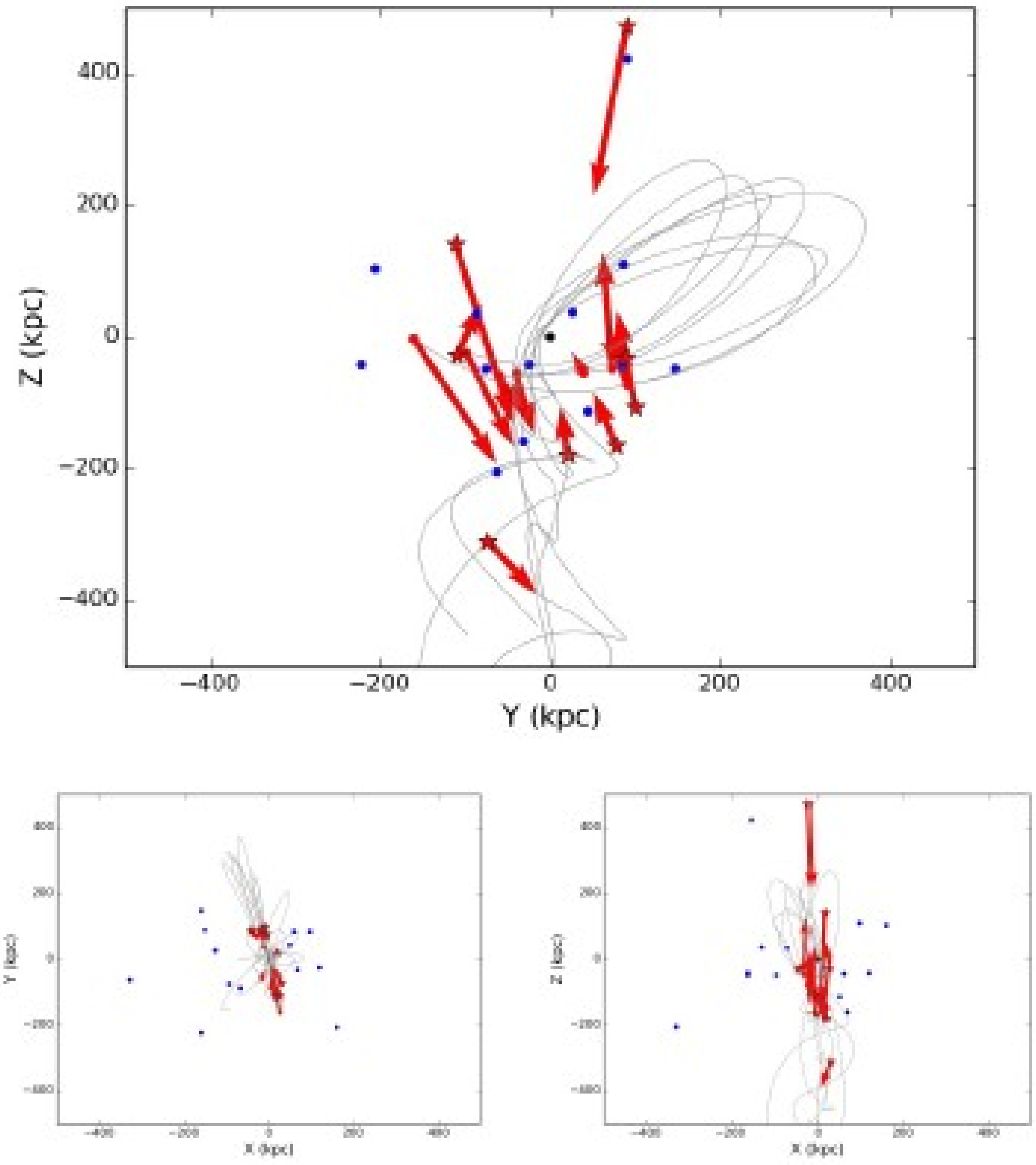
When we explore the **possible magnitudes** of the tangential velocity we find that:

For a certain tangential velocity some resulting orbits go through most of the plane satellites





For 8 out of 15 satellites we found such orbits



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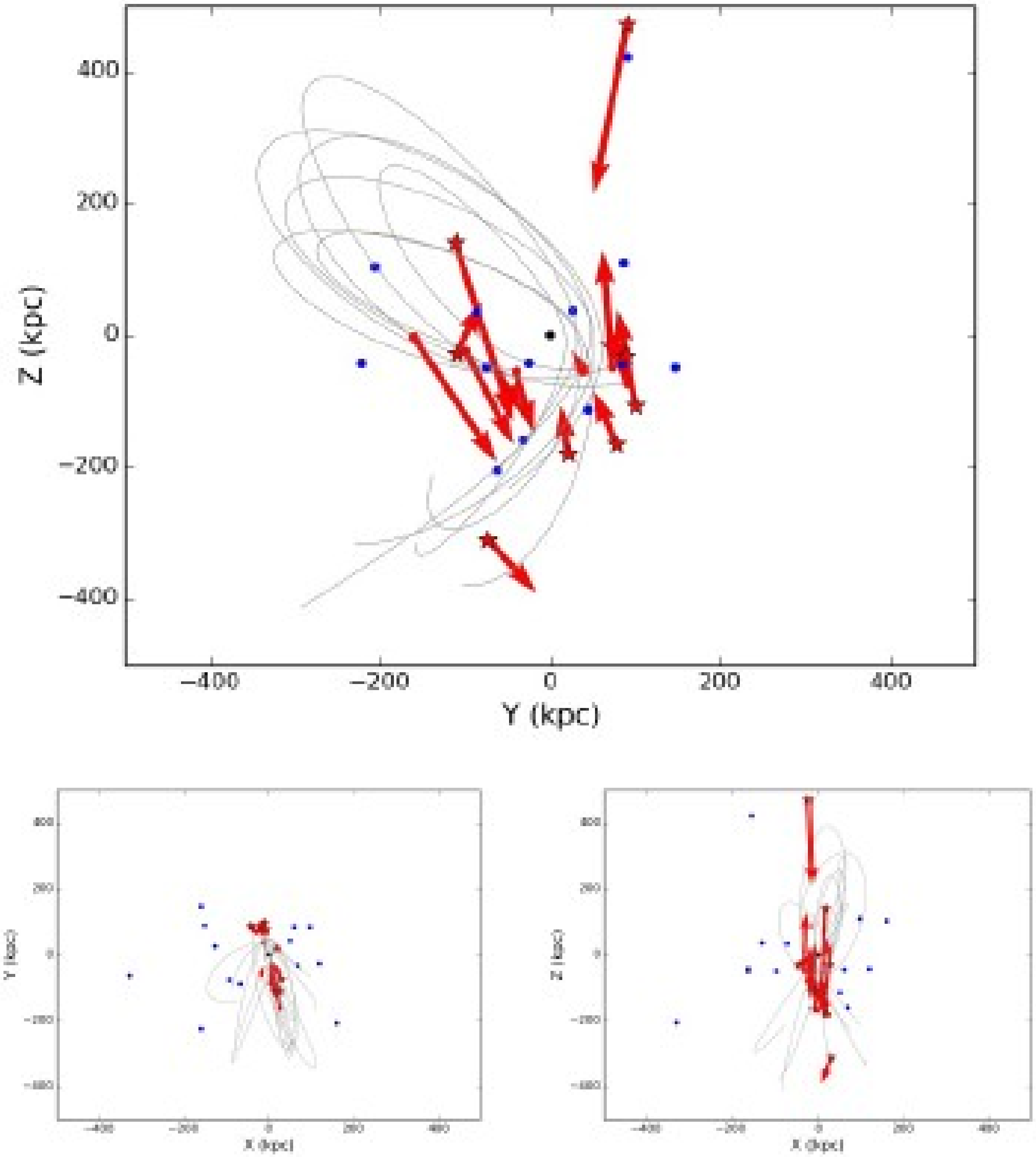


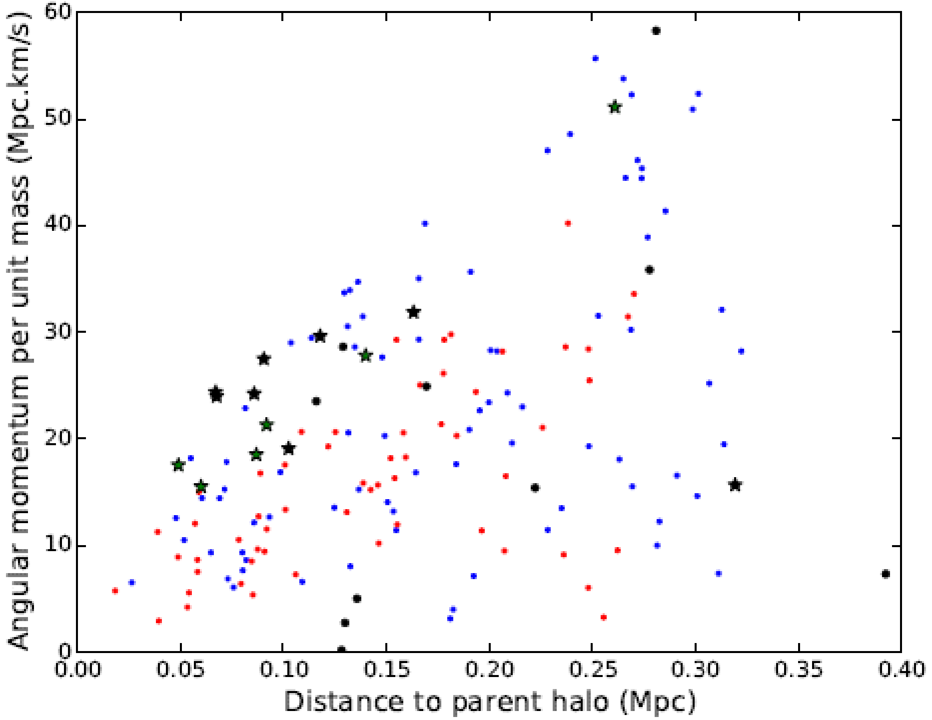
These results are puzzling
(but remember the big assumption)

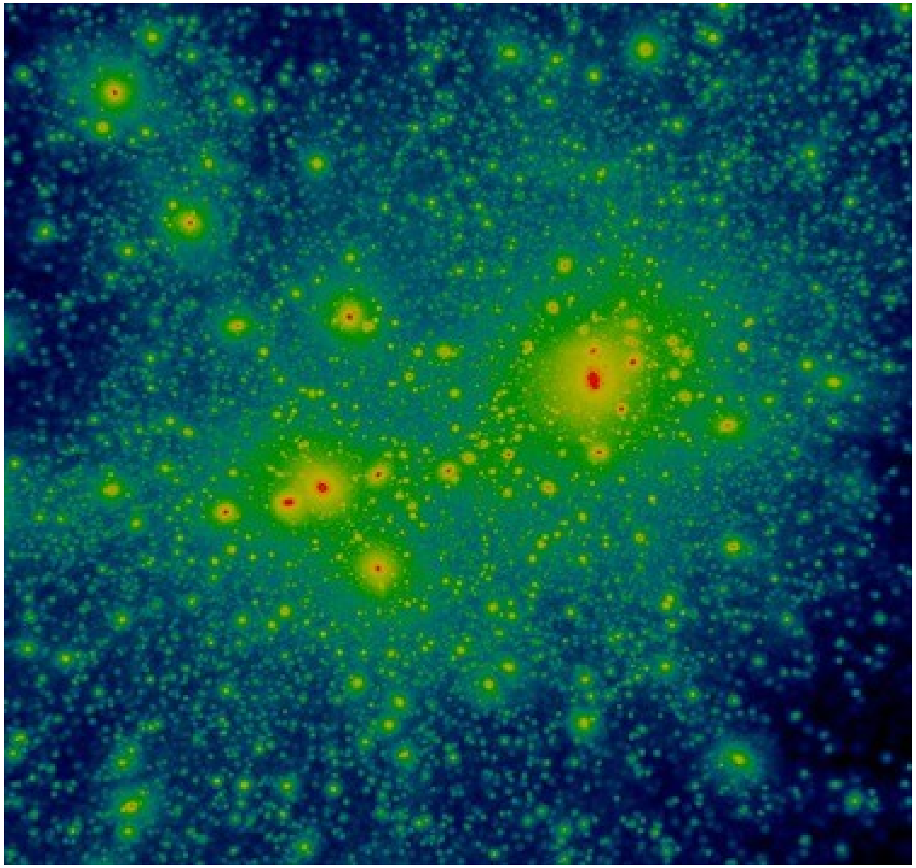
How does such an organized structure form?

We plan to use cosmological simulations to answer this question.

Work in progress...

Comparison with ELVIS

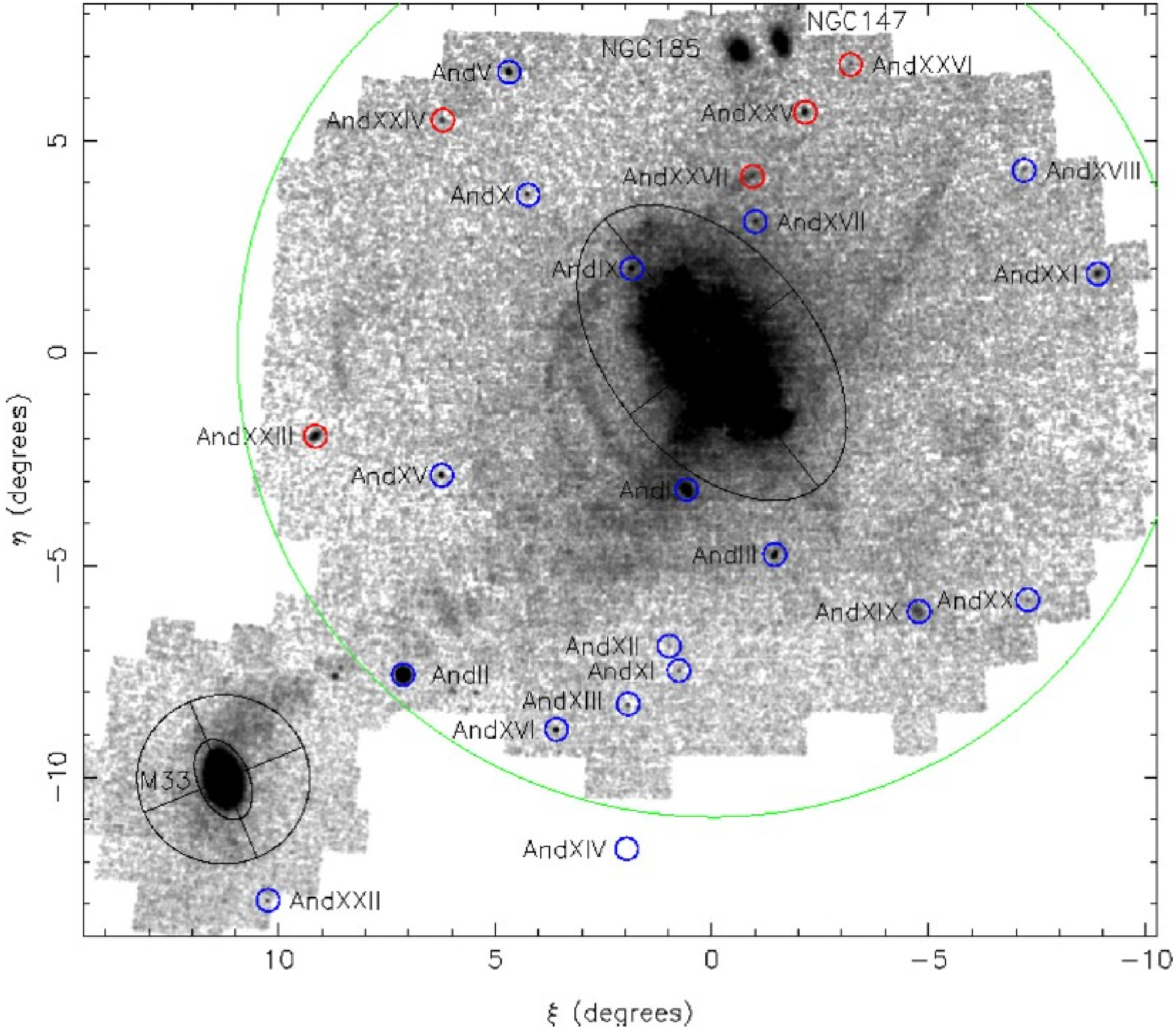




Next step:

Use Clues to explore the orbits of satellites

PAndAS survey: Andromeda



Lewis et al. 2013 (image)
McConnachie et al. 2013

Propiedades de las galaxias satélite de Andrómeda:

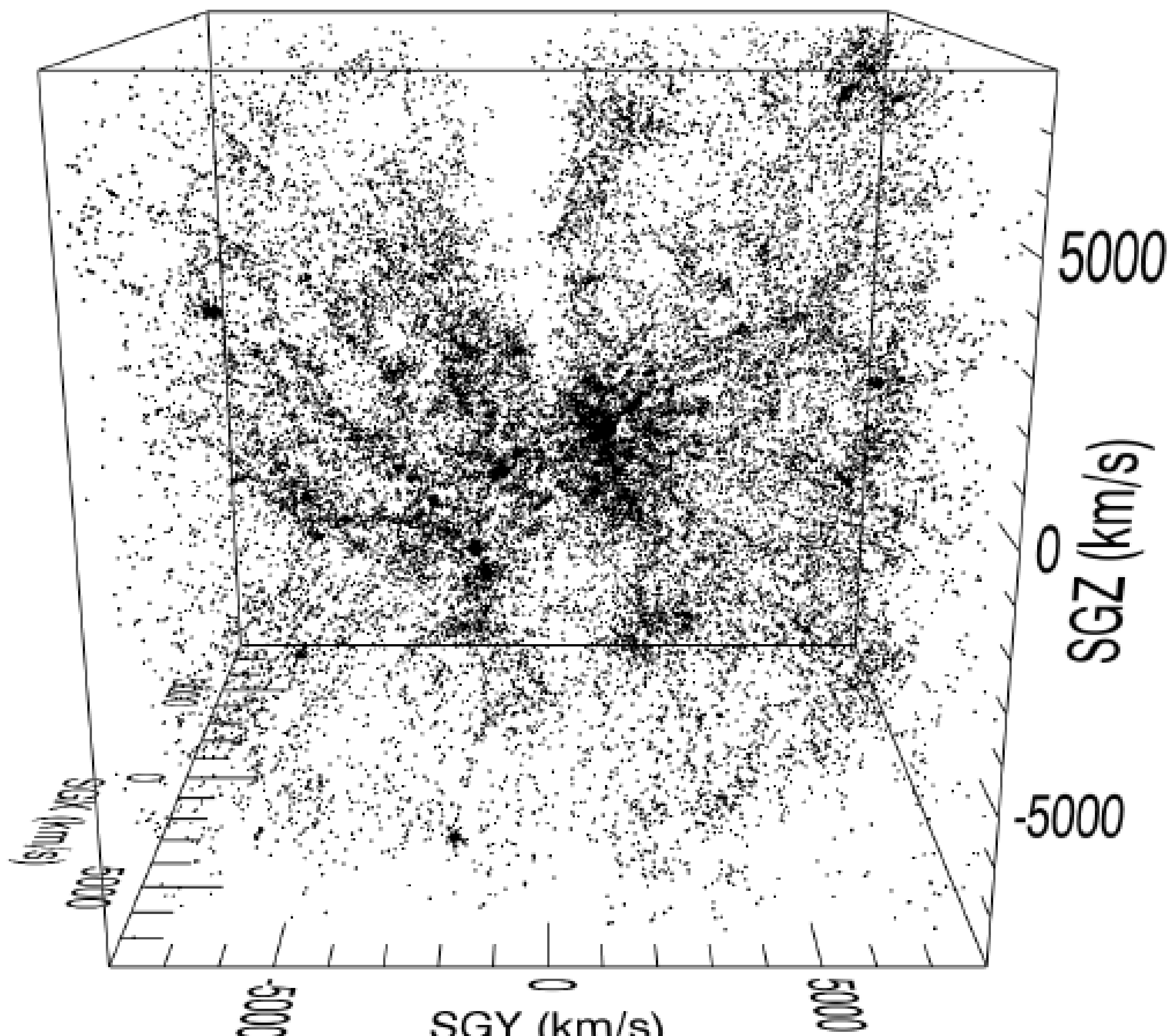
THE ASTROPHYSICAL JOURNAL, 768:172 (36pp), 2013 May 10 COLLINS ET AL.

Table 4
Kinematic Properties of Andromeda dSph Galaxies as Derived within This Work, from Keck I/LRIS, and Keck II/DEIMOS Data

Property	η	v_r (km s^{-1})	σ_v (km s^{-1})	M_{half} ($10^7 M_\odot$)	$[M/L]_{half}$ ($M_\odot/L_\odot$)	$[Fe/H]_{spec}$
And V	2.0	-391.5 ± 2.7	$12.2^{+2.5}_{-1.9}$	$2.6^{+0.66}_{-0.56}$	$88.4^{+22.3}_{-18.9}$	-2.0 ± 0.1
And VI	2.5	-339.8 ± 1.8	$12.4^{+1.5}_{-1.3}$	4.7 ± 0.7	$27.5^{+4.2}_{-3.9}$	-1.5 ± 0.1
And XI	2.5	$-427.5^{+3.5}_{-3.4}$	$7.6^{+4.0(*)}_{-2.8}$	$0.53^{+0.28}_{-0.21}$	216^{+115}_{-87}	-1.8 ± 0.1
And XII	2.5	-557.1 ± 1.7	$0.0^{+4.0}$	$0.0^{+0.3}$	0.0^{+194}	-2.2 ± 0.2
And XIII	2.5	-204.8 ± 4.9	$0.0^{+8.1(*)}$	$0.0^{+0.7}$	0.0^{+330}	-1.7 ± 0.3
And XVII	2.5	$-251.6^{+1.8}_{-2.0}$	$2.9^{+2.2}_{-1.9}$	$0.13^{+0.22}_{-0.13}$	12^{+22}_{-12}	-1.7 ± 0.2
And XVIII	2.5	-346.8 ± 2.0	$0.0^{+2.7}$	$0.0^{+0.14}$	0^{+5}	-1.4 ± 0.3
And XIX	2.0	$-111.6^{+1.6}_{-1.4}$	$4.7^{+1.6}_{-1.4}$	$1.9^{+0.65}_{-0.66}$	84.3^{+37}_{-38}	-1.8 ± 0.3
And XX	2.5	$-456.2^{+3.1}_{-3.6}$	$7.1^{+3.9(*)}_{-2.5}$	$0.33^{+0.20}_{-0.12}$	$238.1^{+147.6}_{-90.2}$	-2.2 ± 0.4
And XXI	5.0	-362.5 ± 0.9	$4.5^{+1.2}_{-1.0}$	$0.99^{+0.28}_{-0.24}$	$25.4^{+9.4}_{-8.7}$	-1.8 ± 0.1
And XXII	2.0	-129.8 ± 2.0	$2.8^{+1.9}_{-1.4}$	$0.11^{+0.08}_{-0.06}$	$76.4^{+58.4}_{-48.1}$	-1.8 ± 0.6
And XXIII	4.0	-237.7 ± 1.2	7.1 ± 1.0	2.9 ± 4.4	58.5 ± 36.2	-2.2 ± 0.3
And XXIV	1.5	-128.2 ± 5.2	$0.0^{+7.3(*)}$	$0.4^{+0.7}_{-0.4}$	82^{+157}_{-82}	-1.8 ± 0.3
And XXV	2.5	-107.8 ± 1.0	$3.0^{+1.2}_{-1.1}$	$0.34^{+0.14}_{-0.12}$	$10.3^{+7.0}_{-6.7}$	-1.9 ± 0.1
And XXVI	3.0	$-261.6^{+3.0}_{-2.8}$	$8.6^{+2.8(*)}_{-2.2}$	$0.96^{+0.43}_{-0.34}$	325^{+243}_{-225}	-1.8 ± 0.5
And XXVII	1.5	$-539.6^{+4.7}_{-4.5}$	$14.8^{+4.3}_{-3.1}$	$8.3^{+2.8}_{-3.9}$	1391^{+1039}_{-1128}	-2.1 ± 0.5
And XXVIII	2.5	-326.2 ± 2.7	$6.6^{+2.9}_{-2.1}$	$0.53^{+0.28}_{-0.21}$	51^{+30}_{-25}	-2.1 ± 0.3
And XXX (Cass II)	2.0	$-139.8^{+6.0}_{-6.6}$	$11.8^{+7.7}_{-4.7}$	$2.2^{+1.4}_{-0.9}$	308^{+269}_{-219}	-1.7 ± 0.4

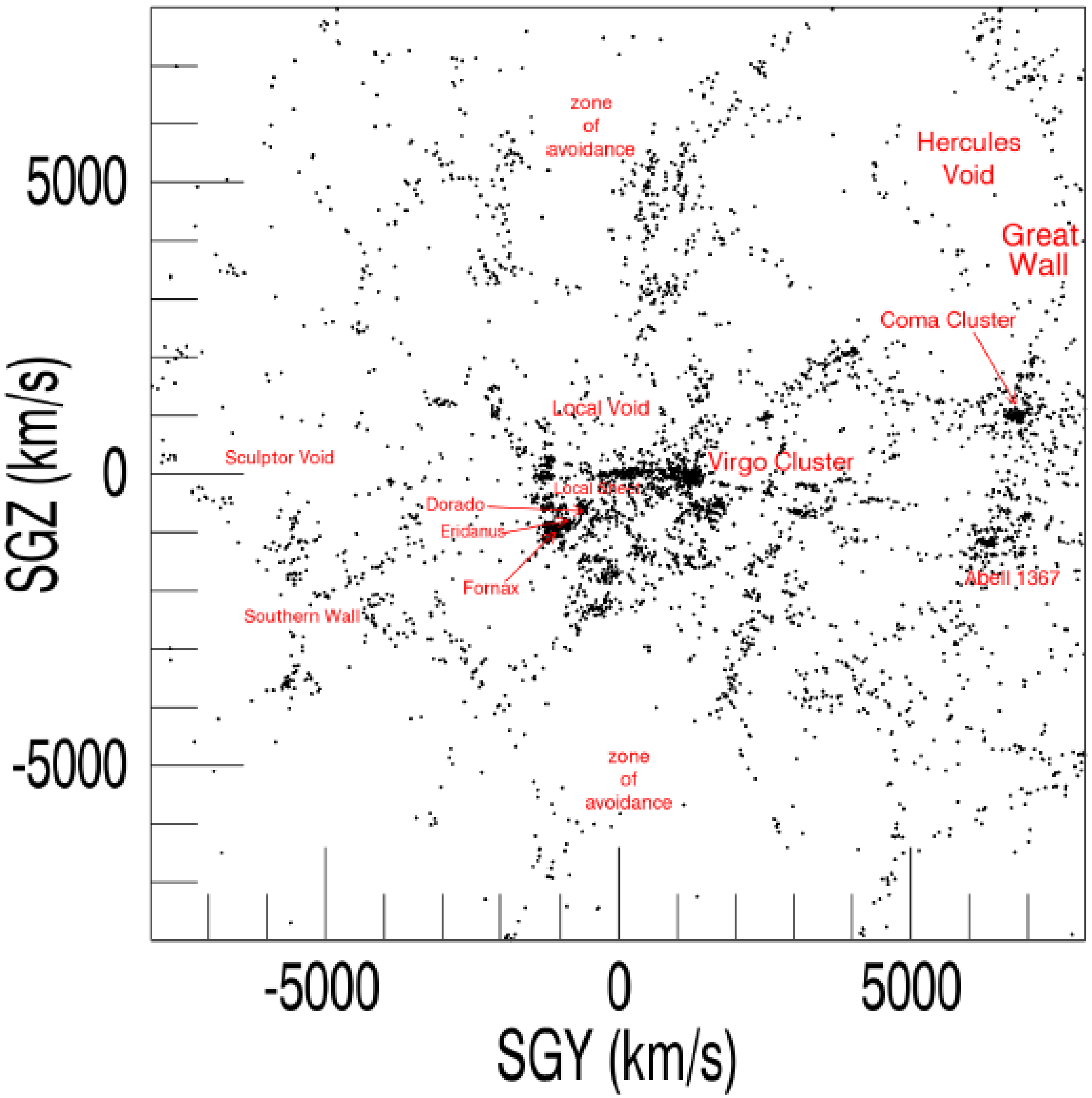
Notes. (*) indicates velocity dispersions derived from fewer than eight members stars, and require confirmation from further follow-up.

Reconstrucción 3D de las observaciones



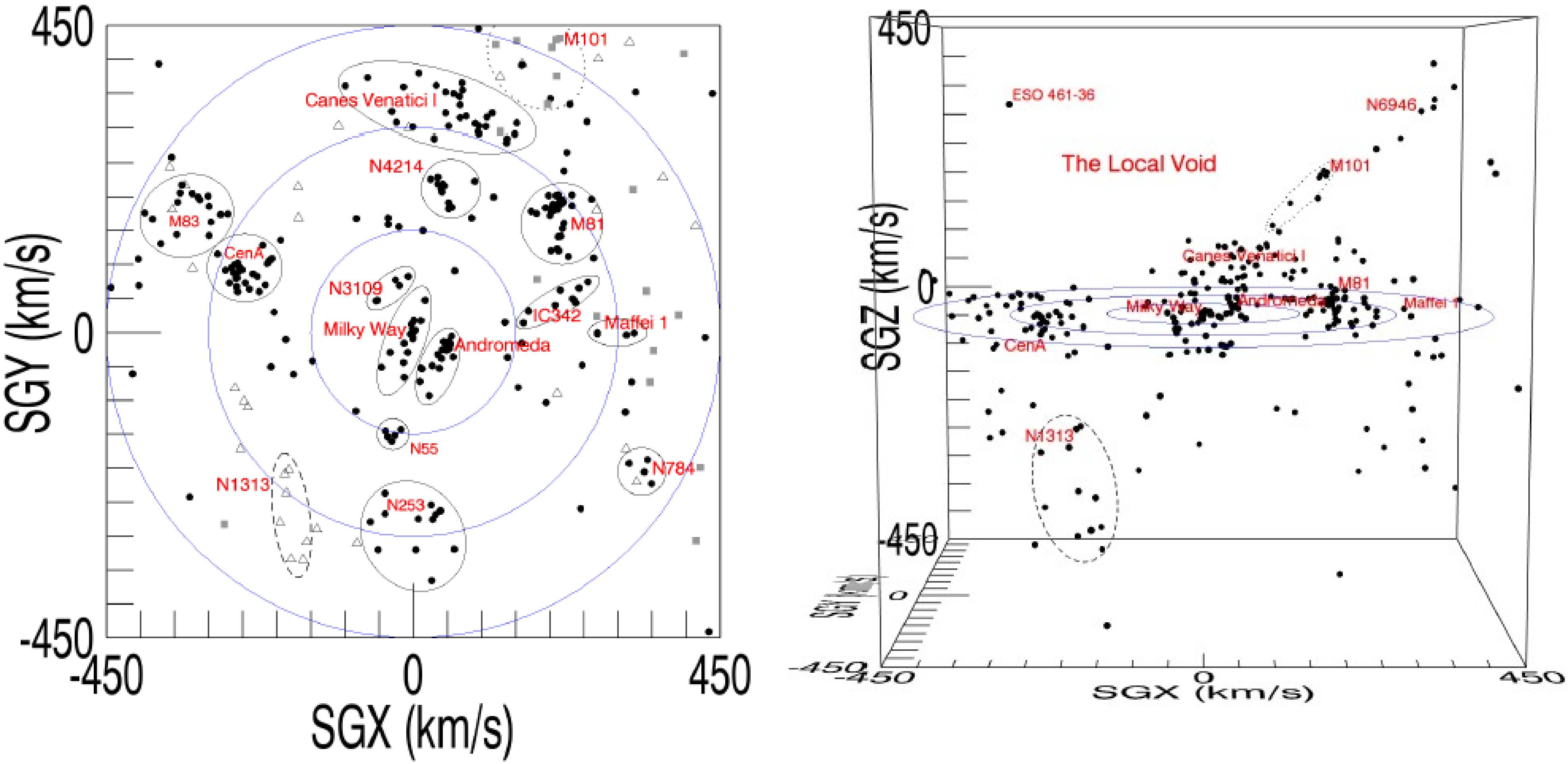
Courtois et al. 2013

Cosmografía del universo local



Courtois et al 2013

Cosmografía del universo local



Courtois et al 2013

Una idea de cómo se forman los planos:

Filamentos frios de gas

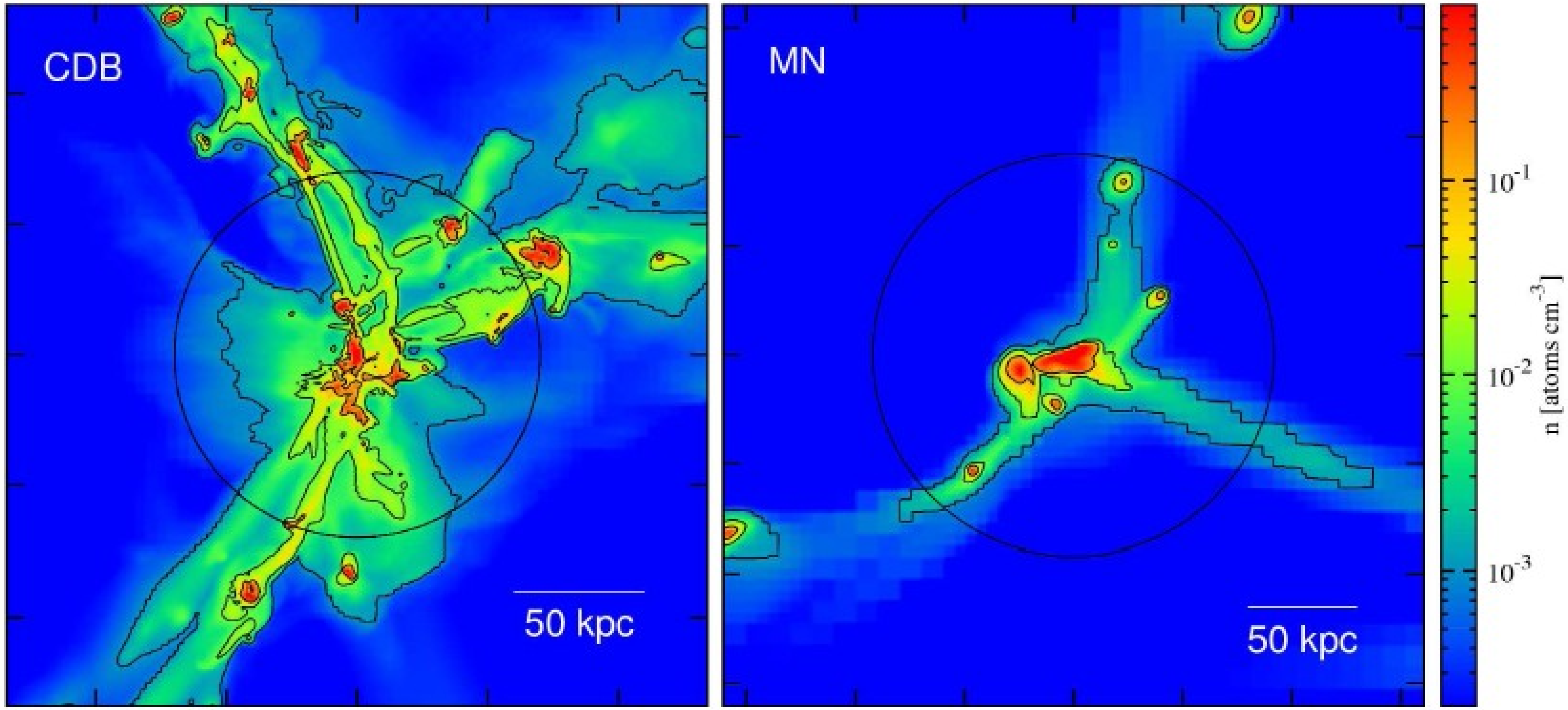


Figure 1. Gas density in simulated galaxies from CDB and MN. The colour refers to the maximum density along the line of sight. The contours mark $n = 0.1$, 0.01 and $0.001\,\mathrm{cm}^{-3}$, respectively. The circle shows the virial radius. Left: a typical CDB galaxy (resolution 70 pc) at $z = 2.3$, with $M_{\rm vir} = 3.5 \times 10^{11} \mathrm{M}_\odot$. Right: one of the MN galaxies (resolution 1 kpc) at $z = 2.5$, with $M_{\rm vir} = 10^{12} \mathrm{M}_\odot$. In both cases, the inflow is dominated by three cold narrow streams that are partly clumpy. The density in the streams is $n = 0.003 - 0.1\,\mathrm{cm}^{-3}$, with the clump cores reaching $n \sim 1\,\mathrm{cm}^{-3}$.