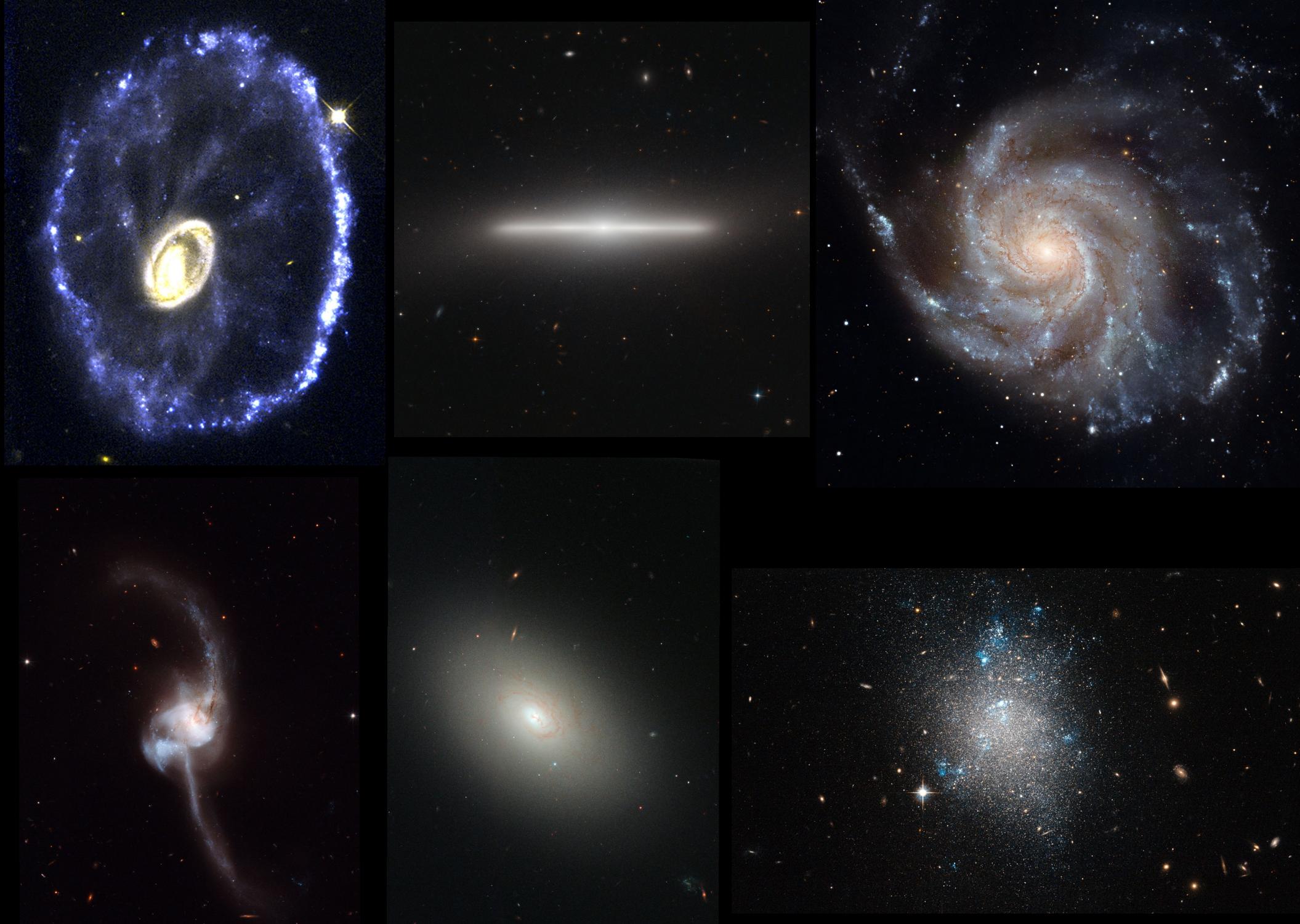


Las Galaxias enanas y su extraña distribución espacial

Verónica Arias
Universidad de los Andes

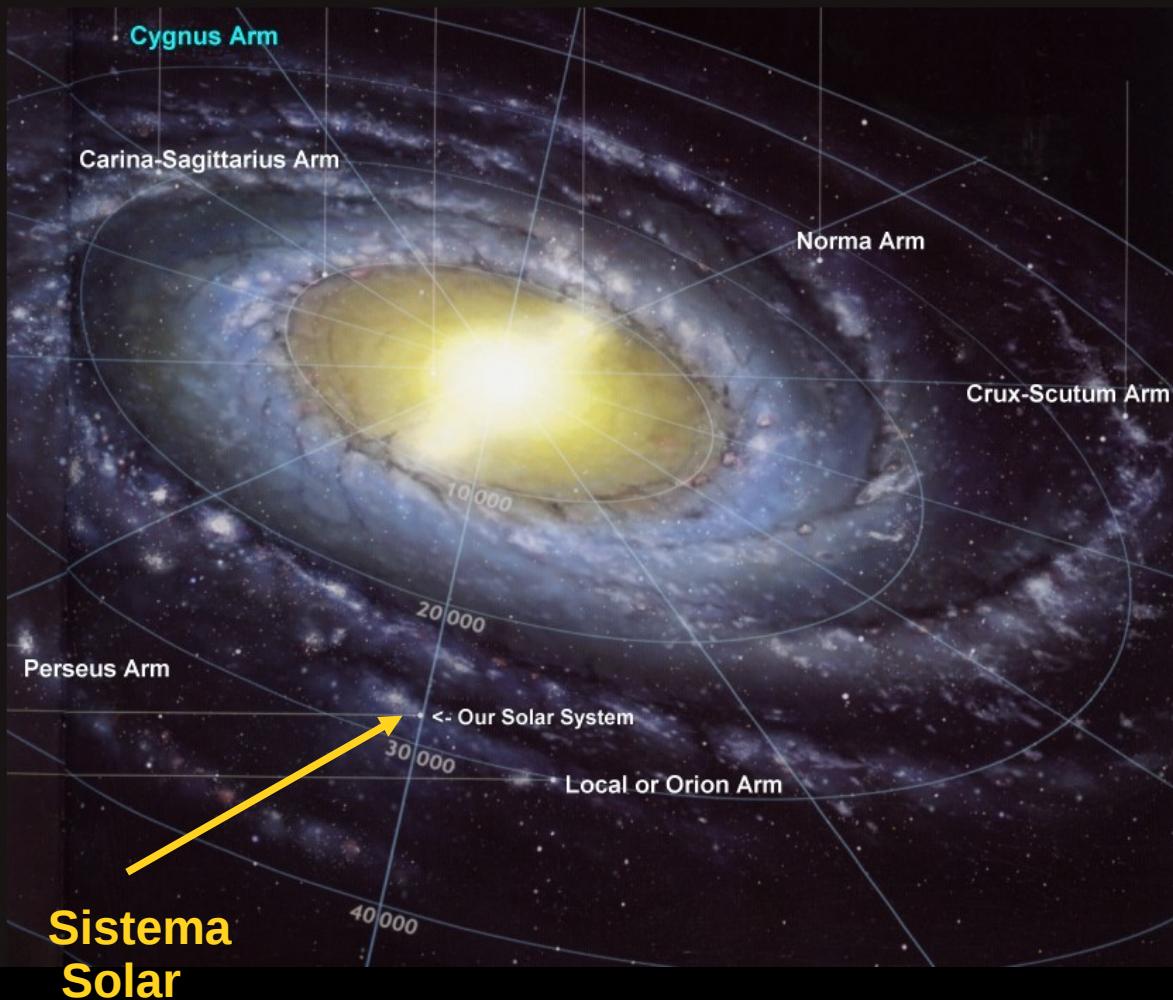
En colaboración con:
Geraint Lewis, Magda Guglielmo and Nuwanthika Fernando
(Sydney university).

Crédito de la imagen: <http://www.spacetelescope.org/images/potw1301a/>



Crédito de las imágenes: <http://www.spacetelescope.org/>

REPRESENTACIÓN de la posición del sol en la Vía Láctea



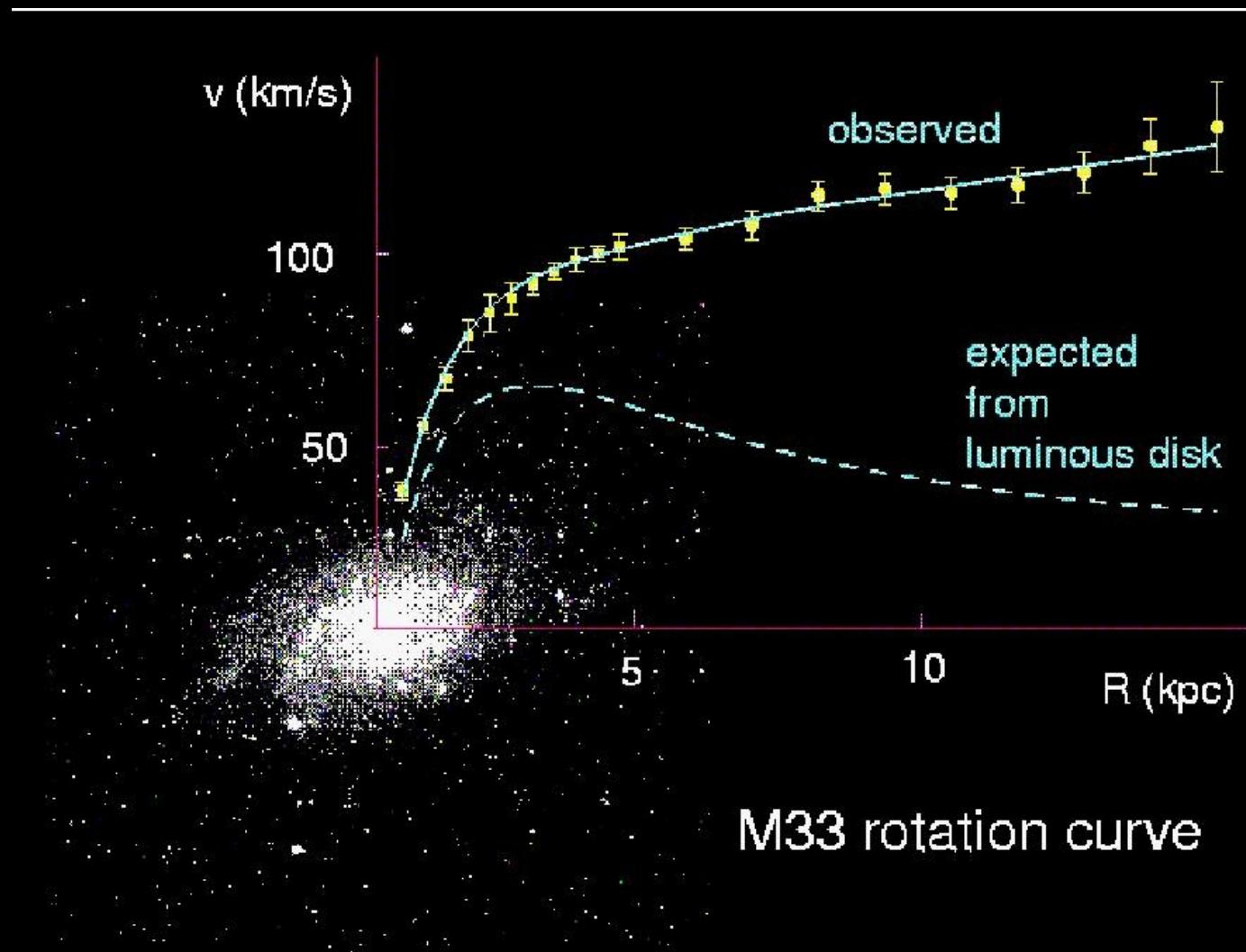
La galaxia de Andrómeda (nuestra vecina)



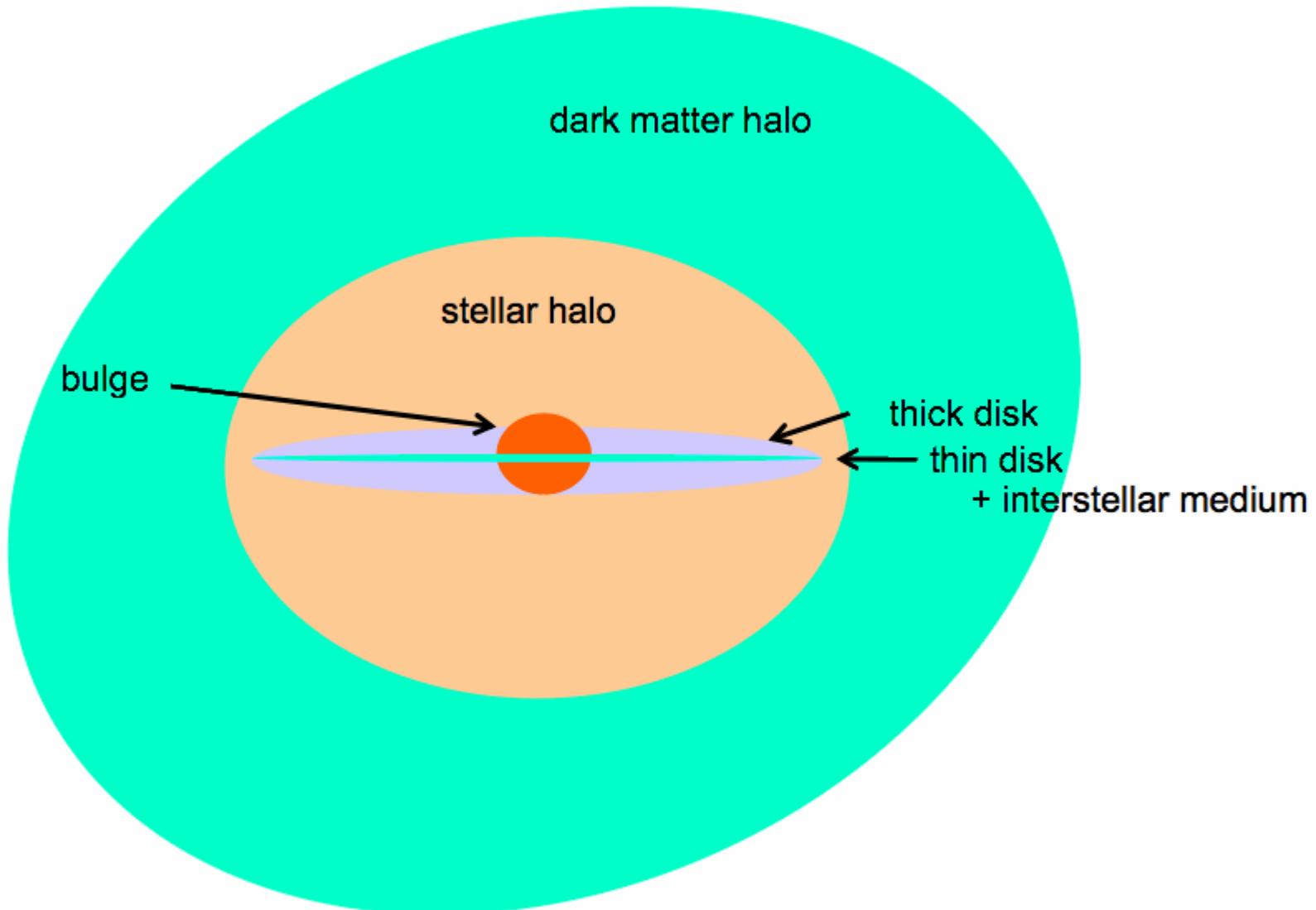
En el cielo se ven así



Dinámica de las galaxias: hay más masa de la que vemos!

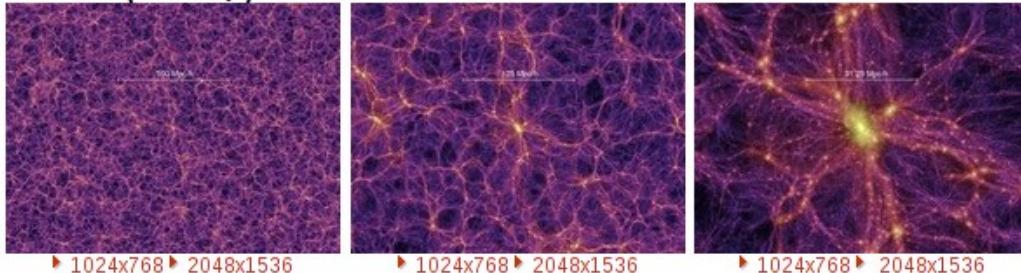


Materia Oscura: Un ingrediente esencial de las galaxias

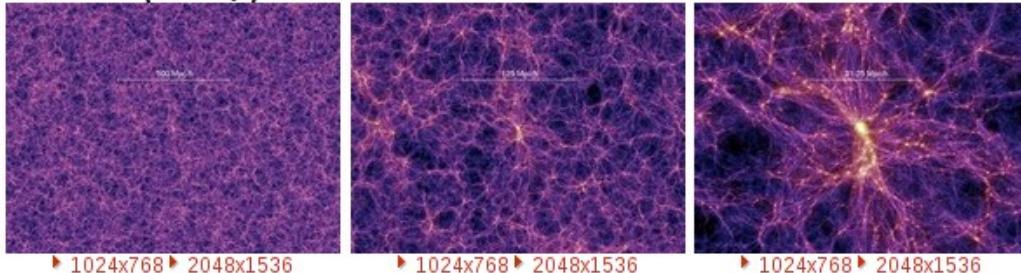


Materia Oscura: Un ingrediente esencial del Universo

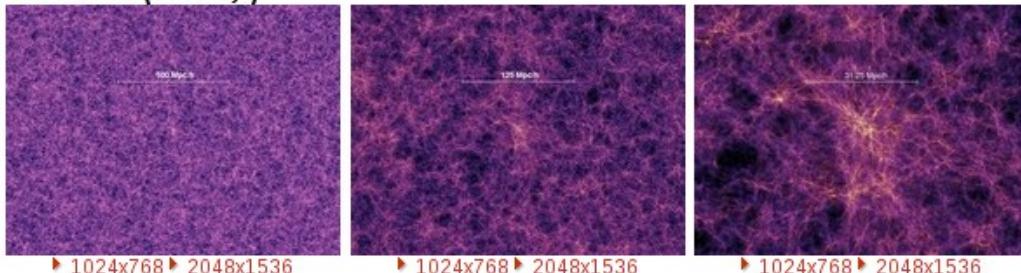
Redshift z=0 ($t = 13.6$ Gyr):



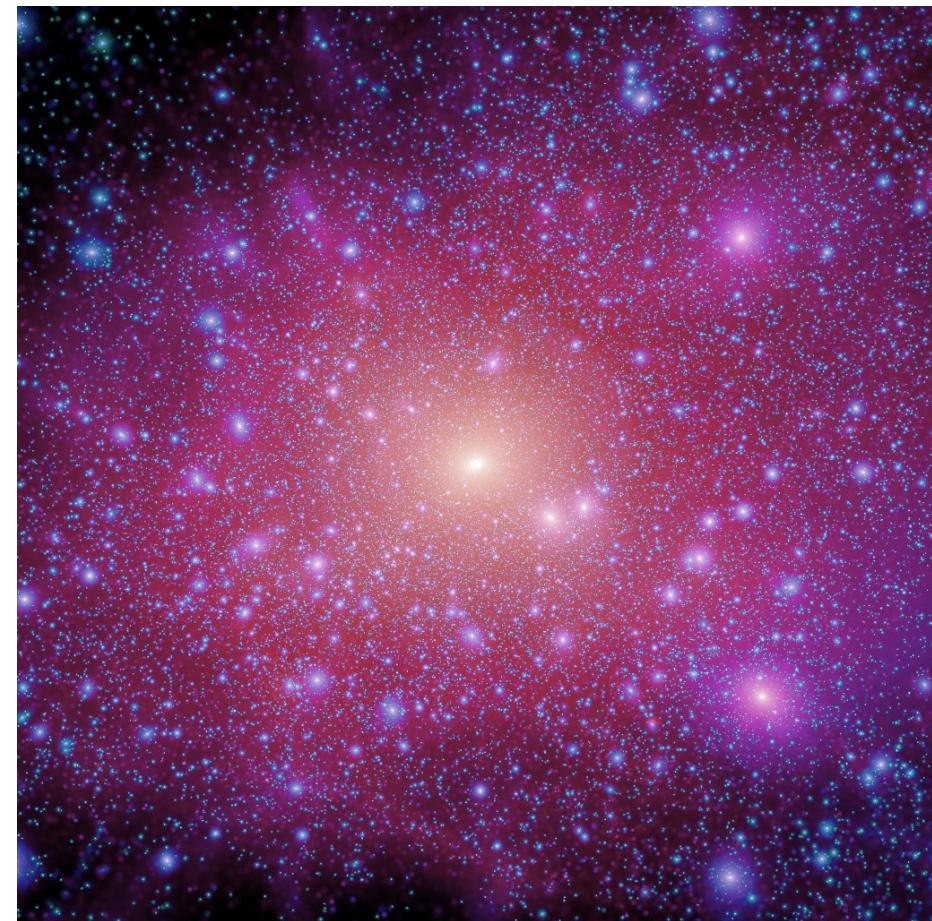
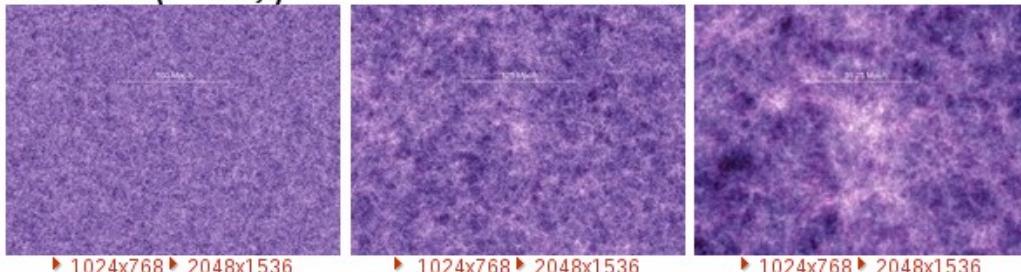
Redshift z=1.4 ($t = 4.7$ Gyr):



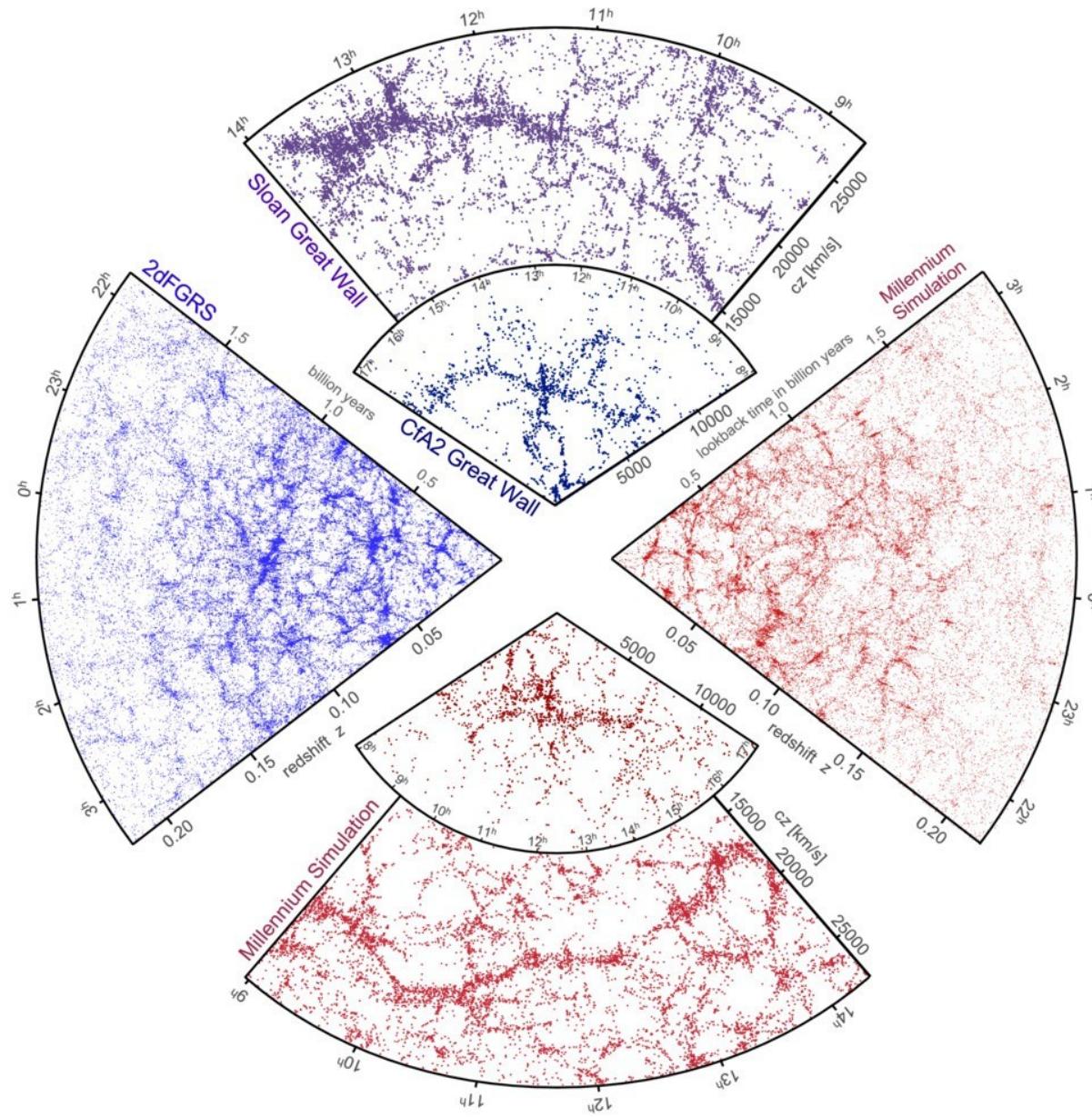
Redshift z=5.7 ($t = 1.0$ Gyr):



Redshift z=18.3 ($t = 0.21$ Gyr):



A Gran escala: modelos versus observaciones



Hay galaxias enanas!



Galaxias enanas

Las galaxias más abundantes

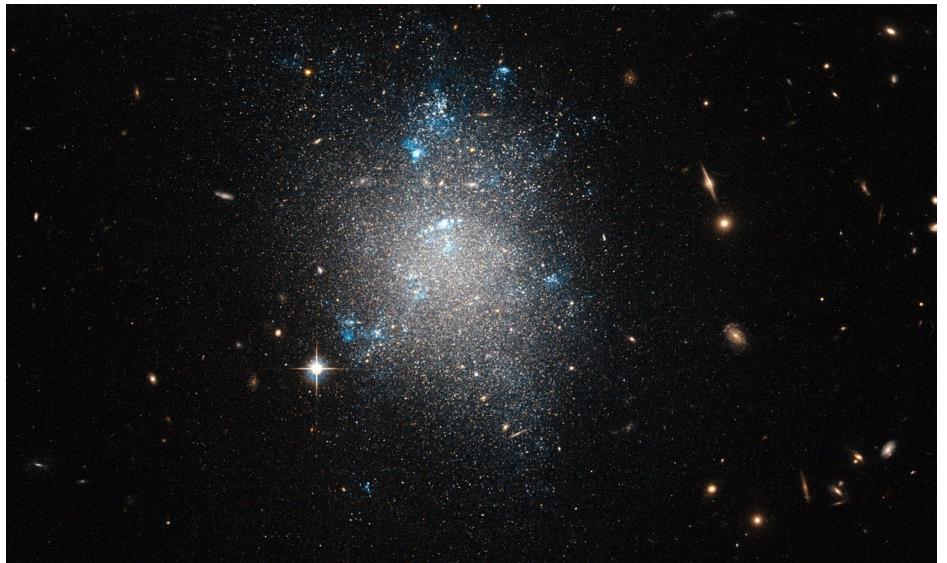
Difíciles de detectar (tenues)

10 o más veces más pequeñas que la Vía Láctea

Alrededor de 100 veces menos masivas que la Vía Láctea.

A veces aisladas, a veces son satélites de galaxias más grandes

NGC 5477



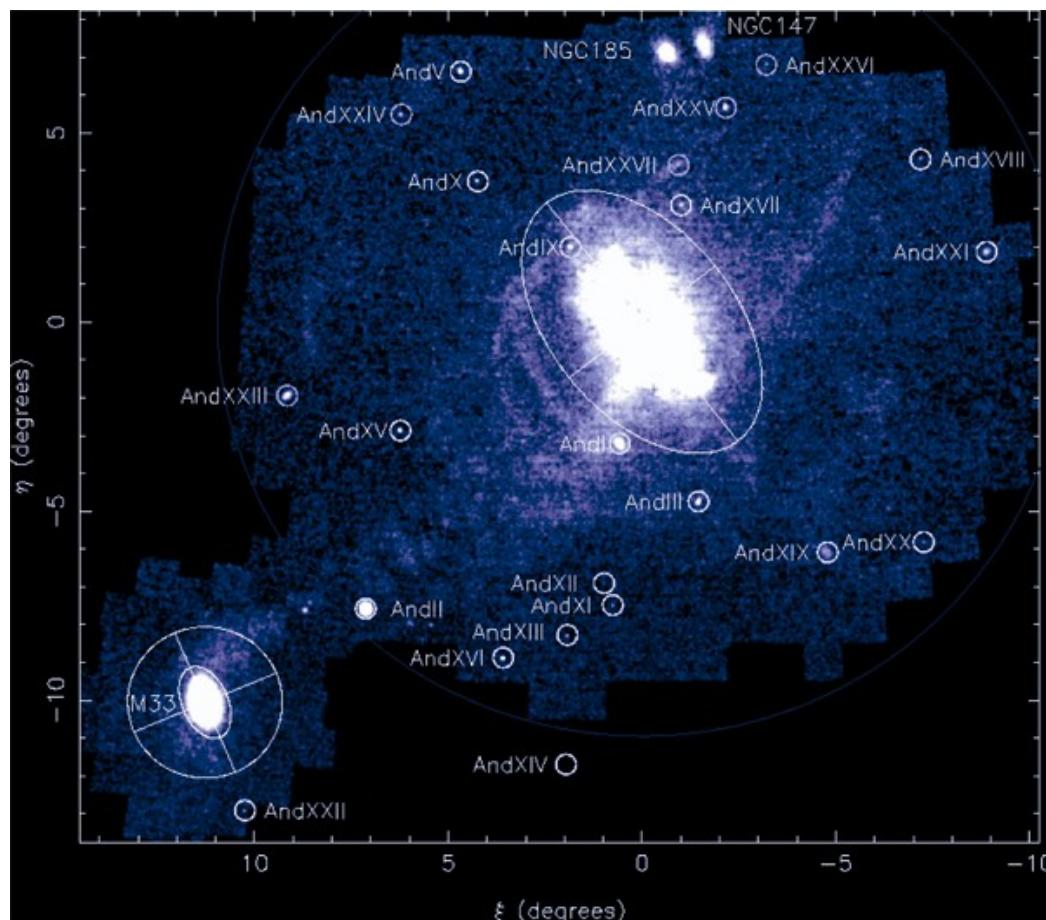
Segue 1



Galaxias satélite:

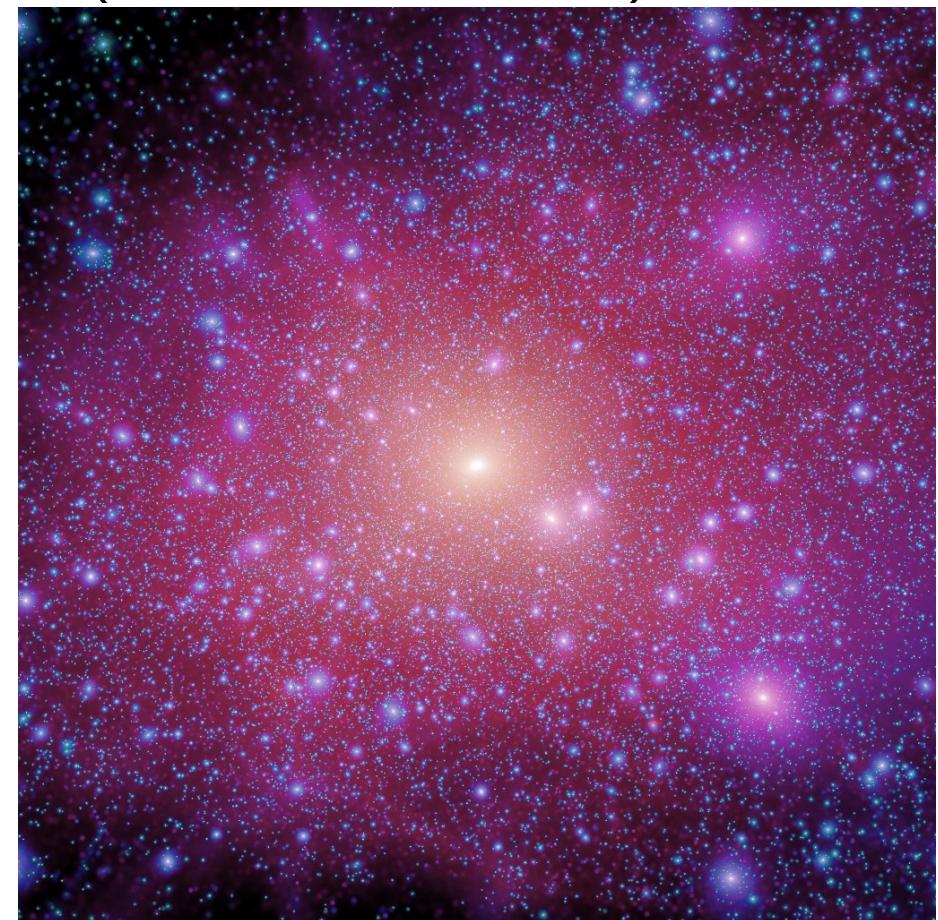
Problemas con el número de galaxias
("Missing satellite problem" y "Too big to fail")

Observaciones (de la galaxia de Andrómeda)



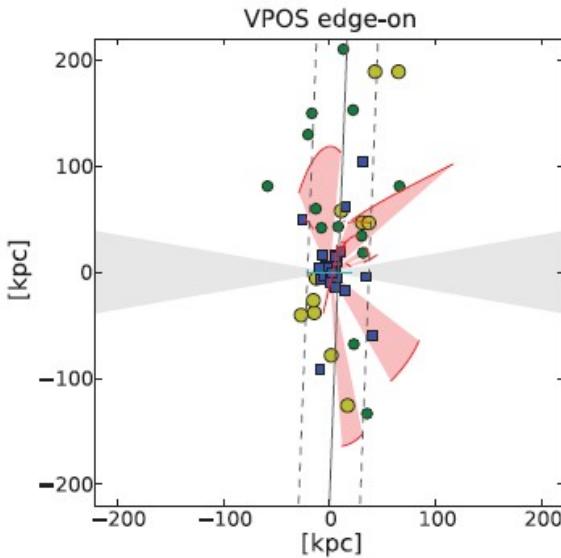
PAndAS survey,
image: Geraint Lewis

Modelos (Sólo materia oscura)



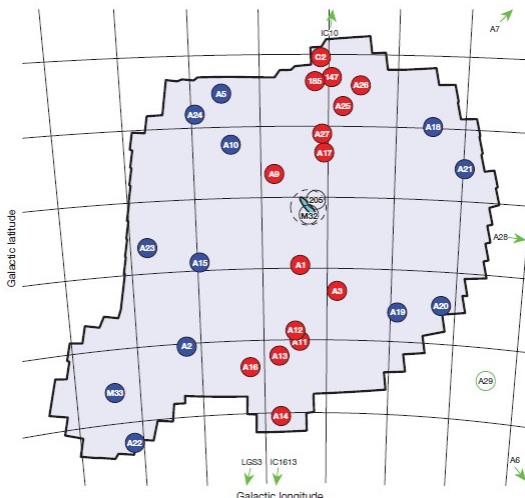
Aquarius simulations,
MPA Garching

Galaxias satélite: Los Planos son un problema



Vía Láctea

Pawlowski et al. 2012, Linden-Bell 1976



Andrómed
a

Ibata et al. 2013, Conn et al. 2013

No hay planos en las simulaciones!
(e.g. Ibata et al. 2014, Pawlowsky et al. 2013)

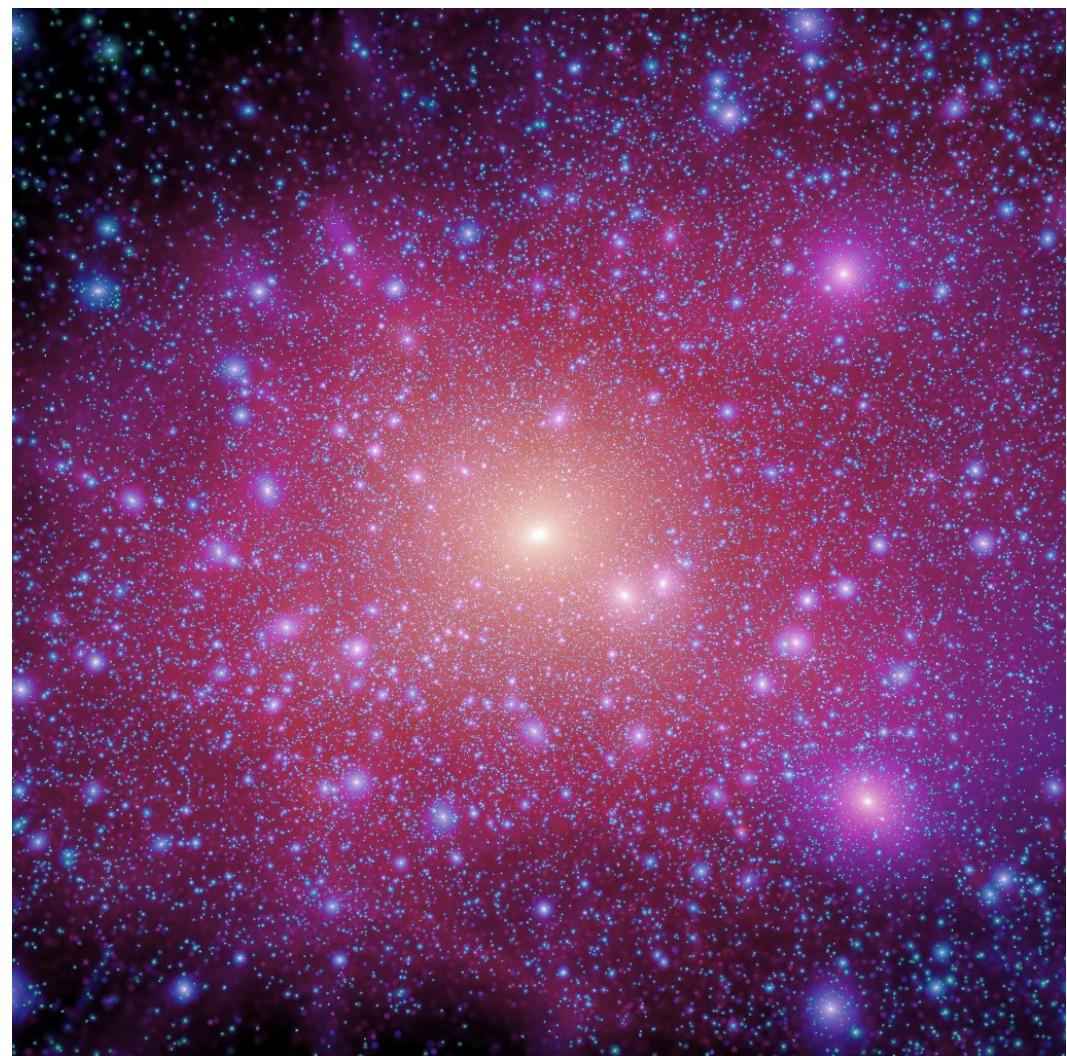
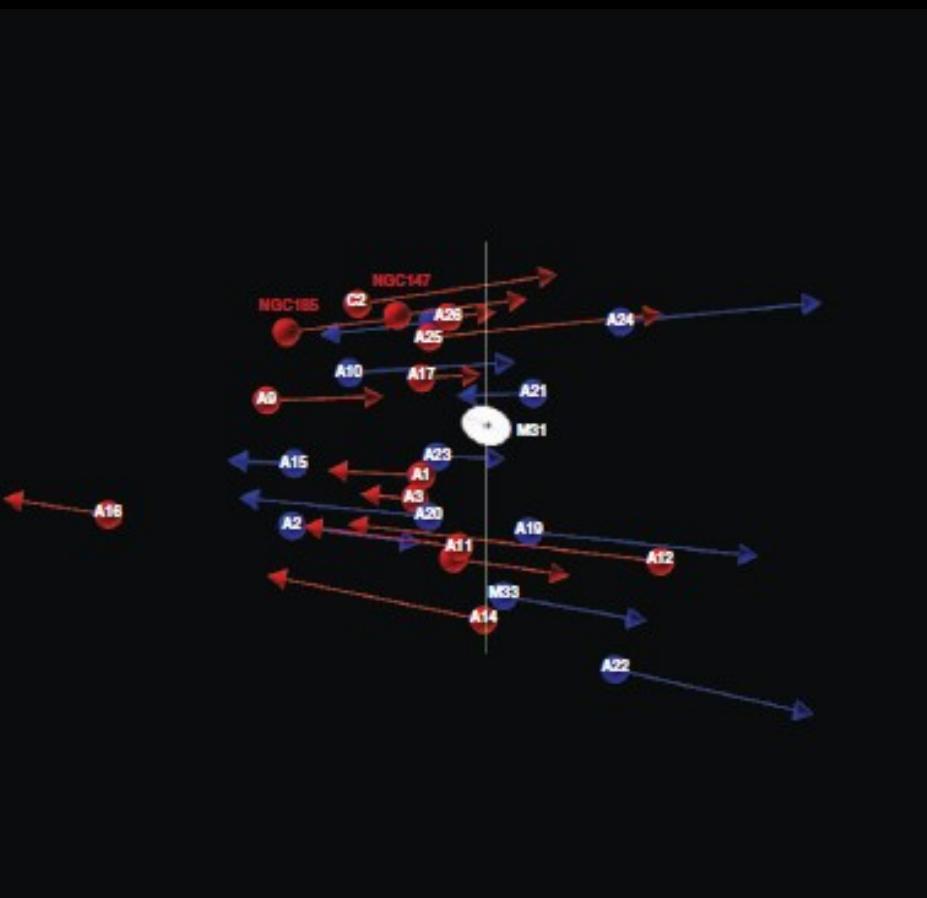


Imagen: Aquarius simulations, MPA Garching

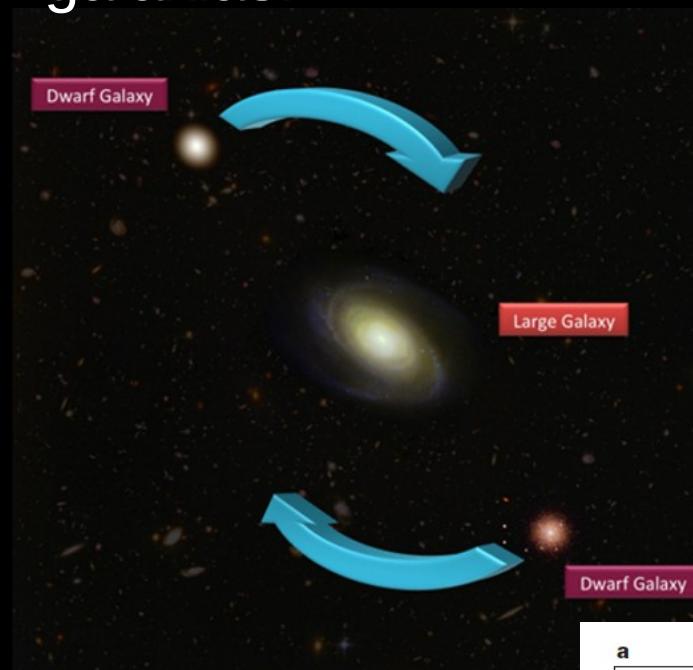
Más evidencias de que los planos son estructuras reales:

El plano de Andrómeda
está rotando ordenadamente

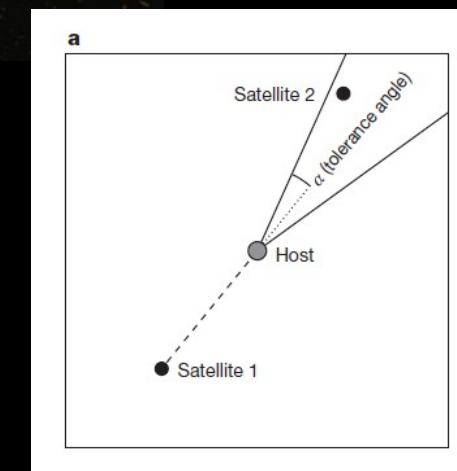


Ibata et al. 2013, Collins et al. 2013

Hay evidencias de rotación
ordenada alrededor de otras
galaxias!



Ibata et al. 2014



Hay evidencias de una estructura
dinámica:

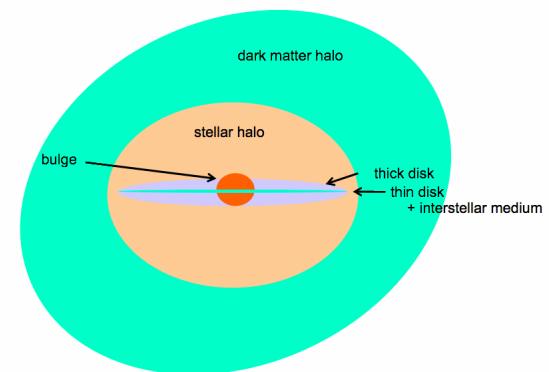
¿Por cuánto tiempo puede sobrevivir?

En colaboración con:
Geraint Lewis, Magda Guglielmo and Nuwanthika Fernando

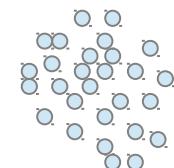
Modelo numérico

Para estudiar la dinámica del planos de galaxias satélite:

- Andrómeda como un potencial rígido
- Las galaxias satélites son masas puntuales
- (+ validación con simulaciones de N-cuerpos)



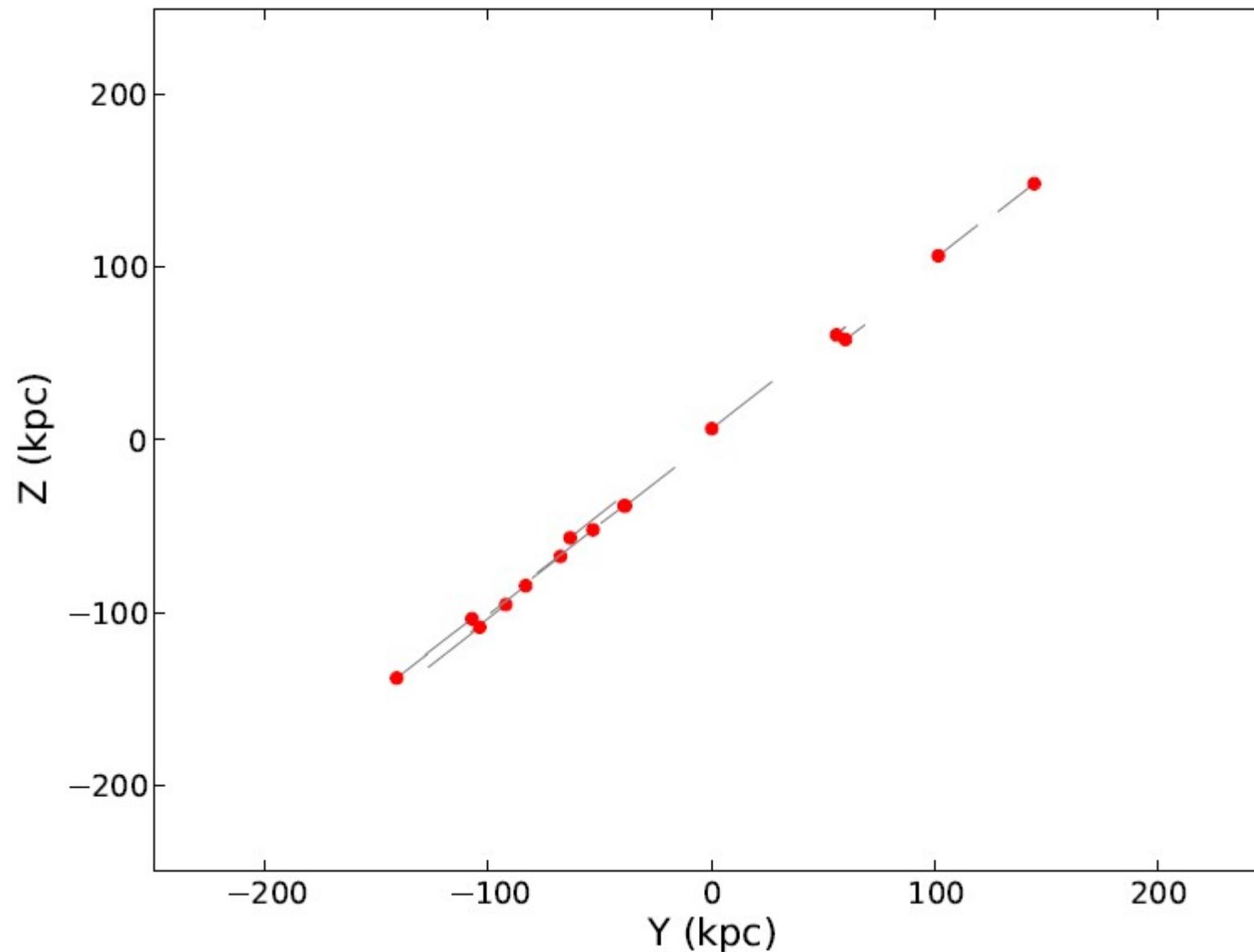
Galaxia satélite



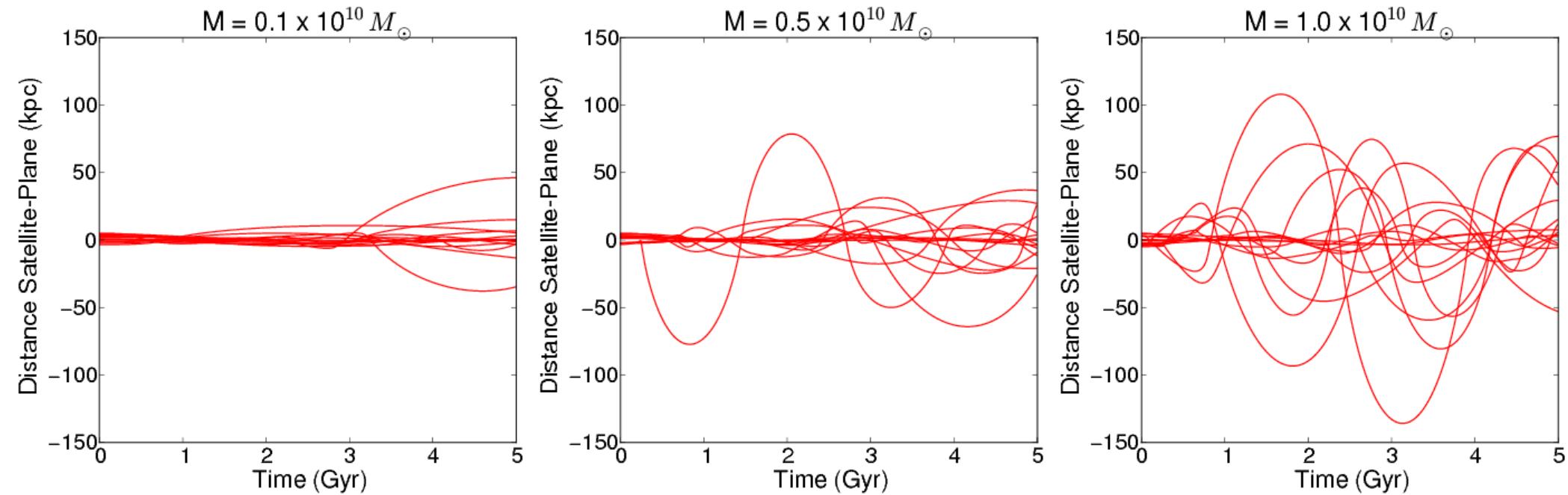
Galaxia satélite

Condiciones iniciales:

Genero un plano de galaxias satélite:

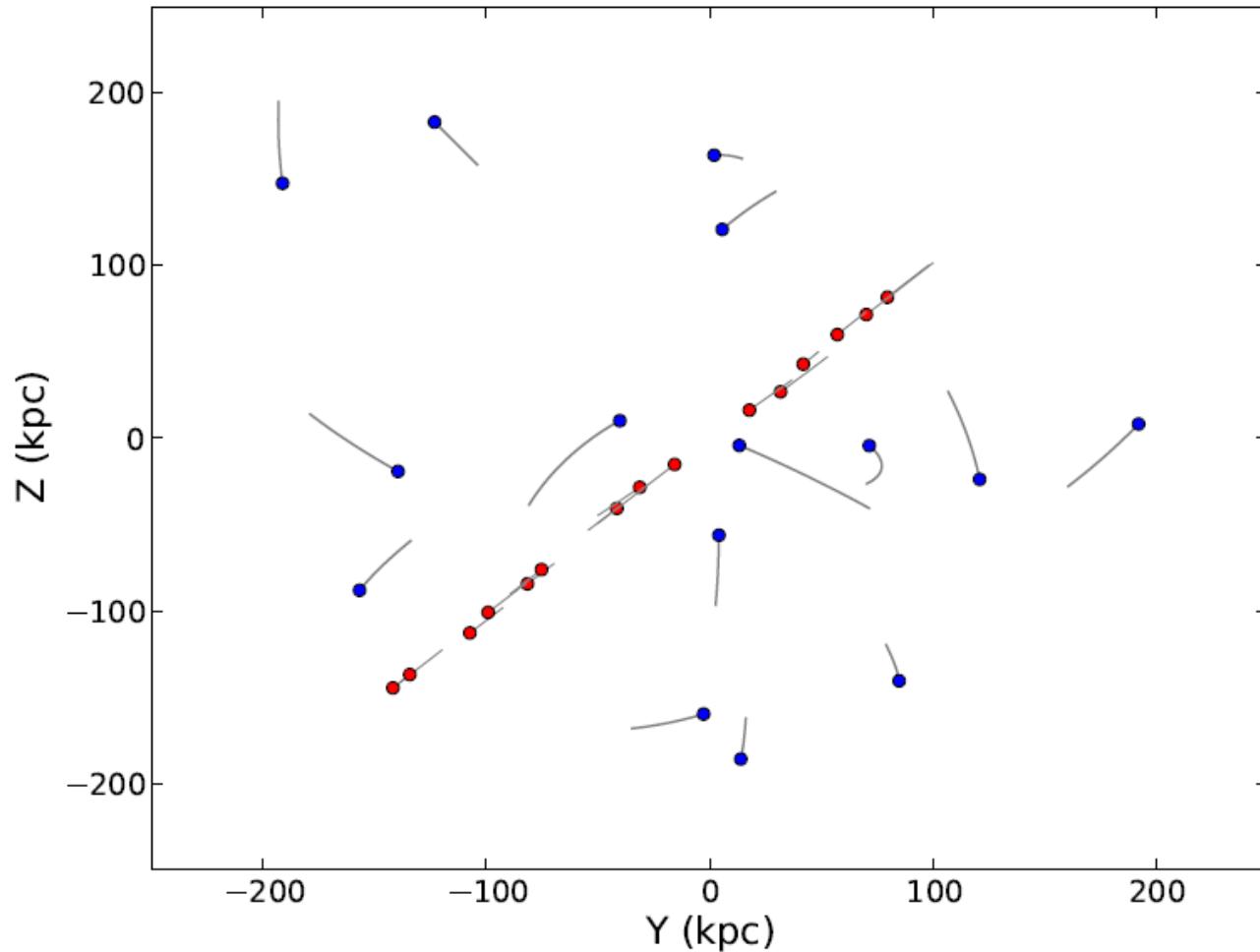


Y varío la **masa** de las galaxias satélite:

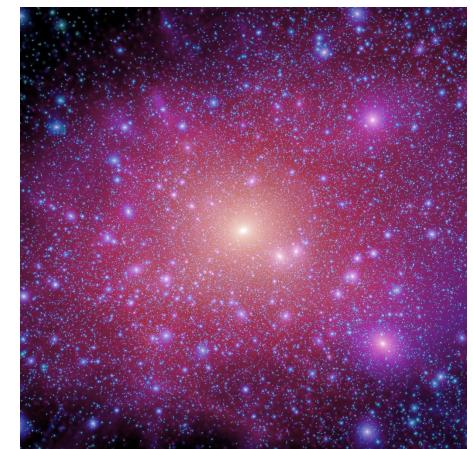


Líneas rojas: distancia de una galaxia satélite al plano
(en función del tiempo)

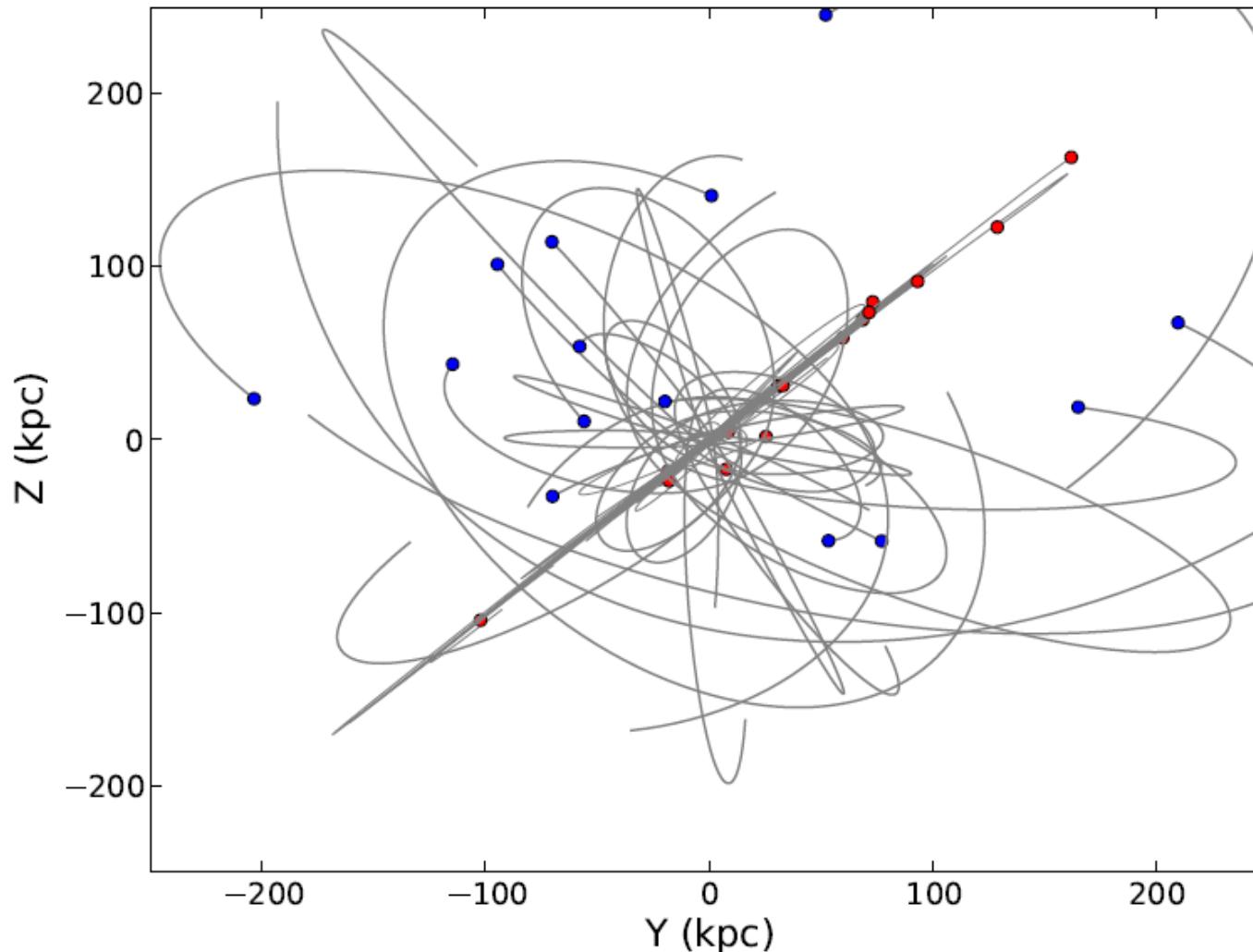
Ahora incluimos sub-halos de sólo materia oscura



Galaxias satélite en rojo,
Sub-halos de materia oscura en azul

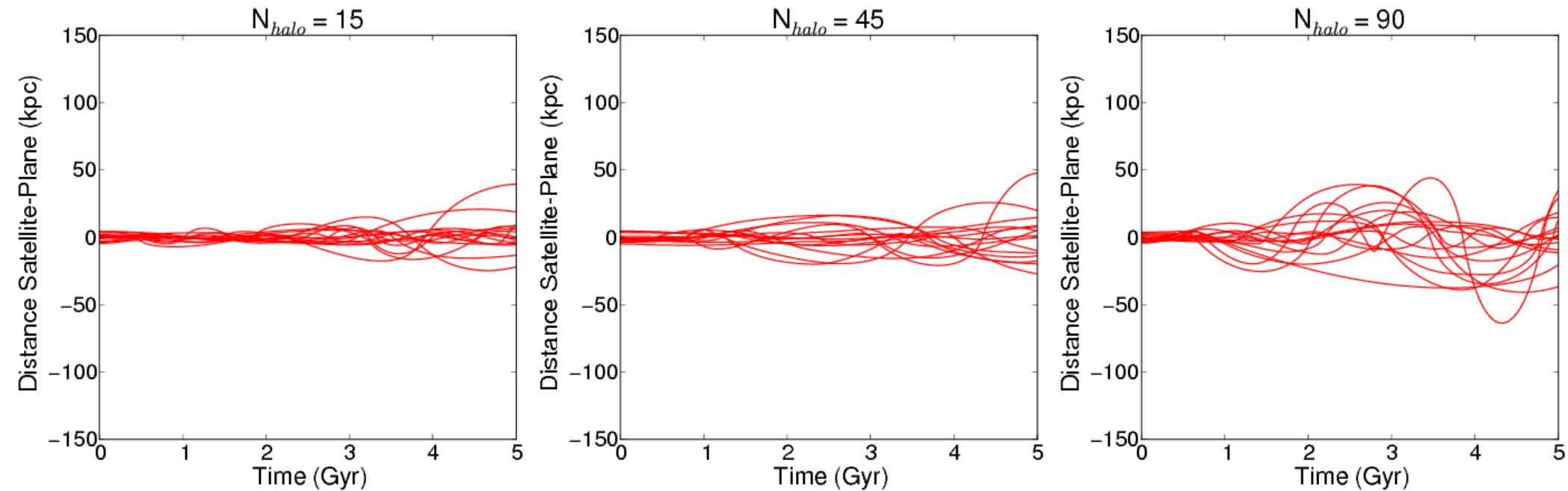


Después de unos cuantos Gyr



Galaxias satélite en rojo,
Sub-halos de materia oscura en azul

Número de sub-halos de materia oscura



Líneas rojas: distancia de una galaxia satélite al plano
(en función del tiempo)

Conclusiones del estudio de estabilidad del plano

Receta para destruir el plano:

- Aumente la masa de las galaxias satélite
- Aumente el número de subhalos (o su masa)
- Use un potencial no esférico

Como vemos un plano:

- Podemos construir límites superiores para los parámetros arriba mencionados.

Pero la pregunta más importante sigue sin respuesta:

Cómo se forman los planos de galaxias satélite?

En eso estoy trabajando ahora...

Ideas (propuestas hasta ahora)

Pawlowski et al. 2013

Liebeskind et al. 2014

Peñarrubia et al. 2014

Goerdt et al. 2013

...

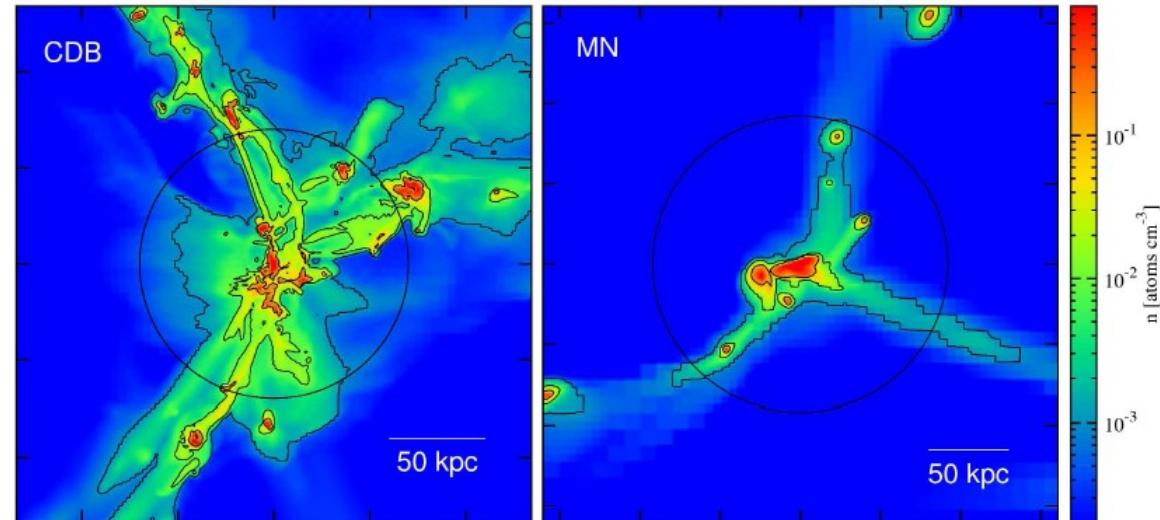
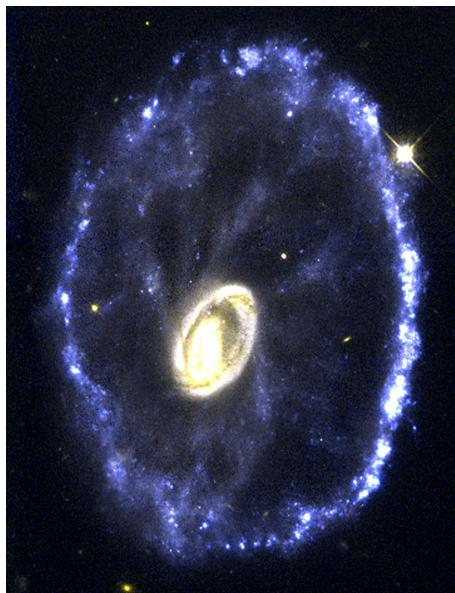
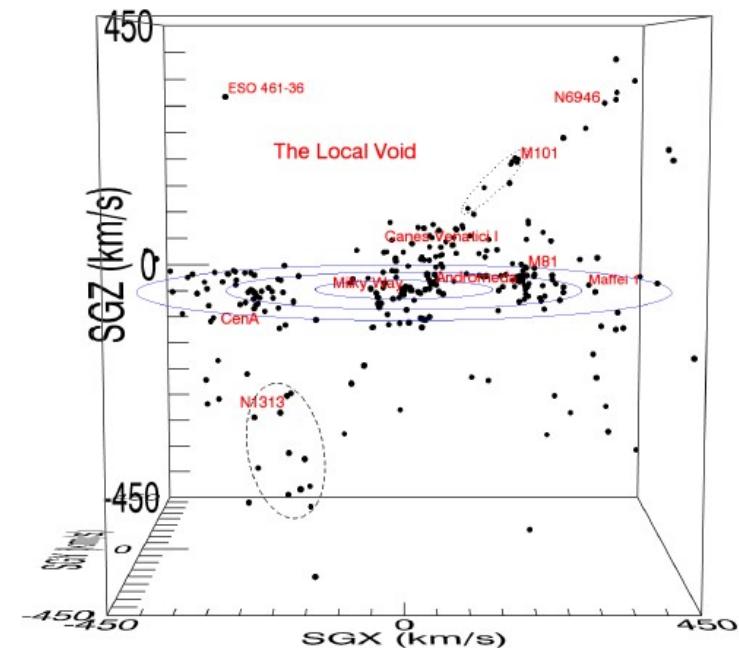
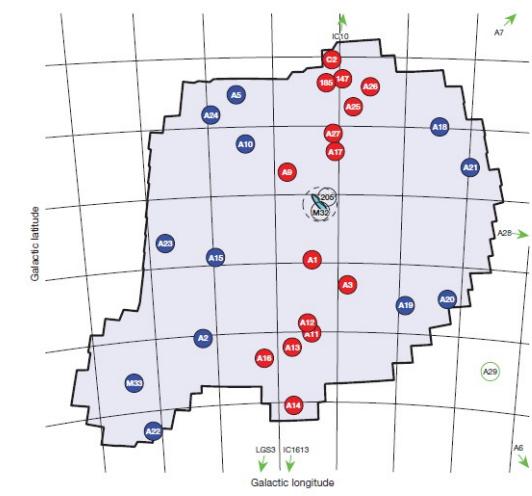
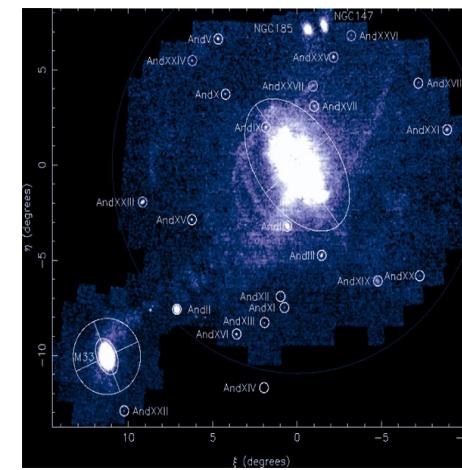
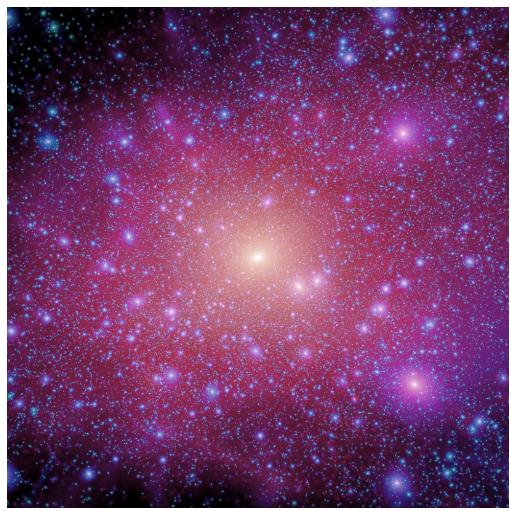


Figure 1. Gas density in simulated galaxies from CDB and MN. The colour refers to the maximum density along the line of sight. The contours mark $n = 0.1, 0.01$ and 0.001 cm^{-3} , respectively. The circle shows the virial radius. Left: a typical CDB galaxy (resolution 70 pc) at $z = 2.3$, with $M_{\text{vir}}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



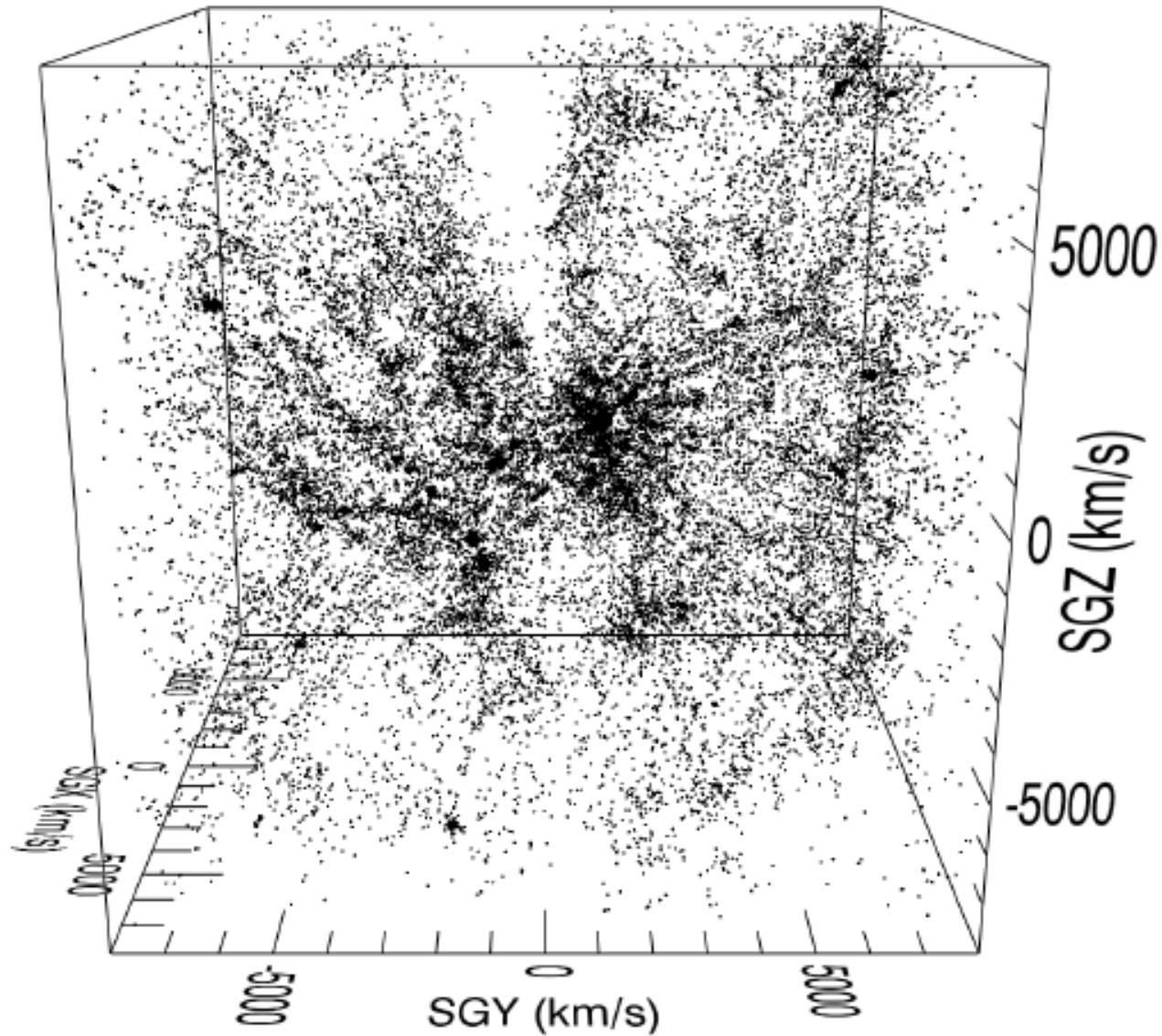
Resumen

Hay problemas entre modelos y observaciones cuando se comparan a pequeña escala:

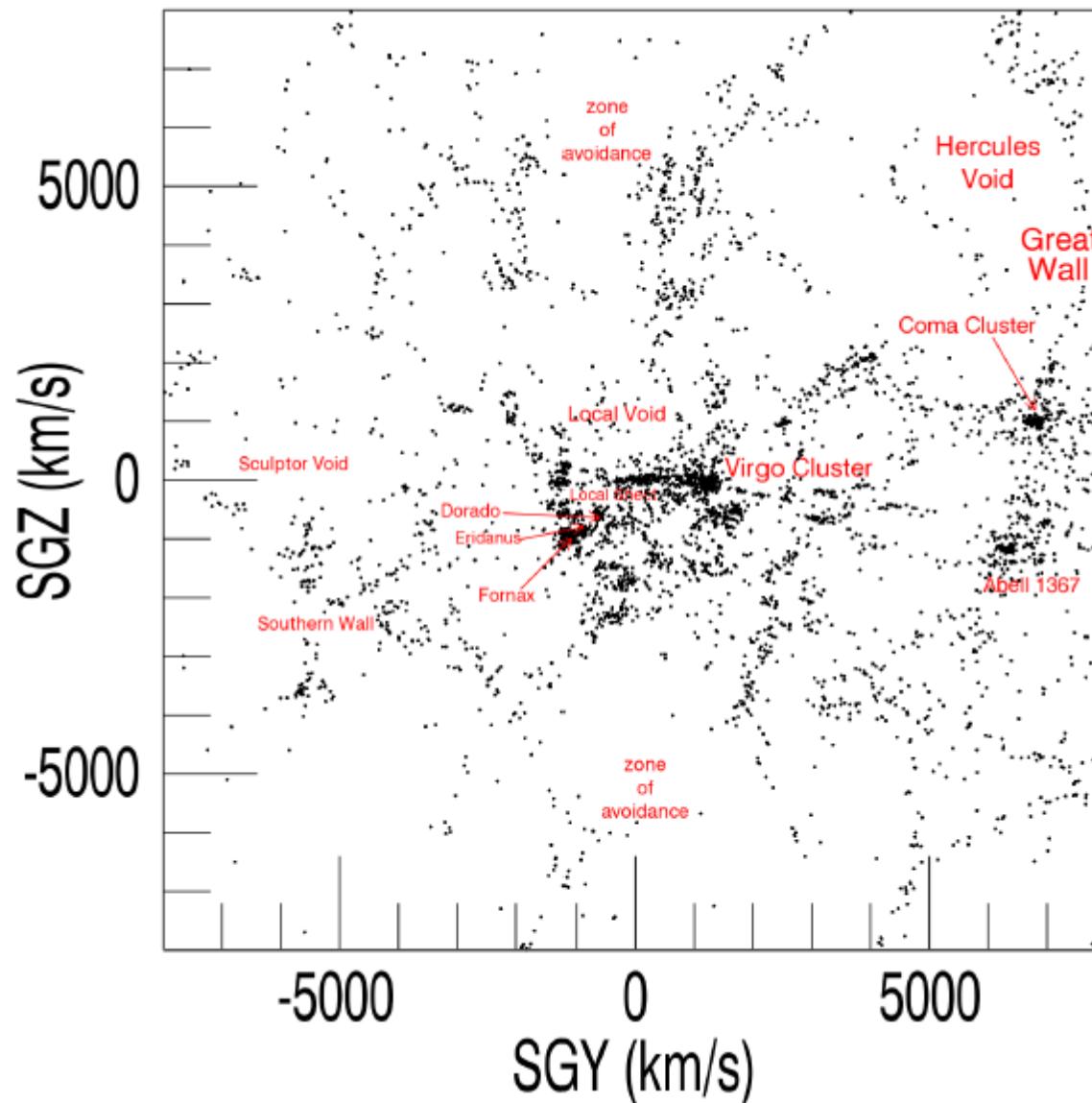


Es necesario explicar el origen de los planes de galaxias satélite

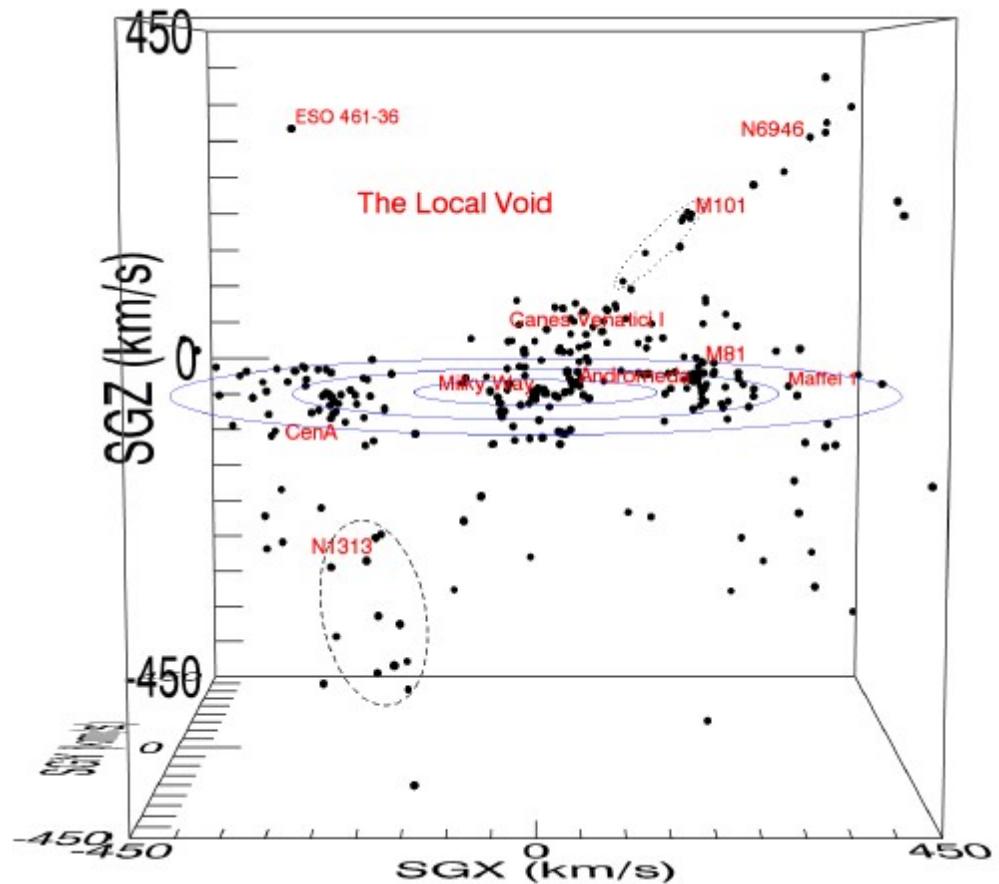
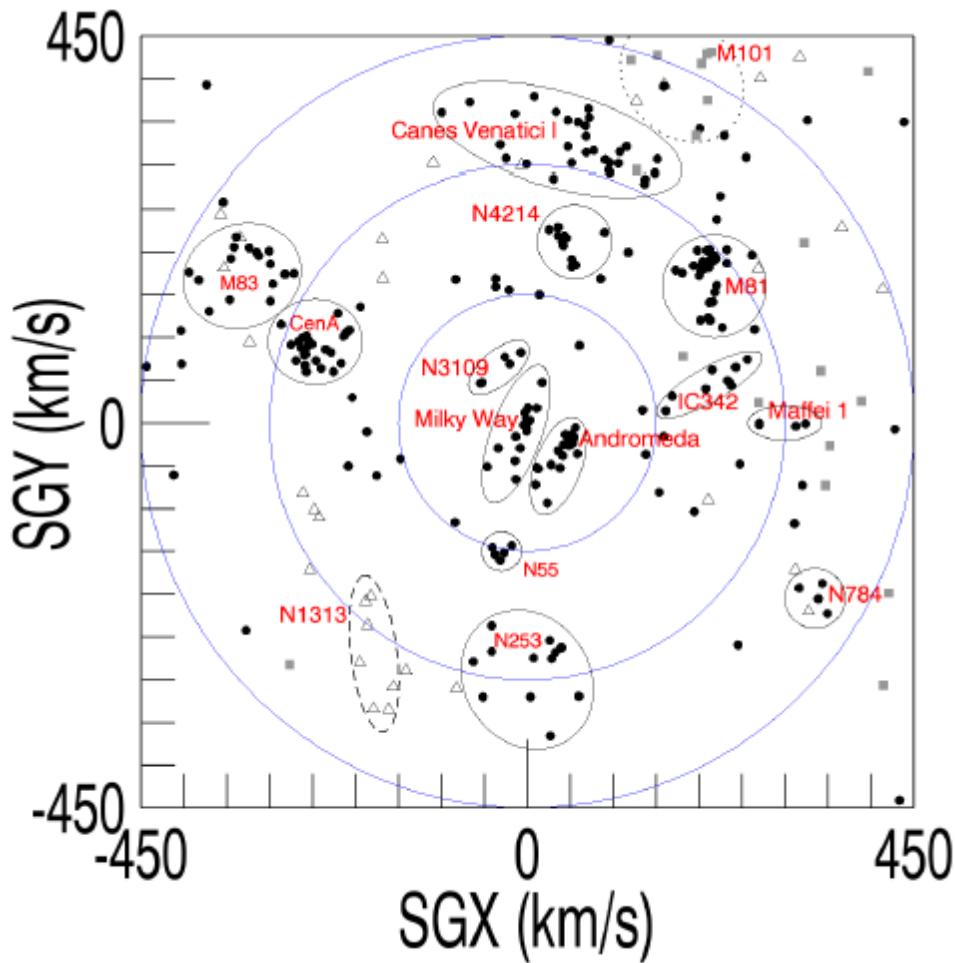
Reconstrucción 3D de las observaciones



Cosmografía del universo local



Cosmografía del universo local



Una idea de cómo se forman los planos:

Filamentos fríos de gas

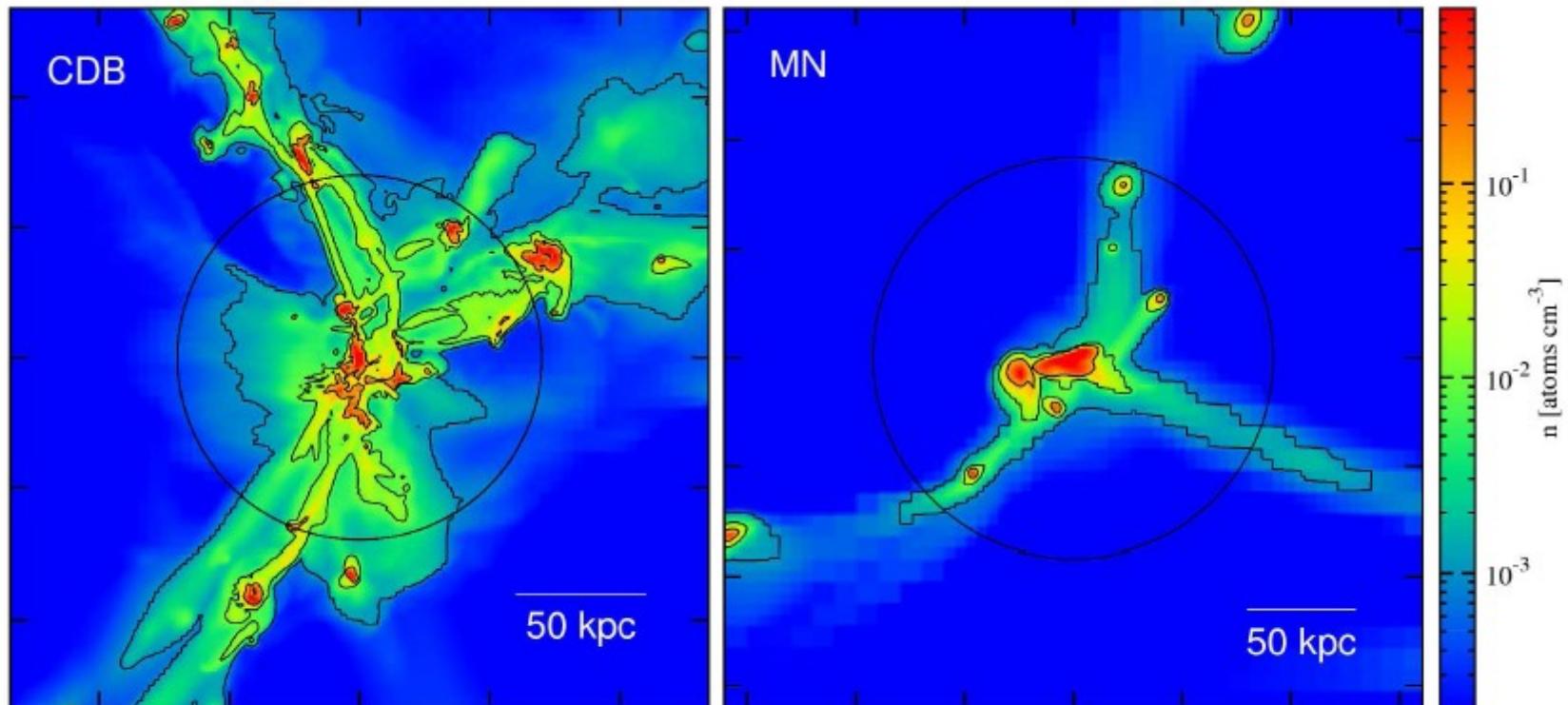


Figure 1. Gas density in simulated galaxies from CDB and MN. The colour refers to the maximum density along the line of sight. The contours mark $n = 0.1, 0.01$ and 0.001 cm^{-3} , respectively. The circle shows the virial radius. Left: a typical CDB galaxy (resolution 70 pc) at $z = 2.3$, with $M_{\text{vir}}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

Propiedades de las galaxias satélite de Andrómeda:

THE ASTROPHYSICAL JOURNAL, 768:172 (36pp), 2013 May 10

COLLINS ET AL.

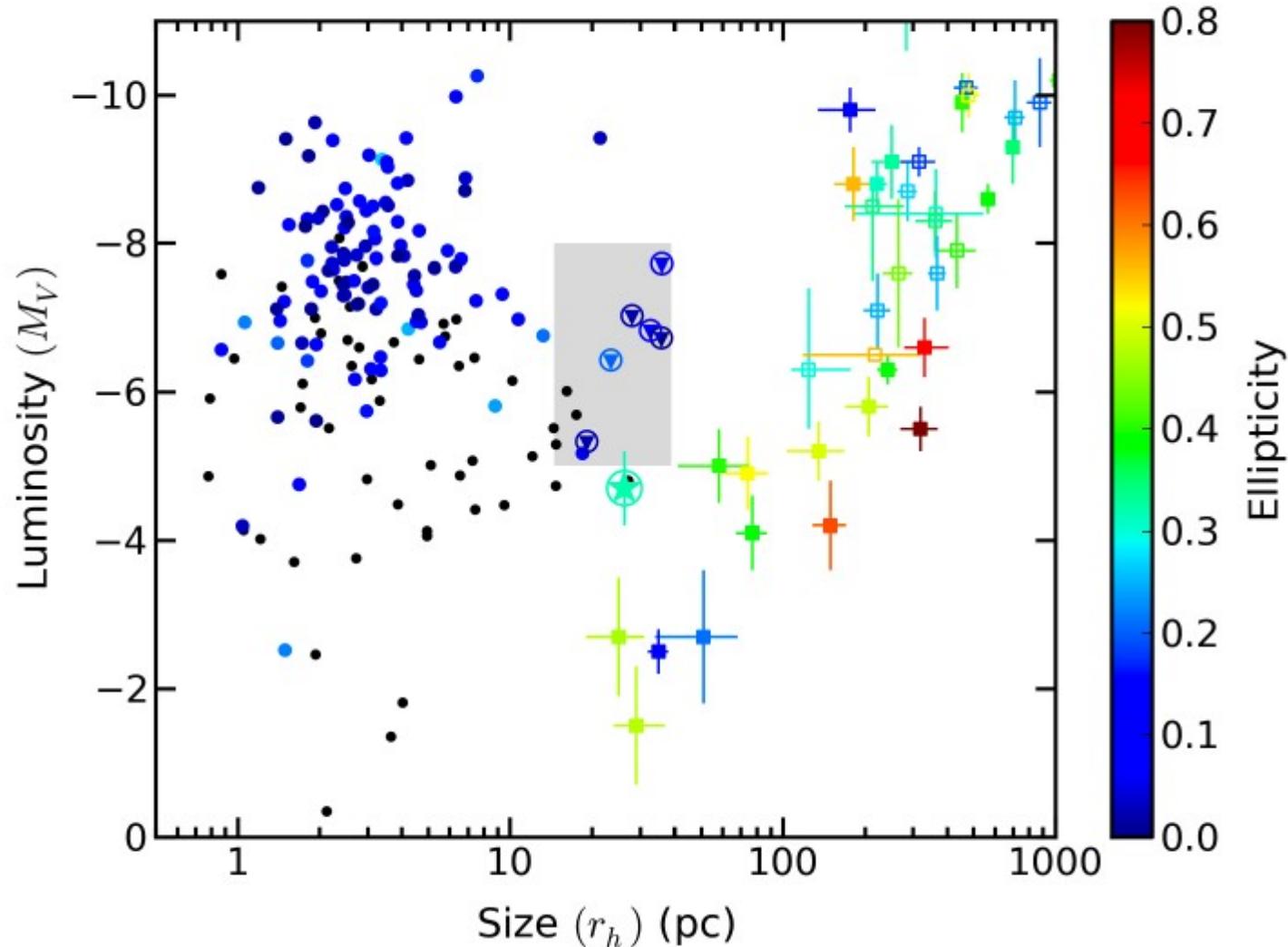
Table 4
Kinematic Properties of Andromeda dSph Galaxies as Derived within This Work, from Keck I/LRIS, and Keck II/DEIMOS Data

Property	η	v_r (km s $^{-1}$)	σ_v (km s $^{-1}$)	M_{half} ($10^7 M_\odot$)	$[M/L]_{\text{half}}$ (M_\odot / L_\odot)	[Fe/H] $_{\text{spec}}$
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	$0.0^{+4.0}_{-0.0}$	$0.0^{+0.3}_{-0.0}$	$0.0^{+194}_{-0.0}$	-2.2 ± 0.2
And XIII	2.5	-204.8 ± 4.9	$0.0^{+8.1}_{-0.0}(*)$	$0.0^{+0.7}_{-0.0}$	$0.0^{+330}_{-0.0}$	-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	$0.0^{+2.7}_{-0.0}$	$0.0^{+0.14}_{-0.0}$	0^{+5}_{-0}	-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	$0.0^{+7.3}_{-0.0}(*)$	$0.4^{+0.7}_{-0.4}$	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.

Galaxia enana o cúmulo globular?

Mackey et al.



Galaxia enana o cúmulo globular?

2

Mackey et al.

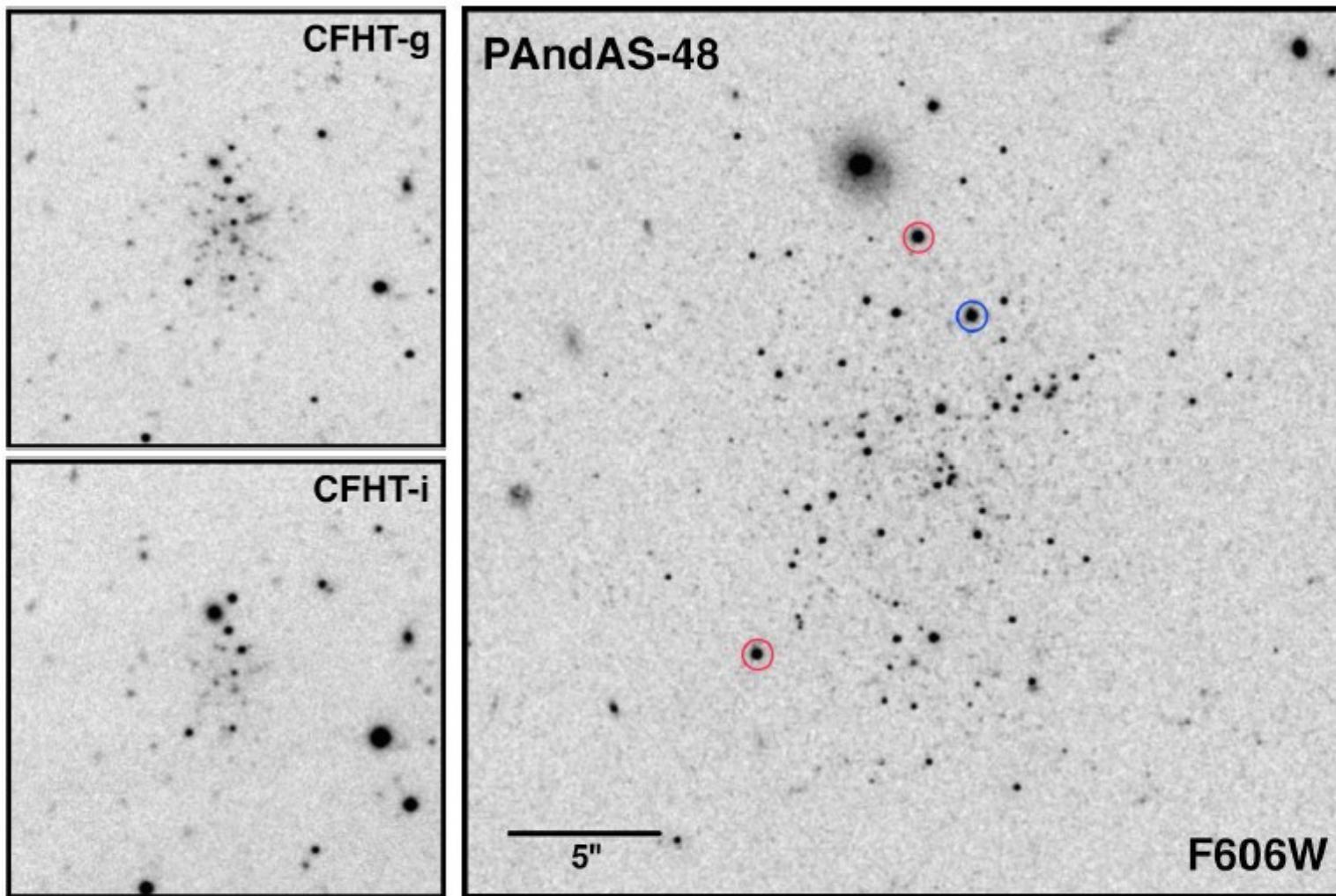
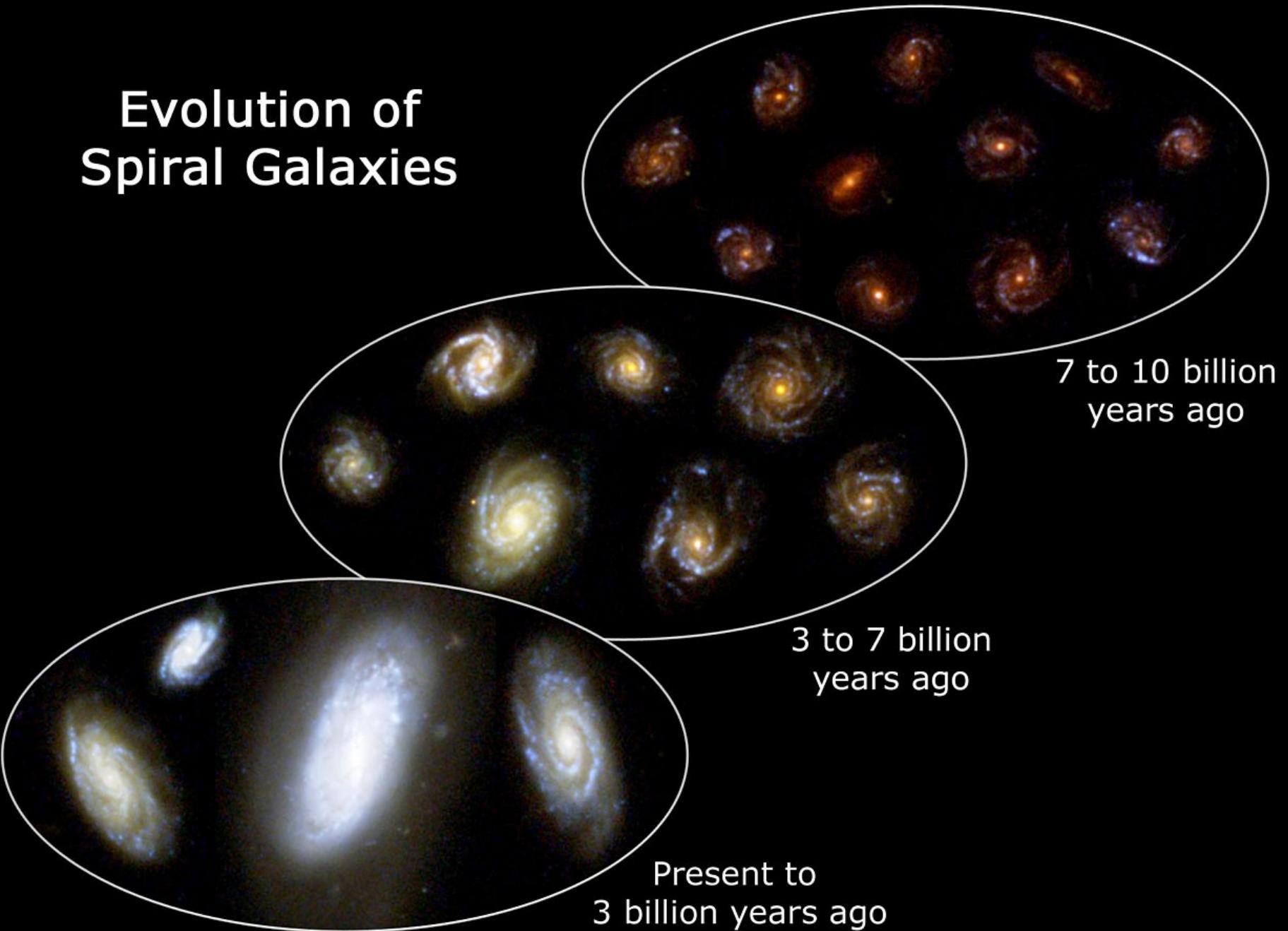
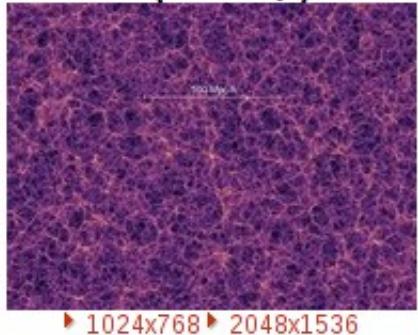


Figure 1. Left panels: PA-48 discovery images, 1' on a side, in the CFHT/MegaCam *g*- and *i*-bands. Right panel: Our $30'' \times 30''$ drizzled F606W ACS/WFC image of PA-48. Star-A and star-C from Section 3.1 are circled in red; star-B in blue. North is to the top and east to the left in all images.

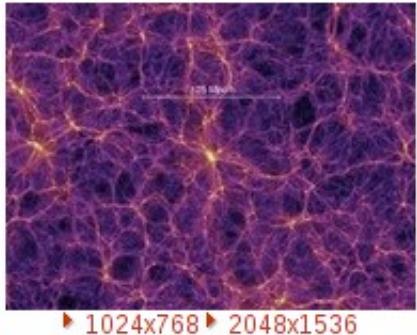
Evolution of Spiral Galaxies



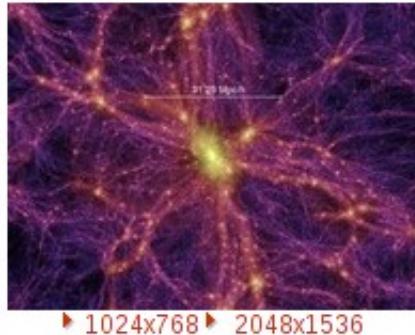
Redshift z=0 (t = 13.6 Gyr):



► 1024x768 ► 2048x1536

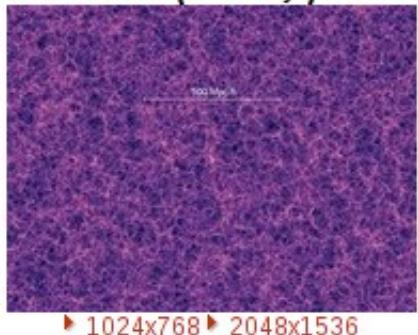


► 1024x768 ► 2048x1536

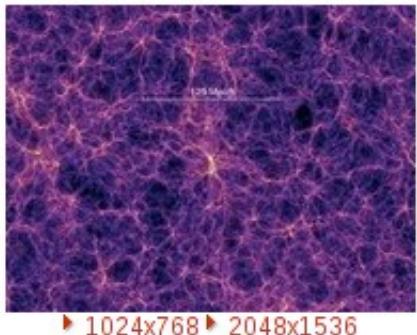


► 1024x768 ► 2048x1536

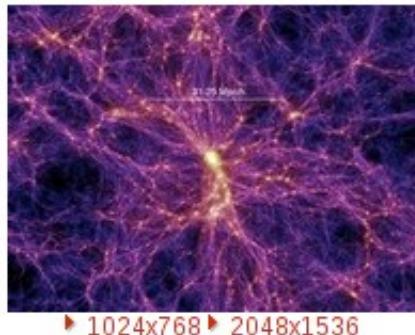
Redshift z=1.4 (t = 4.7 Gyr):



► 1024x768 ► 2048x1536

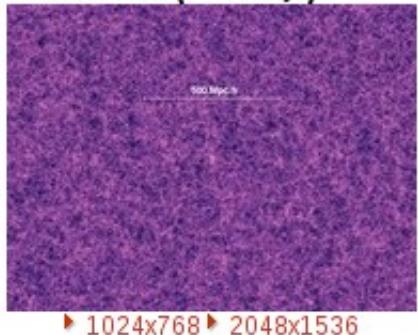


► 1024x768 ► 2048x1536

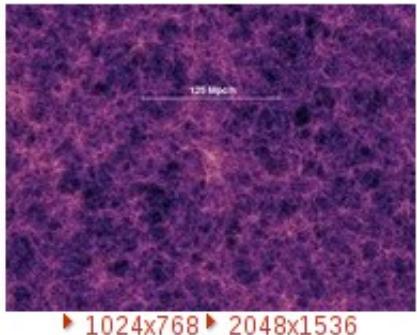


► 1024x768 ► 2048x1536

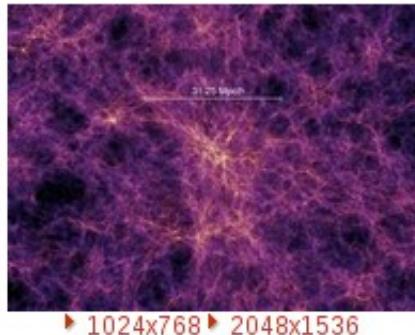
Redshift z=5.7 (t = 1.0 Gyr):



► 1024x768 ► 2048x1536

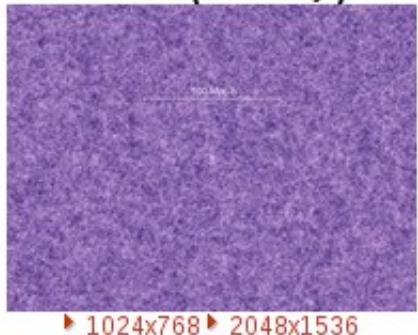


► 1024x768 ► 2048x1536

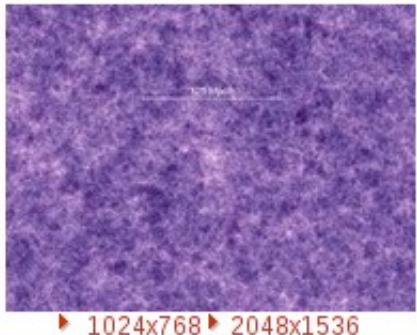


► 1024x768 ► 2048x1536

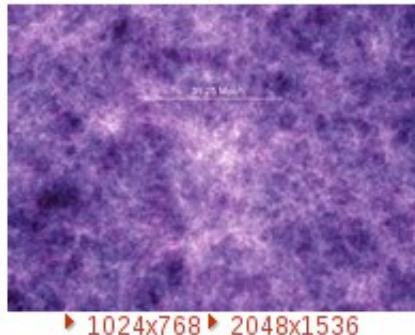
Redshift z=18.3 (t = 0.21 Gyr):



► 1024x768 ► 2048x1536



► 1024x768 ► 2048x1536



► 1024x768 ► 2048x1536

Enlaces interesantes

Scale of the universe:

<http://htwins.net/scale2/lang.html>

Timeline of cosmology:

<http://cosmology.carnegiescience.edu/timeline>

Paper de Prajwal sobre la masa de la MW:

<http://arxiv.org/pdf/1408.1787v1.pdf>

The History of Dark Matter by Joel Primack:

<https://www.youtube.com/watch?v=SJVgC9tUBqM>

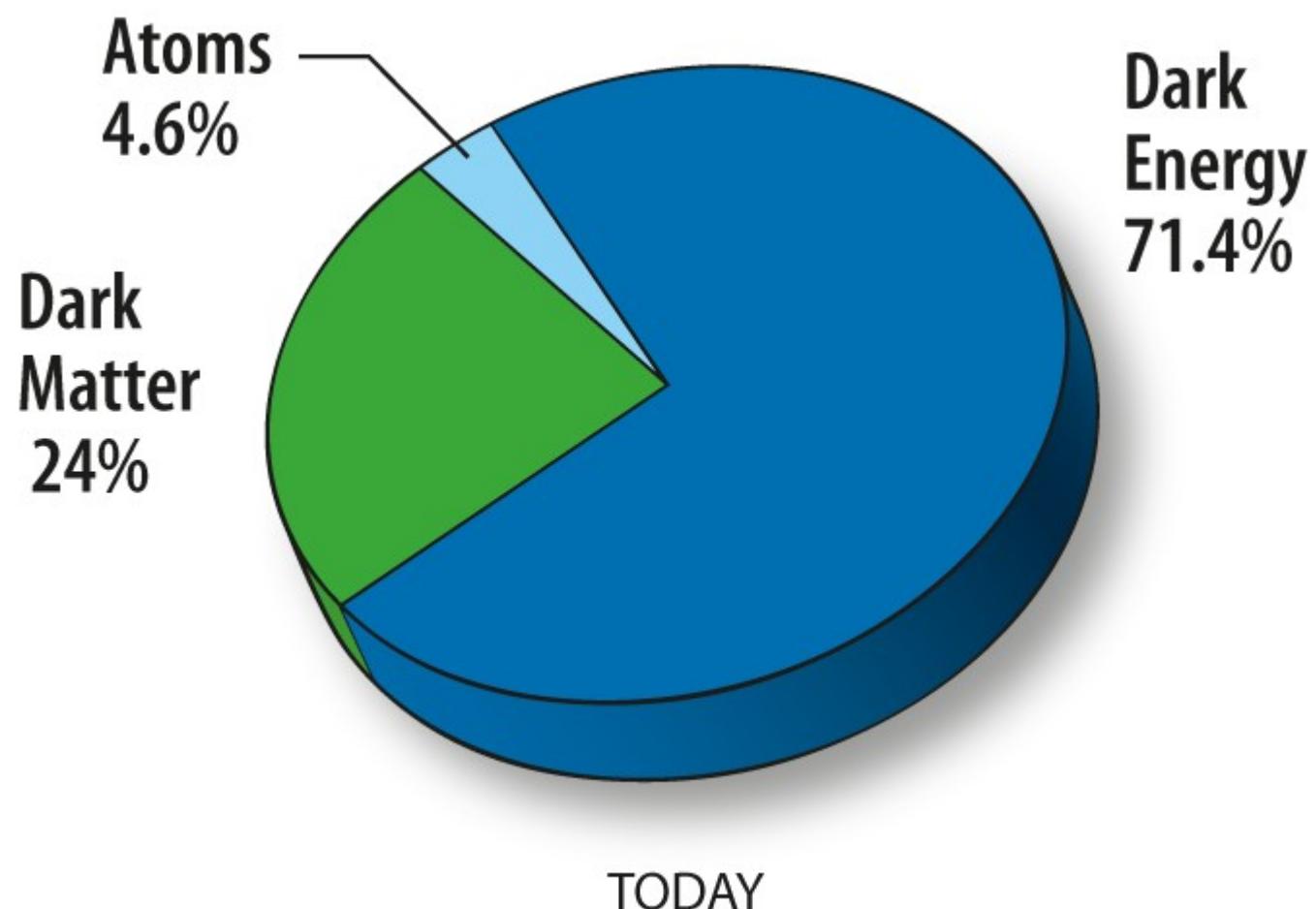
Potsdam thinkshop

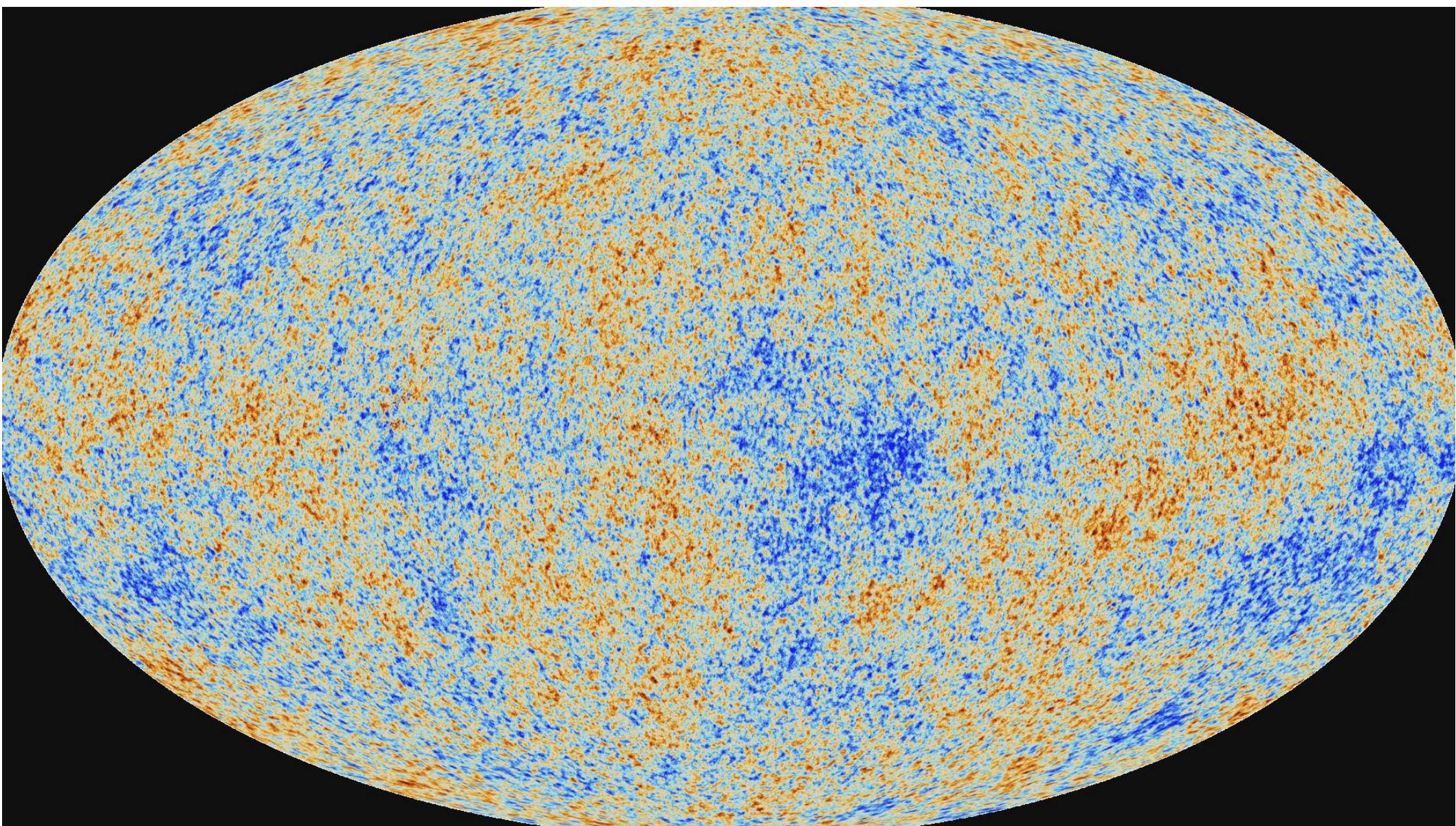
Satellite galaxies and dwarfs in the Local Group

<https://thinkshop.aip.de/dwarfs2014/>

Cold streams:

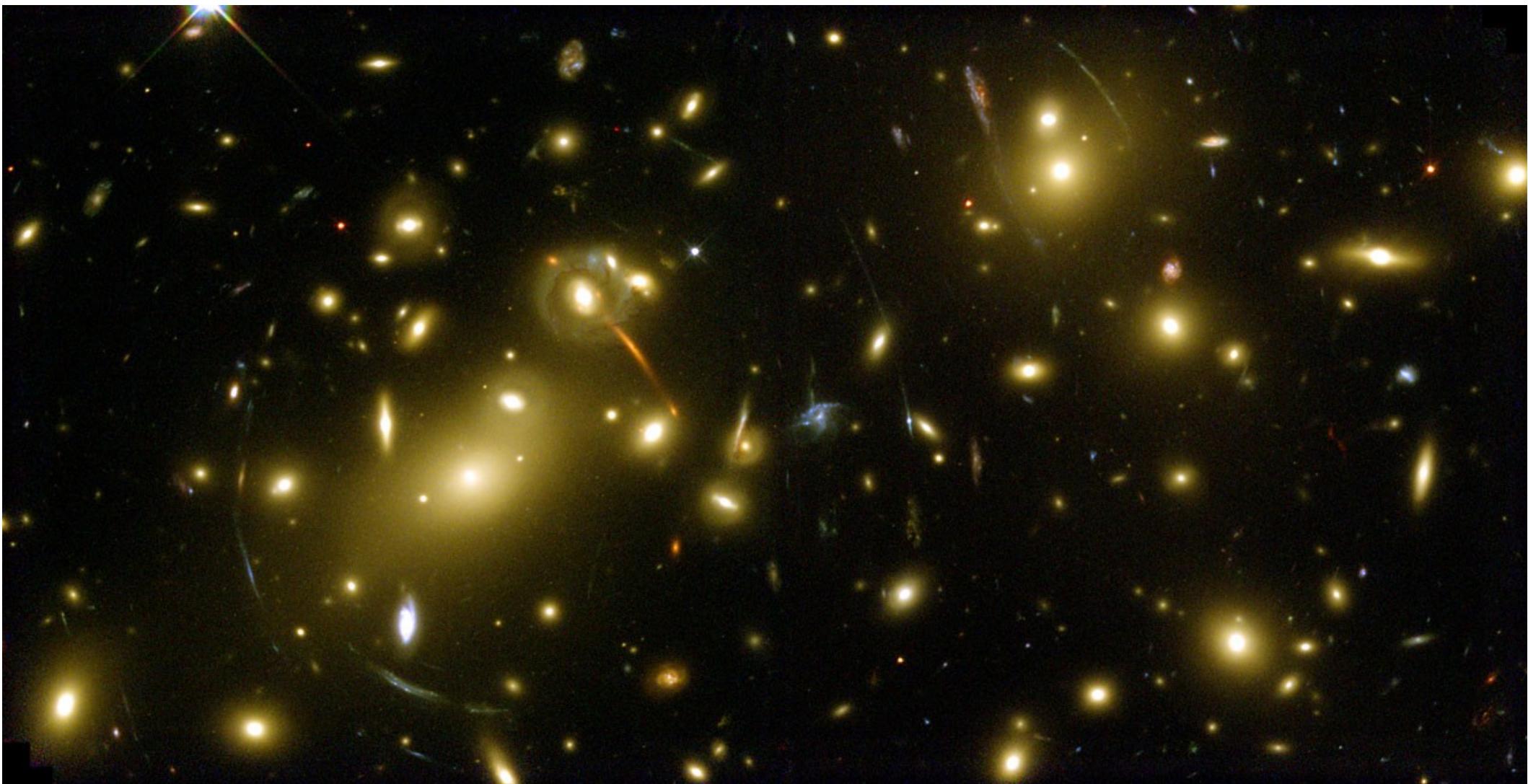
<http://arxiv.org/abs/1307.2102>





Materia Oscura: Otras evidencias

Lentes gravitacionales



Materia Oscura: Otras evidencias

Lentes gravitacionales y gas en el “Bullet Cluster”

