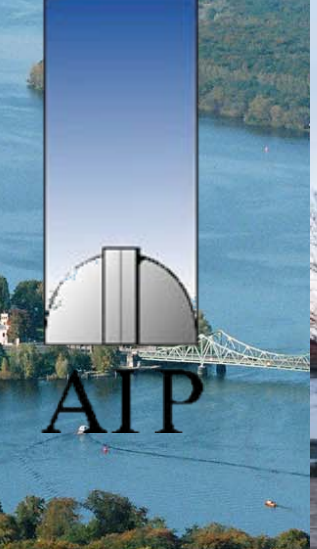
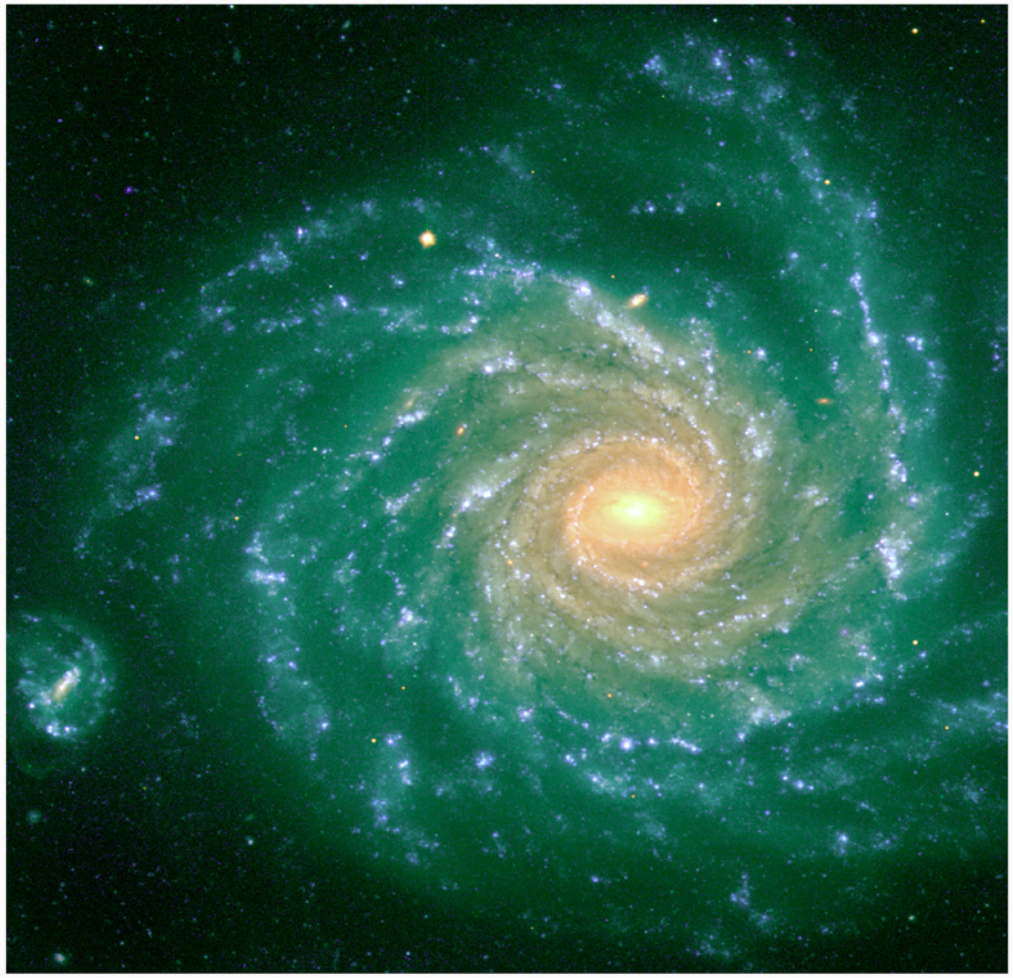
Modelling the Milky Way:

challenges in scientific computing and data analysis

Matthias Steinmetz


AIP

Can we form disk galaxies?



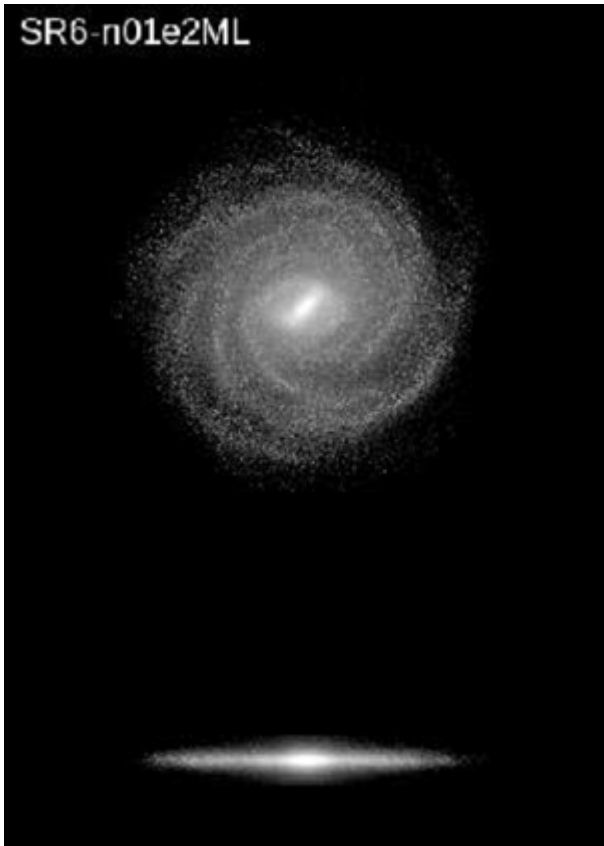
Spiral Galaxy NGC 1232 - VLT UT 1 + FORS1

ESO PR Photo 37d/98 (23 September 1998)

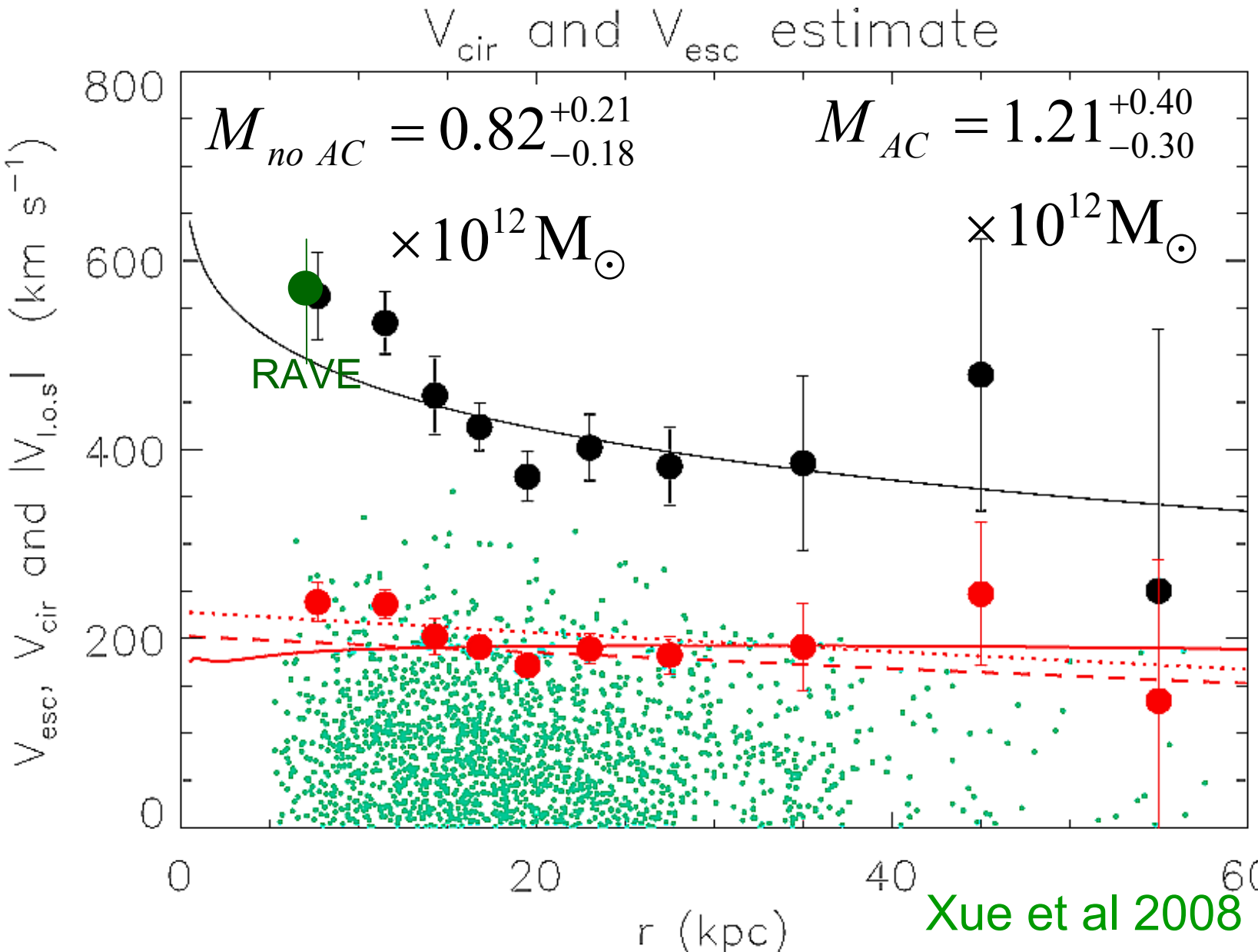
Not really …

- Formation of disks has been notoriously difficult
  - Feedback?
  - Resolution?
  - Numerical Methods?
    - AMR vs SPH
- Remember: on galactic scales, hydrodynamics is an approximation (probably) !
- What is the mass of MW-type DM halo
  - Abundance $M \sim 2.5 \times 10^{12}\, M_{\odot}$
  - Stellar dynamics $M \sim 10^{12}\, M_{\odot}$

Agertz et al, 2010

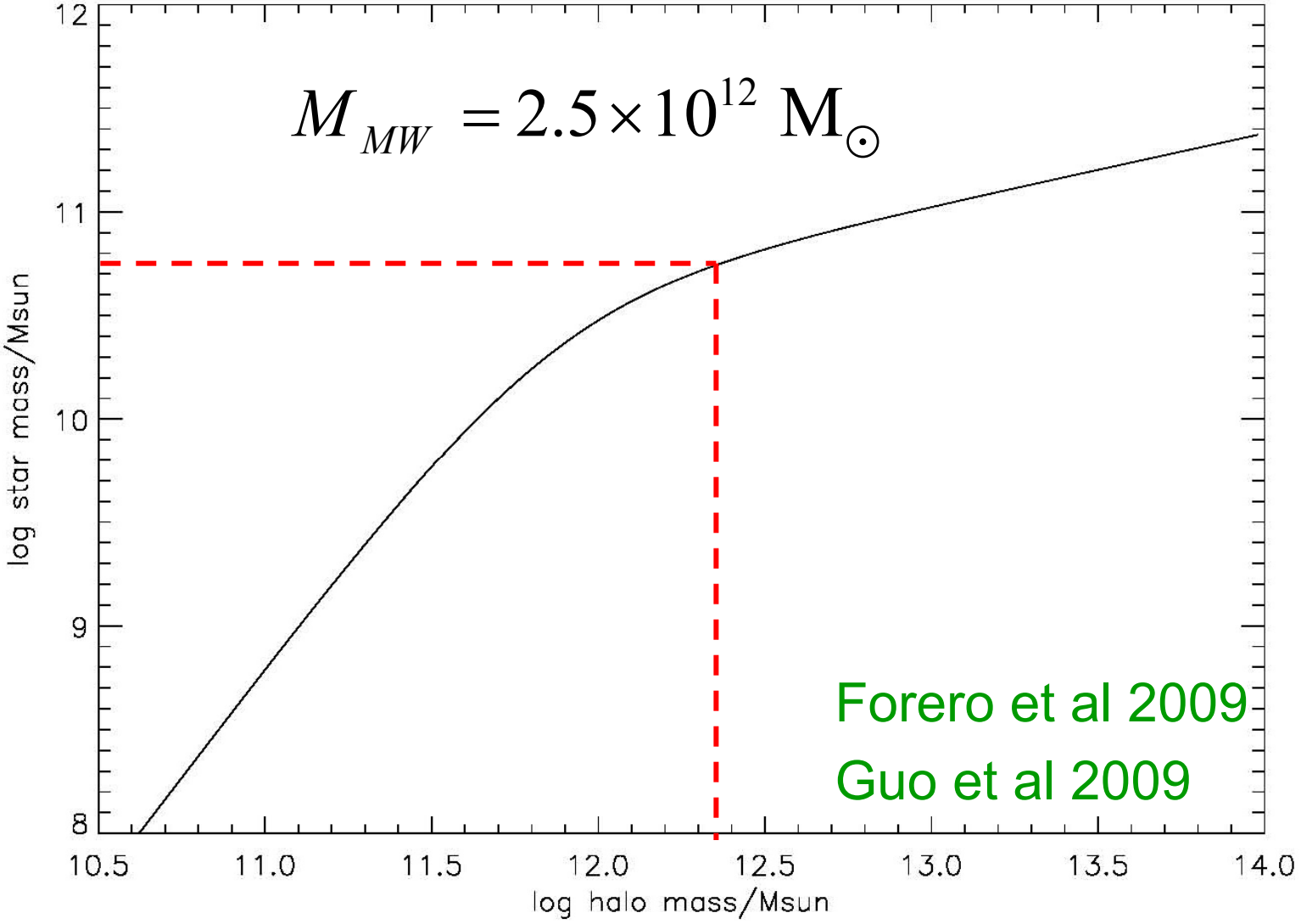


V_{circ} and V_{esc} from SDSS

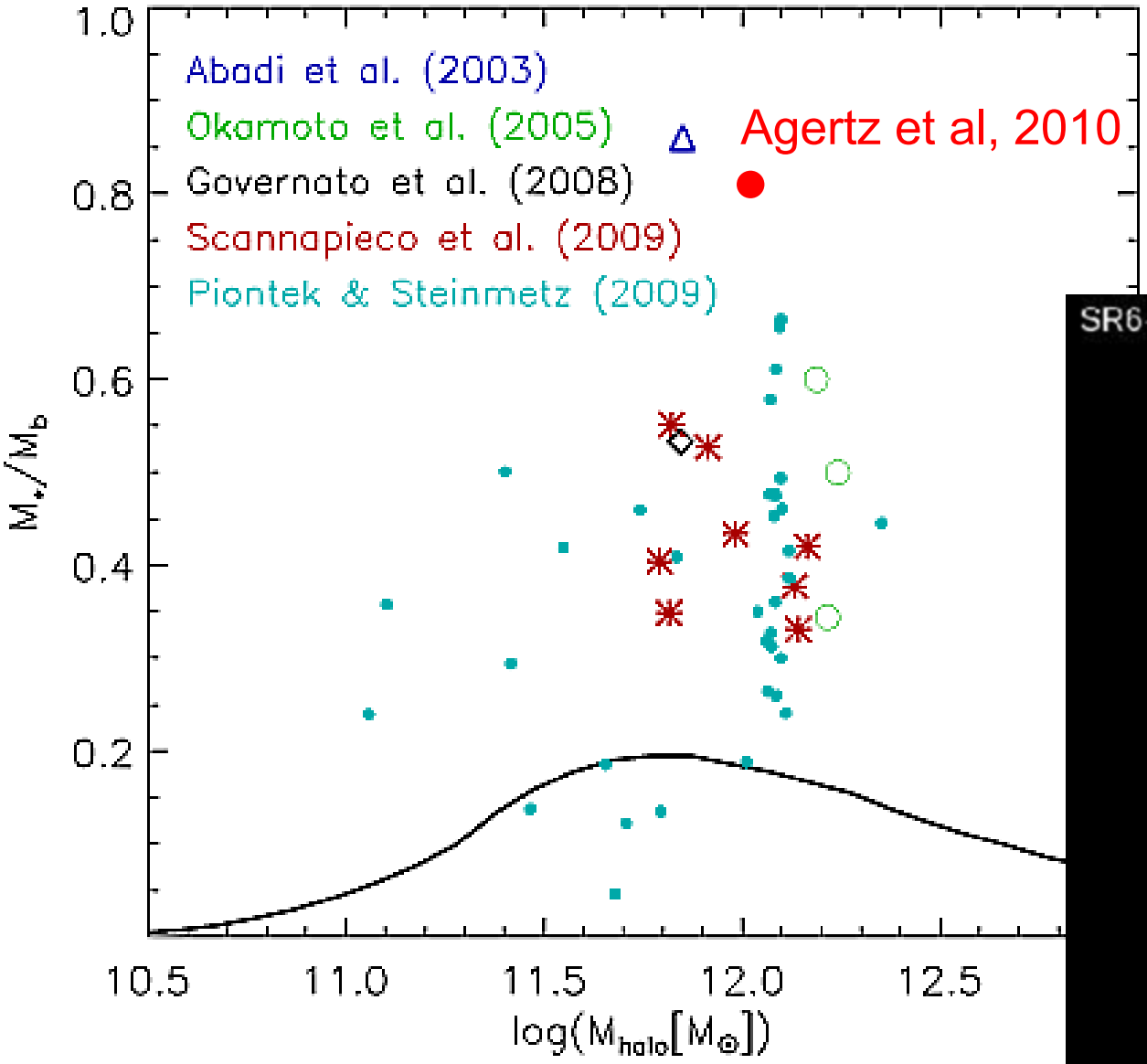


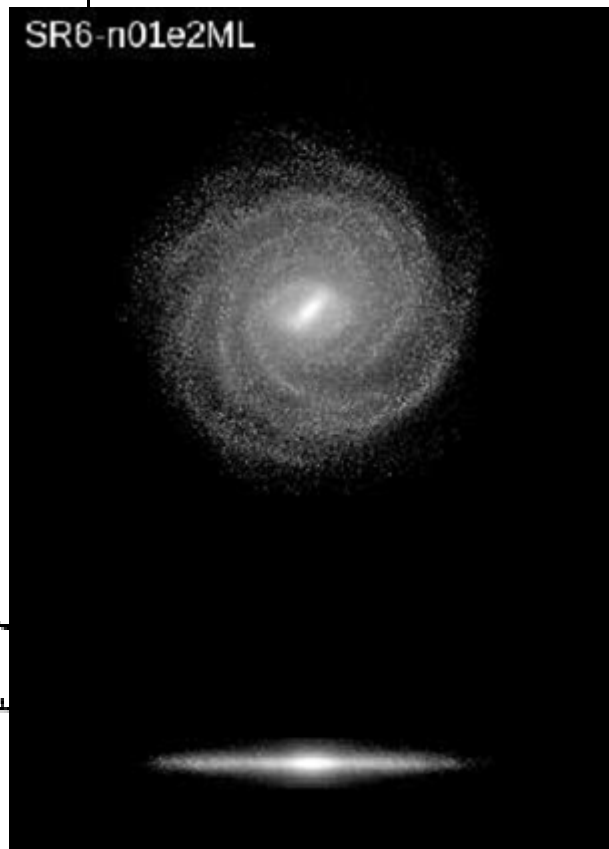
Xue et al 2008

Compare SDSS stellar mass function with DM halo mass function

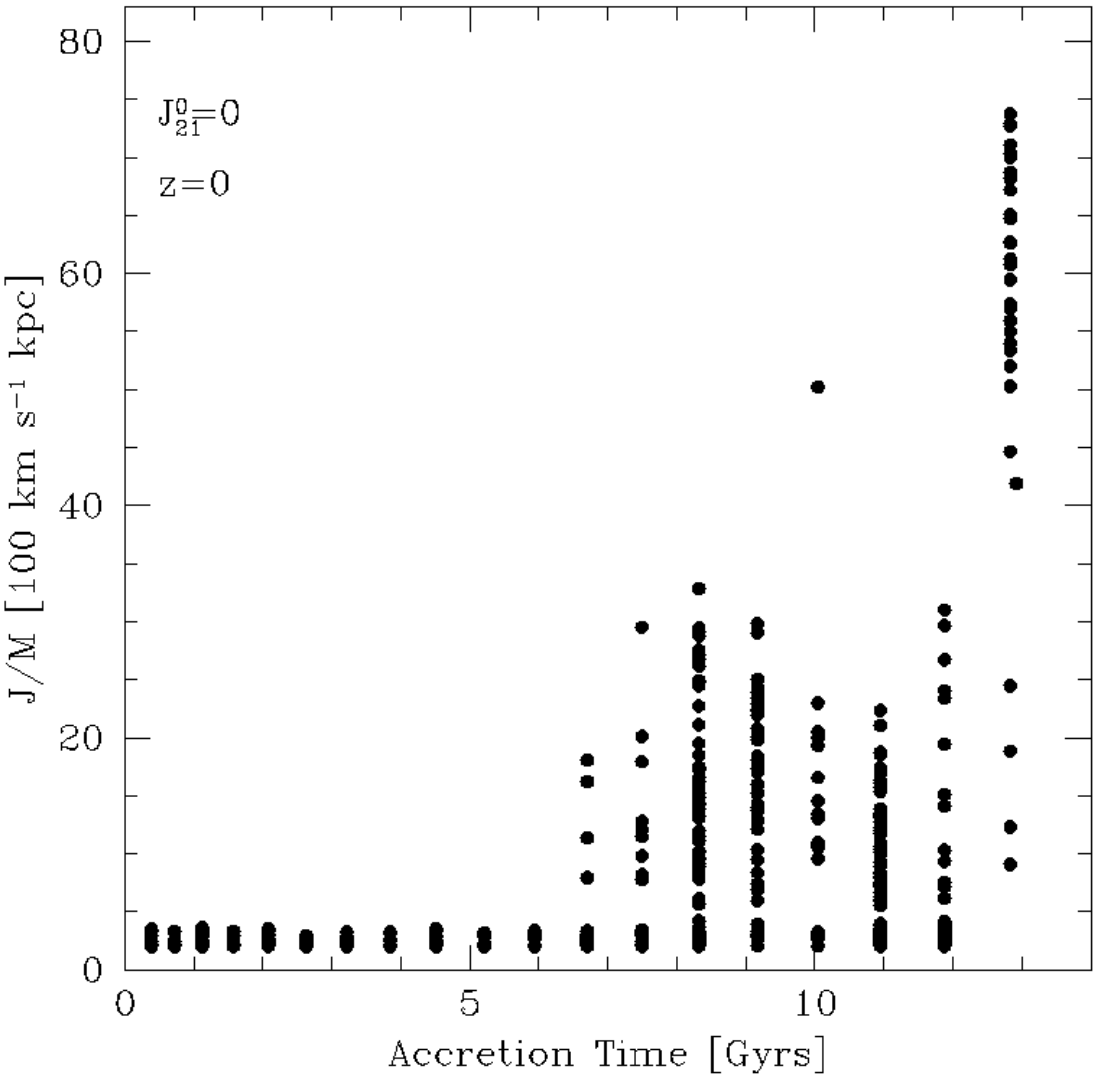


We still do not really understand how to form disk galaxies



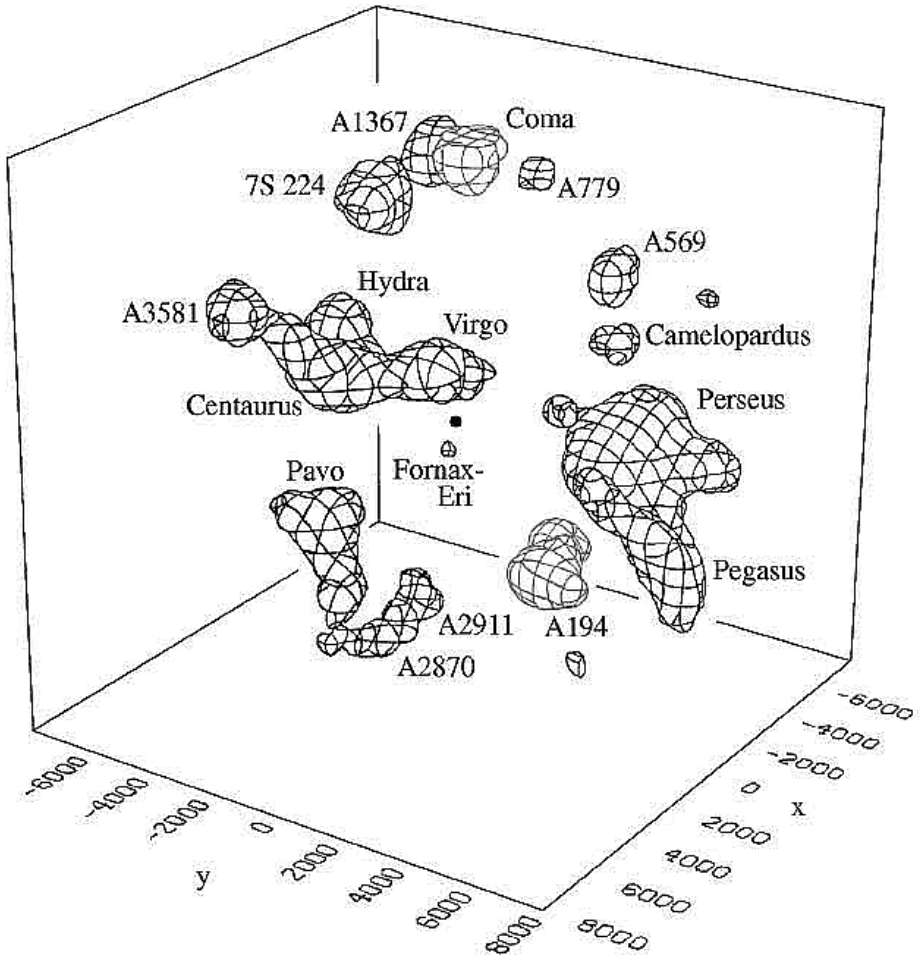


Most of the angular momentum comes in late and thus at low density



Navarro & MS 1997

The local universe is not a representative part of the universe. The MW is situated in a region of relatively low density and with large nearby mass concentrations like Virgo, the local supercluster, Perseus Pisces and Coma



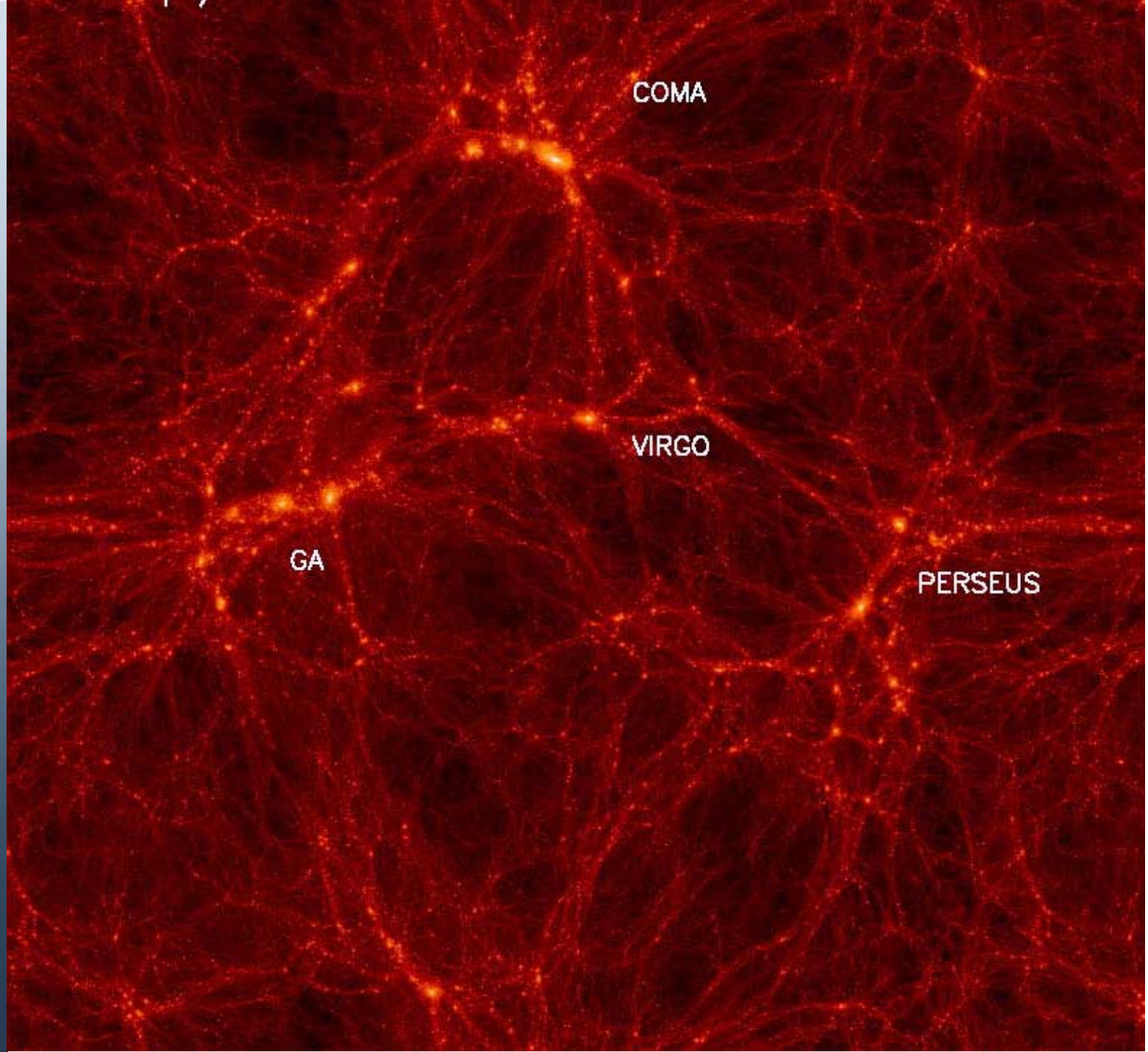
CLUES - Constrained Local UniversE Simulations

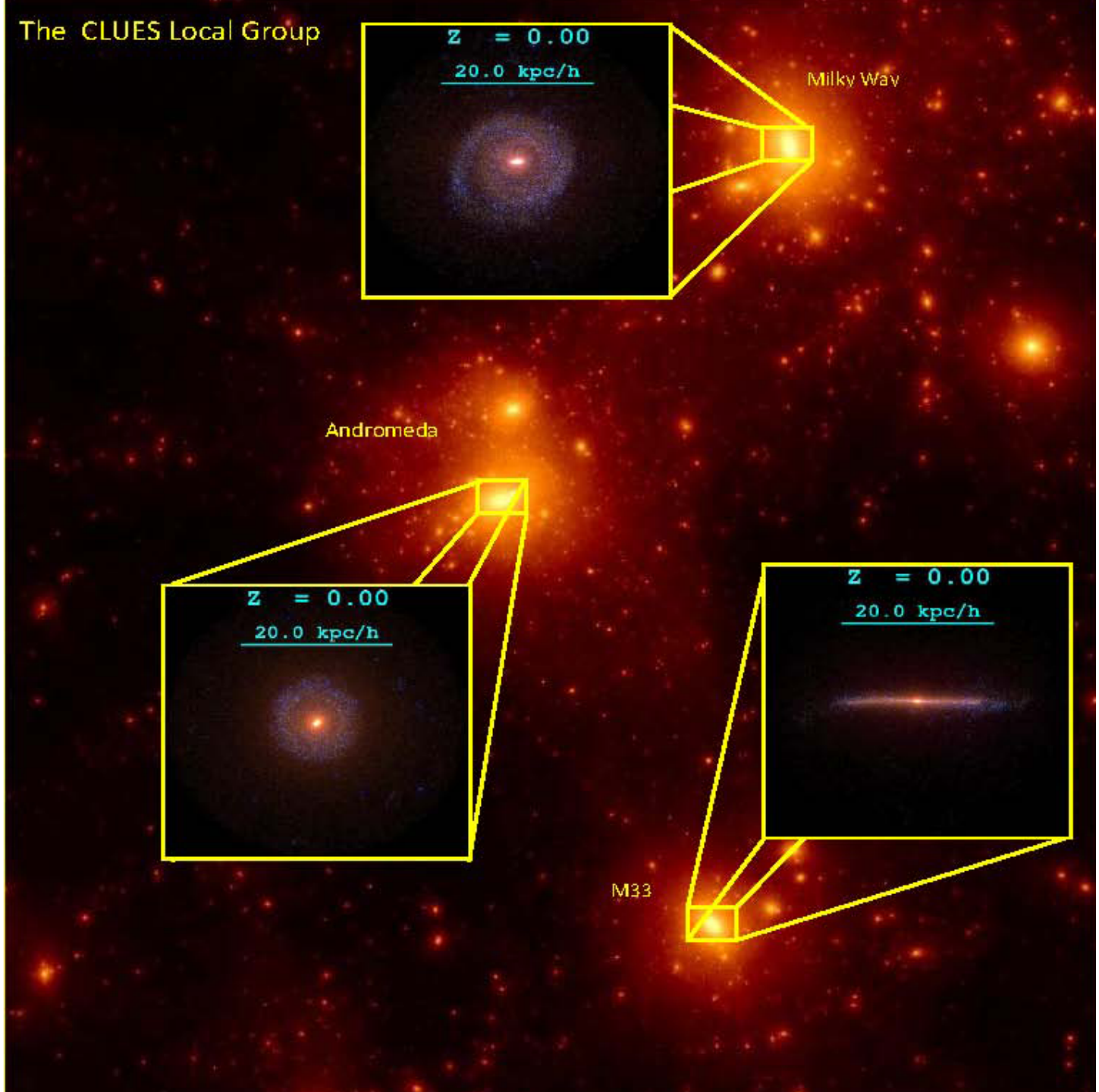
The Local Group and its environment is the most well observed region of the universe. Only in this unique environment can we study structure formation on scales as small as that of very low mass dwarf galaxies. The main goal of the CLUES-project is to provide constrained simulations of the local universe designed to be used as a numerical laboratory of the current paradigm. The simulations will be used for unprecedented analysis of the complex dark matter and gasdynamical processes which govern the formation of galaxies. The predictions of these experiments can be easily compared with the detailed observations of our galactic neighborhood.

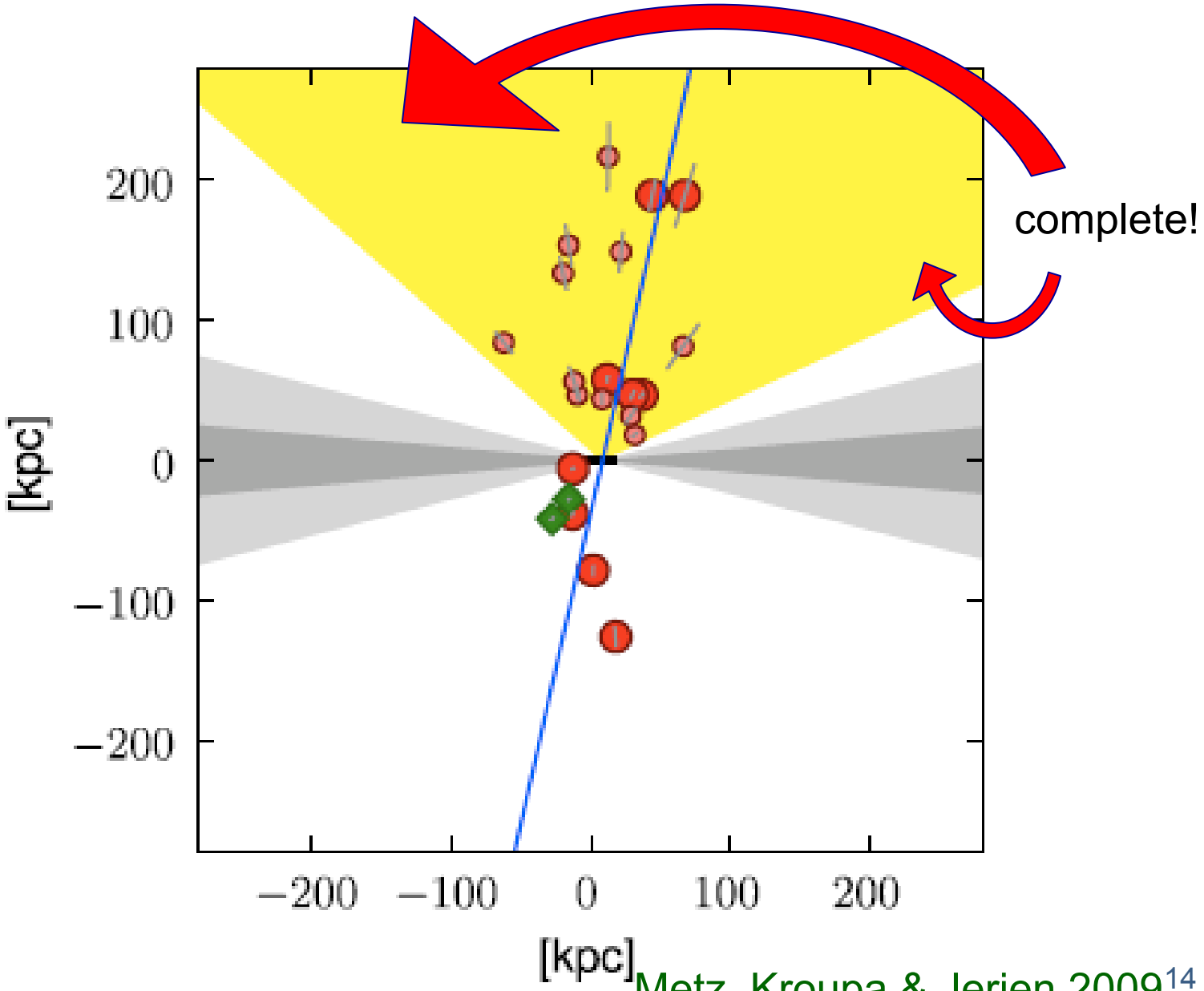
Stefan Gottlöber Yehuda Hoffman Anatoly Klypin Gustavo Yepes

Local Group alikes are pretty rare!

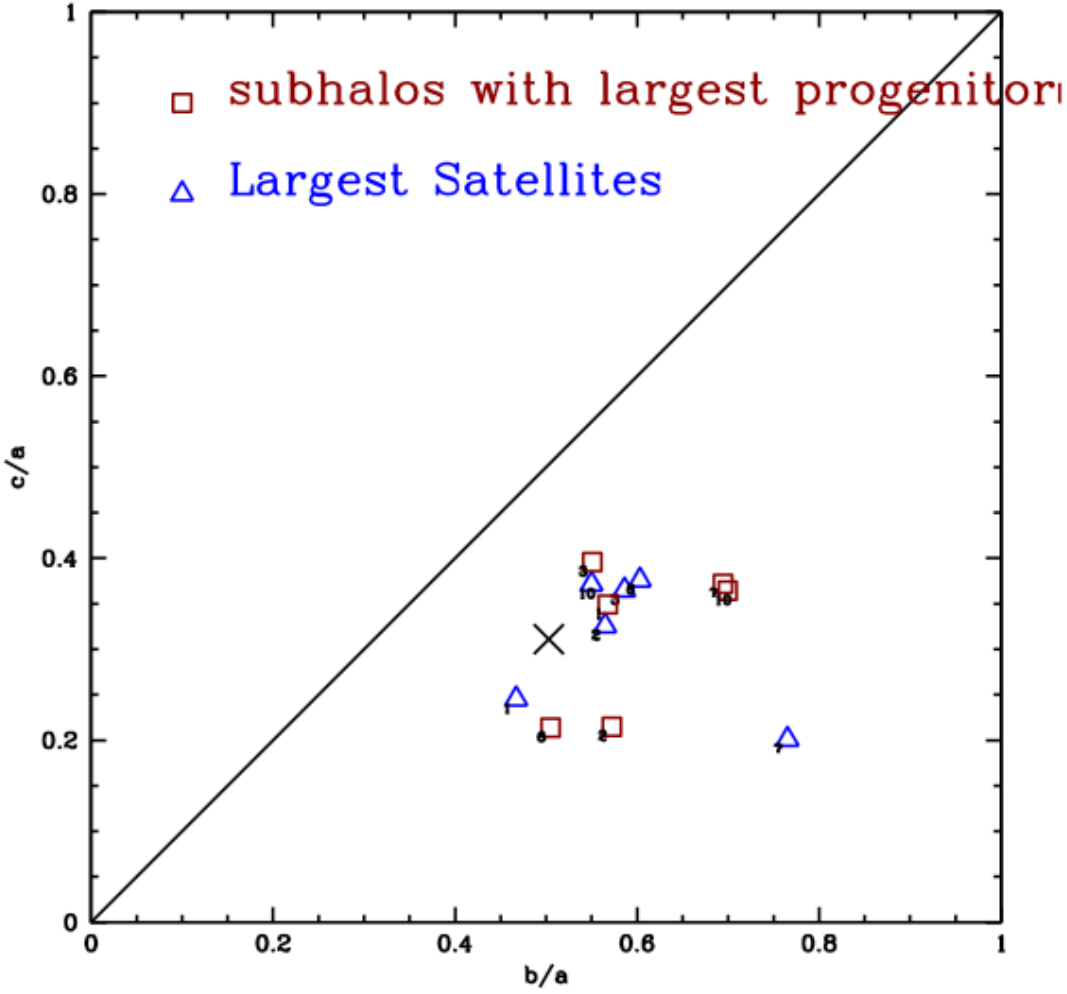
- analysis of 90 Mpc box, constrained simulation
- WMAP5 normalization
- one excellent candidate
  - Virgo:
    - Mass: $1.2\times10^{14}\,M_\odot$ (more massive)
    - distance: 14.9 Mpc (19.0 Mpc ← NED)
  - Fornax:
    - mass: $4.2\times10^{13}\,M_\odot$ ($7.0\times10^{13}\,M_\odot$ ← ApJ 548, L139)
    - distance: 19.2 Mpc (17.6 Mpc ← NED)
  - Local group
    - mass: $3.0\times10^{13}M_\odot$ (lower mass end)
    - MW/Andromeda distance: 690kpc (700kpc)


COMA
VIRGO
GA
PERSEUS


The CLUES Local Group
z = 0.00
20.0 kpc/h
Milky Way
Andromeda
z = 0.00
20.0 kpc/h
z = 0.00
20.0 kpc/h
M33



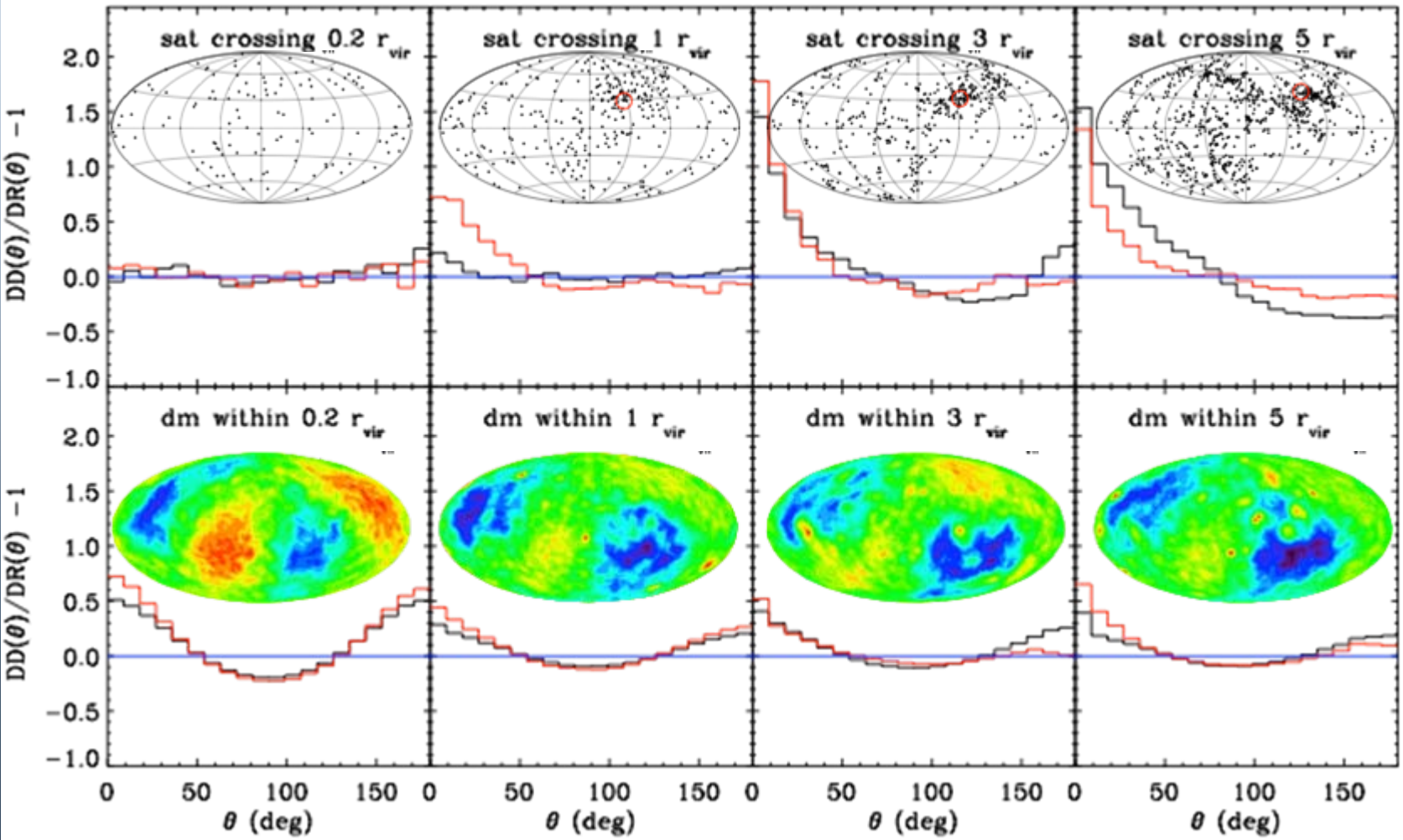
Metz, Kroupa & Jerjen 2009



6 DM only simulations, populated with galaxies semi-analytically.

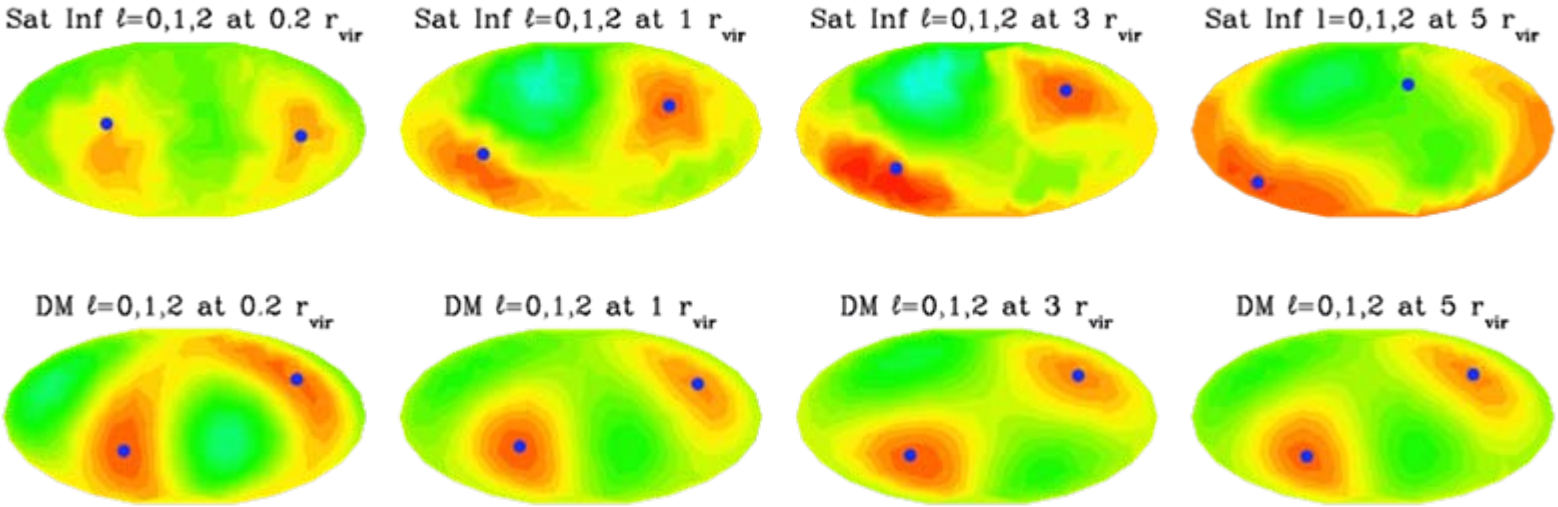
Libeskind et al 2005

Preferential infall of satellites

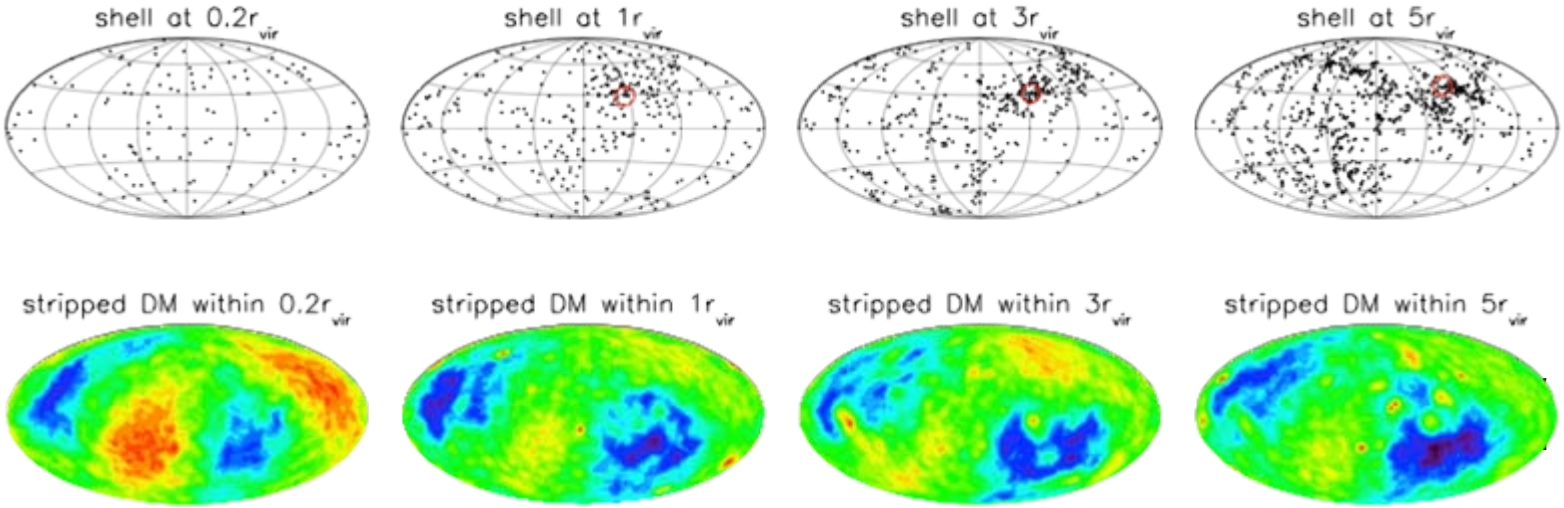


Libeskind et al, 2011

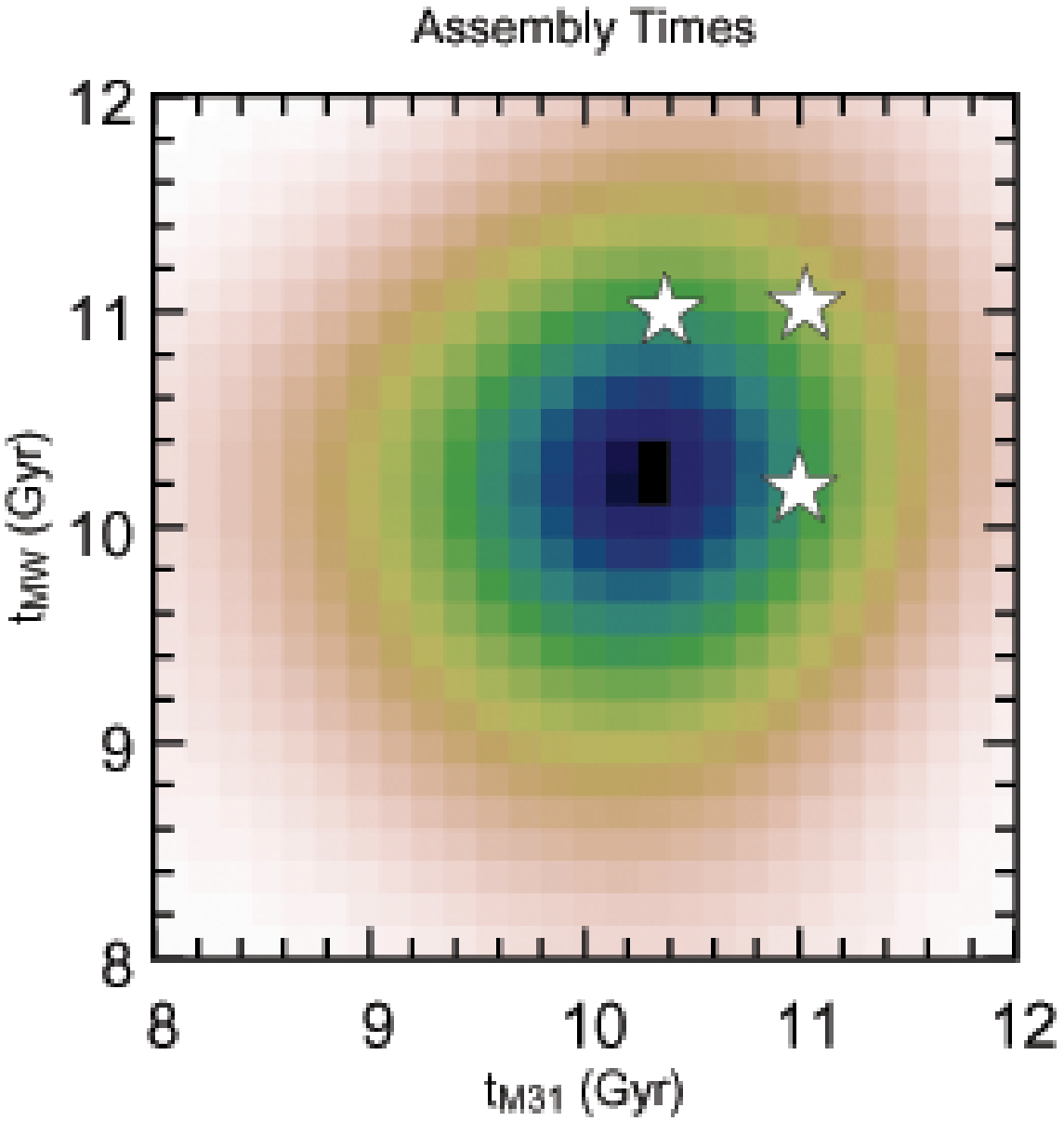
Preferential infall of satellites



Quadrupole: infall along a filament
Pointing towards Virgo



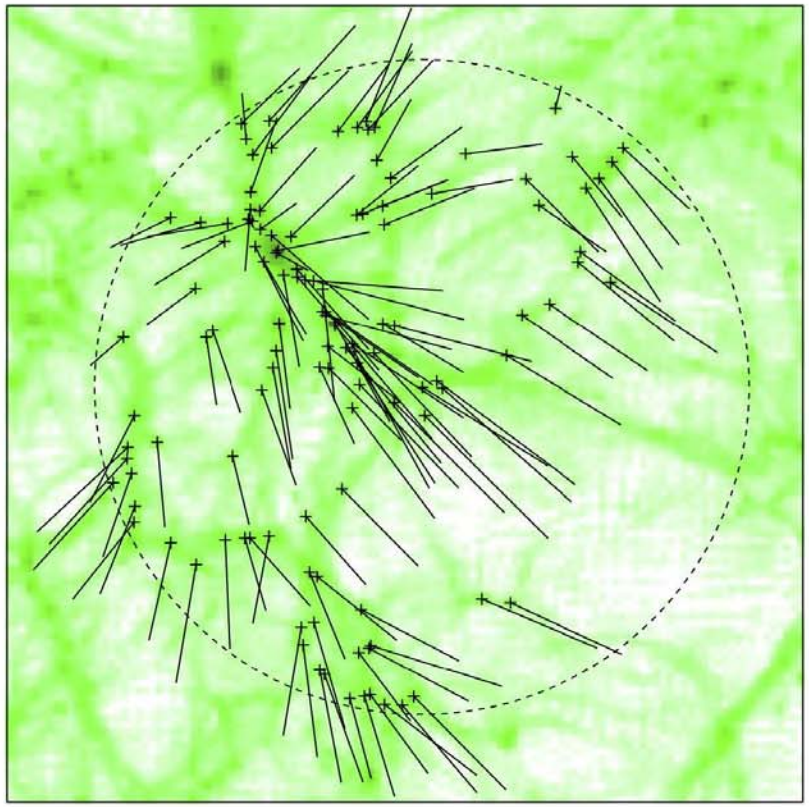
The MW is not a typical galaxy …



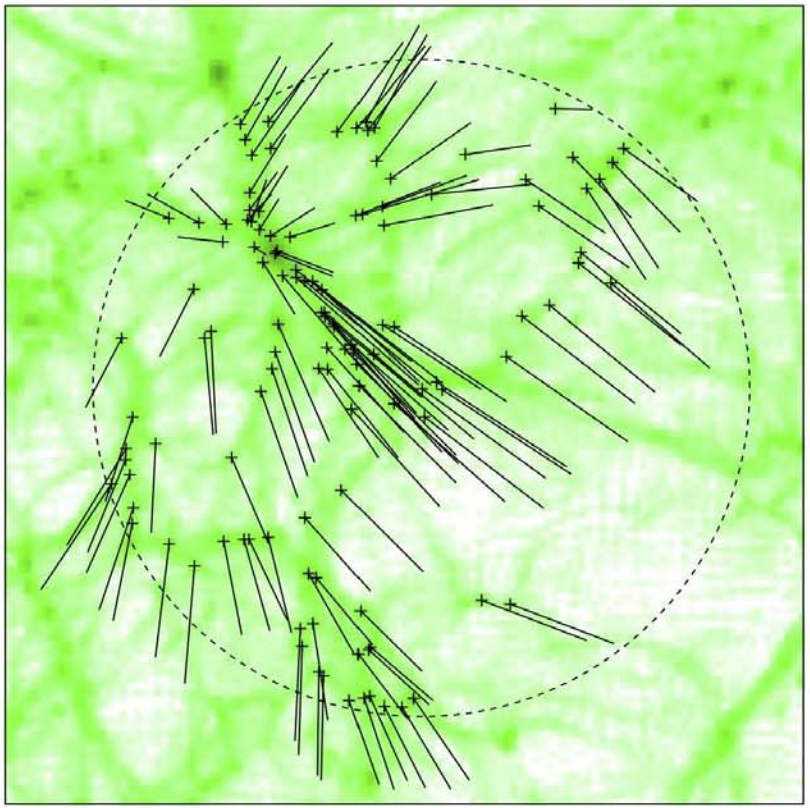
Forero et al, 2011

Original vs. reconstructed halo displacements

Original halo displacement
from initial conditions at z = 0



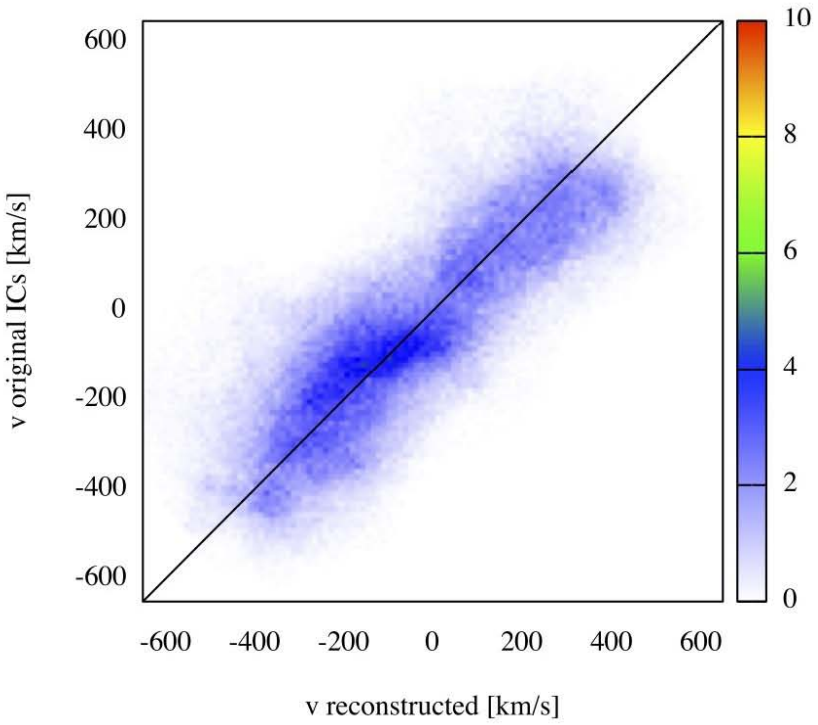
WF reconstructed displacement
(from 558 radial peculiar velocities within R = 30 Mpc/h sphere)



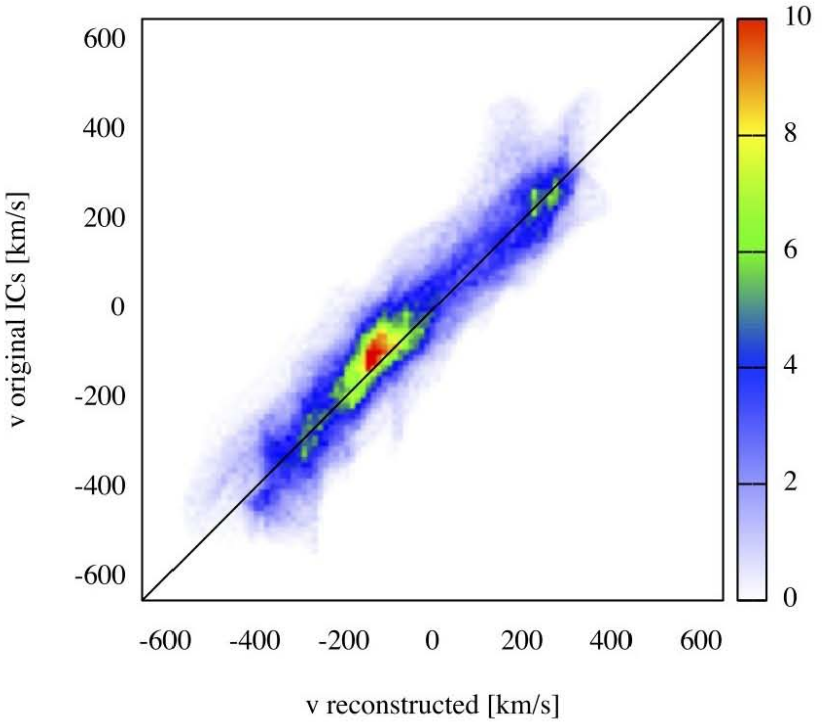
Doumler et al, 2011

Original vs. reconstructed initial conditions

Correlation with non-displaced reconstructed ICs



Correlation with reconstructed ICs + WF displacement reconstruction



Doumler et al, 2011

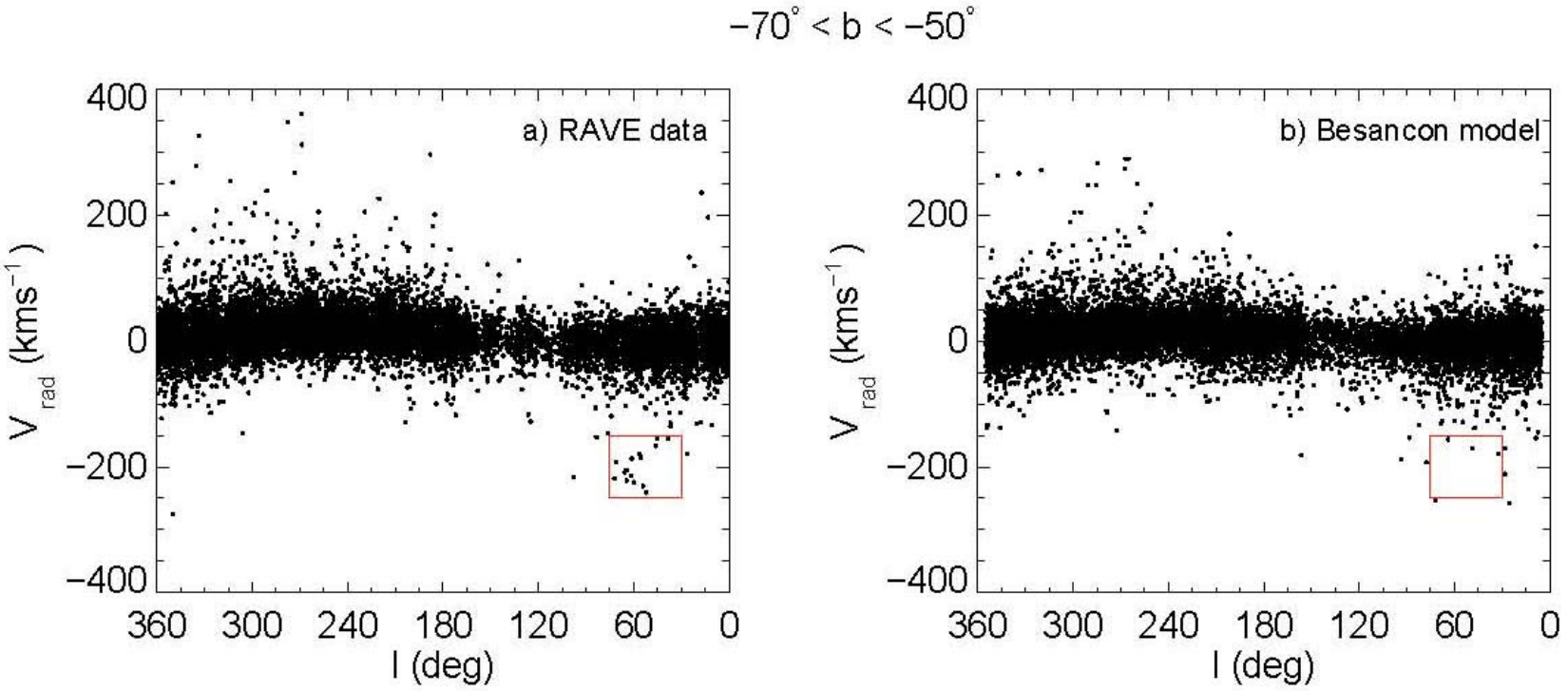
How about observations?

The Milky Way is all around us!

How about observations?

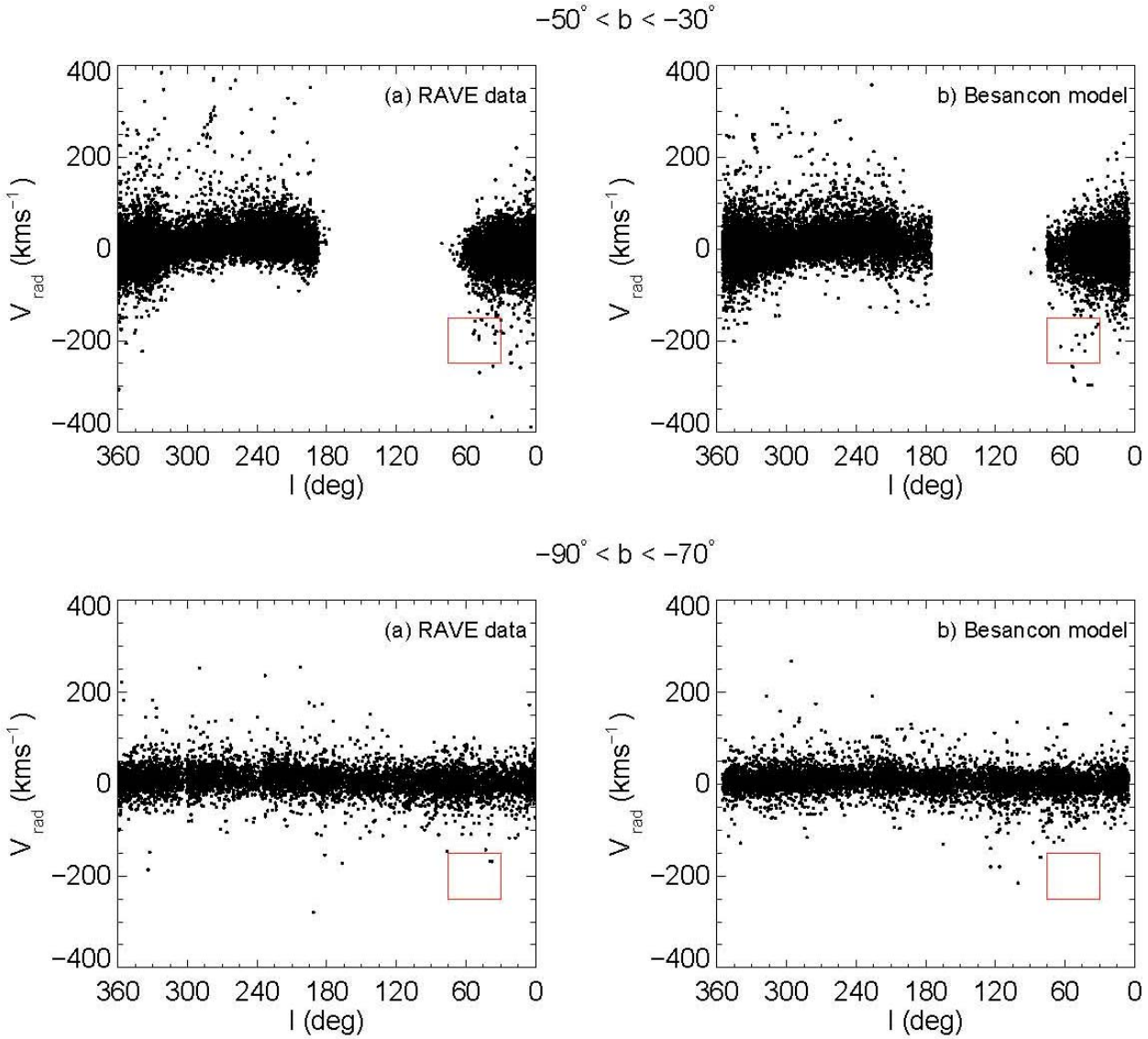
- The substructure crisis
  - Systematic searches using large imaging surveys (SDSS) reveal a considerable (sufficient?) number of new satellites
- Substructure in phase space → tracing the formation history of the Milky Way
  - Lot of activities following the discovery of Sagittarius dwarf
- Imaging
  - SDSS, PanStarrs, Euclid, LSST
- Spectroscopy
  - SDSS, RAVE, GAIA, HERMES, 4MOST
- Astrometry
  - Hipparcos & GAIA

Velocity Substructure in RAVE



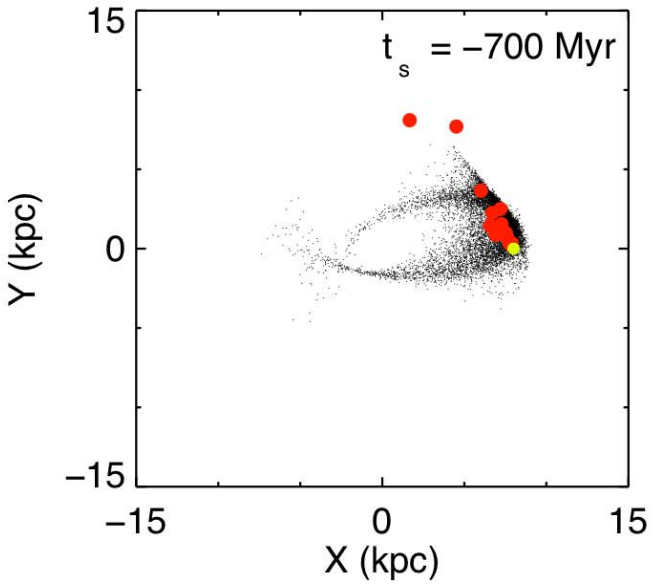
Williams et al, 2010[24]

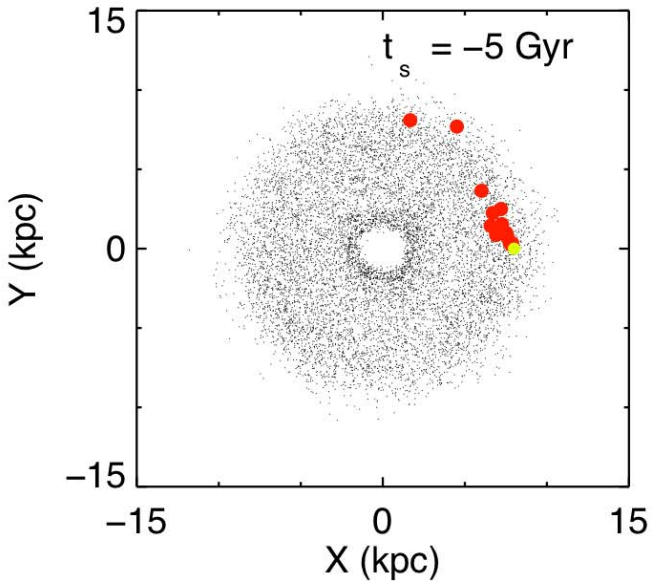
Velocity Substructure in RAVE

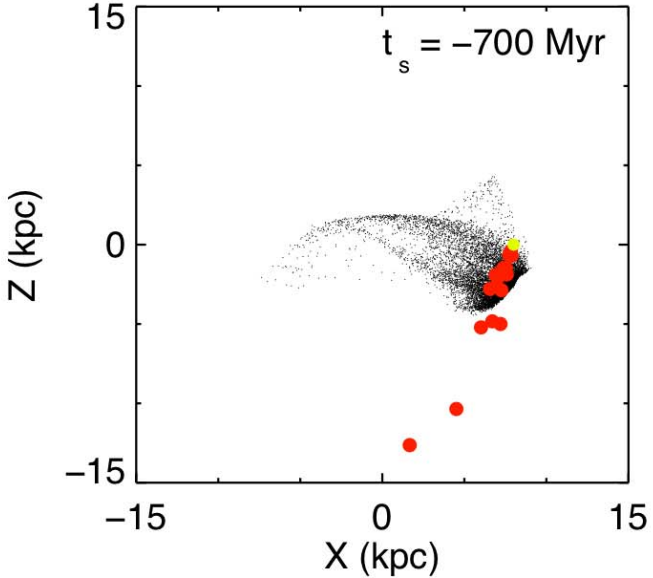


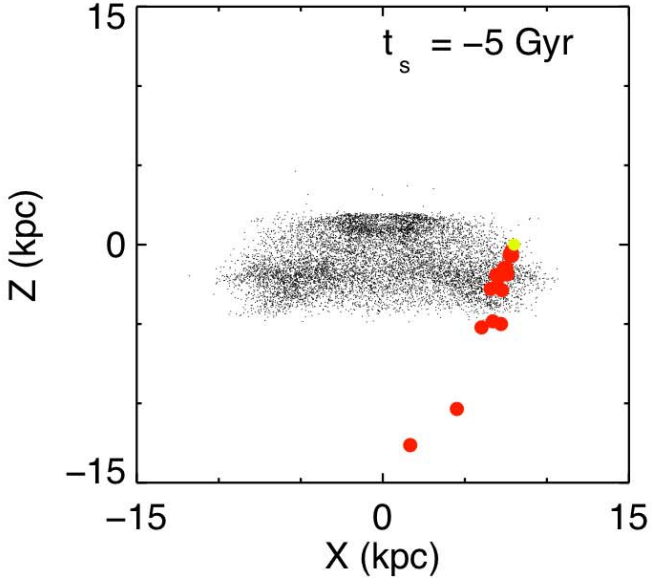
Williams et al, 2010

Illustrative simulations



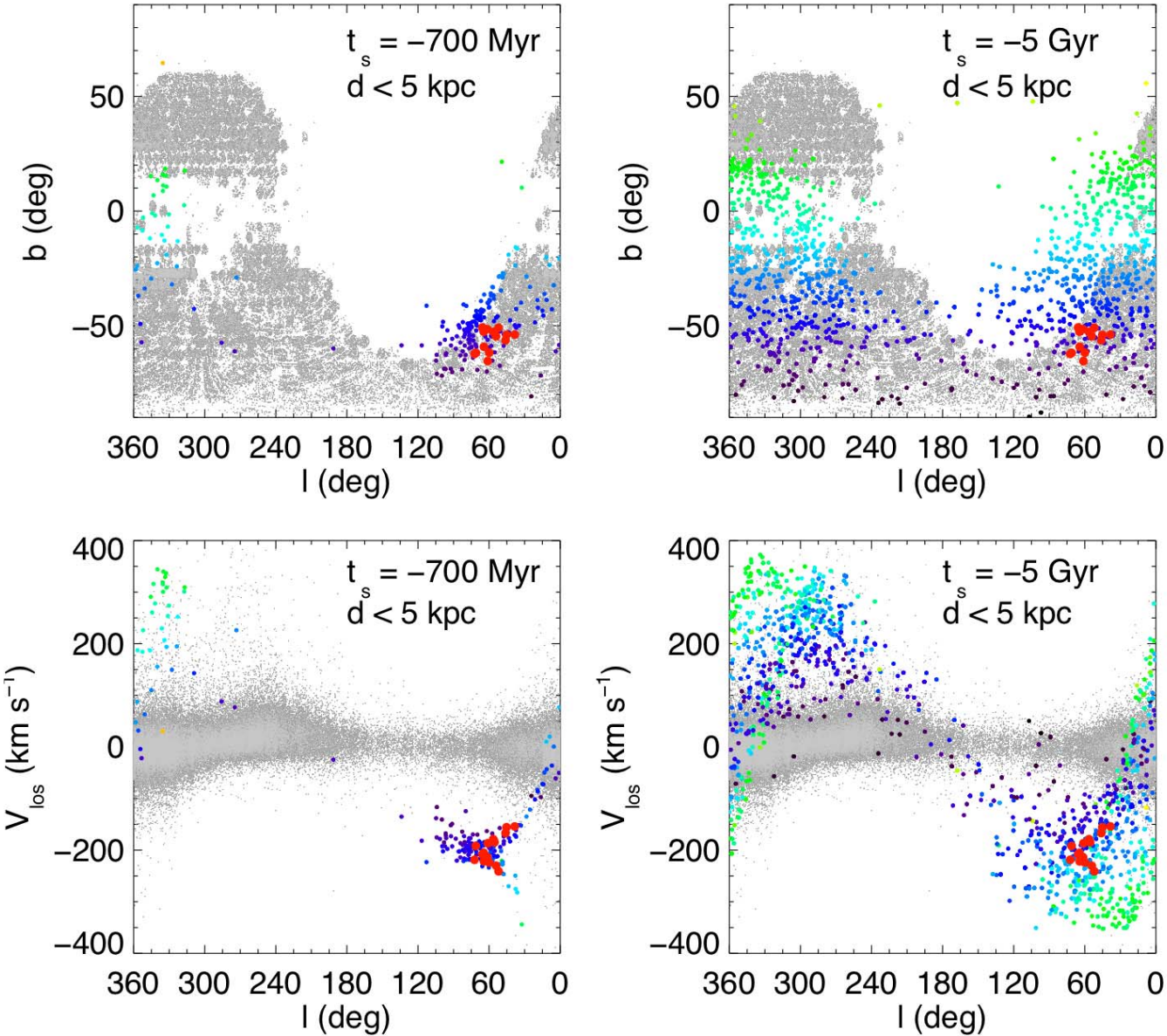






Williams et al, 2010

Recent disruption event



Williams et al, 2010

The Dawning of the Stream of Aquarius in RAVE[1]

M. E. K. Williams[2], M. Steinmetz[2], G. M. Seabroke[3], A. Helmi[4], O. Bienayme[5], J. Binney[6], J. Bland-Hawthorn[7], R. Campbell[8], K. C. Freeman[9], J. P. Fulbright[10], B. K. Gibson[11], G. F. Gilmore[12], E. K. Grebel[13], U. Munari[14], J. F. Navarro[15], Q. A. Parker[16], A. Siebert[5], A. Siviero[14], F. G. Watson[7], R. F. G. Wyse[10], T. Zwitter[17]

sity of Oxford, 1 Keble Road, Oxford OX1 3NP, UK

Outlook: The GAIA epoch

The Future: GAIA

- Cornerstone mission of ESA
- Scheduled for launch in late 2012
- Main objective: To create the largest and most precise three dimensional chart of our Galaxy by providing unprecedented positional and radial velocity measurements for about one billion stars in our Galaxy and throughout the Local Group.

Schedule

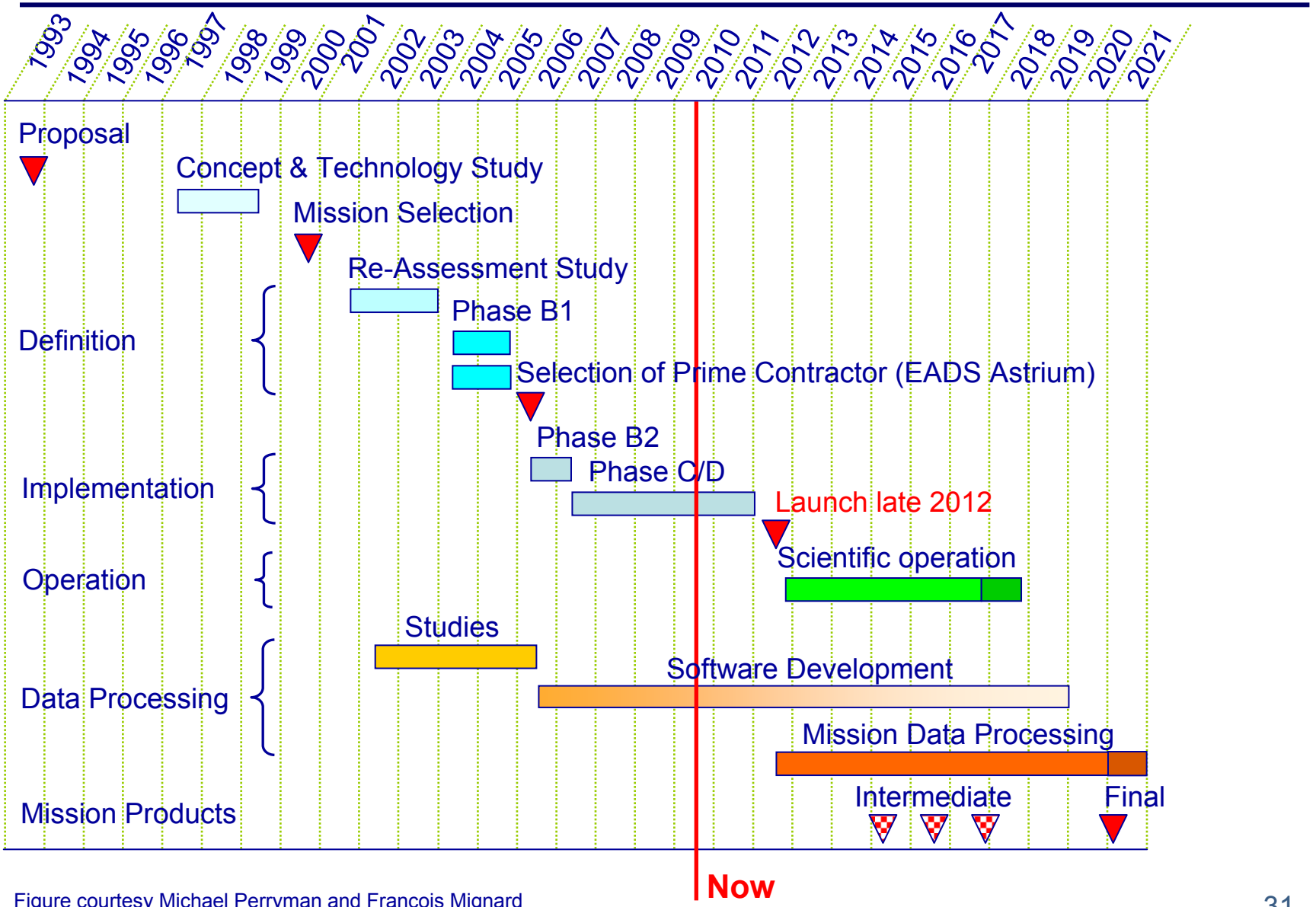
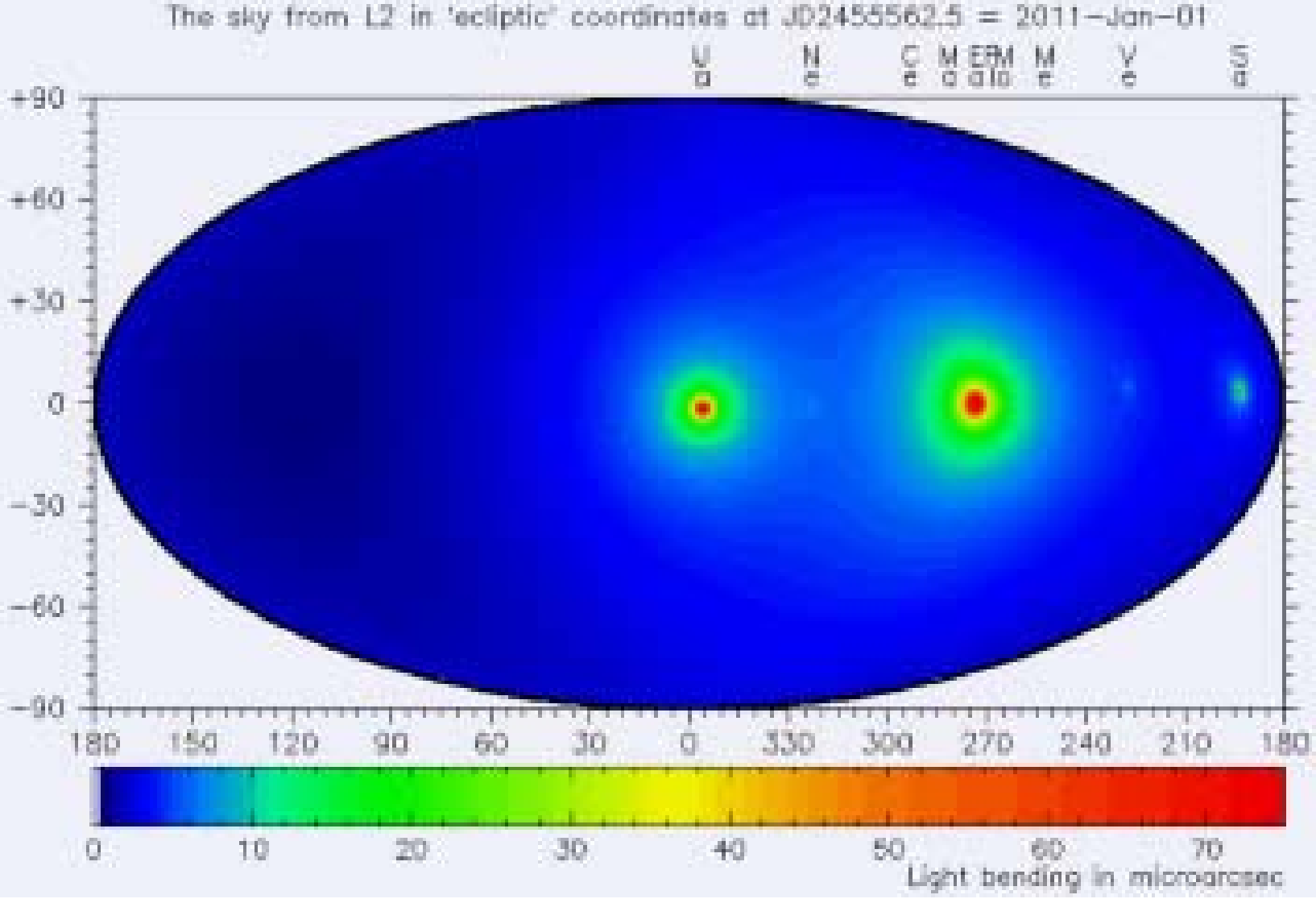


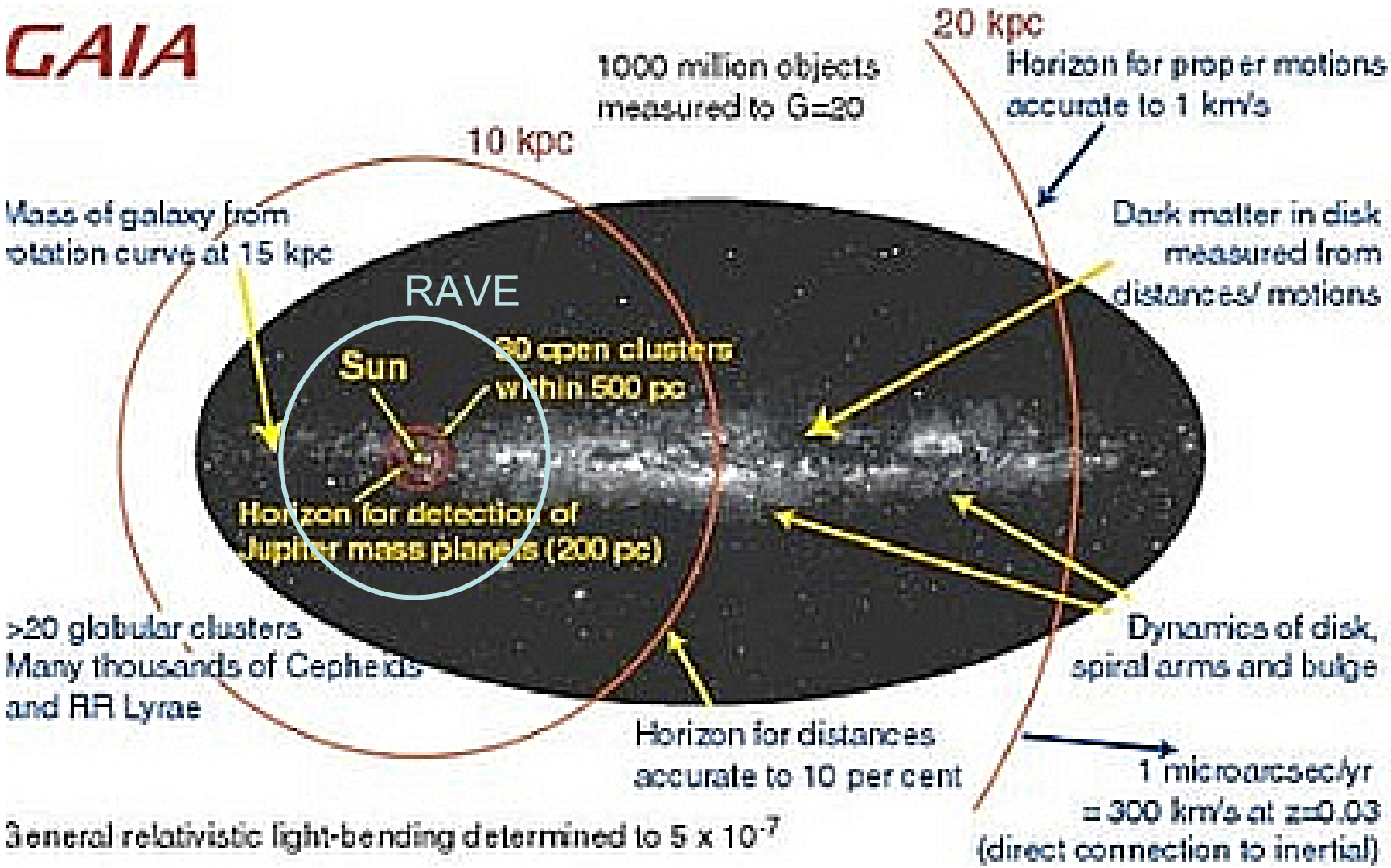
Figure courtesy Michael Perryman and François Mignard

Light Bending in Solar System

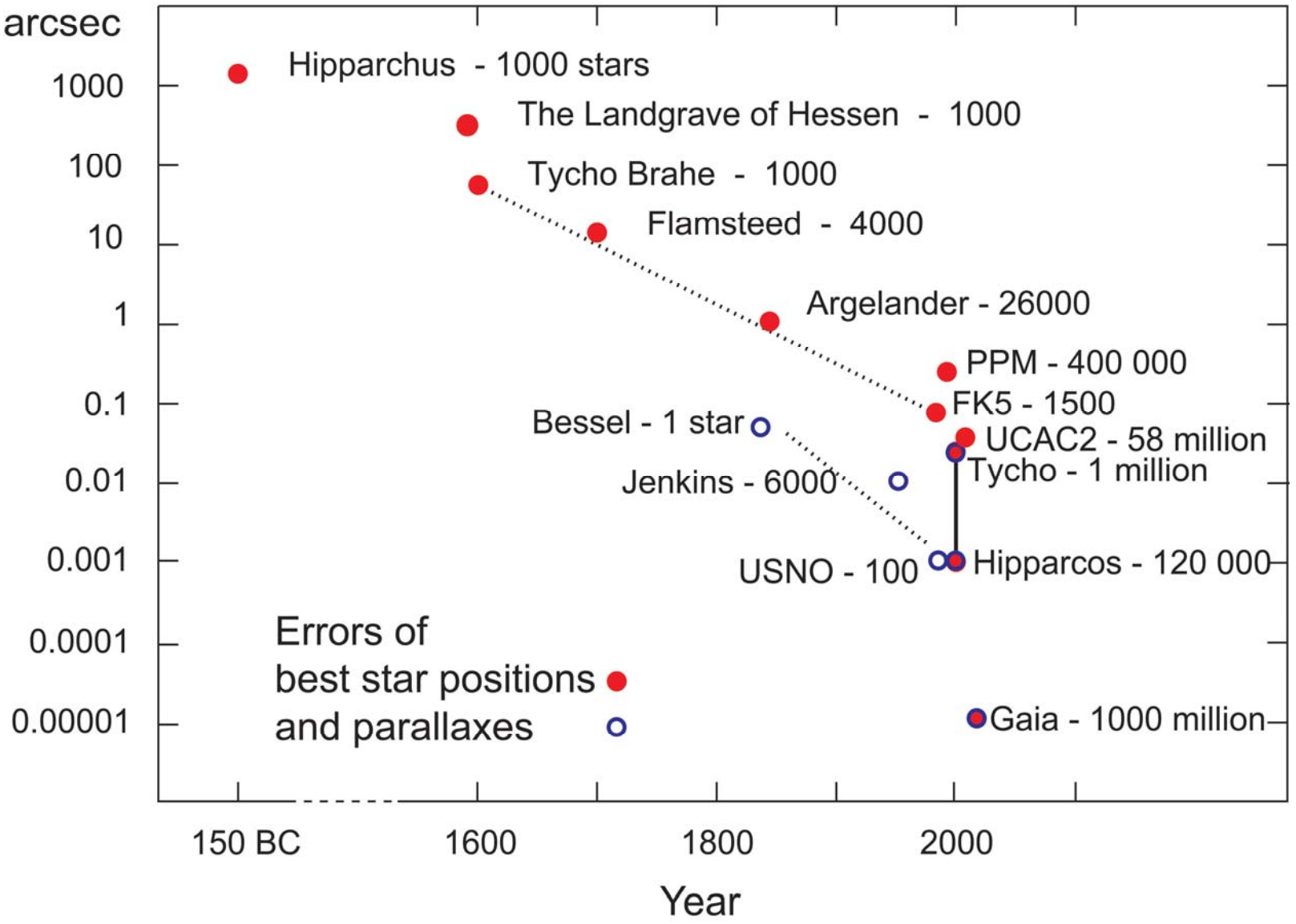


Light bending in microarcsec, after subtraction of the much larger effect by the Sun

The Future: GAIA



GAIA


arcsec
1000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
Hipparchus - 1000 stars
The Landgrave of Hessen - 1000
Tycho Brahe - 1000
Flamsteed - 4000
Argelander - 26000
PPM - 400 000
FK5 - 1500
UCAC2 - 58 million
Tycho - 1 million
Hipparcos - 120 000
Bessel - 1 star
Jenkins - 6000
USNO - 100
Errors of
best star positions
and parallaxes
Gaia - 1000 million
150 BC
1600
1800
2000
Year

One Billion Stars in 3-D will Provide

- in our Galaxy …
  - the distance and velocity distributions of all stellar populations
  - the spatial and dynamic structure of the disk and halo
  - its formation history
  - a detailed mapping of the galactic dark-matter distribution
  - a rigorous framework for stellar structure and evolution theories
  - a large-scale survey of extra-solar planets (~15,000)
  - a large-scale survey of Solar System bodies (~250,000)

- … and beyond
  - definitive distance standards out to the LMC/SMC
  - rapid reaction alerts for supernovae and burst sources (~20,000)
  - QSO detection, redshifts, microlensing structure (~500,000)
  - fundamental quantities to unprecedented accuracy: γ to 2×10-6 (2×10-5 present)

- Fundamental physics - reference frame - solar system - extrasolar planets -
- stellar systems - stellar physics - Galactic astronomy - quasars and galaxies.


(c) Wally Pacholka / AstroPics.com