



AIP

# Modelling the Milky Way:

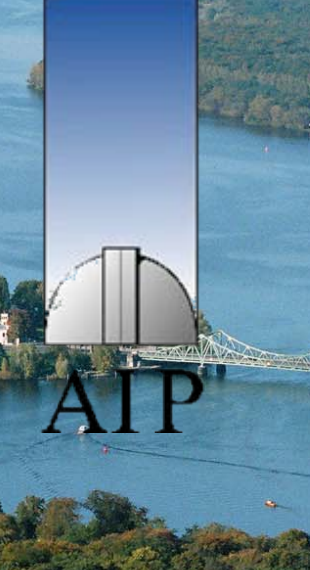
challenges in scientific  
computing and data analysis

(c) Wally Pacholka / AstroPics.com



Matthias Steinmetz







# Can we form disk galaxies?

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Spiral Galaxy NGC 1232 - VLT UT 1 + FORS1

# Not really ...

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- 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

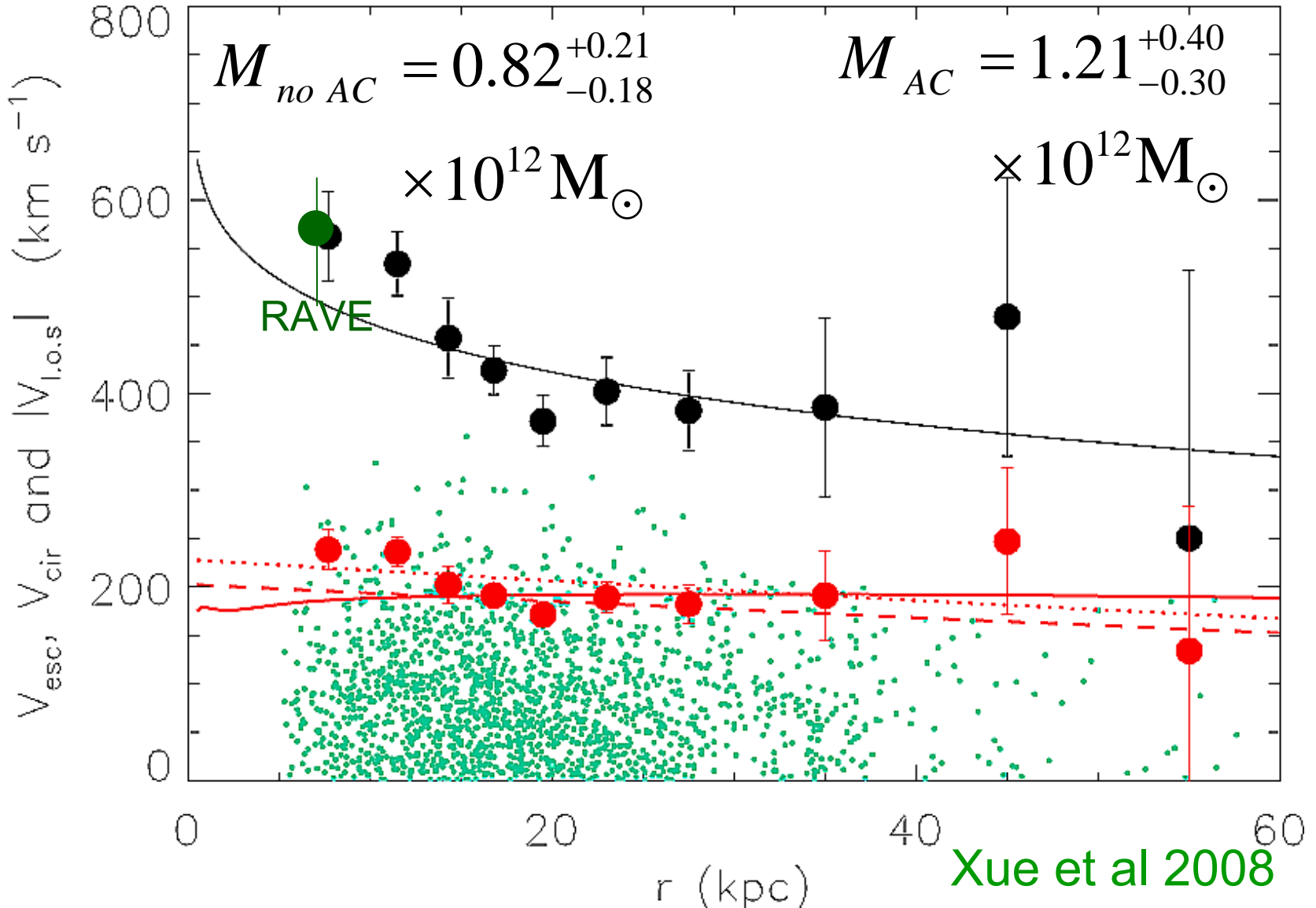
SR6-n01e2ML





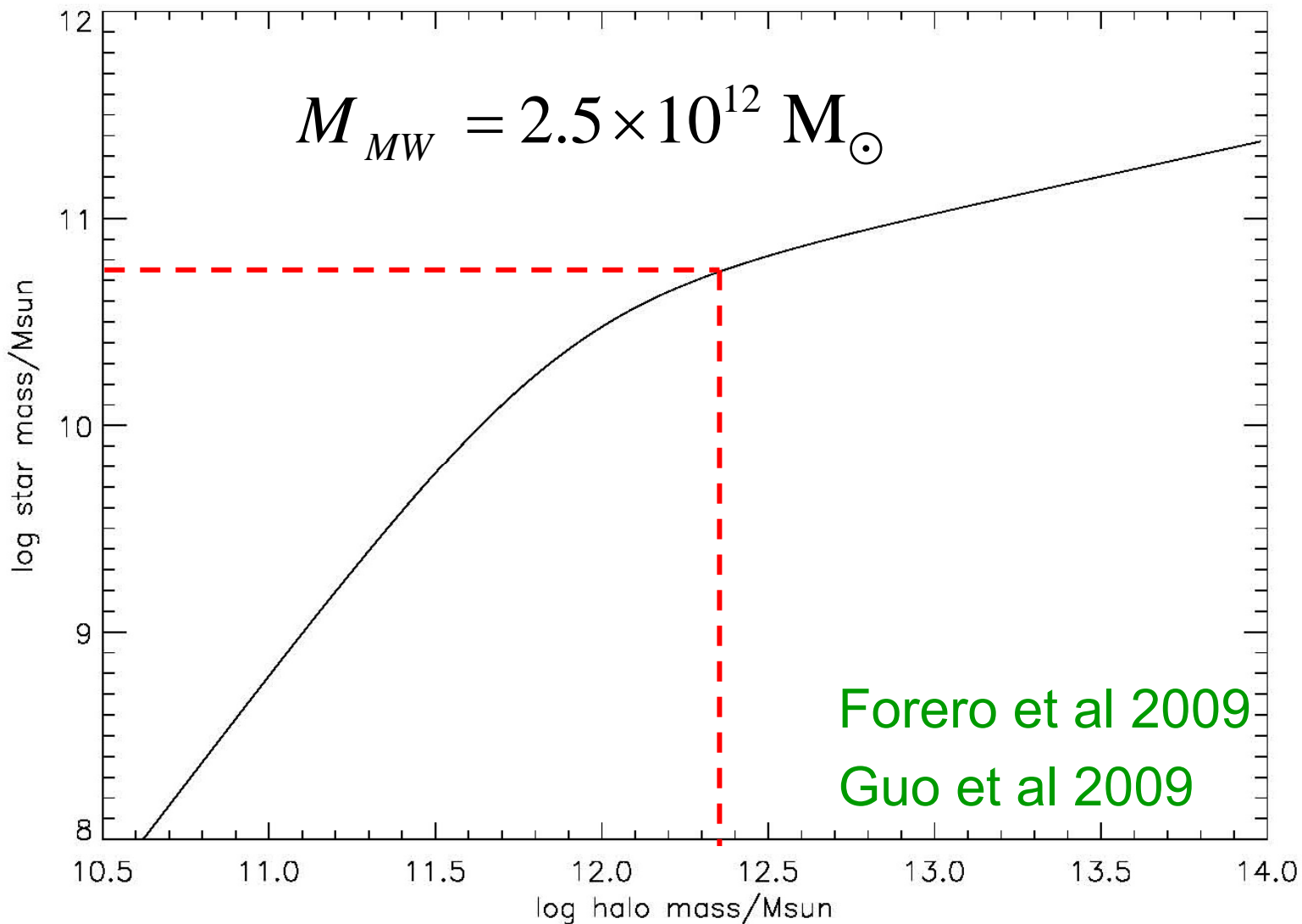
# $V_{\text{circ}}$ and $V_{\text{esc}}$ from SDSS

$V_{\text{cir}}$  and  $V_{\text{esc}}$  estimate



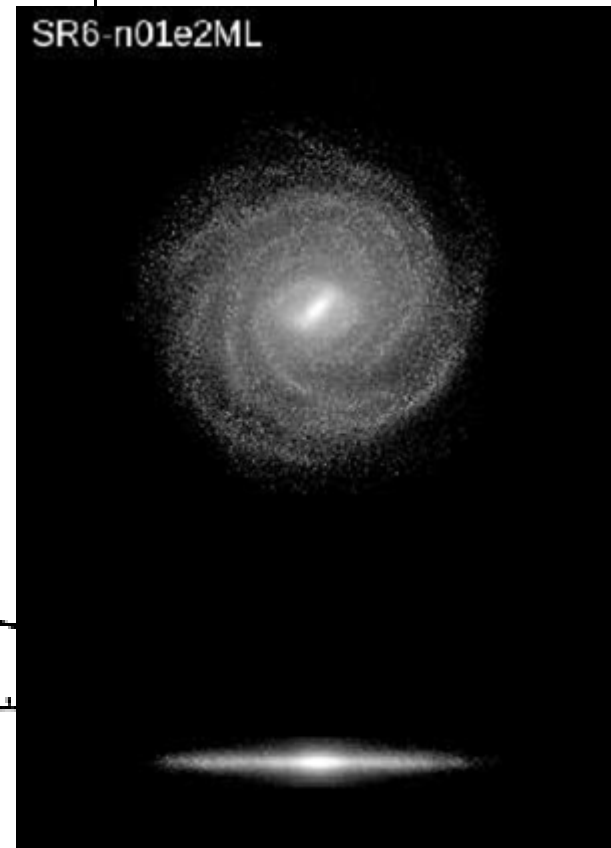
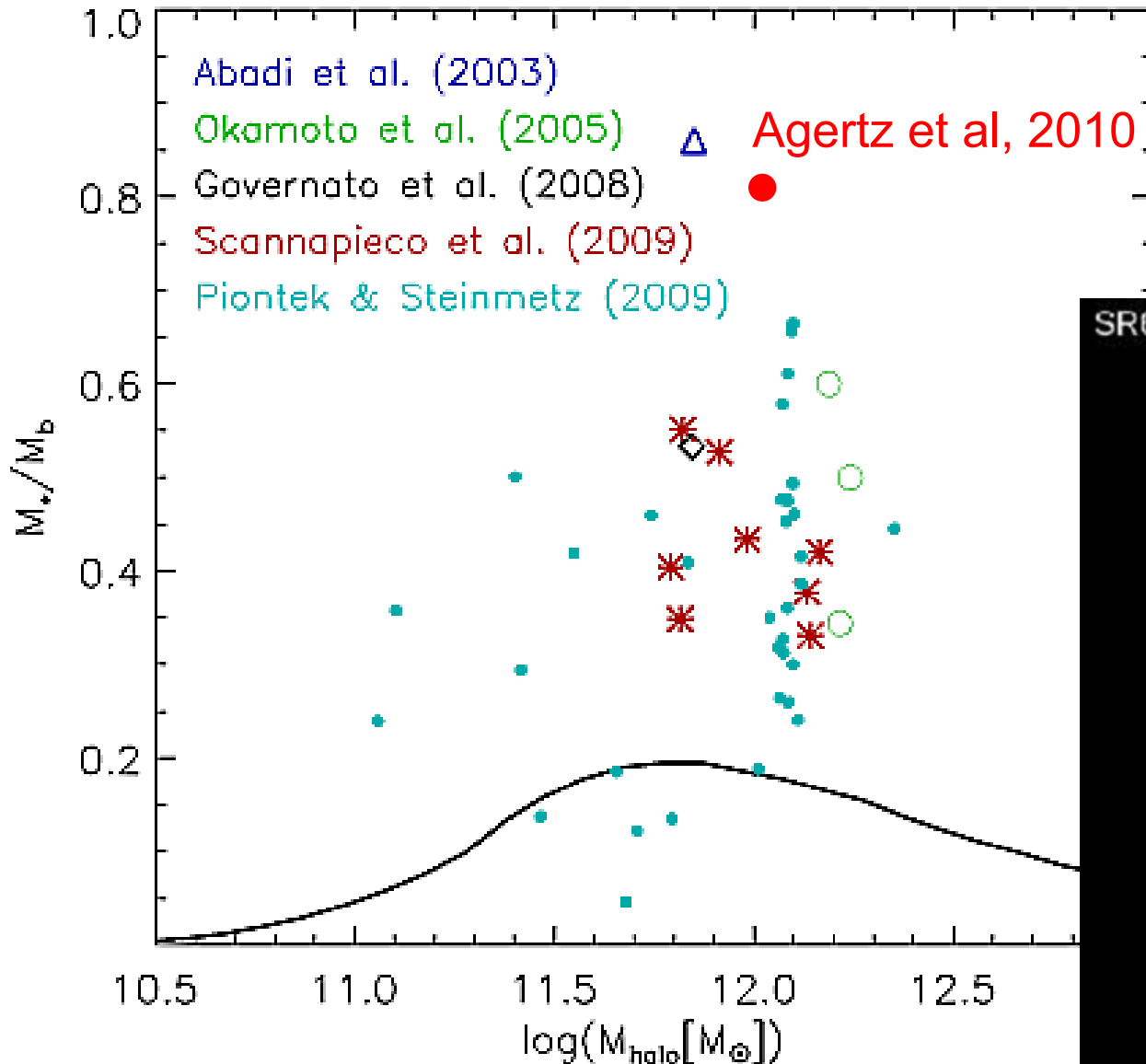


# Compare SDSS stellar mass function with DM halo mass function





# We still do not really understand how to form disk galaxies

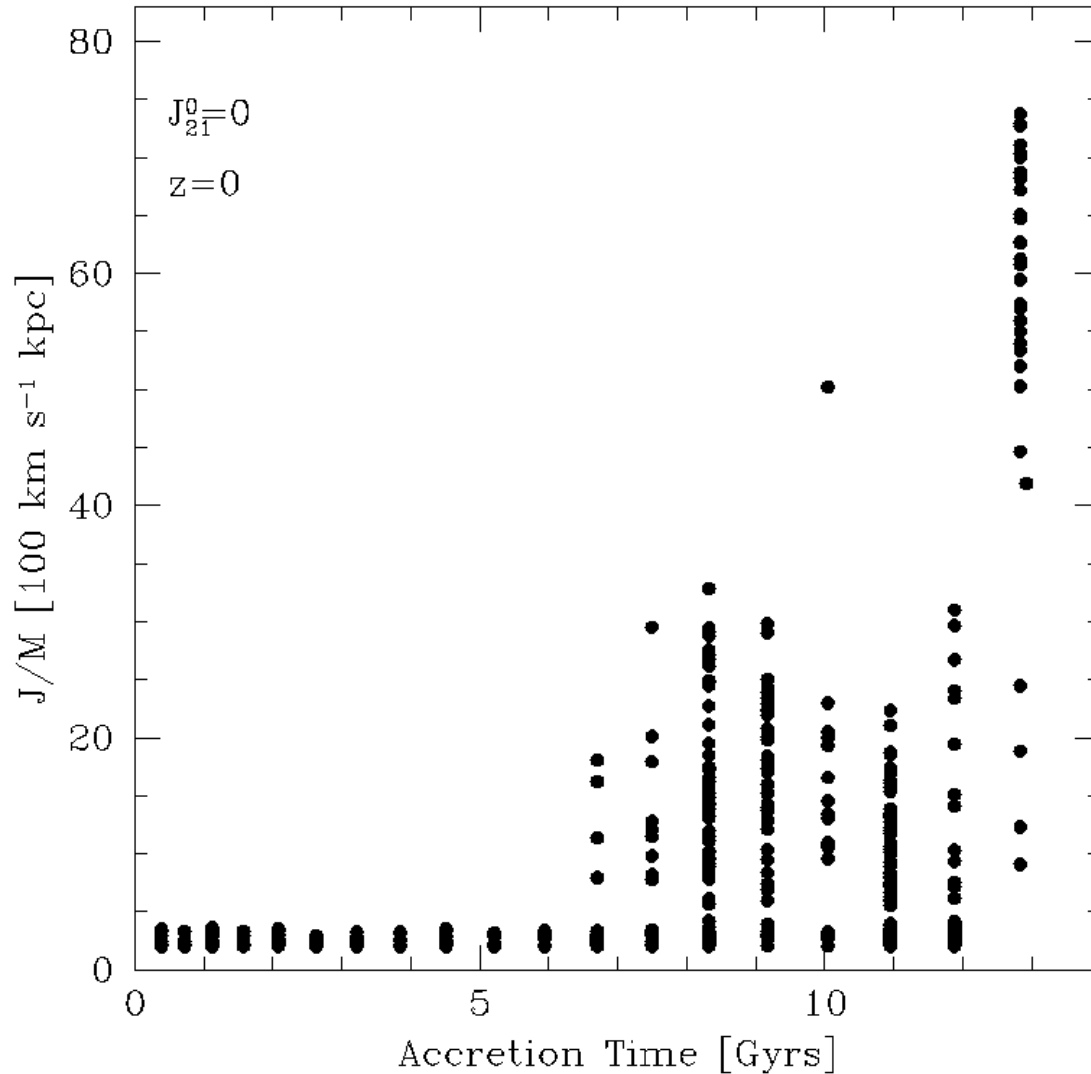






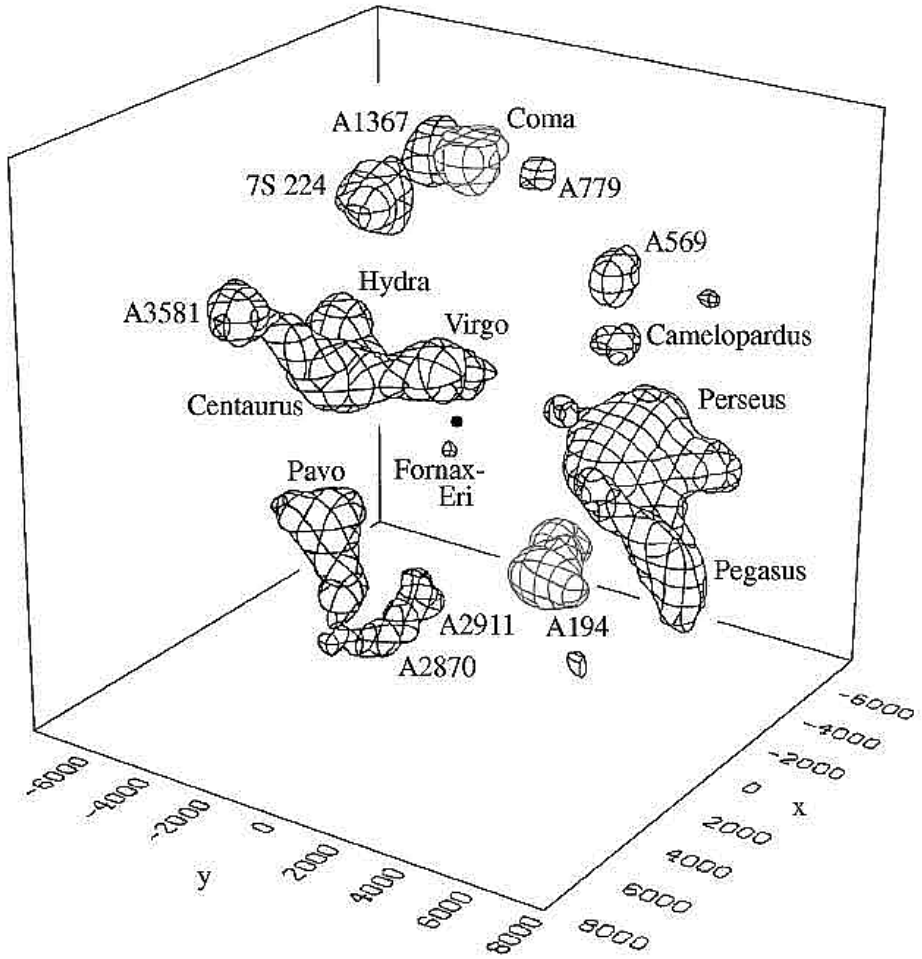
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# Most of the angular momentum comes in late and thus at low density



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







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## 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](#)

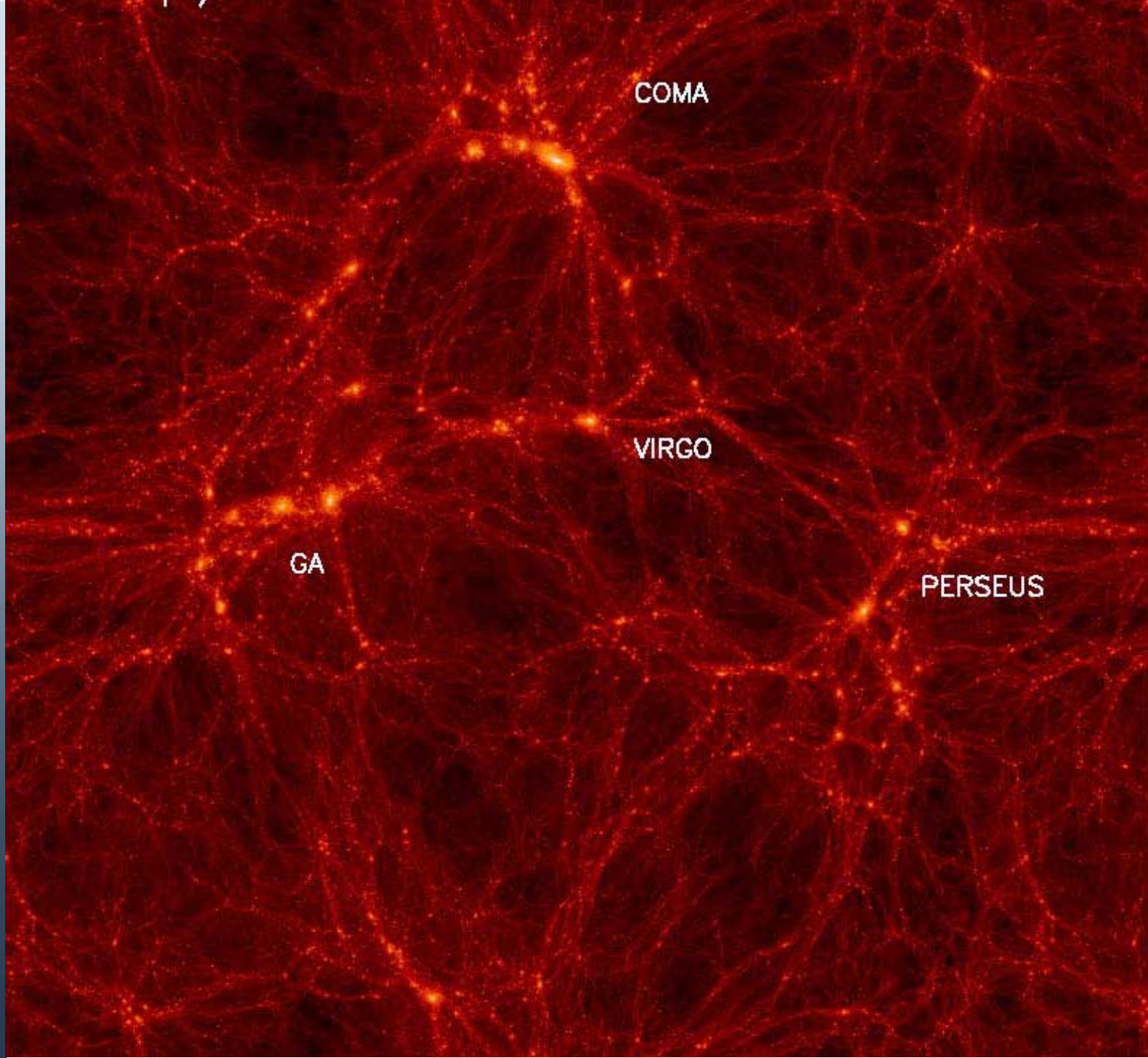
[Gustavo Yepes](#)

# Local Group alike are pretty rare!

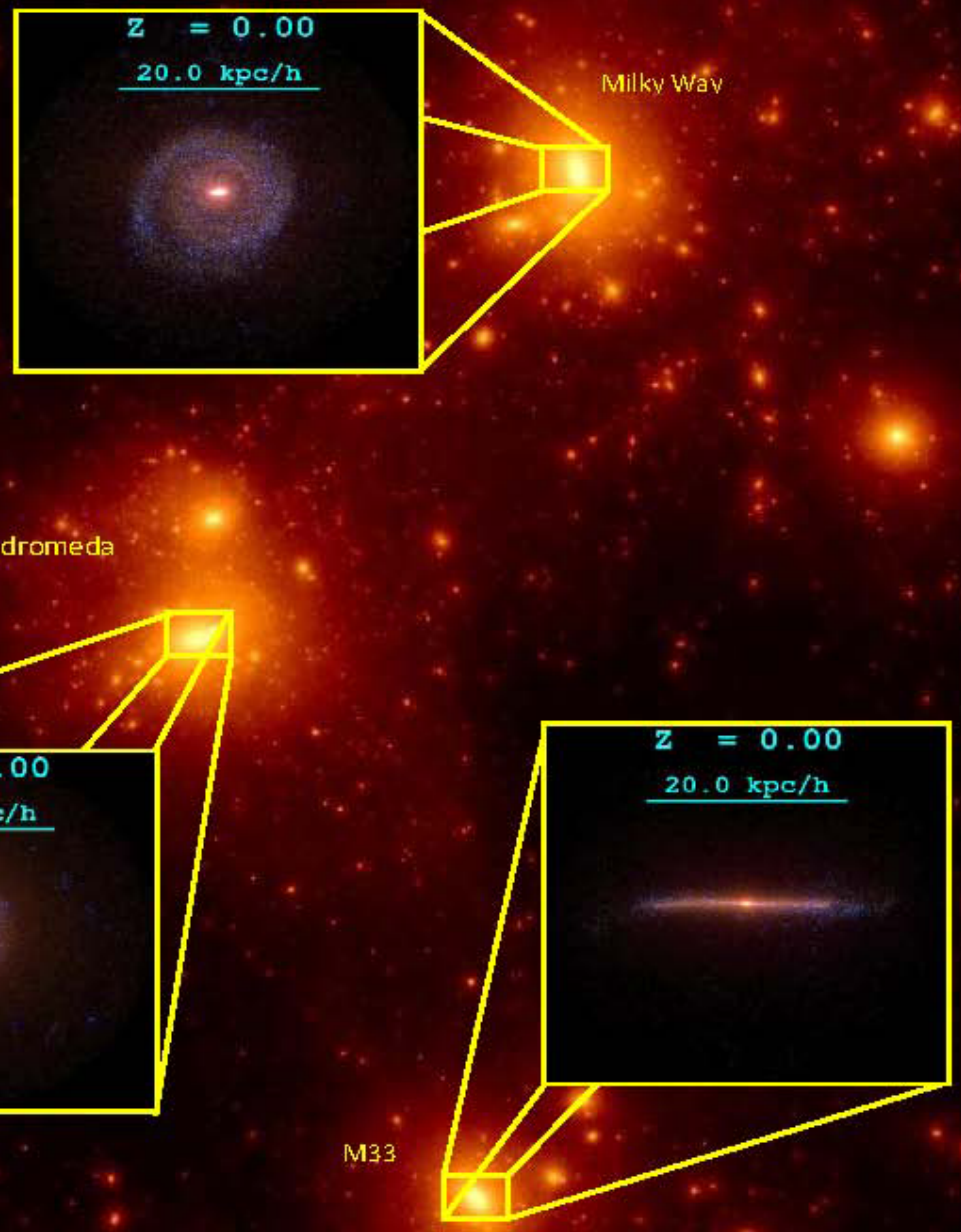
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- analysis of 90 Mpc box, constrained simulation
- WMAP5 normalization
- one excellent candidate
  - ◆ Virgo:
    - Mass:  $1.2 \times 10^{14} M_{\odot}$  (more massive)
    - distance: 14.9 Mpc (19.0 Mpc ← NED)
  - ◆ Fornax:
    - mass:  $4.2 \times 10^{13} M_{\odot}$  ( $7.0 \times 10^{13} M_{\odot}$  ← ApJ 548, L139)
    - distance: 19.2 Mpc (17.6 Mpc ← NED)
  - ◆ Local group
    - mass:  $3.0 \times 10^{13} M_{\odot}$  (lower mass end)
    - MW/Andromeda distance: 690kpc (700kpc)





# The CLUES Local Group

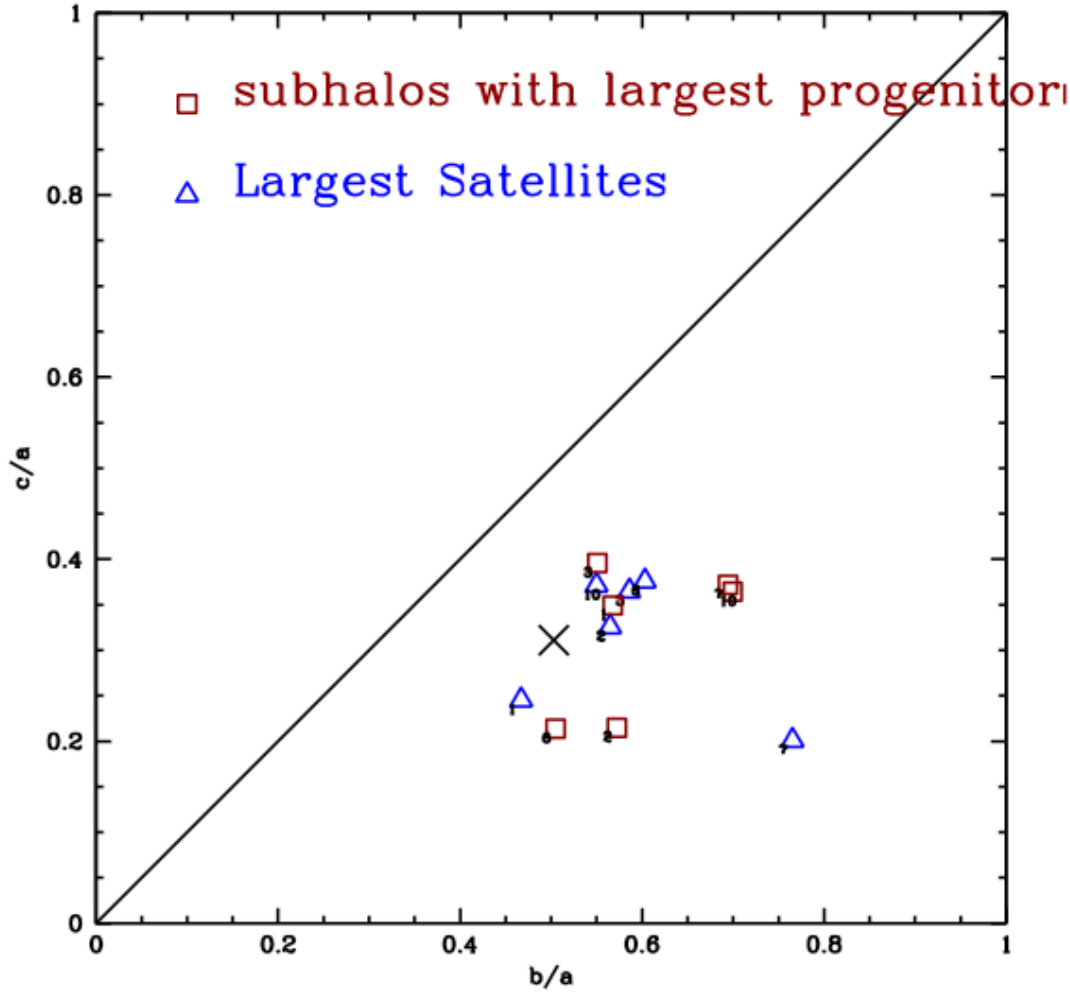








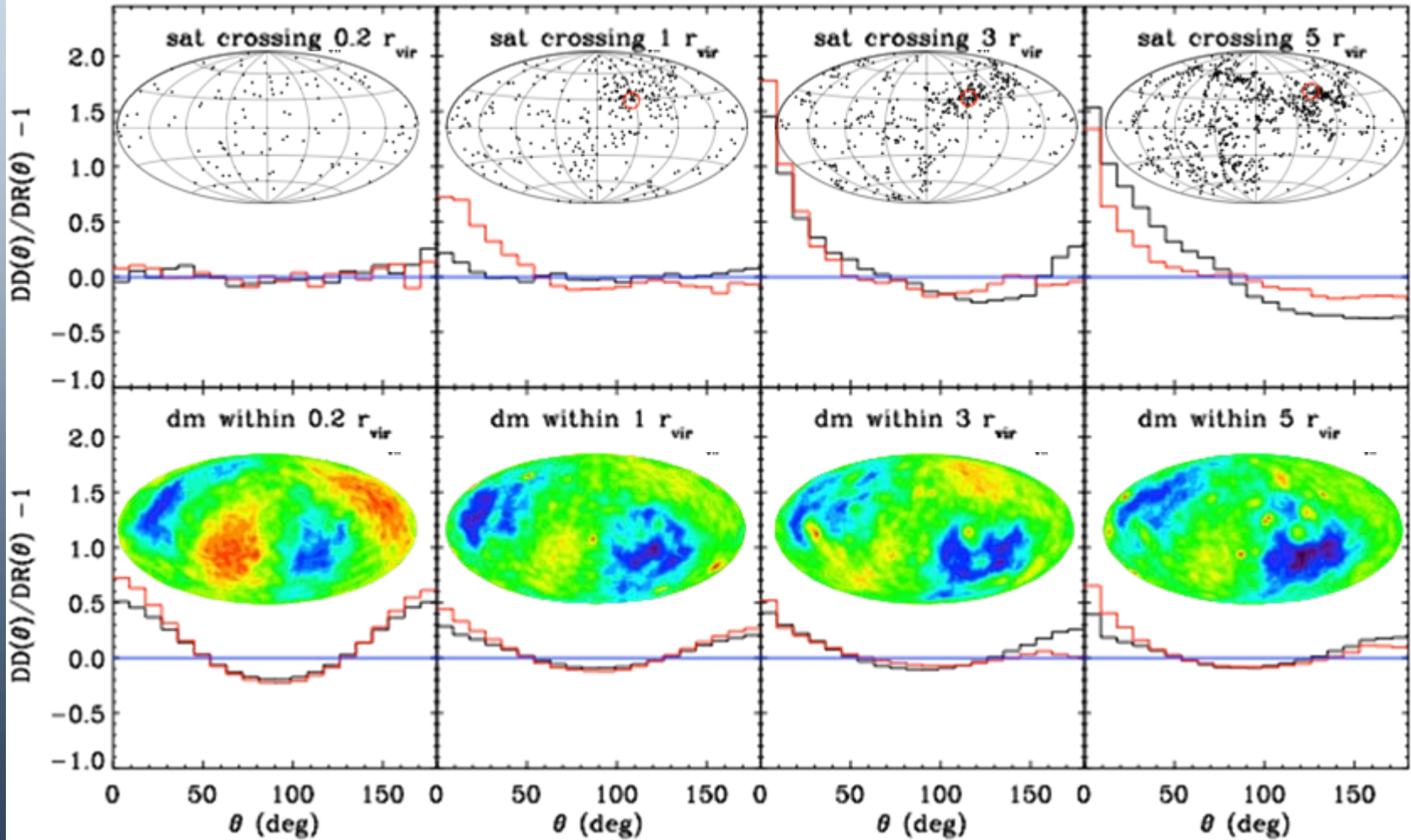
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6 DM only simulations, populated with galaxies semi-analytically.

Libeskind et al 2005

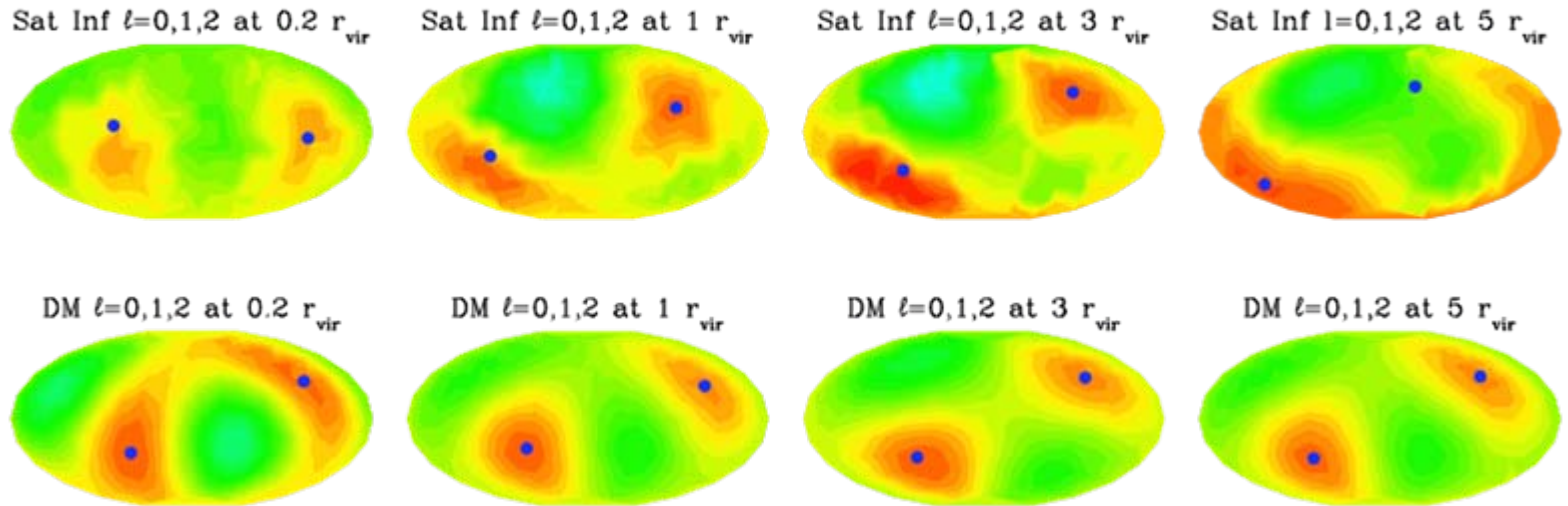
# Preferential infall of satellites



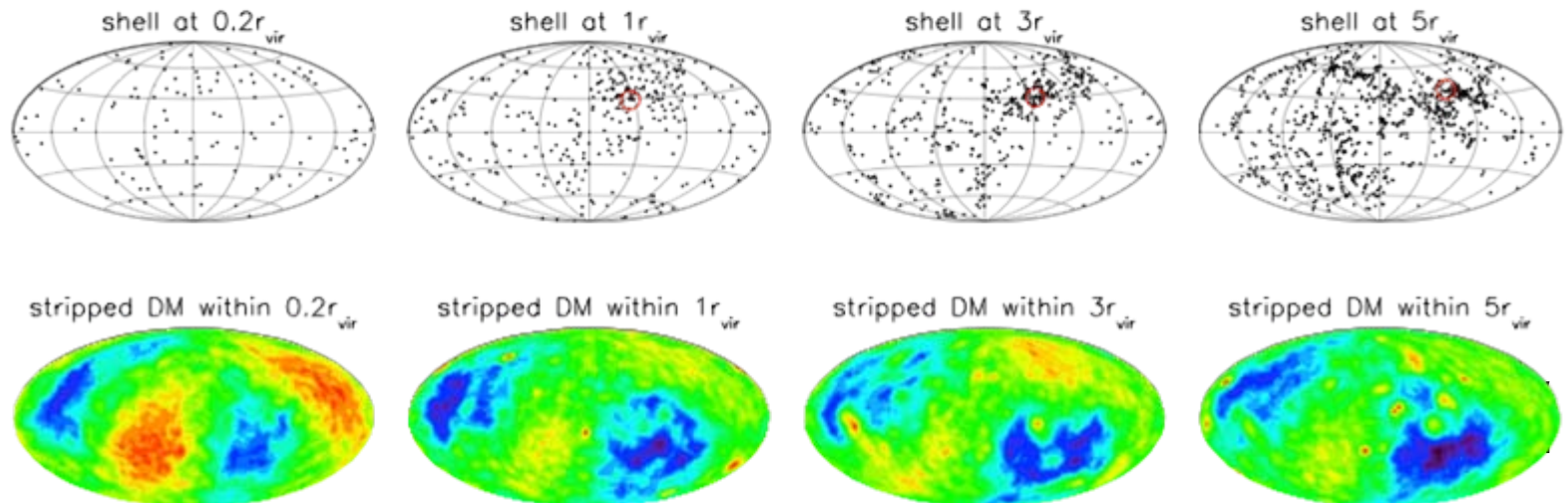
Libeskind et al, 2011



# Preferential infall of satellites

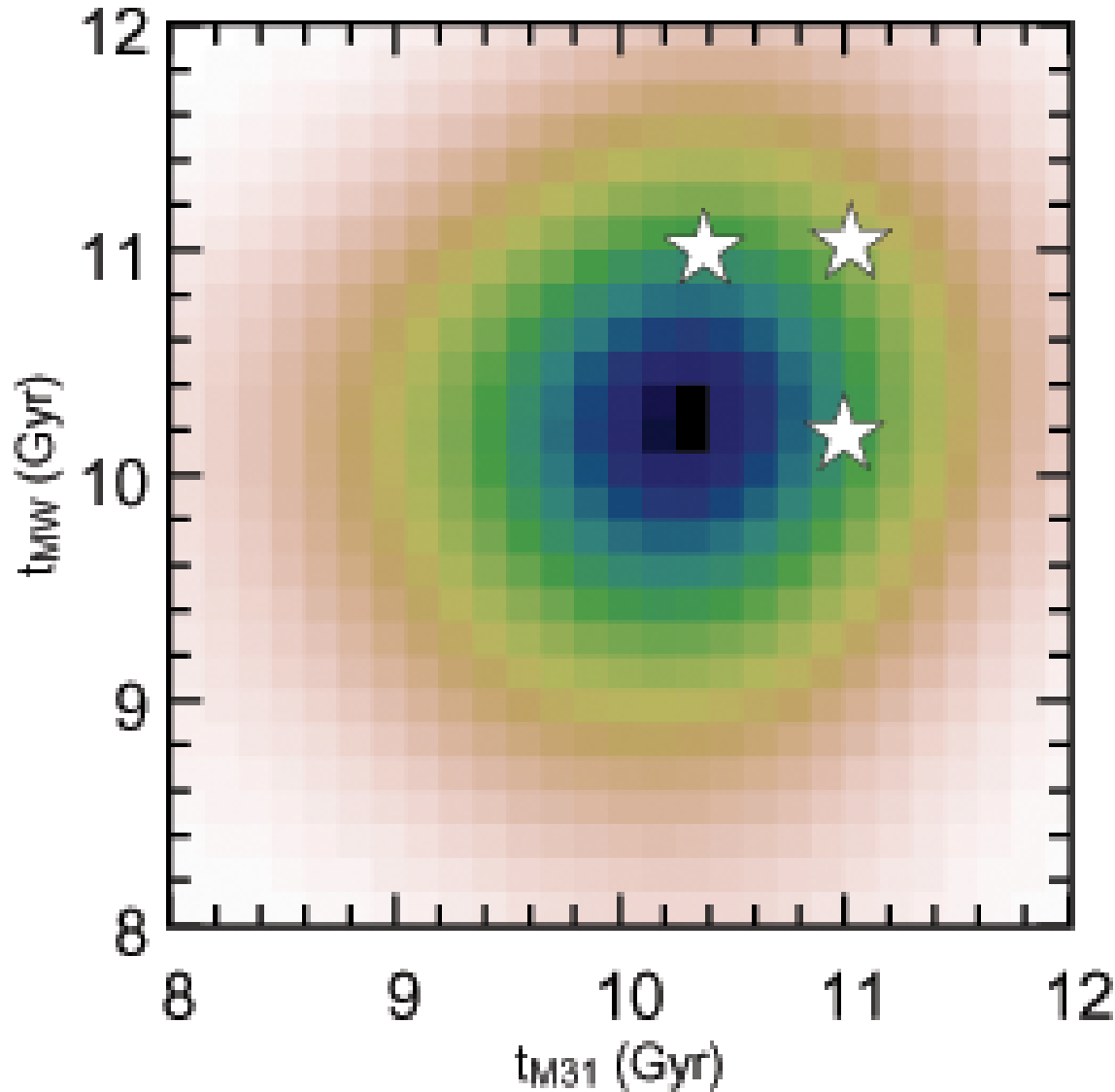


Quadrupole: infall along a filament  
Pointing towards Virgo



# The MW is not a typical galaxy ...

Assembly Times

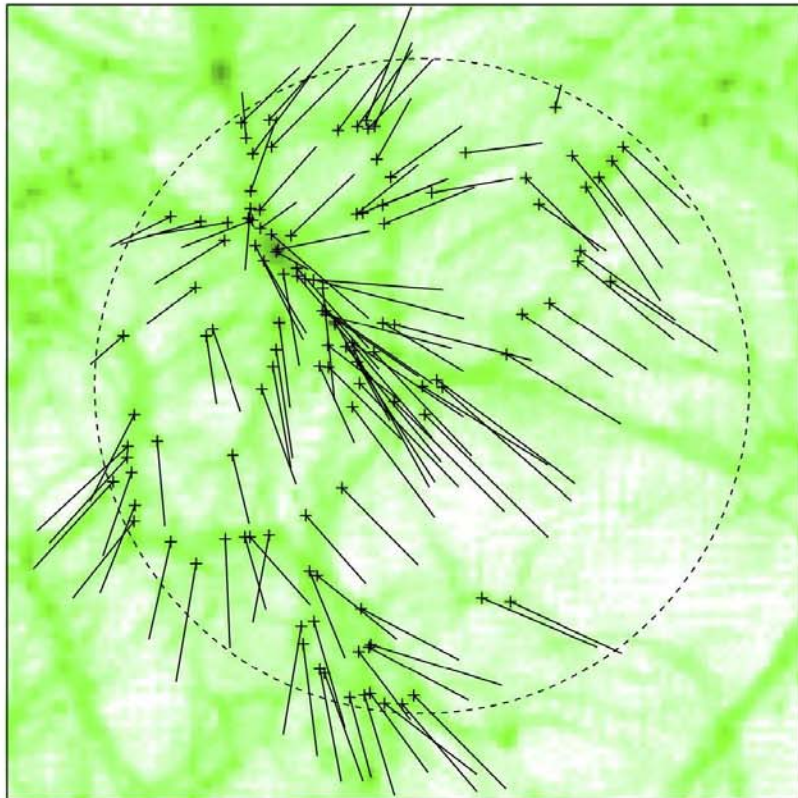


Forero et al, 2011

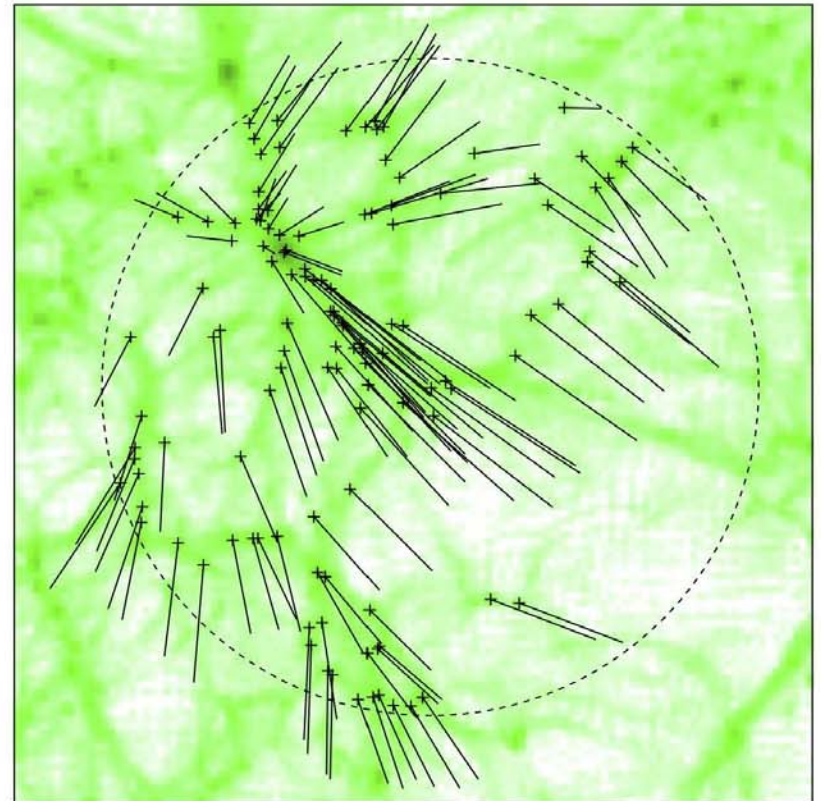
# Original vs. reconstructed halo displacements

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Original halo displacement  
from initial conditions at  $z = 0$



WF reconstructed displacement  
(from 558 radial peculiar velocities  
within  $R = 30 \text{ Mpc}/h$  sphere)

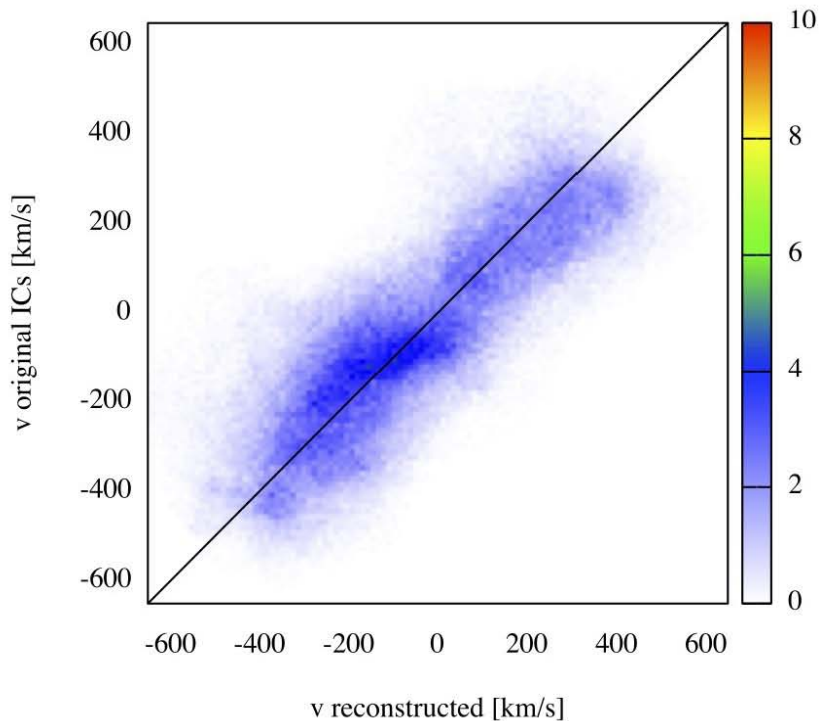


Doumler et al, 2011

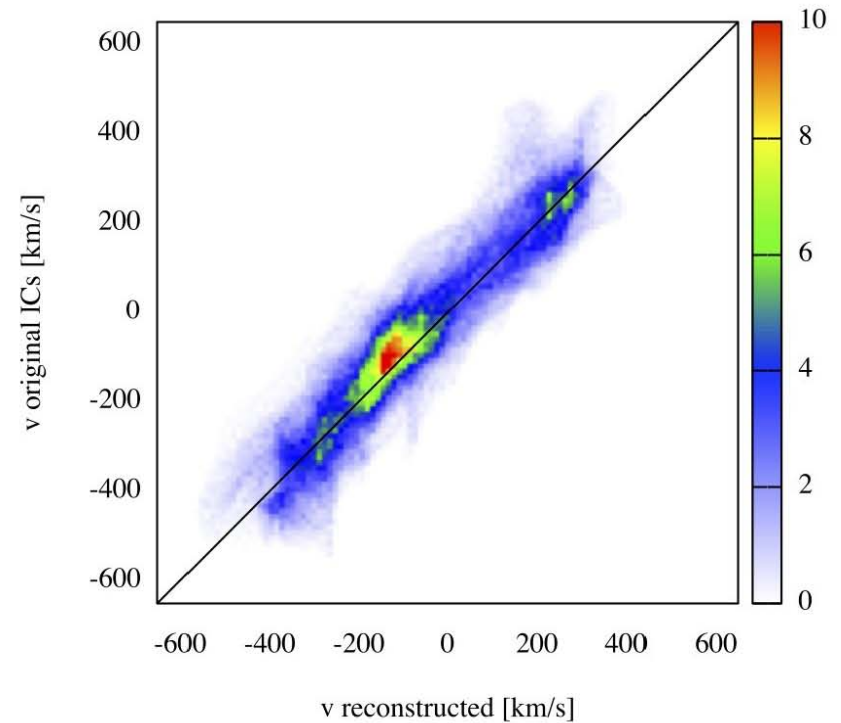


# Original vs. reconstructed initial conditions

Correlation with non-displaced reconstructed ICs



Correlation with reconstructed ICs + WF displacement reconstruction





# How about observations?

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# The Milky Way is all around us!





# How about observations?

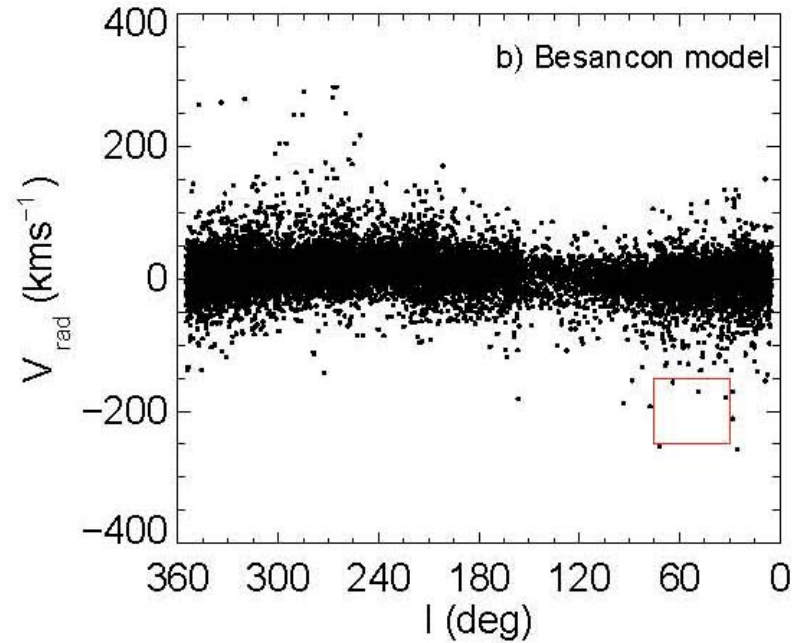
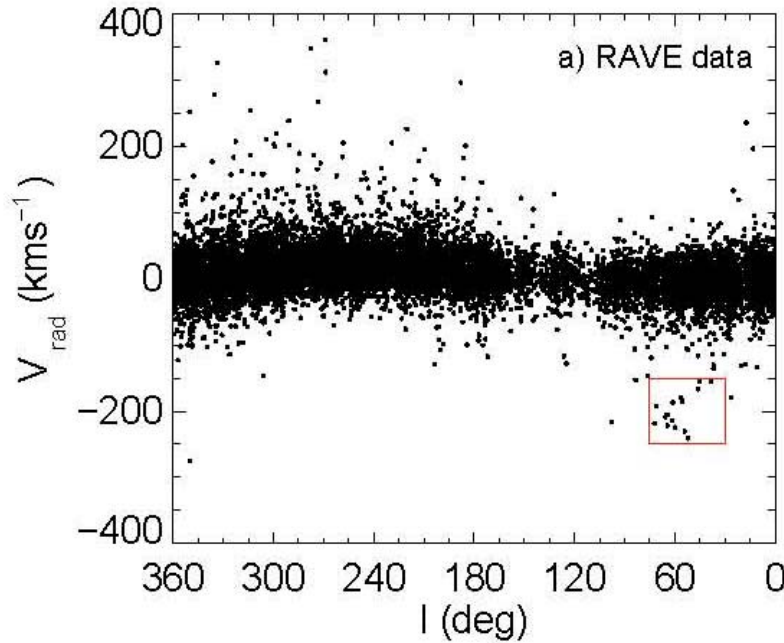
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- The substructure crisis
  - ◆ Systematic searches using large imaging surveys (SDSS) reveal a considerable (sufficient?) number of new satellites
- Substructure in phase space → tracing the formation history of the Milky Way
  - ◆ Lot of activities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

# Velocity Substructure in RAVE



$-70^\circ < b < -50^\circ$



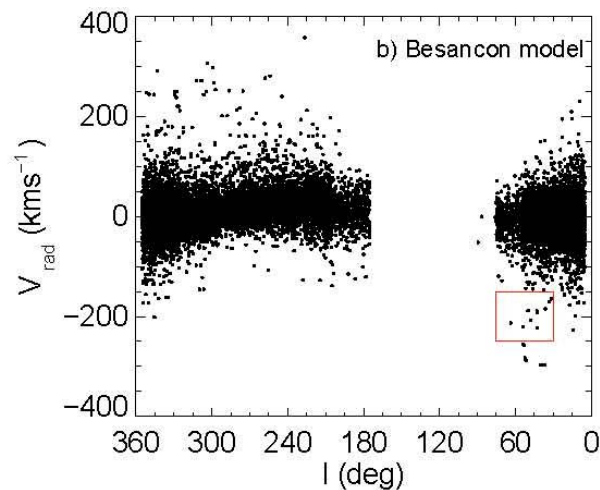
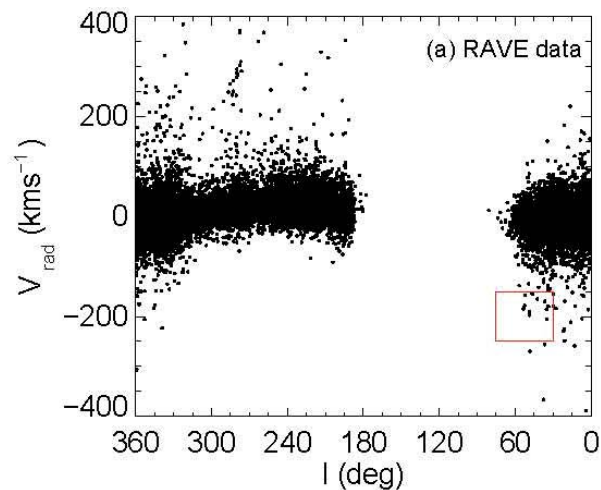
# Velocity Substructure in RAVE



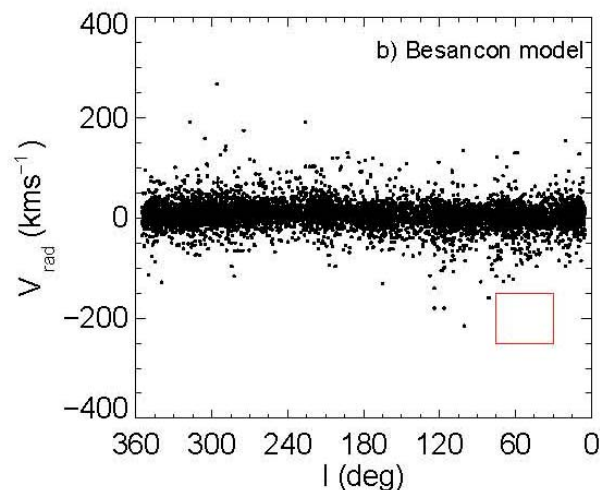
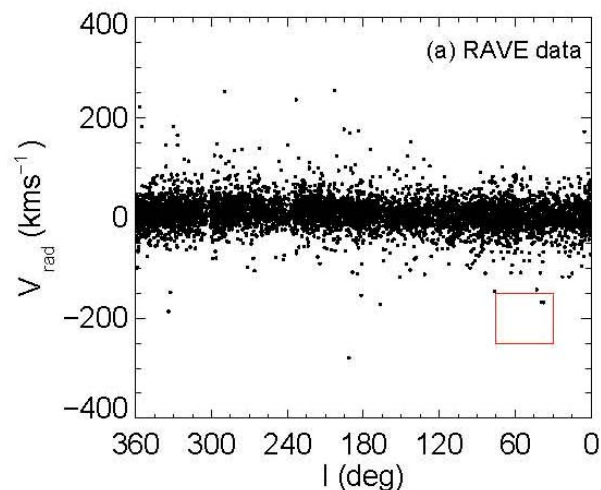
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16 Dec 2010 The Future of Astrocomputing

$-50^\circ < b < -30^\circ$



$-90^\circ < b < -70^\circ$



Williams et al,  
2010

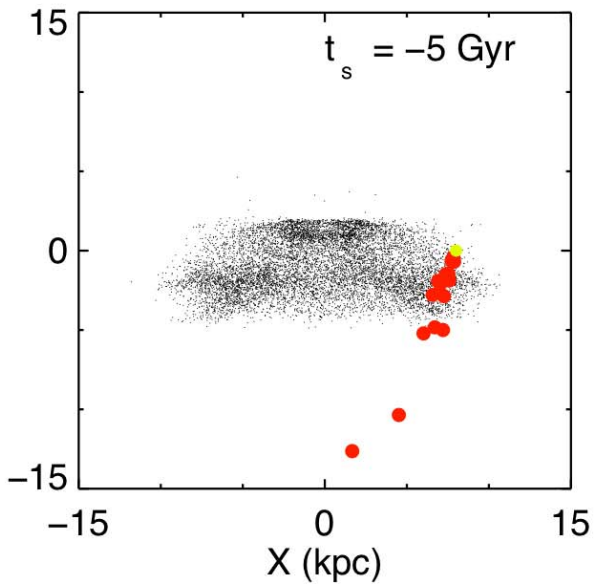
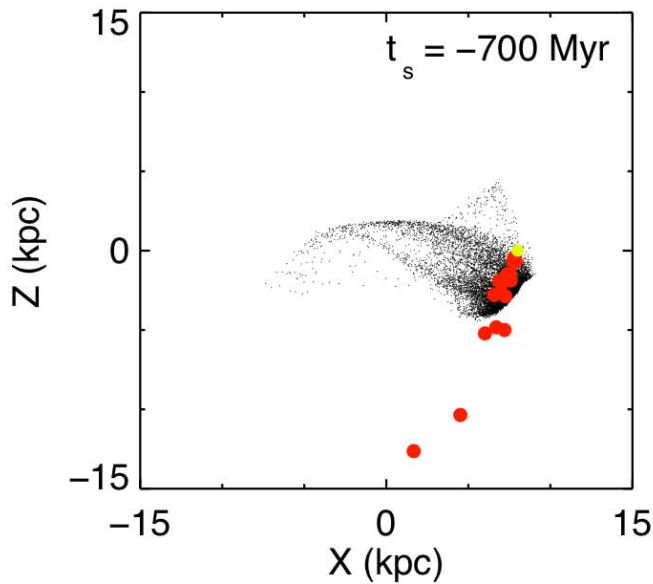
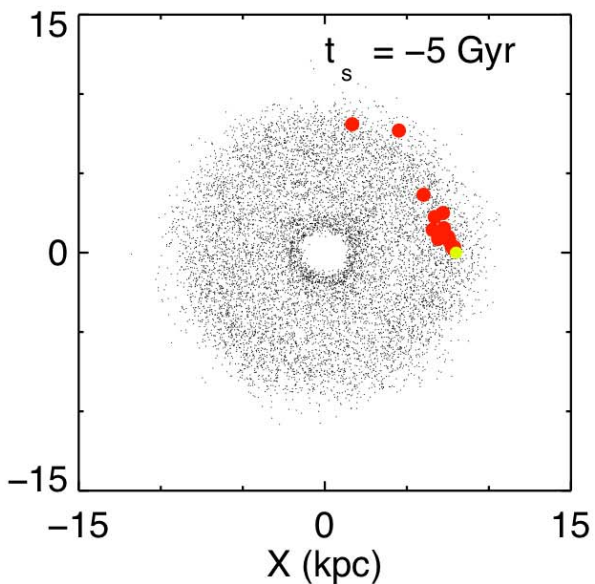
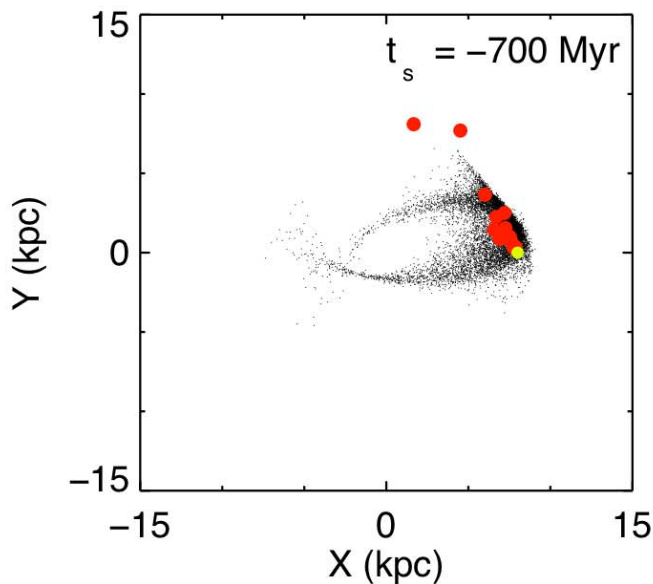


# Illustrative simulations



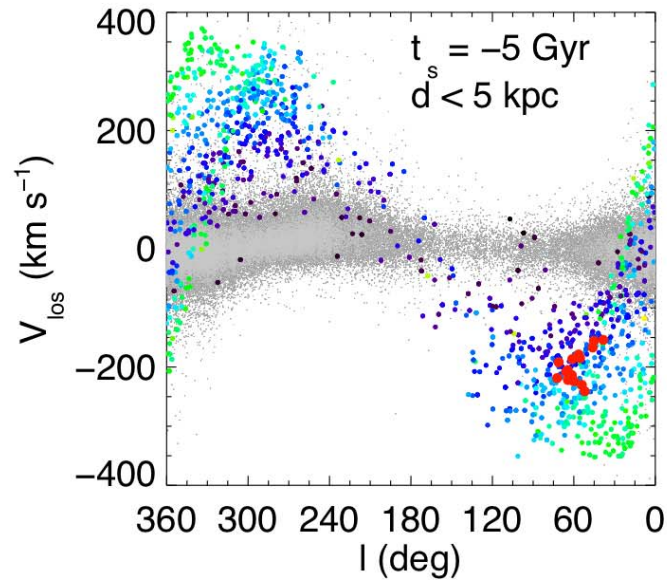
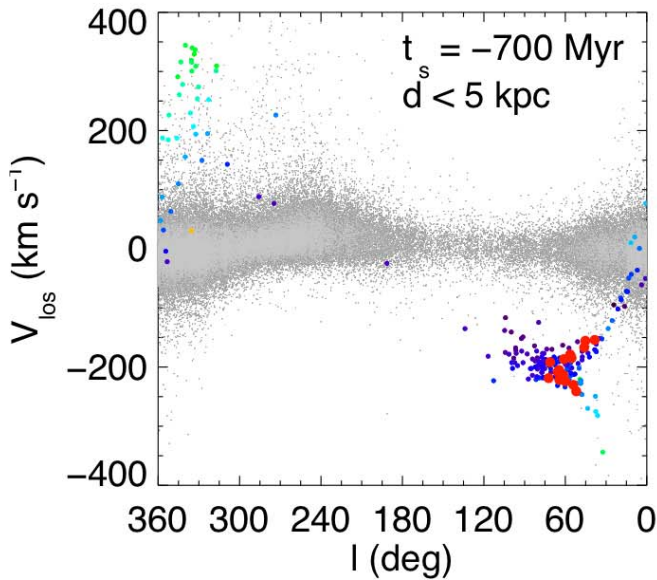
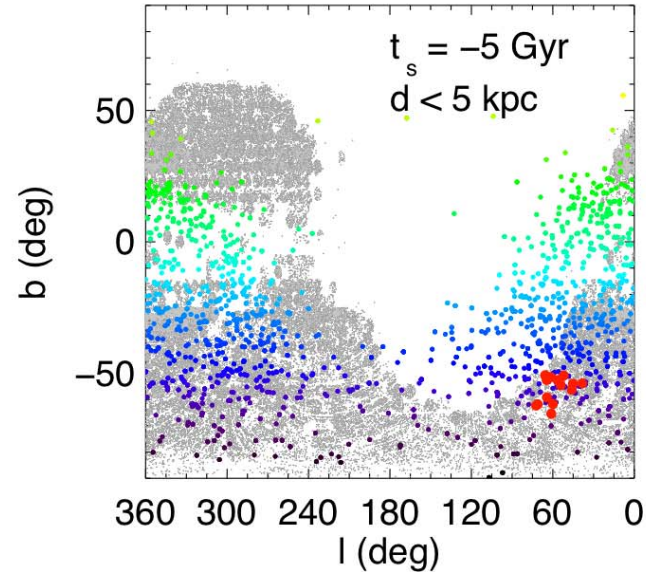
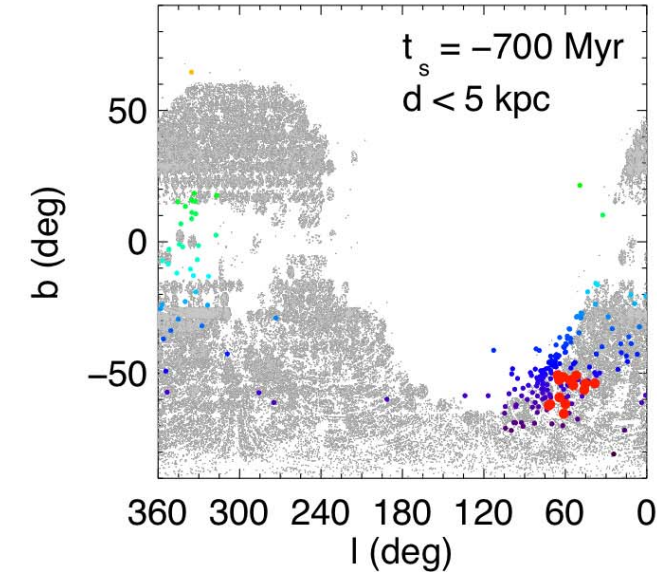
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16 Dec 2010  
The Future of Astrocomputing



Williams et al,  
2010

# Recent disruption event



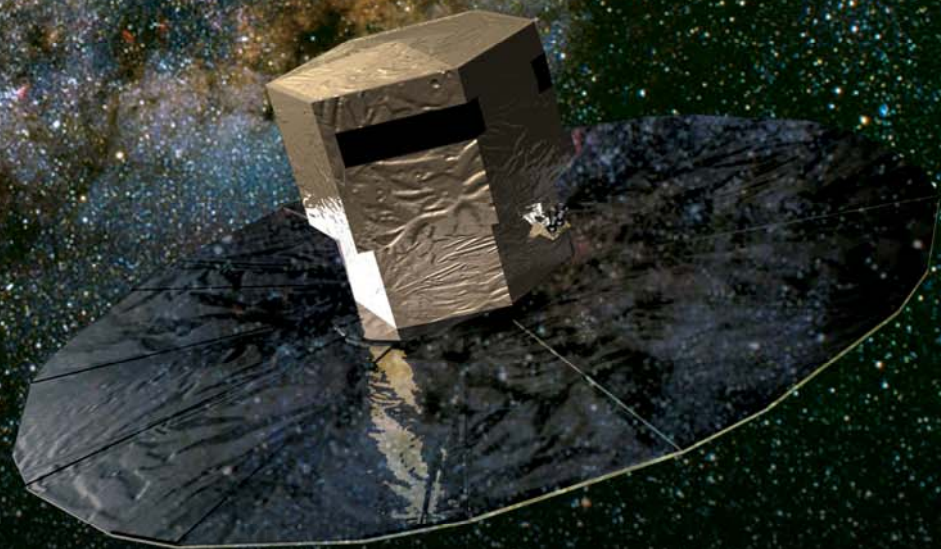
# The Dawning of the Stream of Aquarius in RAVE<sup>1</sup>

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





# Outlook: The GAIA epoch





# The Future: GAIA

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- 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

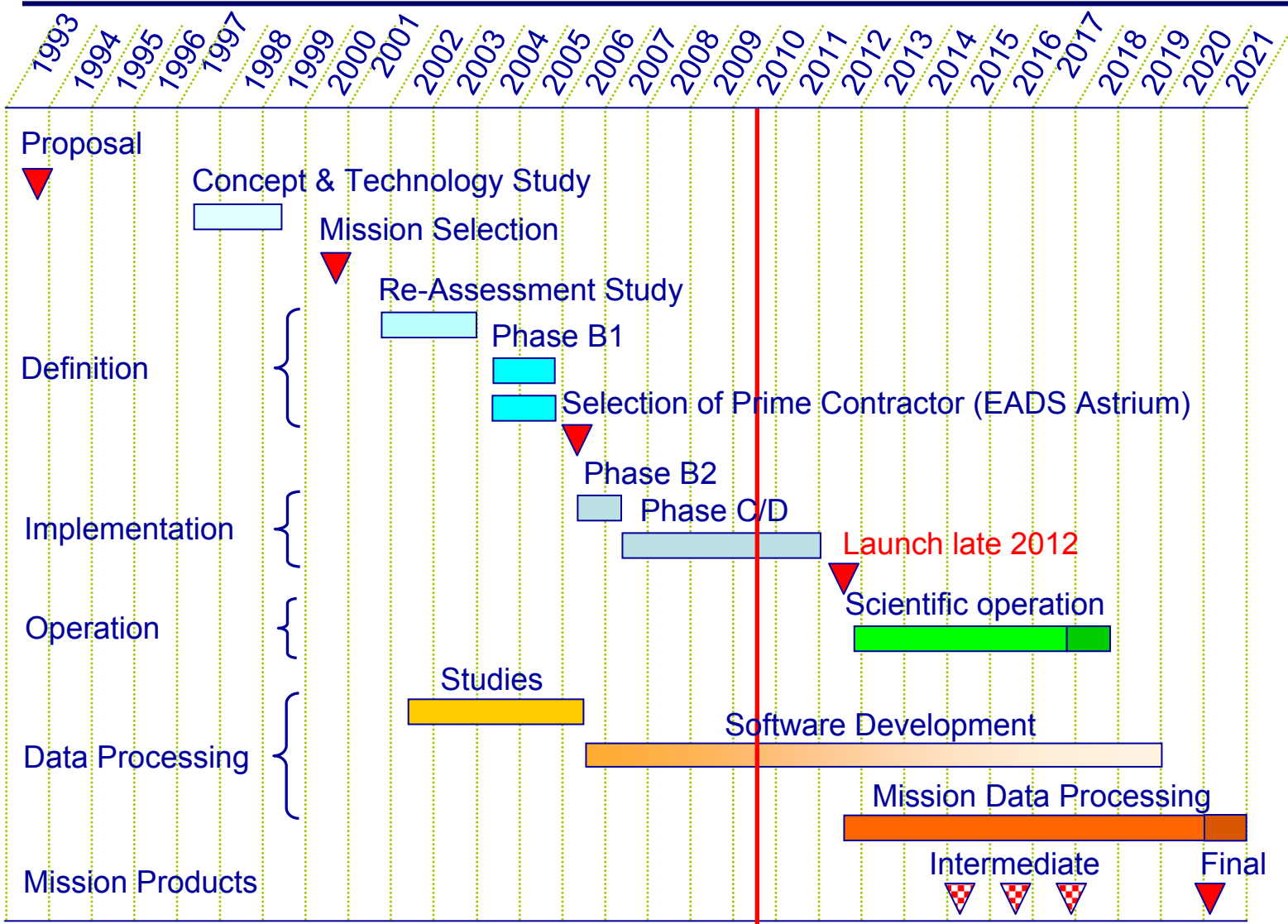
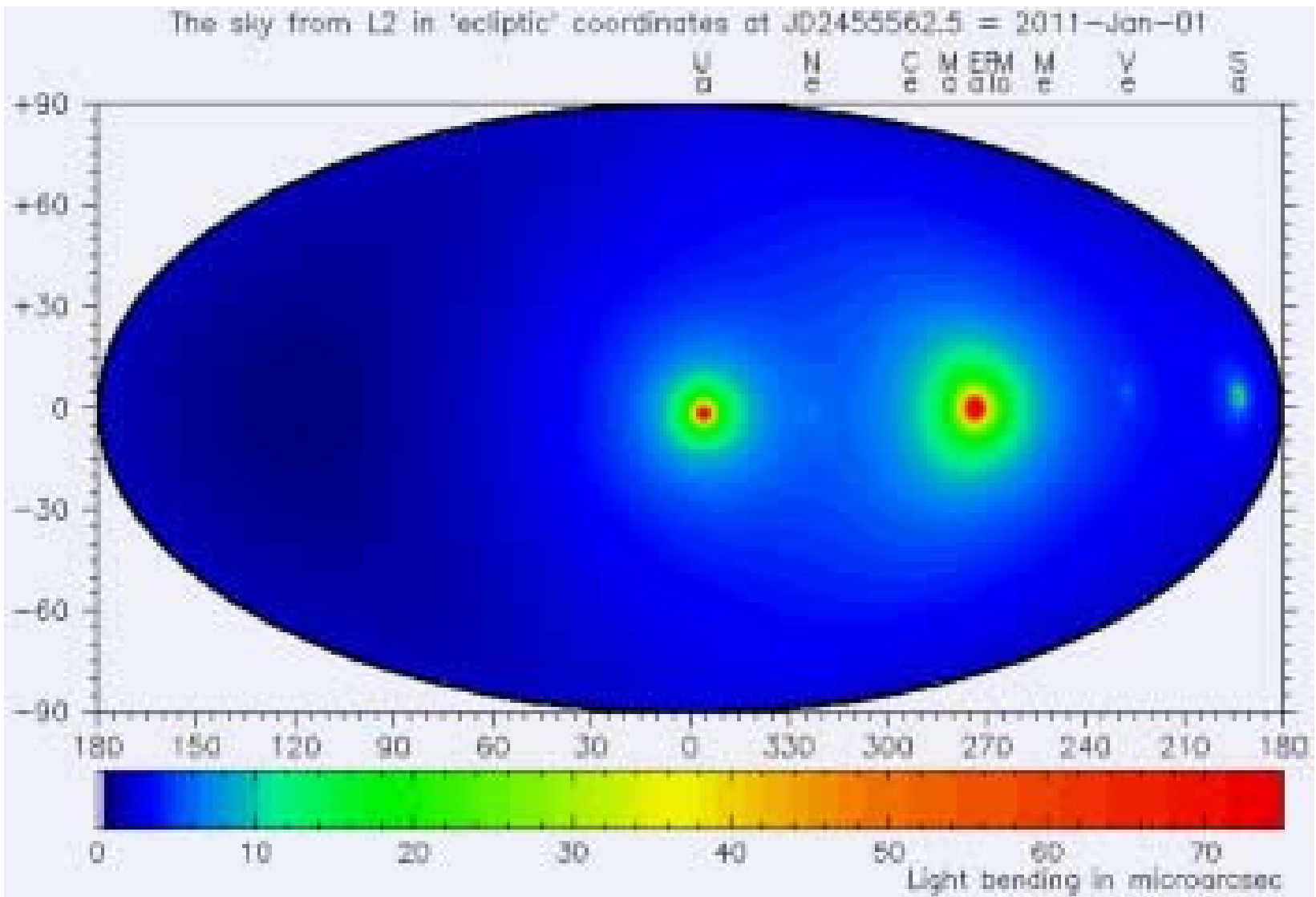


Figure courtesy Michael Perryman and François Mignard

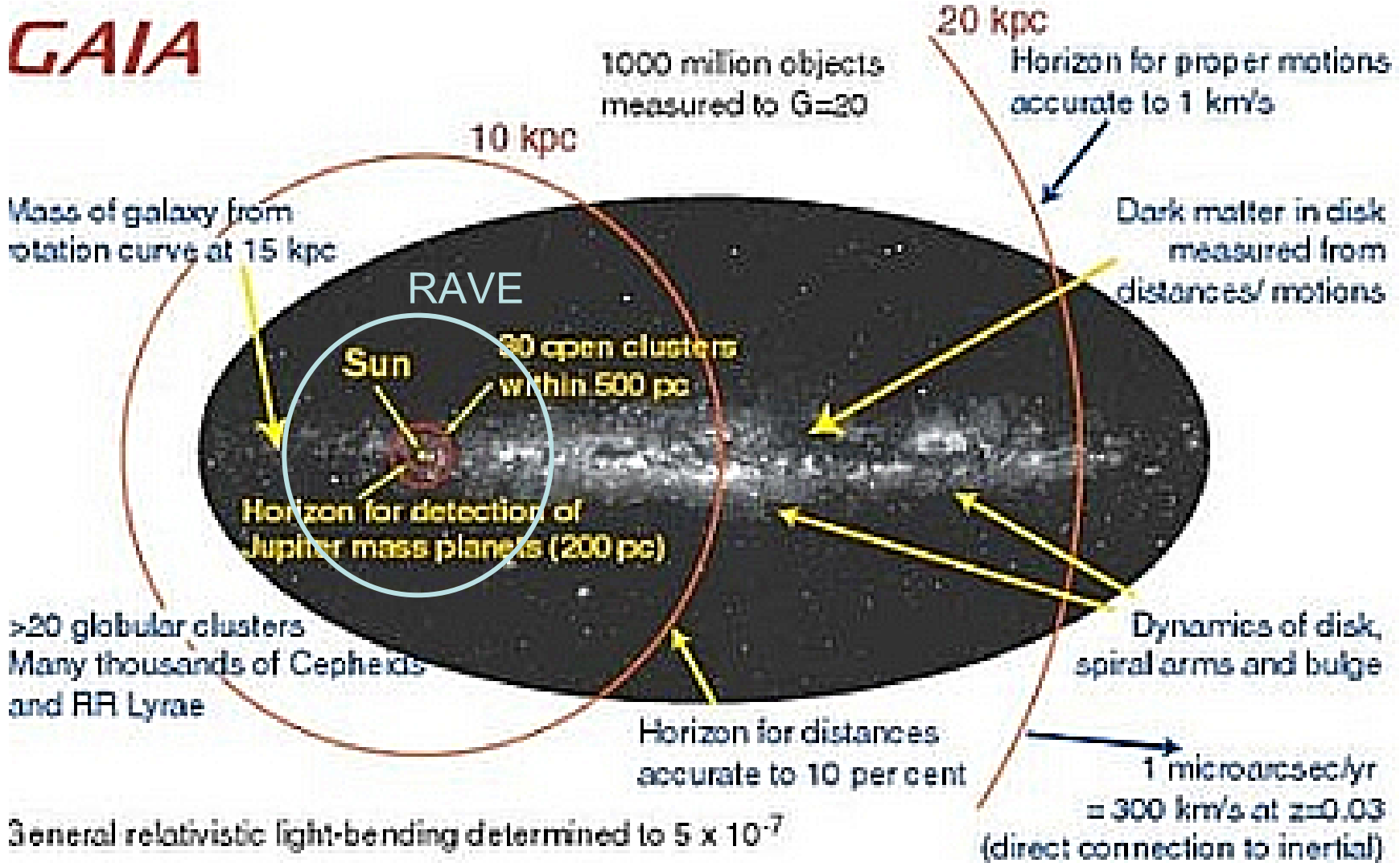


# Light Bending in Solar System



# The Future: GAIA

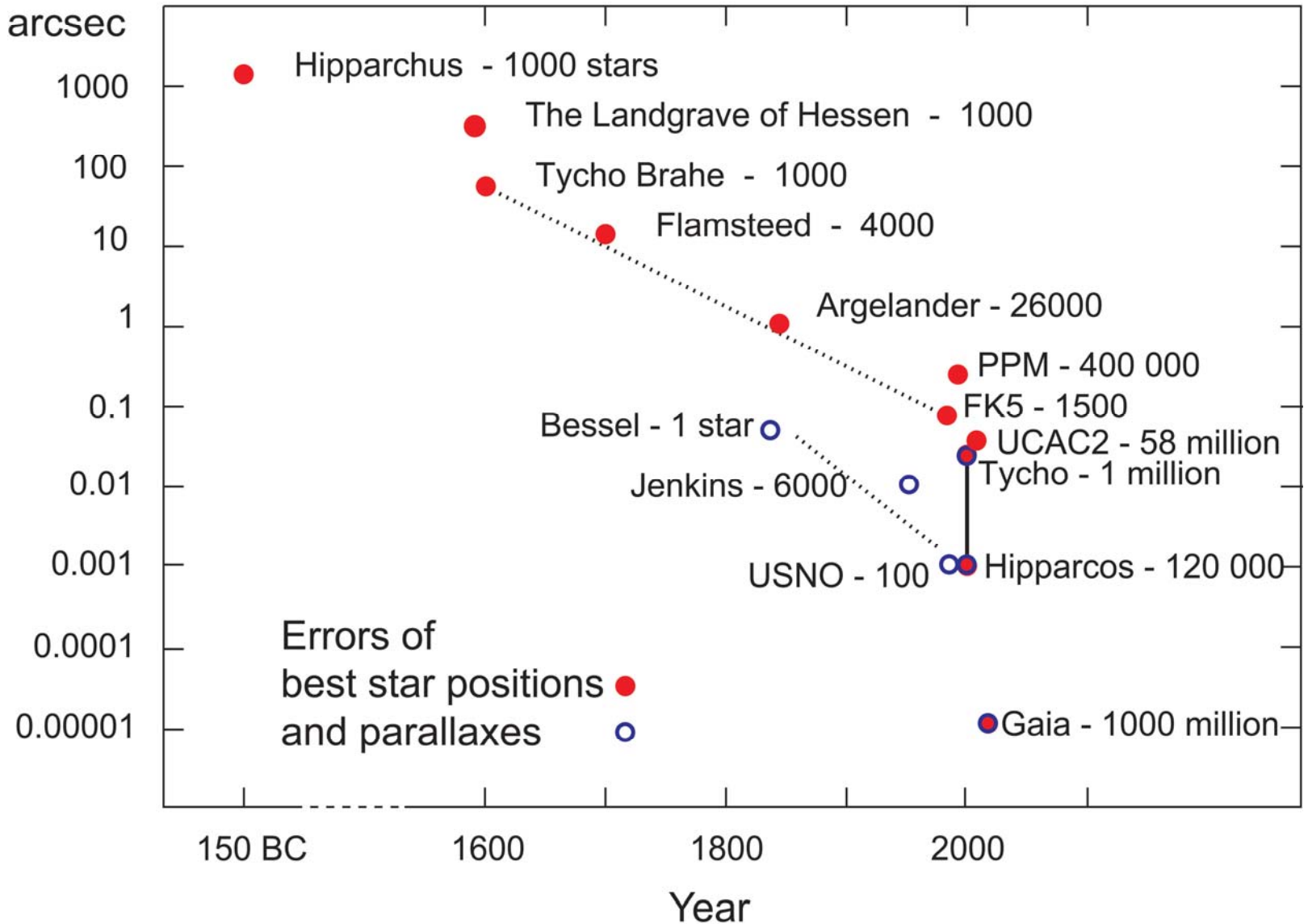
## GAIA



# GAIA



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# 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:  $\gamma$  to  $2 \times 10^{-6}$  ( $2 \times 10^{-5}$  present)
  
- Fundamental physics - reference frame - solar system - extrasolar planets -
- stellar systems - stellar physics - Galactic astronomy - quasars and galaxies.

