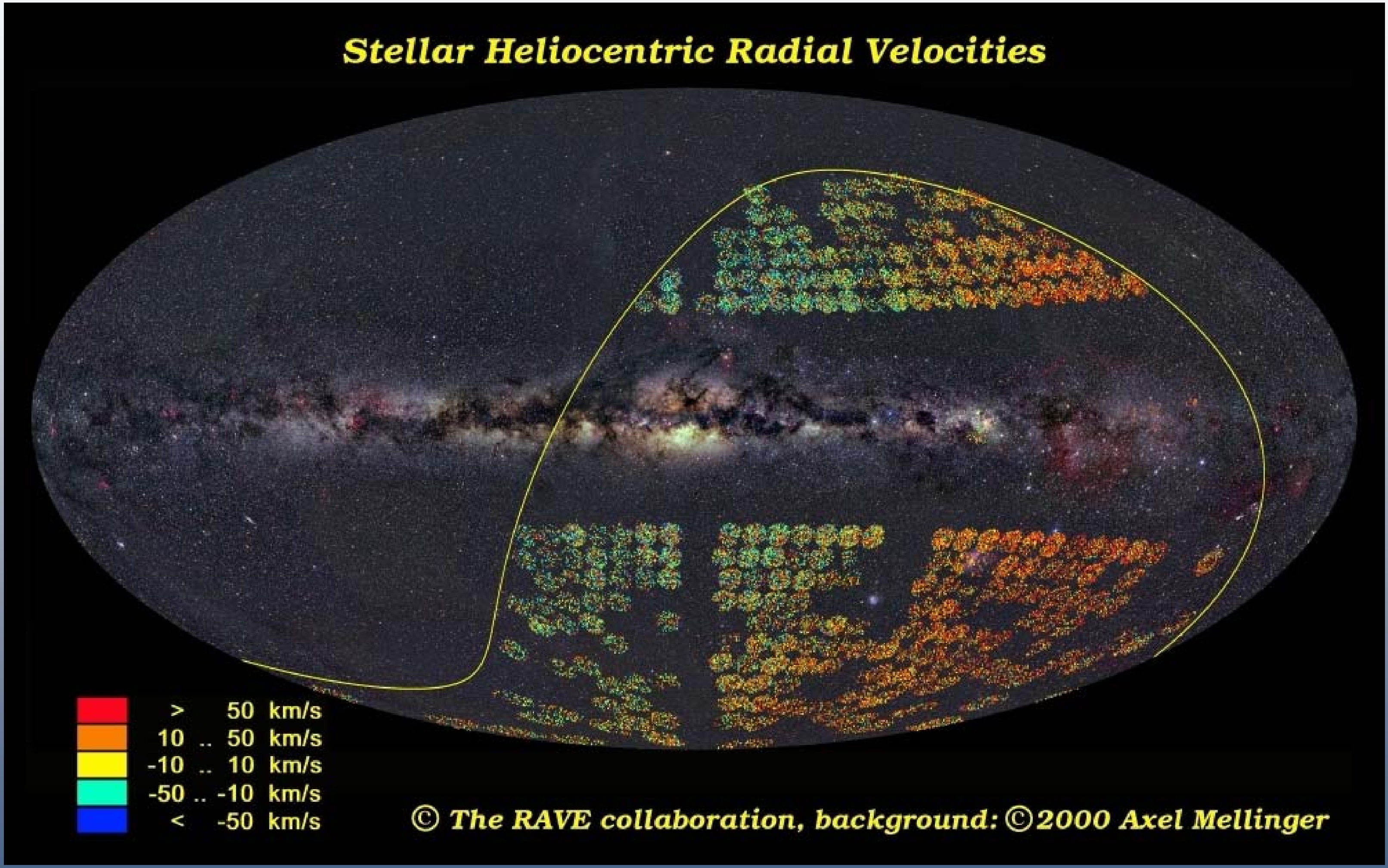
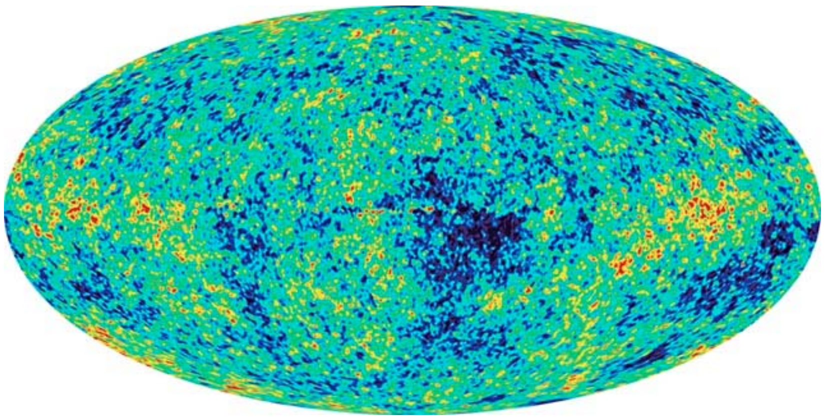
Galactic Archeology in the Era of Mega Surveys



Matthias Steinmetz (AIP)

Hierarchical Galaxy Formation



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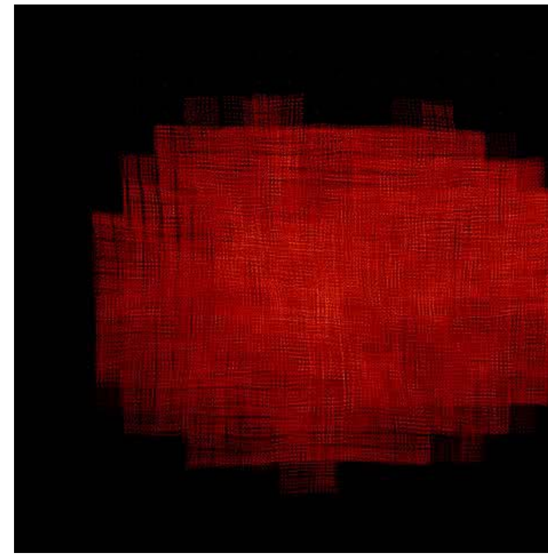

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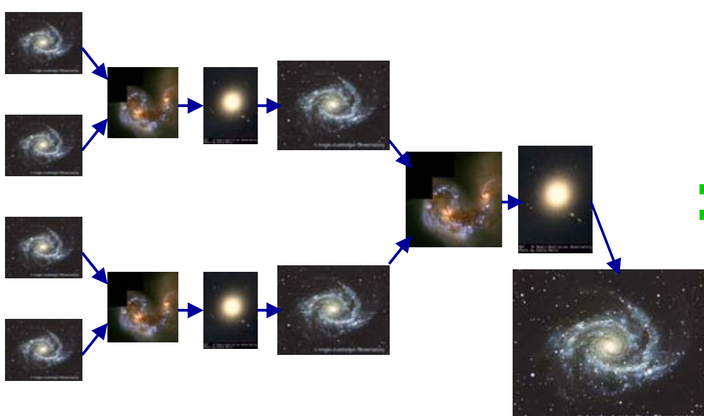

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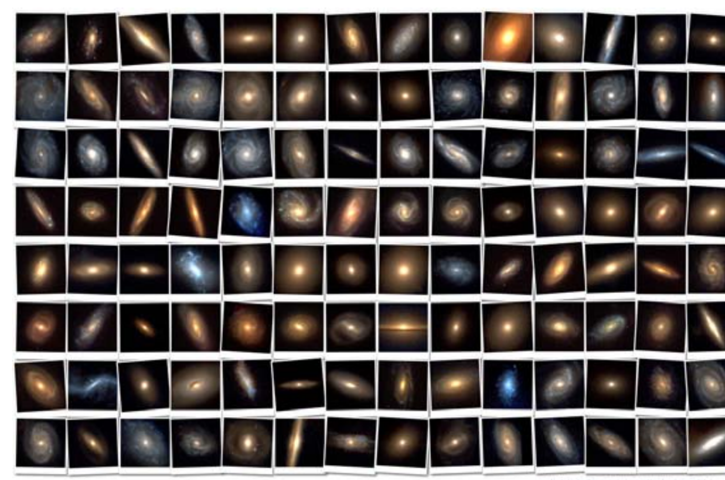
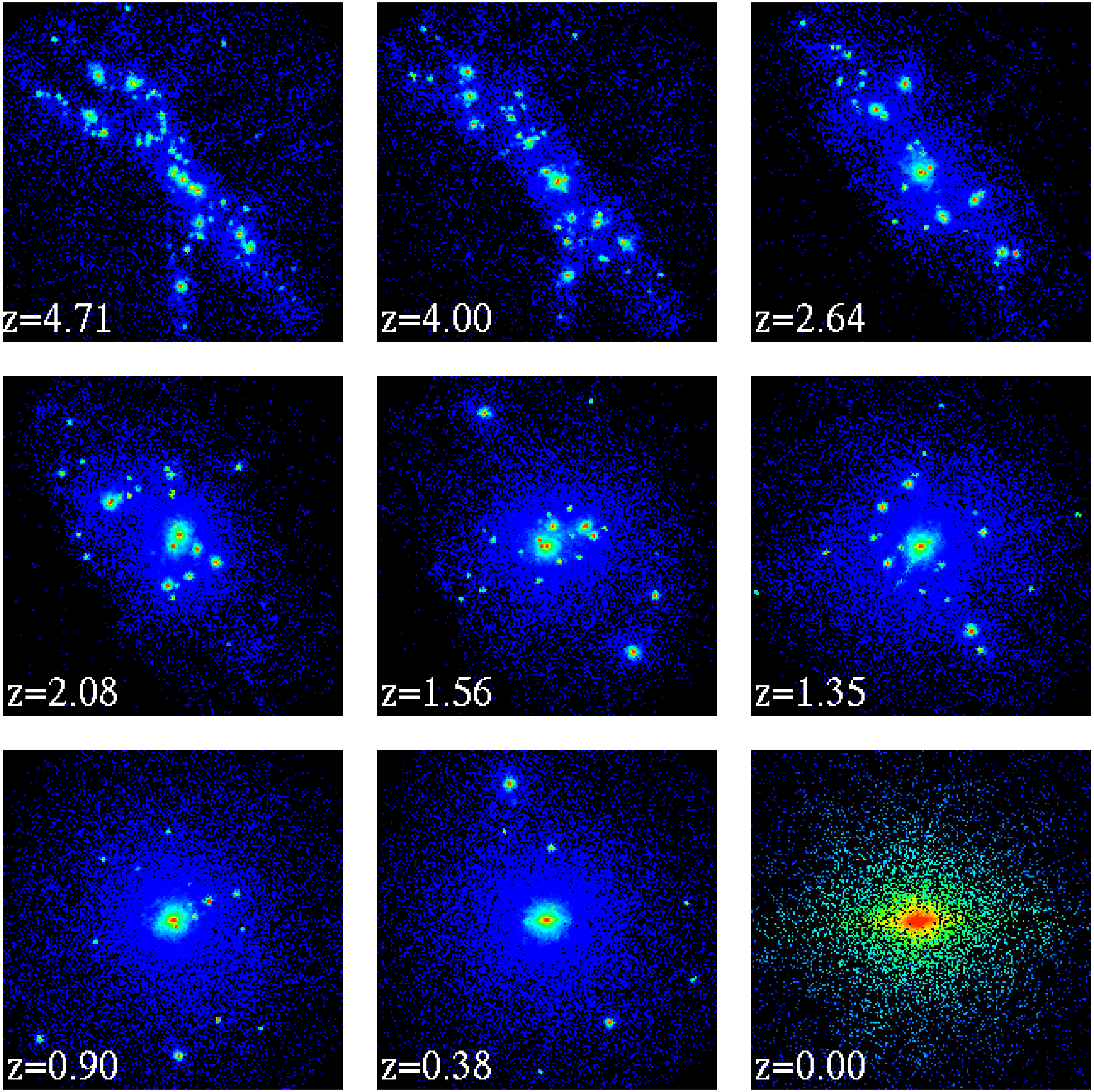
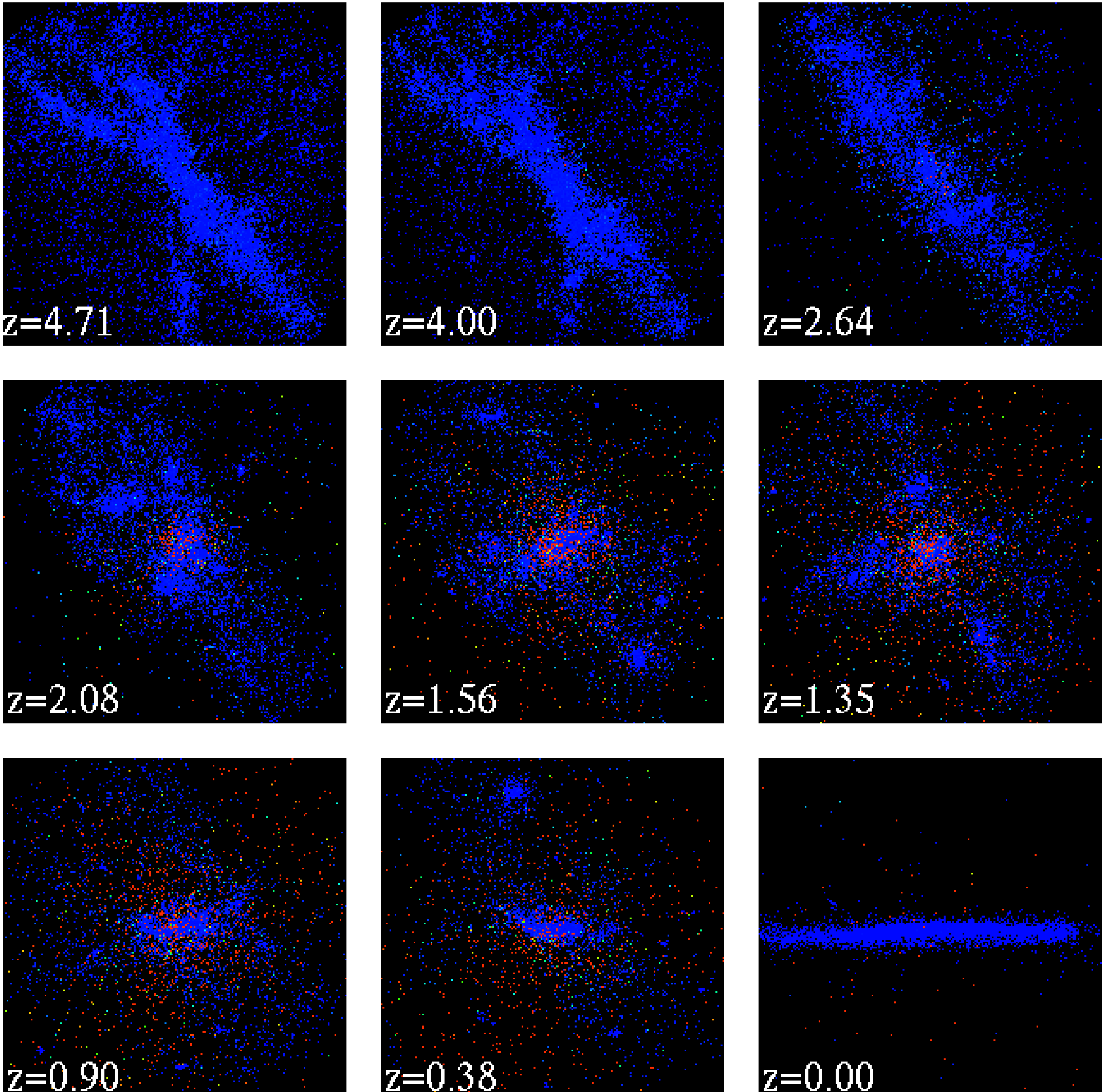


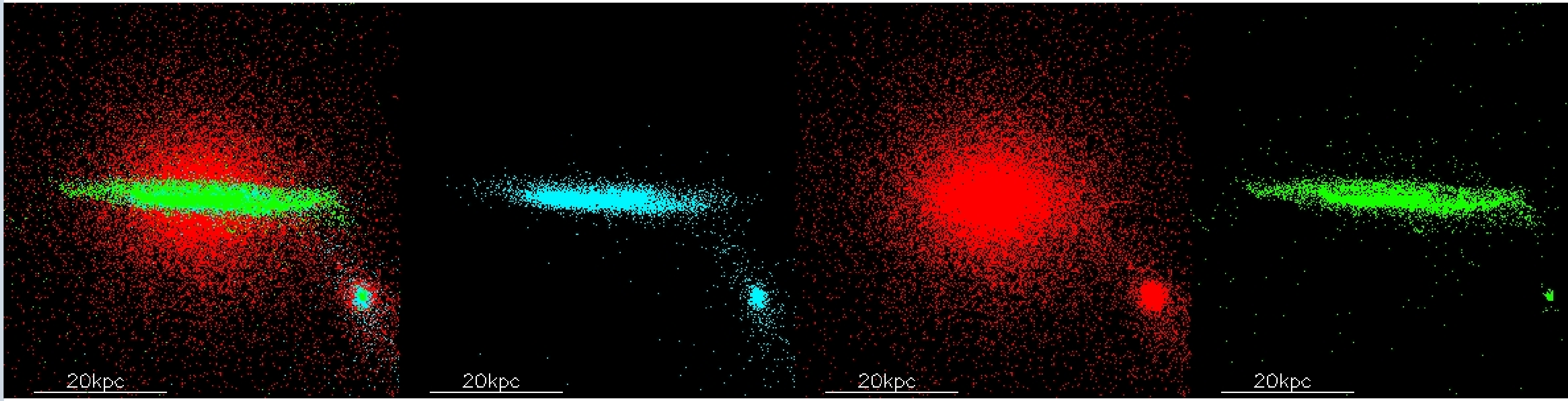
Dark Matter



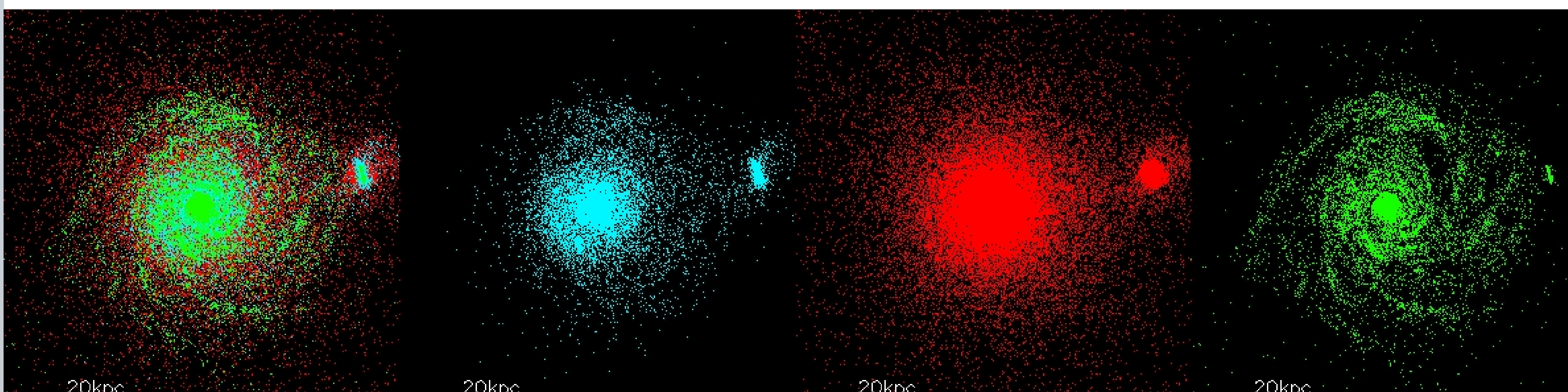
Gas



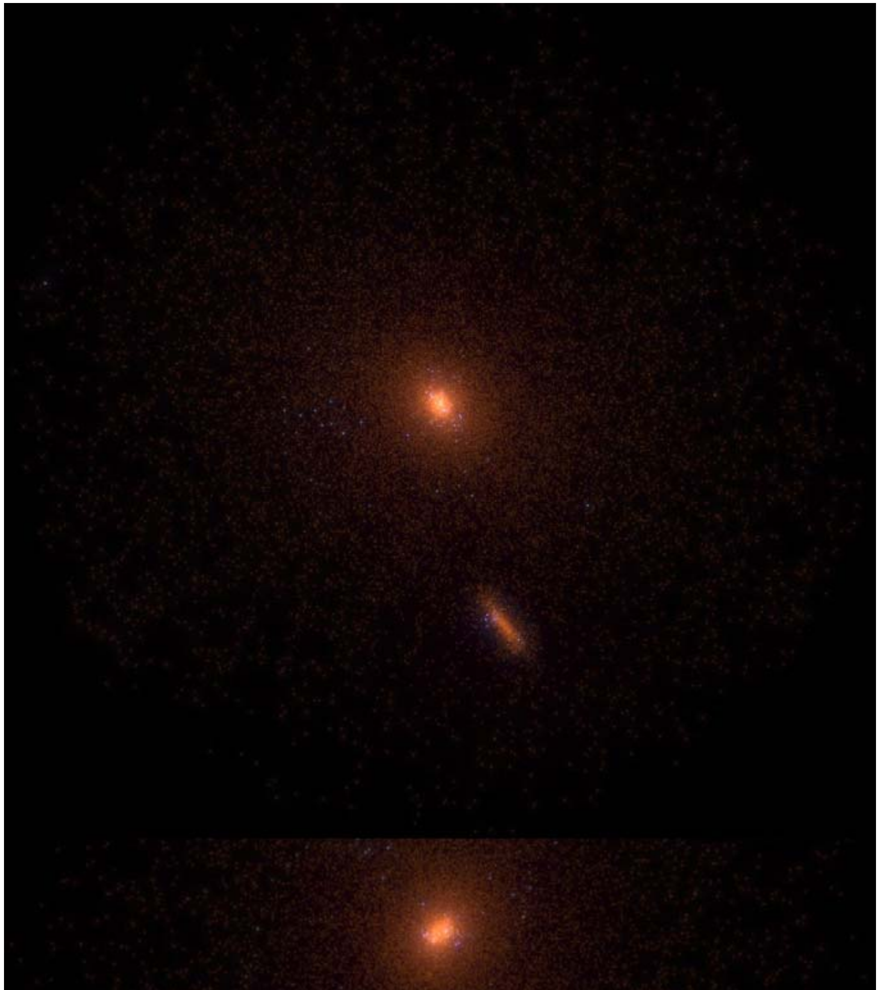
Structure of a simulated galaxy



composite **disk stars** **halo stars** **gas**

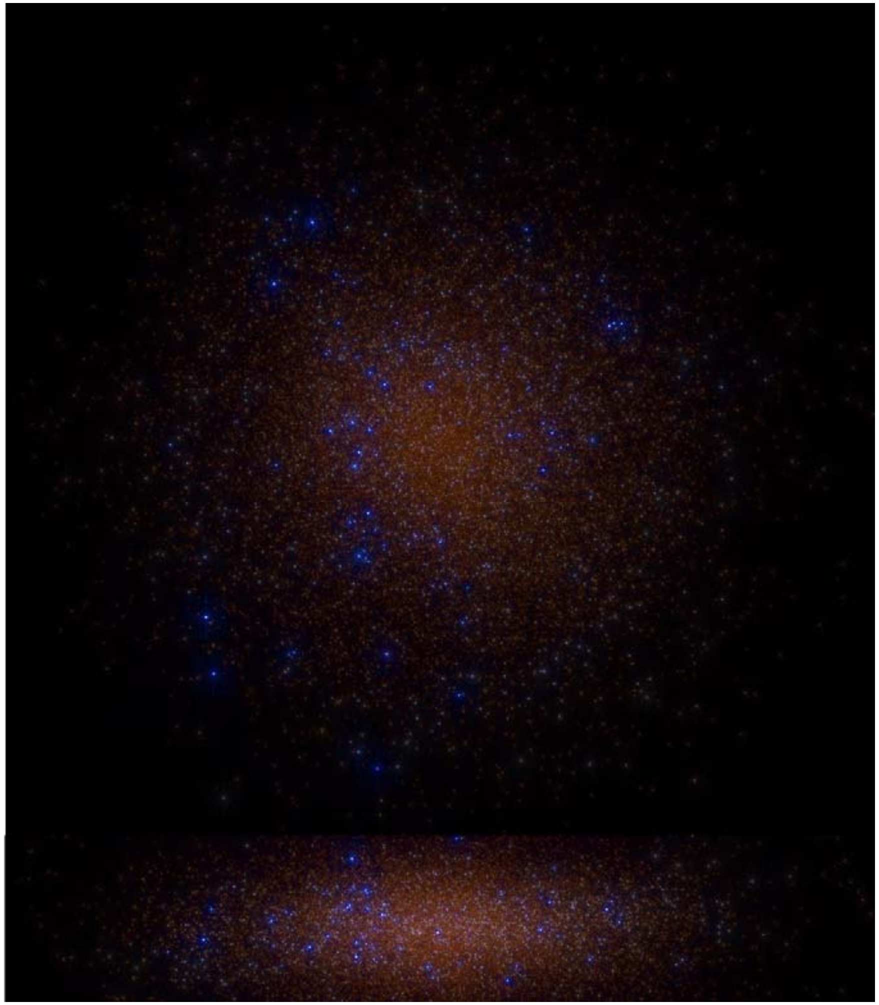


Morphology vs feedback



Piontek & MS, 2008

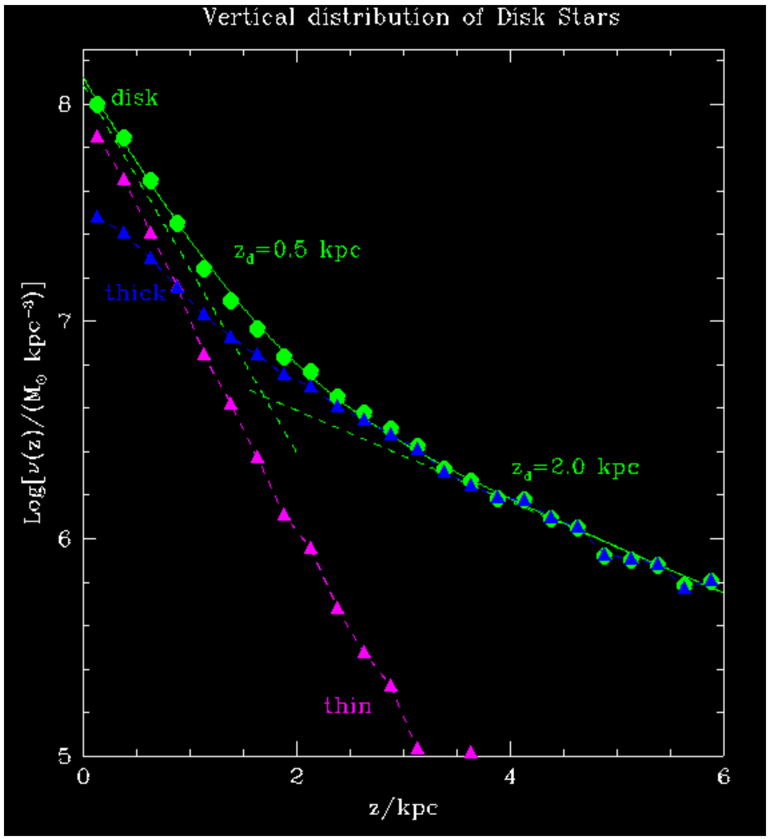
Morphology vs feedback



Piontek & MS, 2008

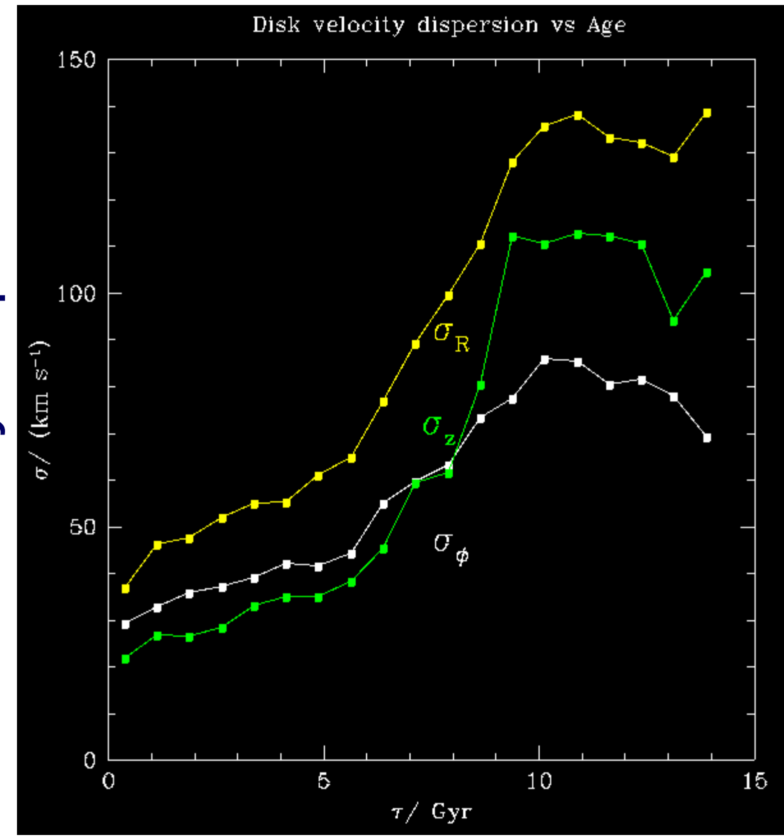
The fine structure of the disk

stellar density



vertical distance

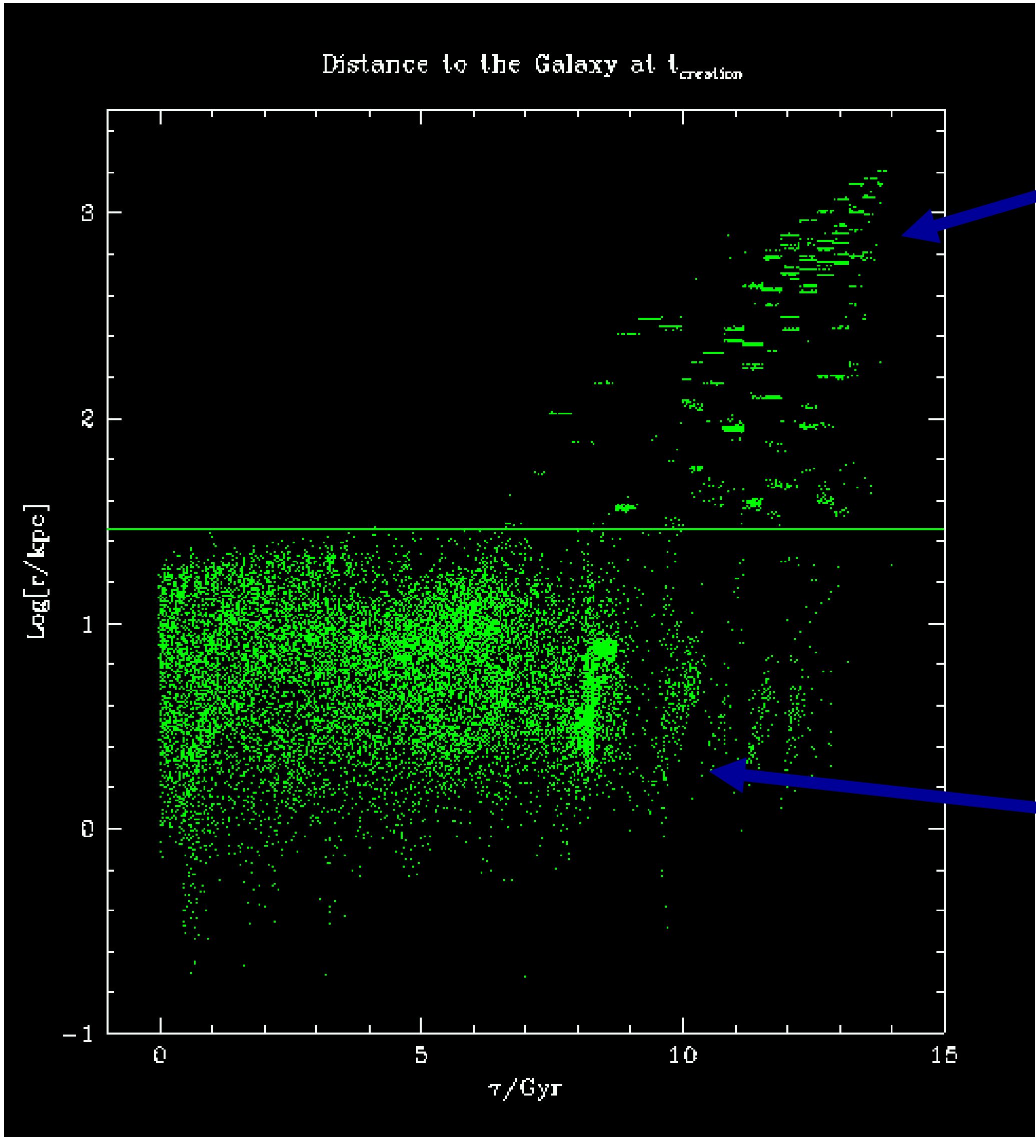
velocity dispersion



age

Abadi et al., 2003

Morphology reflects merging history



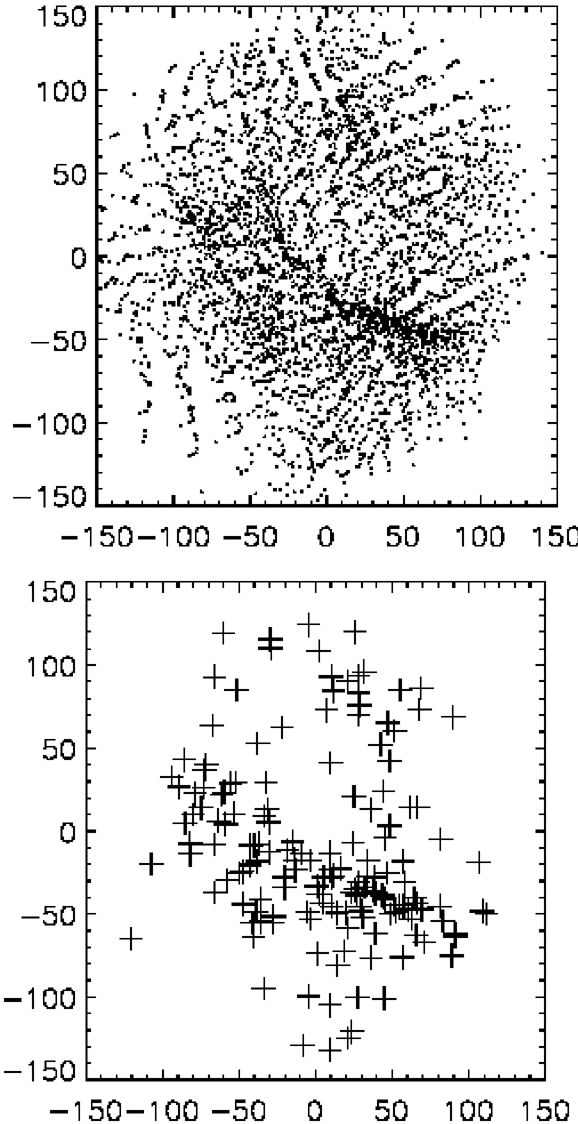
thick disk

the (old) thick disk is *not* a former thin disk thickened by a minor merger but actually the debris from satellite accretion events

thin disk

Abadi, Navarro, Steinmetz & Eke 2003

Origin of stellar populations



turns into bulge stars

turns into halo stars

MS & Müller 1994

Accretion in action

- Sag Dwarf
- Monocerus
- Pal 5
- Andromeda Stream
- Eggen moving groups ?
- Omega Cen ?
- Substructure in the galactic disk ?
- More than anecdotal evidence ?
  - Firm up predictions from models
  - strengthen the case for the MW
  - prove it for other galaxies

What do the textbooks say …

- The Milky Way formed 10 billion years ago
  - the disk is thin ↯ substantial accretion
  - the oldest thin disk stars >10 billion years old
  - rotational support, ordered motion ↯ mixed up by mergers
  - Stellar population of MW satellites systematically different to the stellar population of the MW halo
- however
  - many disks are warped and/or lopsided (>50%?)
  - difficult to create long-living features

What do we know about the MW?

- Some basic properties of the Milky Way are actually quite unknown
  - Mass, extent of the dark halo
  - Potential depth and escape velocity of the Milky Way
  - Is the halo spherical, triaxial, oblate/prolate?
  - Size of the disk
  - Is there a dichotomy thin disk/thick disk?
  - Substructure and streamers: signs of a systematic built up by mergers or anecdotal events?
  - Number of satellites
  - …
  - Is the MW a typical disk galaxy?

Galactic Mega-Surveys

- Photometric
  - 2MASS, DENIS
  - SDSS
  - PanStarrs
  - LSST
- Spectroscopic
  - RAVE: 1 Million Stars (2003-2011)
  - SEGUE I+II: ~500k Stars (2005-2010)
  - GAIA: ~100M Stars (2012-2017)

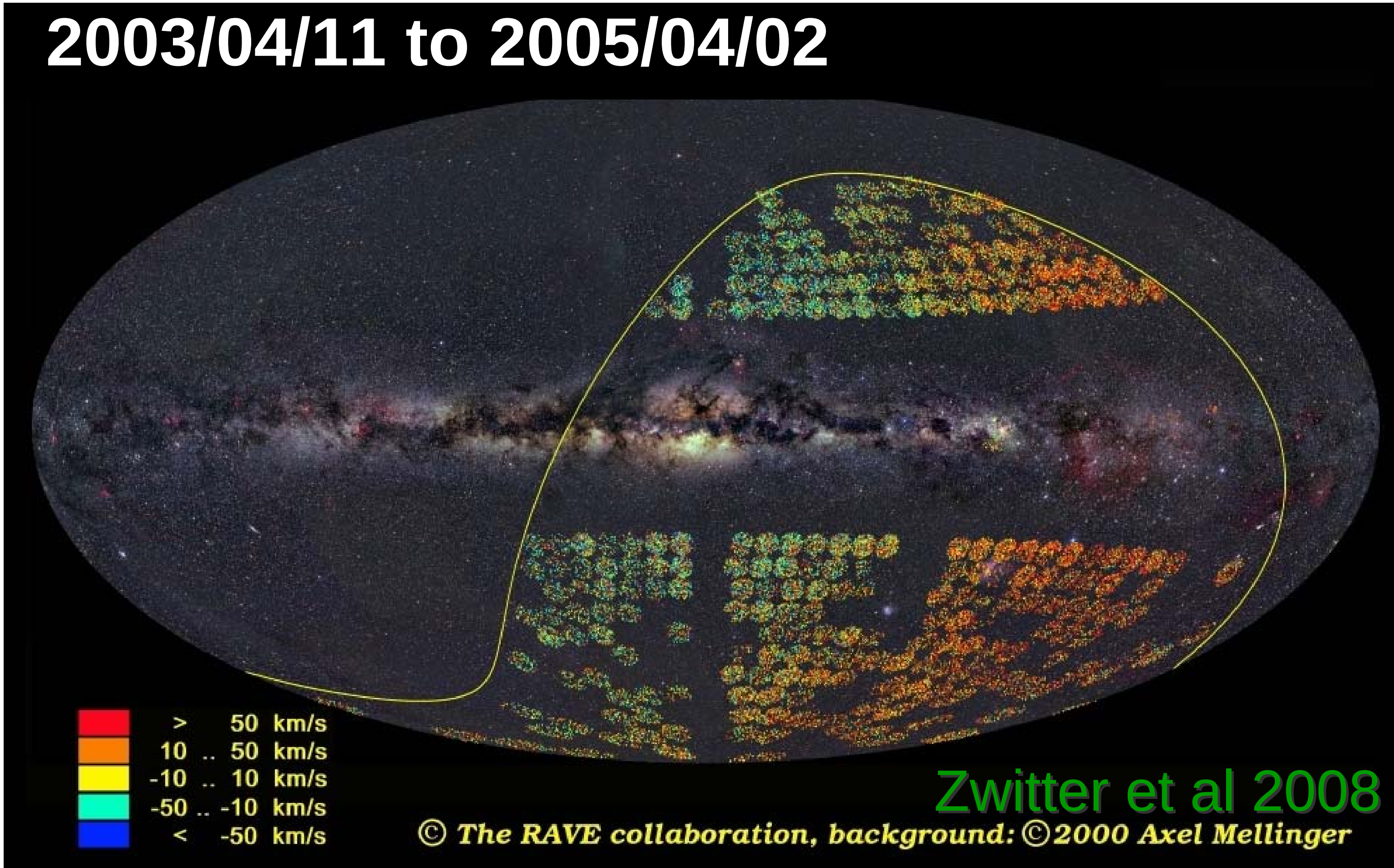
The RAVE survey

- Spectroscopic high latitude survey of the MW
  - 9 < I < 13
- GAIA spectral range and resolution
  - Ca triplet region (8400-8800Å)
  - R_{eff}=7500
- Scheduled operation: 2003 – 2011
  - 6dF MOS on UKST at Siding Spring
  - 7 nights per lunation up to 8/2005
  - >20 nights per lunation since 8/2005
- Goal: 1 Million spectra
- Public data releases

2^{nd} Data Release (preview)

Coverage : ~6800 sq.deg
51,829 radial velocities
49,327 targets

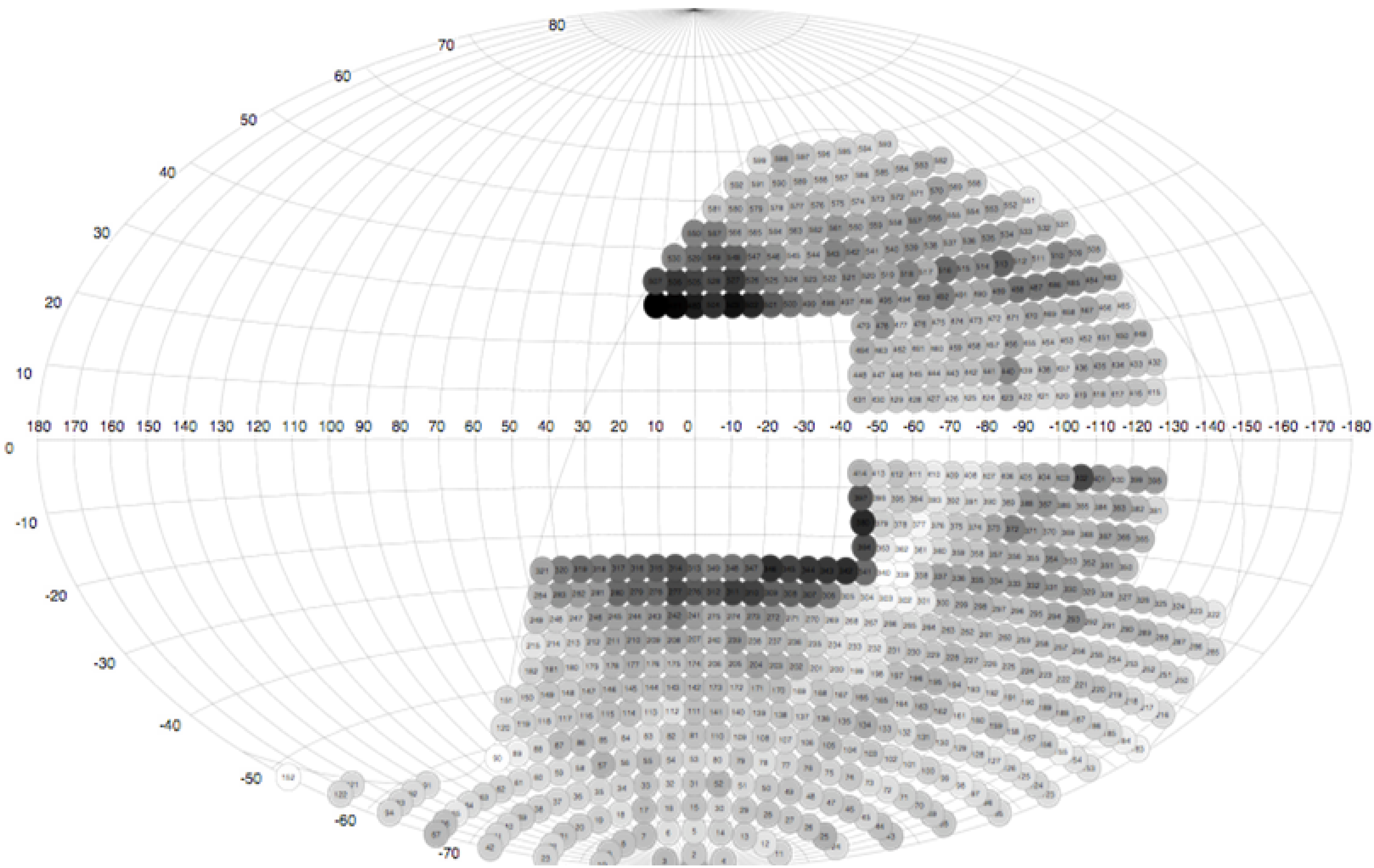
500 fields
5.7° diameter
22407 stellar par.



Some numbers

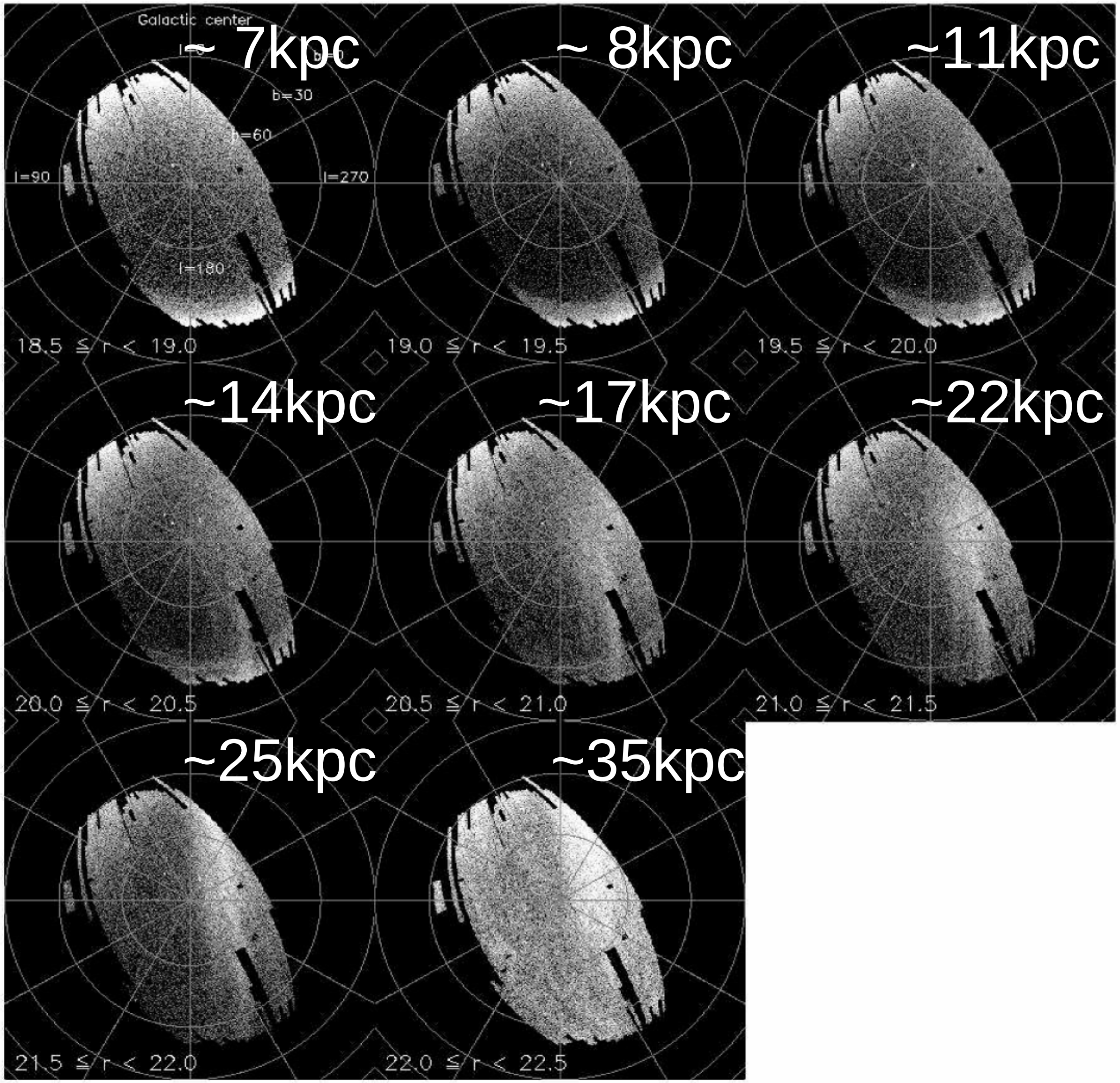
- DR1
  - 25,274 RVs
  - 24,748 individual objects
  - no parameters
- DR2
  - 51,829 RVs (+26,555)
  - 49,327 individual objects (+24,579)
  - 22,407 parameters for 21,121 unique objects
- DR3
  - 87,612 RVs (+35,783)
  - 78,903 individual objects (+29,576)
  - 55,290 parameters for 51,984 unique objects (+33,883) (+30,863)

RAVE’s progress



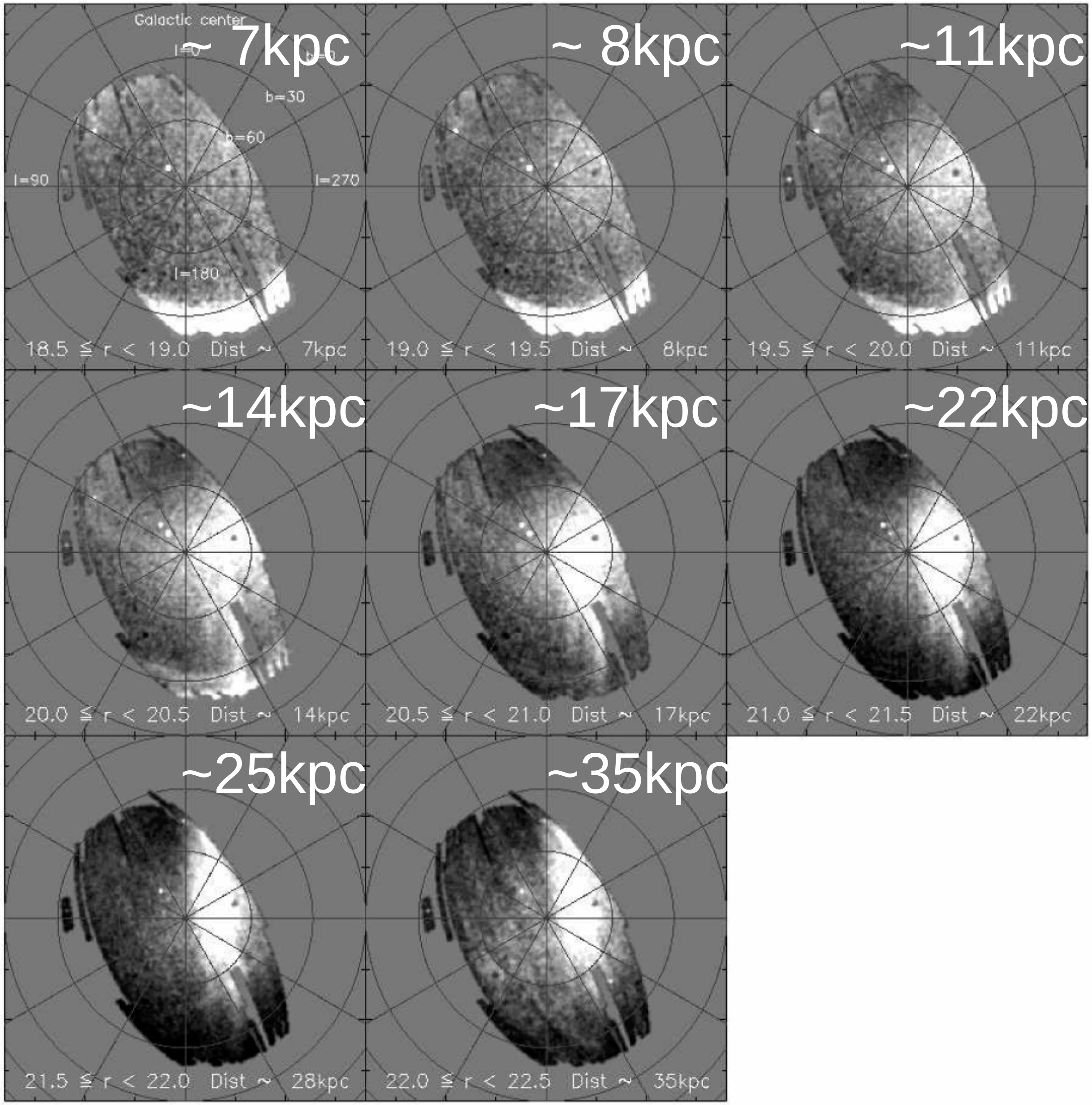
09/15/2008 : 320,000 spectra for 300,000 stars

Structure in the MW halo (SDSS DR5)



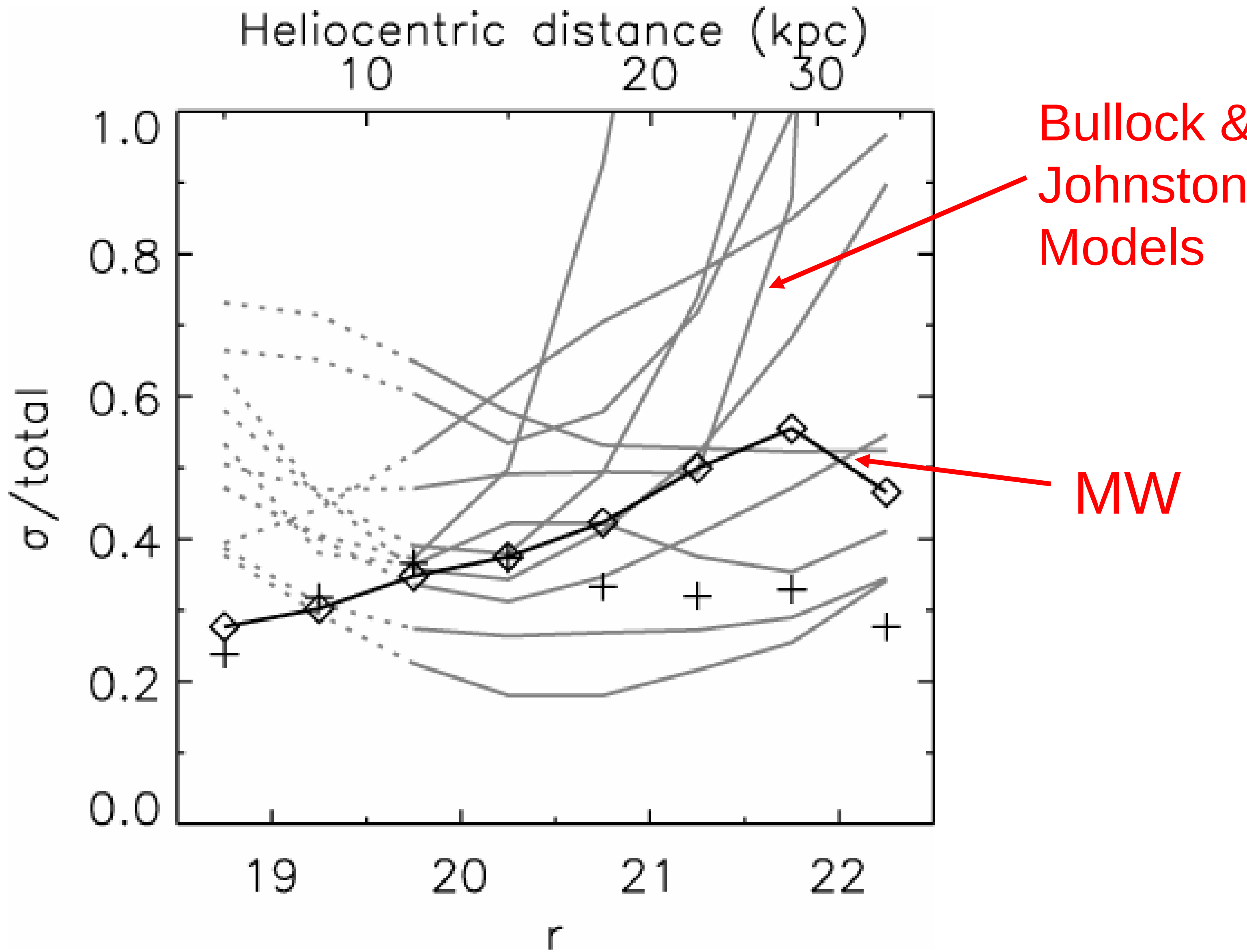
Bell et al 2007

Residual Structure



Bell et al 2007

Structure in the MW halo



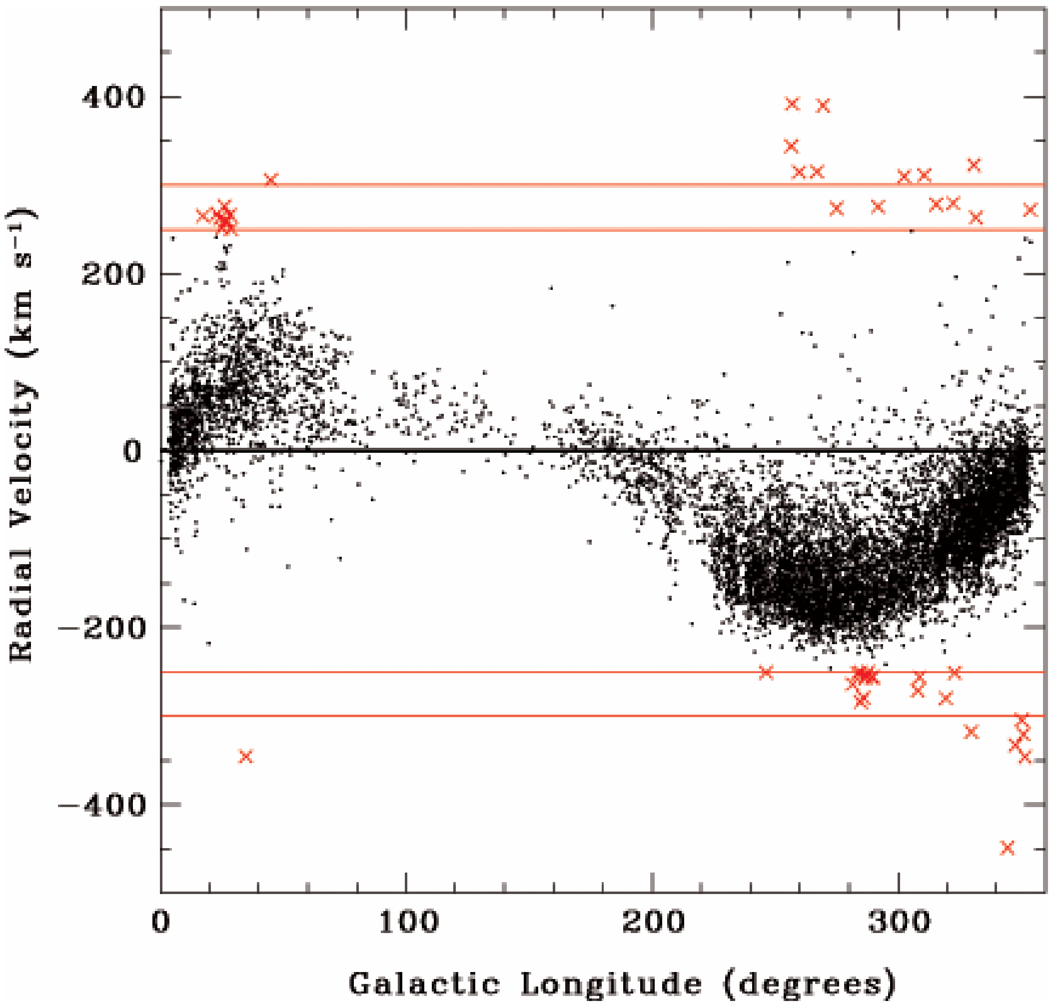
Tidal streams in the Solar neighborhood (Seabroke et al 07)

- Vertical tidal stream in solar neighborhood
  coherent +W (or –W) vertical velocity
- Kuiper test to measure symmetry of vertical velocity distribution of CORAVEL and RAVE stars above and below the plane
- No sign of coherent large scale motion as would be produced e.g. by Sagittarius or the Virgo Over Density

Sample	CORAVEL		RAVE	
	Dwarfs	Giants		
Section	2.5	3.4	4.6	
V (kpc^3)	0.0003	0.0511	7.9052	
N_s (low)	200	200	300	
N_s (high)	600	800	600	
VC (%)	100	100	5	15
ρ_s (low)	0.7×10^6	4000	800	300
ρ_s (high)	2.2×10^6	16 000	1500	500
N Sgr (low)	0.1 (n)	10 (n)	80 (n)	250 (?)
N Sgr (high)	0.4 (n)	80 (n)	590 (y)	1800 (y)
N VOD	30 (n)	6000 (y)	48 000 (y)	144 000 (y)

The Escape Speed of the Milky-Way

Smith, Rutchi et al 2007



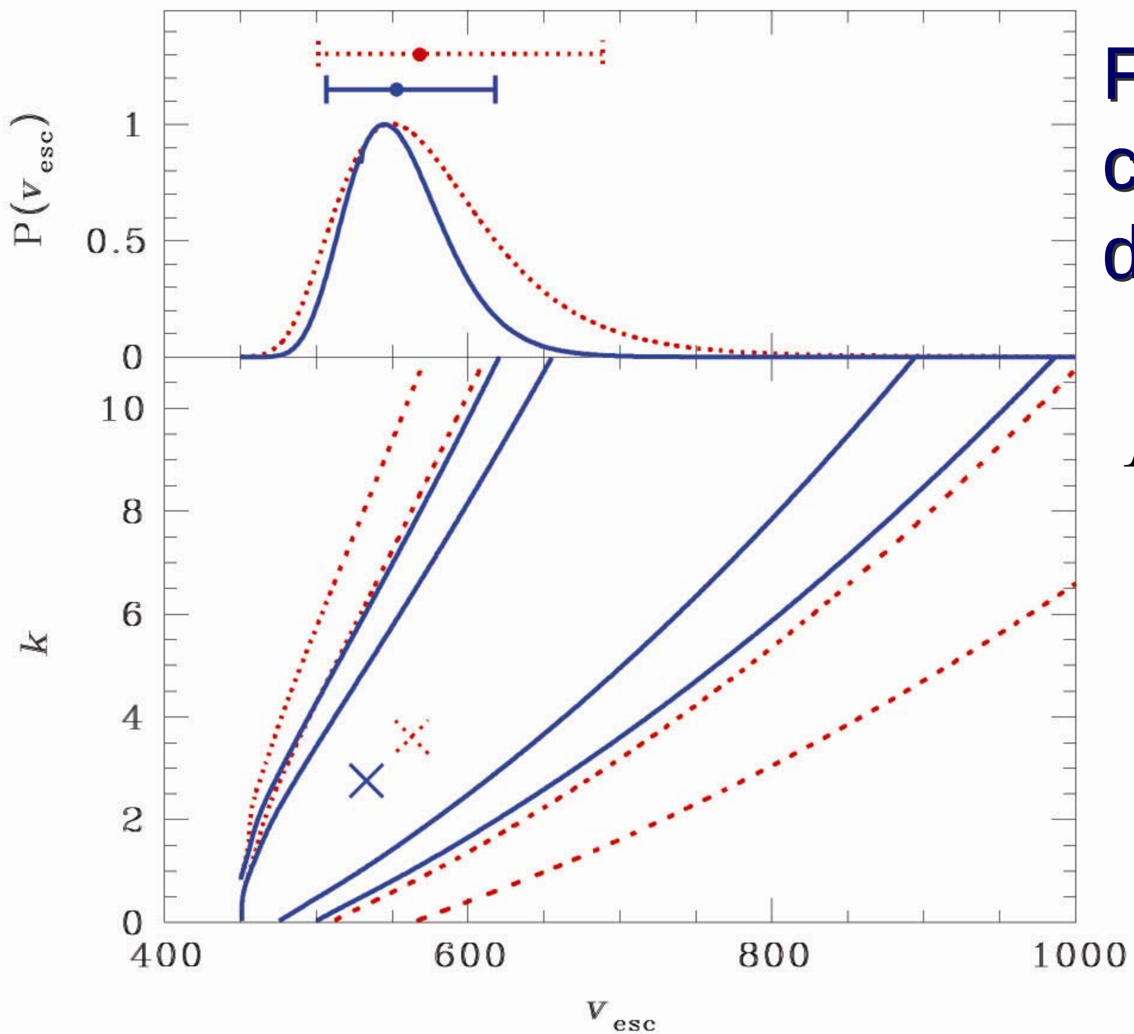
Leonard & Tremaine (1990):

near escape velocity:

$$f(\varepsilon) \propto \varepsilon^k$$

$$\varepsilon = \left(v_e^2 - v^2\right)$$

The Escape Velocity of the Milky-Way



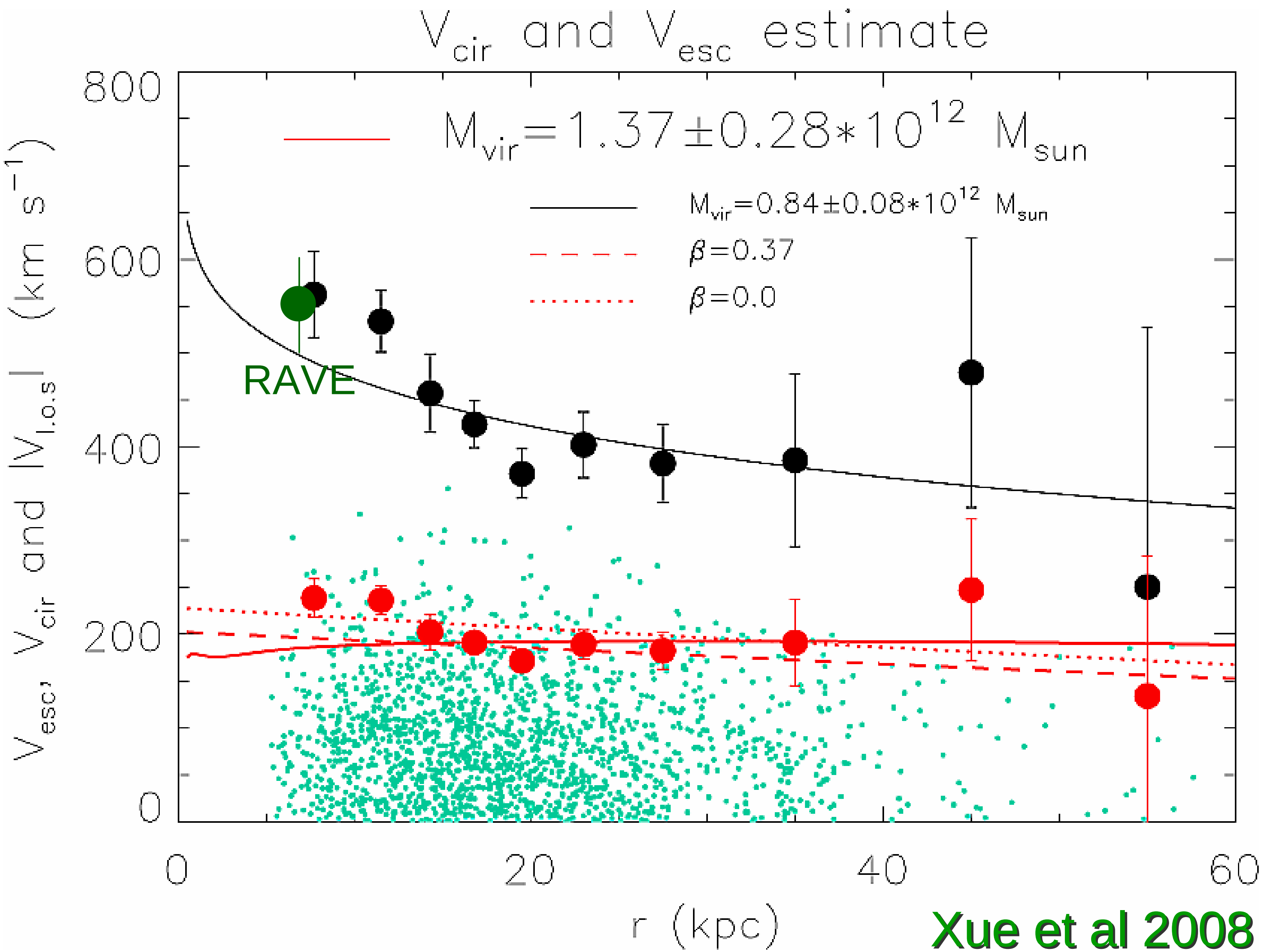
For an adiabatically contracted NFW dark halo:

$$M_{MW} = 1.42^{+1.14}_{-0.54} \times 10^{12}\ M$$

$$v_{vir} \approx 142\ \mathrm{km/s}$$

Smith et al 2007

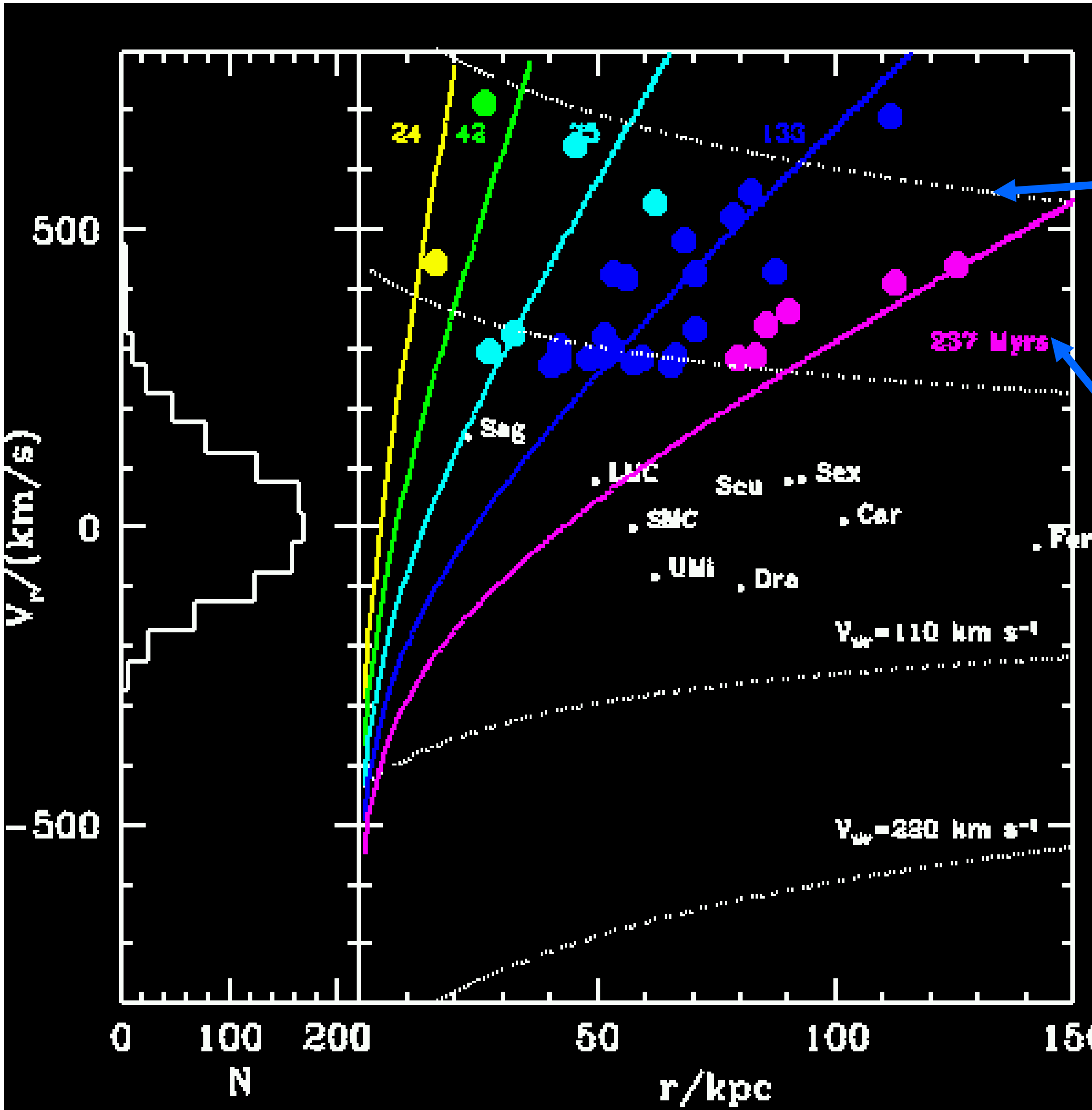
V_{circ} and V_{esc} from SDSS



Xue et al 2008

AIP

Halo potential and hyper velocity stars

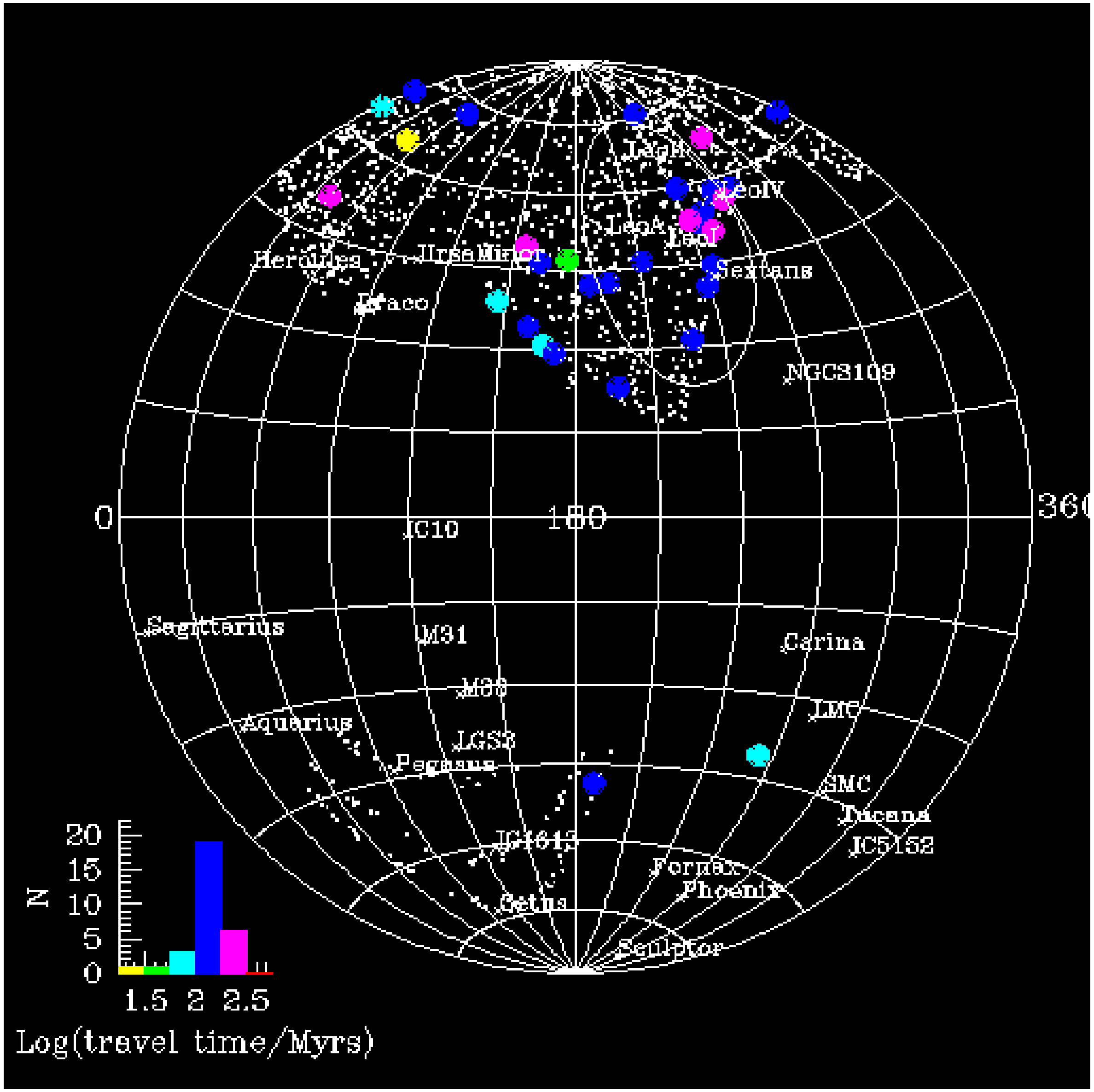


Cosmological prediction for MW potential

Inferred from MW dynamics

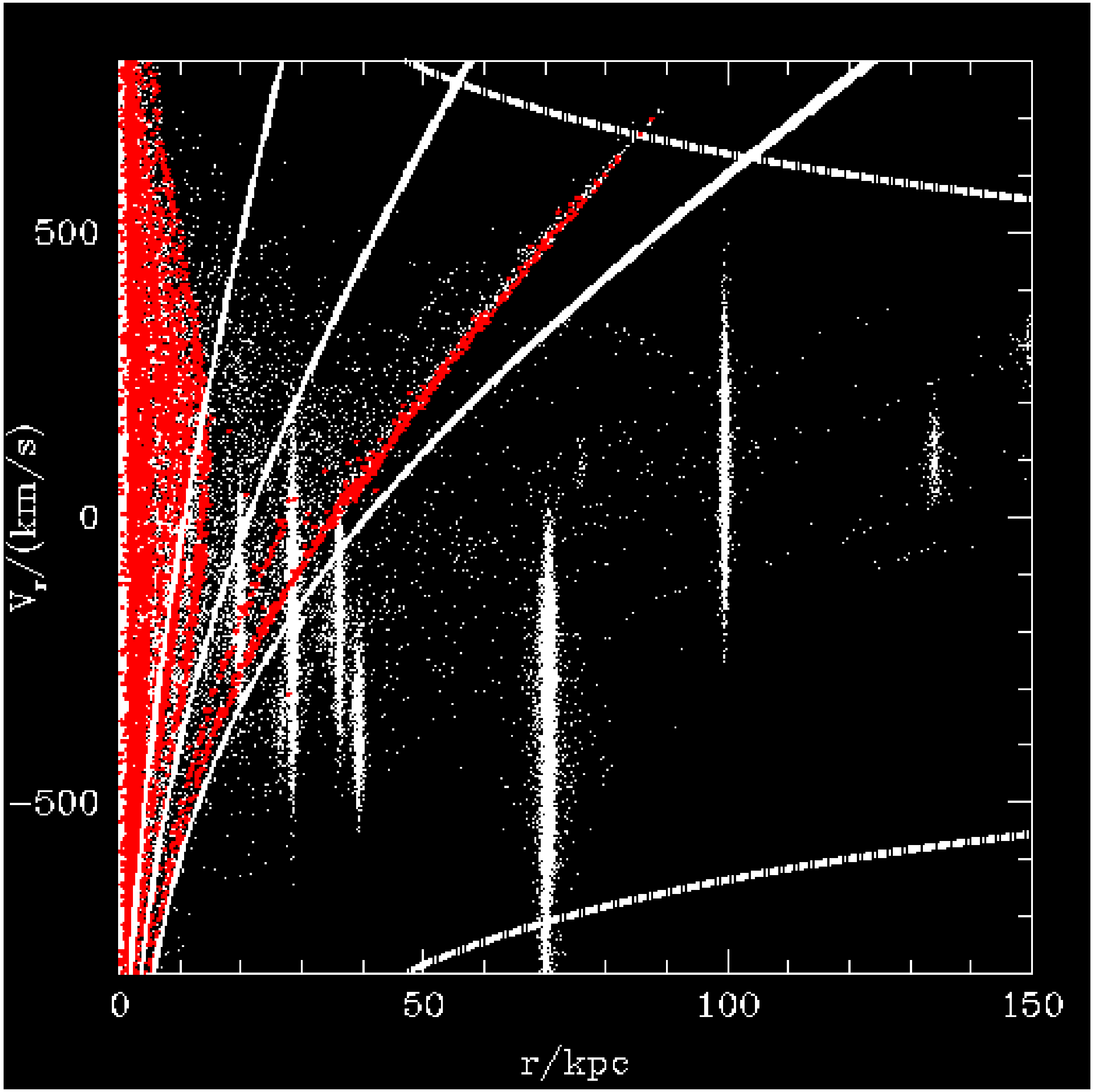
Abadi et al 2008

High velocity stars



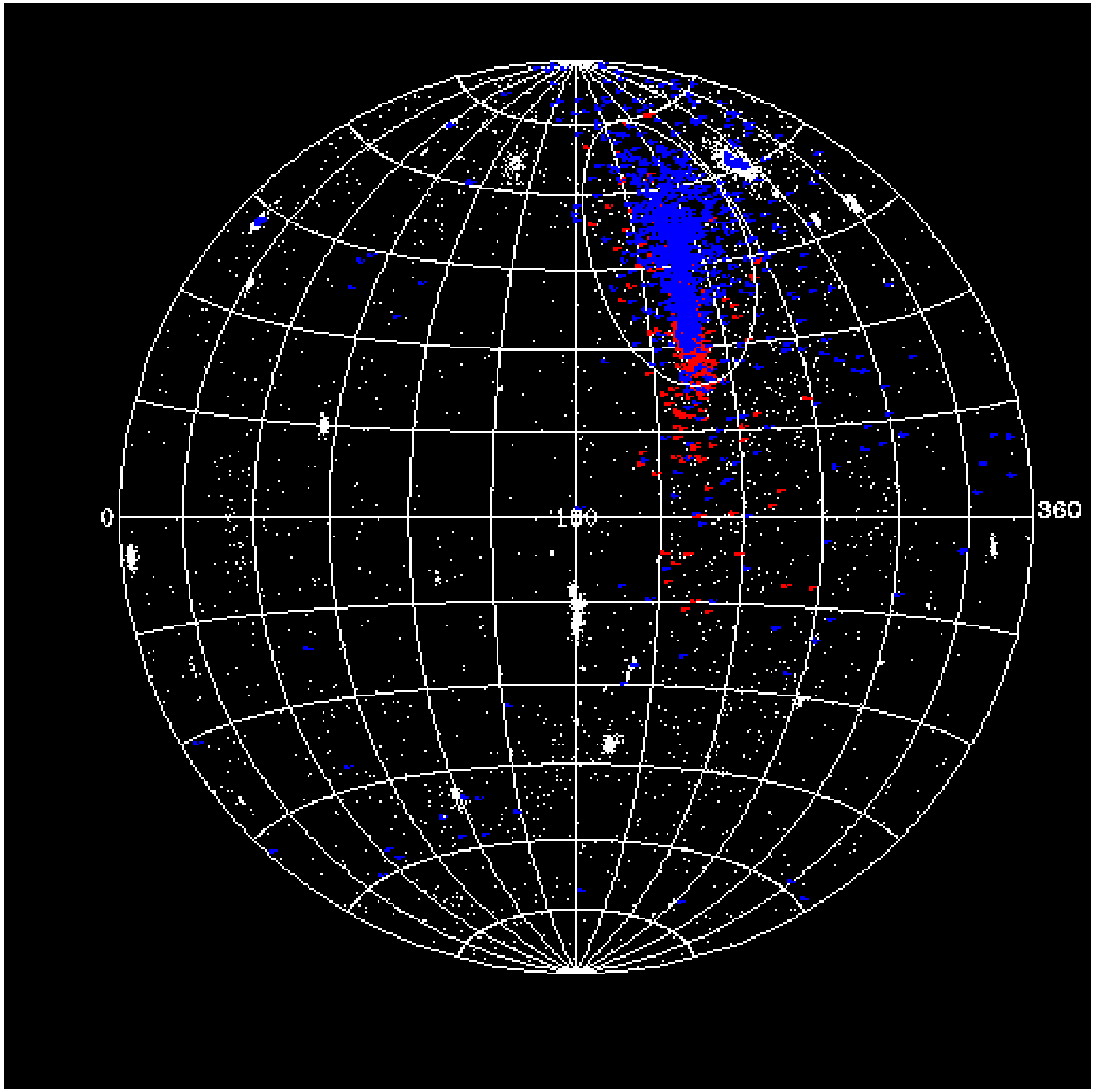
Abadi et al 2008

HVS = disrupted satellites?



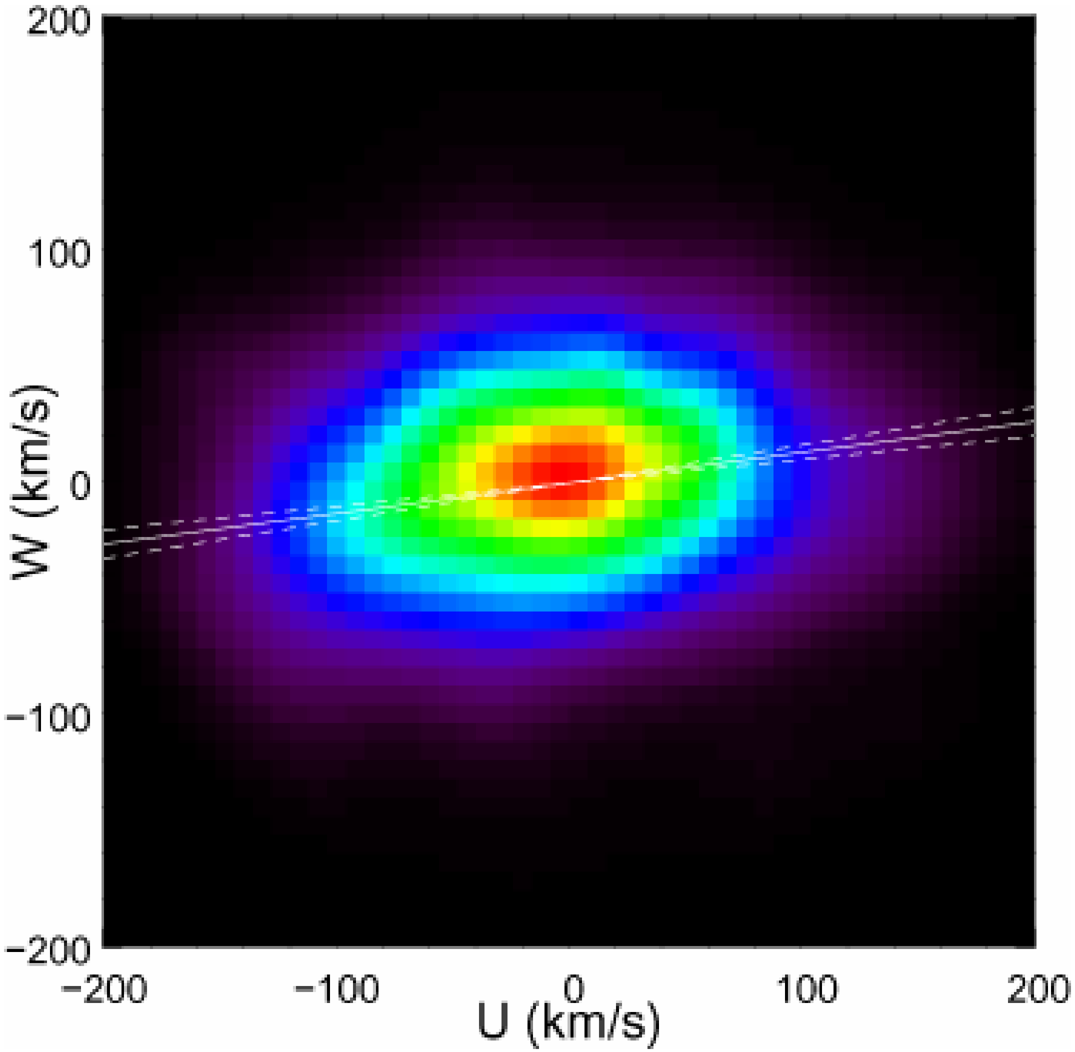
Abadi et al 2008

HVS = disrupted satellites?



Abadi et al 2008

The galactic potential and the tilt of the velocity ellipsoid



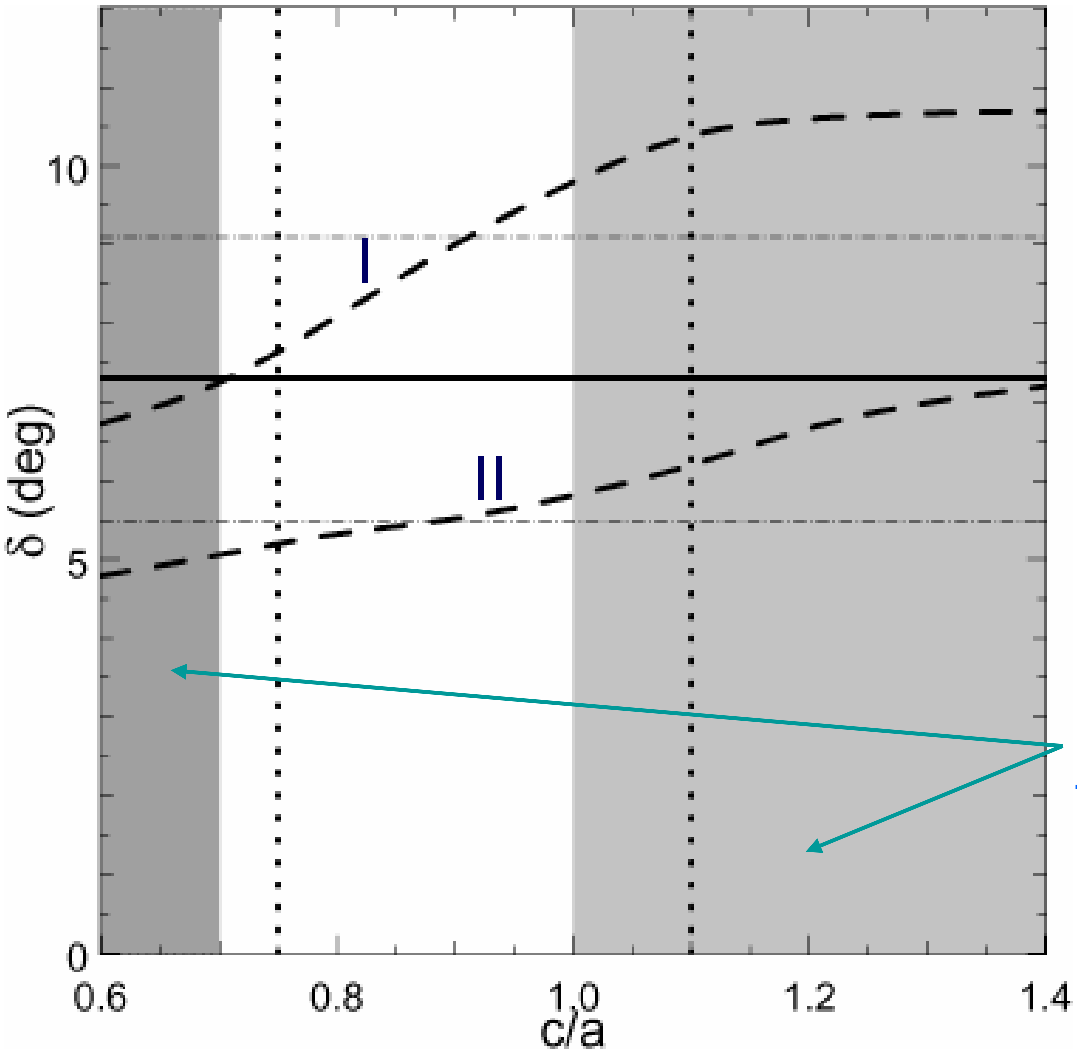
~500 KIII giants

500 < z <1500 pc

Δ=7.3±1.8 deg

Siebert et al, 2008

The galactic potential and the tilt of the velocity ellipsoid



Comparison with Galaxy Model I & II (Binney&Tremaine 08)

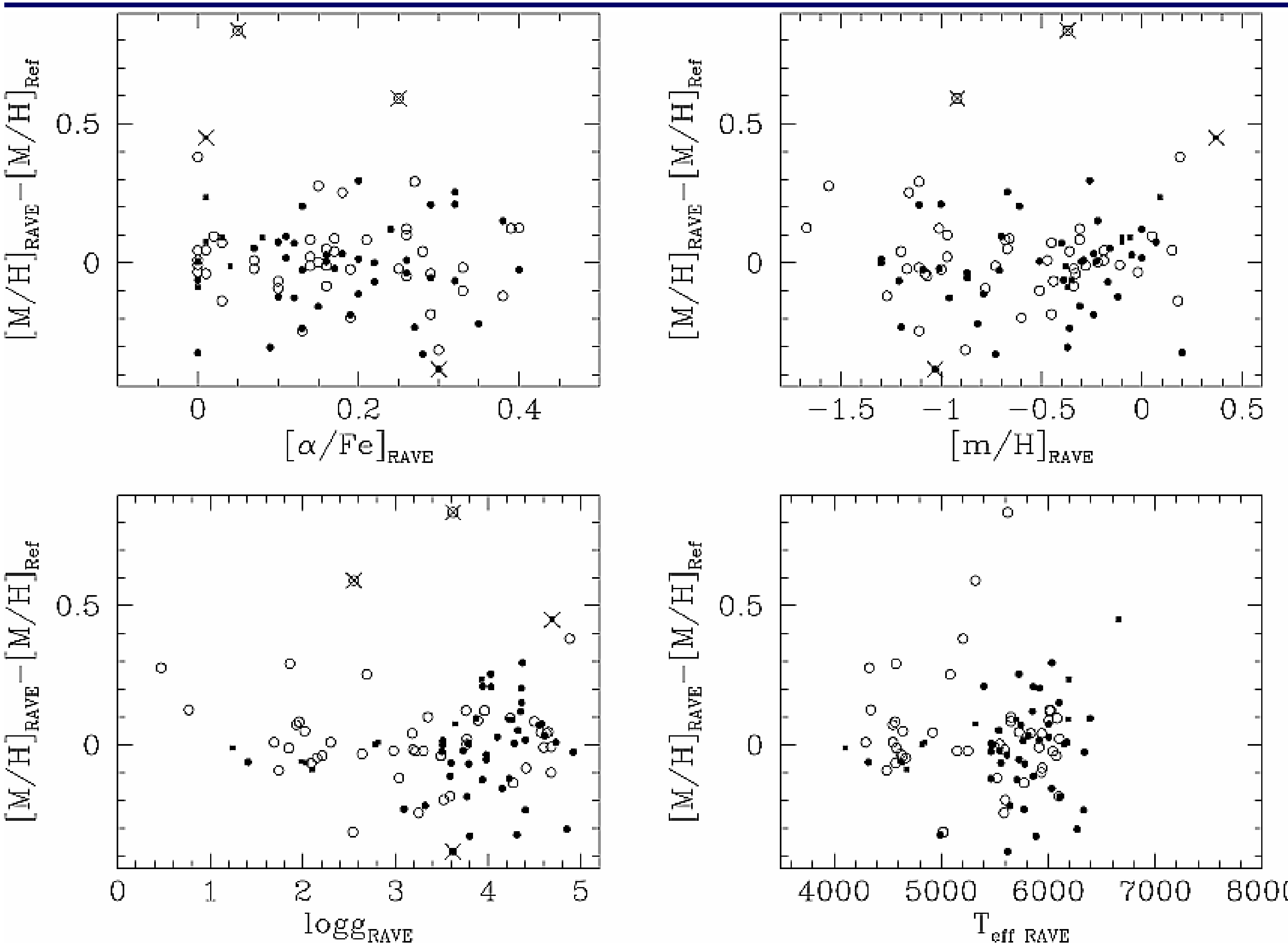
Model I: r_D=2.0kpc
Model II: r_D=3.2kpc

Constraints on Halo flattening from Ibata et al (2001) and Ruzicka et al (2007)

Siebert et al, 2008

Metallicity by template fitting (DR2)

Zwitter et al., 2008



Abundances

RAVE spectral range contains information on various chemical elements

BUT

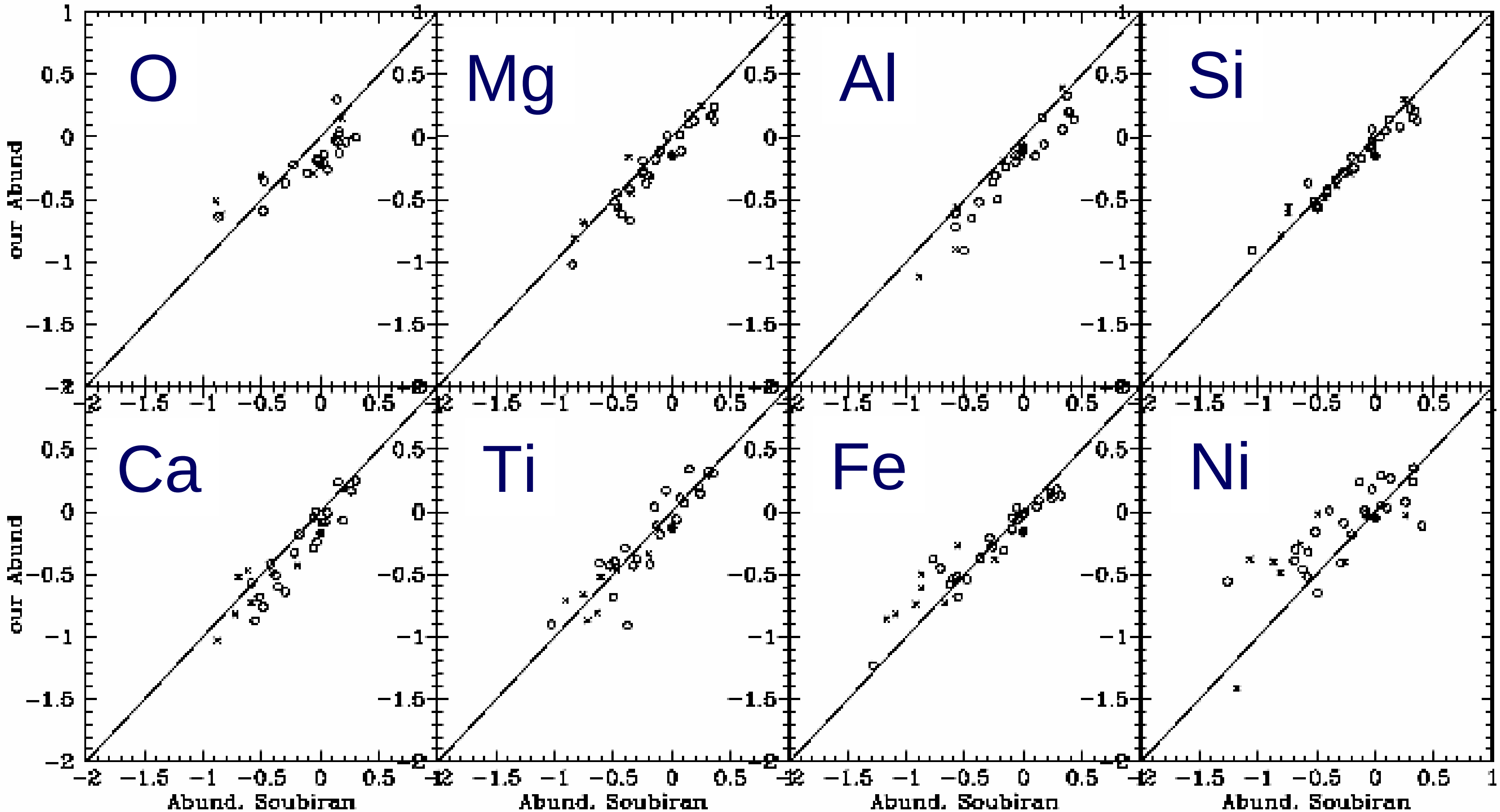
- low signal to noise (SNR~20)
- low spectral resolution (R~7500)

⇒ Need for an efficient algorithm to deblend lines

Elements we can measure:
O, Mg, Al, Si, S, Ca, Ti, Cr, Fe, Co, Ni, Zr

C. Boeche PhD thesis, in progress

Abundances



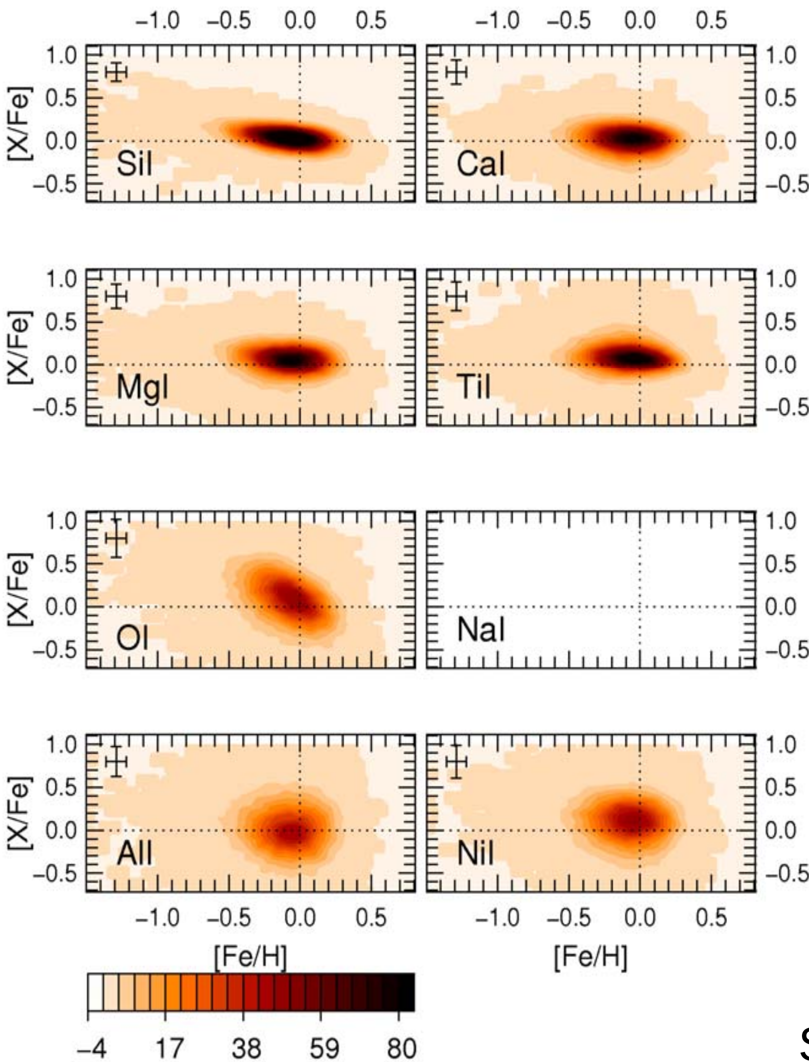
Asplund et al. (2005) solar abundances

- ○ spectra with S/N>=100
- × spectra with S/N<100
- ■ Moon spectrum

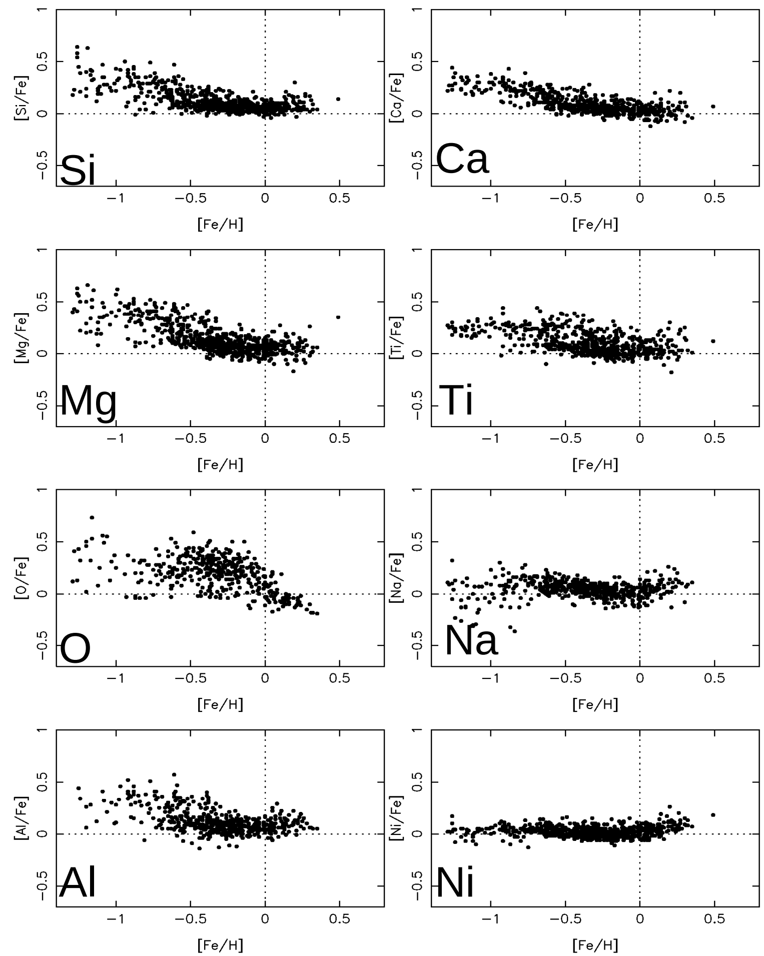
Comparison to Soubiran & Girard

RAVE abundances: comparison with literature data (Boeche et al 08)

32841 RAVE stars

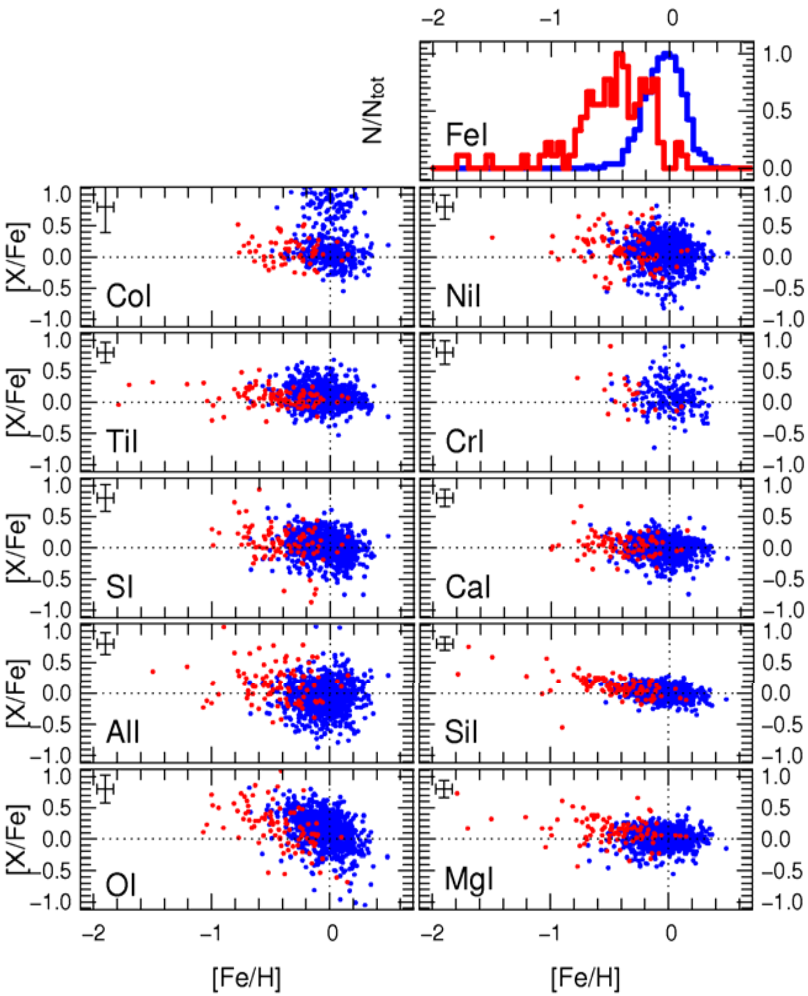


743 stars by Soubiran & Girard



Soubiran & Girard, 2005, A&A, 438, 139

RAVE abundances:thin and thick disk stars (Boeche et al 08)



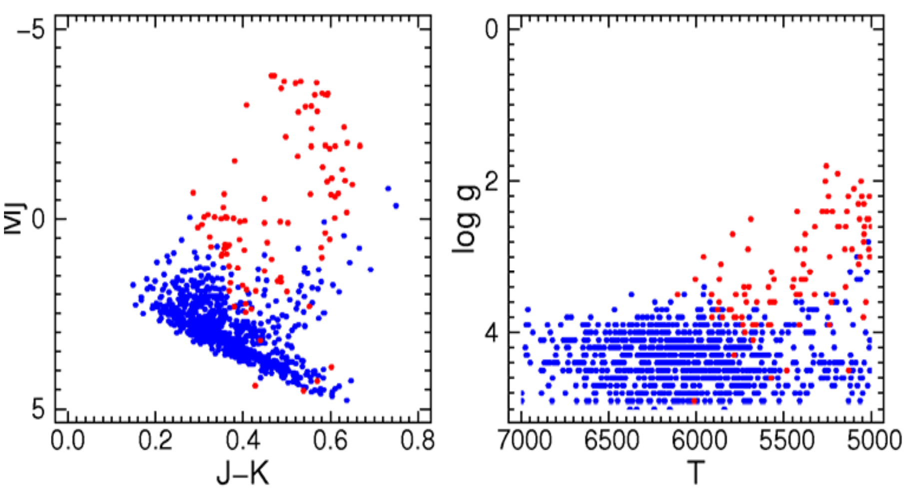
out of 4421 stars, we select:

908 thin disk stars

abs(V)<20 km/sec, abs(W)<16 km/sec, abs(zGal)<0.3 Kpc

97 thick disk stars

V<-100 km/sec, abs(W)>50 km/sec,



Summary

- There are considerable uncertainties w.r.t basic properties of our Galaxy
- Hierarchical formation scenarios provide natural explanations for many galactic properties – but some critical issues still remain
- There is increasing evidence for substantial accretion in the outer areas of the Galaxy
- Next generation of surveys
  - Well defined selection effects
  - Statistics
  - Large enough numbers to allow well defined subsamples