AIP

RAVE

RADIAL VELOCITY EXPERIMENT

Matthias Steinmetz (AIP)

What do we need for Galactic Archeology?

- 6-d coordinates for millions of stars
  - positions on the sky (α,δ) $\rightarrow$ catalogues
  - distances $\rightarrow$ parallaxes
    $\rightarrow$ astrometry from space (GAIA)
  - proper motions on celestial sphere
    $\rightarrow$ astrometry from space or 130yr baselines
  - radial velocities
    $\rightarrow$ spectra; fringe benefit: abundance
- How to analyze these data sets?
- What can we learn from 5-d or 4-d projections ?

4D → 5D, 5D → 6D

- Astrometric mission: (parallaxes)/proper motions
  - Hipparcos: 118 000 stars
  - Tycho-2: 1 million stars
- Radial velocities since 1888-2003:
  - For MW: only ~40000
  - For M31: ~10000
  - Galaxies: few Million

⇒ RAVE
RADIAL VELOCITY EXPERIMENT

The Milky Way is all around us!

Radial velocity surveys

- Geneva-Copenhagen
  - ~20000 stars (Hipparcos)
- SDSS
  - spectra for 500000 stars
- RAVE
  - 10^6 stars all sky to I=13 by 2011; 350k spectra in early 2009; v_r, Z
- Hermes (2011-)
- GAIA (2012 -)

Survey Description

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

RAVE and SEGUE are complimentary

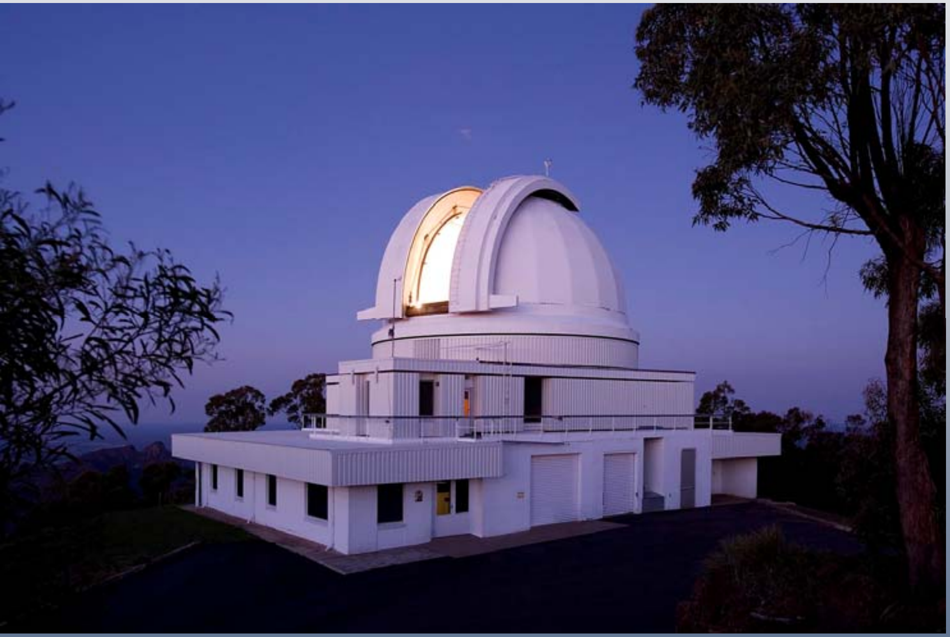
SEGUE

- selected pointings
- deep exposures
- low resolution (R=2000)
- large wavelength coverage
- northern hemisphere

RAVE

- wide angular coverage
- intermediate depth
- intermediate resolution (R=7500)
- limited wavelength coverage
- southern hemisphere

AAO UK Schmidt Telescope

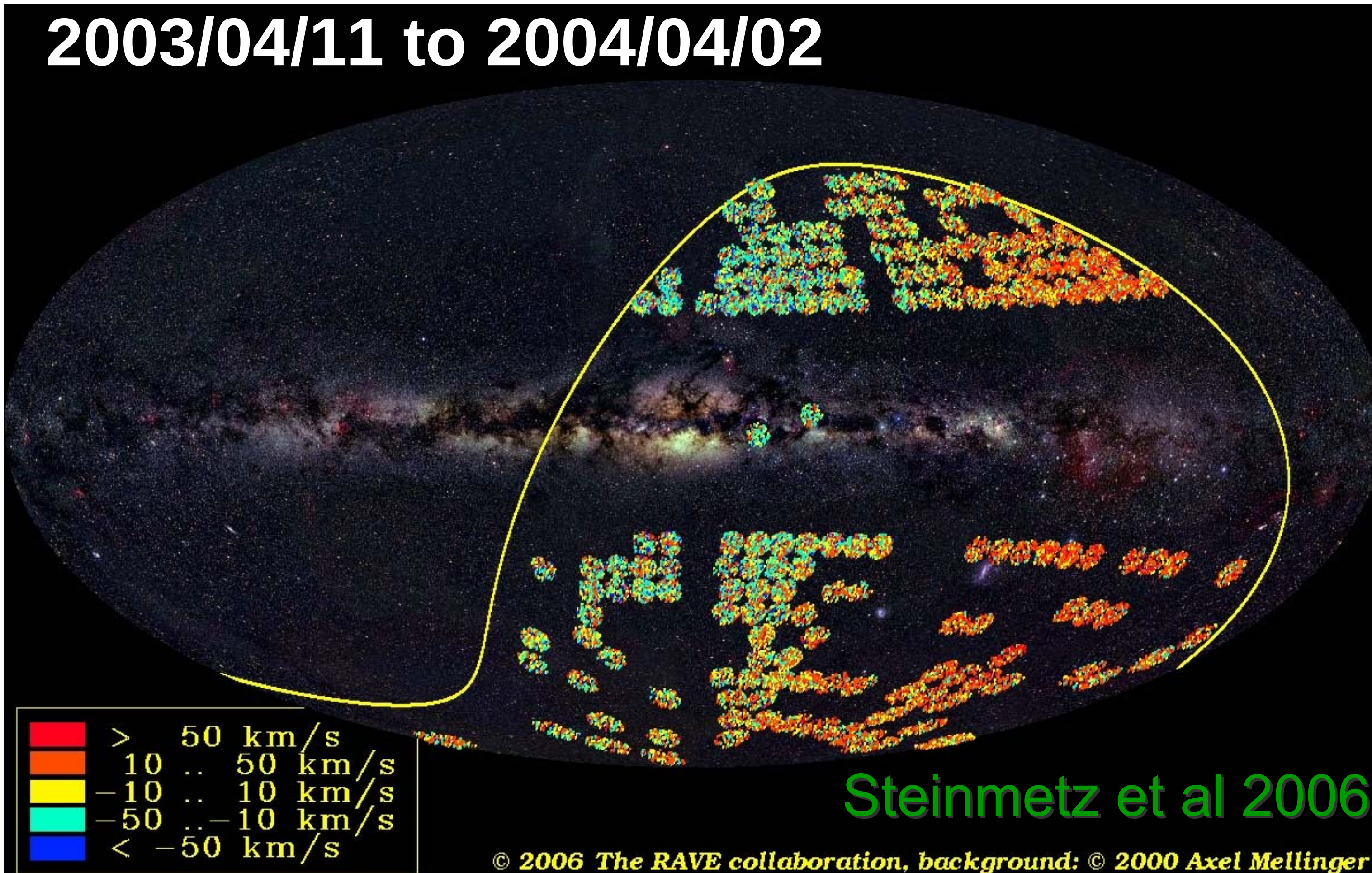


6dF Multi Object Spectograph

1st Data Release

Coverage : ~4,670 sq.deg
25,274 radial velocities
24,748 targets

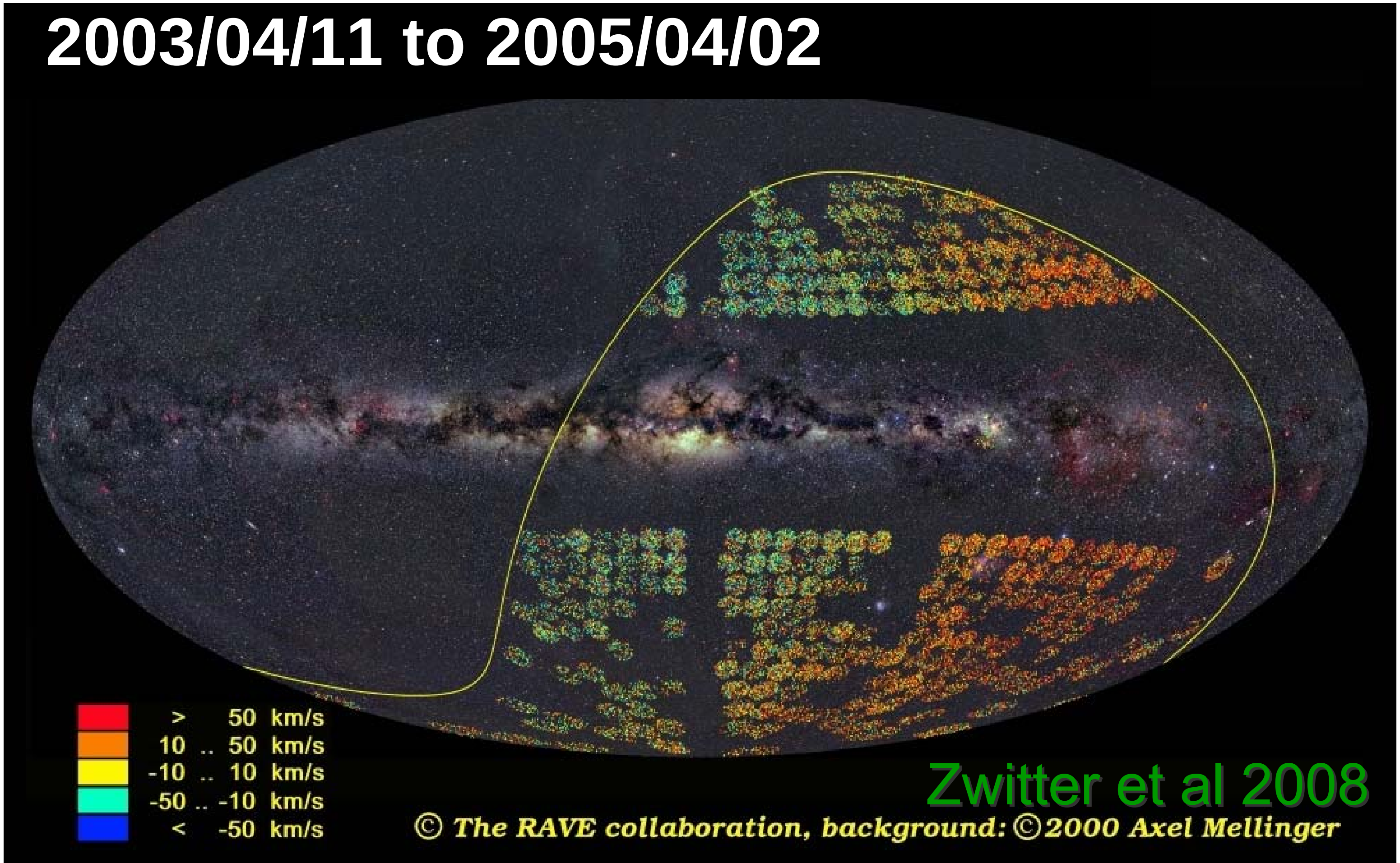
240 fields
5.7° diameter
1 hour exposures



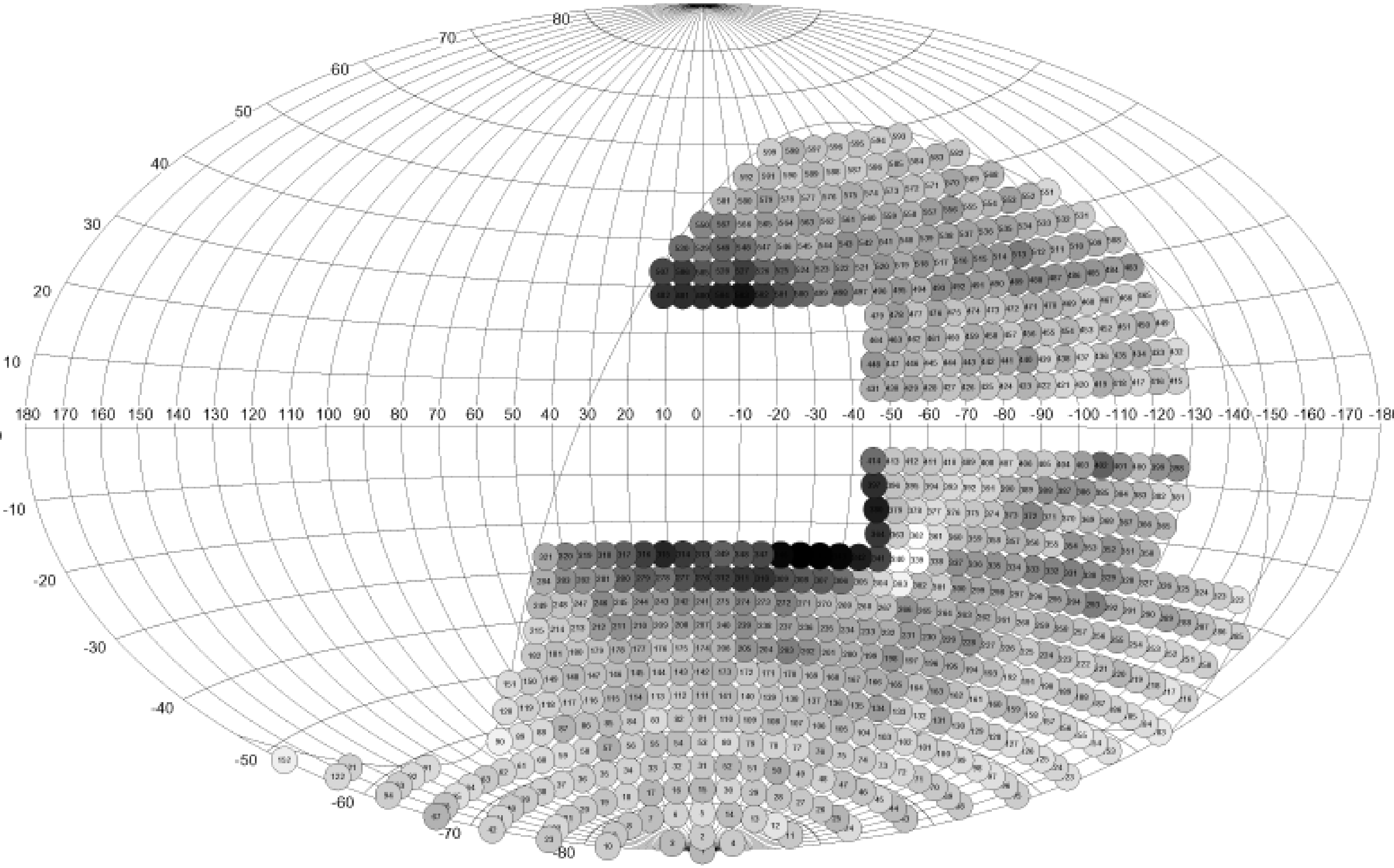
2nd Data Release

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

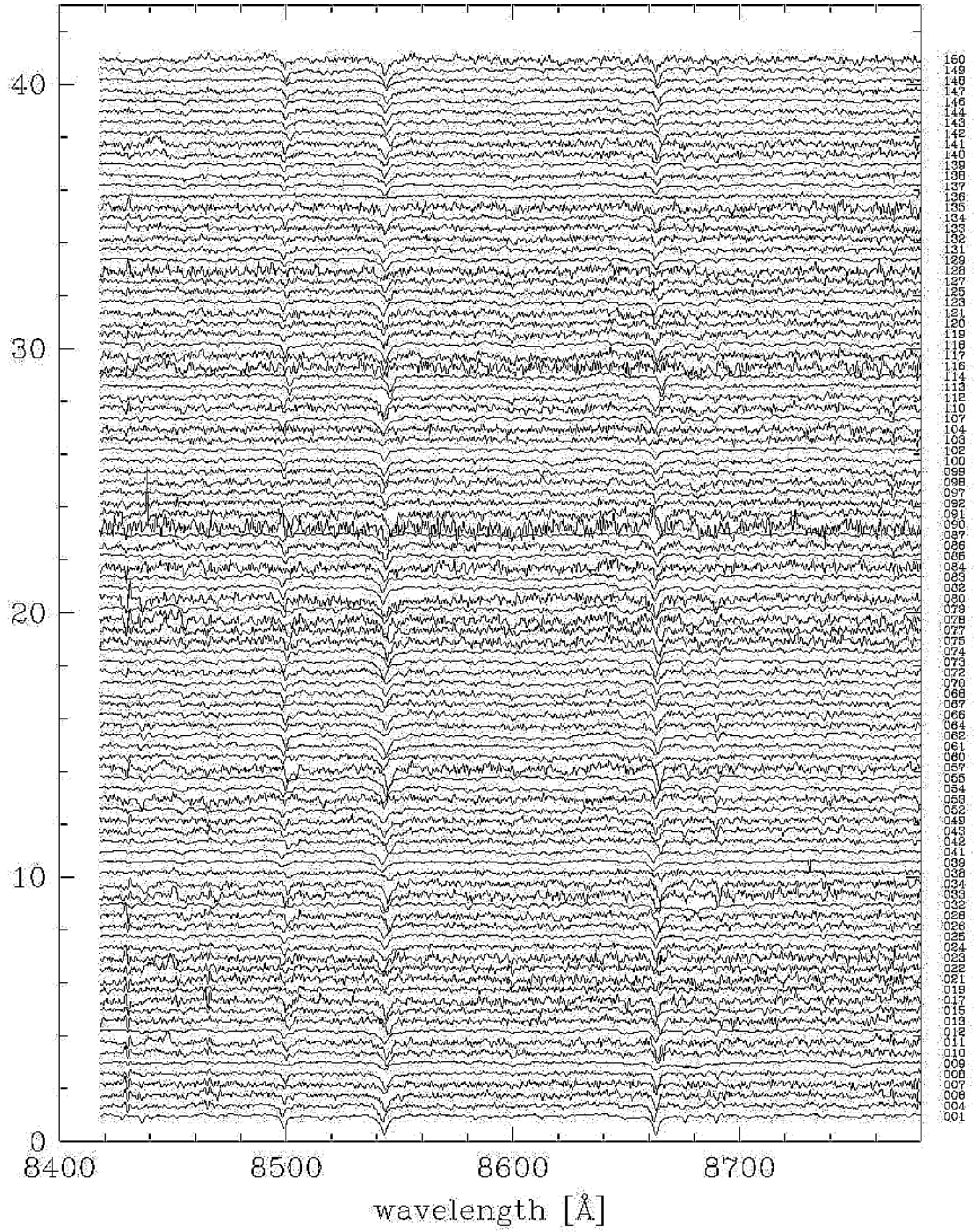
500 fields
5.7° diameter
22407 stellar par.



RAVE's progress



02/27/2008 : 350,000 spectra for 300,000 stars


40
30
20
10
0
8400
8500
8600
8700
wavelength [Å]

Repeats and Standards

- RAVEselect builds in a ~10% repeat rate

No. of times observed	No. of stars in database
1	215,511
2	24,796
3	3129
4	389
5	68
6	101
7	33

Data Product

Some numbers

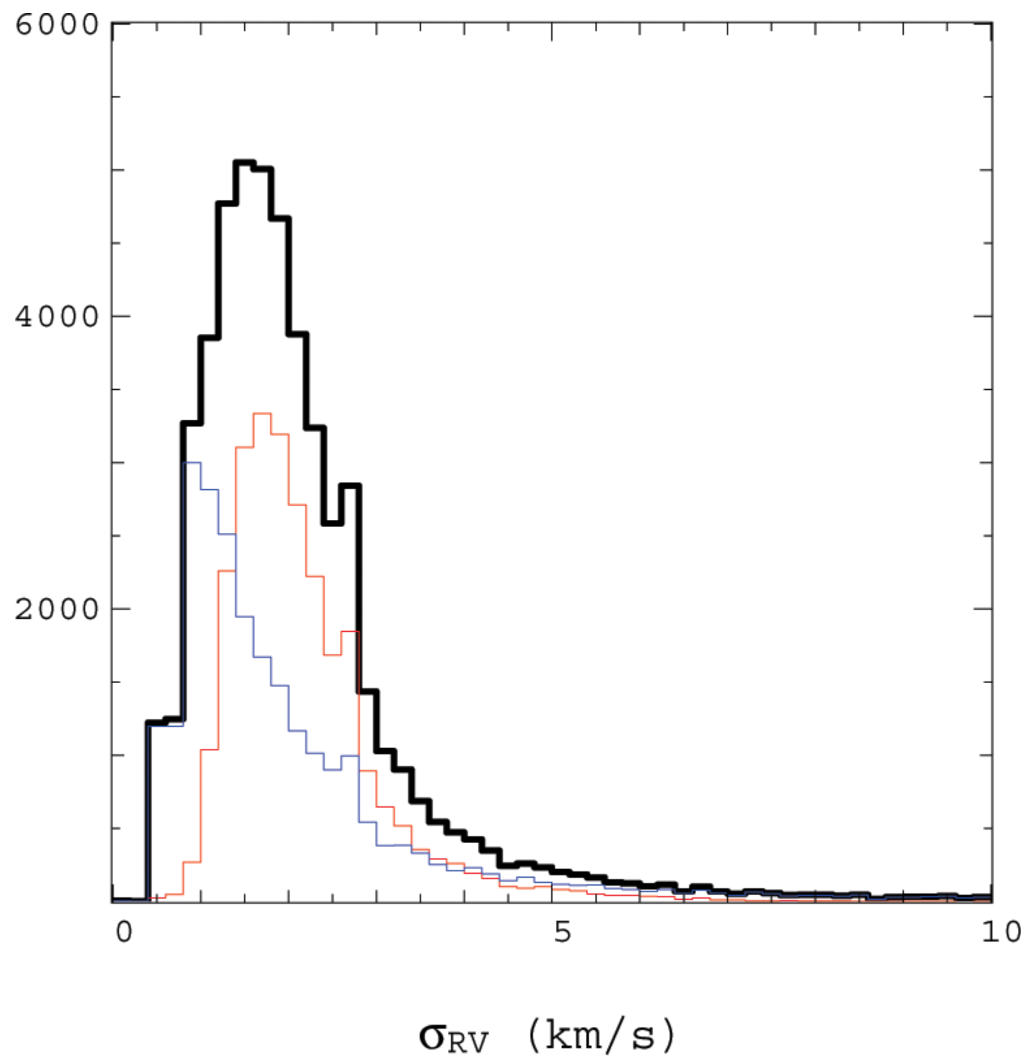
- DR1
  - 25,274 RVs
  - 24,748 individual objects
  - no parameters
- DR2
  - 51,829 RVs (+26,555)
  - 49,327 individual objects (+24,579)
  - 22,407 parameters for 21,121 unique objects
- DR3
  - 87,612 RVs (+35,783)
  - 78,903 individual objects (+29,576)
  - 55,290 parameters for 51,984 unique objects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

DR2 Internal errors:

DR1
Mean : 2.3km/s
Median : 1.9km/s
Peak : 1.7km/s

DR2-DR1
Mean : 2.2km/s
Median : 1.5km/s
Peak : 0.9km/s

DR2
Mean : 2.2km/s
Median : 1.8km/s
Peak : 1.5km/s



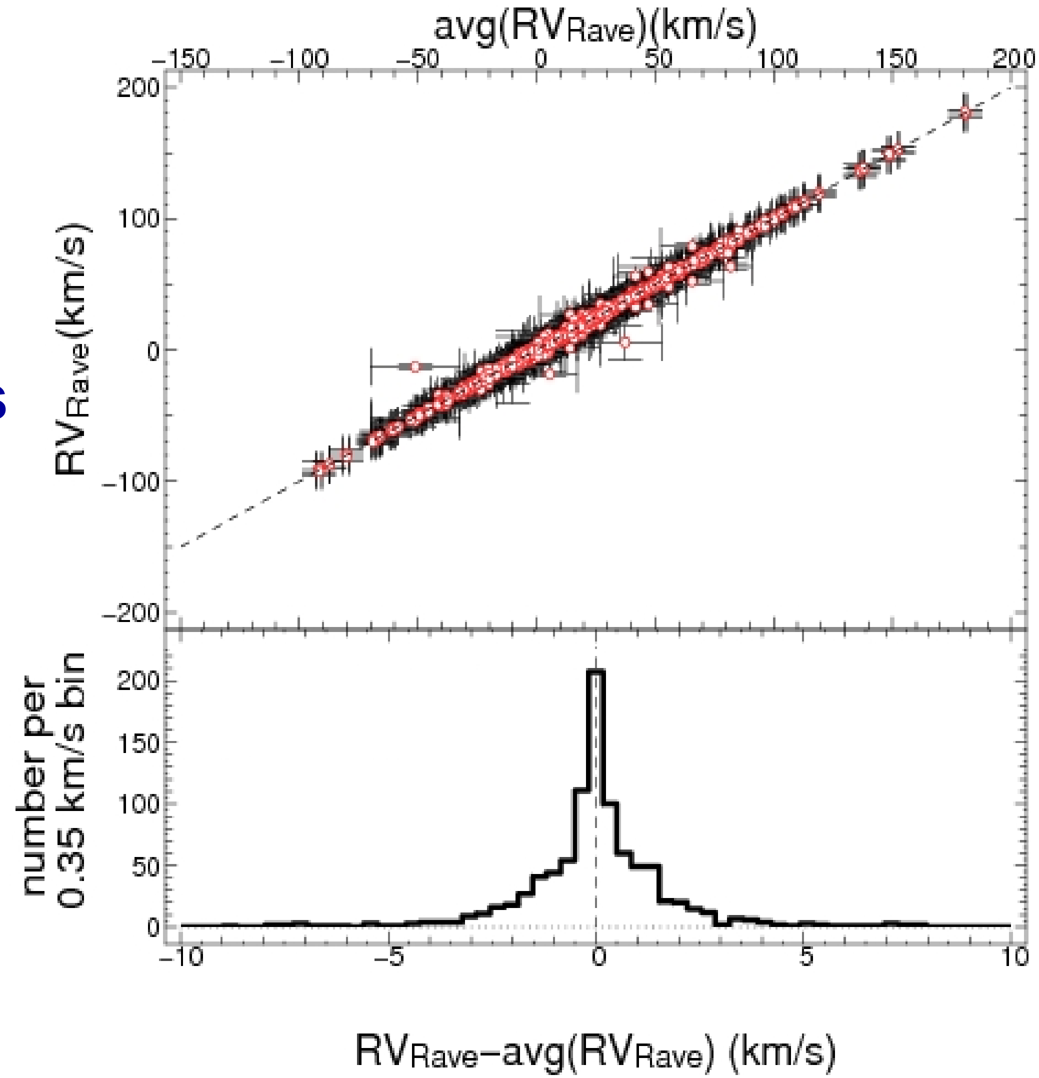
Zwitter et al., 2008

Stability of Radial Velocities

Based on 840 re-observed targets:

mean diff=-0.02 km/s
rms=2.83 km/s

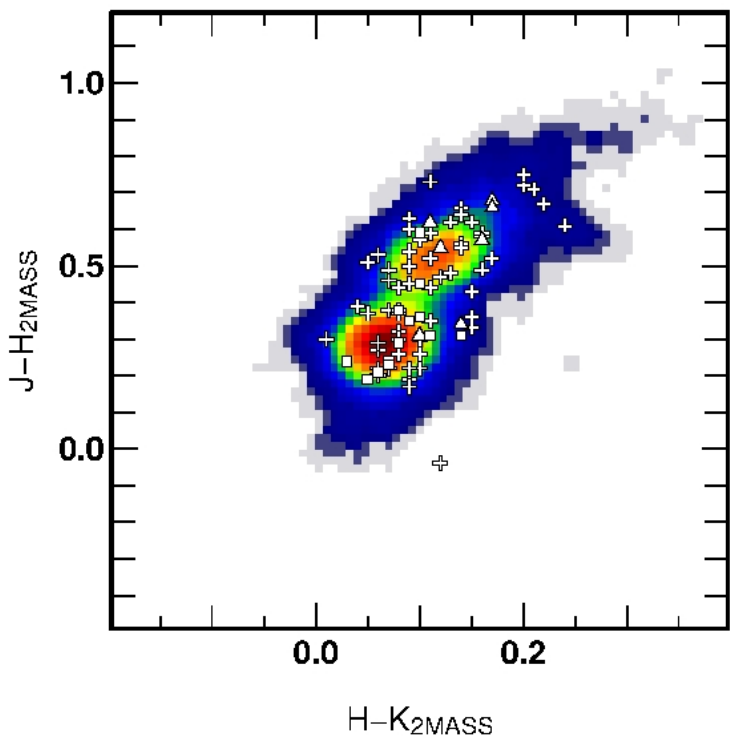
Good stability of solution with time

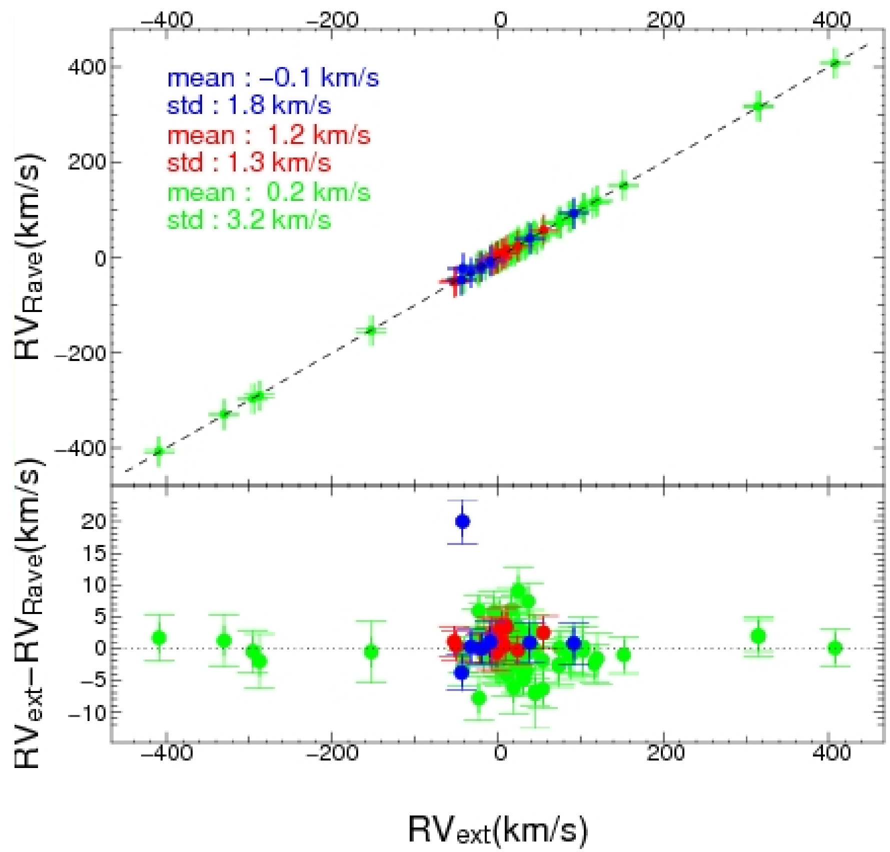


Steinmetz et al., 2006

Comparison to “Standards”

3 external sources:
- **Elodie (high resolution)**
- **2.3m (long slit, medium resolution)**
- **Geneva-Copenhagen (CORAVEL)**

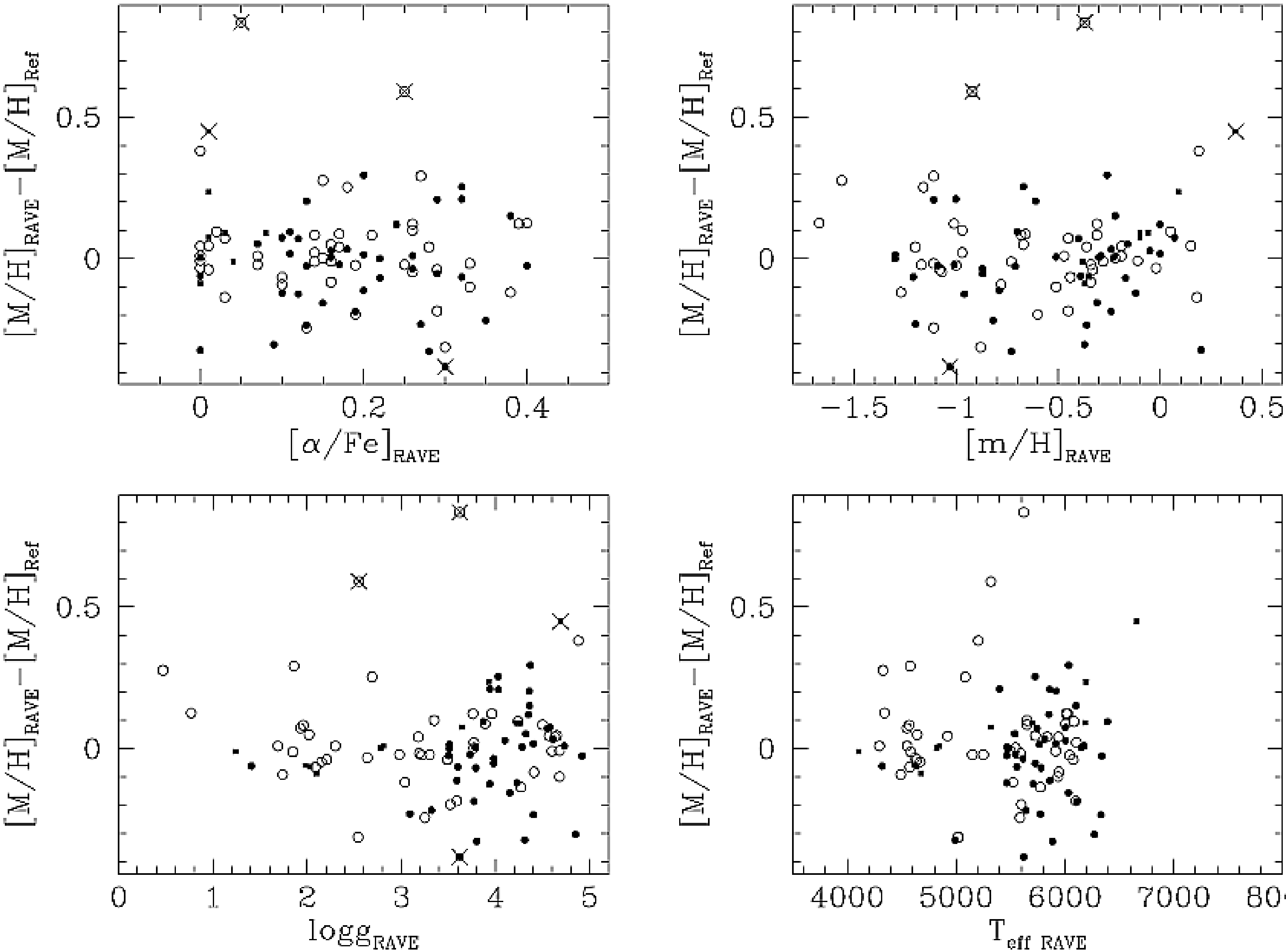




Steinmetz et al., 2006

Metallicity by template fitting (DR2)

Zwitter et al., 2008



Survey Design

Besides the CaII triplet:

Calcium triplet region contains a wealth of chemical information (need for good resolution to measure some of those lines)

	K0 III	A7 IV
HI		5
CI	1	1
NI		11
MgI	11	7
SiI	23	14
SI	5	14
CaI	2	
CaII	3	3
TiI	18	
CrI	7	
MnI	7	
FeI	60	19
FeII		3
CoI	3	
NiI	4	

Gibson (2003)

Also gravity and metallicity tracers

Abundances

RAVE spectral range contains information on various chemical elements

BUT

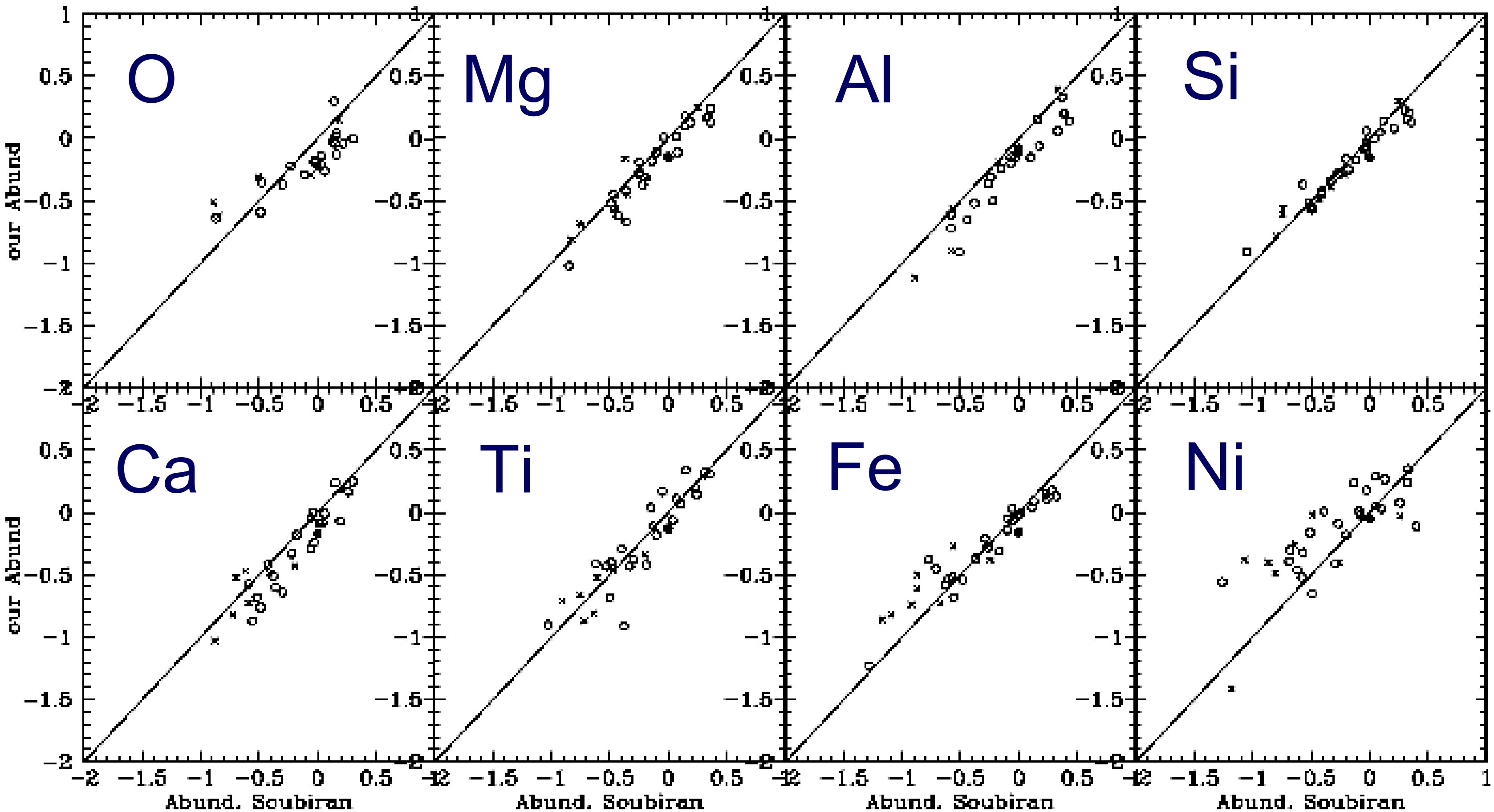
- low signal to noise (SNR~20)
- low spectral resolution (R~7500)

⇒ 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



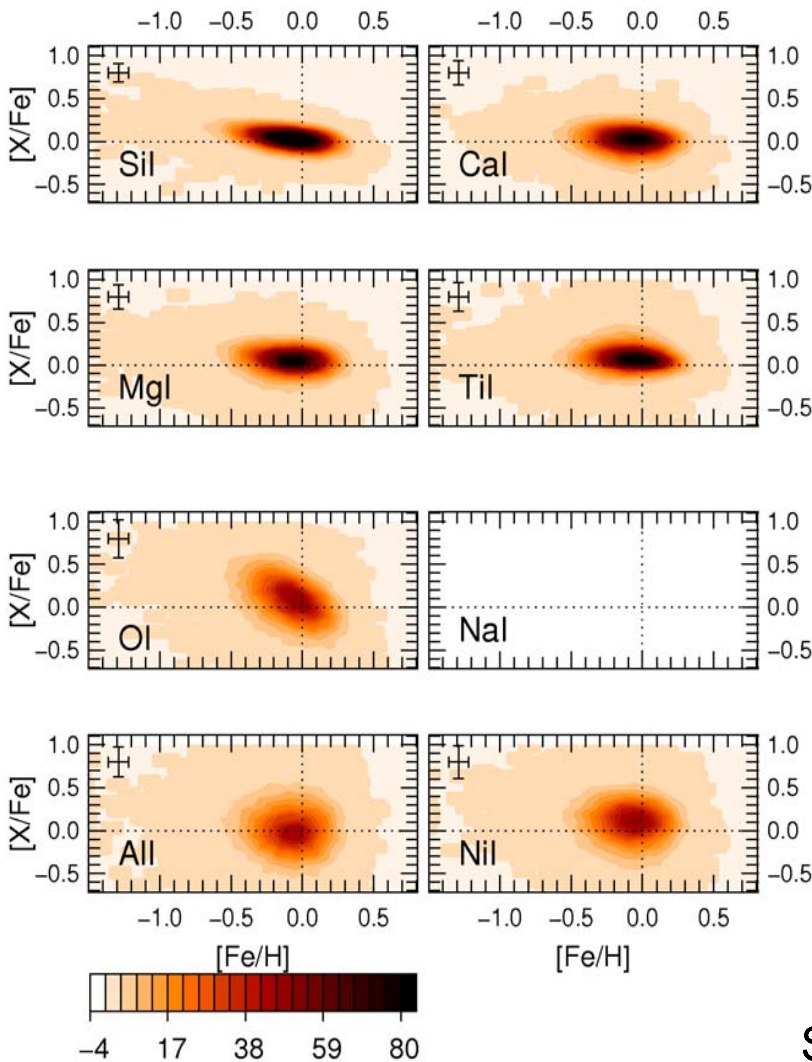
Asplund et al. (2005) solar abundances

- o spectra with S/N>=100
- x spectra with S/N<100
- ▪ Moon spectrum

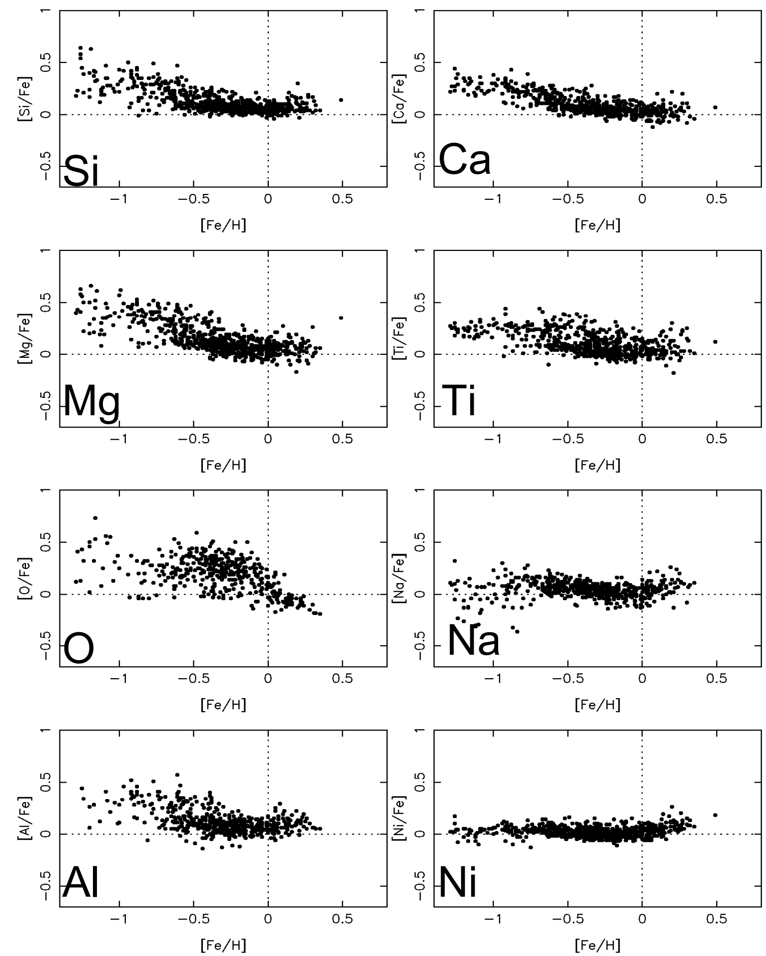
Comparison to Soubiran & Girard

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

32841 RAVE stars

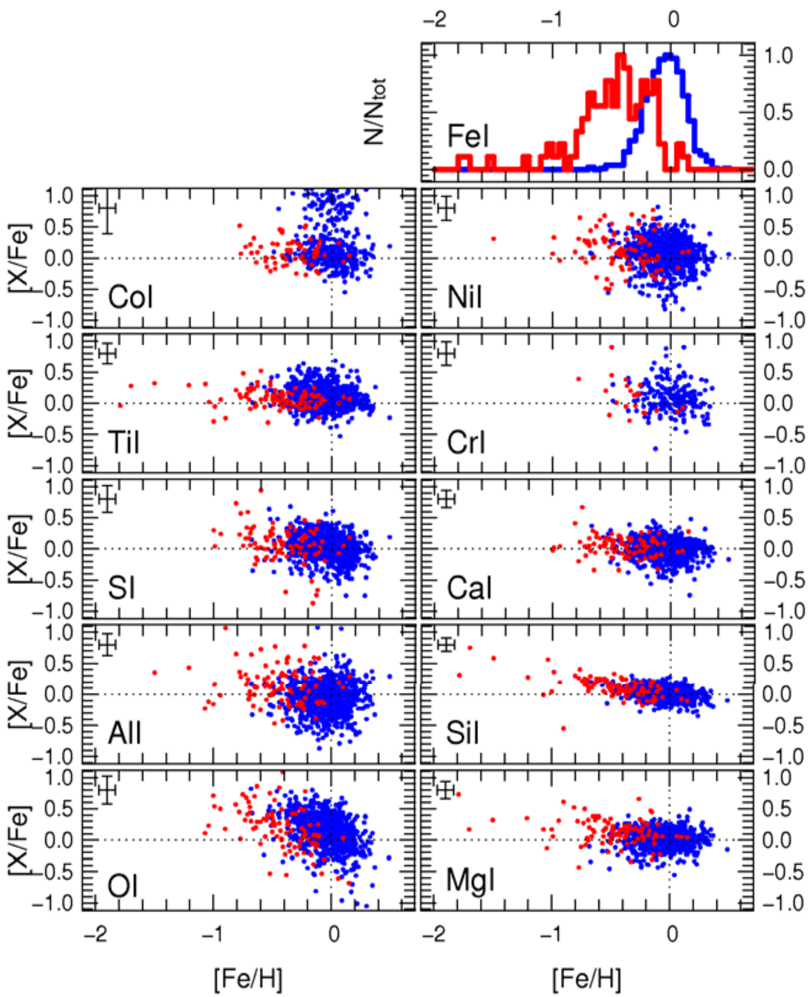


743 stars by Soubiran & Girard



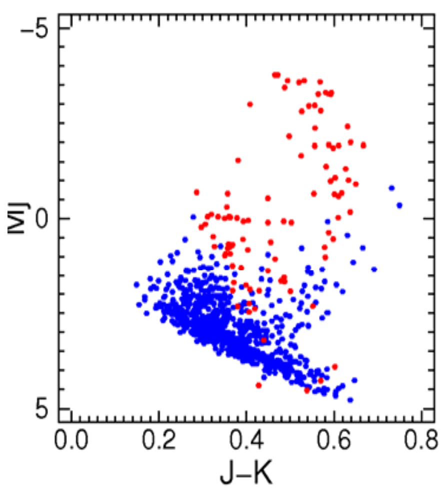
Soubiran & Girard, 2005, A&A, 438, 139

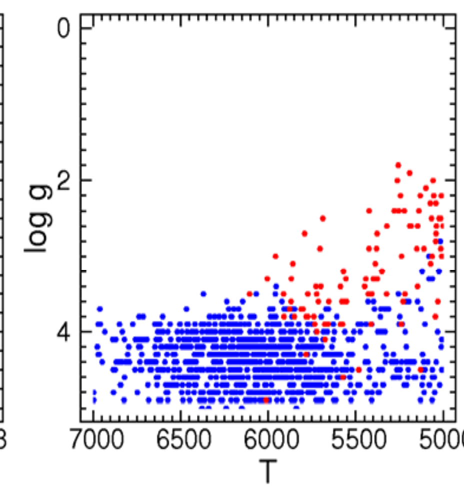
RAVE abundances:thin and thick disk stars (Boeche et al 08)



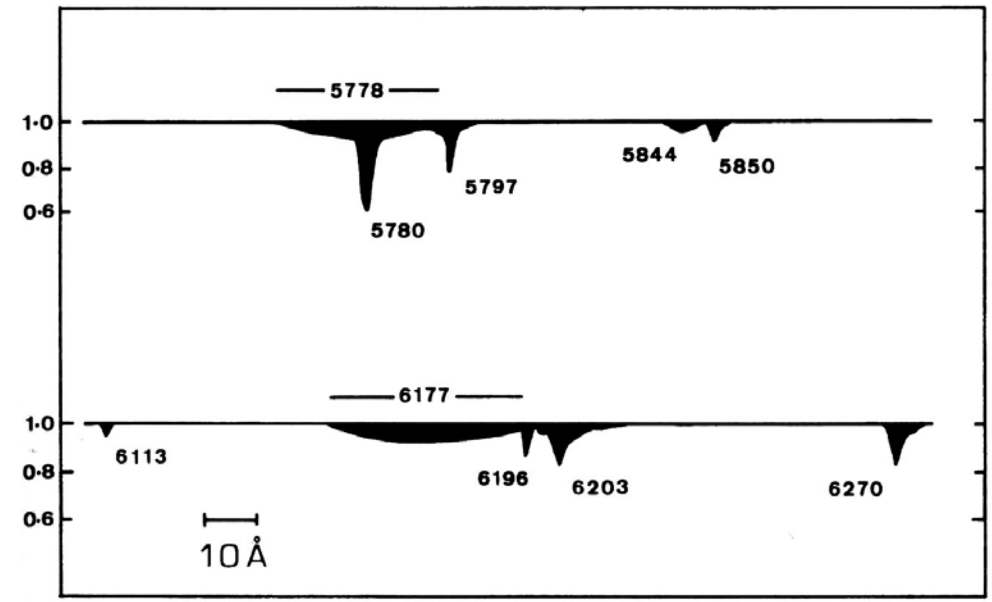
out of 4421 stars, we select:

908 thin disk stars	97 thick disk stars
abs(V)<20 km/sec, abs(W)<16 km/sec, abs(zGal)<0.3 Kpc	V<-100 km/sec, abs(W)>50 km/sec,





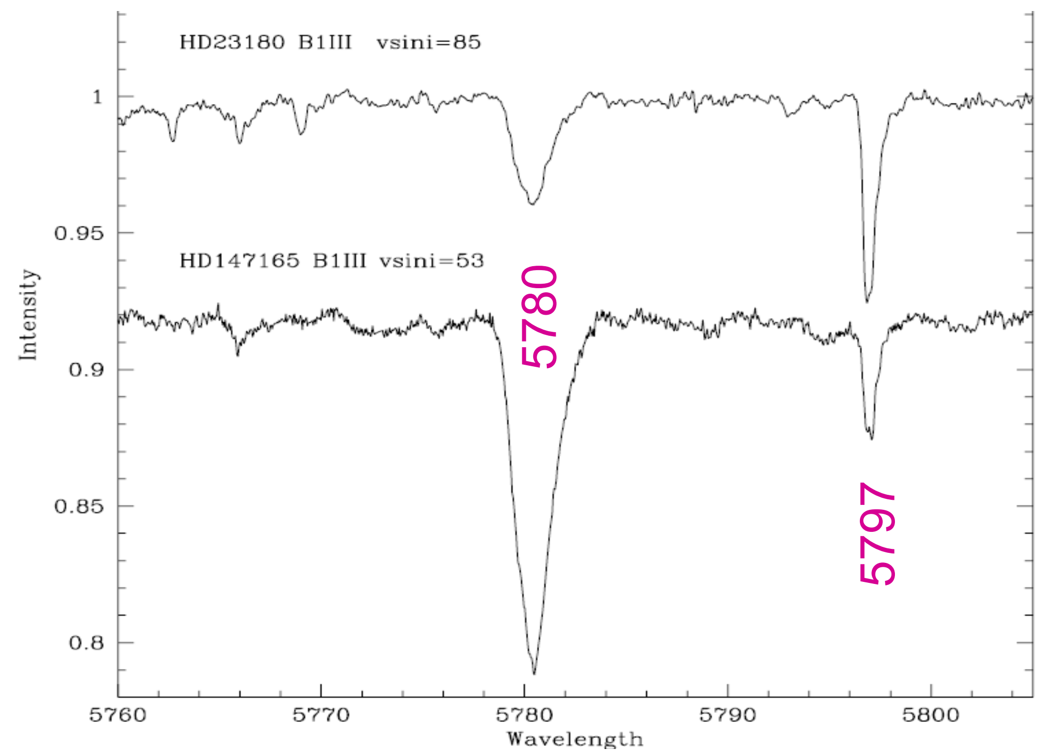
discovered in 1922 as stationary lines in spectra of eclipsing binaries



≥200 DIBs known over the optical range

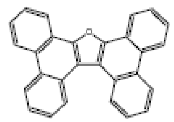
large differences in shapes

and in relative intensity



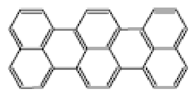
86 years after discovery, the carriers of DIBS are still unknown: the longest living mistery of astronomical spectroscopy

do they originate in the solid or gaseous ISM phase ?



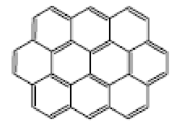
Dinphenanthro (9,10-b;9'-10'-d) furan

$C_{28}H_{16}O$



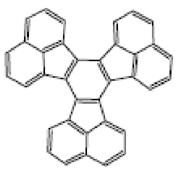
Terrylene

$C_{30}H_{16}$



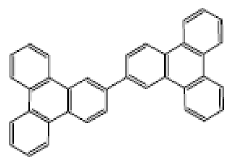
Ovalene

$C_{32}H_{14}$



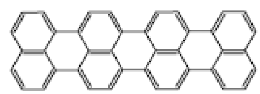
Decacylene

$C_{36}H_{18}$



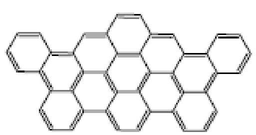
2,2'-Bis-triphenylyl

$C_{36}H_{22}$



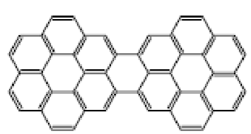
Quaterrylene

$C_{40}H_{20}$



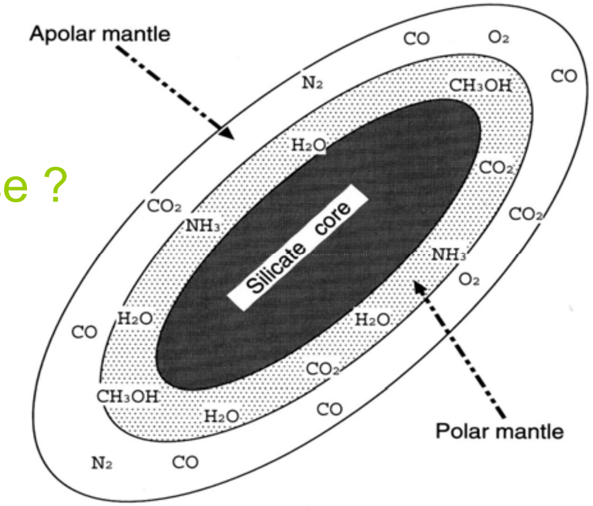
Hexabenzo (a,cd,fgh,jk,m,qrs) peropyrene

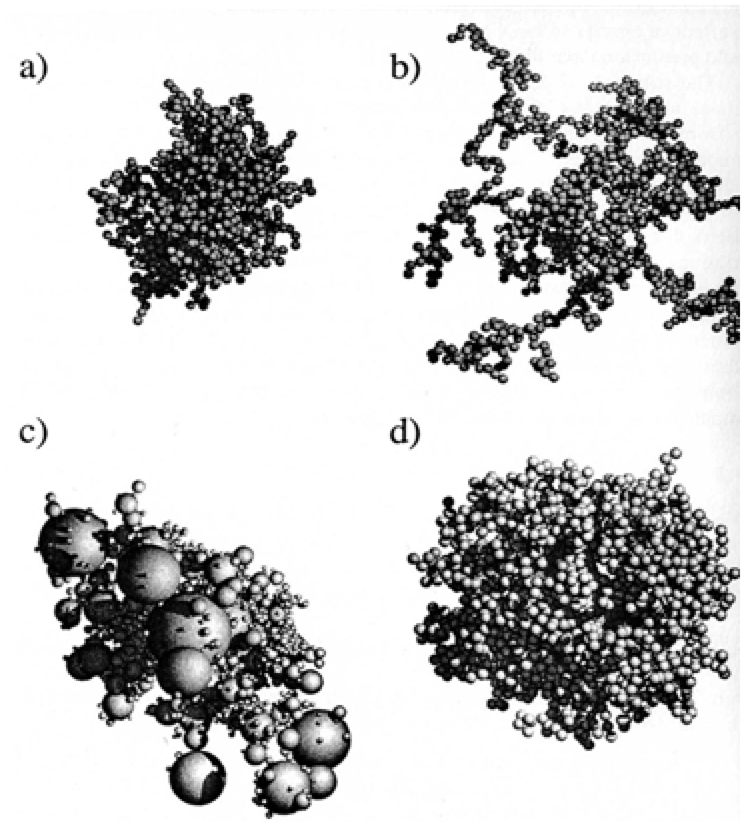
$C_{44}H_{20}$



Dicoronylene

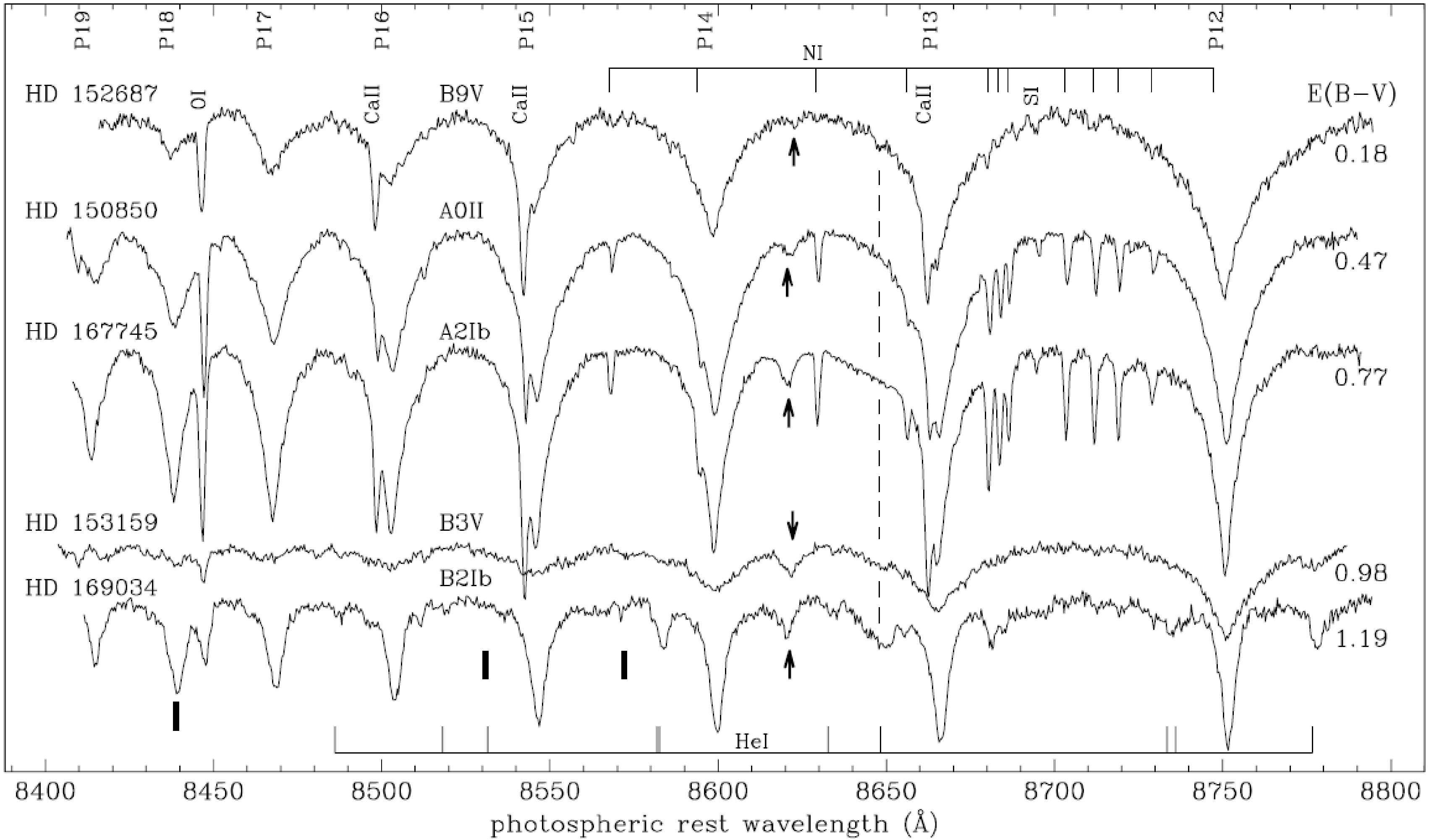
$C_{48}H_{20}$

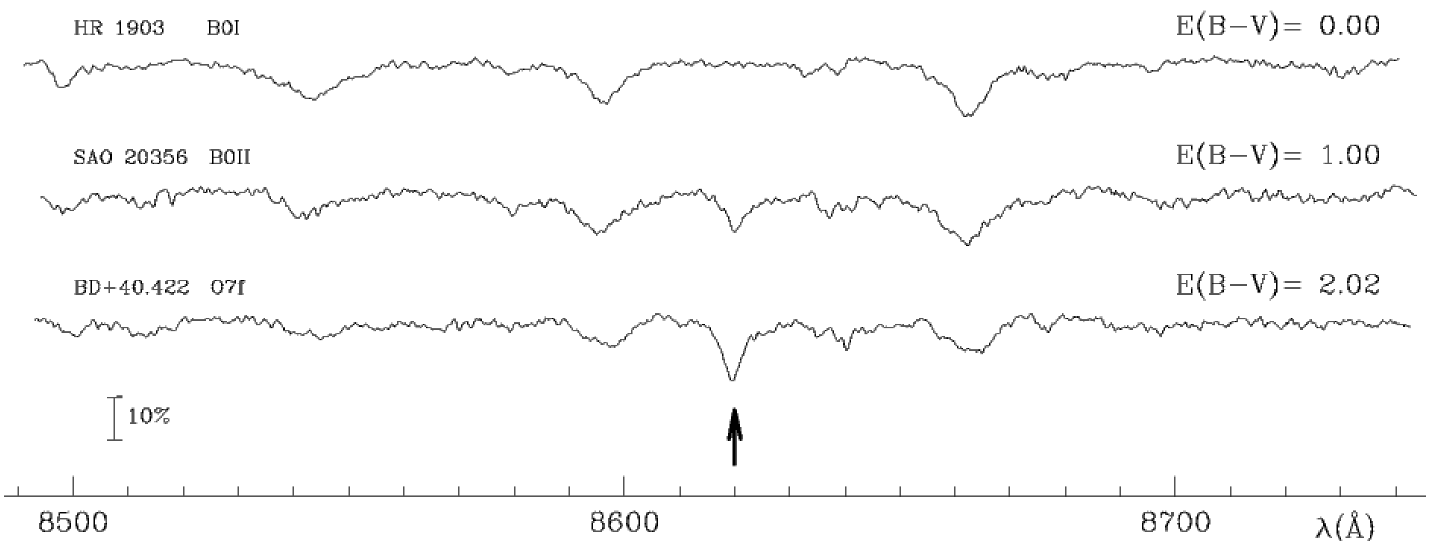


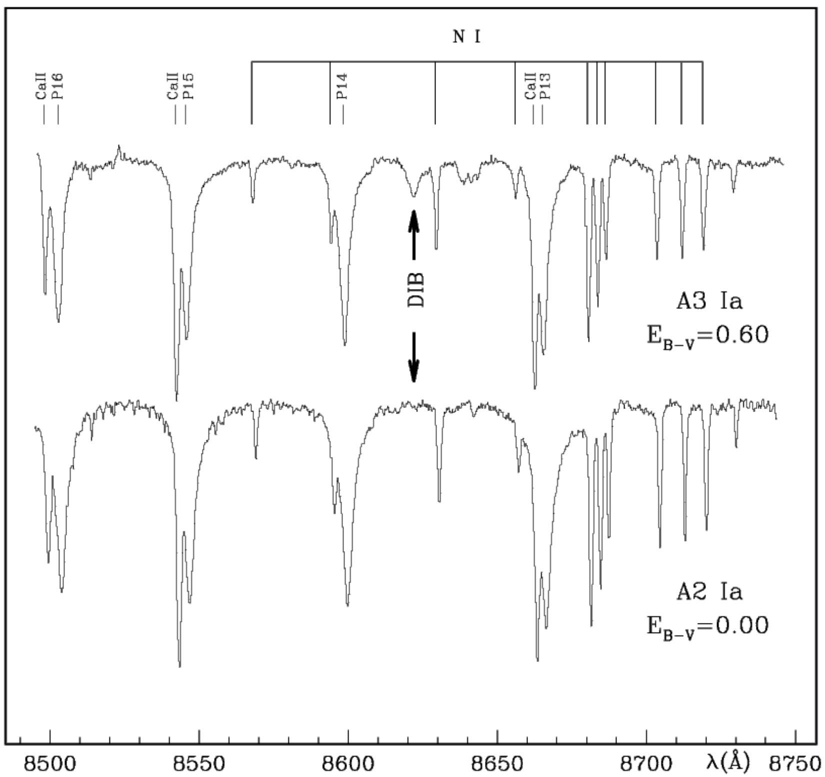


Feb 27 2009 Construction and Evolution of the Galaxy

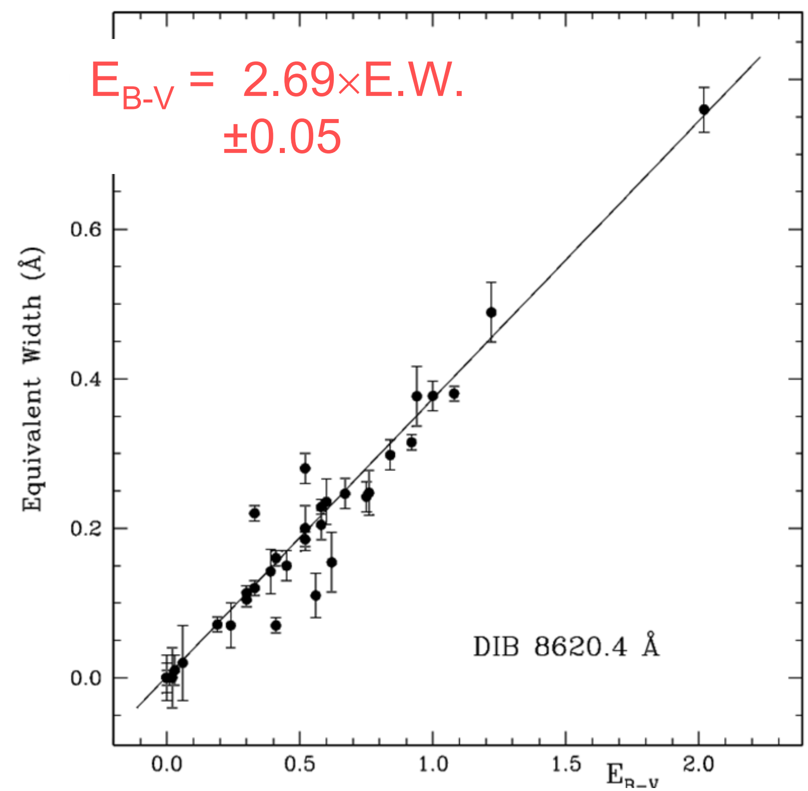
Extinction measurement with DIBs



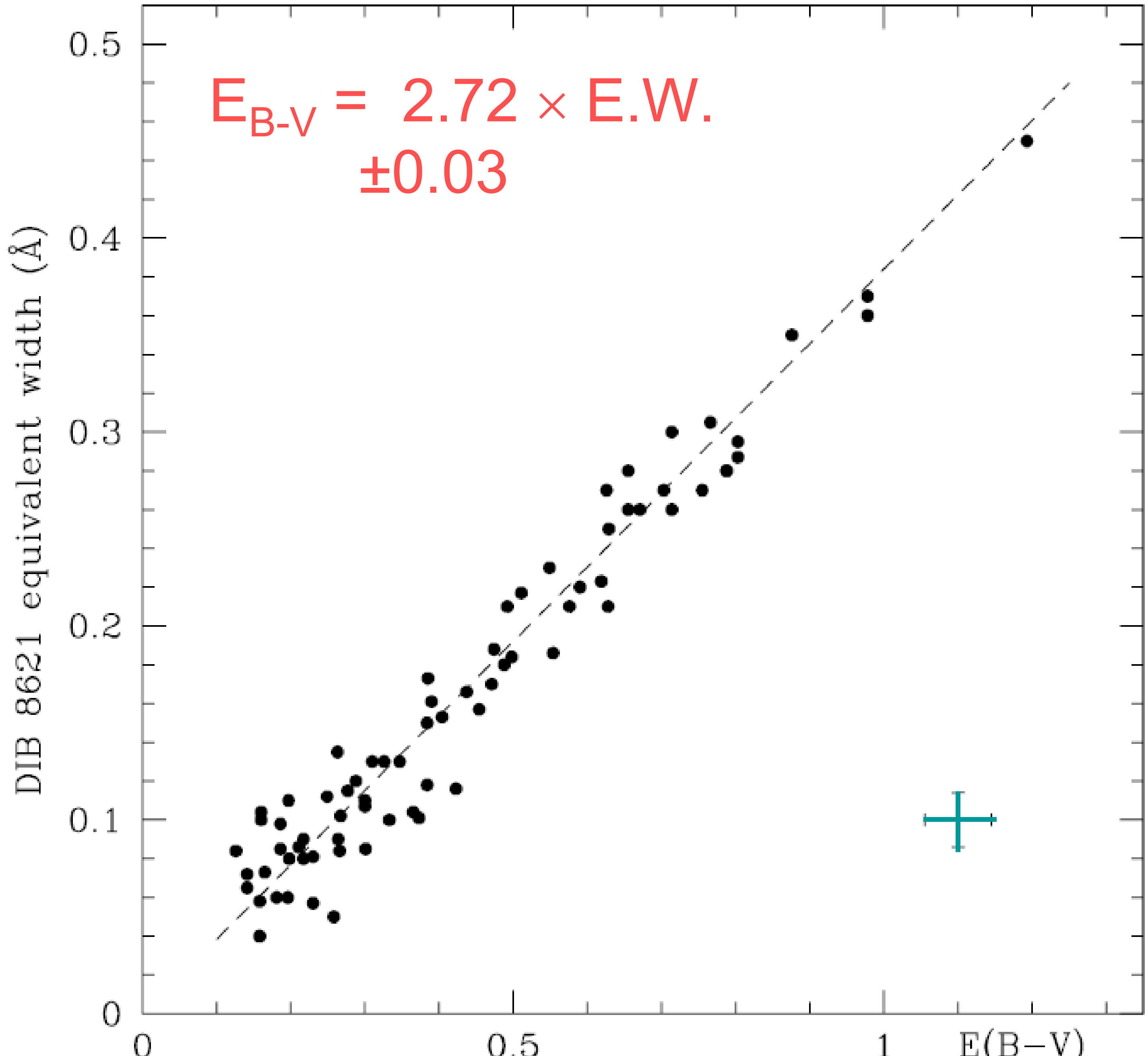




$E_{B-V} = 2.69 \times E.W. \pm 0.05$



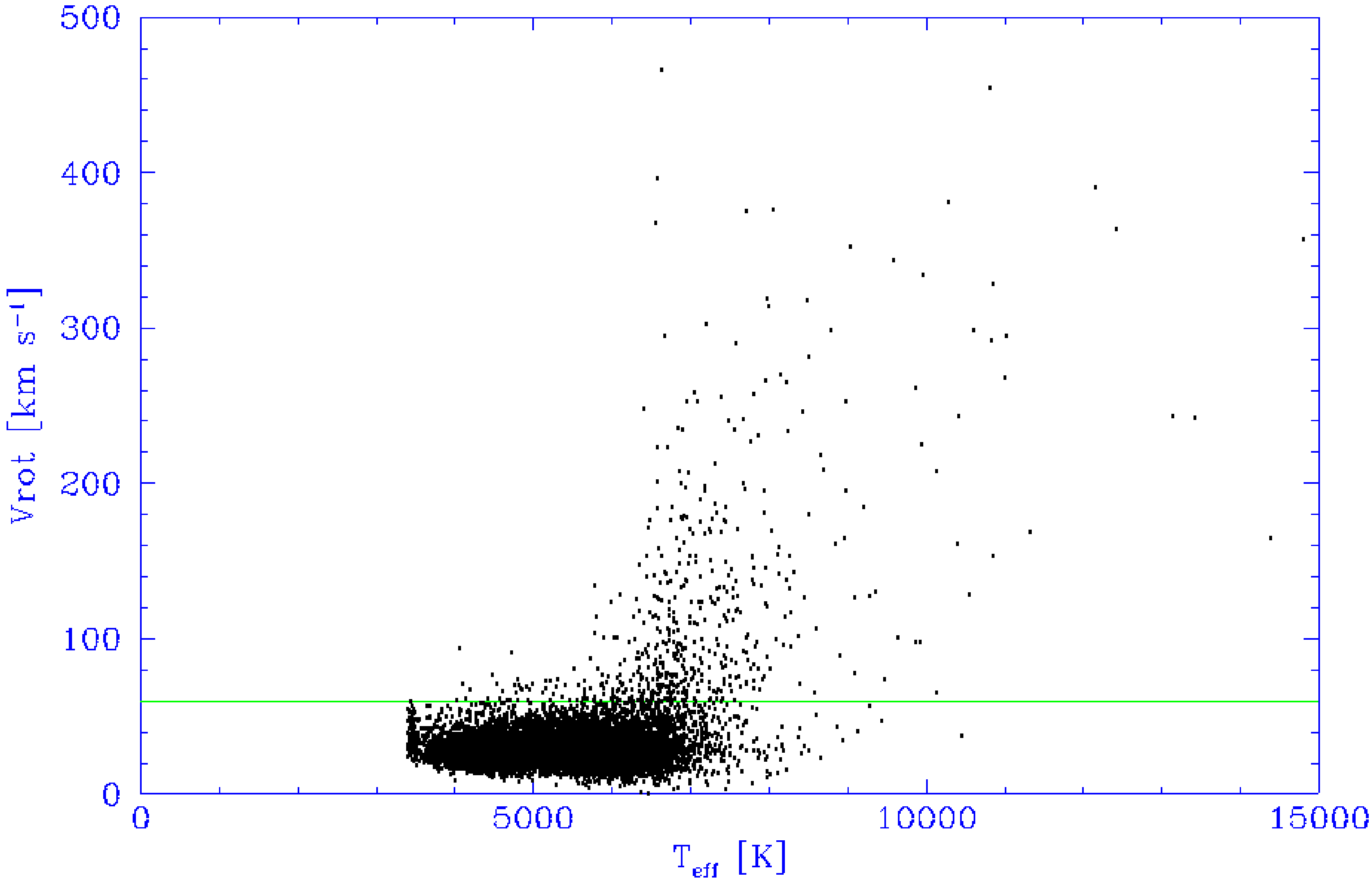
Munari (2000)



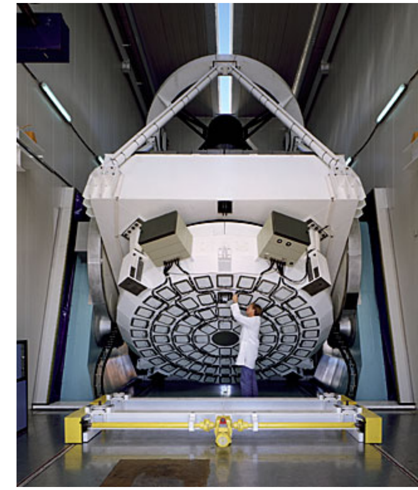
$E_{B-V} = 2.72 \times E.W.$
±0.03
DIB 8621 equivalent width (Å)
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
E(B−V)

Fast Rotators: 547 stars in DR2

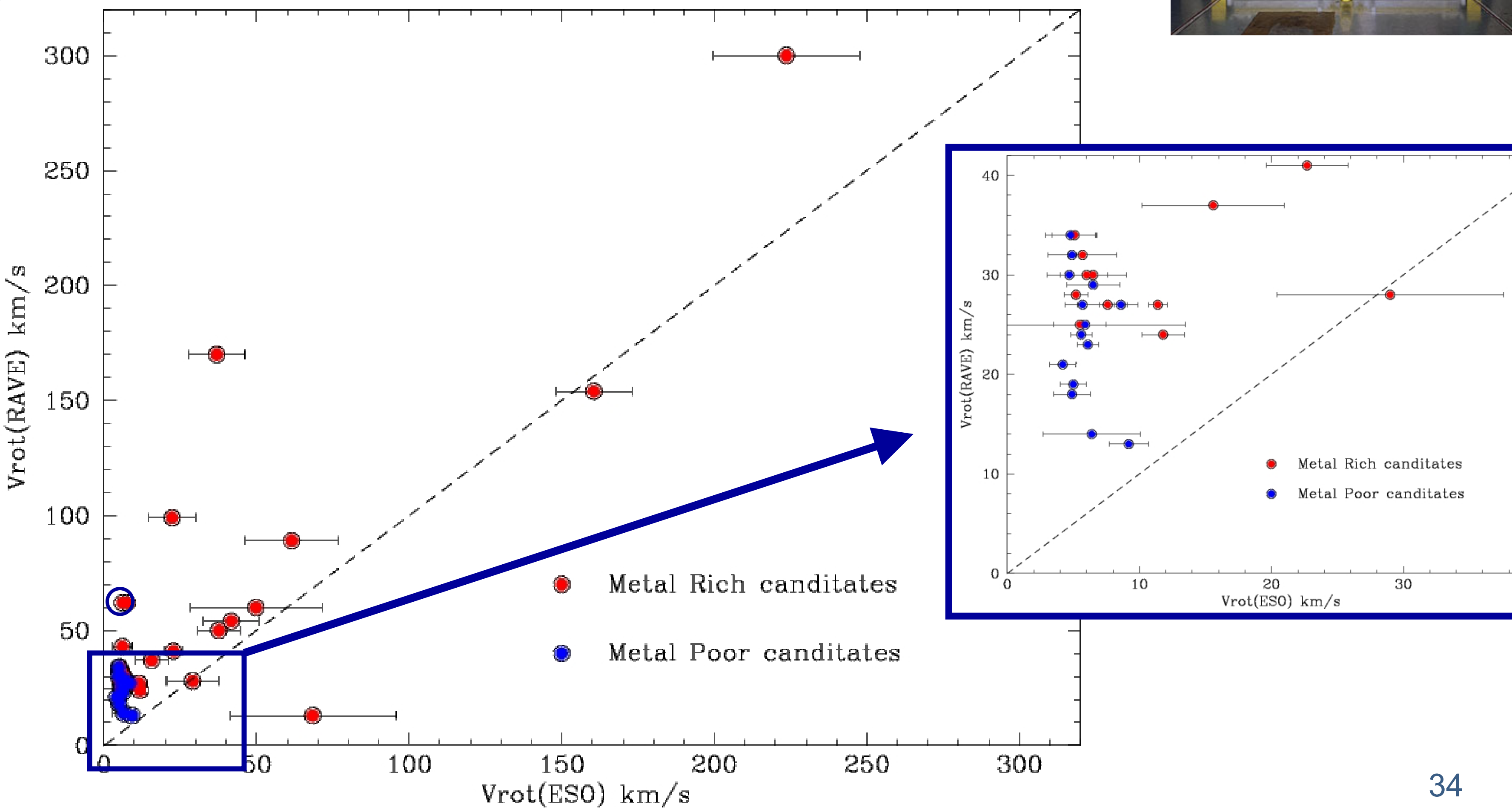
Tomaz Zwitter, Ljubljana



RAVE versus ESO, preliminary comparison



Rotational velocities



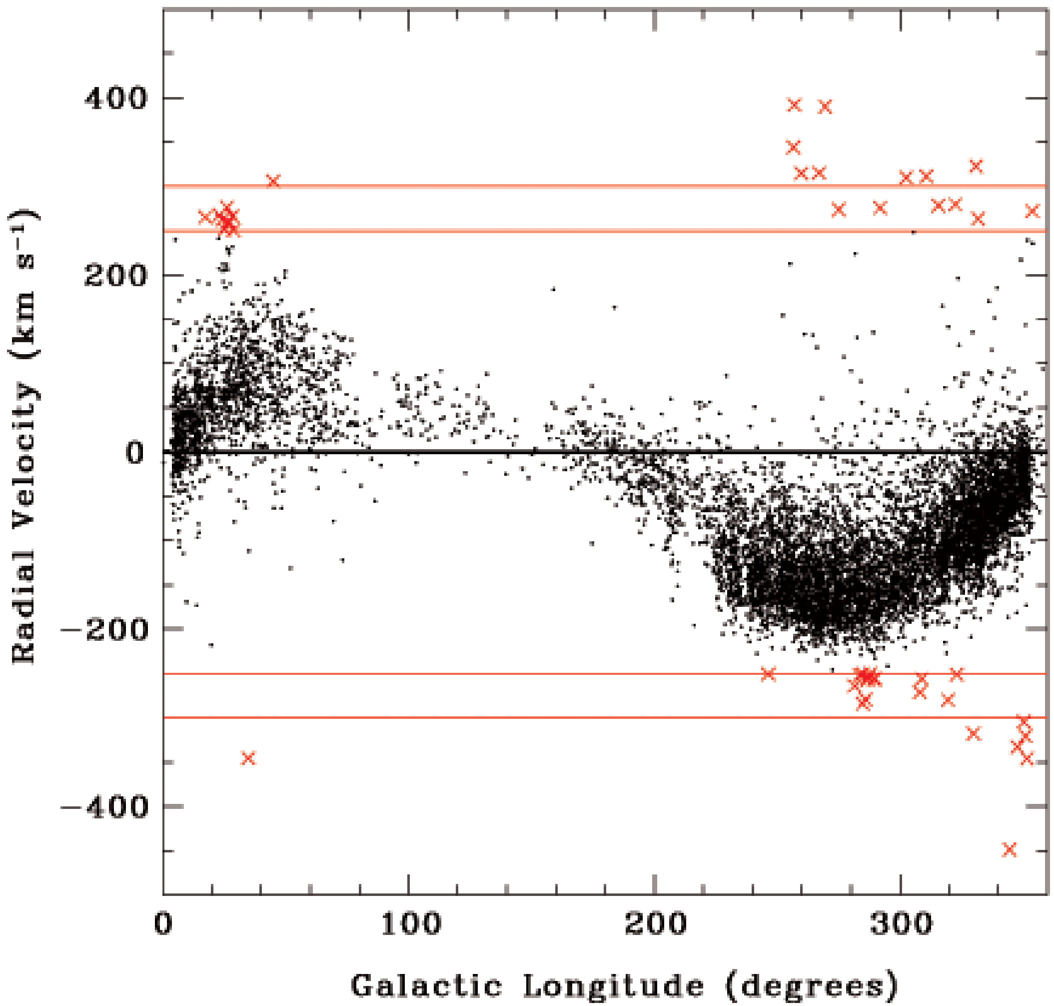
AIP

RAVE
RADIAL VELOCITY EXPERIMENT

Scientific Results

The Escape Speed of the Milky-Way

Smith, Rutchi et al 2007



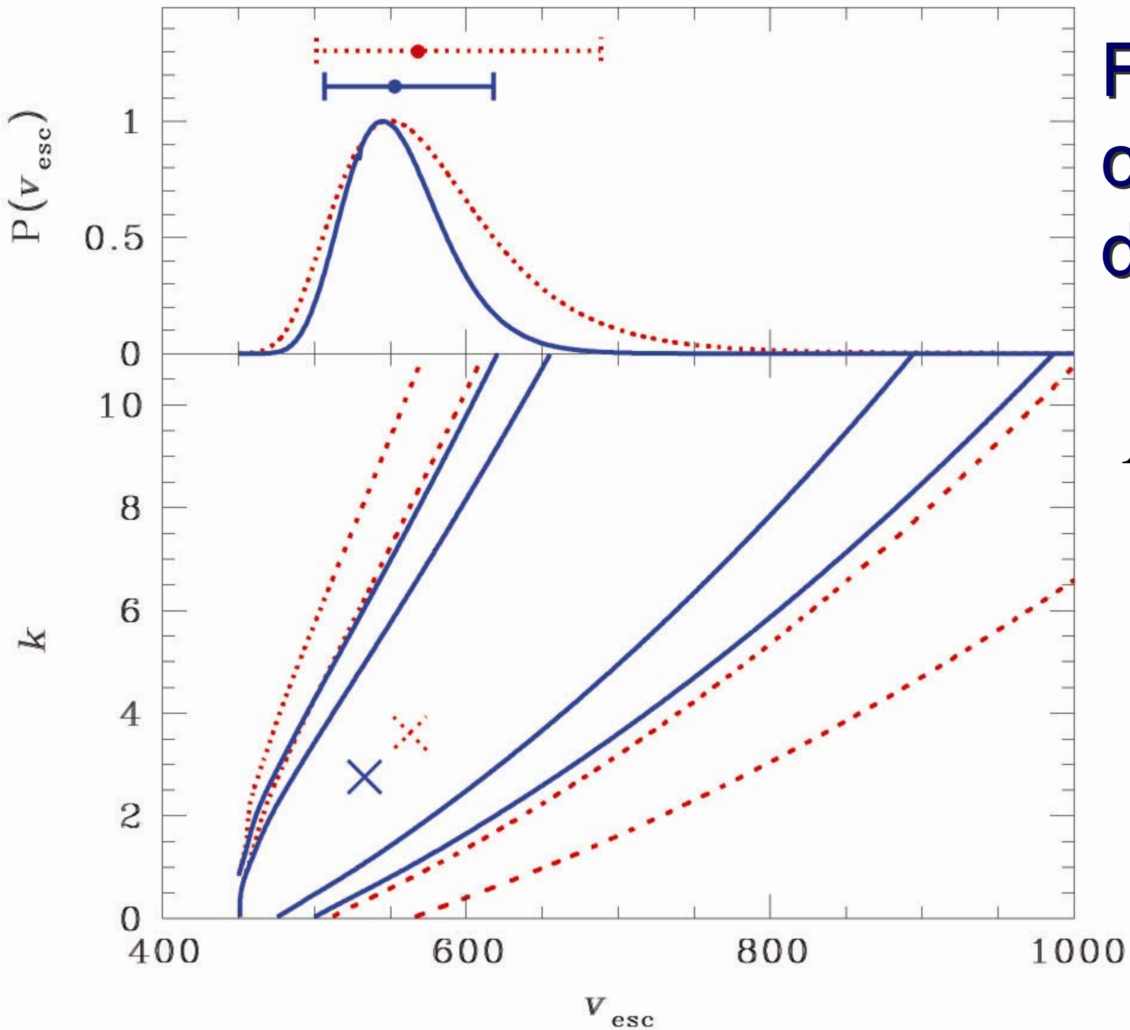
Leonard & Tremaine (1990):

near escape velocity:

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

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

The Escape Velocity of the Milky-Way



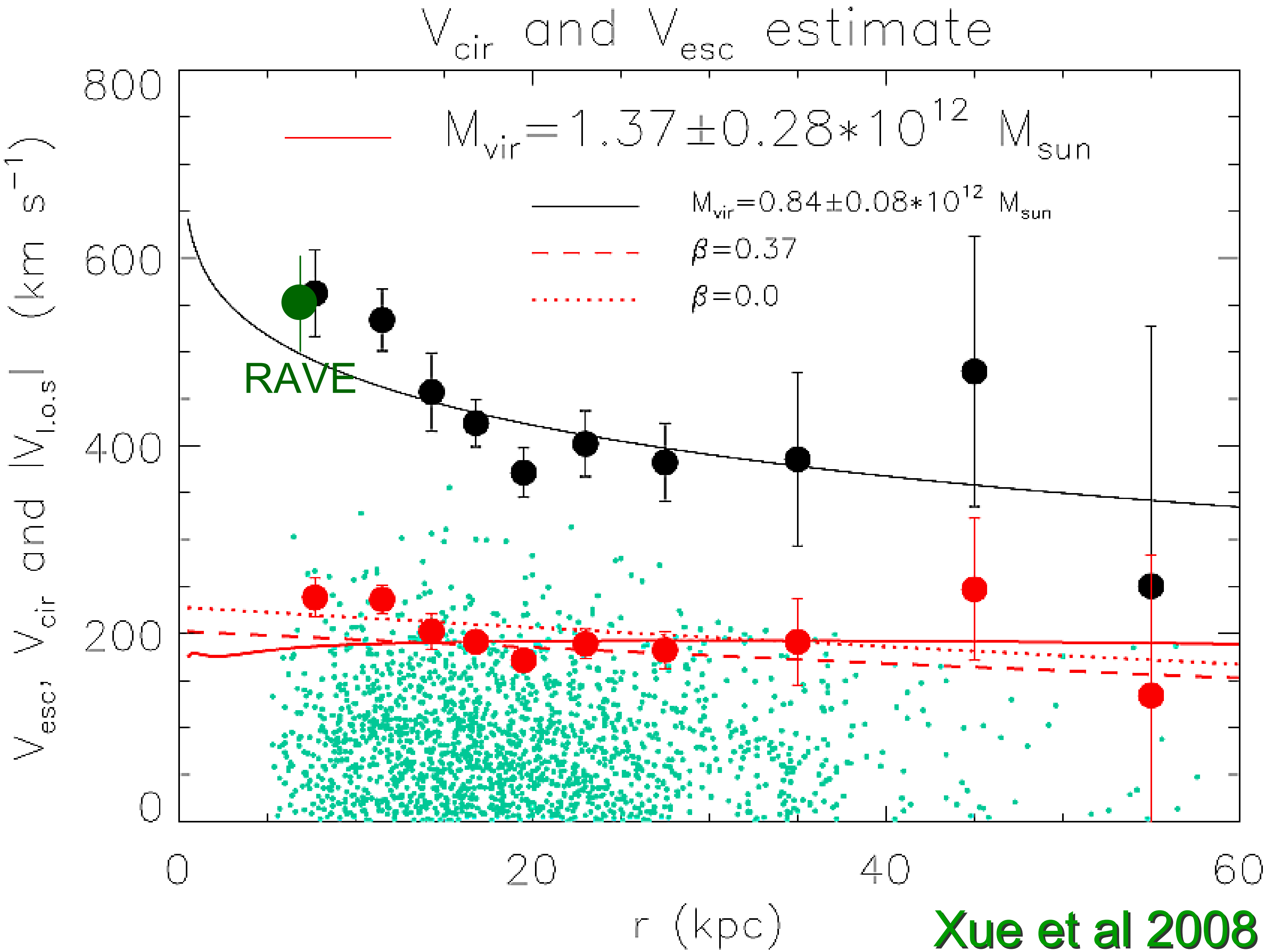
For an adiabatically contracted NFW dark halo:

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

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

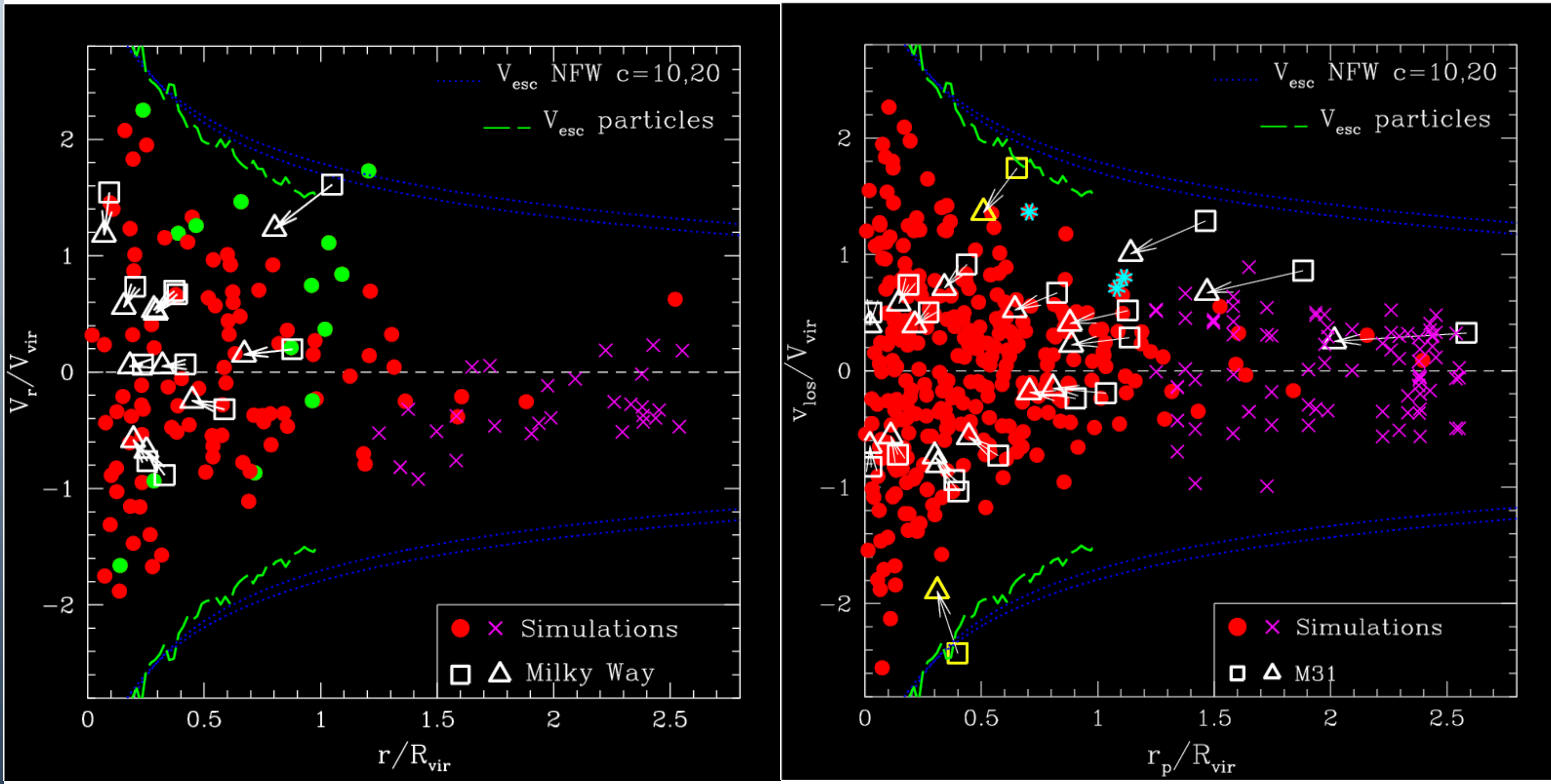
Smith et al 2007

V_{circ} and V_{esc} from SDSS



Xue et al 2008

Estimating v_{vir} via satellites



MW

M31

Construction and Evolution of the Galaxy

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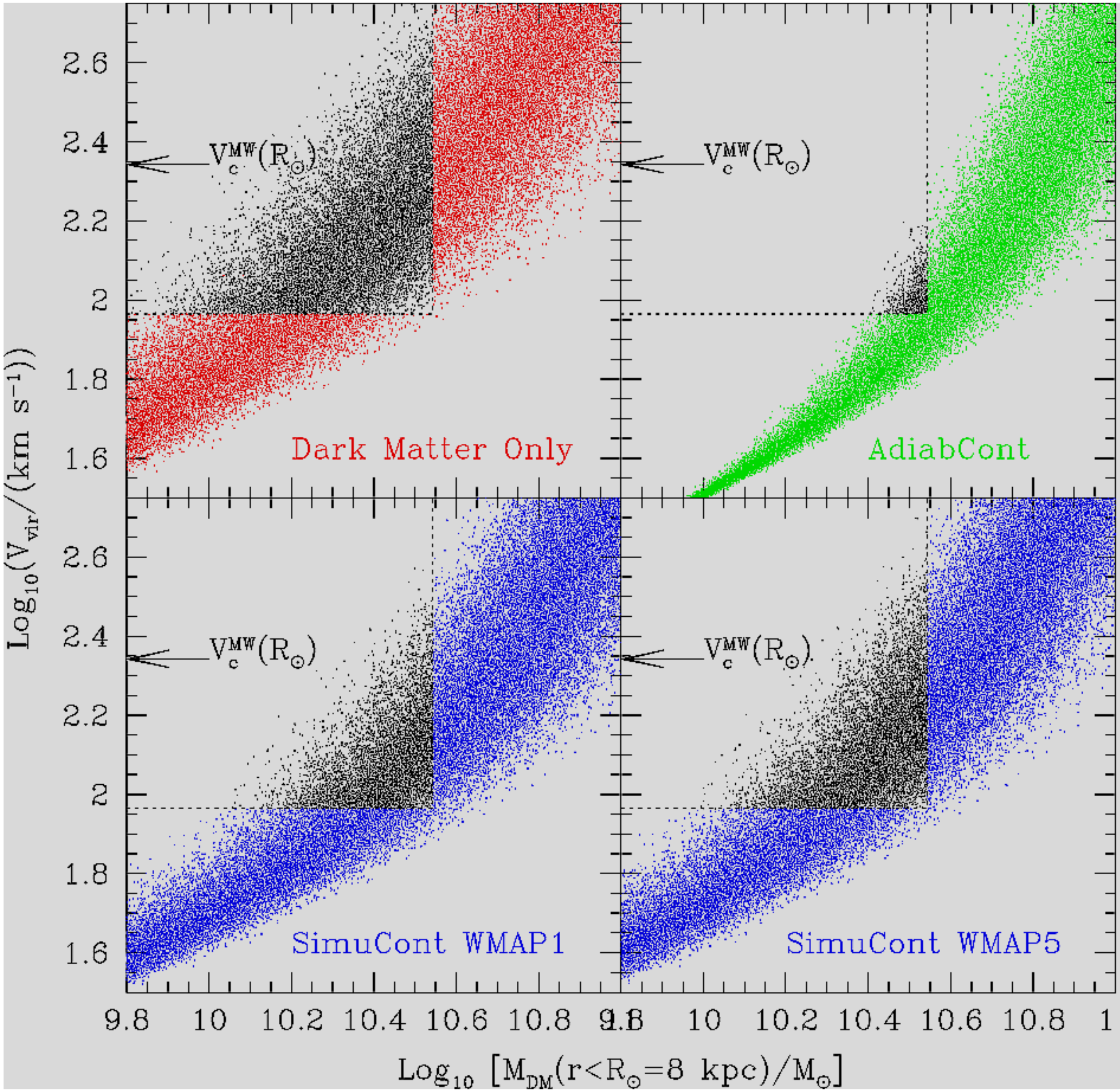
Mass of the MW dark matter halo

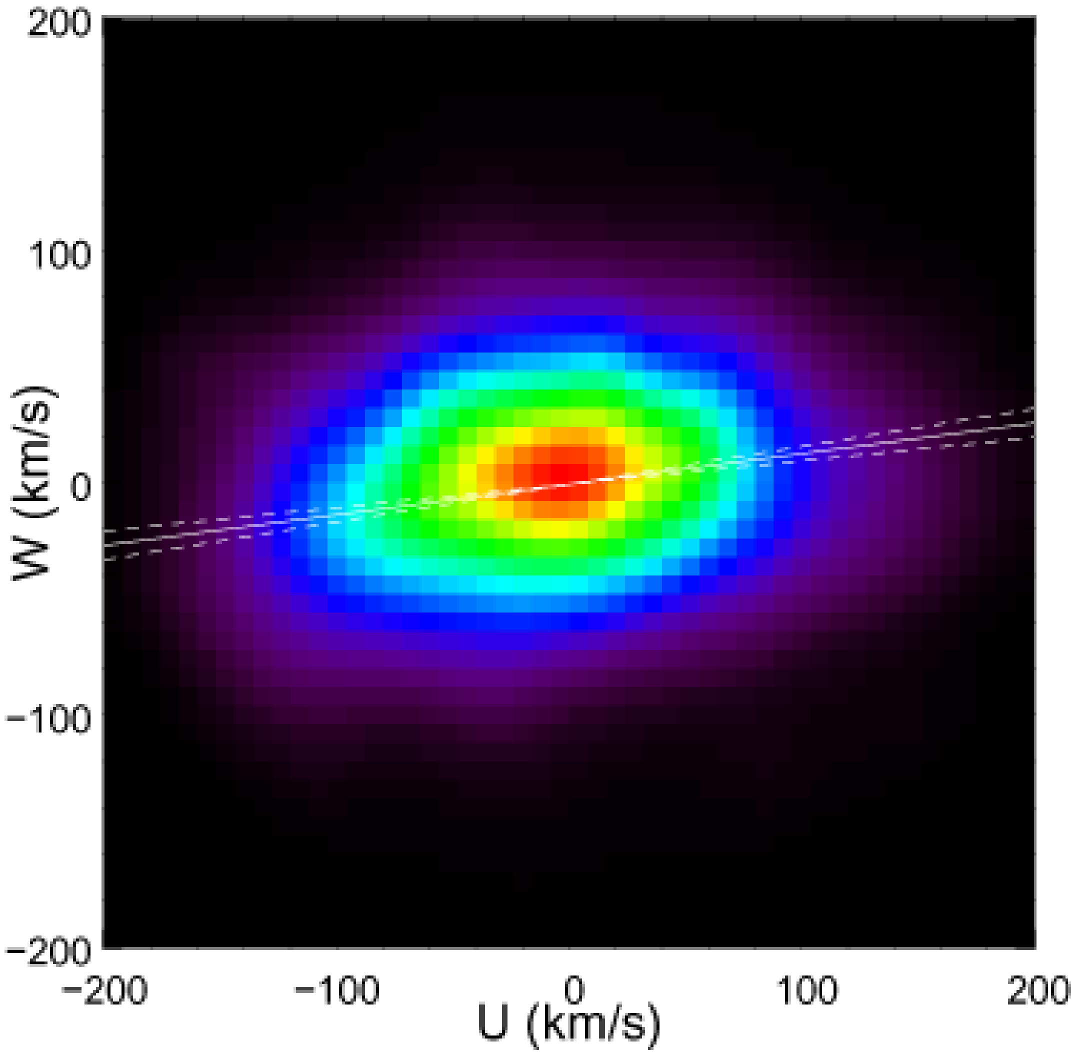


Abadi et al 2009

What does that mean for the MW as a typical LCDM galaxy?

- V_c = 220 km/s (as favored by SAMs)
  - Luminosity function + TF relation
  - Only ~20% of halos suitable hosts
  - 90% of the baryons in the MW unaccounted for
  - Disk size: access to the full angular momentum reservoir
- V_c = 140 km/s
  - MW would be a rather untypical galaxy or over abundant

The galactic potential and the tilt of the velocity ellipsoid



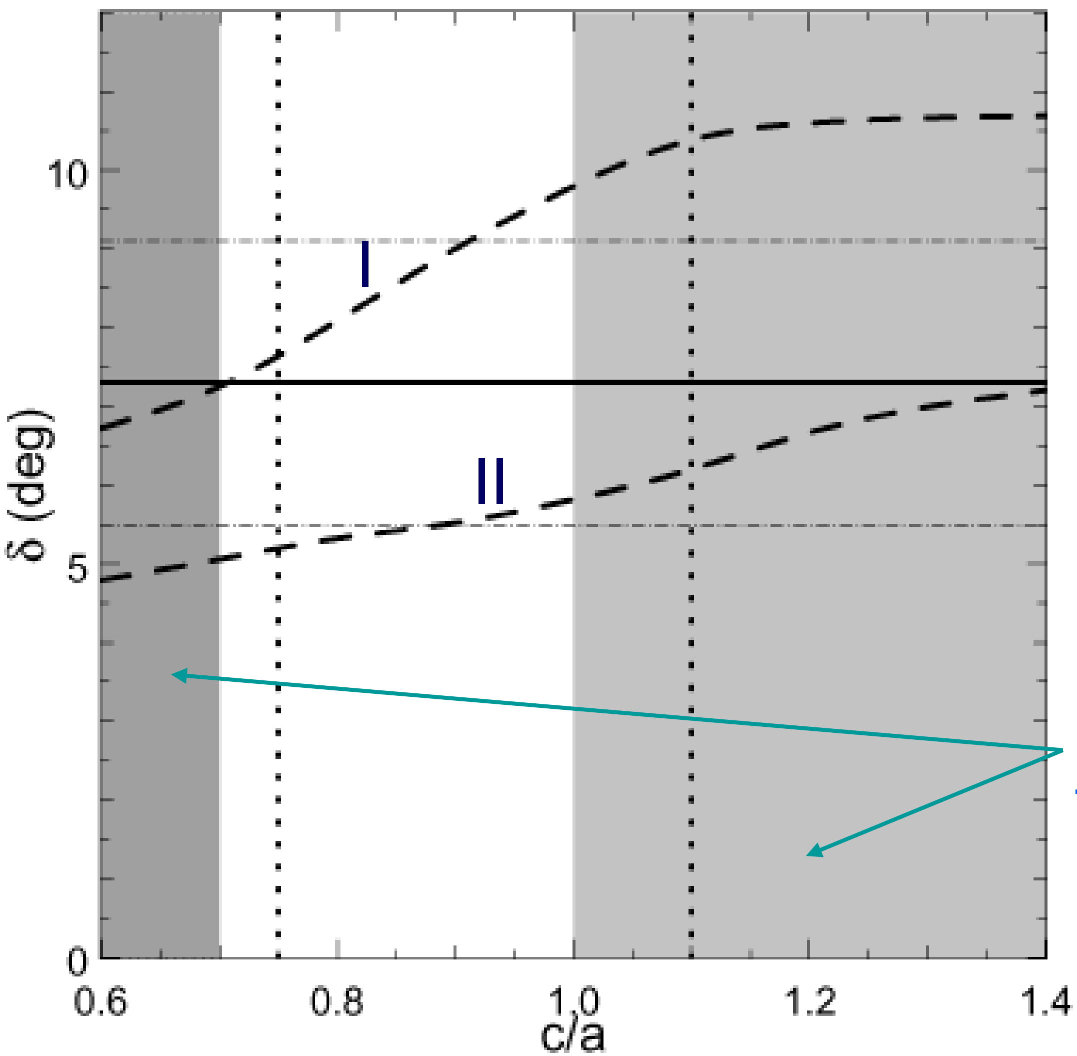
~500 KIII giants

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

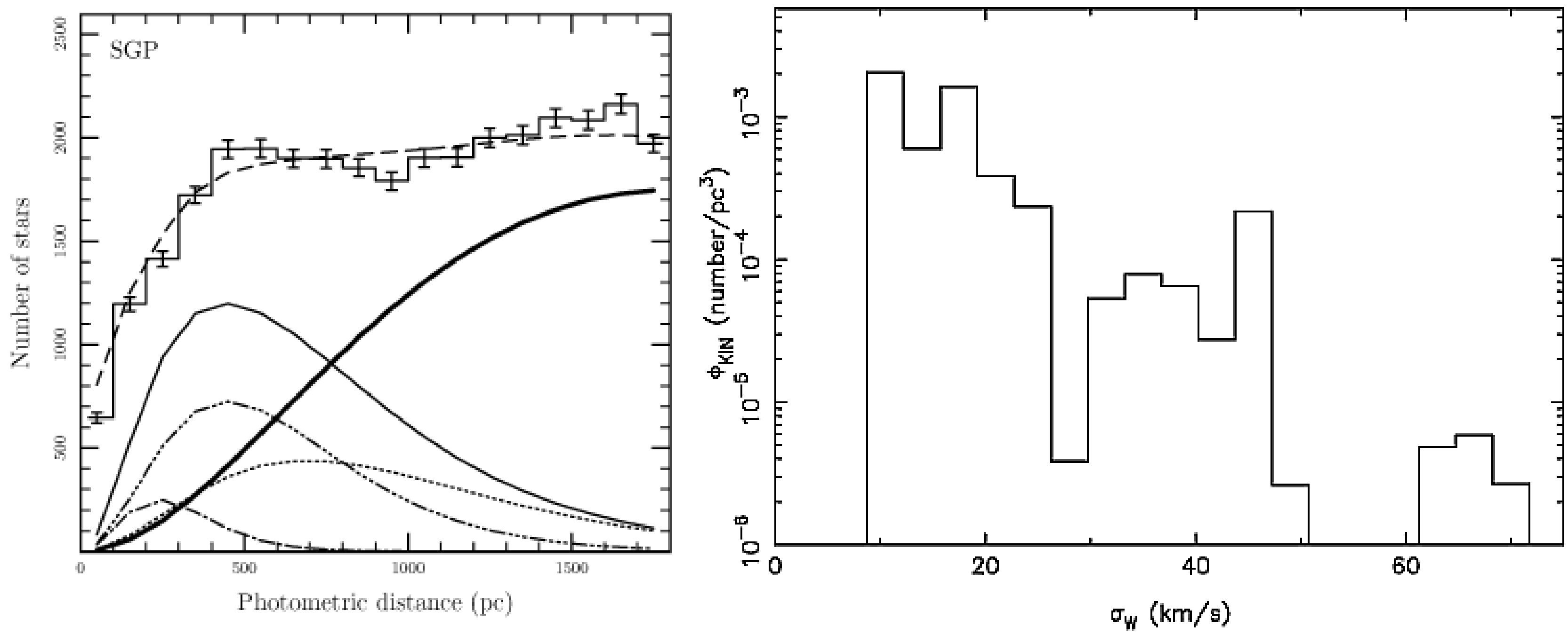
Tidal streams in the Solar neighborhood (Seabroke et al 07)

- 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)

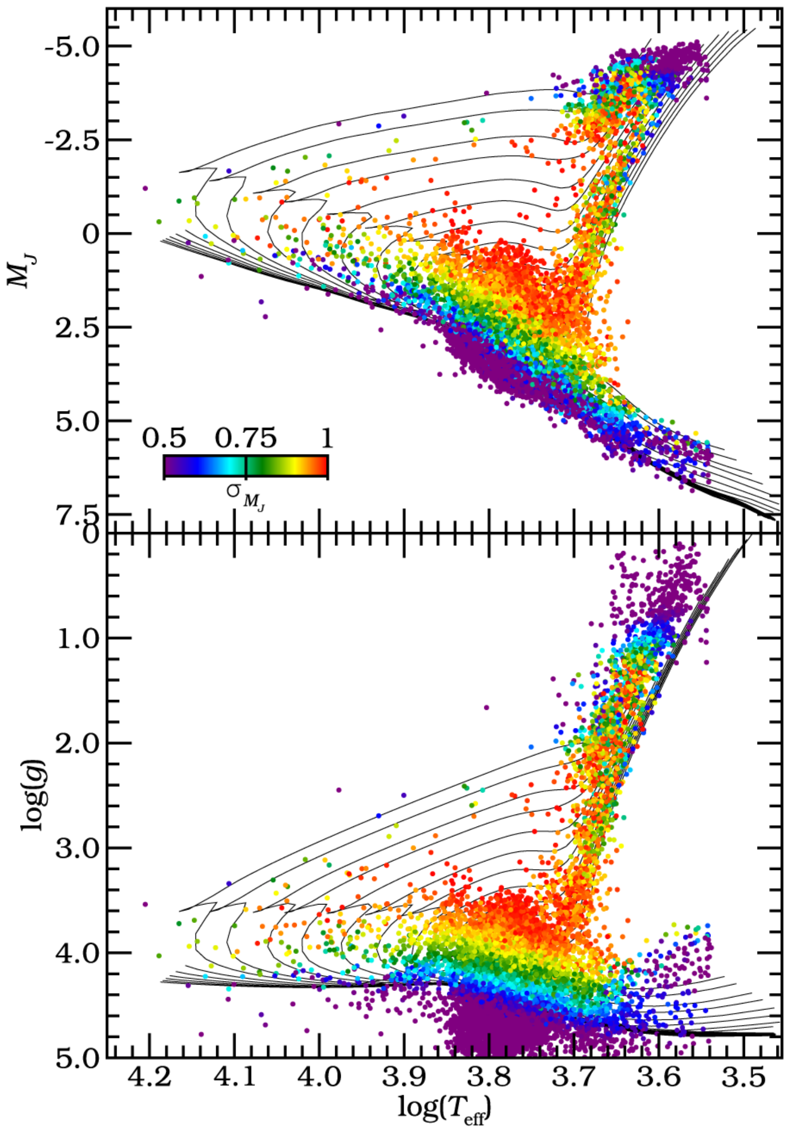
Vertical structure of the Galactic disk (Veltz et al 07)

- Simultaneously measure the vertical scale height of the galactic disk with photometric and kinematical data



- d_{thin} = 225 pc, σ_w<21km/s, d_{thick}=1048 pc, σ_w≈45km/s
- Inconsistent with dynamical heating
- Consistent with satellite accretion

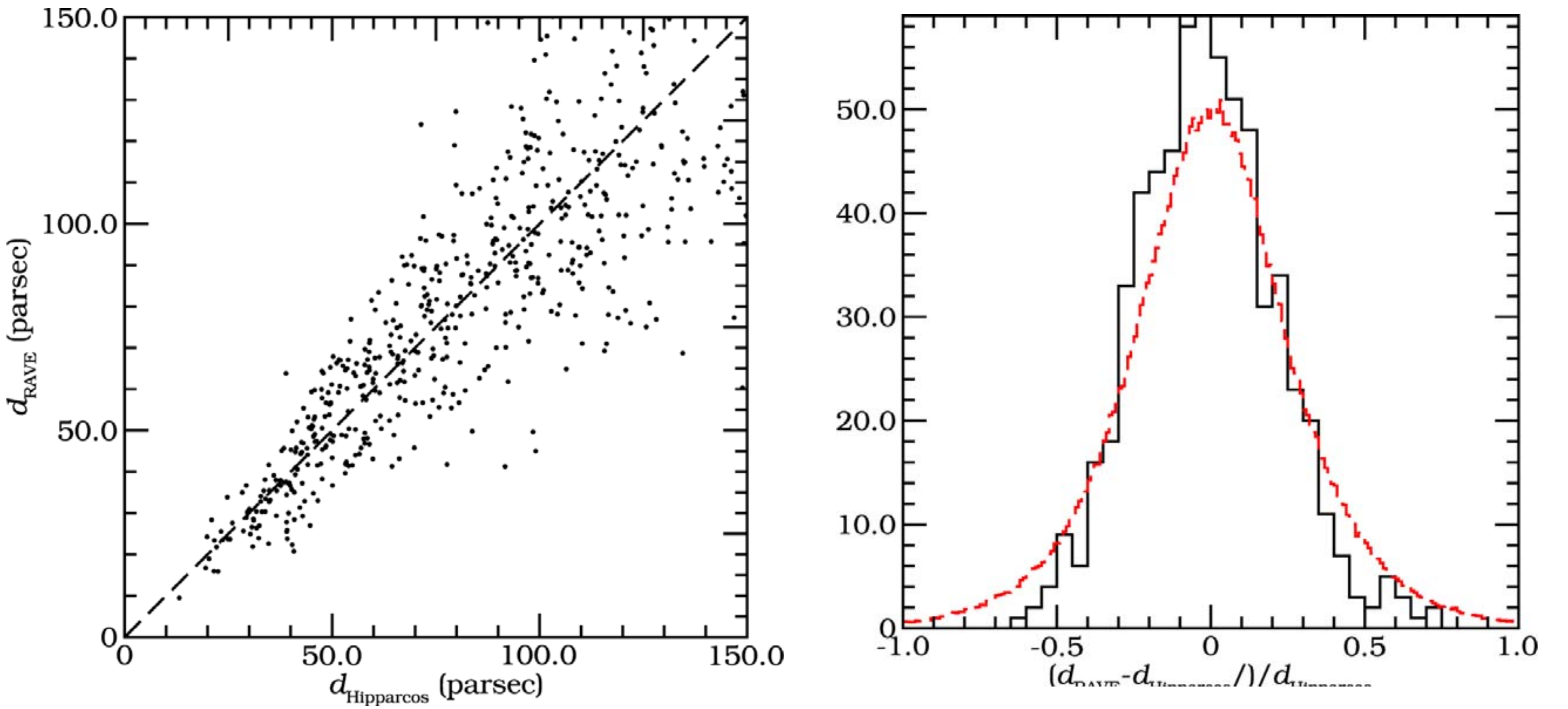
Going 6D: Distances of RAVE stars



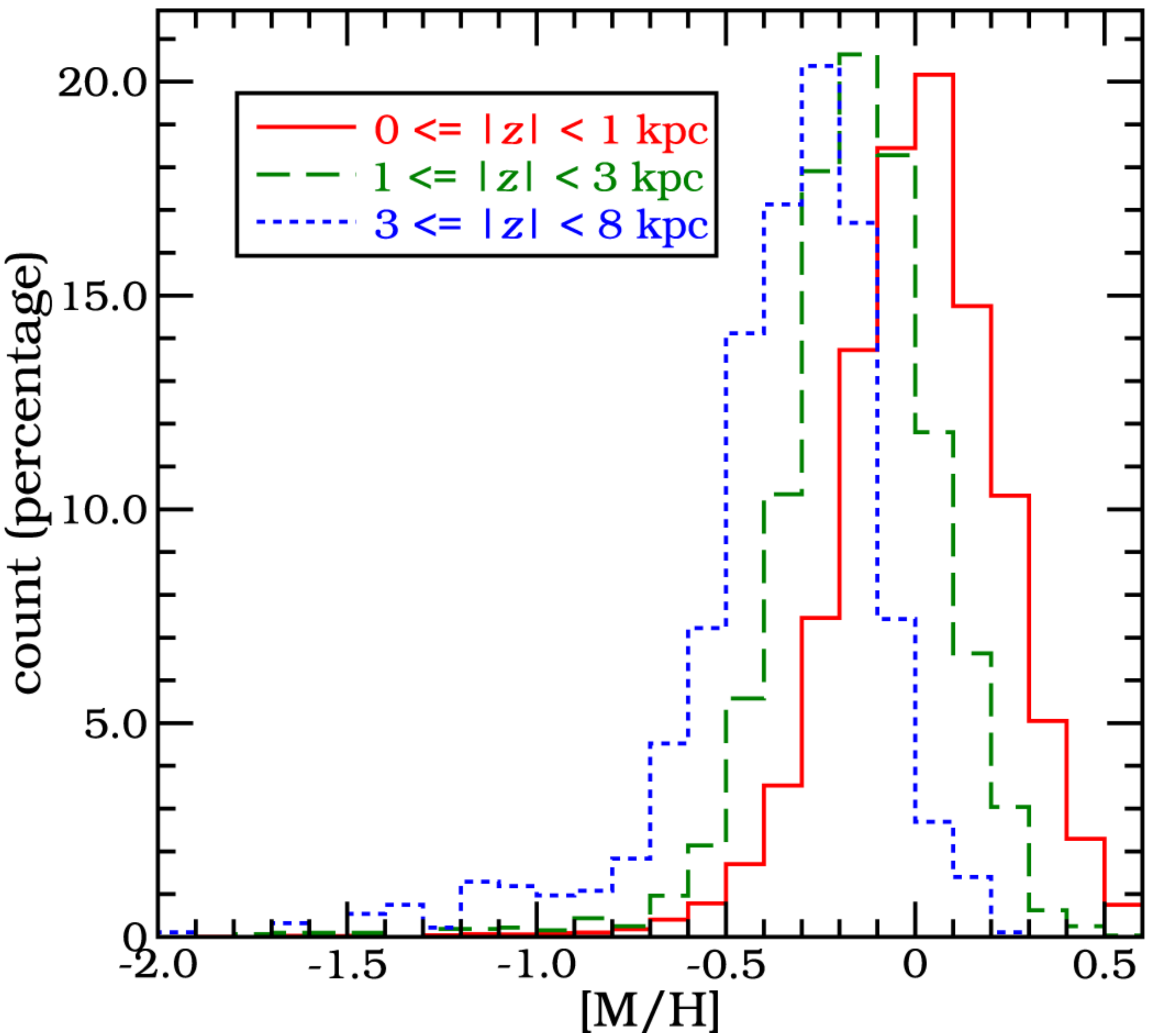
- Fit Y[2]-isochrones (Demarque et al 04) to RAVE data/deduced stellar parameters + J-K colors
  - J-Magnitude
  - Error in J-Magnitude
- Check by Monte-Carlo Sampling
- Result: out of 16663 stars in DR2
  - 2067 better 25%
  - 5294 better 37.5%
  - 12701 better 50%

Breddels et al, 2009

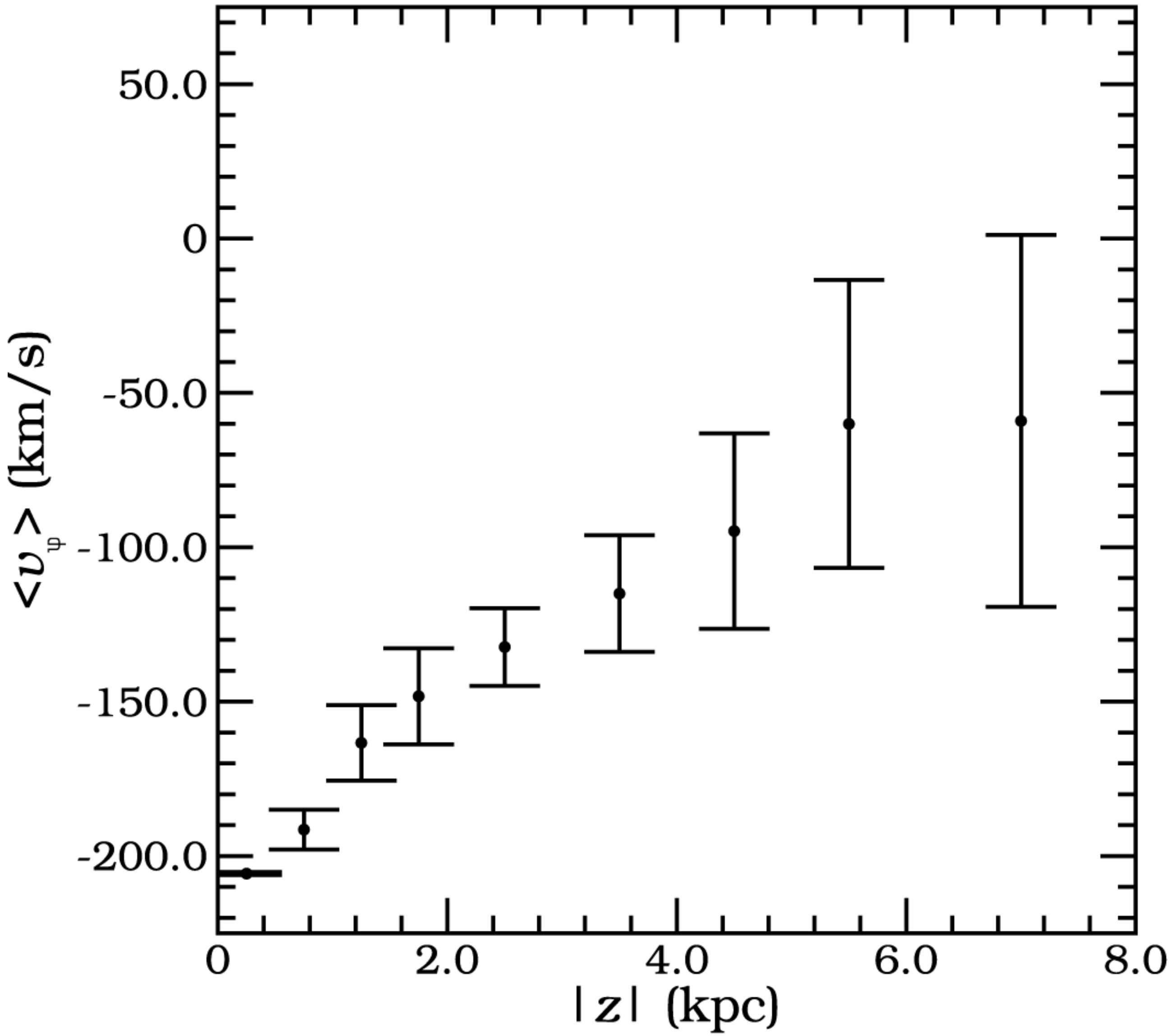
Verfication for stars with Hipparcos distances



Abundances vs height



Rotation velocity vs height




RAVE
OR
DIE!