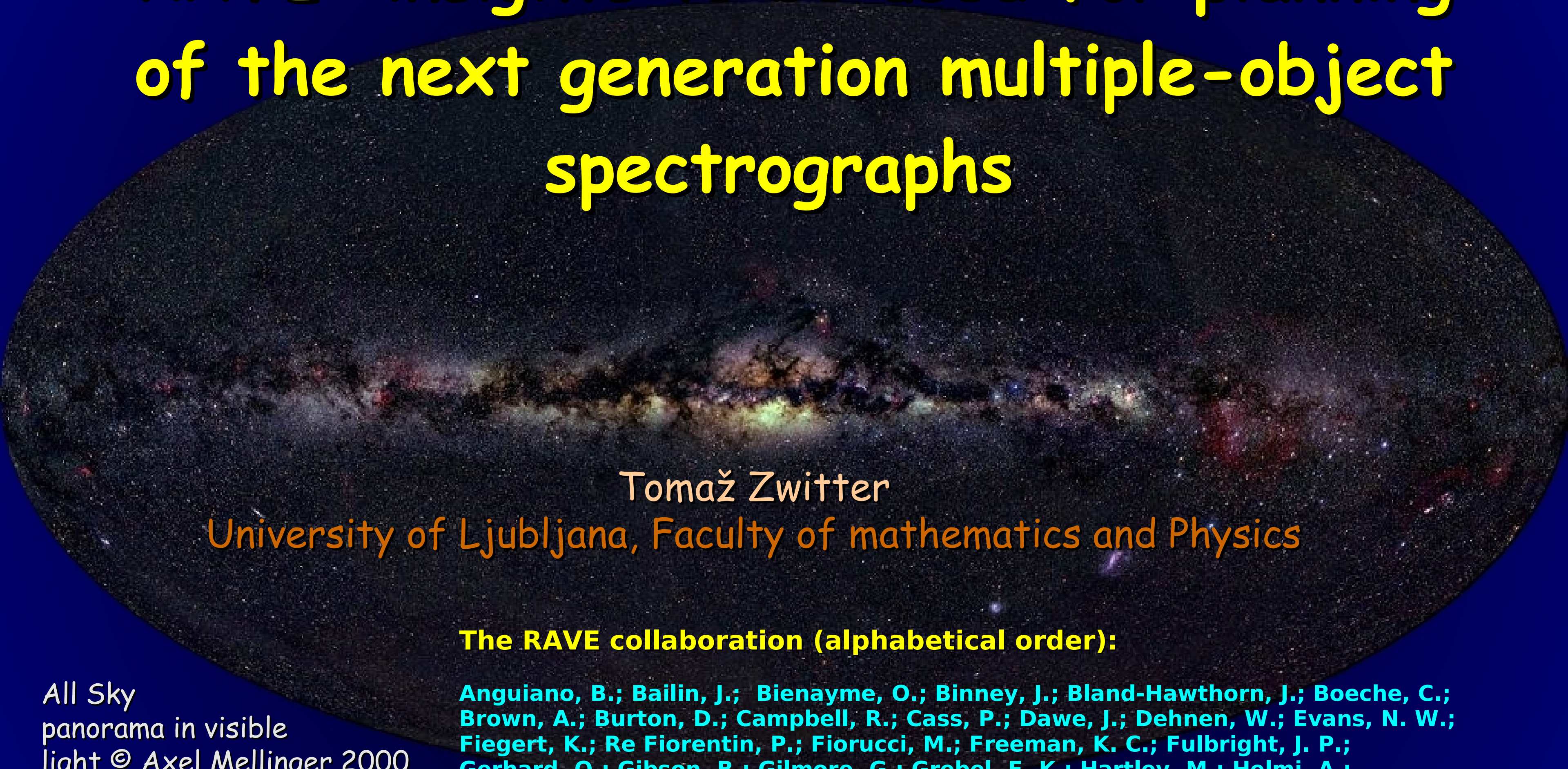
RAVE: insights to be used for planning of the next generation multiple-object spectrographs



Tomaž Zwitter

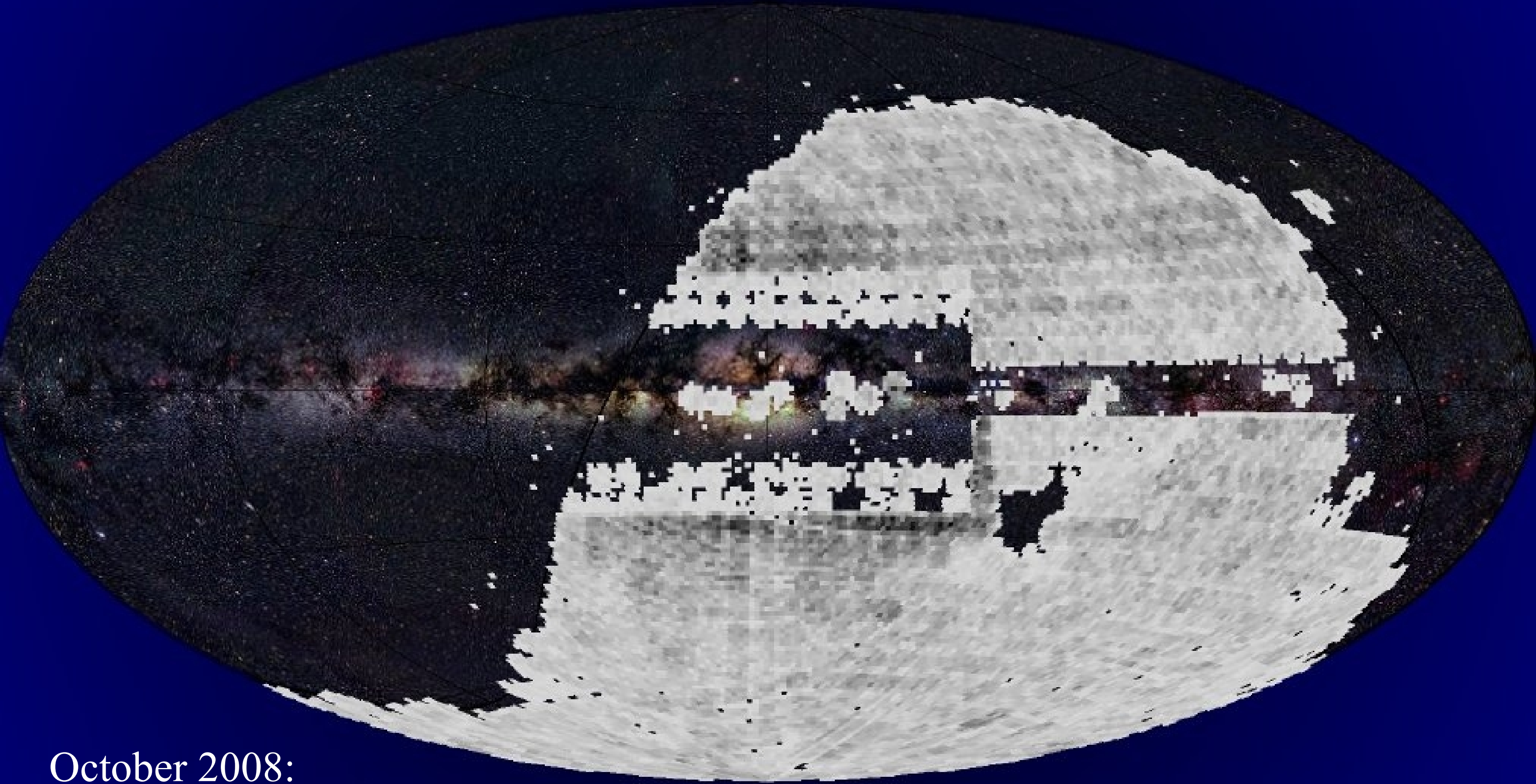
University of Ljubljana, Faculty of mathematics and Physics

All Sky panorama in visible light © Axel Mellinger 2000

The RAVE collaboration (alphabetical order):

Anguiano, B.; Bailin, J.; Bienayme, O.; Binney, J.; Bland-Hawthorn, J.; Boeche, C.; Brown, A.; Burton, D.; Campbell, R.; Cass, P.; Dawe, J.; Dehnen, W.; Evans, N. W.; Fiegert, K.; Re Fiorentin, P.; Fiorucci, M.; Freeman, K. C.; Fulbright, J. P.; Gerhard, O.; Gibson, B.; Gilmore, G.; Grebel, E. K.; Hartley, M.; Helmi, A.; Jauregi, U.; Just, A.; Kelz, A.; Kujken, K.; Matijevic, G.; Minchev, I.; Munari, U.; Navarro, J. F.; Parker, Q. A.; Penarrubia, J.; Quillen, A.; Read, M. A.; Reid, W.; Roeser, S.; Ruchti, G.; Russell, K.; Scholz, R. -D.; Seabroke, G. M.; Siebert, A.; Siviero, A.; Smith, M. C.; Sordo, R.; Steinmetz, M.; Tolstoi, E.; Tomasella, L.; Veltz, L.; Watson, F. G.; Williams, M.; Wylie de Boer, E.; Wyse, R. F. G.; Zwitter, T.

Number of pointings

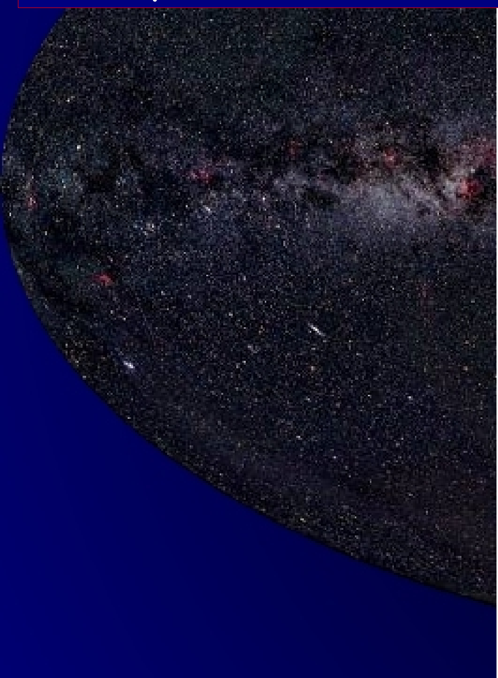


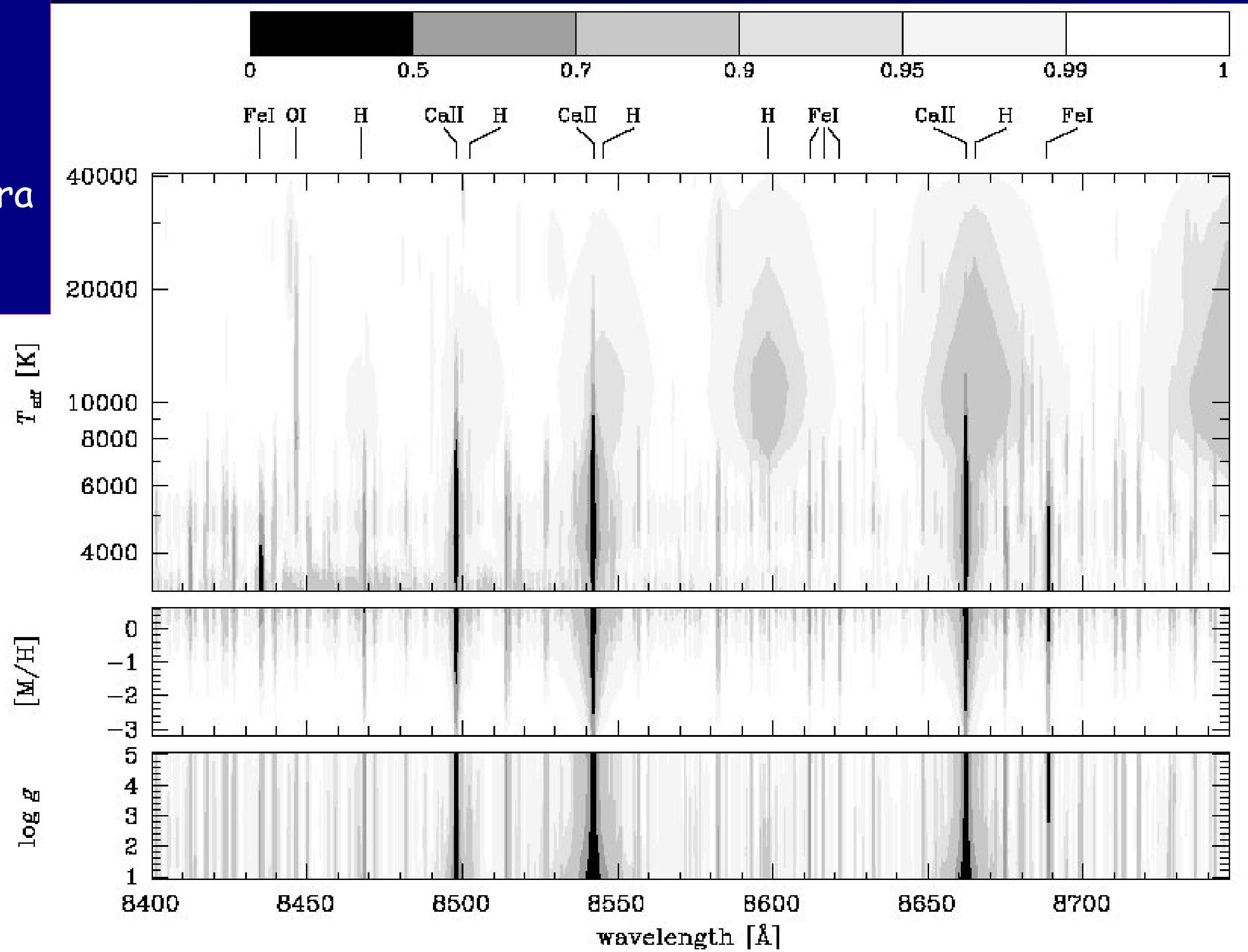
October 2008:
265.710 spectra covering 16891 square degrees (~16 objects per square degree).

Altogether 325.000 spectra were obtained till now.

A reference system

Radial velocities and parameters of stellar atmospheres derived in a reference grid of 50000+ template spectra from the latest Kurucz library





Zwitter et al. 2004
Munari et al. 2005

Changes of a normalized spectrum of a star similar to the Sun, if only one of the principal parameters is changed in each graph ($\lambda / \Delta \lambda = 20000$).

Errors on stellar parameters

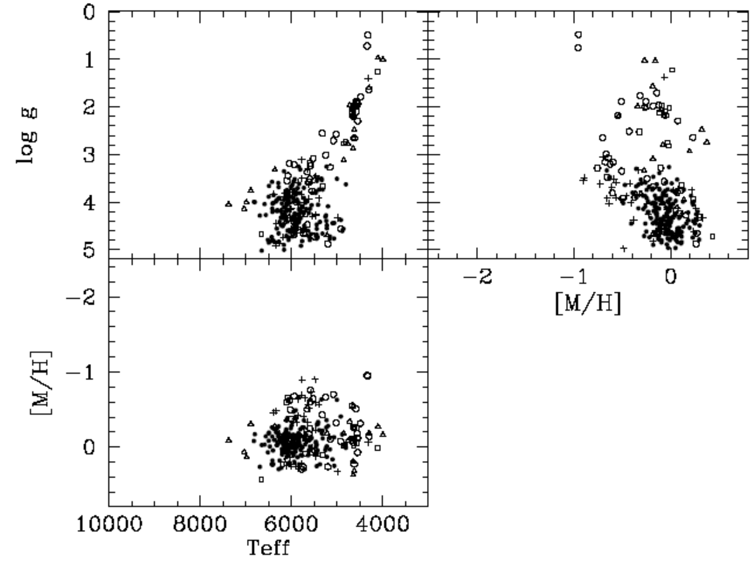


Fig. 13.— Objects from external datasets on the temperature–gravity–metallicity wedge using the values determined from RAVE spectra. Symbols code individual datasets which were used to check the values of stellar parameters: GCS (•), Apache Point (○), Soubiran (+), M67 (□), and Asiago (△).

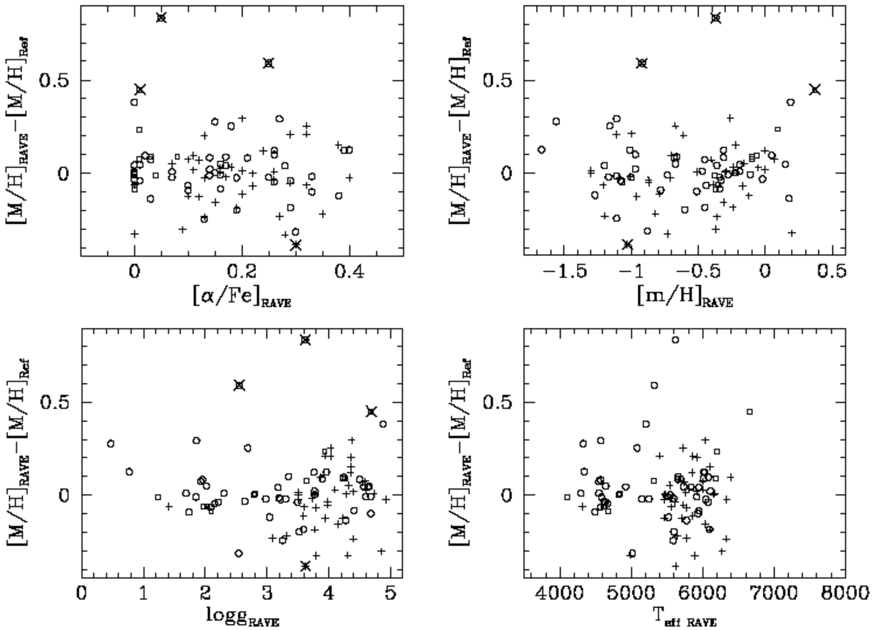


Fig. 16.— Comparison of calibrated metallicities derived by RAVE to the reference values. Symbol types are as in Figure 15. Points rejected during iterative calculation of metallicity calibration are crossed out.

MATCH TO REFERENCES:

	Zero point	Dispersion
Δ Teff	-7 ± 18 K	188 K
Δ log g	-0.06 ± 0.04	0.38
Δ [M/H]	0.0 ± 0.02	0.18

Check with repeated observations

Repeated observations

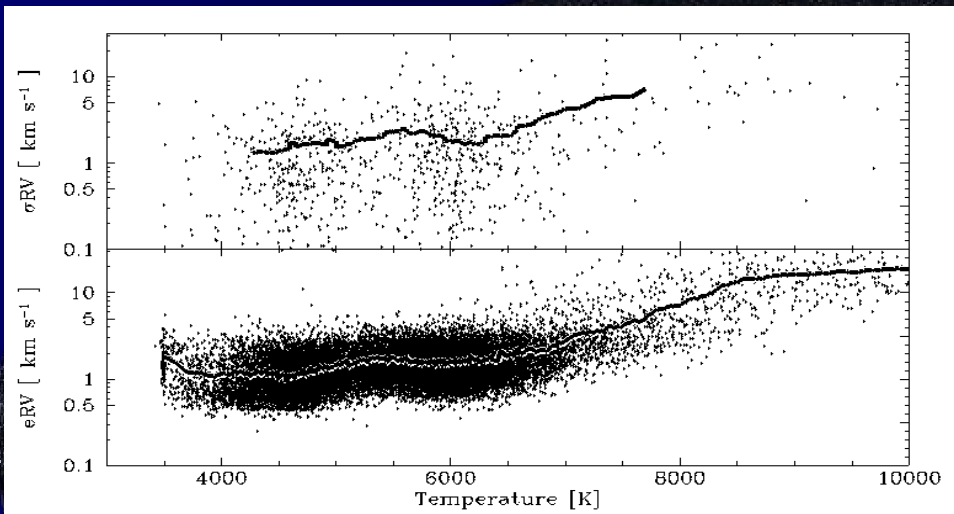
1893 objects with ≥ 2 observations of radial velocity:
Δ RV = 1.8 km/s

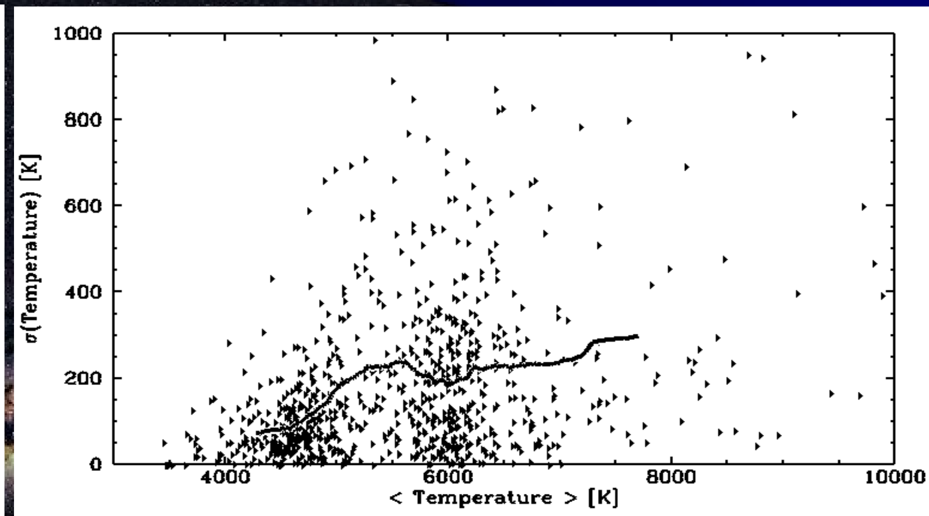
855 objects with ≥ 2 observations of stellar parameters:
Δ Teff = 135 K,
Δ log g = 0.2 dex,
Δ [M/H] = 0.1 dex

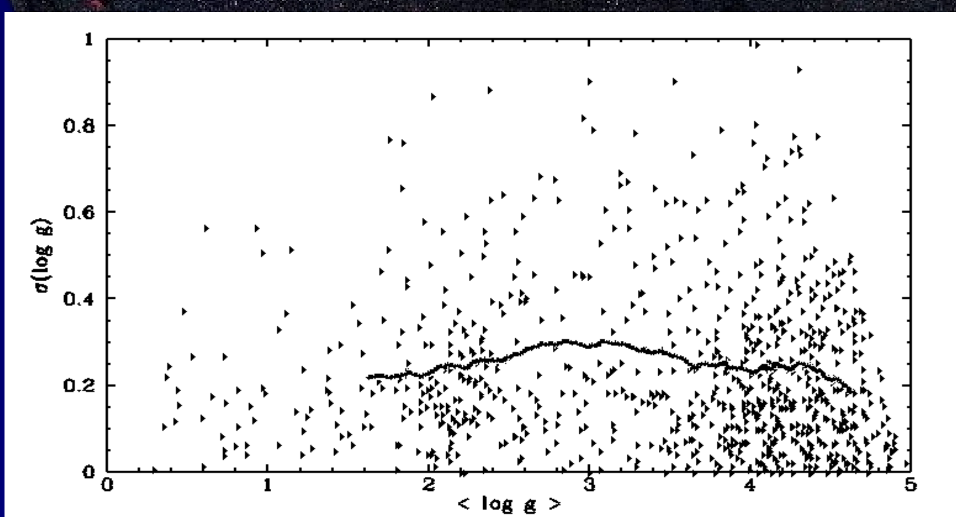
These errors on stellar parameters are <u>less than half</u> of what is derived from comparison with external datasets. So external datasets values may not be error free and RAVE errors are indeed smaller.

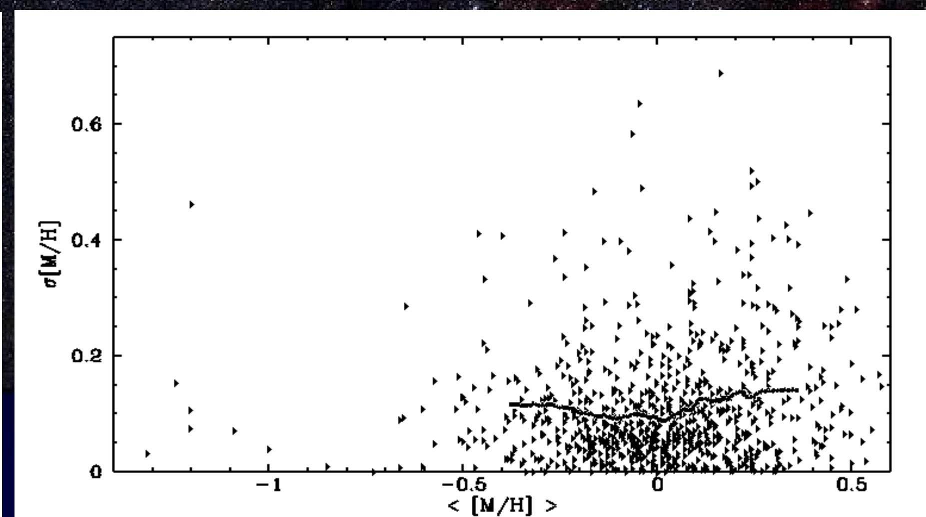
If Δ RV > 5 km/s this is likely due to binarity (single lined spectroscopic binary). This happens in 6% of the cases. In ~0.6% binarity in a form of a double lined spectroscopic binary detected from a single spectrum.

Errors for repeated observations



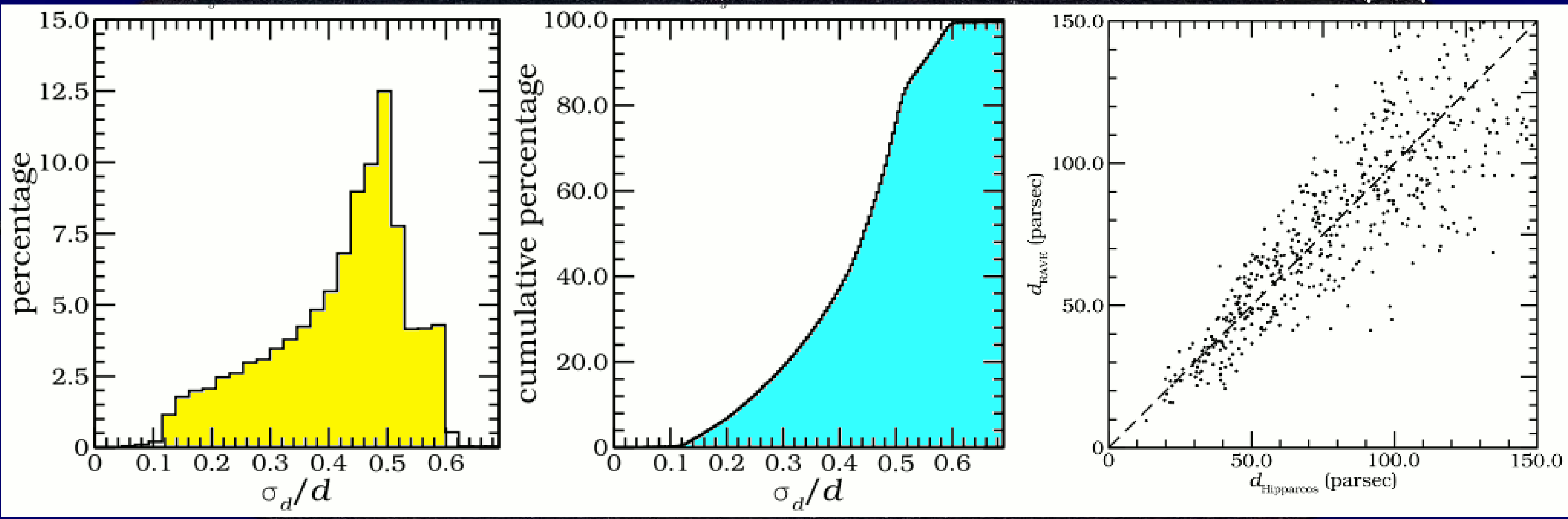






Distance determination using stellar models

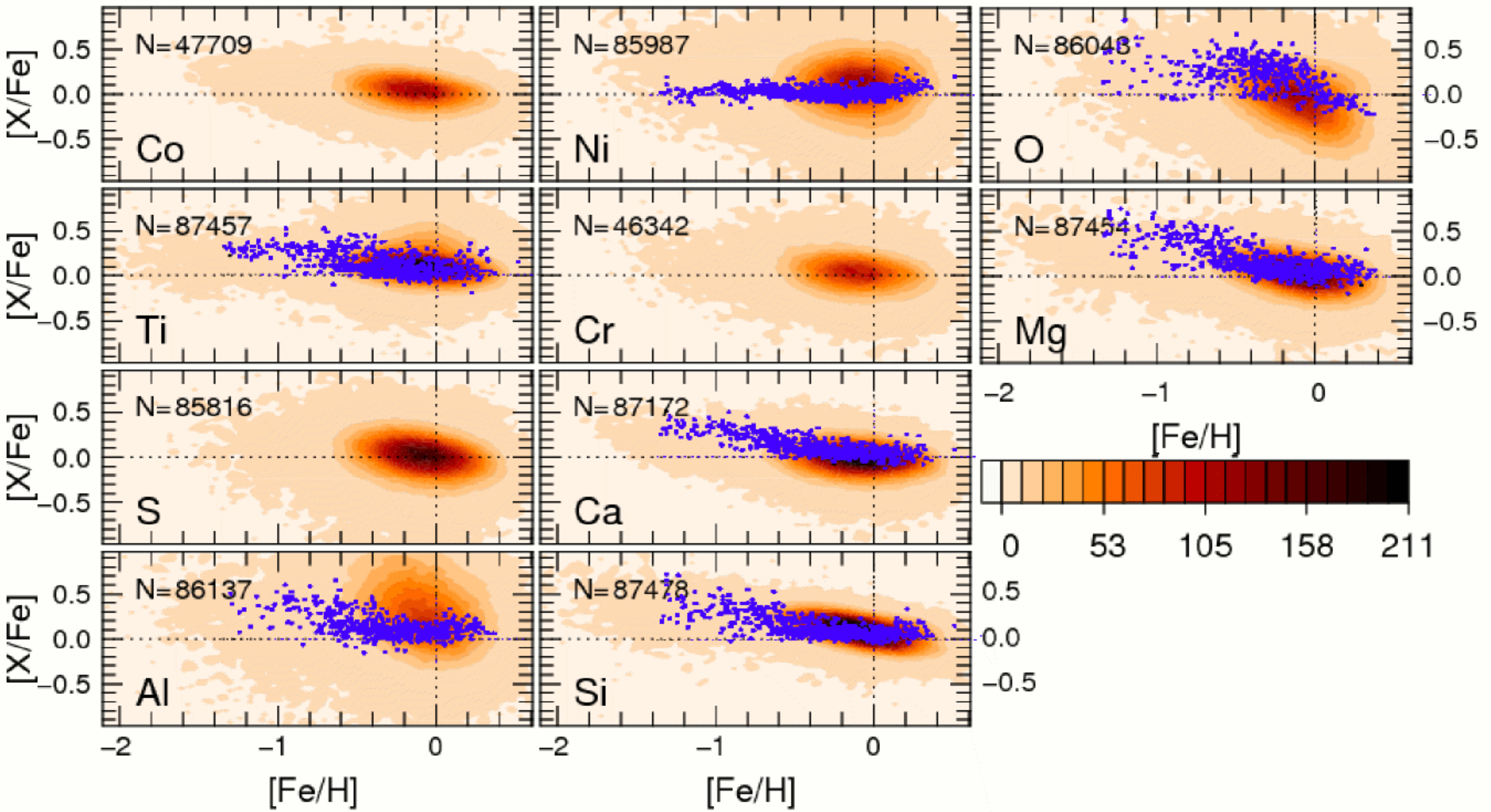
Breddels, Smith, Helmi, et al. 2009, in preparation



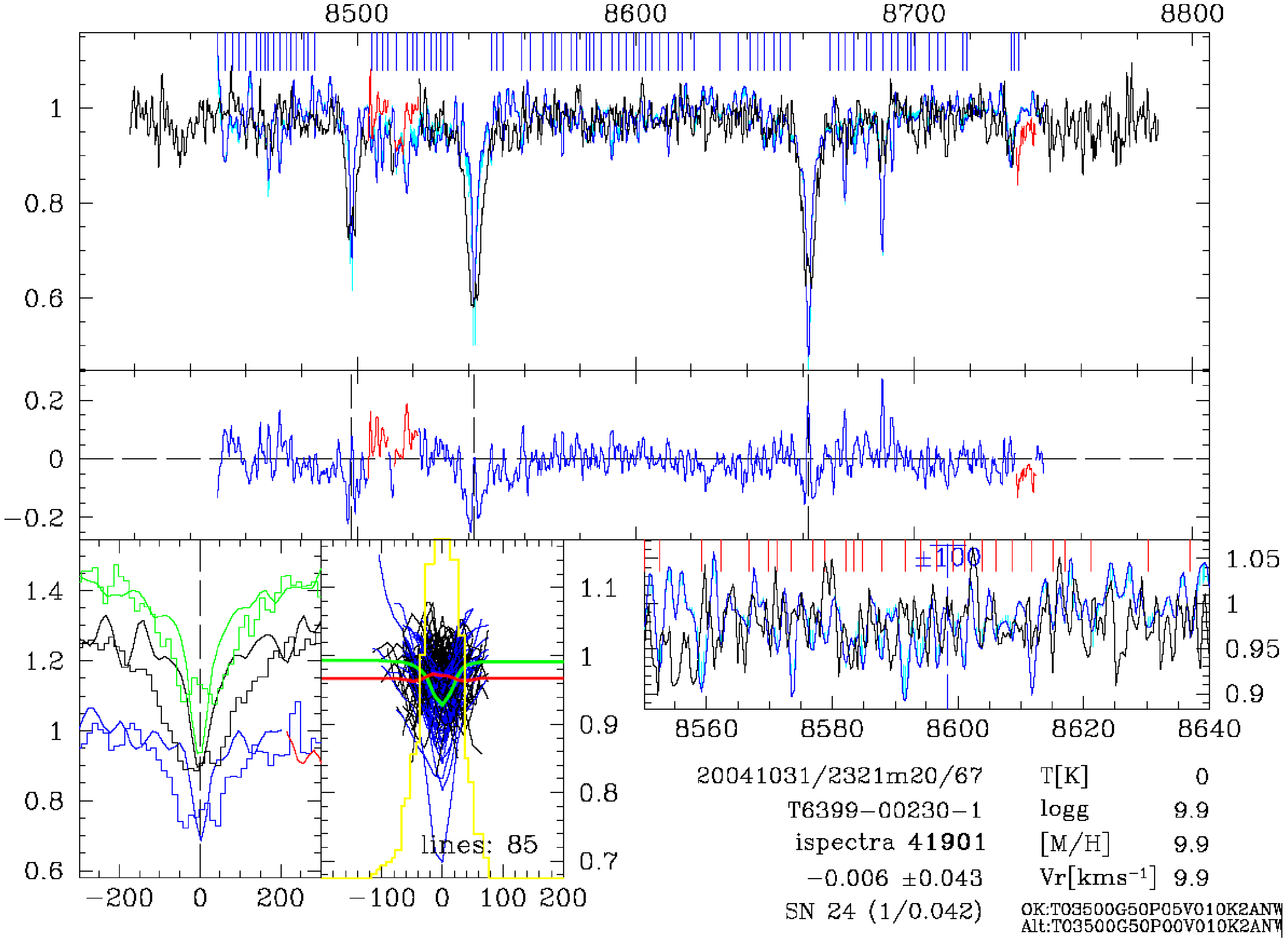
Error distribution (left) and cumulative plot (middle) for distance. These distributions are for a sample of 16.663 stars. Distance from stellar models versus Hipparcos distance (right).

Individual element abundances

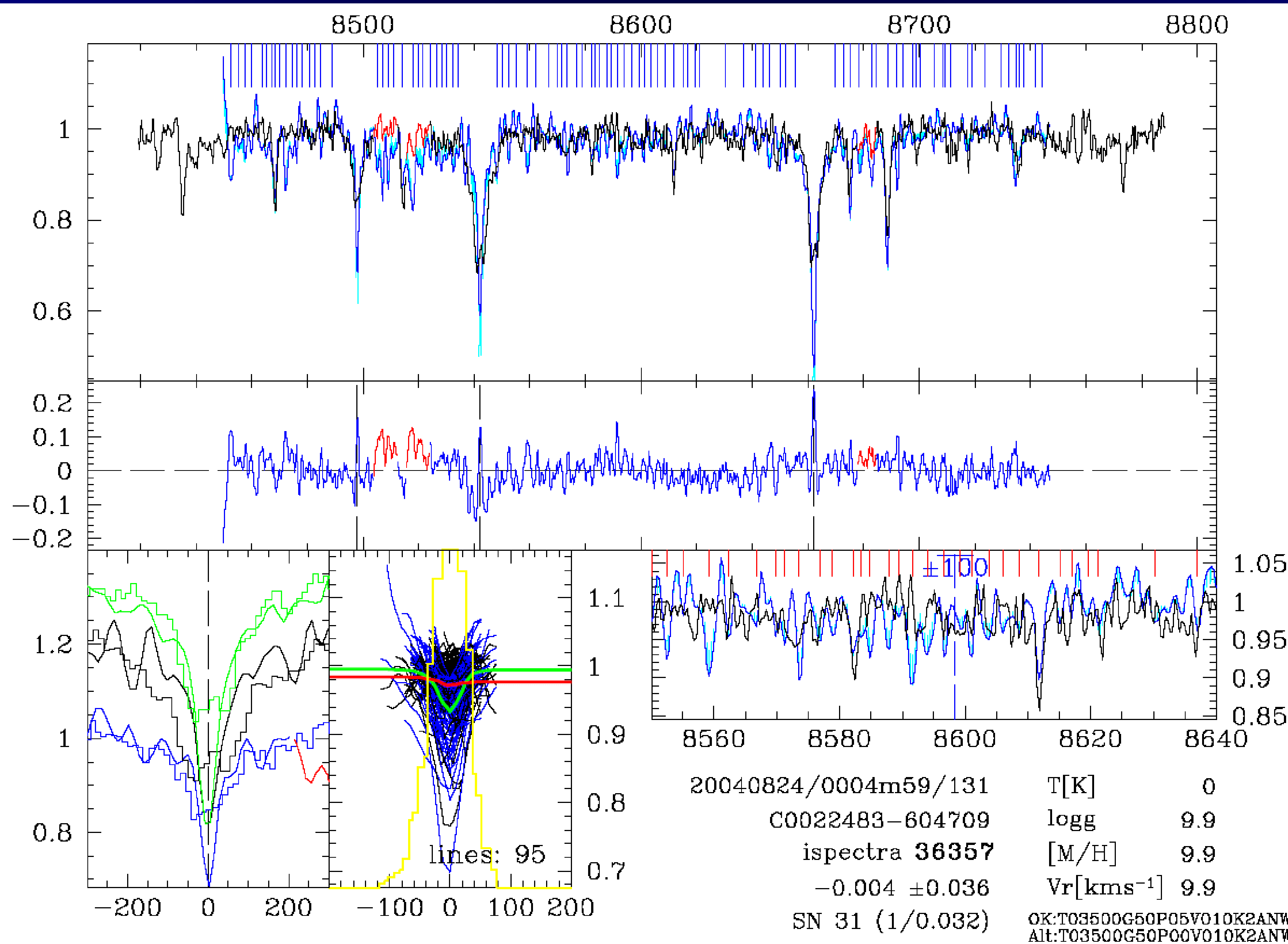
Boeche et al. 2009, in preparation, blue points: Soubiran & Girard (2005).



Systematic errors: a binary star



Systematic errors: a coronal emission star

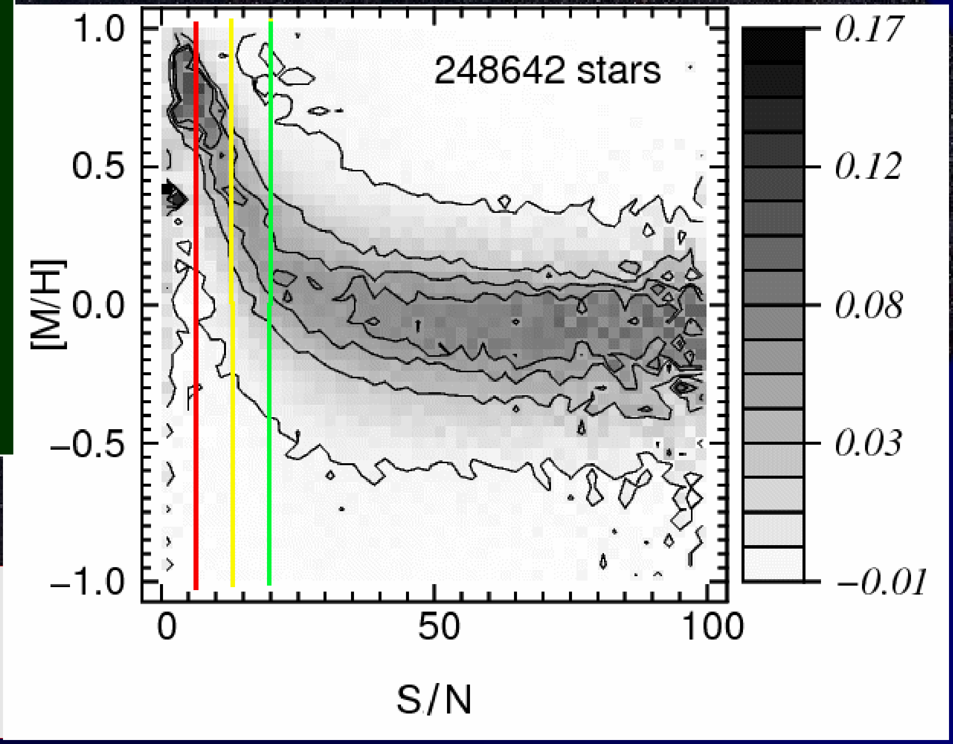


Systematic errors: metallicity at low S/N

- uncertain continuum placement,
- normal stars have absorption spectra, so noise dips interpreted as absorption lines.

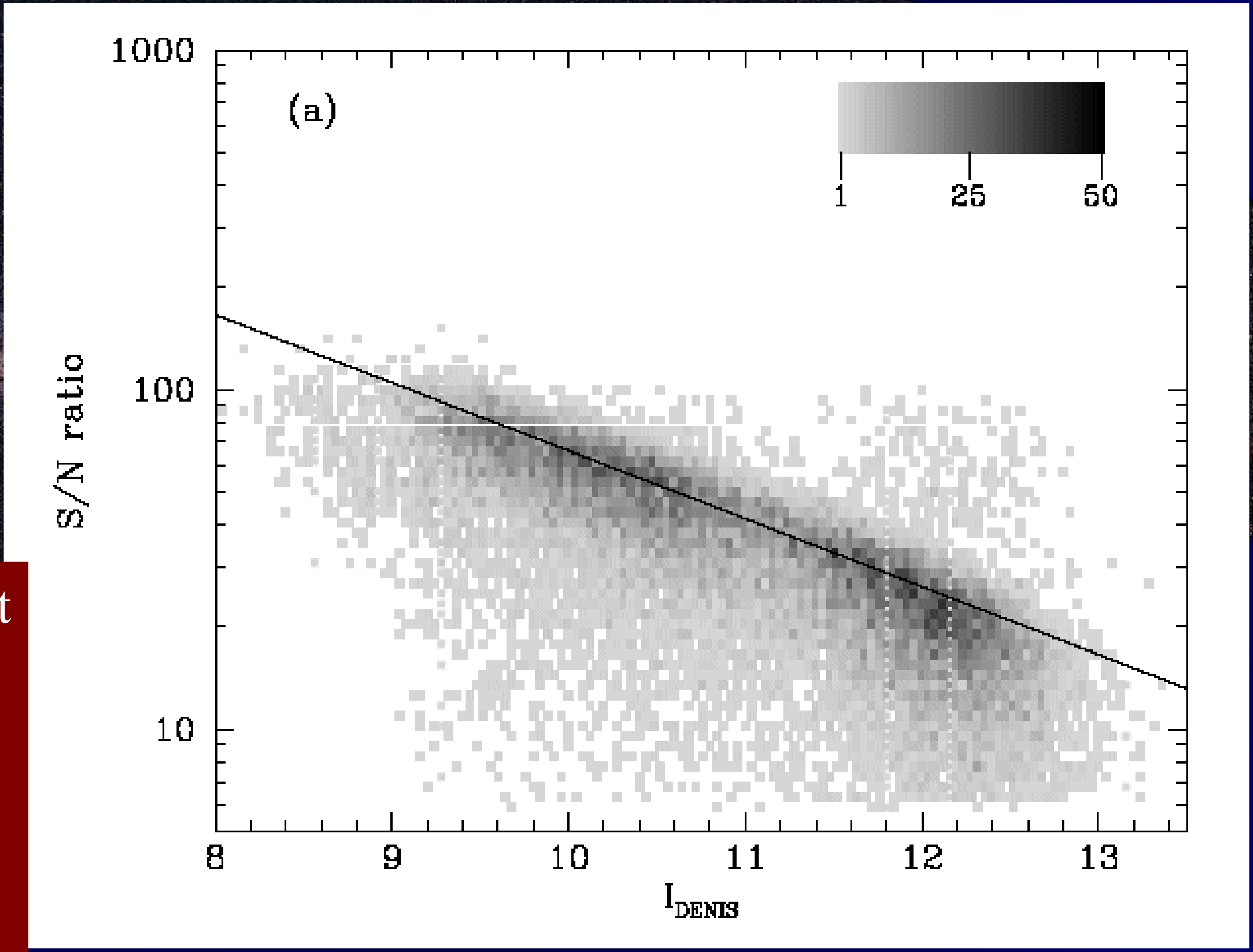
To avoid systematics (Zwitter et al.2008):

- parameters for individual stars reliable at S/N>20 (green line),
- parameters published for statistical use at S/N>13 (yellow line),
- radial velicities published till S/N=6 (red line).



Rough results from the automated RAVE pipeline prior to screening for binaries, coronal emissions and spectral ghosts.

Magnitude and noise distributions



For a typical giant
I = 12.5
corresponds to
V = 13.5
and
g = 14.0.

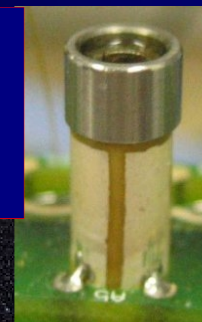
Into the future

	Gaia	Rave
Telescope collecting area	0.725 m^2	1.13 m^2
Total exposure time per object	~528 s	3000 s
Area × time	383 m^2 s	3390 m^2s
CCD readouts per object	~120	5
System throughput	better	worse
Limit for S/N = 13		V~13.5

In Gaia effective temperature could be accurately derived from spectrophotometry, and astrometry yields luminosity. Radial velocity spectrograph onboard provides radial velocities, but in many cases Gaia may not be able to provide any information on chemistry, rotational velocity or peculiarities.

Conclusions & recommendations

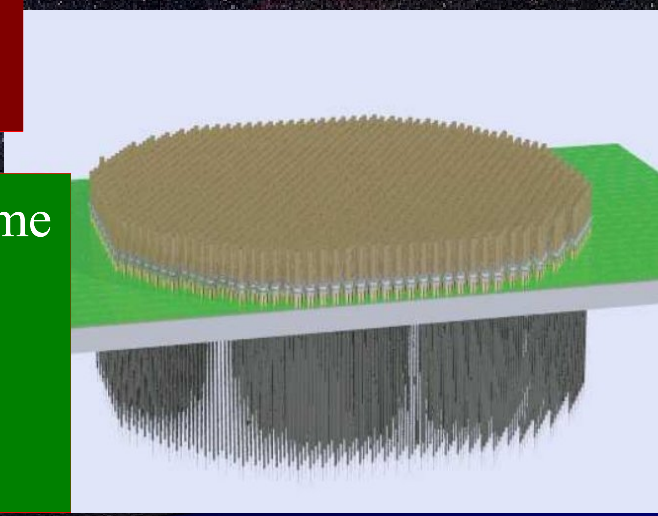
Rave demonstrates that reliable RVs and stellar parameters (temperature, metallicity, for high S/N spectra also individual element abundances) can be derived from R=7500 spectra with S/N > 20.



Echidna actuator and mount (AAO).

Spectrograph with an echidna-type fiber feed and R=7500 is needed to study galactic chemistry.
With 1600 fibers it can obtain 2 million spectra/year.

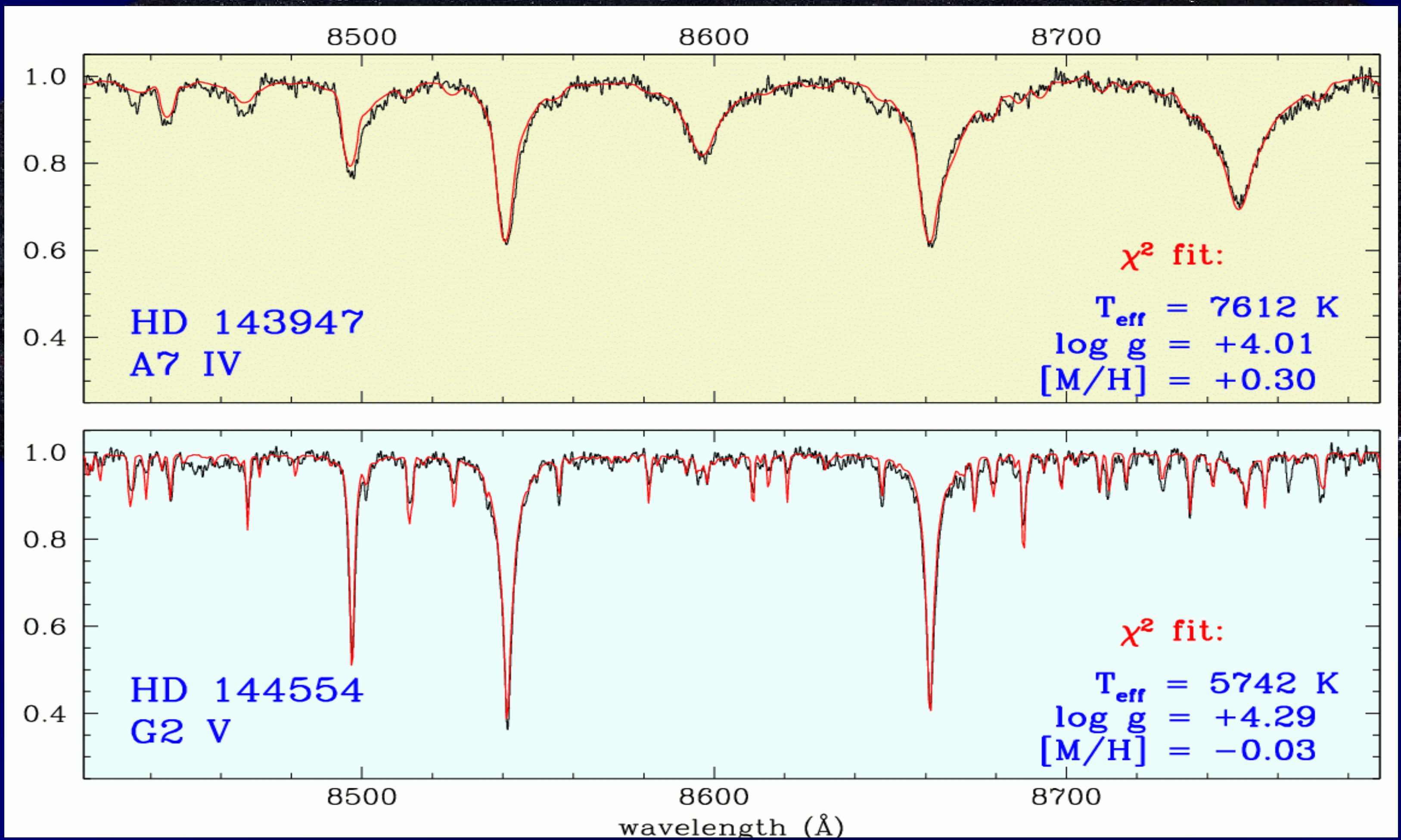
With a 4-m class telescope dedicated to this programme the spectra can provide information on metallicity down to V=17.0, and individual element abundances to V=15.5 (exposure time 3600 s). VLT goes fainter, but may observe less targets (time sharing).



2dF-Echidna positioner core with 1585 fibres in the 2dF focal surface.

If nothing is done, we may know the kinematics, but not the chemistry of the Galaxy.

Determination of stellar parameters with RAVE

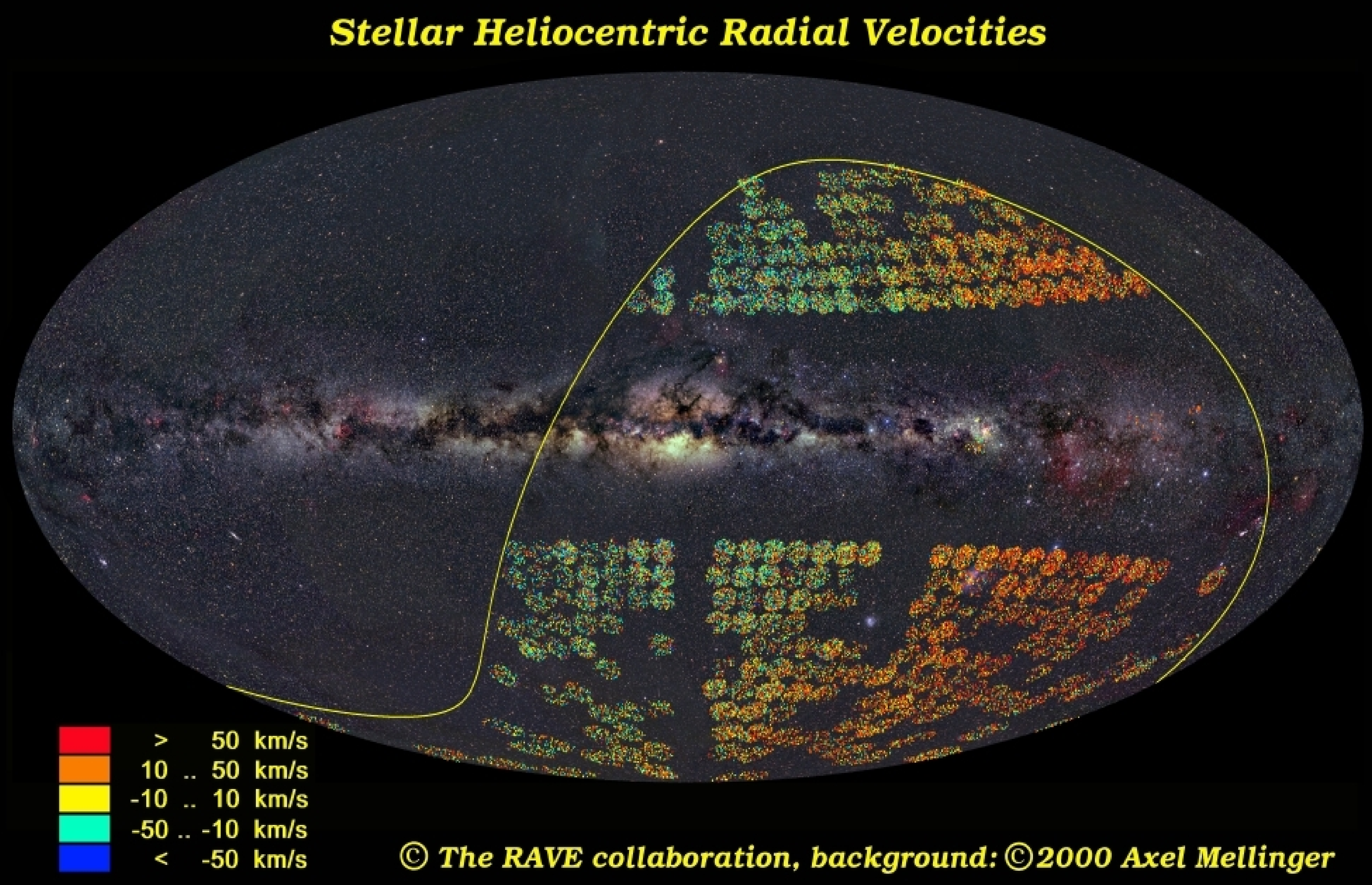


RAVE survey: 2nd data release

Zwitter et al., AJ, issue July 2008 (also public release)
astro-ph:0806.0546

	all data	new in this DR
Number of nights of observation	141	72
Number of fields (incl. repeats)	517	266
Sky area covered (square degrees)	7,200	2,440
Stellar spectra	51,829	25,850
Number of different stars	49,327	24,010
Number of stars observed once	47,492	22,676
Number of stars observed twice	1,618	1,232

Measured radial velocities



Radial velocity errors

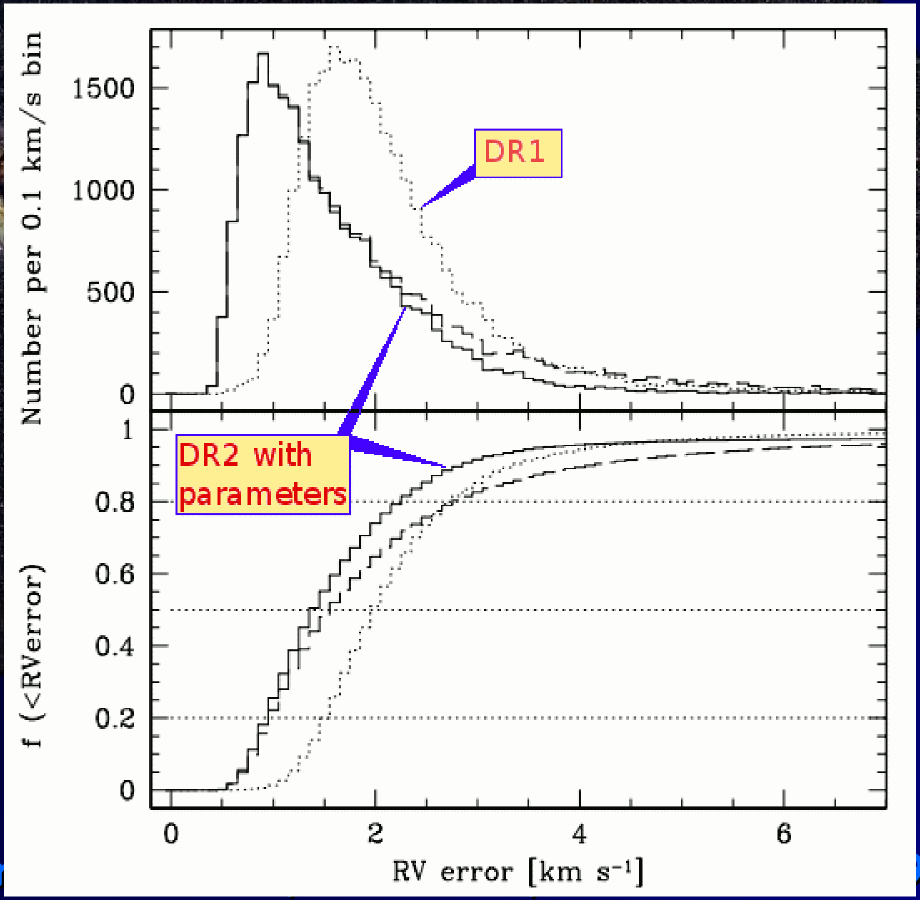
Internal RV Errors

Dataset	Peak ($km\ s^{-1}$)	Average ($km\ s^{-1}$)
Spectra of normal stars new to DR2	0.9	2.0
Spectra of all stars new to DR2	0.9	2.5
Spectra of all stars in DR1	1.7	2.3
All	1.6	2.3

Datasets Used to Check the RV Accuracy

Reference dataset	N	$\langle\Delta RV\rangle$ ($km\ s^{-1}$)	$\sigma(\Delta RV)$ ($km\ s^{-1}$)
GCS	144	0.34	1.83
Sophie observations	33	0.63	1.18
Asiago observations	21	−0.71	1.09
ELODIE observations	15	0.07	1.32
All	213	0.26	1.68
Last three datasets	69	0.10	1.30

Note. ΔRV is the difference between radial velocities derived by RAVE and those from the reference dataset.



RV errors vs. S/N

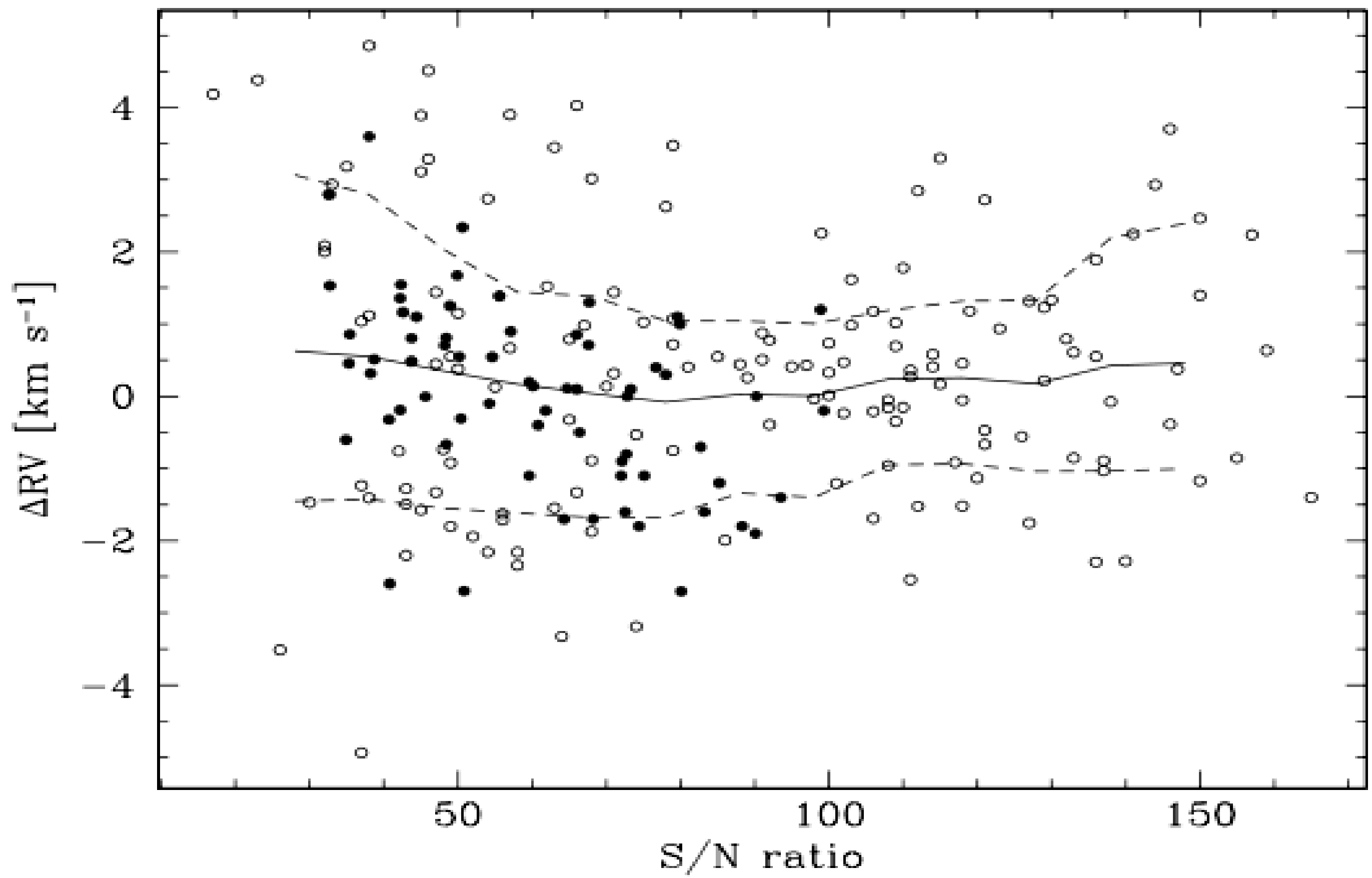


Figure 12. Difference of radial velocities as derived by RAVE and by the reference instruments, as a function of the S/N of the RAVE observation. Dots depict individual measurements, the solid line is a running mean (with a boxcar smoothing of ±15 in S/N). Similarly, the area between the dashed lines includes 68.2% of the measurements, i.e., $\pm\sigma$. The open symbols are measurements of the GCS stars, while the filled ones mark the other three reference datasets.

Errors on stellar parameters

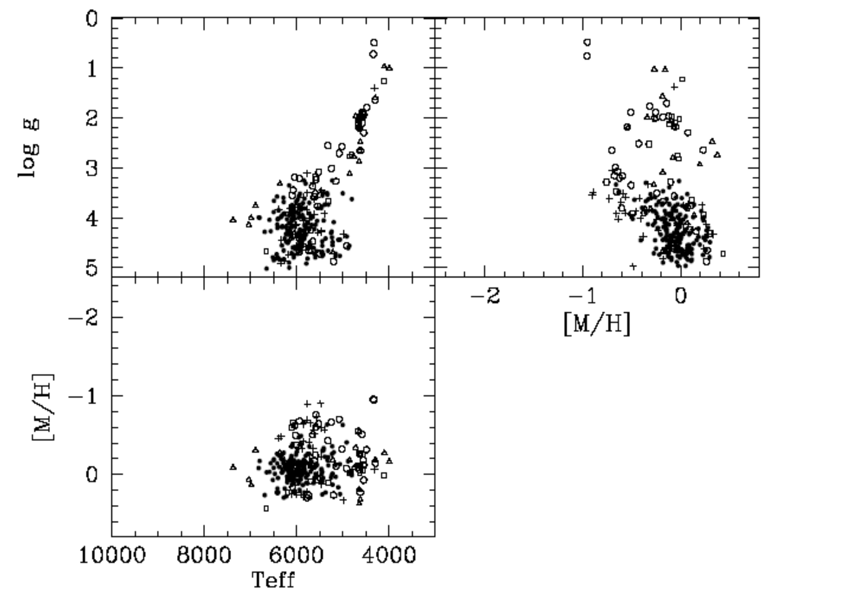
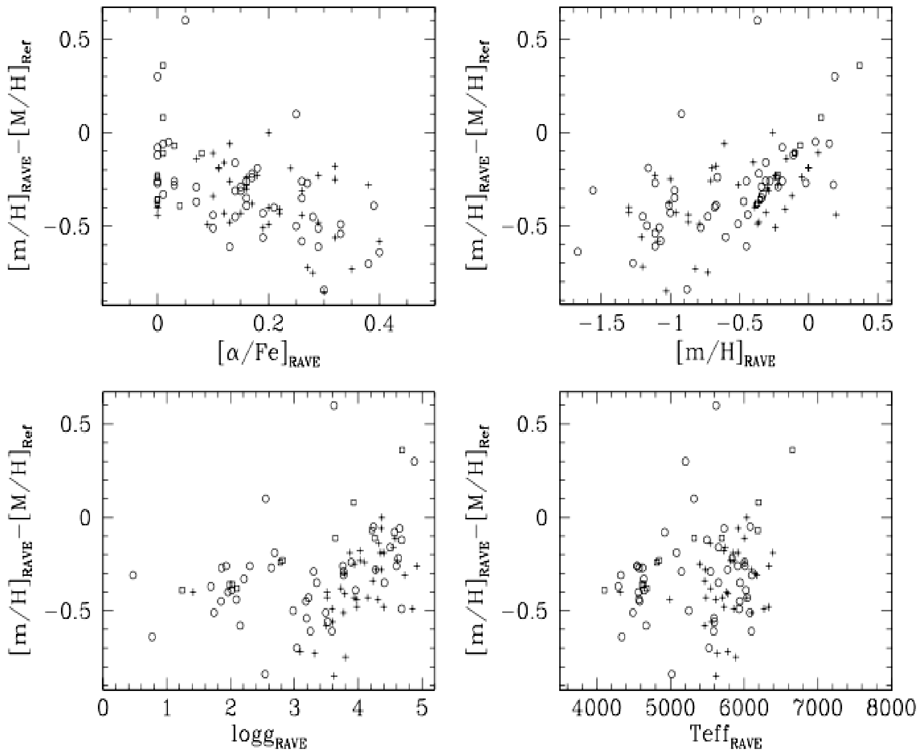


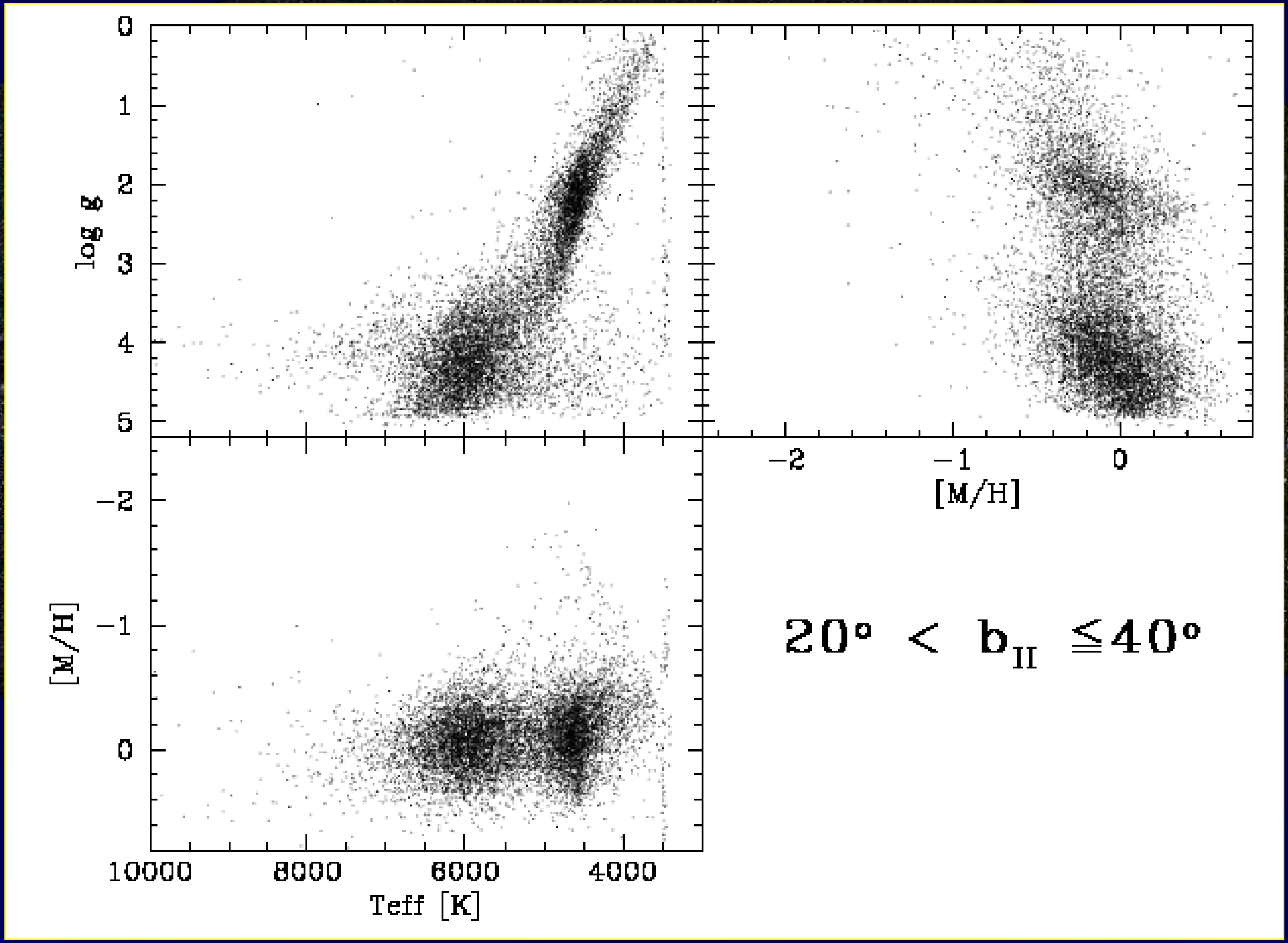
Fig. 13.— Objects from external datasets on the temperature–gravity–metallicity wedge using the values determined from RAVE spectra. Symbols code individual datasets which were used to check the values of stellar parameters: GCS (●), Apache Point (○), Soubiran (+), M67 (□), and Asiago (△).



Datasets used to check stellar parameters

Reference Dataset	N	$T_{\rm eff}$	$\log g$	[M/H]
Apache Point echelle	45	√	√	√
Asiago echelle	24	√	√	√
Soubiran & Girard catalog	49	√		√
M67 members	12			√
Geneva Copenhagen Survey	211	√		

Derived stellar parameter values



Giants & dwarfs

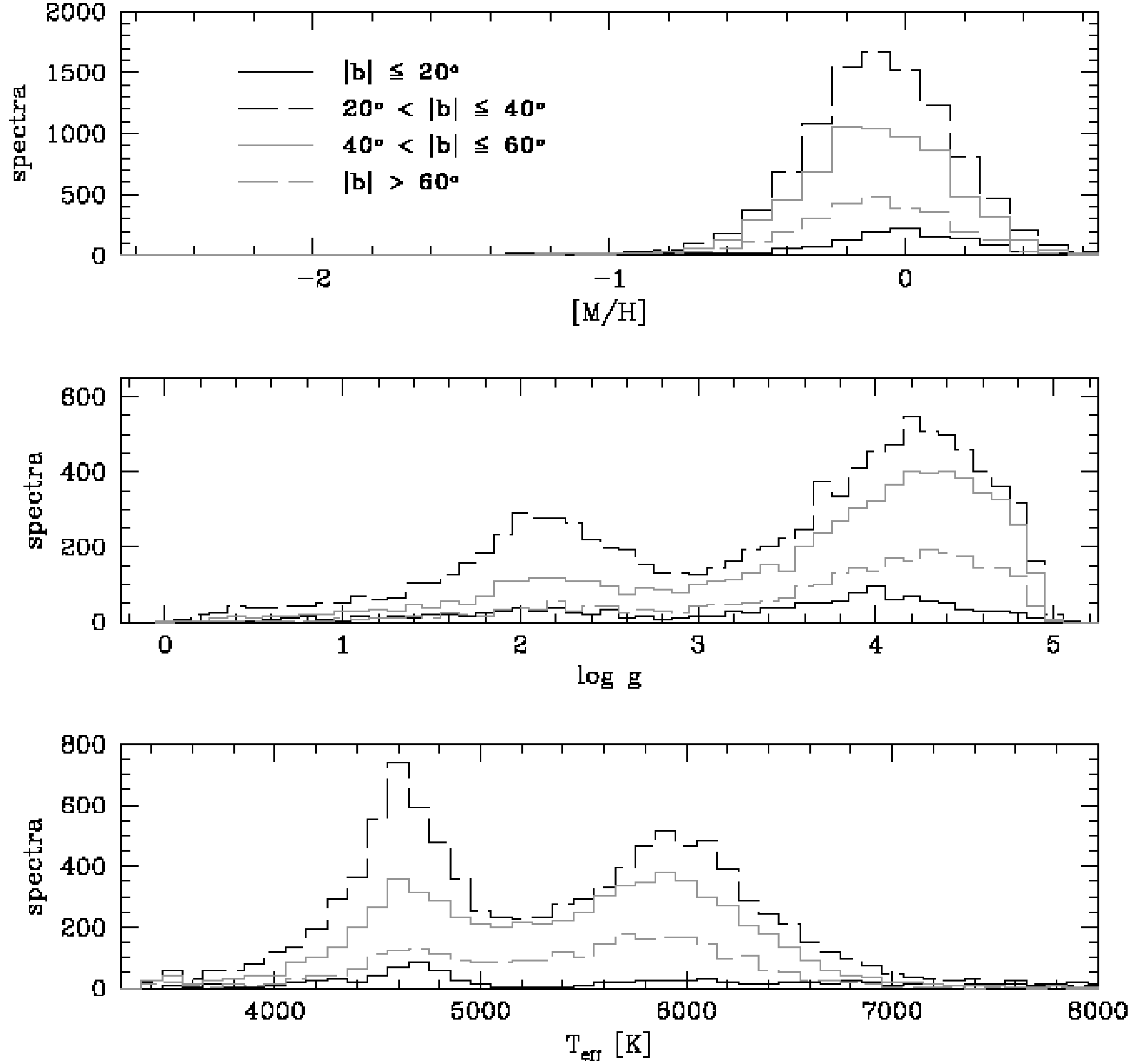


Fig. 23.— Temperature, gravity, and metallicity histograms for spectra with published stellar parameters. Histograms for individual Galactic latitude bands are plotted separately with the key given in the top panel. Spectra with $|b| \leq 20^o$ are calibration fields. Note the increasing fraction of main sequence stars at high Galactic latitudes.

Complementary photometric and astrometric data

Number and fraction of RAVE database entries with a counterpart in the photometric catalogs

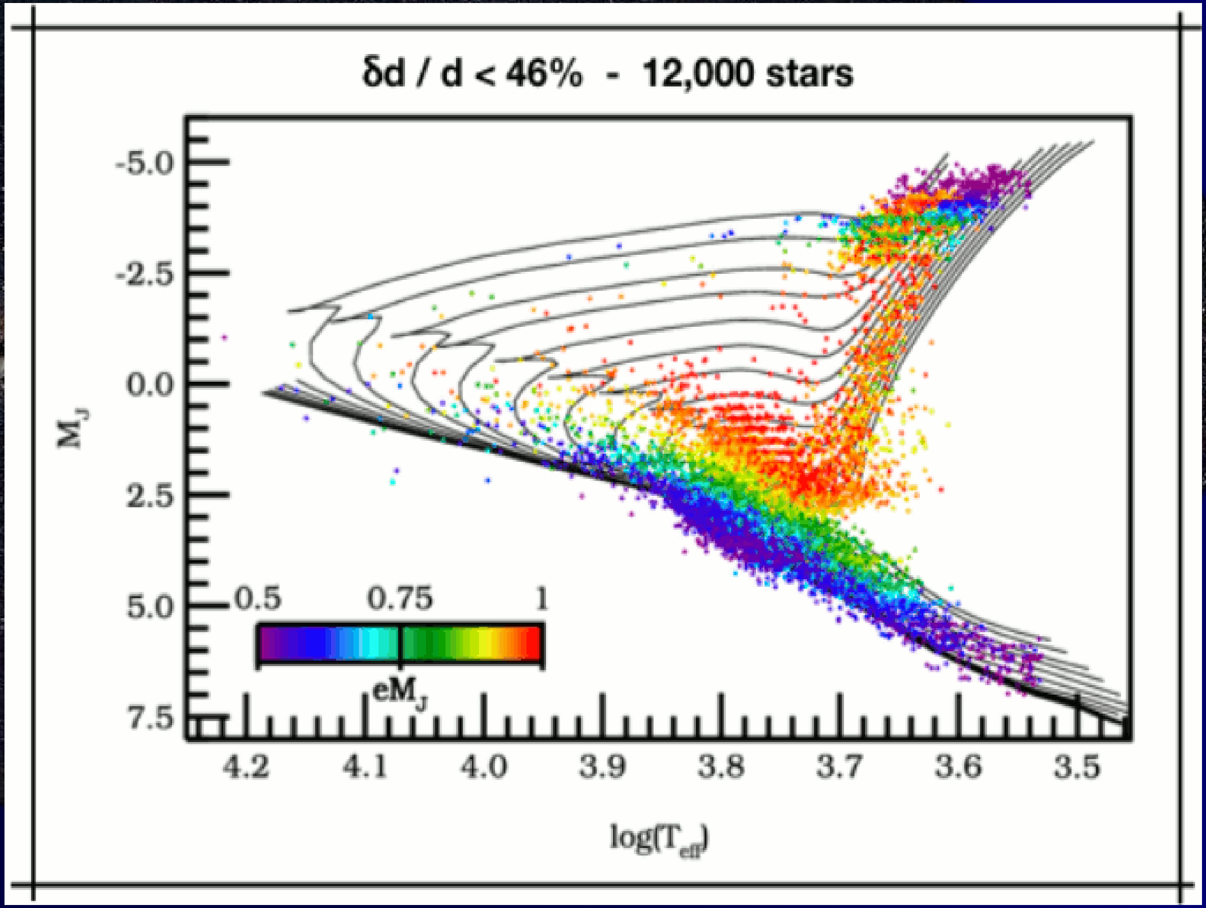
Catalog name	Number of Entries	% of Entries with Counterpart	% with quality flag A	B	C	D
2MASS	51,813	99.97%	99.6%	0%	0%	0.4%
DENIS	40,106	77.4 %	73.7%	23.5%	2.3%	0.5%
USNO-B	51,466	99.3 %	99.2%	0.5%	0%	0.3%

Summary of proper motion sources and their average and 90% errors

SPM Flag	Catalog Name	Number of Entries	Fraction of entries	Average PM error [mas yr^{-1}]	90% PM error [mas yr^{-1}]
0	No proper motion	74	0.1%		
1	Tycho-2	879	1.7%	2.9	4.0
2	SSS	3,427	6.6%	23.7	31.7
3	STARNET 2.0	31,739	61.2%	3.3	4.6
4	2MASS+GSC 1.2	62	0.1%	18.7	26.1
5	UCAC2	15,047	29.0%	6.7	11.1
1-5	all with proper motion	51,154	98.7%	5.7	10.6

Closing the loop: photometric distances

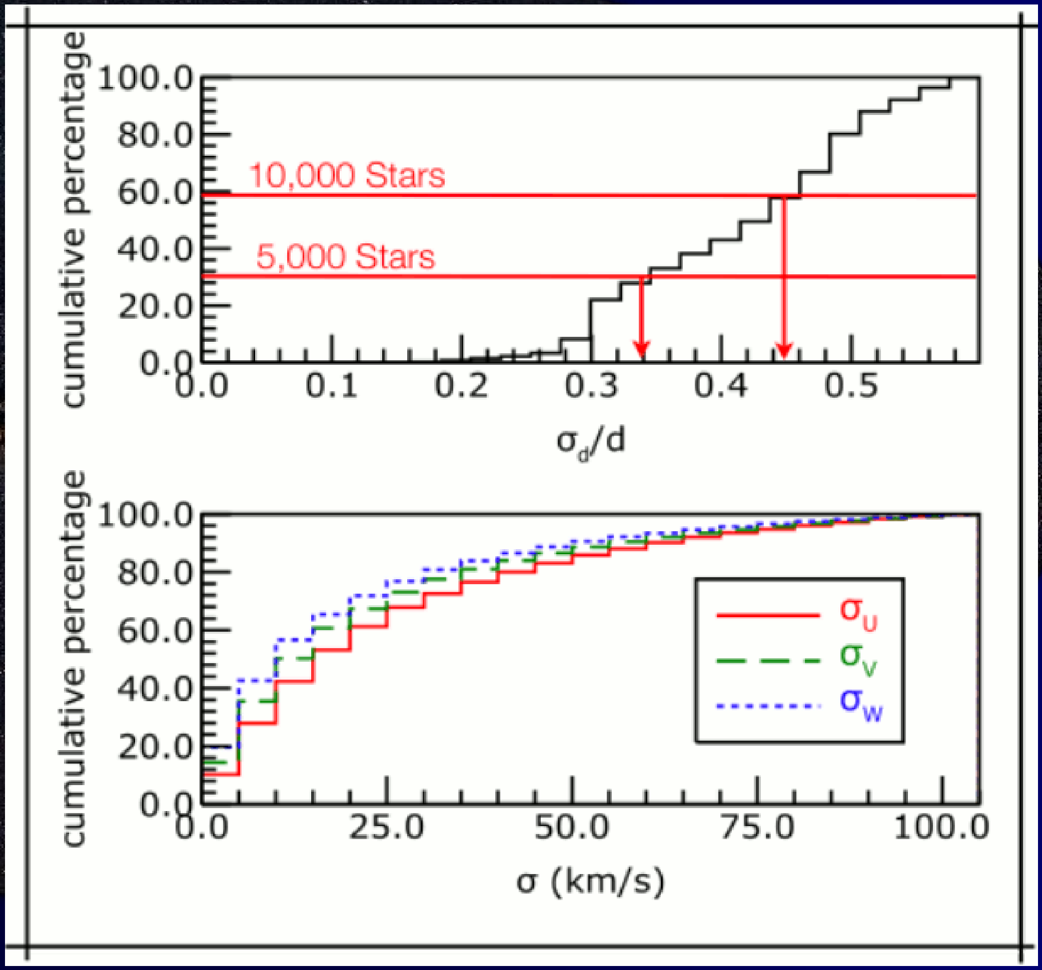
Breddels, Helmi, Smith et al. in preparation



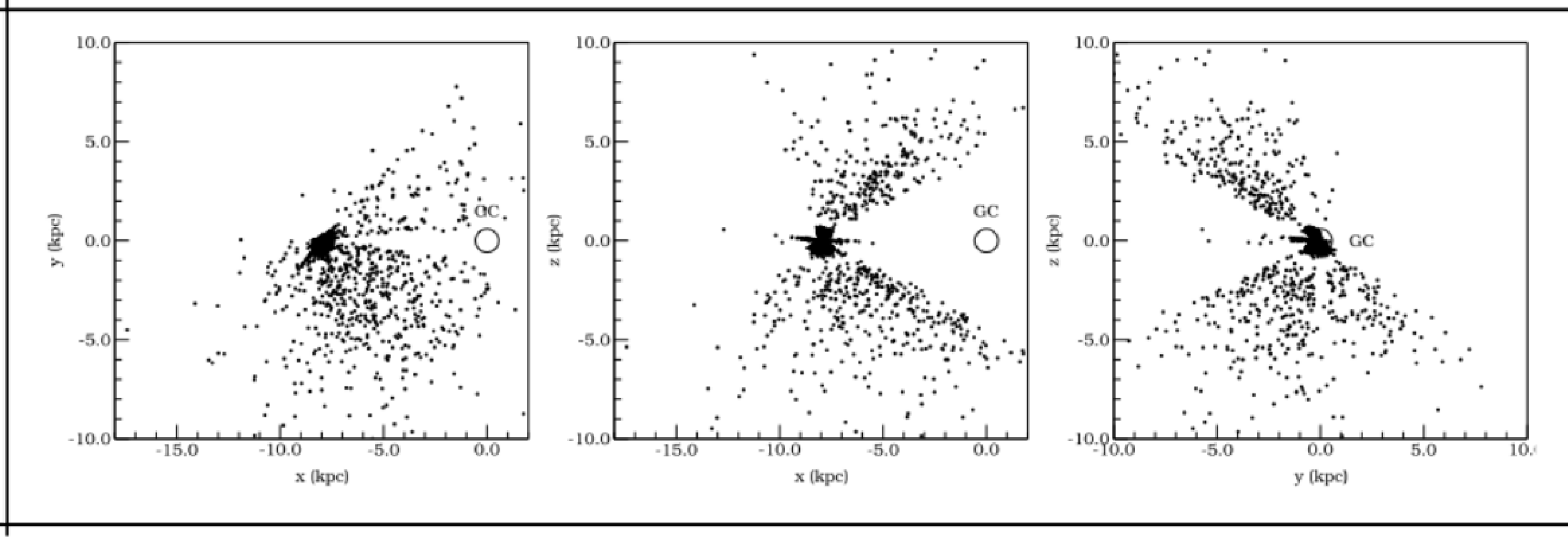
Distances determined for ~17,000 stars. For 5,000 stars distance errors are < 35%.

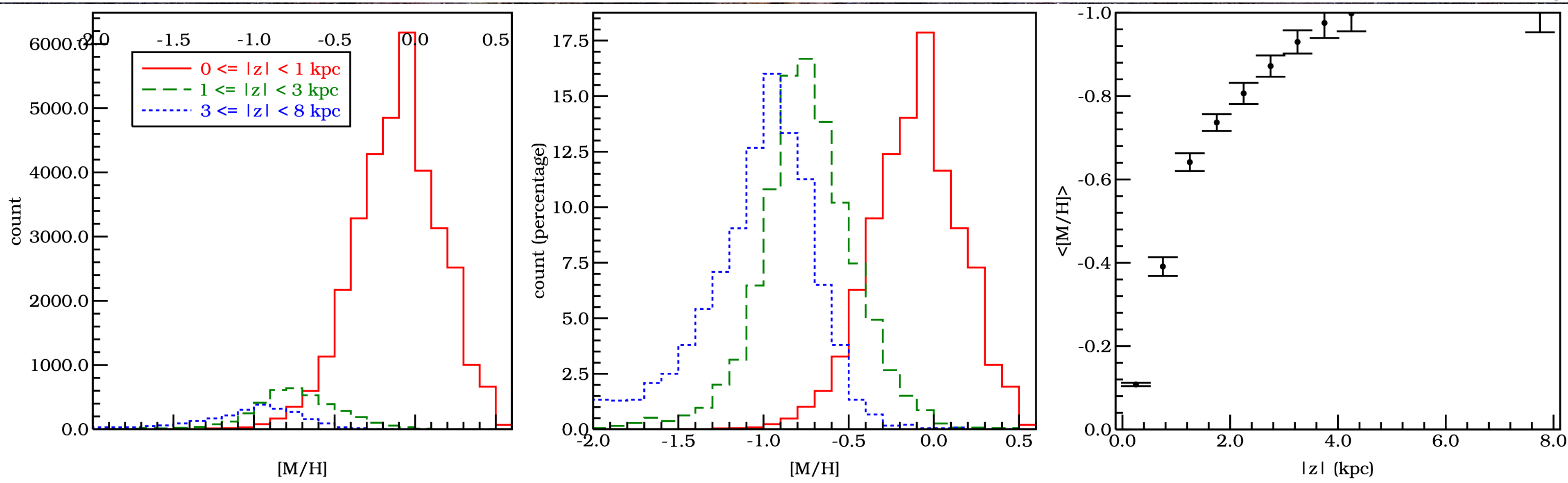
Closing the loop: photometric distances

Breddels, Helmi, Smith et al. in preparation



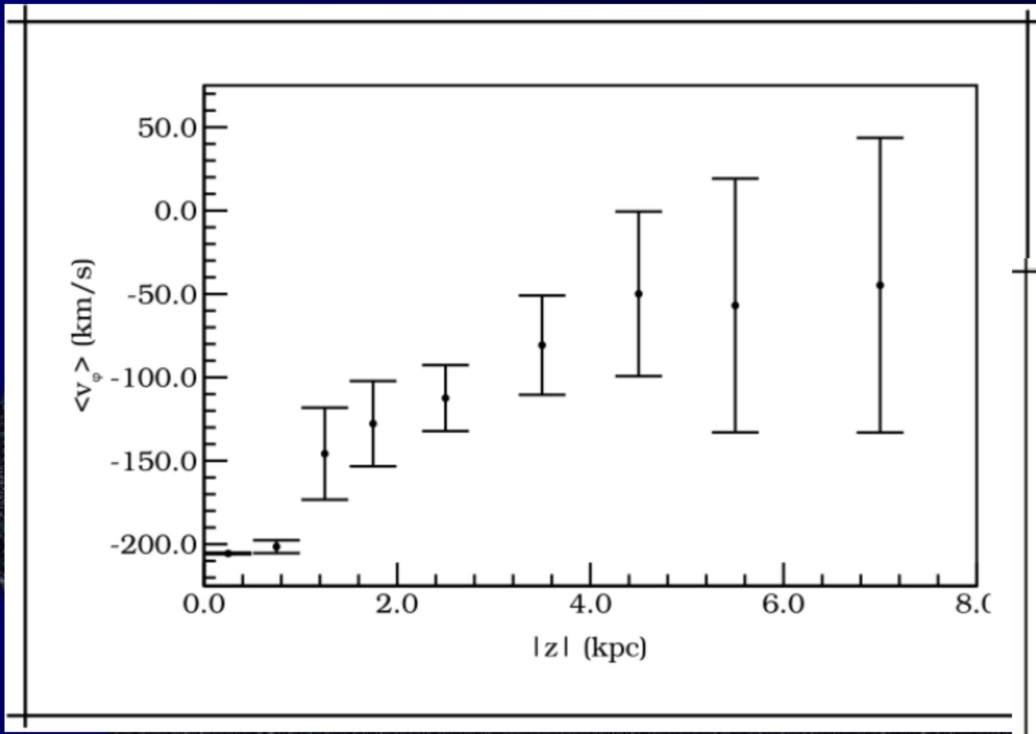
Distances determined for ~17,000 stars. For 5,000 stars distance errors are < 35%.

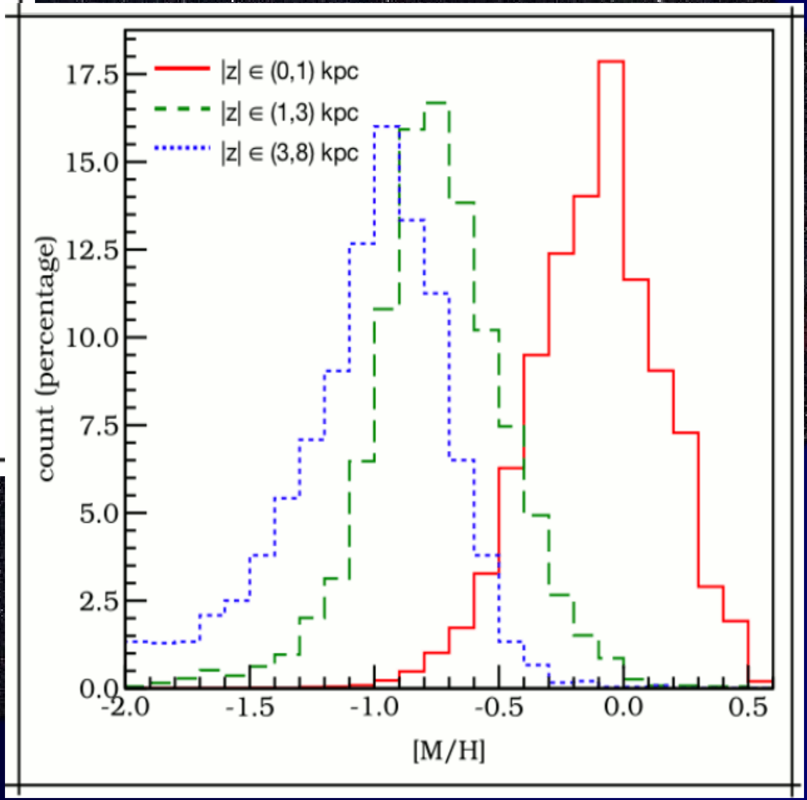




Breddels, Helmi, Smith et al. in preparation

Galactic rotation and metallicity vs. height





Breddels, Helmi, Smith et al. in preparation

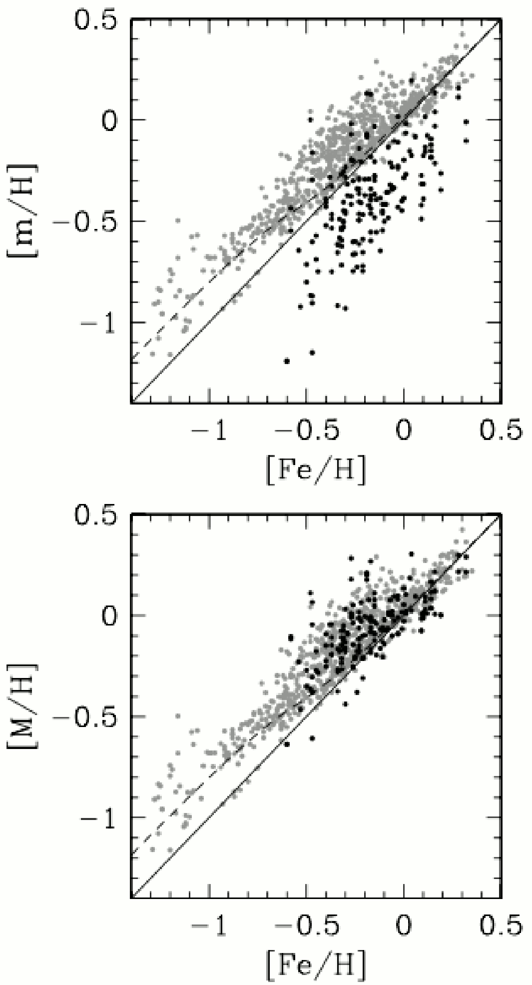


Figure 17. Relation between iron abundance and metallicity. The gray points mark the positions of all stars in the Soubiran & Girard (2005) catalog. The black ones are RAVE observations of stars from the GCS, with the uncalibrated values of metallicity in the top graph and the calibrated ones in the bottom one. The solid line traces the 1:1 relation, while the dashed one is the mean relation between the iron abundance and the metallicity derived from the APO observations (Equation (21)).

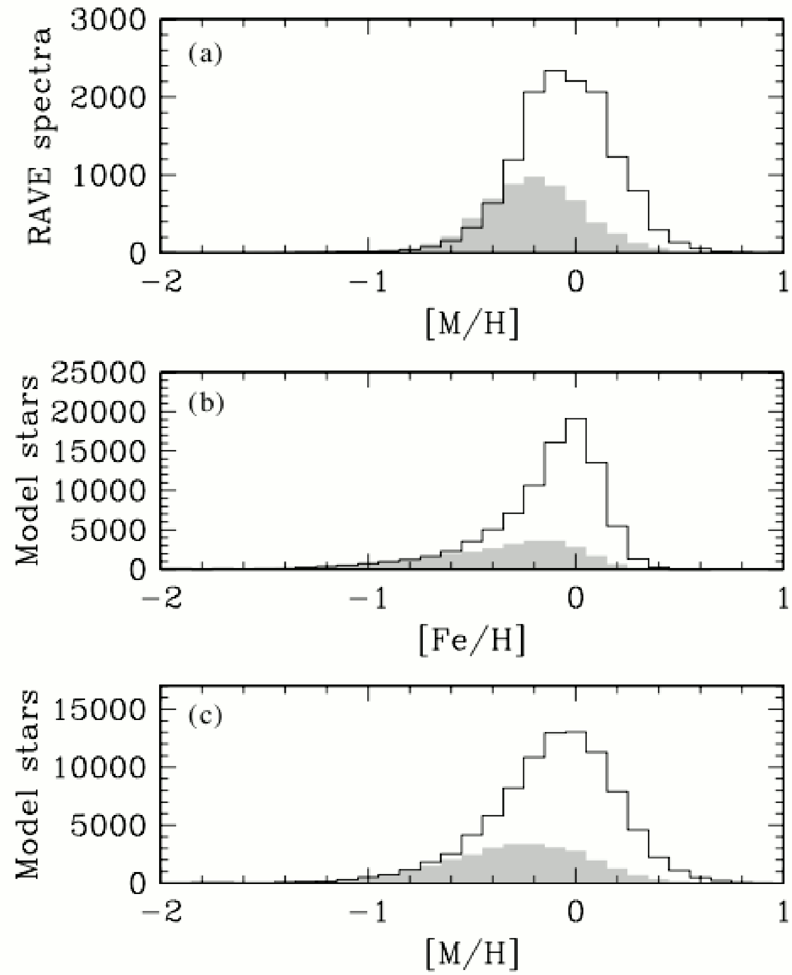
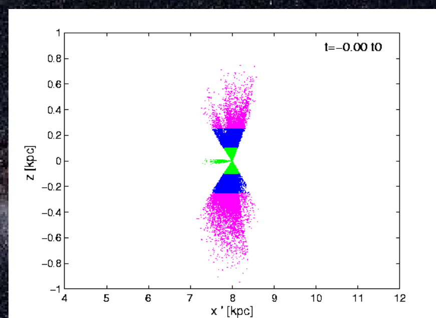


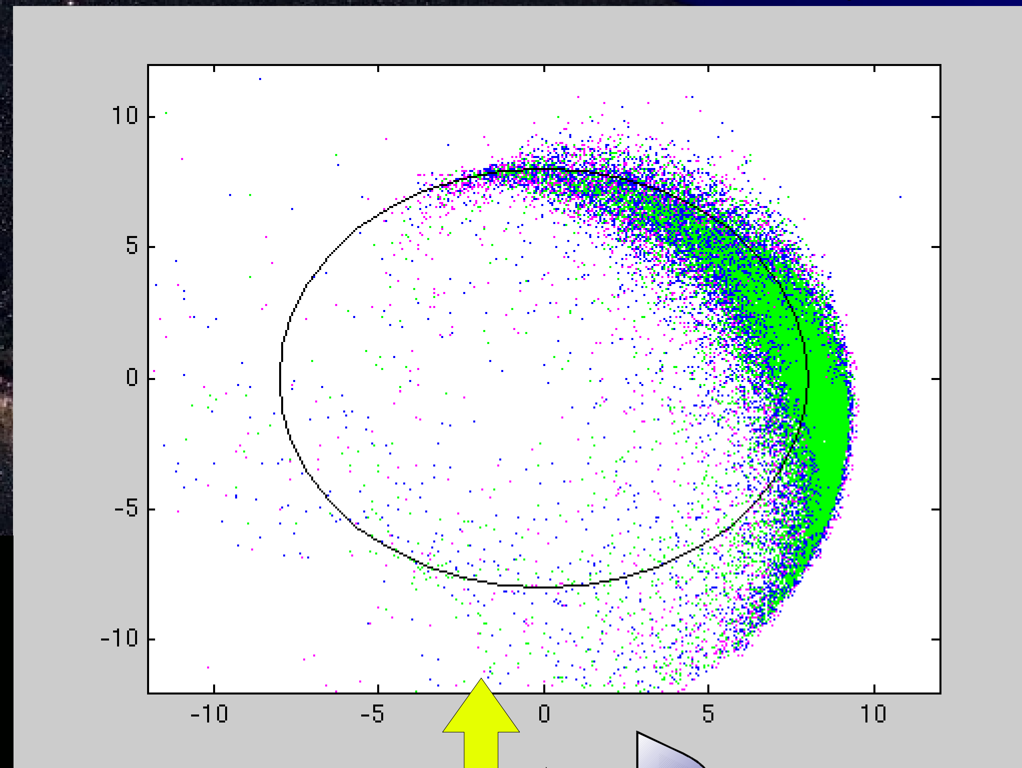
Figure 18. Comparison of the metallicity of the observed targets to the iron abundances from the Besançon model. The clear and the shaded histograms mark high gravity ($\log g > 3.0$) and low gravity ($\log g \leqslant 3.0$) objects. Panel (a) plots all RAVE spectra with $|b| \geqslant 25^{\circ}$. Panel (b) is a distribution of stars drawn at random from the Besançon model. The stars are more than 25° from the plane and have the same distribution of I apparent magnitudes as I_{DENIS} magnitudes in RAVE. Panel (c) is a histogram from the same Besançon model, using the iron abundance to metallicity relation from Equation (21) and convolved with typical RAVE observational errors.

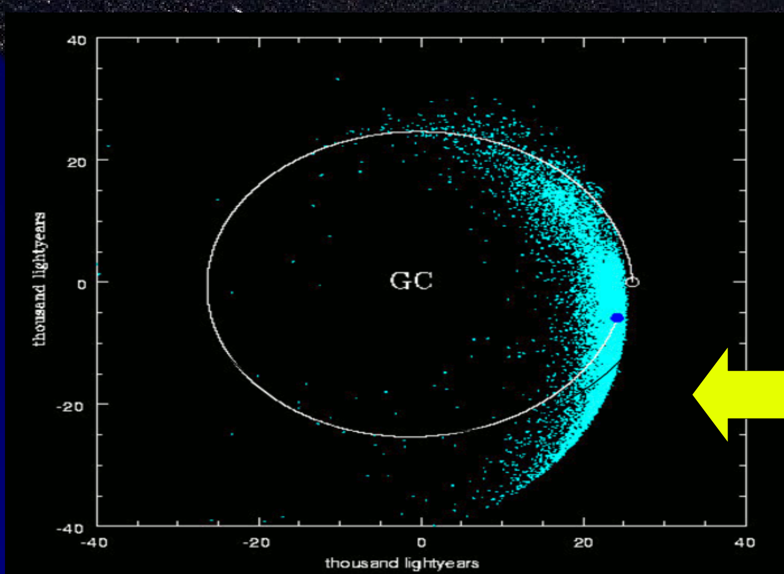
Face-on with of RAVE stars 220 million years ago

Liza Mijović, 2005

Colour-coding according to the present distance from the Galactic plane.







RAVE

GCS

Conclusions – what is available

www.rave-survey.org

Data release	Reference	Status	What's published		
			Radial velocities	Stellar parameter sets	Spectral tracings
	Steinmetz et al.(2006)	published	25k		
	Zwitter et al.(2008)	in print	50k	25k	
	Siebert et al. (2009)	in prep.	~150k	~100k	[X/Fe]
	observed so far		~280k	200+ k	yes

+ lists & properties of discovered binaries, emission & peculiar stars
+ automated schemes for (quentitative) classification & quality control (see poster by Paola Re Fiorentin)
+ derived papers on Galactic physics (poster by B. Anguiano, and many talks of RAVErs)