Lessons from RAVE for a stellar science with GCDS



Tomaž Zwitter & Ulisse Munari

The talk can be found at www.fiz.uni-lj.si/astro/tmp/zwitter_nice20101103.pdf

Results

Burnett et al. 2010, Distance determination for RAVE stars III: The nature of the RAVE survey and Milky Way chemistry
Williams et al. 2010, The Dawning of the Stream of Aquarius in RAVE
Siebert et al. 2010, Detection of a radial velocity gradient in the extended local disc with RAVE
Coskunoglu et al. 2010, Local Stellar Kinematics from RAVE Data I. Local Standard of Rest
Wilson et al. 2010, Testing formation mechanisms of the Milky Way's thick disc with RAVE
Pasetto et al. 2010, Thin disk kinematics from RAVE and the solar motion
Pasetto et al. 2010, Thick disk kinematics from RAVE and the solar motion
Fulbright et al. 2010, The RAVE survey: rich in very metal-poor stars
Zwitter et al. 2010, Distance determination for RAVE stars using stellar models II. Most likely values assuming a standard stellar evolution scenario
Kiss et al., 2010, A search for new members of the βPictoris, Tucana-Horologium and εCha moving groups in the RAVE data base
Ruchti et al. 2010, Origins of the Thick Disk as Traced by the Alpha Elements of Metal-poor Giant Stars Selected from Rave
Matijevič et al. 2010, Double-lined Spectroscopic Binary Stars in the Radial Velocity Experiment Survey
Breddels et al. 2010, Distance determination for RAVE stars using stellar models
Munari et al. 2009, RAVE spectroscopy of luminous blue variables in the Large Magellanic Cloud
Siebert et al. 2008, Estimation of the tilt of the stellar velocity ellipsoid from RAVE and implications for mass models
Munari et al. 2008, Diffuse interstellar bands in RAVE survey spectra
Zwitter et al. 2008, The Radial Velocity Experiment (rave): Second Data Release
Veltz et al. 2008, Galactic kinematics with RAVE data. I. The distribution of stars towards the Galactic poles
Seabroke et al. 2008, Is the sky falling? Searching for stellar streams in the local Milky Way disc in the CORAVEL and RAVE surveys
Smith et al. 2007, The RAVE survey: constraining the local Galactic escape speed
Steinmetz et al. 2006, The Radial Velocity Experiment (RAVE): First Data Release

Plan of the talk

RAVE:

- project structure,
- data reduction,
- standard of reference,
- external and internal quality control,
- errors on stellar parameters including distances.

Stellar science:

- Stellar ages of main sequence stars from gyro-chronology.
- Understanding the contributions from SLOAN photometry.
- Interstellar reddening from photometry, IS lines and DIBs.

Lesson 1: What is in the name?



Lesson 1: What is in the name?

GCDS



Lesson 1: What is in the name?

Good Citizen Dog Training Scheme, the UK's largest dog training programme

GCDS

The Kennel Club Good Citizen Dog Scheme is the largest dog training scheme in the UK. Its aim is to promote responsible dog ownership and in turn, enhance our relationship with our pets and to make the community aware of the benefits associated with dog ownership.

You can search GCDS dog training clubs by county here



The **Good Citizen Dog Scheme Guidelines** handbook is available to purchase from the Online Shop book section. Price is £3.00.

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- Dog training - getting started
- GCDS Bronze Award (PDF)
- GCDS Silver Award (PDF)
- GCDS Gold Award (PDF)
- GCDS Puppy Foundation (PDF)
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Lesson 1: What is in the name?



Structure of the Project

RAVE RAdial Velocity Experiment People



Workpackages

Radial Velocity Pipeline			
Arnaud	Siebert	Potsdam	(Germany)

Metallicity and Abundances			
Corrado	Boesche	AIP	(Germany)
Arnaud	Siebert	Potsdam	(Germany)

Binaries Detection			
Arnaud	Siebert	Potsdam	(Germany)
Tomaz	Zwitter	Ljubjana	(Slovenia)

6dFdr			
George	Seabrook	Cambridge	(UK)

Flat Fielding			
Ken	Freeman	Mount Stromlo	(Australia)

Data Reduction Pipeline			
Tomaz	Zwitter	Ljubjana	(Slovenia)

Cross-talk and Bootstrapping			
Ken	Freeman	Mount Stromlo	(Australia)

Data reduction Quality			
Rachel	Campbell	MacQuarie	(Australia)
Quentin	Parker	MacQuarie	(Australia)

Cross Identification			
Ivan	Minchev	Rochester	(USA)
Alice	Quillen	Rochester	(USA)

PSF Variation			
Quentin	Parker	MacQuarie	(Australia)

Independant Observations			
Olivier	Bienayme	Strasbourg	(France)
Ken	Freeman	Mount Stromlo	(Australia)
Ulisse	Munari	Padova	(Italy)

Observing Schedule			
Rachel	Campbell	MacQuarie	(Australia)





Principal Investigator			
Matthias	Steinmetz	Potsdam	(Germany)

Project Scientist			
Tomaz	Zwitter	Ljubjana	(Slovenia)

Project Manager			
Fred	Watson	AAO	(Australia)

Science Coordinator			
Ken	Freeman	Mount Stromlo	(Australia)

Data Managment Group			
Quentin	Parker	MacQuarie	(Australia)

Input Catalog Group			
Rosie	Wyse	Johns Hopkins	(USA)

Executive Board			
Olivier	Bienayme	Strasbourg	(France)
Ken	Freeman	Mount Stromlo	(Australia)
Gerry	Gilmore	Cambridge	(UK)
Eva	Grebel	Basel	(Switzerland)
Amina	Helmi	Groningen	(Netherlands)
Ulisse	Munari	Padova	(Italy)
Julio	Navarro	Victoria	(Canada)
Matthias	Steinmetz	Potsdam	(Germany)
Fred	Watson	AAO	(Australia)
Rosie	Wyse	Johns Hopkins	(USA)
Tomaz	Zwitter	Ljubjana	(Slovenia)



RAVEing Institutes:			
Astrophysical Institute Potsdam	Germany	Astronomisches Recheninstitut Heidelberg	Germany
Anglo-Australian Observatory	Australia	University of Basel	Switzerland
IoA Cambridge	UK	Steward Observatory	USA
University of Oxford	UK	Observatoire de Strasbourg	France
University of Leicester	UK	University of Ljubljana	Slovenia
Swinburne University	Australia	Institue for Astronomy Edinburgh	UK
University of Groningen	The Netherlands	University of Rochester	USA
Padova Observatory	Italy	University of Victoria	Canada
Macquarie University	Australia	Johns Hopkins University	USA
Mount Stromlo Observatory	Australia		

Input Catalog Group			
Olivier	Bienayme	Strasbourg	(France)
Ken	Freeman	Mount Stromlo	(Australia)
Gerry	Gilmore	Cambridge	(UK)
Rosie	Wyse	Johns Hopkins	(USA)
George (Ulisse	Seabroke Munari)	Cambridge Padova	(UK) (Italy)

Observers			
Donna	Burton	AAO	(Australia)
Paul	Cass	AAO	(Australia)
John	Dawe	AAO	(Deceased)
Kristin	Fiegert	AAO	(Australia)
Malcolm	Hartley	AAO	(Australia)
Ken	Russel	AAO	(Australia)

PhD / Postdoc Observers			
Dominik	Argast	Basel	(Switzerland)
Corrado	Boeche	Potsdam	(Germany)
Rachel	Campbell	MacQuearie	(Australia)
George	Seabrook	Cambridge	(UK)
Lional	Veltz	Strasbourg	(France)

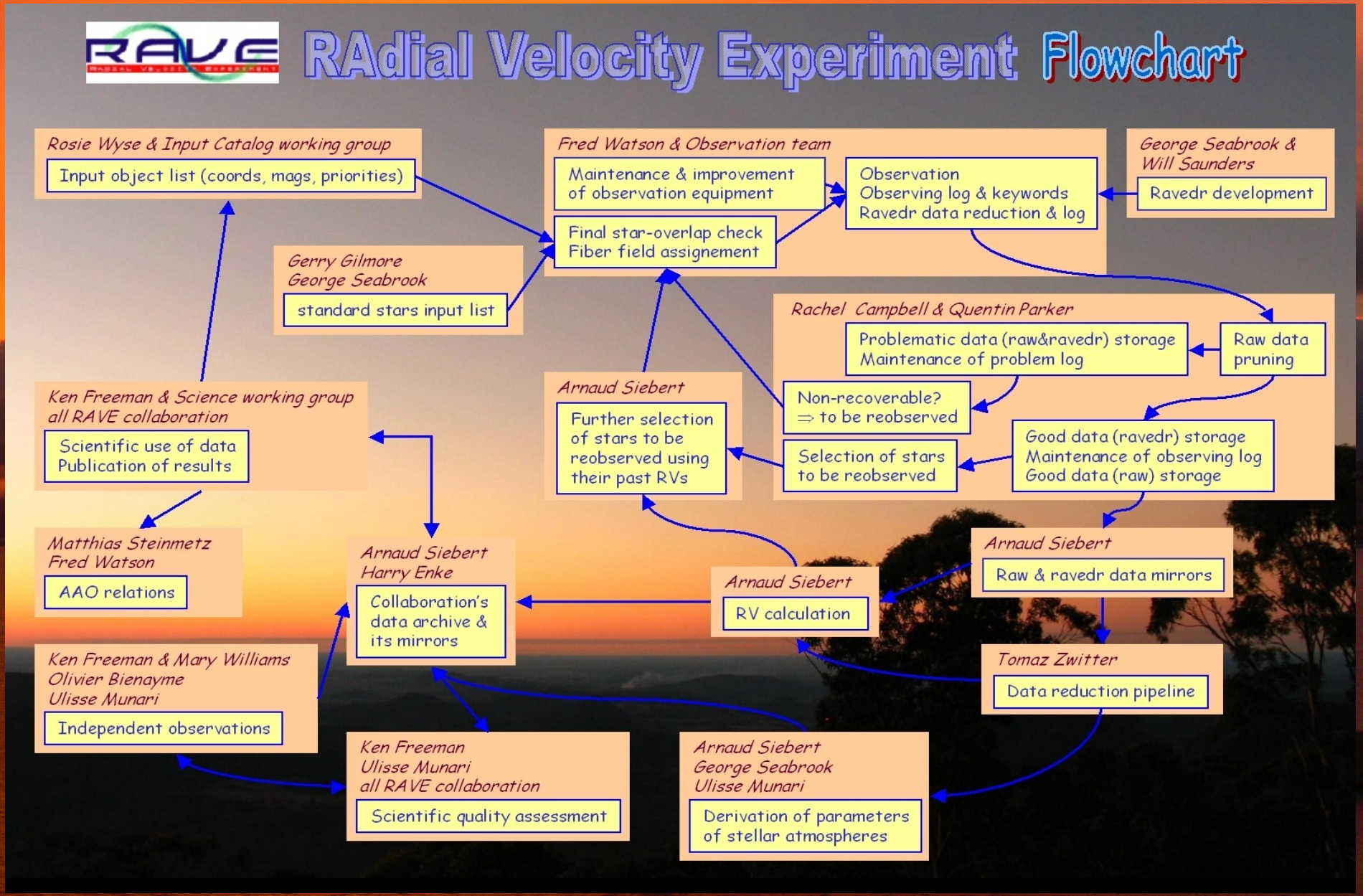
Data Management Group			
Olivier	Bienayme	Strasbourg	(France)
Corrado	Boeche	Potsdam	(Germany)
Rachel	Campbell	MacQuarie	(Australia)
Ken	Freeman	Mount Stromlo	(Australia)
Urtzi	Jauregi	Ljubjana	(Slovenia)
Ivan	Minchev	Rochester	(USA)
Ulisse	Munari	Padova	(Italy)
Quentin	Parker	MacQuarie	(Australia)
Alice	Quillen	Rochester	(USA)
Mike	Read	Edinburgh	(UK)
Siegfried	Roeser	Heidelberg	(Germany)
George	Seabrook	Cambridge	(UK)
Arnaud	Siebert	Potsdam	(Germany)
Tomaz	Zwitter	Ljubjana	(Slovenia)



Science Working Group			
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Gerry	Gilmore	Cambridge	(UK)
Eva	Grebel	Basel	(Switzerland)
Amina	Helmi	Groningen	(Netherlands)
Ulisse	Munari	Padova	(Italy)
Julio	Navarro	Victoria	(Canada)
Matthias	Steinmetz	Potsdam	(Germany)
Rosie	Wyse	Johns Hopkins	(USA)

RAVE Collaboration			
Jeremy	Bailin	Swinburne	(Australia)
Olivier	Bienayme	Strasbourg	(France)
James	Binney	Oxford	(UK)
Corrado	Boeche	AIP	(Germany)
Joss	Bland-Hawthorn	AAO	(Australia)
Brian	Boyle	AAO	(Australia)
Donna	Burton	AAO	(Australia)
Laurent	Cambresy	Strasbourg	(France)
Rachel	Campbell	MacQuarie	(Australia)
Paul	Cass	AAO	(Australia)
John	Dawe	AAO	(Deceased)
Walter	Dehnen	Leicester	(UK)
Daniel	Eisenstein	Arizona	(USA)
Wyn	Evans	Cambridge	(UK)
Kristin	Fiegert	AAO	(Australia)
Massimo	Fiorucci	Perugia	(Italy)
Ken	Freeman	Mount Stromlo	(Australia)
Alain	Fresneau	Strasbourg	(France)
Jon	Fulbright	Johns Hopkins	(USA)
Ortwin	Gerhard	Basel	(Switzerland)
Brad	Gibson	Swinburne	(Australia)
Gerry	Gilmore	Cambridge	(UK)
Eva	Grebel	Basel	(Switzerland)
Malcolm	Hartley	AAO	(Australia)
Mike	Hawkins	Edinburgh	(UK)
Amina	Helmi	Groningen	(Netherlands)
Urtzi	Jauregi	Ljubjana	(Slovenia)
Daisuke	Kawata	Swinburne	(Australia)
Andreas	Kelz	Potsdam	(Germany)
Erik	Mamajek	CfA	(USA)
Ivan	Minchev	Rochester	(USA)
Ulisse	Munari	Padova	(Italy)
Julio	Navarro	Victoria	(Canada)
Quentin	Parker	MacQuarie	(Australia)
Genevieve	Parmentier	Cambridge	(UK)
Alice	Quillen	Rochester	(USA)
Mike	Read	Edinburgh	(UK)
Sabine	Reffert	Sterrewacht Leiden	(Netherlands)
Siegfried	Roeser	Heidelberg	(Germany)
Ken	Russel	AAO	(Australia)
Gregory	Ruchti	Johns Hopkins	(USA)
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Ralf	Scholz	Potsdam	(Germany)
George	Seabrook	Cambridge	(UK)
Arnaud	Siebert	Potsdam	(Germany)
Martin	Smith	Groningen	(Netherlands)
Matthias	Steinmetz	Potsdam	(Germany)
Lionel	Veltz	Strasbourg	(France)
Fred	Watson	AAO	(Australia)
Mary	Williams	Mount Stromlo	(Australia)
Rosie	Wyse	Johns Hopkins	(USA)
Tomaz	Zwitter	Ljubjana	(Slovenia)

Structure of the Project



Data reduction: monitoring fiber performance

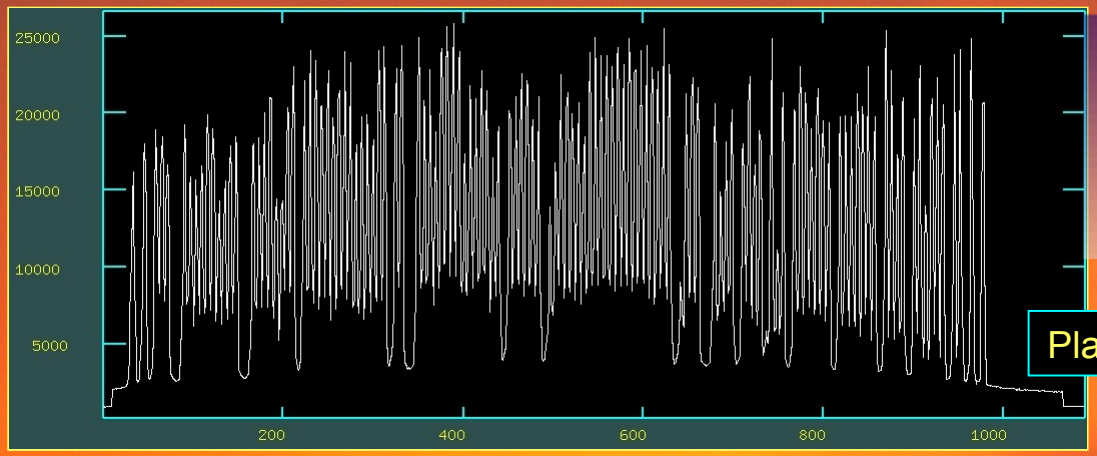


Plate 3

Median of 5x14 sec flat fields

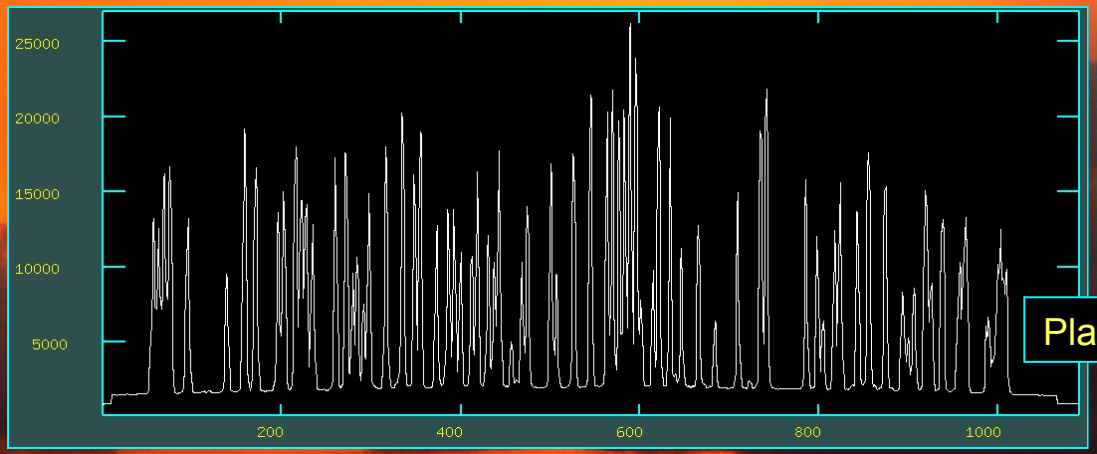


Plate 2 – prior to its current refurbishment

Median of 5x25 sec flat fields

Very important: easy access to fiber repairs

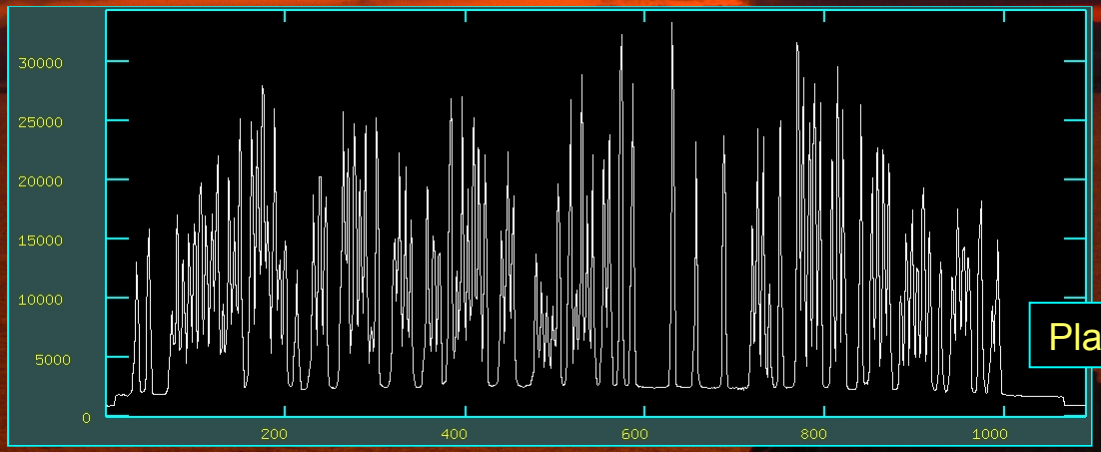
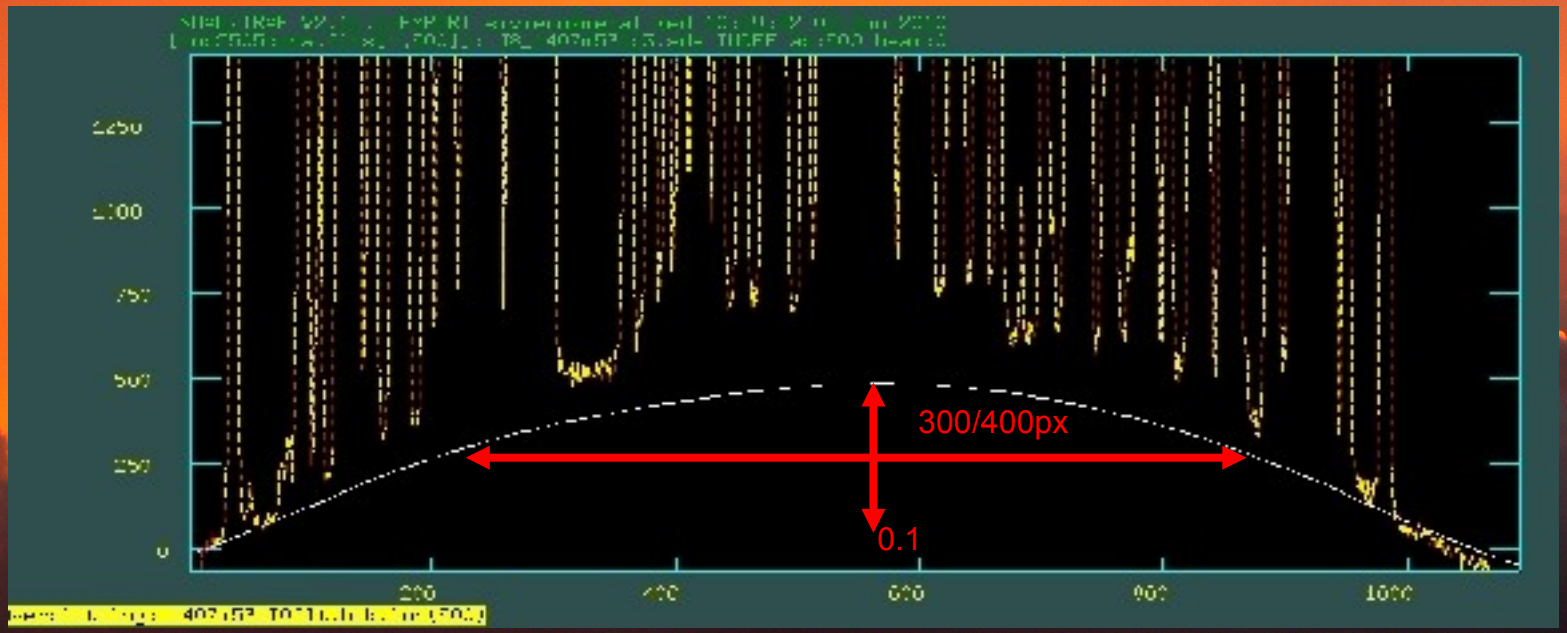


Plate 1 – after it was refurbished in May 2009

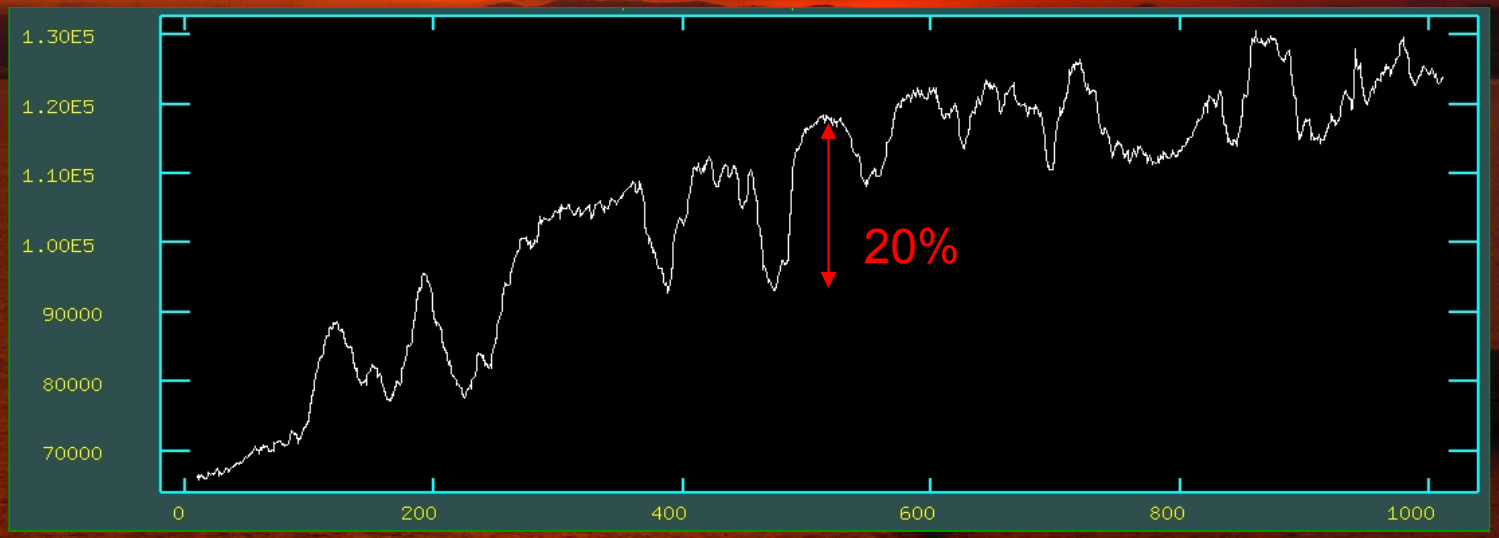
Median of 5x25 sec flat fields

Courtesy: A. Siviero

Scattered light, fiber cross-talk & fringing

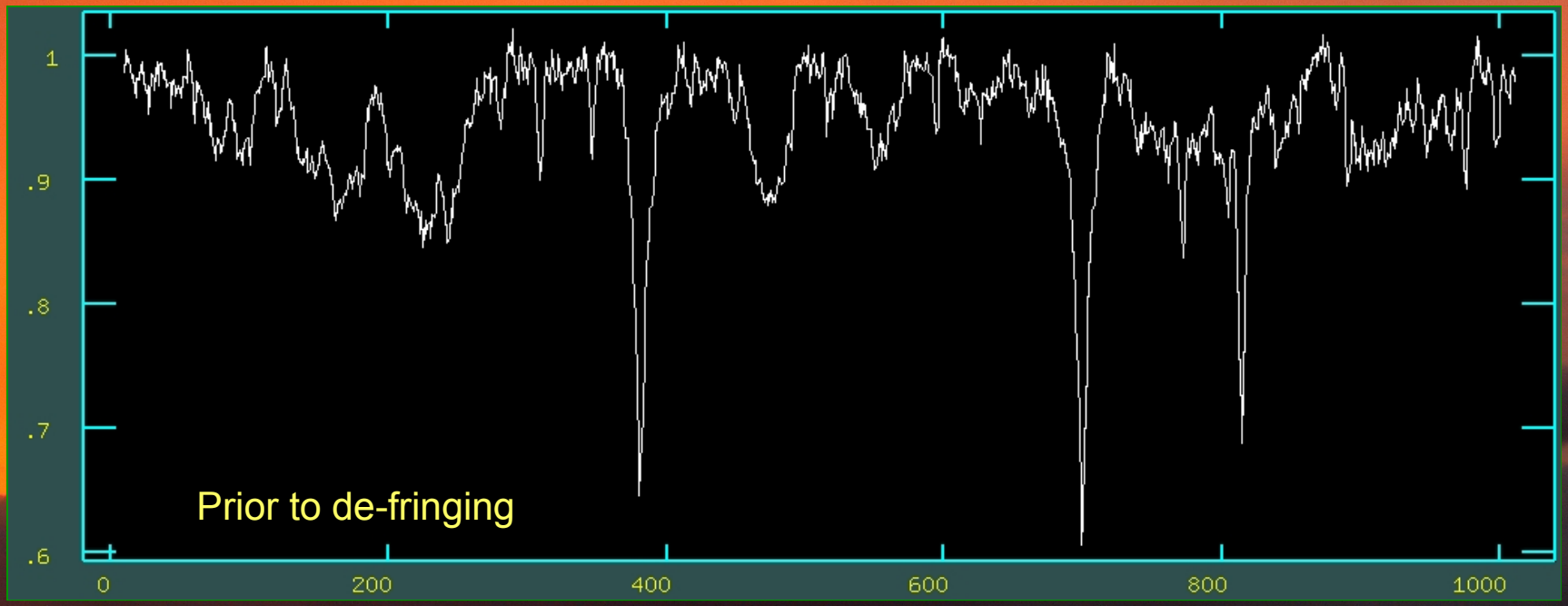


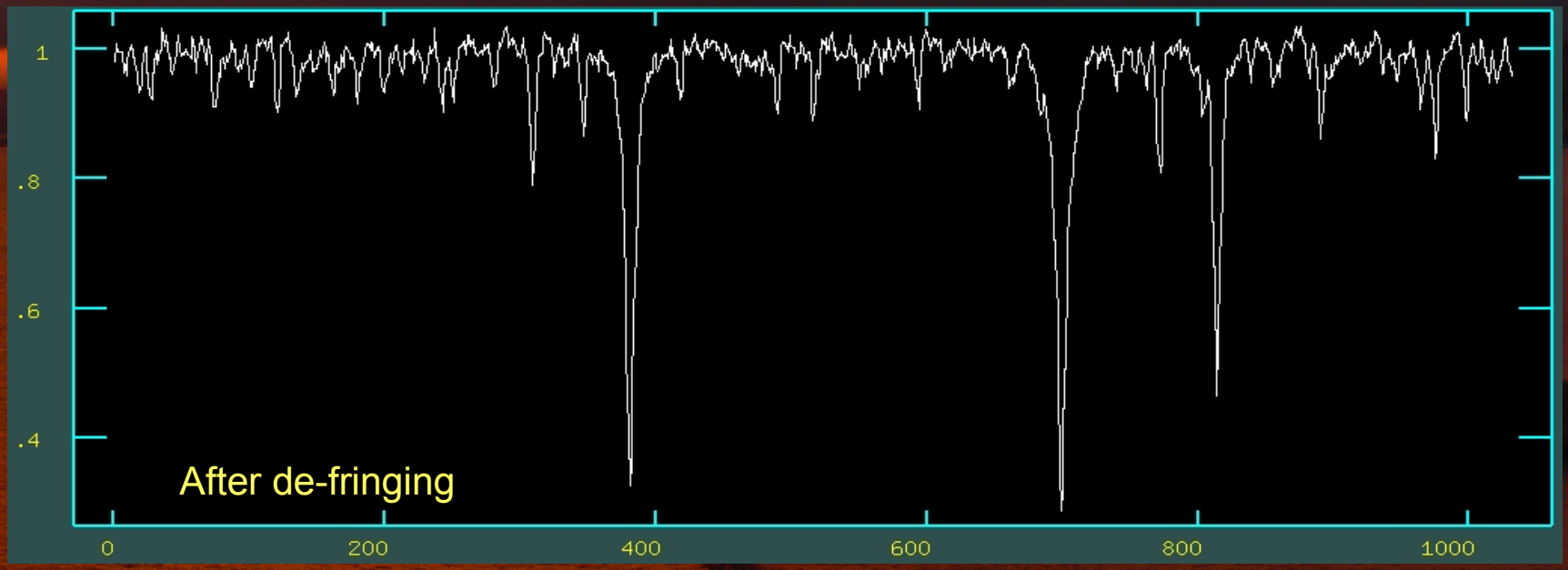
Modelling the scattered light.



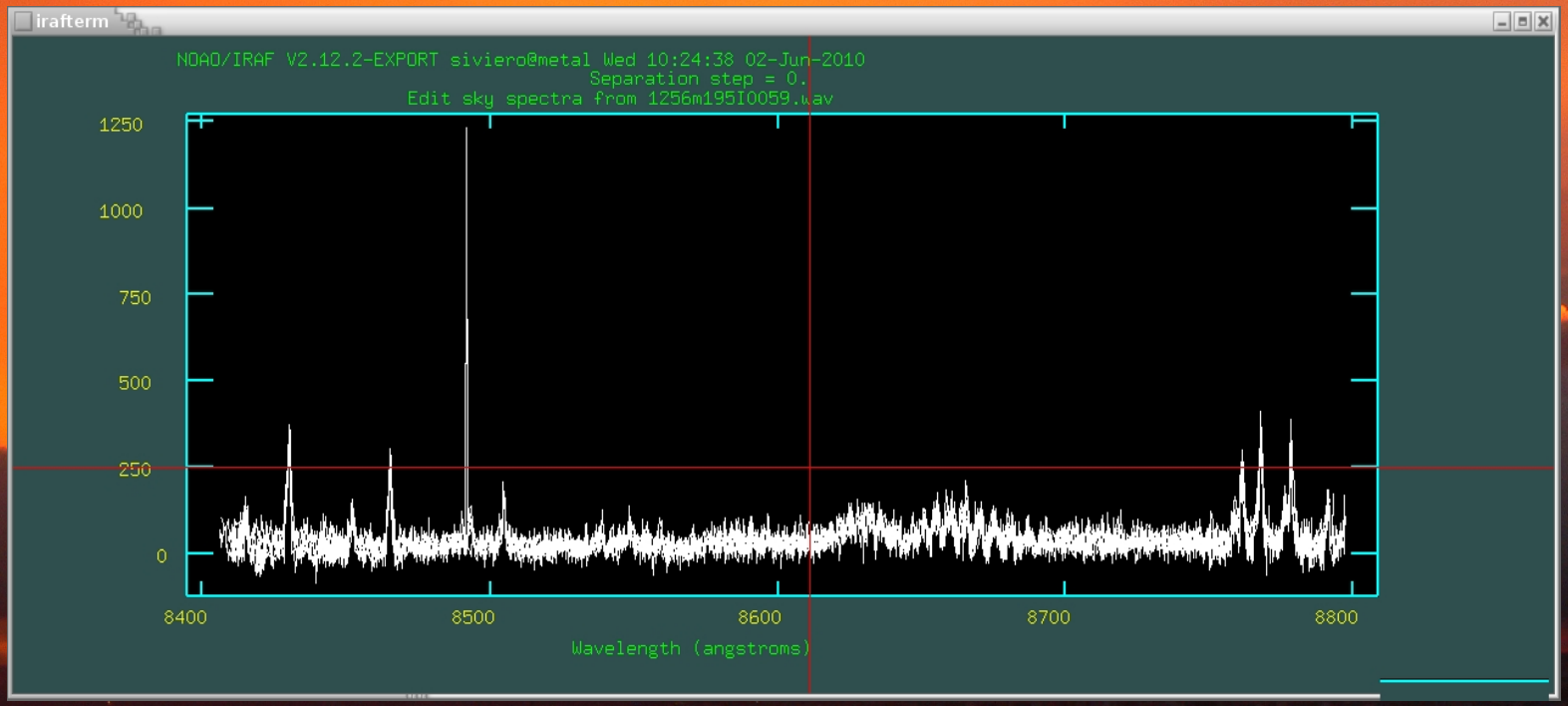
Fringing on a flat-field exposure.

Scattered light, fiber cross-talk & fringing

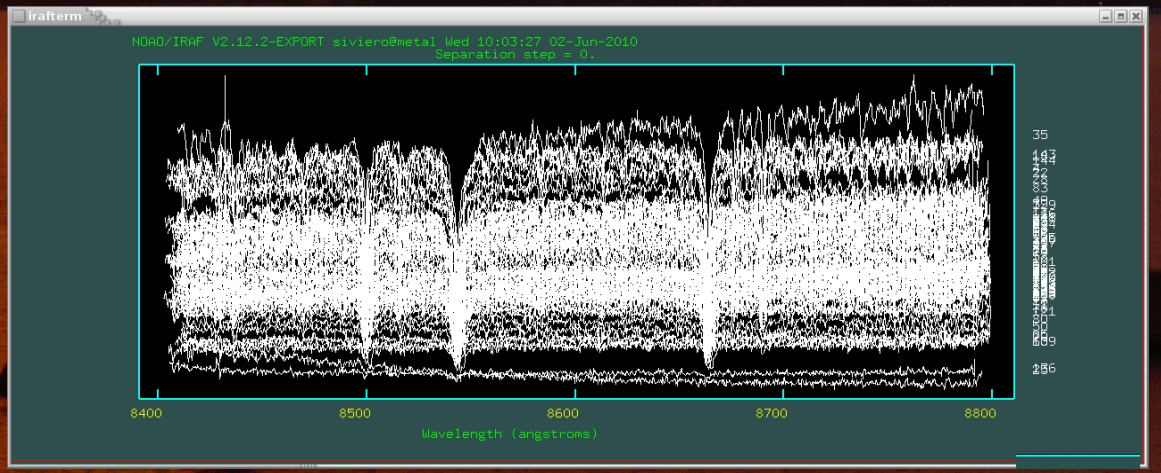




Sky subtraction, quality control

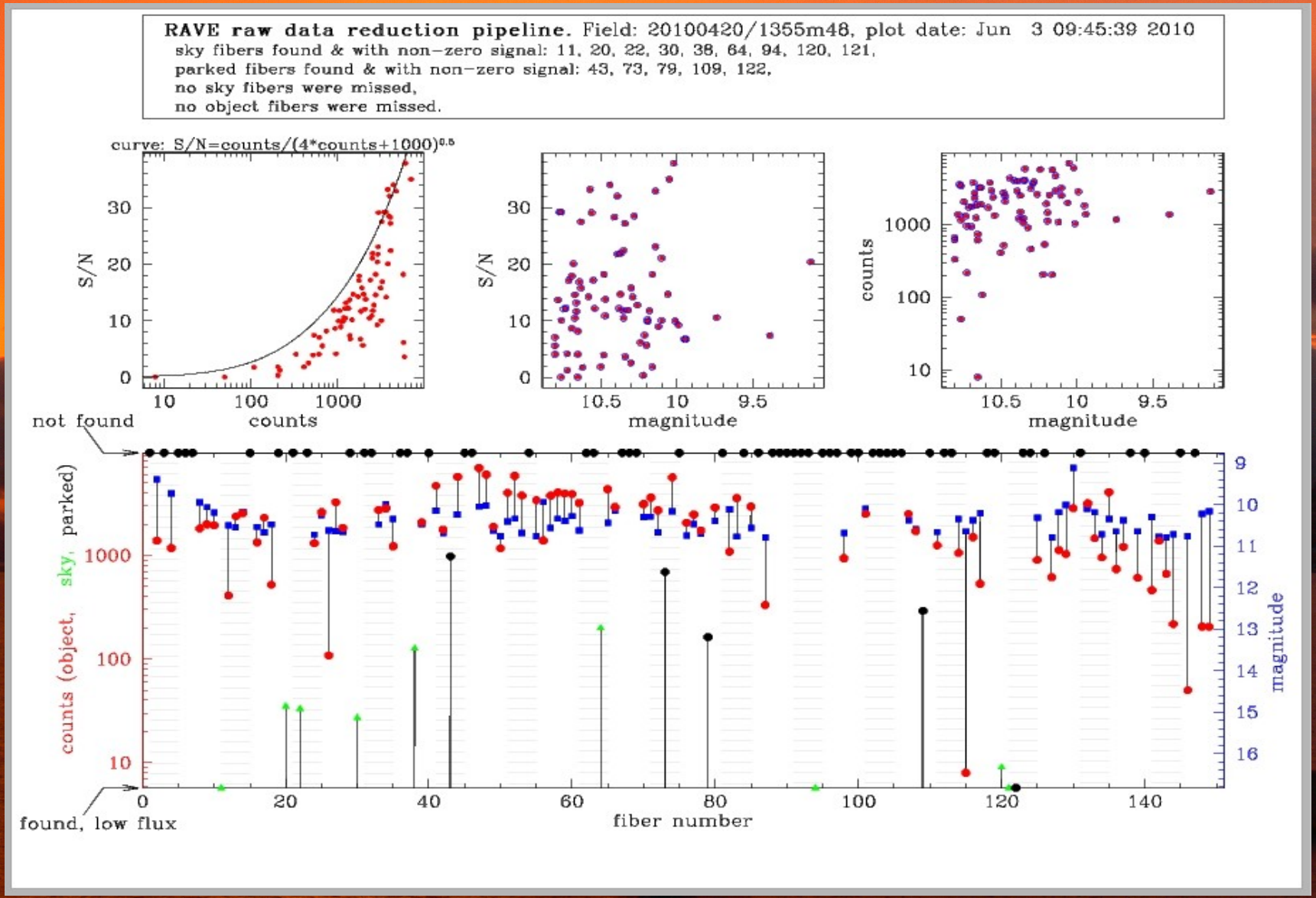


Sky background subtraction.



Final visual control.

Control of consistency



Adopted standard of reference

For each spectrum RAVE derives:

- radial velocity,
- values of atmospheric parameters (T_{eff}, gravity, metallicity, internally also α-enhancement and $V_{rot}\sin i$), using a technique better than χ^2.
- photometric distance (and reddening).

Calibrations for some of these quantities may change over time.

- But we always perform computations using the same grid of Kurucz spectra (Munari et al. 2005).
- If needed the quantities are re-calibrated a posteriori.
- So we (and the users) can always trace back the original results, whatever changes in calibrations get adopted.

External quality control

Table 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.

Zwitter et al. (2008)

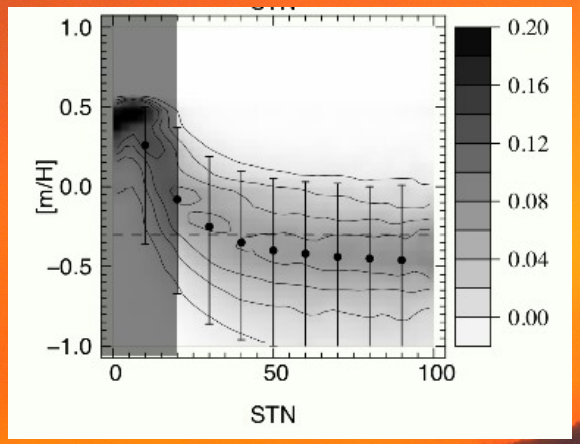
Table 4
Datasets Used to Check Stellar Parameters

Reference dataset	N	$T_{\rm eff}$	log g	[M/H]
APO	45	√	√	√
Asiago echelle	24	√	√	√
Soubiran & Girard catalog	49	√		√
M67 members	12			√
GCS	211	√		

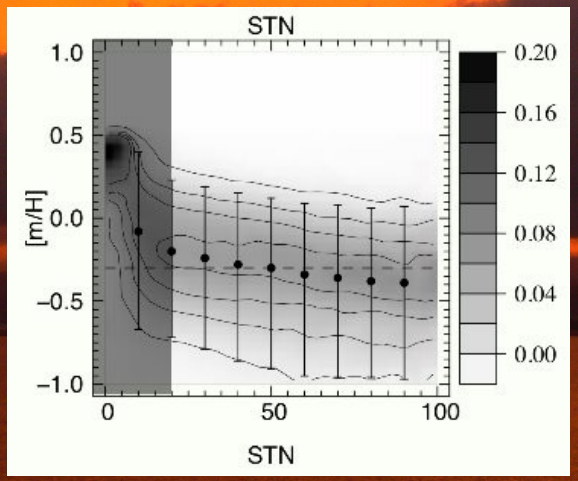
Table 5
Zero-Point Offsets and Dispersions of the Differences Between RAVE and Reference Stellar Parameter Values

Parameter	Zero point	Dispersion
Temperature (without GCS dataset)	-7 ± 18 K	188 K
Temperature (with GCS dataset included)	53 ± 14 K	238 K
Gravity	-0.06 ± 0.04	0.38
Uncalibrated metallicity ([m/H])	-0.26 ± 0.03	0.37
Calibrated metallicity ([M/H])	0.0 ± 0.02	0.18

Internal quality control



2009, Δ = 0.38



2010, Δ = 0.20

Improved parameter derivation
(C. Boeche, M. Williams)

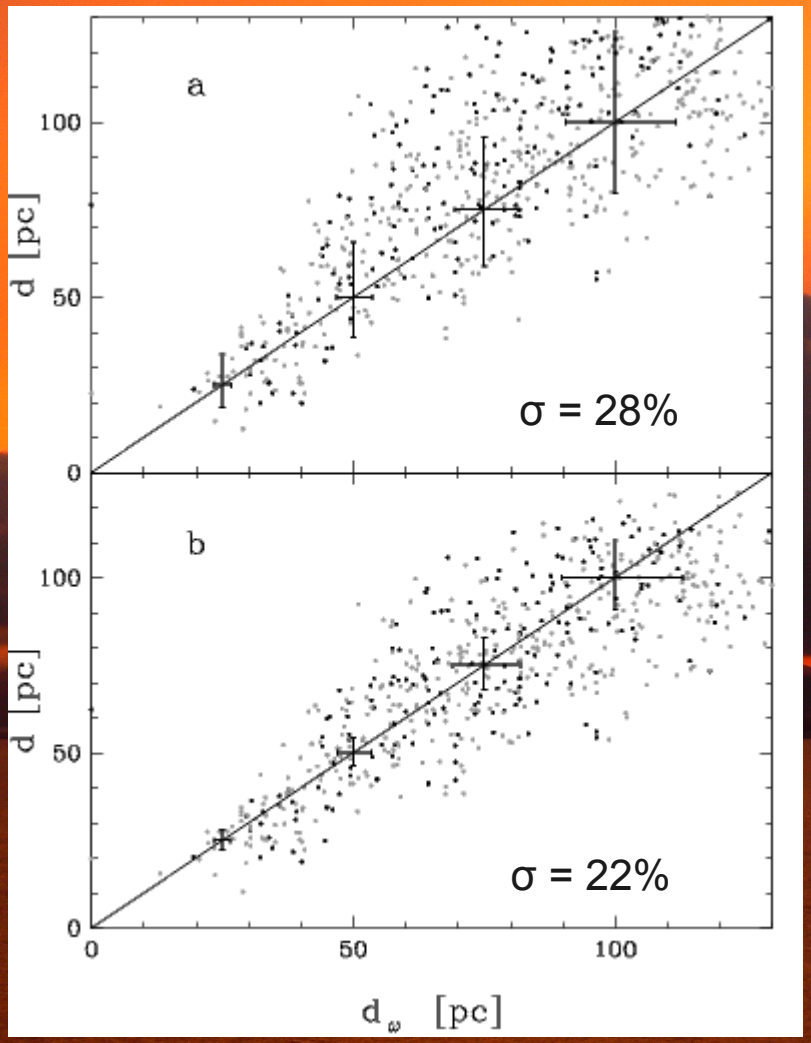
Checks with repeated observations

Teff \ logg	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
4000	0.06	0.08	0.08	0.09	0.14	0.42	0.13	0.26	0.10	0.07	0.11
4500		0.07	0.09	0.08	0.07	0.07	0.08	0.09	0.09	0.09	0.06
5000				0.28	0.07	0.09	0.09	0.09	0.08	0.07	0.05
5500					0.13	0.17	0.17	0.12	0.10	0.08	0.05
6000		scatter				0.36	0.43	0.11	0.10	0.09	0.07
6500		[M/H]					0.35	0.13	0.10	0.10	0.08
7000								0.08	0.10	0.12	0.12
7500								0.11	0.08	0.11	0.21

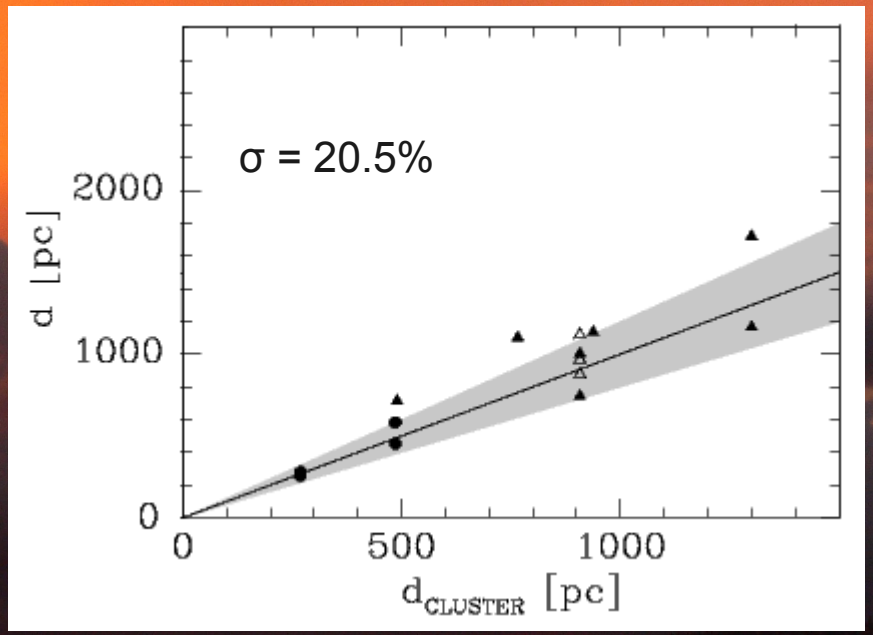
Teff \ log g	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
4000	0.07	0.16	0.19	0.21	0.43	0.29	0.81	0.62	0.17	0.16	0.05
4500		0.12	0.18	0.20	0.18	0.19	0.22	0.34	0.16	0.17	0.06
5000				0.58	0.17	0.21	0.24	0.20	0.16	0.14	0.06
5500					0.39	0.29	0.38	0.27	0.14	0.12	0.08
6000		scatter				0.98	0.89	0.28	0.15	0.14	0.08
6500		log g					1.13	0.18	0.14	0.16	0.08
7000								0.13	0.12	0.17	0.07
7500								0.16	0.10	0.15	0.19

Teff \ log g	0	0.5	1	1.5	2	2.5	3	3.5	4	4,5	5
4000	30	40	50	50	80	180	500	200	100	100	110
4500		50	60	60	50	50	60	160	120	70	50
5000				180	70	70	90	110	100	80	50
5500					600	200	180	190	130	120	90
6000		scatter				850	300	180	110	120	100
6500		Teff					400	140	110	130	130
7000								160	150	150	140
7500								200	110	200	500

Distances (before & beside Gaia)



Comparison to Hipparcos stars:
a: conservative errors,
b: errors from repeated observations



Distances of open cluster members

2MASS photometry + spectroscopic values of stellar parameters permit to determine star's distance to within ~20%.

Breddels et al. (2010),
Zwitter et al. (2010),
Burnett et al. (2010, in preparation).

RAVE star positions



blue: dwarfs (log g>3.5)
red: giants (log g<3.5)

animation by G. Matijevič

RAVE star positions 220 million years ago



blue: dwarfs (log g>3.5)
red: giants (log g<3.5)

animation by G. Matijevič & M. Vodopivec





RAVE & Geneva Copenhagen survey

blue: dwarfs (log g>3.5)
red: giants (log g<3.5)

animation G. Matijevič



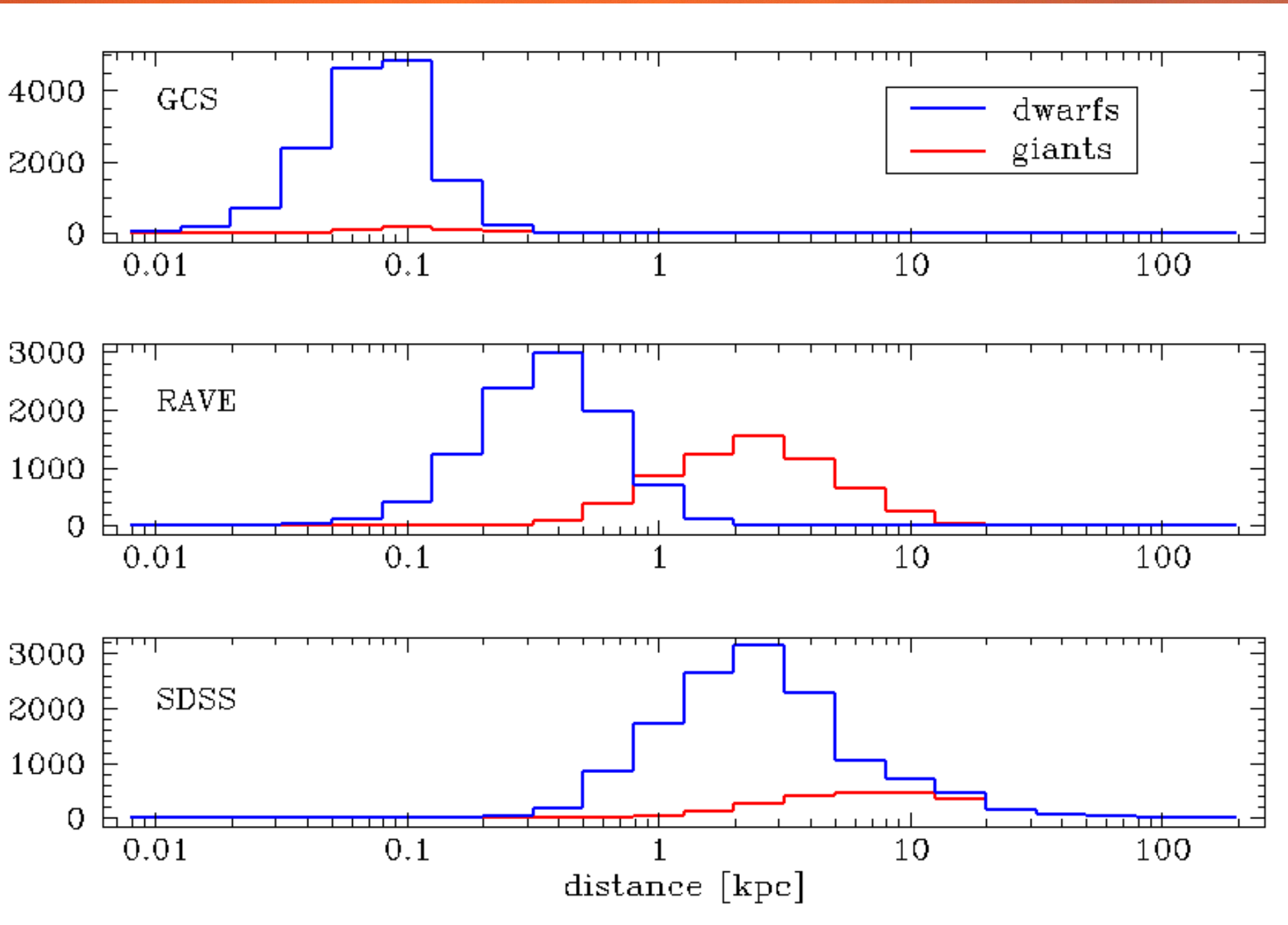


RAVE & SDSS survey

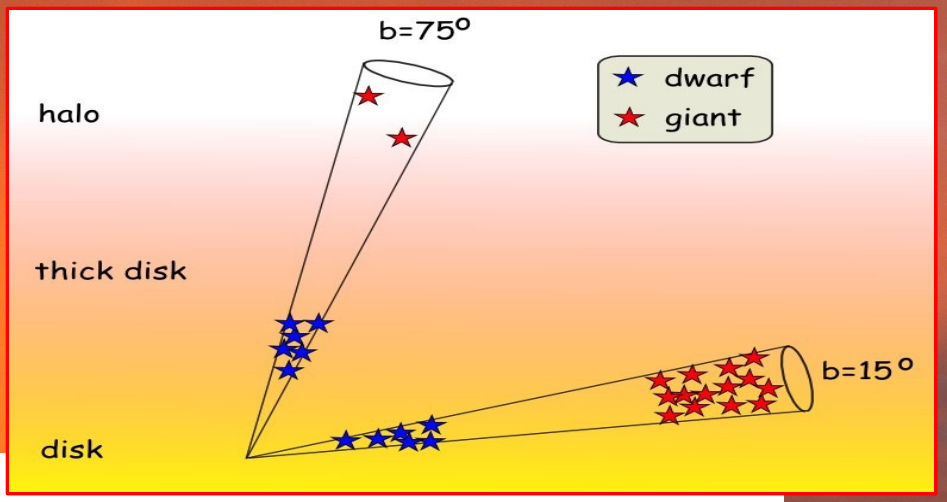
blue: dwarfs (log g>3.5)
red: giants (log g<3.5)

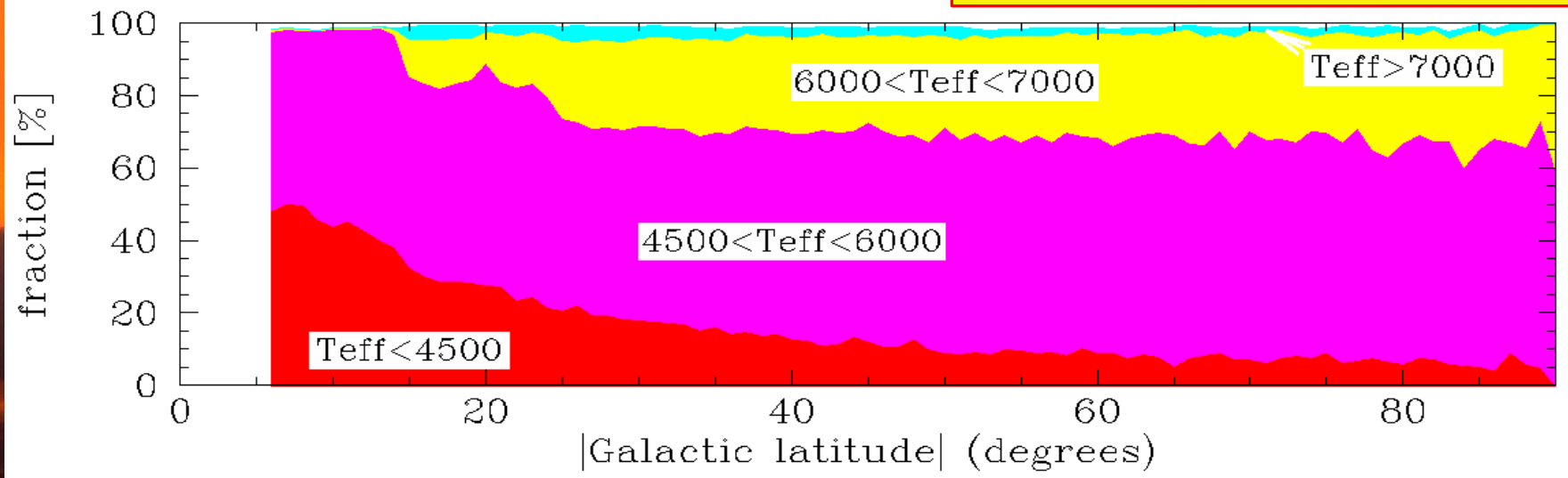
SDSS data by P. Re Fiorentin,
animation G. Matijevič

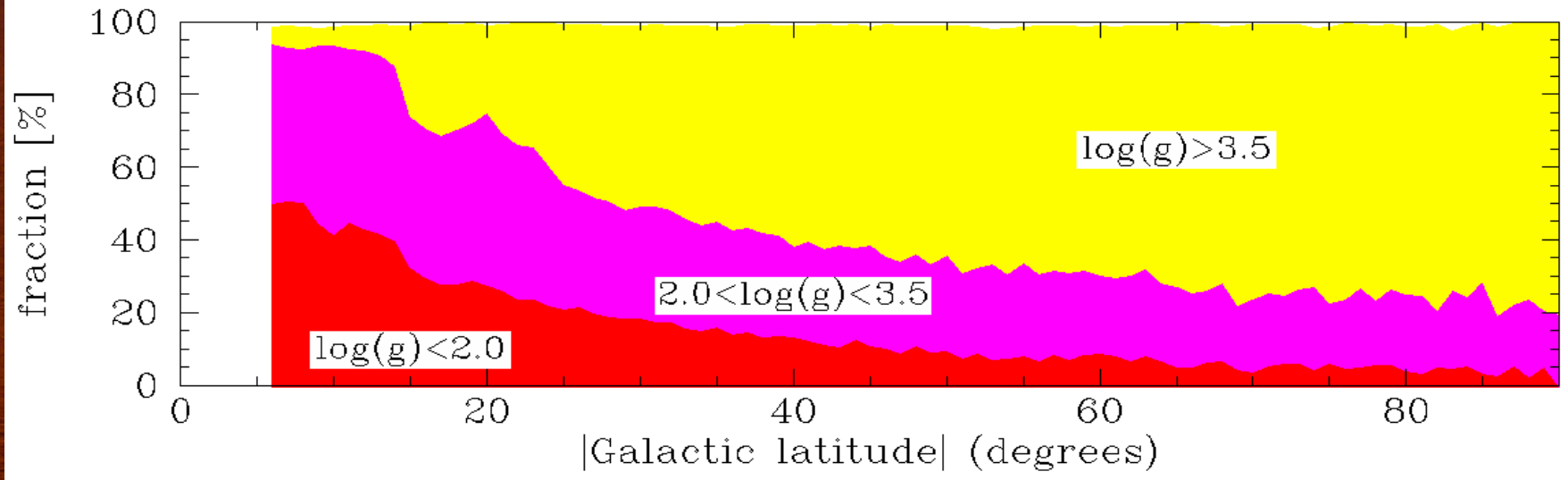
Distances in GCS, RAVE & SDSS



Presence of giants & dwarfs

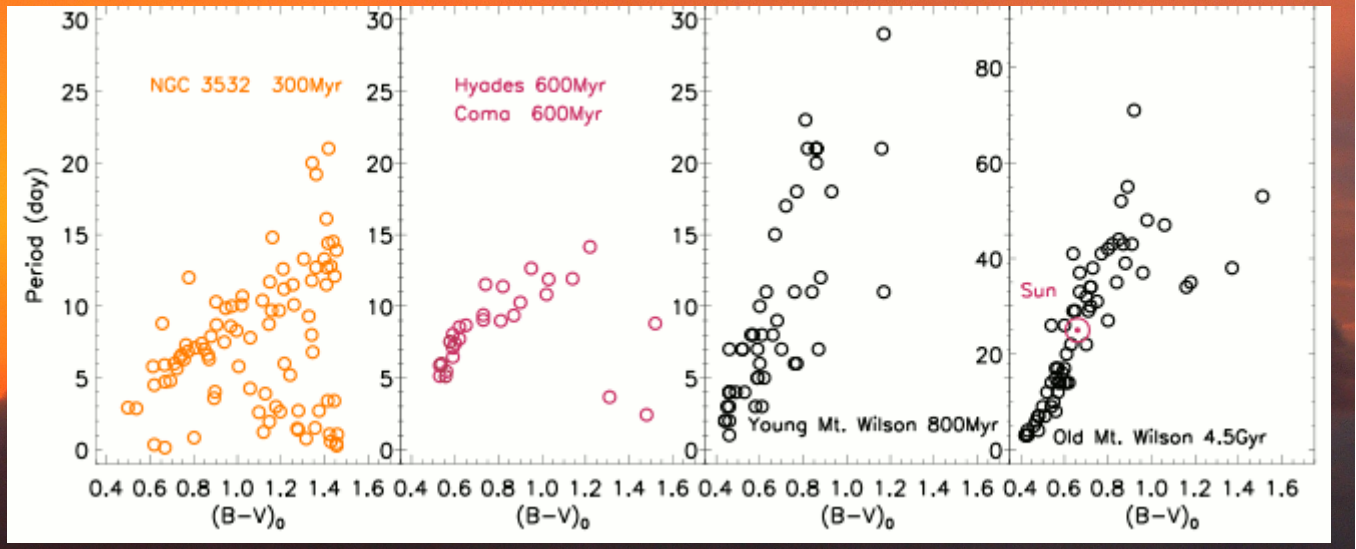






Ages of main sequence stars

Barnes (2003)

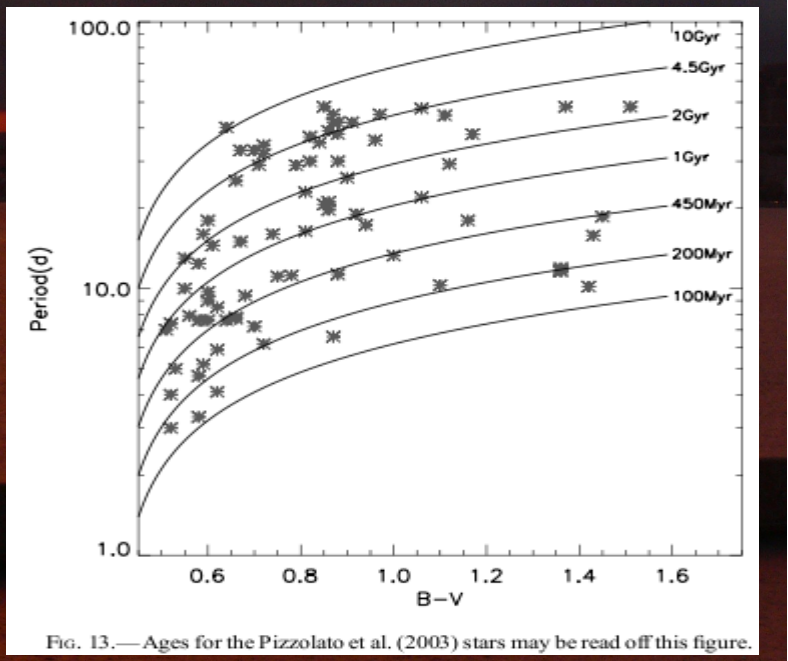


Stellar position on the [rotational period, B-V] plane tells stellar age for field MS stars older than ~300 Myr (see a number of papers by Barnes, the last in Sep 2010).

This 'gyro-chronology' steps in when other age indicators get problematic.

It requires rotational period, not just V_{ROT} sin i. Even if we cannot separate V_{ROT} and inclination in slow rotators, this gives an upper age limit.

Rotational period is derived from photometric modulations due to stellar spots. So an accurate differential multi-epoch photometry is needed (→ Panstars, LSST?).



Barnes (2007)
Age errors ≥15%.

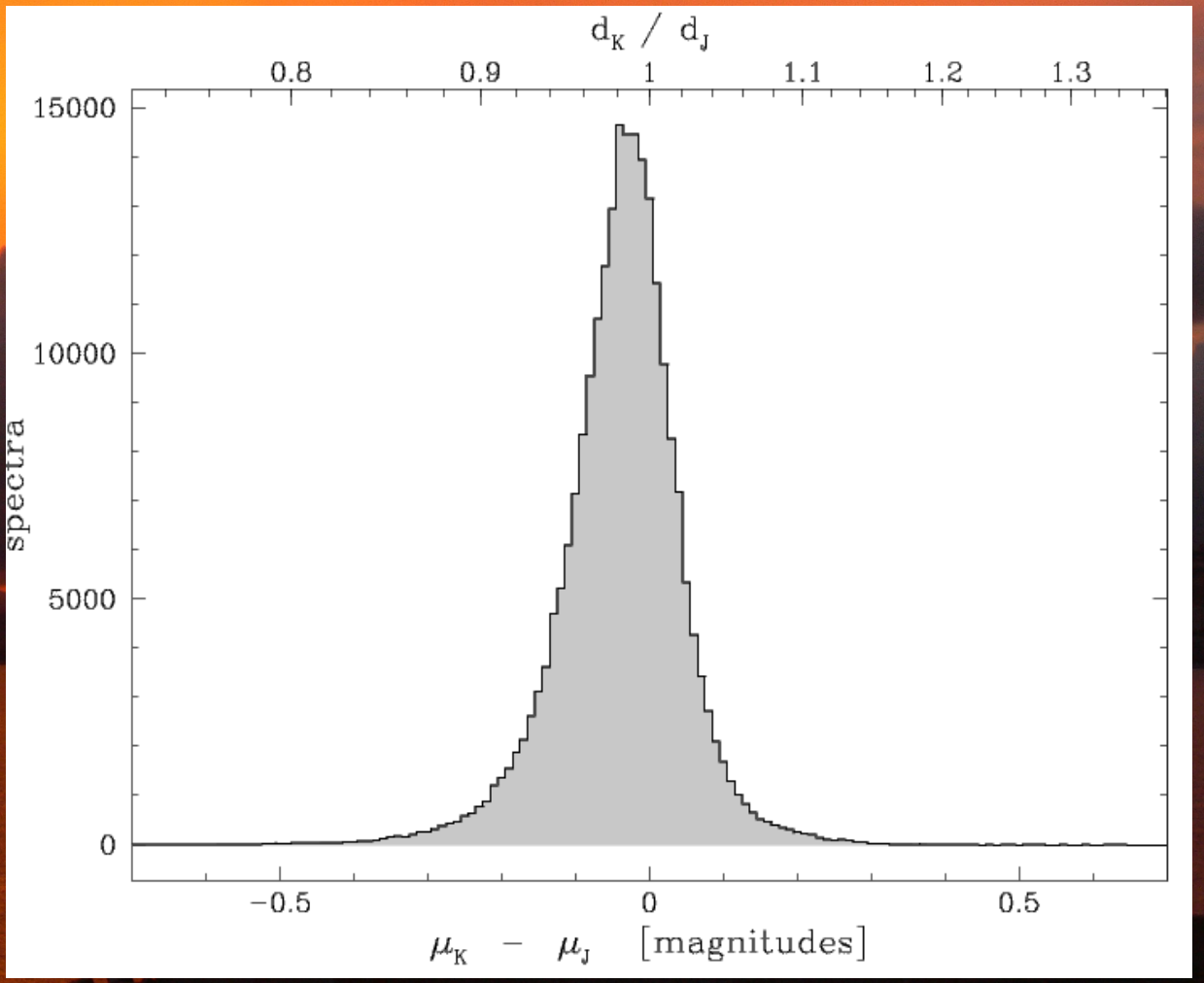
FIG. 13.—Ages for the Pizzolato et al. (2003) stars may be read off this figure.

Interstellar reddening

Distance moduli from J_{2MASS} and K_{2MASS} are close but not the same.

The reason is interstellar reddening.

With 2 filters we can derive a consistent distance and E(B-V), assuming R = 3.1. With 3 filters we could check the solution and derive R.



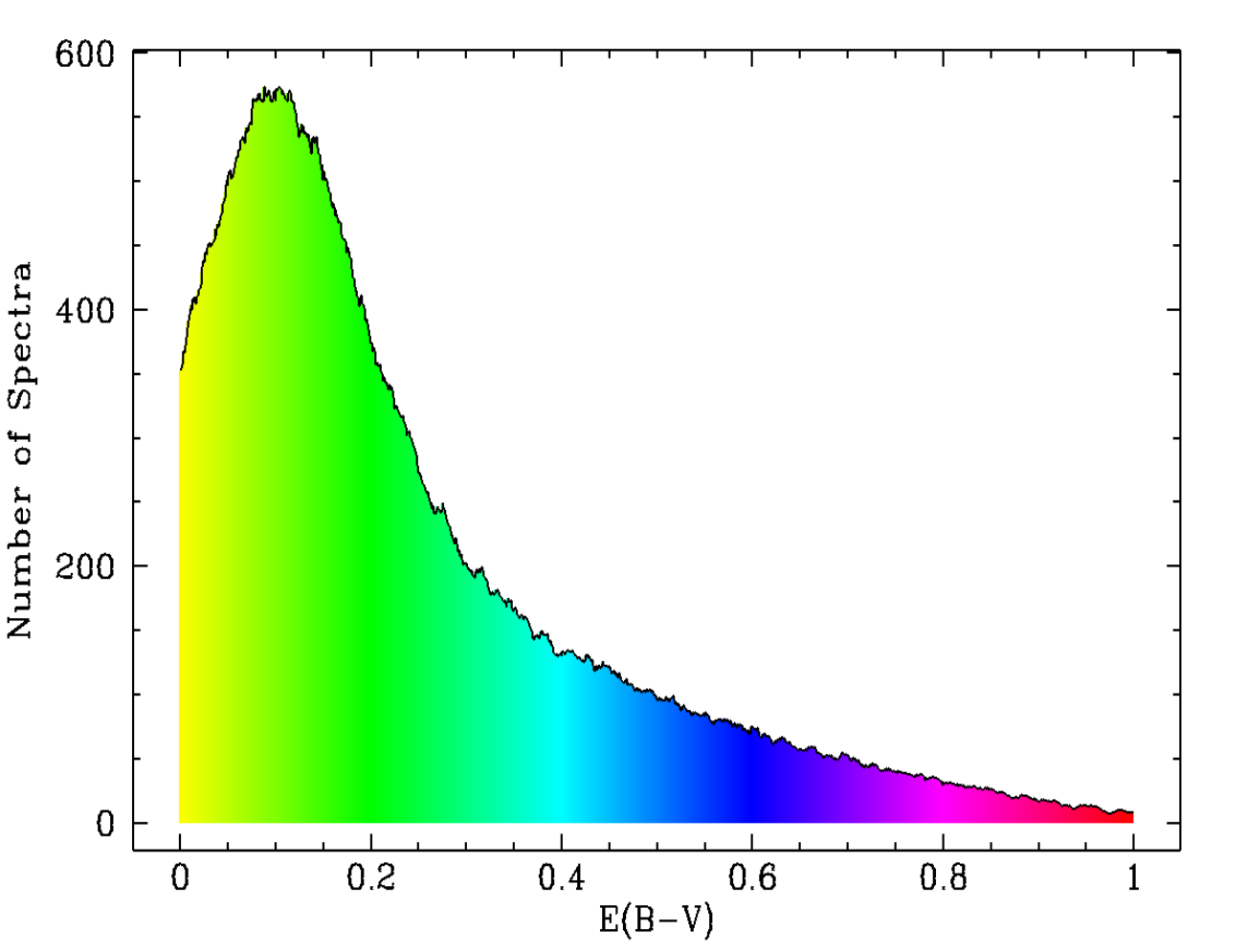
Zwitter et al. (2010).

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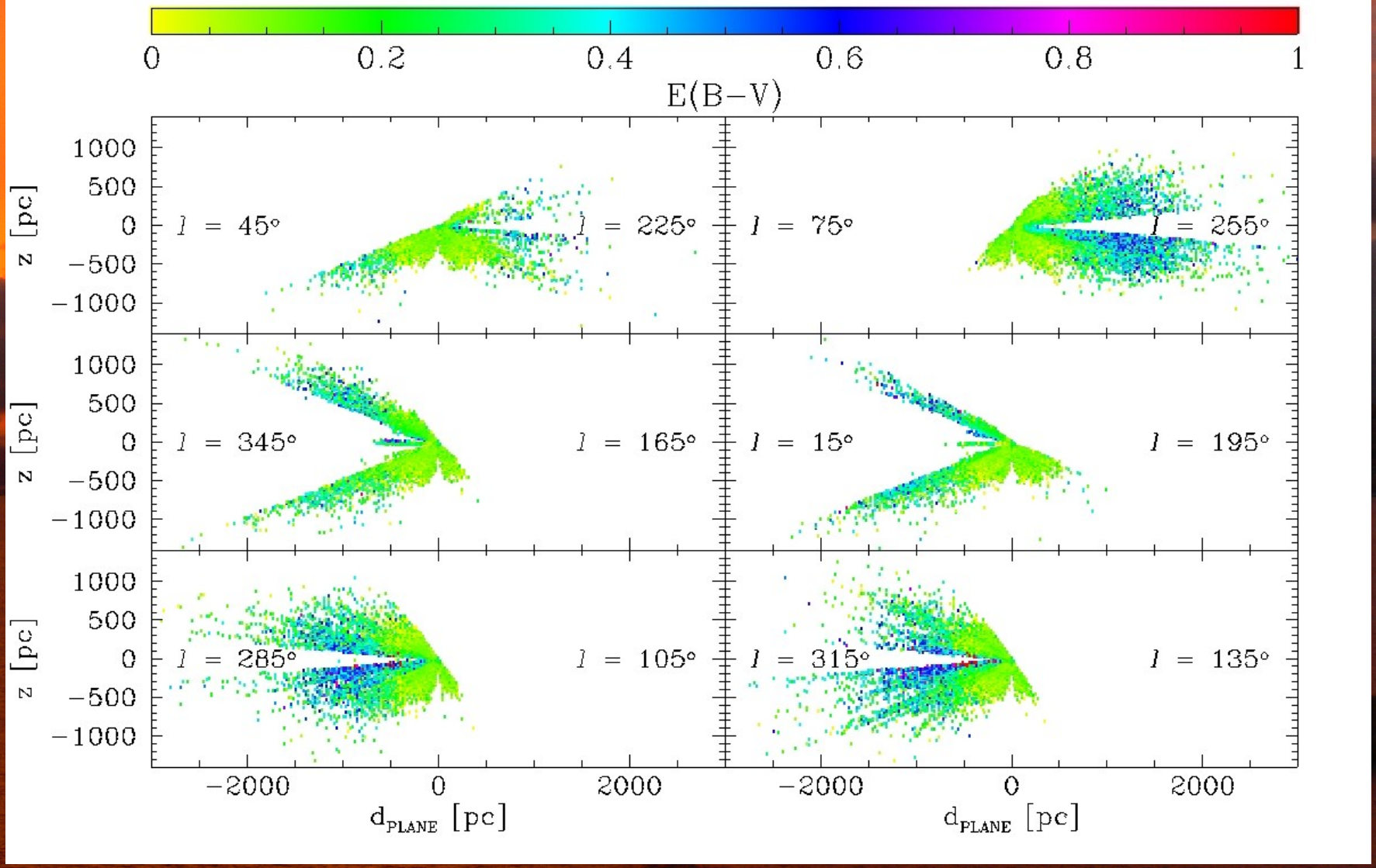
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Interstellar reddening

E(B-V) for 276.982 RAVE stars (Zwitter et al., in preparation).

Galactic vertical cross-sections with 30-degree steps in Galactic longitude.



Values of stellar parameters and interstellar reddening

RAVE and GCDS derive their parameters from spectroscopy, so not influenced by reddening.

But can photometry serve as a prior to improve derived values of stellar parameters?

A very nice recent advance is the work of Casagrande, Ramirez, Melendez, Bessell & Asplund (2010). They used Solar twins to fix the absolute temperature scale for dwarfs and subgiants using the infrared flux method.

As an example:

for 2MASS photometry and dwarfs with -5.0 < [Fe/H] < 0.4 and 0.07 < J-K < 0.80 they derive:

$$5040/T_{eff} = 0.6393 + 0.6104\,(J-K) + 0.0920\,(J-K)^2 - 0.0330\,(J-K)[Fe/H] + 0.0291\,[Fe/H] + 0.0020\,[Fe/H]^2$$

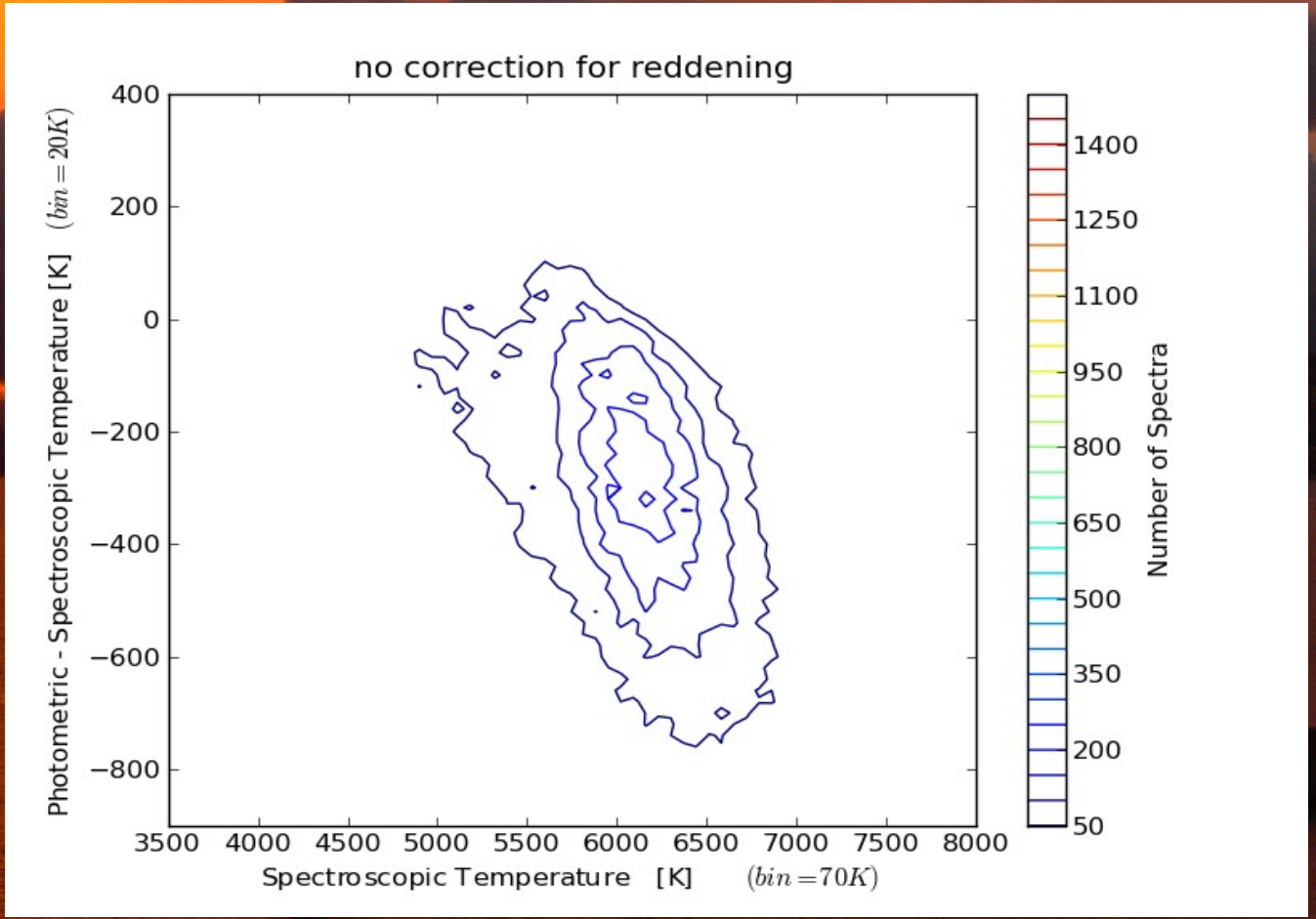
For 412 stars they get $\sigma\,(T_{eff}) = 132$ K.

Values of stellar parameters and interstellar reddening

Photometric temperature derived from J-K colour using the relation from Casagrande et al. 2010.

Comparison of photometric and spectroscopic temperature for RAVE dwarfs is not encouraging, even though RAVE observes away from the Galactic plane.

Photometric temperature from 2MASS photometry is ~300 K cooler than the spectroscopic one derived by RAVE, if no reddening correction is applied.

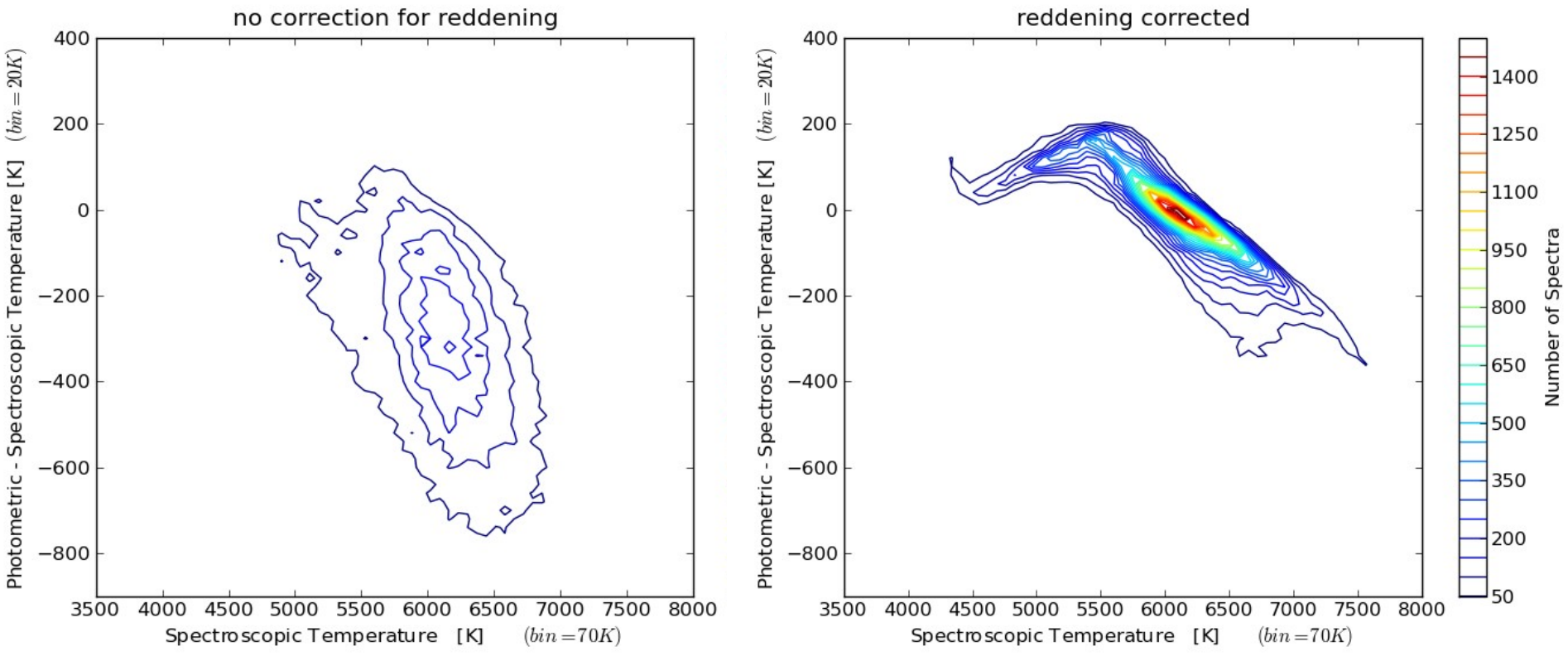


Values of stellar parameters and interstellar reddening

Reddening correction significantly improves the results.

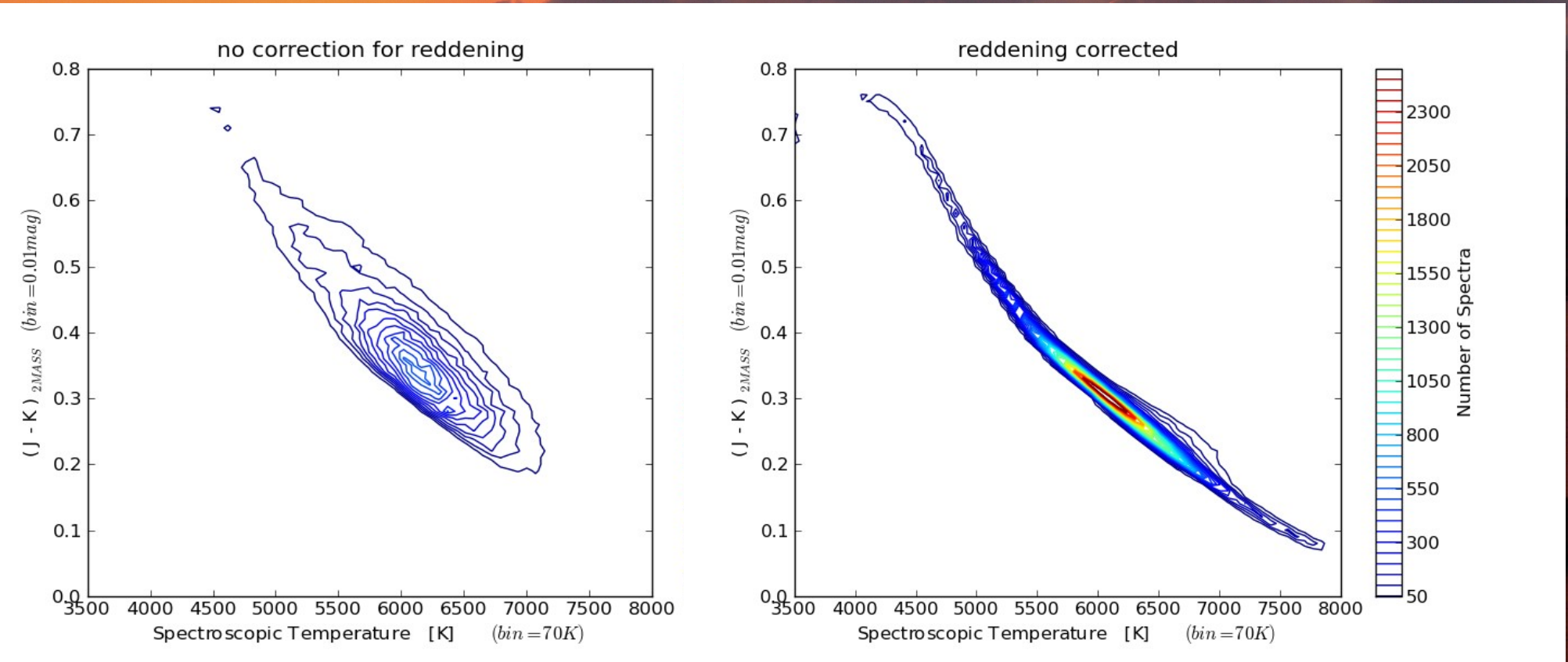
There is no zero-point offset.

The remaining trend possibly due to the adopted rough temperature dependence of E(B-V) vs. A_J-A_K, and/or discrepancy between the Padova isochrone and Casagrande et al. temperature scales.



Values of stellar parameters and interstellar reddening

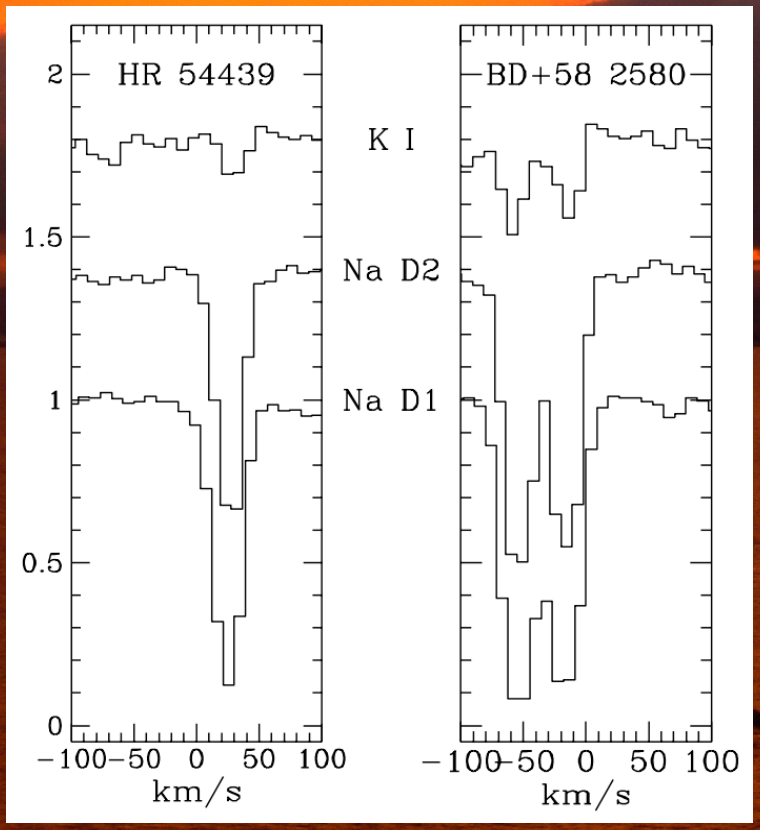
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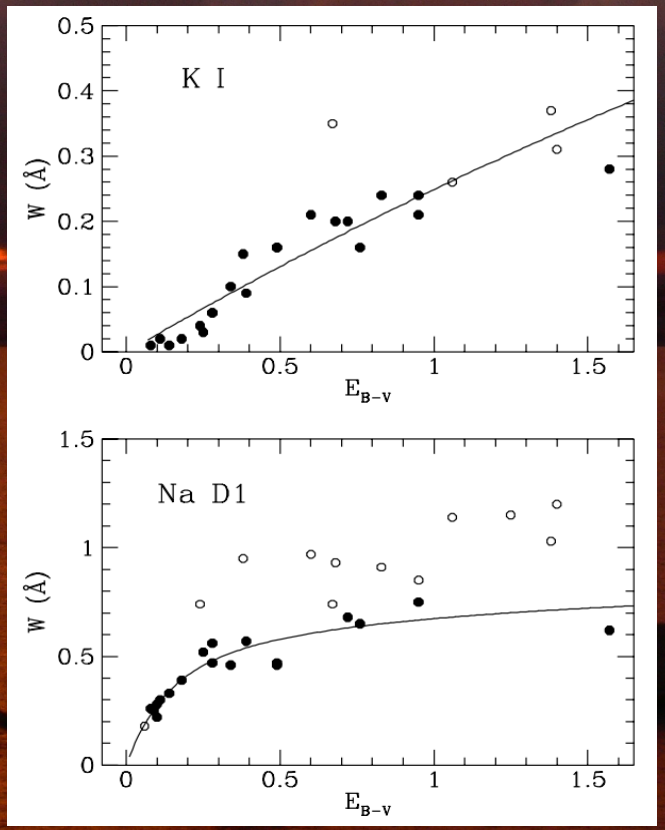
IS reddening from spectroscopy

Resonant interstellar doublets of Na I (5890 Å) and K I (7699 Å) are correlated with E(B-V).
The method (Munari & Zwitter 1997) takes care of saturation and multiple-component effects.
It is now routinely used to determine IS reddening towards supernovae etc..
Na I and K I doublets to be observed with GCDS?

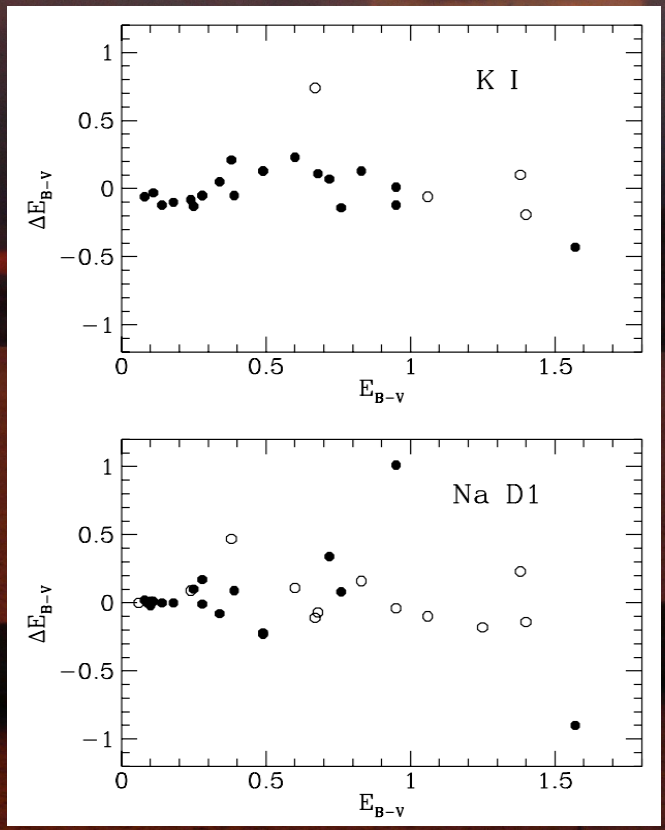
Single and multiple-component IS lines.



Equivalent width vs. E(B-V).

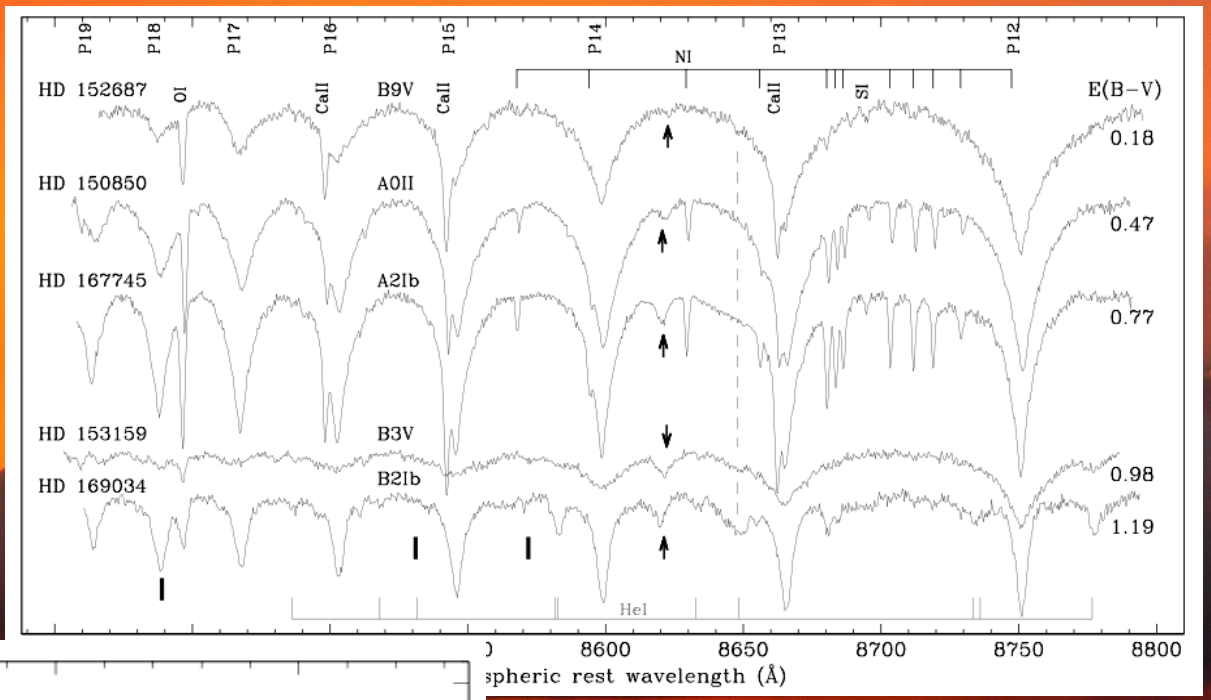


Residuals, useful also at low E(B-V).

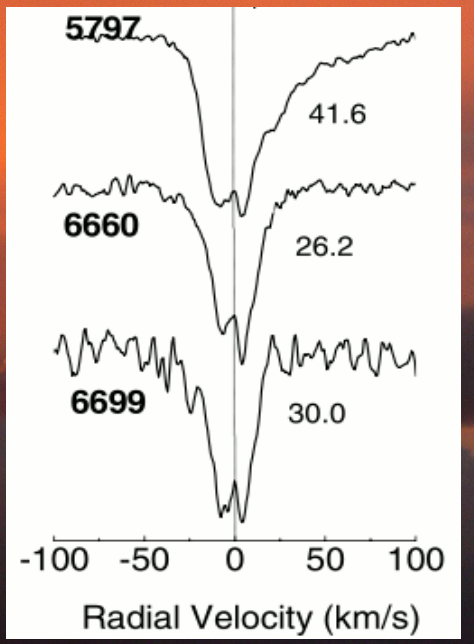


Diffuse interstellar bands

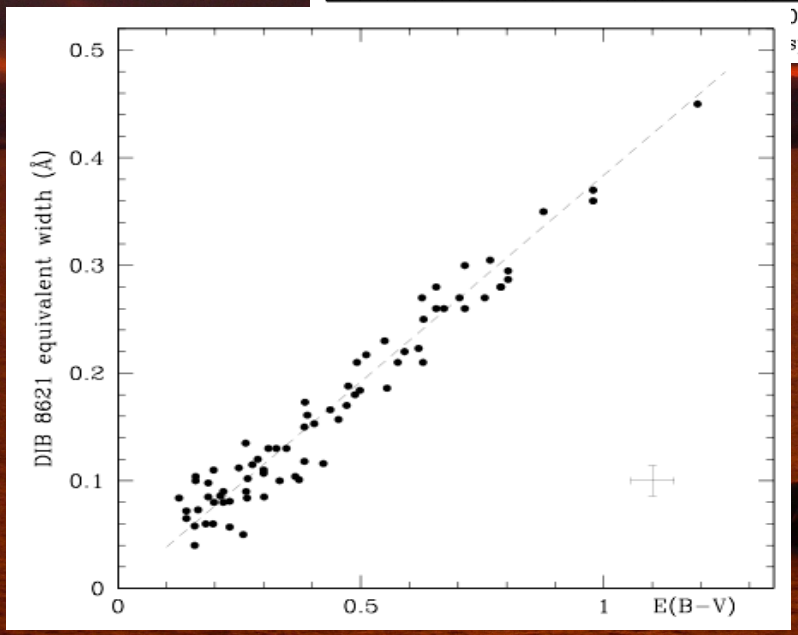
DIB at 8620 Å



Munari et al. (2008)



DIB profiles in HD147889, Galazutdinov et al. (2008)



- The DIB at 8620 Å has an excellent correlation with reddening, other DIBs generally do not.
- The only common property of DIBs is the lack of identification (Galazutdinov et al. 2008).
- GCDS can resolve DIB profiles, including the ones at 5797, 6660, and at 6699 Å and observe many EWs.
- Can it contribute to identification of DIB physical carriers, a shame to be closed in the 21st century?

The talk can be found at www.fiz.uni-lj.si/astro/tmp/zwitter_nice20101103.pdf

Conclusions

With Ulisse Munari we think we can primarily contribute in three areas:

1. DATA REDUCTION

Drawing from our experience with RAVE, Gaia and ELSA:

Advice on various issues, including quality control and complimentary observations.

2. SUPPORT PHOTOMETRY

Better understanding of the SLOAN photometric system, connection to people doing south sky:

to derive distances, E(B-V), and priors on parameters of stellar atmospheres.

3. INTERSTELLAR MEDIUM

GCDS can study its:

dust phase (reddening, for now primarily from 2MASS & SLOAN photometry),

gas phase (Na I lines, in special cases also stellar winds), and

grain/complex-molecular phase (diffuse interstellar bands, some with resolved profiles).

The goal is to study ISM towards every star and follow it pencil-like through the MW.

Observations to be conducted for Galactic archaeology are adequate for ISM studies.