www.royer.se/melchiors.html



Melchiors: a new library of 2000 stars with high-spectral fidelity

UNIVERSITÉ LIBRE DE BRUXELLES

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Submitted to A&A



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Observed spectral libraries

Library	N_*	N_{sp}	λ_{min}	λ_{max}	Resolution	Reference
Gunn & Strycker	175		313	1 0 8 0	200	Gunn & Stryker (1983)
Silva & Cornell	72		351	893	550	Silva & Cornell (1992)
James	83		350	750	800	James (2013)
Kitt-Peak	161		351	742	1 000	Jacoby et al. (1984)
Pickles	131		115	2 500	1 000	Pickles (1998)
NGSL	378		167	1 0 2 5	1 000	Gregg et al. (2006)
SDSS-MaStar	3 3 2 1	8 6 4 6	362	1 0 3 5	1 800	Yan et al. (2019)
STELIB	249		320	930	2 000	Le Borgne et al. (2003)
MILES	985		352	750	2 000	Falcón-Barroso et al. (2011)
SDSS-BOSS	324		365	1 0 2 0	2 000	Kesseli et al. (2017)
Diaz et al.	106		790	910	2 300	Diaz et al. (1989)
MUSE library	35		480	930	3 000	Ivanov et al. (2019)
Indo-US	1 2 7 3		346	946	5 000	Valdes et al. (2004)
XSL	683	830	350	2480	10 000	Gonneau et al. (2020); Verro et al. (2022)
ELODIE	1 388	1962	390	680	42 000	Prugniel & Soubiran (2001, 2004); Prugniel et al. (2007)
FGKM library	404		499	641	60 000	Yee et al. (2017)
Gaia-FGK	34	71	300	1 0 2 0	80 000	Blanco-Cuaresma et al. (2014)
UVES-POP	394		304	1 0 4 0	80 000	Bagnulo et al. (2003)

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HERMES fibre-fed spectrograph at Mercator telescope in La Palma



HERMES spectrograph

Detector 2048 by 4608 pixels

with anti-reflective coating

62.21 mm

The spectrograph characteristics (Raskin+ 2011):

- Limiting visual magnitude ~12
- Wavelengths coverage from 3800 to 9000 Å
- Resolving power of 85000
- 2.5 arcsec octagonal fibre equipped with an image slicer
- optimised for high efficiency

Melchiors spectral library is the result of the filler program by Pierre Royer running from 2010 to 2020

The spectrograph reduction pipeline:

- bias correction
- background substraction
- flat-field correction
- cosmic ray clipping
- spectral order merging
- wavelength calibration
- barycentric correction



Additional data reduction I: instrumental response correction

14 calibrators from 7000 to 15000 K are used.

- Calibrator observed spectrum (flat-field corrected and atmospheric extinction and telluric corrections)
- Calibrator model from GSSP (Tkachenko 2015)
- Instrumental response function
 - ratio of the observed/model
 - smooth version using median filter
 - Spline function using knot points

The density of knot points used to fit the spline is chosen locally depending on the complexity of the response.

Then all the spectra of a night are divided by the effective instrumental response function.

Additional data reduction II: atmospheric extinction and telluric corrections



Two corrections:

- Atmospheric extinction (continuous scattering) wavelength dependent
- Telluric absorptions (molecular absorption by H₂O, O₂, etc.) Using Molecfit (Smette+ 2015, Kausch+2015)

Additional data reduction III: normalisation

The method is conceptually similar to a sigma-clipping process.

High-order polynomials are flexible enough on instrumental response corrected spectra

Brute force approach

For a given order (from 0 to 40):

- fit a polynomial on flux densities
- Division of the spectrum by this polynomial
- Computation of the d score: d = p n
 - *p* is the median of the flux densities above 1 (always \geq 1)
 - *n* is the median of the flux densities below 1 (always \leq 1)
- Remove of flux densities below the polynomial function

The best score d, d_{best} , is taken as the minimum score d, reflecting the best normalising function

+ a minimum sampling density over the 5200 Å (at least 1 sample per 10 Å)



Additional data reduction III: normalisation



Library content: overview I



S/N

• Median S/N \sim 200 in V band

Library content: overview II



Melchiors include 3256 spectra for all spectral types and luminosity classes but biased toward:

- early spectral types
- high luminosity classes

Library content: overview II

	WR	0	B	Α	F	G	K	Μ	S/C	Total
V	0	29	129	123	151	90	50	3	0	575
IV	0	14	103	107	67	73	25	0	0	389
	0	20	109	72	60	107	132	107	1	608
II	0	9	46	24	24	37	50	9	0	199
Ι	0	19	15	5	4	3	5	2	0	53
N/A	4	4	24	18	37	23	47	54	7	218
Total	4	95	426	349	343	333	309	175	8	2042

Library content: overview III



 \mathcal{M}_{G}

Library content: overview III



50% of stars have at least 2 spectra

25% of stars are binaries

* -	583 Star	1
PM*-	543 High proper-motion Star	
SB*-	227 Spectroscopic binary	
** -	196 Double or multiple star	
LP*-[84 Long-period variable star	
V*-[75 Variable Star	
dS*-	47 Variable Star of delta Sct type	
EB*-	42 Eclipsing binary	
Be*-	30 Be Star	
LP? -	23 Long Period Variable candidate	
bC*-	22 Variable Star of beta Cep type	
a2*-[] 17 Variable Star of alpha2 CVn type	
s*b-	15 Blue supergiant star	
RS*-	14 Variable of RS CVn type	
Em*-	13 Emission-line Star	
BY*-	11 Variable of BY Dra type	
Pu*-	10 Pulsating variable Star	
Ro*-[8 Rotationally variable Star	
RG*-	8 Red Giant Branch star	
Er*-	8 Eruptive variable Star	
Pe*-]	7 Peculiar Star	
S*-[7 S Star	
AB*-[6 Asymptotic Giant Branch Star (He-burning)	
Y*O -	6 Young Stellar Object	
Mi*-[4 Variable Star of Mira Cet type	
gD*-	4 Variable Star of gamma Dor type	
ĂВ*-]	4 Horizontal Branch Star	
WR*-	4 Wolf-Rayet Star	
Ce*-	3 Cepheid variable Star	
cC*-	3 Classical Cepheid (delta Cep type)	
C*-	3 Carbon Star	
Or* -	2 Variable Star of Orion Type	
s*r-	2 Red supergiant star	
sg*-	2 Evolved supergiant star	
Ae*	2 Herbig Ae/Be star	
TT*-	1 T Tau-type Star	
s*y-	1 Yellow supergiant star	
HXB-	1 High Mass X-ray Binary	
LM*-	1 Low-mass star (M<1solMass)	
mul-	1 Composite object	
El*-	1 Ellipsoidal variable Star	
V*? -	1 Star suspected of Variability	
Sy*-	1 Symbiotic Star	
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Melchiors: luminosity effects



Melchiors: the solar spectrum



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Comparison on Arcturus (K1.5III): UVES-POP https://www.eso.org/sci/observing/tools/uvespop/interface.html +ES ARCTURUS UVES PARANAL OBSERVATORY PROJECT E30 PROGRAM 266.D-5655(A) 2×10^4 Units) Ηα (Arbitrary 10^{4} Flux 6550 450 6500 6600 0 6000 4000500070008000 Wavelength (Å) 15

Comparison on Arcturus (K1.5III): Melchiors https://www.royer.se/melchiors/melchiors_table.html



What can you find on in Melchiors

- Access:
 - www.royer.se/melchiors.html
 - Will also be available at CDS
- Content:
 - The spectral library itself:
 - Wavelengths
 - Normalized flux densities
 - Telluric absorption and instrument response corrected flux densities
 - Raw flux densities (output of the HERMES pipeline)
 - The calibration spectra use to derive the instrumental response for every observing night
 - The models of the calibration stars
 - The meta-data information:
 - For the spectral library: observation + Simbad information
 - For the calibration spectra
 - Cross-match table with Gaia DR3
 - Web interface: quick-look view and filtering possible

The Melchiors spectral library: the web interface https://www.royer.se/melchiors/melchiors_table.html

Melchiors

Information and bulk downloads: see here

Quick-look and individual downloads:

obsid#/ quick look	TARGET \$	starname \$	$\mathbf{V} \diamondsuit$	B-V +	stype \$	ra 🗢	dec \$	airmass ‡	bsn ‡	vsn 🗢	rsn ‡	Spectrum
										Start		
										End	\$	
<u>307233</u>	HD 1404	NSV 118	4.52	0.05	A2V	00:18:19.70	36:47:06.79	1.261	172.5	209.3	185.5	<u>307233.fits.g</u>
<u>307234</u>	HD 1404	NSV 118	4.52	0.05	A2V	00:18:19.70	36:47:06.79	1.277	234.7	284.5	252.2	<u>307234.fits.g</u>
<u>307238</u>	HD 224893	HIP 124	5.57	0.4	A8II	00:01:37.00	61:13:22.12	1.553	209	317.2	307.5	<u>307238.fits.g</u>
<u>307337</u>	HD 1843	HIP 1844	7.78	1.79	K7V	00:23:19.50	62:18:50.62	1.393	56.5	190.5	260.4	<u>307337.fits.g</u>
<u>307340</u>	HD 15588	HIP 11622	6.77	0.19	A5/7III	02:29:55.40	-22:40:59.52	1.82	195.4	279	259.9	<u>307340.fits.g</u>
<u>307451</u>	HD 224893	HIP 124	5.57	0.4	A8II	00:01:37.00	61:13:22.12	1.587	127.3	189.8	191.1	<u>307451.fits.g</u>
<u>307452</u>	HD 224893	HIP 124	5.57	0.4	A8II	00:01:37.00	61:13:22.12	1.528	120.4	180	181.4	<u>307452.fits.g</u>
<u>307453</u>	HD 123	V* V640 Cas	6.4	90	G3V+G8V	00:06:15.80	58:26:12.19	1.485	88.7	157.6	168.5	<u>307453.fits.g</u>
<u>307468</u>	HD 1843	HIP 1844	7.78	1.79	K7V	00:23:19.50	62:18:50.62	1.212	27.8	91.2	128.5	307468.fits.g
<u>307469</u>	HD 1843	HIP 1844	7.78	1.79	K7V	00:23:19.50	62:18:50.62	1.224	39.3	127.7	178.8	<u>307469.fits.g</u>
<u>307472</u>	HD 1843	HIP 1844	7.78	1.79	K7V	00:23:19.50	62:18:50.62	1.259	35.7	116.9	164.3	307472.fits.g
<u>307473</u>	HD 15588	HIP 11622	6.77	0.19	A5/7III	02:29:55.30	-22:40:59.52	1.603	117.2	160	153.5	307473.fits.g
<u>307477</u>	HD 2302	HIP 2135	6.65	0.48	F7IV	00:27:04.60	25:02:31.42	1.361	116.1	183.2	189.3	<u>307477.fits.g</u>
<u>307478</u>	HD 1439	HIP 1493	5.88	-0.02	A0IV	00:18:38.30	31:31:01.99	1.443	166.8	191.5	175.1	<u>307478.fits.g</u>
<u>307479</u>	HD 3379	V* AG Psc	5.86	-0.15	B2.5IV	00:36:47.30	15:13:54.19	1.532	176.5	192.3	172.4	307479.fits.g
<u>307480</u>	HD 3651	NSV 245	5.88	0.83	K0.5V	00:39:21.80	21:15:01.69	1.512	85.1	158.1	177.1	<u>307480.fits.g</u>
<u>307530</u>	HD 1279	HIP 1372	5.85	-0.09	B8III	00:17:09.00	47:56:50.71	1.681	125.6	143.9	134.6	<u>307530.fits.g</u>
<u>307531</u>	HD 1279	HIP 1372	5.85	-0.09	B8III	00:17:09.00	47:56:50.71	1.593	121.8	139.8	131.2	<u>307531.fits.g</u>
<u>307535</u>	HD 2589	LTT 10171	6.2	90	K0IV	00:30:55.10	77:01:09.91	1.559	64.9	132.5	150.8	<u>307535.fits.g</u>
<u>307536</u>	HD 2589	LTT 10171	6.2	90	K0IV	00:30:55.10	77:01:09.91	1.548	55.8	114.8	131.8	<u>307536.fits.g</u>
<u>307542</u>	HD 1601	HIP 1639	6.47	0.53	G0	00:20:30.90	48:58:07.10	1.067	86.5	145.4	155.6	<u>307542.fits.g</u>
<u>307543</u>	HD 1601	HIP 1639	6.47	0.53	G0	00:20:30.90	48:58:07.10	1.068	95.3	160.3	171.3	<u>307543.fits.g</u>

KATHOLIEKE UNIVERSITEIT



Summary

- Melchiors: new homogeneous and large observed spectral library of stars with $\delta > -30^{\circ}$
- 3256 spectra of 2043 stars (including the Sun) of all spectral types and luminosity classes
- Spectral range : [3800, 9000] Å, resolving power: 85000
- Median S/N \sim 200 in V band
- The sample is 80% complete for V < 4 and reaches $V \sim 12$
- Paper (Royer, Merle et al. submitted) under revision

but spectral library already available at: www.royer.se/melchiors.html



Backup – Melchiors spectral library



Best d score versus B-V





Theoretical atmospheric extinction on La Palma as a function of wavelength and airmass



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Spectral type effects



Variability of the instrumental response function



Fig. 5. Red: standard deviation of the ratio between subsequent responses derived for our programme indicative of the additional uncertainty on the low-frequency components of the continuum for the stars with stdnight=0. grey: standard deviation computed over all responses, regardless of their acquisition time (see text for details).