

A Pan-Spectral Method of Abundance Determination

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Introduction

- 1 Essential developments in observational high-precision and high-resolution spectroscopy
- 2 Fast growing computing facilities



We elaborated a new pan-spectral method of abundance determination based on the weighted cumulative line-widths.

The pan-spectral method of abundance determination

The method is based on the quantities Q_λ :

Weighted cumulative width

$$Q_\lambda = \int_{\lambda_0}^{\lambda} \left| \frac{dR_\lambda}{dZ} \right| (1 - R_\lambda) d\lambda$$

R_λ – residual flux (intensity), $Z = \log(N_{elem}/N_{tot})$.

$\left| \frac{dR_\lambda}{dZ} \right|$ is used as the weight function

This quantity differs from zero only in the spectral intervals sensitive to change in abundance of studied element.

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Corrections to the abundances

For small abundance changes we can replace derivative by differences:

$$\frac{dR_{\lambda}}{dZ} = \frac{R_{\lambda}^{+} - R_{\lambda}^{-}}{Z^{+} - Z^{-}}$$

where flux R_{λ}^{+} corresponds to abundance $Z^{+} = Z + \delta Z$ ($\delta Z = 0.1$ or 0.2),
flux R_{λ}^{-} corresponds to abundance $Z^{-} = Z - \delta Z$.

Correction to the abundance of studied element

$$\Delta Z = \frac{(Z^{+} - Z^{-})(Q_{\lambda}^{obs} - Q_{\lambda}^{syn})}{Q_{\lambda}^{+} - Q_{\lambda}^{-}}$$

where Q_{λ}^{obs} is found from the observed spectrum,
 Q_{λ}^{syn} corresponds to the synthetic spectrum,
 Q_{λ}^{+} and Q_{λ}^{-} – to synthetic spectra with abundances Z^{+} and Z^{-} .

Main features and application possibilities

- All lines of the studied element(s) are included
- Contribution of blended lines is duly taken into account
- The method works well for line-rich elements
- This method can be easily reduced to the equivalent spectral lines width method

- The method can be applied also for determination of parameters T_{eff} and $\log g$
- Pan-spectral peculiarities of line profiles of different chemical elements can be studied from their summed profiles

Spectrum of the HgMn star HD175640 (B9 V)

HD175640 is a single star with $T_{eff} = 12\,000$ K, $\log g = 3.95$

Spectral atlas by Castelli & Hubrig 2004 (A&A 425, 263–270)
High-quality UVES* spectrum:

- spectral region 3 000 – 10 000 Å
- spectral resolution 110 000 in visible and 90 000 in UV region
- signal-to-noise ratio 200 – 400

Excluded regions:

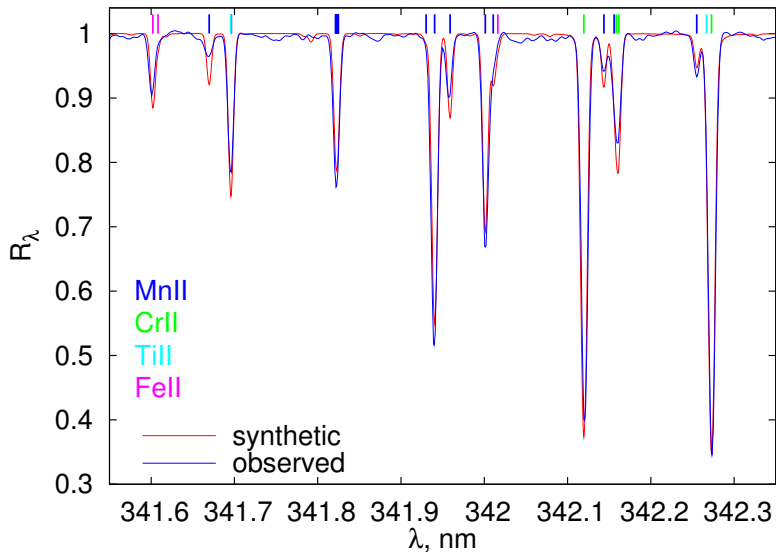
- most of IR spectrum due to telluric lines
- regions with weak overlap or gaps between some echelle spectral orders

*obtained at the ESO 8 m UT2 telescope

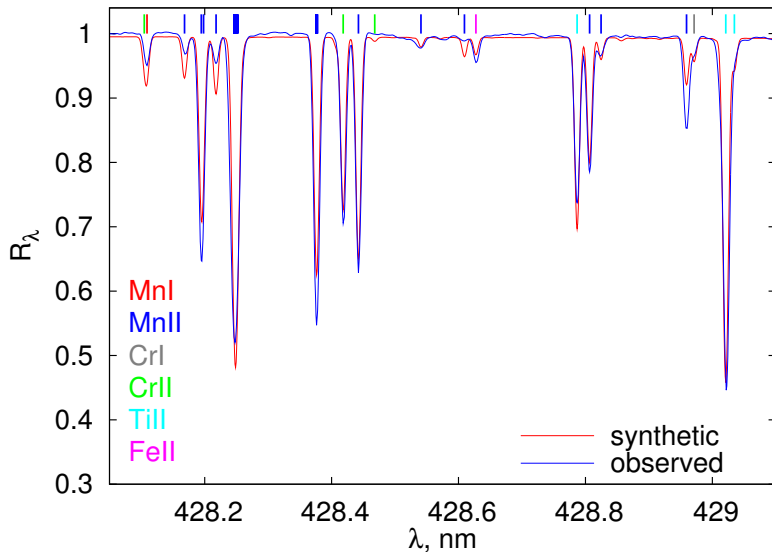
Synthetic spectrum of the HgMn star HD175640

- Model atmosphere (Kurucs ATLAS9) with parameters:
 $T_{eff} = 12000$ K, $\log g = 3.95$, $\xi = 0$ km/s
- Element abundances by Castelli & Hubrig (2004)
- Spectral resolution 500 000
- Spectra calculated with our program SMART
 - SMART is composed by our team during last decade
 - present version is FORTRAN 90/95
 - SMART is a compact and simple software, suited for study of different physical processes in hot stellar atmospheres.

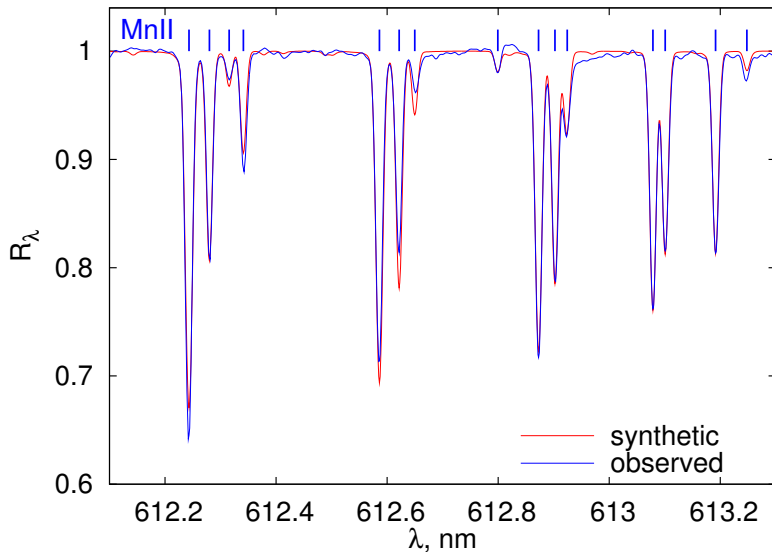
Comparison of observed and synthetic spectra



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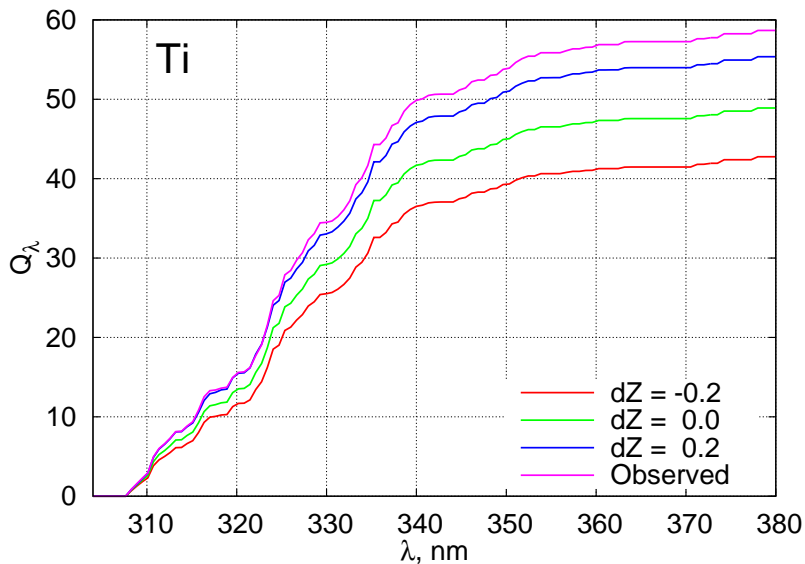
Comparison of observed and synthetic spectra



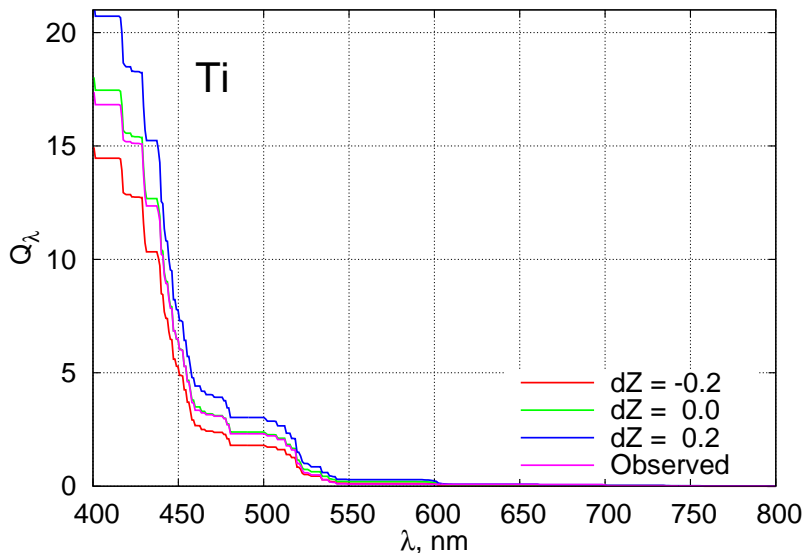
Application of the pan-spectral method

- The regions of Balmer and Paschen continua were studied separately
- We studied abundances of 12 line-rich elements:
Visual: Mn, Ti, Cr, Fe, Y, Mg, Si, Ca, O, S, Yb, Ni
UV: Mn, Ti, Cr, Fe, Y, Mg, Ca, Yb, Ni
- To apply the method we determined:
 - the best fit Gauss broadening parameter
 - the noise cutoff parameter
- For better results we used iterative modelling of spectra
 - 1 iteration: abundances Z_0 (as Castelli & Hubrig), $\delta Z = 0.2$
 - 2 iteration: abundances Z_1 (separate for UV and visual), $\delta Z = 0.1 \rightarrow$ corrections are small, final abundances obtained.

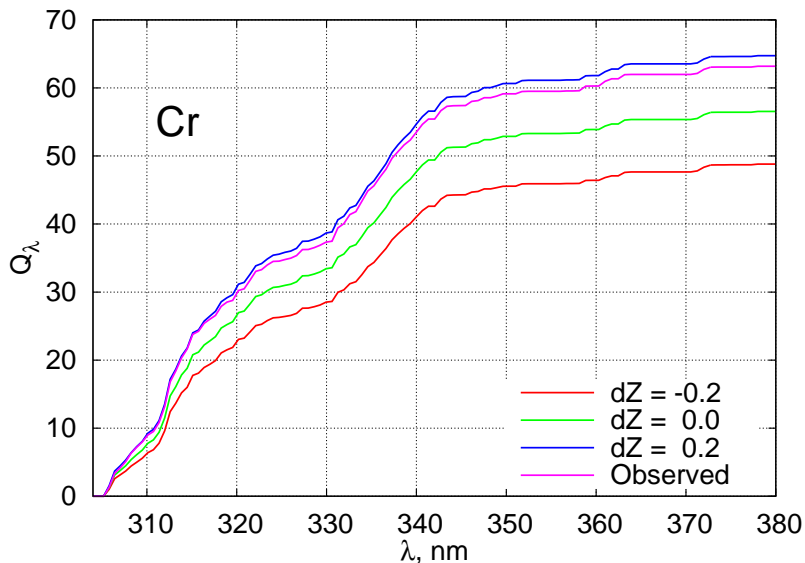
Weighted cumulative width Q_λ for titanium (UV)



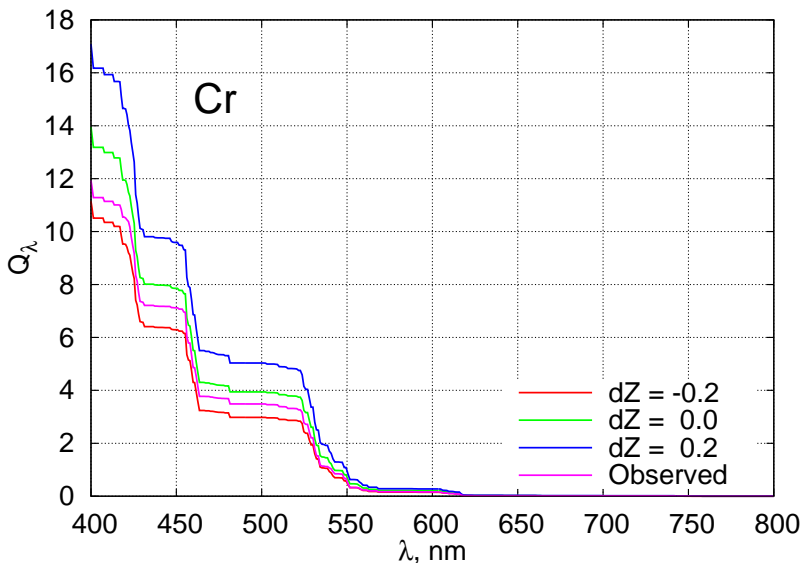
Weighted cumulative width Q_λ for titanium (Visual)



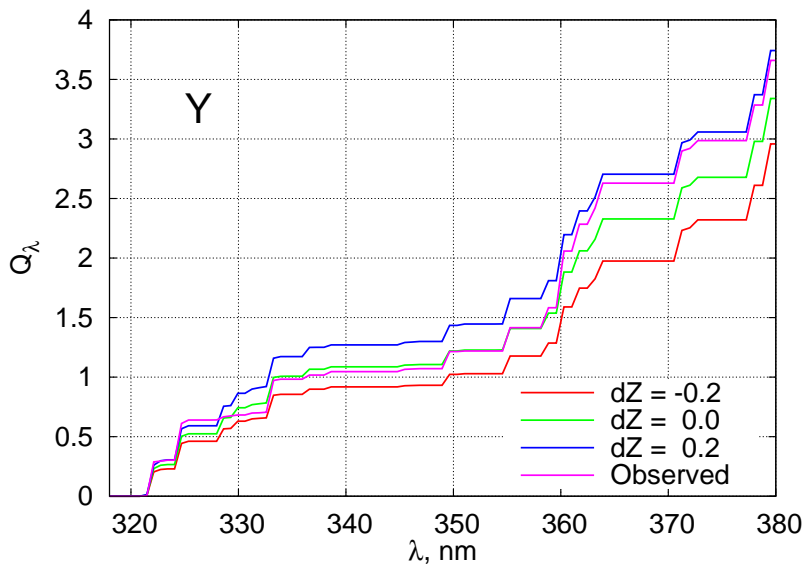
Weighted cumulative width Q_λ for chromium (UV)



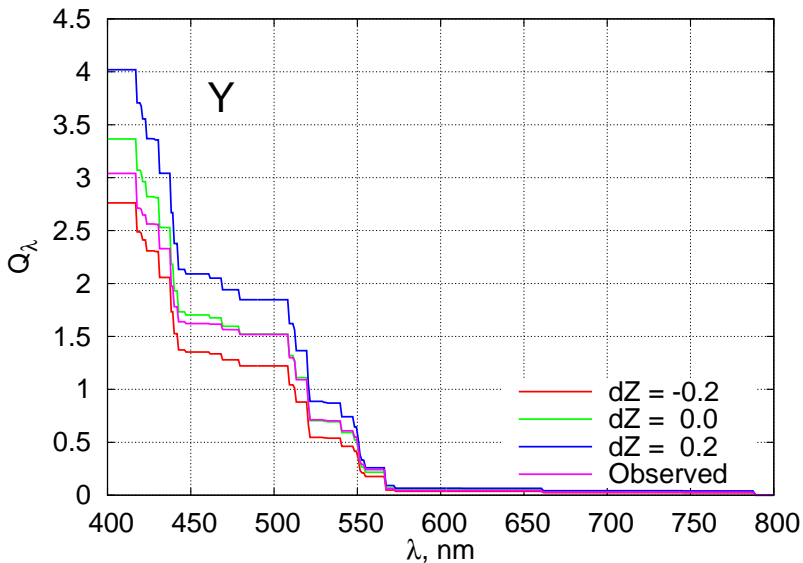
Weighted cumulative width Q_λ for chromium (Visual)



Weighted cumulative width Q_λ for yttrium (UV)



Weighted cumulative width Q_λ for yttrium (Visual)



Iterative corrections to abundances $Z = \log(N_{elem}/N_{tot})$

	Solar	Z_0	Correction 1		Z_1		Correction 2		Z_2	
			UV	Vis	UV	Vis	UV	Vis	UV	Vis
Mn	-6.65	-4.23	+0.35	+0.15	-3.88	-4.08	-0.02	0.00	-3.90	-4.08
Ti	-7.02	-5.67	+0.30	-0.05	-5.37	-5.72	-0.03	+0.01	-5.40	-5.71
Cr	-6.37	-5.27	+0.16	-0.14	-5.11	-5.41	-0.02	0.00	-5.13	-5.41
Fe	-4.53	-4.79	+0.06	-0.07	-4.73	-4.86	-0.03	0.00	-4.76	-4.86
Y	-9.80	-6.66	+0.16	-0.10	-6.50	-6.76	-0.04	0.00	-6.54	-6.76
Mg	-4.46	-4.67	+0.06	+0.13	-4.61	-4.54	-0.04	-0.01	-4.65	-4.55
Si	-4.49	-4.65	-	+0.43	-	-4.22	-	-0.06	-	-4.28
Ca	-5.68	-5.48	-0.06	0.00	-5.54	-5.48	-0.04	+0.04	-5.58	-5.44
O	-3.21	-3.18	-	+0.06	-	-3.12	-	+0.01	-	-3.11
S	-4.71	-5.24	-	+0.58	-	-4.66	-	-0.02	-	-4.68
Yb	-10.96	-7.66	+0.50	-0.38	-7.16	-8.04	-0.16	-0.13	-7.32	-8.17
Ni	-5.79	-6.09	+0.24	-0.06	-5.85	-6.15	-0.06	-0.07	-5.91	-6.22

Element abundances $[N/N_{\odot}]$ for HD175640

	Castelli & Hubrig 2004						Present study	
	UV			Vis			UV	Vis
	ion I	ion II	ion III	ion I	ion II	ion III		
Mn	+2.47	+2.40	–	+2.46	–	–	+2.75	+2.57
Ti	–	+1.43	–	–	+1.30	–	+1.62	+1.31
Cr	+1.19	+1.03	–	+1.13	+0.96	–	+1.24	+0.96
Fe	-0.36	–	–	-0.21	-0.30	–	-0.23	-0.33
Y	–	+3.38	–	–	+3.01	–	+3.26	+3.04
Mg	–			+0.18	-0.25	–	-0.19	-0.09
Si	–			–	-0.23	-0.09	–	+0.21
Ca	–	-0.15	–	+0.42	+0.06	–	+0.10	+0.24
O	–			+0.03	–	–	–	+0.10
S	–			–	-0.41	–	–	+0.03
Yb	–	+3.14	+3.66	–	+2.76	–	+3.64	+2.79
Ni	–	-0.22	–	–	-0.35	–	-0.12	-0.43

Main conclusions

- The pan-spectral method of abundance determination needs high-precision observed and synthetic spectra
- This method can be implemented for automatic processing of high-quality observed spectra
- This method can help to find vertical abundance profiles of elements in CP stellar atmospheres
- The abundances of heavy metals in the upper atmospheric layers, found from UV spectrum turn to be ~ 0.3 dex higher than in the deeper layers determined from visible spectrum
- For better results more complete and accurate data of spectral line strengths, their damping constants and electron impact cross-sections are needed.

Program SMART: capabilities and restrictions

Spectra and Model Atmospheres by Radiative Transfer

Authors: Arved Sapar, Raivo Poolamäe and Anna Aret (Tartu Observatory)

1 Stellar atmospheres of O, B and A spectral classes

(9 000 – 40 000 K)

2 Capabilities:

- Stellar spectra – radiative flux through the stellar atmosphere
- Stellar models – by iterative correction of initial model
- Diffusive separation of elements and isotopes in CP stars
- Relaxational formation of NLTE
- Accelerations of clumps in stellar wind
- Spectra of rotating stars and eclipsing binaries
- Radiative transfer in lines in stellar wind

3 Restrictions:

- plain-parallel and static stellar atmosphere
- chemically homogeneous atmosphere
- LTE
- no molecules