Common Methods of Stellar Spectra Analysis and their Support in VO

Petr Škoda Astronomical Institute Academy of Sciences Ondřejov Czech Republic

ESA workshop "Astronomical Spectroscopy and the Virtual Observatory", ESAC,Spain, 22 March 2007

Outline of the Talk

- Motivation (biased to stellar x VO people)
- Basic methods using only spectra and time
 - Visual
 - RV + other moments
- More advanced methods estimated period
 - Period analysis Folding
- Complex methods
 - Fourier space disentangling
 - Doppler imaging, tomography
- Report on VO enabled tools (no SDSS SS!)
- Conclusions What ? When ? Why ? (legacy)

Visual Spectral Analysis

- (Over) Ploting spectra
- Different objects
- Different ranges (UV over IR)
- Different time (RV, profile changes)
- All heritage packages (bplot, splot, specplot, spectool, DIPSO, XALICE) can do this
- And VO-enabled as well !

Measured Pulsations



Rho Pup – del Sct type

Eps Cep - del Sct type

Simulation of NR Pulsations



Aerts 2003

WD Models by Fitting wavelength scale



Kawka 2005

Different Lines overploted RV scale



V838 Mon: Kipper et al. 2004

Dynamic Spectra



Interactive features, color cuts, LUT Multiple lines at the same time Quotient or Differential X axis : lambda or RV Y axis : phase or time

For study of LPV (asteroseismology, winds) Requires

time (JD) - winds period (see Period analysis) - phase (LPV) change of template (average, median) removing bad data (interactive overplotting)

CX Dra: Skoda and Koubsky 1998

Dynamic Spectra



Netolický 2004

Rectification (Normalization)



SPEFO (SPLAT) – Hermit. polynoms (+Akima)

Anchor the edges -edges bad (chip,optics)
How flexible is it ?
Visible interaction – extrapolation
The REAL continuum – (V838 – Pcyg)
IRAF – select region - only existing data
Chi^2 ? - Model
Wavelet - C_infty = continuum ???
Merged echelle – many different unblazed ?





Merged Echelle



Arcturus: Hinkle et al.

Echelle Spectra Problems







Measurement of RV, z

- Normalization
- Fits of Gauss, Maxwell, Voigt
- Asymetry ??



RV by Mirroring

Shift until best match of direct and flipped profile - interactive Complicated profiles (Be) Adjustable region of interest (wing/core) Needs reference line position

SPEFO - Oscilloscopic

		X Starlink SPLAT-VO; <plot0></plot0>		. = ×
Measured comparison line N. 7 6348.737A	upper spectrum	File Analysis Edit Options Graphics Help		
+/- zoom x ↓ zoom y Shift + ↓ shift y	Del chng line width	Displaying: D:\SPEFO\LA280060.RUI	▼ Y limits Ø: automatic ▼ □:V-h	air
		LAMBDA : 6343.689	D:\SPEFO\LA280060.RUI: 0.9938 🗌 :log 🗌 :Trac	ck free
		X Starlink SPLAT-VO: Flip/translate spectrum	Y scale: 7.446524 💌 + 🗕	
		File Options Help		
		Copy current: V Flip Flip centre: 6347.091		
		Create copy		
$(\land \land$		Spectrum: Flip of: D:\SPEFO\LA280060.RUI 💌		
		Translation:		
		Redshift		
		Increment 0.1		
		Values:		1
		Corrected offset = 0.85 BV = 40148.09135397617		
		Notes:		
		Save to SPFEQ.log file		
			VV	
		🖉 Reset 🛛 🔴 Close		
>> (+ Shift) Move line Ins(sert) setting End next	line Esc no meas pos		99999999	
		KeVM 🖳 🍌 1 2 3 4 5 6 🛄 charon 📃 cha	aron 🗙 Starlink SPL 🗙 Starlink SPL 🗙 Starlink SPL	31:25

SPLA

Mirorring Method

Separate match of core from match of wings – where in depth ?

Different physics (shells, shears, winds)

Asymetry – how to handle ?



Bisector Method



Bisector Analysis

- Quantitative study of LPV
- Searching exoplanets
- High resolution echelle
- Rectified (normalized) spectra
- Various smoothing
- Cuts in relative depth of line half of span
- Zoom of bisectors position
- Results in 3D cube (time, line, depth)

RV by Cross Correlation



IRAF xrv

Template!

Normalization

Rotational Broadening



Hot stars

needed to use synthetic spectrum limb darkening problem estimate of v sin i interactively overplot model complicated in non-LTE absorption in Ha – double peak emission (Hadrava)

FT of Line Profile



Changes of EW in Time

Moments in general (asteroseismology – mode identification)
Emission lines – negative EW
Estimates of expanding shell
Sensitive to continuum placement – shallow lines
Abundances - check normalization – different lines same ion



Omi Cas : Koubsky et al. 2004

HD6226 : Slechta and Skoda 2004

Period Analysis

PDM, Fourier (CLEAN), many others (LombScargle) Rectified spectrum Time Ranges Initial estimate of period





Power spectrum FT

Theta statistics

Periodogram of Line Profile NRP





Lambda Sco: Uytterhoeven 2004

Period in local RVs – Different Depths



Zet Oph: Koubsky et al. 2005

Doppler Imaging - Bumps

Vogt & Penrod -80s Zet Oph Ball VOGT

Requires high SNR

- (>300-500)
- Perfect rotation coverage
- Artefacts otherwise
- NRP or solar spots
- Doppler Tomography
 - Accretion jets in Algols
 - Orbits in RV phase space



Spectra Disentangling

- For blended spectra of binary (multiple) stars
- Very powerful
- Requires good orbital coverage, estimate of orbital parameters (SIMBAD)
- Wavelength space disentangling computing power, space
- Fourier disentangling perfect continuum, cut regions, log lambda
 - P. Hadrava KOREL
 - S. Ilijic FDBINARY

Many Spectra Overploted





V436 Per Janík 2003

Spectra Disentangling in Fourier Space - KOREL



HD208905: Koubsky et al. 2006

VOSpec (ESAC)

- Very simple
- Polynomial fits
- No RV measurement
- No complex operations
- In VizieR now
- Can work with SLAP!
- Theoretical VO supported
- Rapid development :-)



SpecView (STScI)



Pan



- Fitting profiles from models
- Simple polynomials
- Analysis strong (deredening, CLOUDY)
- Supported !!
- Not good for IRAF WCS (1D FITS)
- BinTables+Extension

SPLAT-VO

🗙 Starlink	SPLAT-VO:	<plot0></plot0>									/////// - 🗆 X
File Analys	is Edit O	ptions Graphics	s Help								
Displaying:	—— D:	SPEFO (LA2800)	60.RUI				▼	Y limits (%): a	utomatic 🔻		🗌 :V-hair
LAMBDA :	6528.643	:lo	g		D:\SP	EFO\LA28006	50.RUI:	0.9882333		🗌 :log	🗌 :Track free
X scale:	1.0	• +	-			γ	scale:	0.5	▼	+	-
(u м				2-d co	mpound coo	rdinate syste	em				
	~~~	Mapleon Annual	rinin	and a second second second	NAMO AND	NM.	Marine				
<u> 등</u> 0.95		· · · ·			իստ իր	ſħ.,	r ^e		V		
.5 0.9					1	- M /					
0.85						$-\Lambda$					
0.8											
00 0.0						- M					
10./2											
0 0.7											
G 0.65E	6300		6400	6450	6500	<u></u>	660	0 6650	6700	675	
ä	0300	, 0350	0400	0450		٥٥٥٥	000	0 0000	0700	0/3	v l
4 300000											00000000000000000

- Custom line list
- Development not justified ?
- Most advanced for stellar astronomy
- JCMT now
- Plastic
- Reads 1D FITS...

### **FROG - Period04**



### Conclusions

To convince stellar astronomers – give them VO tools working in similar manner Easy publishing of FITS files – even for restricted access archive Functionality in client easy – but is this the real VO idea? Server side (Igor mentioned) - plugins for different data processing (Apache mods) Seamless unit transformation If pipeline processed – keep the unprocessed together (normalization of continuum) Switch on and off in client When will be SSAP finished? (should it be complete, intermediate stage!) SSA by query without RA, DEC (Jupiter spectra, Solar VO?)

# Is VO fighting against Data Avalanche?

