KOREL disentangling of the LMC eclpising Algol OGLE-LMC-DPV-065

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Observing techniques, instrumentation and science
for metre-class telescopes II

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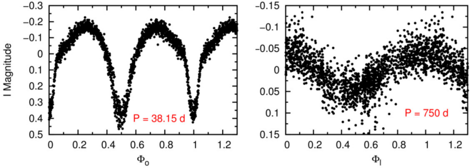
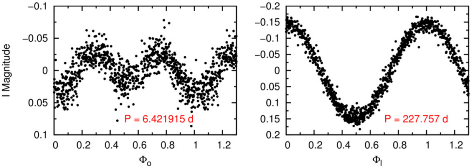
Outline

Introduction - DPV's

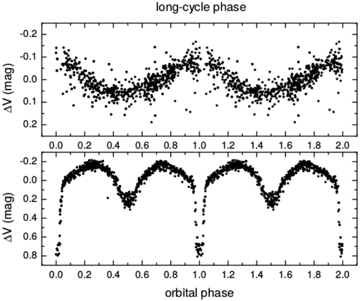
- were discovered by Mennickent et al. (2003) in the LMC (most of them) and SMC.
- $M_{prim} \gtrsim 7 M_{\odot}$
- secondary $\rightarrow$ filling its Roche lobe
- both period are related by $P_l \sim \alpha P_o$, where $24 \lesssim \alpha \lesssim 39$



Light vurve of LMC-DPV-074, (Poleski et al., 2010)

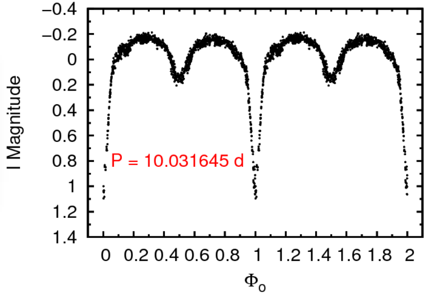


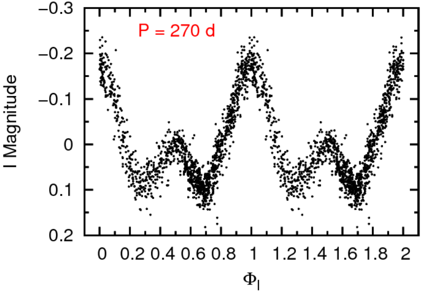
Light vurve of LMC-DPV-031, (Poleski et al., 2010)



Disentangled light curve for V495 Cen

Introduction - LMC-DPV-065





Long cycle variability of the eclipsing Algol LMC-SC6-57364, in prep.
R. E. Mannickent, M. Cabezas, G. Djurasevic, T. Rivinius, P. Hadrava, R. Poleski, I. Soszynski, L. Celedón, N. Astudillo-Defru, Raj, J. Fernandez-Trincado, I. Porritt

- one of the brightest DPV in LMC
- V = 14.74 mag, B -V = -0.07 mag
- $P_o = 10^d.031645 \pm 0.000033$ (Poleski et al., 2010).

Introduction - Disentangling

- Whats mean "disentangling"?
  enable method used to determine efficiently the orbital parameters and simultaneously decompose the spectra
- decomposition of spectra methods:
  - Wavelenght domain (Simon & Sturm, 1994)
  - Radial velocities (González & Levato, 2006)
  - Fourier transform (Hadrava, 1995)
- when is usefu/possible to use the method?
  - for blended spectra
  - good distribution in ϕ_o
  - for normalized spectra

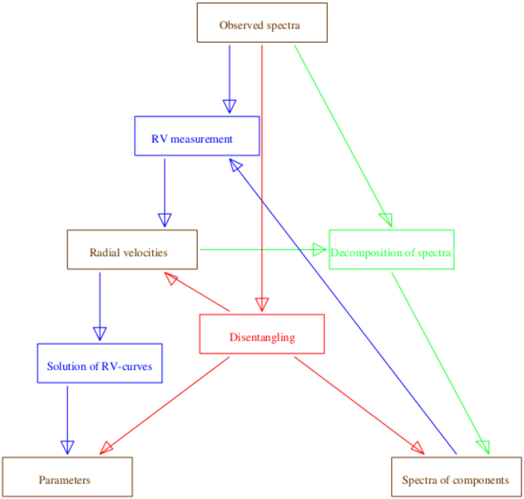


Figure 1: Schema of comparison between the disentangling method with classical methods (Hadrava, 2009)

Disentangling method - KOREL

- **KOR**elation **EL**ements
- Fortran code for disentangling of spectroscopically variable stellar system using Fourier Transformation(FT).
- KOREL was developed by P. Hadrava (1995) on the basis of experience with his code FOTEL (FOTometric Elements, 1994) and inspiration by the Cross-correlation method.
- precise normalization of the input spectra is needed
- KOREL determines the contributon of components to the composite spectra, the orbital parameters and radial velocities.
- More details in Hadrava (2004b)

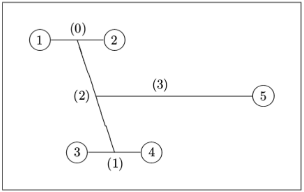
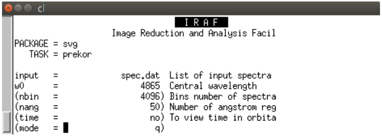


Figure 2: The structure of the stellar system (Hadrava, 2004a, figure 5)

i	orbital element	
1	P	period [in days]
2	t_0	time of periastron passage [in days]
3	e	eccentricity
4	ω	periastron longitude [in degrees]
5	K	semiamplitude of radial velocity of the component with the lower index [in km/s]
6	q	the mass ratio of the component with the higher to that with the lower index
7	$\dot{\omega}$	the rate of periastron advance [in degrees/day]
8	$\dot{P}$	the time derivative of the period
9	$\dot{e}$	the time derivative of the eccentricity [in day^{-1}]
10	$\dot{K}$	the time derivative of K-velocity [in km/s/day]
11	$\dot{q}$	the time derivative of mass ratio [in day^{-1}]

PREKOR



1. select spectral region → *specXX.asc*
2. *specXX.asc* → *PREKOR.LST*
   (spec file | hjd | weight)
   weight∼ $(S/N)^2$
3. *PREKOR.LST*→PREKOR
   - under DOS
   - rebin the spectra in $\ln(\lambda)$
   - prepare the input data, *korel.dat* in ASCII
   - gives the "orbital parameters" for telluric lines

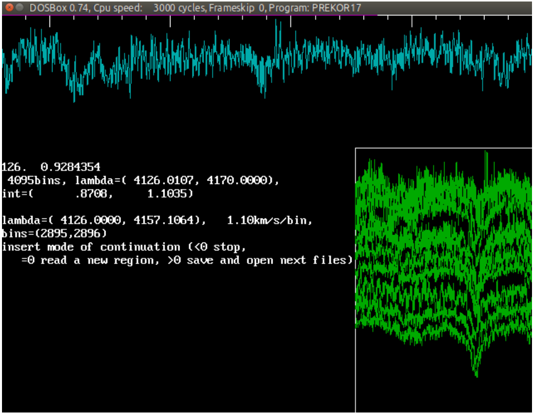


Figure 3: Example of PREKOR

KOREL files

1. Korel input
   - korel.dat
     - Time series of composite spectra(from PREKOR)
   - korel.par
     - Definition of a hierarchical system
     - initial values of parameters
     - converge parameters
   - korel.temp
     - telluric lines
2. KOREL output
   - korel.res
     - orbital parameter values
     - decomposed spectra
     - sum of residal square
     - radial velocities
   - phg.ps
     - plot of decomposed spectra

```
56983.73270 6520.0244  1.106   .346    4096
1.02964 1.02102 1.01478 1.00835 1.00078  .99371  .98572  .97478  .96773  .97676
1.00211 1.04545 1.08462 1.07493 1.03605 1.01213 1.00949 1.01302 1.02077 1.03398
1.03304 1.01372  .99180  .98141  .98728 1.00783 1.03208 1.05263 1.06212 1.05110
1.02939 1.01646 1.01671 1.02231 1.02523 1.02218 1.01709 1.01502 1.01667 1.02318
1.03525 1.04432 1.03288 1.00270  .98147  .97826  .97717  .95925  .92829  .91728
 .94523  .98359 1.00719 1.02003 1.01696 1.00705 1.00618 1.01506 1.01825 1.01358
1.02364 1.03986 1.03199  .99536  .96441  .96739  .99116 1.00535  .99649  .97891
 .97764 1.00165 1.02978 1.03107 1.00148  .97592  .98642 1.00153 1.00728 1.01499
1.02227 1.01582  .99895  .98520  .97197  .95394  .94040  .93119  .93009  .94528
```

Figure 4: korel.dat

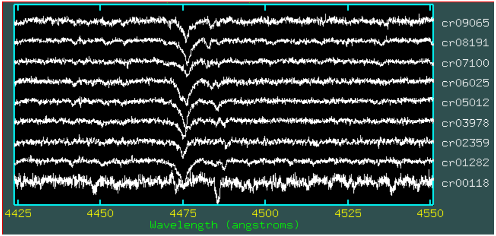
```
1 1 0 0 1 1 0 2 12 |key(5), k= Nr. of spectra, filter, plot, print
o 0  1 0 1 1    10.031855500    0.000 = PERIOD(0)
o 0  2 0 1 1 53392.218000000    0.001 = PERIASTRON EPOCH
o 0  3 0 1 1     0.000000000    0.002 = ECCENTRICITY
o 0  4 0 1 1    90.000000000    0.000 = PERIASTRON LONG.
o 0  5 0 1 1    43.297264666    0.157 = K1
o 0  6 0 1 1     0.202470528    0.001 = q = M2/M1,  K2 =   213.844775799
o 0  7 0 1 1     0.000000000    0.000 = d omega/dt
o 0  8 0 1 1     0.000000000    0.100 = d P/dt
o 0  9 0 1 1     0.000000000    0.100 = d e/dt
o 0 10 0 1 1     0.000000000    0.100 = d K1/dt
o 0 11 0 1 1     0.000000000    0.100 = d q/dt
o 3  1 0 1 1   365.256360000    0.100 = PERIOD(3)
o 3  2 0 1 1 51547.520600000   10.000 = PERIASTRON EPOCH
o 3  3 0 1 1     0.016710220    0.001 = ECCENTRICITY
o 3  4 0 1 1    43.756057815   10.000 = PERIASTRON LONG.
o 3  5 0 1 1     0.001000000    0.000 = K1
o 3  6 0 1 1     0.000454714    0.000 = q = M2/M1,  K2 =     2.199184542
o 3  7 0 1 1     0.000009111    0.000 = d omega/dt
o 3  8 0 1 1     0.000000000    0.100 = d P/dt
o 3  9 0 1 1     0.000000000    0.100 = d e/dt
o 3 10 0 1 1     0.000000000    0.100 = d K1/dt
o 3 11 0 1 1     0.000000000    0.100 = d q/dt
```

Figure 5: korel.par

Spectroscopic data

i) UVES

- 27 spectra with $R \sim 55000$
- October 2, 2013 - February 1, 2015
- echelle spectrograph, UVES .
- 3760-4980 Å.
- airmas 1.4
- exp. time 3000s
- S/N 65 (4800Å)

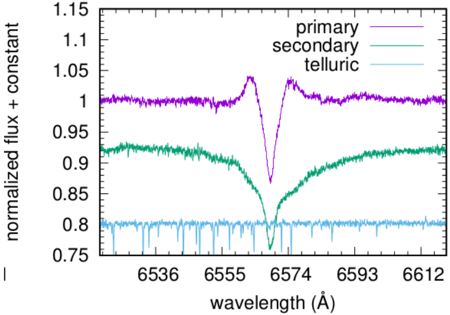


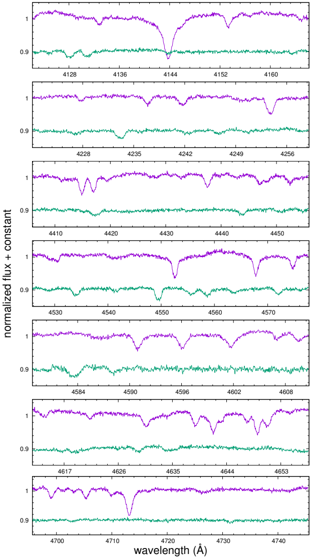
date-ut	*HJD*	Φ_o
2013-10-02	56567.7689	0.547
2013-10-04	56569.8218	0.751
2013-10-06	56572.8075	0.049
2013-10-07	56584.7162	0.236
2013-10-19	56587.8479	0.548
2013-10-22	56648.5833	0.603
2013-12-22	56650.7561	0.819
2013-12-24	56661.6647	0.907
2013-12-31	56675.6735	0.303
2014-01-04	56676.6249	0.398
2014-01-18	56699.5976	0.688
2014-01-19	56703.5569	0.083
2014-02-11	56704.5526	0.182
2014-02-15	56901.8820	0.853
2014-02-16	56964.8370	0.128
2014-09-01	56981.7855	0.818
2014-11-03	56986.7551	0.313
2014-11-20	56987.7523	0.413
2014-11-22	56999.6148	0.595
2014-11-25	57000.7640	0.710
2014-11-26	57000.7687	0.710
2014-11-27	57005.6626	0.198
2014-12-08	57005.6695	0.199
2014-12-09	57042.5660	0.877
2014-12-14	57042.5709	0.877
2015-01-20	57054.5867	0.075
2015-02-01	57054.5922	0.075

run KOREL

Table 1: Summary of resolution for each spectral region.

Spectral range Å	RV/bin km s^{-1}
4126-4170	0.773
4225-4263	0.653
4410-4460	0.821
4530-4582	0.831
4583-4615	0.508
4615-4662	0.723
4700-4750	0.772
average	0.726





Solutions I and II

Spectral range Å	τ -2453300.0	K_1 km s^{-1}	K_2 km s^{-1}	q	$\frac{\Sigma(o-c)^2}{N}$
4126-4170	92.311010	42.585424	206.375845	0.206348	0.006253
4225-4263	92.263258	42.552037	218.883717	0.194404	0.006033
4410-4460	92.325566	42.566616	217.980012	0.195277	0.006236
4530-4582	92.296613	42.702544	214.191599	0.199366	0.006227
4583-4615	92.309639	42.553583	207.360914	0.205215	0.006401
4615-4662	92.292585	42.597010	215.240906	0.197903	0.006488
4700-4750	92.324279	42.585746	202.413316	0.210390	0.006671
Solution I	**92.303279**	**42.591852**	**211.778044**	**0.201272**	–
stdev	0.021596	0.05171173	6.366115	0.006090	–
Solution II	**92.317179**	**42.074334**	**204.368038**	**0.205875**	**0.00631857**

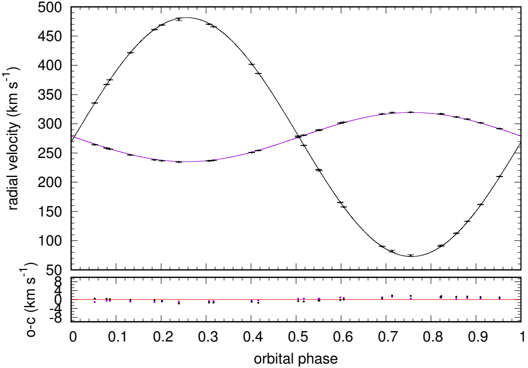
Final solution

	Solution					
Parameter	I	II	III	IV	V	VI
VII	VIII					
Period P (d)	10.0318555	10.0318555	10.0318555	10.0318555	10.0318555	10.0318555
τ*	92.303 $\pm$ 0.022	92.317	92.316 $\pm$ 0.010	92.280	92.225 $\pm$ 0.003	92.218 $\pm$ 0.003
K_1(km s^{-1})	42.592 $\pm$ 0.052	42.074	41.796 $\pm$ 1.925	42.228	43.566 $\pm$ 0.084	43.566 $\pm$ 0.080
K_2(km s^{-1})	211.778 $\pm$ 6.366	204.368	211.717 $\pm$ 7.960	208.289	210.837 $\pm$ 0.765	213.906 $\pm$ 0.780
q	0.201 $\pm$ 0.006	0.206	0.198 $\pm$ 0.009	0.203	0.206 $\pm$ 0.001	0.203 $\pm$ 0.001
ω(deg)	90	90	90.017 $\pm$ 0.434	90.465	90	90
e	0	0	0.005 $\pm$ 0.006	0.010	0	0

* $T_0 - 2400000.0$

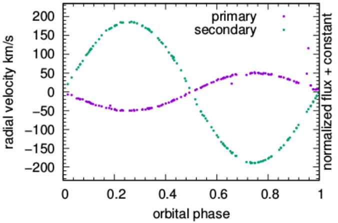
- Solution I : Average all regions, $e = 0$, $\omega = 90$ deg
- Solution II : multiregion mode, $e = 0$, $\omega = 90$ deg
- Solution III: Average all regions, $e \neq 0$
- Solution IV : multiregion mode, $e \neq 0$
- Solution V : KOREL solutions, $e = 0$ + FOTEL unweighted solutions
- Solution VI : KOREL solutions, $e = 0$ + FOTEL weighted solutions

Radial velocity curve

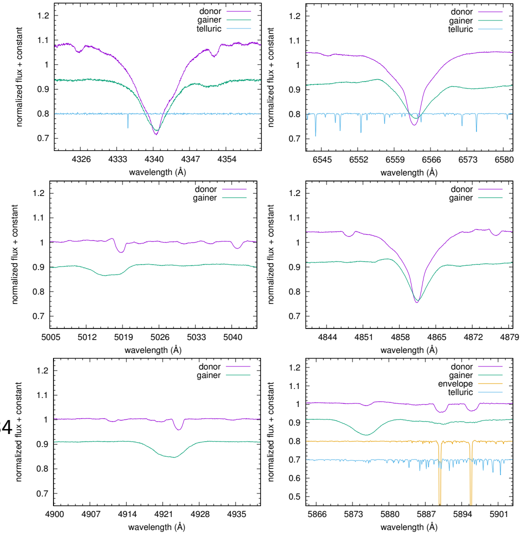


V356 Sgr

- **Refined parameters for V 356 Sgr and its accretion disk**, in prep. *(M. Cabezas, R. E. Mennickent, G. Djurasevic, P. Hadrava, I. Araya, D. Graczyk, and M. Cure)*



- V356 Sgr (HD 173778), $V_{max} = 6.84$ mag, $P_o = 8.8961$ Popper (1955)
- Algol type, semidetached
- supergiant A2 + brighter B3V



Spectroscopic data - Metre class telescopes

i) CHIRON[1] (Schwab et al., 2012), 1.5 m Cerro Tololo Inter-American Observatory (CTIO)

- 125 spectra with $R \sim 80000$
- echelle spectrograph .
- 4589-8760 Å.
- $\text{disp}_{H_\alpha} \rightarrow 0.01648$ Å/px or RV$= 0.751$ km s^{-1} per pixel
- CNTAC proposal CN2013A-91 and CN-2014A-26

ii) CORALIE[2] (Queloz et al., 2001), 1.2m Euler telescope (La Silla ESO Observatory)

- 36 spectra with $R \sim 40000$.
- 3865-6900 Å.
- $\text{disp}_{H_\alpha} \rightarrow 0.005$ Å/px or RV$= 0.228$ km s^{-1} per pixel

[1] http://www.ctio.noao.edu/
[2] https://www.eso.org/public/teles-instr/lasilla/

Conclusions and Future work

1. We applied the KOREL code to extract the spectral components of DPV065.
2. The method of disentangling of spectra is precise and at the same time less laborious (after to learn how works) than the classical methods of measurement of radial velocities and subsequent solution of radial-velocity curves.
3. With the disentangling method, it is possible to study each component independently in order to understand in a better way the phenomenon and fundamental parameters of DPV stars.
4. Using the disentangling of spectra we found for first time an evidence of acretion disc the DPV 065.

- To study the physical parameters of the system by comparison with synthetic spectra
- To include into the FOTEL and KOREL codes new options and to test them on this and other multiple stars.
- improve the code to make it more user-friendly.
- write an updated user guide
- upload VO-version (include PREKOR)
- include errors of solutions

Thank you for your atention! - mauricio.cabezas@asu.cas.cz

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