

Highlights of a half century of the **UBV** photometry at Hvar

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Beginnings

- ▶ Hvar Observatory was built in the old fortress Napuljun at altitude of 260 m above the town of Hvar and opened in 1972. Main partners: Faculty of Geodesy of the Zagreb University, Astronomical Institute of Academy of Sciences in Ondřejov, and Astronomical Institute of Charles University.
- ▶ A 0.65 m Cassegrain reflector with a single-channel *UBV* photometer, both designed and built by Pavel Mayer.

Telescope with photometer

Originally in Napoljun fortress, then in a dome north of the main building



Collaborators

Luboš Perek



Pavel Mayer



Initial motivation

- ▶ The idea about a possible role of duplicity for the origin of the Be phenomenon was gradually born in the Ondřejov team through the works of Mirek Plavec, Svatopluk Kříž, Jiří Horn, Pavel Koubský, Jiří Krpata and Petr Harmanec. At suggestion of Pavel Koubský, spectroscopic observations of bright Be stars were started in 1971 with the coude spectrograph of the 2 m reflector in the effort to detect their binary nature.

Initial motivation

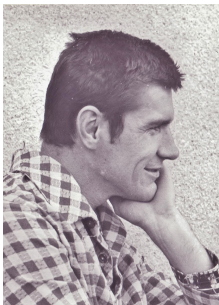
- ▶ The idea about a possible role of duplicity for the origin of the Be phenomenon was gradually born in the Ondřejov team through the works of Mirek Plavec, Svatopluk Kříž, Jiří Horn, Pavel Koubský, Jiří Krpata and Petr Harmanec. At suggestion of Pavel Koubský, spectroscopic observations of bright Be stars were started in 1971 with the coude spectrograph of the 2 m reflector in the effort to detect their binary nature.
- ▶ When the photometry became available at Hvar, the main motivation was to search for eclipsing binaries among all bright Be stars observable there.

Collaborators

Pavel Koubský



Jiří Krpata



Jiří Horn



Beginnings

- ▶ First *UBV* observations at Hvar were secured on July 29, 1972 by Pavel Koubský and Petr Harmanec.
- ▶ Main programs: systematic observations of Be stars, eclipsing binaries (initially promoted by Pavel Mayer) and also CP stars (collaboration of Krešimir Pavlovski with Mike Maitzen, also Jiří Grygar and Zdeněk Mikulášek).
- ▶ Need for stable and accurate transformation to the standard system over many years: non-linear transformations and monitoring of extinction changes during observing nights.

The Be Star program

- ▶ We selected groups of bright Be stars with obligatory comparison, check and red standard stars having *UBV* values published by Johnson.
- ▶ International observing campaign organized via Be Star Newsletters. Large contributions by John Percy with students (Toronto, KPNO, APT-15), Lin Huang with collaborators (Xing Long near Beijing), later Hicran and Volkan Bakis (Canakkale, Turkey).
- ▶ All comparisons and checks with *UBV* values were used to transformations to save time.
- ▶ First large revision and homogenization: Harmanec, Horn and Juza (1994).

A large revision of 50 seasons

- ▶ Since July 2014 the primary and selected secondary Johnson's *UBV* standard stars were observed several times in the course of good observing nights to bracket observations of all program stars.
- ▶ New robust mean *UBV* values of all these Johnson standard stars were derived from individual observations by Johnson et. al. (1966).
- ▶ New standard *UBV* values of all comparison and check stars used were derived from the reduction of these seasons and all previous seasons back to 1972 were re-reduced with them and with an improved version of the reduction program HEC22, which allowed to monitor the changes of the extinction during observing nights. Currently the archive contains over 75000 differential *UBV* observations for 685 stars.

Quality tests

- ▶ Already after the 1994 revision it was possible to derive reliable transformations of the Hipparcos H_p magnitude to Johnson V magnitude (Harmanec 1998) based on Hvar UBV values and the same was also achieved for several other photometric systems like *uvby*, the Canadian DAO system, Johnson 13-C system and some old photometries with diodes (Harmanec and Božić 2001).

Another quality test

The red star 51 And served as a red standard in two different, and often observed Be stars and has 835 Hvar all-sky observations.

φ Per, comp 4 Per [$V = 5.009$, $B - V = -0.073$, $U - B = -0.305$; B8III], 597 obs and

o Cas, comp. HR189 [$V = 5.674$, $B - V = -0.125$, $U - B = -0.571$; B5V], 621 obs.

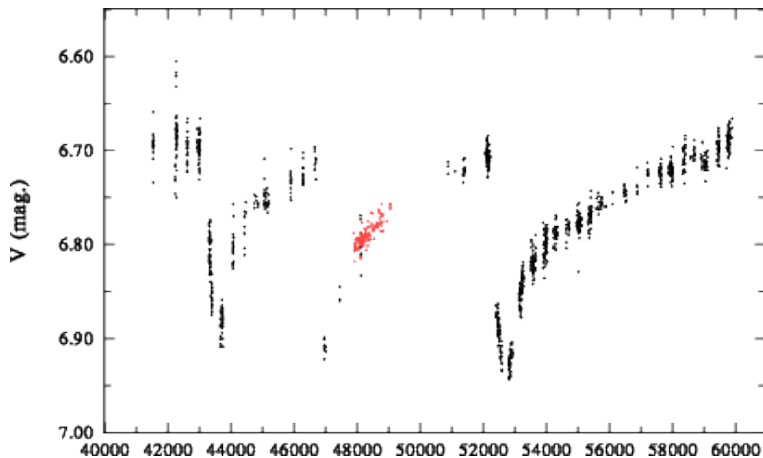
	V	B	U	$B - V$	$U - B$
to HR189	3.602	4.882	6.313	1.280	1.431
to 4 Per	3.602	4.883	6.313	1.281	1.430
all-sky	3.600	4.881	6.313	1.281	1.432

Main messages of Hvar photometry

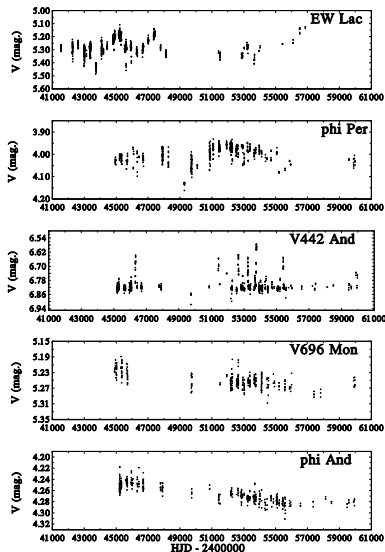
- ▶ Systematic observations led to general realization that all Be stars are light and colour variables on several time scales.
- ▶ Distinct types of long-term variations were recognized and classified, the important limiting cases being the positive and inverse correlation between the brightness, colours and emission strength.
- ▶ A few eclipsing and ellipsoidal binaries were discovered among Be stars but in most cases, the orbital modulation had only a small amplitude and was masked by other types of changes, detectable in only very long series of observations.

The longest Hvar series for a Be star

V744 Her = 88 Her

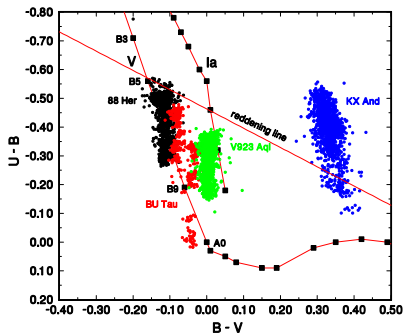
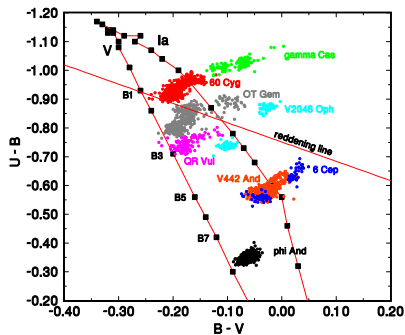


Examples of long-term brightness changes



Positive and inverse correlation

Behaviour in the $U-B$ vs. $B-V$ diagram



Eclipsing and ellipsoidal binaries

Several semi-detached systems with Be primaries and Roche-lobe filling secondaries were studied, usually in broad collaboration.

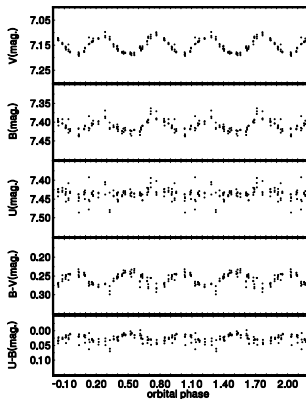
Name	HD	P(d)	$T_{\text{eff. 1}}$	$T_{\text{eff. 2}}$	Type	Ref.
BR CMi	61273	12.92	9500	7000	ELL	1
HIP 46377	81357	33.77	12900	4260	ELL	2
CX Dra	174237	6.696	20000	7000	ELL	3
β Lyr	174638	12.93	30000	14500	ECL	4
V360 Lac	216200	10.09	18000	5900	ELL	5

References:

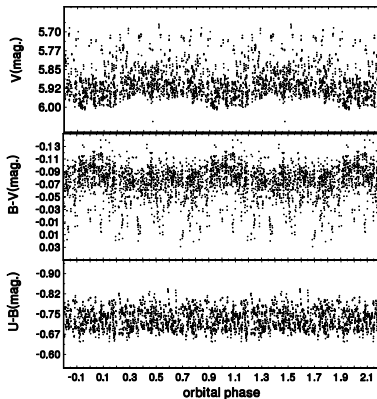
- 1... Harmanec et al (2015) A&A 573,A107
- 2... Koubský et al. (2019) A&A 629, A105
- 3... Richards et al. (2000) ApJ 531, 1003
- 4... Brož et al. (2021) A&A 645, A51
- 5... Linnell et al. (2006) A&A 455, 1037 .

Orbital light curves: two extremes

BR CMi
no secular changes



CX Dra
strong secular changes



V832 Cyg = 59 Cyg = HD 200120

SB2 B1+OVI $P=29.19$ d Peters et al. 2013 ApJ 762:2, Maintz
(2003) PhD dissertation, Univ. Heidelberg, Harmanec et al.
(2002) A&A 387, 580

Phase-locked RV and V/R changes Relatively mild long-term
changes with little colour variations

V832 Cyg = 59 Cyg = HD 200120

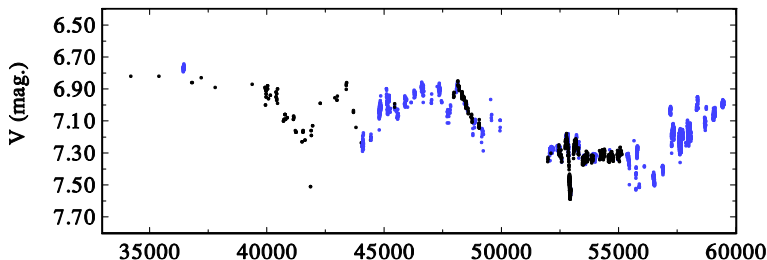
Mild orbital modulation of the brightness after prewhitening for long-term changes

Various goals...

- ▶ A number of emission-line binaries with peculiar light curves was observed at Hvar, e.g. RX Cas ($P=32.3$ d), α Cas = HD 4180 ($P=1031.6$ d), γ Cas = HD 5394 ($P=202$ d), ε Aur = HD 31964 ($P=9890$ d), UX Mon = HD 65607 ($P=5.90$ d), V1507 Cyg = HD 187399 ($P=27.97$ d), V1765 Cyg = HD 187459 ($P=13.37$ d), KX And = HD 218393 ($P=38.92$ d)
- ▶ With the exception of several dedicated campaigns, Hvar photometry is not suitable for the study of rapid light variations.
- ▶ The fourth time scale documented in several cases.

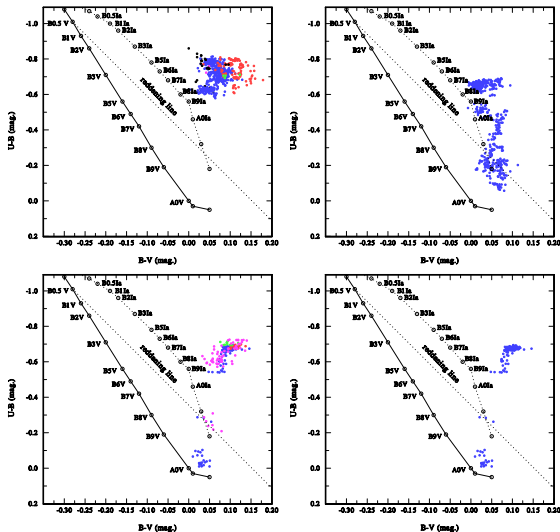
V1294 Aql = HD 184279

Harmanec et al. (2022) A&A 666, A136: A very remarkable, large amplitude light variable, discovered to be a spectroscopic binary, $P=192.9$ d. Two large brightness decreases recorded. Very complicated variability patterns combining several types of behaviour.



V1294 Aql = HD 184279

Bottom panels correspond to data from two different sharp light decreases.



Summarising...

- ▶ Many Croatian and Czech observers helped to accumulate Hvar photometric observations. We are currently preparing two large papers (emission-line objects, and other variables observed at Hvar) co-authored by the whole team of observers, where the results will be published in detail.
- ▶ Still under consideration are detailed studies of individual interesting objects, based not only on the Hvar photometry but on all available observing data.
- ▶ Collaboration of interested colleagues on such future studies is welcome.