High precision photometry as a test of stellar model atmospheres and evolution theory

Jiří Krtička¹, Zdeněk Mikulášek¹, Jan Janík¹, Theresa Lüftinger², Milan Prvák¹

¹Institute of Theoretical Physics and Astrophysics, Masaryk University, Brno, Czech Republic
²Institut für Astronomie, Universität Wien, Türkenschanzstraße 17, 1180 Wien, Austria

Abstract: Chemically peculiar stars represent a large class of upper main sequence stars. The processes of radiative diffusion and gravitational settling in their atmospheres give rise to pronounced deviations in the chemical composition of these stars from the solar value. Some chemically peculiar stars show inhomogeneous surface distribution of chemical elements on their surface. The uneven surface distribution of various elements, together with radiative flux redistribution and rotation, is the origin of these stars’ light variability. The comparison of the predicted light variability (derived from model atmospheres using surface abundance maps) with observed light variability provides a very precise test of model atmospheres. Moreover, the periodical light variability may serve as a very precise clock that is able to detect even very minute changes of rotational period. Therefore, space-based photometry may serve as test of internal structure and evolutionary models of the stars with global magnetic field.

Our testbed: magnetic chemically peculiar stars

Magnetic chemically peculiar stars constitute an exceptional group of hot stars with peculiar abundances of various elements. Such unusual surface chemical composition originates from the radiative diffusion, possibly modulated by magnetic fields and weak stellar winds. Chemically peculiar stars show inhomogeneous surface distribution of different elements, including helium, silicon, or iron. Their observed periodical light variations are explained by the redistribution of the emergent flux due to the bound-free (continuum) and bound-bound (line) transitions in the stellar atmosphere (Krtíčka et al., 2007, 2014, Figs. 2, 3).

The nature of the light variations provides an opportunity to test the predictions of stellar model atmospheres. Moreover, the tight connection of the variability to the stellar rotation provides a very precise clock that is able to detect even very minute changes of rotational period.

The testbed at a glance

Test of stellar atmospheres

The surface abundance maps can be derived from spectroscopy using the technique called the Doppler inversion. With the help of model atmospheres the derived abundance maps can be used to construct the surface brightness map. At the end this yields the photometric light curve, that can be compared with observations. Because the photometric variations are connected with flux redistribution caused by the opacity that varies across the surface, a precise photometric curve may provide a detailed test of model atmospheres.

Test of stellar evolution theory

The rotationally modulated light variability of chemically peculiar stars provides a very precise clock, that enables us to detect even minute changes of rotational period of the stars. The detected period changes may serve as additional test of stellar structure and evolutionary models that include rotation.

Fig.1 Predicted surface brightness variation of V901 Ori in the vcolour calculated for different phases using the silicon and helium surface distribution from Khokhlova et al. (2000).

Fig.2 Comparison of the predicted (lines) and observed (circles) light variations of V901 Ori in different colours.

Fig.3 Comparison of the predicted (lines) and observed (circles) light variations of θ Aur in different colours.

Fig.4 Rotational period variations of V901 Ori derived from photometric observations (Mikulášek et al., 2011).

Fig.5 Rotational period variations of CU Vir derived from photometric observations (Mikulášek et al., 2011).

Acknowledgement: This work was supported by grant GA ČR P209/12/0217 and MSMT 7AMB14AT015.

Literature

Khokhlova, V. L., Vasilchenko, D. V., Stepanov, V. V., & Ramanyuk, I. I., 2000, Astl. 21, 177

Mikulášek et al. (2008) and Mikulášek et al. (2011) detected period changes of V901 Ori and CU Vir of the order of $P \approx 10^{-9} - 10^{-11}$ (see Figs. 4, 5). The changes are most likely caused by the interaction of the stellar rotation and magnetic fields.

The order-of-magnitude estimate of the uncertainty of the period change is

$$\Delta P \approx \frac{12}{s} \frac{P^2}{A^2}$$

where s is the standard deviation of one measurement, A is the amplitude of the light variations, P is the rotational period, and A is duration of observations. For a space-based photometry with $s = 10^{-4}$ mag the evolutionary period changes with $P \approx 10^{-11}$ become just at the verge of the detection. Therefore, there is a prospect of the detection of evolutionary changes of stellar rotational period for massive stars.