University of Szeged
Faculty of Natural Sciences and Informatics
Doctoral School of Physics

The role of metallicity in stellar pulsation

Summary of PhD thesis

Katalin Sziládi

Supervisor: *Dr. József Vinkó* senior research fellow
MTA CSFK Konkoly Observatory
SZTE Department of Optics and Quantum Electronics

Advisor: *Dr. László Szabados* research professor emeritus
MTA CSFK Konkoly Observatory

Szeged, 2018

1. Introduction

Classical Cepheids are variable stars with essential importance from both astrophysical and cosmological points of view. These are massive giant- or supergiant stars that are located within the Instability Strip on the Hertzsprung–Russell diagram (HRD), and they exhibit stable, periodic light variation. This variability is due to radial pulsation that are excited and governed by the astrophysical process called kappa-mechanism.

The importance of pulsating stars, especially Cepheids, is given by the fact that we can reveal details on the internal structure and evolution of these stars by studying their oscillations. In cosmology they are mainly used as distance indicators, because the existence of the period-luminosity relation discovered 100 years ago make them useful for measuring distances on extragalactic (i.e. several megaparsecs) scale.

A small subgroup of Classical Cepheids contain stars that pulsate in two excited modes simultaneously. These are called double-mode, or beat Cepheids. Modeling these stars dates back to the 1990s, and it was recognized quite early that the period ratio (P_1/P_0) depends strongly on other physical parameters like effective temperature, mass, luminosity and metallicity. Nevertheless, checking the theoretical predictions with observations was limited for a while, because, for example, having metallicity information for such stars requires high resolution, high signal-to-noise measurements that are feasible only with modern state-of-the-art instruments.

By the beginning of the 21st century only about two dozens of double-mode Cepheids were known within the Milky Way. On the other hand, hundreds of such stars were discovered in the Large- and Small Magellanic Cloud by the MACHO and OGLE sky surveys. Unfortunately, due to instrumental constraints, only the Milky Way (Galactic) Cepheids could be studied by high-resolution spectroscopy to measure their metallicities directly. This is why new methods that attempt to derive physical parameters, like metallicity, solely from photometry gained more attention by now. My PhD dissertation focuses on studies related to these problems.

2. Scientific aims and methods

The aim of my work is to reveal new details on the metallicity dependence of the pulsational properties of beat Cepheids.

Galactic beat Cepheids are so bright that their metallicities can be measured directly with high-resolution spectroscopy using big telescopes. In 2004, our foreign collaborators obtained such measurements for 17 beat Cepheids using the FEROS spectrograph attached to the 2.2 m telescope of the European Southern Observatory (ESO) at La Silla, Chile. 4 of our program stars have been studied before only with photometry. After reducing and analysing these data, my work focused on quantifying the correlation between the period ratio and metallicity that was revealed by theoretical studies earlier.

At present, high-resolution optical spectroscopy is the best method for determining the chemical composition of astronomical objects. The effective and reliable practical application of this method requires observed spectra having both high resolution and wide wavelength coverage. Cross-dispersed echelle spectrographs are the most effective instruments for this purpose, that is why the the FEROS spectrograph was used in my work. The reduction and calibration of digital echelle spectra is a long and complex process that depends on not only the technical specialities of the instrument but also the astrophysical characteristics of the studied objects. Thus, a significant part of my work was devoted to the development of a pipeline for getting reduced and calibrated echelle spectra taken with FEROS.

As an application of my results, I examined the double-mode Cepheids in the Large- and Small Magellanic Cloud attempting to correlate their metallicities with the Fourier-parameters of their light curves. Fourier analysis is a widely and extensively applied mathematical method for characterizing the shape of measured light curves, thus, I used it for this purpose. After collecting the existing photometric data from literature, first, I derived the Fourier amplitude ratios and phase differences of the light curves that characterize the shape of the light curves. After that I looked for correlations between these Fourier-parameters and the metallicities obtained from period ratios using the relation that I determined for the Galactic beat Cepheids.

3. Results

1. New physical parameters and metallicities for double-mode Cepheids

- Using new high-resolution spectroscopic data I derived the following physical parameters for 17 Galactic double-mode Cepheids: effective temperature ($T_{\rm eff}$), surface gravity ($\log g$) and metallicity expressed as the relative abundance of iron to hydrogen, $[{\rm Fe/H}] = \log(N_{\rm Fe}/N_{\rm H}) - \log(N_{\rm Fe}/N_H)_{\odot}$. These were the first spectroscopic metallicities for 4 of the program stars that were studied before only photometrically. Years later, using more recent metallicity measurements collected from literature, I derived homogenized metallicities for all the program stars by bringing them onto a consistent metallicity scale reducing the systematic offsets plaguing the early metallicity measurements.

Related publications: **[1], [2], [3]**

2. Period - period ratio - metallicity relation

- Based on new spectroscopic data I quantified and improved the period - period ratio - metallicity ($\log P$ - P_1/P_0 - $[{\rm Fe/H}]$) relation that is valid for beat Cepheids pulsating in the fundamental mode and the first overtone simultaneously. By extrapolating the relation toward lower metallicities I estimated the metallicities of double-mode Cepheids in the Large- and Small Magellanic Clouds.

Related publications: **[2], [3]**

3. Photometric metallicities

- I collected photometric data for double-mode Cepheids in the Magellanic Clouds from the online databases of the OGLE-III and OGLE-IV surveys. I made a sample of 98 Cepheids pulsating in the fundamental and first overtone modes. Then I characterized the shape of their light curves by computing the Fourier amplitude ratios and phase differences, and I determined their $[{\rm Fe/H}]$ metallicities using the period - period ratio - metallicity relation mentioned above.

- I found that the main amplitude and the R_{21} amplitude ratio are the most sensitive photometric parameters to metallicity. For the fundamental mode there is also a correlation between metallicity and the phase difference between the main frequency and first harmonics ($\varphi_{21} = \varphi_2 - 2\varphi_1$), although it was not significant for the first overtone, probably because of the lower signal-to-noise of those data.

- I pointed out that the previously published relations describing the connection between the Fourier parameters and the metallicities of Classical Cepheids that pulsate only in the fundamental mode are not valid for the more metal-poor Magellanic Cloud beat Cepheids that have shorter periods and lower amplitudes. Instead, I established new relations that predict more reliable metallicities in this parameter regime.

Related publications: **[4]**

4. Publications related to the results

[1] **Sziládi, K.**, Vinkó, J., Poretti, E., Szabados, L., and Kun, M., "Echelle Spectroscopy of Double-Mode Cepheids", in: Astrophysics of Variable Stars, Edited by Sterken, C. and Aerts, C., ASP Conference Series, Vol. 349, p. 347 San Francisco: Astronomical Society of the Pacific, (2006)

[2] **Sziládi**, K., Vinkó, J., Poretti, E., Szabados, L., and Kun, M., "New homogeneous iron abundances of double-mode Cepheids from high-resolution echelle spectroscopy", Astronomy and Astrophysics, 473, pp. 579-587, (2007)

[3] **Sziládi**, K., Vinkó, J., Szabados, L., Kun, M., and Poretti, E., "Iron Abundances of Southern Double-mode Cepheids from High-resolution Echelle Spectroscopy", in: Precision Spectroscopy in Astrophysics, Proceedings of the ESO/Lisbon/Aveiro Conference held in Aveiro, Portugal, 11-15 September 2006. Edited by N.C. Santos, L. Pasquini, A.C.M. Correia, and M. Romanielleo; Garching, Germany, pp. 169-172 (2008)

[4] **Sziládi**, K., Vinkó, J. Szabados, L., "Metallicity Estimates for Double-Mode Cepheids from Photometry" Acta Astronomica, közlésre elfogadva (2018)

5. Other publications

Csak, B., Kiss, L. L., Szabo, Gy., Sarneczky, K., and **Sziladi, K.**, "New Field Variable Stars I", Information Bulletin on Variable Stars, 4875 (2000)

Csak, B., Kiss, L. L., **Sziladi, K.**, Sarneczky, K., and Szabo, Gy., "New Field Variable Stars II", Information Bulletin on Variable Stars, 4881 (2000)

Csak, B., Kiss, L. L., Szabo, Gy., **Sziladi, K.**, and Sarneczky, K., "New Field Variable Stars III", Information Bulletin on Variable Stars, 4989 (2000)

Kiss, L. L., Csák, B., Szatmáry, K., Furész, G., and **Sziládi, K.**, "Spectrophotometry and period analysis of the sdB eclipsing binary HW Virginis", Astronomy and Astrophysics, 364, pp. 199-204 (2000)

Kiss, L. L., Thomson, J. R., Ogloza, W., Furész, G., and **Sziládi, K.**, "The 2000 outburst of the recurrent nova CI Aquilae: Optical spectroscopy", Astronomy and Astrophysics, 366, pp. 858-864 (2001)

Vinkó, J., Csák, B., Csizmadia, Sz., Fürész, G., Kiss, L. L., Sárneczky, K., Szabó, Gy., **Sziládi, K.**, and Bíró, I. B., "Distance to the Active Galaxy NGC 6951 via the type Ia Supernova 2000E", Astronomy and Astrophysics, 372, pp. 824-832 (2001)

Kiss, L. L., Szabó, Gy. M., **Sziládi, K.**, Furész, G., Sárneczky, K., and Csák, B., "A variable star survey of the open cluster M 37", Astronomy and Astrophysics, 376, pp. 561-567 (2001)

Szabó, Gy. M., Kiss, L. L., Sárneczky, K., and **Sziládi, K.**, "Spectrophotometry and structural analysis of 5 comets", Astronomy and Astrophysics, 384, pp. 702-710 (2002)

Vinkó, J., Bíró, I. B., Csák, B., Csizmadia, Sz., Derekas, A., Furész, G., Heiner, Z., Sárneczky, K., Sipocz, B., Szabó, Gy., Szabó, R., **Sziládi, K.**, and Szatmáry, K., "The Type Ia Supernova 2001V in NGC 3987", Astronomy and Astrophysics, 397, pp. 115-120 (2003)

Veréb, G., Zakar, M., Kovács, I., **Pappné Sziládi, K.**, Kertész, Sz., Hodúr, C., László, Zs., "Effects of pre-ozonation in case of microfiltration of oil contaminated waters using polyethersulfone membrane at various filtration conditions", in Desalination for the Environment Clean Water and Energy. 318 p., Róma, Olaszország, 2016.05.22-2016.05.26. Róma: p. 181. 1 p. (2016)

Horváth, Zs. H., Szeg, I., Szabó P., B., **Papp-Sziládi, K.**, Véha, A ., "Change of the colour agent content of paprika powders with added oleoresin in course of storage" In: Szent István Egyetem Élelmiszertudományi Kar; Proceedings of 1st International Conference on Biosystems and Food Engineering.; Budapest, Magyarország, 2016.12.08 Budapest: Szent István Egyetem, Élelmiszertudományi Kar, 2016. Paper E-120. 8 p. (2016)

Beszédes, S., **Papp-Sziládi, K.**, Keszthelyi-Szabó, G., Hodúr, C., "Detection of Biodegradation Degree of Sludge Using Dielectric Measurement" In: Monostori Tamás (szerk.) 15th Wellmann International Scientific Conference: book of abstracts: Towards sustainable agriculture: an interdisciplinary approach. 79 p.; Hódmezővásárhely, Magyarország, 2017.05.03; Szegedi Tudományegyetem Mezőgazdasági Kar, 2017. p. 26. (2017)

Veréb, G., Zakar, M., Kovács, I., **Pappné Sziládi, K.**, Kertész, Sz., Hodúr, C., László, Zs., "Effects of pre-ozonation in case of microfiltration of oil contaminated waters using polyethersulfone membrane at various filtration conditions", DESALINATION AND WATER TREATMENT, 73, pp. 409-414. (2017)

Kovács, R., **Sziládi, K.**, Keszthelyi-Szabó, G., Beszédes, S., "Mérési körülmények hatásának vizsgálata folyadékok dielektromos jellemzőinek meghatározásánál" JELENKORI TÁRSADALMI ÉS GAZDASÁGI FOLYAMATOK, 12:(4) pp. 49-59. (2017)