European Organisation for Astronomical Research in the Southern Hemisphere

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APPLICATION FOR OBSERVING TIME PERIOD: **102Z**

DDT

Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of CoIs and the agreement to act according to the ESO policy and regulations, should observing time be granted.

1. Title Category: **D–1**

Heavy element abundance in the spectrum of the primary component in an extremely rare eclipsing binary HD 66051: solving the mistery of the origin of the peculiar nature of HgMn stars

2. Abstract / Total Time Requested

Total Amount of Time:

The rare eclipsing binary HD 66051 with an orbital period of about 4.75 d hosts as a primary a HgMn-related star, and an A-type star as a secondary component (Niemczura et al. 2017). While the abundance analysis of the primary indicates highly peculiar composition with an overabundance of the iron-group, heavy (e.g. Hg and Pt) and the REE elements, the recent work by Kochukhov et al. (2018) using ESPaDOnS data characterizes the primary as a classical Si-strong Bp star with a longitudinal field of the order of 50–100 G. In contrast to HgMn stars, the presence of heavy elements in magnetic Si-strong Bp stars is not expected, nor such stars are members of very close SB2 systems. Since the available spectroscopic material is rather poor, we suggest to obtain a high-resolution, high signal-to-noise UVES spectrum of HD 66051 to firmly establish the HgMn peculiarity of the primary which could be the first HgMn star with a definitely detected magnetic field.

3. Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	102	UVES	0.8h	any	n	1.2	THN	s	

4. Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:		
b) still required to complete this project:		

5. Special remarks:

One year ago, we submitted a DDT proposal asking for two spectropolarimetric observations of the same target with HARPSpol in service mode. Due to its time critical aspect, the proposed observations were not approved by the DDT Committee. The same target was observed with ESPaDOnS by a competing group, who discovered the presence of a weak magnetic field. However, their abundance work based on rather low quality spectra (S/N=90–150) significally contradicts our results and states that the primary is not a HgMn-related star.

6. Principal Investigator: ENIEMCZURA

6a. Investigators:

All CoIs moved to the end of the document.

7. Description of the proposed programme

A – Scientific Rationale: The region of the Main Sequence centred on A and B stars, also referred to as the "tepid stars", represents an ideal laboratory to study a wide variety of physical processes that are at work in most stellar types. These processes include radiation driven diffusion, differential gravitational settling, grain accretion, magnetic fields and non-radial pulsations. While their observable manifestation is particularly prominent in tepid stars, some or all of them do play a significant role in the physics, formation and evolution of most stars. Their understanding is becoming increasingly important for the refinement of stellar evolution models and for the improved treatment of the stellar contribution in studies of galactic evolution.

Among the tepid stars, one identifies a number of groups that differ from each other by the combination of physical properties that characterise them: surface abundance patterns, strength and structure of the magnetic field, pulsation, rotation and multiplicity. These groups, which include, among others, the classical magnetic Ap and Bp/Si-rich stars, the Am stars, the HgMn stars, and the λ Boo stars, result from different formation and evolution scenarios. Thus their study allows one to gain insight into the above-mentioned physical processes from differentperspectives.

Niemczura et al. (2017, NatSR 7, 5906) discovered an eclipsing binary HD 66051 with an orbital period of about 4.75 d hosting as a primary a highly peculiar, HgMn-related star and a slowly rotating A-type star as a secondary component. In their analysis, the authors used HARPS and HIDES spectra at the resolution $R = 110000$ and $R = 50000$ and signal-to-noise (S/N) ratios of about 90 and 70, respectively. Niemczura et al. (2017, NatSR 7, 5906) show that the highly peculiar composition of the primary component is reminiscent of another HgMn-related star HD 65949. Notably, in contrast to a few other HgMn stars with studied abundances, the primary star exhibits enhanced (by $\approx$1 dex) silicon abundance, which is usually indicative of the presence of magnetic fields. Indeed, very recently, using fourteen ESPaDOnS polarimetric spectra, Kochukhov et al. (2018, MNRAS 478, 1749) announced for the primary a firm discovery of a longitudinal magnetic field of the order of 50–100 Gauss. Surprisingly, opposite to the results of the abundance analysis of Niemczura et al., Kochukhov et al. put in question the overabundance of certain key chemical elements, including heavy elements, which are usually used for assigning the HgMn peculiarity type. The authors conclude that due to the definite detection of a global magnetic field, the primary should be considered as a classical magnetic Bp star. On the other hand, it should be noted that the ESPaDOnS spectra used in their study were only of a limited quality with S/N between 50 and 150. Thus, using such low S/N spectra, a conclusive identification and reliable abundance measurement of heavy elements were certainly challenging.

To better highlight the problem of assigning of a proper peculiarity type in late-B type stars we present below the properties used to characterise the groups of the HgMn and classical magnetic Bp stars:

- most of HgMn stars are spectroscopic binaries with primaries of spectral types B7–B9 and orbital periods between 3 and 20 days. Therefore, observations of HgMn stars contribute not only to the understanding of the formation mechanism of HgMn stars, but also to the general understanding of late-B type star binary system formation: based on the inspection of SB systems with a late B-type primary in the 9th Catalogue of Spectroscopic Binary Orbits (Pourbaix et al., 2004, A&A, 424, 727), all but one late B-type stars formed in binary systems with such orbital periods become HgMn stars (Schöller et al. 2013, CEAB 37, 369). In contrast, only one presumably classical late-B type close system, HD 5550, with a very weak longitudinal magnetic field of 26 Gauss and $P_{\rm orb} = 6.8$ d (Alecian et al. 2016, A&A 589, A47) is known. However, no abundance analysis was carried out for this system so that a proper classification of the primary remains unknown.
- in their vast majority, HgMn stars exhibit large excesses of P, Mn, Ga, Br, Sr, Y, Zr, Rh, Pd, Xe, Pr, Yb, W, Re, Os, Pt, Au, and Hg, and underabundances of He, Al, Zn, Ni, and Co (e.g. Castelli & Hubrig 2004, A&A 425, 263), as well as isotopic anomalies of Ca, Pt, and Hg with patterns changing from one star to the next (e.g. Hubrig et al. 1999, A&A 341, 190). In contrast, classical magnetic Bp stars show strong overabundances of the rare earth elements, but never show overabundance of heavy elements, such as Pt, Au and Hg. While silicon is usually solar in HgMn stars, the classification of classical magnetic Bp stars is usually based on $\approx$1 dex overabundance of silicon.
- most of HgMn stars display line profile variability with the stellar rotation period, due to the inhomogeneous distribution of chemical elements over their surface (e.g., Nuñez et al. 2011, in Magnetic Stars, Proc. Intern. Conf., p. 361). Different groups of elements, in particular iron-peak and heavy elements, show different distributions (Hubrig et al. 2006, MNRAS 371, 1953), and the abundance patches undergo dynamical evolution on a time scale from a few months to years (Hubrig et al. 2010, MNRAS 408, L61; Briquet et al. 2010, A&A 511, A71). In contrast, classical magnetic Bp star show strong inhomogeneous distribution of the rare-earth elements.
- the presence of weak magnetic fields in HgMn stars is still under debate. Early detections of weak longitudinal magnetic fields in HgMn stars from spectropolarimetric observations with the ESO instruments CASPEC and FORS1, and with SOFIN at the NOT (e.g., Mathys & Hubrig 1995, A&A 293, 810; Hubrig & Castelli 2001, A&A 375, 963; Hubrig et al. 2006, AN 327, 289; 2010, MNRAS 408, L61) were questioned by subsequent studies (e.g. Makaganiuk et al. 2011 A&A 525, A97; Kochukhov et al. 2011, A&A, 534, L13). On the

7. Description of the proposed programme and attachments

Description of the proposed programme (continued)

other hand, the application of the moment technique to the HARPS and SOFIN spectra indicated a possible presence of a weak longitudinal magnetic field, a quadratic magnetic field, and the crossover effect on the surface of several HgMn stars (Hubrig et al. 2012, A&A 547, A90). In contrast, classical magnetic Bp stars usually show large-scale organized fields of kG order.

Based on the presented differences in the properties of these two groups of peculiar stars, it is obvious that the unambiguous line identification and confirmation of the overabundance of heavy elements in the spectrum of the primary component of HD 66051 will remove any reported discrepance in the assigning the HgMn peculiarity type. Moreover, due to the clear detection of the magnetic field in the HgMn primary, the SB2 system HD 66051 will offer an important insight into the long-standing problem of the generation of magnetic fields and the origin of extreme chemical peculiarities in close binary systems. Answering the question whether magnetic fields play a significant role in the development of abundance anomalies in HgMn stars is also important for the understanding of the processes taking place during the formation and evolution of B stars in multiple systems in general.

B – Immediate Objective: We plan to obtain a high quality, high-resolution, high signal-to-noise UVES spectrum of the close SB2 system HD 66051 to derive abundances of elements typical for HgMn stars, in particular heavy elements, and other elements such as P, Mn, Ga, Br, Sr, Y, Zr, Rh, Pd, Xe, Ar, etc. The appropriate synthetic spectra will be computed with the SYNTHE code, which calculates intensity stellar spectra for a given model atmosphere under the assumption of LTE. The atomic data are available on the F. Castelli's website and were supplemented with the data taken from the Vienna Atomic Line Database (VALD). An example of the comparison of the observed HARPS spectrum and the synthetic spectrum around the Pt II λ4046.4 line is presented in Fig. 1, where the blue line indicates the synthetic profile calculated with the Pt solar abundance and the red line the profile calculated with a Pt overabundance of 5.5 dex.

Attachments (Figures)

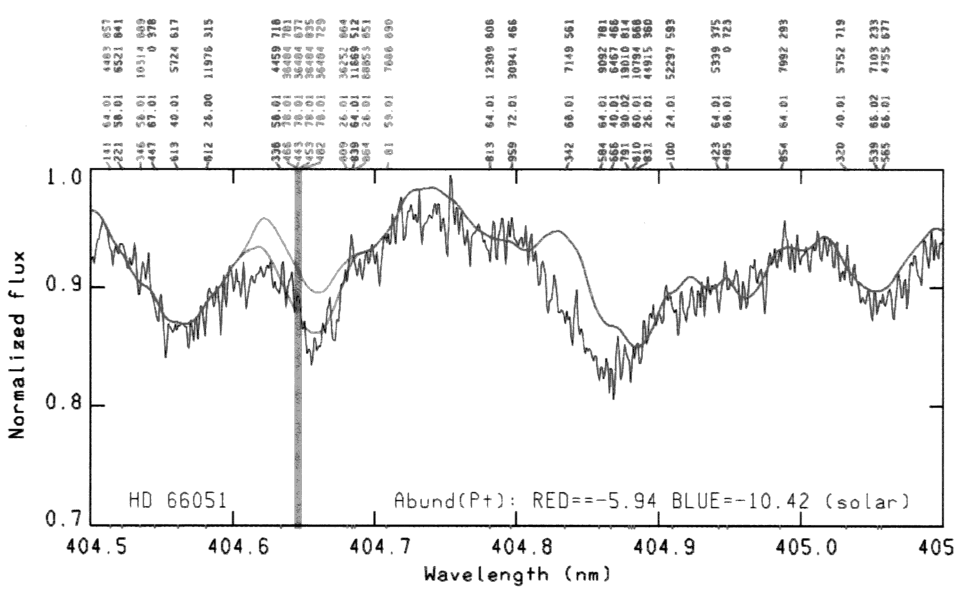

Fig. 1: The comparison of the observed HARPS spectrum and the synthetic spectrum around the Pt II λ4046.4 line. The blue line indicates the synthetic profile calculated with the Pt solar abundance and the red line the profile calculated with a Pt overabundance of 5.5 dex.

8. Justification of requested observing time and observing conditions

Lunar Phase Justification: No restrictions.

Time Justification: (including seeing overhead) We plan to use DIC1 346+580 and DIC2 437+760 and the 0.4 arcsec slit for the blue arm ($R = 80\,000$) and 0.3 arcsec slit for the red arm ($R = 110\,000$) to cover the whole visual wavelength region. Based on our experience, for determination of chemical abundances with the best precision, a S/N ratio of 300 at 4046 Å is necessary and sufficient. Using the UVES ETC (version P103.3), the estimated time is 48 min, where we added overheads of about 10 minutes allowing for the acquisition, setup and readouts.

8a. Telescope Justification:

UVES on UT2 is the only instrument worldwide that can provide us with spectroscopic data of the desired quality, i.e. high spectral resolution and high signal-to-noise ratio required in the studies of close SB2 systems.

8b. DDT Justification:

In this proposal we ask for the UVES observation of a SB2 system with a strongly peculiar primary component. The presence of a magnetic field in a chemically peculiar components of binary systems is a hot and highly competitive scientific topic. As of today, no one close binary with a magnetic HgMn primary is known. The obtained chemical abundances will lead to the opening of a new era in theoretical studies of the origin of magnetism in upper main sequence binary systems.

8c. Calibration Request:

Standard Calibration

9. Report on the use of ESO facilities during the last 2 years

Report on the use of the ESO facilities during the last 2 years (4 observing periods). Describe the status of the data obtained and the scientific output generated.

9a. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If so, explain the need for new data.

There are no UVES spectra for our target in the ESO archive.

9b. GTO/Public Survey Duplications:

There is no duplication with either GTO or public survey programmes.

10. Applicant's publications related to the subject of this application during the last 2 years

Niemczura, E., Hümmerich, S., Castelli, F., et al., 2017, Nature Scientific Reports, 7, 5906 "HD 66051, an eclipsing binary hosting a highly peculiar, HgMn-related star"

Castelli, F., Cowley, C. R., Ayres, T. R., Catanzaro, G., Leone, F., 2017, A&A, 601, A119: "An abundance analysis from the STIS-HST UV spectrum of the non-magnetic Bp star HR 6000"

Hubrig, S., Järvinen, S. P., Madej, J., Bychkov, V. D., Ilyin, I., Schöller, M., Bychkova, L. V., 2018, MNRAS, 477, 3791: "Magnetic and pulsational variability of Przybylski's star (HD 101065)"

Hubrig, S., Przybilla, N., Korhonen, H., Ilyin, I., Schöller, M., Järvinen, S.P., et al., 2017, MNRAS 471, 1543: "Characterising the magnetic field and spectral variability of the He-strong star CPD $-57°$ 3509"

Hümmerich, S., Niemczura, E., Walczak, P., et al., 2018, MNRAS, 474, 2467: "A spectroscopic and photometric investigation of the mercury-manganese star KIC 6128830"

Hümmerich, S., Bernhard, K., Paunzen, E., et al., 2017, MNRAS, 466, 1399 "An investigation of four chemically peculiar stars with photometric periods below 12 h"

Järvinen, S.P., Carroll, T., Hubrig, S., et al., 2018, ApJ, 858, L18: "Weak Magnetic Fields in Two Herbig Ae Systems: The SB2 AK Sco and the Presumed Binary HD 95881"

Paunzen, E., Fedurco, M., Hełminiak, K. G., et al. 2018, A&A, 615A, 36: "Orbital parameters and evolutionary status of the highly peculiar binary system HD 66051"

Monier, R., Gebran, M., Royer, F., et al., 2018, ApJ, 854, 50: "HR 8844: A New Transition Object between the Am Stars and the HgMn Stars?"

Schöller, M., Hubrig, S., Fossati, L., et al., 2017, A&A 599, A66: "B fields in OB stars (BOB): Concluding the FORS2 observing campaign"

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	HD 66051	08 01 24.6	-12 47 35.7	0.8	8.8			

12. Scheduling requirements

13. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
102	UVES	A	DIC-1	Standard setting: 346+580
102	UVES	A	DIC-2	Standard setting: 390+760

6b. Investigators:

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F.	Castelli	1347
E.	Paunzen	1480
S.	Hümmerich	5677
R.	Monier	1361
S.	Hubrig	1135
S.	Järvinen	1135
K.	Bernhard	5677
F.-J.	Hambsch	5677
K.	Hełminiak	1569