European Organisation for Astronomical Research in the Southern Hemisphere

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APPLICATION FOR OBSERVING TIME

PERIOD: **94A**

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–7**

Measuring the orbital decay of the close sdB+WD binary CD−30 11223 caused by gravitational wave emission

2. Abstract / Total Time Requested

Total Amount of Time:

Short period binaries are predicted to be strong sources of gravitational waves. Here we propose to use time resolved FORS2 photometry of the bright, eclipsing, short-period sdB+WD binary CD−30 11223, to constrain the value of the orbital decay $\dot{p}$, as indirect evidence of gravitational wave emission. We want to improve the SNR on the shallow eclipses and improve the orbital parameters determination of this unique binary. Combining the new, high-precision eclipse times with archive data, we will be able to detect the predicted shrinkage of the orbit.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	94	FORS2	4h	any	n	n	THN	s	

4. Number of nights/hours

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:

6. Principal Investigator: sdhawan

6a. Co-investigators:

S.	Geier	1258
T.	Kupfer	1638

7. Description of the proposed programme

A – Scientific Rationale: The recent discovery of primordial gravitational waves (GW) in the B-mode polarization power spectrum of the CMB has led to a renewed interest in the hunt for gravitational waves. One of the possible, but yet unconfirmed, methods of detecting GW is through direct measurements from ground and spaced-based missions. A more indirect method for detecting the presence of gravitational waves is by using short-period compact binary systems. General relativity (GR) predicts that close binary systems will lose energy in the form of emission of GW. This leads to orbital shrinkage which can be inferred from the observables of the system, especially the change (shortening) of the orbital period. Such an inferrence was first made with the famous Hulse-Taylor binary pulsar (PSR B1913+16). Extensive observations over a period of decades confirmed the shift of the periastron (Hulse and Taylor [1975]). This remarkable discovery led to the authors getting the Nobel Prize in 1993.

It was expected that such orbital decays should also be observable in close binaries with compact components other than pulsars. Especially, if such compact binaries should show eclipses. Eclipsing binaries are resourceful astrophysical laboratories. Precise measurements of the eclipses and radial velocities allow us to evaluate the masses and radii of the components. Furthermore, a measure of the change in period over time ($\dot{p}$) provides indirect evidence of gravitational waves from the shrinkage of the orbit. Since the range of inclinations for the eclipses to be observable is very small, such systems are very rare and we therefore require detailed studies of known objects. The recent discovery of a double white dwarf (WD) binary (Brown et al. [2011]) with a period of 765 s provided an independent opportunity to confirm the shortening of the period. Hermes et al. [2012] were able to put constraints on the orbital shrinkage of J0651. They measured a shift of $-9.8 \pm 2.8 \times 10^{-12}\,\mathrm{ss}^{-1}$ which is roughly consistent with the predictions from GR of $-8.2 \pm 1.7 \times 10^{-12}\,\mathrm{ss}^{-1}$ (see Fig. 2). Since the object is very faint ($g = 19.1\,\mathrm{mag}$), it required extensive observations over a 13 month period in order to get sufficient accuracy. This makes further follow-up difficult and limits the accuracy that can be reached.

However, most recently the tight, eclipsing binary system ($CD - 30,^{\circ}\,11223$, see Fig. 1, Geier et al. [2013], hereafter G13) has been discovered, which turned out to be much brighter ($V = 11.9\,\mathrm{mag}$). $CD - 30^{\circ}11223$ is composed of a hot subdwarf star (sdB) and a carbon/oxygen WD. It has a short period of only 0.048 days (1.2 hrs). In G13, the authors perform a detailed spectroscopic and photometric analysis of this object. Because $CD - 30,^{\circ}\,11223$ is a single-lined system, plausible assumptions have to be made to find a unique solution. G13 therefore derived the binary parameters using two different approaches. Firstly, they assume tidal synchronisation of the sdB primary. From this they arrive at a radius for the WD, which is 10 % smaller than the predicted value from the zero-temperature mass-radius relation. In this case, the mass of the sdB is constrained to 0.47, the of the WD companion to $0.74_{\odot}$. They obtain a slightly different set of parameters by restricting the WD to be within 2 % of the theoretical mass-radius relation. This leads to higher values of 0.54 and 0.79 $\mathrm{M}_{\odot}$ for the masses of the sdB and the WD. Based on SWASP photometry gathered between 2006 and 2011, G13 derive an upper limit for the orbital decay of $-4.4 \times 10^{-12}\,\mathrm{ss}^{-1}$, only about one order of magnitude higher than the theoretically expected decay of $6 \times 10^{-13}\,\mathrm{ss}^{-1}$. The authors conclude that within a few years from the last observation, the orbital shrinkage will be detectable.

Furthermore, the authors use the formalism given in Roelofs et al. [2007] to calculate gravitational wave strain h. They find a high log h of -21.5 $\pm$ 0.3 and thus expect the object to be a strong source for detection of gravity waves using future space based missions like NGO/eLISA (Kilic et al. [2012]). Thus, this candidate will act as verification binary and offers a unique opportunity to anchor GW missions in the future, by comparing GW measurements to those in the optical wavelengths. Being a very bright object, $CD - 30,^{\circ}\,11223$ is the perfect laboratory for studying such effects.

B – Immediate Objective: Here were propose time-resolved photometry of $CD - 30,^{\circ}\,11223$ with FORS2 to detect the shrinkage of the orbit by combining these data with existing photometry from the ASAS and SWASP planetary transit surveys and the SOAR telescope (G13) as described in Hermes et al. [2012] covering a total timebase of 15 years. Since the data from ASAS and SWASP were obtained with small telescopes, the achievable accuracy of the $\dot{p}$ measurement is limited. However, combined with only a few more high-precision eclipse times obtained with FORS2, we will be able to measure the cumulative shift of eclipse timing of $\sim 28\,\mathrm{s}$ (calculated as outlined in Piro [2011]). Furthermore, we want to resolve the discrepancy between the orbital parameters derived under the two separate assumptions. The different component masses should lead to subtle differences in the shape of the light curve, which is dominated by the sinusoidal signal originating from the ellipsoidal deformation of the sdB primary. Once we solved the discrepancy and determined the parameters of the system with high accuracy, $CD - 30,^{\circ}\,11223$ will be a perfect verification binary for future space based gravitational wave missions like NGO/eLISA, in contrary to the semi-detached ultracompact binaries which have in general high uncertainties on the derived parameters. Light curves of highest accuracy are necessary to achieve both goals, measuring the orbital decay and derive system parameter with high accuracy. Available measurements with SOAR provide an SNR of ~ 200, whereas observations with FORS2 can increase this value ten-fold to ~ 2000. **Due to its brightness, the observations can be conducted under unfavorable conditions.**

7. Description of the proposed programme and attachments

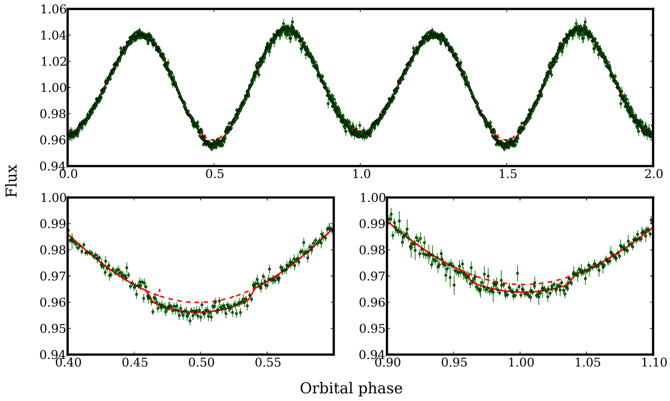

Fig. 1: Upper panel: V-band light curve of CD−30°11223 taken with SOAR/Goodman (green) with superimposed model (red) plotted twice against the orbital phase for better visualisation. The dashed red curve marks the same model without transits and eclipses. The sinusoidal variation is caused by the ellipsoidal deformation of the hot subdwarf as a result of the tidal influence of the compact white dwarf. The difference in the maxima between phase 0.25 and 0.75 originates from the relativistic Doppler boosting effect, which is usually not detectable with ground-based telescopes. Lower panels: Close-up on the transit of the WD in front of the sdB (left). It is even possible to detect the eclipse of the WD by the sdB (right).

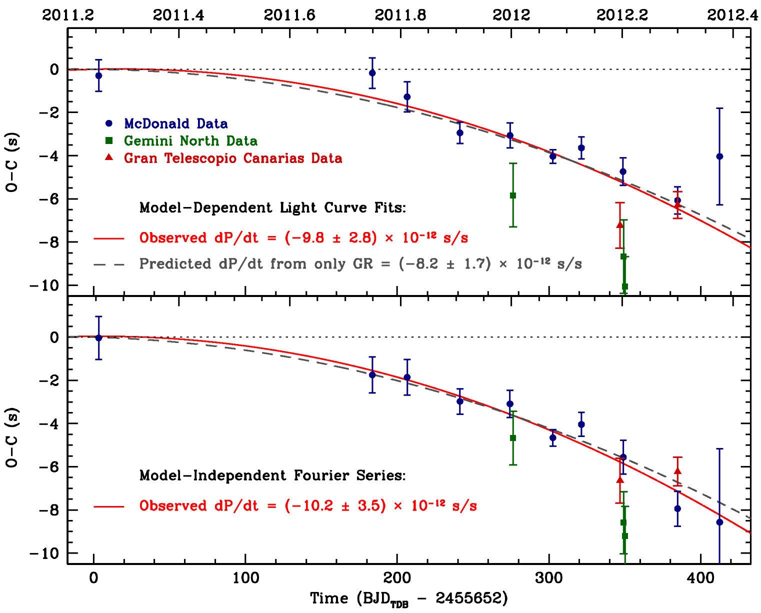

Fig. 2: $O - C$ diagrams of the orbital evolution in J0651 since April 2011 (Hermes et al. [2012]); blue dots represent data from McDonald Observatory and APO, green squares from Gemini-North, and maroon triangles from GTC. The top panel shows the change in mid-eclipse times as determined by light curve modeling, and the best-fit parabola yields an estimate for the observed rate of orbital period change. Additionally, the bottom panel shows the results from a model-independent, linear least-squares fit using the orbital period and higher harmonics. The dotted line at $(O - C) = 0$ shows the line of zero orbital decay, while the grey dashed line shows the predicted orbital decay expected solely from gravitational wave radiation. Using both methods, early results match the GR prediction to the 1-σ level.

8. Justification of requested observing time and observing conditions

Lunar Phase Justification: We do not require a specific lunar phase since our candidate object is bright and can be observed, even at 14 days after new moon.

Time Justification: (including seeing overhead) We calculate exposure times without a preference for lunar phase or sub-arcsecond seeing. The template spectrum is Pickles B2IV and the detector with the blue optimized CCD. For our required signal to noise of about 2000, we need single 2 second exposures with FORS2 in the B band. We will use the B-type star TYC 7281−1465−1 at a distance of 4.5 arcmin as comparison object. It has similar colours and a similar brightness of $V = 11.6\,\mathrm{mag}$. Furthermore, a light curve obtained by the ASAS survey shows no variations. In this way we will be able to correct for airmass and other atmospheric variations. In order to achieve an accurate measurement of the eclipse times, we request 1 hour of consecutive single exposures (matching one service mode block), which is sufficient to cover a significant part of the orbital period of 1.2 hours. In order to measure the $\dot{p}$, we require 4 such observations distributed over the semester.

8a. Telescope Justification:

Available data for $CD - 30°11223$ include photometry from the ASAS and SWASP surveys taken from 2000 to 2011 and a short V-band light curve from the SOAR telescope taken in 2012. However, the precision on the period is not sufficient for a measurement of the $\dot{p}$. With FORS2 we will achieve the required precision in the eclipse times with only a few hours of observing time, because we will be able to clearly see the shallow eclipses ($\sim 0.5\%$) in each of the high-quality light curves. This is not guaranteed, if we would use a smaller telescope. The SOAR light curve for example was taken under exceptionally good conditions. **In contrast to that, due to the brightness of the object, the observation can be conducted under otherwise unfavorable conditions as a filler programme with FORS2.**

8b. Observing Mode Justification (visitor or service):

Since this is only one target to be observed and is bright enough to be observed in sub-ideal weather conditions, we have applied for service mode observations

8c. Calibration Request:

Standard Calibration

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

090.D-0012: Geier, Heber, Schaffenroth, et al. (Hot subdwarf stars with substellar companions): Spectroscopic follow-up of RV-variable subdwarfs, 75% lost due to bad weather.
091.D-0038: Geier, Heber, Schaffenroth, et al. (Hot subdwarf stars with substellar companions): Spectroscopic follow-up of RV-variable subdwarfs, 90% success. Paper in preparation.
092.D-0040: Geier, Heber, Schaffenroth, et al. (Hot subdwarf stars with substellar companions): spectroscopic follow-up of RV-variable subdwarfs, 100% success. Paper in preparation.
093.D-0127: Geier, Heber, Kupfer, et al. Hot subdwarfs at hypervelocity - donor remnants of double-detonation SN Ia?: time allocated in service mode, no observations yet

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.

No,the data for the object are not available in the ESO Archive

9b. GTO/Public Survey Duplications:

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

Barlow, B. N., Kilkenny, D., Drechsel, H., et al. 2013, MNRAS, 430, 22: EC 10246-2707 an eclipsing subdwarf B + M dwarf binary
Geier, S. 2013, A&A, 549, 110: Hot subdwarf stars in close-up view III. Metal abundances of subdwarf B stars
Geier, S., & Heber, U. 2012, A&A, 543, 149: Hot subdwarf stars in close-up view. II. Rotational properties of single and wide binary subdwarf B stars
Geier, S., Heber, U., Edelmann, H., et al. 2013, A&A, 557,112: Hot subdwarf stars in close-up view IV. Helium abundances and the 3He isotopic anomaly of subdwarf B star
Geier, S., Heber, U., Heuser, C., et al. 2013, A&A, 551, 4: The subdwarf B star SB 290 - A fast rotator on the extreme horizontal branch
Geier, S., Marsh, T, R., Wang, B., et al. 2013, A&A, 554, 54: A progenitor binary and an ejected mass donor remnant of faint type Ia supernovae
Geier, S., Schaffenroth, V., Hirsch, H., et al. 2012, AN, 333, 431: MUCHFUSS - Massive Unseen Companions to Hot Faint Underluminous Stars from SDSS
Geier, S., Østensen, R., Heber, U., et al. 2014, A&A,562,95: Orbital solutions of eight close sdB binaries and constraints on the nature of the unseen companions
Kupfer, T., Groot, P. J., Levitan, D., et al. 2013, MNRAS, 432, 2048: Orbital periods and Accretion disc structure of four AM CVn systems
Østensen, R., Geier, S., Schaffenroth, V., et al. 2013, A&A, 559, 350: Binaries discovered by the MUCHFUSS project. FBS 0117+396: An sdB+dM binary with a pulsating primary
Schaffenroth, V., Geier, S., Drechsel, H., et al. 2013, A&A, 553, 18: A new bright eclipsing hot subdwarf binary from the ASAS and SuperWASP surveys
Schaffenroth, V., Geier, S. Heber,U. et al. 2014, A&A, in press: Binaries discovered by the MUCHFUSS project: SDSS J162256.66+473051.1 - An eclipsing subdwarf B binary with a brown dwarf companion

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	$CD-30^{\circ}11223$	14 11 16.2	-30 53 03	4	11.9			

12. Scheduling requirements

13. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
94	FORS2	A	IMG	B