PI information
Name: Odette Toloza,
Email: otoloza@npf.cl
Affiliation: Universidad Tecnica Federico Santa Maria (USM)
Status: postdoctoral researcher

CO-Is information:
Matthias Schreiber, Matthias.Schreiber@usm.cl, Universidad Tecnica Federico Santa Maria.
Boris Gansicke, Boris.gaensicke@warwick.ac.uk, University of Warwick
Diogo Belloni, diogo.belloni@inpe.br, Universidad Tecnica Federico Santa Maria.

Proposal information:

Title: "*Hunting planets breaking apart around polluted white dwarfs and testing predictions of the formation of magnetic fields in cool polluted white dwarfs*"

Abstract: A large fraction of white dwarfs (25-50%) present pollution in their atmospheres due to material that is accreted from planet(esimal)s that have been broken apart. However, the detection of a planet(esimal) orbiting around white dwarfs has been reported in only five systems, where two of them are in the current process of disruption. The numbers are very small to elaborate solid explanations of dynamics and evolution of these systems. In addition, the accretion of the disrupted material spins up the white dwarf which might be a key element to explain the high incidence of magnetism in cool (<7500K) white dwarfs over hot white dwarfs. Here, we propose to observe 13 metal strong polluted white dwarfs to find a third body ongoing the process of disruption, and to test a consequence of the formation of magnetic fields in cool white dwarfs, which predicts that strong metal polluted white dwarfs are fast rotators.

Instrument: SMART1.0/**Y4KCam**

Time requested: 91 hours is the minimum time needed (however doubling the time of the eight metal polluted white dwarfs, i.e. 147 hours would increase the sensitivity towards longer orbital periods of the planetesimals)

preferred dates: Due to the visibility of the targets we preferably request the observations to be scheduled during the second half of October (8 nights) and during the first half of February (5 nights).

The maximum length of this file is **5 pages TOTAL** (7 for long-term, large programs) and it must include the following aspects: scientific aim and rationale (3-page limit including figures/tables and references), description of the current status of the project including publications (1-page limit), technical description (1-page limit), justification for long-term status if applicable (1 page limit) and work plan for large-programs (1-page limit). **This template must not be edited. This means no alteration of font size of main texts or margins. Please DO REMOVE these paragraph as it is intended as information only.**

Astrophysical context: Planets and planetesimals that survived the evolution of their host stars, end orbiting the burnt-out cores of the host stars (i.e. white dwarfs). These systems have shown to have very complex dynamical evolution (3; 20). Some planet(esimals) venturing too close to white dwarfs are disrupted and subsequently, the fragments are deposited onto the white dwarfs polluting their atmospheres. Observational evidence for this has been provided by infrared emission from the dust in the disc formed from the disrupted planetary material (e.g. 23), the presence of metal absorption lines in the optical (e.g. 12, and Figure 1) and ultraviolet (e.g. 22) spectroscopy of white dwarfs. *In only two cases even the direct observation of the disruption process has been witnessed in the form of transits in the process of disintegration* (See Figure 2). Such systems provide important insight into the physical structure of the planetary bodies that survived the evolution of their host stars, as well as into the architectures of evolved planetary systems (e.g. 15). In addition, the accretion of these pollutants transfer angular momentum which spins up the white dwarf, which alongside with core crystallization (a natural effect that starts when the white dwarf has cooled down to effective temperatures $\lesssim$8000 K) could explain the drastic mismatch of occurrence rates between cool (<7500 K) and hot magnetic white dwarfs (11).

We propose to observe 13 strongly metal polluted white dwarfs simultaneously tackling two science cases with SMARTS photometry: (1) discovery of new white dwarfs hosting planet(esimals) to enlarge the very limited known sample (only 2 systems), and (2) test theoretical predictions on the formation of magnetic fields in cool white dwarfs that accrete planetary remnants.

Exo-planetary bodies breaking apart! N-body simulations show that the outer surviving planet(esimals) in evolved planetary systems can be scattered deep into the white dwarf's gravitational potential (e.g. 1). In fact, recently even the stunning discovery of a Jupiter-size planet transiting the white dwarf WD1856+534 in a 1.4-day orbit was reported (19). But, while, $25-50$ % of white dwarfs show mild to strong traces of metals (24; 13), only in few white dwarfs, the presence of planet(esimals) have been detected so far (18; 14; 5; 17; 19). The prototype, the white dwarf WD1145+017 shows transits of debris clouds from a disintegrating planetesimal in the optical lightcurve that recur every 4.5h (18, See Figure 2). The in-depth analysis of the photometric and spectroscopic observations, place robust constraints on the mass and the internal structure of the planetesimal around WD1145+017 (8; 21) and permit to derive a detailed composition of the debris and its geometry within the system (9). The more recent discovery of the second planetesimal transiting a white dwarf (ZTFJ0139+5245) proves the potential of photometry discovering transits and placing strong constraints on the physical parameters of the orbiting planet (17).

The roadmap for discovering new transits: The current sample of white dwarfs is largely biased towards young white dwarfs (< 1 Gyr; 7). However, our dedicated all-sky spectroscopic survey of white dwarfs within the SDSS-V, is providing the largest homogeneous and unbiased spectroscopic sample of white dwarfs, and since the recent start of the operations, SDSS-V has discovered many more white dwarfs which show traces of metals (Figure 1), turning them into potential candidates to host planet(esimals). The discovery of ZTFJ0139+5245 from the first data release of Zwicky

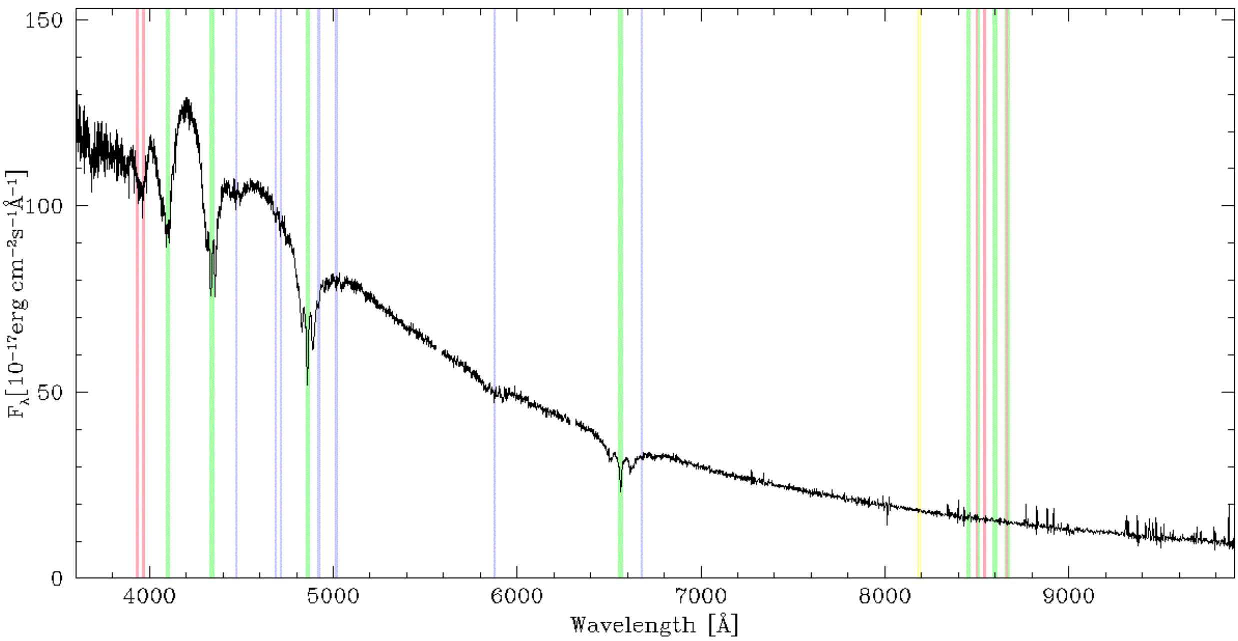

Figure 1: SDSS-V spectrum of SDSSJ020143.65-030200.1, which shows a mixed helium/hydrogen atmosphere (green and blue vertical lines, respectively), and clear absorption of Calcium H&K lines (red lines). In addition, the absorption lines shows Zeeman splitting more evident in the hydrogen lines due to the presence of a strong magnetic field.

Transient Facility corroborates feasibility of identifying transits from moderate-sized ($\simeq$1 m) ground-based telescopes. Besides, the size of the debris discs around white dwarfs are comparable to the rings in Saturn, thus the majority of the transits are expected to have short periods (hours). Thus, obtaining continuous photometry of a well defined sample of metal polluted white dwarfs provides the potential to discover the third planetesimal transiting a white dwarf. SDSS-V provides such a target sample and we propose here to start a follow-up campaign.

While our main objective is the discovery of additional close-in planet(esimals) to enlarge the current sample, this project will contribute significantly towards another important aspect of white dwarf science.

Testing the generation of magnetic fields in cool white dwarfs: The incidence of magnetism has been found to be significantly higher in white dwarfs polluted with heavy elements compared to the general white dwarf population ([10]). While $\simeq$40-50% of polluted white dwarfs with effective temperatures below 7 000 K are magnetic ([10; 11]), none has been discovered with temperature within 7 000-10 000 K. A possible explanation that links these two facts could be that the magnetic field forms as a consequence of a dynamo effect produced in a crystallizing and rapidly rotating white dwarf ([16]). On one hand, the formation of a solid core (crystallization) is a natural consequence of white dwarf cooling and is expected at the observed temperatures (7,000-10,000 K; [25]). If the accretion of planetary material (and angular momentum) could speed up the rotation of white dwarfs, both conditions for the dynamo to work would be fulfilled. So far, only three cool magnetic white dwarfs have their rotation periods determined ([6]), which their reduced rotation periods are consistent with the hypothesis described above. The observations proposed here will allow us to measure the rotation periods of the magnetic white dwarfs in our sample thereby providing a crucial test for the recently proposed dynamo mechanism.

Scientific aims: We have two immediate objectives: A) identify (a)symmetric transits in the optical lightcurve, and B) measure the rotation period of five magnetic white dwarfs based on the variability caused by the heated spot of accretion coming in and out of the view.

A) Modeling the lightcurve will provide constraints on the orbital parameters of the planet(esimals) (e.g. 4; 9; 17). In addition, our fits to the SDSS spectroscopy will provide the atmospheric parameters of the white dwarfs, and the chemical composition of the shredded body. The analysis of the orbital parameters and the characterization of the physical properties will allow us to investigate the process of the ongoing disruption of exo-planetary bodies. The long-term evolution of these systems will provide tight constraints of the internal structure, their origin, as well as clues onto the causes for their white dwarfs plunging orbits (e.g. 21).

B) Starspots are caused by the inhibition of convection in the stellar atmosphere by the magnetic field and hence the rotation causes a periodic variability in the lightcurve. Modeling the lightcurve of our magnetic white dwarfs will therefore provide their rotation periods (2). Moreover, we will evaluate correlations between the strength of the metal pollution, white dwarf's effective temperatures, strength of the magnetic fields, and rotation periods.

We propose to observe 13 white dwarfs, which all show the strong metal absorption lines, and five of them present clear signatures of hosting a strong magnetic field.

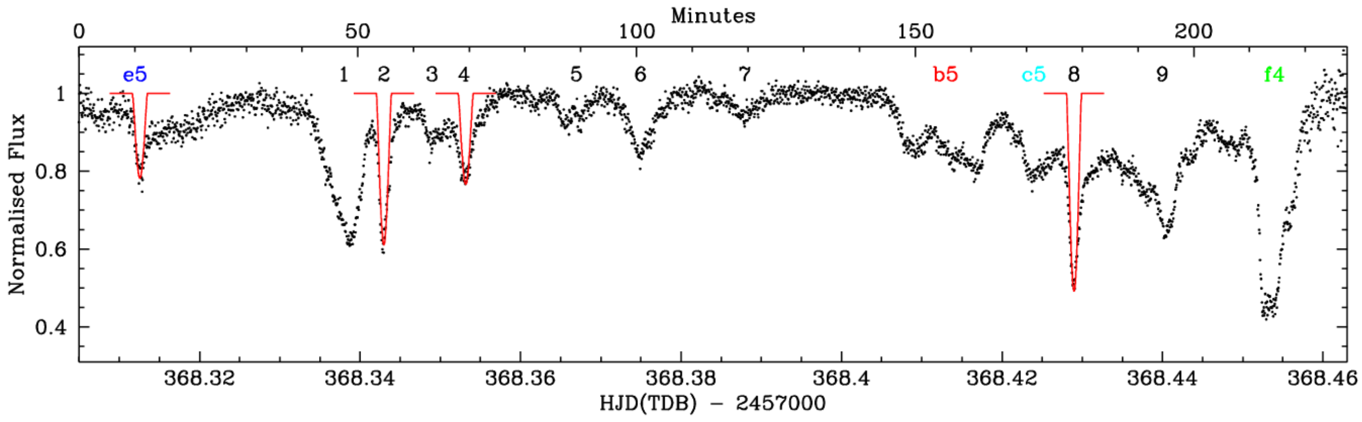

Figure 2: Optical lightcurve of the white dwarf WD1145+017, which shows that the shape of the transits are varied and complex in nature. Some sub-structure corresponds to the superposition of several shorter events.

References

[1] Antoniadou K. I., Veras D., 2019, A&A, 629, A126
[2] Brinkworth C. S., et al., 2013, ApJ, 773, 47
[3] Duncan M. J., Lissauer J. J., 1998, Icarus, 134, 303
[4] Gänsicke B. T., et al., 2016, ApJ, 818, L7
[5] Gänsicke B. T., et al., 2019, Nature, 576, 61
[6] Gänsicke B. T., et al., 2020, MNRAS, 499, 2564
[7] Gianninas A., et al., 2011, ApJ, 743, 138
[8] Gurri P., et al., 2017, MNRAS, 464, 321
[9] Izquierdo P., et al., 2018, MNRAS, 481, 703
[10] Kawka A., Vennes S., 2014, MNRAS, 439, L90
[11] Kawka A., et al., 2021, MNRAS, 500, 2732
[12] Koester D., et al., 1997, A&A, 320, L57
[13] Koester D., et al., 2014, A&A, 566, A34
[14] Manser C. J., et al., 2019, Science, 364, 66
[15] O'Connor C. E., Lai D., 2020, MNRAS, 498, 4005
[16] Schreiber M. R., et al., 2021, Nature Astronomy,
[17] Vanderbosch Z., et al., 2020, ApJ, 897, 171
[18] Vanderburg A., et al., 2015, Nature, 526, 546
[19] Vanderburg A., et al., 2020, Nature, 585, 363
[20] Veras D., Scheeres D. J., 2020, MNRAS, 492, 2437
[21] Veras D., et al., 2017, MNRAS, 465, 1008
[22] Xu S., et al., 2014, ApJ, 783, 79
[23] Zuckerman B., Becklin E. E., 1987, Nature, 330, 138
[24] Zuckerman B., et al., 2010, ApJ, 722, 725
[25] van Horn H. M., 1968, ApJ, 151, 227

CURRENT STATUS OF THE PROJECT

Thanks to the next generation multi-object-spectroscopic surveys as WEAVE, 4MOST, DESI and SDSS-V, which have dedicated programs to observe white dwarfs, the sample of metal polluted white dwarfs is rapidly increasing. Hence, follow-up photometry will be needed to characterize the orbital properties of these new discoveries throughout the surveys. This proposal acts as a pilot project of a starting large campaign. The success of these observations will help in various aspects of evolution, dynamics, and statistics of evolved planetary systems. So far, our group has made important discoveries (14; 5), and predictions in the field of metal polluted white dwarfs (16) and proven capable to model photometric data (9).

Relevant publications

[P1] C. J. Manser, B. T. Gänsicke, S. Eggl, M. Hollands, P. Izquierdo, D. Koester, J. D. Landstreet, W. Lyra, T. R. Marsh, F. Meru, A. J. Mustill, P. Rodríguez-Gil, O. Toloza, D. Veras, D. J. Wilson, M. R. Burleigh, M. B. Davies, J. Farihi, N. Gentile Fusillo, D. de Martino, S. G. Parsons, A. Quirrenbach, R. Raddi, S. Reffert, M. Del Santo, M. R. Schreiber, R. Silvotti, S. Toonen, E. Villaver, M. Wyatt, S. Xu, and S. Portegies Zwart "A planetesimal orbiting within the debris disc around a white dwarf star", Science, vol. 364, Apr. 2019.

[P2] B. T. Gänsicke, M. R. Schreiber, O. Toloza, N. P. Gentile Fusillo, D. Koester, and C. J. Manser "Accretion of a giant planet onto a white dwarf star", Nature, vol. 576, Dec. 2019.

[P3] M. R. Schreiber, D. Belloni, B. T. Gänsicke, S. G. Parsons, and M. Zorotovic "The origin and evolution of magnetic white dwarfs in close binary stars", Nature Astronomy, Apr. 2021.

[P4] P. Izquierdo, P. Rodríguez-Gil, B. T. Gänsicke, A. J. Mustill, O. Toloza, P.-E. Tremblay, M. Wyatt, P. Chote, S. Eggl, J. Farihi, D. Koester, W. Lyra, C. J. Manser, T. R. Marsh, E. Pallé, R. Raddi, D. Veras, E. Villaver, and S. Portegies Zwart "Fast spectrophotometry of WD 1145+017", MNRAS, vol. 481, Nov. 2018.

TECHNICAL DESCRIPTION

The targets in this proposal have been observed with *TESS*, however, given the faintness of the targets, and the pixel size, the available *TESS* data is not sufficient to resolve dips in the lightcurves.

Observing strategy: Given the sizes of the debris discs around white dwarf, the timescale of orbital periods are expected to be ∼hours, and the length of the transits are expected to be of the order of minutes. Therefore to increase the chances of detecting transits, we propose to observe one metal polluted target per night (i.e. seven hours on target). The same strategy can be applied to the magnetic white dwarf, based on the three known rotation periods we expect periods less than ∼ 15 hours. Thus 7 hours per target will resolve at least half of their rotation cycle.

Given the range of brightnesses of our targets (G$\simeq$ 16.6 − 19.7 mag; see table 1) we will have exposures times in the range of 40-100 seconds. Photometric (*ugriz*) observations of WD 1145+017 show that the depth of the transits is not wavelength-dependent ([9]), thus we will make use of the Y4KCam using the g' filter that fully cover the Balmer lines (β and γ) and several of the strongest helium lines. We will make use of a 2x2 binning to reduce overheads. Finally, we have no constraints on the lunar phase during the observations, though it is preferable to avoid bright times for the fainter (G>18.5 mag) targets. Due to the visibility of the targets we preferably request the observations to be scheduled during the second half of October (8 nights) and during the first half of February (5 nights).

In summary, we request 91 hours out of the 167 hours available of SMART1.0 photometry spread-out in 13 nights (7 hours per night).

Table 1: Targets

Name	RA	DEC	G (mag)
SDSSJ000557.45+001833.1	00 05 57.23	00 18 33.25	18.7056
SDSSJ013831.17+003101.6	01 38 31.13	00 31 01.68	19.3834
SDSSJ015601.01-015002.3	01 56 01.06	-01 50 01.73	18.3371
SDSSJ015748.17+003314.7	01 57 48.15	00 33 15.15	19.3066
SDSSJ020143.65-030200.1	02 01 43.65	-03 01 59.83	16.9614
SDSSJ024422.28-014243.2	02 44 22.19	-01 42 42.40	17.0506
SDSSJ051156.09-033600.5	05 11 56.07	-03 36 00.39	19.7253
SDSSJ051212.72-050504.1	05 12 12.79	-05 05 03.36	17.5345
SDSSJ073737.19+154131.0	07 37 37.21	15 41 31.55	16.6066
SDSSJ090051.79+033149.5	09 00 51.92	03 31 49.34	18.4869
SDSSJ090618.45+022311.5	09 06 18.44	02 23 11.66	18.1553
SDSSJ093720.35+014803.6	09 37 20.36	01 48 03.47	19.4032
SDSSJ112513.30+094929.3	11 25 13.32	09 49 29.68	18.8105