Onsala Proposal

Trigo 0108.F-9311

A search for maser emission from the cataclysmic variable WZ Sge

Semester: may2021 **Science Cat.: Late stages of stellar evolution**

Abstract

We propose to search for water maser emission from the accretion (and/or circumbinary) disc in the eclipsing cataclysmic variable (CV) WZ Sge. Water masers are prominent in the discs of active galactic nuclei (AGN) and allow to set the conditions on the disc and determine black hole masses. The temperature of CV discs is similar to that of AGN discs due to both classes of systems showing similar ionising spectra, thus opening the possibility of the presence of maser emission also in CVs. If found, CV masers would provide among others the means to precisely determine the mass of the white dwarf via eclipse mapping thus providing essential information about whether accreting white dwarfs exist near the Chandrasekhar mass, or if Type Ia supernovae form entirely through channels that lack a steady accretion phase.

Applicants

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Is this a long term proposal: No

No overall scheduling requirements

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	APEX	nFLASH230 (200-270 GHz)	6h (6h)	225.5	any		We will use nFLASH230 tuned to a setup centered around 225.5 GHz, which will cover CO(2-1) (and SO_2, CH_3OH, HC_3N) in the USB (229-237GHz) and 13CO, C18O, SiO, H2CO, SO, CH3OH in the LSB (213-221GHz).
B	APEX	SEPIA180 (159-211 GHz)	9h (9h)	183.272	< 0.5mm		

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
wz sge	20:07:36.50	+17:42:14.7	J2000	62.3	390	A	
wz sge	20:07:36.50	+17:42:14.7	J2000	62.3	552	B	

Scientific Rationale

Powerful maser emission is known to trace warm, dense gas associated with energetic astrophysical conditions and shocks, i.e. in regions where the pumping mechanism for maser amplification can be sustained. These conditions can be found in the accretion discs around supermassive black holes (BHs) in active galactic nuclei (AGN, Neufeld et al. 1994), in the material heated by jet activity and wide-angle accretion disc winds (Greenhill et al. 2003) in both AGN (Peck et al. 2003) and young stellar objects (e.g. Matthews et al. 2010), in the shells of evolved stars (Richards et al. 2014) and in supernova remnants (e.g. Yusef-Zadeh et al. 2008). Thanks to their high brightness temperatures, these masers can be imaged at high angular resolution to determine exact geometries and spatial distributions, the dynamics of the masing gas, and proper motions through multi-epoch observations. Because of this, they have been a powerful tool to determine accurate BH masses (e.g. Kuo et al. 2011), the size of our Galaxy and M33 (Brunthaler et al. 2005), distance to galaxies (e.g. Gao et al. 2015) and, through parallax, to stars within our Galaxy (Reid et al. 2014). Furthermore, sensitive observations of maser emission can provide a measure of magnetic fields (e.g. Kemball & Diamond 1997) and physical conditions of the underlying the gas (temperature, density). When observed in jets, masers provide information on the evolution of jets and their hot-spots. Simultaneous measurements of line and continuum flux densities, through reverberation mapping, allow the determination of the speed of the material in the jet (Peck et al. 2003). Finally, outflow masers trace the velocity and geometry of the nuclear wind.

The same ingredients that give rise to these masers are also present in binary systems with a compact object, namely X-ray binaries and Cataclysmic Variables (CVs, see below). However, no maser emission has been ever reported for such systems. **The aim of this proposal is to explore the existence of masers in the accretion and circumbinary discs of CVs**. If found, such masers will allow firstly to establish physical conditions in the accretion discs (temperature, density, electron density) and precisely determine white dwarf masses. Follow-up full polarization observations will further enable measurement of the magnetic fields of these systems. Through multi-epoch monitoring we may also trace source activity.

CVs as scaled-down AGN

CVs are systems with a white dwarf (WD) accreting from a companion star via an accretion disc. Compared to AGN, the accretion discs in CVs are smaller, with sizes of $\sim 10^{10}$–10^{11} cm, or 10^5–$10^6 r_s$. However, despite their size, they are significantly cooler than X-ray binary discs (which shine in X-rays) and are instead similar to AGN discs, also peaking at UV/EUV wavelengths. This is so due to CVs and AGN featuring a similar ionising spectrum.

CVs also show the disc outflows characteristic of accretion onto compact objects and radio emission has been interpreted as arising in jets (although such interpretation is still debated, Coppejans & Knigge 2020). Because of their well-determined distances and their large number, resulting in a range of physical properties, CVs have been instrumental to gain insight into accretion phenomena and the physics of compact objects.

Maser emission in accretion discs

Maser emission from AGN accretion discs has been detected mainly in systems that are observed at high inclinations (edge-on) at a distance of 0.1–1 pc (equivalent to 10^5–10^6 Schwarzschild radii (r_s) for a 10^6 $M_\odot$ BH. The most likely masers to be associated with discs are water masers (see Fig. 1, left), thought to arise at temperatures of 400–3000 K and densities of 10^{8-10} cm^{-3} by heating of disc gas via illumination of the central X-ray source. While some megamasers are from geometrically thin edge-on discs (e.g. NGC 4258, see Greenhill et al. 1995), there are examples of masers in AGN discs that are thicker and clumpy (e.g. NGC 3079, see Kondratko et al. 2005), implying that a variety of disc geometries could give rise to maser emission. Geometrically thin accretion discs are also present in CVs and thicker circumbinary discs have been reported (e.g. Solheim & Sion 1994).

Why WZ Sge?

Here, we propose APEX observations of WZ Sge, one of the closest known CVs, with an astrometrically measured distance of 43.5 ± 0.3 pc (Thorstensen 2003, Gaia DR3). The light curves of WZ Sge show eclipses from the donor, which allow to determine its period, 1.36 hours, and an inclination of >80° (Patterson et al. 1998). The long-elusive nature of the donor (due mostly to the absence of clear absorption CO features) has been recently determined to be an early type L dwarf, based on radial velocity measurements in the J-band (Harrison 2017). Most importantly, WZ Sge is the only CV where molecular line emission (from both H_2 and CO) from the disc has been observed (Howell et al. 2004, see Fig. 1, right), indicating that there are cooler (Teff $\lesssim$ 4000 K), high density regions in the disc. While such molecular emission has not been reported for other CVs yet, this may be simply to the lack of systematic searches and to WZ Sge being the closest CV. In summary, **the short distance, high disc inclination and presence of disc molecular line emission make WZ Sge ideal for a first exploratory search of molecular masers in the class of CVs.** Should masers be found, they will provide among others the means to precisely determine the mass of the white dwarf via eclipse mapping, thus indicating whether accreting white dwarfs exist near the Chandrasekhar mass, or if Type Ia supernovae form entirely through channels that lack a steady accretion phase.

Proposed observations

We aim to explore for the first time the presence of water masers in the accretion disc and/or circumbinary disc of a CV with SEPIA at 183 GHz. We also propose to explore the presence of CO (and other molecules) from the circumbinary disc with NFLASH at 225 GHz. To our knowledge, line emission from CVs at mm frequencies has not been explored. However, if the circumbinary disc is relatively cold or optically thin due to being shadowed or having little dust in the IR-emitting inner region, significant emission from CO should be detectable at mm wavelengths (Dubus et al. 2004). Detecting one or more CO transitions would therefore allow to unambiguously characterise for the first time the properties of the putative circumbinary disc in WZ Sge opening an avenue for systematic searches of such discs at mm wavelengths.

For the maser search we target the 183 GHz water line (SEPIA180 tuned to 183.272 GHz in the LSB), the strongest (sub)mm extragalactic water maser detected to date. The 183 GHz transition is thought to be pumped over a wider range of physical conditions compared to e.g. the radio water maser at 22 GHz (e.g. Yates et al. 1997) and is consequently more suitable for a first search. The width of masers detected up to now spans from a few km/s (e.g. Menten & Melnick 1989) to a few hundred km/s (e.g. Greenhill et al. 2003). Therefore, we request the finest spectral line resolution but use a 5 km/s bandwidth to calculate the time needed to achieve the requested rms with SEPIA180. The large bandwidth (4-8 GHz) ensures line detection even if the lines happen to be Doppler shifted. The flux densities of masers per resolution element are generally high (few tens of mJy to Jy) but the sample is most likely biased towards high fluxes due to the limited noise of current surveys. Therefore, we request a rms as low as 5 mK (or ∼0.1 Jy) per 5 km/s spectral resolution element, achievable in 9.2 hours (including overheads and assuming 60° elevation and 0.4 mm PWV). We will use a range of spectral resolutions during data analysis to explore the existence of both low flux/broad lines and high flux/narrow lines and maximize the chances of detection. We also ask to observe ^{13}CO, ^{12}CO and C^{18}O with nFLASH230 down to a sensitivity of 1 mK per 5 km/s spectral element resolution and use the same setup to explore the presence of SiO and methanol. The requested total time for this setup is 6.5 hours (estimated with the ON-OFF observing time calculator at APEX V7.3 using NFLASH230 tuned to 225.5 GHz in the LSB, a source elevation of 60° and a PWV of 1.8 mm).

To conclude, detecting maser emission will open a new avenue for studies of accretion physics. If masers are not detected, we will set strong constraints to its existence and to the presence of molecular line emission at mm wavelengths arising from potentially cold circumbinary discs.

References

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Figures

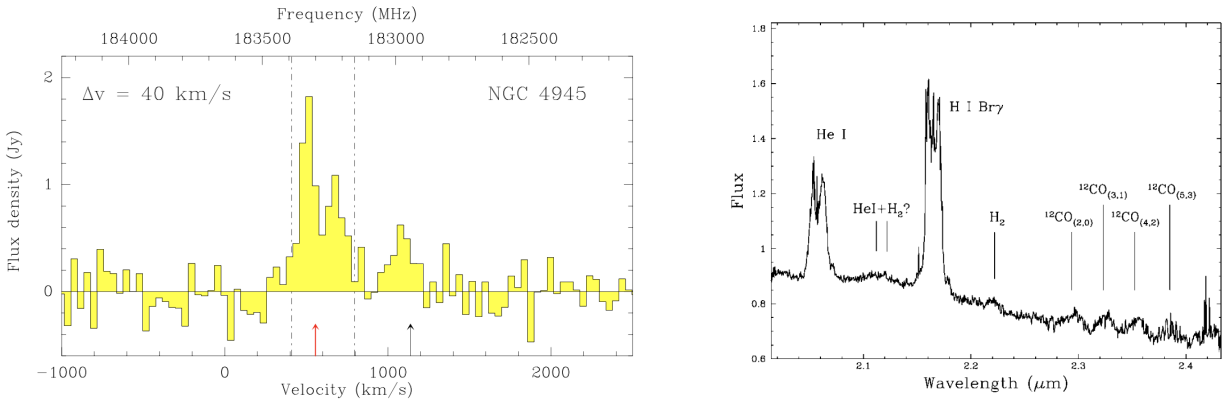

Figure 1: *Left*: 183 GHz water emission towards NGC 4945 as detected by SEPIA180 (Humphreys et al. 2016). *Right*: Radial Velocity-corrected, unsmoothed summed spectrum of WZ Sge taken with NIRSPEC1 on Keck II in 2003. Besides the typical HI and HeI emission lines, molecular emission from CO and H_2 are seen as well. The y-axis is relative flux in units of ergs s^{-1} cm^{-2} $Å^{-1}$ (from Howell et al. 2004).

No PhD Students involved

Linked proposal submitted to this TAC: No

Linked proposal submitted to other TACs: No

Relevant previous Allocations: No

Additional remarks

ESO=<mdiaztri>

Observing run info :