Onsala Proposal

Velilla-Prieto 0108.F-9305

Spectral line survey of V Hydrae

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

Abstract

The overall aim of this proposal is to study the growth of chemical complexity during an enigmatic key stage of stellar evolution, the post-AGB phase, through a spectral scan of V Hydrae. V Hya constitutes an excellent object for a detailed study of the chemical content of a shock-influenced and transitional post-AGB object, in a search for main molecular tracers and new detections in the nebula. This study will allow us to provide a more complete molecular inventory of the source, with good chances to detect new molecules, test out chemical models, and assess the impact that shocks and ices have on circumstellar chemistry and interstellar medium enrichment.

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	SEPIA180 (159-211 GHz)	38h (30h)	170	1-2 mm	8-14	We request a spectral scan of the whole band 5 with SEPIA. More details about the spectral configuration can be found in the attached PDF of the justification (Fig. 2). There are no essential constraints. For the minimum useful time, we have reduced the requested RMS from 3 to ~6 mK (@ 1km/s resolution).

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
V HYA	10:51:37.26	-21:15:00.3	J2000	-16.0	2400	A	

Spectral line survey of V Hydrae[1]

Immediate objectives

The overall aim of this proposal is to study the growth of chemical complexity during an enigmatic key stage of stellar evolution, the post-AGB phase, through a spectral scan of V Hydrae. This study will allow us to provide a more complete molecular inventory of the source, with good chances to detect new molecules, test out chemical models, and assess the impact that shocks and ices have on circumstellar chemistry and interstellar medium enrichment. The results will be put into chemical evolution context by comparing the obtained results to what we know about the chemistry of stellar outflows.

Scientific Rationale

Low-mass stars are major contributors to the interstellar medium (ISM) enrichment and the growth of chemical complexity in the Universe (Habing & Olofsson, 2004). Substantial outflows of dust and gas are formed during the Asymptotic Giant Branch (AGB). All this material will be injected into the ISM, and incorporated into molecular clouds that collapse to form new stars which can potentially host a planetary system and perhaps life itself. Indeed, dust grains found in our Solar System are known from their isotopic composition to have originated in AGB stars (Hoppe & Zinner, 2000). During the post-AGB, fast shocks disrupt the spherically symmetric AGB envelopes activating a complex chemistry (dissociation, desorption, evaporation, re-formation...) that is poorly characterized, both theoretically and observationally.

The growth of the chemical complexity in post-AGB objects occurs most likely due to the presence of shocks and ices. Gas compression and heating due to shocks produces a variety of radicals and ions and it also causes the release of material from the dust grains that activate a vast collection of non-equilibrium chemical reactions. In fact, post-AGB molecular richness and content resembles that of the outflows of Young Stellar Objects (YSOs) (e.g. Sánchez Contreras et al., 2015, Velilla Prieto et al., 2015, Burkhardt et al., 2016), which highlights the growing chemical complexity in post-AGBs. In the case of the YSO L1157, the formation of methanol, for example, is mainly due to shocks, either due to the liberation of methanol from the ice mantles in the grains or favored by the enhanced densities in the recently shocked material surrounding the grains. Interestingly, it has been discovered emission of methanol in the Calabash nebula, as well as in the post-RGB/AGB star HD 101584, which is a signpost of this ice/shock-induced chemistry (Olofsson et al., 2017, Sánchez Contreras et al., 2018).

The Calabash nebula is currently the chemically richest post-AGB as unveiled thanks to a wide spectral scan (80–350 GHz) with the IRAM-30 m telescope (Velilla Prieto et al., 2015), and now we know that the different species in its outflow trace different components and chemical processes in the source. Certain molecules such as CS or H_2S trace the remnant slowly-expanding AGB circumstellar envelope (CSE). Other molecules such as HCO^+ or N_2H^+, that are not detected toward standard AGB CSEs (Velilla Prieto et al., 2017), selectively trace the high velocity component of these outflows (Velilla Prieto et al., 2015, Sánchez Contreras et al., 2018, Olofsson et al., 2019). Such a detailed characterization of a source was only possible thanks to the wide frequency coverage, otherwise, many lines and species would have remained undiscovered. Moreover, an accurate excitation analysis of the different molecular species in a source requires observations of at least two rotational lines of a given species with different excitation energies. Therefore, the best strategy to chemically characterize a source is to do a spectral scan with a frequency coverage as large as possible. However, very little is known about the chemical evolution for post-AGB objects (see Table 1). Only a few post-AGBs have been comprehensively studied: the C-rich stars CRL 618 (Pardo et al., 2007) and AFGL 2688 (Zhang et al., 2013), and the O-rich OH 231.8 + 4.2 (Sánchez Contreras et al., 2015, Velilla Prieto et al., 2015).

[1]This is a resubmission of the accepted proposals 105.F-9304(A,B) and 107.F-9302(A). It was not completely observed due to the reduction of the APEX operations and some technical problems with the SEPIA receiver.

Planned observations and methods

We propose to carry out a spectral scan of band 5 (SEPIA180) and 6 (nFLASH230) of V Hya (see the proposed strategy in Fig. 2). The observations of band 6 with nFLASH have been started during the last semester, with an achieved RMS of 6–8 mK (at 1 km s^{-1} resolution). There is only one unobserved gap between 220–228 GHz in band 6. The project is currently scheduled and we expect that at least the band 6 part is finished this summer. Band 5 observations will depend on the re-start of SEPIA operations, which could take place in June or July according to the indications of the staff.

V Hya is a carbon AGB star located at ∼480 pc displaying particularly strong and extended CO emission ($r \sim 13''$), well covered by the APEX beam (~ 23–$40''$), and high-velocity wings (see Fig. 1). It shows a bipolar structure and its circumstellar properties are interpreted as characteristics of post-AGB objects, that may have experienced a binary common envelope evolution phase between the AGB and the PN stage with shocked gas (Kahane et al., 1996, Hirano et al., 2004). V Hya constitutes an excellent object for a detailed study of the chemical content of a shock-influenced and transitional post-AGB object, in a search for main molecular tracers and new detections in the nebula.

Lines of HCN, CS, SiO, SiS, HCO^+, CCH, HC_3N, HC_5N, C_2H, or CH_3OH, among others, as well as their isotopologues, can be observed in both bands. Only a few can be observed exclusively in one of the bands (N_2H^+, HNC, or CN). This project will represent the fourth comprehensive chemical study of a shock-affected CSE, after CRL 618, AFGL 2688 and OH 231, and will provide valuable information regarding circumstellar post-AGB evolution from the physical and chemical points of view. This chemical characterization will help us to determine which routes were activated in order to produce the chemical content and abundances that will be determined. We will determine the molecular content of the source, using available molecular catalogues such as the CDMS and JPL (Pickett et al., 1998, Müller et al., 2005). The lines will be measured and fitted in order to determine their integrated intensities, peak temperatures, and widths, which will be used to determine mainly column densities, rotational temperatures, and isotopic ratios with the use of excitation diagrams, radiative transfer, and chemical models (see e.g. Velilla Prieto et al., 2015, De Beck, & Olofsson, 2018).

According to the APEX archive, V Hya band 5 molecular emission has been only characterized in the HCN J=2–1 line. Outside of the band 5, only lines of CO, [CI] 1–0 (Saberi et al., 2018), and SiO $J = 7$–6 and 6–5 have been targeted so far with APEX. With the IRAM-30 m and the PdBI, CO $J = 1$–0 and 2–1 lines, plus one narrow spectral range centered at 131 GHz have been observed. Other observatories such as SMA or ALMA have targeted only CO lines and a small ∼ 16 GHz wide frequency range in bands 3 and 7. Therefore, the full molecular content of V Hya remains unknown, as most of the post-AGB CSEs in our Galaxy.

Technical justification: time estimate

We have estimated the observing time using the on-line time estimator, considering 2 mm of pwv (average for the third quartile in the period between April and August) and a source elevation of 45° (on June 1, 2021, V Hya is above 45° in the LST range 8–14$^{\rm h}$). We request an rms over 1 km s^{-1} resolution of 4 mK, except for the setups close to the water line at 183 GHz where we have relaxed the rms to 10mK. The expected linewidths are $\gtrsim 8$ km s^{-1} as already observed for the lines in band 6 (see Fig. 1). Therefore, the XFFT spectrometer will provide an excellent spectral resolution (equivalent to ~ 0.1 km s^{-1}). Spectral binning can be done to improve SNR.

The rms value is derived from the ^{29}SiO $J = 3$–2 line observed with the IRAM-30 m telescope, which has a peak temperature of ∼ 9 mK (at ∼ 1 km s^{-1} resolution the rms is 3 mK). We aim at a SNR of ∼3 for the ^{29}SiO $J = 4$–3 and 5–4 lines, which should have peak temperatures of ∼ 12 and 15 mK, respectively (considering LTE). ^{29}SiO is less abundant than other typical molecules in the CSEs of C-rich sources (see e.g. Fig.1), thus, we expect other more abundant species to be detected with SNR > 3. The total requested time to finish the project is ∼ 37.5 h assuming that band 6 observations are finished in the current observing run starting in May 2021. In case that the band 5 part of the project is observed, the recommended observing time should be reduced accordingly.

References

Bachiller, R., et al. 1997, A&A, 324, 1123

Brunner, M., et al. 2018, A&A, 617, A23

Bublitz, J., et al. 2019, A&A, 625, A101

Burkhardt, A. M., Dollhopf, N. M., Corby, J. F., et al. 2016, ApJ, 827, 21. doi:10.3847/0004-637X/827/1/21

Cernicharo, J., et al. 2000, A&AS, 142, 181

De Beck, E., & Olofsson, H. 2018, A&A, 615, A8

Habing, H. J. & Olofsson, H. 2004, Asymptotic Giant Branch Stars, Edited by Harm J. Habing and Hans Olofsson. ISBN: 9781441918437, Astronomy and Astrophysics Library. Springer, 2004.. doi:10.1007/978-1-4757-3876-6

Hirano, N., et al. 2004, ApJ, 616, L43

Hoppe, P. & Zinner, E. 2000, JGR, 105, 10371. doi:10.1029/1999JA900194

Kahane, C., et al. 1996, A&A, 314, 871

Kamiński, et al. 2013, ApJS, 209, 38

Müller, H. S. P., et al. 2005, JMS, 742, 215

Olofsson, H., Vlemmings, W. H. T., Bergman, P., et al. 2017, A&A, 603, L2. doi:10.1051/0004-6361/201731170

Olofsson, H., et al. 2019, A&A, 623, A153

Pardo, J. R., et al. 2007, ApJ, 661, 250

Pickett, H. M., et al. 1998, JQS&RT 60, 883-890

Saberi, M., et al. 2018, A&A, 612, L11

Sánchez Contreras, C., et al. 2015, A&A, 577, A52

Sánchez Contreras, C., et al. 2018, A&A, 618, A164

Velilla Prieto, L., et al. 2015, A&A, 575, A84

Velilla Prieto, L., et al. 2017, A&A, 597, A25

Zhang, Y., et al. 2013, ApJ, 773, 71

Additional material: tables

Table 1: Research status on chemical studies of outflows of evolved stars

Evolutionary stage	Type	Sources
		low-mass stars **(**$< 8\,M_\odot$**)**
AGBs	C-type	IRC + 10216, CIT 6, CRL 3068, U Hya, Y CVn, II Lup, LP And, IRC + 40450, V358 Lup, AI Vol
	M-type	IK Tau, R Dor, Mira, W Hya, RX Boo, TX Cam, R Leo
	S-type	W Aql, χ Cyg, R And
post-AGBs	C-type	CRL 618, AFGL 2688
	M-type	OH 231.8 + 4.2, HD 101584†
PNe	Unknown	M 4-9, NGC 6772, NGC 7008,
	C/O > 1	NGC 6781, NGC 7027, BD + 30°3639
	C/O < 1	M 2-48, NGC 6445, NGC 6537, NGC 6543, NGC 6720, NGC 6853, NGC 7293
		high-mass stars **(**$> 8\,M_\odot$**)**
RSGs	O-rich	VY CMa, AFGL 2233
YHGs	O-rich	IRC + 10420, AFGL 2343

Notes. We list objects that have been targeted in the context of chemical studies or partial mm-wavelength spectral scans. Some on-going works are also listed.
References: Bachiller et al. (1997), Brunner et al. (2018), Bublitz et al. (2019), Cernicharo et al. (2000), De Beck, & Olofsson (2018), Kamiński et al. (2013), Olofsson et al. (2019), Pardo et al. (2007), Velilla Prieto et al. (2015), Velilla Prieto et al. (2017), Zhang et al. (2013).
† Uncertain classification: post-AGB/post-RGB.

Additional material: figures

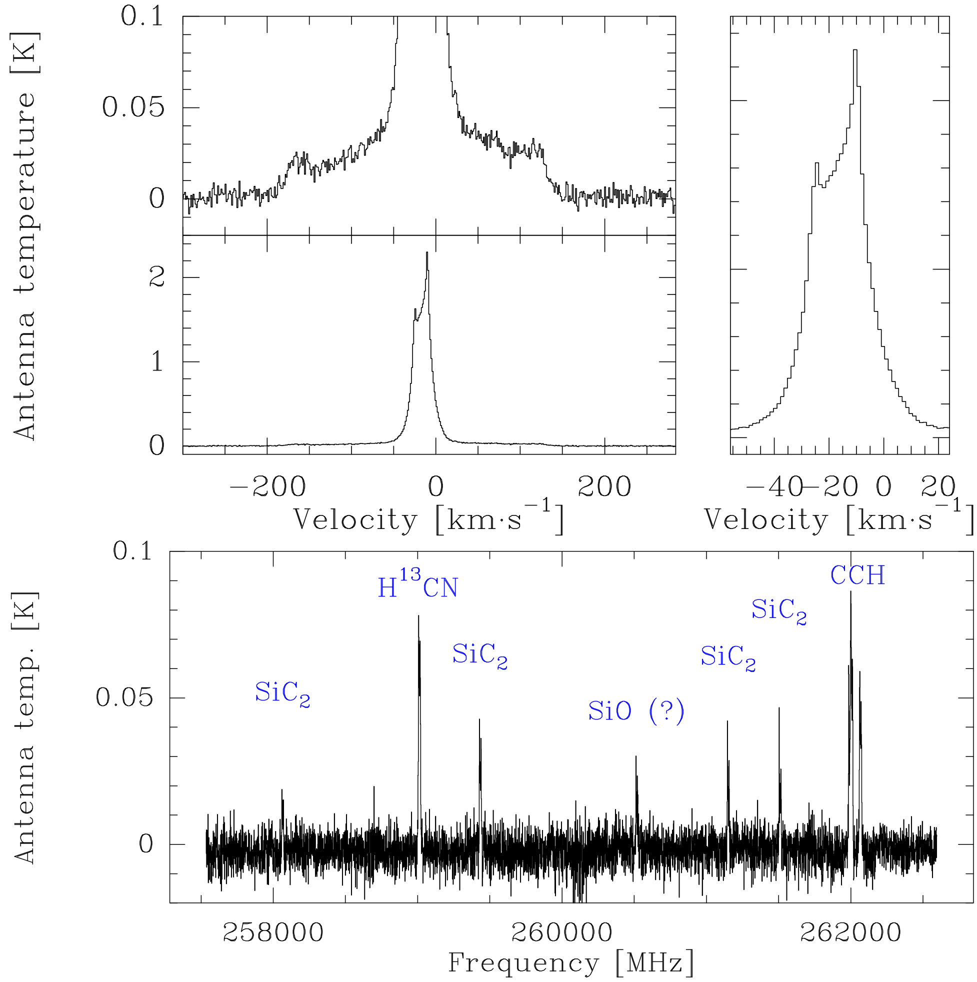

Figure 1: V Hya spectrum as observed with APEX in the previous observing run of this project. The top panels show the CO $J=2$–1 line, which displays very broad wings corresponding to the high velocity outflow. The bottom panel shows a small frequency range where several lines of different species are detected. The average density of lines is close to two lines per GHz.

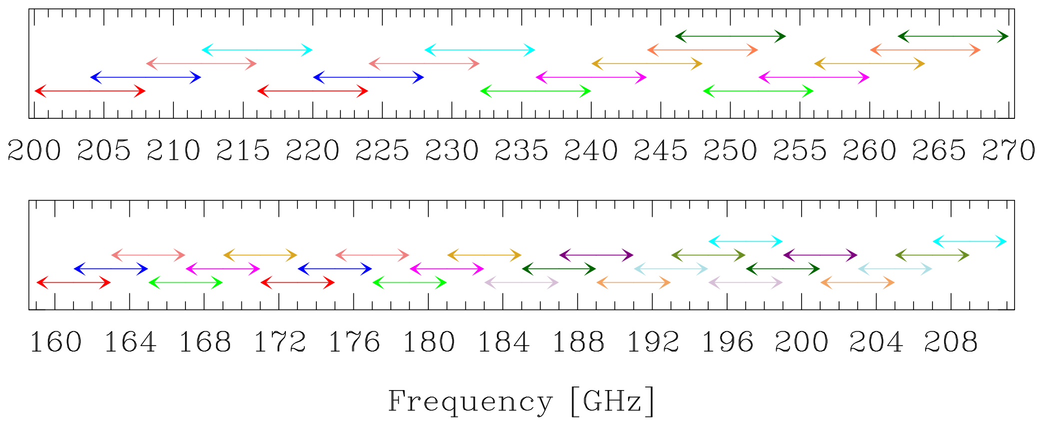

Figure 2: Suggested configuration to cover both bands. Each setup is plotted with different colours, with a 8 GHz gap between the LSB and the USB. This configuration has a half-sideband overlap between consecutive setups (except in the edges), which allows to check calibration issues.

No PhD Students involved

Linked proposal submitted to this TAC: No

Linked proposal submitted to other TACs: No

Relevant previous Allocations: Yes

This is a resubmission of an unfinished project, with previous IDs: 105.F-9304(A,B) and 107.F-9302(A). The band 6 (nFLASH) part is almost observed and will be (most likely) completed during the current runt in the summer of 2021. If SEPIA operations are re-started during this period and this projects becomes observed, the recommended time for the following run should be reduced accordingly.

No additional remarks

Observing run info :