Poster P2-34: Envelopes of carbon-rich stars as seen by HIFI - case of V Cyg

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Abstract

We present Herschel/HIFI observations of carbon-rich star V Cyg. Altogether 8 emission lines from C-based molecules (CO, HCN and their ^{13}C isotopologues), and 2 from O-based molecules (SiO and para-water) were detected. Analysis of line profiles with high excitation temperature suggests that gas acceleration in envelopes of C-rich stars is quite efficient. We present also modelling of dust continuum and CO line profiles in this source with aim to determine mass loss history and kinematics of circumstellar envelope in V Cyg.

1. Introduction

V Cyg is a bright carbon-rich star classified as a Mira variable with a 421 day period at rather uncertain distance of 200-500 pc as inferred from the Hipparcos measurements. From the Period-Luminosity (P-L) relation for galactic carbon-stars a luminosity of 6200 $L_\odot$ was inferred (Groenewegen & Whitelock, 1996, MNRAS, 281, 1347), and effective temperature of about 2000 K was estimated (e.g., Wallerstein & Knapp, 1998, ARA&A, 36, 369). Its apparent V magnitude varies between 7.7 and 13.9 mag (between 8.67 and 10.58 mag in the Hipparcos data). V Cyg has a moderate mass loss, estimated to be about 1.2 10^{-6} $M_\odot$/yr (Schöier & Olofsson, 2000, A&A, 359, 586).

Observations of V Cyg were performed under HIFISTAR project (PI. V. Bujarrabal) with aim to gain deeper insight into the structure, thermodynamics, kinematics and chemistry of its circumstellar envelope. Altogether 12 carbon-rich stars will be observed in this project. Observations of V Cyg were done in dual side band (DSB) mode by Herschel/HIFI on March 2010 using in total 7261 sec of HIFI time in 6 frequency settings. Altogether 8 molecular lines of CO and HCN with their ^{13}C isotopologues were detected. In addition, 2 transitions of O-rich molecules (a high-J transition of SiO, and, the most surprisingly, a ground state transition of para-H2O) were found (see poster P2.28 by D. Neufeld for details on para-water vapour modelling).

2. Molecular transitions detected in V Cyg by Herschel/HIFI

Continuum-subtracted spectra of all transitions detected in V Cyg (except of para-water) are shown in **Fig.1**, and parameters of these detections are summarized in **Table 1**.

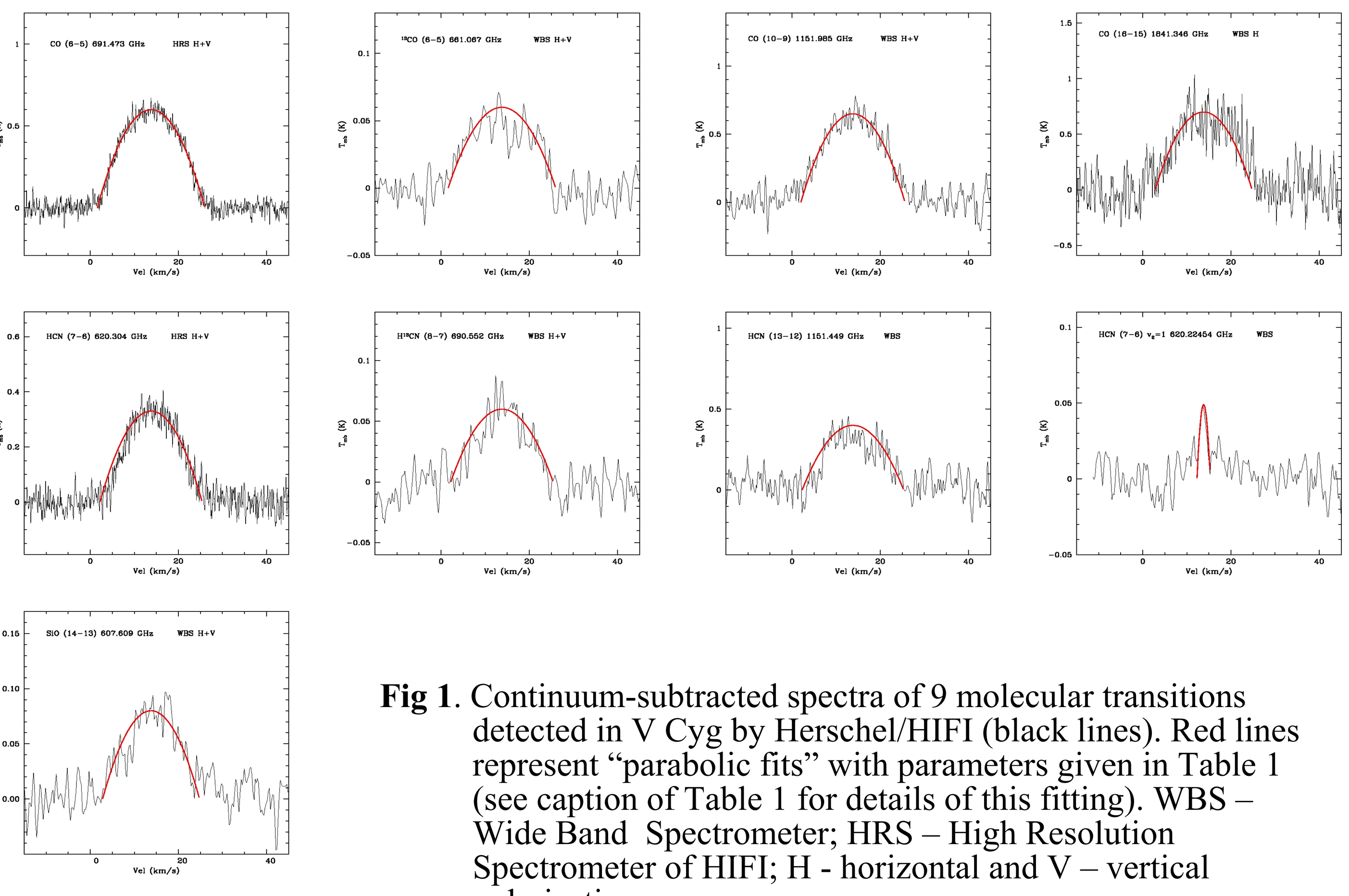

Fig 1. Continuum-subtracted spectra of 9 molecular transitions detected in V Cyg by Herschel/HIFI (black lines). Red lines represent "parabolic fits" with parameters given in Table 1 (see caption of Table 1 for details of this fitting). WBS – Wide Band Spectrometer; HRS – High Resolution Spectrometer of HIFI; H - horizontal and V – vertical polarization.

Transition	freq. [GHz]	HPBW ["]	η	V_{LSR} [km/s]	V_{exp} [km/s]	T_{mb}^{peak} [K]	Int{T_{mb}dV}
CO (6-5)	691.473	32.8	0.699	13.8	12.2	0.6	9.7
^{13}CO (6-5)	661.067	34.4	0.700		12.2	0.06	0.9
CO (10-9)	1151.986	19.5	0.661		11.8	0.65	10.4
CO (16-15)	1841.346	12.3	0.582		11.0	0.7	10.9
HCN (7-6)	620.304	36.5	0.703		11.6	0.33	4.9
$H^{13}CN$ (8-7)	690.552	32.8	0.699		11.6	0.06	0.6
HCN (13-12)	1151.449	19.5	0.661		11.5	0.4	5.1
HCN (7-6) v=1	620.225	36.5	0.703		1.5	0.05	0.12
SiO (14-13)	607.609	37.0	0.703		11.0	0.08	1.2

Table 1. Parameters of the observed transitions and the obtained parabolic fits. From the fitting parabola to the CO (6-5) line the Local Standard of Rest (LSR) velocity, V_{LSR}, of 13.8 km/s has been determined. This V_{LSR} has been adopted then during fitting parabola to the other line profiles, with the only free parameters being expansion velocity, V_{exp}, and main beam temperature at the peak, T_{mb}^{peak}. HPBW is Half Power Beam Width of the Herschel telescope at the corresponding transition frequency, and η is beam efficiency used for conversion of antenna temperature to the T_{mb}.

3. Dust continuum fit

Radiative transfer modelling of dust continuum in V Cyg has been performed with our 1D code (MRT – Multi dust component Radiative Transfer - see Szczerba et al. 1997, A&A, 317, 859). As a dust responsible for the observed continuum we considered amorphous carbon "cel800" from Jäger et al. (1998, A&A, 332, 291) with slope in far infrared (β) modified to be equal 1, and silicon carbide from Laor & Draine (1993, ApJ, 442, 441). Results of our modelling are shown in **Fig.2**. The main input parameters of the model are: L=6200 $L_\odot$; stellar temperature of 2000 K; distance of 325 pc;

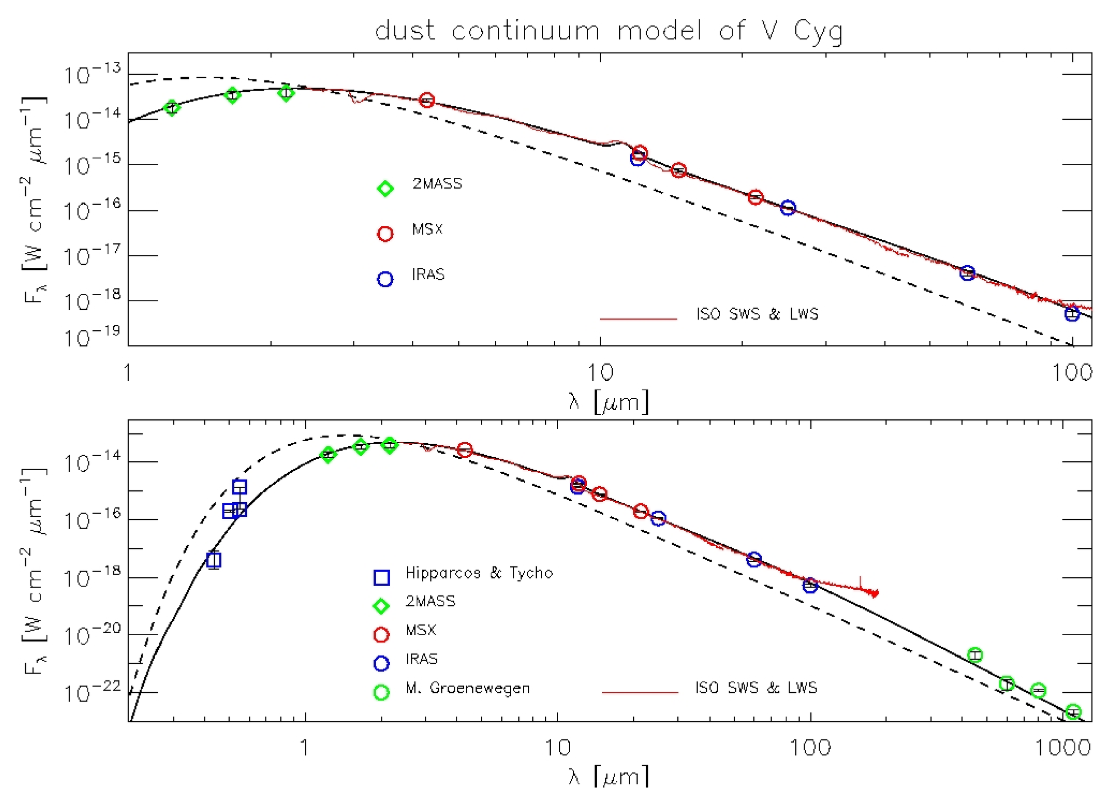

Fig 2. Spectral Energy Distribution (SED) of V Cyg fitted with our 1D radiative transfer model. Observational data used are described on the plots. Dashed line shows input spectrum of central star emitting as a black-body, while solid line indicates output spectrum of the model.

inner radius, R_{in}, of dust shell determined by the average temperature of dust equal 1000 K (in this case it corresponds to R_{in}=1.66 10^{14} cm; outer radius R_{out}=5 10^{17} cm; constant dust shell velocity of 11.8 km/s; radial dust distribution proportional to $R^{-2.1}$; power law dust size distribution with index -3.5 between 0.005 and 0.25 μm. The resulting optical depth of the model at V, A_V=3.6; dust mass loss rate at R_{in} is 2.2 10^{-9} and at R_{out} is 1.0 10^{-9} $M_\odot$/yr; total mass of dust inside the envelope is 1.5 10^{-5} $M_\odot$.

4. Modelling of CO line profiles

For the solution of the multilevel radiative transfer in molecular lines we have applied our code which uses approximate Newton-Raphson operator in comoving frame (Schönberg & Hempe, 1986, A&A, 163, 151). The molecular model was limited to 40 rotational levels of the ground state of CO. Our "self-consistent" approach, with gas temperature determined by gas-dust (from the dust continuum modelling) interaction gives still not fully satisfactory line strengths. Therefore, in **Fig.3** we present results of modelling of CO lines (mostly those observed by HIFI) with "empirical" gas temperature (red line in the top left panel), which is resembling that obtained self-consistently (green dashed line). The obtained gas mass loss rates vary from 4 10^{-6} $M_\odot$/yr for R<5 10^{16} cm and 1.1 10^{-6} $M_\odot$/yr above.

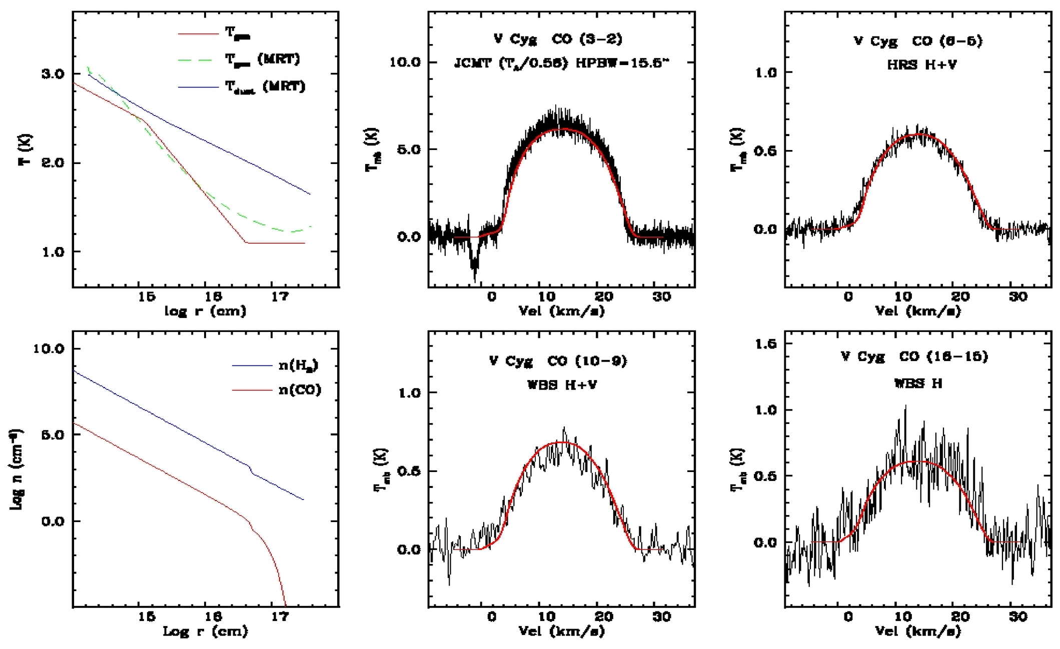

Fig.3. Results of (mostly) HIFI CO-line modelling with "empirical" gas temperature (red line in the top left panel) assuming that V Cyg is at distance of 325 pc. Dashed green line shows gas temperature obtained from "self-consistent" modelling using dust amount and properties from the MRT modelling; blue solid line shows average dust temperature from our dust continuum model. Lower left panel shows density distribution of molecular hydrogen (blue line) and CO (red line).

5. Summary

- We have detected 10 molecular lines with different excitation temperature from CO, HCN (including their ^{13}C isotopologues), SiO and p-H_2O in carbon-rich star V Cyg using Herschel/HIFI.

- HCN lines (similarly to the detected para-water transition) show blue-shifted absorption – probably due to the high optical depth, while CO lines obtained with Herschel/HIFI are quite symmetric.

- Analysis of expansion velocities, obtained from parabolic fits to the line profiles, suggests that expansion velocity of the shell probed even by the high-J transitions is quite large and close to the terminal velocity of about 12 km/s. This means that gas acceleration in C-rich stars is rather quick (the conclusion confirmed by our CO line modelling with different velocity laws – not shown here).

- HCN(7-6) v_2=1 line (V_{exp}=1.5 km/s) probes regions of the envelope close to the dust formation zone.