HIFI p(ion)eers inside the winds of IK Tau and VY CMa

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Abstract: Asymptotic Giant Branch stars and Red Supergiants return large amounts of gas and dust to the interstellar medium via their dense stellar winds. It is thus of prime importance to quantify their mass loss and to characterise the chemical species and reaction networks present in their envelopes. In the framework of the **HIFISTARS** Guaranteed Time Key Program (PI: V. Bujarrabal) we use the HIFI spectrometer to observe many molecular transitions in the circumstellar envelopes of evolved stars such as the Asymptotic Giant Branch star IK Tau and the Red Supergiant star VY CMa. Line profiles provide direct kinematical information on the envelope and its structure. The observations of high-excitation lines of e.g. SiO and H_2O trace the intermediate wind regions, where the gas and dust are being accelerated outwards. Tracing the velocity structure throughout the circumstellar envelopes provides us with more information on the efficiency of the wind driving in these oxygen-rich evolved stars. Emission lines of isotopologues, e.g. $H_2{}^{16}O$, $H_2{}^{17}O$ and $H_2{}^{18}O$, provide insight in chemical reactions at work and chemical evolution.

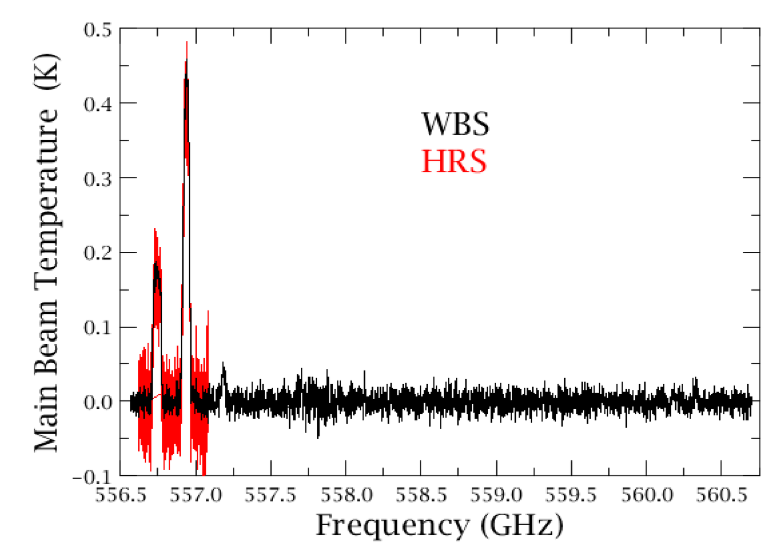

Fig. 1: Band 1b WBS (black) and HRS (red) spectra of IK Tau, baseline subtracted, velocity corrected and converted to main beam temperature.

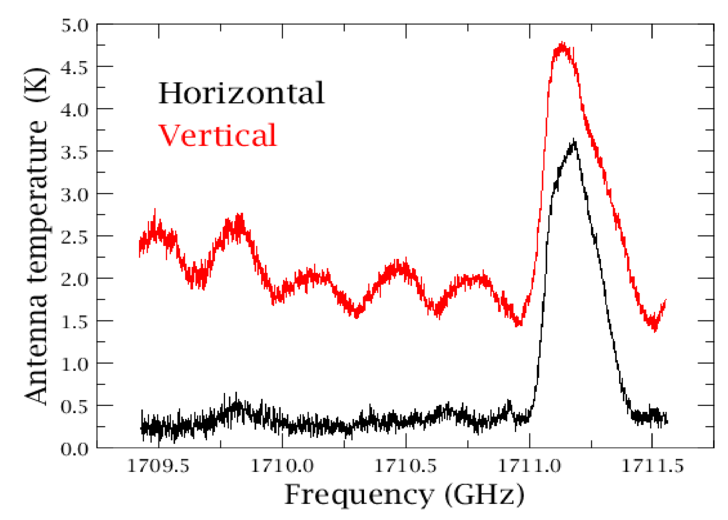

Fig. 2: Comparison between horizontal (black) and vertical (red) polarisation WBS spectra in a band 7a observation towards VY CMa.

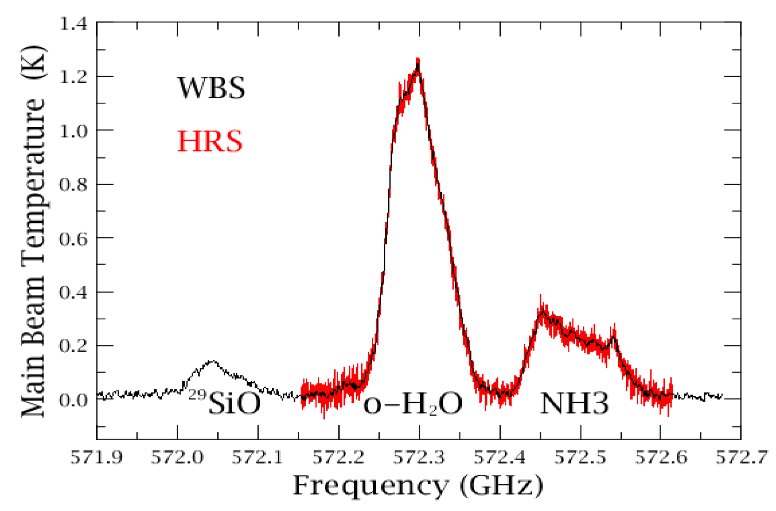

Fig. 3: WBS and HRS observations of three different species towards VY CMa. The complex profiles reflect the presence of multiple kinematical components.

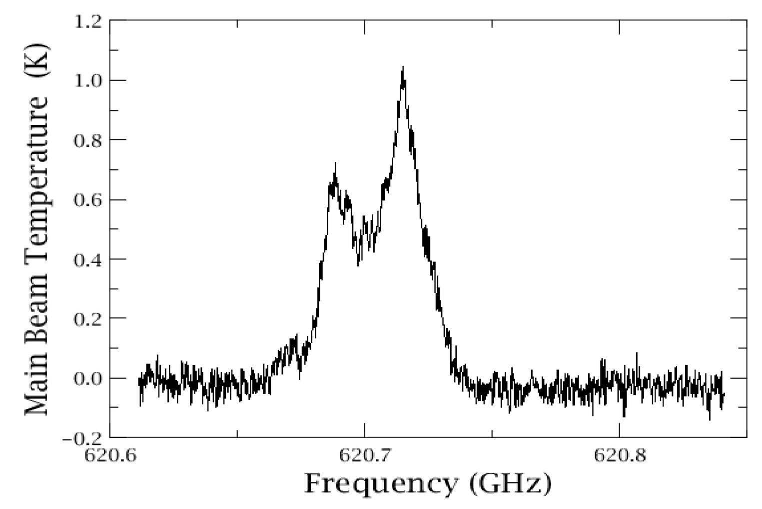

Fig. 4: Band 1b HRS spectrum with a velocity resolution of 0.06km/s of the maser line $H_2O(5_{3,2}-4_{4,1})$ towards IK Tau.

I. Data

a. Quick look

Using the HIFI instrument, we obtained single pointing observations towards IK Tau and VY CMa in a frequency range from 556GHz to 1870GHz. The wideband spectrometer (WBS) and the high-resolution spectrometer (HRS) were used simultaneously, with HRS resolutions of 120kHz and WBS resolutions of 500kHz. The instantaneous bandwidths for WBS observations in bands 1-5 are 4GHz, for the HEB bands 6 and 7 that is 2.4GHz. The standard Dual Beam Switch (DBS) observing mode was used for observations in all bands, except for bands 6 and 7, where FastDBS was applied for stability reasons.

b. Data quality

Overall we obtained very high quality data, with high signal-to-noise ratios, for bands 1-5. A band 1b observation is shown in Fig 1. The observations using bands 6 and 7 show strong residual standing waves. Also, the observations in vertical polarisation in these bands are often of significantly lower quality than those in horizontal polarisation (Fig. 2). Careful treatment of the individual subsets of data is needed in these cases.

II. Kinematics, dynamics

a. Line profiles

The emission lines seen in the spectra of VY CMa (Fig. 3) hold a lot of information on the complex kinematics in the envelope of this target. Clear asymmetries are seen and all three lines shown in the figure indicate the presence of a 3-component structure, as presented by Ziurys et al. 2007 (Nature, Vol. 447, Issue 7148, pp1094-1097).

b. Masers

For both IK Tau and VY CMa we detect maser lines. An example of a HRS observation of the $H_2O(5_{2,4}-4_{3,1})$ masering transition for IK Tau is shown in Fig. 4. The excitation regions of these masers are well bound by molecular densities (many collisions cause thermalisation) and optical depths.

c. Velocities

From the observed emission lines of IK Tau we derive expansion velocities of 14.5km/s up to 20km/s. The lower expansion velocities indicate line excitation in the so-called intermediate wind regions, that are not yet fully accelerated to the terminal velocity. We show measured expansion velocities of CO, SiO, HCN and H_2O (and isotopologues) and the extent of the line excitation regions in Fig. 5, overplotted on theoretical velocity profiles: a simple power law and the solution of the momentum equation. Further observations will trace the inner regions of lower expansion velocity.

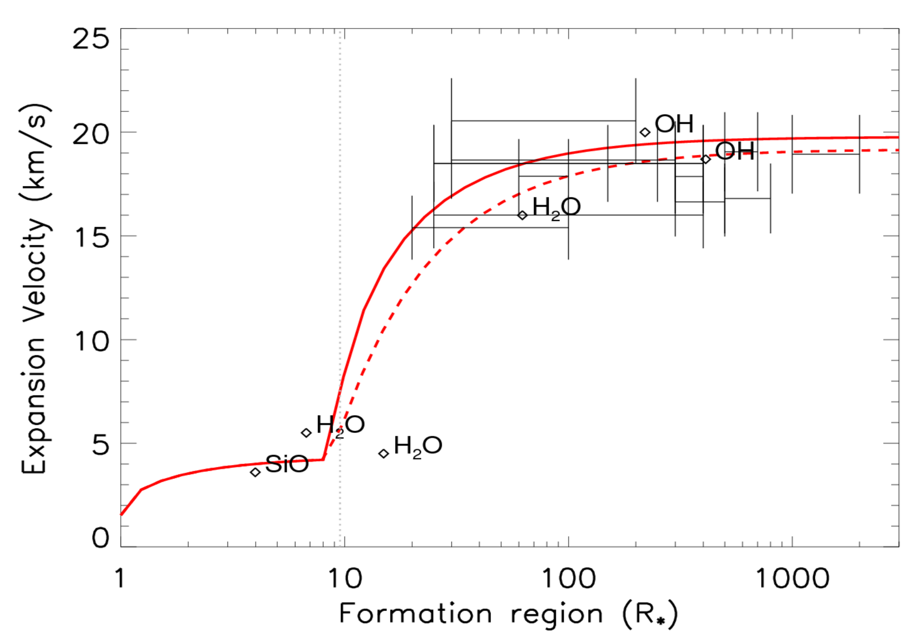

Fig. 5: Emission lines observed with HIFI partly trace the acceleration zone. Horizontal bars indicate the extent of their excitation regions. Theoretical velocity profiles are plotted in red: (full line) solution of the momentum equation, (dashed) a power law. The diamonds show ground-based measurements of maser lines.

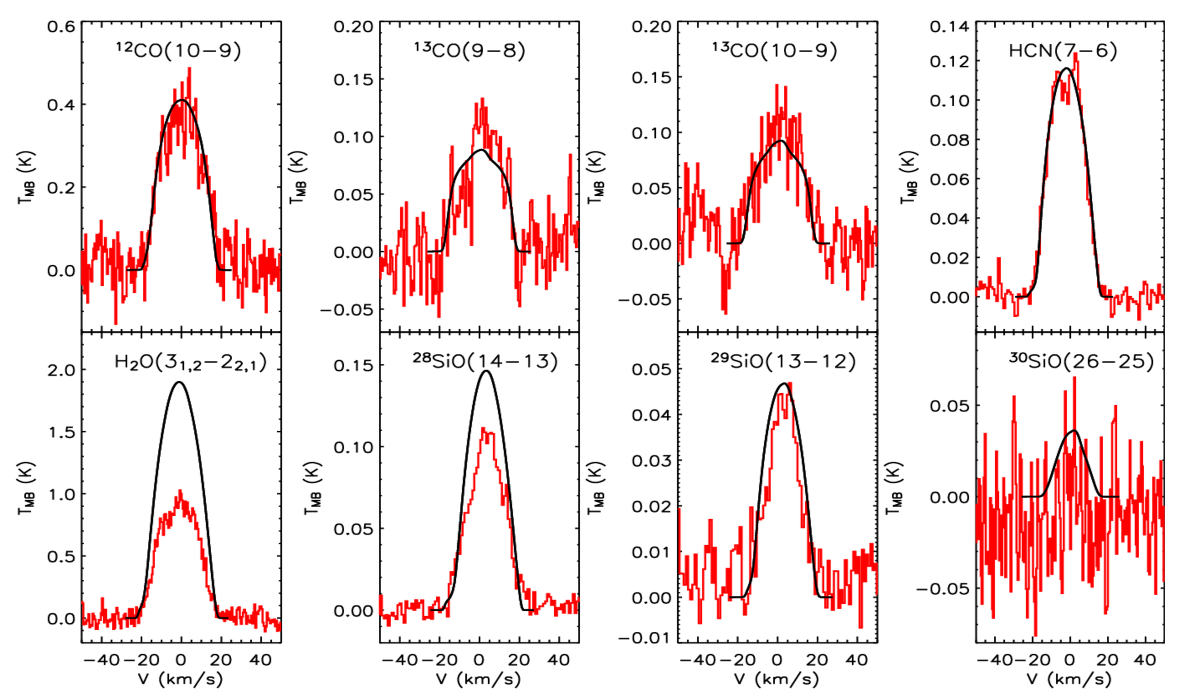

Fig. 6: HIFI spectra and fits of CO, HCN, H_2O and SiO emission lines in the envelope of IK Tau. The fits (in black) are based on the results presented by Decin et al. 2010 (A&A, *in press*).

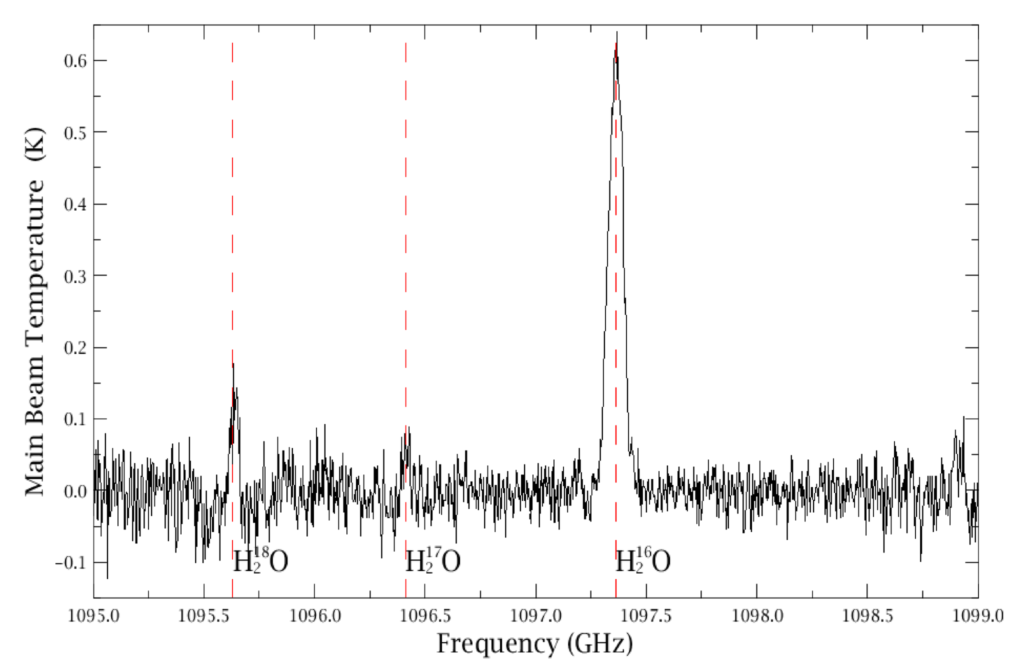

Fig. 7: Band 4b WBS spectrum of IK Tau showing the $(3_{1,2}-3_{0,3})$ transition for $H_2{}^{16}O$, $H_2{}^{17}O$ and $H_2{}^{18}O$.

III. Chemistry

a. Models

Decin et al. 2010 (A&A, *in press*) modelled ground-based data of IK Tau, using the non-LTE radiative transfer code GASTRoNOoM. They discuss emission lines of CO, SiO, HCN, H_2O, SiS, CN, CS and some of their isotopologues. In Fig. 6 we show the fits of these models to some of the HIFI spectra of CO, HCN, H_2O and SiO.

b. Isotopes

Emission lines of different isotopologues provides information on the chemical evolution of the star. We detected emission lines from species such as ^{12}CO and ^{13}CO, ^{28}SiO, ^{29}SiO and ^{30}SiO and $H_2{}^{16}O$, $H_2{}^{17}O$ and $H_2{}^{18}O$. In Fig. 7 we present the detection of the $(3_{1,2}-3_{0,3})$ transition for $H_2{}^{16}O$, $H_2{}^{17}O$ and $H_2{}^{18}O$ in one WBS spectrum towards IK Tau.

IV. Prospects

a. HIFI

Further improvement on the data reduction of HEB band data is in progress. A few more observations will be carried out for IK Tau and VY CMa within the HIFISTARS programme. These will provide extra physical and chemical constraints on the current models for the circumstellar environments of AGB and supergiant stars.

b. HIFI + PACS + SPIRE + ground-based

Targets observed in the HIFISTARS and MESS (PI: M. Groenewegen) GTKPs largely overlap. We will combine the high-quality data from all three instruments on board Herschel and available ground-based data to construct a detailed view of the kinematics, dynamics, chemistry and mass loss of these evolved stars.

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Research topic
Chemistry and physics of circumstellar envelopes of Asymptotic Giant Branch and Red Supergiant stars