Illustrated Conception of V Hydra

Fig. 2

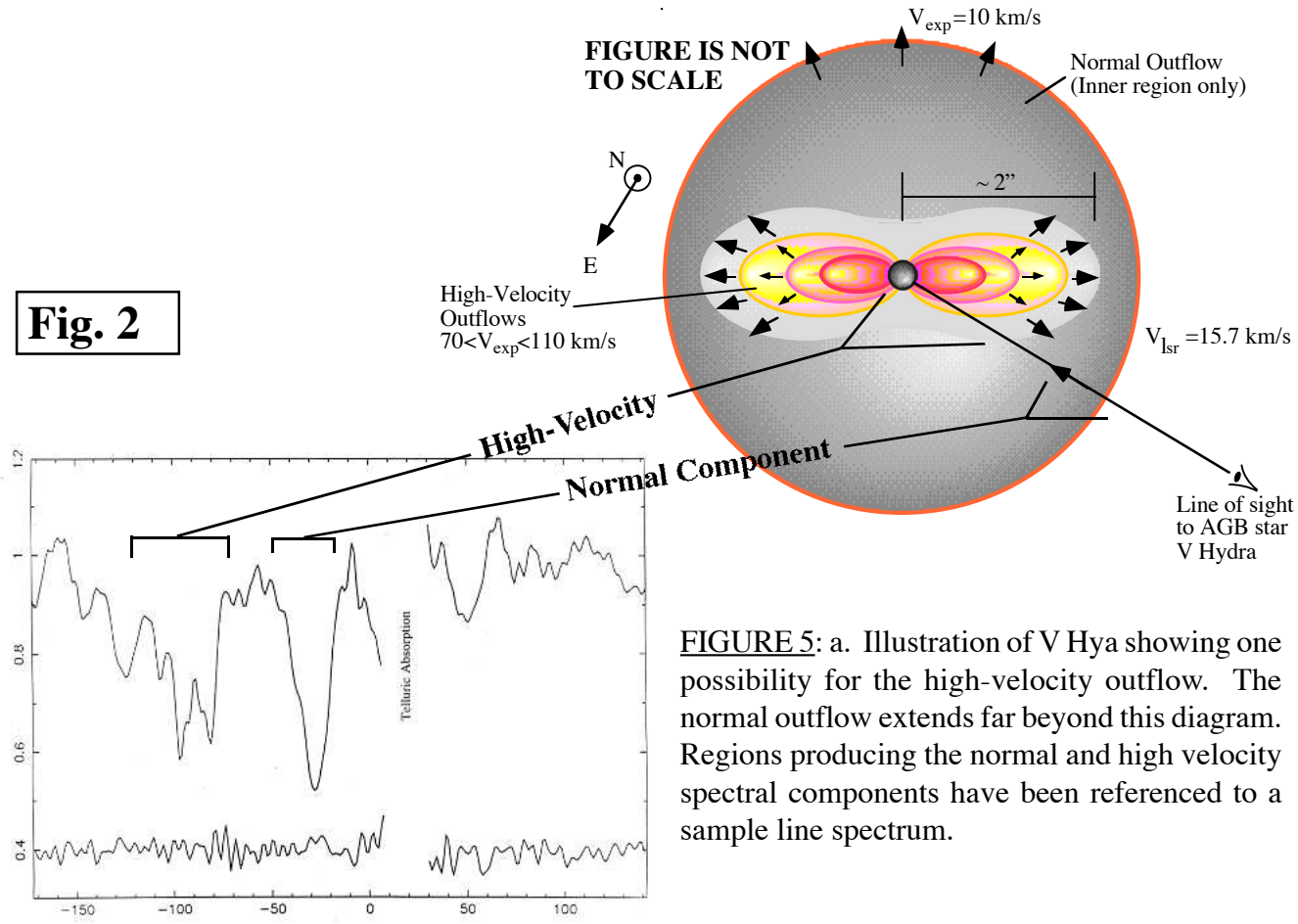
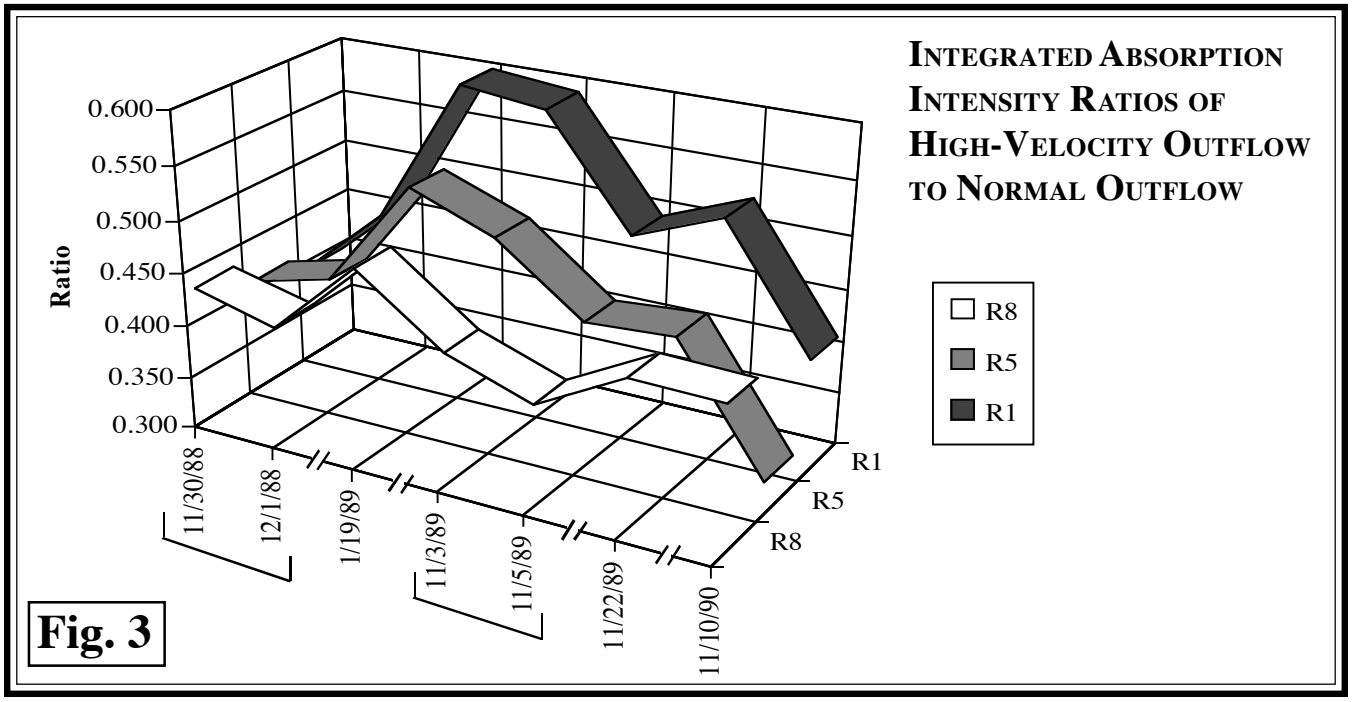
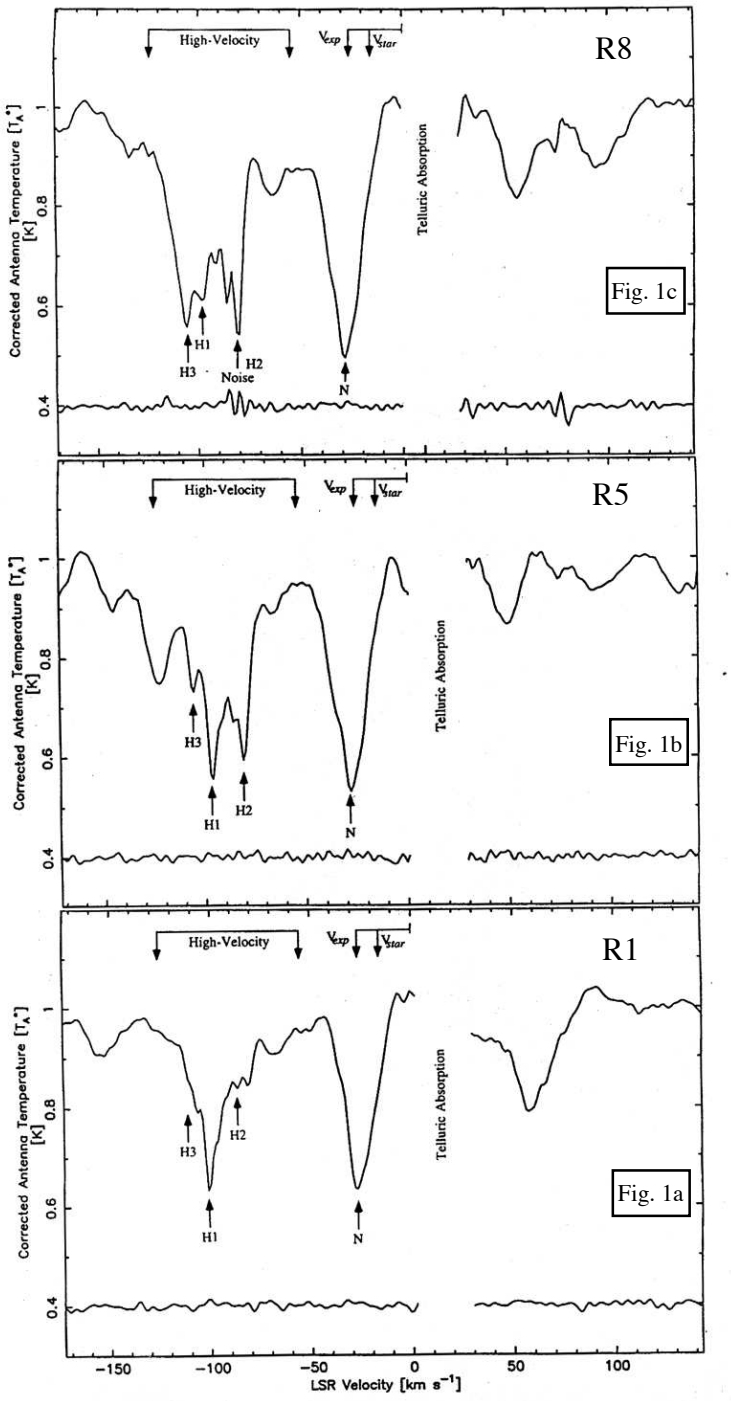


FIGURE 5: a. Illustration of V Hya showing one possibility for the high-velocity outflow. The normal outflow extends far beyond this diagram. Regions producing the normal and high velocity spectral components have been referenced to a sample line spectrum.

Fig. 3



and high-velocity outflows expanding from V_{exp}=70 to 120 km/s containing at least six kinematic components. Integrated absorption intensity ratios indicate that the high-velocity region is changing on a timescale of two days, which constrains the outflow extent to within ~10^{16} cm. Understanding the physical mechanisms and nature of the various outflows of V Hya will not only contribute to our theories of mass-losing AGB stars, but will also make an important contribution to our understanding of the physical processes which mediate the transformation of mass-losing stars like V Hya into bipolar planetary nebulæ.



FIGURES 1a-c: Weighted average spectra for the ^{12}COR1, R5 and R8 lines. The -45 to -65 km/s region is the "interaction region" where the high-velocity outflow collides with the normal outflow. Absorption in this region increases from R1 to R8, indicating highly excited gas.

VII. References

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The structure of these components is not understood; the HV region is probably composed of a complex expanding outflow, possibly as shown in figure 2. The normal component due to the slow outflow, denoted **N**, and three of the stronger HV components, denoted **H1**, **H2**, and **H3** are marked on figures 1a-c.

The intensity of the H1 component, compared to the normal component, appears to decrease from R1 to R8. The H2 component appears much more strongly in R5 than R1, indicating that it arises in more highly excited gas than H1. Similarly, the H3 component, appearing most strongly in R8, arises in still more highly excited gas. The integrated absorption intensity *I* over the full HV region nearly doubles from ^{12}COR1 (*I*=8.0) to R5 (*I*=12.6) to R8 (*I*=14.9). This shows that the high-velocity outflow is primarily composed of high-excitation gas.

The region between -45 and -65 km/s exhibits absorption presumably arising in the region of hydrodynamic interaction between the HV and normal outflows. Comparison of the absorption strengths from R1 to R8 clearly show this is highly excited gas, as expected.

We can see structure in the normal component indicative of the presence of kinematic perturbations superimposed on the predominant expansion at 10 km/s. The blue wing of the normal component is anomalously wide compared to that in other mass-losing stars. The half-power point lies roughly 9 km/s beyond the outflow velocity of the normal component in V Hya, compared to < 5 km/s in other mass-losing red-giants. This probably results from increased turbulence in the normal component due to interaction with the HV outflow.

We have integrated the absorption intensity in the normal and H1 absorption features across fixed velocity ranges (-40 to -14 and -105 to -95 km/s respectively) in seven epochs (Mar 28, 1988 was omitted since the normal component coincides with the telluric absorption) and computed the intensity ratios of H1/N. Errors have been calculated based on uncertainty in the continuum level and RMS noise. Integrated intensity ratios for ^{12}COR1, R5 and R8 have been plotted in figure 3. The integrated absorption intensity ratios shown in figure 3 show unexpected results. The strong variations in ratios for each line support previous evidence for changes in the physical properties of the HV outflow over year-long time-scales. However, we also find rapid variation in the ratios from 11/30/88 to 12/1/88, and from 11/3/89 to 11/5/89, providing strong evidence for changes in the HV components over very short time-scales (~2 days).

IV. Discussion and Further Work

The short-term variations imply that the upper limit on the size of the region must be less than the distance light travels during this time. This implies that the HV component is constrained within $\sim 10^{16}$cm. This result is in good agreement with that of Sahai and Wannier (1988) who, using independant arguments, found the HV features to be constrained within 2.5", corresponding to $\sim 1.4\times10^{16}$ cm at a distance of 390 pc.

Many questions remain unanswered at this point: What causes the short time-scale variations in the HV outflow? V Hya is believed to have a central binary star (Barnbaum, *et al*, 1995). Is the binarity somehow related to the characteristics of the HV outflow?

Further detailed study of the structure of, and variations in, the various absorption components is in progress. We will analyse ^{12}CO21 and ^{13}CO lines to respectively probe higher excitation and denser gas. Gaussian deconvolution of the HV kinematic structure will allow us to measure gas temperatures and column densities in individual kinematic components. These will help constrain the nature of the HV outflow and its hydrodynamic interaction with the normal outflow.

VI. Conclusions

Using high-resolution spectroscopic data covering the 4.6μm band of CO taken over 8 epochs, we have found the circumstellar envelope of V Hya to consist of a slow-moving normal outflow (V_{exp}=10±2 km/s),

Multiple Winds from the Carbon Star V Hydra

STUDYING TIME-VARIATIONS USING HIGH-RESOLUTION SPECTROSCOPY OF THE 4.6 μm CO LINES

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I. Introduction

The carbon-rich AGB star V Hydra (V Hya) is believed to be at a short-lived but critical stage in the evolution of a mass-losing AGB star into a bipolar planetary nebula. (Tsuji, *et al,* 1987) Observations of mm-wave CO lines show that V Hya possesses not only a slowly-expanding (V_{exp}≈15 km/s), largely spherically-symmetric "normal" circumstellar envelope (CSE), but also a fast (V_{exp}≈30 km/s) secondary bipolar outflow. (Kahane, 1988)

Observations of individual P and R-branch lines in the fundamental vibration-rotation band of CO at 4.6μm over two epochs by Sahai and Wannier (1988) showed the presence of several absorption components due to very fast-moving (up to V_{exp}≈120 km/s) gas. These lines showed significant differences between the two epochs, implying changes in the physical properties of the multiple high-velocity (HV) outflow over year-long time-scales. This study provided the first direct evidence of a very high-velocity stellar wind around a mass-losing AGB carbon star embedded within a roughly isotropic, slowly expanding envelope. Sahai and Wannier interpreted that the observed high-velocity features in V Hydra arise in a high-velocity polar outflow from an accretion disk in a binary system, as proposed in the recent mass-loss model for bipolar envelopes by Morris (1988). Evans (1991) has found outflow velocities up to 155 km/s from optical data. Luttermoser and Brown (1992) have found 3.6 cm continuum emission suggesting a shock-related mechanism in the HV outflow.

Using high-resolution spectroscopic data covering the 4.6μm band of CO and its isotopomers, taken over 8 epochs, we are studying in detail the various outflows to constrain the nature of the HV outflow and its hydrodynamic interaction with the normal outflow.

II. Observations & Data Reduction

•Apparatus: Fourier Transform Spectrometer on the Kitt Peak 4-m Mayall Telescope.

•Observation: 4.6μm lines of the fundamental CO vibration-rotation band in the 2100-2200 cm^{-1} range, at an unapodized resolution of 0.0089 cm^{-1}

•8 Epochs: Mar. 27, Nov. 30, Dec. 1, 1988; Jan. 19, Nov. 3, Nov. 5, Nov. 22, 1989; Nov. 10, 1990

•Data Reduction: Each spectrum was divided by the instrumental frequency-response determined by observing a tungsten lamp source. The spectra were then corrected for telluric absorption at the air mass of the source observation. Atmospheric opacity was derived from the lunar spectrum divided by the lamp. (Sahai and Wannier, 1985)

III. Results

We chose spectral windows with $\Delta\nu$≈2.6 cm^{-1} around individual absorption lines (e.g. ^{12}COR1, R5, R8) which are free from strong telluric lines or stellar lines from another CO isotopomer. We have averaged the data over all epochs; the weighted average spectra for ^{12}COR1, R5 and R8, are shown in figures 1a-c (normalized to a local continuum level of 1). The clean separation of the absorption features due to the slow and HV outflows allow us to determine a precise expansion velocity of the normal component (V_{exp}=10±2 km/s), which is smaller than previously published mm-wave results. Averaging the R1, R5 and R8 spectra reveals roughly 6 individual kinematic components, covering a region of approximately 70 km/s.

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