On the central symmetry of the circumstellar envelope of RS Cnc*

P.T. Nhung[1,2], D.T. Hoai[1,2], J. M. Winters[3], P. Darriulat[1], E. Gérard[4] and T. Le Bertre[2]

[1] VATLY/INST, Vietnam; [2] LERMA, Observatoire de Paris, France; [3] IRAM, France; [4] GEPI, Observatoire de Paris, France

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We present a phenomenological study of CO(1-0) and CO(2-1) emission from the circumstellar envelope of the Asymptotic Giant Branch (AGB) star RS Cnc. It reveals departures from central symmetry that turn out to be efficient tools for the exploration of some of the star properties. We use a wind model including a bipolar flow with a typical wind velocity of ~8 kms^{-1} decreasing to ~2 kms^{-1} near the equator to describe Doppler velocity spectral maps obtained by merging data collected at the IRAM Plateau de Bure Interferometer and Pico Veleta single dish radio telescope. Parameters describing the wind morphology and kinematics are obtained, together with the radial dependence of the gas temperature in the domain of the circumstellar envelope probed by the CO observations. Significant north-south central asymmetries are revealed by the analysis, which we quantify using a simple phenomenazological description. The origin of such asymmetries is unclear for the moment.

Introduction

A detailed study of the circumstellar gas distribution and kinematics of the semi-regular variable star RS Cnc, presently in the thermally pulsing phase of the AGB, on spatial scales ranging from ~100 a.u. to ~0.2 pc has been published recently (Hoai *et al.*, A&A 565, A54, 2014 & poster S1-07 at this conference). The model used in the study is centrally symmetric with respect to the star (standard model), except for self-absorption in the CO lines, which induces negligible asymmetries.

The present work studies the central symmetry of the gas distribution and kinematics, namely to which extent diametrically opposite gas volumes (with respect to the centre of the star) have equal *densities* and *temperatures* and opposite *velocities*. Searching for a possible central asymmetry in the circumstellar envelope of RS Cnc provides useful information to constrain the physical mechanisms that could be responsible for shaping the circumstellar shell.

Best fit results of the standard model and its modified asymmetric version

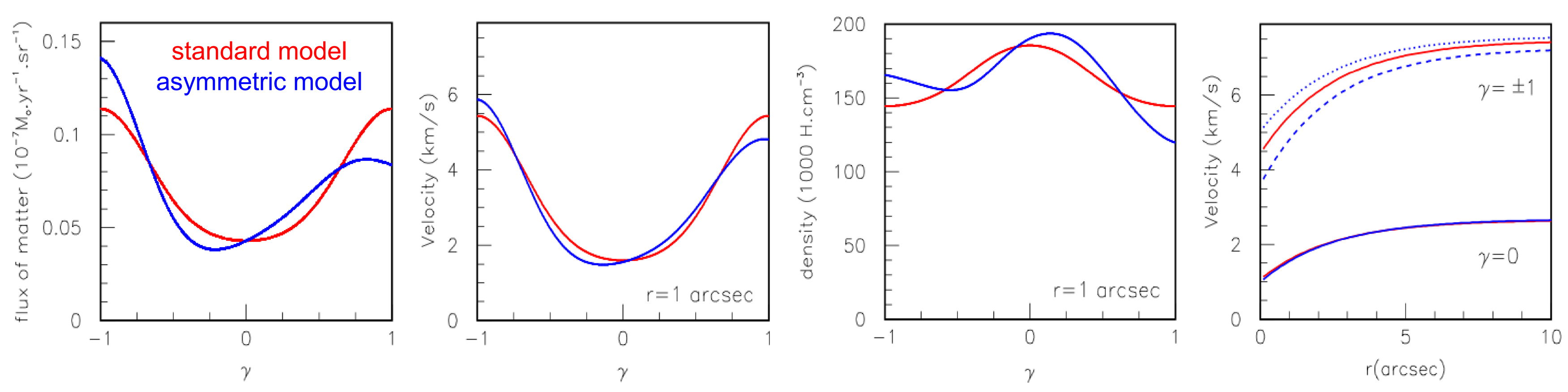

Fig. 2 Dependence over the sine of the latitude (γ) of the wind velocity, density and flux of matter, and the r-dependence of the wind velocity.

Parameterization of the asymmetries along the star axis

The standard model has been modified in a simple way to reproduce the observed central asymmetries (*1 for the bipolar flow, 2 for the slow wind*).

Mass loss rates: $(1+\varepsilon_{M1}\gamma)M_1$, $(1+\varepsilon_{M2}\gamma)M_2$; $\varepsilon_{M1} = -0.96$, $\varepsilon_{M2} = 0.95$

Velocities: $(1+\varepsilon_{V1}\gamma)V_1$, $(1+\varepsilon_{V2}\gamma)V_2$; $\varepsilon_{V1} = -0.40$, $\varepsilon_{V2} = 0.70$

The asymmetries obtained from the modified model are qualitatively in good agreement with observations, but they fail to reproduce them quantitatively (**Fig. 3**). The new asymmetric model improves the quality of the fit. However, there are still some deviations, especially in the centre, between the observations and the model (**Fig. 4**). Lacking a clear physical interpretation of the observed asymmetries, we did not attempt refining the model.

Description of CO(1-0) and CO(2-1) emission using a centrally symmetric model

A major difference between the CO(1-0) and CO(2-1) observations is the larger extension of the former with respect to the latter.

The radial dependence of the ratio of the CO(2-1) and CO(1-0) emission constrains the values taken by $T(r)$. A detailed comparison of the CO(1-0) and CO(2-1) emission (**Fig. 1**) reveals the need for the gas to reach lower temperatures than expected over the radial range probed by CO emission.

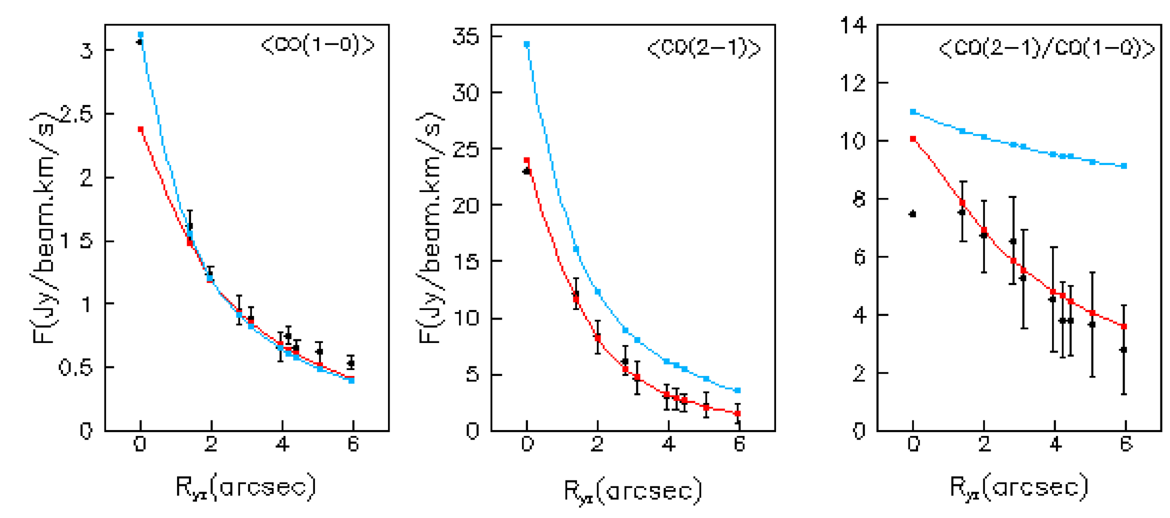

Fig. 1 Angular distance distributions from the star centre of *<CO(1-0)>*, *<CO(2-1)>* and *<CO(2-1)/CO(1-0)>* as observed (black symbols) and obtained from the standard model in its present version (red curves) or in the version used in Hoai *et al.* (cyan curves).

Signatures of central symmetry

If the source is symmetric with respect to its centre:

Density: $n(x,y,z) = n(-x,-y,-z)$

Wind velocity: $\mathbf{V}(x,y,z) = -\mathbf{V}(-x,-y,-z)$

Flux at velocity *v, integrated along a line of sight*: $F(v,y,z) = F(-v,-y,-z)$

The symmetric and anti-symmetric components of each pair of diametrically opposite spectra [(y,z), $(-y,-z)$], respectively labelled *dir* (for direct) and *mir* (for mirror), are defined as:

$$\Sigma_{dir}(v,y,z) = F(v,y,z)+F(v,-y,-z), \quad \Delta_{dir}(v,y,z) = F(v,y,z)-F(v,-y,-z)$$

$$\Sigma_{mir}(v,y,z) = F(v,y,z)+F(-v,-y,-z), \quad \Delta_{mir}(v,y,z) = F(v,y,z)-F(-v,-y,-z)$$

Signatures of central symmetry:

$$\Sigma_{dir}(v,y,z) = \Sigma_{dir}(-v,y,z); \quad \Delta_{dir}(v,y,z) = -\Delta_{dir}(-v,y,z); \quad \Delta_{mir} = 0$$

The Δ_{dir}, Δ_{mir}, Σ_{dir} and Σ_{dir} distributions (**Fig. 3**) display a dominance of two features: a narrow low velocity spike between ~0 and ~2 kms^{-1} in the northern part of the sky, mostly in the CO(1-0) data; and a broad velocity span in the southern part, mostly in the CO(2-1) data.

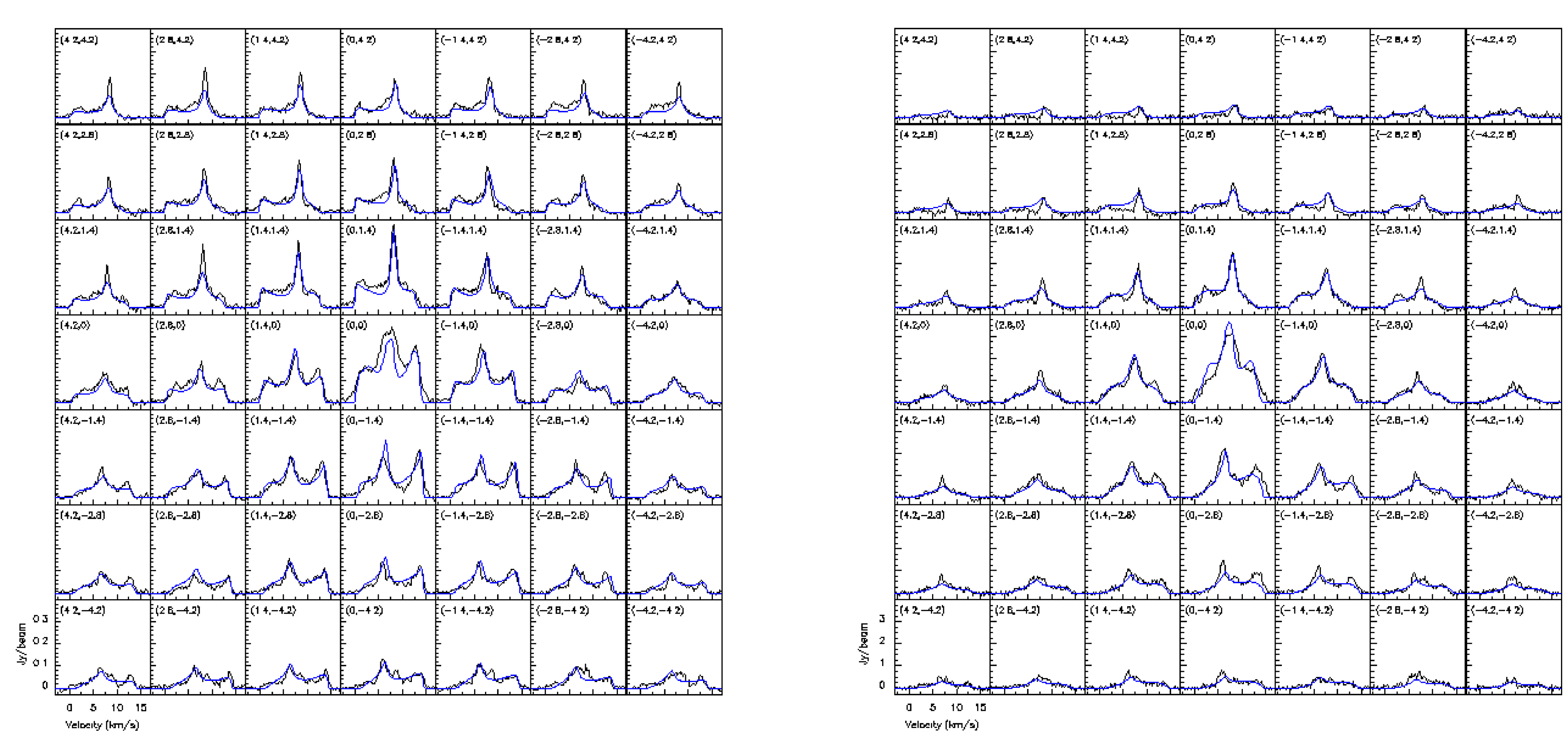

Fig. 4 Spectral map centred on the star of the CO(1-0) and CO(2-1) observations (black) and best fit results of the modified asymmetric version of the standard model (blue). Steps in right ascension and declination are 1.4”. The synthesized circular beams are Gaussian with a full width at half maximum of 1.2”.

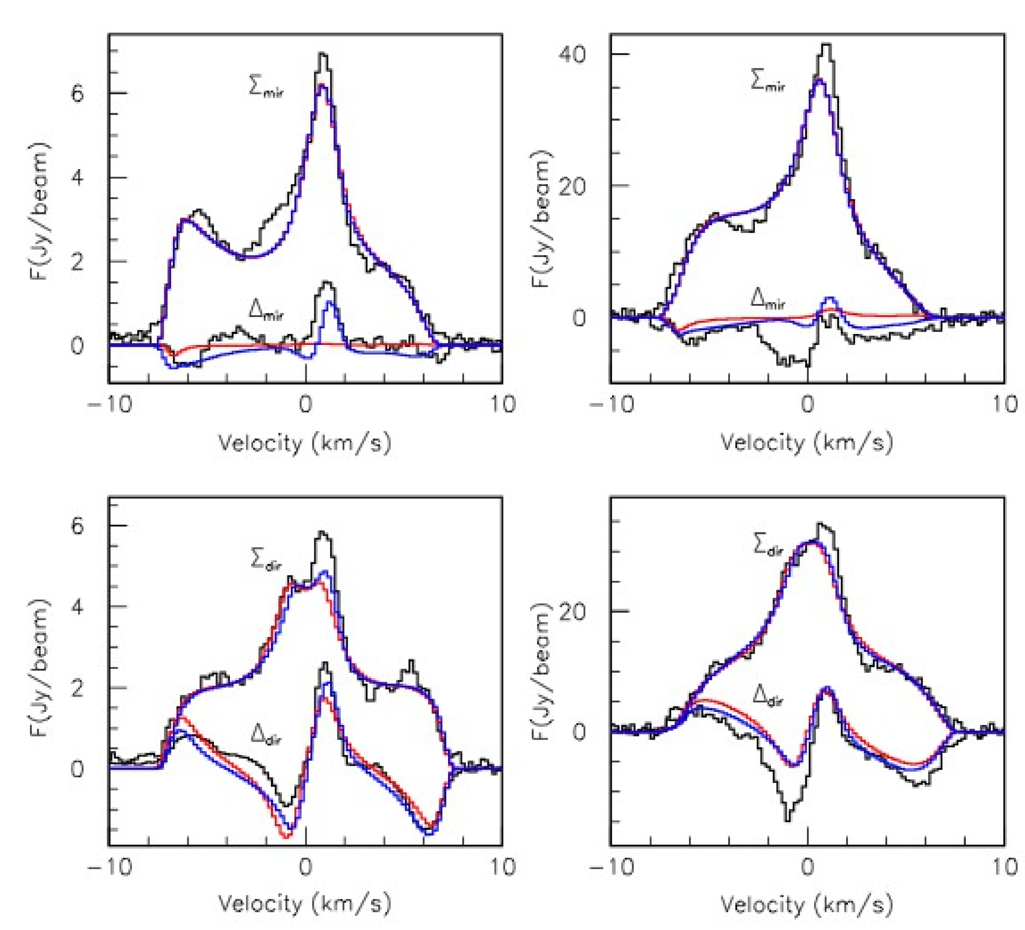

Fig. 3 Velocity distributions of Σ_{dir}, Δ_{dir}, Σ_{mir} and Δ_{mir}, for the 24 pairs of diametrically opposite spectra of the CO(1-0) and CO(2-1) spectral maps. Data are shown in black, best fit results of the standard model in red and of its modified asymmetric version in blue.

Summary

The study of the central asymmetry of the wind morphology and kinematics has revealed the presence of significant central asymmetries that can be schematically summarized as a northern excess confined to a narrow spike of low velocity, mostly in CO(1-0) data, and a southern excess covering a broad velocity range, mostly in CO(2-1) data.

A detailed comparison of CO(1-0) and CO(2-1) emission reveals the need for the gas to reach lower temperatures than expected over the radial range probed by CO emission. The observation of HI emission further out seems therefore to require some reheating.

A possible source of central asymmetry is the suggested existence of a companion source located ~0.98” West and ~0.63” North of the main source (see Fig. 4 in S1-07 poster). Observations with a higher spatial resolution are needed to better describe the close environment of the central star and to constrain the nature of the companion.