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FRACS: modelling of the dust disc of the B[e] CPD-57° 2874 from VLTI/MIDI data

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Abstract. The physical interpretation of spectro-interferometric data is strongly model dependent. On one hand, models involving elaborate radiative transfer solvers are in general too time consuming to perform an automatic fitting procedure and derive astrophysical quantities and their related errors. On the other hand, using simple geometrical models does not give sufficient insights into the physics of the object. We developed a numerical tool optimised for mid-infrared (mid-IR) interferometry, the Fast Ray-tracing Algorithm for Circumstellar Structures (FRACS).Thanks to the short computing time required by FRACS, best-fit parameters and uncertainties for several physical quantities were obtained, such as inner dust radius, relative flux contribution of the central source and of the dusty CSE, dust temperature profile, disc inclination.

Keywords. circumstellar matter, stars: emission-line, Be, techniques: interferometric

1. Introduction

B[e] supergiants are luminous, massive post-main sequence stars presenting non spherical wind, forbidden lines, and hot dust on a disc-like structure. We use mid-IR spectro-interferometric observations from VLTI/MIDI to resolve and study the CSE of the Galactic B[e] supergiant CPD-57°2874 (Domiciano de Souza et al. 2011). For a physical interpretation of the observables (visibilities and spectrum) we used our ray-tracing radiative transfer technique (FRACS). FRACS is based on the ray-tracing technique, without scattering, supplemented with the use of quadtree meshes and the full symmetries of the axisymmetrical problem to signicantly decrease the computing time necessary to obtain e.g.monochromatic images and visibilities.

2. Parametrized Model

FRACS is fully described in Niccolini *et al.* (2011). We assume the specific intensity from the central regions of the star to be a power-law : $I^{\rm s}_{\lambda} = I^{\rm s}_{\lambda_0}\,\left(\frac{\lambda_0}{\lambda}\right)^{\alpha}$ A radius $R_{\rm s}$=54 $R_{\rm sun}$ was adopted for the central region as a scaling factor. The number density of dust grains is given by: $n(r,\theta) = n_{\rm in}\,\left(\frac{R_{\rm in}}{r}\right)^2\,\left(\frac{1+A_2}{1+A_1}\right)\,\frac{1+A_1\,(\sin\theta)^m}{1+A_2\,(\sin\theta)^m}$ where (r,θ) are the radial coordinate and co-latitude, and $n_{\rm in}$ is the dust grain number density at $\theta = 90°$ and at $r = R_{\rm in}$, which is the inner dust radius where dust starts to survive. A_1 controls the ratio between the equatorial and polar mass loss rates. A_2 indicates how much faster is the polar wind compared to the slow equatorial wind. Parameter m controls how fast the mass loss drops from the equator to the pole. The dust grain opacity was calculated in the Mie theory for silicate dust and for a dust size distribution following a power-law $\propto a^{-3.5}$, where a is the dust grain radius. The temperature structure of the dusty region is given by: $T(r) = T_{\rm in}\,\left(\frac{R_{\rm in}}{r}\right)^{\gamma}$ where $T_{\rm in}$ is the dust temperature at the disc inner radius

$R_{\rm in}$. The inclination of the disc plane towards the observer is i, and the position angle (from North to East) of the maximum elongation of the sky-projected disc is $\rm PA_d$. Thus, the 10 free parameters of the model are: $I^{\rm s}_{\lambda_0}$, α, $T_{\rm in}$, γ, $R_{\rm in}$, i, $\rm PA_d$, A_2, $n_{\rm in}$, and m.

3. FRACS philosophy

The radiative transfer equation (RTE hereafter) is integrated along a set of rays making use of the symmetries of the problem. We seek to produce intensity maps within seconds and we want our numerical method to deal with a large range of density and temperature structures. Regarding the above mentioned constraints, the numerical integration of RTE is more efficiently computed using a mesh based on a tree data structure (quadtrees/octrees). The mesh also distribute the integration points along the rays according to the variations of the medium emissivity. From a computed intensity map it is then possible to derive flux and a set of visibilities using the observationnal bases. A fit of the observed data is then possible by means of a χ^2 minimization algorithm.

4. Experimental DATA

The interferometric observations of CPD-57 2874 were performed with MIDI, the mid-infrared 2-telescope beam-combiner instrument of ESOs VLTI. All four 8.2 m unit telescopes (UTs) were used. The N-band spectrum as well as spectrally dispersed fringes have been recorded between $\lambda \simeq 7.5\mu$m and $\lambda \simeq 13.5\mu$m with a spectral resolution of R $\simeq$ 30 using a prism. In total, $n_B = 10$ data sets have been obtained with projected baselines ranging from 40 m to 130 m, and baseline position angles between $\simeq 8°$ and $\simeq 105°$ (from North to East). VLTI/MIDI also provides spectral uxes of CPD-57°2874 in the N band.

5. Results

We give the best-fit model (visibilities and fluxes) parameters and uncertainties derived from a χ^2 minimization (minimum reduced $\chi^2 = 0.54$). The uncertainties were estimated from the $\chi^2_{\rm r}$ maps. Values are computed for an estimated distance (from FEROS spectroscopic observations) of 1.7 kpc: $I^{\rm s}_{\lambda_0}$ $(10^5\,{\rm W\,m^{-2}}\ \mu{\rm m^{-1}\,str^{-1}}) = 2.2\ ^{+0.7}_{-0.7}$, $\alpha = 2.4\ ^{+1.3}_{-1.2}$, $T_{\rm in}(K) = 1500$, $R_{\rm in}(AU) = 12.7^{+3.6}_{-2.9}$, i $(°) = 61.3\ ^{+10.8}_{-18.2}$, $\rm PA_d$ $(°) = 140.3^{+12.3}_{-14.0}$, $A_2 = -0.98$, $n_{\rm in}$ $({\rm m^{-3}})$= 0.30 ,$m = 332$

6. Conclusion

FRACS is a method to fit inteferometric data, fast enough to make an automatic search of glogal minimum in a multi dimensional physical parameter space. It is just between pure geometrical methods which are very fast but avoid to reach physical parameters and Monte Carlo methods which give a deep physical caracterization but which are extremely computational time consumers.

References

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