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Parsamian 21: a FUor surrounded by an edge-on disc

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Abstract
FU Orionis objects (FUors) are young stars that have recently undergone major outbursts, probably powered by enhanced accretion from the circumstellar disc to the star. Parsamian 21 is a unique FUor, as it is thought to be surrounded by an edge-on circumstellar disc, making it an ideal case for studying the geometry and structure of the circumstellar material. In this paper we report on new adaptive optics assisted near-infrared direct and polarimetric measurements of Parsamian 21 taken with the NaCO instrument on the VLT. With the help of these observations, we search for companions and study the innermost part of the circumstellar disc with an unprecedented resolution and contrast.
Keywords: *stars: circumstellar matter, stars: individual: Parsamian 21*

1 Introduction

Parsamian 21 is a young star situated close to the Galactic plane, in the constellation Aquila. The star (also known as HBC 687) is located at the apex of a bright cometary nebula, which was first mentioned in the catalogue of Parsamian (1965). The estimated distance of the object is 400 pc (Neckel & Staude, 1984; Hillenbrand et al., 1992; Pezzuto et al., 1997). Taking into account that its radial velocity is $+27 \pm 15\,\mathrm{km\,s^{-1}}$ (Staude & Neckel, 1992), Parsamian 21 appears

to be related to "Cloud A", a molecular cloud in the Galactic plane (Henning et al., 1998).

Although no eruption has been observed, because of its spectral characteristics Parsamian 21 is thought to be an FU Orionis-type star (FUor) surrounded by a circumstellar disc (Staude & Neckel, 1992). Polarimetric observations by Draper et al. (1985) and Hajjar et al. (1997) also suggest that the star is surrounded by a flat, disc-like structure. Bastien & Ménard (1990) interpreted the polarization maps of Parsamian 21 in terms of multiple scattering in flattened, optically thick structures and derived an inclination angle of 80-85° and a size of 12 000 AU × 3200 AU. From 1.3 mm measurements Sandell & Weintraub (2001) derived a mass of 0.3 $M_\odot$ for the circumstellar material. Staude & Neckel (1992) identified bipolar Herbig-Haro outflows along the polar axis of the nebula.

In this paper we report on new near-infrared direct and polarimetric measurements of Parsamian 21 taken with the NaCO instrument on the VLT. Due to the combination of adaptive optics and the new technique of differential polarimetric imaging, these measurements allow us to investigate the size and geometry of the circumstellar material at small spatial scales ($\sim$30 AU), as well as to search for close low-mass companions that are often suggested to be the outburst triggers for FUors.

2 Observations and data reduction

Table 1 lists the observations of Parsamian 21 used in this paper. We have obtained near-infrared imaging and polarimetric observations using the NaCO instrument on the UT4 of ESO's Very Large Telescope at Cerro Paranal, Chile, on 18 June 2004. NaCO consist of the NAOS adaptive optics system and the CONICA near-infrared camera. Direct imaging was obtained through H (λ_c = 1.66 μm), K_S (λ_c = 2.18 μm) and L′ (λ_c = 3.8 μm) filters; Tab. 1 shows the pixel scales and exposure times used for each filter.

Polarimetric observations were obtained using the polarimetric differential imaging technique (DPI, Kuhn et al., 2001; Apai et al., 2004). The basic idea of this method is to take the difference of two orthogonally polarized, simultaneously acquired images of the same object in order to remove all non-polarized light. As the non-polarized light mainly comes from the central star, after subtraction only the polarized light, such as the scattered light from the circumstellar material remains. We obtained polarimetric images with NaCO through the H filter, using a Wollaston prism with a 2″ Wollaston mask. Parsamian 21 was observed at four different rotator angles of 0°, 45°, 90° and 135°. At each

Table 1: *Log of VLT/NaCO and HST/WFPC2 observations of Parsamian 21*

Instrum.	Filter	Mode	Pixel scale mas/pixel	Exp. Time	Sky mag/□″	Limiting mag
NaCO	H	Imag.	13	8×30 s	13.6	22.8
NaCO	K_S	Imag.	13	8×20 s	12.4	21.6
NaCO	L′	Imag.	27	48×0.2 s	2.7	15.2
NaCO	H	Pol.	27	72×10 s, 24×80 s		
WFPC2	F814W	Imag.	100	2×500 s		23.5

angle a 3-point dithering was applied.

In case of the VLT/NaCO images, data reduction was done with self-developed idl routines. Raw images were flat fielded using lamp-flats in case of H and Ks filters and sky-flats in case of L′ filter. Sky frames were calculated by taking the median of all images taken with the same filter, then images were sky-subtracted. Since a 4-point dithering was applied, individual frames were shifted and co-added to obtain a final mosaic. This resulted in an image of 21.″4×21.″4 in case of H and Ks filters, and 43.″8×43.″8 in L′. VLT/NaCO polarimetric measurements were reduced using a previously developed software which is described in detail in Apai et al. (2004).

In addition to the VLT/NaCO observations, there are archival HST/WFPC2 images on Parsamian 21. These images were obtained on 30 July 2001, with the broadband F814W filter ($\lambda_{\rm pivot} = 0.801\,\mu$m). High-Level Science Products based on these images can be downloaded from the HST Archive.

3 Results

3.1 Large-scale structure of the nebula

Figure 1 displays the central part of the VLT/NaCO and the HST/WFPC2 images. The appearance of the nebula can be understood in the following way: the star drives a bipolar outflow (Staude & Neckel, 1992), which had excavated a conical cavity in the dense circumstellar material. The star illuminates this cavity and the light is scattered towards us mainly from the walls of the cavity. Since the scattering is more efficient at shorter wavelengths, the nebula seems

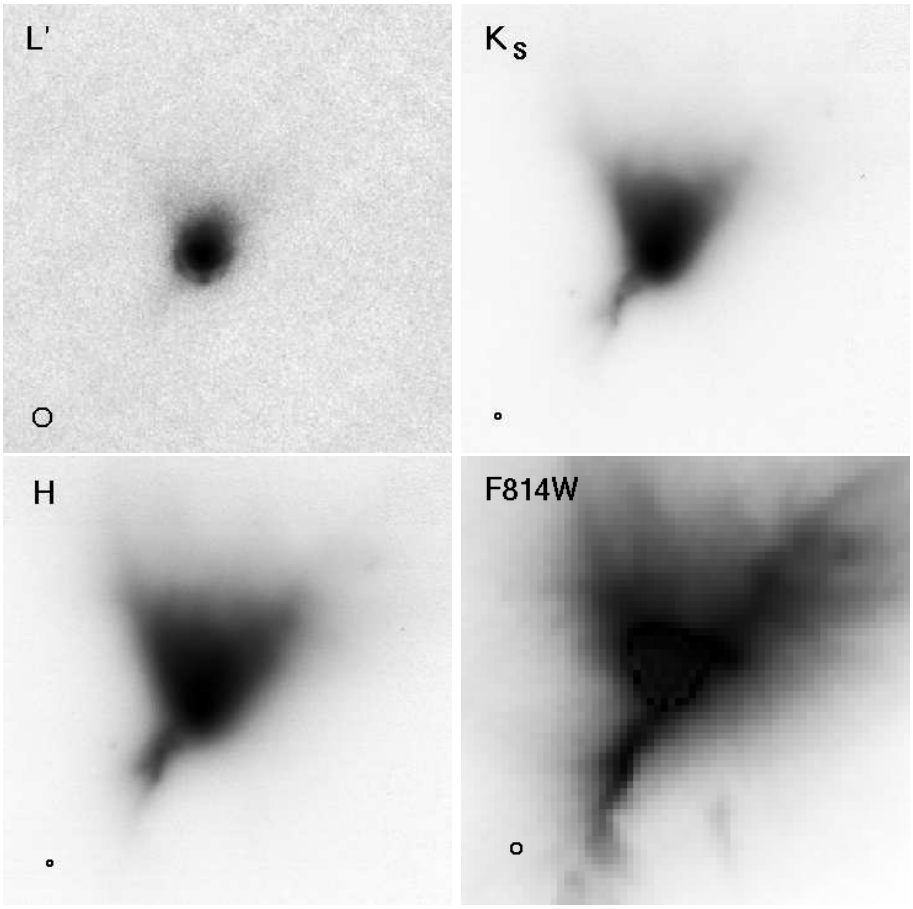

Figure 1: *VLT/NaCO (with filters and L', K_S and H) and HST/WFPC2 (with filter F814W) images of Parsamian 21. Circles at the left bottom corners indicate the FWHM at the centre of the corresponding image. The displayed area is $6\farcs5 \times 6\farcs5$.*

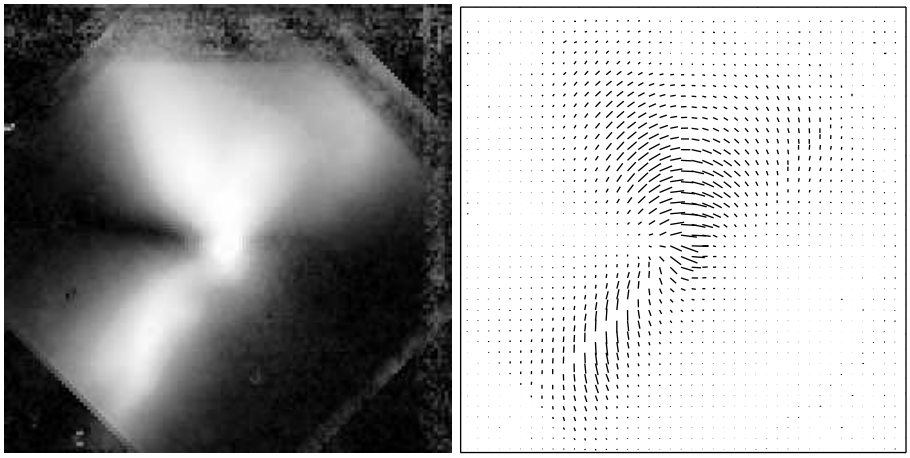

Figure 2: *Polarized intensity (left), and polarization map (vectors are displayed in arbitrary units) of Parsamian 21 (right). The displayed area is approximately* $3'' \times 3''$.

to be more extended at these wavelengths (see Fig. 1). It is worth to notice that the source is extended even in the L′-band. In the K_S and H bands, mainly the northern lobe of the reflection nebula can be seen, but at 0.814 μm the southern part is also visible, suggesting that it is rather a bipolar than a cometary nebula as stated previously.

3.2 Small-scale structure of the nebula

The spectral energy distribution (SED) of FUors are usually flat, which cannot be explained by a simple flat accretion disc model. Instead a flared disc and/or an extended envelope is necessary to reproduce the SED (Hartmann & Kenyon, 1996; Turner et al., 1997). This assumption, however, has never been observationally proven.

During the VLT/NaCO observations, we obtained H-band images of the scattering circumstellar material around Parsamian 21. Due to the DPI technique, unprecedented contrast and resolution could be achieved, enabling us to probe the disc structure closer to the star than any previous observation.

Fig. 2 displays the polarized intensity as well as the polarization map of the surroundings of Parsamian 21. On both panels of Fig. 2 a horizontal weakly polarized band can be seen across the star. This can be interpreted as the

signature of an edge-on disc, since the reduced polarization is due to multiple scattering in the optically thick disc (Draper et al., 1985). On the polarized intensity image, this band clearly has a flaring shape indicating a flared disc geometry. The disc can be followed as close as 0.″15 (60 AU) to the star.

3.3 Possible companions

Close companions are often suggested as possible outburst triggers for FUors (eg. Hartmann & Kenyon, 1996). However, to date only a couple of FUors are proved binaries. The majority of FUors have not been studied with sufficiently high resolution and contrast to verify if all of them have companions.

We have searched for possible companions in all four direct images. In order to establish a detection limit for source detection, we measured the sky brightness on the VLT/NaCO images (before sky-subtraction), and estimated a limiting magnitude for each filter. The resulting values can be seen in the last two columns of Tab. 1. In case of the HST/WFPC2 image, the larger ($75'' \times 75''$) field of view made it possible to estimate a limiting magnitude using star counts. Due to the bright reflection nebula, the detection limit is somewhat less sensitive close to the star.

The two closest objects we found are the following: one star to the east, at a distance of 1.″4 (560 AU at 400 pc), which has an $H - K = 1.2 \pm 0.2$ mag; and another one to the northwest, at a distance of 3.″3 (1320 AU at 400 pc), which has an $H - K = 1.1 \pm 0.1$ mag. Neither of these stars are visible at 3.8 or 0.801 μm. As they are very red, they can equally be heavily reddened field stars, or stars with infrared excess (indicating that they might be associated with Parsamian 21). Further multifilter observations may help to clarify the nature of these objects.

4 Summary

In this paper we report on new adaptive optics assisted near-infrared measurements of Parsamian 21, an FU Orionis-type young star in Aquila. We present VLT/NaCO L′, K_S and H images, as well as archival HST/WFPC2 F814W images, and we discuss the morphology of the reflection nebula around the star. We have also obtained H-band polarimetric images of Parsamian 21 using the differential polarimetric imaging technique. Polarization measurements indicate that the circumstellar disc around the star is seen edge-on, shows a flaring shape, and can be discerned even as close as 60 AU to the star. The high resolution

observations presented here will allow for the first time the characterisation of the geometry of an FU Orionis-type disc on a $\sim$ 30 AU spatial scale providing a direct observational test to the accretion disc models.

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