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The environment of the very red object Orion n

A possible low mass companion?

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Abstract. We have imaged at high angular resolution the close environement of the very red source Orion n with NACO at the VLT UT4. We report the detection of a faint point like object 0.6″ away from this source. Assuming a distance of 450^{+50}_{-50} pc and an age of 1 Myr, the photometry of this candidate companion is consistent with an object of mass 70−150 $M_{\rm J}$ assuming a visible extinction of $A_{\rm V}$ = 3–17. The relationship between this object and Orion n is discussed hereafter.

Key words. stars: formation – stars: low-mass, brown dwarfs – stars: pre-main sequence

1. Introduction

As one of the closest dense star-forming regions, the Orion region is studied extensively. In particular, many efforts have been devoted to derive the IMF, see, e.g., Mc Caughrean et al. (1994); Luhman et al. (2000); Hillenbrand & Carpenter (2000) and references therein. Improved instruments have recently allowed study of the low mass end of the IMF, down to the brown dwarf (BD) regime. In the near IR survey of the Trapezium cluster, Lucas et al. (2000) found that 30% of the 500 sources observed are BDs, including objects with masses down to the planetary regime. These so-called free floating planets have been questioned by Hillenbrand & Carpenter (2000). However, recent spectroscopic observations in the σ Orionis cluster (Zapatero et al. 2002) report the detection of a methane dwarf with a mass of 3^{+5}_{-1} $M_{\rm J}$ (for an age ranging between 1 and 8 Myr), which tends towards proving the existence of such objects. The existence of isolated planetary mass objects raises the question of their formation mechanism, as up to now the standard point of view has been that planets form within stellar environments.

To further investigate the process(es) of BD and planet formation, both isolated and bound objects must be found and studied. So far, only a few BDs bound to stars have been discovered at small separations (≤4 AU) with RV surveys ("brown dwarf desert" phenomenon; Halbwachs et al. 2000). At larger separations (typ. 1000 AU), more BDs have been found using imaging techniques (Gizis et al. 2001). However, data are still missing to derive good statistics over a wide range of separations and contrasts.

In the course of the Orion observations with NACO, we recorded near IR images of the region South East of the star BN. The use of an IR wavefront sensor on the VLT AO system allows the acquisition of data of unprecedented quality. In the observed field originally dedicated to astrometric calibrations, a faint companion candidate to the very red source Orion n was discovered. The observations are described in Sect. 2. In Sects. 3 and 4, the properties of this new object are derived and discussed.

2. Observations

2.1. Observing log

Observations of the surroundings of Orion were performed in November 2002 with the newly installed NACO instrument at VLT-UT4. The NAOS adaptive optics system (Rousset et al. 2003; Lagrange et al. 2003) provides diffraction limited images in the near infrared (IR) and feeds the observing camera CONICA (Lenzen et al. 1998), equipped with an Alladin detector, covering the 1−5 μm range. Noticeably, NACO is equipped with an IR wavefront sensor (WFS), allowing servoing on very red objects such as BN. The light from the telescope was split between NAOS and CONICA with a dichroic that transmits 20% of the IR flux towards NAOS and its IR WFS and

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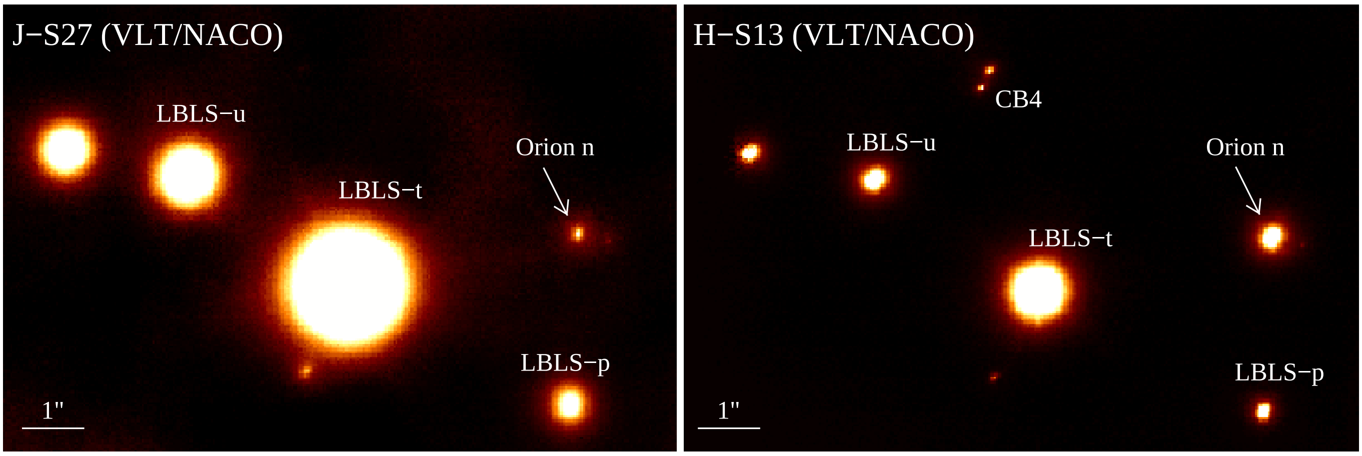

Fig. 1. VLT/NACO images of the observed field in Orion in *J* band (*left*) and in *H* band (*right*). The identification of the objects in the field is superimposed (see Table 2). The CB4 source refers to the binary identified by (Stolovy et al. 1998). On both images, north is up and east is left. BN located 10″ north and 4″ west was used for AO servoing.

Table 1. Observing set-up.

Filter	λ (μm)	$\Delta\lambda$ (μm)	DIT (s)	NDIT	Cam.	WFS/Dich.
J	1.27	0.25	10	40	S27	IR/N20C80
H	1.66	0.33	2	400	S13	IR/N20C80

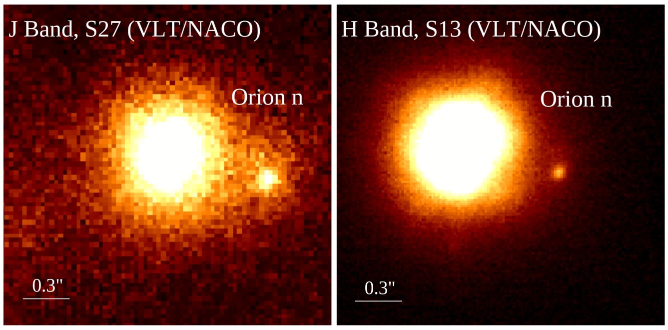

Fig. 2. Zoom on the close environment of Orion n in *J* band (*left* and in *H* band (*right*). A faint companion is detected 0.6″ away. North is up, east is left.

the rest towards CONICA. Images of Orion n were obtained at *J* and *H* bands. Table 1 summarizes the observations. The sky was clear but not perfectly photometric. The seeing conditions were not particularly good, ~1.4″ during observations in *J* band and ~1.1″ in *H* band. The corresponding strehl and *FWHM* performed by the AO system were ~10% and ~0.16″ in *J* and ~20% and ~0.08″ in *H*. BN (K = 6.4; Simon et al. 1999), located at about 10″ north and 4″ west from Orion n was used as the AO reference star. The cameras used were the S27 in *J*, which provides a ~27.0 mas/pixel sampling, and S13 in *H* with a pixel scale estimated at 13.24 ± 0.05 mas/pixel using the astrometric field of Orion n in Fig. 1 (Luhman et al. 2000; Mc Caughrean et al. 1994). The orientation was found to lie to the west of the vertical by $-0.05 \pm 0.1°$. It should be stated that the *J* data are under-sampled.

2.2. Data reduction

To allow a proper background subtraction and the minimisation of instrumental effects, each observation consisted of several images offsetted by a few arcseconds combined with a jitter of a few milliarcseconds. The individual raw data images were flat fielded using a gain map normalized to unity. This gain map was derived from sky images taken during day time. An artificial sky+background image was generated by taking a median across the jittered images and flat fielding. The individual flat-fielded images were then corrected from the sky+background image and stacked together using a cross correlation algorithm.

The reduction was performed using the ECLIPSE package developped by ESO and IDL.

2.3. Photometric measurements

Figures 1 and 2 show the resulting images in *J* and *H* bands. Table 2 gives the identification of the sources together with published photometry. The names of the target refer to Lonsdale et al. (1982). Orion n, at the right of the image, is a very red source (F(110 nm) − F(160 nm) = 4.25; Luhman et al. 2000), first detected by Lonsdale et al. (1982) and identified as a reddened star by Wynn-William et al. (1984). Our new high resolution images show the presence of a faint companion at 0.609″ ± 0.005 from Orion n, with a PA of 256.1° ± 0.5. The companion clearly appears to be bluer than Orion n. Signal extraction was performed by a deconvolution algorithm using a PSF in the field (Veran 1997) to extract flux ratios and relative positions. For PSFs, we tried both LBLS-u and LBLS-p, and the resulting contrasts matched to within 0.1 magnitude.

Conversion to fluxes was performed using LBLS-p (the closest object to Orion n) as a photometric reference and using as a first step NICMOS data in F110W and F160W Luhman et al. (2000). To correct for the differences between NICMOS

Table 2. Stars used to perform photometry. L and (1) refers to Luhman et al. (2000); S to Simon et al. (1999); H and (2) to Hillenbrand & Carpenter (2000).

Name	RA(2000)	Delta(2000)	F110 (1)	F160 (1)	*H* (2)	Comments
LBLS-u	05:35:14.86	−05:22:31.8	13.06	11.73	11.58	S53; L75; H453
LBLS-p	05:35:14.36	−05:22:36.3	15.11	12.91	12.94	S34; L52; H439
Orion n, LBLS-n	05:35:14.35	−05:22:32.9	16.23	11.98	11.47	S32; L50; H448

Table 3. Resulting magnitudes of the observed sources.

Object	*J* (mag)	*H* (mag)	Separation (″)	PA (°)
LBLS-u	12.85	11.63		
LBLS-p	14.45	12.72		
Orion n A	15.77	11.42		
Orion n B	17.57	15.88	0.609 ± 0.005	256.1 ± 0.5

and NACO filters, we used the following laws (Brandner et al. 2001):

$$m_{110} - J = (0.263 \pm 0.020)(m_{110} - m_{160}) + (0.083 \pm 0.022)$$

$$m_{160} - H = (0.072 \pm 0.041)(m_{110} - m_{160}) + (0.032 \pm 0.045).$$

Table 3 displays the derived magnitudes after correction. The correction effect is much stronger in J band than in H. For our objects, the correction may be as high as 0.6 mag for the J band and but is less than 0.2 mag in H band. If we compare the derived H magnitudes to those provided by Hillenbrand & Carpenter (2000), the data also agree within 0.2 mag. Finally, we estimate conservatively that given the various steps of photometric determinations, errors of 0.3 magnitude for the H band and 0.6 for J band must be adopted.

3. Orion n B properties

Given the strong absorbing molecular cloud behind this region, we can reasonably assume that the Orion n companion is not a background object (Goldsmith et al. 1997). According to Besançon galactic models, the probability of the object to be in the background is less than 0.1%. The $(J - H \geq 1)$ color also excludes the possibility that the object is a foreground Main Sequence or young star. We therefore assume that the object is located in Orion, i.e. at a distance ≃450 pc. To get the de-reddened magnitudes of the objects, we use the extinction law of Rieke et al. (1985) who assume $A_J = 0.282\ A_V$ and $A_H = 0.175\ A_V$, hence $E(J - H) = 0.107\ A_V$.

The visual extinction towards this region is not known precisely; it is extremely variable and can reach very high values (Luhman et al. 2000; Gezari et al. 1998). The latter find respective values of 17 and 58 towards the very red sources BN and IRC2 from 10.8 μm silicate absorption. From the same data, one can estimate the A_V towards Orion n to be ranging between 30 and 35. However, the angular resolution (≃0.8″) of

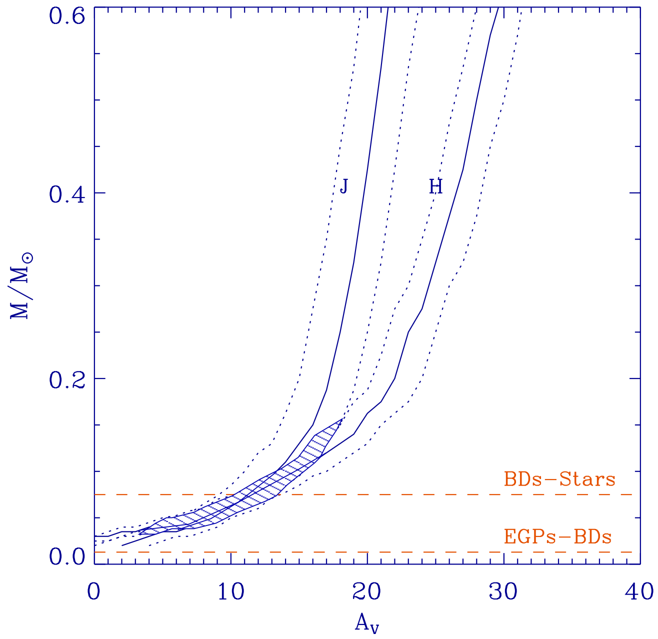

Fig. 3. Theoretical model predictions of Baraffe et al. (1998) for an age of 1 Myr were used to derive the masses yielding the observed J and H magnitudes as a function of the extinction A_V. The hatched region shows the parameters space compatible with both the model and the measurements (including errors) of the J and H photometry.

those spectroscopic measurements is relatively low. As a result, different values of extinctions in the direction of Orion n B must be considered. Figure 3 gives the ranges of mass derived from the observed J and H magnitudes and based on Baraffe et al. (1998) models as a function of visual extinction, between 0 and 40. The hatched region shows the parameters space compatible with both the model and the measurements (including errors) of the J and H photometry. The corresponding companion mass lies between 70 and 150 M_J for an extinction A_V between 3 and 17. We note that larger values for the extinction, especially as large as the one expected towards Orion n have to be excluded.

4. Connection to Orion n

Orion n is a very peculiar object, with a strong IR flux. Its position coincides (to within 0.1″) with that of a peculiar double radio source (PA ≃ 190°; Menten et al. 1995) as well as CO emission in the 2 μm region (Luhman et al. 2000). The H_2O maser emission is similar to those found in high mass star forming regions. Both authors agree that this puzzling object might drive a mass outflow and could take a role in the energetic phenomena in this region. Gezari et al. (1998) also quote the region around Orion n as one of the possible sources of the strong luminosity of the BN region, even though mid IR data do not indicate that it is “exceptionnally luminous” in the IR. The PA and separation of the companion do not match any of the double peak observed at 8.4 GHz (Menten et al. 1995) nor do they match the center of expansion of the high velocity water masers observed by Genzel et al. (1981). Hence there is no indication for any link between this new object and the radio sources.

If we proceed for Orion n as in Sect. 3, the J band values are compatible with Orion n being a high mass star and having a large extinction (≥15). This results is compatible with that of Gezari et al. (1998). Considering both J and H magnitudes, no single extinction is compatible, assuming the intrinsic SED of a high mass star. This is not surprising regarding the real source’s rising spectrum at near IR (Luhman et al. 2000). As previously established, Orion n cannot be modeled as a simple high mass star and an additional source of IR luminosity (circumstellar dust?) must be added.

The present observations have not revealed the presence of bright near IR sources close to Orion n down to a separation of ≃20 AU. Until higher spatial resolution data are available, Orion n must be viewed as a single high mass star, with an extra source of IR luminosity.

If the companion is located at the distance of Orion n, the relatively lower extinction observed on its line of sight might signify that the extinction towards Orion n is localised. This may be explained by the presence of a dense circumstellar disk surronding Orion n. Notably, similar conclusions were reached from the modeling of the very red source BN (Dougados et al. 1993).

5. Concluding remarks

We have detected a faint companion ∼0.6′′ away from the very red and peculiar source Orion n using NACO. The photometric data are compatible with a 70−150 $M_{\rm J}$ object, with an extinction $A_{\rm V}$ of 3−17. More precise photometric data should help to better constrain the properties of this object. The present data are not sufficient to verify whether the object is physically bound to Orion n or not. If bound, this object should correspond to a low mass star or BD located 270 AUs away from a high mass star. If not, it is just another isolated low mass object as many dozens of others known today in the sight line of Orion.

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