

# Search and characterization of T-type planetary mass candidates in the $\sigma$ Orionis cluster

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**Abstract.** We present new photometric and astrometric data available for S Ori 70 and 73, the two T-type planetary-mass member candidates in the  $\sigma$  Orionis cluster ( $\sim 3 \pm 2$  Myr,  $d \sim 360$  pc). S Ori 70 ( $J \sim 19.9$  mag) has a spectral type of  $T5.5 \pm 1.0$  measured from published near-infrared spectra, while no spectroscopic data are available for S Ori 73 ( $J \sim 21$  mag). We estimate the spectral type of S Ori 73 by using  $J$ ,  $H$ , and  $CH_{4\text{off}}$  ( $\lambda_c = 1.575 \mu\text{m}$ ,  $\Delta\lambda = 0.112 \mu\text{m}$ ) photometry and comparing the  $H-CH_{4\text{off}}$  index of S Ori 73 with the colors of field stars and brown dwarfs of spectral types in the range F to late T. The locations of S Ori 70 and 73 in the  $J-H$  vs  $H-CH_{4\text{off}}$  color-color diagram are consistent with spectral types  $T8 \pm 1$  and  $T4 \pm 1$ , respectively. Proper motion measurements of the two sources are larger than the motion of the central  $\sigma$  Ori star, making their cluster membership somehow uncertain.

**Keywords.** infrared: stars, brown dwarfs, planetary systems, open clusters and associations: individual ( $\sigma$  Orionis)

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## 1. Motivation

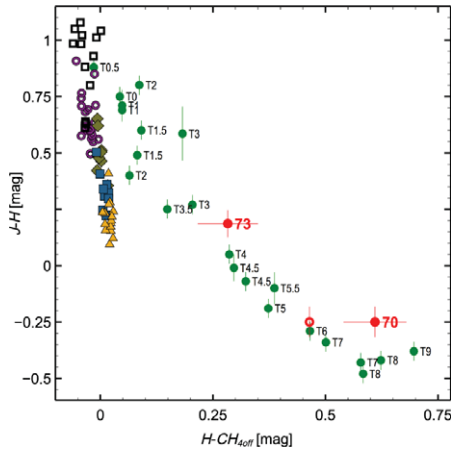
Knowledge of the low-mass end of the initial mass function (IMF) is crucial to understand the formation mechanisms giving rise to substellar objects. In the  $\sigma$  Orionis cluster ( $\sim 3 \pm 2$  Myr,  $d \sim 360$  pc), there are only two T-type planetary mass candidates: S Ori 70 ( $J \sim 19.9$  mag), which has a spectral type of  $T5.5 \pm 1.0$  measured from near-infrared low-resolution spectra (Zapatero Osorio *et al.* 2002), and S Ori 73 ( $J \sim 21$  mag), which has no spectra available so far (Bihain *et al.* 2009). We present new photometric and astrometric data for S Ori 70 and 73 to study the methane nature of the latter and to assess their cluster membership via proper motion analysis.

## 2. Observational data

Imaging data are summarized in Table 1. HAWK-I and OSIRIS observations were intended to image S Ori 70 and 73, covering areas of  $\sim 120$  and  $\sim 220$  arcmin<sup>2</sup>, respectively. VISTA data covers the entire region of the  $\sigma$  Orionis cluster. HAWK-I and OSIRIS images were reduced following standard procedures; aperture and point-spread-function instrumental photometry were obtained and calibrated into observed magnitudes using the UKIDSS DR7 database for the near-infrared wavelengths (Lawrence *et al.* 2007) and photometric standard stars from Smith *et al.* (2002) for the optical. The VISTA (science verification) data were reduced by the Cambridge Astronomy Survey Unit (CASU) and only aperture photometry of  $2''$  in diameter was performed.

**Table 1.** Log of optical and near infrared observations.

Telescope	Instrument	Filter	Date	Exp.time [s]	Seeing [arcsec]	Completeness [mag]	Limiting [mag]
GTC	OSIRIS	i'	2009 Oct 15	3146	0.80	25.0	26.0
			2010 Jan 11	9360	1.10		
	OSIRIS	2009 Oct 13,14,15	9438	0.70			
		2009 Nov 19	3198	1.10			
VISTA	VIRCAM	Z	2009 Oct 20,21	6084	0.80	22.6	23.2
		Y	2009 Oct 20	1008	0.90	21.0	21.4
		J	2009 Oct 19,20	2112	0.90	21.4	21.8
		H	2009 Oct 20	288	0.90	19.6	20.0
		K <sub>s</sub>	2009 Oct 20	288	0.70	18.6	19.1
UT4	HAWK-I	J	2008 Sep 19	160	0.64	22.4	23.4
		H	2008 Dec 8	8410	0.34	22.5	23.4
		C H <sub>4off</sub>	2009 Feb 24	13500	0.52	22.5	23.1
UT4	HAWK-I	C H <sub>4off</sub>	2009 Mar 28	13500			
		J	2008 Oct 27	160	0.75	21.8	22.8
		H	2009 Mar 28	8410	0.52	20.5	21.8
		C H <sub>4off</sub>	2009 Mar 16	13500	0.57	21.3	22.4



**Figure 1.** Color-color diagram (including the methane filter) for T (green), L (black), M (magenta), K (olive green), G (blue), and F (yellow) type field sources. The photometry of S Ori 70 and 73 is plotted as red filled circles. The red open circle corresponds to the synthetic methane color of S Ori 70 derived from its spectrum (Zapatero Osorio *et al.* 2002).

### 3. Results

We estimated the spectral types of S Ori 73 and S Ori 70 by comparing their  $J-H$  and  $H-CH_{4\text{off}}$  colors with those of field dwarfs of known classification. We derived  $T4 \pm 1.0$  for S Ori 73, and  $T8 \pm 1.0$  for S Ori 70. The “methane” nature of S Ori 73 is thus confirmed. The typing of S Ori 70 is slightly cooler, though still consistent within error bars, than the value previously reported in the literature ( $T5.5 \pm 1$ ). From our astrometric analysis we derived the following proper motions:  $(\mu_{\alpha} \cos \delta, \mu_{\delta}) = (30.8 \pm 11.0, 18.2 \pm 8.0)$  mas  $\text{yr}^{-1}$  for S Ori 70, and  $(\mu_{\alpha} \cos \delta, \mu_{\delta}) = (43.2 \pm 10.0, -3.7 \pm 7.0)$  mas  $\text{yr}^{-1}$  for S Ori 73. These values are larger than the Hipparcos proper motion of the cluster central star ( $\sigma$  Ori) by at least  $2\text{-}\sigma$ , making the cluster membership of the two T dwarfs somehow uncertain.

We also carried out a photometric search for additional T-type candidates in the cluster using the HAWK-I ( $\sim 120$  arcmin<sup>2</sup> and completeness magnitude of  $J \sim 21.8$  mag), VISTA and OSIRIS data. The selection photometric criteria ( $i'-J \geq 5$ ,  $Z-J \geq 2.5$ ,  $J-H \leq 0.5$  and  $H-CH_{4\text{off}} \geq 0.15$  mag) did not yield any additional candidate with the colors expected for  $\geq T3$  dwarfs.

### References

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