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# Deep imaging survey of the environment of $\alpha$ Centauri (Research Note)

## II. CCD imaging with the NTT-SUSI2 camera<sup>★</sup>

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### ABSTRACT

*Context.* Thanks to its proximity,  $\alpha$  Centauri is an outstanding target for an imaging search for extrasolar planets.

*Aims.* We searched for faint comoving companions to  $\alpha$  Cen located at angular distances of a few tens of arcseconds, up to 2–3 arcmin.

*Methods.* We obtained CCD images from the NTT-SUSI2 instrument in the Bessel *V*, *R*, *I*, and *Z* bands, and archive data from 2MASS.

*Results.* We present a catalogue of the detected objects inside a 5.5 arcmin box around this star. A total of 4313 sources down to  $m_V \approx 24$  and  $m_I \approx 22$  were detected in the SUSI2 images. The infrared photometry of part of these sources has been extracted from the 2MASS images.

*Conclusions.* No comoving companion to  $\alpha$  Centauri were detected between 100 and 300 AU, down to a maximum mass of  $\approx 15$  times Jupiter. We also mostly exclude the presence of a companion more massive than  $30 M_J$  between 50 and 100 AU.

**Key words.** stars: individual:  $\alpha$  Centauri – planetary systems – stars: imaging – solar neighbourhood – astronomical data bases: miscellaneous

## 1. Introduction

Our closest stellar neighbour, the  $\alpha$  Cen visual triple star ( $d = 1.34$  pc), is an extremely attractive target for extrasolar planet detection. The main components  $\alpha$  Cen A (HD 128620) and B (HD 128621) are G2V and K1V solar-like stars, while the third member is the red dwarf Proxima (M 5.5V). In all imaging planet searches, the main difficulty is to retrieve the planetary signal in the bright diffuse halo from the star. As discussed in Paper I (Kervella et al. 2006), there are indications that the gravitational mass of  $\alpha$  Cen B could be higher than its modeled mass. For these reasons, we engaged in a search for companions to  $\alpha$  Cen at two different angular scales: a few arcseconds, using adaptive optics (Paper I), and a few tens of arcseconds, using CCD imaging (present work). To our knowledge, this is the first wide-field search for companions to  $\alpha$  Cen.

## 2. Observations

Very close to the two stars, within a radius of about  $20''$ , adaptive optics imaging allows to reach the best sensitivity. At distances of more than  $20''$ , the diffused light is less of a problem, and atmosphere limited imaging is the most cost-effective solution. We thus observed  $\alpha$  Cen using ESO's 3.6 m NTT, equipped with the SUp erb Seeing Imager 2 (SUSI2). This instrument is based on a mosaic of two  $2k \times 4k$  thinned EEV CCDs ( $15 \mu\text{m}$  pixels). In order to avoid an heavy saturation of the detector, we

positioned the  $\alpha$  Cen pair aligned within the 8 arcsec gap between the two detectors. The Nasmyth adapter of the telescope was rotated to align the two stars with the direction of the gap. The pixel scale of SUSI2 is  $0.0805''/\text{pixel}$ , therefore providing an excellent sampling of the point spread function.

We obtained a series of exposures through four filters, Bessel *V*, *R*, *I*, and *Z*<sup>1</sup>, in order to be able to confirm potential companions based on their colors. The individual exposures times were short, typically 30 to 60 s, to limit the saturation of the detector to a small area around  $\alpha$  Cen. The journal of the SUSI2 observations is presented in Table 1. The total shutter open time obtained on  $\alpha$  Cen with SUSI2 in all bands reaches almost 4 h.

In order to obtain infrared photometry for part of the sources detected in the SUSI2 images, we retrieved from the IPAC archive<sup>2</sup> the FITS images from the 2MASS survey (Skrutskie et al. 2006) covering the field of view of our SUSI2 images. The selected images were all obtained in early 2000.

## 3. Data reduction

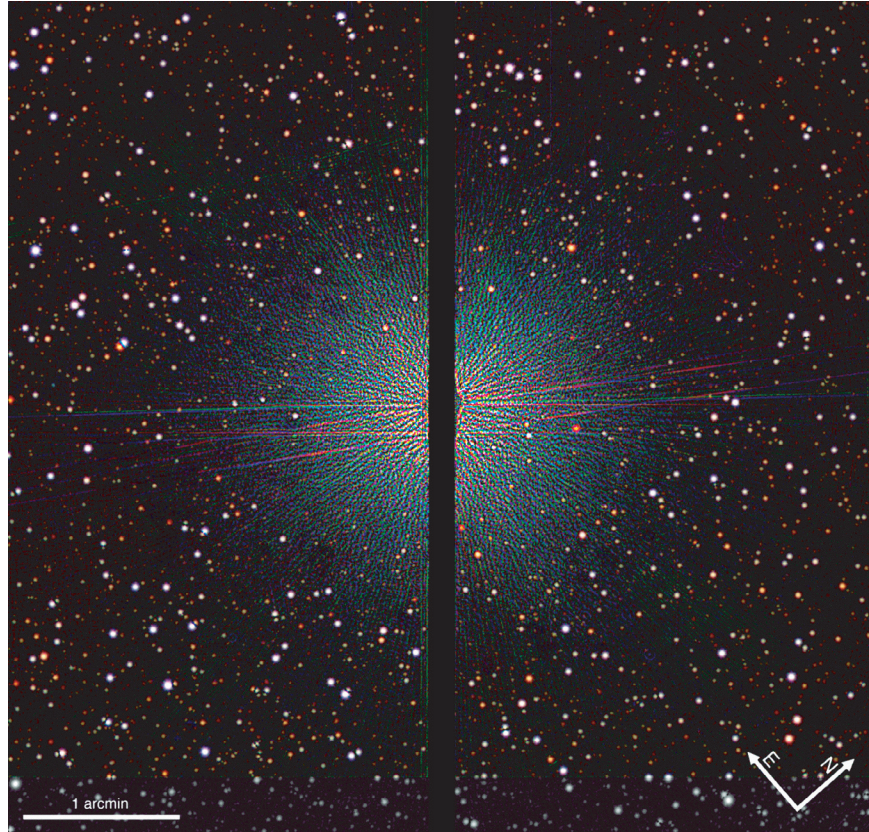
### 3.1. Raw data processing and astrometry

We applied the standard CCD image processing steps to our SUSI2 images, using IRAF: bias subtraction, flat-fielding, bad pixel masking. The 2MASS images are available fully calibrated from the IPAC archive. The resulting SUSI2 band image is

<sup>1</sup> The transmission curves of the SUSI2 filters are available from <http://www.ls.eso.org/lasilla/sciops/ntt/susi/docs/SUSIfilters.html>

<sup>2</sup> <http://irsa.ipac.caltech.edu/>

<sup>★</sup> The catalog is only available in electronic form at the CDS via anonymous ftp to <cdsarc.u-strasbg.fr> (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/464/373>



**Fig. 1.** Tricolor filtered image from the SUSI2 images of  $\alpha$  Cen (February–April 2004).

**Table 1.** Log of the SUSI2 observations of  $\alpha$  Cen. The indicated UT time corresponds to the middle of the exposures,  $\theta$  is the FWHM of the point spread function of the composite images, and AM is the airmass. The observations of 26 Feb. 2004 were excluded due to poor seeing.

Date	UT	Filter	Total exp. (s)	$\theta$ (")	AM
2004-02-25	6:40	R	1185	0.74	1.30
2004-02-26	7:48	V	555	2.67	1.20
2004-02-29	6:31	I	2010	0.81	1.29
2004-02-29	7:54	V	1305	0.84	1.19
2004-04-02	2:55	Z	2360	0.89	1.51
2004-04-02	4:21	V	1305	1.01	1.29
2004-04-02	5:49	I	2010	0.97	1.19
2006-04-11	8:29	I	1649	1.01	1.30
2006-08-17	1:22	I	1649	0.65	1.49

presented in Fig. 1, where the *VRI* images have been mapped to the blue, green and red colors. The lower  $\approx 10\%$  area of this image is shown in grey levels as only two colors are available. The astrometric calibration of our SUSI2 images has been obtained by matching the coordinates of the brightest sources with their counterparts in the 2MASS images. The astrometric accuracy of the 2MASS images is about  $0.1''$  (Skrutskie et al. 2006). Due to the presence of stronger diffused light in the visible, we estimate our astrometric uncertainty at  $0.2''$  over the SUSI2 field, therefore this astrometric calibration method is sufficient for our purpose.

### 3.2. Sources extraction

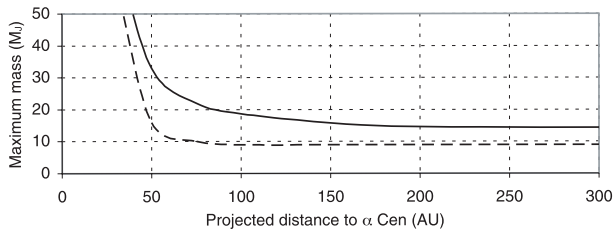
The SUSI2 sources were extracted using the SExtractor tool (Bertin & Arnouts 1996), completed by a manual selection of

the sources close to  $\alpha$  Cen. We applied the same hybrid selection procedure on the 2MASS images. We then obtained the photometry of the sources using IRAF and 12 pixel apertures for SUSI2 ( $1''$  radius). This relatively small aperture is justified by the variable background from the diffused light of  $\alpha$  Cen and the relative crowding of the field. For the 2MASS images, we used  $3''$  apertures. The SUSI2 airmass coefficients were taken as the average values for La Silla (ESO User's Manual 1993, see also Burki et al. 1995):  $k_V = 0.11$ ,  $k_R = 0.07$ ,  $k_I = 0.02$ , and  $k_Z = 0.01$  mag/airmass. In all cases, the airmass corrections are negligible, with values below 0.04 mag. The aperture corrections for SUSI2 were determined on a bright, isolated star located relatively far from  $\alpha$  Cen to ensure a flat sky background. They were found to range between 0.20 and 0.42 mag depending on the color and the observation epoch. The photometric zero points were taken from ESO's routine instrument monitoring program for SUSI2, and from the image headers for 2MASS. Considering the difficulty of estimating accurately the sky background level, we chose to add a systematic  $\pm 0.20$  mag uncertainty to the SUSI2 magnitudes. For the 2MASS images, we applied the aperture correction recommended by IPAC for a  $3''$  aperture, i.e.  $0.05 \pm 0.02$  mag in all three *JHK* bands.

The catalogue of the objects detected in the SUSI2 and 2MASS images is available in electronic format<sup>3</sup>. A total of 4313 sources were identified on the SUSI2 images, with 391 recovered in the 2MASS images (9.1%). Among the detected background sources, several objects present extreme color indices. We checked that their presence is expected based on Galactic models (Robin et al. 2003).

<sup>3</sup> <http://vizier.u-strasbg.fr/viz-bin/VizieR>





**Fig. 2.** Maximum mass of the possible companions orbiting  $\alpha$  Cen. The solid curve corresponds to the model masses by Baraffe et al. (2003) for our SUSI2 limiting magnitudes in the  $I$  band. The dashed curve corresponds to the faintest detected objects.

#### 4. Sensitivity and companion limits

To define our practical limiting magnitudes, we chose to consider the median magnitude of the detected sources. This definition has the advantage to give an empirical, statistically meaningful definition of the sensitivity, that can be expressed as a function of the distance to the two bright stars by computing the median within angular distance bins. We computed the median magnitude of the detected objects in the SUSI2  $VRIZ$  bands for four angular distance bins: 23–50'', 50–100'', 100–150'', 150–200'' and 200–236''. In all bands, the limiting magnitudes (as defined above) at large angular distances are in the 20–22 range, with the faintest objects at magnitudes of 23–25. The limiting magnitudes decrease to 16–18 for an angular separation of 35''. For the 2MASS images, the limiting magnitudes as defined above are 13–14 for the  $JHK$  bands at large angular separations (the faintest sources are at 15–16).

We carefully searched our SUSI2 images for moving sources using blinking and image subtraction techniques, without success. Using planetary models from Baraffe et al. (2003) for the age of  $\alpha$  Cen (5 Gyr, from Thévenin et al. 2002; see also Eggenberger et al. 2004), we can estimate the maximum mass of the possible companions. The most constraining limits are provided by our  $I$  band images. The  $Z$  filter did not provide a significant improvement in sensitivity, due to the cutoff of the CCD quantum efficiency. The  $I$  band provides in addition a better defined average wavelength that makes the comparison with model magnitudes more accurate. Figure 2 gives the sensitivity of our search in terms of companion mass. We can set a maximum mass of  $\approx 15 M_J$  for projected separations larger than 100 AU. This limit can be extended down to  $10 M_J$  if we consider our faintest detected objects. Between 50 and 100 AU, the presence of a companion with a mass larger than about  $30 M_J$  is highly unlikely.

#### 5. Conclusion

From deep CCD images of  $\alpha$  Cen, we did not identify any comoving companion. Within the explored area, this negative result sets an upper mass limit of 15–30  $M_J$  to the possible companions orbiting  $\alpha$  Cen B or the pair, for separations of 50–300 AU. When combined with existing radial velocity searches (e.g. Endl et al. 2001) and our adaptive optics results (see Fig. 7 in Paper I), this mostly excludes the presence of a 20–30  $M_J$  companion within 300 AU. This non-detection should have consequences on the modeling of the stellar interior of  $\alpha$  Cen in particular, but also of other stars. In order to settle the debate on the masses of  $\alpha$  Cen (and in particular of B), one should now check one by one the hypotheses made for the calibration of this system. This also implies that the new abundances of Asplund et al. (2004) should be considered as soon as possible. As an illustration of the importance of this parameter, it has been debated recently a possible underestimate of the Ne solar abundance that could counter balance the effect of the decrease of the solar opacity due to the decrease of the oxygen abundance from 3D models (Young 2005). Liefke & Schmitt (2006) have published a new value of the chemical abundance ratio of Ne/O based on coronal studies. These recent results will be advantageously introduced in the determination of the metallicity of the  $\alpha$  Cen binary to better model the evolutionary track of both stars.

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