LETTER TO THE EDITOR

A new submm source within a few arcseconds of lpha Centauri ALMA discovers the most distant object of the solar system

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ABSTRACT

Context. The understanding of the formation of stellar and planetary systems requires the understanding of the structure and dynamics of their outmost regions, where large bodies are not expected to form.

Aims. Serendipitous searches for Sedna-like objects allows the observation of regions that are normally not surveyed.

Methods. The Atacama Large Millimeter/submillimeter Array (ALMA) is particularly sensitive to point sources and it presents currently the only means to detect Sedna-like objects far beyond their perihelia.

Results. ALMA observations 10 months apart revealed a new blackbody point source that is apparently comoving with α Cen AB. Conclusions. We exclude that source to be a sub-/stellar member of the α Cen system, but argue that it is either an extreme TNO, a Super-Earth or a very cool brown dwarf in the outer realm of the solar system.

Key words. Stars: individual: α Cen AB – Stars: brown dwarfs – Submillimeter: stars – Planetary systems: Kuiper Belt, general –

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Received; accepted

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1. Introduction

One of the most exciting and expanding areas of current astronomical research concerns planets around other stars. For direct detection, we would need to focus on the most nearby stars. α Cen, our nearest neighbour (D = 1.34 pc), has long been known to be a triple star. For α Cen C, named Proxima and which is more than 2 degrees distant from the binary α Cen AB, the membership had been established on the basis of their common proper motion already at the beginning of the 20th century (Innes 1917). Both Proxima and the pair have been extensively searched for companions, which eventually culminated in the announcement of an Earth-mass planet around α Cen B (Dumusque et al. 2012). However, the existence of α Cen Bb, or of any other companion for that matter, still awaits confirmation (Hatzes 2013; Demory et al. 2015; Rajpaul et al. 2016).

Deep imaging observations from the ground (VLT-NACO) in 2004 to 2005, combined with coronagraphy from space (HST-ACS), did not reveal any comoving sources brighter than K_s ~ 18 within 5" to 7" (7 to 9 AU) from α Cen B (Kervella et al. 2006). The irregular and incompletely sampled map measures

18 within 5" to 7" (7 to 9 AU) from α Cen B (Kervella et al. 2006). The irregular and incompletely sampled map measures an overall area of $\lesssim 45'' \times 35''$. Because of the intense brightness of the binary at these wavelengths, a region of 5"-radius around the stars could not be observed, and hence any object inside this "hole" would have passed unnoticed. The brightest object in the sample has $K_s = 12$ and the limiting magnitude was 22 out to a radius of 20". In addition, earlier CCD imaging blanked out regions that were within 8", and no comoving sources with $V \le$ 24 where found within the observed 5:5 (Kervella & Thévenin 2007).

A decade later, the infrared field of view around α Cen had moved more than half an arcminute west, so that there is no skyoverlap with our ALMA observations, which in 2014 and 2015 revealed a high-proper-motion source that potentially could be a member of the α Cen system (Fig. 1). The projected separation would correspond to being midway between Jupiter and Saturn in the solar system. In this *Letter*, we discuss the possible nature of this object.

2. Observations and data reduction

The binary α Cen AB was observed, and spatially resolved, in six ALMA continuum bands during the period July 2014 to May 2015 (Table 1). The field of view (primary beam) varied from about 10" for the shortest wavelength to about 1' for the longest. Similarly, the angular resolution (synthesized half power beam width) ranged from 0"2 to 1"5. The ALMA program code is 2013.1.00170.S and the observations in Band 3, 7 and 9 have already been described earlier (Liseau et al. 2015). The observational procedures and reduction for Bands 4, 6 and 8 are similar and details will be provided in a forthcoming paper.

3. Results

The J2000-coordinates for α Cen A and B at the different observing dates are presented in Table 2, together with those for an unidentified source that was clearly detected on two occasions (we dismiss instrumental effects as the cause, see the accompanying paper by Vlemmings et al.). The frequencies of the bands

Table 1. Primary beam corrected flux density, $S_{\nu} \pm \Delta S_{\nu}$ (mJy) and [S/N], of an unidentified source near α Centauri

679 GHz	445 GHz	343.5 GHz	233 GHz	145 GHz	97.5 GHz
Band 9 (442 μm) 18 July, 2014	Band 8 (740 \(\mu \text{m} \)) 2 May, 2015	Band 7 (872 μm) 7 July, 2014	Band 6 (1287 μm) 16 December, 2014	Band 4 (2068 µm) 18 January, 2015	Band 3 (3075 μm) 3 July, 2014
< 10.5	3.64 ± 0.17 [21.4]	2.09 ± 0.48 [4.3]	< 3.2	< 0.5	< 0.2

Table 2. J 2000 positions in Right Ascension and Declination of ALMA point sources within the primary beam

Date	aCen A		aCen B		UID		ALMA
yyyy-mm-dd	hh mm ss.s	o / //	hh mm ss.s	0 / //	hh mm ss.s	0 / //	Band
2014-07-03	14 39 28.893 -	60 49 57.86	14 39 28.333	-60 49 56.94			3
2014-07-07	14 39 28.883 -	60 49 57.84	14 39 28.325	-60 49 56.91	14 39 28.583 -6	04952.30	7
2014-07-18	14 39 28.870 -	60 49 57.83	14 39 28.309	-60 49 56.89			9
2014-12-16	14 39 28.650 -	60 49 57.60	14 39 28.120	-604956.32			6
2015-01-18	14 39 28.624 -	60 49 57.63	14 39 28.110	-604956.27			4
2015-05-02	14 39 28.439 -	60 49 57.44	14 39 27.934	-604955.85	14 39 28.487 -6	04951.87	8

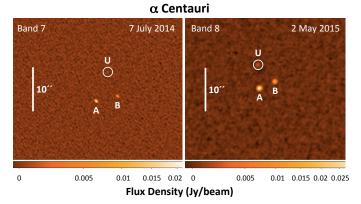


Fig. 1. Left: Band 7 observation of α Cen AB on 7 July 2014. Apart from the well known binary α Cen A and α Cen B, a previously unknown source, and designated U, is seen NNE of the secondary B. **Right:** That object is more clearly evident in our Band 8 observation on 2 May 2015, 5"5 north of α Cen A.

are given in Table 1, where the primary beam corrected flux densities, S_{ν} , are reported together with their statistical errors.

4. Discussion

4.1. A new member of the α Centauri system: α Cen D?

At the epochs of Band 7 and 8 observations, a comoving unidentified source, preliminarily named α Cen D, was within 5"5 from the pair. If this is commensurate with an orbital period (or corresponds to slow motion over long periods of time), then α Cen D could not have been detected with the VLT-NACO data because, due to the intense glare from α Cen AB, it was intentionally blocked out of view. In Fig. 2, together with α Cen A and B, the track in the sky of α Cen D is also shown, with predictions for future observations. These are based on the assumption that α Cen D is indeed at the same distance as α Cen (Table 3). Observations at only two epochs leaves a more refined analysis impossible, and details of these "predictions" have to be viewed with caution. However, these seem to indicate that follow-up observa-

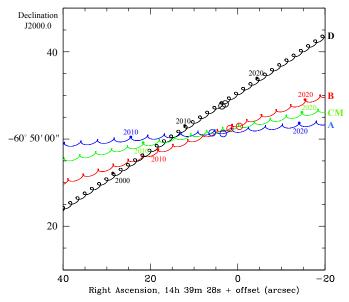


Fig. 2. A 1' × 1' region of the sky with tracks for α Cen A (blue), B (red) and their centre of mass CM (green). These tracks include orbital motion (based on the elements of Pourbaix et al. 2002), proper motion (van Leeuwen 2007) and annual parallax (http://naif.jpl.nasa.gov/naif/toolkit.html). In black, the track of " α Cen D" is shown, assuming unbound motion but that it shares the parallax with the binary (π = 0."742, Table 3). The modeled proper motion vectors are μ_{α} = -1650 mas yr⁻¹ and μ_{δ} = +1090 mas yr⁻¹. Years since 2000 are marked along the tracks as filled dots. Observed ALMA positions (FK 5) in 2014 and 2015 are indicated by open circles that are much larger than the positional uncertainties (< 0."02).

tions ought to be feasible for some years to come, which should help to elucidate the nature of this source.

The Band 7 and 8 data, together with the upper limits for the other bands, permit the estimation of the spectral slope, i.e., $d \log S_{\nu}/d \log \nu = 2.1 \pm 0.4$ in the submm (Fig. 3), consistent with that of a blackbody (Rayleigh-Jeans tail). The temperatures and radii of main-sequence stars are known, so that for a given flux, the only unknown is the distance to the star. In Figure 4, we

Table 3. Velocity and parallax data for the α Cen system

α Cen	μ_{lpha}	μ_{δ}	error	$v_{ m hel}$	π	Notes and
	(mas yr^{-1})	(mas yr^{-1})	ellipse ^a	$(\mathrm{km}\mathrm{s}^{-1})$	(mas)	References
A B	-3679.25 -3614.39	+473.67 +802.98	3.89, 3.24, 0 20.48, 19.52, 0	-21.40 ± 0.76 -20.7 ± 0.9	754.81 ± 4.11 796.92 ± 25.90	SIMBAD ^b SIMBAD
CM ^c	-3637.17	+694.03	3.88, 3.23, 0	-22.3 ± 0.9	742	priv. com., SIMBAD
C U ^d	-3775.75 -1650	+765.54 +1090	1.63, 2.01, 0 10, 10, 0	-22.40 ± 0.5	768.13 ± 1.04	Proxima, SIMBAD This work, ALMA

Notes. ^a Semimajor axis, semiminor axis, position angle, in units of mas yr^{-1} and degree. ^b J2000 data from SIMBAD, http://simbad.u-strasbg.fr/simbad/sim-fid ^c Proper motion data by N. Phillips (private communication) ^d Unidentified source in Bands 7 and 8; proper motion data in the table assume a parallax π of CM (AB) and a measured -865, +600 mas yr^{-1} .

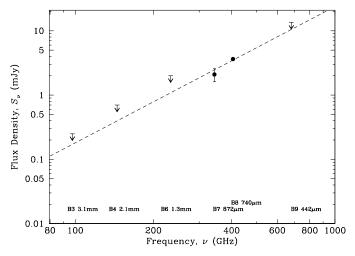


Fig. 3. The submm/mm-SED of the unidentified source near α Cen. The slope of the linear regression is 2.1 \pm 0.4. Allowing for the remote possibility that the 4.3 σ result of Band 7 is not real, the slope would still be constrained at the given level.

present a temperature-distance diagram for the observed Band 8 flux density, a detection at more than $20\,\sigma$ (Table 1), and include the positions (D, $T_{\rm eff}$) of main sequence stars of late spectral type. To give an example, Proxima Centauri (α Cen C) has a visual magnitude of 11 and is of spectral type M 6, but is nowhere near the indicated distance of the α Cen system, represented by the vertical dotted line. Instead, the M 6 star of the diagram is at about 0.4 pc. This apparently awkward result is due to the fact that we keep the flux constant, at the observed value. Both temperature and radius of an M 6 star are simply to small to match that flux value at 1.34 pc.

Instead, at the distance of α Cen, the measurement for α Cen D would correspond to an M 2 star, where we have used the calibrations of Bessell (1991), Rajpurohit et al. (2013) and Cox (2000), and according to which the star would be brighter than sixth magnitude in the visual and as such should be listed in the Bright Star Catalogue, which it is not. On the basis of the available evidence, it can of course not be excluded that the object is farther away. However, the high proper motion of the source would likely limit the distance to within 5 pc as, for instance, toward an early G-type star at \sim 4 pc (Fig. 4). Also in this case, the extremely high apparent brightness of $V \sim$ 3 mag invalidates the stellar hypothesis. It is entirely incomprehensible that

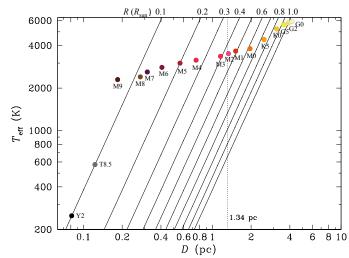


Fig. 4. Location of late-type main-sequence stars in the $T_{\rm eff}$ -distance diagram for an $S_{\rm 445\,GHz}=3.64\,{\rm mJy}$, with radii along the slanted lines in solar units as parameters (see top of frame) and with their spectral classes indicated. α Cen D, at the distance of α Centauri system, would correspond to an M2 main-sequence star (see the dashed vertical line at 1.34 pc). Brown dwarfs would slide along the $R_{\rm Jup}\sim0.1\,R_{\odot}$ line and be at different distances. Two very cool sources, of type T 8.5 and Y 2 respectively (Leggett et al. 2015), thus have assumed radii of about $R_{\rm Jup}$.

a star that bright, and with such high proper motion, would have remained unnoticed.

On the other hand, compact objects that are *not stars* generally have radii that are much smaller. Fig. 4 also displays the rather extreme low-temperature brown dwarf (ULAS J003402.77-005206.7, T 8.5, Leggett et al. 2015), assuming a typical Jupiter size (Oppenheimer et al. 2000). That object was assigned a temperature of 575 K. An even cooler object is WISE J085510.83-071442.5 (Y 2, Leggett et al. 2015) with an estimated $T_{\rm eff}=250$ K. An extremely cool brown dwarf at a distance of nearly 20 000 AU may be a viable candidate for the new object's identification. However, like the Y2-source, the Widefield Infrared Survey Explorer (WISE, 2009-2011) should have picked it up, unless the moderate angular resolution of WISE (>6%0) prevented its detection close to the very bright α Cen AB.

The obvious question then is, what is its nature and why has it escaped earlier detection? Is it always too close to the binary? Is it too cold? In that case, i.e., at temperatures below a hundred Kelvin or so, the non-detection at shorter wavelengths, with e.g. WISE, would be reconcilable.

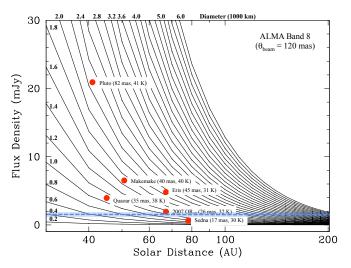


Fig. 5. Band 8 flux density as function of the distance from the Sun with diameters as parameter, in $10^3\,\mathrm{km}$ and next to or atop the curves and arbitrarily limited to $6000\,\mathrm{km}$, i.e. slightly smaller than the diameter of Mars. This figure is similar to Fig. 4, except that both temperature and radius are a priori undetermined. A few known TNOs with their names are shown by the red dots (www.minorplanetcenter.org/iau/lists/Sizes.html). In parentheses, the apparent diameter in milli-arcseconds and the estimated blackbody temperature are given. The size of the ALMA synthesized beam, $\theta=120\,\mathrm{mas}$, is given in the upper right corner, confirming that these objects would be point-like to ALMA. The observed Band 8 flux density of the unidentified object is indicated by the horizontal blue-shaded dashed line $(\pm 3\sigma)$. The distance to the U-source remains to be determined.

4.2. A new member of the solar system: an ETNO?

At -42° ecliptic latitude α Cen and source U are far from the plane of the ecliptic. In projection, they are however essentially in the galactic plane, toward the inner Galaxy. To explain source U in terms of a contaminating background source could hardly be considered compelling¹, given that that object had to share the high proper motion of α Cen. On the other hand, if a passing object, it had to be in the far outskirts of the solar system, belonging to the Edgeworth-Kuiper Belt or the Oort cloud (Fig. 5). The probability could be low though, since we would need to catch it very close to the footprints of the loop of the parallax motion (cf. Fig. 2). In addition, bound motion at a distance of, say, 1000 AU (the aphelion of Sedna) would result in an orbital motion of less than 40" yr⁻¹, but the apparent motion in the sky would be dominated by the annual parallax (~200"). Curiously, when we examined a total of 766 925 known solar-system objects² for being within 15' around α Cen at the time of observation, we found no source down to the limiting V-magnitude of 26.0. Again, a low-albedo, thermal Extreme Trans Neptunian Object (ETNO), such as the hypothetical super-Earth of Trujillo & Sheppard (2014), would be consistent with our flux data (e.g., for $R \sim 1.5 R_{\oplus}$, $D \sim 300$ AU, $T_{\rm bb} \sim 15$ K, $\theta \sim 80$ mas, Fig. 5).

One may expect the distribution of the Oort cloud TNOs initially to be isotropic. However, the vast majority of known TNOs are not very far off the ecliptic³. For instance, Sedna is at $i \sim 12^{\circ}$, and other Sedna-like objects, Biden (2012 VP₁₁₃) and V774104

(10 November 2015, Science, DOI: 10.1126/science.aad7414) are at $i = 24^{\circ}$ and within 15°, respectively. This is certainly due to observational bias, as one generally scans the sky around the ecliptic (Schwamb et al. 2010). However, high inclinations are not excluded, with the most massive dwarf planet Eris at $i = 44^{\circ}$ being a prime example.

For reasons of sensitivity (or rather, lack thereof), TNOs on highly eccentric orbits have traditionally been firstly detected when close to their perihelia. Further away, there would have remained unseen (e.g., Sheppard et al. 2011). However, a sizable population of such bodies is expected to exist at large distances from the Sun. It is clear, therefore, that ALMA with its high submm sensitivity provides presently the only existing means to detect TNOs far from their perihelia, where temperatures are merely some tens of Kelvin. There must be a vast reservoir of objects between, say, roughly 100 and 1000 AU, of which we hitherto have seen only a tiny fraction (see also de la Fuente Marcos & de la Fuente Marcos 2014, and references therein).

5. Conclusions

Within ten months between 2014 and 2015, ALMA imaging observations revealed a new source in two of the bands, at 0.74 mm (Band 8) and 0.87 mm (Band 7) respectively, whereas the noise was too high in the other bands. Staying within 5".5 of both α Cen A and B, this object essentially shared the high proper motion of α Cen. With a spectral slope of 2, its submm-SED appears thermal. However, simple arguments convince us that this object cannot be an ordinary star. We argue that the object is most likely part of the solar system, in prograde motion, albeit at a distance too far to be detectable at other wavelengths, viz. an ETNO (\gg 100 AU), a hypothesized Super-Earth (\sim 300 AU) or a super-cool brown dwarf (\sim 20 000 AU).

Acknowledgements. Our thanks go to the members of the Nordic ARC node⁴ and to the ALMA staff for their assistance with the observations. We enjoyed interesting discussions with R. Cumming, K. Justtanont, K.K. Knudsen, M. Olberg and T. Lunttila. This paper makes use of the following ALMA data: ADS/JAO.ALMA#2013.1.00170.S. ALMA is a partnership of ESO (representing its member states), NSF (USA), and NINS (Japan), together with NRC (Canada) and NSC and ASIAA (Taiwan), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO, and NAOJ.

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 $^{^{1}}$ We omit the unlikely possibility that there would be two extragalactic out-of-phase variable sources, separated by 0"8. For an area $10'' \times 10''$, number counts give $n(S_{870\,\mu\text{m}} > 2 \text{ mJy}) < 0.004$. Also, these objects are slightly extended, whereas source U is not (Simpson et al. 2015).

² http://www.minorplanetcenter.net/cgi-bin/mpcheck.cgi

³ http://www.minorplanetcenter.org/iau/lists/TNOs.html

⁴ http://www.nordic-alma.se/