Searching for proto-brown dwarfs

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ABSTRACT

We present a multi-wavelength search for cool, very low luminosity objects in the Barnard 213 dark cloud, which is located at 140 parsecs. We have collected data ranging from near infrared at 1.1 μm up to radio wavelengths at 6 cm, including data from the Calar Alto Observatory, Spitzer Space Telescope, the Caltech Submillimetre Observatory, the IRAM 30 metre antenna and the Very Large Array. One of our sources has a bolometric temperature of 165 K, whereas the central object seems to have an effective temperature, based on theoretical models, in the range 800-1700 K. The Spitzer photometry and Spectral Energy Distribution allow us to classify it as a Class I object. There is also an extended envelope with a mass of about 10-30 M_{Jup} and a temperature of 15–25 K, which might present a cavity at its centre. If it is located at the distance of the parental cloud, the bolometric luminosity would be 0.003 $L_{\odot}$, which would put this object well below the characteristics of other Very Low Luminosity objects discovered up to date. With these characteristics, this object can be the best proto-brown dwarf candidate identified so far.

MOTIVATION OF THIS WORK

Since the discovery of the first brown dwarfs (Nakajima et al. 1995; Rebolo et al. 1995), a large number of substellar objects has been identified and studied. However, their formation mechanism is still unclear: do they form like stars, from collapse and fragmentation of the initial molecular cloud, since we do not see any change in their properties when we compare them with low-mass stars? Or do they form like planets, from the circumstellar material present around more massive stars, and are later expelled due to gravitational interactions? Or, perhaps, are they protostellar cores which have lost their envelopes due to the action of strong winds coming from nearby, massive stars? (Padoan & Nordlund 2004; Reipurth & Clarke 2001; Bate et al. 2002; Whitworth & Zinnecker 2004). Since stars and brown dwarfs evolve very rapidly during the first million years, the answer to the formation mechanism (or mechanisms) must be in the study of their properties when they are extremely young. However, no brown dwarf has been unambiguously discovered at early age (i.e., in the proto-brown dwarfs evolutionary stage), when they are supposed to be embedded in an envelope of dust and gas, submerged in the original natal cloud, and thus corresponding to the Class 0–I phase in the protostellar evolutionary scheme of Lada (1987).

THE SEARCHING STRATEGY

The aim of this work was to select a sample of very low luminosity Class I objects. In order to fulfill this goal we have relied primarily on Spitzer data, by using color-color and color magnitude diagrams. The first step was the selection of an optimal area to conduct our analysis. To do so we have used the following strategy:

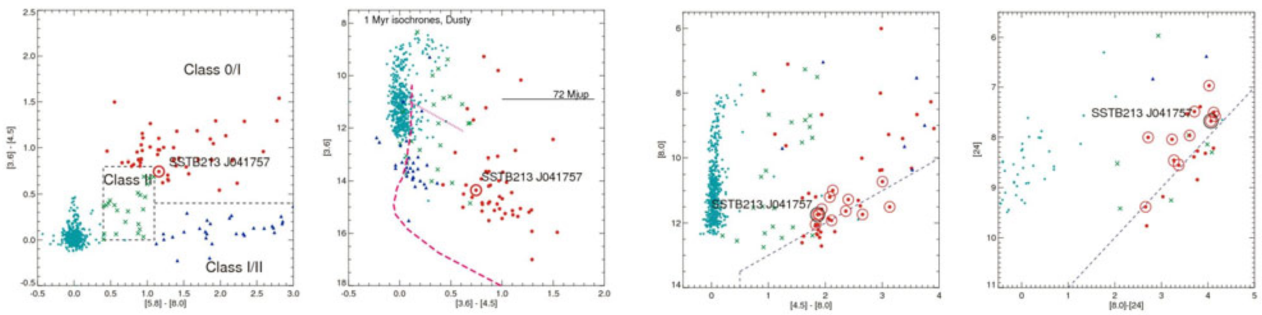
i) We have selected a sample of Class 0 and Class I protostars, taken from Froebrich (2005), located at distances < 350 pc and with declinations >-10º.

ii) We have looked into the Spitzer and 2MASS databases in order to check the near- /mid-IR characteristics of the regions around the protostars and to extract the photometry. Spitzer/IRAC color-color diagram, [3.6]-[4.5] vs. [5.8]-[8.0], was used to target possible candidates. Samples selected in such way can be polluted with background extragalactic sources and thus, we have followed the method described in Harvey et al. (2006) to minimize this effect.

iii) We have selected a region showing a high density of Class 0/I sources with respect to Class I I objects.

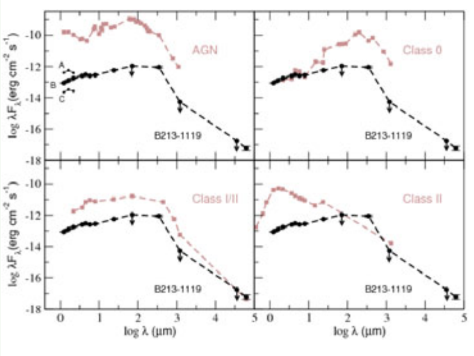
Following the above criteria, the best candidate region to carry out our study was B213 (140 pc).

SELECTION OF VERY LOW LUMINOSITY OBJECTS



Above these lines we show several color-color and color-magnitude diagrams, using the Spitzer measurements, which allow us to select several faint, red candidate members of this dark cloud (red dots are Class I objects, green crosses are Class II sources and blue triangles are ClassI/II sources). Models of Baraffe et al. (1998) and Chabrier et al. (2000) predict that most of our selected Class I sources should be below the substellar limit. However, due to the inhomogeneous and strong extinction, some of these proto-brown dwarfs candidates could be low mass stars heavily reddened by the effect of the dust, or perhaps background objects (giant stars or galaxies). The two diagrams on the right were used to separate extragalactic contaminants. Objects marked with a large open circle in those diagrams were selected for follow up at longer wavelenghts (based on their position in the diagrams and the shape of their SEDs). In particular, one object, named SSTB213 J041757, has very interesting properties.

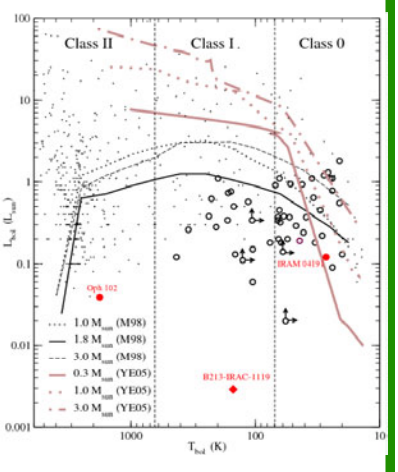
THE BEST PROTO-BROWN DWARF CANDIDATE



Spectral Energy Distribution from 1.1 μm up to 6 cm of SSTB213 J041757 and comparisons with several sources. Our fluxes come from Omega2000 (near-IR), Spitzer IRAC and MIPS (mid-IR), CSO at 350 μm, IRAM 30m at 1.2 mm and VLA at 3 and 6 cm.

The shape of the SED indicates we have a very young object with a circumstellar disk, essentially seen at shorter wavelengths, which is embedded in a large (~30", as derived from the CSO image at 350 μm) and cold (~15–25 K) envelope, responsible of the submillimetre emission. The mass of the envelope, using also the 350 μm measurement, should be in the range 10–30 M_{Jup}, depending on the dust temperature assumed, and adopting the opacity law for the dust of Ossenkopf & Henning (1994). Between this envelope and the proto-brown dwarf candidate, it seems that there is a cavity, responsible of the reduced flux at the far infrared. However, this fact depends strongly on the assumed upper limit at 70 μm. Assuming that the fluxes at the J and H bands are less affected by the presence of a disk and/or an envelope, a COND model by the Lyon group (Baraffe et al. 2003) for an age of 1 Myr and a distance of 140 pc corresponds to an object with a mass of 1– 2 M_{Jup}, a radius of 0.17 $R_{\odot}$ and a Teff of 940-1300 K (these numbers are only indicative, since the observed phenomenology is much more complex than the theoretical models and, the object could be younger).

The comparison of the location of the proto-brown dwarf candidate in a Lbol vs. Tbol diagram (after Young & Evans (2005); and Dunham et al. (2008)) clearly shows that our object is different to anything found so far. For comparison, the 50 sources compiled by Dunham et al. (2008) are shown as open black circles.



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