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LETTER

Letter to the Editor

Detection of Young Stellar Objects with ISO

L. Testi[1,6], M. Felli[2], A. Omont[3], M. Pérault[4], P. Séguin[4], G. Comoretto[2], and G. Gilmore[5]

[1] Dipartimento di Astronomia e Scienza dello Spazio, Università degli Studi di Firenze, Largo E. Fermi 5, I-50125 Firenze, Italy
[2] Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy
[3] Institut d'Astrophysique de Paris, CNRS, 98bis Boulevard Arago, F-75014 Paris, France
[4] Laboratoire de Radioastronomie Millimétrique, ENS, 24 rue Lhomond, F–75005 Paris, France
[5] Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge, CB3 OHA, United Kingdom
[6] visiting astronomer: Institut d'Astrophysique de Paris, CNRS, 98bis Boulevard Arago, F-75014 Paris, France

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Abstract. Preliminary 15μm results obtained with ISOCAM are compared with deep K-band and H_2O maser observations of a 0.244 deg^2 field in the galactic plane at l = +45°. A new maser source is found to be associated with the infrared source with the largest colour index, $(m_K – m_{15\mu m}) \gtrsim 10$, most probably a young star in its earliest evolutionary phase. Other three objects with $(m_K – m_{15\mu m}) \gtrsim 9$, probably young stars, are also found in the observed region.

Key words: stars: formation – ISM: masers – infrared: stars

1. Introduction

Even though originally found in close association with diffuse HII regions, most of the interstellar H_2O masers (up to 80%) may not be associated with them (Palla et al. 1993). In fact, H_2O masers are now believed to trace the earliest evolutionary phases of massive stars, much before the onset of an ultra compact (UC) HII region (Codella et al. 1994; Codella & Felli 1995). This picture has been confirmed both by high resolution radio observations and high sensitivity near infrared (NIR) observations (Felli et al. 1996; Testi et al. 1994; Tofani et al. 1995) as well as by molecular line and 3mm continuum high resolution observations (Cesaroni et al. 1994a; 1994b; Codella et al. 1996; Olmi et al. 1996). The NIR observations are expected to trace not the stellar photosphere, which would be too extincted to be detectable, but the hottest layers of the dust cocoon in which the newborn star is embedded (Felli & Testi 1996).

Send offprint requests to: L. Testi, testi@arcetri.astro.it

H_2O masers are thus the ideal indicators of the youngest massive stars which have not yet swept out their parental cocoon, and are the best targets for the identification of regions of recent star formation.

Unfortunately, the best studied star forming regions are the most luminous ones and may contain several bright early type stars, making the interpretation more complex. The coexistence of objects in different evolutionary stages, and the presence of (moderately) evolved objects that have already strongly interacted with the surrounding medium, make it difficult to study the youngest and lower luminosity objects. Comparison of low resolution IRAS and radio observations may give only global results for the entire complex. Both high resolution and sensitivity are needed to separate young stars with different luminosities and in different evolutionary status (Felli et al. 1996; Hunter et al. 1995; Palla et al. 1995).

Although NIR imaging (especially at K= 2.2 μm) has proved to be a useful tool to investigate these regions, mid and far infrared high resolution observations are urgently needed. In fact, it is in this range of wavelengths that the bulk of the emission from the youngest massive stars is expected. Even more important, *isolated* massive young stellar objects should be studied, in order to unveil the formation of the *first* generation of massive stars, without the difficulties and the complexities that arise in regions where other stars have already formed. When combined with near infrared and water maser unbiased surveys, high resolution and sensitivity ISOCAM 15μm observations (Omont 1996; Pérault et al. 1996) which purposely avoid the brightest IRAS sources (with $F_{12\mu m} > 6$ Jy) are an unique tool to detect young early type stars.

In this paper we report the detection of one source which very likely belongs to the class outlined above, together with three other potential candidates in a region of about ~ 0.244 deg^2 at approximately l = +45°, b = 0°.

2. Observations

All the observations have been carried out in the frame of a survey at 15μm of the inner galaxy, the ISOGAL project (Pérault et al. 1996). In particular the observations used in this work are those of the field at l = +45°. Both the radio and NIR observations are part of a preparatory/followup program for the ISO data. Here we will briefly summarize the fundamental observational parameters.

2.1. ISO observations

The ISO observations where carried out during April 1996. ISOCAM was used to observe a ~ 0.244 deg^2 field around the position l=+45° b=0.0°. The filter used was the 15μm broadband LW3 filter (passband from 12 to 18μm), and the pixel field of view 6″. After image reduction (Pérault et al. 1996) about 700 point sources were extracted with a preliminary photometry. The completeness limiting flux achieved was approximately 10 mJy. The magnitude at 15μm ($m_{15\mu m}$) has been computed assuming $m_{15\mu m}$=9 for a 5 mJy source.

2.2. NIR observations

The K-band observations of a slightly larger field than that observed by ISOCAM were carried out during October 1995, using ARNICA (Lisi et al. 1996) mounted at the TIRGO[1] telescope. ARNICA is equipped with a NICMOS3 detector, the plate scale at the TIRGO is $\sim$ 0.96 arcsec/pixel. For a comprehensive description of the instrument performance at the TIRGO see Hunt et al. (1996a). Photometric calibration was performed by observing a set of the ARNICA standard stars (Hunt et al. 1996b), the calibration accuracy is about 10%. The limiting magnitude achieved in the observations ($3\sigma, 4''$ aperture) was $\sim$ 15.4 (0.46 mJy).

The K-band data was astrometrically calibrated using a large set of optical stars extracted from the Digitized Sky Survey as described by Testi (1993). K stars positions then were used to astrometrically calibrate the ISO images. The present astrometric precision achieved is $\lesssim 1''$ for the K-band data and $\lesssim 3''$ for the ISO data.

On the 3rd July 1996, a small region ($\sim 2' \times 2'$) around the position of the H_2O maser was observed at UKIRT[2] at K and nbL (3.4μm). The 2.2μm data are about two magnitude deeper than the TIRGO data. All the sources previously detected are confirmed, and a background of fainter objects suggests that these images are confusion limited at K$\sim$ 18. In the nbL image $\sim$ 10 stars corrensponding to the brightest K sources are detected, plus a faint object ($m_{nbL} \sim 11.3$) without a bright K counterpart. The limiting magnitude of the 3.4μm image is $\sim$ 12.

2.3. H_2O maser observations

A new H_2O maser was discovered during an unbiased survey of the l = +45° field, which is presently on-going at the Medicina[3] radio telescope. The observing setup, the sensitivity and the spectral resolution of the observations closely resemble those described by Brand et al. 1994. The Full Width at Half Power (FWHP) of the Medicina antenna at 22 GHz is $\sim 1.9'$. Up to now $\sim$ 25% of the field has been observed. Taking into account the beamwidth and the pointing accuracy, we estimate an error of $\sim 30''$ on the maser position.

3. Results and discussion

In this section we will briefly discuss the four sources in our field that are possible candidates for young deeply embedded (proto-)stars. All of the sources have a colour index (m_K–$m_{15\mu m}$) greater than 9, calculated as the difference between the observed magnitudes. Such large excess is probably due to the reprocessing of the stellar radiation by optically thick dust cocoons. In fact, for both unreddened main sequence and evolved stars (giant branch and asymptothic giant branch stars), the value of the colour index should be in the range $0 - 3$. Reddening in the galactic plane cannot increase this value up to 9 even for very distant objects.

3.1. The H_2O maser source

In Fig. 1 the spectrum of the H_2O maser observed at Medicina is reported. The velocity of the two main components ($-95, -20$ km s^{-1}) are on the lowest side of the values expected for this galactic longitude. A "mean" velocity of ~ -57 km s^{-1} could be obtained for objects at large distance ($\gtrsim 15$ kpc). In the Columbia ^{12}CO survey (Cohen et al. 1986) and in the radio recombination line observed toward the nearby HII region G45.45 + 0.06 (Lockman 1989) the bulk velocity is $\sim$ 55 km s^{-1}. No H_2O emission was detected at this velocity (in Fig. 1 only a small part of the spectrum is shown). In Table 1 the parameters of the observed H_2O maser and of the closest ISO source together with its associated K-band and 3.4 μm source are reported.

Due to the extremely large number of K-band sources in the field ($\sim$ 34000) and the relatively large astrometric error, a reliable association between 15μm sources and K-band sources is a major problem in these regions, which is presently being studied in a thorough statistical way. In this case we have considered all the K sources detected in our image within 10″ from

[1] The TIRGO telescope is operated by the C.A.I.S.M.I.–C.N.R., Firenze, Italy

[2] UKIRT is the United Kingdom Infrared Telescope, Mauna Kea, Hawaii

[3] The Medicina telescope is operated by the I.R.A.–C.N.R., Bologna, Italy

Table 1. Parameters of the H_2O maser, and of the associated infrared source

	α	δ	F_{peak}	F
	(2000.0)		(Jy)	(Jy km s^{-1})
22 GHz	19 : 12 : 46	10 : 45 : 30	17 ± 2	110 ± 10
	α	δ	mag	F_ν
	(2000.0)			(mJy)
15μm	19 : 12 : 46.5	+10 : 45 : 55	4.34	370 ± 37
3.4μm	–[a]	–[a]	11.3	8.5 ± 0.9
2.2μm	19 : 12 : 46.5	+10 : 45 : 56	14.7	0.87 ± 0.08

[a]) No astrometry performed at nbL. The source is coincident with the K band source.

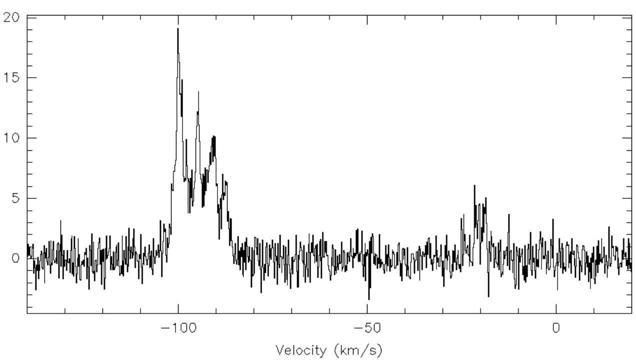

Fig. 1. Spectrum of the H_2O maser observed at Medicina. The intensity scale is in Jansky.

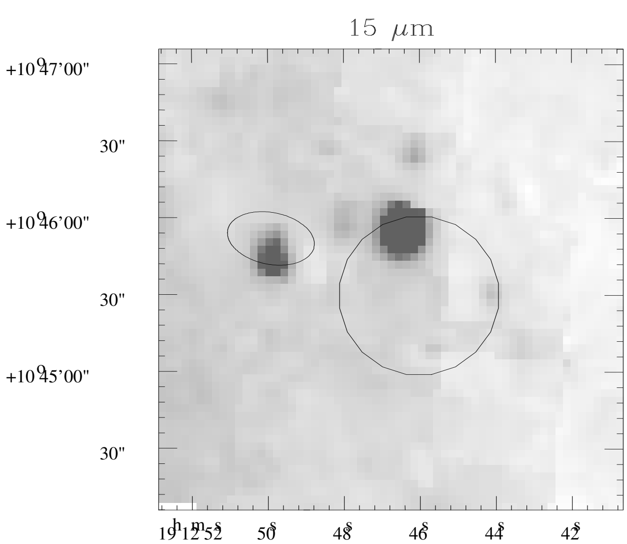

Fig. 2. Greyscale 15μm image. The small ellipse represents the IRAS-PSC error box, the circle marks the position of the H_2O maser, the diameter of the circle is approximately equal to the Medicina pointing error box. The epoch of the coordinates is 2000.

the ISO source, finding only three, very faint candidates. The source given in Table 1 is the closest to the ISO source ($\sim 1.3''$), the other two are at a distance of $\sim 6''$ and $\sim 9''$ respectively. All have a magnitude greater than 14.4 in K, implying that, regardless of which of them is associated with the ISO source, the (m_K–$m_{15\mu m}$) colour index is in any case greater than 10. Note that even taking into account the flux calibration uncertainties of the 15μm and the K-band data, the resulting colour index must exceed 9.5 (which remains one of the highest measured).

Four other 15μm sources are detected close to but outside the error box of the H_2O maser position. The closest is at $\sim 40''$, and the others are at $\gtrsim 50''$, from the maser position. Although the possibility that the H_2O maser may be associated with one of these sources cannot be completely ruled out, this seems unlikely, and in the following we will assume that the maser is associated with the closest 15μm source. Certainly higher resolution observations of the H_2O maser are needed to settle this point.

Somewhat surprisingly, there is no IRAS point source closely related to this source. The error ellipse of the closest IRAS-PSC source (IRAS19104+1040) is shown in Fig. 2, and it is almost coincident with a 15μm source which is not associated to masers and does not show a large infrared excess (m_K–$m_{15\mu m} \sim 2$). Given the large infrared excess of our source one would expect a steeply rising spectrum toward the longer wavelengths. Inspection of the HIRES IRAS maps shows indeed that there are two sources in a $1.5' \times 1.5'$ area, and that there is a peak at 25 μm at the position of the ISO source associated with the water maser.

One important question to be addressed is if the maser is associated with a late type star or with a young stellar object. In fact, sources with large H_2O spectra and associated with IRAS have been suggested to be late type stars (see e.g. IRAS19134+2131 in Engels et al. 1984, and IRAS16342−3814 in Likkel & Morris 1988). However, we believe that the ISO source is probably a YSO, even though only detection of OH maser or CO emission could settle this point. The extreme colour index observed for the infrared source can be explained only in terms of warm dust emission, most probably heavily extincted at K. From the fluxes reported in Table 1 it can be clearly seen that the spectral energy distribution of this source is steeply rising toward the long wavelengths, with a spectral index greater than 2, as expected for young stellar objects still embedded in optically thick cocoons (Shu et al. 1987).

No radio continuum emission was detected from this source at 20 cm in the VLA survey of Zoonematkermani et al. (1990). This implies that no HII region has formed or that, if present, is too faint or compact (and self-absorbed) to be detectable at 20 cm, thus confirming the young nature of the object.

3.2. Other Young Stellar Objects candidates

In the 0.244 deg^2 field observed at 15μm we found a surprisingly large number (210) of sources with a (m_K–$m_{15\mu m}$) colour index greater than 6, corrensponding to $\sim$ 900 sources per square degree. Among these, three have a colour index greater than 9. None of these three sources are near the position of the HII region G45.45 + 0.06, which was not observed with ISOCAM to avoid saturation. A remarkable difference with this bright radio HII region, is that none of the 15μm sources have a radio continuum counterpart in the 20 cm VLA observations of Zoonematkermani et al. (1990), which excludes the presence of an evolved HII region, leaving only the possibility of an associated UCHII region, optically thick at 20 cm.

In order to check that the large colour index observed is not due to a spurious association with a faint background K-band star, but due to an intrinsic infrared excess of the sources, we have searched around the position of the candidate 15μm sources for the presence of bright nearby K sources, but with no success. The main difference in the infrared morphology between these three sources and that associated with the maser is that all of them show faint extended emission (on arcminute scale) at 15μm. The nature of this extended emission is currently under investigation. All the three sources coincide with an IRAS point source, but only in one the IRAS colours are those of a typical UCHII regions (Wood & Churchwell 1989). None of these sources have yet been observed in the H_2O maser line.

4. Conclusions and future work

We have presented preliminary results obtained by the ISOGAL team during the 15μm survey of the inner galaxy. An infrared source with (m_K–$m_{15\mu m}$) colour index greater than 10 is found and is associated with a newly discovered H_2O maser. This finding confirms that ISO can detect young massive (proto-)stars in their earliest evolutionary stages. In these stages, massive stars have not yet developed an HII region around them, and, being deeply embedded in their parental dusty cocoon, can be studied only at infrared and sub-millimiter wavelength.

In the same field we observed more than 200 point sources with (m_K–$m_{15\mu m}$) $\gtrsim$ 6, three of which with a colour greater than 9. They could be young stars still embedded in dusty envelopes. These results confirm the finding of Pérault et al. (1996), who found $\sim$ 1300 objects with similar colours per square degree in a field at $l = -45°$. In our case, the association of the source with the largest colour index with a water maser confirms that we are indeed detecting a YSO. The low 15 μm fluxes of these objects (when compared with bright IRAS YSOs) suggests that, at least statistically, they might be intermediate luminosity YSOs not detectable by IRAS.

These findings prove the effectiveness of the ISOGAL observations in detecting *new* very young stars away from the luminous, well known star forming regions, when compared with deep K-band observations.

Clearly the objects presented here, and in particular that associated with the H_2O maser, deserve to be studied in detail at other wavelengths with high resolution and sensitivity, in order to ascertain their nature. ISOCAM observations at other wavelengths would also be advisable, due to the high resolution and sensitivity achievable in spectral regions not easily accessible from the ground.

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