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# Near-Infrared Imaging Observations of the Orion A-W Star Forming Region

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**Abstract** We carried out near-infrared imaging observations of the Ori A-W region using the Italian 1.5 m TIRGO infrared telescope at Gornergrat. A group of infrared objects is visible on the K band image, including an IRAS source (IRS 1). From its IRAS flux density the IRAS luminosity is derived to be $45L_\odot$, which shows that IRS 1 is a low-mass protostar. By superimposing the position of the VLA $H_2O$ maser on the K image, we can identify the less evolved object IRS 1 as the excitation source of the $H_2O$ maser, within a projected distance of 470 AU. This would be evidence that the maser effect is associated with the youngest phase of stellar evolution. The first probable HH object candidate in the Ori A-W region is discovered from the $H_2$ S(1) 1 − 0 observation. Comparing the position of the $H_2O$ maser with the direction of the molecular hydrogen emission in the region, we suggest that the observed $H_2O$ maser could be tracing the circumstellar disk of IRS 1.

**Key words:** Stars: formation — ISM: jets and outflows

## 1 INTRODUCTION

Star formation process is one of the most challenging topics in modern astrophysics. $H_2O$ masers can be used to trace the early evolutionary phases of Young Stellar Objects (YSOs). The 22 GHz water masers have been observed in many star forming regions. However, some key issues have not been settled so far, for instance, the engines and the physical features of masers.

Water masers can be found only in the region within $10^{2-4}$ AU of an energy source, where sufficient power is available either in the form of infrared radiation or of J-type/C-type shocks; see the models proposed by Elitzur et al. (1989). In order to probe the interactions between YSOs and their circumstellar material, high resolution near-infrared imaging observations are needed. Before our work some near-infrared observations have been carried out (e.g. Testi et

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al. 1994), all of which showed that the near-infrared observation may be a very good tool to unveil the powering source of water masers.

## 2 OBSERVATIONS

We acquired the near-infrared imaging observations of the Ori A-W region on Nov.9 1995, using the 1.5 m TIRGO telescope with the Arcetri near-infrared camera (ARNICA) at Gornergrat Observatory. The ARNICA detector is a NICMOS3 256×256 pixel HgCdTe array. The scale on the detector is roughly 0.95″/pixel. We obtained J, H and K broad-bands and $H_2$ S(1) 1 − 0, narrow bands images. For each filter nine frames were taken. All the observed images were reduced using the ARNICA and IRAF software packages. We combined all the images centered on the star forming region to produce a mosaic image. Photometry was performed using the DAOPHOT routines of IRAF and the magnitudes of all the sources in the area were obtained. Some standard stars from the ARNICA standard star list were also observed for absolute flux calibration. The limiting magnitudes are 16.9, 15.0 and 15.8 in J, H and K bands respectively, for the whole mosaic image.

Table 1 presents the results of astrometry and photometry for six infrared sources in the Ori A-W region. Note that all the sources are in a small region in the center of the mosaic image and all are above the detection limit of K band.

**Table 1** The Results of Near-Infrared Photometry and Astrometry

| Name | R. A. (1950) | Decl. (1950) | Q | J | ej | H | eh | K | ek | J–H | J–K | H–K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IRS 1 | 5 30 14.36 | –5 37 50.3 | 0 0 1 | >16.9 | - | >15.0 | - | 12.1 | 0.012 | - | - | - |
| IRS 2 | 5 30 14.37 | –5 38 15.4 | 0 0 1 | >16.9 | - | >15.0 | - | 13.5 | 0.031 | - | - | - |
| IRS 3 | 5 30 14.95 | –5 37 54.6 | 0 0 1 | >16.9 | - | >15.0 | - | 13.3 | 0.035 | - | - | - |
| IRS 4 | 5 30 15.22 | –5 37 59.6 | 0 0 1 | >16.9 | - | >15.0 | - | 12.7 | 0.021 | - | - | - |
| IRS 5 | 5 30 15.52 | –5 38 0.8 | 0 0 1 | >16.9 | - | >15.0 | - | 13.2 | 0.033 | - | - | - |
| IRS 6 | 5 30 16.12 | –5 38 0.8 | 1 1 1 | 12.9 | 0.006 | 12.1 | 0.015 | 10.5 | 0.003 | 0.78 | 2.349 | 1.571 |

Q = quality of the JHK observations. 1 for “detectable”, 0 for “below detection limit”. ej, eh and ek are the errors in J, H, K. The limiting magnitudes are 16.9 (J), 15.0 (H) and 15.8 (K).

## 3 ANALYSIS AND DISCUSSION

Ori A-west is a class I YSO associated with IRAS 05302–0537, and its bipolar molecular outflow was found in an unbiased survey of the Orion southern molecular cloud by Fukui et al. (1986). A weak, almost unresolved, radio continuum source was detected by Tofani et al. (1995), coincident with the position of the water maser. However, the question whether the source is an UC HII region, a stellar wind, a collisionally ionized region, or a non-thermal source, remains unclear. On the other hand, the radio emission is much higher than what is expected from a low-luminosity YSO and the water maser emission shows a strong variability on a short time scale.

At the molecular outflow position, a group of infrared objects is visible on the K band image shown in Fig. 1. At least two of these objects are associated with a localized nebulosity. There is also a curved nebular feature in the K band image, while the other two panels (H and J) only show the brightest of the infrared objects. This object is identified as IRS 6, which is an emission line star with visual magnitude 16.7. Its infrared excess is very small and it seems to be a more evolved object than the other objects in the region. Figure 2 shows the DSS map in the Ori A-W area, in which the only optically visible object is the emission line star IRS 6. The 2MASS point sources are superimposed on the DSS map and marked as crosses and the positions of the sources are nearly coincident with their positions on our K image.

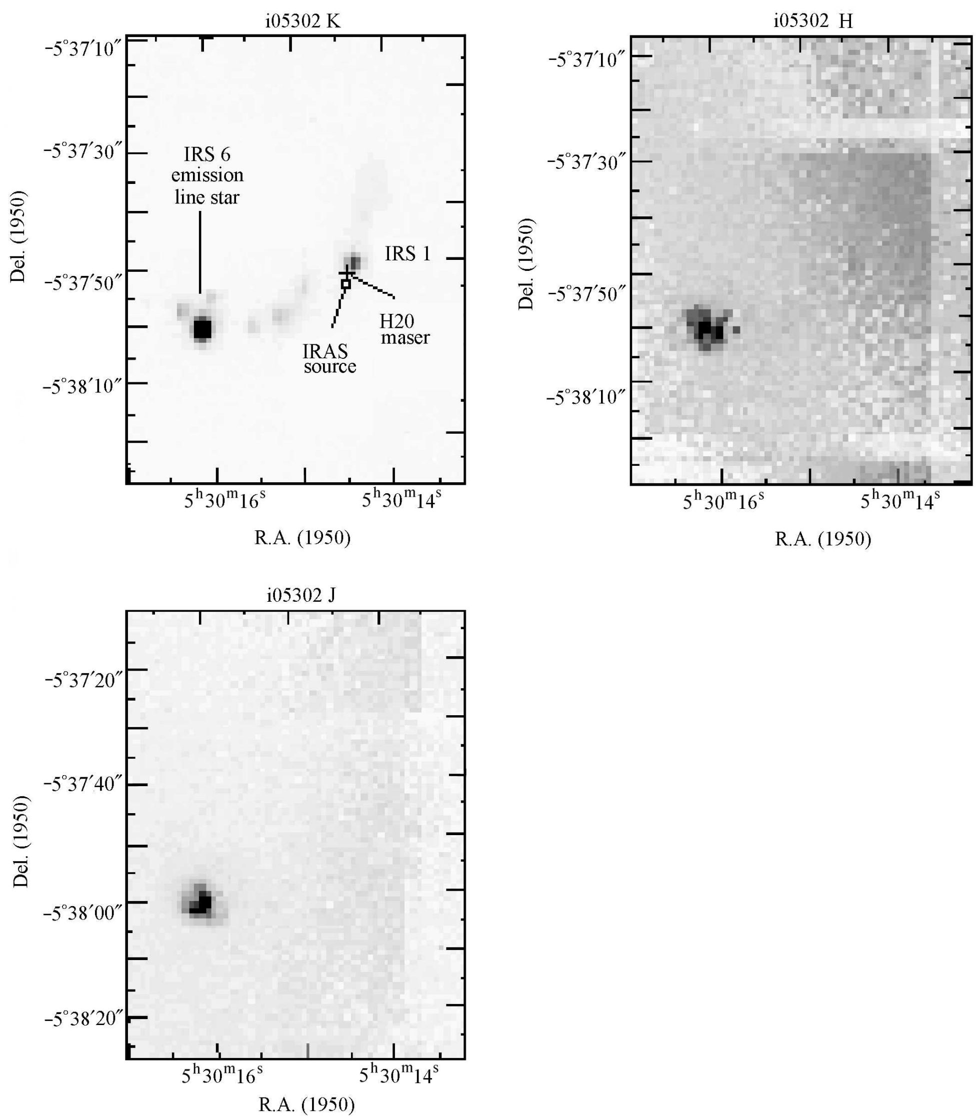


Fig. 1 The J, H and K broad band images of the Ori A-W star forming region. The three panels are the enlarged central parts of original mosaic images.

The IRAS position is marked on both Figs. 1 and 2. In the vicinity of the IRAS source, only IRS 1 appears. Considering the error of IRAS positions, IRS 1 should be the same object as the

IRAS source. We calculated the IR luminosity by using the formula in Morgan & Bally (1991)

$$L(L_\odot) = 23.0(D/500\text{pc})^2 \int (S/\lambda^2)\text{d}\lambda \,,$$

where $S$ is the IRAS flux density in Jy, $D$ is the distance to the source, and $\lambda$ is the wavelength. The IRAS luminosity can be derived to be $45L_\odot$ from the four IRAS flux values, 4.3, 19.3, 55.3 and 82.4 Jy, so the source proved to be a low luminosity source. From Fig. 3, obviously IRS 1 is a source with the largest infrared excess in the bent cloud and possibly is one of the youngest objects in this region with a very thick dust envelop.

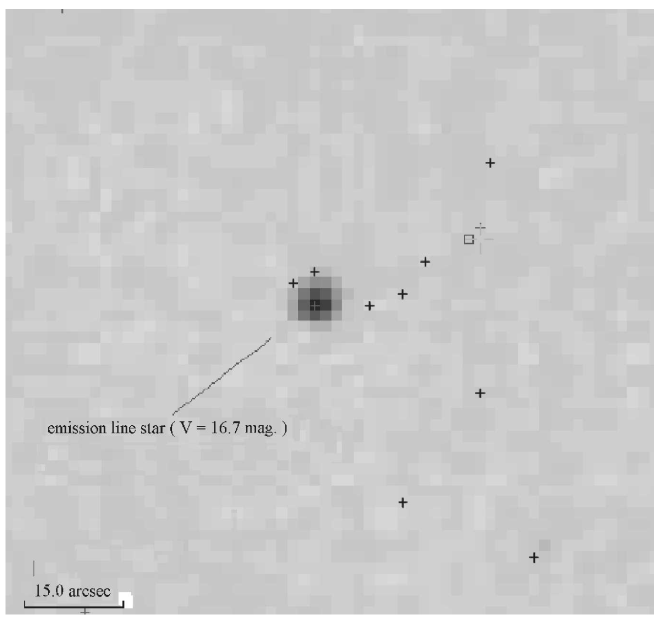


Fig. 2 Digital Sky Survey map in the Ori A-W area. Crosses mark 2MASS point sources. The small square marks the position of the IRAS source.

In the panel i05302K of Fig. 1, the water maser position, which was observed by VLA (Tofani et al. 1995), is also coincident with IRS 1. The positional accuracy of the maser is better than $0''.1$ while the separation between the maser and IRS 1 is $0.94''$, corresponding to a projected distance of 470 AU for a heliocentric distance of 500 pc. Tofani et al. (1995) suggested that the water masers can be found only in a region $10^{2-4}$AU from an energy source. Also based on the "near" model (Testi et al. 1994), we can identify IRS 1 as the excitation source of the $H_2O$ maser. This would be evidence that the maser effect is correlated with the youngest phases of stellar evolution, when the YSO is still embedded in a dense cocoon.

Figure 4 presents the narrow band images of $H_2$ S(1) 1 − 0. In the panel i05302 (h2–k) of Fig. 4, a weak molecular hydrogen emission can be seen in the upper middle part, it seems to be an HH object candidate with a bow shock feature. We find that it is collimated to IRS 1 from the shape of the bow shock. This is the first probable HH object candidate in the Ori A-W region. Furthermore, considering that the IRAS color excess $\log(f25/f12)=0.65$, $\log(f60/f25)=0.46$, $\log(f100/f60)=0.17$, satisfies the criteria of HH energy source (Wu 2001), the excitation source (IRS 1) of $H_2O$ maser could also energize the molecular hydrogen emission.

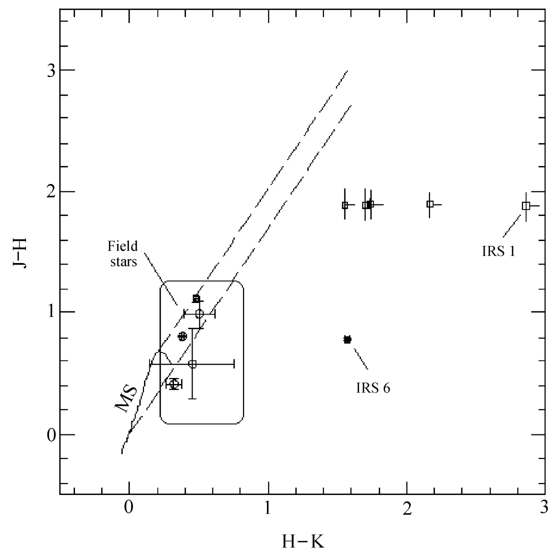


Fig. 3 Near-infrared color-color diagram. All our detected sources in the Ori A-W belt-like region are marked as small squares, the stars within the large rectangle are field stars outside the Ori A-W region. The two dash lines mark the main-sequence lane.

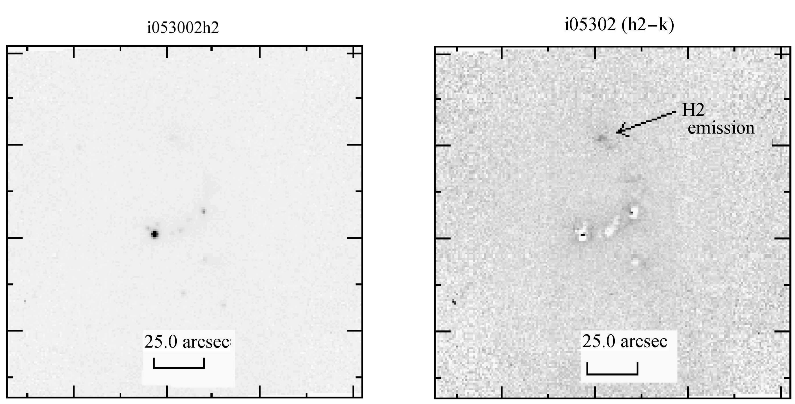


Fig. 4 $H_2$ S(1) 1 – 0 at 2.12$\mu$m and $H_2$–K images.

It has been proposed that $H_2O$ masers can trace either outflows or disks around YSOs (Torrelles et al. 1998). The systems in which $H_2O$ masers trace disks are less evolved than those in which masers trace outflows. Comparing the position of the $H_2O$ maser with the direction of outflow and molecular hydrogen emission in the Ori A-W region, it can be clearly seen that they are perpendicular to each other. The $H_2O$ maser appears to the south-east of IRS

1, whereas the outflow and $H_2$ emission are from the north-east to the south-west. Therefore the observed $H_2O$ maser could not be tracing the outflow, but possibly be tracing the circumstellar disk of IRS 1.

## 4 CONCLUSIONS

Based on the NIR imaging observations of the Ori A-W star forming region, the object IRAS 05302–0537 is identified as the low-mass, near-infrared source IRS 1. By superimposing the position of the VLA $H_2O$ maser on the K image, we have deduced that IRS 1 could be the excitation source of the $H_2O$ maser. The projected distance between the $H_2O$ maser and IRS 1 is 470 AU. The identification of the first probable HH object candidate in the Ori A-W region is based on the $H_2$ S(1) $1-0$ observation. By comparing the position of the $H_2O$ maser with the direction of the molecular hydrogen emission in the region, we suggest that the observed $H_2O$ maser could be a tracer of the circumstellar disk of IRS 1 rather than of IRS 1 itself.

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## References

Elitzur M., Hollenbach D. J., McKee C. F., 1989, ApJ, 346, 983
Fukui Y., Sugitani K., Takaba H. et al., 1986, ApJ, 311, L85
Morgan J. A., Bally J., 1991, ApJ, 372, 505
Testi L., Felli M., Persi P., Roth M., 1994, A&A, 288, 634
Tofani G., Felli M., Taylor G. B., Hunter T. R., 1995, A&AS, 112, 299
Torrelles J. M., Gomez J. F., Rodriguez L. F. et al., 1998, ApJ, 505, 756
Wu J. W., 2001, Thesis for MS degree, Peking University