

## High Resolution 18 $\mu\text{m}$ Imaging of Hot Molecular Cores

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**Abstract.** I present the latest results from a search for hot molecular cores at mid-infrared wavelengths from the largest optical telescopes available at the present time. Three well-observed hot molecular cores were imaged, G29.96-0.02, G19.61-0.23, and G34.26+0.15. Even though mid-infrared sources have been claimed to be detected previously at the hot molecular core locations of both G19.61-0.23 and G34.26+0.15, only the hot molecular core in G29.96-0.02 resulted in a detection. New upper limits on mid-infrared emission are given for the hot molecular cores that were not detected.

### 1. Introduction

Hot molecular cores (HMCs) are believed to represent the earliest stages of massive stellar birth, however there are very few observations of these objects to date. The basic characteristics of hot molecular cores are: 1) they are compact sources seen in radio wavelength ammonia (or molecular line) images but have little or no radio continuum emission; 2) they lie in massive star forming regions near ultracompact HII (UC HII) regions; 3) they are too young and/or embedded to be seen in the optical or near infrared; and 4) they are often coincident with water maser emission. Only a small number of sources exist that have had such a holistic set of observations performed.

Cesaroni et al. (1994) argue that the dust and gas in these HMCs are well-mixed and that the gas temperatures derived from ammonia line imaging should be an approximation to the dust temperatures. Since emission from a 160 K blackbody peaks at 18  $\mu\text{m}$  and these HMCs have gas temperatures of 50-200 K, the mid-infrared is a good wavelength regime to try to detect these types of sources.

I present here sub-arcsecond 18  $\mu\text{m}$  images of the sites of three hot molecular cores. All three sites are certified massive star forming regions due to the presence of UC HII regions. All sites contain water masers that are isolated from centimeter radio emission sources. Furthermore, all three sites have been found to contain ammonia emission coincident with the water maser locations, as observed through high-resolution molecular line imaging.

The 18  $\mu\text{m}$  observations of these HMCs were performed at the Gemini North and W.M. Keck II telescopes using OSCIR. The reasons for using such large telescopes are two-fold: 1) to separate the mid-infrared emission of the HMC from that of any other nearby sources, like extended UC HII regions; and 2) to exploit the higher sensitivity of the larger telescopes so that detections

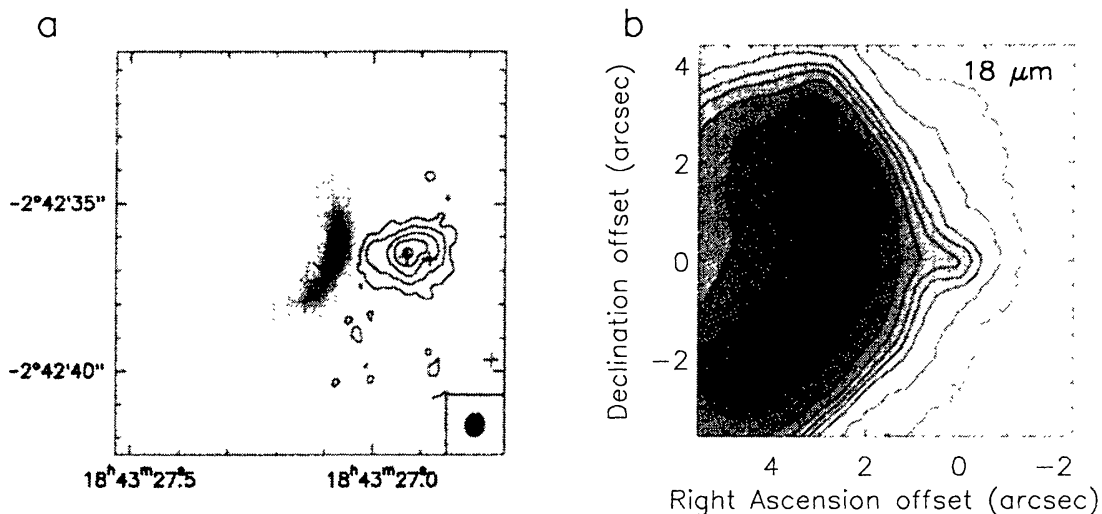


Figure 1. Observations of G29.96-0.02. (a) A figure from Cesaroni et al. (1998). Shown are the UC HII region at 1.3 cm (grayscale), and the HMC seen in ammonia line emission (contours). Water masers are plotted as crosses. (b) The 18  $\mu\text{m}$  image of the same region shown as filled contours. The HMC can be seen as a “bump” on the UC HII region to the west.

are made more readily, or so that stringent upper limits can be placed on the mid-infrared emission coming from those sources not detected.

## 2. Observations

The University of Florida mid-infrared imager and spectrometer OSCIR was used for all observations. OSCIR employs a Rockwell 128 $\times$ 128 pixel Si:As BIB (blocked impurity band) detector. All observations were taken through the International Halley Watch 18  $\mu\text{m}$  (*IHW18*) filter, which has an effective central wavelength at 18.06  $\mu\text{m}$ , and a filter width of 1.7  $\mu\text{m}$ . Background subtraction was achieved during the observations via the standard chop-nod technique.

While at the Keck II 10-m telescope, OSCIR had a pixel scale of 0<sup>''</sup>.0616 pixel<sup>-1</sup>. During the observations point-spread function stars were observed, yielding an estimate of the effective resolution of the observations of 0<sup>''</sup>.41. At the Gemini North 8-m telescope, OSCIR had a pixel scale of 0<sup>''</sup>.084 pixel<sup>-1</sup> and an effective resolution of 0<sup>''</sup>.63.

There were no detections of mid-infrared sources at the locations of 2 of the 3 hot molecular cores.

## 3. The Detection

### 3.1. G29.96-0.02

In the region of G29.96-0.02 lies a cometary shaped ultracompact HII region around a spectral type O7 star (Watson & Hanson 1997). In Figure 1a (from

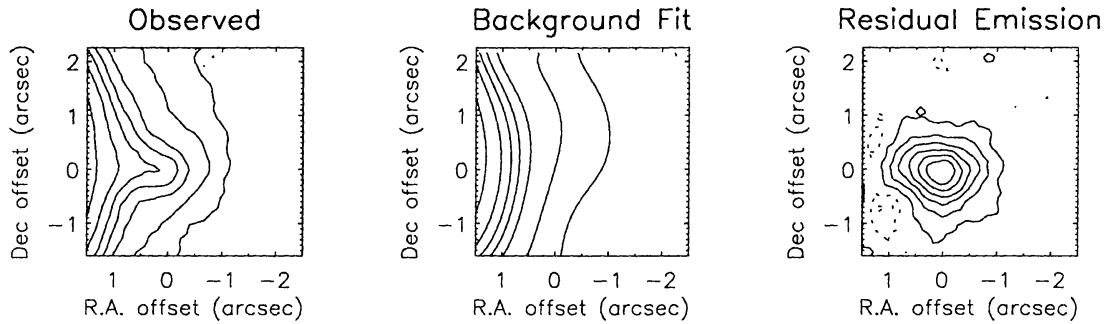


Figure 2. Isolating the HMC emission in G29.96-0.02. The three panels show, from left to right, a portion of the original  $18\ \mu\text{m}$  image from Gemini containing the HMC, the background polynomial fit of 5th order in  $x$  and  $y$ , and the HMC in the residual frame. The contours shown are -16, -8, 8, 25, 42, 59, 76, and 93% of the peak flux density of  $1.9\ \text{Jy}\ \text{arcsec}^{-2}$ .

Cesaroni et al. 1998) the grayscale shows the UC HII region at  $1.3\ \text{cm}$  and the crosses mark the positions of water masers. These water masers are offset and do not seem to be associated with the UC HII region. Instead they appear to be associated with a source seen only in ammonia emission (contours). It was claimed by Cesaroni et al. (1994) that this source seen in ammonia emission may be a hot molecular core. Figure 1b shows the  $18\ \mu\text{m}$  image from Gemini North of the same region (grayscale with contours for emphasis). The UC HII region appears more extended in the mid-infrared, but the HMC can be clearly seen as a “bump” on the western side of the UC HII region.

The HMC in G29.96-0.02 is difficult to see in the mid-infrared because it is still partially embedded in the extended emission from the nearby UC HII region. However, a two-dimensional polynomial surface was fit to this background emission (excluding a  $2''$  by  $2''$  region around the HMC), isolating the emission from the HMC alone. The three panels in Figure 2 show, from left to right, a portion of the original  $18\ \mu\text{m}$  image from Gemini containing the HMC, the background polynomial fit of 5th order in  $x$  and  $y$ , and the HMC in the residual frame.

Figure 3a shows a grayscale image of the  $1.3\ \text{cm}$  continuum observations of Cesaroni et al. (1998). The overlaying contours are from the  $18\ \mu\text{m}$  mid-infrared data presented in Figure 1. Good morphological agreement for the UC HII region is found between the two wavelengths, adding credibility to the astrometry. The large, thin cross marks the position of the ammonia peak of the hot core from Cesaroni et al. (1998). The small, thick cross marks the peak in the mid-infrared dust emission from the hot core. Figure 3b shows a close up view centered on the mid-infrared peak of the hot core. Apparent in this figure are the offset peaks of the mid-infrared (thick contours) and ammonia emission (thin contours), possibly due to optical depth effects, or more likely showing there are two different embedded objects here (De Buizer et al. 2002). Filled black circles mark the locations of the water masers from Hofner & Churchwell (1996), and the filled triangle marks the location of the methanol maser group from Minier, Conway, & Booth (2001).

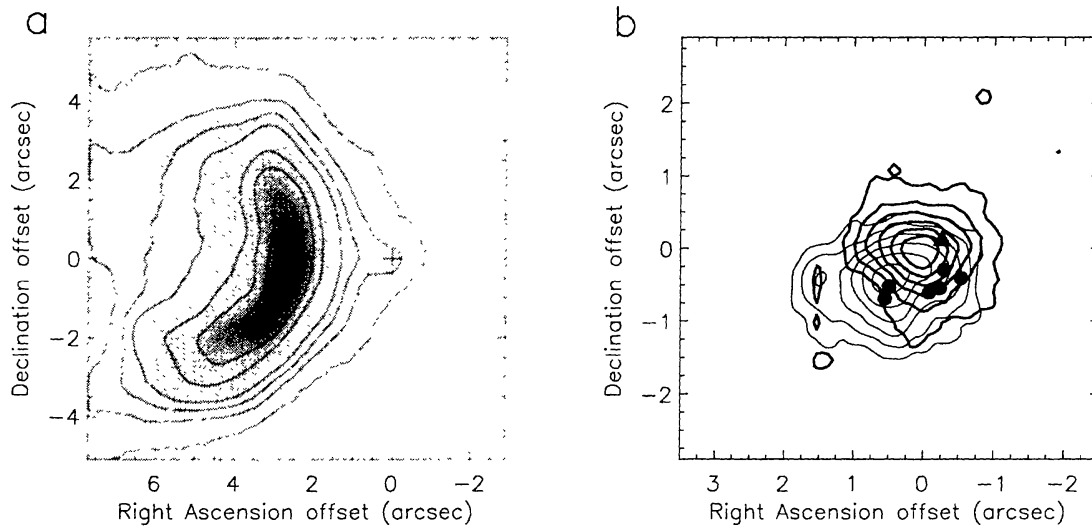


Figure 3. Comparing the HMC seen in ammonia and at 18  $\mu\text{m}$ . **(a)** An overlay of 18  $\mu\text{m}$  emission (contours) on the 1.3 cm emission of Cesaroni et al. (1998) showing the similarity in UC HII region morphology. The large, thin cross marks the position of the ammonia peak of the hot core and the small, thick cross marks the peak in the mid-infrared dust emission. **(b)** A close up view centered on the mid-infrared peak of the hot core. There is an apparent offset between the peaks of the mid-infrared (thick contours) and ammonia emission (thin contours). Filled black circles mark the locations of the water masers from Hofner & Churchwell (1996), and the filled triangle marks the location of the methanol maser group from Minier, Conway, & Booth (2001).

A full discussion of the detection of the HMC in G29.96-0.02 can be found in De Buizer et al. (2002).

## 4. The Non-Detections

### 4.1. G19.61-0.23

G19.61-0.23 is an extremely complex region of massive star formation. There are several (at least six) UC HII regions that can be seen in both radio continuum emission (Garay et al. 1998) and in the mid-infrared. Figure 4a shows contours of the whole region at 18  $\mu\text{m}$  from NASA's InfraRed Telescope Facility 3-m telescope (De Buizer 2000). The stars denote the locations of three clusters of water masers. The middle of the three water maser clusters was found to be coincident with a mid-infrared source seen only at 18  $\mu\text{m}$  at a detection level of  $2.5\text{-}\sigma$  (230 mJy) by De Buizer (2000). Since such a low detection level is by no means conclusive, this site required further observation.

The box in Figure 4a delineates the field of view in Figure 4b taken from Gemini North. In this figure, contours of ammonia emission (dark gray lines) from Garay et al. (1998) are overlaid, along with the water masers (crosses) from Forster & Caswell (1989). The very bright UC HII region seen in the mid-

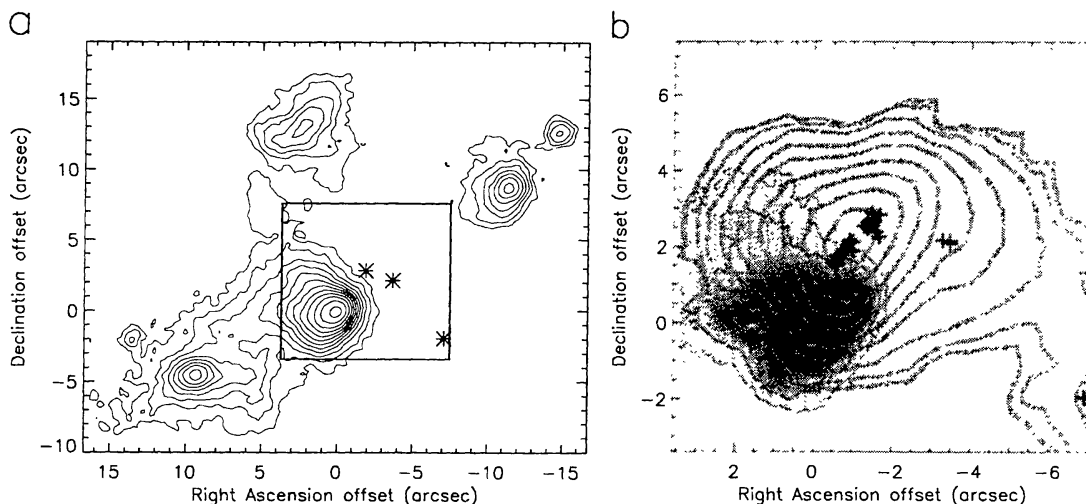


Figure 4. G19.61-0.23. (a) Large-scale  $18\ \mu\text{m}$  emission from De Buizer (2000). The stars denote the locations of three clusters of water masers, and the box delineates the field of view of (b). (b) The  $18\ \mu\text{m}$  emission as seen from Gemini North (grayscale and thin black contours). Overlaid are contours of ammonia emission (dark gray lines) from Garay et al. (1998) and water masers (crosses) from Forster & Caswell (1989). We do not detect a source at any of the three maser cluster locations.

infrared is not coincident with the masers, but the masers *are* associated with the ammonia emission. We do not detect a source at any of the three maser cluster locations at a  $3\text{-}\sigma$  upper limit of  $12\ \text{mJy}$  at  $18\ \mu\text{m}$ , including the middle maser cluster. The weak mid-infrared emission seen by De Buizer (2000) was apparently noise.

#### 4.2. G34.26+0.15

Like G29.96-0.02, this site has many masers out in front of the apex of a cometary shaped UC HII region. However, the masers are more spread out, and some do appear to be associated with the sharp UC HII boundary. Figure 5a is from Gaume, Fey, & Claussen (1994) and shows 2 cm contours of the UC HII region and two nearby compact sources, as well as the water (crosses) and OH (circles) masers. In Figure 5b, the light gray contour lines show the location of ammonia emission from Keto et al. (1992) which is to the east of this UC HII region and coincident with many masers in the region. Interestingly, Keto et al. (1992) present a  $12.5\ \mu\text{m}$  image of this site which shows a faint ( $70\ \text{mJy}$ ) mid-infrared source in the area of the water masers and ammonia emission. The grayscale image underneath these ammonia contours in Figure 5b is the  $18\ \mu\text{m}$  image from Gemini North (with thin black contours for emphasis). No source was detectable at the location of this ammonia clump at a  $3\text{-}\sigma$  upper limit of  $20\ \text{mJy}$  at  $18\ \mu\text{m}$ . This site was also imaged at  $10\ \mu\text{m}$  by De Buizer (2000) with no detection at this maser/ammonia location. Therefore, the validity of the source seen by Keto et al. (1992) is questionable.

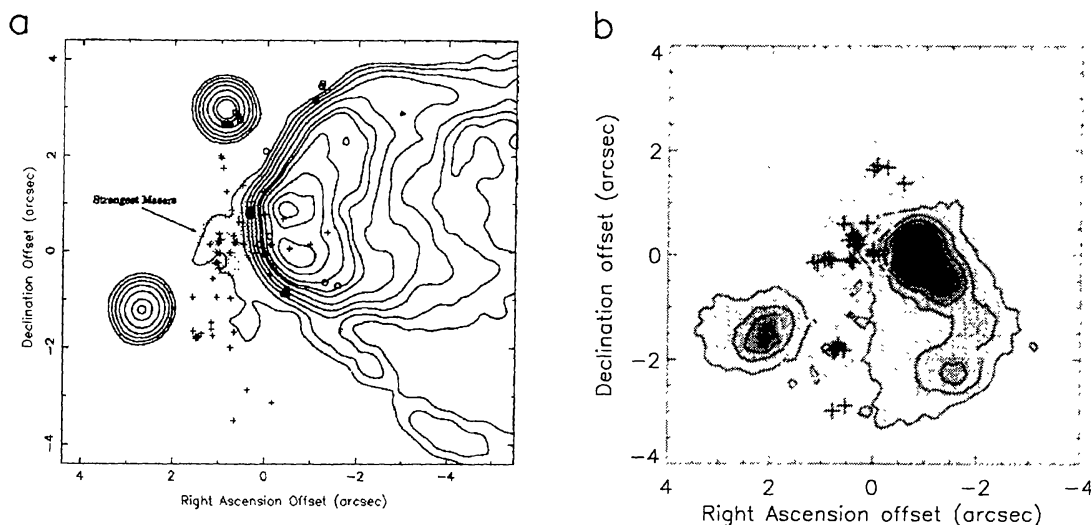


Figure 5. G34.26+0.15. (a) A figure from Gaume, Fey, & Claussen (1994) showing the 2 cm contours of the UC HII region and two nearby compact sources, as well as the water masers (crosses). (b) The 18  $\mu\text{m}$  image from Gemini North shown as grayscale with thin black contours. The light gray contours are the ammonia emission from Keto et al. (1992) with the water masers in the region plotted as crosses. No HMC was detected in the mid-infrared.

## 5. Conclusions

Three well-observed hot molecular cores were imaged at 18  $\mu\text{m}$ , G29.96-0.02, G19.61-0.23, and G34.26+0.15. Only the hot molecular core in G29.96-0.02 resulted in a detection. This was a surprise considering the previous “detections” of HMCs in the sites of both G19.61-0.23 and G34.26+0.15. This small research program has shown that the mid-infrared can be useful in observing and studying some HMCs. It has also shown that the resolution and sensitivity afforded by the 8 to 10-m class telescopes are important to perform this research effectively.

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