N91-14918

INFRARED IMAGES OF REFLECTION NEBULAE AND ORION'S BAR : FLUORESCENT MOLECULAR HYDROGEN AND THE 3.3 μm FEATURE

M.G. Burton*, A. Moorhouse**, P.W.J.L. Brand**,
P.F. Roche*** and T.R. Geballe****

* NASA Ames Research Center, Moffett Field, California 94035, USA.
** Department of Astronomy, University of Edinburgh, Blackford Hill, Edinburgh, EH9 3HJ, Scotland.
*** Royal Observatory Edinburgh, Blackford Hill, Edinburgh, EH9 3HJ, Scotland.
**** Joint Astronomy Center, 665 Komohana Street, Hilo 96720, USA.

Abstract

Images have been obtained of the (fluorescent) molecular hydrogen 1–0 S(1) line, and of the 3.3 μm emission feature, in Orion's Bar and three reflection nebulae. The emission from these species appears to comes from the same spatial locations in all sources observed. This suggests that the 3.3 μm feature is excited by the same energetic UV–photons which cause the molecular hydrogen to fluoresce.

Observations

We have obtained infrared images of emission from molecular hydrogen and the 3.3 μm feature in the ionisation front Orion's Bar, and in portions of three reflection nebulae, NGC 1333 SVS 3, NGC 2023 and Pars 18. In all these sources ultra–violet radiation is beleived to be responsible for the excitation of the molecular hydrogen. The data was obtained at the UKIRT in January of 1988 using the infrared camera IRCAM with 0.6$''$ pixel scale. Narrow band (1%) filters were used to image the 3.3 μm emission feature, the molecular hydrogen v=1–0 S(1) line (2.12 μm), and the atomic hydrogen Brackett γ line (2.16 μm). The images shown here were constructed by mosaicing together several overlapping frames (note that East is to the right in the figures). Typical integration times were 5 minutes a frame. Images were also obtained through narow band filters at 2.1 μm and 3.1 μm to assess the contribution of continuum radiation to the emission. Apart from emission from stars, there was essentially no continuum detected at any of the positions observed.

Contour maps of the H_2 line emission from the two reflection nebulae NGC 1333 SVS 3 and NGC 2023, overlapped on those of the $3.3\,\mu$m emission feature, are shown in Figures 1 & 3 (the image for Pars 18 is not shown). In all three nebulae there is a tight correlation between the location of the $3.3\,\mu$m feature emission and the fluoresced molecular hydrogen emission. Although the relative proportions of S(1) and $3.3\,\mu$m emission vary between the sources, this correlation suggests they arise from the same spatial locations in each source. Brackett γ recombination line emission from ionised gas was not detected in these sources.

In Orion's Bar the $3.3\,\mu$m emission feature is clearly defined by a sharp, linear, ridge (Fig. 2). The ridge is parallel to the ionisation front seen in optical recombination lines (Munch & Taylor 1974), but lies behind it. The emission reaches a maximum within $5''$ of the ionisation front, and then falls off approximately exponentially. The feature is still detected $30''$ away. There are two components to the H_2 line emission beyond the ionisation front, with the strongest emission located in a layer about $15''$ away from it. There is $3.3\,\mu$m emission in front of and behind this layer.

The Reflection Nebulae

In the reflection nebulae observed, the H_2 and $3.3\,\mu$m emission arises in photodissociation fronts. Beyond the front there are insufficient UV photons with enough energy to photo-dissociate the molecules. The structure of such fronts has been modelled by several authors (*e.g.* Tielens & Hollenbach 1985, Black & Van Dishoeck 1987). The UV flux can heat, through the photo-electric mechanism, a column of gas near the cloud surface to high temperatures ($\sim$ 100 to 1000 K). UV-pumping can excite the molecular hydrogen, leading to an appreciable amount of vibrationally excited H_2 in the gas. Cooling occurs primarily by the OI $63\,\mu$m and CII $158\,\mu$m lines. The near-infrared spectrum of NGC 2023 is dominated by emission from high-vibrational states of molecular hydrogen (Gatley *et al.* 1987), demonstrating that the emission is fluorescently excited.

In all of the reflection nebulae observed the $3.3\,\mu$m emission arises in almost exactly the same regions as the (fluorescent) H_2 emission. The correlation is particularly tight in NGC 2023. These emission regions form shell-like structures around the exciting stars of the nebulae, with the fluoresced H_2 located at an optical depth

$A_v \sim 1$ from the stars. The relative intensity of the H_2 and $3.3\,\mu m$ emission does vary between sources, and in the northern portion of NGC 1333 SVS 3, H_2 line emission was not detected. This may just be a sensitivity effect, the S(1) line flux falling below the detection limit. In addition, the extinction to the S(1) line, at $2.1\,\mu m$ is greater than to the $3.3\,\mu m$ feature; the variation may result from variable extinction.

The $3.3\,\mu m$ emitting gas must therefore also lie in the photo-dissociation region with the excited H_2. This strongly suggests that the same UV–photons which excite the molecular hydrogen (with $\lambda = 912 - 1100$Å) can also excite the $3.3\,\mu m$ emission feature. This is in fact slightly surprising for it is likely that UV photons with wavelengths greater than 1100Å can also excite the $3.3\,\mu m$ feature, whereas they cannot induce H_2 to fluoresce. This may account for the more extended $3.3\,\mu m$ emission region in NGC 1333 SVS 3 than the H_2, with lower energy photons penetrating further into the surrounding molecular cloud. However in NGC 2023 and Pars 18 the emission regions appear coincident. If the optical depth is rising rapidly behind the emission shell, then all energetic photons will be effectively stopped and neither H_2 nor $3.3\,\mu m$ feature will be excited beyond it.

Alternatively the 3.3 μm emitting material may be preferentially formed in the hot, dense photo-dissociation regions. If this were the case, though, we might expect to observe the feature away from the photo-dissociation front if UV photons were not responsible for its excitation. This has not been observed in the reflection nebulae. The absence of Br γ line emission in any of the sources indicates that the excitation of the $3.3\,\mu m$ emission feature is not related to presence of ionised gas.

Orion's Bar

Orion's Bar appears is a classical example of an edge-on ionisation front. The edge is well defined by the $3.3\,\mu m$ image of the Bar (Fig. 2), lying just behind the ionisation front. It shows clearly that the $3.3\,\mu m$ emission feature arises from the neutral region behind the front, as other evidence indicates (*e.g.* Sellgren 1981, Aitken *et al.* 1979). The approximately exponential fall-off of the emission strength with distance from the front is consistent with what would be expected if UV radiation were responsible for the feature's excitation, with the optical depth of the emitting region increasing linearly with distance into the cloud from the source of UV photons.

The H_2 v=1–0 S(1) line emission is more complicated, possibly containing two components. There is in fact diffuse H_2 line emission from all over the mapped region. The emission may arise from both shocked and fluorescent line emitting regions in the gas (Hayashi *et al.* 1985). The H_2 line emission nearer the front, around the $3.3\,\mu m$ emission ridge, is probably excited by UV-fluorescence, as in the reflection nebulae. The emission is weaker, relative to the $3.3\,\mu m$ emission, than the H_2 line emission from the reflection nebulae. This could result from an underabundance of H_2 molecules, which may occur if the grains become so hot that reformation of dissociated hydrogen molecules is inefficient. The carriers of the $3.3\,\mu m$ feature are then presumably not dissociated to a comparable extent as the hydrogen molecules.

The strongest H_2 line emission observed originates $15''$ behind the front, in a layer assigned as shocked emission by Hayashi *et al.* There is $3.3\,\mu m$ emission behind and in front of this layer. If this is indeed a shocked layer, it would indicate that that the shock does not significantly affect the material responsible for the feature emission.

We feel it more likely, however, that the H_2 line emission from this layer arises in a dense photo-dissociation region rather than behind a shock. It is hard to drive a shock wave by an expanding HII region into molecular gas sufficiently fast to excite the molecular hydrogen. The shock front would also be expected to lie adjacent to the ionisation front, rather than be offset $15''$ from it. If the molecular gas is sufficiently dense ($\geq 10^5 - 10^6\ cm^{-3}$), collisions can thermalise the fluoresced molecules before they can radiate. The emission spectrum from such a region can therefore appear similar to that from hot, shocked gas, although UV-fluorescence is responsible for its excitation.

References

Aitken, D.K., Roche, P.F., Spenser, P.M. & Jones B., 1979. *Astron. Astrophys.*, **76**, 60.

Black, J. & Van Dishoeck, E., 1987. *Astrophys. J.*, **322**, 412.

Gatley, I., Hasegawa, T., Suzuki, H., Garden, R., Brand, P., Lightfoot, J., Glencross, W., Okuda, H. & Nagata, T., 1987. *Astrophys. J. (Lett)*, **318**, L73.

Hayashi, M., Hasegawa, T. Gatley, I., Garden, R. & Kaifu N., 1985 *Mon. Not. R. astr. Soc.*, **215**, 31p.

Munch, G. & Taylor, K., 1974. *Astrophys. J. (Lett)*, **192**, L93.

Sellgren, K., 1981. *Astrophys. J.*, **245**, 138.

Tielens, A.G.G.M. & Hollenbach, D.J., 1985. *Astrophys. J.*, **291**, 722.

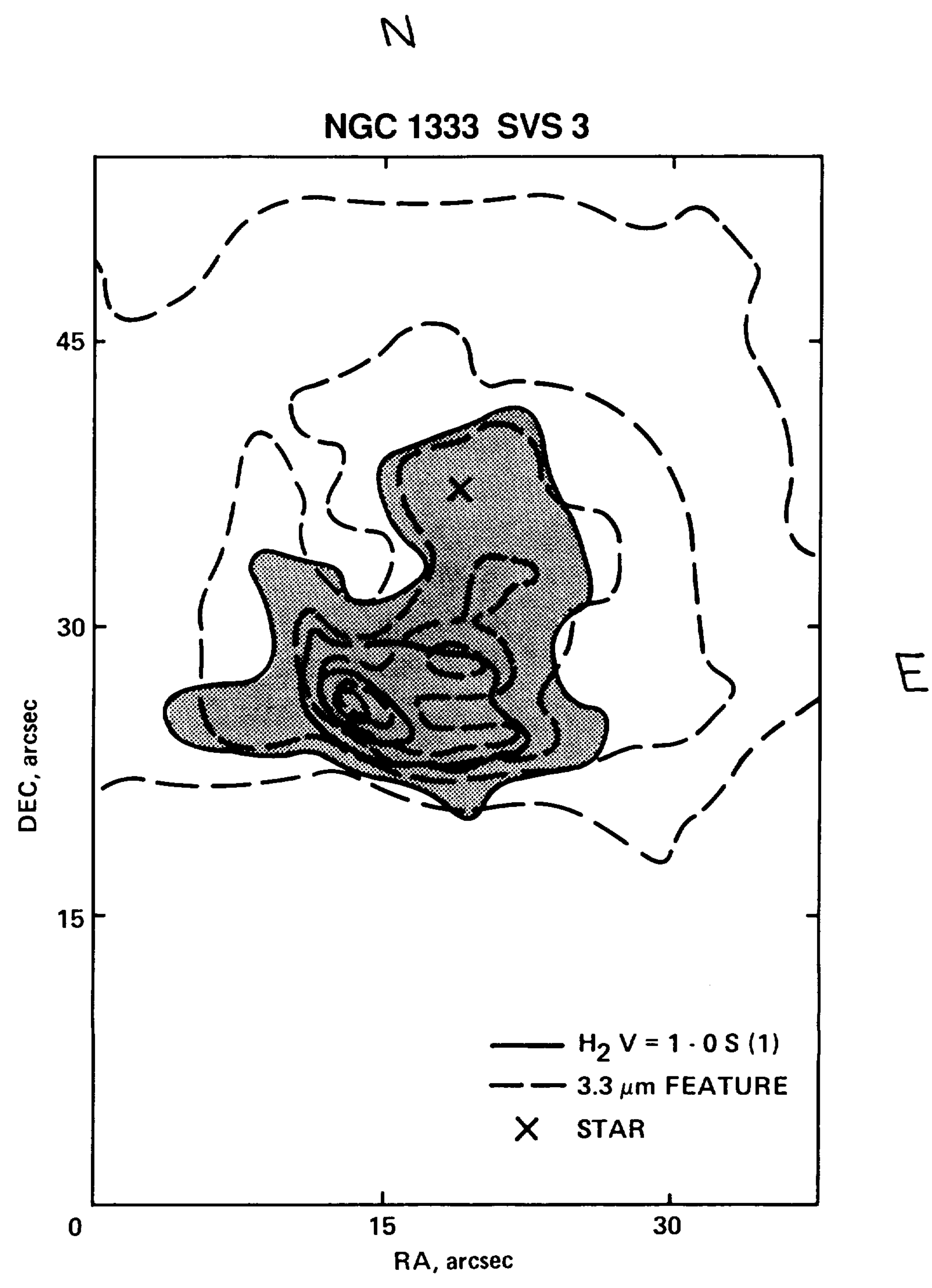


Figure 1. Contour maps of the molecular hydrogen v=1-0 S(1) line (2.12μm) (continuous line, shaded region) and the 3.3μm emission feature (dashed line) in the refelction nebula NGC 1333 SVS 3. The location of the exciting star is marked by the X. The image scale is 0.6" and the map consists of two overlapping frames.

Figure 2.

ORIONS BAR

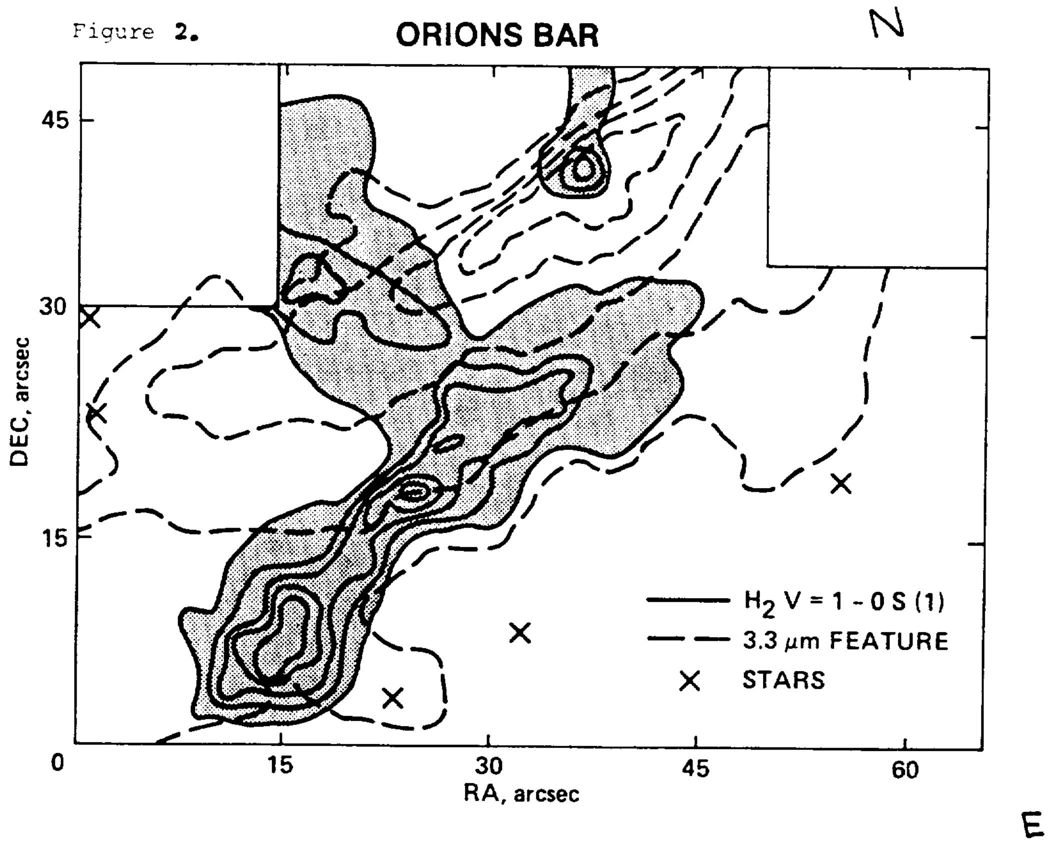
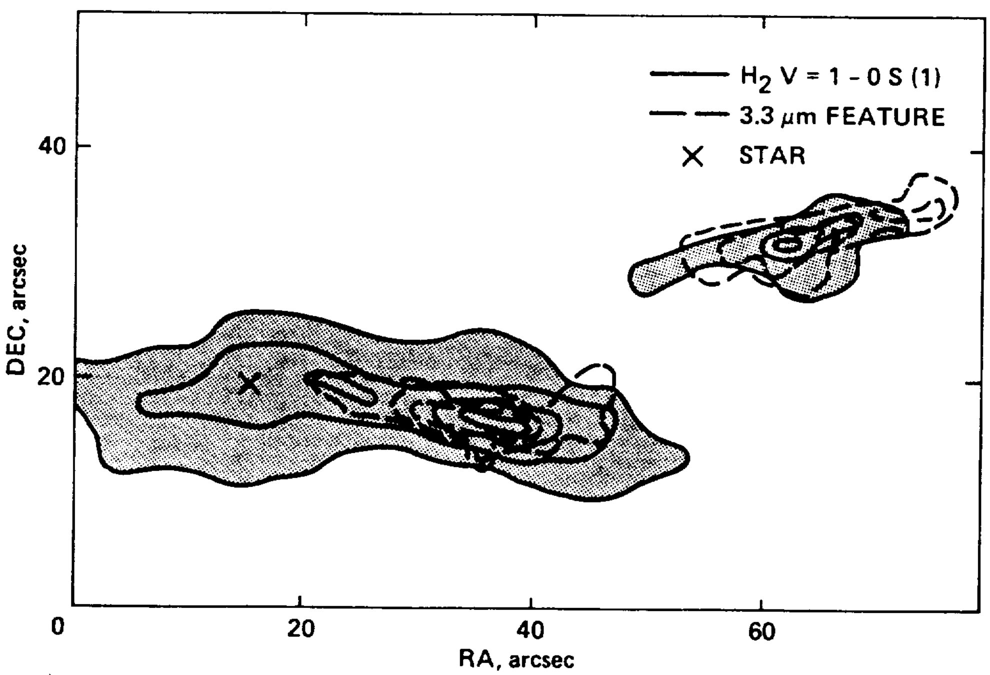


Figure 3.

NGC 2023



Figures 2 & 3. Contour maps of the molecular hydrogen v=1-0 S(1) line (continuous line, shaded region) and the 3.3μm feature (dashed line) in Orion's Bar and the reflection nebula NGC 2023. The ionisation front of the HII region of the Bar is to the NW of the ridge of 3.3μm emission. The exciting star for NGC 2023 is located 80" N of the peak of the molecular hydrogen emission.