Star Formation
Toward the "Quiescent" Core NGC 6334 I(N)

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At the time of their birth, young massive stars are deeply embedded in the dense molecular cores from which they form, thus making it impossible for us to observe them directly. The very early stages of massive star formation can therefore only be detected *indirectly* through the effects they have on the surrounding cloud via massive bipolar outflows, enhancements of certain molecular species, or infrared emission from heated dust grains.

At a distance of 1.7 kpc, NGC 6334 is one of the nearest and most prominent regions of ongoing high-mass star formation (Neckel, 1978), but because of its southernly location, it is not well studied. The nebula is associated with a remarkable, filament-like giant molecular cloud (GMC) which contains a chain of 6 distinct sites of recent high-mass star formation (McBreen et al., 1979). Additional evidence for star formation is the emission of vibrationally excited H_2, detected in a large, 20″ resolution map by Straw & Hyland (1989). This map shows bright emission in the H_2 1-0 S(1) line extended over several square parsecs toward the GMC.

In July 1998, we mapped the H_2 1-0 S(1) and Brγ lines toward a significant fraction of the molecular cloud using the Fabry-Perot on IRAC2 at the 2.2-m. This provided *a factor 400 improvement* in spatial resolution over the previous H_2 1-0 S(1) maps of Straw & Hyland (1989). Furthermore, using the SEST in June 1998, we conducted a multi-frequency study of the molecular gas in the NGC 6334 cloud. From these data we find that the NGC 6334 I & I(N) molecular cores, shown in Figure 1, probably contain the youngest sites of high-mass star formation within the NGC 6334 GMC. NGC 6334 I incorporates an ultracompact H II region, two mid-IR sources, a young stellar cluster, a plethora of masers, and at least one (probably two) bipolar outflow(s). The shock-

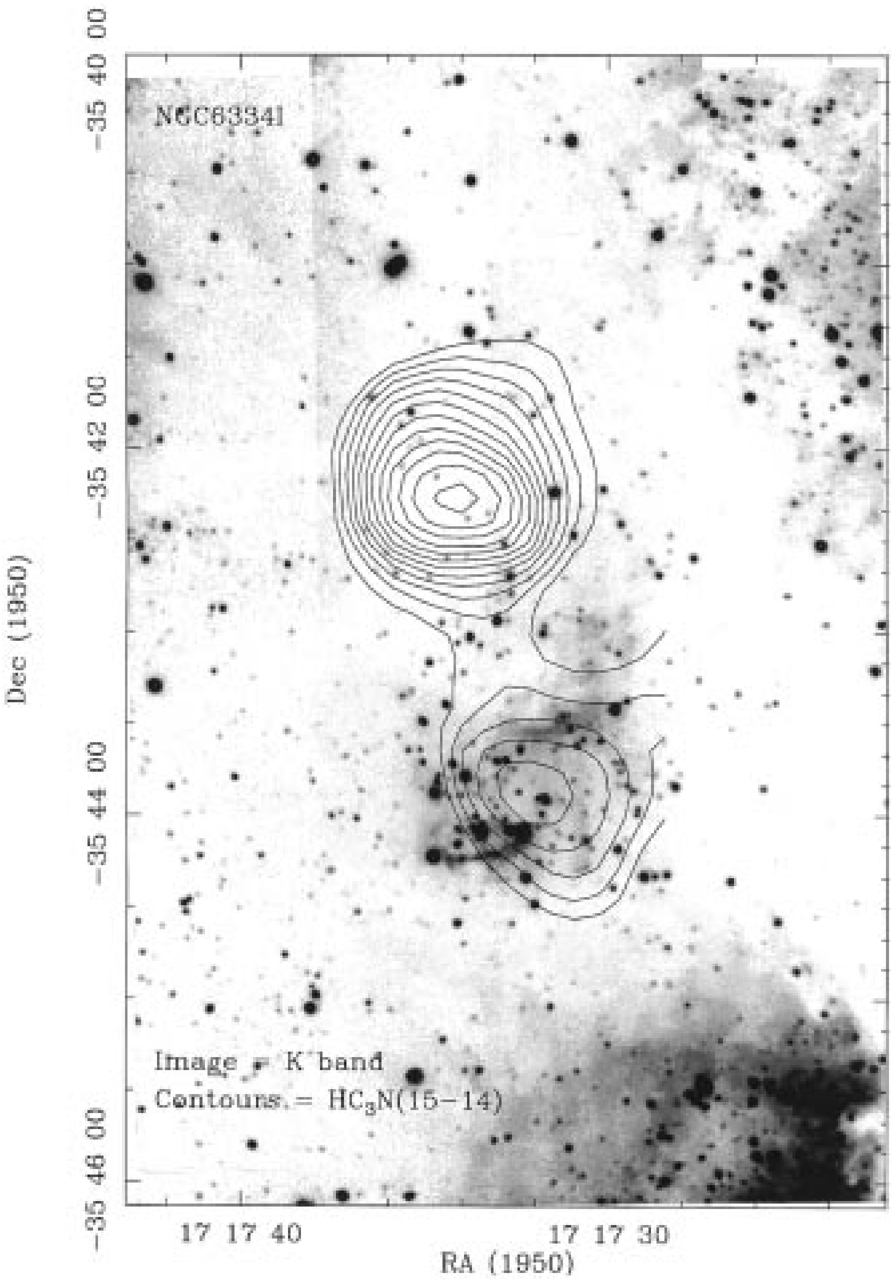
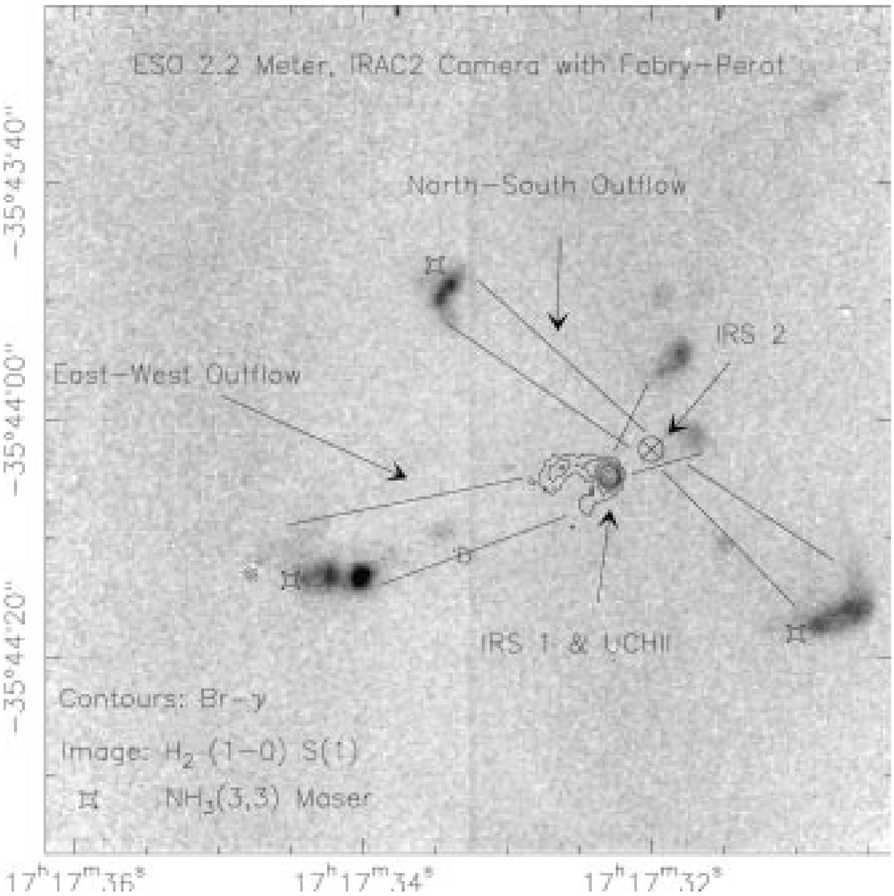


Figure 1: A K-band mosaic (ESO 2.2-metre) of the entire NGC 6334 I region (including I(N)) overlaid with a HC_3N (15–14) emission map (SEST 15-metre). The contour levels are 3 to 9 by 0.5 K km s^{-1}. The dense gas (10^5 cm^{-3}) traced by HC_3N is concentrated into two clumps, the southern clump is coincident with the FIR source NGC 6334 I and the northern core is coincident with I(N). I and I(N) have virial masses of ≈ 790 $M_\odot$ and ≈ 470 $M_\odot$, respectively. We note that $C^{18}O$, which traces moderate density gas (~ 1000 cm^{-3}), is found throughout the mapped regions. The southern core, NGC 6334 I, is clearly a site of active star formation: a young stellar cluster and ultracompact H II region are apparent. Interestingly, the K mosaic shows no clear evidence for star formation in the northern core, I(N).

Figure 2: H_2 image of the NGC 6334 I core with contours of Brackett-γ emission. These data had been obtained in an earlier run with the ESO 2.2-metre with a 1″ resolution in the 0.33″ pixel mode. We have outlined the North-South outflow and its candidate source and a proposed East-West outflow. We also show the location of the Brγ line and the close relationship of the NH_3 masers (Kraemer & Jackson, 1995) and the H_2 emission.



excited H_2 1-0 S(1) emission we detected in bow-shock shaped emission knots toward the NH_3 masers detected by Kraemer & Jackson (1995) (cf. Fig. 2), and the broad non-Gaussian line wings detected in the molecular line emission, impressively display these outflows toward NGC 6334 I. In contrast, I(N), a cooler source has only been detected at submillimetre or millimetre wavelengths. Interestingly, I(N) contains several masers whose presence, far from any known site of active star formation, has been an enigma.

From our SEST data, we confirm that the NGC 6334 I(N) core is chemically quiescent and much cooler when compared to its southernly neighbour NGC 6334 I. Considering the apparent cluster embedded within the NGC 6334 I core, this is not surprising as much of the molecular material within this core must have been heated and processed by the embedded young stars. However, NGC 6334 I(N) shows some very surprising peculiarities: bright emission lines of sulfur-bearing molecules and SiO line emission with broad line wings. These strong lines and their attendant line wings are clear evidence for a molecular outflow and shock chemistry in this seemingly quiescent molecular core. Maps of the blue and red line wings in the observed transitions of SiO indicate a bipolar flow (cf. Fig. 3). The near-infrared maps obtained with the 2.2-m provide further evidence for outflows in I(N) through the detection of vibrationally ex-

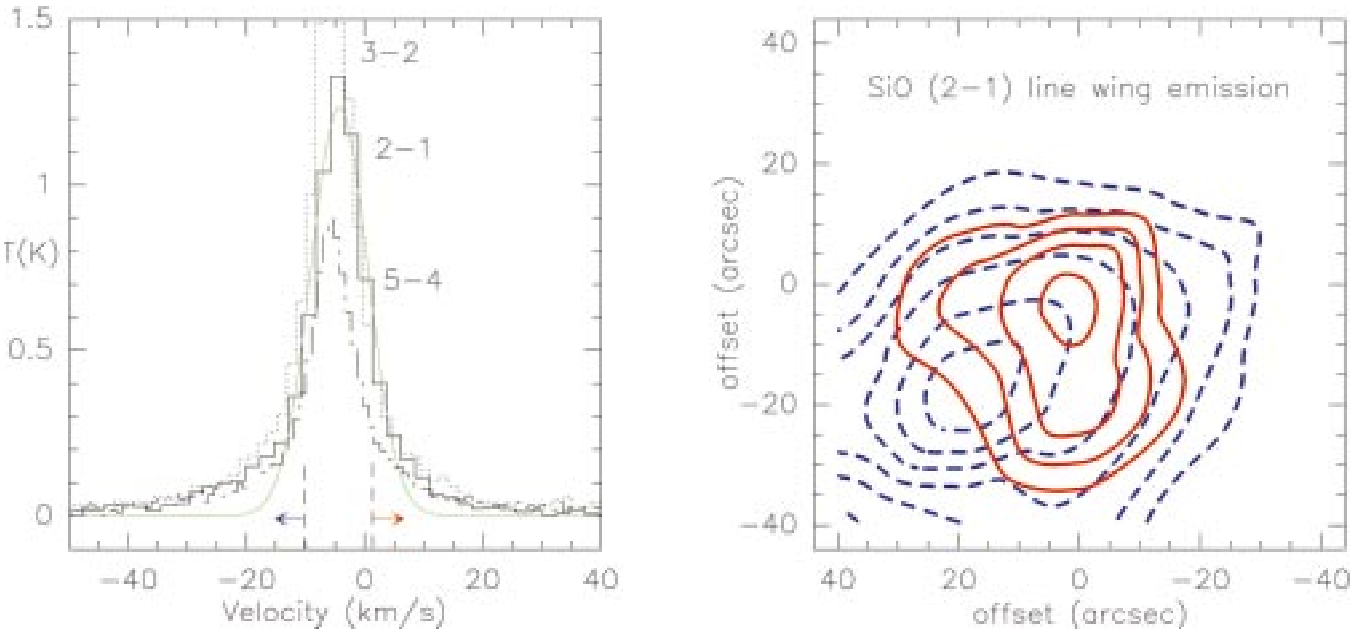


Figure 3: The panel on the left shows the SiO spectra obtained toward NGC 6334 I(N). The line intensities are about twice as strong as for the SiO detected toward NGC 6334 I. A Gaussian has been fitted to the SiO(2-1) line. For all transitions non-Gaussian line wings out to ≈ –40 km s^{-1} and ≈ 25 km s^{-1} can be detected. The panel on the right shows the integrated emission from the blue and red line wings of the SiO(2-1) line as indicated in the left panel by the two arrows. The bipolar outflow is clearly detectable and has also been mapped with about half the FWHM beamsize at the frequency of SiO(5-4).

cited H_2 emission toward NGC 6334 I(N) (cf. Fig. 4). Thus, NGC 6334 I(N) now appears to harbour ongoing star formation, which explains the previously enigmatic presence of masers toward I(N). We suggest that I(N) is in an interesting transition phase, transforming from a chemically quiescent to a shock/outflow-dominated molecular core. Assuming that its southernly companion, NGC 6334 I, passed through a similar transition phase before entering the observed hot core chemistry, these two molecular cores, embedded within the same parental molecular cloud and separated by less than 0.5 pc, will allow for a unique case study of the chemical and physical evolution of molecular cores in their earliest phases after the onset of star formation (Megeath & Tieftrunk, Tieftrunk & Megeath, in preparation).

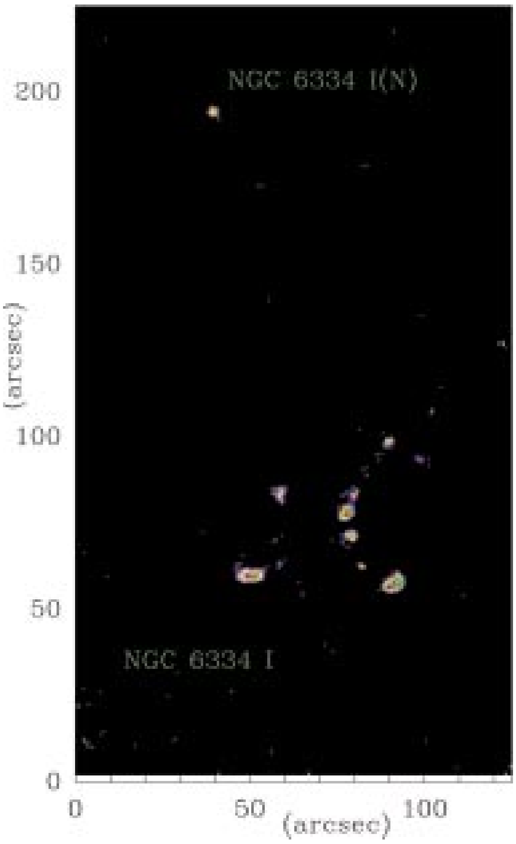


Figure 4: $H_2$1-0 S(1) emission toward NGC 6334 I and I(N) from our Fabry-Perot imaging with the 2.2-m in July 1998. The lower part of this figure shows the same H_2 emission knots as Figure 2, but with higher dynamic range. Relative offsets are given in arcseconds from an arbitrary off-position, chosen to align the two FP-fields. We caution the reader that the registration of the data in this figure is preliminary and may have absolute errors of several arcseconds. Note that no *continuum and* no *Brγ emission could be detected toward the shock-excited H_2 emission knots.*

References

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Molecular Gas in 30 Doradus

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Introduction

The Large Magellanic Cloud (LMC) contains numerous star-forming regions (SFRs) in an environment considerably different from the Galaxy. As in our Milky Way, SFRs in the LMC include complexes of ionised gas, patches of dust, and clusters of young stars and share the same markers of star formation: protostellar objects (Jones et al. 1986; Hyland et al. 1992), compact infrared sources (Schwering & Israel 1990; Rubio et al. 1992), OH and H_2O masers (Whiteoak & Gardner 1986; Caswell 1995), etc. They show, however, significant differences: the ionising radiation is stronger, the luminous stars are less deeply embedded, there is a lack of far-IR brightness peaks, and substantially less cold molecular gas (Cohen et al. 1988; Israel et al. 1993; Kutner et al. 1997; Johansson et al. 1998). The SFRs in the LMC should be important stepping stones between Galactic SFRs and those in more distant galaxies. In particular, the giant H II region 30 Doradus is thought to be a keystone object for understanding the "starburst" phenomenon in active galaxies (cf. Walborn 1991). Much larger than any Galactic SFR, the 30 Doradus region contains luminous clusters of massive young stars emitting intense UV radiation and powerful stellar winds which have created loops and shells of ionised gas, and shows evidence for a highly efficient formation mechanism unmatched in Galactic molecular clouds (Massey and Hunter 1998). We summarise here the results of an ongoing investigation of the characteristics of the highly excited molecular gas and cold molecular gas toward the centre of the 30 Doradus region, made through observations of H_2 and CO(2→1) line emission, respectively.

Cold Molecular Gas

CO emission from the 30 Doradus region was first detected, using the Columbia millimetre radio telescope, by Melnick & Rubio (1985). Their pointed, low angular resolution (8.8′) observations showed a weak CO line emission with several velocity components. Higher sensitivity CO mapping of a region of $\sim 1°$ centred near the exciting cluster of the H II region (hereafter the R136 cluster), made with the same instrument, were reported by Garay et al. (1993). They suggested that the CO emission from the 30 Doradus region arises from small, dense molecular clumps that are embedded in a mainly atomic but partly molecular interclump medium where CO has been destroyed by photodissociation due to the strong UV radiation field present in the area.

As part of the ESO-SEST Key Programme: CO in the Magellanic Clouds, Johansson et al. (1998) mapped the CO(1→0) line emission from the 30 Doradus region with a tenfold higher angular resolution (45″) than in previous works. They identified more than 30 molecular clouds within a region of $24' \times 24'$, having typically sizes of 10 pc and masses of $\sim 2 \times 10^4$ $M_\odot$, confirming the suggestion made by Garay et al. (1993). In particular, close to the R136 cluster, Johansson et al. (1998) detected two CO clouds located toward the north-east and west of R136 (clouds # 10 and 13, respectively) and which lie close to the edg-