# HIRES Dust Imaging of the NGC 6334 Star Forming Complex

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## FINAL REPORT

We present here our final report for the NASA grant "HIRES Dust Imaging of the NGC 6334 Star Forming Complex" This project was designed to study the photodissociation regions surrounding several OB stars in this cloud complex. NGC 6334 is unique in having at least seven distinct massive star forming regions in the same molecular cloud complex. The obvious advantage of studying young stars in the same molecular complex is that the stars all formed in the same global environment. Consequently, global factors like density waves, abundances, global magnetic field strength, and age of the parental molecular cloud cannot contribute to the differences among the star forming regions. Instead, the differences must arise only from local effects such as the mass, age, and UV fields of the individual stars. A study of NGC 6334 will greatly simplify the general problem of comparing different star formation regions by eliminating global effects.

## Results

We used the HIRES algorithm on the IRAS database to image the NGC 6334 cloud complex at 12 $\mu$m, 25 $\mu$m, 60 $\mu$m, and 100 $\mu$m. The algorithm has been successfully applied to produce $\sim 1'$ or better resolution maps at each of these wavebands. This provides a large improvement over previous images in both resolution and sensitivity.

The new HIRES images, which delineate the warm and cool dust, have been compared with other tracers of the interstellar medium. To probe the distribution of the neutral molecular gas, we have obtained CO 2-1 images of NGC 6334 using the Caltech Submillimeter Observatory. To probe the dense molecular cloud cores, we have imaged $NH_3$ (1,1), (2,2) and (3,3) emission with the Very Large Array. With the same VLA data, we have mapped the 1.3 cm radio continuum emission to study the ionized gas. Finally, to study the photodissociated gas we have imaged the complex with the KAO in the [C II] and [O I] FIR fine structure lines.

The HIRES data have revealed a great deal about PDRs in NGC 6334 (see Figure 1 and Table 1). One important puzzle the HIRES data has helped to solve is a puzzling source of photodissociated gas with no apparent ionizing source. In general, the [C II], which traces the photodissociated gas, peaks on or near the known OB stars, with the notable exception of a [C II] peak at offset postion $[-600'', -600'']$. This [C II] peak is *not* coincident with any radio continuum source. Hence, at this position there is a great deal of photodissociated gas but no significant Lyman continuum flux. Two possibilities might explain this result. (1) The [C II] peak is illuminated by a B star which emits only soft UV radiation capable of ionizing of carbon but incapable of ionizing hydrogen. (2) The [C II] peak is a ridge of gas illuminated by a hard UV field not from an embedded source, but from a more distant O star.

The HIRES data have revealed that this [C II] peak is coincident with strong 12 $\mu$m emission in the

IRAS HIRES images, but *not* at any longer wavelength. Because this dust is very warm, it obviously arises in a PDR. Moreover, because it is extended it is unlikely to be an isolated, embedded star. We concluded that the "[C II] peak" is a ridge of photodissociated material ionized by a more distant star, although the ionizing star is as yet unidentified. Follow-up VLA observations confirm this conclusion.

Another important result the HIRES data have revealed is the nature of NGC 6334 V. NGC 6334 V is a strong FIR continuum source, but it is puzzling because, although it is luminous, it apparently lacks a significant UV flux (as would be revealed by its radio emission). This object has been show to be unresolved at all of the IRAS wavelengths even at the best HIRES resolution. This object also has the coldest dust temperature among the OB stars in NGC 6334. These properties suggest that the object is most likely a protostar that as yet lacks any significant UV flux.

From the PDR models of Wolfire et al., we have incorporated the FIR HIRES continuum data along with the spectral line data to infer the densities, temperatures, and UV field strengths of the photodissociated gas. The models suggest temperatures of $\sim 200 - 500$ K and densities of $10^4 - 10^5$ cm$^{-3}$, both quite reasonable for PDRs.

This work formed part of the PhD dissertation work of Kathleen Kraemer at Boston University. Preliminary accounts of our results were presented at the Washington AAS meeting in January 1994 and at the NASA Ames Airborne Astronomy Symposium in July 1994. Some of this work also appeared in the paper "A 2000 $M_\odot$ Rotating Molecular Disk Around NGC 6334 A," Kraemer, K.E., Jackson, J.M., Paglione, T.A.D., and Bolatto, A.D., *Astrophysical Journal*, 478, 614, 1997. The rest of the work will be published in a future paper.

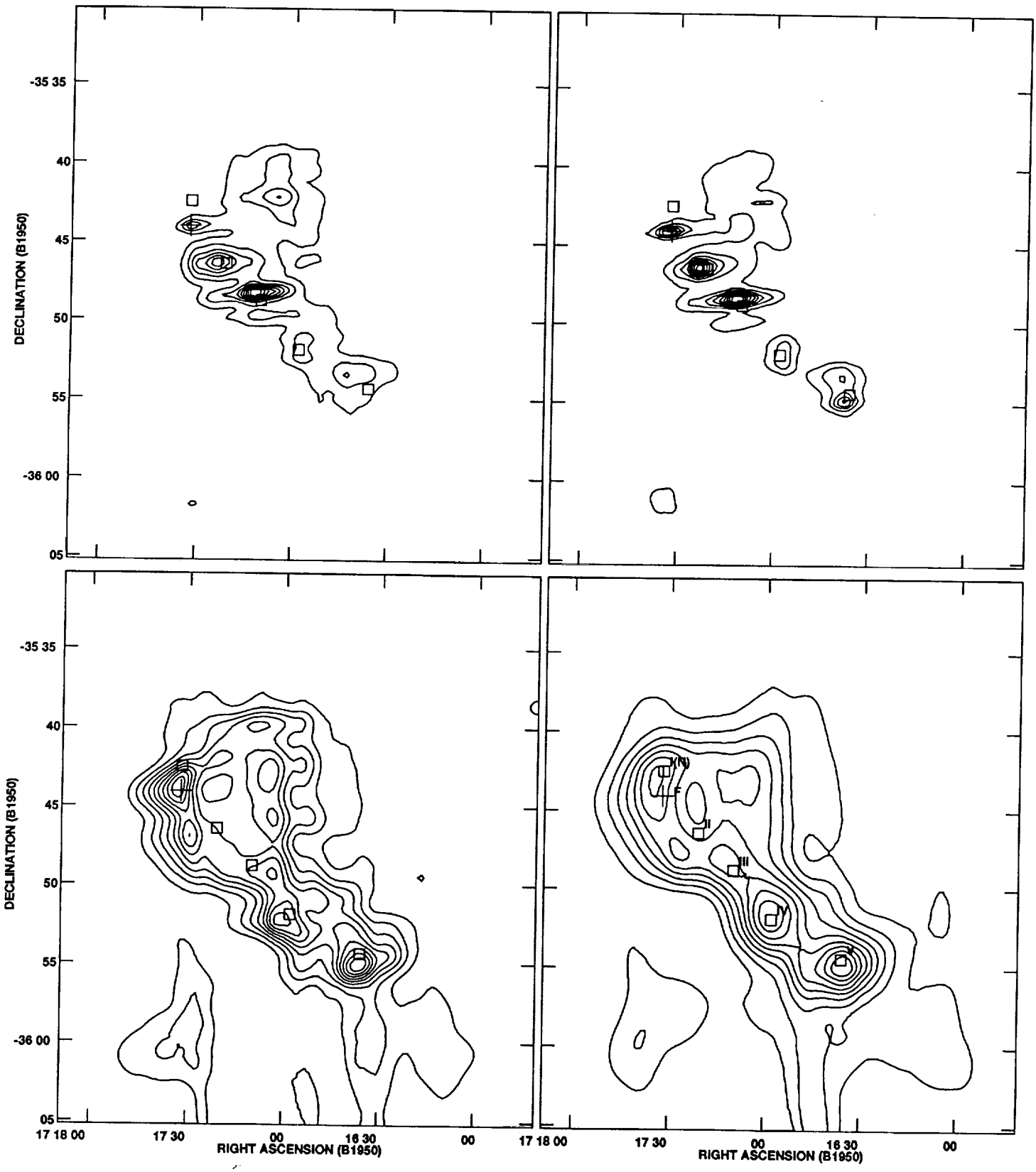


Figure 1: HIRES IRAS images;(a)12 $\mu$m, peak intensity 4.26 kMJy/ster; (b) 25 $\mu$m, peak intensity 26.31 kMJy/ster; (c) 60 $\mu$m, peak intensity 33.11 kMJy/ster; (d) 100 $\mu$m, peak intensity 34.17 kMJy/ster; contours at 10% intervals.

NGC 6334 IRAS Intensity Ratios and Temperatures

| Source | 100/60 $\mu$m | $T_{dust}$ | 25/12 $\mu$m | $T_{dust}$ |
|---|---|---|---|---|
| A | 1.13 | 45 | 6.83 | 138 |
| C | 1.13 | 45 | 5.54 | 135 |
| D | 0.95 | 50 | 7.56 | 137 |
| E | 0.85 | 53 | 7.83 | 125 |
| F | 0.71 | 60 | 8.33 | 123 |
| I(N) | 1.29 | 43 | 5.99 | 134 |
| V | 1.08 | 46 | 29.57 | 98 |