# Far Infrared Spectroscopy of the Orion Nebula

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## ABSTRACT

A coarse resolution spectrum of the Orion Nebula between 65 and 125 microns closely fits the color dependence of a $75^{\circ}K$ blackbody. A high resolution search for O III at 88.16 microns yields an upper limit below theoretical predictions.

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## Introduction

A number of far infrared lines from fine structure transitions in ionized atoms have been predicted to be strong in the spectra of H II regions (Petrosian, 1970; Simpson, 1975; Bergeron, 1975). These lines promise to provide information which in many cases cannot be derived from radio-frequency or optical observations. In particular, cal calculations for the (O III) line at 88.16 microns indicate that it should be strong in the diffuse H II regions, and that its strength, when compared to the strength of optical forbidden lines, would provide a sensitive measure of the electron density in H II regions detectable at visible wavelengths. This line is at a wavelength where there is good atmospheric transmission from above the tropopause, and hence should be detectable from airplane-borne telescopes.

Here we shall present the results of a search for this line in the Orion Nebula, plus a coarse resolution spectrum of Orion from 75 to 120 microns.

## Observations

The observations were carried out in November of 1974 using the 31-cm gyrostabilized telescope mounted in the NASA Lear Jet. During the flights we maintained an altitude of 14 km in order to be above the tropopause and reduce the atmospheric extinction, which is mainly due to water vapor. The

Lear telescope has a chopping secondary, which we ran at 30 Hz with a 15 arc minute separation between beams.

The instrument employed was a fully liquid helium cooled grating spectrometer with a 3 mm entrance slit that gave a square beam on the sky, 5 arc minutes in diameter. The detector was a Ga:Ge photoconductor, with a Yoshinaga filter and black polyethylene used to block radiation shortward of 65 microns.

Data was taken at both high (1.5 micron) and low (5 micron) resolution, but the same general observing procedure was followed on all flights. The observations consisted of a series of runs through grating positions covering the observed spectral region. At each position signal levels were measured on and off the source in order to eliminate the offset signal from the chopping secondary. The source position was established at the start of each observing period by finding the guiding position which maximized the signal. It should be noted that this position was centered on the peak of the infrared emission, rather than on the Trapezium, but this should not affect the line results since the angular separation between the infrared peak at 100 microns and the Trapezium is only about one arc minute (Harper, 1974; Fazio et al., 1975), much smaller than our beam size and comparable to the diffraction-limited angular resolution of the telescope.

The high resolution measurements were concentrated around the (O III) line position, running from about 85 to 92 microns, while the coarse resolution observations covered the available bandpass of the instrument, which was 75 to 120 microns.

Moon spectra were used to correct for instrumental profile and atmospheric transmission, and the wavelength determination was obtained from ground calibrations and atmospheric absorption features. The spectra were normalized to correct for air mass effects and daily variations in sensitivity. The data are plotted in Figures 1 and 2, with the error bars being one standard deviation. The major noise source was telescope guiding error.

The coarse resolution spectrum is shown in Figure 1. Each point represents an average derived from four observing flights. The blackbody curve which best fits the spectrum corresponds to a temperature of 75°K, but curves for 50°K and 100°K are also drawn to give an idea of the variation of fit with temperature. It can be seen that the 100°K curve also fits the data well. The spectrum is very smooth, and what bumps exist can be explained by calibration errors, since they lie near strong atmospheric transmission features. The spectrometer has a higher effective resolution for a source like Orion which does not fill the entrance slit, and thus atmospheric effects are accentuated in the Orion spectrum relative to the lunar calibration spectrum. In general, the coarse resolution spectrum is consistent with continuum dust emission, and there is no strong evidence of grain emissivity effects. This agrees with the findings of Houck, Schaack and Reed (1974).

The higher resolution data is shown in Figure 2. Each point here represents the average of data from one flight for a given grating position; but because of instrumental changes between flights, measurements were taken at slightly different wavelength settings on successive flights. The line is a $75^{\circ}$K blackbody curve diluted to fit all points except those around the (O III) line position. The absolute flux level is taken from Harper (1974) who also used a 5 arc minute beam.

The only obvious features are the bump at 91 microns and the dip at 90 microns due to atmospheric transmission variations which have not been completely removed by lunar calibrations. However, the atmospheric transmission is quite uniform around 88 microns, and no major calibration problems should exist there. The wavelength of the (O III) line is known to within at most $\pm$ 0.1 microns from observations of optical lines, and the wavelength scale is in error by at most $\pm$ 0.3 microns. Thus we must conclude that it is not possible to detect the (O III) 88.16 micron line in Orion at our resolution and sensitivity.

In order to establish an upper limit on the flux in the line, we approximated our instrumental response to a narrow line, using a sawtooth function of a half-width corresponding to our resolution. We ran this through the spectrum between 87 and 89 microns, and got no significant maximum. At three standard deviations, our upper limit is $2 \times 10^{-15}$ watts/cm$^2$ in the line.

Discussion

One of the parameters which is difficult to determine in H II regions is the electron density $n_e$. Most forms of emission are proportional to the square of the electron density, and so the observed quantity is usually the emission measure of the region. Forbidden lines which can be easily de-excited by collisions allow determinations of electron density over certain ranges of densities, but the (O II) 3726/3729 Å doublet is the only optically observed line which allows such a determination. Some of the far infrared fine structure lines have emission proportional to $n_e$ for values of electron density which are expected in H II regions (Petrosian 1970), and if these lines were observable they would provide useful information concerning the density and hence the mass of the emitting region. The (O III) 88.16 micron line is expected to be one of the strongest infrared fine structure lines. Predicted values for the flux expected from Orion are $3.9 \times 10^{-15}$ watts/cm$^2$ from Petrosian (1970), and $2 \times 10^{-15}$ watts/cm$^2$ (after scaling to our beam size) by Simpson (1975). Our results indicate that the actual flux is lower than these estimates.

In the Orion Nebula, observations of (O II) 3726/3729 indicate high electron densities (Osterbrook and Flather, 1959), high enough that homogeneous spherical models would yield far too much radio flux. Hence any spherical model must have high density clumps containing the O II surrounded by a more tenuous medium (Simpson 1973) in order to explain the observations. This type of model is supported by the fact that observations of (O II) and (O III) give different temperatures. Another possibility is that the Orion Nebula is a thin sheet oriented roughly perpendicular to the line of sight (Zuckerman 1973).

Bergeron (1975) has shown that the strength of the (O III) 88 micron line can be used to test the parameters of the spherical model. The values of the electron density are of the order of $10^3$ $cm^{-3}$, and at these densities the emission of (O III) 88.16 microns divided by the emission of (O III) 5007 Å is proportional to $n_e^{-1}$, assuming the electron temperature is known. Hence it should be possible to determine the electron density in the doubly ionized phase of a two phase model. For our upper limit on the (O III) 88.16 micron line, her calculations indicate that for a spherical model a major part of the (O III) 5007 Å emission would have to come from dense clumps, and that the dense clumps would contain an important fraction of the mass of the nebula.

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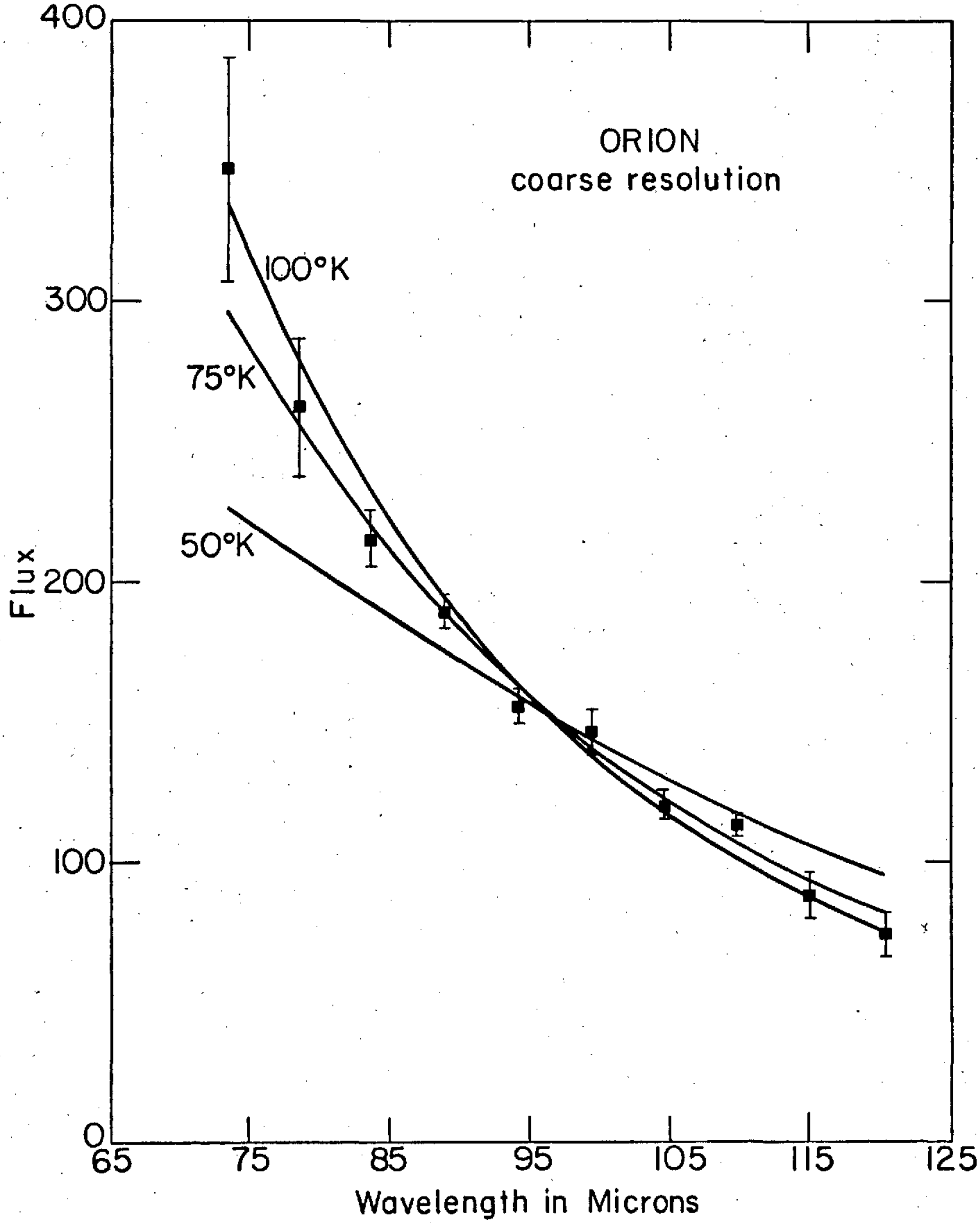
## Figure Captions

Figure 1. Orion spectrum at 5 micron resolution. Blackbody curves at the indicated temperatures are diluted to fit the data.

Figure 2. Orion spectrum at 1.5 micron resolution. Fitting curve is a $75^{\circ}$K blackbody diluted to fit the data. Flux calibration is from Harper (1974).



ORION
coarse resolution
100°K
75°K
50°K
Flux
400
300
200
100
0
65
75
85
95
105
115
125
Wavelength in Microns


Figure 1

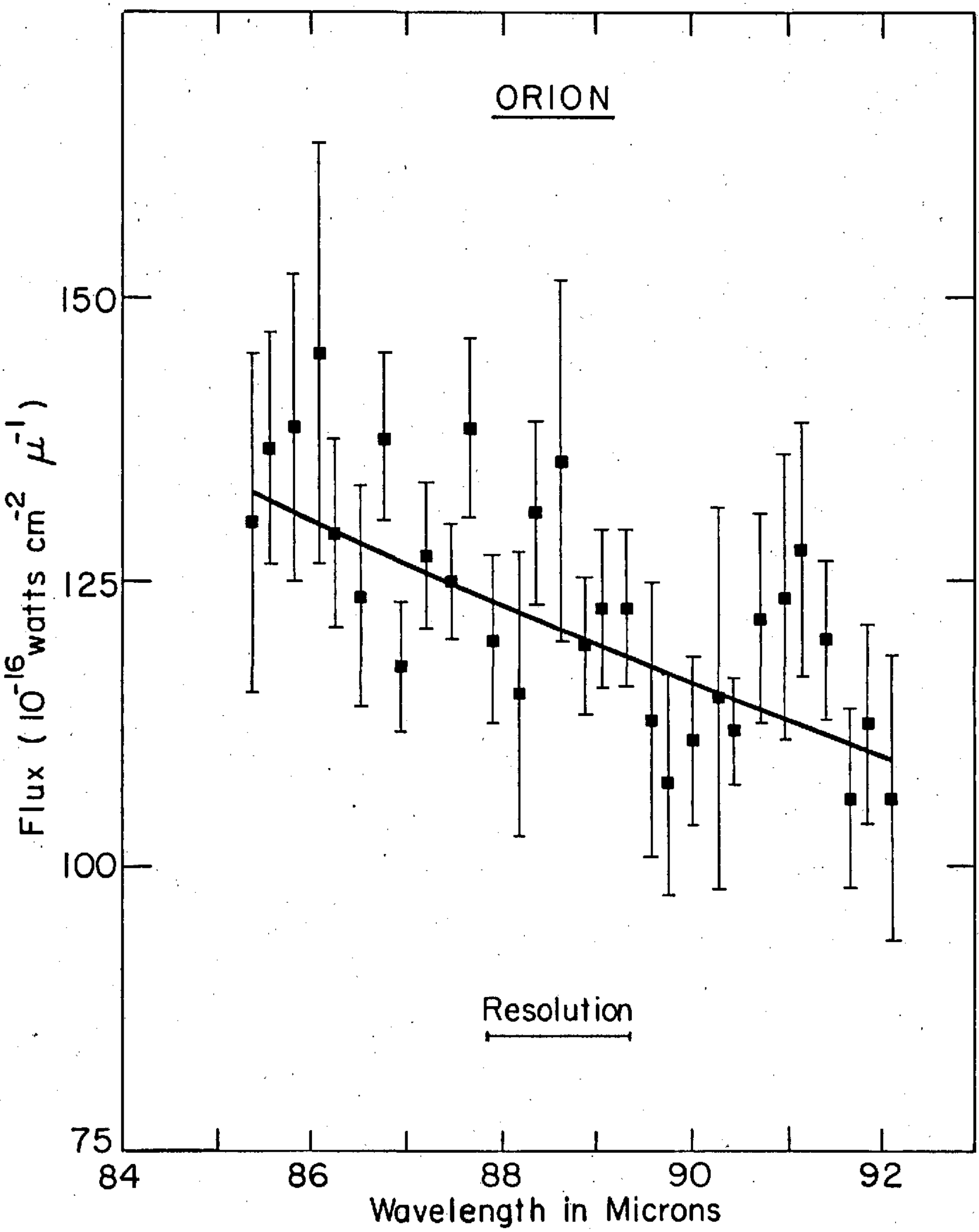

ORION
Flux ( $10^{-16}$ watts $cm^{-2}$ $\mu^{-1}$ )
150
125
100
75
84
86
88
90
92
Wavelength in Microns
Resolution

Figure 2