THE ASTROPHYSICAL JOURNAL, **186**:L19–L22, 1973 November 15

OBSERVATION OF THE $J=2$ TO $J=1$ TRANSITION OF INTERSTELLAR CO AT 1.3 MILLIMETERS

T. G. PHILLIPS AND K. B. JEFFERTS
Bell Laboratories, Murray Hill, New Jersey

AND

P. G. WANNIER
Princeton University Observatory
Received 1973 September 4

ABSTRACT

We report the observation of 1.3-mm line radiation from interstellar sources due to the $J=2$–1 transitions of $^{12}C^{16}O$ and $^{13}C^{16}O$. The Orion Nebula CO system is found to be thermalized and to show a peak excitation temperature of approximately 76° K.

Subject headings: molecules, interstellar — radio lines

Since the initial observation of intense line emission at the frequency of the $J=1$ to $J=0$ ($J=1$–0) rotational transition of interstellar $^{12}C^{16}O$ (Wilson, Jefferts, and Penzias 1970) it has become evident that the CO molecule will play an important role in understanding interstellar matter. However, such understanding will be considerably extended by observations of higher rotational transitions, and this *Letter* reports the initial detection of $J=2$ to $J=1$ ($J=2$–1) radiation from $^{12}C^{16}O$ at a frequency of 230.5 GHz and also $^{13}C^{16}O$ at 220.4 GHz.

The observations reported here were made on the NRAO 36-foot (11-m) antenna at Kitt Peak,[1] using a novel type of millimeter-wave superheterodyne receiver which has a liquid-helium–cooled hot-electron bolometer mixer as the detecting element. A 115-GHz version of this receiver has recently been described (Phillips and Jefferts 1973). The 230-GHz receiver differs most significantly in that it derives its local-oscillator power by harmonic generation from a 115-GHz klystron. It has a double-sideband system noise temperature of approximately 500° K when mounted at the prime focus of the antenna. In these observations the receiver was used in a single-channel mode with the bandwidth reduced to 1 MHz from its nominal value of 4 MHz. The sidebands (20–500 kHz) above and below the local-oscillator frequency are both in use, and the system temperature is properly given by the double-sideband value. Frequency-switching techniques were used for both spectral scans and strip maps. In the case of spectral scans the telescope was also switched on and off the source. For the strip maps, the ON half of the frequency switching cycle was set at the values corresponding to the velocity offsets given in the figure legends.

Figure 1 shows a strip map in right ascension and a spectrum for $^{12}C^{16}O$, $J=2$–1, in the Orion Nebula. The laboratory frequency of this line is 230.53797 GHz in the NBS tables (Wacker *et al.* 1964), and figure 1*b* shows that the line occurs at a velocity of $+9$ km s^{-1} with respect to the local standard of rest (LSR) and has a width at half-height of 6 km s^{-1}. The right-ascension strip is compared with the similar plot for $J=1$–0 $^{12}C^{16}O$ (Wilson *et al.* 1970) which has been adjusted to take into account the differences in beamwidths. The $J=1$–0 plot has been scaled

---

[1] The National Radio Astronomy Observatory is operated by Associated Universities Inc. under contract with the National Science Foundation.

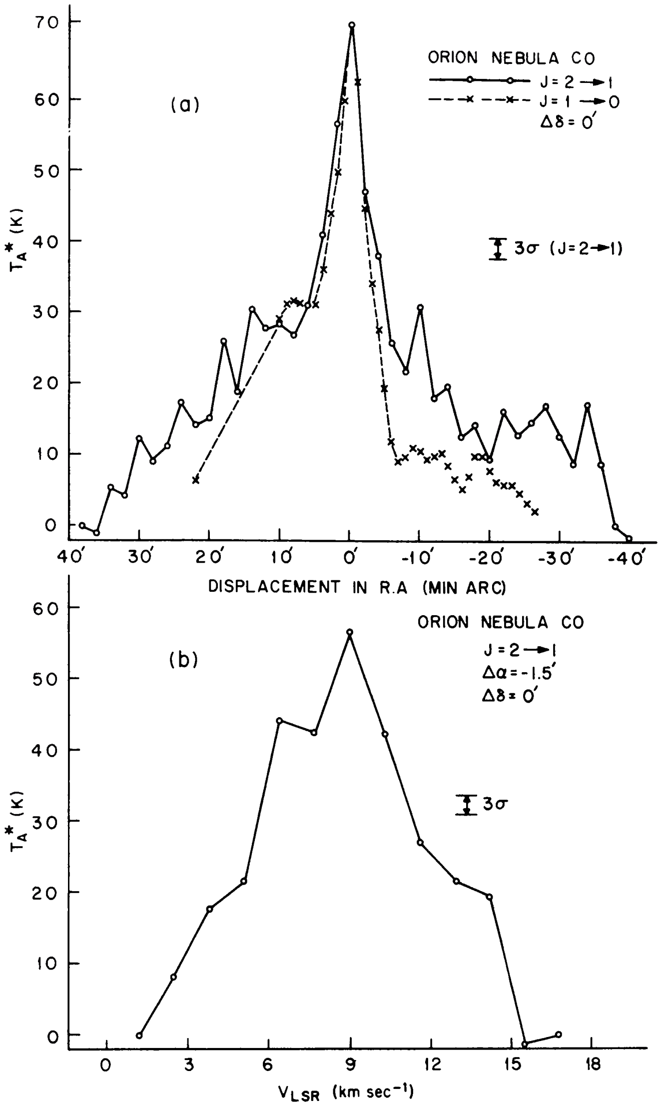

FIG. 1.—(*a*) The corrected antenna temperature T_A^* (see text) for $J = 2$–1 $^{12}C^{16}O$ in the Orion Nebula as a function of right ascension. The center of the Nebula is taken to be $5^h32^m47^s$ in right ascension and $-5°24'24''$ in declination (1950 coordinates). The LSR velocity offset is $+9$ km s^{-1}. Also shown is a similar map for $J = 1$–0 (after Wilson *et al.* 1970) which has been scaled to fit at the peak. (*b*) A spectrum of $J = 2$–1 $^{12}C^{16}O$ taken near the peak of the nebula. The width at half-height is approximately 6 km s^{-1}.

to fit at the peak. Comparison of the absolute intensities of these two lines was made according to the standard concept of corrected antenna temperature,[2] which we denote by T_A^*. Interpretation of T_A^* should be made with caution, bearing in mind the implied assumptions. Our peak brightness temperature (T_B) for $J = 2$–1 $^{12}C^{16}O$ is 76° K,

---

[2] We define T_A^* as the antenna temperature corrected for all telescope and atmospheric losses. It represents the received intensity as determined by comparison with the receiver response to hot calibration loads such as the Sun, ambient chopper, and liquid-nitrogen load. It is therefore a measure of absolute temperature only if $h\nu \ll KT$. Unfortunately at these frequencies this may not always be the case ($h\nu = 11°$ K at 230 GHz). The brightness temperature must be found from the relation $KT_B = h\nu/\ln[(h\nu/KT_A^*) + 1]$.

which is remarkably close to the most recent value for $J = 1$–0 of 75° K (Liszt *et al.* 1973).

For the Orion Nebula peak we might expect that the $J = 2$–1 line would be more opaque than $J = 1$–0. With a model in which the velocity dispersion is due to large-scale motions (Liszt *et al.* 1973), the similarity between the T_B values in the central region of the Nebula (fig. 1*a*) indicates that the system is totally opaque and thermalized, with a peak excitation temperature of 76° K. If the velocity dispersion is due to small-scale motion, the T_B agreement also implies relatively uniform excitation temperature along the line of sight, which seems unlikely. It is interesting that in the western wing the $J = 2$–1 $T_A{}^*$ values are approximately double those for $J = 1$–0. It is possible that this indicates that the wing is thin, allowing the determination of excitation temperatures (Goldsmith 1972) and also ${}^{12}C/{}^{13}C$ ratios (which would be anomalously small, however). It is also possible that such a situation can arise by photon trapping in a nearly opaque region, and this is to be investigated.

${}^{13}C^{16}O$ $J = 2$–1 emission was also observed. Figure 2 shows declination strip maps of the Orion Nebula for both ${}^{12}C^{16}O$ and ${}^{13}C^{16}O$. The ${}^{13}C^{16}O$ frequency was cal-

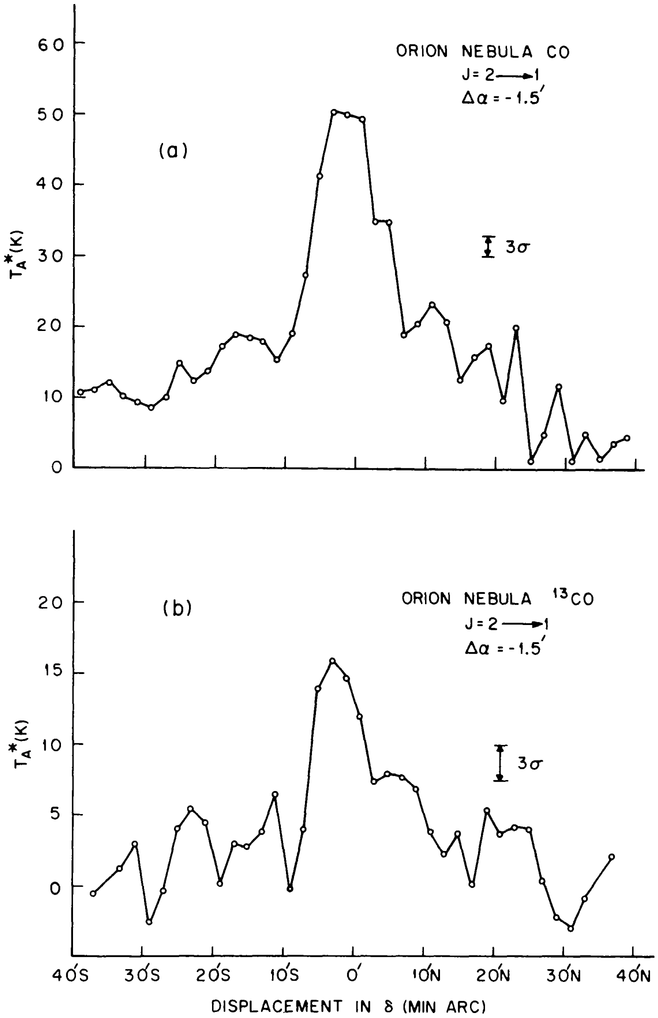

FIG. 2.—(*a*) A declination strip map of the Orion Nebula for $J = 2$–1 ${}^{12}C^{16}O$. The LSR velocity offset is $+9$ km s^{-1}. (*b*) A similar map for ${}^{13}C^{16}O$.

culated to be 220.3984 GHz from the $J = 1$–0 frequency and an estimate of the centrifugal stretching constant obtained from the $^{12}C^{16}O$ frequencies. This was found to be accurate within our spectral resolution. Also observed at this time were the sources W51, DR 21, and a point in ρ Oph (Encrenaz 1973) for both $^{12}C^{16}O$ and $^{13}C^{16}O$, but this will be reported separately.

Calibration of the system was made somewhat difficult at such a high frequency by the reduced efficiency of the antenna and the increased absorption of the atmosphere (~3.5 db per air mass during most of the period 1973 July 2–8). In the case of the Orion Nebula a good calibration was possible since the Sun was observable at comparable elevations during our observing period. The effect of elevation changes was calculated by observing the Sun and the atmosphere at various elevations. This also permitted an approximate determination of beam efficiency and spillover factors. These both depend to some extent on the individual feed horn, and in our case the combined antenna loss was about 5 db. The Sun was observed through the radome which was found to have an attenuation of 2.9 db at 230 GHz. The beam profile was obtained by scanning across the Sun and was found to consist of a $1\overset{'}{.}75$ central beam plus an apparently Gaussian component of about $8'$ width at half-height and of strength —8 db.

We would like to thank G. T. Wrixon for private communication of his independent measurements of antenna efficiency and atmospheric effects at 230 GHz and for providing Schottky diodes used in harmonic generation. We thank A. A. Penzias and R. W. Wilson for their continued interest and support plus many useful conversations. Also we thank E. K. Conklin, B. L. Ulich and the staff of the 36-foot NRAO antenna for their kind assistance. One of us (P. G. W.) was supported in part by NASA contract NSR 31-001-901.

REFERENCES

Encrenaz, P. 1973, to be published.
Goldsmith, P. F. 1972, *Ap. J.*, **176**, 567.
Liszt, H. S., Wilson, R. W., Penzias, A. A., Jefferts, K. B., Wannier, P. G., and Solomon, P. M. 1973, submitted to Ap. J.
Phillips, T. G., and Jefferts, K. B. 1973, *Rev. Sci. Instr.*, **44**, 1009.
Wacker, P. F., Mizushima, M., Peterson, J. D., and Ballard, J. R. 1964, *NBS Monog.* No. 70, Vol. **1**.
Wilson, R. W., Jefferts, K. B., and Penzias, A. A. 1970, *Ap. J.* (*Letters*), **161**, L43.