Distance Estimates for Two Thermal Galactic Radio Sources

A. H. Bridle and M. J. L. Kesteven
Astronomy Group, Department of Physics, Queen's University at Kingston, Ontario, Canada
(Received 4 November 1971)

Kinematic distances of 3.2 and 4.1 kpc are suggested for the thermal galactic ratio sources NRAO 589A and 4C 51.12, from observations of their 21-cm absorption profiles.

OBSERVATIONS of the 21-cm absorption of galactic radio continuum sources by cold features in the interstellar neutral hydrogen place lower limits on the kinematic distances of the sources: the limit is in each case the distance of the furthest cold feature present in the absorption profile. The technique does not usually provide unique distance estimates, as the cold material cannot be assumed to be present in all possible radial-velocity ranges along the line of sight to a source. Distances can, however, be estimated for some thermal radio continuum sources associated with H II regions, for which neutral hydrogen absorption and Hα emission-line data can be combined to resolve distance ambiguities implicit in the galactic kinematics, or for which the absorption data confirm an association between the radio source and an optical nebulosity. In this paper we use neutral hydrogen absorption data in both of these ways, to estimate the distances of the thermal sources NRAO 589A (G35.2–1.8) and 4C 51.12 (G151.6–0.2). In the accompanying paper (Butler and Hughes 1972), microwave continuum observations of the sources are used to define their physical parameters.

I. INSTRUMENT AND DATA REDUCTION

The observations were made with the 300-ft transit telescope of the National Radio Astronomy Observatory (operated by Associated Universities Inc. under contract with the National Science Foundation) and the 100-channel digital autocorrelation spectrometer (Weinreb 1963). The system noise was $\sim$200°K and the channel bandwidth 6.25 kHz (1.32 km·sec^{-1}). The angular resolution of the telescope was 10.3 arc min in right ascension by 11.1 arc min in declination.

Each observation of a given source consisted of a drift scan with the telescope set at a constant declination. The receiver output was digitized after integration periods of 10 sec both in the hydrogen-line frequencies and in a continuum bandwidth of 5 MHz near 1420 MHz. Absorption profiles were derived from the drift curves by the following procedure. The output of the spectrometer at each radial velocity was fitted with a polynomial "baseline" and a superimposed "feature" whose right-ascension profile and position were determined by the output in the continuum channel. If the radiation from the source is absorbed at a given velocity, the amplitude of the fitted "feature" is negative and proportional to the absorption temperature. This method of analysis, which has also been used by Kerr and Knapp (1970), usually permits genuine absorption features to be distinguished from chance fluctuations of the neutral hydrogen emission in the vicinity of a source, as the latter can only occasionally mimic the response of the telescope to a continuum source. Furthermore, the rms deviation of the data from the fitted model provides an objective estimate of the reliability of the absorption profile at each radial velocity.

II. THE DISTANCE OF NRAO 589A

The source is part of a group of three objects commonly designated Westerhout 48 (Westerhout 1958). The detailed features of the group are discussed in the accompanying paper (Butler and Hughes 1971), where the designations NRAO 588 = G35.1–1.5, NRAO 589A = G35.2–1.8, and NRAO 589B = G35.4–1.8 are suggested for the three sources. The neutral hydrogen emission profile in this direction extends over the radial-velocity range -60 to $+110$ km·sec^{-1}, which was too wide to be observed at a single setting of the local oscillator. The velocity ranges -70 to $+35$ km·sec^{-1} and $+10$ to $+125$ km·sec^{-1} were therefore observed separately and combined in the data reduction. Three complete sets of drift scans were obtained at 1950.0 Dec. 01°08′15″ and were later averaged. At this declination the sources NRAO 588 and NRAO 589A pass through the maximum of the antenna response. As these sources are only $\sim$16 arc min apart in right ascension, they were not fully separated by the instrument, but were treated independently in the data reduction. Further sets of drift scans were obtained with the telescope set to 1950.0 Dec. 01°03′15″ and 01°13′15″.

Confusing fluctuations in the surrounding line emission prevented us from determining the absorption profile of NRAO 588 at this angular resolution. The confusing features could, however, be satisfactorily removed by the baseline fitting procedure for NRAO 589A. The resulting absorption profile, and the emission profile interpolated to the position of the source, are shown in Fig. 1. There are significant absorption lines in the radial-velocity ranges $+5$ to $+15$ km·sec^{-1} and $+35$ to $+45$ km·sec^{-1}. The reality of these features was confirmed by the drift curves obtained with the telescope offset in declination, in which the absorption features were attenuated in proportion to the response to NRAO 589A in the continuum. The remaining

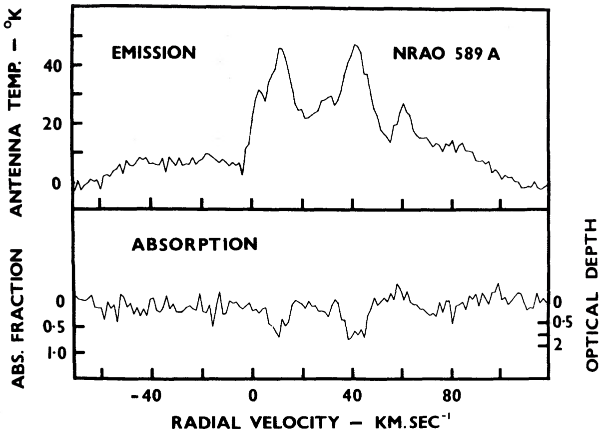

FIG. 1. 21-cm emission and absorption profiles in the direction of NRAO 589A. The emission profile has been interpolated to the position of the source by the procedure described in the text; it has not been corrected for the effects of the sidelobes of the telescope.

features of the absorption profile are either comparable with the channel-to-channel noise fluctuations, or show large rms deviations in the fitting procedure: they are therefore not significant. The absorption features correspond well in radial velocity with the two major emission concentrations observed in this direction, and imply that NRAO 589A is at $\gtrsim 3.1$ kpc from the Sun, using the Contopoulos–Strömgren galactic rotation curve (Mihalas and Routly 1968).

Schraml and Mezger (1969) and Reifenstein *et al.* (1970) report an observation of the H109α emission line from the direction of NRAO 589A, the former at $+45.2$ km·sec^{-1} and the latter at $+46.5\pm2.4$ km·sec^{-1}. As NRAO 589A has a thermal continuum spectrum, it is probable that this recombination line arises in the continuum source. Its radial velocity corresponds to a "near" distance ~ 3.2 kpc or a "far" distance ~ 13.2 kpc from the Sun. Schraml and Mezger do not attempt to resolve this ambiguity, but Reifenstein *et al.* suggest that the nearer distance be adopted, on the grounds that NRAO 589A would otherwise be unusually far below the galactic plane. Our absorption profile favors this interpretation, as there is no significant absorption between $+45$ km·sec^{-1} and the rotational tangent-point velocity of $\sim +100$ km·sec^{-1}. It is unlikely that the line of sight could extend for 10 kpc beyond the 'near' distance without encountering any absorbing material, so the distance of ~ 3.2 kpc appears more likely for NRAO 589A.

III. THE DISTANCE OF 4C 51.12

Caswell (1969) suggested that the radio source is associated with the dense core of NGC 1491. The radio position (Butler and Hughes 1971) agrees more closely, however, with that of the nebula Sharpless 209 (Sharpless 1959). The neutral hydrogen emission profile in this direction ($l=151\overset{\circ}{.}6$, $b=-0\overset{\circ}{.}2$) extends from -85 to $+20$ km·sec^{-1}, and was observed at a single local oscillator setting. Two drift scans were obtained at 1950.0 Dec. 51°01′00″ and were later averaged: the resulting absorption profile, and the emission profile interpolated to the position of the source, are shown in Fig. 2. There are significant absorption lines in the radial-velocity ranges 0 to -10 km·sec^{-1} and -17 to -13.7 km·sec^{-1}. The latter implies that 4C 51.12 is at $\gtrsim 3.3$ kpc from the Sun.

Emission appears in the profile in the velocity range -38 to -48 km·sec^{-1}. This is due to a confusing emission feature contributing a peak antenna temperature ~ 15°K centered on 1950.0 R.A. 04^h07^m and radial velocity -47 ± 2 km·sec^{-1}. This feature cannot be adequately removed by our baseline fitting procedure, and prevents determination of the absorption profile in the radial-velocity range -55 to -37 km·sec^{-1}. The widths of the feature between half-brightness points are approximately 3 min in right ascension and 6.5 km·sec^{-1} in radial velocity.

The radial velocity of the optical Hα emission from Sharpless 209 is -44.8 ± 4.5 km·sec^{-1} (Georgelin and Georgelin 1970). As there is significant absorption of the continuum from 4C 51.12 to the most negative

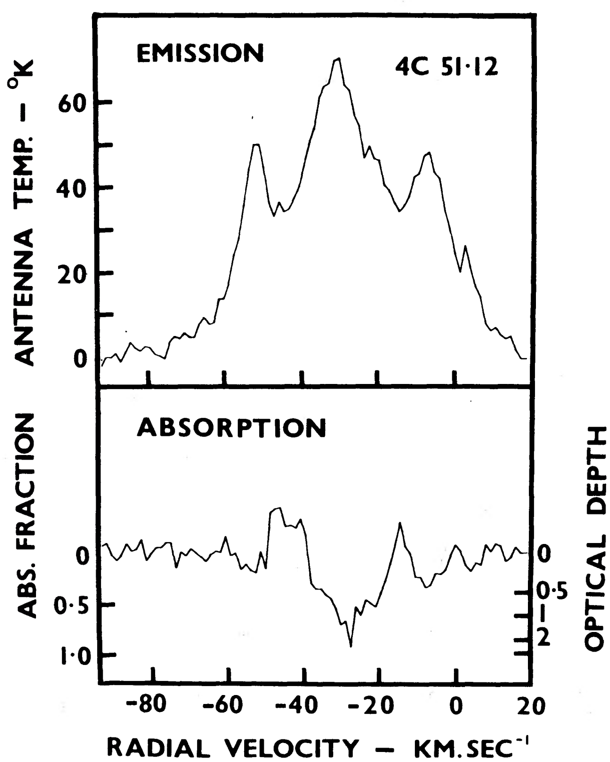

FIG. 2. 21-cm emission and absorption profiles in the direction of 4C 51.12. The emission profile has been interpolated to the position of the source by the procedure described in the text; it has not been corrected for the effects of the sidelobes of the telescope.

radial velocity for which the absorption profile can be determined in the presence of the emission feature, the identification of the radio source with Sharpless 209 appears very plausible. Its kinematic distance can then be estimated as 4.1 kpc, from the Hα emission velocity. It also appears likely that the thermal radio source and the optical nebulosity are associated with the neutral-hydrogen-emission feature described above.

IV. CONCLUSIONS

The neutral hydrogen absorption profile of NRAO 589A resolves the distance ambiguity in the H109α emission data on the source, and implies that its distance is 3.2 kpc. The profile of 4C 51.12 reinforces its identification with Sharpless 209, implying a distance of 4.1 kpc for this source. An extended neutral-hydrogen-emission feature is nearly coincident with both 4C 51.12 and Sharpless 209 in right ascension, and has a radial velocity close to that of the Hα emission from the nebula. Further observations will be necessary to delineate this feature in declination.

ACKNOWLEDGMENTS

We thank the Director of the National Radio Astronomy Observatory for allocating observing time on the 300-ft telescope, and the observatory staff for technical assistance. We are grateful to Dr. R. Butler for assisting with these observations. This research was supported by operating grants from the National Research Council of Canada.

REFERENCES

Butler, R., and Hughes, V. A. 1972, *Astron. J.* **77**, 201.
Caswell, J. L. 1969, *Observatory* **89**, 230.
Georgelin, Y. P., and Georgelin, Y. M. 1970, *Astron. Astrophys.* **6**, 349.
Kerr, F. J., and Knapp, G. R. 1970, *Aust. J. Phys. Astrophys. Suppl.* No. **18**, 9.
Mihalas, D., and Routly, P. M. 1968, in *Galactic Astronomy* (Freeman, San Francisco), p. 142.
Schraml, J., and Mezger, P. G. 1969, *Astrophys. J.* **156**, 269.
Sharpless, S. 1959, *Astrophys. J. Suppl.* **4**, 257.
Reifenstein, E. C. III, Wilson, T. L., Burke, B. F., Mezger, P. G., and Altenhoff, W. J. 1970, *Astron. Astrophys.* **4**, 357.
Weinreb, S. 1963, *Tech. Report No. 412*, *Res. Lab. Electron.* (M.I.T., Cambridge, Mass.).
Westerhout, G. 1958, *Bull. Astron. Inst. Neth.* **14**, 215.