Reports

Quasi-Stellar Sources: Variation in the Radio Emission of 3C 273

Abstract. *Evidence is presented for the first time for large fractional variations in the radio emission of the quasi-stellar sources 3C 273, 3C 279, and 3C 345, all of which have flat radio spectra at centimeter wavelengths.*

Since July 1962 repeated measurements of the flux densities of some 35 nonthermal radio sources have been made at 8000 megacycles per second (wavelength, λ, 3.75 cm) with the University of Michigan's 85-foot (26-m) parabolic antenna. Since the report of the observed light variations (*1*) of the quasi-stellar object identified with the radio source 3C 273, special attention has been given to this source in an attempt to detect a variation in its radio emission. This report presents evidence for a more or less steady increase of 40 percent in the radio emission of 3C 273 at 8000 Mc/sec in the past 1000 days. Until the recent announcement of a cyclic variation in CTA 102 at 940 Mc/sec (*2*), no variations in the radio emission of extragalactic sources had been reported.

Forty-seven separate sets of measurements of the ratio of the antenna temperatures of 3C 273 to Virgo A were made with a pencil beam of 5.9 minutes of arc. Virgo A was chosen as a reference source since the position of Virgo A is only about 10 degrees north of 3C 273. Both sources were observed within 1 hour of the meridian on the same day. The measured antenna temperatures were corrected (*3*) for the finite extent of Virgo A, the differential change in antenna gain with orientation, atmospheric extinction, and the linear polarization component of the sources. The overall corrections were 3 percent for 3C 273 and 5 percent for Virgo A, and any changes in these corrections were too small to detect.

The results of the measurements are shown in the upper half of Fig. 1. Each point represents an average of at least two separate observations made on a given day. The bars are standard deviations computed from the system noise and the number of observations on the particular day. The ratio of the antenna temperature of 3C 273 to Virgo A has increased between 31 July 1962 and 14 April 1965 from 0.525 to 0.74. The measured ratio of Virgo A to Cygnus A over the same period (lower half of Fig. 1) does not show any systematic trend or variation and supports the assumption that the flux density of Virgo A did not change significantly during the period of these observations.

If a flux density for Virgo A at 8000 Mc/sec of 45.0×10^{-26} watt m^{-2} cps^{-1} (cps, cycles per second) (*4*) is adopted, then the flux density of 3C 273 has increased from 23.6 to 33.3 in units of 10^{-26} watt m^{-2} cps^{-1}, corresponding to an increase in antenna temperature of from 2.18° to 3.07°K over the above period.

The radio source 3C 273 consists of two components separated by 20 seconds of arc (*5*). Component 3C 273A, identified optically with a faint jet (*6*), has a nonthermal radio spectrum with a steep spectral index ($\alpha \approx -0.7$), while component 3C 273B, identified with a quasi-stellar object, has a nearly flat ($\alpha \approx 0$) radio spectrum. The steep spectrum of component A dominates the observed composite spectrum at frequencies below 1000 Mc/sec while the nearly flat spectrum of component B dominates above.

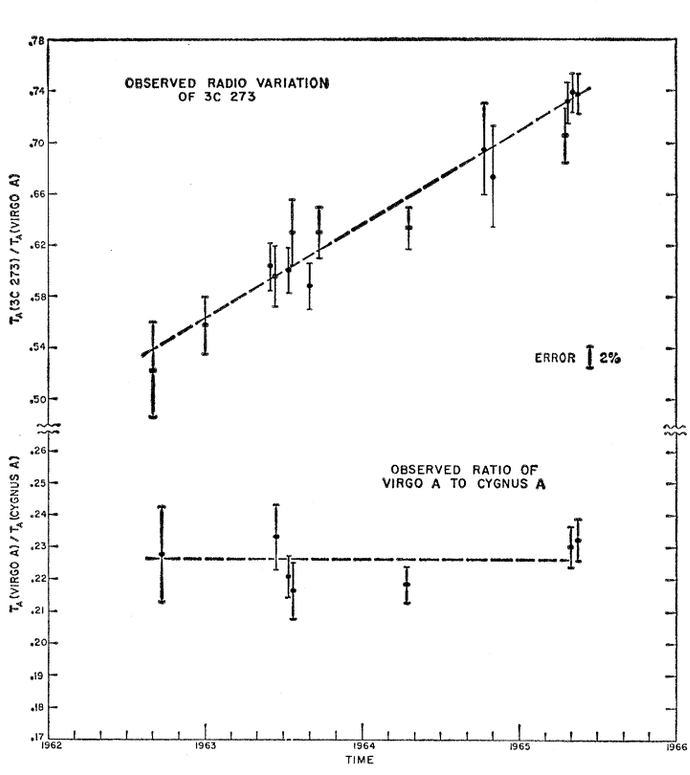
At 8000 Mc/sec the flux density of component B is about five times that of component A (*7*). Thus if the 8000-Mc/sec emission from the quasi-stellar component is varying, it must increase at a rate of approximately 17 percent per year compared to the much larger variation of 84 percent per year required if the increasing emission is from the jet. The fact that such a large annual variation has not been reported for this source at frequencies below 1000 Mc/sec strongly supports the assumption that the radio variation is due to the quasi-stellar component. This assumption is further supported by the fact that 3C 273B shows light variations having an irregular period of about 13 years (*8*). Continued radio observations of 3C 273 over a longer time base will establish whether its radio variation is also periodic.

Photometric observations (*9*) of 3C 273B over a 10-month interval in 1963 reveal a decrease in the optical emission in each of three colors of about 0.2 magnitude or 20 percent. This suggests that there may be a coupling between the mechanisms responsible for the optical continuum and the observed radio spectrum. If the optical continuum is synchrotron radiation then the decay of the radiating electrons ($\sim 10^{12}$ ev) to lower energies by radiation and inverse Compton losses will produce an increase in the radio emission.

In addition to 3C 273, there is some evidence for variations at 8000 Mc/sec in two other quasi-stellar sources. Figure 2 shows measurements of the ratios of the corrected antenna temperatures of three sources to the antenna temperature of Virgo A. The optically identified (*10*) quasi-stellar sources 3C 279 and 3C 345 show a net decrease of about 17 and 19 percent, respectively, in their radio emission over the past year; the data are too sparse to rule out shorter-termed variations. Observations of the quasi-stellar sources 3C 286 and 3C 147 (not shown) do not allow any variations greater than 10 percent over the past 2 years.

Like 3C 273, the observed radio spectra of both 3C 279 and 3C 345 are composite, with a steep and a flat spectral component (*4*, *7*); the principle contribution to the total flux density at 8000 Mc/sec is due to the flat spectral component. Thus it appears that variable radio emission may be associated with quasi-stellar sources having flat spectra, whereas the quasi-stellar sources with steep noncomposite radio spectra like 3C 147 and 3C 286 do not show obvious or large rates of variation.

This correlation suggests that quasi-stellar sources with flat spectra are more unstable and probably younger



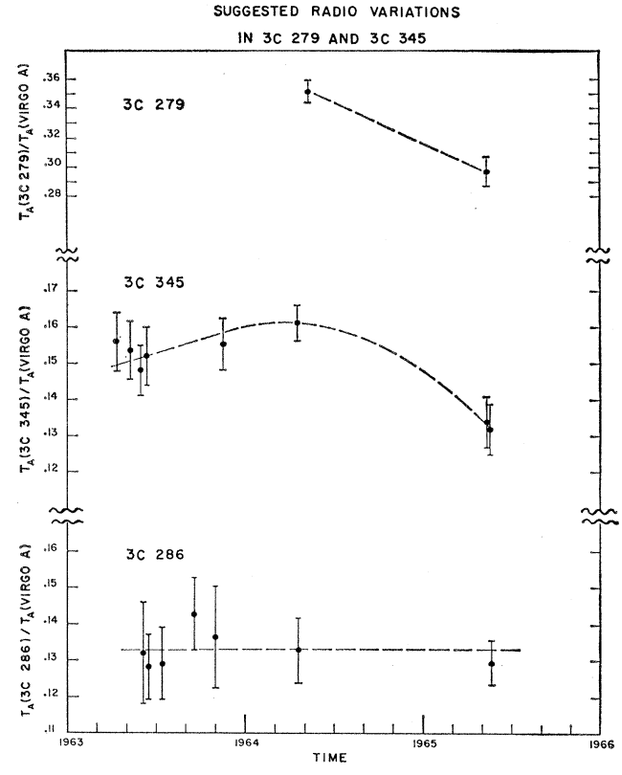


Fig. 1 (left). The ratio of the corrected antenna temperature, T_A, at 8000 Mc/sec of the quasi-stellar source 3C 273 to that of Virgo A, showing the observed 40-percent increase in the radio emission over a nearly three-year period. The measured ratio of Virgo A to Cygnus A shows no variation over the same period. Fig. 2 (right). Evidence for possible variations in the radio emissions of the quasi-stellar sources 3C 279 and 3C 345 at 8000 Mc/sec, and for a lack of variation in the quasi-stellar source 3C 286. Like 3C 273, which shows variations, both 3C 279 and 3C 345 have flat radio spectra at 8000 Mc/sec.

than the evolutionarily older sources whose initial spectra were probably flat and have since been steepened by synchrotron radiation losses and inverse Compton energy losses of the radiating electrons. The presence of both a steep and a flat component in the spectra 3C 273, 3C 279, and 3C 345 could suggest that recurrent outbursts have occurred in these sources.

The time scale of the observed radio variation of 3C 273B is short and is probably of the same order as the 13-year period of the optical variations. Since large fractional variations in the emission must occur over a time scale greater than the "light-travel" time through the source (*11*), the upper limit to the linear size of the radio component of 3C 273B is less than about 13 light years or 4 parsecs. Thus, knowledge of the angular diameter of the varying component will give an upper limit to the distance of the source.

The large red shift, $\Delta\lambda/\lambda = 0.158$, observed for 3C 273 (*6*) has been taken to indicate a distance of about 470 megaparsecs on the basis of Hubble's law (*12*). However, at a distance of 470 megaparsecs the linear size deduced above would subtend an angle of less than 0.002 seconds of arc, and the source would be opaque at 8000 Mc/sec owing to synchrotron self-absorption for a magnetic field greater than 10^{-5} gauss (*13*). Since the radio spectrum of 3C 273B is nearly flat ($\alpha = 0$) above at least 400 Mc/sec (*7*) and is not characteristic of self-absorption ($\alpha = 2.5$), the apparent angular diameter of 3C 273B must be greater than 0.1 second if the emission is synchrotron radiation.

Lunar occultation observations of 3C 273 at 1420 Mc/sec (*5*) show that 3C 273B consists of a central bright core component about 0.5 second of arc in diameter which contributes about 80 percent of the total flux density embedded in a weaker 7-second diameter halo. If an angular diameter of 0.5 second at 8000 Mc/sec is adopted, the upper limit of 4 parsecs to the linear size of the radio component of 3C 273B would set an upper limit to its distance at 2 megaparsecs and thus place 3C 273 within our own local group of galaxies.

It should be emphasized that this deduced distance is based on an assumed angular diameter of 3C 273B. If the angular diameter of 3C 273B is actually very much smaller than the reported measured value (*5*) or if the radio source at 8000 Mc/sec consists of a 0.002-second diameter nucleus of variable radio emission embedded in a much larger 0.5-second diameter nonvarying core, then the distance to the source could still be 470 megaparsecs. However, in both of these cases the radio emission from 3C 273B could not be due to synchrotron radiation, since self-absorption effects are not observed in the radio spectrum. A similar argument applies against a cosmological interpretation of the recently reported red shift (*14*) of CTA 102, unless its radio emission is not synchrotron radiation. It should be noted that a measured angular diameter greater than a few thousands of a second of arc for the varying components of these quasi-stellar sources will exclude a cosmological interpretation of their red shifts.

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References and Notes

1. H. J. Smith and D. Hoffleit, *Nature* **198**, 650 (1963).
2. G. B. Sholomitsky, Commission 27 of the International Astronomical Union, Information Bulletin No. 83, 27 February 1965.
3. W. A. Dent and F. T. Haddock, in preparation.
4. ———, *Nature* **205**, 487 (1965).
5. C. Hazard, M. B. Mackey, A. J. Shimmins, *ibid.* **197**, 1037 (1963).
6. M. Schmidt, *ibid.* **197**, 1049 (1963).
7. W. A. Dent and F. T. Haddock, in *Quasi-Stellar Sources and Gravitational Collapse*, I. Robinson, A. Schild, E. L. Shucking, Eds. (Univ. of Chicago Press, Chicago, 1965), p. 381.
8. H. J. Smith, *ibid.*, p. 221.
9. A. R. Sandage, *Astrophys. J.* **139**, 416 (1964).
10. ——— and J. D. Wyndham, *ibid.* **141**, 328 (1965).
11. J. Terrell, *Science* **145**, 918 (1964).
12. J. G. Greenstein and M. Schmidt, *Astrophys. J.* **140**, 1 (1964).
13. V. I. Slish, *Nature* **199**, 682 (1963).
14. M. Schmidt, *Astrophys. J.* **141**, 1295 (1965).

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Alkyl Iodide–Iodine Exchange and the Szilard-Chalmers Effect

Abstract. *The rate of isotopic exchange between liquid ethyl iodide and dissolved iodine is of zero order with respect to iodine concentration. Apparent isotopic exchange is thus very rapid at low concentrations of iodine, and previously reported values of organic "retention," obtained in studies of* (n, γ) *recoil in alkyl iodide, are placed in doubt.*

In studies of the Szilard-Chalmers effect (*1*) several theories regarding retention of I^{128} activity in the organic phase have been proposed (*2*). Libby (*3*) has attributed retention to a cage effect on the hot atom, and Willard (*4*) has indicated that impurities in the ethyl iodide may be responsible. Shaw and Collie (*5*) found that thermal exchange occurs, but, on the basis of the work of Lind *et al.* (*6*), they assumed that ethyl iodide and iodine could not exchange activity; they further reasoned that the exchange must be between ethyl iodide and an iodine-containing intermediate such as HI:

$$C_2H_5I + HI^{128} = C_2H_5I^{128} + HI \quad (1)$$

Reduction of the ethyl iodide-128 yield on addition of molecular iodine was attributed to the reaction:

$$HI^{128} + I - I = I - I^{128} + HI \quad (2)$$

This theory was also consistent with Willard's because the impurity could have been the intermediate HI. In all these treatments the exchange reaction between ethyl iodide and iodine was assumed to be slow in relation to the (n, γ) process and, therefore, has not been considered in interpreting experimental data. We have found the fundamental law for rate (R) for the transfer of isotopically labeled iodine atoms between I_2 and ethyl iodide, without net chemical change,

$$C_2H_5I + I - I^{131} = C_2H_5I^{131} + I - I \quad (3)$$

to be represented experimentally by

$$R = k(C_2H_5I)^2 \quad (4)$$

Equation 4 is valid within experimental error over a very wide range of concentrations of iodine (10^{-8} to $10^{-3}M$), from pure ethyl iodide to $3M$ solutions of ethyl iodide, at temperatures from 0° to 40°C. The value of k was found (*7*) to be $3.5 \times 10^{-9}M^{-1}$ hr^{-1} at 23°C, with a measured Arrhenius activation energy of 23 kcal/mole and an activation entropy of 40 calories per degree Celsius. This value of the rate constant was independent of exposure to air or room light; source, type, and intensity of iodine activity; presence of several common impurities; methods of purification of ethyl iodide; and oxidaton of I^- to I_2. The rate constant increased in highly polar solvents and in extensive glass surfaces. The corresponding k for the isopropyl iodide–iodine exchange system was about ten times smaller than that for ethyl iodide.

As McKay showed (*8*), the activity X of ethyl iodide is related to initial activity X_o and the activity at isotopic equilibrium, X_∞, by the molarities of the ethyl iodide and iodine pools a and b as follows:

$$\ln\left[\frac{X\infty - X_o}{X\infty - X}\right] = \left[\frac{a+b}{ab}\right]RT \quad (5)$$

For very low iodine concentrations ($b << a$) the rate law for exchange between ethyl iodide and iodine may be represented by combining Eqs. 4 and 5 and by simplifying them to

$$\ln\left[\frac{X\infty - X_o}{X\infty - X}\right] = \frac{Rt}{b} = \frac{k(C_2H_5I)^2t}{(I_2)} \quad (6)$$

Equation 6 shows that the half-time for exchange equals $0.693\ (I_2)/k(C_2H_5I)^2$. Thus the apparent or observed exchange reaction proceeds more rapidly the lower the iodine concentration, as was corroborated by experiments at $10^{-11}M$ I_2.

In Szilard-Chalmers experiments the fraction of newly formed activity retained in the target molecules is designated retention. In studies of this type on alkyl iodides the post-irradiation exchange has usually been ignored. However, any exchange that occurs before separation of the organic iodide and the recoil activity must be taken into account.

It can be seen that, even though the rate law is independent of iodine concentration, the apparent exchange (as measured by organic retention of activity) is dependent on it. At very low concentrations of iodine, apparent exchange is very fast, but, as the iodine concentration is increased, the measured apparent exchange rate falls off. If Eq. 6 were valid at extremely low concentrations of iodine, the apparent exchange rate would be too fast for measurement by standard techniques and the organic retention would be ~ 100 percent. At high concentrations of iodine the observed exchange rate becomes so slow as to require the use of very high activity levels of the isotope tracer; at such high levels the exchange induced by radiation becomes important (*9*).

The small amounts of iodine added in organic-retention studies to "carry" the activity produced in the (n,γ) reaction should also have a drastic effect on the organic retention. The half-time of the apparent exchange reaction is predicted to be 5×10^{-2} seconds in $10^{-11}M$ I_2 and 5×10^3 seconds in $10^{-6}M$ I_2. The latter value is of the same order of magnitude as the half-life of I^{128}.

The overall effect of this exchange is to lower the organic retention at higher concentrations of iodine until none is observed to arise from the exchange reaction in the period between neutron irradiation and separation of "organic" and "inorganic" species (measurement of retention). According to Eq. 6, diluting the ethyl iodide with inert solvents will decrease the exchange rate, which will also depend on the polarity of the solvents employed; this dependency is consistent with data reported for this system (*2–5*).

The experimental technique used should also be considered because of the rapid nature of the exchange. According to these earlier arguments there should be post-irradiation exchange, as has been reported by Schuler (*10*). Thus, if solutions are not quenched or sampled immediately after bombardment, there may be a large amount of