LETTERS TO THE EDITOR

ASTRONOMY

Interplanetary Scintillation of 3C273

In the period between September 15 and October 14, 1965, the radio source 3C273, observed with the east-west arm of the "Northern Cross" at 408 Mc/s, showed interplanetary scintillation. Comparison of the three records obtained with the three independent beams of the instrument excludes spurious effects due to instability or interference. The distance of the line of sight from the Sun during the period investigated ranged between 0.3 and 0.08 astronomical units. We observed a continuous increase in scintillation as the distance decreased. Taking into account the limit stated by Hewish¹, extrapolated to our frequency, the diameter of the core of the *B* component of the source 3C273 should be equal to or less than 0.1 sec of arc. This is in contrast to the value of 0.5 sec of arc calculated by Scheuer² from the record of the lunar occultation observed by Hazard³. This discrepancy is explained by the recent discovery of the composite structure of the *B* component⁴.

Fig. 1.

The radio source 3C273 was observed with the same technique used in the B1 survey⁵. The availability of three independent beams, shifted about 20 sec in right ascension, enabled us to record three passages each day. The narrowness of the beams in relation to the mean period of the scintillation prevented us from measuring the percentage scintillation accurately. In some cases there was a deformation of the sides only of the recorded profile: in some cases, however, there were marked oscillations at the top of the curve. The evaluation of the percentage scintillation is therefore very subjective. Fig. 1 gives a plot of the percentage scintillation against the distance of the line of sight from the Sun.

GIANFRANCO SINIGAGLIA

Laboratorio di Radio Astronomia,
Department of Physics,
University of Bologna,
Italy.

¹ Hewish, A., Scott, P. F., and Wills, D., *Nature*, **203**, 1214 (1964).

² Scheuer, P. A. G., *Mon. Not. Roy. Astro. Soc.*, **129**, 199 (1965).

³ Hazard, C., Mackey, M. B., and Shimmins, A. J., *Nature*, **197**, 1037 (1963).

⁴ Adgie, R. L., Gent, H., Slec, O. B., Frost, A. D., Palmer, H. P., and Rowson, B., *Nature*, **208**, 275 (1965).

⁵ Braccetti, A., et al., *Nuovo Cimento*, **40**, B, 1 (1965).

High Order Frequency Shift Measurement and General Relativity

In the theory of general relativity, the path of the photon is described as a null geodesic. If the field is static, this implies that the path of the photon obeys a Fermat principle of least (co-ordinate) time, the speed of the photon being given by

$$\frac{d\sigma}{dt} = c \sqrt{g_{44}} \quad (1)$$

where $d\sigma$ is the relativistic spatial line element; t the co-ordinate time; and g_{44} the time component of the metric. c is the speed of the photon in the absence of a gravitational field. In this communication, I want to point out that the general relativistic effect contained in equation (1) gives rise to a high order frequency shift.

I have calculated the frequency shift that would be measured if the emitter and the receiver were in motion in the field of the Sun as described by the Schwarzschild metric

$$ds^2 = \left(1 - \frac{2M}{r}\right) dt^2 - \left(1 - \frac{2M}{r}\right)^{-1} dr^2 - r^2 (d\theta^2 + \sin^2 \theta d\phi^2) \quad (2)$$

where M is the mass of the Sun. We adopt $c = G = 1$ where G is the gravitational constant and we set $x = r \sin \theta \cos \phi$, $y = r \sin \theta \sin \phi$, $z = r \cos \theta$. We assume (Fig. 1): $x_e = x_r = x_n$, $y_r > y_e$, $z_r = z_e = 0$, where the subscript letters e and r refer to the emitter and to the receiver. Using methods based on the corpuscular aspect¹ and on the wave aspect² of the emitted electromagnetic signal and writing $(v_e - v_{er})/v_e = S_1 + S_2$, where v_e is the frequency of the emitter and v_{er} the frequency of the emitter as measured at the receiver, we find*

$$S_1 = v_R^y [1 + v_e^y + (v_e^y)^2] + \frac{1}{2} (1 - v_R^y) \left[v_e^2 - v_r^2 + 2M \left(\frac{1}{r_e} - \frac{1}{r_r} \right) \right] \quad (3)$$

where $v^y = dy/dt$, $v_R^y = v_r^y - v_e^y$ and $v^2 = (v^x)^2 + (v^y)^2 + (v^z)^2$. In S_1 we recognize the non-relativistic Doppler shift (first term), the special relativistic (in v^2) and the general relativistic (in M/r) time dilatations. S_1 contains the results of previous derivations of the frequency shift^{1,3,4} carried up to the second order in v . S_2 is given by

$$S_2 = \frac{M}{x_n \Delta y} \left\{ [A_r \sin \phi_r - A_e \sin \phi_e] [v_r^x y_e - v_e^x y_r] + A_r \cos \phi_r [\Delta y v_r^y + x_n v_R^x] - A_e \cos \phi_e [\Delta y v_e^y + x_n v_R^x] \right\} \quad (4)$$

where $\Delta y = y_r - y_e$ and $A = (1 + \sin^2 \phi)$. As is the case for the bending of light rays⁵ and for the time delay effect⁶, S_2 results directly from the general relativistic corrections to the motion of the photon contained in equation (1). A frequency shift measurement to detect S_2 could then constitute a test of general relativity††.

S_2 can be more important near the superior conjunction of the source ($y_e y_r < 0$, $|x_n| \ll -y_e$, $|x_n| \ll y_r$). If we neglect terms of order $Mv/\Delta y$, it is given by

$$S_2 = - \frac{4M}{x_n} \dot{x}_n \quad (5)$$

* We neglect terms of order $v(M/x_n)^2$, $v^2(M/x_n)$, v^4 , where $v = v_r, v_e$. (We assume $v^2 \gg (M/r)$ with $r = r_r, r_e$.)

† We also have $S_2 = [d(\Delta t)/dt](1 + O(v^2))$ where Δt is the general relativistic correction to the time delay between the emission and the reception of a photon. For this reason, time delay measurements and frequency shift measurements (so far as S_2 is concerned) should both agree or both disagree with general relativistic predictions.

†† Because of the dependence on the "impact parameter" x_n , S_2 can be separated from S_1 .