Dependence of Doppler Shift on Photon Rest Mass

FOLLOWING renewed interest in the possible existence of a finite photon rest mass, Goldhaber and Nieto[1] have presented an excellent review of the general methods which have been adopted in an attempt to establish an upper limit for this rest mass. At present the lowest upper limit obtained experimentally is $\mu_0 \leq 4 \times 10^{-48}$ g (ref. 2), involving magnetic anomalies in the geomagnetic field. Suggestions have also been made[1] on methods whereby an improved upper limit to μ_0 may be determined. We present here a novel method for pursuing this goal based on a departure from the conventional Doppler shift for photons.

It follows from Lorentz invariance of 4-momentum

$$\pi = (p, iE/c)$$

that the energy of the photon will transform according to the following relation

$$E' = \gamma(E - vp_x) \quad (1)$$

for inertial frames S and S' moving with relative velocity v in the x–x' direction.

Substitution into equation (1) of the relations

$$E = h\nu$$

and

$$E^2 = p^2c^2 + \mu_0{}^2c^4$$

results in

$$\nu' = \nu\gamma \left\{1 - \frac{v}{c}\left[1 - \frac{\mu_0{}^2c^4}{(h\nu)^2}\right]^{\frac{1}{2}} \cos\theta\right\} \quad (2)$$

for the "anomalous" Doppler shift. In terms of a rest-frequency (corresponding to the energy of the photon in its rest-frame) $\nu_0 \equiv \mu_0 c^2/h$, below which electromagnetic waves are not expected to propagate, the above equation can be written

$$\nu' = \nu\gamma \left\{1 - \frac{v}{c}\left[1 - \left(\frac{\nu_0}{\nu}\right)^2\right]^{\frac{1}{2}} \cos\theta\right\} \quad (3)$$

This equation obviously reduces to the conventional Doppler relation when $\mu_0 = \nu_0 \equiv 0$; but a departure from the normal Doppler effect should be observable when the photon frequency ν is of order ν_0. The experiment which suggests itself is decidedly difficult since it involves the production and measurement of low electromagnetic frequencies to high accuracy. The rapid advance in electronic technology, however, had perhaps made it a distinct possibility. One advantage of the Doppler frequency technique over time dispersion wavelength experiments is that the frequency is independent of the propagation medium and is not masked by plasma dispersion and similar effects.

As an illustration, consider the measurements of longitudinal Doppler shift in a contra-rotating two-satellite experiment or some other arrangement. An emitted frequency from one satellite is measured on approach and recession of the other. The resulting frequency separations would be

(*a*) Conventional Doppler effect

$$(\Delta\nu')_{\mathrm{C.D.}} = 2\nu\gamma\beta \quad (4)$$

(*b*) Anomalous Doppler effect

$$(\Delta\nu')_{\mathrm{A.D.}} = 2\nu\gamma\beta\,(1 - \nu_0{}^2/\nu^2)^{\frac{1}{2}} \simeq 2\nu\gamma\beta[1 - \nu_0{}^2/2\nu^2 + \ldots] \quad (5)$$

where $v = \beta c$ is the relative velocity of the two satellites. Since $(\Delta\nu')_{\mathrm{C.D.}}$ can be calculated, the departure

$$[(\Delta\nu')_{\mathrm{A.D.}} - (\Delta\nu')_{\mathrm{C.D.}}]/\nu \simeq \beta(\nu_0/\nu)^2 \quad (6)$$

will yield a value for ν_0 (hence μ_0).

To improve on the current limit of $\mu_0 \sim 10^{-48}$ g ($\nu_0 \sim 0.2$ Hz), a frequency measurement accurate to better than 1 in 10^{10} would be required for photons of frequency $\nu \gtrsim 100$ Hz (assuming a typical value of $v \sim 100$ km s^{-1} for satellite speed).

A. R. LEE
J. LIESEGANG

Physics Department,
La Trobe University,
Bundoora, Victoria 3083

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1 Goldhaber, A. S., and Nieto, M. M., *Rev. Mod. Phys.*, **43**, 227 (1971).
2 Goldhaber, A. S., and Nieto, M. M., *Phys. Rev. Lett.*, **21**, 567 (1968).

Importance of High Time Resolution in Flare Star Observations

PHOTOELECTRIC observations of UV Ceti type flare stars, almost all dMe, have been widely reported[1–4]. The typical flare phenomenon reported shows a rapid rise of brightness followed by a quasi-exponential decay. This work has been done with time resolution of several seconds at best and large numbers of flare curves have been published showing smooth curves connecting a few observational points.

Flare star observations have been made here of about 75 events on 7 UV Ceti type stars, using time resolutions as short as 50 ms. Most of the observations were obtained with the 82-inch (208-cm) Struve reflector at McDonald Observatory, using an uncooled 'Amperex 56 DVP' photomultiplier tube. The complete high speed pulse counting system has been described by Nather and Warner[5].

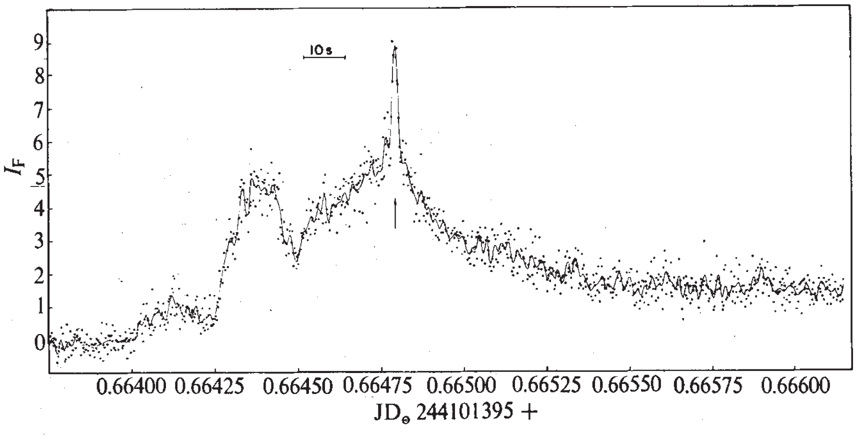

Fig. 1 Flare observed on Wolf 359 in the U-band on March 19, 1972. Integration time was 200 ms.