References and Notes

1. H.-S. Liu and J. A. O'Keefe, *Science* **150**, 1717 (1965); L. J. Laslett and A. M. Sessler, *ibid.* **151**, 1384 (1966); W. H. Jefferys, *ibid.* **152**, 301 (1966); H.-S. Liu, *J. Geophys. Res.* **71**, 3099 (1966).
2. W. E. Warren, *Amer. Inst. Aeron. Astron. J.* **11**, 2569 (1963).
3. P. Goldreich and S. J. Peale, *Nature* **209**, 1078 (1966).
4. F. Birch, *J. Geophys. Res.* **57**, 227 (1952).
5. I thank R. K. Squires and E. R. Lancaster for assistance. The computer programing was performed by W. R. Trebilcock and A. Proffitt. Also I thank J. A. O'Keefe for suggestions and discussions.

19 September 1967

Search for a Frequency Shift of the 21-Centimeter Line from Taurus A near Occultation by Sun

Abstract. *The 21-centimeter absorption line from the direction of Taurus A was used for detection of a shift in frequency when the source passed near Sun. A possible decrease in frequency of 150 cycles per second was detected, which cannot be caused by general relativity or by the plasma around Sun.*

A search for a shift in frequency of the 21-cm neutral hydrogen-absorption line from Taurus A during its near-occultation by Sun was made with the U.S. Naval Research Laboratory's 25.6-m radio telescope at Maryland Point. When, every June, Sun approaches the line Earth–Taurus A one can check the influence of Sun's vicinity on the frequency of the line. A shift in frequency is expected because of three effects:

1) According to general relativity the optical path of an electromagnetic wave depends on the strength of the gravitational potential along its path (*1, 2*). Whenever the optical path changes with time, a shift in frequency results. Thus, as Sun moves toward the line Earth–Taurus A, the optical path gradually increases, giving rise to a red shift when it approaches the Earth–Taurus line and to a blue shift when it recedes (*3, 4*).

The fractional change in frequency is

$$\Delta\nu/\nu = -(1/c)\,(dL/dt)$$

where the optical path $L = L_0 + c\cdot\Delta Tr$; L_0 is the classical distance, and ΔTr is the additional time delay predicted by the general theory of relativity. According to Shapiro (*1*)

$$\Delta Tr = \frac{2GM}{c^3}\left(\ln\frac{4XeXp}{l^2} - \frac{3Xe+Xp}{2Xe}\right)$$

for one-way propagation, where G is the gravitational constant, M is Sun's mass, Xe is the distance along the line of sight from Earth to the point of closest approach to Sun, Xp is the distance from this point to Taurus A, and l is the distance from this point to the center of Sun. Differentiation of ΔTr with respect to time gives

$$\frac{\Delta\nu}{\nu} = \frac{4GM}{lc^3}\frac{dl}{dt} = \frac{1.93\times10^{-5}}{l}\frac{dl}{dt}$$

Thus the frequency shift is independent of the distances Xe and Xp, and for a ray passing at 1.25 deg from Sun (where it was on the day of closest approach, 15 June 1967), and for

$$dl/dt = 20.7 \text{ km/sec } (5)$$

$\Delta\ \nu/\nu$ is equal to 1.16×10^{-10}. The maximum expected shift, due to general relativity, in the 21-cm line from Taurus A is 0.16 hertz; the shift predicted as a function of time is plotted in Fig. 1.

2) The plasma around Sun also causes a shift in frequency. The time delay due to plasma, Tp, is related to the distance from the center of Sun by (*1*)

$$Tp = [(6.5\times10^{24})/\nu^2 l]\times[\tan^{-1}(Xp/l) + \tan^{-1}(Xe/l)]$$

and the shift in frequency is then

$$(\Delta\nu/\nu)\,p \cong -(dTp/dl) = (6.5\times10^{24})/l^2\nu^2\times(dl/dt)$$

The ratio between the relativistic and the plasma shifts is

$$\Delta\nu r/\Delta\nu p \cong [(1.93\times10^{-5})/(6.5\times10^{24})]l\nu^2 = 1.45$$

for the 21-cm line when Taurus A is 1.25 deg away from Sun (*6*).

3) The third effect is highly speculative but worth examining nevertheless. Assuming an analogy between electrons and photons, Fürth (*7*) hypothesized that, whenever a deflection of light occurs due to gravitational effect of a mass, a decrease in frequency follows; thus he can explain the cosmological red shift and the excessive red shift found for some of the spectral lines from Sun. A wave passing at a distance l from the center of Sun will be red-shifted by

$$\Delta\nu/\nu = K\,(4GM/lc^2)$$

where K is of the order of 1. At the closest approach of Taurus A

$$\Delta\nu/\nu = 1.64\times10^{-6}$$

which fact implies a shift of 2300 hertz for the 21-cm line.

The general relativistic and the plasma effects are too small to be detected with our present instrumentation. The resolution of frequency is limited by

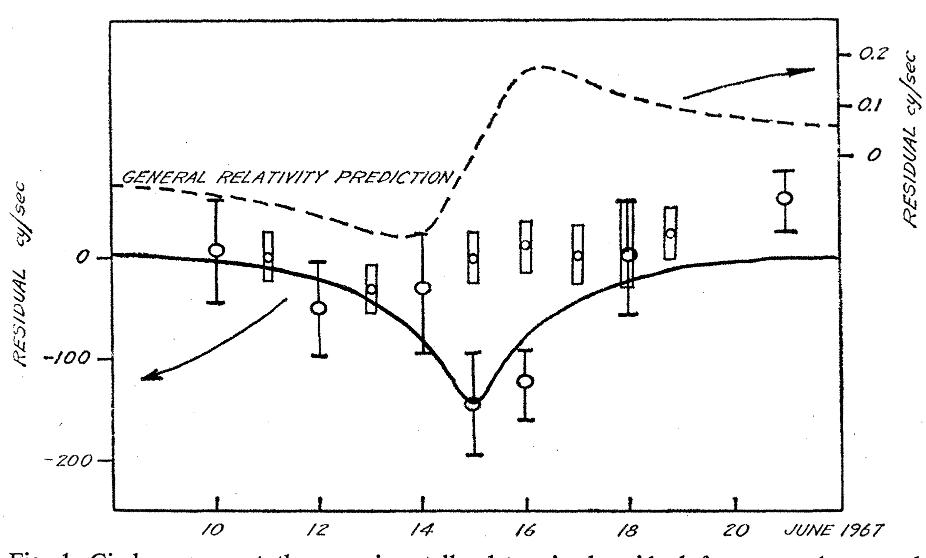

Fig. 1. Circles represent the experimentally determined residual frequency (measured minus calculated) of the 21-cm line during the days before and after the closest approach of Taurus A to Sun. The error flags represent the actual spreads of the 20 measurements of frequency taken each day. The solid curve is a tentative $1/r^2$ line that seems to fit the data. The dashed line is the general relativistic effect of the change of frequncy as Sun approaches the line of sight Earth–Taurus, as predicted for the situation in June 1967. The rectangles represent Taurus-A data received during 7 days of testing between 7 and 15 March 1967, when Sun was far away from Taurus A. The results exclude a theory by Fürth; the small decrease in frequency found by us has yet to be confirmed with better instrumentation.

the width of the Taurus-A line; thus the only predicted shift that could be observed was the Fürth effect. The Taurus-A 21-cm absorption line was observed during June and July 1967 with a multichannel 21-cm receiver. The method used for determining the shift in frequency was the same as the one used for current experimental measurement of the astronomical unit (*8*). All known Doppler shifts, such as those due to Earth's orbital revolution, rotation, motions in the Earth-Moon orbit, and other minor effects, were computed and subtracted from the frequency measured by observation so as to give the residuals. Observations made over a period of several days, a few months before our measurements, had confirmed the method of prediction. The rectangles in Fig. 1 give the results of this control measurement and show that the residuals are near the zero line as they should be. Although the frequency-switching technique effectively canceled the solar sidelobe radiation, it was important to evaluate any possible solar interference. Before 15 June, tests were made with the antenna pointed within 1 deg of Sun, with no noticeable degradation in performance of the system. Nevertheless there remains a possibility that Sun's radiation affects the equipment in an unpredicted way. The near-occultation observations commenced on 10 June. Taurus A was observed for several hours daily for 5 days before and after the solar approach. The residuals (observed minus calculated frequencies) are plotted in Fig. 1; each point is the average of about 20 individual data points, the scatter being represented by an error bar. There appears to be a decrease of about 150 hertz in frequency near closest approach; however, on the basis of statistical analysis, the probability that this is a real decrease is only 90 percent.

An experiment (*4*) in which the frequency of radar pulses reflected from Venus and Mercury was measured sets an upper limit of 1/70 on the constant K of Fürth's theory (as was presented by Fürth; that is, with a $1/r$ dependent). In order to reconcile the Venus experiment with the apparent decrease of 150 hertz found by us one would have to assume that the effect is proportional to $1/r^2$. In this case the experiment of Shapiro *et al.* (*4*) could not detect the effect as the radar pulses passed some 80 solar radii away from Sun. A $1/r^2$ dependence is also indicated by the shape of the plot in Fig. 1. On the other hand, the $1/r^2$ dependence does not agree with red-shift measurements of the Na lines from the limb of Sun. The gravitational red shift should amount to

$$\Delta\nu/\nu = 2 \times 10^{-6}$$

and was experimentally found (*9*) to agree with the predicted value within 10 percent. If the effect found in our experiment depends on $1/r^2$ one should see the Na line red-shifted by

$$\Delta\nu/\nu = (150 \times 5^2)\ (1.4 \times 10^9 \times 2) = 1.3 \times 10^{-6}$$

(Our experiment showed a shift of 150 hertz, out of 1.4×10^9 hertz, when the rays passed at five solar radii. The Na lines are emitted from one solar radius but are affected by Sun only half as much as is the 21-cm line.) This shift, added to the gravitational red shift, should become

$$\Delta\nu/\nu = 3.3 \times 10^{-6}$$

which is inconsistent with the $2 \times 10^{-6} \pm 0.2$ found experimentally.

In conclusion, a possible decrease in frequency of the 21-cm line was observed, with an indicated dependence of $1/r^2$. This decrease could be of great significance, as it indicates a red shift for waves passing near a mass, but a higher degree of statistical confirmation is needed. The general relativistic effect could not be tested by use of the 21-cm line from Taurus A. Using the largest antenna and the best equipment available one could measure the shift within 1 hertz, which degree is still an order of magnitude greater than the effect. However, if a narrow and intense line were found near the ecliptic, the gravitational shift could be detected. Oxygen-hydrogen emission regions could provide such lines, but the accuracy of the measurement depends on (i) the width of the line, (ii) the intensity of the line, and (iii) the distance of the source from the ecliptic. Although the OH lines are much narrower than the hydrogen line, we could not find a line that was sufficiently intense and close enough to Sun.

D. SADEH
S. H. KNOWLES
B. S. YAPLEE

E. O. Hulbert Center for Space Research, Naval Research Laboratory, Washington, D.C. 20390

References and Notes

1. I. I. Shapiro, *Phys. Rev. Letters* **13**, 789 (1964).
2. D. K. Ross and L. T. Shiff, *Phys. Rev.* **141**, 1215 (1966).
3. A shift in frequency in the radar echoes from a planet, as a test for general relativity, was proposed by D. Sadeh [*Phys. Letters* **8**, 316 (1964)] and ——— and I. I. Shapiro [*Tech. Rept. 368* (Lincoln Laboratory, Lexington, Mass., 1964)]; J. R. Richard [*Tech. Rept. 628* (Univ. of Maryland)] calculated the effect from a purely general relativistic argument.
4. I. I. Shapiro, M. E. Ash, M. J. Tausner, *Phys. Rev. Letters* **17**, 933 (1966).
5. The relation between dl/dt and the orbital velocity V of Earth around Sun is $dl/dt = V \sin \tan^{-1} Vt/d$, where d is the distance from the center of Sun to the line Earth–Taurus A at the time of closest approach, and t is the time after closest approach. The maximum that dl/dt can attain is 0.7 $V = 20.7$ km/sec.
6. The value $(\Delta\nu/\nu)\,p$ is correct only within an order of magnitude as the plasma changes during the solar cycle; therefore the value 1.45 is only a crude estimate.
7. R. Fürth, *Phys. Letters* **13**, 221 (1964).
8. S. H. Knowles, in preparation.
9. J. E. Blamont and F. Roddier, *Phys. Rev. Letters* **7**, 437 (1961); Brault, thesis, Princeton Univ. (1962).
10. Supported by NSF grant GS 6823. Dror Sadeh, who is on leave from the University of California, Los Angeles, and the University of Tel Aviv, thanks W. F. Libby for constant support.

22 November 1967

Binocularly Driven Neurons in Visual Cortex of Split-Chiasm Cats

Abstract. *In cats with midsagittal section of the optic chiasm, some visual cortex neurons can be driven not only by the ipsilateral eye, through the direct geniculocortical pathways, but also by the contralateral eye, through the opposite visual cortex and corpus callosum. The receptive fields and the response characteristics observed upon stimulation of the contralateral eye are very similar to those observed upon stimulation of the ipsilateral eye; the two monocular receptive fields of a given cell lie in corresponding points of heteronymous halves of the visual field in close contact with the vertical meridian, thus adding in visual space and forming a binocular receptive area which crosses the vertical meridian and extends equally on either side of it.*

In mammals, the connections between the eyes and the brain are such that each half of the visual field is projected to the contralateral hemisphere only. Perceptual unity of the cerebral hemispheres in the act of seeing is thought to result largely from the activity of commissural pathways,