precession camera with 40 kilovolt, collimated, unfiltered copper radiation from a Jarrell-Ash microfocus x-ray unit. All work was done in a cold room at 8° to 10° C. Crystals still gave clear diffraction patterns after 100 hours exposure in the x-ray beam.

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References and Notes

1. A. Garen, *Science* **160**, 149 (1968).
2. M. W. Nirenberg and P. Leder, *ibid.* **145**, 1399 (1964).
3. J. T. Madison, *Annu. Rev. Biochem.* **37**, 131 (1968).
4. K. A. Marcker, *J. Mol. Biol.* **14**, 63 (1965).
5. J. Hurwitz, M. Gold, M. Anders, *J. Biol. Chem.* **239**, 3474 (1967).
6. F. Skoog, D. Armstrong, J. Cheravil, A. Hampel, R. Bock, *Science* **154**, 1354 (1966).
7. J. A. Lake and W. W. Beeman, *J. Mol. Biol.* **31**, 115 (1968).
8. T. Ishida and N. Sueoka, *Proc. Nat. Acad. Sci. U.S.* **58**, 1080 (1967); A. Adams, T. Lindahl, J. R. Fresco, *ibid.* **57**, 1684 (1967).
9. L. Stryer, *Annu. Rev. Biochem.* **37**, 25 (1968).
10. R. M. Bock and J. D. Cherayil, in *Meth. Enzymol.* **12**, 638 (1967); R. W. Holley, J. Apgar, G. A. Everett, J. T. Madison, M. Marquisee, S. H. Merrill, J. R. Penswick, A. Zamir, *Science* **147**, 1462 (1965); J. F. Weiss, R. L. Pearson, A. D. Kelmers, *Biochemistry* **7**, 3479 (1968); I. Gillam, D. Blew, R. C. Warrington, M. von Tigerstrom, G. M. Tener, *ibid.*, p. 3459.
11. A. Dury, *Science* **162**, 621 (1968).
12. A. D. Kelmers, *J. Biol. Chem.* **241**, 3540 (1966).
13. U. L. RajBhandary and H. P. Ghosh, *ibid.*, in press.
14. H. D. Keith, in *Physics and Chemistry of the Organic Solid State*, D. Fox, M. Labes, A. Weissberger, Eds. (Interscience, New York, 1963), vol. 1, p. 462.
15. B. F. C. Clark, B. P. Doctor, K. C. Holmes, A. Klug, K. A. Marcker, S. J. Morris, H. H. Paradies, *Nature* **219**, 1222 (1968).
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Nondependence of Frequency on Mass: A Differential Experiment

Abstract. A differential Loran C experiment, which is independent of variations in clock rates, shows that the frequency of a radio transmission is not affected by the mass of the earth.

Sadeh *et al.* have reported that the frequency of a radio transmission propagated along the surface of the earth decreases by 2 parts in 10^{12} every 1000 km (*1*). The frequency of the Loran C radio transmission from Cape Fear, North Carolina, controlled by a cesium-beam atomic clock, was compared to the frequency of a similar clock mounted in a truck at distances up to 1500 km away; the frequency was found to decrease with distance. This change in received frequency, which is here called the "horizontal effect," was attributed to the mass of the earth. It is not the same as the gravitational red shift of relativity, which relates the difference in frequency of two atomic clocks at different potential heights.

Announcement of the horizontal effect (*1*) was puzzling because it is contrary to the theory of relativity. Therefore, additional experiments have been conducted at Marquette University. In the first set, completed 6 September 1968, the frequencies of transmissions received from Loran C stations and from U.S. Naval radio stations as far away as Northwest Cape, Australia (17,000 km), were compared with the cesium-beam atomic clock at Marquette. These transmissions are controlled in time and frequency by the U.S. Naval Observatory, where calibration of the atomic clocks at the transmitters and the clock at Marquette was done. However, no change in frequency was found within the errors of observation at Marquette for any station (*2*). For Northwest Cape, the computed decrease based on the horizontal effect is 3.4 parts in 10^{11}, or one order larger than the maximum change observed at the Naval Research Laboratory (*1*).

Results from both NRL and Marquette would be affected by changes in the rates of the atomic clocks at either the transmitting or observing stations. However, we can eliminate the effects of changes in clock rates by performing a differential Loran C experiment. Loran C is a pulsed, hyperbolic, radio navigational system, which operates on 100 khz. The stations of a chain are synchronized through the continual interchange of pulses (*3*). The pulses emitted at each station are locked to the frequency of the carrier wave. Hence, the transmitted frequencies are the same for all stations of a chain. Measurement of the difference in arrival times of selected cycles of pulses from day to day gives the difference in frequencies of the carrier waves as received. The difference is independent of variations in the rates of any clocks

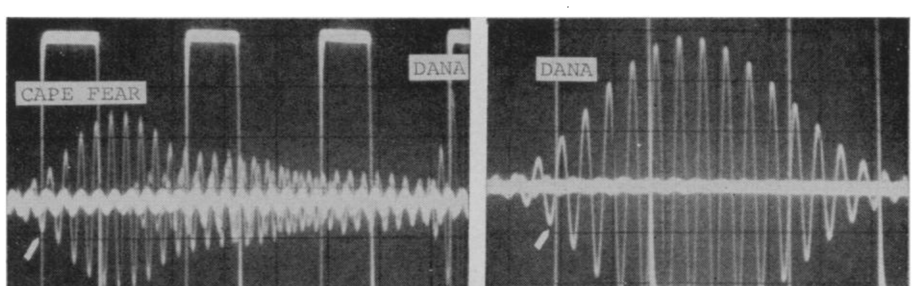

Fig. 1. Loran C pulses from Cape Fear, North Carolina, and Dana, Indiana, received at Marquette 19 October 1968 at 1530 U.T. (universal time) and time markers. Periods are 10 μsec for Loran C cycles and 100 μsec for markers. Cycles measured are marked with arrows. (A) When a minimum from Cape Fear coincided with a time marker, the minimum from Dana was 2.4 μsec ahead of the nearby marker. (B) The pulse from Dana has been expanded horizontally with the amplitude reduced for measurement. Coincidence setting on the pulse from Dana was made after photographs were taken. Early cycles are measured to ensure reception of the ground wave. Sky waves, which have slightly variable transmission times, arrive after the ground wave.

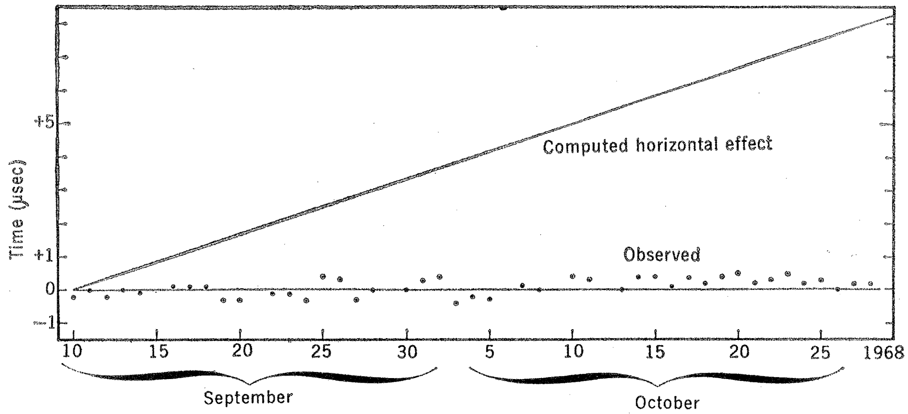

Fig. 2. Difference in times of arrival (K) of cycles from Cape Fear, North Carolina, and Dana, Indiana. The quantity plotted is ($K - 2$) in microseconds. The difference is ($100\,n + K$) μsec, where n is some fixed integer.

used. If the horizontal effect were real, then when the NRL group was at Cape Fear, it should have found that the frequency of Loran C at Nantucket, Massachusetts, was lower than that at Cape Fear by 2 parts in 10^{12}, and that the frequency was higher by 2 parts in 10^{12} when at Nantucket.

A differential experiment can also be performed at a fixed site. Such an experiment was initiated at Marquette on 10 September 1968, monitoring cycles from Dana, Indiana, and Cape Fear, North Carolina. The respective distances from Milwaukee are 350 and 1320 km. If the horizontal effect were real, the Cape Fear value should be lower in frequency by 2 parts in 10^{12}, and a particular cycle from Cape Fear should arrive later each day than the one from Dana by 0.17 μsec.

Loran C is monitored at Marquette by a simple but highly precise visual technique. The incoming carrier waves are amplified and displayed on a dual-trace oscilloscope, which also displays time markers produced by the Marquette clock. The carrier waves from both Cape Fear and Dana are displayed on the same trace (Fig. 1). Coincidence settings of minima with time markers are made to 0.1 μsec with a phase shifter.

Figure 2 shows the difference in times of reception of cycles from Cape Fear and Dana. There is no daily shift, as would be required by the horizontal effect. Hence, the frequency of a radio transmission is not affected by mass (except in accordance with the gravitational red shift of relativity).

In the NRL experiment, the moving clock was checked against a fixed clock at Cape Fear at the beginning and end of the experiment. However, no differential checks were made. In view of the definitive nature of the differential experiment reported here, which is independent of clock rates, it does not appear that a discrepancy exists which contradicts relativity.

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References and Notes

1. D. Sadeh, S. Knowles, B. Au, *Science* **161**, 567 (1968).
2. W. Markowitz, *Advances in Metrology* (Instrument Society of America, Pittsburgh, 1968), vol. 5, paper No. 68-627.
3. To avoid interference, pulse groups are emitted in sequence from the various stations of a chain with a fixed time separation maintained to 0.1 μsec.

4. The Time, Frequency, and Polar Motion Laboratory was established in April 1968 through equipment grants by NSF and the Marquette University Committee on Research. Support provided in part by the Office of Naval Research on behalf of the U.S. Naval Observatory.

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Radar Scattering from Venus at Large Angles of Incidence and the Question of Polar Ice Caps

Abstract. *Spectrum analysis of radar waves backscattered from an anulus near the limb of Venus shows that a uniform scattering model applies over regions extending from the equator to within approximately 15 degrees of the poles. These observations indicate that large polar ice caps extending to latitudes as low as 60 degrees are very unlikely.*

A report by Libby (*1*) suggests that the Mariner V and Venera 4 observations of Venus do not discount the possibility of polar ice caps on the surface of this planet. However, a more recent report by Weertman (*2*) shows that if the amount of water present on the earth were locked up as polar ice caps on Venus, the ice caps would have to extend to below 60° latitude. A reply by Libby (*3*) indicates that ice caps extending as low as 45° latitude may not be unreasonable. The data on radar scattering reported here indicates that ice caps at these latitudes are very unlikely.

During the 1967 inferior conjunction of Venus, a number of radar observations were made to study the backscattering properties of Venusian surface at large angles of incidence. Some of these observations were of such quality that acceptable delay-Doppler spectra (maps) could be obtained from the recorded data for incidence angles approaching 80°. Higher quality spectra, of course, can be obtained for smaller incidence angles. However, by choosing the spectra as near the limb of the planet as possible, all latitudes from the equatorial region to the polar region may be observed in a single spectrum, as illustrated in Fig. 1. In such observations, any absorption or ray-bending caused by a uniform atmosphere will be constant over the entire spectrum.

If extensive polar ice caps exist on Venus, what effect might they have on the delay-Doppler spectra? At large incidence angles, the backscattered power is greatly dependent upon the surface roughness. Rough surfaces have a larger number of facets per unit area directed normal to the incident waves, therefore more power is backscattered to the radar. Rocks and other debris that have diameters nearly equal to the radar wavelength contribute extensively to the backscatter, since they scatter roughly isotropically. The backscattered power is also dependent upon the dielectric constant and conductivity of the materials. Materials with high dielectric constants have greater reflection coefficients, which results in greater backscattered power. The conductivity of most natural materials is sufficiently small so that the reflection coefficient is controlled mainly by the dielectric constant. The equatorial region of Venus is known to be very hot (about 600° to 700°K), and the surface material is probably a mixture of granulated solids and rocks of various sizes that have a dielectric constant of 5 over a wide range of radar frequencies. The surface is less rough than that of the moon at centimeter wavelengths, and the average scattering properties are in good agreement with a model by Muhleman (*4*).