rent.

The experimental uncertainties are at present too large to place really useful limits on isotensor effects: For the decays of the lowest $T=2$ levels in mass 32 to the two lowest 1^+ $T=1$ levels, $R(T_z=+1)/R(T_z=0)=1.07\pm0.28$. However, comparisons such as the one reported here can in principle be made much more precise, for example, by using the same high-resolution detection system for measuring the decays of both members of the multiplet. It is, of course, important to avoid cases where one of the decays a or b is highly inhibited since in such circumstances it is well known that a small isospin impurity can have a large effect on the rate.

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Observations of Intensity Modulation of Starlight at Discrete Radio Frequencies*

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Components modulated in intensity at discrete radio frequencies have been detected in the light from several stars. The effect is believed to be due to time-dependent, very small-angle scattering of the starlight by enhanced electron density fluctuations in the ionosphere.

Radio-frequency intensity-modulated components have been detected in the light from several stars. Within the limits imposed by the receiver resolution, sensitivity, and response time, the observed modulation spectra are all characteristic of cw, single-frequency modulating signals. The modulating signal frequencies are in the range from 1 to 20 MHz with most signals occurring in the range from 3 to 8 MHz. Modulation factors are of the order of 10^{-2}. The signals are transient in nature, but have lifetimes up to several tens of minutes. For a given star, the signals are not always present and in general they do not appear at the same frequencies on different nights. Data taken on several different stars on the same night also show different modulation frequencies for the different stars.

This new and unexpected result cannot reasonably be attributed to the stars themselves nor to any known effect in the interstellar medium. There is also no known effect due to earth's lower atmosphere which could explain the result. Scintillations caused by atmospheric turbulence exhibit a spectrum extending to at most 1 kHz and ordinary Mie or Rayleigh scattering produces no such effect.[1,2] For reasons discussed briefly below, the phenomenon is believed to be due to time-dependent, very small-angle scattering of the starlight by enhanced electron density fluctuations in the ionosphere. That is, the amount of scattered component entering the detector is modulated by the periodic density fluctuations.

The apparatus used in the experiment consists of a 40-cm-diam Cassegrain telescope and the electronics shown in block diagram form in Fig. 1. The photometer unit mounts on the telescope and contains the photomultiplier first detector, a mechanical chopper, and auxiliary optics. The remainder of the system constitutes a spectrum analyzer with a low (40-kHz/sec) scanning speed. The analyzer output is the modulating signal spectrum (power versus frequency) over the range from 1 to 20 MHz. The spectrum is recorded on the *xy* plotter. The system is operated as a null-balancing radiometer to achieve stability against gain fluctuations and to compensate for atmospheric-induced scintillations.[3,4]

In order to increase the effective signal-to-noise ratio and make signal identification more positive, post-recording signal processing was used. The analyzer spectral plots were digitized and fed to a computer. Several successive scans could then be added together in the computer and the sum played back to the *xy* plotter. Assuming the signal to be present throughout the data-taking interval, this technique provides an effective signal-to-noise ratio $(S/N)_{\text{eff}} \simeq n^{1/2}(S/N)$, where n is the number of runs added together and (S/N) is the value for one run. In many cases, the addition of two curves was adequate to make the signal easily recognizable. Ordinarily, up to 16 runs were added together and signal-to-noise ratios as high as 5 were sometimes achieved. Once a signal had been identified, its time history was followed by checking individual scans or by adding analyzer scans in pairs successively, i.e., scan 1 + scan 2, 2 + 3, 3 + 4, etc. Persistence of modulation signals over periods of time up to 50 min has been observed.

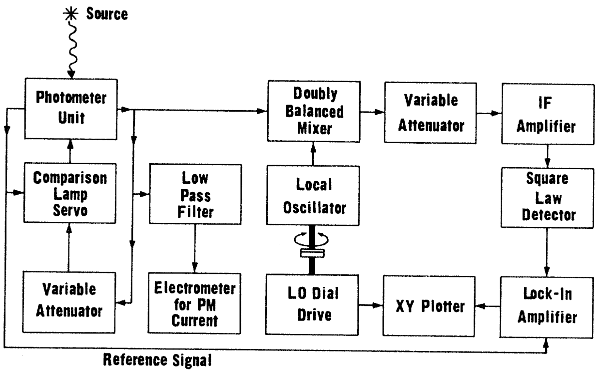

FIG. 1. Block diagram of the experimental apparatus used in detecting rf intensity-modulated components in starlight.

Portions of three typical spectrum analyzer traces are shown in Fig. 2. The number of scans added together for each case is shown in the figure. Figure 2(a) shows results for a weakly

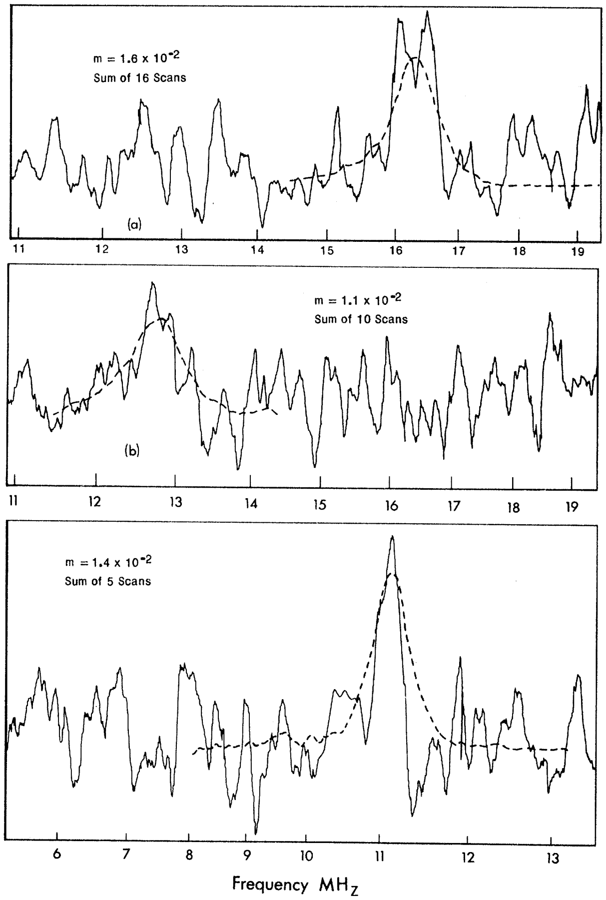

FIG. 2. Three typical modulation spectral plots. (a) Weakly modulated laboratory source, (b) the star α-Lyrae during the interval from 1003 to 1046 UT, 10 April 1969, (c) the star α-Lyrae during the interval from 0822 to 0853 UT, 17 May 1968.

modulated laboratory light source. This source was used to check overall system performance including the addition process. Figures 2(b) and 2(c) are spectrum-analyzer plots for the star α-Lyrae obtained on two different nights. As is evident from Fig. 2(c), well-defined signals were sometimes observed with only a few scans.

The dashed curve superimposed on each spectrum is the analyzer response to a cw signal with the same center frequency and rms amplitude as the modulation signal. These curves were obtained using a laboratory oscillator as a source, and they are free of the noise (filtered photomultiplier shot noise) which appears on the modulation signal spectra. Comparison of the analyzer response to this known narrow-bandwidth signal with its response to the modulation signal indicates that the modulation signals are also single-frequency cw signals. This was, of course, the case for the modulated laboratory light source. However, the intensity-modulated starlight signals are also narrow bandwidth indicating a relatively well-defined and homogeneous source. The resolution of the analyzer is $\simeq 1.0$ MHz, and any structure in the spectrum finer than this would not be seen.

It is important to rule out any possibility that the signals might be only fluctuations in the system noise. But the occurrence of an apparent signal at a specific receiver tuning frequency with the proper phase and duration on each of ten successive scans is exceedingly difficult to explain on the basis of random fluctuations. The signal shown in Fig. 2(b), for example, is discernible on each of the ten individual traces which were added together to obtain this result. The scans are taken at about 3-min intervals and are completely independent. Instrumental effects are ruled out by the fact that different signal frequencies were observed for different stars even though no change was made in the instrument except the position of the telescope. Stringent tests with unmodulated laboratory light sources failed to turn up any spurious responses in the instrument.

For a cw single-frequency modulated signal, intensity modulation is described by $I(t) = I_0(1 + m \cos\omega_M t)$. $I(t)$ is the instantaneous intensity, I_0 the average unmodulated intensity, m is the modulation factor, and $\omega_M = 2\pi f_M$ is the angular modulation frequency. The distribution of observed modulating signal frequencies (f_M) is shown in Fig. 3. Signals with frequencies in the range from 1 to 2 MHz were plotted at 1.5 MHz and so on for the remaining signals out to 20 MHz. The simple histogram of Fig. 3 shows that most signals have frequencies in the range from 3 to 8 MHz. Modulation factors for the signals plotted in Fig. 3 varied from 0.9×10^{-2} to 2.5×10^{-2}. There is no apparent correlation between modulating signal frequency and modulation factor m.

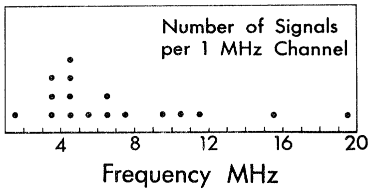

FIG. 3. Plot of number of signals observed versus modulation frequency in 1-MHz intervals. Data from nine different stars were lumped together for this plot.

In taking the data shown in Figs. 2 and 3, all of the light collected by the telescope was imaged, unfiltered, on the photocathode of the detector. An S-11 photocathode was used which responds from approximately 3300 to 6000 Å (20% points) with the peak response at 4500 Å. Using filters, an attempt was made to see if the modulated components were confined to one portion of the above spectral region. Every indication was that the modulation process affected all wavelengths in the spectral range observed. Because of this, a simple scattering process seems the most likely cause of the modulation.

The distribution of frequencies in Fig. 3 suggests an ionospheric origin for the modulation. Consequently, an explanation was sought along these lines. Several processes were considered, most of which were easily eliminated as possibilities.

Rf intensity modulation of light *emitted* by a plasma has been observed under a variety of conditions.[5,6] However, the intensity of the light emitted by the ionospheric volume within the telescope's field of view is completely insignificant compared to that received from the first- or second-magnitude stars studied. The airglow, even if it were modulated in intensity, is far too weak to cause the relatively large effect observed here. It follows that the modulation is connected with the starlight and is not merely a coincidental measurement of intensity modulated airglow.

The refractive index of a plasma is given by $n^2 = 1 - \omega_p^2/\omega^2$ and for the ionosphere $\omega_p^2/\omega^2 \sim 10^{-16}$ for ω in the optical range. Spatial and temporal variations in the index due to instabilities (waves) would be a fraction of this latter amount. Consequently, despite the long path lengths available, effects associated with periodic refractive index variations in the ionosphere (e.g., a grating effect) are negligible at optical wavelengths.

Beats between light waves with frequencies ω and $\omega \pm \omega_p$ (e.g., incident light and a satellite line) through mixing at the photocathode of the detector could conceivably produce the modulation. Insofar as the instrumentation is concerned, the result would be indistinguishable from intensity modulation at the frequency ω_p. Beats obtained by mixing light from incoherent sources have been observed,[7] but with much difficulty. In any case, the process requires an optical linewidth less than the beat frequency ω_p. Such a situation is unlikely here.

The remaining process considered is that of scattering by ionospheric plasma electrons. Because of the small cross section, incoherent scattering by thermally induced electron density fluctuations is too small to observed here, and it would not produce the modulation. However, when plasma-wave instabilities are present, the scattering cross section is increased by as much as 10 orders of magnitude compared to that for a plasma in thermal equilibrium.[8,9] Also, if the density fluctuations are periodic in space and time, the intensity of the scattered component is modulated.[9] Stern and Tzoar[10] have measured scattering from plasma oscillations under controlled laboratory conditions and obtained good agreement with theory. Farley[11] has measured scattering from ionospheric plasma instabilities and found enhancements of 10^7 to 10^8 times the amount expected from incoherent scattering.

The angular field of view of the telescope was set at 100 sec of arc, i.e., at 0.48×10^{-3} rad. At an altitude of 250 km the field of view was a circle ~120 m in diameter. Consequently, a large scattering volume was available. For example, if the active region were assumed to be 10 m thick at an altitude of 250 km, the scattering volume would be $\sim 10^{11}$ cm^3. It is important to note that a far larger volume exists for scattering into the telescope acceptance solid angle than exists for scattering out of it. In the absence of any scattering, the photons received by the detector would be those in the central 40-cm-diam telescope beam. Scattering of any of these out of the beam would cause a decrease in the received light intensity. However, this total volume is relatively small. The scattering volume which is outside the central beam but which is still within the field of view is far larger, as previously noted. Scattering of any photons into the acceptance solid angle from the larger volume causes an increase in received light intensity. Scattering of photons away from the acceptance solid angle in the larger volume has no effect on received light intensity because these photons would not have been seen anyway.

The large scattering volume and enhanced cross section make it possible to observe the scattering when plasma-wave instabilities are present in an ionospheric layer between the star and the observer. Order-of-magnitude estimates indicate a modulation of about the size observed. Qualitatively then, the modulation reported here can be explained as being due to time-varying, very small-angle (≤ 0.24 mrad) scattering of the starlight by enhanced electron density fluctuations in the ionosphere.

The effect reported here may be of interest in the fields of aeronomy, space communications, and stellar interferometry. Indeed, independent evidence for the modulation can be found in the reports from the stellar interferometer at Narrabri, Australia. That instrument utilizes a correlation interferometer to measure intensity-fluctuation correlations in the light from a star as observed by two, well-separated photodetectors. For the initial measurements made at Narrabri, a receiver bandwidth of 0 to 110 MHz was used. Measurements made on α-Lyrae showed uncertainties of 20%.[12] The bandwidth was later changed to 10 to 110 MHz with two results: The measured correlation at a given detector spacing dropped appreciably and the uncertainty in the measurement dropped to 8%.[13]

The modulation reported here would contribute appreciably to a correlation measurement such as described. Moreover, the additional contribution would be random in time and amount. However, narrowing the receiver bandwidth to eliminate signals below 10 MHz would have eliminated most of this additional source of correlation (see Fig. 3). The Narrabri results constitute additional, if indirect, evidence for the effect discussed here.

It is a pleasure to acknowledge the generous cooperation of Dr. George Wallerstein and the University of Washington Astronomy Department in allotting time on their telescope. Mr. Leo Alexander, Jr., was of invaluable assistance in building much of the equipment and in reducing the data.

*This experiment was performed while the author was a staff member of the Plasma Physics Laboratory, Boeing Scientific Research Laboratories, Seattle, Wash.

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Evidence for a Primary Cosmic-Ray Particle with Energy 4×10^{21} eV

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We describe the analysis of an extremely energetic air shower produced by a primary cosmic-ray particle of energy 4×10^{21} eV. The arrival direction of this cosmic ray is right ascension 20 h 14.5 min and declination 24°. The directions of 3C409 (radio source) and AP2015+28 (pulsar) are inside the uncertainty of the arrival direction. Information on muons and the total number of charged particles in this air shower indicates no drastic change of nuclear interactions from 10^{17} to 10^{21} eV.

Analysis of an extremely large air shower (LAS) observed by the Institute for Nuclear Study, University of Tokyo (INS), air shower (AS) array and the INS LAS array at 17 h 55 min (JST) on 10 November 1970 indicates that the total number of charged particles (size) was 2×10^{12}. The energy of the primary particle which produced the air shower was 4×10^{21} eV. This energy is more than ten times higher than the energies of the largest showers reported previously.[1-4]

The INS LAS and AS arrays are shown in Fig. 1. The INS LAS array consists of four stations and the INS AS array is inside the INS LAS array and is separated by 300 m from station I. Each station of the INS LAS array consists of two unshielded 2-m^2 scintillation detectors separated by 50 m. Station IV was being constructed when the shower described in this paper was recorded. The INS AS array consists of 22 unshielded 1-m^2 scintillation detectors, a 20-m^2 spark chamber, four 2-m^2 scintillation detectors underground at a depth of 5 m ($E_\mu \geqslant 1.5$ GeV), four 2-m^2 scintillation detectors underground at a depth of 15 m ($E_\mu \geqslant 5.0$ GeV), and five $\frac{1}{4}$-m^2 fast-timing detectors. When the shower was recorded, ten $\frac{1}{4}$-m^2 scintillation detectors shielded with 1 cm of iron and thirteen $\frac{1}{4}$-m^2 scintillation detectors shielded with 1 cm of iron and 15 cm of lead were also being operated.

The arrival direction of the shower was determined by both the time differences of three stations of the INS LAS array and those of five $\frac{1}{4}$-m^2 fast timing detectors of the INS AS array. The arrival directions determined by both methods are consistent, and the zenith angle is 20° and the azimuthal angle is shown in Fig. 1. Uncer-

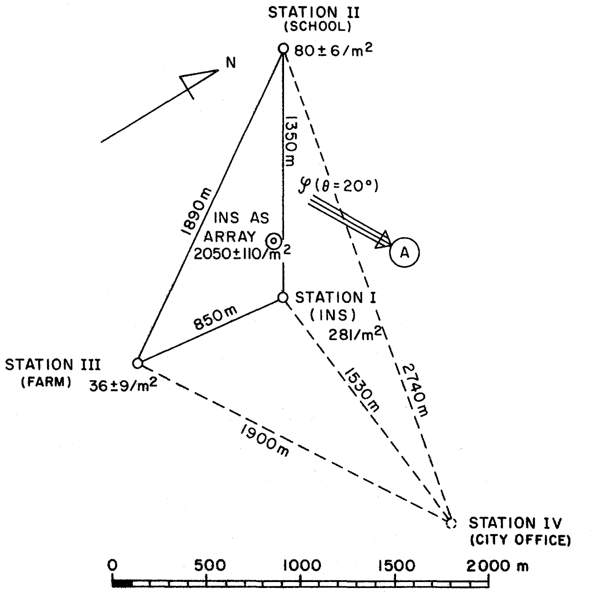

FIG. 1. INS LAS array with INS AS array inside, and the density pattern of the shower. The numbers near the stations and the INS AS array show the number of particles per m^2. A is the location of the shower axis.