Reports

Radar Observations of the Corona and Mariner II Measurements of the Flux in the Solar Wind

Abstract. *Radar observations of the corona can be used with a specified model of the corona to derive the particle flux in the solar wind at Earth. The most plausible model considered gives good agreement with the results obtained directly by the Mariner II plasma probe.*

The solar atmosphere above approximately 1.1 $R_\odot$ (where $R_\odot$ is the solar radius) is essentially a completely ionized gas at a temperature of 1 to 2 $\times 10^6$ degrees Kelvin. This portion of the solar atmosphere, the corona, is clearly visible in photographs of solar eclipses. Radar observations of the corona by Chisholm and James (*1*) at a frequency of 38.26 Mc/sec indicate a general expansion of 16 km/sec where the radio energy is reflected; this frequency is the plasma frequency for an electron density of 1.8×10^7 electrons per cubic centimeter. Extrapolation from these results to give the flux of the solar wind serves to confirm the results of the Mariner II probe (*2, 3*).

On the basis of a spherically symmetric Baumbach-Allen (*4*) corona, Chisholm and James (*1*) have suggested that the reflection occurs near the 1.5 $R_\odot$ level. However, the height of reflection and the flux in the solar wind at Earth will depend considerably on the specific model chosen; I adopt the electron density distribution for solar minimum (equator) and solar maximum given by de Jager (*5*). The results for several models appear in Table 1.

Model I. The corona is assumed to be homogeneous, expanding, and spherically symmetric; the radar reflection occurs where the mean electron density is 1.8×10^7 cm^{-3}.

Model IIa. The corona is assumed to be expanding, with large-scale spherical symmetry, but with local density fluctuations. Van de Hulst (*6*) has shown that the density in the polar rays is some five times the density between the rays; if this value is typical for the entire corona, the radar reflection would occur where the mean electron density is only 3.6×10^6 cm^{-3}.

Model IIb. This is the same as model IIa except that the expansion occurs from only one-third of the solar surface. This is approximately the value that one would assign by assuming that expansion is permitted only in the larger density areas, perhaps corresponding to large magnetic structures such as streamers (*7*, fig. 10).

Model IIIa. Here the expansion is assumed to take place only from the great streamers. Michard (*8*) has given a value of 9 for the density increase at 2 $R_\odot$ in a great streamer over the mean density; thus the radar reflection should occur where the mean electron density is 2×10^6 cm^{-3}. Expansion is considered to take place only in the streamers which may occupy one-half the solar surface at solar maximum.

Model IIIb. This is the same as model IIIa except that the streamers occupy only one-tenth of the solar surface, perhaps appropriate to solar minimum.

Clearly many different models could be constructed, but perhaps these three simple ones serve to illustrate the possible range in mean flux and density. Other explanations are possible: for example, the Doppler shifts may be due to plasma wave phenomena in the corona.

The calculations are straightforward, with the flux at the reflecting height in the corona being the product of the mean electron density involved in the expansion and the expansion velocity; the flux is then extrapolated to Earth by the inverse-square law. For example, the reflection on model IIb for solar minimum occurs at a height of 1.72 $R_\odot$ where the mean electron density is 3.6 $\times 10^6$ cm^{-3}. Since the expansion occurs from only one-third of the solar surface, the mean electron density involved in the expansion is 1.2×10^6 cm^{-3} and the flux is (1.2×10^6) cm^{-3} $\times$ (1.6×10^6) cm sec^{-1}, which is equal to 1.9×10^{12} electrons cm^{-2} sec^{-1}. The mean Earth-Sun distance is about 215 $R_\odot$. Hence, the flux is reduced by a factor $(1.72/215)^2$ to give 1.2×10^8 electrons cm^{-2} sec^{-1} at Earth.

Model I is rendered quite unlikely by (i) photographs of the corona, (ii) the fluctuations in the flux and density at Earth observed by Snyder and Neugebauer (*3*), and (iii) the variation in the radar cross section of Sun and in the strength of the echo signal (*1*). The same general argument applies against model IIa. I have no strong argument against the other models; however, one might expect model IIIb to predict much more variation than is observed (*1–3*). Lastly, the postulation that streamers cover one-half the solar surface may be valid only near solar maximum; it probably does not apply to the radar observations (*1*) which were averages of observations on 31 May and 4, 8, and 10 June 1963. Hence, model IIb survives as the only model to escape direct, reasonable objection.

The various numbers appear in Table 1 and again the range is large. The height of reflection varies between 1.30 and 2.55 $R_\odot$, depending on the model chosen. The predicted fluxes at Earth range from 1.2 to 20.3×10^8 electrons cm^{-2} sec^{-1}. Model IIb, with a flux of 1 to 2×10^8 electrons cm^{-2} sec^{-1}, is thought to be the most reasonable and is in good agreement with the flux data from Mariner II: 1.2 to 3.6×10^8 electrons cm^{-2} sec^{-1}. The main consequence

Table 1. Flux and density at the orbit of Earth computed from radar observation of the corona.

Model	Solar minimum			Solar maximum		
	Height of reflection ($R_\odot$)	Flux, $N_e w$ (10^8 cm^{-2} sec^{-1})	Electron density N_e(cm^{-3})*	Height of reflection ($R_\odot$)	Flux, $N_e w$ (10^8 cm^{-2} sec^{-1})	Electron density N_e(cm^{-3})*
I	1.30	10.5	21.0	1.65	17.0	34.0
IIa	1.72	3.7	7.4	2.22	6.1	12.2
IIb	1.72	1.2	2.5	2.22	2.0	4.1
IIIa	1.95	11.8	23.6	2.55	20.3	40.5
IIIb	1.95	2.4	4.7	2.55	4.1	8.1

* Assuming an expansion velocity w of 500 km sec^{-1}.

of this comparison is that the radar and space-probe results can be made to agree, with reasonable assumptions concerning the coronal structure.

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References and Notes

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Accurate Length Measurement of Meter Bar with Helium-Neon Laser

Abstract. *A helium-neon gas laser has been successfully used in conjunction with an automatic fringe-counting interferometer to measure the length of a meter bar. The agreement obtained was 7 parts in 100 million with respect to the assigned length of the bar.*

In a recent article in this journal, McNish (*1*) reported that experiments were being undertaken at the National Bureau of Standards to measure length with a laser-illuminated, automatic fringe-counting interferometer. These experiments have now been successfully completed; the equipment used is schematically shown in Fig. 1.

A helium-neon laser with external confocal mirrors of 60-cm focal length, operating at 633 nm, was used. It was kept in single mode by adjustment of the radio-frequency power supply; the single-mode operation was monitored throughout the experiment by means of a spectrum analyzer. The laser was "unstabilized" in the sense that no electronic feedback mechanism was used to lock its wavelength to the center of the neon line. Variations of its wavelength had been minimized by rigid connection of the cavity mirror to a sturdy fused-quartz spacer tube. Its absolute wavelength stability, relative to a standard line of mercury-198, had previously been measured to be a few parts in 10^7, for averaging times of several minutes (*2*). The laser was made to oscillate still closer to the center of the neon line by piezoelectric tuning of the cavity length, so that the fringe visibility in the interferometer was at a maximum at each reading.

The automatic fringe-counting interferometer (line-scale comparator), as described in (*1*) and (*3*), permits the measurement of lengths up to 1 meter, the limit of travel for the carriage holding the line scales to be calibrated. However, its practical range was previously limited to a few decimeters by the limited coherence of the mercury-198 standard lamp used.

Since the wavelength produced by the laser was not known with sufficient accuracy, it had to be determined before accurate length measurements could be carried out with the laser. Thus, interference fringe counts were obtained over various portions of a decimeter line standard, first by use of the standard mercury-198 lamp and then by use of the laser. From the fringe counts and the internationally accepted value (*4*) for the mercury-198 wavelength at 436 nm, the wavelength of the laser used was obtained as 632.81983 nm under standard metrological conditions (air at 20°C, standard atmospheric pressure, 59 percent relative humidity, and 0.03 percent CO_2 content).

The fringe-counting interferometer, with the laser as the light source, was then used to measure the length of a meter bar in terms of this wavelength. From a total count of 3 160 460.33 fringes, or half-wavelengths, the length of the meter bar was determined to be 1.000 000 98 m. This length agreed to within 7 parts in 100 million with an assigned value of 1.000 001 05 m for this bar. In addition, measure-

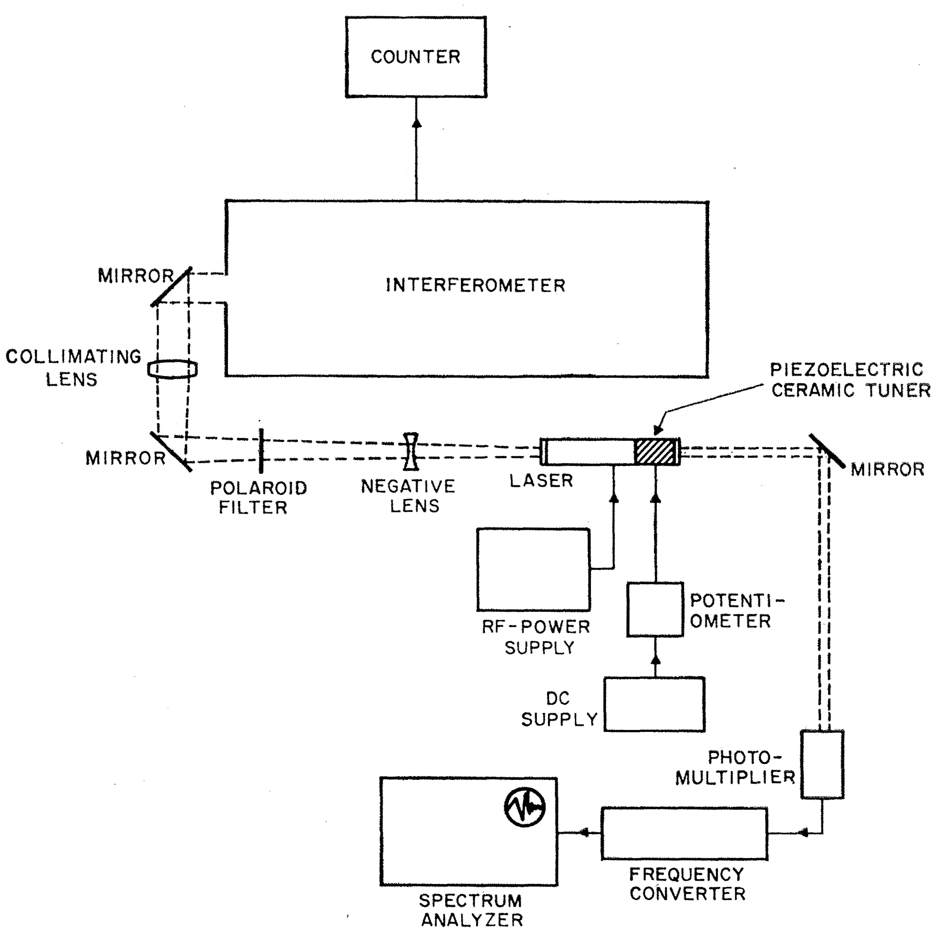

Fig. 1. Equipment used to measure length with a helium-neon laser. As a meter bar inside the interferometer is moved over its entire length, interference fringes produced by a laser are automatically counted. The total number of fringes thus obtained is multiplied by one-half the value previously determined for the laser wavelength. Thus, the accurate length of the meter bar is obtained.