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APPENDIX

SOME SPECTROSCOPIC OBSERVATIONS OF THE INTERACTION BETWEEN A PLASMA WIND AND A DIPOLE MAGNETIC FIELD

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INTRODUCTION

The experiment as a whole is designed to reduce the scale of some of the phenomena associated with the solar wind-magnetosphere interaction to laboratory size. A schematic diagram of the experimental apparatus is shown in Fig. 1. The plasma, simulating the solar wind, is produced by discharging a capacitor through a coaxial plasma gun; the central electrode of the gun can be seeded with various materials. The plasma travels down a pipe and enters a spherical chamber where it interacts with a model terrella that has a magnetic dipole field.

This interaction has been observed photographically and examined with electrical and magnetic probes[1]. It was considered worthwhile to make a preliminary spectroscopic investigation in order to determine whether different components of the wind material could be correlated with various regions of the interaction.

The interaction lasts for only a few tens of microseconds, but a time integrated photograph, such as in Fig. 2a, shows the important phenomena. The wind is incident on the left of the terrella and the south "geomagnetic" pole points upward. The most striking feature is the bright crescent-shaped region of luminosity, in front of the terrella, which has a form similar to that of the Van Allen belts. To the left of this is the stand-off boundary region where the pressure of the plasma wind equals the magnetic pressure. In some of the previous work, this has shown up more clearly, however, this is typical of the interaction observed in the present spectroscopic investigation. In some cases a "polar blob" was seen above and windward of the poles, but although it can be seen faintly in the photograph (see Fig. 2a) it is not discernable in the spectra.

This study was of an exploratory nature utilizing the various optical components that were readily available in our laboratory. The experiment could, therefore, be improved somewhat, but in its present form it did provide useful spectra.

EXPERIMENTAL TECHNIQUES

The simulated solar wind-magnetosphere interaction was observed optically by seeding the plasma with ions having emission lines in the visible region. This was accomplished by adhering either $BaNO_3$ or $BaCl_2$ on the surface of the anode of the plasma gun. Consequently, the plasma contained an assortment of excited ions: heavy Ba^+ and relatively light N^+, 0^+ or Cl^+ ions (the electrons were not observed). The capacitor bank voltage was 7.5KV and the magnetic field at the equator of the terrella was 2Kgauss. These values were maintained throughout the experiment.

The radiation emitted from the interaction belts was analyzed with a grating spectrometer and the resulting spectra recorded photographically. The grating used was a transmission grating with 600 lines per mm and was operated in the second order. The resolution attained in the experiment was limited by the linear dispersion at the film. This was $\lesssim 5$Å. A mercury spectrum superimposed on the spectra was used for the wavelength calibration and the various spectral lines were identified from the MIT Wavelength Tables.

In order to display the spatial intensity distribution of the spectral lines, a filament of the terrella region was imaged on the slit by means of a lens. With a demagnification of about 3, the slit corresponds to a line element 7cm in length; the diameter of the terrella is 6.7cm. The spectrometer was arranged so that it could be moved to select any region of interest and positioned with the slit either perpendicular or parallel to the solar wind direction.

EXPERIMENTAL RESULTS

The interaction of the plasma wind and the magnetic field of the terrella is shown in Fig. 2a. There are two regions of interest: a bright inner "Van Allen" belt and an outer diffuse stand-off region whose boundary follows that of the magnetosphere - the polar blobs seen in earlier work[2] were not observed in the present experiment. To indicate the spatial resolution, a picture of the terrella superimposed on that of the slit is shown in Fig. 2b. The same magnification as in the case of the spectra was used.

The spectra of the radiation emitted from the interaction belts are shown in Figs. 3 to 6. Not all of the spectral lines could be unambiguously identified, and only the most prominent and readily identifiable are listed. However, there is no evidence of any contribution from neutral atoms as is expected. There also appears to be no lines due to molecular or negative ions. This latter statement may prove to be not entirely correct when better spectra are taken.

In the case of the $BaNO_3$ seeding, the plasma ion components are Ba^+, N^+ and O^+. It is seen from Figs. 3 and 4 that the emission lines from N^+ and O^+ originate to a large extent, in the Van Allen belt, whereas the heavier Ba^+ ions, to the same degree, appear to be confined in the outer belt. An interesting effect occurs when the magnetic field of the terrella is reversed. The "Van Allen" belt shifts in the east-west direction with respect to the surface of the terrella, as is indicated in Fig. 4. The Ba^+ spectral lines, on the other hand, are not affected with the change in polarity of the magnetic field.

These observations are confirmed by the results with the $BaCl_2$ seeding, the corresponding spectra are shown in Figs. 5 and 6. Again the lighter ions, namely Cl^+, are confined mainly to the inner belt and the Ba^+ ions to the outer standoff region. Similar effects concerning the reversal of the magnetic field are also indicated.

That the Van Allen belt contains little, if any, Ba^+ ions is evident by the reduction in intensity of the Ba^+ spectra in this region. The intensity that is there is presumably a contribution from the position of the outer belt which is in front of, and surrounds the Van Allen belt.

The gun was also seeded with colloidal graphite to see if a simple spectrum could be obtained. The spectrum, however, was found to be largely due to impurities in the gun from previous seedings. With further shots, the intensity decreased and so the experiment was not carried on any further.

DISCUSSION

One possible explanation of the separation of the components of the wind into two regions concerns the background gas. The three gases nitrogen, oxygen and chlorine which along with barium make up the seeding materials used, could be present in the vacuum system as contamination. They would have to be evolved continuously from the gun or walls, or in the case of nitrogen and oxygen from a leak, for there to be much contamination left from one shot to the next. The time constant for the reduction of the partial pressure of one of the components by 1/e can be approximated by dividing the volume of the vacuum system by the pumping speed (taken as $\frac{1}{2}$ rated value). That is $\frac{150\ \mathrm{l}}{300\ \mathrm{l/sec}} = \frac{1}{2}$ sec, which is small compared to the time between shots, usually the order of minutes. Given a source for these gases, the mechanism for producing the inner belts is as follows. The contaminant gas in the region of the terrella is ionised by precursor high energy particles, which precede the wind, or by radiation given off by the gun. The wind, which follows, compresses the magnetic field, which in turn excites and compresses the ionization in this region and thus increases the luminosity.

There is evidence from other experiments that suggests there is ionization in the belt region prior to the arrival of the main wind. These are: photographic, which shows a faint, noncompressed belt in this region that becomes visible about the same time that the first sign of the magnetic field compression is seen with a magnetic probe; and double probe results, which have also indicated a plasma being formed early in the interaction.

Another mechanism for the formation of the inner belts, is by negative ions. These ions, formed by the dissociation of the barium salt, travel down with the wind, and are accelerated by the Rosenbluth sheath into the inner regions. Since the Rosenbluth sheath voltage is large enough to stop the positive ions it could conceivably give the negative ions enough energy to become neutral, and also be ionized upon collision. This would be difficult to observe experimentally as there is no excitation spectra of negative ions. The spectra of formation, which is a continuum with a limit, has been observed but is of no use to this problem. The above explanation which requires negative ions is quite hypothetical and requires more experimental evidence to substantiate it. If, however, the lighter components of the wind are in the form of positive ions, one would expect to see their spectra in the same region of the stand-off where the barium spectra is most intense, since they should be diverted from their paths by a similar mechanism. Their spectra is not observed strongly in this region which supports the above theory but this could be dependent on an excitation mechanism that excites the barium preferentially.

One can think of various experiments which would help clear up some of these important points. The spectra of the wind with no terrella would be useful but would probably require multiple exposures to get enough intensity. The spectra of the interaction region with no magnetic field to see if surface effects are important, would also be interesting. Then to study the importance of the background gas, the amount of contamination could be increased by decreasing the pumping speed, and decreased by increasing the time between gun firings. If this is found to have a marked effect on the spectra, various gases could be admitted and their role in the interaction deduced. The pumping speed has been reduced and total light pictures taken with little noticable change. One would also like to see the interaction if the plasma consisted of a single species of ion. This could be accomplished with a gas injection plasma gun or perhaps another type of seeding, say mercury frozen on to the centre electrode. If this single gas became multiply ionised the importance of the charge to mass ratio e/m, could be ascertained. Mixtures such as $LiCl_2$ or NaCl and $BaCl_2$ would also give the necessary range of masses, if they could be ionized uniformly.

To understand the spectra of the interaction fully, it may be necessary to do a time resolution of it. The ideal way would be to use an image converter camera as the spectrograph camera. Unfortunately, our image converter camera does not have enough sensitivity. Otherwise, one could use a streak camera method to time resolve certain lines using the whole slit, or time resolve the whole spectra looking at a small portion of the slit. The first method would have the advantage of looking at a long filament in the interaction region, but only one line of the spectra; the second would have the advantage of looking at the whole spectra, but only one point in the interaction.

A method that would use only the equipment available in the laboratory at present would be to use a spectrograph with two photomultipliers, each looking at a single line of one of the components of the wind in a small region of the interaction.

The question of the spectra of the polar blobs will have to wait until they are observed with sufficient luminosity and the apparatus and personnel are available to do a longer study. The same applies to the separation of the wind components which will require more work, both experimental and theoretical, before it is fully understood.

REFERENCES

1. Osborne, F.J.F., M.P. Bachynski and J.V. Gore (1964), J. Geophys. Res. 69, No. 21, 4441.
2. Harrison, G.R., M.I.T. Wavelength Tables, (1963) M.I.T. Press.

LIST OF FIGURES

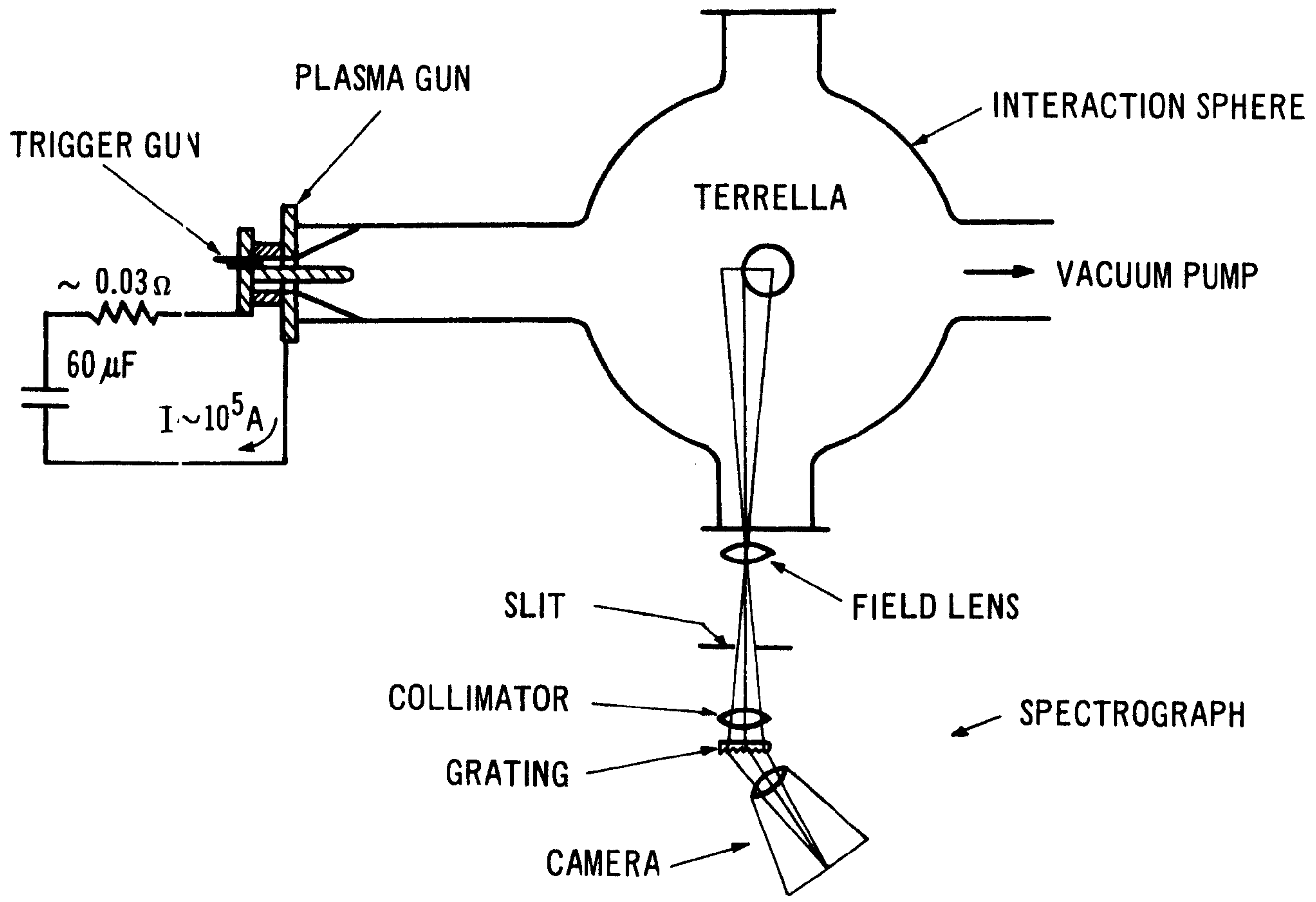


Figure 1 – Top View of Interaction Experiment

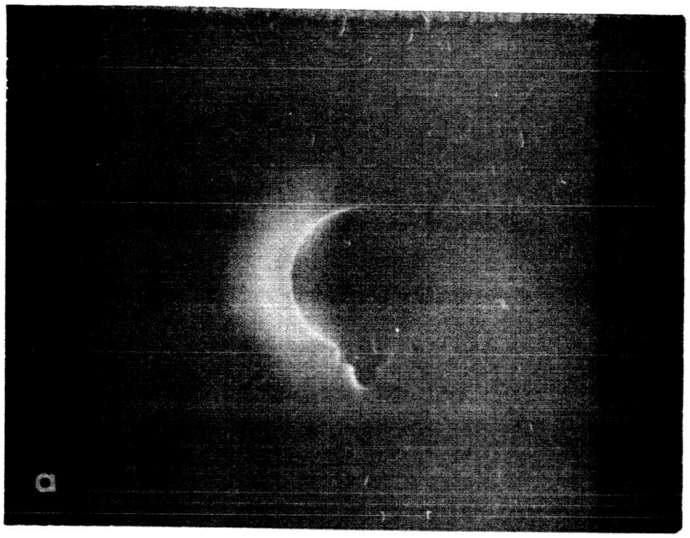


Figure 2a

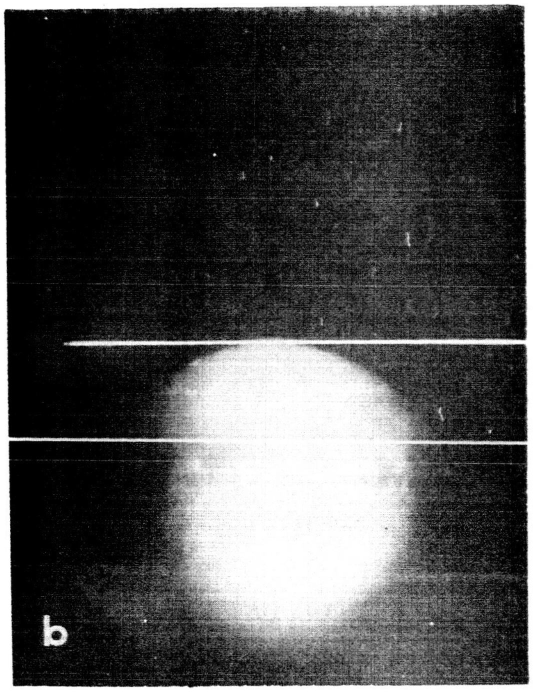
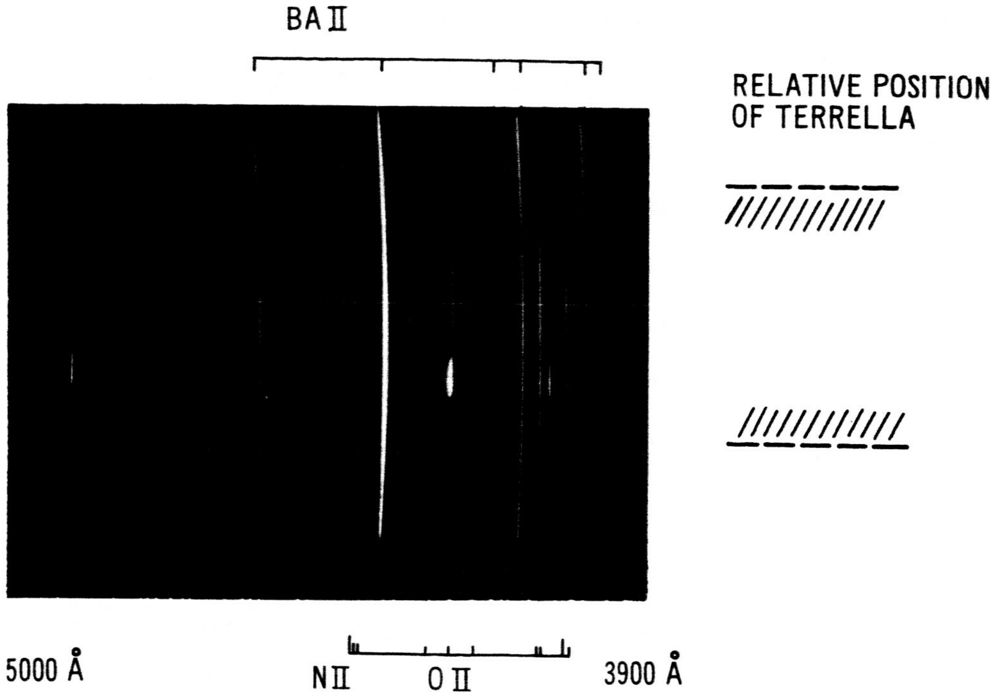


Figure 2b



BaNO$_3$ SEEDED PLASMA (7.5 kV)
10 SHOTS
SLIT PERPENDICULAR TO SOLAR WIND
1.2 cm FROM EDGE OF TERRELLA

Figure 3a

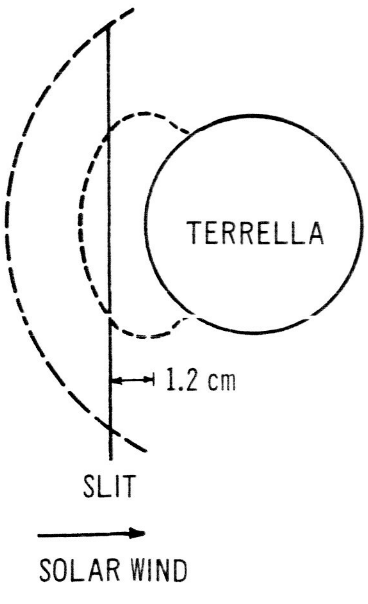


Figure 3b

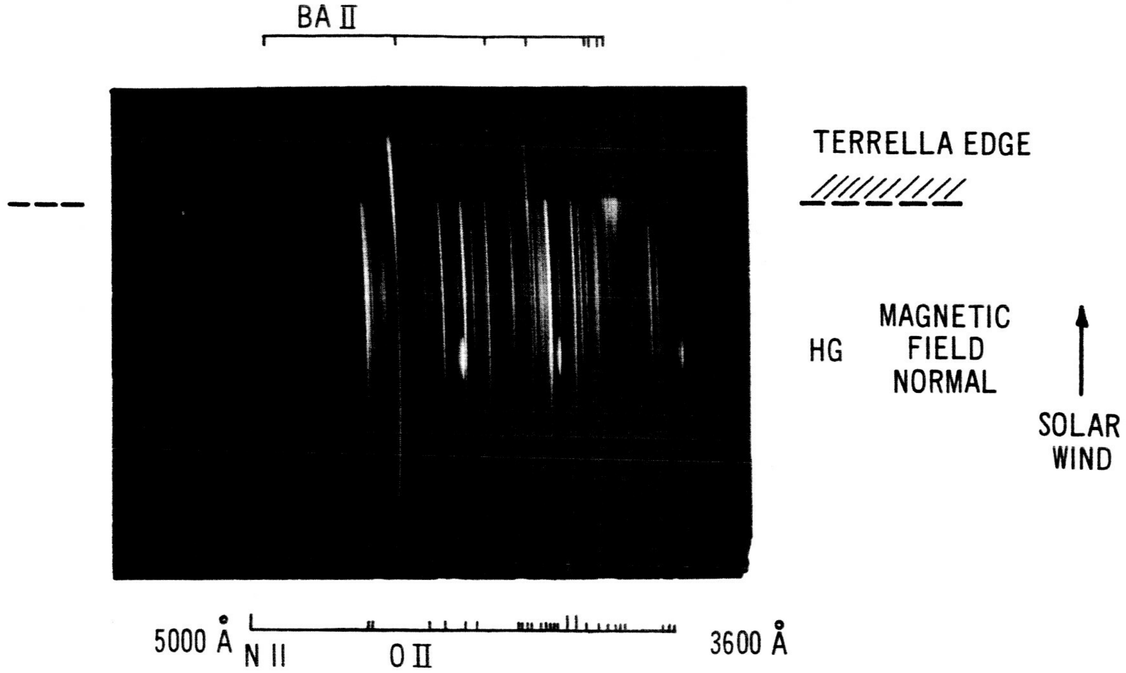
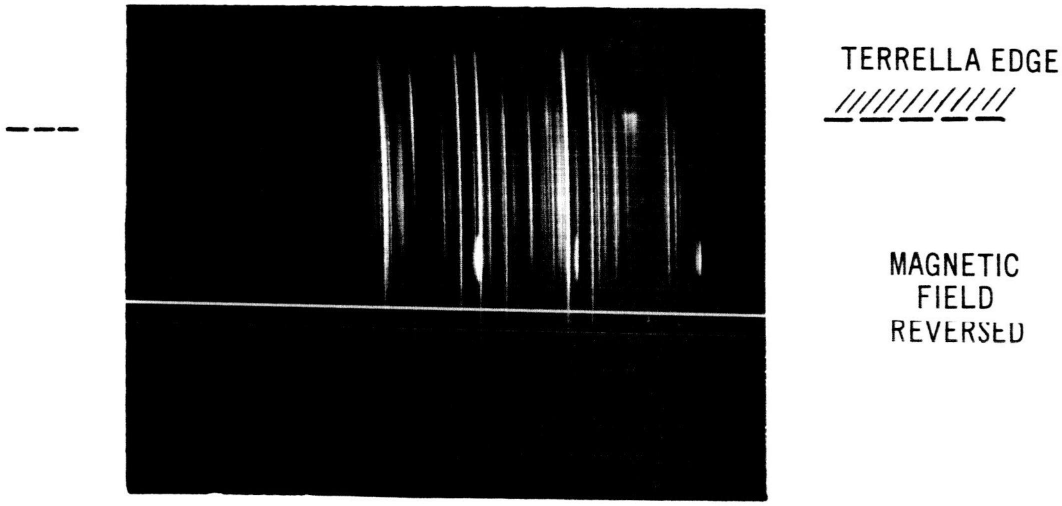


Figure 4a



$BaNO_3$ SEEDED PLASMA
5 SHOTS
SLIT AT CENTRE OF TERRELLA PARALLEL TO THE SOLAR WIND
7.5 kV

Figure 4b

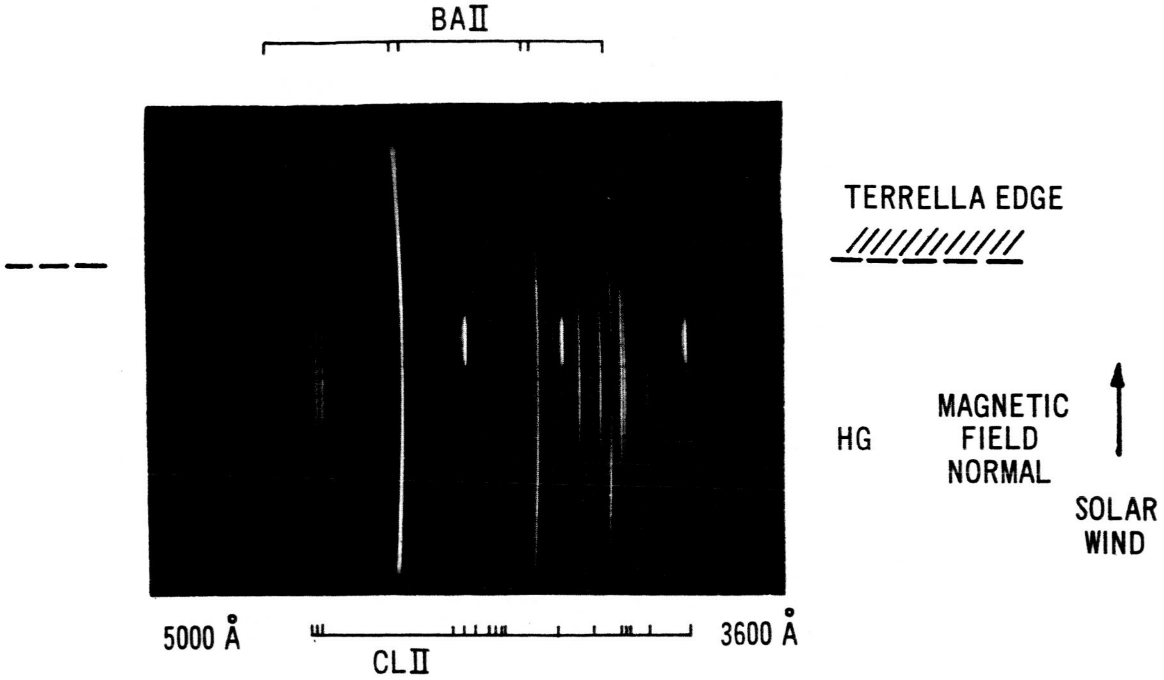
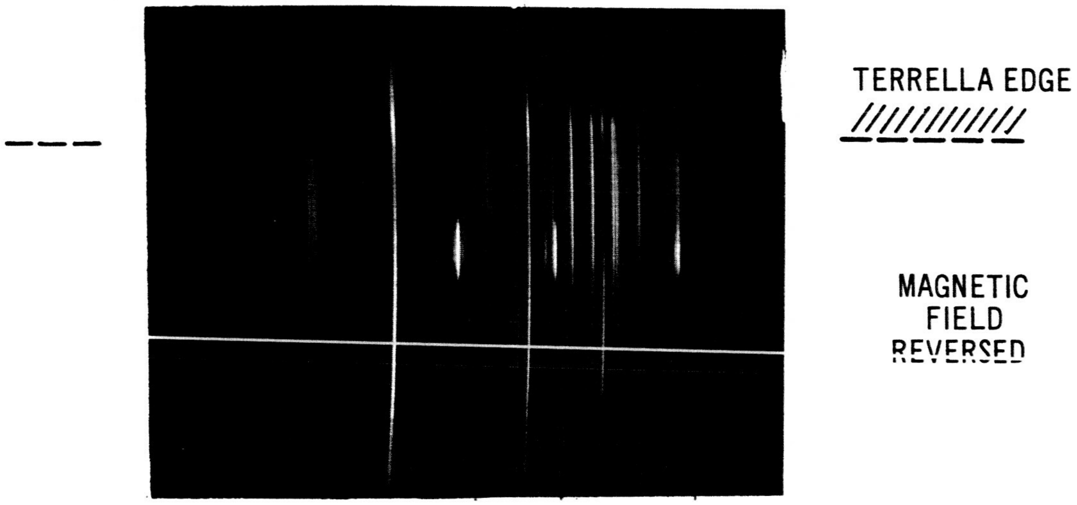


Figure 5a



BACL$_2$ SEEDED PLASMA
1 SHOT
SLIT AT CENTRE OF TERRELLA PARALLEL
TO THE SOLAR WIND
7.5 kV

Figure 5b

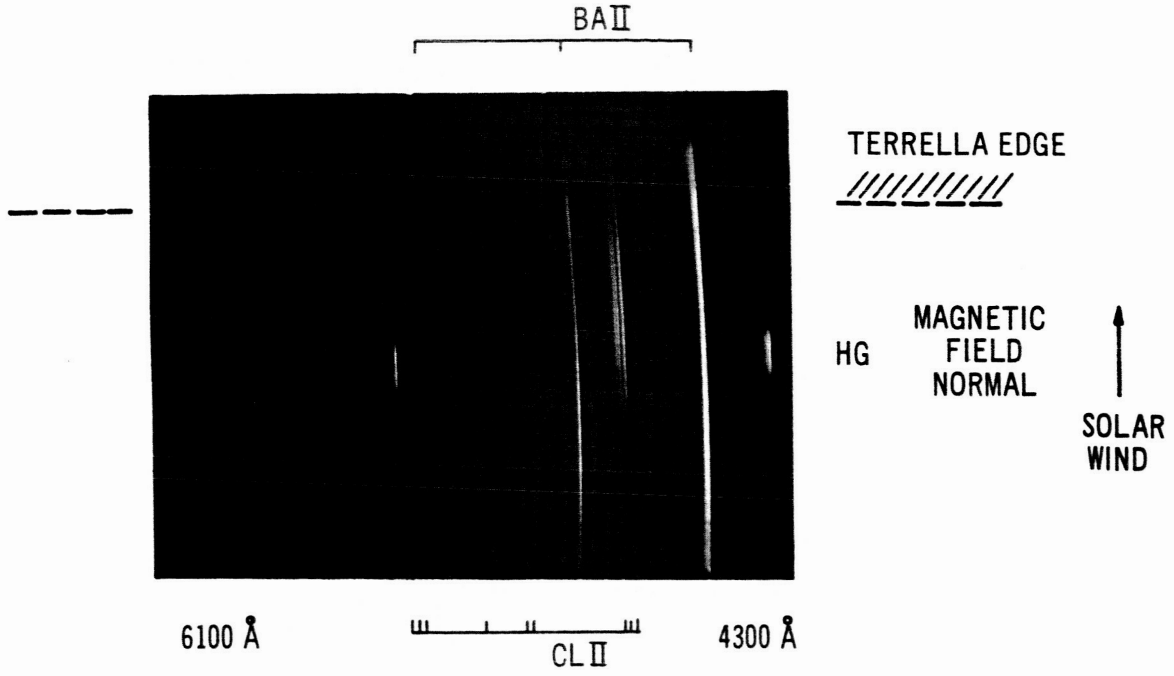
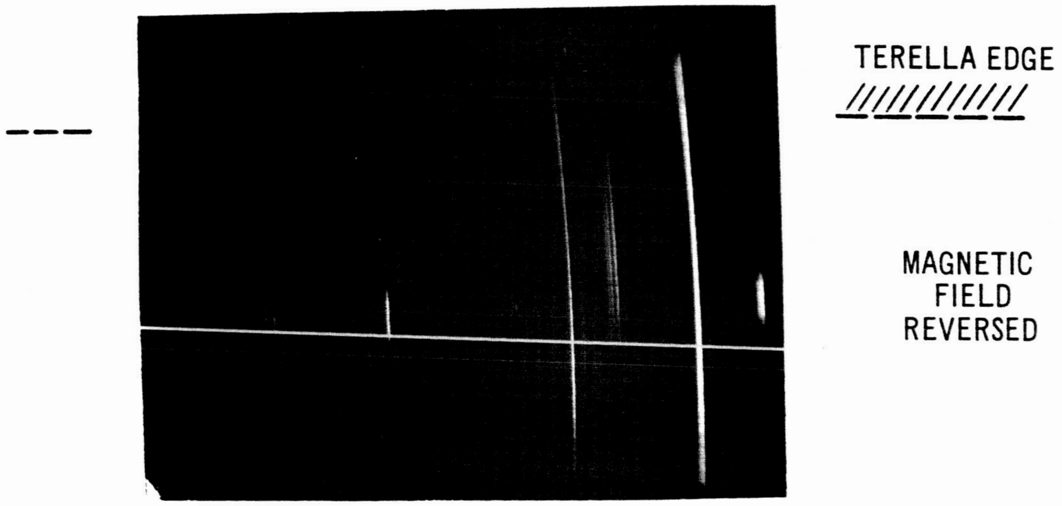


Figure 6a



$BACL_2$ SEEDED PLASMA
1 SHOT
SLIT AT CENTRE OF TERRELLA PARALLEL TO THE SOLAR WIND
7.5 kV

Figure 6b