COMPARISON OF THERMAL PLASMA OBSERVATIONS ON SCATHA AND GEOS

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ABSTRACT

Thermal plasma measurements on the SCATHA and GEOS satellites show the existence of the plasmasphere out to beyond geosynchronous orbit in the dusk bulge region. On at least one occasion, this plasma population persisted until local midnight, as observed by both satellites. These observations establish the context for the 'hidden ion' population reported by Olsen [1982] as the outer plasmasphere. The GEOS electrostatic analyzers, which were on biased booms, were able to measure the cold plasma with a -8 V bias. The SCATHA electrostatic analyzers were unable to measure this plasma in sunlight, but could in eclipse. The floating potential of the GEOS satellite in sunlight in this 50 cm -3 plasma was about +3 V, and it is apparent that SCATHA was at a similar potential. This potential was sufficient to prevent the measurement of the 0.6-0.7 eV temperature plasma.

1. INTRODUCTION

Plasma measurements made on the SCATHA satellite in eclipse showed the existence of a normally 'hidden' ion population. Ions with energies from 1 to 5 eV appeared as the photoelectron current and the spacecraft potential dropped in eclipse [Olsen, 1982]. Due to the unique nature of these observations, it was difficult to place them in context, though it was clear that the satellite was in either the outer plasmasphere or the inner plasma sheet. It was suggested that this 'hidden ion' population was the difference between the plasma population measured by the wave experiments and the particle detectors on GEOS-1 [Decreau et al. 1978b].

The purpose of this paper is to compare the thermal plasma properties determined on the two satellites, in order to determine an 'absolute' density for the SCATHA measurements, and to see if the difference between the particle and wave measurements on GEOS can be explained as a result of positive spacecraft potentials.

1.1 Spacecraft and Instruments

The SCATHA satellite was launched on January 30, 1979, into a near geosynchronous orbit, with perigee at 5.5 RE and apogee at 7.5 RE. It had a spin rate of 1 rpm. GEOS-2 was launched into a geosynchronous orbit in July 1978. GEOS-2 had a 10 rpm spin rate. Since the SCATHA satellite was not quite geosynchronous, it drifts by GEOS-2 every 70 days, allowing comparison of simultaneous measurements within an earth radius in distance and an hour local time.

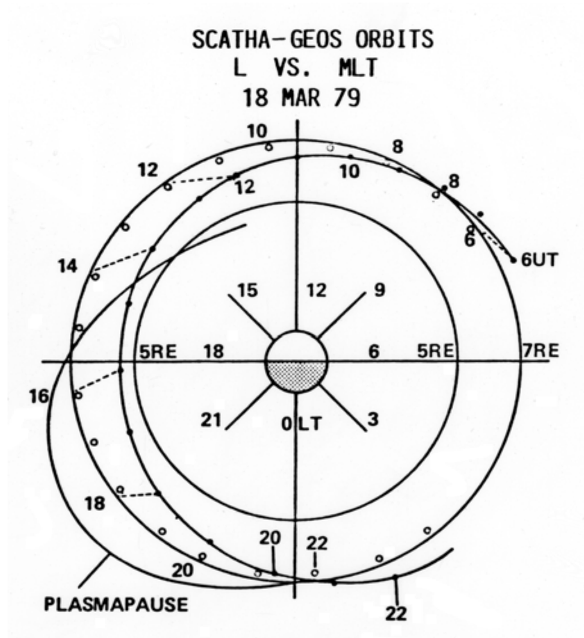

Figure 1. SCATHA and GEOS orbits on March 18, 1979 (day 77). The GEOS-2 orbit is at L = 7.1, indicated by open dots. The SCATHA orbit is indicated by solid dots. The plasmapause location is determined from the GEOS and SCATHA encounters with that boundary. The extension beyond the GEOS orbit is speculative.

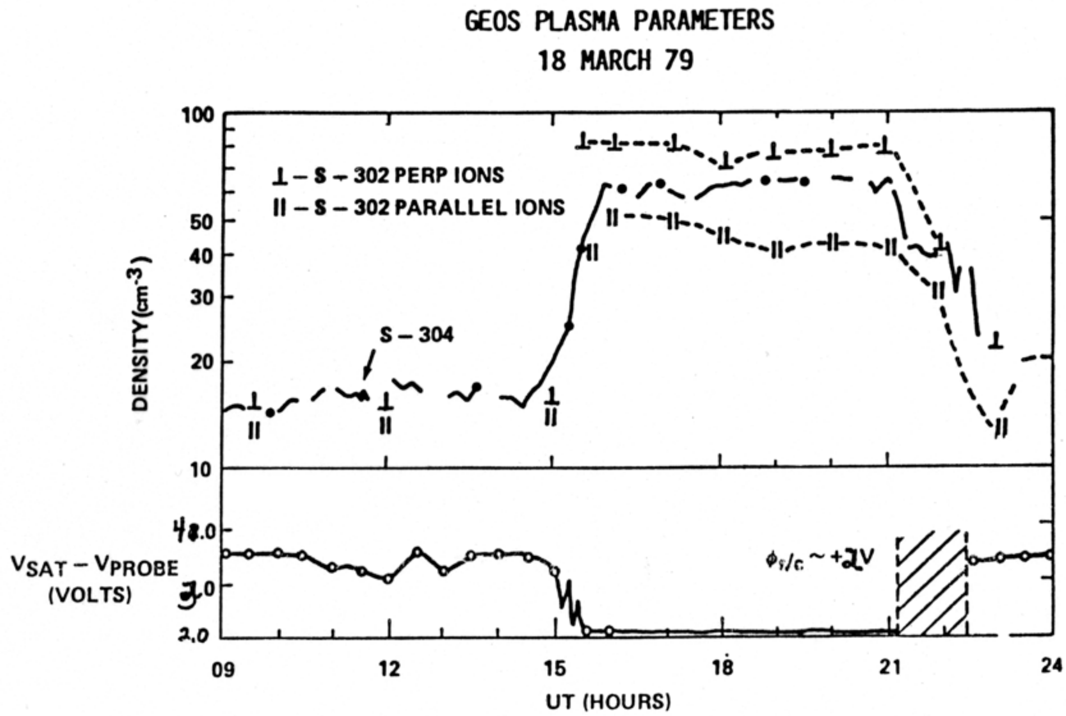

Figure 2. GEOS plasma parameters on March 18, 1979 (day 77). In the top panel, the solid line is the density determined by the mutual impedance experiment (S-304). The "⊥" sign is the density from the SPA analyzer viewing perpendicular to the magnetic field, the "||" sign for the SPA data parallel to the magnetic field. In the bottom panel, the difference between the DC electric field antenna and satellite is plotted.

The payload of the GEOS-2 satellite included a comprehensive passive and active wave package, and several particle experiments. The instruments used in this paper were the S-302, supra-thermal plasma analyzers [Johnson et al. 1978], the S-300 mutual impedance probe [Decreau et al. 1978a,b], and the S-300 quasi-static electric field monitor [Pedersen et al., 1978]. The suprathermal plasma analyzers (SPA), covering the 0.5- to 500.0-eV energy range, are mounted on 1.8-meter booms and are provided with the capability of being biased from +28 V to -28 V with respect to the spacecraft. The negative bias voltage provides the possibility of overcoming the normal positive spacecraft potential and measuring the cold ion population. The mutual impedance probe works by measuring the impedance versus frequency, and determining the plasma frequency and Debye length. The electric field antennae are also provided with an active capability. A 50-100 nA current is forced into the spherical probes in order to bring the probes down from their normal 1-10 V potential to near plasma potential. As a result, it is possible to monitor the spacecraft floating potential at high time resolution. By comparing the floating potential to the plasma density measurements made by the wave experiments, it has been possible to obtain a monotonic relation between the two, giving the added capability of a high time resolution density monitor.

The SCATHA electrostatic analyzers cover the 2-1800 eV and 2-eV to 81 keV energy ranges. The analyzers have an energy resolution of 20%, and require 16-s for one 64-step energy scan. It requires several minutes to obtain a good pitch angle distribution under normal circumstances [Olsen, 1982].

2. OBSERVATIONS

2.1 Observations on March 18, 1979

Data from March 18, 1979 illustrate a GEOS orbit where the satellite passed through the dusk bulge, and the eclipsed SCATHA satellite provided measurements of the 'hidden ion' population. The orbits of the two satellites are illustrated in Figure 1, a plot of McIlwain 'L' value versus magnetic local time (MLT). In the midnight region, the SCATHA satellite leads GEOS by about 1 hour. GEOS crossed the plasmapause at 1530 UT, as shown by all three instruments, and left the plasmasphere near 2130 UT, at local midnight. SCATHA entered the plasmasphere shortly after 1400, as determined by the changes in the electric field antenna (Aggson, private communication), and the changes in the electrostatic analyzer data. Further increases in plasma density may have occurred near 1500 UT, as the satellite crossed the magnetic equator, and 1630 UT where the 1.0 to 10.0 keV electrons drop in intensity and the "deep proton minimum" rises up to 0 eV.

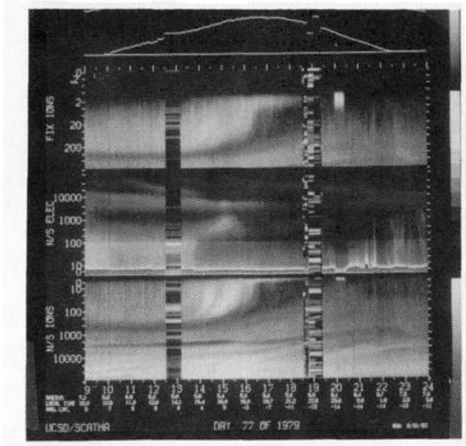

Figure 3. SCATHA/UCSD electrostatic analyzer data for March 18, 1979 (day 77).

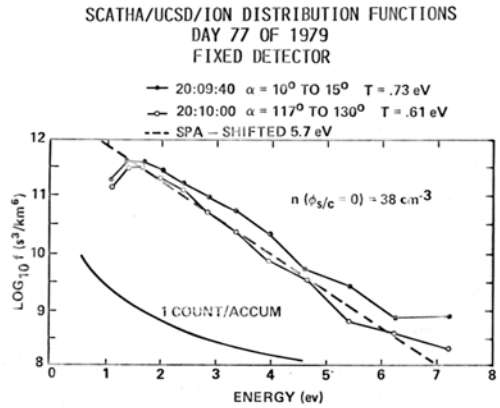

Figure 5. SCATHA/UCSD distribution functions for March 18, 1979.

The GEOS plasma data are summarized in Figure 2, a plot of plasma density and spacecraft potential from 0900 to 2400 UT. The plasma density rises abruptly at 1530 UT, and the spacecraft potential falls. The plasma is nearly isotropic, with the trapped ions enhanced over the field aligned by about 50%. The satellite leaves the plasmasphere in the middle of the eclipse, near 2200 UT. (Eclipse is from 2106-2215 UT.) The satellite potential is zero to one volt more positive than the VSAT VPROBE value plotted in the bottom panel of Figure 2, giving a satellite potential of about volt in sunlight prior to eclipse.

The SCATHA data over this time period are shown in Figure 3, an energy-time spectrogram for the electrostatic analyzer data. The top panel shows the 2-1800 eV ion data from the body mounted sensor, the next two panels the ion and electron data from the 1-eV to 81-keV sensors. The grey scale starts with black for zero counts, increasing to white with higher count rates. The eclipse of the satellite from 2001 to 2020 causes the locally generated photoelectrons to disappear, and a low energy ion population appears. This ion flux was hidden from the detector by a spacecraft potential of 3 to 5 V in sunlight.

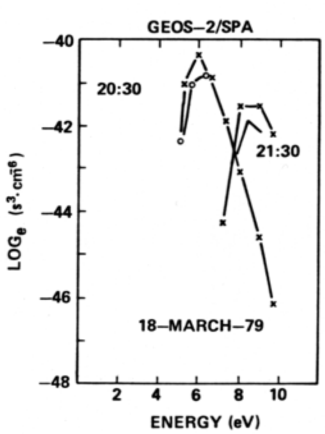

Figure 4. GEOS-2/SPA distribution functions for March 18, 1979. Data at 20:30 are in sunlight, data at 21:30 are in eclipse, 'x's are perpendicular to B, '0's are parallel to B.

The ion distribution functions measured on GEOS in sunlight and eclipse are illustrated in Figure 4, showing that the distribution function is visible under both conditions when a -8 V bias is applied. The eclipse data are taken near the plasmapause boundary, causing a drop in the distribution function. It is clear from these data, however, that there is a cold ion distribution, and that the satellite potential is near +3 V in sunlight and near 0 V in eclipse.

The ion distribution functions measured in eclipse on SCATHA are shown in Figure 5. The field-aligned and perpendicular distributions are similar, showing the plasma to be nearly isotropic. The GEOS measurement at 20:30 is superimposed on the SCATHA measurement, with a shift of 5.7 eV to account for the apparent differences in spacecraft potential. Since a single Maxwellian also appears to be invariant under a change in density, only the agreement in temperature is clearly valid. The apparent agreement in density is encouraging, however. The agreement here indicates the satellites passed through the same plasma regime, and provides an absolute density for the SCATHA measurements. A density of 38 cm^{-3} would be the SCATHA density if the spacecraft potential was 0 V. Increasing the SCATHA density to 75 cm^{-3} , the value from the GEOS mutual impedance probe, requires that exp ($e\varphi/kT$) be approximately 2, so the spacecraft potential should be approximately equal to the plasma temperature, i.e about +0.5 V.

These observations show that in the 50-100 cm^{-3} density regime, the biased electrostatic analyzers successfully measured the 'hidden' ion population, while the UCSD detectors on SCATHA could only measure this plasma in eclipse. If the satellite was only 3 or 4 V positive in sunlight, it is possible that a more sensitive instrument could have seen the tail of the distribution on this day.

2.2 Observations on October 14, 1979 (day 287)

The question raised by Decreau et al. [1978b] was whether the particle and wave instruments could be brought into agreement in a more tenuous plasma, where the density was less than or near 10 cm^{-3}. Data taken near local midnight on 14-October-79 are close to this situation. Figure 6 shows an orbit plot for SCATHA and GEOS, again showing L vs. MLT. This time, GEOS leads SCATHA through the local midnight region, and SCATHA crossed this region slightly inside the L = 7 of GEOS-2.

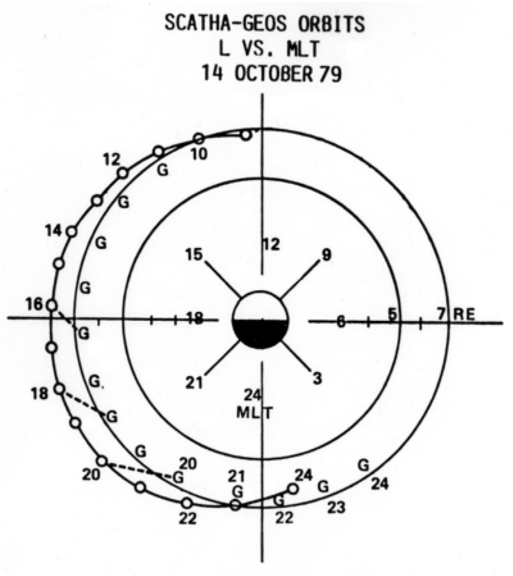

Figure 6. SCATHA-GEOS orbit plot for 14-October-79 (day 287).

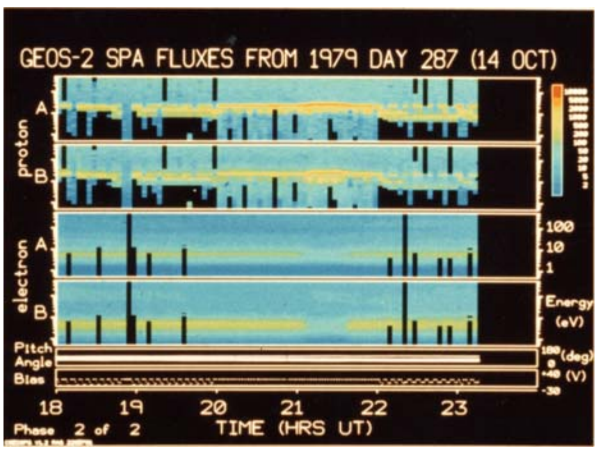

Figure 7. GEOS/SPA data in spectrogram form for 14-October-79 (day 287).

The electric field experiment shows the probe potential with respect to the satellite is between 5.0 and 5.5 V from 2030-2130 UT, indicating a spacecraft potential of 6.0 to 6.5 V. The mutual impedance probe shows a nearly constant plasma density of 8 cm 3. The GEOS/SPA shows a density of 4 cm -3 for the trapped component, and nearly 10 cm -3 for the field-aligned ions, a reversal of the anisotropy seen in the more dense plasma measured on 18-March. Figure 7 shows the GEOS/SPA data in spectrogram form. The

eclipse of the satellite from 2107 to 2136 UT causes the drop in photo-electron fluxes, and a rise in the energy of the cold ion population. The -28 V bias brings the cold ions into the plasma analyzer in spite of the substantial spacecraft potential. Distribution functions are not available for these data, but it is clearly possible to measure the density and anisotropy with the biased probes.

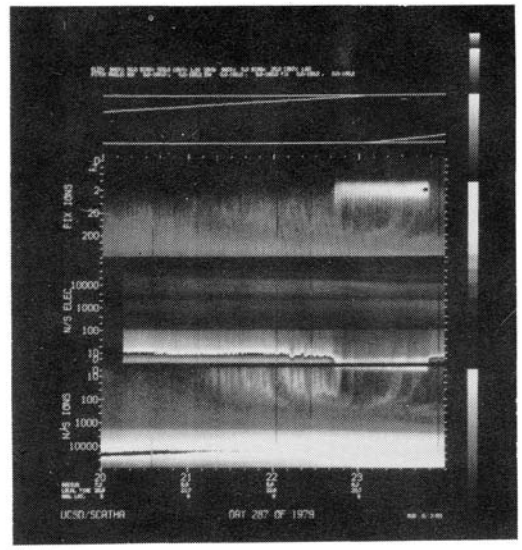

Figure 8. SCATHA/UCSD data in spectrogram form for 14-October-79 (day 287).

The SCATHA data for this period are shown in spectrogram form in Figure 8, using the same format as in Figure 3. Again the drop in spacecraft potential, appearance of the 'hidden ions', and the disappearance of photoelectrons is clear. The plasma sheet electrons extend up to 10 keV, but this is a population which has existed for several hours, as determined by the absence of injection signatures in the high energy ions. The plasmapause, as signalled by a sharp density gradient is not apparent on this day. The 10 cm -3 plasma extending into the plasma sheet may be the outer plasmasphere.

This day illustrates the need for the complementary wave and particle instruments found on GEOS. Although the S-300 experiment provides an absolute density and an electron temperature, the anisotropy of the ion population is only visible to the particle detectors. Although variations in mass composition have not been stressed here, it is clear that this characteristic must also be measured directly.

This is shown in Figure 9a and 9b, ion distribution functions from the SCATHA experiment. Figure 9a shows the ion distribution perpendicular to the magnetic field, a two-temperature distribution with a break at 4 eV. This distribution is only visible in eclipse. Figure 9b shows the field-aligned measurements in sunlight and eclipse. The higher temperature of the field-aligned distribution function and the higher energy tail allows the plasma to be measured in sunlight as well as eclipse, and shows that the satellite potential is shifted by 4 to 5 V. Both distributions give a density of 15 cm 3, assuming a spacecraft potential near 0 V. This density would be doubled for a likely potential of +0.5 V. This is higher than the GEOS measurement, but SCATHA is inside the GEOS orbit and 2 hours behind. During a quiet period such as this, there would probably be an increase in the plasma density over this interval. Clearly, both particle and wave measurements are necessary to complete the plasma parameter determination.

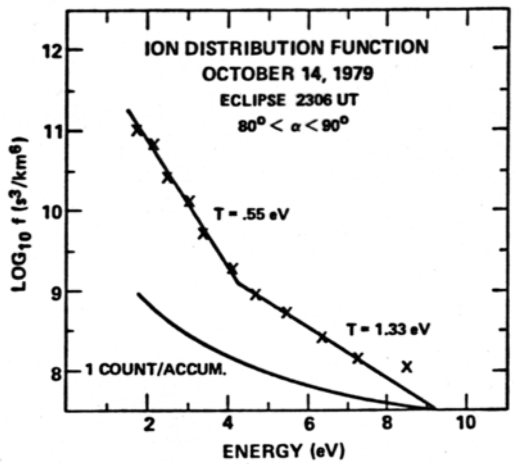

Figure 9a. SCATHA/UCSD ion distribution functions for 90° pitch angle.

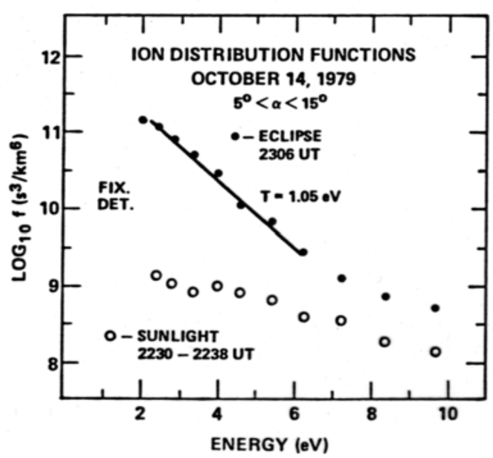

Figure 9b. SCATHA/UCSD ion distribution functions for field-aligned ions.

3. CONCLUSIONS

The objective of this paper was to compare the SCATHA and GEOS observations, in order to determine the relationship between the 'hidden ion' population measured by SCATHA, and the missing density component of the GEOS particle detectors. An intermediate level of success is apparent. Clearly, the wave instruments on GEOS measure the cold plasma population which is only visible to the SCATHA/UCSD detector in eclipse. Given a -28 V bias, the GEOS/SPA can also measure this plasma, at the cost of little or no energy resolution on the cold plasma. It is not clear if the missing component of the plasma found at apogee on GEOS-1 [Decreau et al. 1978b] has been identified. Further examination of the second example presented here may shed light on this topic.

4. ACKNOWLEDGEMENTS

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