TITLE OF INVESTIGATION: **The Properties of Cusp Diamagnetic Cavities**

PRINCIPAL INVESTIGATOR/INSTITUTION: **Robert Sheldon, The University of Alabama in Huntsville**

We propose to analyze the peculiar distribution of cusp diamagnetic cavities (CDC) that preferentially appear in the high-altitude outer cusp, as discovered by the high inclination orbit of POLAR. These cavities appear to contain plasma of solar wind origin, which would makes them an important step of the process that transports mass and energy through the semi-permeable magnetopause into the Earth's magnetosphere. In addition, these cavities are macroscopic objects that respond to plasma forces, enabling us to treat them as tracers of quite global MHD equilibria, so that, for example, independent of their source or origin, they should rapidly move to the cusp field line where there exists a force-free location. The radial coordinates of this force-free location depend on the strength of the magnetopause current system as well as the macroscopic size of the cavity. Thus the location and distribution of these cavities provide global diagnostics of the Earth's magnetic equilibrium over quite large length scales.

Furthermore, it seems likely that the formation of these CDC is related to turbulence and conditions in the magnetosheath or even upstream in the solar wind. Understanding the occurrence frequency of these DC may lead to a better understanding of the solar wind conditions favorable for mass and energy transport into the magnetosphere, and hence, improved predictive abilities. Finally, there is some evidence that some fraction of the energetic particles in these CDC are accelerated *in situ*, which, if true, would provide a novel means of energy flow from the solar wind into the magnetosphere. Not only is the quantity of energy important to understand, but the quality of the energy is very significant. If this energy appears as MeV particles, then these CDC may be responsible for many of the deletrious effects of "hard radiation" on spacecraft electronics. This gives an added emphasis to the determination and prediction of CDC.

Since the European mission, CLUSTER II, will be exploring the cusp later this year with four spacecraft, we expect detailed analysis of the microphysics of the cusp diamagnetic cavities within a year. The time seems opportune for POLAR to provide the global context within which the CLUSTER II data will be interpreted and understood.

Definition of a Cusp Diamagnetic Cavity A cusp diamagnetic cavity (CDC) is a force free structure in which the local plasma energy dominates over the magnetic energy, or the plasma pressure exceeds the magnetic pressure. This local increase in plasma density and/or temperature forms a "bubble" in the magnetic field, which expands until it is constrained by compressed and/or strained magnetic field lines. The fully magnetized plasma could escape parallel to the field line unless it were additionally constrained by increasing field strength along the field line, a magnetic bottle. Such a magnetic bottle geometry is possible in the Earth's cusp, where an off-equator minimum forms as a consequence of the magnetopause currents.

Now if the plasma injection or plasma heating is sudden enough, the rapid expansion of the bubble will reduce the magnetic field within the bubble, and by compressing the external "draping" magnetic fields, generate a higher magnetic field at the borders of the bubble. The plasma at the outer edge of the bubble then experiences a large gradient curvature drift, and forms a circular current around the perimeter. It is this current, then, that "cancels" the external magnetic field, much like the Earth's ring current, and causes the interior of the bubble to have such low field strength, often indistinguishable from zero. The process has a positive feedback, so that once a bubble forms, it rapidly evolves into a diamagnetic cavity. From basic physics considerations, the size of the cavity is determined or limited by the excess energy of the plasma versus the work required to inflate the bubble. Once such a diamagnetic cavity forms, it is unstable to the growth of mirror mode waves, so that the interior of the bubble is often filled with electromagnetic turbulence.

Therefore the observational evidence for diamagnetic cavities are the following: high electromagnetic turbulence, small average magnetic field with occasions of zero field, large plasma pressure and/or temperature, and sharp transitions (large gradients) between interior and exterior conditions. The existence of keV or MeV plasma is possible, but not a necessary condition for a diamagnetic cavity. As an example, we refer to figure 1, from a GRL paper on these cavities.

Cusp Diamagnetic Cavities as Topological Tracers Since a CDC has a finite size, then like a bubble in water, it experiences a buoyant force found by integrating the pressure over the surface area of the bubble.

Unlike water, the magnetic pressure is not a simple function of height, so that as the CDC is made larger, it finds a new "hydrostatic" equilibrium point. Thus we predict that larger CDC should be found closer to the Earth, and indeed, as our analysis tools improve, we can determine the topology of the magnetic field over a large volume by measuring the location and size of CDCs.

Origin of Cusp Diamagnetic Cavities The origin of these CDCs could be an explosive heating event or a sudden injection of cold plasma. The topology of the cusp favors a sudden injection, possibly with the additional heating of a shock. If it were sudden injection, one would expect the existence of magnetosheath plasma in the core of the CDC, as indeed, is often found. On the other hand, solar wind shocks and/or quasi-perpendicular bow shocks may also be associated with the formation of these cavities. Since MHD codes are unable to resolve the gradient curvature drifts that provide the defining characteristic of diamagnetic cavities, we must rely on kinetic simulations and even more importantly, data to validate the correct theories.

Acceleration in Cusp Diamagnetic Cavities The high turbulence and trapped plasma characteristics of a CDC make it a potential candidate for plasma heating. Such heating can be far more efficient than suspected because of two significant properties of CDCs: their location, and their field strength. Because a CDC is found in the cusp, it is located in a turbulent environment. Studies have shown the cusp to be an effective "feed horn" for focussing magnetosheath fluctuations into the magnetosphere. These fluctuations normally do little to heat the plasma because they do not couple efficiently to the plasma, and instead are observed as enhanced Alfvenic turbulence in the ionosphere. The CDCs, however, can act as efficient absorbers of this energy flow. It is as if we placed black circles of construction paper on our bedroom window and found that they became much hotter than the glass beside them. The reason is related to their field strength and limited size. Particles with the CDC find that the weak magnetic field causes their gyroperiod, their bounce period (within the magnetic bottle), and their drift period (time to circle the cavity) to be nearly identical. Thus violations of the third invariant (drift) caused by a magnetosonic waves are easily transmuted into violations of the second (bounce) or the first (gyro). Which is to say, diffusion in energy is greatly enhanced in these CDCs generating a wide spectral distribution and greatly enhanced temperature (fig 2).

Thus a determination of temperature and residence time of the plasma can indicate the heating rate of the CDCs. A determination of the heating rate with CDC size, can then estimate the production of highly energetic plasma from the broadened tail of the distribution. This estimate can then be compared to the known production of energetic plasma produced in storms as a guide to the importance of this mechanism for producing hazardous energetic particle enhancements.

Tasks There is a slight overlap with work done at Boston University, though we believe this work is entirely complementary. We will use the same automated software to identify CDCs, which unlike CEPs, require only the standard magnetic field products from the POLAR magnetometer. The second task is to accumulate statistics on the location of the CDCs in a "standard" T96 model magnetosphere, which will have different statistics than CEPs. We will attempt to use Dst and solar wind data to model the location of the cusp as accurately as possible. From the location of the front and back edges of a given CDC, and the best fit T96 cusp model, we will determine the location of the cusp field line, and hence the best fit bubble diameter or size that explains the data.

For as many CDCs as possible, we will calculate the plasma temperature and density from the HYDRA, TIMAS and IPS and CAMMICE data sets, attempting to characterize the spectrum and correlate it with bubble diameter or T96 model parameters.

Wherever CAMMICE data is available and solar wind species identified, we determine the charge state ratios of Oxygen and Helium, in order to estimate the residence time of the plasma. That is, solar wind is expected to be entirely He++, which at energies below 640 keV, charge exchanges with the ambient hydrogen geocorona to become He+. Thus measuring the He++/He+ ratio determines the residency time of the solar wind plasma. The uncertainties are high with one species, but the existence of O6+ and lower charge states give several independent measures of residency time (as well as average geocoronal density and initial mixing ratios).

Finally, we test the existing theories for agreement with the above statistics. For example, the quasi-parallel shock theory suggests that CDCs form from wave heating and mixing occuring at the magnetopause. Residence times and heating rates will be far different for this solution than the *in situ* theories.

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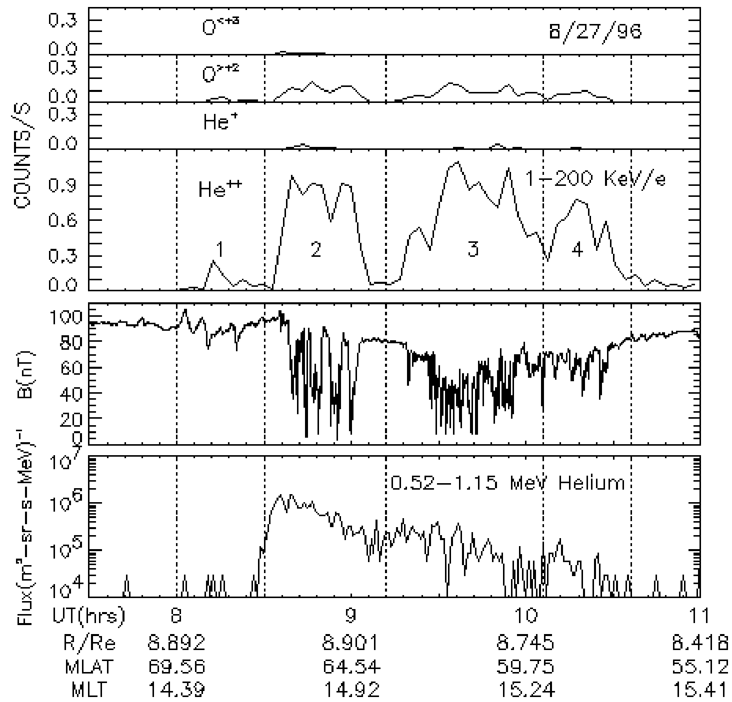

Figure 1: Three cusp diamagnetic cavities with solar wind plasma observed by POLAR on August 27, 1996. The panels from top to bottom show the counting rate for O<+3, O>+2, He+, He++ versus time, the corresponding variation of the local geomagnetic field, and the flux of the 0.52 - 1.15 MeV helium, respectively, where the vertical dashed lines mark the four different regions comprising individual events. The distance of POLAR from the Earth (in RE), the magnetic latitude (MLAT), and the magnetic local time (MLT) are shown at the bottom of the figure. (Fritz et al., 1999)

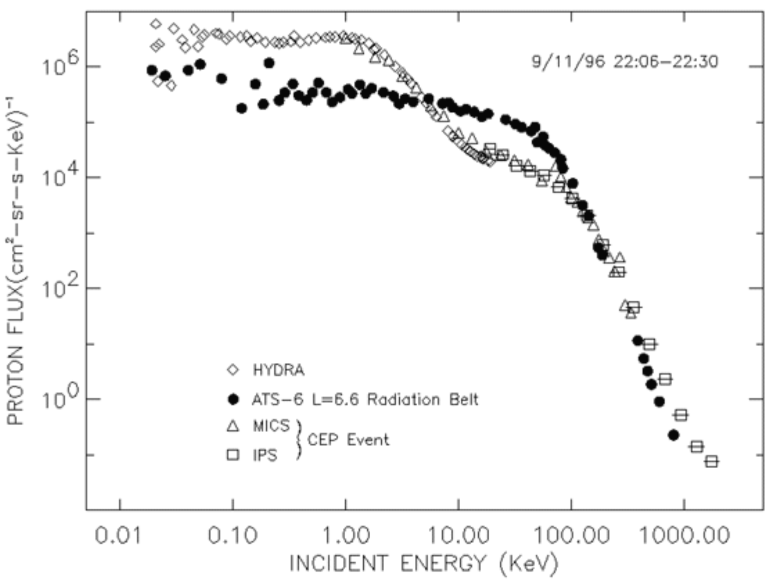

Figure 2: Composite figure showing the proton energy spectrum measured by the POLAR satellite in the high altitude cusp during a CEP event and by the ATS-6 satellite at the geostationary orbit on the nightside of the Earth.

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE
UAH RESEARCH PROPOSAL 2000–000
Cusp Diamagnetic Cavities
COST ESTIMATE FOR A ONE–YEAR PERIOD
(January 1, 2000 – December 31, 2000)

	Year One (1/1/01–12/31/01)	Total
A. SALARIES AND WAGES /1/		
1. Dr. R. B. Sheldon, Principal Investigator *		
100.00% x 15 / 52 wks x $72,110	20,801	20,801
2 Graduate Student		
100.00% x 12 / 12 mo. x 1 $16,000	16,000	16,000
TOTAL LABOR	36,801	36,801
B. FRINGE BENEFITS /2/		
1. 25% A.1–2.	5,200	5,200
2. GRA Tuition ($416/$433/450/468 mo.)	5,009	5,009
TOTAL FRINGE BENEFITS	10,209	10,209
TOTAL SALARIES, WAGES & FRINGE	**47,010**	**47,010**
C. OPERATING COSTS		
1. Travel (see below) /3/	2,000	2,000
		0
TOTAL OPERATING COSTS	**2,000**	**2,000**
TOTAL ESTIMATED DIRECT COSTS	**49,010**	**49,010**
D. FACILITIES & ADMINISTRATIVE COST /4/		
43% Modified Total Direct Costs** *	21,074	21,074
UAH TOTAL ESTIMATED COST BY YEAR	**70,085**	**70,085**

/1/ See paragraph 2.a. of financial data sheet
/2/ See paragraph 2.b. of financial data sheet
/3/ See paragraph 2.c. of financial data sheet

*These personnel hold an academic (37 week) year appointment. Their salaries have been convert
to the calendar (52 week) equivalent (ac.yr. X 1.405 = cal.yr.)
***F&A rate is provisional after 10/1/00.