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Technical Report to the
National Aeronautics and Space Administration
on Grant NAGW-269

Numberical Simulation of the Effects of Radially
Injected Barium Plasma in the Ionosphere

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by

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The major effort has been to understand the morphology of the ion cloud

in the radial shaped charge barium injection experiments of Wescott et al

(1980). Basically these experiments consisted of projecting barium

perpendicular to the earth's magnetic field by a radially symmetric explosive

shaped charge. The experiments were conducted from rocket-borne payloads at

an altitude where interaction with the ambient neutral atmosphere is

negligible.

The basic feature we have attempted to understand is the shape of the ion

cloud that remains after the explosive products and neutral barium clears

away. Panel D of Figure 1 shows the ion cloud which has the configuration of

a rimless wagon wheel. The major features are the 2.5 km radius "black hole"

in the center of the cloud, the surrounding ring of barium ion and the spokes

of barium ionization radiating away from the center. The cloud shows no

evolution after it emerges from the neutral debris, so it must have formed

within 5 seconds of the event.

Panels A-C of Figure 1 show the expanding neutral barium. The most

notable feature is the inhomogeneous or blobby structure of the expanding

neutrals. The spokes in the ion cloud can then be explained as the trail of

ionization left behind by a neutral blob as it photoionizes. The ambient

magnetic field is effective in halting the outward expansion of the ions as

they are created.

The existence of the black hole, however, requires the outward transport

of ionization within 2.5 km of the explosion, and the nature of the transport

mechanism is the major problem addressed in this work. To this end a numerical model was set up to calculate the motion of ions and electrons subject to the electrostatic and Lorentz forces, and subject to being collisionally driven by the expanding neutrals. The velocity of the neutrals was calculated based on the motion of neutrals deduced from television imaging of the event. The electric potential was determined from the quasi neutrality condition derived from requiring the divergence of the current to be zero. This gives an equation for the potential of the type

$$\nabla \cdot \Sigma_p \nabla \phi + \nabla \Sigma_H \times \nabla \phi = S \qquad (1)$$

where Σ_p and Σ_H are the field line integrated Pedersen and Hall conductivities respectively, and S is a source term proportional to the velocity of the barium neutrals.

The investigation has been frustrated by our inability to find a convergent iterative scheme to obtain solution to (1). The large Hall term destabilized the iterative schemes we have tried.

As an alternative we have modified the calculation by dividing the space into pie-slice segments of angular width $\Delta\theta$ where $\Delta\theta = 2\pi/n$, n an integer. Each segment was divided into two subsegments of angular width $\Delta\theta_1 + \Delta\theta_2$ where $\Delta\theta_1 + \Delta\theta_2 = \Delta\theta$. To represent the azimuthal variation in the density of neutrals, one neutral gas density was assigned to the segment $\Delta\theta_1$ and another to the $\Delta\theta_2$ segment. The pattern repeats n times. The grid lines are on the lines separating the $\Delta\theta_1$ and $\Delta\theta_2$ sectors. The potential is determined by the condition that the current remain divergence free. Electrons can flow from one sector to another, but the ions are assumed to have no azimuthal drift.

The result from this simplified model is that the polarization electric field allows the unimpeded transport of plasma across the magnetic field at

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the velocity of the neutrals. Figure 2 shows the computed ionization density at 1 sec after the event for the case where the neutral density in the $\Delta\theta_1$ and $\Delta\theta_2$ segments was the same. This was at a time when all ion motion had ceased. The large peak in density near the origin can be seen. This is inconsistent with the existence of the black hole in Frame D of Figure 1. Figure 3 shows the results when the density in the two sectors differed by a factor of 10. The density minimum at the origin is consistent with the black hole.

The calculations show that the azimuthal variation in the density of the neutrals is critical to the formation of the black hole. The limitation of the model is that it does not allow azimuthal motion of ions, which we believe is important to the formation of the ring of barium ion around the black hole. The results of this work were presented to the Fall 1984 meeting of the American Geophysical Union in San Francisco (Hollerbach et al, 1984).

A more definitve simulation of the radia' shaped charge experiment will require the solution to (1). We are proceeding along two tracks. One is to calculate the number density by transporting the electrons rather than the ions. This should produce density gradients more nearly parallel to the potential gradient and thus reduce the magnitude of the destabilizing form in (1), $\nabla\Sigma_H \times \nabla\phi$. If this does not result in convergent iterations, we shall use sparse matrix methods to obtain a direct solution to (1).

References

Wescott, E. M., H., C. Stenbaek-Nielsen, T. J. Hallinan, C. S. Deehr, G. J. Romick, J. V. Olson, J. G. Roederer and R. Sydora, A high altitude barium radial injection experiment, Geophys. Res. Lets., 7, 1037, 1980.

Hollerbach, U. D. W. Swift and E. M. Wescott, Numerical simulation of the radially injected barium experiment, EOS, 65, 1059, 1984.

Figure Captions

Figure 1.   A sequence of TV pictures showing the evolution of the King Crab radial barium injection experiment (Wescott et al., 1980). Panel A and B show barium neutrals, while in C a ring of barium neutrals can be seen expanding away from a faint barium ion cloud. Panel D shows the barium ion cloud through a filter.

Figure 2.   Calculated radial distribution of barium ion density at one second computed for the neutral velocity distribution in the Bubble Machine experiment, assuming a radially symmetric expansion. The motion of the ions is stopped by the electrons which remain rigidly tied to magnetic field lines.

Figure 3.   Similar to Figure 2, except that the time is at 3 seconds and that a 10 to 1 azimuthal variation in neutral density is assumed. The barium is moving at essentially the neutral expansion speed.
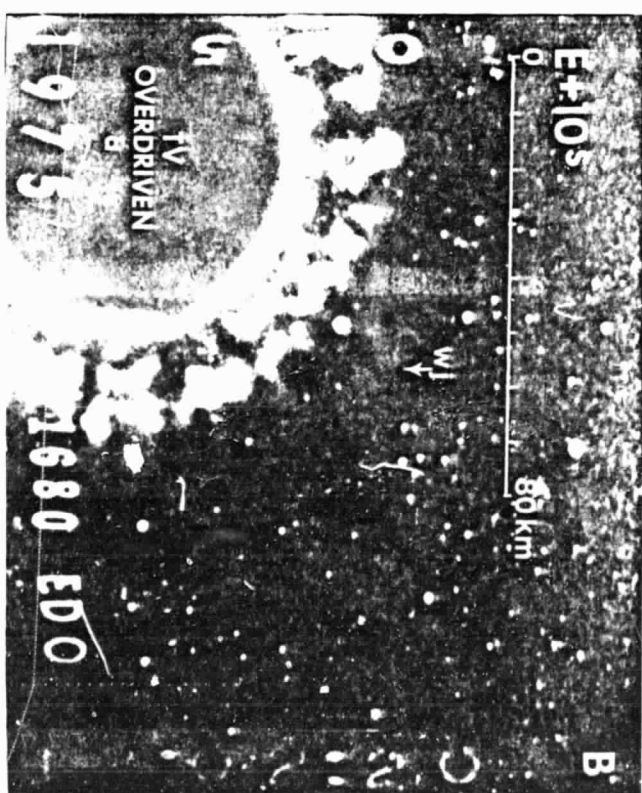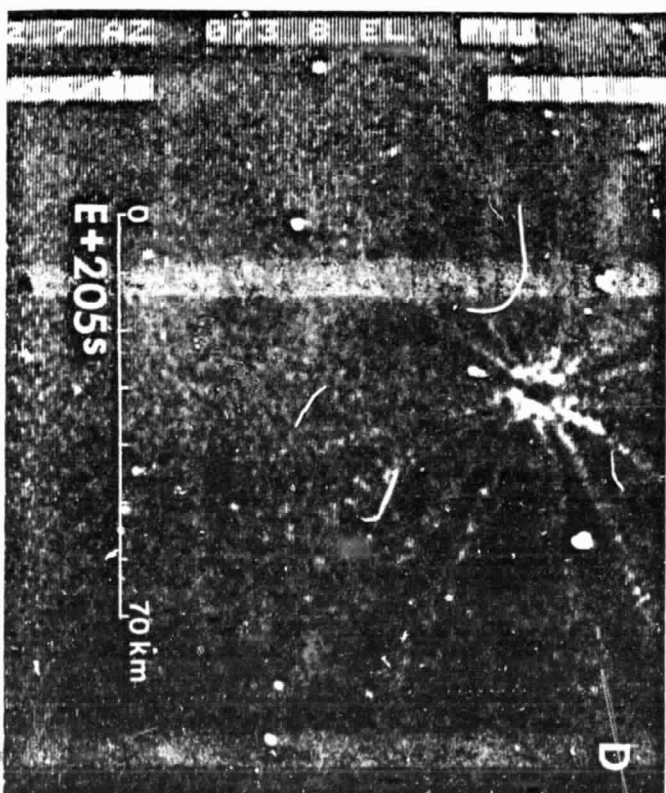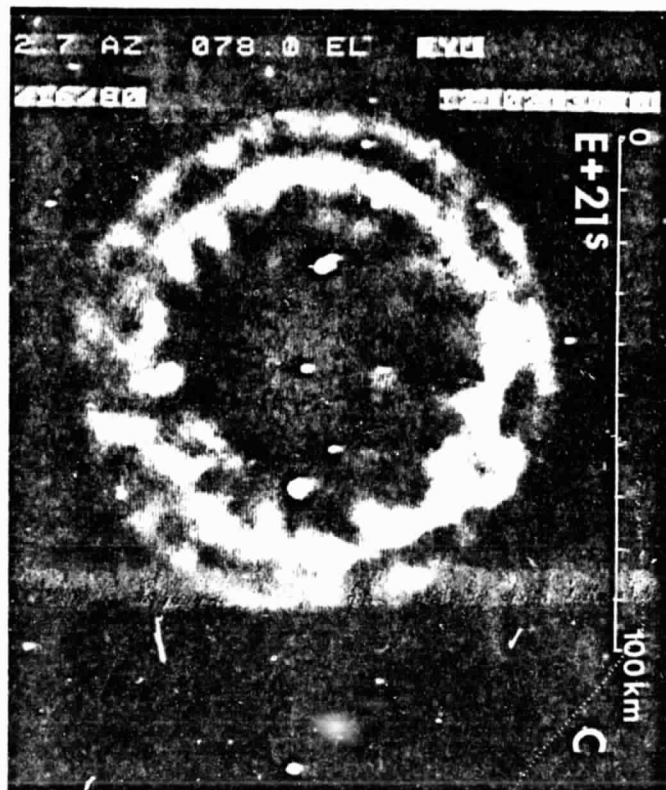
Fig 1

DENSITY
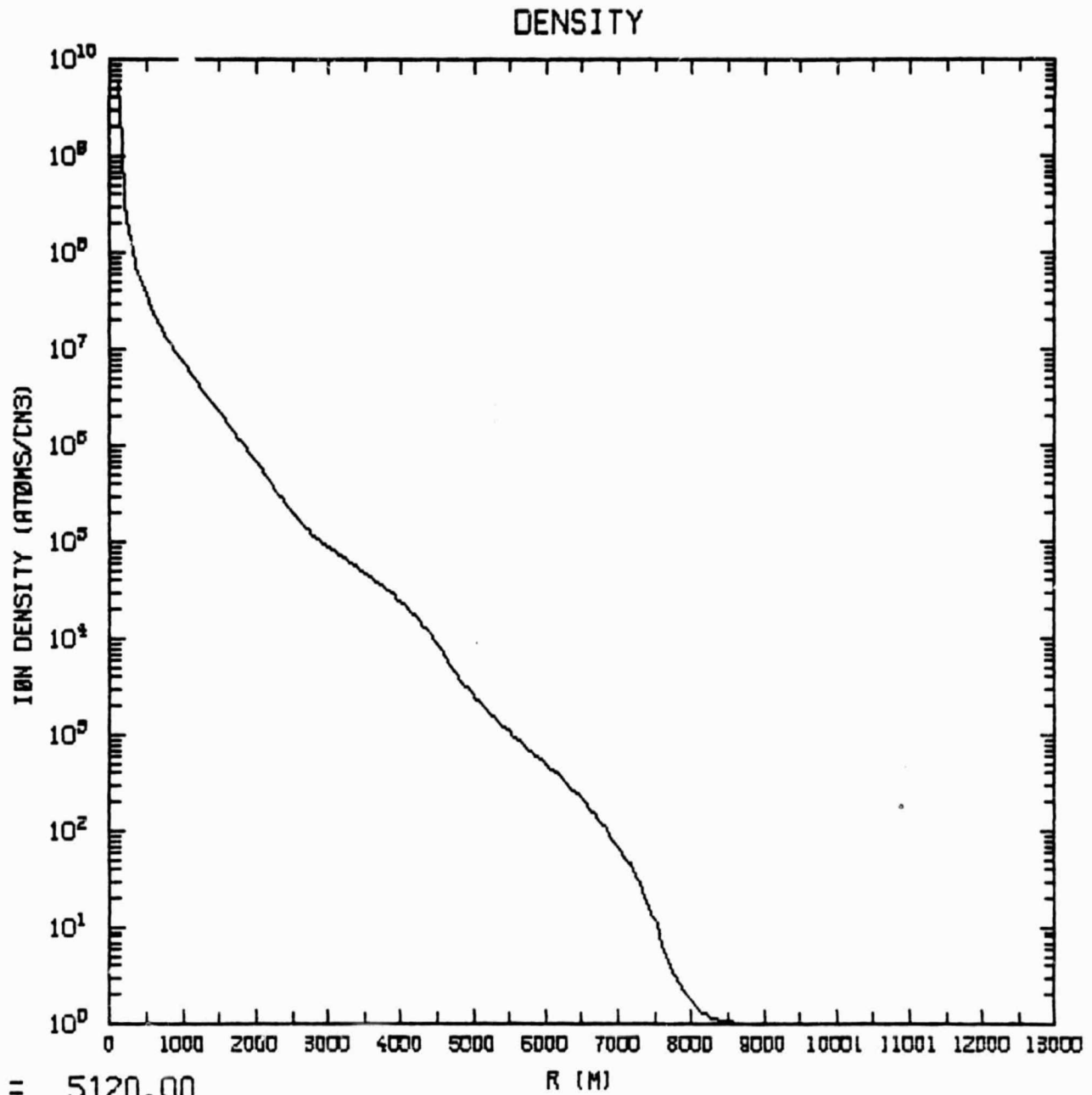
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TIME = 1.048684
TAU =   20.00

Figure 2
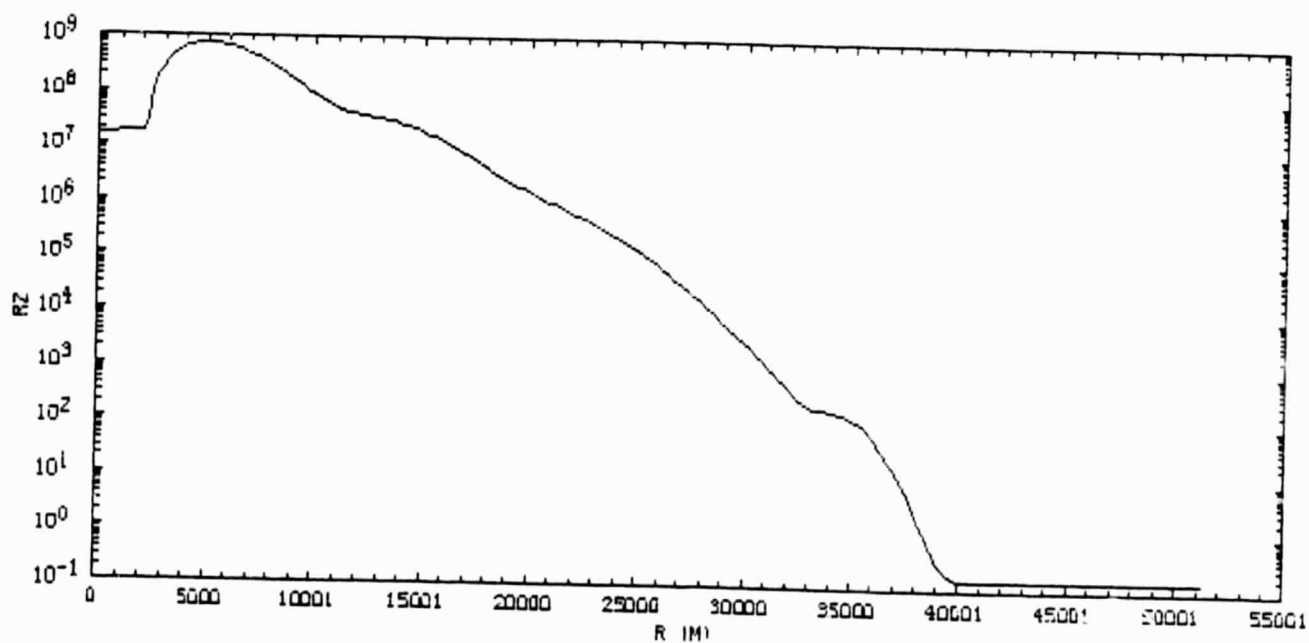
ASYMMETRIC $n_2/n_1 = 10$ $t = 3$ sec

Figure 3