Measurements of the creation of a diamagnetic cavity and transport barrier in a laboratory supersonic plasma and comparison with computer simulations

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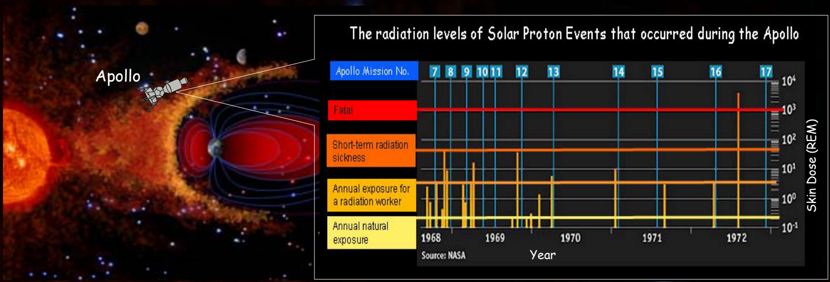
Introduction : The luck of Apollo

Following NASA's lead, the European Space Agency's (ESA) 'AURORA' Programme aims to land a man or woman on the Moon then Mars in the next few decades.



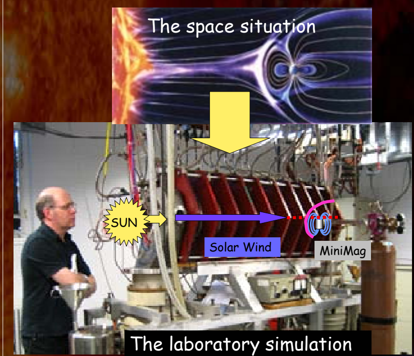
No astronauts have been outside the protection of Earth's magnetosphere since the Apollo Moon landings. Even then, their stay was never for extended periods of time. This makes the health risks much more of an issue than it has been for 40 years.

The Mini-Magnetosphere Concept

A small, portable, electromagnetically confined plasma "bubble" around the space craft that could protect the occupants in a similar way as the natural magnetosphere does around the Earth. Here computer simulations combined with laboratory experiments have been used to re-examine the feasibility of mini-magnetospheres for astronaut protection using modern knowledge of diamgnetic cavities and plasma transport barriers.

The laboratory experiment

- The dimensionless parameters of the Vlasov Equ are intensified here so as to scale the space plasma environment into the lab.
- For solar wind plasma
- Maintain collisionless shock regime.
- The plasma flow is supersonic in the target chamber as to be able to recreate the Bow Shock.



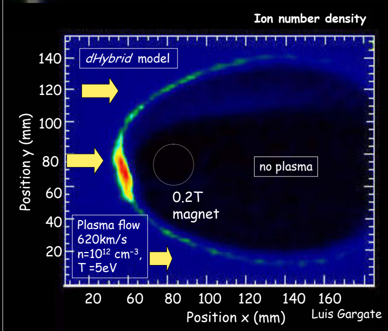
Details

Source:
Linear hydrogen Plasma beam (equivalent of the Solar Wind)

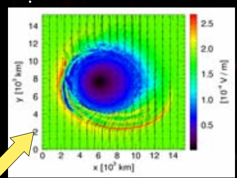
- Beam diameter 10-20 mm,
- Te ~ 5-15 eV,
- n~ 10^{19} cm^{-3},
- B field ~ 0.05 T
- Ion Larmor radii r_{Li} ~ 10mm, r_{Le} ~ 0.2mm
- Mean free path ~ 0.5 m,
- Ion flow vel ~ 80km/s,
- MACH ~ 3.5 (ion flow/ion acoustic)

Target:
Permanent magnet (equivalent of spacecraft active "deflector shield")
25mm dia, 0.5T (central field)

Simulation



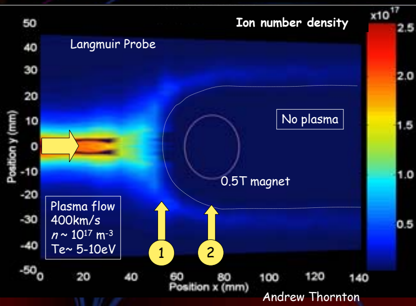
Code:
dHybrid
3D PIC code
Ions kinetic
Electrons fluid



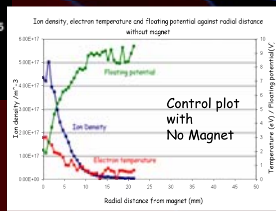
Shows a diamagnetic cavity, or a region free of "solar wind" plasma.

Extrapolating to the space environment using simulation shows the electric field intensity and field lines in the xy plane.

Measurement

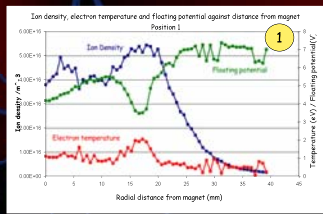


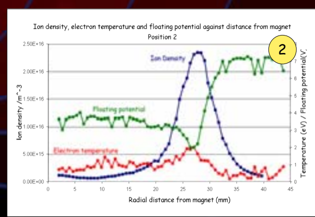
Langmuir probe data provides an in situ measurement of the plasma parameters (n, Te,V) outside, across and inside the barrier.



The stand-off distance (from magnet axis to magnetopause/seperatrix) in simulation and measurement is within 7% of each other.

Detailed plots of radial profiles show the narrowness of the plasma region





The probe measurements of ni, Te, Vf inside, across and outside the diamagnetic transport barrier show that the ion density is effectively zero inside - thus the "solar wind" is seen to be deflected away from the magnet.

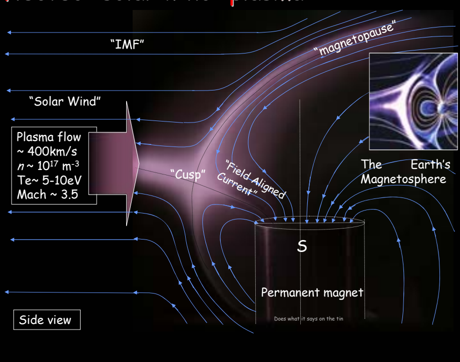
Plasma shield in operation. Stage 1: Magnetic "piston"

A permanent magnet with NO internal plasma source (yet) creates a "mini-magnetosphere" away from the magnet. These results show the action of one component of the shield the "magnetic piston".

Here the ion Larmor orbit is of the order of the size of the target. The impacting "solar wind" plasma is deflected by > 15mm away from the magnet. The barrier depth is ~3-7mm ie of the order of the electron skin depth.

A photograph of deflected "solar wind" plasma

The H⁺ plasma flows from left to right. The H_α & H_β light indicates the location of the plasma as the chamber is filled with neutral H_2 gas.



with magnetic field lines superimposed

Summary & Conclusions

In light of the ESA AURORA goals, the physics behind mini-magnetospheres as an active shield for astronaut protection is being re-examined using plasma physics of transport barriers incorporating particle kinetics. This involves computer simulations and laboratory experiments. The initial results shown here are very promising.

An established hybrid code (dHybrid) (*Gargate et al 2004*) and has now been used to simulate the laboratory re-creations of the "magnetic piston" component of a mini-magnetosphere shield for astronaut protection.

Both model and laboratory confirmed the creation of a diamagnetic cavity in the solar wind plasma in which a space craft would be protected from the energetic particles of a solar event. The very narrow transport barrier created by both simulation and experiment, showed that the important scale size is the *electron* Larmor radius and *not* the *ion* Larmor radius. This illustrates that the microphysics dominates and MHD is not an appropriate model for this application (*Gargate et al excepted by Plasma Phys & Cont. Fus. 2007*).

These initial model and experimental results suggest that small artificial magnetospheres may be practical - the shield is more effective and would require much less power than previously thought.

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