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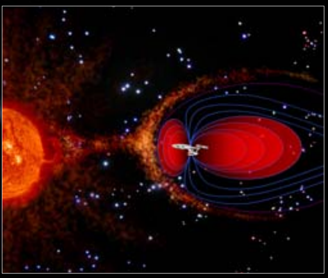

"Raise Shields, Scotty": Initial Experimental Results of a Laboratory "Mini-Magnetosphere" for Astronaut Protection

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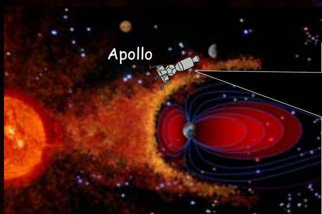
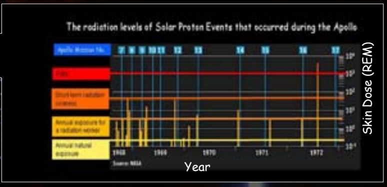
Introduction

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.

The luck of Apollo





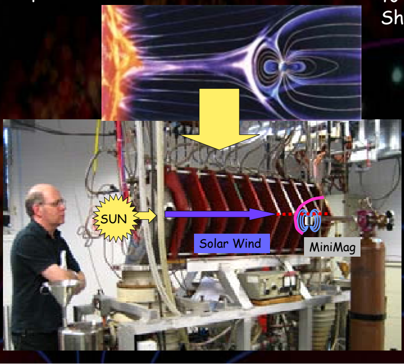
No astronauts have been outside the protection of Earth's magnetosphere since the Apollo Moon landings. Even then their stay was never for extended periods of time. This makes the health risks much more of an issue than it has been for 40 years.

Mini-Magnetospheres

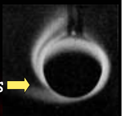
The mini-magnetosphere is one possible solution: to create a small, portable, electromagnetically confined plasma "bubble" around the space craft that could act in a similar way as the natural magnetosphere does around the Earth. It was first suggested in the 1960's but dismissed for power reasons mostly. But power estimates were based on either the electric, magnetic or plasma particles creating a shield separately. In fact all the forces are used when the plasma physics of two interacting plasmas is considered on the kinetic level. Here computer simulations combined with laboratory experiments have been used to re-examine the feasibility of mini-magnetospheres for astronaut protection.

The laboratory experiment

The solar wind in a bottle (below). The linear device (originally built for fusion edge physics studies), produces the laboratory "solar wind" magnetized beam. A magnetised target represents the dipole field of a mini-magnetosphere on a spacecraft.



The plasma parameters (such as Larmor orbits) are intensified here so as to scale – this was not needed for auroral studies like Birkeland's terrella experiments.



Also this plasma is supersonic so as to be able to recreate the Bow Shock.

Details: The hydrogen plasma from the high-output source produces a plasma stream (equivalent of the Solar Wind) (10-20 mm Dia, Te~ 5-15 eV, n~ 10^{14} cm^{-3}), confining axial magnetic field of 0.03 T (equivalent of the IMF field). In the initial experiments the "target" was a 0.5T (central field) permanent magnet (equivalent of spacecraft active "deflector shield").

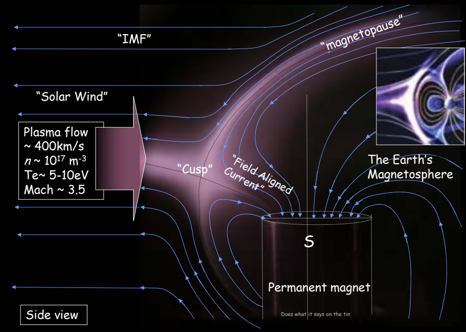
Plasma shield in operation. Stage 1: Magnetic "piston"

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.

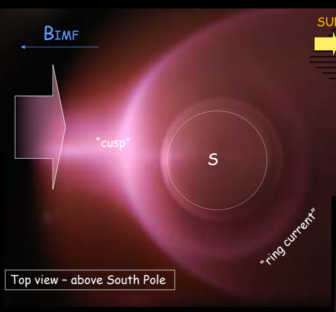
A photograph of deflected "solar wind" plasma

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.



Plasma flow
~ 400km/s
n ~ 10^{17} m^{-3}
Te~ 5-10eV
Mach ~ 3.5

with magnetic field lines superimposed

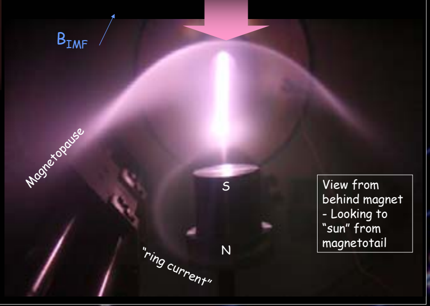


Top view – above South Pole

The Earth's plasmasphere as seen by EUV instrument on the IMAGE satellite.

Key features of these experiments are the use of a plasma with both charges not just electron beam, the supersonic impact and the appropriate scaling of the dimensionless Vlasov equations.

Many aspects of the Earth's magnetosphere are made visible in miniature – such as field aligned (Birkeland) currents and the ring current. On the movies Alfvén or ion-acoustic waves can be seen.



View from behind magnet - Looking to "sun" from magnetotail

Model – Measurement comparisons

Both show how the diamagnetic cavity, a region free of "solar wind" plasma, is created.

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

Here the ion density of the "solar wind" is seen to be deflected away from the magnet.

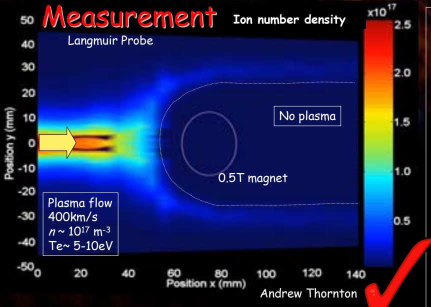
Modelling

Computer Simulations of mini-magnetospheres are very sensitive to the boundary physics. MHD fluid approximation is not appropriate as it doesn't distinguish charge species. Previous simulations have shown that finite ion Larmor radius effects are important specially where the ion Larmor radius can be comparable to the size of the mini-magnetosphere; only a fully kinetic treatment of the ions can properly take into account these effects.

dHybrid - used here - is a computationally demanding PIC code that is a hybrid of both fluid and particle codes.

Note that the preliminary results as the simulation were done before more precise input parameters from the experimental setup were known. Nevertheless the qualified comparison is excellent. Both show the importance of shocks in creation of the transport barrier and the stand-off distance (from magnet axis to magnetopause/seperatrix) is within 7% of each other.

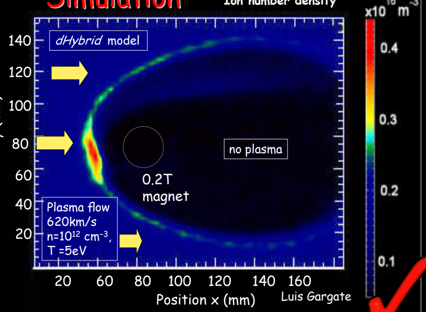
Measurement



Plasma flow
400km/s
n ~ 10^{17} m^{-3}
Te~ 5-10eV

Andrew Thornton

Simulation



Plasma flow
620km/s
n=10^{12} cm^{-3},
T =5eV

Luis Gargate

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) previously validated on AMPTE simulations (*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 electrodynamic 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 submitted to Special Issue of 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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