MiniMags

a radiation shield for protection of spacecraft and astronauts

an engineer's perspective (not a plasma physicist!)

6th Appleton Space Conference

9th December 2010

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RAL Space

a little history…

an Englishman ……

working for NASA ……

on an oil-rig converted to become a satellite launch platform …..

near one of Kenya's tropical paradise resorts – Malindi …..

on a rocket range ……

run by the Italian Air Force !!!

So, in 1971, on San Marco Equatorial Range,
I had the privilege of meeting one of the iconic figures of the Space Age:– **Dr Wernher von Braun**

I had always thought of von Braun as the father of rocketry –

from V2s in WW2 …

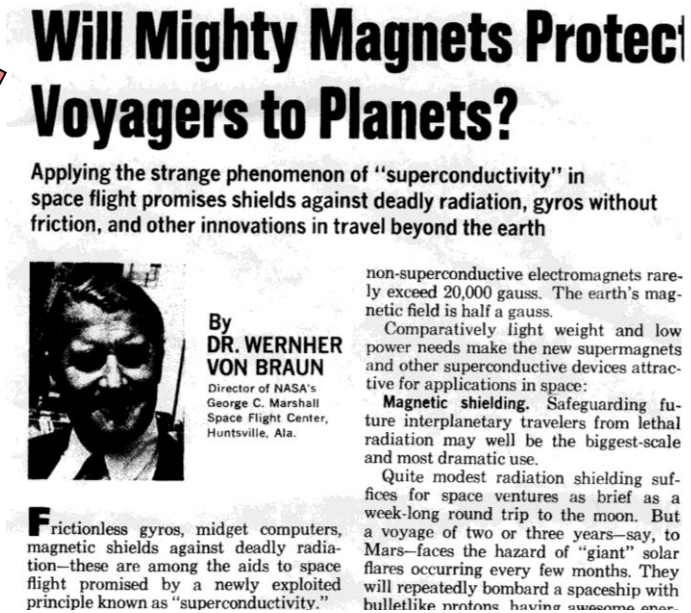
to Saturn V and the Apollo moon-landing programme

What I didn't know then was that as Director of MSFC he had become increasingly concerned about the potentially lethal effects of space radiation on his astronauts

- In 1969, 2 years before I met him, von Braun had proposed that a very powerful magnetic field around a spacecraft could protect it from space radiation by forming a mini-magnetosphere that would divert the high energy particles around it

- However, the thinking at the time (and unenlightened thinking today) was that such a shield could only be produced by using massive super-conducting magnets to create a very intense magnetic field

- What we have now shown is that there are local charge-separation effects at the boundary of the magnetic field and the interplanetary plasma, that form an effective shield at a fraction of the power originally envisaged



Will Mighty Magnets Protect Voyagers to Planets?

Applying the strange phenomenon of "superconductivity" in space flight promises shields against deadly radiation, gyros without friction, and other innovations in travel beyond the earth

By **DR. WERNHER VON BRAUN**
Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Frictionless gyros, midget computers, magnetic shields against deadly radiation—these are among the aids to space flight promised by a newly exploited principle known as "superconductivity."

non-superconductive electromagnets rarely exceed 20,000 gauss. The earth's magnetic field is half a gauss.

Comparatively light weight and low power needs make the new supermagnets and other superconductive devices attractive for applications in space:

Magnetic shielding. Safeguarding future interplanetary travelers from lethal radiation may well be the biggest-scale and most dramatic use.

Quite modest radiation shielding suffices for space ventures as brief as a week-long round trip to the moon. But a voyage of two or three years—say, to Mars—faces the hazard of "giant" solar flares occurring every few months. They will repeatedly bombard a spaceship with bulletlike protons having awesome ener-

NASA/TM—2005–213688

Revolutionary Concepts of Radiation Shielding for Human Exploration of Space

J.H. Adams, Jr., D.H. Hathaway, R.N. Grugel, and J.W. Watts
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

T.A. Parnell and J.C. Gregory
The University of Alabama in Huntsville, Huntsville, Alabama

R.M. Winglee
University of Washington, Seattle, Washington

March 2005

the clues to MiniMags:- AMPTE

Active Magnetospheric Particle Tracer Explorers

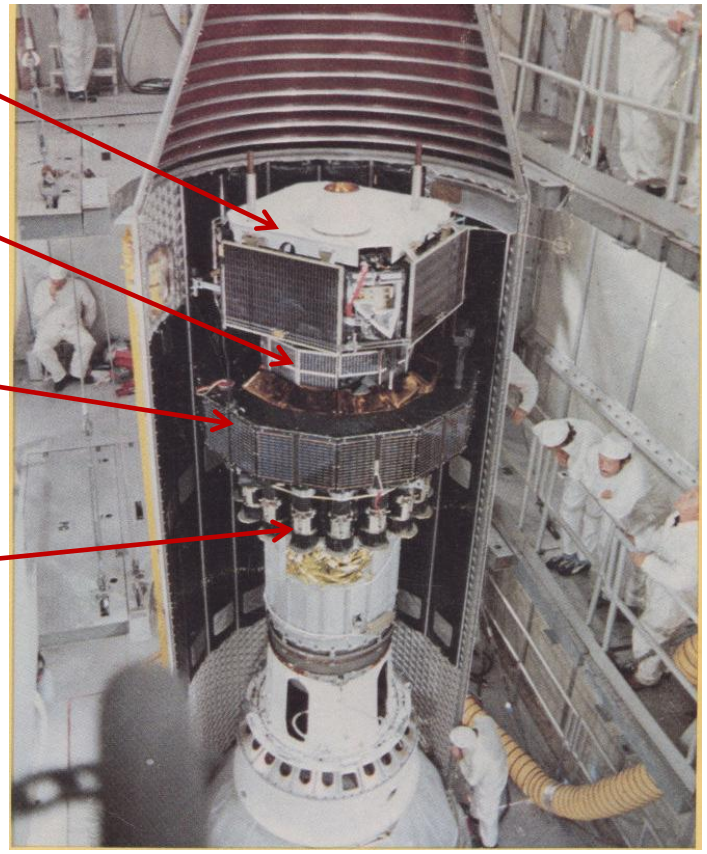
NASA / APL
CCE - Charge Composition Explorer

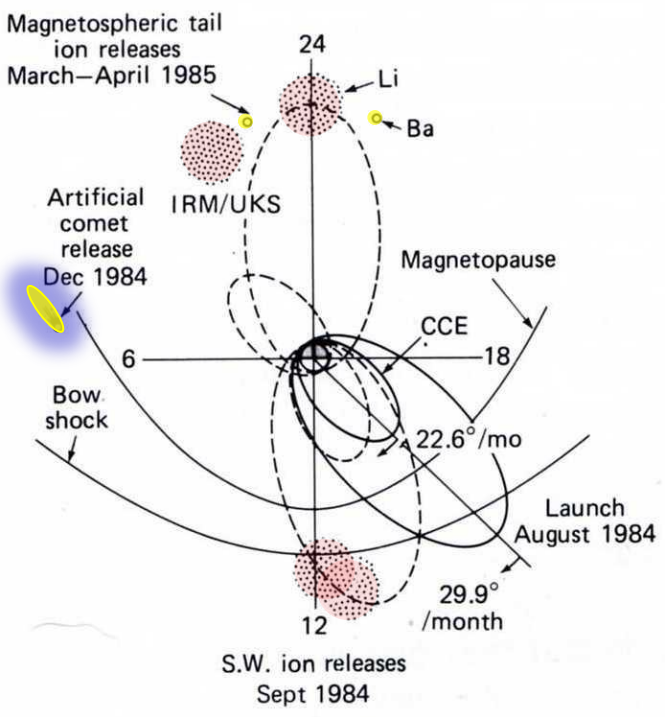
RAL / MSSL
UKS - UK Sub-Satellite

Max Planck
IRM - Ion Release Module

Lithium & Barium mix with copper-oxide in cylinders

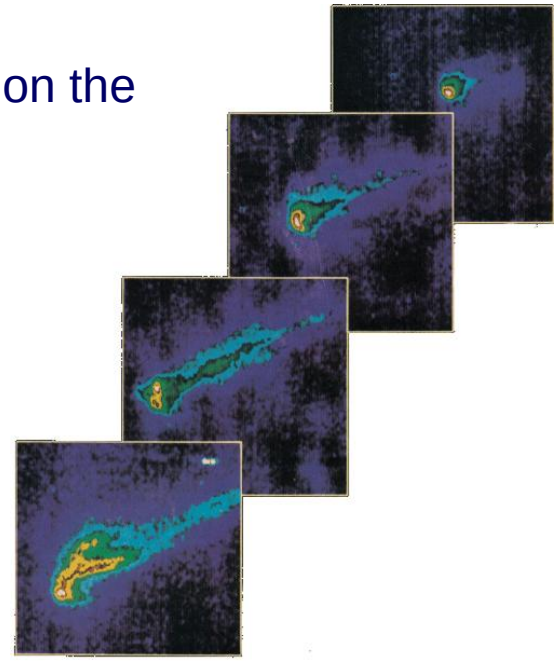
Released into the solar wind; thermite reaction; ionized by solar radiation; hoped to trace ions down to CCE in lower orbit

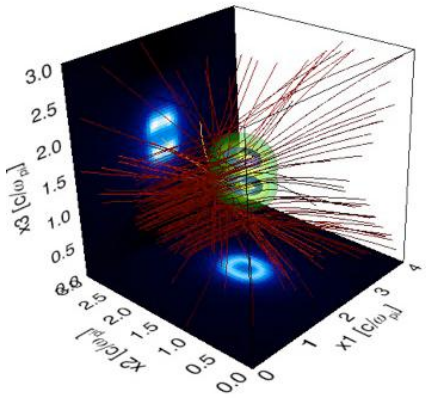




AMPTE

- The tracing aspect of the mission was unsuccessful – the CCE never saw any lithium or barium ions
- The UKS was able to monitor in-situ the local effects on the magnetosphere of the ion releases from ~200km
- The artificial comet release formed a dia-magnetic cavity that totally excluded the solar wind plasma – all the high energy particles were deflected around this ‘bubble’ – no existing theory (MHD code, which treats the plasma as a fluid) could explain the dynamics of what had been observed





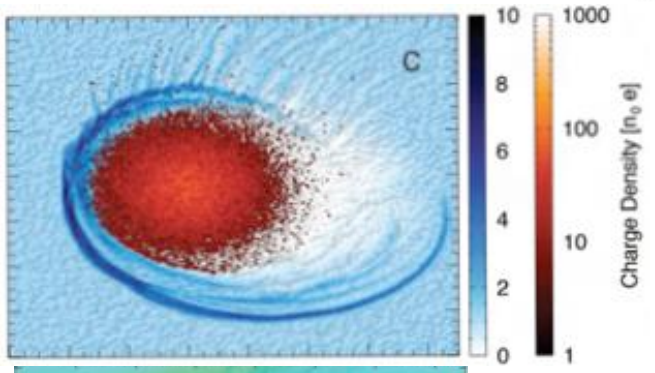
dHybrid simulation box

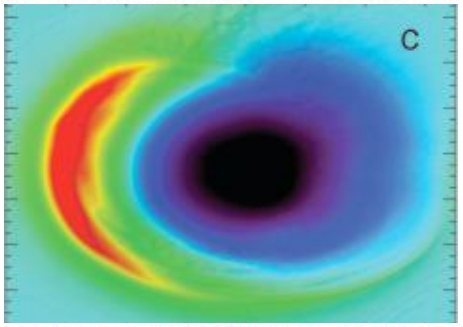
A new massively parallel hybrid code, **dHybrid**, was developed by RAL’s Bob Bingham and his team, (which later included UCLA and IST Lisbon) that successfully simulated the cavity that had been observed in the AMPTE ion releases

How does it work?

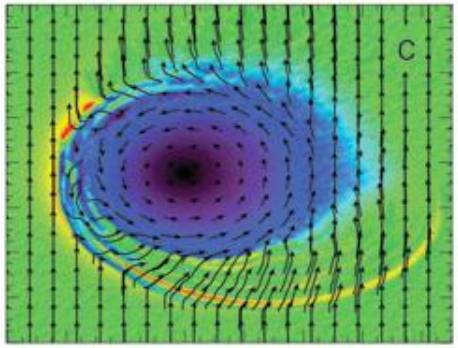
- When the neutral plasma encounters the magnetic field boundary the electrons are more easily deflected than the ions and thus charge separation occurs, resulting in the build-up of a large electric field which further strengthens the barrier
- The Toys R Us effect….
- MHD simulations, which treat the plasma as a fluid, do not capture the physics – ideally a fully kinetic code with all particles treated individually would be required – not practical
- Bingham's **dHybrid** code treats the electrons as a fluid and the ions as individual particles – this technique successfully simulates the AMPTE artificial comet release in a totally self-consistent manner

Plasma density





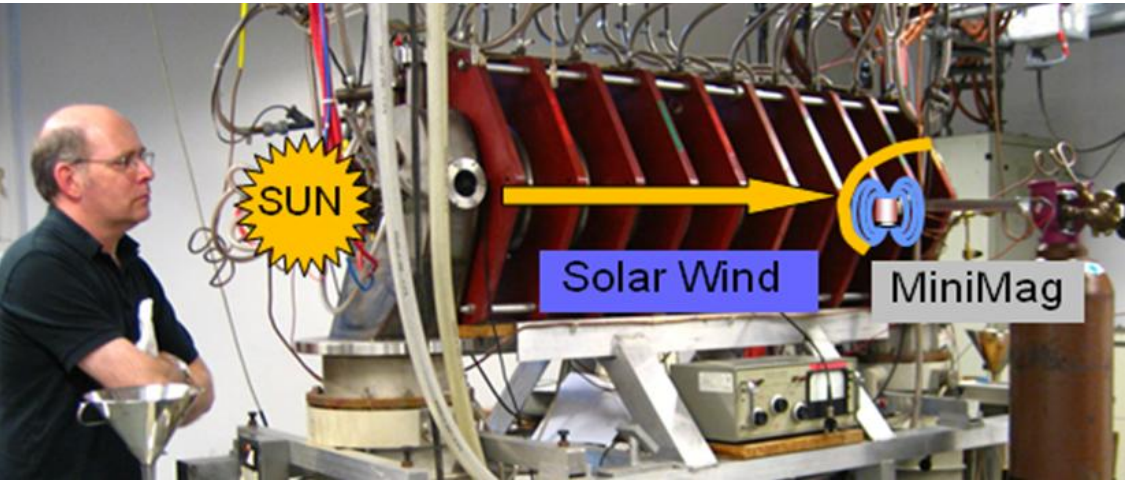
Magnetic field

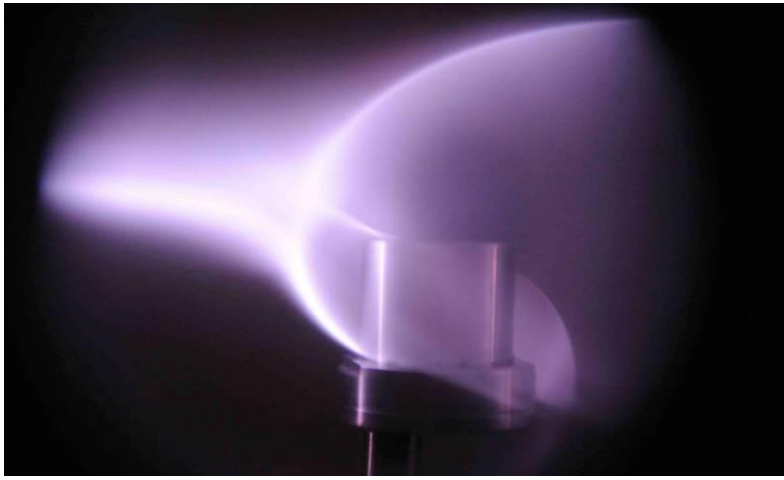


Electric field

The MiniMagnetosphere

- RAL plasma physicists had observed deflections of high energy particles around magnetic field bubbles in plasma chambers at JET
- RAL's Ruth Bamford thought it should be possible, using a combination of the AMPTE-style plasma bubble and the JET-style magnetic field bubble to form an effective Mini-Magnetosphere
- Simulations using the **dHybrid** code showed that it was indeed possible to generate such a shield – preliminary experiments using a solar wind simulator have successfully demonstrated it at RAL





Where are we now?

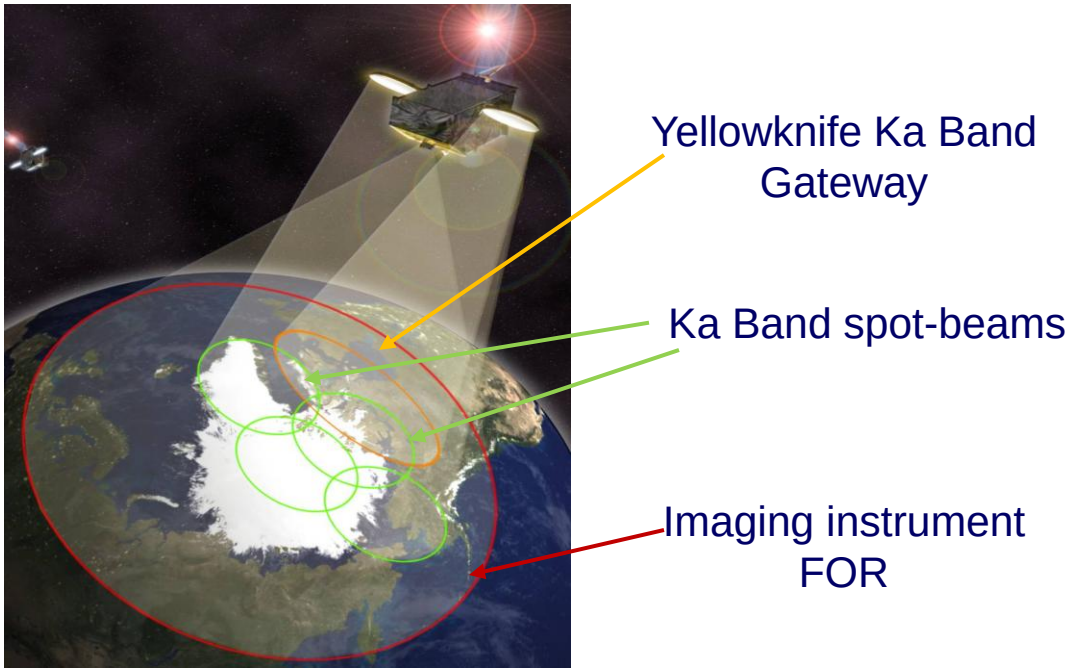
- A robust UK patent is in place
- The early experimental work was supported by in-house funding
- Some additional innovation funding has kept the project ticking over
- There is a need to raise MiniMags Technology Readiness Level to something that can be considered for flight demonstration: ≥TRL-6
- TRL-raising will involve a comprehensive experimental programme to design and develop MiniMags hardware, characterise shield parameters and spacecraft resource requirements, explore shield shaping and enhancement techniques; all backed by sophisticated simulations using the **dHybrid** code to confirm the results
- In the current climate UK government funding is not easily obtainable so there is an urgent need for external funding
- Most promising prospects for doing this (unless serious interest is shown in Europe) are joint developments with the Canadians and/or Americans

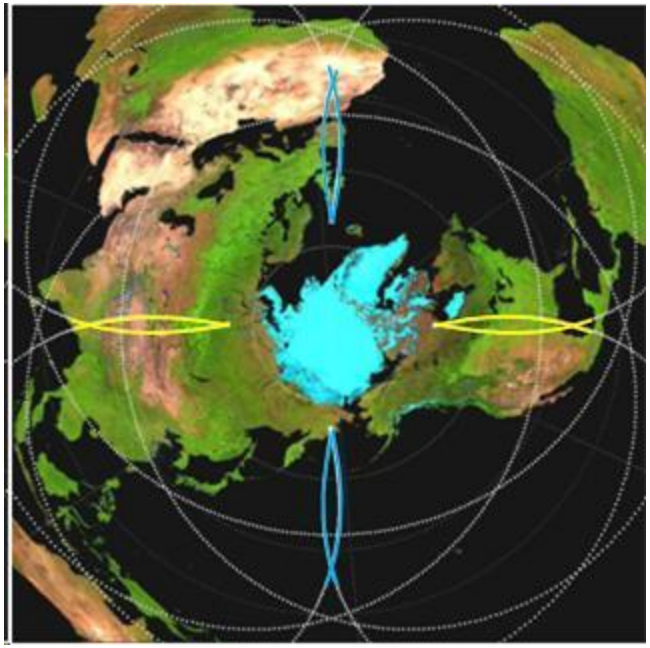
Development Opportunities

a) Canadian Space Agency

PCW – Polar Communications and Weather Satellite

- CSA, in partnership with several other Canadian govt agencies is committed to a 20-year comms/weather mission
- PCW will have 2 spacecraft in a 12-hour high-radiation Molniya orbit providing continuous coverage over the polar region





Development Opportunities

a) CSA - PCW (cont)

- CSA plan to achieve the 20-year life by replacing pairs of spacecraft whenever they deteriorate to the point that operations are compromised - estimating every 5-6 years
- Guess each spacecraft will cost >$250M, so would save >$500M if a pair of replacement spacecraft could be eliminated by extending their life with MiniMags shields
- Discussed with CSA possible UK participation in the PCW mission via the ‘Critical Technologies’ programme to take MiniMags from TRL-2/3 to TRL-6 in 36 months
- We will be working with a small Canadian company that has regular access to TRIUMF – Canada’s National Lab for Particle and Nuclear Physics with a 500MeV beamline

Development Opportunities

b) NASA

- MiniMags was presented to the NASA Associate Administrator, Chris Scolese, in Dec 2009
- He was very interested and requested a visit of the MiniMags team to NASA HQ and GSFC to meet a large gathering of solar physicists, space radiation experts and human spaceflight experts, which we did in March 2010
- We presented the theory behind MiniMags, discussed further development of the shield, and a possible demo mission
- Very well received – now looking for the right mechanism to fund MiniMags development work with NASA – probably via the new Office of the Chief Technologist, OCT
- JSC have offered access to the Brookhaven 100MeV beamline

Development Opportunities

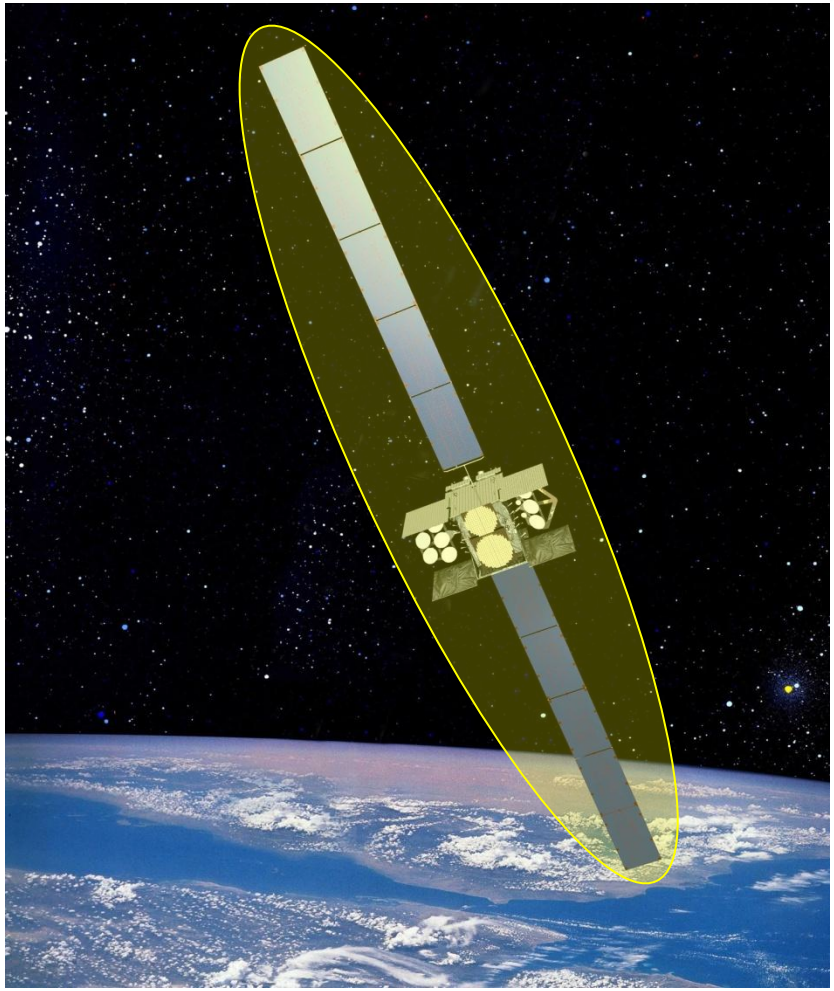
c) Lockheed

– MiniMags team met with Lockheed space radiation experts in March 2010 – they are particularly interested in the potential for MiniMags to protect com-sat solar arrays – a major cost driver

– RAL has started to look at a multi-pole magnetic architecture to create a 'picket fence' magnetic field structure to form a cigar-shaped MiniMags shield

– Much more RAL work needed on the magnetic field generation, power requirements, plasma enhancement and **dHybrid** simulation of the shield

– Lockheed will be looking at spacecraft system aspects such as power availability, attitude/pointing perturbations, and possible effects of strong magnetic fields on other spacecraft subsystems



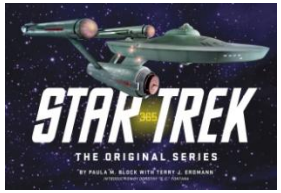
Development Opportunities

d) Other

Contacts have been made with a number of other organisations who have all expressed interest in MiniMags, although discussions are not as advanced as with our north-American colleagues. These organisations include:

- ESA
- Astrium
- CNES
- Roskosmos
- Boeing

Conclusions

- MiniMags is not a 

gimmick – it's real !!

- Wernher von Braun's original (impractical) idea for protecting astronauts with a magnetic shield has been revisited, reworked and rendered practical by ***RAL Space*** scientists, plasma physicists, theoreticians and engineers

- It works essentially because charge separation at the shield/ space plasma boundary induces very large electric fields that massively increase the effectiveness of the shield

- It can be used to protect com-sats, especially those in HEO, from damage caused by the Van Allen belts; and astronauts on missions outside the Earth's magnetosphere from high energy space radiation, particularly that caused by solar CMEs

- It is looking more likely than not that continued MiniMags shield development will proceed in north America rather than Europe…