Space Research Experiments with Bulk Superconductors

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HTS production
>1 ton precursors

powder, targets
(55%)
Y, Dy, Gd, Sm, BZO

sintered components
(5%)
high density, max. 92%

REBCO bulks (40%)
single, multi-seed,
melt textured

2nd generation CC
high in-field I_c
mech. strength
low AC loss

thin film

L~27 500 km !
4 mm; 1 µm

screening

HTS bulks

high Jc
trapped field B
mech. strength
robust
long term stab.

bulk devices

HTS bearings
mobile cryostats
motor elements

space application

Align of research strategy to those of industrial partners!

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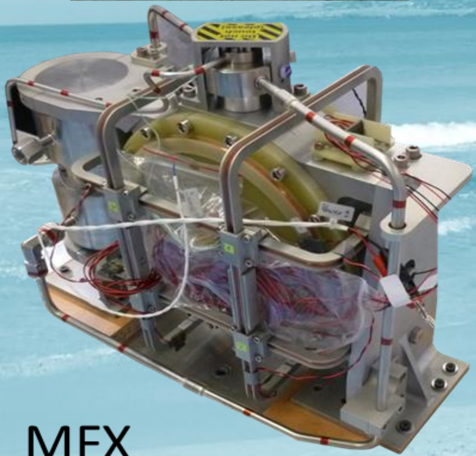
HTS bulk materials in space application

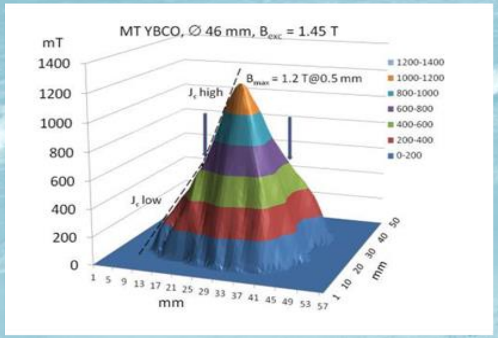
YBCO bulk

YBCO back

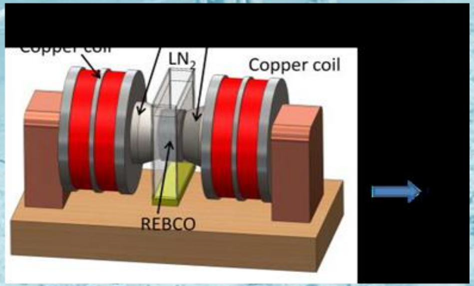
Comparison & analysis



MFX



Trapped field pattern



Magnetic excitation

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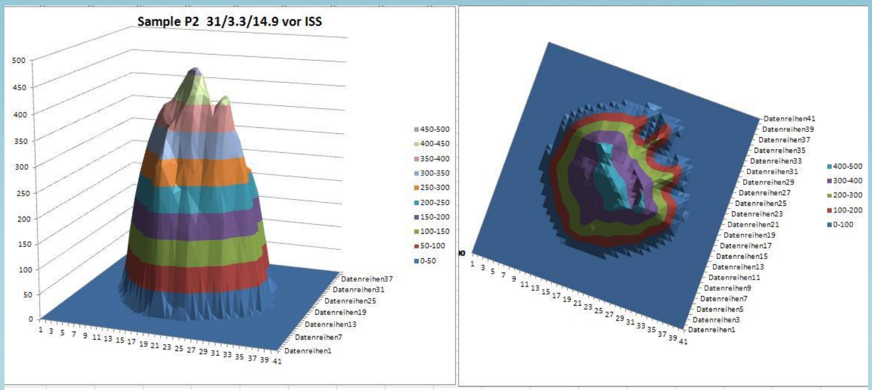
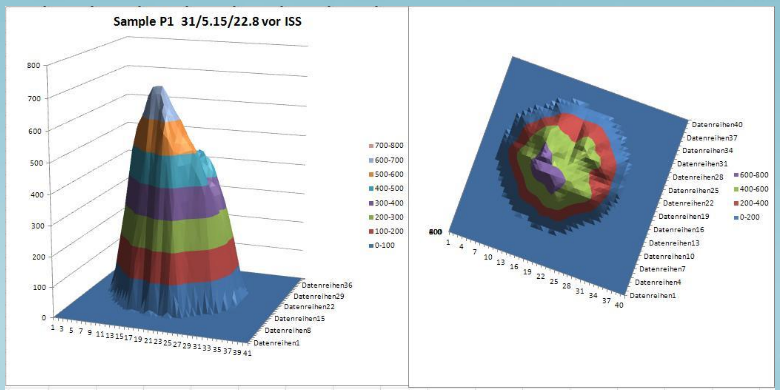
YBCO bulk scanning experiments

BEFORE

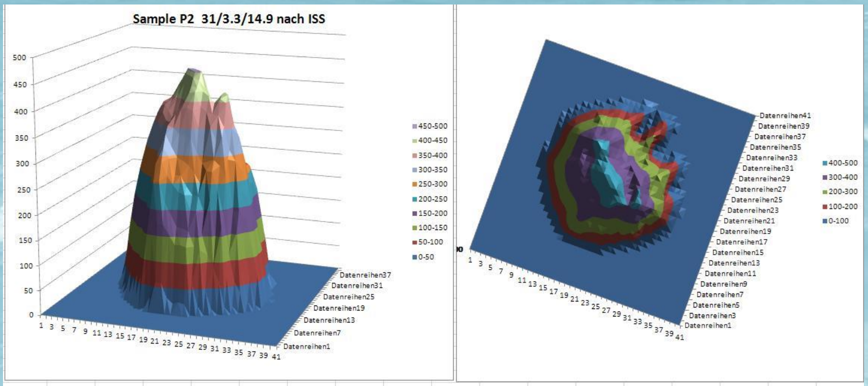


75,11 Mittelwert Av 75,11 462 Max Max 462

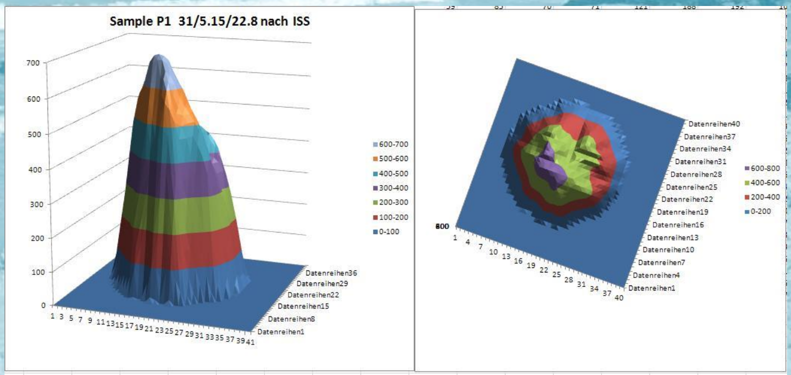


110,8 Mittelwert Av110.8 702 Max Max 702

AFTER



76,49 Mittelwert Av 76.49 453 Max Max 453



110,5 Mittelwert Av 110.5 693 Max Max 693

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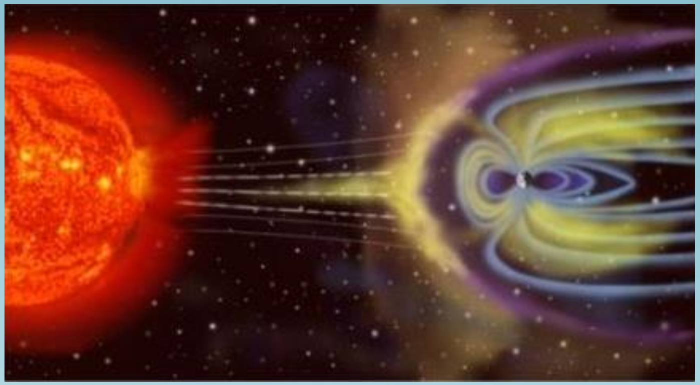
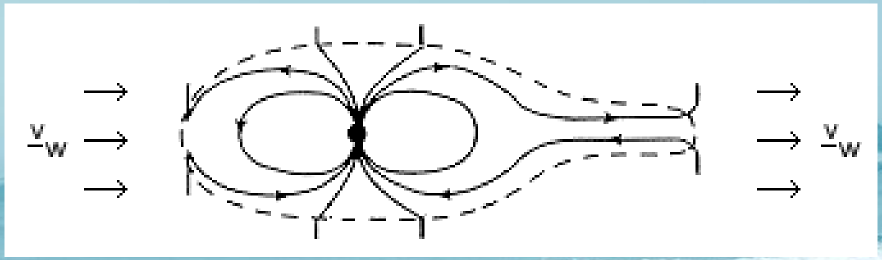
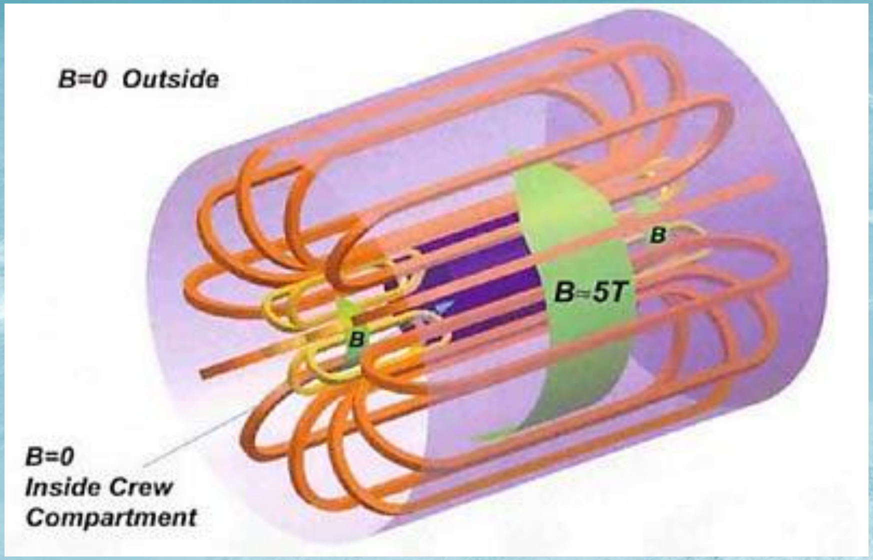
Earth Magnetosphere – screens the solar wind

The Earth's magnetic field shields the Earth's surface from the direct impact of the solar wind (or of a comet's poisonous tail).

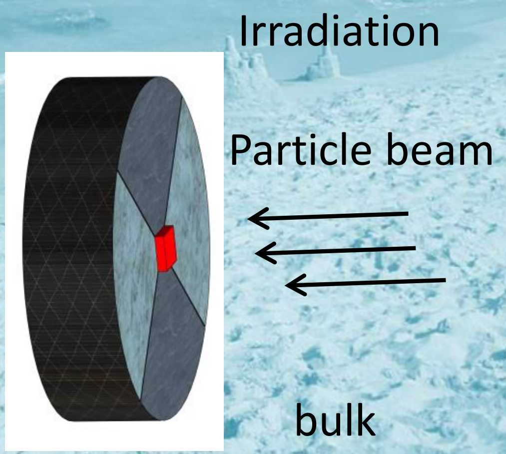






Ref. J. Hoffman, MIT 2005

Coil or bulk



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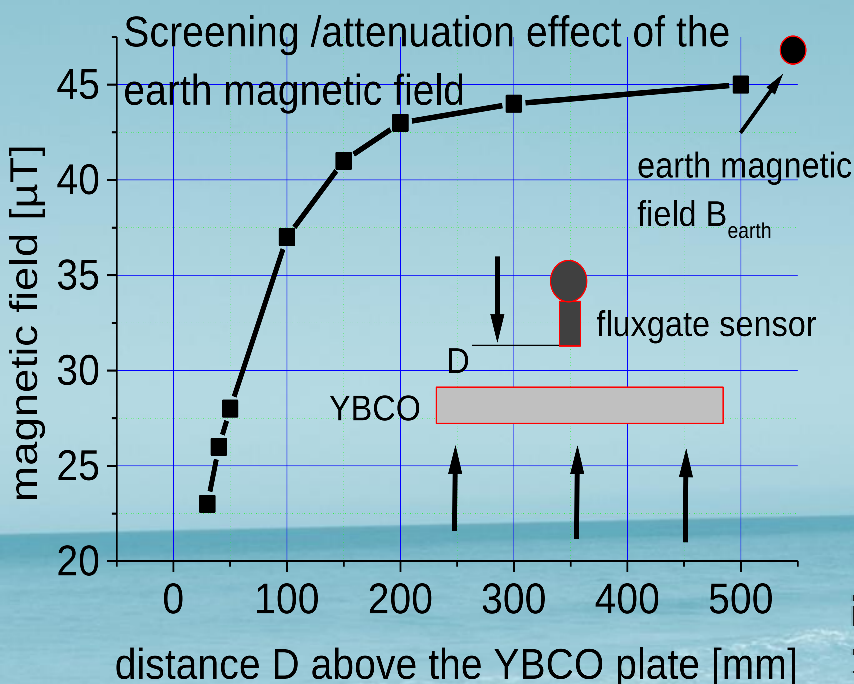
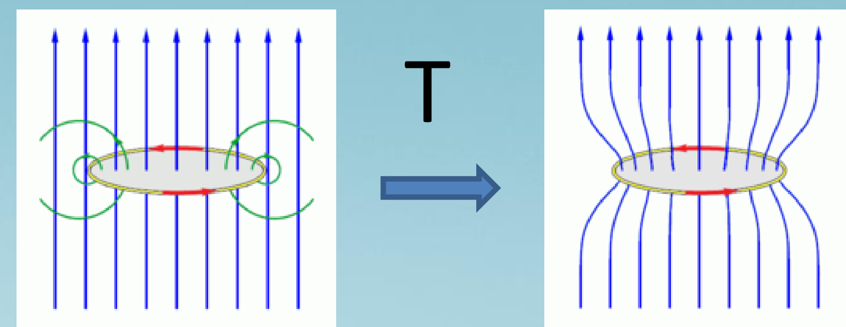
Earth magnetic field interacts with bulk HTS

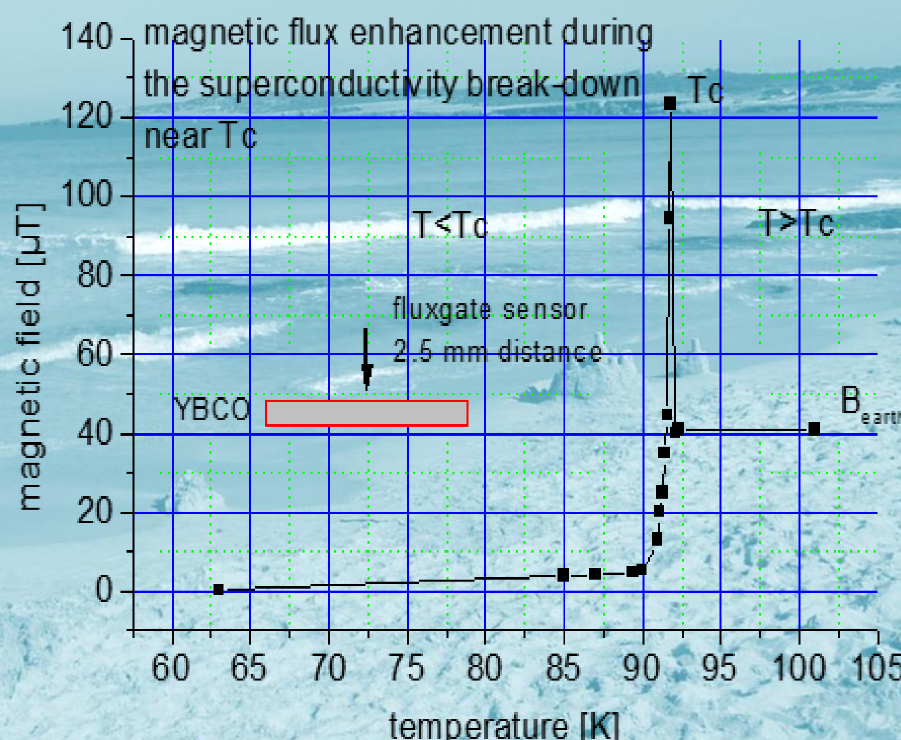


Shielding B_{earth} by bulk HTS

(D 270 mm x H 7 mm

Flux compression (transient)





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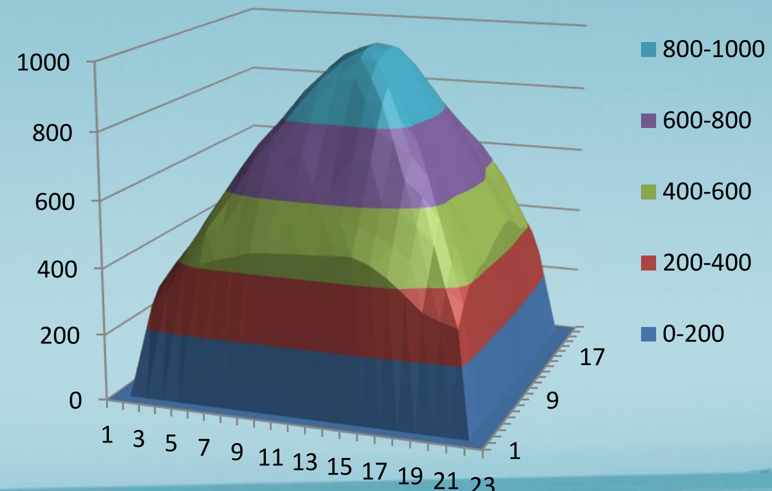
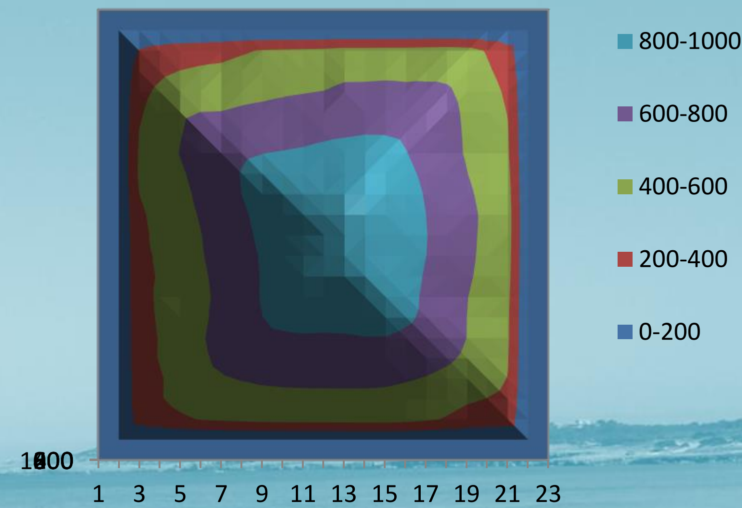
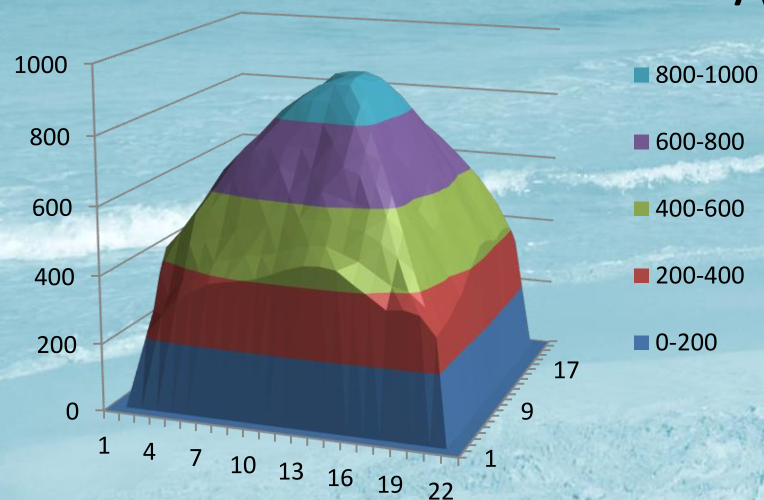
Proton irradiation tests (2x10 kRAD

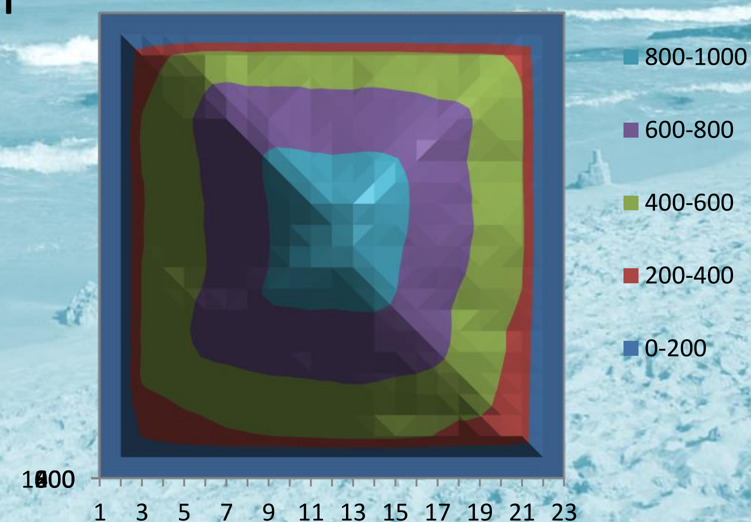
Before





After





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Hall probe scanning and proton irradiation of melt textured YBCO bulk

Sample YBCO	B av / B max	B av / B max	2. irrad. B av / Bmax	Change B av %	Change B max %
3-seed Z14-8	425 / 832 original	401 / 791 No irradiation	402 / 814 No irradiation	-5.6 %, -5.4 %	-4.9%, -2.2 %
3 - seed Z 14 - 2	444 / 903 original	427 / 841 10 kRAD Prot.	423 / 846 10 +10 kRAD	-3.8%, -4.7%	-6.8%, -6.3%

Relative change:	1. measurements	2. measurements
Proton beam tested samples:	ΔB_{max} = -6.75% (10 kRAD)	ΔB_{max} = -6.3% (10 + 10 kRAD)
	ΔB_{av} = -3.75% (10 kRAD)	ΔB_{av} = -4.7% (10 * 10 kRAD)
Untested samples; non-irrad.	ΔB_{max} = -4.80%	ΔB_{max} = -3.1%
	ΔB_{av} = -3.55%	ΔB_{av} = -5.5 %

Conclusion:

After 10 kRAD + 10 kRAD proton irradiation no changes in the trapped field measurements could be detected!

Hence, it is assumed that the performance of HTS bulk devices in space application due to proton impact shows no degradation in the critical current density and in the structure of the magnetic domains.

Space application: MAGVECTOR
Interaction between Earth magnetic field and variable (super)conductor

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Protection Shielding

Radiation has long been recognized as one of the most serious health probelems facing astronauts exploring space beyond the Earth‘s magnetic shield.

The Mars rover Curiosity mission has allowed to calculate the averaged radiation to 1.84 mS/day which is for a 180-day journey an exposure of more than 8 times higher than the radiation limit for a worker in a nuclear power plant in the same time.

Protection a cylindrical habitable volume **2.5 m diameter, 3.5 m length** with enough aluminium to absorb protons with kinetic energies less than Eg is given by

$$M(kg) = E_k(MeV)^{1.67}$$

To stop protons with energies less than 1.2 GeV **requires 139 tons** of shielding material.

The mass of magnetic systems would be **one or two orders of magnitude** less than the mass of an equivalent aluminum shield.

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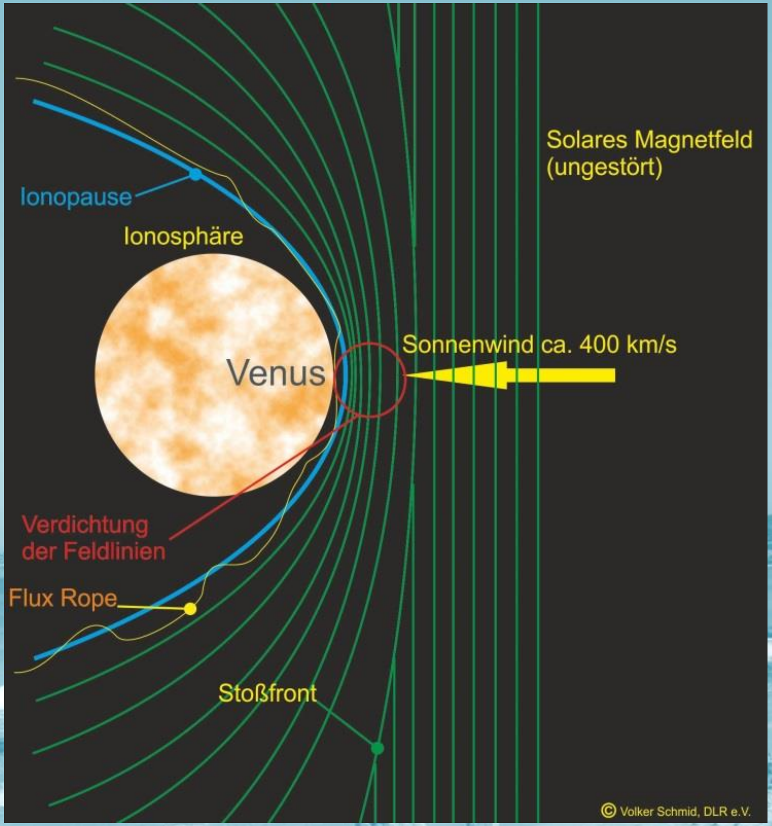
MFX (Magnetic Field Experiment); funded by DLR e.V. and BMFT

Moving electrical conductor and sensors through Earth‘s magnetic field
Measurement of the field conditions of the ram
and wake side of the conductor.
ISS is a perfect lab for this measurement
Set up and initial operation phase by
ESA astronaut Alexander Gerst
Intention to continue scientific campaign until 2016



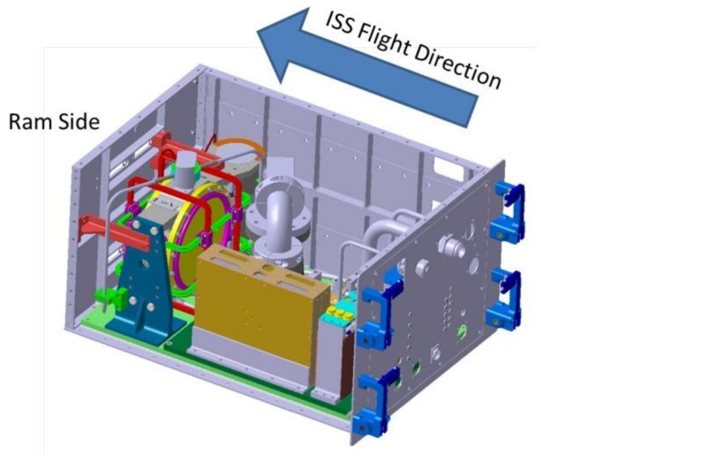
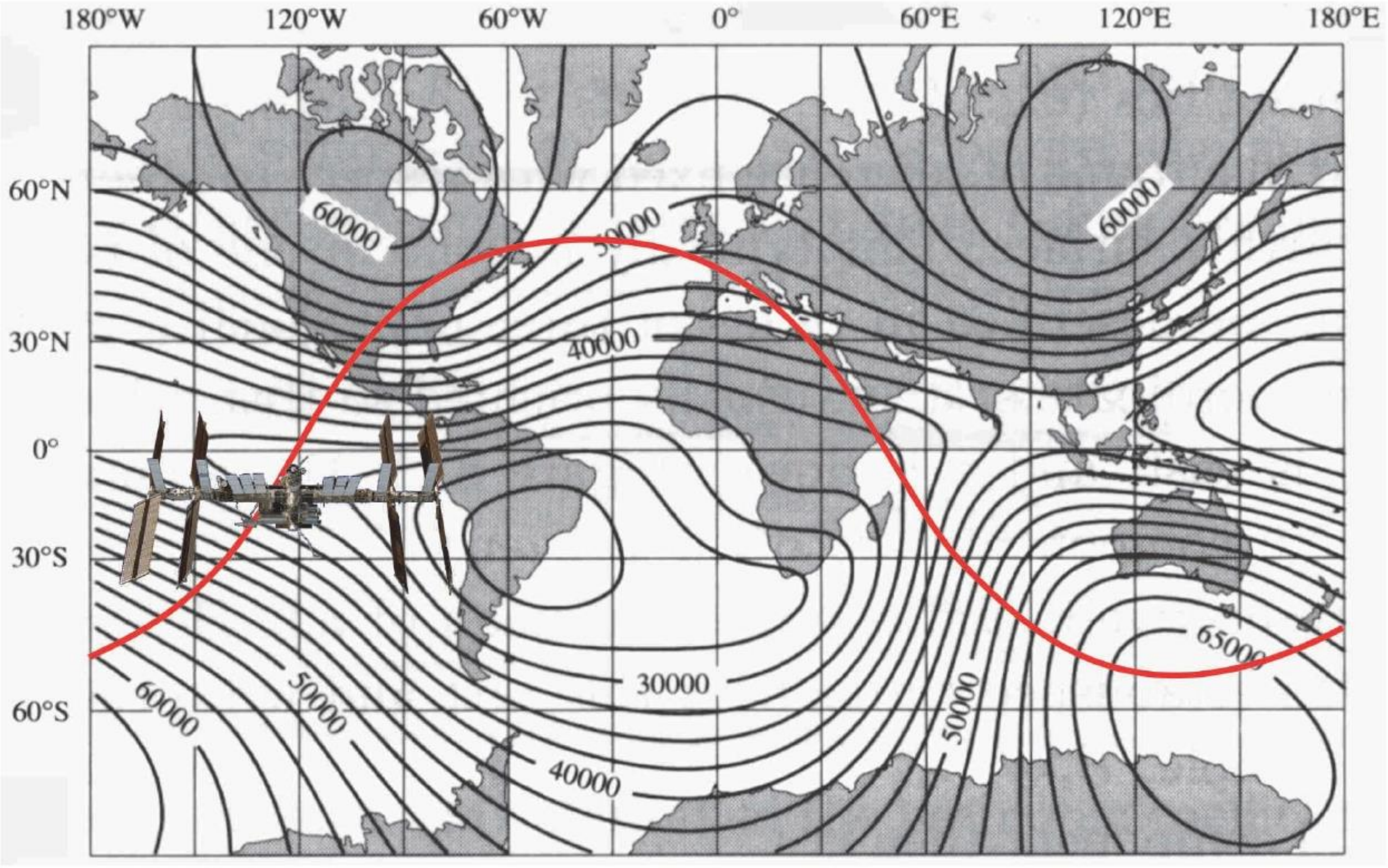


Figure 3: MFX Accommodation concept inside ISIS Drawer

Gefördert vom BMWi



180°W
120°W
60°W
0°
60°E
120°E
180°E
60°N
30°N
0°
30°S
60°S
60000
30000
40000
60000
65000
30000
50000
60000
50000
40000

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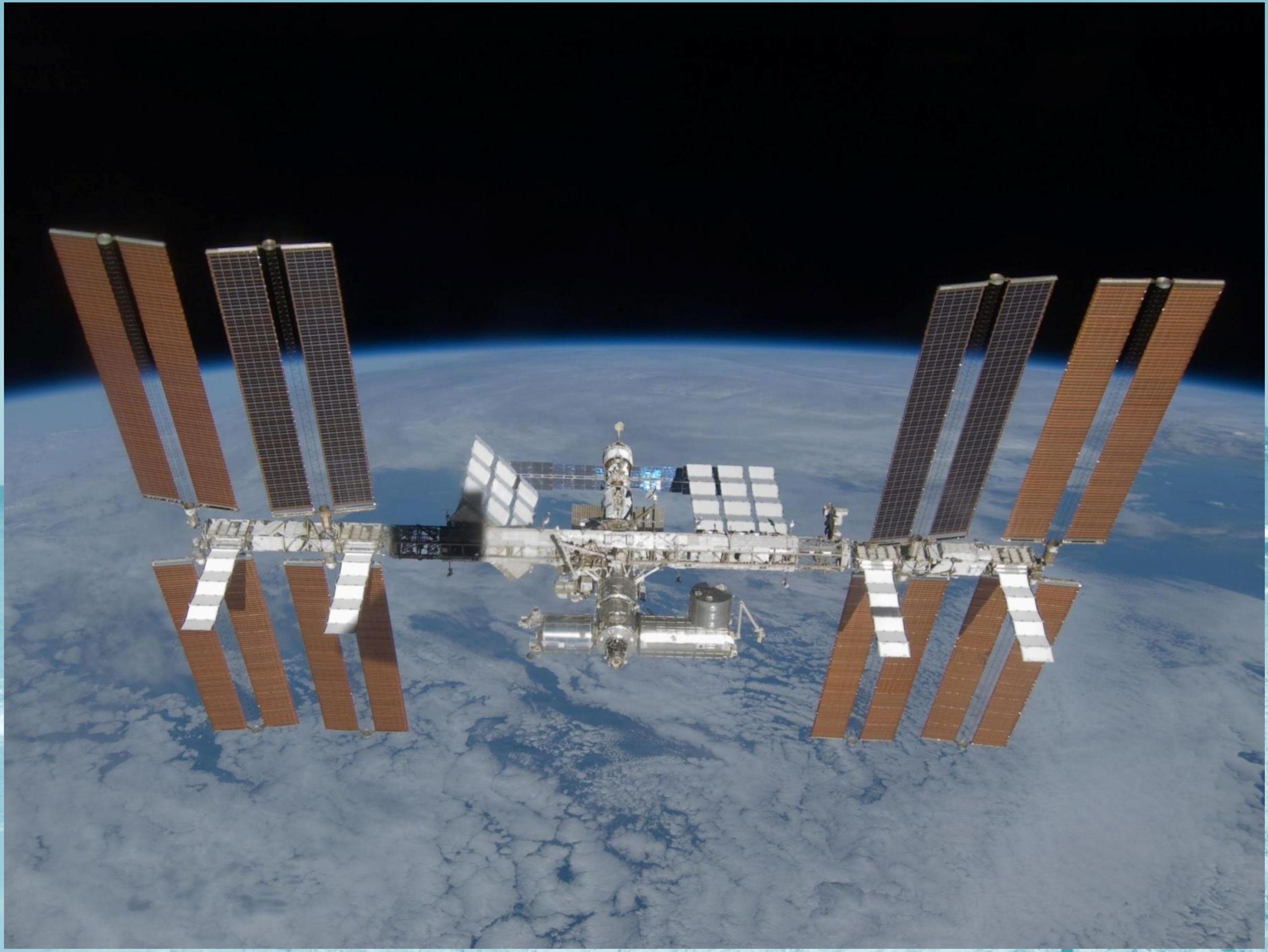
International Space Station (ISS)



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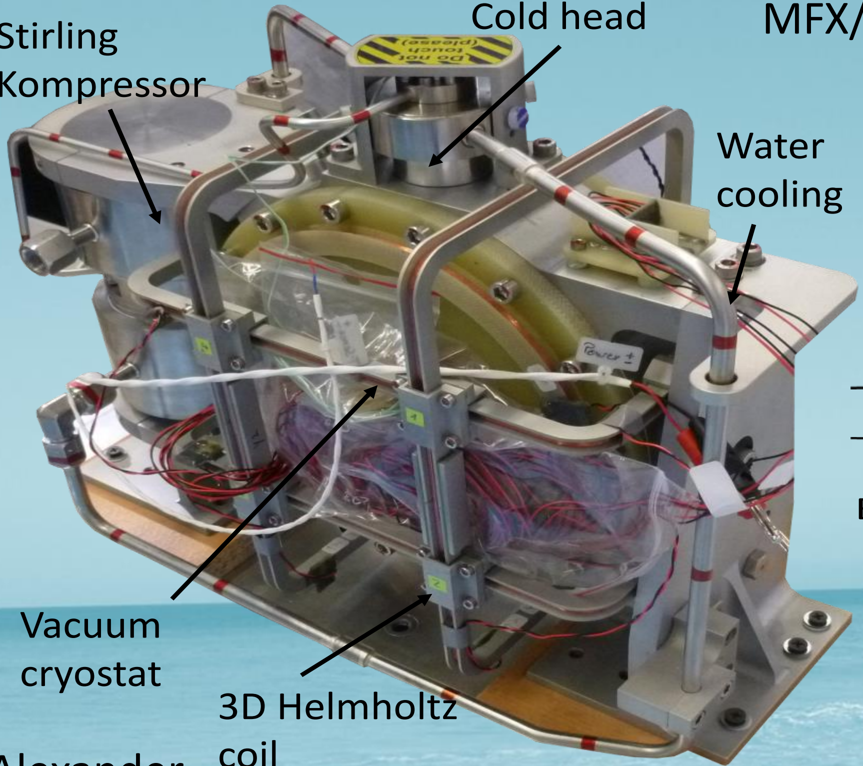
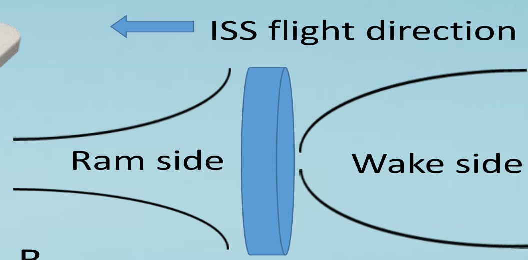
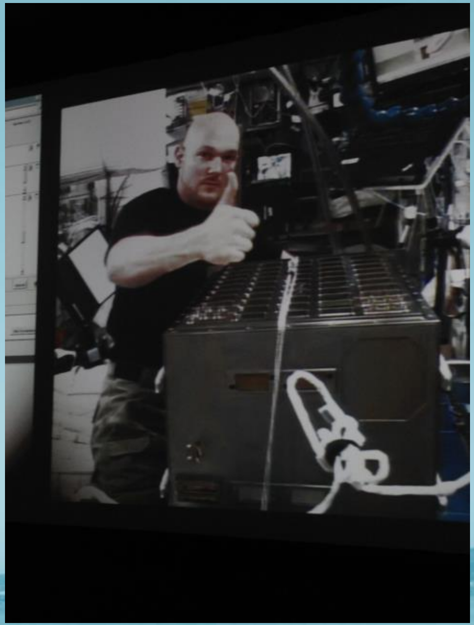
MFX/ MagVector Experiment



MFX/ MagVector cryostat





Installation ISS

Alexander Gerst

ISIS Drawer, ~ 75 kg

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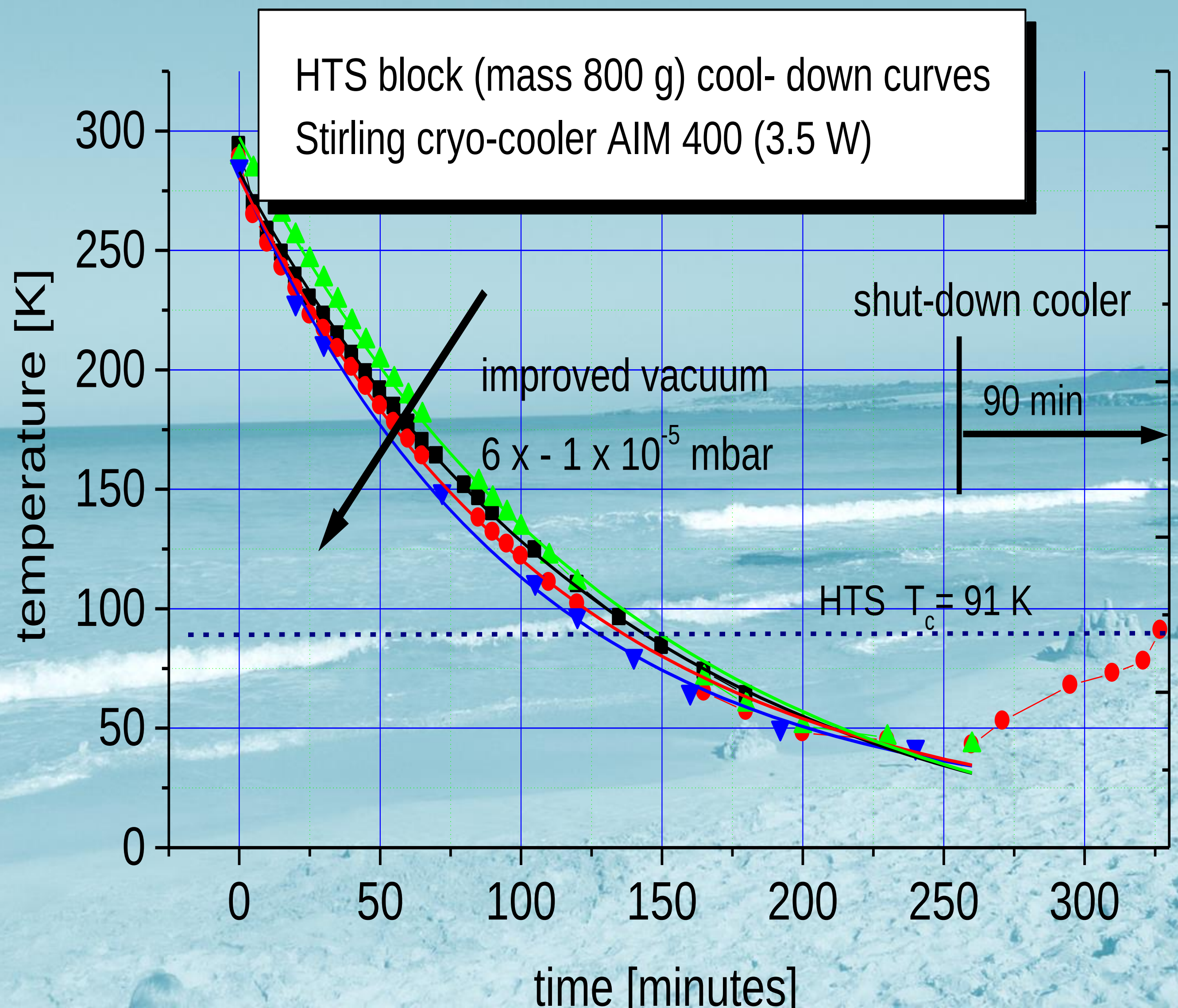
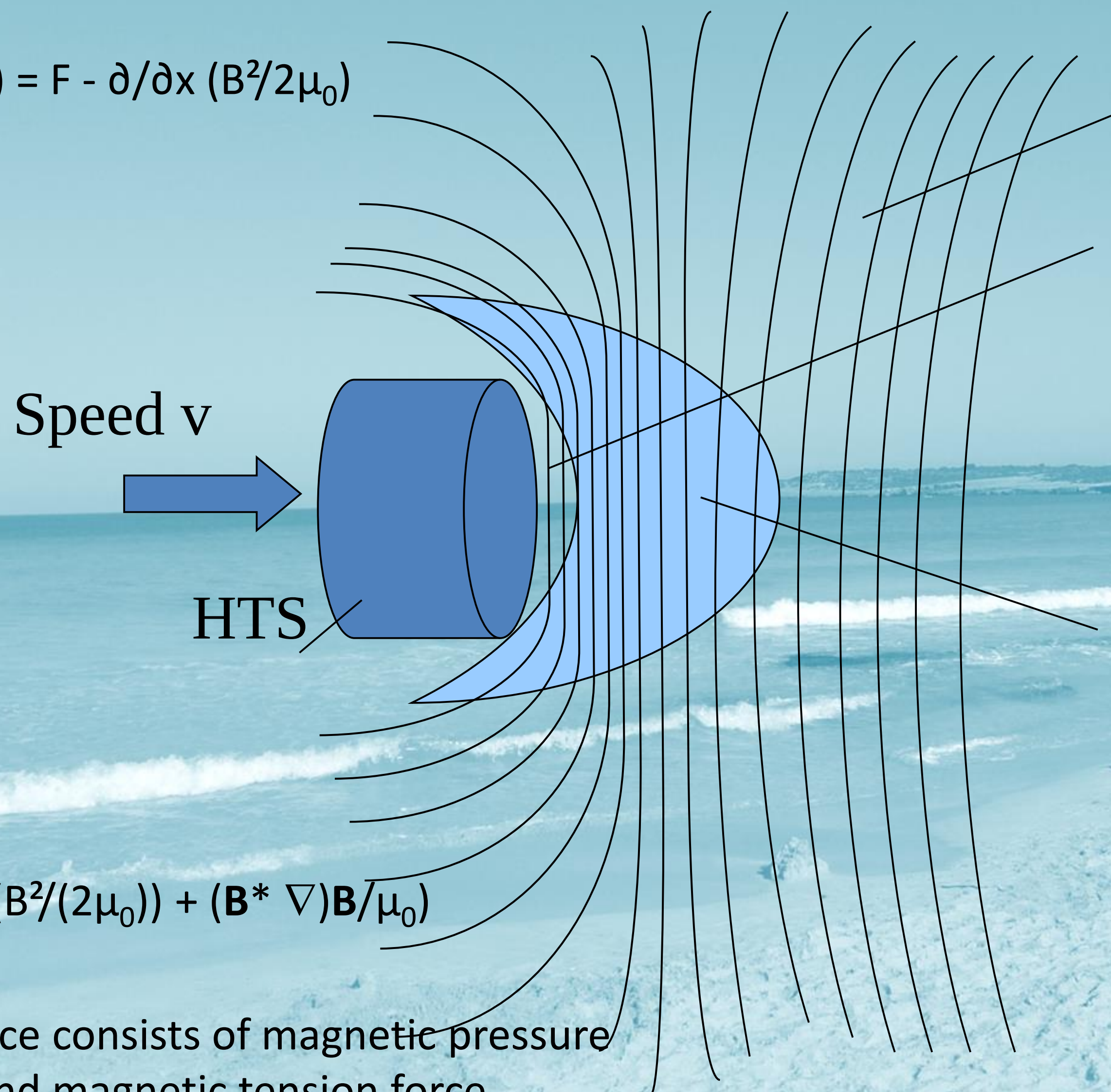
Cooling –down MFX



MHD / Magnetic pressure consideration: Re- entry magnetic heat shield

$\partial/\partial t\ (v x\ \rho) = F - \partial/\partial x\ (B^2/2\mu_0)$



$\mathbf{J} \times \mathbf{B} = -\nabla (B^2/(2\mu_0)) + (\mathbf{B}^* \nabla)\mathbf{B}/\mu_0)$

Lorentz force consists of magnetic pressure force and magnetic tension force.

Superconductors can shrink the size and weight of the magnet considerably ,
and possibly provide extremely large focusing fields

Conclusion

- Bulk high-Tc superconductor is becoming a prominent material in space application
- Magnetic shielding and thermal induced flux compression capability is demonstrated
- 20 kRAD proton bombardment on YBCO bulk in a cyclotron revealed no significant changes.
- MFX/MAGVECTOR experiment at the ISS since 2014 give insides into ways how magnetic fields influence electrical conductors
- MFX will continue with new mission „Horizons“ in 2018

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