Artificial Solar Wind for Space Material Developments

DLR Institute of Space Systems
Mechanics and Thermal Systems, Material Ageing Group

Patric Seefeldt, patric.seefeldt@dlr.de

Maciej Sznajder

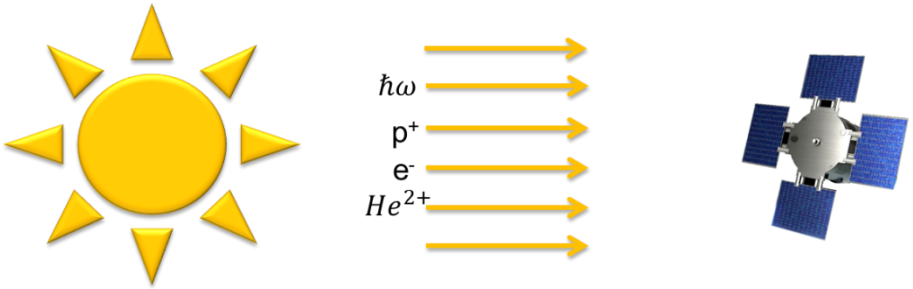
Thomas Renger

Peter Spietz

Andreas Witzke

Introduction

- Spacecraft operate in a unique radiation environment that is very different to the environment on earth.



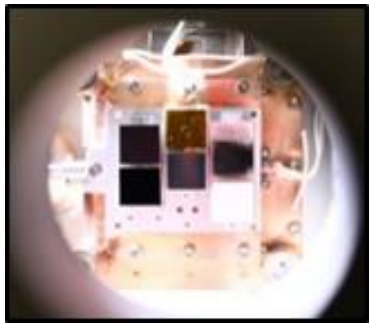
- Electromagnetic radiation (full spectrum not shielded by atmosphere)
  - Solar Constant $S_0 = 1361\mathrm{W/m^2}$

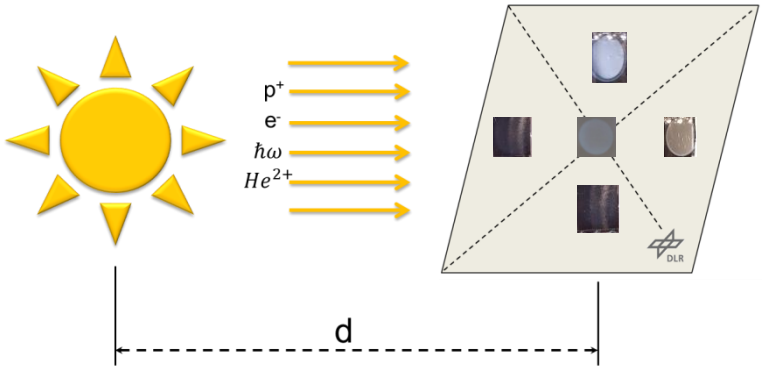
- Solar wind
  - Mainly protons, electrons and Helium ions (alpha particles)
  - Most particles have energies up to 10keV
  - Particle energies can also be several MeV

- Complex Irradiation Facility (CIF)
  - Study materials under space environment conditions

Content

- Complex Irradiation Facility (CIF)
  - ➢ Test conditions
  - ➢ Electromagnetic sources
  - ➢ Corpuscular radiation sources
- Test activities
- Exemplary Study
  - ➢ Solar Sail propulsion limitation due to hydrogen blistering



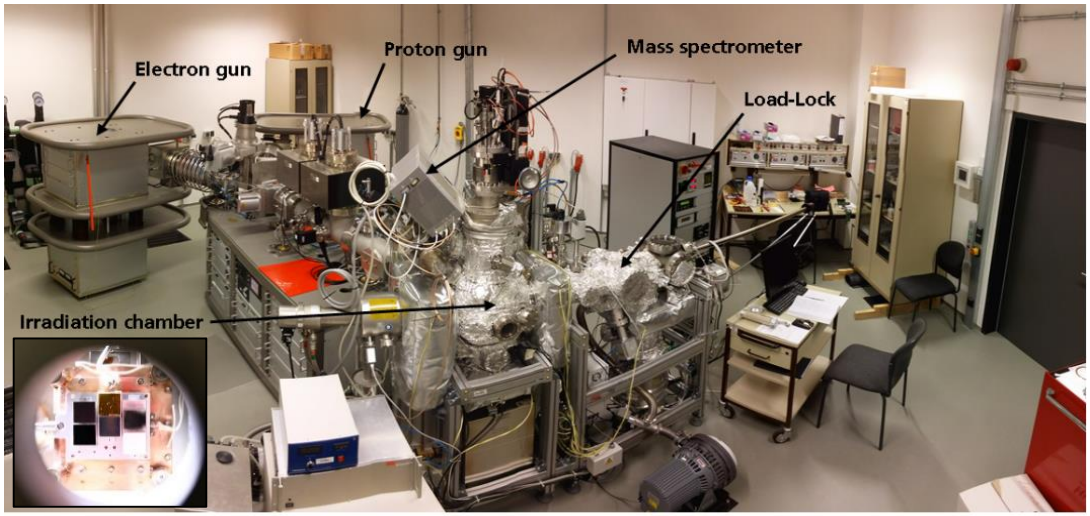


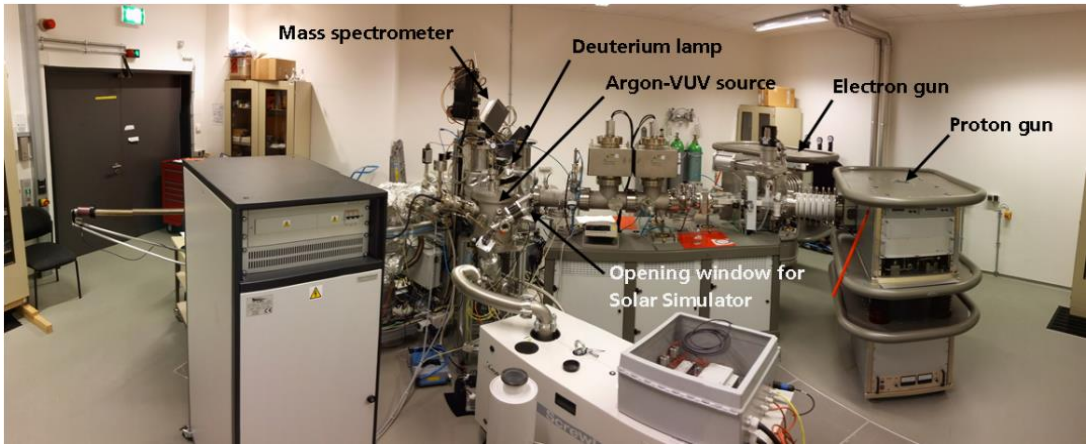
Complex Irradiation Facility

- **A solar wind and radiation simulator**

Material samples exposed to electromagnetic and corpuscular radiation:

- Irradiated area: 80mm diameter
- Vacuum:
  - < 10^{-8} mbar without VUV-source
  - < 10^{-6} mbar with VUV-source
- Temperature control
  - Heating with halogen lamps up to 450°C
  - Cooling with thermostat -30°C
  - Cooling with LN2 -170°C

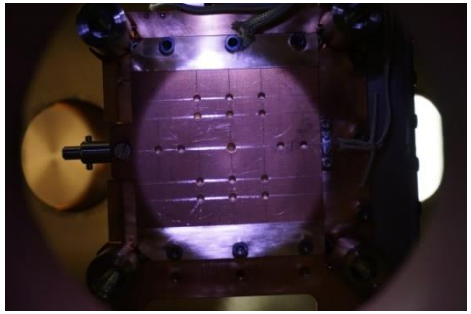




Electromagnetic Sources

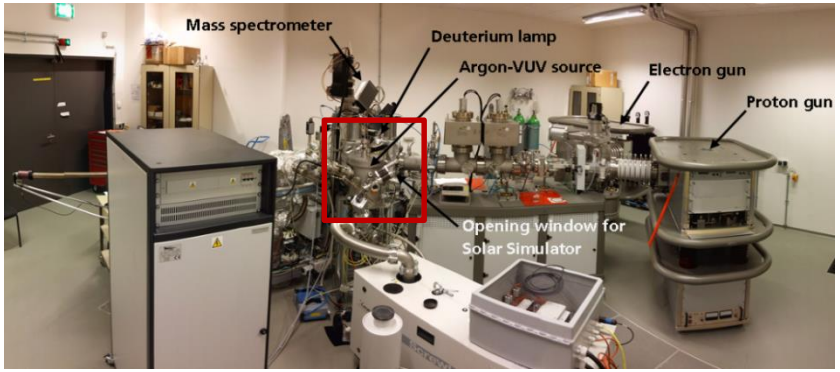
- Argon VUV-source
  - 40 nm – 410 nm

- Deuterium UV-source
  - 112 nm – 410 nm

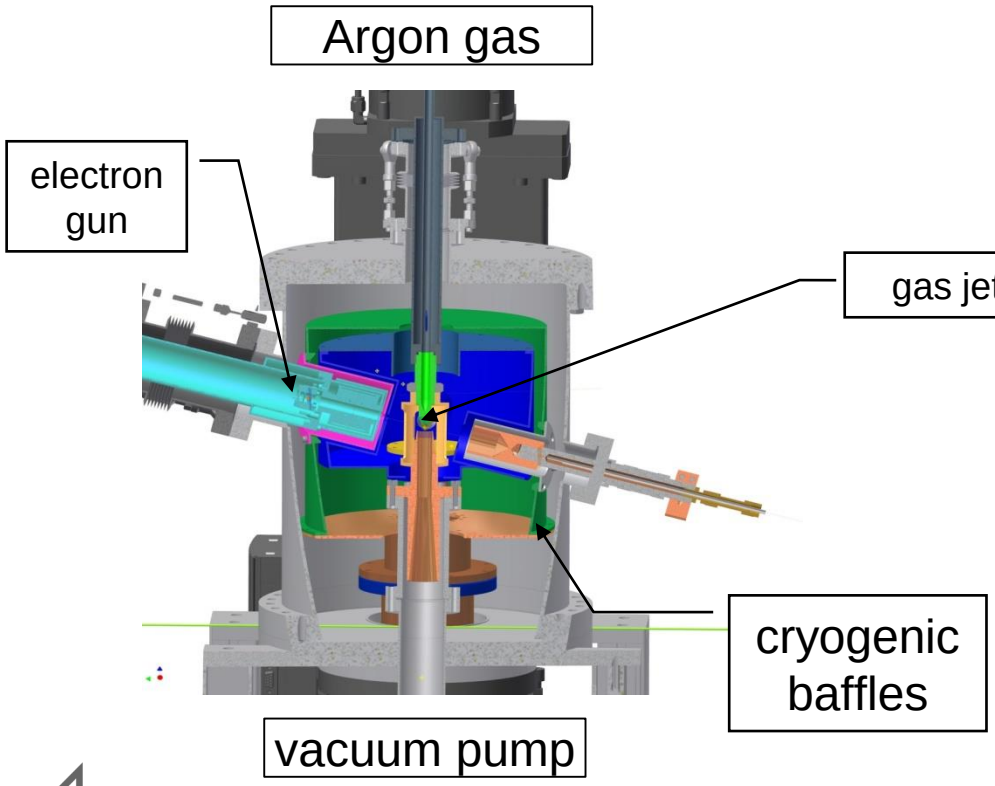


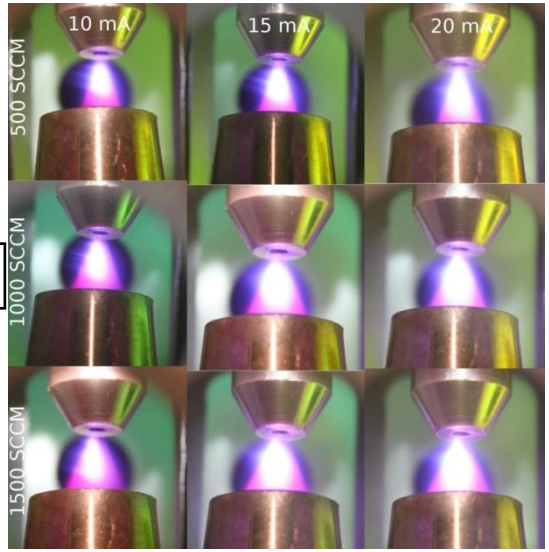
- Xenon-lamp
  - 250 nm – 2150 nm

Argon gas jet VUV-source



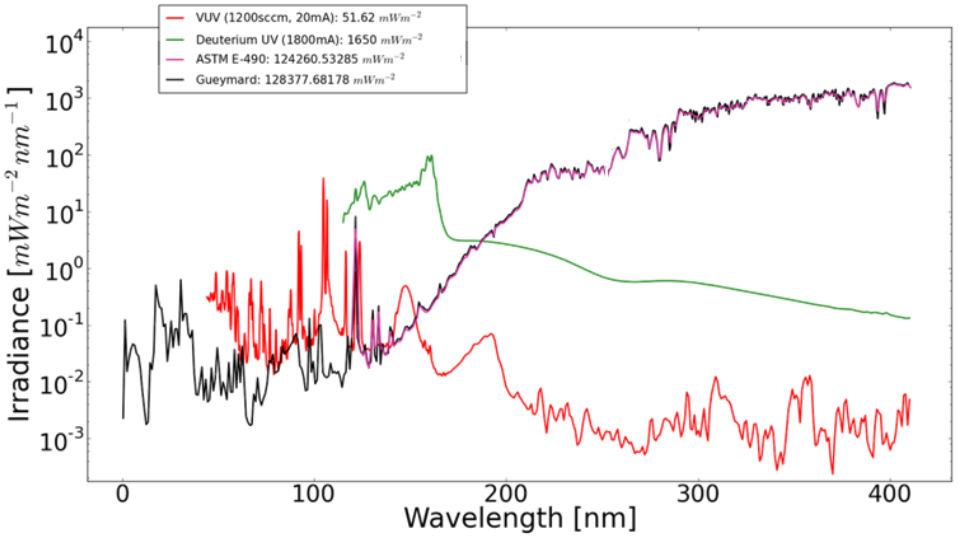
- Argon gas is excited by electrons
- When electrons fall back to ground level photons between 40 nm – 410 nm are emitted
- Max. acceleration factor 26.32

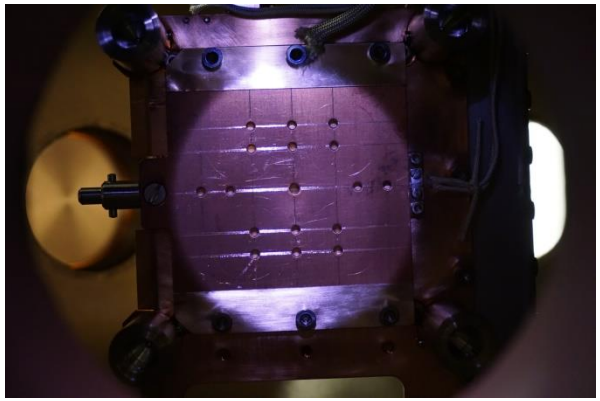




Deuterium UV-source

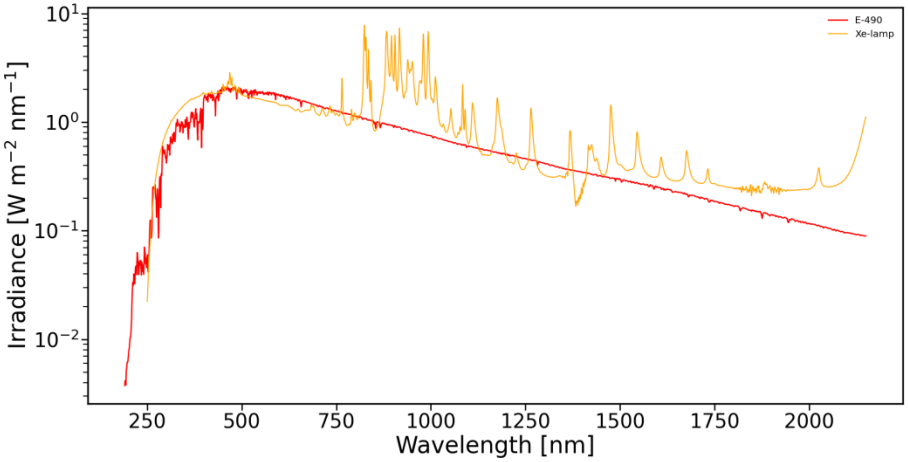
- Hamamatsu L1835 gas discharge lamp
- 112 nm – 410 nm
- Max. acceleration factor 16.8



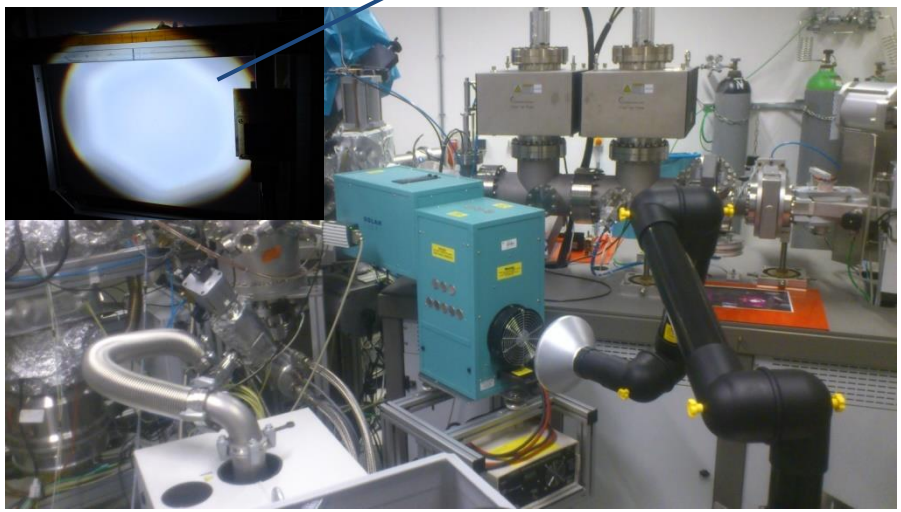


Solar Simulator (1600W Xe-lamp)

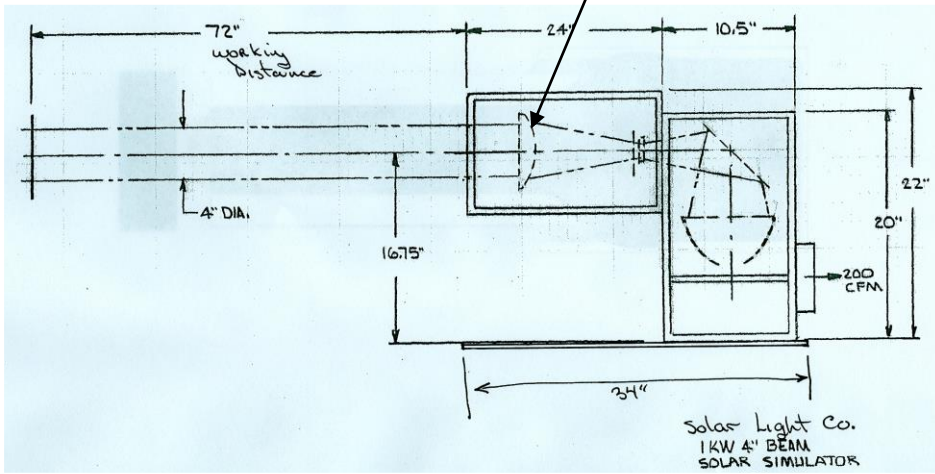
- Intensity output depends strongly on lenses settings
  - ➢ Spot size
  - ➢ Homogeneity



inner 10cm spot 4.6% dev. from mean value (1897.5W/m^2), acceleration factor 1.39

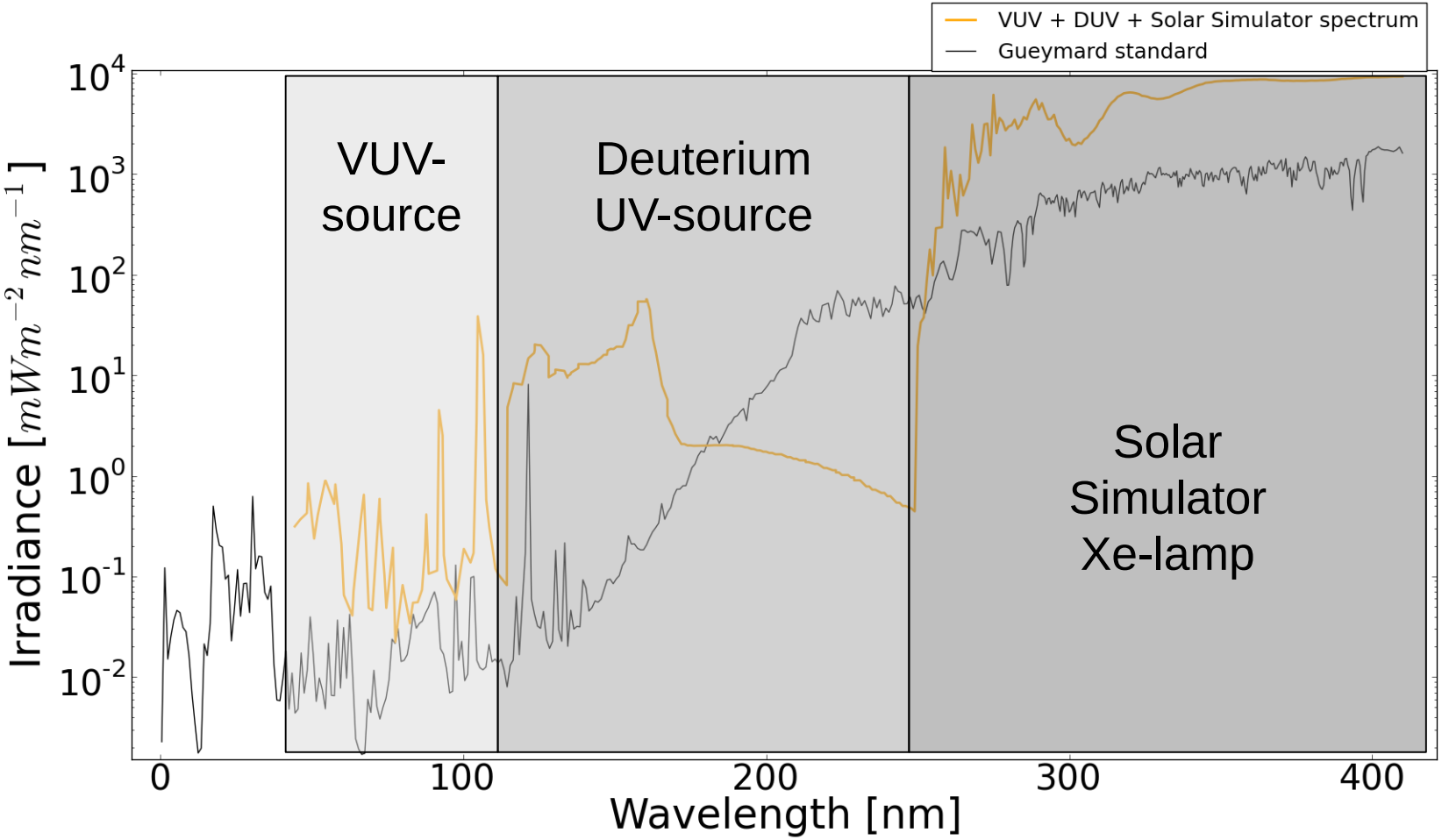


lenses



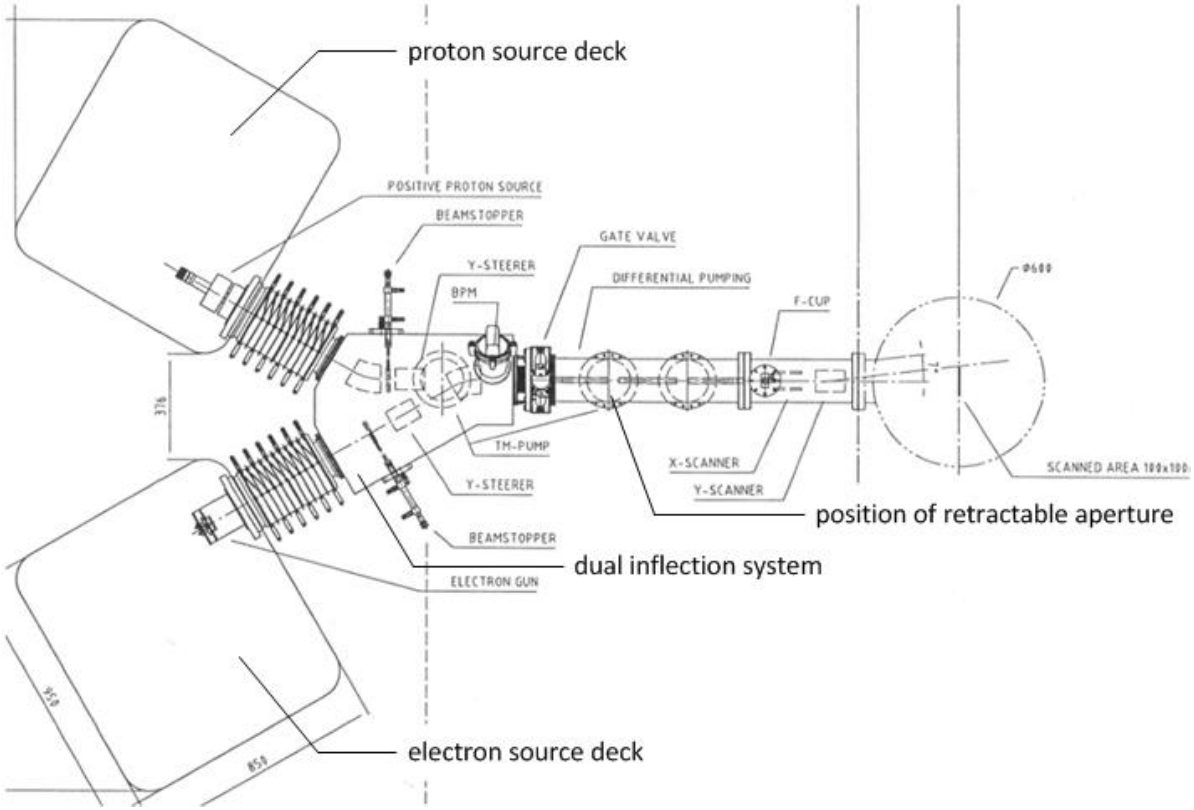
CIF Spectrum in comparison to sun spectrum

- Example for one setting, spectra are measured with grating spectrometer for certain test setups



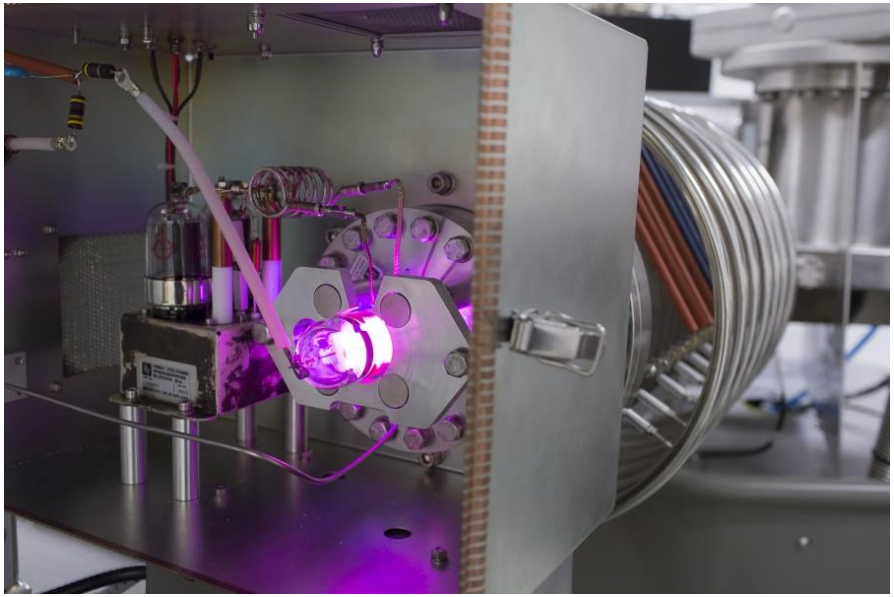
Proton and electron accelerators

- Lanthanum boride cathode as electron source combined with linear accelerator (2keV..100kev)
- Hydrogen ionization with high frequency oscillator as proton source combined with linear accelerator (2keV..100kev)



Proton source

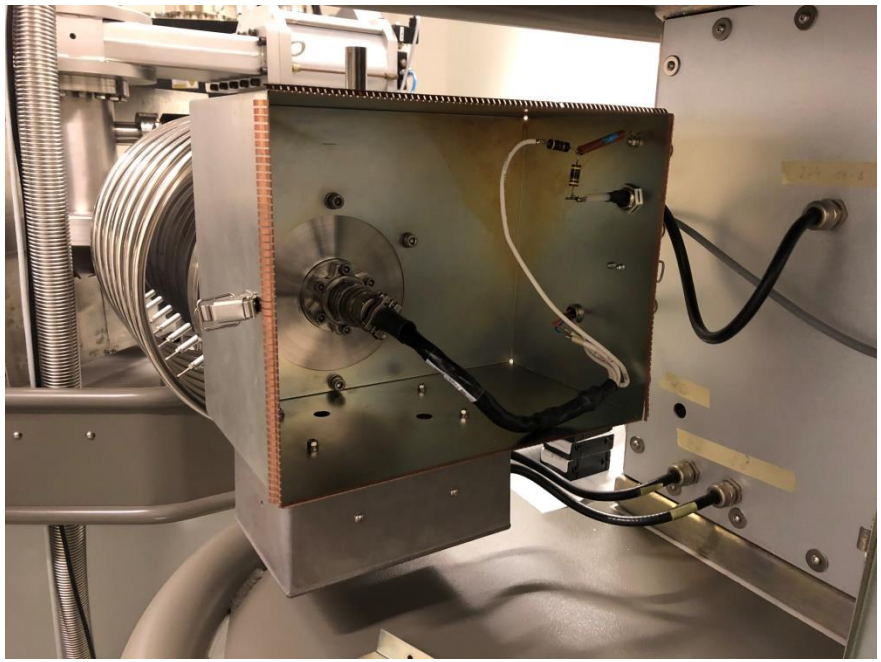
- Hydrogen ionization with high frequency oscillator as proton source combined with linear accelerator generate a beam of protons



CIF	energy	current
p+	2 to 10keV	1 to 100 nA
	10 to 100keV	0.1 to 100 µA

Electron source

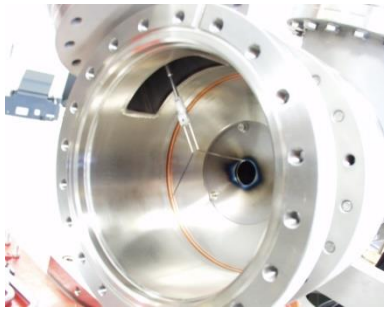
- Lanthanum boride cathode as electron source combined with linear accelerator generates 2keV to 100kev electrons

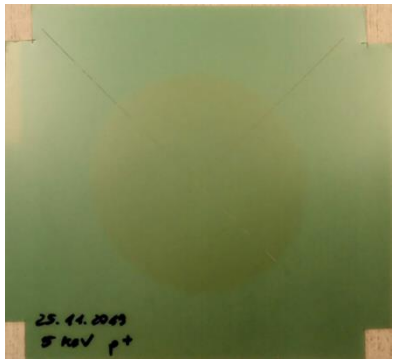


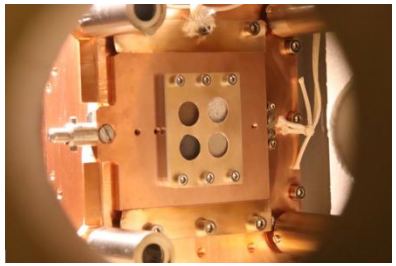
CIF	energy	current
e-	2 to 10keV	1 to 100 nA
	10 to 100keV	0.1 to 100 µA

Beam monitoring and calibration

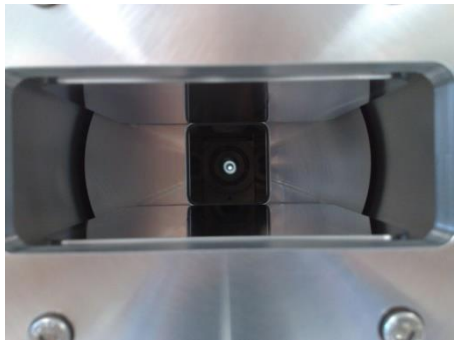
- Beam profile monitor → shape of the beam cross section (real time)
- X-ray film → radiated area at the sample station after radiation
- Faraday Cup at the test chamber entrance → total current of the beam
  - ➢ Total current and radiated area allow calculation of flux
- Test specific Faraday Cup setups at the sample station if required

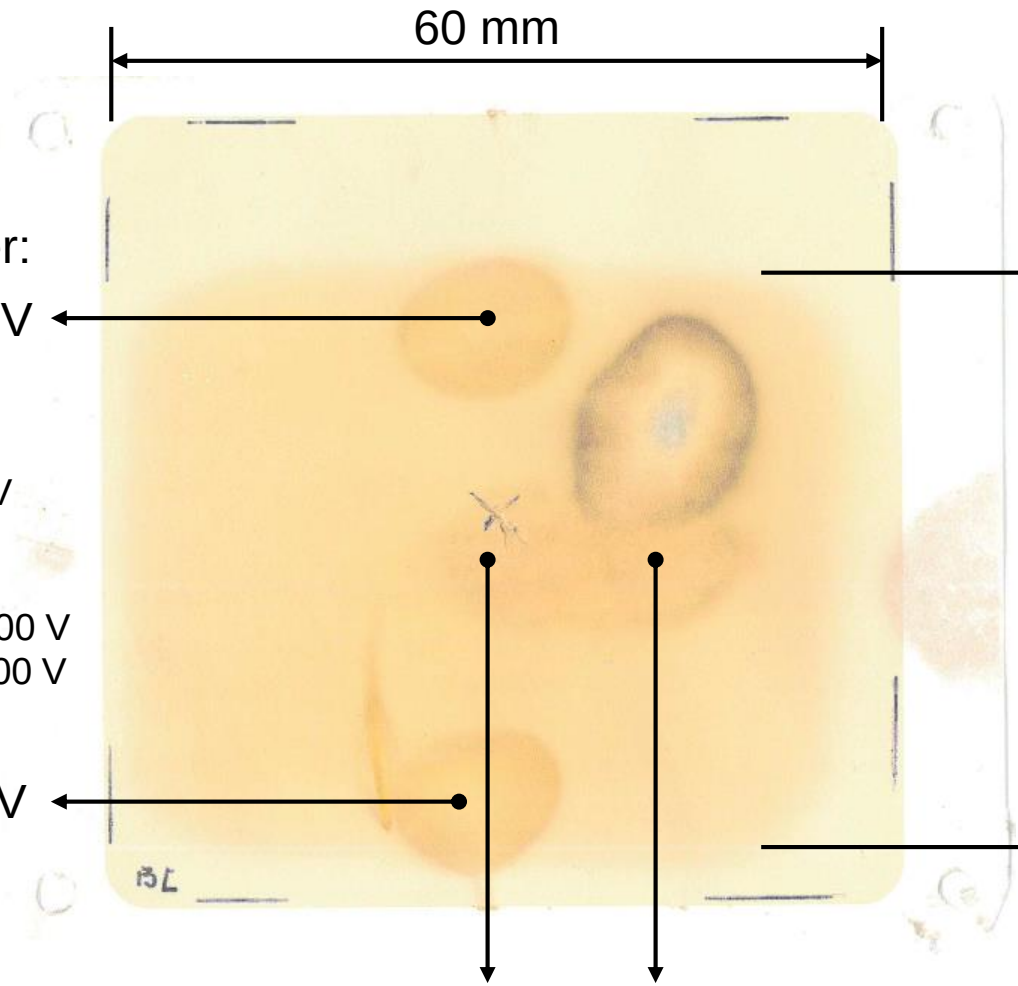






Proton beam sweep (100 keV; 43.8 µA)





Material Analysis

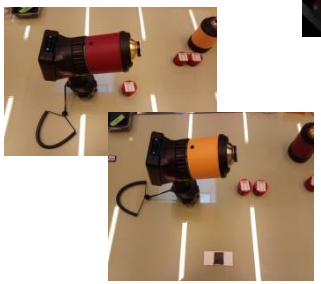
Confocal microscope (Keyence VHX 7000)

Optical Spectroscopy

- Bruker 80v FTIR spectrometer
  - e.g. for thermo-optical properties
  - 250-2500nm (α), 3-25µm (ε)

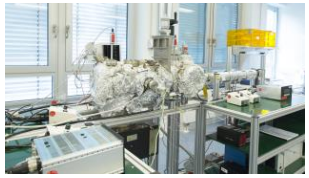
- SPECTRO 320 grating spectrometer
  - e.g. for electromagnetic source specification

- Handheld reflectometer (410 Solar) and emissometer (ET-100)
  - e.g. quick reflectance measurements (multiple samples, in-between experiments)
  - 330 – 2500 nm, 1.5 – 21 µm



Mass spectrometry (HiQuad)

- Inside CIF for direct in-situ analysis
- UHV outgassing analysis for space components



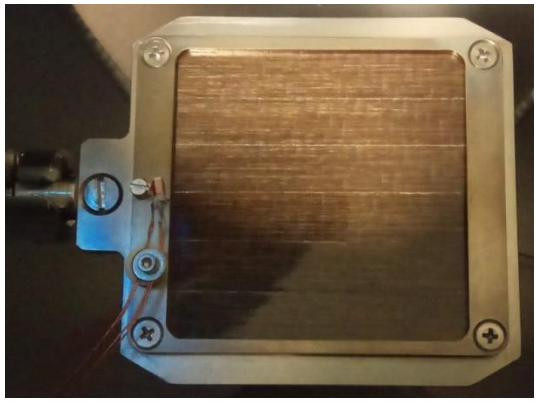
Material outgassing

- ESA certified ECSS-Q-ST-70-02C outgassing tests

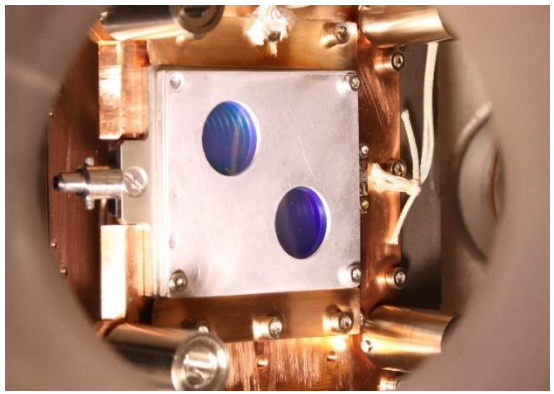
DLR

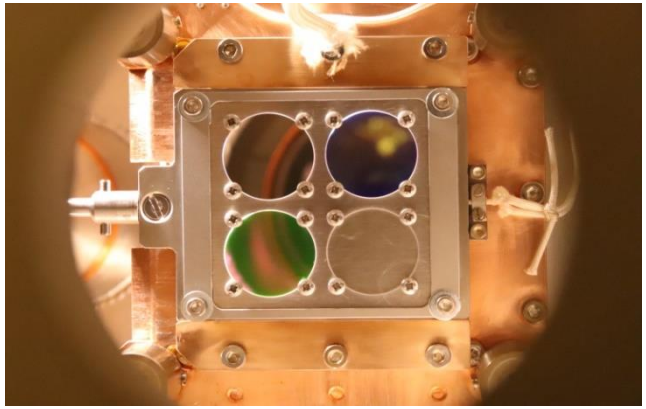
Test activities at DLR-Bremen

- Fiber Reinforced Polymer exposed to VUV/UV light of 5800 ESH



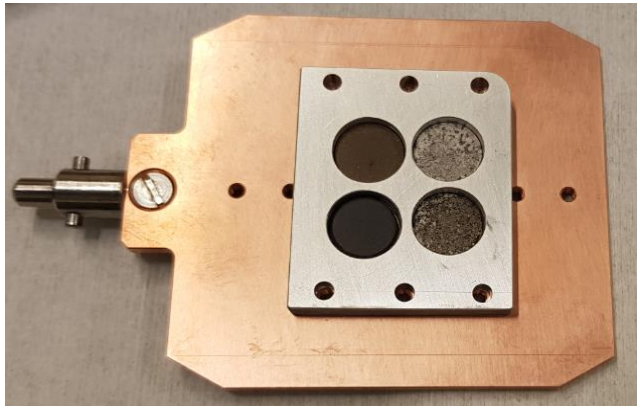
- Glass substrates coated and exposed to corpuscular radiation



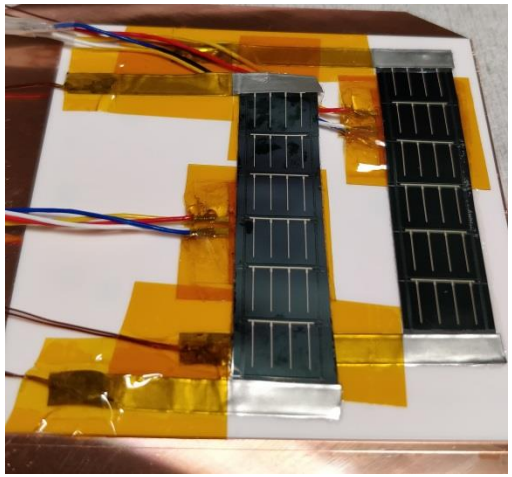


Test activities at DLR-Bremen

- Regolith material representing asteroid surface exposed to low energy protons

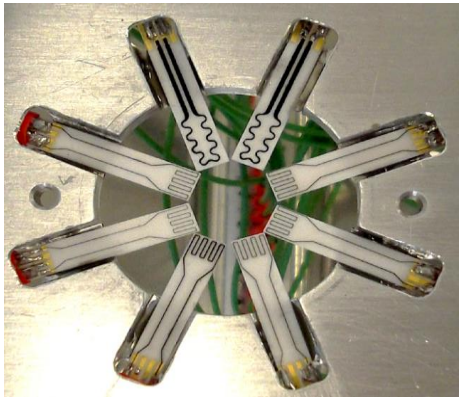


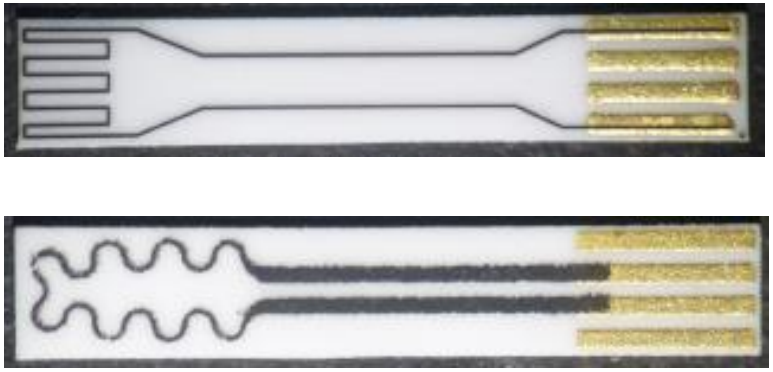
- Thin film CIGS PV modules exposed to UV-VIS-NIR electromagnetic radiation of AM0 standard under UHV conditions



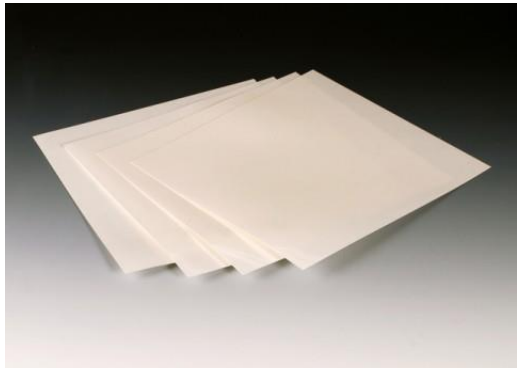
Test activities at DLR-Bremen

- Radiation sensors based on single- and multi-wall carbon nanotubes exposed to VUV-UV-VIS-NIR electromagnetic radiation





- Al2O3 ceramic exposed to 0.1 MeV electrons

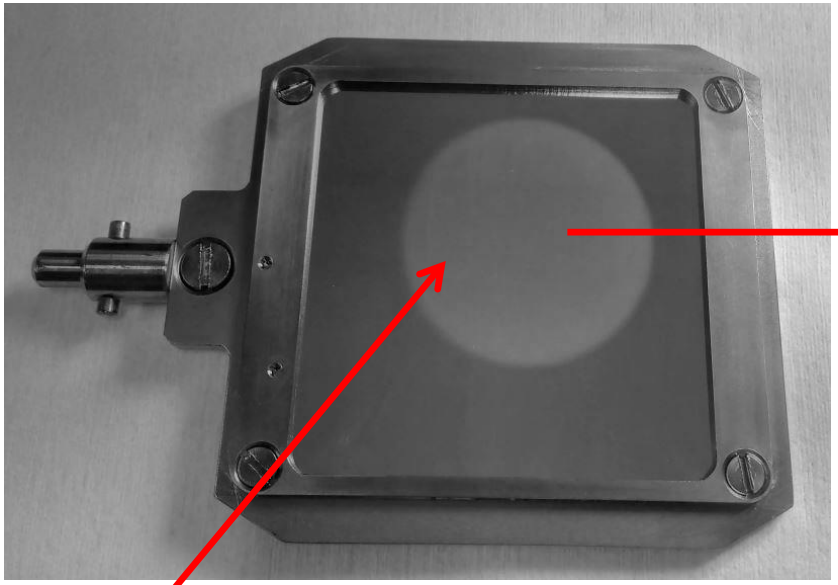


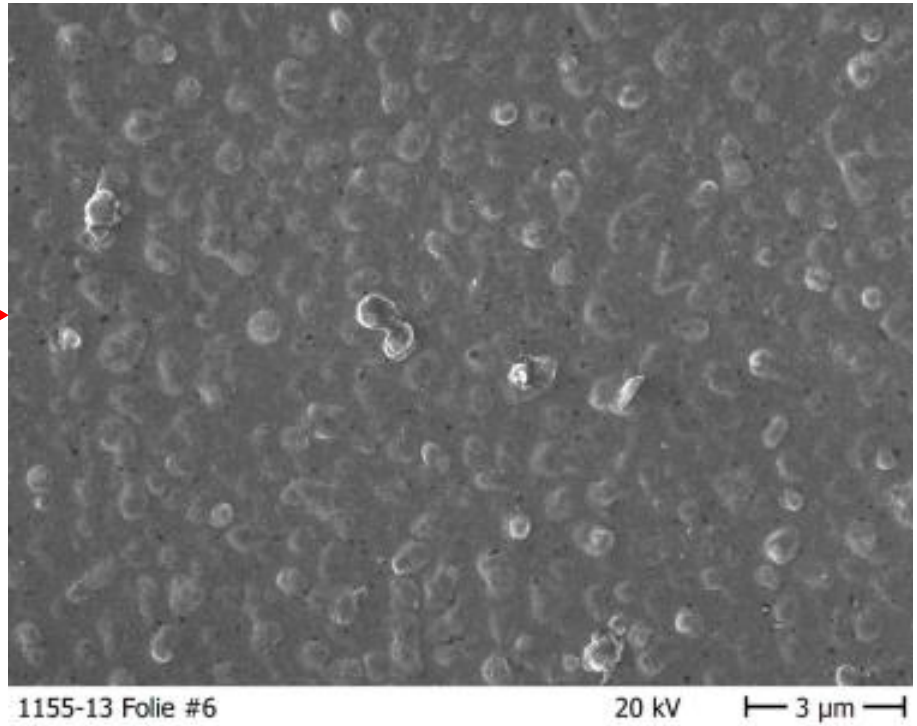
0.1 MeV electrons

Test activities at DLR-Bremen

- Thin polyimide film both sides coated with 100 nm vacuum deposited Aluminum exposed to 2.5 keV protons

Proton flux = 1.36 x 10^{12} p^+ cm^{-2} s^{-1}

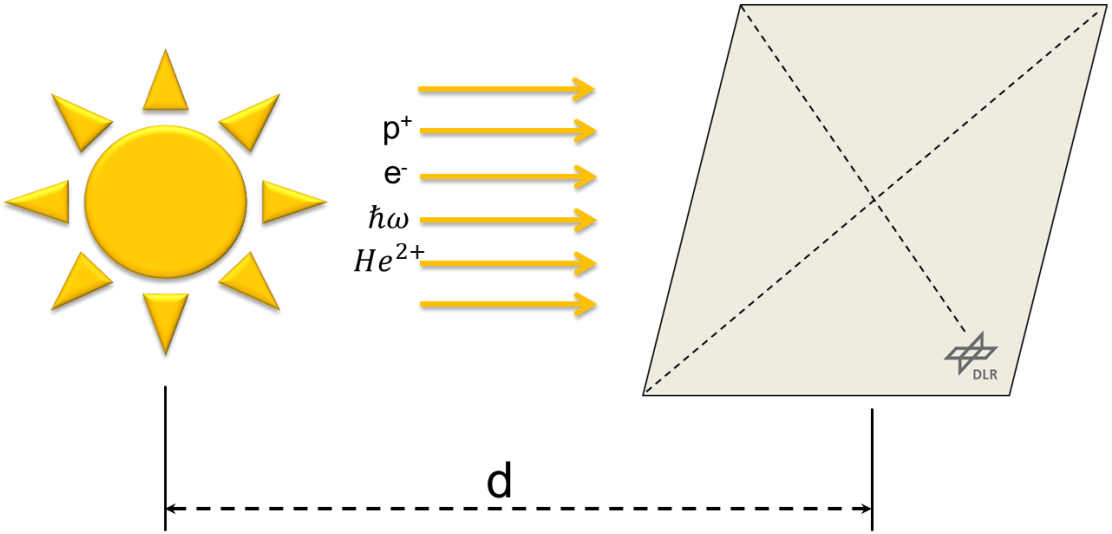




Area of the VDA exposed to 2.5 keV protons

Exemplary Study Solar Sail propulsion limitation due to hydrogen blistering

- A joint study with NASA Langley Research Center



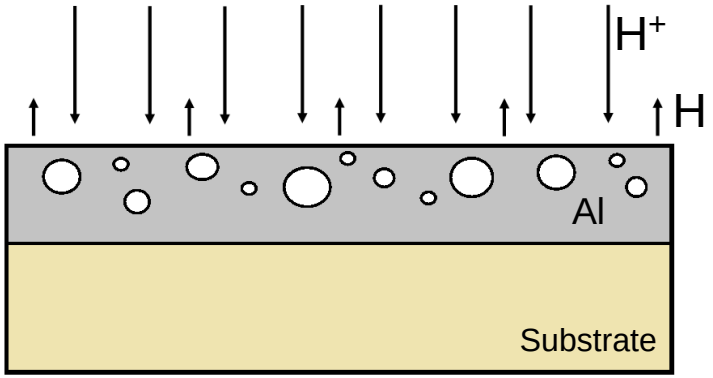
Which degradation processes take place in the interplanetary space?

What is the impact of space degrading factors
on solar sail propulsion performance?

DLR

Exemplary Study Solar Sail propulsion limitation due to hydrogen blistering

- Hypophysis: Reflectance loss due to formation of molecular hydrogen blisters

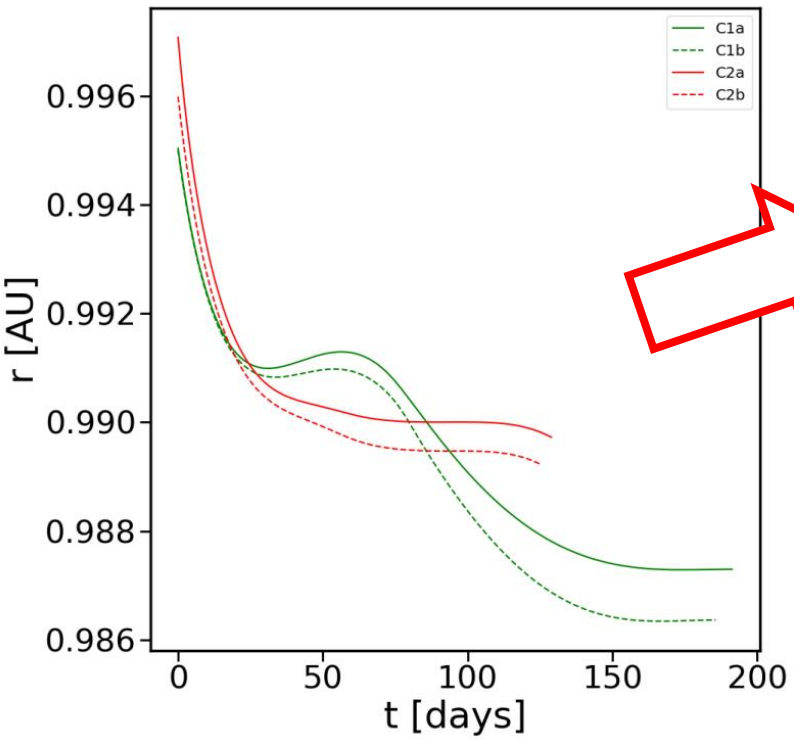


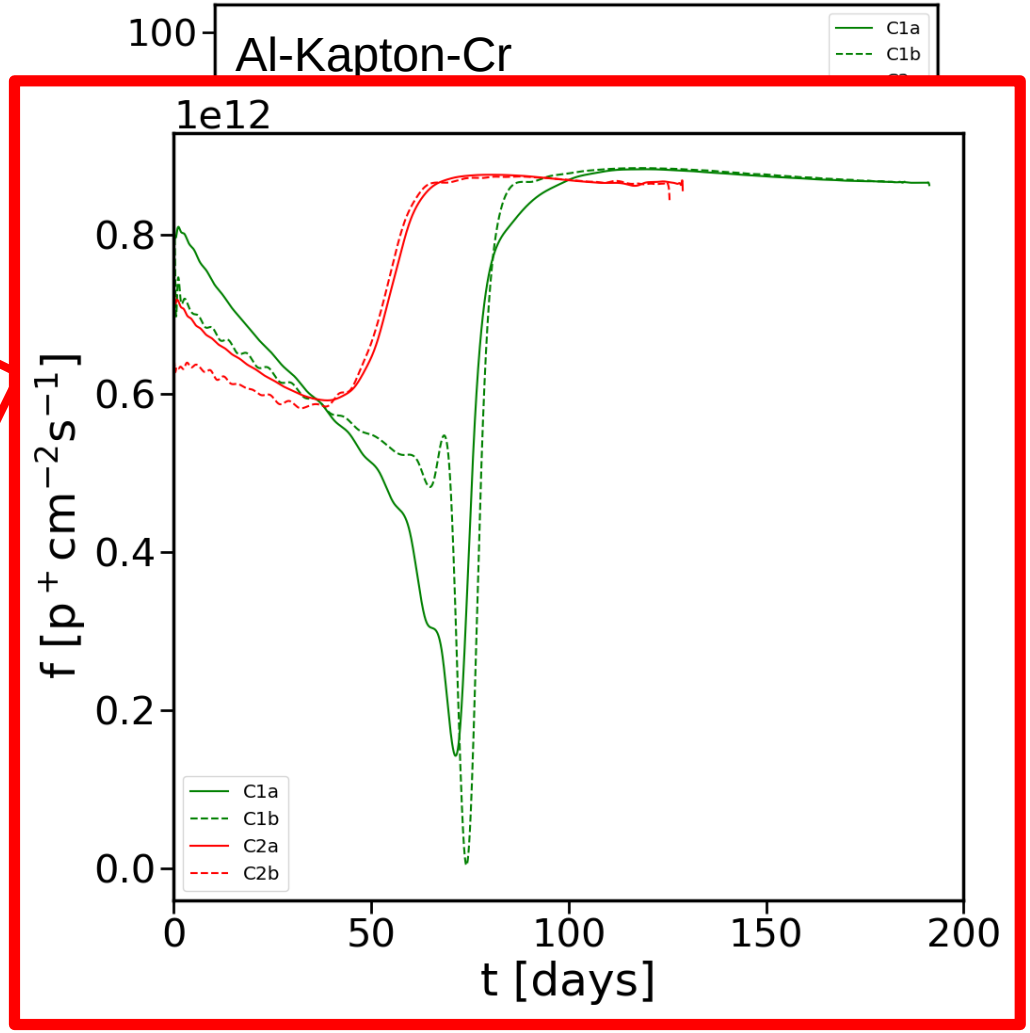
The presence of H atoms in metal cause strain in its lattice

- H implantation changes the energy of the system (lattice energy), the energy may be decreased by the aggregation of the H atoms into H clusters
- When the H and H_2 content in the metal exceeds the limit of its solubility, H and H_2 start to agglomerate to form blisters.

Exemplary Study Solar Sail propulsion limitation due to hydrogen blistering

- Reference mission analysis:
  - ➢ solar sail mission to L1

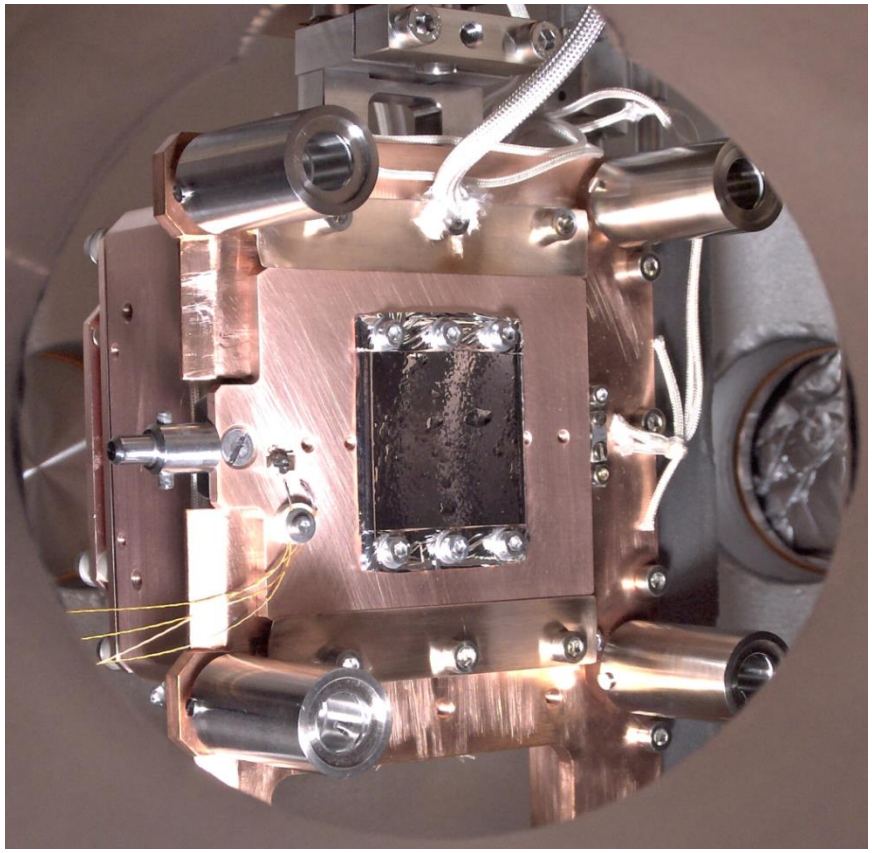




C1 → artificial eq. point of sub-L1

C2 → fly-out from GTO to Halo L1

Exemplary Study Solar Sail propulsion limitation due to hydrogen blistering



Sample	T irr. [°C]
S1	-176
S2	-100
S3	31.6
S4	75
S5	113

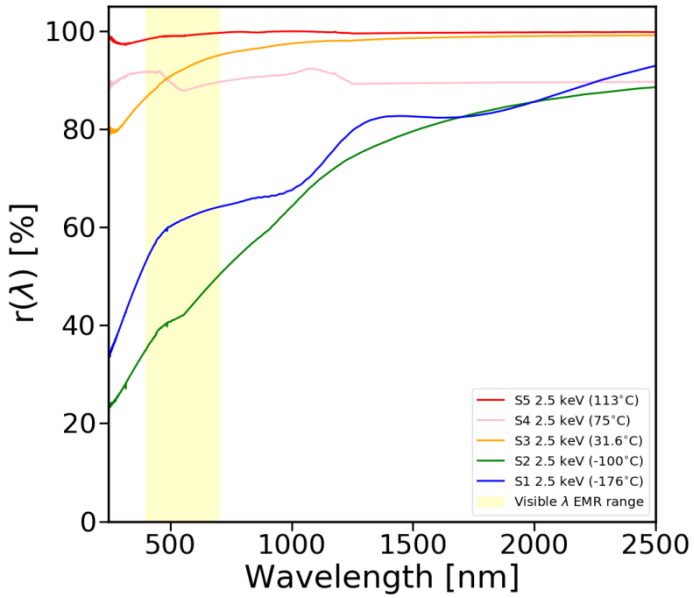
- Energy of p^+: 2.5 keV
- Flux of p^+: 2 x 10^{12} H^+ cm^{-2} s^{-1}
- Fluence of p^+: 2.2 x 10^{17} H^+ cm^{-2}

(equivalent of 3.5 days in space at 1AU distance from the Sun)

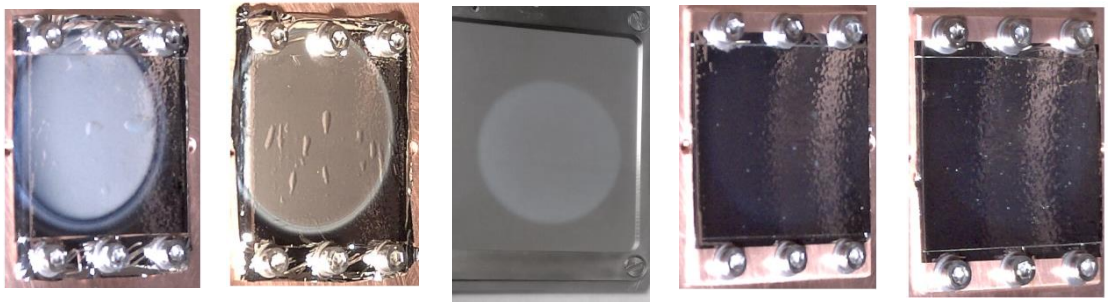
Exemplary Study Solar Sail propulsion limitation due to hydrogen blistering

- Relative change of reflectance is evaluated
- Notice the strong temperature dependence
- Mainly a change from specular to diffuse reflectance
- The presented study corresponds to about **3.5 days** in space at 1AU

  → **significant mission impact**



S1 S2 S3 S4 S5



Sample	T irr. [°C]
S1	-176
S2	-100
S3	31.6
S4	75
S5	113

References

M. Sznajder, P.Seefeldt et al. **Solar sail propulsion limitations due to hydrogen blistering,** *Advances in Space Research*, 2020, doi: https://doi.org/10.1016/j.asr.2020.06.034

M. Dembska, T. Renger, M. Sznajder **Thermo-Optical Property Degradation of ITO-Coated Aluminized Polyimide Thin Films Under VUV and Low-Energy Proton Radiation,** Metallurgical and Materials Transactions A 51, 2020, doi: https://doi.org/10.1007/s11661-020-05906-x

E. Abbe, T. Renger, M. Sznajder et al. **A material experiment for small satellites to characterize the behavior of carbon nanotubes in space – development and ground validation,** Advances in Space Research 63, 2019, doi: https://doi.org/10.1016/j.asr.2018.12.020

U. Banik, K. Sasaki, N. Reininghaus, ..., M. Sznajder et al., **Enhancing passive radiative cooling properties of flexible CIGS solar cells for space applications using single layer silicon oxycarbonitride films**, Solar Energy Materials and Solar Cells, 2020, doi: https://doi.org/10.1016/j.solmat.2020.110456

M. Sznajder, U. Geppert, M. R. Dudek, **Hydrogen blistering under extreme radiation conditions**, Nature Partner Journal Materials Degradation 2, 3 2018, doi: https://www.nature.com/articles/s41529-017-0024-z

DLR

References

M. Sznajder, U. Geppert, M. Dudek, **Degradation of metallic surfaces under space conditions, with particular emphasis on Hydrogen recombination processes**, Advances in Space Research 56, 2015, doi: https://doi.org/10.1016/j.asr.2015.03.032

T. Renger, M. Sznajder, A. Witzke, U. Geppert, **The Complex Irradiation Facility at DLR-Bremen**, Advances in Solar Sailing, Springer Praxis Books, ISBN: 978-3-642-34906-5, pp. 541-557, 2014, doi: https://doi.org/10.1007/978-3-642-34907-2_34