Qualification of space laser optics for ESA LIDAR missions

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DLR

German Aerospace Center (DLR)

Approx. 8000 employees across
33 institutes and facilities at 20 sites.

Offices in Brussels, Paris,
Tokyo and Washington.

Gefördert durch:

Bundesministerium
für Wirtschaft
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aufgrund eines Beschlusses
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DLR

Institute of Technical Physics

Director: Prof. Dr. Thomas Dekorsy

Topics:
Laser systems for applications in:
Aeronautics / Space / Security / Defense

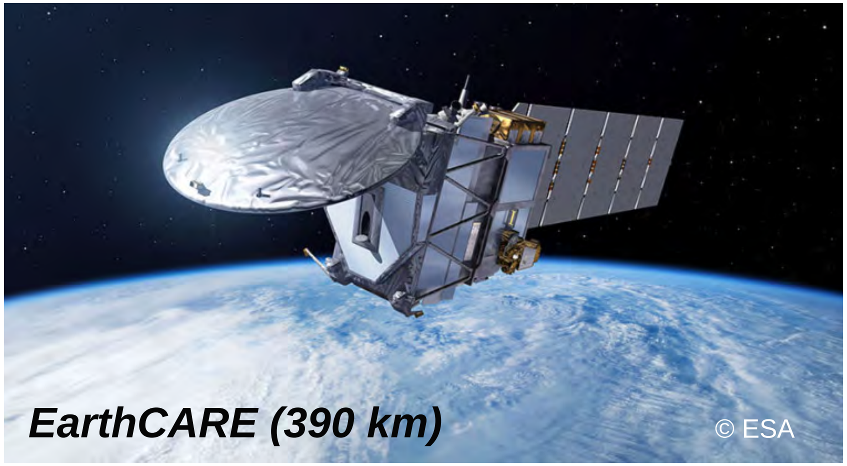
Staff:
3 departments
70 employees

Our motivation: Upcoming ESA LIDAR space missions

Atmospheric Dynamics Mission (ADM) Aeolus

Global measurement of wind profiles

- Sun-synchronous orbit with 7 days repeat cycle
- Launch period: 11/2017 – 01/2018 **soon!**
- Projected lifetime: 3 years
- Laser: **ALADIN** (Atmospheric Laser Doppler Instrument)
- Specs: 50 Hz, ~ < 120 mJ @ 355 nm, 20 ns
- Partial pressure oxygen: ~ 40 Pa



EarthCARE

Global profiling of aerosols

- Expected launch in Q4/2018
- Design lifetime: 3 years
- Laser: **ATLID** (Atmospheric LIDAR)
- Specs: 51 Hz, >35 mJ @ 355 nm
- Pressurized (artificial air)

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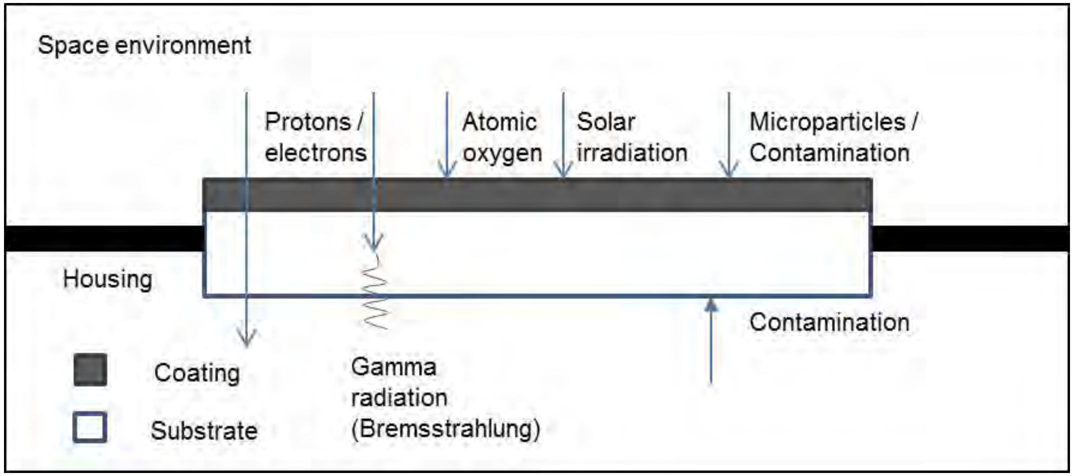
Challenges for laser components / sub-modules in space

Specific mission requirements (ESA ADM Aeolus)

- 3 years of operation in orbit -> ~ 4.7 billion laser pulses -> long term stability of laser components
- High pulse energy (up to 120 mJ, 20 ns) in the UV (355 nm) -> high damage threshold of components

Space environmental effects (impacting the performance of space optics)



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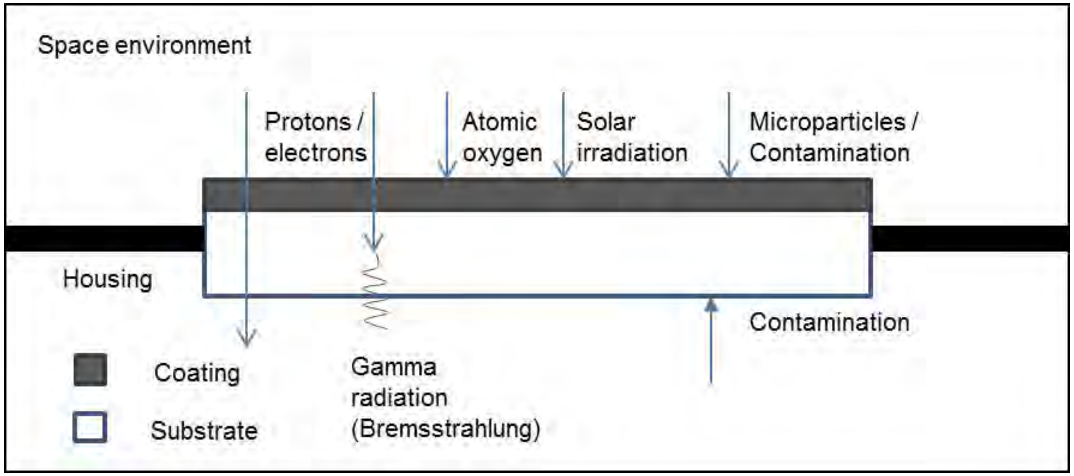


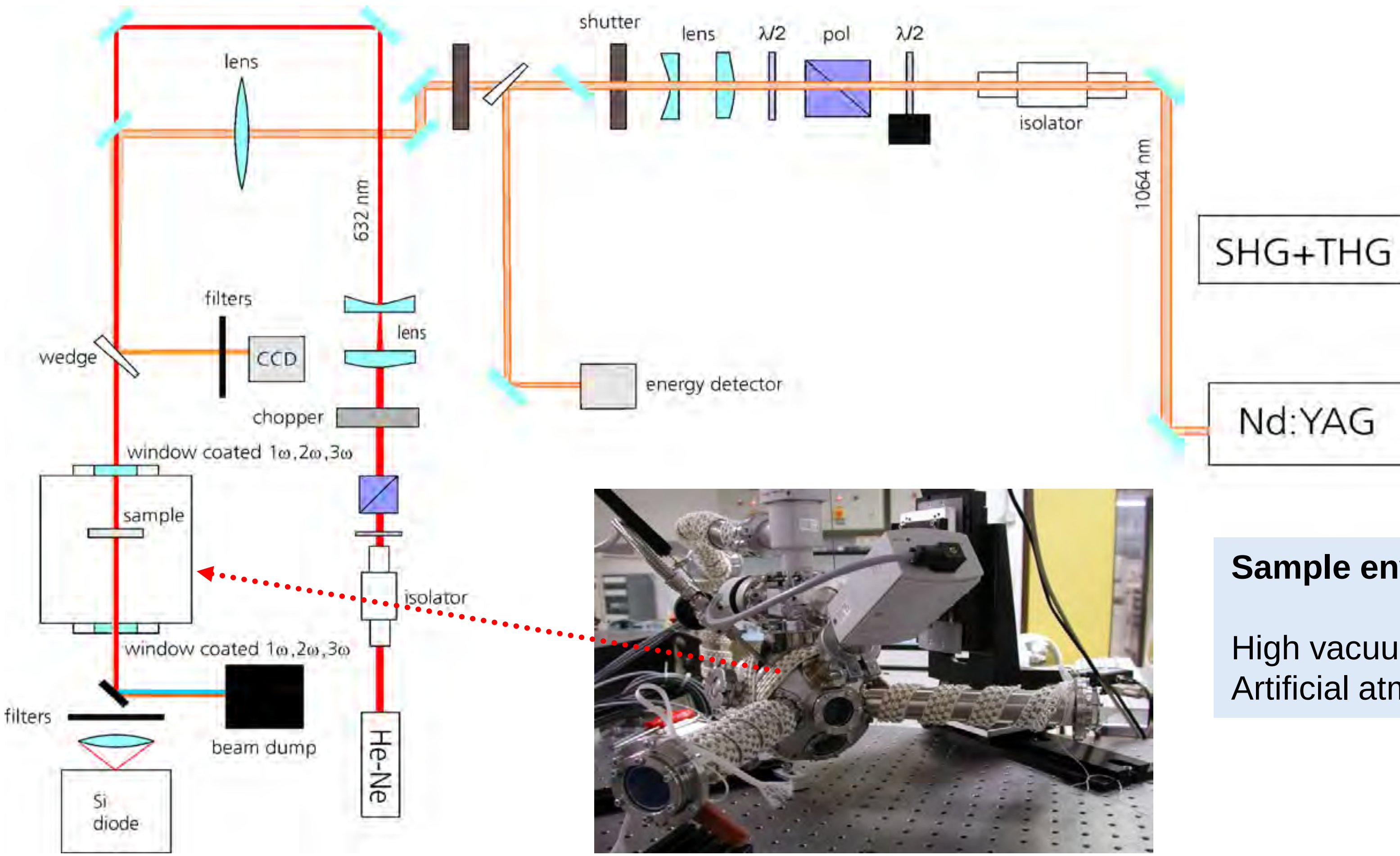
Need for on-ground test setups and test procedures for simulation of space environment

No service visit possible ;-)

Test bench for LIDT evaluation under high vacuum

- 1-on-1 / S-on-1 tests according to ISO 21254
- Testing under high vacuum (10^{-6} mbar) or artificial atmosphere
- Fundamental mode laser (Gaussian beam profile on sample) M^2 ~ 1.5
- Nd:YAG wavelength and harmonics: 1064, 532, 355, 266 nm
- Damage detection by scatter probing and pressure sensing (threshold ~ µm size)

LIDT setup (IR beam line)

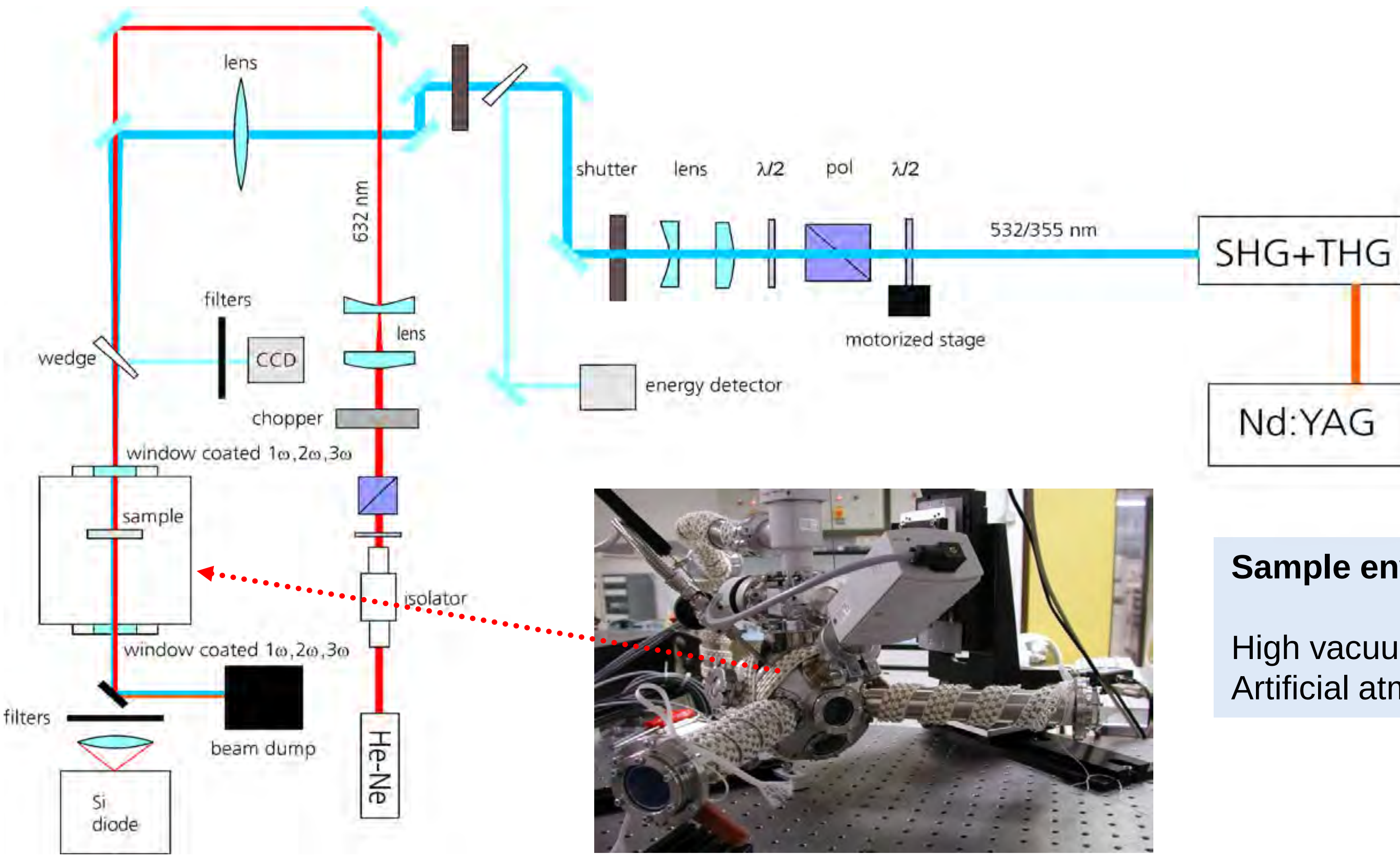


High vacuum stainless steel chamber

Sample environment

High vacuum 10^{-6} mbar
Artificial atmosphere (<5 bar)

LIDT setup (UV beam line)



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Sample environment

High vacuum 10^{-6} mbar
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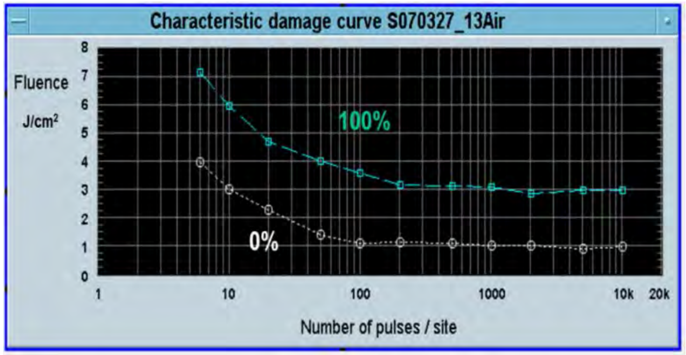
Large database of space laser optics: Vendor / batch screening

Optic	Coating	Wavelength [nm]	Fluence* F_{10000} [J/cm²]
waveplate	AR	1064	12.4
reflector	HR0	1064	21.7
polarizer		1064	27
folding mirror	HR45	1064	19.5
window	AR	1064	23.5
waveplate	AR	355	4.4
polarizer		355	5.1
folding mirror	**HR45**	**355**	**11.1**
window	**AR**	**355**	**8.5**

- 350 space laser optics tested
- 10 years of test campaign

- 20 different types
- 355, 532 and 1064 nm

40% IR, 10 % VIS, 50 % UV
10 European / 6 US vendors



Best LIDT values of optical components exposed to 1064 / 355 nm pulses

Large database of space laser optics: Vendor / batch screening

All critical laser optics for ESA ALADIN were tested in our facilities!

Optic	Coating	Wavelength [nm]	Fluence* F_{10000} [J/cm²]
waveplate	AR	1064	12.4
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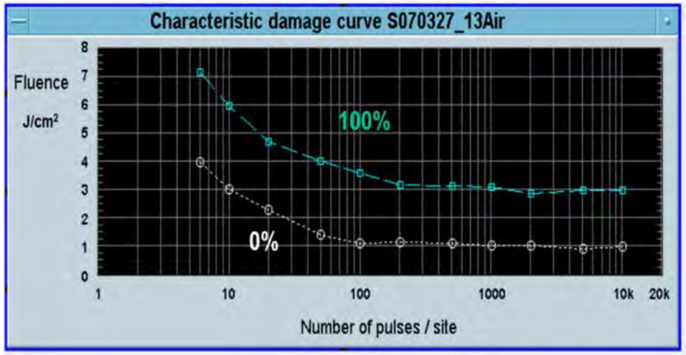

Best LIDT values of optical components exposed to 1064 / 355 nm pulses

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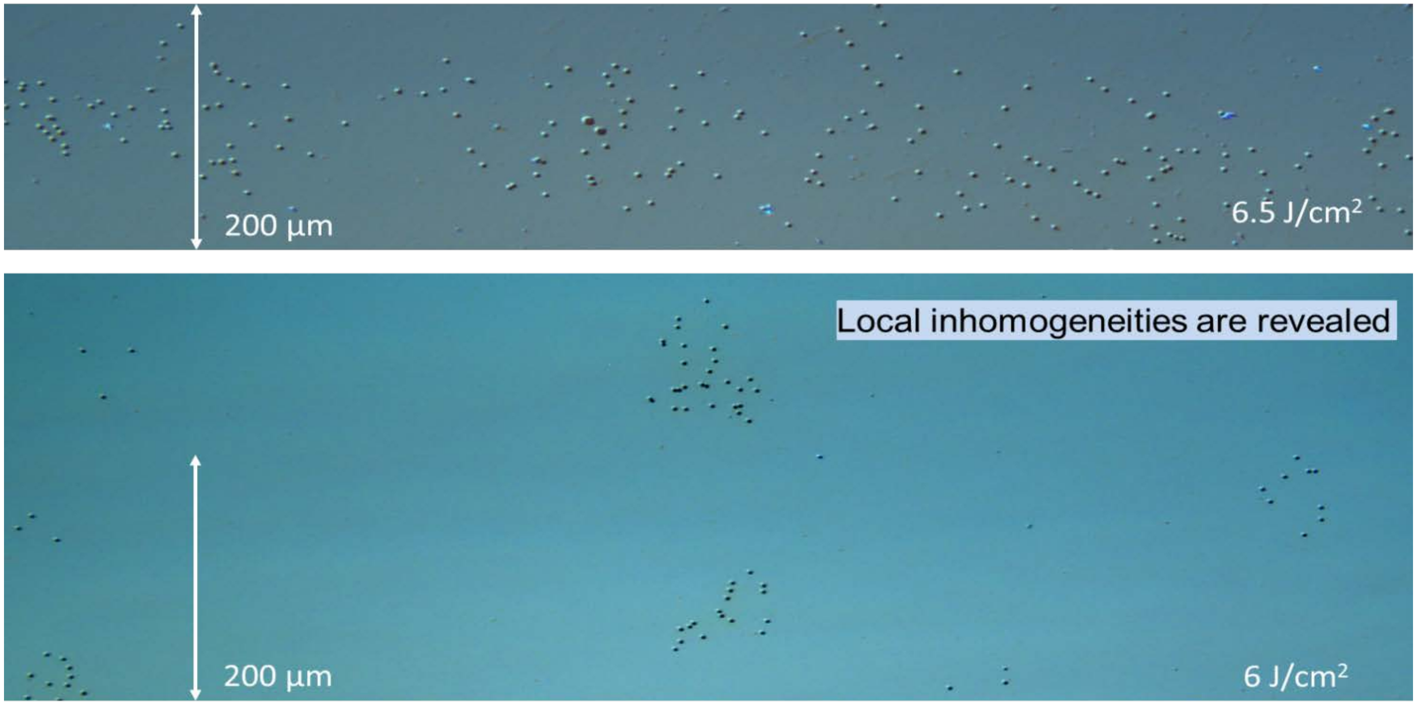
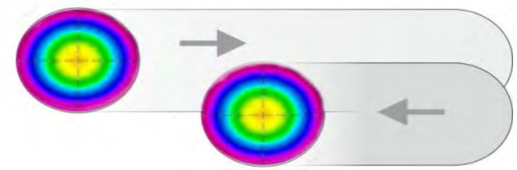
Raster scans – supplemental test for flight modules

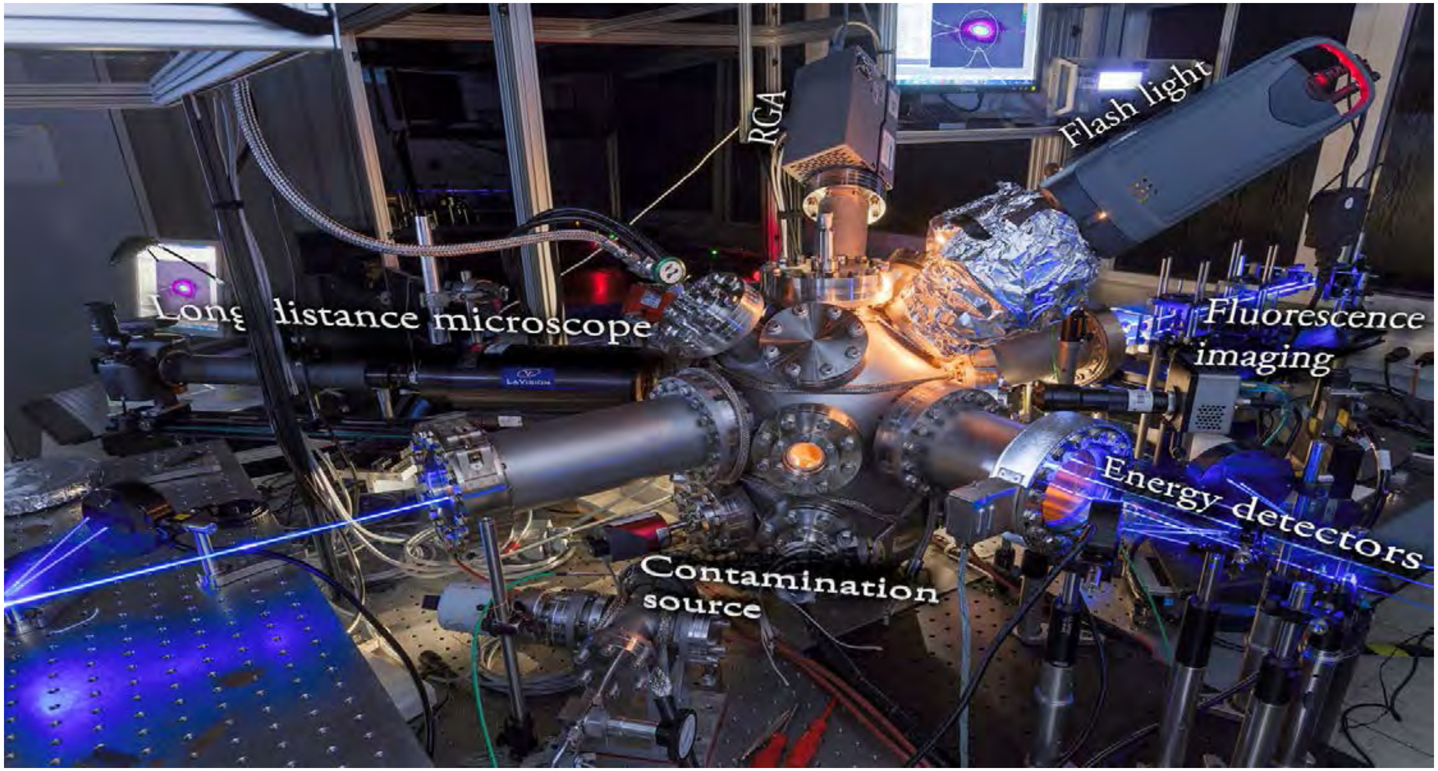
Interrogation of large test areas (up to 100 mm²)

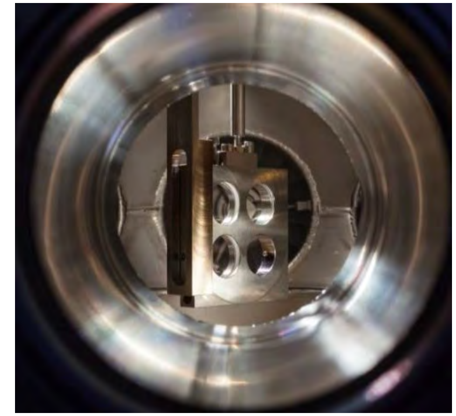




Optical micrographs of AR 355 coating (with activated damage sites)

Setup for laser-induced contamination tests





- Stainless-steel UHV chamber
- 4 parallel beam lines allow for simultaneous sample testing (identical conditions)
- Non-depletable contamination source
- Long distance microscope
- Online fluorescence / transmission monitoring

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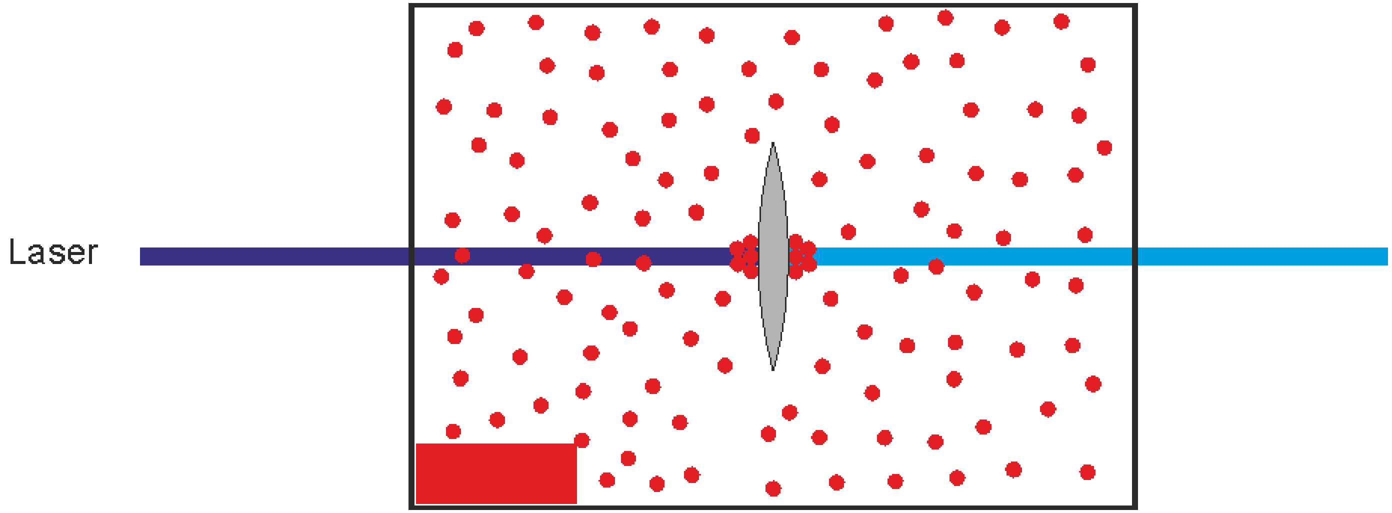
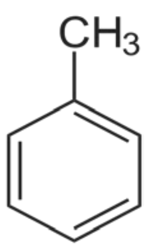
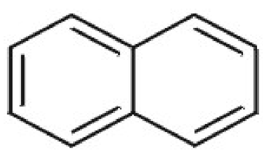
LIC scheme: Deposit formation on the surface of optics

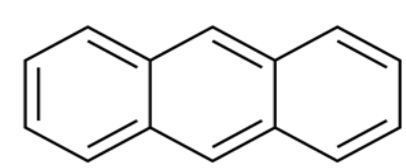




Toluene



Naphthalene



Anthracene

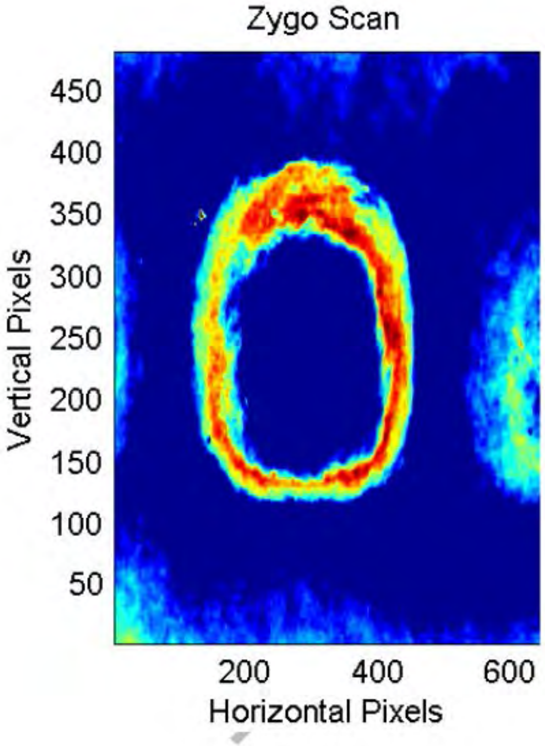
Hydrocarbons used for lab tests (purity, handling)

and CV 2566, Solithane, A12 Epoxy ………

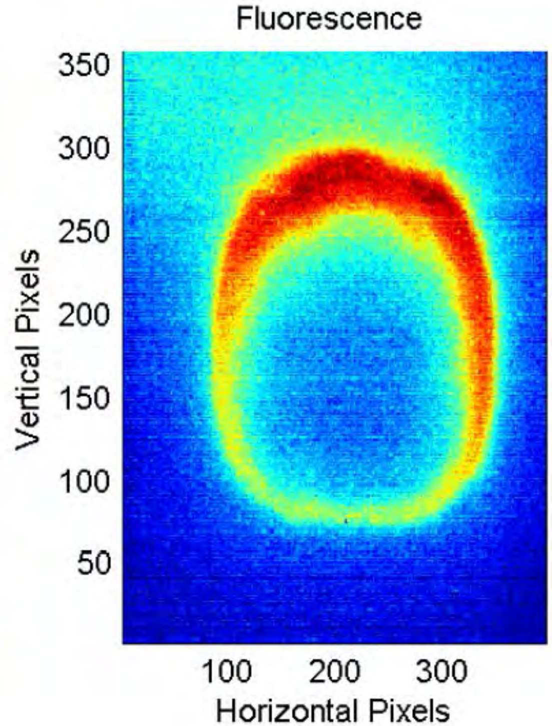
Space qualified glues, adhesives…

Laser-induced fluorescence detection of deposits

Correlation between deposit thickness and fluorescence intensity



Zygo scan



Fluorescence distribution

Test parameters*:

Temperature: 100°C
Contaminant: A12 epoxy
Pressure: HV
Wavelength: 355 nm

Fluorescence detection limit: few nanometers

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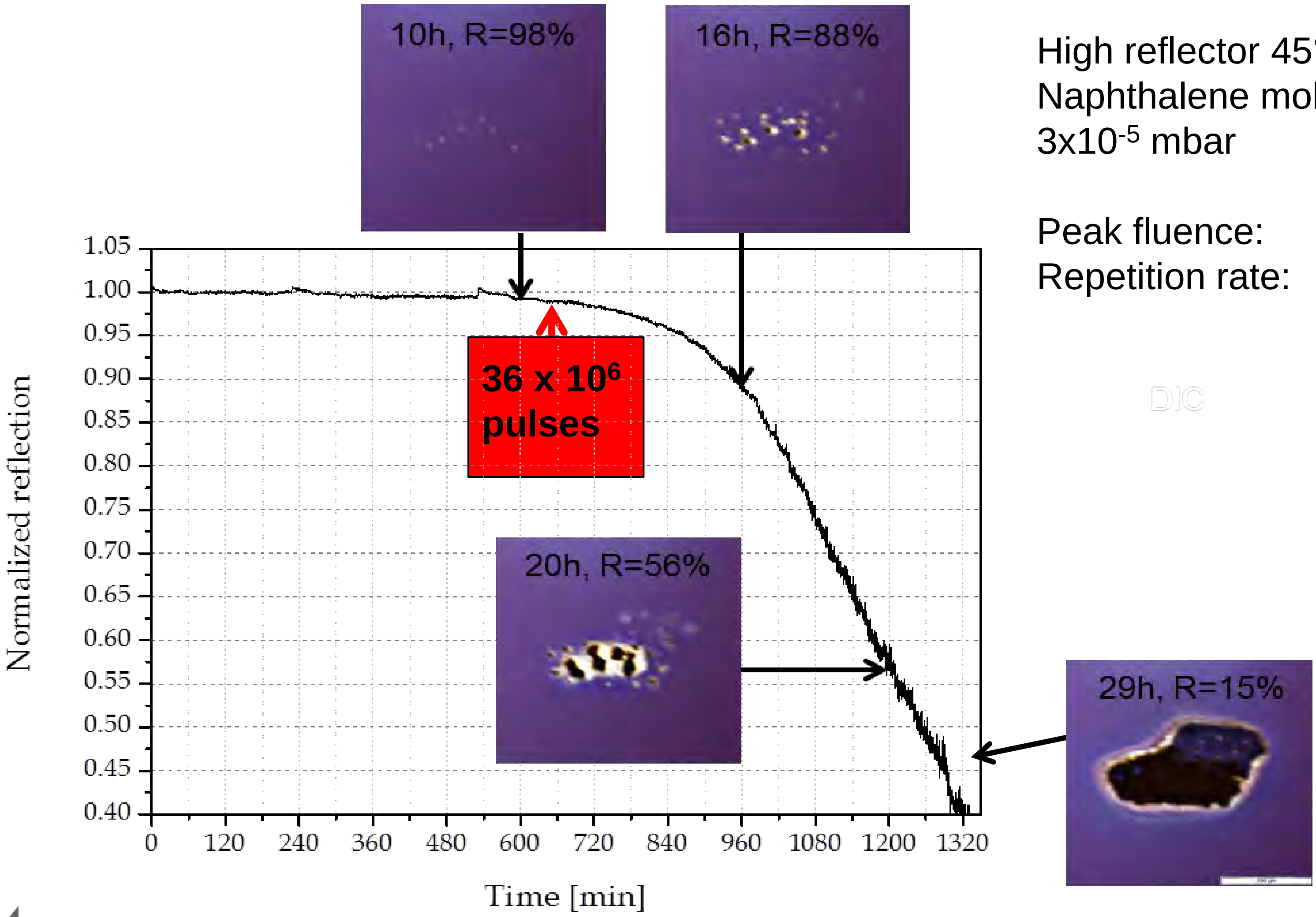
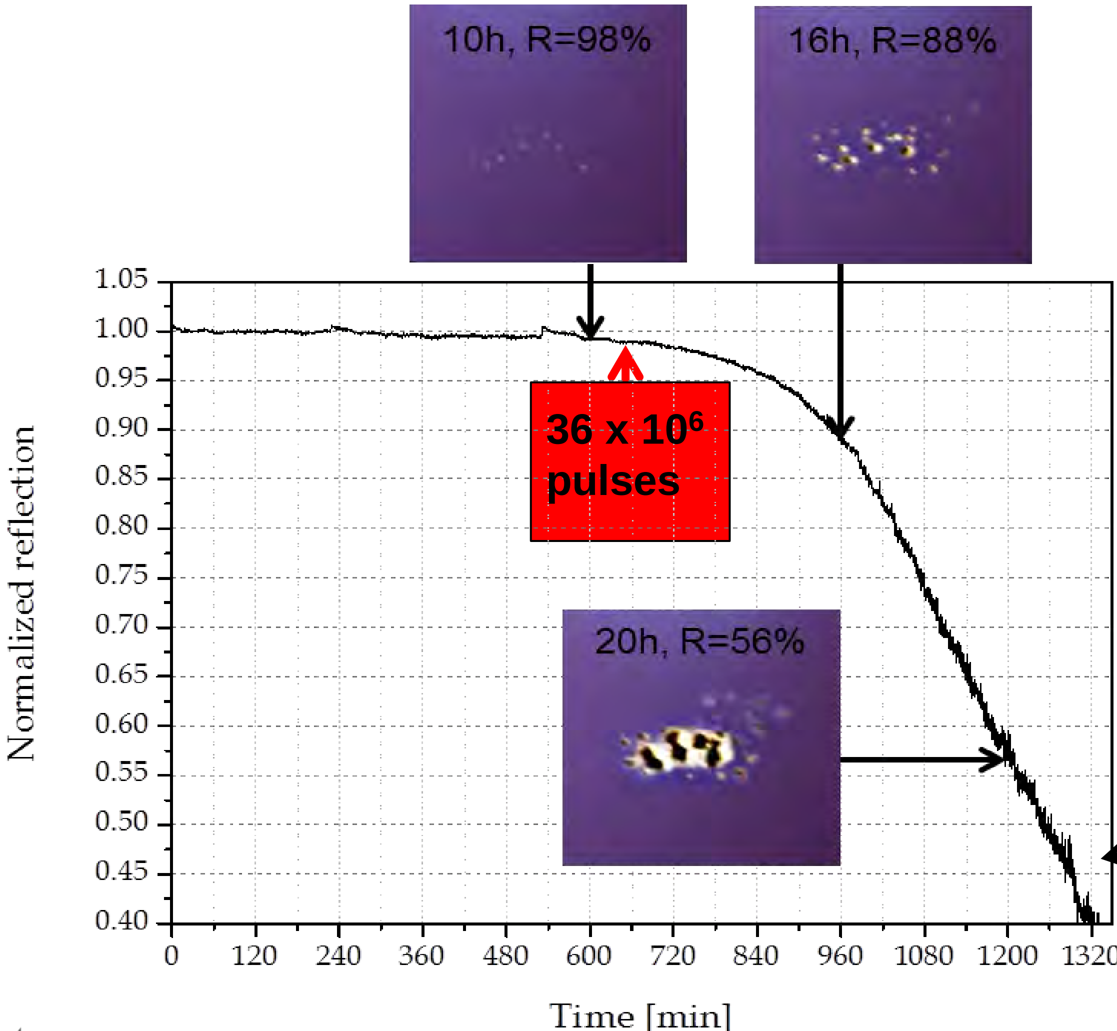
Contamination induced damage: in-situ microscopy

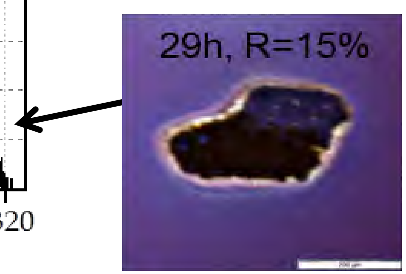


High reflector 45°@ 355 nm
Naphthalene molecular contamination
$3x10^{-5}$ mbar

Peak fluence:	**0.4 J/cm²**
Repetition rate:	1000 Hz

Contamination induced damage: in-situ microscopy





High reflector 45°@ 355 nm
Naphthalene molecular contamination
3x10^{-5} mbar

Peak fluence:	**0.4 J/cm²**
Repetition rate:	1000 Hz

Very small threshold fluence for damage under presence of molecular contamination

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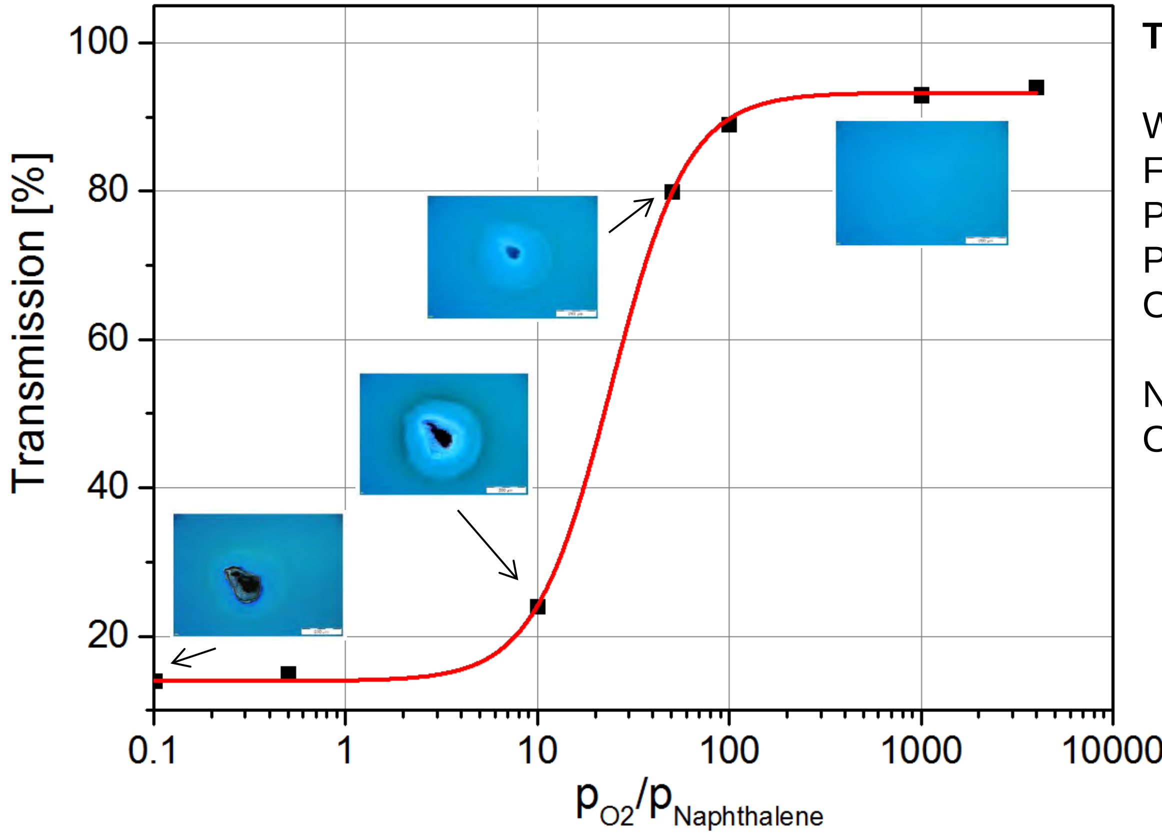
Contamination induced damage: Mitigation by oxygen



Test conditions:

Wavelength: 355 nm
Fluence: 1.0 J/cm²
Pulse number: 3.6 Mio shots
Pulse repetition rate: 1 kHz
Optical samples: fused silica, AR @355nm

Naphthalene partial pressure fixed: 10^{-5} mbar
O_2 pressure variable: 10^{-6} – 4 10^{-2} mbar

- Threshold behavior of oxygen pressure ratio
- Cleaning of contaminated surface by UV irradiation in O_2 atmosphere

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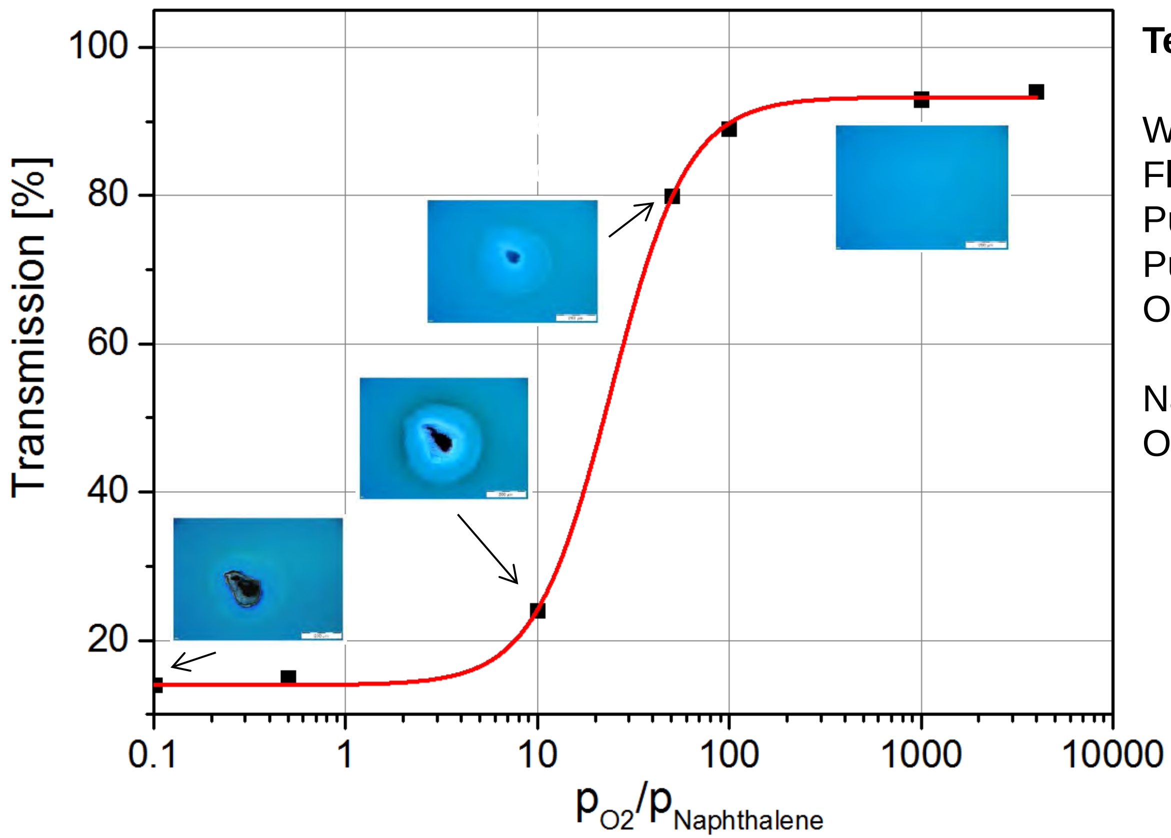
Contamination induced damage: mitigation by oxygen



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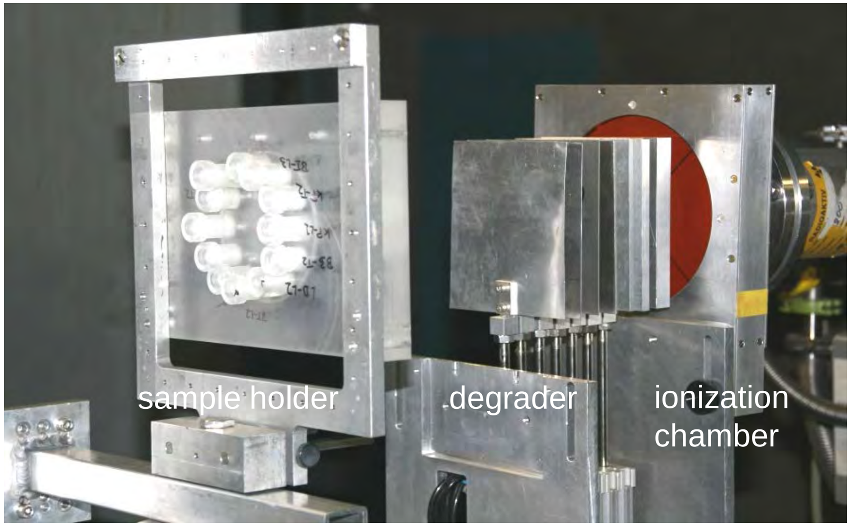
Naphthalene partial pressure fixed: 10^{-5} mbar
O_2 pressure variable: 10^{-6} – 4 10^{-2} mbar

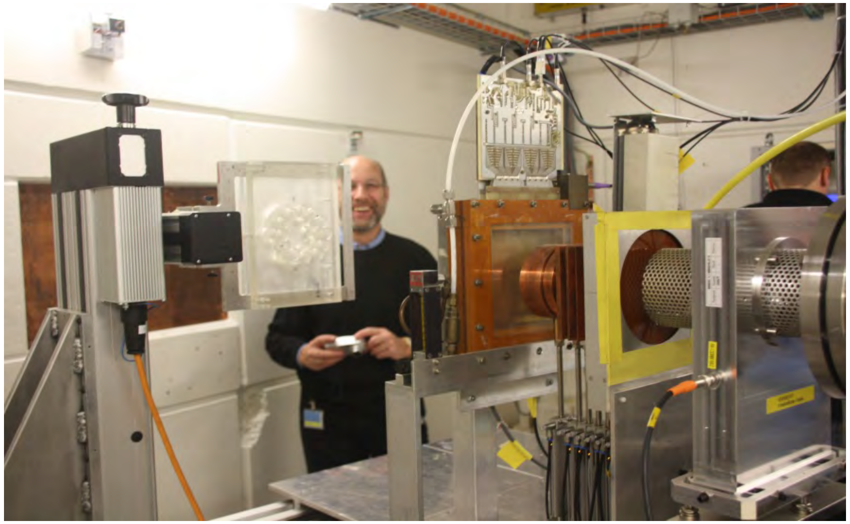
Small partial pressures of oxygen suppresses contamination effects

- Threshold behavior of oxygen pressure ratio
- Cleaning of contaminated surface by UV irradiation in O_2 atmosphere

Proton radiation tests of nonlinear crystals



Proton irradiation facility PIF @ PSI, CH



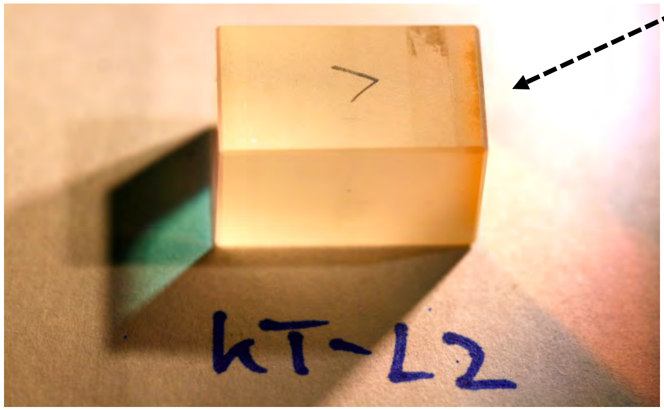
Proscan high energy facility @ PSI, CH

Test philosophy:
3 year equivalent orbital dose of p^+
(applied in 1 hour)
Dose: < 10^{12} p^+/cm^2
Flux: < 5 10^8 $p^+/(cm^2\,s)$
Irradiation in air
p^+ radiation tests at **10 MeV**

Test philosophy:
3 year equivalent orbital dose of p^+
(applied in 1 hour)
Dose: < 10^{12} p^+/cm^2
Flux: < 2 10^8 $p^+/(cm^2\,s)$
Irradiation in air
p^+ radiation tests at **100 & 230 MeV**

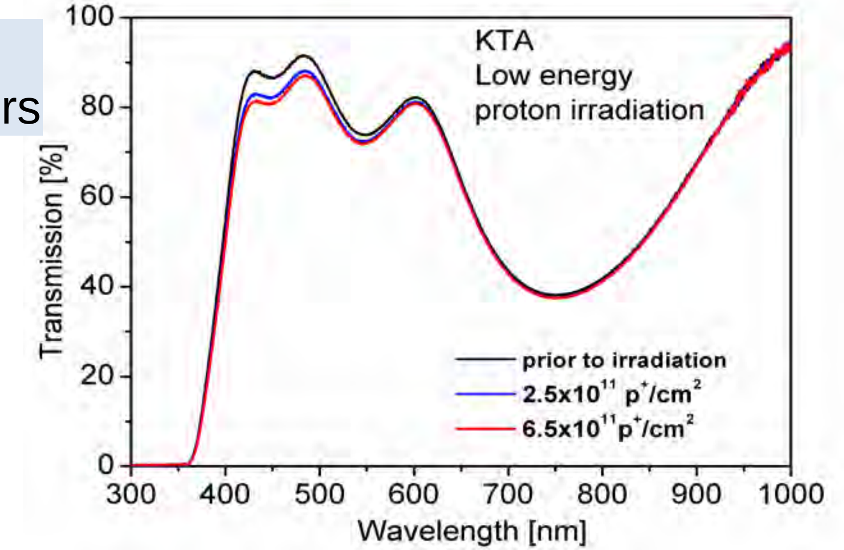
Low energy (10 MeV) proton radiation test

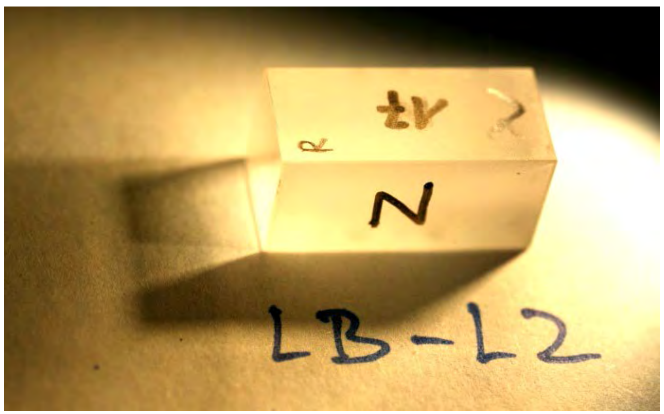
color centers



KTA, after 6.5 10^{11} p^+/cm^2
darkening

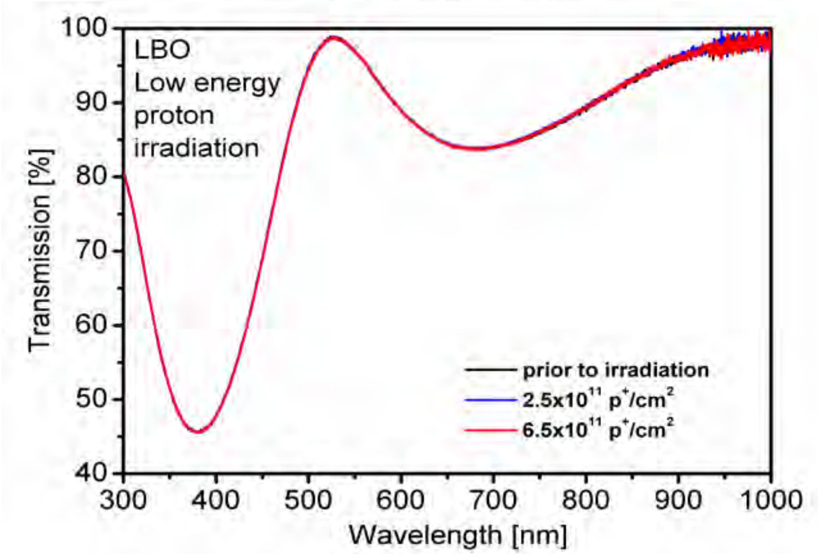
p^+



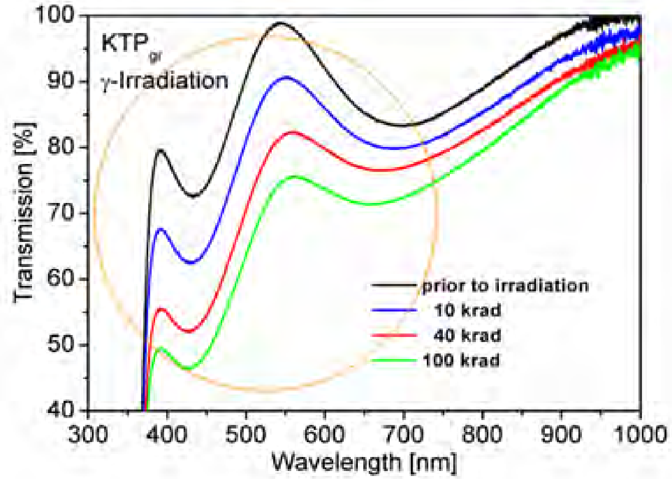


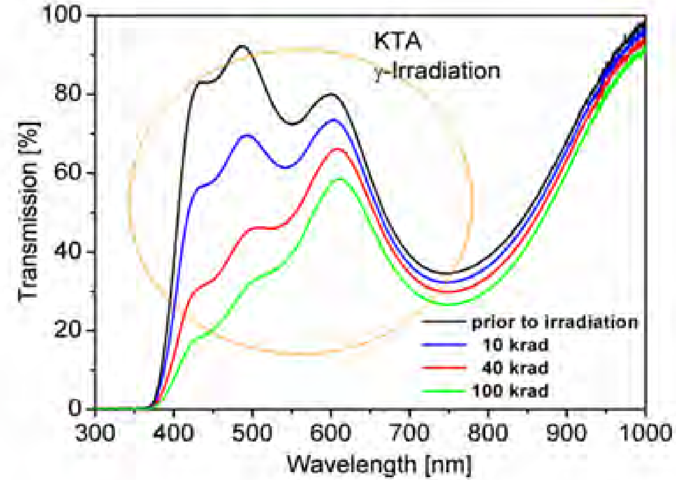
LBO, after 6.5 10^{11} p^+/cm^2
no darkening

p^+



Radiation effects on nonlinear crystals (gamma irradiation)





Test philosophy:
3 year equivalent orbital dose
Gamma energy: 1.17 / 1.33 MeV
Typical radiation flux: 36 rad/min
ESA test specs:
100 krad overall dose

Strong degradation for Titanyls (KTP, RTP, KTA)

No degradation for Borates (BBO, LBO, BIBO)

Summary

- Operation of qualification test benches for high-power space laser optics (LIDT, LIC, raster scanning)

- Damage testing of all critical laser optics of ALADIN instrument (ADM mission)

- Sensitive in-situ monitoring technologies (eg fluorescence imaging)

- Identification of risks for laser optics in space (contamination effects may reduce the LIDT)
- Investigation of LIC mitigation effects (O_2 pressurizing)

- Exposure of nonlinear optical crystals to energetic radiation (borates show only minor effects)

Thank you for your attention

The support by ESA/ESTEC is kindly acknowledged!