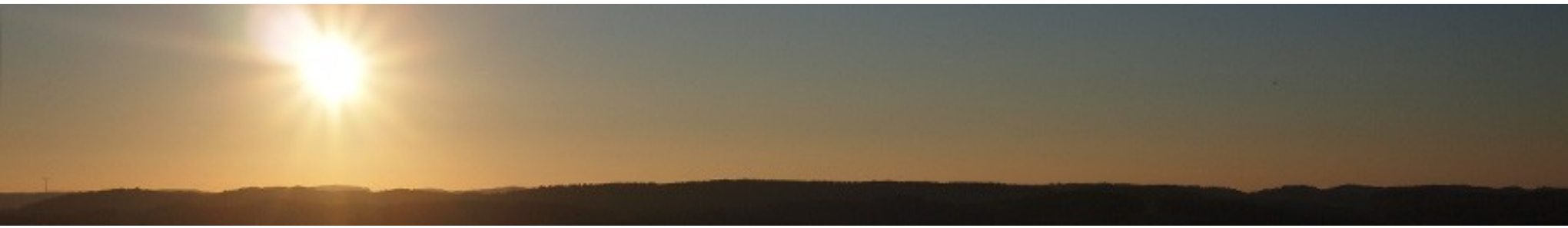


SHIPS

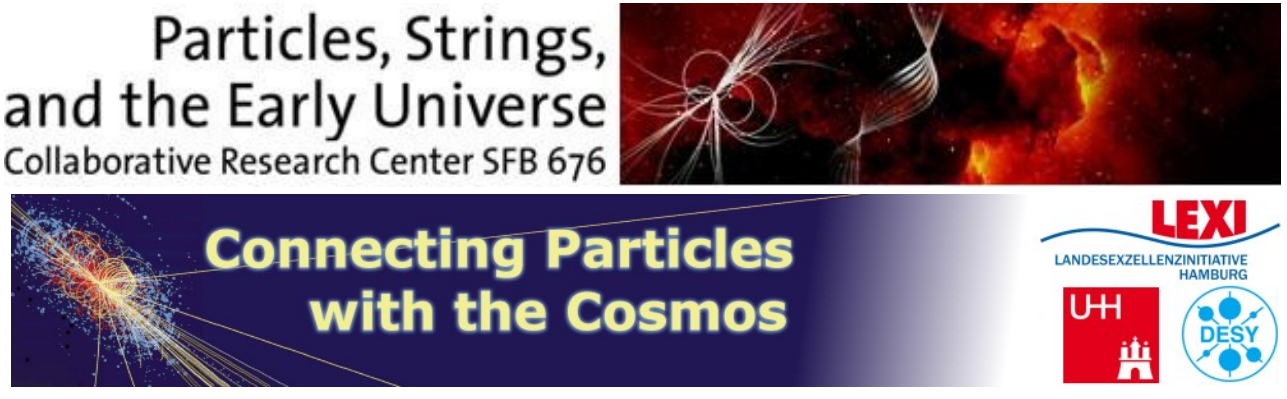
Solar Hidden Photon Search

Matthias Schwarz

A. Ringwald, G. Wiedemann, J. Redondo, A. Lindner, M. Schneide,
J. Susol, E.-A. Knabbe, C. Blohm, C. Martens,
E.-O. Saemann, Z. Eskandarian

Collaboration of DESY and University of Hamburg

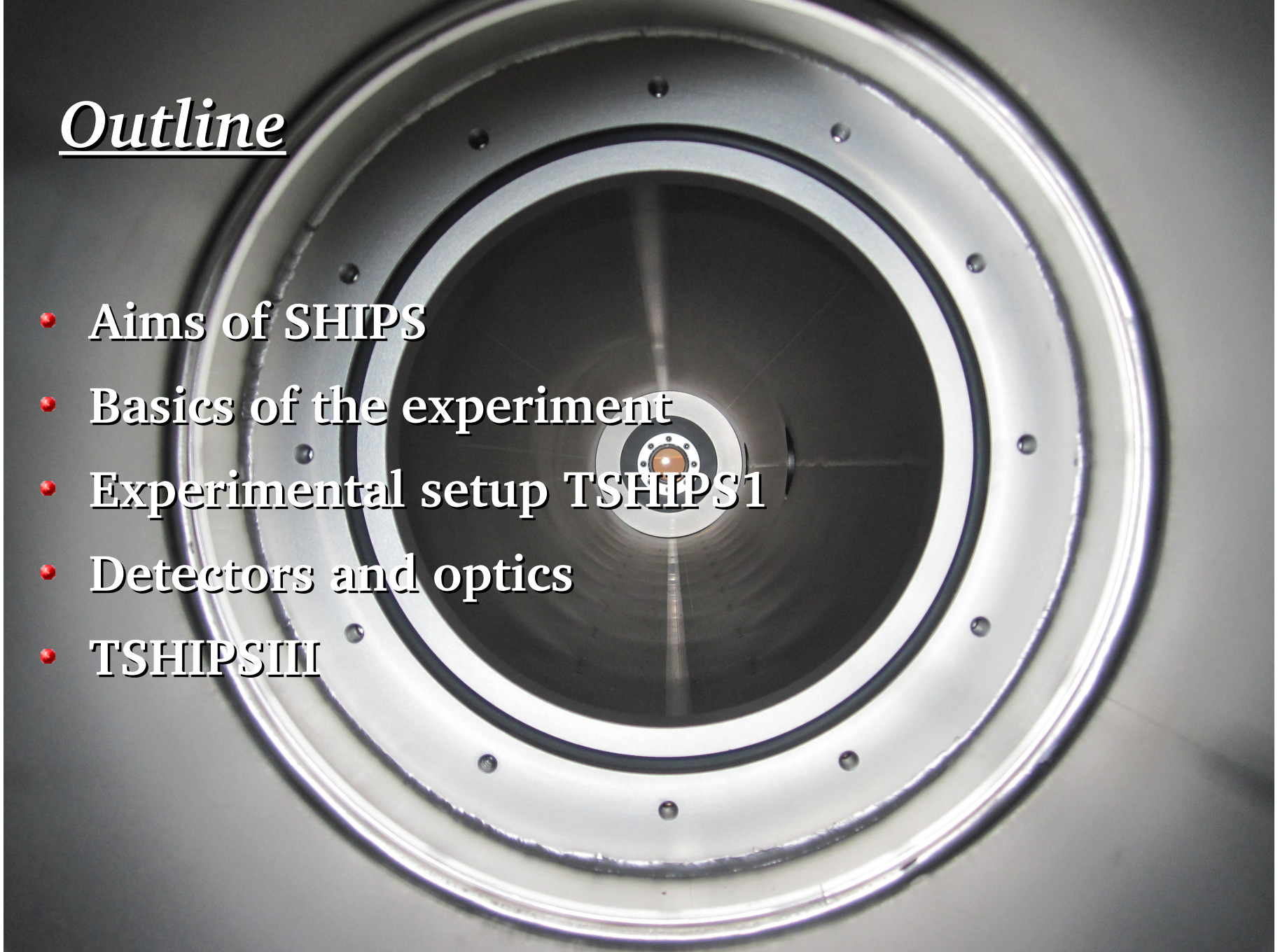
SFB 676 and LEXI



C1 – Theory and phenomenology of weakly interacting light particles beyond the Standard Model

Principal investigators:

Andreas Ringwald, Desy - Günter Wiedemann, University of Hamburg



Outline

- Aims of SHIPS
- Basics of the experiment
- Experimental setup TSHIPS1
- Detectors and optics
- TSHIPSIII

Optical fresnel astronomy

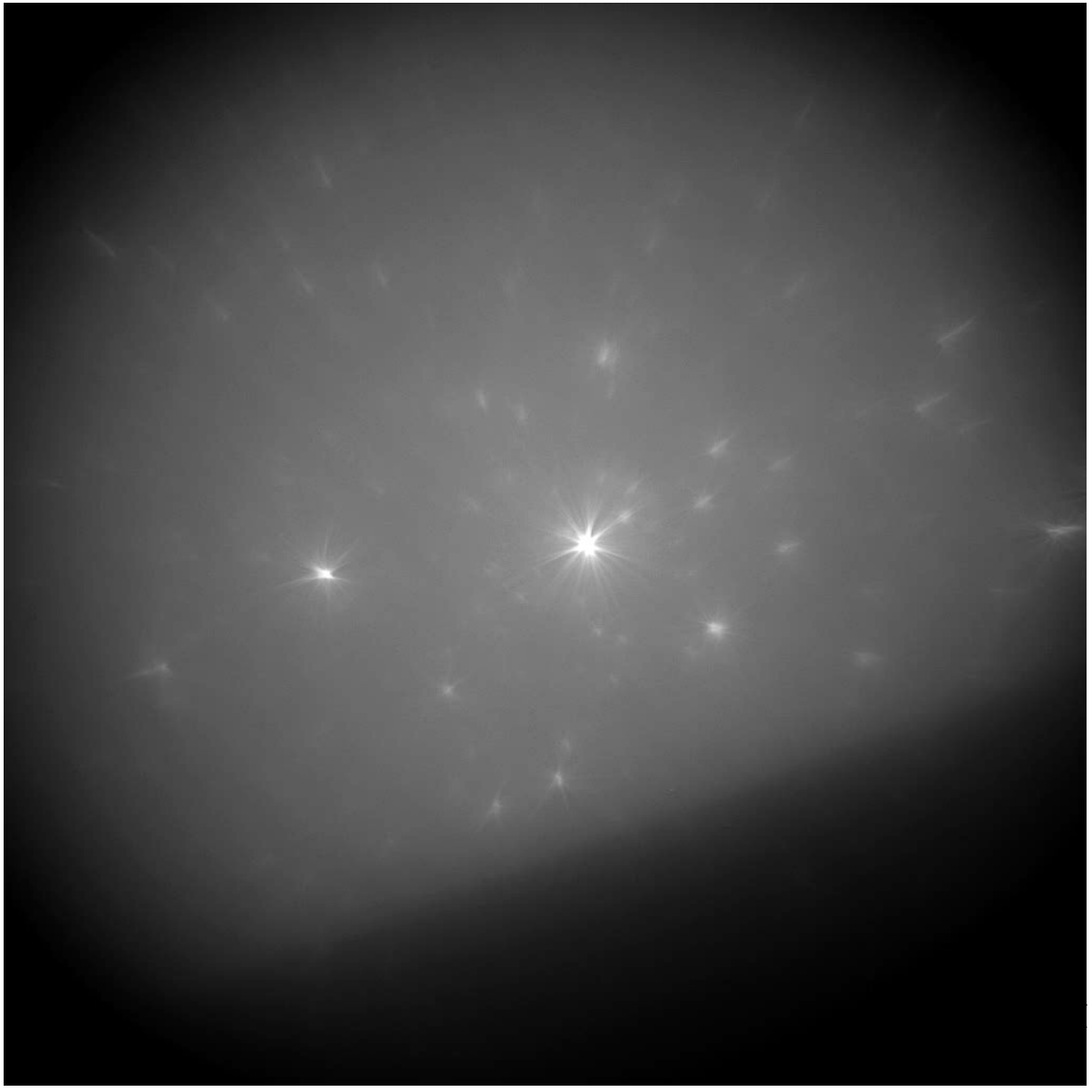
- HIP113622

by TSHIPS1

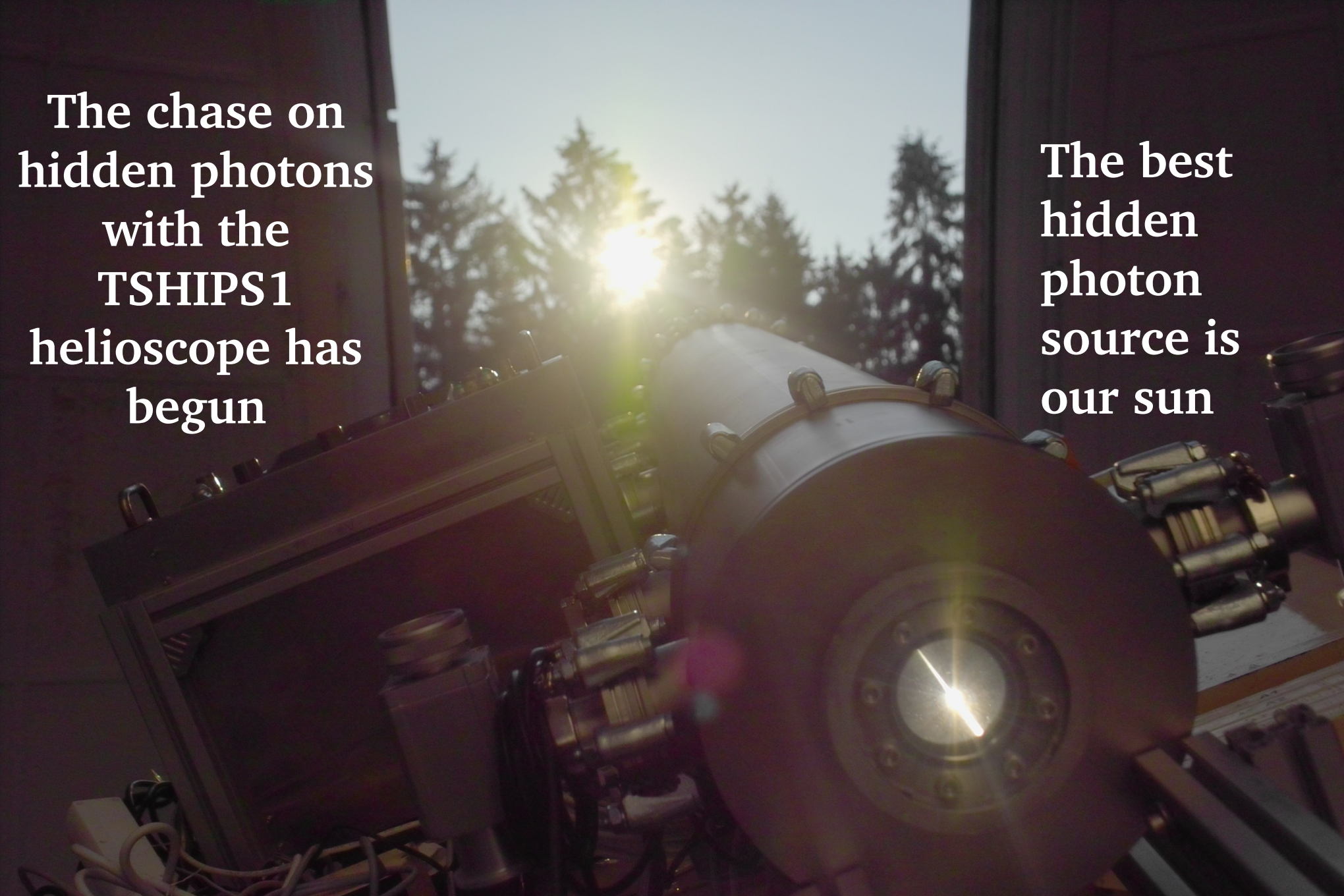
fresnel lense

FL 20 cm

iKon-M



11.10.2012


The chase on hidden photons with the TSHIPS1 helioscope has begun
The best hidden photon source is our sun

Aims of the SHIPS-Project

- Further improvement of constraints to hidden sector boson parameters

or even better

- Detection of hidden photons
- Estimation of hidden photon mass and coupling parameter χ

Important points about SHIPS

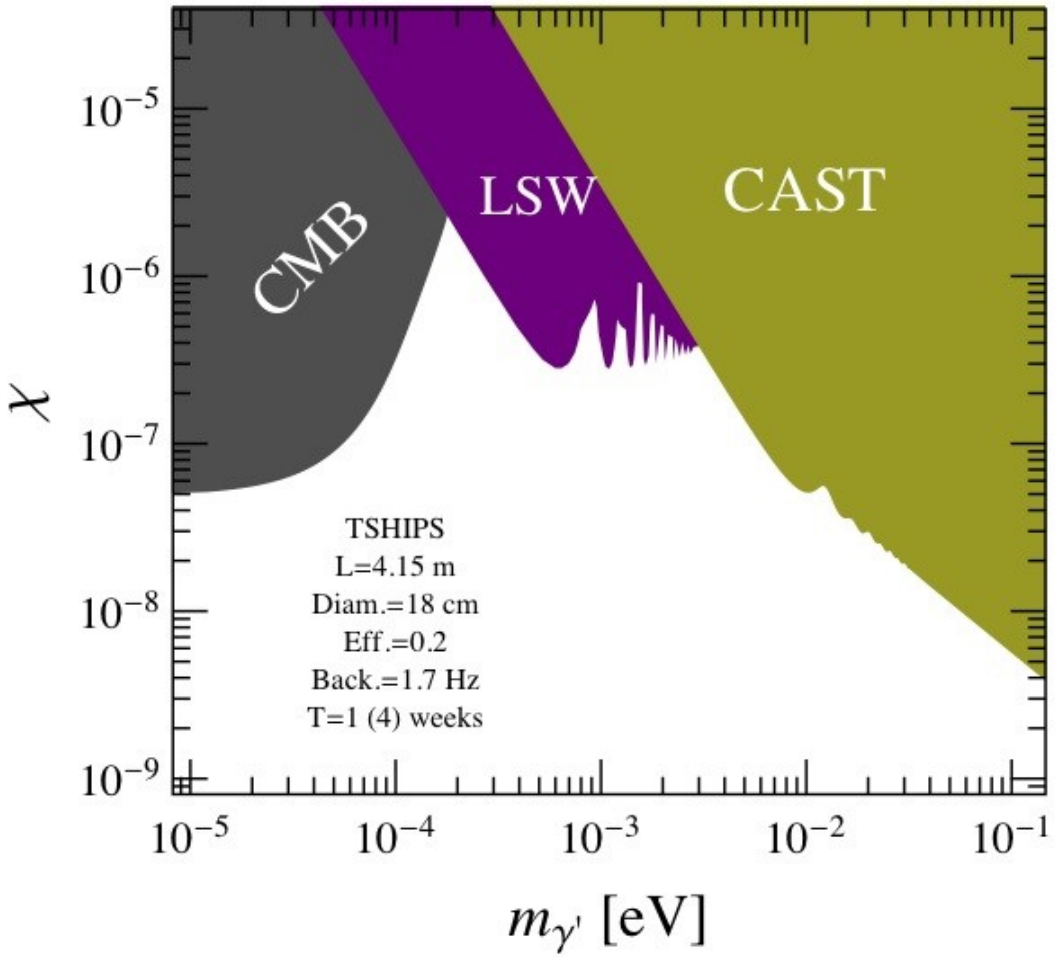
- Solar astroparticle search conducted by DESY and HS
- Best hp source to be exploited is our sun
- Flavor changing between hp and ordinary photon
- Oscillations make hps from the sun detectable with telescopes, so called helioscopes.
- Measurements mainly in optical and near-infrared frequency range

Important points about SHIPS

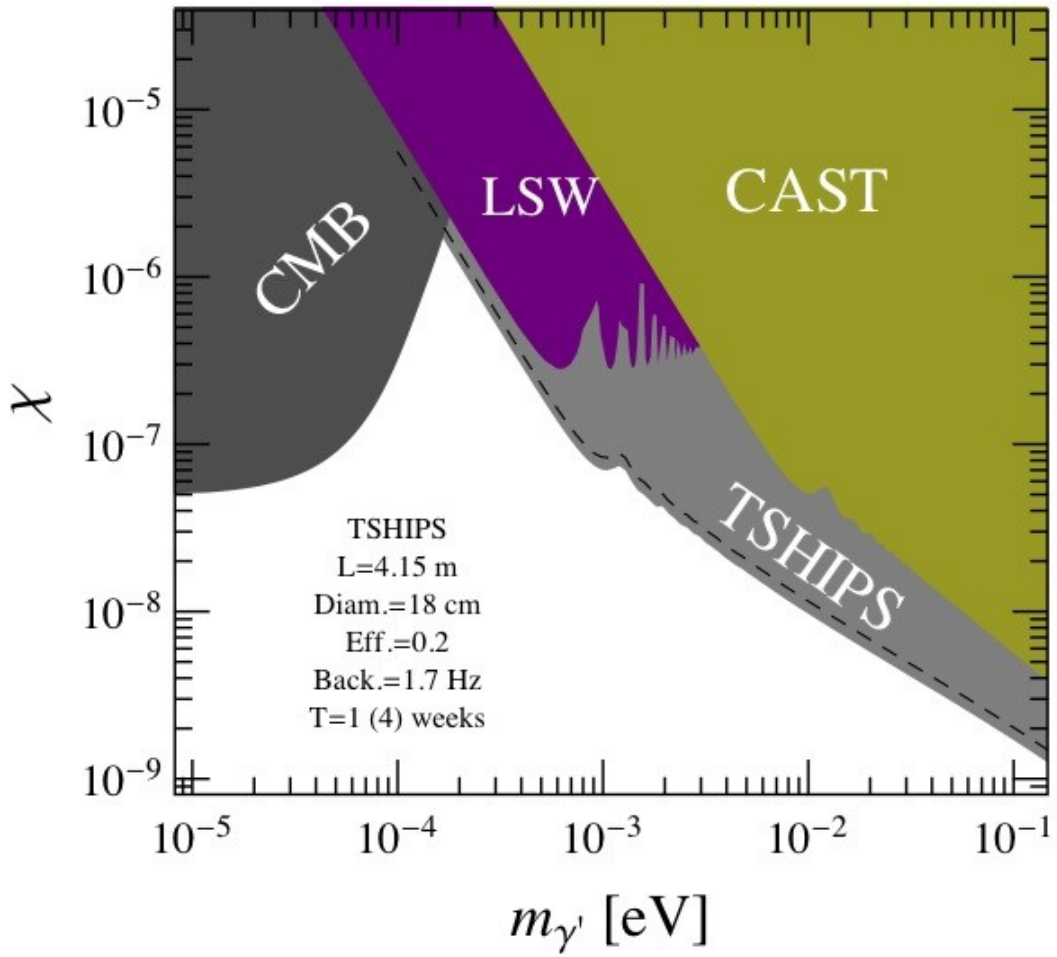
- Low pressure increases reconversion probability

  → vaccum pressures with at most 10^{-4} *mbar*
- Expected signal strength depends on the volume of the vacuum vessel
- PMTs or CCDs as detectors for totally light-shielded helioscope
- Determination of hidden photon mass and coupling parameter χ or estimation of their best limits

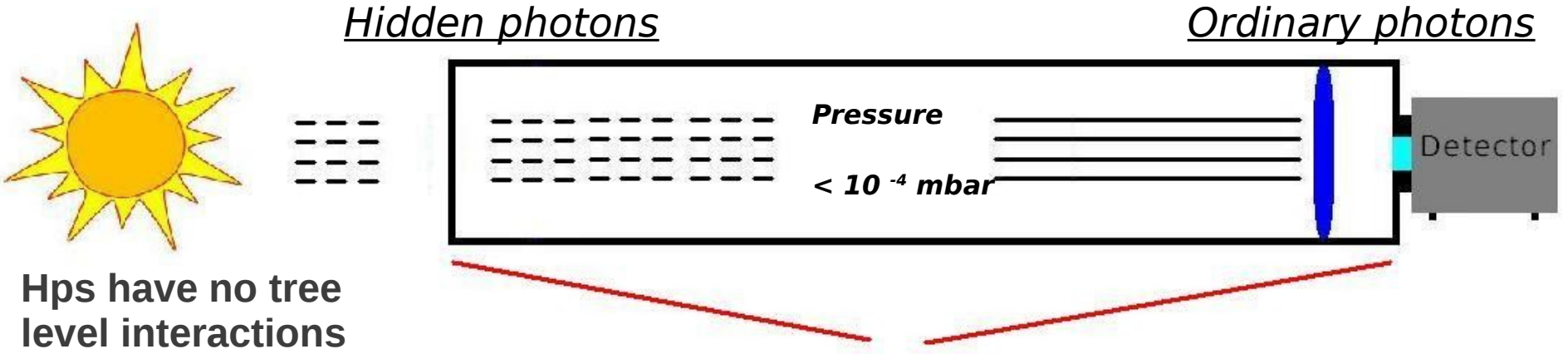
Hidden photon mass and coupling plane



Hidden photon mass and coupling plane



Helioscope design



Hps have no tree level interactions with SM particles and can pass matter freely

- *Totally shielded from daylight*
- *No magnetic field requiered*

Tracing hidden photons

$$N_{\gamma'} = \int \frac{d\Phi_{\gamma'}}{d\omega} \cdot A \cdot T \cdot P_{(\gamma' \to \gamma)}(\chi, m_{\gamma'}, \omega, L, \Delta n) d\omega$$

with m = hp mass, L = path length, ω = photon energy,

$\Delta n = n - 1$, n: index of refraction of the medium

Tracing hidden photons

$$N_{\gamma'} = \int \frac{d\Phi_{\gamma'}}{d\omega} \cdot A \cdot T \cdot P_{(\gamma' \to \gamma)}(\chi, m_{\gamma'}, \omega, L, \Delta n)\, d\omega$$

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Photon - hidden photon oscillations

- The probability of photon - hp oscillations is given by:

$$P(\gamma \rightarrow \gamma') = \frac{\sin^2 2\chi}{\left(cos2\chi + \frac{2\omega^2 \Delta n}{m_{\gamma'}^2}\right)^2 + \sin^2 2\chi} \sin^2 \frac{m_{\gamma'}^2 \cdot L \cdot \sqrt{\left(cos2\chi + \frac{2\omega^2 \Delta n}{m_{\gamma'}^2}\right)^2 + \sin^2 2\chi}}{4\omega}$$

with m = hp mass, L = path length, ω = photon energy,

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- Oscillations are significantly smaller when $\Delta n > 0$
- For visible light a pressure below 10^{-4} mbar ensures that oscillations will not be damped

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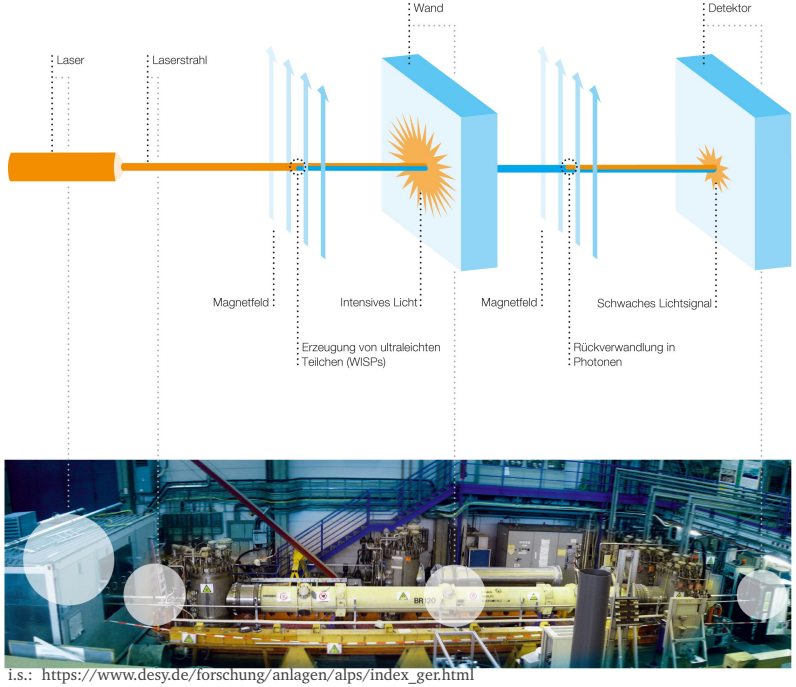
Solar Hidden Photon Search

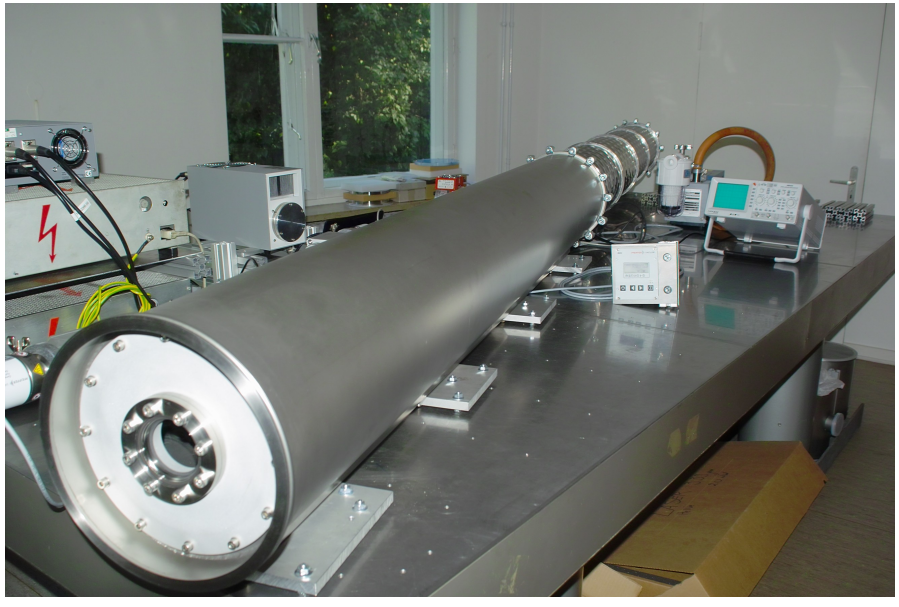
SHIPS is an offspring of the ongoing ALPS projects at DESY. Unlike the laboratory experiments ALPS and ALPS II, SHIPS does not involve magnetic fields.



i.s.: https://www.desy.de/forschung/anlagen/alps/index_ger.html

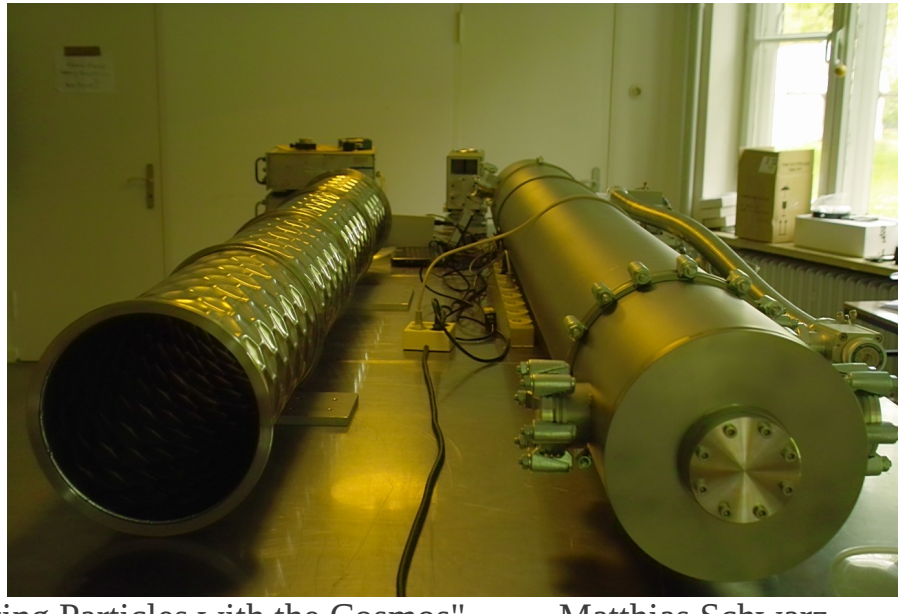
The SHIPS helioscope is operated at the Hamburger Sternwarte in Hamburg-Bergedorf.

TSHIPS helioscope(s)



- TSHIPS1 helioscope is a 4.3 m long tube combined from two single TSHIPS tubes plus detector compartment.
- Both single TSHIPS tubes are fully functional helioscopes and also serve as test-bench for the much longer and wider TSHIPSIII.

- Vault structure tube assembled from 50 cm segments welded together.
  Wall thickness of 0.8 mm with same solidity of the second tube (3mm) yields a significant weigth reduction (75 kg/14.5 kg).



OLT - mount for TSHIPS1

- Fully remote controlled Oskar-Luehning-Telescope (OLT) located at the Hamburger Sternwarte used as telescope mount for TSHIPS1:

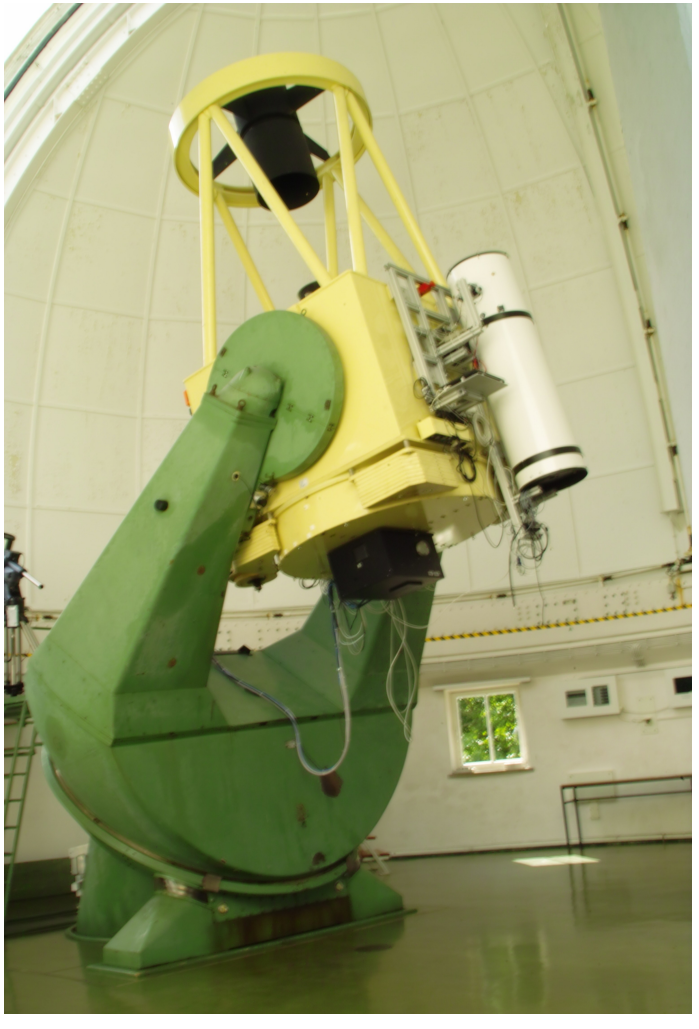
  - Type: Ritchey-Chretien telescope

  - Mirror diameter: 1.2 m

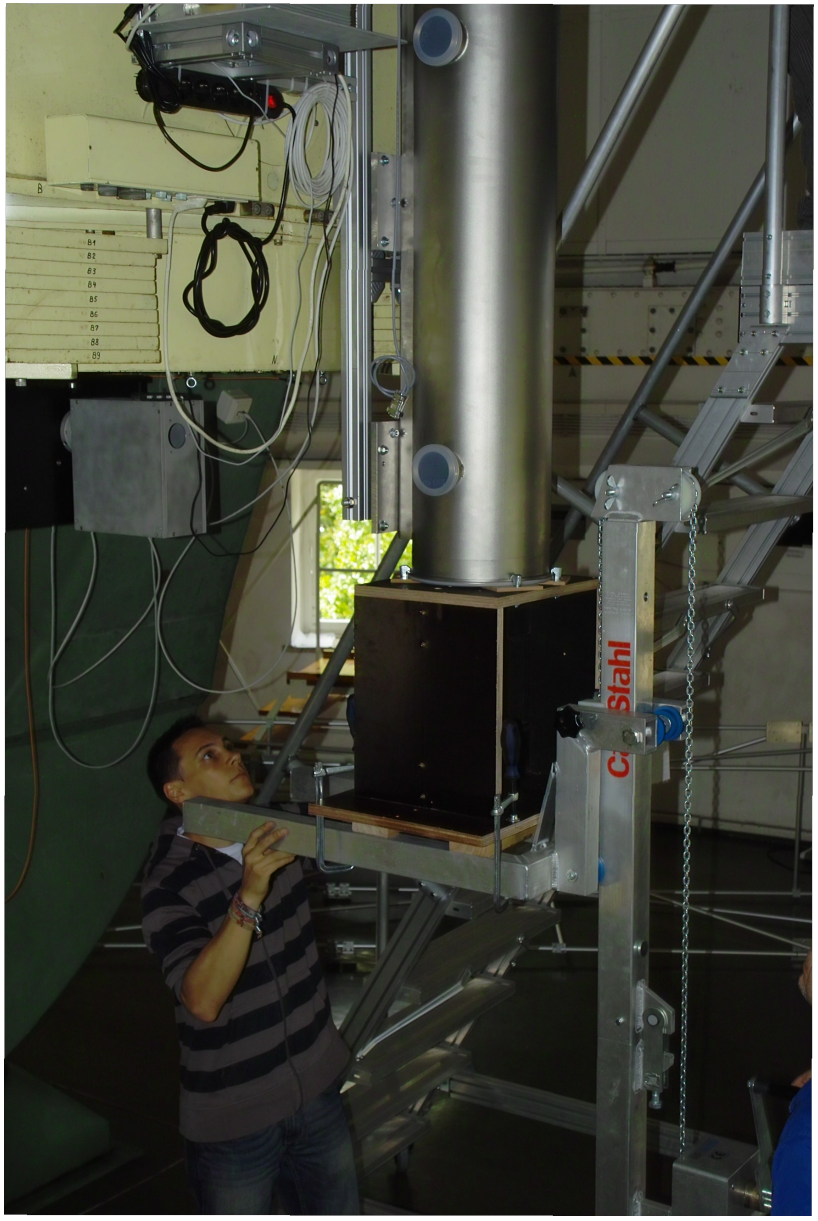
  - Focal length: 15.6 m

  - CCD: Cooled Apogee with 1024 x 1024 pixels, FOV: 5.4' x 5.4'

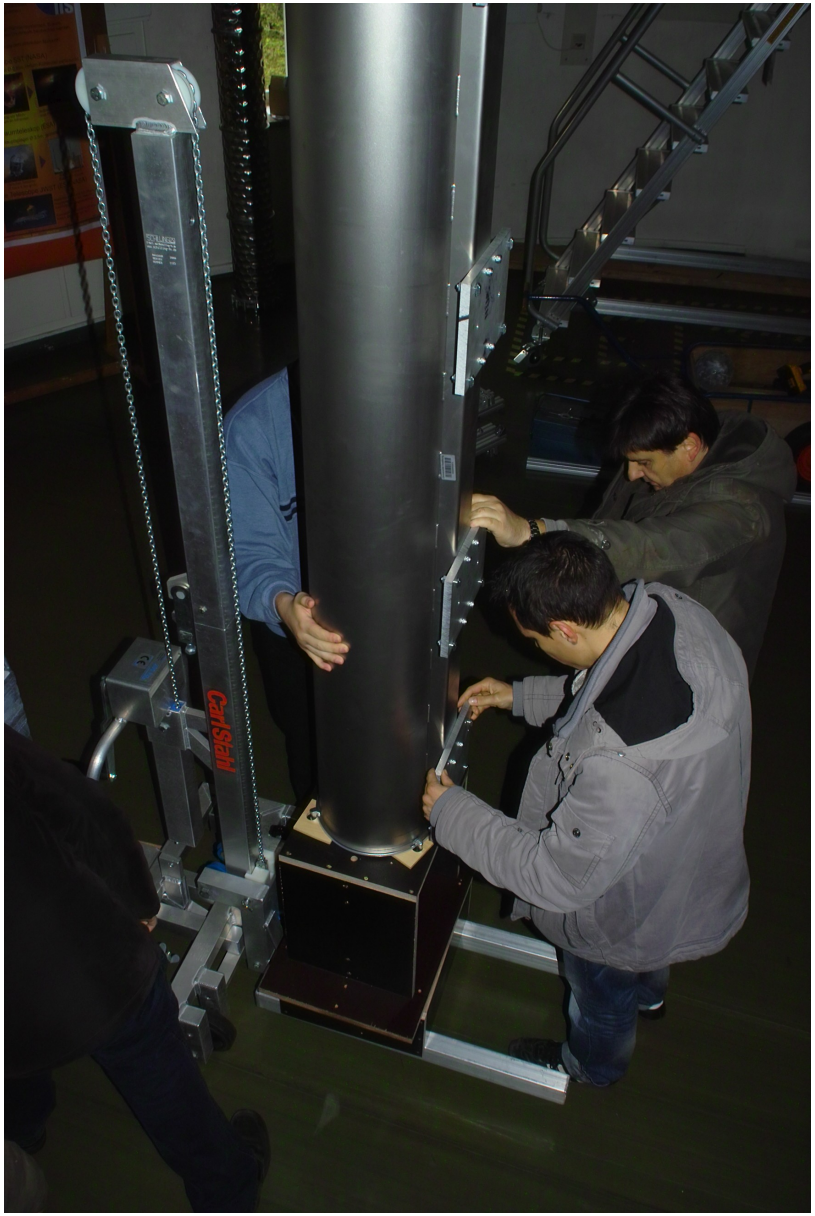
- The next phase, a much longer and wider TSHIPSIII including its own mount is under development.

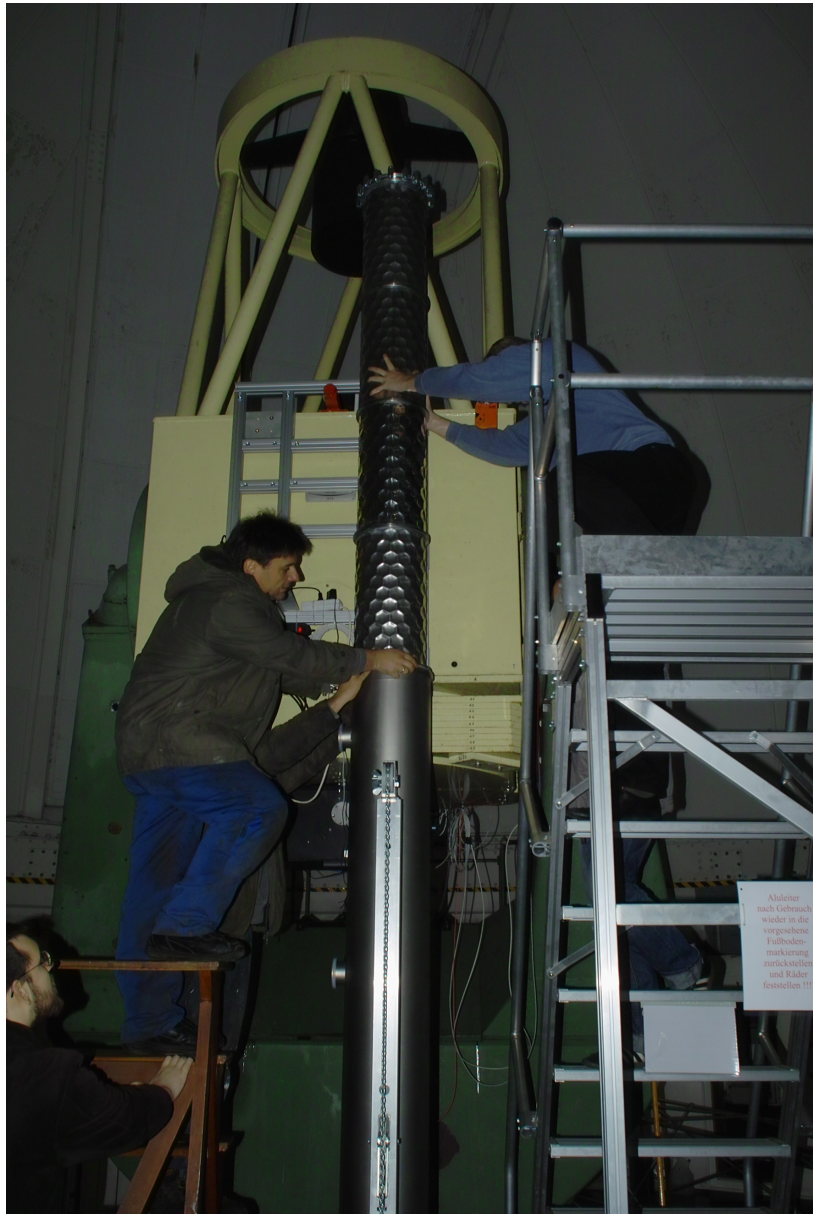


TSHIPS1 mounted onto the OLT



TSHIPS1 mounted onto the OLT





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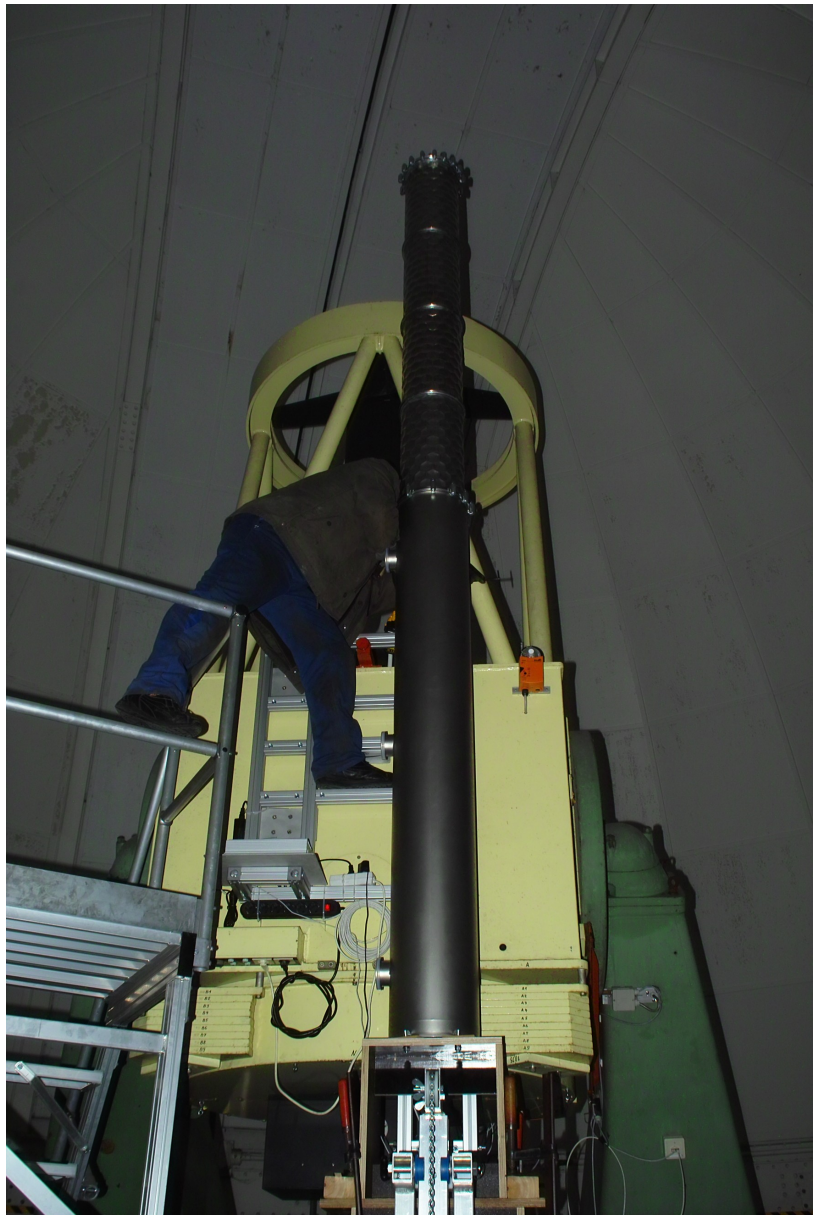
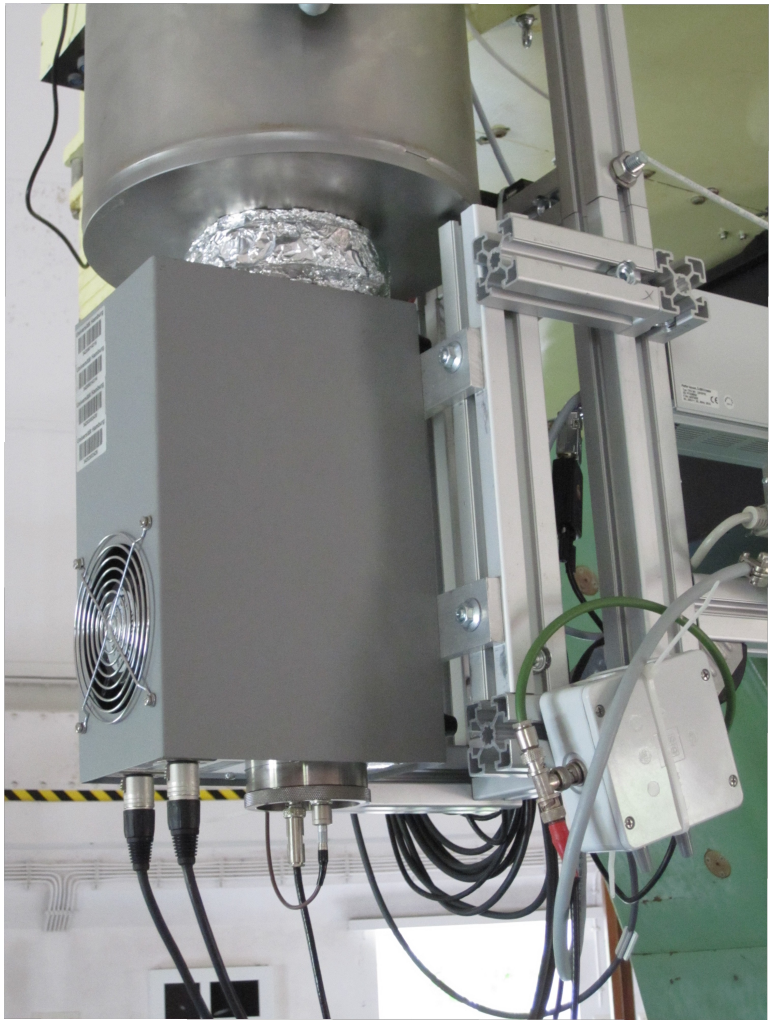
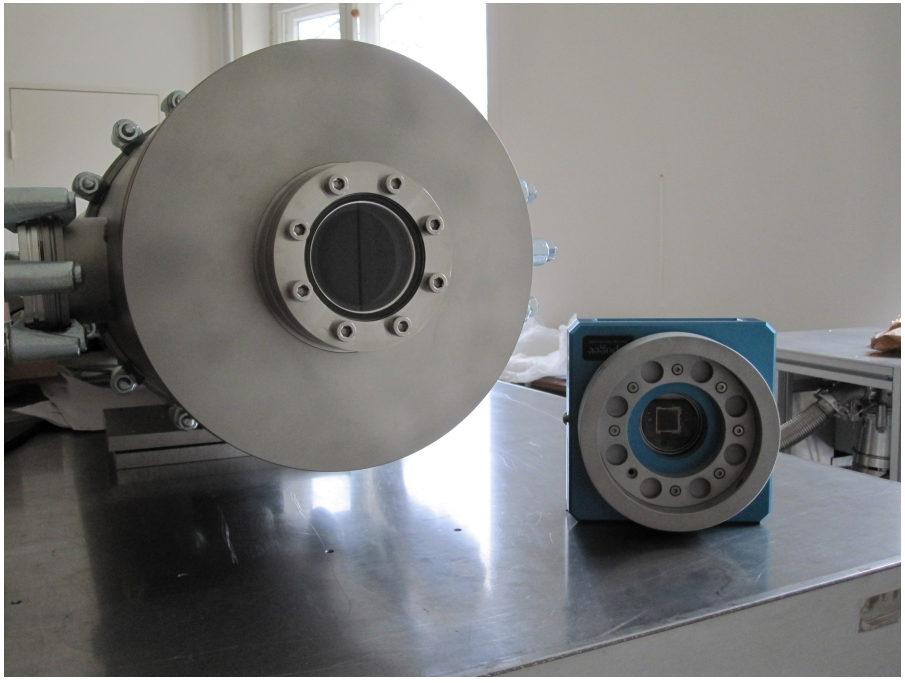


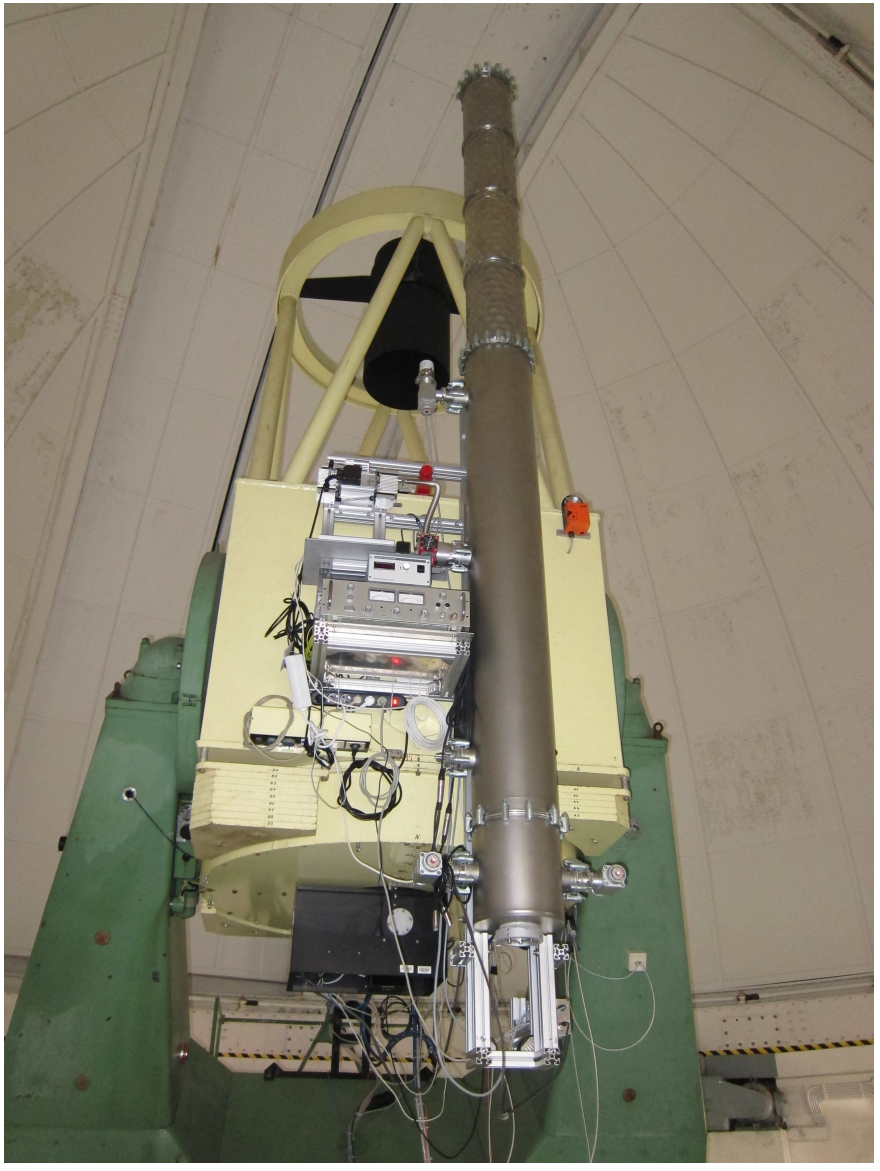
Detector interface

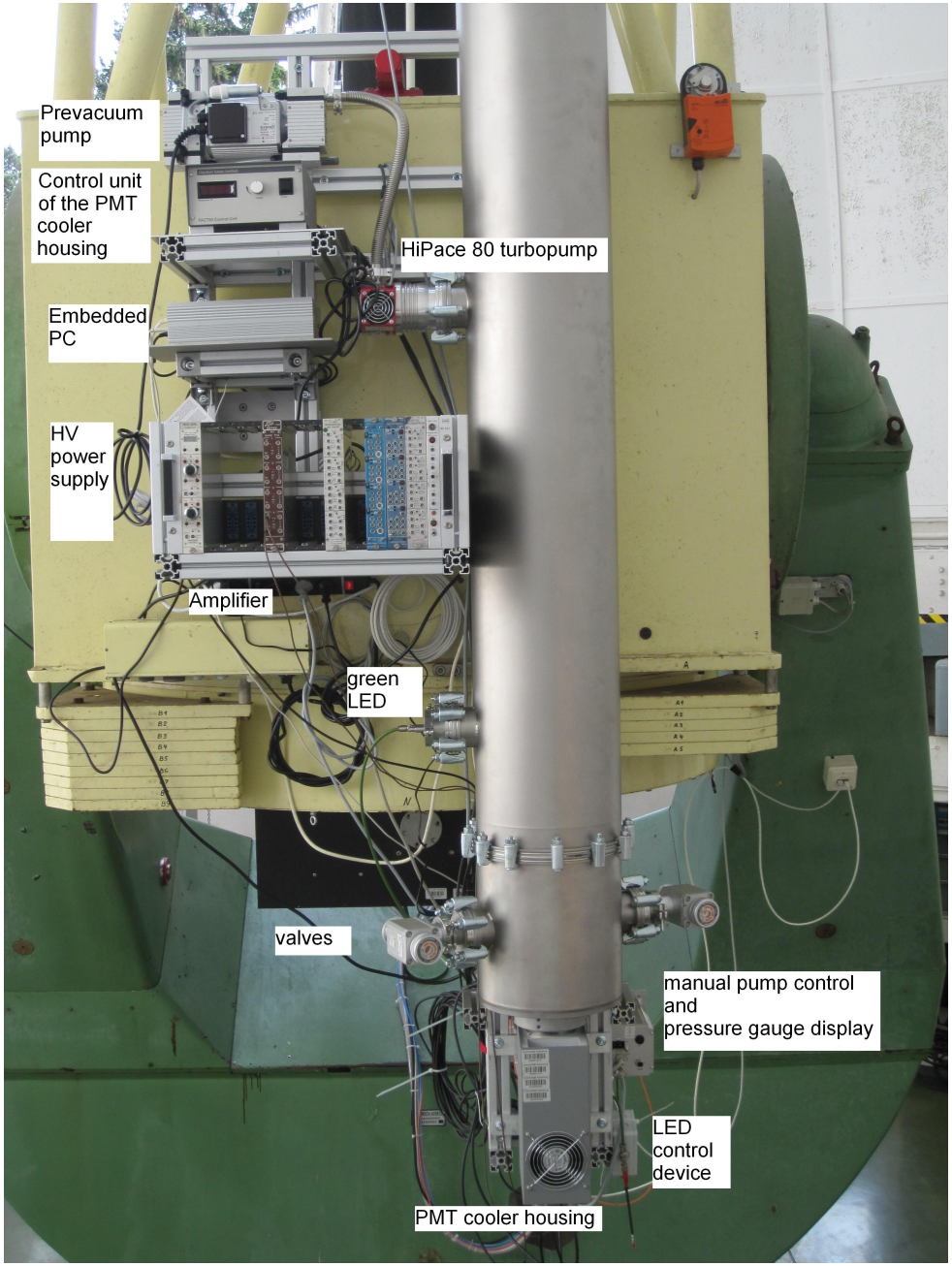


- Flexible and easily adapted detector interface allows an uncomplicated variation of different detectors (CCDs and PMT cooler housing)



TSHIPS1





Setup of the helioscope

- LED for artificial photon flux/signal
- Valves for further devices
- Pressure gauge
- Power supply
- PC
- Vacuum and prevacuum pumps
- Control units

All data like pressure, temperatures, time, etc. is recorded

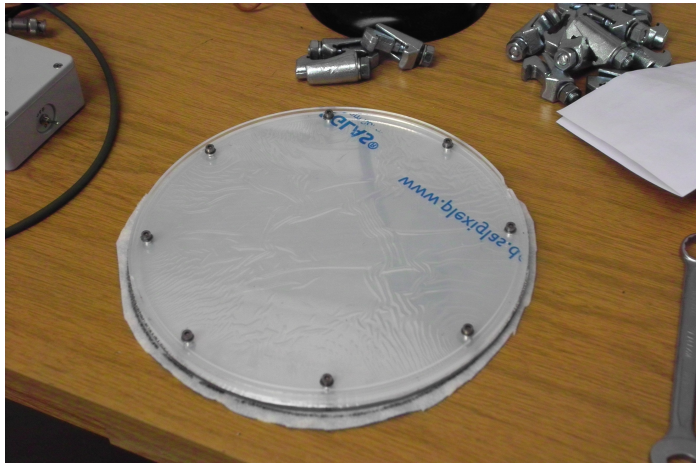
Matthias Schwarz

Vacuum pumps

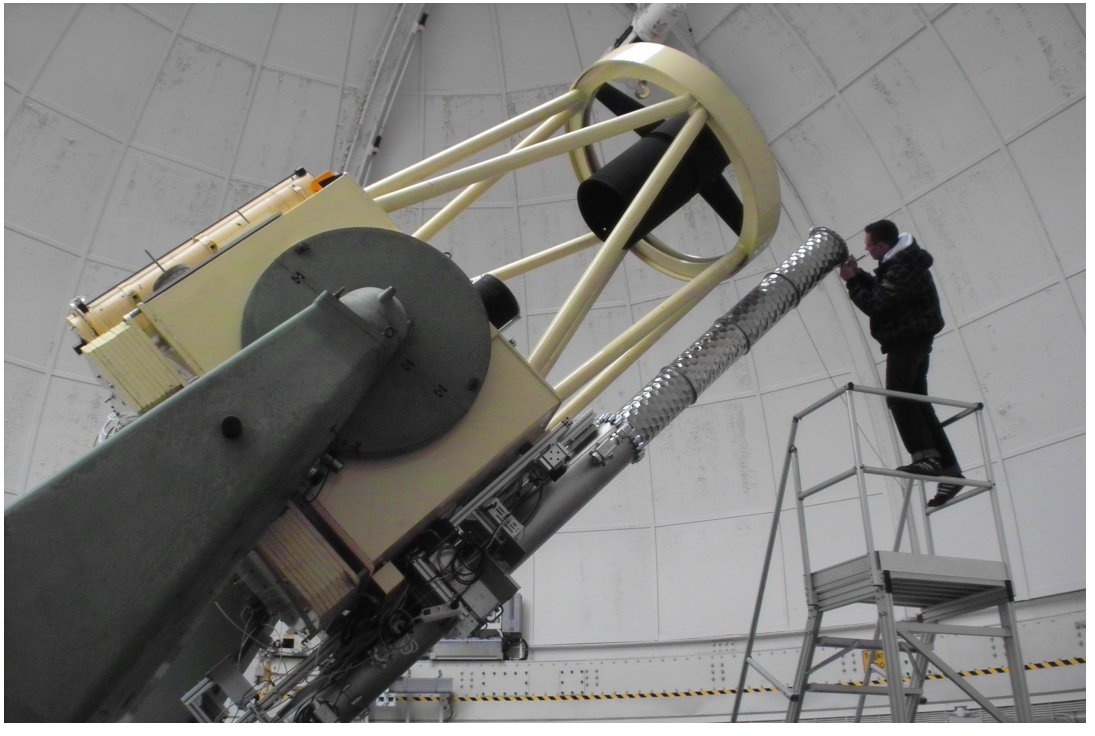
High Pace 80 and MVP 15-4:

- Generates a vacuum pressure of about 10^{-6} mbar
- Short connection of just 50 cm
- Fast rotating turbo pump has to be operated very carefully (1500 Hz). No fast motions.

Pointing and tracking accuracy

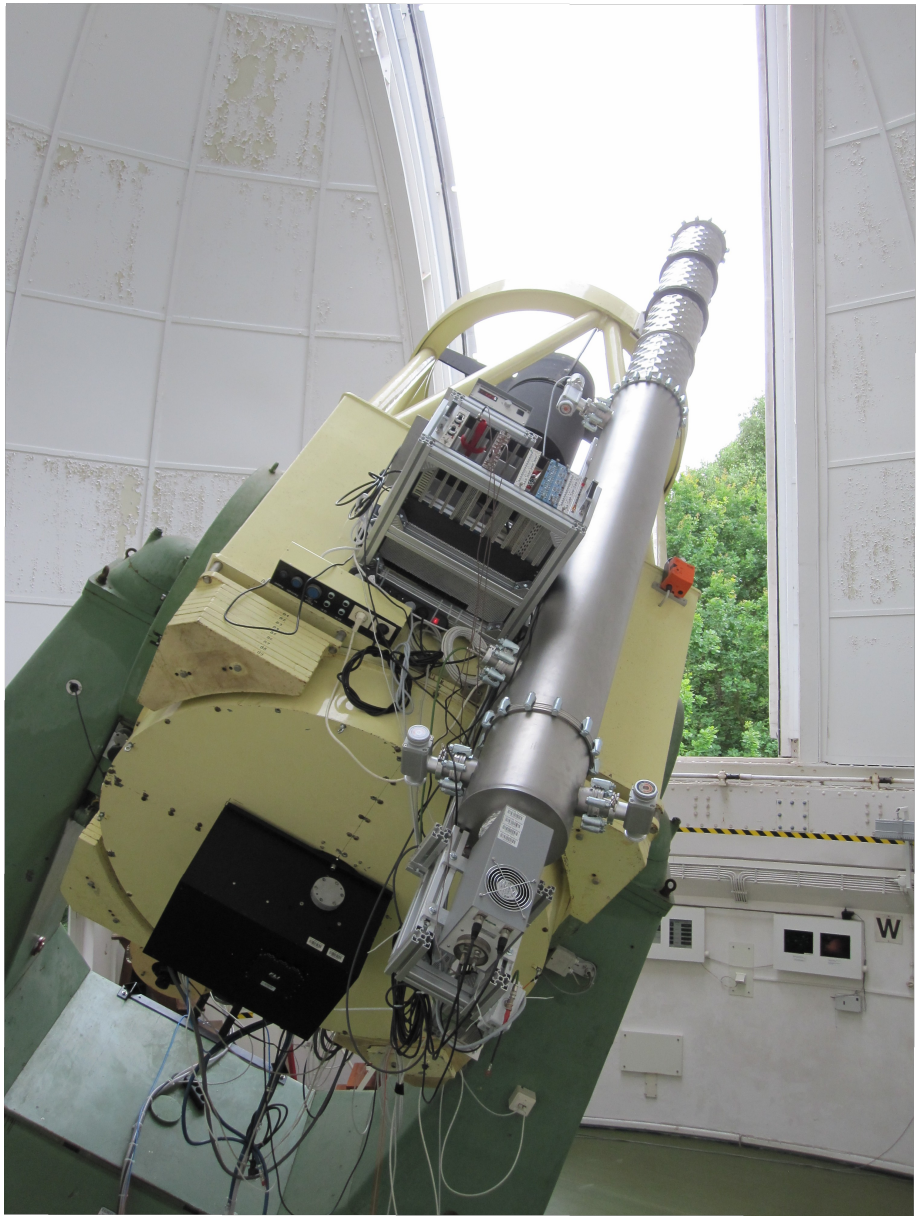


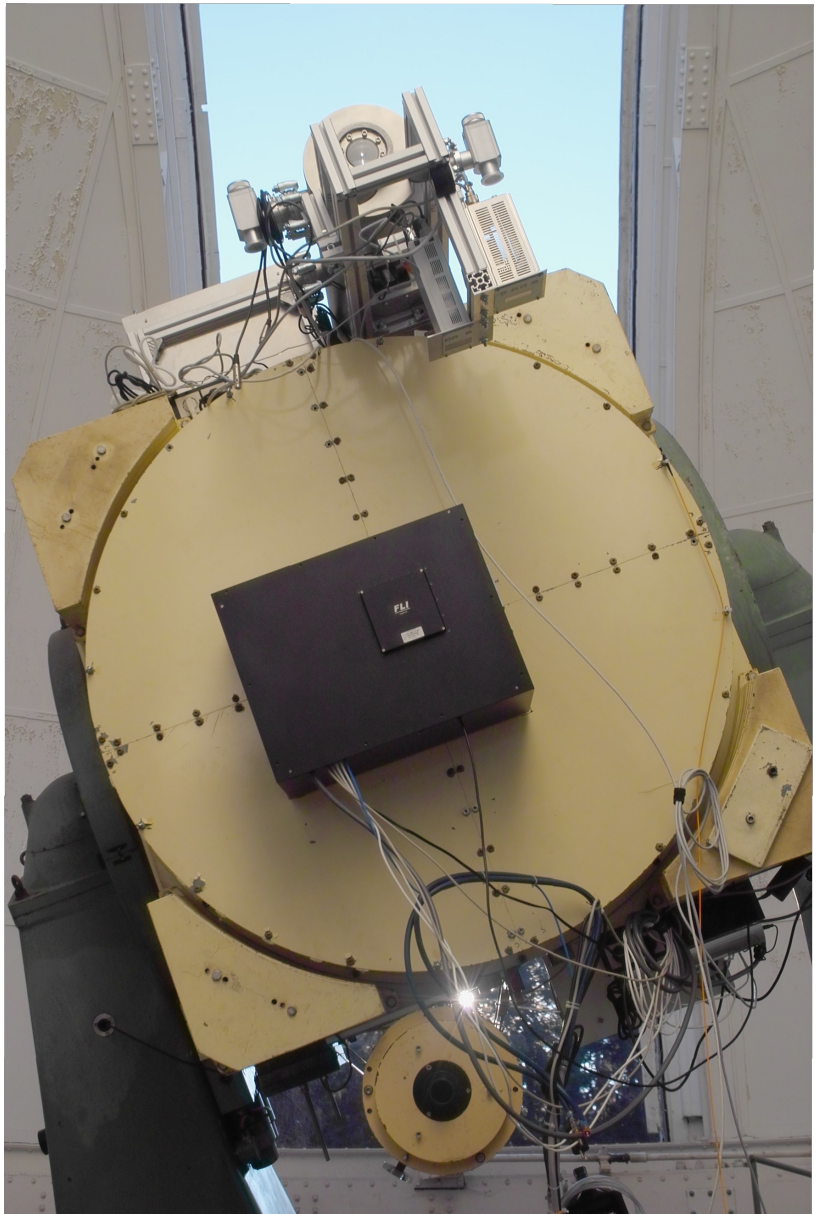
← Solar filter (10^{-5}) fixed by two acrylic glass discs



- Precise positioned counterweight
- Direct sun observations (filter) for accurate TSHIPS1 pointing and the proper tracking for long time
- Guiding camera for tracking corrections not yet available
- Even without correction, position of the sun's image on chip varied a fraction of pixel number within hours.
- Good sun tracking is guaranteed.

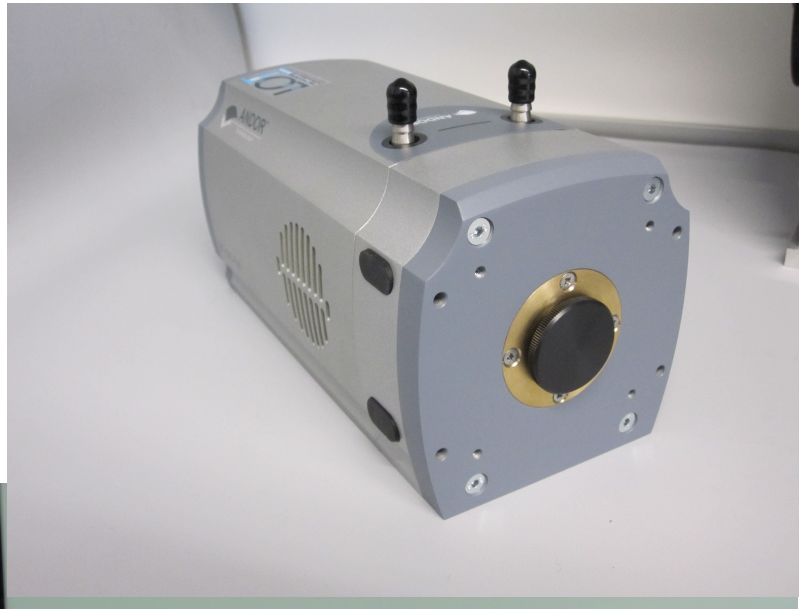
TSHIPS1 in action

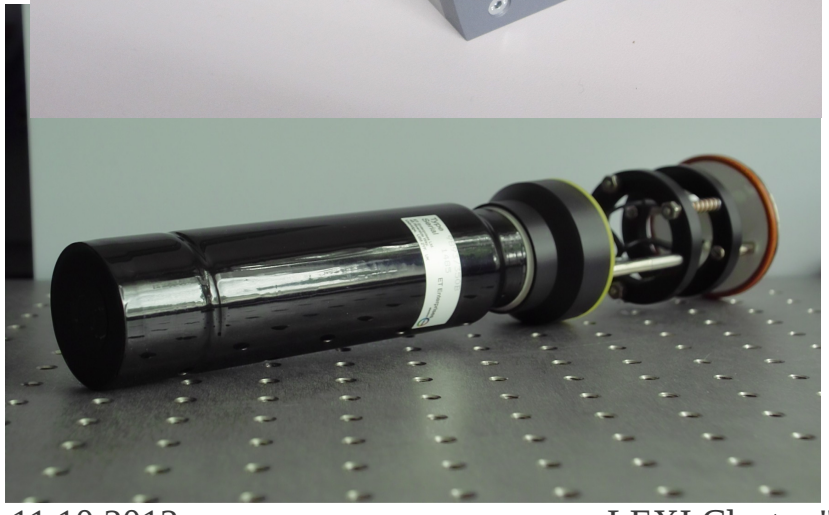




Two Detectors for SHIPS at present

CCD & PMT

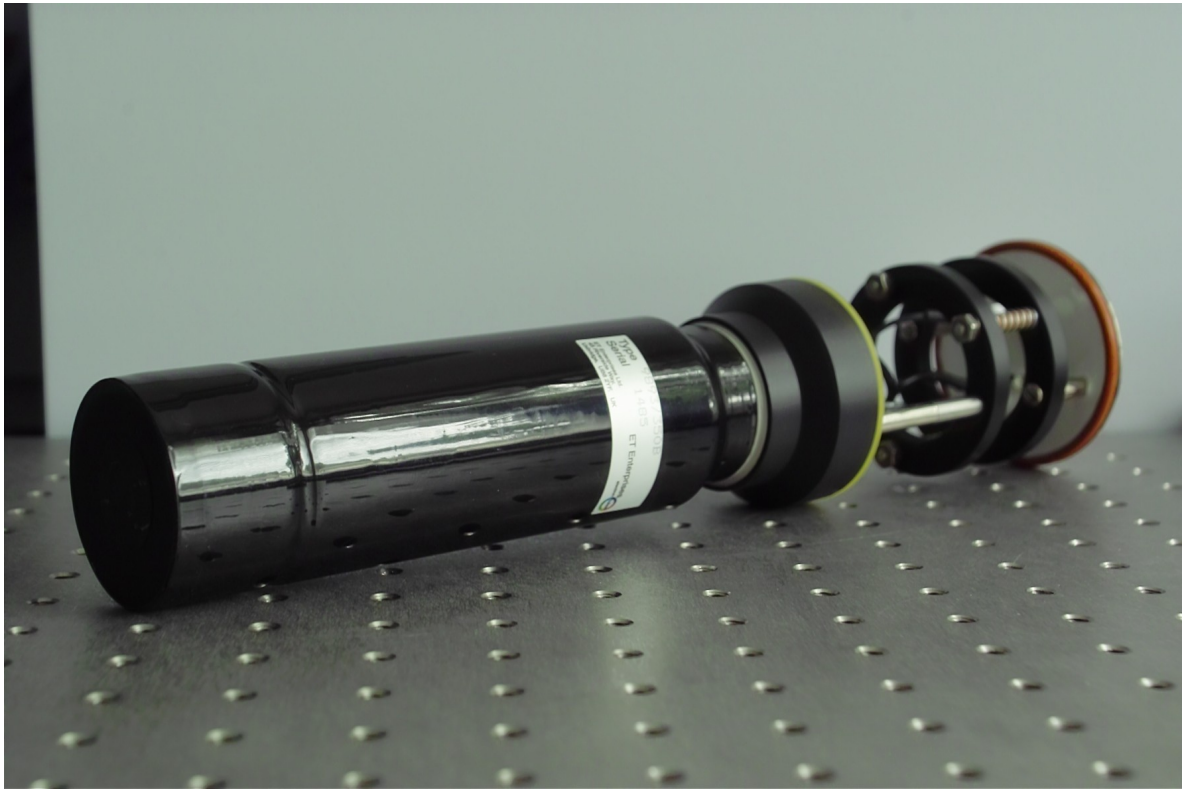




- Low noise properties necessary
- Potential structure in the data requires spatial resolution (CCD)
- PMT lower noise
  CCD detector much higher QE

Detectors for SHIPS

Photomultiplier 9893/350B

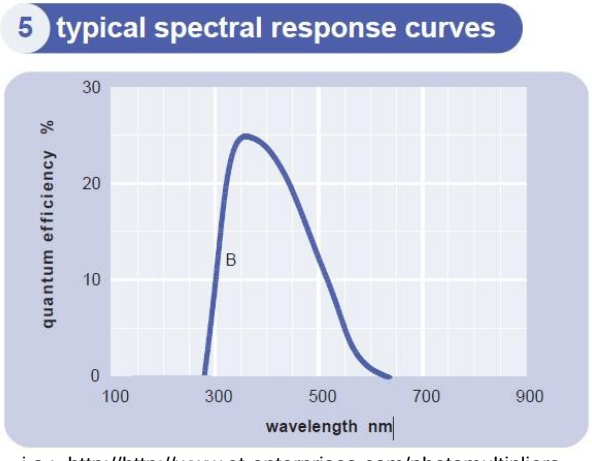


ET Enterprises
9893/350B:

- Low noise: dark current ~ 0.4 Hz
- Single photons detectable
- Operated at -20°C
- Active diameter 9 mm
- Quantum efficiency at peak 25%
- Blue-green sensitive photocathode
- 14 BeCu dynodes of linear focused design for fast timing and extended linearity

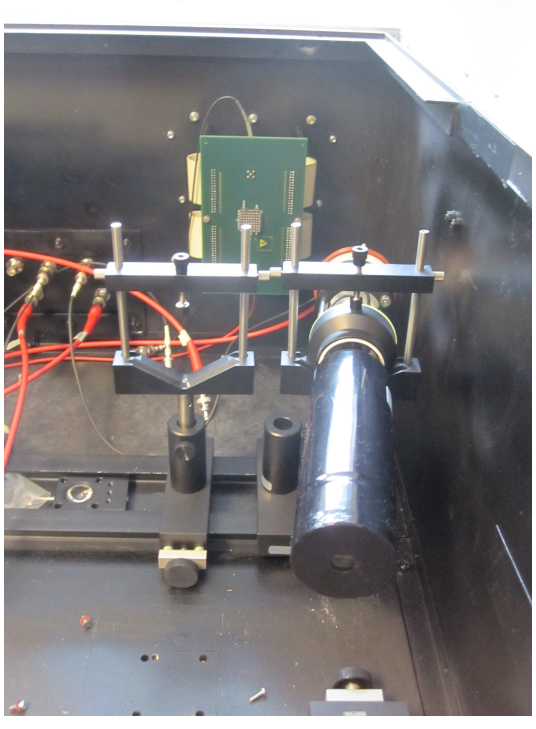
Detectors for SHIPS

Photomultiplier 9893/350B



i.s.: http://http://www.et-enterprises.com/photomultipliers

Lab test in a black box
with a blue LED and filters
of different strength
→ PMT replaced



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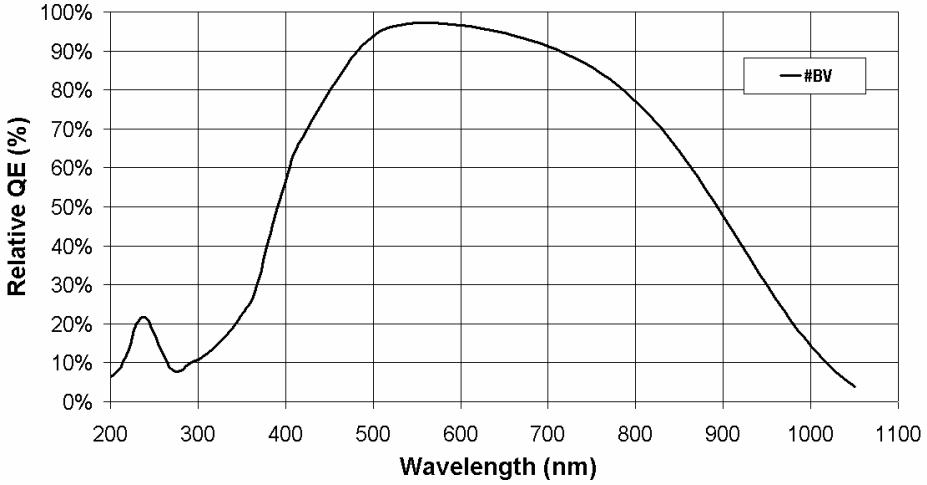
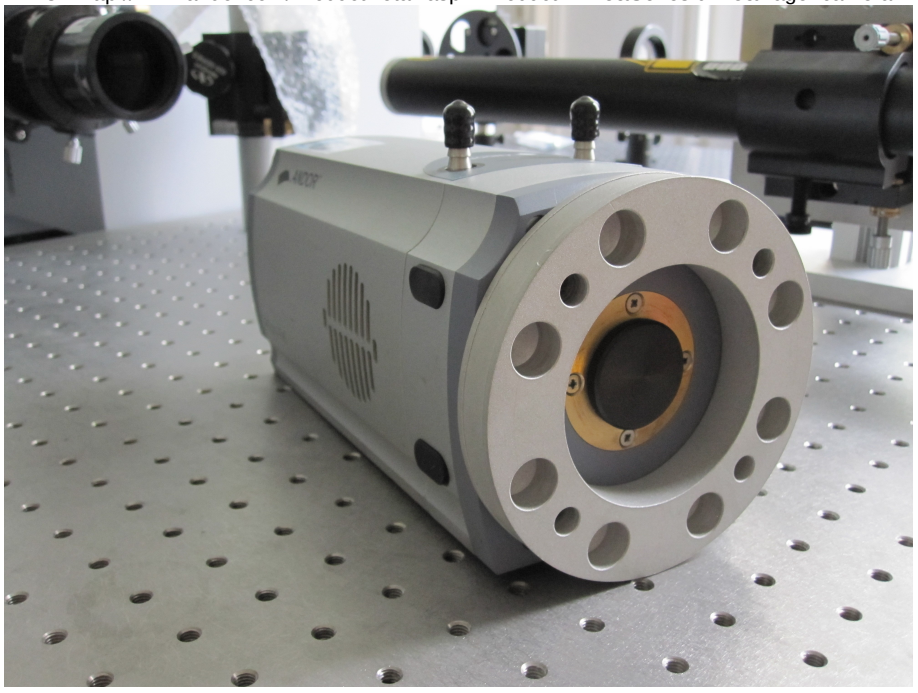
Andor iKon-M



i.s.: http://www.andor.com/ProductDetail.aspx?ProductID=75&SeriesId=75&Page=camera

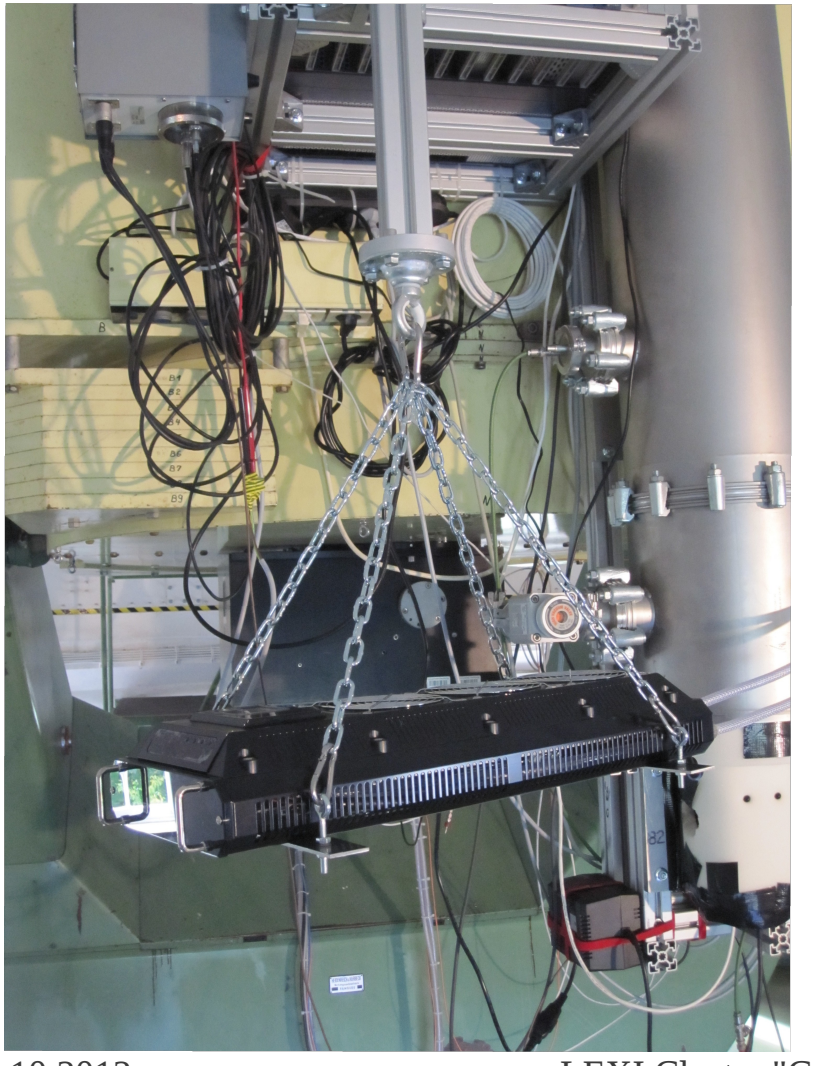


- Cooled back illuminated CCD
- Very low noise output amplifiers
- Read out noise about 3 e^-

  Goal < 1 e^-
- 1024 x 1024 pixels
- 13 μm each pixel
- Up to over 95% QE
- Digitization 16 bit
- Air cooling up to -80°C
- Water cooling up to -100°C
- Frame rate up to 8 fps

Matthias Schwarz

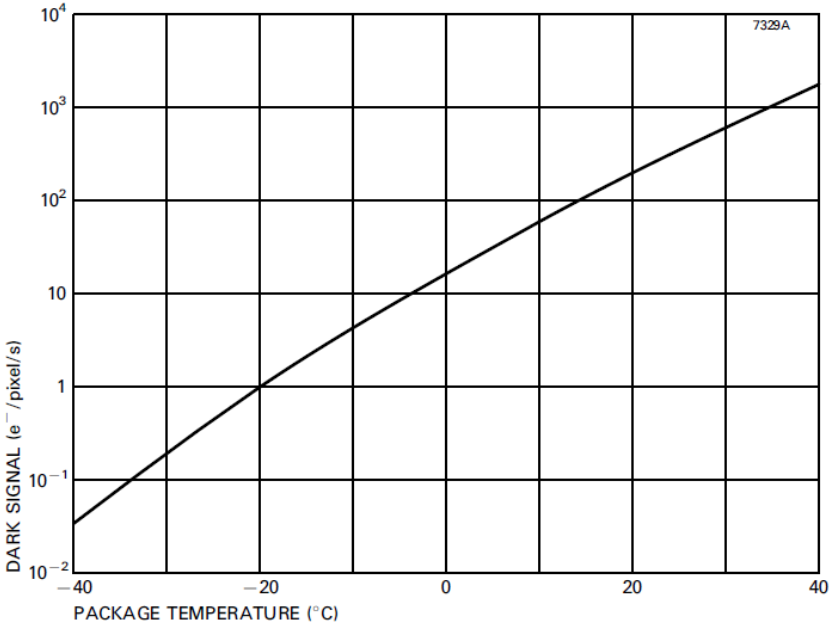
CCD cooling



- Air cooling up to -80°C
- Water cooling up to -100°C
- Koolance EX2-750BK-V2
- -100 °C: Dark current is reduced by more than 3/4 compared to the DC at -80 °C

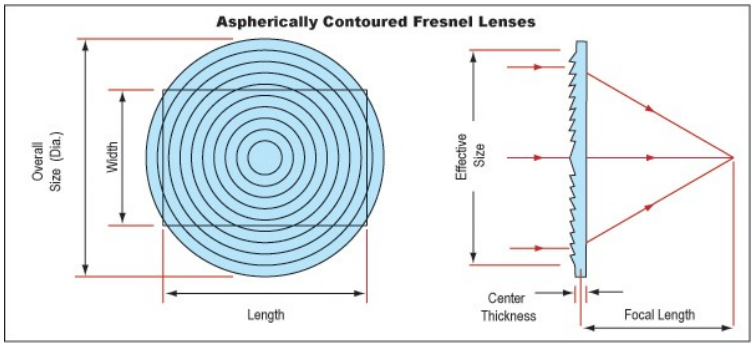
CCD47-10 AIMO Back Illuminated High Performance CCD Sensor

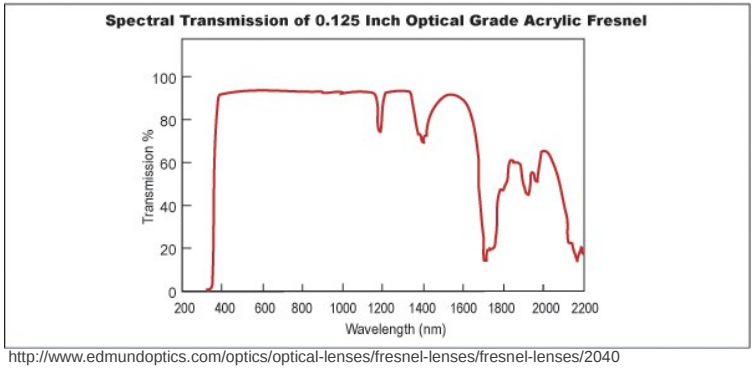
TYPICAL VARIATION OF DARK SIGNAL WITH TEMPERATURE (V_{SS} = +9.5 V)



- Dark current @ -80 °C (typical)
  0.0005 e-/pixel/sec
- Dark current @ -100 °C (typical)
  0.00012 e-/pixel/sec
  → Water cooling

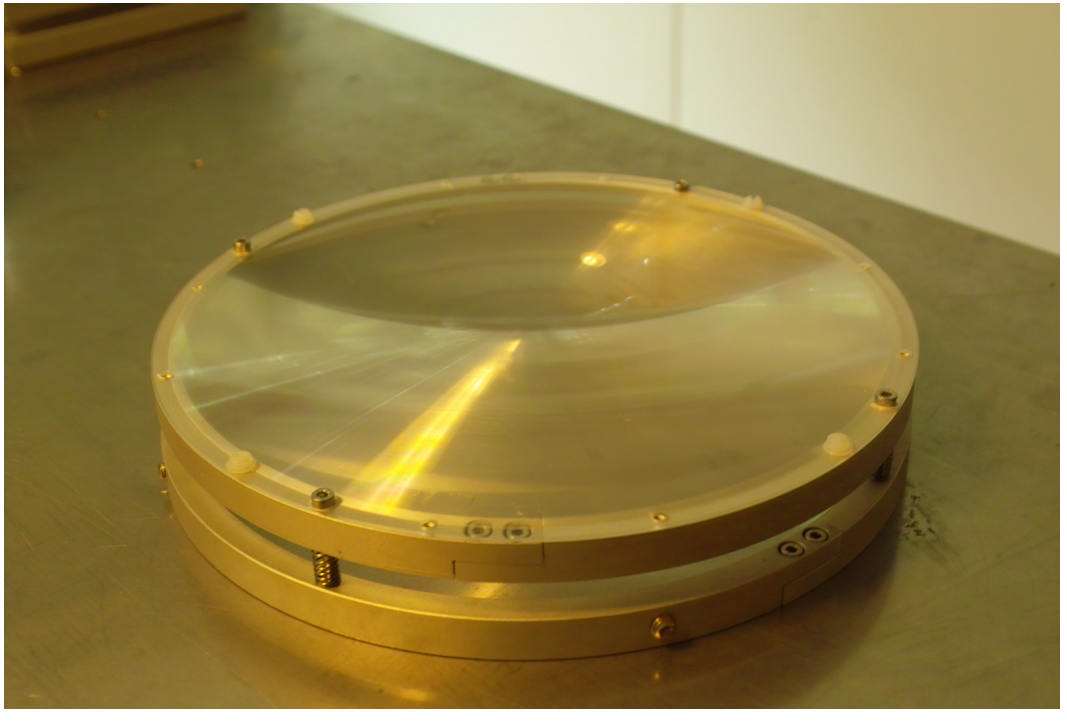
Optics





http://www.edmundoptics.com/optics/optical-lenses/fresnel-lenses/fresnel-lenses/2040

Fresnel lenses ensure a ***high transmission and image quality*** in the optical and near-infrared spectral range. Short focal length of 20 cm.



Optical fresnel astronomy

- HIP4520

by TSHIPS1

fresnel lense

FL 20 cm

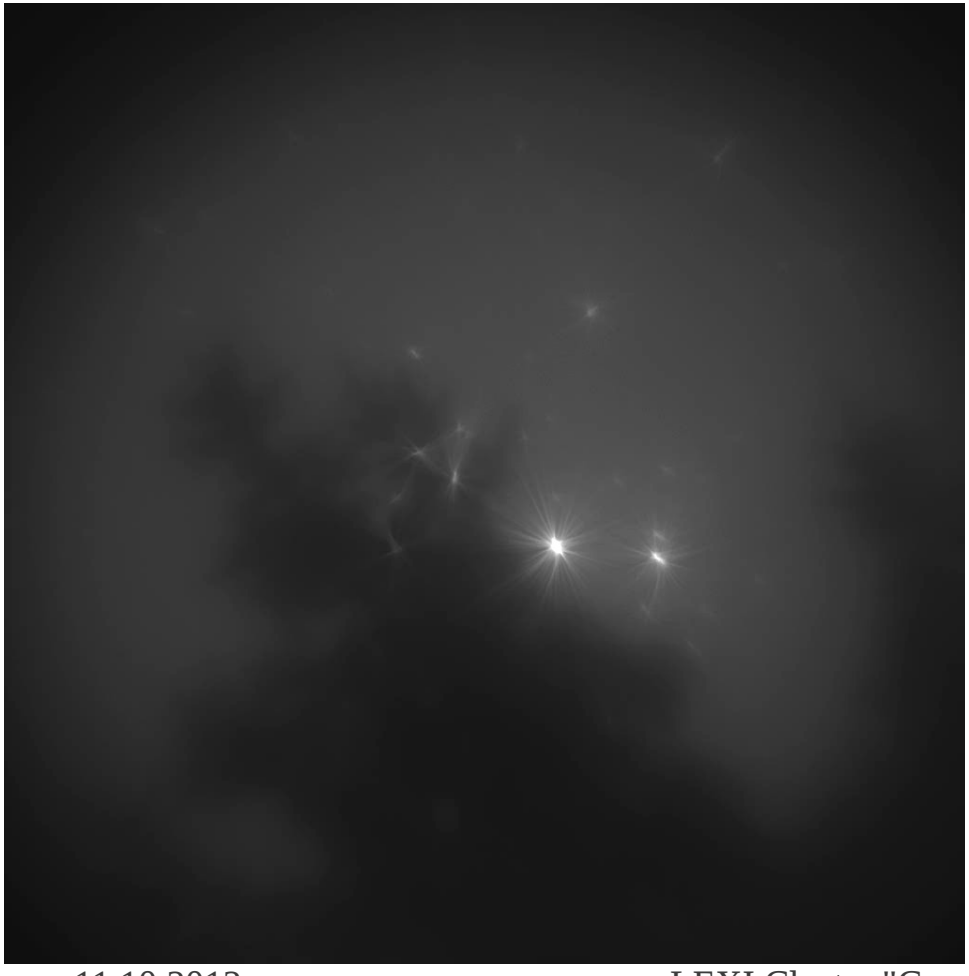
iKon-M

11.10.2012

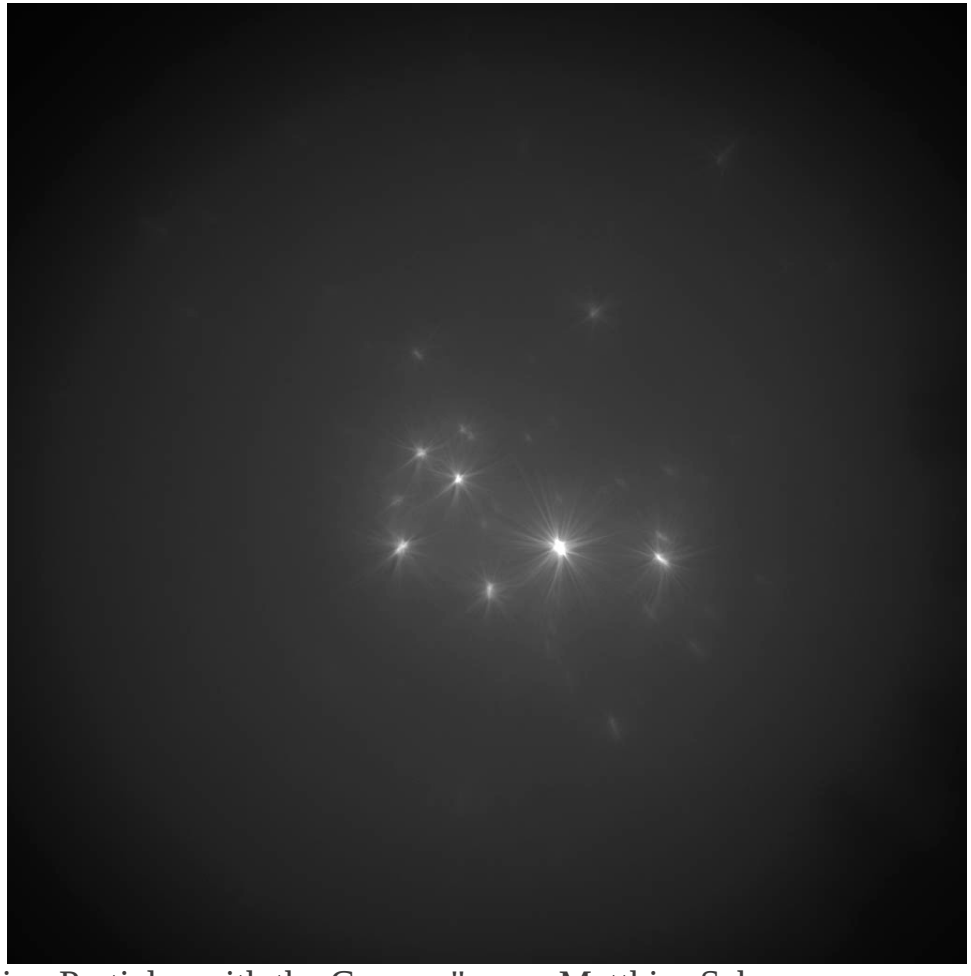
Optical fresnel astronomy

Pleiades

- Astronomy with pines



- Astronomy without trees



Optical fresnel astronomy

- HR0791

by TSHIPS1

fresnel lense

FL 20 cm

iKon-M

11.10.2012

Live sun observations with TSHIPS1

- **Friday session**

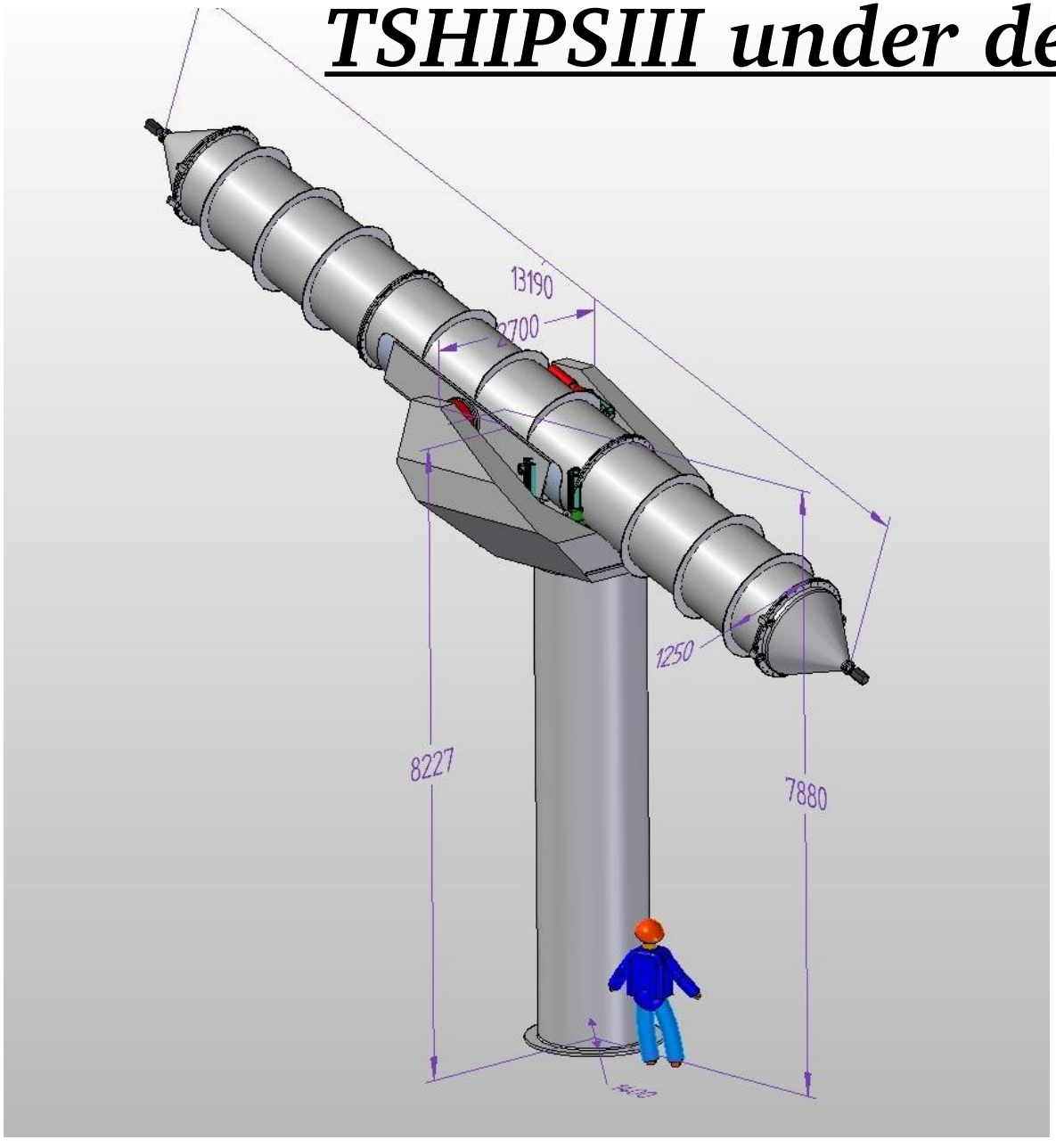
  ”Accelerators and Detectors”

- **14:10**

  ”A deep Cooled CCD Prototype as an

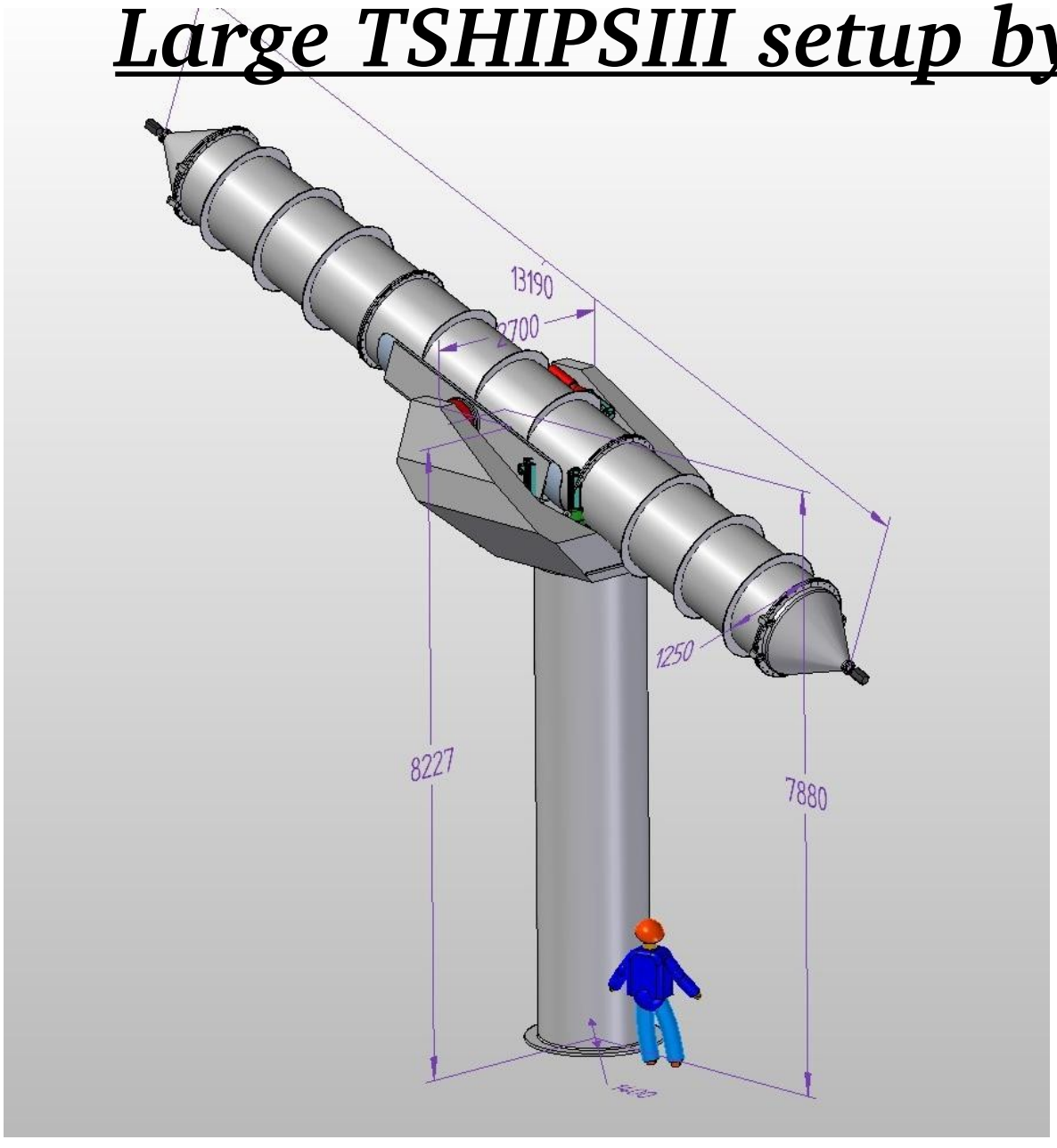
  Alternative Detector for SHIPS”

TSHIPSIII under development



- In the next SHIPS step a larger and wider helioscope is planned - TSHIPSIII
- All findings from TSHIPS1 will be used here
- More effective hp detector
- Better sensitivity for hp mass and coupling parameter

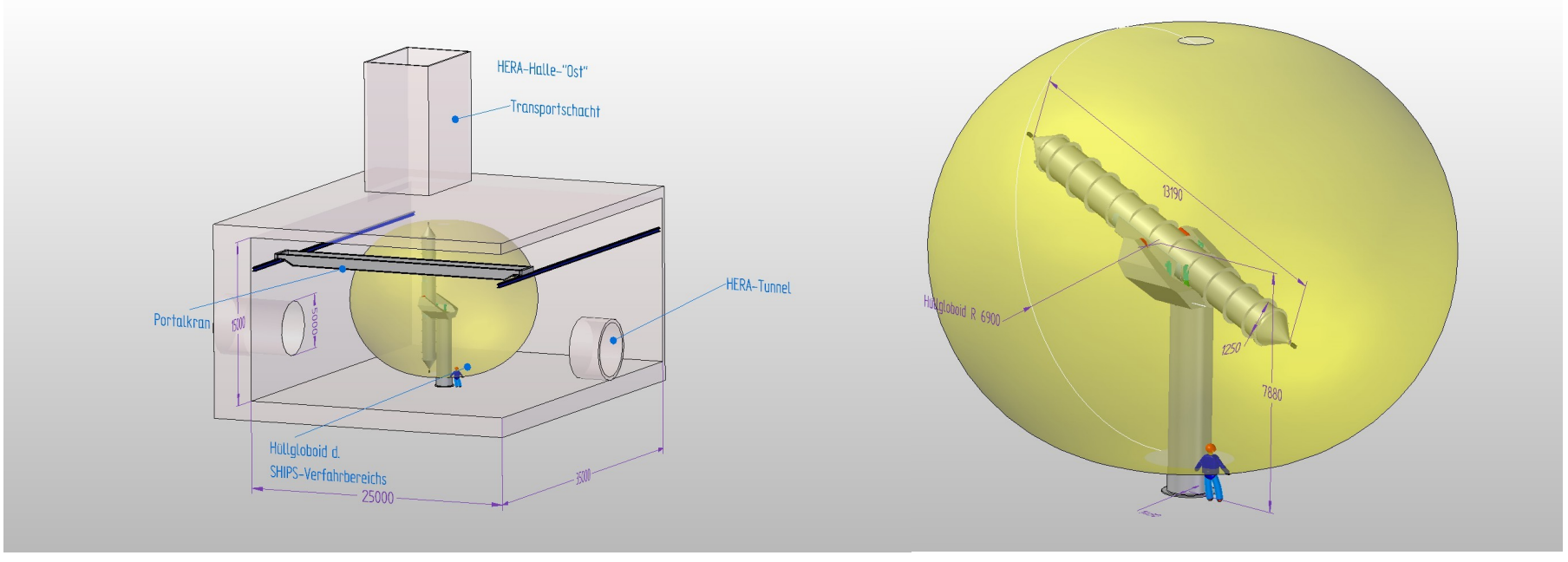
Large TSHIPSIII setup by ZM 1 (DESY)



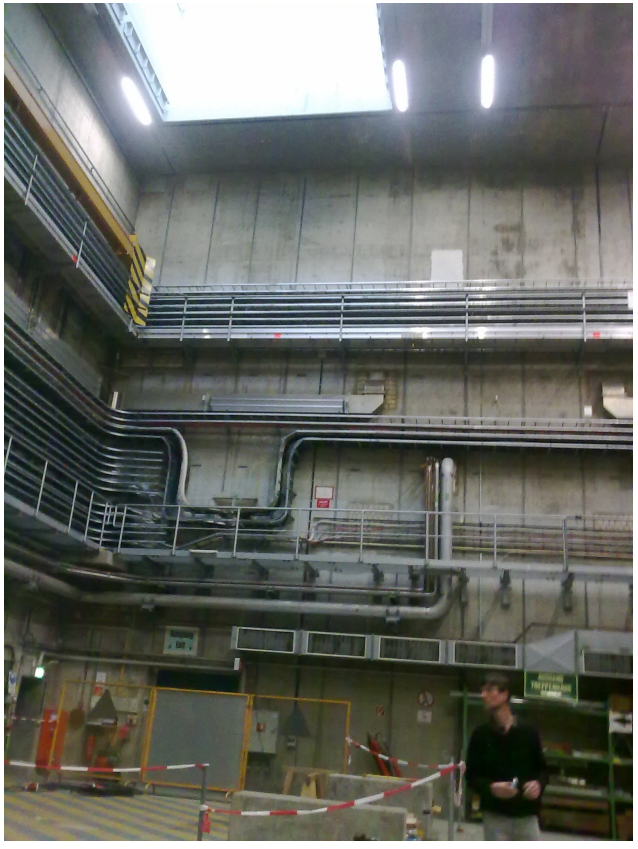
- Tube length up to 13 m and 1.25 m diameter
- Alt-az mount
- Cost reduction:

  Planned to be placed inside a hall of the shut down HERA accelerator ring at DESY

Large TSHIPSIII setup by ZM 1 (DESY)



Zeus hall at Hera accelerator ring



- Site testing at empty ZEUS-hall of HERA ring at DESY
- Hall available
- Substantial reduction in costs and construction time

Conclusions

- Measurements for detection of sub-eV hidden sector photons succesfully started
- Ongoing data taking
- Estimating of new constraints to hidden sector boson parameters
- We keep on course

Thank you!

ALesage

***WÖTAS* -Largest Reptile Species of the TSHIPS Family - in Action : Searching for Hidden Photons in Dark Matter**

*WÖlbstruktur Teleskopfür A Stroparticles

Observations

- We estimated the dark current noise Φ_{noise} (single PMT + tube) to be 1.7 counts/sec
- The SHIPS sensitivity (with 3σ) is given by:

$$\Phi \simeq 3\sqrt{\left(\frac{\Phi_{noise}}{T}\right)}$$

- Estimating a flux of one hp every 100 seconds on our SHIPS tube, a discovery could be achievable during a long term sun observation of about 2 days
- New constrains for m and χ can be gained by ~ 3 weeks

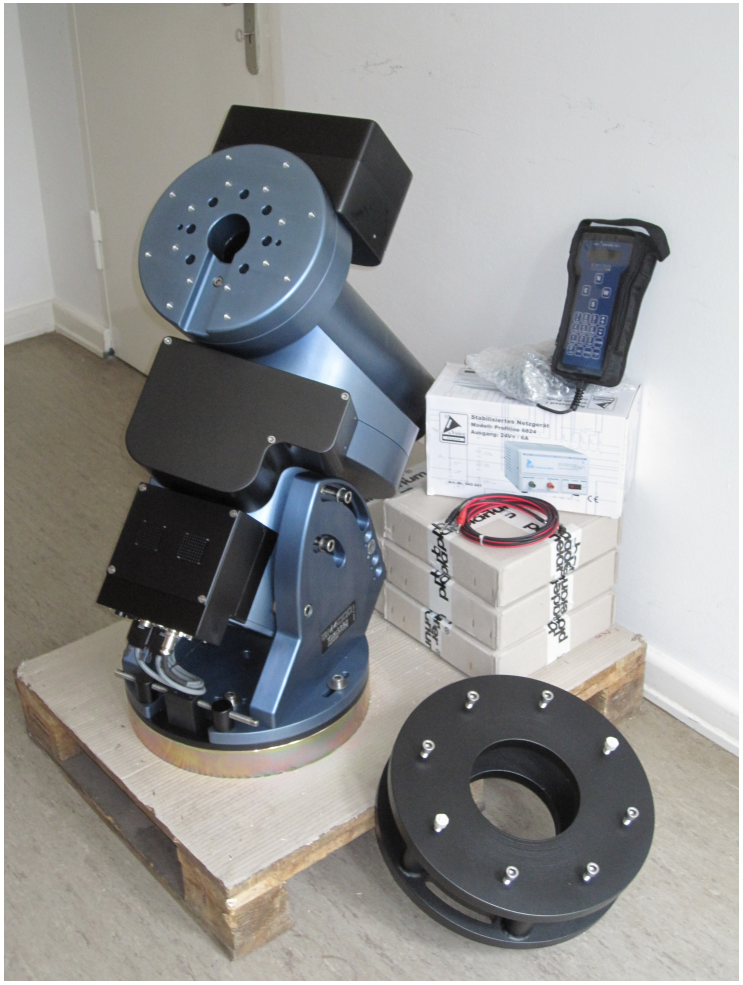
Optional TSHIPS shelter refurbished

- Weatherproof building with big opening to the south for direct sun observations (pointing and tracking accuracy tests)
- 24 h observations possible
- Massive fundament present already

Shelter for single TSHIPS

- Highly stable - almost no vibrations on the fundament
- Ideal for a telescope or helioscope (single tube)
- Mount obtained and ready
- 24 h observations feasible

GM4000 – TSHIPS telescope mount



- Equatorial German mount
- Up to 150 kg instrument weight
- Pointing precision < 2“
- Mean tracking precision < +/- 3“
- Enables 24 h observations
- 120 kg heavy

DRS4 Evaluation Board

i.s.: http://drs.web.psi.ch/evaluation/

- Used for analyses of the PMT signals
- Longtime measurements (allmost perfect)
- Counting and recording of every electron/photon peak
- Switched Capacitor Array digitizing 8 channels at sampling speed up to 5 Gsps.
- Equivalent to a four channel 5 Gsps digital oscilloscope
- 16-bit DAC to generate all on-board control voltages
- AD9245 ADC to digitize signals from the DRS4 chip
- Xilinx Spartan 3 FPGA for readout control
- Channel cascading