HI Instrument Optical Design

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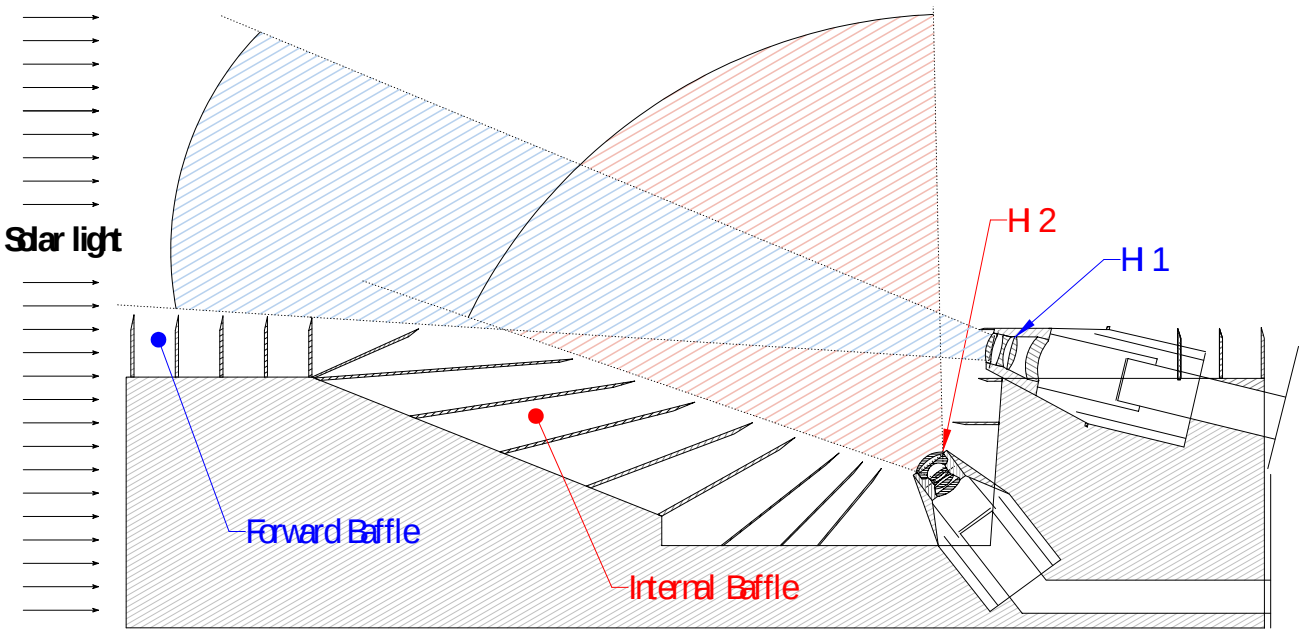
Optical Requirements

- **HI-1**
  - **FOV: 20° From 13.7 to 88.7 Rs**
  - **Image Area = 28 mm x 28 mm (13.5 µm pixels)**
  - **Spectral Range: 630 - 730 nm**
  - **Aperture: 16 mm**
  - **Max Background Noise: 5 10^{-13}**
- **HI-2**
  - **FOV: 70° From 68.9 to 331.4 Rs**
  - **Image Area = 28 mm x 28 mm (13.5 µm pixels)**
  - **Spectral Range: 400 - 900 nm**
  - **Aperture: 7 mm**
  - **Max Background Noise: 10^{-14}**

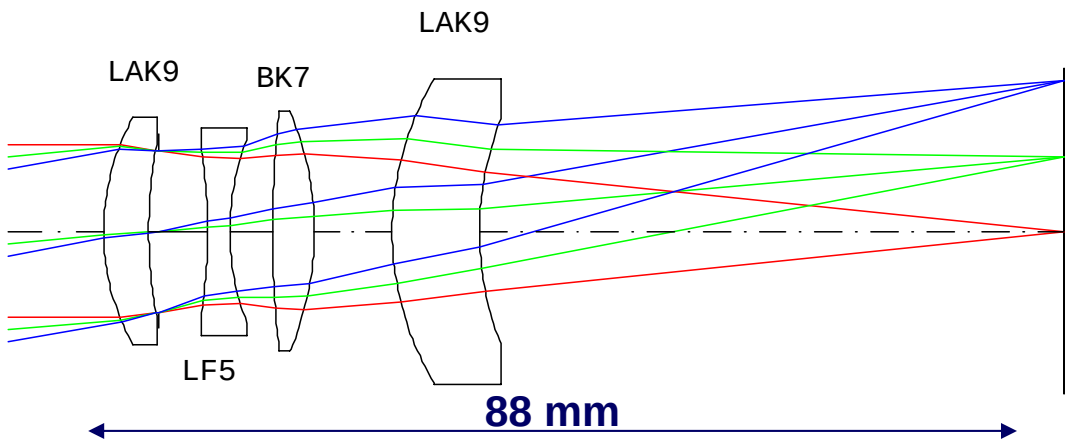
Optics Design

- **Main Challenges:**
  - **Faint Detection Capability ⇒ High Stray-Light Rejection Requirements (Ghosts)**
  - **Large FOV ⇒ Specific Optics HI-1 and HI-2**
  - **Large Spectral Range for HI-2**



Optics Design: HI-1

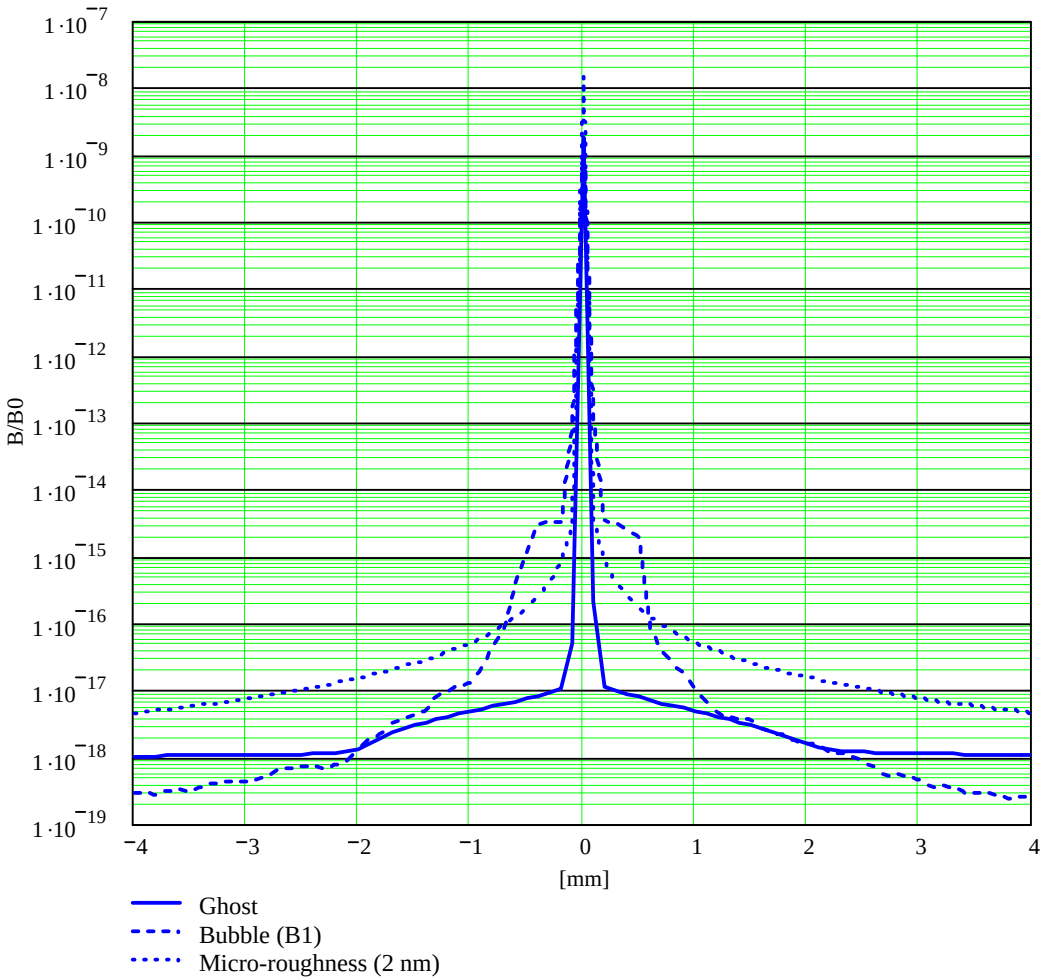
- **Design Drivers:**
  - **Minimize Size of Lens #1 (Entrance Pupil on Lens #1)**
  - **20° FOV**
  - **Radiation Tolerant Glasses**
  - **Ghost Rejections**
  - **Margins on Mechanical Mount**



f = 78 mm
Aperture 16 mm
FOV 20°

- **Design Performance:**
  - **Minimized RMS Spot Diameter**
  - **Designed for Extended Thermal Range [-20°C , +30°C]**

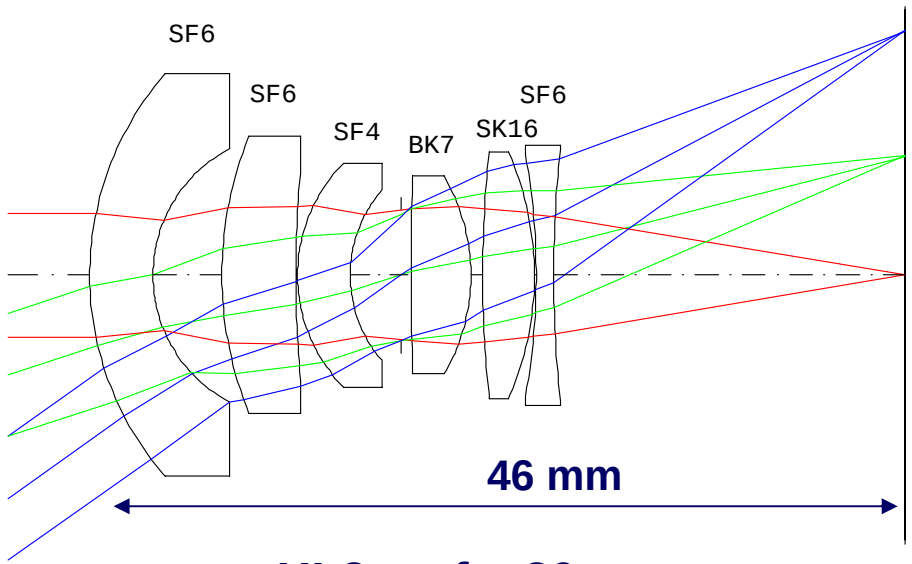
Optics Design: HI-1



- **RMS Spot Diameter:**
  - **Φ < 20.7 µm**
- **Ghost Images:**
  - **Φ > 3.5 mm**
- **Coatings:**
  - **SiO2 on Surface #1**
  - **High Pass Coating > 630 nm**
  - **Low Pass Coating < 730 nm**
  - **AR Coatings on Other Surfaces**

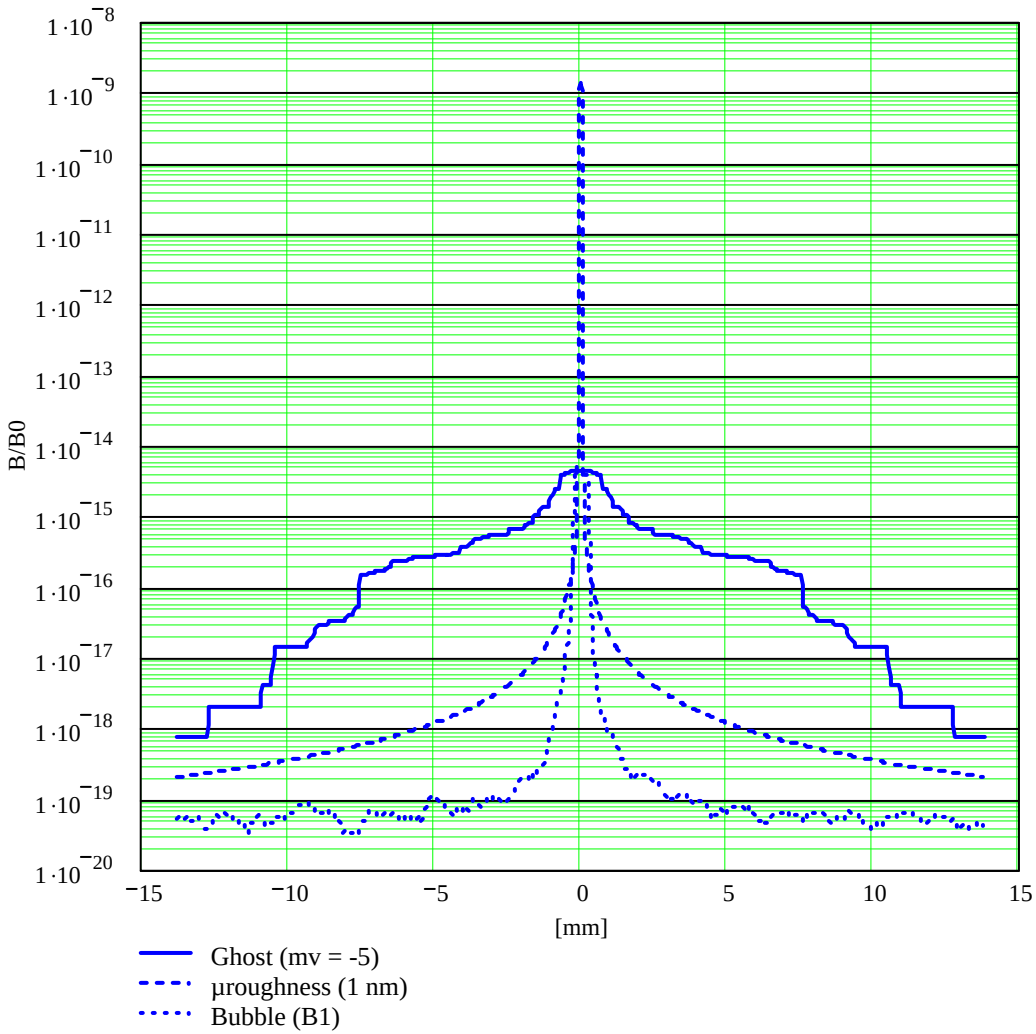
Optics Design: HI-2

- **Design Drivers:**
  - **Ghost Images**
  - **Large Spectral Range (400-900 nm)**
  - **70° FOV**
  - **Radiation Tolerant Glasses**
- **Design Performance:**
  - **Minimized RMS Spot Diameter**
  - **Maximized Ghost Diameters**
  - **Designed for Extended Thermal Range [-20°C , +30°C]**
  - **Minimized Incidence Angle on Optical Surfaces for Coating Efficiency**



HI-2 **f = 20 mm**
Aperture 7 mm
FOV 70°

Optics Design: HI-2



- **RMS Spot Diameter:**
  - **Φ < 47.2 µm**
- **Ghost Images:**
  - **Φ > 3 mm**
- **Coatings**
  - **SiO2 On Surface #1**
  - **AR Coatings on Other Surfaces (MgF2)**
  - **No Bandpass Filter**

Optics Design: Budgets

HI-1

- **Error Budget Including:**
  - **Lens Figuring**
  - **Lens Positioning**
  - **Glass Properties Uncertainties**
  - **Thermal Changes With Titanium Lens Mounts Within [-20°C,+30°C]**
  - **Detector Positioning**
  - **⇒ RMS Spot Diam. Between 45 μm and 69 μm**

HI-2

- **Error Budget Including:**
  - **Lens Figuring**
  - **Lens Positioning**
  - **Glass Properties Uncertainties**
  - **Thermal Changes With Titanium Lens Mounts Within [-20°C,+30°C]**
  - **Detector Positioning**
  - **⇒ RMS Spot Diam. Between 105 μm and 145 μm**

Changes Since PDR

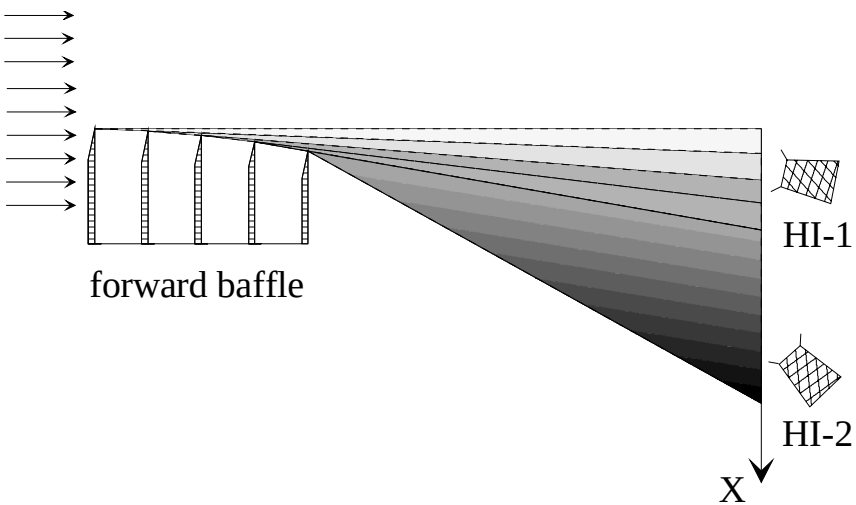
- **HI-1 Spectral Range Slightly Shifted From 650-750 to 630-730 nm (to Allow Interferometric Tests at 633 nm)**
- **HI-2 Effective Focal Length Adjusted to Cope With Distortion Effects**
- **Glass Selection With Supplier Availability (HI-1 & HI-2)**
- **Tolerance Budget Updated With Lens Barrel Design and Thermal Behavior**

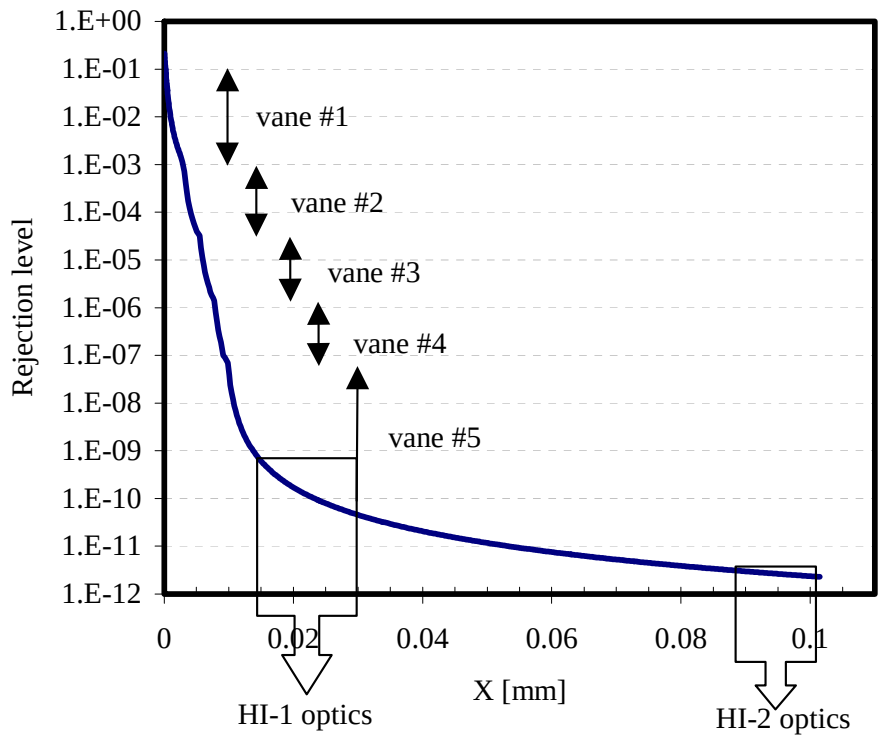
HI Baffle Design

- **Stray-Light Rejection Requirements:**
  - **HI-1: Instrumental Background <5 10^{-13} B_0**
  - **HI-2: Instrumental Background<10^{-14} B_0**
- **Major Stray-Light Contributors and Dedicated Baffles:**
  - **Direct Solar Light (B_0): Front Baffle**
  - **Bright Sources in and Out FOV (Planets, Stars): Inner Baffle**
  - **Payload Elements Near UFOV: Perimeter Baffle**

HI Baffle Design: Front Baffle

- **HI Front Baffle Is Key Element in Background Light Reduction**
- **It Has to Provide a 10^{-9} Rejection Factor for HI-1 (Assuming 10^{-4} Internal Rejection) [a Single Vane System Would Only Provide a 10^{-4} Rejection]**

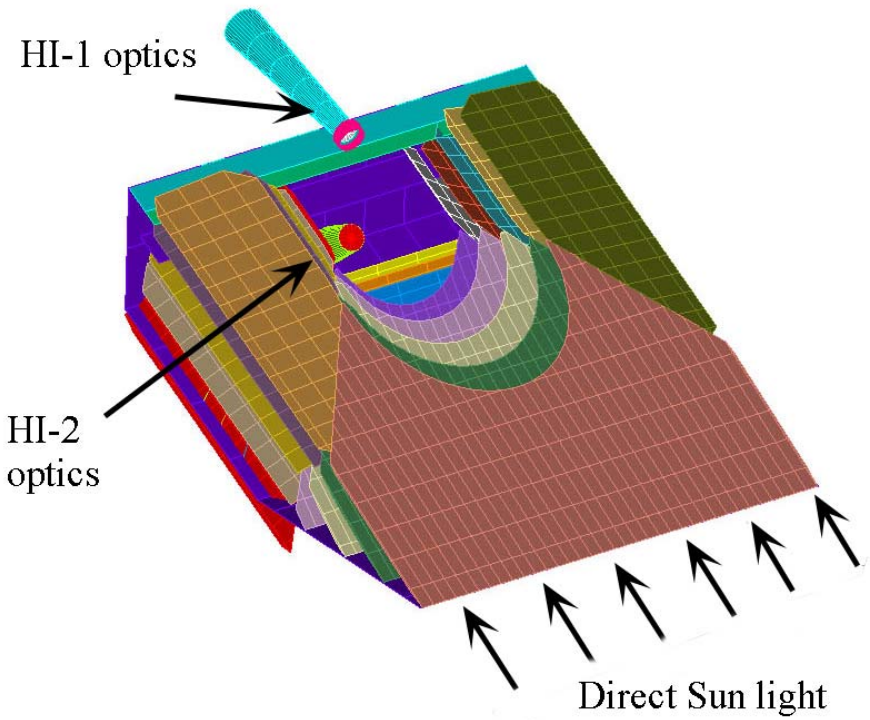




Cascade Fresnel Edge-Diffraction System

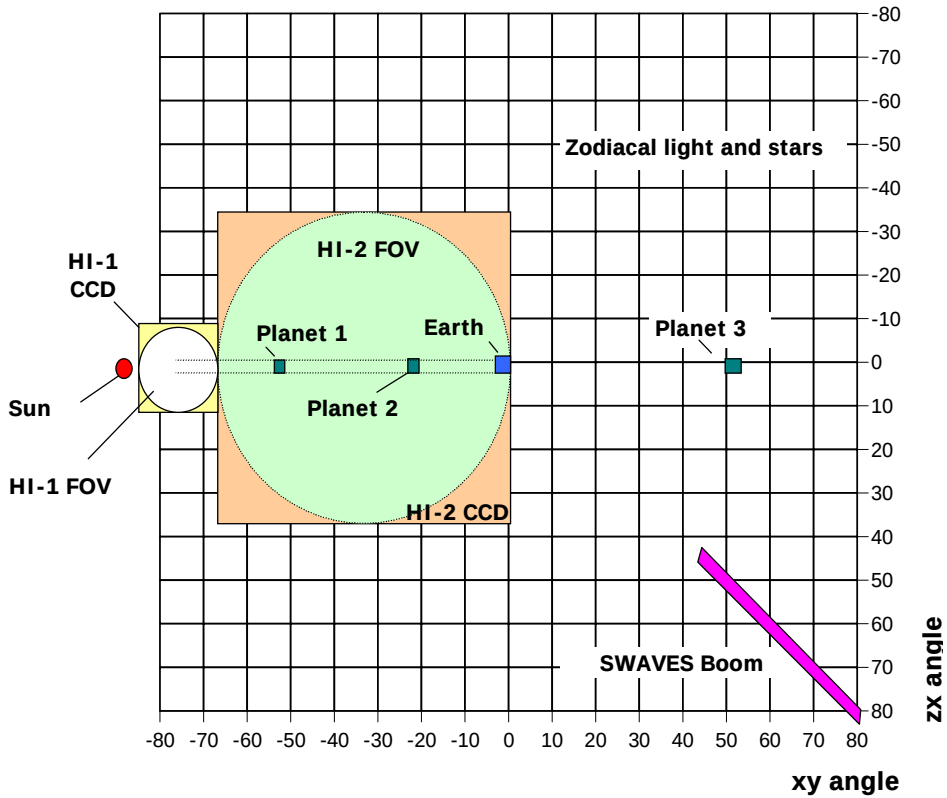
HI Baffle Design: Inner Baffle

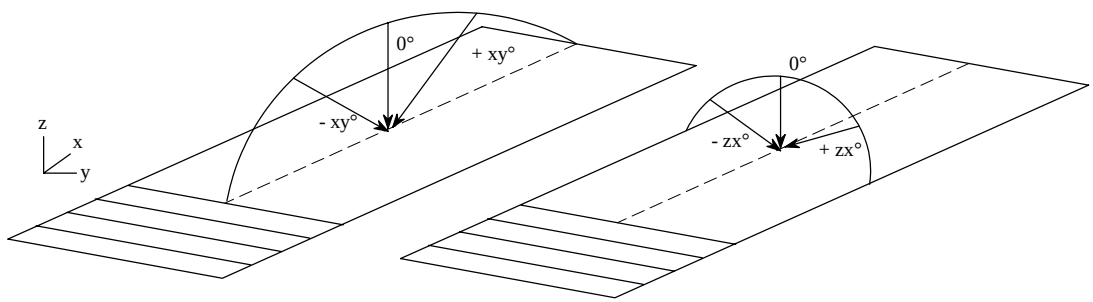
- **HI Inner Baffle Is Based on Multi-Reflections on Absorbing Surfaces**
- **It Has to Protect HI-1 and HI-2 From Planets and Bright Stars Light Reflection on HI Structure**
- **Ray Trace Analyses Were Used to Define and Optimize Baffle Geometry, Taking Into Account Manufacturing Constrains**



HI Optical Analysis

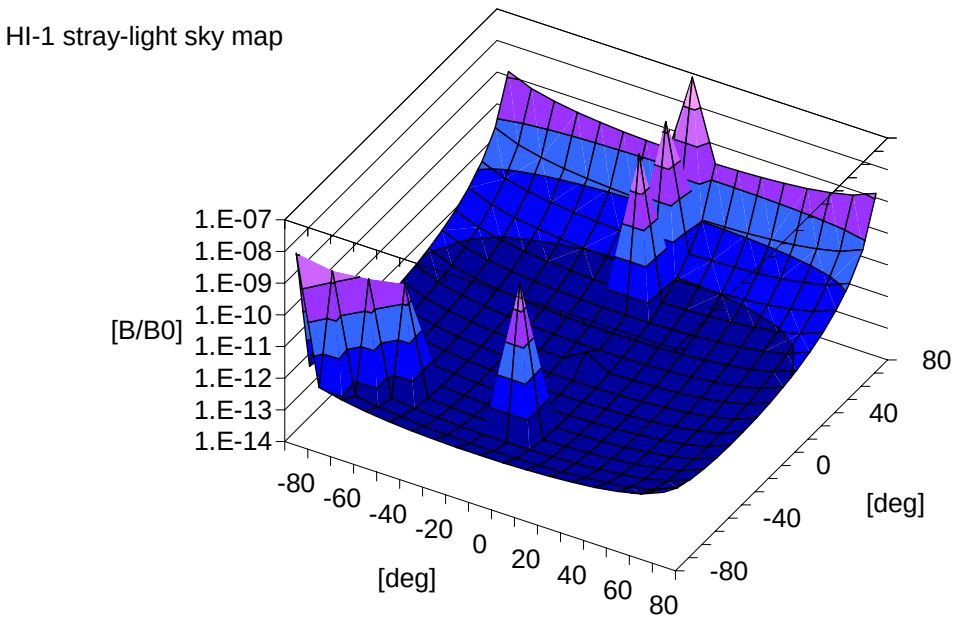
- **Contributors to Instrument Background:**

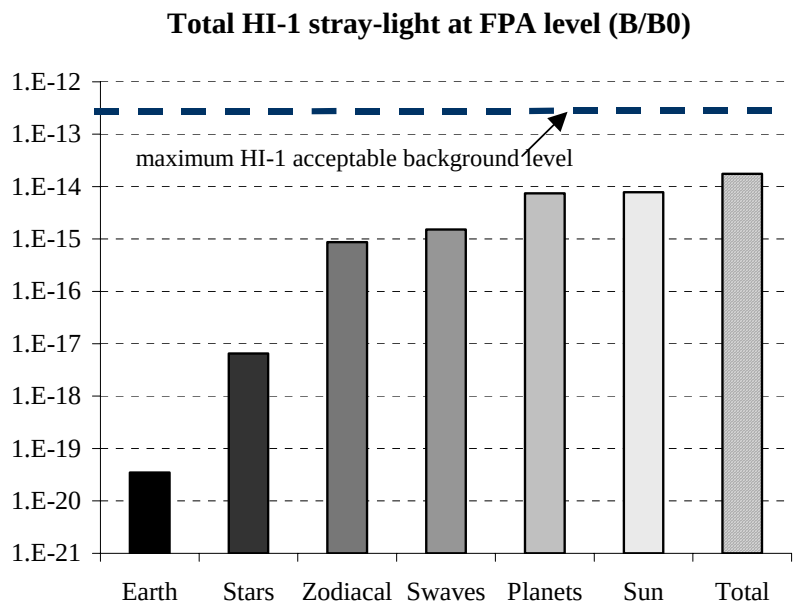




HI Optical Analysis

- **Overall Stray-Light Background in HI-1**

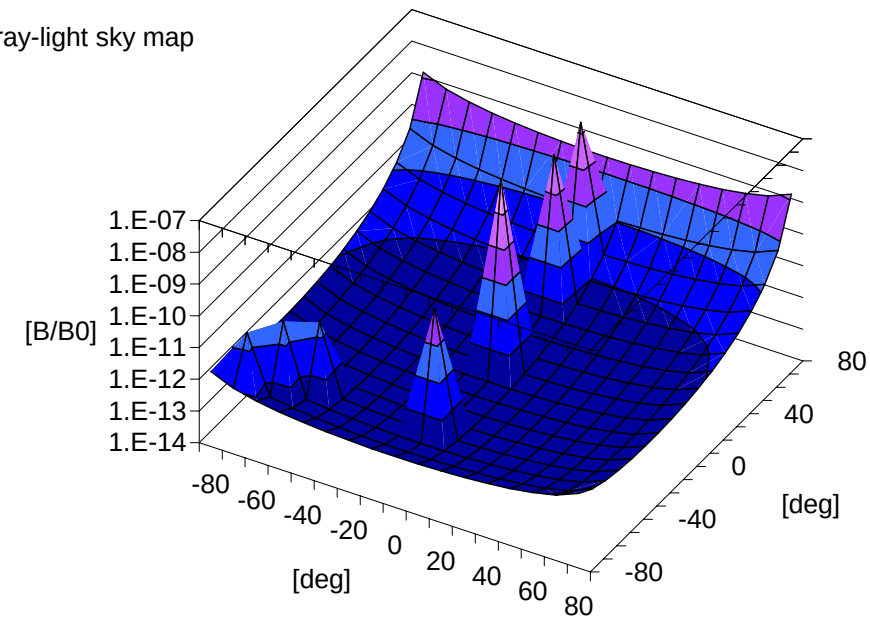


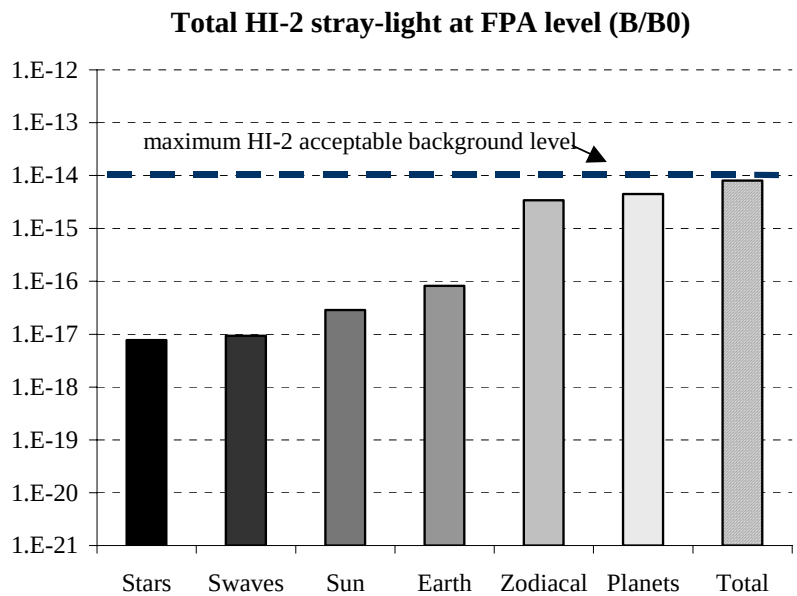


HI Optical Analysis

- **Overall Stray-Light Background in HI-2**

HI-2 stray-light sky map





HI Optical Analysis – Conclusions

- **Front Baffle Has Been Designed to Provide Required Rejection of Sun Light (Better Than 10^{-9} for HI-1 and 10^{-11} for HI-2)**
- **Internal Baffle Has Been Designed to Provide a 2.10^{-14} and $9.\ 10^{-15}$ Rejection Level for HI-1 and for All Other Stray-Light Sources**
- **Optics Have Been Optimized to Avoid Ghost Problems**
- **Raytrace Studies Have Shown an Additional Margin Due to Lens Barrel and Focal Plane Out-of-Field Attenuation (10^{-6} Rejection)**
- **Overall Theoretical Straylight Background Meets Science Requirement**

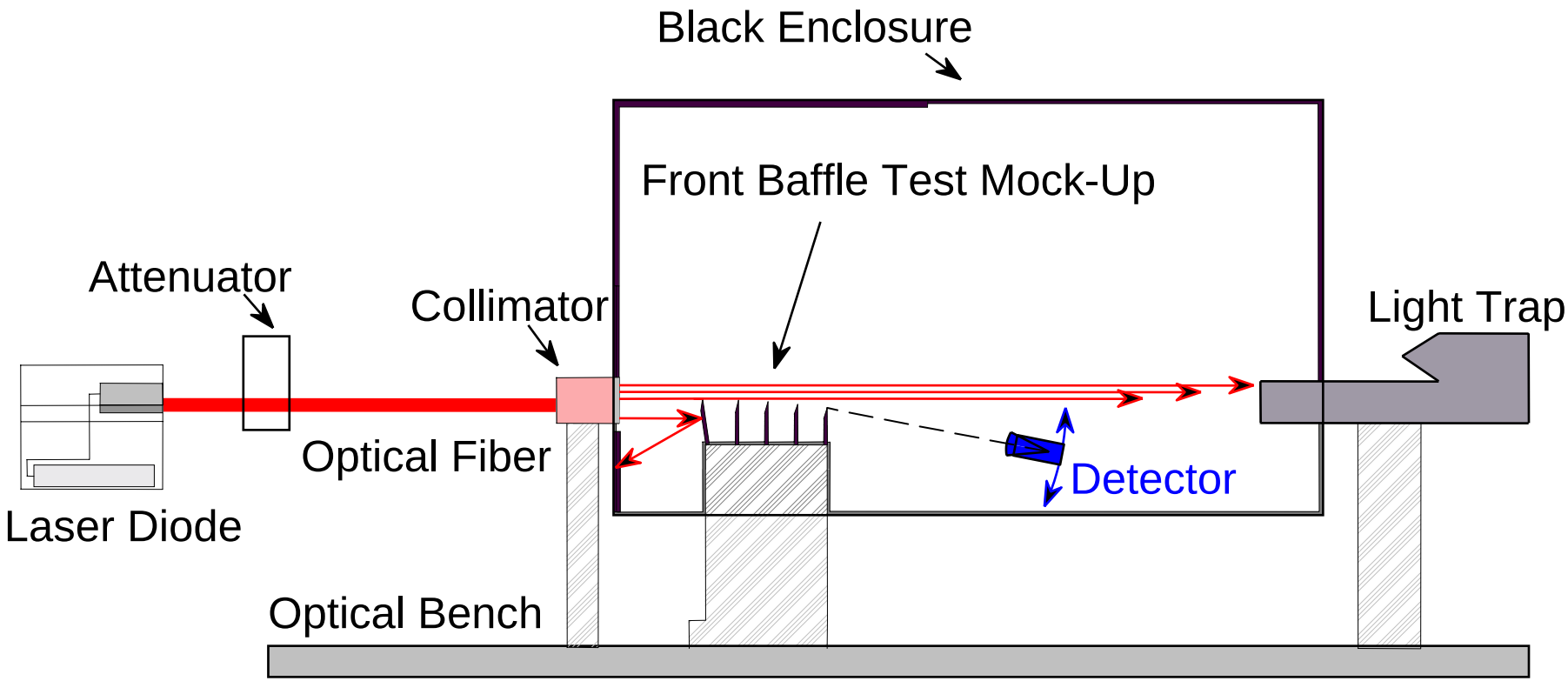
HI Optical Testing

- **HI Success Directly Relies on Rejection Performance of Front Baffle (< 10^{-9} at HI-1 Level)**
  - **Design Is Based on Theoretical Analyses (Fresnel Diffraction)**
  - **Preliminary Verifications Indicated Rejection Better Than 10^{-6}**
- **Inner Baffle Performance Is Directly Related to Absorbing Properties of Black Coatings Used on CFRP Vanes**
- **Verification Program Has Been Set up to Demonstrate Experimentally Front Baffle Performance and Black Coating Scattering Properties in Facilities of Centre Spatial De Liège (B)**

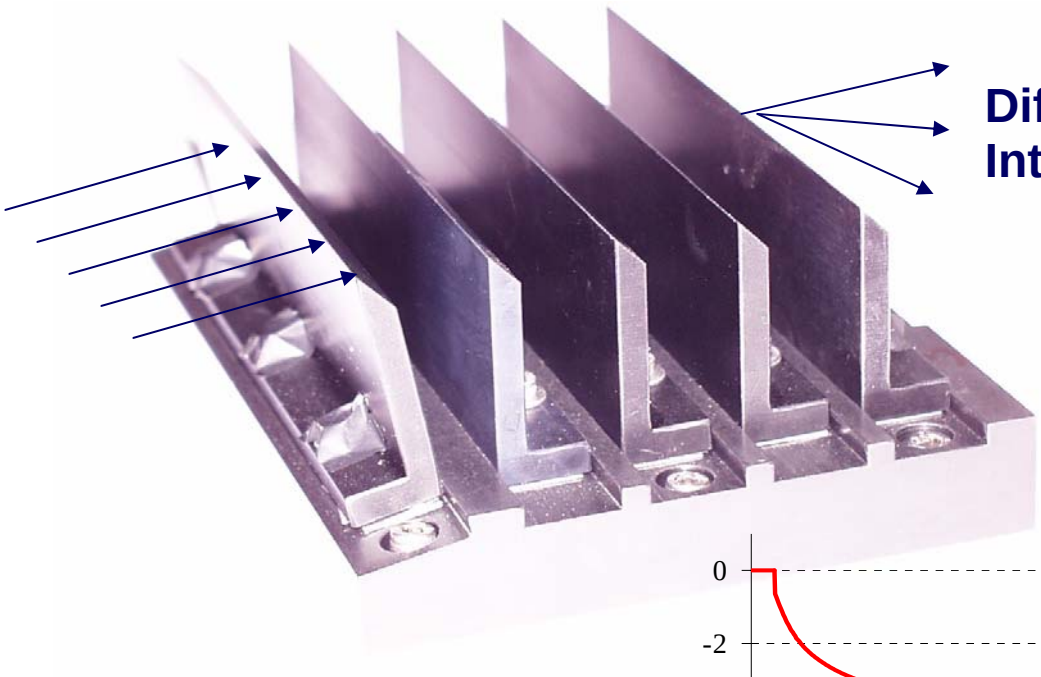
Optical Testing: Test Set-Up

- **Goal: Measure Diffracted Light by Cascade Knife Edge System at Level of HI-1 and HI-2 (10^{-9} and 10^{-11} Rejection Factors)**
  - **Front Baffle Mock-Up**
  - **Powerful Collimated Beam: 20 W Continuous Laser Diode + Optical Fiber + Collimator**
  - **High Sensitivity Detector: Photomultiplier Used in Photon Counting Mode**
  - **Protection Against External Light and Internal Reflection: Set-Up Is Installed in a Black Enclosure**
  - **"Super Light Trap" to Absorb All Unshaded Direct Flux (10^{8} Efficiency)**
  - **Possibility to Run Test Under Vacuum to Avoid Air Perturbations: Test Set Up Is Implemented in a Vacuum Chamber**

HI Optical Testing: Test Set-Up



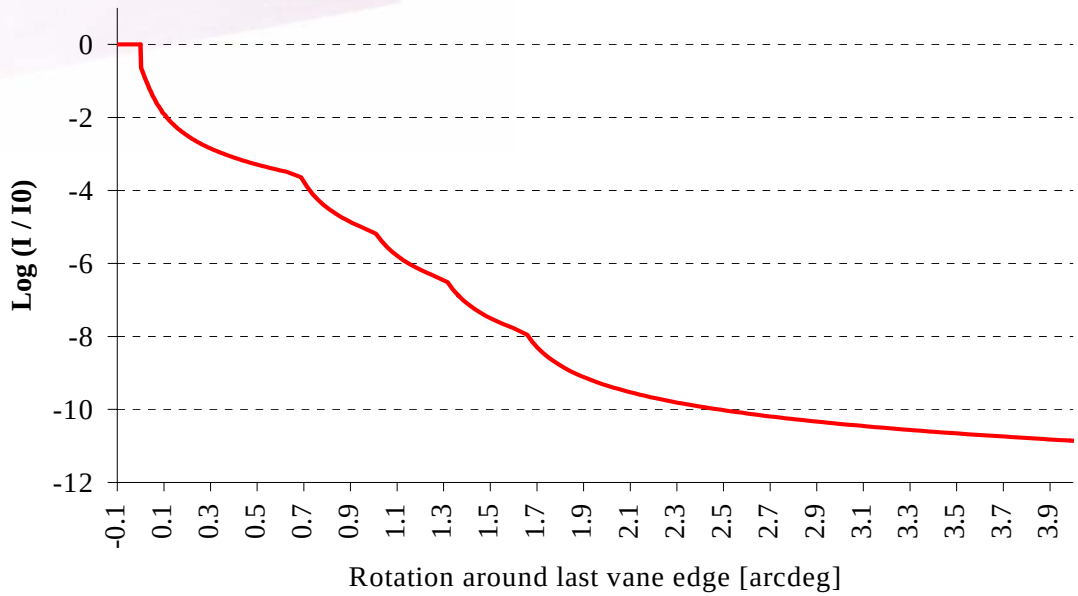
HI Optical Testing: Test Mock Up



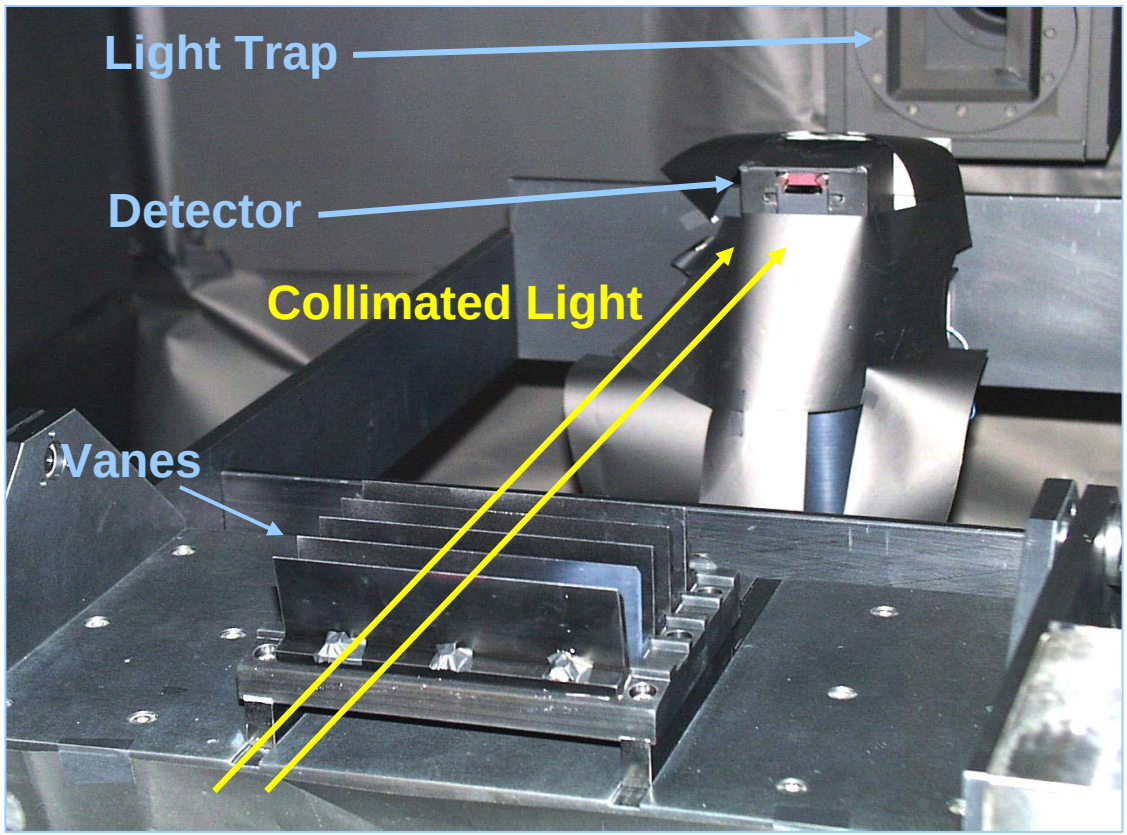
Diffracted Intensity

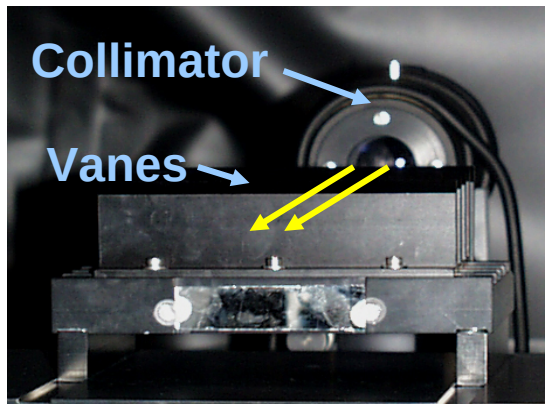
Detector

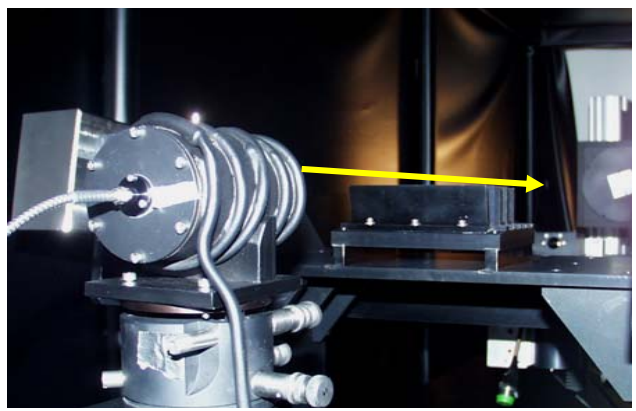
Predicted Shadow Distribution:



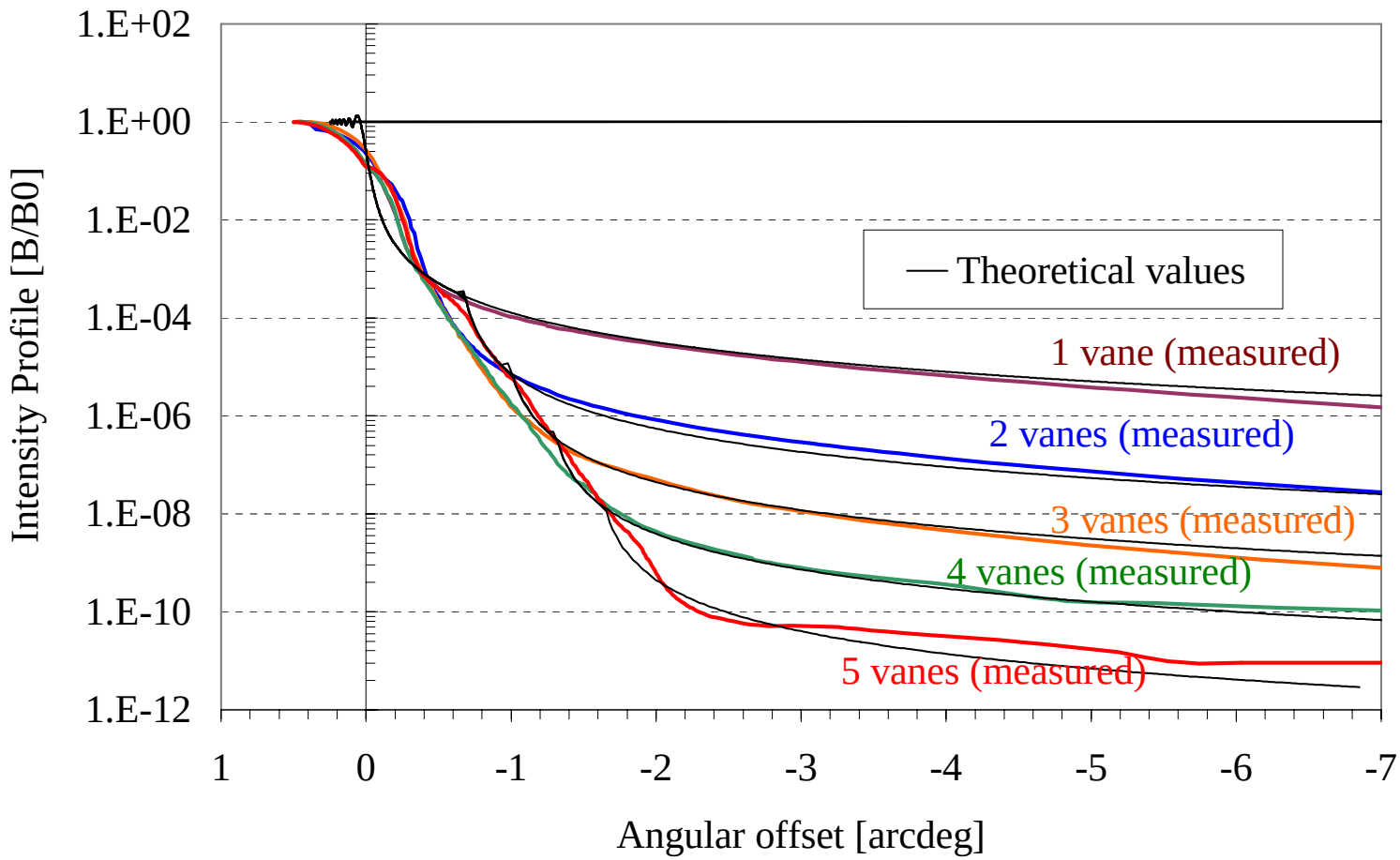
HI Optical Testing: Test Set-Up



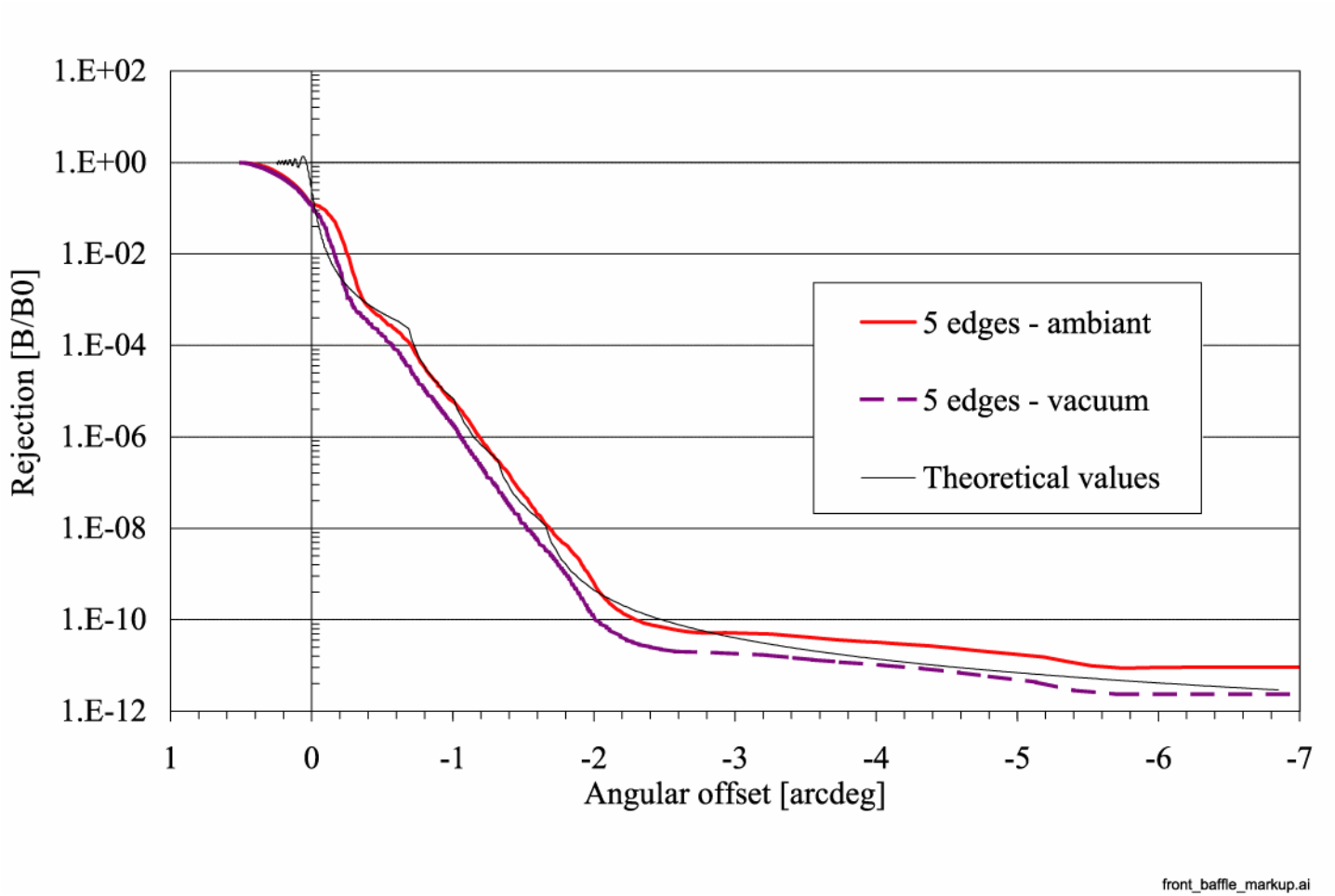




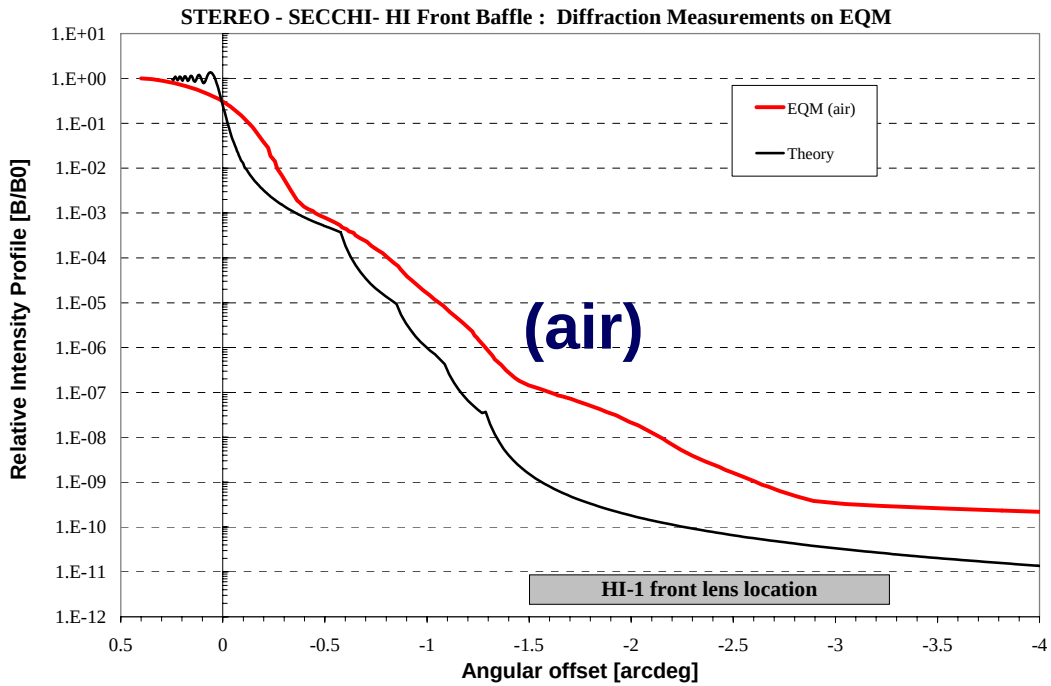
Front Baffle Mockup Tests in Air



Front Baffle Mockup: Air/Vacuum Comparison



Front Baffle QM: Preliminary Measurements



- ⇒ **Good Indications That the Front Baffle Will Meet the Specification for Rejection Requirements**
- **Test to Be Pursued With Alignment and Dimensional Checks**

Front Baffle Tests - Conclusions

- **Concept of Front Baffle Has Been Demonstrated by Analyses and Tests**
- **New Test Set-Up Has Been Developed and We Have Measured Unprecedented Experimental Data With Rejection Levels Down to 10^{-11}**
- **Measurements Are Consistent With Theoretical Data (Mock-Up Tests) Therefore We Can Rely on Our Theoretical Data for:**
  - **Design Optimization**
  - **Misalignment Sensitivity Evaluations**
- **Tests on HI Hardware Still Need to Be Pursued, and Are Going on at CSL**

Inner Baffle Verification: BRDF Measurements

- **BRDF = Major Input for Raytrace Analysis of Inner Baffle**
- **Z307 Data Not Yet Published**
- **Raytrace Analyses Conducted With Z306 Data**
- **Measurements Shows Similar BRDF, Which Confirms Our Previous Analyses**