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Estimation of cyclic error due to scattering in the internal OPD metrology of the Space Interferometry Mission

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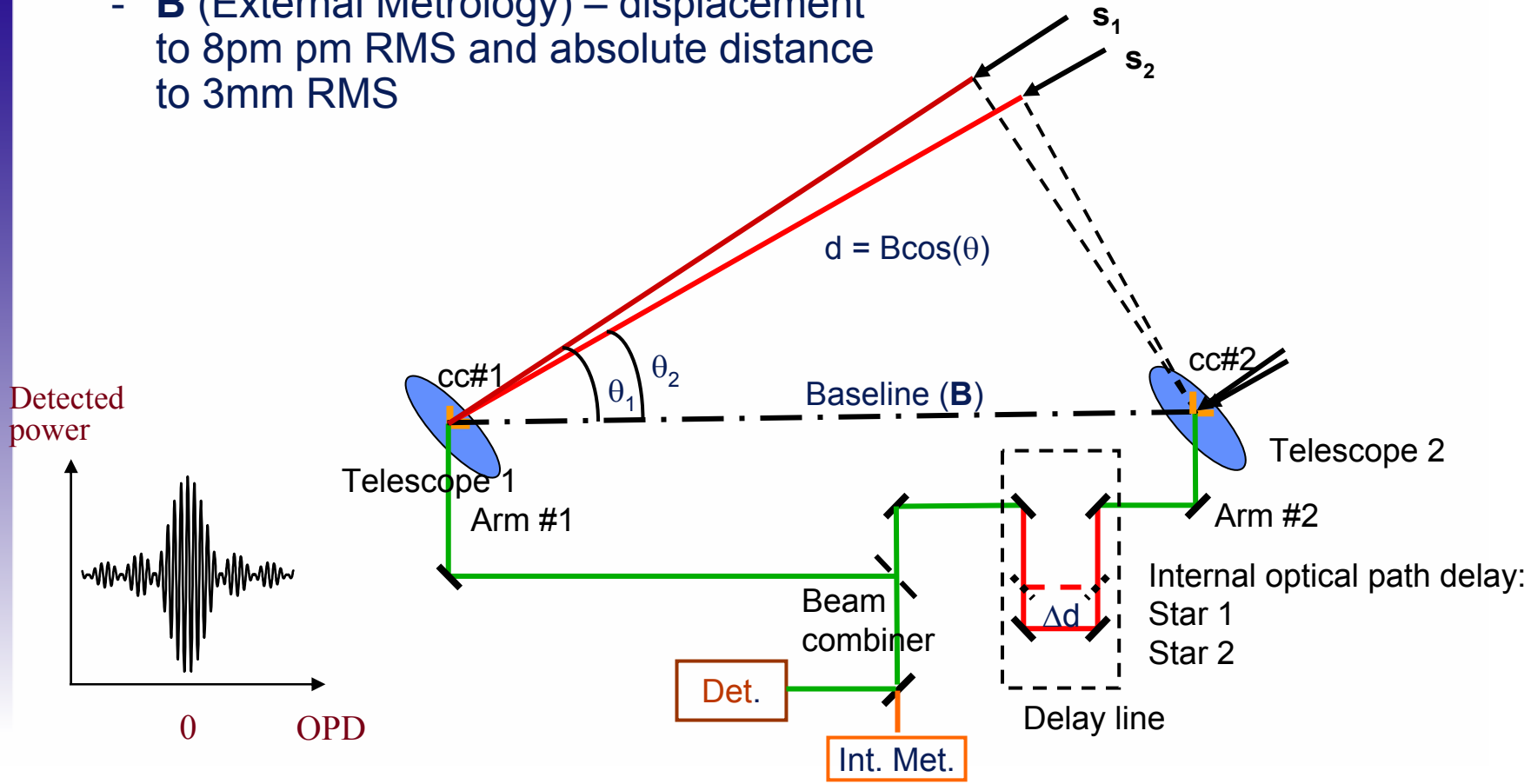
Basic Measurements in SIM

- SIM model in its simplest form: $\Delta d = \vec{B} \bullet (\vec{s}_1 - \vec{s}_2)$
- Laser metrology gauges to measure:
  - Δd (Internal Metrology) – displacement to 3pm RMS
  - **B** (External Metrology) – displacement to 8pm pm RMS and absolute distance to 3mm RMS



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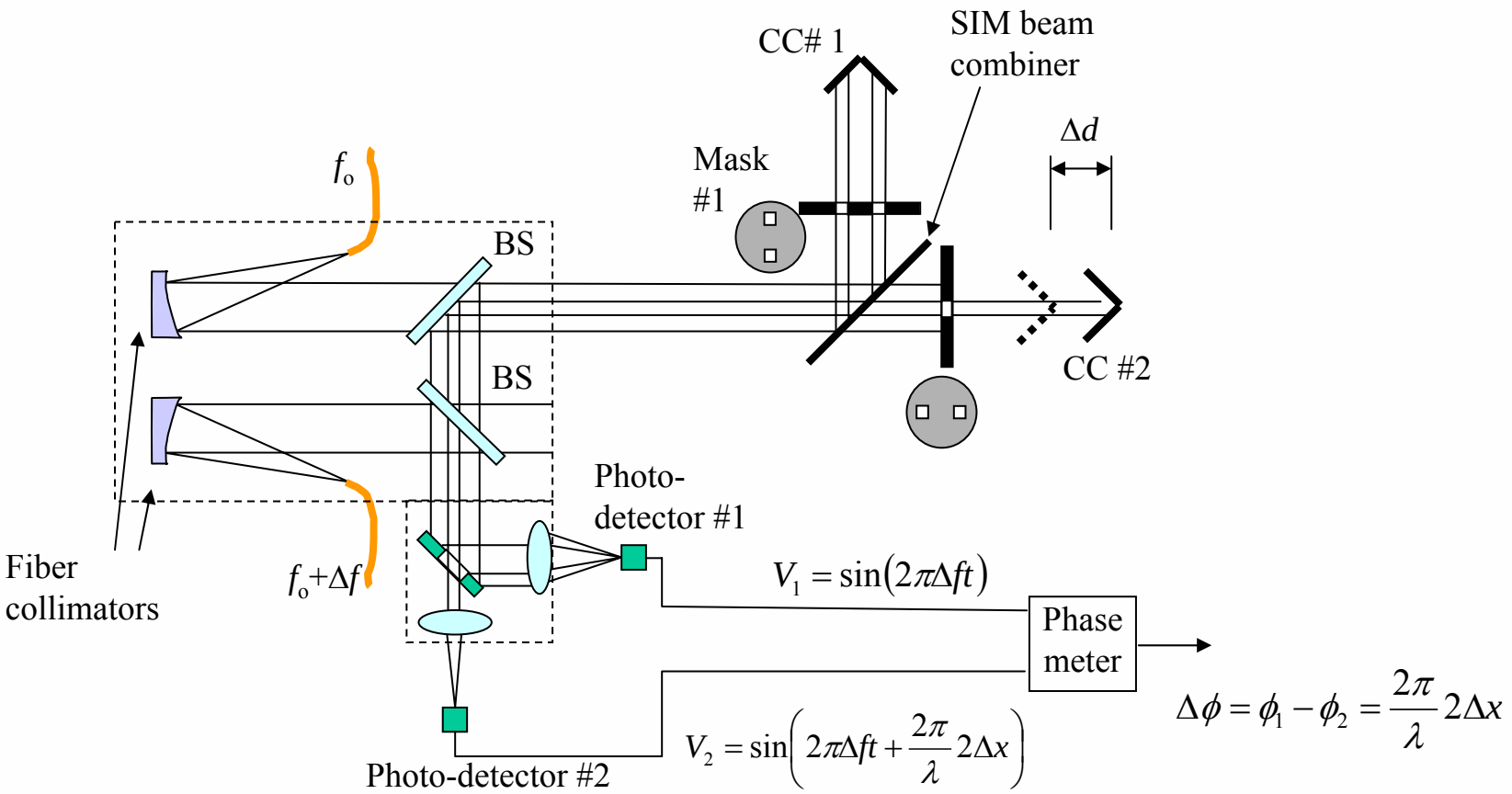
Common-Path Heterodyne interferometer

- COPHI
  - Distance to be measured is $\Delta d = \Delta\phi \cdot \lambda/4\pi$
  - Single interferometer measures OPD in two arms



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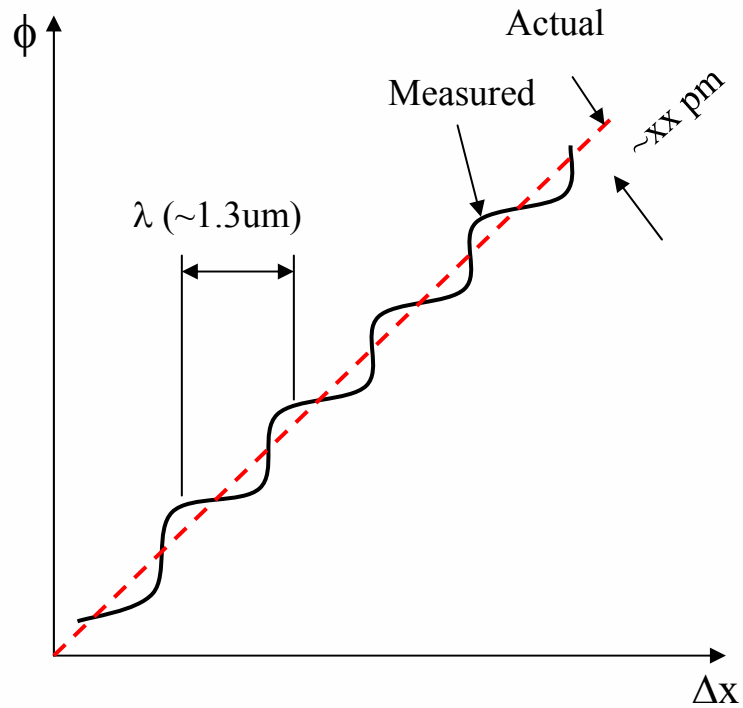
Cyclic error

- Defined as “periodic (λ) nonlinearity” between measured phase and actual displacement
- Caused by “contamination” to the heterodyne signals: diffraction, scattering, multiple reflection, etc.

$$|dx| = \frac{\lambda}{4\pi}\left|\frac{dA}{A}\right| = \frac{\lambda}{4\pi}\sqrt{\left|\frac{dP}{P}\right|},$$

A and P are amplitude and power of heterodyne signal

dA and dP are amplitude and power of contamination



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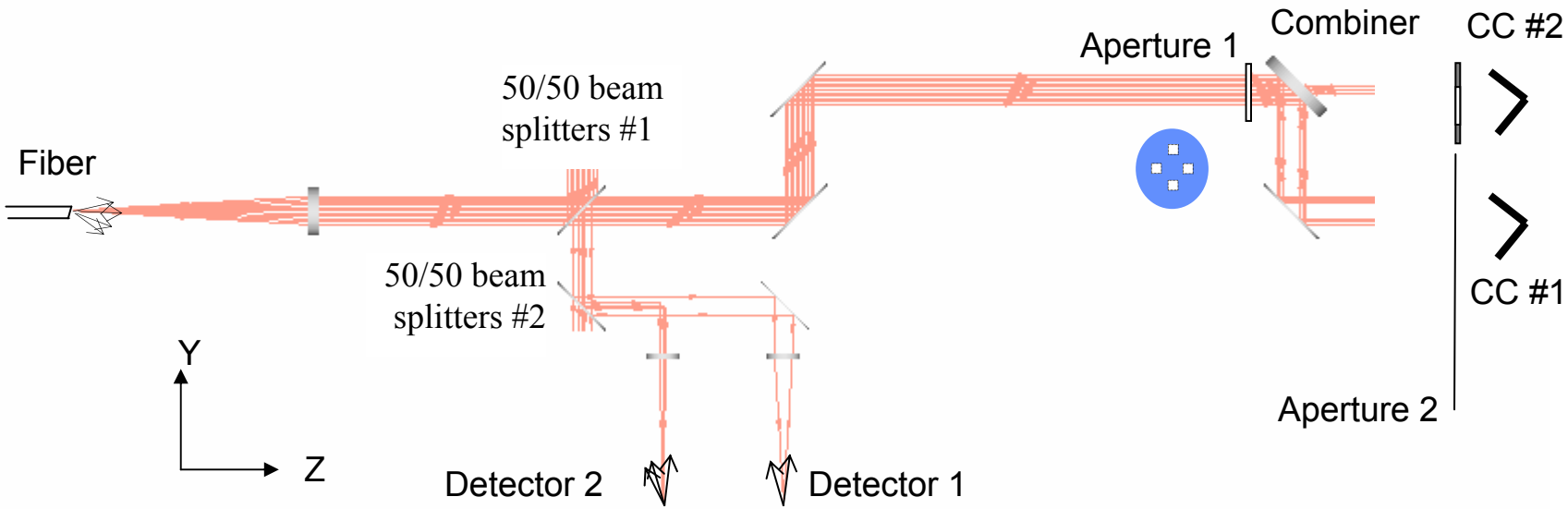
Optical layout

- Laser beam propagation through the system
- Estimation of the amount of scattering that reaches the detector.
- Scattering surfaces: Fiber, detector and corner cube.
- Cyclic error due to inter and intra beam contamination.



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Advanced System Analysis Program

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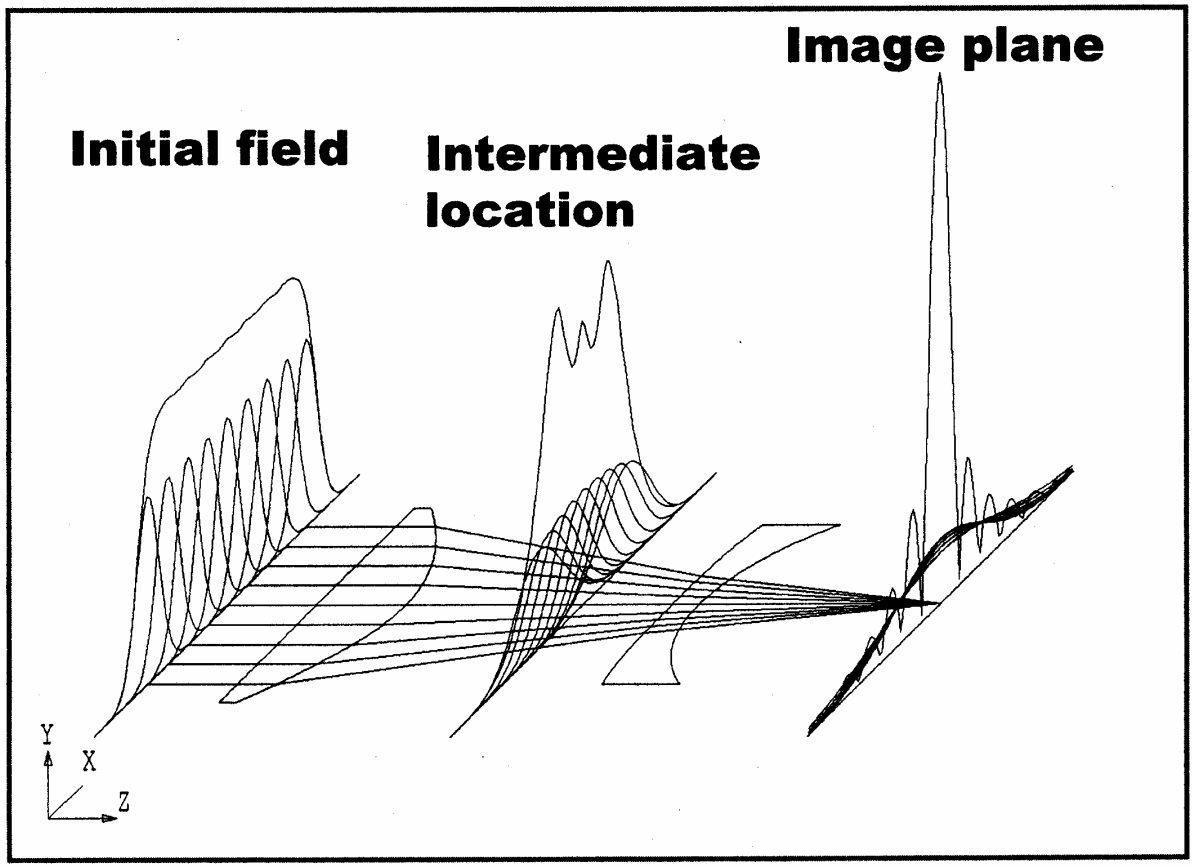
ASAP propagates optical fields by using a Gaussian decomposition

Basic idea: represent an arbitrary field as a super-position (amplitude and phase) of Gaussian beams



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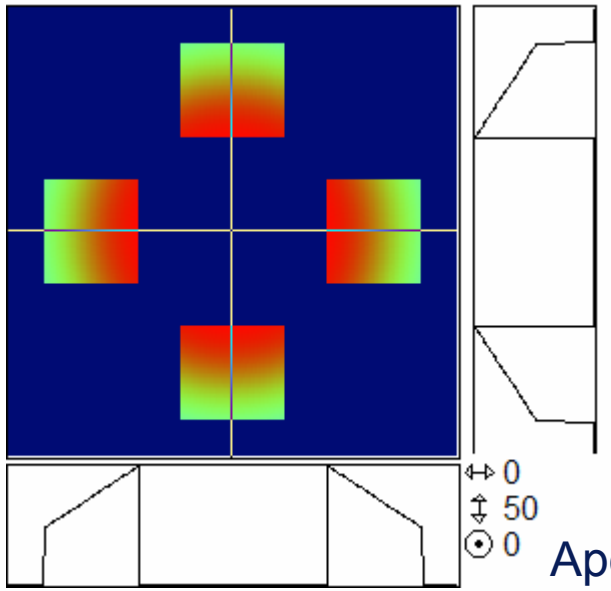
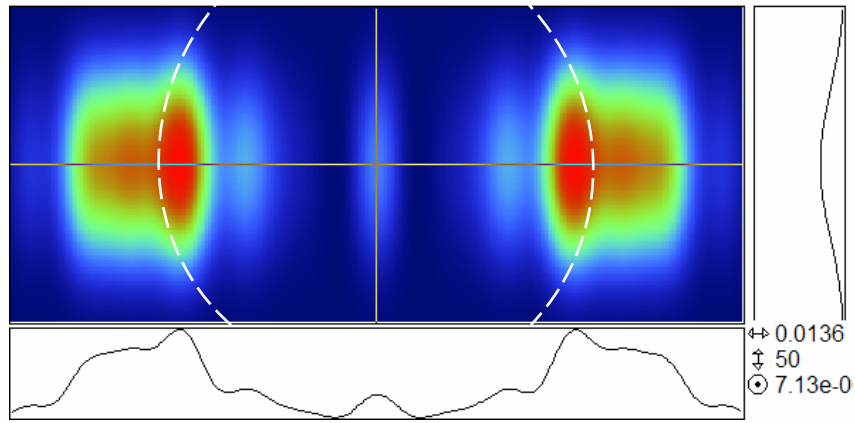
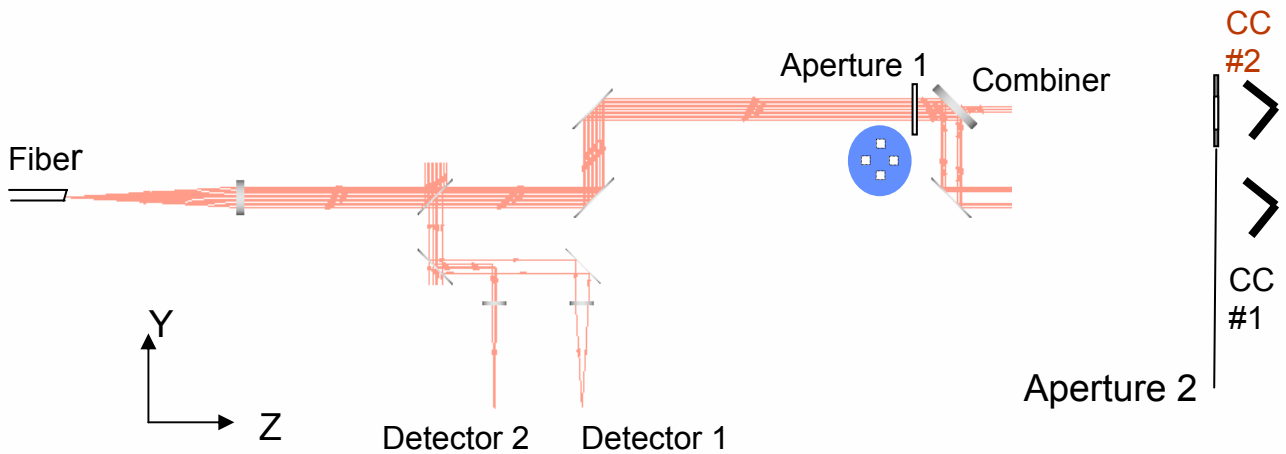
Irradiance distributions of light in arm 2



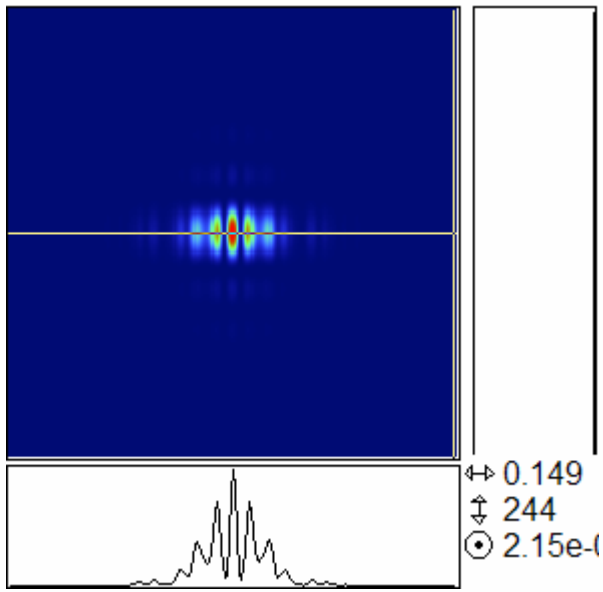
Aperture 1



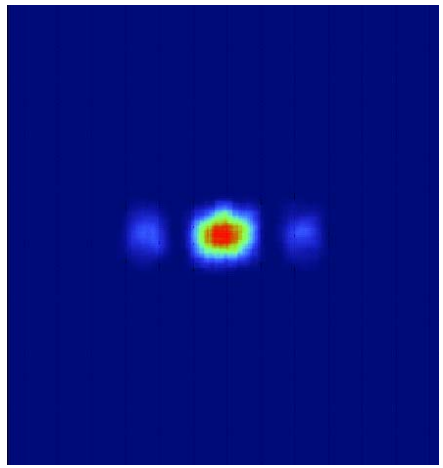
At aperture 2



Irrad. dist. of scattered light @det2



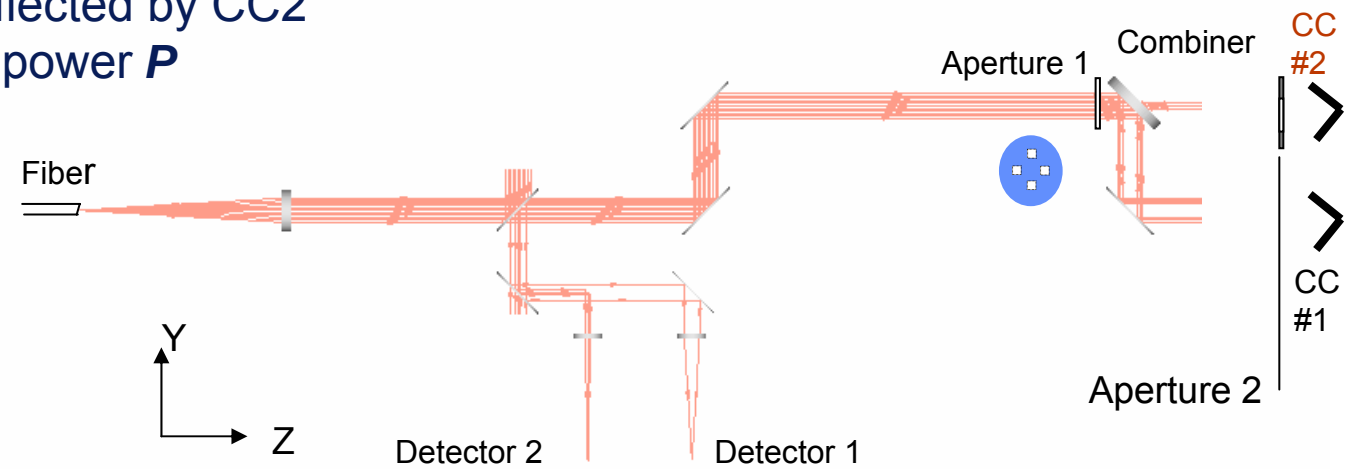
Specularly reflected by CC2
@detector 2, power ***P***



Scattered by CC2
@detector 2, power ***dP***

dP/P = -81 dB

➔ **9 pm cyclic error**



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Harvey model

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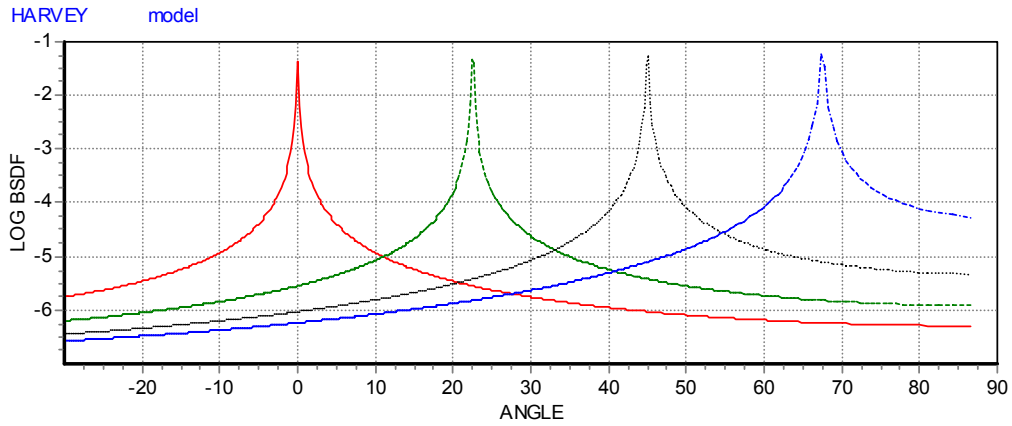
The bi-directional scattering distribution function

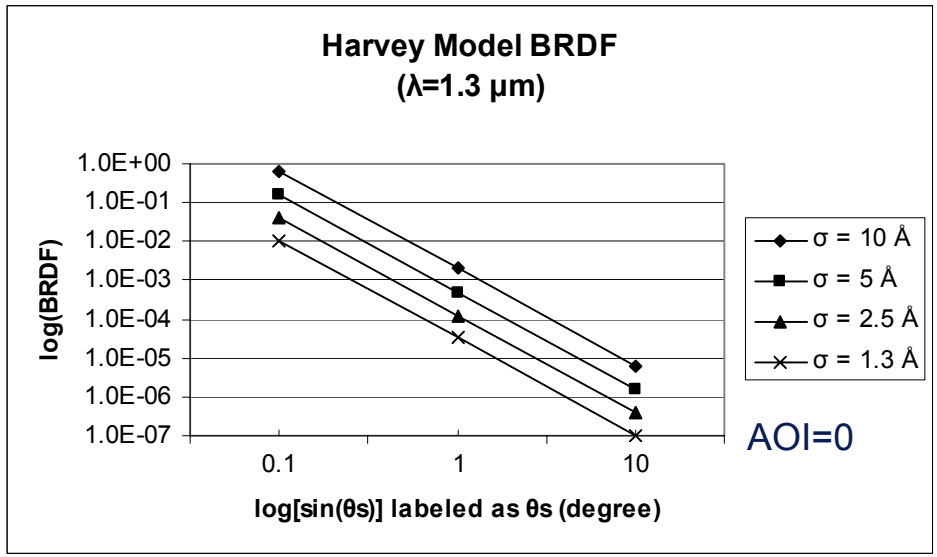
Angles of incidence: 0˚, 22.5˚, 45˚, 67.5˚

Polished optical surfaces scatter close to Harvey model

Surface σ double BSDF up 6 dB



Angle: 1= 0.0 2= 22.5 3= 45.0 4= 67.5
% TIS: 0.0012 0.0011 0.0011 0.0009



Summary of results

- Assumption: All scattering surfaces σ = 5 Å.
- Scattering of fiber tip received by detector #2 after another round trip is -110 dB (angle polished at 8˚).
- Scattering of the detector #2 received by itself after another RT is -85 dB (R = 2%, normal incidence).
- Tilting the detector => scattering reduced significantly.
- Inter-arm cross-talk due to scattering is less than -110 dB, i.e. much less than 1 pm cyclic error. Diffraction is the main source of inter-arm cross-talk.

Acknowledgement

- This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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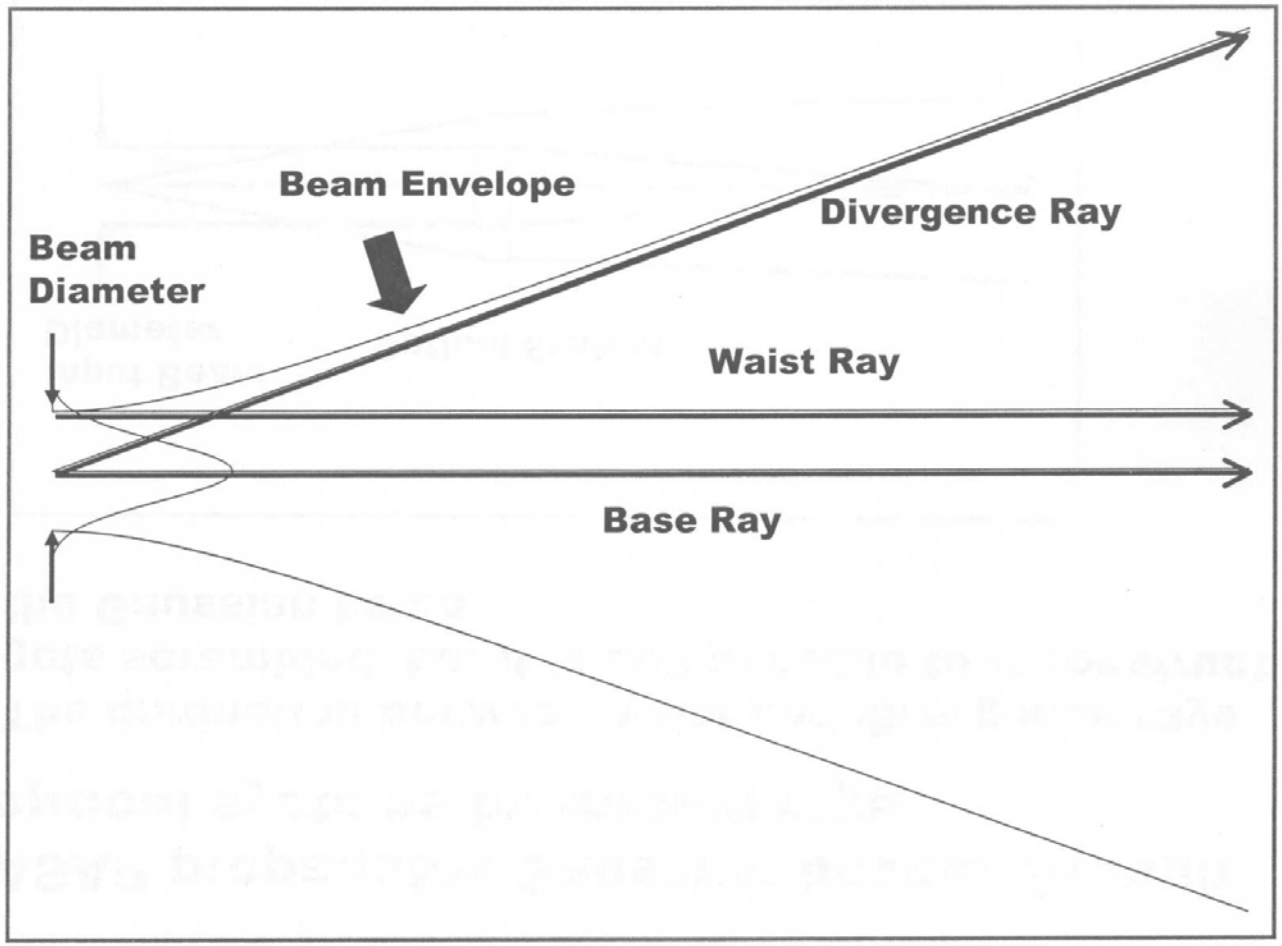
Back up slides

Propagating Gaussian Beams and Tracing Rays



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