Retroreflector Diffraction Modeling for SIM

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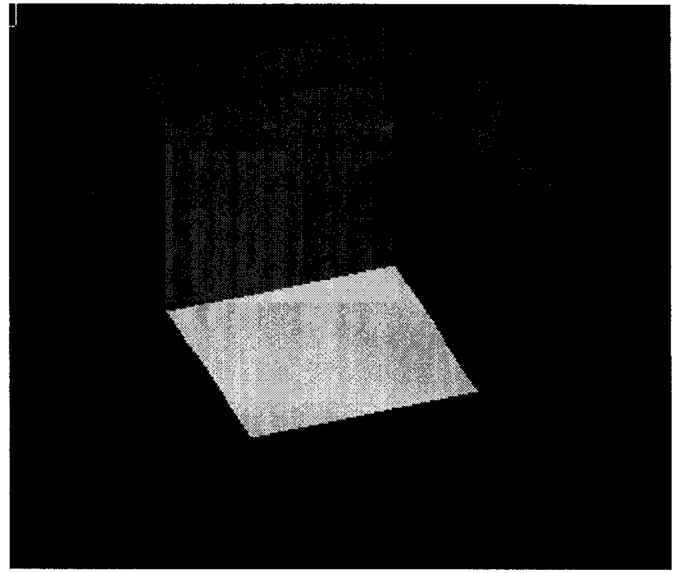
The questions you are entitled to ask yourself now are:

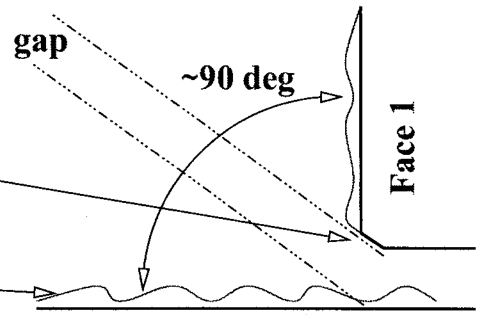
What on Earth is a retroreflector ?
How am I going to solve the Grand Unified Theory with it ?



A retroreflector is an optical device that reflects light (visible, UV or IR) in the direction where it came from. Retroreflectors are commonly used on bicycles. There are two main types of retroreflectors used in optics experiments: cat's eyes and cornercubes. In this study, we will consider only cornercubes, such as the one represented here -------> A ray of light hitting one of the faces of the corner cube will, depending on it's incidence angle, hit one or two more surfaces and come straight back (see 3-d layout on separate sheet) at the source. One always sees his eyes in a cornercube !

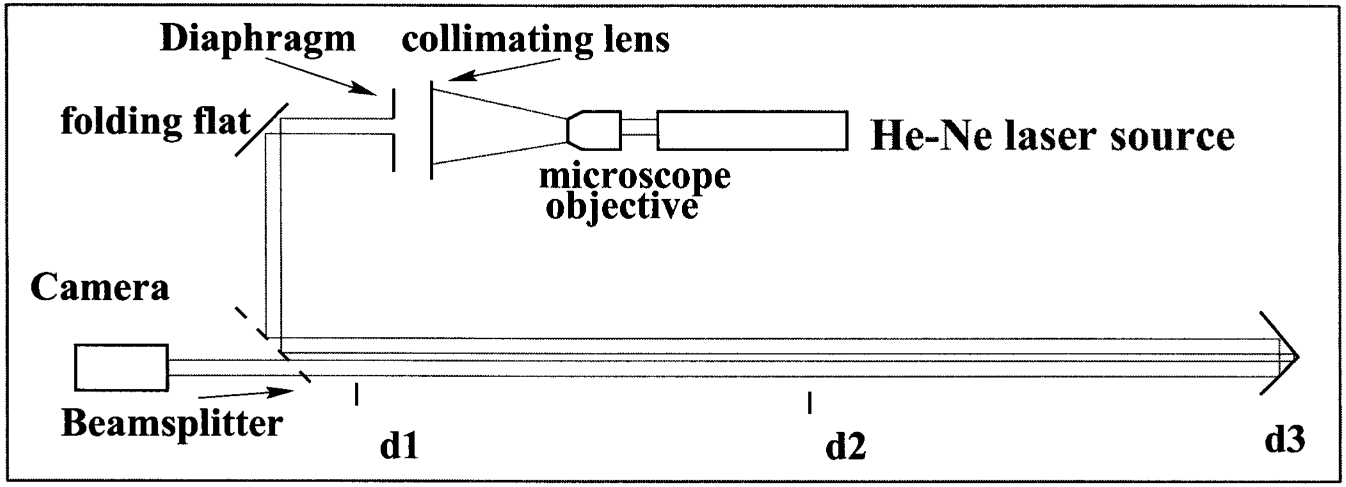
A cornercube might not help you solve the GUT challenges but it might help us discover planets, adjust the cosmic distance scale or find the distribution of the dark matter in the Galaxy. See your local cornercube dealer for details or the next slide right here ---->

There is no perfect optical component and therefore, corner-cubes have their share of defects :



- The faces, even superpolished, still have imperfections: this is the surface figure error.
- The faces are not exactly at 90 degrees from eachother: this is the dihedral error.
- There is a gap where two faces meet: this is the gap error.

Getting cornercube diffraction patterns: the experiment !

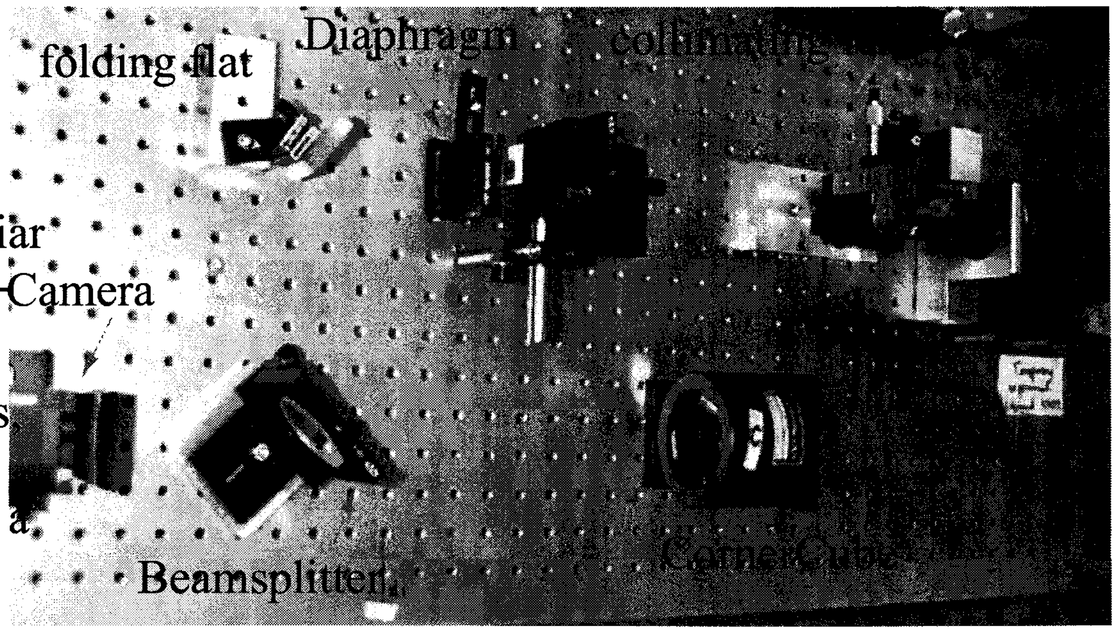


In order to build a strong optical model, we chose to start with a simple beam shape: a collimated top hat beam. Hence the presence of a collimating lens and a diaphragm.

The experiment consisted in taking images of the near-field diffraction patterns at three positions, d1,d2 and d3, of various reflectors: 3 cornercubes and a flat mirror. The images are 640x480 frames, such as the ones shown on sheet # 4. We varied the collimation of the beam (f1, f2, f3) to get more information out of the experiment.

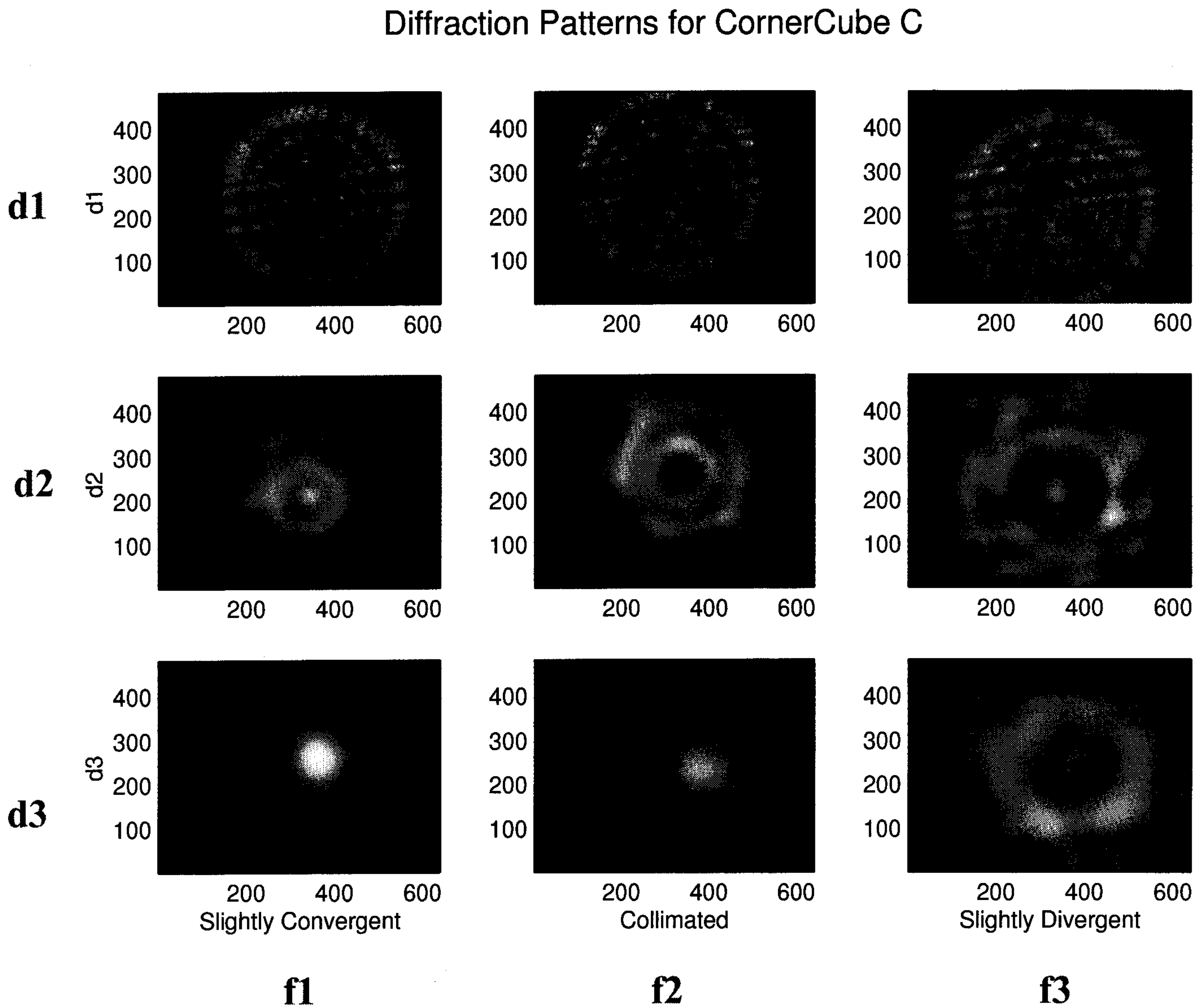
Since the initial beam is truncated with an iris, in order to create a top hat beam, the diffraction patterns contain both a ringing pattern due to the diaphragm and the peculiar shape pattern due to the gaps on the corner-cube. We solve for both.

The collimating lens introduces aberrations, mainly spherical aberration, that will be taken into account in the model, by adding a Zernike-type surface.



This is a typical set of images obtained with this experiment. At short distance (d1), the effects of the gaps are clearly visible. At longer distances, one can still see the hexagonal shape of the pattern, due to the cornercube geometry.

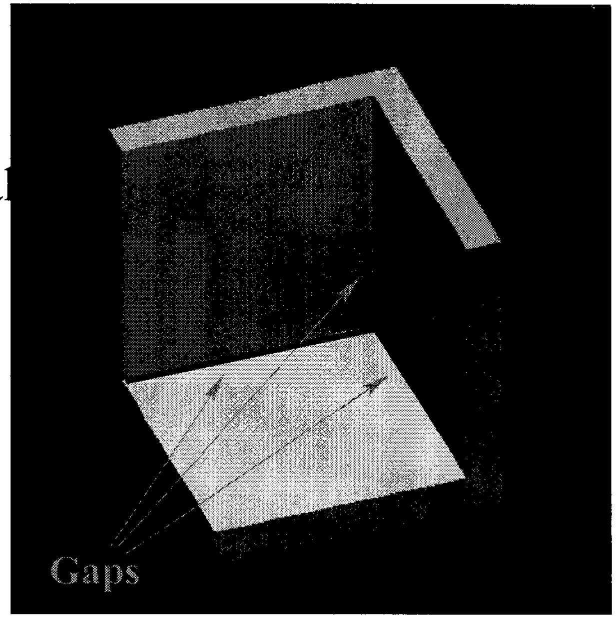
The raw images are then recentered and filtered, in order to remove some side effects, such as reflections on the camera window.



Modeling a cornercube with MACOS

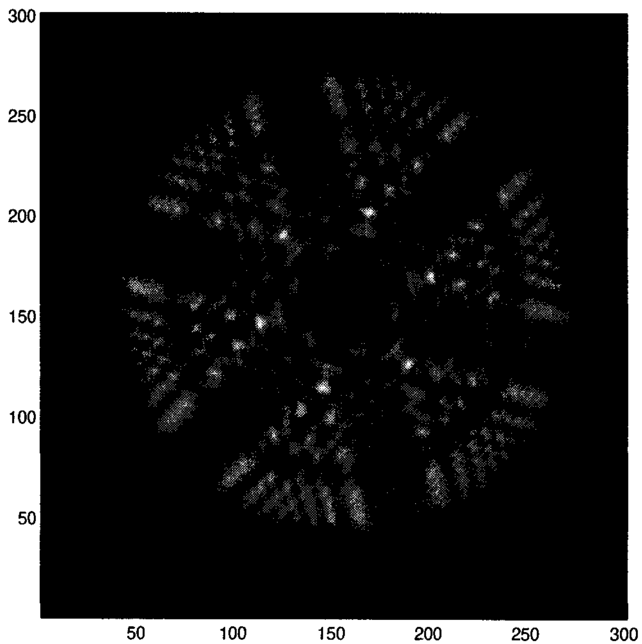
Generating a cornercube model in Macos is at the same time simple and complex, in the sense that many parameters can be taken into account. For Macos, a cornercube is a set of 3 non-sequential surfaces. On each of these, the user is free to set and vary geometrical and optical parameters such as:

- Zernike Polynomials Coefficients (up to 45)
- Position, Orientation parameters
- Obscurations on the surfaces to simulate gaps



What is MACOS ?

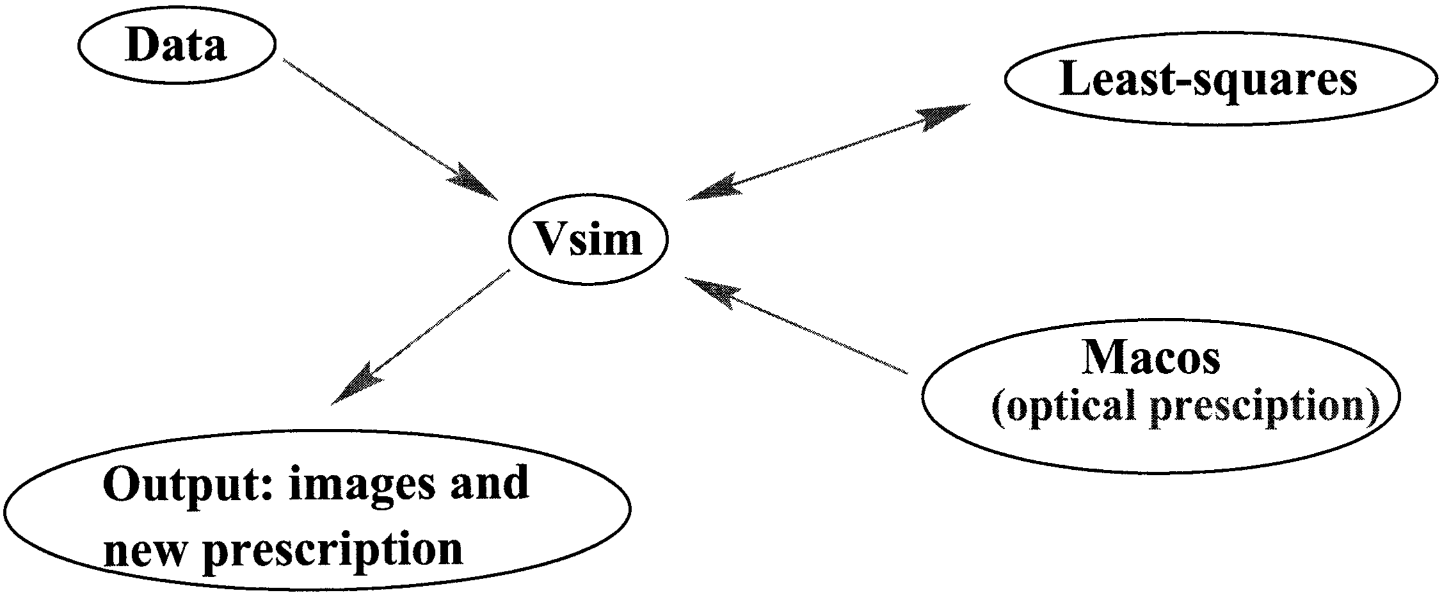
MACOS (Modeling and Analysis for Controlled Optical Systems) is an optical analysis and model generation program, developed at JPL by David Redding et al. It allows the user to generate and exercise fast, accurate and detailed models combining ray-trace, differential ray-trace and diffraction techniques. Macos provides unique modeling capability for system-level design and analysis tasks.



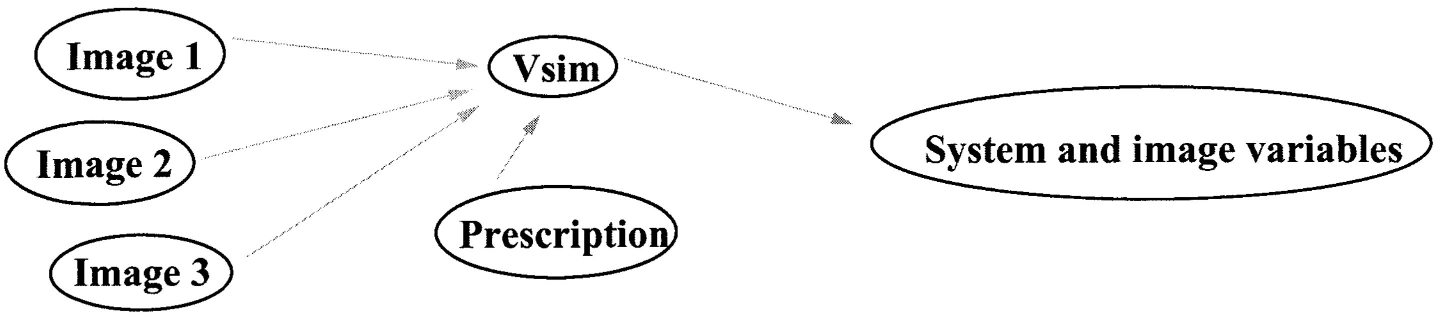
Left: A typical image obtained with Macos: this is the simulated near-field diffraction pattern of a corner-cube with 60 micron gaps between its faces and a uniform beam. The total propagation distance is 60 cm.

Validating the model: the Method

Vsim is an interface between images, optical prescriptions for Macos and a least-squares solver. We use Vsim to adjust the prescriptions to match the experimental data, by varying parameters in the prescription.

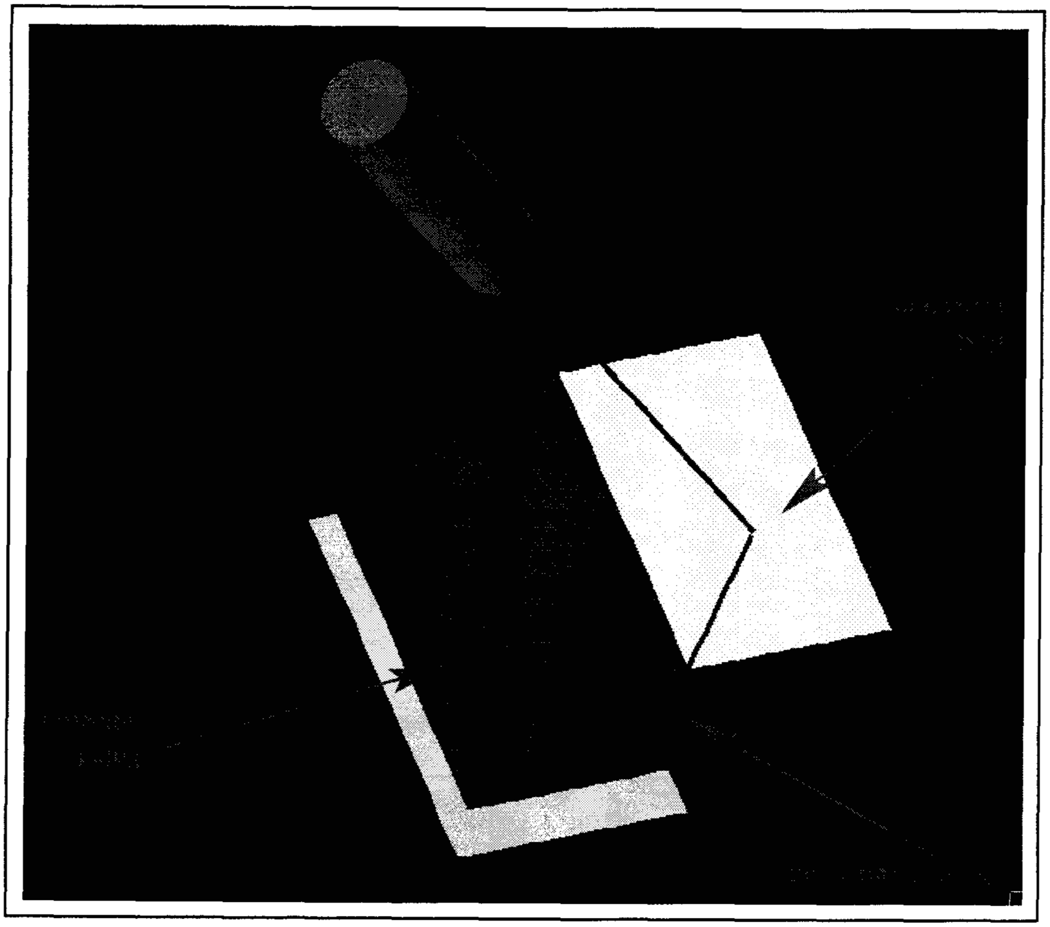


Vsim supports multiple data entries and drives Macos to produce the best matching images in the least-squares sense.

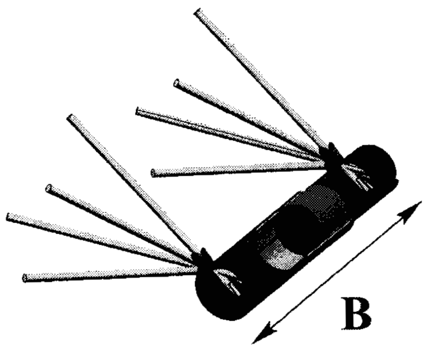


Typically, we first tune by hand the variables of the model in order to obtain a reasonable starting point. Then, we try to solve for more parameters:

- Flux, background, image center.
- Positional parameters: x,y,z orientation; x and y Tilts; x and y Decenter;
- Propagation distance for diffraction
- Zernikes : defocus, spherical aberration, coma, astigmatism (up to 45 Zernikes)
- Width of the gaps between faces



Metrology Systems and Retroreflectors



With three interferometers sharing the same baseline, the Space Interferometry Mission strives to pinpoint several tens of thousands of stars to an accuracy of a few microarcseconds. In order to do so, the geometry of the instrument itself (the cosmic ruler) must be known to a very high accuracy: the precision required for the metrology system measuring the baseline B is about 50 picometers.

The SIM metrology subsystem is a heterodyne laser metrology system, utilizing cornercubes, beamsplitters and two laser sources with known ultrastable frequencies. The pattern obtained from heterodyning the two polarized beams gives precise information on the relative positions of the cornercubes (for details on the metrology system, please consult the papers on this subject in the proceedings of this conference).

It is thus of paramount importance to understand the effects of the cornercubes on the laser beam itself. Because of its imperfections, a cornercube will produce a near-field diffraction pattern that may have dramatic effects on the metrology subsystem. The purpose of this study is as follows:

Build an optical cornercube model

Validate the model

Quantify and qualify the diffraction effects of a cornercube

Integrate this model into a metrology subsystem model

Simulate and quantify non-linear effects on the phase of the metrology beam wavefront as a function of pathlength

This poster presents the first three steps of this study.

Current work, future improvements, additions to the model and other subtle refinements

- The first step is, of course, to get better images. In order to do so, we have to use a better camera. This one has 768 x 494 pixels (pixel size is 8.4 x 9.8 microns), which makes the chip only half a centimeter across. Having a larger chip with more pixels will improve the quality of our data a lot.

- It turns out that this simple experiment requires a much higher precision than we thought at first. The setup will soon be placed on optical rails so as to ensure, for instance, a consistent propagation distance, as well as a consistent placement of the beam on the optics.

- Integrate a complete cornercube model into a metrology subsystem model, simply consisting, at first, of two such cornercubes : the idea is to recombine the beams having hit each cornercube and examine the wavefront. Eventually, a complete athermalized beamlauncher will be modeled.

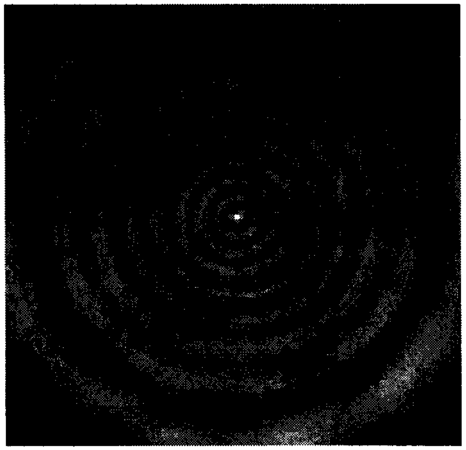
- Once the uniform beam model is validated, we will switch to gaussian beams, which will eliminate the need for some of the optics we are using, thus reducing the aberrations of the system.

Current Results and Conclusions

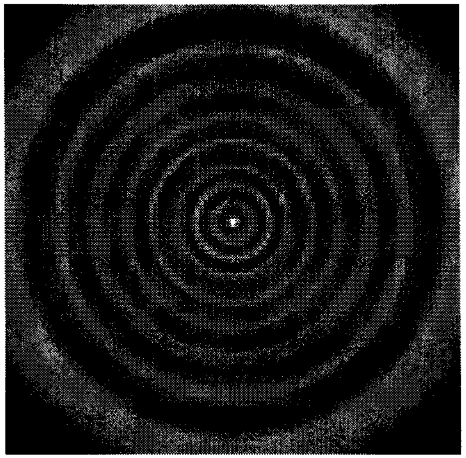
Flat mirror:

- We were able to to solve for orientation parameters as well as Zernike coefficients for the flat mirror.

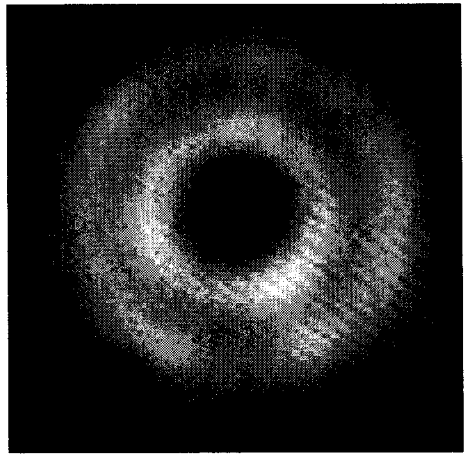
Vsim was first setup to solve individually for 2 different positions, d1 and d2, and gave strong matches
Both positions were then solved consistently and obtained good results, shown below:



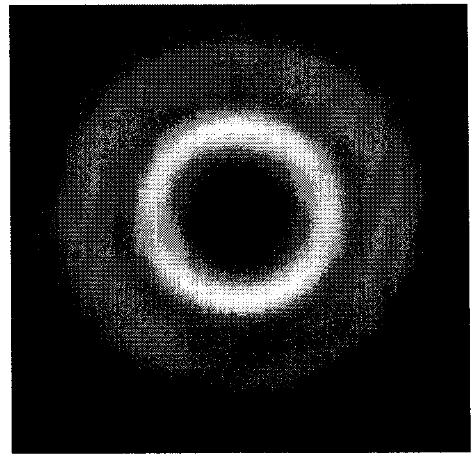
Data, position D1



Simulation, poistion D1



Data, position D2



Simulation, position D2

Cornercubes: