Membrane Reflectors for Large Aperture Telescopes

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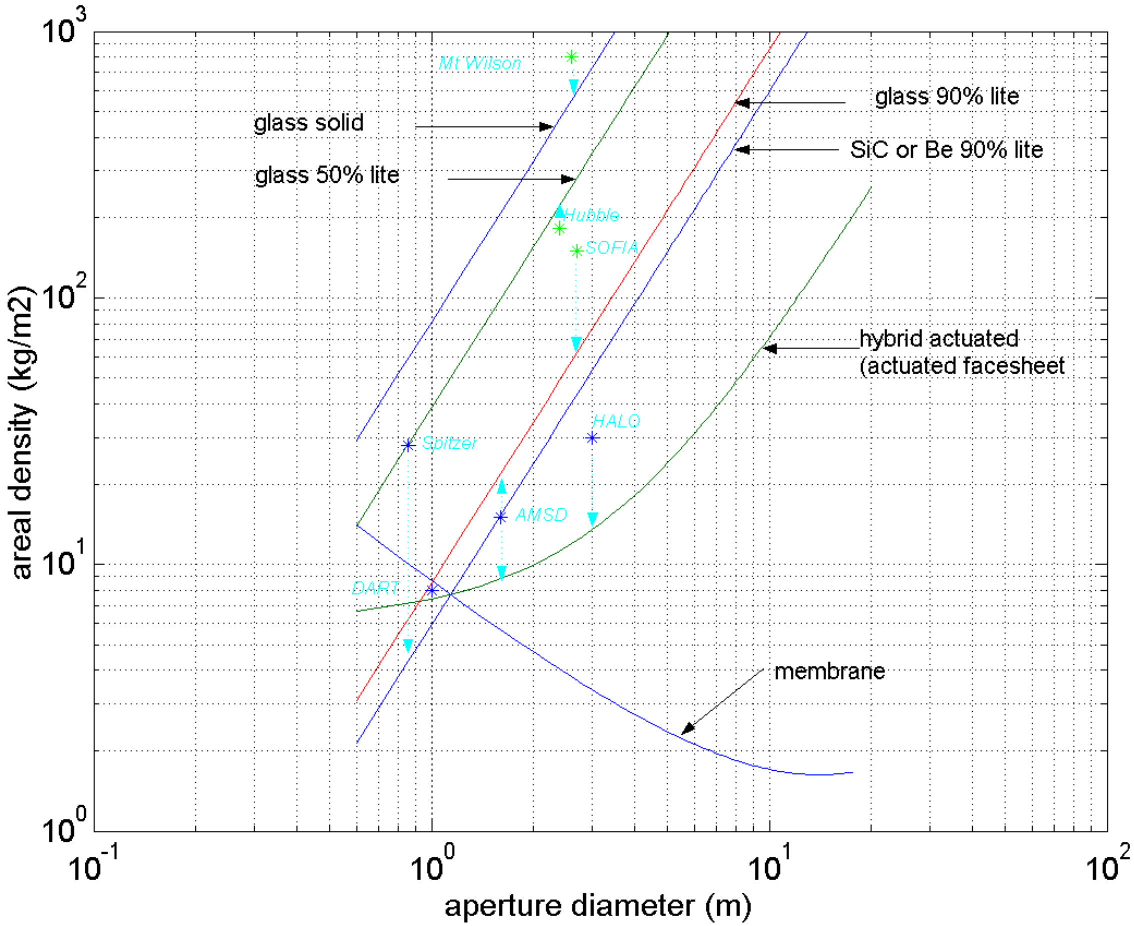
Introduction

- Progress in the development of reflective telescope technology and the associated instrumentation has at least a 350 year history.
  - The problem of constructing telescopes using polished metal mirrors has a long history tracing back to Gregory (1663), Newton (1672), and Cassegrain.
  - The first successful mirrors with silver reflecting surfaces on a glass substrate were constructed independently in the late 1850's by von Steinheil and by Foucault.
- Current state-of-the-art reflectors can trace their roots back to this technology.
  - The function of the substrate (whatever its composition) is to support the thin layer of high reflectivity material; the glass or metal substrate is formable into a shape that has useful optical properties.
  - In current state-of-the-art telescopes the mass of the substrate is 10^3 -10^6 times the mass of the reflecting layer.
  - The mass density of a polymeric membrane can approach the physical limit of 8×10^{-3} Kg/m^2 .

Clearly, new perspectives on telescope systems are necessary to reduce the cost and mass of the primary element

Mass density scaling relations for traditional and membrane reflectors



•Since cost is proportional to mass, a membrane reflector can be a less expensive option, with the performance benefits of an unsegmented off-axis design.

Membrane Surfaces

- Deformable surfaces are naturally categorized by their Gaussian
- curvature, an intrinsic property of any surface.

- All surfaces can be broadly categorized as 1) those that have zero Gaussian curvature, and 2) all others. As is well known from differential
- geometry the Gaussian curvature is given by

$$K = \kappa_1 \kappa_2$$

- where κ_1 and κ_2 are the principal curvatures at a given point on the surface. Membrane surfaces with both zero and non-zero Gaussian curvature can be constructed and are considered in turn.

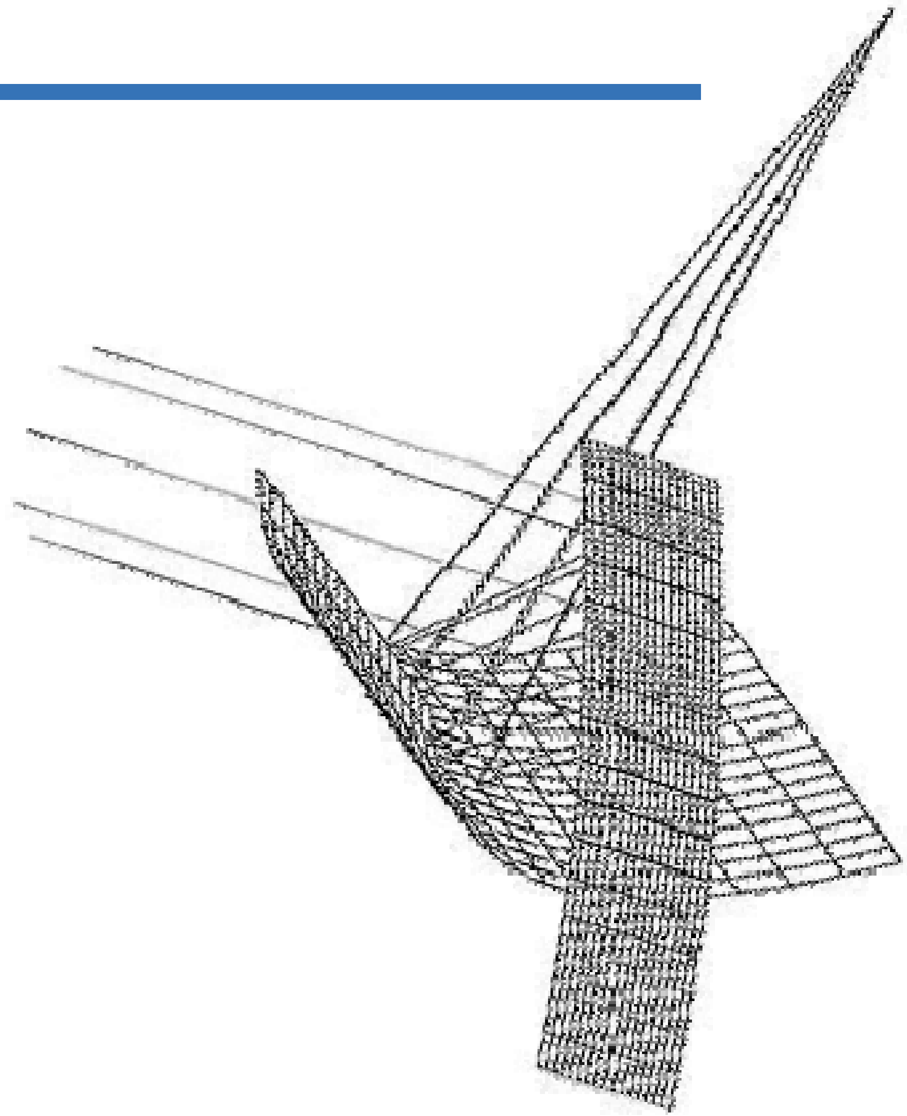
Zero Gaussian Curvature

- A surface with zero Gaussian curvature is either flat or has the shape of a trough, so that one of the principal curvatures is always zero.

- Such a surface can be formed by bending along only one axis. If the shape of the surface in the curved direction is a parabola, then a line focus results for an incident plane wave.

- To produce a point focus, a system of two trough-shaped reflectors
- properly oriented with respect to each other must be used. A perspective
- view of such a system is presented on the next slide.

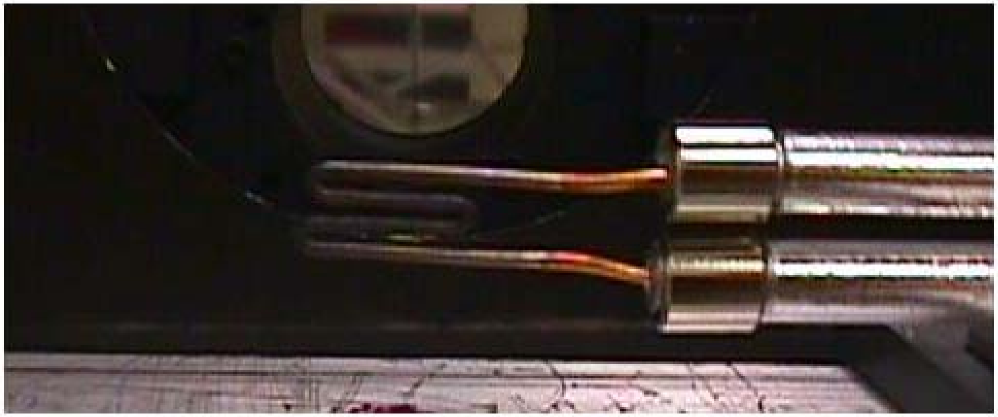
The DART System



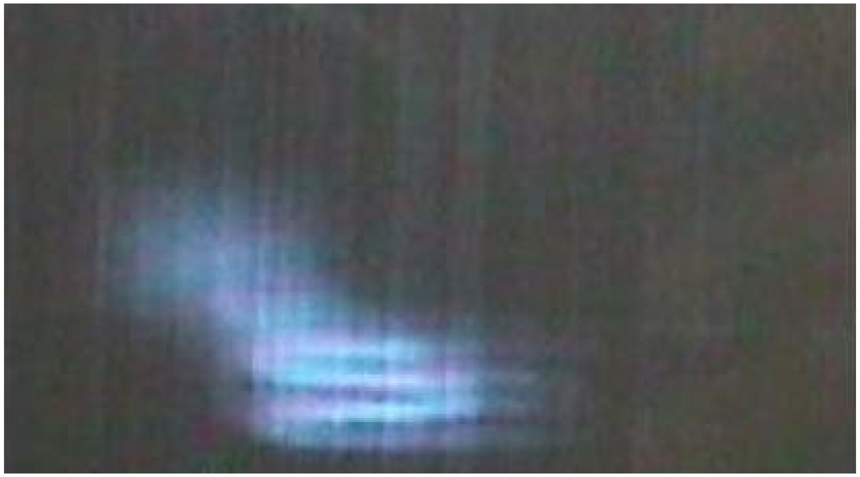
The layout of a two mirror reflector system where the individual reflectors are parabolic cylinders.
The orientation and curvatures of the individual reflectors are chosen so that a point focus results for an incident plane wave. The reflectors as illustrated are greatly oversized to emphasize the curvatures of each reflective element.

It is clear by inspection that the system is completely unobstructed.

IR Image Through DART System



The source is a hot soldering iron



The image is taken with a 10 micron camera

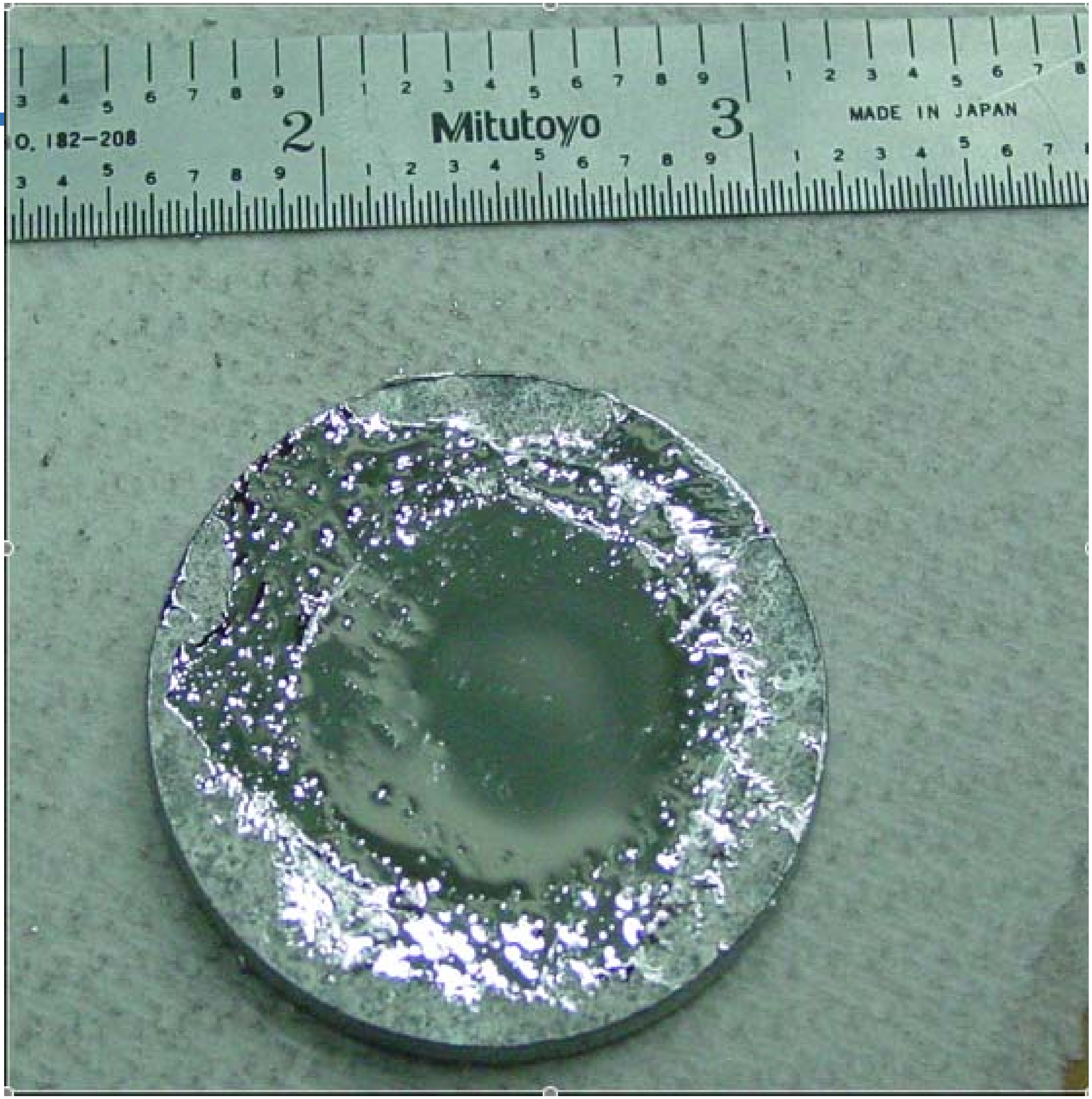
Non-zero Gaussian Curvature

- Surfaces with non-zero Gaussian curvature can only be formed by stretching or deforming a membrane along both axes. The shape and curvature the surface assumes depends sensitively upon the boundary over which the membrane is stretched, the pressure, and the mechanical material properties of the membrane.
- If the boundary is circular an axisymetric reflector results.
- However, the boundary need not be circular, nor planer; the only
- requirement is that it is described by a space curve that closes upon
- itself.

- A pressurized membrane takes on a shape that minimizes the total energy of the system consisting of the membrane, the gas and the structure rigidly holding the membrane.

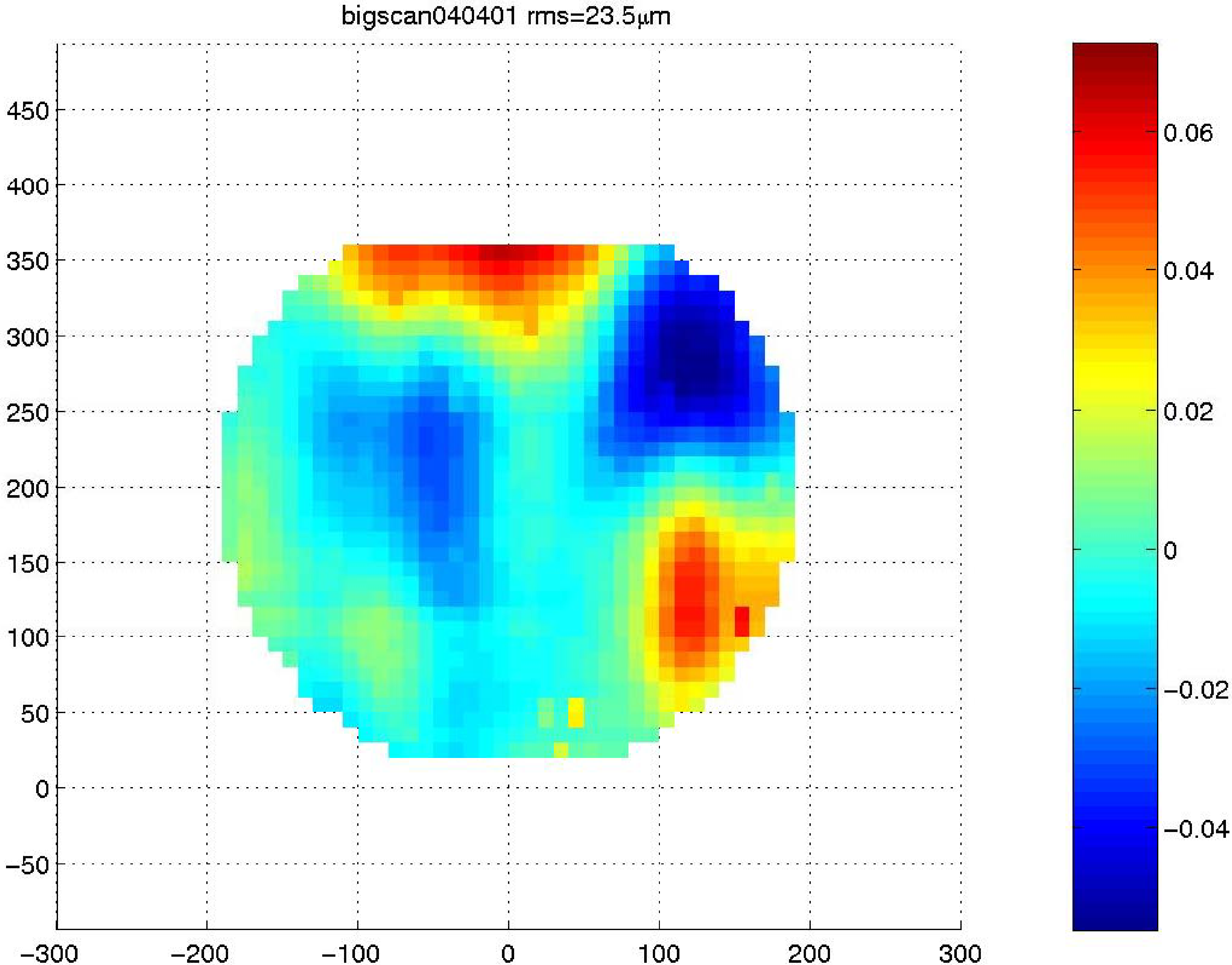
- Liquid membranes (eg soap films) take on shapes that minimize the energy of the film. Since the energy of the film is proportional to the surface area, the question of finding the minimal energy surface reduces to finding the surface of minimal area satisfying the boundary conditions.

Polymeric rigidized bubble with Aluminum reflective coating

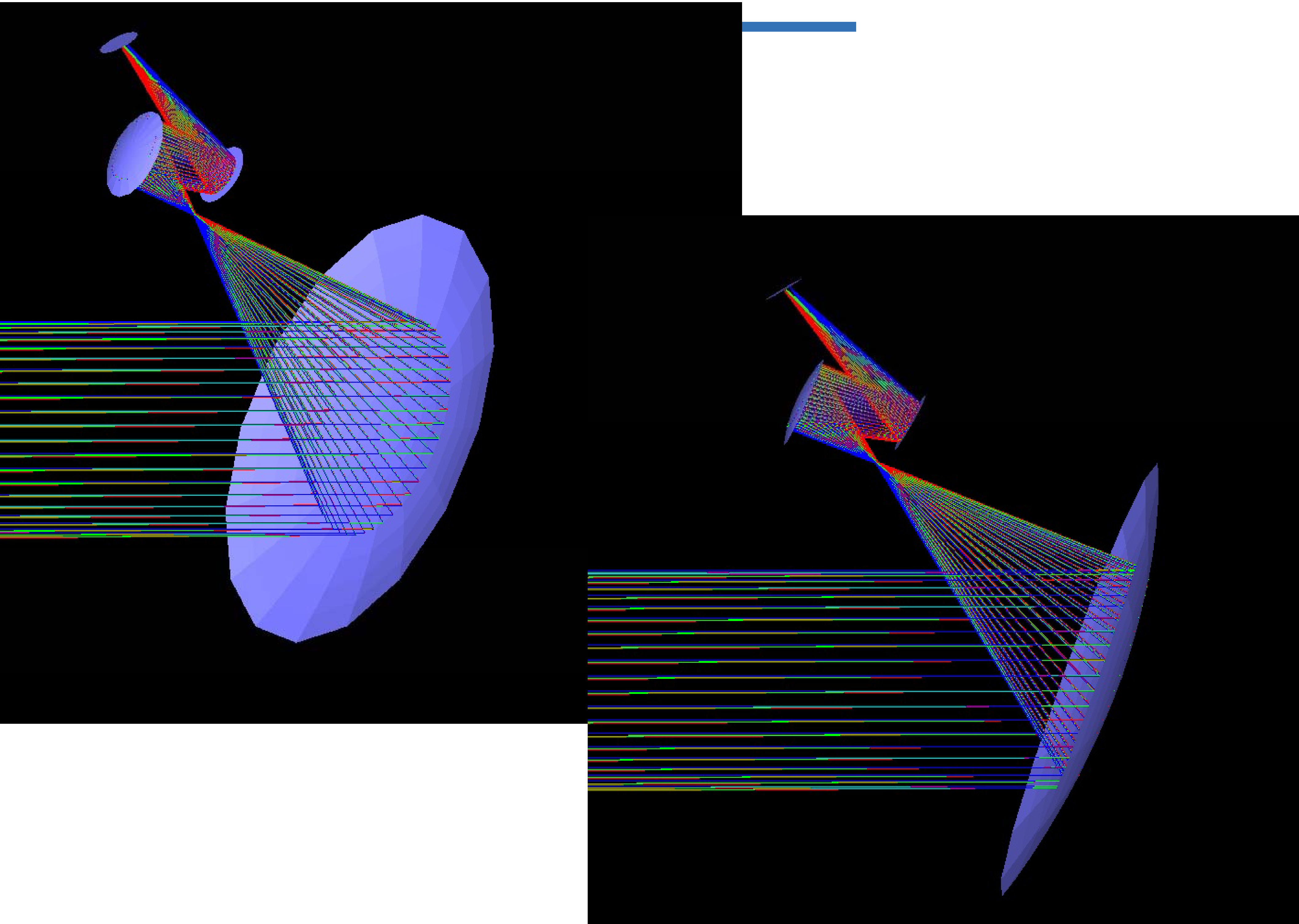


Above is a photograph of the liquid metal membrane. By inspection, one can see the bumpy surface caused by the oxide layer. Although it is difficult to see in this picture, the membrane is only about 25 microns thick. The size is limited by the weight of the membrane. If the experiment could be done in zero gravity, the metal film could be made much larger limited by the surface tension and tensile strength of the alloy.

Measurement of a membrane surface using a non-contacting profilimeter



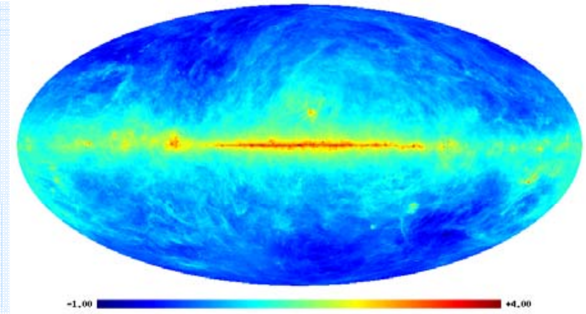
Layout of a single element reflector system with corrective secondary and tertiary mirrors

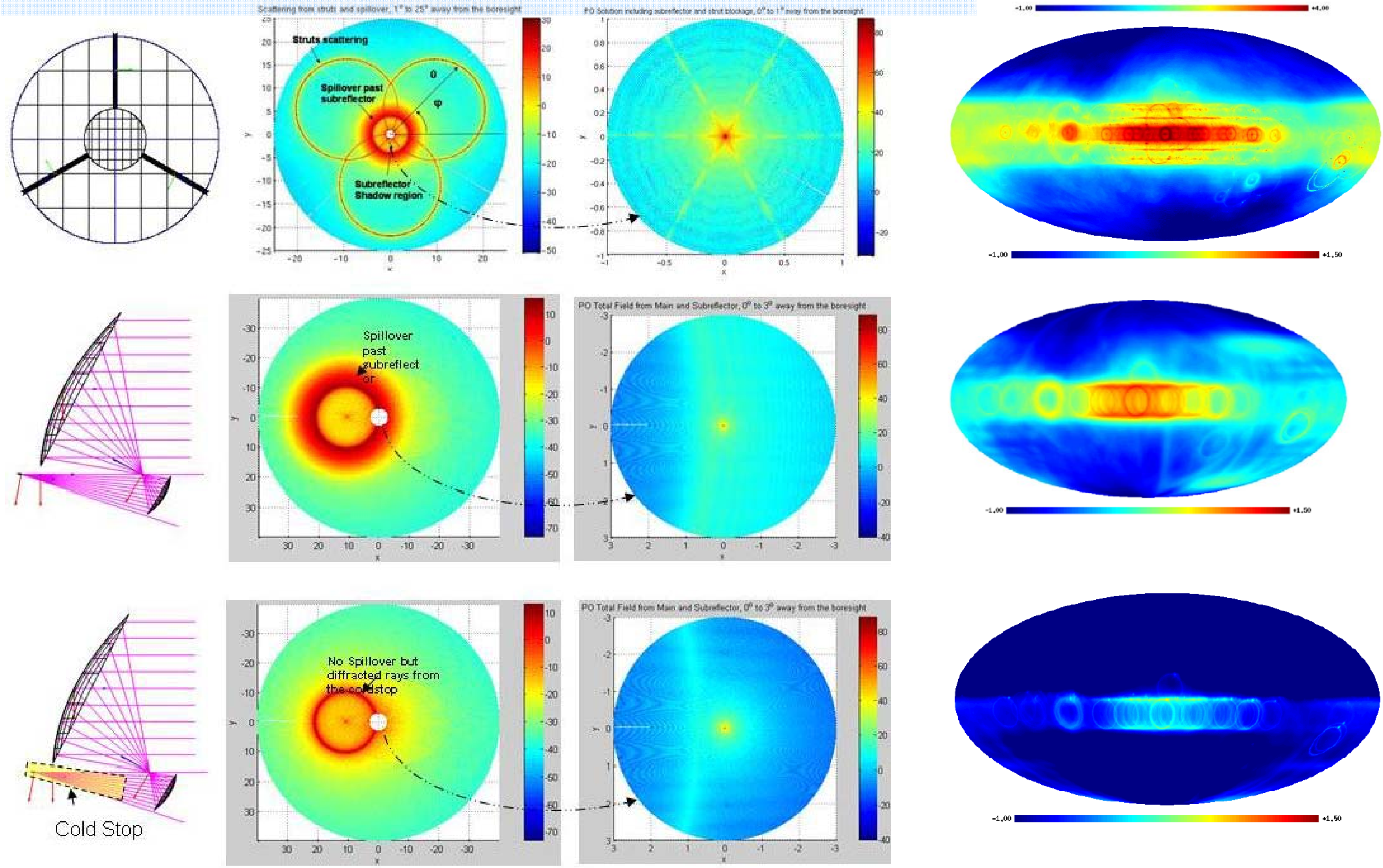


Analysis of a FIR/Submillimeter Cryogenic Telescope

To evaluate the effect of the far sidelobes on performance of the telescope system, we convolve a 100 micron sky map with the beam pattern of the sidelobes (the main beam is surpressed)..

Symmetric and offset telescope designs have been investigated , calculating radiation patterns. Shown here for each configuration (left column) the response on large angular scale (middle column) and on smaller scale (right column). For each configuration the distribution of power collected from a model of the Galactic plane at 100 μm is calculated. The main lobe and inner side lobes have been suppressed. The scale is log ($I_{100\ \mu m}$ /MJy sr^{-1}).





Summary

•A rigidizable polymeric membrane can produce ultra-lowmass membrane reflectors.

•Corrective secondary and tertiary optics need to be used in conjunction with the membrane primary to achieve the largest focal surface.

•Instrumentation exists at JPL for the construction and characterization of membrane surfaces.