# NIRSPEC

**UCLA Astrophysics Program** **U.C. Berkeley** **W.M. Keck Observatory**

**Don Figer** **April 2, 1996**

## NIRSPEC Optics Design Note 12.00
## Front-end Bid Package

### 1. Introduction

The front-end bid package is reproduced in its entirety on the following pages. It was sent to the vendors listed below; full addresses and phone numbers for the manufacturers can be found in another design note. Vendor responses are summarized at the end of this document.

Advanced Optical Exploration & Technology
Ken Futton

Applied Physics Specialties Limited
Martin High
President

OFC Corporation
Mr. Bob Clark
Director Advanced Systems Development

SORL
Fred Kingsley
Sales Manager

SSG, Inc.
Joe Robichaud

Speedring Systems, Inc.
Dale Sabo
Director of Sales and Marketing

# NIRSPEC

**UCLA Astrophysics Program** **U.C. Berkeley** **W.M. Keck Observatory**

## Request for Formal Quote

Two K-mirror Assemblies for NIRSPEC
November 10, 1995

### 1.0 Introduction

This document is a solicitation for formal quote to produce two opto-mechanical assemblies, each containing three mirrors. The assemblies will be used in the fore-optics of the NIRSPEC instrument, a high resolution spectrometer being built for the Keck II telescope. We have provided the design specifications, manufacturing tolerances, clear aperture ray traces, and a drawing of one of the assemblies surrounded by neighboring elements in the final system. We have been purposely vague about the opto-mechanical details because we would like vendor input on these issues.

### 2.0 Summary of Design

All items to be made in this work package will normally be operated at 77 K, inside the NIRSPEC vacuum chamber, although they will be periodically warmed up to room temperature for testing and maintenance. The optics must be coated for maximum reflectivity at near-infrared wavelengths, 1 to 5 :m. Performance is diffraction limited on axis in the wavelength region of interest.

Both assemblies resemble a "K-mirror" configuration, each having two flats and an off-axis element with power (see Figure 1). The first assembly is referred to as the "image rotator." It will be mounted on a mechanism which rotates about the input optical axis; this motion provides selectable field rotation. The second assembly is referred to as the "f/converter" because it refocuses the collimated beam at f/10 while the input beam to the instrument is f/15.

Each assembly consists of 3 mirrors:

1. a **flat** which directs the beam away from the input optical axis
2. an **off-axis parabola (OAP)** which collimates the beams, and sends them back toward the input optical axis
3. a second **flat** which directs the beam back onto the input optical axis

## 3.0 Statement of Work

This statement defines the responsibilities of both the vendor and UCLA for the proposed contract. We are quite flexible at this point and therefore request vendor input in modifying and refining this statement. The vendor will be responsible for all non-recurring engineering, fabrication, and testing to deliver finished assemblies which meet the specifications in this document. At the time of granting the contract, UCLA and the vendor will finalize a formal verification and acceptance procedure to be performed before final payment. We expect that a successful job would include the following tasks, although acceptable assemblies need only meet the specifications listed elsewhere in this document:

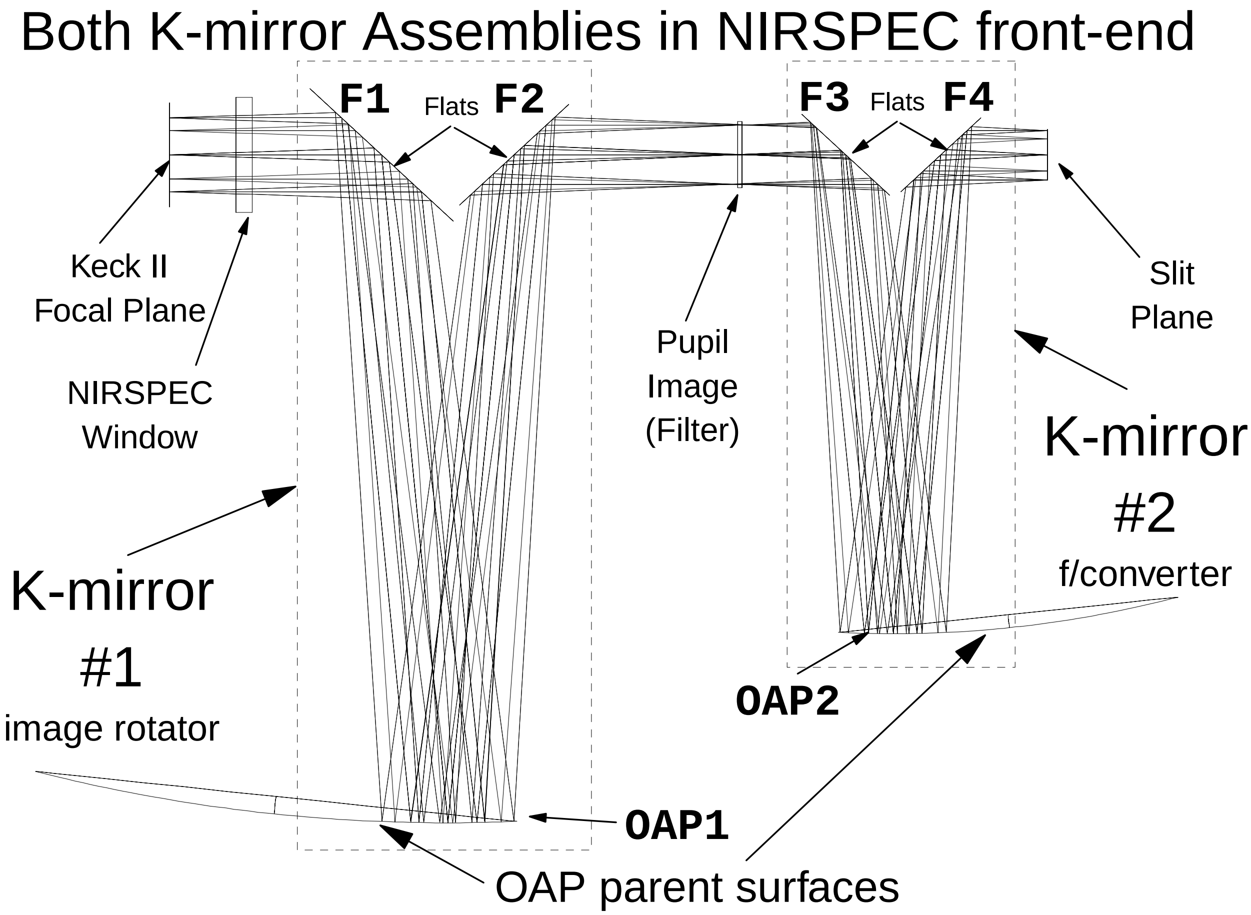
1. Opto-mechanical design of mirror substrates and support structure
2. FEA modeling of stress and thermal changes for cryogenic use at 77 K
3. Design and procurement of all fixturing and test equipment
4. Substrate preparation
5. Initial figuring
6. Electroless nickel plating
7. Final finishing and post-polishing
8. Gold coating
9. Final testing and qualification at 77 K

## 4.0 Specifications

### 4.1 Optical Prescription

Figure 1 shows a side view of both K-mirrors along with neighboring elements. The rays propagate from left to right and have been traced from various field points including the most extreme corner field points. The apertures are sufficiently oversized to accommodate the square field as it appears to rotate with the rotation of the assembly.

The full optical prescription is provided in Table 1. “Distance” refers to the distance between the surface and the next element. The rotations are all about the x-axis (out of the page in Figure 1) and measured with respect to the vertical in Figure 1.



Both K-mirror Assemblies in NIRSPEC front-end
F1
Flats
F2
F3
Flats
F4
Keck II
Focal Plane
NIRSPEC
Window
Pupil
Image
(Filter)
Slit
Plane
K-mirror
#2
f/converter
K-mirror
#1
image rotator
OAP2
OAP1
OAP parent surfaces


**Figure 1**

**Table 1:**
**Optical Prescription**

| Surface | Radius | Distance | Aperture | | Rotation[1] |
|---|---|---|---|---|---|
| | | | x | y | |
| | mm | mm | mm | mm | |
| Window | - | 60.000 | - | - | - |
| F1 | infinity | 304.085 | 58.1 | 89.6 | 47.9 |
| OAP1 | 791.830 | 304.085 | 39.6[2] | | 0 |
| F2 | infinity | 103.647 | 40.3 | 68.0 | -47.9 |
| Filter | - | 48.000[3] | 30.0[2] | | 0 |
| F3 | infinity | 218.002 | 34.9 | 54.6 | 47.9 |
| OAP2 | 529.358 | 218.002 | 31.5[2] | | 0 |
| F4 | infinity | 49.432 | 32.6 | 49.6 | -47.9 |

[1]rotation is along axis out of page, measured from vertical in Figure 1
[2]radius for circular aperture
[3]does not include the 2 mm filter thickness

## 4.2 Opto-mechanical Tolerances

The tolerances were generated by assuming that we can accept a total weighted wavefront error (WFE) of 0.12**8**$_{2.2\ :m}$ RMS. This condition ensures that the system gives 90% ensquared energy (ESE) within a 97 **:**m square field at the final (slit) focal plane for field points within the slit; the slit is rectangular and spans ±15O X ±0.2O on the sky. This WFE condition also ensures that the system gives 80% ESE within a 97 **:**m square field over the full square field of view of the slit viewing camera (SCAM); the SCAM covers ±23O on the sky. These performance criteria have been measured when the image rotator K-mirror is in the ideal configuration, i.e. **2**$_{IROT}$ = 0°. The weight ratios are 3:2:1 for the central field point:slit edge field points:SCAM FOV corner field points.

In some cases, requirements other than those due to image performance provided tighter constraints. These other requirements are listed below. The tolerance tables contain symbols following each tolerance value. These symbols are described below and at the bottom of each table. They indicate which requirement was used to calculate the tolerance value.

- **Image wander (iw)**. Requires a maximum image wander radius of ½ of a slit width, or 97 **:**, at the slit focal plane. The image wander constraint does not apply to the f/converter K-mirror because it is stationary.
- **Beam displacement (b)**. Requires a maximum lateral offset of 1.0 mm on any part from the beam's point of view. For instance, the beam could be displaced by 1.5 mm on the folding flats, but that would only result in a displacement of 1.0 mm from the beam's point of view. For downstream elements, this requirement amounts to a maximum allowable field for upstream elements. For instance, a tilt in the last flat mirror of the f/converter K-mirror assembly will mean that the imaged field will be offset at the instrument window. This offset is considered to be the same as "beam displacement."
- **Mechanical (m)**. Requires that parts remain within a reasonable profile for housings.
- **Pupil wander (pw)**. Requires a maximum of 1% in lateral offset of the pupil image; this amounts to 0.267 mm.
- **Scattering (s)**. Requires negligible scattering between 1 and 5 **:**m.

The last section of each table refers to the nominal clear aperture center as opposed to the vertex position. This distinction is only relevant in the case of the OAPs, where the clear aperture is considerably offset from the parent vertex.

## Table 2:
## Opto-mechanical Tolerances for Image Rotator

| Tolerance | units | F1 | OAP1 | F2 | Module |
|---|---|---|---|---|---|
| Surface | | | | | |
| Radius | mm | - | -3.5p<br>+1.0p | - | - |
| Irregularity[1] | $8_{632.8nm}$<br>(P-V) | 1/5p | 1/5p | 1/10p | - |
| RMS surface roughness | Å<br>(RMS) | < 55s | < 55s | < 55s | - |
| Orientation | | | | | |
| x-tilt | mrad | 0.3pw | 0.2iw | 0.1iw | 0.3pw |
| | asec | 62 | 41 | 21 | 62 |
| y-tilt | mrad | 0.5pw | 0.2iw | 0.2iw | 0.3pw |
| | asec | 103 | 41 | 41 | 62 |
| z-tilt (clocking) | mrad | 30m | 3.5pw | 30m | 30m |
| | asec | 6188 | 722 | 6188 | 6188 |
| Center Position | | | | | |
| x-decenter | mm | 1.0b | 0.3pw | 1.0b | 0.3pw |
| y-decenter | mm | 1.5b | 0.4pw | 1.5b | 0.3pw |
| z-decenter | mm | 0.1iw | 1.0p | 0.2pw | 1.0m |

Tolerances are measured with respect to local coordinate axes. The z-axis is normal to the clear aperture tangent plane. The x-axis is out of the page in Figure 1. The y-axis is orthogonal to the x- and z-axes.
Tolerance codes:

- **p** - image performance gives 90% ESE within a 97 :m per side square for slit field points, and 80% ESE for SCAM FOV corner field points
- **iw** - image wander radius = 97 :m at slit plane
- **b** - 1.0 mm offset of beam footprint on any element
- **m** - mechanical clearance
- **pw** - pupil wander radius = 267 :m (1% of pupil diameter)
- **s** - negligible scattering between 8 = 1 and 5 :m

[1]Irregularity is per beam. The specs were originally 1/10 for the first flat and the OAP and 1/20 for the second flat. These were changed after received considerable resistance from vendors and after reviewing the wavefront error budget.

## Table 3:
## Opto-mechanical Tolerances for f/converter

| **Tolerance** | **units** | **F3** | **OAP2** | **F4** | **Module** |
|---|---|---|---|---|---|
| Surface | | | | | |
| Radius | mm | - | -0.5p<br>+1.5p | - | - |
| Irregularity[1] | $8_{632.8nm}$<br>(P-V) | 1/20p | 1/10p | 1/10p | - |
| RMS surface roughness | Å<br>(RMS) | < 55s | < 55s | < 55s | - |
| Orientation | | | | | |
| x-tilt | mrad | 1.3b | 1.3b | 6.8b | 2.6b |
| | asec | 268 | 268 | 1403 | 536 |
| y-tilt | mrad | 1.8b | 1.3b | 10b | 1.9b |
| | asec | 371 | 268 | 2063 | 392 |
| z-tilt (clocking) | mrad | 30m | 13b | 30m | 30m |
| | asec | 6188 | 2681 | 6188 | 6188 |
| Center Position | | | | | |
| x-decenter | mm | 1.0b | 0.6b | 1.0b | 0.7b |
| y-decenter | mm | 1.5b | 0.6b | 1.5b | 0.7b |
| z-decenter | mm | 1.5b | 1.0p | 0.7b | 1.0m |

Tolerances are measured with respect to local coordinate axes. The z-axis is normal to the clear aperture tangent plane. The x-axis is out of the page in Figure 1. The y-axis is orthogonal to the x- and z-axes.

Tolerance codes:

- **p** - image performance gives 90% ESE within a 97 :m per side square for slit field points, and 80% ESE for SCAM FOV corner field points
- **iw** - image wander radius = 97 :m at slit plane
- **b** - 1.0 mm offset of beam footprint on any element
- **m** - mechanical clearance
- **pw** - pupil wander radius = 267 :m (1% of pupil diameter)
- **s** - negligible scattering between 8 = 1 and 5 :m

[1]Irregularity is per beam. The specs were originally 1/10 for the first flat and the OAP and 1/20 for the second flat. These were changed after received considerable resistance from vendors and after reviewing the wavefront error budget.

## 4.3 Qualified Clear Apertures

Clear aperture diagrams are shown in the following 6 figures. The rotator angle refers to the angular position of the image rotator assembly about the input optical axis. In some cases, we overlaid two separate sets of spots for rotator angle = 0° and 45° in order to generate the full aperture size. The final dimensions were calculated to give 2 mm of extra space around the beam footprint for each part. Because this extra space is defined in terms of the beam, we require about 3 mm of extra surface on diagonally tilted flats.

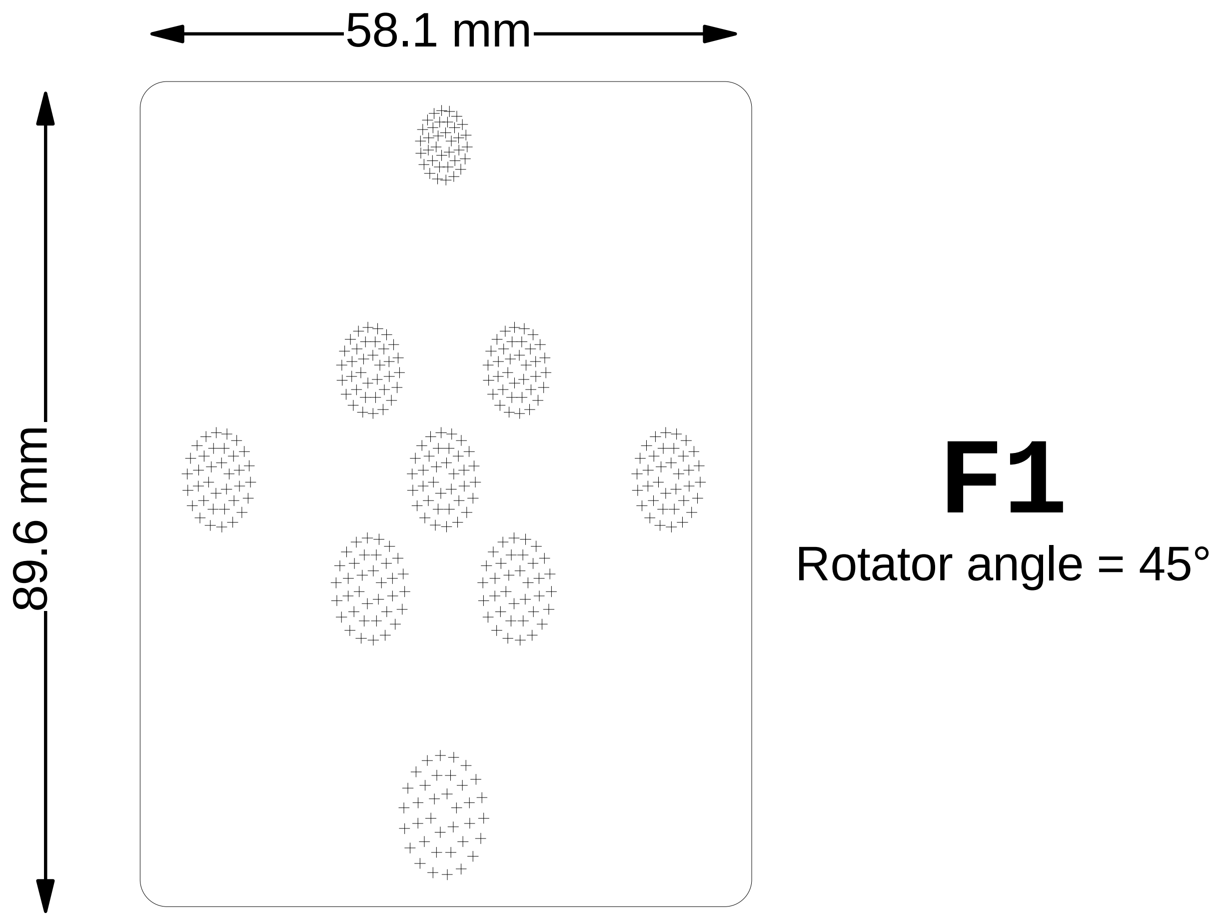



**Figure 2**

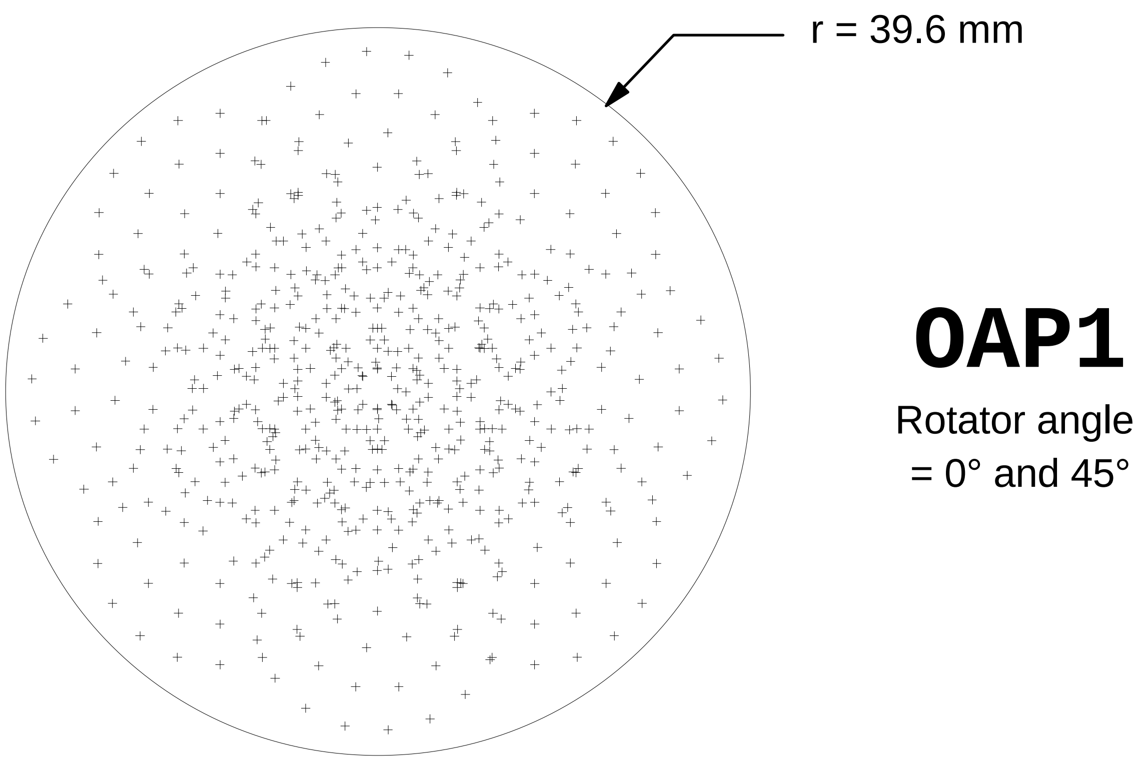



**Figure 3**

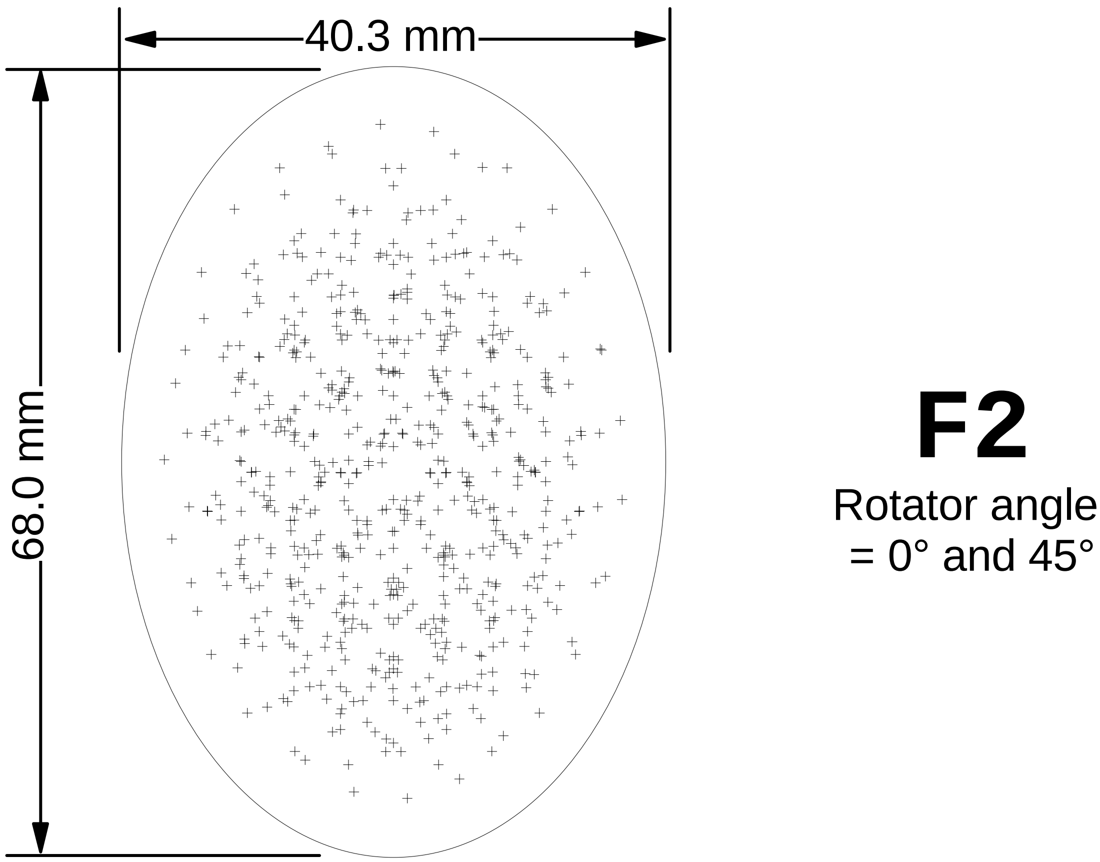
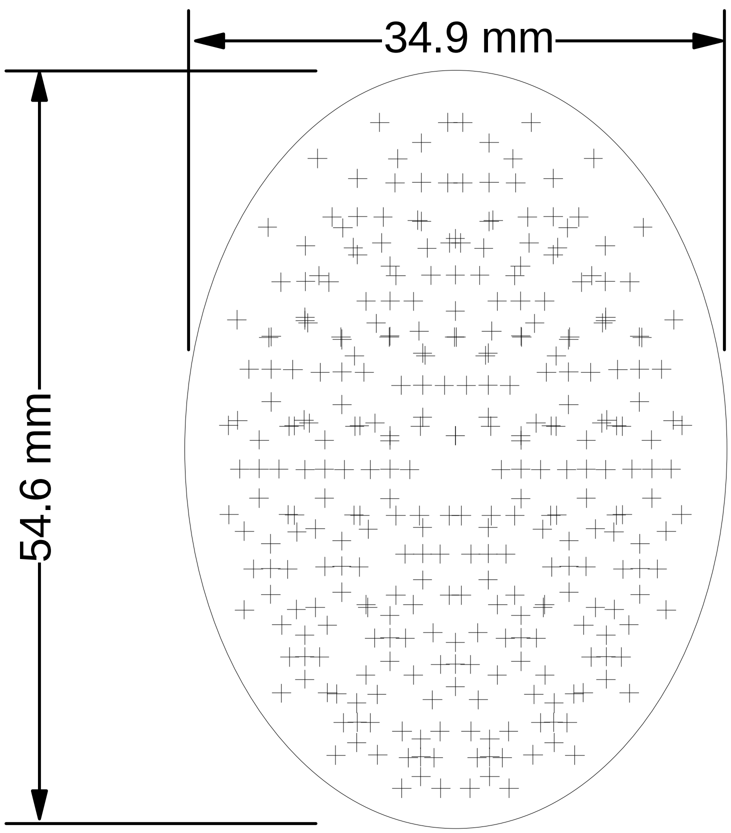
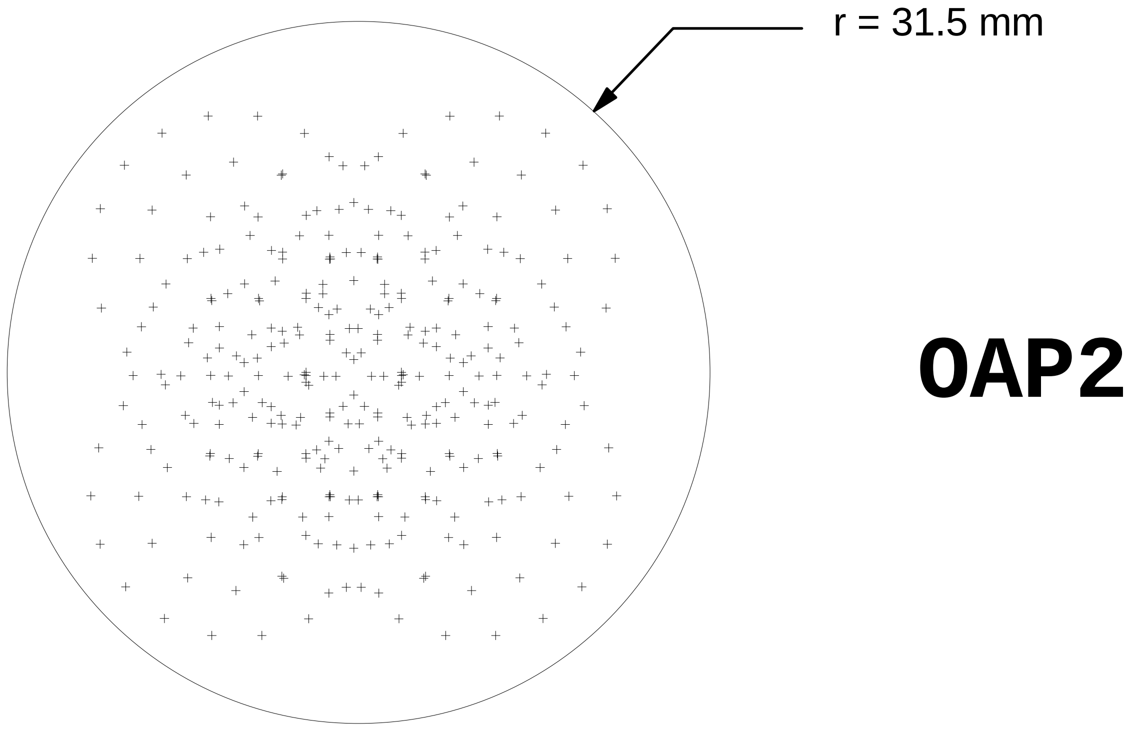


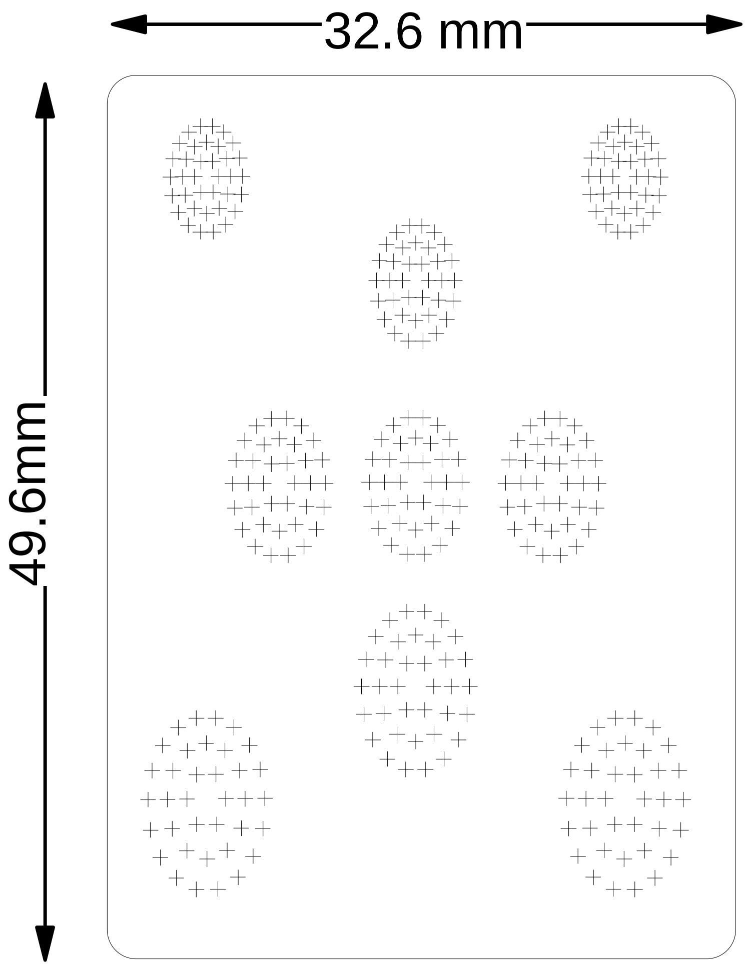

**Figure 4**




**F3**

**Figure 5**


r = 31.5 mm
OAP2




**F4**

**Figure 7**

### 4.4 Coatings

The mirror surfaces should be coated for maximum reflectivity from 1 to 5 :m, comparable to either a FSS-99 or FSG-98 coating from Denton Vacuum (Morrestown, NJ). The best choice of coating for performance, adhesion, and durability should be jointly determined during the initial portion of the contract.

### 4.5 Thermal Requirements

We require that the delivered assemblies perform to the specifications in this document at the operating temperature of 77 K, and that this performance be maintained after many thermal cycles. The procedure for thermal cycling and stress relieving of the mirror substrates is to be determined by the vendor, who will also provide documentation.

After electroless nickel plating, the diamond turning and post-polishing should be controlled so that a minimum of material is removed. A minimum remaining thickness should be called out over the mirror surface. This amount is to be determined, but should be part of the proposed specifications and should be addressed in the contractor’s response.

### 4.6 Mechanical Requirements

The vendor will be responsible for the mechanical design of mirror substrates, support structure, tooling, fixturing, machine mounts, and optical reference surfaces. There is flexibility in this solicitation for the vendor to propose enclosed housing and baffling design and construction.

Figure 8 shows the position of the image rotator K-mirror relative to the instrument window and the filter wheel. Each component within the assembly will have a mechanical housing and reference surfaces. The common substrate for the flats is for illustrative purposes, although this concept might provide a viable possibility for mounting and aligning these surfaces.

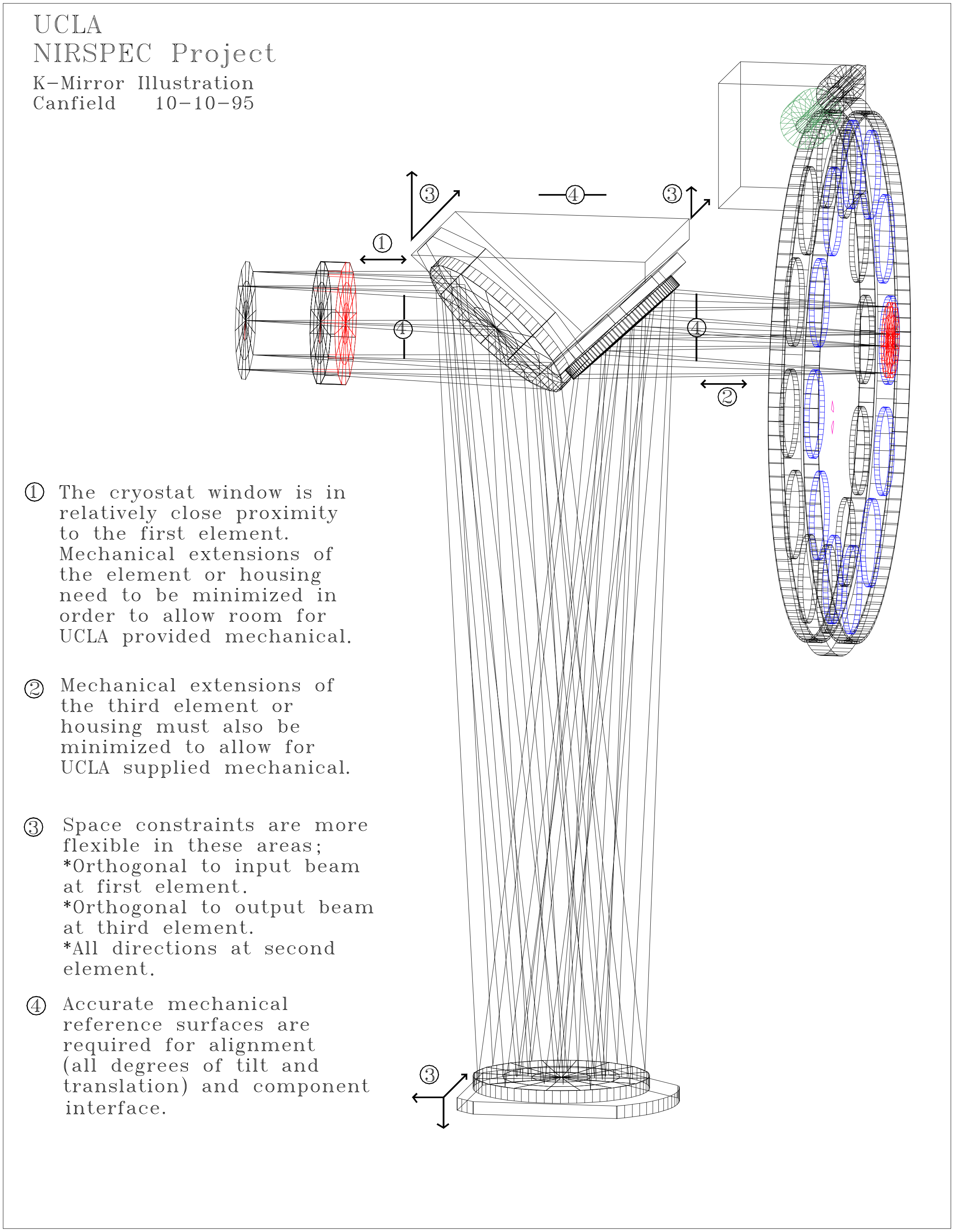



**Figure 8**. Perspective drawing of image rotator K-mirror assembly and neighboring elements.

## 5.0 Acceptance Testing and Documentation

Testing of individual mirror surfaces and qualification of the assemblies should be considered the major task of the fabrication effort. Although tests and procedures need to be agreed upon between the vendor and UCLA, we expect the following issues to be addressed in the response to this solicitation:

1. Qualification of mirror surfaces
2. Measurement of critical dimensions
3. Qualification of assembled units
4. Expected end-to-end performance, room temperature
5. Cryogenic performance, end-to-end
6. Any fixturing or null optics needed during the testing process
7. Qualification of null optics and test equipment
8. Measured values for all parameters in Table 1

## 6.0 Vendor Options

The vendor may propose additional work beyond the scope of the required work in this bid request. We encourage the vendor to consider additional work in the following areas:

1. Baffles
2. Housings

# Vendor Responses

The vendor responses are summarized below. The actual responses are included as attachments. SORL's response is too large to attach, but it can be found on file; the title is, "Technical Proposal - NIRSPEC K-Mirror Assemblies." The response from Speedring stretches over several communications over the period of a few months. A package with these communications can be found in another document.

**Advanced Optical Exploration & Technology**

no response

**Applied Physics Specialties Limited**

The bid totalled $79,500 including cryogenic testing and manufacture to our specifications without exception. Our primary concern was their lack of experience in producing such optics.

**OFC Corporation**

The bid totalled $84,994.11 and included cryogenic testing at UCLA. They took exception to the specifications signing up to 70 Å RMS surface roughness instead of our desired < 55 Å RMS. They also state that they take exception to the irregularity, signing up to twice the values given in the original RFQ, however the values in the original RFQ were half the value shown in Tables 2 and 3 (see the notes at the bottoms of the tables). So, in fact, OFC was signing up to the irregularities we prescribe above.

**SORL**

SORL gave the most comprehensive response, producing a thorough Technical Proposal. They actually gave 2 quotes, one on November 17, 1995, and another on December 15, 1995. Both are for the same work, but the latter resulted from my request to have them break out costing from the first quote. It turns out that they found some missing items in the first quote, so the price actually was greater in the second quote. The second bid was $141,995 to $145,295, the range due to uncertainty in the field service.

The bid included cryogenic verification at UCLA.

**SSG, Inc.**

In typical SSG-fashion, their response was primarily a two-phase proposal requiring a design-study phase before the production phase. They were concerned with fully understanding: boresight stability, the relationship between WFE and alignment errors and other fabrication errors, what to relax in the WFEB, and pupil wander.

They proposed a design phase costing $10K-$20K, and estimated a production cost of $150K.

**Speedring Systems, Inc.**

We eventually settled on Speedring for the following reasons: previous experience with cryogenic systems, reasonable cost (not the most expensive, but not much less than SSG's ROM bid), and the fact that having SSG do all the optics would put too much responsibility on one vendor. We were particularly impressed by their (Mike Sweeney) understanding of metals in a cryogenic environment.

We worked with them through several iterations to arrive at a final firm-fixed price. I visited once in December, 1995, and Dale Sabo, Mike Sweeney, and Mike Roberts visited once in January. As of February 26, 1996, their bid was $146,800 for best effort, and another $30,000 to correct any deviations from our specifications. The cost for iterative compensation is a cap, so they might be able to correct any problems for less than this amount, but certainly no more than this amount.