Gemini iR multiBand Imager
Concept Design v1.2
A High Throughput MultiBand Imager for Gemini-N

Overview

The Gemini Observatory has established itself as the international leader in multi-instrument queue observing, a capability which this proposal seeks to exploit with a new multi-band high-throughput infrared imager - The Gemini iR multiBand Imager (GRB Imager). By its acronym, the instrument is particularly well suited to follow-up Gamma Ray Bursts (GRBs), especially those at extremely high redshifts. However, its capability is far broader than that, with the instrument proposed being the highest throughput IR imager on an 8-m class telescope, ideally suited to queue observing of single objects, especially those of a transient nature, such as are focus of Gemini Partner initiatives including (but certainly not limited to) Pan-Starrs, Palomar Transit Factory, SkyMapper, Kepler, HAT-net and HAT-SOUTH, and eventually LSST.

The core-principal of the GRB Imager is simplicity - a feature which minimizes the number of elements in the instrument (and thereby provides high throughput), and which enables the instrument to built at a moderate cost in rapid time frame. The instrument will re-use much of what the RSAA instrumentation group developed in expeditiously delivering GSAOI in 2006, making the often-made, but seldom-realized promise of a fast-tracked instrument achievable.

In its simplest form, The GRB Imager features simultaneous imaging of the same field in Z/Y,J, H, K bands of a 2’ FOV using 4 Hawaii2RG detectors at 0.06”/pixel. The GRB Imager features > 45% end-to-end transmission in all bands (excluding telescope), diffraction limited image quality (albeit not fully sampled) in the central regions of the field in all bands, and a single moving part within the cryostat. Depending on the views of the GSC, Directorate, and Board, it is possible to provide a set of filters for each detector, and/or increase the FOV to approximately 2.5’ with a less-AO friendly pixel scale of (0.08”/pixel).

We present here an instrument conceptual design demonstrating an optical design that provides the performance quoted above, and believe that with quick action, that the GRB Imager could be on-sky in 2013 for a cost of ~US$5M. The costs and time-frame will need to be confirmed with a detailed Phase-B design.
Scientific Landscape and Positioning

Gemini’s NIRI is approaching its end of life, and has served as one of Gemini’s workhorse instruments. At the same time, a new breed of wide-field IR imagers has come available, UKIRT and VISTA are dedicated wide-field IR instruments on 4-m telescopes. On 8-m class telescopes, SUBARU+MOIRCS provide a 4’x7’ FOV in the north, and the VLT HAWK-I provides a 7.5’x7.5’ FOV imager in the south. Gemini’s GEMS will deliver 1.3’x1.3’ MCAO imager next year in the south. Towards the end of the decade, JWST+NIRCAM will deliver a space-based diffraction limited 2.2’x2.2’ FOV with sensitivity far greater than can be achieved from the ground.

In the post-NIRI era, Gemini will have no IR imaging capability in the North until a new instrument is brought on line. Our proposed GRB-Imager offers many benefits for Gemini and its user community:

✴ The GRB Imager is a different capability than existing and planned 8-m capabilities. It collects information in 4 bands simultaneously, a feature especially suited for quickly varying events such as GRBs, transiting planets, and some variable stars.

✴ The GRB Imager collects photons for a broad range of IR-imaging projects at a much higher rate than existing facilities due to both its simplicity and multi-band approach, and exploits Gemini’s world-class strength of queue observing.

✴ The GRB Imager is a simple instrument which is relatively cheap and quick to build, using the availability of new detectors, existing designs, and an instrument group with a track-record of delivering instrument on-time and on-budget within Gemini. The GRB Imager will be on the sky long before a more complicated instrument could be, with a price tag that will enable instruments with other capabilities to be pursued in the short to medium-term.

✴ The GRB Imager, while not an ideal AO-capable instrument, none-the-less provides 0.06”/pixel for use with ALTAIR, which will be useful in a huge variety of high-resolution imaging applications. AO imaging would be implemented using drizzling techniques developed for HST which have a similarly (or more) under-sampled PSF. These are particularly relevant as near-infrared observations with the imager will be dithered, so that drizzling reductions can recover sub-pixel sampling, while retaining the full astrometric and photometric precision of the data.

✴ The GRB Imager, compared to instruments with many moving parts, will be extremely stable, providing an ideal platform for precision astrometry. It will also enable on-the-fly photometric reductions, necessary to quickly identify interesting transient objects, such as GRBs at high redshift, for immediate follow-up with Gemini spectroscopic capabilities.

Instrument Conceptual Design

The GRB Imager is based around the successful GSAOI imager, using the same basic dewar design, and detectors (HAWAII 2RGs). Our conceptual design features 4 IR channels, each channel being fed...
by a dichroic which reflects light blue-ward of a cutoff to a camera, and transmits the remainder of the light to the next dichroic. The unfolded design is shown in figure 1.

This design is detailed in appendix 1, but provides a number of desirable features:

- 3 identical cameras for the Z/Y, J, and H bands (K requires a different camera)
- Diffraction limited imaging in the central array region (larger area compared to what is required by ALTAIR)
- Low distortion (<2%) for all cameras
- High total throughput (>45% in all bands)
- Can be folded into a standard cryostat in a such a way to minimize flexure, aiding to the stability of the array

Not shown in figure 1, is a blocking slide, which would be inserted in front of the collimator, to allow dark images to be obtained with the array. This is potentially the only moving part within the cryostat. There is a low precision of movement required of this piece, making it a relatively cheap, low-risk, and high-reliability component, compared to other cryogenic mechanisms.
Potential Modifications to the Conceptual Design

One of the desirable qualities of the GRB Imager is its simplicity which will enable it to be built quickly and cheaply. However, it should serve the Gemini community as broadly as possible. Possible modifications include increasing the FOV of the instrument to approximately 2.5′ (with a correspondingly larger pixel scale). The disadvantages of this FOV increase is that it undermines the utility of the GRB Imager in conjunction with ALTAIR, and it makes it more difficult to situate the camera to minimize the effects of flexure. Creating a larger FOV than 2.5′ would require major modifications to the GSAOI Dewar design. Modifications would be required to both increase the FOV beyond a 2.7′ FOV, limited by the dewar window (which is constrained by the interface to the telescope), and to make a larger dewar which could fit the required scale of the instrument. We believe such increase of scope is not tenable for this instrument.

Another modification would be the addition of small filter wheels between each camera and the dichroic. These low-precision devices would enable a few filters to be available for each channel of the Imager. Due to the small size of these filters, this would be a modification that, while increasing the complexity of the instrument, (with the associated impacts on costs, delivery time, and long-term reliability), should be carefully considered in any phase-B.

The Path Forward

The GRB Imager is not meant to be a battleship class facility, with a multi-mode capability that caters to every conceivable part of the community. It is meant to provide a powerful and broad capability which serves the community in the near term, in a period of time when Gemini-N could find itself wanting in key instrumentation capabilities.

The RSAA instrumentation group has a window of opportunity to work on this project over the coming two years. While we believe that the simplicity of this instrument, and its alignment with our current capabilities and past experience, is such that we could deliver it in 2013 at a cost of approximately US $5M, we are not proposing to take any short-cuts from our successful strategy of delivering NIFS and GSAOI.

If Gemini believes the GRB Imager is an instrument which they would potentially like to pursue, we would propose commencing a full Phase-B study in mid 2011, which would provide both a complete design and fully costed proposal to the observatory. As part of this Phase-B, we envision some work packages will need to be undertaken outside of RSAA, such as the detector system (we have had informal discussion with the University of Hawaii). The Phase-B would allow Gemini to evaluate the true cost and time scale of this instrument compared to other instruments, without fully committing the observatory to the project. The Phase-B completion is required before long-lead time items, such as the cryostat are ordered, and if Gemini is prepared to act quickly on the Phase-B, this approach could result in very little delay compared to a full commitment now, with minimal risk to the observatory.
Appendix 1:
GRB Imager Technical Overview
Gemini Imager

BANDPASSES

The new GRB Imager would allow simultaneous imaging in four specific pass bands in the NIR.

<table>
<thead>
<tr>
<th>Name</th>
<th>CWL $\mu$m</th>
<th>Pass band $\mu$m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>1.02</td>
<td>0.97 – 1.07</td>
</tr>
<tr>
<td>J</td>
<td>1.25</td>
<td>1.15 – 1.33</td>
</tr>
<tr>
<td>H</td>
<td>1.65</td>
<td>1.49 – 1.78</td>
</tr>
<tr>
<td>K(prime)</td>
<td>2.12</td>
<td>1.95 – 2.30</td>
</tr>
</tbody>
</table>
### DETECTORS

**HAWAII-2RG™ specification table for infrared arrays**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>1.7 μm</th>
<th>2.5 μm</th>
<th>5.3 μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read-out integrated circuit (ROIC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Pixels (f)</td>
<td></td>
<td></td>
<td>2048 x 2048</td>
<td></td>
</tr>
<tr>
<td>Pixel Size</td>
<td>Om</td>
<td></td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Number of Outputs</td>
<td></td>
<td></td>
<td></td>
<td>Programmable 1, 4, 32</td>
</tr>
<tr>
<td>Power Dissipation (f)</td>
<td>mW</td>
<td>≤ 0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detector Material</td>
<td></td>
<td>HgCdTe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detector Substrate</td>
<td></td>
<td>CdZnTe - Removed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cutoff wavelength (50% of peak QE):</td>
<td>Om</td>
<td>1.65 - 1.80</td>
<td>2.45 - 2.65</td>
<td>5.1 - 5.5</td>
</tr>
</tbody>
</table>
The dichroics may be considered to have the following specifications. Normally it is considered to be more efficient to reflect the shorter wavelengths and transmit the longer wavelength.

- Y band dichroic. $R < 1.07 \mu m$ \hspace{1em} $T > 1.17 \mu m$
  - 50% edge at $\sim 1.12 \mu m$

- J Band dichroic. $R < 1.33 \mu m$ \hspace{1em} $T > 1.49 \mu m$
  - 50% edge at $\sim 1.41 \mu m$

- H Band dichroic. $R < 1.78 \mu m$ \hspace{1em} $T > 2.03 \mu m$
  - 50% edge at $\sim 1.905 \mu m$
Gemini Imager

General specs

• Consider two Optical design options

  – A spec of 60mas pixels (18 micron x 2040)
    • Approx 2 arc min square on the detector
    • ~ F/8 beams onto the detector

  – A spec of 80 mas pixels (18 micron x 2040)
    • Approx 2.7 arc min square on the detector
    • This is approx maximum field for a standard window aperture
    • ~ F/5.8 beams onto the detector

Image quality

  anywhere on detector 80% EE < 1 pixel
  central 40 sec field – diffraction limited
Gemini Imager

Optical design concept

- Designs are from Damien Jones, Prime Optics.

- All designs are room temperature glasses.
- But all materials have known cryogenic properties
  - Expansion and Refractive index data
- The adjustment of the design for cryogenic data
  - Is carried out at a latter stage in the design process.
  - The dispersion and relative partial dispersion properties of the materials change little with cryogenic data. If the design works at room temperature, the same materials will also work at cryogenic conditions.
Gemini Imager

60 mas/pixel Optical Design (unfolded)
Footprint of the 2 arc min square field On the Cryostat window (160 diam) 
60 mas design
Gemini Imager

Focal plane field stop for the 2 arc min square- 76 mm square
60 mas design
Gemini Imager

Collimator 60 mas design

- Common to all beams
- Materials are common to existing cryogenic instruments
  - CaF2 (single crystal), Silica (IR grade), ZnSe (Zinc Selenide)
- Large blanks
  - Diam ~ 150 mm
- Needs to be a BBAR coating for the W/L range
Gemini Imager

Collimator Optics 60 mas design

Opto-Mechanical Design, Gabe

Friday, 25 March 2011
Gemini Imager

Dichroics

- Three dichroics
- First is to reflect the Y band & transmit (J + H + K bands)
- Second to reflect the J band & transmit (H + K bands)
- Third to reflect the H band & transmit (K band)

- Dichroics are inclined at 22.5 degrees
  - Small angle for max efficiency designs and minimize polarization issues
- Dichroics are Cold mirrors designs,
  - ie reflect the shorter W/L’s & transmit the longer W/L’s
  - Most efficient designs
Gemini Imager

BS1 Y Dichroic Footprint -130 mm diam -60mas design
Gemini Imager

BS2 J Dichroic Footprint - 100 mm diam -60mas design
Gemini Imager

BS3 H Dichroic Footprint - 80 mm diam - 60mas design
Gemini Imager

Cameras

• The three cameras for the Y, J, and H arms are identical designs.
  – ie exact copies in fabrication
  – Materials
    • BaF2 (single crystal), S-NPH2 (glass), CaF2 (single crystal)

• May wish to optimize the AR coatings for a specific waveband!
  – Simple two layer V coat?

• The K band camera is a unique design
  – Optimized for materials with best transmission in this region.
  – Materials
    • BaF2 (single crystal), Silica (IR grade), ZnSe (Zinc selenide), CaF2 (single crystal)
Gemini Imager

Camera Optics (YZ, J & H bands) – 60 mas design
Gemini Imager

Camera Optics (K-band) 60 mas design
Gemini Imager

Filters!

• The assumption is that nominal bandpass filters will be used as additional elements and would be placed close to the Pupils in the cameras.

• These were not shown in the optical layout.

• Should have no effect on image quality as the beams are ~ collimated at this point.
Gemini Imager

Spot diagrams & EE performance data & etc

- A series of 4 spot diagrams,
  - One for each camera & its specific Waveband
  - Spots for full field
  - Spots for the small AO corrected field
  - EE for diffraction
  - EE based on the Geometric calculation
  - Distortion plots
Gemini Imager

Y Camera – 60mas design - Spot diagrams
Full 2 arc min square field - Box is 2 pixels square

Opto-Mechanical Design, Gabe

Friday, 25 March 2011
Gemini Imager

Y Camera – 60mas design - Spot diagrams
Central 1 arc min square field - Box is 2 pixels square – Airy disk shown
Gemini Imager

Y Camera – 60mas design – Ensquared Energy (Diffraction)
Full 2 arc min square field – Axis is one pixel

Opto-Mechanical Design, Gabe
Friday, 25 March 2011
Gemini Imager

Y Camera – 60mas design – Ensquared Energy (geometric)
Full 2 arc min square field – Axis is one pixel
Gemini Imager

J Camera – 60mas design - Spot diagrams
Full 2 arc min square field - Box is 2 pixels square
Gemini Imager

J Camera – 60mas design - Spot diagrams

Central 1 arc min square field - Box is 2 pixels square – Airy disk shown

Opto-Mechanical Design, Gabe

Friday, 25 March 2011
Gemini Imager

J Camera – 60mas design – Ensquared Energy (Diffraction)
Full 2 arc min square field – Axis is one pixel

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**Opto-Mechanical Design, Gabe**

Friday, 25 March 2011
Gemini Imager

J Camera – 60mas design – Ensquared Energy (geometric)
Full 2 arc min square field – Axis is one pixel
Gemini Imager

H Camera – 60mas design - Spot diagrams
Full 2 arc min square field - Box is 2 pixels square

Opto-Mechanical Design, Gabe

Friday, 25 March 2011
Gemini Imager

H Camera – 60mas design - Spot diagrams
Central 1 arc min square field - Box is 2 pixels square – Airy disk shown
Gemini Imager

H Camera – 60mas design – Ensquared Energy (Diffraction)
Full 2 arc min square field – Axis is one pixel

Opto-Mechanical Design, Gabe  
Friday, 25 March 2011
Gemini Imager

HCamera – 60mas design – Ensquared Energy (geometric)
Full 2 arc min square field – Axis is one pixel
Gemini Imager

**K Camera** – 60mas design - Spot diagrams
Full 2 arc min square field - Box is 2 pixels square

![Spot Diagram](image)
Gemini Imager

K Camera – 60mas design - Spot diagrams
Central 1 arc min square field - Box is 2 pixels square – Airy disk shown
Gemini Imager

K Camera – 60mas design – Ensquared Energy (Diffraction)
Full 2 arc min square field – Axis is one pixel
Gemini Imager

K Camera – 60mas design – Ensquared Energy (geometric)
Full 2 arc min square field – Axis is one pixel
Gemini Imager

Y Camera Geometric Distortion – Full field – 60mas design

Grid Distortion

23/03/2011
Field: 0.0330 w 0.0330 h Degrees
Image: 35.63 w 35.63 h Millimeters
Maximum distortion: 1.8569%
Scale: 1.000X, Wavelength: 1.0200 μm

Configuration 1 of 4
J Camera Geometric Distortion – Full field – 60mas design
Gemini Imager

Camera Geometric Distortion – Full field – 60mas design

Grid Distortion

23/03/2011
Field: 0.0330 w 0.0330 h Degrees
Image: 35.62 w 35.62 h Millimeters
Maximum distortion: 1.8422%
Scale: 1.000X, Wavelength: 1.6500 µm
Configuration 3 of 4
K Camera Geometric Distortion – Full field – 60mas design
Gemini Imager

Potential Through Put of Instrument – 60 mas Design

- Using reasonable data for all coatings, detector QE, & Filters

- Y band camera  T% = 49

- J band camera  T% = 48

- H band camera  T% = 47

- K band camera  T% = 45
Gemini Imager

60 mas / pixel Optical design

- Optical Quality
  - Easily passes the criterion for a seeing limited instrument
  - Can achieve diffraction limited imaging,
  - especially near the central 1 square arc min field

- Can be folded to a standard Cryostat!

  - *Would be an a useful luxury to have focusing on the detectors!*
Next the 80 mas / Pixel Optical Design

- As about as big as you can pass thru a standard cryostat window!
- Field is \( \sim 2.72 \) square arc min
- Same type of a lay-out for the Optics
- Just bigger!
Gemini Imager

80 mas/pixel Optical Design (unfolded)
Gemini Imager

Footprint of the 2.72 arc min square field On the Cryostat window (200 diam)

80 mas design
Gemini Imager

80mas design - Focal plane field stop for the 2.72 arc min square
- 100 mm square
80 mas design - Collimator Optics
Gemini Imager

BS1 Y Dichroic Footprint -150 mm diam – 80 mas design
Gemini Imager

BS2 J Dichroic Footprint - 120 mm diam – 80 mas design
Gemini Imager

BS3 H Dichroic Footprint -90 mm diam – 80 mas design
Gemini Imager

Camera Optics (YZ, J & H bands) – 80 mas design
Gemini Imager

Camera Optics (K band) – 80 mas design
Gemini Imager

Y Camera – 80mas design - Spot diagrams
Full 2.72 arc min square field - Box is 2 pixels square

Spot Diagram

23/03/2011 Units are μm. Airy Radius: 6.716 μm
Field 1 2 3 4 5 6 7 8 9
Box width: 36 Reference: Centroid

Configuration 1 of 4
Gemini Imager

Y Camera – 80mas design - Spot diagrams
Central 1 arc min square field - Box is 2 pixels square – Airy disk shown
Gemini Imager

Y Camera – 80mas design – Ensquared Energy (Diffraction)  
Full 2.72 arc min square field – Axis is one pixel
Y Camera – 80mas design – Ensquared Energy (geometric)
Full 2.72 arc min square field – Axis is one pixel
Gemini Imager

J Camera – 80mas design - Spot diagrams
Full 2.72 arc min square field - Box is 2 pixels square
J Camera – 80mas design - Spot diagrams
Central 1 arc min square field - Box is 2 pixels square – Airy disk shown
Gemini Imager

J Camera – **80mas design** – Ensquared Energy (Diffraction)

Full 2.72 arc min square field – Axis is one pixel
J Camera – 80mas design – Ensquared Energy (geometric)
Full 2.72 arc min square field – Axis is one pixel
Gemini Imager

H Camera – 80mas design - Spot diagrams
Full 2.72 arc min square field - Box is 2 pixels square

Opto-Mechanical Design, Gabe

Friday, 25 March 2011
Gemini Imager

H Camera – 80mas design - Spot diagrams
Central 1 arc min square field - Box is 2 pixels square – Airy disk shown

Opto-Mechanical Design, Gabe

Friday, 25 March 2011
Gemini Imager

H Camera – 80mas design – Ensquared Energy (Diffraction)

Full 2.72 arc min square field – Axis is one pixel
Gemini Imager

H Camera – 80mas design – Ensquared Energy (geometric)
Full 2.72 arc min square field – Axis is one pixel
Gemini Imager

K Camera – 80mas design - Spot diagrams
Full 2.72 arc min square field - Box is 2 pixels square
Gemini Imager

K Camera – 80mas design - Spot diagrams
Central 1 arc min square field - Box is 2 pixels square – Airy disk shown
Gemini Imager

K Camera – 80mas design – Ensquared Energy (Diffraction)
Full 2.72 arc min square field – Axis is one pixel

Opto-Mechanical Design, Gabe

Friday, 25 March 2011
K Camera – **80mas design** – Ensquared Energy (geometric)
Full 2.72 arc min square field – Axis is one pixel
Gemini Imager

Y Camera Geometric Distortion – Full field – 80mas design
Gemini Imager

J Camera Geometric Distortion – Full field – 80mas design
Gemini Imager

H Camera Geometric Distortion – Full field – 80mas design

Grid Distortion

23/03/2011
Field: 0.0444 w 0.0444 h Degrees
Image: 35.94 w 35.94 h Millimeters
Maximum distortion: 1.5638%
Scale: 1.000X, Wavelength: 1.4900 μm

Configuration 3 of 4
K Camera Geometric Distortion – Full field – 80mas design
Gemini Imager

80 mas |design |ThroughPut

- Same as the 60 mas design
- No diff in number of elements
- Probably not quite possible to position within the GSAOI cryostat
- If desired this option could be scaled down slightly to achieve the maximum FOV possible

- Optical Quality
  - Easily passes the criterion for a seeing limited instrument
  - Can achieve diffraction limited imaging,
  - especially < the central 1 square arc min field

  - Perhaps not as good as the 60 mas design
Appendix 2: 
Prime Optics Optical Design
Gemini IR Multi-band (GRB) Imager:

Prototype Development

March 21 2011
1. Preamble

This note describes the development of a multi-band NIR imager as a replacement for NIRI on Gemini North.

The functional requirements for this instrument are contained in the attachment: “GRB_ImagerFunctionalRequirements_and_Letter.pdf”.

In a nutshell, the instrument must make use of the existing cryostat mechanical design as used by the NIRI, GSAOI and NIFS instruments.

Two image scales are to be investigated: 60 mas per pixel (Option 1, to be defined below) and 80 mas per pixel (Option 2). The instrument may at some future time be fed by the Gemini AO system but for now is limited to natural seeing with focus and tip-tilt correction supported by the ODGW (on detector guide windows) function of the H2RG-18 detector.

2. Optical Design Path

2.1. Collimators

The multi-band functionality calls for 4 channels, 3 of which are to be fed via a beamsplitter. The 4 channels are known as “Y”, “J”, “H” and “K” and are defined as follows:

<table>
<thead>
<tr>
<th>Band</th>
<th>SWL (µm)</th>
<th>CWL (µm)</th>
<th>LWL (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>0.97</td>
<td>1.02</td>
<td>1.07</td>
</tr>
<tr>
<td>J</td>
<td>1.15</td>
<td>1.25</td>
<td>1.33</td>
</tr>
<tr>
<td>H</td>
<td>1.49</td>
<td>1.65</td>
<td>1.78</td>
</tr>
<tr>
<td>K</td>
<td>1.95</td>
<td>2.12</td>
<td>2.30</td>
</tr>
</tbody>
</table>

The K-band, and arguably the H-band, also need space for a well-defined cold stop.

Thus a broadband collimator is required to deliver a collimated beam space of sufficient length to achieve this.

A simple 3-element collimator is demonstrated as a first step. A single field lens controls the pupil imagery whilst a spaced doublet acts as a collimator. A typical layout is shown in Figure 1a and accompanying spot diagrams in Figure 1b. It is evident that this type of collimator is unable to deliver imagery of sufficient quality.

The poor field imagery is the result of residual field curvature in the system combined with comatic and astigmatic residuals. Thus some means must be found to mitigate the net effects of these.

One method is to use thick negative meniscus components of low refractive index in a “Double Gauss” or “Tessar” type configuration. Such components are also the key to controlling lateral and axial colour.

Thus the field lens is replaced with a doublet of CaF2 and Silica while the ZnSe field lens is translated and transformed into a low power meniscus whose main function is to control the residual colour, as is often the case in NIR systems composed primarily of CaF2 and Silica.
Figure 1a: Typical 3-element collimator and paraxial cameras
Option 2, 44 mm pupil (cold stop)
Figure 1b : Typical 3-element collimator spot diagrams with paraxial cameras
Option 2, 44 mm pupil (cold stop)
Box is 10 pixels or 180 microns square

Similar layouts for the 60 mas (Option 1) and 80 mas (Option 2) options are shown in Figures 2a, 2b, 3a & 3b. It can be seen that the collimator’s performance is now vastly improved and an examination of the Petzval coefficients indicates an approximate 10% – 20% reduction for the respective options.
Figure 2a: Typical 5-element collimator and paraxial cameras
Option 1, 35 mm pupil (cold stop)
CWS (cold work surface) reference edges shown
Figure 2b: Typical 5-element collimator and paraxial cameras
Option 2, 44 mm pupil (cold stop)
Figure 3a: Typical 5-element collimator spot diagrams with paraxial cameras
Option 1, 35 mm pupil (cold stop)
Box is 10 pixels or 180 microns square

Figure 3b: Typical 5-element collimator spot diagrams with paraxial cameras
Option 2, 44 mm pupil (cold stop)
Box is 10 pixels or 180 microns square
2.2. Cameras

Camera focal ratios for the respective options are approximately f/5.6 and f/8.

This range of focal ratios lends itself to camera constructions not limited by high-speed Petzval systems requiring field flatteners close to the detector thereby avoiding a particular class of detector ghosts.

In this case residual Petzval curvature can be controlled with the use of a telephoto construction, in other words, a positive group followed by a negative group with substantial clearance to the image surface.

Typical cameras are shown in Figures 4a and 4b. Spot diagrams for the different options and bands are shown in Figures 5 and 6.

![Figure 4a](image)

**Figure 4a** : Typical Y-, J- and H-band camera

![Figure 4b](image)

**Figure 4b** : Typical K-band camera
Figure 5a: Complete imager spot diagrams, Y-band
Option 1, 35 mm pupil (cold stop)
Box is 10 pixels or 180 microns square

Figure 5b: Complete imager spot diagrams, J-band
Option 1, 35 mm pupil (cold stop)
Box is 10 pixels or 180 microns square
Figure 5c: Complete imager spot diagrams, H-band
Option 1, 35 mm pupil (cold stop)
Box is 10 pixels or 180 microns square

Figure 5d: Complete imager spot diagrams, K-band
Option 1, 35 mm pupil (cold stop)
Box is 10 pixels or 180 microns square
Figure 6a: Complete imager spot diagrams, Y-band Option 2, 44 mm pupil (cold stop)
Box is 10 pixels or 180 microns square

Figure 6b: Complete imager spot diagrams, J-band Option 2, 44 mm pupil (cold stop)
Box is 10 pixels or 180 microns square
Figure 6c: Complete imager spot diagrams, H-band
Option 2, 44 mm pupil (cold stop)
Box is 10 pixels or 180 microns square

Figure 6d: Complete imager spot diagrams, K-band
Option 2, 44 mm pupil (cold stop)
Box is 10 pixels or 180 microns square
It is evident that the cameras in both configurations have not added significantly to the net system aberrations. 80% geometric ensquared energy (80% EER) is within one pixel across all bands and fields.

2.3. Beamsplitter Configuration and Folding

The beamsplitters have been arranged in a strictly linear fashion without branches. This probably necessitates a little extra collimated beam space – of the order of 25%.

It is possible in theory to split the 2 shorter wavebands off first and then subdivide those thereby effectively reducing the required collimated space by one beamsplitter’s worth of room.

In practice, though, little may be gained. As the collimated beam space contracts the two collimator groups will draw apart by a more or less equivalent distance meaning that the net shortening of the collimator optics plus collimated space is small.

One folding scheme has been attempted and seems to be able to fit in the available volume. This is shown in Figure 7.

![Figure 7: One folding schema for Option 1, 35 mm pupil. The Y and J cameras are folded down.](image-url)

However, this process is probably best left to someone more skilled than I in this particular art!
3. Concluding Remarks

Prototype imagers to replace NIRI have been demonstrated.

Their performance is mostly at the sub-pixel level and should be quite acceptable for an AO feed.

One option, at least, fits within the existing mechanical constraints of the standard Dewar.

Relevant ZEMAX optical files have already been submitted. They are:

“GRB-Imager-AllBands-60mas-35mmPupil-unFolded-20110318.ZMX” and

“GRB-Imager-AllBands-80mas-44mmPupil-unFolded-20110318.ZMX”.
Appendix 3: Imager Folding Concept with GSAOI Cryostat
60mas GRB Imager Folding Concept

The input beam is folded down through the cold work surface (CWS). The focal plane mask is positioned above the CWS while the hole through the CWS will be covered by a slow shutter, most likely in the form of a sliding mechanism.

(cryostat up–side down)
After passing through the CWS light is folded for the second time towards a side corner of the CWS hexagon plate and then sent across the CWS by the third fold mirror. This places all three folds and collimator optical elements conveniently close the CWS, assuring the maximum stiffness of the mirror/lens mounts. After the collimator lenses light is folded by the Y-arm dichroic and consequently folded back through the CWS by the 4th fold mirror.

This positions the Y-arm camera optical axis perpendicular to the CWS and mountable in an enclosed optical table structure similar to the one used in the GSAOI/NIFS instruments.

Light that passes the Y-arm dichroic is folded in a similar fashion by the J-arm dichroic and the subsequent 4th fold mirror. The J-arm camera is positioned vertically to the CWS within the same optable volume as the Y-arm camera.
Since the H arm camera is considerably shorter than the first two cameras, its dichroic is used to fold it towards the optable on the other side of the CWS. Its optical axis forms 45° angle with the CWS.

Finally, the K-arm camera is folded up by the 4th fold mirror to be positioned in the same optable volume as the other 3 cameras.

The main reason for this folding arrangement is to position all four detectors at the same vertical level from the CWS and enclosed in the same mechanical structure in order to minimize differential flexure between them. This layout can be optimized further by placing the H dichroic inside the Y-arm camera which would make the overall length of the K-arm shorter.
Full folded layout – 2 sections: input and Y arm – yellow; J arm – red; H arm – green; K arm – blue.