Optics

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Level 1 Requirements

- Three filter passbands and image scales as specified in optical and photometric specifications. $\Delta\lambda/\lambda=0.5$ passbands at 60, 110, and 200 μm. Two pixels per Airy disk fwhm.
- Diffraction-limited performance across the 12x32 array
- Stable and reproducible image placement on array
- Stable throughput characteristics during operation
- No re-focus required when switching between bands
- Maximize throughput for each band
- Internal point source can be inserted into focal plane for self-calibration tests during ground checkout or flight

Level 1 Requirements 2

- Internal source can diffusely illuminate detector array to monitor relative detector gains during and between flights
- Lenses can be inserted into optical path to image instrument pupil onto detector array to verify uniformity of pupil illumination

Design Approach

- Heritage from KAO far infrared cameras
- Separate sets of refractive optics for each wavelength allow independent optimization of throughput and image scale
- Parfocality of separate lens sets achieved by cryogenic lab measurements, warm adjustment, and re-test. No internal focus control during normal operations.
- 6-position carousels allow mounting redundant lens/filter sets. Facilitates testing during development, monitoring of system performance during normal operations, and provides backups which can be deployed without opening the cryostat.

Design Approach 2

- Mounting of optics
  - Four mechanisms:
    - Aperture (shutter) carousel carries focal-plane field masks, point source(s), and cold shutter blank-offs
    - Carousel for field lenses
    - Carousel for transfer lenses located at internal pupils (Lyot stops) which re-image the focal plane onto the detector array and efficiently reject stray light from the telescope and telescope cavity
    - Carousel for three auxiliary lenses which can be rotated into the optical path between transfer lenses and detector array to image pupil onto array
  - Adjustment via shims
  - Kinematic mounts maintain alignment during temperature cycling

Design Approach 3

- Internal sources:
  - Use COBE-heritage implanted-silicon sources
  - AC modulation of source by application of AC electrical stimulation
  - Point source mounted on aperture/shutter carousel
- Lenses
  - Simple lenses (minimizes number of surfaces) with long focal lengths (minimizes aberrations)
  - Using refractive optics simplifies layout and provides excellent baffling of stray light
  - Materials will be polyethylene, crystalline quartz, or sapphire (TBD through design studies/prototyping/testing of anti-reflection coatings)

Design Approach 4

- Filters
  - Baseline for 60, 110, and 200 μm bandpass filters is to procure metal-mesh interference filters from Queen Mary College
  - Alternate/backup for 60 μm filter is a stack of crystalline sapphire, calcium fluoride, and KRS-5 (as used on KAO cameras)
  - Backup for 110 and 200 μm filters is to construct them at University of Chicago (as done on KAO cameras)
- Cryostat pressure window
  - High-density polyethylene coated on its inner surface with diamond dust (blocks short wavelength radiation from hot sources). Construction at University of Chicago. (Lear Jet and KAO heritage).

Design Approach 5

- Optically black coatings
  - Baseline is Ball IR Black paint based on DeSoto Black
  - Alternatives will be investigated during detailed design phase
- Field apertures
  - Large field lenses yield sharp beam patterns which maximize telescope/instrument coupling efficiency and effectively reject stray light. During the design phase we will examine the trade-offs between focal-plane apertures which are square (maximizes beam sharpness) and rectangular (minimizes heat load from external radiation).

Performance Modeling

- Zemax ray-tracing shows required image quality can be attained in all three bands across the entire field of the 12x32 array (adequate for 32x32)
- Baseline design also meets image quality specifications if lenses are tilted by 5 degrees (in case required to eliminate ghost images)
- Stray light analysis will be done during detailed design phase
  - In conjunction with BRO Research modeling of SOFIA telescope if possible
  - If not, we will perform a simple first-order ray-trace analysis and check it by prototyping the design using glass lenses at visual wavelengths

Performance Modeling 2

- First-order estimates of transmissions of optics and atmosphere will be refined by more comprehensive mathematical modeling during detailed design phase
  - Results will provide a baseline for comparison with lab and flight tests
  - Results will also provide a basis for trade studies to determine optimal choices for lens and filter materials

Test/Verification Plan

- Design checked by prototyping with off-the-shelf equivalent glass lenses at visual wavelengths in mock-up of optical-bench assembly and again in actual flight system (aberrations, alignment, stray light, and deflections due to changes in cryostat orientation)
- Individual lenses physically checked for proper curvature, diameter, and thickness after procurement
- Transmissions of filters verified at GSFC infrared spectroscopy facility
- End-to-end imaging performance of the system verified by laboratory testing with focussed-beam source after installation of detector array

Test/Verification 2

- End-to-end spectral spectral response verified at GSFC infrared spectroscopy facility
- Repeatability of optical alignment and constancy of throughput will be monitored throughout development testing using internal and external calibration sources

Issues and Concerns

- Risks associated with lenses, filters, internal sources are low. Baseline specifications are based on heritage designs with proven performance.
- Possible procurement/delivery problems with interference filters mitigated by option of constructing them at UC
- Large crystalline lens elements may be difficult to anti-reflection coat. Polyethylene tends to de-laminate from large (>1 cm diameter) surfaces after repeated temperature cycling. Laboratory experimentation/testing during design/development phase could substantially enhance trade studies and enable improvements in system throughput.