Design of a Mid-IR Polarimeter for SOFIA

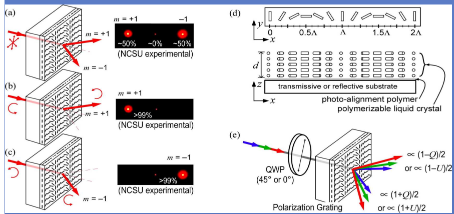
C. Packham[a], M. Escuti[b], G. Boreman[c], I. Quijano[c], J. C. Ginn[c], B. Franklin[c], D. J. Axon[d], J. H. Hough[e], T. J. Jones[f], P. F. Roche[g], M. Tamura[h], C. M. Telesco[a], N. Levenson[i], J. M. Rodgers[j], J. P. McGuire[j]

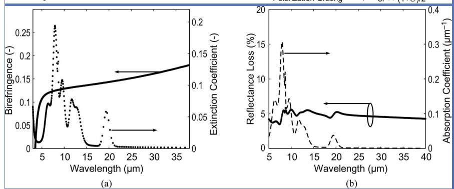
[a]University of Florida; [b]North Carolina State University; [c]University of Central Florida; [d]RIT; [e]University of Hertfordshire; [f]University of Minnesota; [g]Oxford University; [h]National Astronomical Observatory of Japan; [i]University of Kentucky; [j]Optical Research Associates

Abstract

Mid-infrared polarimetry remains an underexploited technique; where available it is limited in spectral coverage from the ground, and conspicuously absent from the *Spitzer*, *JWST* and *Herschel* instrument suites. The unique characteristics of SOFIA afford unprecedented spectral coverage and sensitivity in the mid-infrared waveband. We discuss the preliminary optical design for a 5-40µm spectro-polarimeter for use on SOFIA, the SOFIA Mid-InfraRed Polarimeter (SMIRPh). The design furthers the existing 5-40µm imaging and spectroscopic capabilities of SOFIA. We discuss the use of polarization gratings and this characteristics at mid-IR wavelengths. A conceptual optical design exploiting polarization gratings is presented. Combined with the synergy between the possible future far-IR polarimeter, Hale, this instrument would provide the SOFIA community with unique and exciting science capabilities, leaving an exclusive scientific legacy.

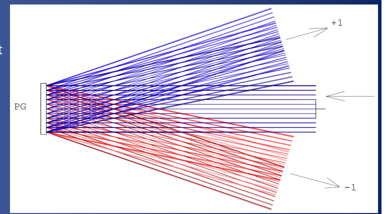
Polarization Gratings

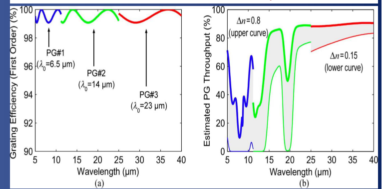




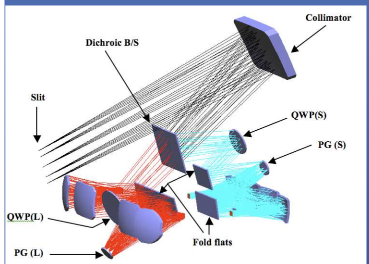
A novel polarizing beamsplitter using birefringent gratings (Oh & Escuti, 2007, Escuti et al. 2006) is being pioneered at NCSU. The key optical element is called a polarization grating (PG, Tervo & Turunen 2000), which is a thin-film beamsplitter that is functionally analogous a Wollaston prism (see top left), although it operates on a completely different principle. The beamsplitter is made up of a thin polymer film (<300µm) comprising a liquid crystal polymer coated optionally on a reflective or transparent substrate, and can be made with almost any surface area. At optical and near-IR wavelengths, PG diffraction efficiency has been shown to be > 99% (nearly no absorption or scattering), diffracting incident light into one of only three orders (m=0, ±1) based on the incident polarization state (see figure top left). In NCSU's nearly ideal experimental gratings, the m=0 beam is unpolarized, but contain typically <0.5% of the incident flux when optimized for visible wavelengths (Escuti & Jones 2006), and <0.125% when optimized at 1550nm (Kim et al. 2008). The m=±1 orders are very highly perpendicularly polarized (>99%), making the PG component a potentially ideal alternative to other analyzers. We show a simple implementation of a PG in the figure at top right. Our provisional MIR optimized PG are shown in the lower left and right, where the level of birefringence (lower left) is excellent throughout our wavelengths of interesting, and the grating efficiency and transmission (lower right) is excellent at all wavelengths >20µm. With a relatively minor change in the construction of the PG (e.g. carbon nanotube doping) we expect to significantly improve the PG throughput, and this is shown in the thick line (lower right).

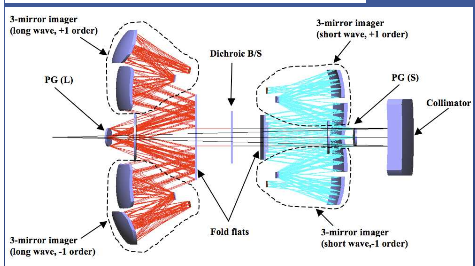
Future work will continue optimization work on the transmission of the PGs, and refining our preliminary measurements, which are likely pessimistic as the absorption bands are likely significantly more narrow than we show above. At the time of writing, we are currently working on an optimized MIR PG and will report the transmission and birefringence results in a later publication. At the conceptual level of this design study, we have shown that SMIRPh can indeed by based around PG technology and in the next section we produce an optical design based on PGs.



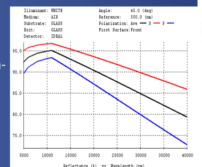


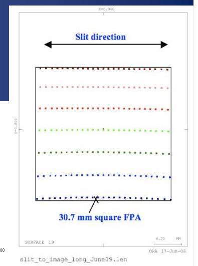
Primary Design Inputs





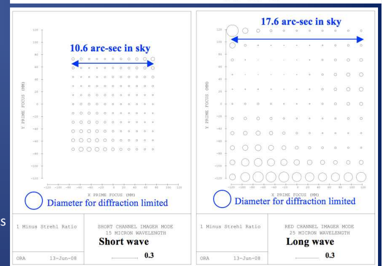
1. Two spectral bands are required, spanning 5-25µm and 25-40µm, henceforth the blue and red arms respectively
    1. The 5-25µm array is based-lined around Raytheon's Aquarius array, a 1024^2 Si:As based detector
    2. The 25-40µm array is base-lined to be the same pixel size and number as the Aquarius, likely a Si:Sb array
2. If possible, simultaneous observations in the red and blue arm with a minimal transition in wavelength space between the arms
3. The optics must be diffraction limited at all wavelengths >15µm, the shortest wavelength at which SOFIA is expected to deliver diffraction-limited observations
4. The plate scale is set to Nyquist sample the shortest wavelength at which SOFIA is expected to deliver diffraction-limited observations
    1. In the blue arm, this is at λ=15µm, resulting in a plate scale of 0.62" per pixel
    2. In the red arm, this is at λ=25µm, resulting in a plate scale of 1.03" per pixel
5. Instrument must be a dual-beam polarimeter to maximize efficiency and minimize spurious polarization due to variable sky transmission, emission and image quality
    1. Images in orthogonally polarized beams must be of indistinguishable image quality to ensure minimal instrumental polarization
6. Instrumental polarization must be low (<1%)
7. Imaging- and spectro-polarimetry must be available, with [total flux] imaging available as a goal
8. Spectroscopic resolution optimized to disperse entire wavelength window onto one array
9. The system should be an all reflective design, as far as possible, to minimize chromatic aberrations
10. Optics must be readily able to be fabricated
11. The instrument must conform to the SOFIA space envelope





Design Performance

The conceptual design is shown in the figures (left), where we implement two arms per polarimetric plane in addition to the two color channels. This is required to particular polarization grating tilt, the space envelope and drive to have the images in the orthogonally polarized beams indistinguishable from each other would have lead to optics that were extremely difficult, if not impossible, to manufacture. The instrumental polarization from SOFIA's M3 mirror will be variable vs. wavelength, and up to 15% (see figure right). The diffraction limited performance of the design shown (right) as is an image of the slit and seven wavelengths in the red arm.



Acknowledgements

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