FABSOAR -- A Fabry-Perot Spectrometer for Oxygen A-band Research

Final Technical Report

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Part 1. Executive Summary

Because this was a Phase I project, it did not add extensively to the body of A-band knowledge. There was no basic research performed on that subject. The principal addition was that a mechanical and optical design for a triple-etalon Fabry-Perot interferometer (FABSOAR) capable of A-band sensing was sketched out and shown to be within readily feasible instrument fabrication parameters. The parameters for the proposed triple-etalon Fabry-Perot were shown to be very similar to existing Fabry-Perots built by Scientific Solutions. See Part 3 for details.

The mechanical design for the FABSOAR instrument incorporated the design of previous Scientific Solutions imagers, condensing the three three-inch-diameter etalons into a single, sturdy tube. The design allowed for the inclusion of a commercial off-the-shelf (COTS) filter wheel and a thermo-cooled CCD detector from Andor. The tube has supports to mount to a horizontal or vertical optical-table surface, and was to be coupled to a Scientific Solutions pointing head at the Millstone Hill Observatory in Massachusetts for Phase II calibration and testing. See Part 3 for details.

Part 2. Comparison of Phase I Accomplishments with Objectives

The technical objectives listed in the Phase I proposal are given in Table 1.

Table 1. FABSOAR Phase I Technical Objectives	
<i>Technical Objective</i>	<i>Question(s) to Answer</i>
Modify a single etalon at Millstone Hill Observatory to 100- mm gap and 3-in-diameter aperture.	<i>The proposed FABSOAR etalons will meet throughput, free spectral range, sensitivity characteristics outlined in this proposal.</i>

Table 1. FABSOAR Phase I Technical Objectives	
Develop a strawman model the performance of a two (or three) etalon spectrometer in retrieving aerosol and cloud properties.	<i>The tunability, field of view, and contrast of the tandem etalon system will match in detail the requirements for the retrieval of the first three moments of PDF-GP.</i>
Develop a forward model for retrieval of the PDF-GP data for clouds and aerosols from the FABSOAR instrument data.	<i>Additional code to be written for data processing.</i>
Combine strawman performance model and data retrieval model to guide the mechanical design of the FABSOAR unit, for subsequent downpooling to shop quality drawings	

Because of the limitations of Phase I, the single-etalon test was performed with a HeNe laser source, not near the O₂ A-band. Because of this, it did not answer the technical questions about the full three-etalon instrument's sensitivity, throughput, or free-spectral range. However, the values measured for those quantities (presented in Part 3) were comparable to those required for the O₂ A-band FABSOAR instrument, and thus fulfilled the technical objective as well as could be achieved in this Phase I.

The strawman model for the three-etalon Fabry-Perot (three etalons were required to obtain the desired out-of-band rejection; see Part 3) was completed and its FSR and out-of-band rejection were calculated. The full results of this are presented in Part 3.

The forward model development was only sketched out in Phase I, as the complexity of the techniques required was discovered through late Phase I work by Dr. Lara Waldrop. The proposed details of data extraction are included in Part 3, presented as possibilities to be explored in Phase II development.

Part 3. Project Activities Summary

Section 3A. Modeling Work

Oxygen A-band (759-771 nm) spectroscopy has been employed as an atmospheric remote sensing tool since the 1960s. O₂ A-band applications of cloudy atmosphere remote sensing are based on the technique of differential optical absorption spectroscopy (DOAS), in which the depth of known absorption features provides a means to characterize the probability distribution function of total geometric path lengths (PDF-GP) traversed by solar photons, provided the number density of the absorber is known [Platt, 1994]. The DOAS technique has been demonstrated, both theoretically and observationally, as a sensitive diagnostic of spatial structure of clouds [Dianov-Klokov et al., 1972; Portmann et al., 2001; Bennartz et al., 2006].

Figure 1. Direct Sun observations of the atmospheric O₂ A band absorption lines at various solar zenith angles. Taken from Pfielsticker et al., 1998.

The O₂ A-band is uniquely suited for investigating the solar photon PDF-GP. Not only are the A-band lines spectrally distinct from absorption bands of other atmospheric gases (see Figure 1) and the brightness of the solar A-band source reasonably large, but, more importantly, O₂ is a major, well-mixed, atmospheric constituent whose altitude distribution is known to high accuracy. Furthermore, the absorption coefficient in the A-band varies over approximately seven orders of magnitude, so that cloud optical parameters can be treated independently of wavelength.

The use of O₂ A-band measurements from airborne or satellite platforms as a means to infer surface pressure and cloud-top heights was pioneered in the 1970s and since then has been used extensively [Dianov-Klovov et al., 1970; Gechko et al., 1973; O'Brien and Mitchell, 1992]. Recently, interest has been growing in using ground-based O₂ A-band spectroscopy to investigate statistical moments of the photon path length distribution and relate them to cloud column properties [Pfielsticker et al., 1998; Min and Harrison, 1999; Portmann et al., 2001]. As described below, photon path length measurements offer a means to both infer physical cloud properties as well as diagnose the process of gaseous absorption of shortwave solar radiation in the presence of complex cloud covers. While the early cloud-top and surface pressure remote sensing efforts amounted to determining the mean photon path length, estimation of higher order moments requires enhanced measurement sensitivity, resolution, and out-of-band rejection [Min et al., 2004]. The proposed approach to path length

investigations based on O₂ A-band spectroscopy exploits FABSOAR's state-of-the-art measurement capabilities, which allow for an unprecedented characterization of the PDF-GP in arbitrary cloudy atmospheres, including the first ever estimation of statistical moments higher than two.

3A.1 Photon path length distributions. The key concept behind photon path length investigations is that each photon, originating from the sun and entering the top of the atmosphere (TOA), follows a different path governed by its sequence of stochastic, multiple-scattering events. In the presence of extinction, regarded as constant gaseous absorption along the path, the transmission of photons, $T_\lambda(L)$, along a specific path L at a specific wavelength λ , is given via Beer's Law as $T_\lambda(L) = \exp\{-\alpha L\}$, in terms of the wavelength-dependent absorption coefficient, α , which in turn is the product of the number density of the emitters and the wavelength-dependent absorption cross section. The probability that a photon will have a total geometric path length L is given by the probability density function of the geometrical path lengths, $P(L)$. Thus the total transmission of all occurring paths can be expressed as the integration of the path length distribution weighted by the Beer factor:

$$T(\lambda) = \frac{I(\lambda)}{I_0(\lambda)} = \int_0^\infty P(L) e^{-\alpha(\lambda)L} dL \quad (1)$$

Here, transmission is defined from the observational standpoint using measured radiances $I(\lambda)$, where I_0 is the radiance at an absorption free wavelength close to the absorption band (i.e., in the wings). This equation represents an expression of the principle of equivalence, whereby path length distribution measurements in near-IR wavelength bands are representative of the shortwave region as a whole, since the scattering properties of cloud and aerosol vary slowly and predictably with wavelength [van de Hulst, 1980].

3A.2 PDF-GP derivation from O₂ A-band spectroscopy. The above relationship describing the "principle of equivalence" (between absorption response and knowledge of path lengths) is strictly valid only when extinction along the path is constant, in other words, only for an isotropic atmosphere. In reality, multiple scattering of solar photons throughout atmospheric gases serves to introduce temperature and pressure dependencies in the spectral signatures of gaseous absorption, particularly for those such as the O₂ A-band with optically thick transmission at line center. This complication is typically handled by changing the independent variable α to the vertical optical depth $VOD = \alpha L_{ver} (= \tau_{ver})$, and letting path length be measured in units of vertical paths through the atmosphere based on actual meteorological conditions. In this case, the independent variable of the PDF-GP changes from L to $L' = L/L_{ver}$. Since α is not constant along the path, a mean absorption coefficient, integrated over altitude, is used instead [Funk et al., 2003]. Also, since for zenith-viewing, ground-based observations, path lengths shorter than L_{ver} cannot occur, the distribution is typically shifted by one vertical path, introducing a factor of e^{-VOD} in the Laplace transform.

An additional, more serious, complication is that the expression above is mathematically equivalent to a Laplace transform of $P(L)$ (with respect to the absorption coefficient α) whose complex part is unconstrained. Any direct inverse transformation is therefore inherently ambiguous [Funk et al., 2003]. Most recent applications of DOAS remote sensing impose, *a priori*, physical assumptions

on the functional form of $P(L)$ and use analytically-constrained inverse transformations in order to estimate its statistical moments. This approach, described in 3A.2.1 below, may yield a sufficiently accurate characterization of the PDF-GP through a homogeneously scattering atmosphere but performs poorly under complex cloud conditions. Growing support that photon transmission through real atmospheres is governed by anomalous, rather than classical, diffusion is described in 3A.2.2, and the so-called Levy index may prove to be a key observable in the characterization of how solar radiation interacts with a complex cloud cover.

An alternative numerical approach to PDF-GP estimation, developed by *Bennartz et al.* [2006] and described below in C2.2.3, exploits a finite elements representation of $P(L)$ which allows for the estimation of the entire probability density function, at a spatial resolution determined by the measurements, from which moments can be calculated *a posteriori*. This approach has been shown to yield more accurate PDF-GP estimations than analytical Laplace inversions under conditions of multi-layered cloud cover and non-negligible surface albedo [*Bennartz et al.*, 2006], though such conclusions relied on synthetic data and have yet to be tested experimentally.

3A.2.1 Analytical representations of $P(L)$. Most previous applications of O₂ A-band spectroscopy involve calculation of the inverse Laplace transformation based on *a priori* assumptions regarding the analytical form of $P(L)$ [*Pfister et al.*, 1998; *Min and Harrison*, 1999; *Funk et al.*, 2003]. The most common assumption is that the PDF-GP is Gamma-distributed with explicit dependencies on the first and second moments, $\langle L \rangle$ and $\langle L^2 \rangle$, respectively, of the path length distribution:

$$P(L) = \frac{1}{\Gamma(\kappa) \left(\frac{\langle L \rangle}{\kappa} \right)^\kappa} L^{\kappa-1} e^{-\frac{\kappa L}{\langle L \rangle}} \quad (2)$$

where

$$\kappa = \frac{\langle L \rangle^2}{\langle L^2 \rangle - \langle L \rangle^2} \quad (3)$$

Alternatively, a parameterized log-normal distribution can be used to approximate the PDF-GP and has been reported to yield superior PDF-GP estimation under some conditions [*Funk et al.*, 2003], though owing to a more stable convergence behavior, the Gamma distribution remains the more popular choice for this approach. Under the latter approximation, whose inverse Laplace transformation is known analytically, the free parameters (here, the first two moments of the path length distribution) may be estimated via standard cost-function minimization routines using observed intensity ratios across the O₂ A-band.

Cloudy sky photon path length distributions in a homogeneously scattering atmosphere have been shown to be approximately Gamma-distributed (*van de Hulst*, 1980; *Marshak et al.*, 1995), but scattering problems in real cloudy atmospheres likely lead to more complicated PDF-GPs since clouds tend to be patchy (even fractal) and/or multi-layered. For conditions of multi-layered cloud cover or significant surface albedo in particular, photon path lengths can exhibit multi-modal distributions owing to reflections between the cloud layers and/or the ground. Figure 2 depicts

simulated and derived path length distributions for two typical cloud conditions that illustrate this effect, which is difficult to capture using parameterized formulations of the PDF-GP.

Figure 2. PDF GP for extended cumulus cloud (left) and low level stratus cloud with thin cirrus layer (right) as a function of vertical path length. Shown are a Monte Carlo PDF model (MC PDF), results from a direct fit of the PDF model (labeled PDF direct), and results from a fit to the transmission spectra associated with the MC PDF using either a Gamma distribution approximation (left) or a log normal distribution (right) for the PDF formulation (labeled “result”). Taken from *Funk et al.*, [2003].

Furthermore, analysis of derived low-order PDF-GP moments has revealed a relationship between the first two moments that suggests that classical diffusion, whereby photons experience random walks through a uniform medium, is generally invalid for arbitrary scattering atmospheres [*Pfister et al.*, 1998, *Min et al.*, 2001, *Scholl et al.*, 2006]. A quantitative measure of this “anomalous” diffusion, via the so-called Levy index described below, provides an indication of when non-classical photon transport theory must be considered when calculating radiation deposition in cloudy atmospheres.

3A.2.2 Anomalous diffusion. The empirical recognition that photon path statistics for complex cloud geometries are more likely to support individual step size distributions that allow for more frequent extreme steps (see Figure 3) [*Pfister et al.*, 1998; *Pfister*, 1999; *Davis et al.*, 2004; *Scholl et al.*, 2006] was sparked in part by the suggestion of *Davis and Marshak* (1998) that Levy-type diffusion, characterized by individual step size distributions decreasing according to power laws, may be more appropriate for cloudy sky scattering phenomena.

For optically thick cloud covers, *Pfister* [1999] reported that the mean in-cloud photon path length, $\langle L \rangle$ is proportional to the rescaled cloud optical depth $\tau^* = (1-g)\tau$ (where cloud depth τ is scaled in terms of the asymmetry factor for Mie scattering g), such that

$$\langle L_c \rangle \approx l_{tr} (\tau^*)^\alpha \quad (4)$$

Figure 3. Random walk under classical diffusion vs. Levy flight characterized by more frequent large displacements. Taken from *Brockmann, 2005*.

where α is the so-called Levy index and the constant of proportionality l_r represents the "transport" photon mean free path. The Levy index is known to span a range between 1 and 2, where $\alpha = 2$ is the classical diffusion case (occurring in the limiting case of a single, compact, plane-parallel cloud layer) and $\alpha = 1$ describes a predominance of direct transmission through the region (i.e., clear skies). Diffusion characterized by Levy indices between these two extremes is called "anomalous," where the value of α is typically interpreted as a useful measure of spatial complexity in the cloudy atmosphere.

3A.2.3 Finite-elements representation of $P(L)$. An alternative approach to PDF-GP characterization more suitable for complex cloudy atmospheres is based on a finite elements method, which makes no assumptions regarding the functional form of $P(L)$ [Bennartz *et al.*, 2006]. In this case, the PDF-GP is represented mathematically as a discrete step function, having N steps with different likelihoods P_i ($i = 1, \dots, N$):

$$P(L) = \frac{1}{P_T} \begin{cases} P_1 & \text{for } w_0 < L \leq w_1, \\ \dots & \dots \\ P_N & \text{for } w_{N-1} < L \leq w_N \end{cases} \quad (5)$$

where the required normalization is given by

$$P_T = \sum_{i=1}^N (w_i - w_{i-1}) P_i. \quad (6)$$

For equally spaced intervals having a fixed width Δw , the number of free parameters reduces to N (the individual likelihoods P_i) (refer to Bennartz *et al.*, [2006] for original equations). These can be estimated using standard cost function minimization techniques from a set of radiance observations

$T(k_j)$ (for $j = 1, \dots, M$), provided that enough ($M > N$) independent radiance observations are taken at different gas absorption optical depths k_j [Bennartz and Fischer, 2000].

Figure 4. Simulated PDF-GP (thick line) compared with a finite elements fit (thin line) to simulated transmission spectra for four cases: (A) Low level stratocumulus cloud over a black surface (B) Same cloud as A, but with a surface albedo of 0.5; (C) Same conditions as A, but with an additional cirrus cloud of optical depth 0.5 at 9 km altitude; (D) Same clouds as C, but with a surface albedo of 0.5. Taken from Bennartz *et al.* [2006]

Figure 4 depicts results reported by Bennartz *et al.*, [2006] from a finite elements fit to transmission spectra derived via the principle of equivalence from “true” PDF-GPs, which were in turn derived via Monte-Carlo radiative transfer simulations for one- and two-layer clouds with and without surface reflection. The reported comparisons between the simulated and derived PDF-GP are described in terms of path length excess relative to the direct path followed by the photons that enter the TOA and experience no scattering events. Note that negative path length excess is associated with photons that exit the TOA after few scattering events instead of reaching the ground (i.e., they reflect from the cloud top), while photons experiencing significant multiple scattering within the cloud layer or reflection between layers experience a positive excess.

Figure 5. Simulated PDF GP (thick line) compared with a inverse Laplace transform of the simulated transmission spectra assuming Gamma distributed path lengths (thin line) for the same four cases as in Figure 5. Taken from *Bennartz et al.* [2006]

As evident from the “true” PDF-GPs (thick lines), both surface reflection and the presence of multiple cloud layers significantly affects the path length distribution. As illustrated in Figure 5 and reported by *Bennartz et al.* [2006], the first two statistical moments of the complex PDFs are more accurately estimated using the finite differences method relative to the analytical approach which parameterizes $P(L)$ in terms of a two-moment Gamma distribution. Non-negligible surface albedo in particular leads to significant underestimation of both the first and second moments by the inverse Laplace method, while the presence of multiple-cloud layers impacts primarily the estimation of PDF-GP standard deviation [*Bennartz et al.*, 2006].

Though the finite elements method for PDF-GP characterization has been demonstrated to yield superior estimates of statistical moments of simulated spectra, it has yet to be applied to measured sky spectra.

Section 3B. Single Etalon Fabry-Perot HeNe Laser Test

In the very preliminary Phase I prospective design, an etalon with a gap of 100 microns was included in the system. As a physical representation and precursor to the action of the Phase II FABSOAR spectrometer, it was proposed in Phase I that a single etalon made of flat plates already on-hand at Scientific Solutions be used to produce a representative Haidinger fringe pattern using Helium-Neon (HeNe) laser light. The use of a single etalon to probe the optical attributes of a triple-etalon system such as FABSOAR was always an incomplete test, since many of the properties of a triple-etalon system are distinct from those a single-etalon instrument can achieve. This was made even more true by an updated FABSOAR design that eliminated the 100-micron-gap etalon (see next section). Still, setting up a single Fabry-Perot etalon with a 100-micron gap, to view a HeNe laser, was extremely useful in helping develop Scientific Solutions' Ringtool Fabry-Perot fringe analysis software package, which became a primary focus of this task. Of particular importance was Ringtool's use of ring-summing to improve signal-to-noise ratio. The ring-summing technique is described in more detail in the previous section.

The ring pattern from the HeNe laser image through the 100-micron-gap etalon constructed by Scientific Solutions for the FABSOAR Phase I is shown in Figure 6, along with its analysis. The fringe pattern is shown in the context of a screenshot of the Ringtool analysis software. The etalon's glass plates and mechanical housing were already on hand at Scientific Solutions; only the spacers to hold the plates apart were bought new for the Phase I.

The resolution and free spectral range measured by Ringtool for this single etalon Fabry-Perot conform to expectations for those values from that instrument, marking a successful Phase I test. The reflective finesse for the etalon was measured as nearly 17.

Figure 6. (*above*) Screenshot of Scientific Solutions Ringtool software package, used on the FABSOAR Phase I etalon HeNe emission ring pattern. (*below*) The analyzed spectrum resulting from that ring summed Ringtool analysis.

Figure 7. Etalon model in wavelength space using gaps chosen for low resolution whole band observations.

Section 3C. FABSOAR Optical Design -- Triple Etalon

As mentioned in Section C2.2.4, two techniques for retrieval of the probability distribution function of geometric path lengths are being planned in parallel in FABSOAR Phase II. One of these involves the high-resolution analysis of an O₂ A-band line, and the other the low-resolution examination of a larger spectral range. Both of these techniques can be accommodated by the FABSOAR instrument, by preparing two sets of triple etalons with different gap spacing ratios: one triplet for high-resolution, the other for low resolution. Both of these schemes were designed in the FABSOAR Phase I.

Figure 14 presents the spectral model of the low-resolution system. Figure 15 presents a plot of the three spectra model of the triple etalon for high-resolution design, with an additional spectral model plot focusing on a single line to demonstrate the resolution attainable by this system.

Figure 8. (top) An FP model in wavelength space, showing the performance of three etalons using spacers selected for the high resolution mode. In this mode just one element of the a band will be observed and analyzed for line shape. (bottom) Closeup of a single resolution element of the high resolution option. This demonstrates the 1 pm spectral resolution capable with this device.

Figure 9. (left) Model in angle (or pixel) space of the resolving etalon imaged onto the 1024 x 1024 CCD in low resolution mode. This image contains nearly 27 orders of the resolving etalon. (right) Combined model of the resolver and the intermediate etalon, this demonstrates both the constructive interference possible when combining multiple etalons (the bright line) and the problem of some orders not being sufficient blocked (so called ghosts).

Figure 10. (left) Final model output of all three etalons in low resolution mode, showing how the ghosts are eliminated (less than 3%) but the constructive interference remains. (right) The model line width of the final three

The action of the multiple etalons in FABSOAR was also modeled, for the low-resolution mode, in angle, or CCD pixel, space in Phase I. Those results are presented in Figures 9 and 10,

showing how the fringe pattern changes under the expected order suppression of the multiple etalon system.

Section 3D. Signal-to-noise Calculation

Signal-to-noise ratio (SNR) computations were done for this optical system in the same manner as outlined in [Coakley *et al.*, 1996], except that signal and background are further divided by the number of azimuthal bins into which the data will be divided. The different parameters along with the result of the calculations are summarized in Table 2.

Table 2. Efficiency Values for FABSOAR Optical Train	
<i>Optical Element</i>	<i>Total Efficiency</i>
Lenses (2 @ 0.94)	0.88
Pressure Windows (6 @ 0.98)	0.89
Fabry-Perot Etalons (3 @ 0.50)	0.125
Periscope Mirrors in Pointing Head (2 @ 0.90)	0.81
Order-sorting Filter, average	0.65
GRAND TOTAL EFFICIENCY	0.05

The signal-to-noise calculation starts from a background sky intensity of 2-3 Mega-Rayleighs [J. Baumgardner, private comm.], assuming each A-band line that has a spectral width of less than 0.25 Å, and a peak absorption of 80%. The 5% efficiency of the system is a conservative estimate based on the values in Table 1. The plate area corresponds to an illuminated etalon plate diameter of 3 inches. All other parameters are obtained from the various analyses or design already accomplished. The only free parameters are the total integration time and the number of azimuthal bins that the data will be divided into.

A cylindrical column with an area of 1 m² extending from the imager to the target sees an emission from each element of the observed volume at time *t* and wavelength λ of

$$dL = \frac{\epsilon(l,t,\lambda)}{4\pi} dl \left[\frac{\text{photons}}{\text{s} \cdot \text{m}^2 \cdot \text{sr}} \right] \quad (7)$$

Integrating along the line of sight, *l*, gives

$$4\pi L = \int_0^\infty \epsilon(l,t,\lambda) dl \quad (8)$$

which is the column emission rate used as a radiometric unit in airglow and aurora called the Rayleigh [Hunten *et al.*, 1956]. In MKS units the Rayleigh is

$$1 \text{ Rayleigh} = 10^{10} \left[\frac{\text{photons}}{\text{m}^2 \cdot \text{s} \cdot \text{column}} \right] \quad (9)$$

$$L = \frac{10^{10} I}{4\pi} \left[\frac{\text{photons}}{\text{m}^2 \cdot \text{s} \cdot \text{sr}} \right] \quad (10)$$

The relationship between a column emission rate I in Rayleighs and the spectral radiance (L) is The signal model is developed assuming that the full aperture of the etalons will be used. The instrument also needs to operate at several different viewing geometries. The assumed sky brightness ranges from 2-3 MegaRayleighs (MR) with the sun near the horizon to 100 MR for observations made near the sun at zenith (ASTM Reference Spectra, <http://rredc.nrel.gov/solar/spectra/am65>). The number of photons reaching the image plane is calculated using:

$$n = T t A_{\text{ccd}} I \frac{10^{10}}{16 f_{\text{num}}^2} [\text{photons}] \quad (11)$$

The number of photoelectrons is

$$N_e = Q_e n [e^-] \quad (12)$$

The signal to noise ratio can be calculated by using [Shepherd, 2002]:

$$SNR = \frac{N_e}{\sqrt{N_e + N_d + N_R^2}} \quad (13)$$

where N_d is the dark current per pixel and N_R is the read noise of the camera. The EEV 47-10 detector has a read noise of ~10 electrons and a QE of 80% at 765 nm, for the short exposures used here the dark charge is negligible. The signal-to-noise was calculated for both the background and the peak of the A-band elements. The A-band absorption was assumed to be about 80% [Min, 2004; Bennartz, 2006]. Near local noon, with a geometry similar to that in Min [2004], the signal- to-noise off-band was 416 while the on-band signal to noise was 186 with an exposure time of 0.1 seconds.

Section 3E. FABSOAR Mechanical Design

Figure 11. (left) Phase I conceptual model of the FABSOAR triple etalon system, with pointing head. (right) A cutaway view of the triple etalon system, showing the individual pressure control chambers and the detector.

For deployment at either the ASR facility in Lamont, Oklahoma, or either of the mobile facilities especially the newer aircraft platform compactness, low weight, and robustness are very desirable attributes for the FABSOAR spectrometer. As an interferometer, FABSOAR already enjoys the *Jacquinot advantage* in luminosity-resolution product interferometers have over slit spectrometers. This means that, at a given resolution, FABSOAR can be much smaller than a grating spectrometer, while still matching the grating spectrometer's throughput, or etendue. This is partly because the high resolution of an interferometer like FABSOAR does not depend on slit width, or on grating dispersion (which requires longer optical path to attain higher resolution).

Figure 12. The Scientific Solutions Mini NIR All Sky Imager, whose design inspired the FABSOAR superstructure.

To use this small-size advantage to greatest effect, the FABSOAR spectrometer will be built into a tube construct (Figure 11) which will house all three

etalons, a filter wheel, and a detector section with lenses and a CCD. The spectrometer will be easy to mount to any standard optical table or bench. Its design was inspired by the Mini-NIR imager built by Scientific Solutions (Figure 12). Though the imager is not a Fabry-Perot spectrometer, its basic tubular design readily accommodates all the optical elements of FABSOAR, including the three etalons.

All the mechanical components in the conceptual design of Figure 1 have been downspun to shop drawings, as specified in the Phase I technical objectives.

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