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A.15 ATMOSPHERIC COMPOSITION: SURFACE, BALLOON, AND AIRBORNE OBSERVATIONS

Airborne Sunphotometry Upgrades via Spectrometry of Sun and Sky Radiation

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ACRONYMS

AASE	Airborne Arctic Stratospheric Expedition
AATS	Ames Airborne Tracking Sunphotometer
ACE	Aerosol Characterization Experiment
AERONET	Aerosol Robotic Network
AIRS	Atmospheric InfraRed Sounder
AOD	Aerosol Optical Depth
ARM	Atmospheric Radiation Measurement
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
BAER	Bay Area Environmental Research Institute
CAD	Computer Aided Design
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAM	Computer Aided Manufacturing
CDR	Critical Design Review
CLAMS	Chesapeake Lighthouse & Aircraft Measurements for Satellites
CPU	Central Processing Unit
DAS	Data Acquisition System
DC	Direct Current
DIAS	Direct beam Irradiance Airborne Spectrometer
DOE	Department of Energy
EOS	Earth Observation System
EVE	Extended-MODIS-λ Validation Experiment
FWHM	Full Width at Half Maximum
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring Experiment
INTEX or INTEX-NA	Intercontinental Chemical Transport Experiment-North America
INTEX-A or -B	Phase A or B of INTEX-NA
IOP	Intensive Observation Period
IR	Infrared
ITCT	Intercontinental Transport and Chemical Transformation
J-31	Jetstream 31
LWV	Layer Water Vapor
MAS	MODIS Airborne Simulator
MILAGRO	Megacity Initiative: Local and Global Research Observations
MISR	Multi-Angle Imaging Spectroradiometer
MODIS	Moderate-resolution Imaging Spectroradiometer
MW	Multi-Wavelength
NEMA	National Electrical Manufacturers Association
NIR	Near Infra-Red
NRA	NASA Research Announcement
NSPIRES	NASA Solicitation and Proposal Integrated Review and Evaluation System
OMI	Ozone Monitoring Instrument
PI	Principal Investigator
PNNL	Pacific Northwest National Laboratory
POAM	Polar Ozone and Aerosol Measurement
RF	Radio Frequency
ROSES	Research Opportunities in Space and Earth Sciences
SAGE	Stratospheric Aerosol and Gas Experiment
SCIA-MACHY	SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SSA	Single Scattering Albedo
SSFR	Solar Spectral Flux Radiometer
4STAR	Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research
TARFOX	Tropospheric Aerosol Radiative Forcing Observational Experiment
TOMS	Total Ozone Mapping Spectrometer
UAS	Unmanned Aerial System
UV	Ultraviolet

Summary for NSPIRES

We propose several upgrades to the abilities currently provided by the 14-channel Ames Airborne Tracking Sunphotometer (AATS-14). The upgrades will provide calibrated measurements of (1) direct-beam Sun irradiance and (2) sky radiance vs. angular distance from the sun, all in many more wavelength channels, and with finer resolution, than now provided by AATS-14. Together these upgrades will provide improved measurements of H_2O, O_3, and aerosols in the stratosphere and troposphere, while enabling measurements of additional gases such as NO_2. The improved aerosol measurements will enable retrievals of size distribution modes extending to larger sizes than possible with AATS direct-beam transmission measurements, and will provide information on aerosol type via retrievals of complex refractive index and shape, all provided by the first AERONET-like measurements from aircraft. They will thus extend robustly into the future the productivity enabled by AATS-14 and its predecessor AATS-6. AATS measurements of H_2O, O_3, and aerosols in numerous field campaigns have yielded >80 publications describing their use to validate data products from satellites, lidars, and chemical-transport models, to test consistency between in situ and radiometric measurements, and to study radiative effects of atmospheric composition.

Our proposed approach to providing these upgraded capabilities is to link rack-mounted spectrometers to auto-steered entrance ports via fiber optics in a relatively compact, modular design that permits easier integration on a wider range of aircraft, as well as straightforward substitution of more specialized spectrometers in future versions. Successful implementation of this approach requires overcoming the following technological challenges:

1. Fiber optic couplings with 1% calibration stability through connections and rotations
2. Stray light rejection to enable measurement of skylight within 3° of the sun
3. Sensitivity to enable completing a sky scan within 100 seconds (10 km in flight at 100 m s^{-1})
4. Overall instrument calibration stable to 1% over a period of several months.
5. Pointing accuracy of 0.2˚ for sun tracking and sky scanning during aircraft pitch, roll, and yaw changes up to 6˚ s^{-1}.

To demonstrate the feasibility of this approach, we have developed and extensively tested a ground-prototype Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research (4STAR-Ground). These tests and our AATS experience have demonstrated that our approach can overcome the above challenges in an airborne version (4STAR-Air).

We propose development and ground-testing in a 2-year period, followed by aircraft integration, flight testing, and demonstration in an airborne mission within a third year, and by improvement and preparation for future missions in a fourth year. Key milestones include: (1) Critical design review, (2) Procure motion system components, (3) Fabricate instrument head and mounting hardware, (4) Fabricate spectrometer, motion control, and data system chassis, (5) System integration and testing , (6) Full system testing on ground, (7) Aircraft integration, (8) Flight test program, (9) Demonstration field program, and (10) Improvement and preparation for future missions. The proposing team is a collaboration that brings together key members of the teams that have developed and extensively applied AATS-6 and -14, 4STAR-Ground, and AERONET.

1 SCIENTIFIC/TECHNICAL/MANAGEMENT SECTION

a. Background, overall goal, and general approach

Background. Since 1985 the NASA Ames Airborne Tracking Sunphotometers (AATS-6 and -14) have made extensive measurements of atmospheric constituents via their effect on the Sun's direct-beam transmission through the atmosphere. Constituents measured to date include O_3 [e.g., *Livingston et al.*, 2005; *Pitts et al.*, 2006; *Swartz et al.*, 2005], H_2O [e.g., *Ferrare et al.*, 2000b, 2006; *Livingston et al.*, 1998, 2000, 2003, 2007a, 2008; *Pilewskie et al.*, 2000; *Redemann et al., 2003*; *Revercomb et al.*, 2003; *Schmid et al.*, 2000, 2001; 2003a] and aerosols [see references below]. AATS measurements are used extensively to validate and supplement satellite retrievals of stratospheric and tropospheric constituents (e.g. Table 1, Figure 1), validate airborne and ground-based lidar data products, characterize horizontal and vertical distributions of gas and aerosol properties, study closure (consistency) with in situ samplers aboard many aircraft, test chemical-transport models, and study the radiative effects of atmospheric constituents and Earth surfaces that are important to both climate and remote measurements. AATS measurements and analyses are described in more than 80 publications since 1987. Example publications are listed below, grouped by selected field campaign:

- **AASE II** [*Russell et al.*, 1993; *Toon et al.*, 1993],
- **TARFOX** [*Hegg et al.*, 1997; *Hobbs et al.*, 1998; *Russell et al., 1999a,b; Tanre et al.*, 1999; *Veefkind et al.*, 1999; *Ferrare et al.*, 2000a,b; *Hartley et al.*, 2000; *Redemann et al.*, 2000a,b; *Bergstrom et al.*, 2002],
- **ARM Water Vapor IOPs** [*Schmid et al.*, 1999, 2001; *Pilewskie et al.*, 2000; *Revercomb et al.*, 2003],
- **ACE-2** [*Livingston et al.*, 1998, 2000; *Russell et al.*, 1998b; *Schmid et al.*, 1998, 2000; *Collins et al.*, 2000; *Durkee et al.*, 2000; *Gasso et al.*, 2000; *Russell and Heintzenberg*, 2000; *Welton et al.*, 2000],

Table 1. Publications using AATS data to validate data products from satellite sensors or their airborne simulators

Sensor, Constituent	Publication	Sensor, Constituent	Publication
AIRS H_2O	*Livingston et al.*, 2007a	MODIS Aerosol	*Livingston et al.*, 2003; *Levy et al.*, 2003, 2005; *Schmid et al.*, 2003b; *Redemann et al.*, 2005, 2006a; *Chu et al.*, 2005; *Anderson et al.*, 2005; *Russell et al.*, 2007
ATSR-2 Aerosol	*Veefkind et al.*, 1999, *Schmid et al.*, 2003b		
AVHRR Aerosol	*Veefkind et al.*, 1999, *Durkee et al.*, 2000; *Livingston et al.*, 2000; *Schmid et al.*, 2000		
GMS-5 Aerosol	*Wang et al*, 2003b	MODIS H_2O	*Livingston et al.*, 2007a
GOES-8 Aerosol	*Livingston et al.*, 2003 ; *Wang et al.*, 2003a	POAM Aerosol	*Russell et al.*, 2005
GOME O_3	*Livingston et al.*, 2005	POAM O_3	*Livingston et al.*, 2005
MAS Aerosol	*Tanré et al.* 1999	SAGE 3 Aerosol	*Russell et al.*, 2005
MISR Aerosol	*Schmid et al.*, 2003b*; Kahn et al.*, 2004; *Redemann et al.*, 2005; *Reidmiller et al.*, 2006; *Russell et al.*, 2007	SAGE 3 O_3	*Livingston et al.*, 2005
		SeaWiFS Aerosol	*Hsu et al.*, 2002
		TOMS Aerosol	*Livingston et al.*, 2003; *Schmid et al.*, 2003b
		TOMS O_3	*Livingston et al.*, 2005

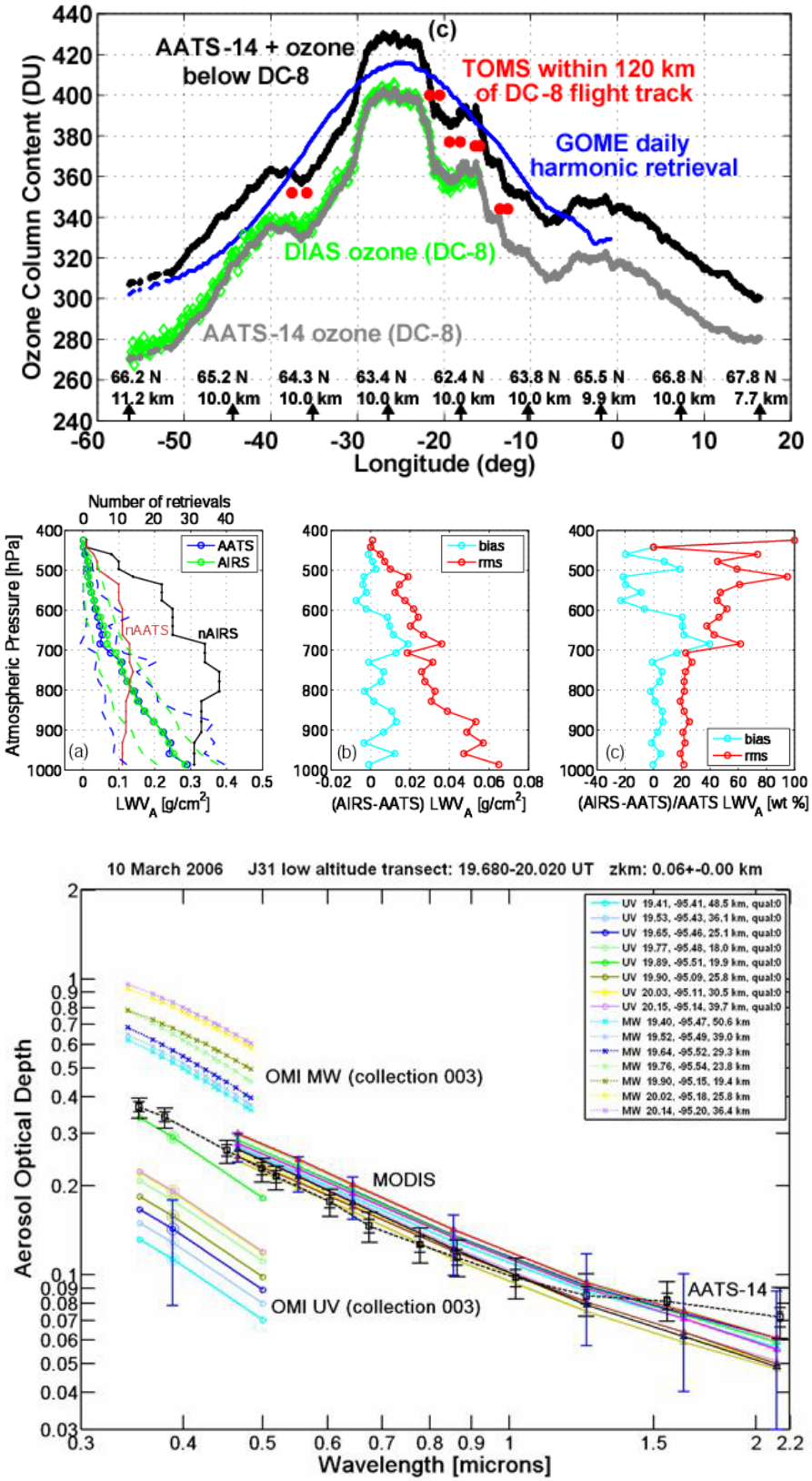

Figure 1. Examples of AATS measurements of O_3, H_2O, and aerosols and their use to validate satellite data products.

Top row: O_3 [*Livingston et al.*, 2005]: Comparison of columnar ozone retrieved from AATS-14 measurements on the DC-8, 21 Jan 2003. AATS-14 (gray) and DIAS (green) ozone above DC-8 altitude, and AATS-14 (black), along-track GOME (blue) and near-track TOMS (red) total column ozone.

Middle row: H_2O [*Livingston et al.*, 2007a]: Comparisons of AIRS and AATS retrievals of layer water vapor in AIRS retrieval layers (LWV_A) for AIRS retrievals with Qual_Temp_Profile_Bot = 2 and within 80 km of an AATS vertical profile measured on the J-31. (a) Means (open circles with solid lines) and ranges (dashed lines) of AIRS and AATS LWV_A profile retrievals, numbers of AIRS and AATS retrievals at each altitude; (b) absolute AIRS-minus-AATS LWV_A biases and RMS differences; (c) % biases and RMS differences.

Bottom row: aerosol optical depth (AOD) [*Livingston et al.*, 2007b]: comparison of OMI on Aura (MW and UV retrievals), MODIS on Aqua and AATS, 10 Mar 2006.

- **PRIDE** [*Colarco et al.,* 2003; *Livingston et al.,* 2003; *Reid et al.,* 2003; *Wang et al.,* 2003a],
- **SAFARI-2000** [*McGill et al.,* 2002; *Bergstrom et al.,* 2003; *Gatebe et al.,* 2003; *Kaufman et al.,* 2003; *Magi et al.,* 2003, 2008; *Pilewskie et al.,* 2003; *Schmid et al.,* 2003b; *Kuzmanoski et al.,* 2007c],
- **ACE-Asia** [*Wang et al.,* 2002; *Murayama et al.,* 2003; *Redemann et al.,* 2003; *Schmid et al.,* 2003a; *Wang et al.,* 2003b; *Bergstrom et al.,* 2004; *Kahn et al.,* 2004; *Anderson et al.,* 2005; *Chu et al.,* 2005; *Kuzmanoski et al.,* 2007a,b],
- **CLAMS** [*Chowdhary et al.,* 2005; *Gatebe et al.,* 2005; *Jin et al.,* 2005; *Levy et al.,* 2005; *Magi et al.,* 2005; *Redemann et al.,* 2005; *Reidmiller et al.,* 2006; *Smith et al.,* 2005],
- **SOLVE II** [*Livingston et al.,* 2005; *Pitts et al.,* 2006; *Russell et al.,* 2005; *Swartz et al.,* 2005],
- **ARM Aerosol IOP** [*Andrews et al.,* 2006; *Ferrare et al.,* 2006; *Hallar et al.,* 2006; *Ricchiazzi et al.,* 2006; *Schmid et al.,* 2006; *Strawa et al.,* 2006],
- **EVE** [*Redemann et al.,* 2006a],
- **INTEX-A** [*Fehsenfeld et al.,* 2006; *Livingston et al.,* 2007; *Redemann et al.,* 2006b; *Russell et al.,* 2007; *Singh et al.,* 2006].
- **INTEX-B** [*Coddington et al.,* 2008].

AATS participation in the above campaigns was funded by NASA's Upper Atmospheric Research, Radiation Sciences, Tropospheric Chemistry, and New Investigator Programs, and by several NOAA, Navy, and DOE programs. AATS characteristics that contributed to its selection for, and productivity in, these field programs include its versatility (measuring both gases and aerosols over a relatively broad wavelength range, 354-2139 nm), relatively compact and automated design, ability to fly on a wide range of aircraft (e.g., Figure 2) from globally distributed locations, reliability, and applicability to a wide range of studies, often enabled by collaborations with a diversity of experimenters and modelers. These characteristics have enabled AATS and its team to provide a unique bridge between a wide variety of satellite, airborne and surface-based sensors, helping to advance knowledge not only of atmospheric constituents and their effects, but also of a range of measurement technologies.

Overall goal. The overall goal of the research proposed here is to develop and demonstrate several upgrades of airborne sunphotometry that will provide information on gases and aerosols extending far beyond what can be derived from AATS-14, while preserving or enhancing many of the above desirable AATS features (e.g., compactness, versatility, automation, reliability). The enhanced instrument we propose is an airborne prototype Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research (4STAR-Air), which is based on the ground prototype (4STAR-Ground) that we have developed and extensively tested over the past several years. Each 4STAR (Ground and Air) combines the sun-tracking ability of the current 14-Channel NASA Ames Airborne Tracking Sunphotometer (AATS-14) with the sky-scanning ability of the ground-based AERONET Sun/sky photometers, while extending both AATS-14 and AERONET capabilities by providing full spectral information from the UV (210 nm) to the SWIR (1690 nm).

Figure 3 shows how the essential features of 4STAR relate to AATS-14 and AERONET. Figure 4 shows how the wavelengths of the AATS-14 channels (defined by interference filters) relate to atmospheric spectra and to the wavelength ranges of the two 4STAR-Ground spectrometers (UV-VIS-NIR, already installed and tested, and NIR, purchased for installation this year).

General approach. The general approach we propose is illustrated in Figures 5 and 6, which show a conceptual design and block diagram for 4STAR-Air. An important feature is the

Figure 2. A subset of the aircraft installations of AATS-6 and -14 (Not shown: DOE Twin Otter and NASA CV-990, C-130, and P-3B).

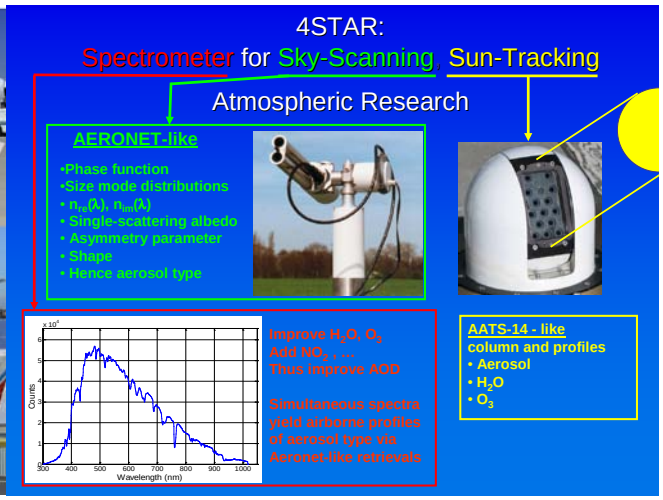

Figure 3. Essential features of 4STAR as related to AATS-14 and AERONET.

modularity and extensibility of the optics within the instrument rack. New measurement capability may be added without requiring changes to the collector fore optics simply by substitution of different spectrometers or addition of more fiber bifurcations for different detectors such as a 2.2 μm photodiode, for example. More information on our proposed approach is in Sections 1.c-1.f below.

b. Scientific advantages, uniqueness, and potential future applications/configurations

Scientific advantages and uniqueness. Scientific advantages of the 4STAR design are many. The continuous spectrum measurements in 1536 wavelength pixels (Figures 3 and 4) improve on AATS-14's 14 discrete wavelengths, enabling measurements of trace gases not possible with AATS-14, such as NO_2, plus improved accuracy of AATS-14's current H_2O and O_3 measurements. (See also **Potential future applications and configurations**, below.) In addition, the scattered sunlight measurements enable determination of (1) the size of larger particles (e.g., mineral dust and seasalt) than possible with direct-beam transmission measurements, and (2) aerosol type, composition and absorption information via retrievals of complex refractive index and shape. The increased trace-gas measurement capability of continuous spectra has been demonstrated by many space-, air-, and ground-based instruments [e.g., *Bhartia et al.*, 2002; *Cede et al.*, 2006, 2008; *Chance et al.*, 1998; 2002; *Kroon et al.*, 2008; *Pilewskie et al.*, 2000; *Shetter and Muller*, 1999; *Shetter et al.*, 2003; *Swartz et al.*, 2005] but never in a compact airborne instrument also capable of (1) the well calibrated direct-beam transmission measurements needed for aerosol studies and (2) the relatively unrestricted pointing capabilities of 4STAR's aircraft rooftop mounting. The increased information content of scattered sunlight measurements has been demonstrated by NASA's AERONET program [e.g., *Holben et al.*, 2001], but never on an airborne instrument. 4STAR's radiance measurements, absolutely calibrated using a laboratory integrating sphere, with field checks using a small portable sphere, will also be useful for satellite validation and radiation budget studies. Together, these capabilities make 4STAR-Air unique in not just one but several ways. 4STAR is targeted for autonomous operation on a variety of aircraft, including small or unmanned aircraft (see Figure 5). 4STAR will be used in airborne field campaigns focused on aerosol and trace gas research.

Science applications include radiative closure studies, satellite validation, and surface, airborne, and space based lidar validation.

Potential future applications and configurations. To limit costs and increase chances of success, this proposal focuses on the limited set of goals comprising the development and demonstration of the airborne prototype 4STAR-Air. An example limitation is focusing on measurements of H_2O, O_3, NO_2, and aerosols using the spectrometers already purchased for 4STAR-Ground (see, e.g., Figures 4 and 6). Although much will be achievable with this initial 4STAR-Air configuration, 4STAR-Air's modular, flexible design provides the versatility to achieve a wider range of objectives, especially by taking advantage of 4STAR's rack mounting

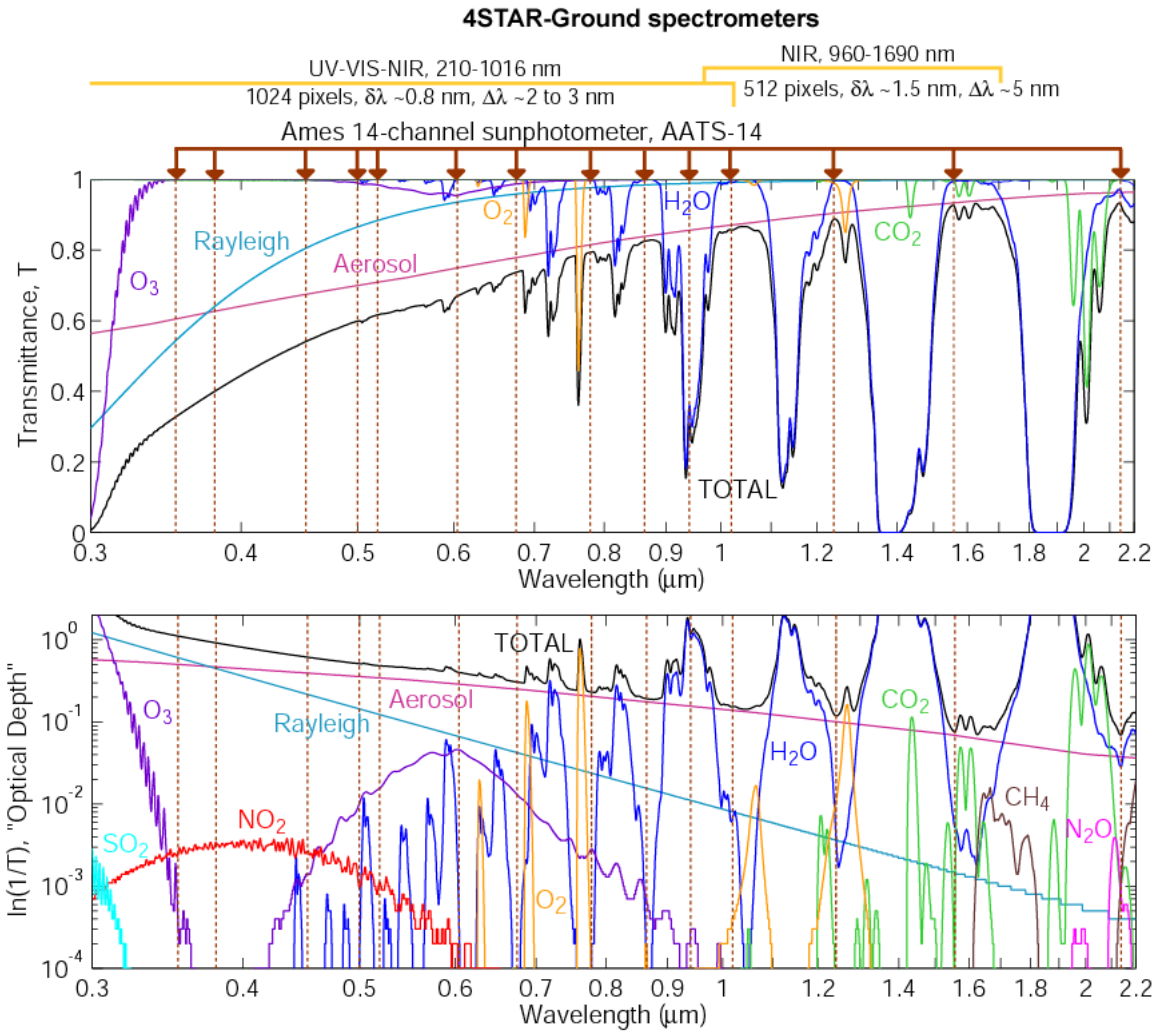

Figure 4. Wavelength ranges and resolutions of the two 4STAR-Ground spectrometers in relation to AATS-14 channel wavelengths (vertical lines with arrows) and atmospheric spectra. δλ=spacing of pixel centers; Δλ=pixel FWHM. The spectra of transmittance T of the direct solar beam at sea level were calculated using MODTRAN-4.3 with a Midlatitude Summer atmosphere, a rural spring-summer tropospheric aerosol model (Vis = 23 km), and the sun at the zenith. Current center wavelengths of AATS-14 channel filters are 354, 380, 453, 499, 519, 604, 675, 778, 865, 941, 1019, 1241, 1558, 2139 nm. Filter full widths at half-maximum (FWHM) are 5 nm, except for the 354 and 2139 nm channels, which have FWHM 2 and 17 nm, respectively.

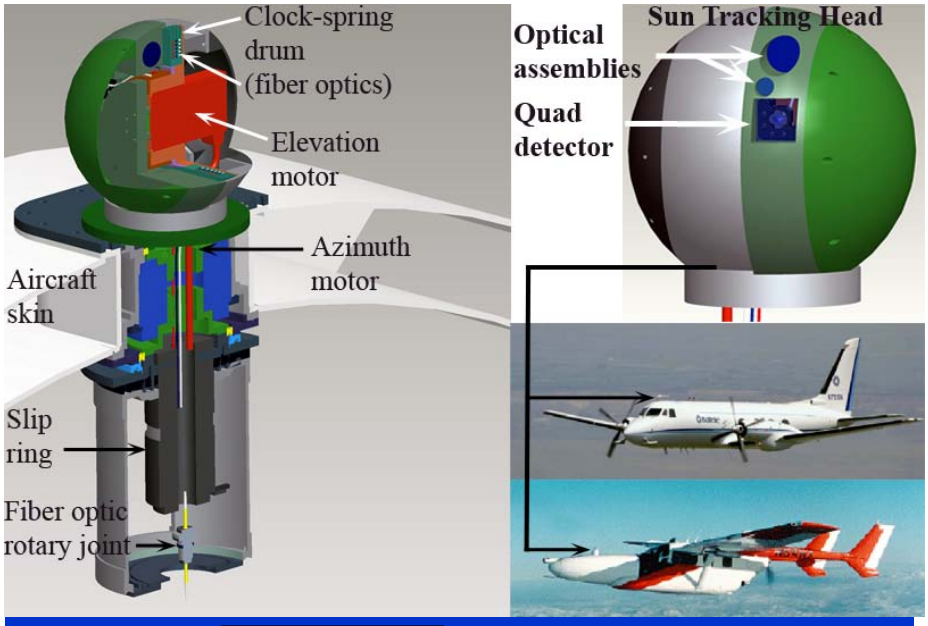

Figure 5. A conceptual design for 4STAR-Air. Tracking head diameter is 7.7 inches (19.6 cm), slightly less than AATS-14's head diameter. The 4STAR design shown requires a considerably smaller A/C port size than the 12 inch diameter required for AATS-14.

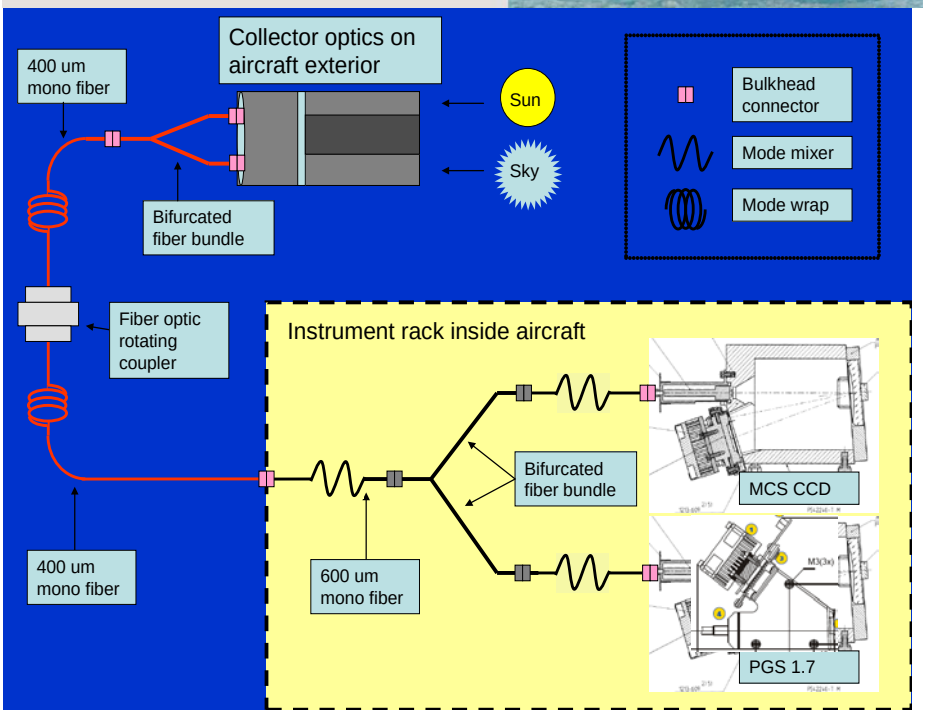

Figure 6. 4STAR-Air conceptual block diagram, illustrating its modularity and the extensibility of its dispersion and detection hardware within the instrument rack. Different spectrometers or discrete photodiodes (e.g., at 2.2 μm to match AATS-14's longest wavelength channel) could be substituted or added without changing the foreoptics tracking head.

of spectrometers to substitute more specialized spectrometers for particular applications. As an example, note in Figure 4 that 4STAR's wavelength range includes prominent absorption bands of CO_2, CH_4, and O_2. The CO_2 and O_2 bands have been used for SCIAMACHY measurements of CO_2 dry mole fractions by focusing on the 1558–1594 and 755–775 nm spectral regions, using a resolution of ~1 nm [*Buchwitz et al.*, 2007]. Substitution of corresponding spectrometers into 4STAR-Air would permit analogous airborne studies of CO_2 and CH_4 mole fractions. Other constituents with absorption bands in the 4STAR range include BrO, OClO, and O_2-O_2 (not all shown in Figure 4), which are used by OMI, GOME, and SCIAMACHY to measure those constituents [e.g., *Chance*, 2002]. With similarly targeted spectrometers, 4STAR-Air could make analogous airborne measurements. An advantage of 4STAR-Air for such studies is its direct-

beam measurement capability, which removes the need to account for the Ring effect (filling in of Fraunhofer absorption bands by Raman scattering) and greatly reduces airmass uncertainties, both of which are prominent sources of retrieval uncertainty in the satellite measurements of diffuse reflectance spectra [e.g., *Cede et al.,* 2006]. 4STAR-Air would have the potential to extend to airborne studies the NO_2 satellite validation measurements conducted using the ground-based PANDORA spectrometer developed by NASA Goddard [e.g., *Herman et al.,* 2007; *Cede et al.,* 2008].

c. Statement of relevance to NASA's goals, objectives, science questions, and the NRA

The research proposed here addresses the following strategic sub-goal, science questions, and science goals from Table 1 of the ROSES 2008 Summary of Solicitation:

Strategic Sub-goal 3A: Study Earth from space to advance scientific understanding and meet societal needs.

Science Questions:
- How is the global Earth system changing?
- What are the primary causes of change in the Earth system?
- How does the Earth system respond to natural and human-induced changes?
- How will the Earth system change in the future?

Research Objectives:

3A.1 Understand and improve predictive capability for changes in the ozone layer, climate forcing, and air quality associated with changes in atmospheric composition.

3A.5 Understand the role of oceans, atmosphere, and ice in the climate system and improve predictive capability for its future evolution.

As noted by the ROSES 2008 Summary of Solicitation, NASA addresses these questions and objectives by using an integrated observational strategy that combines observations from space with suborbital and ground-based measurements.

This proposal responds specifically to Appendix A.15 of the ROSES 2008 call, which solicits proposals for atmospheric field measurement systems that monitor trace gas composition in the upper troposphere and stratosphere from ground, aircraft, and balloons. Such measurements include those made in field missions to study processes that influence upper tropospheric and stratospheric composition, and validation and augmentation of data products from NASA's atmospheric composition related satellite instruments, and provide a transition to future missions. Included are airborne in situ and remote observations of the upper troposphere and stratosphere that address the priorities of NASA's atmospheric composition focus area, have the potential to be used in future airborne field campaigns, and can be used to enhance data products from atmospheric composition satellites. Especially sought are efforts that will enhance and maintain the abilities of existing established measurement techniques.

d. Technological Challenges, Ground-based Prototype, and Test Results

Our proposed approach to the above upgrades (Figures 5 and 6) entails using fiber optics to link motor-steered sun and sky entrance optics to rack-mounted compact spectrometers. Successful implementation of this approach requires overcoming the following technological challenges:

1. Fiber optic couplings with 1% calibration stability through connections and rotations
2. Stray light rejection to enable measurement of skylight within 3° of the sun
3. Sensitivity to enable completing a sky scan within 100 seconds (10 km in flight at 100 m s^{-1})
4. Overall instrument calibration stable to 1% over a period of several months.

5. Pointing accuracy of 0.2˚ for sun tracking and sky scanning during aircraft pitch, roll, and yaw changes up to 6˚ s^{-1}.

Figure 7. Ground prototype Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research (4STAR-Ground).

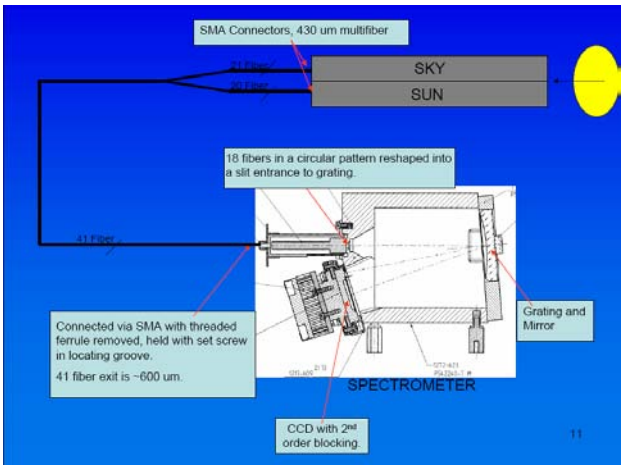

Figure 8. Optical block diagram of 4STAR-Ground. The NIR spectrometer (not shown) will be installed before proposed work starts.

To demonstrate the feasibility of overcoming these challenges, we have developed and extensively tested a ground-based prototype Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research (4STAR-Ground, see Figures 7, 8). Using 4STAR-Ground we have demonstrated that:

- Throughput of a Fiber Optic Rotating Joint (FORJ) purchased for 4STAR shows a sinusoidal behavior repeatable to within a few tenths of a percent (see Figure 9).
- 4STAR-Ground is able to perform direct-beam measurements on par with AATS-14 (see Figure 10).
- We can radiance calibrate 4STAR-Ground with the same fidelity as AERONET instruments (see Figure 11).
- 4STAR sky radiance scans are on par with AERONET (see Figure 11).
- Straylight rejection for scattering angles >3º is on par with AERONET and PREDE (smaller scattering angles are discarded in the AERONET inversion). See Figure 12.
- We can run our own inversions using the AERONET code and the inverted size distributions from 4STAR and AERONET are in good agreement. See Figure 13.
- The 4STAR-Ground sky light collector (Figure 14), when coupled to the UV-VIS-NIR spectrometer via 4STAR-Ground fiber optics, produces signal sufficient to complete a sky scan in 100 s (10 km of flight at 100 m s^{-1}). The collector optics provide a gain of 81 relative to a collector consisting only of a baffled tube.

e. Next Steps (Using Current Funding)

i. Langley calibration at Mauna Loa Observatory

We will conduct simultaneous Langley-plot calibrations of 4STAR- Ground and AATS-14 in August 2008 at Mauna Loa Observatory (MLO). The exceptionally clean conditions at MLO typically yield Langley regressions with uncertainties in extrapolated top-of-atmosphere

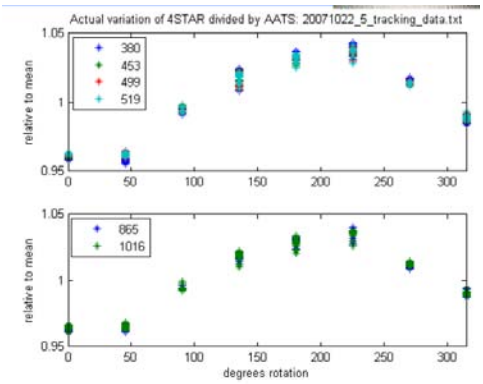

Figure 9. The Fiber Optic Rotating Joint (FORJ) purchased for 4STAR-Ground, with measured throughput repeatability.

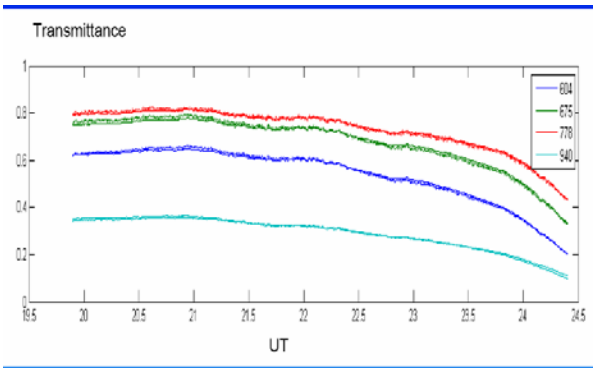

Figure 10. Comparison of direct-beam transmittance measurements by 4STAR-Ground and AATS-14, at selected AATS-14 channel wavelengths. Note: 2 curves per color.

irradiance of a fraction of 1%. This is about an order of magnitude better calibration for the sun barrel than is possible for the sky barrel calibration via integrating sphere. In addition, the MLO measurements will permit detailed comparisons of 4STAR and AERONET sky radiance scans and aerosol inversions using AERONET's inversion code. These MLO measurements will be a collaborative effort by this proposal's Co-I Stephen Dunagan of NASA Ames and Collaborators Beat Schmid and Connor Flynn of PNNL.

ii. Add NIR spectrometer

Using current funding we have purchased the Zeiss NIR-PGS 1.7 spectrometer described in Figure 4 and shown in Figure 6. This single component spectrometer fits into the modular 4STAR concept perfectly. Like our existing Zeiss MCS CCD UV-VIS-NIR spectrometer (Figures 4 and 8), the NIR-PGS 1.7 features a rugged design with no moving parts and the InGaAs detector, grating, and fiber optic coupler permanently mounted to a rigid spectrometer body. Such Zeiss spectrometers have performed well in several airborne instruments, including the NASA Ames-developed Solar Spectral Flux Radiometers [SSFR, *Pilewskie et al.*, 2000] and the NCAR-developed CCD Actinic Flux Spectroradiometers [CAFS, *Shetter and Hall*, 2008]. The spectrometers include high-sensitivity scientific-grade Hammamatsu array detectors, using dual-stage thermoelectric cooling and 16-bit A/D converters to maxize sensible signal, while minimizing read noise and destabilizing thermal effects. The detectors are read using custom electronic readout boards developed by Tec5. These circuits are optimized for high speed, with features to permit ensemble averaging to increase signal/noise ratio. Digitized signals are read and stored by a National Instruments digital data acquisition card mounted in the backplane of a compact PCI industrial data acquisition system (DAS) chassis. The DAS comprises a dual core processor operating at 1.5 GHz, 2 GB of SDRAM, and multiple on-board serial ATA disk interfaces. The Compact PCI backplane permits the addition of modular system components for additional required functionality, including high-speed networking, serial data exchange, IRIG-B time encoding, and additional CPU boards to control parallel processes, such as motion control. The operating system is Microsoft Windows XP, with readily available device drivers for all subsystem elements. The National Instruments LabVIEW data acquisition software provides a simple programming environment to quickly develop and debug the data acquisition and motion control software. The software may be configured in flight operator mode for manned flight experiments, or to run remotely over a network process as required for UAS operations.

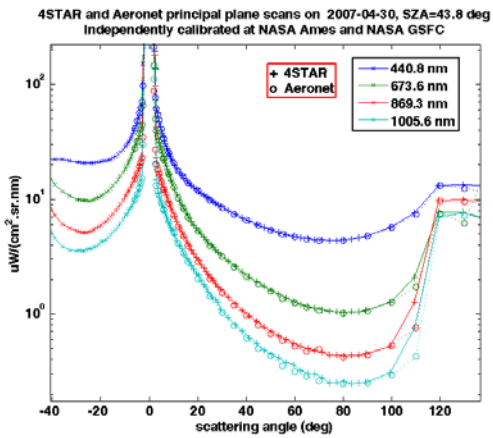

Figure 11. Comparison of radiances measured in simultaneous principal plane scans by 4STAR-Ground and an AERONET Cimel sun-sky photometer (independently calibrated by integrating spheres at NASA ARC and NASA GSFC).

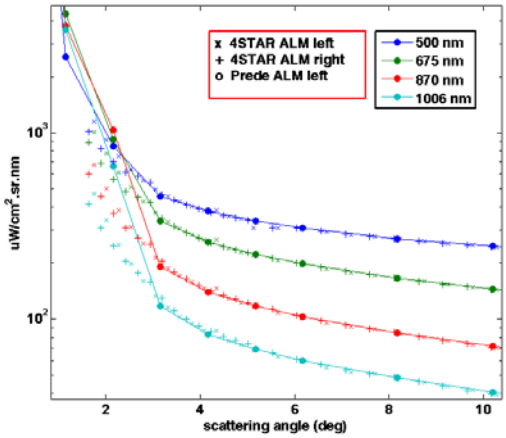

Figure 12. Comparison of radiances measured in simultaneous almucantar scans by 4STAR-Ground and a PREDE sun-sky photometer for angles within 10˚ of the sun. Note: radiances for Θ<3˚ are not used in retrievals.

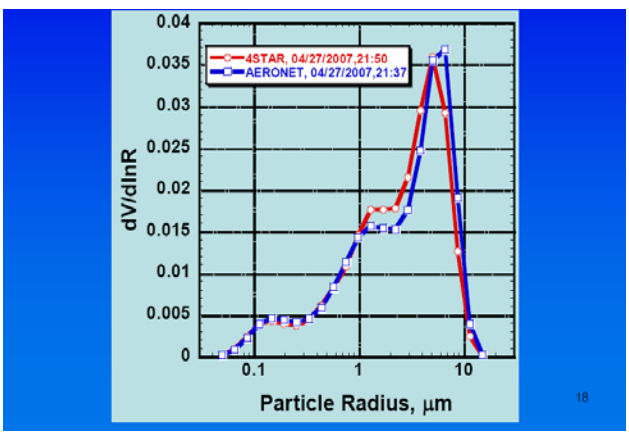

Figure 13. Comparison of aerosol size distributions retrieved from 4STAR and AERONET Cimel Sun and skylight measurements. Retrievals performed at PNNL using the AERONET inversion code provided by Brent Holben of GSFC.

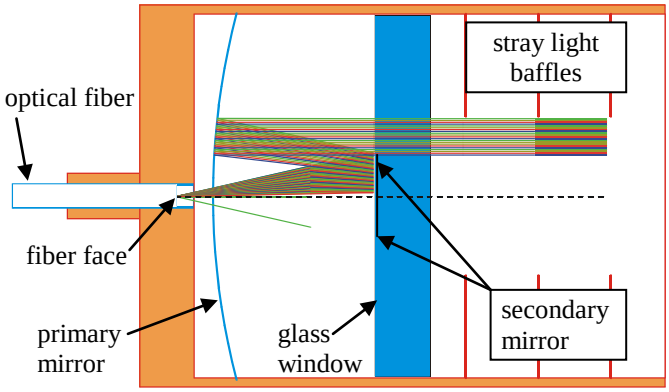

Figure 14. Mechanical cross section of 4STAR-Ground skylight collector.

As with our 4STAR-Ground Zeiss MCS CCD, the fiber optic connection will permit the NIR-PGS to be mounted safely within the instrument rack coupled to the optical head on the aircraft exterior with a bifurcated fiber optic. The NIR spectrometer, with spectral range 960 - 1690 nm, will improve retrievals of H_2O and of aerosol properties for larger mode aerosols. We plan to integrate it into 4STAR-Ground and thoroughly test it before receipt of funding for this proposal.

iii. Continue spectral inversion development/adaptation

Current funding at PNNL, which produced the inversions shown in Figure 13 by Evgueni Kassianov, will be used to continue development of inversion codes, using in part new measurements from the August 2008 MLO measurements described above. Included will be

adaptations to account for changing aircraft pitch, roll, and yaw during skylight scans, by using aircraft nav-system information to change inversion kernels to reflect actual scattering angles.

iv. Procure 4STAR-Air head prototype components and test with 4STAR-Ground

Using current funding we will build a prototype head assembly comprising a miniaturized baffle tube for the direct beam, a compact cassegrain reflector for diffuse sky, a fiber optic assembly to transmit the signal to the rack-mounted spectrometers, a quadrant detector for tracking the sun, solenoid-actuated shutters on the collector tubes, and stepping-motor motion control for the elevation and azimuth axes. (Figure 14 shows the mechanical cross section of a 4STAR skylight collector we are currently testing.) The objective of this prototype development is to build and test the smallest, most nearly spherical head assembly that achieves required collection and stray light rejection, with attention to minimal mass, low cost, ease of manufacture, and durablility. A coiled spool assembly for the fiber optic and the wiring for the quadrant detector and shutter solenoids to accommodate over 200˚ of elevation motion will be tested. This prototype will also permit testing of the fiber optic rotary joint (FORJ, Figure 9) and slipring assemblies (Figure 5) that will permit continuous azimuth rotation of the instrument through an arbitrary turn sequence.

v. Spec 4STAR-Air prototype motion system

With current funding we will design, build and test a motion control system for 4STAR-Air using industrial standard NEMA 17, 23, and 34 series framed stepping motors of the type used in 4STAR-Ground. All motors will be fitted with integrated resolver circuitry for accurate position feedback to the controller. Gear reduction for the azimuth and elevation axes will use helical ring and pinion gearing and helical planetary gearing, respectively. All gear reducers will be specified to have lost motion (backlash) <0.033˚. Optical component miniaturization will permit the head to be packaged in a spherical cowling with minimal protrusion, which will minimize drag-induced torque loads on both axes. The azimuth drive will use a high load capacity, crossed roller bearing, hollow shaft mechanism to permit on-axis ducting of fiber optics and wires to the slipring and FORJ components (Figure 5).

A tilt table test stand will be designed and fabricated for use in testing the frequency response and tracking capability of the motion control system. This will permit testing at various combinations of roll and pitch, through continuous turning maneuvers. If the stepping motor drives are unable to drive the system at required frequencies and amplitudes, high-performance DC servomotor components in mechanically interchangeable NEMA standard geometries will be substituted. A final upgrade option would rely on open frame DC servomotors.

vi. Long-term calibration stability tests

With current funding we will continue to evaluate 4STAR-Ground's long term radiometric and spectral stability. This will include the Mauna Loa calibration and cross-calibrations using a field portable integrating sphere, spectralon panels with direct solar illumination, and NIST-calibrated solar simulator tungsten filament lamps. Spectral stability will be evaluated using argon, mercury, and krypton line emission lamps with lines throughout the VNIR and SWIR spectrum, plus a NIST calibrated monochromator. Potential error sources include degradation of reflecting surfaces in the skylight collector, UV-induced solarization in the fiber or optical elements, degradation of the FORJ elements, changes of spectrometer internal configuration, and degradation of detector and readout electronics via over-exposure or circuit degradation.

vii. Start development of 4STAR-Air Software

Using current funding we will begin to develop 4STAR-Air software. It will be divided into two modules: one to control the motion axes for sun tracking and sky scans and the other to manage

shutter operation for the sun and sky barrels as well as data acquisition from the spectrometers. For sun tracking measurements the modules will operate independently. A secondary metadata system such as the aircraft inertial navigation unit (INU) will provide roll, pitch, and yaw attitude data to be used in post-processing to calculate the scattering angle for each data point in the scan.

Initially we will investigate (extensive) modifications to the existing National Instruments LabView programs utilized on 4STAR-Ground, with particular attention to CPU-efficient algorithm design. Although LabView introduces considerable CPU overhead, experience with LabView on 4STAR-Ground suggests that we may be able to achieve adequate closed loop motion control frequency response with this software running on a modern dual core processor.

f. Detailed Description of Proposed Work

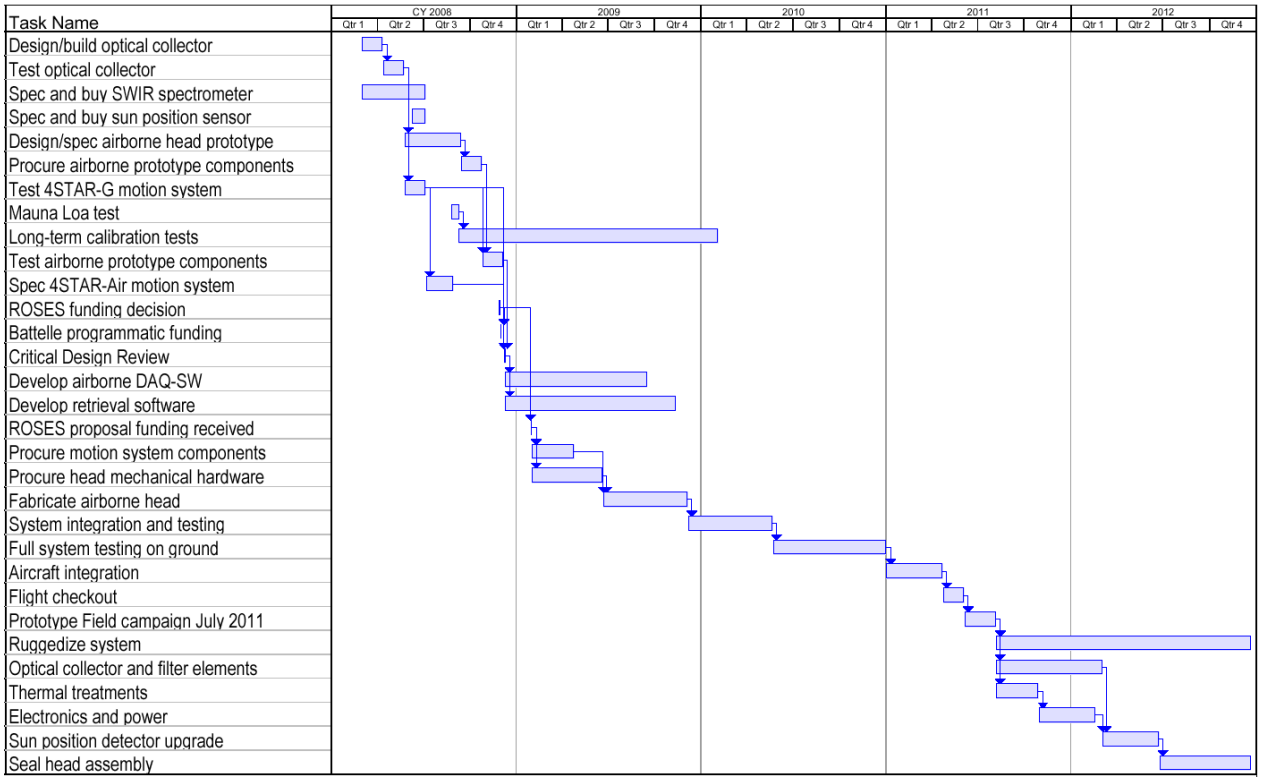

Figure 15. Instrument development schedule.

Figure 15 shows our proposed schedule for the major tasks, culminating in a prototype that will be demonstrated in a summer 2011 field campaign, followed by improvement and preparation in 2012 for more extensive and challenging missions beyond 2012.

i. Critical design review

Just after proposal selection we will conduct a Critical Design Review (CDR) of the optical, mechanical, and motion control subsystems, with software design reviewed at the conceptual level. The review panel will include NASA and PNNL participants experienced in program management, motion control, detectors, and fiber optical components. The review will include an examination of more innovative elements to detect aircraft attitude with respect to the sun for tracking and skylight scanning.

ii. Procure motion system components

Following CDR we will start to procure all motors, drivers, position detectors, and driver electronics required for sun tracking and sky scanning in the 2011 demonstration mission. These components may be quite inexpensive and straightforward to integrate, if the low-cost solutions identified above perform at the level required for that mission (in a low-altitude, unpressurized aircraft). However, if frequency response issues are encountered in this prototype test phase, we will be prepared to proceed with more expensive and complex open frame DC servomotor hardware and the accompanying complexity required to incorporate bearings, seals, and position detectors into the custom mechanical hardware that will comprise the head assembly during the 2012 improvement phase. We have reserved this work for 2012 because procurement lead times may be quite long for such custom open frame motors, and the machine work to build the motor frames (supporting bearings, seals and position detectors) will also add to both cost and schedule.

iii. Fabricate instrument head and mounting hardware

We will fabricate the optical head hardware based on the CDR design. Figure 5 shows the key components and the aerodynamic shell that protrudes into the airflow. The shape and complexity of these custom components is highly dependent on the selection of motion system components. The solid model in Figure 5 shows the most cost effective concept of several explored to date, and will be adopted so long as its smaller motors provide adequate control authority to achieve the needed sun tracking capability, demonstrated through the prototype testing described above.

The design has been optimized to minimize the envelope of the baffle and power optic components of the direct beam and sky-scan collectors. This approach minimizes aerodynamic loading on the motion control system, reducing the importance of that loading in sizing the motors. The split-sphere geometry accommodates easy and inexpensive lathe and metal spinning fabrication methods. Motor bearing loads considered in our design include cantilever loading, which for the elevation axis is almost negligible owing to the small split-sphere offset. The full aerodynamic drag on the head, acting over the considerable offset from the azimuth bearing set creates significant cantilever loads. However, the crossed roller bearing set specified in the prototype design should manage the load with minimal motor drag. Finally, this approach avoids complex load paths through the structure (and the accompanying analysis) and permits the total mass and inertia of the head to be reduced, further improving frequency response of the motion control system and widening the range of aircraft that can accommodate 4STAR-Air. For improved cleaning and inspection, the optical front surfaces will be built flush or slightly protruding. The motors have been specified to handle the small aerodynamic effect of these protrusions.

If prototype testing shows that more aggressive motors are needed to get adequate frequency response, existing preliminary design work, including a detailed Pro Engineer solid model, is available to support direct computer aided manufacturing (CAM) of the complex motor housing parts. Ames's Engineering Division supports direct transfer of computer aided design (CAD) data for CAM upload, providing maximum efficiency in the fabrication of complex geometries.

iv. Fabricate spectrometer, motion control, and data system chassis

4STAR-Air will use the two Zeiss spectrometers purchased for 4STAR-Ground, described in Section 1.e.ii. We will assemble these and their DAS into the 4STAR-Air rack along with the motion control components, including a motor controller and amplifier/driver boards for each motor integrated in a single chassis. A second spectrometer chassis will house a fiber optic bundle configured as a Y splitter to provide optical signal to the two Zeiss instruments, and the

Tec5 readout electronics. This modular packaging will permit future upgrades to newer or more specialized instrument components, including spectrometers, with minimal cost. Furthermore, the optical signal will be immune to RF or EMI noise effects as it is transmitted to rack mounted detectors, which will operate in the relatively benign cabin environment. Only the collection optics, shutter electronics, and tracking sensor will be exposed to the airstream environment, and care has been taken with these component designs to ensure robust operation.

v. System integration and testing

We will assemble and test the instrument at both the subsystem and system level. Motion control subsystems will be tested using a dual axis tilt/rotation table to provide pitch and roll motion at adjustable amplitude and frequency, and to simulate these motions through aircraft maneuvers. Both motion control and data acquisition software will be tested. This will include testing the LabVIEW-based software described in Section 1.e.vii. If LabVIEW CPU overhead precludes its effective use for motion control, two options may be exercised, including use of a dedicated motion control CPU or more efficient software (e.g. C++). This phase will include testing the head components including the tracking detector subsystem and the coil mechanisms designed to provide the necessary range of elevation axis motion without compromising the bend radius limitations of the fiber optic. This testing will include careful radiometric measurements of system transmission stability throughout the full mechanical pointing range of the instrument.

vi. Full system testing on ground

The full system will be tested using the tilt table to simulate the attitude sequence of an aircraft mission, to ensure that the motion control and data acquisition subsystems are well matched to meet the temporal requirements for data acquisition. Further Langley plot data acquisition will be used in ongoing testing of the long term stability of the light connection and detector elements.

vii. Aircraft integration

We will integrate the 4STAR-Air prototype into an aircraft such as the PNNL G-1 or the CIRPAS Twin Otter. The G-1 is attractive because it can be operated unpressurized for demonstration purposes. However, integration on the G-1 would require modifying a roof hatch, at a cost not included in this proposal. The CIRPAS Twin Otter already has a port that could accommodate 4STAR-Air, but flight hours would have to be provided by another program.

viii. Flight test program

We will fully flight test 4STAR-Air by performing flight maneuvers that verify 4STAR-Air's tracking design specifications. In addition we plan to carry out flight tests near an AERONET ground site to be able to compare the sky radiance measurements taken in flight to the ground-based observations.

ix. Demonstration field program and analyses

We will demonstrate 4STAR-Air's ability to acquire scientifically valuable data of the type described in the Introduction. A candidate field program is the Western Atlantic Tropospheric Aerosol Campaign (WATAC), which has been proposed for 2011 to study air pollution off the US East Coast. Both AERONET and satellite climatologies have shown that the WATAC region frequently experiences the aerosol conditions (AOD(500 nm)>0.4) required for successful AERONET retrievals of complex refractive index and other properties [e.g., *Dubovik et al.*, 2002]. 4STAR's aircraft mounting will allow us to fly it to the areas of largest AOD in satellite footprints, thus providing a unique complement to the AERONET station measurements. Demonstration data analyses will include use of the adapted AERONET algorithm described in

Section 1.E.iii, which will account for changing aircraft pitch, roll, and yaw during skylight scans, by using aircraft nav-system information to calculate actual scattering angles vs time, which will be used in the inversion kernels. Analyses will also include retrievals of H_2O or O_3 and a gas not retrievable by AATS-14, such as NO_2, using 4STAR spectrometry. The WATAC region experiences not only large AOD values, but also large NO_2 columns [e.g., *van der A et al.*, 2008], so using 4STAR's spectrometric capabilities to separate the aerosol and NO_2 signals will be an important part of the demonstration analyses to be conducted in 2012.

x. Improvement and preparation for future field programs

Using lessons learned from the 2011 flight tests and field program we will improve 4STAR-Air and prepare it for future field programs to be conducted beyond 2012. Areas of particular attention will include seals and bearings suitable for operation on a pressurized aircraft operating at higher altitudes.

g. Management Plan

i. Roles of PI, Co-Is, and other key personnel supported by this task

Dr. Philip B. Russell will be Principal Investigator, responsible for overall direction, project management, and communication with NASA HQ. He will be responsible for completing the work on time and within budget. Dr. Stephen Dunagan will be Co-investigator and lead engineer, responsible for engineering integrity of 4STAR designs, cost estimates, and manufacturing approaches, with emphasis on mechanical and optical aspects. Dr. Jens Redemann will be Co-Investigator, with primary responsibility for developing plans for deployment of 4STAR-Air in the first mission. Mr. Roy Johnson will provide engineering support with emphasis on electrical and electronic aspects. Mr. Jhony Zavaleta will provide drafting support, including development of solid models and files to drive numerically controlled machining. Mrs. Cecilia Chang will provide engineering software support. This team has worked together on AATS-14 and 4STAR development, modification, testing, and field use, demonstrating the necessary technical and collaborative skills required to make 4STAR-Air succeed.

ii. Roles of collaborators (funded separately)

Dr. Beat Schmid will lead the collaborating team at PNNL. He will participate fully in the design of 4STAR-Air and in oversight of its development and testing. He will also lead the PNNL team in collaborating with NASA Ames on the aircraft integration and demonstration flight mission. Dr. Connor Flynn will support 4STAR development through detailed data analysis of 4STAR spectral data and design of measurement and testing scenarios. Dr. Evgueni Kassianov will be responsible for 4STAR retrievals, modifying his algorithms to exploit the additional spectral information provided by 4STAR, and adapting the AERONET inversions for airborne use.

Dr. Brent Holben of NASA GSFC will provide consultation on 4STAR-AERONET comparisons, including data retrievals via AERONET algorithms implemented by PNNL.

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3 BIOGRAPHICAL SKETCHES

a. PI and Co-Investigators

Philip B. Russell, PI

Scientific Contributions

Leadership of many studies of atmospheric aerosol and trace gas effects on radiation and climate, using remote and in situ measurements from space, air, ground, and ship platforms.

Development of the NASA Ames Airborne Tracking Sunphotometers (AATS, U.S. Patent 4,710,618) and leadership of their worldwide, diverse uses ranging from validation of satellites and models through studies of atmospheric composition and aerosol radiative forcing of climate.

Membership on many satellite science teams, including Earth Observing System Inter-Disciplinary Science (EOS-IDS), Solar Occultation Satellites (SOSST), Stratospheric Aerosol and Gas Experiment (SAGE), and Stratospheric Aerosol Measurement (SAM) II.

Professional Experience

NASA Ames Research Center: Senior Research Scientist (1995-present); Chief, Atmospheric Chemistry and Dynamics Branch (1989-95); Acting Chief, Earth System Science Division (1988-89); Chief, Atmospheric Experiments Branch (1982-89). Project Manager, Stratosphere-Troposphere Exchange Project (STEP, 1982-93).

SRI International (1972-82): Physicist to Senior Physicist, Atmospheric Science Center.

National Center for Atmospheric Research (1971-72, at University of Chicago and NCAR): Postdoctoral Appointee.

Education

Ph.D. and M.S., Physics, Stanford University (1971 and 1967, Atomic Energy Commission Fellow).

M.S., Management, Stanford University (1990, NASA Sloan Fellow).

B.A., Physics, Wesleyan University (1965, Magna cum Laude; Highest Honors).

Honors and Awards

NASA Ames Honor Award (2002, for excellence in scientific research). NASA Ames Associate Fellow (1995, for excellence in atmospheric research; Ames's highest annual award). NASA Exceptional Service Medal (1988, for managing Stratosphere-Troposphere Exchange Project). NASA Space Act Award (1989, for inventing Airborne Autotracking Sunphotometer). NASA Group Achievement Awards (1989-2006).

Member, Phi Beta Kappa and Sigma Xi.

Scientific Societies/Committees/Community Service

Fellow, American Association for the Advancement of Science (elected 2005 for "pioneering work and scientific leadership in the measurement of aerosol properties and the effects of haze on the Earth's energy budget and climate"). Reviewer, *Climate Change 1995*, Intergovernmental Panel on Climate Change (IPCC). Editor-in-Chief (1994-95) and Editor (1993, 1996), *Geophysical Research Letters*; Member, Board of Editors and Atmospheric Science Executive Committee, American Geophysical Union. Guest Editor, *Journal of Geophysical Research* Special Issues (1988-1993). Chair, American Meteorological Society International Committee on Laser Atmospheric Studies (1979-82, Member, 1978-82). Member, National Research Council Committee on Army Basic Research (1979-81). Member, American Meteorological Society Committee on Radiation Energy (1979-81).

Publications

Over 130 peer-reviewed publications. Selected publications are listed below.

Russell, P. B., et al., Multi-grid-cell validation of satellite aerosol property retrievals in INTEX/ITCT/ICARTT 2004, *J. Geophys. Res.*, *112*, D12S09, doi:10.1029/2006JD007606, 2007

Russell, P., et al., Aerosol optical depth measurements by airborne Sun photometer in SOLVE II: Comparisons to SAGE III, POAM III and airborne spectrometer measurements, *Atmos. Chem. Phys*., *5*, 1311–1339, 2005.

Russell, P. B., et al, Sunlight transmission through desert dust and marine aerosols: Diffuse light corrections to Sun photometry and pyrheliometry, *J. Geophys. Res*., 109, D08207, doi:10.1029/2003JD004292, 2004.

Schmid B., J. Redemann, P. B. Russell, et al., Coordinated airborne, spaceborne, and ground-based measurements of massive, thick aerosol layers during the dry season in Southern Africa, *J. Geophys. Res*., 108(D13)8496, doi:10.1029/2002JD002297, 2003.

Russell, P. B., et al., Comparison of aerosol single scattering albedos derived by diverse techniques in two North Atlantic experiments, *J. Atmos. Sci.*, *59*, 609-619, 2002.

Redemann, J., P. B. Russell, and P. Hamill, Dependence of aerosol light absorption and single scattering albedo on ambient relative humidity for sulfate aerosols with black carbon cores, *J. Geophys. Res.*, *106*, 27,485-27,495, 2001.

Russell, P. B., and J. Heintzenberg, An overview of the ACE-2 Clear Sky Column Closure Experiment (CLEARCOLUMN), *Tellus B 52*, 463-483, 2000.

Schmid, B., Livingston, J. M., Russell, P. B., et al. Clear sky closure studies of lower tropospheric aerosol and water vapor during ACE 2 using airborne sunphotometer, airborne in-situ, space-borne, and ground-based measurements. *Tellus B 52*, 568-593, 2000.

Bergstrom, R. W., and P. B. Russell, Estimation of aerosol radiative effects over the mid-latitude North Atlantic region from satellite and in situ measurements. *Geophys. Res. Lett.*, *26*, 1731-1734, 1999.

Russell, P. B., P. V. Hobbs, and L. L. Stowe, Aerosol properties and radiative effects in the United States Mid-Atlantic haze plume: An overview of the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX), *J. Geophys. Res*., *104*, 2213-2222, 1999a.

Russell, P. B., et al., Aerosol-induced radiative flux changes off the United States Mid-Atlantic coast: Comparison of values calculated from sunphotometer and in situ data with those measured by airborne pyranometer, *J. Geophys. Res.*, 104, 2289-2307, 1999b.

Russell, P. B., S. Kinne and R. Bergstrom, Aerosol climate effects: Local radiative forcing and column closure experiments, *J. Geophys. Res.*, *102*, 9397-9407, 1997.

Russell, P. B., et al., Global to microscale evolution of the Pinatubo volcanic aerosol, derived from diverse measurements and analyses. *J. Geophys. Res*., *101*, 18,745-18,763, 1996a.

Russell, P.B., et al., The tropical experiment of the Stratosphere-Troposphere Exchange Project (STEP): Science objectives, operations, and summary findings. *J. Geophys. Res.*, *98*, 8563-8589, 1993.

Russell, P.B., et al., Post-Pinatubo optical depth spectra vs. latitude and vortex structure: Airborne tracking sunphotometer measurements in AASE II. *Geophys. Res. Lett.*, *20*, 2571-2574, 1993.

Russell, P.B., and M.P. McCormick. SAGE II aerosol data validation and initial data use: An introduction and overview. *J. Geophys. Res*., *94*, 8335-8338, 1989.

Russell, P.B., et al. Satellite and correlative measurements of the stratospheric aerosol: III. Comparison of measurements by SAM II, SAGE, dustsondes, filters, impactors, and lidar. *J. Atmos. Sci.*, *41*, 1791-1800, 1984.

Russell, P.B., and B.M. Morley, 1982: Orbiting Lidar Simulations: II. Density, Temperature, Aerosol and Cloud Measurements by a Wavelength-Combining Technique, *Applied Optics*, *21*, 1554-1563.

Russell, P.B., et al. Satellite and correlative measurements of the stratospheric aerosol: I. An optical model for data conversions. *J. Atmos. Sci.*, *38*, 1270-1294, 1981.

Russell, P.B., J.M. Livingston, and E.E. Uthe. Aerosol-induced albedo change: measurement and modeling of an incident. *J. Atmos. Sci.*, *36*, 1587-1608, 1979.

Russell, P.B., and G.W. Grams, 1975: Application of soil dust optical properties in analytical models of climate change, *J. Appl. Meteorol*., *14*, 1037-1043.

Stephen A. Dunagan, Co-I

Education

B.S. 1979 Mechanical and Aerospace Engineering, University of Missouri, Columbia.
M.S. 1980 Mechanical and Aerospace Engineering, University of Missouri, Columbia.
Ph.D. 1986 Mechanical and Aerospace Engineering, University of Missouri, Columbia.

Professional Experience

NASA Ames Research Center
- Research Scientist, Biospheric Research Branch. (March 2002 to present).
- Technology Manager, National Rotorcraft Technology Center (March 2000 to Feb. 2002)
- Branch Chief (acting), Ecosystem Science and Technology Branch. (Oct. 1999 to March 2000).
- Aerospace Engineer, Ecosystem Science and Technology Branch (1995 to 1999)
- Aerospace Engineer, Rotorcraft Aeromechanics Branch, (1984 to 1995)

University of Missouri, Columbia, MO (1980-1984)
- Graduate Research Associate, Teaching Assistant

Industrial
- Kansas City Power and Light Co. (1979), Plant Engineer, mechanical systems
- Mobay Chemical Corporation (1977, 1978) Plant Engineer, production systems

Scientific and Engineering Accomplishments

21 years managing development of unique experimental instrumentation for application to specific problems in fluid dynamics measurements and remote sensing, including:
- Principal Investigator for Innovative Partnerships Hyperspectral SmallSat Missions project
- Project Manager for Mars Astrobiology Science and Technology Experiment.
- Instrument Engineer for multi sensor mission adaptive payload demonstrating UAV-borne sensor web functionality in conjunction with the Earth observing system.
- Project Manager and Instrument Engineer for UAV Coffee mission.
- Project Manager and Instrument Engineer for Digital Array Scanned Interferometer mission
- Principal Investigator for Long-range confocal backscatter Schmidt Cassegrain laser velocimeter for large wind tunnel applications.
- Principal Investigator for development of rotating frame laser velocimeter instrument.
- Principal Investigator for development of holographic interferometry for shock wave-boundary layer interactions.

Selected Publications

38 publications including 10 refereed journal articles. 5 selected publications:

Dunagan, S. E., Berthold, R., Fladeland, M., Pieri, D., 2007, "Small UAS Technologies to Enable Earth Science Missions", 32nd annual ISRSE, San Jose, Costa Rica.

Ambrosia, V.G., Steven S. Wegener, Donald V. Sullivan, Sally W. Buechel, Stephen E. Dunagan, James A. Brass, Jay Stoneburner, 2003. Demonstrating UAV-Acquired Real-Time Thermal Data Over Fires, Photogrammetric Engineering and Remote Sensing, 69(4):391-402.

Dunagan, S.E., P.D. Hammer, R.D. Slye, D.V. Sullivan, and W.H. Smith, “Interferometric Imagery from a Solar Powered RPV” presented at IGARSS'98, Seattle WA, July 7-10, 1998.

Dunagan, S. E., “Long- Range Schmidt-Cassegrain Laser Velocimeter for Large Wind-Tunnel Applications”, AIAA Journal, Vol 34, no. 3, March 1996.

Dunagan, S. E., Brown, J. L., and Miles, J. B.; “Holographic Interferometry Study of an Axisymmetric Shock-Wave/Boundary Layer Strong Interaction Flow,” AIAA Journal, Vol 25, no. 2, Feb., 1987.

Jens Redemann, Co-I

Professional Experience

Director, Remote Sensing Group	BAERI, Sonoma, CA	Jan. 2008 to present
Deputy Group Leader	NASA Ames, Satellite-Sunphotometer Group	Apr. 2008 to present
Group Leader	BAERI, Sonoma, CA	Sept. 2006 to present
Senior Research Scientist	BAERI, Sonoma, CA	April 1999 to Sept. 2006
Research Assistant & Lecturer	UCLA, CA	May 1995 to March 1999
Research Assistant	FU Berlin, Germany	June 1994 to April 1995

Education

Ph.D. & M.S. in Atmospheric Sciences, UCLA (1999, 1997).
M.S. in Physics, FU Berlin, Germany (1995).

Relevant Research Experience

- Principal Investigator for a grant to study the vertical distribution of aerosol radiative effects from a combination of CALIPSO, MODIS and MISR data. CALIPSO science team member.
- Principal Investigator for the study of the spatial variability of aerosol products in the vicinity of clouds from MODIS and MISR. MODIS science team member.
- Mission Principal Investigator and Mission Scientist for the Extended-MODIS-λ Validation Experiment (EVE) in 2004, an airborne field campaign to validate MODIS near-IR AOD measurements of Asian dust transported across the Pacific basin.
- PI, NASA New Investigator Program (NIP), 2003-2005.
- PI for the participation of AATS-14 (an airborne sunphotometer) in the CLAMS satellite validation study (July 2001). Member of the CLAMS science team.
- Devised a novel, observationally-based approach for combining airborne sunphotometer and spectral solar flux radiometer measurements to derive the direct aerosol radiative forcing efficiency.
- Related airborne sunphotometer, lidar and spectral solar flux radiometer measurements to in situ measurements of atmospheric aerosols and gases derive the vertical structure of aerosol-induced radiative flux changes in Earth's atmosphere.
- Participated as PI, scientist, or platform scientist in the SAFARI-2000, ACE-Asia, PRIDE, CLAMS, ADAM , ARM Aerosol IOP, EVE, INTEX-A&B, and ARCTAS field experiments. Responsible for daily flight planning and platform coordination in CLAMS, INTEX and EVE.
- Utilized satellite derived aerosol optical depth fields and aerosol properties from the ACE-Asia campaign to determine the aerosol radiative forcing of climate in the Pacific Basin troposphere.
- Developed a coupled aerosol microphysics and chemistry model to study the dependence of the aerosol single scattering albedo on ambient relative humidity.

Honors / Organizations / Synergistic Activities

Member of Science Working Group for the ACE (Aerosol, Cloud, and Ecosystem) Decadal Survey Mission; Invited presentations at the AGU Annual meeting, the AGU Joint Assembly meeting and other International Conferences (2002-2008); NASA Group Achievement Awards (2002&2005); Member of technical committee: NASA Earth System Scholars Network; Outstanding Student Paper Award, AGU Fall meeting (1998); NASA Global Change Research Fellowship Awards (1995-1998), UCLA Neiburger Award (1997).

Bibliography

44 peer-reviewed journal articles (10 first-authored), 100+ conference presentations (60+ first-authored).
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b. Collaborators

Beat Schmid, PNNL Lead Collaborator

Education and Training

Institution	Degree	Field	Dates
University of Bern, Switzerland	Liz. Phil. Nat. (M.S.)	Physics	1991
University of Bern, Switzerland	Ph.D.	Physics	1995

Research and Professional Experience

2006 – present	Associate Director, Atmospheric Science and Global Change Division, Pacific Northwest National Laboratory, Richland, WA
2003 – 2006	Group Leader, Bay Area Environmental Research Institute, Sonoma, CA.
1997 – 2003	Senior Research Scientist, Bay Area Environmental Research Inst., Sonoma, CA
1995 – 1997	Postdoctoral Researcher, University of Bern, Switzerland
1995 (Oct.) – 1996 (Jan.)	Visiting Scientist, University of Arizona, Tucson, AZ
1989 – 1995	Research Assistant, University of Bern, Switzerland

Synergistic Activities:

- Technical and Mission Science Director for DOE ARM Aerial Vehicle Program (Aug. 2007 - present)
- Technical Coordination of ISDAC, Fairbanks, AK, April 2008
- Airborne Coordinator (9 aircraft) and Platform Scientist for CIRPAS Twin Otter aircraft in CLASIC/CHAPS (Oklahoma, June 2007)
- Chair of DOE ARM Aerosol Working Group; Member ARM Science and Infrastructure Steering Committee; Member ARM Climate Research Facility Science Board (2005 – present)
- Lead scientist for ARM September 2005 Aerosol Lidar Validation Experiment (ALIVE)
- Platform scientist for portions of the EVE (Monterey, 2004) and INTEX-NA/ITCT (Gulf of Maine, 2004) missions. Direction and execution of research flights of the CIRPAS Twin Otter and Sky Research J-31 aircraft.
- Co-led planning of ARM May 2003 Aerosol Intensive Observation Period. Led 10 principal investigators during field campaign as platform scientist on CIRPAS Twin Otter aircraft.
- Employed NASA Ames Airborne Sun photometers in campaigns all over the world and made processed data available to the research community through web-based archives.
- Led the conceptualization of airborne sun-sky spectrometers and the development of 4STAR-Ground while employed by a cooperative agreement at NASA Ames (2000-2006).
- Associate Editor, *Journal Geophysical Research* – Clouds and Aerosols (2002- present)
- Member Glory/APS Science Advisory Group
- Member MODIS Science Team (2005-2007)
- NASA Group Achievement Awards: INTEX and SOLVE II Science Teams
- Member AMS and AGU

Bibliography

- 60 peer-reviewed journal articles (10 first-authored and 50 co-authored) + 2 submitted
- 222 conference publications (61 first-authored and 161 co-authored)
- 20 invited talks at conferences, workshops and seminars

Connor Flynn, PNNL Collaborator

Education and Training

Institution	Degree	Field	Dates
Eastern Washington University	B.S.	Physics	1989
University of Idaho	Ph.D.	Atomic Physics	1995

Research and Professional Experience

2003 – present Senior research scientist, Climate Physics Group, PNNL

1999 – 2003 Staff research scientist, Climate Physics Group, PNNL

1995 – 1999 Post-doctoral fellowship, AWU/PNNL

1990 – 1995 Graduate research assistant, University of Idaho physics department

1988 – 1989 Undergraduate research assistant, Eastern Washington University physics dept.

Synergistic Activities:

ARM instrument mentor for numerous passive and active remote sensors:

1996 – 2005: Micropulse lidar (MPL)

1996 – 2000: Belfort ceilometer (BLC)

1996 – 2001: FTIR instruments (AERI, ASTI, SORTI)

1999 – 2005: Vaisala ceilometer (VCEIL)

2008 – current: Shortwave Spectrometer (SWS)

ARM Aerosol Working Group Translator responsible for facilitating routine production of aerosol products:

- MFRSR / NIMFR Langley calibration
- Cloud-screened Aerosol Optical depths
- Bulk and intensive aerosol optical properties from ARM Aerosol Observation Systems
- Aerosol "Best-Estimate"

Instrument design:

- Designed and deployed a prototype depolarization MPL system. Final designs based on this prototype are commercially available.
- Designed and built a dual-polarization scanning elastic backscatter lidar. The lidar was successfully deployed at Crystal FACE (Jul. 2002), at MPACE (Oct. 2004), and at TWP-ICE (Jan. 2006).

Extensive field campaign experience in every climate regime (arctic, temperate, tropical, desert, marine) and from wide ranging platforms (ground-based, ship-borne, airborne).

Current 4STAR involvement, Matlab routines for data reduction and analysis, radiance and irradiance calibrations, optics design.

Bibliography

- 12 peer-reviewed journal articles (2 first-authored and 11 co-authored)
- 3 invited talks at conferences, workshops and seminars
- > 30 first author conference presentations

Evgueni Kassianov, PNNL Collaborator

Education

Ph.D./Optics	Institute of Atmospheric Optics, Tomsk, Russia, 1995
M.S/Thermal physics (w/honors)	Tomsk Polytechnic University, Tomsk, Russia, 1984

Experience

2001-current	**Senior Research Scientist**	PNNL, Richland, WA
1999-2001	**Visiting Scientist**	PNNL, Richland, WA
1997-1999	**Visiting Scientist**	CIMMS, University of Oklahoma, Norman, OK
1996-1997	**Senior Researcher**	Institute of Atmospheric Optics, Tomsk, Russia

Dr. Kassianov has published 29 peer-reviewed and over 40 conference papers, dealing mostly with radiative transfer in cloudy atmospheres, stochastic radiative transfer and Monte Carlo methods. He applicaties radiative transfer models to evaluate and improve retrievals of cloud/aerosol properties from surface and satellite observations. Dr. Kassianov has worked with AERONET staff to install and test up-to-date AERONET retrieval codes at PNNL and has successfully duplicated retrieval results using both AERONET and 4STAR data as input.

Recent Refereed Publications

Kassianov E.I., and M. Ovtchinnikov. 2008: On Reflectance Ratios and Aerosol Optical Depth Retrieval in the Presence of Cumulus Clouds, *Geoph. Res. Lett.*, **35(6)**: Art. No. L06807. doi:10.1029/2008GL033231

Barnard J.C., C.N. Long, **E.I. Kassianov**, S.A. McFarlane, J.M. Comstock, M. Freer, and G. McFarquhar. 2008: Development and Evaluation of a Simple Algorithm to Find Cloud Optical Depth with Emphasis on Thin Ice Clouds, *Atmos. Sci*. (open), **2**, 46-55.

Berg, L, and **E.I., Kassianov**, 2008: Temporal Variability of Fair-Weather Cloud Statistics at the ARM SGP Site, *J. Climate* (in press).

Kassianov E.I., C.J. Flynn, T.P. Ackerman, and J.C. Barnard. 2007: Aerosol Single-Scattering Albedo and Asymmetry Parameter from MFRSR Observations during the ARM Aerosol IOP 2003, *Atmospheric Chemistry and Physics*, **12**, 3341-3351.

Barnard J.C., **E.I. Kassianov**, T.P. Ackerman, K.S. Johnson, B.M. Zuberi, L. Molina, and M.J. Molina. 2007: Estimation of a "radiatively correct" black carbon specific absorption during the Mexico City Metropolitan Area (MCMA) 2003 field campaign, *Atmospheric Chemistry and Physics*, **6**, 1645-1655.

Doran J.C., J.C. Barnard, W.P. Arnott, R. Cary, R.L. Coulter, J.D. Fast, **E.I. Kassianov**, L.I. Kleinman, N.S. Laulainen, T.J. Martin, G.L. Paredes-Miranda, M.S. Pekour, W.J. Shaw, D.F. Smith, S.R. Springston, and X. Yu. 2007: The T1-T2 Study: Evolution of Aerosol Properties Downwind of Mexico City, *Atmospheric Chemistry and Physics*, **6**, 1585-1598.

Slingo A, T.P. Ackerman, R.P. Allan, **E.I. Kassianov**, S.A. McFarlane, G.J. Robinson, J.C. Barnard, M. Miller, J.E. Harries, J.E. Russell, and S. Dewitte. 2006: Observations of the impact of a major Saharan dust storm on the atmospheric radiation balance, *Geophys. Res.Lett.*, **33**, L24817. doi:10.1029/2006GL027869

Kassianov, E. I., T. P. Ackerman, and P. Kollias, 2005a: The role of cloud-scale resolution on radiative properties of oceanic cumulus clouds, *J. Quant. Spectrosc. Radiat. Transfer*, **91**, 211-226.

Kassianov, E. I., J. C. Barnard, and T. P. Ackerman, 2005d: Retrieval of aerosol microphysical properties by using surface MFRSR data: Modeling and observations, *J. Geophys. Res.*, **110**, D09201, doi:10.1029/2004JD005337.

Cahalan RF, L Oreopoulos, A Marshak, K.F. Evans, A. Davis, R.M. Pincus, Jr., K.H. Yetzer, B. Mayer, R. Davies, T.P. Ackerman, H.W. Barker, E.E. Clothiaux, R.G. Ellingson, M.J. Garay, **E.I. Kassianov**, S. Kinne, A. Macke, W. O'Hirok, P.T. Partain, S.M. Prigarin, A.N. Rublev, G.L. Stephens, F. Szczap, E.E. Takara, T. Varnai, G. Wen, and T.B. Zhuravleva, 2005: The International Intercomparison of 3D Radiation Codes (I3RC): Bringing together the most advanced radiative transfer tools for cloudy atmospheres, *Bull. Amer. Meteor. Soc.*, **86**, 1275-1293.

Barnard, J. C., E. I. **Kassianov**, T. P. Ackerman, S. Frey, K. Johnson, B. Zuberi, L. T. Molina, M. J. Molina, J. S. Gaffney, and N. A. Marley, 2005: Measurements of Black Carbon Specific Absorption in the Mexico City Metropolitan Area during the MCMA 2003 Field Campaign. *Atmos. Chem. Phys. Discuss.*, **5**, 4083-4113.

Brent Holben, GSFC Lead Collaborator

Present Position	AERONET Project Scientist Code 614.4 Biospheric Sciences NASA's Goddard Space Flight Center	Phone: 301 614-6658-2975 FAX: 301 614-6695 E-mail: @aeronet.gsfc.nasa.gov

Research Interests Aerosol optical and radiometric properties and measurements, Global radiative forcing and vegetation remote sensing in the SW and Mid IR region.

Summary of Experience Brent Holben has worked at NASA's GSFC for 28 years performing research in both ground-based and satellite remote sensing of vegetation and aerosols. Additionally he has developed innovative methods for in orbit calibration of satellite visible and near-IR sensors. He is the project leader for the AERONET sun-sky radiometer network that is providing aerosol spectral concentrations and properties for the EOS algorithm validation program as well as validation for a variety of other satellite systems. Holben has received several awards most recently in November 2005 for Goddard's highest award for contributions to environmental science, the William Nordberg Memorial award. Holben has over 140 peer reviewed journal articles, three with citations exceeding 500.

Recent Selected Papers

2006, Zibordi, G., **B Holben**, S.B. Hooker, F.Melin, J-F Berthon, I. Slutsker, D. Giles, D. Vandemark, H. Feng, K. Rutledge, G. jSchuster and A. Mandoos, 2006, A Network forStandardized Ocean Color Validation Measurements, Eos Geophysical Transactions, accepted for publication.

2005, Eck, T.F., **B.N. Holben**, O. Dubovik, A. Smirnov, P. Goloub, H.B. Chen, B. Chatenet, L. Gomes, X.Y. Zhang, S.C. Tsay, Q. Ji, D. Giles, and I. Slutsker, Columnar aerosol optical properties at AERONET sites in central eastern Asia and aerosol transport to the tropical mid-Pacific, *J. Geophys. Res.*, **110** , D06202, doi:10.1029/2004JD005274.

2002, Dubovik, O., **B.N.Holben**,T. Lapyonok, A.Sinyuk, M. I. Mishchenko, P. Yang, and I.Slutsker: Non-spherical aerosol retrieval method employing light scattering by spheriods,*Geophys. Res. Lett*., **29**, 54-1 - 54-4.

2001, **Holben, B.N**., D. Tanré, A. Smirnov, T.F. Eck, I. Slutsker, B Chatenet, F. Lavenue,Y. Kaufman, J.V. Castle, A. Setzer, B.Markham, D. Clark, R. Frouin, N A. Karneli. O'Neill, C. Pietras, R. Pinker, K. Voss, G. Zibordi, An emerging ground-based aerosol climatology: Aerosol Optical Depth from AERONET, *J. Geophys. Res*, **106**, 12067-12097.

2000, Smirnov, A., **B.N.Holben**, T.F.Eck, O.Dubovik, I.Slutsker, Cloud screening and quality control algorithms for the AERONET data base, accepted to *Rem. Sens. Environ.*, **73**, 337-349.

2000, Dubovik**,** O., A.Smirnov, **B.N.Holben**, M.D.King, Y.J. Kaufman, T.F.Eck, and I.Slutsker, "Accurasy assessments of aerosol optical properties retrieved from AERONET Sun and sky-radiance measurements", *J. Geophys. Res.*, ***105,*** 9791-9806.

1998, **Holben, B.N.**, T.F. Eck, I Slutsker, D. Tanré, J.P. Buis, A. Setzer, E. Vermote, J.A. Reagan, Y.J. Kaufman, T. Nakajima, F. Lavenu, I. Jankowiak, A. Smirnov, 1998. AERONET-A Federated Instrument Network and Data Archive for Aerosol Characterization, Rsens. Environ.E, **66,**1-16.

4 CURRENT AND PENDING SUPPORT

a. P. Russell

Short Title	Agency/Task No. Total award	Duration / WY for P. Russell
Airborne Sunphotometry in INTEX-B: Measurements and Analyses…	NASA Task 281945.02.22.01.17 $1070k through 2008 (Co-PI)	10/2005-9/2008 0.25 WY
4STAR Bridge Funding	NASA Radiation Science Program $225k in FY08 (PI)	4/2008-3/2009 0.20 WY
Spatial variability of MODIS and MISR derived data products	NASA EOS / NNG04GM63G $340.7k (Co-I)	10/2003–9/2007 0.03 WY
Simultaneous validation and combined analysis of Aura and CALIPSO	NASA NNH04ZYS004N (Co-I)	6/2007-5/2010 0.08 WY
Airborne Sunphotometry in ARCTAS	NASA ROSES 2007 A.13 $170k (PI)	9/2007-8/2009 0.06 WY
P-3 Science Coordination in ARCTAS	NASA ROSES 2007 A.13 $130k (PI)	9/2007-8/2009 0.4 WY

b. J. Redemann

Short Title	Agency/Task No. Total award	Duration / WY for J. Redemann
Using MODIS, MISR and suborbital aerosol products in the vicinity of clouds and in clear skies to assess aerosol radiative effects	NNH06ZDA001N-EOS $45k (PI)	7/2008-6/2011 0.05 WY
Airborne Sunphotometry in INTEX-B: Measurements and Analyses…	NASA AURA/04-0000-0297 $1106.4k (Co-PI)	10/2005-9/2008 0.20 WY
A combination of mesoscale aerosol transport modeling, suborbital data, CALIPSO and other A-Train aerosol observations to study the vertical structure of aerosol radiative effects	NASA NNH05ZDA001N-CCST $ 765.5k (PI)	7/2007-6/2010 0.25 WY
Airborne sunphotometer measurements of aerosols and water vapor to study aerosol radiative forcing and boreal forest fires in ARCTAS	NASA ROSES 2007 A.13 $713.5k (PI)	9/2007-8/2009 0.25 WY
P-3 Science Coordination in ARCTAS	NASA ROSES 2007 A.13 $130k (Co-I)	9/2007-8/2009 0.15 WY
4STAR Bridge Funding	NASA Radiation Science Program $225k in FY08 (Co-I)	4/2008-3/2009 0.10 WY

c. S. Dunagan

Short Title	Agency/Task No. Total award	Duration / WY for S. Dunagan
Current:		
4STAR Bridge Funding	NASA Radiation Science Program $225k in FY08 (Co-I)	4/2008-3/2009 0.50 WY
Small-Sat Technologies for Cost Effective Hyperspectral Remote Sensing of the Environment	Innovative Partnerships Program Partnership Seed Fund Proposal-2007, $275K in PY2008 (PI)	10/2007-9/2008 0.5 WY

5 STATEMENTS OF COMMITMENT

a. Co-Investigators

TO: Philip B. Russell

FROM: Stephen E. Dunagan

I acknowledge that I am identified by name as Co-Investigator to the investigation entitled "**Airborne Sunphotometry Upgrades via Spectrometry of Sun and Sky Radiation"**, that is submitted by Dr. Philip B. Russell to the NASA Research Announcement ROSES2008A.15 (NNH08ZDA001N), and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Signed:

Stephen E. Dunagan
Date: 16 June 2008

TO: Philip B. Russell

FROM: Jens Redemann

I acknowledge that I am identified by name as Co-Investigator to the investigation entitled "**Airborne Sunphotometry Upgrades via Spectrometry of Sun and Sky Radiation"**, that is submitted by Dr. Philip B. Russell to the NASA Research Announcement ROSES2008A.15 (NNH08ZDA001N), and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Signed:

Jens Redemann

b. Collaborators

The following statements were received by email.

TO: Philip B. Russell

FROM: Beat Schmid

I acknowledge that I am identified by name as a separately funded collaborator to the investigation entitled "**Airborne Sunphotometry Upgrades via Spectrometry of Sun and Sky Radiation"**, that is submitted by Dr. Philip B. Russell to the NASA Research Announcement ROSES2008A.15 (NNH08ZDA001N), and that I intend to carry out all responsibilities identified for me in this proposal (assuming appropriate funding will be available). I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Signed:

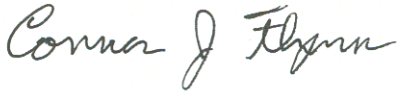
Beat Schmid
Date: 16 June 2008

TO: Philip B. Russell

FROM: Connor Flynn

I acknowledge that I am identified by name as a separately funded collaborator to the investigation entitled "**Airborne Sunphotometry Upgrades via Spectrometry of Sun and Sky Radiation"**, that is submitted by Dr. Philip B. Russell to the NASA Research Announcement ROSES2008A.15 (NNH08ZDA001N), and that I intend to carry out all responsibilities identified for me in this proposal (assuming appropriate funding will be available). I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Signed:



Connor J. Flynn
Date: 16 June 2008

TO: Philip B. Russell

FROM: Evgueni Kassianov

I acknowledge that I am identified by name as a separately funded collaborator to the investigation entitled "**Airborne Sunphotometry Upgrades via Spectrometry of Sun and Sky Radiation"**, that is submitted by Dr. Philip B. Russell to the NASA Research Announcement ROSES2008A.15 (NNH08ZDA001N), and that I intend to carry out all responsibilities identified for me in this proposal (assuming appropriate funding will be available). I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Signed:

Evgueni Kassianov
Date: 16 June 2008

TO: Philip B. Russell

FROM: Brent Holben

I acknowledge that I am identified by name as a separately funded collaborator to the investigation entitled "**Airborne Sunphotometry Upgrades via Spectrometry of Sun and Sky Radiation"**, that is submitted by Dr. Philip B. Russell to the NASA Research Announcement ROSES2008A.15 (NNH08ZDA001N), and that I intend to carry out all responsibilities identified for me in this proposal (assuming appropriate funding will be available). I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Signed:

Brent Holben
Date:

6 BUDGET JUSTIFICATION: NARRATIVE AND DETAILS

a. Budget Narrative

As specified by Section IV of the ROSES 2008 NRA and Section 2.3 of the 2008 NASA *Guidebook for Proposers*, this section includes the *Table of Personnel and Work Effort* and the description of facilities and equipment, as well as the rationale and basis of estimate for all components of cost including procurements, travel, publication costs, and all subawards. The *Table of Personnel and Work Effort* includes the names and/or titles of all personnel necessary to perform the proposed investigation.

Table of Personnel and Work Effort

		2009			2010			2011			2012			TOTAL	
1. DIRECT LABOR		Work Yr	$K /WY	Cost, $K	Work Yr	$K /WY	Cost, $K	Work Yr	$K /WY	Cost, $K	Work Yr	$K /WY	Cost, $K	Work Yr	Cost, $K
Civil Service (FTE)	Philip Russell, PI	0.20			0.20			0.20			0.20			0.80	
	Stephen Dunagan, Co-I	0.40			0.24			0.25			0.25			1.14	
	Roy Johnson, Engineer	0.25			0.25			0.25			0.25			1.00	
	Mgt., Admin & Clerical Support	0.09			0.07			0.07			0.07			0.29	
	Sub Total	0.94			0.76			0.77			0.77			3.23	
Co-Op	Jens Redemann, Co-I,BAERI	0.00			0.08			0.16			0.16			0.40	
	Jhony Zavaleta, Drafter, BAERI	0.29			0.13			0.00			0.00			0.42	
	S. Ramirez, Data analyst, BAER	0.05			0.05			0.04			0.04			0.18	
	Co-op overhead included above														
	Sub Total	0.34			0.26			0.20			0.20			1.00	
	Total Labor (NASA CS + Co-op)	**1.28**			**1.02**			**0.97**			**0.97**			**4.23**	

Collaborators (funded separately):

PNNL	Beat Schmid, Battelle PI	0.05			0.05			0.05			0.05			0.20	
	Connor Flynn, Scientist	0.19			0.20			0.20			0.20			0.79	
	Evgueni Kassianov, Scientist	0.10			0.10			0.10			0.10			0.40	
	Total Battelle	0.34			0.35			0.35			0.35			1.39	
NASA GSFC	Brent Holben	0.05			0.05			0.05			0.05			0.05	

The work commitments shown in this section are based on our best estimate of the work required to conduct the proposed development and bring the effort to a successful conclusion via design, manufacturing, assembly, tests, flights, data archival, presentations and publications.

Facilities

The proposing partners bring several important facility resources to this work. Four NASA Ames labs are directly useful to this project. A dedicated 4STAR lab includes optical and electronics workstations and integrating sphere equipment, including a small, field-portable sphere for checking 4STAR calibration between flights. The AATS-14 lab provides additional electronics bench and maintenance workspaces. The ARC Rooftop laboratory provides space for unobstructed sky viewing, with networking connectivity for remote instrument monitoring and operation. Finally, the Airborne Sensor Development Lab provides extensive capabilities for developing end-to-end designs for airborne instruments, electronics workbench facilities, a light controlled optical laboratory/clean-room, many NIST-calibrated integrating sphere and monochromator light sources, and a test chamber to simulate high altitude conditions.

Two sun photometer instruments will be used for validation measurements. These include AATS-14 for direct solar measurements and a PNNL PREDE instrument for both sun and sky scanning measurements. The PREDE instrument is functionally comparable to the AERONET Cimel instruments and will be cross-calibrated with the AERONET-Cimel at Mauna Loa. The ARC team has long experience in testing equipment at Mauna Loa Observatory and an informal agreement permitting frequent access. The PNNL partner also brings a significant aircraft asset to the table in this project. The PNNL G1 aircraft has a roof hatch that might be modified to accommodate the 4STAR-Air head. PNNL will contribute flight hours on this aircraft as part of their collaboration.

b. Budget Details

As specified by Section IV of the ROSES 2008 NRA, and Section 2.3 of the 2008 NASA *Guidebook for Proposers*, this section includes this section includes the detailed proposed budget including Direct Labor and Other Direct Costs.

Justification for the listed costs is as follows:

Network and computer support: This is an allocation to the proposed project of a share of charges billed to Dr. Russell's group for maintaining the network and system administration in Ames Building 245. These costs are not covered by Ames G&A or Allocated Service Pools but are billed to research tasks.

Other included support costs identified are for Directorate and Division operating accounts.

Budget

1. DIRECT LABOR		2009 Work Yr	2009 $K /WY	2009 Cost, $K	2010 Work Yr	2010 $K /WY	2010 Cost, $K	2011 Work Yr	2011 $K /WY	2011 Cost, $K	2012 Work Yr	2012 $K /WY	2012 Cost, $K	TOTAL Work Yr	TOTAL Cost, $K
Civil Service (FTE)	Philip Russell, PI	0.20	195.7	43.1	0.20	206.0	45.3	0.20	216.8	47.7	0.20	228.1	50.2	0.80	186.2
	Stephen Dunagan, Co-I	0.40	195.7	86.1	0.24	206.0	54.4	0.25	216.8	59.6	0.25	228.1	62.7	1.14	262.8
	Roy Johnson, Engineer	0.25	167.3	46.0	0.25	176.0	48.4	0.25	185.3	51.0	0.25	195.0	53.6	1.00	199.0
	Mgt., Admin & Clerical Support	0.09		incl above	0.07		incl above	0.07		incl above	0.07		incl above	0.29	incl above
	Sub Total	0.94		175.2	0.76		148.1	0.77		158.3	0.77		166.5	3.23	648.1
Co-Op, Student	Jens Redemann, Co-I,BAERI	0.00	190.8	0.0	0.08	240.4	19.2	0.16	252.4	40.4	0.16	265.0	42.4	0.40	102.0
	Jhony Zavaleta, Drafter, BAERI	0.29	117.0	33.9	0.13	122.4	15.9	0.00	128.1	0.0	0.00	134.5	0.0	0.42	49.8
	S. Ramirez, Data analyst, BAER	0.05	95.0	4.8	0.05	101.4	5.1	0.04	106.5	4.3	0.04	111.8	4.5	0.18	18.6
	Co-op overhead included above														0.0
	Sub Total	0.34		38.7	0.26		40.2	0.20		44.6	0.20		46.9	1.00	170.4
	Total Labor	**1.28**		**213.8**	**1.02**		**188.3**	**0.97**		**202.9**	**0.97**		**213.4**	**4.23**	**818.5**
2. OTHER DIRECT COSTS															
a. Parts, repairs				73.0			9.3			3.0			4.3		89.6
b. Network & computer s				5.0			6.0			7.0			8.0		26.0
c. Shipping				0.0											0.0
d. Publications							0.0			0.0			0.0		0.0
e. Travel															
	Program Direct CS						3.1			9.9			1.9		14.9
	Co-Op						3.0			10.0			1.1		14.0
f. Other															0.0
															0.0
	Total Other Direct Costs			**78.0**			**21.4**			**29.9**			**15.2**		**144.5**

3. FACILITIES & ADMINISTRATION COST		2009			2010			2008			2008			TOTAL	
	Direct Workyears	0.94			0.80			0.85			0.85			**2.58**	
	Allocated Workyears	0.04			0.04			0.04			0.04			**0.12**	
	Total Workyears	0.98			0.84			0.89			0.89			**2.70**	
	G&A*		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0
	Allocated Service Pool*		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0
	Code S Management	0.19	195.7	37.4	0.14	206.0	29.0	0.12	216.8	26.3	0.12	228.1	27.7		92.8
	Division Reserve		1.5%	4.4		1.5%	3.1		1.5%	3.3		1.5%	3.4		10.8
	Total Facilities & Admin	**0.98**		**41.8**	**0.84**		**32.1**	**0.89**		**29.7**	**0.89**		**31.1**		**134.7**
4. OTHER COSTS															
		0.00	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0		0.0
		0.00	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0		0.0
	Total Other Costs			0.0			0.0			0.0			0.0		0.0
5. Total (Labor, Travel and Procurements)				**333.6**			**241.8**			**262.5**			**259.8**		**1097.7**

***Excluded pursuant to Full Cost Simplification.**

Parts list, with costs ($) by year:

WBS	Part name	existing	2009	2010	2011	2012
1	**Optical collector**					
	Sun Tube	1000				
	Sun Baffle 1	200				
	Sun Baffle 2	200				
	Sun Baffle 3	200				
	Sun Baffle 4	200				
	Sky Tube	1000				
	Sky Baffle 1	200				
	Sky Baffle 2	200				
	Sky Baffle 3	200				
	Window/Secondary	1000				
	Primary	1000				
	Fiber optic head bundle	1200				
	Fiber optic take-up spool		4000			
	Fiber optic rotary joint	3500				
	Fiber optic spectrometer fan-out	1200				
2	**Spectrometer**					
	VNIR Spectrometer	12000				
	SWIR Spectrometer	12800				
	VNIR readout interface	2000				
	SWIR readout interface	1950				
3	**DAS**					
	Data Acquisition System	2000				
4	**Sun Position**					
	Quad detector	300				
	Alignment mount	40				
	Wiring harness	400				
	Quad detector signal conditioning	2000				
5	**Motion system**					
	Elevation motor		4,900.00			
	Elevation encoder		6,450.00			
	Elevation wiring harness		500.00			
	Azimuth motor		6,400.00			
	Azimuth encoder		8,450.00			
	Azimuth wiring harness		500.00			
	Slipring		4,500.00			
	Wiring harness to rack					
	Elevation motor amplifier		1,550.00			
	Azmuith motor amplifier		1,575.00			
	Motion control computer		2,000.00			
	El/Azi motion controller card		5,050.00			
6	**Head hardware**					
	Elevation rotor frame					
	Elevation rotor shroud					
	Elevation stator frame					
	Elevation stator shroud					
	Azimuth rotor frame					
	Azimuth rotor shroud					

	Azimuth stator frame					
	Elevation stator shroud					
	Estimate of fab costs for above	10000	25000	5000	1500	2000
	Heater filament					40
	Heater controller					50
	Insulation blanket					200
	Elevation seal			200		
	Elevation bearings (2)			1000		
	Azimuth seal			200		
	Azimuth bearings (2)			1200		
7	**System Health**					
	Temperature and pressure sensors		200			300
	Digitizer					200
8	**Power**					
	Power Supply	2,000.00				
9	**Tools**					
	Pro Engineer	1,500.00	1,500.00	1,500.00	1,500.00	1,500.00
	Shop tooling		400	200		
	Totals	58290	72975	9300	3000	4290

Travel Budget

	Airfare			Per Diem			Car					Total incl.
	Trips	$/trip	Total	Days	$/day	Total	Days	$/day	Total	Misc	**Total**	**Co-op O'head**
FY2010												
Calibration trip												
CS	1	1400	1,400	6	144	864	3	55	165	100	$2,529	$2,529
BAERI	1	1000	1,000	10	144	1,440		55	0	100	$2,540	$2,985
											FY10 BAER Total	**$2,985**
											FY10 SRI Total	**$0**
											FY10 Civil Servant Mgt Travel (per Ames Pricing Template)	**$541**
											FY10 Civil Servant Total	**$3,070**
FY2011												
Field mission planning, assumed US												
CS	1	700	700	3	150	450	2	55	110	300	$1,560	$1,560
BAERI	1	700	700	2	150	300	2	55	110	300	$1,410	$1,657
Field mission, assumed US												
CS	2	700	1,400	26	200	5,200	26	55	1430	300	$8,330	$8,330
BAERI	1	1000	1,000	26	200	5,200	26	55	1430	300	$7,930	$9,318
											FY11 BAER Total	**$9,987**
											FY11 SRI Total	**$0**
											FY07 Civil Servant Mgt Travel (per Ames Pricing Template)	**$480**
											FY08 Civil Servant Total	**$9,890**
FY2012												
Field mission, assumed US												
CS	0	700	0	0	200	0	0	55	0	300	$300	$300
BAERI	0	1000	0	0	200	0	0	55	0	300	$300	$353
Science meeting, assumed San Francisco												
CS	2	500	1,000		250	0				100	$1,100	$1,100
BAERI	1	500	500		250	0		55	0	100	$600	$705
											FY12 BAER Total	**$1,058**
											FY12 SRI Total	
											FY07 Civil Servant Mgt Travel (per Ames Pricing Template)	**$501**
											FY09 Civil Servant Total	**$1,901**