SI-Traceable Calibrations of Celestial Objects

C. Cramer

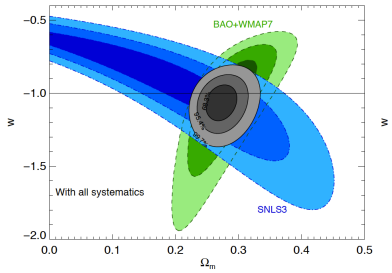
18 April, 2012

Fermilab

Brief Motivation

SNLS Photometric Uncertainties

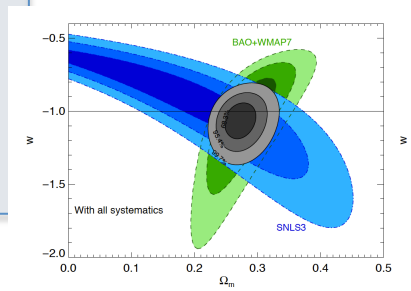
Description	w for $\Omega_m = 0.27$	Rel. Area
Stat only	-1.031 ± 0.058	1
All calibration	-1.06 ± 0.10	1.79
Colors of BD 17° 4708	-1.075 ± 0.075	1.31
SED of BD 17° 4708	-1.026 ± 0.073	1.23
SNLS zero points	-1.030 ± 0.069	1.21
Low-z zero points	-1.044 ± 0.065	1.13
SDSS zero points	-1.028 ± 0.060	1.02
MegaCam bandpasses	-1.017 ± 0.066	1.20
Low-z bandpasses	-1.027 ± 0.059	1.04
SDSS bandpasses	-1.026 ± 0.059	1.02
HST zero points	-1.027 ± 0.058	1.03
NICMOS nonlinearity	-1.029 ± 0.059	1.05



Conley, *et al., ApJ Sup.* 2011

SNLS Photometric Uncertainties

Description	w for $\Omega_m = 0.27$	Rel. Area
Stat only	-1.031 ± 0.058	1
All calibration	-1.06 ± 0.10	1.79
Colors of BD 17° 4708	-1.075 ± 0.075	1.31
SED of BD 17° 4708	-1.026 ± 0.073	1.23
SNLS zero points	-1.030 ± 0.069	1.21
Low-z zero points	-1.044 ± 0.065	1.13
SDSS zero points	-1.028 ± 0.060	1.02
MegaCam bandpasses	-1.017 ± 0.066	1.20
Low-z bandpasses	-1.027 ± 0.059	1.04
SDSS bandpasses	-1.026 ± 0.059	1.02
HST zero points	-1.027 ± 0.058	1.03
NICMOS nonlinearity	-1.029 ± 0.059	1.05



Conley, *et al.*, *ApJ Sup.* 2011

Vega: the best-calibrated star??

8 % discrepancy at the best-calibrated wavelength (555.6 nm)

Possible to obtain 0.7 % agreement between measurements by throwing out apparently bad lamp calibration

At least some of the included values made a *retrospective* correction for atmospheric extinction

Megessier, *A&A,* **296** p.771-778 (1995)

NIST*
and
Astronomy

*National Institute of Standards and Technology

What is NIST?

The National Institute of Standards and Technology:
a set of government laboratories in the Department of Commerce
physically located in Boulder, CO and Gaithersburg, MD

Mission: To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

Vision: NIST will be the world's leader in creating critical measurement solutions and promoting equitable standards. Our efforts stimulate innovation, foster industrial competitiveness, and improve the quality of life.

NIST's core competencies: Measurement science
Rigorous traceability
Development and use of standards

NIST Laboratory Structure

Standards Coordination Office
Special Programs Office

Center for Nanoscale Science and Technology (CNST)
Center for Neutron Research (CNS)
Engineering Lab (EL)
Information Technology Lab (ITL)
Materials Measurement Lab (MML)
Physical Measurement Lab (PML)

- Radiation and Biomolecular Physics
- Semiconductor and Dimensional Metrology
- Quantum Measurement
- Sensor Science (was Optical Technology)
- Quantum Electronics and Photonics
- Electromagnetics
- Time and Frequency
- Quantum Physics
- Office of Weights and Measures

NIST Astronomy Programs

Characterization of emission line sources (lamps) and gas absorption cells for wavelength calibration

Craig Sansonetti, Gillian Nave

Atomic Spectroscopy Group

Quantum Measurement Division

Laser frequency combs for wavelength calibration of high-resolution spectrographs

Scott Diddams, et al.

Optical Frequency Measurements Group

Time and Frequency Division, Boulder

Astronomy in the Laser Applications Group

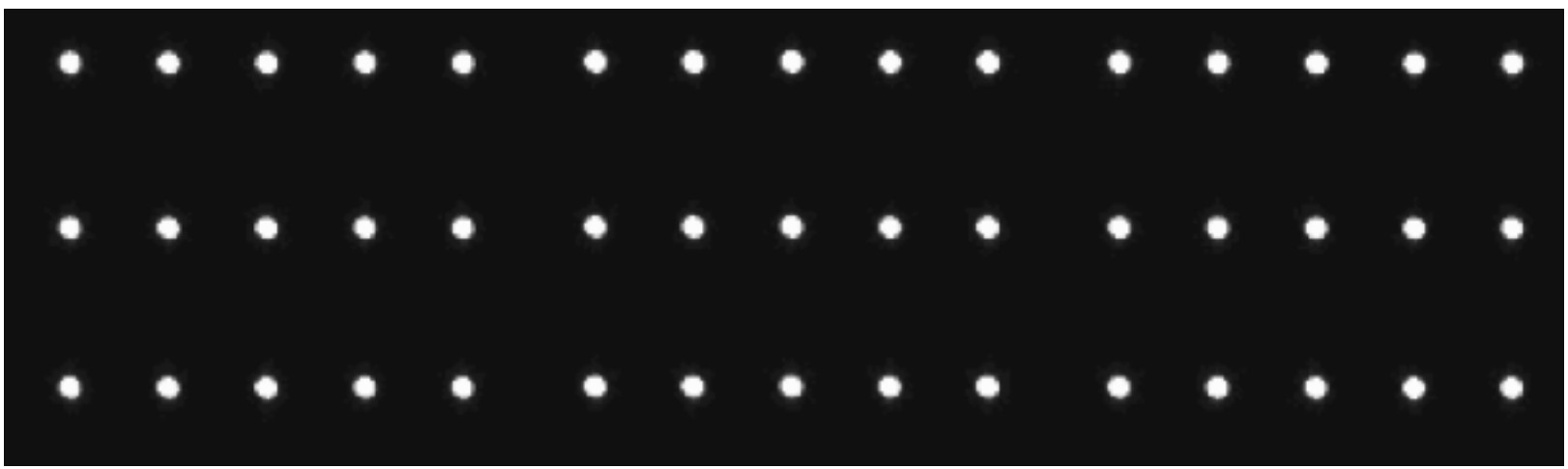
In situ throughput measurements of telescopes and instruments

Flux calibration of stellar spectra

PSF characterization

Wavelength calibration

Removal of stray and scattered light (a.k.a. sky subtraction)



Establishing SI-traceable spectrophotometric standard stars

Absolute Calibration of Vega, Hayes & Latham, 1975

Absolute Calibration of Vega, Hayes & Latham, 1975

Hayes & Latham Technique

Calibrate a telescope by observing a blackbody; observe Vega with calibrated telescope

Use nightly mean extinction coefficients extracted from stellar observations to correct for atmospheric extinction along the vertical path to the star

Extrapolate the horizontal extinction between the telescope and blackbody from the vertical extinction

Improvements over 1975 calibration:

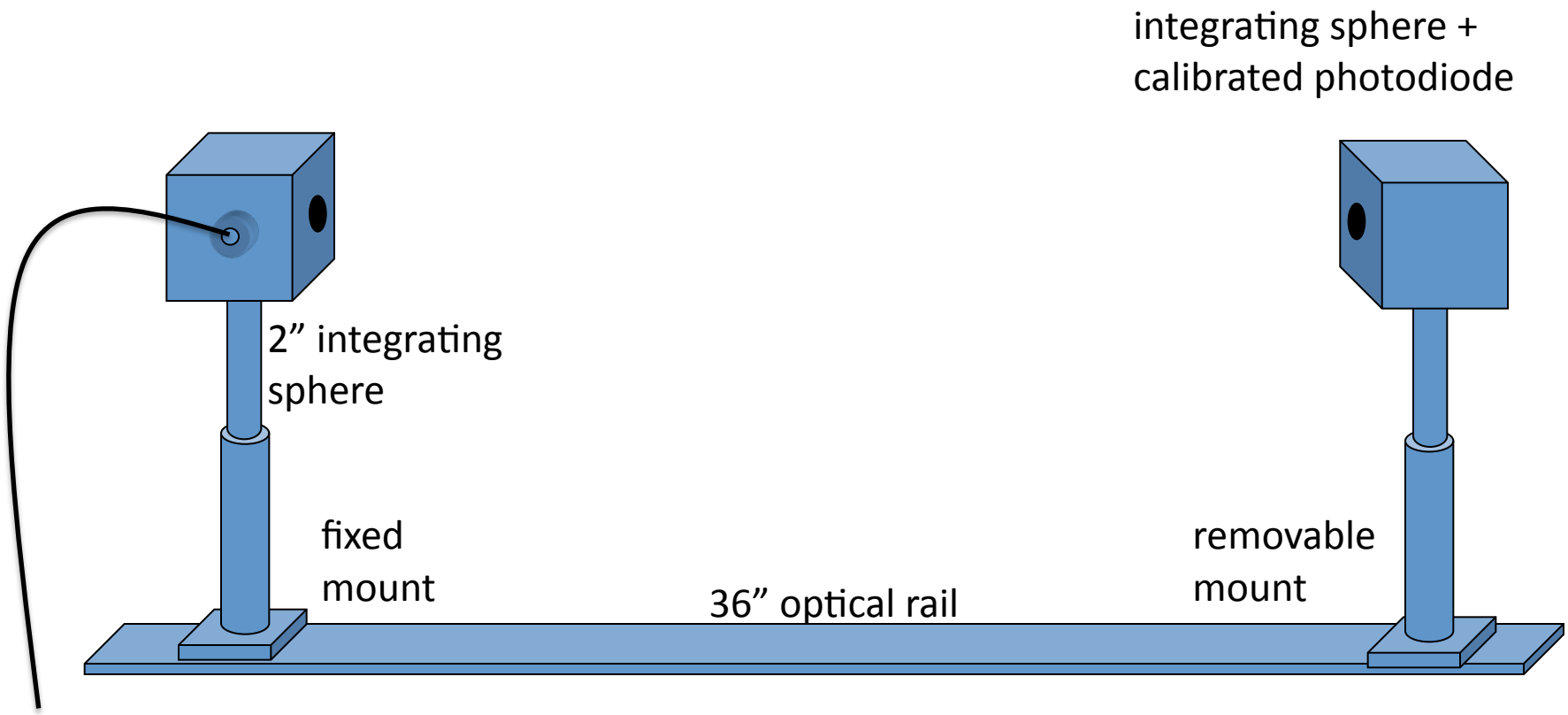
Use a light source that better matches the stellar spectrum

Shift from a source-based standard to a modern detector-based standard

Measure the horizontal transmission directly during telescope calibration

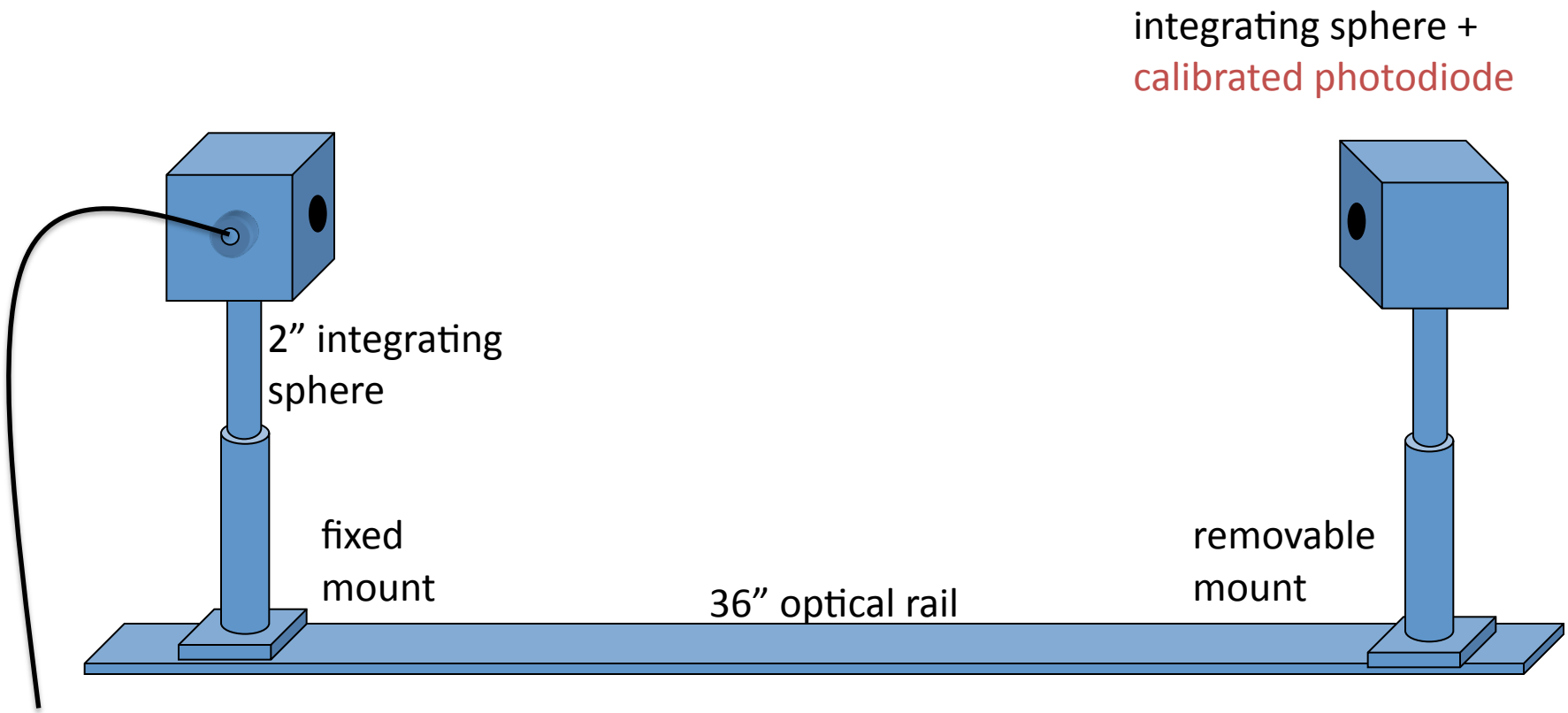
Independently measure the atmospheric extinction along the line of sight to target stars in real time

Integrating Sphere Source



incandescent lamp, tunable laser, HLE;
port on other side connects to CAS
spectrometer via optical fiber

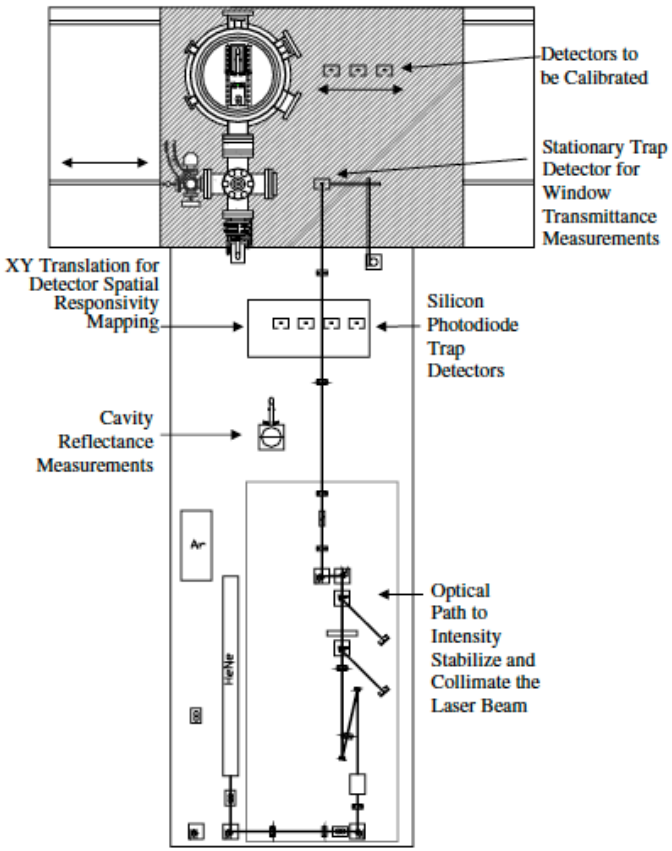
Integrating Sphere Source



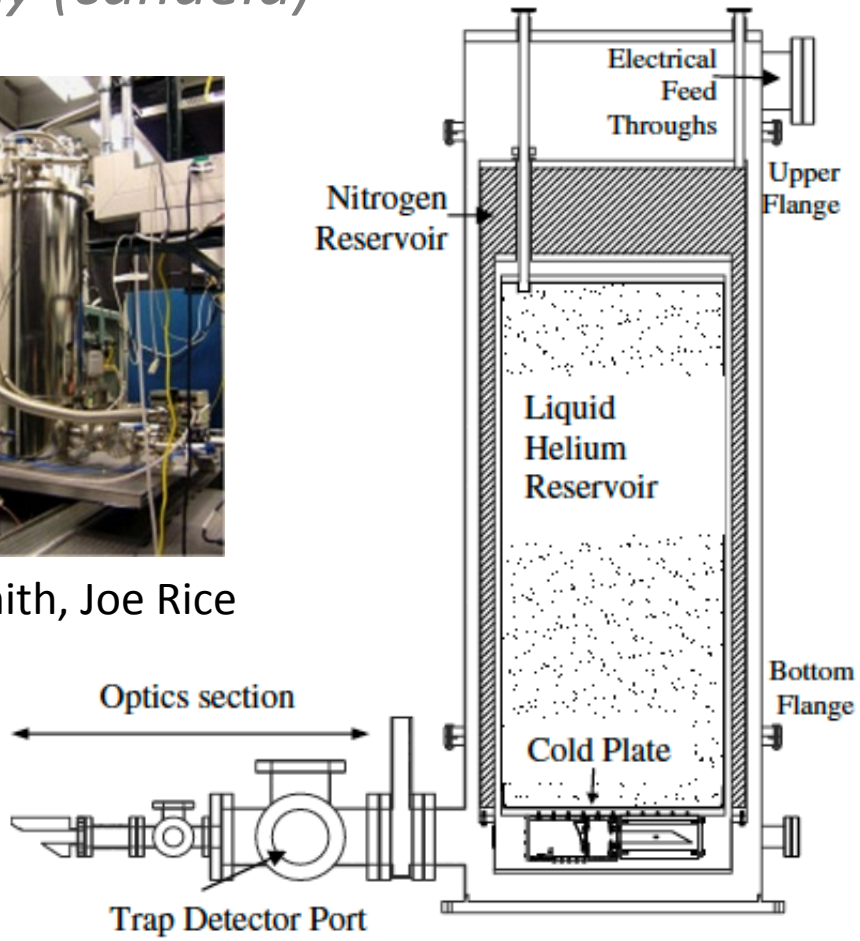
incandescent lamp, tunable laser, HLE;
port on other side connects to CAS
spectrometer via optical fiber

POWR

Primary Optical Watt Radiometer: ties together units of electrical power (W), temperature (K), and luminous intensity (candela)

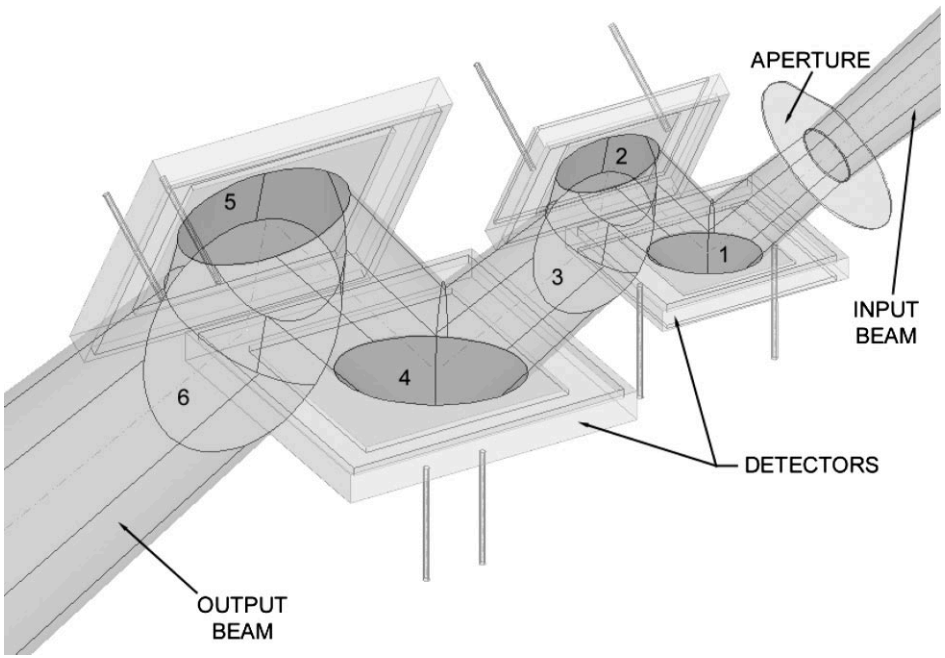


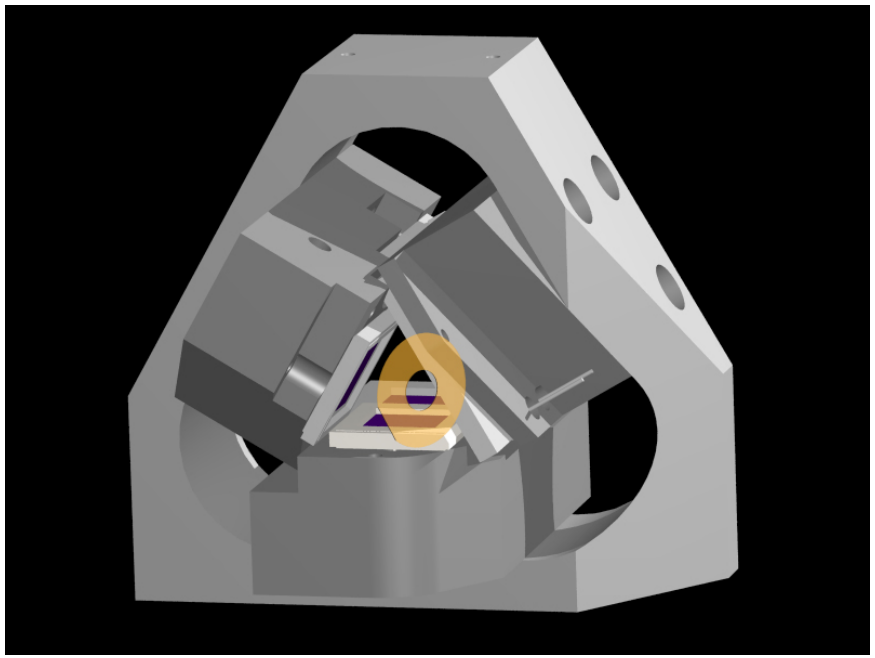
Allan Smith, Joe Rice



Transfer Standard Detectors

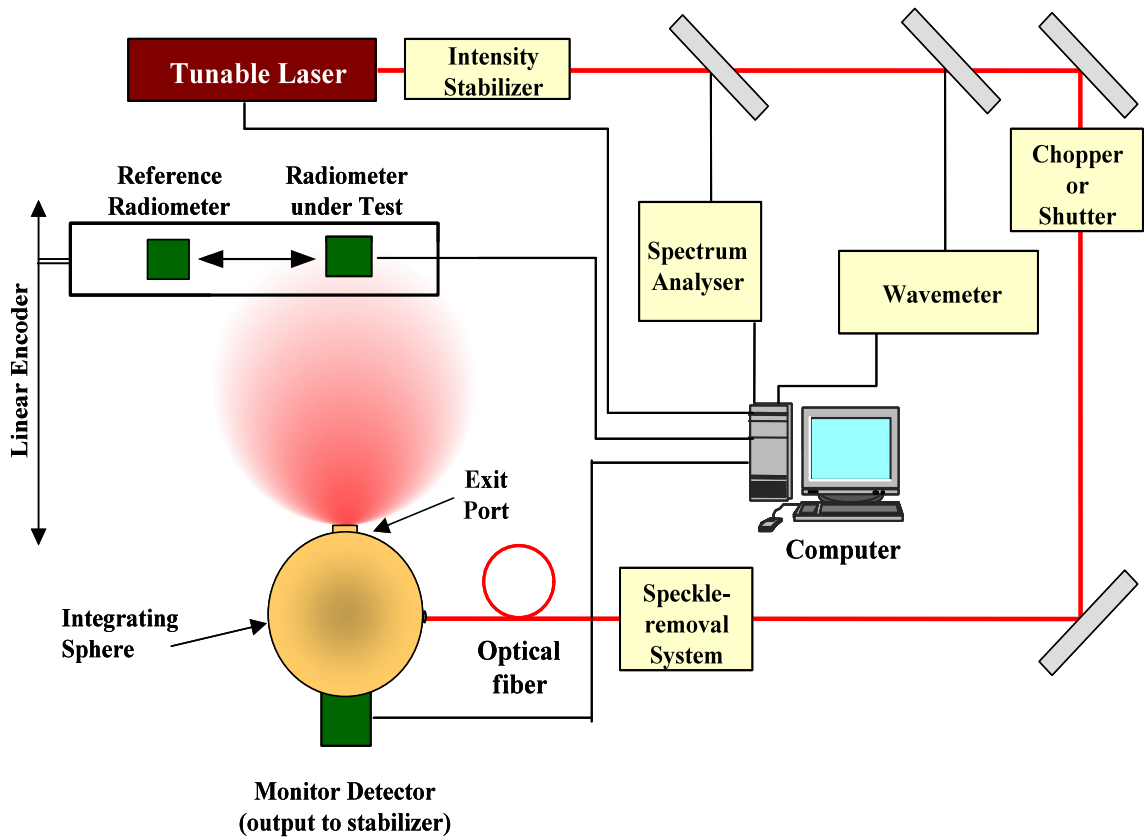
- Si tunnel trap:





SIRCUS

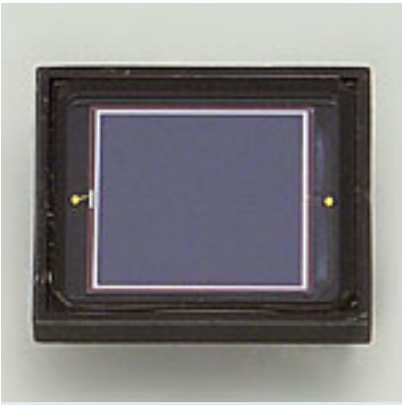
Spectral Irradiance and Radiance Calibrations Using Uniform Sources

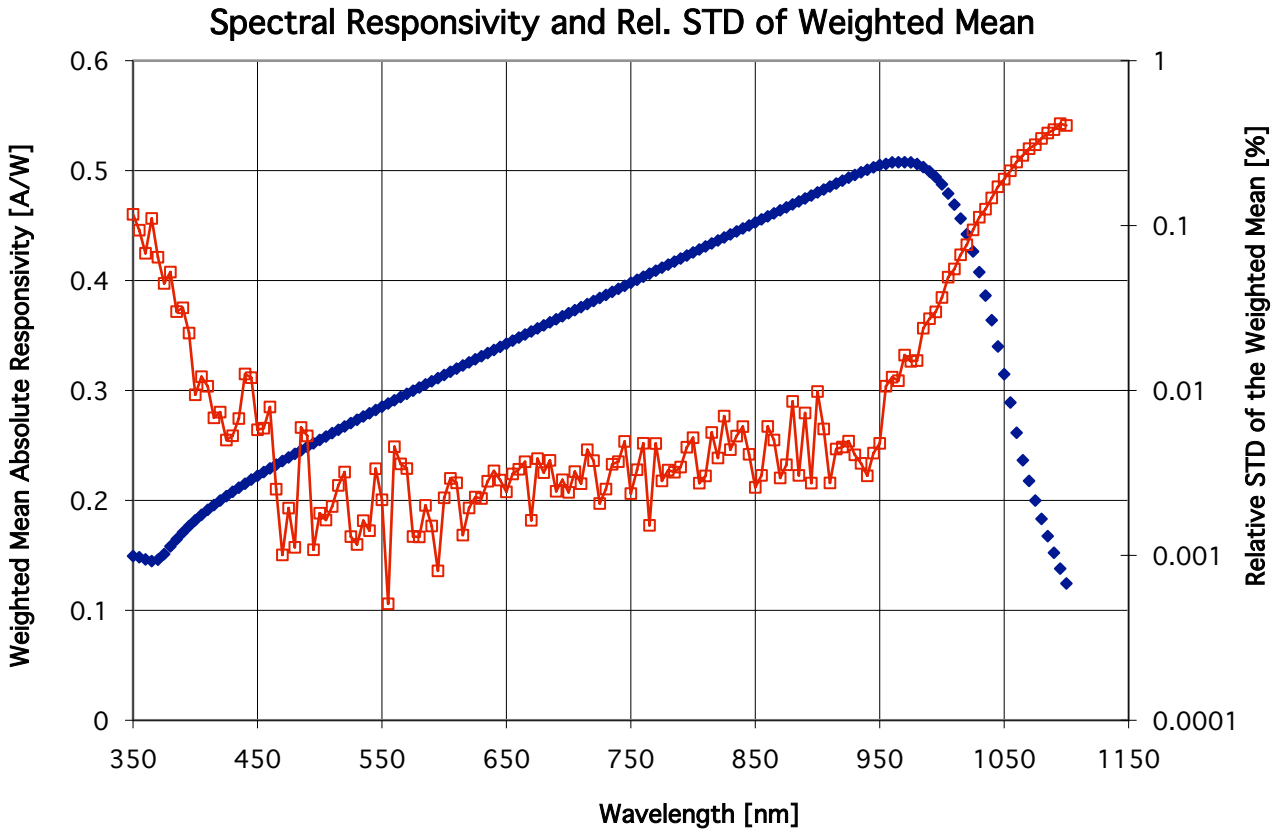


Keith Lykke
Steve Brown
CEC
Allan Smith
John Woodward
Mike Lin

Calibrated Photodiodes

- Hamamatsu 1337/2281





SIRCUS/POWR Accomplishments

Detector-based illuminance responsivity scale

- *uncertainty improved by a factor of two*

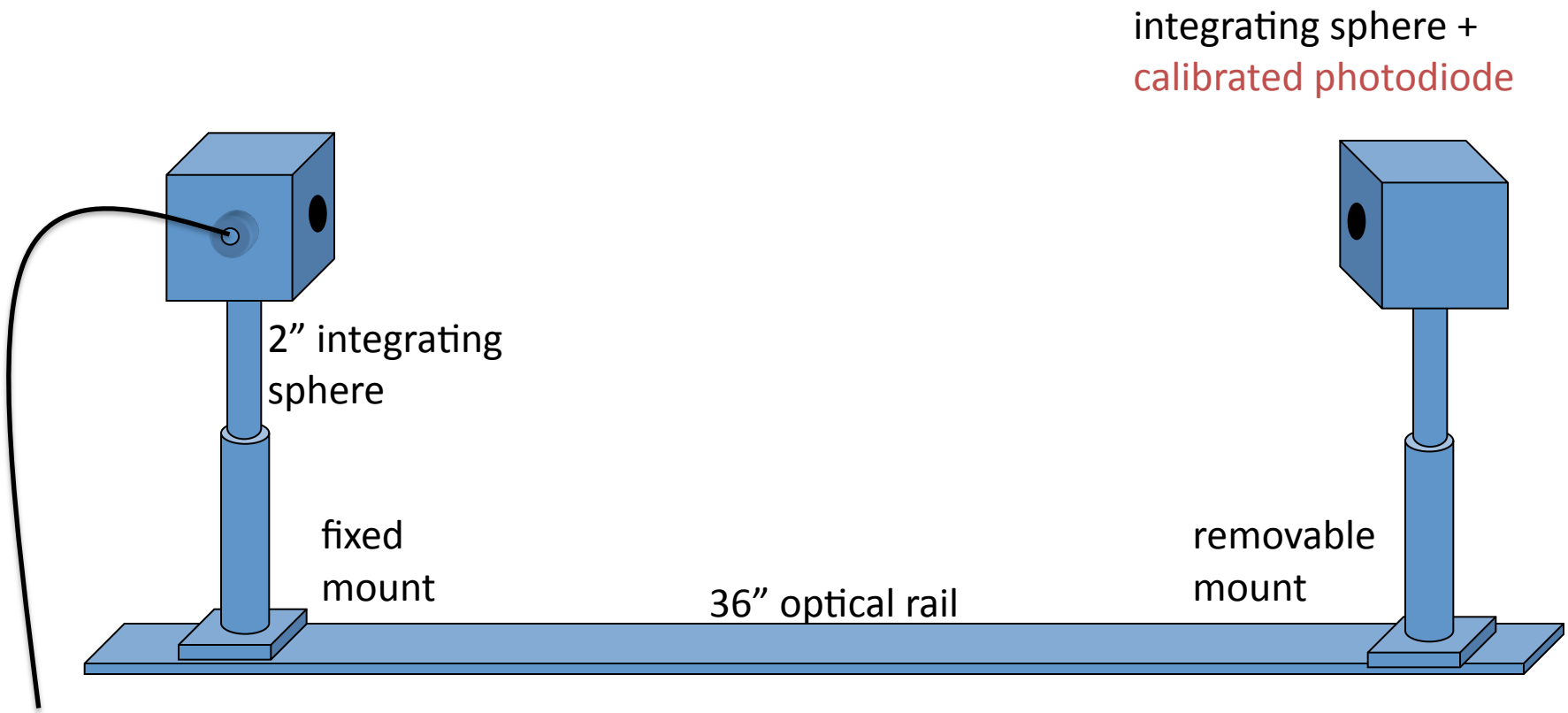
Spectral irradiance responsivity scale

- *uncertainty of candela improved, directly traceable*

Detector-based radiation temperature scale

- *enables low-uncertainty thermodynamic temperature measurements from 430-2700 K*

Integrating Sphere Source



incandescent lamp, tunable laser, HLE;
port on other side connects to CAS
spectrometer via optical fiber

Calibrating the CAS

Instrument Systems Compact Array Spectrometer*

- CCD-based fiber-fed slit spectrograph
- 380 nm to 1040 nm
- 3 nm resolution
- extremely stable

Laboratory calibration:

1. FEL lamp
2. SIRCUS
3. Hyperspectral Light Engine (HLE)

Stray light correction:

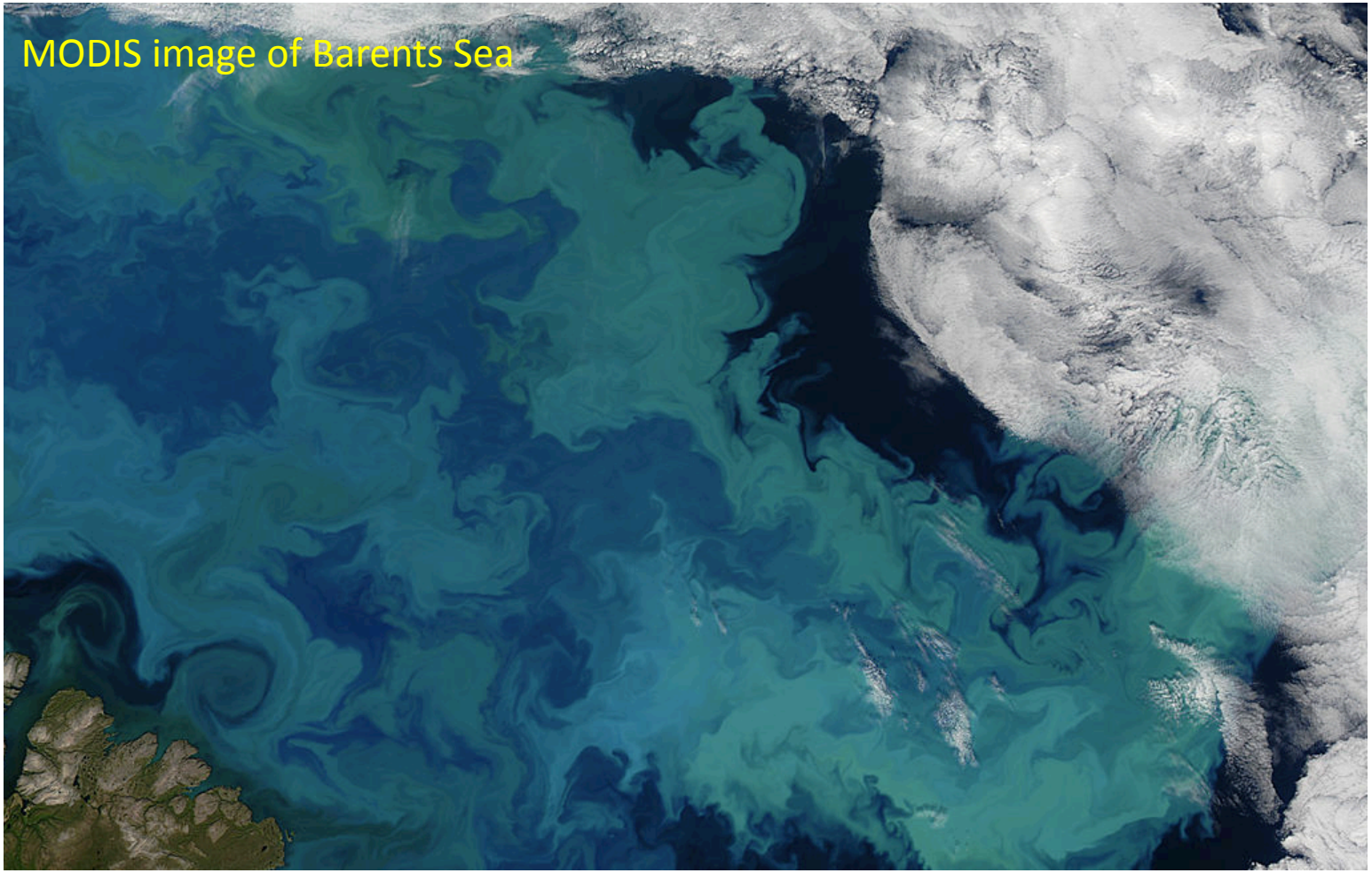
SIRCUS + Zong, *et al.* (2007)

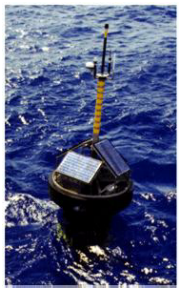
People:

John Woodward
Ping Shaw
Yuquin Zong

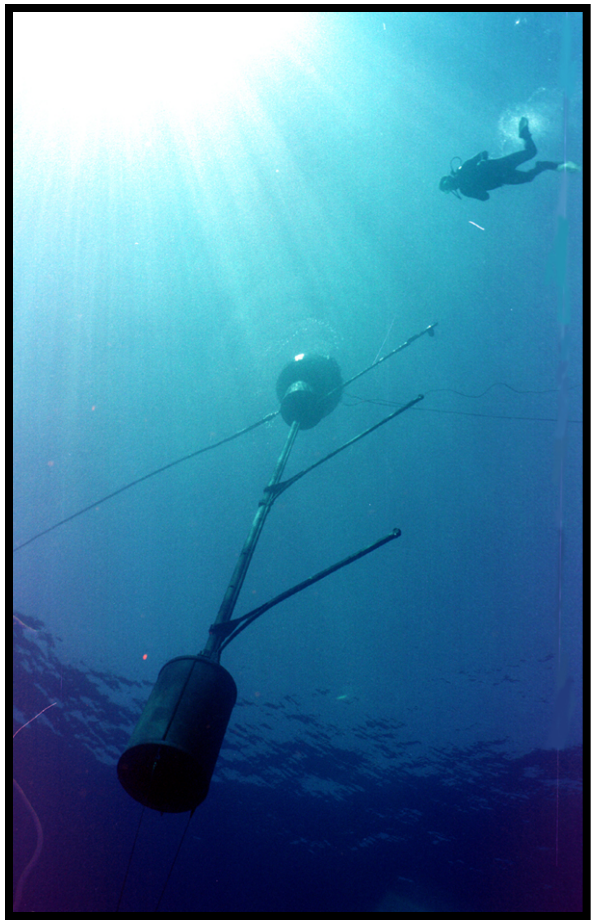
*Any mention of commercial products is for information only; it does not imply recommendation or endorsement by NIST.

Stray Light Correction

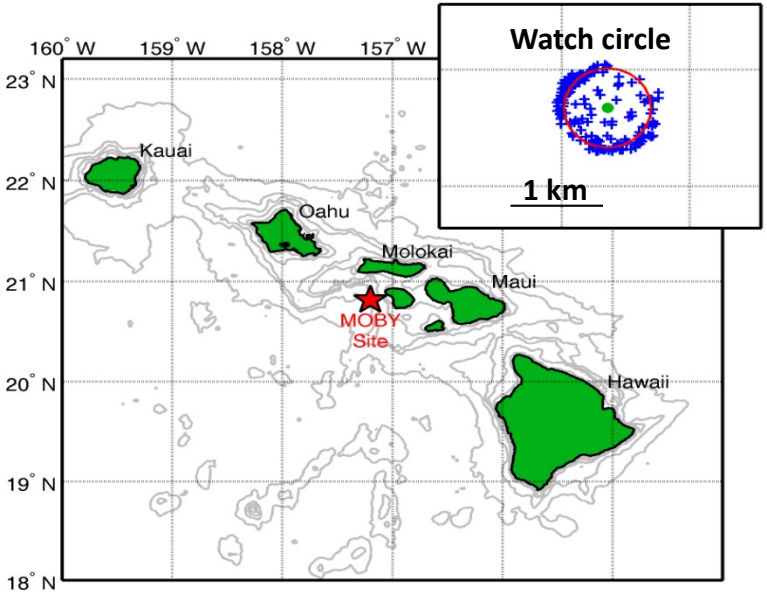




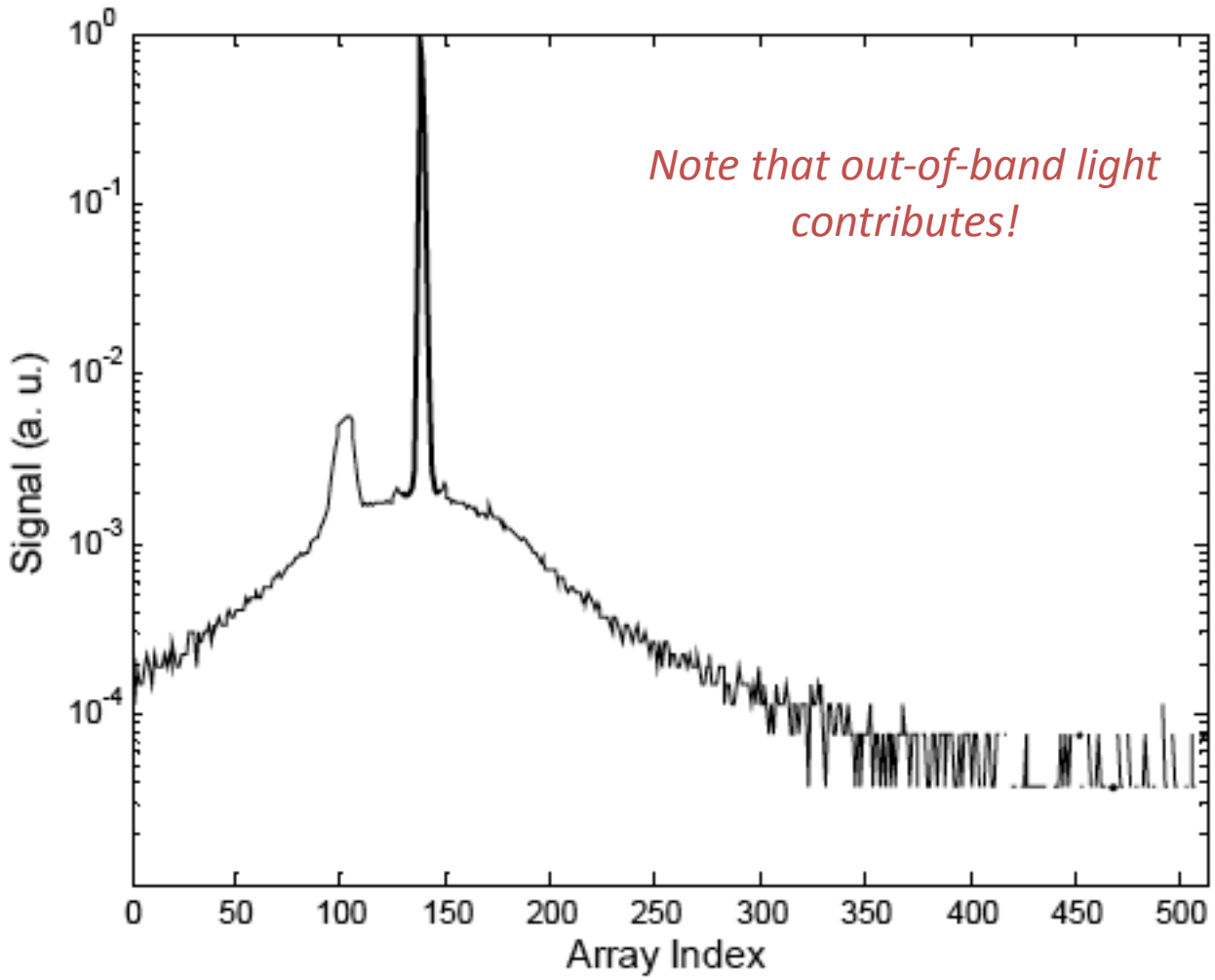
MOBY: the Marine Optical Buoy



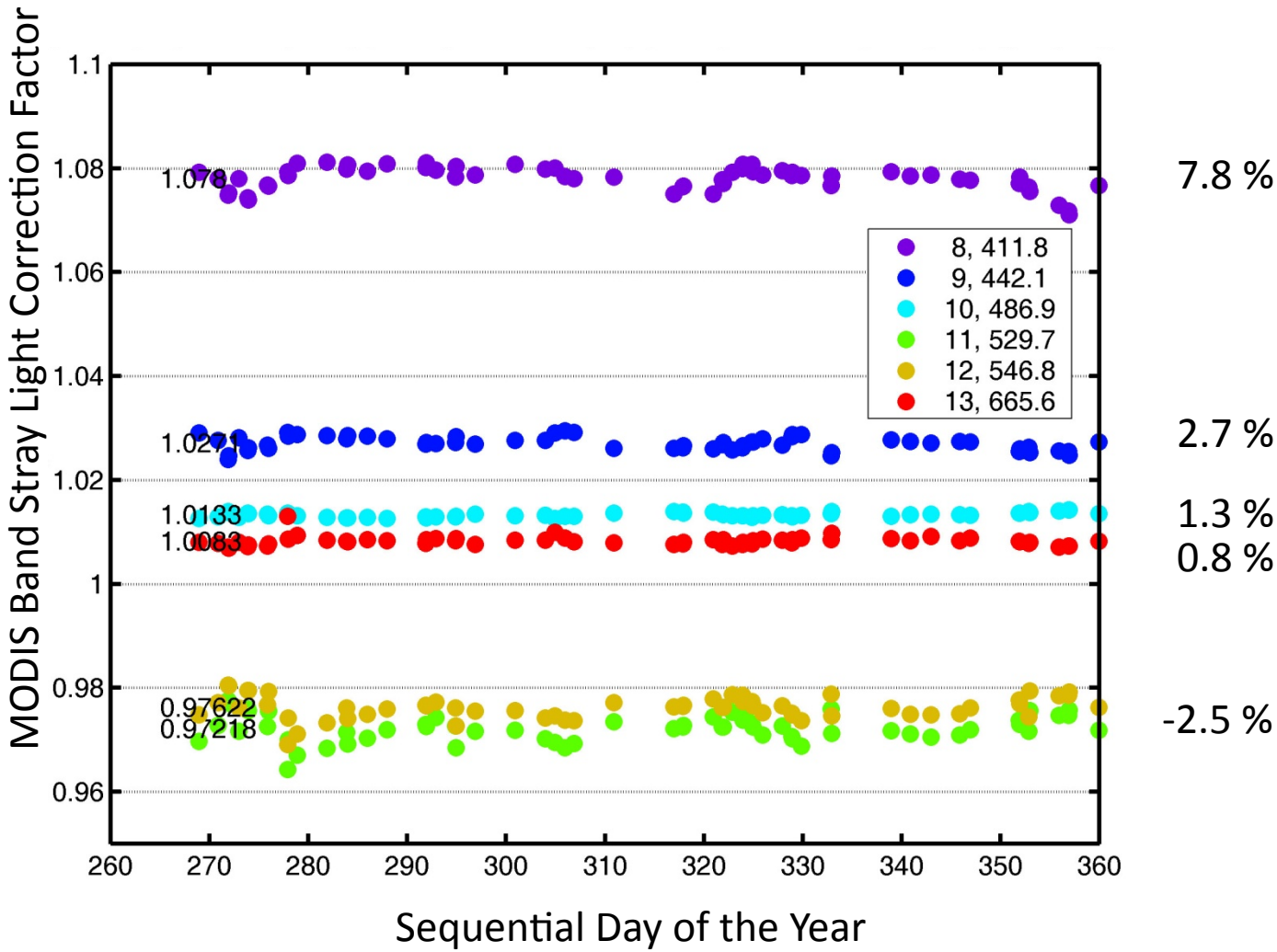
Primary Vicarious Calibration Reference Standard for Climate Quality Ocean Color Time Series Data



Monochromatic Laser Light in MOBY



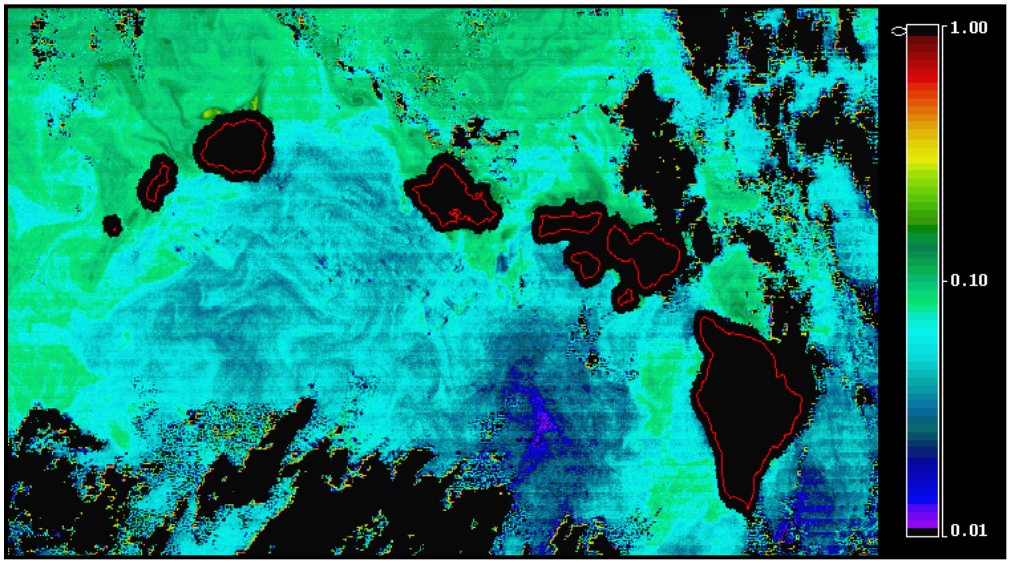
Stray Light Correction of MOBY Applied to MODIS Calibration



Bio-Optical Algorithm uses Band 9/Band 12 Ratio —— 5 %

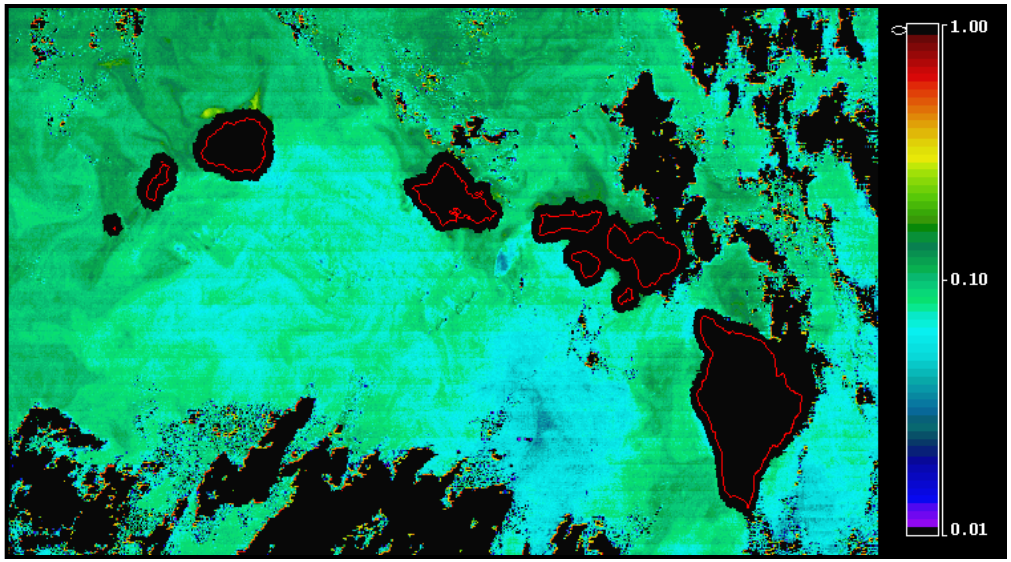
MOBY Stray Light Correction
Applied to a Satellite Data Product Image

uncorrected for stray light



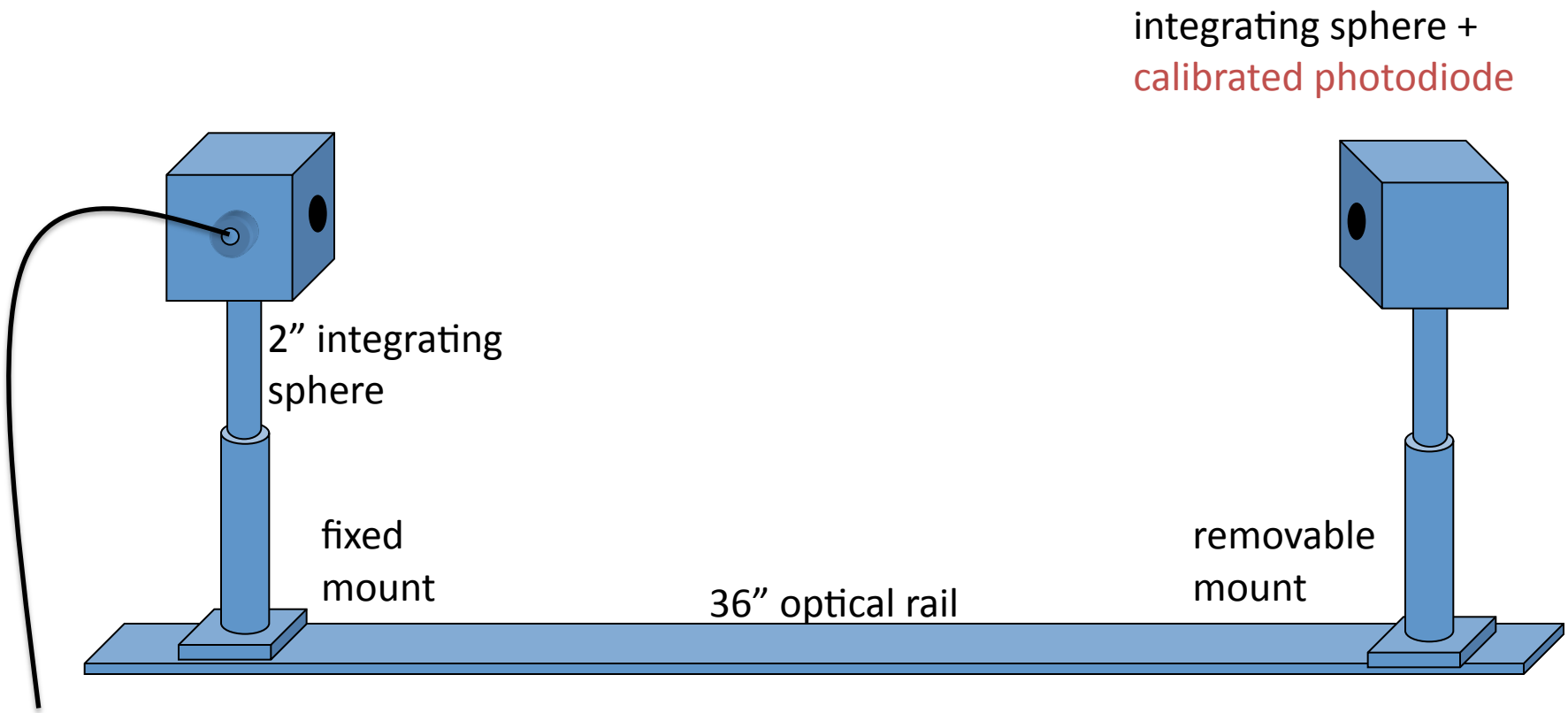
Log of Total Chlorophyll-a

corrected for stray light

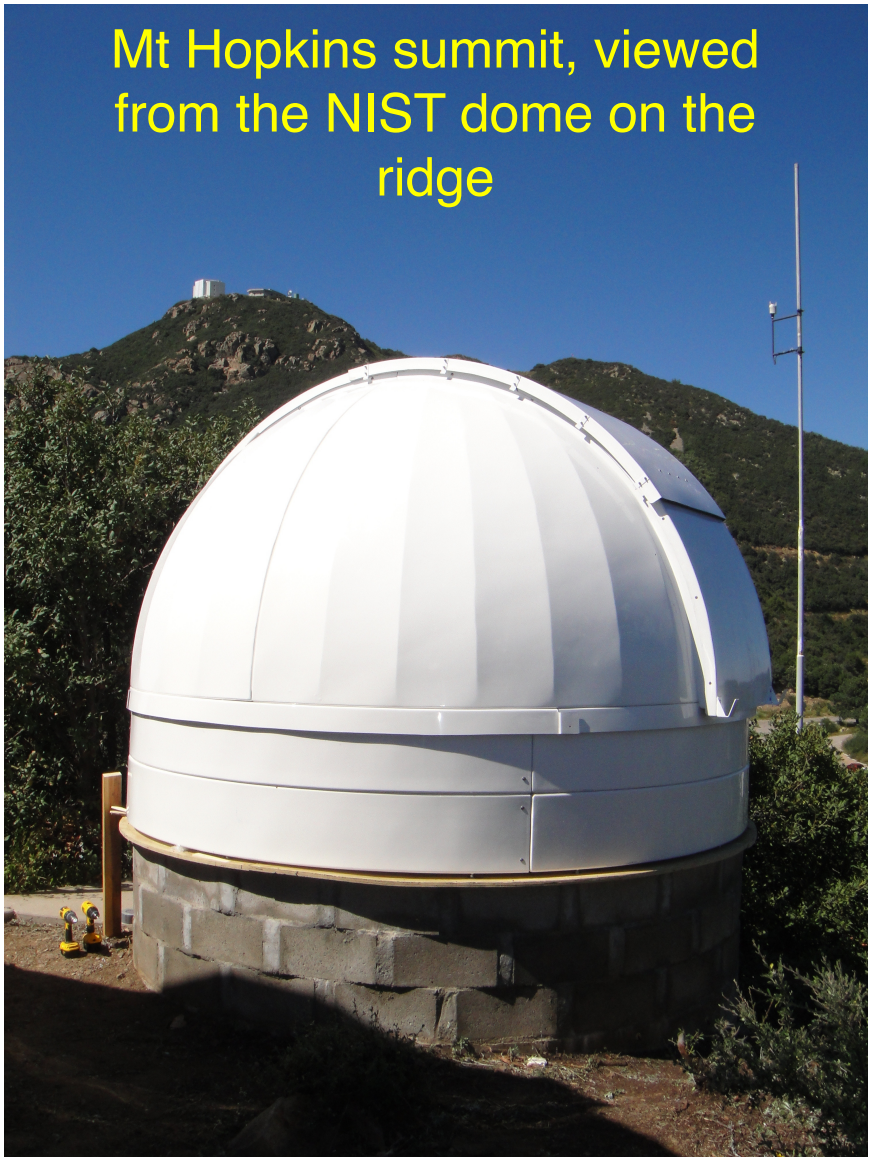


Log of Total Chlorophyll-a

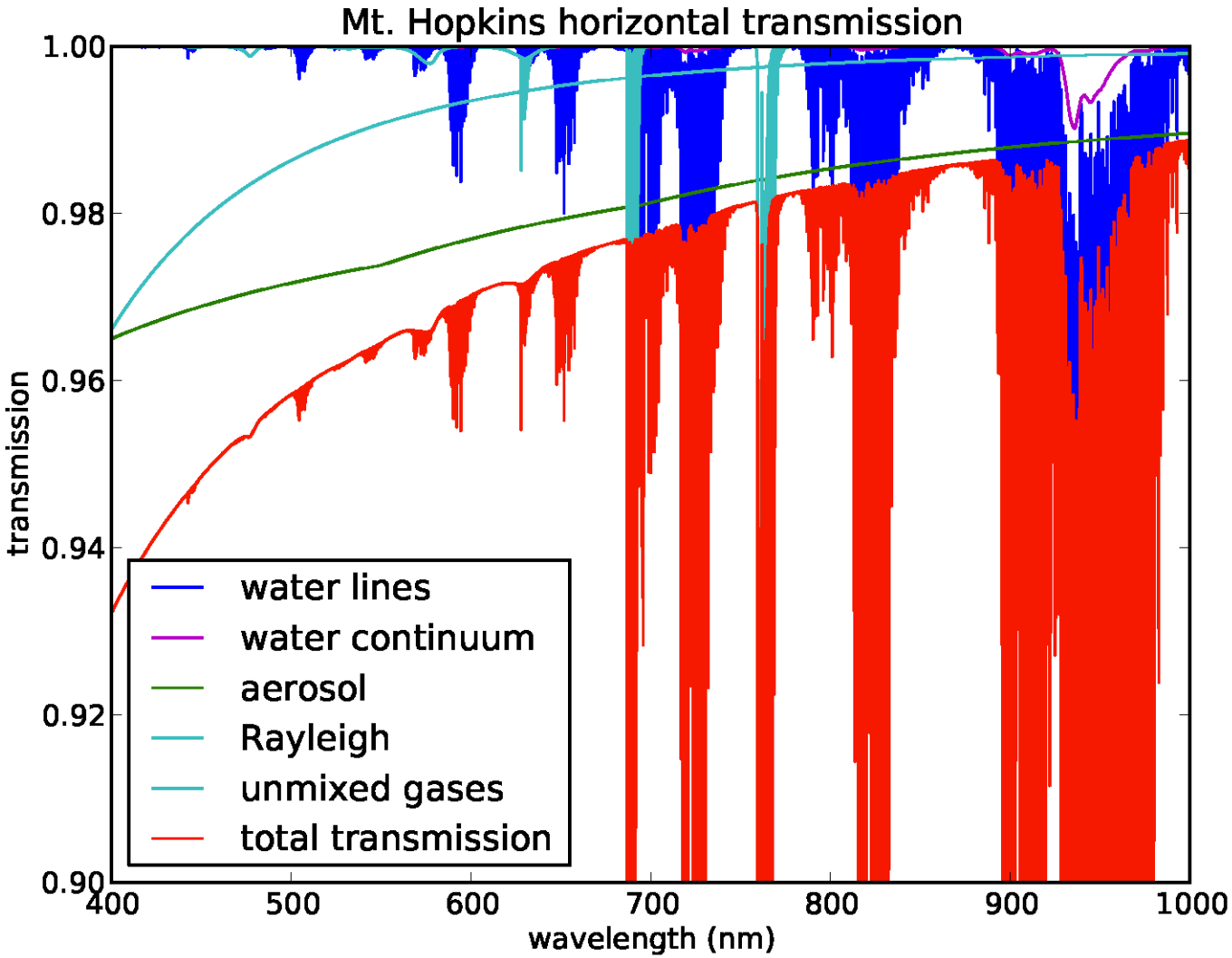
CAS calibration in the field



incandescent lamp, tunable laser, HLE;
port on other side connects to CAS
spectrometer via optical fiber

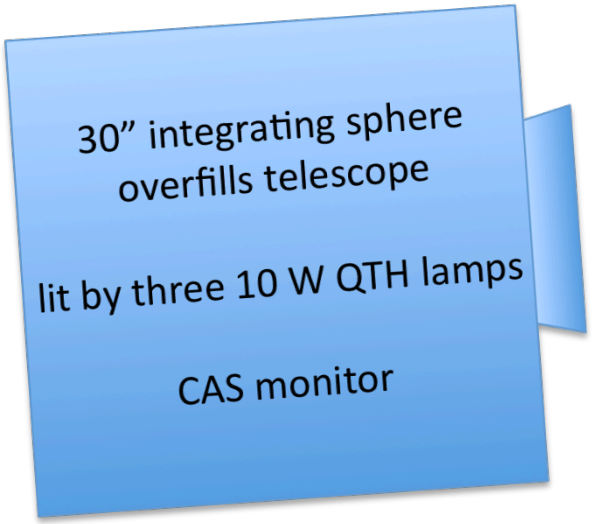

Mt Hopkins summit, viewed from the NIST dome on the ridge

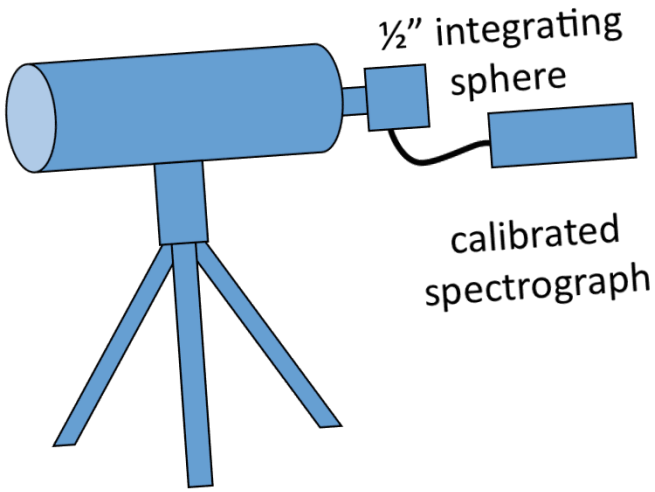
Expected Horizontal Transmission



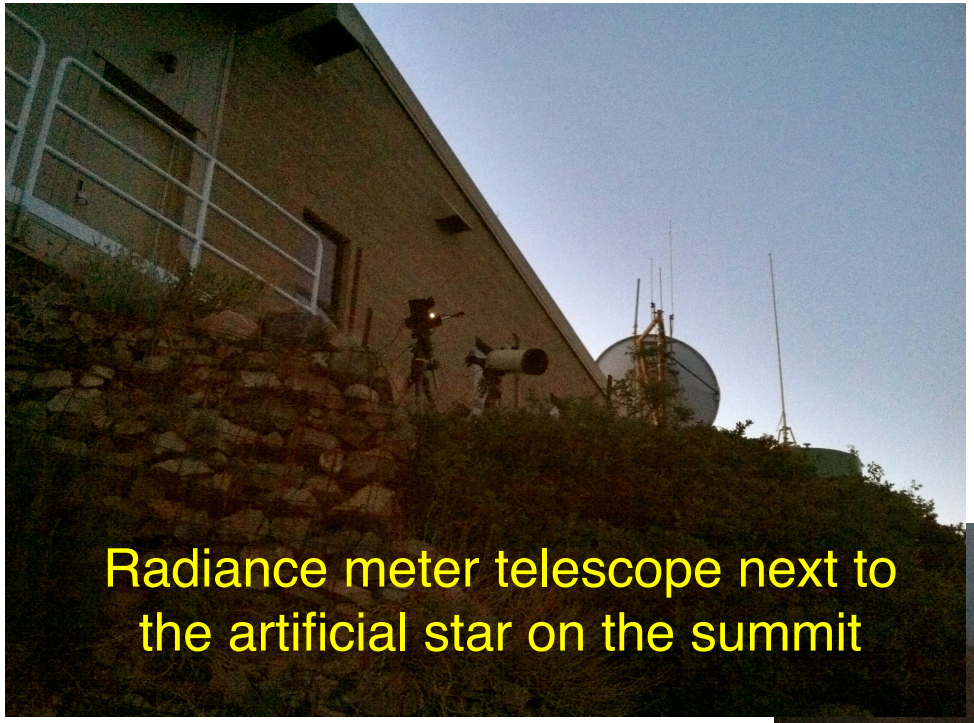
Horizontal Attenuation Monitor

known emitter + calibrated radiance meter





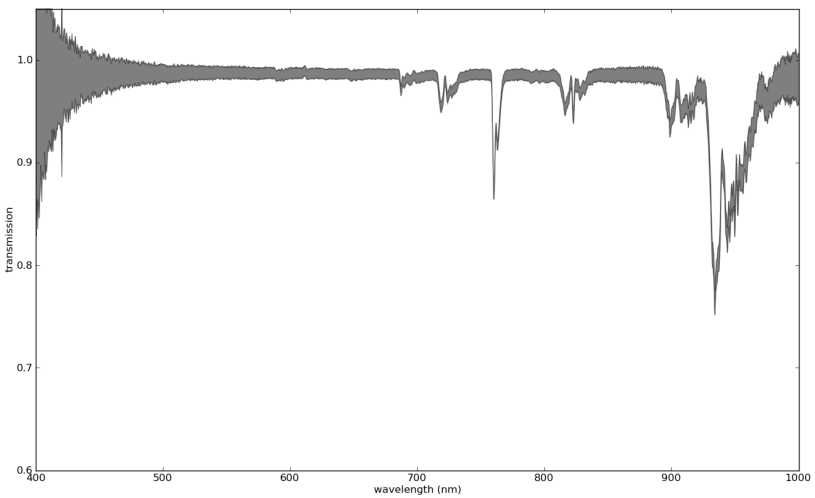
John Woodward,
measuring radiance

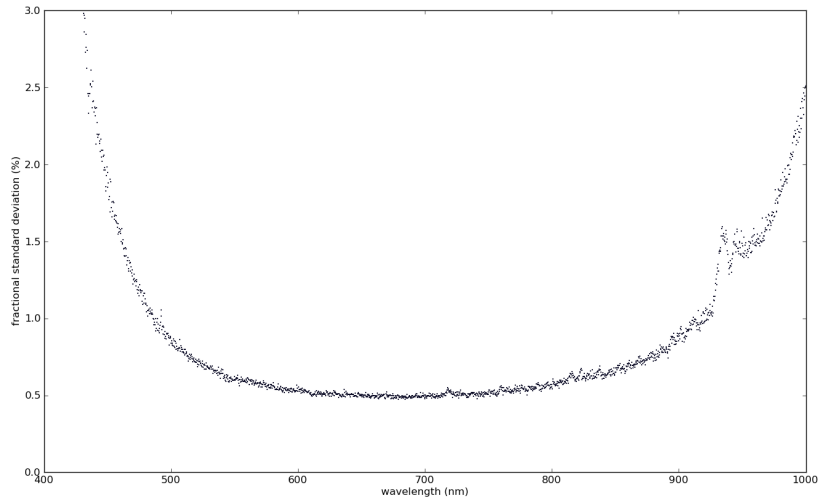


Radiance meter telescope next to the artificial star on the summit

Large integrating sphere as seen from the summit

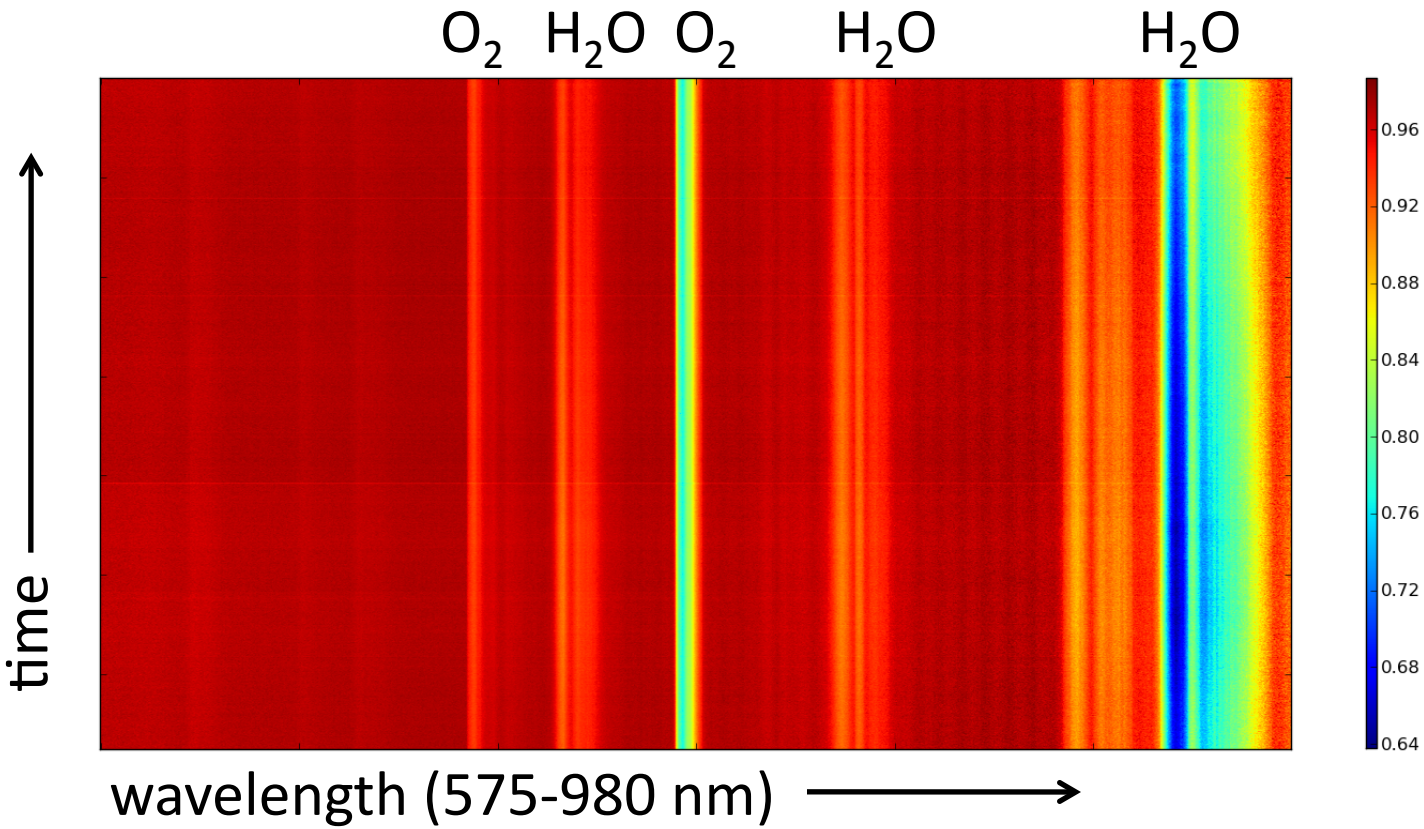
Monitoring the Hallway



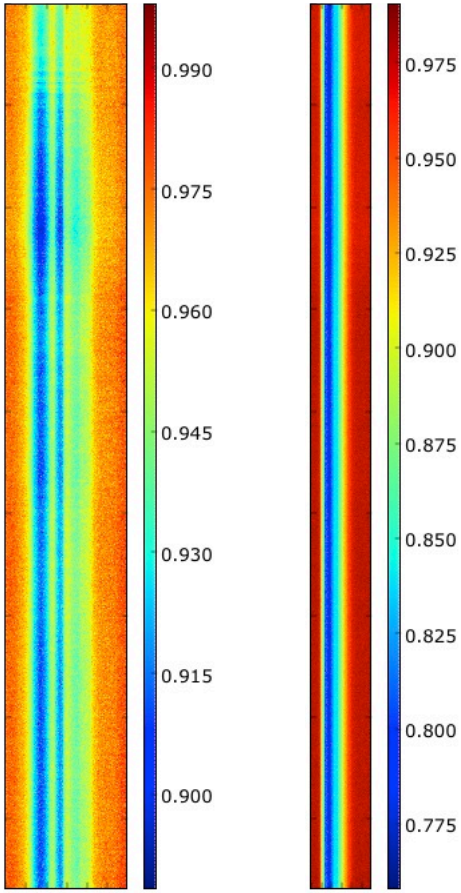


We monitored a 160 m path in the NIST hallway for one hour. Measured transmission (left) is shown with one standard deviation about the mean shaded. The standard deviation is less than 1% over most of the visible spectrum, except where we measure sub-percent variations in the water vapor absorption.

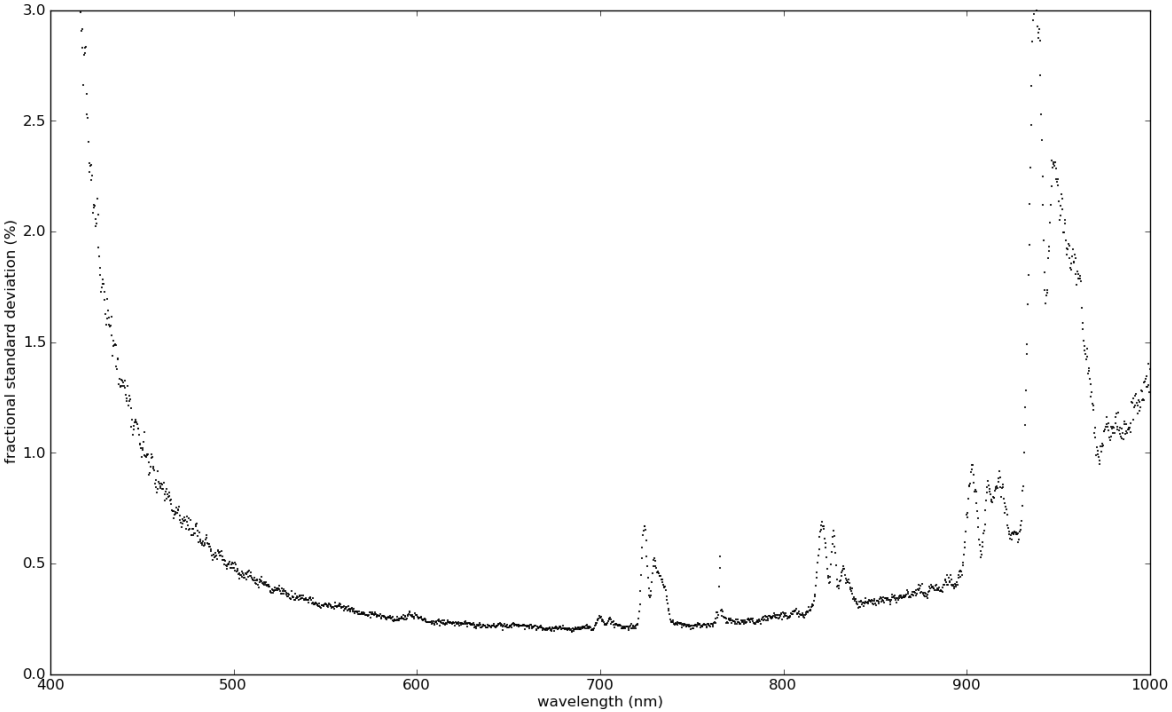
Monitoring the Mountain



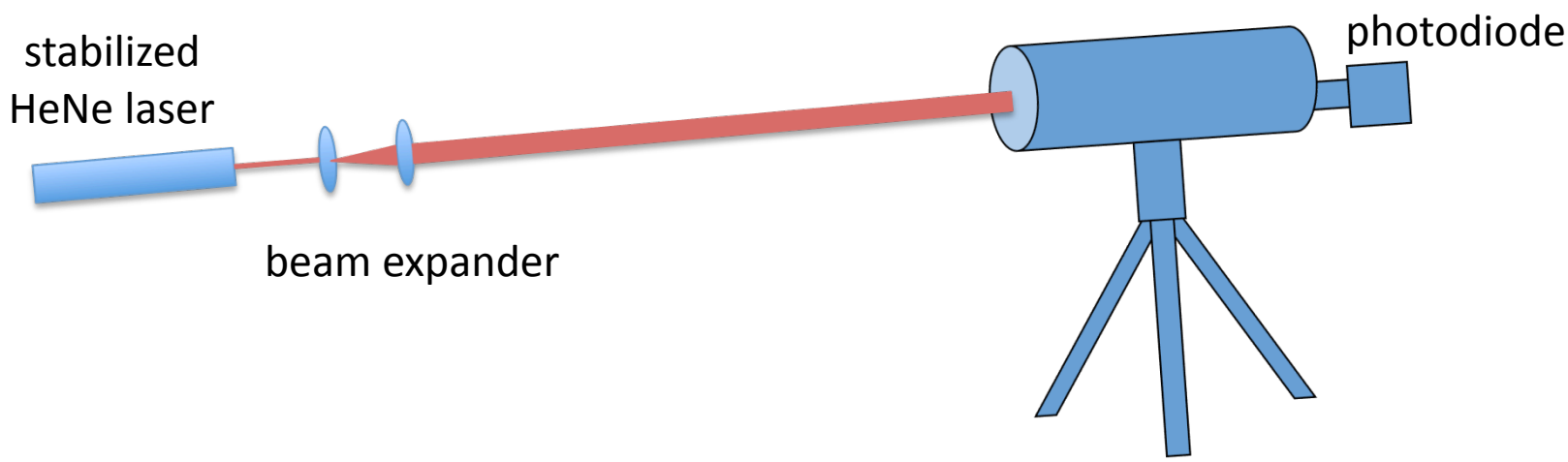
Monitoring the Mountain



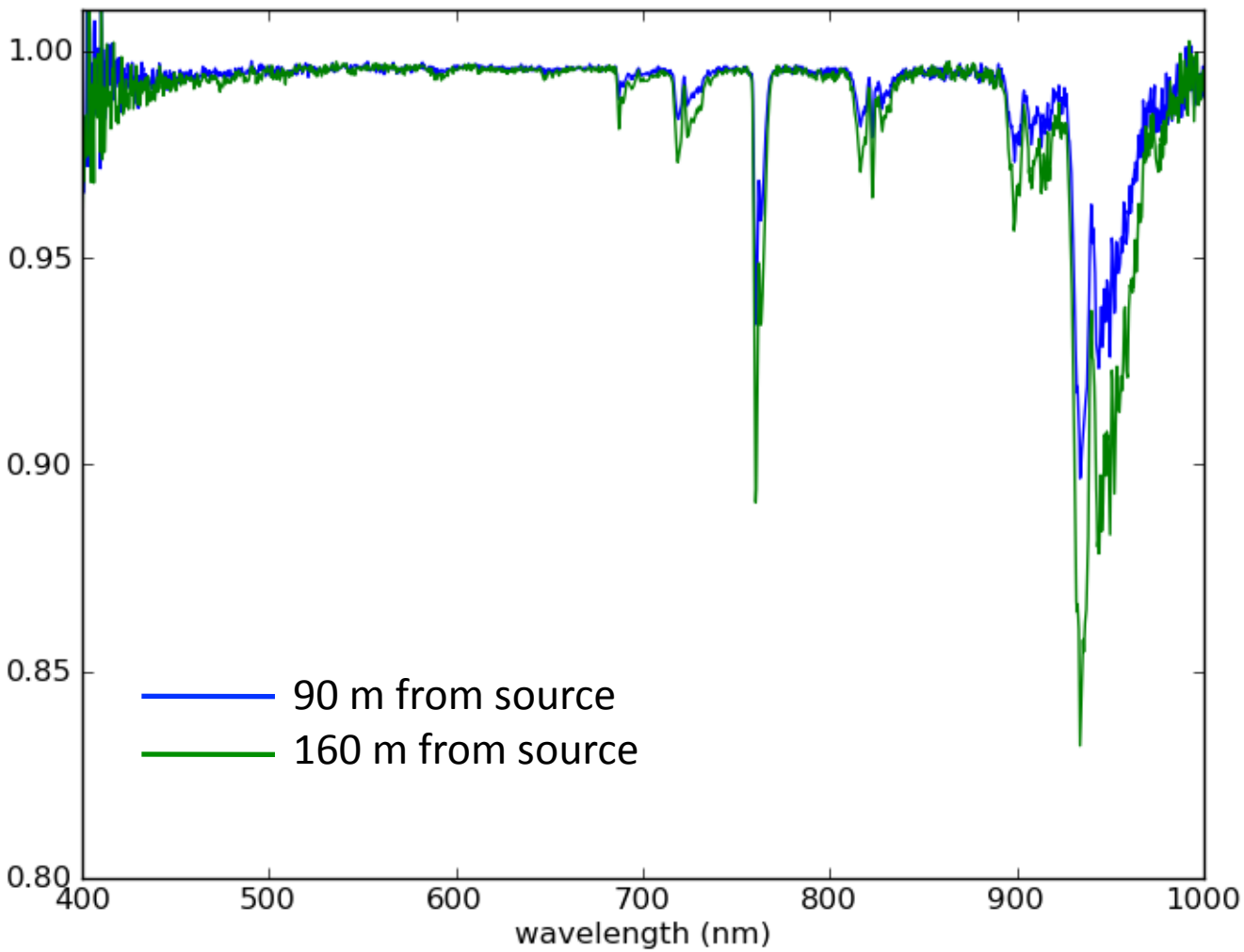
H_2O O_2



Laser Verification of HT Measurement



Laser + Sphere Test



Improvements over 1975 calibration:

Use a light source that better matches the stellar spectrum

Shift from a source-based standard to a modern detector-based standard

Measure the horizontal transmission directly during telescope calibration

Independently measure the atmospheric extinction along the line of sight to target stars in real time

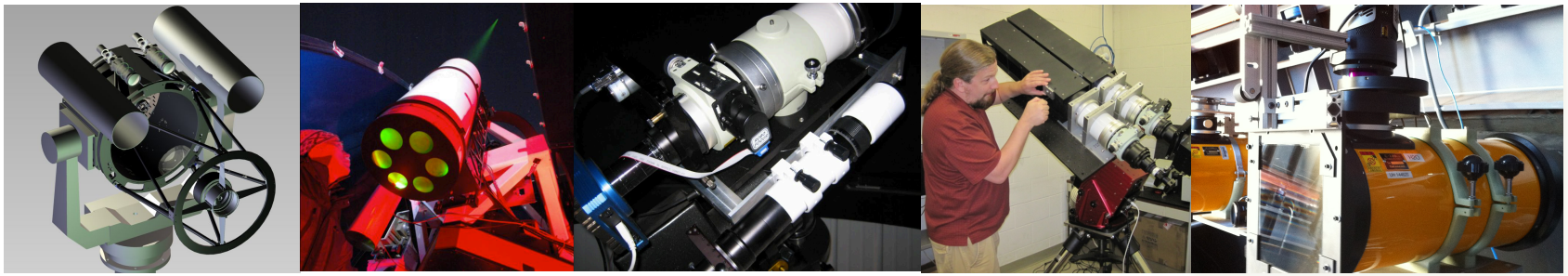
Summer 2012:

Goal: 1 % calibration of Vega at wavelengths unaffected by PWV

Verify line-of-sight extinction with multiple techniques:

ALE/FLAME: 3-wavelength elastic backscatter lidar (John McGraw's talk)
Harvard/PanStarrs objective grating spectrometer (Chris Stubbs' talk)
Multiband imager (similar to Ting Li's aTmCam)
Langley plots (e.g., Hayes & Latham)
HSRL lidar (later)

Independent verification with AESoP (Pete Zimmer's talk and poster)
Coordinated with Harvard/Dartmouth balloon flights (Max Fagin's talk)



Future Plans

Observe more stars:

Primary targets: Vega, Sirius
Secondary targets: 0-5 mag., coordinated with other observing programs

Verify calibrations with above-the atmosphere measurements:

ACCESS (Mary Beth Kaiser's talk)
STIS (Ralph Bohlin, in the ~~purple~~ shirt)

If you would like to be included in our informal network of star-calibrating-people, email me and/or Susana Deustua.

Opportunities at NIST

SURF: *Summer Undergraduate Research Fellowship*
applications due in Feb., apply through your institution
http://www.nist.gov/surfgaithersburg/

NRC Postdoctoral Fellowship:
federally funded, 2 year term, applications due in Feb. and Aug.
http://sites.nationalacademies.org/PGA/RAP/index.htm

Spectrophotometric Standard Collaborators

NIST:

- Keith Lykke
- Steve Brown
- CEC
- Allan Smith
- Ping Shaw
- John Woodward

Harvard:

- Chris Stubbs
- Peter Doherty
- Amali Vaz

UNM:

- John McGraw
- Pete Zimmer

SAO:

- Emilio Falco

Dartmouth:

- Yorke Brown
- Max Fagin