Application of Hyperspectral Camera for Aerosol Characterization

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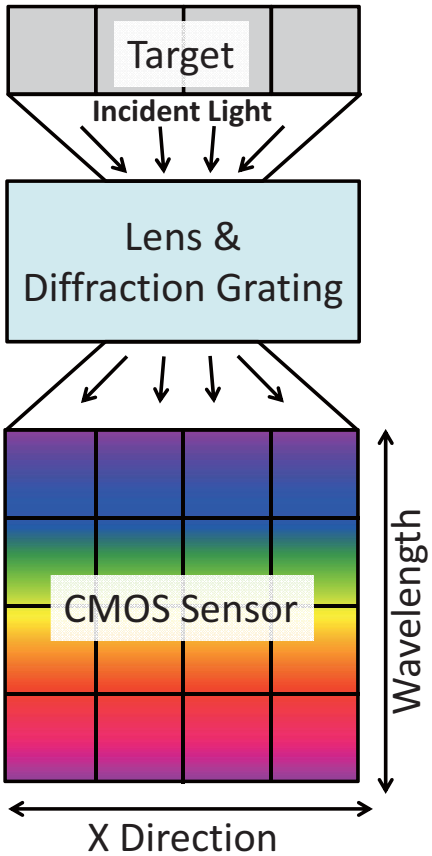
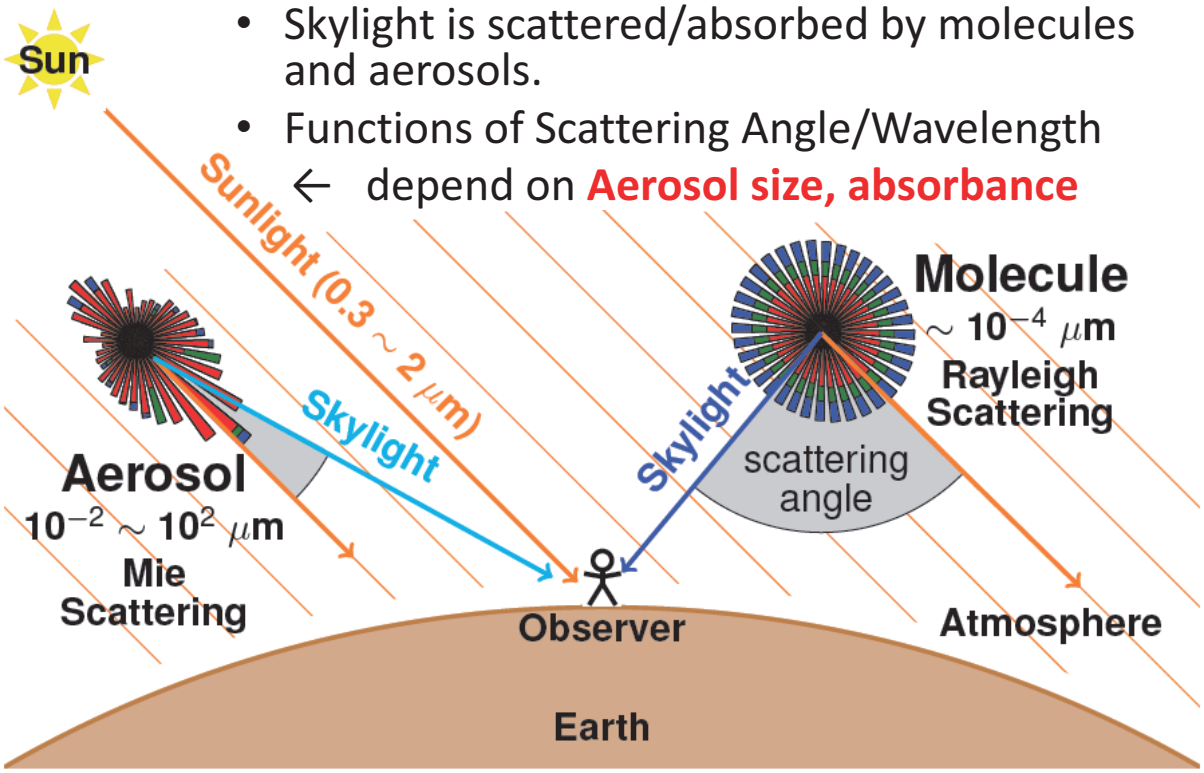
Principle of Hyperspectral Camera

- Hyperspectral Camera is a kind of “color camera”, which can distinguish not only 3 colors but hundreds of colors.
- An oblong object is spread in the X direction on a CMOS sensor.
- Different wavelengths are spread in the other direction.
- Vertical scan is needed to see a prolong object.

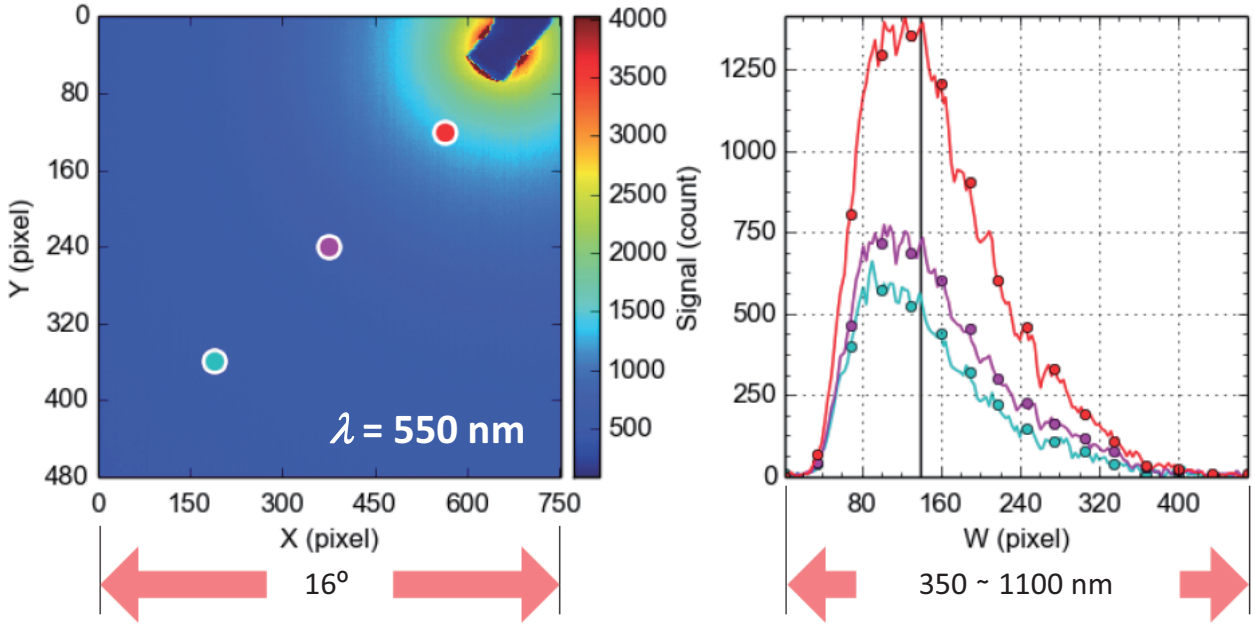


Skylight Observation

- Skylight is scattered/absorbed by molecules and aerosols.
- Functions of Scattering Angle/Wavelength
  ← depend on **Aerosol size, absorbance**



Hyperspectral Image of the Sky



- X/Y pixel number ⇒ Separation Angle
- W pixel number ⇒ Wavelength
- Signal count ⇒ Radiance

Hyperspectral Camera for Our Study

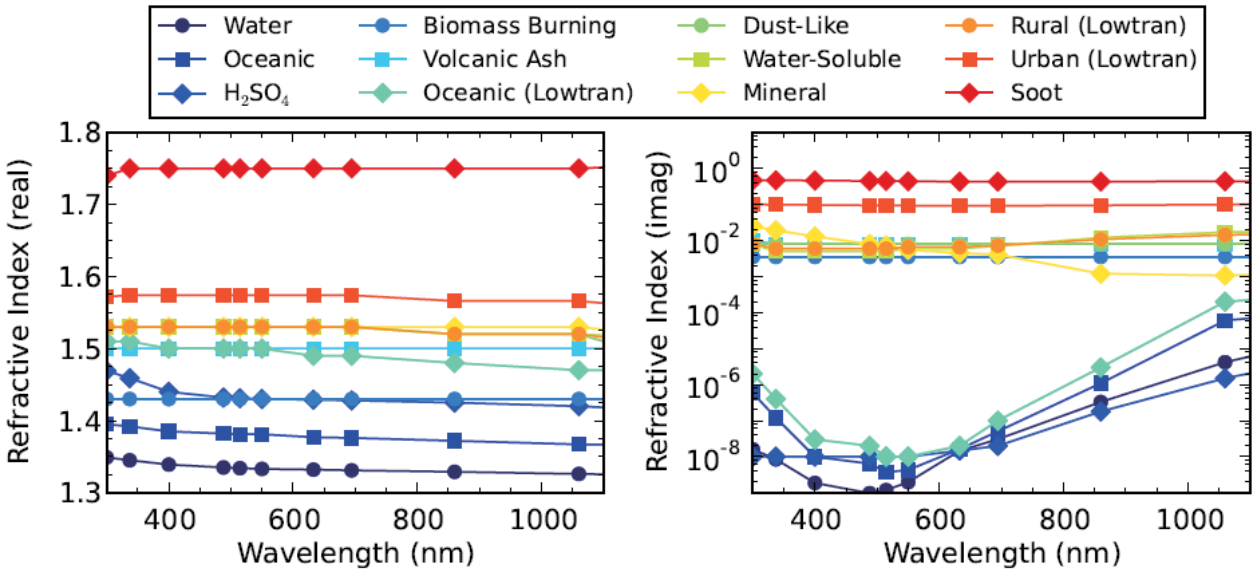
- Manufacturer:
  - EBA JAPAN Co. , Ltd.
- Optics
  - Transmission Diffraction Grating
  - Less sensitive to polarization
- Portable
  - Built-in scanning system
  - No device other than a PC is needed
- Customizable
  - NH-2 was customized for Chiba-U.

Major Specifications of NH-2 HS camera	
Sensor Type	CMOS
Max. Image Size	752 × 480
Field of View	16° × 10°
Sampling/Resol.	0.02° / 0.07°
Wavelength Size	480
Wavelength Range	350 – 1100 nm
Sampling/Resol.	1.6 nm / 6 nm
Color Depth	10 bit
Body Size	76 × 62 × 193 mm^3
Weight	850 g

How to Retrieve Aerosol Characteristics

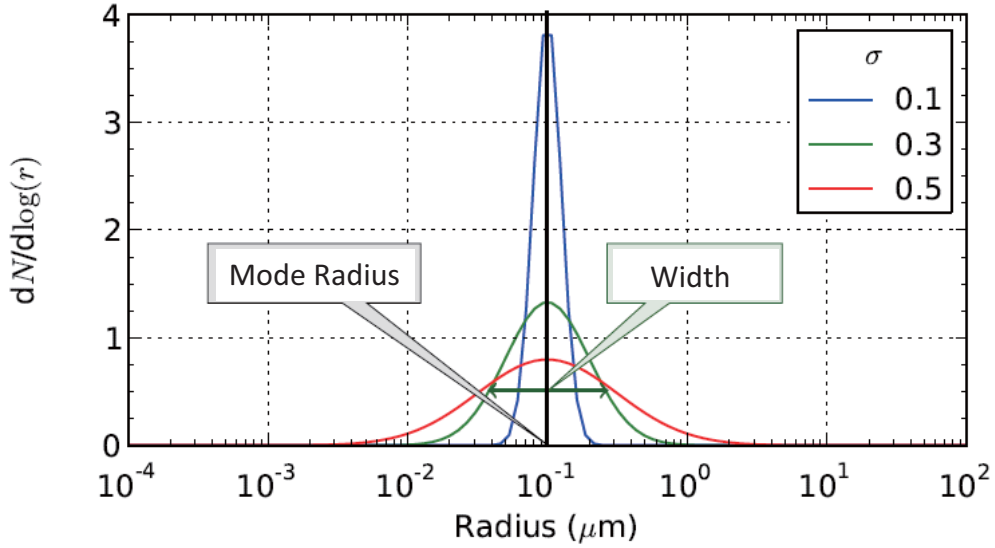
1. Obtain Spectral Radiance Distribution of Skylight (SRDS)
   - **Calibration**
     - Wavelength, Radiance, Viewing Angle, etc.
2. Calculate SRDS using Radiative Transfer Simulation
   - MODTRAN
     - Atmospheric Model
     - **Aerosol Model**
     - **Complex Refractive Index**
     - **Size Distribution**
     - **Vertical Profile**
     - Instrument Model
3. Modify aerosol model parameters to reproduce the observed SRDS

Aerosol Model (Complex Refractive Index)



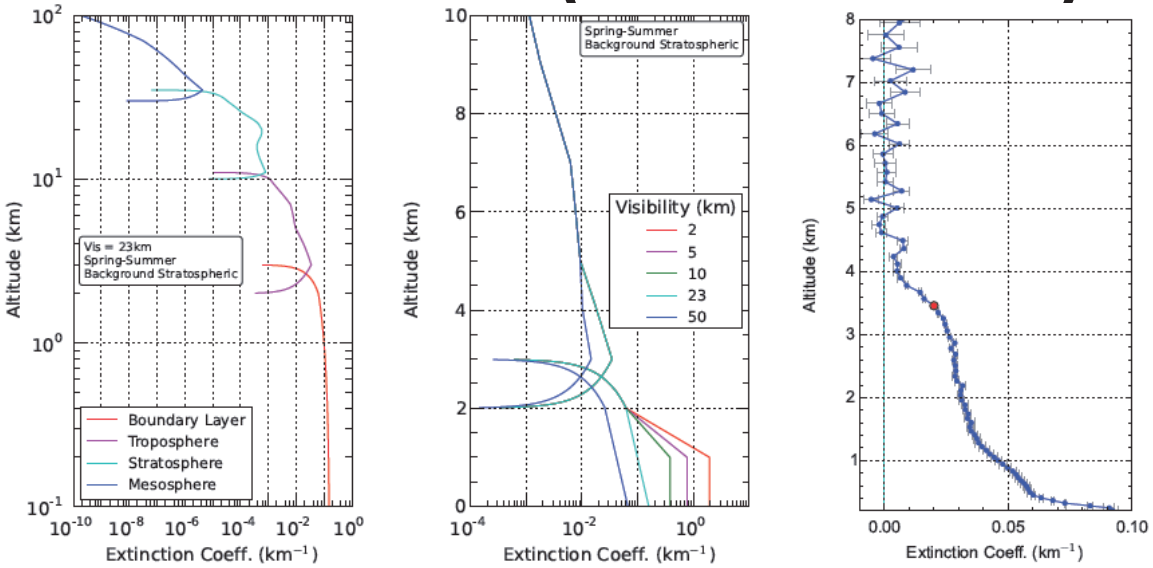
- 3 Component Aerosol Model
  - Mixing Ratio of 3 components (water soluble, oceanic, and soot)
- 1 or 2 Component Aerosol Model
  - Real/Imaginary parts of complex refractive index

Aerosol Model (Size Distribution)



- Lognormal Size Distribution
  - Mode Radius/Width
  - Mode radius and width cannot be optimized independently
    ⇒ Width parameter is fixed

Aerosol Model (Vertical Profile)

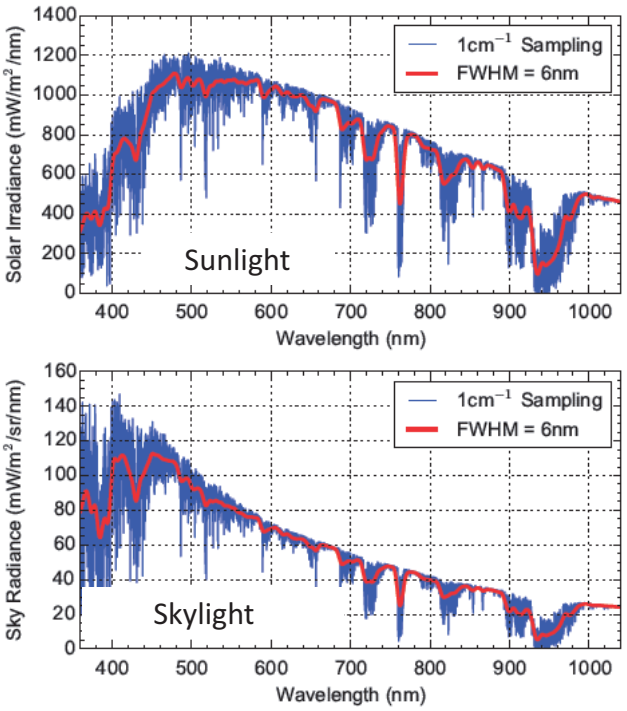


- MODTRAN's built-in models are used.
  - Absolute value of extinction coefficient adjusted so that integrated value becomes the optical depth.

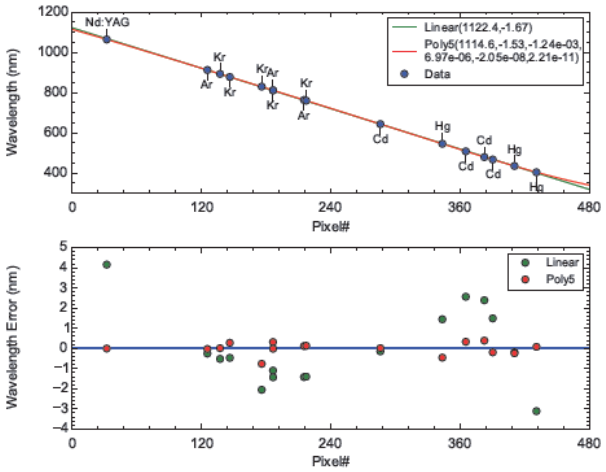
Radiative Transfer Simulation

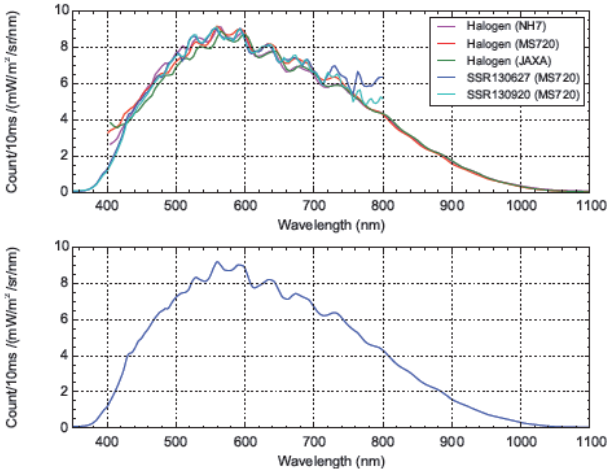
- MODTRAN (ver. 4)
  - ➢ Extinction Coeff.
  - ➢ Absorption Coeff.
  - ➢ Phase Function
  - ➢ Vertical Profile

- Extinction Coeff., Absorption Coff., and Phase function can be calculated from the aerosol model with the Mie theory.



Calibration (Wavelength/Radiance)

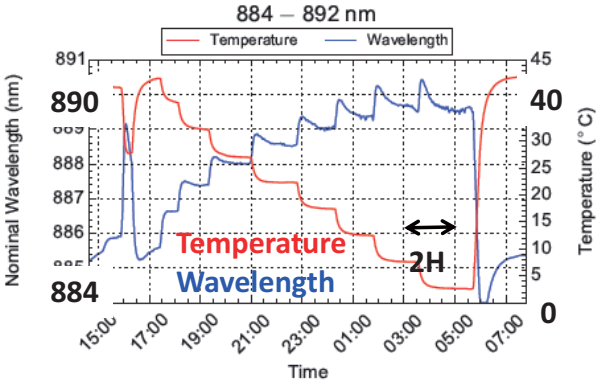


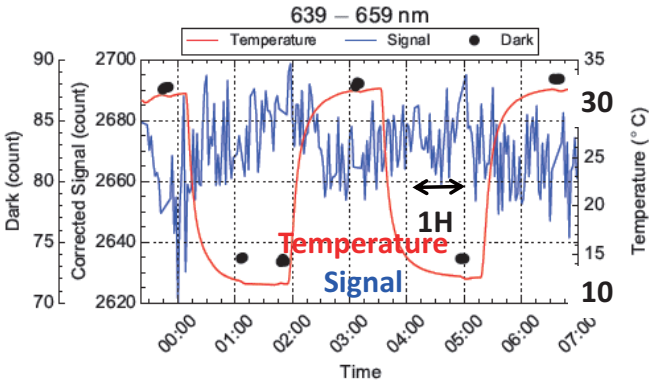


- Wavelength calibration
  - Discharge Lamp Hg, Ar, Cd, Kr) and Nd:YAG Laser
- 14 emission liness are used to obtain 5th order polynomial
- Fitting error: 0.29 nm

- Radiance calibration
  - Skylight
  - Integrating Sphere
- Peak sensitivity @550 nm
- Sensitivity range 350 – 1100 nm

Calibration (Temperature Dependence)



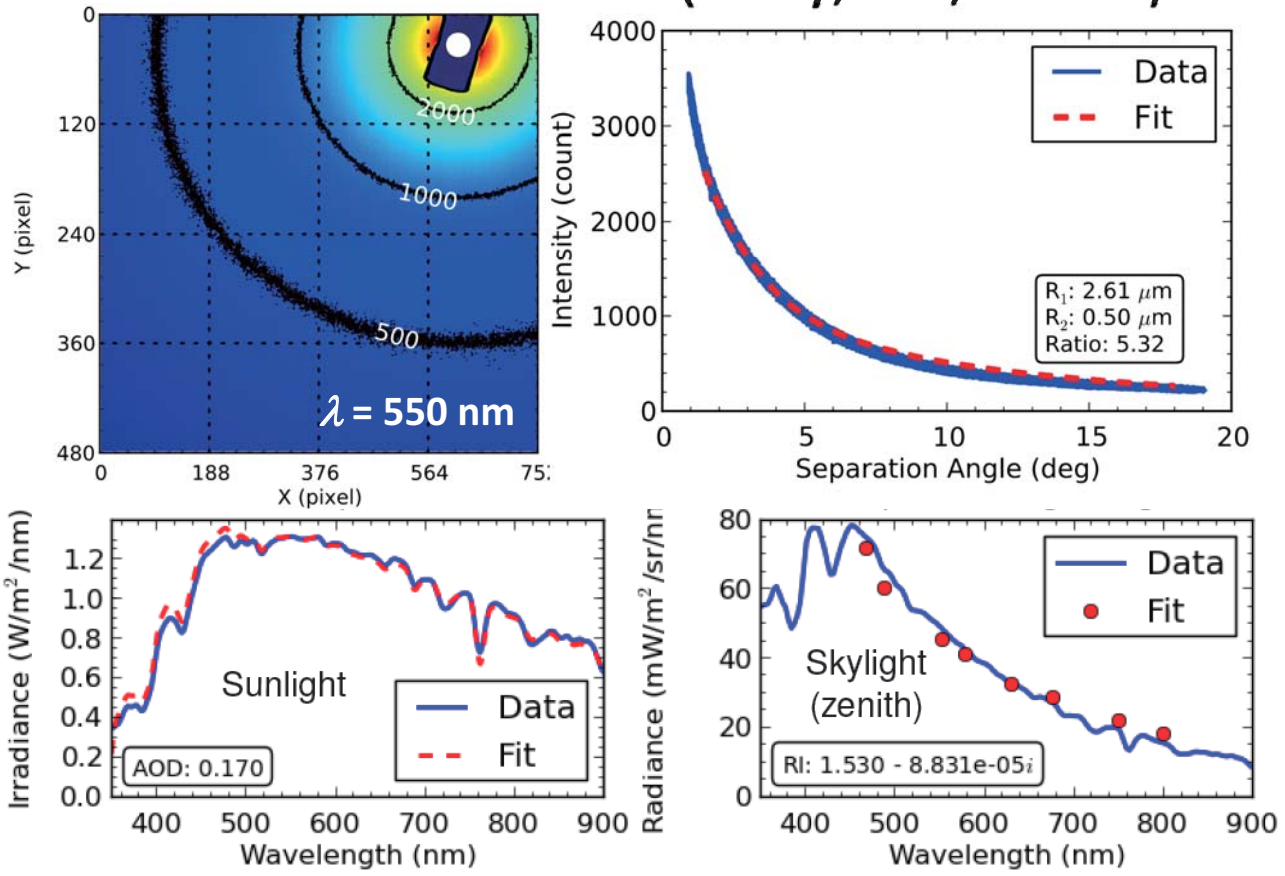


- Wavelength
  - Xenon Lamp
- Wavelength shift:
  - ➢ -1 nm – 1 nm (< 30°C)
  - ➢ 2 nm (< 40°C)
- Fitting error: 0.1 nm

- Radiance
  - Halogen Lamp
- Correction factor:
  - 5% (500 nm – 900 nm)
  - 30% (other wavelengths)
- Fitting error:
  - ➢ 0.2% (< 40°C)

Observation at Chiba University

Test Observation (May, 24, 2013)



Test Observation Result

Aerosol Optical Depth	0.17	
H_2O Scale^{*a}	0.25	
	Component 1	Component 2
Refractive Index (real)	(1.53)	(1.53)
Refractive Index (imag)	8.8E-05	
Mode Radius (μm)	2.61	0.5
Distribution Width	(0.26)	(0.26)
Mixing Ratio^{*b}	(1)	5.32

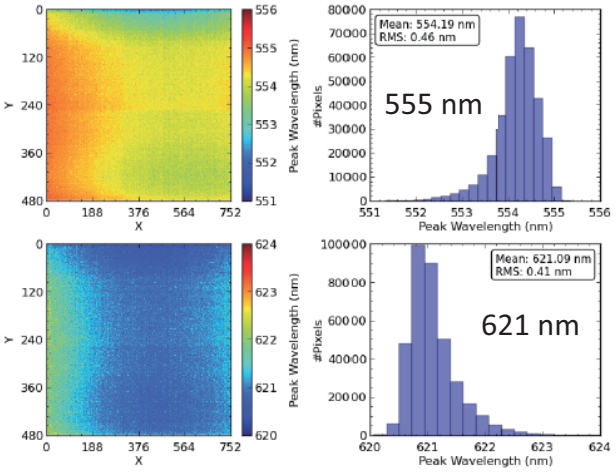
$*a$ Factor to scale the MODTRAN's default value

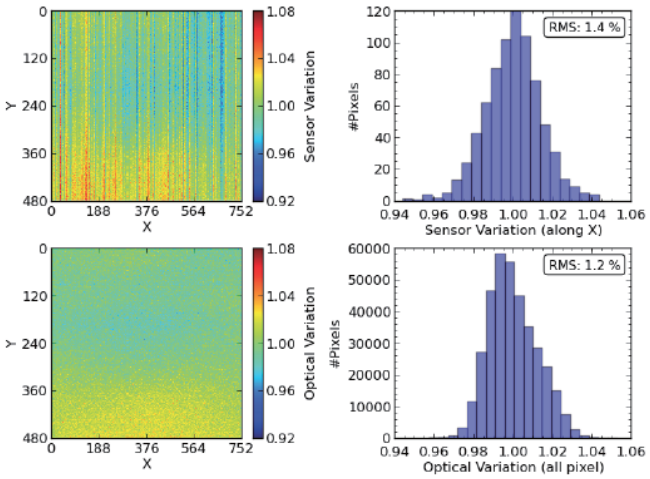
$*b$ Weighted with the extinction cross-section at 550 nm

- Skylight is measured at the zenith only.
- Aureole is used for the angular dependence at 550 nm only.
- The two component aerosol model can reproduce the angular dependence of aureole well, while the one component aerosol model cannot reproduce the steep slope near the sun.

- Thank you very much for your attention!

Calibration (Sensor Uniformity)

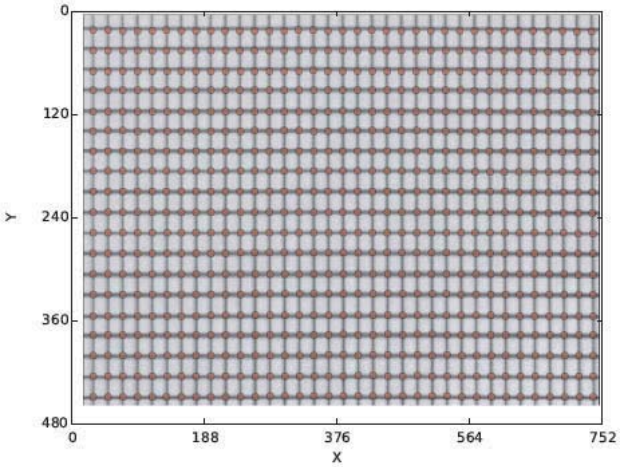




- Wavelength Uniformity:
  - Fluorescent Lamp + diffuser
- Non-uniformity (RMS): 0.4 nm

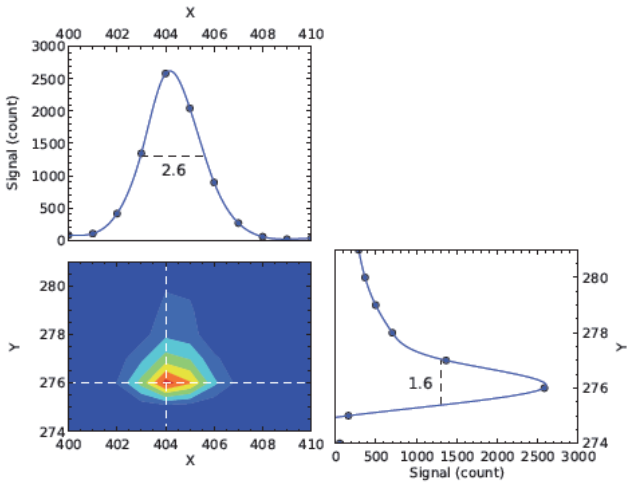
- Radiance Uniformity:
  - Twilight flat
- Sensor non-uniformity: 1.4%
- Optics non-uniformity: 1.2 % (including the light source)

Calibration (Viewing Angle)



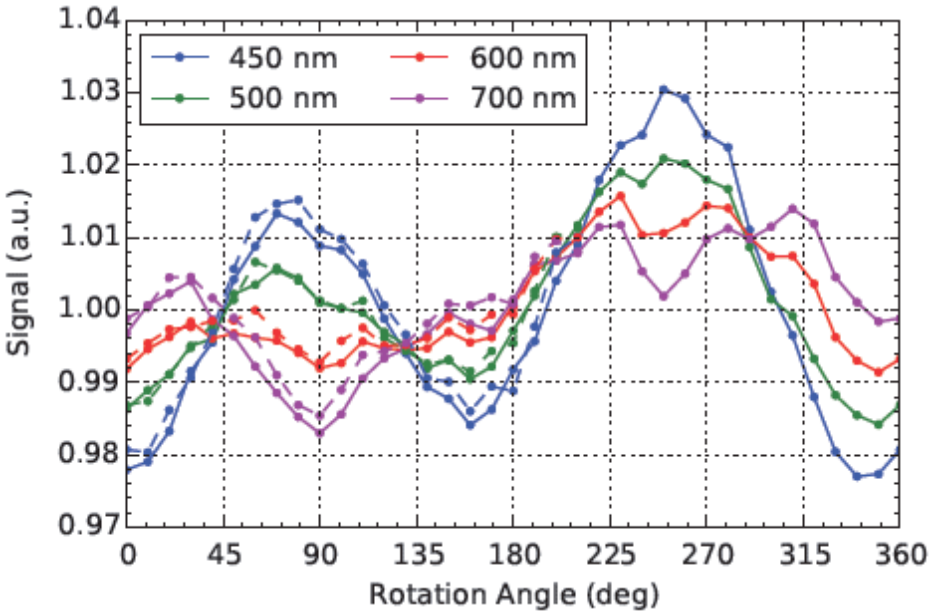
- Relationship between pixel number and angular coordinates are estimated from a image of cross-section paper.
- X direction: 0.022 deg/pixel ← pixel size
- Y direction: 0.020 deg/pixel ← step size of scanner
- Image distortion is small

Calibration (Spatial Resolution)



- Point Spread Function
  - X direction: 0.057 degree
  - Y direction: 0.053 degree
  - Radial direction: 0.07 degree

Calibration (Polarization Dependence)



- Polarization dependence is less than 2%