High-resolution Oxygen A-band Spectrometer (HABS) and Photon path distribution

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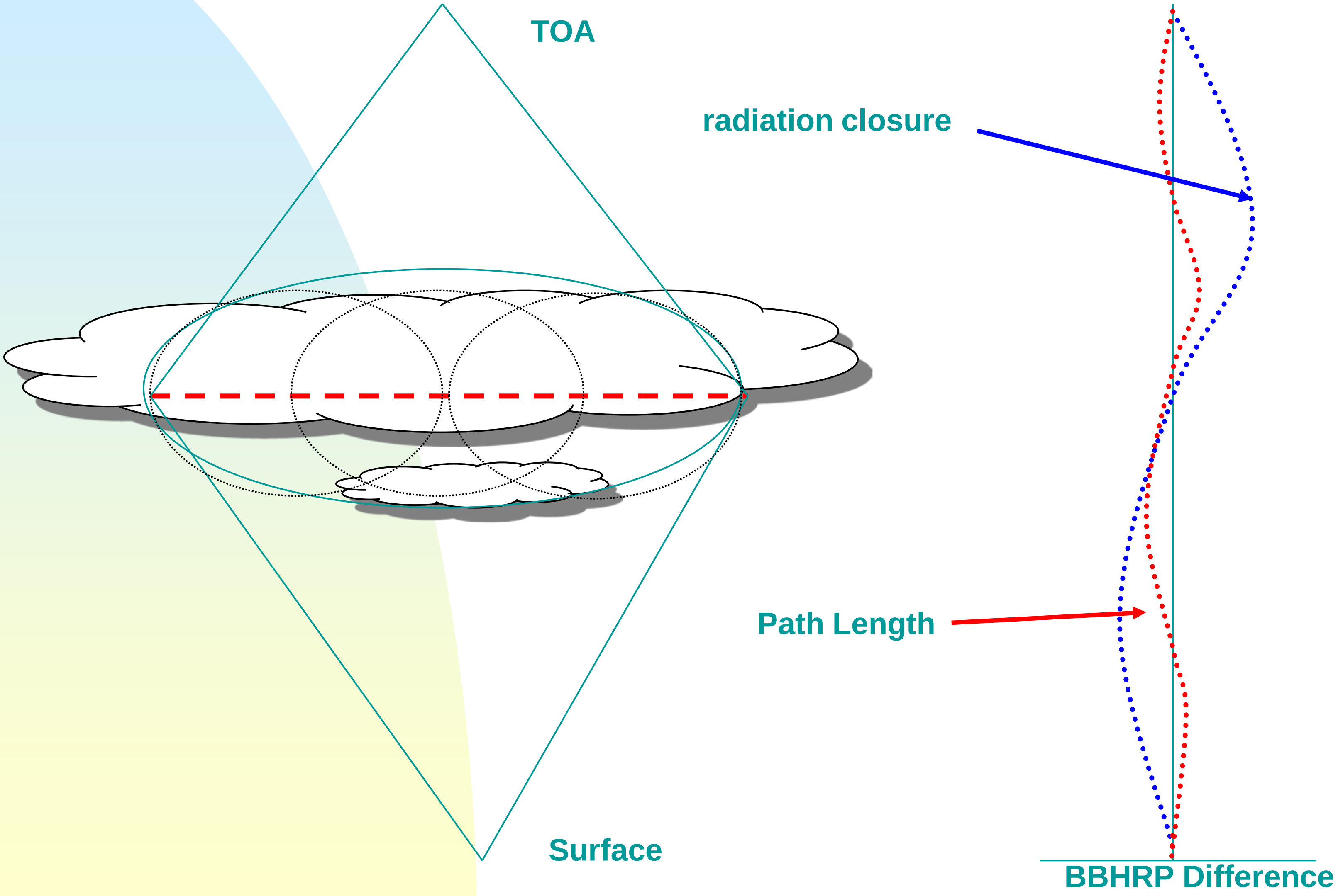
Validate Broadband Heating Rate Profiles (BBHRP)



TOA

radiation closure

Path Length

Surface

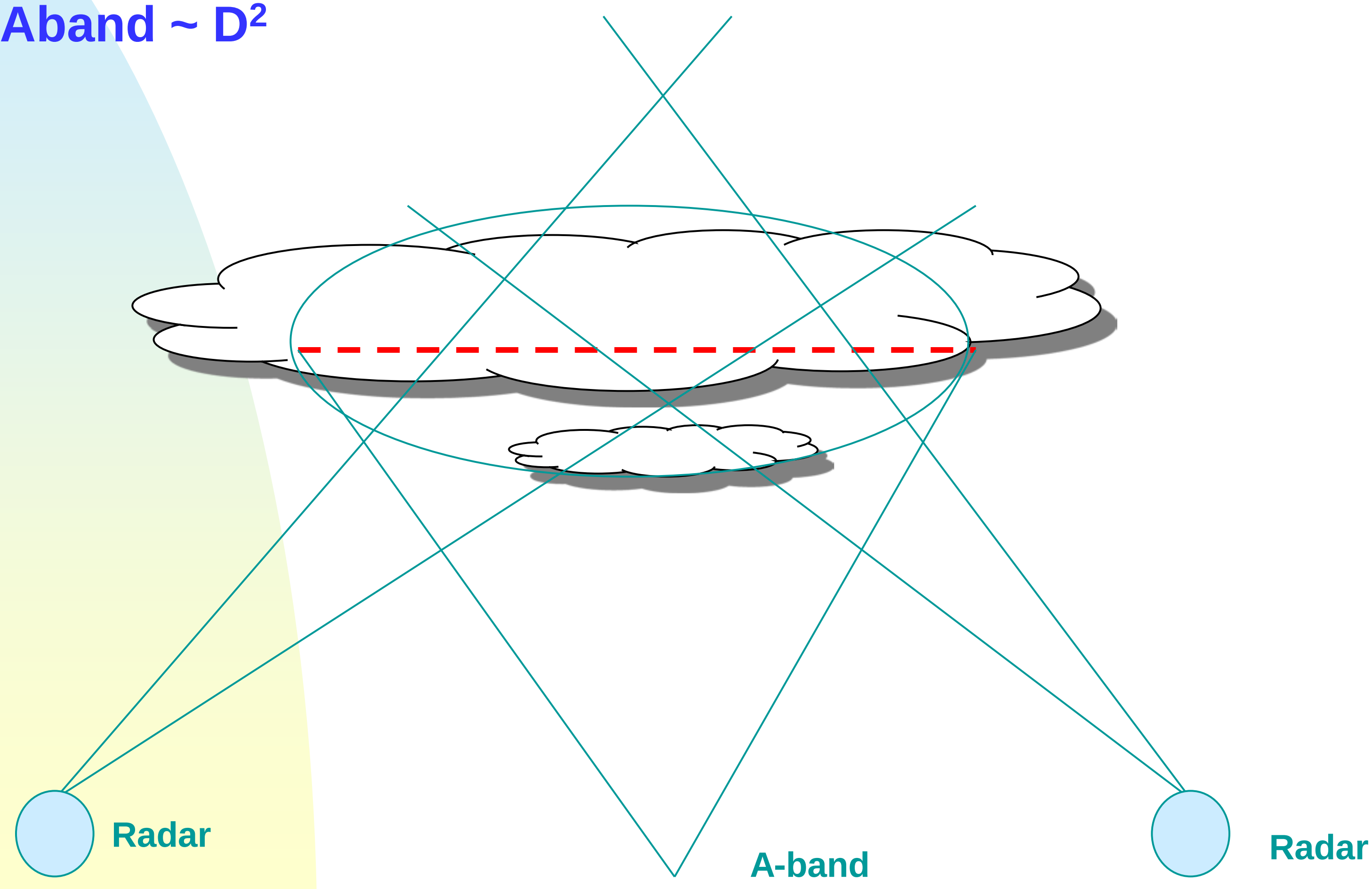
BBHRP Difference

AVA and A-band (Active and passive)

LWP $\sim D^3$

R_radar $\sim D^6$

T_Aband $\sim D^2$



Radiative Transfer and Photon Pathlength Distribution

Equivalence Theorem: [Irvine, 1964]

$$I_\nu(\mu,\phi;\mu_0,\phi_0) = I_0(\mu,\phi;\mu_0,\phi_0)\int_0^\infty p(l,\mu,\phi;\mu_0,\phi_0)e^{-\kappa_\nu l}\,dl$$

Where ***p(l)*** **is photon path length distribution with path length** ***l***

K_v is gaseous absorption coefficient

$I_0(\mu,\phi;\mu_0,\phi_0) \Rightarrow$ **cloud optical properties**

$p(l,\mu,\phi;\mu_0,\phi_0) \Rightarrow$ **cloud geometry**

$\Rightarrow$ **Radiation field**

- **Mean path length to ensues the radiation closure at the surface and TOA**
- **Higher moments to ensure the accuracy of heating profiles**

Radiative Transfer and Photon Pathlength Distribution

Equivalence Theorem: [Irvine, 1964]

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Where ***p(l)*** **is photon path length distribution with path length** ***l***

K_ν is gaseous absorption coefficient

Taking inverse Laplace transform:

$$p(l,\mu,\phi;\mu_0,\phi_0) = L^{-1}\left(\frac{I_\nu(k_\nu,\mu,\phi;\mu_0,\phi_0)}{I_0(\mu,\phi;\mu_0,\phi_0)}\right) = L^{-1}R(k_\nu,\mu,\phi;\mu_0,\phi_0)$$

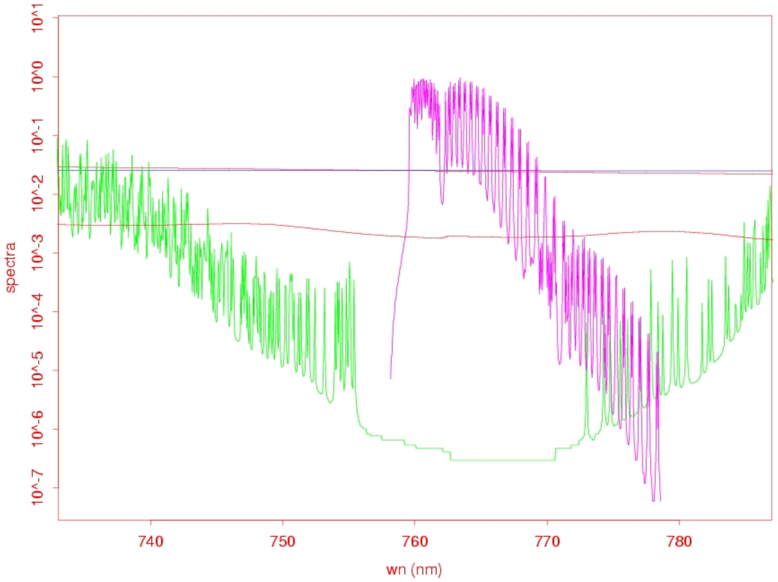
Radiation measurements of $I_0(\mu,\phi;\mu_0,\phi_0)$ **and** $R(k_\nu,\mu,\phi;\mu_0,\phi_0)$

provide a complete set for understanding RT in the atmosphere

Photon Pathlength Distribution and Oxygen A-band

Oxygen A-band: 759 -770 nm

- Vertical profile of Oxygen is well known (uniform mixture)
- No other absorbers interfere within Oxygen A-band
- A number of absorption lines cover a suitable dynamic range
- The lines are regular and “looser” to be resolved by an instrument
- 760nm is the central wavelength to represent SW



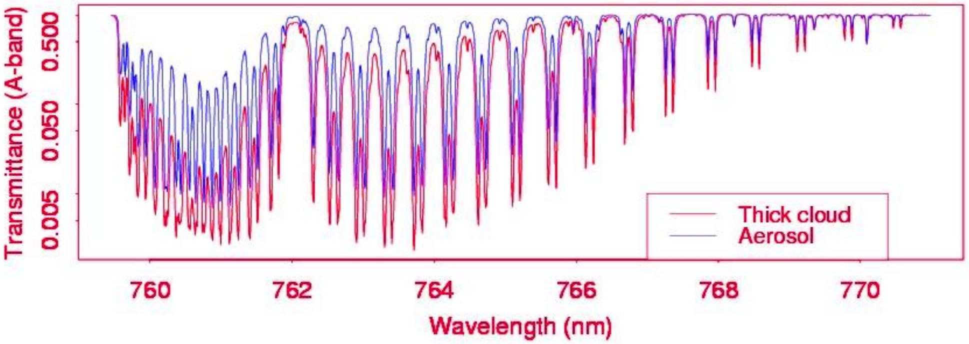
In the lower atmosphere, the line shape of Oxygen A-band

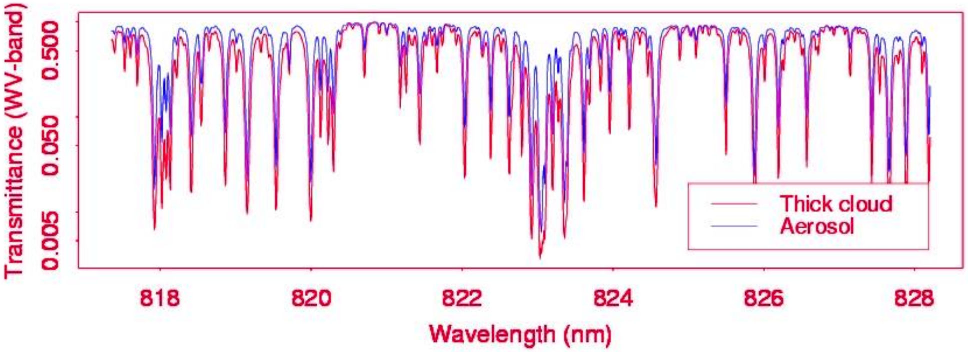
$$k_i = \frac{S_i}{\pi}\frac{\alpha_i}{(\upsilon-\upsilon_i)^2+\alpha_i^2}$$

$$\alpha_i = \alpha_i^0 \frac{p}{p_0}\left(\frac{T_0}{T}\right)^{1/2}$$

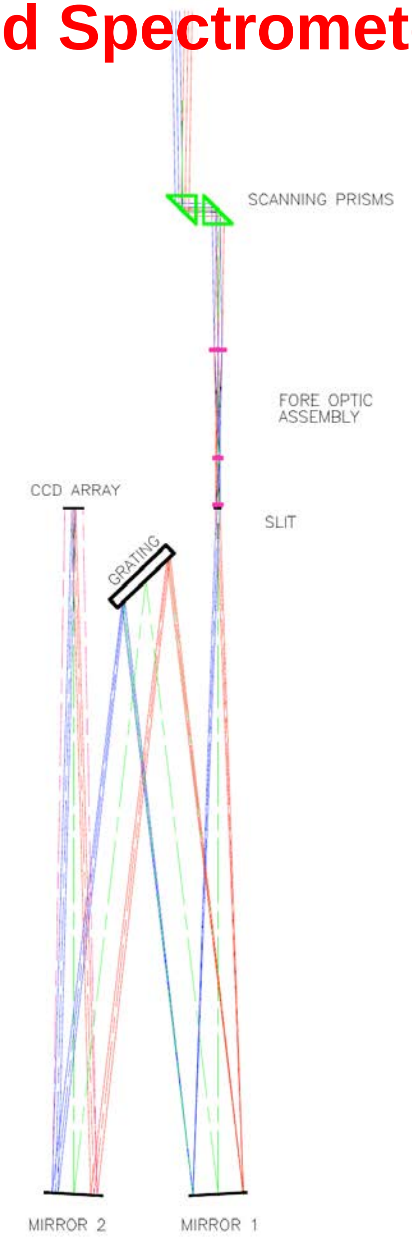
$$S_i = S(T_0)\frac{T_0}{T}\exp[1.439E''(\tfrac{1}{T_0}-\tfrac{1}{T})]$$

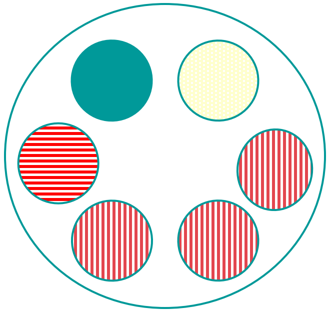
High resolution A-band and Water vapor band Spectrometer (HAWS)





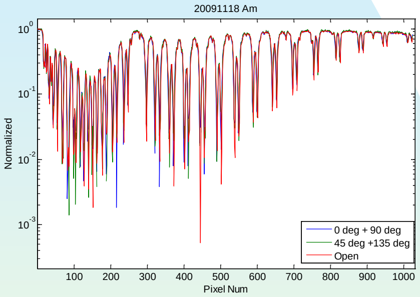
High Resolution Oxygen A-band Spectrometer (HABS)

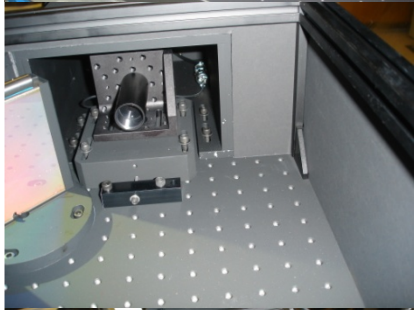


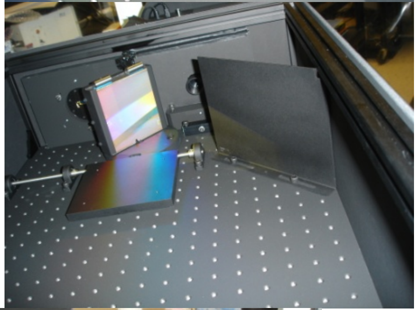


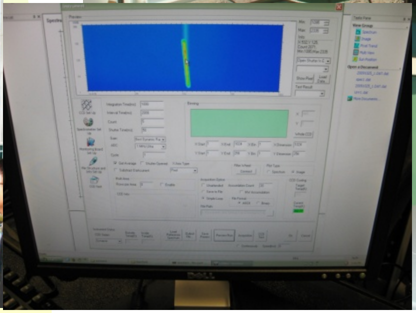
1. Open
2. 0-Polarization
3. 45-Polarization
4. 90-Polarization
5. 135-polarization
6. Diffusor

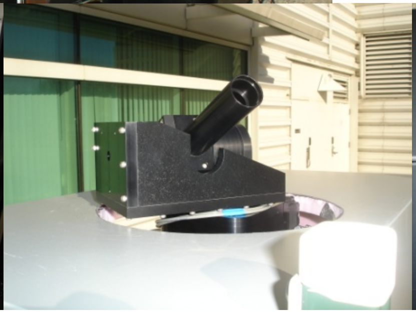
High Resolution Oxygen A-band Spectrometer (HABS)

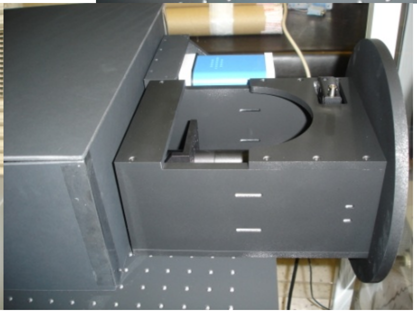






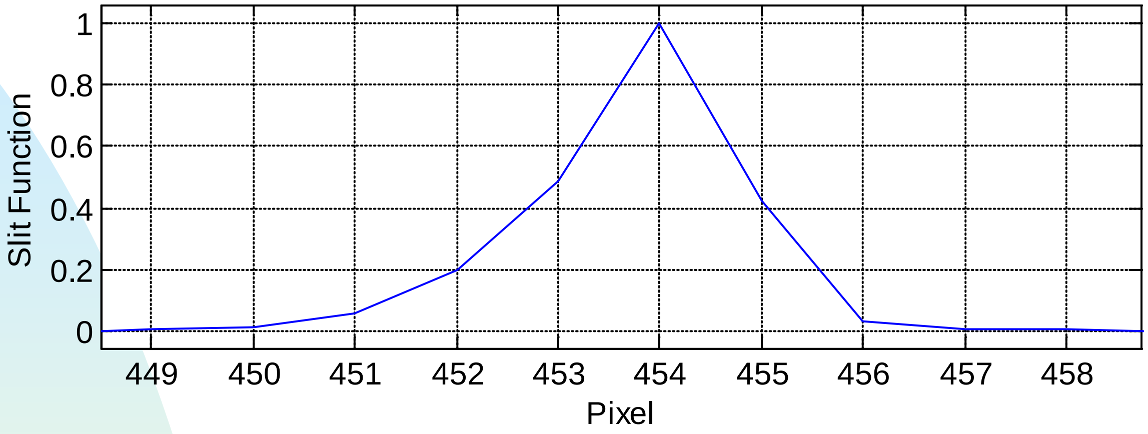


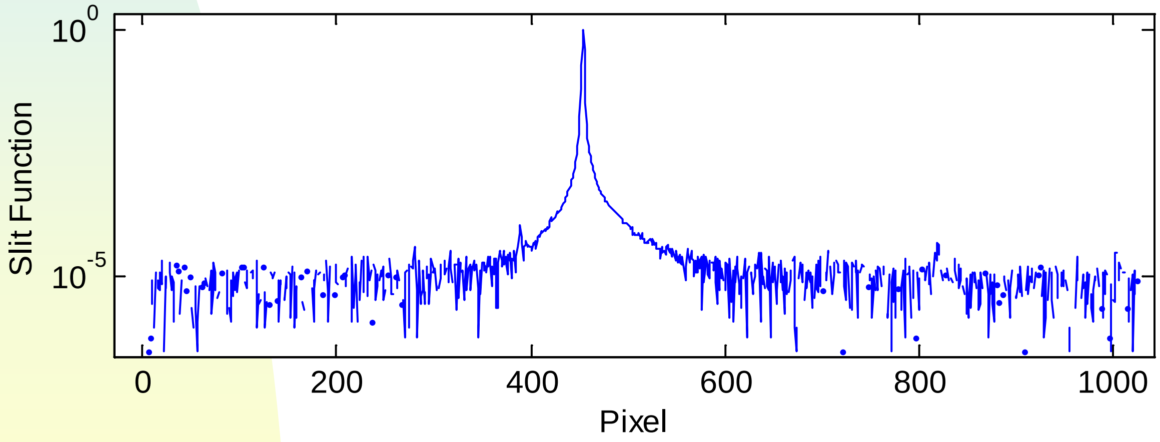




High Resolution Oxygen A-band Spectrometer (HABS)

Slit Function:

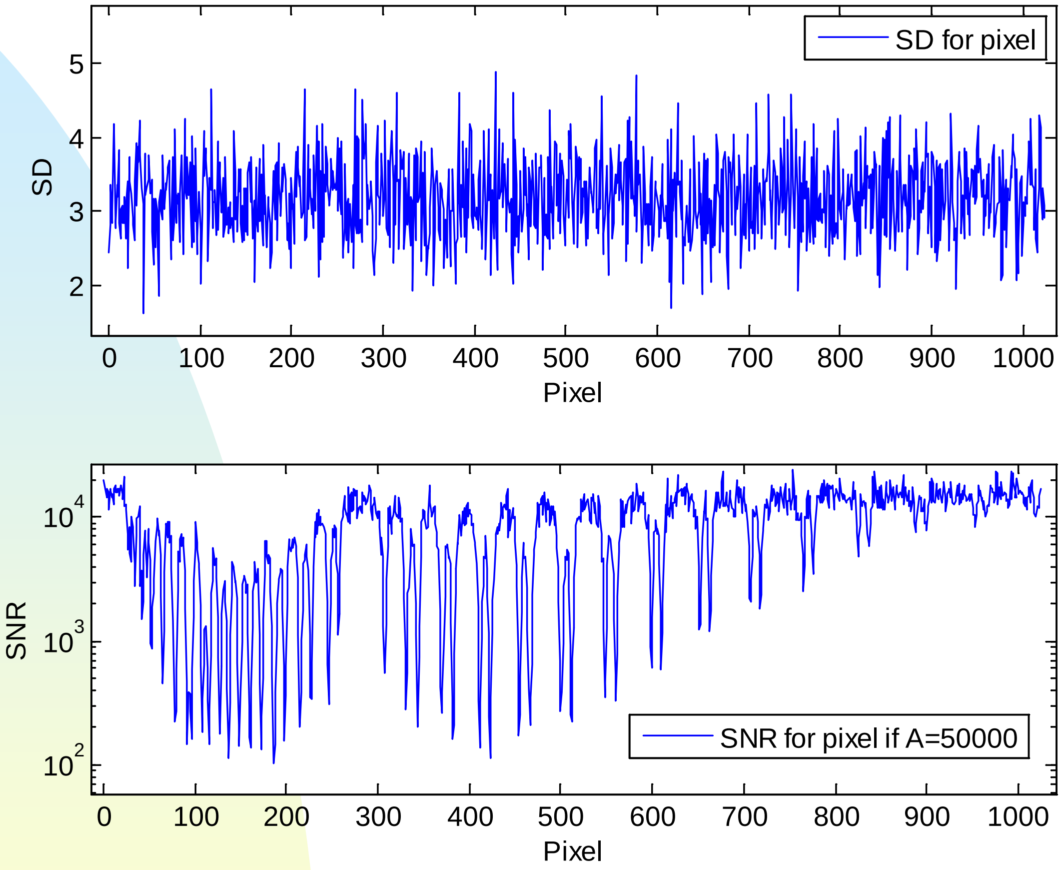




- the FWHM is about 1.85 pixels or 0.019 nm, which is better than 1/3 of wavenumber.
- The out of band rejection of the HABS is 10-5, better than the requirement.

High Resolution Oxygen A-band Spectrometer (HABS)

Signal-to-Noise Ratio (SNR):

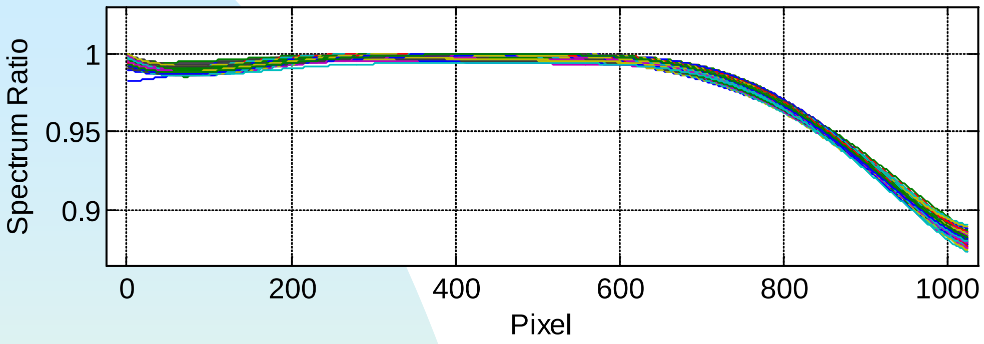


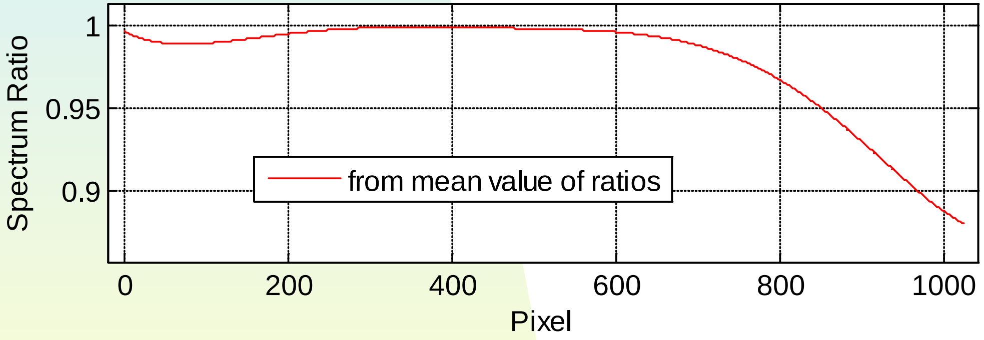
Our test shows that the maximum readout noise is 8.35 e, slightly larger than manufactory specification (6 e).

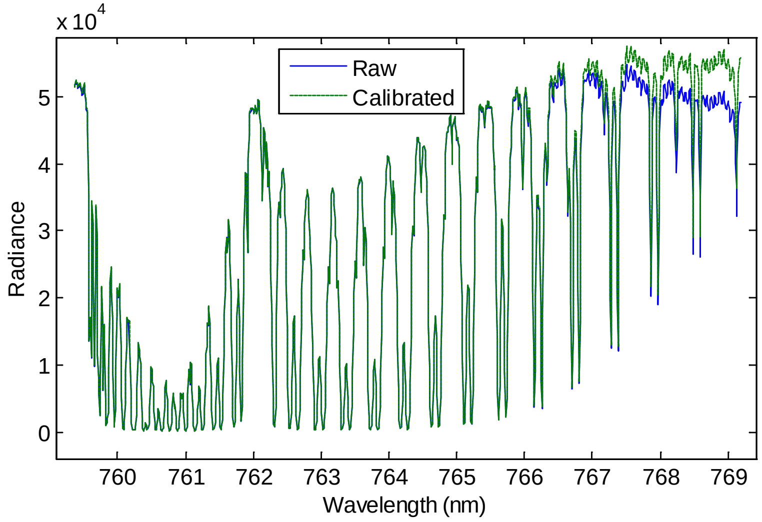
- **With an optimized exposure for zenith measurements, the SNR is above 100 even for the darkest pixel.**
- **It demonstrates the SNR is better than our design requirement.**

High Resolution Oxygen A-band Spectrometer (HABS)

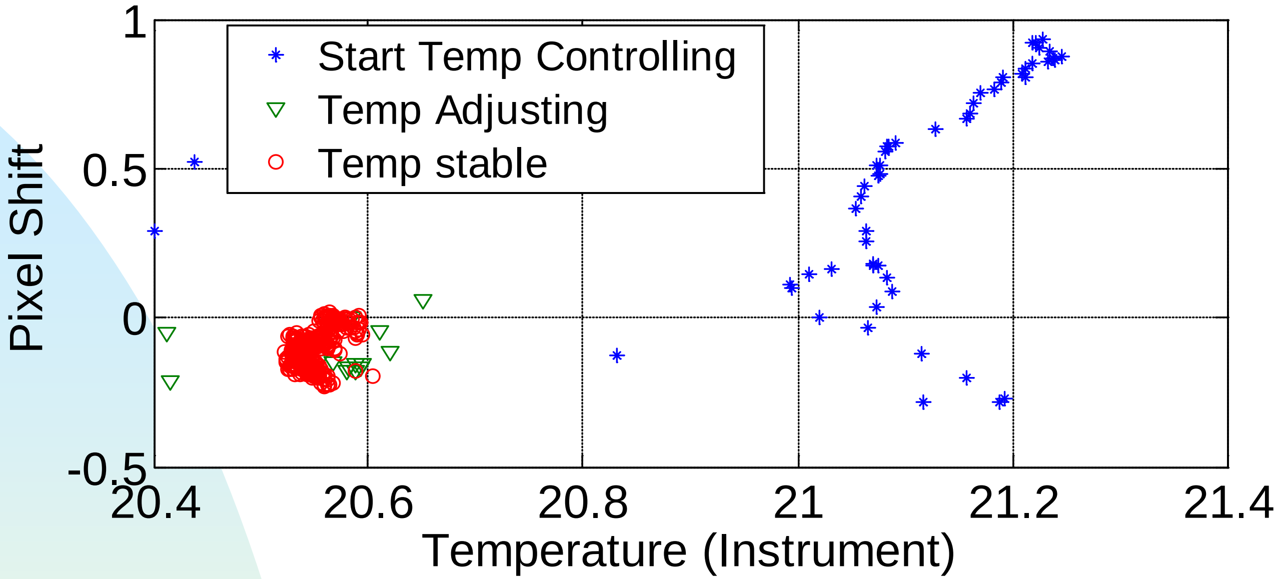
Spectral calibration



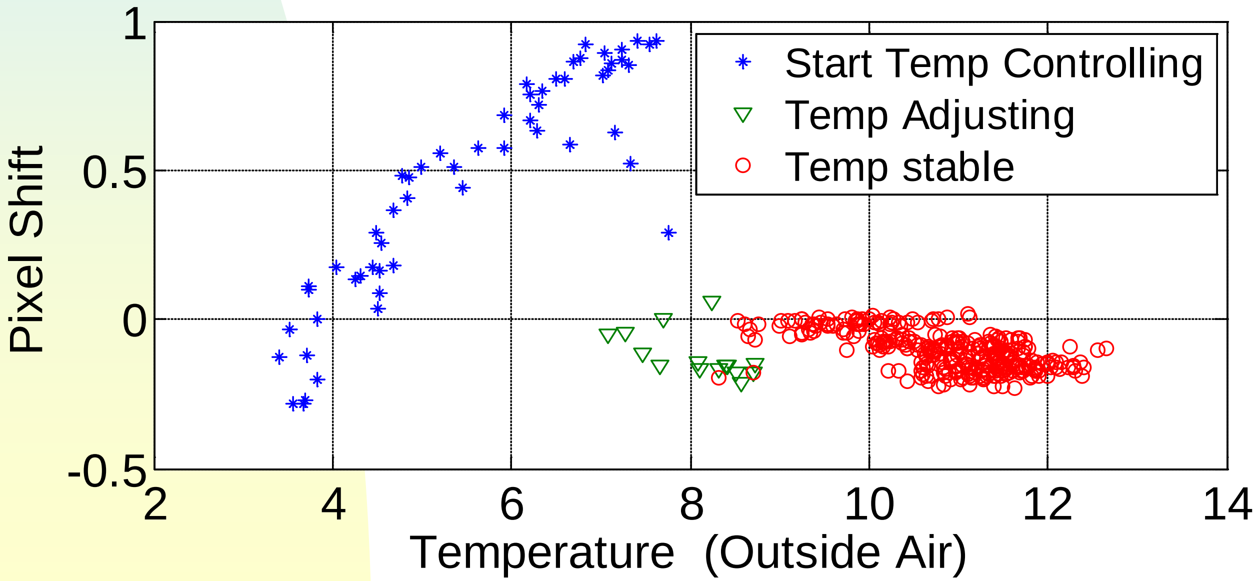




- **The response of overall filter function has been calibrated using GS0937 lamp .**
- **The tail at the long wavelength is calibrated up and consists with radiance at the short wavelength.**

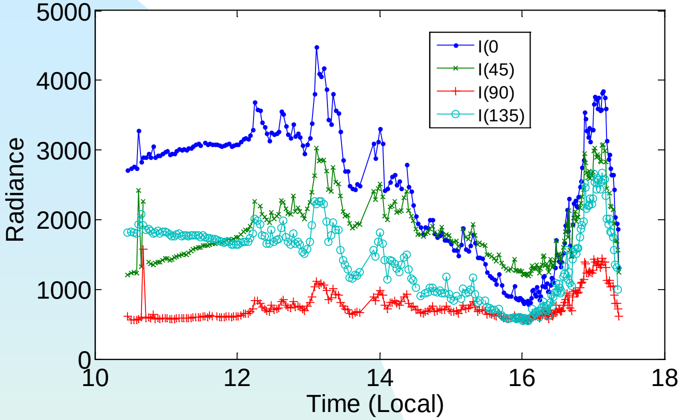


Start Temp Controlling
Temp Adjusting
Temp stable
Pixel Shift
1
0.5
0
-0.5
20.4
20.6
20.8
21
21.2
21.4
Temperature (Instrument)



Start Temp Controlling
Temp Adjusting
Temp stable
Pixel Shift
1
0.5
0
-0.5
2
4
6
8
10
12
14
Temperature (Outside Air)

HABS polarization (and polarization Spectrum)

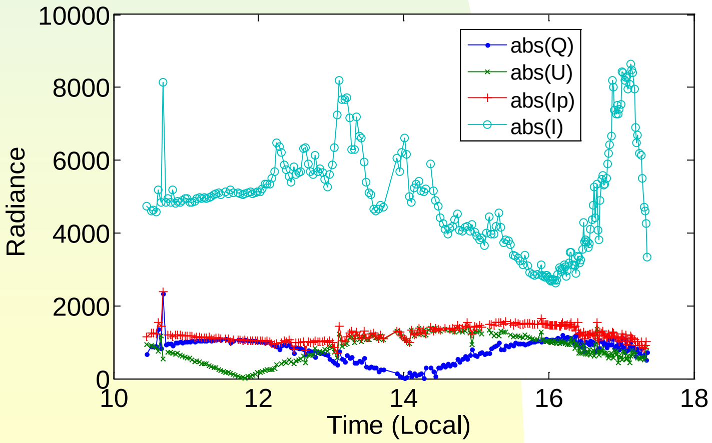


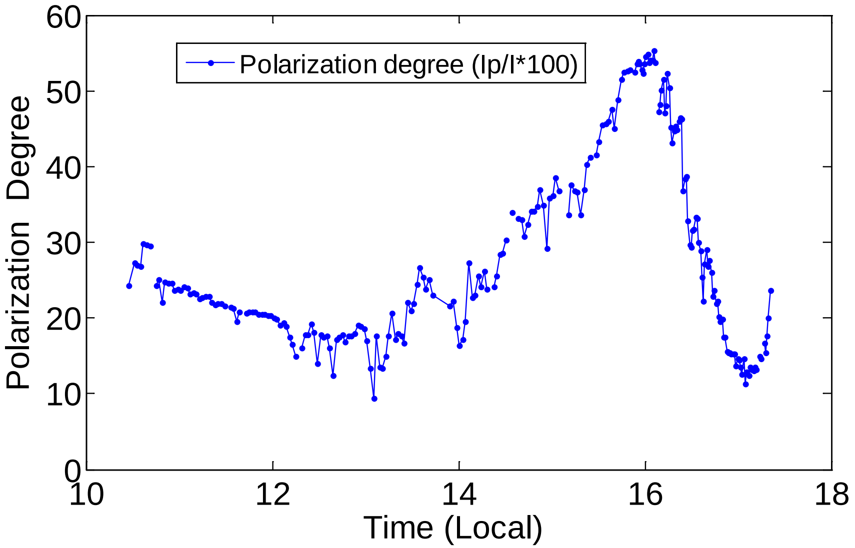
$$I_0' = I_2(0°) + I_2(90°) / R_G$$

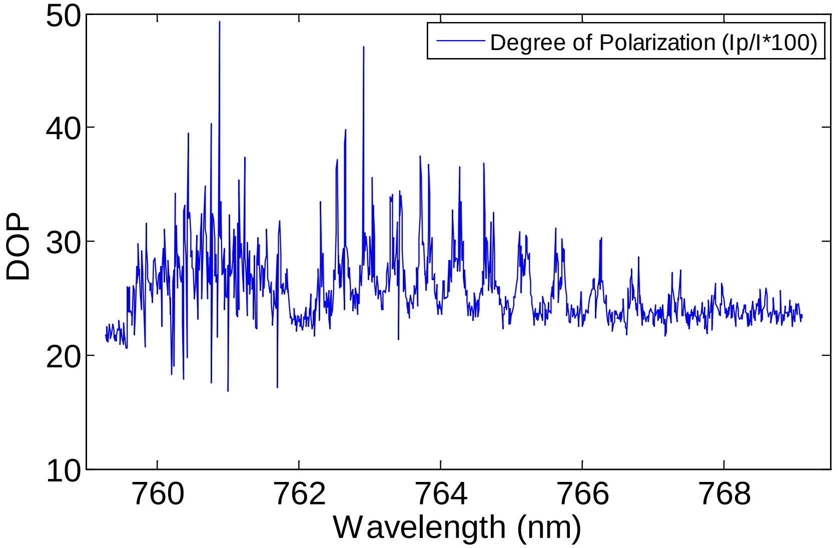
$$Q = I_2(0°) - I_2(90°) / R_G$$

$$U = \left(I_2(45°) - I_2(135°)\right) R_{12}$$

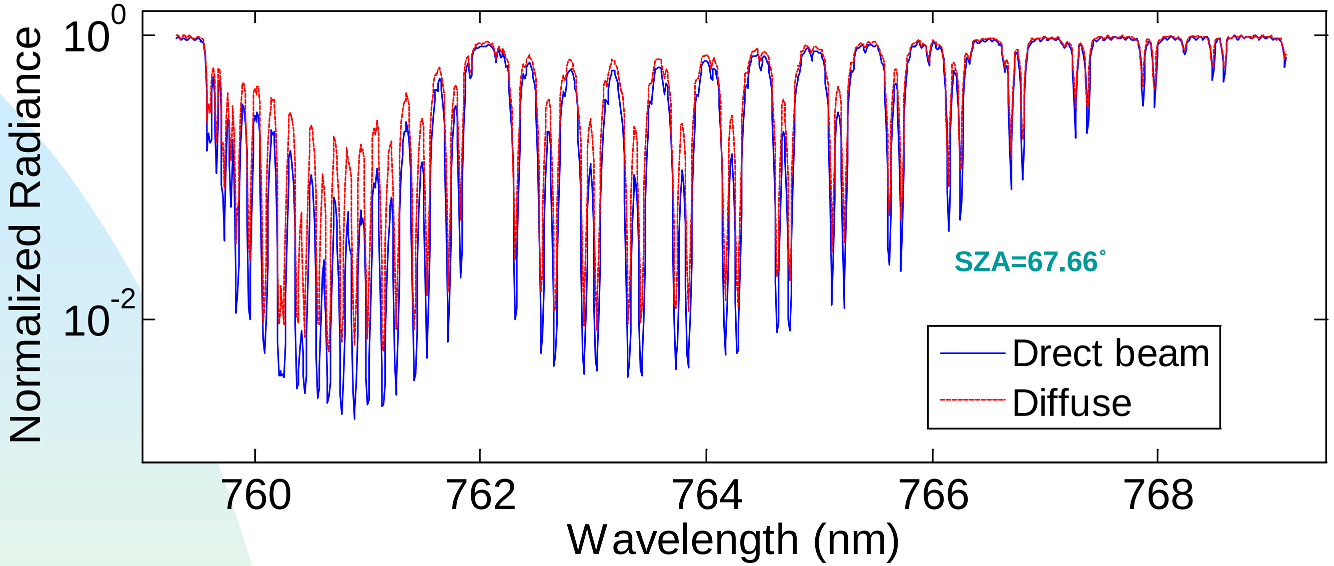
$$I_{0P}' = \sqrt{Q^2 + U^2}$$

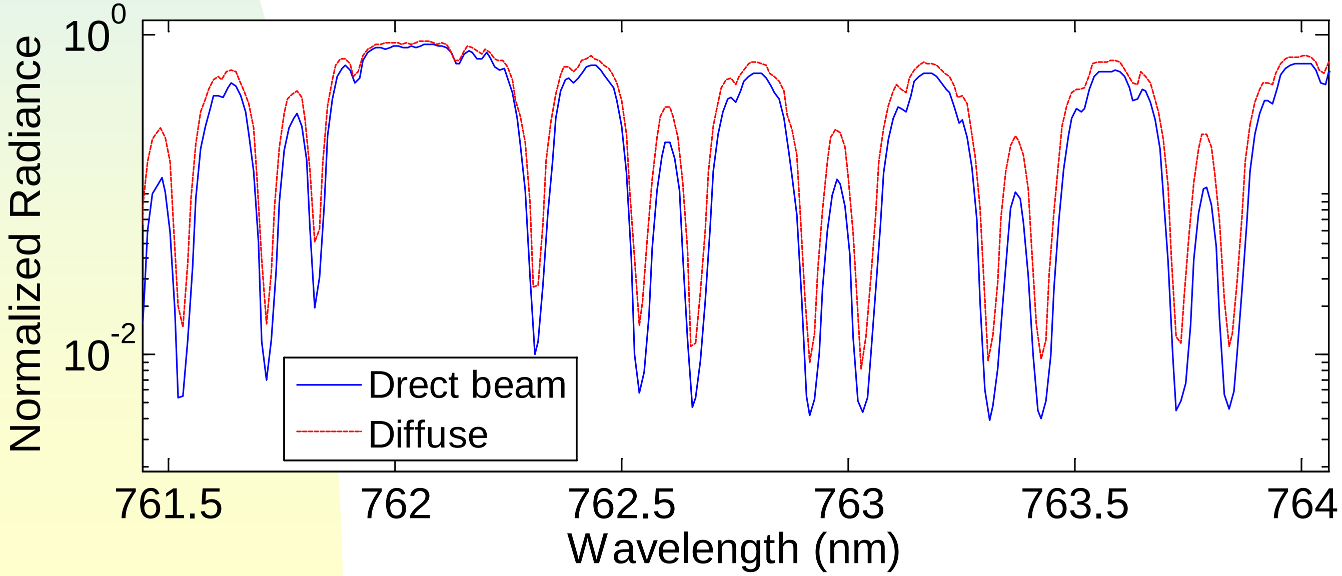




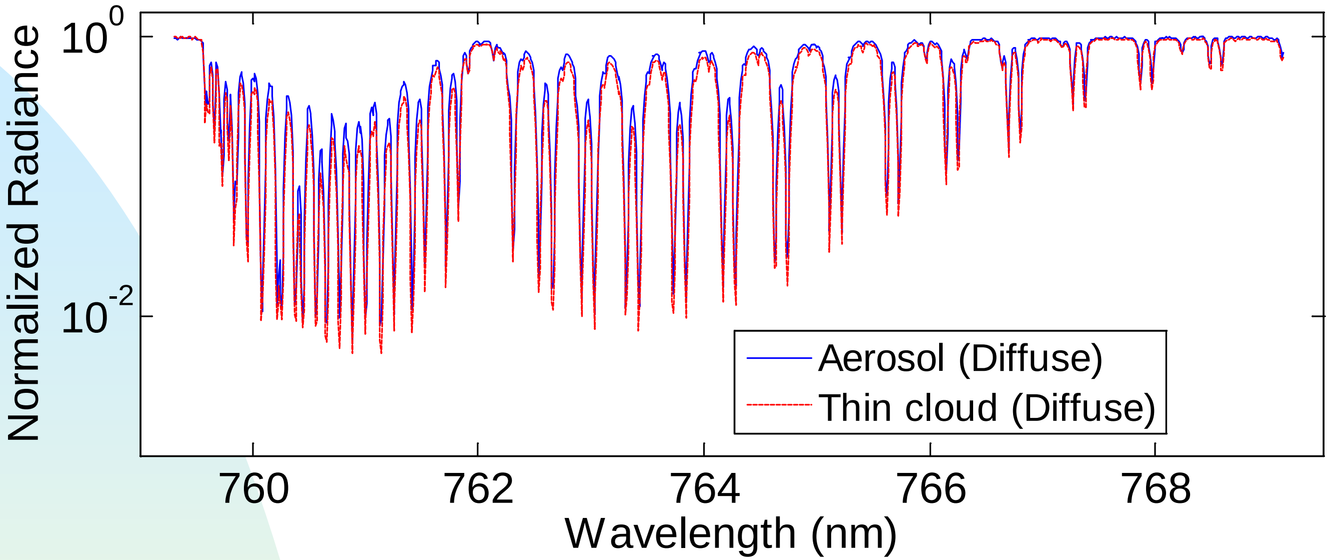


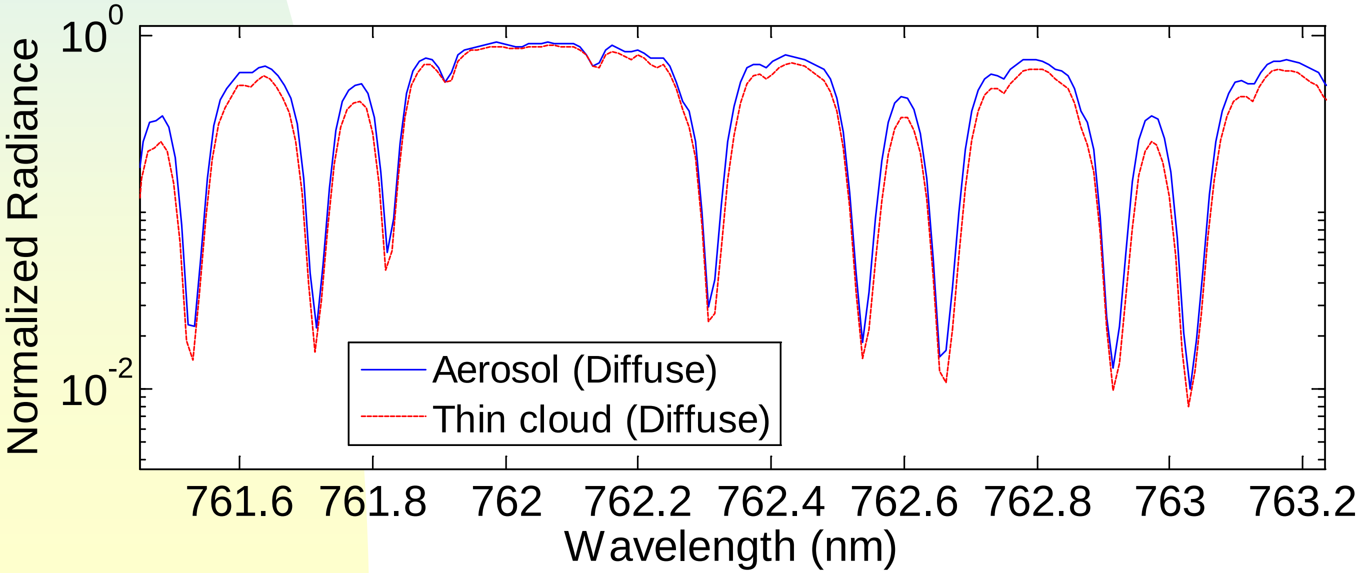
Direct beam vs. diffuse

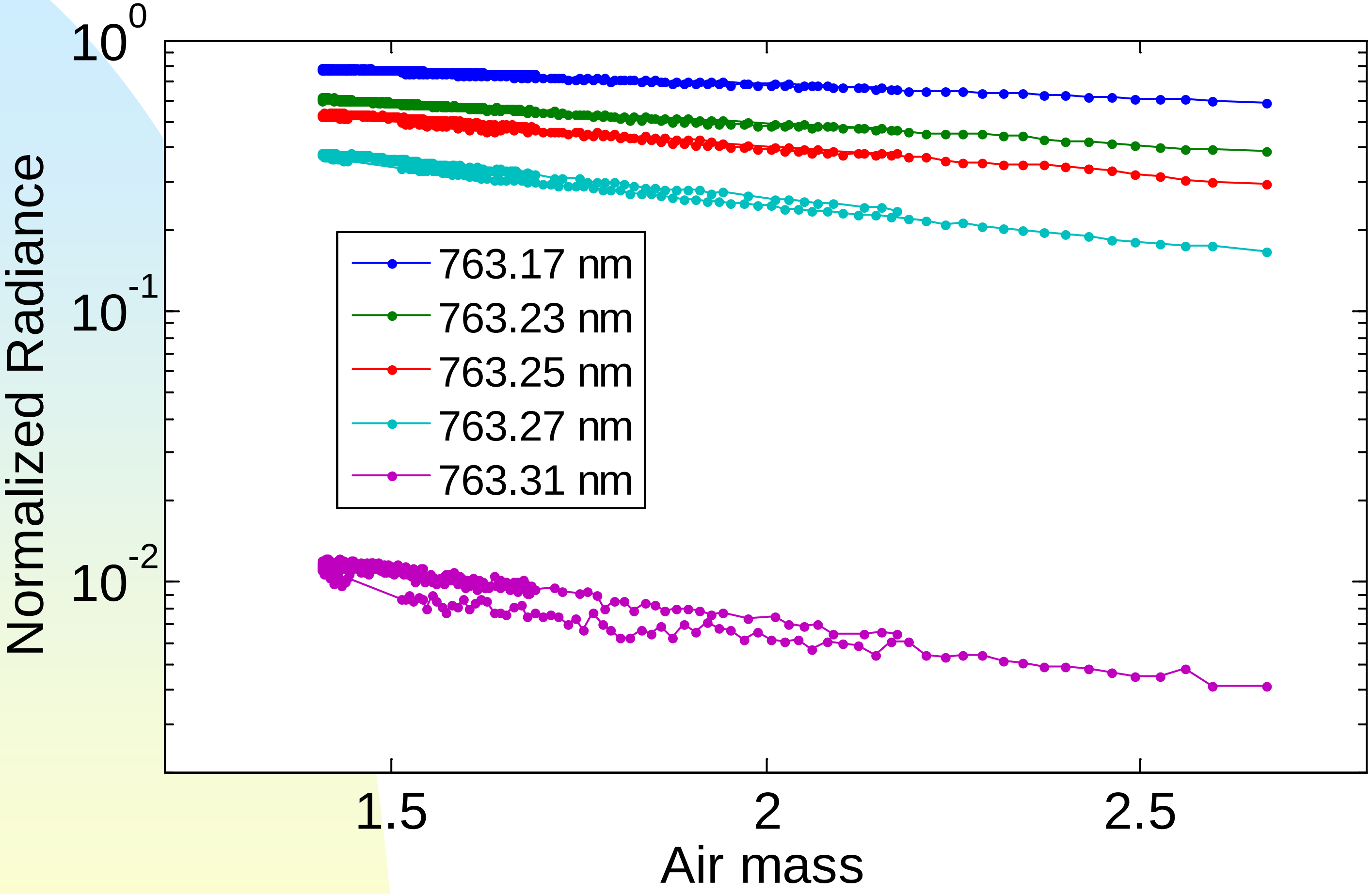




Aerosol vs. Thin cloud





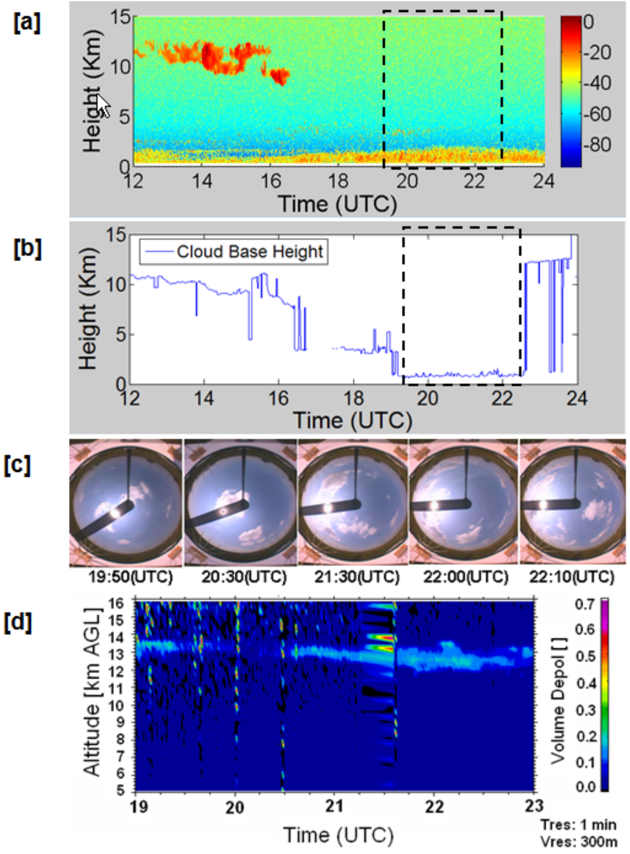


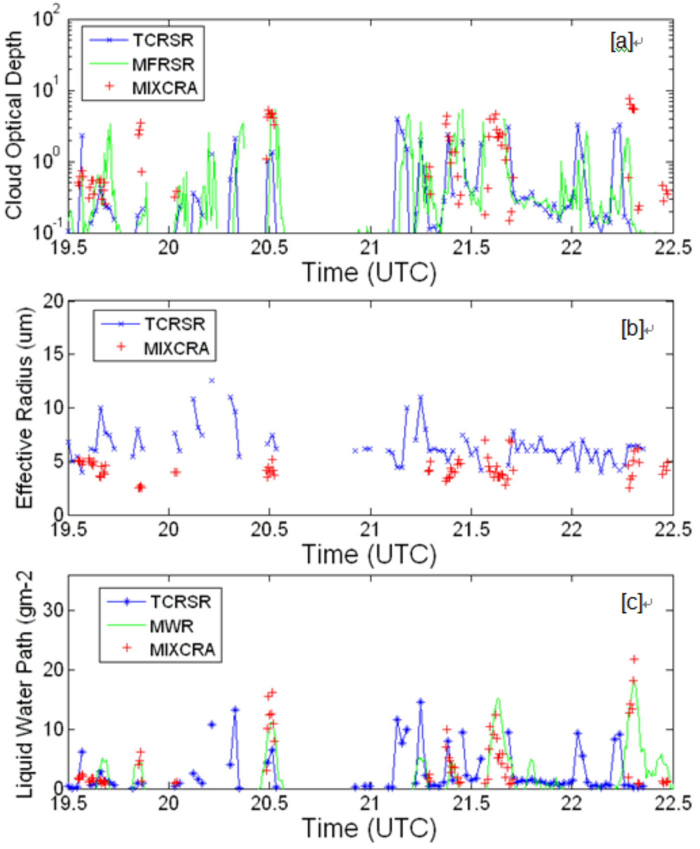
10^0
10^{-1}
10^{-2}
Normalized Radiance
1.5
2
2.5
Air mass
763.17 nm
763.23 nm
763.25 nm
763.27 nm
763.31 nm

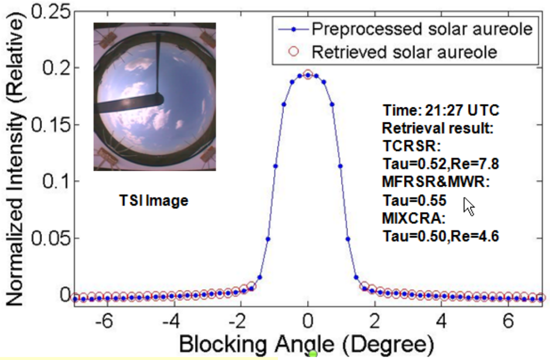
High Resolution Oxygen A-band Spectrometer (HABS)

- **Has the capability to measure both zenith and direct-beam radiances with a field of view of 2.7 degrees. The direct-beam measurements can be used to calibrate the spectrometer and construct retrieval kernels for zenith measurements.**
- **Measures polarizations of A-band spectra with four polarizers, which substantially enhances the retrieval ability for aerosols and ice clouds.**
- **Achieves an out-of-band rejection of 10^{-5}, a resolution of better than 0.3 cm^{-1}, and a high signal-to-noise ratio**

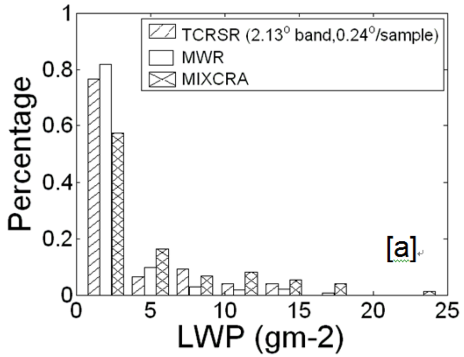
TCRSR retrievals for optically thin clouds: poster by Yin et al.



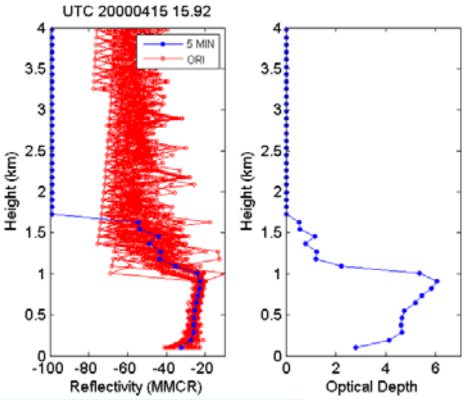




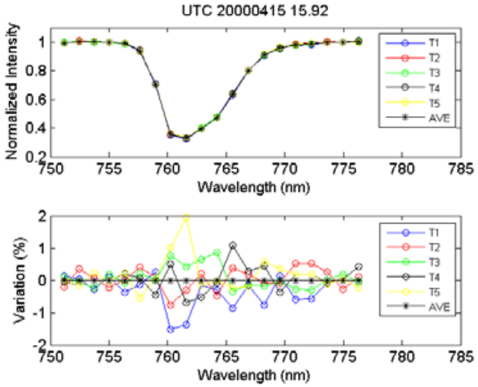
Time: 21:27 UTC
Retrieval result:
TCRSR:
Tau=0.52,Re=7.8
MFRSR&MWR:
Tau=0.55
MIXCRA:
Tau=0.50,Re=4.6

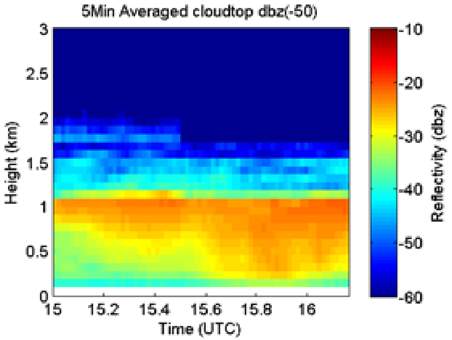


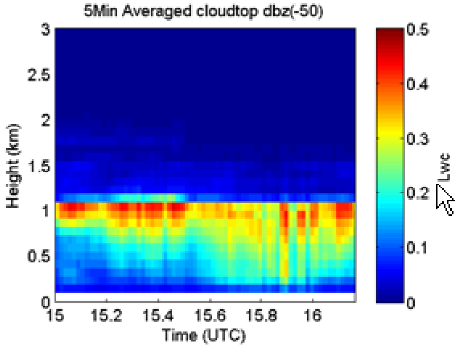
Combining Radar and A-band to retrieve cloud optical property profiles:

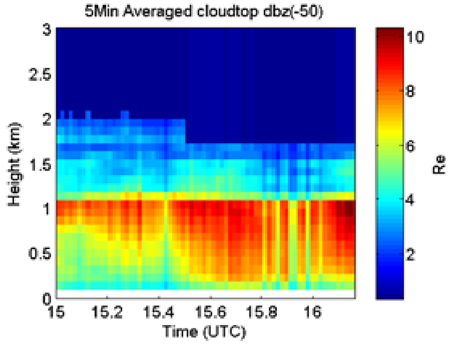


MMCR reflectivity: Re=a f(Z) &LWC=b f(Z)
RSS A-band and MFRSR Tau









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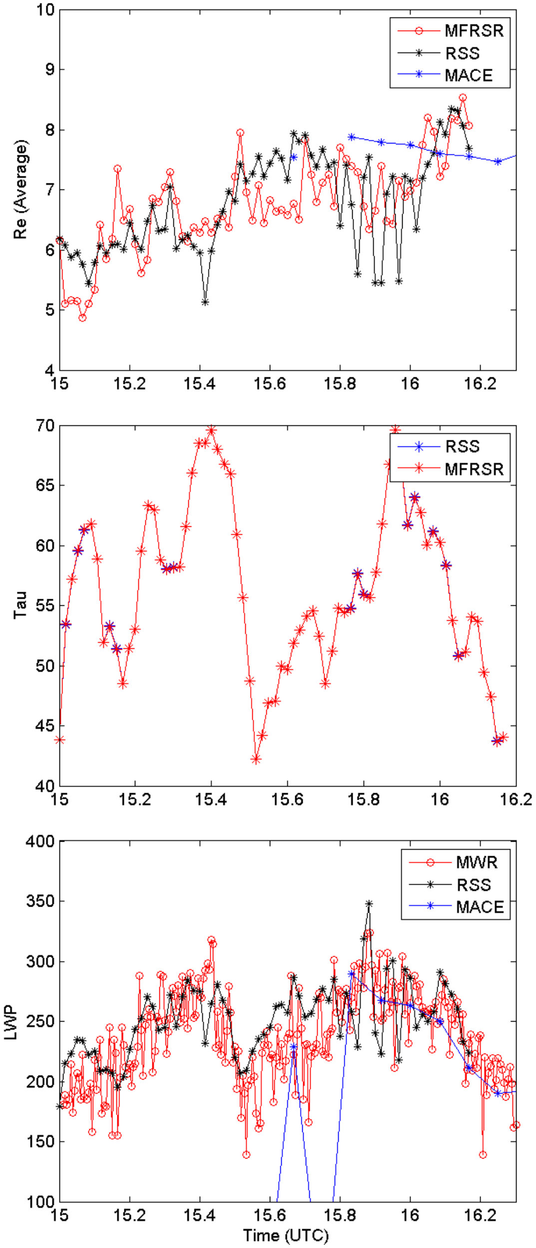
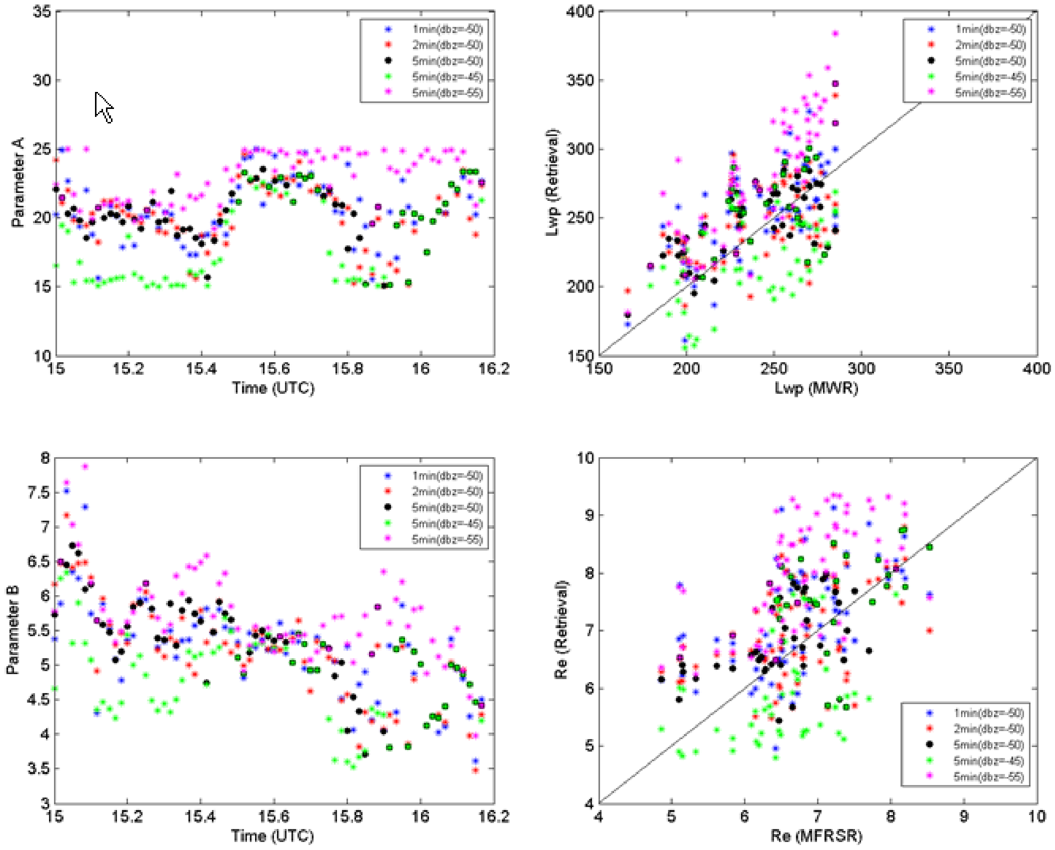
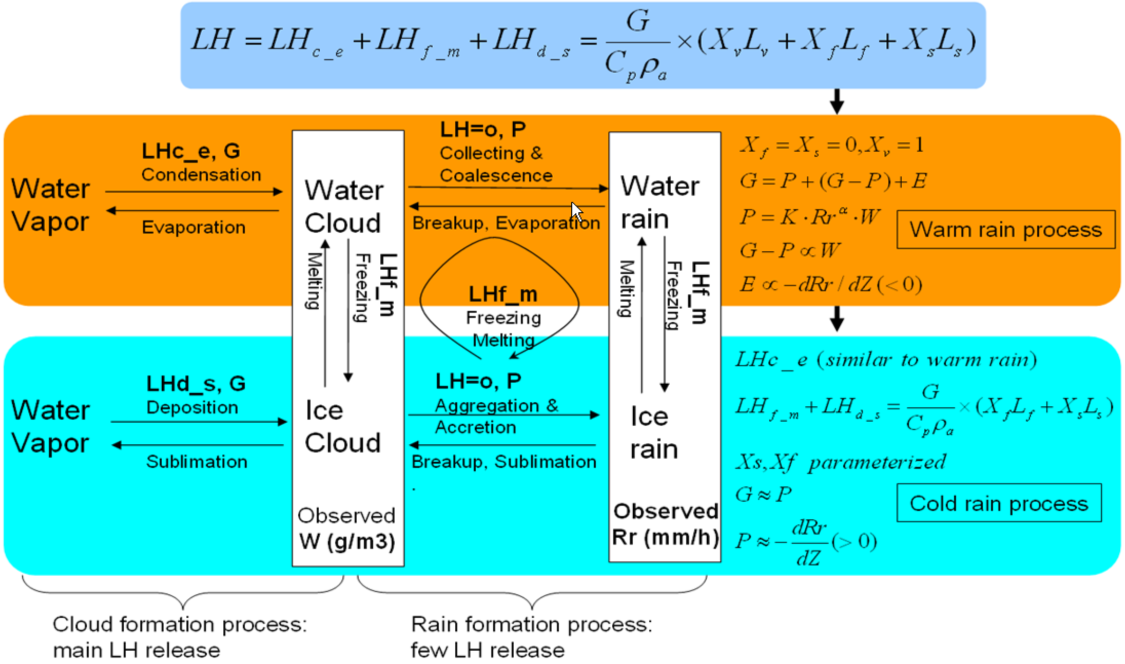




Retrievals are sensitive to the top portion of clouds and temporal variation

Retrieving Latent Heat Vertical Structure Using Precipitation and Cloud Profiles and Cloud Resolving Model Simulations

Poster by Li, Min, and Wu



$$LH = LH_{c\_e} + LH_{f\_m} + LH_{d\_s} = \frac{G}{C_p \rho_a} \times (X_v L_v + X_f L_f + X_s L_s)$$

Water Vapor

LHc_e, G
Condensation

Evaporation

Water Cloud

Melting

Freezing

LHf_m

LH=o, P
Collecting & Coalescence

Breakup, Evaporation

LHf_m
Freezing
Melting

Water rain

Melting

Freezing

LHf_m

$X_f = X_s = 0, X_v = 1$

$G = P + (G - P) + E$

$P = K \cdot Rr^{\alpha} \cdot W$

$G - P \propto W$

$E \propto -dRr / dZ \, (<0)$

Warm rain process

Water Vapor

LHd_s, G
Deposition

Sublimation

Ice Cloud

Observed
W (g/m3)

LH=o, P
Aggregation & Accretion

Breakup, Sublimation

Ice rain

Observed
Rr (mm/h)

LHc_e *(similar to warm rain)*

$$LH_{f\_m} + LH_{d\_s} = \frac{G}{C_p \rho_a} \times (X_f L_f + X_s L_s)$$

Xs, Xf *parameterized*

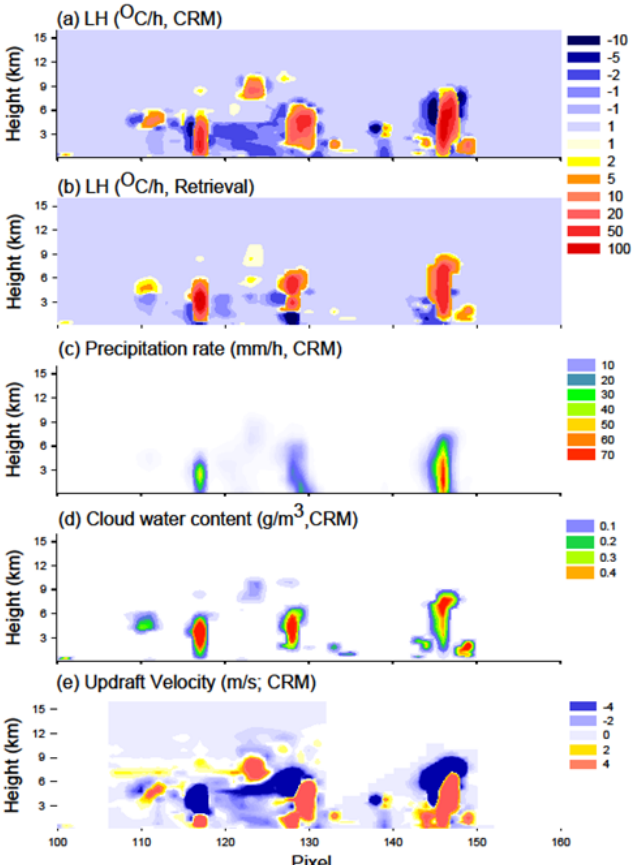
$G \approx P$

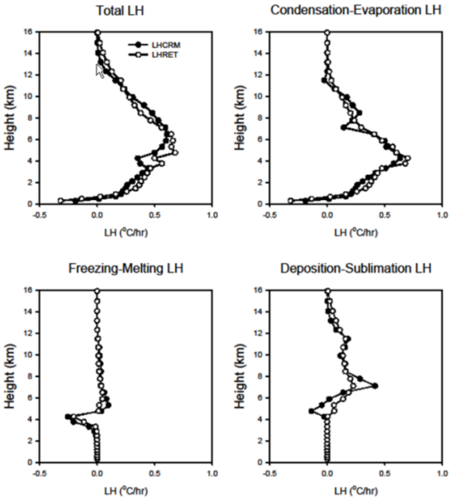
$$P \approx -\frac{dRr}{dZ} \, (>0)$$

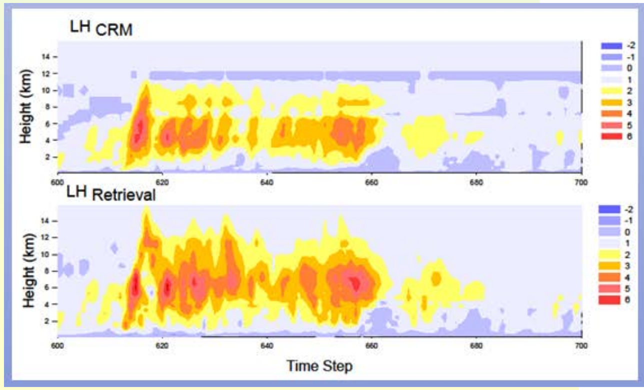
Cold rain process

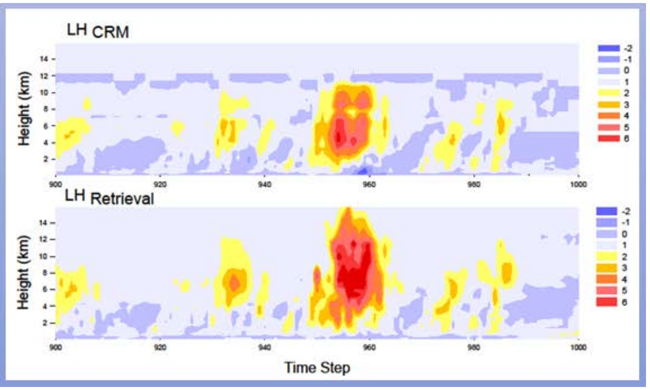
Cloud formation process:
main LH release

Rain formation process:
few LH release

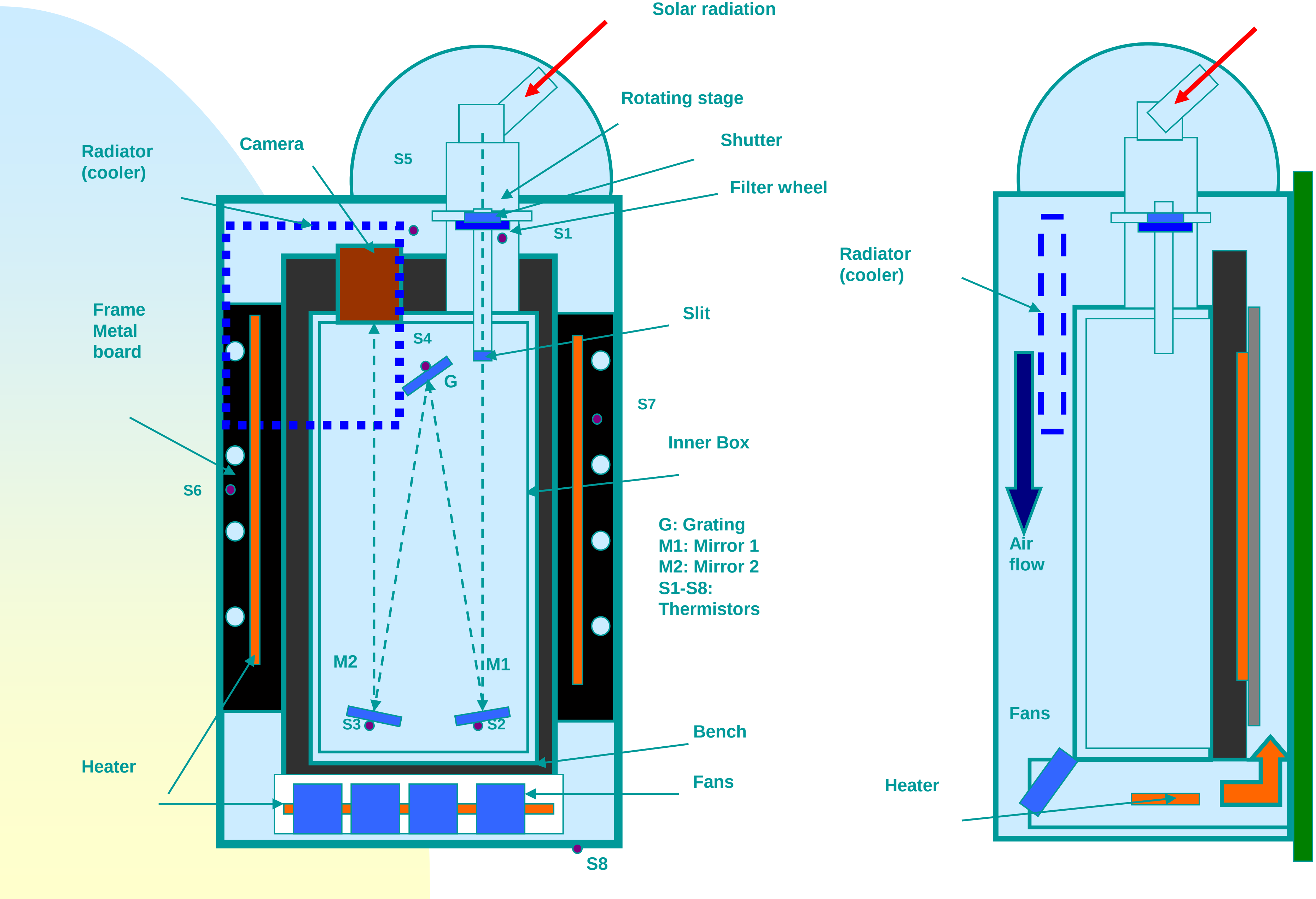








Sketch map of the O2 A-Band Spectrometer



G: Grating
M1: Mirror 1
M2: Mirror 2
S1-S8: Thermistors