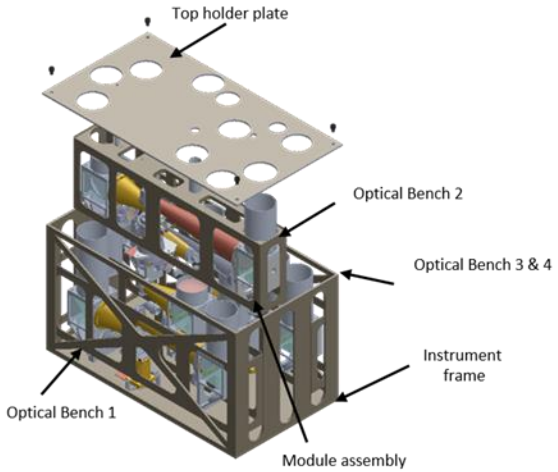
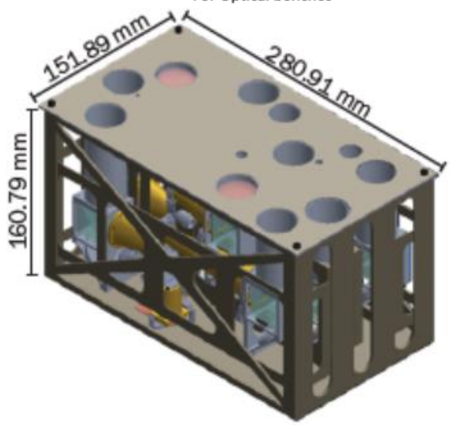
The GLO (GFCR Limb Occultation) Sensor: *A New Sensor Concept for Upper Troposphere and Lower Stratosphere (UTLS) Composition and Transport Studies, and Middle Atmospheric Monitoring*

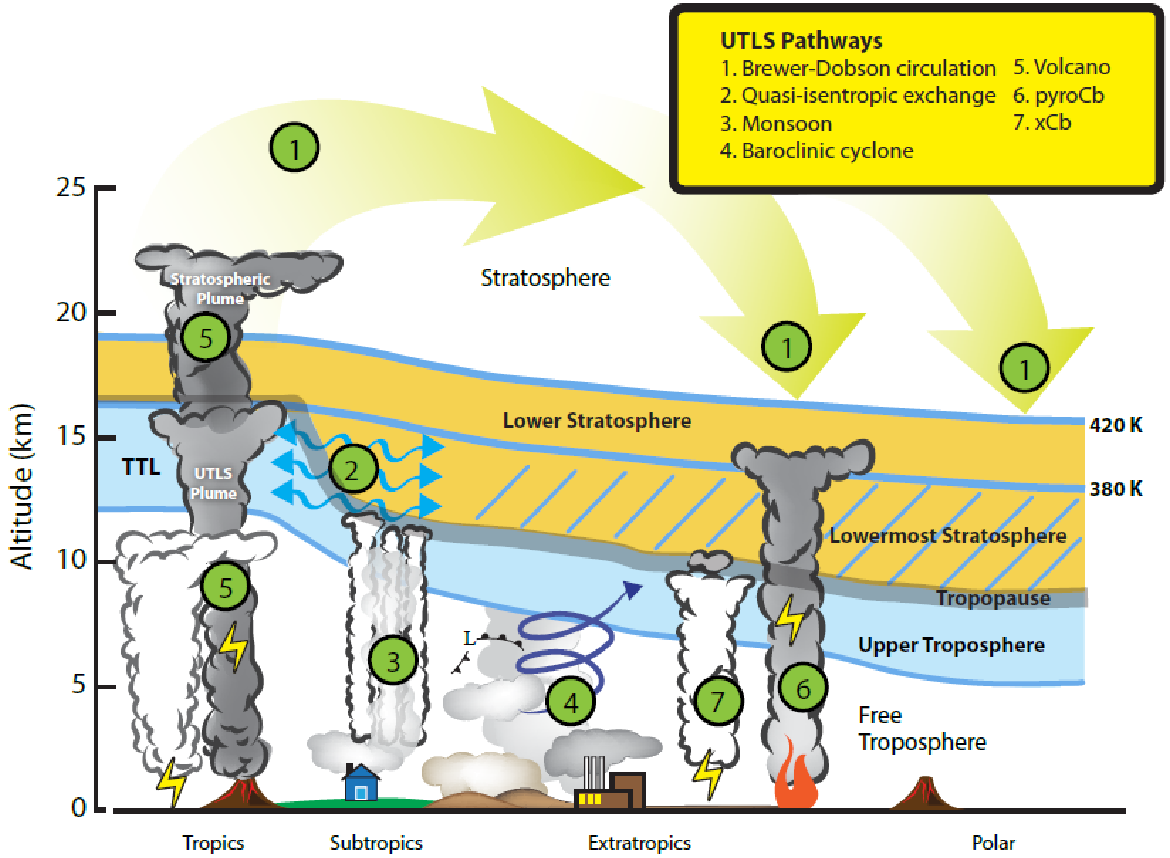


PI: S. Bailey (Virginia Tech)
DPI: R. Bevilacqua (Naval Research Laboratory (NRL))
Instrument: S. Restaino, D. Korwan, J. Bobak, F. Santiago (NRL),
A. Marchant (USU), L. Gordley, and T. Marshall (GATS)
Science: M. Hervig (GATS), C. Randall (LASP), K. Hoppel, M. Fromm, and G. Nedoluha (NRL)



Richard Bevilacqua
NRL Remote Sensing Division
rich.bevilacqua@nrl.navy.mil

GLO designed to study the role of the UTLS in the climate system by quantifying transport pathways which establish the composition of the UTLS



UTLS Radiative Forcing Drivers:

- H_2O radiative forcing peaks near the trop. with a very narrow vertical scale *(Solomon et al., 2010).*
- Aerosol loading between the trop. and 15 km contributes 30-70% stratospheric aerosol radiative forcing *Ridley et al. (2014).*

- These processes are expected to change as the climate changes
- The way in which these predicted changes will alter the composition of the UTLS, and resultant radiative forcing impacts, represent potentially important climate feedbacks that are currently unquantified.

GLO Measurement Requirements

A measurement system designed to study UTLS composition, transport and radiative impacts should have the following attributes:

- **Constituent Measurements:**
  - **Key non-well mixed radiatively active gases important in the UTLS.**
  - **Atmospheric aerosol (extinction plus composition identification)**
  - **Suite of long-lived tracers for quantifying transport pathways that control the distribution of radiatively active constituents**
  - **Gases important in stratospheric ozone photochemistry**

- **Altitude Range: 3 km below the tropopause to 50 km.**

- **Vertical Resolution: ≤1 km (driven by the vertical scale of radiative processes).**

- **High precision and accuracy: to delineate and distinguish transport pathways (established by field measurements).**

- **Capability to make measurements in the presence of aerosols.**

Proposed Sensor Solution:

- VNIR/SWIR GFCR.
- Solar occultation.
- Suitable for orbital constellation:
  - SmallSat compatibile
    - Inexpensive
    - Small SWAP
    - Modest s/c requirements

GLO Measurements

- **Constituent Measurements:**
  - **Key radiatively active gases: H_2O, O_3, CH_4, N_2O**
    - **CO_2 not required because of its long lifetime and small vertical gradients**
    - **CFCs not required because of their long lifetimes.**
  - **Aerosol extinction from the visible to SWIR (for integrated properties of the aerosol size distribution, and particle composition identification)**
  - **Transport tracers: HCN, CO, HDO, HF, HCl**
  - **Temperature**
- **Altitude Range: 3 km below the tropopause to 50 km.**
- **Vertical Resolution: 0.5 km (from 600 om orbit)**
- **High precision and accuracy (including in the presence of heavy aerosol loading).**

Pathway	Diagnostic
Volcanic eruptions	**ash,sulfates,HCl, SO_2**
PyroCbs	**Smoke,CO,CO_2,HCN**
Baroclinc cyclones	**Mineral dust**
Deep convection (xCbs)	**H_2O,HDO**
Monsoon transport	**O_3,H_2O,HCl,HDO,HCN**
Brewer-Dobson and Quasi Isentropic Exchange	**H_2O,O_3,CH_4,N_2O,HF, HCl**

NASA Instrument Incubator Program has provided the opportunity to build a prototype GLO sensor and fly it on a high altitude (35 km float altitude) NASA balloon in September 2019

Top system-level requirements (subset)

- **0.5 km vertical resolution from 600 km orbit**
- **SNR: 300,000:1 above the atmosphere**
- **SWaP: 29x16x16cm (O), 5.25 kg (O), 28.2 W (O)**

Top level derived requirements (subset)

- **Image full sun for pointing knowledge - automated edge detection**
- **Solar diameter of 211 pixels for signal aggregation (supports SNR and vertical resolution requirements)**

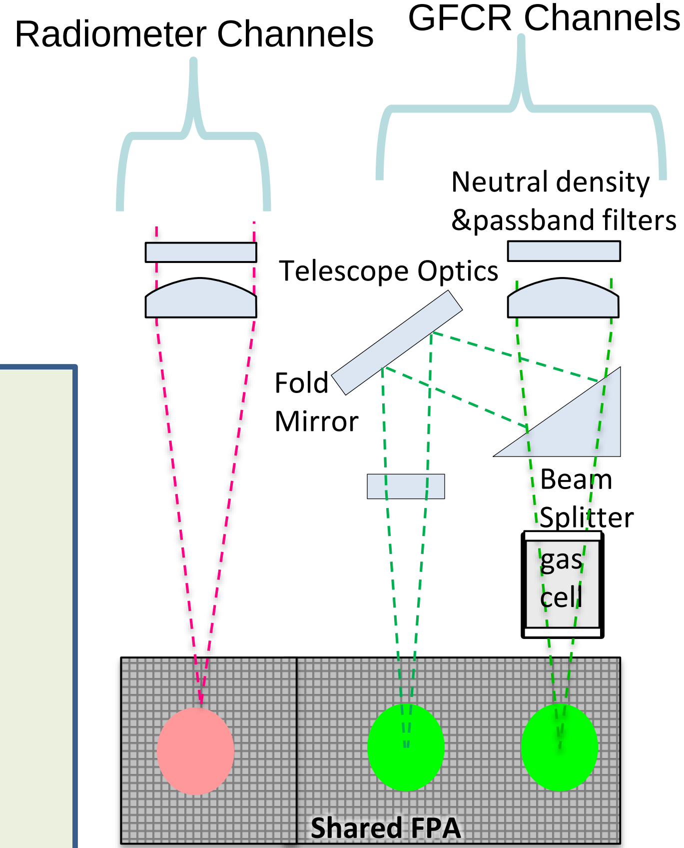
9 GFCR Channels

Channel	λ_0 (µm)	$\Delta\lambda$
CH_4	2.305	0.0461
CO	2.335	0.0537
HF	2.455	0.0491
O_3	2.475	0.0371
H_2O	2.503	0.0626
HCN	3.005	0.0601
HCl	3.380	0.1014
HDO	3.710	0.1113
N_2O	3.905	0.0976

5 Single (broadband) Radiometer Channels

Channel	λ_0 (µm)	$\Delta\lambda$
aerosol	0.45	0.0045
aerosol	1.02	0.0102
aerosol	1.556	0.0156
H_2O	2.60	0.052
CO_2	2.80	0.056

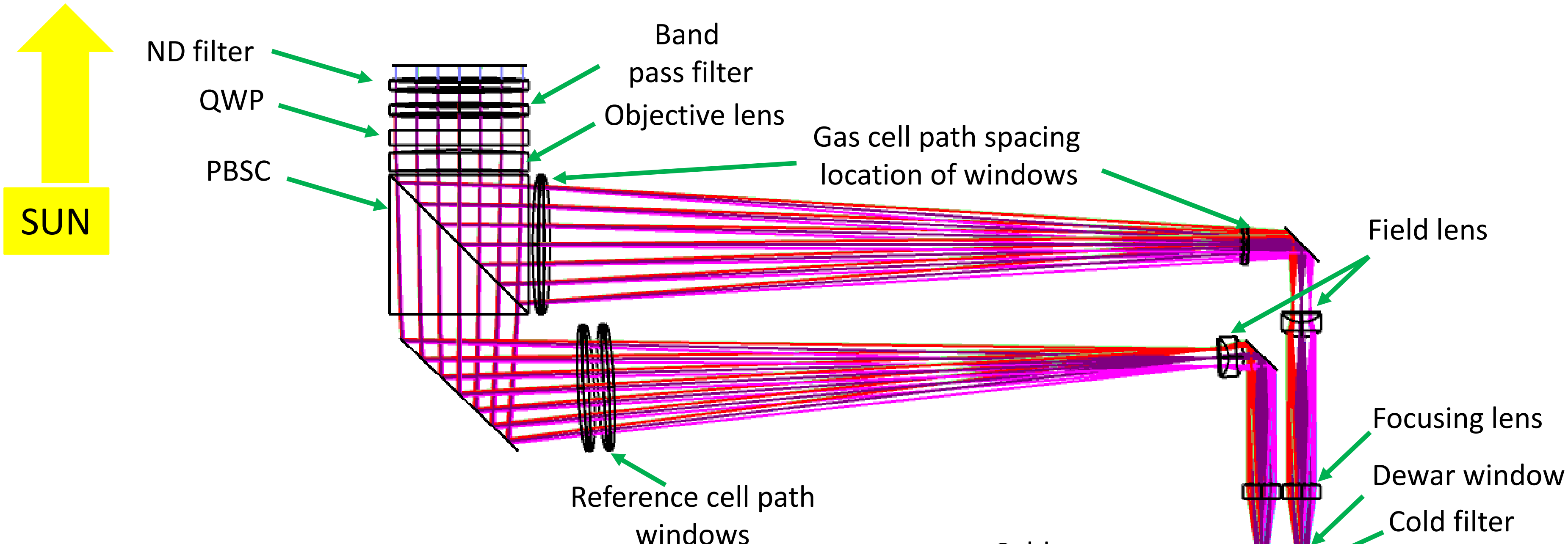
Basics of instrument approach

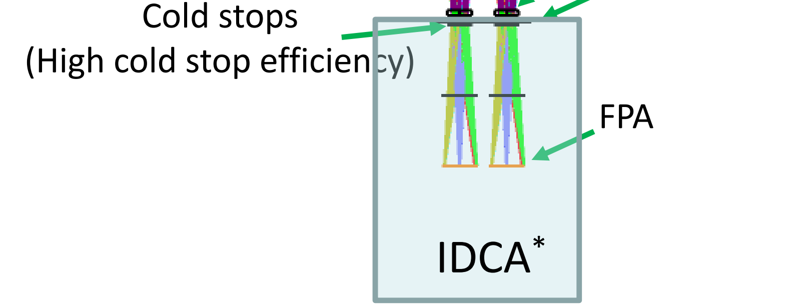


6 images of the sun on each detector

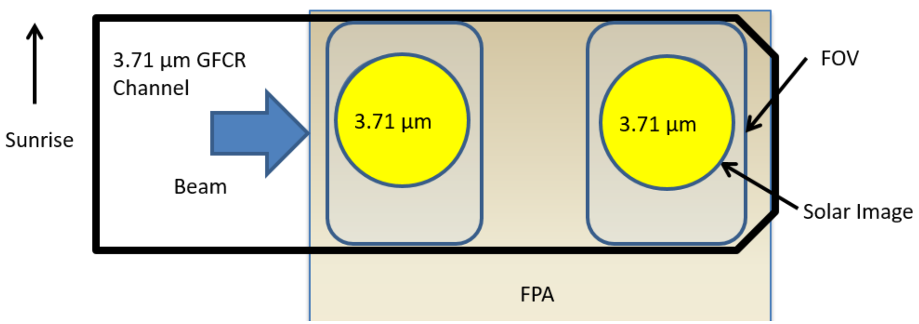
Optical telescope configuration

Telescope for the 3.71µm (HDO) channel





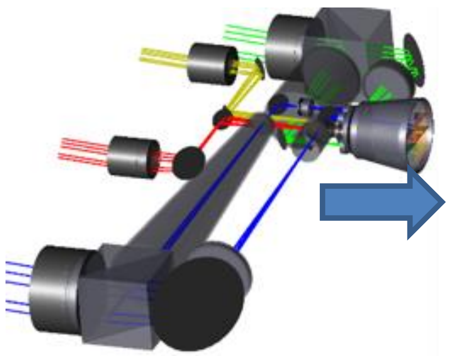
Representation of two solar images for one GFCR channel orientation and location on the FPA

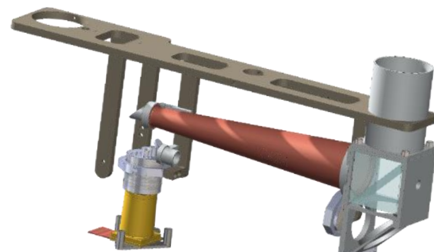


*Integrated Detector & Cooler Assembly

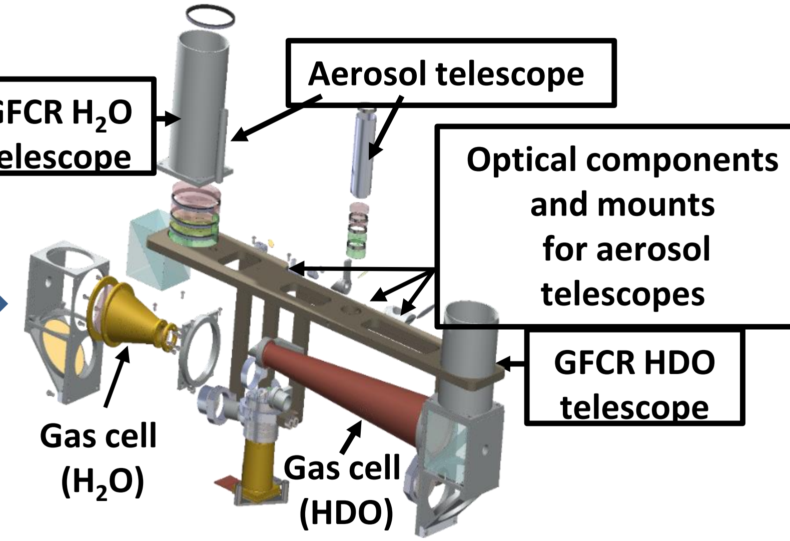
GLO Optomechanical Design

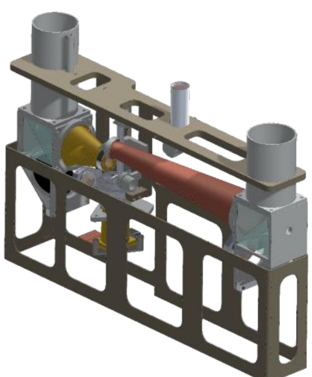
Optical bench



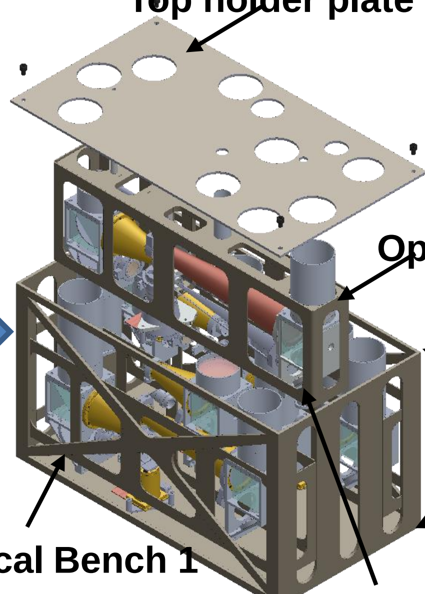


Assembled channel in the Optical Bench structure

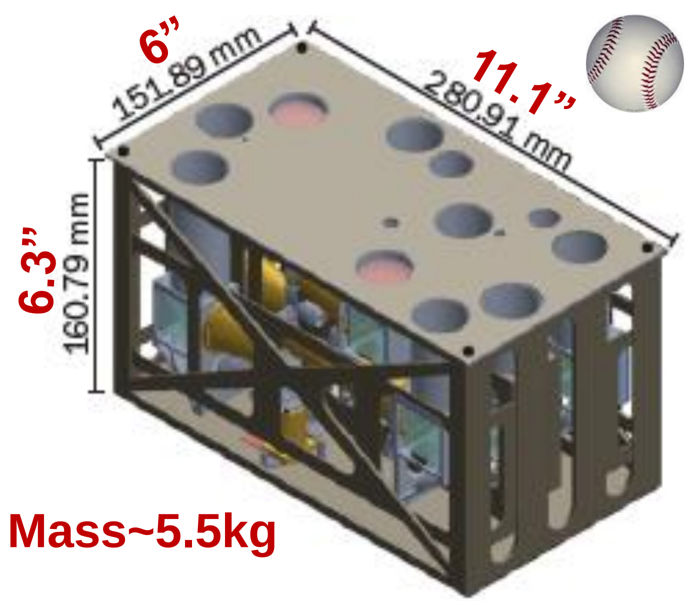




Optical Bench 2 in mounting structure



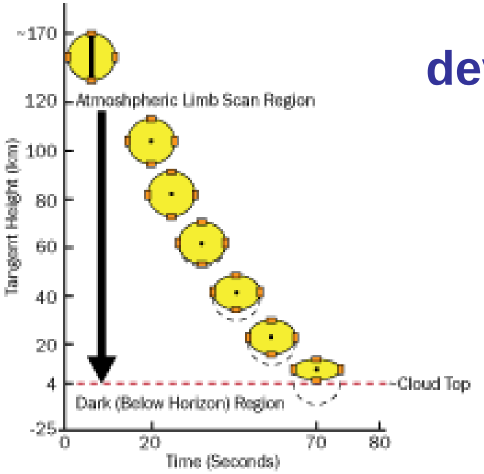
Module assembly For Optical benches

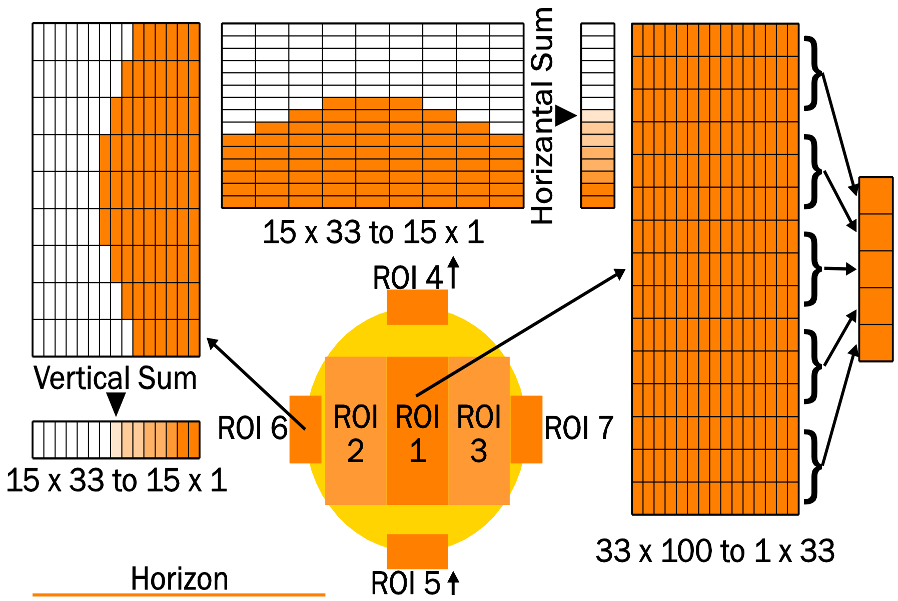


Mass~5.5kg

GLO Data Acquisition

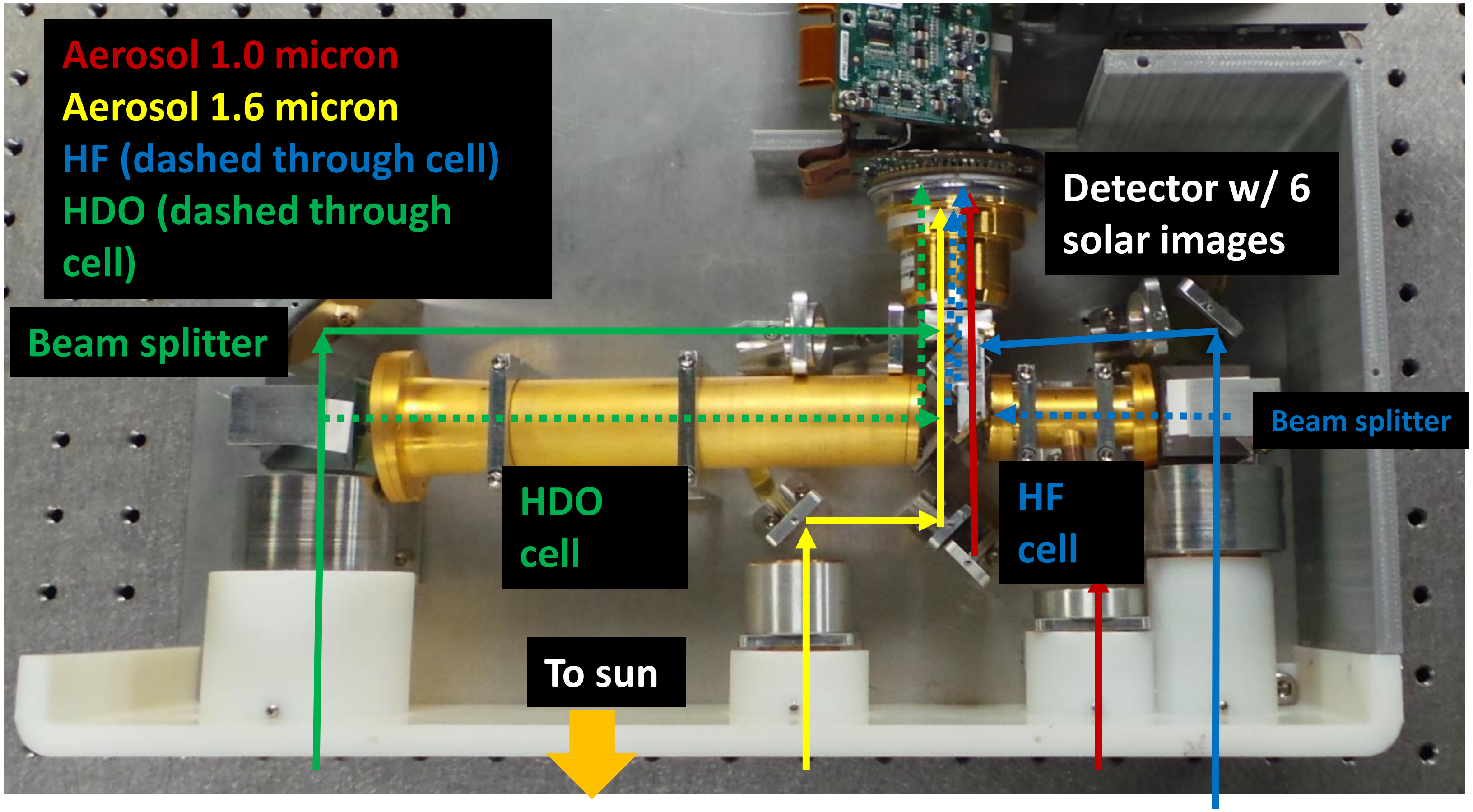
GLO uses the solar edge detection algorithm developed and used operationally on SOFIE for 10 years





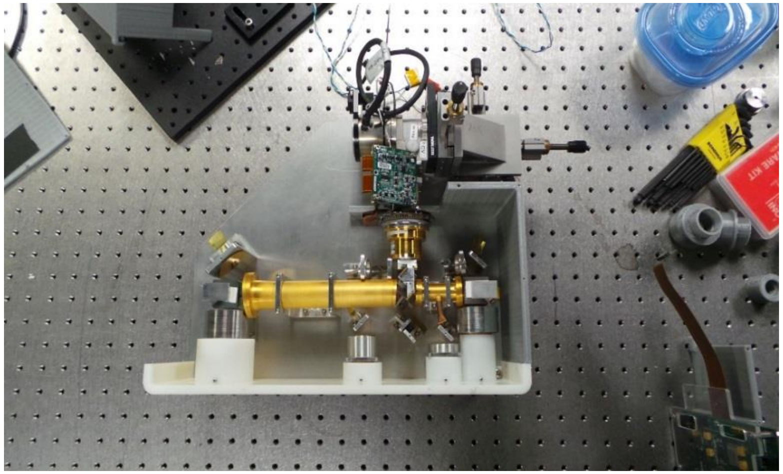
- **1024x1280 FPA.**
- **6 images of the sun on each FPA.**
- **Solar diameter subtends 211 pixels:**
  - **From orbit ~125m/pixel**
  - **From balloon ~21m/pixel**
- **SOFIE demonstrated solar edge detection to ~1 m from orbit.**

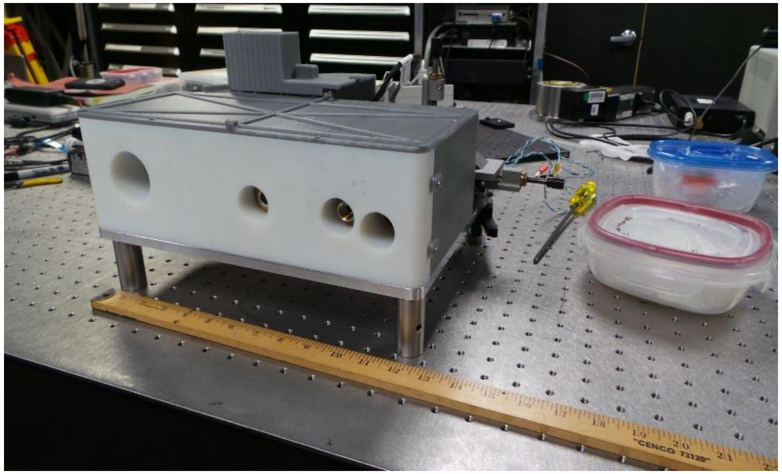
GLO Demonstration Unit

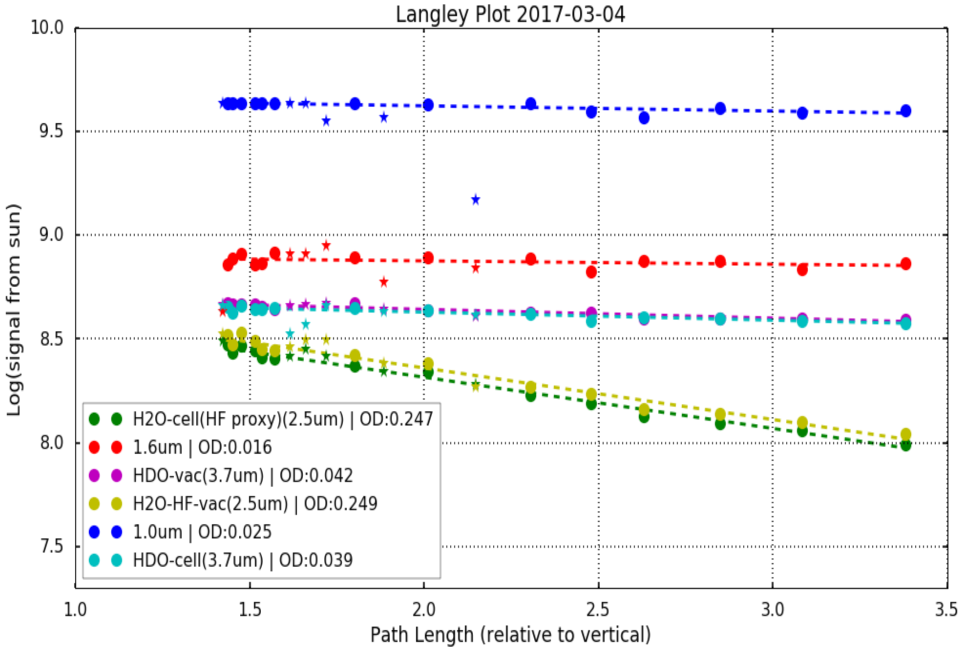


2 GFCR channels
2 aerosol channels
6 solar images on one FPA

GLO Demonstration Unit







GLO demo aerosol optical depth compared to NASA Goddard AERONET site

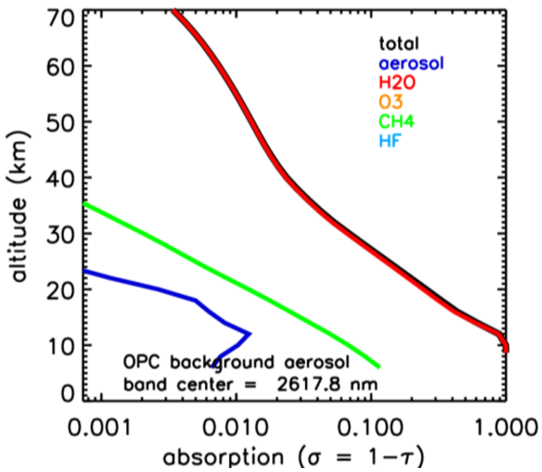
Date	λ(μm)	GLO	GSFC
11/7/16	1.0	0.015	0.018
	1.6	0.011	0.012
3/4/17	1.0	0.025	0.026
	1.6	0.016	0.013

Proxy GFCR: HF used in cell to select O_3 and H_2O

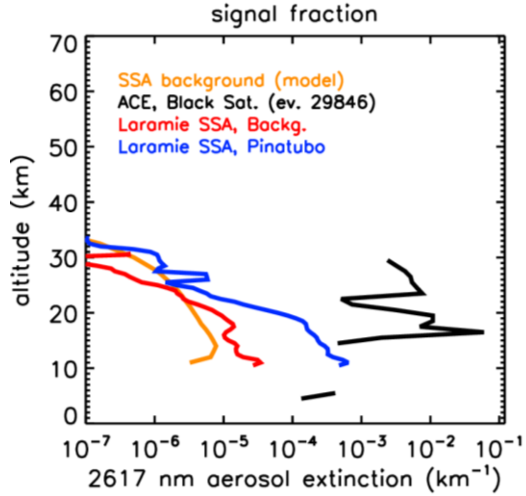
GLO includes a broadband (bb) and GFCR H_2O measurement

GLO Channel 9, bb H_2O(λ=2.6μm±2%)

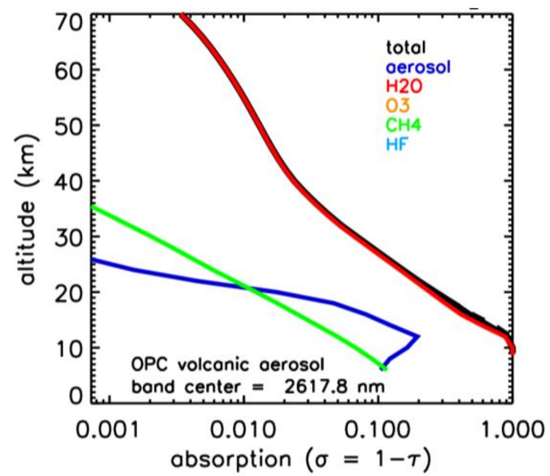
Contributions to channel absorption (background aerosol)



Reference aerosol profiles

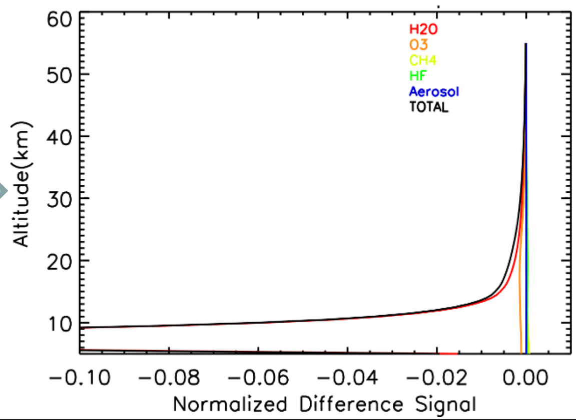


Contributions to channel absorption (volcanic aerosol)



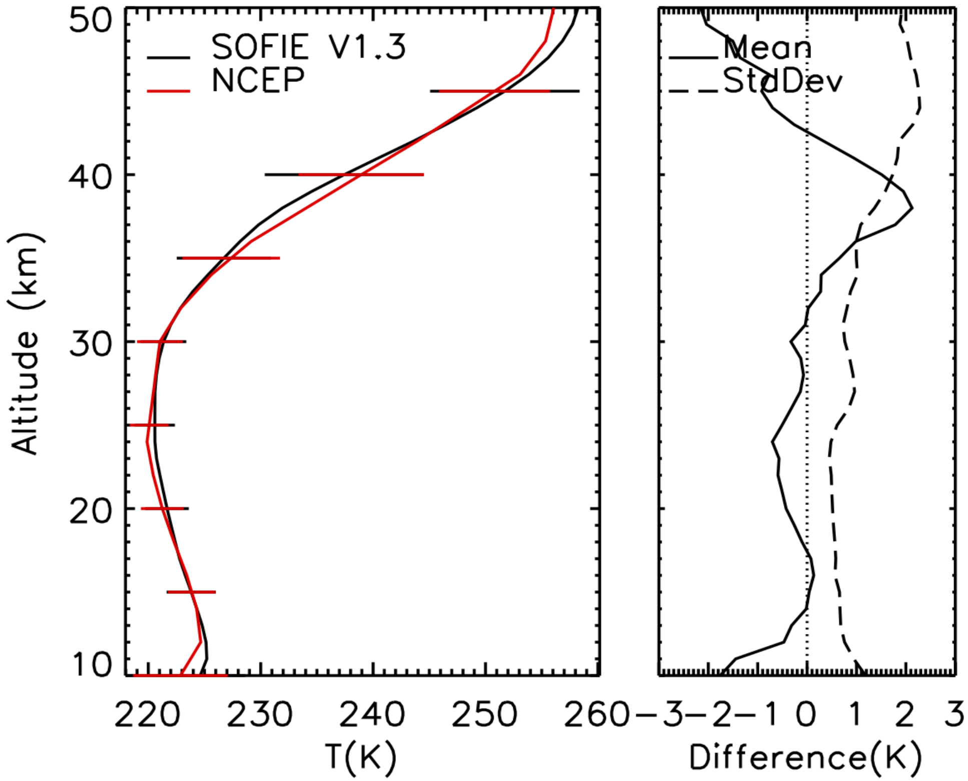
Contributions to channel GFCR signal

GFCR channel (GLO channel 8) for elevated aerosol conditions in the lower stratosphere



GLO Temperature Measurement

GLO will measure temperature using refraction and CO_2 absorption measurements (above 50 km) as done operationally on SOFIE for 10 years (Gordley et al., 2009, Marshall et al., 2011)



SOFIE/NCEP temperature retrievals: April, 2008, 75-80^{o}N

SOFIE has demonstrated T profiling with 0.5 km resolution, and precision of <1K

GLO Aerosol Measurements (GLO includes 3 VNIR spectrally pure bands)

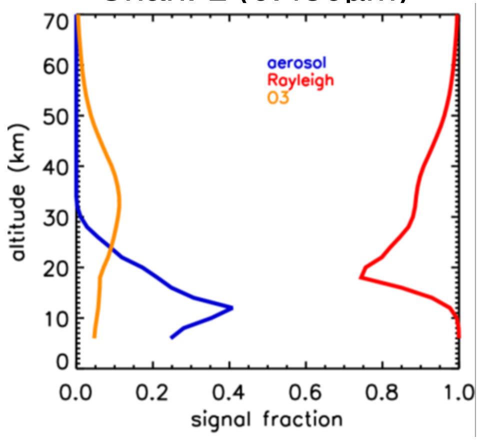
Channel/Type[1]	λ (μm), υ (cm^{-1}), Δυ (%)	Target Primary / Secondary	Interference (aerosol as target)	Aerosol Signal Fraction (%)[2], Bkg (Pinatubo 93-95)	Aerosol Error (%)[2,3,4], Bkg (Pinatubo 93-95)
1 / B	0.450, 22222, 1.0	aerosol	Rayleigh	40 (87)	7 (<1)
2 / B	1.020, 9804, 1.0	aerosol	Rayleigh	65 (91)	3 (<1)
3 / B	1.556, 6247, 1.0	aerosol	Rayleigh	80 (97)	1 (<1)
4 / G	2.305, 4338, 2.0	CH_4	CH_4, H_2O, N_2O, CO	6 (48)	75 (5)
5 / G	2.335, 4283, 2.3	CO	CO, CH_4, H_2O	6 (47)	78 (6)
6 / G	2.455, 4075.0, 2.0	HF / aerosol	HF, H_2O, N_2O, CH_4	17 (69)	24 (2)
7 / G	2.475, 4040, 1.5	O_3 / aerosol	O_3, H_2O, CH_4, HF	11 (63)	40 (3)
8 / G	2.503, 3995, 2.5	H_2O / aerosol	H_2O, O_3, CH_4, HF	9 (56)	51 (4)
9 / B	2.600, 3820, 2.0	H_2O	CH_4, H_2O	1 (20)	>100 (21)
10/ B	2.80, 3590, 2.0	CO_2	CO_2, H_2O	2 (22)	>100 (18)
11 / G	3.005, 3328.0, 2.0	HCN / aerosol	HCN, H_2O, CO_2, N_2O	25 (68)	14 (2)
12 / G	3.380, 2959, 3.0	HCl / aerosol	HCl, H_2O, O_3, N_2O, CH_4	7 (38)	53 (8)
13 / G	3.710, 2695, 3.0	HDO / aerosol	HDO, CH_4, CO_2	26 (68)	14 (2)
14 / G	3.905, 2561.0, 2.5	N_2O / aerosol	N_2O, H_2O, CO_2, CH_4	11 (48)	34 (6)

[1]G = gas correlation; B = broadband. [2]Based on in-situ SSA observations over Laramie (41°N). [3]Assuming 5% errors on all interference. [4]Good aerosol measurements (both high and low loading) in red.

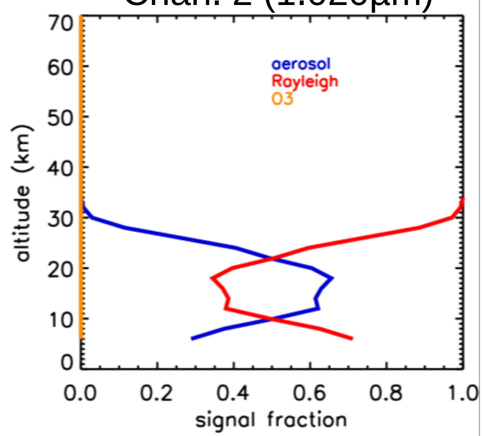
GLO Aerosol Measurements

Fractional constituent absorption/extinction contribution in selected GLO channels (background conditions): GLO differs from HALOE in that includes 3 spectrally pure VNIR bands

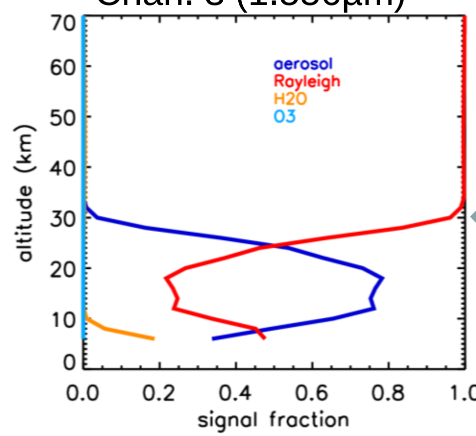
Chan. 1 (0.450µm)



Chan. 2 (1.020µm)



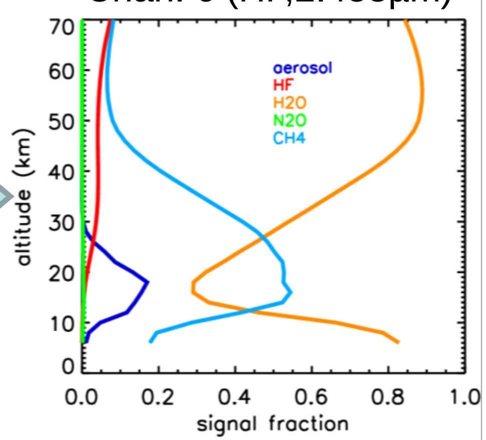
Chan. 3 (1.556µm)



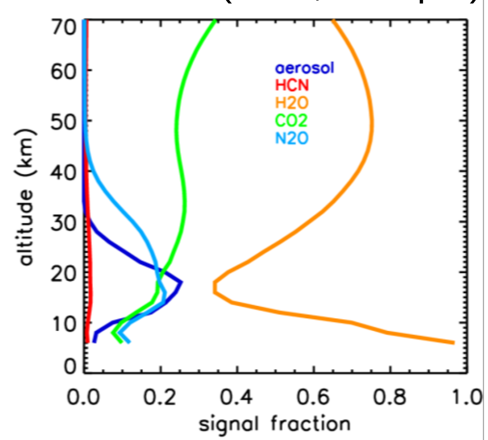
VNIR aerosol channels

SWIR GFCR (vacuum path) channels useful for aerosol

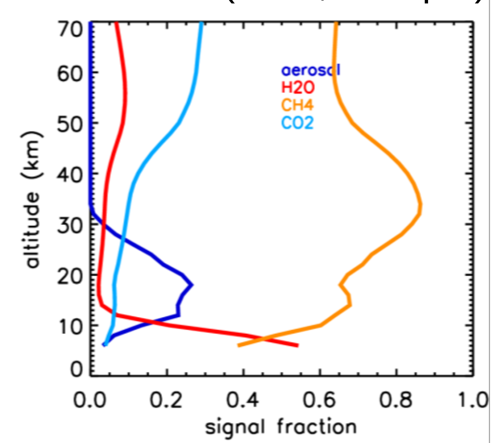
Chan. 6 (HF,2.455µm)



Chan. 11 (HCN,3.005µm)

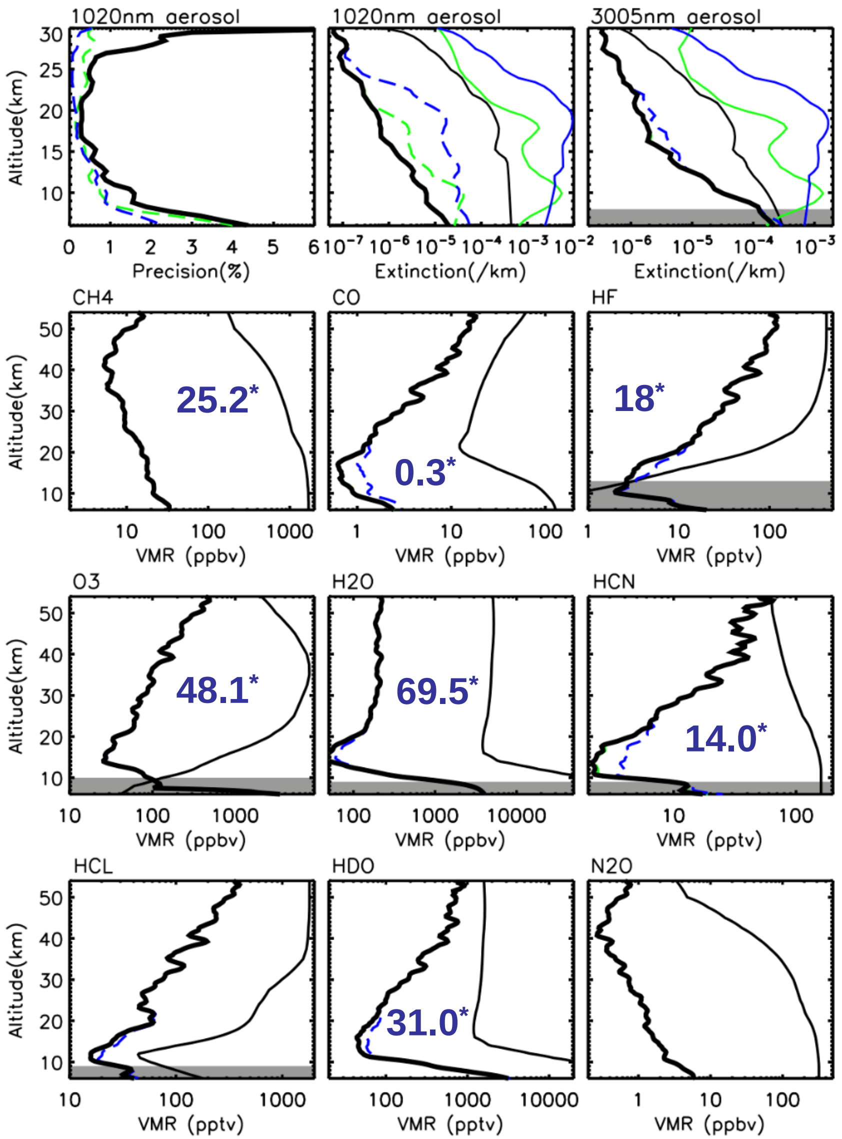


Chan. 13 (HDO,3.710µm)



GLO Retrieval Simulation Analysis (Orbital Case)

- Retrieval performance for cloudless sky
- 0.5 km grid
- Thick black line: background aerosol
- Green dashed line: moderate aerosol (Kasatochi + 1 month)
- Blue dashed line: heavy aerosol (Pinatubo + 1 year)
- Thin lines: VMR or extinction profiles used in the analysis:
  - same color code as above
- Lower limit altitude (cloudless sky):
  - Gas retrievals: τ≈3
  - Aerosol retrievals: τ≈7 (≤ 5 km)
- Cloud top generally determines lower limit:
  - HALOE measurements showed 50% probability of measuring to >3 km below the tropopause.



ACE estimated error @20.5 km (in individual plot units)

GLO Retrieval Simulation Analysis (Aerosol Retrievals)

- Retrieval performance for cloudless sky
- 0.5 km grid
- Thick black line: background aerosol
- Green dashed line: moderate aerosol (Kasatochi + 1 month)
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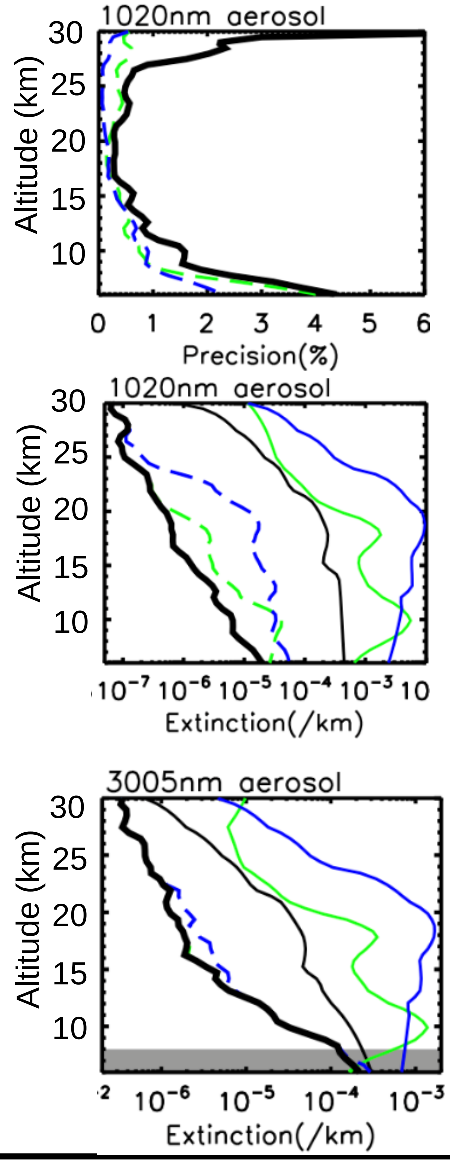
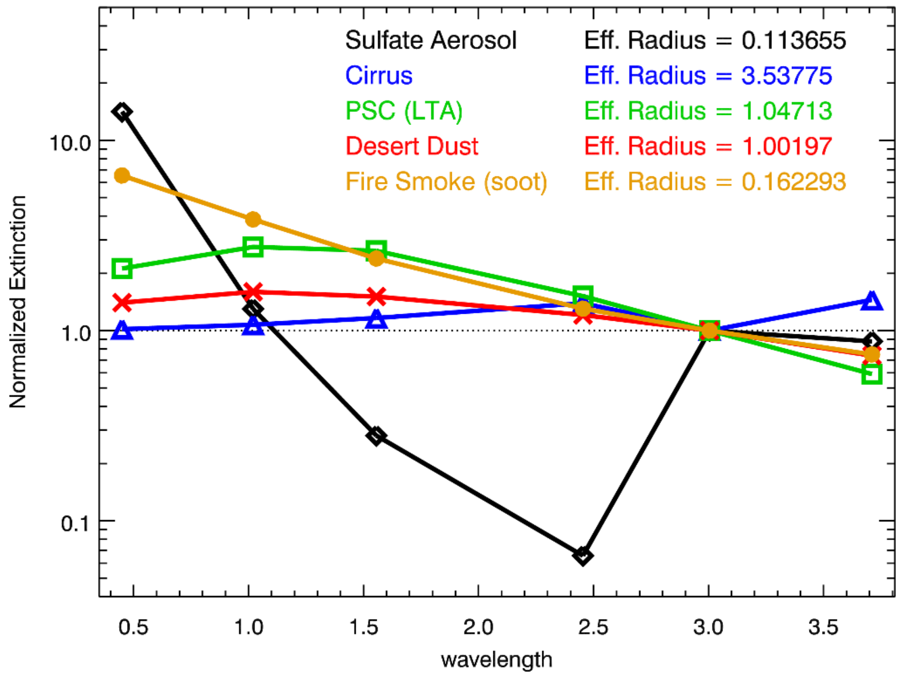


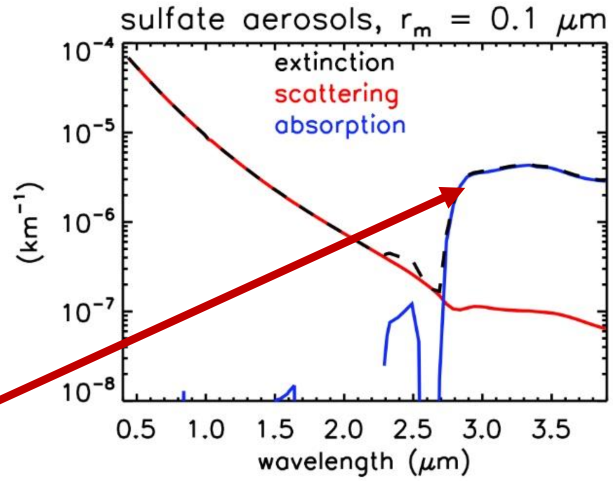
GLO Aerosol Spectra

- **GLO measured aerosol spectra (VNIR + SWIR) provide some composition information.**
- **Combination of wavelengths provide particle size information**

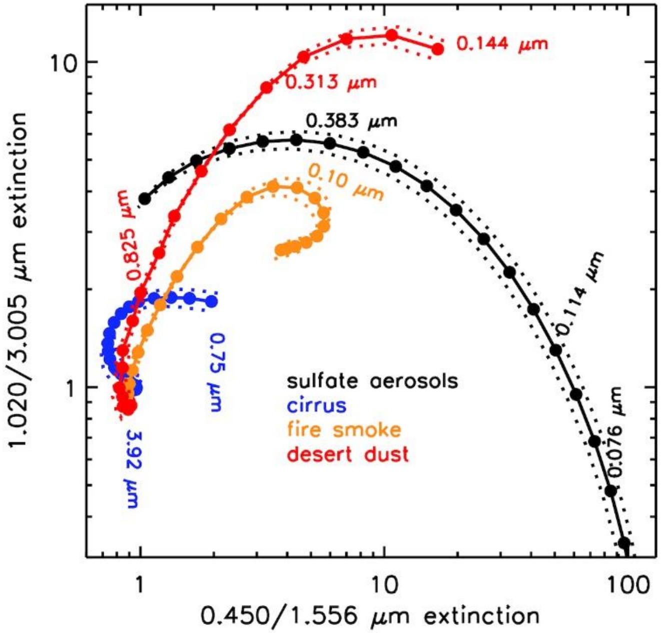
GLO aerosol spectra for indicated particle types



No size information λ > 2.7 µm (pure absorption)

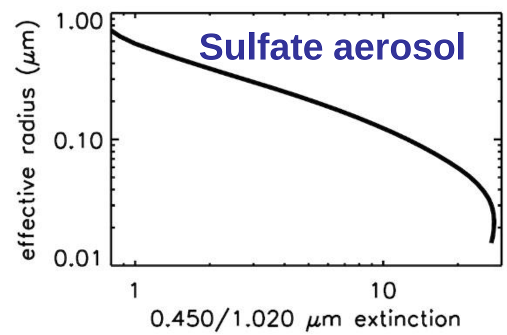


GLO Identification of Aerosol Composition and Integrated Particle Size Distribution Parameters (Hervig and McHugh, 2002)

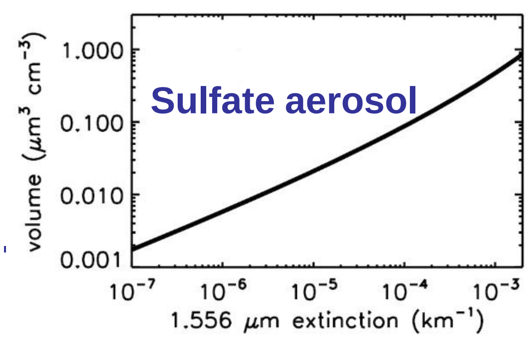


- Variation along the curves is due to changing particle size.
- For large particles (r_m > ~0.8 μm), the ability to distinguish composition is lost.
- Once composition is identified, it will be possible to retrieve particle size & volume density.

Type	R_e(μm)
SSA	0.03-0.8
dust	0.07-2
smoke	0.005-0.5
cirrus	10-500



- The baseline approach is to determine aerosol effective radius (r_e) from a single extinction ratio *(composition dependent).*
- Volume density, V can be determined from the monotonic relationship between V and IR extinction (*composition dependent, and r_e dependent for larger particles*).
- Aerosol concentration given by $N = V / (\pi r_e^3 4/3)$.
- Aerosol surface area density, $A=3V/r_e$.



GLO will measure aerosols at 12 wavelengths (0.5- 3.9 µm).

- **The primary challenge is removal of gas and/or Rayleigh interference.**
- **The 3 VNIR channels, and 3 SWIR channels (2.455, 3.005, and 3.710 µm) should be robust even in background aerosol conditions.**

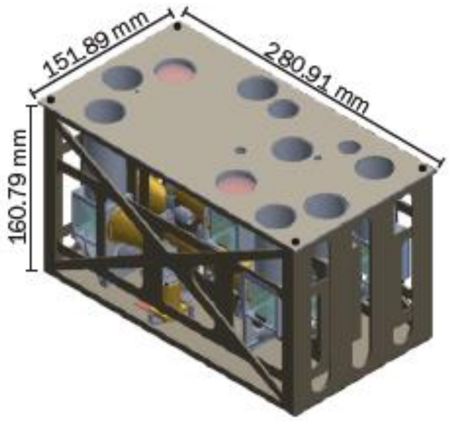
The retrieved aerosol extinction vs. wavelength will yield information on aerosol:

- **Type (composition)**
- **Size**
- **Volume density**
- **Concentration**
- **Potentially size distributions (assuming, e.g., lognormal distribution)**

Next steps:

- **Refine composition, size, refractive index information.**
- **End-to-end simulation of extinctions & subsequent aerosol property retrieval. Include aerosol model results as input.**
- **Mixed aerosol type / composition, with guidance from models / literature.**

GLO Schedule and Status



Current Schedule

April 2017	Project Initiation Meeting and SRR
July	Procure System Components
Feb. 2018	Fabricate Prototype Unit
Oct.	Assemble Prototype Unit
Nov.	Initial System Checkout
Jan.-Feb. 2019	Unit Laboratory Testing
March	Roof-top Testing
June	Mauna Loa, HI Testing
July	Unit Environmental Testing
Sept.	First Balloon Flight Test
Oct.	Analysis of Balloon Flight Test Data
	Second Balloon Flight Possible

Balloon Flight

- Requesting high altitude (40km float altitude) balloon flight via the NASA Columbia Scientific Balloon Facility (CSBF) at Fort Sumner, NM.
- Have discussed teaming with JPL to be co-manifested on the JPL gondola with the MKIV FTIR instrument via NASA proposal
- Would like to explore possibility of having a coordinated *in situ* aerosol balloon launch.