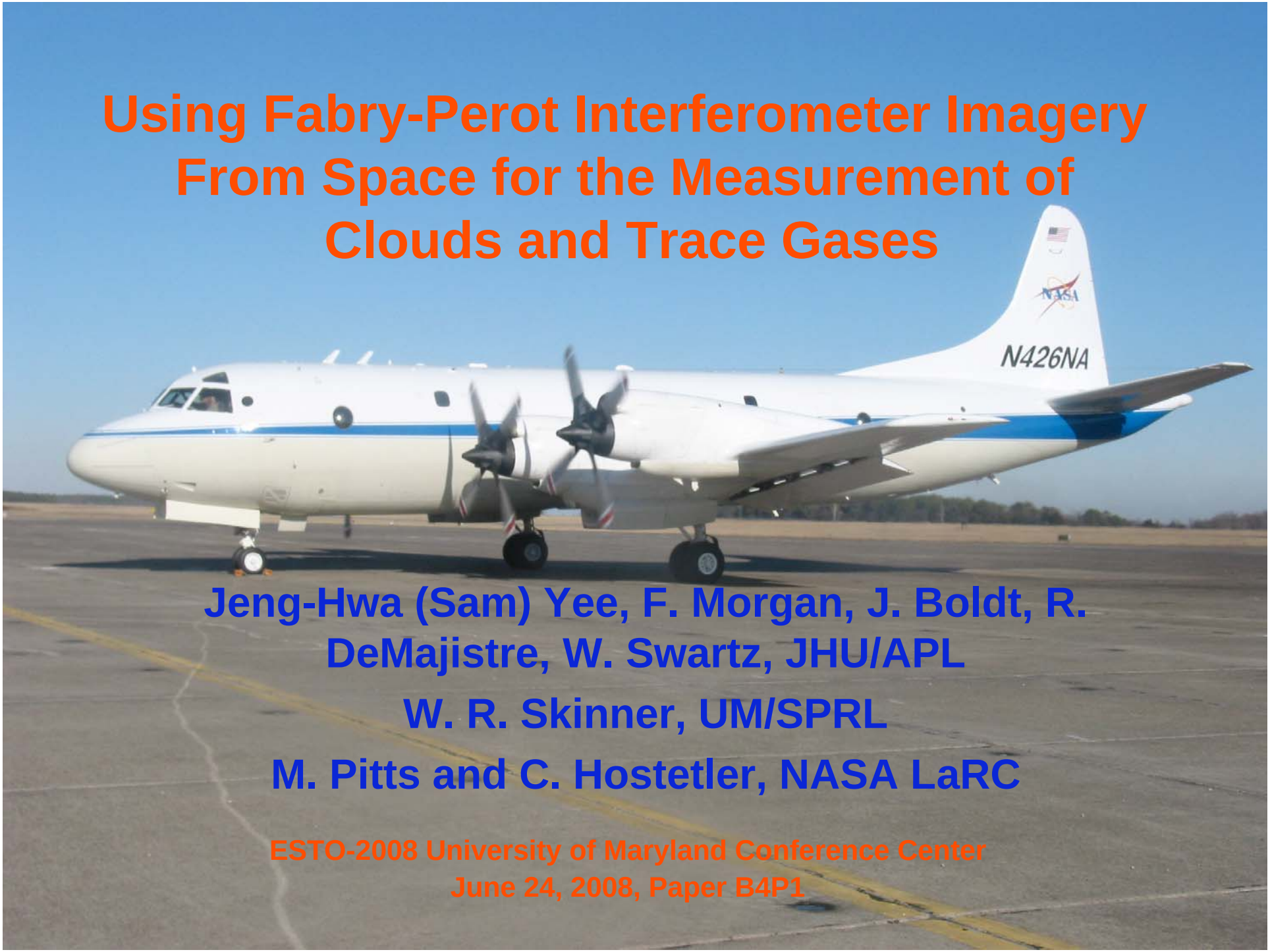
Using Fabry-Perot Interferometer Imagery From Space for the Measurement of Clouds and Trace Gases



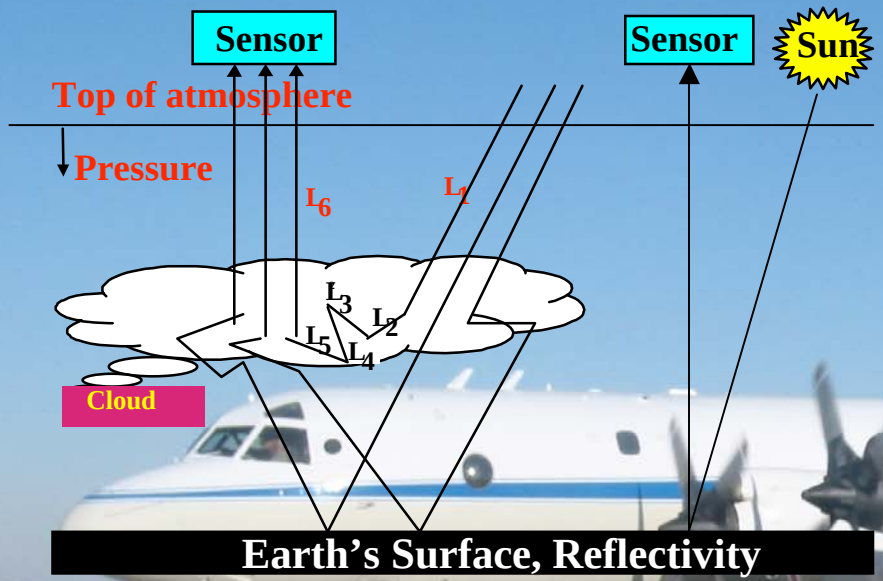
Jeng-Hwa (Sam) Yee, F. Morgan, J. Boldt, R. DeMajistre, W. Swartz, JHU/APL

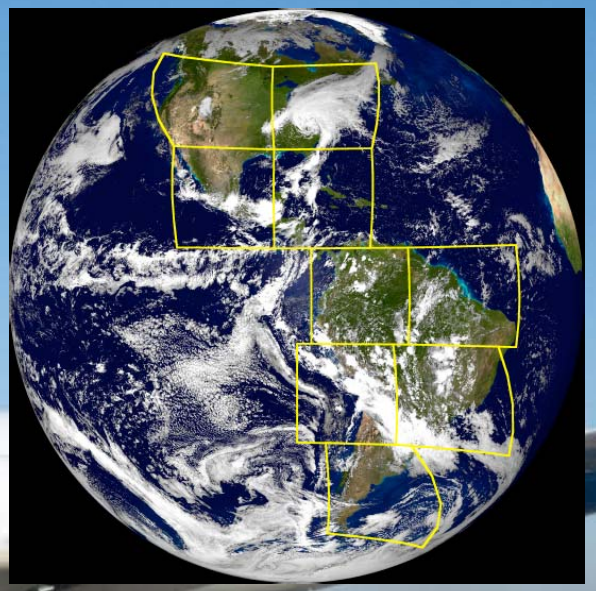
W. R. Skinner, UM/SPRL

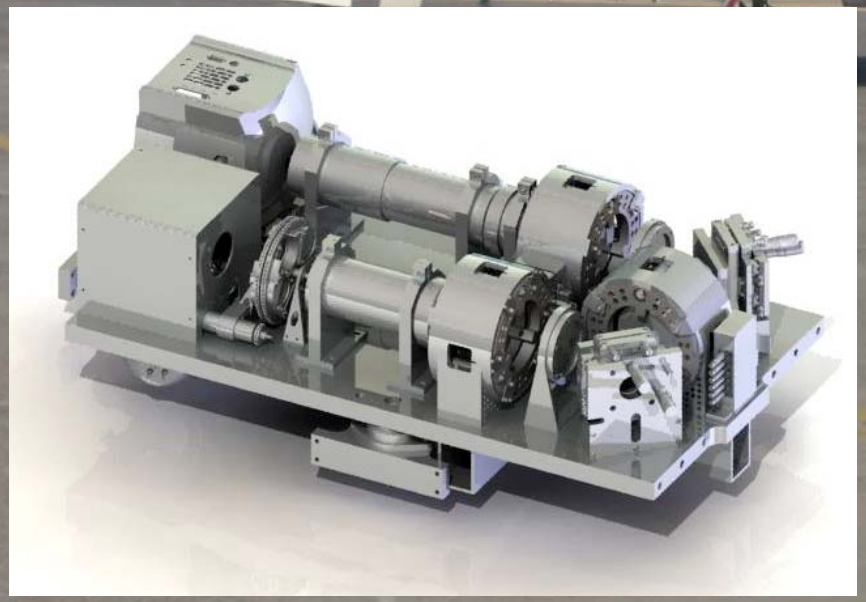
M. Pitts and C. Hostetler, NASA LaRC

ESTO-2008 University of Maryland Conference Center
June 24, 2008, Paper B4P1

Geostationary Imaging Fabry-Perot Spectrometer (GIFS)



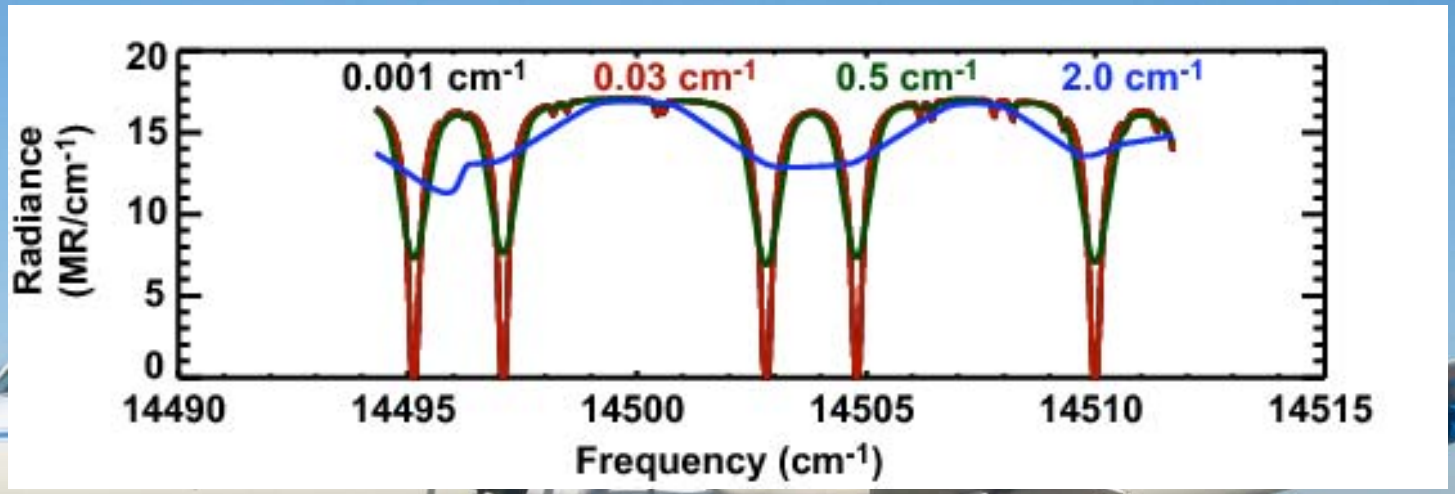




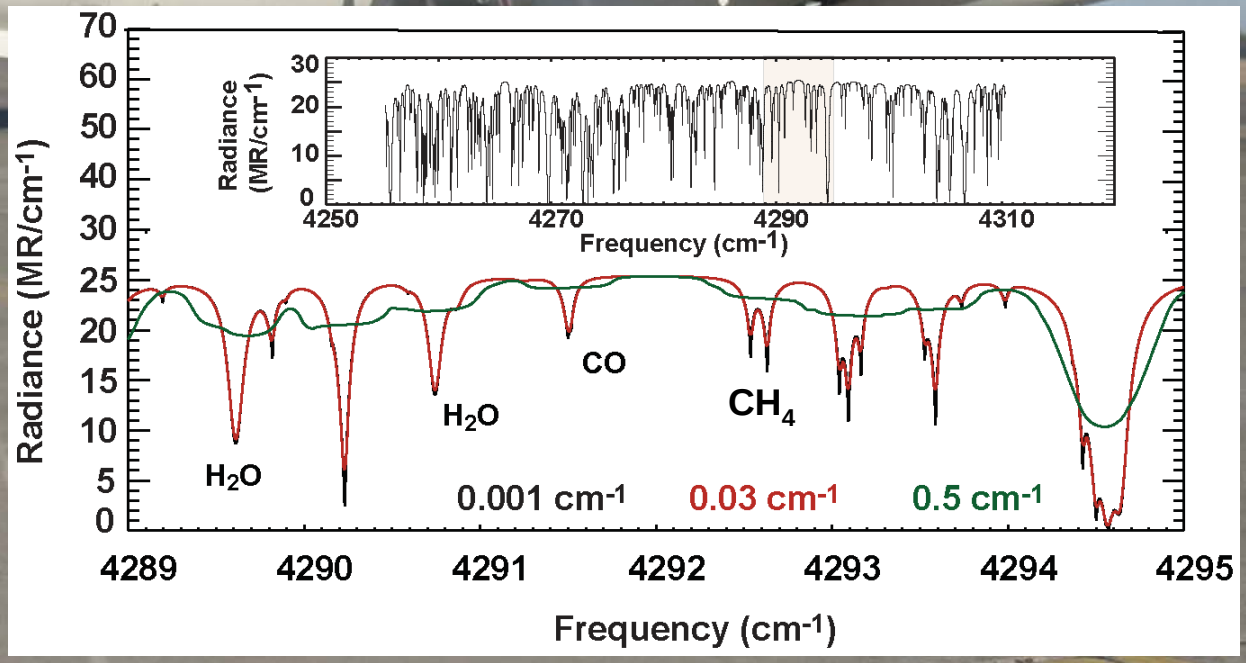
- Geostationary Imaging Fabry-Perot Spectrometer is specially designed to provide high spectral resolution 2-D images of atmospheric absorption line measurements from GEO. This imager, uses a tunable triple etalon optical system and has following unique features:
  - * high spectral resolution
  - * high out-of-band rejection
  - * spectral tunability
  - * spatial imaging capability

Solar Backscatter Spectra

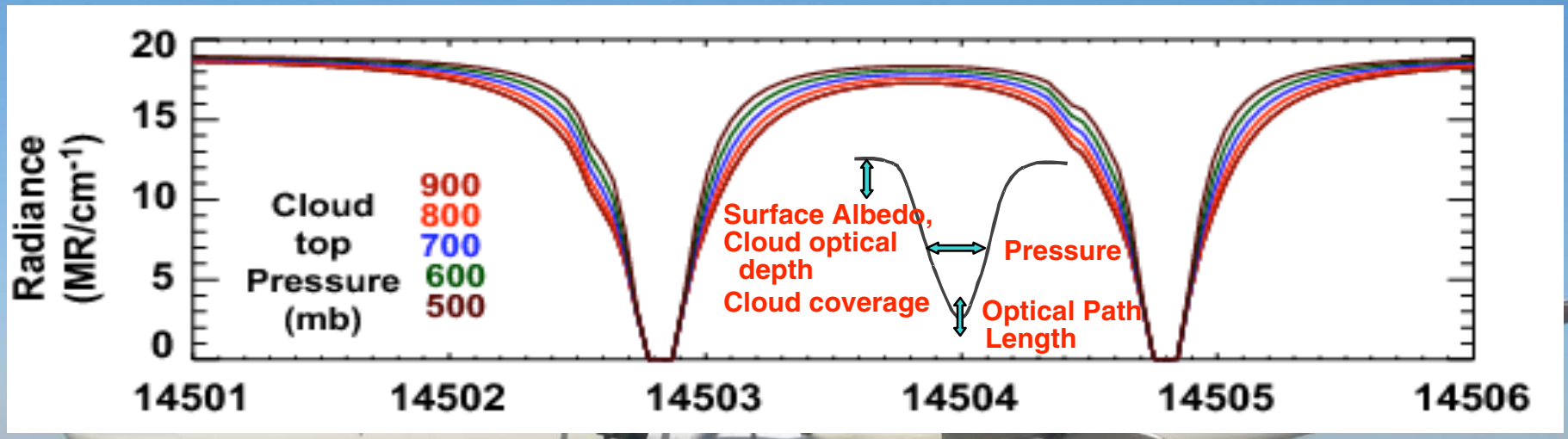
VIS

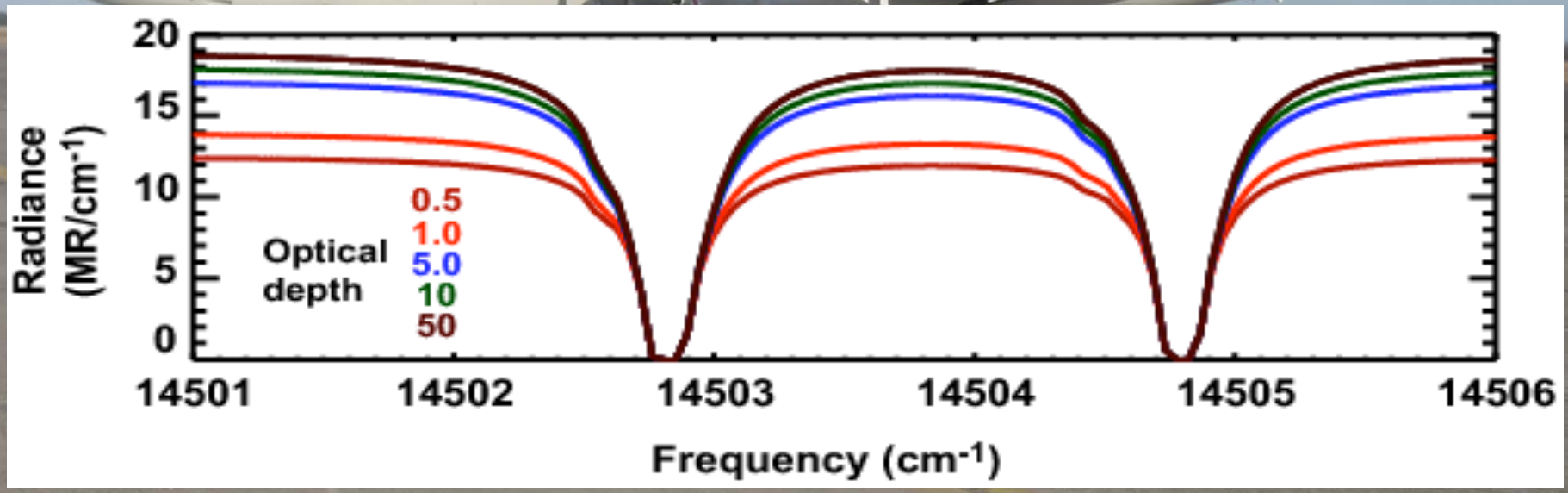


NIR



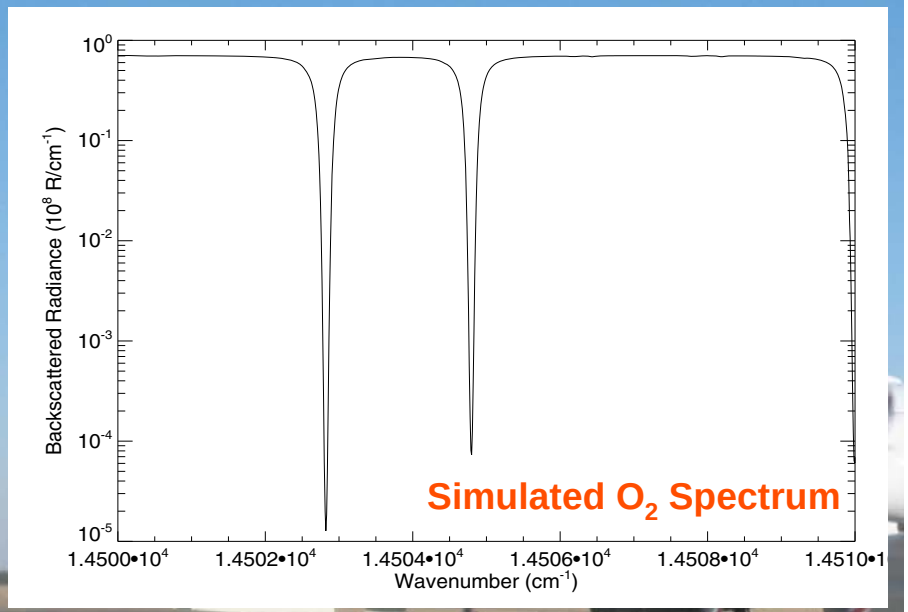
Sensitivities of O_2 Absorption Line Shapes

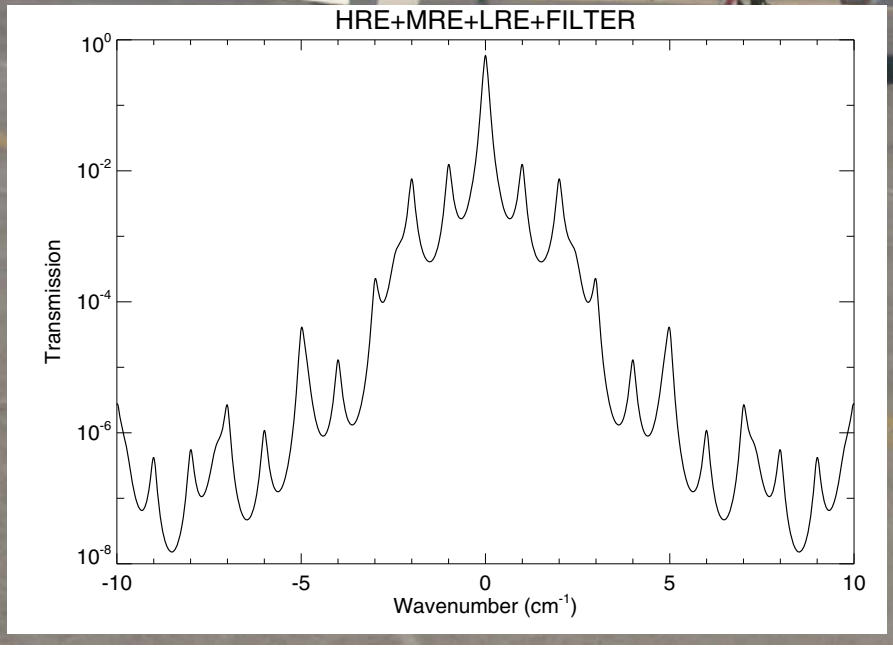


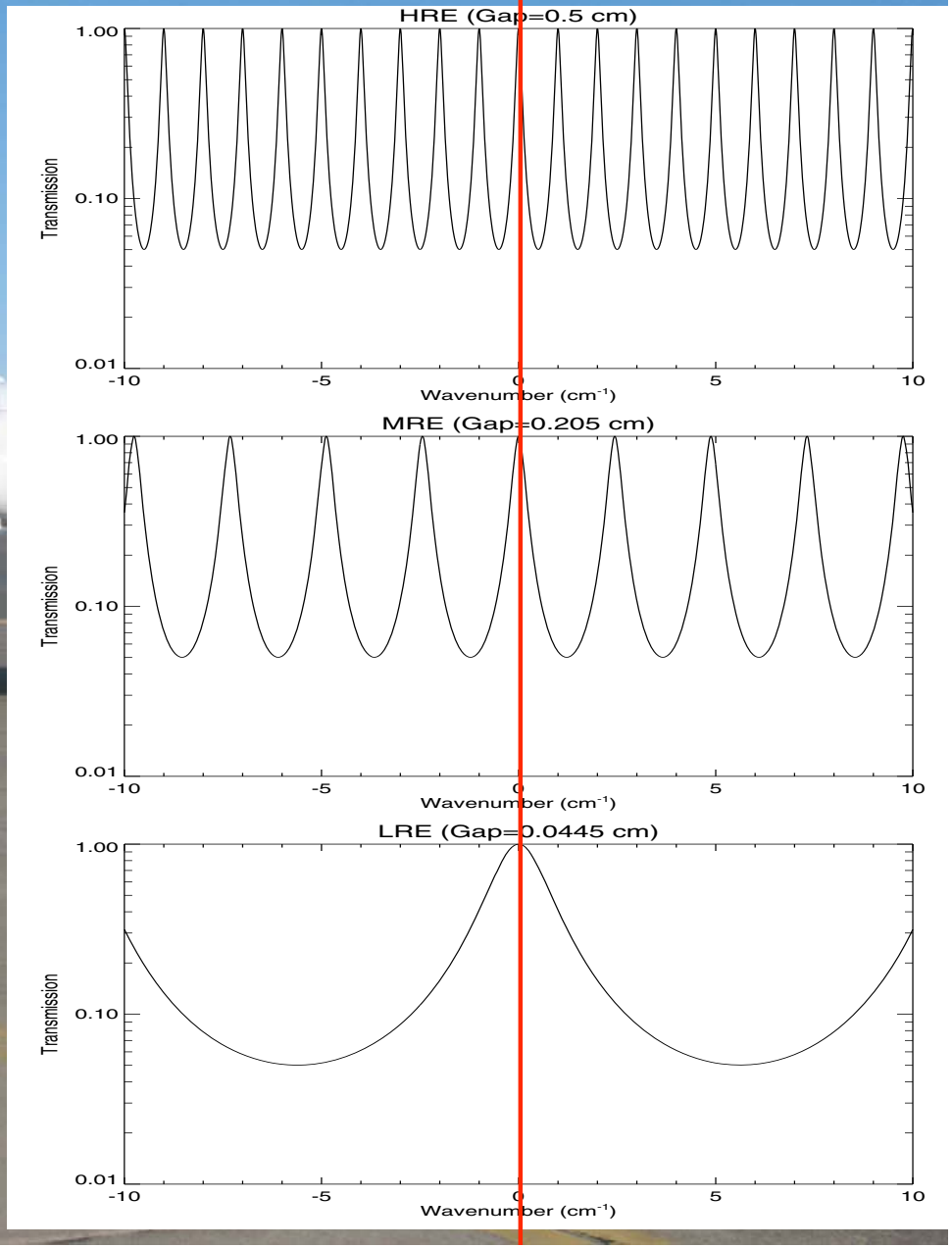


To measure line shapes, one needs a very high spectral resolution and good out-of-band rejection instrument => a triple-etalon Fabry-Perot Interferometer

Triple-etalon FPI Transmission and Spectral Tuning



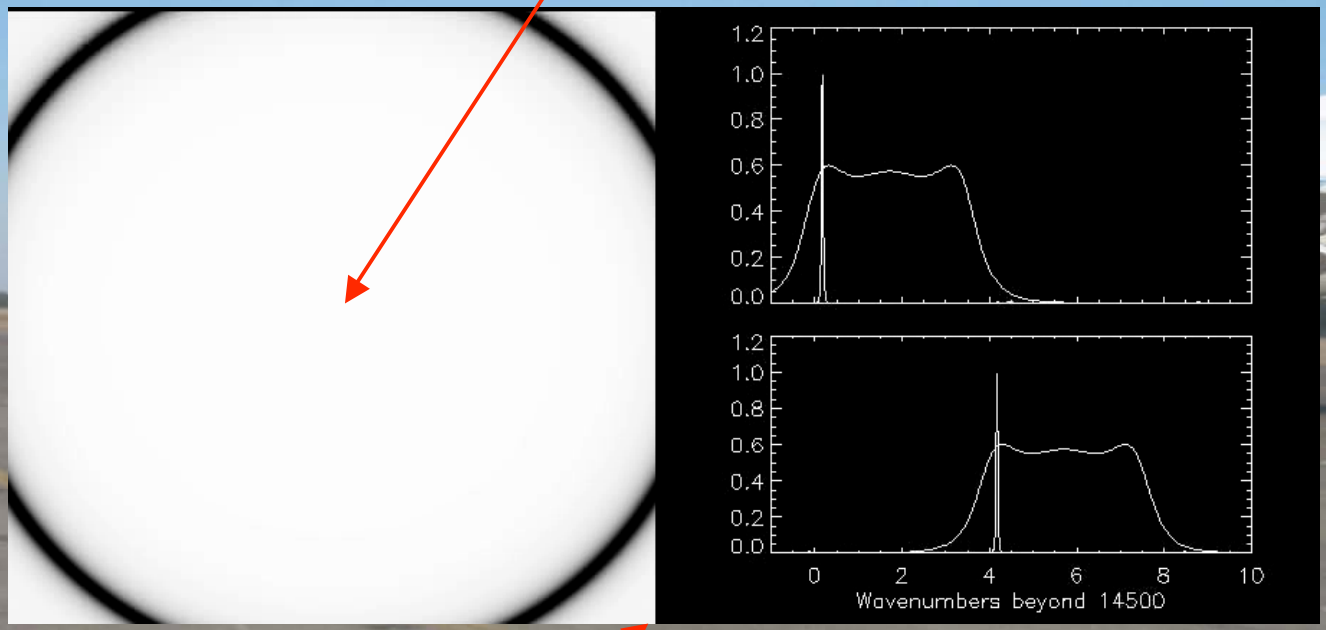




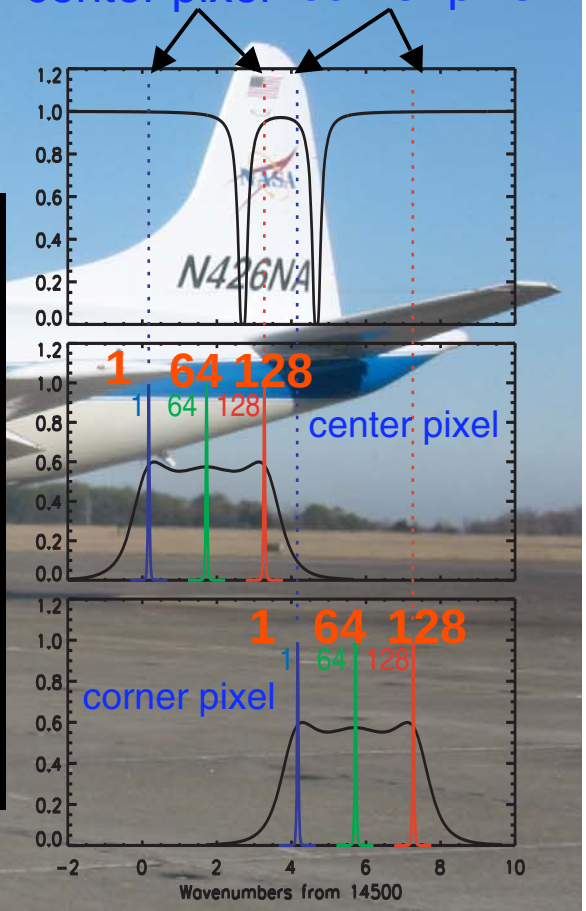
A Triple-Etalon Scanning Fabry-Perot Imager

center pixel

$$\frac{\Delta\nu}{\nu_o} = \frac{\theta^2}{2\mu*}$$



corner pixel



Spectral scanning + spatial imaging => Scene temporal uniformity
=> ideal for Geo applications

GIFS Prototype Instrument Specifications

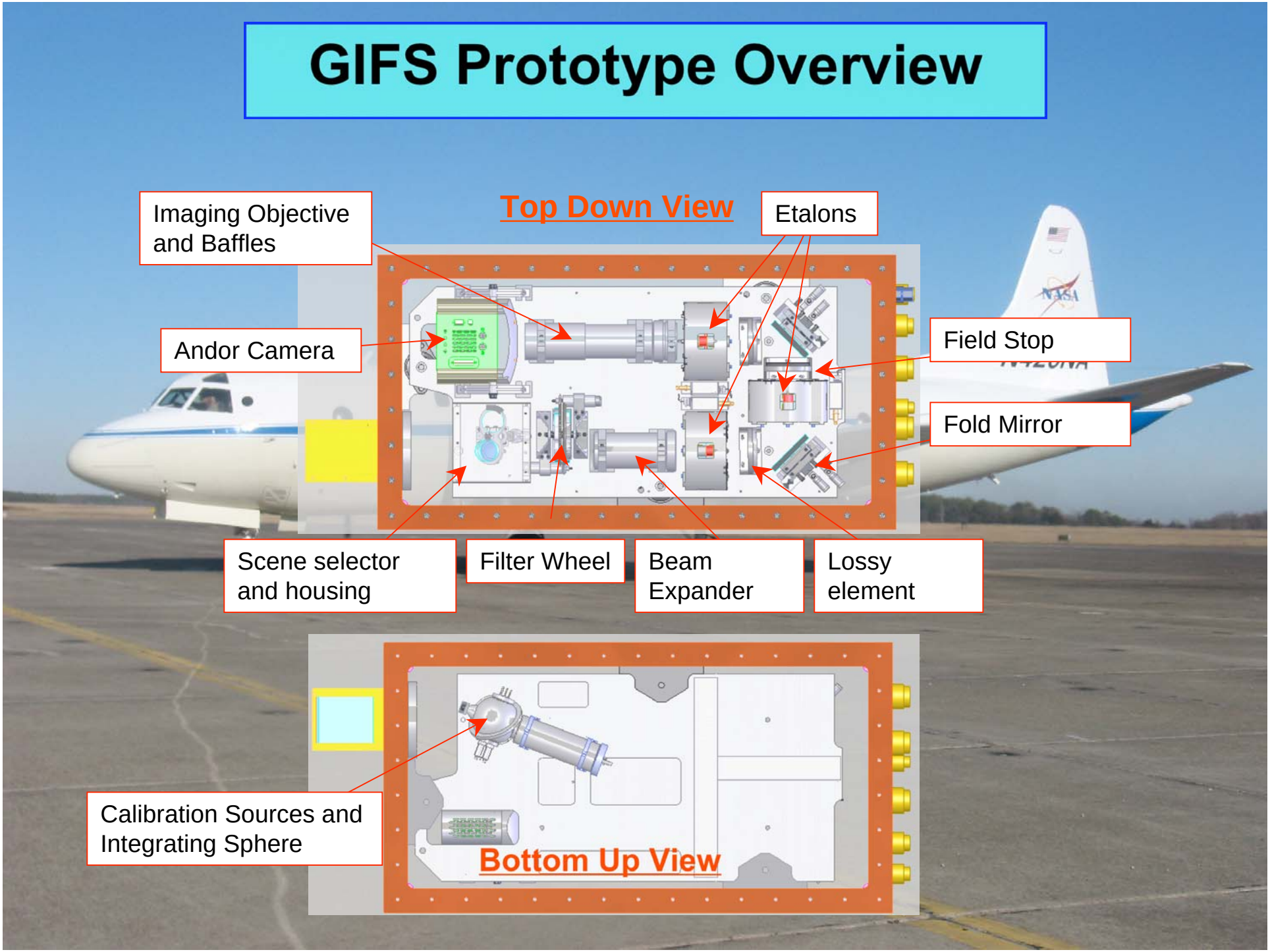
Instrument Parameter	Specification
Operating Wavelength	689.6 (vacuum) 689.4 (air)
Field of View of Instrument	3.60^0
Full Angle Through Etalons	1.90^0
Detector Format	512 x 512
Pixel Size of Detector	16 μm
Divergence through Etalons	65μ rad / pixel
CCD Binning	1 x 1 and programmable
Filter Clear Aperture	2.618 cm (~1”)
Filter Effective Refractive Index	1.89
Collection Altitude	30,000 ft.
Spatial Resolution (w/ 4 x 4 binning)	4.49 m/bin
Full imaged scene	0.33 km^2
F/# of Imaging System	4.9
Required signal at CCD	>20,000 e-/binned pixel
Filter Bandwidth (FWHM)	≤ 8 cm^{-1} (or 0.38 nm)

GIFS Prototype Etalon Specifications

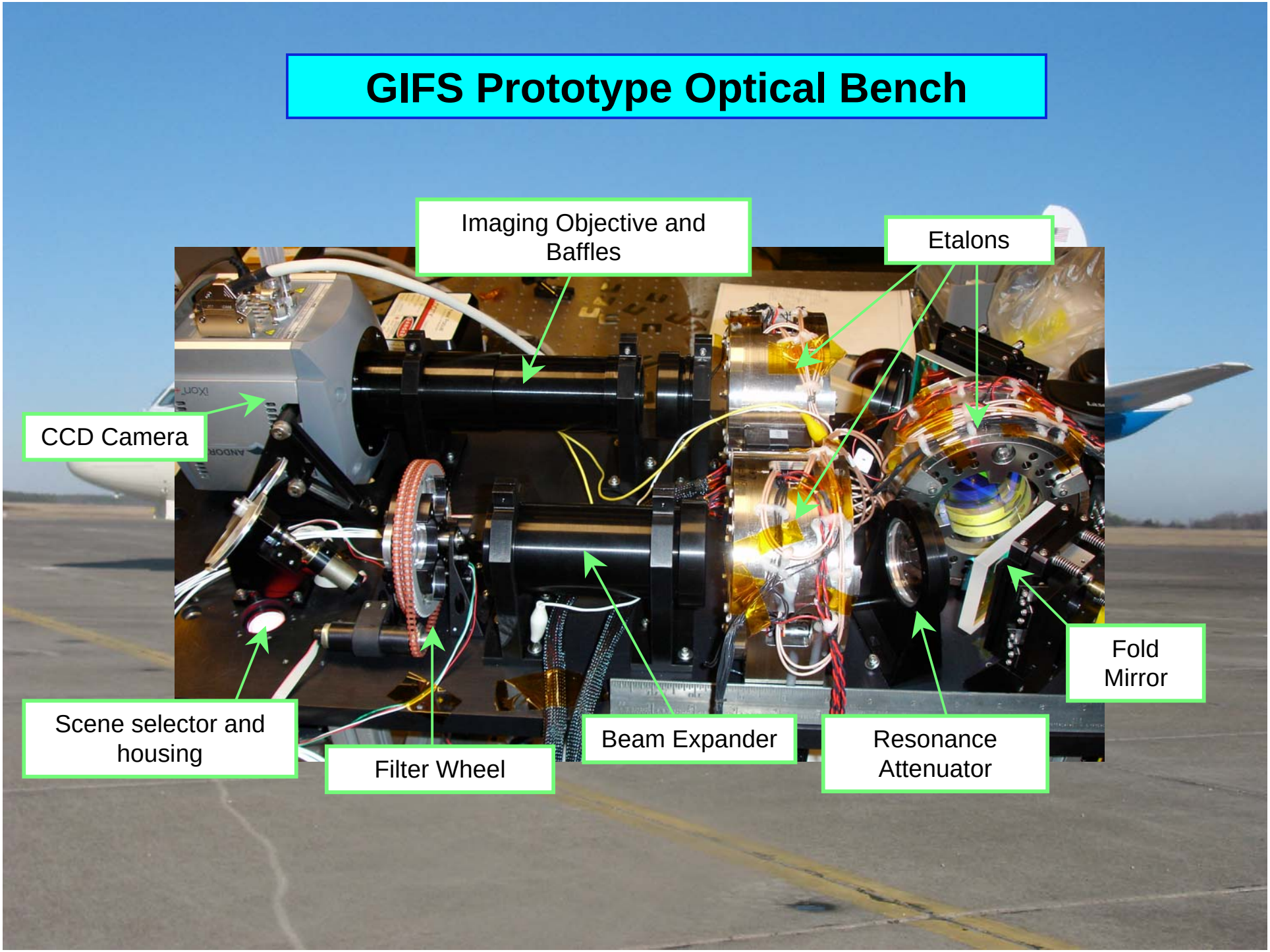
Common Specifications	Value
Clear Aperture	5.0 cm
Reflectivity	85 ± 2%
Coating Wavelength	600-700 nm
Plate Flatness	λ/150 @ 633 nm
Finesse	>15
Spectral Step Resolution	<0.015 cm^{-1}
Gap Step Resolution	<0.5 nm
Dynamic Range	3-5 μm
Tolerance on Gap Spacing	± 0.002 cm
Repeatability	< 3 X 10^{-3} cm^{-1}

	HRE	MRE	LRE
FSR	1.5 cm^{-1}	3.32 cm^{-1}	7.102 cm^{-1}
Gap Spacing	0.333	0.1506 cm	0.0704 cm
# Orders Imaged	1.33	0.602	0.282

GIFS Prototype Overview

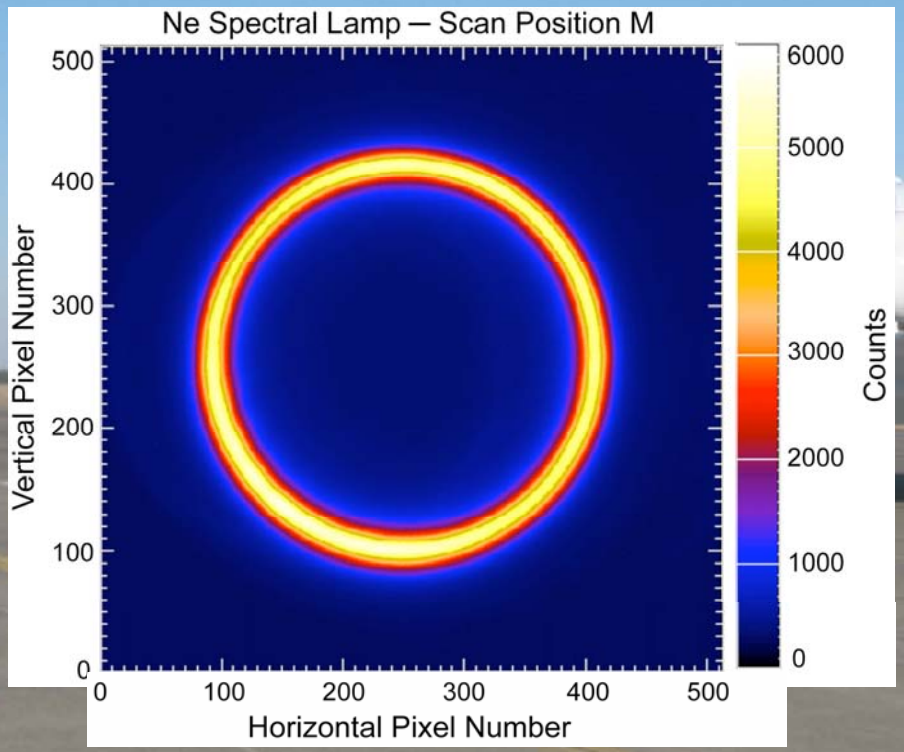


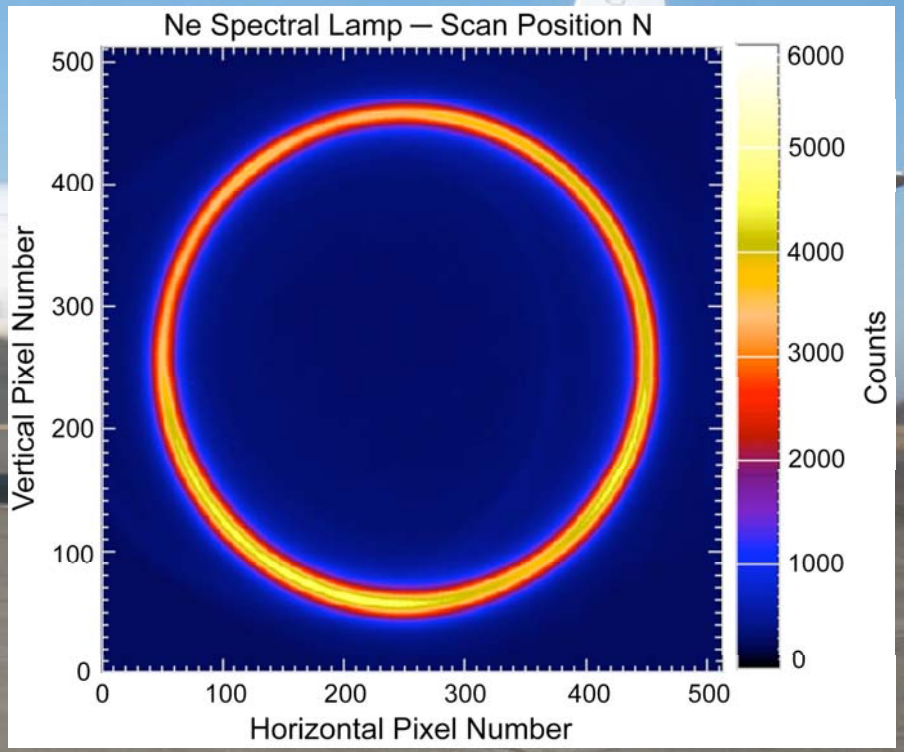
GIFS Prototype Optical Bench



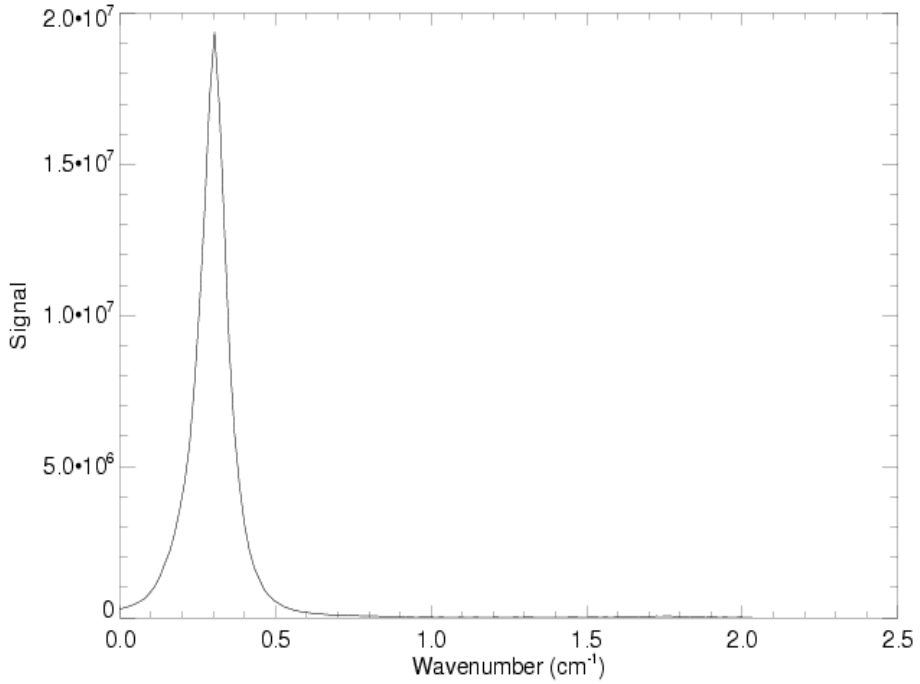
GIFS in Chamber

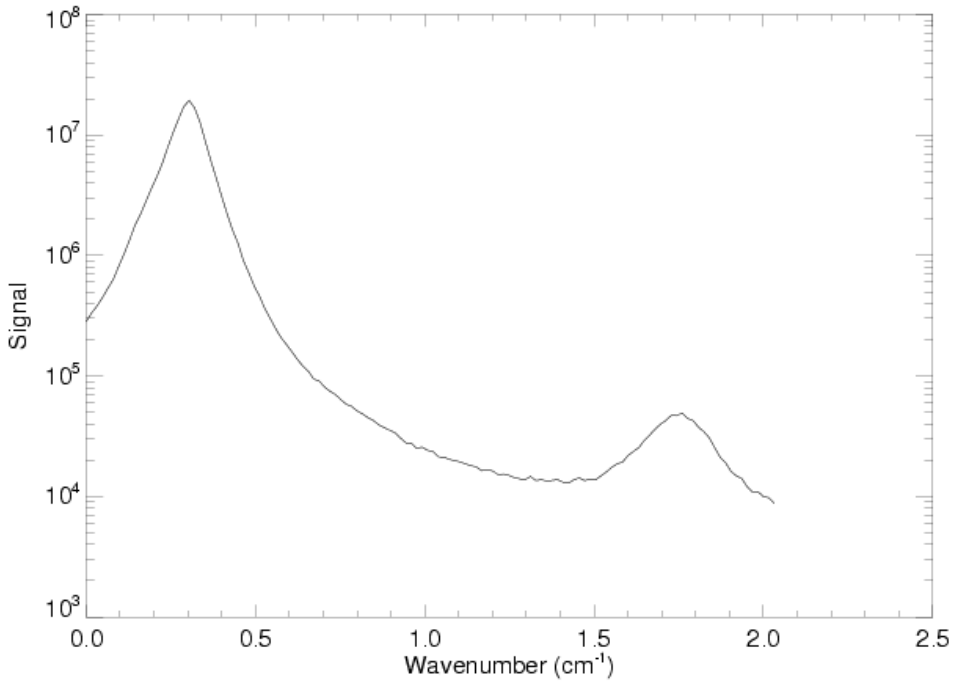
Tuning Capability Demonstration





Instrument Transmission





FSR = 1.5 cm^{-1}

$\Delta\lambda$ = 0.105 cm^{-1}

Finesse = ~14

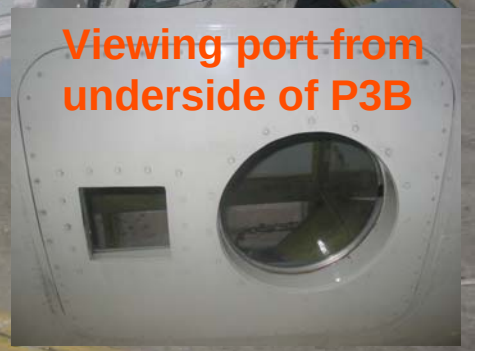
GIFS P3-Flight Experiments

- GIFS conducted its engineering test flight onboard NASA P3 on 1/30/08 and five science flights afterward through 2/14/08.

Electronic Rack

GIFS Imaging interferometer

View Port

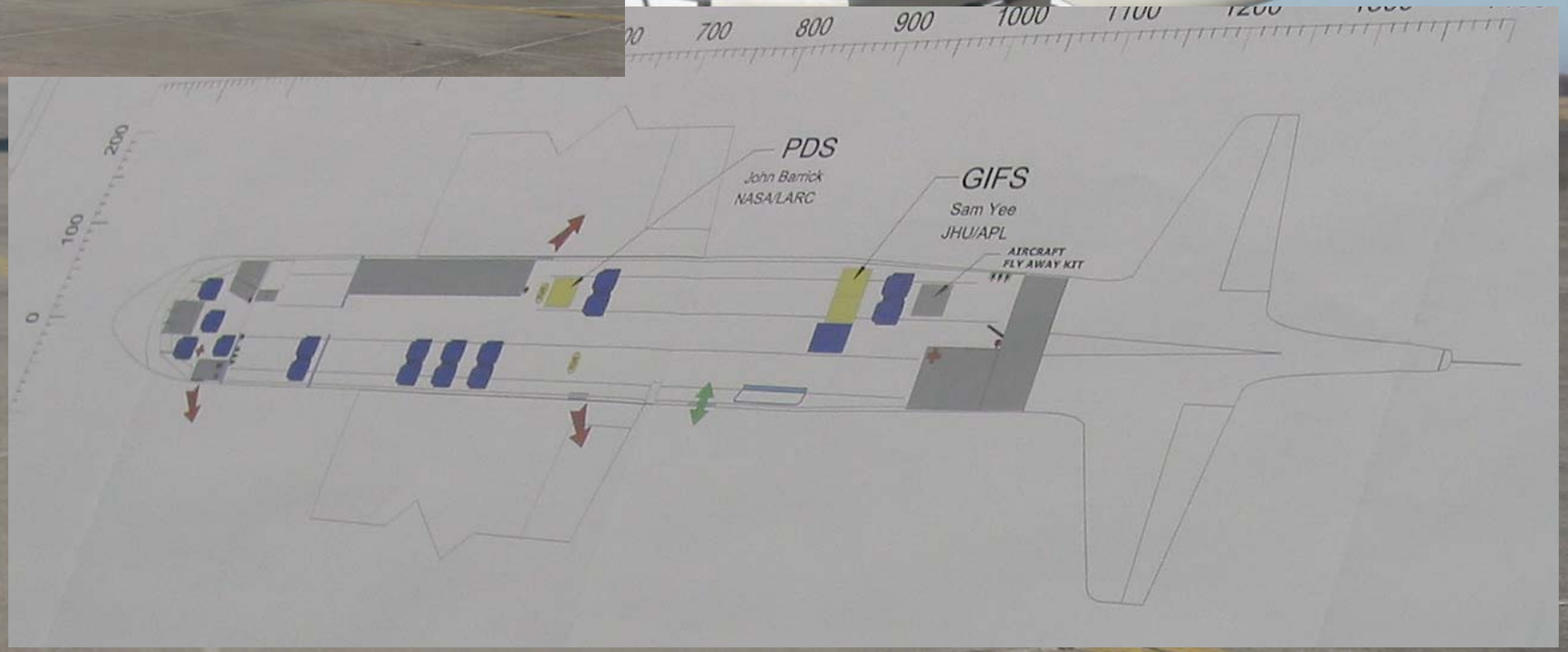


Viewing port from underside of P3B

GIFS Onboard NASA P3B

NASA P3B at Wallops Island

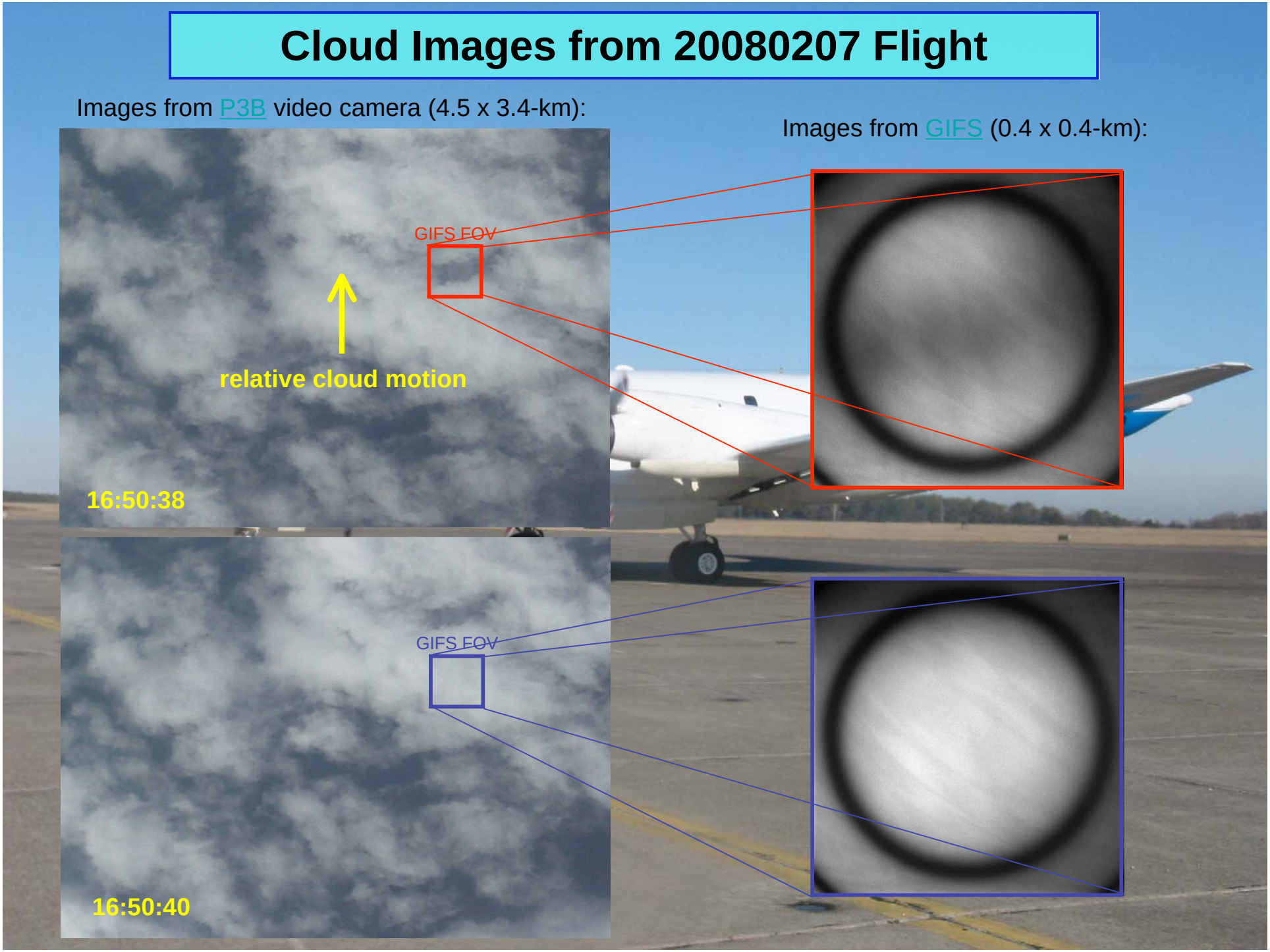
Payload placement



Cloud Images from 20080207 Flight

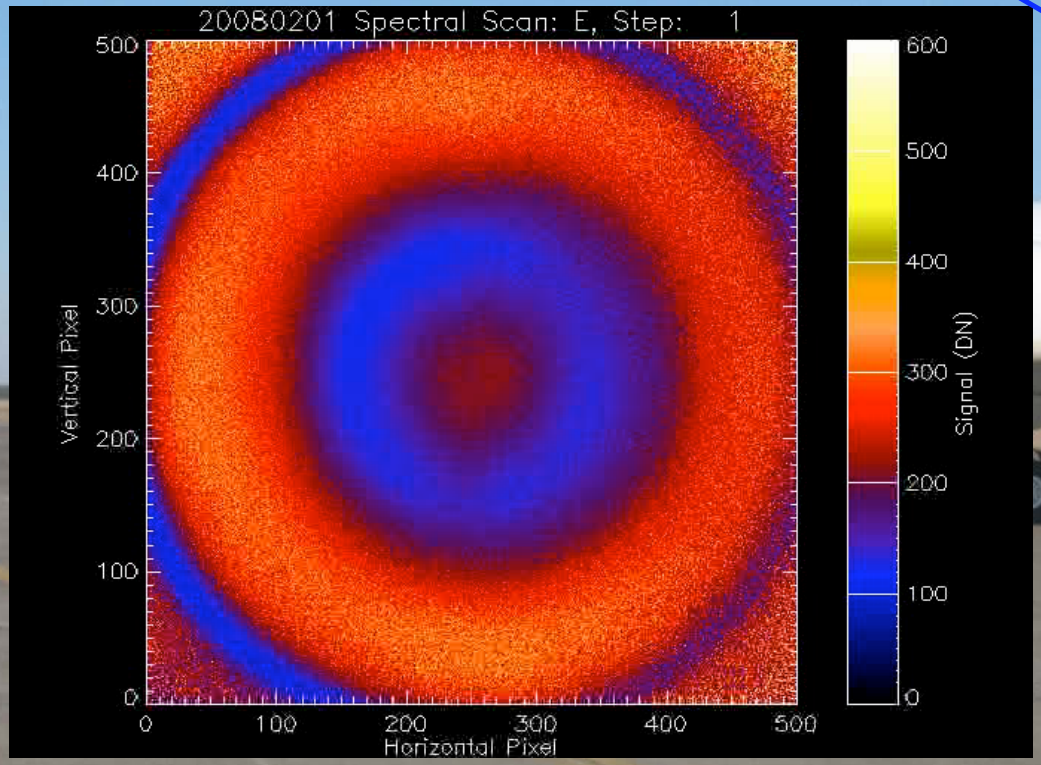
Images from P3B video camera (4.5 x 3.4-km):

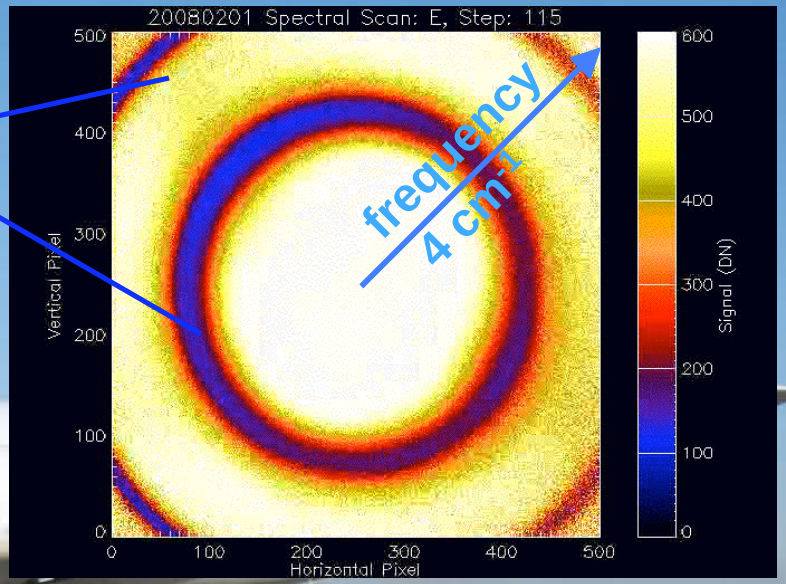
Images from GIFS (0.4 x 0.4-km):

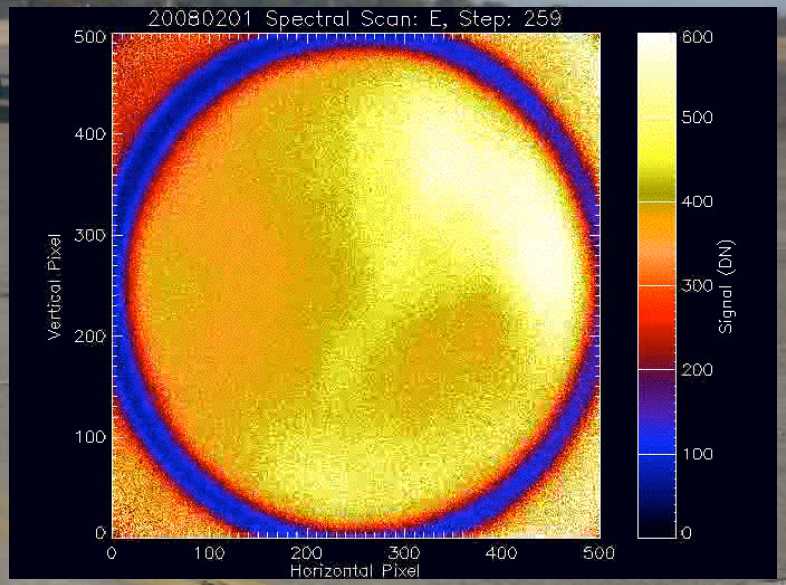


GIFS Image Spectral Scanning

Two O_2 absorption lines







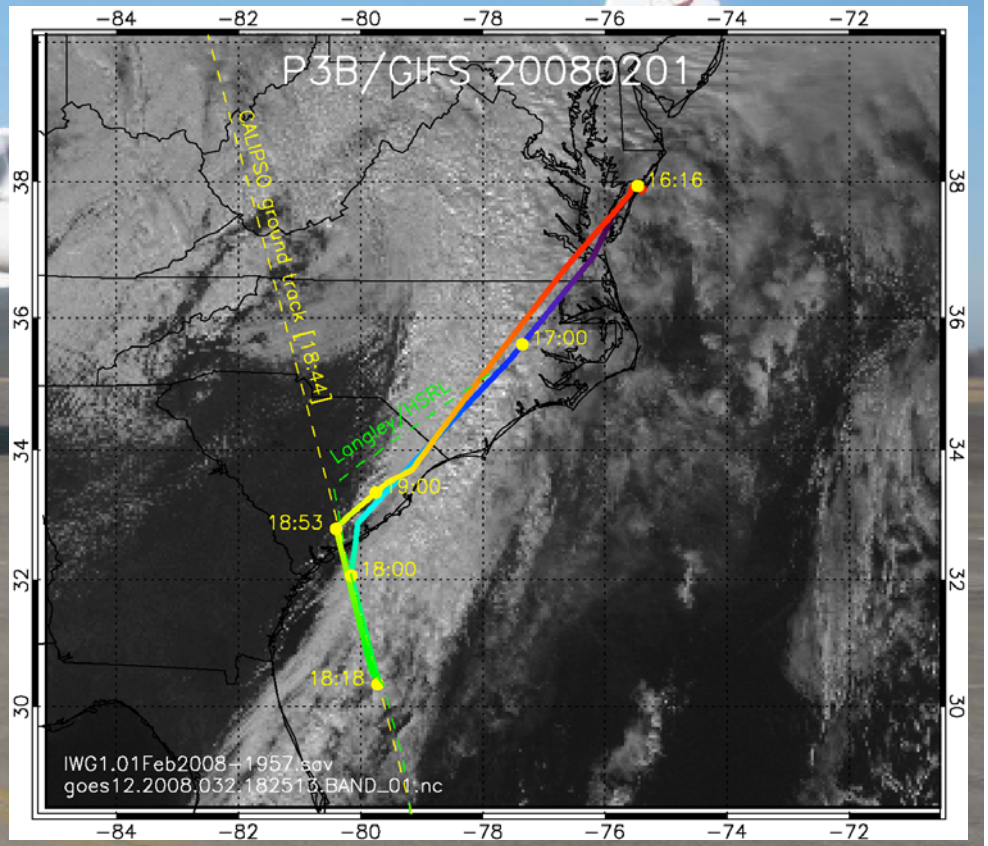
GIFS Image Spectral Scan Animation

At a given pixel location, a spectrum is obtained after a complete spectral scan (in this case, about 2 cm^{-1} for a 64 spectral steps) is completed.

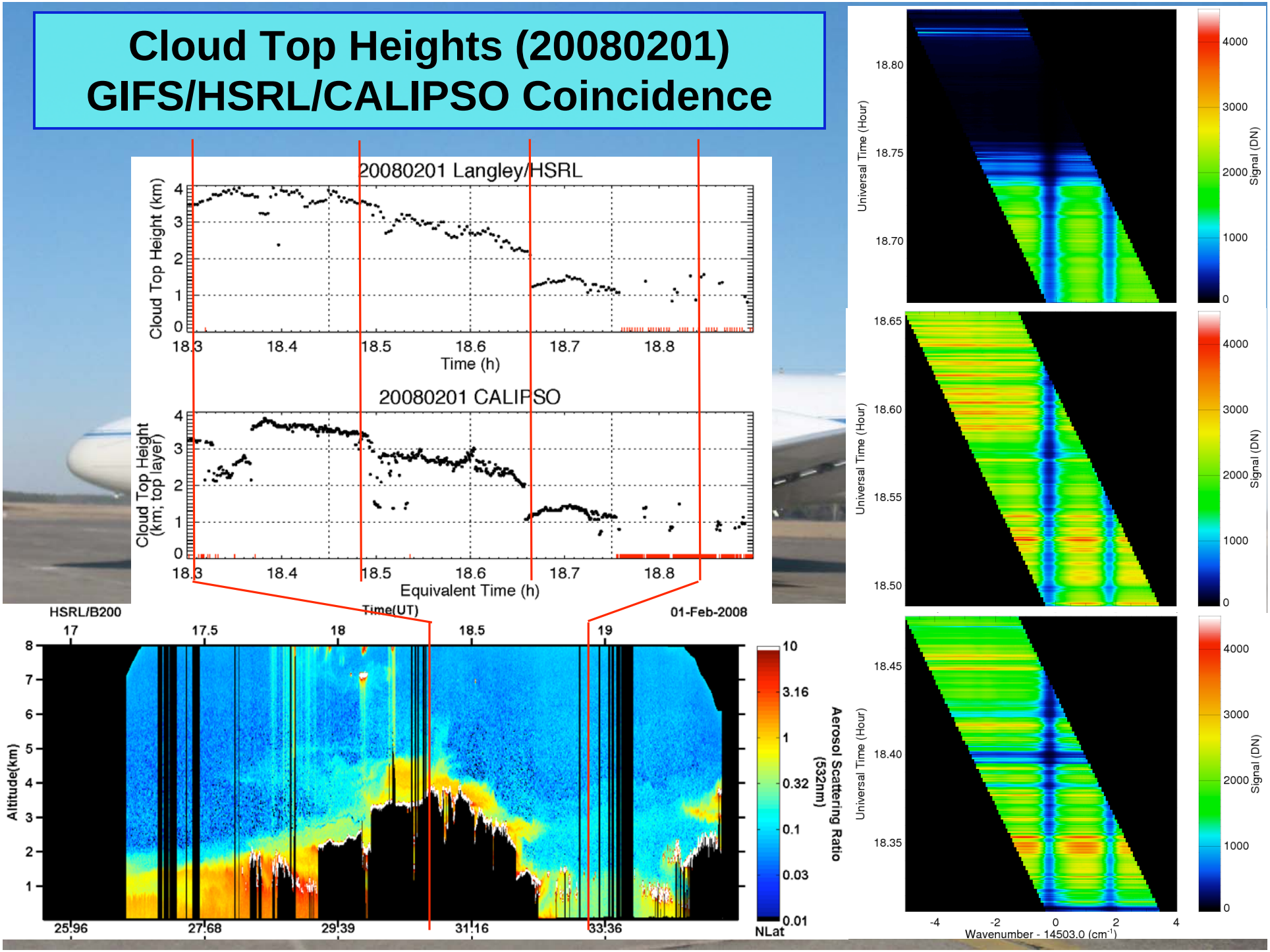
0.4 x 0.4 km^2 from 2,1000 ft (or 0.75 m per pixel)

GIFS Flight Coincidence with Langley HSRL Airborne Lidar + CALIPSO

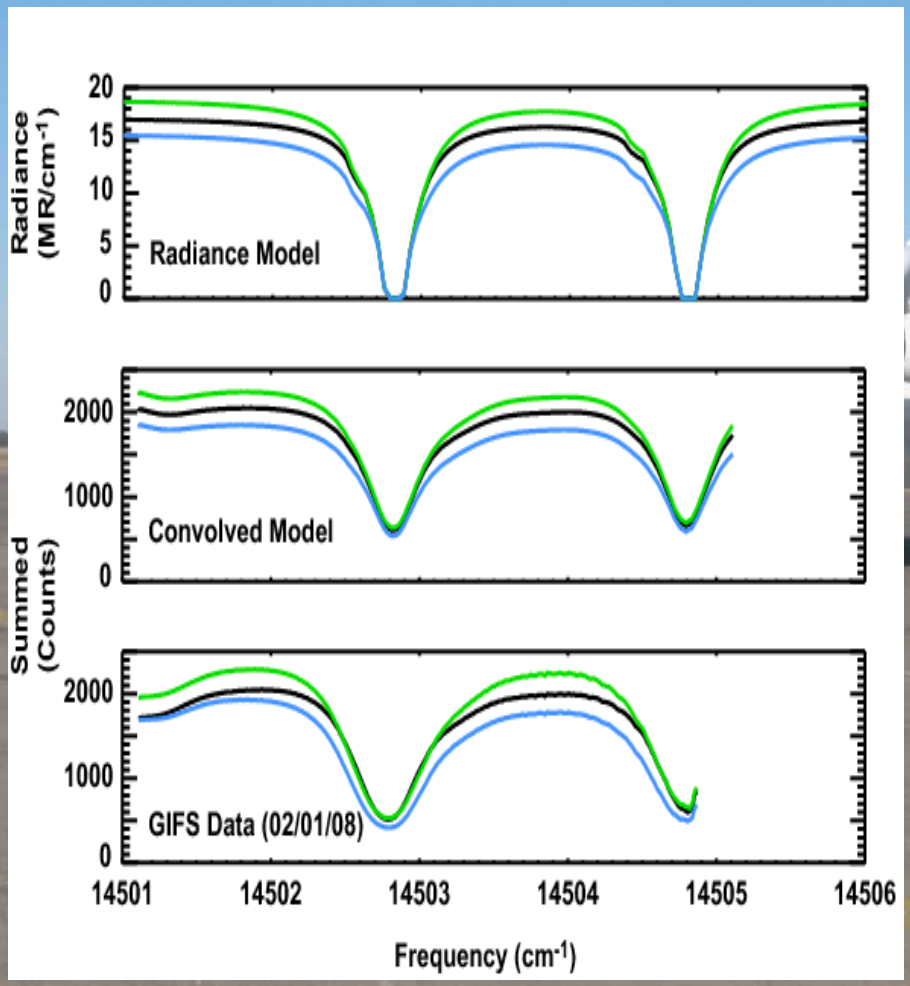
LaRC aircraft, as viewed from P3B, below.

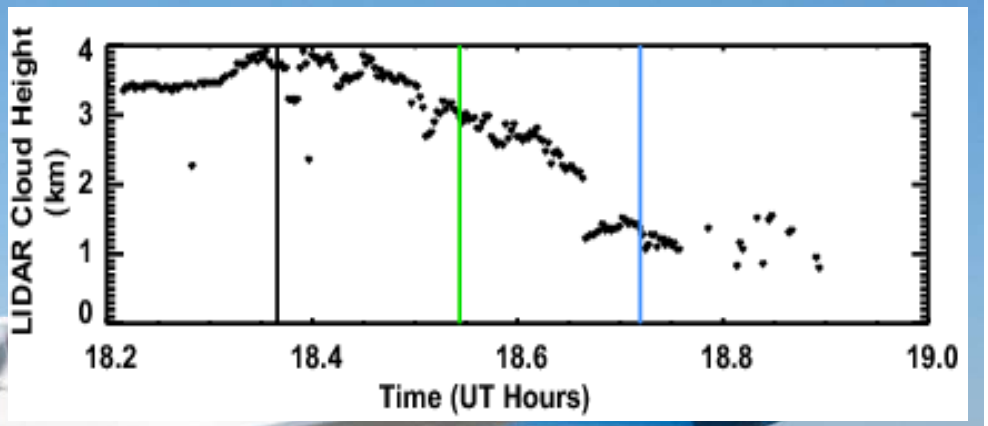


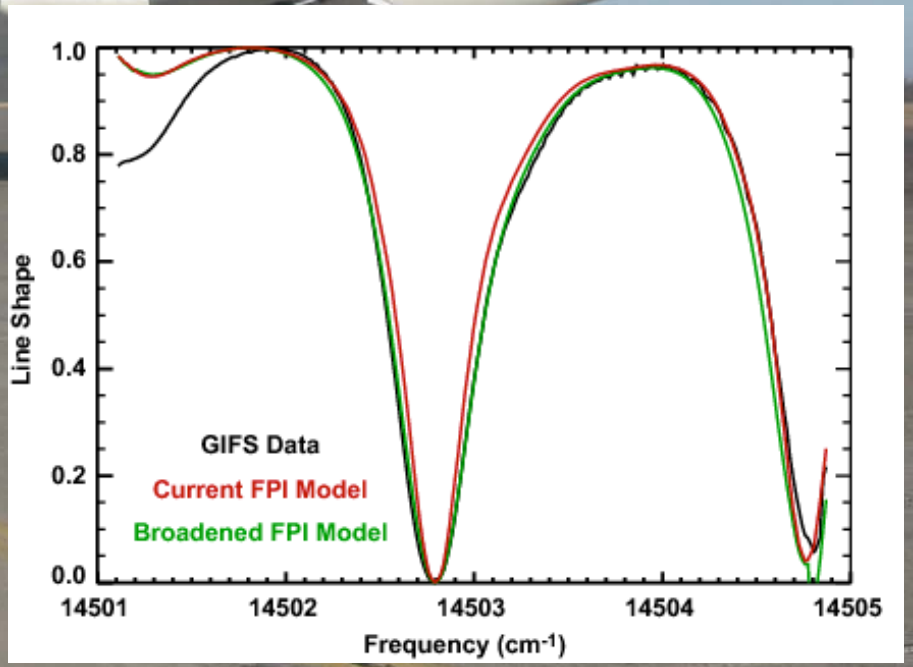
Cloud Top Heights (20080201) GIFS/HSRL/CALIPSO Coincidence



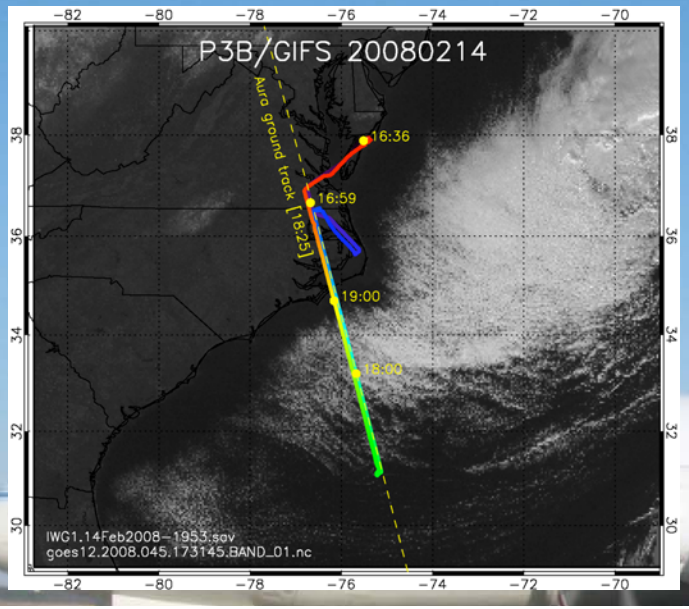
GIFS Measurement Assessment

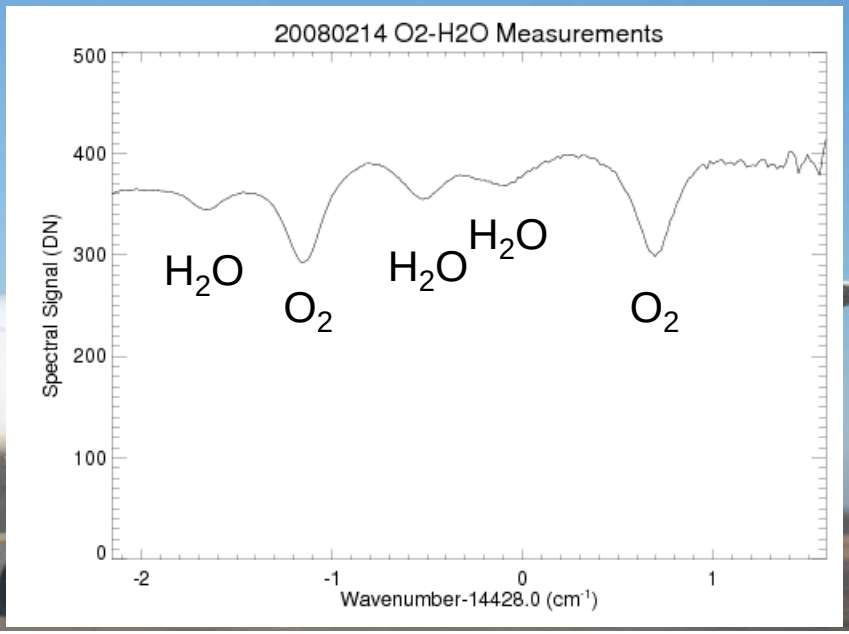


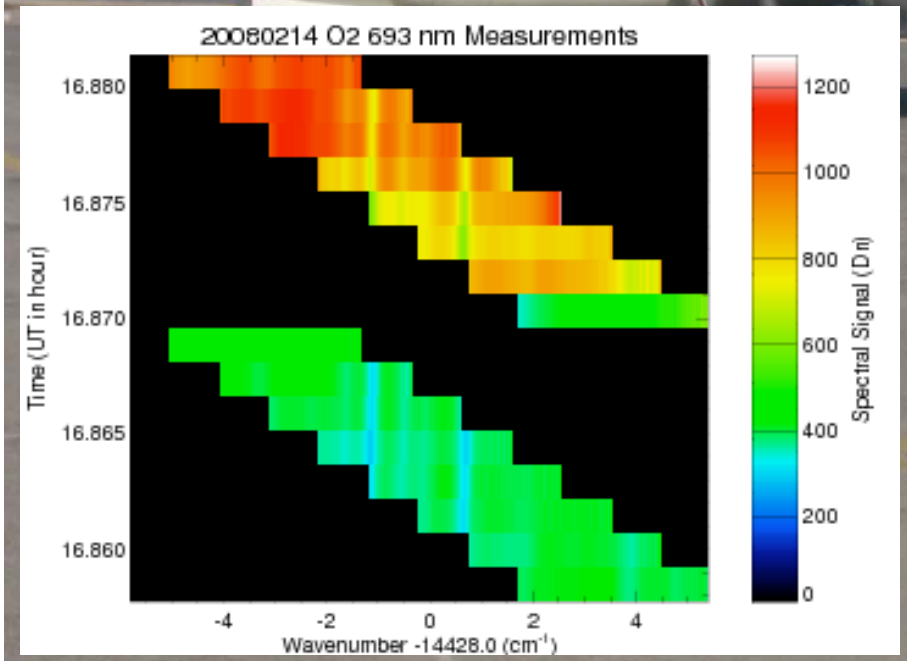


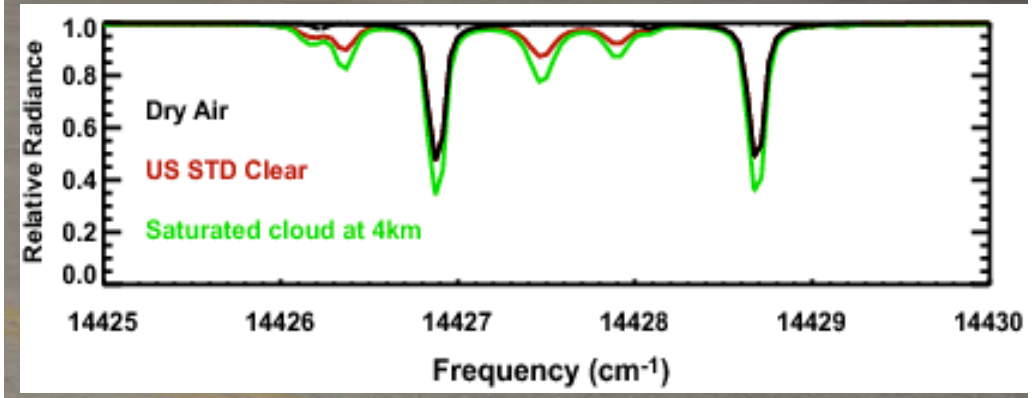


GIFS: Water Mixing Ratio Measurements

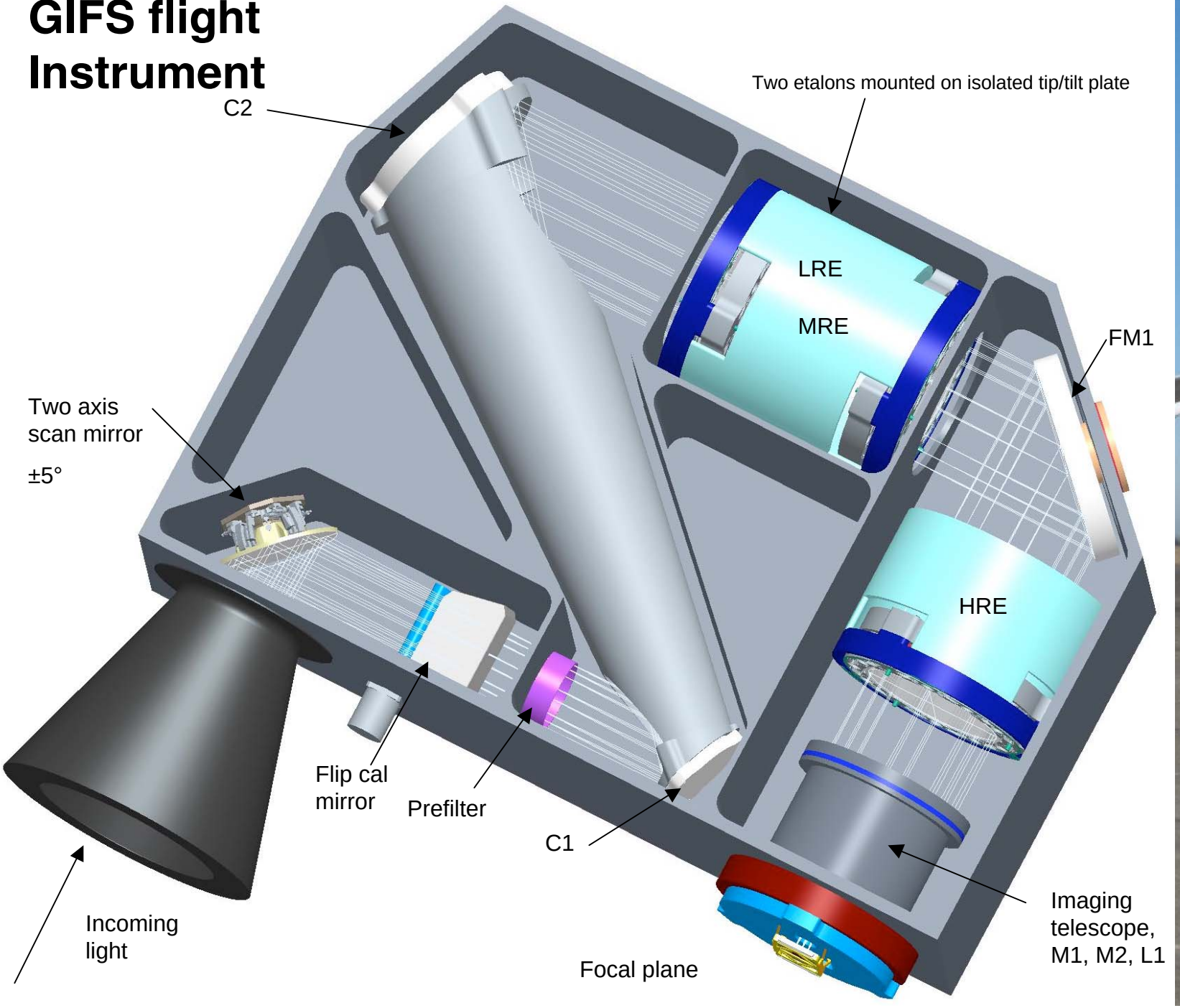








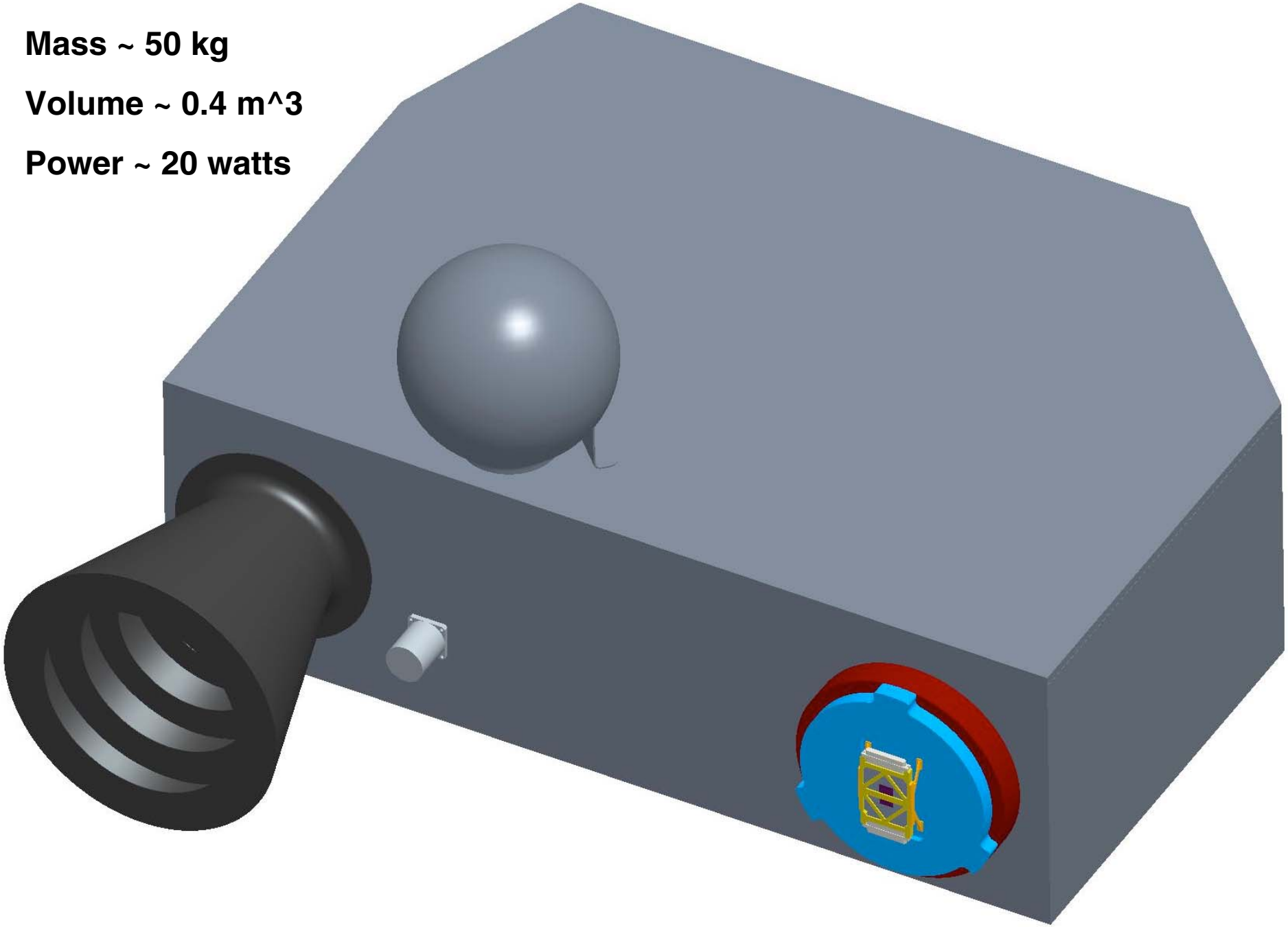
GIFS flight Instrument

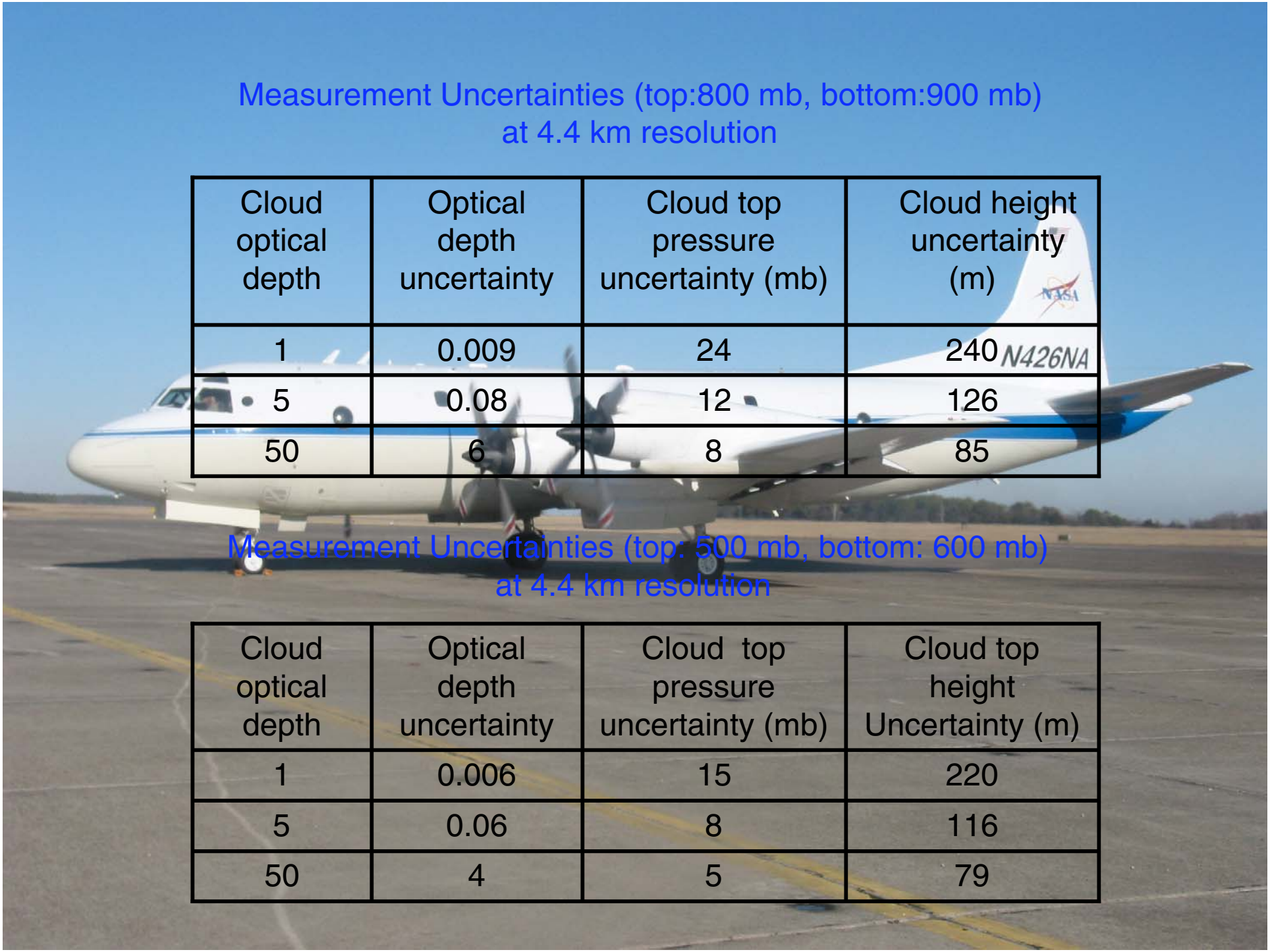


Mass ~ 50 kg

Volume ~ 0.4 m^3

Power ~ 20 watts





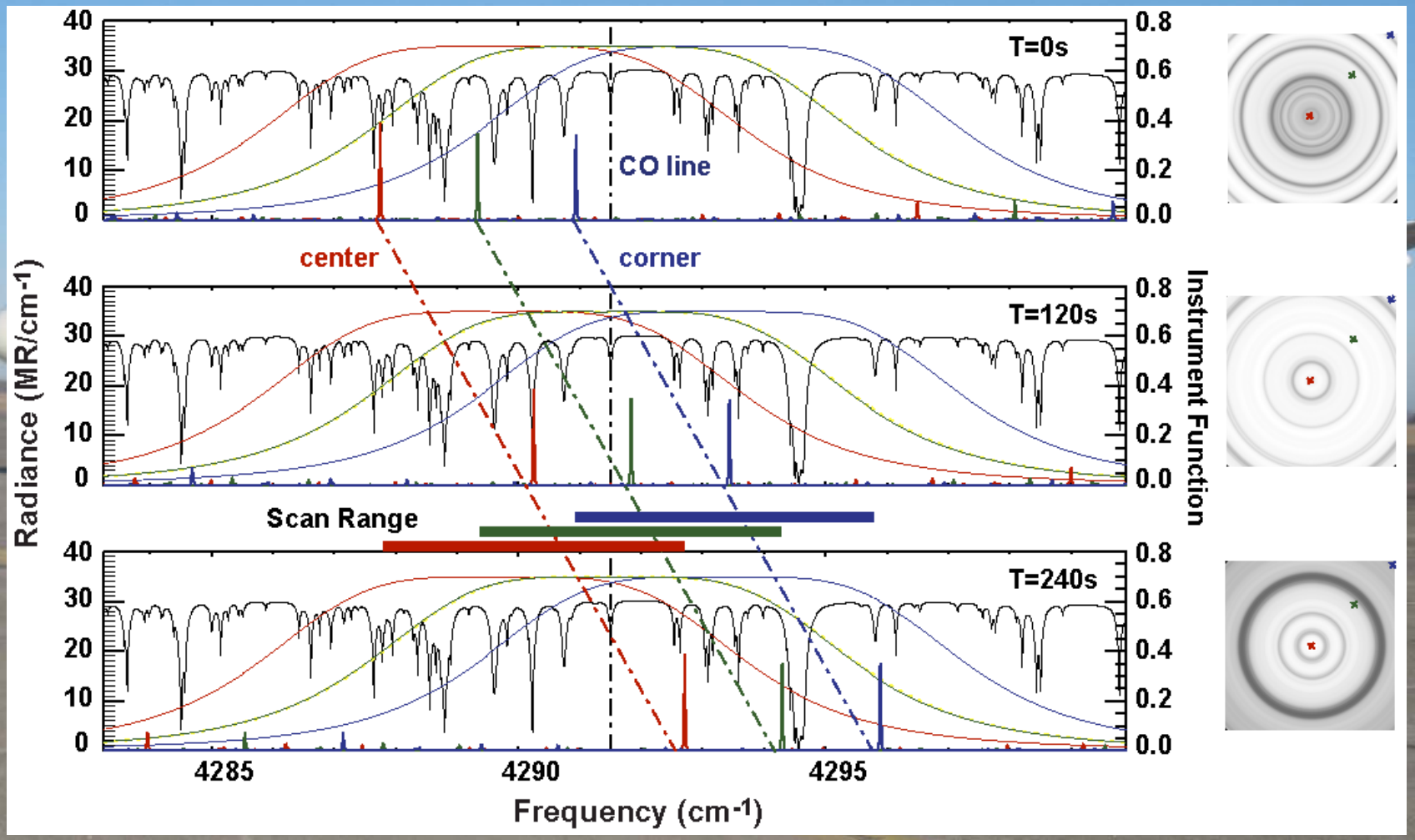
Measurement Uncertainties (top:800 mb, bottom:900 mb)
at 4.4 km resolution

Cloud optical depth	Optical depth uncertainty	Cloud top pressure uncertainty (mb)	Cloud height uncertainty (m)
1	0.009	24	240
5	0.08	12	126
50	6	8	85

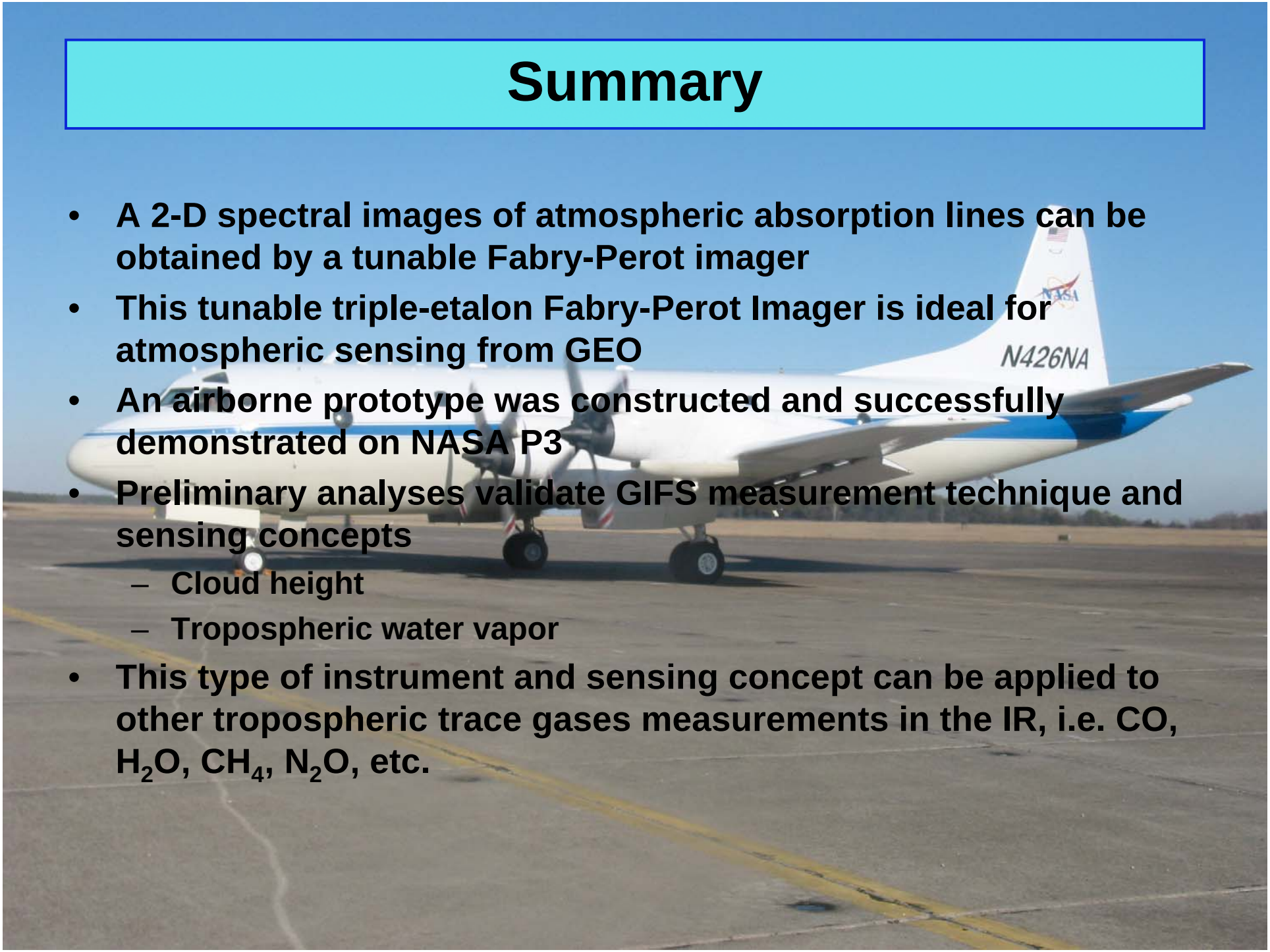
Measurement Uncertainties (top: 500 mb, bottom: 600 mb)
at 4.4 km resolution

Cloud optical depth	Optical depth uncertainty	Cloud top pressure uncertainty (mb)	Cloud top height Uncertainty (m)
1	0.006	15	220
5	0.06	8	116
50	4	5	79

GIFS CO Spectral Scanning (NIR)

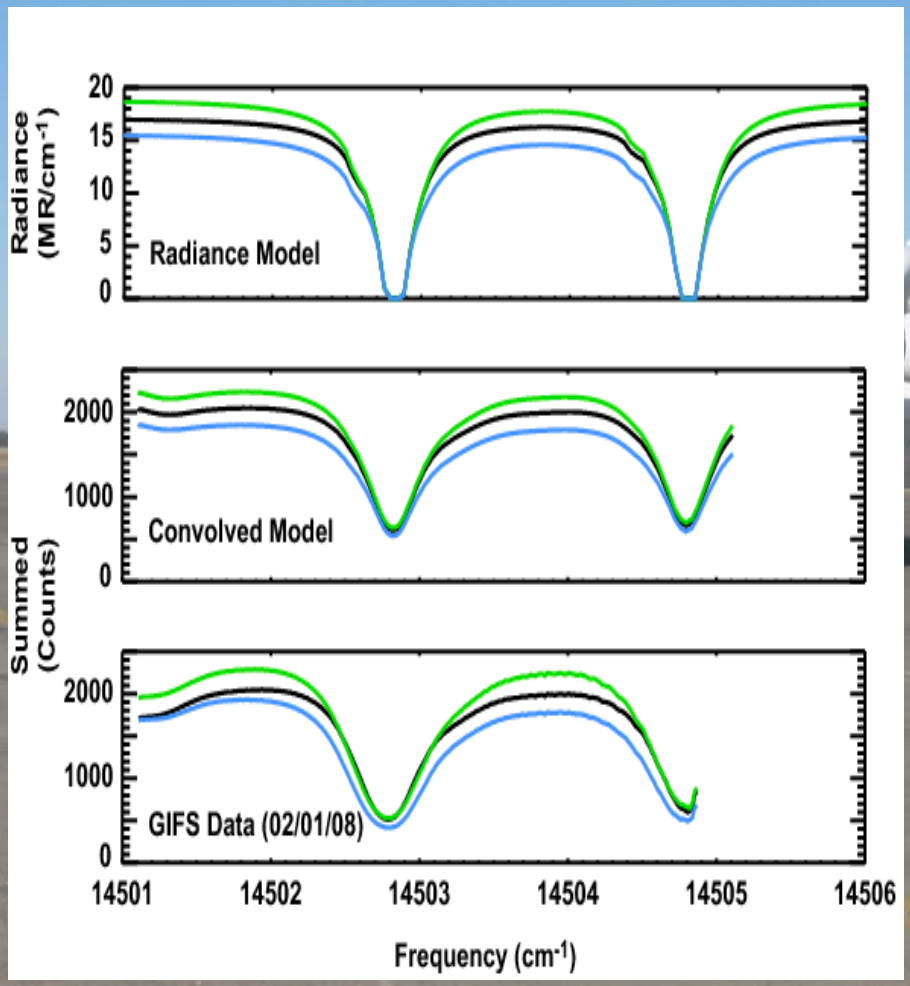


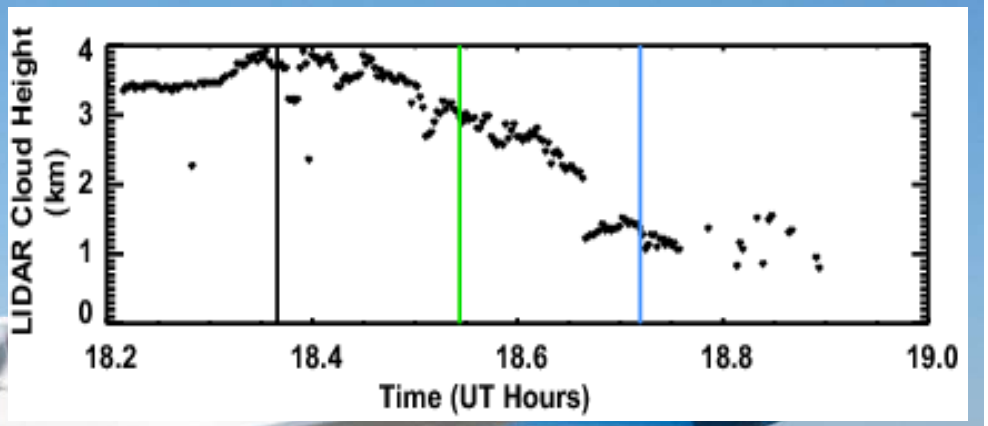
Summary

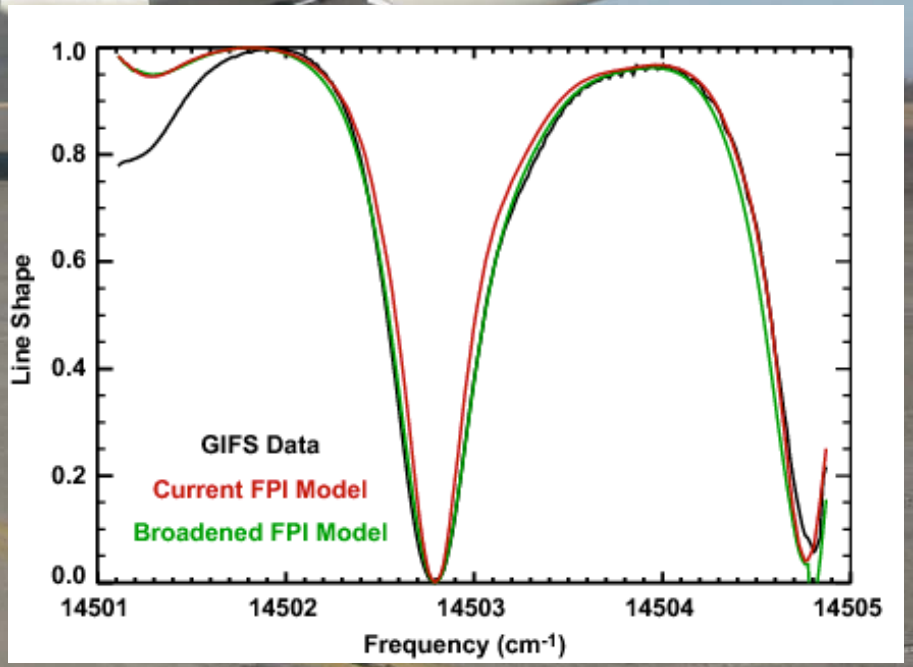


- A 2-D spectral images of atmospheric absorption lines can be obtained by a tunable Fabry-Perot imager
- This tunable triple-etalon Fabry-Perot Imager is ideal for atmospheric sensing from GEO
- An airborne prototype was constructed and successfully demonstrated on NASA P3
- Preliminary analyses validate GIFS measurement technique and sensing concepts
  - Cloud height
  - Tropospheric water vapor
- This type of instrument and sensing concept can be applied to other tropospheric trace gases measurements in the IR, i.e. CO, H_2O, CH_4, N_2O, etc.

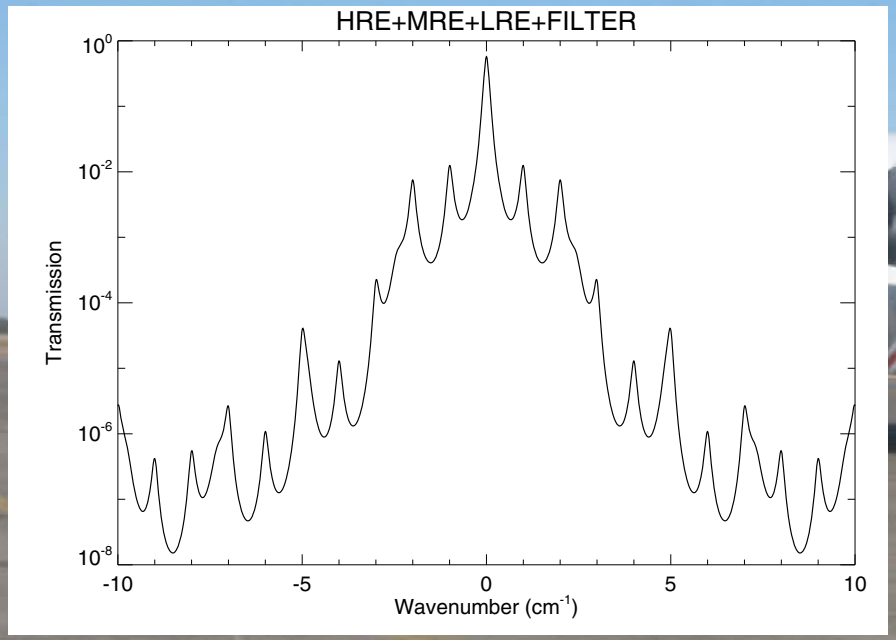
GIFS Measurement Assessment

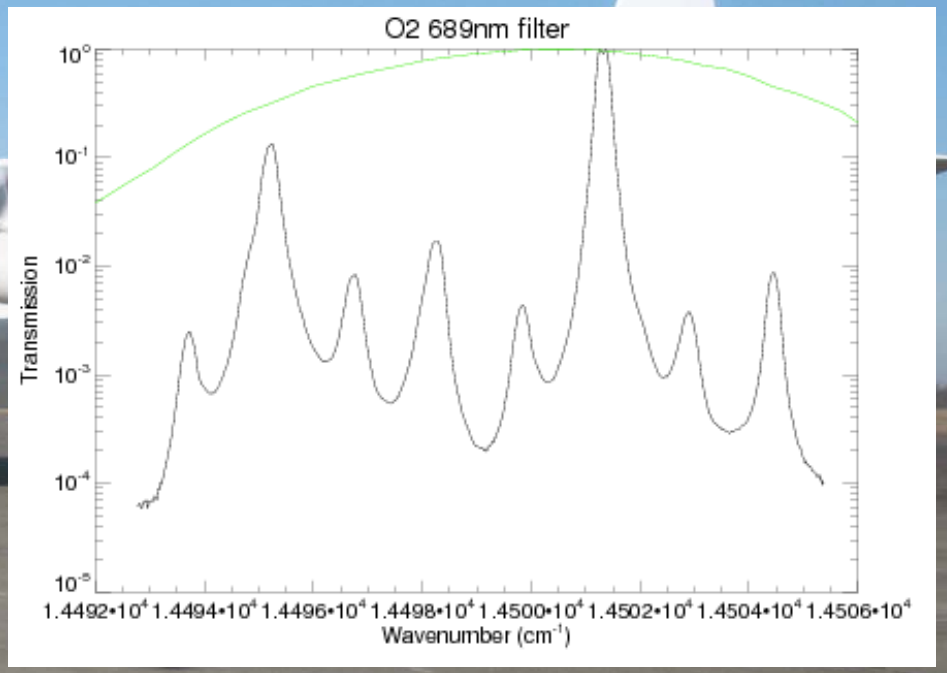






Triple-Etalon FPI Transmission Function

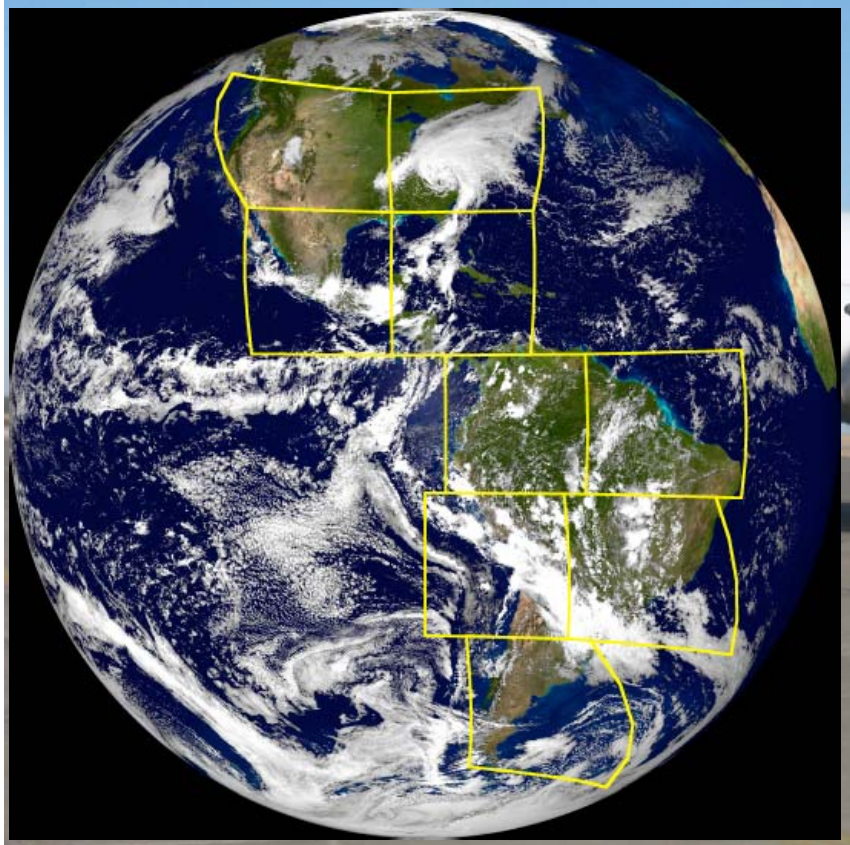


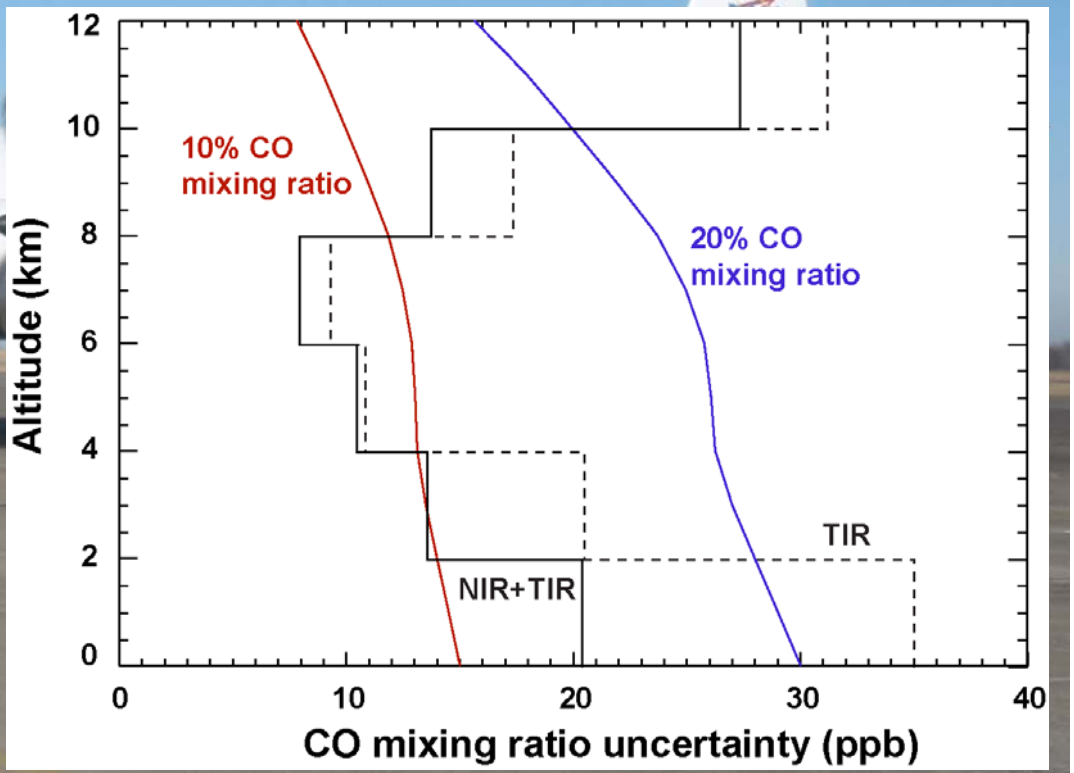


Ideal

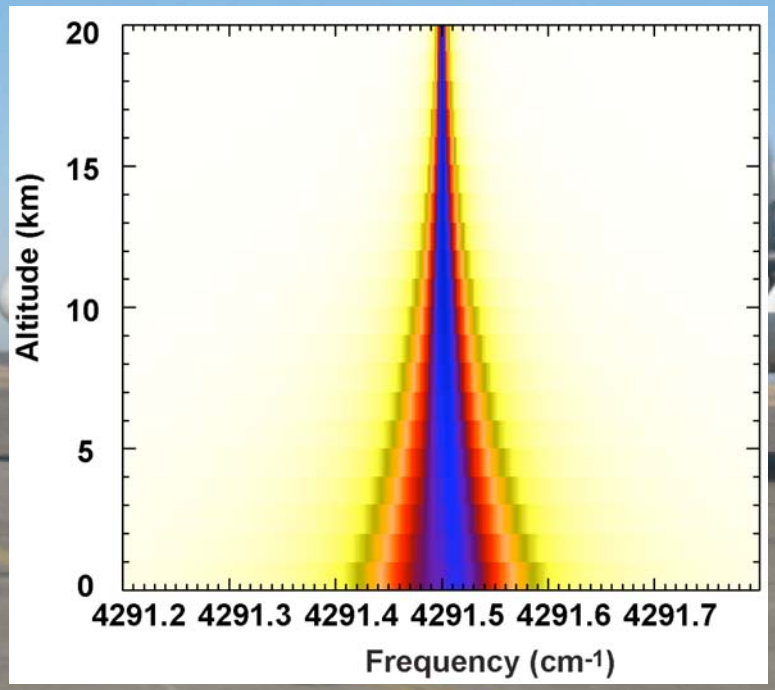
GIFS Prototype

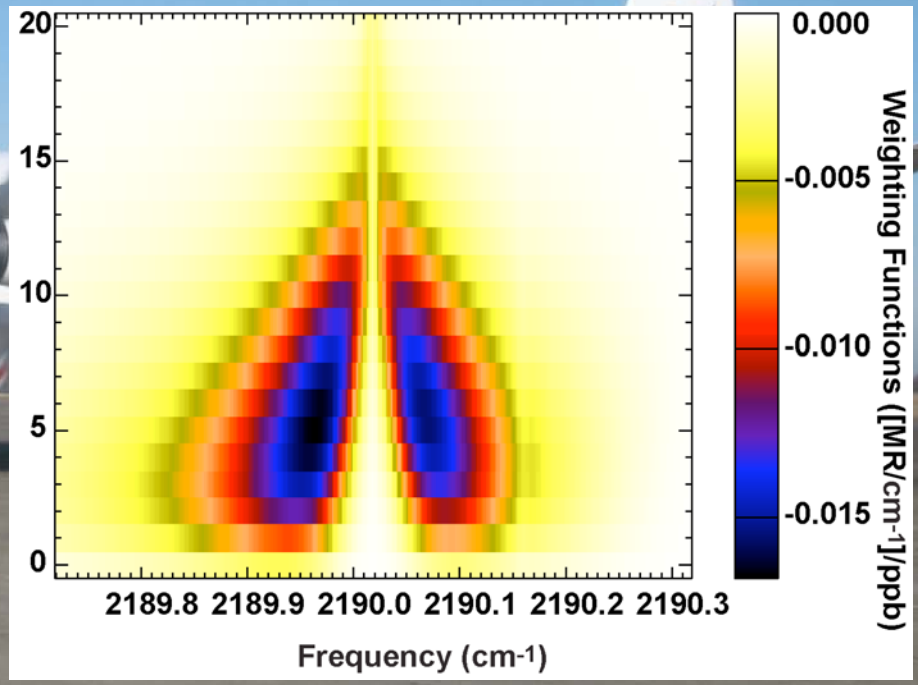
GIFS CO Spatial Scanning & Uncertainty



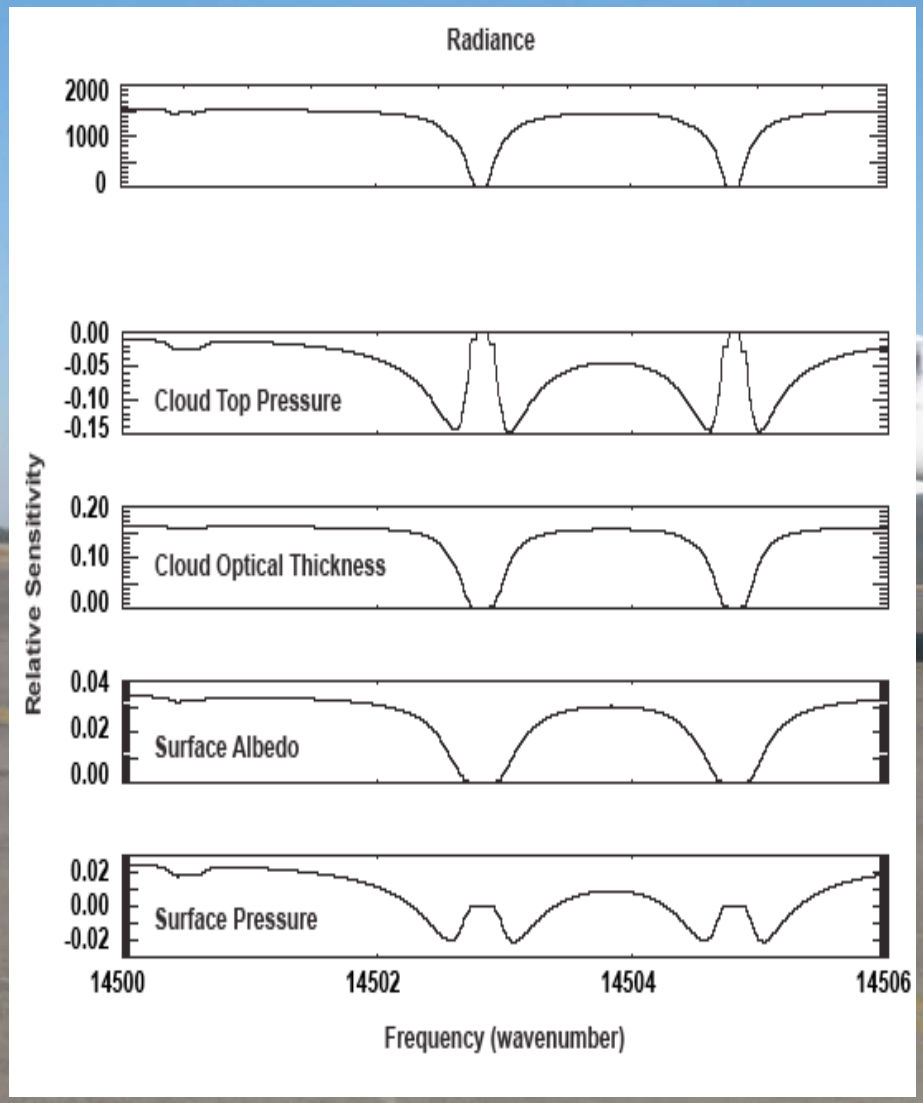


CO Weighting Functions: NIR, TIR

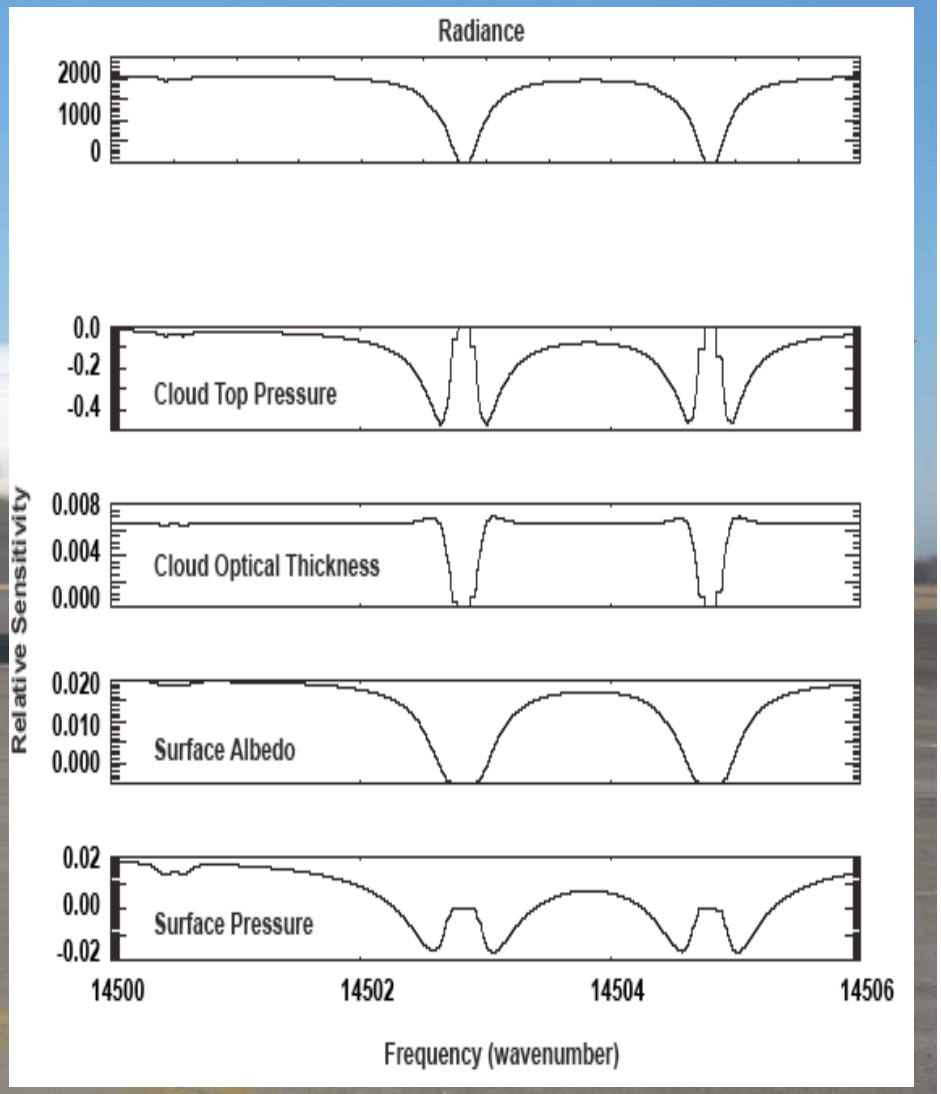




Spectral Sensitivities



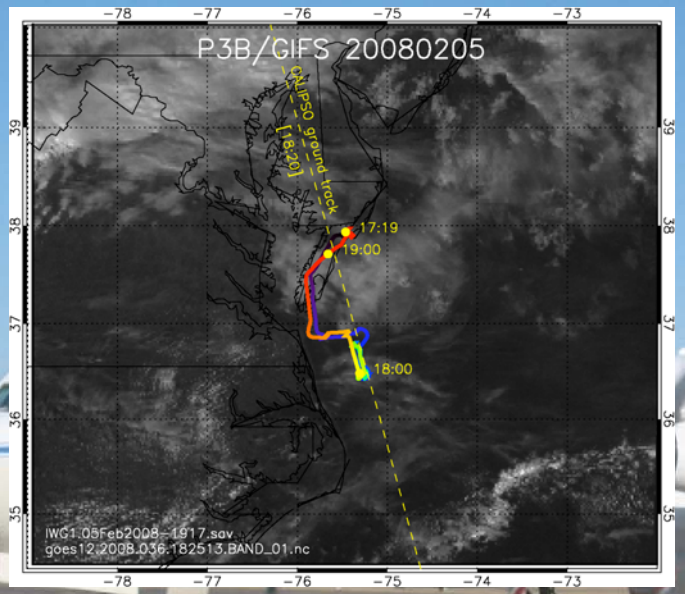
Thin Cloud (OD=100)

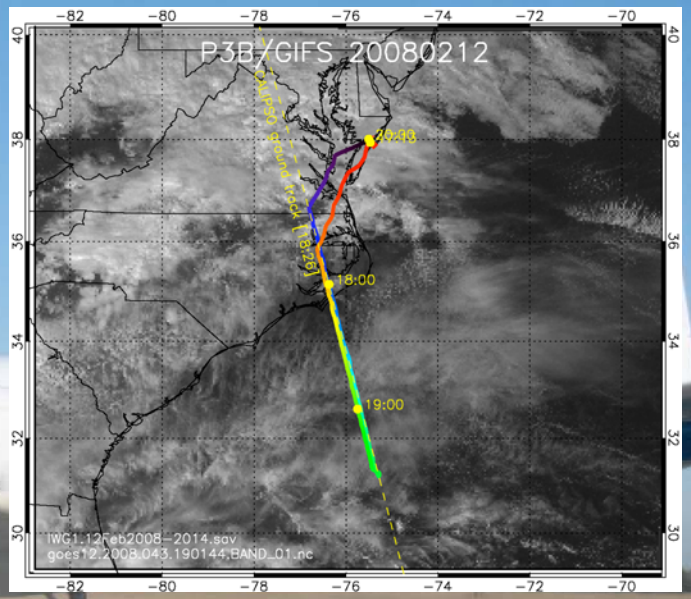


Very Thick Cloud (OD=100)

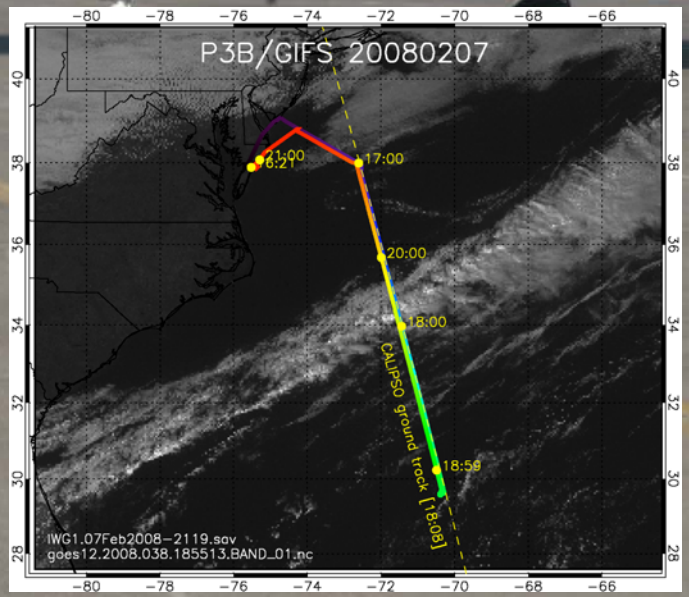
GIFS Flights (cont'd)

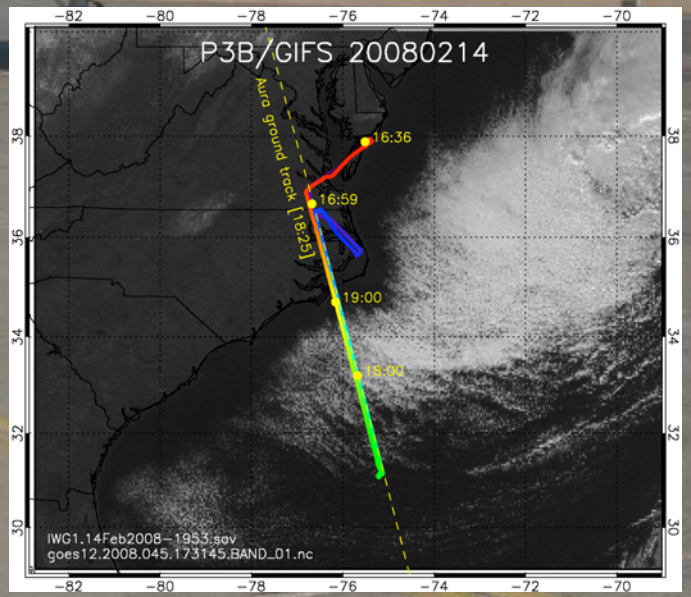
CALIPSO





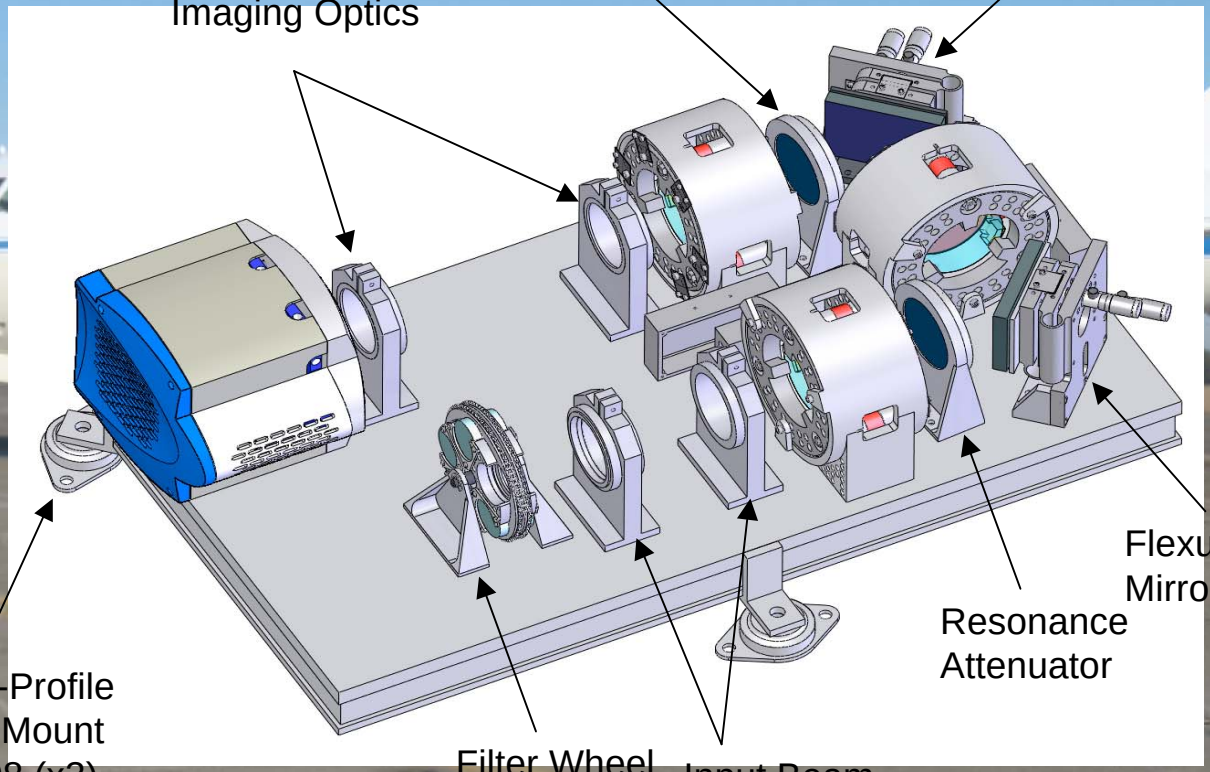
CALIPSO



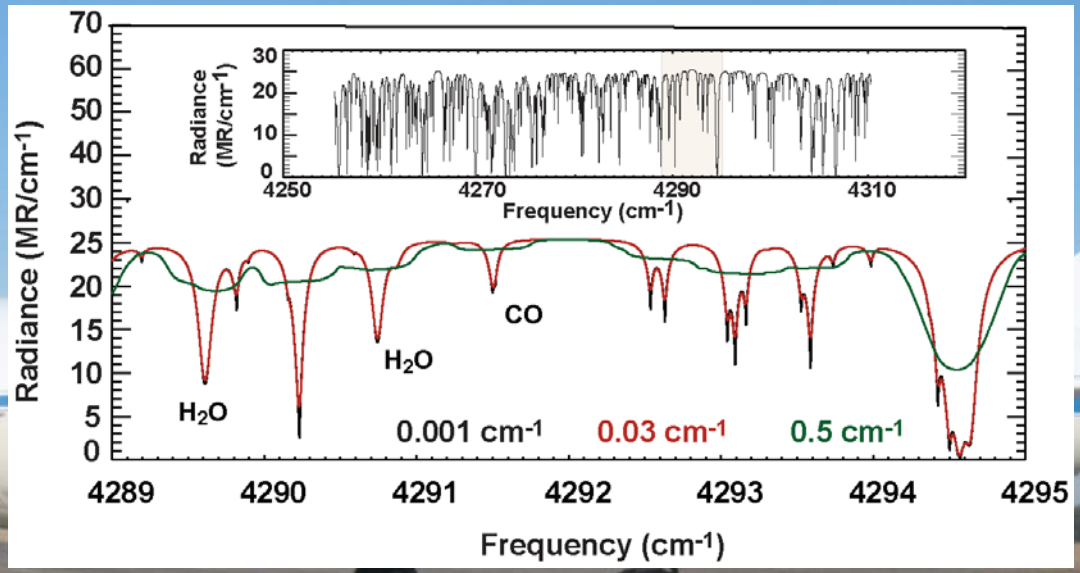


Aura

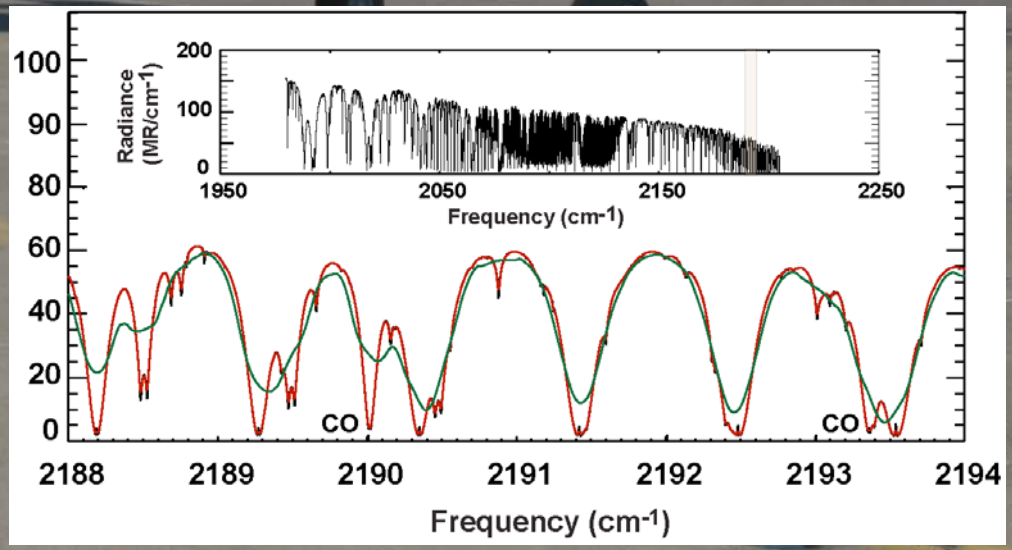
GIFS Interferometer Layout



Application of GIFS Technique: CO
Calculated Daytime Upwelling Radiance



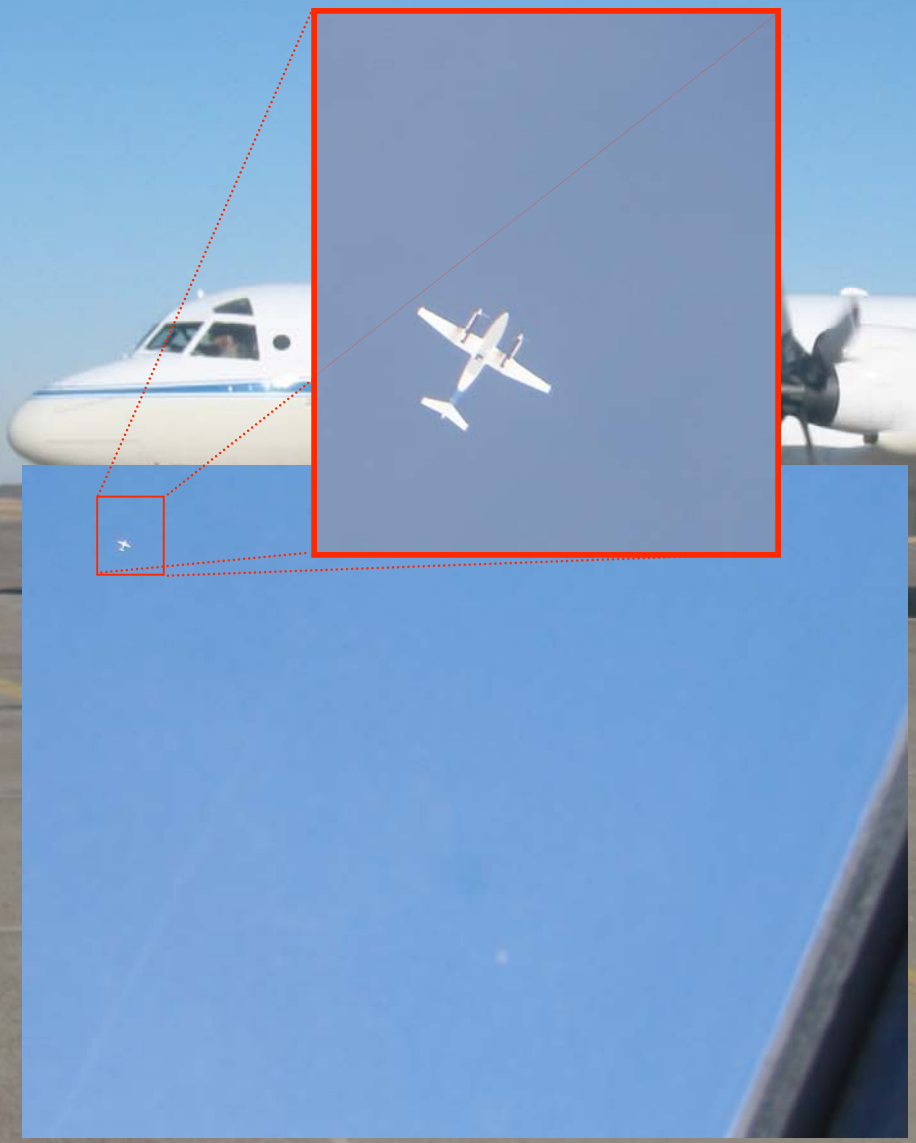
NIR

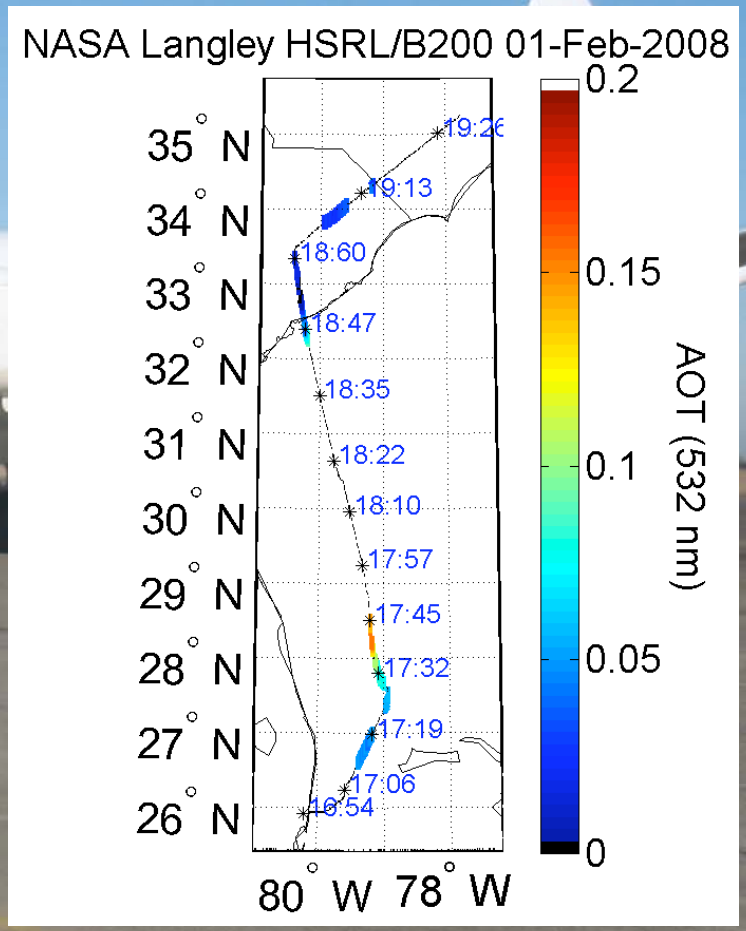


TIR

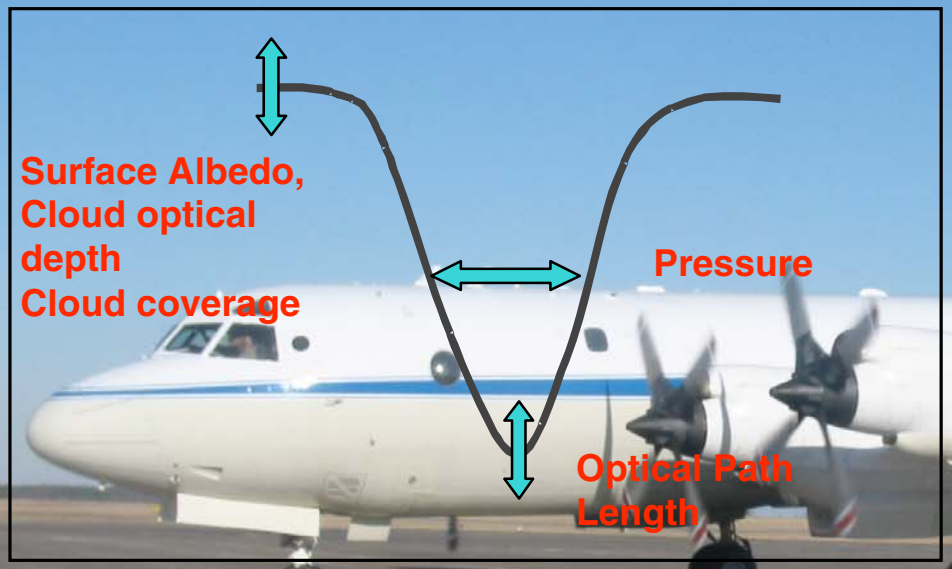
LaRC HSRL 20080201 Flight

LaRC aircraft, as viewed from P3B, below.



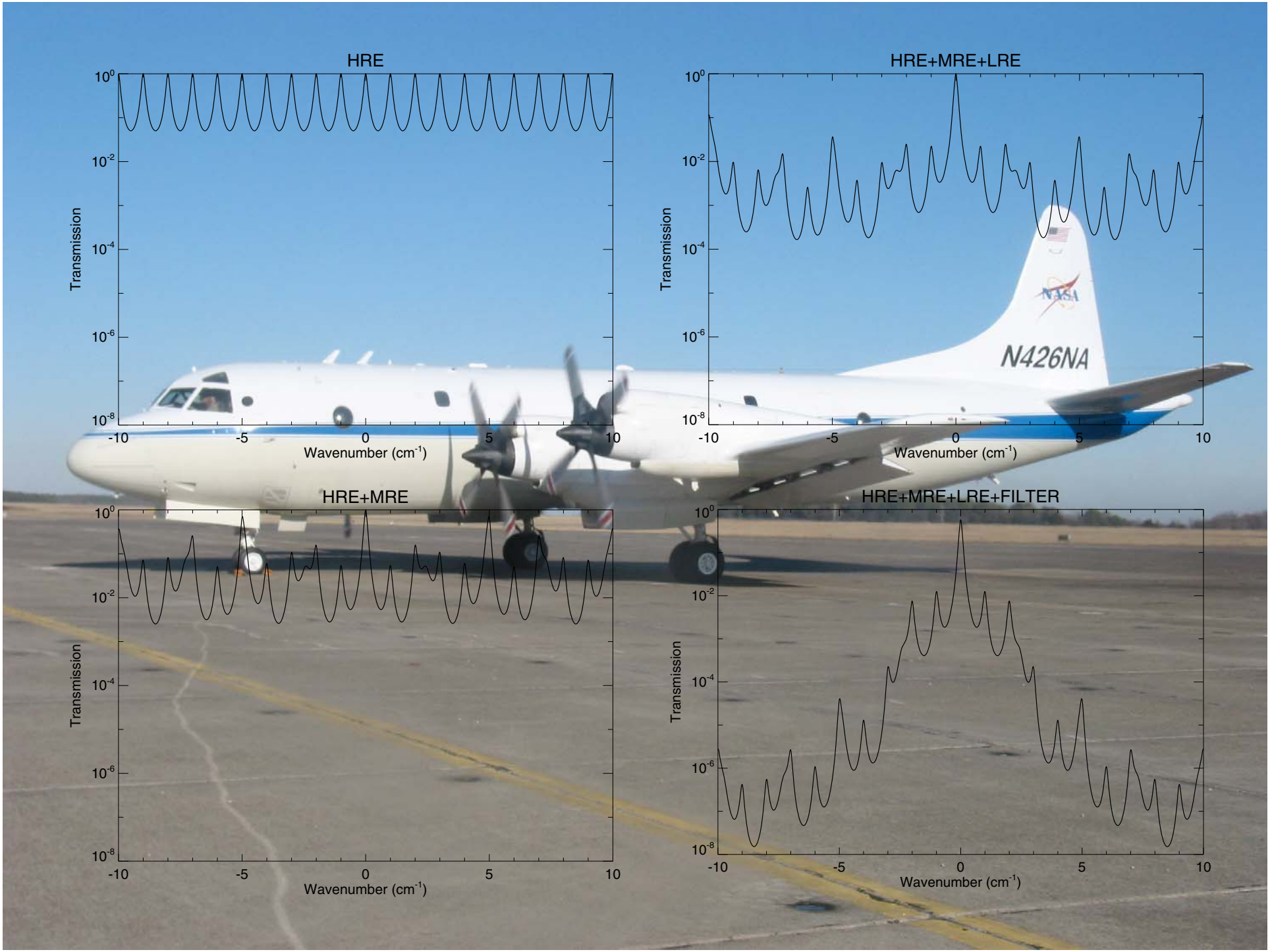


High Spectral Resolution Sensing Technique



- **Line wings influenced by scene brightness without atmospheric absorption**
- **Line width is a proxy for average path pressure and total column density of the absorber of interest along the optical (scattering) path**
- **Line depth related to total optical depth of the absorber and where the absorption occurs**
- **Width and depth are closely related**

- The GIFS remote sensing technique takes advantage of the absorption width, pressure broadening (and shift if useful) information embedded in the absorption line shapes to better determine the low-altitude atmospheric properties, including trace gases (i.e. CO_2, CO, H_2O), column amounts and cloud properties.
- Potential applications:
  - CO_2 mixing ratio for study its sources and Sinks
  - Regional pollution monitoring: (e.g. CO)
  - Cloud property monitoring: cloud top pressure, cloud optical depth, and cloud fraction.


HRE
HRE+MRE+LRE
HRE+MRE
HRE+MRE+LRE+FILTER
Transmission
Wavenumber (cm-1)
N426NA
NASA

Synchronized Cloud Imagery
20080207 Flight

P3B video
(2 Hz)

Webcam video
(5 Hz)

GIFS (static mode)
(~0.33 Hz)