Stray Light Calibration of Orbiting Sensors using Solar or Lunar Observations

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Background

On-orbit calibration using celestial bodies has a long heritage. Examples include:

- SeaWiFS
- MODIS
- NOZOMI XUV Scanner
- CERES
- SABER

SABER on TIMED

DWTS is a new mission concept that will require precise stray light calibration

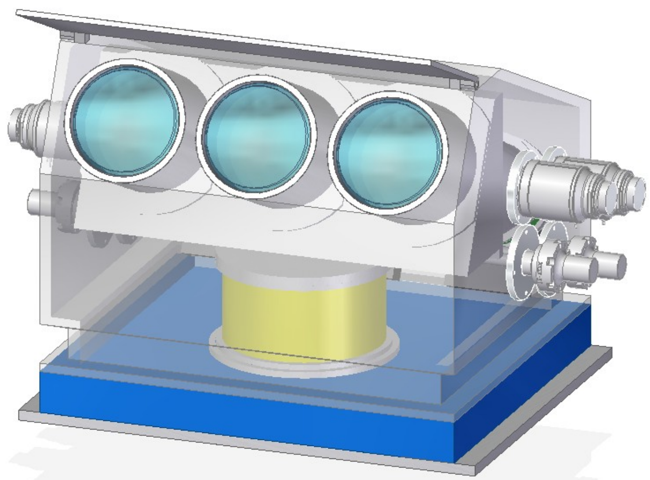
- For DWTS, we will extend the on-orbit procedure used on SABER to characterize the off-axis stray light

DWTS Overview

The Doppler Wind and Temperature Sounder

- Will measure vector winds and temperature from cloud-top to 300 km

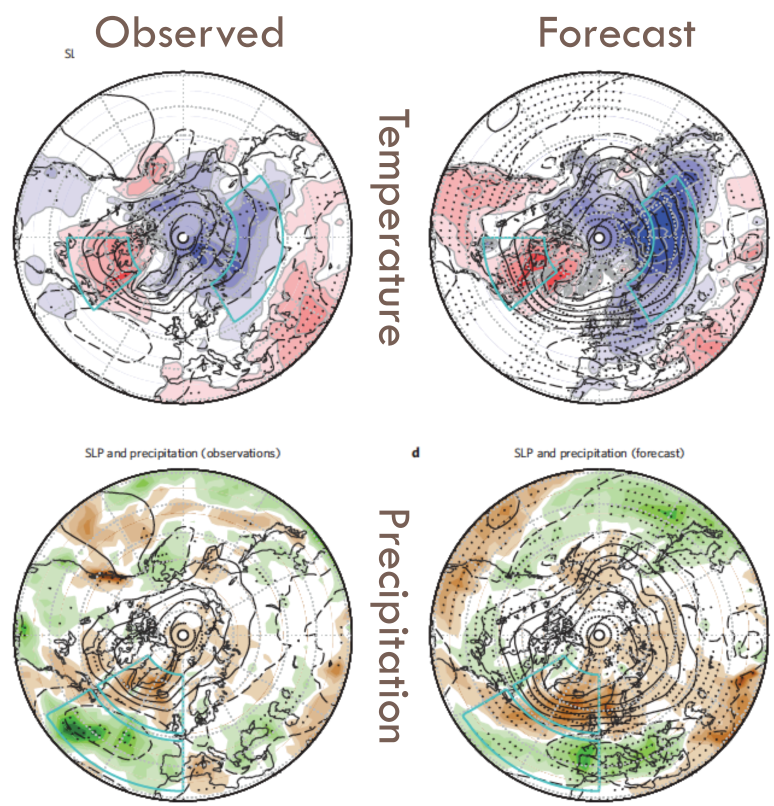
- Mission Motivations
  1. Weather Forecasting
  2. Severe Storm Impact
  3. Space Weather



Courtesy Space Dynamics Lab

Weather Forecasting

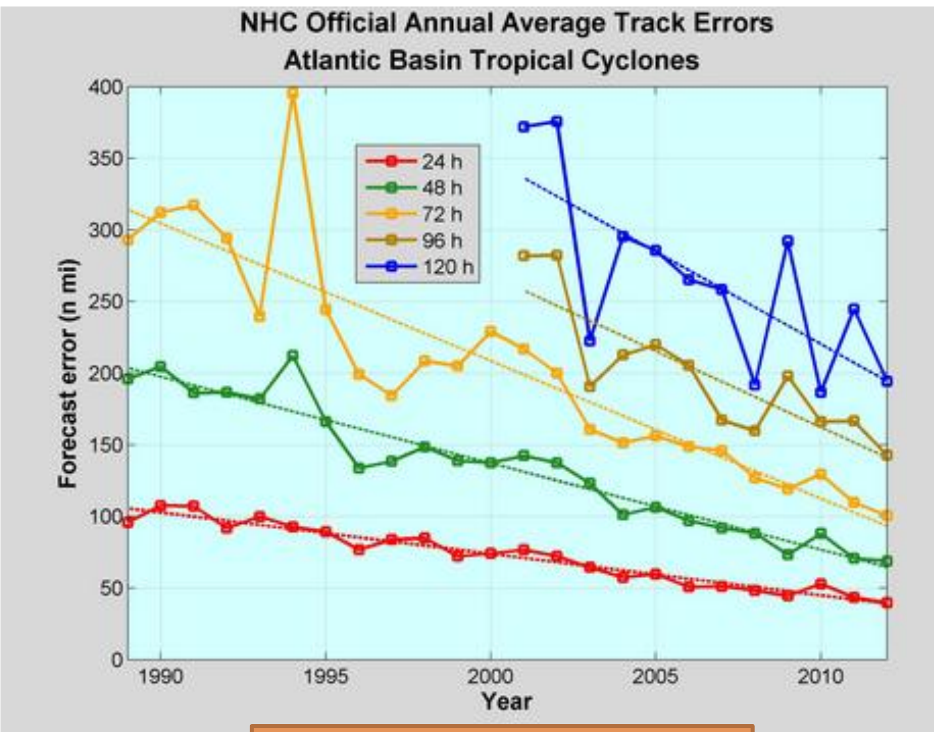
- Medium- and long-range weather is well-known to be significantly affected by stratospheric dynamics
  - *Baldwin and Dunkerton (2001)*: Stratospheric harbingers can be used as a predictor of tropospheric weather regimes
  - *Thompson et al. (2001)*: Dynamic coupling of stratosphere and troposphere yields statistically significant predictability on monthly and yearly timescales
  - *Charron et al. (2010)*: Discuss stratospheric extensions to improve tropospheric forecasts
  - *Sigmond et al. (2013)*: Showed enhanced predictability by using a good representation of the stratosphere.
- Forecast improvements await the first global stratospheric wind and temperature observation system



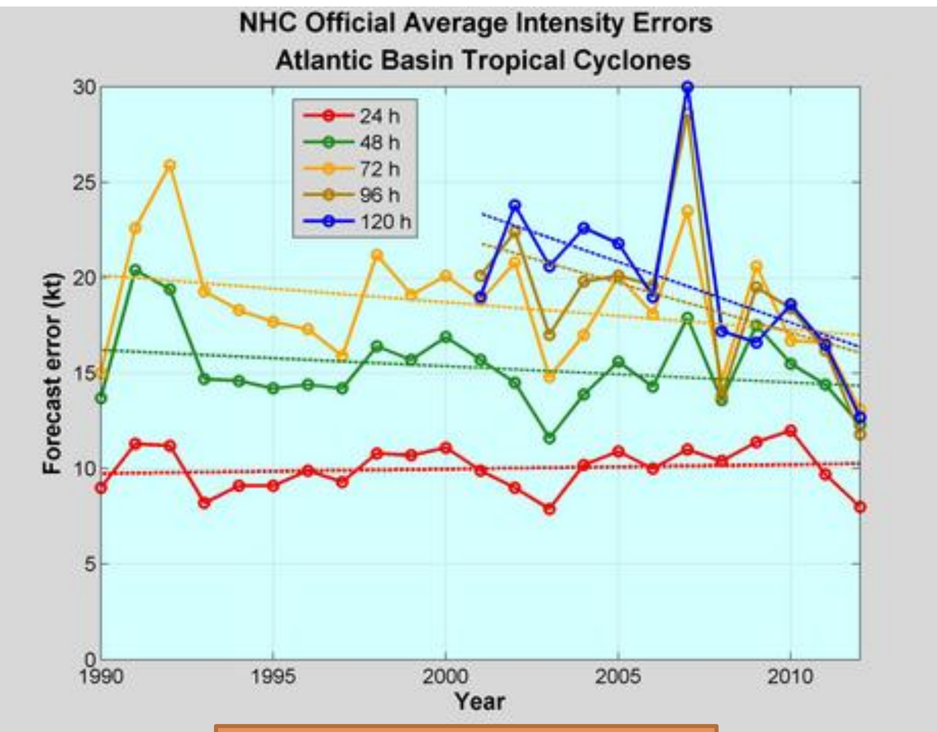
From Sigmond et al., 2013

Severe Storm Intensity

- Predicting tropical cyclone *intensity* has been limited by lack of global stratospheric wind measurements



Track Error



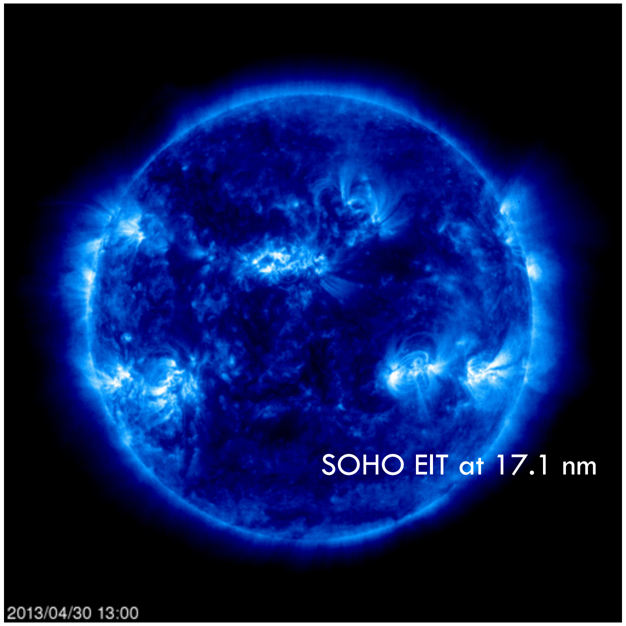
Intensity Error

Space Weather

Recent White House report - calls out the critical gap in space weather observations

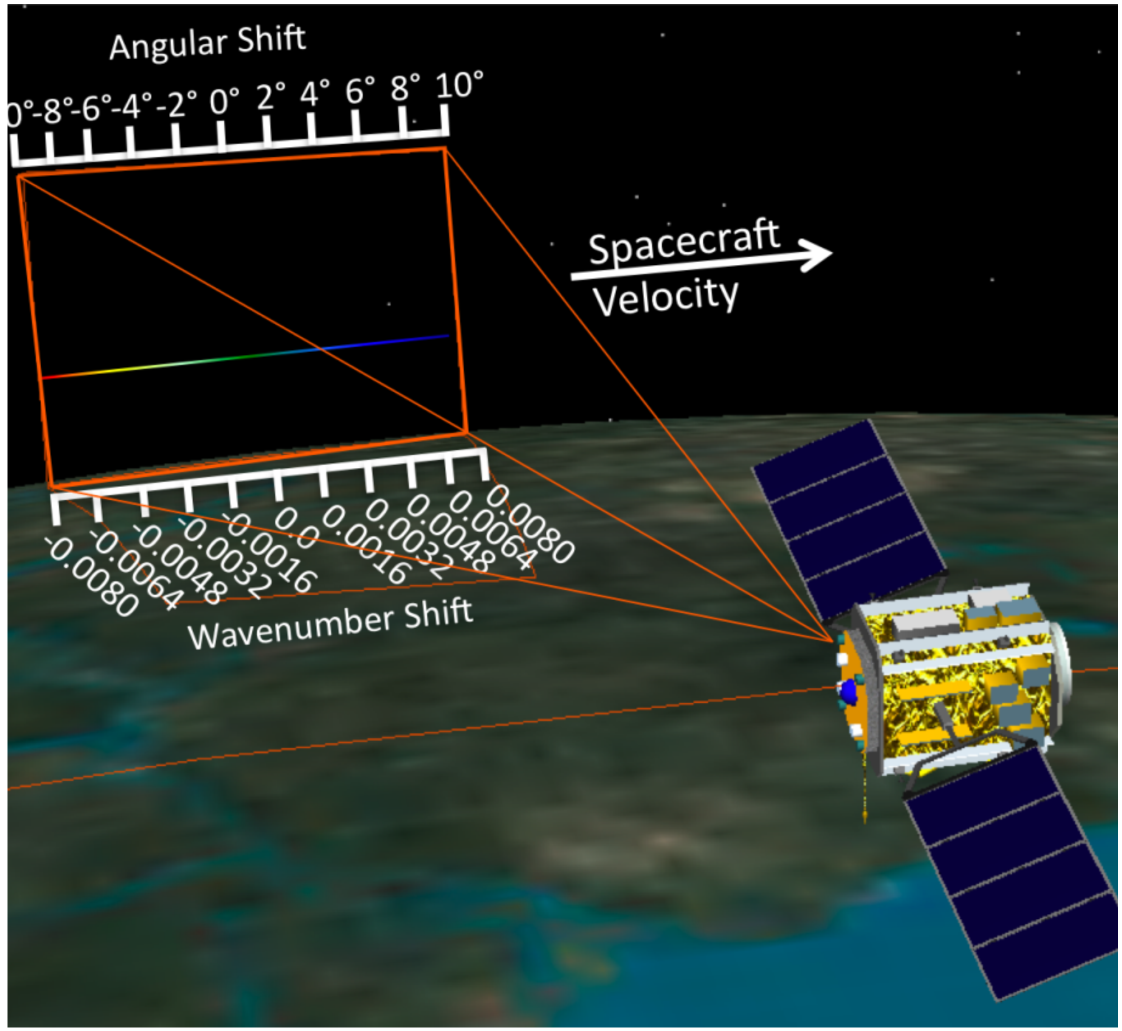
Has critical effects on communication, commerce, civilian and military space assets.

- Electric Power Grid: Large scale blackouts and damage to transformers
- Global Satellite Communications: Widespread service disruptions
- GPS Positioning and Timing: Degradations of military weapons accuracy, air traffic management, transportation, navigation, commerce, wireless comm., and more
- Satellites & Spacecraft: Loss of satellites/space situational awareness, increased risk of satellite loss and to astronaut health

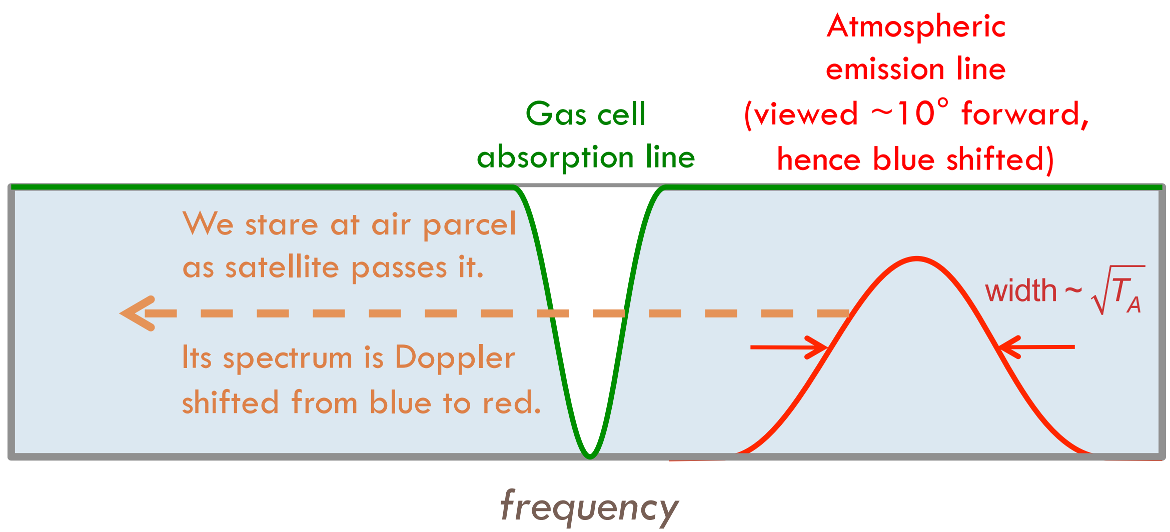


DWTS Measurement Concept

- Technique: *Doppler Spectroscopy*. Images the limb to the side of the spacecraft through an onboard gas cell
- Leading-edge pixels see blue-shifted emission; trailing pixels see red-shifted emission.
- Each row collects a full Doppler scan for each air parcel at that altitude



Doppler Spectroscopy



Doppler Spectroscopy

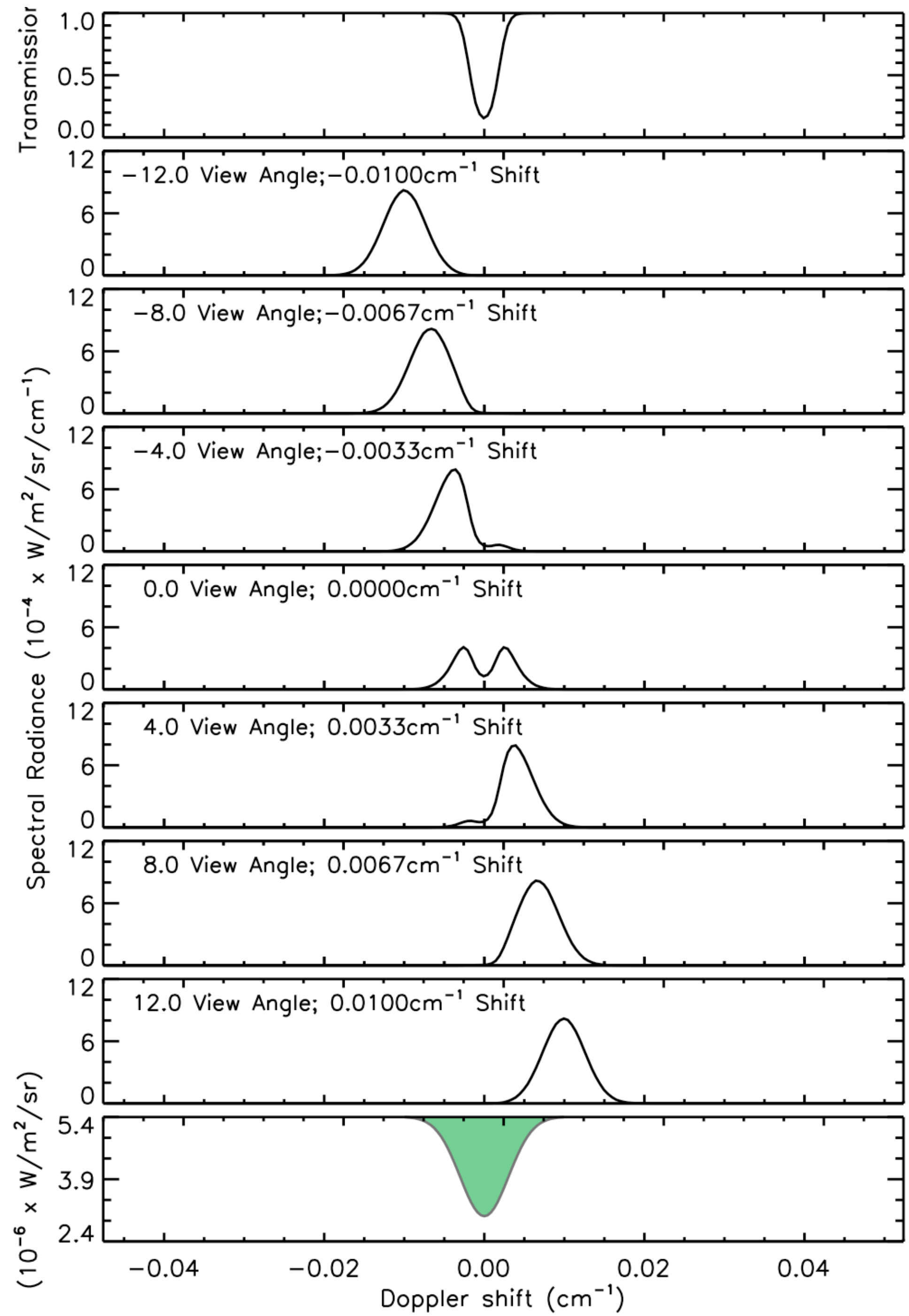
Top: Gas-cell transmittance vs. wavenumber showing a CO_2 absorption line.

Middle 7 panels: Atmospheric emission from this CO_2 line reaching 7 different columns of detector

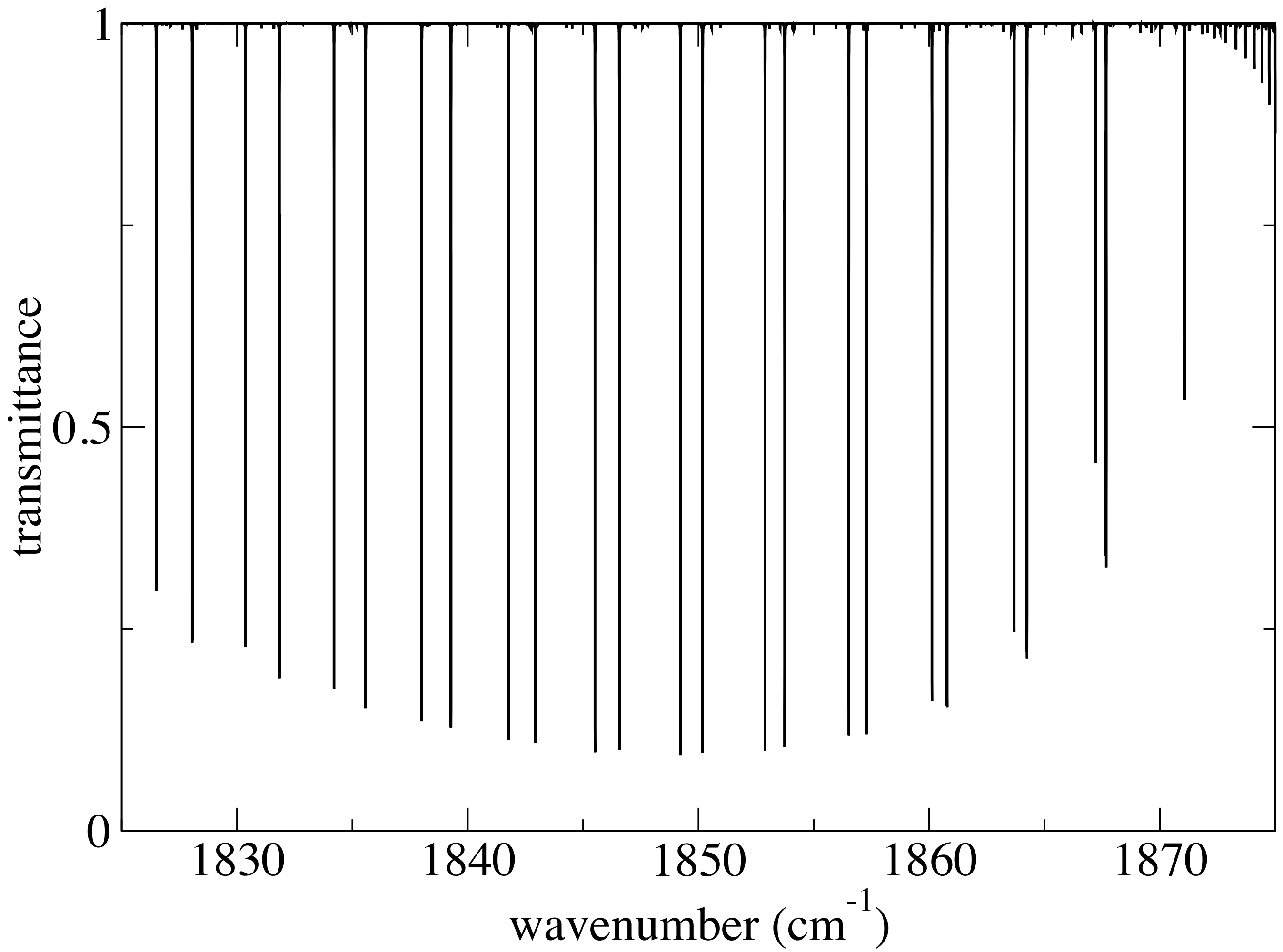
Bottom: Doppler integrated signal is formed by combining measurements across a row.

Width of the measured signal indicates the air temperature.

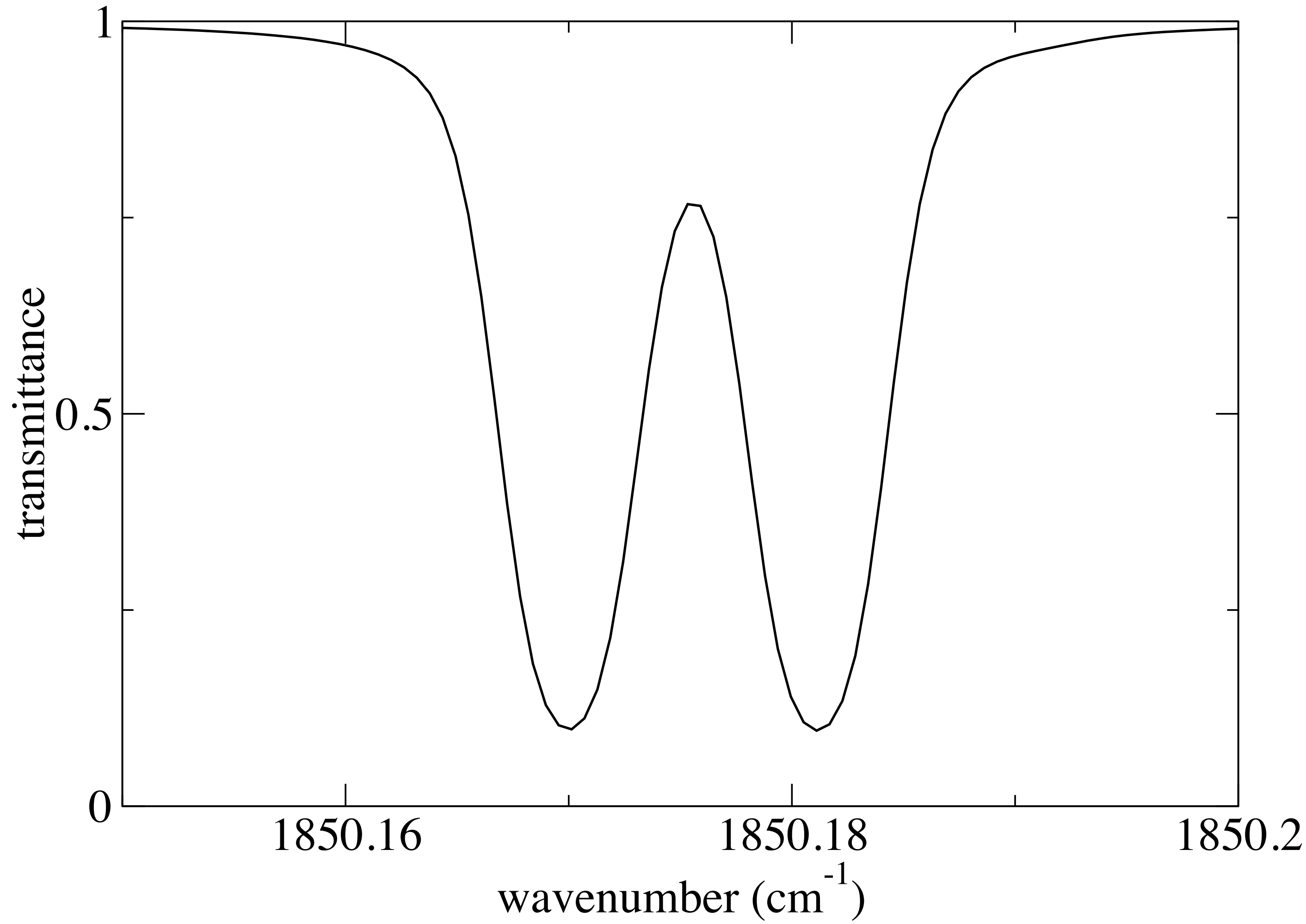
Cross-track winds appear as a shift along horizontal axis. Along track winds scale the horizontal axis. Total area of the signal (normalized by the maximum) provides a direct calibration of cell pressure.



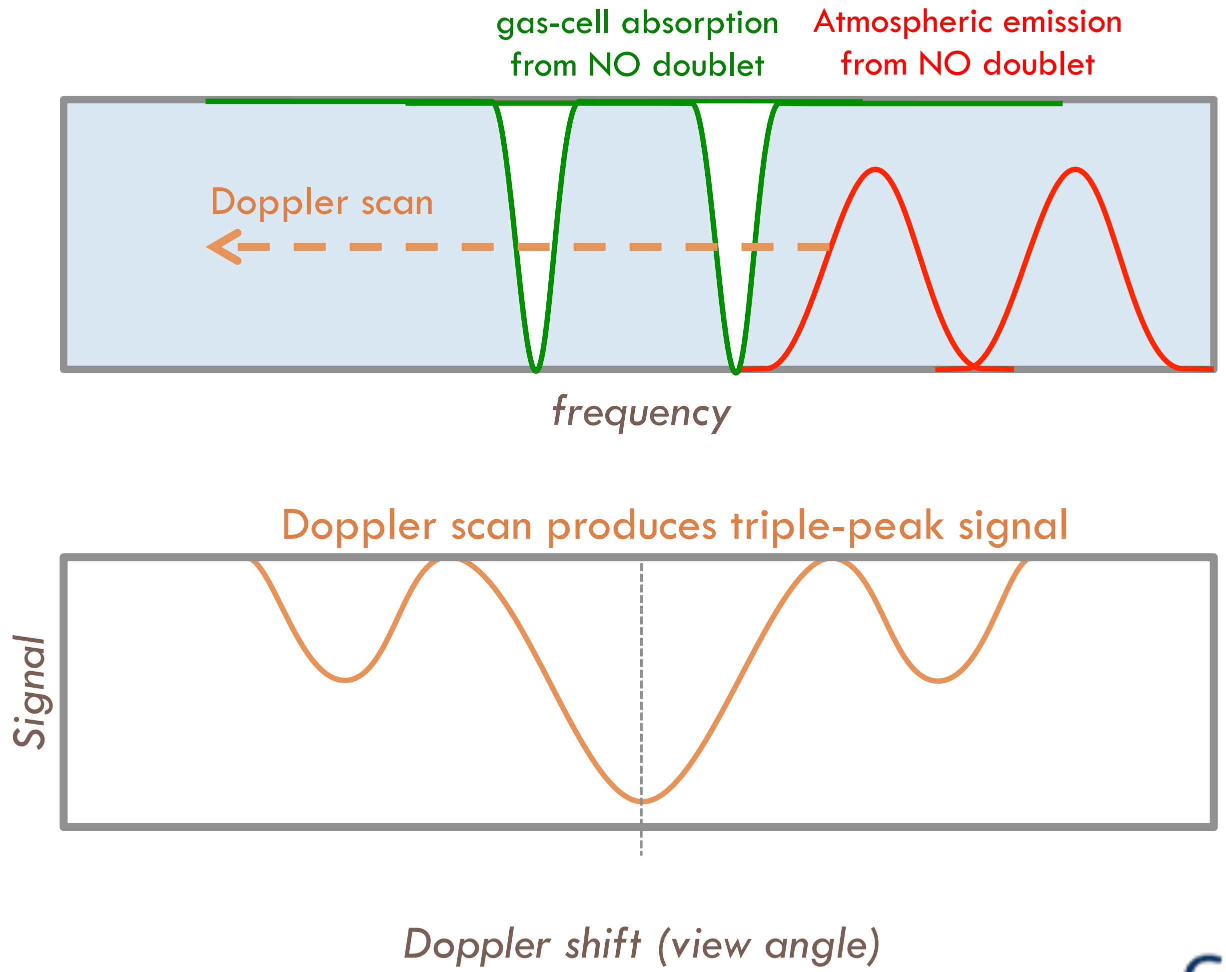
Nitric oxide spectrum at 5.4 microns



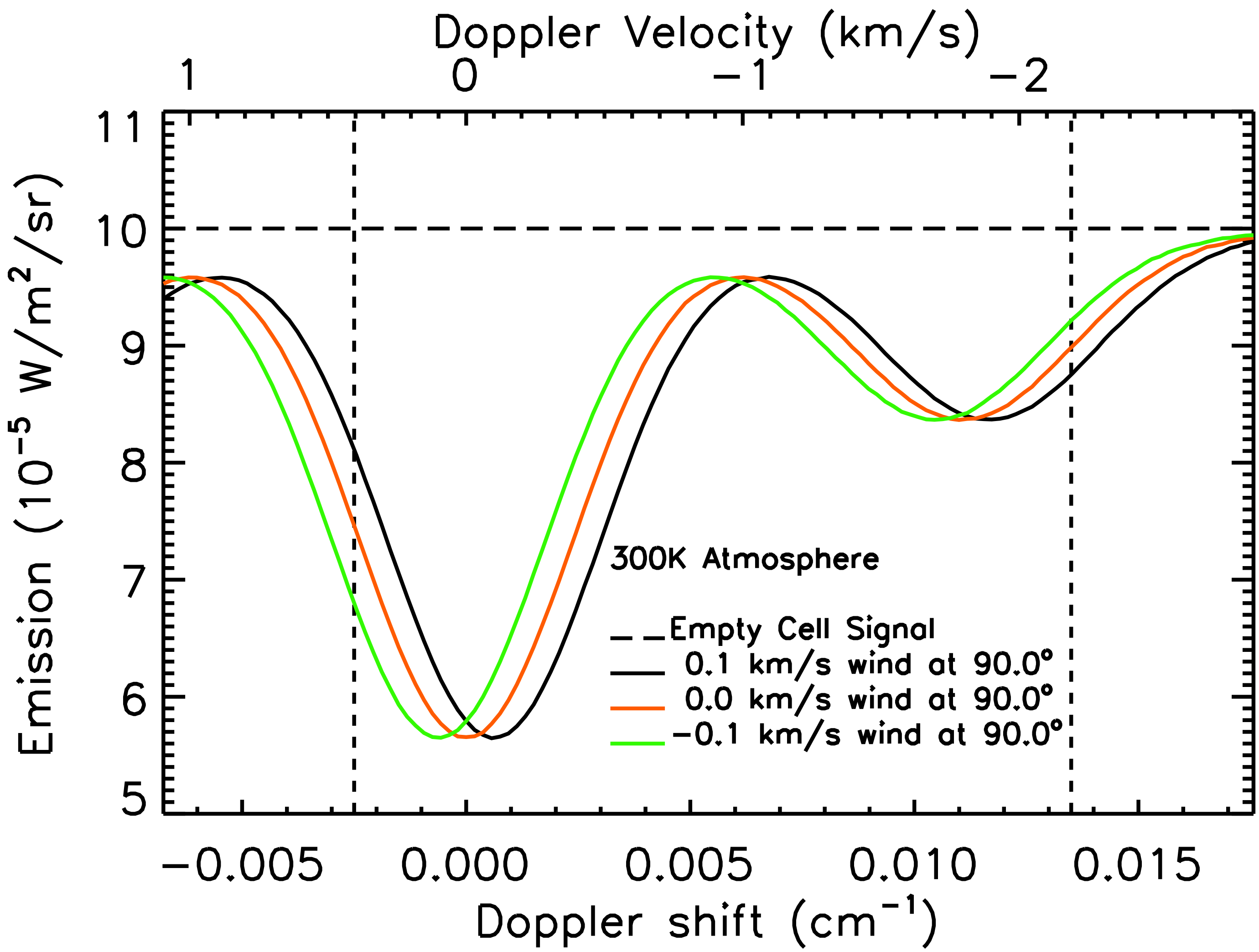
Lambda-doubling in NO spectrum



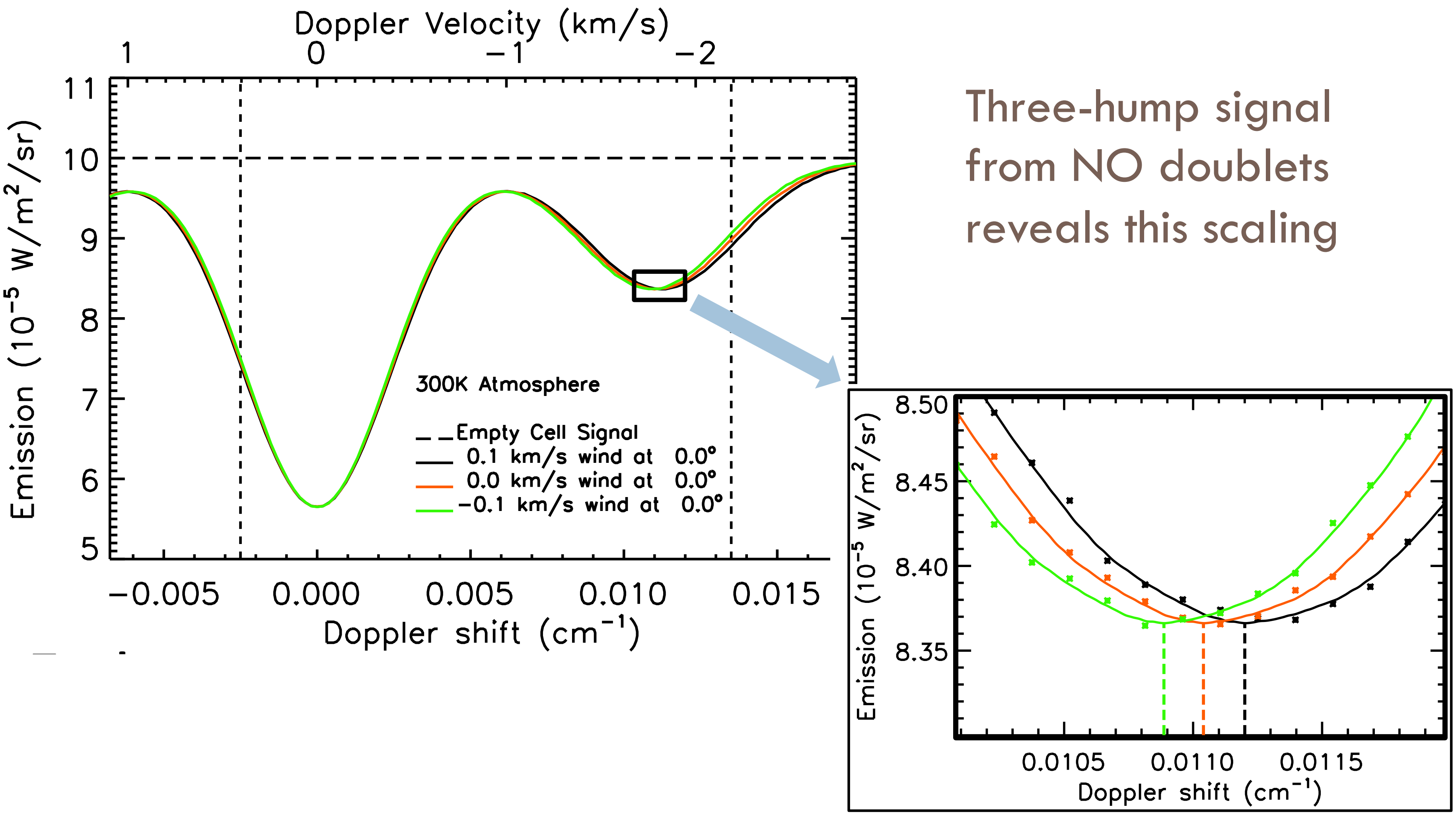
NO doublets produce multi-peak signal



Cross-track winds *shift* the signal

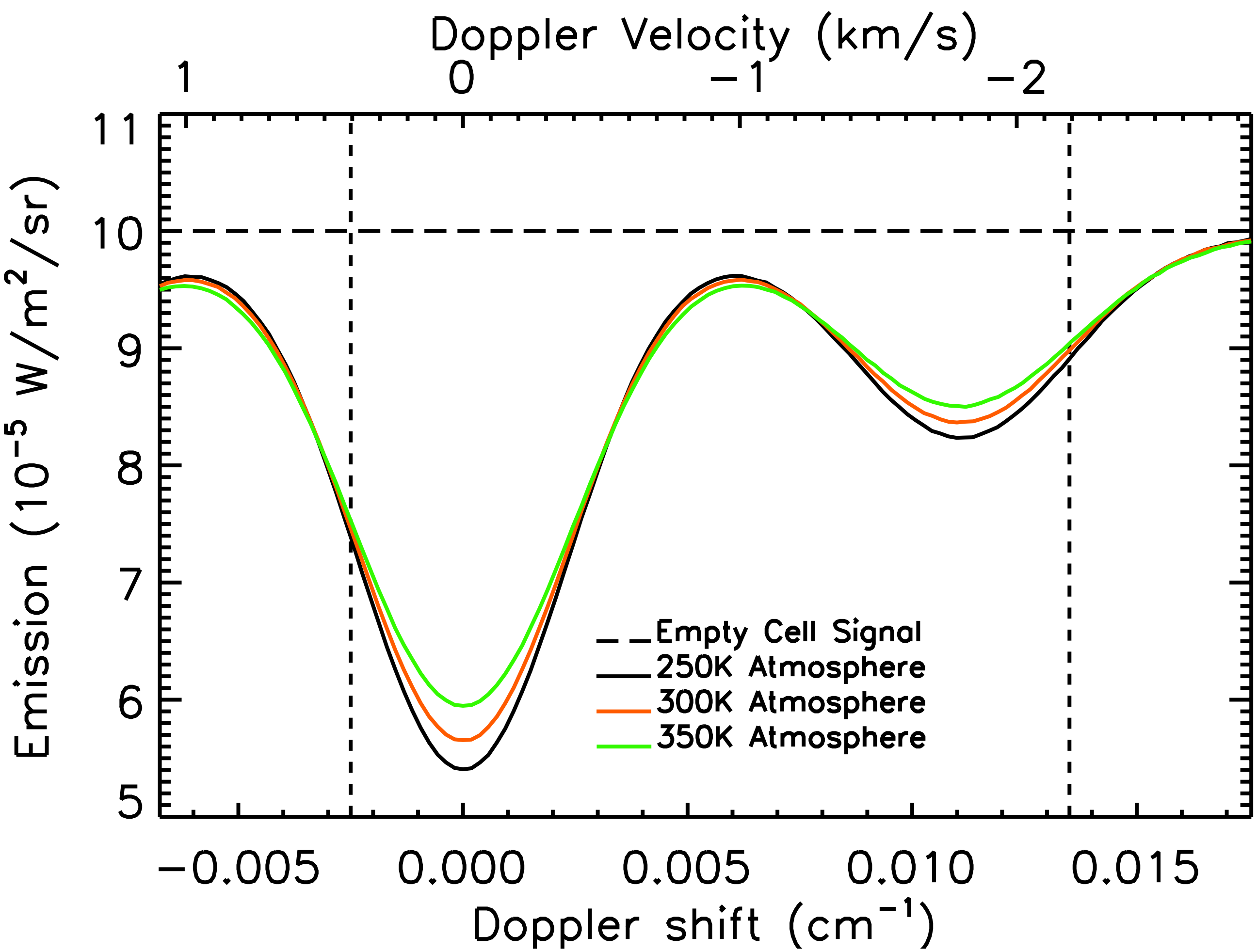


Along-track winds *scale* the spectrum

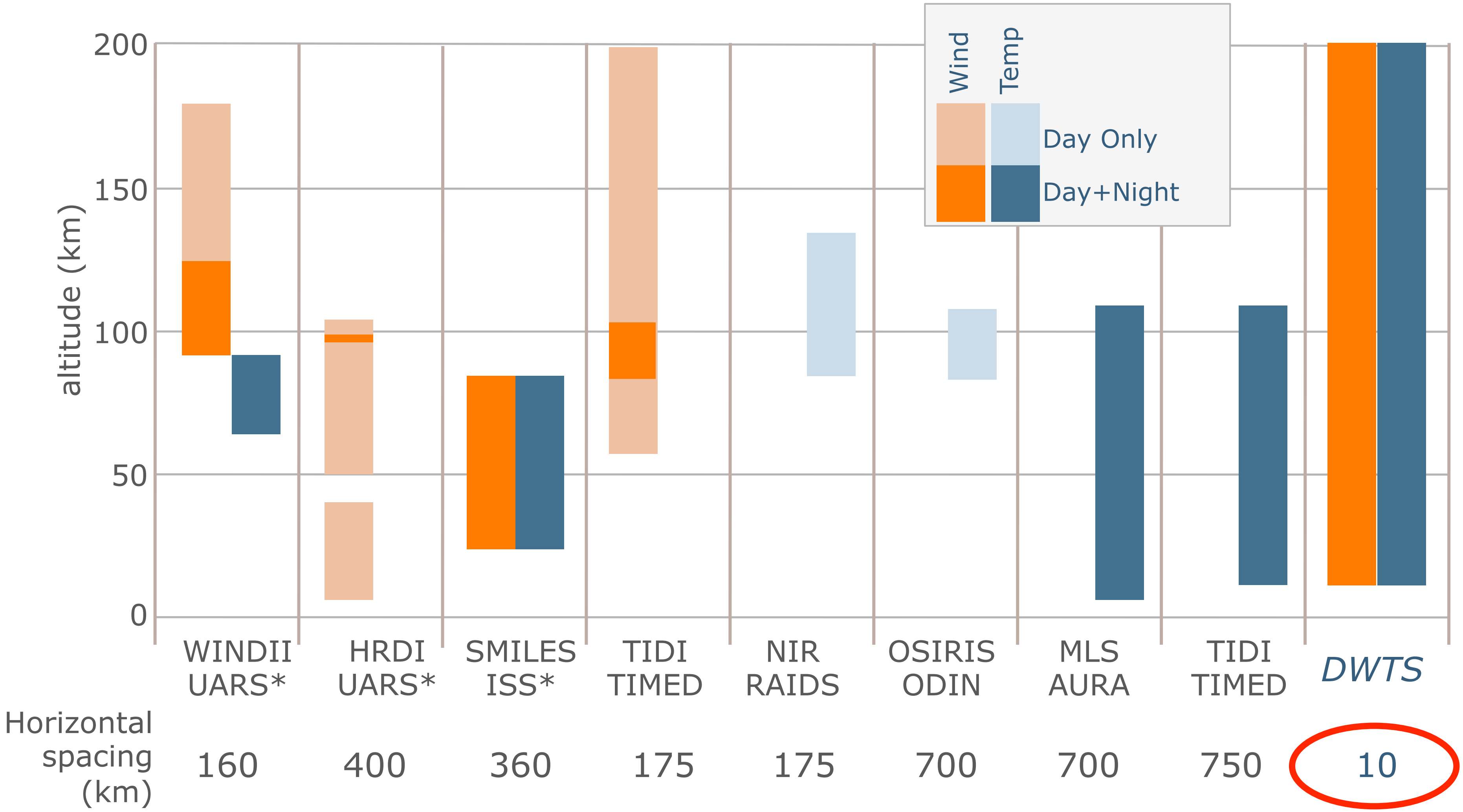


Three-hump signal from NO doublets reveals this scaling

Signal *width* indicates temperature



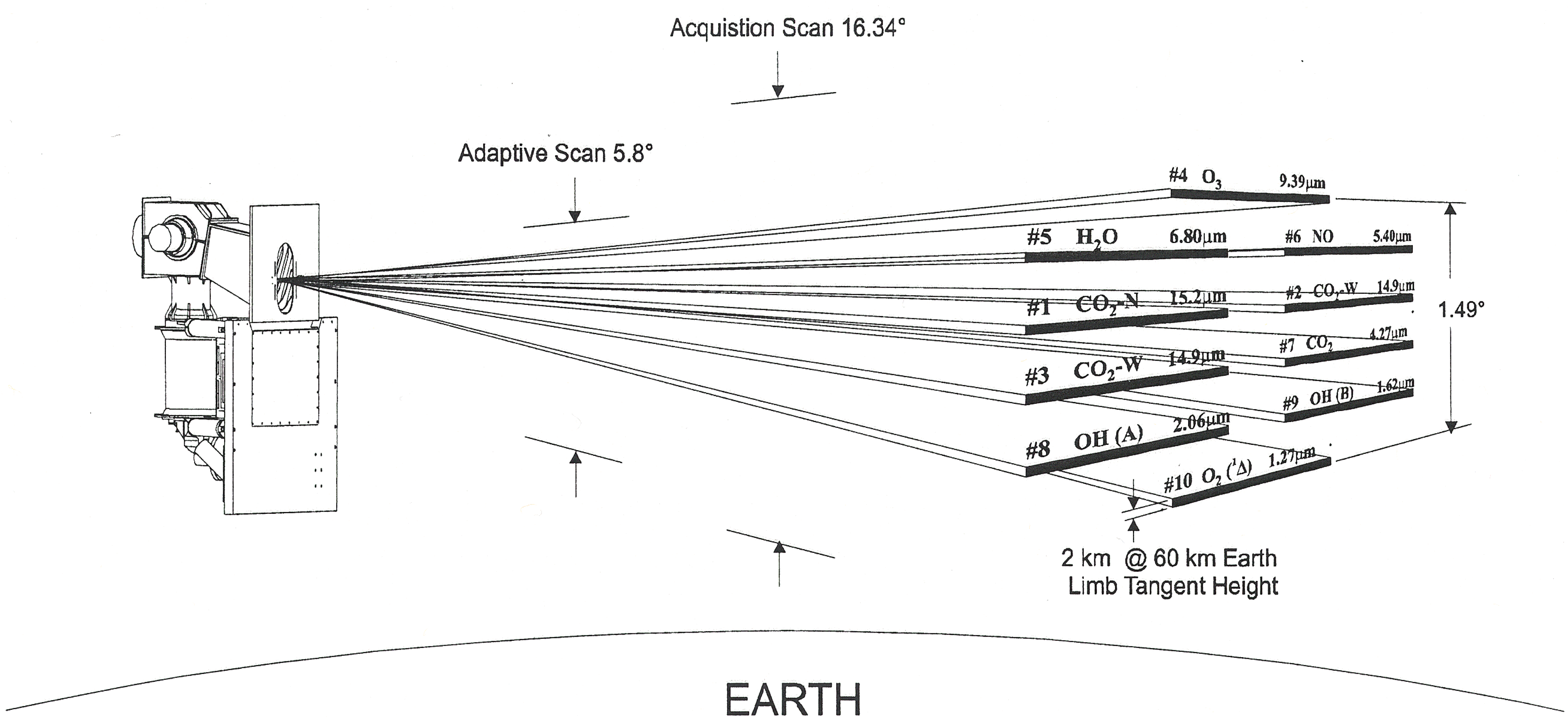
Comparison with Other Instruments



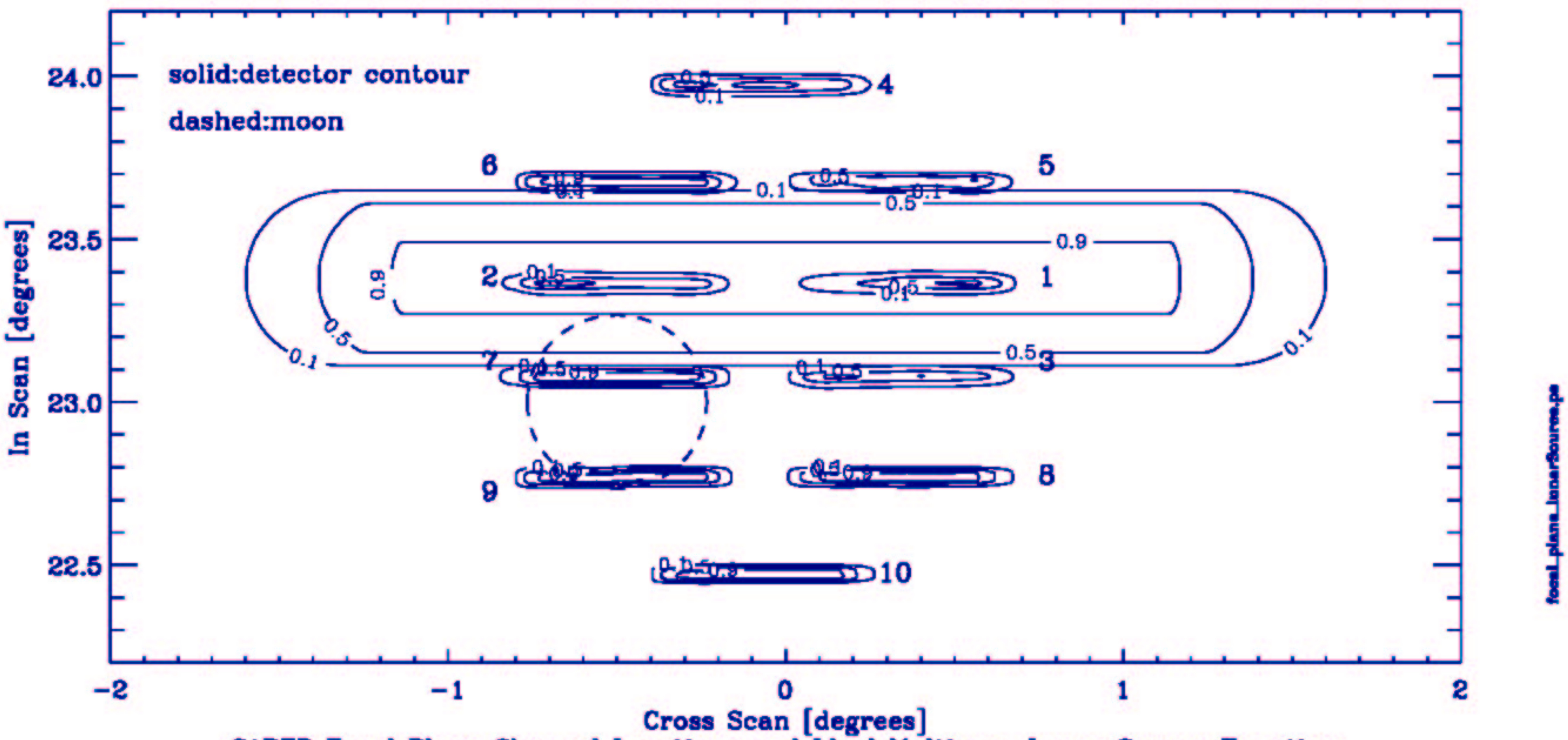
Calibration Needs for DWTS

- *Challenge*: precisely measure the extremely large vertical gradients in the limb without extensive baffling
  - Photon limited continuous FOV sampling
  - Far off-axis stray light calibration can be solved with celestial observations.

The SABER approach

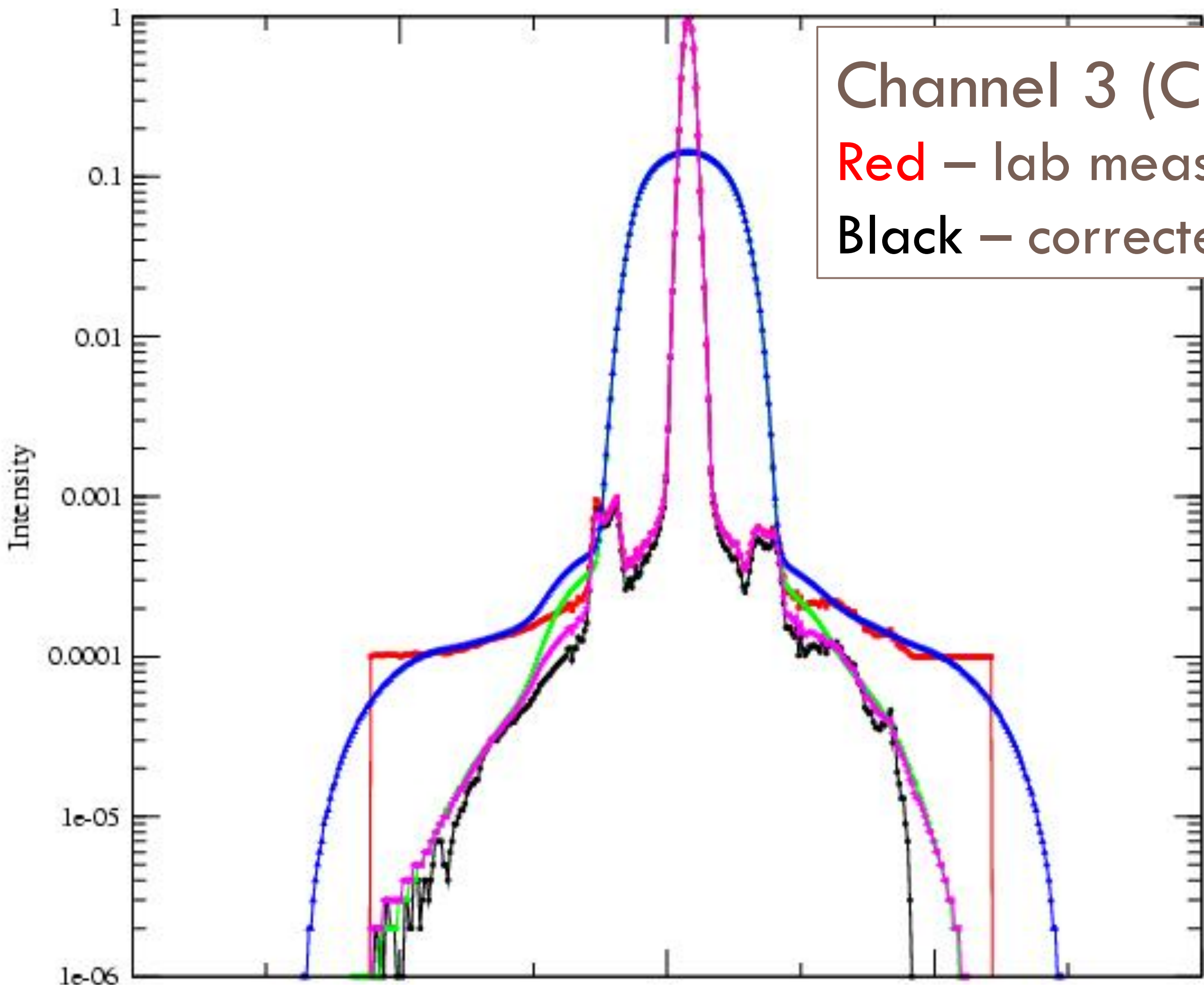


Lunar calibration of Off-Axis Response



SABER Focal Plane Channel Locations and Ideal Multiscan Lunar Source Function

SABER Lunar Calibration Results



Channel 3 (CO_2)

Red – lab measurements

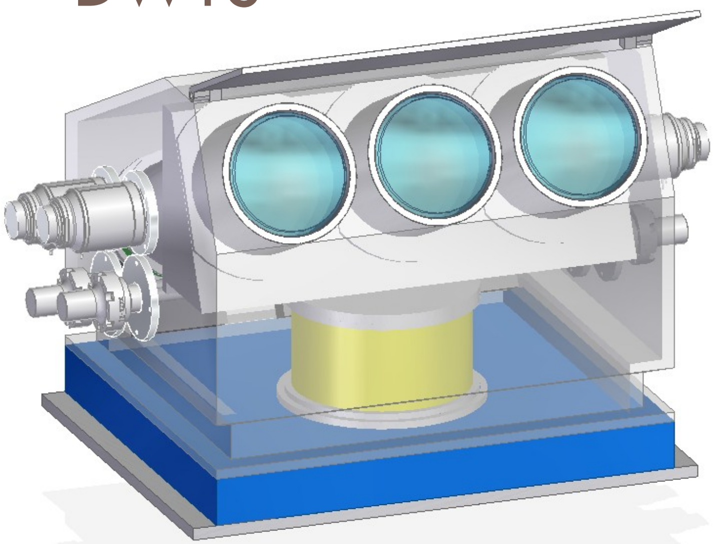
Black – corrected response

Stray Light Calibration for DWTS

- Unlike SABER, DWTS is an imager that continuously observes the whole range of altitudes.
- Calibration Procedure:
  - Near axis FOV response will be calibrated with standard methods in the lab
  - On-orbit solar scans will provide far off-axis response. Each non-illuminated pixel receives a fraction of the light incident on every illuminated pixel. Scanning the sun across the whole array provides complete calibration information.

Summary

DWTS



Courtesy Space Dynamics Lab

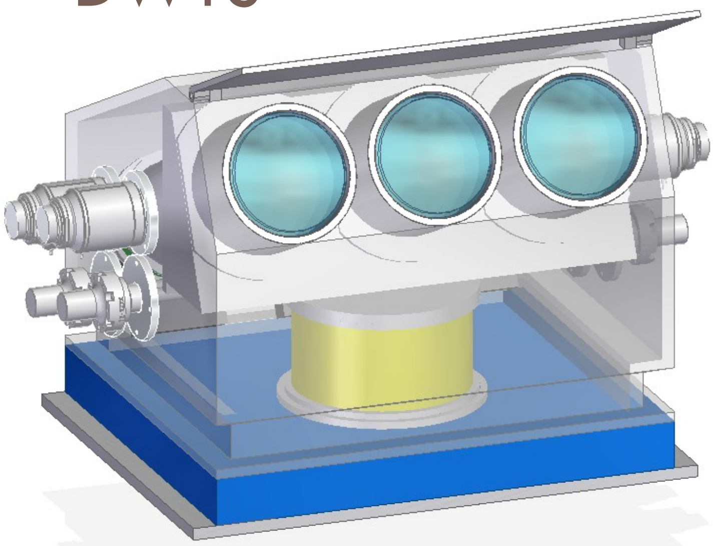
- Modern FPAs are enabling new sensing strategies like DWTS
- Far off-axis stray light challenges must be faced
- Extending historical celestial calibration procedures like those used on SABER will meet this challenge, and enable these powerful new sensor concepts


Thank You!

Backup slides

Compact 3-channel design

DWTS



Courtesy Space Dynamics Lab

DWTS Design Specs	
mass	7.0 kg
power	7.4 Watts
volume	14 x 20 x 30 cm
data rate	20 kbps average
spectral bandpasses	NO 1851 ± 22 cm^{-1} 5.4 μm N_2O 2165 ± 10 cm^{-1} 4.6 μm $^{13}CO_2$ 2270 ± 12 cm^{-1} 4.4 μm
FOV	20 deg x 20 deg
aperture	5 cm diameter
focal length	10 cm