Investigating Geocoronal Absorption for Wavelength Calibration of Sounding Rockets

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Abstract

Due to the high spectral resolution goals (R > 2x10ˆ4) for the upcoming Full-sun Ultraviolet Rocket Spectrograph (FURST), instrument calibration will be particularly important. The Solar Physics groups at NASA MSFC and Montana State University (MSU) have been developing the tools necessary to achieve this goal. These include improved tracking of error propagation, in-situ monitoring of the camera gain with a radioactive Fe-55 source, and even better wavelength calibration. This presentation will focus on the latter. We will highlight the development of a calibration method which uses a two-dimensional second-order polynomial to map pixels to wavelength under a simulated noisy diagnostic lamp signal. Additionally, we have introduced a tilted CCD in order to overcome the Nyquist limit. With this as the background, we have been investigating an effect known well among ground-based imaging: geocoronal absorption. We have been looking into how much this effect will be present in the atmosphere at sounding-rocket altitudes (˜100-200km). Many studies have found ways to correct for these so-called "Telluric" lines. However, it may be that these lines can in fact be a useful tool to further improve our calibration, rather than simply a nuisance to be corrected for!

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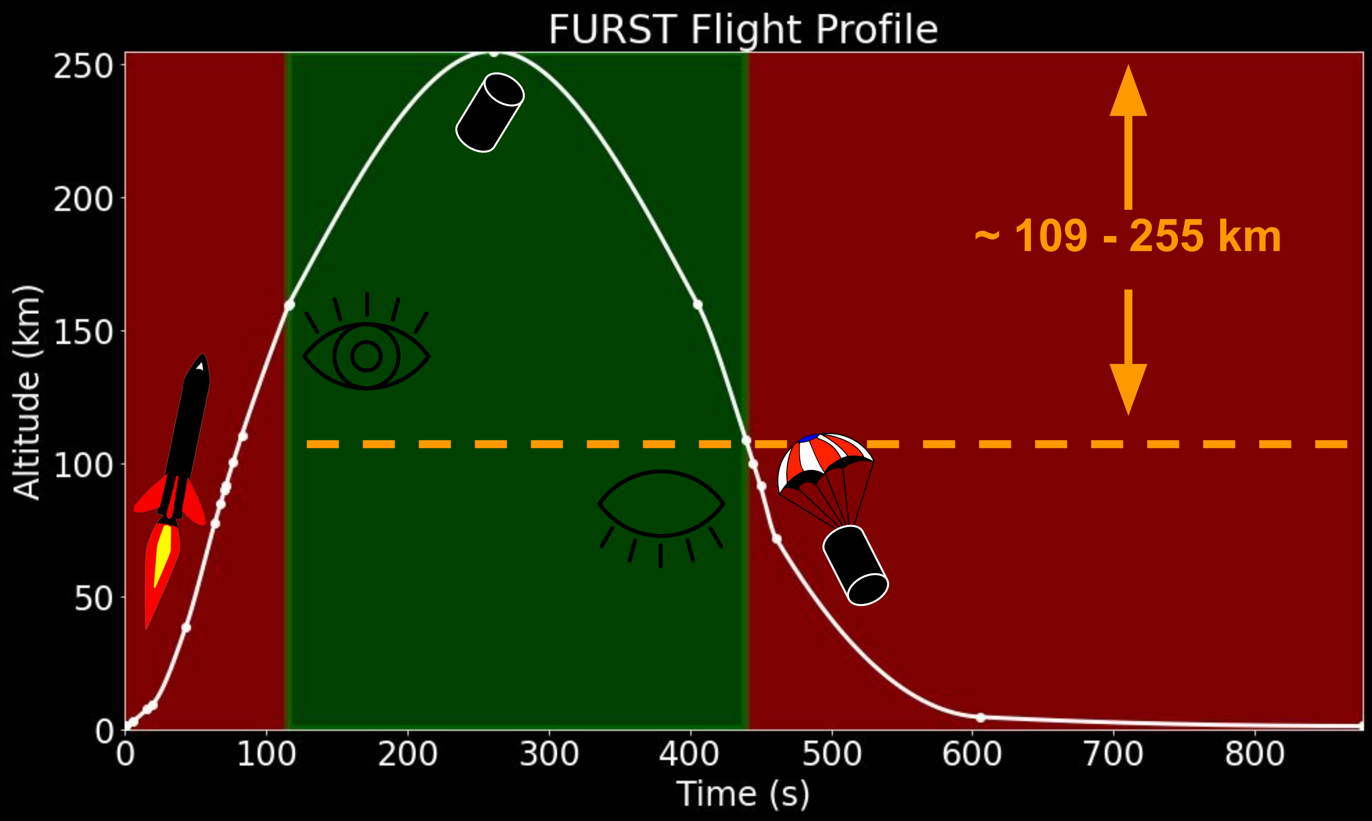
Sounding Rockets are spectroscopic and imaging instruments on-board sub-orbital flights

FURST will image the first **full-sun integrated high-resolution UV** spectra (1200-1810 Å)

- Current UV spectral measurement sources have a limited FOV (such as HRTS) or low resolution
- Will serve as a Hubble-analog



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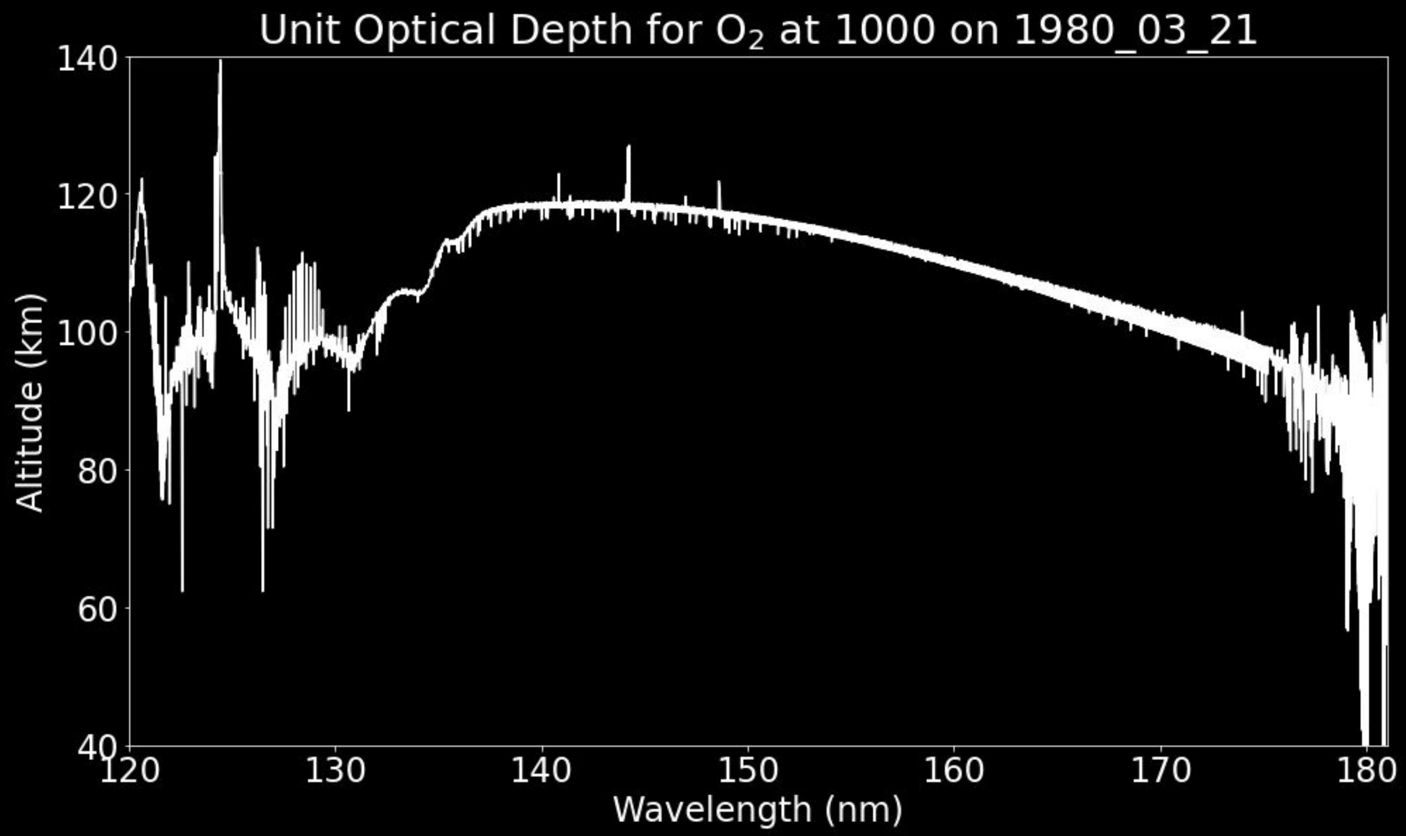
Geocoronal absorption is caused by molecules in the upper atmosphere

Optical depth is the product of the **absorption cross section and number density** integrated vertically with altitude

$$\tau\left(\lambda, z\right) = \sigma\left(\lambda\right) \int_{z'}^{\infty} \eta\left(z\right) dz' = 1$$



INVESTIGATING GEOCORONAL ABSORPTION FOR WAVELENGTH CALIBRATION OF SOUNDING ROCKETS

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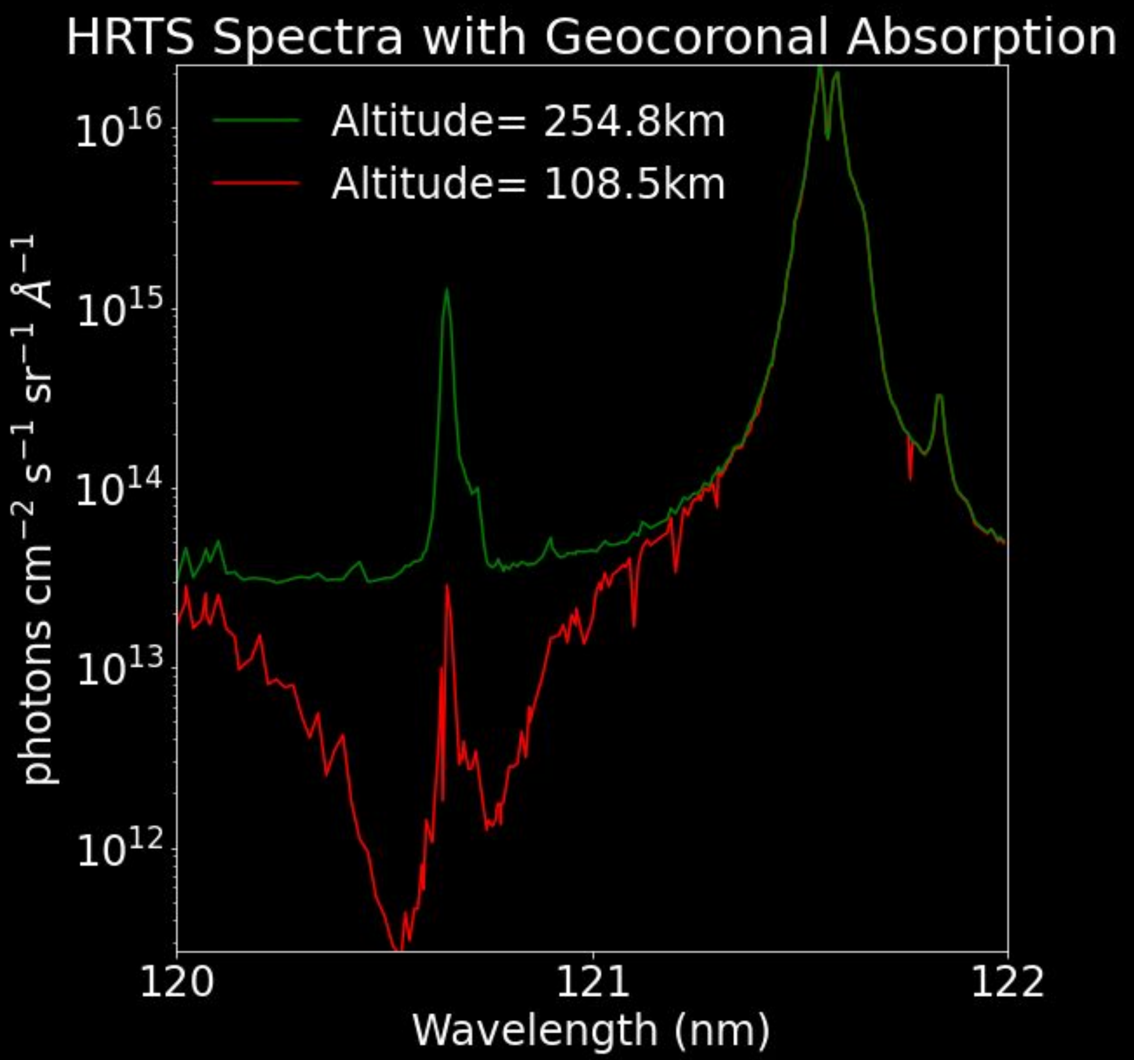
Absorption lowers the spectral signal at known locations

$$I = I_0 e^{-\tau / \cos\theta}$$

These patterns can be useful for **wavelength calibration!**

Additionally, we may also be able to **validate atomic and atmospheric properties**



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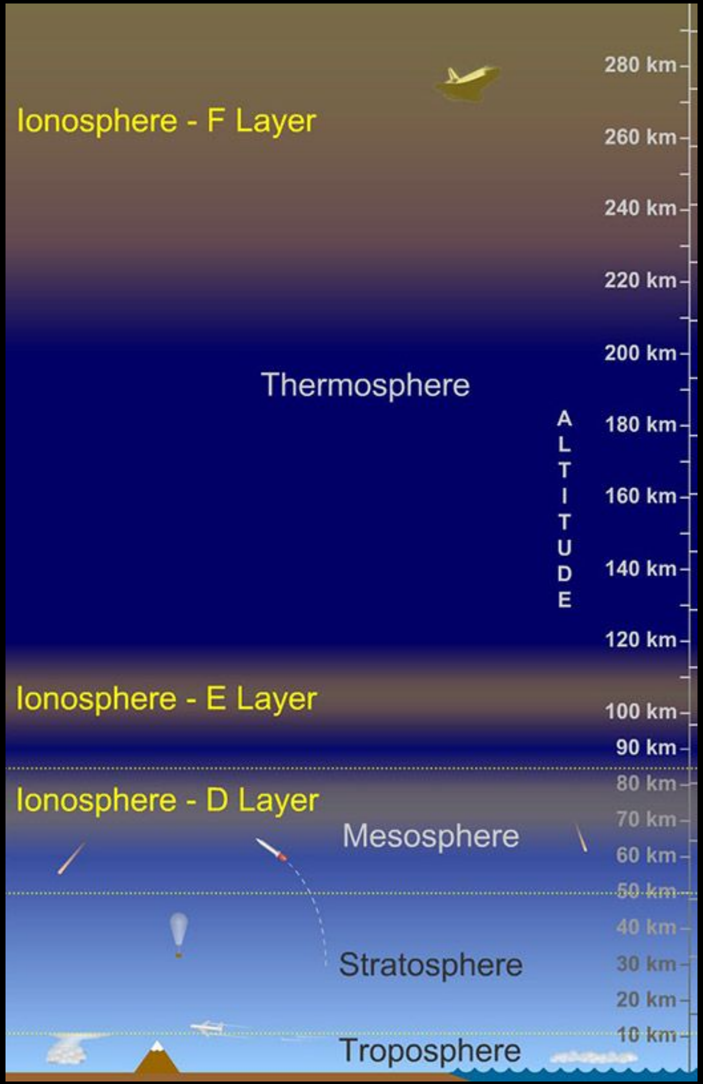
Overview

1. Motivation
2. Background
3. Geocoronal Absorption
4. Wavelength Calibration
5. Conclusion

Motivation→Background→Absorption→Calibration→Conclusion

- FURST is the Full-sun Ultraviolet Rocket SpecTrograph
  - Will produce the **first full-sun integrated high-resolution UV spectrum.**
  - Will serve as a Hubble-analog
- For this work, passing through the thermosphere will provide an opportunity **to verify atmospheric density models and atomic absorption measurements**

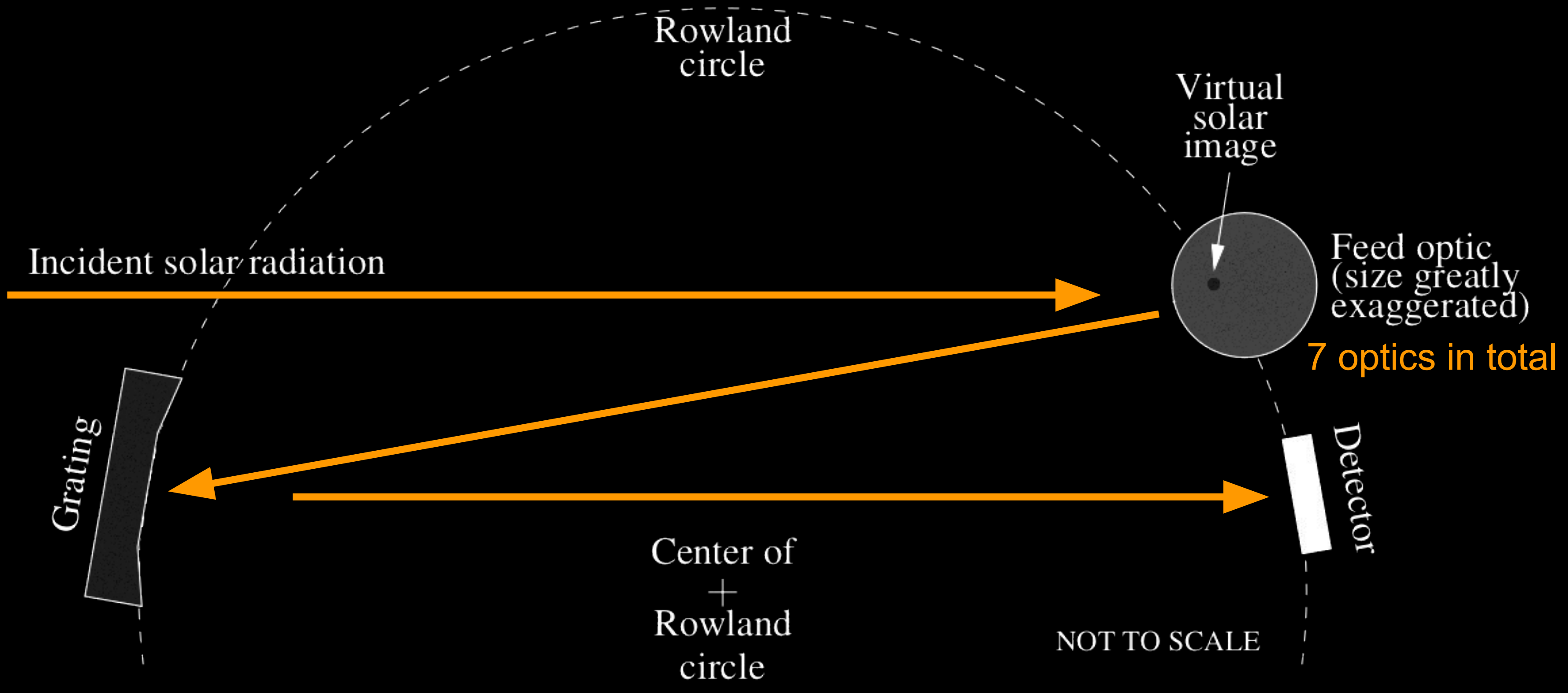


https://scied.ucar.edu/sites/default/files/images/large_image_for_image_content/ionosphere_layers_altitude_diagram_600x810_0.jpg

Motivation→Background→Absorption→Calibration→Conclusion

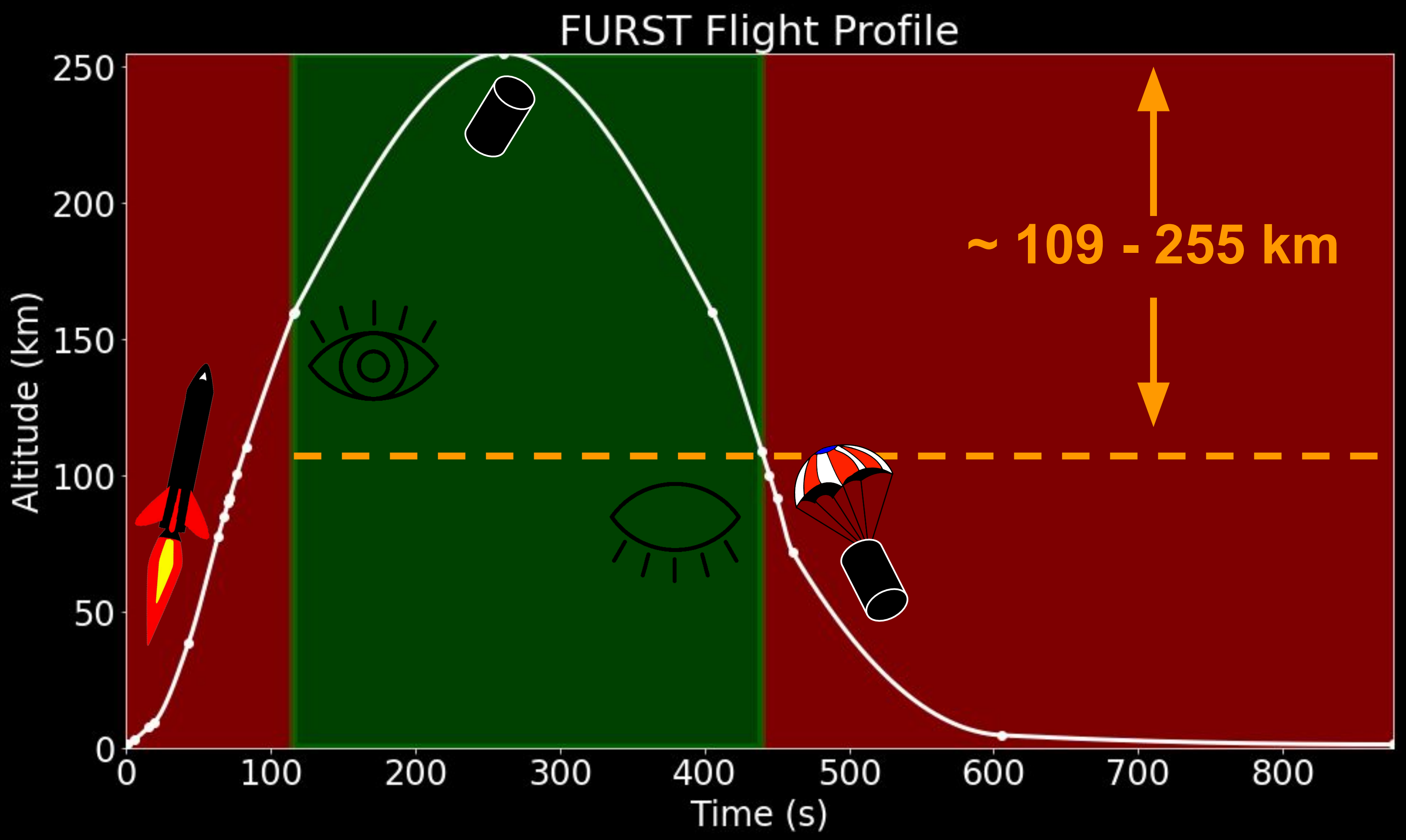
- FURST reduces the **entire solar disk** image to the size of a pixel
- Current UV spectral measurement sources have a limited FOV (such as HRTS) or low resolution

Full-sun Ultraviolet Rocket Spectrograph (FURST) (our future instrument)
full-sun integrated
Range: 1200-1810 Å
R ~ 100,000
Δv ~ 3 km/s



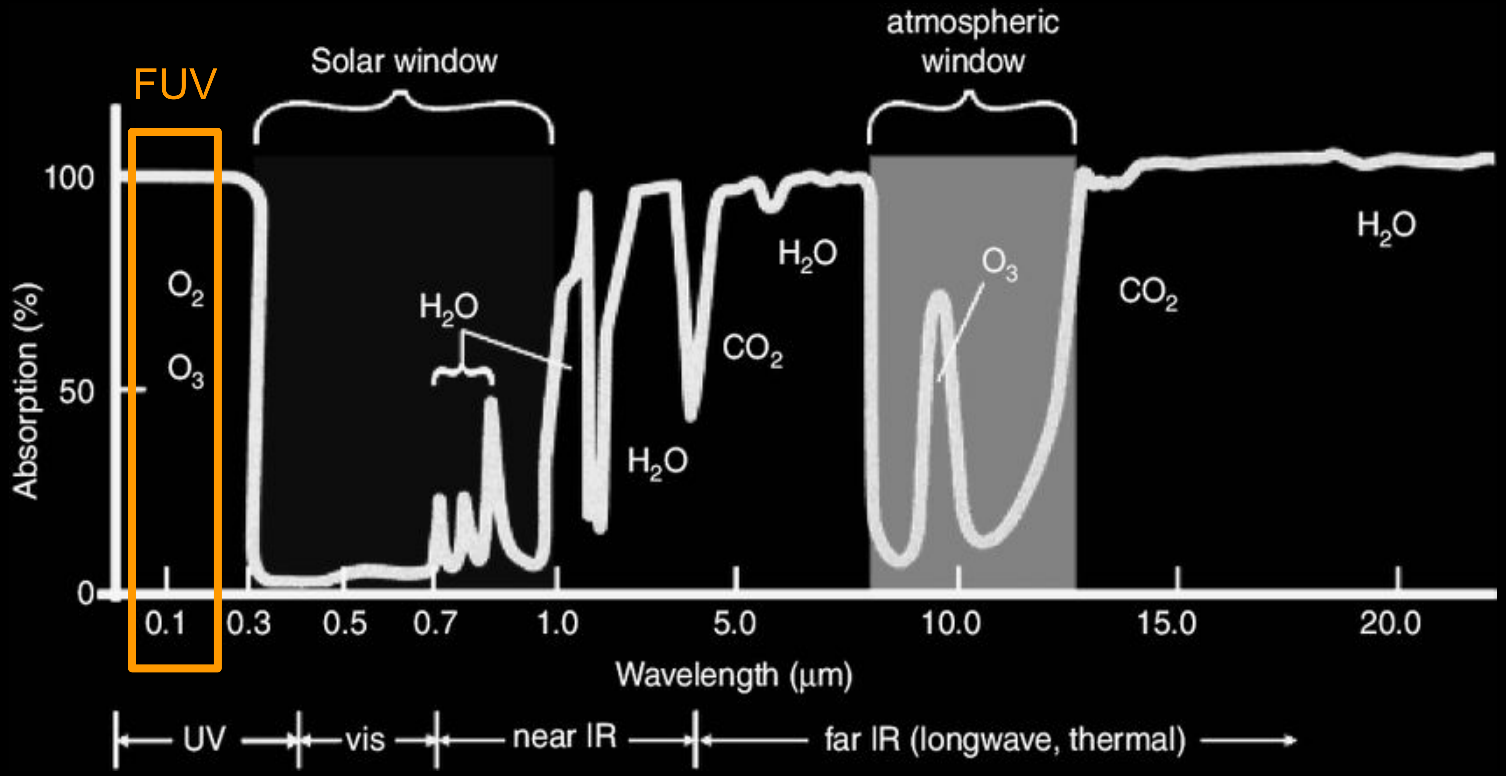
Motivation→Background→Absorption→Calibration→Conclusion

- We use a sounding rocket to get FURST above most of the atmosphere (>109 km)



Motivation→**Background**→Absorption→Calibration→Conclusion

- The molecules in the upper atmosphere **absorb all FUV light** before it reaches the ground
- **O_2 is the main contributor**



www.researchgate.net/figure/The-absorption-profile-of-Earths-atmosphere-from-UV-to-IR-The-graph-shows-the-regions_fig17_320660396

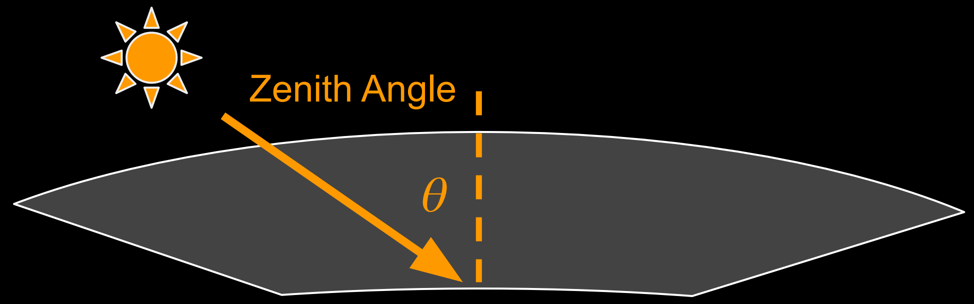
Motivation→**Background**→Absorption→Calibration→Conclusion

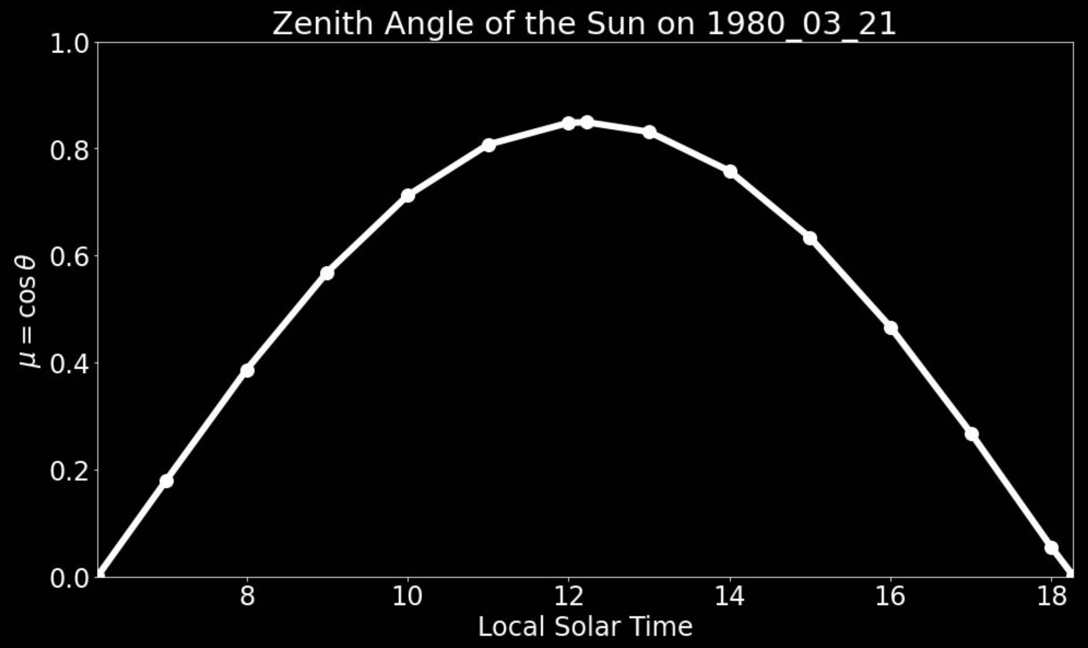
- Optical depth is a unitless quantity defined as the **product of the absorption cross section and number density** integrated vertically with altitude

$$\tau(\lambda, z) = \sigma(\lambda) \int_{z'}^{\infty} \eta(z)\, dz'$$

- The zenith angle attenuates optical depth
  - This is only a rough approximation for smaller angles
  - Imaging will be near solar noon

$$I = I_0 e^{-\tau / \cos\theta}$$

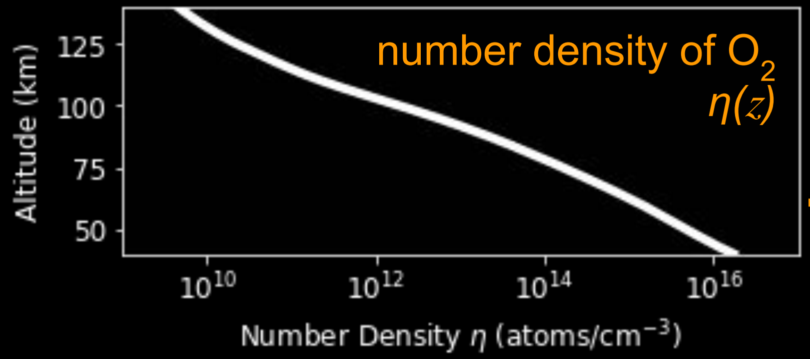


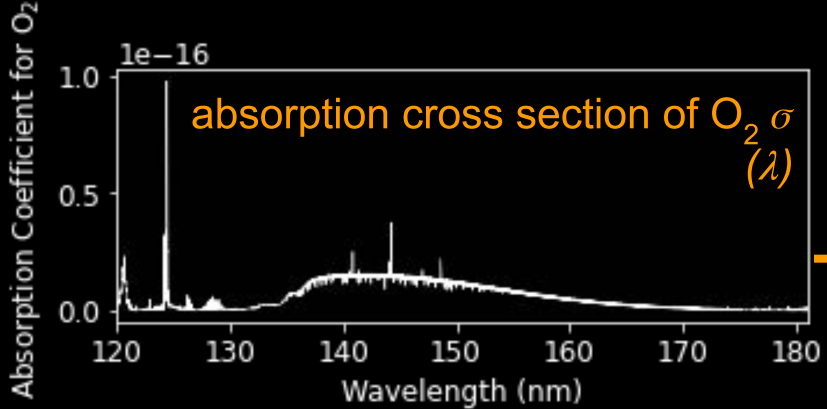


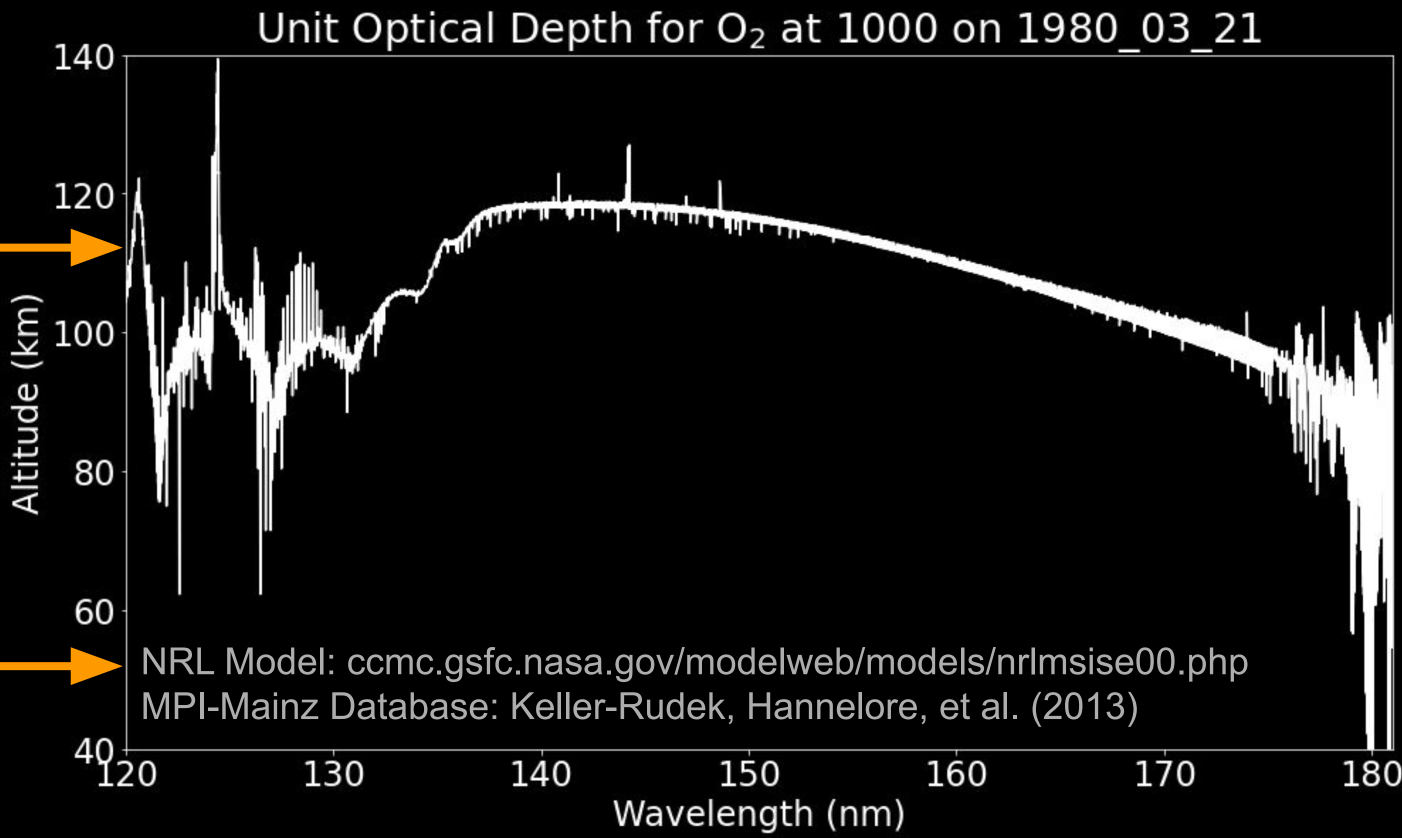
Motivation→Background→**Absorption**→Calibration→Conclusion

- Reproducing Meier 1991
  - Date: 21 March 1980 (Solar Max)
  - Time: 1000 gives cosθ = 0.712
  - Place: White Sands Missile Range, NM

$$\tau(\lambda, z) = \sigma(\lambda) \int_{z'}^{\infty} \eta(z)\, dz' = 1$$





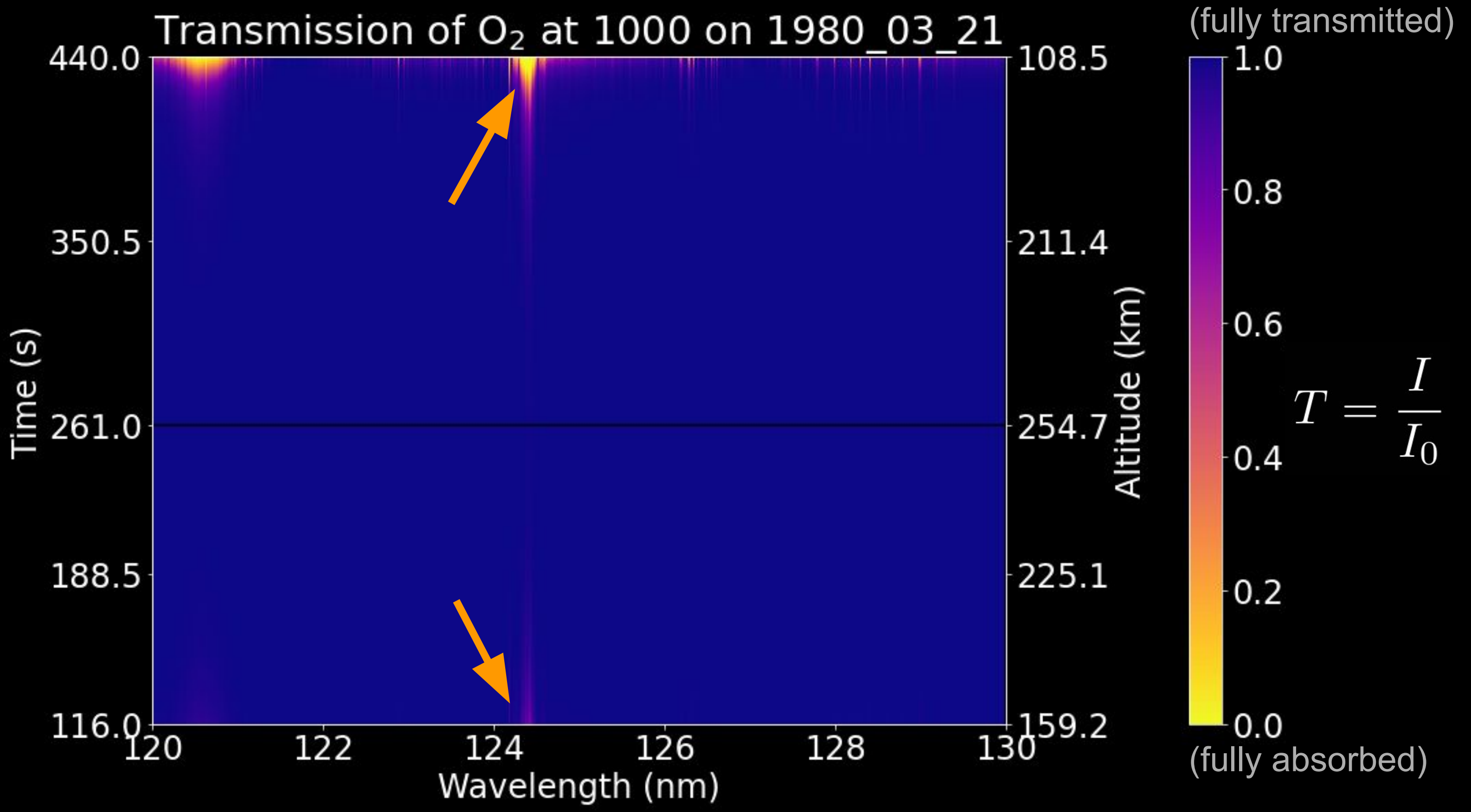


Motivation→Background→**Absorption**→Calibration→Conclusion

- Transmission T:

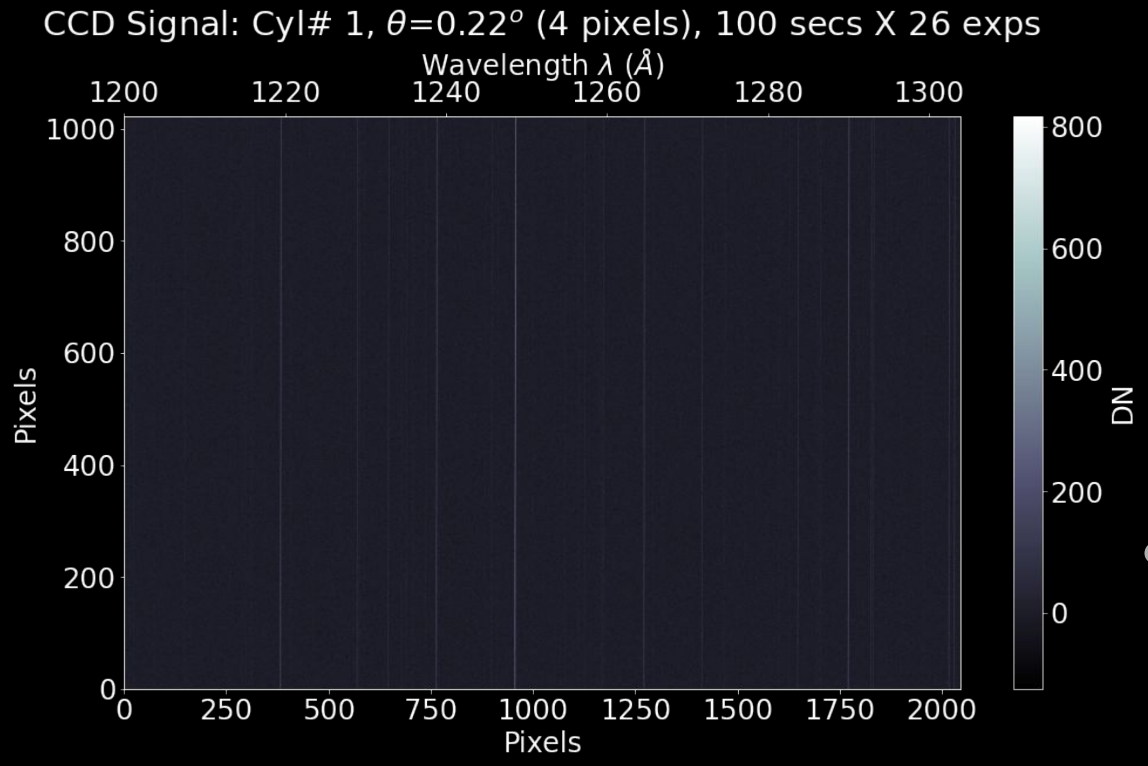
$$T = \frac{I}{I_0} = e^{-\tau/\cos\theta}$$

- We plot transmission during the expected flight profile
  - Noticeable absorption is only expected at the **start and end of open-shutter time**



(only a part of the full range)

Motivation→Background→Absorption→**Calibration**→Conclusion



- Diagnostic lines are used to map CCD pixels to wavelength
  - **Spectral plate scale, tilt, spherical aberration**, etc.

$$\lambda = (\lambda_0 + \Delta\lambda_0) + (A + \Delta A)\cdot x + (B + \Delta B)\cdot x^2 + (C + \Delta C)\cdot y + (D + \Delta D)\cdot y + (E + \Delta E)\cdot x \cdot y$$

- Our goal is to map **λ to within 1.5 mÅ**
  - **Absorption provides additional diagnostics**

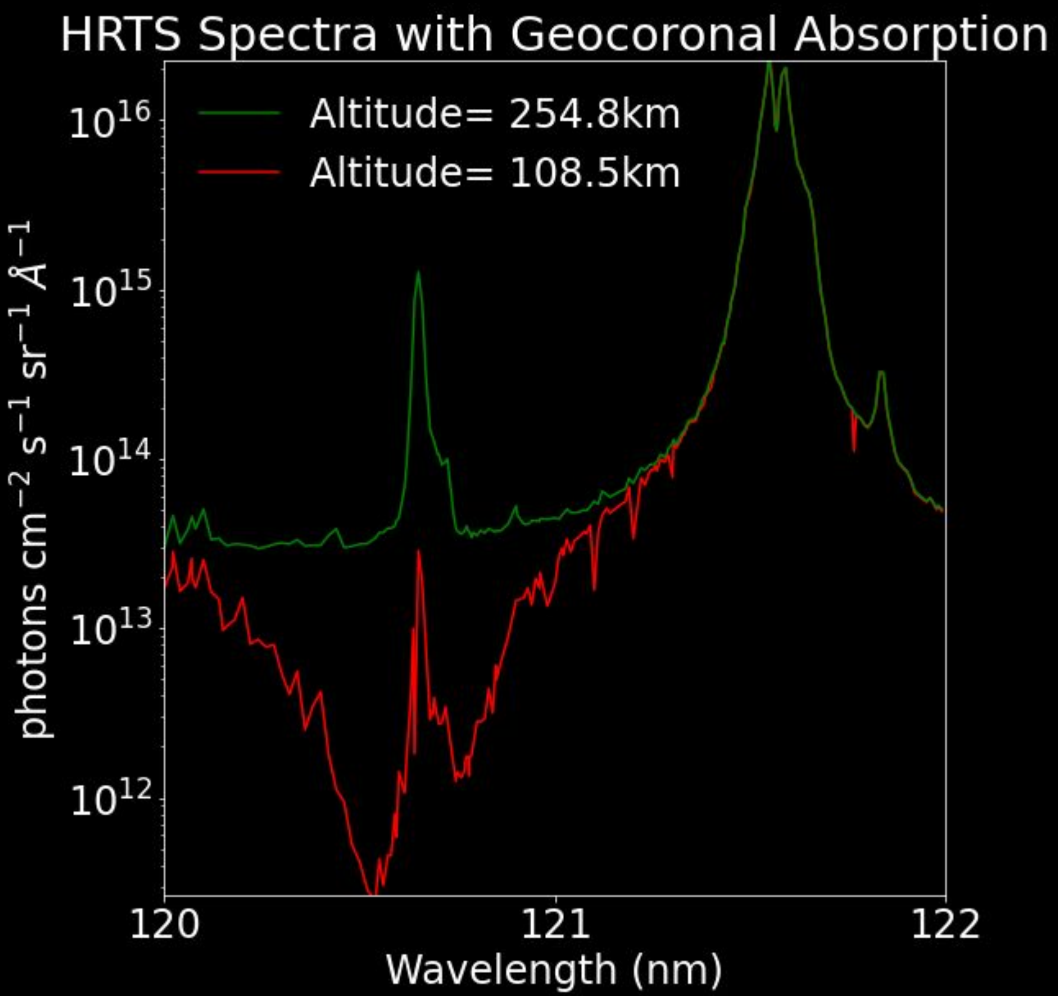
For more, see our latest paper on calibration: Vigil, Genevieve D., et al. (2021)

Motivation→Background→Absorption→**Calibration**→Conclusion

- This plot shows an example signal at the lowest altitude for FURST
  - uses the QS spectral regions from HRTS

$$I = I_0 e^{-\tau/\cos\theta}$$

- Many models exist to correct for atmospheric absorption
  - “Makee” for Keck, ESA Skytools, etc.
- We can use these lines to aid in calibration **before correcting** for them



Makee: www2.keck.hawaii.edu/inst/common/makeewww/index.html
ESA Skytools: www.eso.org/sci/software/pipelines/skytools/

Motivation→Background→Absorption→Calibration→Conclusion

- FURST will measure Full-sun UV spectra in high resolution
  - Will serve as a Hubble analog
- **Precise wavelength calibration is necessary**
  - Pre- and post-flight calibration
  - Absorption lines may provide in-flight calibration

www.nasa.gov/centers/marshall/news/news/releases/2015/nasas-clasp-mission-set-to-gauge-upper-solar-chromospheres-magnetic-field.html

Motivation→Background→Absorption→Calibration→**Conclusion**

- We may also be able to **validate atomic and atmospheric properties**
  - Normally, this correction would be thought of as only a “radiometric calibration” problem
- The next step is integrating with the **calibration work already underway**
- Launch expected to be **August 2022**

www.nasa.gov/centers/marshall/news/news/releases/2015/nasas-clasp-mission-set-to-gauge-upper-solar-chromospheres-magnetic-field.html

Motivation→Background→Absorption→Calibration→Conclusion

Future Work:

- Add H and O **resonant absorption**
- Consider **temperature** effect on absorption bands
- Calculate necessary signal-to-noise ratio for FURST to use these lines.

www.nasa.gov/centers/marshall/news/news/releases/2015/nasas-clasp-mission-set-to-gauge-upper-solar-chromospheres-magnetic-field.html

Thank You!

Feel free to email me with any questions!
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