INVESTIGATING GEOCORONAL ABSORPTION FOR WAVELENGTH CALIBRATION OF SOUNDING ROCKETS

NICOLAS DONDERS [1],
AMY WINEBARGER [2], CHARLES KANKELBORG [3],
GENEVIEVE VIGIL [2], LARRY PAXTON [4], & GARY ZANK [1]

1 CENTER FOR SPACE PLASMA & AERONOMIC RESEARCH
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

2 NASA

3 MONTANA STATE UNIVERSITY

4 JOHNS HOPKINS APPLIED PHYSICS LABORATORY

Overview

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

Motivation→Background→Absorption→Calibration→Conclusion

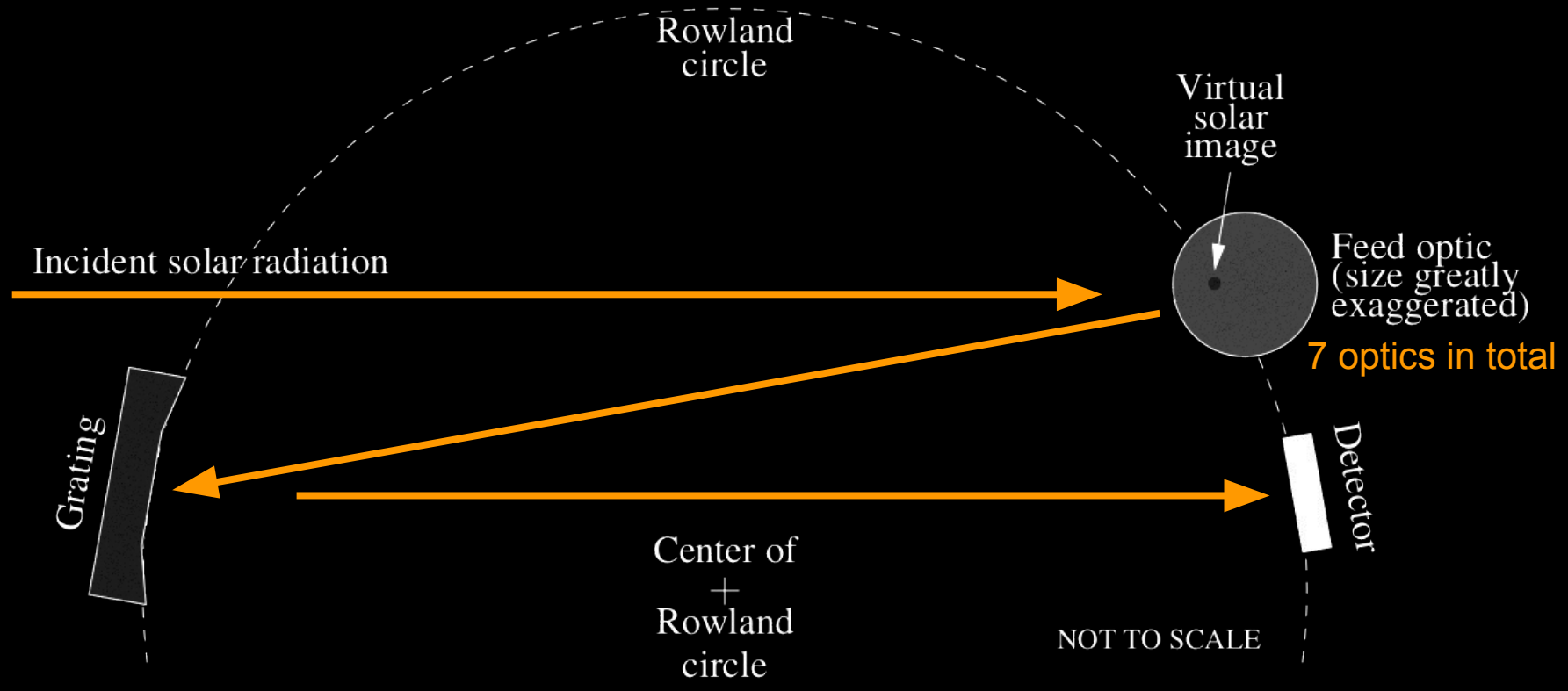
- FURST is the Full-sun Ultraviolet Rocket SpecTrograph
  - Will produce the **first full-sun integrated high-resolution UV spectrum.**
  - Will serve as a Hubble-analog
- For this work, passing through the thermosphere will provide an opportunity **to verify atmospheric density models and atomic absorption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

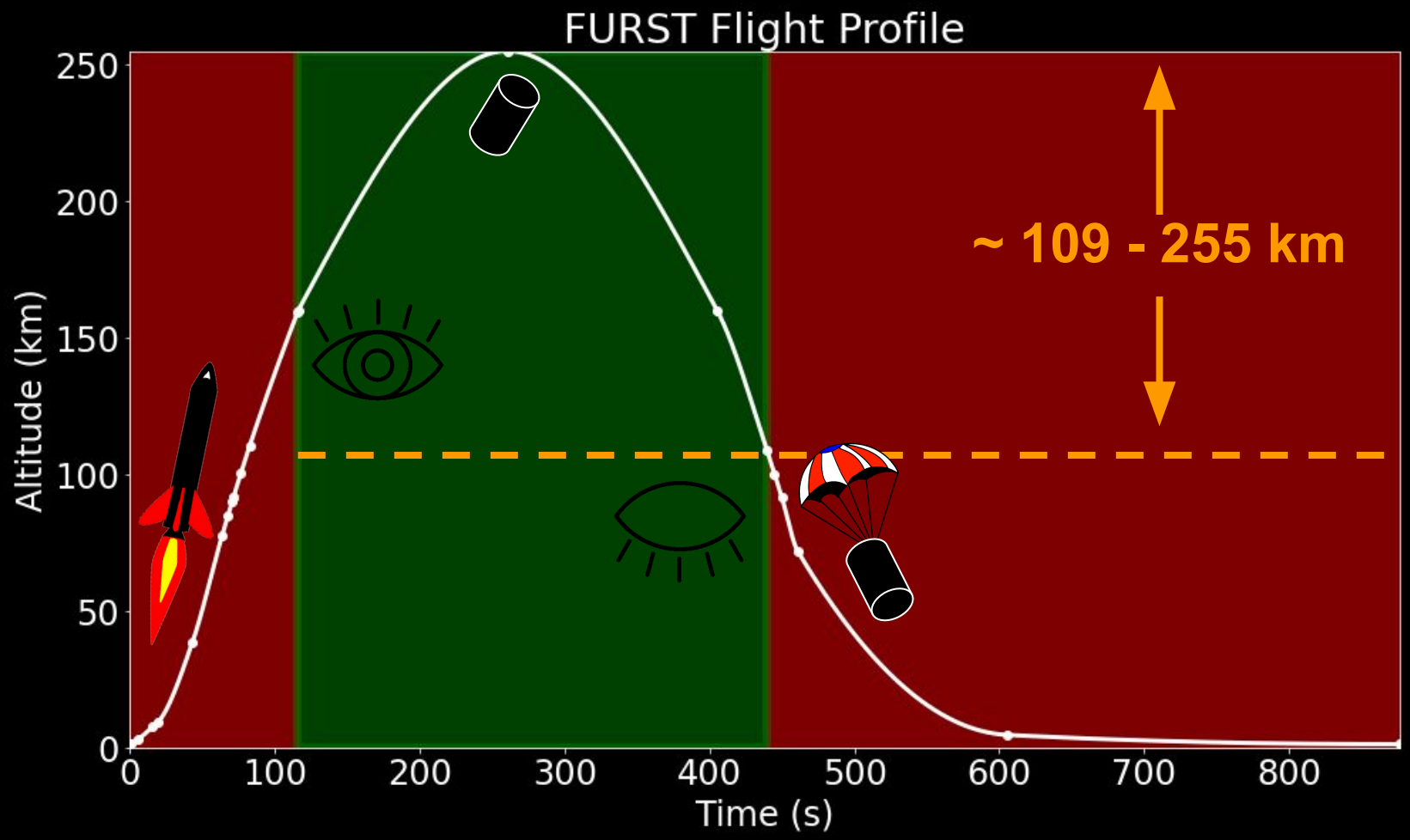
- FURST reduces the **entire solar disk** image to the size of a pixel
- Current UV spectral measurement sources have a limited FOV (such as HRTS) or low resolution

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



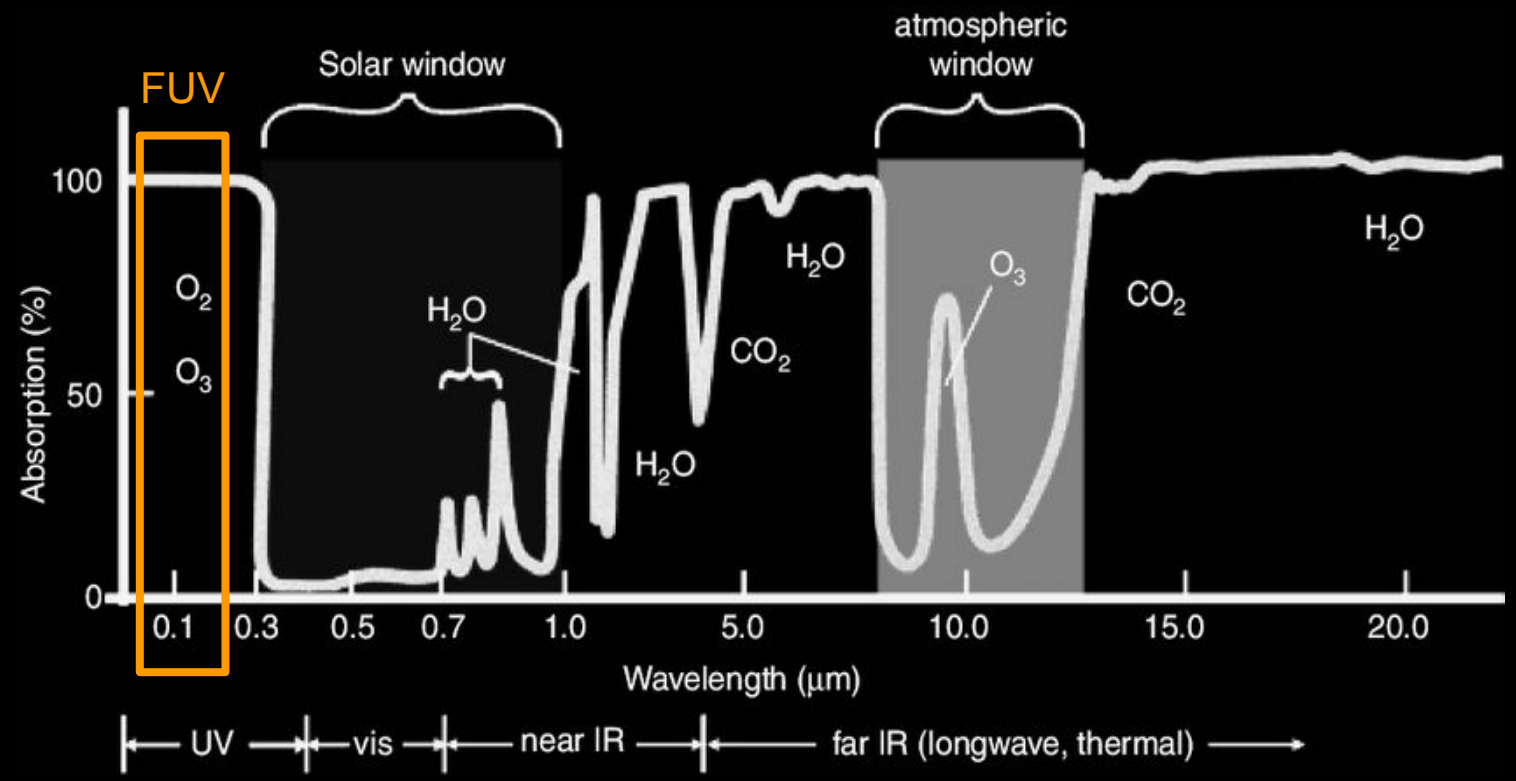
Motivation→Background→Absorption→Calibration→Conclusion

- 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

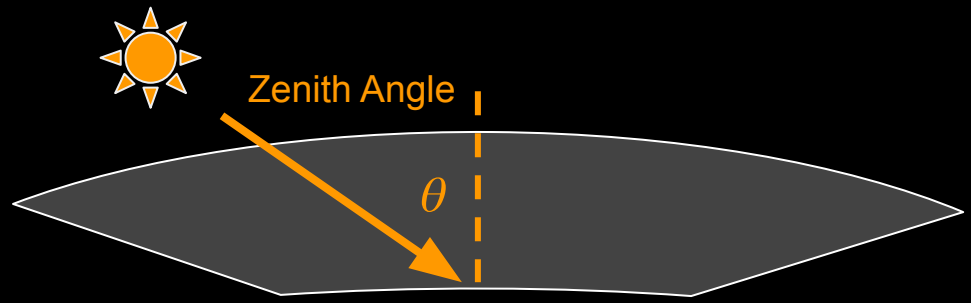
Motivation→**Background**→Absorption→Calibration→Conclusion

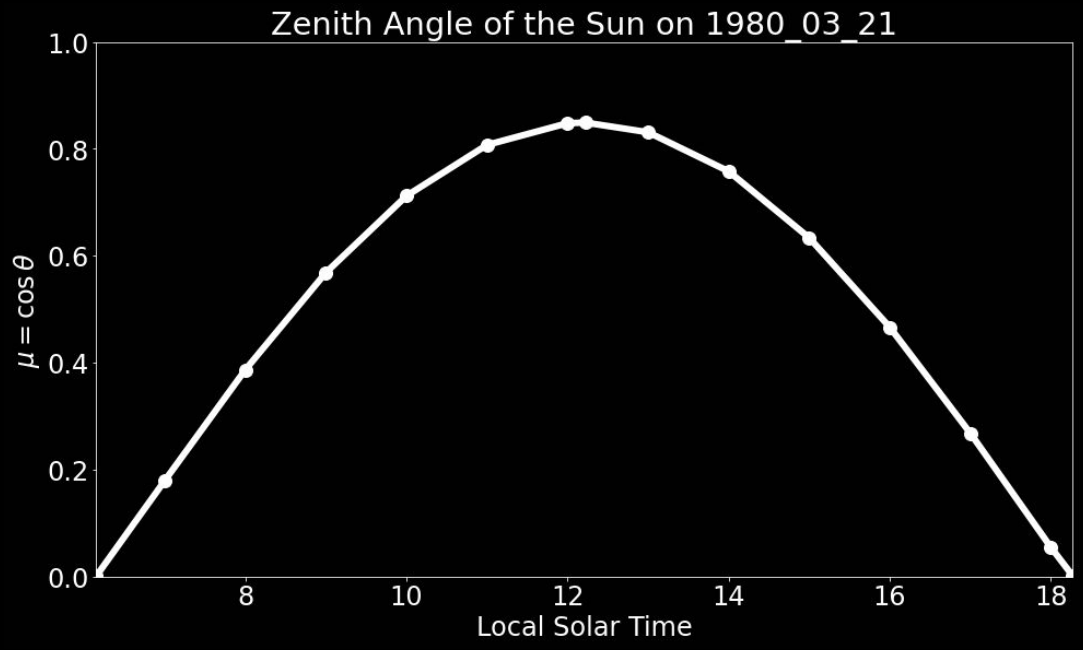
- Optical depth is a unitless quantity defined as the **product of the absorption cross section and number density** integrated vertically with altitude

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

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

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

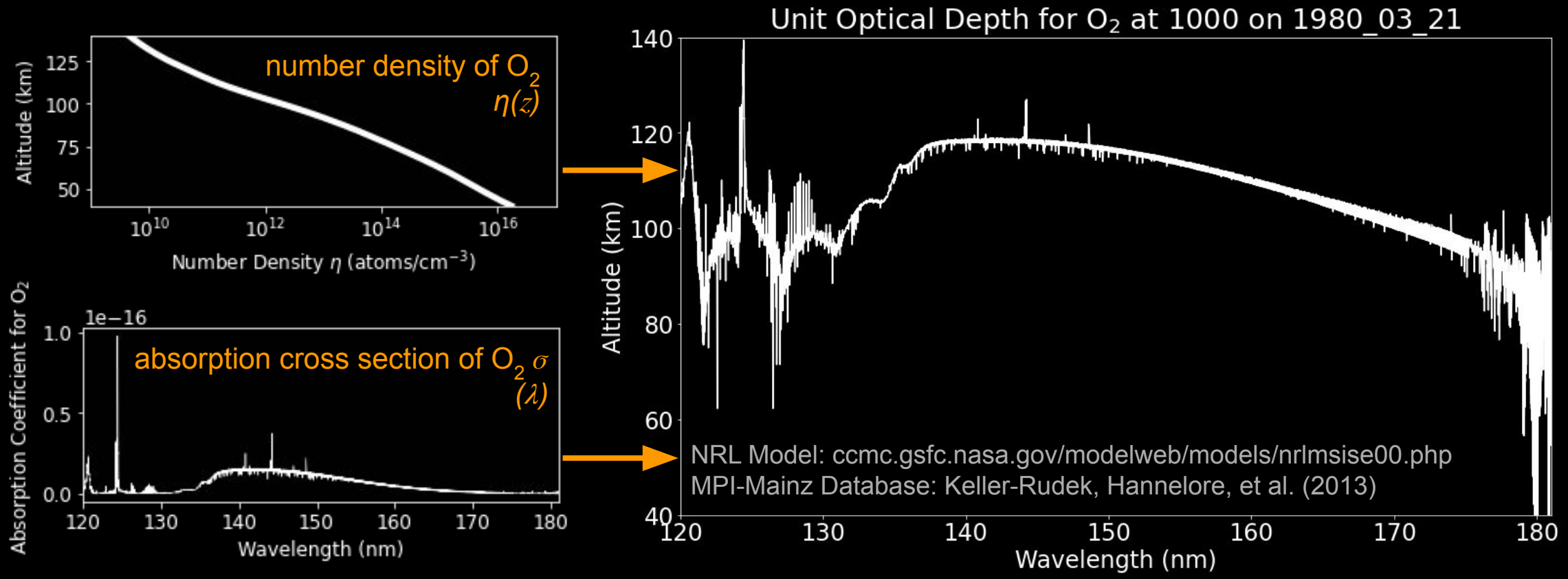




Motivation→Background→Absorption→Calibration→Conclusion

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

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

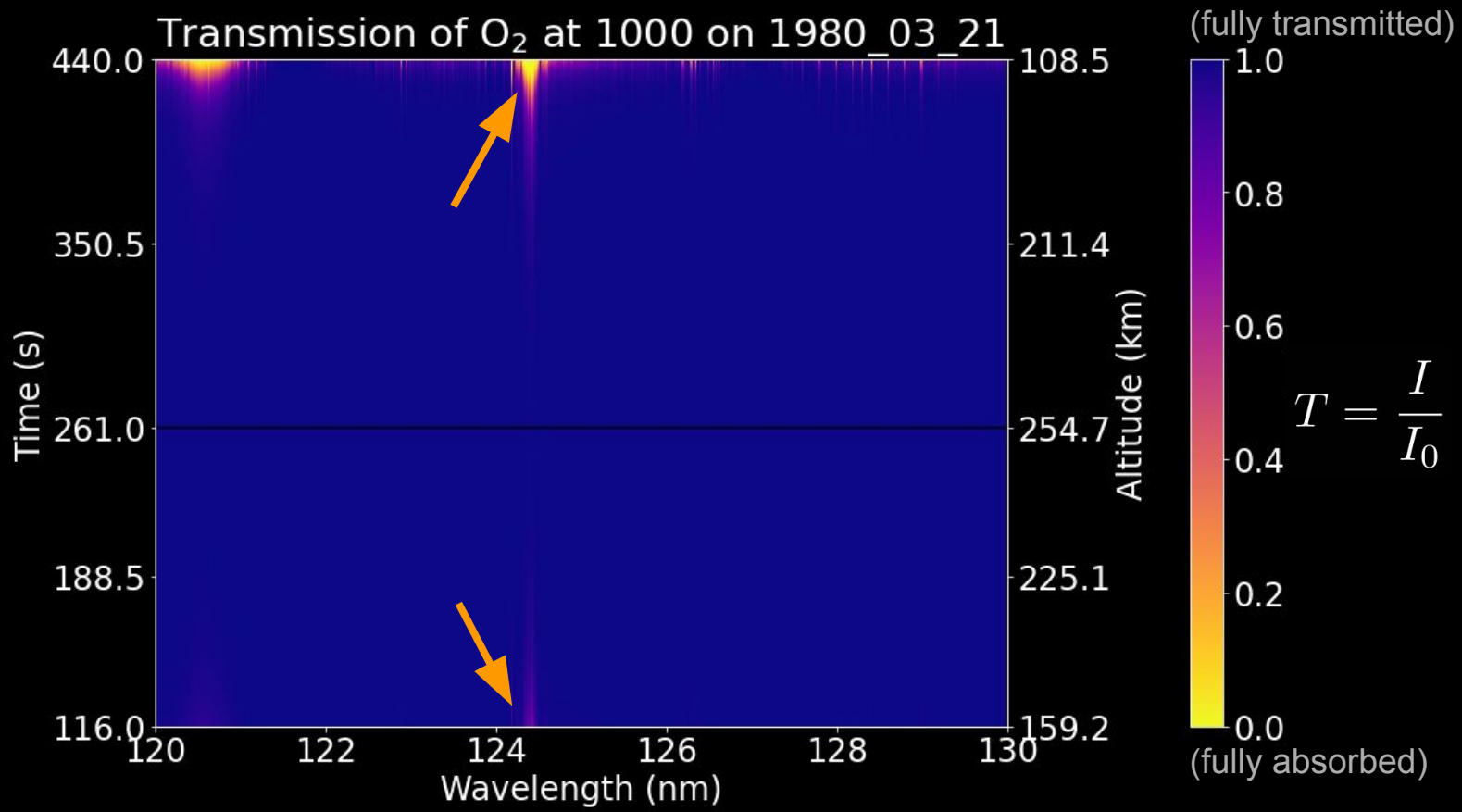


Motivation→Background→Absorption→Calibration→Conclusion

- Transmission T:

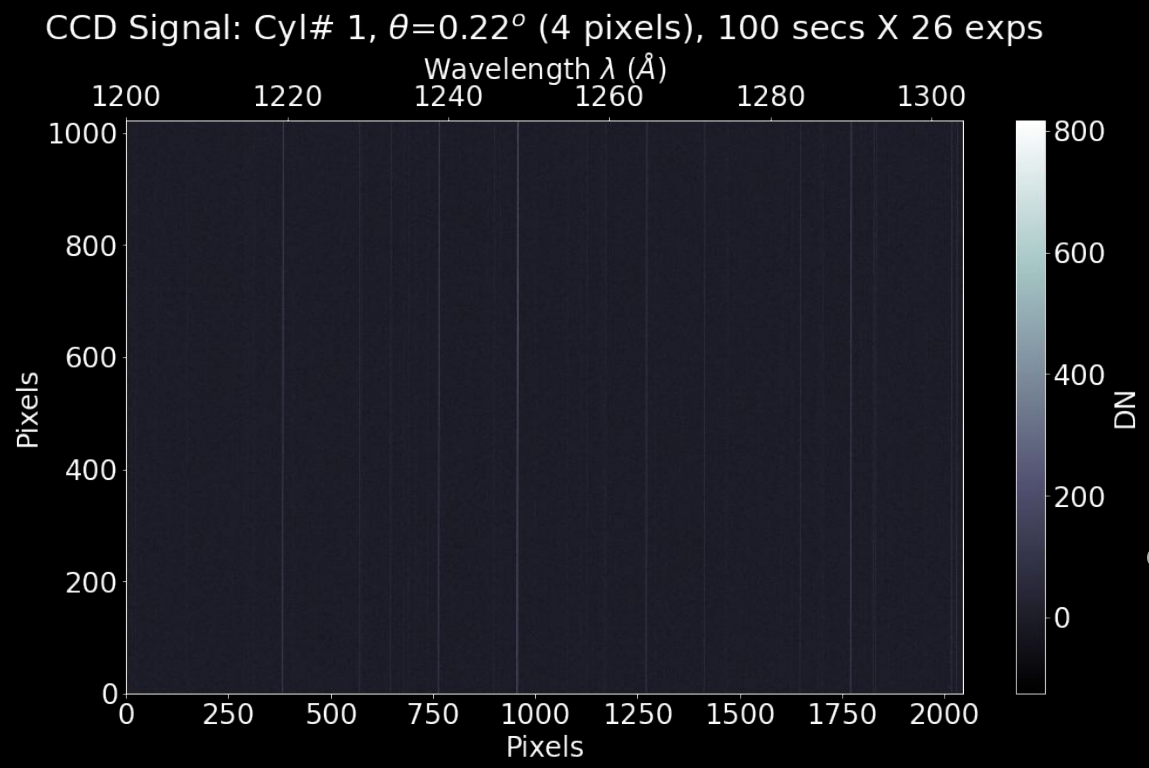
$$T = \frac{I}{I_0} = e^{-\tau / \cos\theta}$$

- 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**

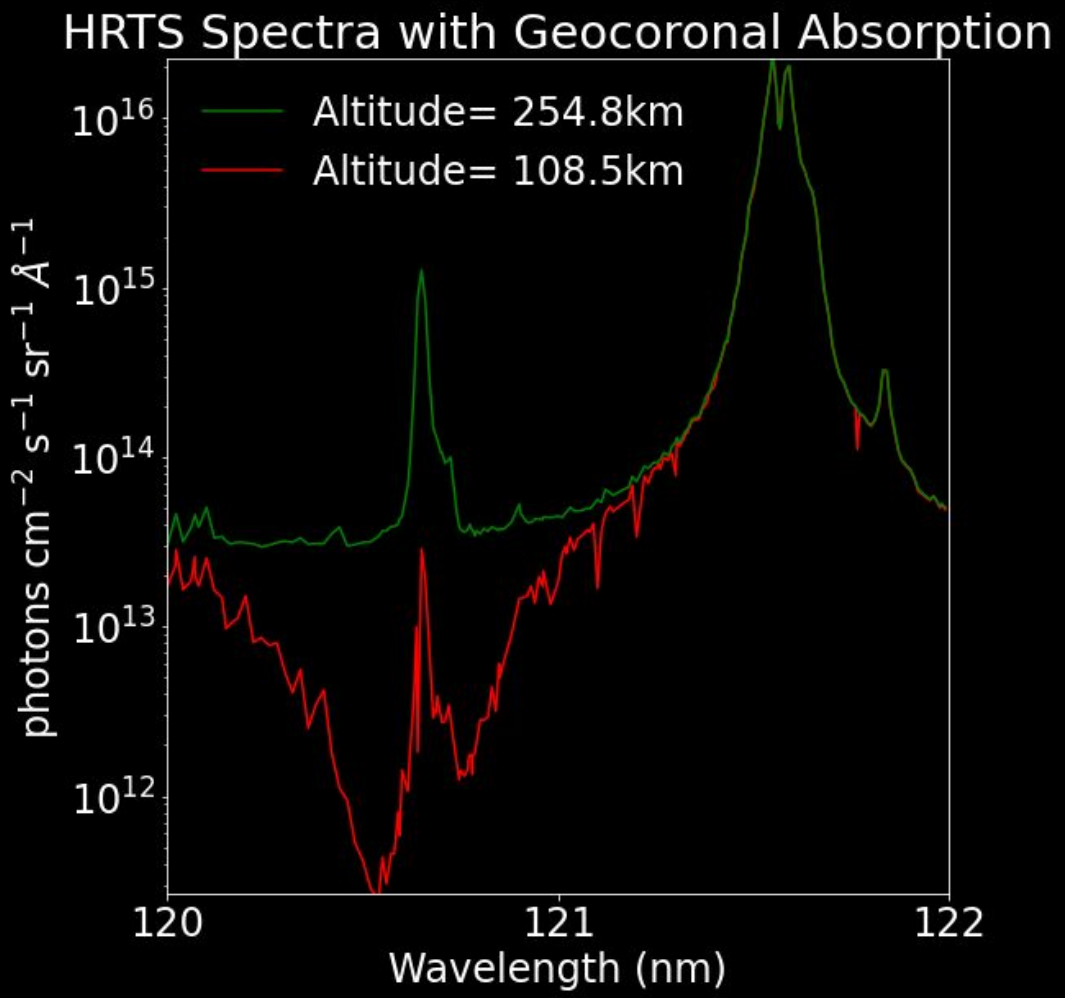
For more, see our latest paper on calibration: Vigil, Genevieve D., et al. (2021)

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!

ngd0004@uah.edu

References:

Slide number:
2. https://scied.ucar.edu/sites/default/files/images/large_image_for_image_content/ionosphere_layers_altitude_diagram_600x810_0.jpg
5. www.researchgate.net/figure/The-absorption-profile-of-Earths-atmosphere-from-UV-to-IR-The-graph-shows-the-regions_fig17_320660396
7. Meier, R. R. "Ultraviolet spectroscopy and remote sensing of the upper atmosphere." *Space Science Reviews* 58.1 (1991): 1-185.
7. NRL Model: ccmc.gsfc.nasa.gov/modelweb/models/nrlmsise00.php
7. MPI-Mainz Database: Keller-Rudek, Hannelore, et al. (2013)
9. Vigil, Genevieve D., et al. "Design for a portable calibration system for the Full-sun UV Rocket SpecTrometer instrument." *Journal of Astronomical Telescopes, Instruments, and Systems* 7.3 (2021): 035009.
10. Makee: www2.keck.hawaii.edu/inst/common/makeewww/index.html
10. ESA Skytools: www.eso.org/sci/software/pipelines/skytools/
11. www.nasa.gov/centers/marshall/news/news/releases/2015/nasas-clasp-mission-set-to-gauge-upper-solar-chromospheres-magnetic-field.html