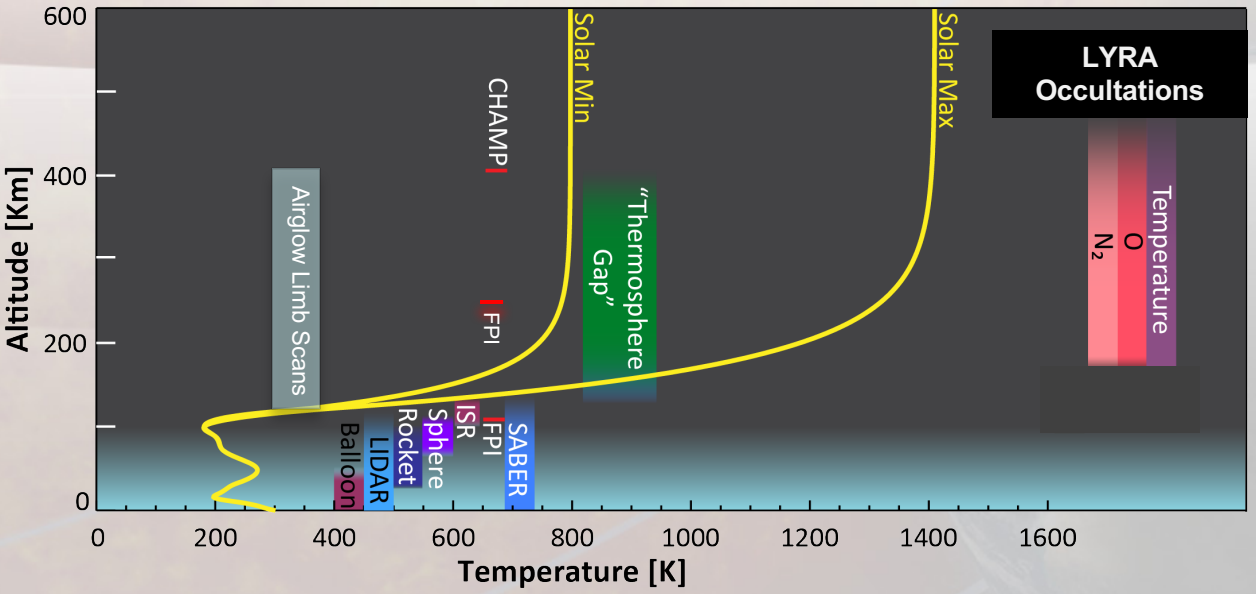
Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

A New Window into Thermospheric Variability Provided by PROBA2/LYRA Solar Occultations

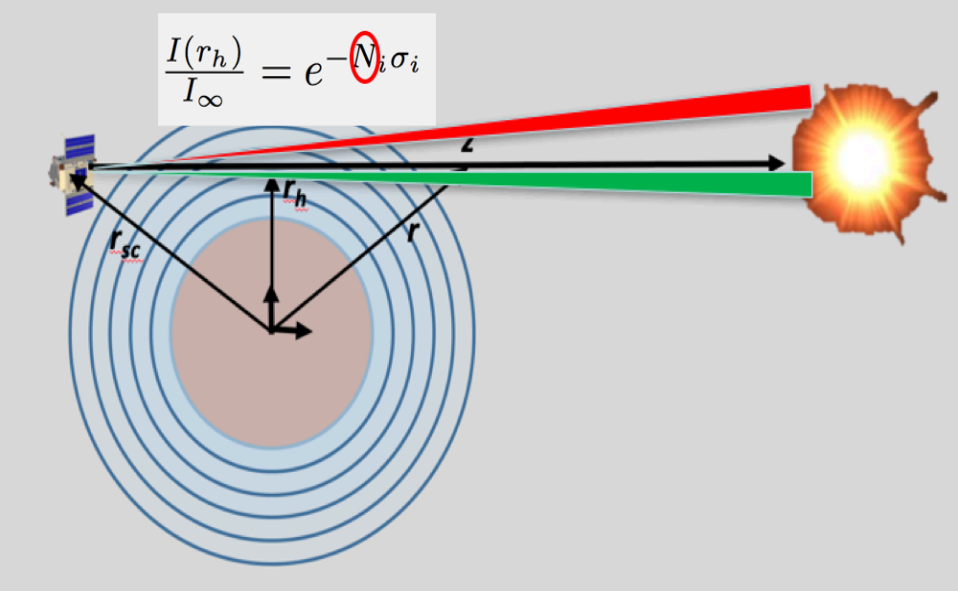
Ed Thiemann, M. Dominique, M. Pilinski, F. Eparvier, M. West, and the LYRA Operations and Data Processing Teams

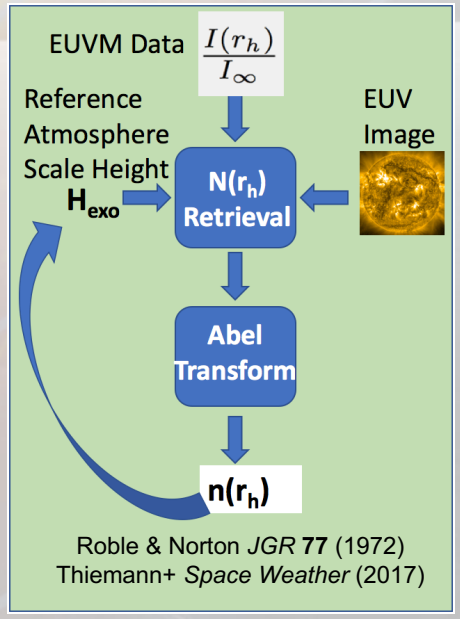
Introduction



- The Earth's thermosphere ranges from ~120-500 km, and is the neutral component of the atmosphere that extends into the space environment.
  - It is highly structured, containing the coldest and hottest temperatures in Earth's atmosphere.
  - It is highly variable and sensitive to space weather.
- Thermospheric structure and variability have important consequences for satellite drag.
- The thermosphere has been historically difficult to measure, LYRA provides visibility into thermospheric variability over the past solar cycle.

Density From LYRA Solar Occultations

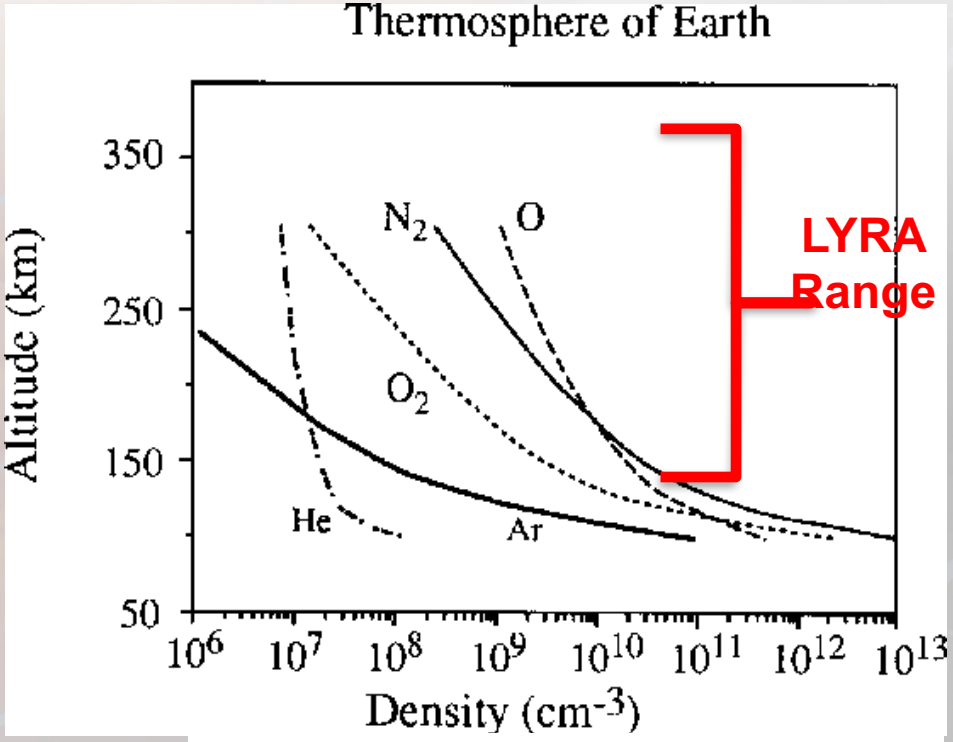




- Density retrievals are complicated by the spatial extent of the Sun being equal to ~2 scale heights.
- Retrieval integrates the solar disk over reference atmosphere to find column density.
- Additionally, EUV varies over the disk, so disk images need to be incorporated into the retrieval.
    - EUV images provided by SWAP.

LYRA Occultation Composition and Cross-sections

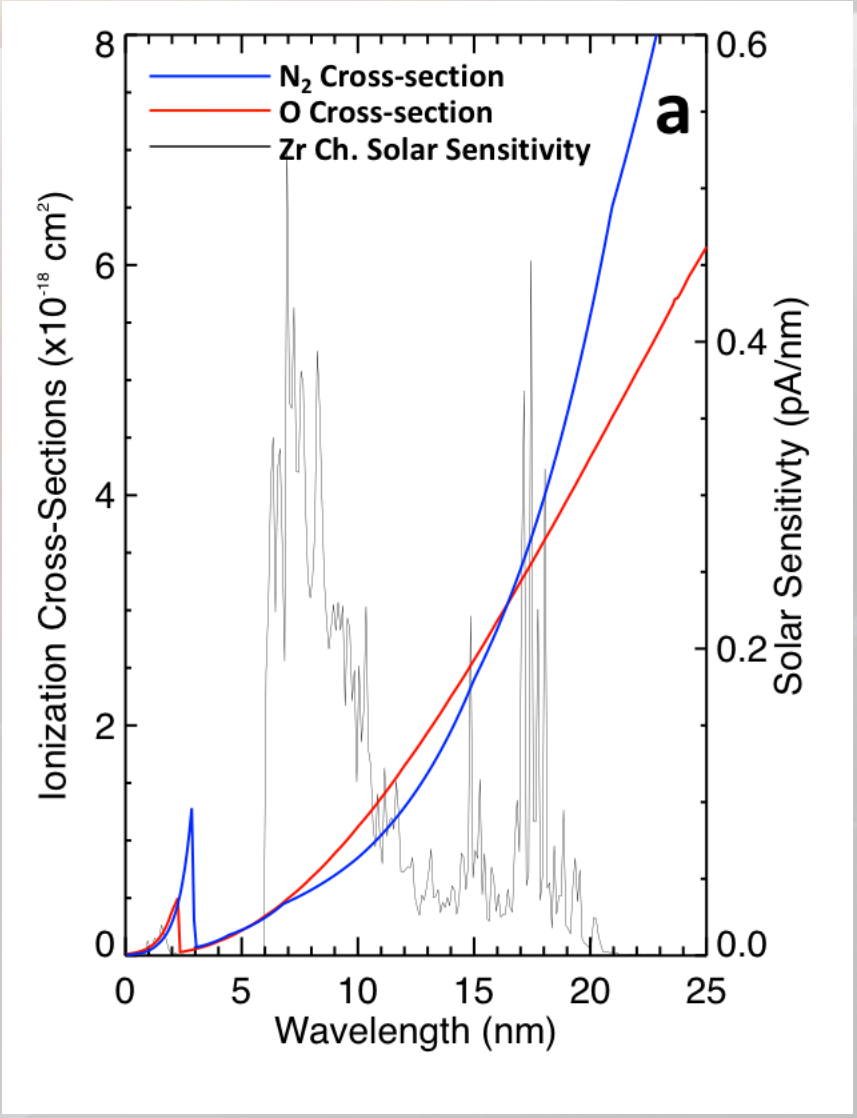
- LYRA measurements are from ~150-450 km.
  - Mostly O on the top-side.
  - Mostly N_2 on the bottom-side.



Cravens (1997) *Phys. Of Sol. System Plasmas.*

LYRA Occultation Composition and Cross-sections

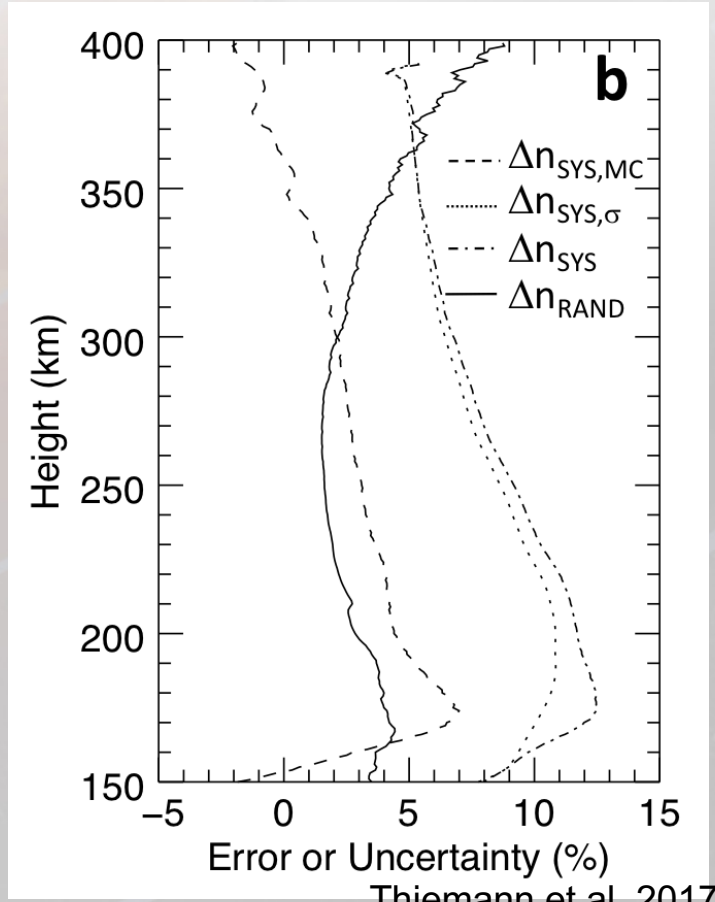
- LYRA measurements are from ~150-450 km.
  - Mostly O on the top-side.
  - Mostly N_2 on the bottom-side.
- O and N_2 cross-sections very similar over Zr channel response.
- Can't distinguish N_2 from O with Zr channel alone.
- → **Can accurately measure N_2 + O sum**



Measurement Error

- Measurement uncertainty can result from instrument noise, solar variability, retrieval algorithms, cross-section assumptions; uncertainty in: solar spectrum, response function.

- MC analysis used to estimate error using MSIS atmospheres as ground truth input into instrument model.
  - Systematic component~5-10%
  - Random component~5-10%



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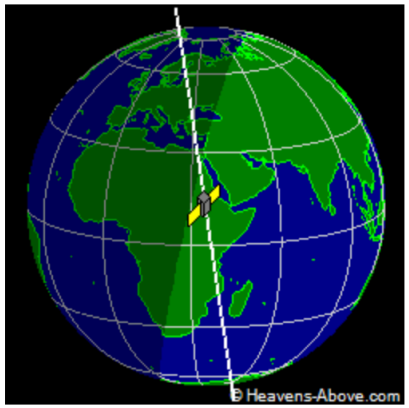
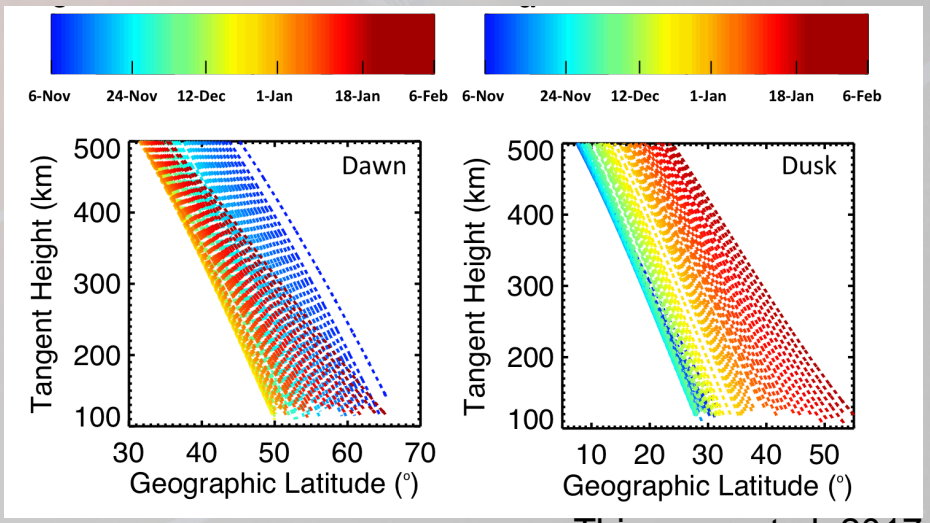
Occultation Seasons and Latitudes

- Sun synchronous orbit results in
  - Occultations only occurring during northern winter.
  - the lower latitude atmosphere occulting line-of-sight at higher altitudes.
- Important for interpreting scale-height temperatures.
  - Denser topside due to horizontal motion will result in hotter scale heights.

View from above orbital plane



View from above satellite



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2010-2011 and 2013-2014 Campaigns

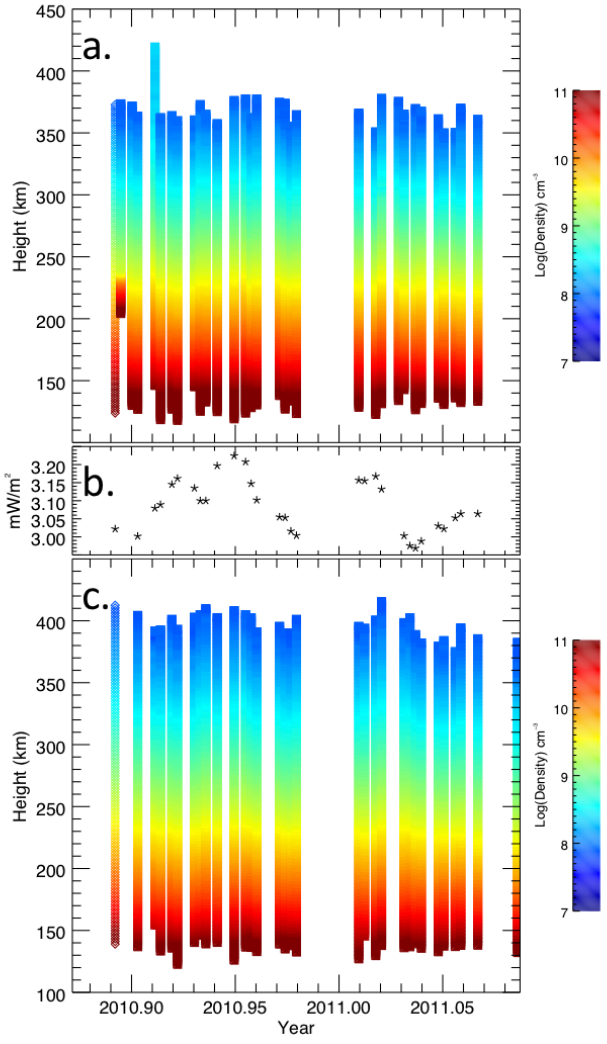
2010-2011

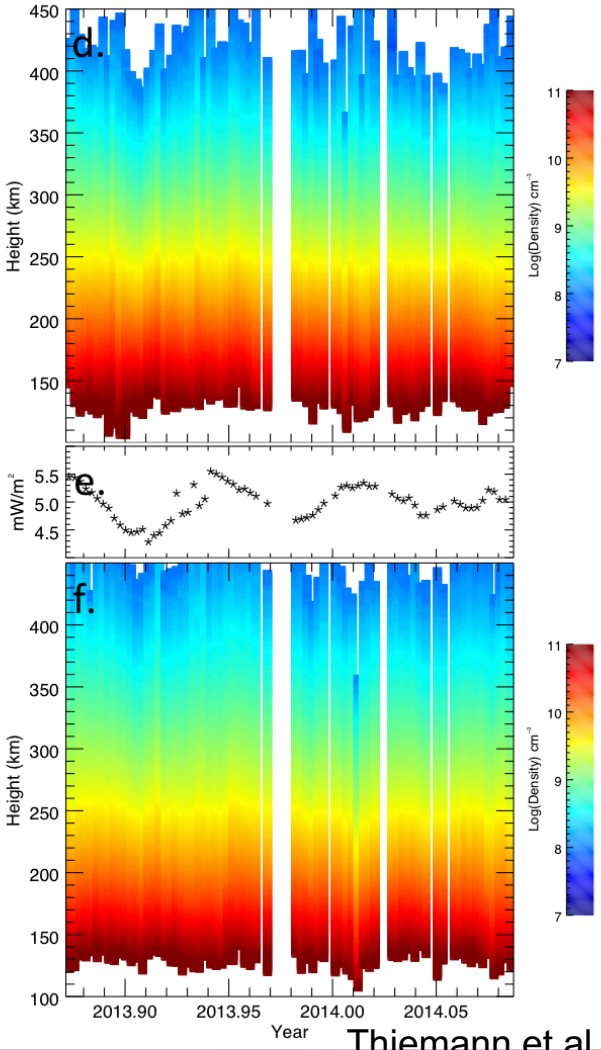
2013-2014

Dawn

0-103 nm EUV

Dusk

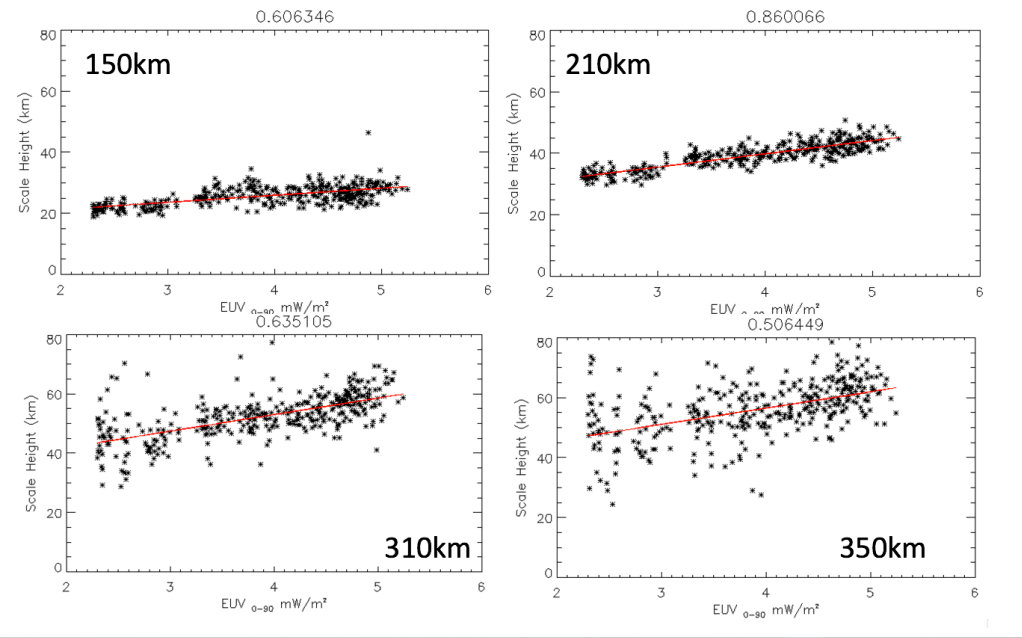


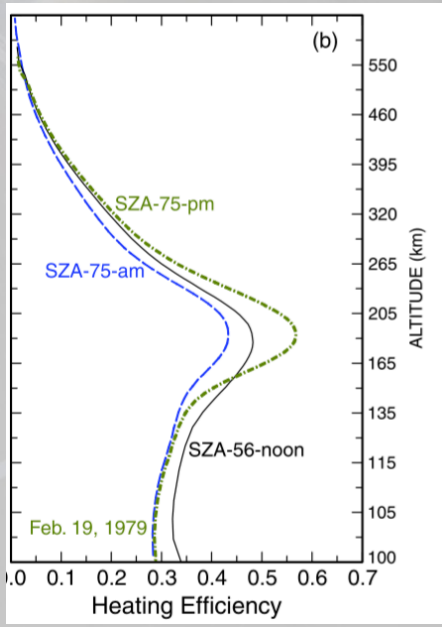


Thiemann et al. 2017

EUV Temperature Sensitivity vs Altitude

- Lower and middle thermosphere temperature highly correlated with EUV irradiance.
- At higher altitudes, correlation breaks down.
  - EUV heating expected to be less significant at high altitudes.
  - At high altitudes, thermal e^- are major contributors to neutral heating.
  - e^- density hard to predict→ high alt. neutral temperature hard to predict.

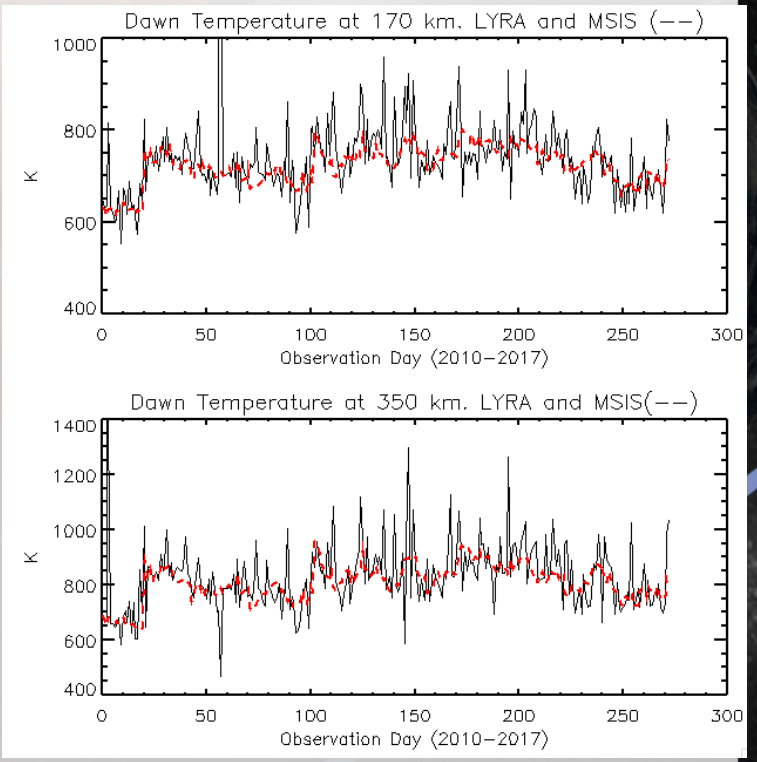


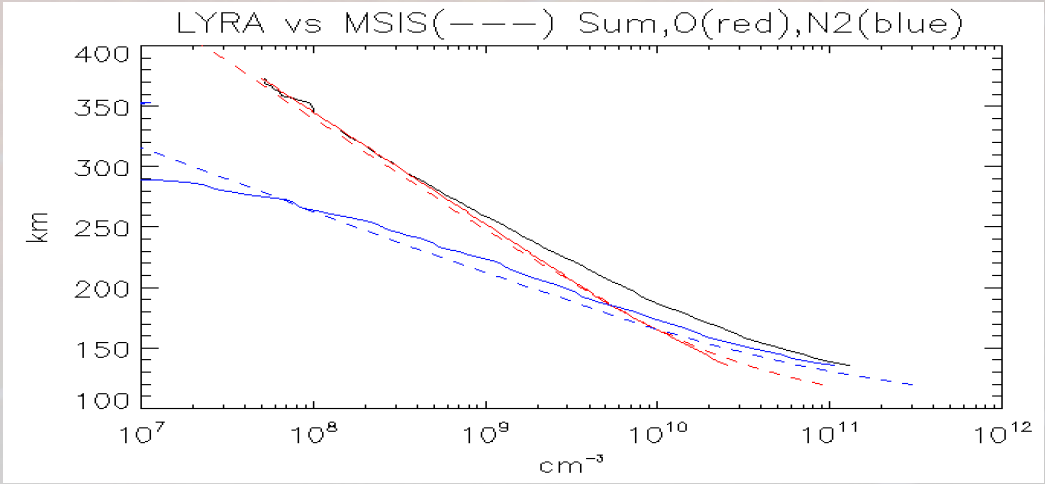


P.G. Richards Can. J. Phys 90 (2012)

Future LYRA Data Products

- Current LYRA data product is the sum of O and N_2 neutral density.
- Thermospheric temperature can be derived if some assumptions are made about abundance.
  - Assume topside is pure O.
  - Bottomside is dominated by N2.
- Use series of exponential atmosphere profiles to determine abundance.
- Preliminary results are in excellent agreement with MSIS.





Summary

- LYRA solar occultations measure N_2+O number density at both dawn and dusk terminators.
  - Thiemann, E. M. B., Dominique, M., Pilinski, M. D., & Eparvier, F. G. (2017). Vertical thermospheric density profiles from EUV solar Occultations made by PROBA2 LYRA for solar cycle 24. *Space Weather*, *15*
- Measurements are made during PROBA2 eclipse season, ~November-February.
- Measurements were made at daily cadence from 2010-2017.
- Measurements at orbit cadence began in Fall 2017.
- Thermospheric density profiles are rare and unique, and the LYRA data should be useful for a range of studies; e.g.:
  - Thermospheric variability over a solar cycle and solar rotations.
  - Space weather event case studies.
  - Wave/tidal forcing studies.
  - Sudden stratospheric warming case studies.
  - Data assimilation studies.
- Methods have been developed to derive thermospheric temperature, expect paper/data to be submitted/published late 2018.

Backup Slides

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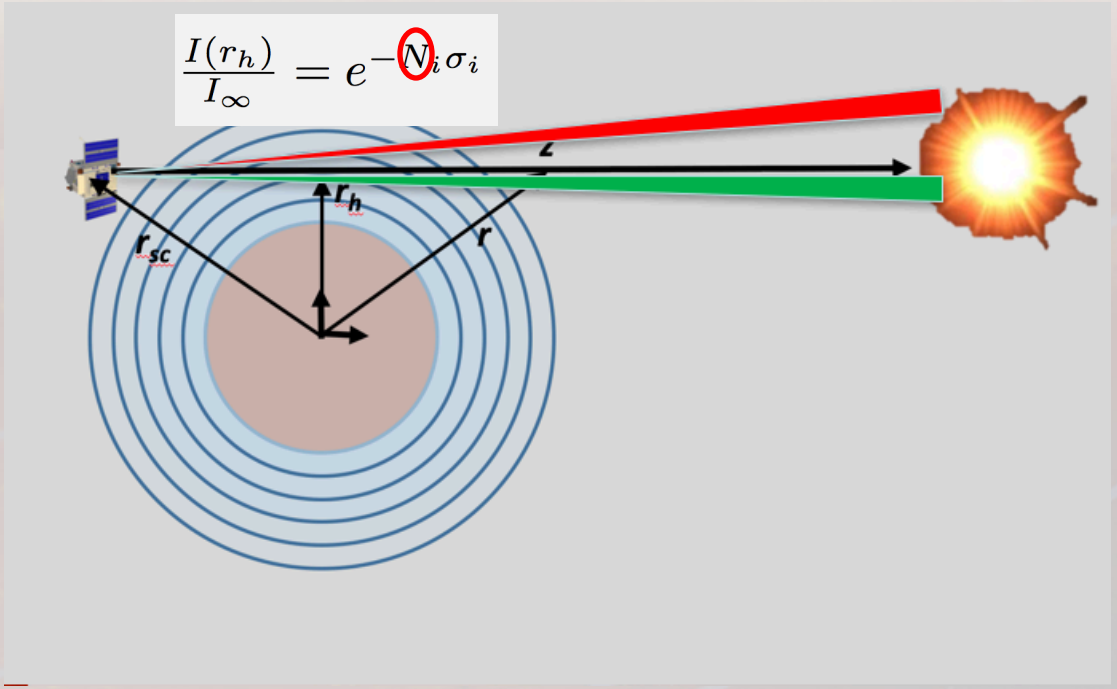
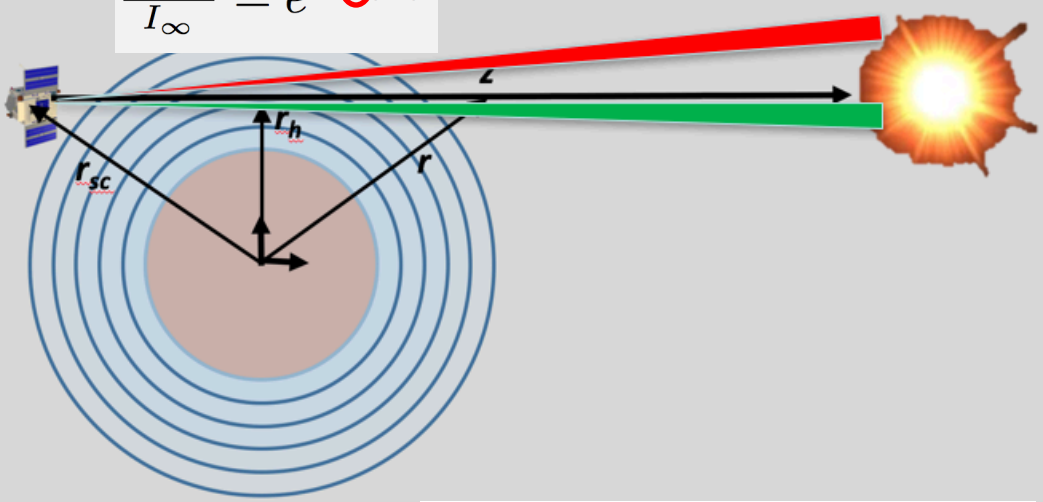
Accounting for the Extended Sun



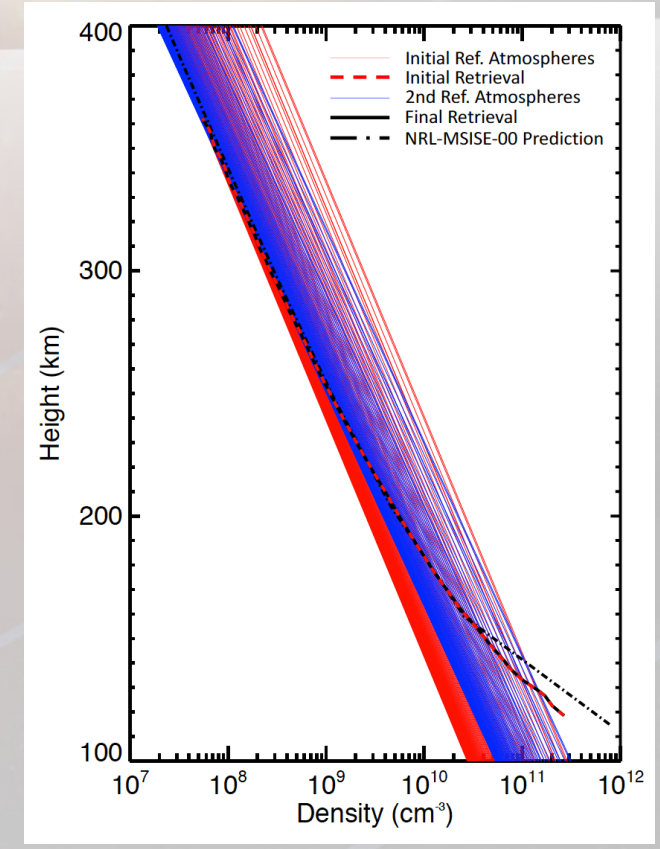
- Red line of sight goes through thinner atmosphere than green line of sight.
- Forward model can't identify just one constant column density.
- What to do?

Accounting for the Extended Sun

$$\frac{I(r_h)}{I_\infty} = e^{-N_i \sigma_i}$$



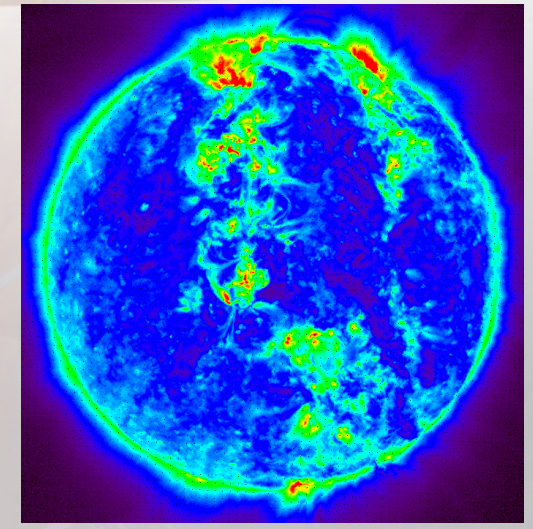
$$n(r) = n_o e^{-(r-r_o)/H}$$

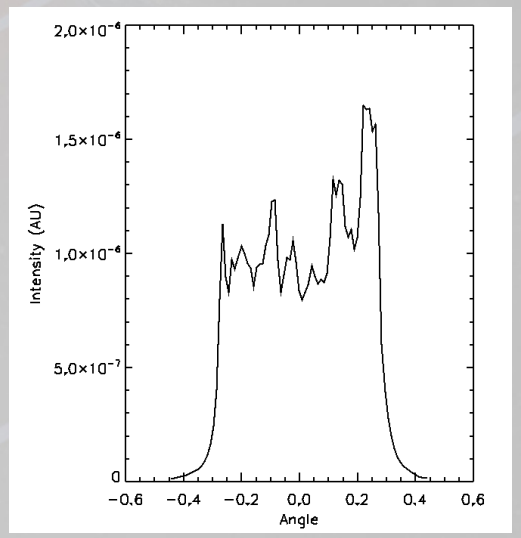


- Roble and Norton [1972] showed that using a simple isothermal atmosphere to integrate the solar disk over when finding the column densities was sufficient above the first scale height change.
- Key is to keep *H* constant while adjusting n_0.
- Iterate until *H* of retrieved density equals *H* of the reference model.

Accounting for the Messy Corona

- 0.1-20 nm radiance is highly variable over the solar disk, and must be accounted for to avoid introducing error.
  - E.g. a bright active region along denser (tenuous) lines of sight will be more (less) readily absorbed.
- Serendipitously, PROBA2 has the SWAP imager to estimate the radiance distribution.





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