Full-Orbit Ultraviolet Ionospheric Tomography and Applications

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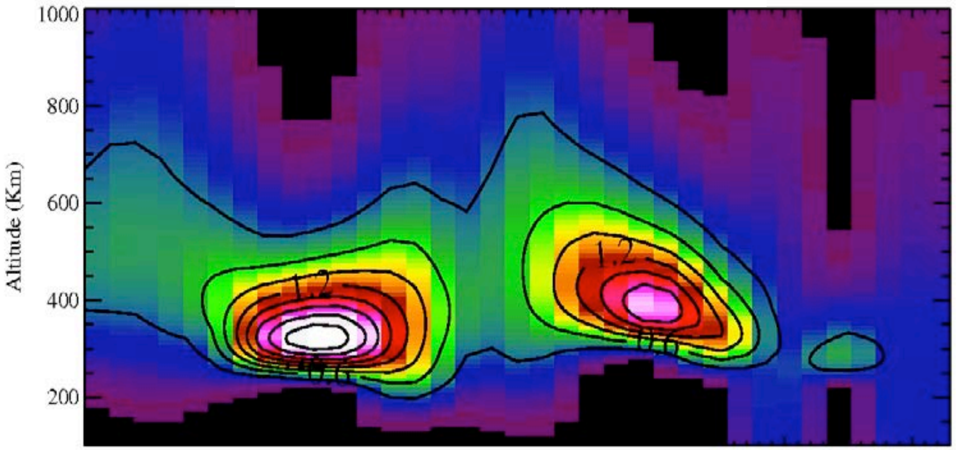
Far-ultraviolet Tomography at NRL

- NRL has performed FUV tomography of the nighttime ionosphere and 2-D algorithms over many years
  - LORAAS, COSMIC TIP+GOX, SSULI missions
- Space-based tomography provides coverage over oceans and other regions of limited access
- Recent innovations include
  - New Image Space Reconstruction Algorithms (ISRAs)
  - Full-orbit volume emission rate tomography
  - Incorporating atmospheric extinction
  - Multiple UV sensor tomography (SSULI+SSUSI)

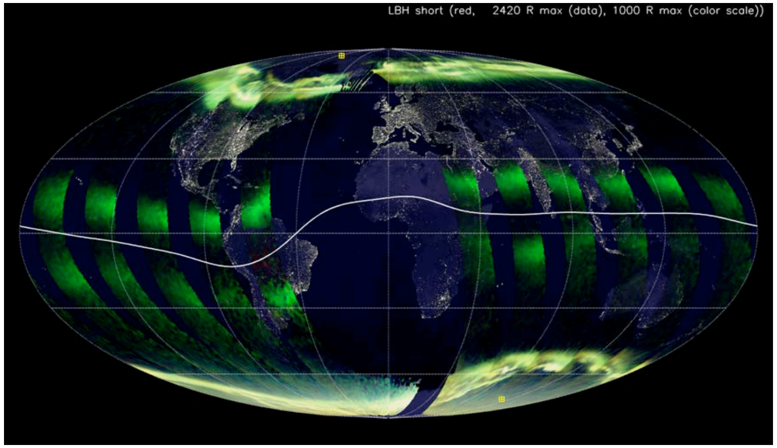
This presentation will focus on full-orbit FUV tomography using SSULI and SSULI+SSUSI

Measuring Ionospheric Airglow on DMSP

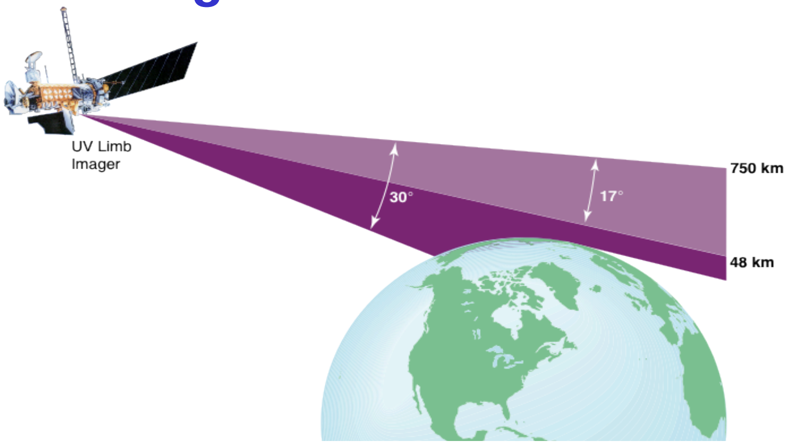
SSULI Nighttime Ionosphere

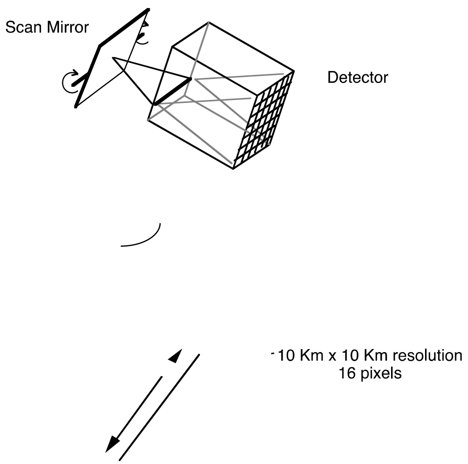


SSUSI Nighttime Ionosphere



- **DMSP SSULI & SSUSI sensors measure ion density (and more), including vertical and horizontal gradients**

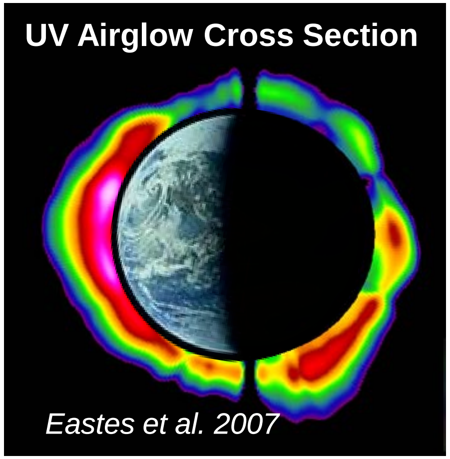




- SSULI scans the limb vertically in the orbital plane
- SSUSI scans the limb and disk perpendicular to the orbital plane

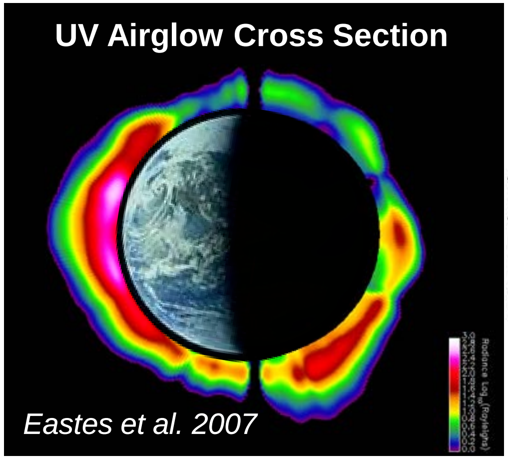
Why Tomography?

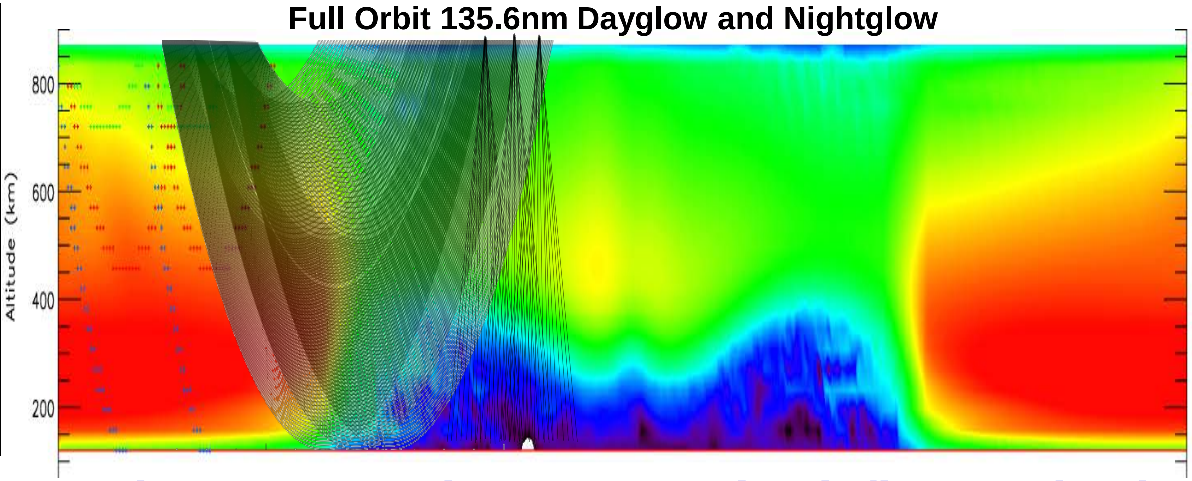
Medical Tomography



- Tomographic reconstruction provides a cross-section revealing density structure and gradients using multiple viewing angles
- DMSP carries two complementary optical sensors SSUSI & SSULI
  - Near-orthogonal viewing angles
  - Compatible or identical measurements (O, N_2, O^+)
  - Combination improves signal-to-noise
  - Different views compensate for particle noise data losses as S/C traverses auroras/SAA
  - Tomographic reconstruction can maximize sensor data volume by eliminating parallax effects (e.g. SSULI aurora and terminator views)
- Optimal reconstruction can be performed before feeding 135.6 data to global assimilative model
  - Reconstruction grid can be tuned to GAIM spatial resolution
  - Can be performed continuously around the orbit independent of airglow excitation processes

Atmospheric Tomography



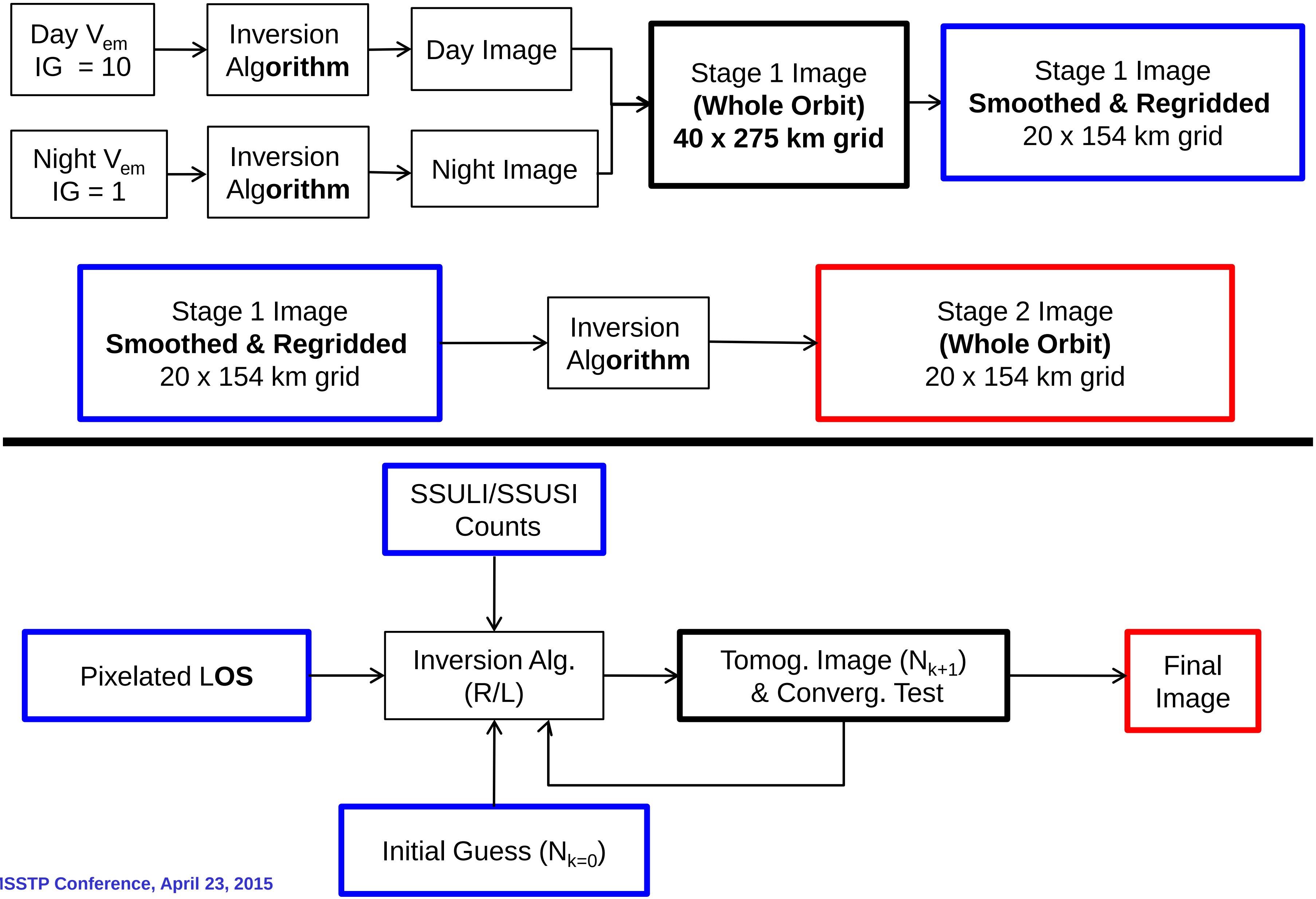


- **Atmospheric tomography resolves key atmospheric/ionospheric structures to constrain drivers in physics-based models**
  - **More accurate physical drivers can improve forecast accuracy**
- **SSUSI & SSULI can jointly perform airglow tomography to unambiguously resolve**
  - **Vertical and horizontal gradient structures in the ionosphere**
    - **Specification is relevant to RF operational applications**
  - **Neutral composition distributions, dynamical features, and temperature**
    - **Relevant to GAIM full-physics ionospheric forecasting**

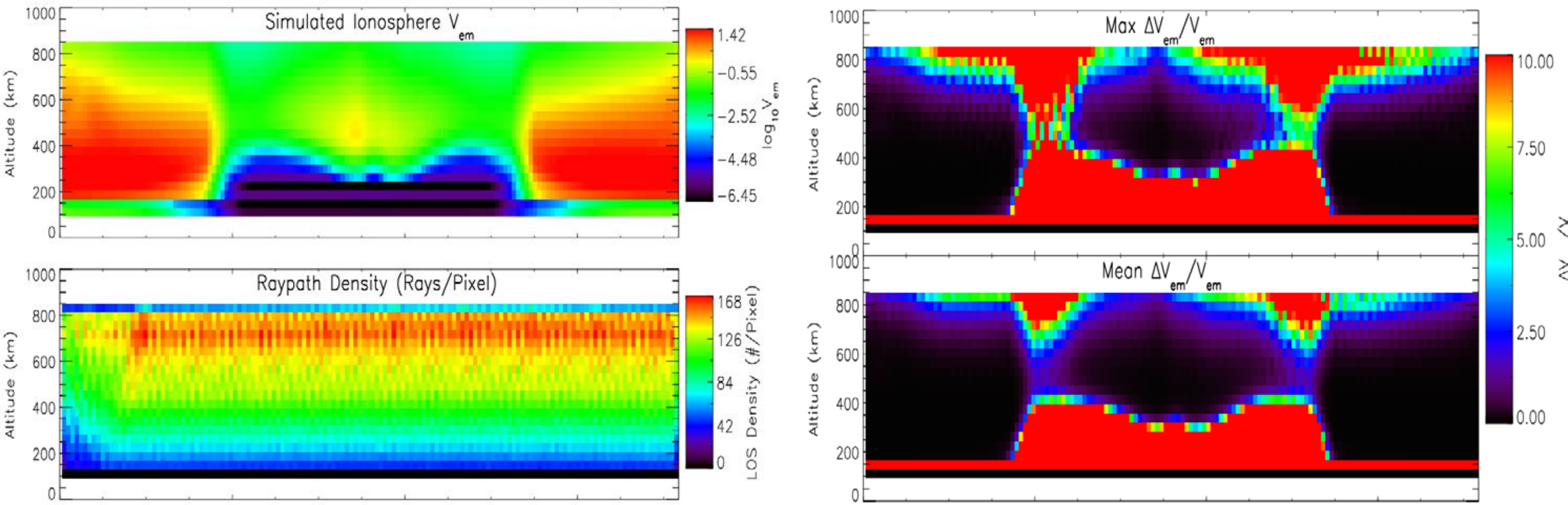
SSULI/SSUSI UV Tomography Method

- 2-D retrieval in orbit angle and altitude along the whole orbit
- OI 1356 airglow emission
  - Image Space Reconstruction Algorithms
    - Reconstruction on volume emission rate
  - No assumptions about physical processes generating airglow
    - Dayglow, nightglow, terminator, aurora handled simultaneously
    - Simply geolocate the emission correctly; then model the physics at a later analysis stage
- Use coincident SSULI and SSUSI observations
  - Co-adding 15 SSUSI pixels directly below DMSP coincides with cross-track width of SSULI
  - Maximize signal-to-noise with fewest assumptions
- Extinction by atmospheric O_2 Schumann-Runge absorption is very important for accurate reconstruction
- Diffusive regularization scheme; regularization is limited on each iteration to be less than the reconstruction algorithm change

SSULI-SSUSI Tomography Approach

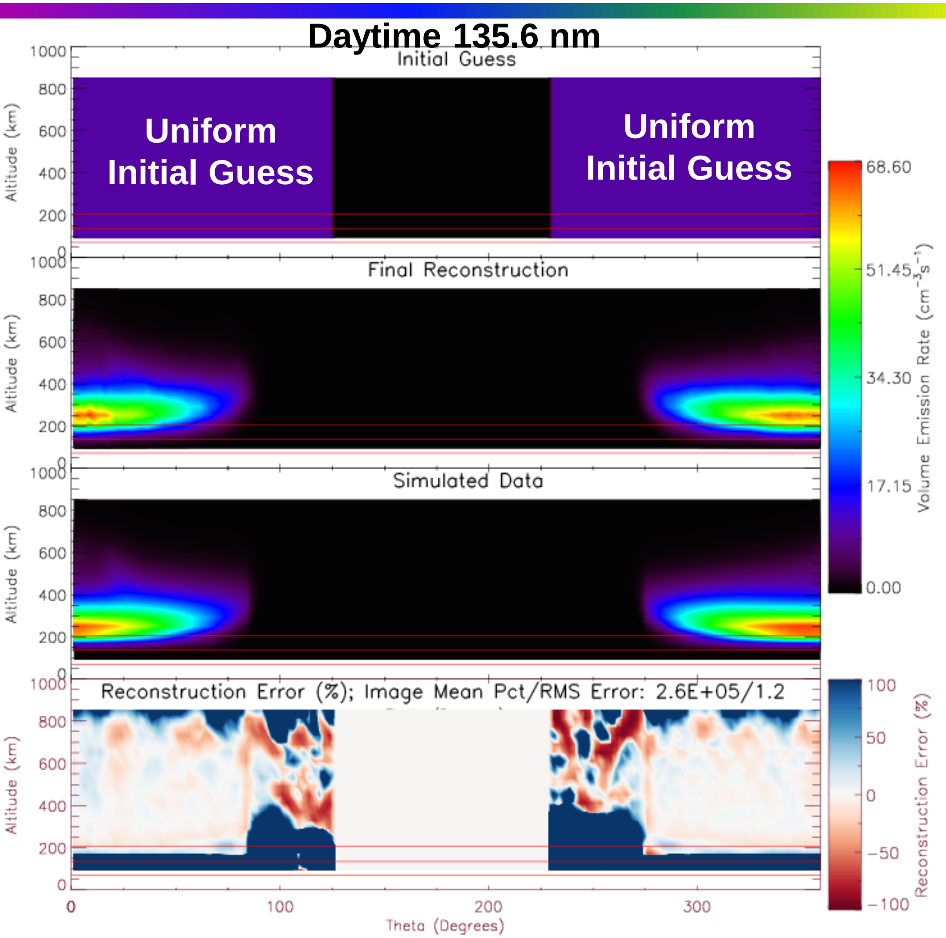


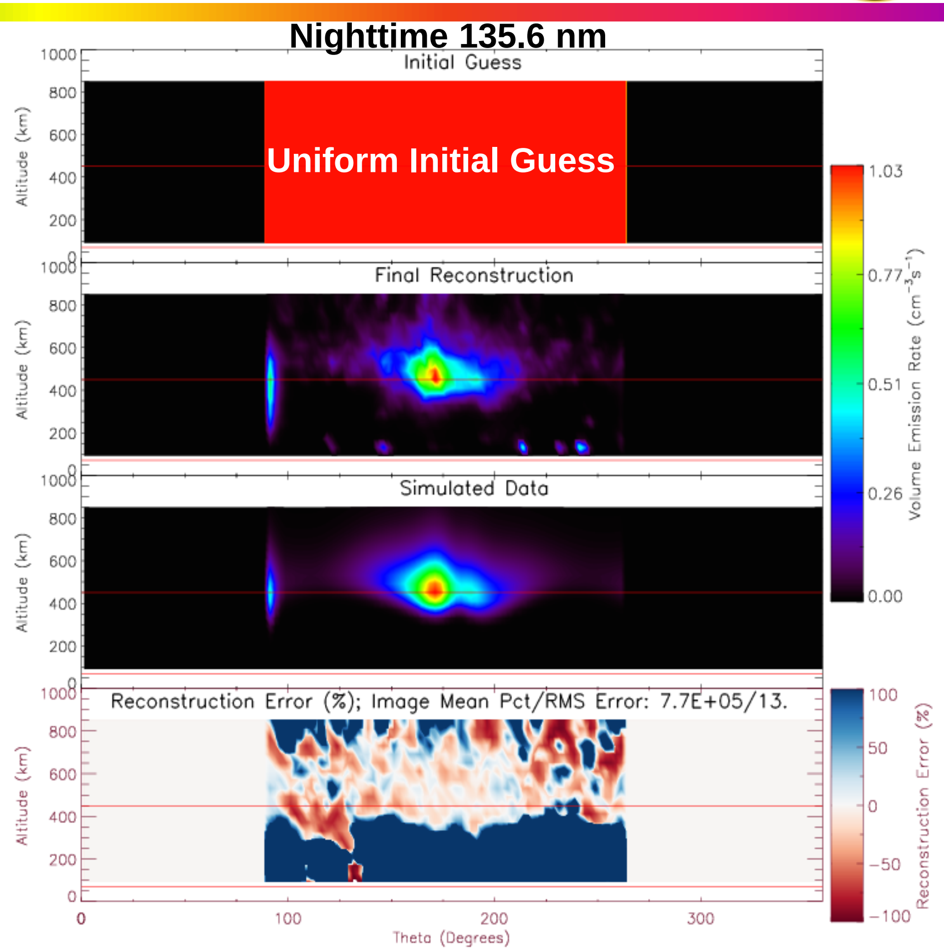
Predicted Reconstruction Fidelity



- Reconstruction accuracy depends upon
  - Dominatied primarily counting statistics of measurement
  - Number of independent line-of-sight measurement
- Regions with low sampling or small Vem have highest uncertainty

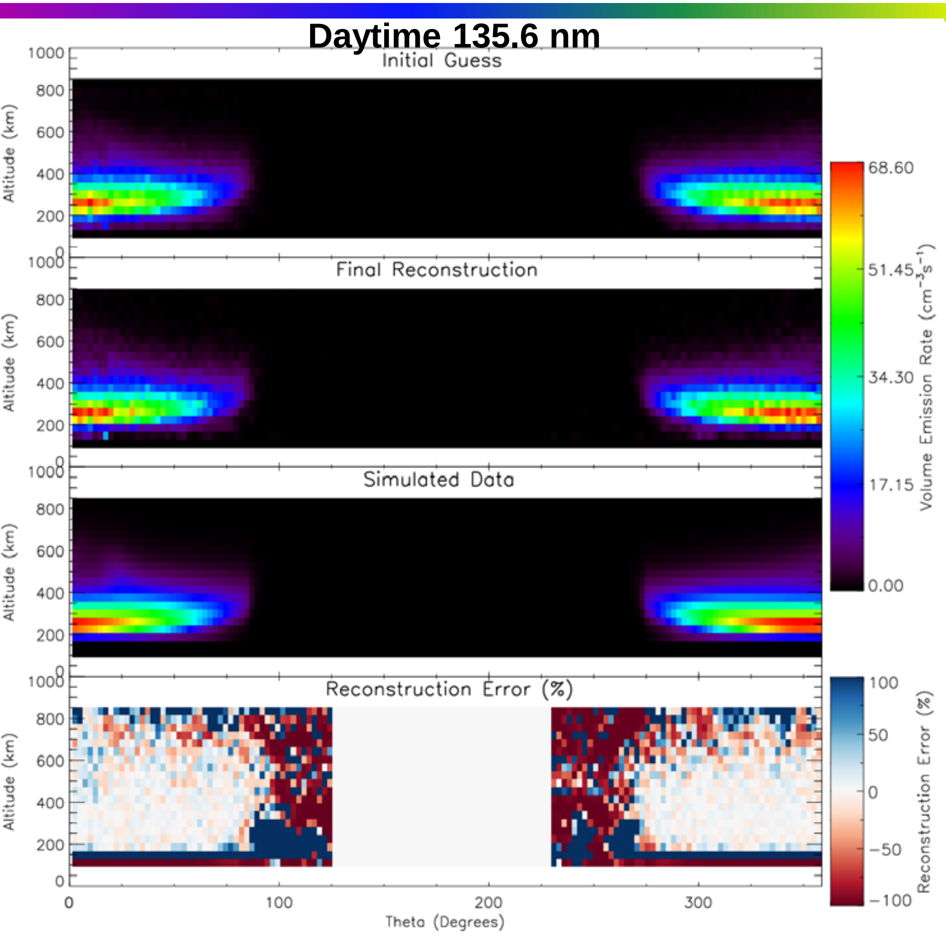
Tomography Simulation: SSULI Only (1/2)

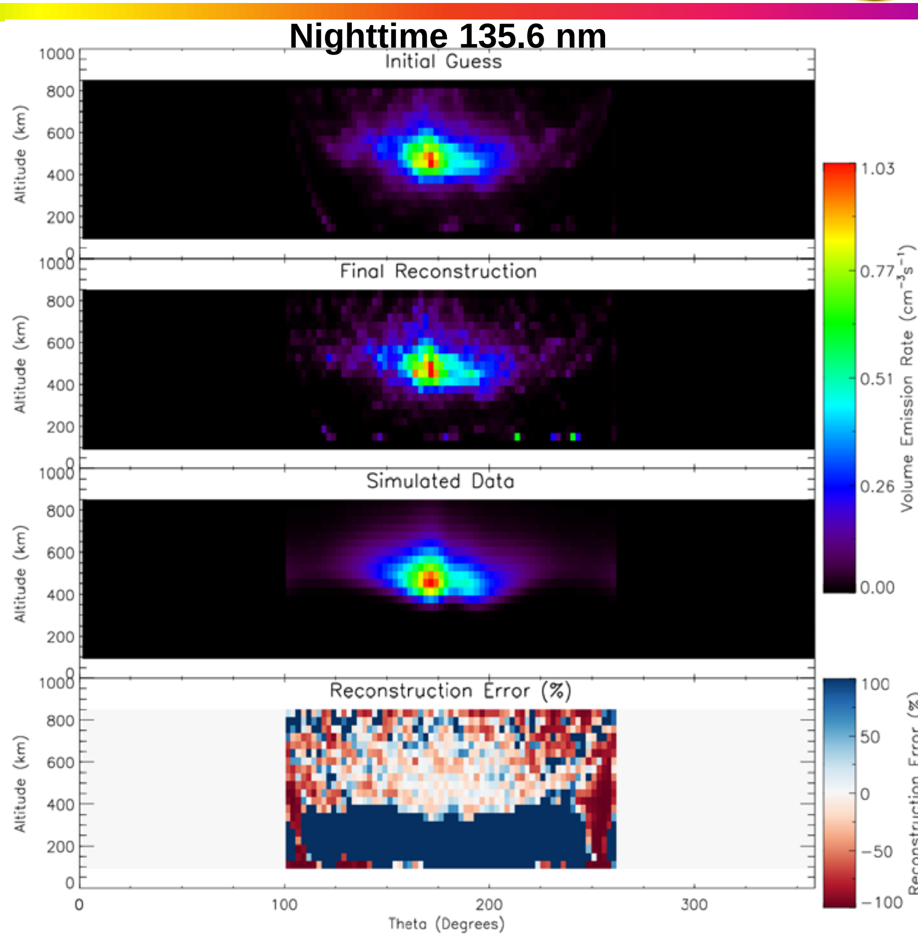




- 5500 SSULI lines-of-sight and modeled 135.6 nm emission
- SSULI samples horizontally and vertically in the orbital plane
  - 100-750 km altitude, 5° cross-track, 5.6° limb scan cadence
  - Good vertical resolution, but limited horizontal resolution

Tomography Simulation: SSULI Only (2/2)

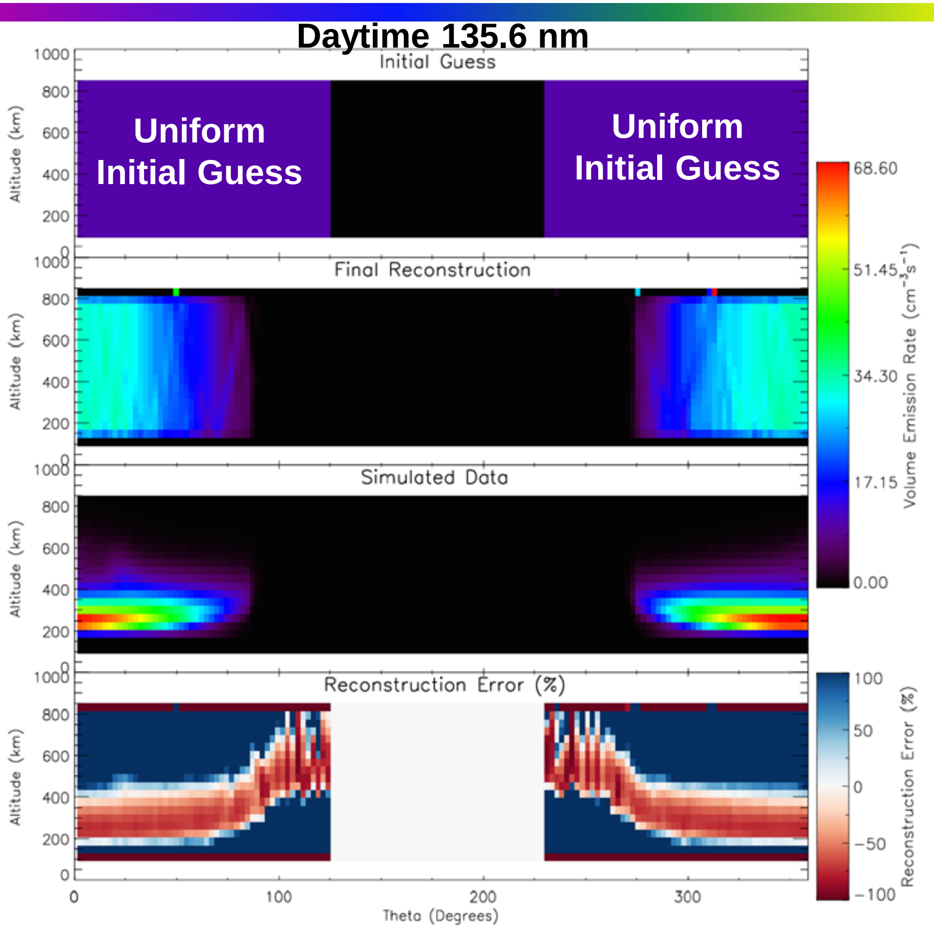


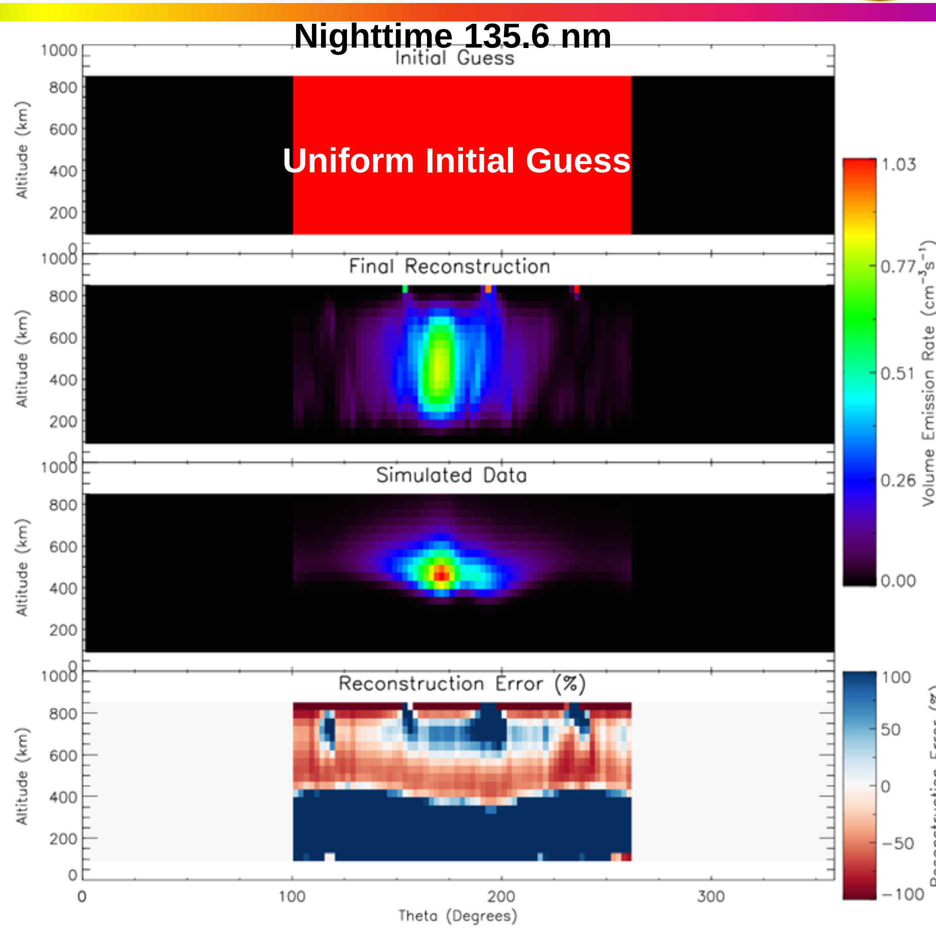


- Dayside at iteration 300
- Showing pixelization of Vem

- Nightside at iteration 10
- Showing pixelization of Vem

Tomography Simulation: SSUSI Only



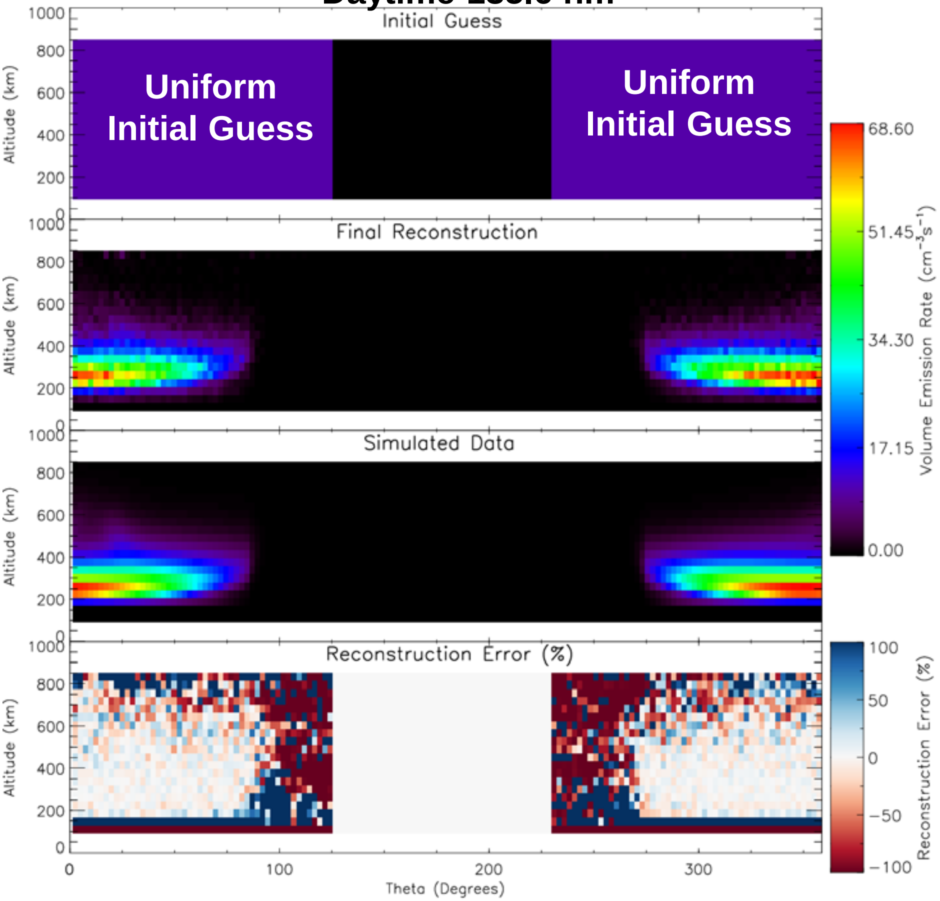


- Dayside at iteration 200
- Showing pixelization of Vem

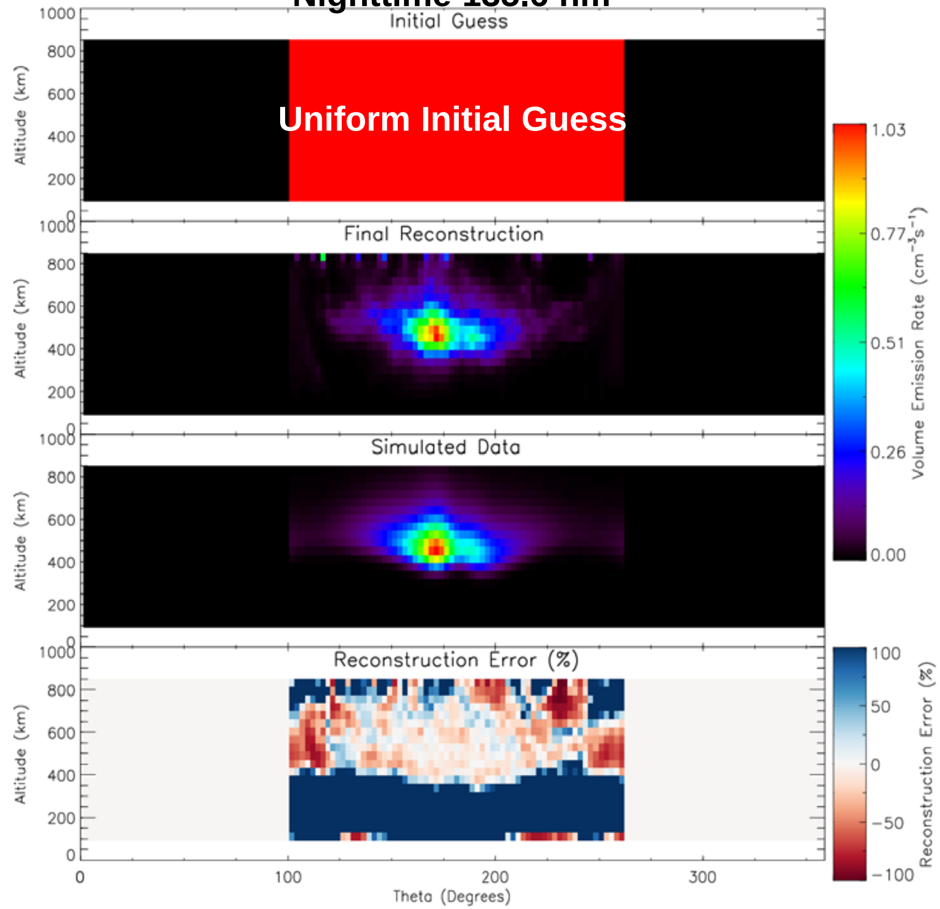
- Nightside at iteration 500
- Showing pixelization of Vem

Tomography Simulation: SSULI+SSUSI (1/2)

Daytime 135.6 nm

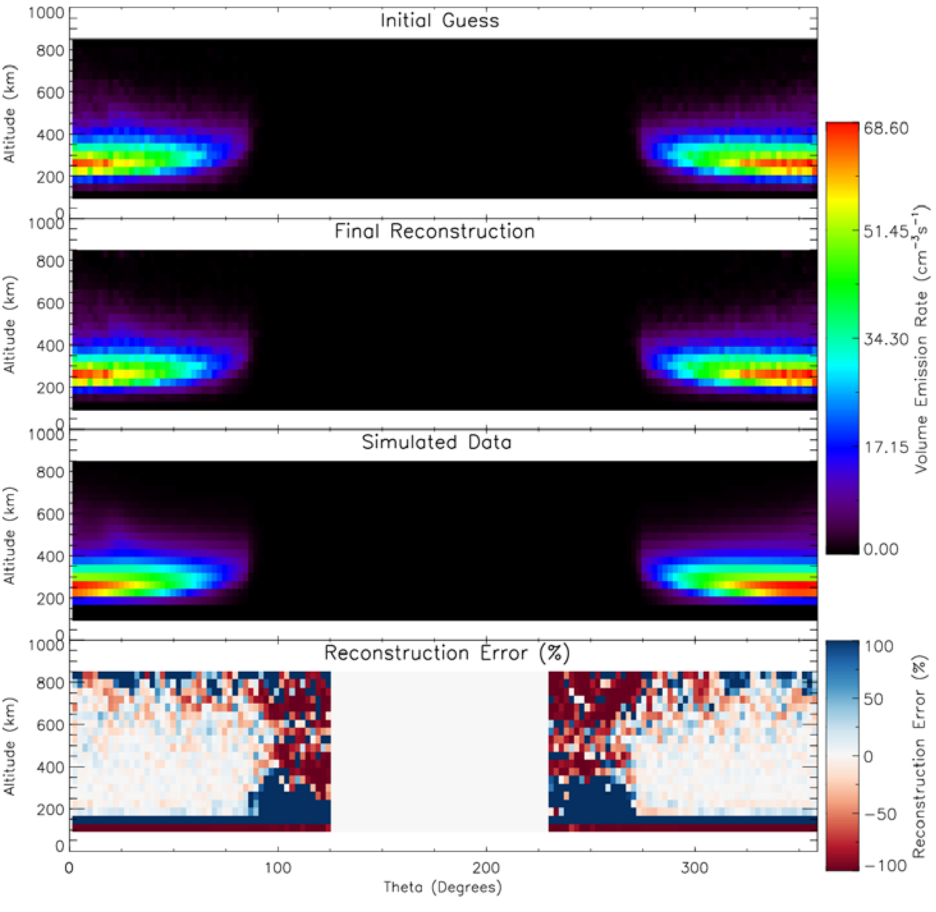


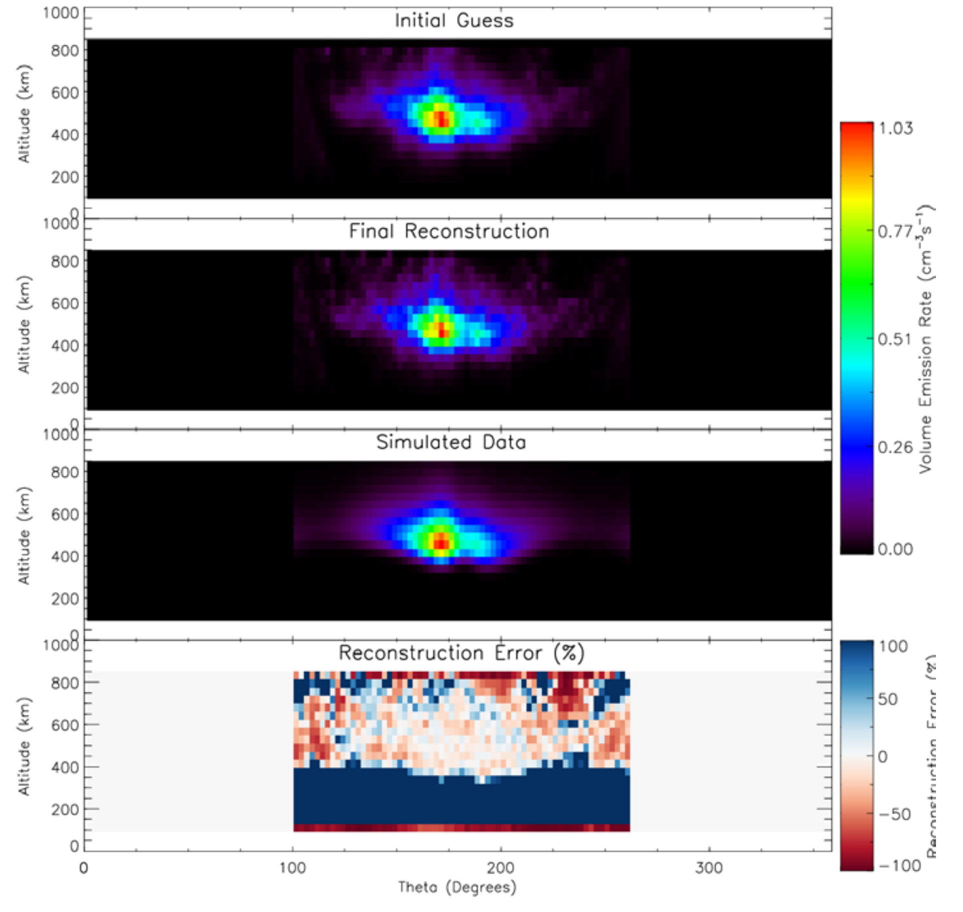
Nighttime 135.6 nm



- ~10000 lines-of-sight and modeled 135.6 nm emission
- Comparable signal-to-noise of two sensors

Tomography Simulation: SSULI+SSUSI (2/2)



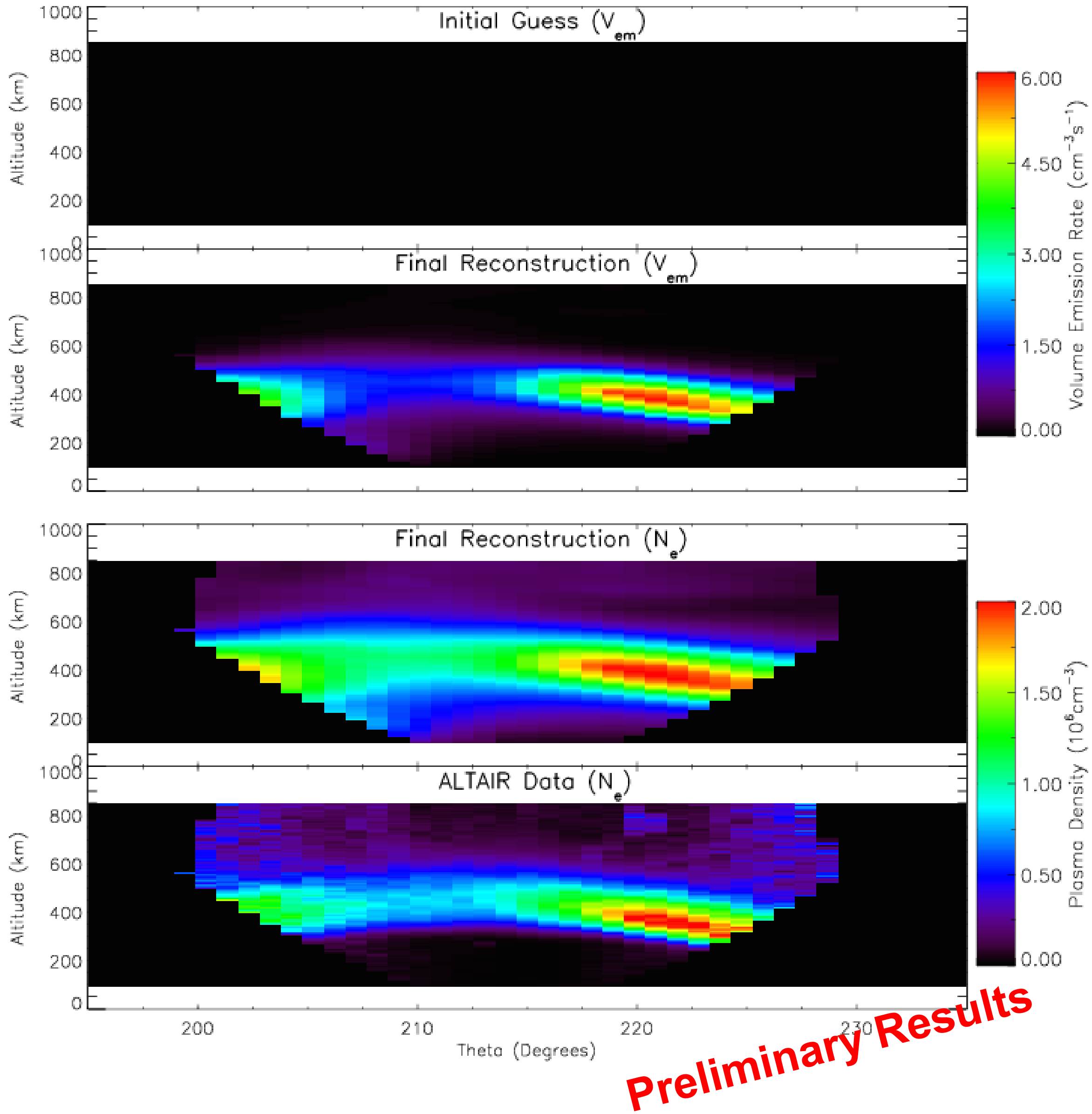


- Dayside at iteration 300
- Showing pixelization of Vem

- Nightside at iteration 10
- Showing pixelization of Vem

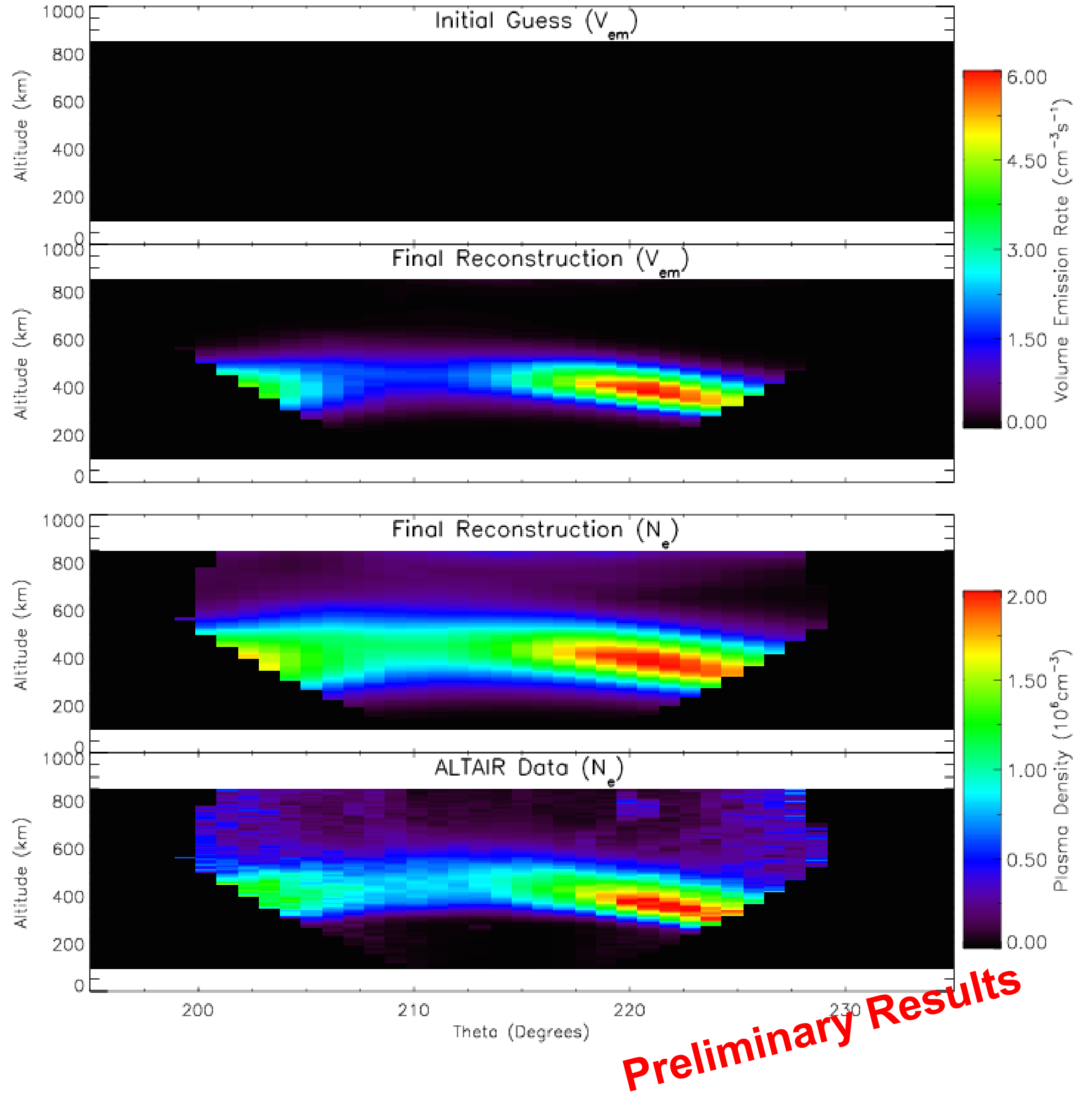
Tomography: SSULI+SSUSI Nighttime Data

- SSULI & ALTAIR ISR data from DMSP F18 Cal-Val
  - April 6, 2010
  - Uniform initial guess
- Volume emission rate reconstruction
  - Restricted to nighttime region over ALTAIR
  - 50 iterations
- Converted to electron density
  - Assumed all Vem attributed to O^{+}+e recombination
  - Expect slight overestimate of Ne due to $O^{+}+O^{-}$
- ALTAIR electron density
  - Provided by Groves, 2010



Tomography: SSULI+SSUSI Nighttime Data

- SSULI, SSUSI & ALTAIR ISR data from DMSP F18 Cal-Val
  - Nominal sensitivites: no cross-calibration scaling
  - Uniform initial guess
- Volume emission rate reconstruction
  - Restricted to nighttime region over ALTAIR
  - 200 iterations
- Converted to electron density
  - Assumed all Vem attributed to O^{+}+e recombination
  - Expect slight overestimate of Ne due to $O^{+}+O^{-}$
- ALTAIR electron density

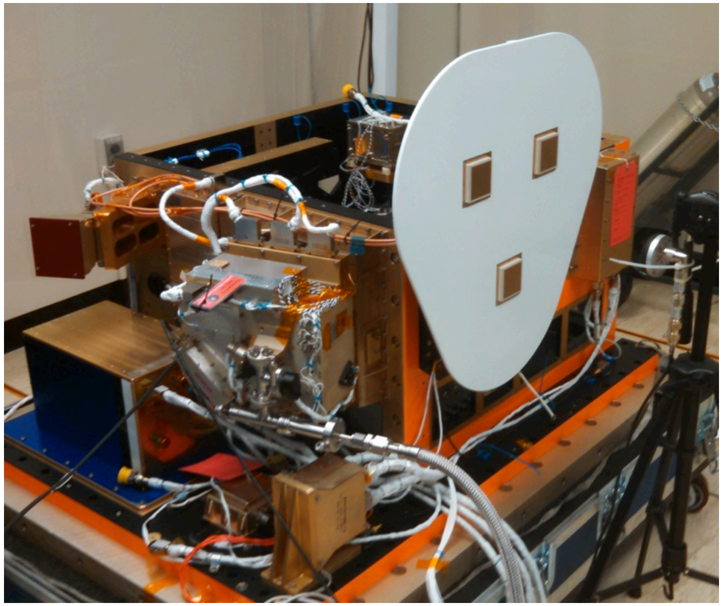


UV Tomography Summary

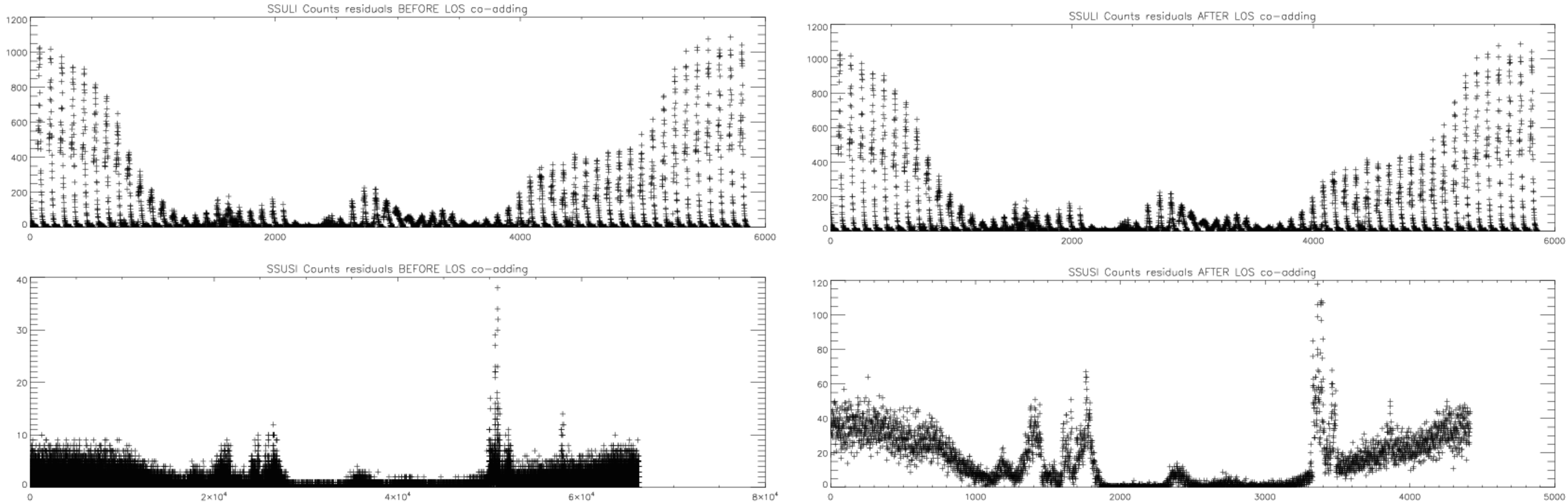
- Key principles:
  - We have developed FUV space-based volume emission rate tomography, irrespective of excitation source
  - Strongly data-centric, very few assumptions
  - Compatible with photon count data (Poisson statistics)
- UV sensors can by design optimize viewing geometry for tomography applications, e.g. SSULI/SSUSI, LITES/GROUP-C
- SSULI and SSUSI together improve signal-to-noise of reconstruction and compensates intrinsic limitations of each sensor
- The Richardson-Lucy reconstruction method is intrinsically positive-definite, compatible with Poisson statistics, and insensitive to initial guess
- Extinction effects must be considered in the UV for accurate reconstructions
- Full-orbit tomography can provide continuous monochromatic images of dayside, nightside, and aurora (e.g. O 135.6 nm, N_2 LBH) corrected for viewing geometry effects

Continuing Work

- Additional SSULI-SSUSI data reconstructions from DMSP F18, F19
- Collaborating with SSUSI team to optimize usage of SSUSI data
- Evaluating tomographic retrievals in vicinity of auroras
- Accounting for non-Poisson uncertainties, such as
  - Pointing uncertainty
  - Within cell non-uniformity
  - O2 extinction
  - Monte Carlo error modeling
- Optimized reconstruction grids (possibly non-uniform) to balance resolution, S/N, and computation time
- STP-H5 GROUP-C & LITES Experiments
  - UV Tomography + GPS occultation and scintillation
  - International Space Station
  - Jan 2016 Launch



Co-adding Lines of Sight



Before Coadding LOS **After Coadding LOS**

- **SSULI and SSUSI have different sensitivities, dwell times, and target brightness**
- **We improve counting statistics by coadding data lines-of-sight**
  - **Intrinsic individual sensor resolutions are higher than reconstruction pixel grid**
  - **Does not affect reconstructionaccuracy**
  - **Reduces computation time**

SSULI Limb Data

- SSULI Limb Scan Data
  - Single Orbit 6/21/2012
    - 65 Vertical Profiles each orbit
  - Tangent Point Locations
    - ~3000 km ahead of DMSP spacecraft