ESTIMATING THERMOSPHERIC DENSITY AND TEMPERATURE FROM COMBINED OPTICAL AND RADAR MEASUREMENTS

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- altitude range: 400-1000 km
- composition: H, He, O ⟶ simplified chemistry
- motivation: effect on satellites, climatological model validation, space weather studies, detection of long term climate change
- routine estimation demands a ground-based approach

THERMOSPHERIC PARAMETER ESTIMATION: OVERVIEW

PARAMETRIC APPROACH: simple, model-independent

- O+ energy balance
- O+ momentum balance

historically used to constrain theoretical estimates of Q, not to derive [O]

FREE PARAMETER: $[\mathrm{O}] \times Q_{\mathrm{O-O+}}$

IN TERMS OF BURNSIDE FACTOR: $[\mathrm{O}] \times Q'_{\mathrm{O-O+}} \times F$

model ($[\mathrm{O}]$) — theory ($Q'_{\mathrm{O-O+}}$)

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- **H+ continuity balance → [O] and Tn**

INVERSE-THEORETIC APPROACH: complicated, model-dep.

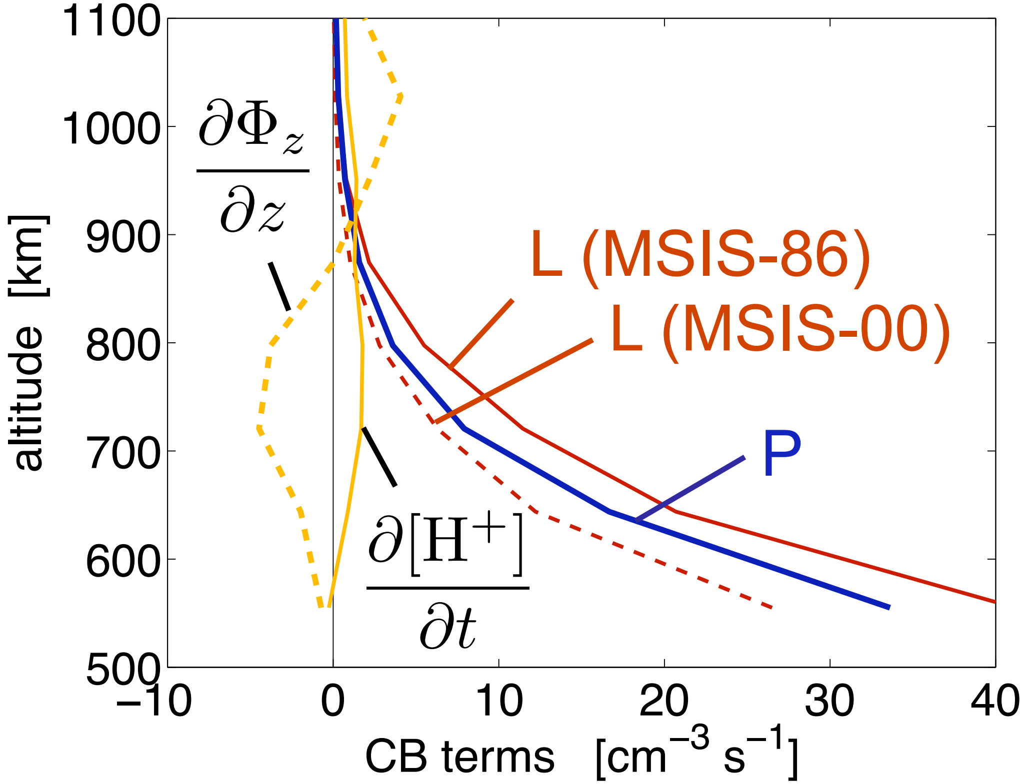
- airglow brightness inversion: **H I 656.3 nm → [H]**; **O I 844.6 nm → [O]**
- emission line profile inversion: **He I 1083 nm → Tn**

H+ CONTINUITY BALANCE

$$\frac{\partial[\mathrm{H}^+]}{\partial t} + \nabla \cdot \Phi = k_f(\mathrm{T_n})[\mathrm{H}][\mathrm{O}^+] + \cdots - k_r(\mathrm{T_i})[\mathrm{H}^+][\mathrm{O}]$$

Production

Loss



October 8-9, 1988
midnight

Waldrop et al., JGR, in press

$[O]_{CB}$ ESTIMATION

$$\frac{\partial [\mathrm{H}^+]}{\partial t} + \nabla \cdot \Phi = k_f(\mathrm{T_n})[\mathrm{H}][\mathrm{O}^+] + \cdots$$

$$k_r(\mathrm{T_i})[\mathrm{H}^+][\mathrm{O}]$$

SOLVE FOR [O]...

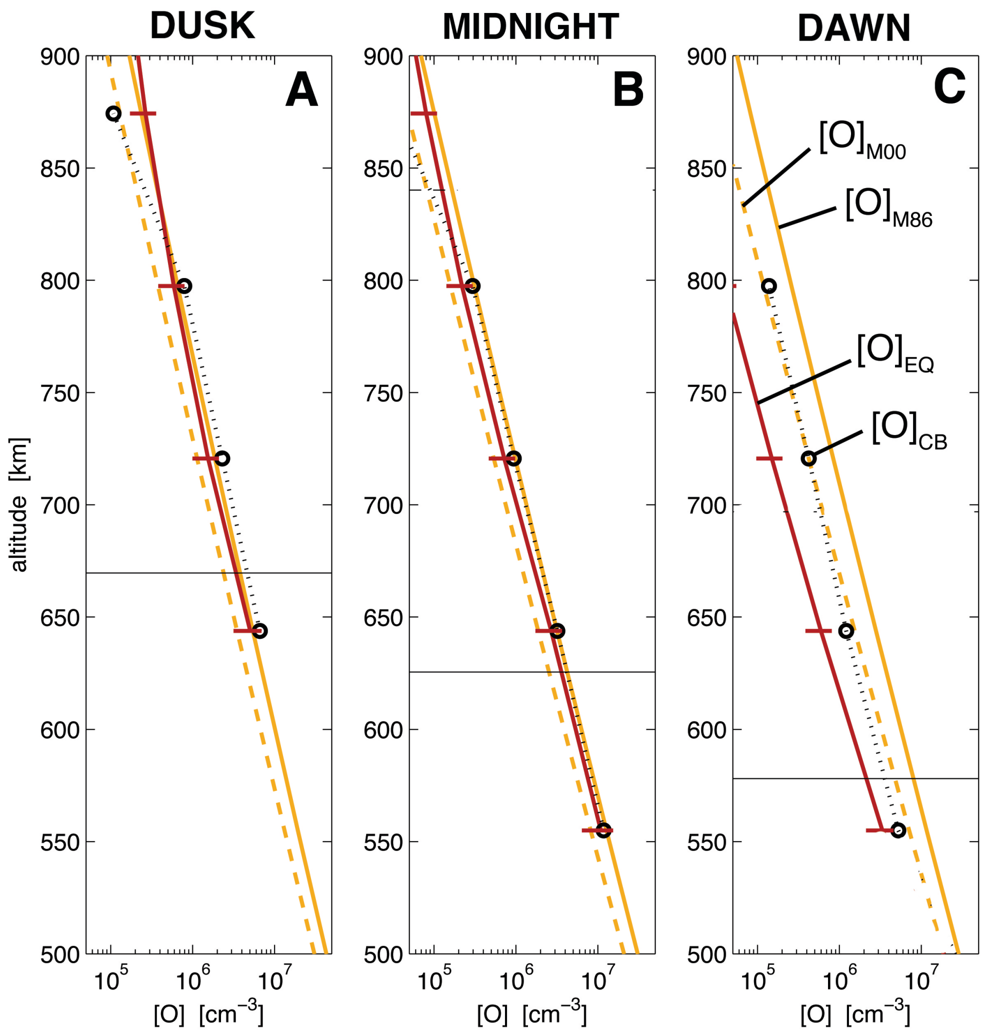
$$[\mathrm{O}] = \underbrace{\frac{k_f(\mathrm{T_n})[\mathrm{H}][\mathrm{O}^+]}{k_r(\mathrm{T_i})[\mathrm{H}^+]}}_{[\mathrm{O}]_{\mathrm{EQ}}} - \underbrace{\frac{\partial[\mathrm{H}^+]/\partial t + \nabla \cdot \Phi}{k_r(\mathrm{T_i})[\mathrm{H}^+]}}_{[\mathrm{O}]_{\mathrm{NEQ}}}$$

$[O]_{CB}$ ESTIMATION

October 8-9, 1988

recent work:

- CB technique appears valid at night between 500-800 km



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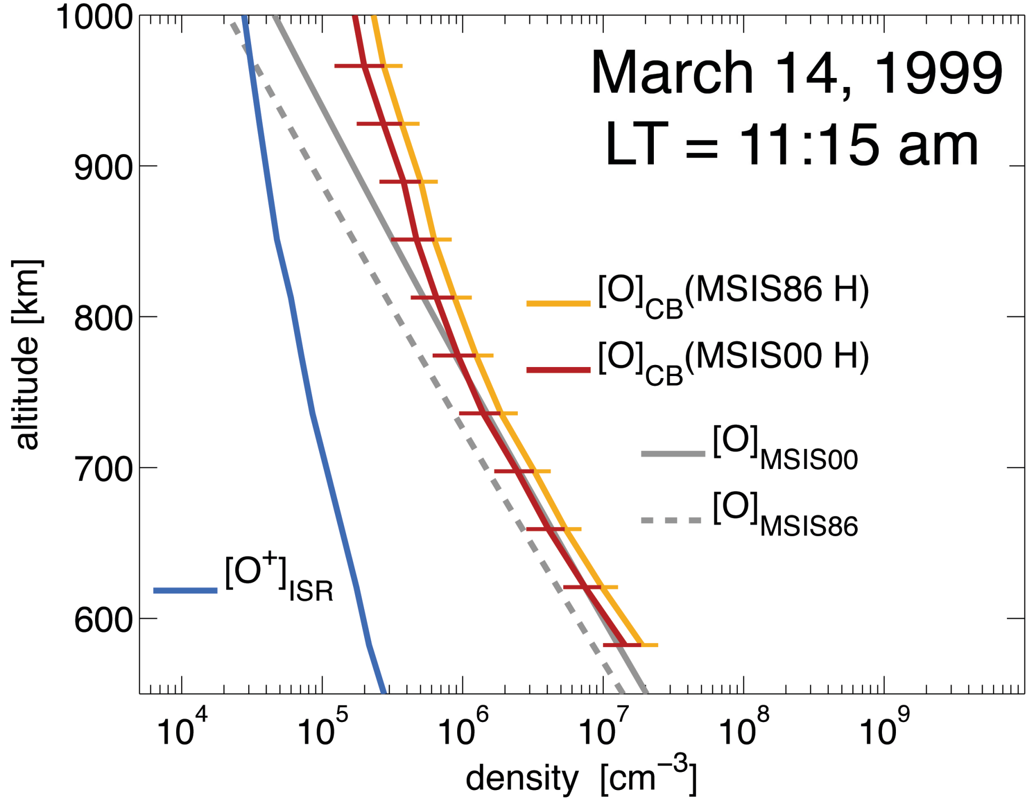
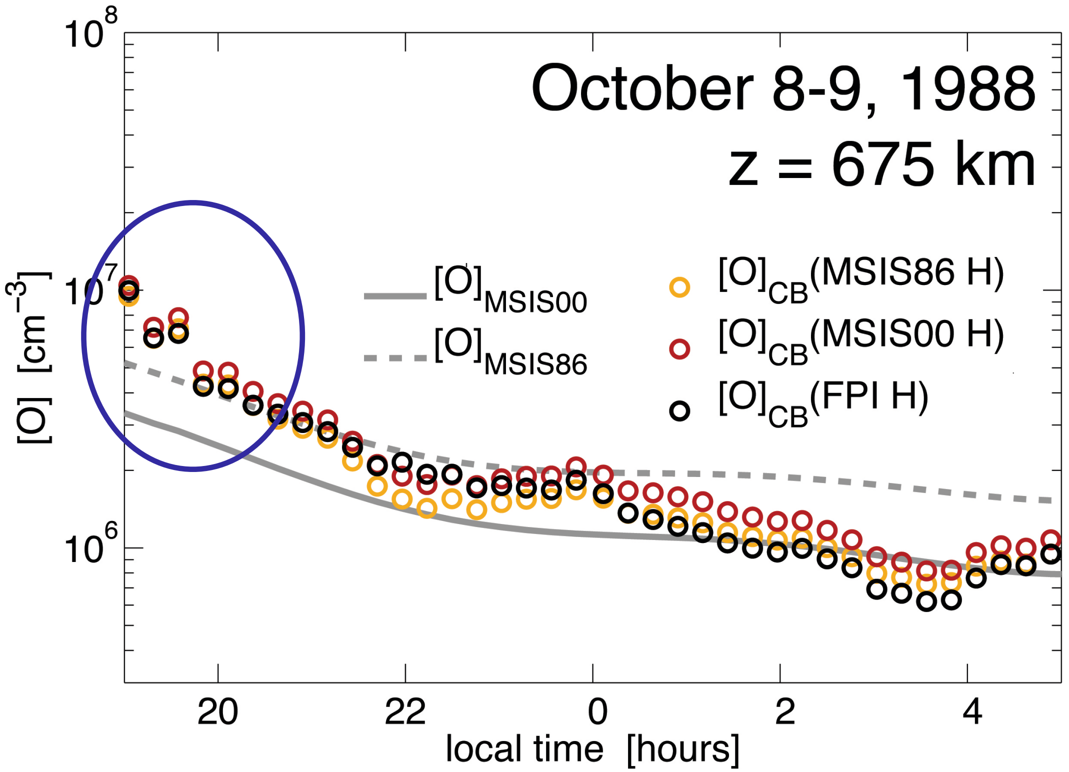
- daytime estimation also may be possible using model specification of [H]



$[O]_{CB}$ ESTIMATION

recent work:

- CB technique appears valid at night between 500-800 km
- daytime estimation also may be possible using model specification of [H]
- unphysical enhancement near sunset?



Waldrop et al., JGR, in press

future work:

- incorporate improved line-of-sight ion velocity estimates via spectral fitting of distinct O+ and H+ velocities (e.g., Vickrey et al., 1976)

- apply CB technique to new dual-beam radar data in order to incorporate horizontal flux divergence:

SINGLE BEAM ALONG ZENITH:

$$\nabla \cdot \mathbf{\Phi} = \nabla \cdot (n\mathbf{V}) \approx \frac{\partial (nV_z)}{\partial z} = n\frac{\partial V_z}{\partial z} + V_z\frac{\partial n}{\partial z}$$

DUAL BEAMS ALIGNED ZONALLY:

$$\nabla \cdot \mathbf{\Phi} \approx n\frac{\partial V_z}{\partial z} + V_z\frac{\partial n}{\partial z} + V_x\frac{\partial n}{\partial x}$$

$[O]_{CB}$ ESTIMATION

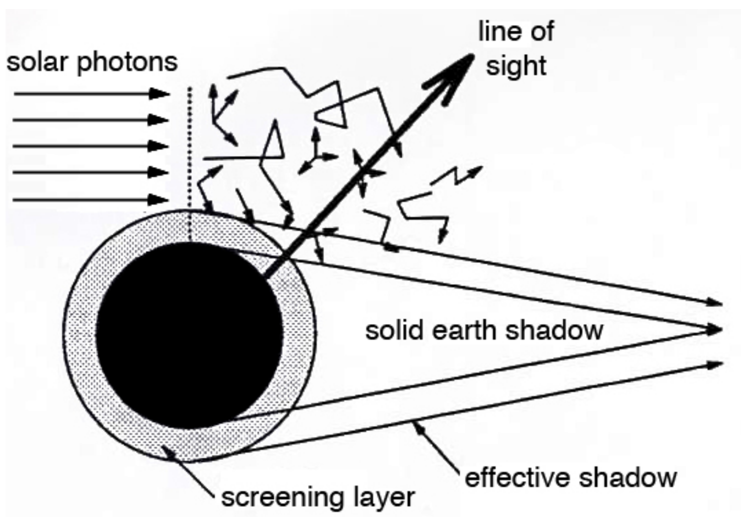
future work:

- improve line-of-sight ion velocity estimation via spectral fitting of distinct O+ and H+ velocities (e.g., Vickrey et al., 1976)
- apply CB technique to new dual-beam radar data in order to incorporate horizontal flux divergence
- apply CB technique to Arecibo MRACF data in order to extend altitude range of derived solutions down to F-region peak
- improve [H] estimation
- **after the above refinements.....incorporate $[O]_{CB}$ estimates into EB and MB equations in order to derive Burnside factor F as an unambiguous constraint on Q**

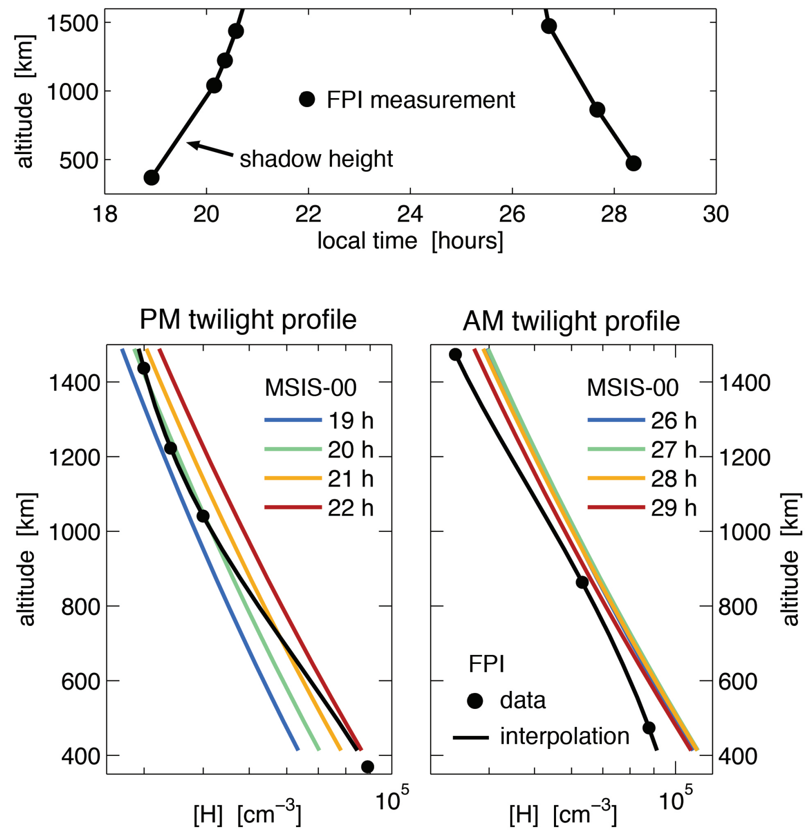
$[H]_{6563}$ ESTIMATION

early work:

- inverse-theoretic technique developed by Kerr and He



He et al., JGR, 1993



Waldrop et al., JGR, in press

$[H]_{6563}$ ESTIMATION

early work:

- inverse-theoretic technique developed by Kerr and He

recent work:

- installed array detector on Arecibo FPI for improved SNR (time resolution)

factor of ~40 improvement in SNR over former PMT system!

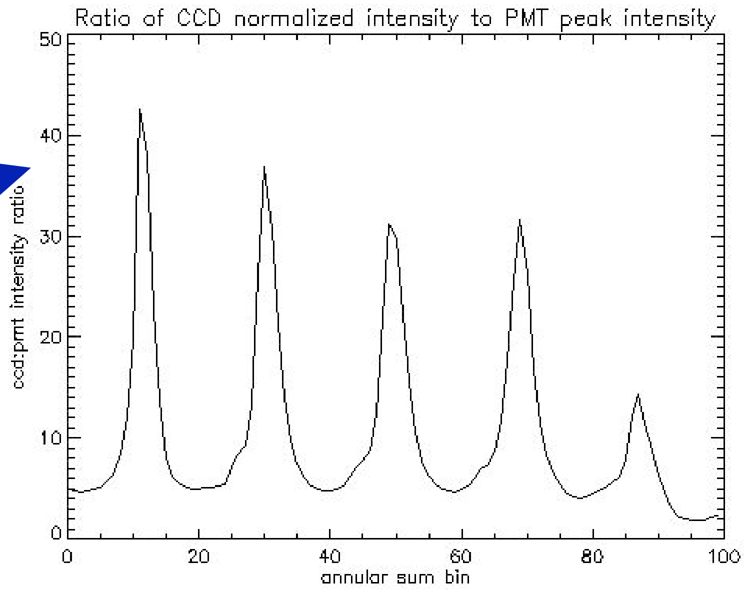


figure courtesy of J. Noto

$[H]_{6563}$ ESTIMATION

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- inverse-theoretic technique developed by Kerr and He

recent work:

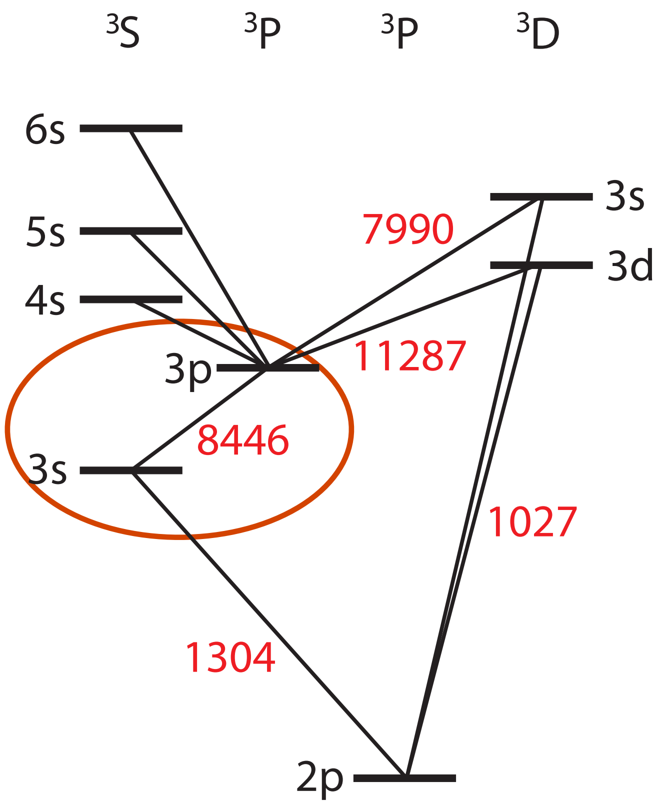
- installed array detector on Arecibo FPI for improved SNR (time resolution)

future work:

- incorporate measured Tn as forward model constraint
- cross-calibrate H alpha brightness with Wisconsin data (Roesler, Mierkowitz, Nossal)

O I 844.6 EMISSION

- faint twilight emission (< 40 R)
- derives from electronic transition >10 eV above ground state
- historically used for auroral studies
- simple excitation chemistry dominated by photoelectron (PE) impact at Arecibo (Lancaster, Kerr)



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- faint twilight emission (< 40 R)
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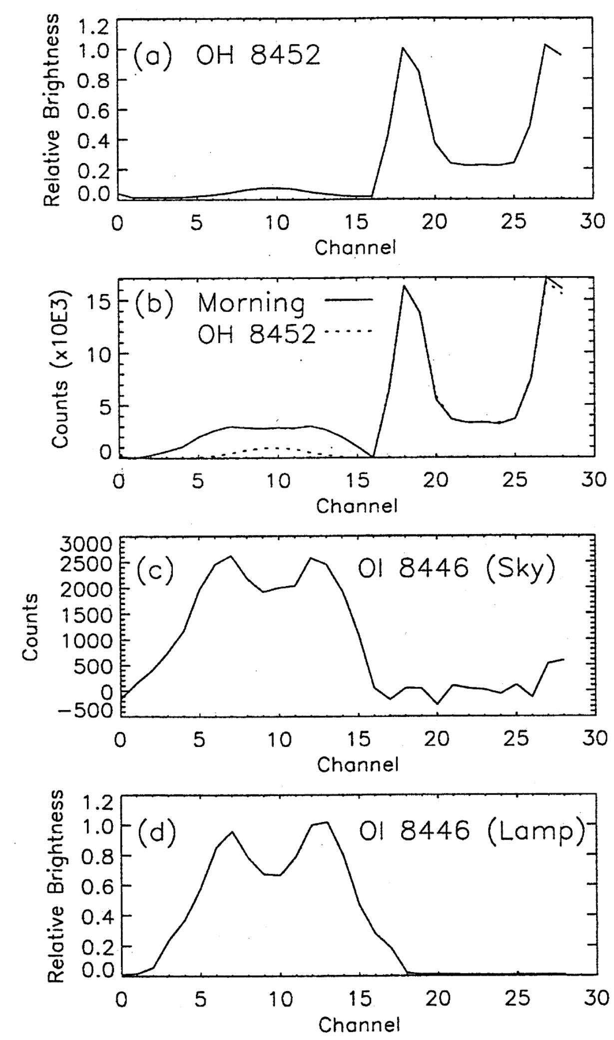
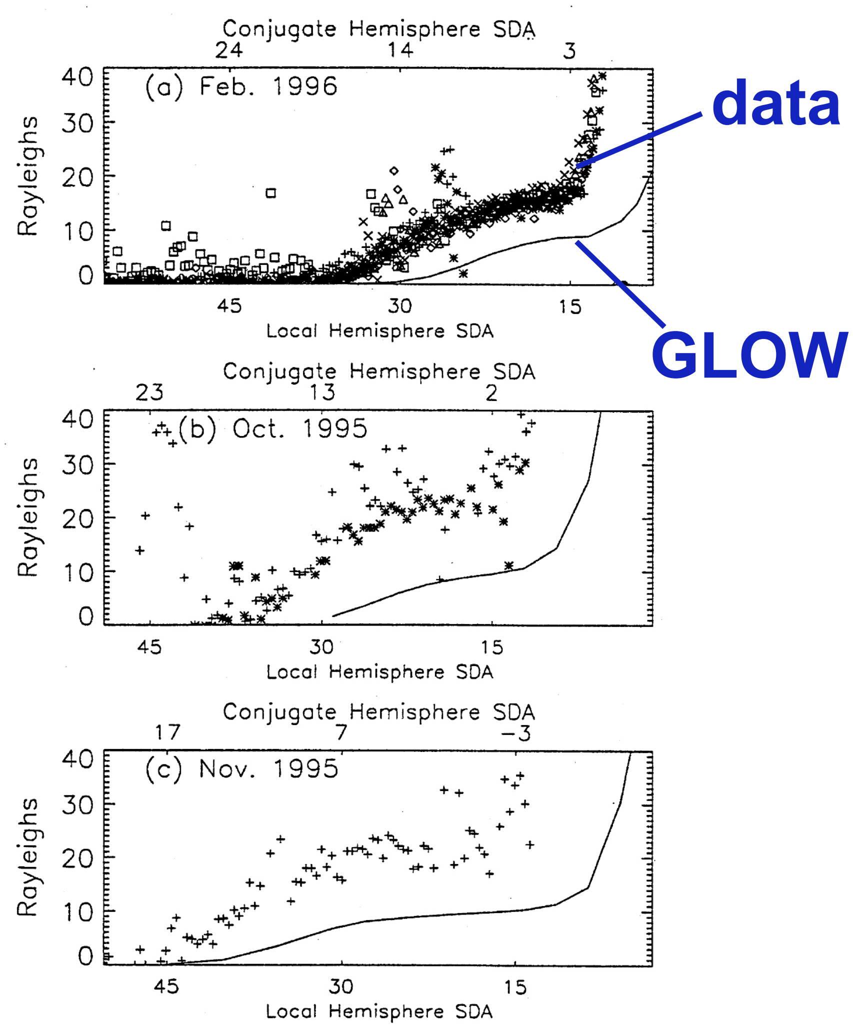
- historically used for auroral studies
- simple excitation chemistry dominated by photoelectron (PE) impact at Arecibo (Lancaster, Kerr)
- emission brightness is measured routinely at Arecibo using a tilting filter photometer:
- PE model inversion of O I 844.6 nm emission brightness is an attractive **candidate means for [O] estimation**



Lancaster et al., JGR, Mar. 2000

early work:

- GLOW consistently underestimates 844.6 nm brightness
- timing of PE onset does not agree with data

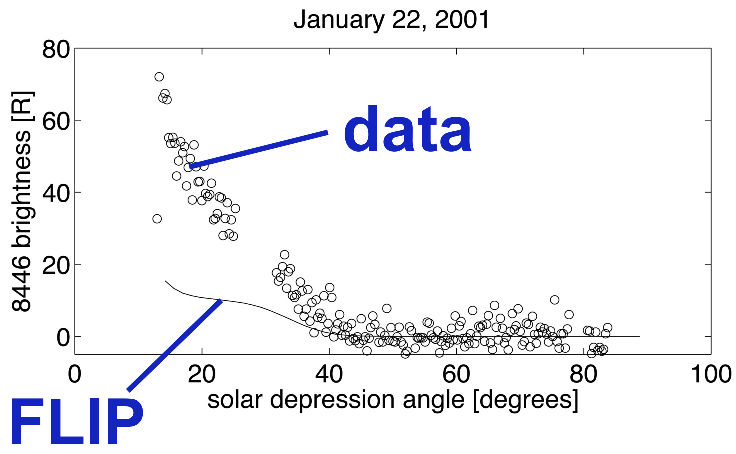


Lancaster et al., JGR, Mar. 2000

$[O]_{8446}$ ESTIMATION

early work:

- GLOW consistently underestimates 844.6 nm brightness
- timing of PE onset does not agree with data

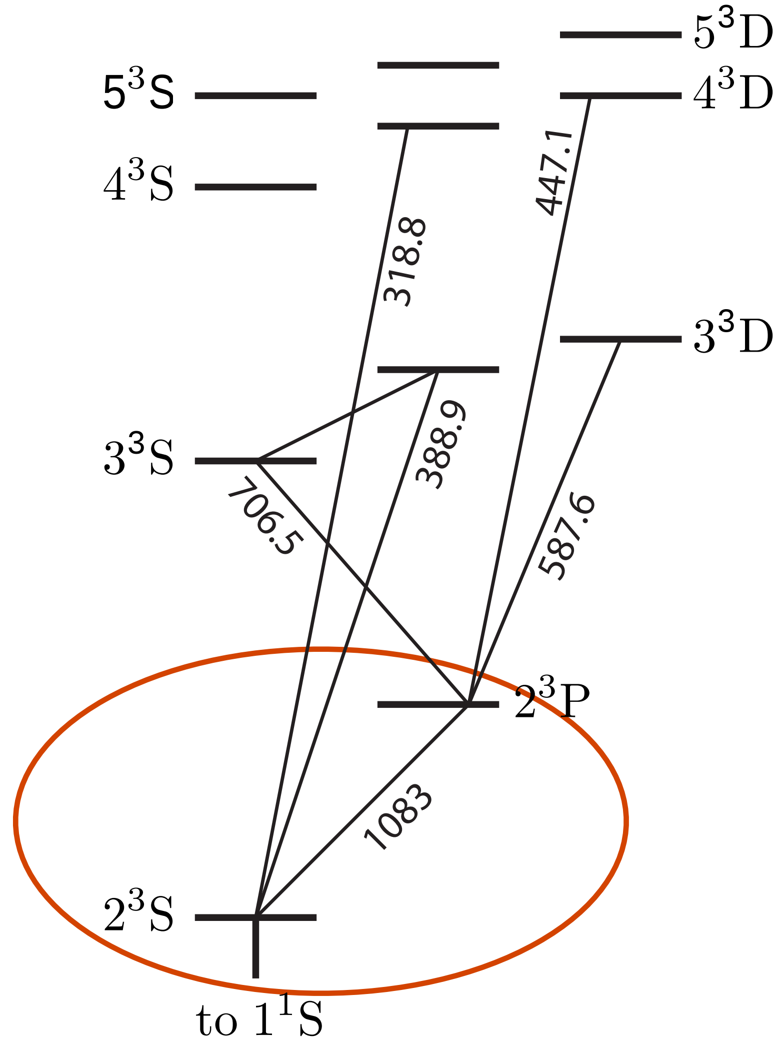


future work:

- FLIP model comparisons (P. Richards): climatological trends
- Other excitation mechanisms, e- sources
- ISR constraints on PE flux *(ideally from conjugate ionosphere)*

He I 1083 nm EMISSION

- metastable He is a minor species (~few atoms/cm^{-3})
- He(2^3S) is formed primarily via PE impact on He(1^1S)
- bright (~1kR) twilight emission at 1083 nm via resonant fluorescence of solar line



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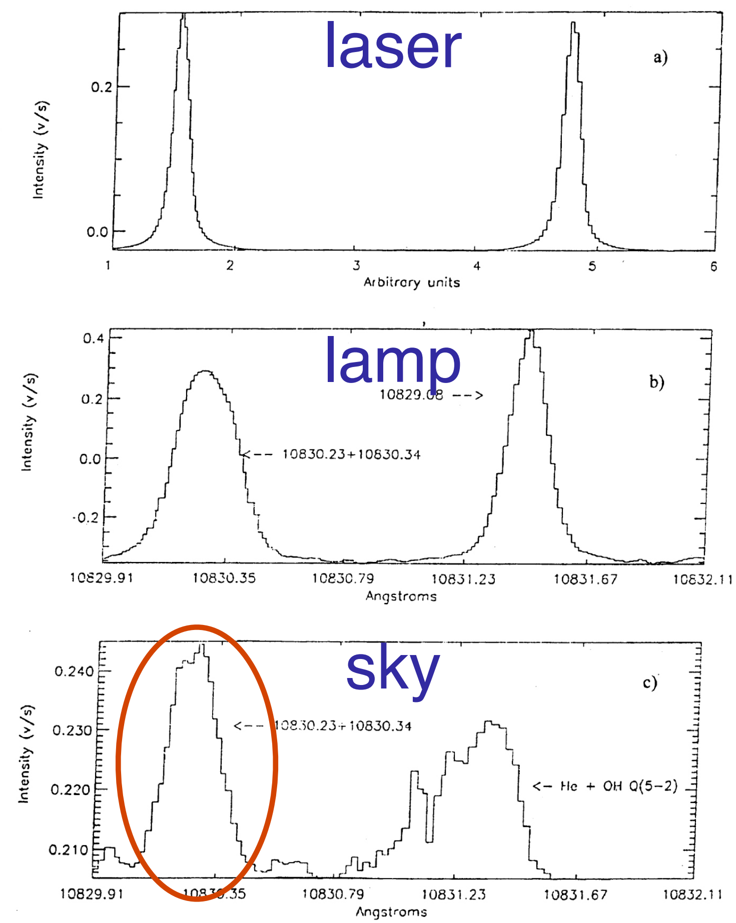
- He(2^3S) is formed primarily via PE impact on He(1^1S)
- bright (~1kR) twilight emission at 1083 nm via resonant fluorescence of solar line
- FPI observations of 1083 nm line profile at Arecibo (Noto, Kerr):
- He I 1083 nm line profile is an attractive **candidate means for temperature and wind estimation** at the exobase (*otherwise inaccessible*)

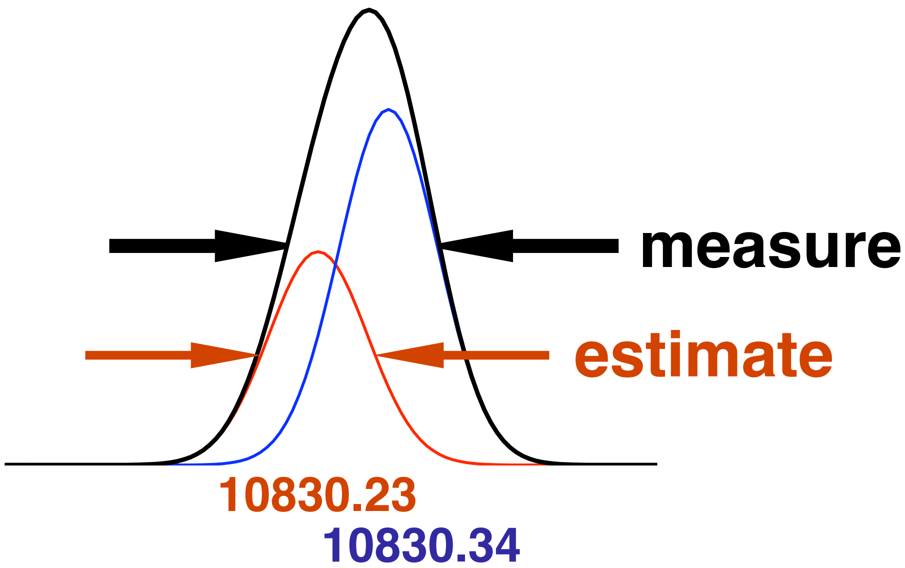


Noto et al., JGR, June 1998

Tn_{1083} ESTIMATION

early work:

- assumed Gaussian shapes for the instrument response function and the doublet source profile in order to derive "effective" neutral temperature



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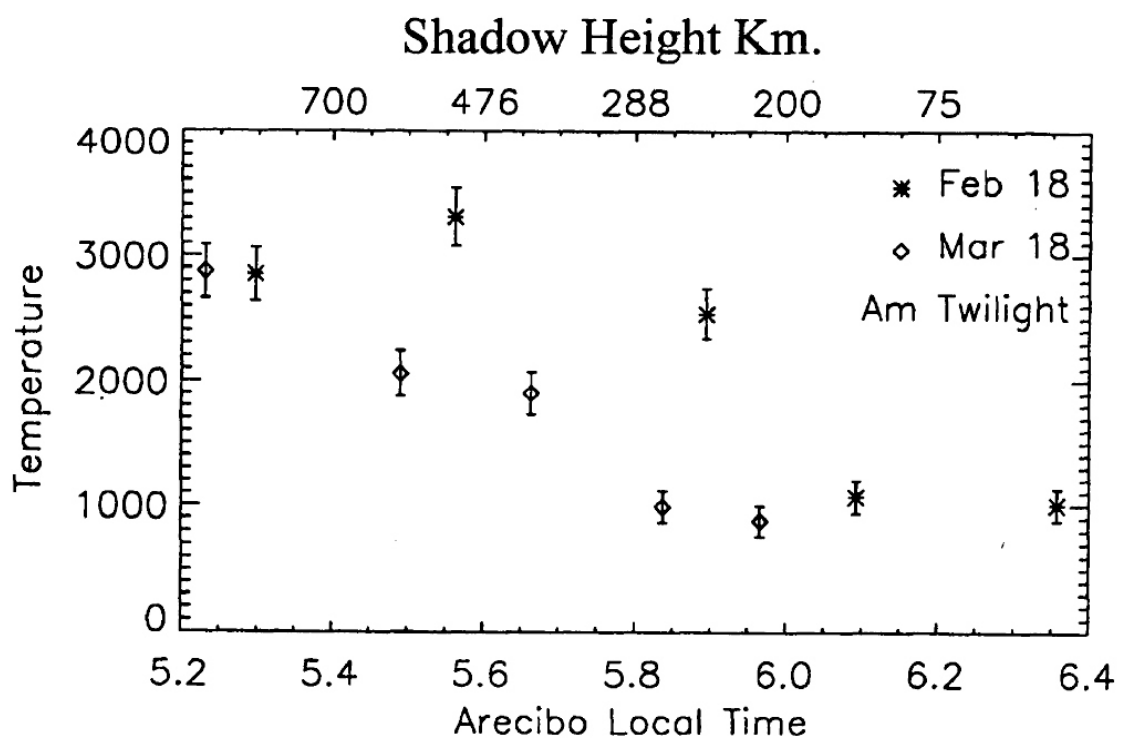
- RESULT: Tn_{1083} increases unphysically with increasing shadow height (Noto, Kerr)



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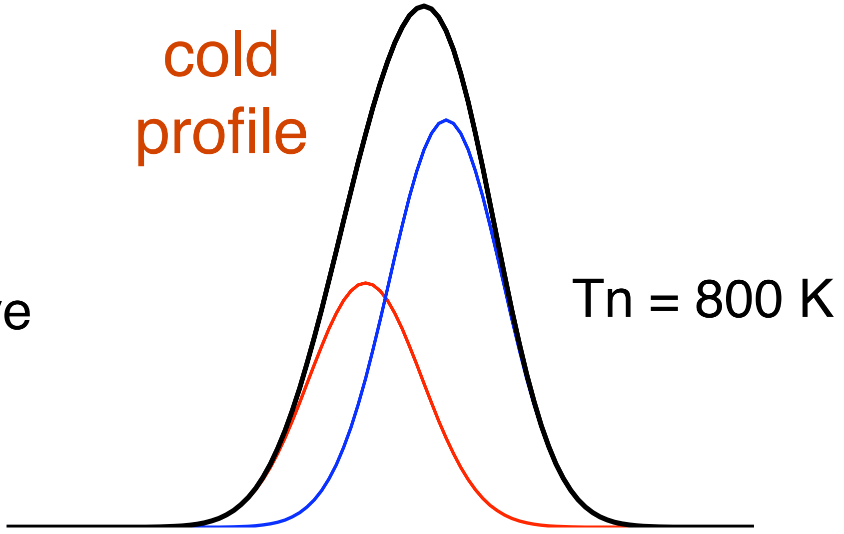
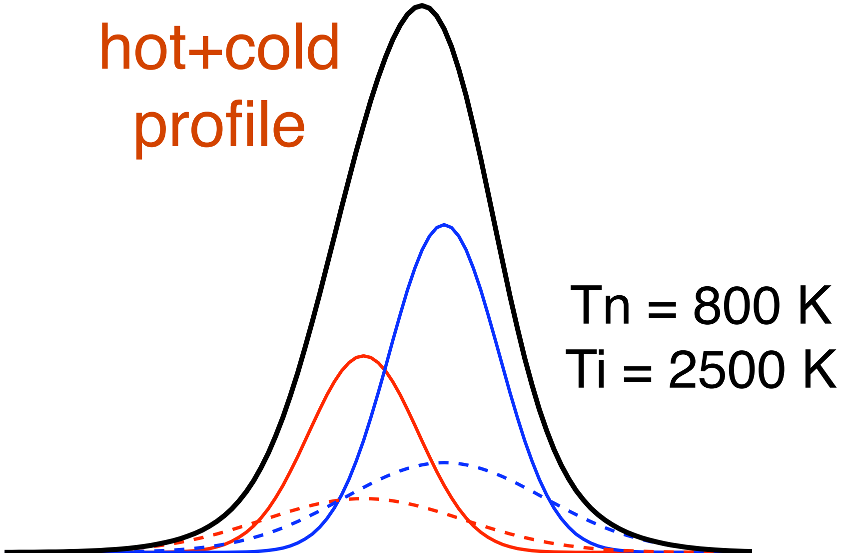
- RESULT: Tn_{1083} increases unphysically with increasing shadow height (Noto, Kerr)

- speculate: **He+ ion recombination is a source of "hot" metastable He**
  - [He+] can be significant
  - Ti > Tn at twilight
  - thermalizing collisions quench metastable He population



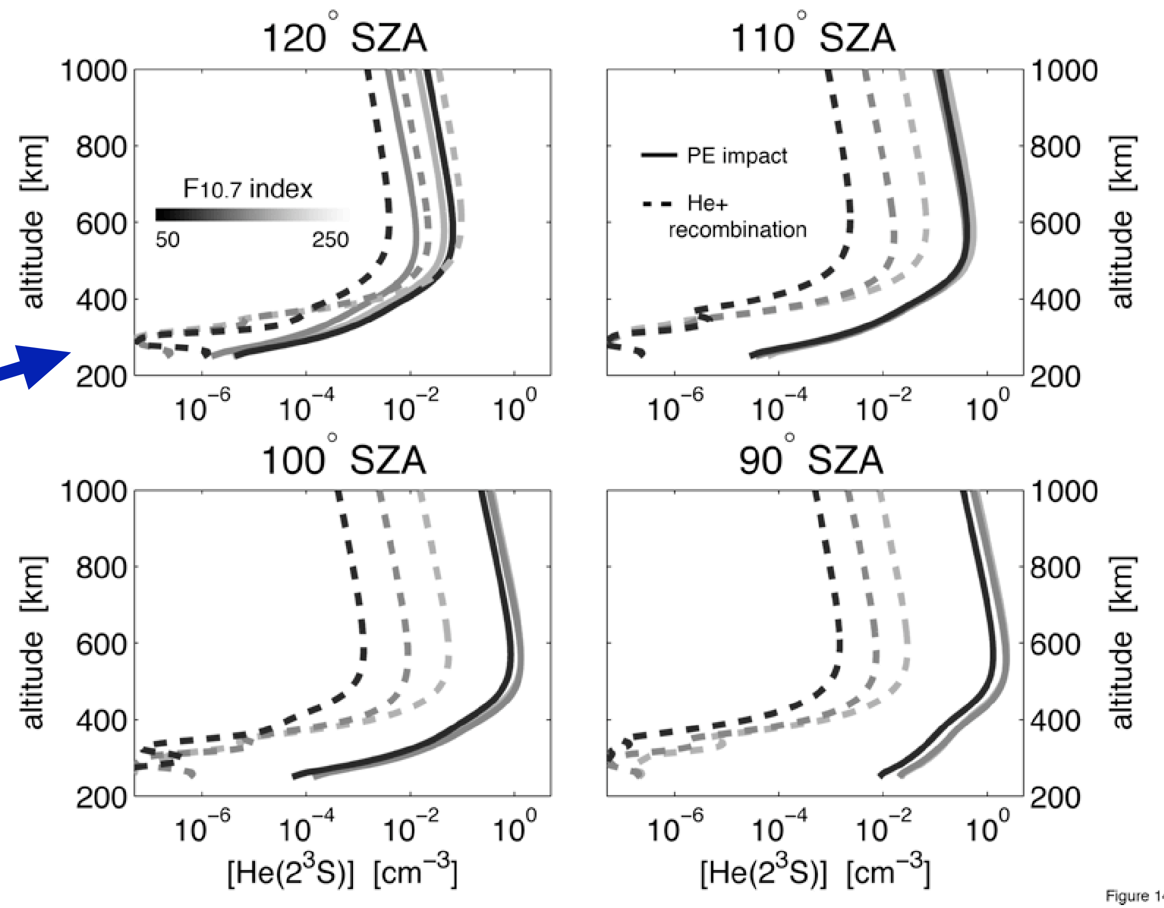


Tn_{1083} ESTIMATION

recent work:

- incorporated He+ recombination souce into model of He(2^3S) production using Arecibo ISR measurements of [He+] and Ti

He+ recombination dominates He(2^3S) production at large shadow heights



Waldrop et al., JGR, 2005

Tn_{1083} ESTIMATION

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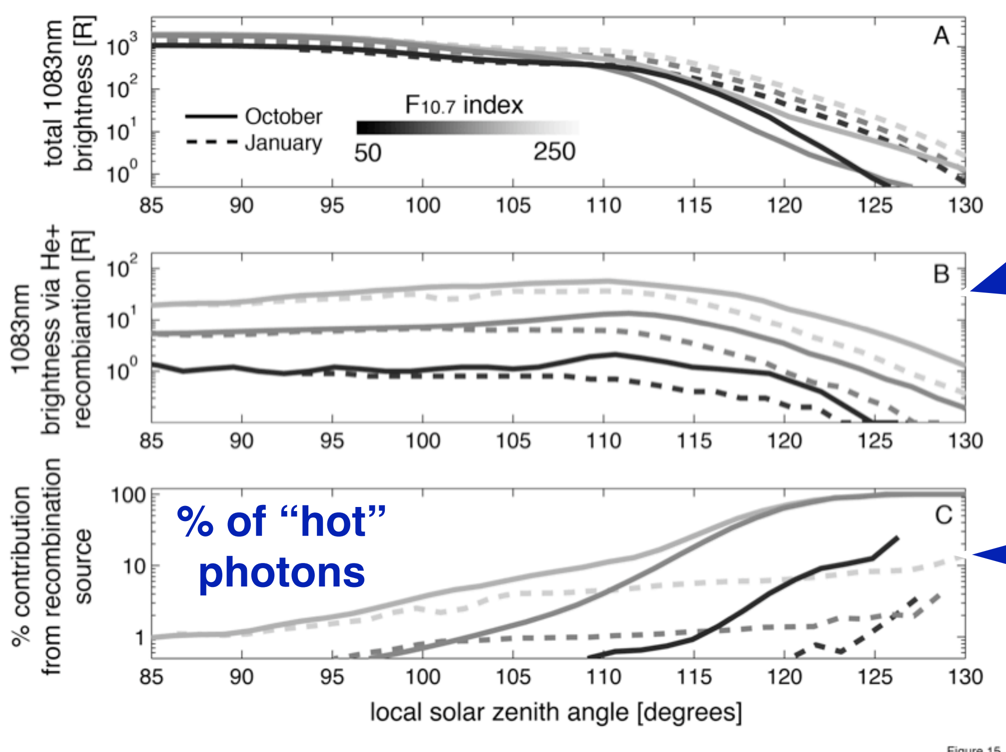
- compiled a climatological description of 1083 nm brightness sources



like [He+], $He(2^3S)$ recombination source is strongest during equinox & solar max

"hot" photons contribute significantly to 1083 nm brightness!

Waldrop et al., JGR, 2005

Tn_{1083} ESTIMATION

recent work:

- incorporated He+ recombination souce into model of He(2^3S) production using Arecibo ISR measurements of [He+] and Ti
- compiled a climatological description of 1083 nm brightness sources
- developed algorithm to deconvolve measured line profile and instrument response function using regularized inversion (Kamalabadi, Reuillon)

future work:

- revisit Tn_{1083} estimation from existing 1083 nm data
- new IR array detector at Arecibo (Noto) will provide increased SNR & resolution of 1083 nm line profile -- underway Fall 2006

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