The Overlooked Potential of O8446 Remote Sensing

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Introduction

- O emission at 844.6 nm (O8446) results from a transition from the triplet Rydberg $3p^3P$ state, at a relatively high excitation energy of 11 eV, to the $3s^3S$ state

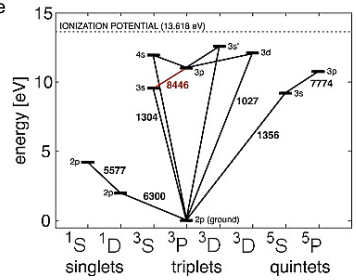

Fig. (1) Partial Grotrian diagram of neutral atomic oxygen. The 844.6 nm emission transition is shown in red. Taken from [Waldrop et. al 2008]

- O8446 is excited almost exclusively by energetic electron impact on ground-state $O(^3P)$ atoms, where the rate of excitation, P_{8446}, is given as a function of altitude z by:

$$P_{8446} = [\mathrm{O}(^3\mathrm{P})](z) \int_E \Phi(z,E)\sigma_{8446}(E)\,dE$$

in terms of the density [O], energy (E) dependent photoelectron (PE) flux, Φ, and cross section, σ_{8446}, for excitation to the $3p^3P$ state due to PE impact

- O8446 emission has long been used in the auroral zone to infer the energy spectrum of precipitating electrons, but mid-latitude data is sparse.
- In the mid-latitude thermosphere, O8446 emission can be excited by both locally-created PE and those originating in the conjugate magnetic hemisphere that are transported along geomagnetic field lines.
- O8446 emission observations are optimal during winter intervals when the local solar zenith angle (SZA) exceeds 90° and the conjugate SZA is less than 90°, yielding characteristic shoulder patterns near twilight.

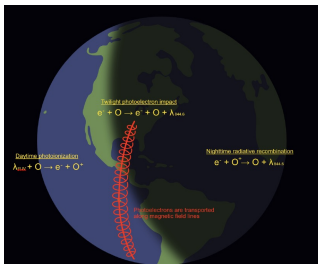

Fig. (2) An overview of the two primary mechanisms for midlatitude O8446 emission: photoelectron impact in the twilight, and radiative recombination, which decays steadily following sunset and is negligible at dawn.

If PE flux is known/specified, then O8446 remote sensing is a promising new approach to measure thermospheric [O] density, whose estimation otherwise currently relies on either total mass density data (inferred from satellite drag) or observed airglow brightness ratios, which constrain [O] in terms of atmospheric [N_2].

Abstract

Neutral atomic oxygen, O, is a critical species in the Earth's thermosphere, yet no remote sensing or in-situ technique is currently available to unambiguously retrieve its density, [O]. The OI 844.6 nm emission line is a promising candidate for routine [O] estimation in the mid-latitude upper thermosphere due to its readily detectable brightness at twilight, relatively simple photochemistry, and well understood excitation mechanisms. In this work, we present the first observations of mid-latitude O8446 emission brightness during a geomagnetic storm and investigate the origin of the observed variability. We also introduce a new O8446 photometer developed by UIUC under NSF support, known as the Sky-Calibrating Imaging Photometer (SCIP). SCIP is well suited to provide unprecedented constraints on mid-latitude thermospheric composition, which is particularly needed to advance understanding of space weather.

Storm-time O8446 Observations

- Twilight decay of O8446 brightness was routinely observed at Arecibo Observatory from 1999 to 2003 using the facility tilting filter photometer (R. Kerr)
- Absolute brightness calibration using lab sources was challenging, but significant variations in the twilight profile shape were observed during a moderate geomagnetic storm (peak DST = -100 nT) on 12–18 January 1999.

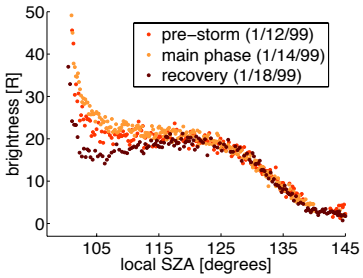

Fig. (3) Pre-dawn O8446 relative radiance profiles observed Arecibo before, during, and after the Jan 1999 storm.

- The characteristic shoulder pattern is clearly observed on each night, with an initial sharp drop off in brightness after local twilight (local SZA> 90°) followed by a plateau while the conjugate hemisphere is still illuminated (105°<SZA< 125°) and a steady monotonic drop-off after conjugate twilight (at local SZA>125°).
- The twilight profile shape changes significantly throughout the lifetime of the storm. From pre-storm to main phase, the relative brightness at SZA = 105° increases, thereafter decreasing to below pre-storm levels in the recovery phase

Modeled O8446 Emission Brightness

- We use the Field Line Interhemispheric Plasma (FLIP) model to investigate the origin of the storm-time variability.
- FLIP calculates the PE flux originating from both local and conjugate hemispheres by solving the equations of energy, continuity, and momentum for ionospheric constituents along the magnetic flux tube over Arecibo.
- The NRLMSISE-00 model is used to specify the [O] distribution, and we find that O8446 twilight decay profile is highly sensitive to its specification.
- The neutral meridional wind speed is another key FLIP input, and various FLIP options for neutral wind specification are considered here.

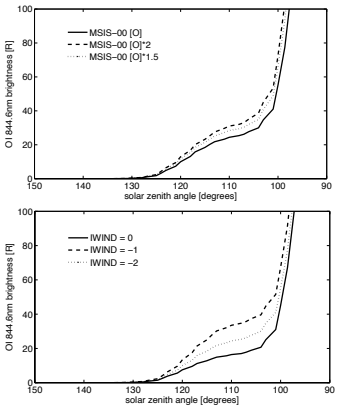

Fig. (4)
(Top) FLIP modeled O8446 brightness sensitivity to scaled MSIS00 neutral oxygen density input.

(Bottom) FLIP modeled O8446 brightness sensitivity to neutral wind input. HWM93b(IWIND=0) , IRI hmF2 (IWIND=-1), IRI NmF2 (IWIND=-2).

Discussion and Conclusions

- O8446 exhibits a strong response to storms that is likely indicative of changes in local thermospheric conditions
- FLIP model sensitivity to [O] supports the potential for interpretation of observed O8446 variations as arising from changes in mid-latitude thermospheric composition
- The modeled O8446 emission brightness is also sensitive to neutral wind, which renders interpretation of observed changes in O8446 in terms of [O] ambiguous.
- **Calibrated photometric sensing of O8446 offers a new means for thermospheric [O] estimation, provided that reliable neutral wind specification is available**

Sky-Calibrating Imaging Photometer (SCIP)

- SCIP is a new ground-based O8446 photometer with the novel capability of autonomous, absolute brightness calibration using astronomical sources.
- SCIP had its first light at Urbana, IL, in Spring 2022
- **With a high sensitivity and independent background detection through on/off band binocular sensing, SCIP is the ideal platform to pursue the novel and important opportunity for unprecedented [O] estimation**

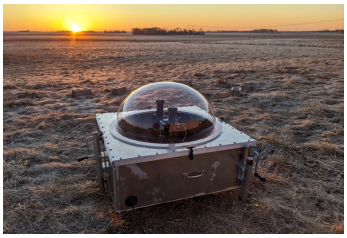

Fig. (5) Image of SCIP in the environmental chamber

References

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Waldrop, Kerr, and Richards, JGR (2008)
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Acknowledgements

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