EXOSpy: A python package to investigate the terrestrial exosphere and its FUV emission

Gonzalo Cucho-Padin[1,2], Dolon Bhattacharyya[4] , David Sibeck[2], Hyunju Connor[1], Allison Youngblood[1], David Ardila[4]

[1]NASA Goddard Space Flight Center, MD, USA
[2]The Catholic University of America, DC, USA
[3]LASP- University of Colorado Boulder, CO, USA
[4]Jet Propulsion Laboratory, CA, USA

THE CATHOLIC UNIVERSITY OF AMERICA

NASA

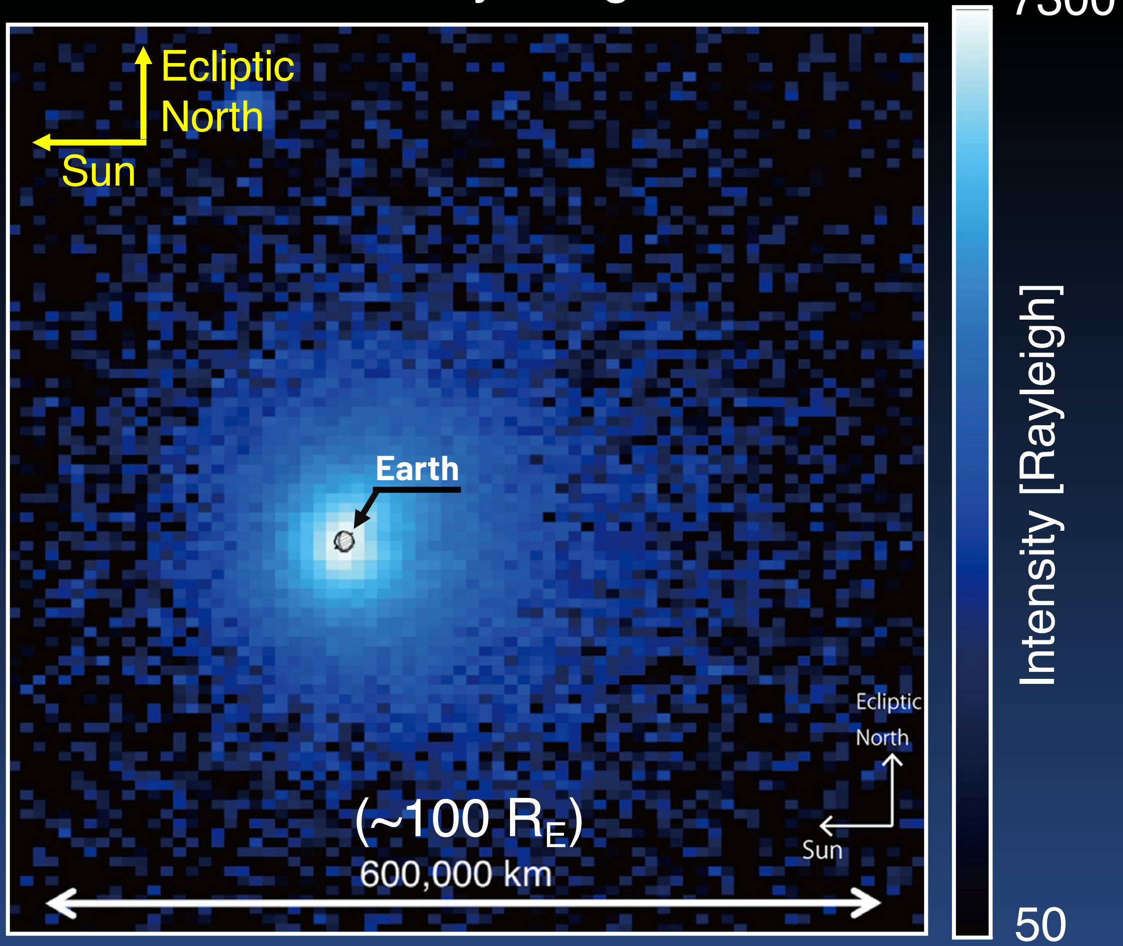
06/30/2023 – CEDAR 2023

What is the Exosphere?

- The exosphere is the uppermost region of the terrestrial atmosphere that extends from 500 km up to 60 Earth radii (1RE ~ 6371 km).
- The main component of this vast region is the atomic hydrogen (H).
- One main feature of H is the resonant scattering of FUV emission (or Lyman-alpha (Ly-a) at 121.56 nm)

Apollo 16 Mission [Carruthers et al., 1976]

Intensity Image



PROCYON/LAICA [Kameda et al., 2017]

Why do we need to study the Exosphere?

The spatial distribution and temporal evolution of the H density is needed:

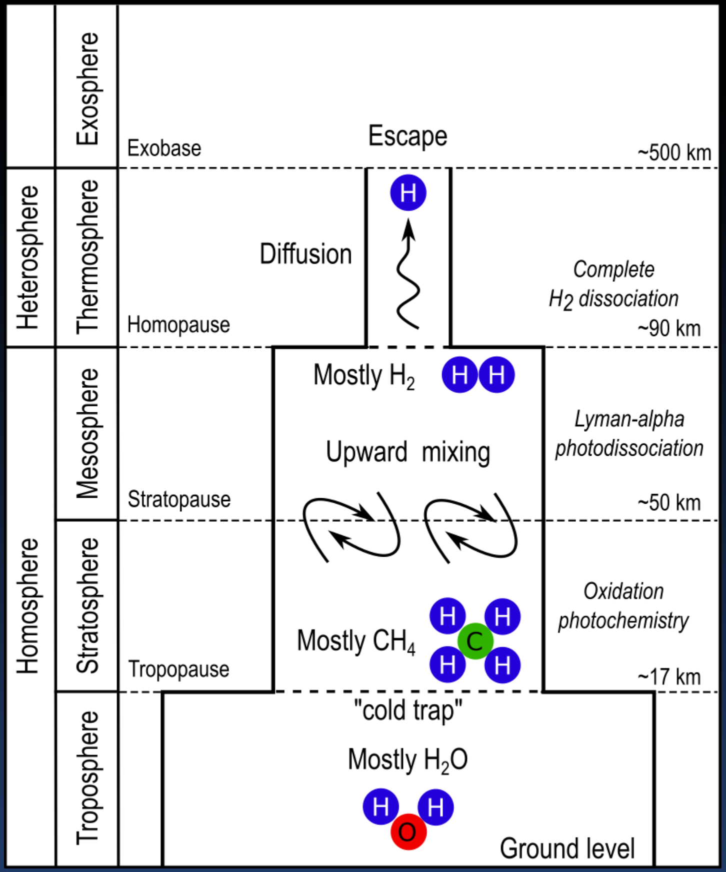
- To understand the planetary atmospheric evolution, i.e., escaping rate.
- To understand its role in inner magnetospheric dynamics during storm time, e.g., plasmaspheric refilling, ring current recovery
- To provide support to magnetospheric imaging missions, e.g., ENA, Soft X-ray.

ENA flux:

$$j_{ENA} = \int j_{ion} \sigma_{H,H^+} n_H \; dl$$

Soft X-ray emissivities:

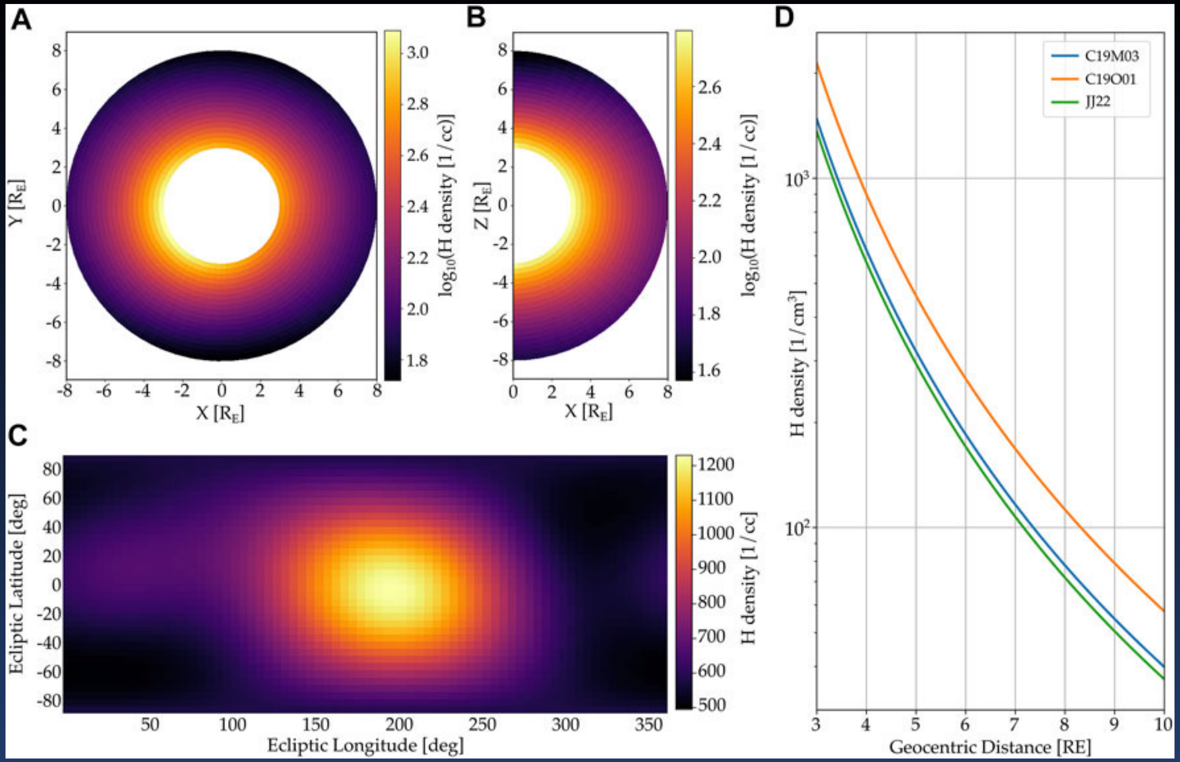
$$P = \alpha n_H n_{sw} \langle g \rangle \; [\mathrm{eV.cm^{-3}.sec^{-1}}]$$



Adapted from [Catling and Kastling, 2017]

What can we do with EXOSpy?

- EXOSpy provides direct access to **several existing terrestrial exospheric models of H density**, both data- and physics-based.
- Data-based model have been generated through inversion of optical data such as Lyman-Alpha or soft X-ray emissions. This models are limited to the optically thin region >3RE.
- The physics-based Chamberlain model is also included in EXOSpy and describe H density from the exobase (~500 km)



References of the exospheric model	Instrument(s)	Dimension, range of validity [R_E]	EXOSpy alias
Bailey and Gruntman, (2011)	TWINS/LAD	3-D, [3–8]	B11
Zoennchen et al. (2015)	TWINS/LAD	3-D, [3–8]	Z15MAX, Z15MIN
Connor and Carter, (2019)	XMM-Newton	1-D, [3–12]	C19O01, C19M03
Zoennchen et al. (2022)	UVIS/HDAC	1-D, [3–15]	Z21
Jung et al. (2022)	XMM-Newton	1-D, [3–12]	J22
Cucho-Padin et al. (2022b)	LAICA	3-D, [6–20]	C22

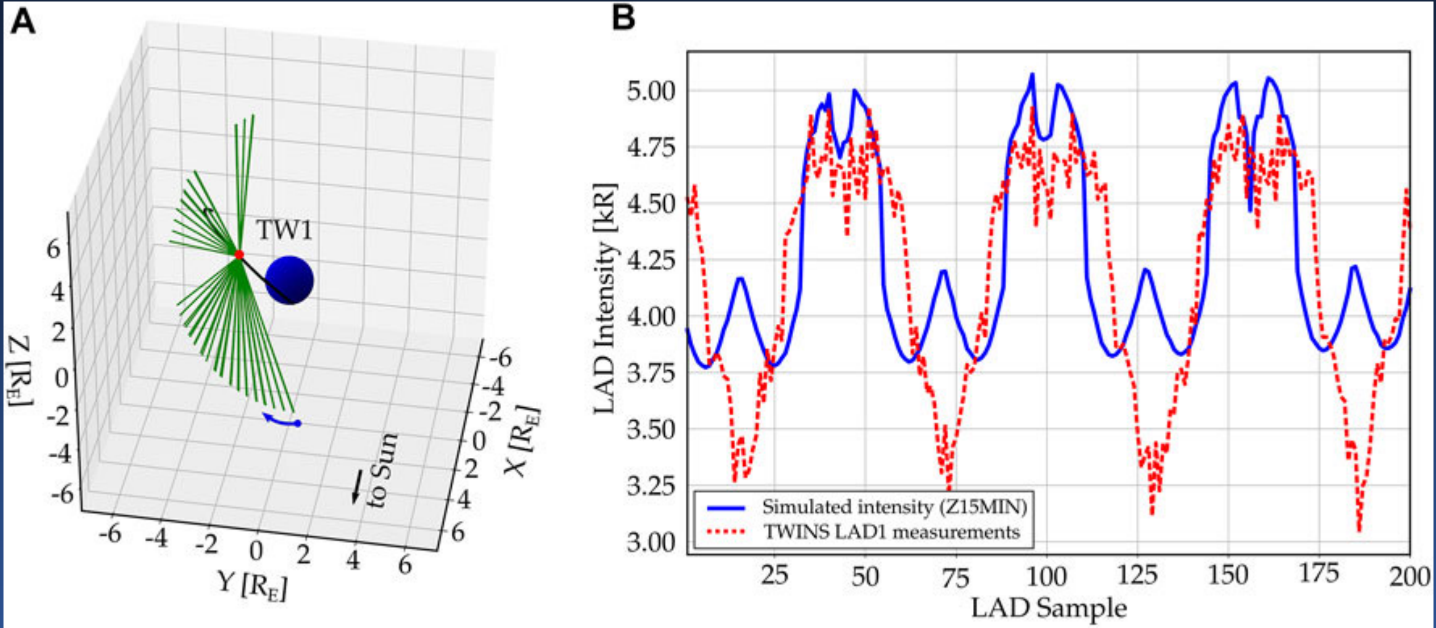
EXOSpy applications: Evaluate current exospheric models

- EXOSpy can estimate the Lyman-Alpha intensity along a given line of sight (LOS) using the following formula:

$$I(\hat{n}) = \frac{g^{*}\Psi(\hat{n})}{10^6}\int_0^{L_{max}} n_H(l)\,dl + I_{IP}(\hat{n})$$

n_H	= H density
g	= scattering factor
Psi	= scattering function
I_p	= Interplanetary Ly-a background emission

- EXOSpy can be used to evaluate current models and compare predicted intensities with actual measurements.



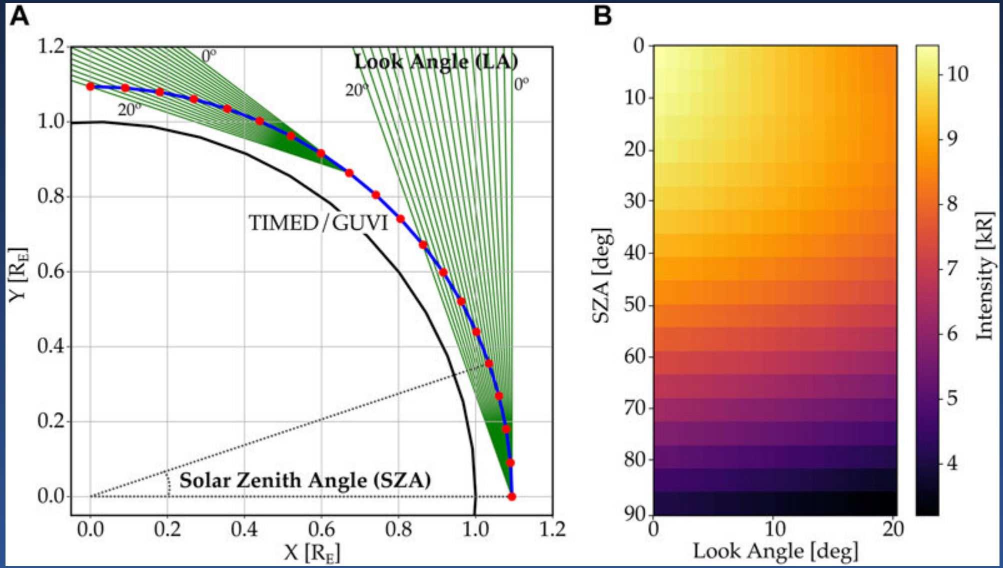
EXOSpy applications: Calculate exospheric contamination

- EXOSpy can estimate the Lyman-Alpha intensity along a given line of sight (LOS) using the following formula:

$$I(\hat{n}) = \frac{\Psi(\hat{n})}{10^6} \int_0^{L_{max}} \left(\varepsilon_0(l)\, T(\tau_{\mathrm{H}}(l))\, e^{-\tau_{\mathrm{O_2}}(l)} + \varepsilon_m(l)\, T(\tau_{\mathrm{H}}(l))\, e^{-\tau_{\mathrm{O_2}}(l)} \right) dl + I_{IP}(\hat{n}),$$

$\varepsilon_0, \varepsilon_m$ = volume emission rate → n_H
Tau = optical depth
I_p = Interplanetary Ly-a background emission

- EXOSpy can be used extract exospheric contamination for current missions observing extra-terrestrial targets (i.e. HST)

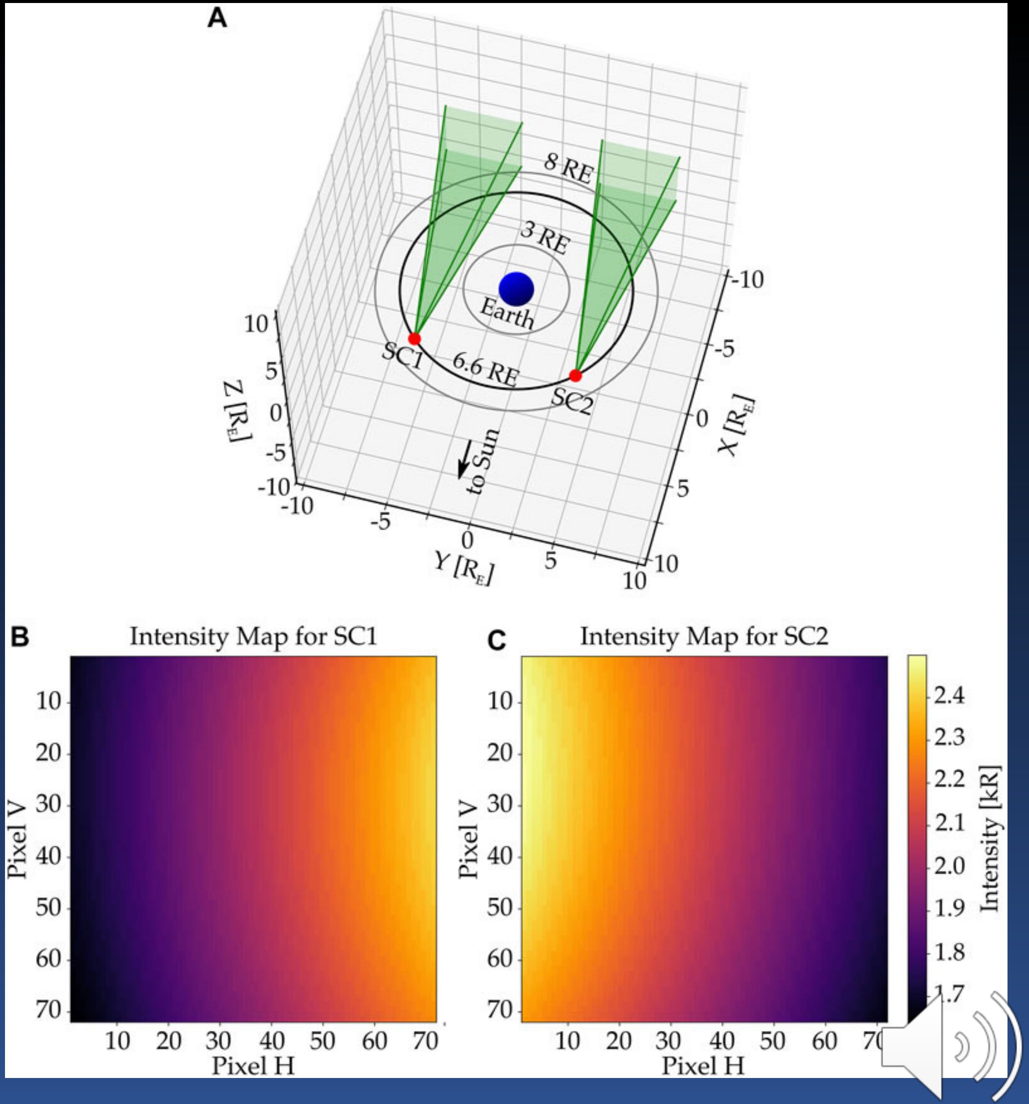


EXOSpy applications: Support UV instrument design

- EXOSpy can be used to design UV instruments to observe, for example, the exosphere in Lyman-alpha.

- This task typically aims to determine several optical parameters such as
  - FOV (in degrees),
  - pixel resolution (in degrees/pixel),
  - sensor responsivity at Ly-a (in cts/s/R),
  - Integration time (in seconds),
  - The optimal ephemeris,
  - The optimal pointing viewing geometry.

- Assessment of parameter selection can be made through SNR measurements or uncertainty in the estimation of by-products such as hydrogen density.



Summary

- EXOSpy can be used:
  (i) to validate exospheric models with actual Ly-α radiance data,
  (ii) to estimate exospheric contamination that may affect extra-terrestrial observations, and
  (iii) to support UV instrument design

- You can easily install EXOSpy using the command:

  pip install EXOSpy == 2.4

  Documentation:

  https://exospy.readthedocs.io/en/latest/

- We invite to submit abstracts to the session on "Dynamic Exospheres of Terrestrial Bodies through the Solar System" at AGU 2023 Fall meeting, session ID 185130

gonzaloaugusto.cuchopadin@nasa.gov
Primary Convener
Early-career convener

EXOSpy: A python package to investigate the terrestrial exosphere and its FUV emission, Cucho-Padin et al., 2023

The Earth's Outer Exospheric Density Distributions Derived From PROCYON/LAICA UV Observations, Cucho-Padin et al., 2022

A New Approach for 4-D Exospheric Tomography Based on Optimal Interpolation and Gaussian Markov Random Fields, Cucho-Padin et al., 2023