SA51C-2718

AGU24 Washington, D.C. | 9–13 December 2024

Performance and accuracy of ICON-FUV nighttime O⁺ density profiles: latest comparison with radio-based observations

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ICON Ionospheric Connection Explorer — LIÈGE université

Abstract

The Far Ultraviolet Imaging Spectrograph (FUV) instrument onboard the NASA-ICON spacecraft provided almost three years of ultraviolet observations of the low and mid-latitude ionosphere from December 2019 to November 2022. In limb mode, the main data product, called L2.5, refers to the nighttime O^+ density profile (ODP) from approx. 200km to about 500km altitude, derived from the inversion of brightness measurements of the atomic oxygen doublet emission at 135.6 nm. Previous validation studies showed that ICON-derived ODPs are accurate to about 10% in peak density (NmF2) and 7 km in peak height (hmF2) when comparing to ionosondes and COSMIC-2 electron density profiles. However, to this accurate mean performance is superimposed a rather important variability: the standard deviation of the differences is about 30% and 20-30km for NmF2 and hmF2, respectively. An explanation for this large variability lies in the presence of strong horizontal density gradients and of additional emission of auroral origin. Those specific conditions, which violate the spherical symmetry hypothesis used for ODP retrieval, lead to distorted profiles which contribute to enlarge the variability of the ICON-FUV profiles with respect to radio-based observations. In the last file version of the L2.5 product released in 2024 (version 6), new flags identify conditions where the altitude profile is contaminated by auroral emissions, or the field of view includes large horizontal gradients of O^+ density. The purpose of this paper is to update the comparison statistics previously computed discarding all flagged cases, i.e. excluding gradients and auroral contamination and discuss their influence. The accuracy improvement is assessed based on statistical comparisons covering the whole ICON mission database (2019-2022) while specific cases showcasing the effect of strong horizontal gradients and auroral emission illustrate the complexity of FUV observations.

1. FUV vs COSMIC-2 comparison

Comparison of v06 FUV Data product 2.5 with COSMIC-2

- FUV Level-2 electron density profiles (N_e) profiles
- Latest file version available : v06 (processed March 2024)
- V06 improvements include new quality flags (see CMAD document) characterizing:
  - brightness contamination by auroral processes → aurora flag
  - breaking of spherical symmetry assumption → asymmetry flag

Aurora Flag

Two criteria are checked, if both are satisfied, then the flag is activated:

1. If the latitude of the tangent point passing through the peak brightness is above 30° N
2. If the altitude of the tangent point passing through the peak brightness is below 220 km

Asymmetry Flag (2 stages)

- **Is there a bright hmF2 dip that lasts for at least 5 Epochs?**
  1. If so, take a 50 Epoch wide time window centered around the midpoint of the dip.
  2. Within the chosen window, flag the profiles with an altitude of peak brightness less than or equal to 250 km.
- **To check if there is a bright hmF2 dip, two conditions are checked:**
  1. Does the altitude of peak brightness go below 200 km?
  2. Is the peak brightness larger than 100 R?

- Updated comparison statistics between COSMIC-2 and FUV L2.5 (2019-2022 entire FUV database), see Wautelet et al. (2023) for comparison details

	Version 5			Version 6		
NmF2 mean +/- std. dev [e/m3]	-3.3 E+09	+/-	1.9 E+11	- 3.5 E+09	+/-	1.9 E+11
NmF2 median +/- IQR [e/m3]	1.8 E+09	+/-	1.8 E+11	1.0 E+09	+/-	1.9 E+11
NmF2 RELATIVE mean +/- std. dev [%]	6	+/-	33	6	+/-	33
NmF2 RELATIVE median +/- IQR [%]	0	+/-	33	0	+/-	33
hmF2 mean +/- std. dev [km]	7	+/-	21	7	+/-	21
hmF2 median +/- IQR [km]	8	+/-	24	8	+/-	24

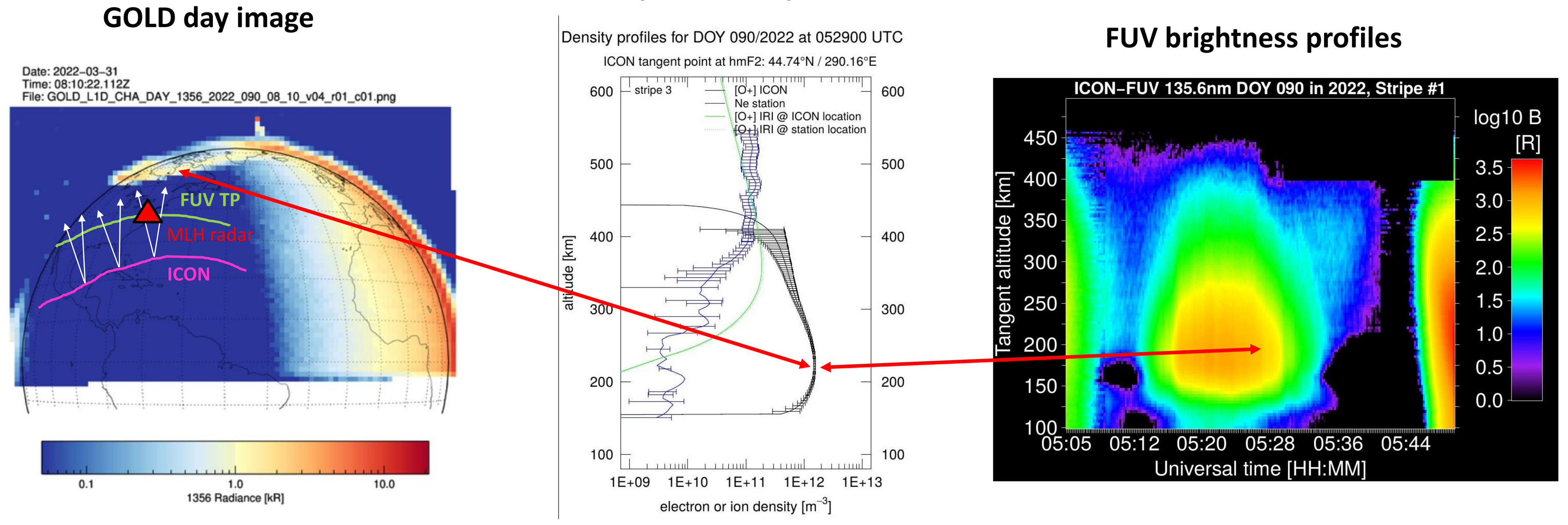
- No significant difference in peak characteristics between v05 and v06, despite rejection of numerous profiles corresponding to auroral or asymmetry conditions
- Large variability in NmF2 differences remains (v05 and v06)

➡ **This work aims at identifying, through examples, the reasons for such remaining discrepancies between radio-occultation data and FUV observations**

Data used :
- COSMIC-2 "ionPrf" electron density profiles (level-2)
- NASA-GOLD 135.6 nm images, day and night (level 1C)
- GNSS-derived Global Ionospheric Maps (GIM) of the Total Electron Content (TEC)
- Millstone Hill (MLH) incoherent scatter radar electron density profiles

2. Auroral flag examples

- **Clear auroral signature**

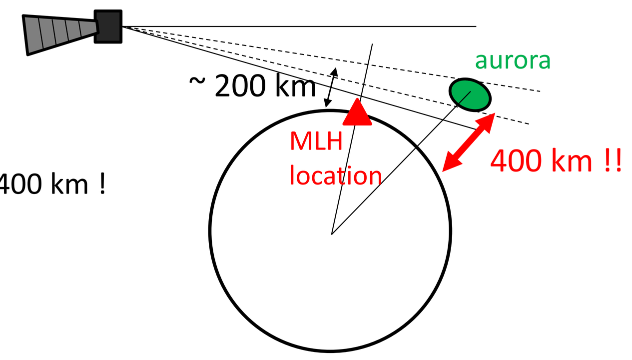


Left: FUV tangent point (TP) location (in green) correspond to the tangent altitude of 300 km. Their location matches that of MLH radar.
Middle: However, the radar vertical sounding shows an EDP (blue curve) very different from that inverted from FUV data (black curve). Note that in this situation, the auroral flag is triggered and the corresponding profile is excluded from our comparison analysis.
Right: FUV brightness measurement (level-1 data) with very bright peak around 150-200km altitude explains that aurora is responsible for the distorted inversion visible in the central panel.

Question: what is the main altitude of the 135.8 nm auroral emission?

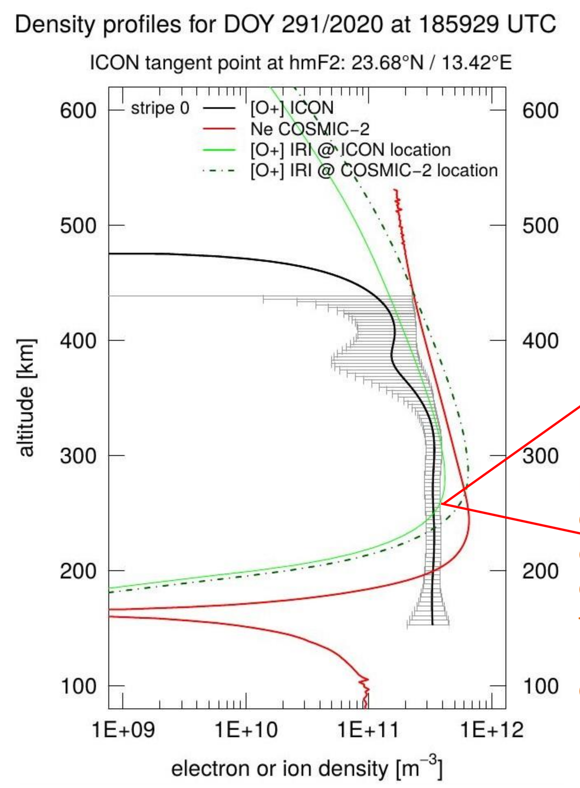
Considering 65° MLAT for the main aurora oval leads to 135.6 nm auroral altitude of about 400 km !

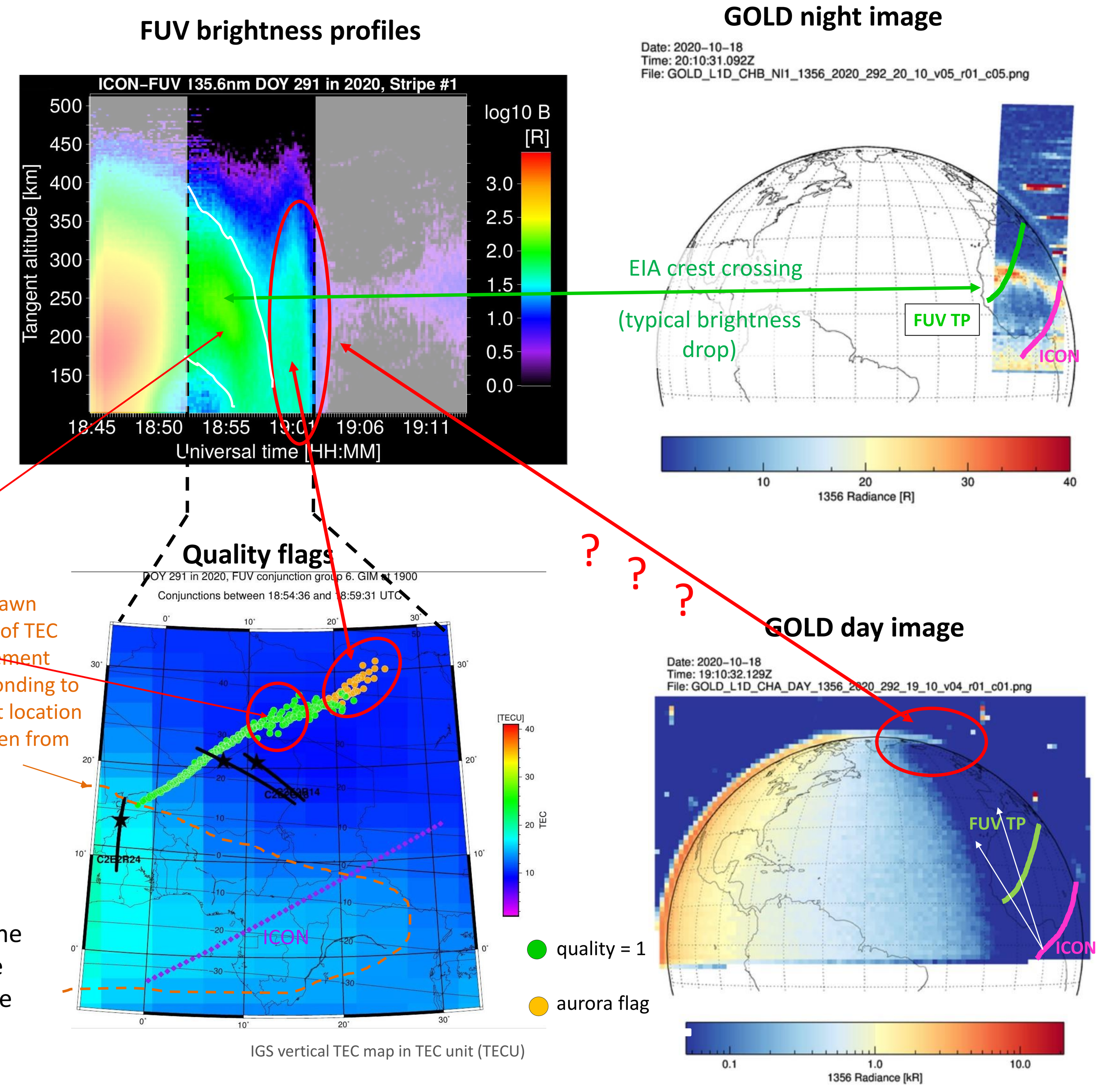
→ Is there enough oxygen at this altitude for such a bright emission (1 kR) ?



- **EIA crest crossing. C2 comparison and aurora false positive flag ?**

Comparison between COSMIC-2 and FUV during "quality = 1" conditions:



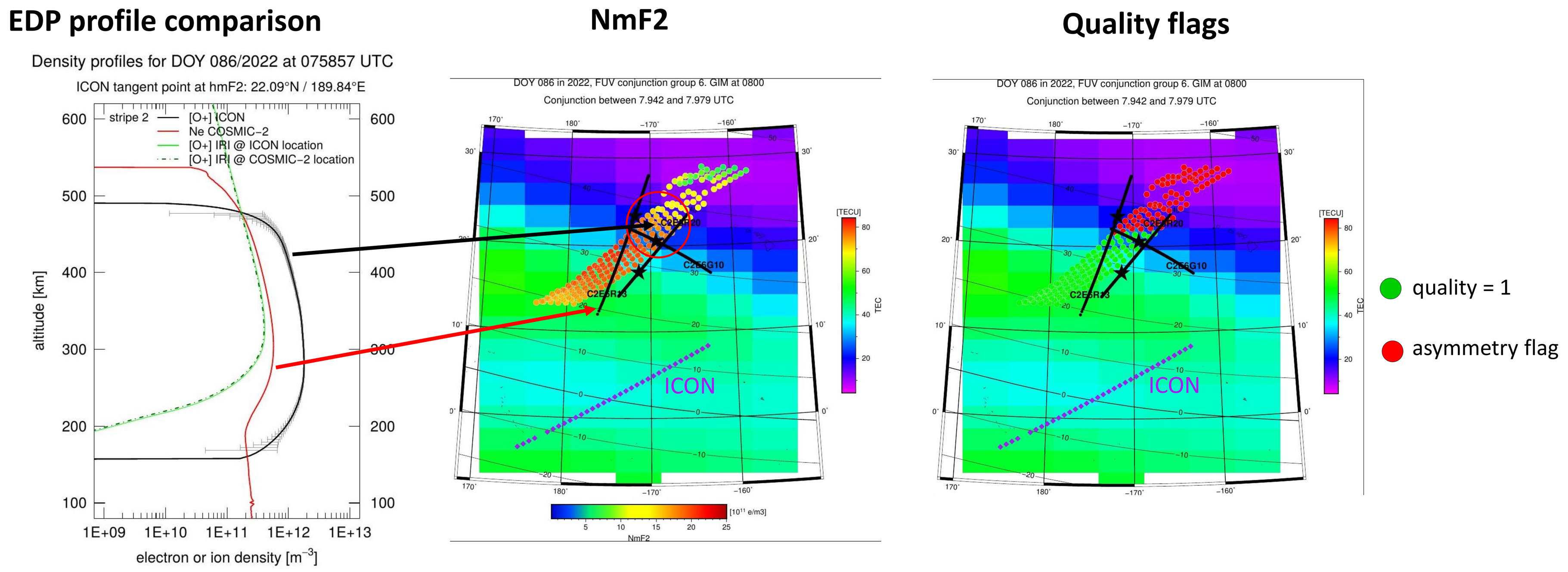


FUV inverted profile (in black) results from the inversion of measurements integrating O^+ enhanced (cyan) and depleted (deep blue, at the COSMIC-2 profile location) density regions (see map), resulting in a rather flat O^+ density profile ranging from 180 km to 330 km altitude

Is the increased brightness signal recorded around 19:01 UT due to auroral emission as suggested by the GOLD image?

3. Gradient crossing example

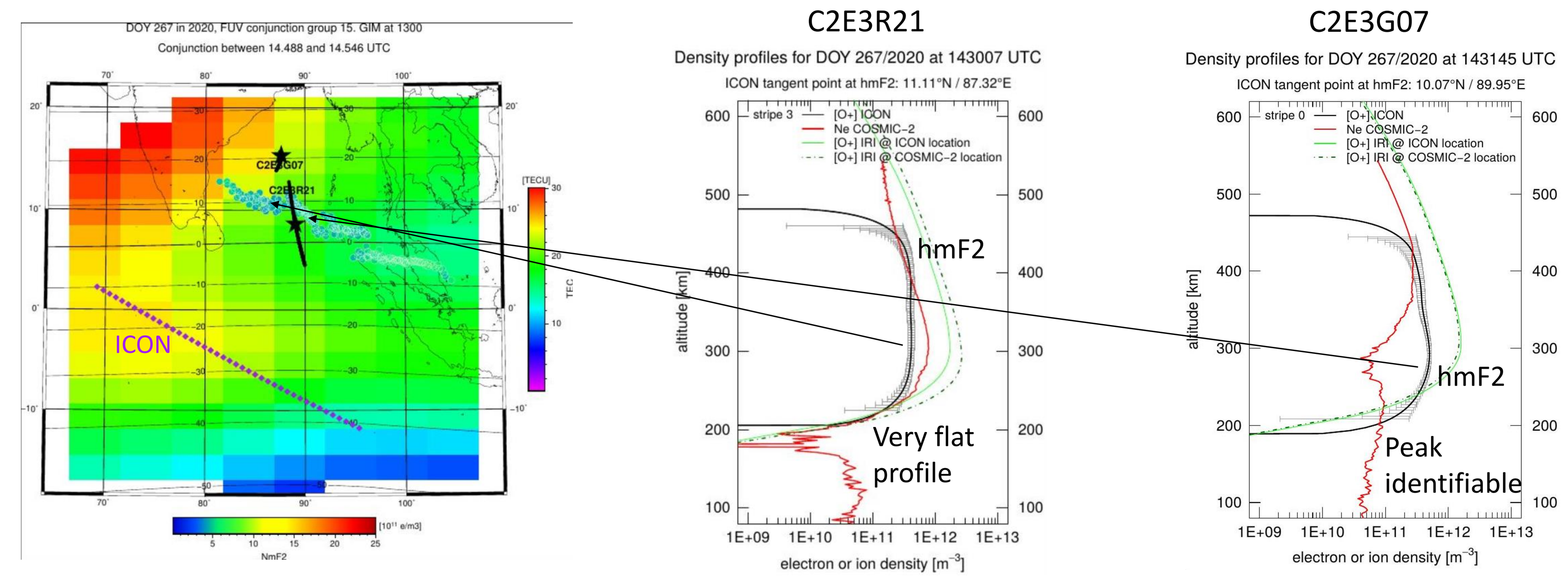
- **Example of asymmetry flagging working properly**



FUV profile is correctly flagged as "asymmetry" (red dots on the right map) when FUV tangent points cross the edge of the equatorial ionization northern crest.

→ This indicates that the EDP (left figure) is distorted by the gradient crossing, which results in large discrepancies with the nearby COSMIC-2 profiles. The flagging procedure therefore prevents to include such profile in our comparisons.

- **Example of moderate asymmetry without flagging (false negative ?)**



- Both COSMIC profiles have rather different shapes, hence a limited comparison "truth" → should we be more restrictive when selecting C2 profiles for comparison, for instance considering smaller smears ?
- No FUV profile is flagged here, despite a line of sight geometry being at the edge of the ionization crest and crossing heterogeneities
  - → Does this situation correspond to a false negative, i.e. would it need to be flagged ?
  - → Is the gradient crossing definition (or asymmetry) sufficient ?
  - → Would GNSS-TEC maps (left map) help to describe the expected gradients, hence the asymmetry ?

Summary and future work

- Global comparison statistics: V06 performs like v05 on the average, despite the flagging of auroral emission and gradient crossing (asymmetry) is working properly
- Several situations corresponding to gradient crossing are not flagged (false negative), and the use of external data source like GNSS-TEC may help
- False positive auroral flagging may reduce the availability of FUV data, but their number is quite limited

Future work and investigation include but are not limited to:

- As being observed in brightness profiles, the EIA crests and in particular their vertical extension and dynamics would be studied in detail using FUV nighttime 135.6 nm emission
- Understand the origin of the auroral signature: why is the 135.6 nm signal so intense at altitude of about 400 km ?

Reference: Wautelet et al. (2023). Update of ICON-FUV hmF2 and NmF2 comparison with external radio observations, *Space Sci. Rev.*, 219:21

Acknowledgments: The authors thank PJ Erickson (MIT) for providing data from the Millstone Hill incoherent scatter radar
The authors acknowledge financial support from the Belgian Federal Science Policy Office (BELSPO) via the PRODEX Program of ESA and FRS-FNRS. ICON is supported by NASA's Explorers Program through contracts NNG12FA45C and NNG12FA42I.