Ionizing sources in the coma of 67P probed by Rosetta

K.L. Heritier,[1] M. Galand,[1] P. Henri,[2] A. Eriksson,[3] E. Odelstad,[3] K. Altwegg,[4] A. Beth,[1] J. Burch,[5] C. Carr,[1] E. Cupido,[1] M. Rubin,[4] X. Vallières,[2] E. Vigren,[3] the RPC and ROSINA teams

[1]Dpt of Physics, Imperial College London, London, UK, [2]Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E), CNRS, Université d'Orléans, Orléans, France, [3]Swedish Institute of Space Physics, Uppsala, Sweden, [4]Physikalisches Institut, Universität Bern, Bern, Switzerland, [5]SouthWest Research Institute (SwRI), San Antonio, TX, USA.

CC BY

ABSTRACT

An ionospheric model has been developed in order to quantify the ion number density in the coma of 67P/Churyumov-Gerasimenko. The model is driven by **Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA)/Cometary Pressure Sensor (COPS)** total neutral number density. The two ionization sources considered are photo-ionization by solar extreme ultraviolet (EUV) radiation and electron-impact ionization. The EUV radiation is estimated from fluxes measured by the Thermosphere Ionosphere Mesosphere Energetics and Dynamics **(TIMED)/ Solar EUV Experiment (SEE),** taking into account the phase shift and the heliocentric distance ratio between Earth and comet 67P. The electron-impact ionization production rates are derived from Rosetta Plasma Consortium **(RPC)-Ion and Electron Sensor (IES)** integrated electron fluxes and corrected for the S/C potential from **RPC-LAngmuir Probe (LAP)** measurements. Our results are compared with in situ measurements of the plasma density from **RPC-Mutual Impedance Probe (MIP)** and RPC-LAP.

At high heliocentric distances, there is a good agreement between the modelled and RPC observed electron densities. The ionospheric model enables to distinguish relative source contributions to the total cometary plasma associated with photo-ionization and electron-impact ionization. Electron-impact ionization becomes the dominant ionization source and is enhanced over the winter hemisphere. As the solar activity has decreased since the beginning of the mission in 2014, the relative importance of photo-ionization has decreased as well.

1. ROBUST DATA-BASED MODEL

Assumption on the continuity equation:

- Optically thin atmosphere in the EUV → photo-ionization frequency $\nu^{h\nu}$ constant with cometocentric distance r. Same is assumed for e- impact ν^{e} providing an upper limit.
- Chemical loss timescale for terminal ions >> transport timescale, so chemical loss ignored.
- Ionospheric velocity u_i radial and constant, equal to the neutral bulk velocity u_n.

TIMED/SEE solar spectral flux estimation at 1 AU $F_{1AU}(\lambda)$ and extrapolated to the Sun-comet distance, d_{AU}

RPC/IES energetic electron flux density

ROSINA/COPS total number density $n_n(t)$, $1/r^2$ dependence down to the surface ($r = r_0$)

RPC/MIP electron density $n_e(t)$

$$\left(\frac{\nu_{1AU}^{h\nu}(t)}{d_{AU}^2} + \nu^{e}(t)\right) n_n(t) \frac{(r-r_0)}{u_n} = \sum_{ions\ i} n_i(t) = n_e(t)$$

Neutral composition estimated with ROSINA/DFMS

Cross calibration

RPC/LAP electron density $n_e(t)$

2. EVOLUTION OF THE IONIZATION SOURCES

	$\nu_{1AU}^{h\nu}[s^{-1}]$	$\nu_{scaled}^{h\nu}[s^{-1}]$	$\nu^{e^-}[s^{-1}]$
2014 Oct 17-20 (3.1 AU)	$\sim 7\times10^{-7}$	$\sim 7\times10^{-8}$	$\sim 5\times10^{-7}$
2016 Mar 18-23 (2.6 AU)	$\sim 4\times10^{-7}$	$\sim 7\times10^{-8}$	$\sim 1\times10^{-7}$
2016 May 25-29 (3.1 AU)	$\sim 4\times10^{-7}$	$\sim 4\times10^{-8}$	$\sim 2\times10^{-7}$

3. PRE-PERIHELION (3.1 A.U.)

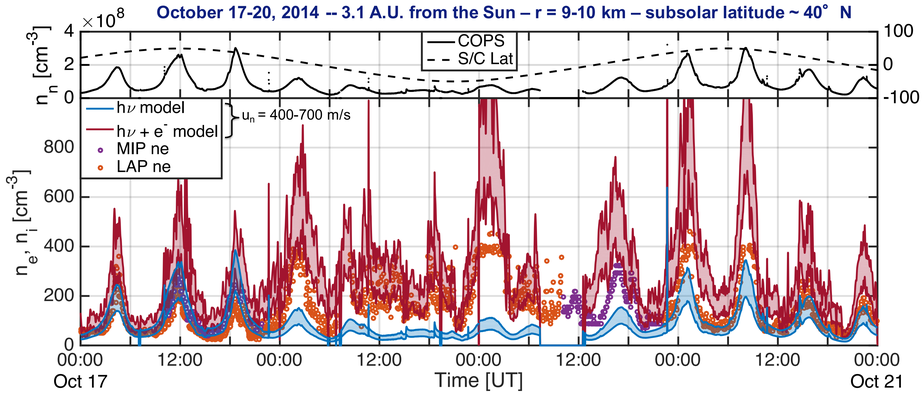


Figure 1:
Top: ROSINA/COPS neutral number density (solid), Spacecraft latitude (dashed)
Bottom: Modelled plasma densities using photo-ionization alone or photo- & e⁻-impact ionization vs. measured RPC/LAP and RPC/MIP electron densities

- **Photoionization is dominant in summer (northern hemisphere).**
- **Electron-impact is dominant in winter (southern hemisphere). [Galand et al. 2016, MNRAS]**

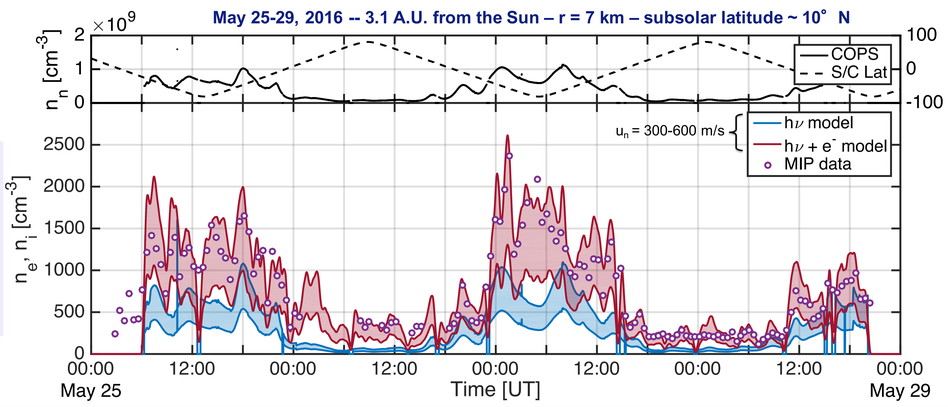
4. POST-PERIHELION (2.6 A.U. and 3.1 A.U.)

Figure 2:
Same as **Figure 1**, but for March 18-23, 2016, at 2.6 A.U. from the Sun

- **Photoionization is significant but electron-impact ionization is necessary to explain the plasma densities over the northern and southern hemispheres.**
- **Maximum densities occur in summer.**

Figure 3:
Same as **Figures 1 & 2,** but for May 25-29, 2016, at 3.1 A.U. from the Sun (no RPC/LAP densities)

- **It is the same heliocentric distance as in October 2014 (Figure 1) but with decreased solar flux.**
- **Electron-impact ionization is the dominant ionization source.**



5. MAIN RESULTS (close to 67P, r < 15 km):

- A simplified data-based model can explain RPC/MIP and RPC/LAP plasma densities and disentangle their sources.
- The escort of comet 67P by Rosetta occurred during a **decreasing phase of the solar cycle.**
- Over the summer hemisphere, the relative importance of **photo-ionization** has decreased due to decreasing solar activity. As a result, **electron-impact ionization has become the main ionization** source post-perihelion.
- Over the winter hemisphere, electron-impact ionization has remained significant. It was however more intense in October 2014 than it was in March and May 2016. As a result, the highest plasma densities were observed in winter in October 2014, while they tended to occur in summer after perihelion.

ACKNOWLEDGEMENTS:

Work at Imperial College London is supported by the consolidated grants from the Science and Technology Facilities Council (STFC) and the Royal Astronomical Society. Work on ROSINA at the University of Bern was funded by the State of Bern, the Swiss National Science Foundation, and the ESA PRODEX Program. The Rosetta Plasma Consortium (RPC) instrument package consists of 5 sensors (RPC-ICA, RPC-IES, RPC-LAP, RPC-MAG, RPC-MIP) and a control unit (RPC-PIU). RPC is operated by Imperial College London in cooperation with SwRI, IRF, IGeP_TU Braunschweig, IRFU, LPC2E. The lead funding agencies are CNES, SNSB, NASA, BMWi and DLR, and STFC. We are indebted to the RPC and ROSINA operation and data processing teams.