Publication Year	2016
Acceptance in OA	2020-05-15T16:29:24Z
Title	An updated approach to the study of proton propagation in the eROSITA mirror system
Authors	Perinati, E., MINEO, TERESA, Freyberg, M., Diebold, S., Santangelo, A., Tenzer, C.
Publisher's version (DOI)	10.1117/12.2231577
Handle	http://hdl.handle.net/20.500.12386/24899
Serie	PROCEEDINGS OF SPIE
Volume	9905

An updated approach to the study of proton propagation in the eROSITA mirror system

Perinati, E., Mineo, T., Freyberg, M., Diebold, S., Santangelo, A., et al.

E. Perinati, T. Mineo, M. Freyberg, S. Diebold, A. Santangelo, C. Tenzer, "An updated approach to the study of proton propagation in the eROSITA mirror system," Proc. SPIE 9905, Space Telescopes and Instrumentation 2016: Ultraviolet to Gamma Ray, 990552 (11 July 2016); doi: 10.1117/12.2231577

Event: SPIE Astronomical Telescopes + Instrumentation, 2016, Edinburgh, United Kingdom

An updated approach to the study of proton propagation in the eROSITA mirror system

E. Perinati[a,*], T. Mineo[b], M. Freyberg[c], S. Diebold[a], A. Santangelo[a] and C. Tenzer[a]

[a]IAAT - Institut für Astronomie und Astrophysik, Universität Tübingen, 72076 Tübingen, Germany
[b]INAF - Istituto di Astrofisica Spaziale e Fisica Cosmica di Palermo, 90146 Palermo, Italy
[c]MPE - Max Planck Institut für Extraterrestrische Physik, 85748 Garching, Germany

ABSTRACT

The German telescope eROSITA will be the first X-ray instrument orbiting around the L-2 lagrangian point. Therefore, modelling the radiation environment in that region of space and its interaction with the instrument is particularly important, as no measured data of other X-ray detectors can be used as a reference to predict how the space conditions will impact the instrumental capabilities. The orbit around L-2 extends well beyond the Earth´s magnetosphere, where the flux of galactic cosmic particles is cut by the geomagnetic field, and fluxes of energetic particles one order of magnitude higher than in low Earth orbits are expected. Furthermore, as experienced by Chandra and XMM-Newton, softer protons may be scattered through the mirror shells and funneled to the focal plane, representing a potential additional source of background. To investigate and assess this component we are developing a ray tracing simulator for protons, that follows the track of each proton from the entrance pupil down to the focal plane. In this paper we report on an updated version of the code that allows to propagate protons in both the polar and azimuthal directions in elastic regime.

1. INTRODUCTION

During the first few weeks of the mission, the front-illuminated CCDs of the ACIS camera aboard Chandra suffered a degradation of the Charge Transfer Efficiency (CTE) far more rapid than expected [1]. On the other hand, the CTE of the back-illuminated CCDs remained almost unchanged. This suggested that the degradation of the FI-CCDs originated from a large-scale displacement damage in the first few microns below the highly sensitive gate region at the detector surface. The source of the damage was identified in relatively soft protons focused to the focal plane after scattering through the mirror shells during orbital crossing of the Earth´s radiation belts. In Silicon, protons with energy below 300 keV deposit their full energy within about 5 μm, therefore they can affect the gate region and the volume just beneath it. Within the same distance, 1 MeV protons leave about 100 keV, which means that they also can contribute to damage in the buried channel, if funneled by the mirrors. XMM-Newton was launched a few months after Chandra into a similar highly elliptical orbit. On the basis of the degradation experienced by the ACIS camera, the EPIC camera is kept in close position below about 45000 km, where the bulk of the radiation belt is located. This countermeasure has permitted to prevent the EPIC FI-CCDs from the damage suffered by the ACIS ones. Nevertheless, a flaring component of the background is present in both the EPIC FI-CCDs (MOS) and BI-CCDs (pn), which heavily affects the observations [2]. Fig.1 shows an example of a lightcurve showing high variable proton flares. These flares are not associated to passages within the radiation belts or to solar activity events. The conjecture is that along the orbit there are clouds of soft protons distributed in a chaotic and unpredictable way, some of which are funneled to the focal plane by the mirror shells when the satellite passes within a cloud. The background count-rate due to such proton clouds can fluctuate on time-scales as short as few seconds, indicating that the density of soft protons can vary quicky within a few kilometers.

*Email: Emanuele.Perinati@uni-tuebingen.de ;Tel.:+49 7071 29 73457

Space Telescopes and Instrumentation 2016: Ultraviolet to Gamma Ray, edited by
Jan-Willem A. den Herder, Tadayuki Takahashi, Marshall Bautz, Proc. of SPIE Vol. 9905, 990552
© 2016 SPIE · CCC code: 0277-786X/16/$18 · doi: 10.1117/12.2231577

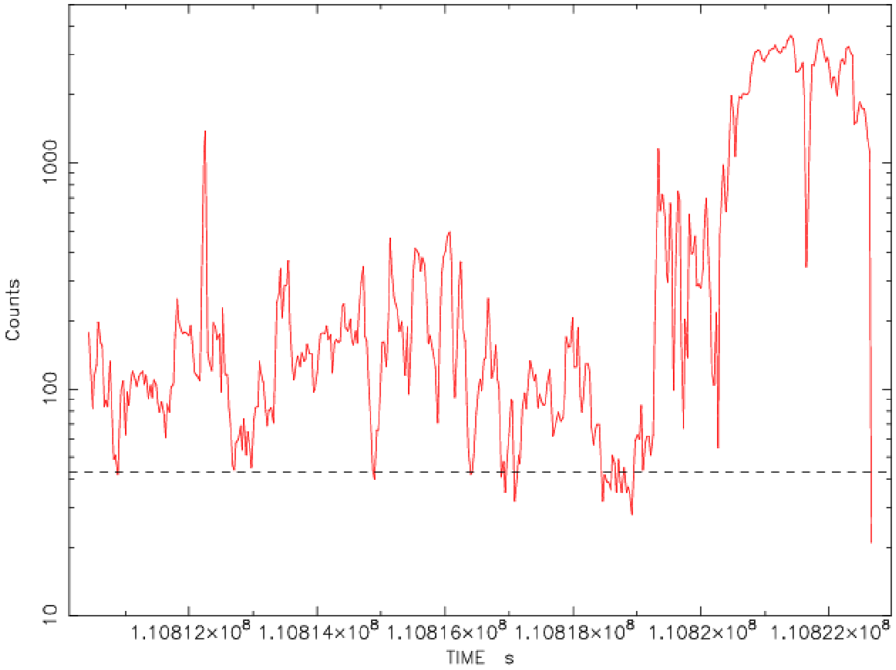

Figure 1. *XMM-Newton* light-curve badly affected by highly variable soft proton flares. The dashed line is the expected count-rate for a typical sky field [3]

In this paper we address the question of the soft protons for the eROSITA [4] mission. As a successor of the ROSAT [5] satellite, eROSITA will perform the first imaging all-sky survey with unprecedented angular and spectral resolution, using seven identical Wolter-I telescopes, each equipped with a pnCCD camera at the focal plane (see Fig. 2). The pnCCD is an advanced version of the pnCCD used aboard XMM-Newton. It is a back illuminated detector, therefore it is not expected to suffer degradation from soft protons possibly focused by the telescope. Nontheless, these protons might contribute to increase the background, if they arrive in a large number. Since eROSITA will be placed in an orbit around the L-2 lagrangian point, trapped protons should not represent an issue, and the fluxes of galactic cosmic particles are expected not too different from those experienced by Chandra and XMM-Newton in their highly elliptical orbits. However, not only particles associated with solar events but also the quiescent solar wind and supra-thermal tails are to be taken into account in the outer regions of the magnetosphere extending into the interplanetary space. Scattered protons have a certain probability to undergo some energy loss through the optical filter as well as at the interaction point with the mirror shells, that implies that a fraction of protons entering the telescope with an energy even much larger than the upper edge of the pnCCD band might reach the focal plane with an energy within the pnCCD band.

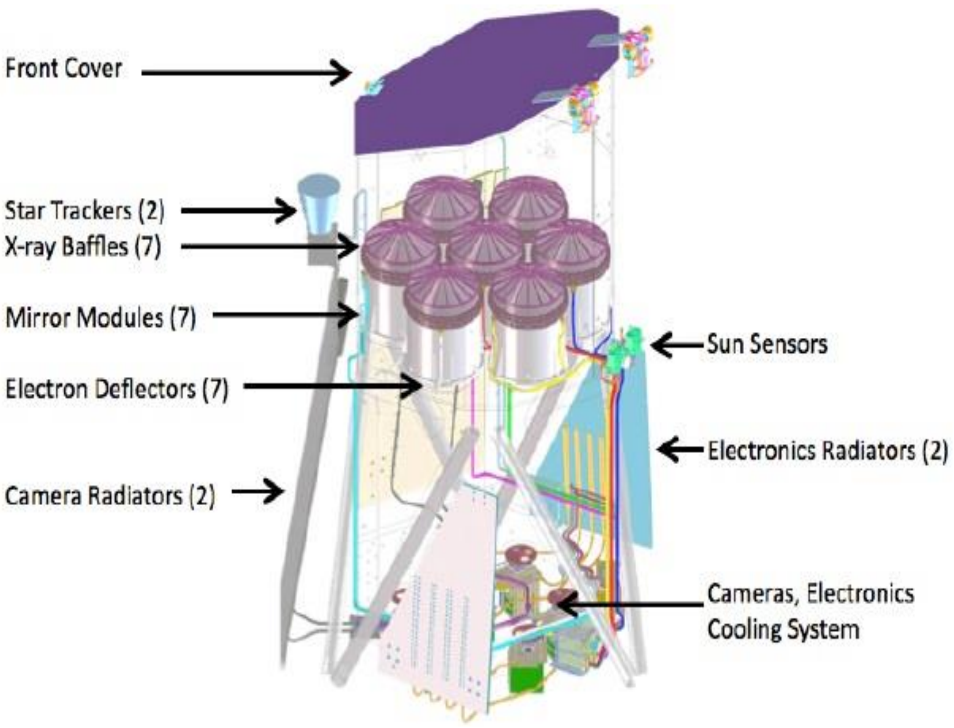

Figure 2. The *eROSITA* payload (credit: MPE)

2. SOFT PROTON SIMULATIONS

2.1 The simulator

The soft proton fluxes at L2 are not well known, due to the lack of low energy particle monitors in that region of space. On one hand, this implies that the predictions of how the environment will impact the sensitivity of eROSITA are to some extent uncertain, on the other hand the eROSITA pnCCDs could be exploited to perform some characterization of the environment by monitoring soft protons possibly funneled through the telescope. Therefore, providing a model of the propagation of soft protons in eROSITA it is useful to support such investigation. We implemented a ray-tracing code to simulate the interaction of soft protons with the eROSITA mirror shells and follow their track from the entrance pupil down to the focal plane.The propagation of the impinging protons is done according to the Remizovich's distribution [7]:

$$W(\Theta,\Phi) = (12\cdot\pi^2\cdot(\Theta/\alpha)^{0.5})^{-1}\cdot[\omega^4\cdot(1+\omega^2)^{-1}+\omega^3\cdot\mathrm{arctg}\omega] \quad (1)$$

with:

$$\omega = (3\cdot\Theta/\alpha)^{0.5}\cdot[(\Theta/\alpha)^2-(\Theta/\alpha)+1+(\Phi/(2\cdot\alpha))^2]^{-0.5}$$

The function W represents the probability that a proton impinging onto a mirror shell with an angle α is reflected in a given direction characterized by a polar angle Θ and an azimuthal angle Φ. We assume that all impinging proton are scattered, i.e. $\int d\Phi \int W(\Theta,\Phi) d\Theta = 1$, and that the scattering is totally elastic at any incidence angle smaller than 10°, i.e. protons are reflected without energy loss. At incidence angles larger than 10° the scatter angle and scatter energy are computed by interpolation of the values at some selected angles and energies, which were derived from simulations with SRIM/TRIM [8]. However, only fewer protons impinge at angles larger than 10°, therefore practically all protons are propagated in a totally elastic regime. Averaging the distribution (1) over all azimuthal angles Φ gives the Firsov distribution:

$$W_F(\Theta)=(0.33\cdot 2\cdot\pi\cdot\alpha)^{-1}\cdot(\alpha\cdot\Theta^{1.5})/(\alpha^3+\Theta^3) \qquad (2)$$

2.2 Results

Fig. 3 shows the proton reflection efficiency versus incidence angle that is obtained using the distribution (1). The efficiency increases with the zenithal angle up to ~40°, then it remains almost constant. It reflects the fact that if the acceptance angle is increased more protons impinge on the entrance pupil, but protons impinging at larger angles are scattered less and at angles larger than 40° are almost not scattered at all, leading to an asymptotic behavior of the efficiency. Notice that the reported efficiencies are calculated assuming an open position of the filter wheel. Actually the standard observation mode foresees the presence of a medium filter composed by a layer of 200 nm Polymide on the filter wheel and 200 nm Aluminum plating on top of the pnCCD. This filter would stop protons up to ~40 keV, implying that the bulk of solar wind should be prevented from reaching the pnCCDs.

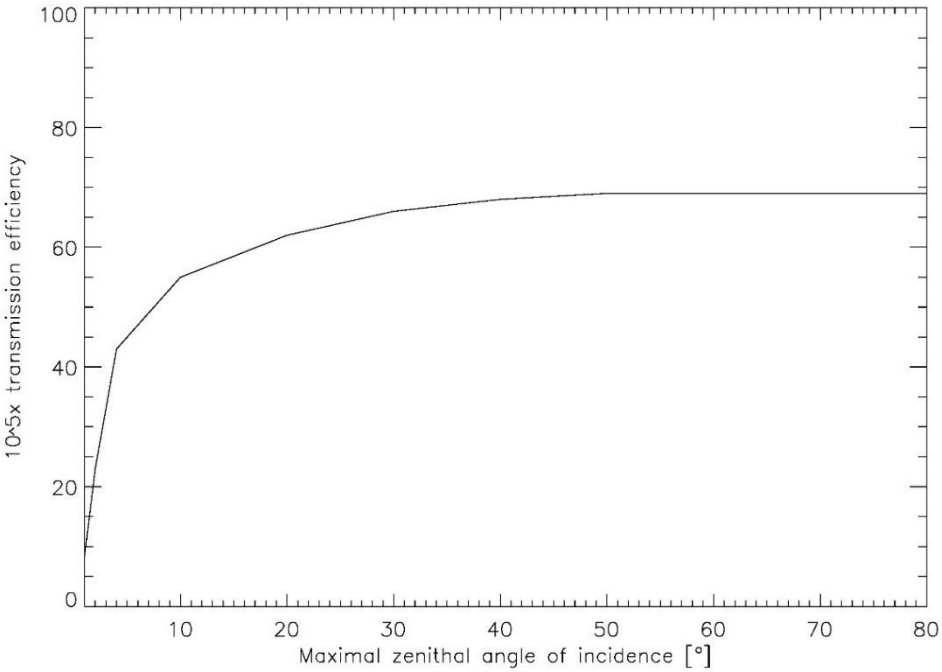

Figure 3. Simulated proton transmission efficiency vs. angle for the eROSITA mirror shells, assuming the Remizovich's probability distribution.

Multiplying the omnidirectional proton flux in the environment by the efficiency gives the flux on the detector. It seems reasonable to assume that at least in the orbital regions far away from the geomagnetic tail the fluxes are quite similar to those at L1. If we consider the quiet-time flux of supra-thermal protons measured by the Advanced Composition Explorer (ACE) [9], as it is shown in Fig. 4, we get a count-rate ~0.035 cts/cm^2/sec on the pnCCD, that is comparable to the background expected from the energetic galactic particles. Taking into account the energy loss in the optical filter, the proton flux in the band reduces to ~0.01 cts/cm^2/sec (Fig. 5).

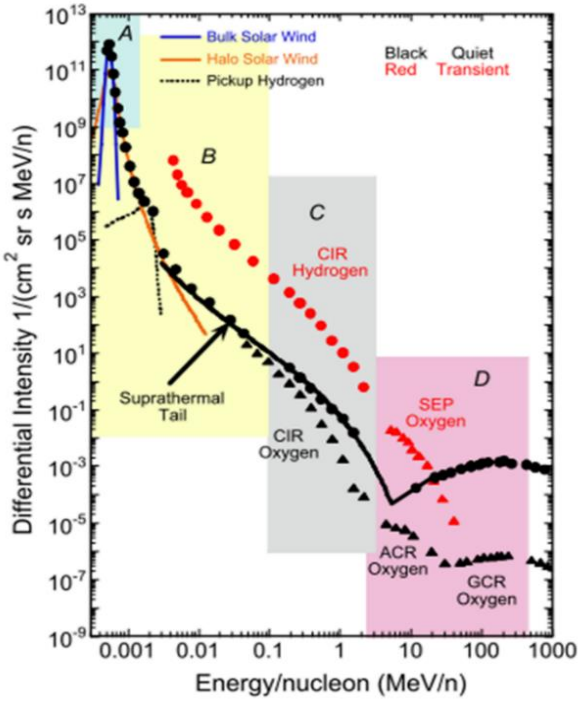

Figure 4. Soft proton fluxes measured by ACE at L1

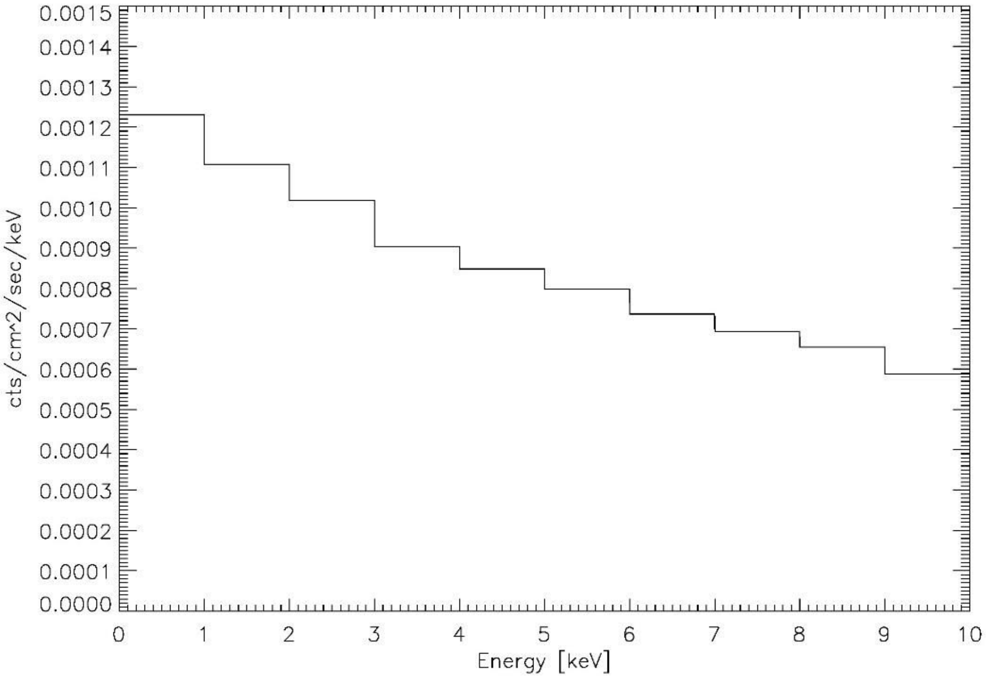

Figure 5. Simulated residual background on the pnCCD assuming at the entrance pupil the average quiet-time flux of soft protons measured by ACE at L1. All protons impinging at angles less than 10° are propagated elastically according to the Remizovich's distribution. Energy loss in the optical filter is taken into account.

The adopted approach can be considered conservative. We assumed that all impinging protons undergo reflection, while in the real case a fraction of protons could be absorbed at the interaction point with the mirror, even at grazing angle incidence. Furthermore, we remark that the totally elastic distribution (1) is an ideal description that does not take into account any peculiarity of the reflecting surface, e.g. material, microroughness. Hence, in the real case some deviations from the theory may be expected. To validate the model we use experimental measurements. Fig. 6 shows a schematic of the laboratory setup. The tests conducted up to now on eROSITA mirror samples [10], although still partial and restricted to an azimuthal angle ~ 0°, indicate that using the totally elastic distribution (1) at any incidence angle leads likely to overestimate the reflectivity. In Fig. 7 some newly taken data are reported, showing that in some cases the discrepancy results quite large. Further tests will be needed to clarify whether there is any threshold angle at which the proton scattering changes from inelastic to an elastic (or quasi-elastic) one.

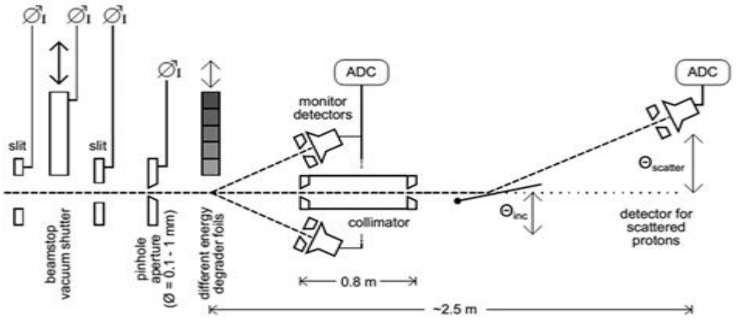

Figure 6. Schematic of the proton scattering setup implemented at the Van de Graaf accelerator of the University of Tuebingen.

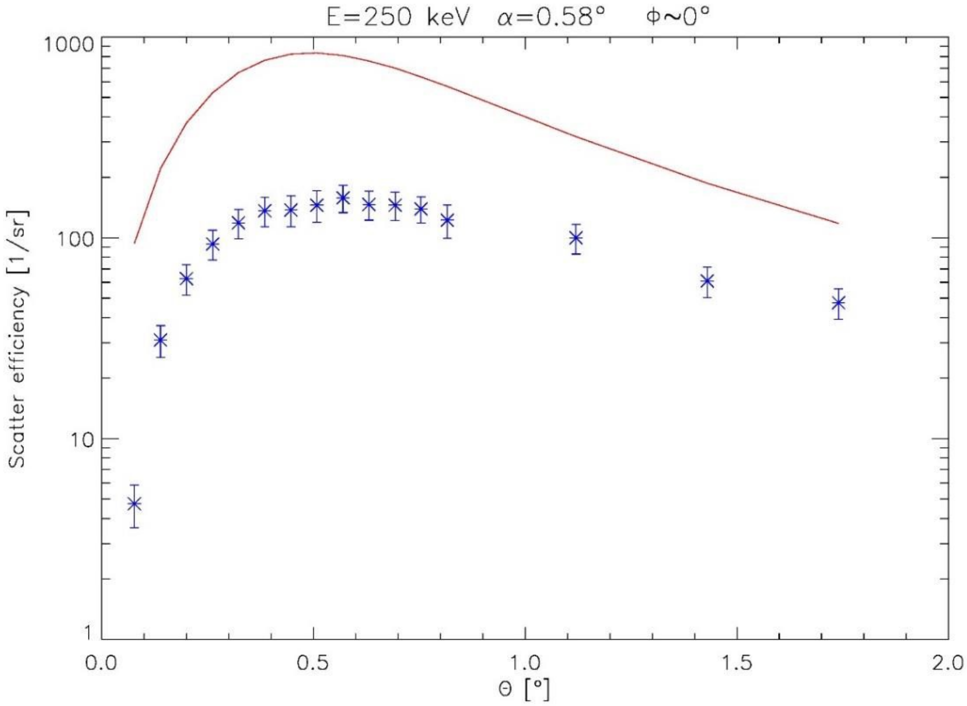

Figure 7. *Blue*: scatter efficiency measured in laboratory for 250 keV protons impinging at 0.58° onto an eROSITA mirror sample. The angle Θ is measured along the polar direction, at an azimuthal angle ~φ0. *Red*: scatter efficiency calculated using the elastic Remizovich's distribution.

3. CONCLUSION

We implemented a simulator to follow the track of protons from the eROSITA entrance pupil down to the focal plane, in order to calculate expected rate and quantify the possible contribution to the pnCCD background. The tool is quite flexible and allows to easily switch from a theoretical model (e.g. the Remizovich's one) of the reflection process to an empirical one that relies on a dataset of scatter angles and energies obtained from TRIM. Laboratory measurements are currently used to validate the adopted models.

ACKNOWLEDGEMENTS

This work is partially supported by the *Bundesministerium für Wirtschaft und Technologie* through the *Deutsches Zentrum für Luft und Raumfahrt e.V. (DLR)* under the grant number FKZ 50 QR 0702

REFERENCES

[1] G. Y. Prigozhin et al.,Proc. of SPIE, 4140, 123, 2000
[2] *XMM-Newton User´s Handbook*
[3] A. De Luca et al., A&A, 419, 837, 2004
[4] P. Predhel et al., Proc. of SPIE, 8443, 8443-1R, 2012
[5] E. Pfefferman et al., Proc. of SPIE, 0733, 519, 1986
[7] V.S. Remizovich et al., Sov. Phys. JETP, 52, 2 ,1980
[8] www.srim.org
[9] www.srl.caltech.edu/ACE/
[10] S. Diebold et al., Exp. Astr., 39, 343, 2015