Monitoring of Night Sky UV Radiation by One-pixel Detector

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AtmoHEAD 2018

Overview

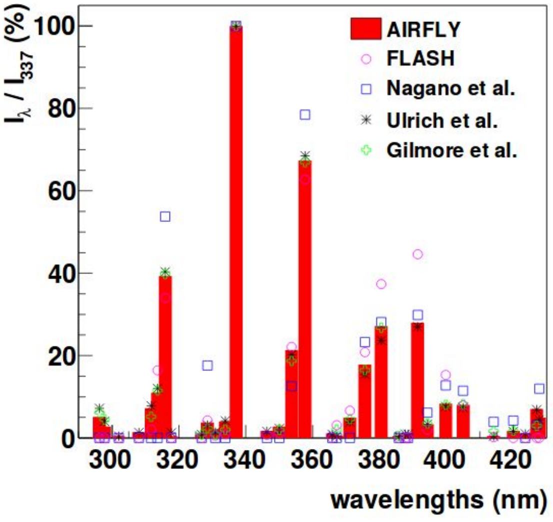
- The role of UV airglow for EAS detection
- Description of UV one-pixel Airglow MONitor (AMON)
- AMON data reduction and first results
- Next steps

Abstract

The night time UV radiation composed of airglow, starlight, and zodiacal light act as a background for detection of the Extensive Air Shower (EAS) fluorescence induced by Ultra-High Energy Cosmic Rays (UHECR). To monitor this background, we have developed the one-pixel instrument that provides the absolute intensities within the spectral range 300 - 480 nm in the one second temporal resolution. The instrument is designed to be unpretending, resistant, and to operate in full automatic mode. Therefore it could be placed in various locations and provide long-term measurements. The first results from four such instruments demonstrate that the data might be useful not only for the high-energy astrophysics purposes but also for the studies of the airglow dynamics.

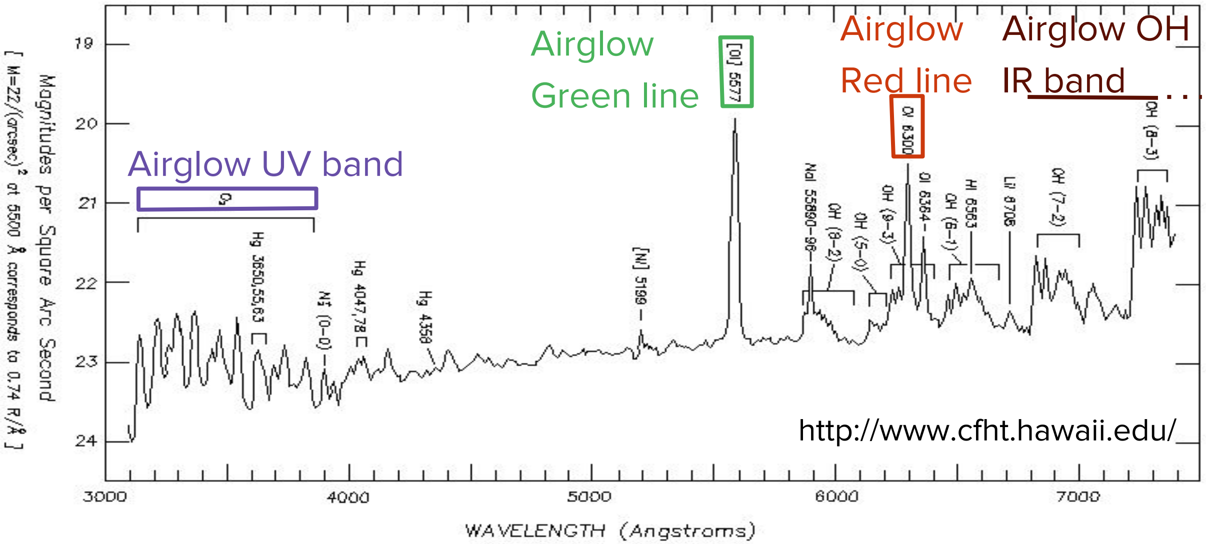

Image by: S. Mackovjak, Slovakia, 2018/05/13

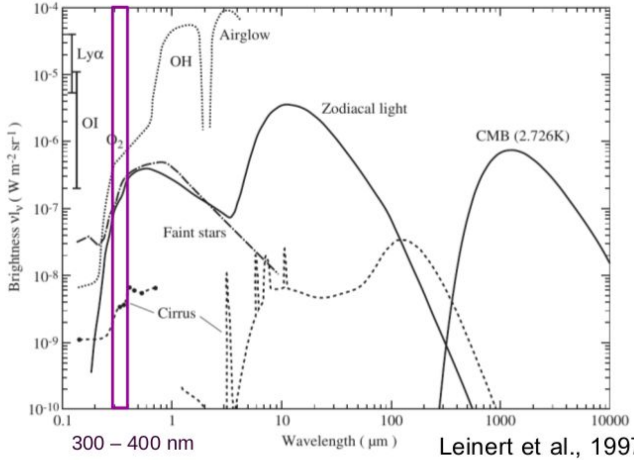
Relative EAS fluorescence intensities



Keilhauer et al. (2012)

Typical spectrum of visible night sky emission at Mauna Kea





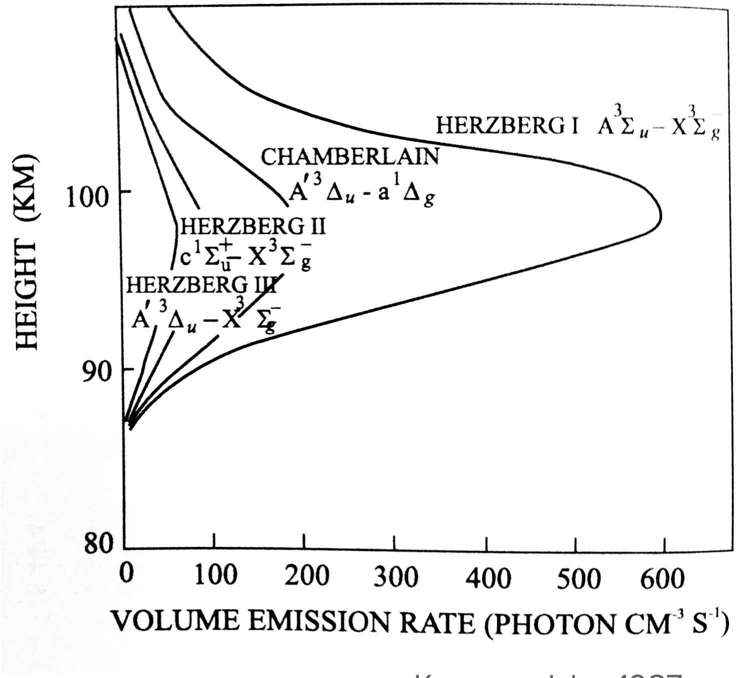
Leinert et al., 1997

- The absolute value of UV background is essential for evaluation of EAS induced by UHECR energy threshold
- The O_2 airglow is main part of UV background

Origin of airglow with λ ~ 250 - 500 nm

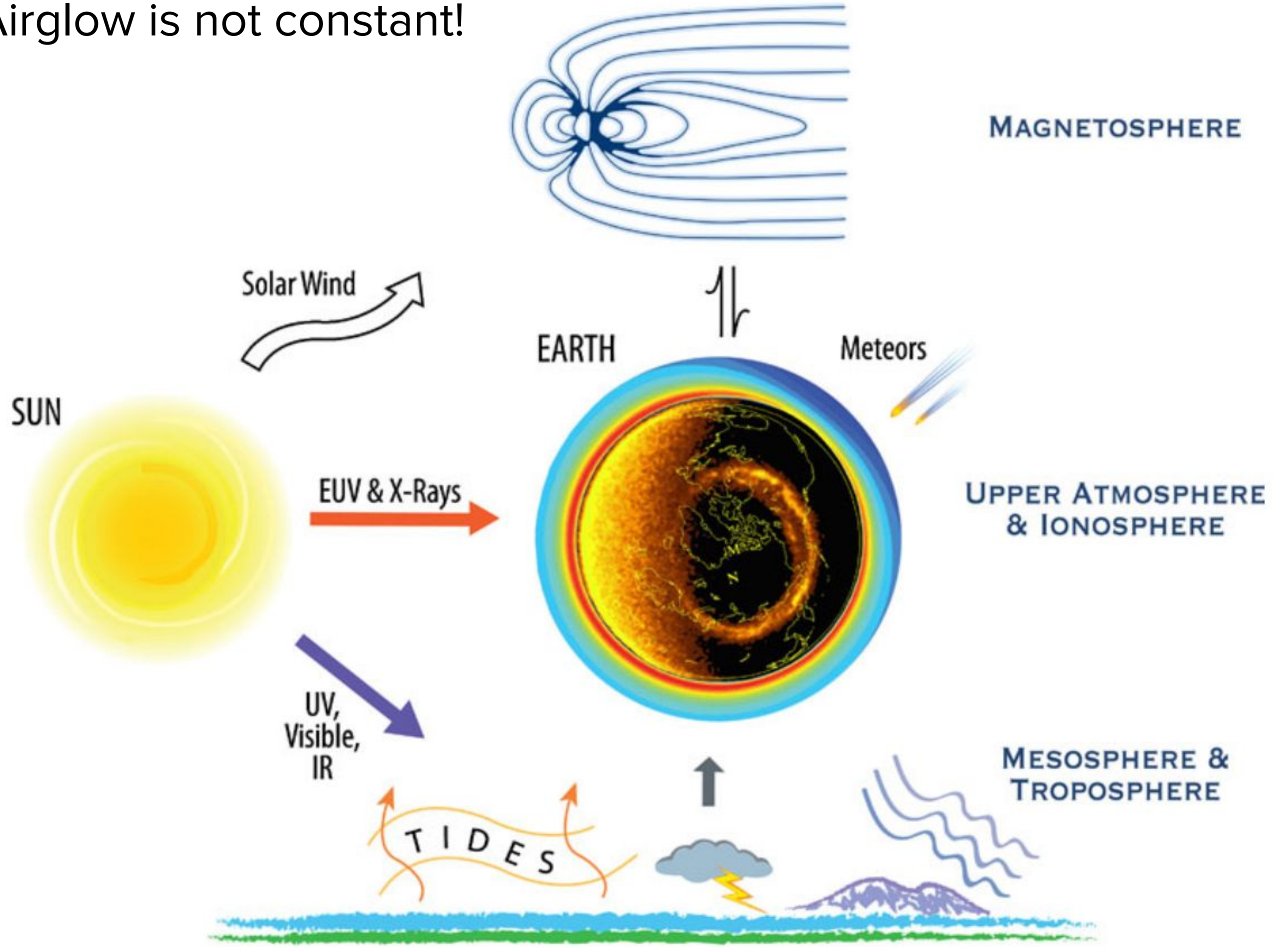
- ➢ Molecules of oxygen (O_2) are dissociated by solar UV radiation (λ < 242.2 nm) during the day
  $O_2 + h\nu \rightarrow O + O$
- ➢ During the night the atoms of oxygen are recombined to O_2^* excited molecules
  $O + O + M \rightarrow O_2^* + M$
- ➢ The molecules in metastable state have short lifetime. It is followed by emission of photon
  $O_2^* \rightarrow O_2 + h\nu$

According electronic transitions responsible for UV emission the band systems are defined. The most intensive is Herzberg I system.



Krasnopolsky, 1987

Airglow is not constant!

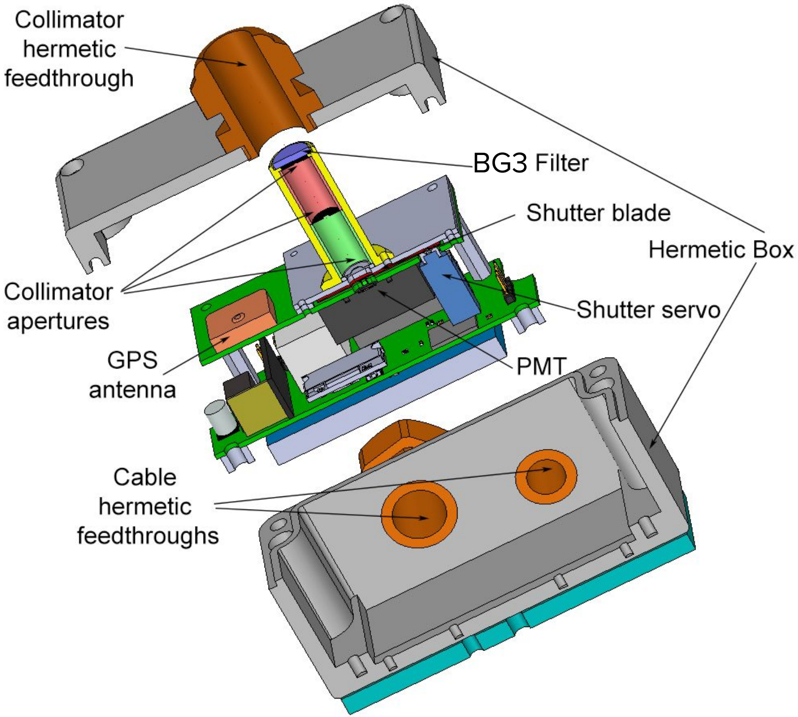


Pfaff, 2012

Global-scale Observations of the Limb and Disk / NASA /2018

/ NASA / 2018

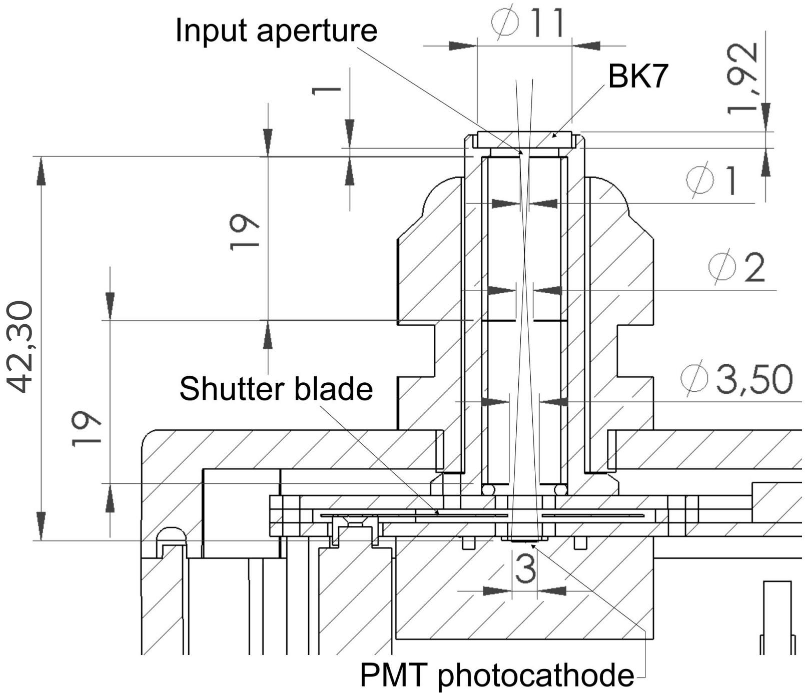
AMON - Airglow MONitor *- developed by DSP*

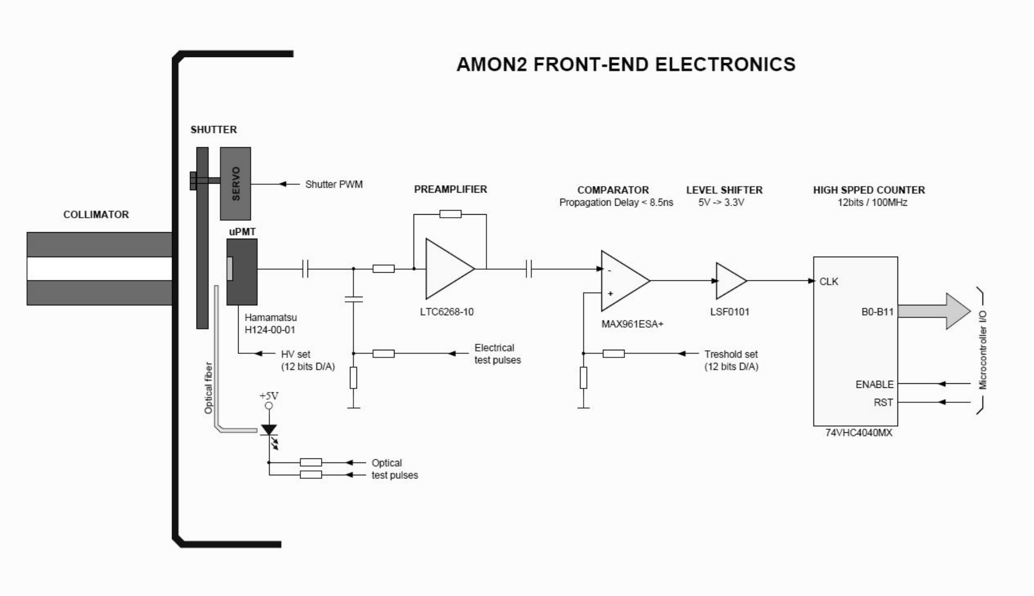


AMON @ AO Kolonica Saddle, Slovakia, 2018/05/23

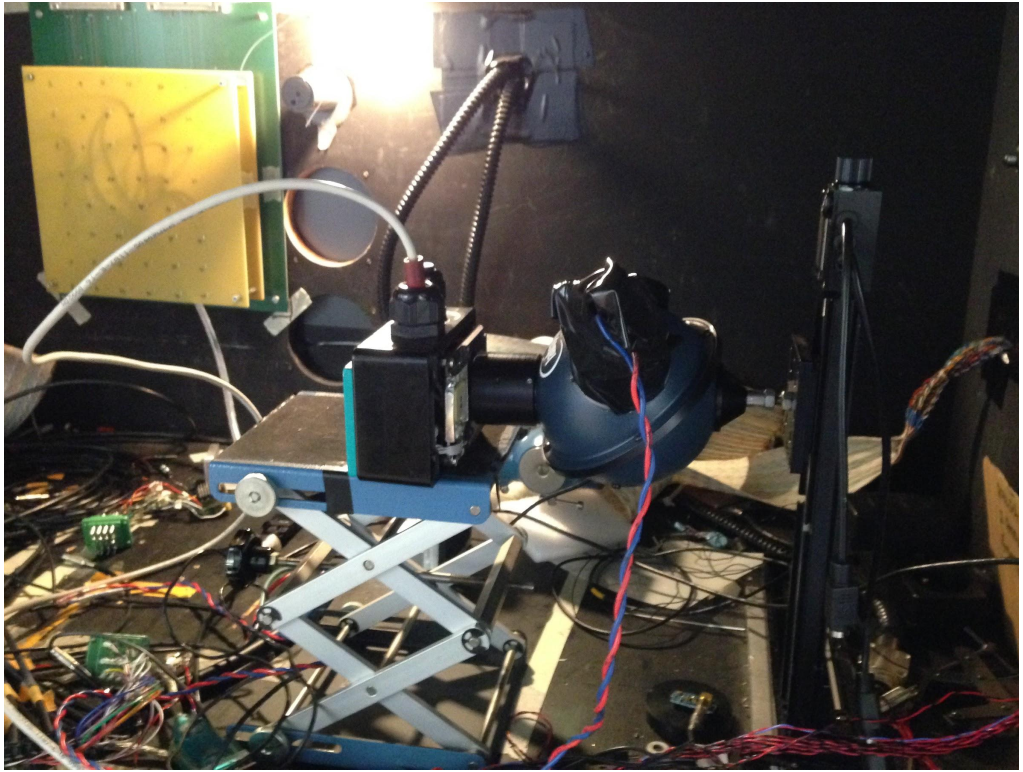
AMON: design

Design is inspired by EUSO instruments (µPMT + BG3 filter) but it is simpler and therefore cheaper

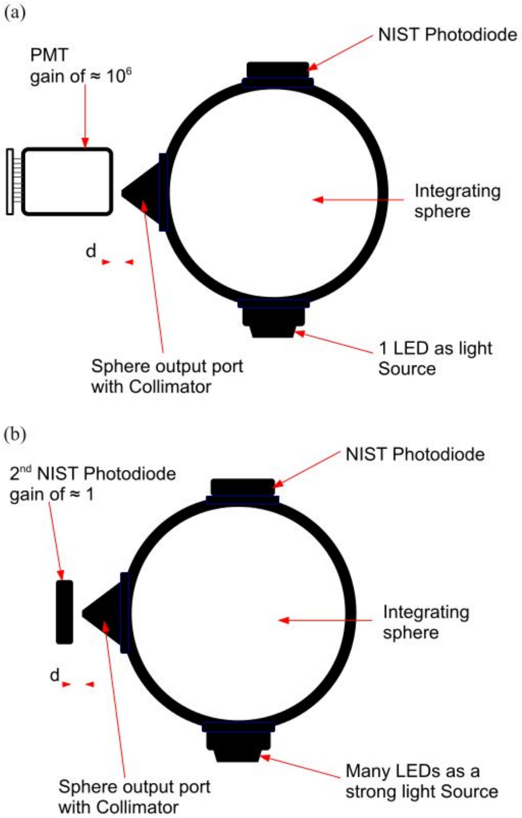




AMON: calibration at APC lab, Paris, France (March 2018)



AMON @ APC, Paris, 2018/03/20

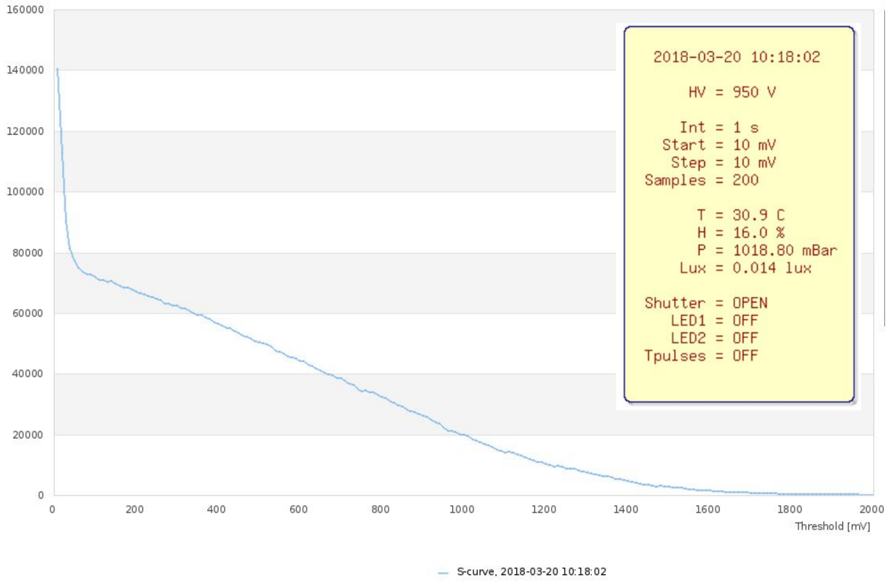


Blaksley & Gorodetzky (2014)

AMON: response

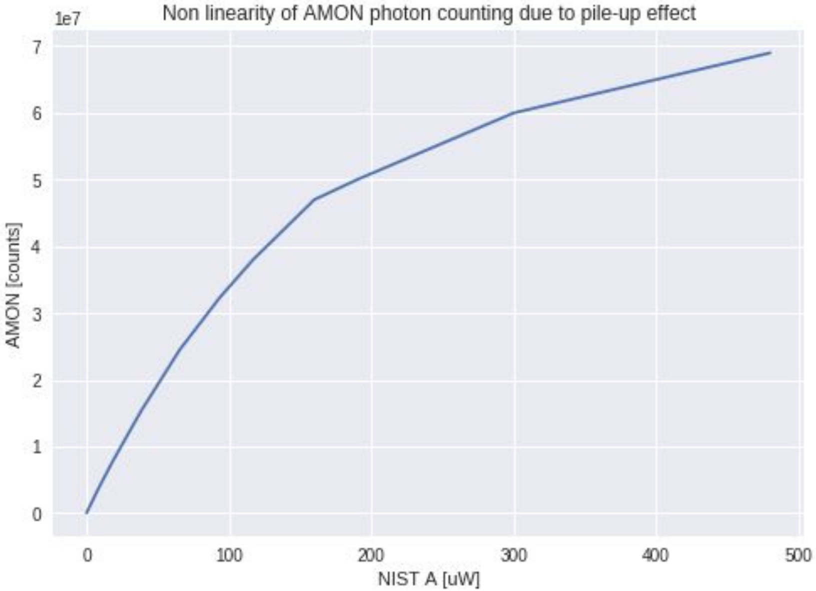
S- curve measurements result:

- HV set to: 950 V
- Threshold: 100 mV



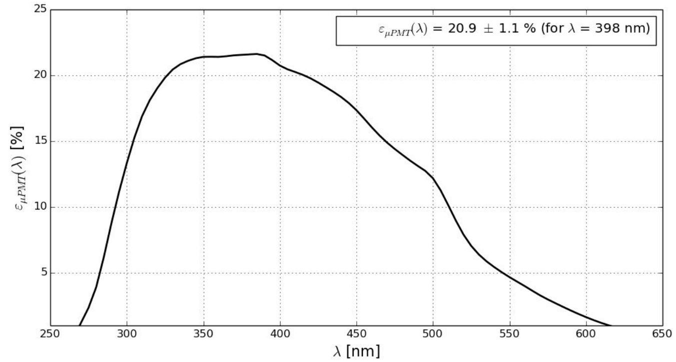
Pile-up measurements result:

- μPMT response is linear up to $3.45x10^6$ counts

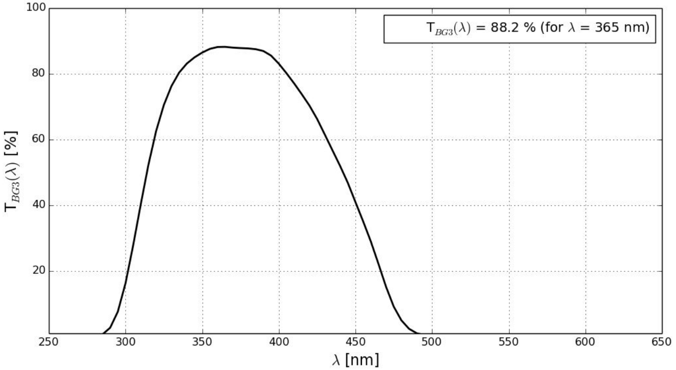


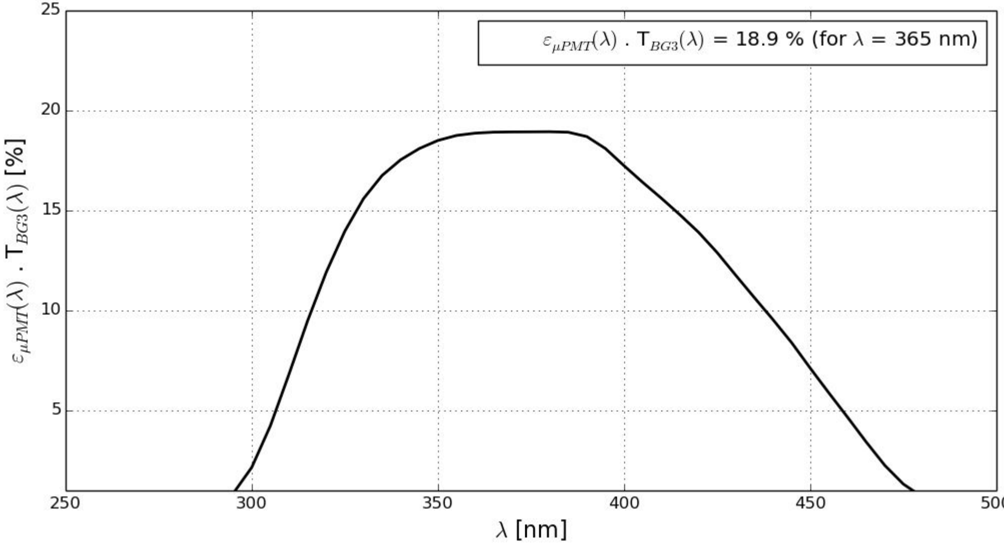
AMON: spectral efficiency ($\varepsilon_{\mu PMT}(\lambda)\ T_{BG3}(\lambda)$)

μPMT: absolute calibration for λ=398 nm + Hamamatsu datasheet



BG3: Thorlabs datasheet





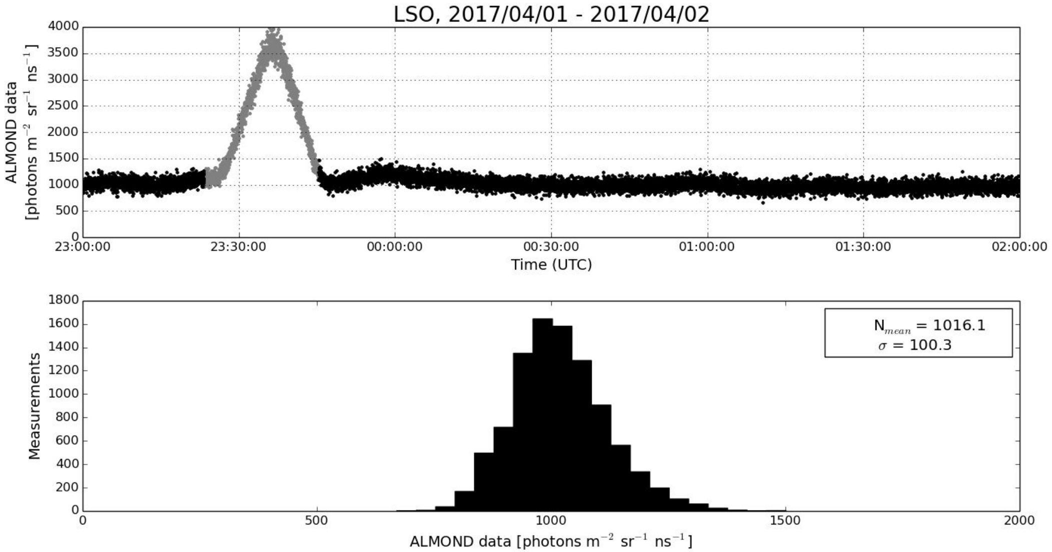
Uncertainty of calibration: 5%

AMON: absolute intensity of NSB

AMON data (R) [counts/s] are converted to [photons m^{-2} sr^{-1} ns^{-1} nm^{-1}] by:

$$\langle NSB \rangle = \frac{R \times 10^{-9}}{GF \int_0^\infty \varepsilon_{\mu PMT}(\lambda)\ T_{BG3}(\lambda)\ d\lambda}$$

assuming $\Delta\lambda$ = 480 - 300 = 180 nm and NSB is constant over this range



total uncertainty: up to 15%

AMON-net: locations

AMON-net: locations

01 - Slovakia
02 - Mexico
03 - La Palma
04 - Germany *

Our thanks to:

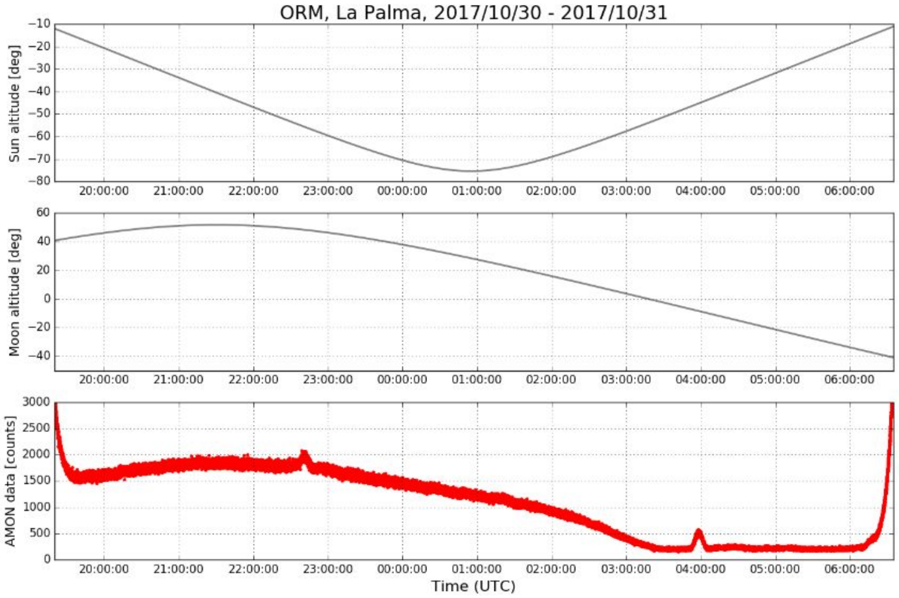
SE: S. Åminneborg, C. Fuglesang
ES: M. R. Garcia Talavera, M. D. Rodriguez Frias
MX: G. Medina-Tanco
IT: M. Bertaina
SK: I. Kudzej
DE: C. Schmidt

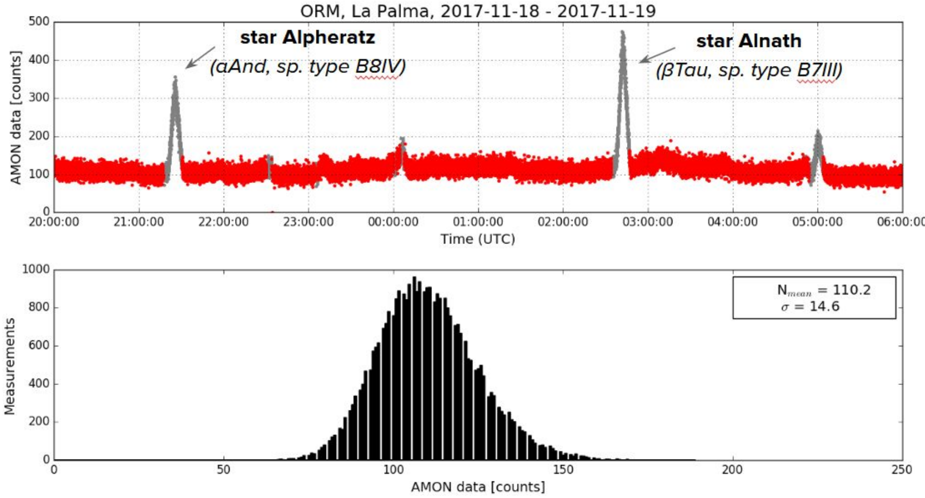
Cooperation @ new locations is welcomed!

Data reduction: influance of astronomical objects

- **The Sun altitude** above horizon - **less than -18 deg**
- **The Moon altitude** above horizon - **less than 0 deg**

- **Contribution from bright stars shall be removed** (eg. by Poisson filter)



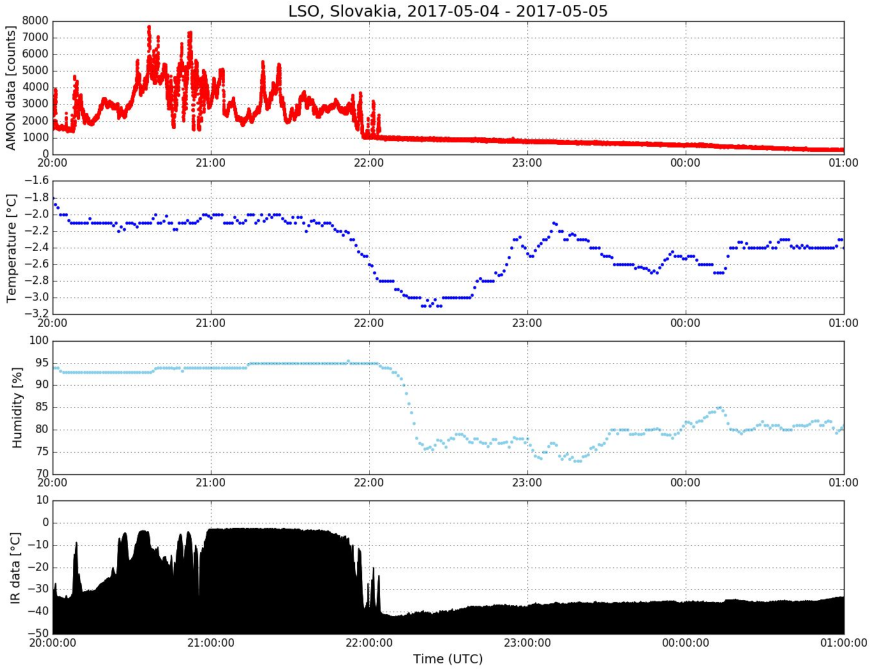


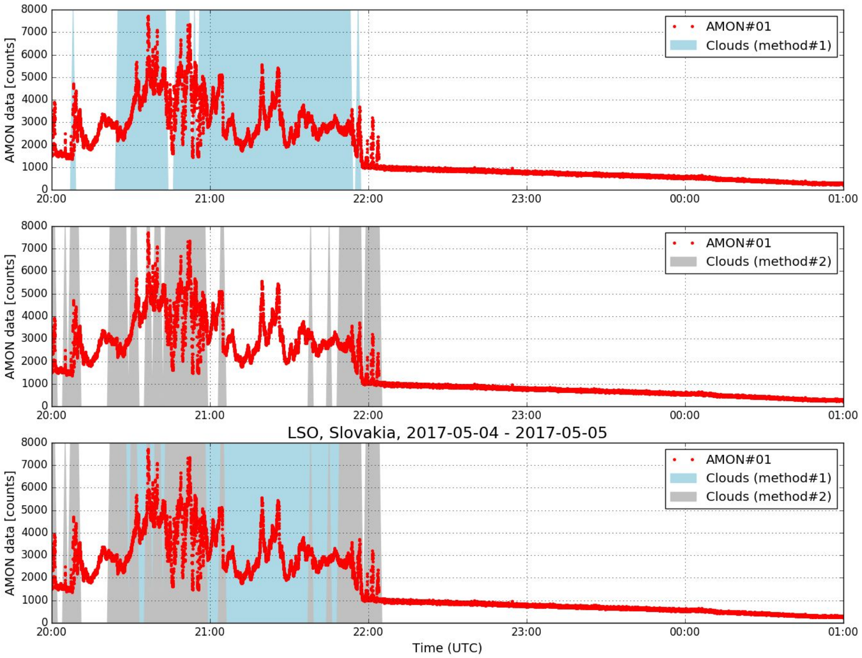
Data reduction: influance of clouds

Effective cloud detection can be done by combination of:

- thermometer
- humidity meter
- 1px infrared (IR) sensor (wvl ~10 - 11.5 μm)

➔ 2 methods described in:
M. H. Ahn et al., 2015, *Atmos. Meas. Tech.*, 8, 553

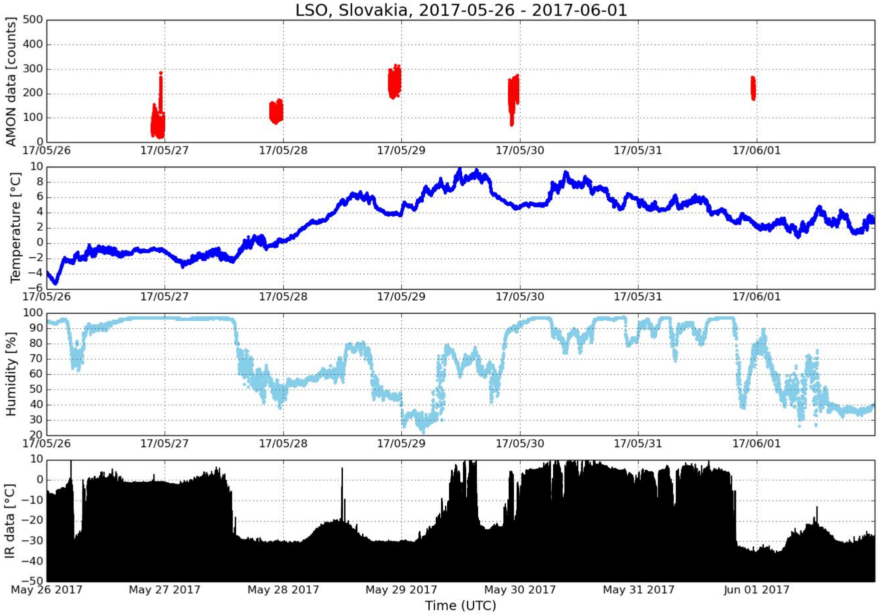


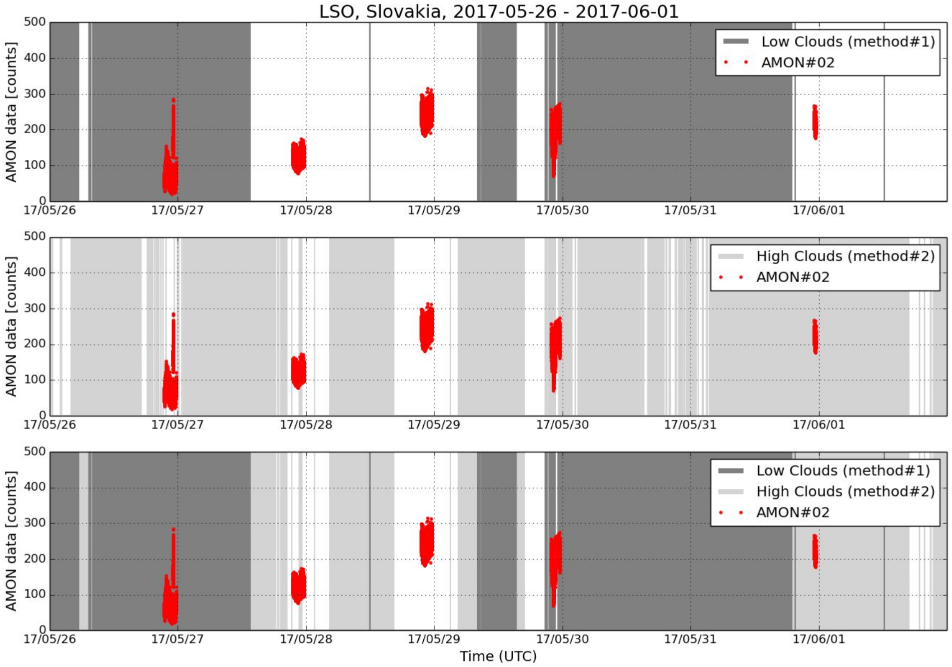


AMON-net: clouds detection

AMON data can't be interpreted without exclusion of contamination

from: Sun, Moon, bright stars & Milky Way, and clouds

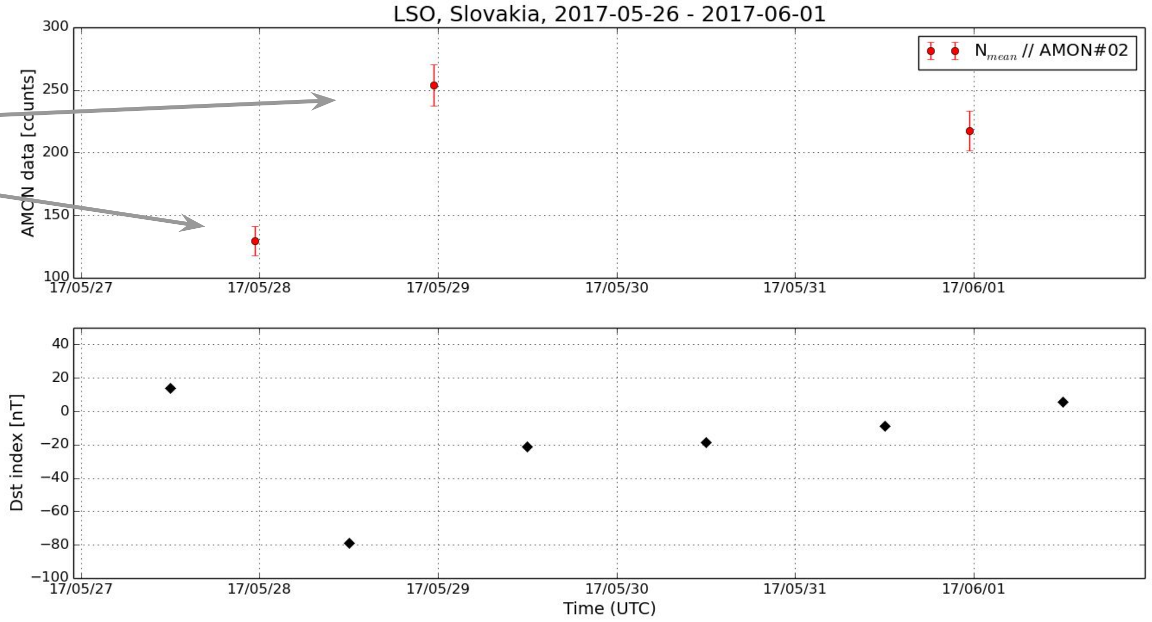


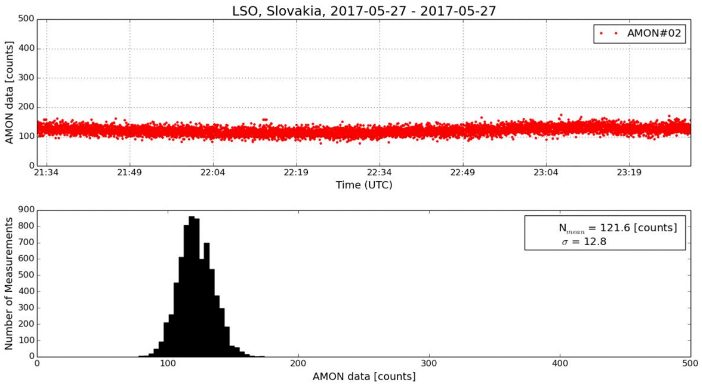


AMON-net: short term variation

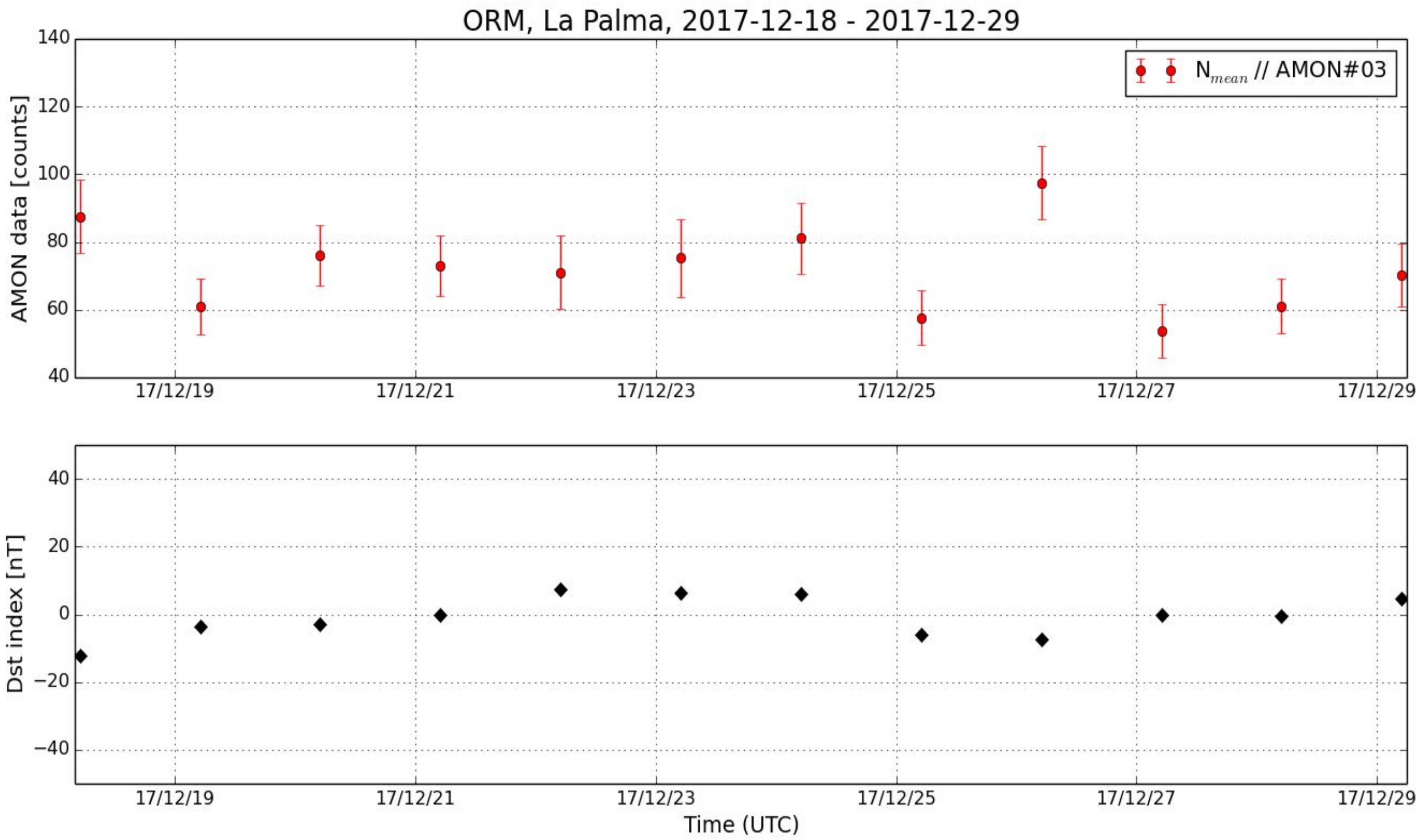
What is source of this variation?

- instrument?
- atmospheric conditions?
- airglow?

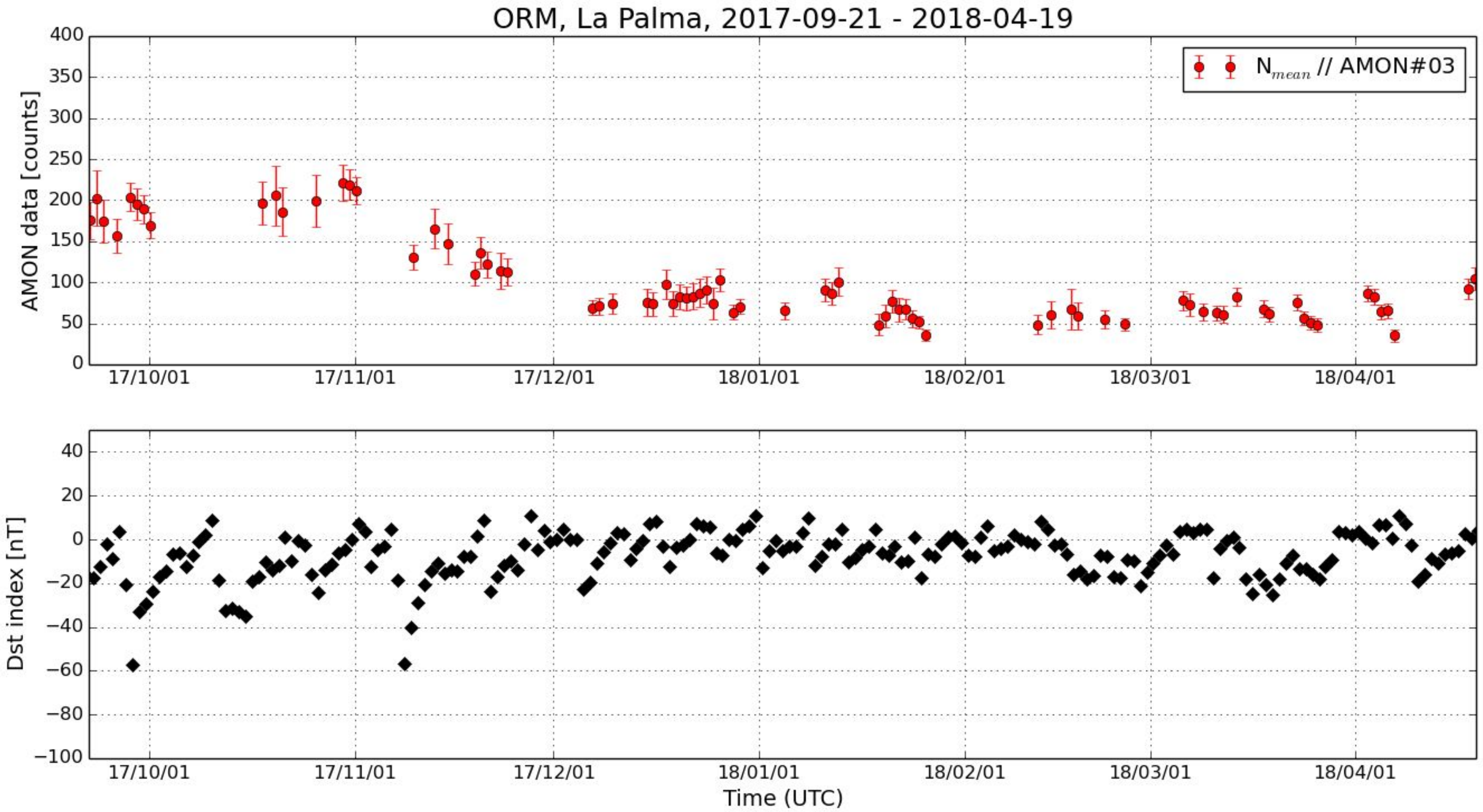




AMON-net: short term variation

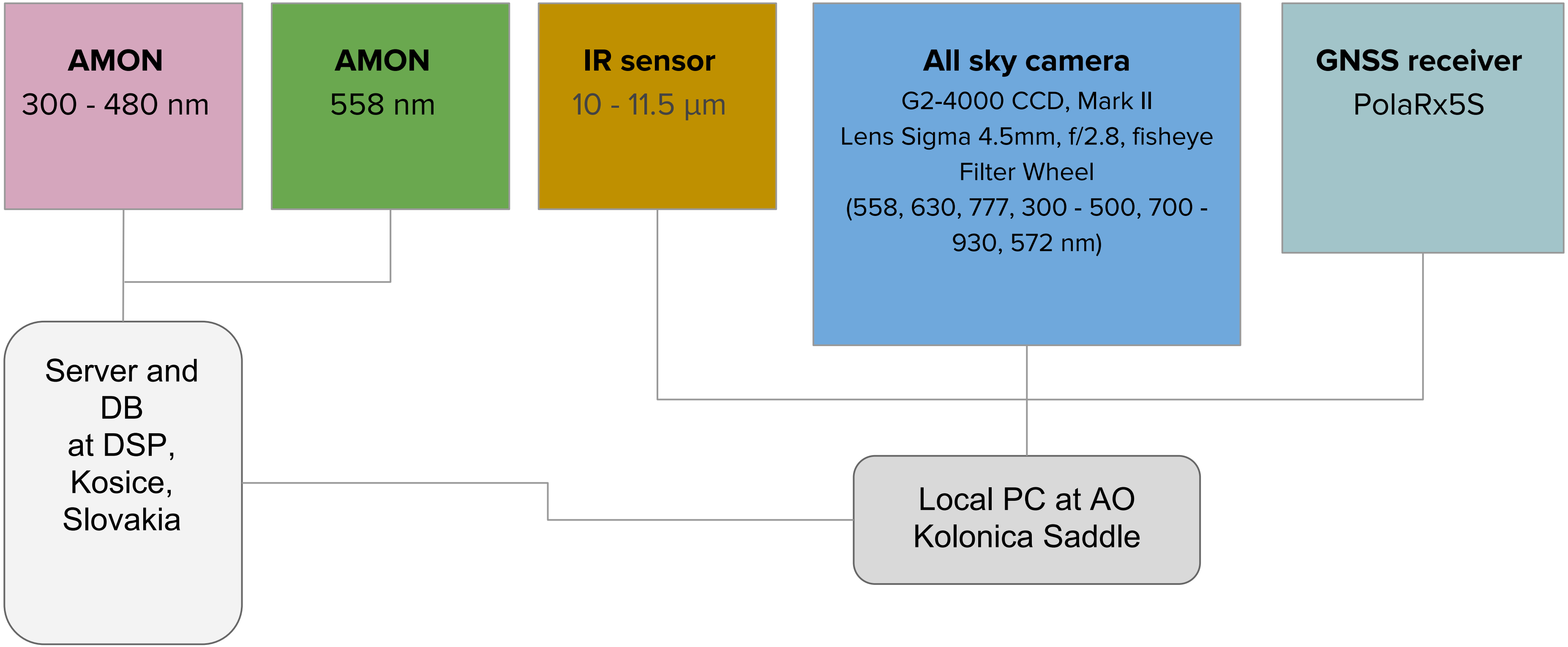


AMON-net: long term variation



AMON-ES: AMON - Extended Station

- Astronomical Observatory at Kolonica Saddle (East Slovakia)



AMON paper

- Description of instrument
- Characterization of the detector and calibration
- Data reduction
- Absolute intensity
- Indication of – airglow variation

- **To be submitted to *Nuclear Instruments and Methods in Physics Research A***

  -> in October 2018

Airglow Monitoring by One-pixel UV Detector

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[b] *AstroParticle and Cosmology Laboratory, University Paris Diderot/CNRS – IN2P3, 10 rue A. Domon et L. Duquet, 75013 Paris, France*

Abstract

The night time airglow is a dynamic phenomenon that acts as a background for the detection of the Extensive Air Shower (EAS) fluorescence. Therefore it is a mandatory task to monitor this background for the ground-based telescopes as well as for the planned space-based telescopes dedicated to observe the EAS events induced by ultra-high energy cosmic rays. To perform this task, we have developed a one-pixel Airglow MONitor (AMON) instrument. This instrument provides the absolute intensities of the measured night sky background in the near-ultraviolet spectral range and in the one second temporal resolution. It is designed to be unpretending to operate in the different locations and so to offer required spatial resolution. The first results demonstrate that AMON data might be useful not only for the high-energy astrophysics purposes but also for the studies of the airglow dynamics.

Keywords: photon detector, airglow, night sky background, extensive air shower, ionospheric disturbances

1. Introduction

The upper atmosphere of the Earth is continuously influenced by solar radiation with short wavelengths. The processes as ionization and dissociation of atmospheric atoms and molecules are followed by recombination and photochemical reactions that lead to the production of a faint light commonly known as an airglow [1] [2] [3]. The airglow can be effectively observed by ground-based detectors during the night time while the direct sunlight is absent e.g. [4] [5]. A such measurements are important for the characterization and understanding of the airglow intensity variations in dependency to geographical position, time, solar cycle, geomagnetic activity and changes in the Earth's atmosphere [6] [7]. The role of the airglow measurements has become important also for high energy astrophysics in the last decades. The night airglow light with contribution of the starlight and the zodiacal light effects as a diffuse Night Sky Background (NSB) for detections of the Extensive Air Shower (EAS) events. The estimation of absolute intensity of this background is essential for energy evaluation of EAS events with low statistics i.e. events induced by interactions of Ultra-High Energy Cosmic Rays (UHECR) or Very High Energy (VHE) gamma rays in the Earth's atmosphere [8] [9].

The EAS fluorescence light is produced when the nitrogen molecules (N_2) are excited by the interaction with EAS secondary particles and the following spontaneous de-excitation generates photons with characteristic wavelengths within range 290 – 430 nm [10]. By looking from the ground, the NSB for these events is composed mainly by the molecular oxygen (O_2) airglow radiation that is generated by the following process. The molecules of O_2 are dissociated by the solar short wavelength radiation during the day. During the night, the atoms of oxygen (O) are recombined to oxygen excited molecules (O_2*). The molecules in metastable state have a short lifetime, therefore the recombination is followed by the emission of the photons. According electronic transitions responsible for near-ultraviolet (NUV) emission, the band systems are defined. The most intensive band systems are Herzberg I, Herzberg II, Herzberg III, and Chamberlain system with the wavelength range 250 – 500 nm and the maximum of production at altitude ~ 90 – 100 km a. s. l. [6].

To measure the absolute intensity of the NSB with respect to the dynamics of the airglow, we have developed an instrument AMON (Airglow MONitor). It is designed to be unpretending to power consumption and data rate, resistant to whether conditions, and to have low construction and operation expenses. All these fea-

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Preprint submitted to Nucl. Instr. Meth. Phys. Res. A *September 21, 2018*

Conclusions and Next steps

- AMON provides absolute intensity that is consistent with results of other authors Preuss et al. (2002), Hampf et al. (2011), Maccarone et al. (2011)
- AMON-net has an ambition to be useful for High Energy Astrophysics and also for airglow science - provide absolute values according input spectrum, season, location

➢ AMON-ES will be constructed (2018-2019)

➢ AMON design will be improved (2019)

➢ AMON-net will be enlarged (2020)

➢ AMON will be employed in EUSO-SPB2 mission (2021)

[contact: mackovjak@saske.sk]

Backup slides

Why UV bg. is important for cosmic ray physics?

- For determination of energy threshold and exposure for EAS observations

$$(\text{Overall exposure}) \propto \int_0^{I_{\mathrm{BG}}^{\mathrm{thr}}} A\left(\sqrt{\frac{\langle I_{\mathrm{BG}}\rangle}{I_{\mathrm{BG}}}}\cdot E\right)\cdot p(I_{\mathrm{BG}})dI_{\mathrm{BG}}$$

- For estimation of duty cycle

$$\eta\left(< I_{\mathrm{BG}}^{\mathrm{thr}}\right) = \eta_{\mathrm{night}}\int_0^{I_{\mathrm{BG}}^{\mathrm{thr}}} p(I_{\mathrm{BG}})dI_{\mathrm{BG}}$$

(JEM-EUSO, Astropart. Phys., 2013)

- In general, for simulations, trigger and data analysis of the main mission

For space-based cosmic ray physics, UV background is just a “background” that need to be monitored and it is not interesting by itself.

But we will have a large amounts of measurements of a such background, so it will be a pity not to use these data for some science.

AMON: geometrical factor (*GF*)

If $L_{pix} << D$: $$GF \simeq \frac{A_{\mu PMT}\, A_{entrance}}{D^2}$$

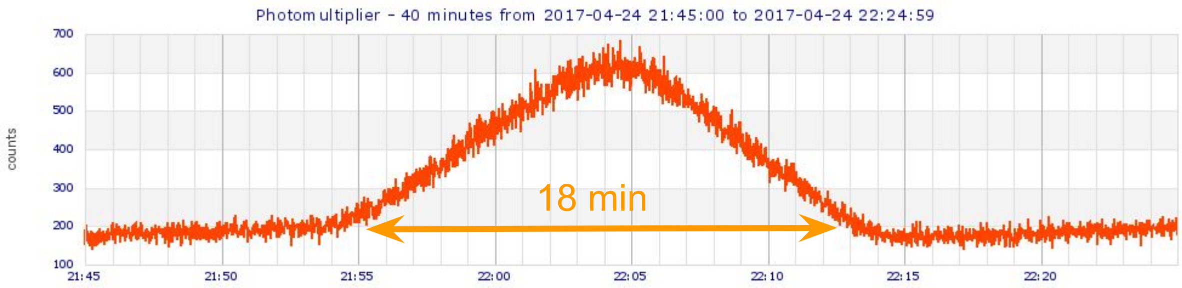
$A_{\mu PMT} = L_{pix\_a}\, L_{pix\_b}$ = 3 mm x 1 mm = 3×10^{-6} m^2 : area of *μPMT*

$A_{entrance} = \pi r^2 =$ 7.85×10^{-7} m^2 : area of entrance at collimator

D^2 = (42.3 mm)^2 = 2.01×10^{-3} m^2: square of distance between $A_{\mu PMT}$ and $A_{entrance}$

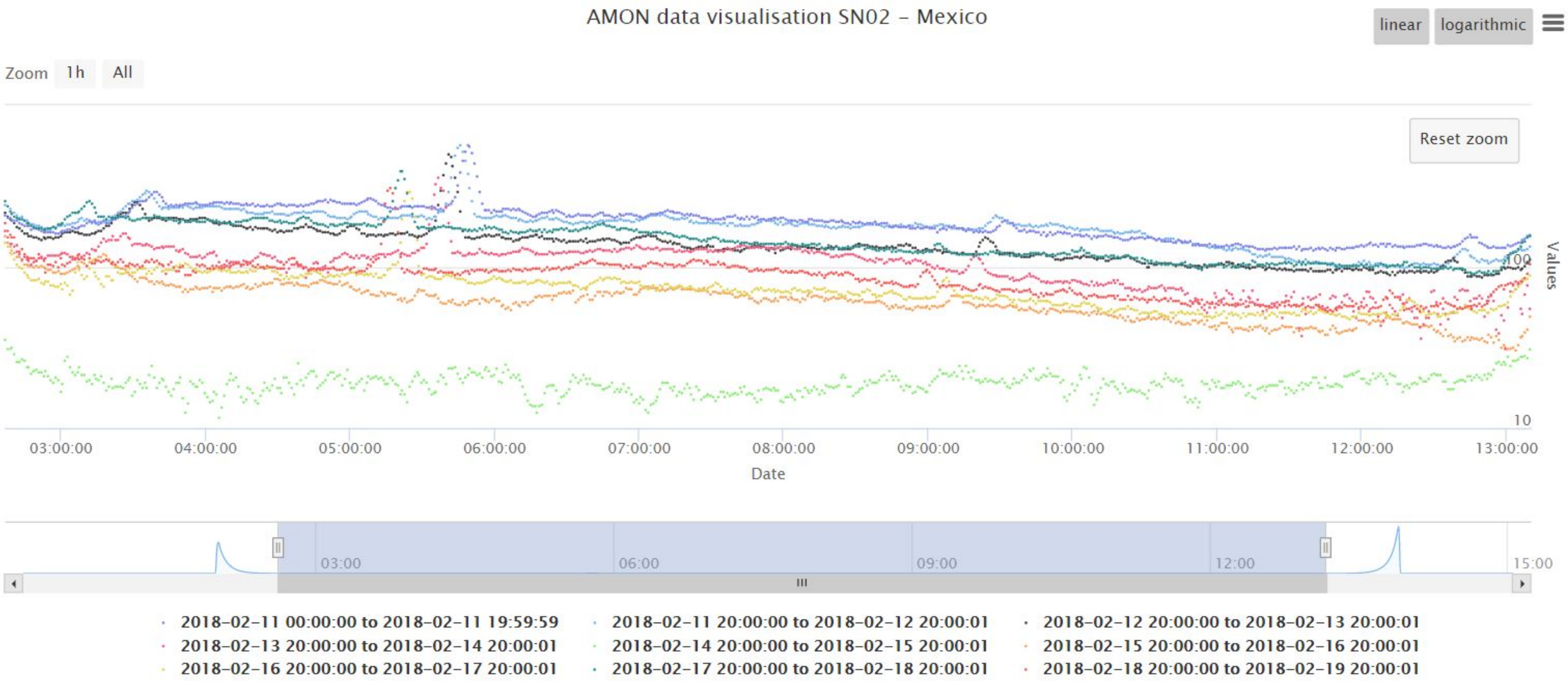
GF = 1.32 x 10^{-9} m^2 sr

consistency within 10 %



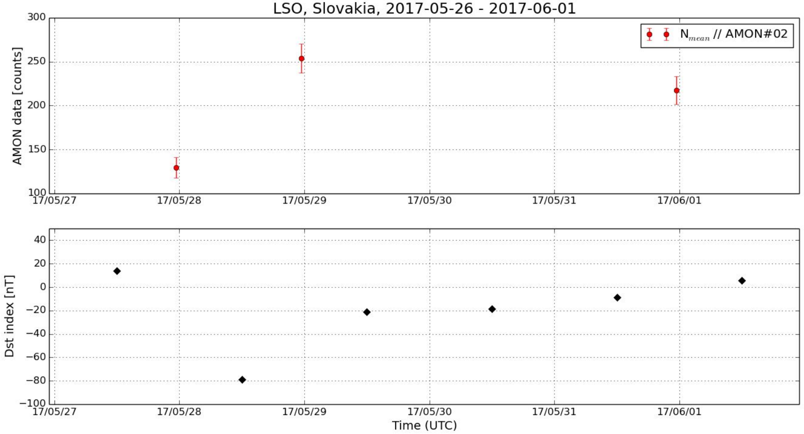
φ = 360 deg * 18 min / 1440 min = 4.5 deg

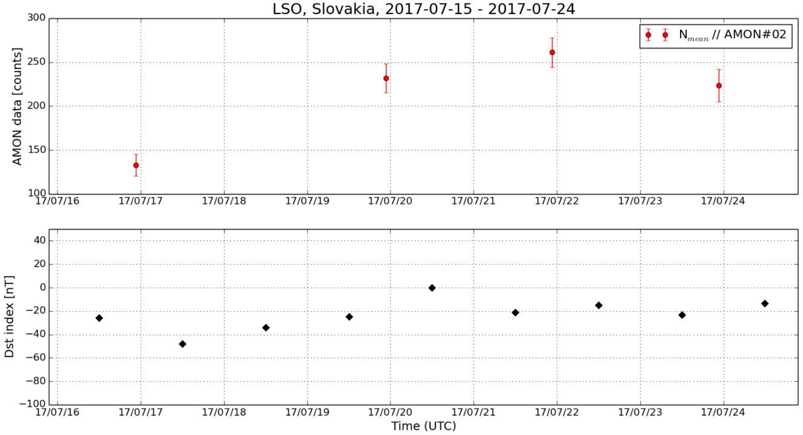
AMON-net Visualizer: http://amonviewer.crmodels.org/

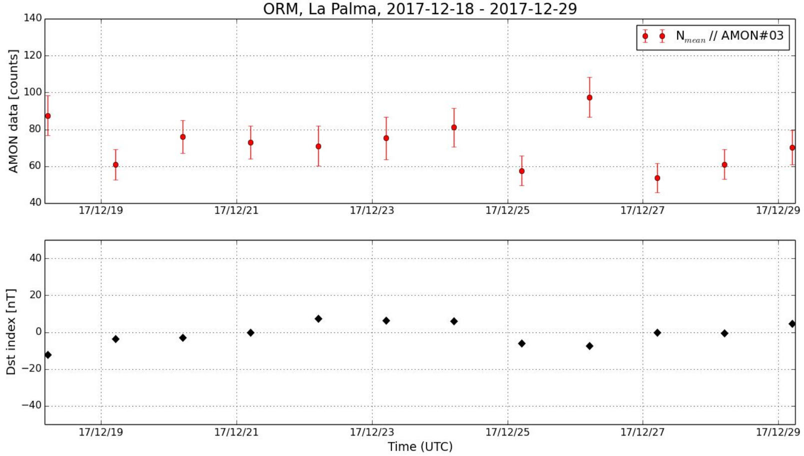


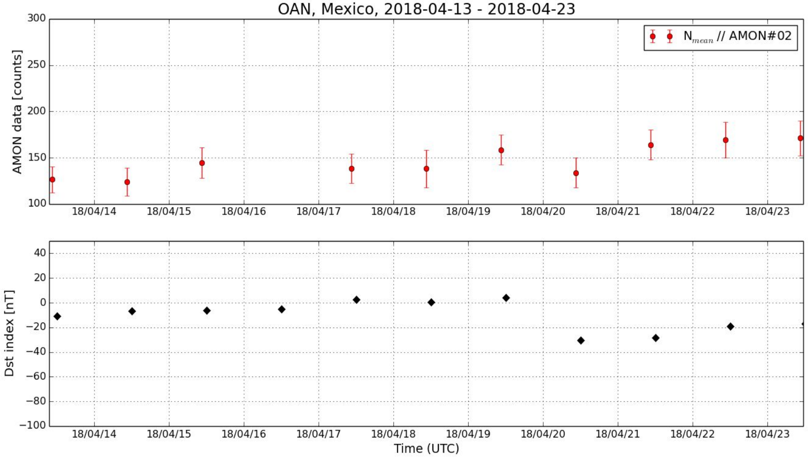
➔ prepared by P. Bobík and his student R. Hreško

AMON-net: short term variation









AMON-net: long term variation