JEM-EUSO duty cycle estimation

Influence of city lights

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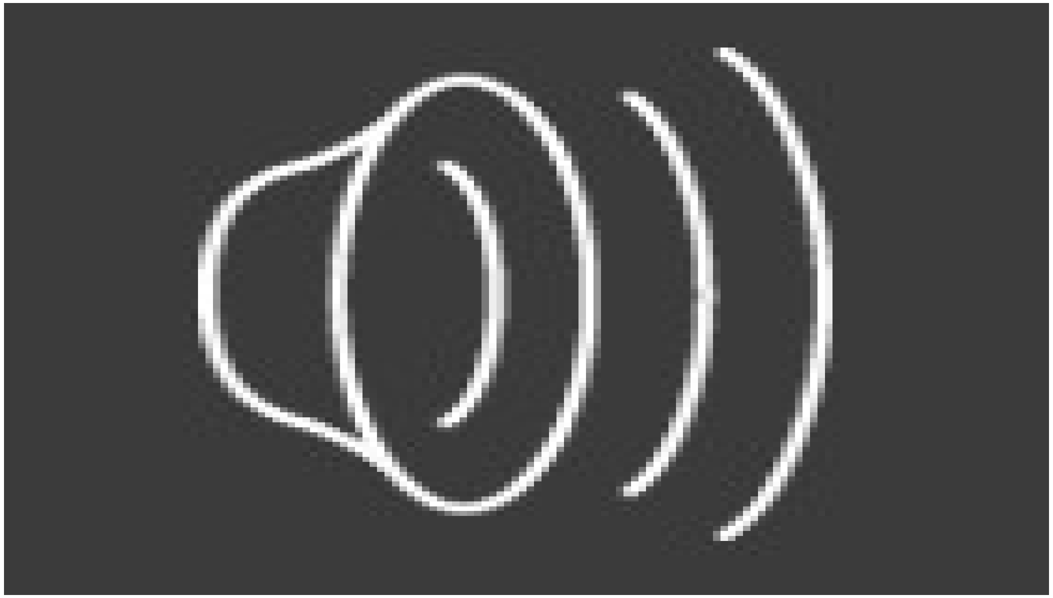
UV background estimation – duty cycle estimation

UV light sources

- sun
- moon
- **airglow/nightglow**
- zodiacal light
- integrated faint star light
- lightnings
- Boreal/austral auroras
- **artificial sources**



This video over the Mediterranean Sea was taken by the crew of Expedition 29 aboard the International Space Station. This sequence of shots was taken on Oct. 6, 2011, from 22:58:09 to 23:13:15 GMT, on an ascending pass from just west of the Strait of Gibraltar, over the Atlantic Ocean to northern Kazakhstan. The first significant landmark is the Strait of Gibraltar, separating Spain and Morocco.

UV background estimation – duty cycle estimation

UV light sources

- sun
- moon
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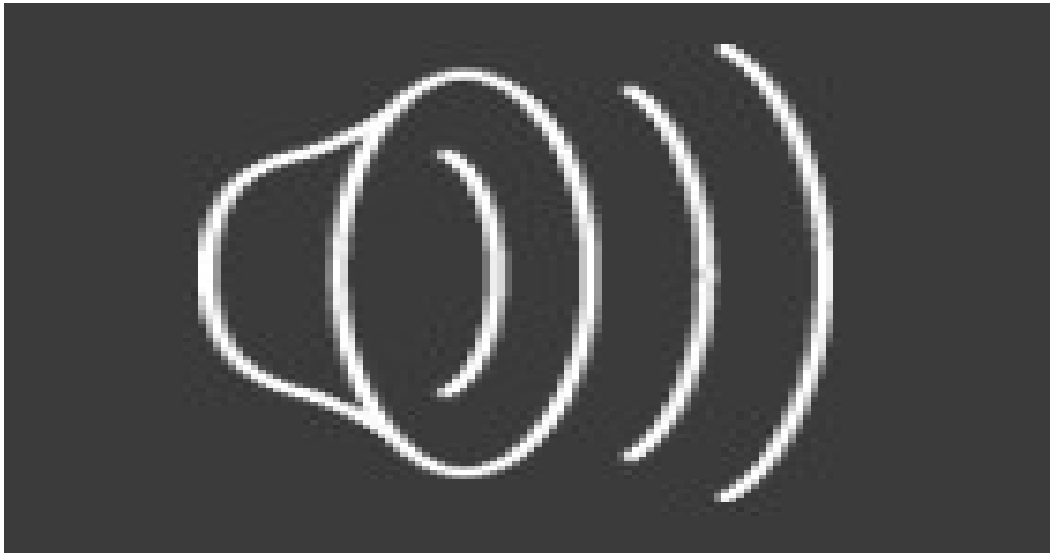
- **artificial sources**

+ night clouds



Video over Southeastern Asia was taken by the crew of Expedition 29 aboard the International Space Station. This sequence of shots was taken on Oct. 7, 2011, from 12:41:10 to 12:50:46 GMT, on an ascending pass from the island of Java to the northeast of Japan. Clouds fill most of the sky until the island of Japan approaches near the end of the sequence.
Tokyo is brightly visible on the eastern-most side of the island.

UV background estimation – duty cycle estimation

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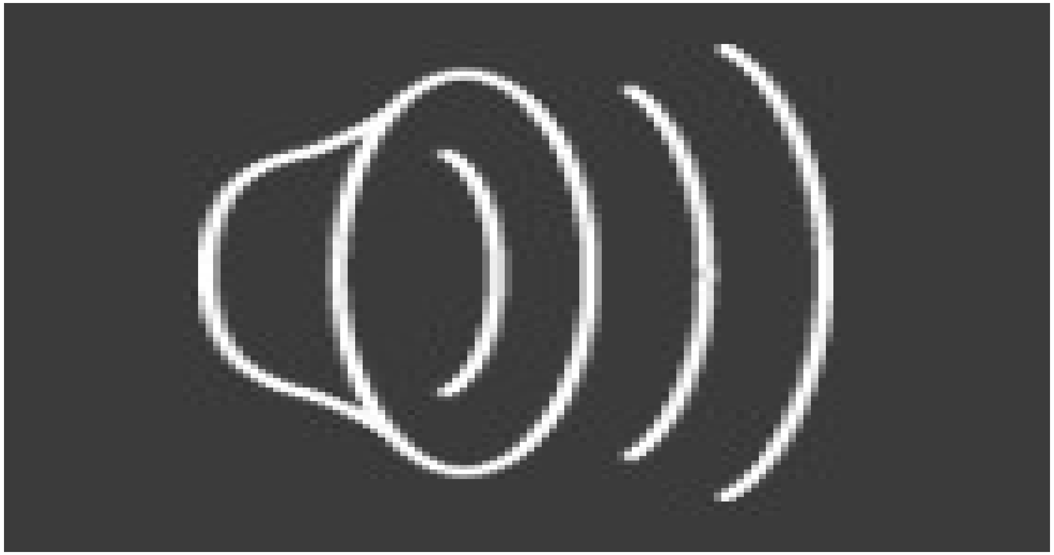
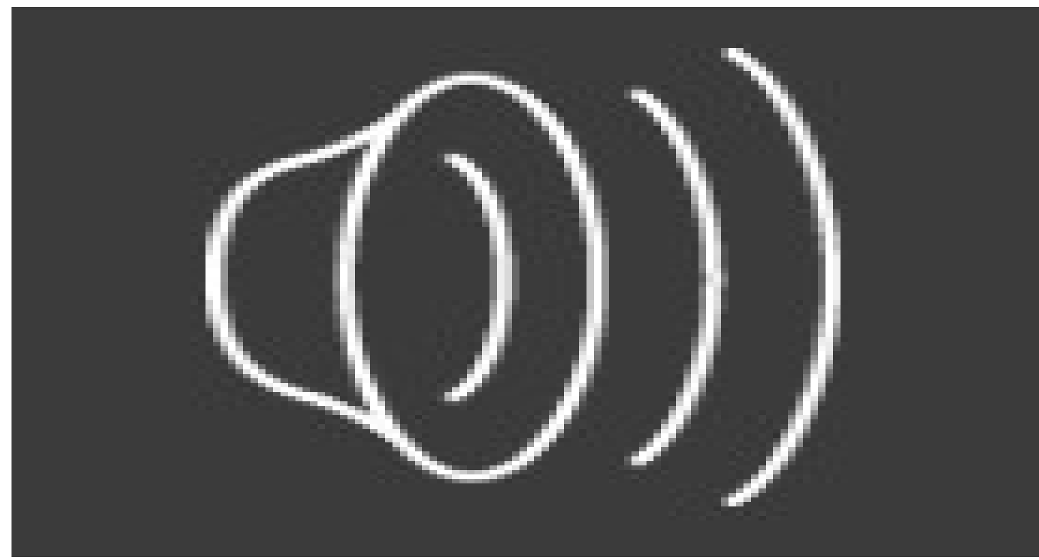


This video over the Sahara Desert and the Middle East was taken by the crew of Expedition 29 aboard the International Space Station. This sequence of shots was taken on Oct. 6, 2011, from 19:46:23 to 19:58:41 GMT, on an ascending pass from the Sahara Desert to western Kazakhstan. The rust color of the Sahara Desert is the first view in this video.

UV background estimation – duty cycle estimation

UV light sources

- sun
- moon
- **airglow/nightglow**
- zodiacal light
- integrated faint star light
- lightnings
- **Boreal/austral auroras**
- artificial sources



Video of the Aurora Australis taken by the crew of Expedition 29 on board the International Space Station. This sequence of shots was taken September 17, 2011 from 17:22:27 to 17:45:12 GMT, on an ascending pass from south of Madagascar to just north of Australia over the Indian Ocean..

JEM-EUSO duty cycle estimation

Previous estimations [1,2] was based on ISS trajectory simulation and moonlight intensity simulations along this trajectory. ISS trajectory was simulated for one year long period with minute time-steps.

The moonlight was estimated from the Moon position and phase at evaluated positions.

The duty cycle was evaluated as a time during the night when UV intensity from moon light was less than the selected value.

This approach do not take into account another sources of UV light on the Earth night side (i.e. zodiacal light, integrated faint star light, artificial lights) and partly also changes in ISS trajectory due to loosing altitude because of a slight atmospheric drag.

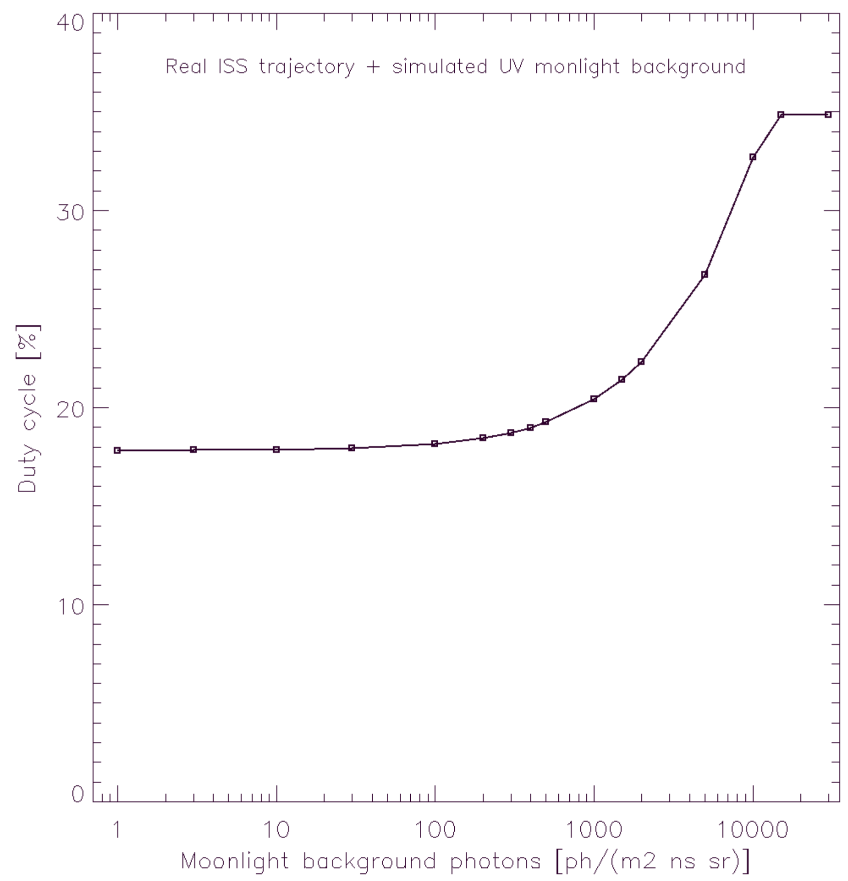
$$I_{Moon}(\theta,\alpha) \approx 1{,}55 \times 10^4 \times \cos\theta \times 10^{-0{,}4\,(1.5|(\alpha)| + 4{,}3\times 10^{-2}\alpha^4)} \quad ph/(m^2\, ns\, sr)$$

Where θ is lunar zenith angle and α is Moon phase.

[1] C. Berat, D. Lebrun, F. Montanet, J. Adams, Proceedings of the 28th International Cosmic Ray Conference, 2003, page 927

[2] F. Montanet, EUSO-SIM-REP-009-1.2, 2004

For the night defined by solar zenith angle bigger than 109.18 deg.



Duty cycle for a set of moonlight induced background values evaluated from real ISS trajectory in years 2005 till 2007 and simulated moonlight BG light.

JEM-EUSO duty cycle estimation

As the night for Tatiana orbit we consider simple cut on the zenith angle [3] by solar zenith angle higher than 119.5 deg..

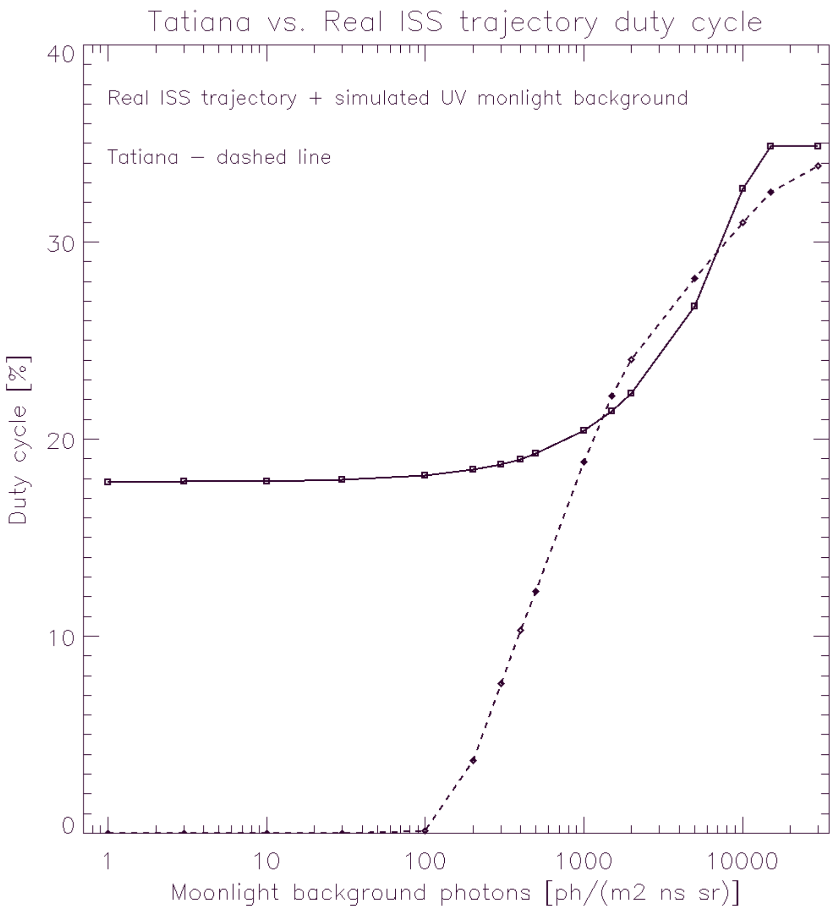
The sun eclipse times are then defined using a simple cut on the zenith angle:

Tatiana in the umbra

$$\theta_z > \pi - arcsin(R / (R + H)) = 119.5°$$

where R is the earth radius (6378 km) and H the Tatiana height above ground level (950 km).

We apply the correction for UV intensity on Tatiana orbit to ISS orbit (~16.89% - the precise value depends on the exact Tatiana altitude) and the correction taking into account the difference between night definition for Tatiana orbit and ISS orbit. Figure shows a duty cycle evaluated from Tatiana data corrected to ISS orbit together with duty cycle evaluated for real ISS trajectory and simulated moonlight.



Duty cycle evaluated from real ISS trajectory (solid line) in comparison with duty cycle from Tatiana data (dashed line).

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JEM-EUSO duty cycle estimation

The night definition by simple cut on the zenith angle could not be very precise approximation for JEM- EUSO measurements. It is possible that we will need to redefine night by shifting the Sun position 19.18 deg. under horizon as presented previously to a higher value.

We have estimated a JEM-EUSO duty cycle for a set of solar zenith angles for allowed background of UV intensity less than 1500 photons/ (m^2 ns sr).

The estimation from Tatiana measurements is presented in Table.

The change of solar zenith angle limit from 108 to 120 degrees decreases the JEM-EUSO duty cycle by about 3.8%.

Solar zenith angle (deg.)	Duty cycle (%)
108	22.2
109	22.1
110	21.9
111	21.7
112	21.5
113	21.3
114	21.0
115	20.6
116	20.3
117	19.9
118	19.5
119	19.0
120	18.4

Defense Meteorological Satellite Program data

Using DMSP (Defense Meteorological Satellite Program) database

– Annual average of cloudfree moonless intensity of ‘**Night Earth**’ in 30 arcseconds grid on surface

• **Light pollution cities mainly consisting of visible range**

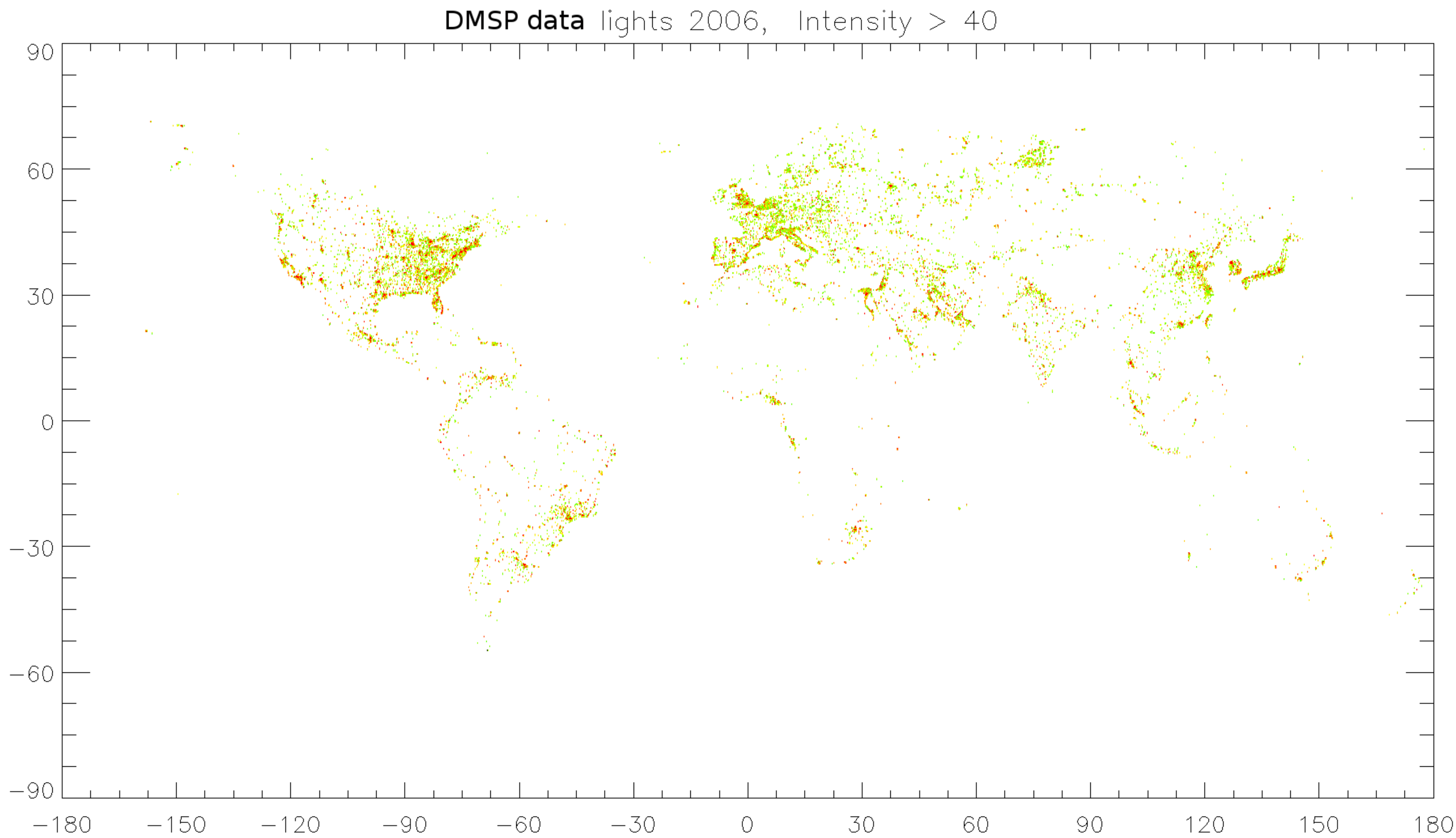
– Assuming UV intensity proportional to visible (data published for range 350 – 2000 nm in 63 levels scale)

• **Estimating background intensity** in a unit of ‘oceanequivalent’

– ‘Oceanequivalent’ background intensity

- assuming $\rightarrow$ 500 UVphotons / (m^2 sr ns)

City lights – selection from DMSP data



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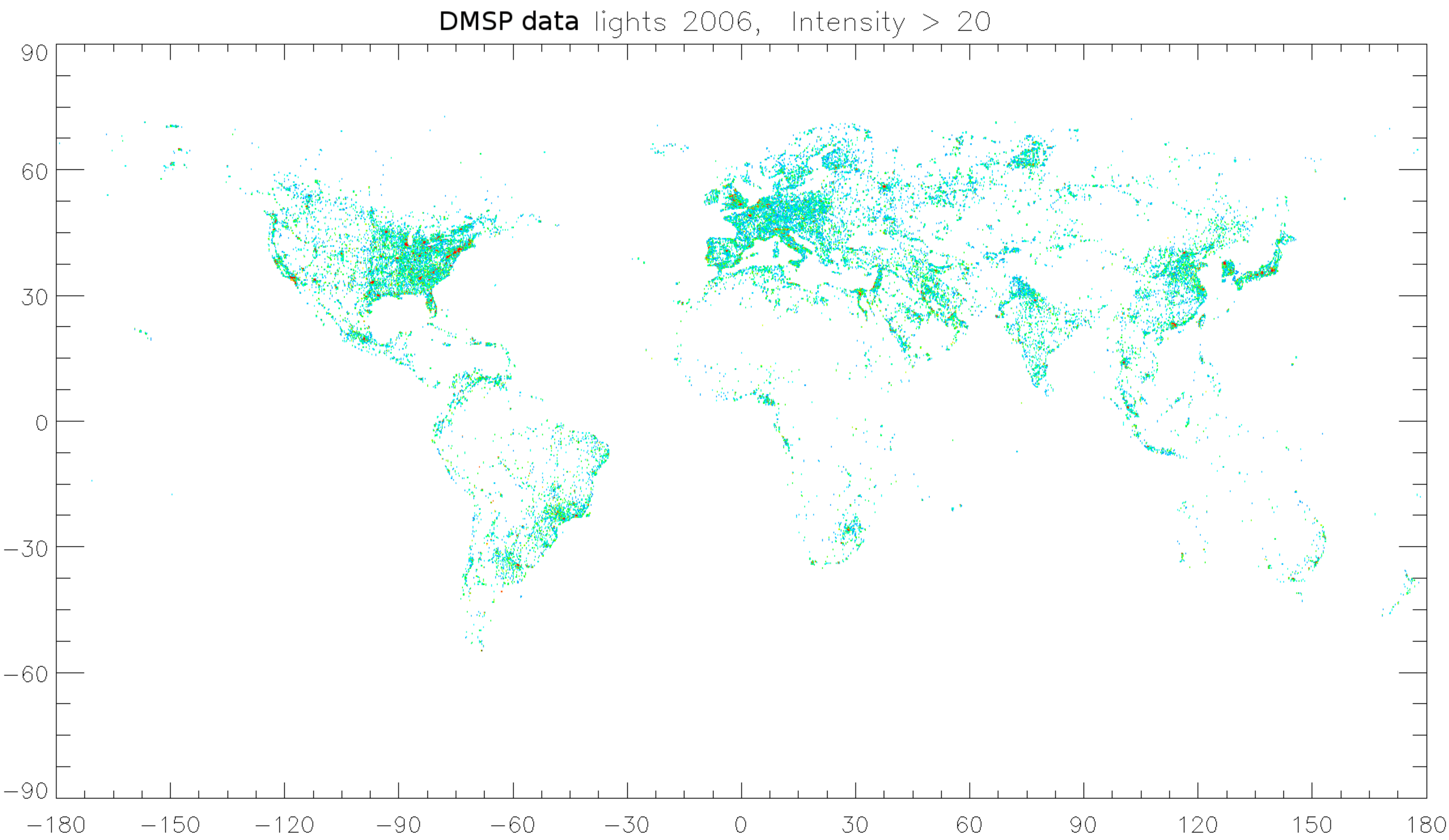
City lights – selection from DMSP data



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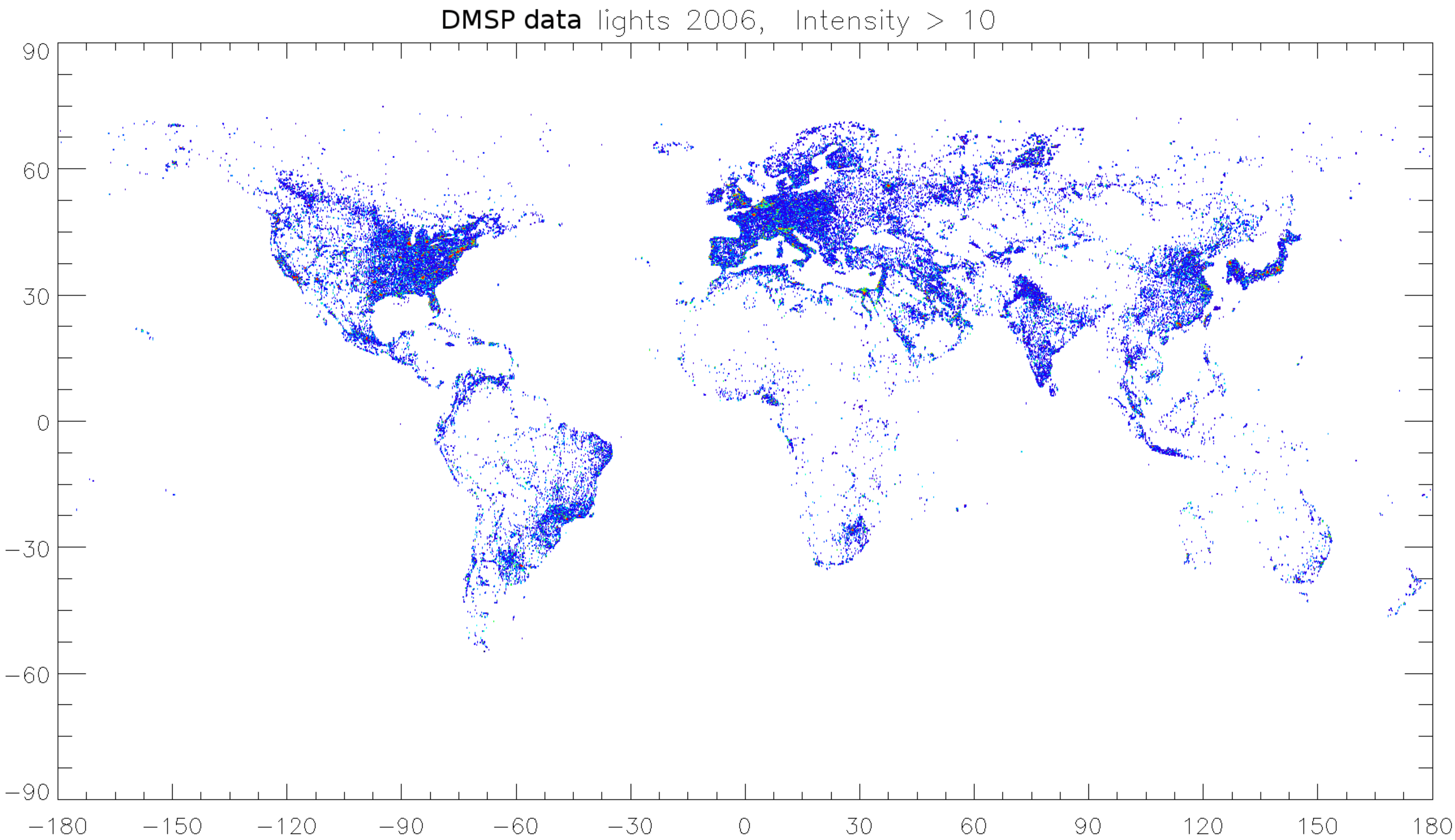
City lights – selection from DMSP data



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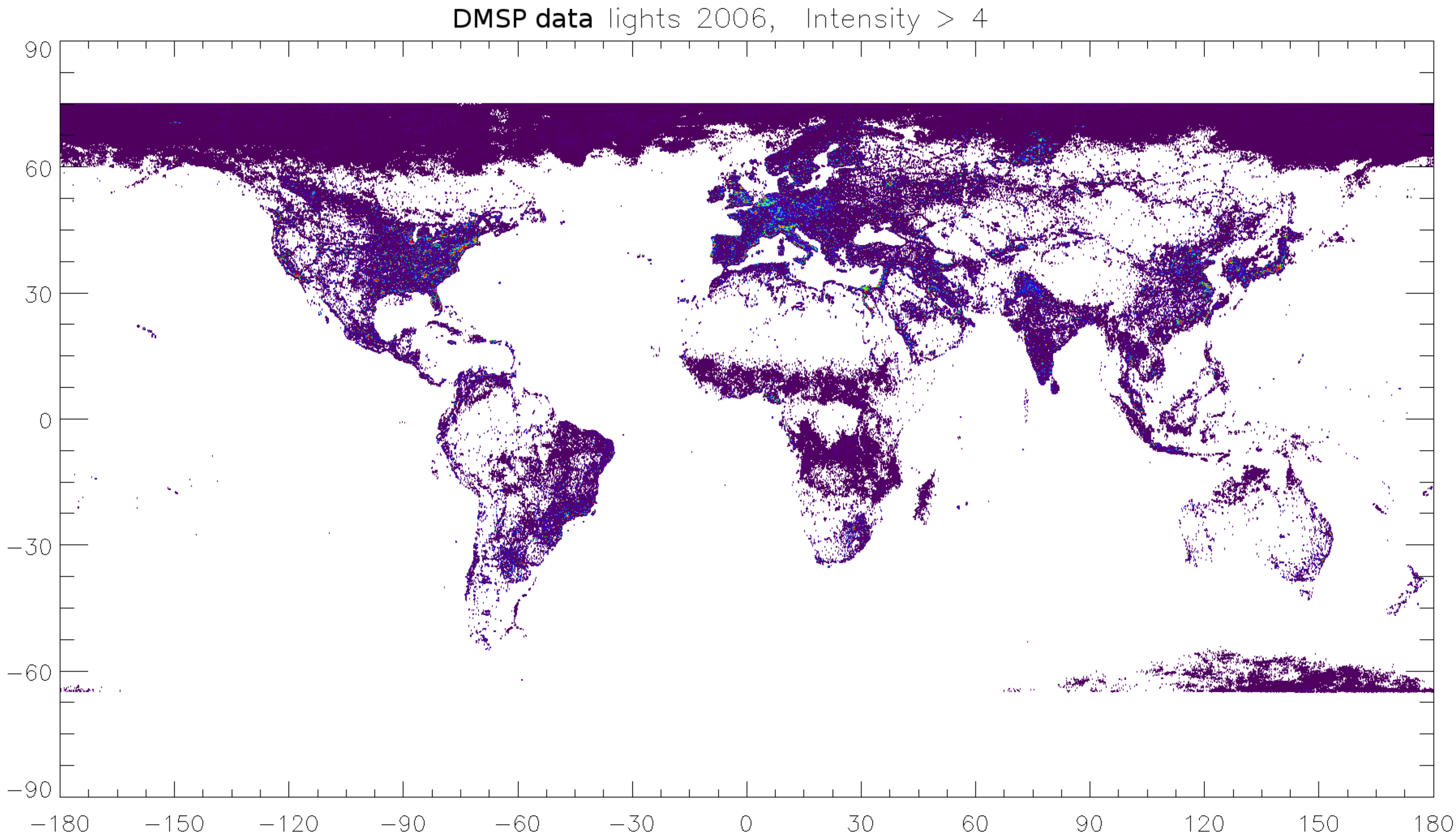
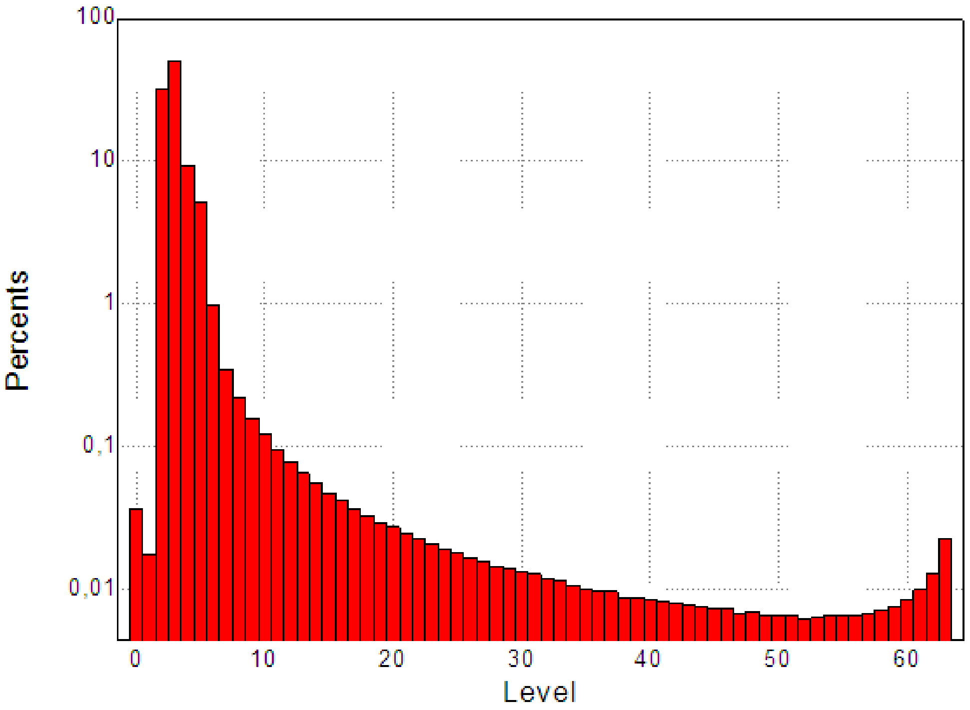
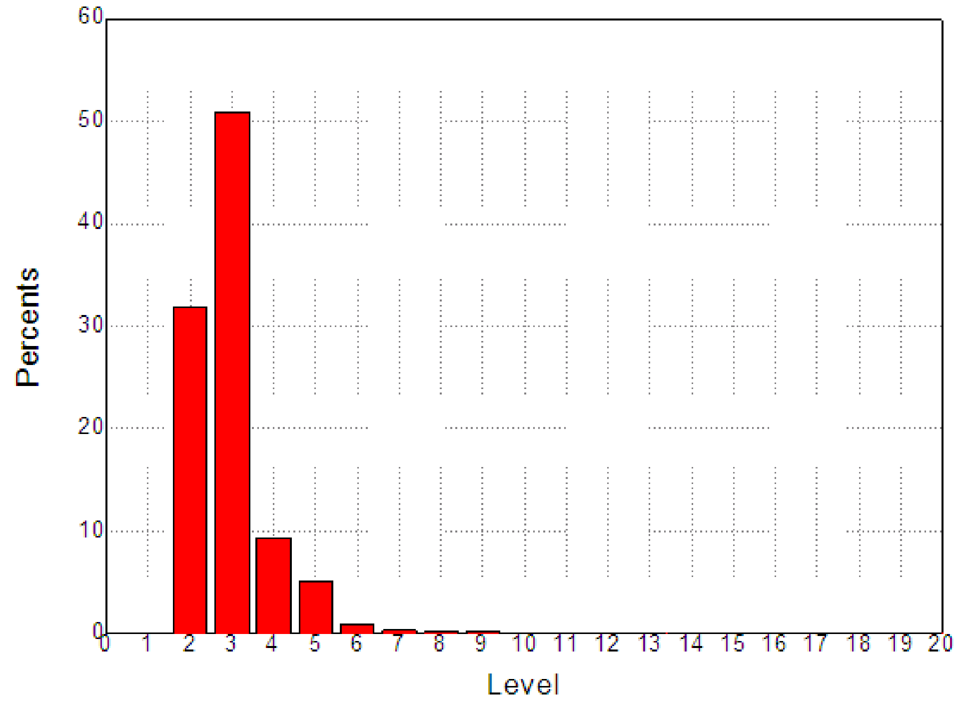
City lights – selection from DMSP data



City lights effect – intensities distribution in DMSP data





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Tatiana and BaBy measurements over cities

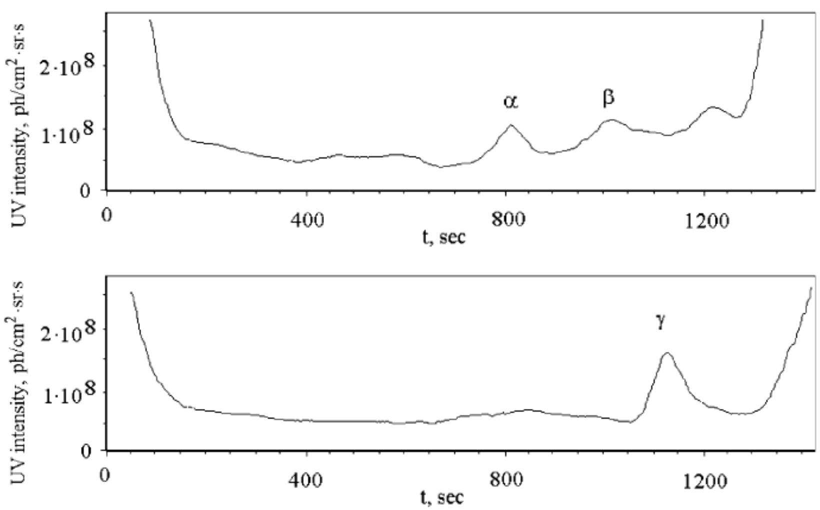


Fig. 5. Examples of UV intensity recording at night side of the Earth. Top panel—the circulation, in which the satellite crosses Mexico City (α) and Houston (β).

G.K. Garipov, B.A. Khrenov, M.I. Panasyuk, V.I. Tulupov, A.V. Shirokov, I.V. Yashin, H. Salazar, UV radiation from the atmosphere: Results of the MSU Tatiana'' satellite measurements, Astroparticle Physics 24 (2005) 400–408

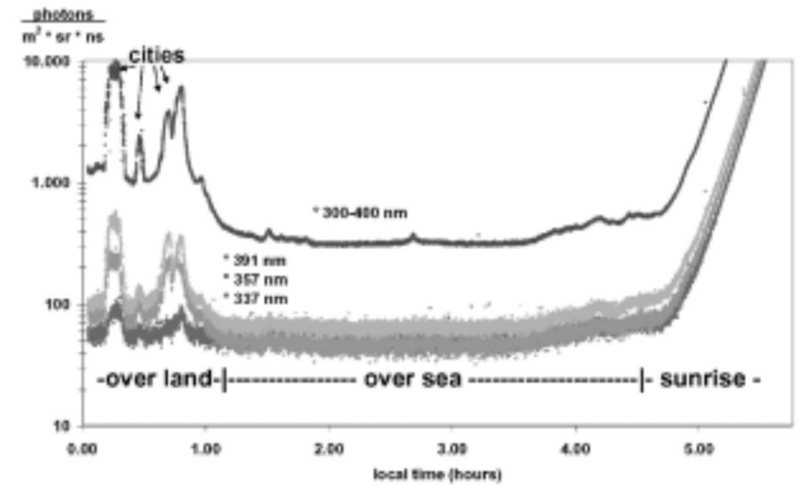
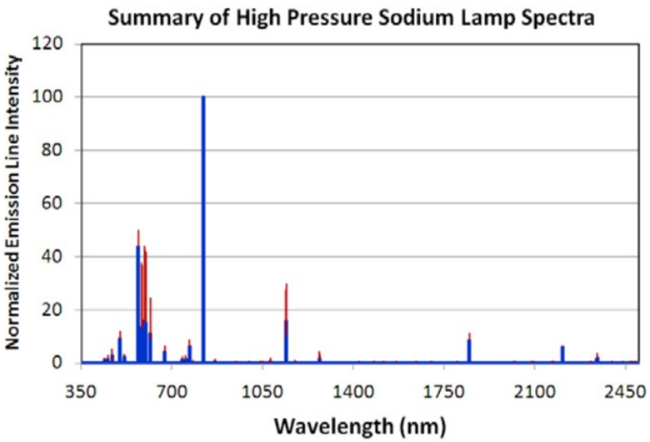


Fig. 1. BaBy 2002 flight Nocturnal Background Photon flux profiles

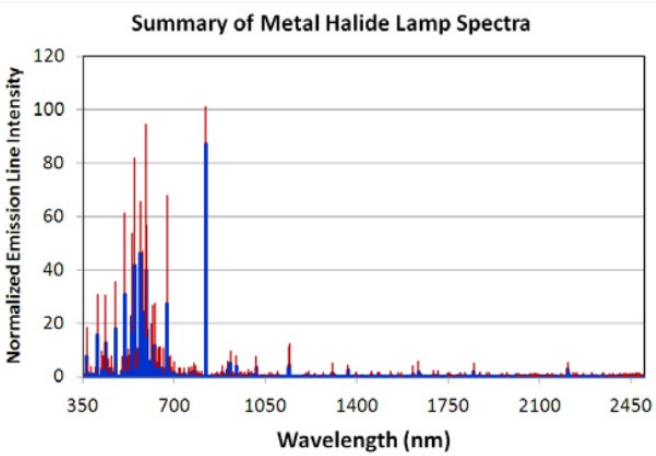
S. Giarrusso, G.Gugliotta,G.Agnetta, P.Assis, B.Biondo, O.Catalano, F.Celi, G.Cusumano, G.D'Al´ Staiti, R.Di Raffaele, M.C.Espirito, Santo, M.Gabriele, G.La Rosa, M.C.Maccarone, A.Mangano, T.Mineo, M.Pimenta, F.Russo, B.Sacco, A.Santangelo, P.Scarsi, B.Tome, Measurements of the UV Nocturnal Atmospheric Back-ground in the 300-400 nm Wavelength Band with the Experiment BaBy During a Transmediterranean Balloon Flight, 28th International Cosmic Ray Conference, pp. 849–852, 2003

Standard color camera images of Chicago, Tokyo and Hong Kong from the International Space Station

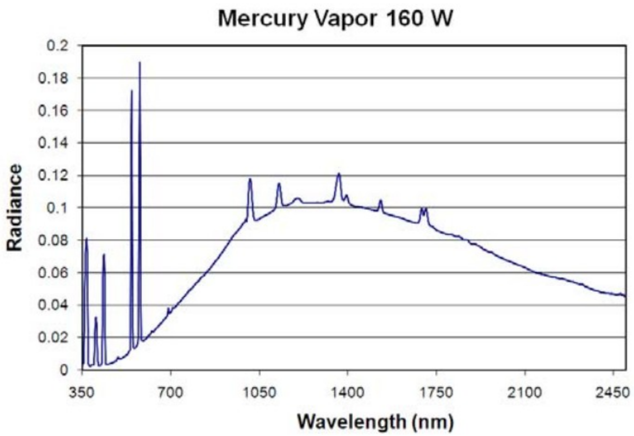
Pettit, D. Cities at night: an orbital perspective. NASA Ask Magazine 2010



Sodium lamp (orange light)



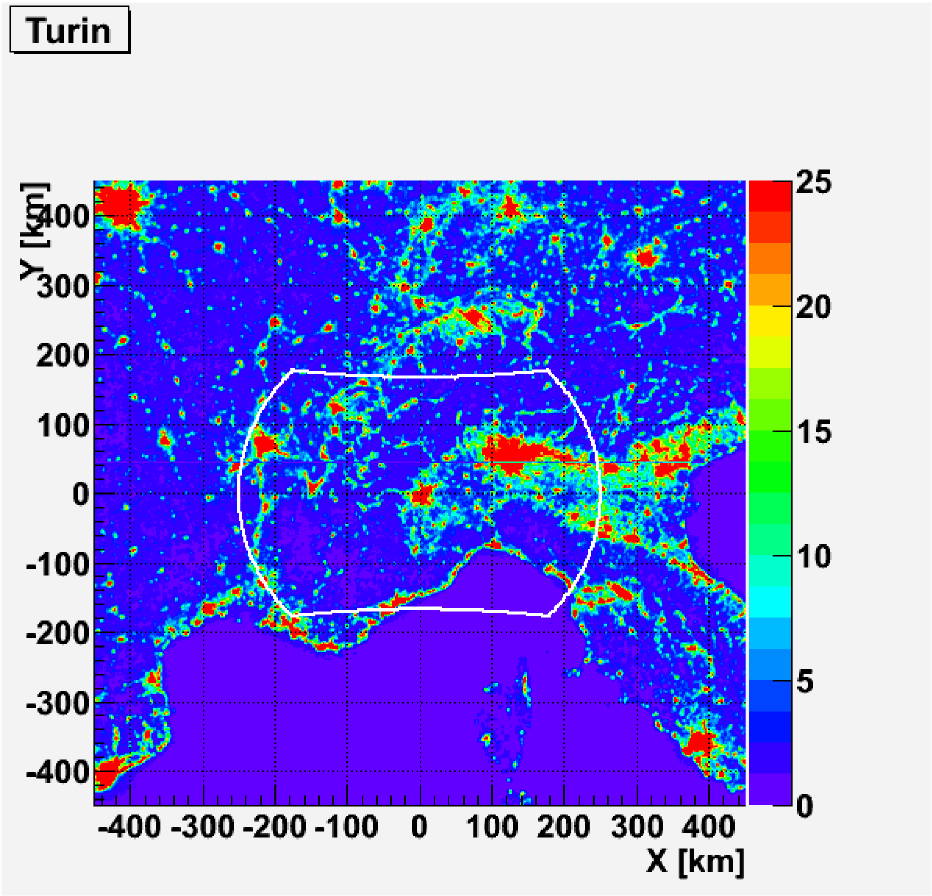
Metal halide (green light)

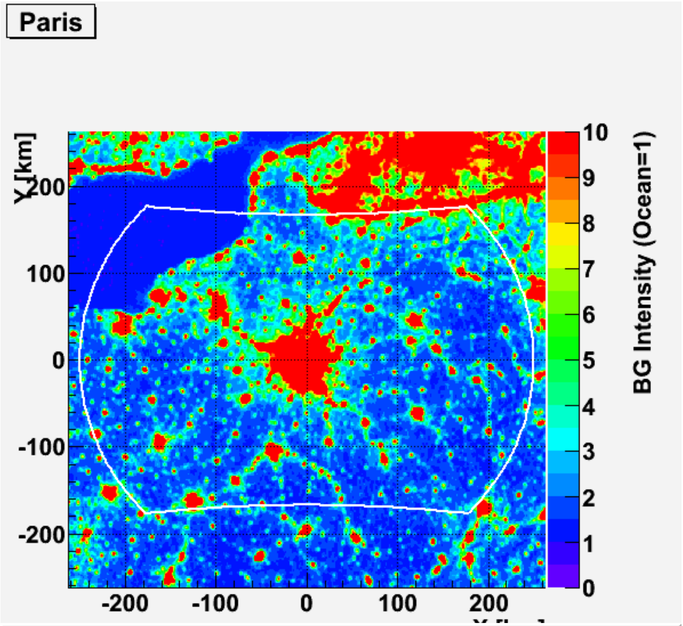


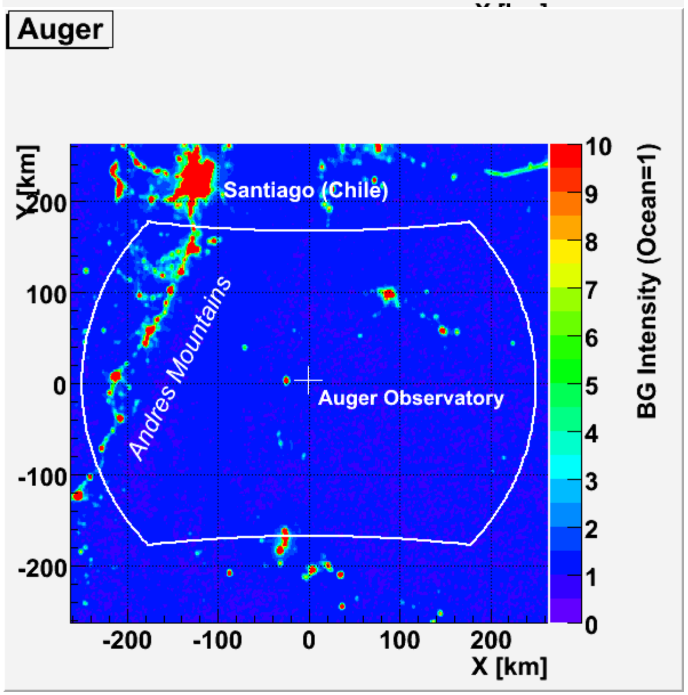
Mercury vapor

Spectral Identification of Lighting Type and Character, Christopher D. Elvidge, David M. Keith, Benjamin T. Tuttle and Kimberly E. Baugh, Vol. 10, p. 3961, Sensors 2010

City lights examples / JEM EUSO aperture





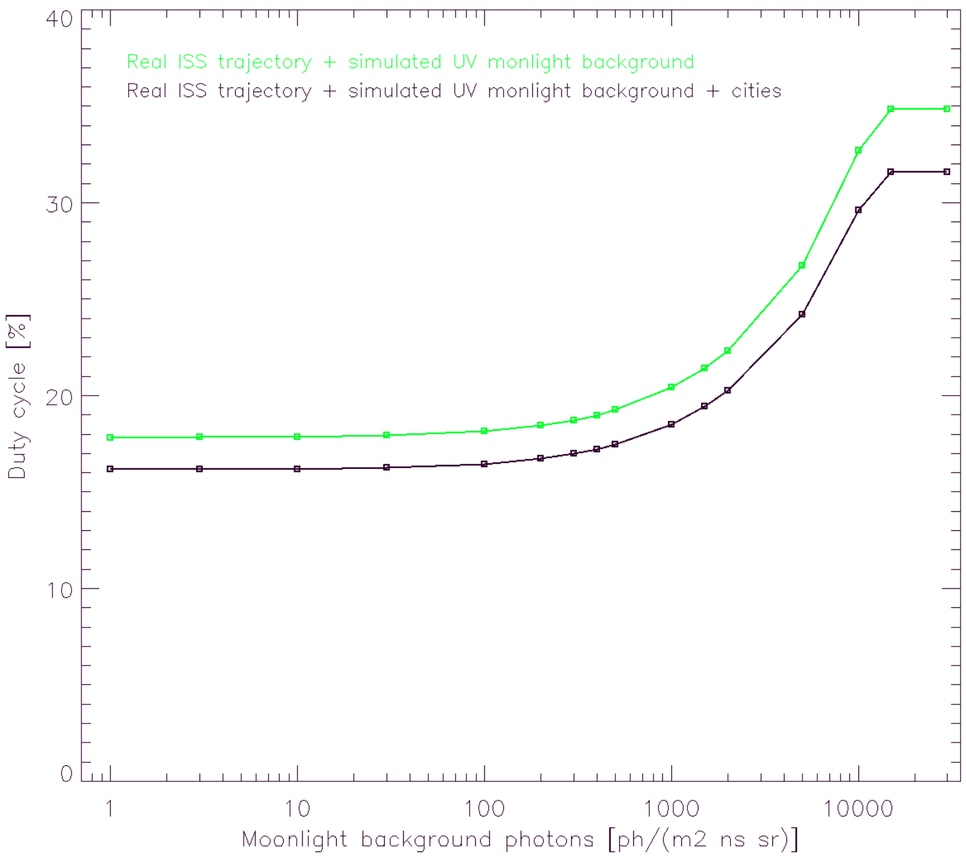


City lights effect - Operational efficiency

- To city identification we use - DMSP data with intensity over level 7
- Real ISS trajectory
- Simulated moon light I_{MOON}
- Nadir mode of detector (area on Earth ~140 000 km^2)
- 137 PDMs projection on Earth surface
- condition to exclude measurements over cities from JEM-EUSO duty/operational cycle – if we have 1 city in PDM = PDM is blind (DSMP resolution 1 km pixels). Zero PDM condition.
- Comparison of duty cycle without and with cities lights

$$BG = BG_{MOON} + BG_{cities}$$

- For allowed background 1500 ph/(m^2 ns sr) we get reduction of detector duty cycle by 2% (from 21.43% to 19.43%)



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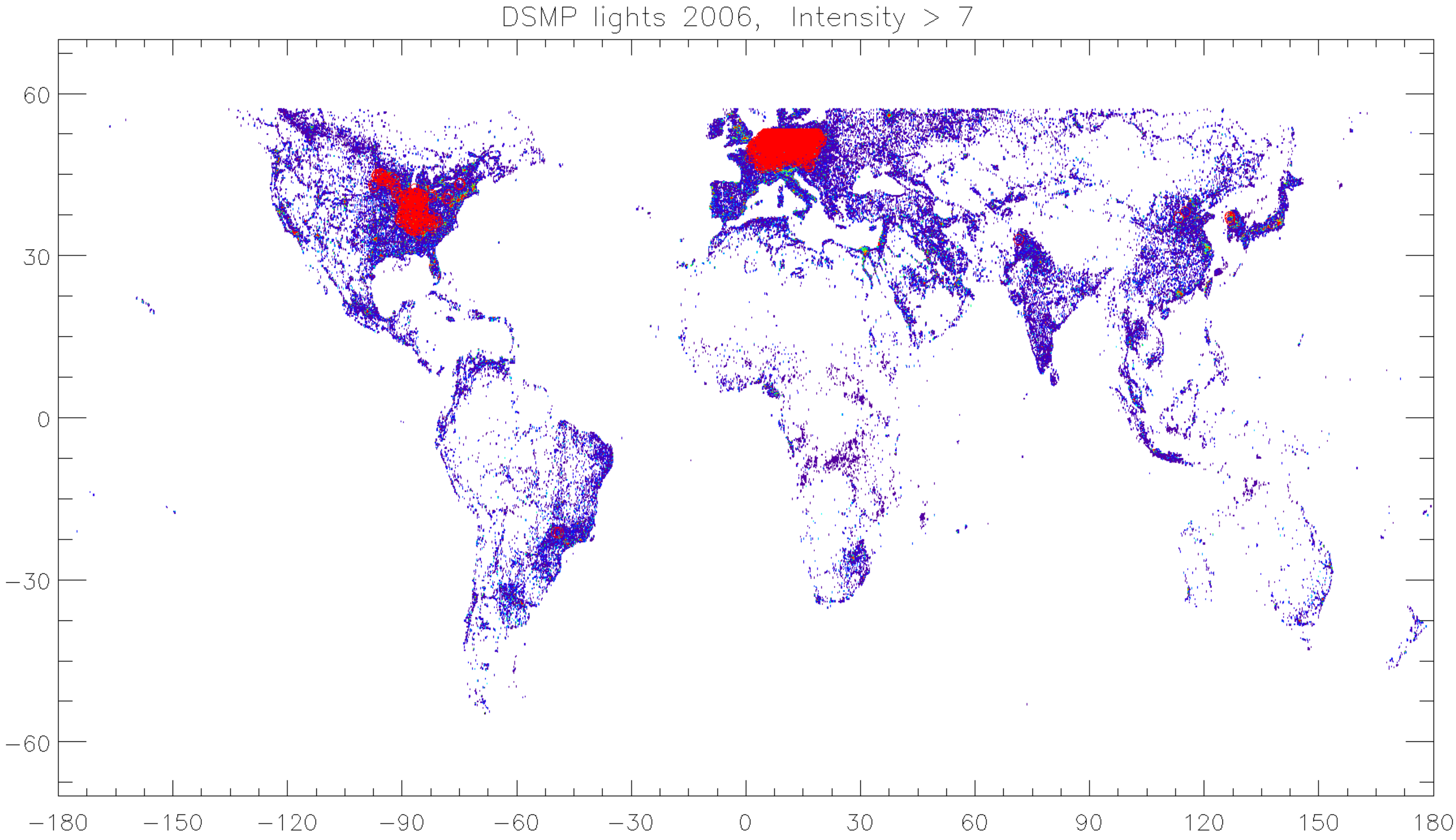
Where we are blind – red circles



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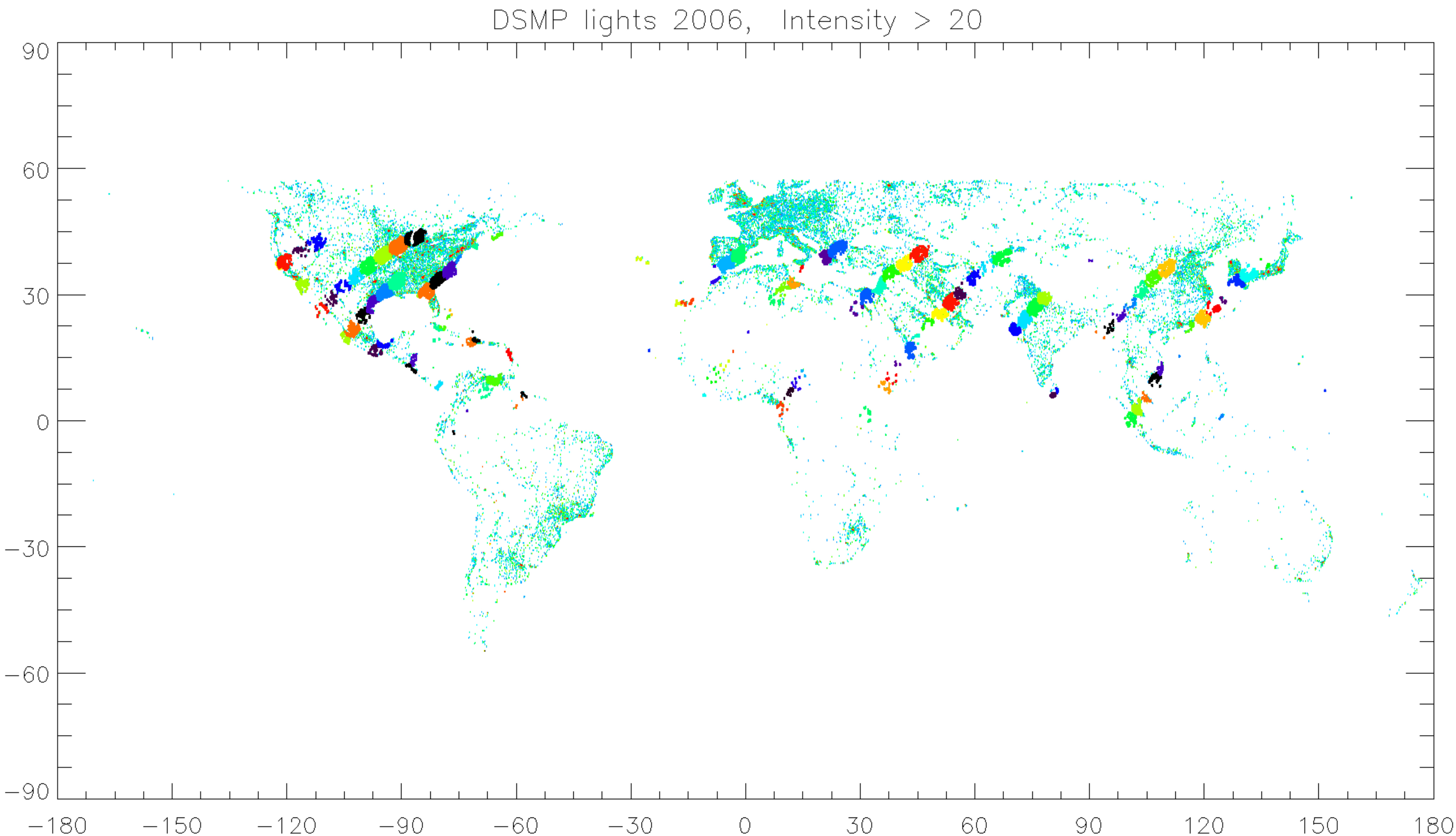
FOV – overlapping of 1 minute trajectory steps on Earth Surface

(example, just randomly selected part of ISS trajectory)



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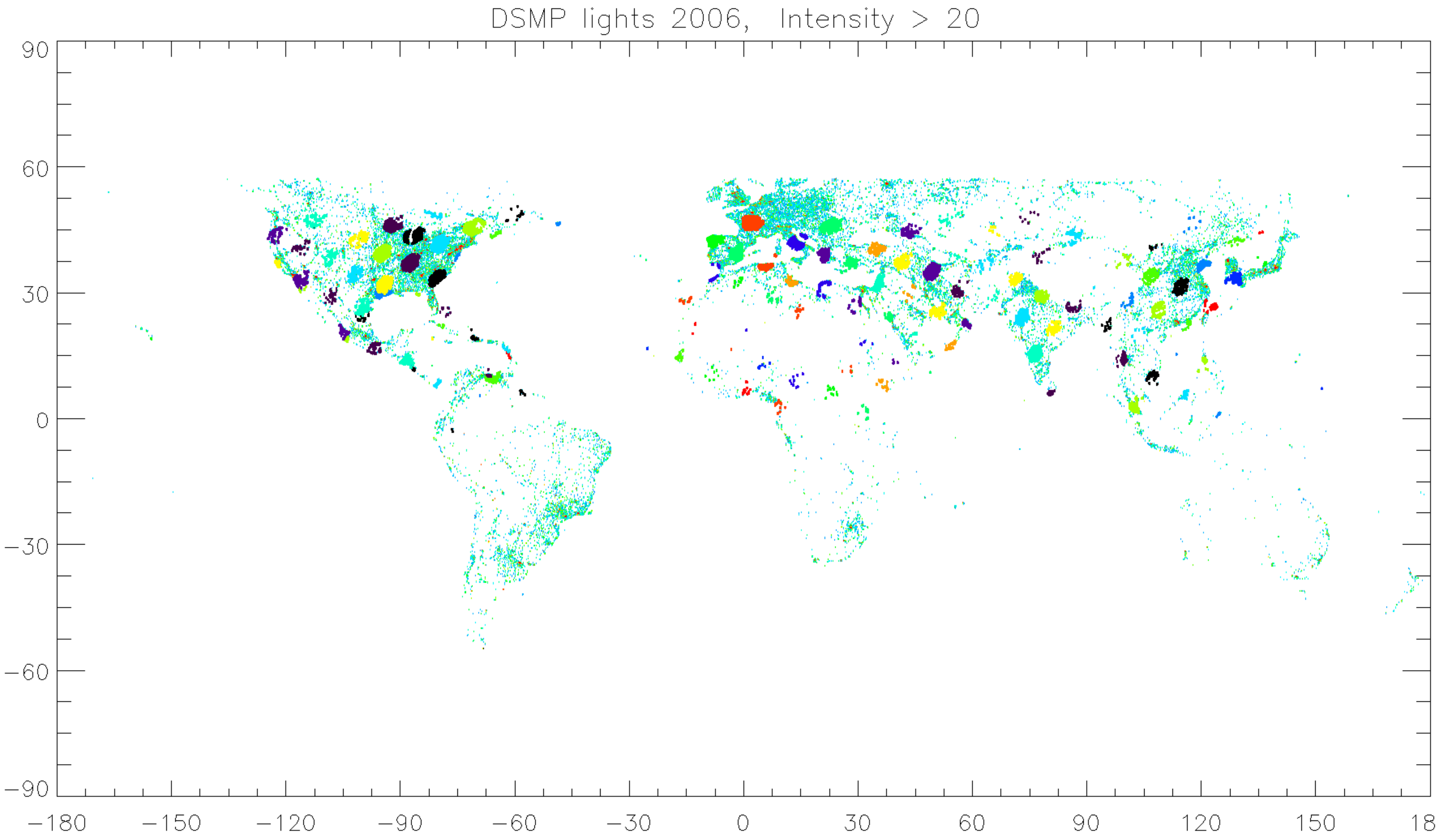
FOV – every 2nd position of traced ISS trajectory

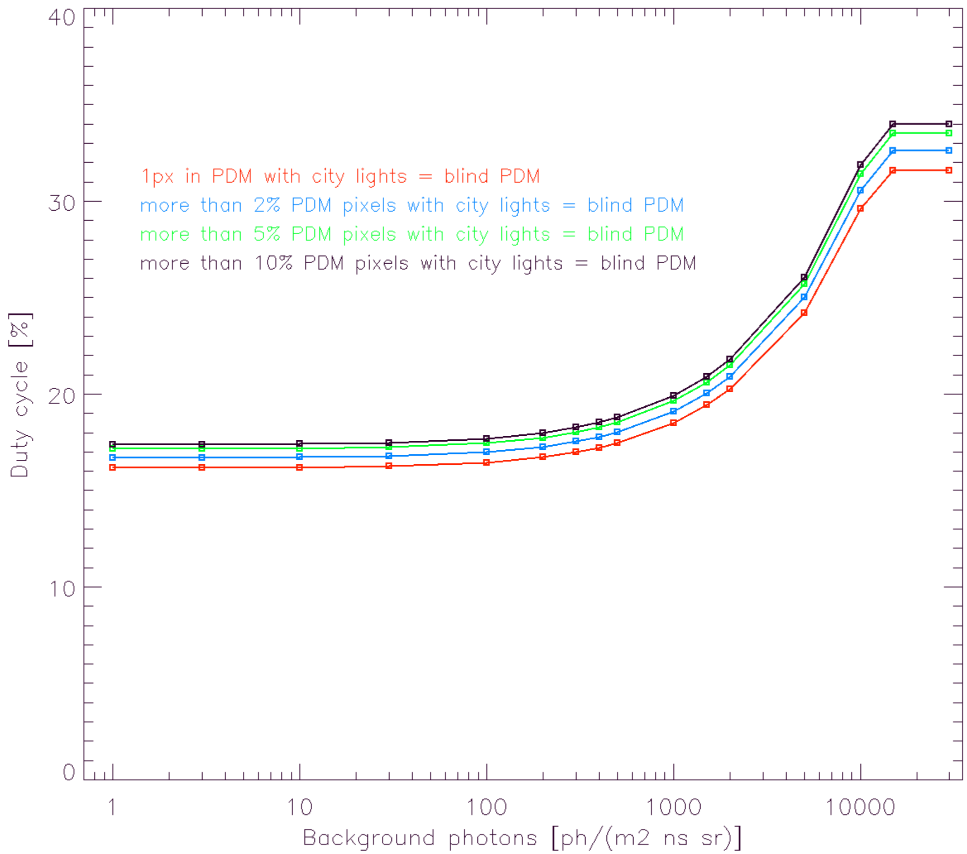
(example, just randomly selected part of ISS trajectory)



City lights effect - Operational efficiency

- DMSP data with intensity over level 7
- Real ISS trajectory, simulated moon light I_{MOON}
- Nadir mode of detector (area on Earth ~140 000 km^2)
- 137 PDMs projection on Earth surface
- conditions to exclude measurements over cities from JEM-EUSO duty/operational cycle – if more than selected number of pixels in PDM are blind (DSMP resolution 1 km pixels).
- $BG = BG_{MOON} + BG_{cities}$
- For allowed background 1500 ph/(m^2 ns sr) we get

Cities in PDM	Duty cycle [%]
0	19.43
< 2 %	20.06
< 5 %	20.62
< 10 %	20.90



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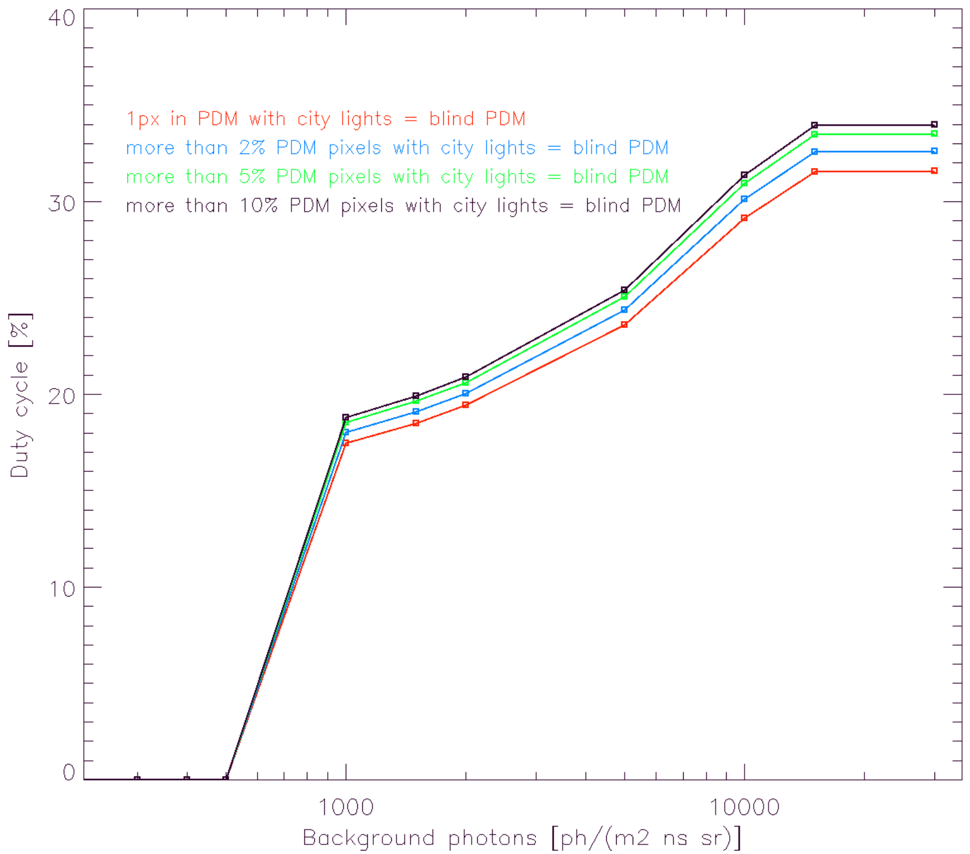
City lights effect - Operational efficiency

- DMSP data with intensity over level 7
- Real ISS trajectory, simulated moon light I_{MOON}
- Nadir mode of detector (area on Earth ~140 000 km^2)
- 137 PDMs projection on Earth surface
- conditions to exclude measurements over cities from JEM-EUSO duty/operational cycle – if more than selected number of pixels in PDM are blind (DSMP resolution 1 km pixels).
- $BG = BG_{MOON} + BG_{OCEANEQ\_500} + BG_{cities}$
- $BG_{OCEANEQ\_500}$ = 500 ph / (m^2 ns sr)
- For allowed background 1500 ph/(m^2 ns sr) we get

Cities in PDM	Duty cycle [%]
0	18.51
< 2 %	19.11
< 5 %	19.64
< 10 %	19.91



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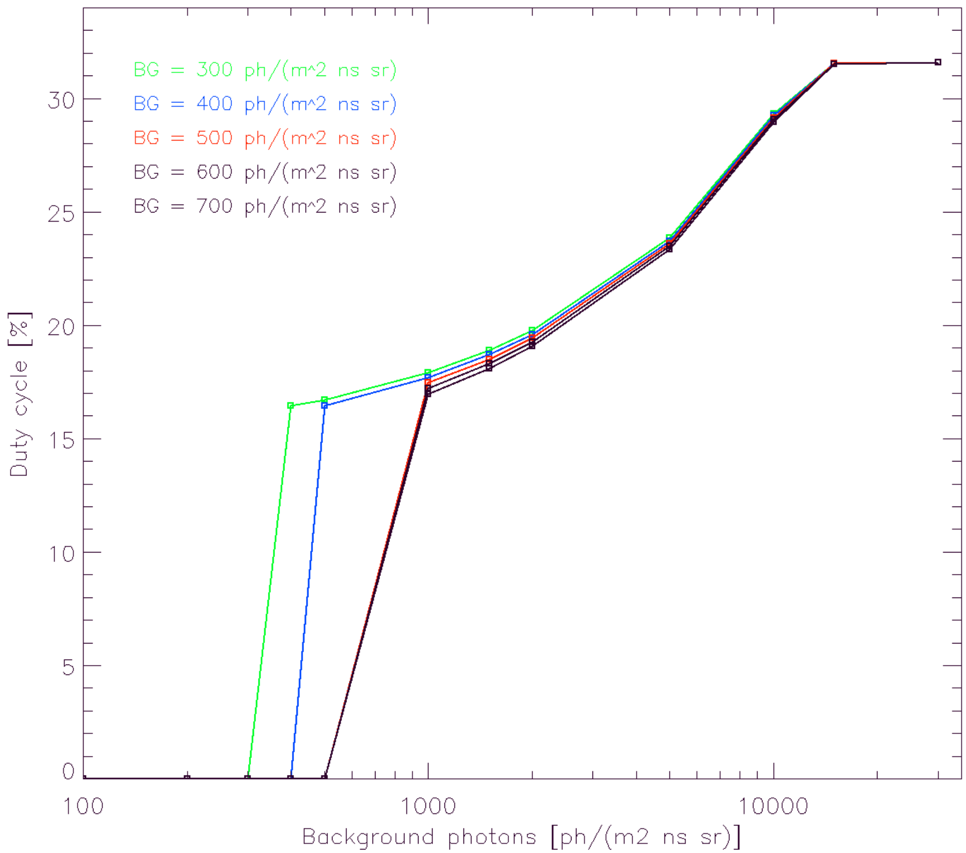
City lights effect - Operational efficiency

$BG_{OCEANEQ}$	Duty cycle [%]
300	18.90
400	18.70
500	18.51
600	18.31
700	18.11

Worst-case scenario



$BG_{OCEANEQ}$ = estimated oceanequivalent background

From nightglow, zodiacal light, integrated faint star light in ph/(m^2 sr ns)

$$BG = BG_{MOON} + BG_{OCEANEQ} + Bg_{cities}$$

BG_{cities} - **zero PDM condition**

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City lights effect - Operational efficiency - Summary

BG sources	Duty cycle [%]
BG_{moon}	21.43
$BG_{moon} + BG_{500}$	20.41
$BG_{moon} + BG_{cities}$	19.43
$BG_{moon} + BG_{500} + BG_{cities}$	18.51

BG_{500} = estimated oceanequivalent background (nightglow, zodiacal light, integrated faint star light) = 500 ph/(m2 sr ns)

Influence/effect of BG_{cities}

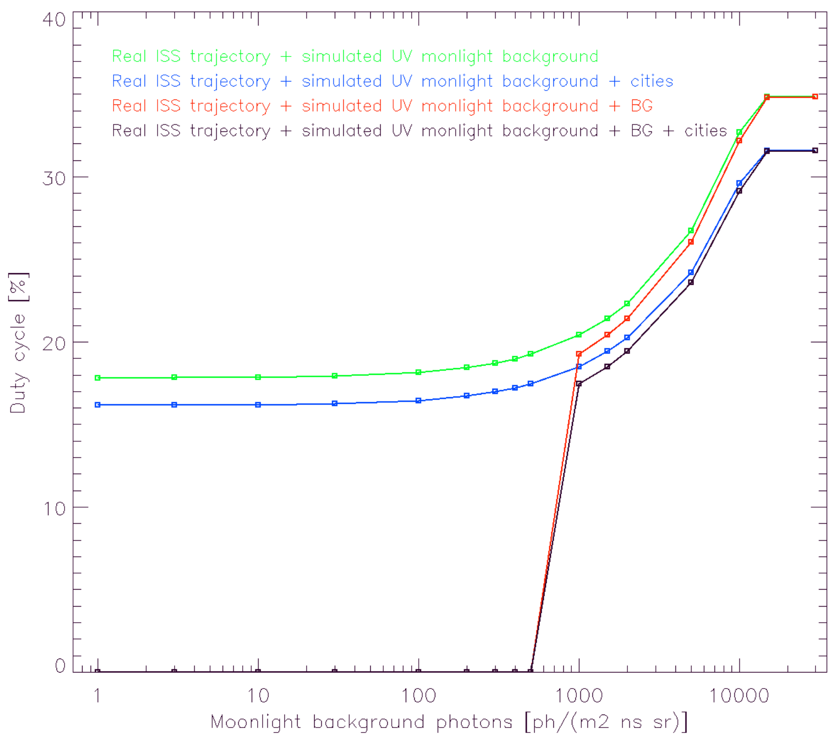
- city is identified by DSMP satellite measurements

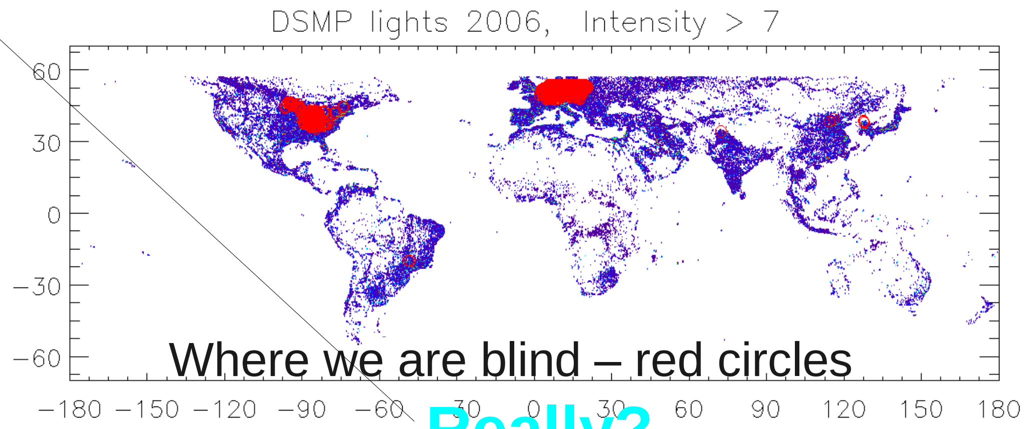
- when one city appear in PDM then -> PDM is blind - **strict condition?** **?**

FOV is divided to 137 areas (PDM) on Earth surface and scan along ISS trajectory for cities.

Influence/effect of BG_{X00}

- effect of different levels of oceanequivalent BG i.e. 300, 400, 500, 600, 700 ph/(m2 sr ns) – is ~0,2% per Δ BG = 100 ph/(m2 sr ns)





City lights effect - Operational efficiency – Como article

- 13th ICATPP Conference on Astroparticle, Particle, Space Physics and Detectors for Physics Applications, Villa Olmo, Como 3-7 October 2011 - http://villaolmo.mib.infn.it
- **Estimation of JEM-EUSO experiment OBSERVATION EFFICIENCY**
- **Deconvolution of effects**
- **... in Conclusion "**... at present stage, 1 bright pixel in the PDM is blinding the entire PDM. If the 1st trigger level could work at EC level (9 elementary cells in PDM), we could gain ~1% (from 18.51% back to 19%) in operational duty cycle.**"**

$I_{Allowed}$ [ph/(m² ns sr)]	I_{SUN} > 109.18°	I_{MOON} only [%]	Cities only [%]	I_{SUN} + I_{MOON} [%]	I_{SUN} + I_{BG} + I_{MOON} [%]	I_{SUN} + I_{BG} + I_{MOON} + Cities [%]
1		50.00	90.14	17.83	0.00	0.00
10		50.11	90.14	17.85	0.00	0.00
100		51.14	90.18	18.14	0.00	0.00
300		53.45	90.18	18.72	0.00	0.00
500		55.92	90.26	19.25	0.00	0.00
1000	34.84	62.06	90.26	20.41	19.25	17.46
1500		**68.08**	**91.06**	**21.43**	**20.41**	**18.51**
5000		89.73	95.97	26.73	26.07	23.61
10000		97.85	98.81	32.69	32.20	29.15
15000		99.99	100.00	34.83	34.80	31.55
30000		100.00	100.00	34.84	34.84	31.58

Conclusion

We have estimated a duty cycle/ operational efficiency for JEM-EUSO detector at ISS orbit for taking to account effects of Sun, Moon, oceanequivalent background and city lights.

City lights effect depend strongly on how many of showers we can reconstruct if part of PDM FOV is blinded by cities. How much cities we can have in FOV?

For allowed max. background limit 1500 ph / (m^2 ns sr) and selection parameters

- Sza > 109.18^o
- $BG_{OCEANEQUIVALENT}$ = 500 ph / (m^2 ns sr)
- < 2% of PDM pixel are blind because cities

is duty cycle 19.11%

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