PROBABILITY OF HAZARDOUS HUMAN EXPOSURE FROM SPACE BASED LASERS

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ABSTRACT

Laser (lidars) are to be used from satellites for measurement of atmospheric properties and may represent an ocular hazard to people on the surface of the earth. The risk of an eye injury depends on a range of parameters such as the energy per pulse, wavelength, beam divergence, space craft orbit, atmospheric conditions, properties of telescopes and other viewing aids, and the viewing behaviour of potentially exposed people.

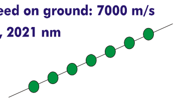
We have developed a fully probabilistic risk model and software to calculate the individual probability for ocular damage for a given population group as well as the total expected number of ocular injuries for a given satellite mission.

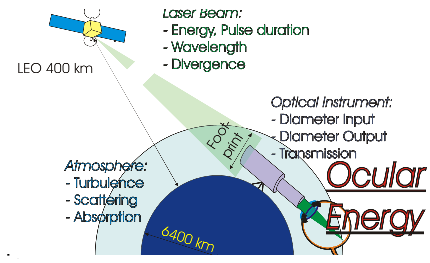
CONCLUSIONS

For the typical satellite based lidar, exposure with telescopes larger than 30-60 cm may lead to ocular damage, however the probability for exposure for the amateur astronomer is less than10^{-9} per hour of using the telescope.

Typical Parameters

***Orbital Altitude:* 400 km -> speed on ground: 7000 m/s**
***Wavelength:* 355 nm, 1064 nm, 2021 nm**
***Pulse energy:* 100 mJ - 500 mJ**
***Pulse length:* 20 ns - 400 ns**
***PRF:* 10 - 100 Hz**
***Footprint diam:* 5-100 meter -> no pulse overlap**

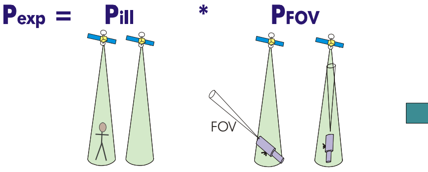




The level of energy to which the eye will potentially be exposed depends on a number of factors.

Typical Parameters

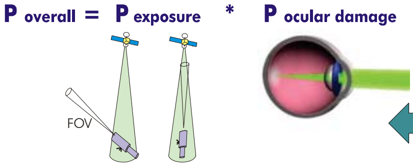
$P_{exp} = P_{ill} * P_{FOV}$



For ocular exposure to occur, the laser beam has to be incident on the location and the satellite has to be in the field of view.

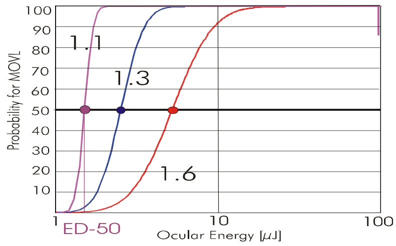
Risk = Probability of Minimal Lesion

$P_{overall} = P_{exposure} * P_{ocular\ damage}$



The overall probability for ocular damage is the combination of the probability to be exposed (per hour of using the optical instrument) and the the probability for ocular damage per exposure.

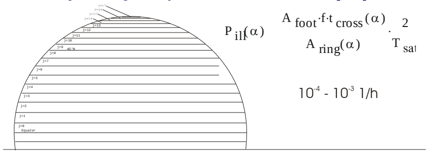
Probability of Ocular Damage



The probabilistic injury function describes the probability for ocular damage as function of the ocular energy. The two parameters of the function are the ED-50, the energy with 50 % probability for ocular damage, and the slope of the curve. MOVL...Minimal ophthalmoscopically visible lesion.

Probability for Illumination

Probability that a given spot on earth is illuminated [1/h]



$$P_{ill}(\alpha) \approx \frac{A_{foot} \cdot f \cdot t_{cross}(\alpha)}{A_{ring}(\alpha)} \cdot \frac{2}{T_{sat}}$$

10^{-4} - 10^{-3} 1/h

A_{foot}... Area of footprint [m²], f...pulse repetition rate [Hz], t_{cross}...time it takes to cross latitude ring, T_{sat}...Period of satellite [h]

Individual – Global Risk

Individual Risk: Probability for ocular injury per hour while using a given type of optical instrument

$$Pind_{OD} = Pexp * P_{OD}$$

$$N_{OD} = Pexp * P_{OD} * N * Ftime$$

1 h per month = 0.0014

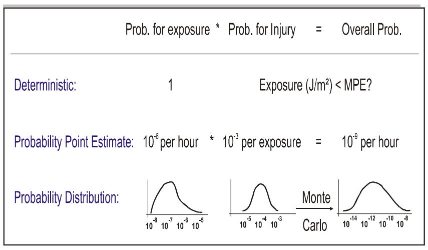
Number per lat degree (for each group)

Prob for ocular damage per exposure

Prob for exposure per hour of using optical instrument

Number of ocular injuries per mission hour (per Group)

"Model-Level of Probability"



A fully probabilistic model is obtained by combining all relevant uncertainties related to the model parameters by Monte Carlo simulation.

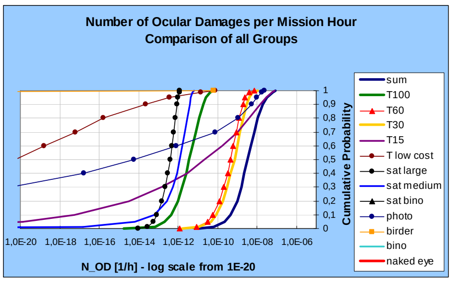
INPUT PARAMETERS	
Energy [J]	0,1
Pulse duration [s]	2,5E-08
Wavelength [nm]	1064
PRF [Hz]	50
Footprint diameter [m]	10
LOS azimuth [°]	0
LOS off nadir [°]	0°-20°
Orbit height [m]	370000
Orbit angle [°]	96,99
Mission duration [y]	3

		Probability of minimal lesion per exposure		Individual probability of exposure per hour of using optical instr.	Individual probability of exposure per hour of using optical instr.	Frequency of exposure per mission hour		Frequency of ocular damage per mission hour	
	Group					tech	nontech	tech	nontech
Nr	Description	OE[J]	P_{OD}	P_{exp_max} [1/h]	P_{OD_max} [1/h]	N_{exp} [1/h]	N_{exp} [1/h]	N_{OD} [1/h]	N_{OD} [1/h]
1	Naked eye	8,63E-08	1,00E-98	2,82E-11	2,8226E-109	1,01E-03	3,81E-03	1,01E-101	3,81E-101
2	Binoculars 5cm	3,69E-07	4,17E-83	2,85E-11	1,18648E-93	1,94E-07	6,58E-09	8,10E-90	2,74E-91
3	Birder 8 cm	9,44E-07	5,89E-56	2,85E-11	1,67698E-66	3,83E-08	1,44E-09	2,26E-63	8,50E-65
4	Photographers	4,28E-05	1,16E-01	1,42E-11	1,64318E-12	2,55E-08	9,61E-10	2,95E-09	1,11E-10
5	Sat viewer bino	9,44E-07	5,89E-56	2,85E-09	1,67698E-64	1,09E-07	3,43E-09	6,45E-63	2,02E-64
6	Sat viewer med. large 30 cm	1,51E-04	1,00E+00	2,85E-09	2,84475E-09	2,53E-13	6,34E-12	2,53E-13	6,34E-12
7	Sat viewer large 60 cm	6,02E-04	1,00E+00	2,85E-08	2,84521E-08	4,28E-14	1,27E-12	4,28E-14	1,27E-12
8	Telescope low cost 8cm	1,36E-05	1,18E-08	2,85E-11	3,34852E-19	1,25E-10	4,70E-12	1,47E-18	5,53E-20
9	Telescope <15 cm	3,76E-05	4,55E-02	4,15E-10	1,8917E-11	9,64E-08	6,05E-09	4,39E-09	2,76E-10
10	Telescope <30 cm	1,51E-04	1,00E+00	4,15E-10	4,15333E-10	2,41E-08	7,58E-09	2,41E-08	7,58E-09
11	Telescope <60 cm	6,02E-04	1,00E+00	5,29E-10	5,29209E-10	6,83E-09	1,93E-08	6,83E-09	1,93E-08
12	Telescope <100 cm	1,67E-03	1,00E+00	1,97E-10	1,97458E-10	6,69E-12	8,00E-11	6,69E-12	8,00E-11
	MPE [J]	1,9E-06	Sum of ocular damages/mission hour over all groups:					3,832E-08	2,74E-08
	D_{MPE1} [cm]:	3,4							

Number of ODs per mission hour [1/h]	6,57E-08
Number of ODs per mission	1,73E-03

mission duration [y]: 3

Probabililty of illumination per hour - maximum	2,85E-07
Number of illuminated people per hour worldwide:	1,13E+02
Number of illuminated people per hour - countries with technical orientation:	1,98E+01



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