SUPERLASERS FOR THE REAL WORLD

Lasery a optika v protidronové obraně (C-UAS)

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hilase

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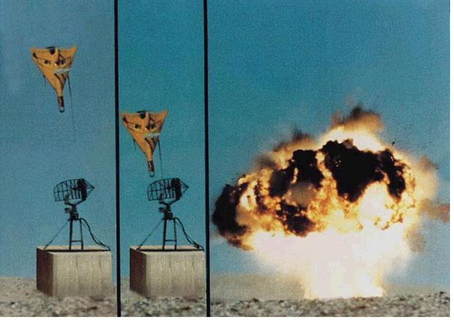
FZÚ



TAXONOMY (coherent with NATO)		Reference information regarding UAV threats			
Threat	**Weight [kg]**	**Reference size [cm^3]**	**Max speed [km/h]**	**Typical altitude [m]**	**Typical RCS [dBm^2]**
Class I (a) and (b) - micro	< 2 kg	25 x 25 x 30	80	100	-20 (objective -30)
Class I (c) - mini	> 2 & < 20	40 x 40 x 30	100	1 000	-13 (objective -20)
Class I (d) - small	> 20 & < 150	200 x 150 x 50	150	1 500	-10
Class II - tactical	> 150 & < 600	1 000 x 700 x 100	300	3 000	-3

	Symmetrical conflict	Asymmetrical conflict	
class I c - d), class II	Air-defence suppression (SEAD),	Hybrid aspectsHybrid aspects	class I a - d)
class I a - c), class II	ISR,	ISR,	class I a - b)
class I b - c)	Vehicle & man hunting,	Vehical & man attacks,	class I b - c)
class I c - d)	Damaging defence infrastructures	Damaging economical /critical infrastructure,	class I b - d)

Problém malých UAV

Rychlost pohybu 16-20 m/s

Váha:

DJI Phantom 4 1480 (2000)g

DJI MINI 2 249 (400) g

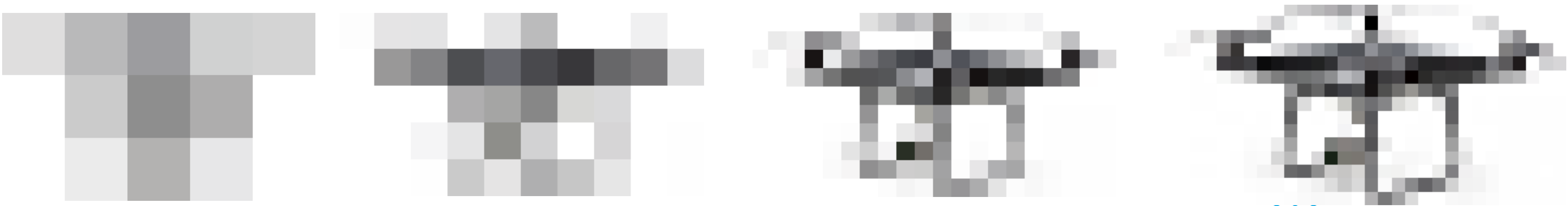
Dolet > 10 km, Dosah > 5 km

- Reakční doba C-UAS cca 40 sekund,
- Rychlost sUAV až 30 m/s,
- C-UAS systémy vyžadují provádění akcí na vzdálenosti kolem 1200 m,

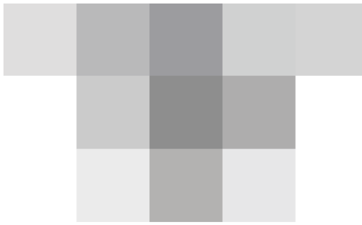
Human-in-loop vyžaduje provedení Klasifikace UAV,
Human-on-loop vyžaduje provedení Identifikace UAV.

C-UAS se neobejdou bez O/E zařízení

	Detection					Tracking					Classification										Identification									
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0
										10										20										30
Pixels in largest cross section required for NATO C-UAS action																														



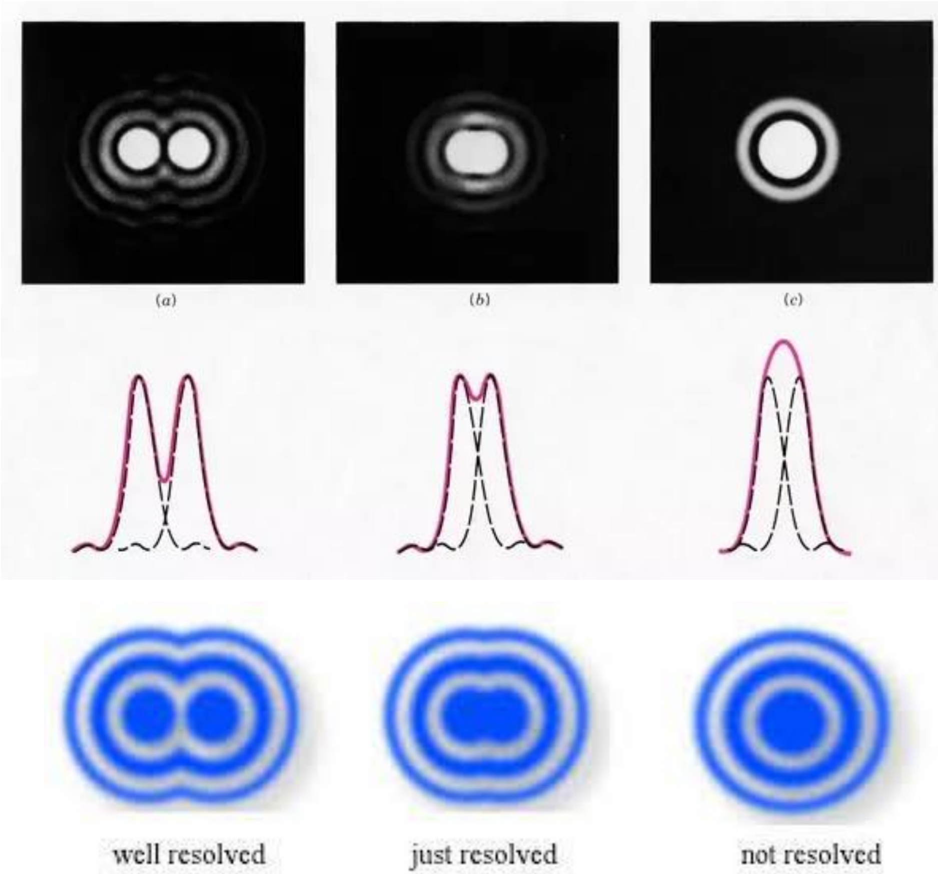
Difrakční limit – Rayleighovo kritérium



$$\theta = \frac{1.22 * \lambda}{D}$$

θ … úhlové rozlišení,
λ … vlnová délka,
D … průměr koncové optiky,

1.22 Rayleighova konstanta pro Gaussovský svazek



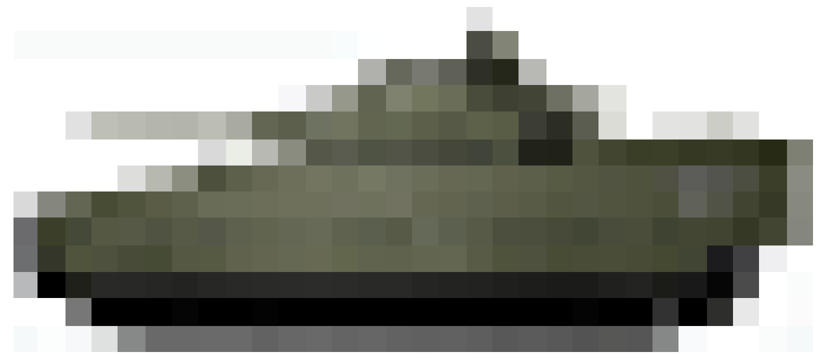
Od úhlu ≥ θ je možné rozlišit 2 body od sebe

„Teaming for Success“

SUPERLASERS FOR THE REAL WORLD

CV90 je:
20x větší než DJI Phantom 4
30x větší než DJI Mini 2

O mnoho řádů vyšší je nepoměr mezi cenou malého UAV + dělostřeleckého granátu proti ceně OT, BVP, MBT (100 tis. Kč vs. desítky až stovky miliónů Kč)



- Při použití běžné optiky na BVP na vzdálenost potřebnou k identifikaci CV90 nebude možné zaručit trekování malých UAV

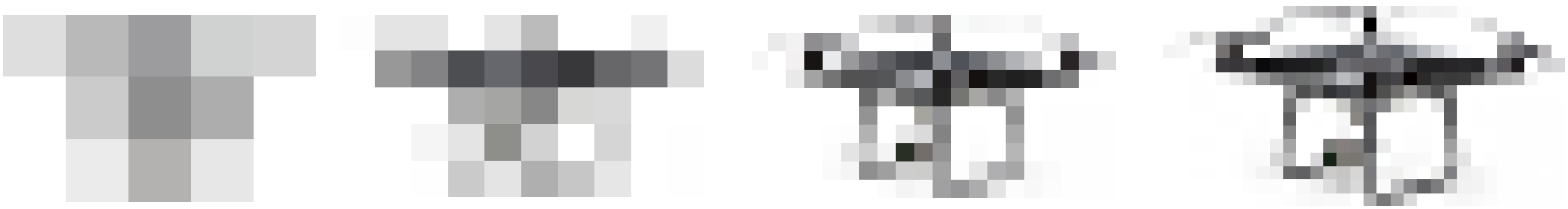
- Je potřeba kombinovat více senzorů

Rozpoznávání obrazu za podmínek den-noc

UAV DJI Phantom 4

- Možnosti O/E systémů jsou i silně závislé na podmínkách osvětlení,
- Šum zvyšuje požadavky na počet bodů pro rozpoznávání obrazu,
- Vzdálenost na klasifikaci a identifikaci pomocí O/E se v noci výrazně zkracuje.

<table>
<tr><td></td><td colspan="5">Detection</td><td colspan="5">Tracking</td><td colspan="10">Classification</td><td colspan="10">Identification</td></tr>
<tr><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td></tr>
<tr><td colspan="11">10</td><td colspan="10">20</td><td colspan="10">30</td></tr>
<tr><td colspan="31">Pixels in largest cross section required for NATO C-UAS action</td></tr>
</table>



LiDARY pro C-UAS

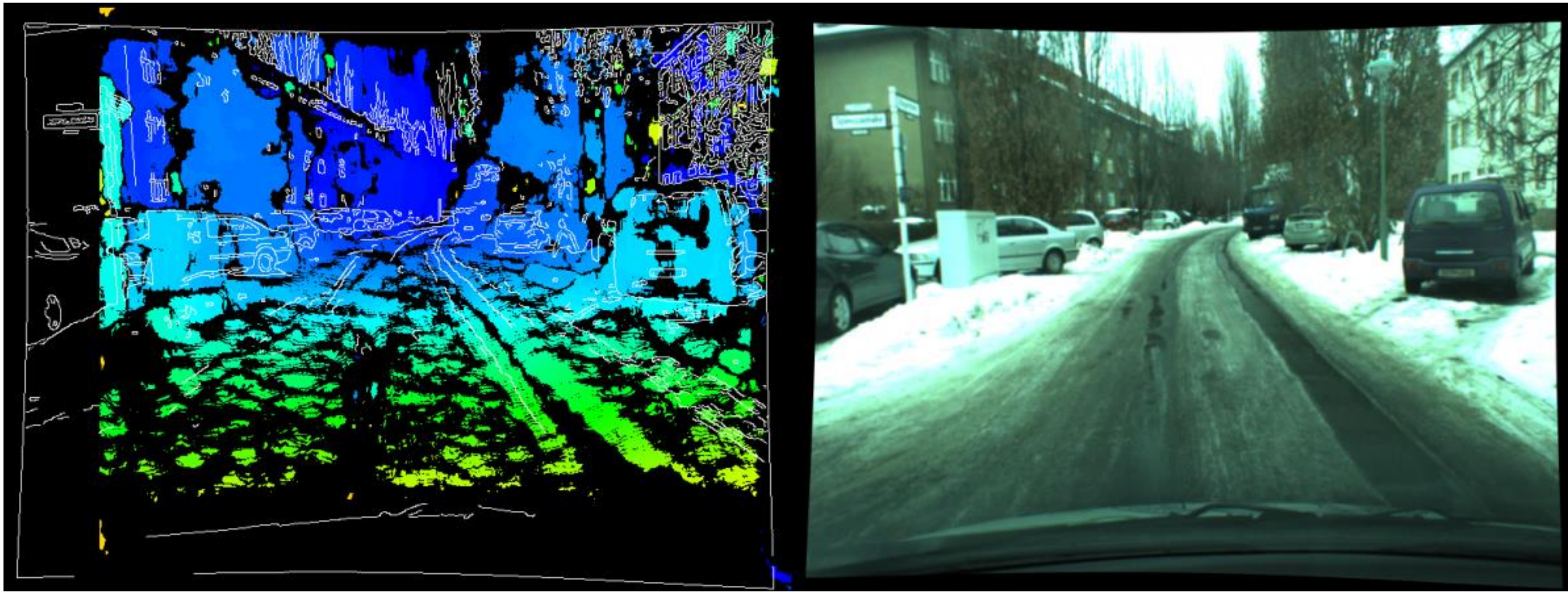
Co mi přináší LiDAR navíc oproti O/E systémům?

- 3D částečný obraz,
- Dopplerovskou a mikro-dopplerovskou informaci.

Jak lze tyto informaci využít?

- Detekce a trekování,
- Identifikace (rozpoznávání) UAV.

Jak stanovit požadavky na LiDAR?



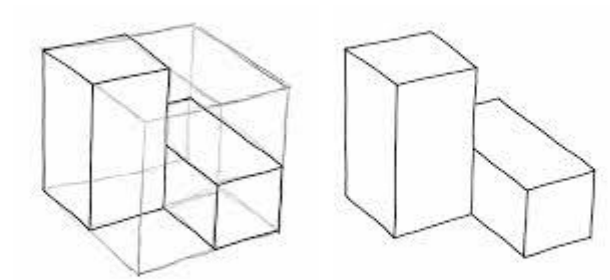
Identifikace je z 600 informačních bodů (30x20) u O/E senzoru.
Model pomocí analogie čára, čtverec -> krychle při zjednodušeném pojetí LiDARu, kde vertikální rozlišení = horizontálnímu.
Pro rozpoznávání musí být objekt rozdělen (počet pixelů):
Pro 2D čtvercový objekt:

$$P = \sqrt{600} \approx 24{,}5$$

Pro 3D krychlový objekt:

$$P = \sqrt[3]{600} \approx 8{,}4$$

Pozor: LiDAR neposkytuje informaci o zádní straně objektu!



Při stejně veliké koncové optice bude dosah systému více jak 2,5x delší v případě LiDARu

Laser-mater interaction

- **There are 2 interactions defined by NATO:**

- Dazzling,
- Burning.

- **There are more levels in chemistry and physics but important is intensity on the spot (target).**

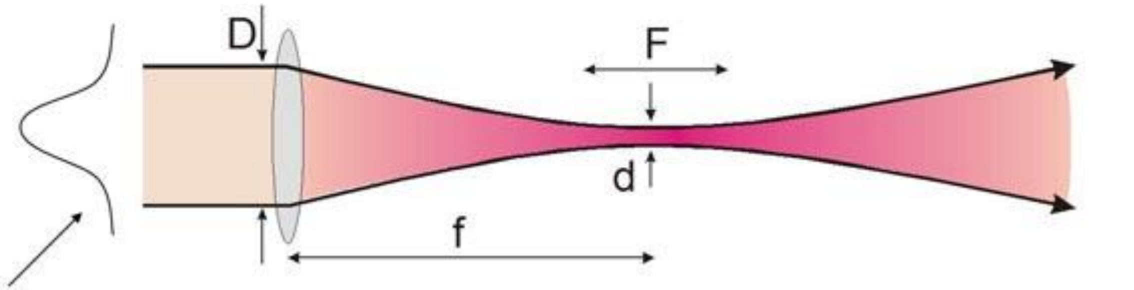
- Initialization of chemical reaction,
- Heating,
- Overheating (liquefaction),
- Evaporation,
- Ablation.

Intensity required for Defence applications

	DEW	DEW	Dazzling	Comm.	Inteligent ammunition	Sensors
Average intensity	100 kW/cm2	1 kW/cm2	100/cm2	< 10 mW	< 10 mW	< 1 mW
Other requirements	CW	CW	CW	pulsed	pulsed	pulsed
	*), **), ***)	*), **), ***)				
Notes	Cutting	Overheating				
*)	Longer wavelengths are better					
**)	Dielectric mirrow laser breadown limit is about 1 GW/cm2 at 1030 nm laser wavelength					
***)	Requirement for continuous wave laser average power could be lowered by combination with pulsed lasers					

Focusing of laser at 1 km distance

Beam diameter 1/e2 [mm]	Laser wavelength [nm]	Spot diameter [mm]
60	1060	22,5
60	1550	32,9
60	2000	42,4
120	1060	11,2
120	1550	16,4
120	2000	21,2
150	1060	9
150	1550	13,2
150	2000	17



$I(r) = I_0 \exp(-2r^2/w^2) = I_0 \exp(-8r^2/D^2)$ Numerical aperture $NA = \sin(D/2f)$

For a Gaussian laser beam:

Diameter of the focal spot

$$d = \frac{4 \cdot f}{\pi \cdot D} \lambda \cong \frac{2 \cdot \lambda}{\pi \cdot NA}$$

Focal depth

$$F = \frac{8 \cdot f^2}{\pi \cdot D^2} \lambda \cong \frac{2 \cdot \lambda}{\pi \cdot NA^2}$$

Increasing of laser intensity by shortening of wavelength is not possible because of scattering of laser beam in atmosphere and safety conditions.

Beam propagation in real atmosphere is far from the laboratory conditions.

Porovnání velikostí

Velikost spotu v ohnisku svazku pro efektivní HPDEW

DJI Phantom 4

CV90

Maximum permissible exposure (MPE)

The single most useful number in laser safety calculations is the maximum permissible exposure. This is the minimum irradiance or radiant exposure that may be incident upon the eye or skin without causing biological damage. The MPE varies by wavelength and duration of exposure and is documented in tables published in ANSI z136.1 standard. Think of the MPE as your laser safety speed limit.

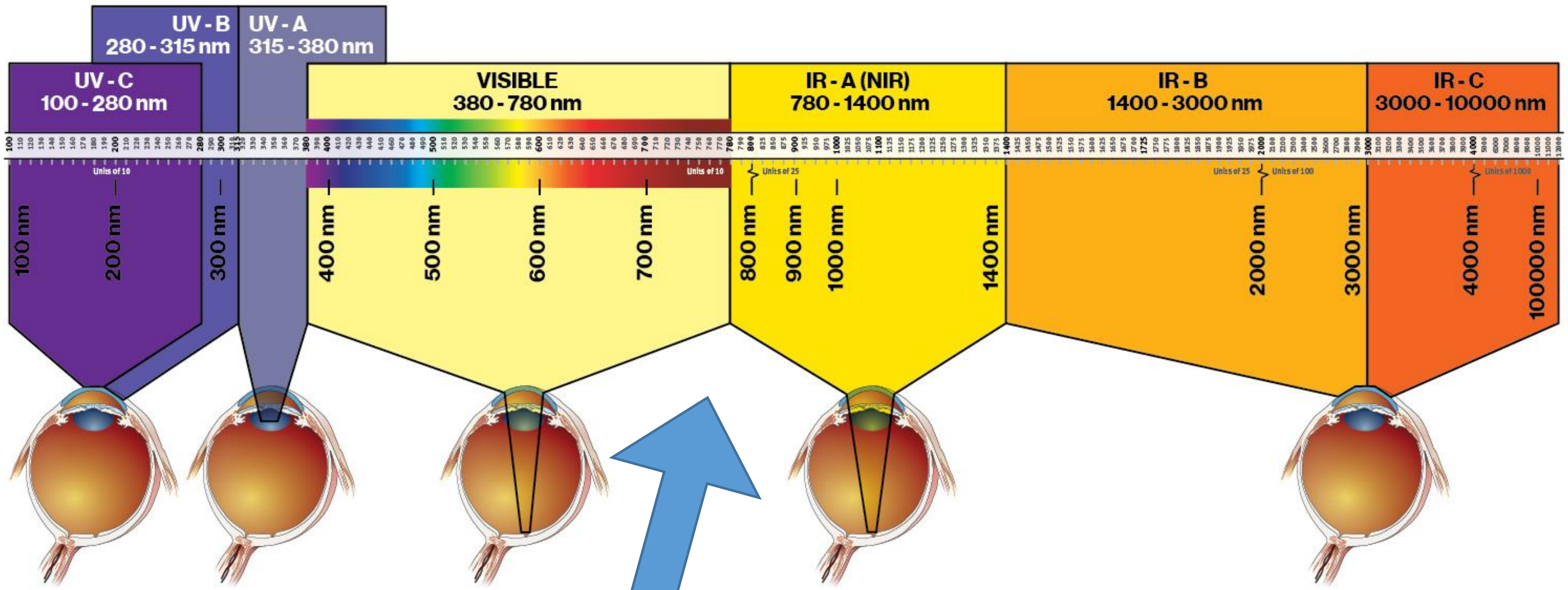
Nominal Ocular Hazard Distance (NOHD)

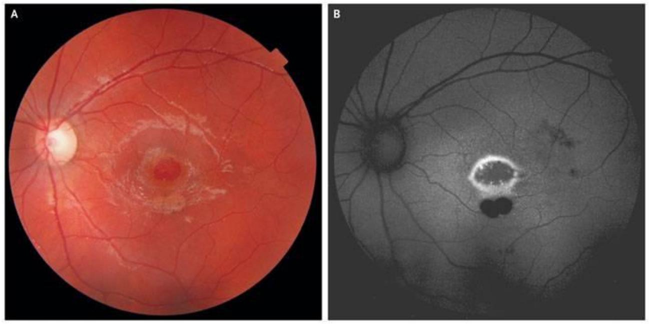
The Nominal Ocular Hazard Distance (NOHD), sometimes referred to as the Nominal Hazard Distance, is the distance along the axis of the emitted beam at which the irradiance is equal to the MPE. The NOHD is dependent on beam characteristics such as the power, diameter, and divergence. The NOHD is usually much greater than the largest dimension of your laboratory space.

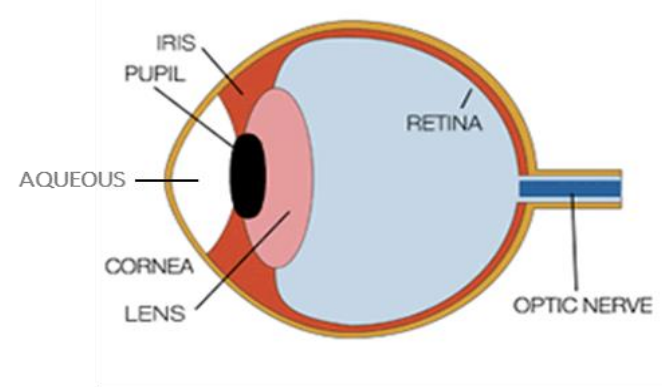
Nominal Hazard Zone (NHZ)

The Nominal Hazard Zone (NHZ). This is a distance within which exposure to a direct, reflected, or scattered beam is greater than the MPE. Mirrors, optics, and reflective materials in the beam path may result in diffuse or specular reflections in unintended directions. Specular reflections are hazardous over a greater range than diffuse reflections. If you are in the NHZ, you are at risk of an exposure above the MPE.

Depth of penetration of electromagnetic radiation in the human eye

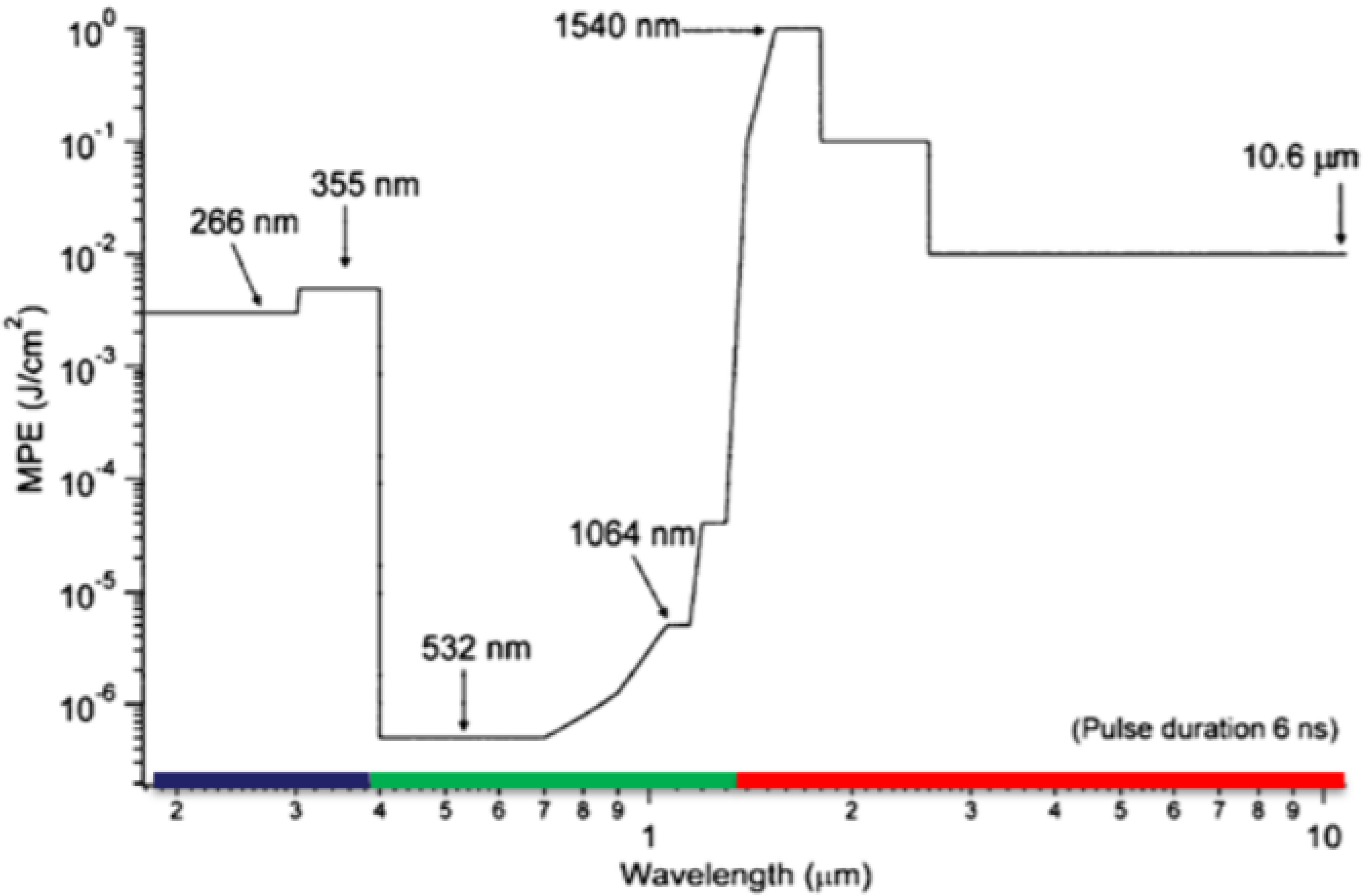






Retina damage is hardest laser limitation

Laser Wavelength Dependence of Maximum Permissible Exposure (MPE) on Eyes and Skin



Adapted from: Gottfried, J. L., F. C. De Lucia, C. A. Munson and A. W. Miziolek (2009). Analytical and Bioanalytical Chemistry 395(2): 283-300.

NOHD

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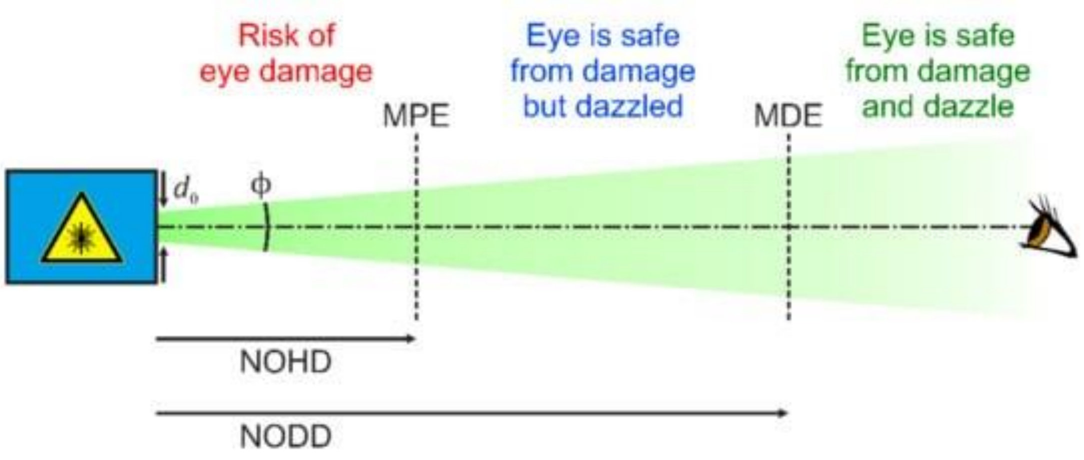
Any effective Laser effector will have NOHD > 1000 km

There should be nothing before and after target in line of laser beam in NOHD (airplanes).



True laser limitation

Nominal Hazard Zone (NHZ)

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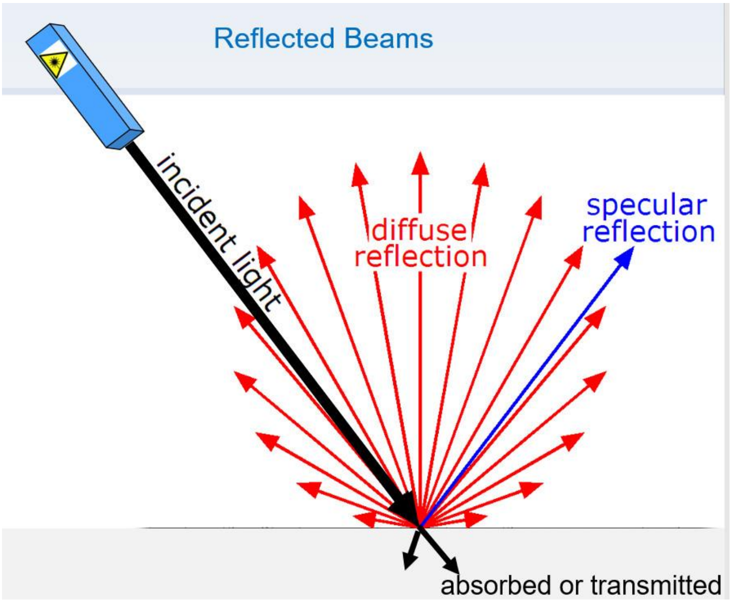

There are both - diffuse and mirror reflection in real conditions!

Will laser plays any role in C-UAS?

Advantages

- Cheapest per shot than any other effector including HP μW,
- Laser cutting is fastest and cheapest way for any mass production,
- Lower collateral damage than guns, missiles and HP μW.

Disadvantages

- Lasers are expensive but overall laser effector will be cheaper than MBT or air-defense cell,
- Strong effect of weather on performance.

Conclusion

There is no laser effector ready to use in EU for CUAS and CRAM

Lasers will enter to operation as a DEW (laser effectors) from following reasons:

- Cheapest for a shot,
- Capability to counter multiple UAVs and swarms,
- Lower collateral damage than guns,
- Multi-role usage.

Lasers disadvantages

- Lasers are very expensive

Thank you for your attention!