ALLSKY-CAMERA SYSTEM FOR MONITORING OF OPTICAL SATELLITE DOWNLINKS

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Outline

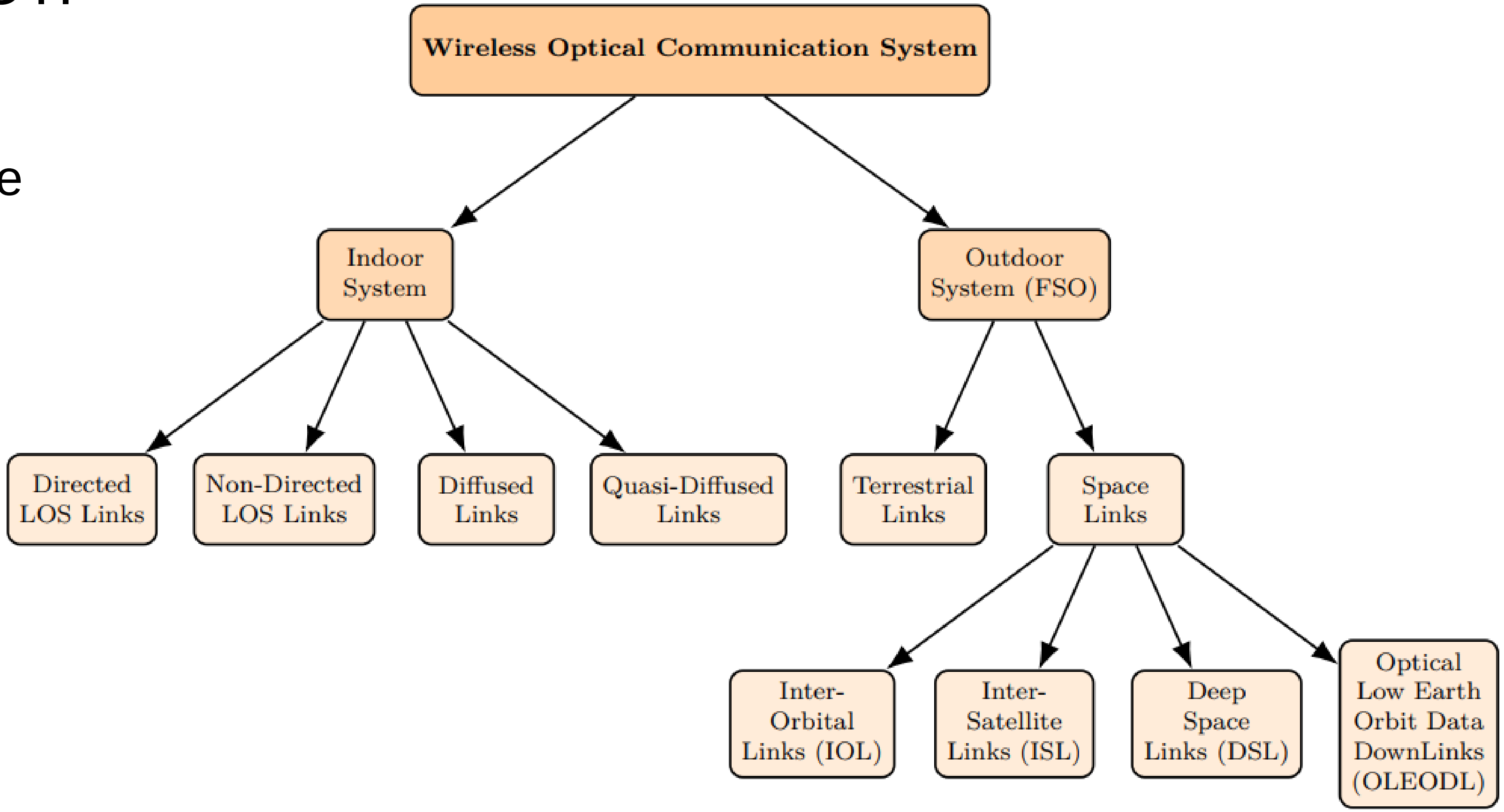
1. Motivation
2. Proposed system
3. Testing
4. Conclusion

MOTIVATION

Free Space Optical Communications Improvements

OVER RADIO-FRECUENCY:

- Up to 50 % less weight of the equipment.
- Up to 25 % power consumption.
- Avoidance of tariffs or regulatory restrictions to RF.



Motivation

OGS' LEO signal detection :

1. Satellite's incorrect orbit data
2. Satellite's laser
3. Visibility / clouds
4. OGS functioning

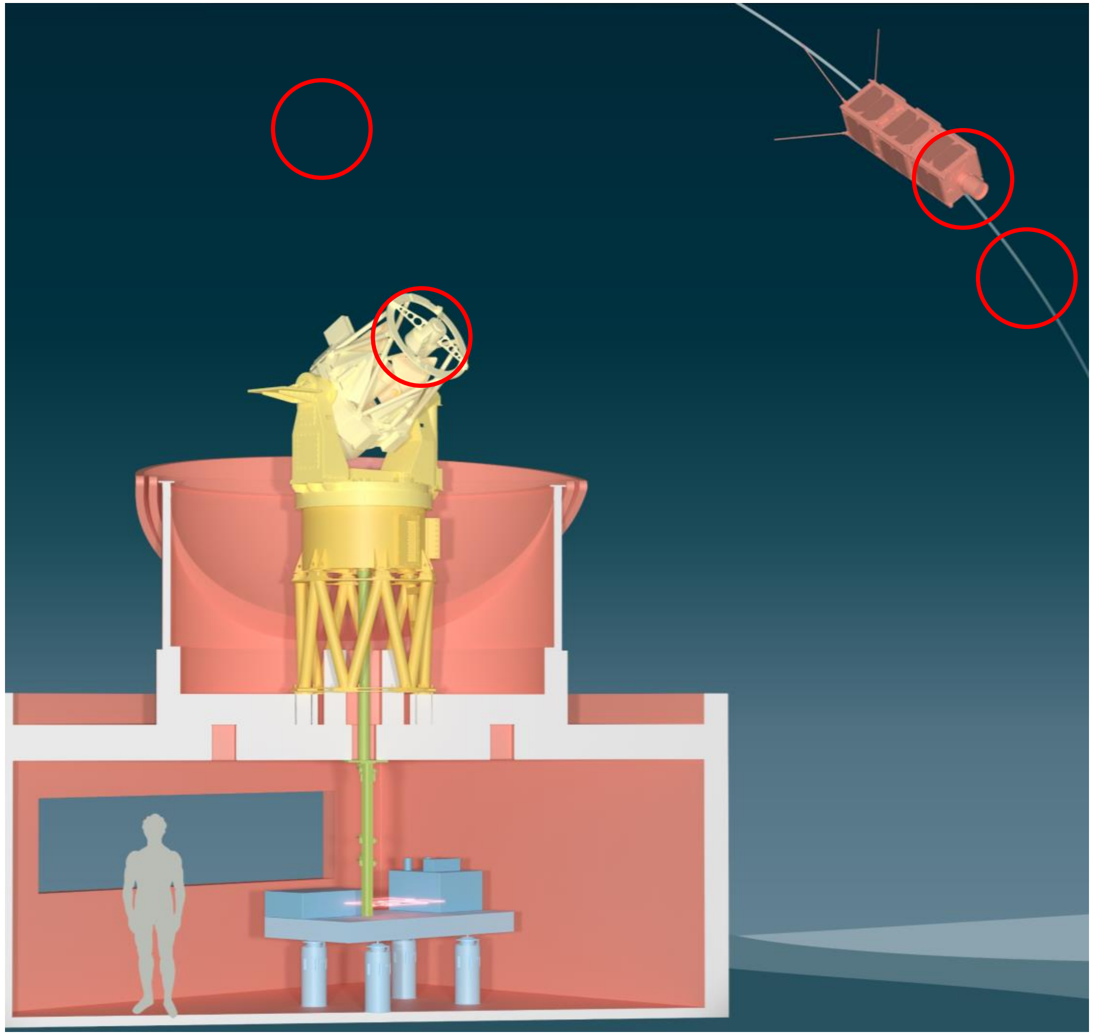


Image credits: DLR Media

Motivation

OGS' LEO signal detection :

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SOURCE OF ERROR UNKNOWN!

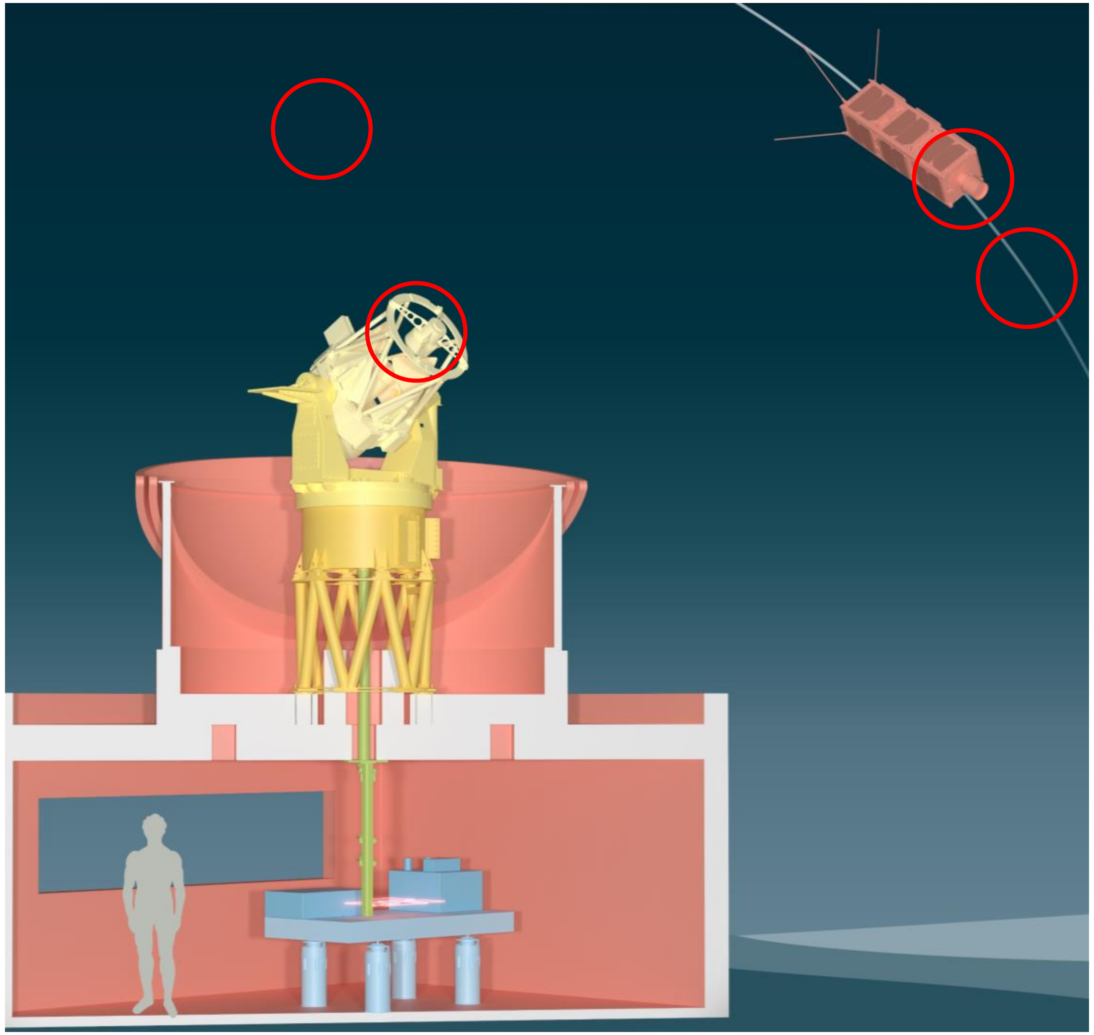


Image credits: DLR Media

Goal
Validation tool usable during link operations

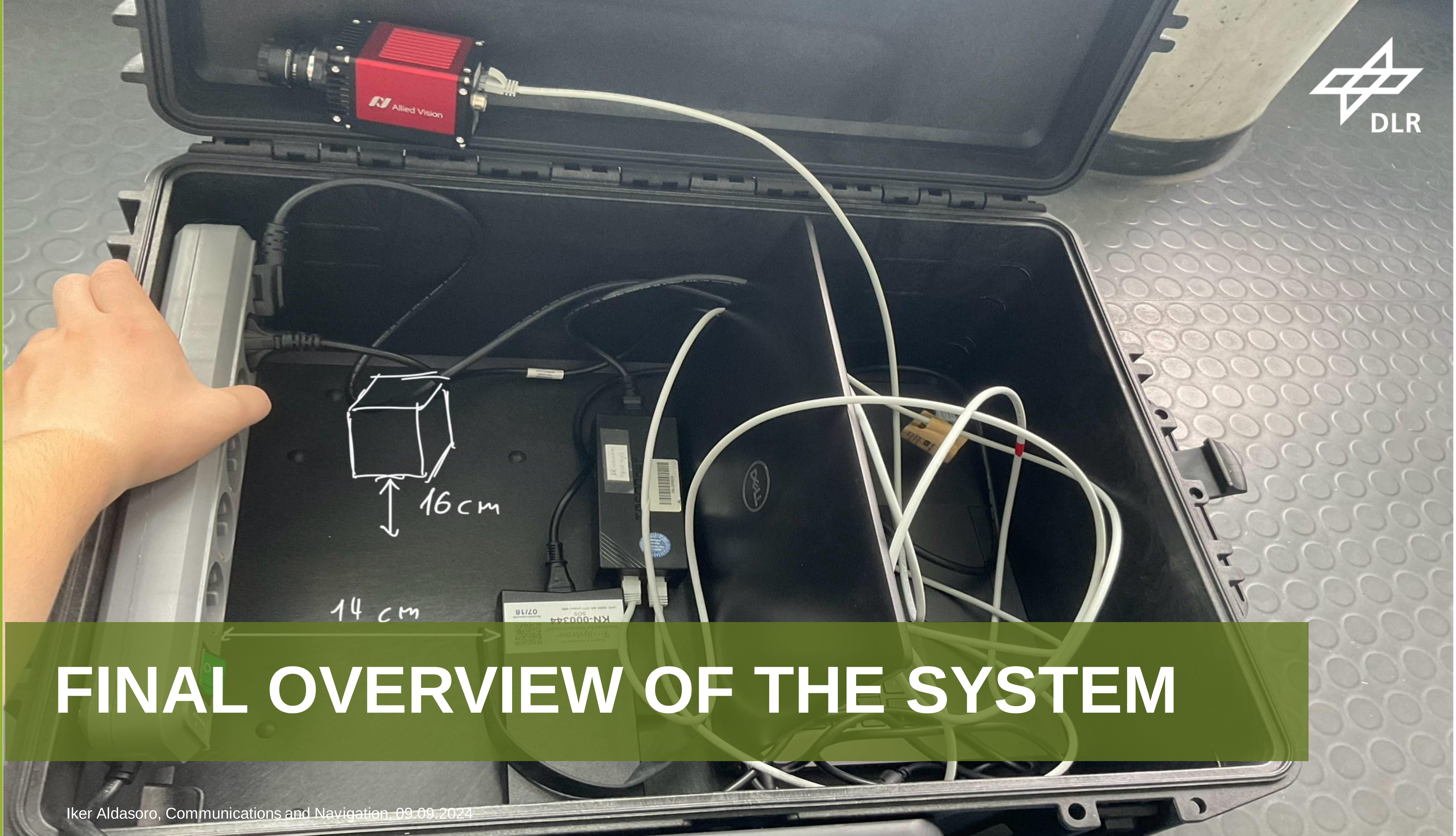
- Full hemisphere coverage, no pointing nor orbit knowledge is needed, as we could see the satellite at all time.

- Compact, portable and self-sufficient.

- Able to detect azimuth, elevation and intensity received by the satellite, allowing evaluation of pointing quality.

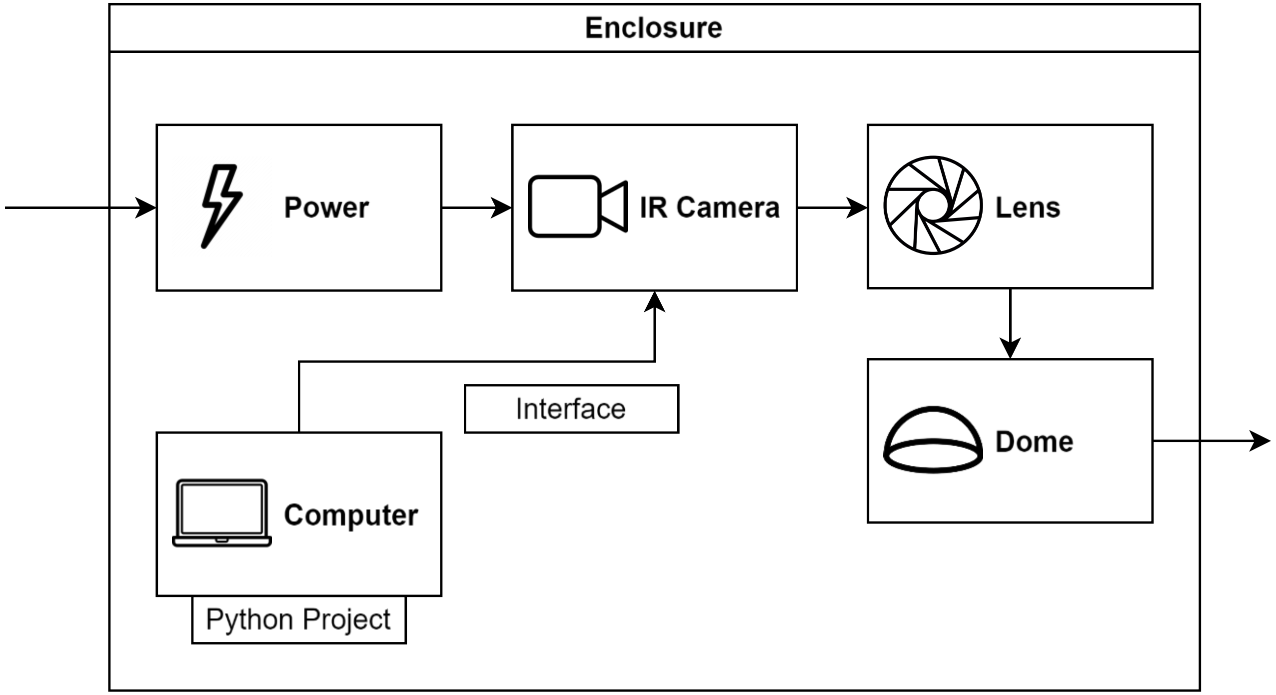
- General application useful for any satellite emitting around 1550nm.

FINAL OVERVIEW OF THE SYSTEM

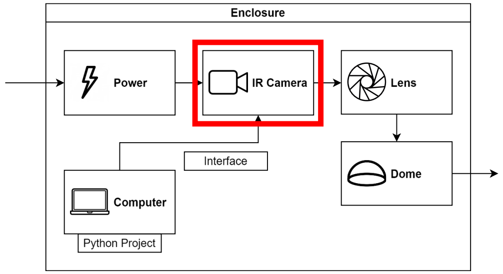


Final System Overview

- The following is the proposed preliminary final system:



InGaAs Camera
Sensor importance



- An InGaAs camera is capable to work from 900nm – 1700nm.

- Sensor resolution and pixel size will influence the angle of view.

$$D_{sensor\ size} = D_{sensor\ res} P_{size}$$

- We should look for the biggest sensor possible.

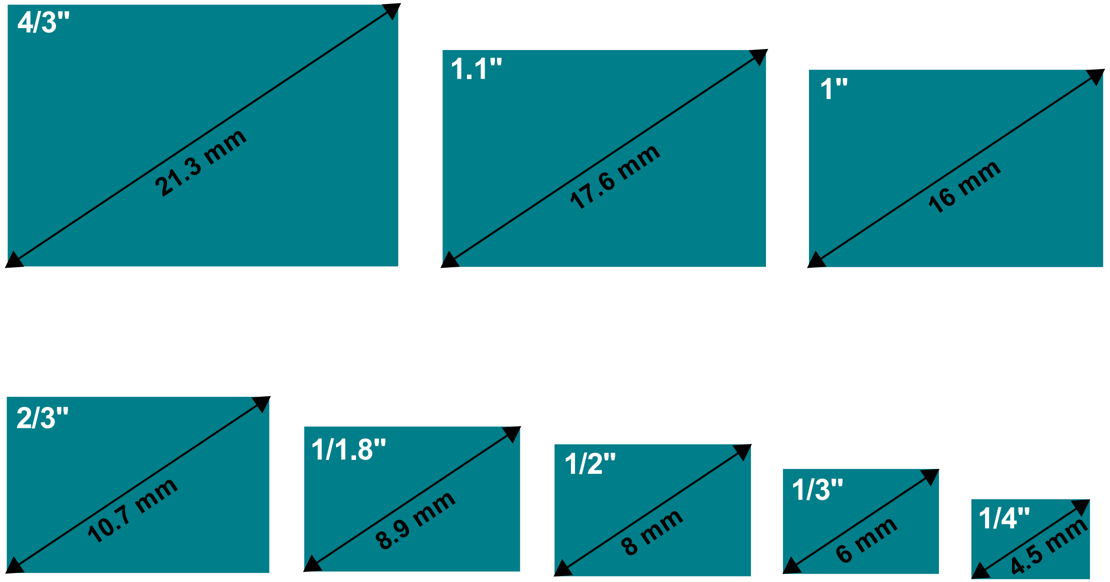
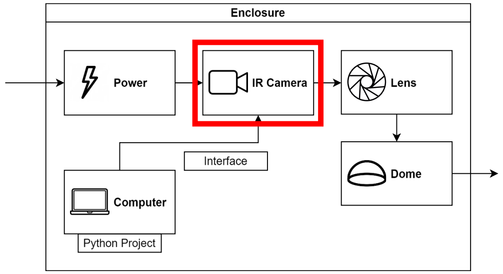


Image credits: https://www.1stvision.com/cameras/IDS/IDS-manuals/en/basics-sensor-size.html



InGaAs Camera
Camera selection

- At first, Sony IMX 990/ 991; ½', ¼' SenSWIR Sensors (400nm – 1700nm).

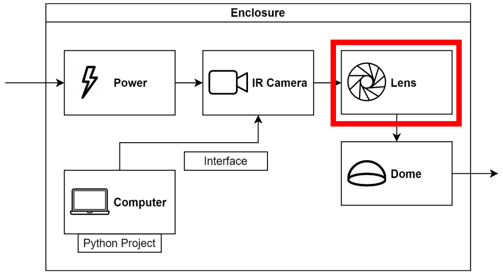
- Wavelength range is not that important for our application.

GSOC – Allied Vision Goldeye G-008

2/3' Sensor size (12.29mm)

Image credits: https://www.alliedvision.com/en/camera-selector/detail/goldeye/g-008-cool-tec1/

Lens
Challenges



- Two options; SWIR lenses or VIR lenses.
- SWIR lenses, expensive, not enough angle of view.
- VIR lenses, wide enough, bad infrared transmission.
- Must be compatible with our sensor size and camera mount.

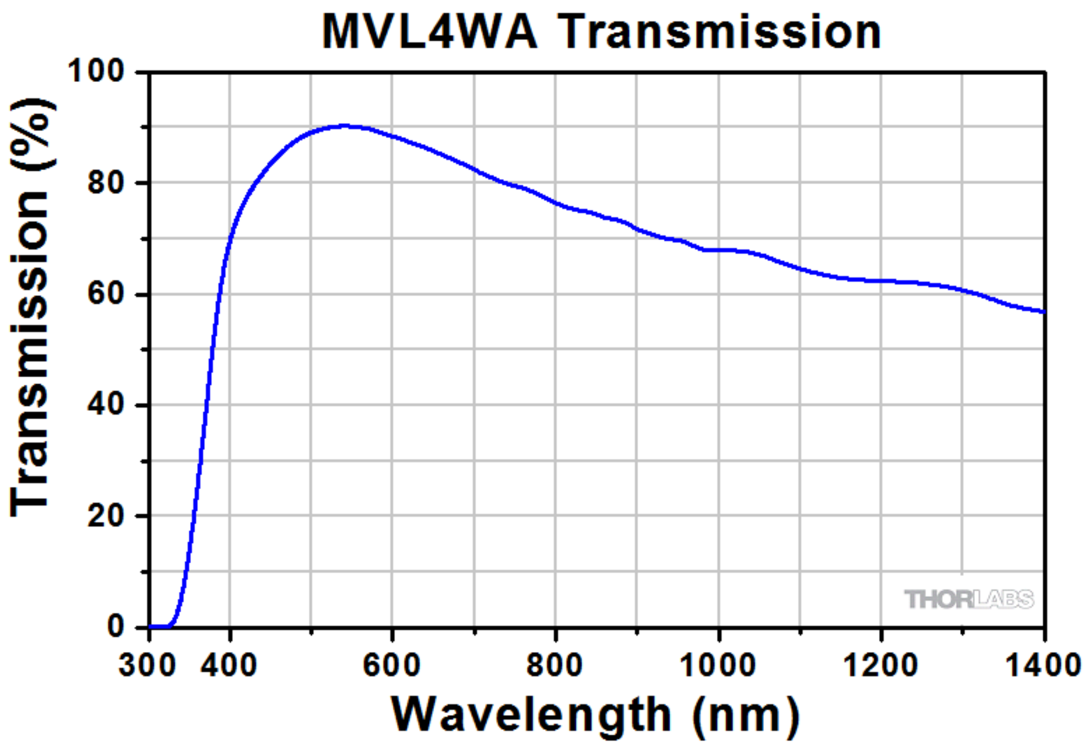
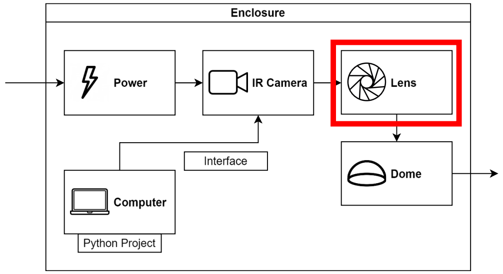


Image credit: https://www.thorlabs.de/thorproduct.cfm?partnumber=MVL4WA

Lens
Lens selection



- Navitar MVL4WA, ½’ 132.1° FOV.
- With 2/3’ sensor, FOV should be higher.
- We are at risk of vignetting or unexpected distortions.
- Clear image 140° FOV.

Image credits: https://www.thorlabs.de/newgrouppage9.cfm?objectgroup_id=1822

Final System Overview

- The following is final system:

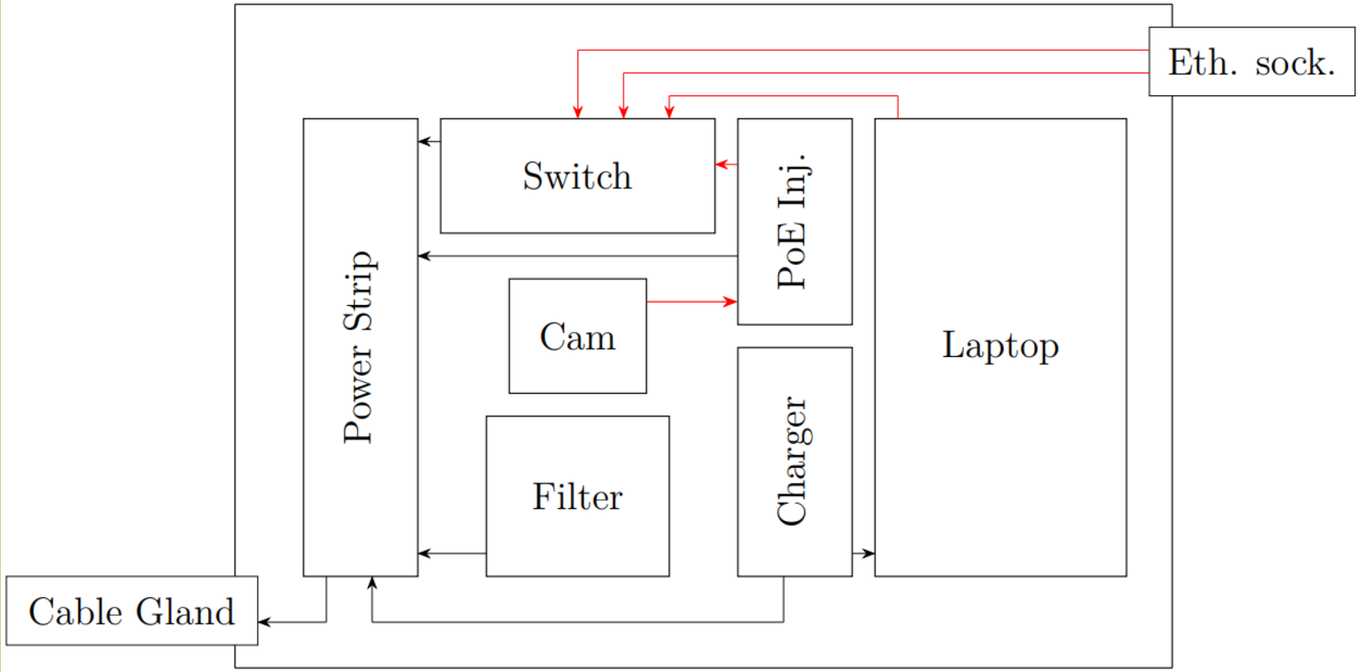
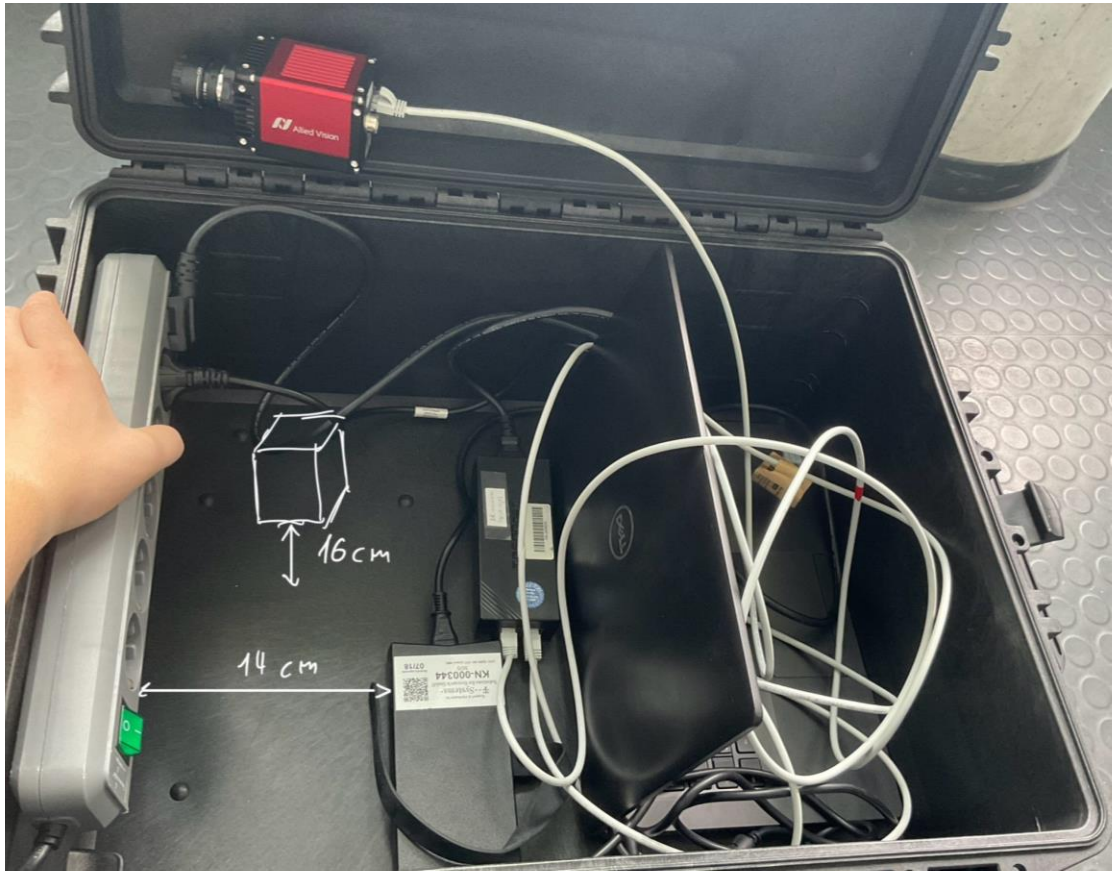
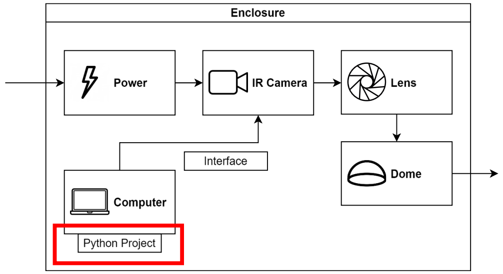
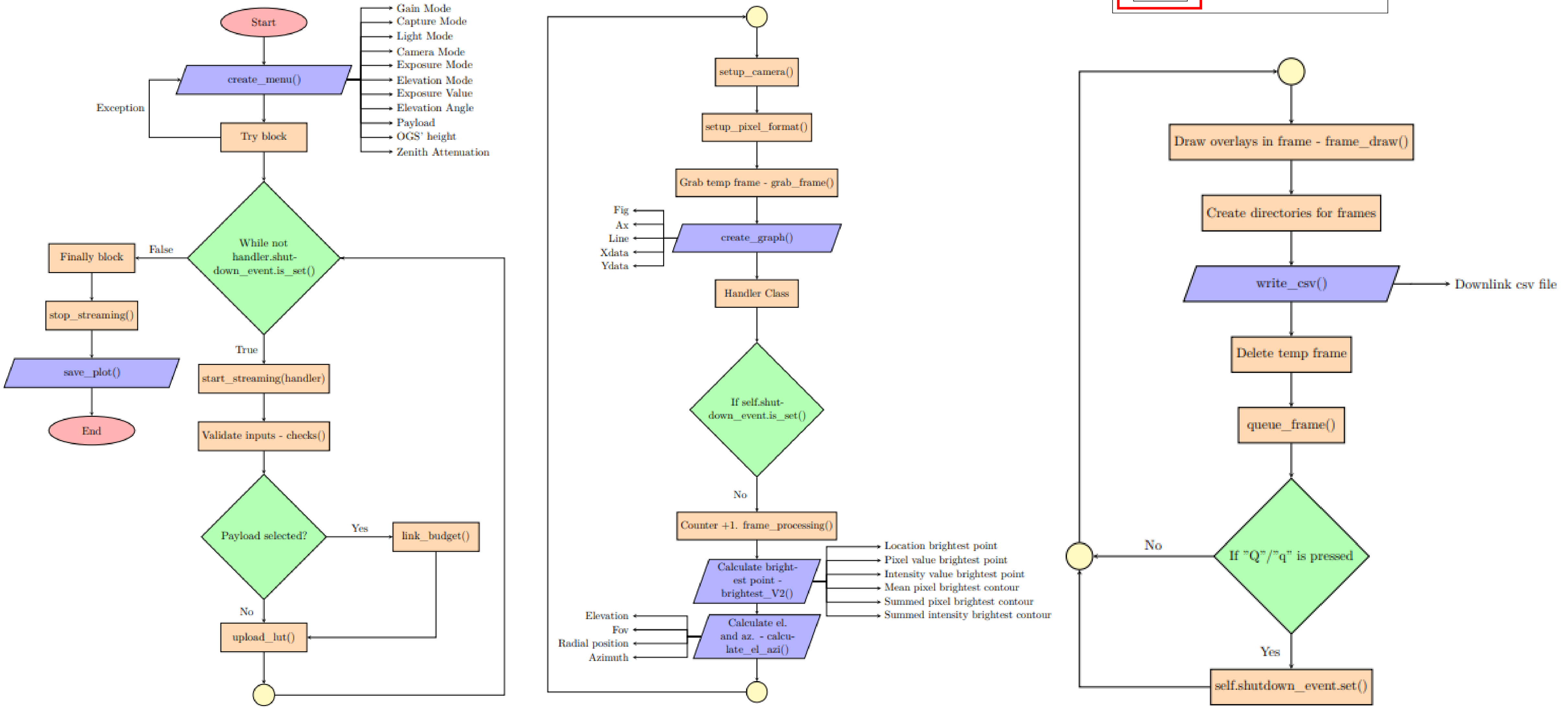


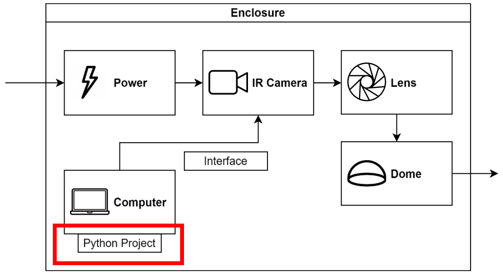
Figure 3.11: Final diagram of the proposed AllSkyCam4OLEODL system. Ethernet cables in red, power cables in black.



Python Script
Flow chart

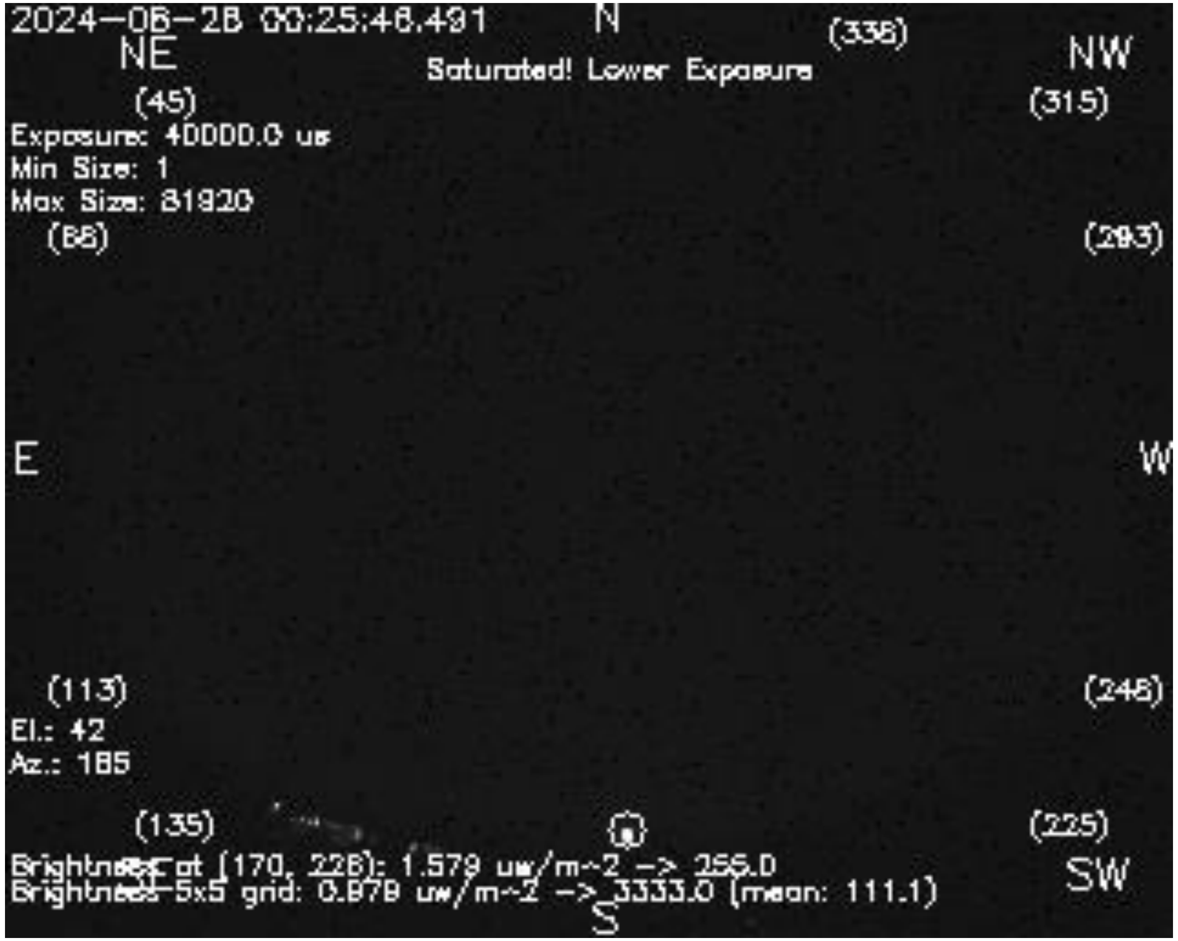




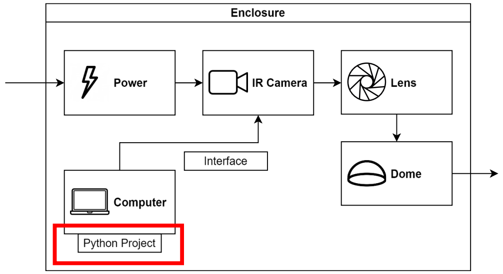


Python Script
Camera modes

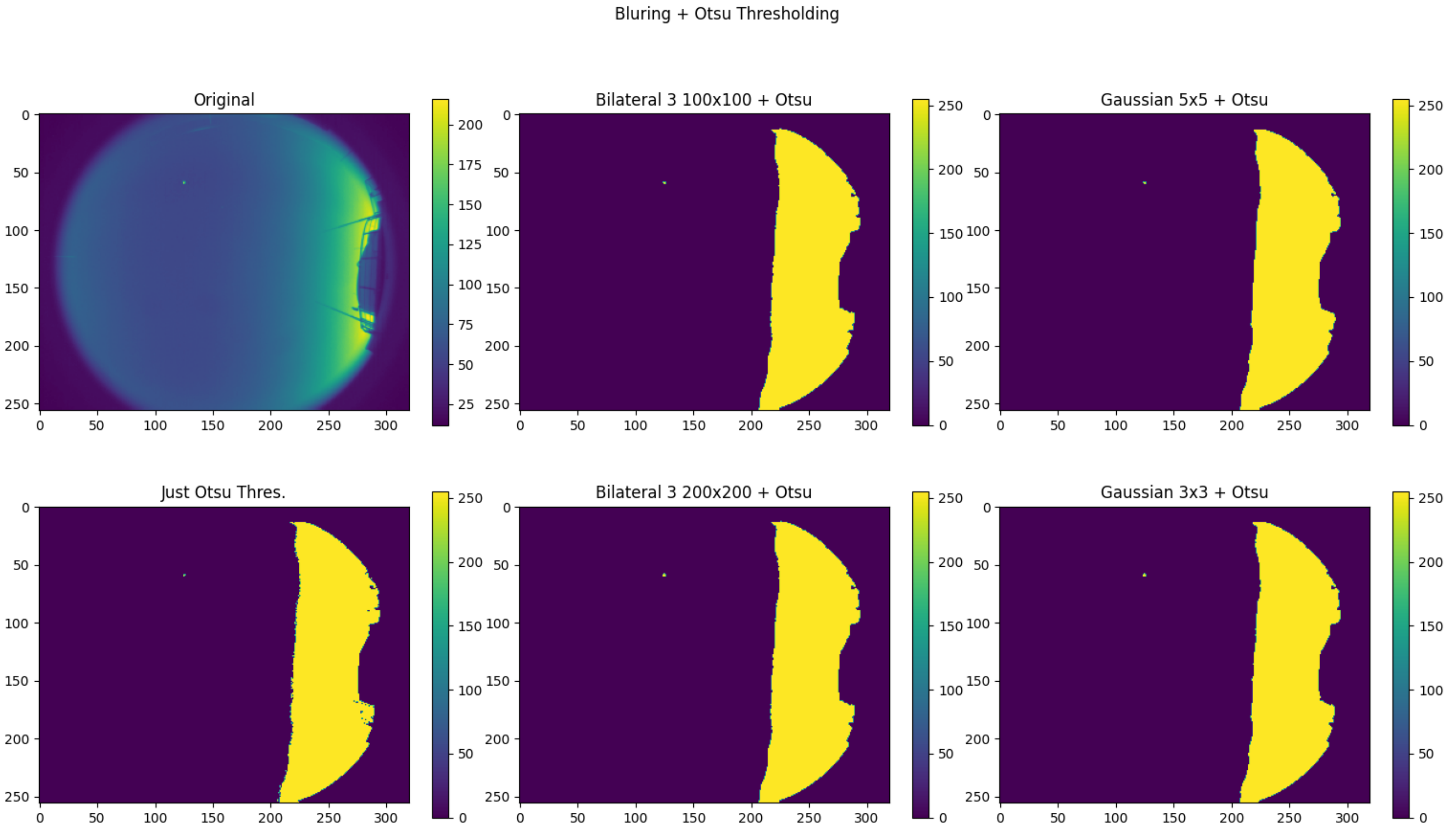
- Normal Operation
- Image Subtraction
- Hot pixel removal:



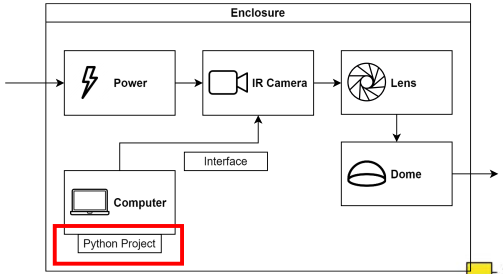
Python Script
Satellite tracking

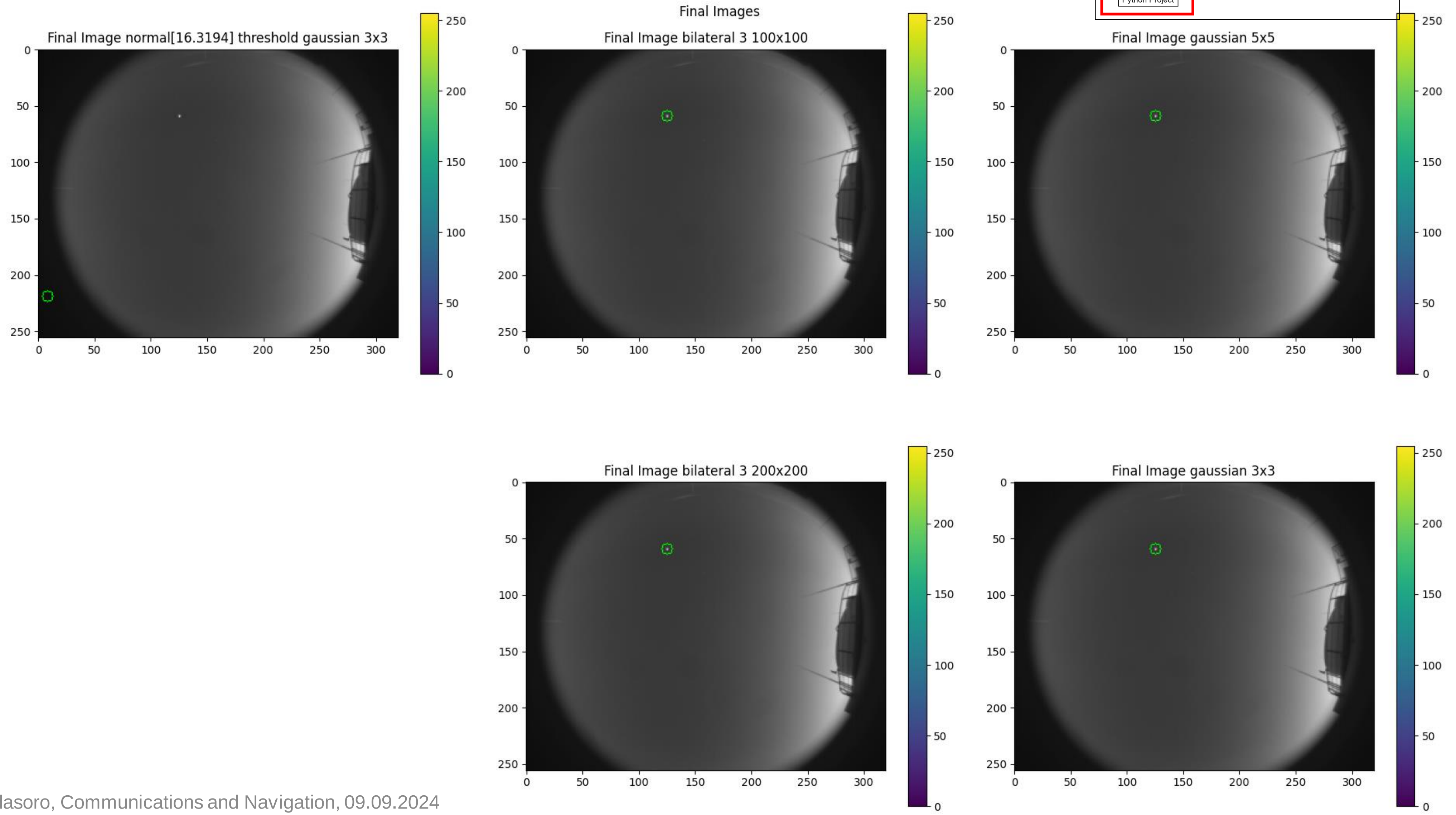


- Normal system:
  - Blurring
  - Thresholding
- Exposure will change during operation
- Different for daytime and night-time

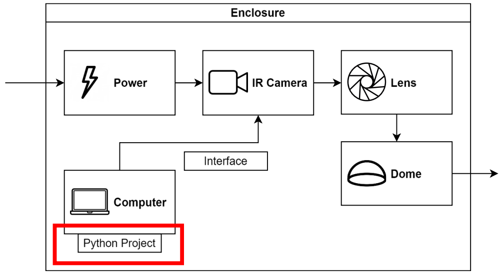


Python Script
Satellite tracking - Daytime





Python Script
Azimuth and elevation - elevation



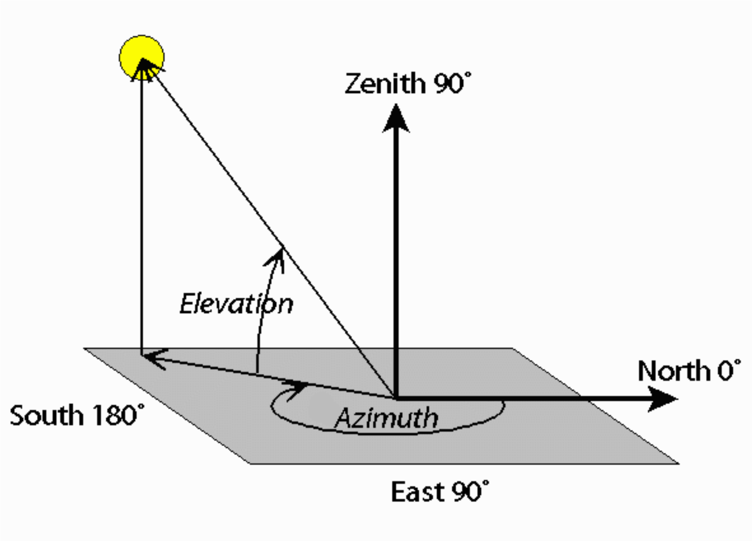
- Equisolid projection:

$$r = 2f \sin\frac{\theta}{2} \longrightarrow \theta = 2 \arcsin\frac{R \cdot P_{size}}{2f}$$

$$r = \sqrt{(x - x_c)^2 + (y - y_c)}$$

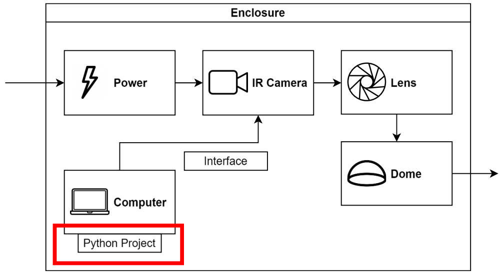
- Elevation angle:

$$elevation = 90 - \theta$$



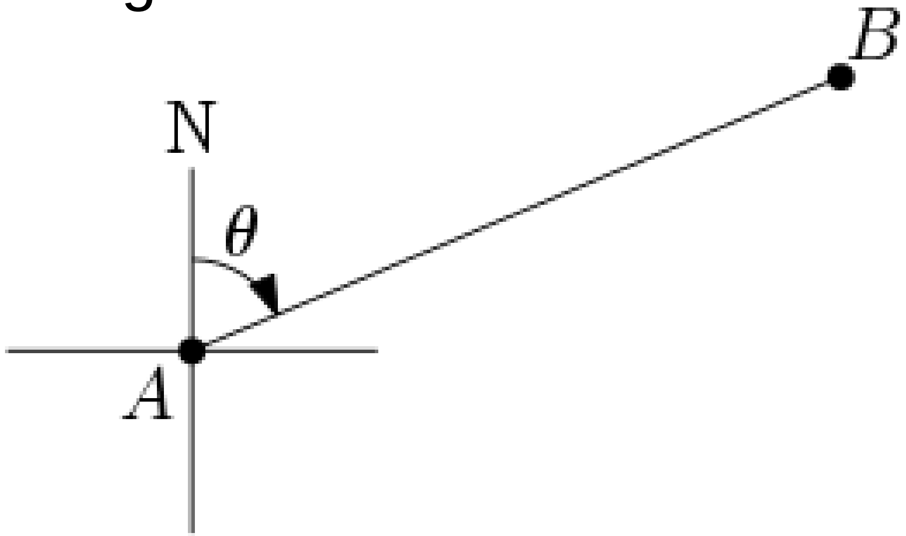
projection	math
equidistant fisheye	$R = f \cdot \theta$
stereographic	$R = 2f \cdot \tan\left(\frac{\theta}{2}\right)$
orthographic	$R = f \cdot \sin(\theta)$
equisolid (equal-area fisheye)	$R = 2f \cdot \sin\left(\frac{\theta}{2}\right)$
Thoby fisheye	$R = k_1 \cdot f \cdot \sin(k_2 \cdot \theta)$ with $k_1 = 1.47$ and $k_2 = 0.713$
PTGui 11 fisheye	$R = \begin{cases} \frac{f}{k} \cdot \tan(k \cdot \theta) & \text{for } 0 < k \leq 1 \\ f \cdot \theta & \text{for } k = 0 \\ \frac{f}{k} \cdot \sin(k \cdot \theta) & \text{for -1} \leq k < 0 \end{cases}$

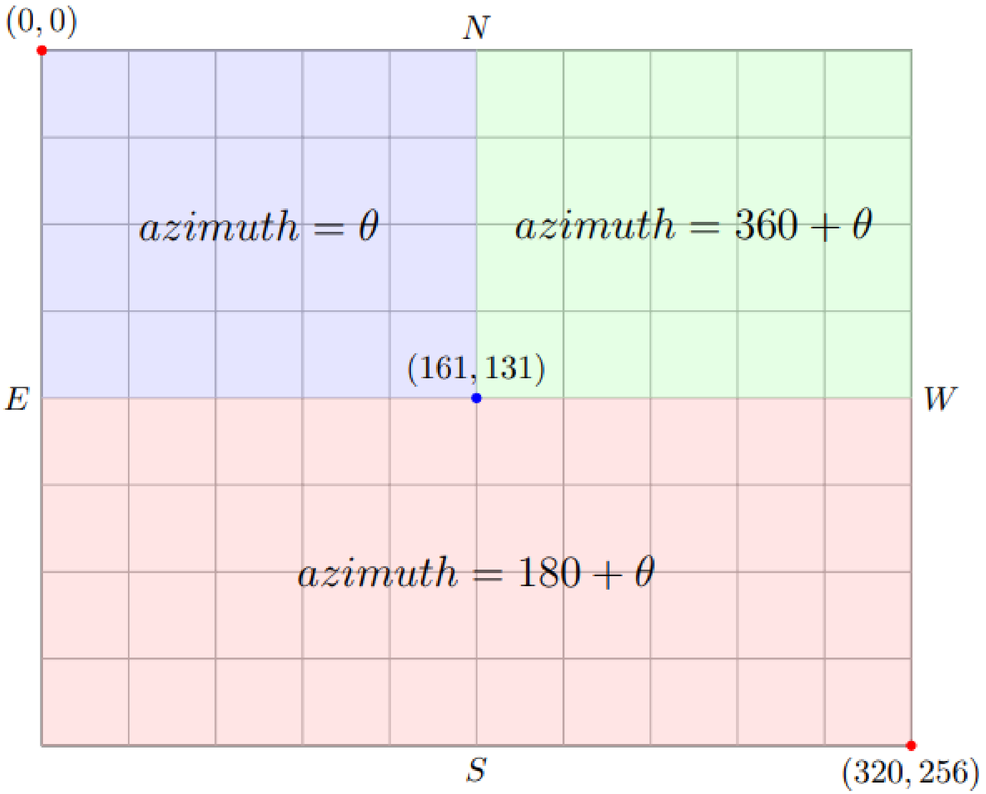
Python Script
Azimuth and elevation - azimuth



- Origin is in the top left of the frame.
- Images are mirrored

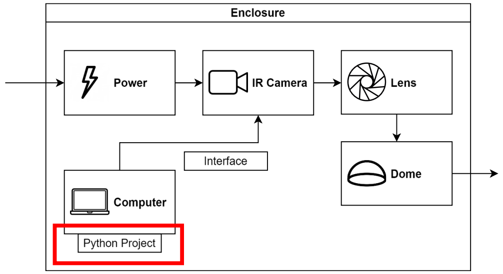
$$\theta = \arctan\left(\frac{b_1 - a_1}{b_2 - a_1}\right)$$

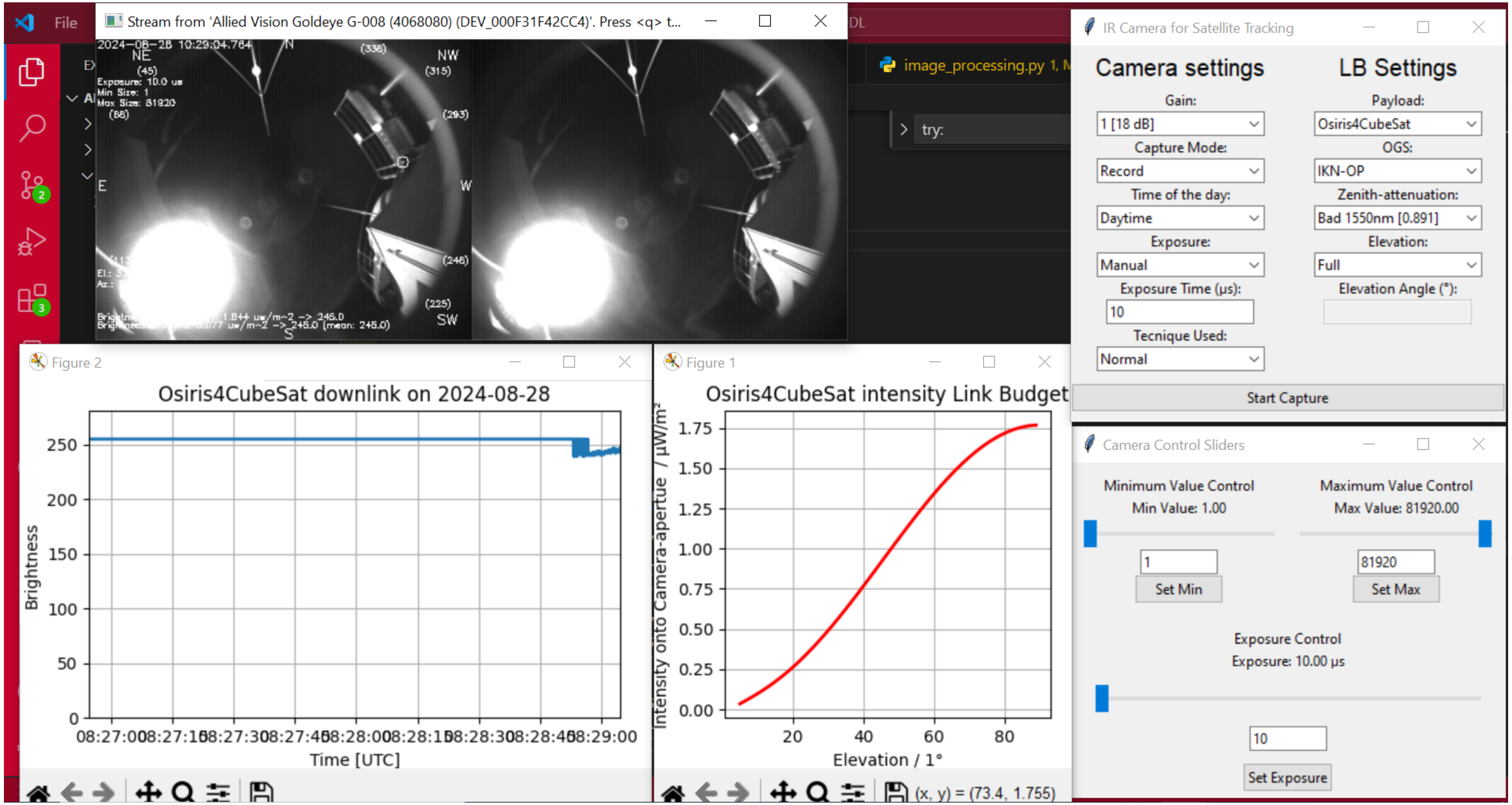




$$(b_1, b_2) = (a_1 + r\sin\theta,\ a_2 + r\cos\theta)$$

Python Script
GUI






202448_191651_frame_166.tiff - IrfanView
File Edit Image Options View Help

TESTING

Link Budget
Flying Laptop

- We are using Flying laptop as it is one of the worse cases we can try.
- Being a camera.
  - No Pointing losses.
  - No Scintillation losses.
  - No Rx internal losses.

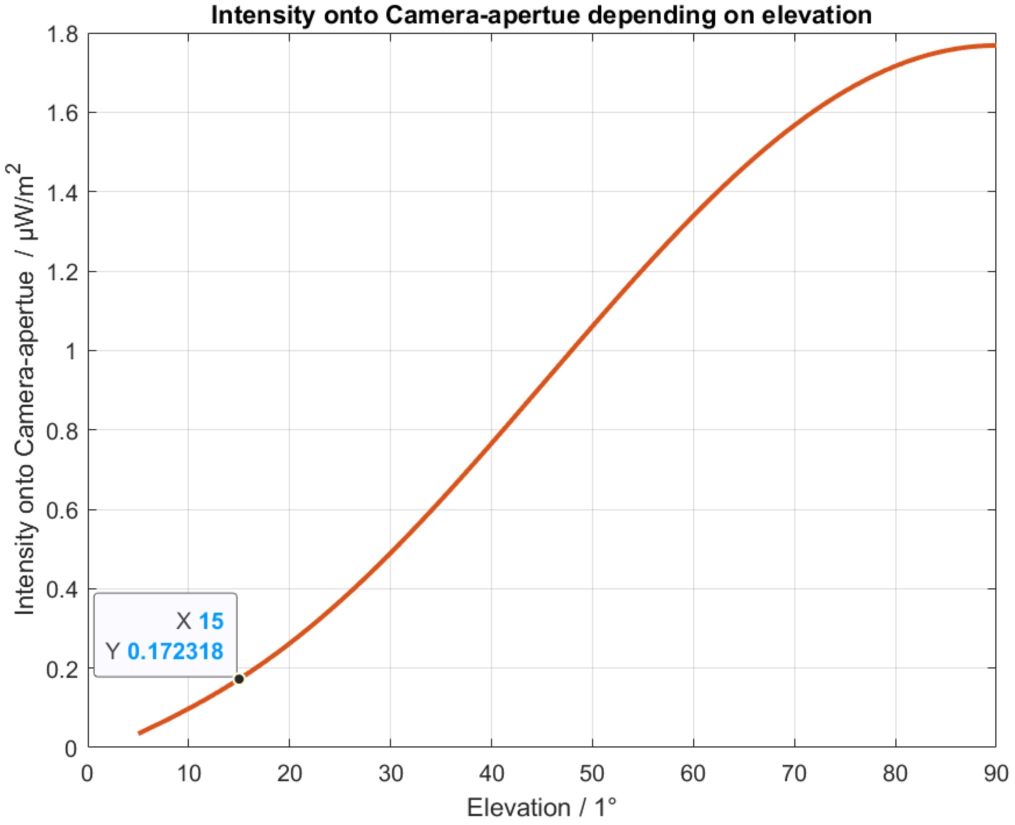
$$I_o(L) = \frac{4ln2}{\pi} * \frac{P_{tx}}{(L * \theta_{FWHM})^2}$$

$Simulated\ testbed$:

$P_{tx} = 0.2\mu W\ (1.6mW - 50dB)$

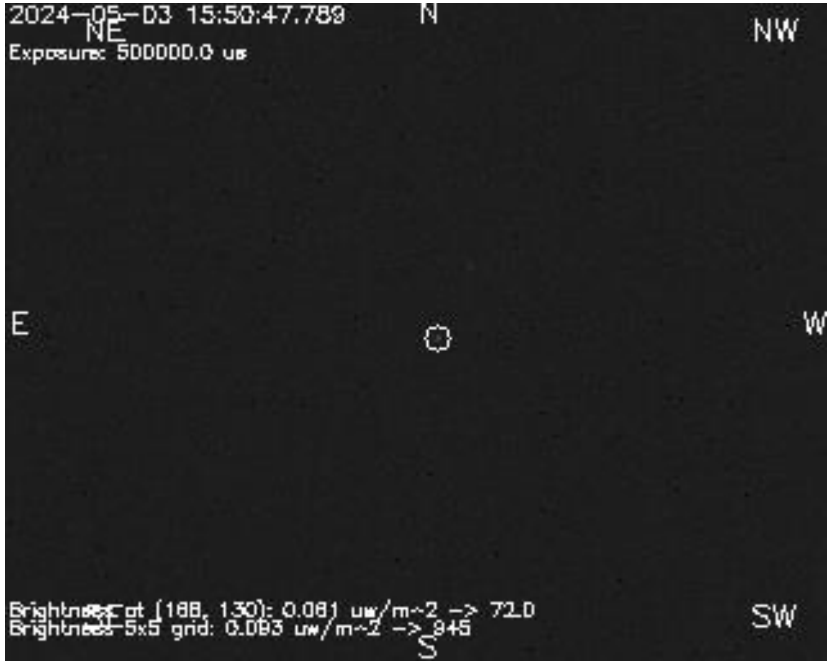
$L = 2.65m$

$\theta_{FWHM} = 0.134\ rad$



Basement Testing
Done with a SMF-28 fiber + 50dB of attenuation

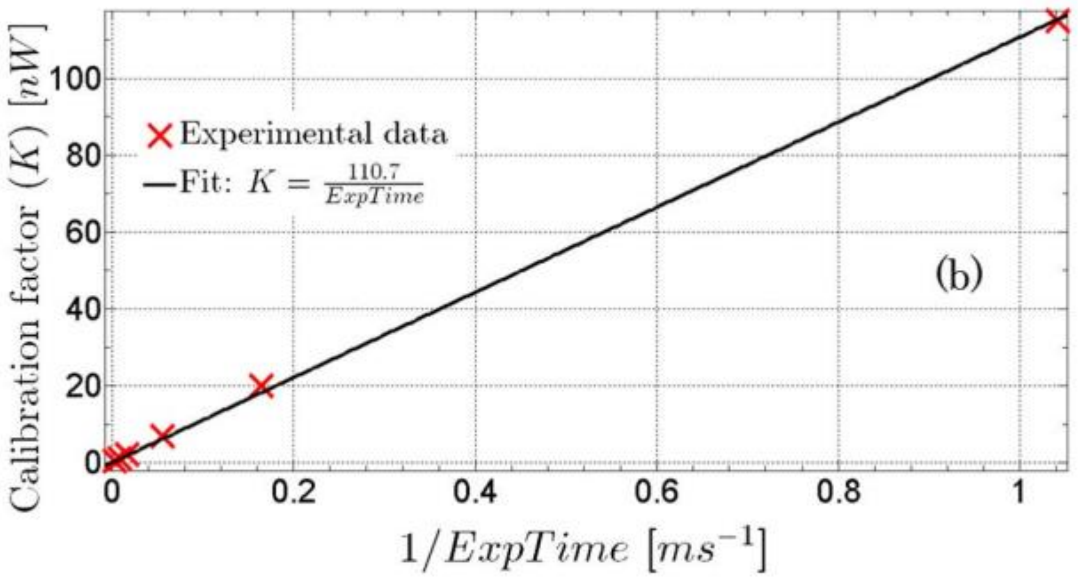
- With the values previously stated $I_o(L)$ should be equal to $0.1396\,\mu W/m^2$.

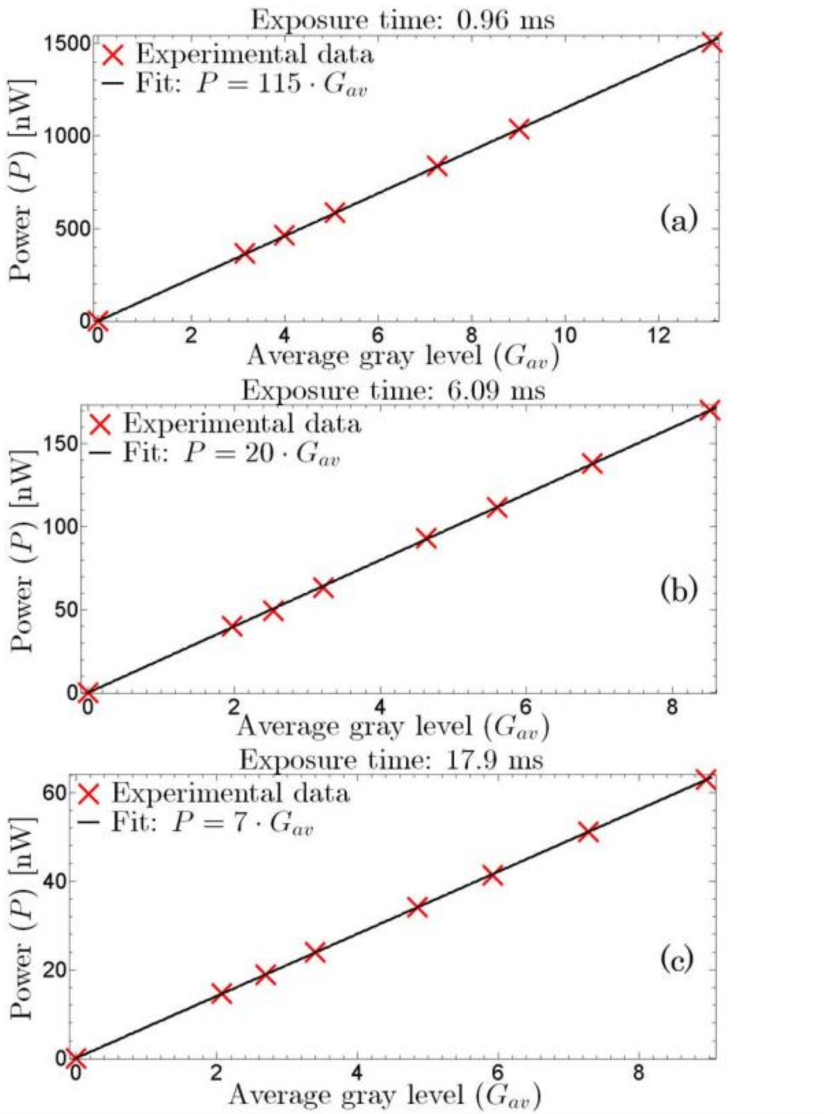


- It is seen, so Flying laptop should be seen as well.

Intensity calibration
Method

- The test tower is too bright (0 dBm).
- Laser that variates the power on a mount






2024-07-08 21:14:15.358
N
NE
NW
Exposure: 580.0 us
E
W
SW
S
Brightness at (180, 33): 1.843 uw/m^-2 -> 219.0
Brightness 5x5 grid: 0.583 uw/m^-2 -> 1854


2024-06-28 00:23:29.567
N
(338)
NE
NW
(45)
(315)
Exposure: 82638.0 us
Min Size: 1
Max Size: 48
(68)
(293)
E
W
(113)
(248)
El.: 24
Az.: 200
(135)
(225)
SW
S

CONCLUSION

Conclusion
Next steps

- We have proven the device to be possible.
- Fine-tune reference intensity to obtain better results.
- More testing is needed.
- Make it able to be operated remotely.

THANK YOU FOR YOUR ATTENTION!