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Modular and Low-Cost Earth Sensor for LEO and GEO Applications

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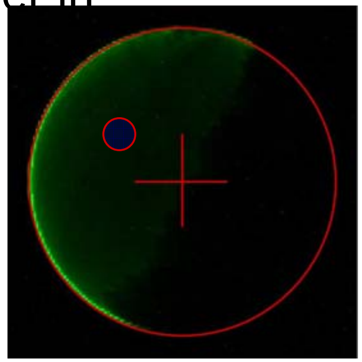
New Concept for an Earth Sensor:

Earth Sensor based on imaging airglow with an array of single photon counters (SPADs):

- Airglow: Permanent light source in the visible (762 nm)
- Low-power, uncooled, sensitive detector
- Compact and low-cost earth sensor

- Angular accuracy: 5° LEO, 0.6° GEO
- primary applications:
  - Earth Presence Failure detector for Telecom missions using star trackers-based AOCS (GEO)
  - Initial acquisition for Earth observation missions (LEO)
  - Back-up sensor for Earth-pointing safe modes (either in LEO or GEO)



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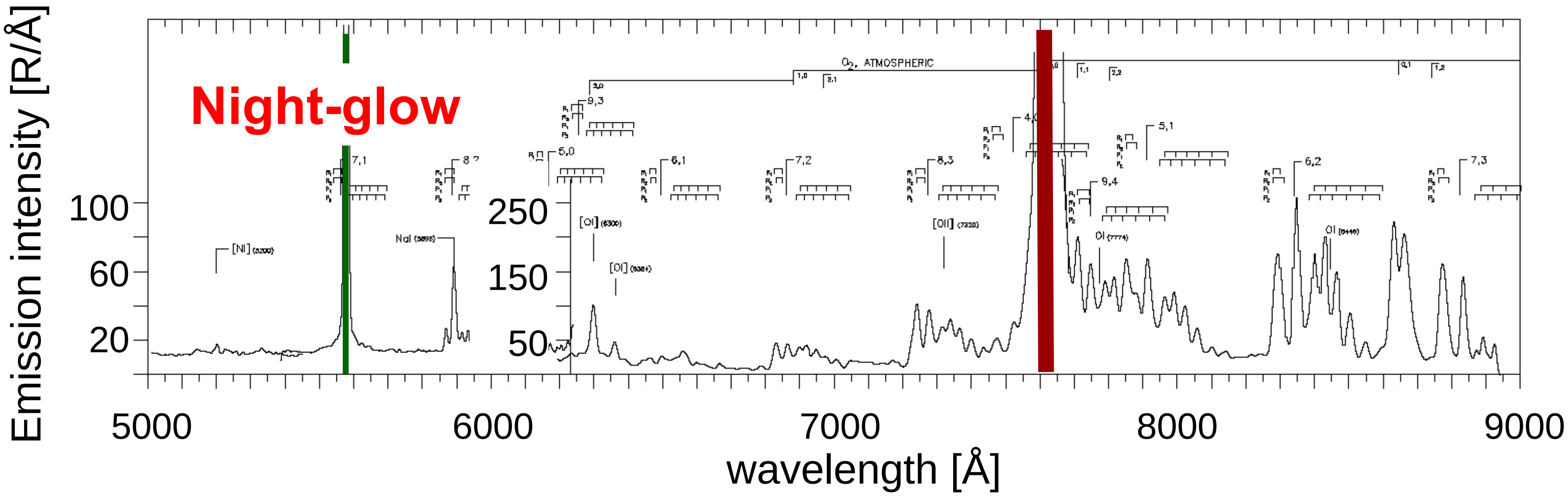
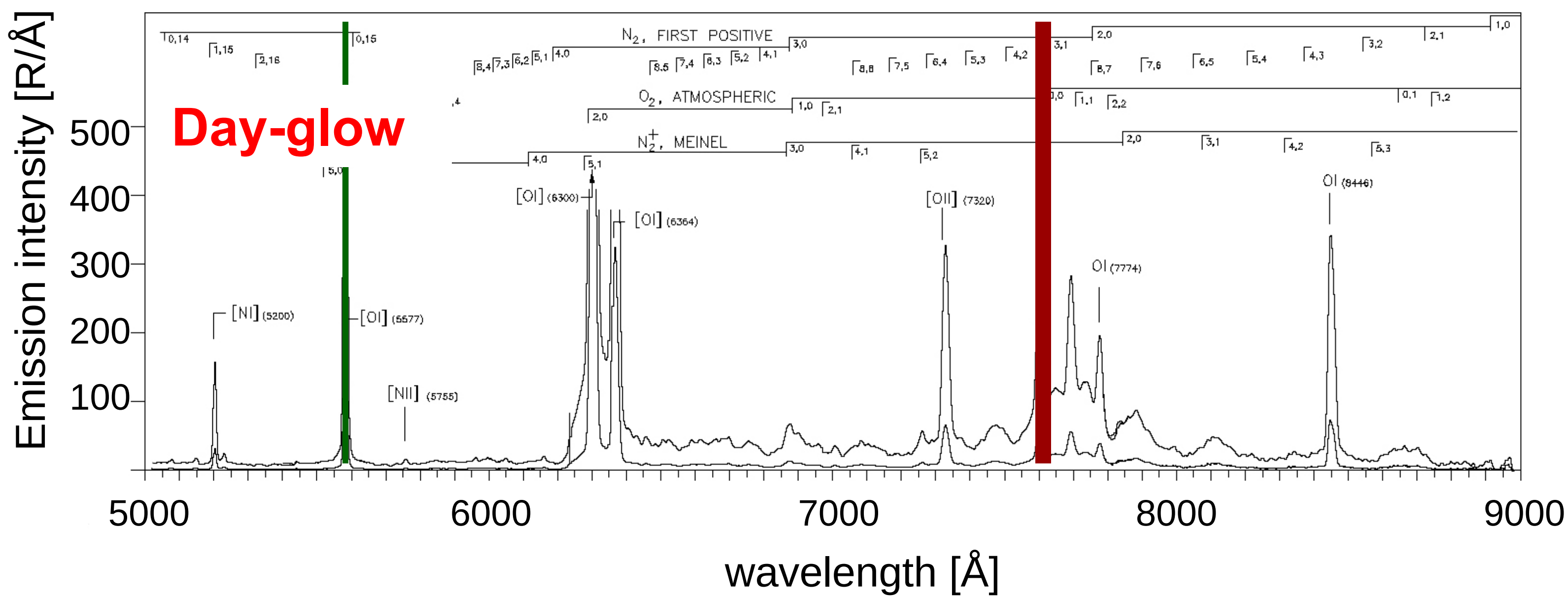
Contents

1. Airglow Emission

2. Earth Sensor Instrument Design

Airglow Emissions





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Airglow Emissions seen from GEO

Expected photon flux in a GEO due to airglow emission [photons/pixel/s]
for an aperture of Ø8 mm and a FOV of 0.16°/pixel

		At zenith	At limb
557.7 nm O(¹S) line			
	At night	6 – 64	70 – 640
	At day	200 – 2 k	2 k – 26 k
	Aurora perturbations	160 – 160 k	80 – 80 k
762 nm O_2(0-0) A-band			
	At night	500 – 2 k	6 k – 26 k
	At day	26 k – 260 k	370 k – 3.2 M
	Aurora perturbations	30 – 1 k	10 – 500

We choose the O_2(0-0) A-band at 762 nm rather than the O(¹S) line at 557.7nm

- ✓ Strongest airglow line (50 times stronger than 557.7nm line)
- ✓ Weaker perturbations by aurora effects (only 10-30% of the nightglow for zenith measurements)

- Not visible from Earth (less data available)

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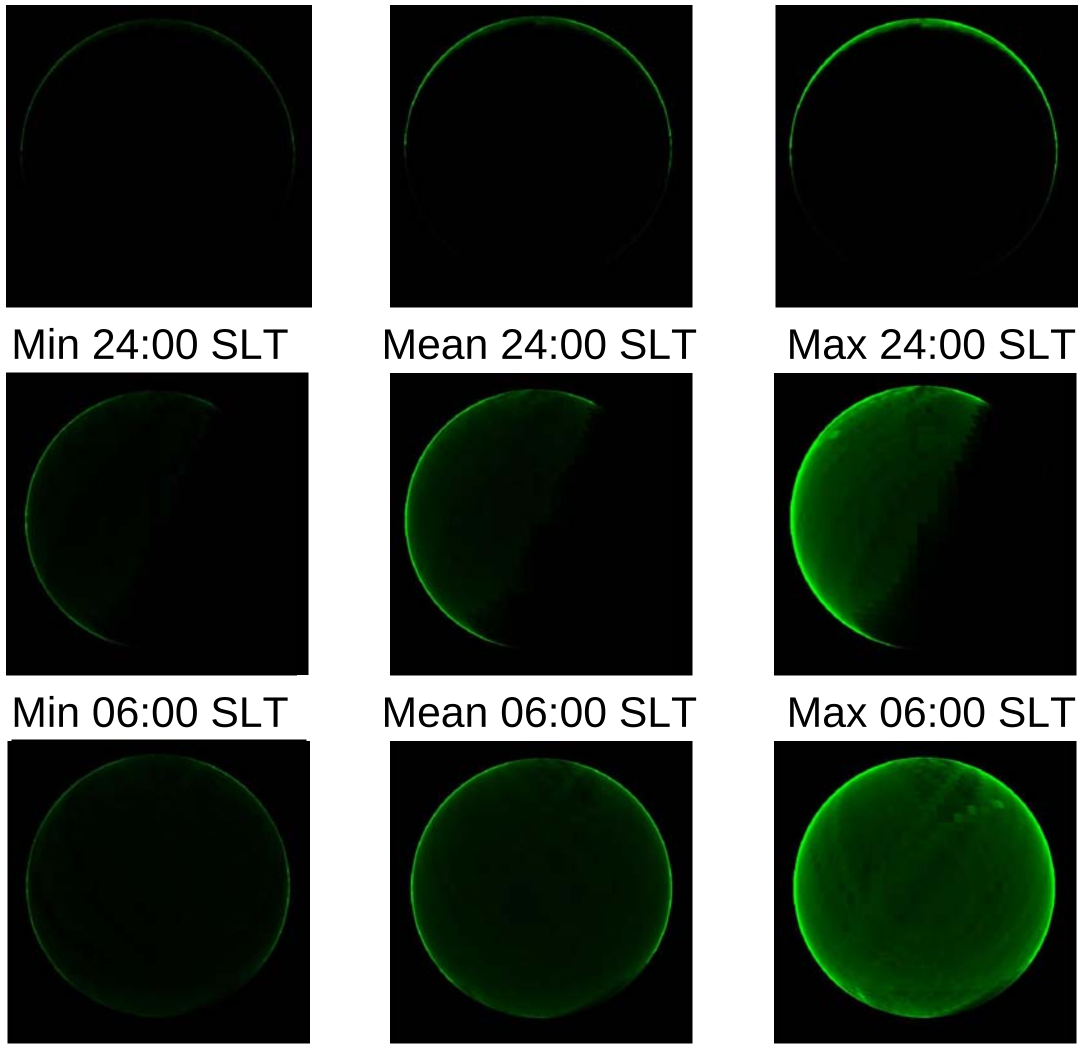
Earth Appearance at 762 nm



Min 24:00 SLT | Mean 24:00 SLT | Max 24:00 SLT

Min 06:00 SLT | Mean 06:00 SLT | Max 06:00 SLT

Min 12:00 SLT | Mean 12:00 SLT | Max 12:00 SLT

Based on UARS and ODIN satellite data

Existing Airglow Data

- HRDI/WINDII on the UARS satellite
  - Limb measurements from 1991 to 1999
  - Covers almost all daylight and nocturnal time
  - Data product:
    - O_2(0-0) A-band volume emission rate depending on altitude, latitude, local solar time and date
- OSIRIS on the ODIN satellite
  - Limb measurements since 2001
  - No detailed data on O_2(0-0) A-band emission available
- Rocket measurements (ex. ETON project)
  - Single zenith measurements
  - Data product:
    - O_2(0-0) A-band volume emission rate depending on altitude, latitude, local solar time and date

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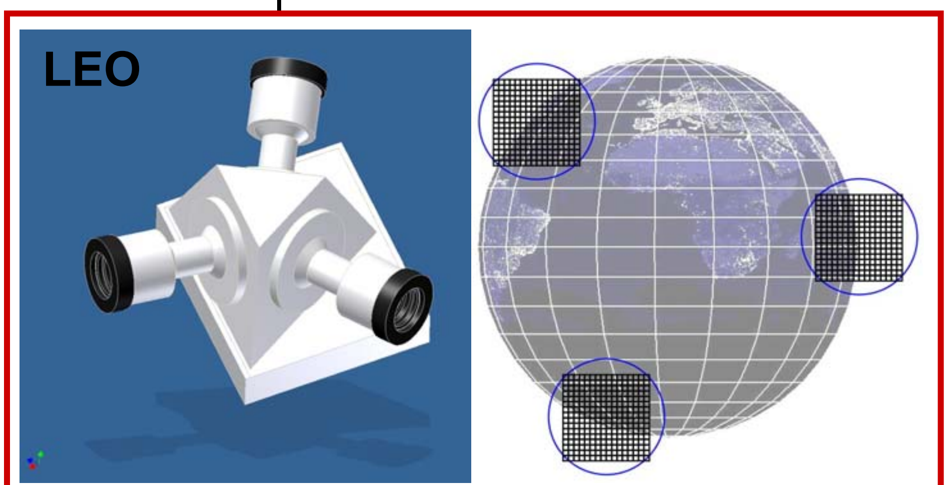
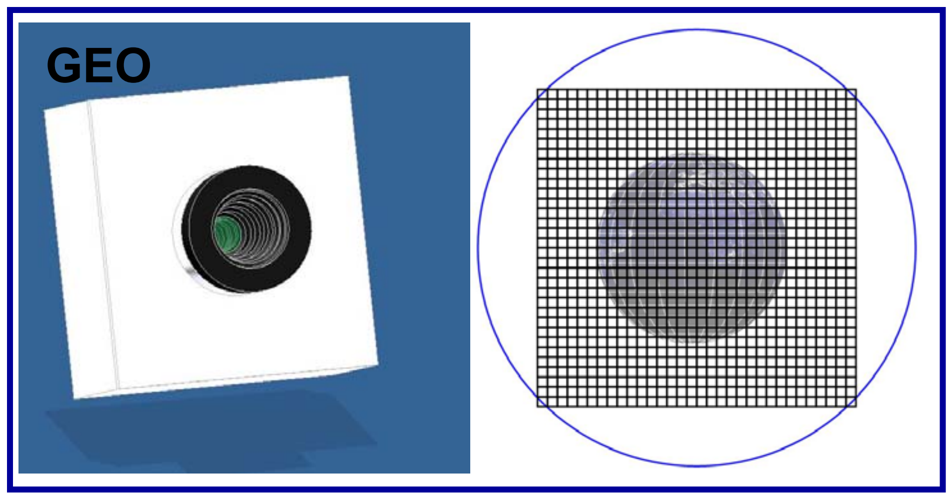
Earth Sensor – GEO and LEO Applications

- ✓ Same wavelength band
- ✓ Same optical sub-system (same telescope)
- ✓ Same power and data interfaces
- ✓ Similar algorithms

- Different optical geometry (1 vs. 3 apertures)





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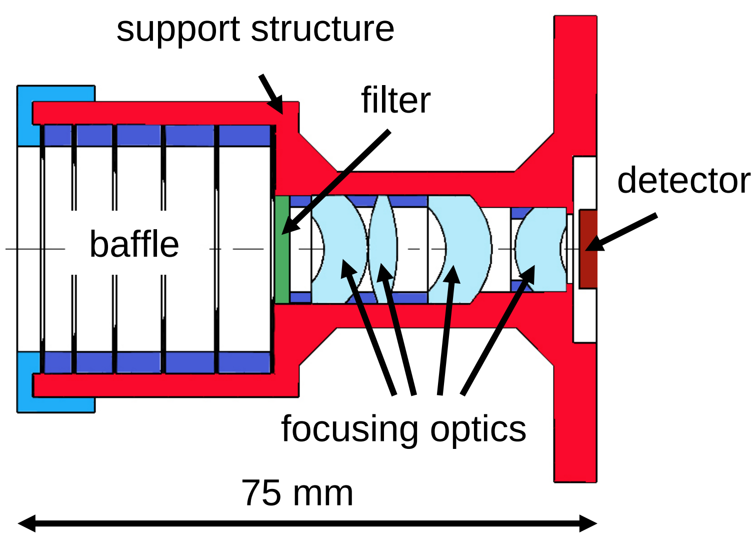
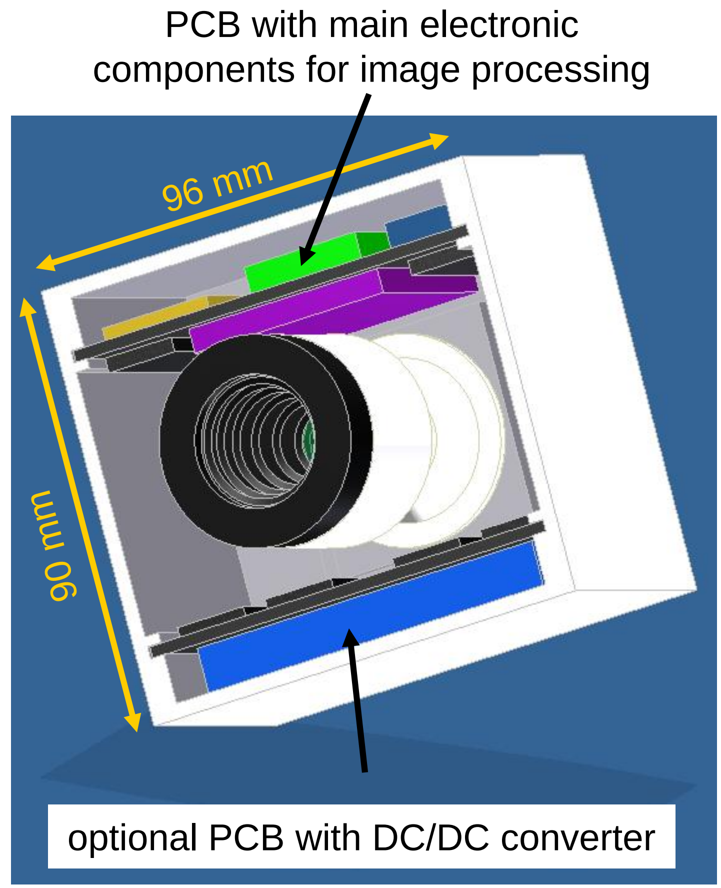
Mechanical Design for GEO Application

- Materials:
  - titanium for elements defining the optical path
  - aluminium for the other components (except PCBs)

- Mass:
  - Tube 200 g ± 20%
  - Motherboard stack 200 g ± 20%
  - Housing 200 g ± 20%
  - Total Mass 600 g ± 20%



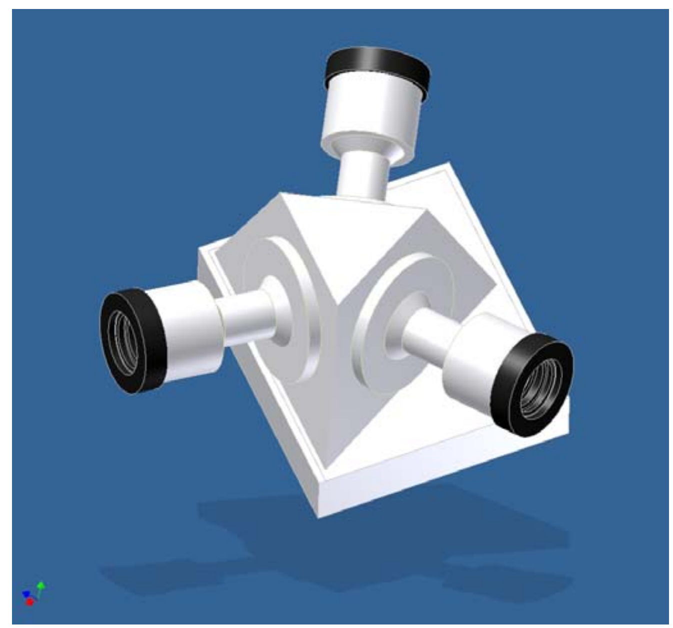


Mechanical Design for LEO Application

- Same optical system for the GEO and LEO application
  - 3 “tubes” instead of 1
  - 3 daughterboards instead of 1
  - 1 single mainboard

- Mass:
  - Tubes 600 g ± 20%
  - Motherboard stack 200 g ± 20%
  - Housing 400 g ± 20%

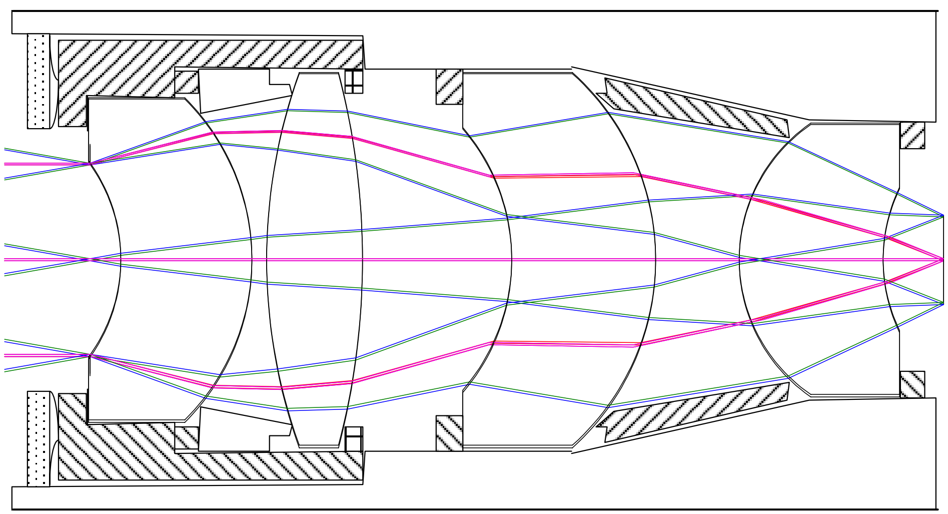
  - Total Mass 1200 g ± 20%



Optical Design

- Main Parameters
  - FOV: 20 °
  - Aperture: 8 mm
  - Focal length: 10.88 mm
  - Pixel pitch: 30 µm

- Mass:
  - All Lenses: 14 g
  - Barrel: 13-18 g



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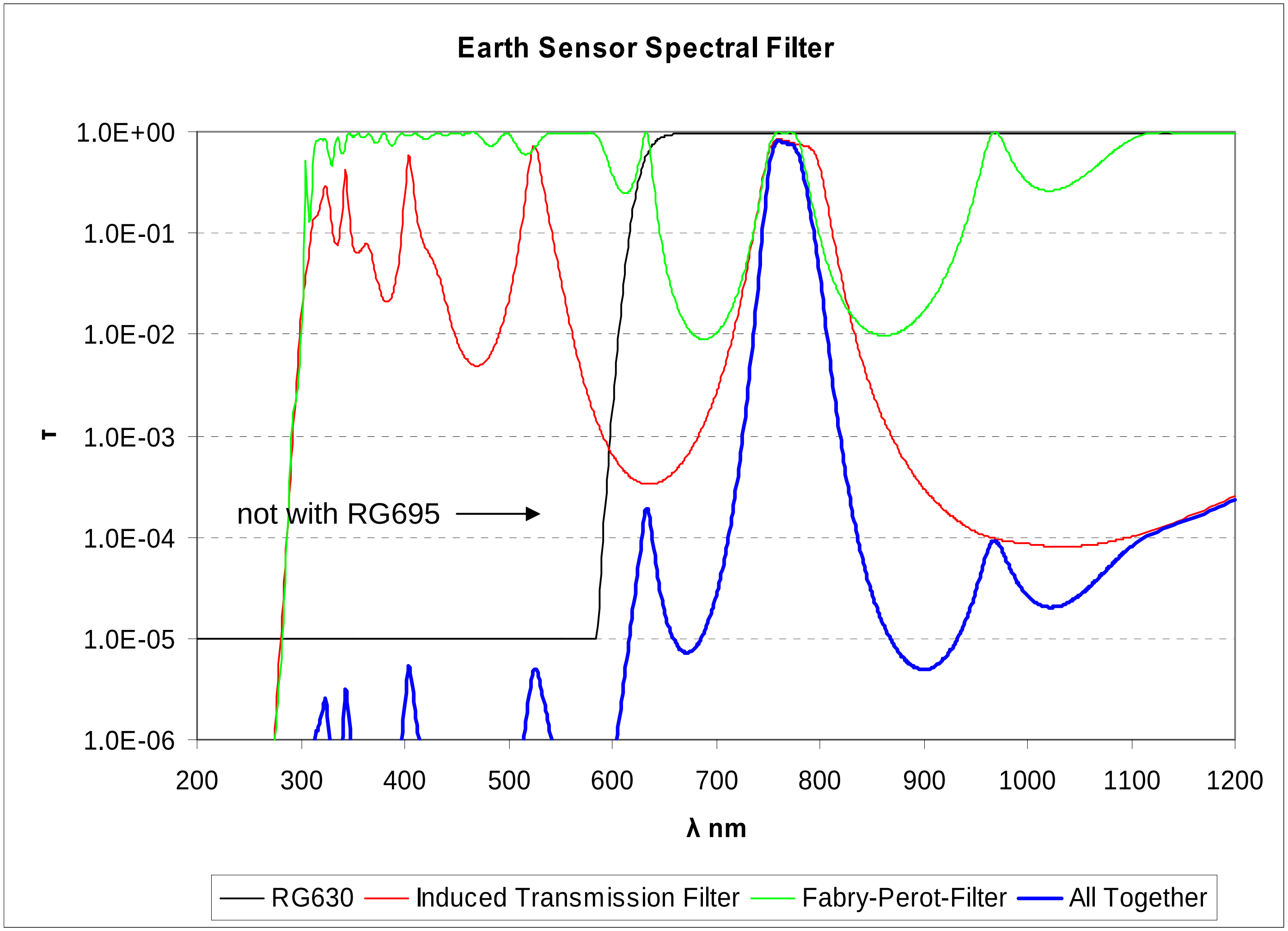
Filter Design (762 nm)



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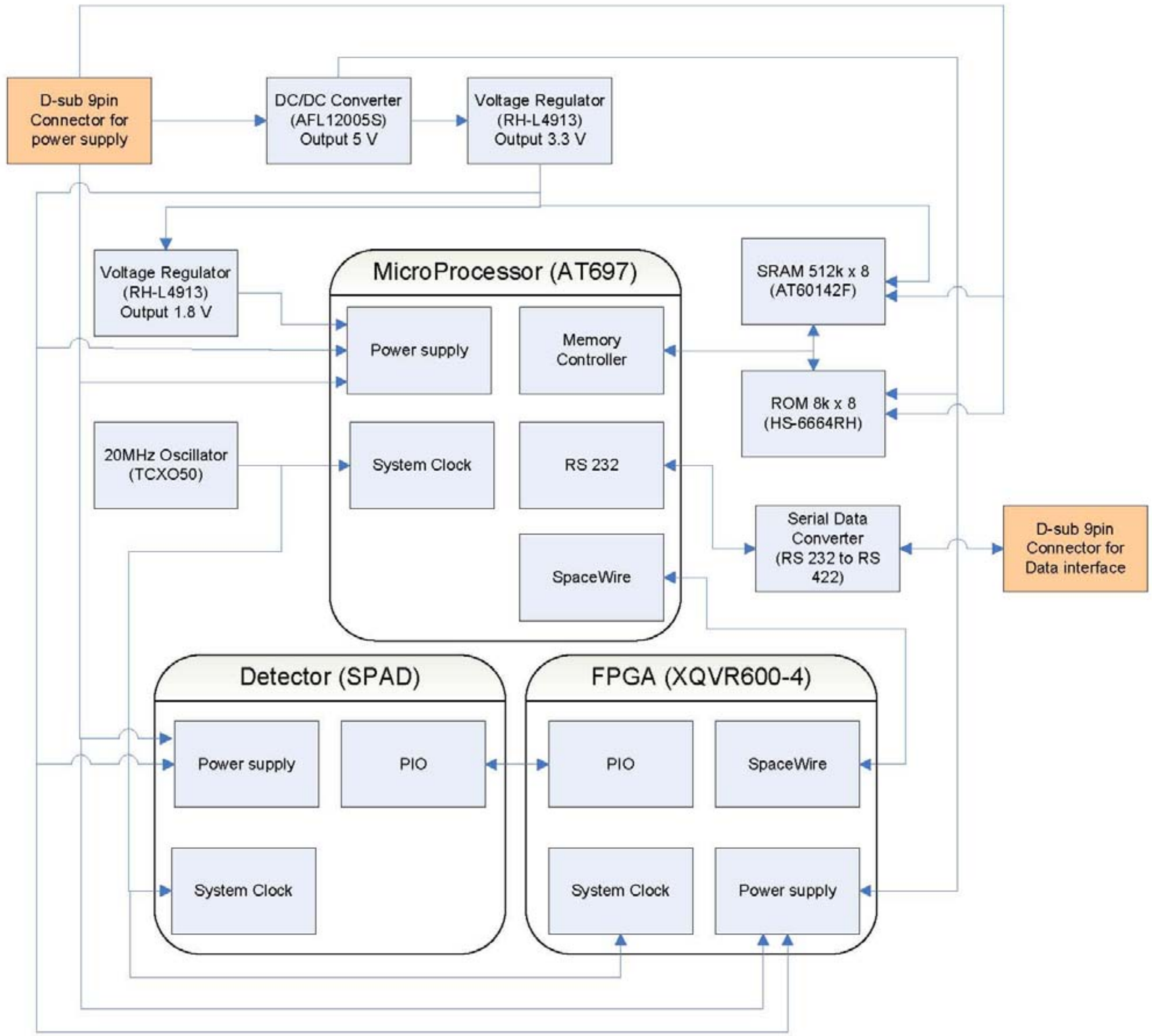
Electrical Design



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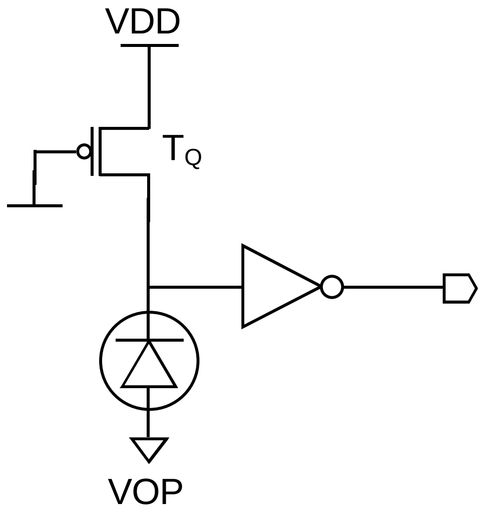
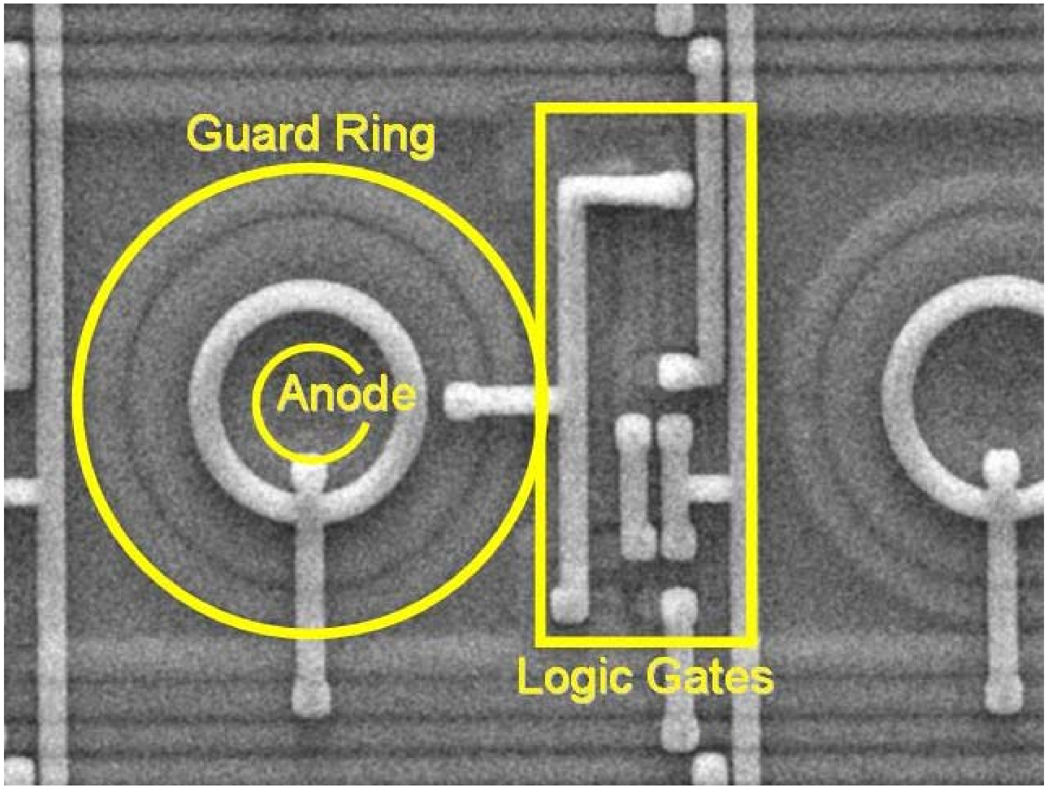
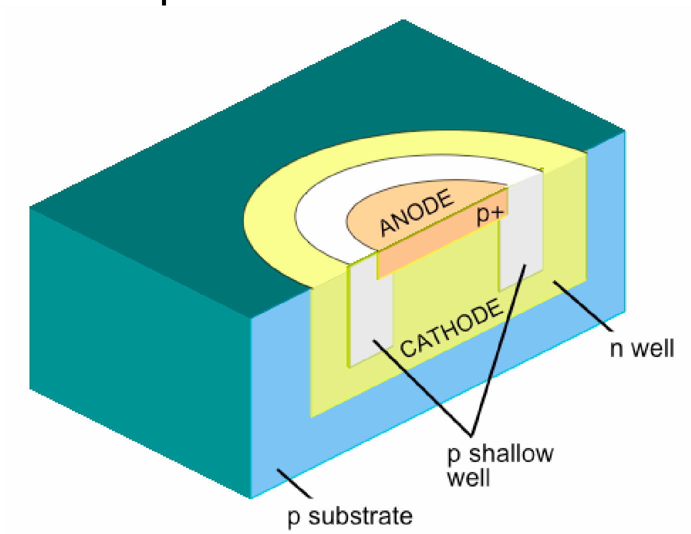
Single Photon Avalanche Diodes



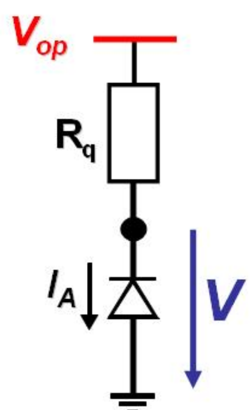




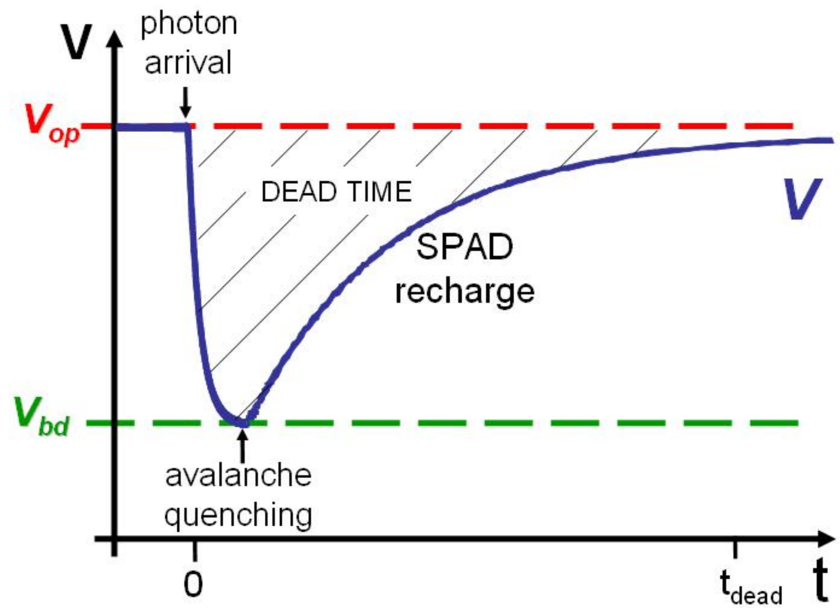
SPADs – Functional Principle

- Dead Time 100 ns
- Photon Detection Probability 40 % (@550 nm, 4% 760 nm)
- Fill-Factor 5 %
- Dark Count Rate 280 Hz

passive quenching:



operation cycle:



Algorithm

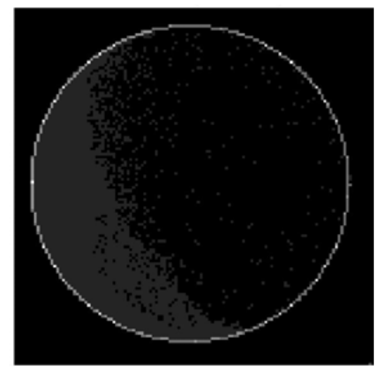
Original Image

Threshold

Erosion

Mexican Hat with maximum intensity gradient

Image after circle fitting with Hough algorithm



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Algorithm

Original Image

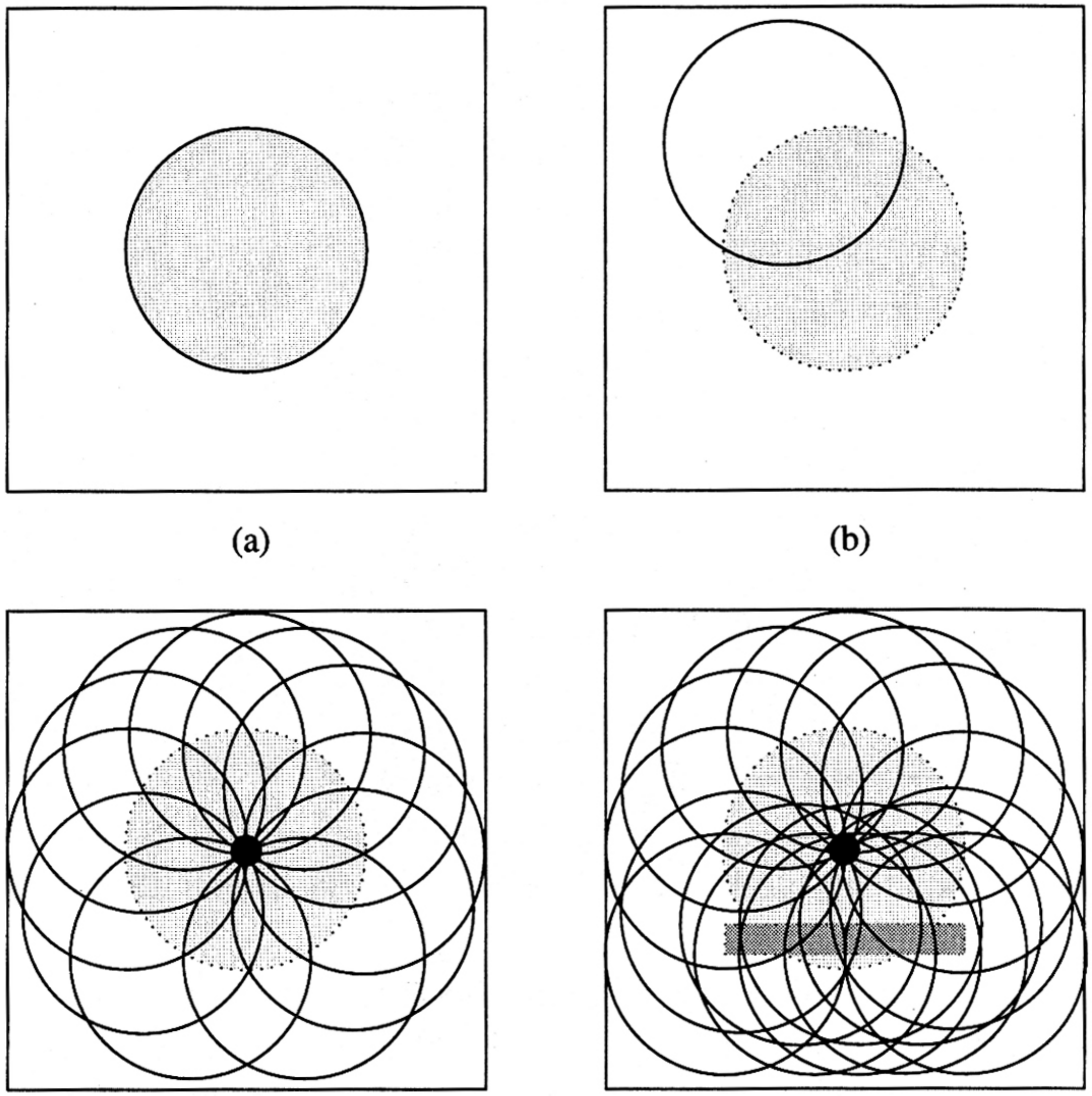
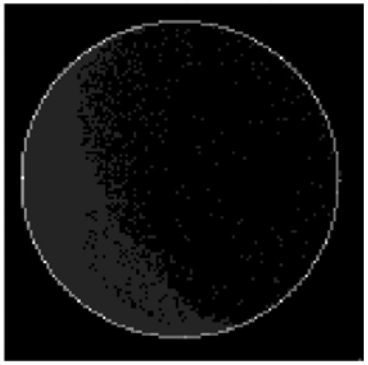


Image after circle fitting with Hough algorithm



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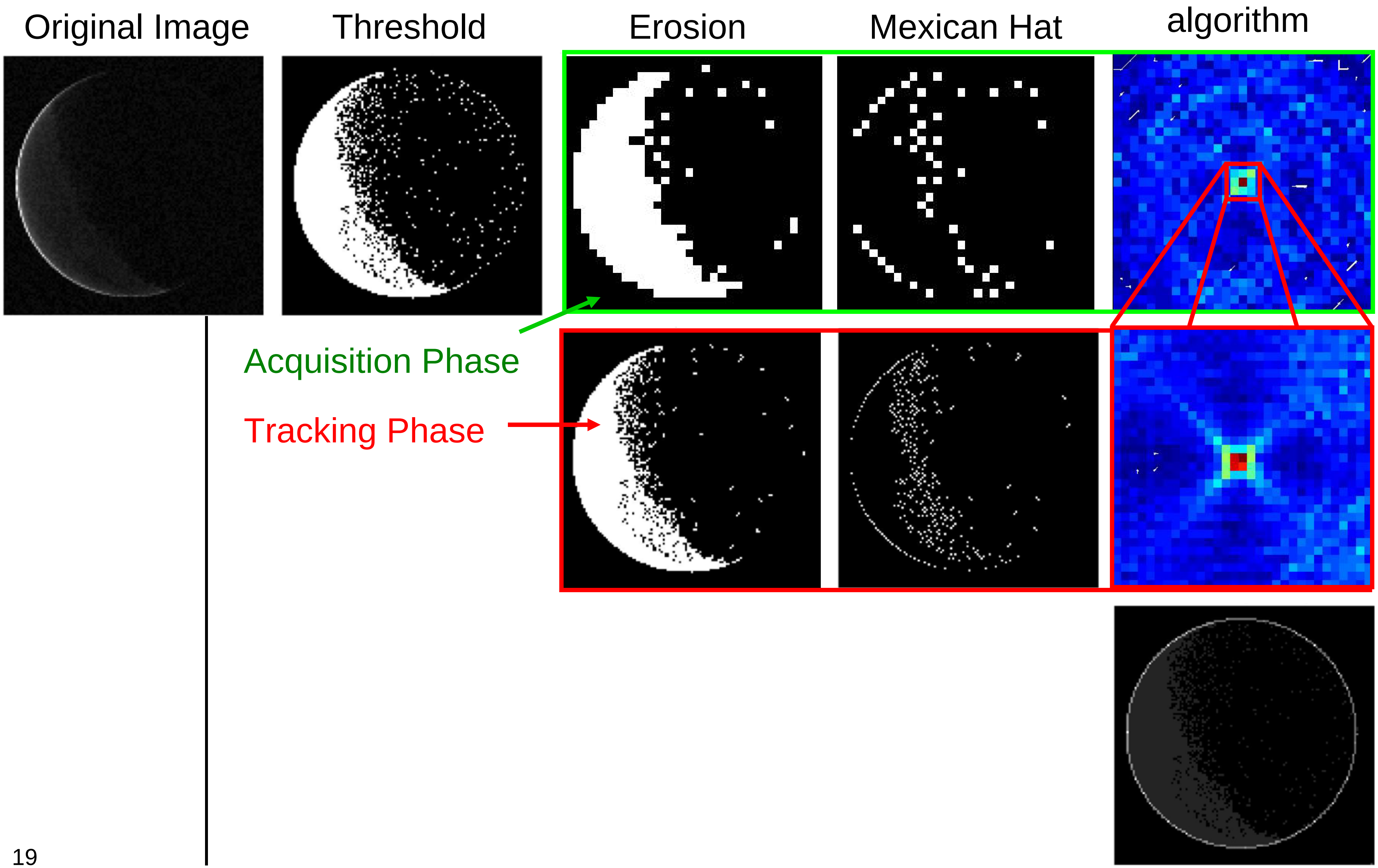
Hough Algorithm with Adaptive Accumulator Array

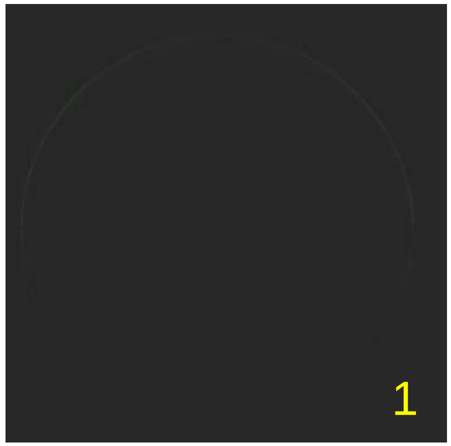
- Objectives
  - Reduce memory requirements and number of operations
  - Increase flexibility of the earth sensor by increasing the range of acceptable earth sizes and the zone where the earth centre can be found
- Acquisition Phase : Coarse determination of the zone where the earth centre is in the image
- Tracking Phase: Detailed determination of the earth centre position

Algorithm

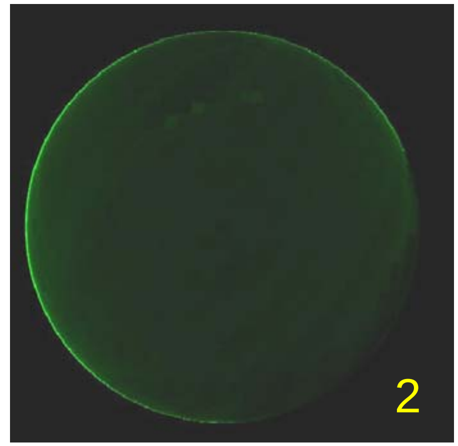

Original Image
Threshold
Erosion
Mexican Hat
Hough algorithm
Acquisition Phase
Tracking Phase

Test Images for the Algorithm Testing

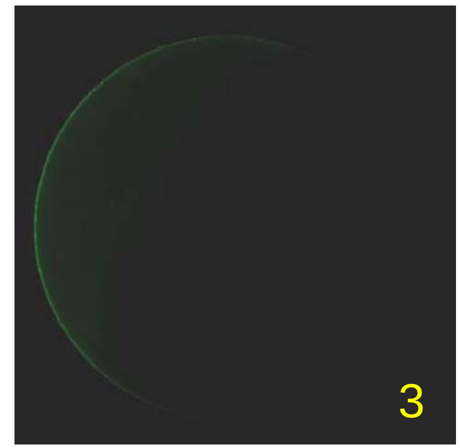
min airglow signal



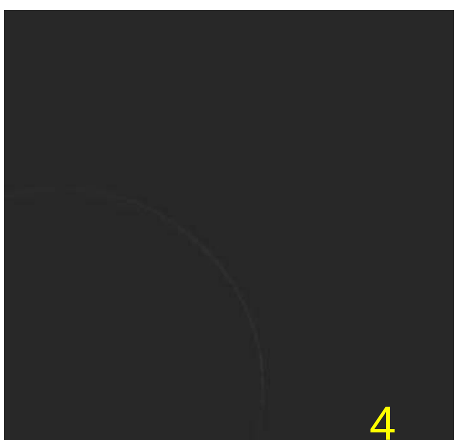
max airglow signal



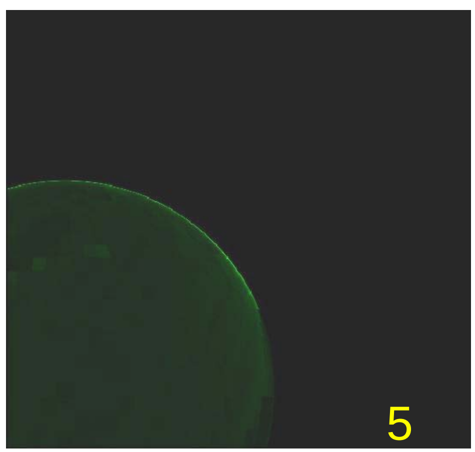
airglow signal
at solar terminator



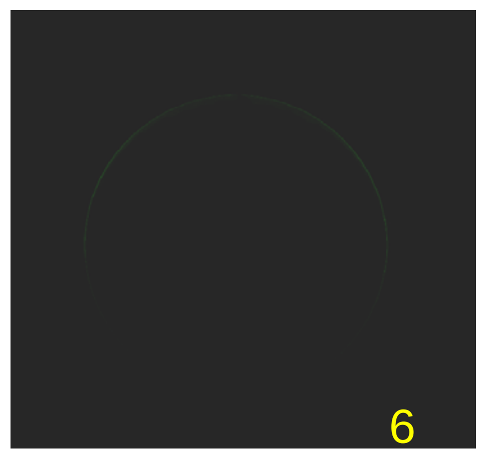
min airglow signal,
earth not centred



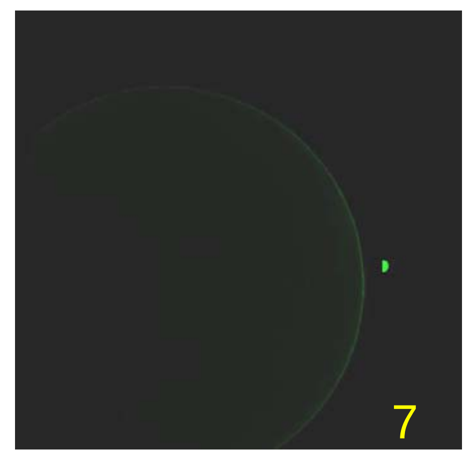
max airglow signal,
earth not centred



min airglow signal,
higher satellite altitude



airglow signal at solar
terminator with moon



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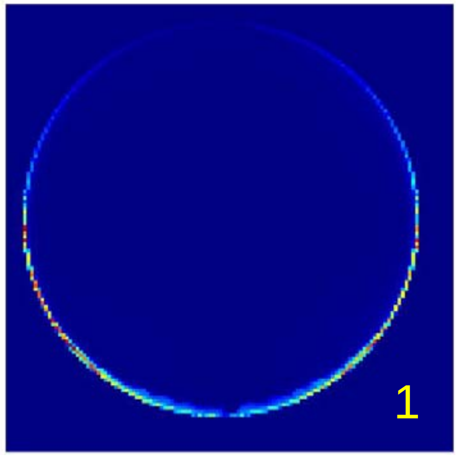
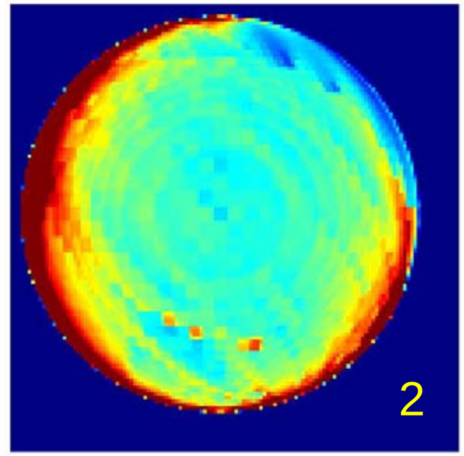
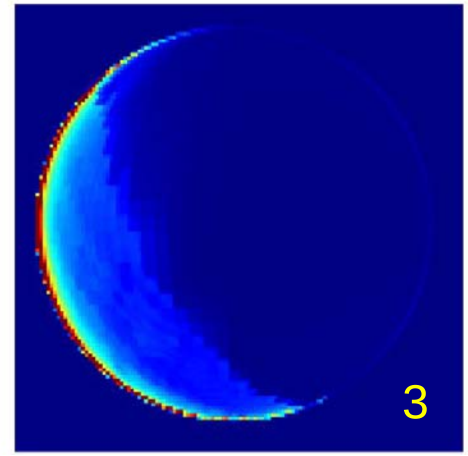


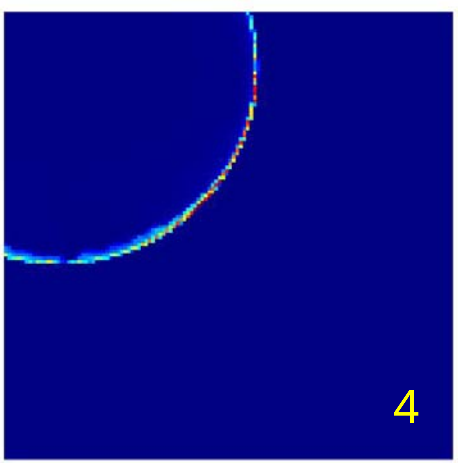
min airglow signal



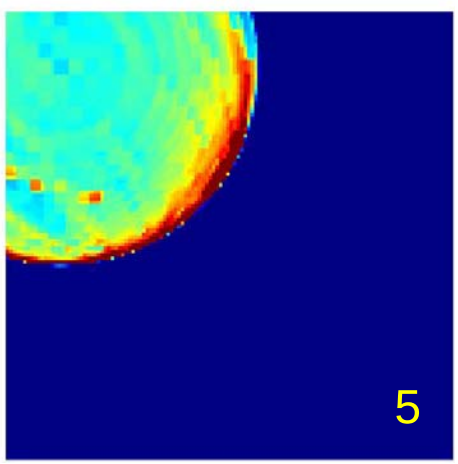
max airglow signal



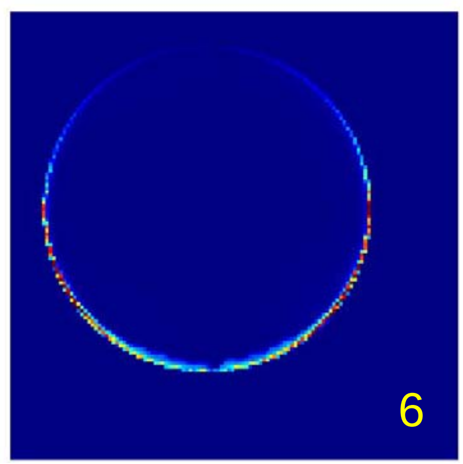
airglow signal at solar terminator



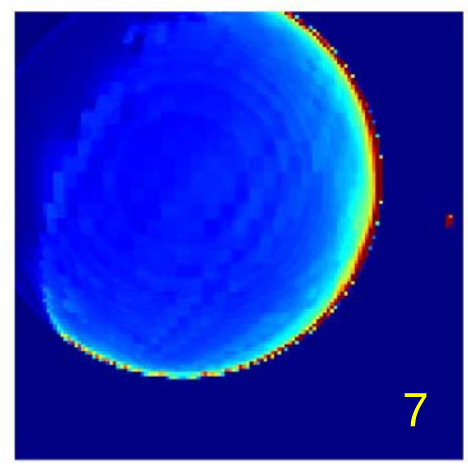
min airglow signal, earth not centred



max airglow signal, earth not centred



min airglow signal, higher satellite altitude

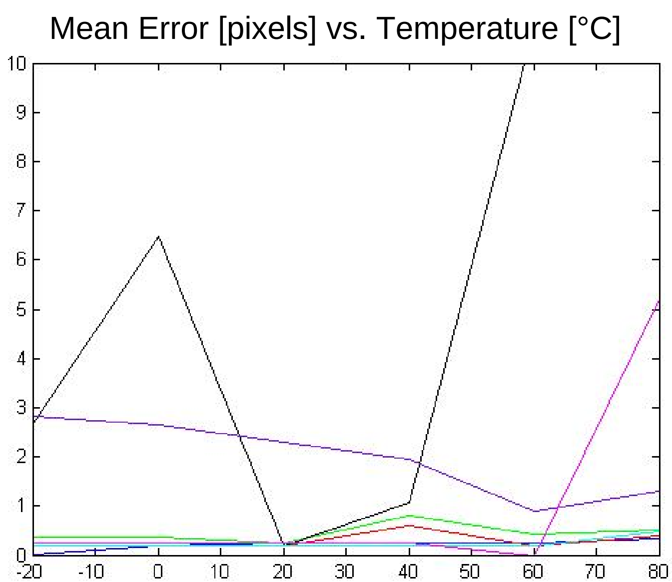


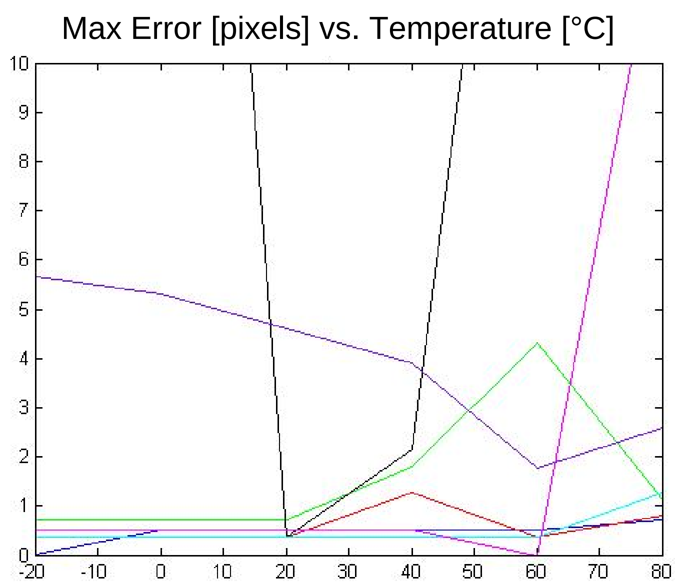
airglow signal at solar terminator with moon

Preliminary Results

- (computed performance based on noise figures for SPADs, e.g. dark count rate)

Test image:
1
2
3
4
5
6
7





Expected Performance

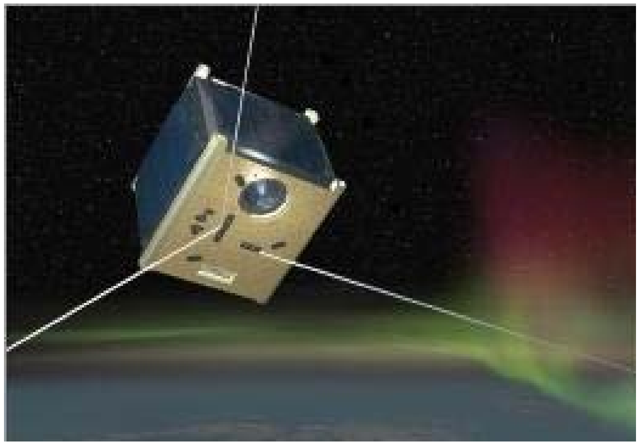
Error source (mean error)	Maximum Expected Error (e_i)
Optics aberrations and correction for distortion	$1 \cdot FOV_{pixel} = 0.16°$
Algorithm (for images completely within the FOV of the instrument)	$1 \cdot FOV_{pixel} = 0.16°$
Smear (pointing stability during measurements)	LEO: $1 \cdot FOV_{pixel} = 0.16°$ GEO: 0.05 °
Angular incertitude of the airglow	LEO: 1 ° GEO: 0 °
Oblatness of the earth	LEO: 1 ° GEO: 0 °
Worst case error $e_{worst\_case} = \sum_i e_i$	**LEO:** $2° + 3 \cdot FOV_{pixel} = 2.5°$ **GEO:** $0.05° + 2 \cdot FOV_{pixel} = 0.4°$
Targeted accuracy	**LEO: 5 °** **GEO: 0.6 °**

SwissCube: Technology Demonstrator

1kg cubic satellite (Cubesat) with a volume of 10 x 10 x 10 cm^3

Science Mission

- Take measurement of the airglow to validate the airglow model developed at LMTS
- Demonstrate feasibility of using airglow as basis for a low-cost earth sensor



http://swisscube.epfl.ch

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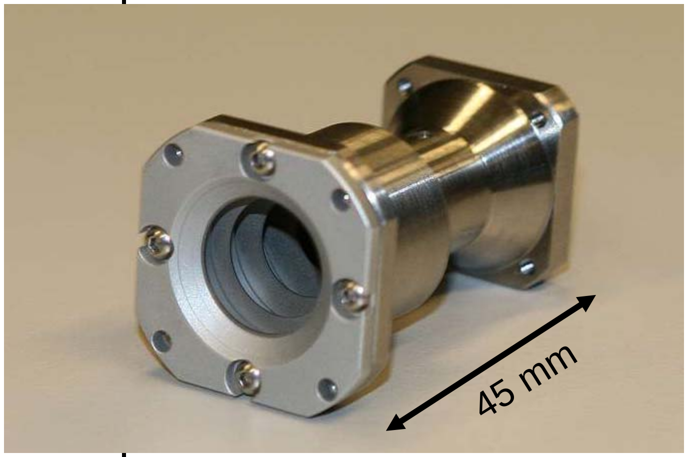
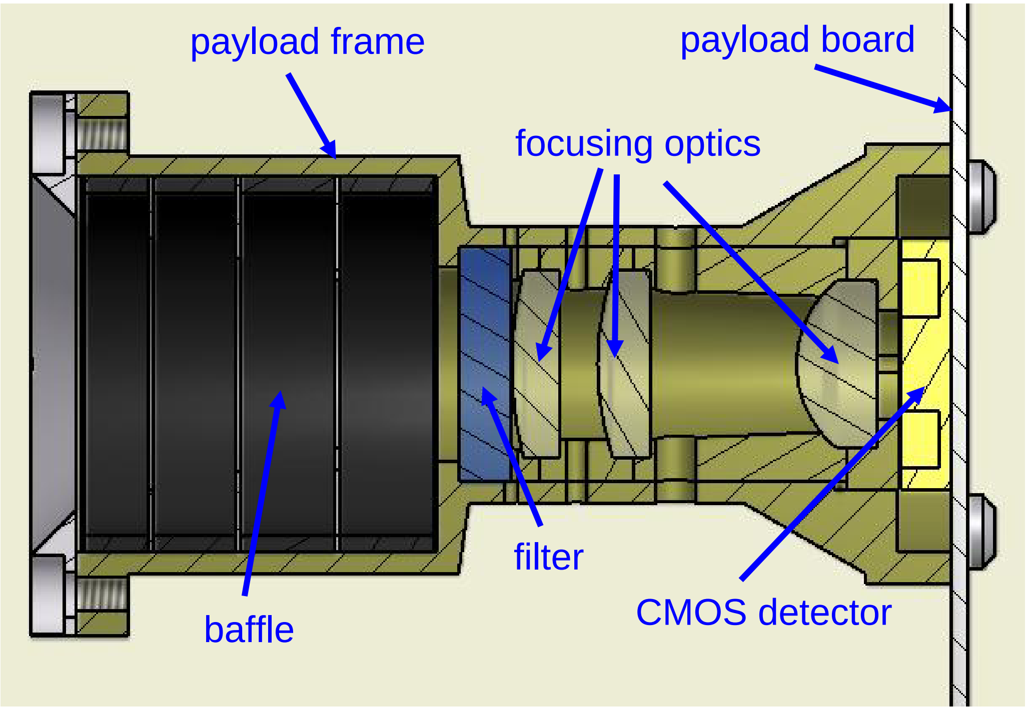
SwissCube Payload

- Triplet design with off-the-shelf components
- FOV 18.8° x 25°
- Resolution 0.16°/pixel
- Baffle for a solar exclusion angle of 30°
- Filter with a central wavelength at 767 nm and a bandwidth of 20 nm





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Conclusion

- ➢ Airglow: Permanent, visible band
- ➢ Detector with high sensitivity

- ✓ Same operation at night and day
- ✓ Modular instrument design for GEO and LEO applications

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Thank you for your attention!