OmniSky

Cilium Engineering – prime contractor
Sybilla Technologies – subcontractor
Nicolaus Copernicus Astronomical Centre - subcontractor

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European Space Operations Centre (ESA/ESOC), Darmstadt, Germany

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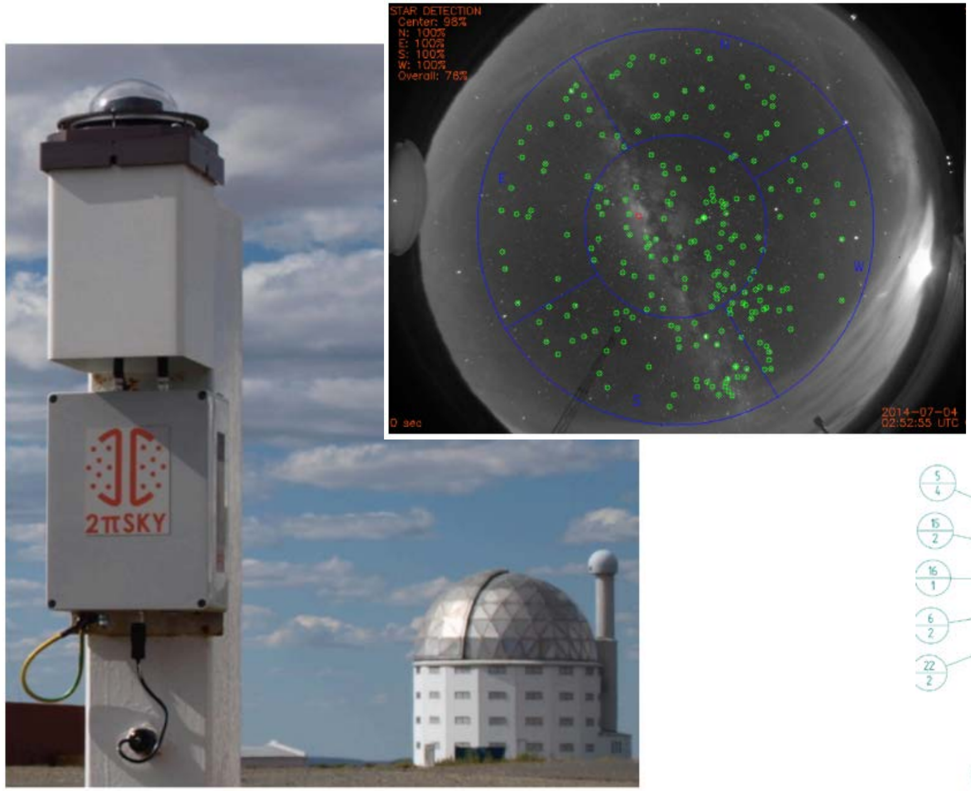
Introduction - Cilium

2PiSky

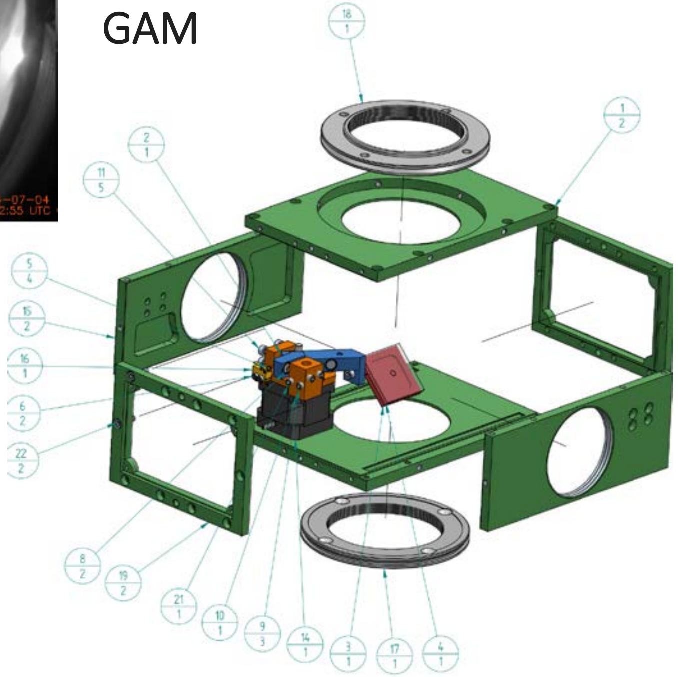
2PiSky is a compact, standalone cloud monitoring system that consists of an all-sky camera couple to an embedded computer module that provides cloud coverage information.


STAR DETECTION
Center: 98%
N: 100%
E: 100%
S: 100%
W: 100%
Overall: 76%

ObservatoryWatch

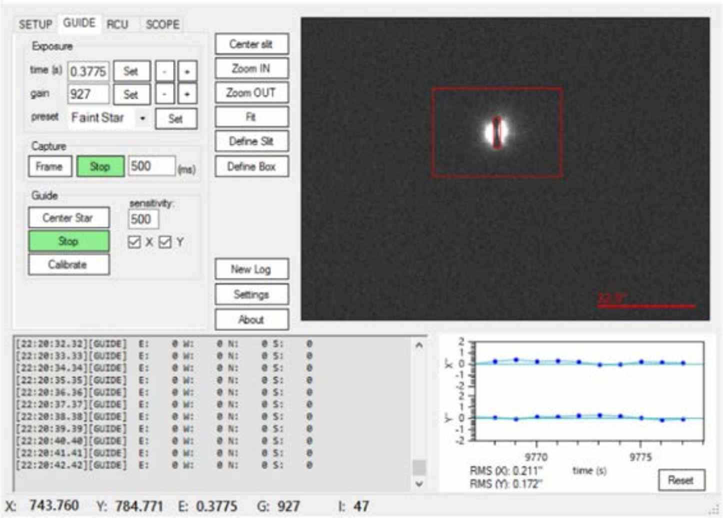
ObservatoryWatch is an inteligent building management system designed for astronomical observatories. It delivers industry-standard solutions in the area of environement monitoring, weather systems, HVAC and security. ObservatoryWatch utilizes custom-designed CilSense sensor modules for environemental data acquistion.

GAM



SpecTrack

Software for guiding on slit-based spectrographs.



time (s) 0.3775
gain 927
preset Faint Star
500 (ms)
sensitivity: 500
☑ X ☑ Y

```
[22:20:32.32][GUIDE]  E:    0 W:    0 N:    0 S:    0
[22:20:33.33][GUIDE]  E:    0 W:    0 N:    0 S:    0
[22:20:34.34][GUIDE]  E:    0 W:    0 N:    0 S:    0
[22:20:35.35][GUIDE]  E:    0 W:    0 N:    0 S:    0
[22:20:36.36][GUIDE]  E:    0 W:    0 N:    0 S:    0
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[22:20:40.40][GUIDE]  E:    0 W:    0 N:    0 S:    0
[22:20:41.41][GUIDE]  E:    0 W:    0 N:    0 S:    0
[22:20:42.42][GUIDE]  E:    0 W:    0 N:    0 S:    0
```

RMS (X): 0.211"
RMS (Y): 0.172"

X: 743.760 Y: 784.771 E: 0.3775 G: 927 I: 47

Astrometry24.NET

ESA-contracted dedicated service for precise SST/NEO astrometric and photometric processing enabling efficient tracklet retrieval from optical images.

Introduction

Sybilla Technologies

Abot – Astronomical Robot

end-to-end solution for robotization of optical telescopes and networks of optical telescopes. Deployed in Solaris and Panoptes networks.

- Cloud Service
- Web Service
- Robotic Service
- Drivers
- Hardware

Chronos SST

Chronos SST is a dedicated component for precise timing astronomical images and position information for astronomical sensors.

Chronos SST is easily-connected component that works in-between camera and workstation to provide high-precision frame-generation information relying on GPS signal.

Chronos SST is already employed in the work of Panoptes network.

Astrometry24.NET

ESA-contracted dedicated service for precise SST/NEO astrometric and photometric processing enabling efficient tracklet retrieval from optical images.

NCAC

Astronomers from the Copernicus Center are involved in a number of major international observational projects such as: H.E.S.S., CTA (observations of ultra high energy photons (TeV) via detection of Cherenkov radiation), Herschel (satellite observations in IR domain), SALT (Southern African Large Telescope), INTEGRAL, Fermi (satellite observations of gamma rays). Project SOLARIS, search for extrasolar planetary systems, financed in part by European Research Council (Starting Independent Researcher Grant) is carried at the Copernicus Center. The ground station for the control of the first Polish scientific satellite BRITE is located at the Copernicus Center as well.

Introduction

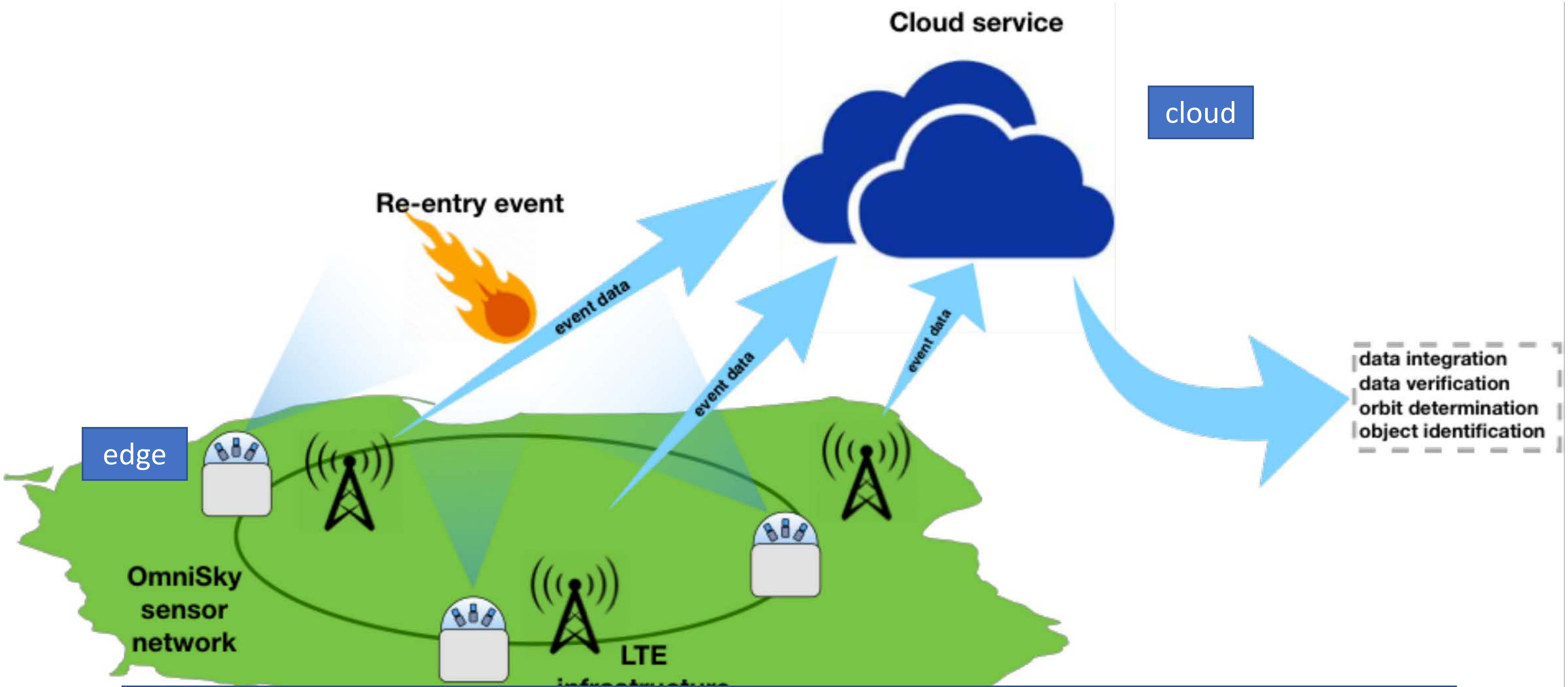
Fireball networks as a guideline for OmniSky

Factors characterizing the equipment used in fireball networks:
- Sky coverage
- Limiting magnitude
- Resolution (or image scale)
- Technique (photographic, CCD or video)

Different approaches:
- All sky stations (fish eye lenses) with high resolution detectors (CCD or dSLRs) -> low limiting magnitude, problems with recording fragmentations
- All sky stations with video cameras -> low resolution, low limiting magnitude
- Narrow field video stations (CAMS) -> small area of sky covered

OmniSky:
- Almost all sky setup
- Limiting magnitude for re-enetry events around +4 mag
- Scale ~2'/pix comparable to best fireball networks
- Video recording with 25-50 fps allows to trace fragmentation with full details

Design concept



How to design the network to get the best of both worlds: edge computing and cloud computing, optimising cost at the same time?

Design concept

Observability

- Magnitude of the observed object is strongly dependent of the distance. Object must be sufficiently close to the stations to be observed.
- Limiting magnitude of the camera for moving objects is lower than for limiting magnitude for stars, it's dependent on the observed angular speed.
- Observed magnitude of the object must be higher than limiting magnitude corrected for angular speed.

Camera FOVs sizes and directions

- More obvious condition: camera FOVs directions and sizes must be properly set to observe common object(s).

LEO satellites rejection

- Very slow moving object (below some rejection threshold) will be rejected as possible LEO's visible on the sky. Very distant deorbit events may be not observable for such reason.

Design concept

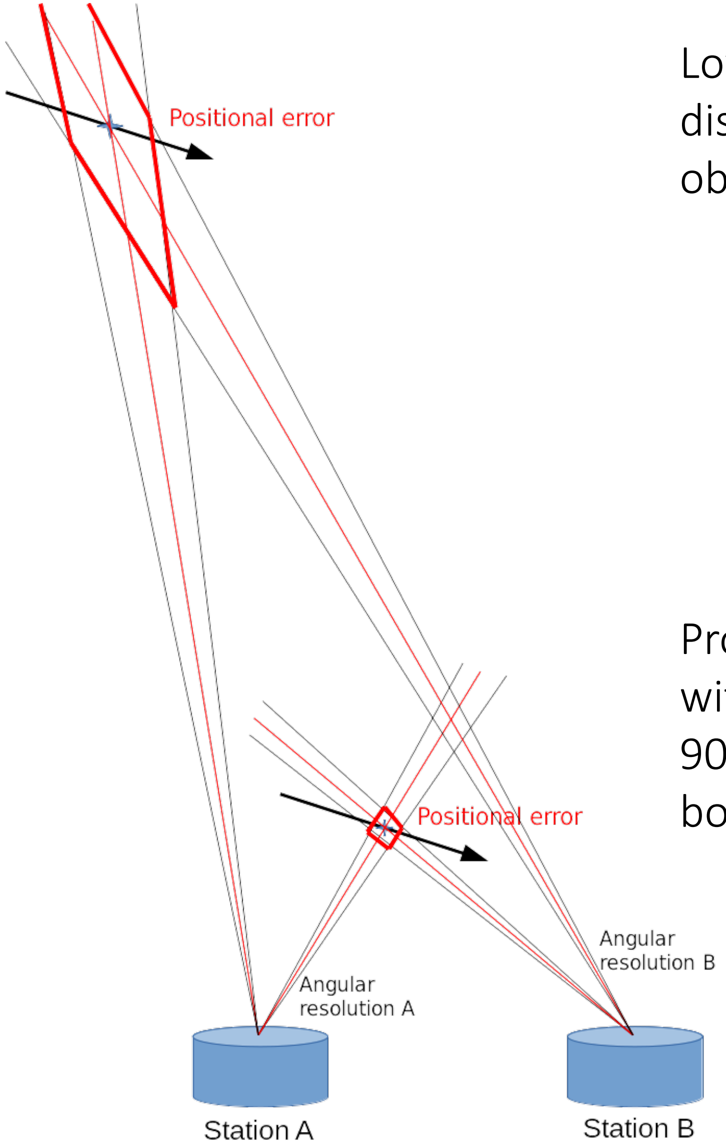
Precision

To obtain proper precision:

- Camera and lens must provide sufficient angular resolution
- Network geometry should be optimal

Optimal network geometry

- Angle between the stations and the object should be sufficiently high. Angles close to 90 degrees are perfects, angles larger than 20-30 degrees are sufficiently good, for very small angles results are almost unusable.
- Distances between stations shouldn't be to large (large distance = large positional errors).
- Distances between stations shouldn't be to small (small intersection angles possible, large cost of the network).
- At least three stations observing the same object (network based on the triangle cells) - at least one pair will work with proper intersection angle.



Low angle, large distance observation

Proper geometry with angle close to 90 degrees, close to both stations

Design concept

set of cameras to maximize FOV and resolution

each camera requires dedicated procesor

no way of storing raw stream, real-time processing is required

device needs to be accessible from the Internet

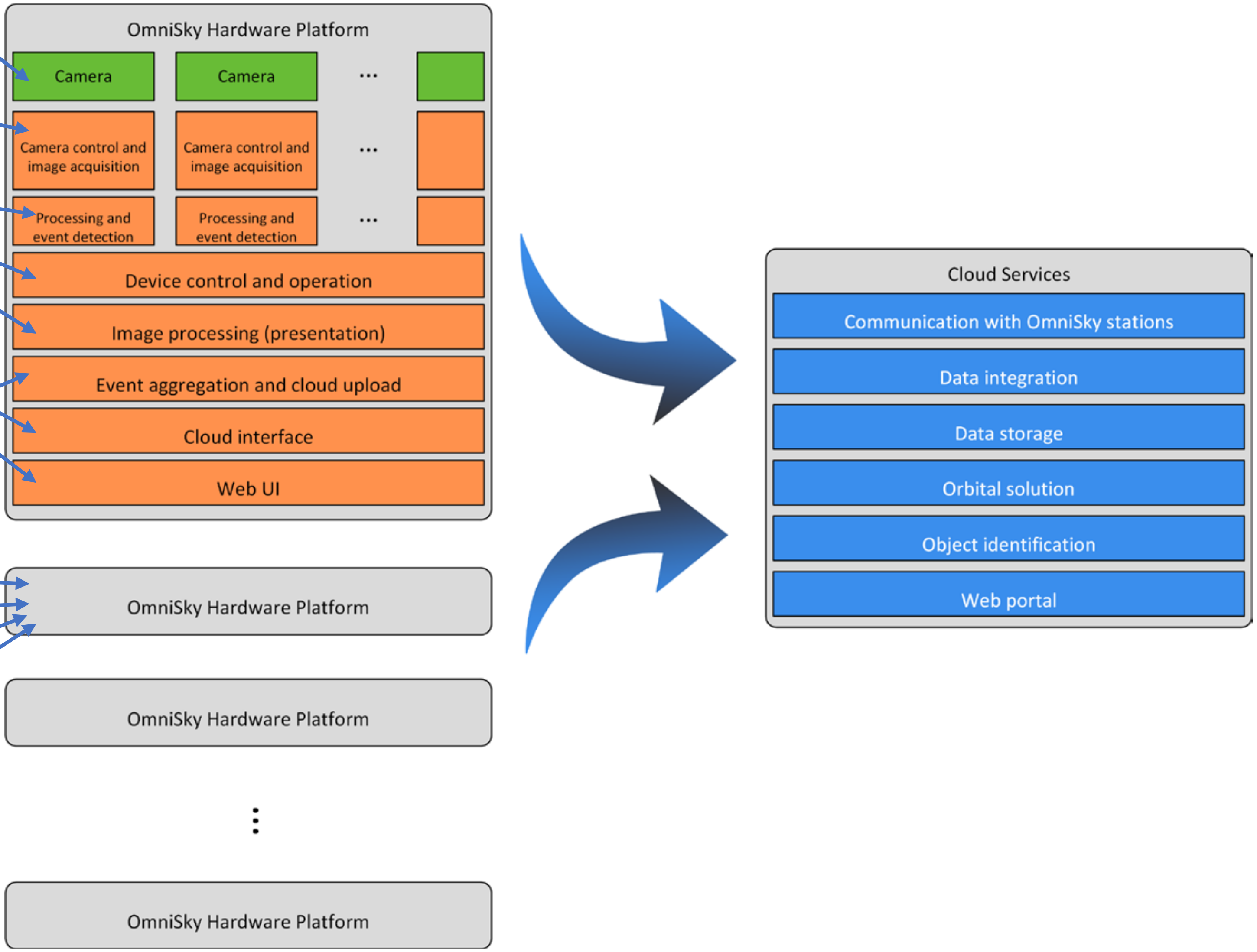
no way of uploading stream to the cloud, event detection must be done on-station

IP65 or higher

custom design

machined housing for robustness and durablity

hardware watchdog and sensors



OmniSky Hardware Platform

Camera

Camera

…

Camera control and image acquisition

Camera control and image acquisition

…

Processing and event detection

Processing and event detection

…

Device control and operation

Image processing (presentation)

Event aggregation and cloud upload

Cloud interface

Web UI

OmniSky Hardware Platform

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Cloud Services

Communication with OmniSky stations

Data integration

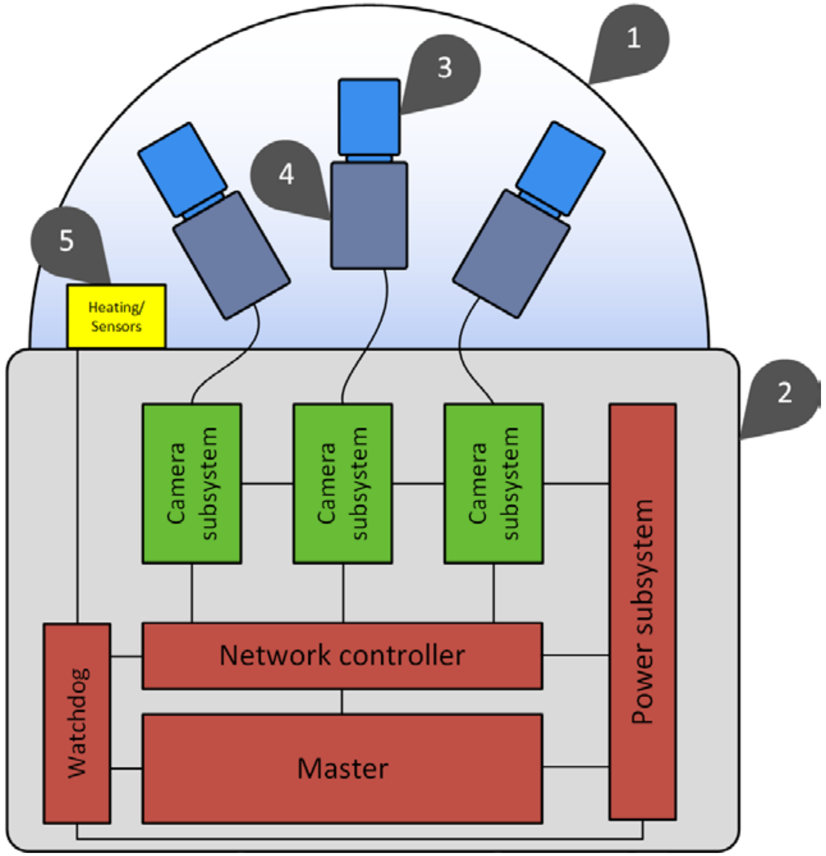
Data storage

Orbital solution

Object identification

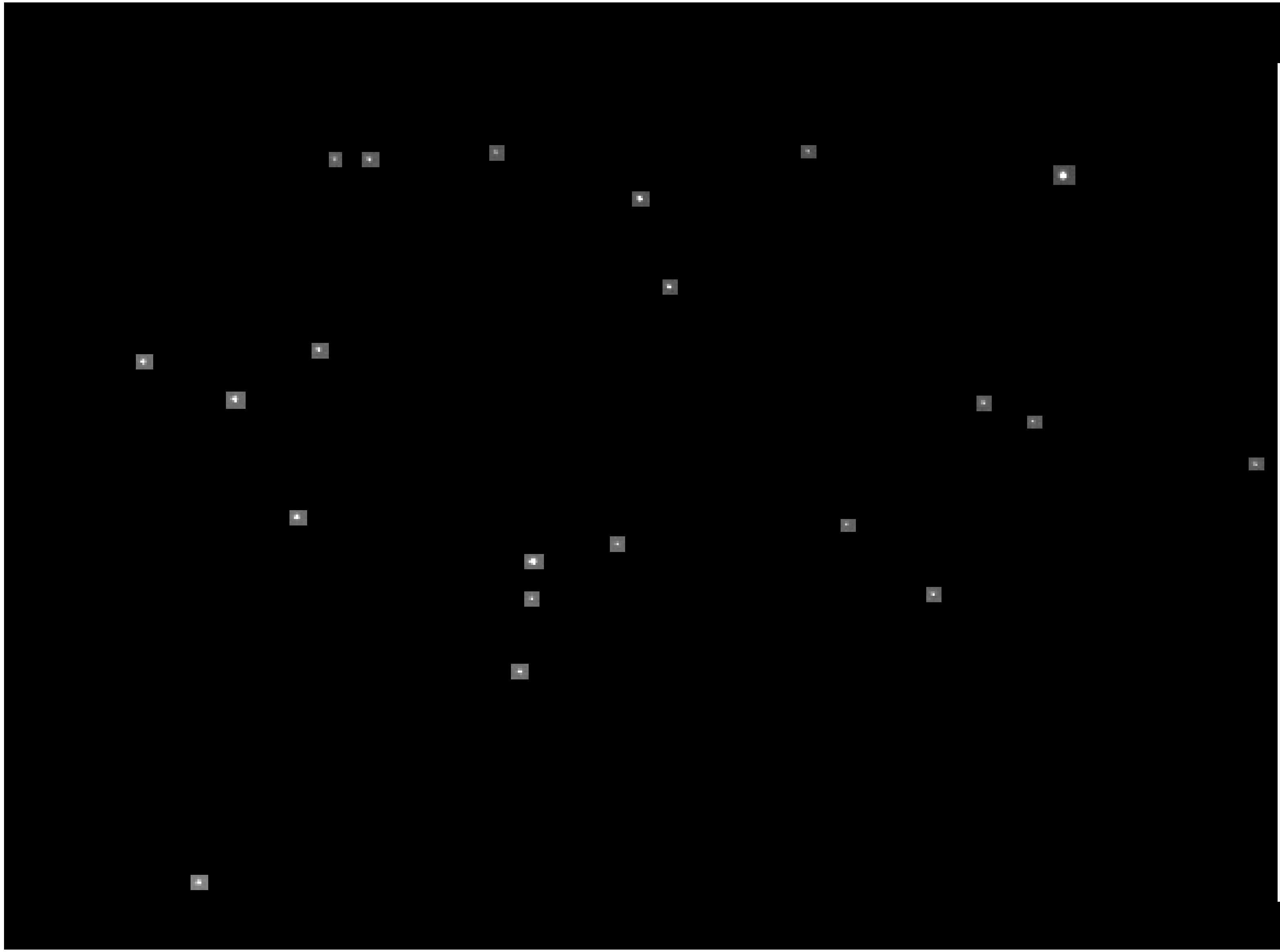
Web portal

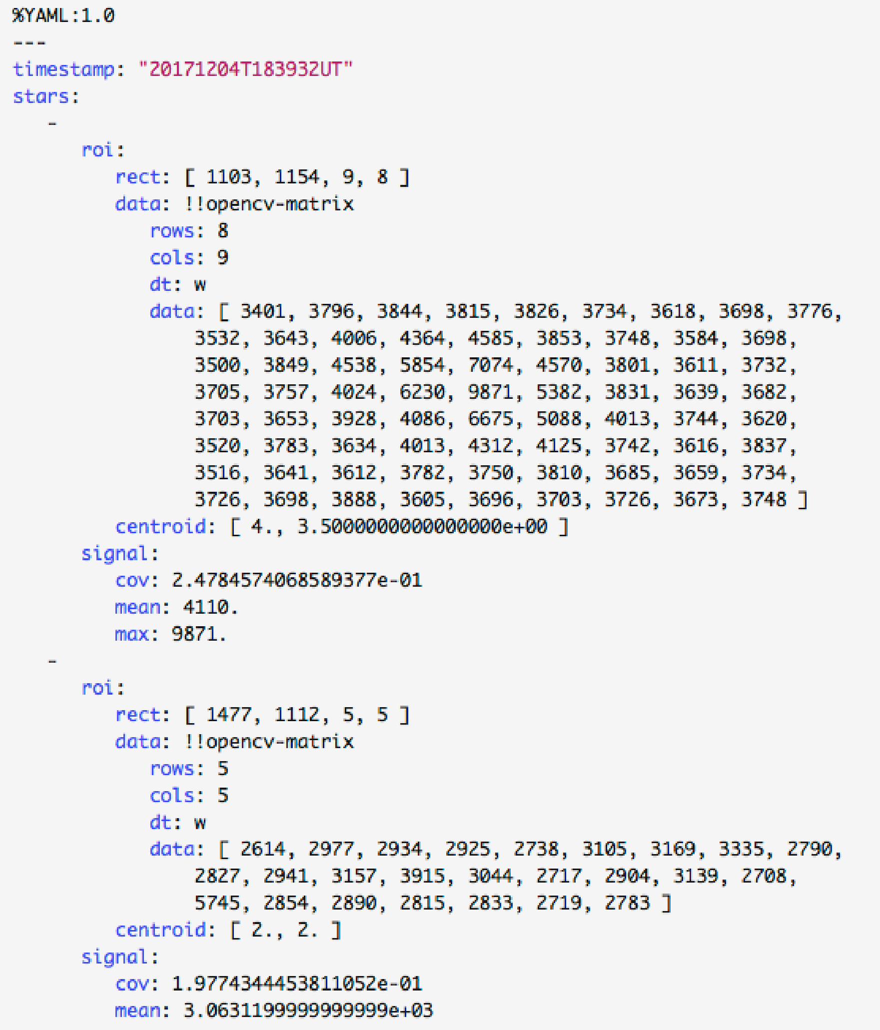
Proposed hardware



Component	Quantity	Unit cost (€)	Total cost (€)
Camera	3	400	1 200
Lens	3	510	1 530
LTE modem	1	100	100
SBC	4	50	200
Power supply	1	200	200
UPS	1	400	400
Networking	1	400	400
Watchdog	1	50	50
Mechanics	1	3 000	3 000
Electronic parts	1	800	800
Assembly & testing	1	5 000	5 000
Total			12 880

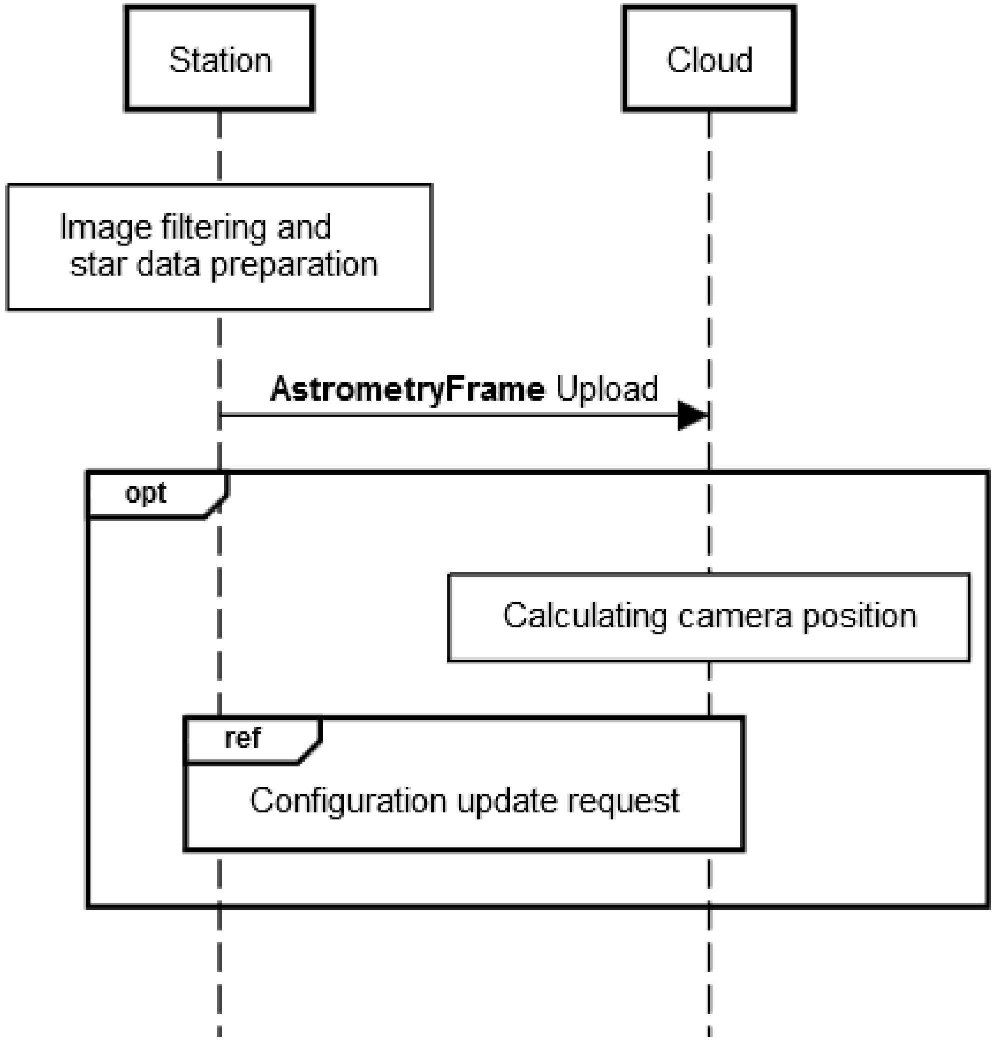
Station - Example Data

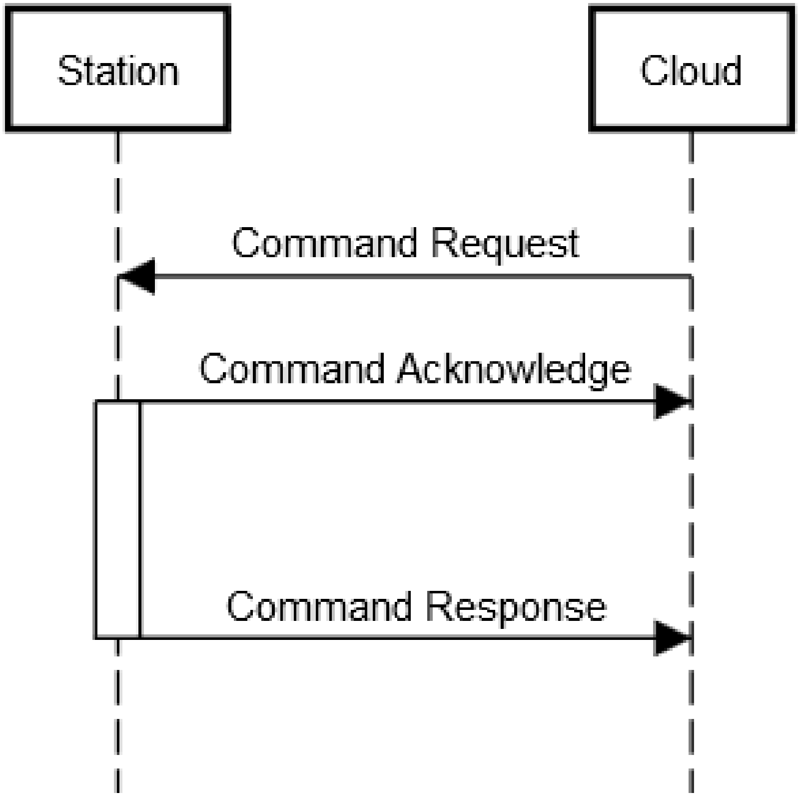




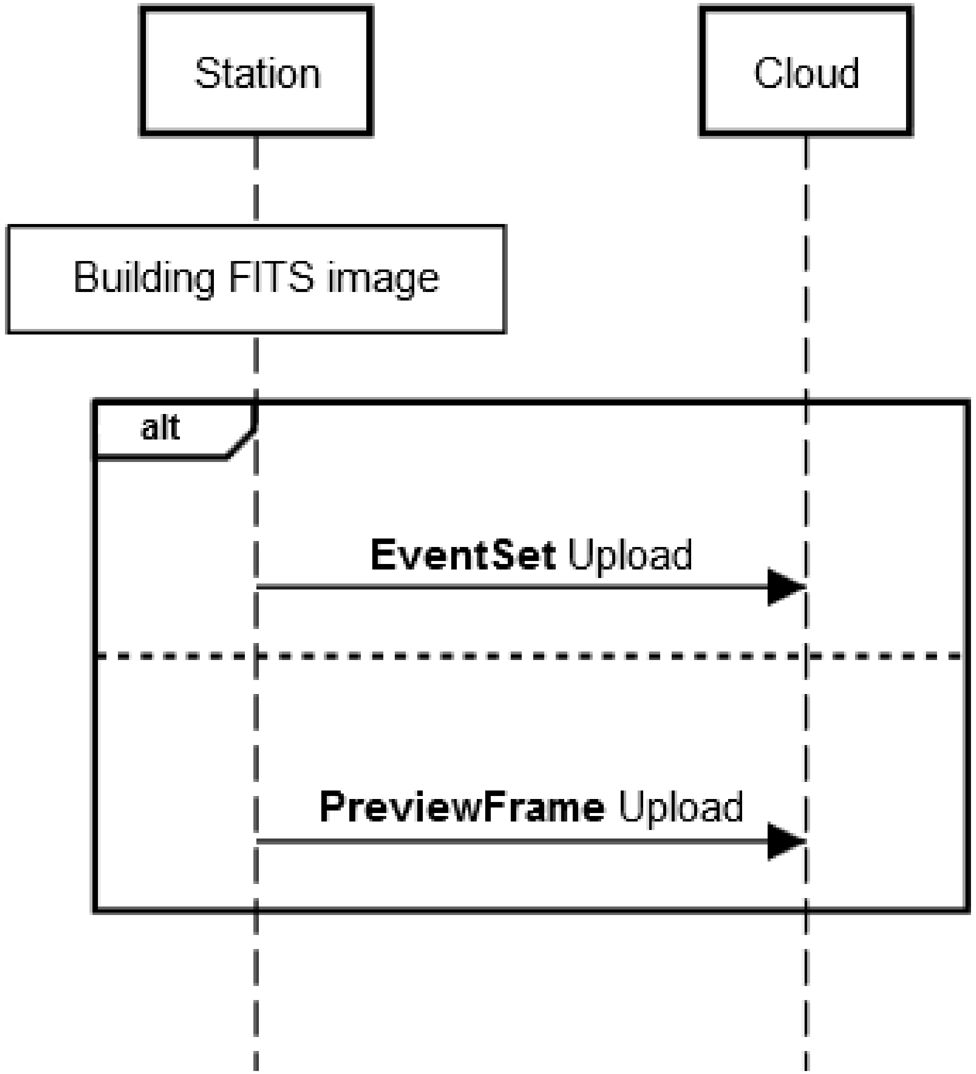
```
%YAML:1.0
---
timestamp: "20171204T183932UT"
stars:
   -
      roi:
         rect: [ 1103, 1154, 9, 8 ]
         data: !!opencv-matrix
            rows: 8
            cols: 9
            dt: w
            data: [ 3401, 3796, 3844, 3815, 3826, 3734, 3618, 3698, 3776,
                3532, 3643, 4006, 4364, 4585, 3853, 3748, 3584, 3698,
                3500, 3849, 4538, 5854, 7074, 4570, 3801, 3611, 3732,
                3705, 3757, 4024, 6230, 9871, 5382, 3831, 3639, 3682,
                3703, 3653, 3928, 4086, 6675, 5088, 4013, 3744, 3620,
                3520, 3783, 3634, 4013, 4312, 4125, 3742, 3616, 3837,
                3516, 3641, 3612, 3782, 3750, 3810, 3685, 3659, 3734,
                3726, 3698, 3888, 3605, 3696, 3703, 3726, 3673, 3748 ]
         centroid: [ 4., 3.5000000000000000e+00 ]
      signal:
         cov: 2.4784574068589377e-01
         mean: 4110.
         max: 9871.
   -
      roi:
         rect: [ 1477, 1112, 5, 5 ]
         data: !!opencv-matrix
            rows: 5
            cols: 5
            dt: w
            data: [ 2614, 2977, 2934, 2925, 2738, 3105, 3169, 3335, 2790,
                2827, 2941, 3157, 3915, 3044, 2717, 2904, 3139, 2708,
                5745, 2854, 2890, 2815, 2833, 2719, 2783 ]
         centroid: [ 2., 2. ]
      signal:
         cov: 1.9774344453811052e-01
         mean: 3.0631199999999999e+03
         max: 5745.
```

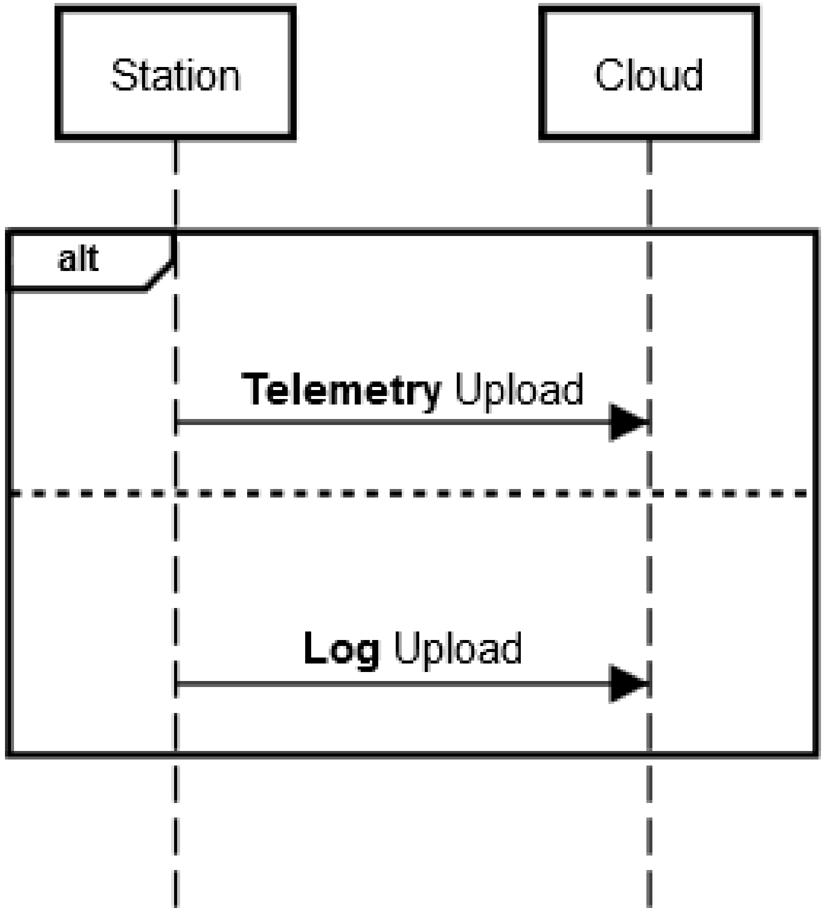
Station - Message Flow



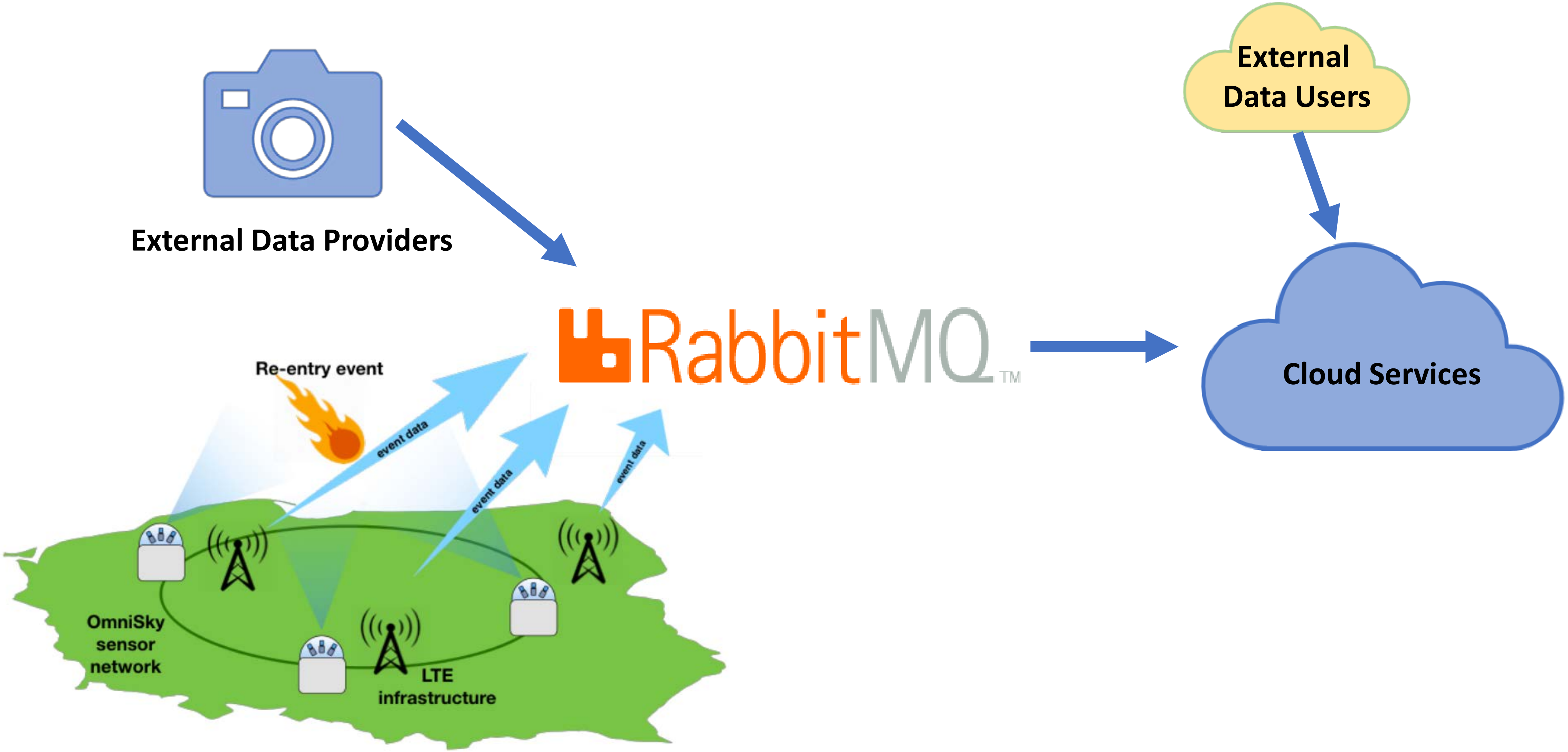


Station - Message Flow





Cloud-computing concept



Data processing, presentation and storage

Small messages test:

- JSON message (564 bytes), auto ack
- 3-4 K messages per second per station
- RabbitMQ node handles 50-60 K messages on default configuration
- may reach 1M messages per second when more working nodes are available (https://content.pivotal.io/blog/rabbitmq-hits-one-million-messages-per-second-on-google-compute-engine)
- pressure on context switching and response latency

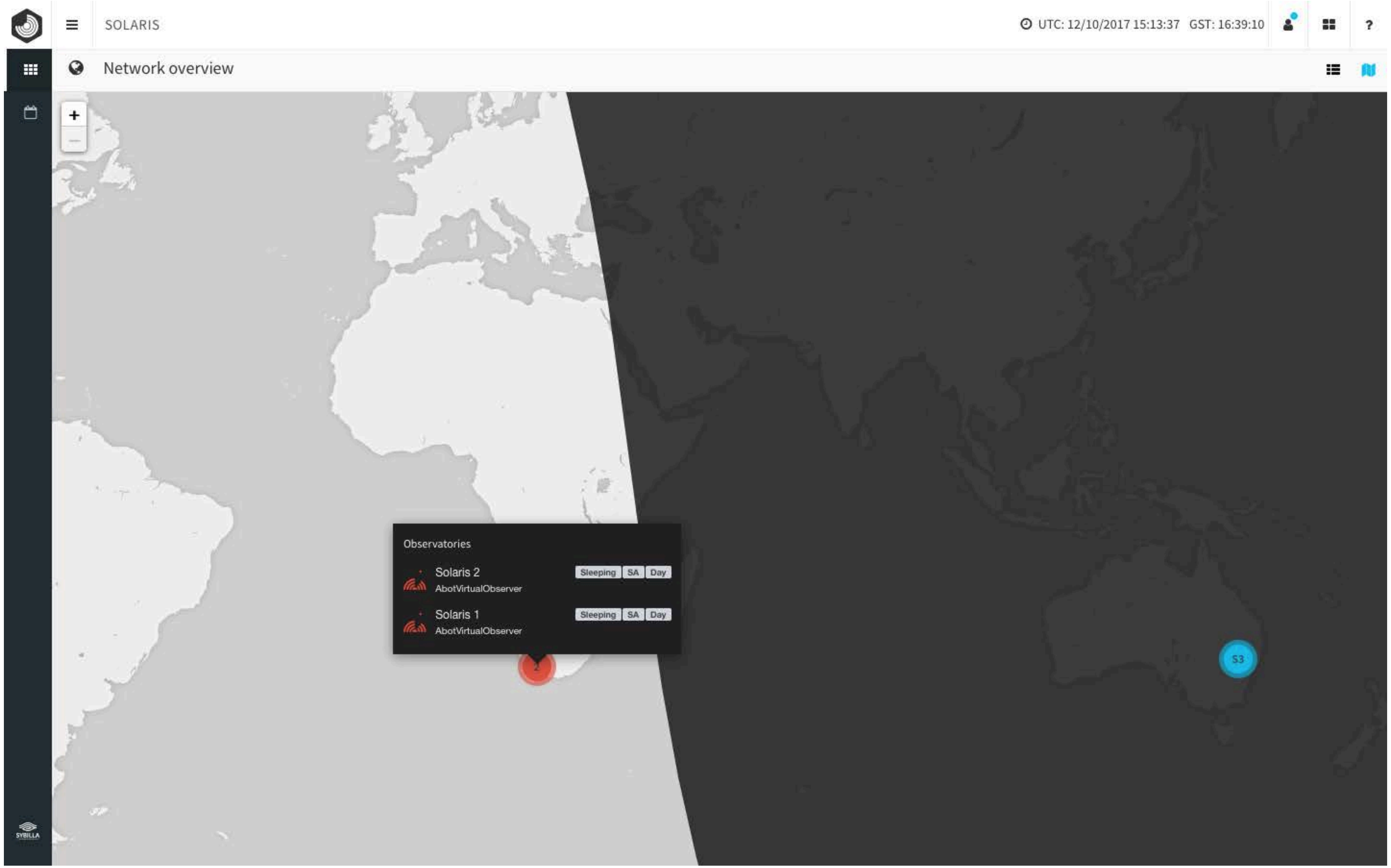
Large messages test:

- 1MB – 1GB messages
- 1 MB feasible for slow connections, 10MB for faster connections, 1GB only for local connections
- high pressure on bandwidth (main limit in tests, 12MBps) and on RAM (if no receiver connected to the queues default limit of 2.7GB memory is quickly reached), 1-2MBps per message per node achieved
- requirement on large buffers and fast recovery of messages from queues

In both tests:

- no pressure on File descriptors
- no pressure on disk space
- no pressure on CPU (a few percent utilization)
- no pressure on socket descriptor or Erlang processes

Data processing, presentation and storage



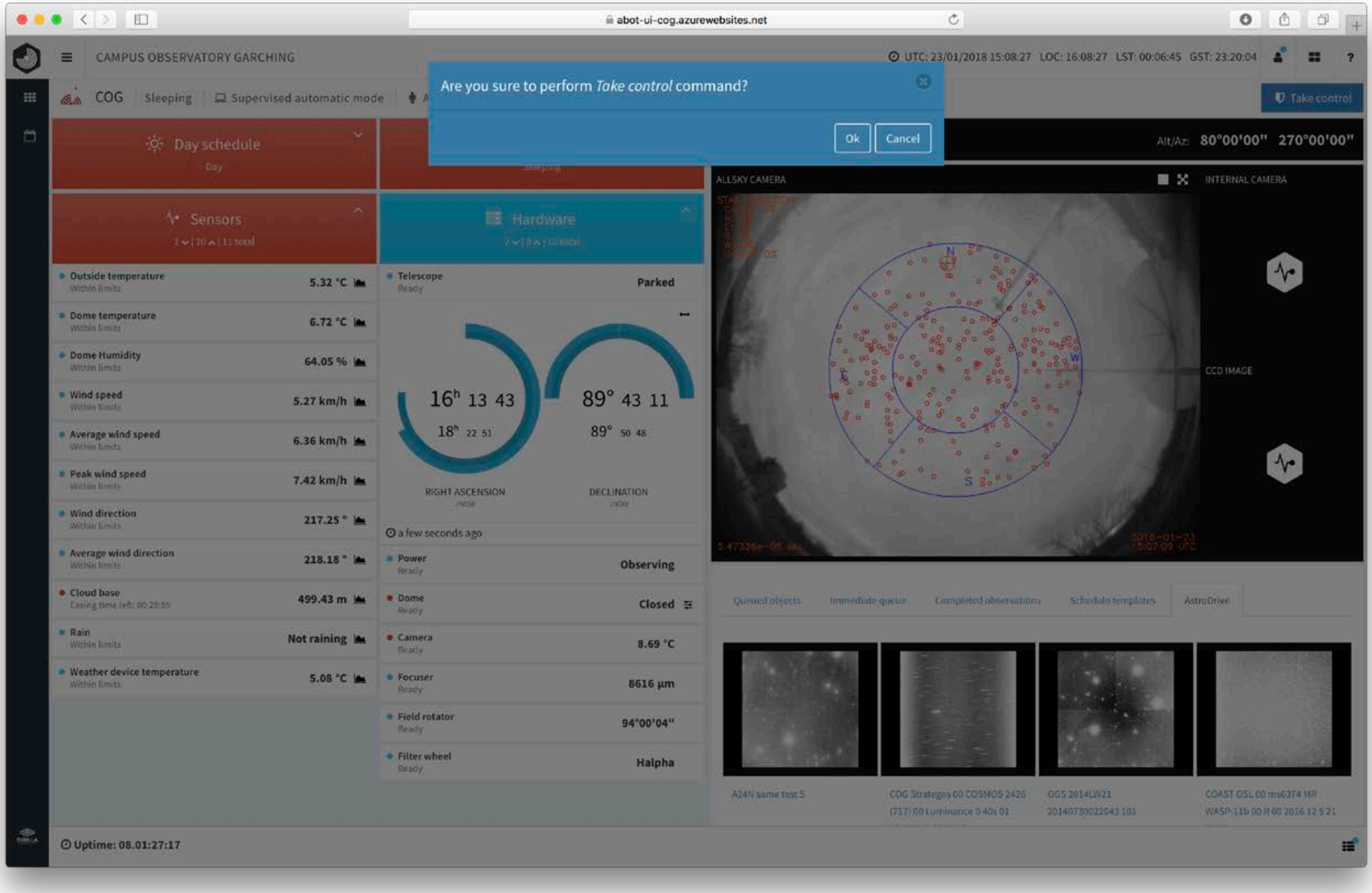
UTC: 12/10/2017 15:13:37 GST: 16:39:10

Observatories

Solaris 2 AbotVirtualObserver Sleeping SA Day

Solaris 1 AbotVirtualObserver Sleeping SA Day

Data processing, presentation and storage



UTC: 23/01/2018 15:08:27 LOC: 16:08:27 LST: 00:06:45 GST: 23:20:04

Are you sure to perform *Take control* command?

Alt/Az: 80°00'00" 270°00'00"

Outside temperature Within limits	5.32 °C
Dome temperature Within limits	6.72 °C
Dome Humidity Within limits	64.05 %
Wind speed Within limits	5.27 km/h
Average wind speed Within limits	6.36 km/h
Peak wind speed Within limits	7.42 km/h
Wind direction Within limits	217.25 °
Average wind direction Within limits	218.18 °
Cloud base Easing time left: 00:20:59	499.43 m
Rain Within limits	Not raining
Weather device temperature Within limits	5.08 °C

Telescope Ready	Parked
Power Ready	Observing
Dome Ready	Closed
Camera Ready	8.69 °C
Focuser Ready	8616 µm
Field rotator Ready	94°00'04"
Filter wheel Ready	Halpha

RIGHT ASCENSION: 16h 13 43 / 18h 22 51

DECLINATION: 89° 43 11 / 89° 50 48

a few seconds ago

A24N same test 5

COG Strategos 00 COSMOS 2426 (717) 00 Luminance 0 40s 01

OGS 2014LW21 20140730022043 101

COAST OSL 00 ms6374 MR WASP-11b 00 R 00 2016 12 5 21

Uptime: 08.01:27:17

Network simulation

Network Efficiency

Network Efficiency can be estimated as a number of deorbit events observed by the network compared to the number of all deorbit events around the world. Such comparison is done for the user specified number of all objects of some specified size (according to available sources).

Algorithm

- Specified number of re-entry events is simulated around the Earth.
- For some area around the simulated network re-entry events are fully simulated.
- For such simulated events observability is checked.
- After the simulation we know how large number of re-entry events was observed by the network, we can compare number of detected events to the number of all events.

Network simulation

3 stations – simplest working configuration
Triangle side length: 200 km

3x DMK33GX174 with 6mm lens per station

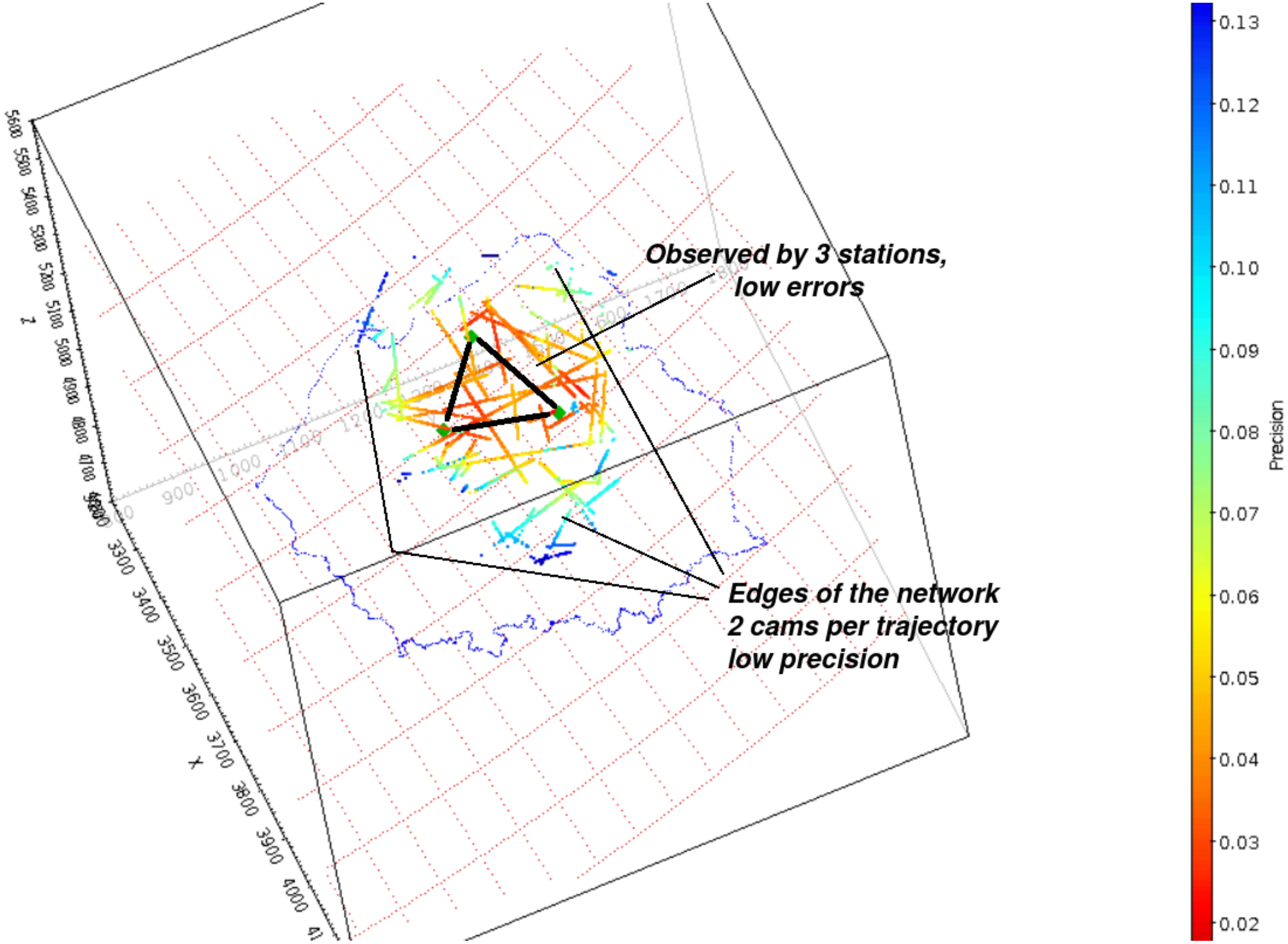
For every station:

Cam 1 – az: 0, alt: 40, FOV 86 x 60 degrees
Cam 2- az: 120, alt: 40, FOV 86x60 degrees
Cam 3 – az: 240, alt: 40, FOV 86x60 degrees

Best precision area: a bit larger than simulated network.

Low precision area: 2 station detections forms a large inverted triangle, much larger than network area.

8 trajectories per year, only 2 precise



Observed by 3 stations, low errors

Edges of the network 2 cams per trajectory low precision

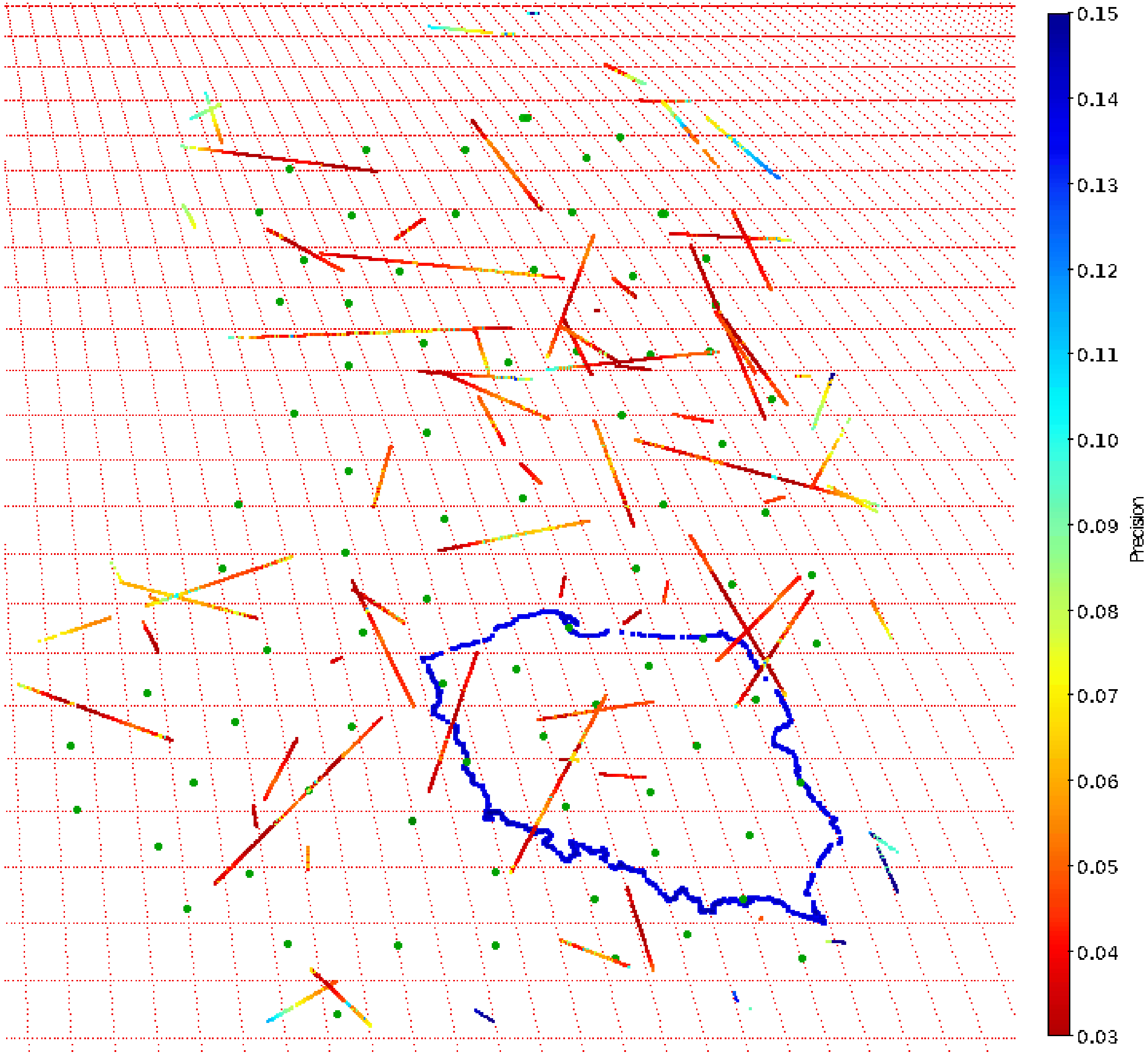
Network simulation

82 stations – coverage of Central Europe and Scandinavia

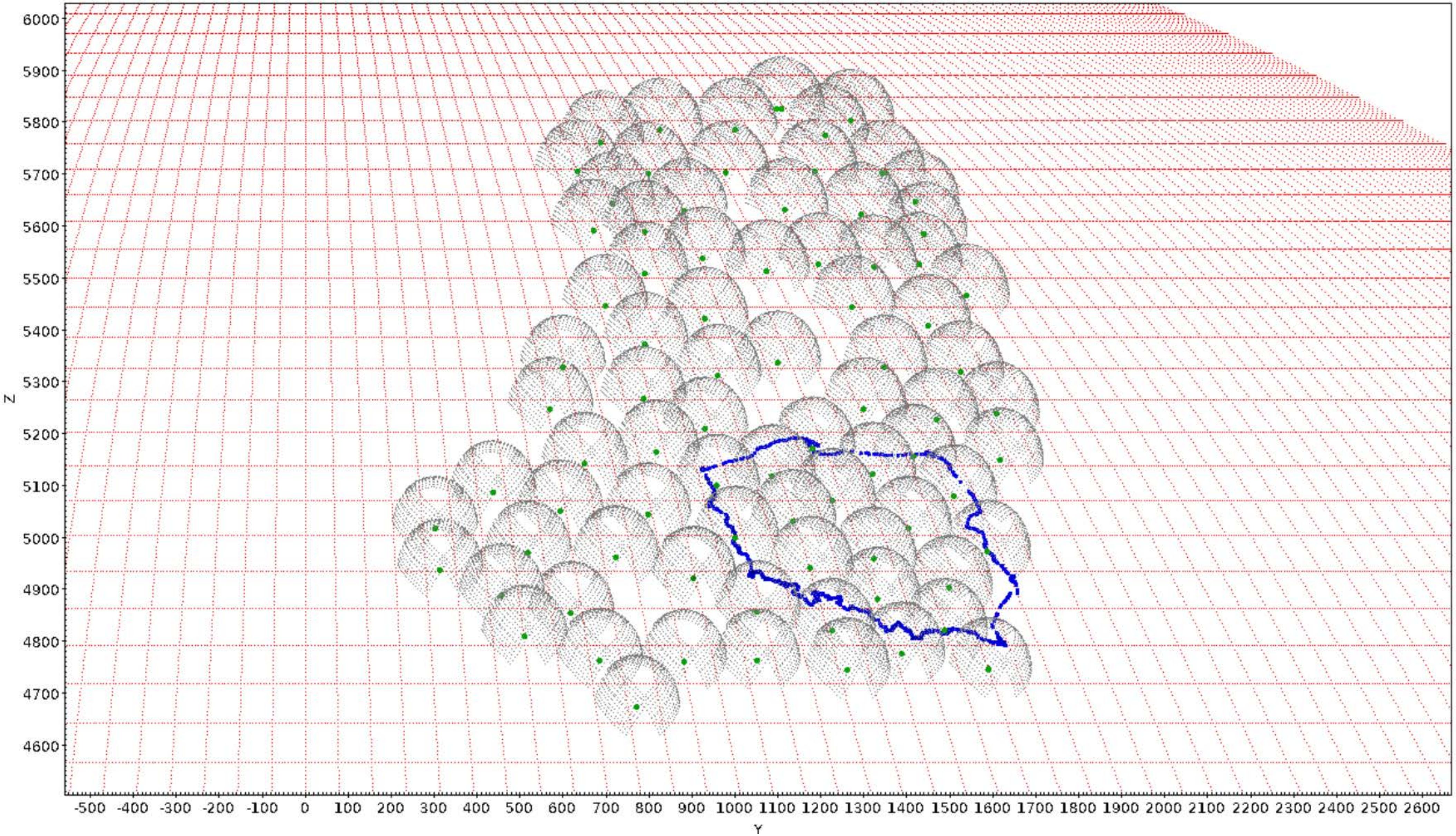
3x DMK33GX174 with 6mm lens per station, the same configuration as before

78 trajectories per year, 48 precise

Low precision areas neglectable, most of trajectories observed by multiple stations with precision better than 50m.



Network simulation



Network simulation

Conclusions:

- Efficiency of a big and properly configured network is proportional to the covered area.
- For big and sufficiently dense networks the intersection geometry inside the network is always very good (most cases between 70 and 90 degrees).
- With good intersection angles precision is mostly dependent on the station-trajectory distance.
- Increasing the limiting magnitude of the system changes the size of the low precision area outside the network and total number of detected events (however precision for such areas will be very low).

Deployment analysis

Simulation	Trajectories	Err < 50m	Err > 100m	Mean err (m)	
3 stations, 200 km, lm +4 mag, M -1 mag	7.7	2.3	2.9	37	
3 stations, 200 km, lm +6 mag, M -1 mag	13.4	1.9	10.5	37	
16 stations, 200 km, lm +4 mag, M -1 mag	19.9	10.9	3.3	37	EUR 820K
10 stations, 250 km, lm +4 mag, M -1 mag	17.6	8.1	2.8	46	EUR 690K
82 stations, 200 km, lm +4 mag, M -1 mag	78	48	10	43	
82 stations, 200 km, lm +4 mag, M +2 mag	820	490	210	38	
13 stations, 500km, lm +4 mag, M -1 mag	26	0	26	307	

Discussion items

1. Interest of other sensor operators to input data to the system.
2. Definition of data interfaces.
3. OmniSky deployment locations and financing.
4. ?

-> workshop discussion, email contact: s.kozlowski@cilium.pl