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Prepared by: Fabrizio Fiore

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Ground station network

High Energy CubeSats

The next few years will see several projects based on nano-sats in the field of High Energy Astrophysics.

In Europe the following missions are already operative today:

GRBAlpha, a 1U cubesat hosting a simple scintillator experiment (Pal et al,. 2020), a precursor of the CAMELOT constellation (Werner et al. 2018). The satellite is built by a collaboration led by **Konkoly Observatory** of the **Eötvös Loránd Research Network** along with **Hiroshima University**, **Spacemanic s.r.o.**, **Needronix s.r.o.**, **Eötvös University**, **Nagoya University**, **Masaryk University** and **Brno University of Technology** while the launch contract and radio license is provided by **Technical University of Košice**. Launch took place on 22 March 2021. GRBAlpha has so far detected 5 GRBs.

VZLUSAT-2, a 3U cubesat, the second nanosatellite made by VZLU (Czech Aerospace Research Centre). VZLUSAT-2 was released from the D-Orbit ION space-tug on January 26th following a SpaceX launch on January 13th (https://www.vzlu.cz/the-main-systems-of-the-vzlusat-2-nanosatellite-put-into-operation/?lang=en). The main payload is an optical high-resolution camera, while the secondary payload is identical to that hosted by GRBAlpha.

Both missions are flying on a SSO LEO, and use UHF/VHF for telecommands upload and data download.

During the next years several other missions should be launched, in particular:

GRBBeta, by the same core collaboration that has built GRBAlpha. It should be launched in 2023-2024

EIRSAT-1, *Educational Irish Research Satellite 1* supported by ESA's *Fly your satellite program*, will carry a gamma-ray module (GMOD) to detect gamma-ray bursts (Murphy et al. 2018). GMOD uses SensL B-series SiPM detectors and a CeBr scintillator. EIRSAT-1 will be launched from the ISS in 2022 (i=51 deg).

HERMES-Pathfinder, a constellation of six 3U nano-satellites hosting simple but innovative X-ray detectors for the monitoring of Cosmic High Energy transients and for the determination of their position (see Fiore et al. 2020, Evangelista et al. 2020, Sanna et al 2020). The HERMES Technological Pathfinder project is funded by the Italian Space Agency while the HERMES Scientific Pathfinder project is funded by the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 821896. HERMES-Pathfinder is an in-orbit demonstration, that should be tested in a low inclination (i<20deg) LEO orbit starting from 2023**.** HERMES-Pathfinder with use S-band for telecommand upload and data download. UHF and VHF are used for backup channels. An IRIDIUM channel is also present for fast GRB trigger dissemination.

SpIRIT (Space Industry - Responsive - Intelligent – Thermal) is a 6U cubesat funded by the Australian Space Agency and managed by the University of Melbourne. SpIRIT will host one HERMES pathfinder payload, and it should be launched on an SSO on Q1/2023 therefore overlapping with HERMES-Pathfinder, forming a constellation of seven satellites in two different orbits, thus greatly increasing the transient localization capabilities. SpIRIT will use S-band UHF and VHF for data download and telecommand upload. IRIDIUM and Globastar channels are also present for fast GRB trigger dissemination

Several other projects are also carried out in the USA:

BurstCube, a 6U CubeSat developed by NASA which will detect GRBs using four CsI scintillators, each with an effective area ~90 cm^2 (Rakusin et al. 2017). BurstCube is expected to be launched during 2022.

MAMBO Mini Astrophysical MeV Background Observatory is a CubeSat mission under development at Los Alamos National Laboratory Vestrand et al. 2019, Bloser et al. 2021. Launch is currently planned for the fall of 2023.

Requirements for a Ground Station network

The missions briefly described in the previous section are flying or will fly on very different LEO orbits: nearly polar, ISS, nearly equatorial. A **network of dedicated GS close to the Earth equator** can therefore be efficiently used to follow the totality of the missions.

Each dedicated GS should be able to cover both the S-band and UHF/VHF bands

One natural site for hosting a dedicated GS is the Malindi station in Kenya, managed by ASI. In the framework of the HERMES-Pathfinder project ASI is funding a dedicated GS, equipped with a 3m S-band antenna, and a VHF/UHF separated antenna.

Equatorial sites are rare, because most of the equatorial band is covered by oceans, and thus expensive. Suitable sites that can host a high-energy-astrophysics CubeSat dedicated ground station has been searched. One very interesting possibility arises through the collaboration between INAF and University of Melbourne on SpIRIT. UoM put us in contact with University of Tasmania (UTAS), who manage the site of Katherine, owned by the Darwin University in the Northern Territories (AU). The Katherine site already host a 12m dish, used for VLBI observation and satellite tracking, and therefore all infrastructures needed for the installation of a new GS are already present (see below). UTAS was interested in joining the project and an Agreement between INAF, Masaryk University (participants of WP11, Task1 of the AHEAD2020 project), UoM and UTAS was signed on September 2021 to develop a new GS dedicated to HEA CubeSats in the Katherine site.

Malindi Site Description

The "Luigi Broglio" Space Center in Malindi in Kenya is managed since the 1960s through the University of Rome "La Sapienza" through the Research Center of the San Marco Project (CRSPM), it represents an ideal site for satellite control activities due to its equatorial location on the Indian Ocean coast.

The Center (Long. 40.19 degrees E - Lat. 2.99 degrees S) covers an area of about 3.5 hectares on the Indian Ocean coast about 32 km from Malindi and can be reached from the Kenya coast. The Center's presence in Kenya, which dates back to 1966, is currently regulated by a renewable fifteen-year intergovernmental agreement, first signed in 1995, which provides for the possibility of launching, acquiring satellite data, remote sensing and training both on site and in Italy. Italy, for its part, undertakes to find the programs, equip and operate the Center, provide the logistics, train and employ local staff, while Kenya makes the site available, upon payment of a modest fee and training and use of local labor by the Italian side. The local government must be informed of the programs benefiting from the Center and requires, for commercial programs, a royalty dependent on the terms of the commercial agreement. After fifteen years, the equipment then becomes owned by Kenya.

The Terrestrial Segment includes a series of masonry and wooden buildings used for both accommodation and services, a small harbor for mooring the vessels connecting to the platforms and 3 Earth Stations (antenna systems) for orbital control and receiving telemetry from satellites and carriers. The 3 stations are:

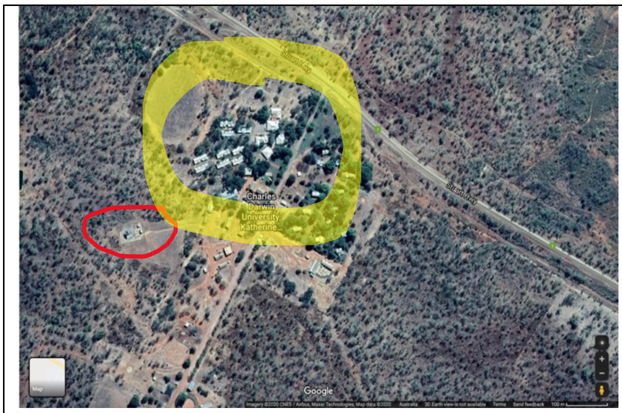
- S-band station, equipped with a 10-meter dish, used for agency programs.
- S / X / L band station, equipped with a 10-meter dish, used to control launch vehicles (Arianespace, Titan) and to support the early flight phases of commercial satellites (LEOP).
- X-Band station, equipped with a 6-meter dish used to receive remote sensing data (ERS2, Spot, Landsat).

The center is connected with Italy through Intelsat satellites within the ASI-net of the Italian Space Agency.
Description provided by "https://www.asi.it/lagenzia/le-basi/centro-spaziale-luigi-broglio/".

Katherine site description

The Katherine radio telescope is a 12-metre dish is at the Charles Darwin rural campus in Katherine (Northern Territory). It is remotely operated from Hobart (UTAS) and have only one casual operator for basic operations.
It haves 3 buildings: antenna, container with electronics (properly cooled) and a second container for tools and workshop. The area is mostly flat. It is not anticipated any visibility issue, that is one of the reasons for installing the 12-m there. The site has plenty of room for the 4-metre S and UHF band antenna.
Marked in red in Figure 1 is the area where the 12m antenna is and, in yellow, where University campus is. The campus includes dormitories, dinner facilities, etc. The campus is very handy when having to stay on site for few weeks for installation, upgrades, and maintenance.

Figure 1: Katherine Facilities. Marked in red is the area where the 12m antenna is, in yellow, where University campus is and in green the site where the new GS dedicated to HEA CubeSats can be placed



The station facilities have the VLBI antenna, some GPS receivers, and it is coming a DORIS station. DORIS is another geodetic positioning technique that relies on communication with dedicated satellites from the French Space Agency. It operates by transmitting from the ground beacon to the satellites at the frequencies of 401.25 and 2036.25 MHz (UHF, S-band). The location of the beacon is not yet defined, but it is not expected that it will cause interferences in the current system or for Hermes.

Mission analysis

The following mission analysis is based on the assumption to have available two GS dedicated to HEA CubeSats.

	Malindi	**Katherine**
Latitude (deg)	-2.995713889	-14.3755
Longitude (deg)	40.19495556	132.152

Figure 2: GS network

The GS equipment has been selected following a market analysis. The performances taken into considerations are reported in the following Table, considering a Yagi antenna for the UHF/VHF and a 3m dish for the S-band.

Band	G_{TX} (dBi)	EIRP (dB)	G/T (dB/K)
UHF/VHF	12.0	25.5	-12.5
S-Band	35.4	48.9	9.9

The satellite visibility analysis was carried out to define the visibility requirements for the FE installation. The elevation margin of 5 degree is adopted to the here reported analysis; therefore, the satellite is visible from ground only whenever its elevation above the local horizon is greater than 5 degree. To take into account uncertainties provoked both at orbit injection by the launcher, and by the possibility for the orbital plane inclination baseline slight change in the future, three inclinations have been adopted to settle simulations, namely 0, 5 and 10 . All three orbits have been propagated with a high fidelity simulator for a period of one year. The resulting sky clearance needed can be seen from the graphs in Fig. 8.11, 8.12 and 8.13, where the blue area represents the portions of the sky that shall not be obstructed in view in the local alt-azimutal reference frame

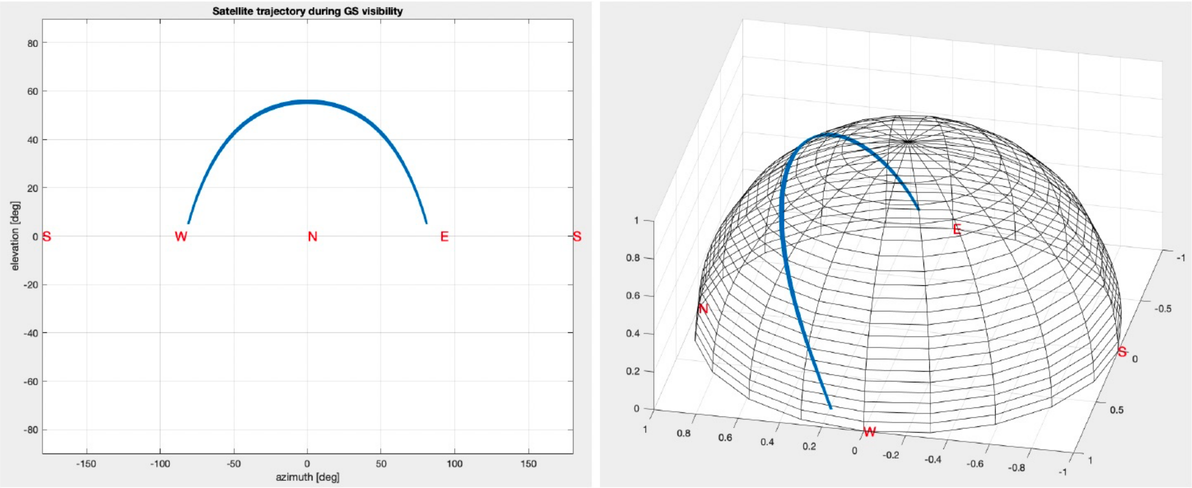


Figure 3 0 degree inclination orbit - azimuth and elevation

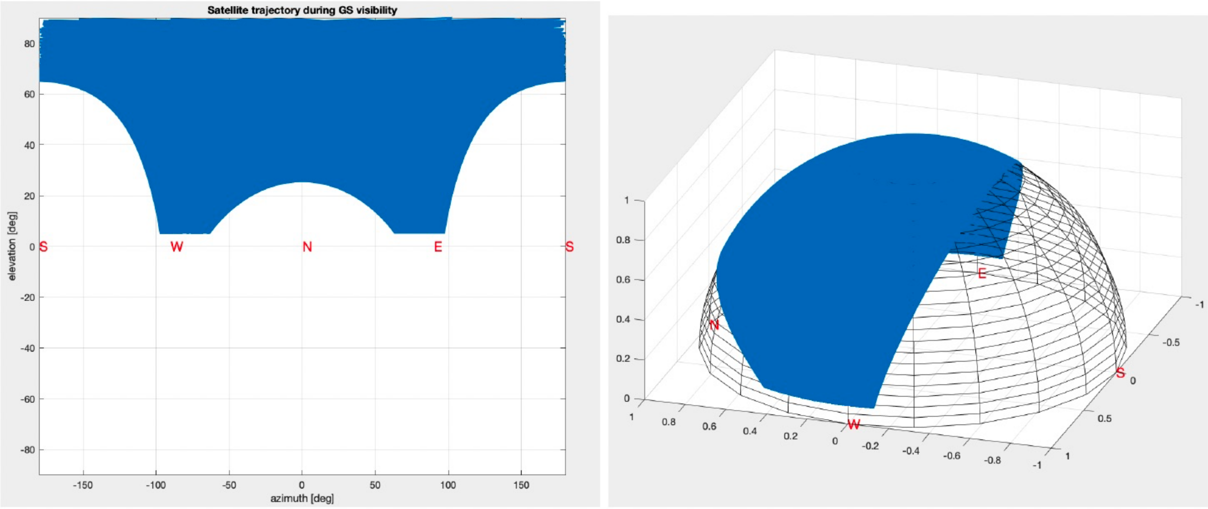


Figure 4: 5 degree inclination orbit - azimuth and elevation.

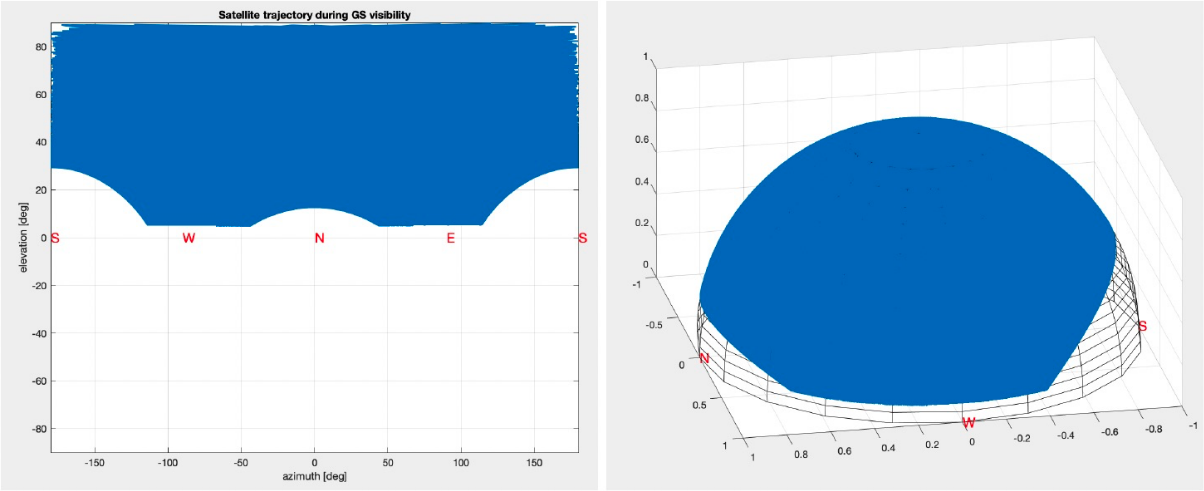


Figure 5: 10 degree inclination orbit - azimuth and elevation

The two communication channels considered in this mission analysis
S-band range: 2200 - 2290 MHz
UHF range 436 – 437 MHz
VHF range 148 – 149 MHz

Equatorial orbit

An analysis of the stations visibilities has been performed based on an **equatorial orbit height of 550 km and a 5-degree elevation margin.**

Considering both Eclipse and Sunlight communications:
Table 1: Operational Ground Stations Visibilities both Eclipse and Sunlight communications

	Malindi	**Katherine**	**Malindi + Katherine**
Mean contact duration (min)	10,25	6,48	16,73
Number of passes per year	5146	5146	5146
Mean revisiting time (min)	102,15	102,15	102,15
Mean communication free time between passes (min)	91,9	95,67	67,72
Cumulative time with 1 sat in visibility (days)	143,26	107,93	251,19
Cumulative time with 2 sat in visibility (days)	32,55	13,51	46,06
Cumulative time with 3 sat in visibility (days)	3,79	1,35	5,14

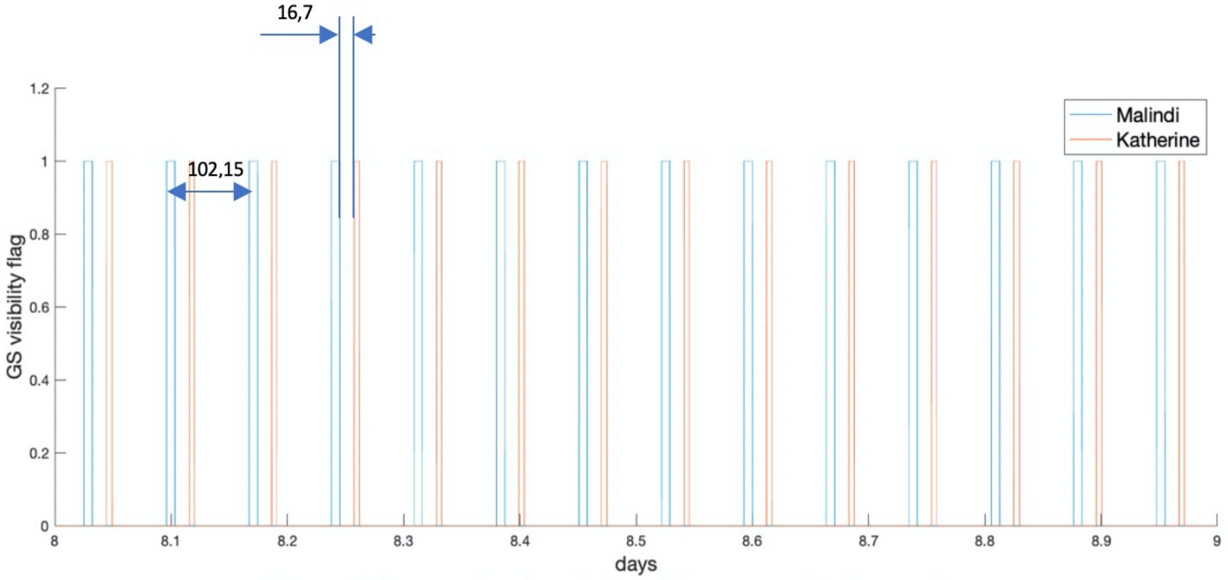


Figure 6: Operational Ground Stations Visibilities (Eclipse + Sunlight)

Considering only Eclipse communications:

Table 2: Operational Ground Stations Visibilities (Eclipse Only)

	Malindi	**Katherine**	**Malindi + Katherine**
Mean contact duration (min)	10,25	6,48	16,73
Number of passes per year	1891	1891	1095
Mean revisiting time (min)	102,15/1013	102,15 / 1013	102,15/~1100
Mean communication free time between passes (min)	91,9/~1000	95,67/~1000	67,7/~1100
Cumulative time with 1 sat in visibility (days)	55,11	40,30	~56
Cumulative time with 2 sat in visibility (days)	10,96	4,71	~9
Cumulative time with 3 sat in visibility (days)	1,24	0,45	~1

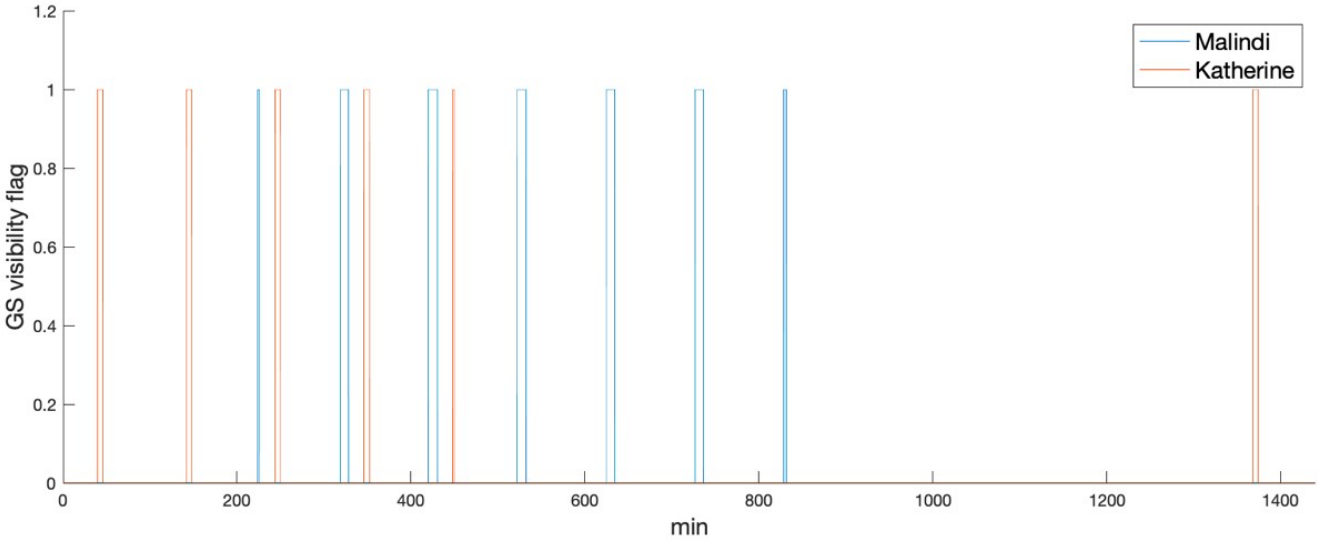


Figure 7: Operational Ground Stations Visibilities (Eclipse only)

ISS orbit

A second analysis of the stations visibilities has been performed based on an **the ISS orbit, height of 430 km and a 51-degree inclination, with 5 degree elevation margin.**

Figure 8 shows a typical distribution of contact windows during a reduced time window (5 days). As can be easily seen, in around 3/4 (depending on the specific day) contacts per day are available for each ground station, for a total number of passage per year equal to 1265 for Malindi e 1333 for Katherine. It is important to underline that not all the passages can be used for the communications, mainly because of the extremely reduced duration of some passages.

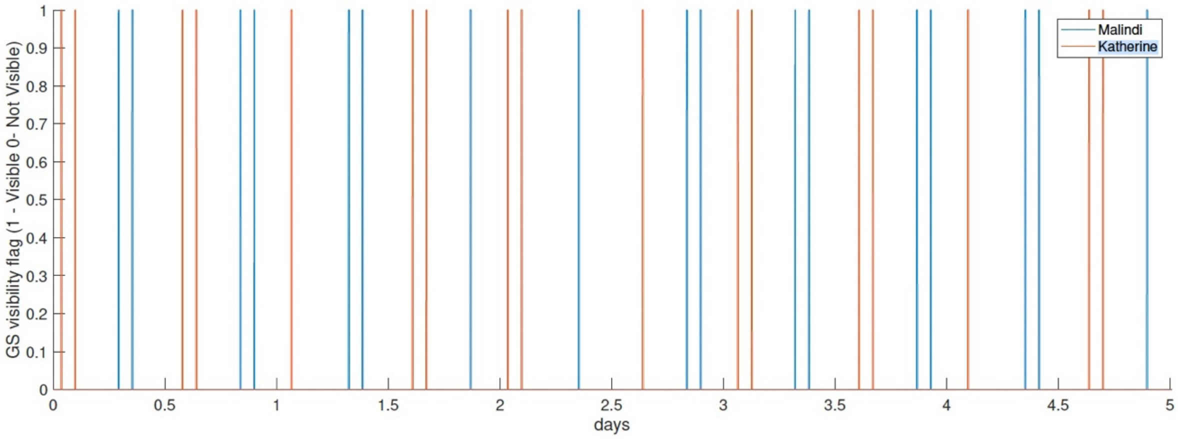


Figure 8: Ground Stations visibility pattern ISS orbit

Due to the inclination of the orbit the duration of the launch windows is not constant, and ranges between 0 s and 480 s. Figure 9 shows the distribution of the passages during one year for the two ground stations, while 4.3 shows the revisiting time for the same ground stations.

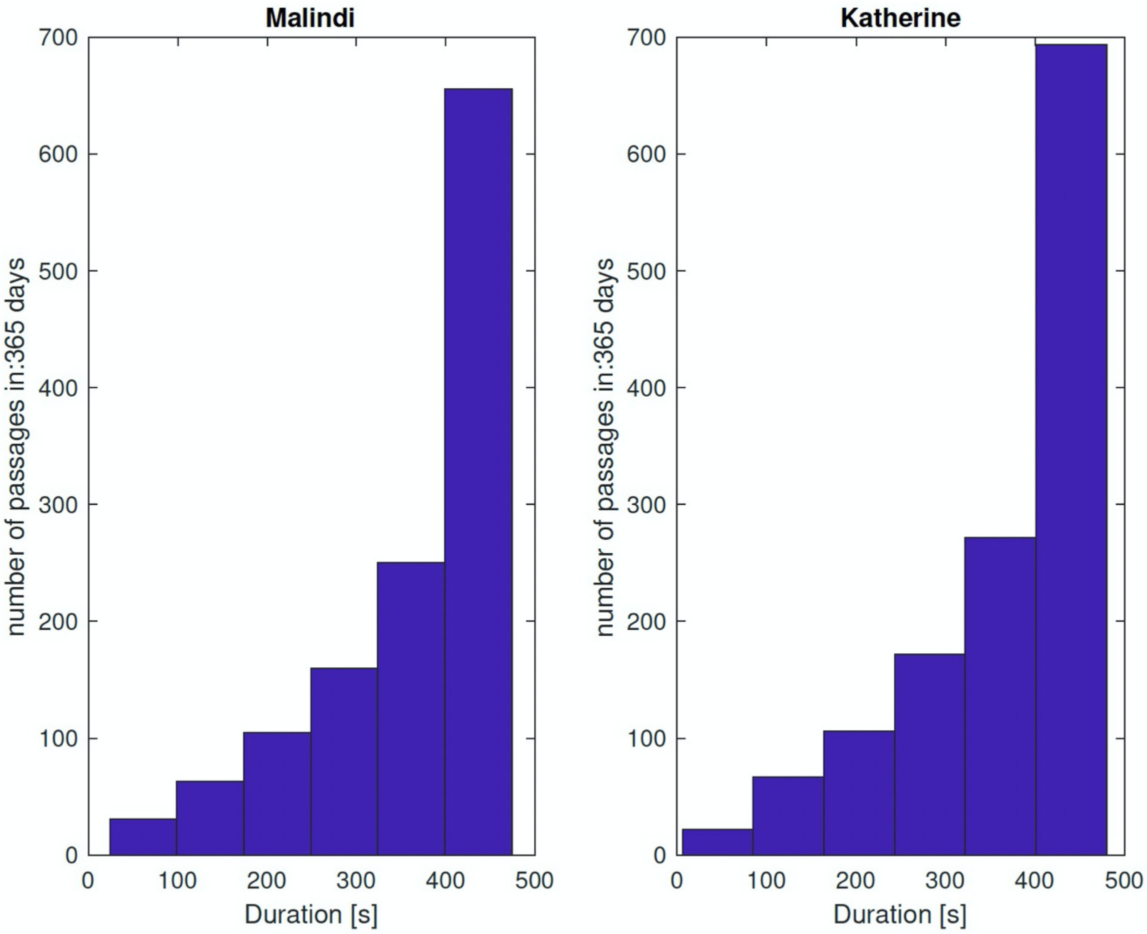


Figure 9 Visibility duration for ISS orbit

SSO orbit

A third analysis of the stations visibilities has been performed based on a Sun Synchronous Orbit (SSO) with**, height of 550 km, 97,6 degree inclination, LTAN 10:30, with a 5 degree margin.**

Figure 10 shows a typical distribution of contact windows during a reduced time window. In one year we will have 1150 passages over Malindi and 1200 over Katherine, a number still quite high, despite the fact that the number of passages will increase for GS locations at higher or lower latitudes. As an example, the number of passages on a GS at the latitude of Roma would be around 1500. Typically we have two 'close' passes on two consecutive orbits, then about 100 minutes apart, and then we have a 10-11 hour gap before the station returns to visibility. Figure 11 show the distribution of the revisiting time at the two locations

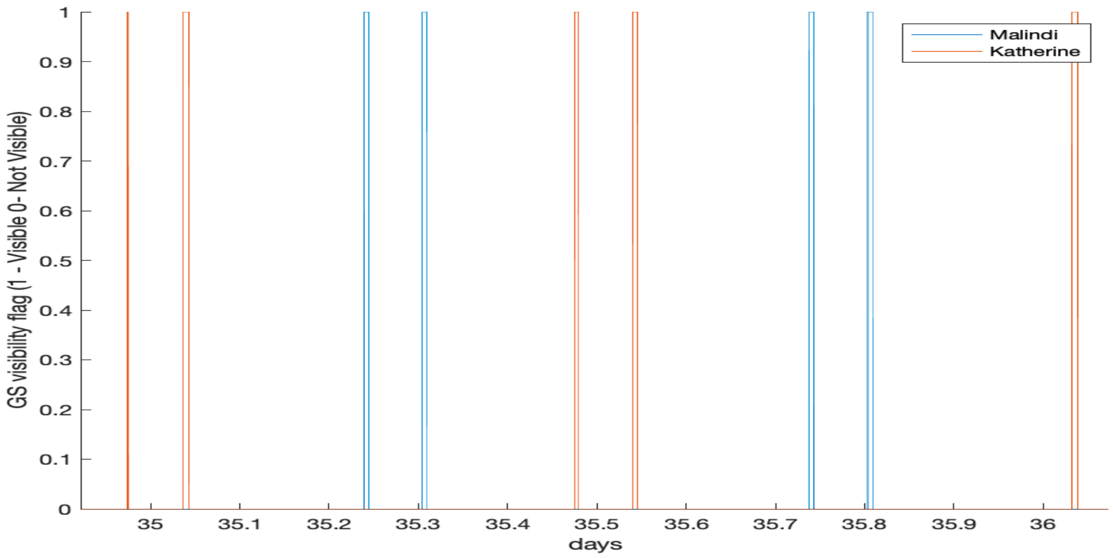


Figure 10: Ground Stations visibility pattern SSO orbit

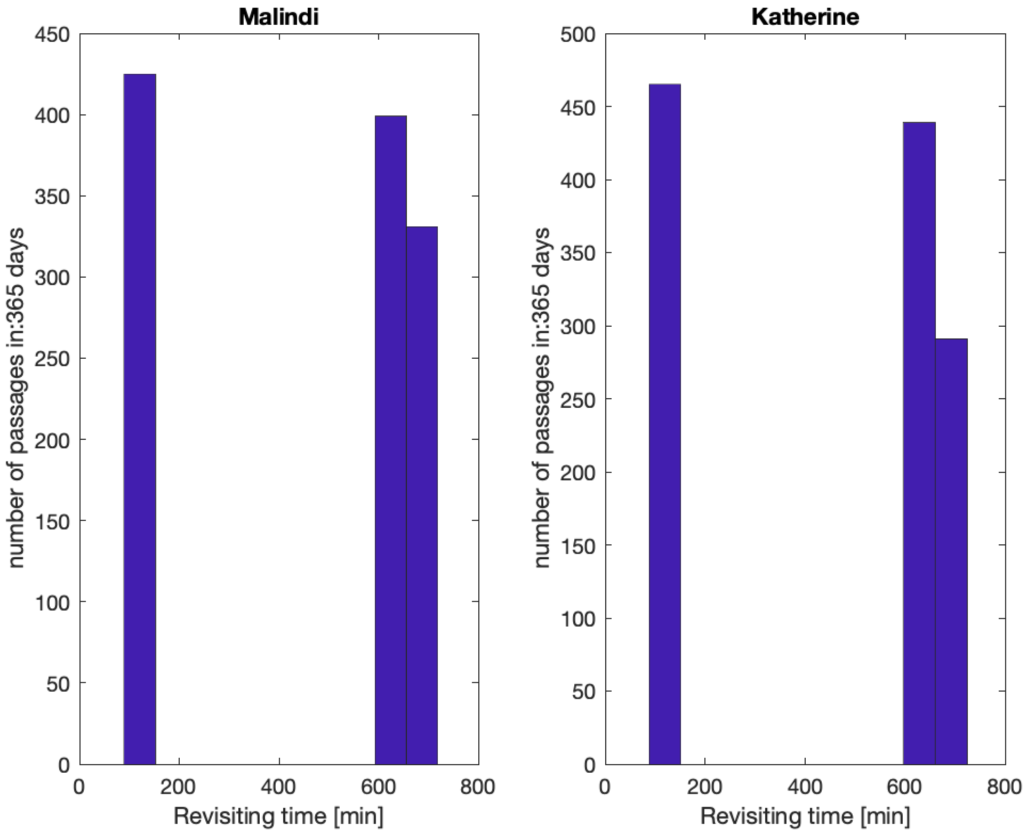


Figure 11: revisiting time for SSO orbits

The average duration of the passage does not depend on the latitude of the GS and therefore is about 7.5m for both stations, see Figure 12.

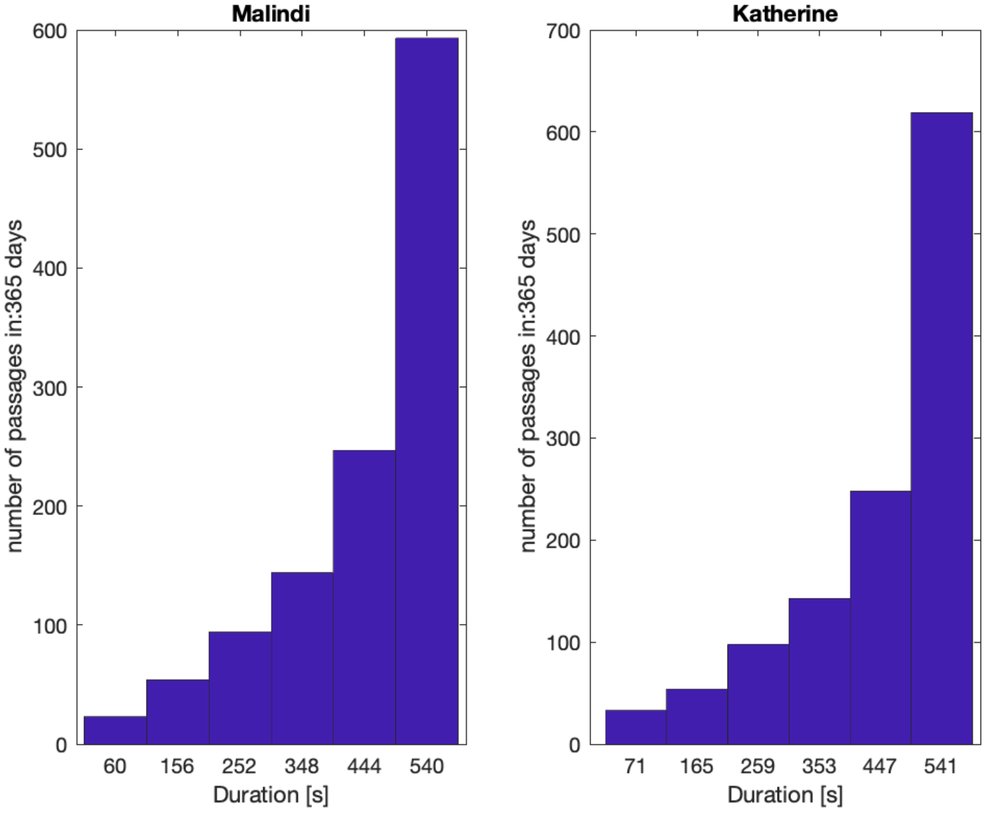
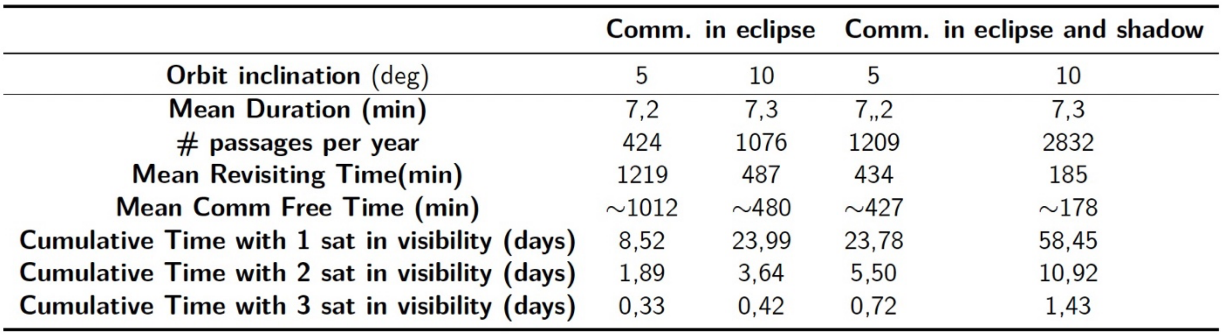


Figure 12: visibility duration SSO orbit

A possible extension of the network

As a final exercise, we studied the possible utilization of **'Tainan' Ground Station in Taiwan**. The location of the GS is Latitude = 22,9396; Longitude = 120,2256. Discussions with SOC/NSPO who handles the Tainan station were held on 2020. The station is currently used to follow nano-sats, and an agreement for its inclusion in the network can be reached, if necessary.

Due to the high latitude of the GS it is impossible to communicate with a satellite in equatorial orbit @ h = 550 km. In order to have a link with an elevation margin of at least 5 degree the minimum inclination of the orbit shall be 1,5 degree. The following Table shoes the results of the simulation for orbit inclined at 5 and 10 degrees.



	Comm. in eclipse		Comm. in eclipse and shadow	
Orbit inclination (deg)	5	10	5	10
Mean Duration (min)	7,2	7,3	7,,2	7,3
# passages per year	424	1076	1209	2832
Mean Revisiting Time(min)	1219	487	434	185
Mean Comm Free Time (min)	~1012	~480	~427	~178
Cumulative Time with 1 sat in visibility (days)	8,52	23,99	23,78	58,45
Cumulative Time with 2 sat in visibility (days)	1,89	3,64	5,50	10,92
Cumulative Time with 3 sat in visibility (days)	0,33	0,42	0,72	1,43

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