SED

Student Experiment Documentation

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Mission: BEXUS 28

Team Name: IRISC

Experiment Title: InfraRed Imaging of astronomical targets with a Stabilized Camera

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Abstract:
This version one of the IRISC Student Experiment Documentation (SED), part of BEXUS 28/29.

Keywords: BEXUS, SED - Student Experiment Documentation, IRISC, InfraRed Imaging of astronomical targets with a Stabilised Camera, Infrared astronomy, Luleå University of Technology

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PREFACE

The Rocket and Balloon Experiments for University Students (REXUS/BEXUS) programme is realized under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Agency (SNSA). The Swedish share of the payload has been made available to students from other European countries through a collaboration with the European Space Agency (ESA).

EuroLaunch, a cooperation between the Esrange Space Center of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. Experts from DLR, SSC, ZARM, and ESA provide technical support to the student teams throughout the project.

The Student Experiment Documentation (SED) is a continuously updating document regarding the BEXUS student experiment IRISC - InfraRed Imaging of astronomical targets with a Stabilized Camera and will undergo reviews during the preliminary design review, the critical design review, the integration progress review, and final experiment report.

The goal of the IRISC experiment is to obtain images in the near infrared (NIR) spectrum from astronomical targets. Possible targets include the Andromeda Galaxy, Pinwheel Galaxy, Iris Nebula, Eagle Nebula and Starfish Cluster. The images are obtained using a highly stabilized telescope with NIR camera mounted on a BEXUS balloon. With this balloon-borne telescope most interference caused by the atmosphere is avoided– a problem for most ground-based telescopes– while keeping the building and operation costs low, compared to an orbital telescope. The stabilization is achieved by a gimbal-like system, this is needed to obtain high quality images while being on a moving platform. For a NIR telescope, it is also important to keep the temperature as low as possible to avoid heat-induced noise. For example, orbital telescopes are kept at only a few degrees above 0 K. IRISC wants to use a NIR camera with a higher operating temperature (closer to 273 K) that requires a relatively simple cooling system. The aim is to develop a simple astronomical research system that is affordable and readily available for integration with other future stratospheric balloon experiments.

Acknowledgements

1 Introduction

1.1 Scientific Background

The universe hides a plethora of information across the entire electromagnetic spectrum. Infrared light is unique as compared to other wavelengths of light in that it can permeate interstellar dust, and corresponds to typically "cold" astronomical phenomena, such as star formation, some nebulae, and older, colder stars, to name a few [3]. Here on the surface of the earth, both visible light and radio waves exhibit near-total transmission through the atmosphere for observation, and experience fewer ill effects from atmospheric interference than other wavelengths, including infrared light, that cannot penetrate the atmosphere at all. The infrared regime lies between visible and microwave radiation, and in an astronomical context this usually corresponds to wavelengths between 0.75 and 300 microns. Within this range, a number of cosmological phenomena can be explored, however only parts of this spectral range are capable of penetrating the earth's atmosphere for observation.

Factors affecting infrared transmission through the atmosphere include molecular absorption (in particular absorption by carbon monoxide, carbon dioxide, water vapour, and oxygen, among others), scattering by dust and other molecules, and distortion of the light by small-scale perturbations in the atmosphere such as pressure and temperature gradients [1]. As with visible light, infrared observations are also not possible on cloudy or overcast nights. To minimise these problems, infrared telescopes are usually situated at very high altitudes, such as the Tokyo Atacama Observatory (TAO) at 5,600 m above sea level [5]. Better still, the Stratospheric Observatory for Infrared Astronomy (SOFIA) is an airborne observatory that flies at an altitude of 13-14 km, thus getting above 99.8% of atmospheric water vapour absorption [2], as well as the majority of scattering and distortion.

1.2 Mission Statement

Studying astronomical targets in the infrared from ground-based observatories is hampered by atmospheric distortion and extinction, limiting the amount and kind of infrared research that can be done. Therefore, having a telescope make observations from above the majority of interfering atmosphere will negate these effects, and improve the SNR and therefore scientific quality of the obtained images. Establishing a functional, low-cost system for performing infrared observations from a stratospheric balloon will help to push the boundaries of infrared astronomy.

1.3 Experiment Objectives

The primary objectives of the experiment can be split into a main scientific objective, and a main technical objective: the primary scientific objective is to establish the SNR improvement (if any) from ground-based observations to stratospheric observations in the infrared. In order to achieve this scientific objective, the primary technical objective is to construct a gimbal system that is capable of stabilising the optics setup to arcsecond accuracy.

Pending success of these primary objectives, secondary scientific and technical objectives include:

I (Scientific) Observations of globular and open star clusters for the purpose of population studies

II (Scientific) Observations and evaluation of galaxies and nebulae for fine structure detail and infrared characteristics

III (Scientific) Comparison of IRISC observations with observations done by other instruments in the same wavelength band

IV (Technical) Construction of a thermal system suitable for maintaining and optimising operation of a near-infrared camera within the BEXUS environment

1.4 Experiment Concept

The experiment will be comprised of a telescope with baffle, a CMOS sensor, and a gimbal stabilisation system, which will work together to obtain long-exposure images of astronomical targets. The control system is responsible for selecting and tracking the astronomical targets using the position and orientation of the BEXUS gondola. It also stabilises the telescope during exposure using an active feedback control. Sensors include a gyroscope, accelerometer, GPS, and a compass/magnetometer, to ensure all vital information for finding and tracking targets is available to the control system. There will a verification system with an additional camera that can indicate poiniting errors if the images obtained by the NIR camera are not as expected. The thermal control system will ensure that an optimal operational temperature is maintained for the duration of the experiment.

1.5 Team Details

1.5.1 Contact Point

Project Manager

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Endorsing Professor

		Thomas Kuhn
	Title	Associate professor
	Address	Rymdcampus 1
		981 92
		Kiruna
		Sweden
	Email	thomas.kuhn@ltu.se

1.5.2 Team Members

The IRISC Team consists of twelve people of a number of different educational and personal backgrounds. All team members are currently studying at the Luleå University of Technology, Kiruna Space Campus.

Diego Octavio Talavera Maya - Management

Current Education: MSc in Space Sciences and Technology (SpaceMaster).

Previous Education: BSc in Aerospace Engineering at the Autonomous University of Baja California (UABC).

Responsibilities: Project Management.

Anja Möslinger - Control system

Current Education: MSc in Space Sciences and Technology (SpaceMaster).

Previous Education: BSc in Mechatronics at the Johannes Kepler University (JKU)

Responsibilities: Control system, Stabilisation system, Camera system

Eligius Franciscus Maria Weterings - Electrical

Current Education: MSc in Space Sciences and Technology (SpaceMaster).

Previous Education: BSc in electrical engineering at the University of Rotterdam (HR) with a specialization in computer sciences and mathematics at the University Utrecht (UU).

Responsibilities: Embedded systems, electrical engineering.

Kimberly Tuija Steele - Science and Optics

Current Education: MSc in Space Sciences and Technology (SpaceMaster).

Previous Education: BSc(Astronomy)(Hons) with a focus on radio astronomy research and instrumentation.

Responsibilities: experiment scientific background and overall objectives; defining experimental parameters; data and image analysis; documenting and publishing findings.

Veronika Haberle - Science

Current Education: MSc in Space Sciences and Technology (SpaceMaster).

Previous Education:

Responsibilities: Outreach & data analysis.

Adam Smialek - Control system

Current Education: MSc in Space Sciences and Technology (SpaceMaster).

Previous Education: BSC in Aerospace Engineering at Warsaw University of Technology (WUT) with a specialisation in Automatics and Flight Systems

Responsibilities: Onboard control system & Outreach.

Ajith Kumar Baskar - Mechanical

Current Education: Master Programme in Spacecraft Design

Previous Education: Bachelor of technology in Aerospace Engineering

Responsibilities: Mechanical engineering.

Jack Hooper - Mechanical

Current Education: MSc in Space Sciences and Technology (SpaceMaster)

Previous Education: Beng in Mechanical and Aerospace Engineering at the University of Adelaide (UoA).

Responsibilities: Optothermal analysis, thermal control systems.

Harald Magnusson - Software

Current Education: Master Programme in Space Engineering, Luleå University of Technology

Responsibilities: Software (onboard & ground station).

Niklas Ulfvarson - Software

Current Education: Master Programme in Space Engineering, Luleå University of Technology

Responsibilities: Software (onboard & ground station).

Sabina Björk - Electrical

Current Education: Master Programme in Space Engineering, Luleå University of Technology

Responsibilities: Energy technology, electrical engineering.

William Eriksson - Software

Current Education: Master Programme in Space Engineering, Luleå University of Technology

Responsibilities: Software (onboard & ground station).

2 Experiment Requirements and Constraints

A list of requirements and constraints are listed below. The requirements are separated in functional, performance, design and operational requirements.

2.1 Functional Requirements

F.1 The telescope shall successfully track the celestial bodies of interest.

F.2 The camera shall take images in the near infrared (NIR) spectrum.

2.2 Performance Requirements

P.1 The gimbal stabilization system shall point the telescope towards the celestial body with an accuracy of at least 1 arc seconds.

P.2 The optics shall be cable of making pictures of 0.5-1.5 x 0.3-1 degrees.

P.3 The NIR camera shall make images in the range of 720-850 to 1200 nm.

P.4 The NIR camera shall have a resolution of at least 16 MP.

P.5 The NIR camera shall be able to make images with exposure times between 0.5 and 150 seconds.

P.6 The experiment shall establish the location and orientation of the gondola.

P.7 The system shall be able to store all the obtained data on board

2.3 Design Requirements

D.01 The experiment shall be able to operate in the temperature profile of the BEXUS environment.

D.02 The experiment shall be able to operate in the pressure profile of the BEXUS environment.

D.03 The experiment shall be able to operate in the vibration profile of the BEXUS environment.

D.04 The absolute position of the telescope relative to the gondola shall be known with a accuracy of 0.1 degrees.

D.05 The supporting structure shall not twist by more than 0.1 degrees.

D.06 The telescope shall not be pointed within 27 degrees of the sun.

D.07 The experiment shall be able to fly during day and night.

D.08 The temperature of the NIR camera shall be held at $0 \pm 5\,^{\circ}\mathrm{C}$.

D.09 The images obtained shall be send to a ground station by the E-link system with a maximum data rate of 1000 kilo bits per second.

D.10 The experiment shall be mounted at the side of the gondola.

D.11 The experiment shall not consume more power than 250 Wh.

D.12 The volume of the experiment shall not exceed $0.11\,\mathrm{cm}^3$.

D.13 The mass of the experiment shall not exceed 20 kg.

D.14 The experiment shall be able to run for at least 2.5 hours.

D.15 The experiment should be able to run for at least 4 hours

D.16 The experiment shall be able to function autonomously.

D.17 The data stored in the experiment shall be able to survive the landing.

2.4 Operational Requirements

O.1 The experiment shall be able to be controlled by the ground station when requested.

O.2 The experiment shall rotate to a 'safe' location during ascent and descent.

2.5 Constraints

C.1 The shared E-link data transfer rates are limited by coverage and quality of reception.

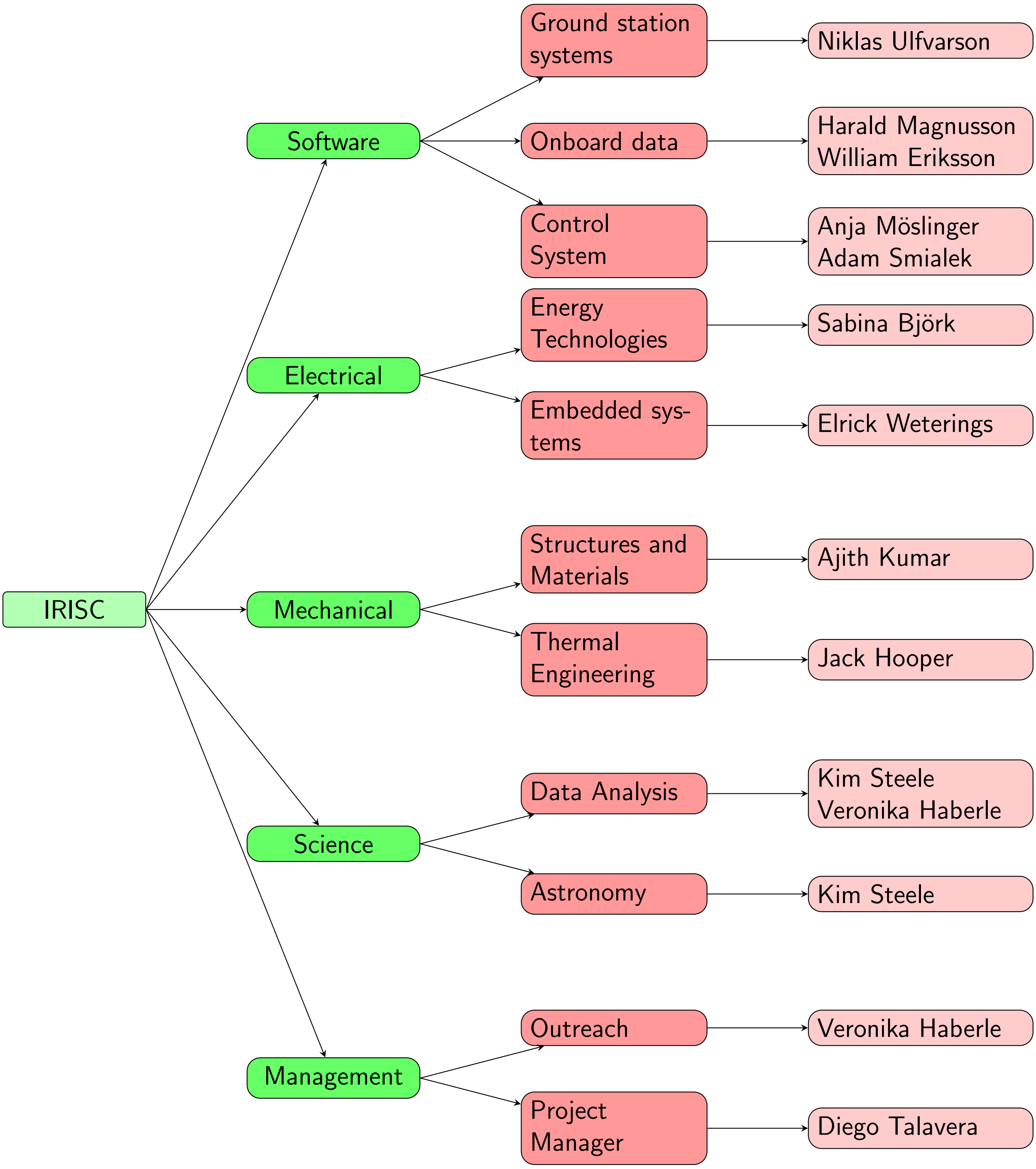
C.2 There shall be no direct internet connection on the ground station.

C.3 The mass and volume should fit inside the gondola together with the other experiments.

C.4 The budget for the experiment is limited by the generous companies and organizations that sponsor IRISC.

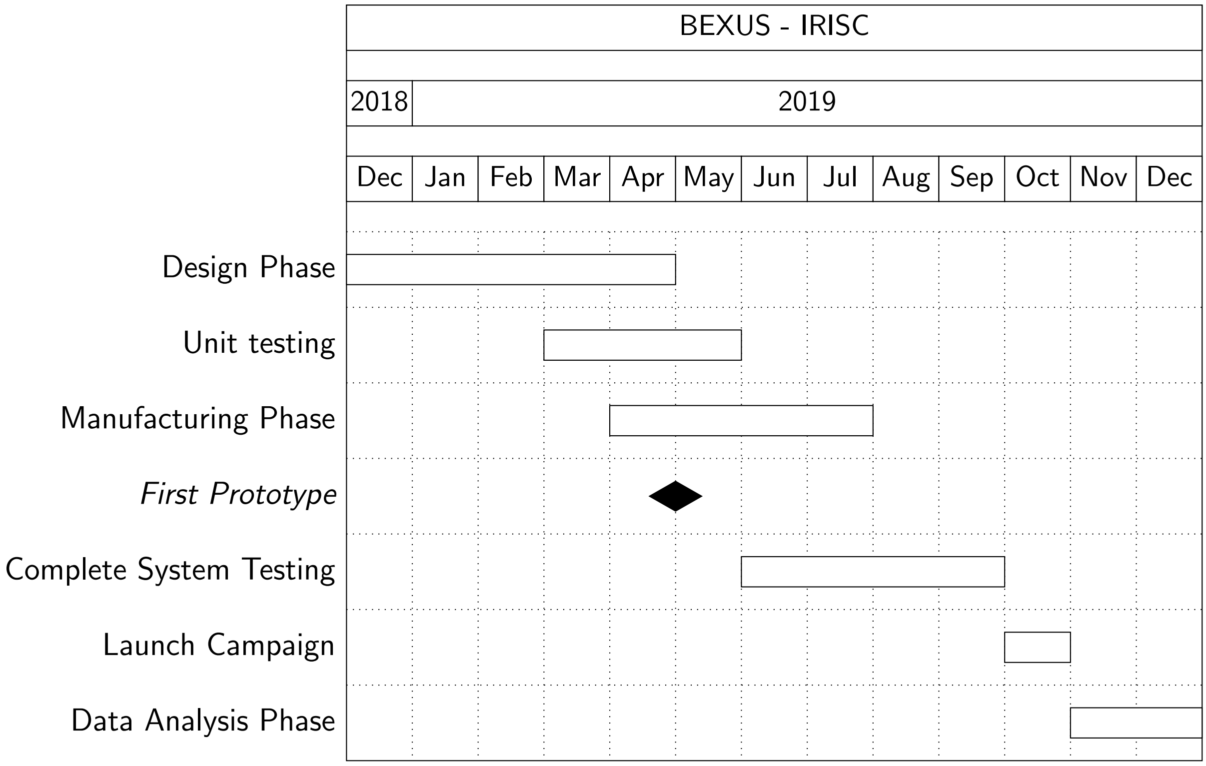
3 Project Planning

3.1 Work Breakdown Structure



The IRISC team is divided in 5 major branches: Management, Science, Mechanical Engineering, Electrical Engineering an Software Engineering. Diego Talavera will also work in the Mechanical Engineering branch whenever needed. The Electrical and Software Engineering branches will work closely together to achieve a correct integration between hardware and software.

3.2 Schedule



3.2.1 Manpower

This section will address the outline for the current available manpower of the IRISC team, this includes the tasks assigned to each member and the hours per week that each team member will dedicate to the project.

Team Member	Tasks Description	hours/week
Diego Talavera	**Team Manager**. Will be in charge of the management of the resources of the team and supervising the overall progress of the activities. Will also provide technical support to the Mechanical Engineering branch.	30-40
Veronika Haberle	**Outreach and data analysis**. Will be in charge of the outreach program development and implementation for the IRISC team as well as provide help with the data analysis after the BEXUS flight campaign.	10
Kimberly Steele	**Astronomy & Data analysis**. Will be in charge of the target selection and provide the technical requirements to achieve proper imaging of said targets. Will also be involved in the data analysis after the BEXUS flight campaign and as well as minor tasks for the outreach campaign.	30

Jack Hooper	**Thermal Engineering**. Will ensure that the thermal requirements for the proper functioning of the experiment during the ascent, flight and descent phases are met. This includes design and selection of active/passive heating and cooling where needed and recommendations regarding materials.	25
Ajith Kumar	. **Structures and Materials**His role will be the design of the structures of the experiment, including the geometry of the gimbal and mounting points of the setup to the gondola, as well as the material selection for the construction of the experiment.	20
Elrick Weterings	**Embedded systems**. Will be in charge of the design and selection for the electronic components including sensors and motors used to stabilize the telescope. Also he will be in charge of designing the necessary printed circuit boards (PCBs).	30
Sabina Björk	**Energy Technologies**. Will ensure that the power required is delivered to all the subsystems during all phases of the experiment.	25-35
Anja Möslinger	**Control System**. Will be the main responsible for the development and testing of the control loop necessary to stabilize the telescope to the required degree of accuracy.	30
Adam Smialek	**Control system**. Will help in the development of the control loop, including the code testing and implementation. He will also help with some tasks in the Outreach branch, like the fundraiser campaign.	20
Harald Magnusson	**Onboard data**. Will be in charge of the development of the software necessary by the experiment in order to function correctly, including data processing, handling and delivery.	30
William Eriksson	**Onboard data**. Will also be involved in the development of the software required on board of the experiment, this also includes data processing and handling, telemetry, etc.	30
Niklas Ulfvarson	**Ground Station System**. Will develop the software needed for monitoring and controlling (if needed) the experiment from the ground as well as to visualize the data received by the telemetry system. Will also help with the onboard software when required	30

3.2.2 Budget

Category	Total Mass [g]	Total Price [EUR]
Structure	3000	500
Electronics Box	2000	500
Telescope	5000	1500
Cables and Sensors		
Tools	–	TBD
Travel	–	TBD
Contingency	–	TBD
Total without Error Margin		**TBD**
Shipping Costs and Error Margin		
Total with Error Margin		**TBD**

Table 3.2.2: Mass and Cost Budget.

3.2.3 External Support

- Mr. Olle Persson. Will provide help with getting access to some testing facilities as well as potential questions in the Mechanical Engineering branch of the project.
- Adam Burgasser, PhD. Will help us with the data analysis and interpretation after the flight with BEXUS.
- LUDD - Luleå Academic Computer Society. They provide the hosting to the official IRISC web page.

3.3 Outreach Approach

An important focus of the project lays in the topic of outreach. During the whole timeline, updates about the project will be shared with as many people as possible. The most effective way of reaching people is via social media. IRISC is represented on the following social media platforms:

- facebook.com/IRISCBexus
- instagram
- twitter/IRISCBEXUS

Additionally to the social media platforms, the team's website with information about the project is available and updates are blogged there regularly.

Future outreach plans include, but are not limited to,:

- articles at university blog of the Luleå university of technology
- articles in local newspaper
- visibility through posters, flyers, etc at university
- presentations during local events

- applications to grants and awards

3.4 Risk Register

Risk ID

TC – Technical/Implementation

MS – Mission (operational performance)

SF – Safety

VE – Vehicle

PE – Personnel

EN – Environmental

OR - Outreach

BG - Budget

Adapt these to the experiment and add other categories. Consider risks to the experiment, to the vehicle and to personnel.

Probability (P)

A Minimum – Almost impossible to occur

B Low – Small chance to occur

C Medium – Reasonable chance to occur

D High – Quite likely to occur

E Maximum – Certain to occur, maybe more than once

Severity (S)

I Negligible – Minimal or no impact

II Significant – Leads to reduced experiment performance

III Major – Leads to failure of subsystem or loss of flight data

IV Critical – Leads to experiment failure or creates minor health hazards

V Catastrophic – Leads to termination of the REXUS/BEXUS programme, damage to the vehicle or injury to personnel

The rankings for probability (P) and severity (S) are combined to assess the overall risk classification, ranging from very low to very high and being coloured green, yellow, orange or red according to the SED guidelines.

Whether a risk is acceptable or unacceptable has been assigned according to the SED guidelines. Where mitigation is written for acceptable risks this details the mitigation undertaken in order to reduce the risk to an acceptable level.

ID	Risk (& consequence if)	P	S	P * S	Action
TC10	Optics and/ or camera destroyed due to testing	C	2	Low	There is budget for a spare part, it is quite easy to get and test where it will likely fail (e.g. drop test) will not be done with this part.
TC20	Optics and/ or camera destroyed due to looking directly into the sun	B	3	Low	A model will be made and sufficient testing will make sure that the probability gets very low.
TC30	Software failure	B	3	Low	A watchdog with power-on-reset will be added to the design.
TC40	Motors of the gimbal are uncontrollable	B	4	Low	It will be made sure that a single component failure will not result in this consequence.
TC50	Motors overloaded	A	3	Very Low	Sufficient testing and modeling will be done to decrease the probability.
TC60	PCB failure	B	3	Low	Sufficient testing will be done on each PCB to decrease the probability.
TC70	Single component failure gives unprecedented failure	B	4	Low	A Failure mode and effects analysis (FMEA) study will be done so that single failure components with a high impact will be documented and migrated.
MS10	Target not found	D	2	Low	The ground station will be able to correct this, or send the system to another target.
MS20	Damage to the system on landing	D	1	Low	Optics will move inside a frame for protection.
MS30	Damage to the storage unit on landing	C	2	Low	Data will be send over telemetry
MS40	Storage unit full during flight	A	3	Very Low	Sufficient modeling will be done to decrease the probability.
MS50	BEXUS balloon power failure	A	4	Very Low	-
MS60	BEXUS balloon telemetry failure	B	2	Very Low	The system will be able to function autonomously.
SF10	Components falling off the gondola	A	4	Very Low	All parts sufficiently fastened. Testing conducted to ensure fastening is able to hold all parts in place in case of turbulence. Where possible, add assurance by adding additional fixations.
VE10	Short circuiting	B	3	Low	A fuse is in the power system added.
VE20	Collision of telescope with landing mechanism	A	4	Very Low	The experiment will be inside a frame for protection.

PE10	Miscommunication in the team	B	2	Very Low	The management team should be responsible for ensuring proper information is conveyed to all team members.
PE20	People are not available	C	1	Very Low	An availability sheet is made so a planning can be made. This will be kept up to date during the entire project.
PE30	Management team unavailable to oversee project	C	1	Very Low	There is always someone as a backup.
PE40	Sudden resignation of project members	B	2	Very Low	Management team ensure morale remains high through a variety of techniques (group building activities).
EN10	Rays focused on someone due to damage to the telescope (camera)	A	4	Very Low	Calibration of telescope set properly so that rays do not get misguided

Table 3.4.1: Risk Register.

4 Experiment Design

4.1 Experiment Setup

The experiments mounts a telescope with an attached CMOS sensor inside the gondola, looking out as shown in figure 4.1.1. The telescope is mounted on a gimbal system that provides stabilisation along two axis (three if required, depending on simulation results, hardware is available) and tracking in three dimensions. The sensor/telescope/gimbal system will be shielded from the Sun's radiation and climatized in order to provide the required operation temperatures. This is achieved by using Peltier elements where heating or cooling may be necessary (e. g. the sensor) and heating pads where there is only a chance of freezing (e. g. the moving parts of the gimbal). The general setup with data flows can be seen in figure 4.1.4. The individual sections of the experiment are described below.

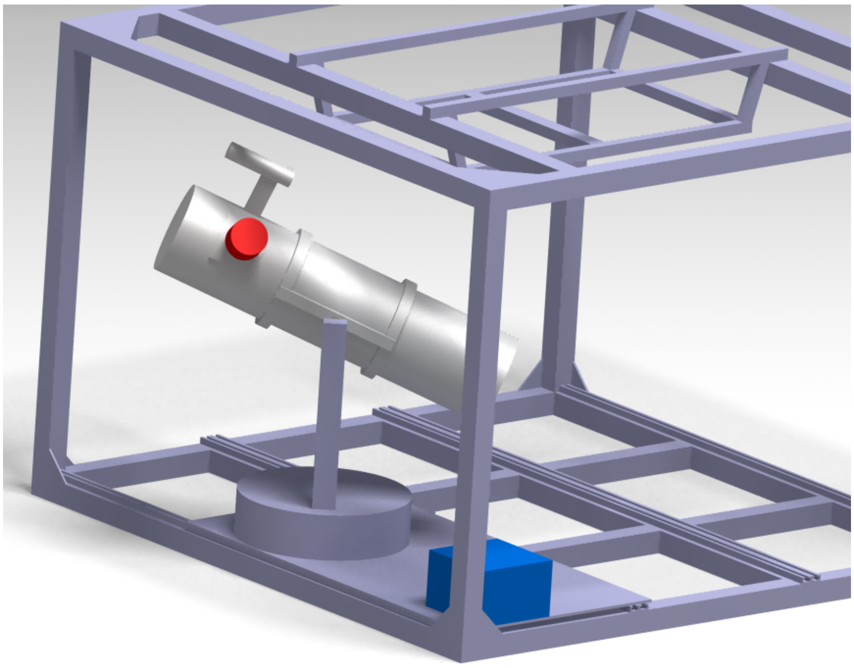


Figure 4.1.1: CAD-model of the experiment

4.1.1 Telescope and CMOS sensor

The telescope chosen is a Sky-Watcher BKP 130 DS (see figure 4.1.2), a parabolic newtonian reflector with a focal length of 650 mm, an optical diameter of 130 mm and therefore featuring an aperture ratio of $f/5$.

The imaging sensor used is ZWO ASI183MM (mono) (see figure **??**), a CMOS sensor with only one channel (mono, not color) with a resolution of 20.18 MP (5496x3672), a sensor size of 13.2x8.8 mm (diagonal: 15.86 mm) and a pixel size of 2.4x2.4 μm. To limit the wavelength bandwidth imaged, an IR filter that filters out any wavelengths below 720 nm is used in order to use the sensor as a NIR camera.

This combination of telescope and sensor features the following specifications:

- **Field of View (FoV):** the field of view determines the astronomical targets that can be

Figure 4.1.2: Sky-Watcher BKP 130 DS

Figure 4.1.3: ZWO ASI183MM (mono) [?]

observed. It depends on the sensor size and the focal length of the telescope. Naturally, there is a horizontal, a vertical and a diagonal field of view:

$$\mathsf{FoV}_{\mathsf{horizontal}} = \arctan\frac{13.2\,\mathsf{mm}}{650\,\mathsf{mm}} = 1.16° \tag{1}$$

$$\mathsf{FoV}_{\mathsf{vertical}} = \arctan\frac{8.8\,\mathsf{mm}}{650\,\mathsf{mm}} = 0.757° \tag{2}$$

$$\mathsf{FoV}_{\mathsf{diagonal}} = \arctan\frac{15.86\,\mathsf{mm}}{650\,\mathsf{mm}} = 1.382° \tag{3}$$

- **Sensor resolution:** the angular resolution per pixel defines the precision of the scientific data collected.

$$\text{Resolution} = \arctan\frac{2.4\,\mu\mathsf{m}}{650\,\mathsf{mm}} = 0.7616'' \tag{4}$$

In order to examine the field of view in case the images sent down via downlink do not show the expected astronomical targets, an additional imaging sensor is installed on a guiding telescope that has a shorter focal length than the main telescope, implying a larger field of view. With the help of these pictures it will be able to correct offset errors in the pointing mechanism of the control system due to e. g. temperature drift of the sensors. In addition to this a small sanity camera with a wide angle lens (very large field of view) to keep track of the system status and detect possible errors if neither the NIR images nor the images from the guiding telescope show the expected results may be installed (not included in figures 4.1.1 and 4.1.4).

4.1.2 Electronics

The On-Board Computer is hosted by the electronics box that also features the onboard storage as well as the power supply unit, one set of gyroscopes and accelerometers to measure the movement of the gondola in order to provide input data to the control system, a GPS (for the control system), temperature sensors for housekeeping data and the heat management system inside the electronics box and heating elements. The sensors are located on a PCB designed by the electronics team, along with the power supply unit. In order to minimise disturbances by the power electronics and actuators, the gyroscopes are housed by a separate gyro-box that is shielded by a metal housing.

The CMOS sensor data is transmitted to the On-Board Computer where it is compressed with lossless compression and sent down via E-link and is also stored onboard the BEXUS balloon. The onboard storage is located in the electronics box that is designed considering compatibility

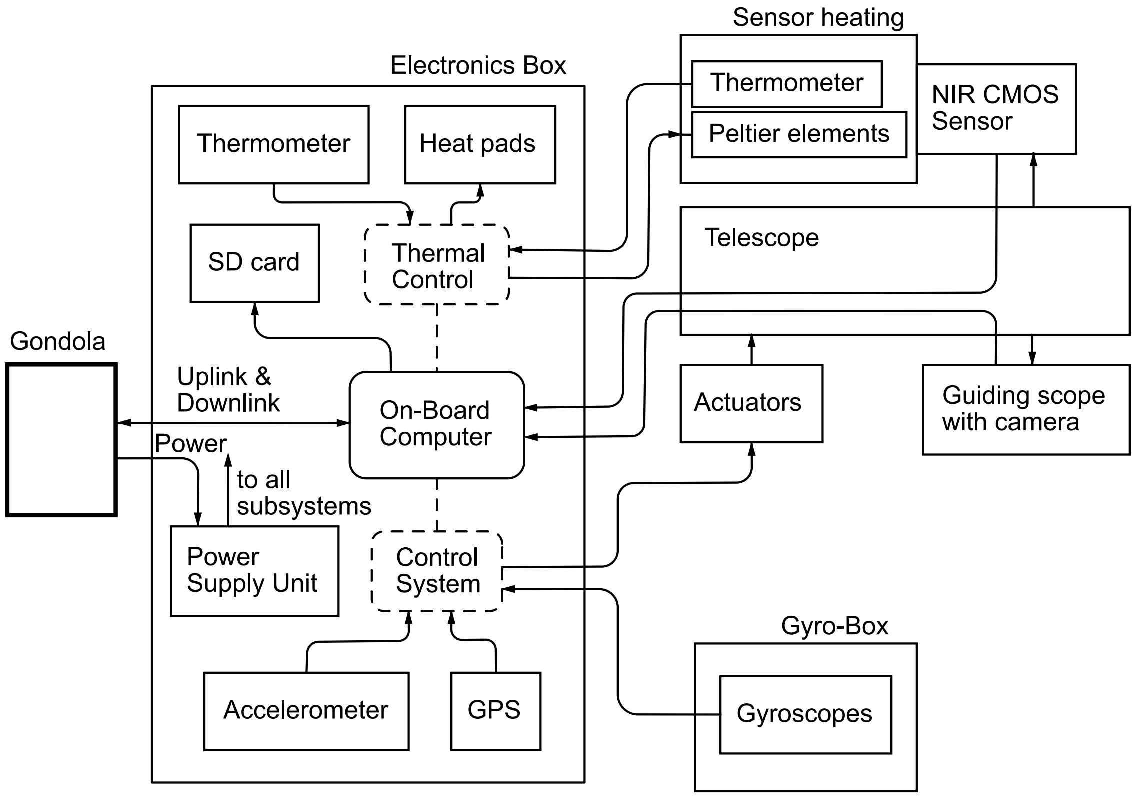


Figure 4.1.4: Block diagram of the experiment setup

with the harsh environmental conditions as well as redundancy. The mechanical structure that features the onboard storage ensures survival in case of shock due to hard impact when landing or if the BEXUS balloon lands in a lake or wetlands.

4.1.3 Control system

The control system is responsible for tracking the target in the sky and stabilising the telescope during exposure. The tracking uses the current orientation of the gondola along the z-axis measured by a magnetometer as well as the orientation of the telescope within the gondola using encoders. Based on the current time and position (measured by the GPS system) as well as the operational field of view, the control system will select and track the target in order to point the telescope towards the astronomical targets and avoid star trails due to the sky's rotation as seen from an observer on Earth. The stabilisation system is responsible for keeping the telescope steady during exposure by counteracting the gondola movements measured by the gyrometers and accelerometers located on the sensor PCB in the electronics box.

4.2 Experiment Interfaces

4.2.1 Mechanical Interfaces

The experiment mounting platform will be attached to the upper rails of the gondola.

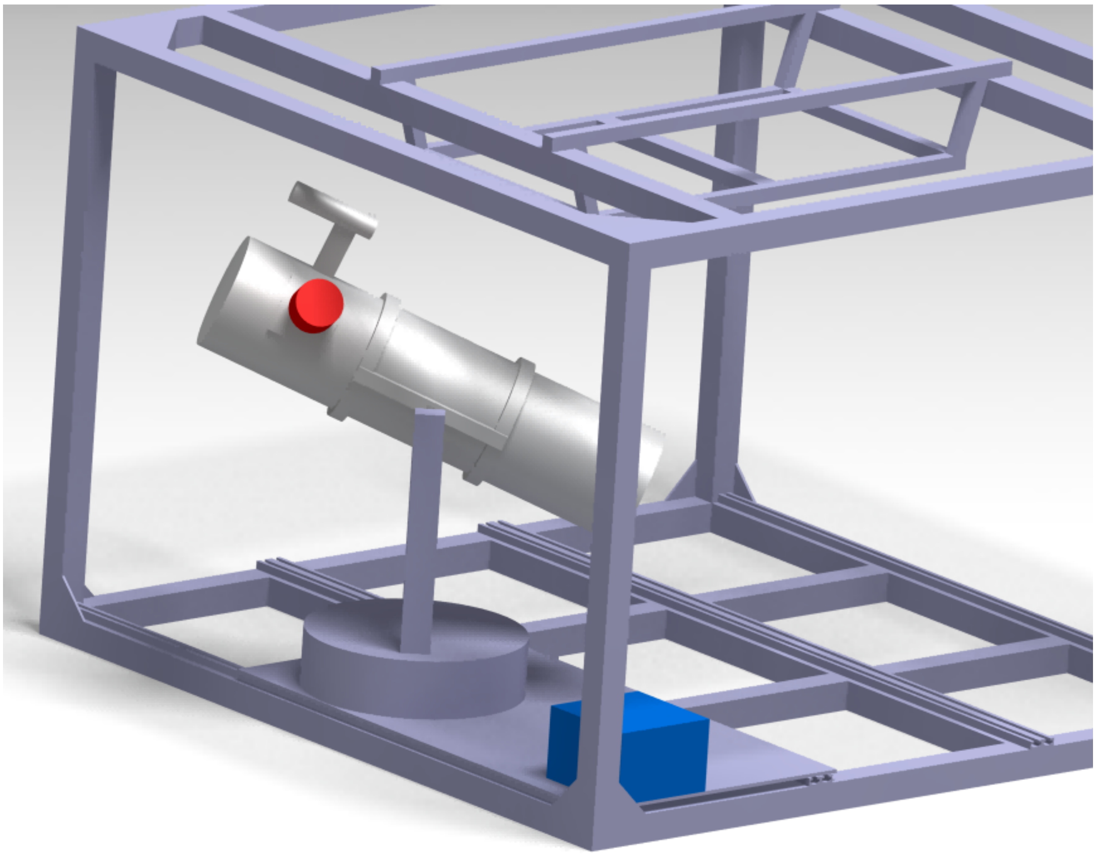


Figure 4.2.1: Instrument position on gondola

4.2.2 Thermal Interfaces

The IRISC experiment will be shielded from heat sources that could potentially introduce noise to the measurements. Once the final selection of components is made, Finite Element Analysis will be used to optimize the configuration of the components to ensure a good system performance.

4.2.3 Electrical Interfaces

E-link:
The uplink will be used to send occasional commands to control the experiment. One command will be [TBD] in size. The TCP/IP protocol will be used for uplink, so the total size of one transmission will be the data plus the TCP header (maximum 480 bits), the IP header (maximum 480 bits) and the Ethernet frame (144 bits).

$$bits\, per\, uplink\, packet \leq [TBD] + 480 + 480 + 144$$

The downlink will be used to send science and housekeeping data to the ground station. The data in the downlink packet is estimated to be [TBD]. For downlink, UPD protocol will be used, as the reliability of the data is not as crucial as during the uplink and to compensate for the size of the data packet. The total size of one packet will be the data plus the UDP header (32 bits), the IP header (maximum 480 bits) and the Ethernet frame (144 bits).

$$bits\,per\,downlink\,packet \leq [TBD] + 32 + 480 + 144$$

Power:

Power will be delivered to the electric box from the provided 28.8 V/1 mA (13 Ah) battery pack. Only one pack is required. The expected minimum current is [TBD], the average is [TBD] and the maximum is [TBD]. More details in 4.7.

Connectors:
The power cable are attached as it can be seen on Figure **??**, and the E-link cables are attached as on Figure **??**.

4-experiment-design/img/interfaces/power_cables

Figure 4.2.2: [PLACEHOLDER] Position of power cable socket

4-experiment-design/img/interfaces/elink_cables

Figure 4.2.3: [PLACEHOLDER] Position of E-link cable socket

Info about power cables, their length/resistivity and thus power loss, their connection to gondola power relay.

Connectors:

Protection:

Grounding:

4.2.4 Radio Frequencies (Optional)

4.3 Experiment Components

4.3.1 Electrical Components

Table 4.3.1 shows all required electrical components with their total mass and price.

ID	Component Name	Supplier	Supplier Code	Qty	Mass Each [g]	Cost Each [EUR]	Note	Status
E001	Raspberry Pi 3B+	TBD	TBD	1	50	TBD		Defined
E002	Micro SD 32GB	TBD	TBD	1	0.27	TBD		Defined
E003	DC motor	TBD	TBD	3	TBD	TBD		Defined
E004	Encoders/potentiometers	TBD	TBD	1	TBD	TBD		Defined
E005	Buck Converter	TBD	TBD	1	TBD	TBD		Defined
E006	Gyroscope	TBD	TBD	2	TBD	TBD		Defined
E007	Magnetometer	TBD	TBD	1	TBD	TBD		Defined
E008	GPS	TBD	TBD	1	TBD	TBD		Defined

Table 4.3.1: Electrical components.

4.3.2 Mechanical Components

Table 4.3.2 shows all required mechanical components with their total mass and price.

ID	Component Name	Supplier	Supplier Code	Qty	Mass Each [g]	Cost Each [EUR]	Note	Status

Table 4.3.2: Mechanical components.

4.3.3 Other Components

Table 4.3.3 shows other components which contribute to the mass and/or price.

ID	Component Name	Supplier	Supplier Code	Qty	Mass Each [g]	Cost Each [EUR]	Note	Status
O001	ASI183mm	TBD	TBD	1	140	TBD	Mono color camera	Defined
O002	TBD	TBD	TBD	1	TBD	TBD	Guiding camera	Defined
O003	TBD	TBD	TBD	1	TBD	TBD	Sanity camera	Defined
O004	130PDS telescope	TBD	TBD	1	3660	TBD		Defined
O005	NIR filter 1.25”	TBD	TBD	1	TBD	TBD		Defined

Table 4.3.3: Other components.

4.4 Mechanical Design

4.4.1 Structure

The experiment itself has only two components that are placed inside the Gondola. Firstly, the electronic box and then the gimbal on which the telescope is mounted. We require the gimbal to be placed at the edge of the Gondola so that we will be able to perform rotating mechanism that pops the telescope out of the gondola while operation.

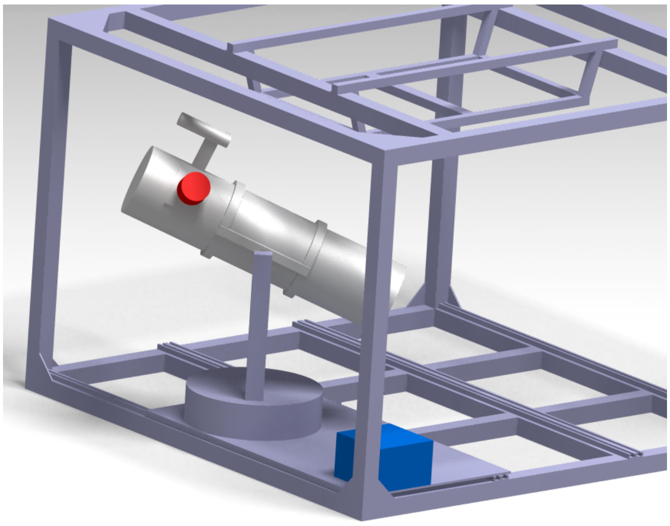


Figure 4.4.1: Gimbal structure

4.4.2 Electronic box

The electronic box has a dimension 10x10x10 cm which is placed directly inside the gondola. It is estimated to weigh 1.5 kg. The box is made of aluminium side plates with a thick layer of styrofoam placed on the inside of the aluminium plates which protects the electronics. The box has rubber cusion feet that acts as a shock absorber and also thermal insulator from the gondola.

4.4.3 Gimbal

We intend to use a three axis gimbal so we have a maximum field of view. We use CFRP to manufacture the gimbal. The gimbal along with telescope is estimated to weigh around 10kg.

4.4.4 Fixing interface

The telescope itself has certain fixture points. So,we make the gimbal with matching fixture points. The gimbal is directly fixed on the gondola. The gimbal along with the fixing points will first be tested with Finite Element Analysis (FEA) in order to ensure that the whole structure can withstand the loads indicated in the BEXUS manual.

4.5 Electrical Design

4.5.1 Block Diagram

The architecture of the electrical design is shown in figure 4.5.1.

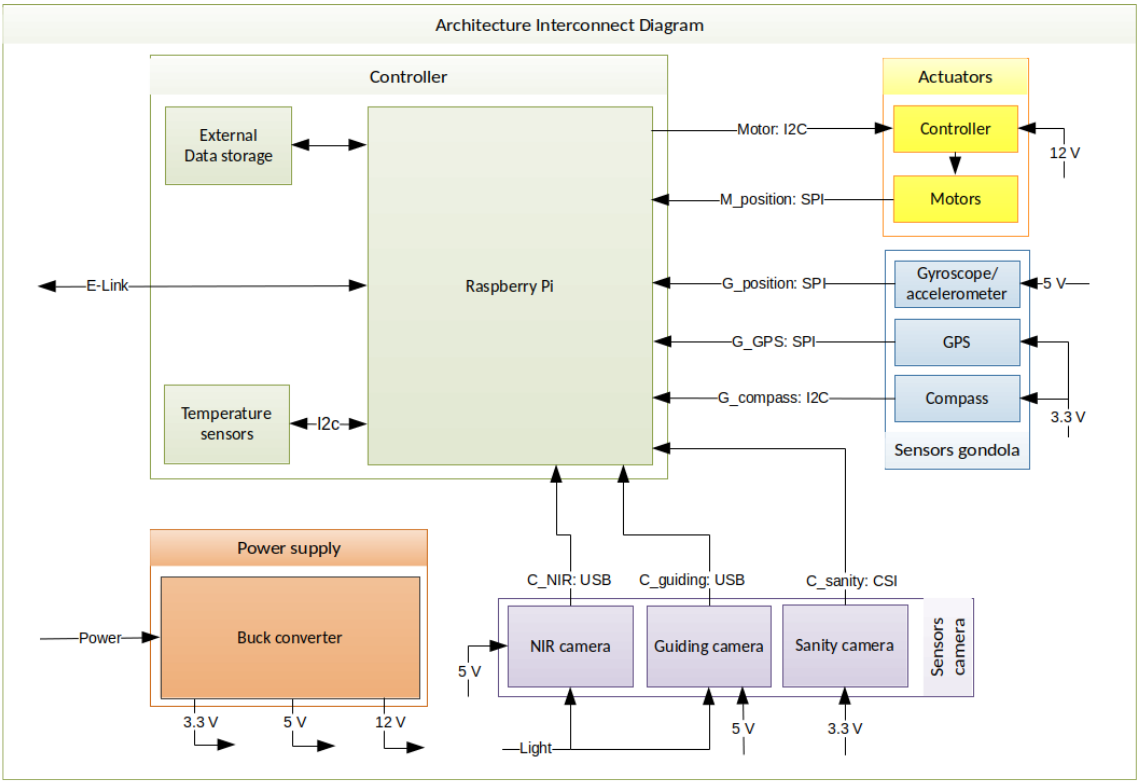


Figure 4.5.1: An architecture diagram of the electronics.

4.5.2 Schematic

See Appendix c.

4.5.3 PCB Layout

There will be three PCB:s, which are listed below:

- Power system & Motor control
- Gyroscopes
- Sensors

The two PCB:s, Power system & Motor control and Gyroscopes, will be located in the main electrical box. They will be placed on top of each other.

While the third PCB will be placed in its own second electrical box. Because this PCB includes the sensors as GPS, accelerometers and magnetometer. Thus the PCB should not be too close to the other PCB:s or the DC motors due to disturbances, such as for example magnetic field changes. The schematics of all the PCB:s can be found in appendix C.

4.6 Thermal Design

4.6.1 Optothermal considerations

In order to ensure minimise measurement error in acquiring photographs, the effect of temperature on the optics must be considered, and the temperature must be controlled if needed to ensure that the error is within an acceptable range.

SNR Dark current is small residual currents that are present in the camera, generated irrespective of whether there is incident illumination. This dark current becomes present in the data in the form of random noise that is not trivial to subtract. By decreasing the operating temperature of the camera optics, the magnitude of dark current can be minimised and the signal to noise ratio increased. This relationship between signal to noise ratio and dark current is as follows

$$SNR = \frac{I \times QE \times t}{\sqrt{I \times QE \times t + Nd \times t + Nr^2}}$$

I = Photon flux (photons/pixel/s)
QE = Quantum efficiency
t = Integration time (s)
Nd = Dark current (electrons/pixel/s)
Nr = Read noise (electrons)

The ASI183 camera is specified as having a read noise of 1.6e @30db gain and a QE peak of 84%. The camera also has the following relationship between dark current and sensor temperature. Calculations will be considered for an exposure time of 300s, which is the longer intended exposure time for higher quality imaging.

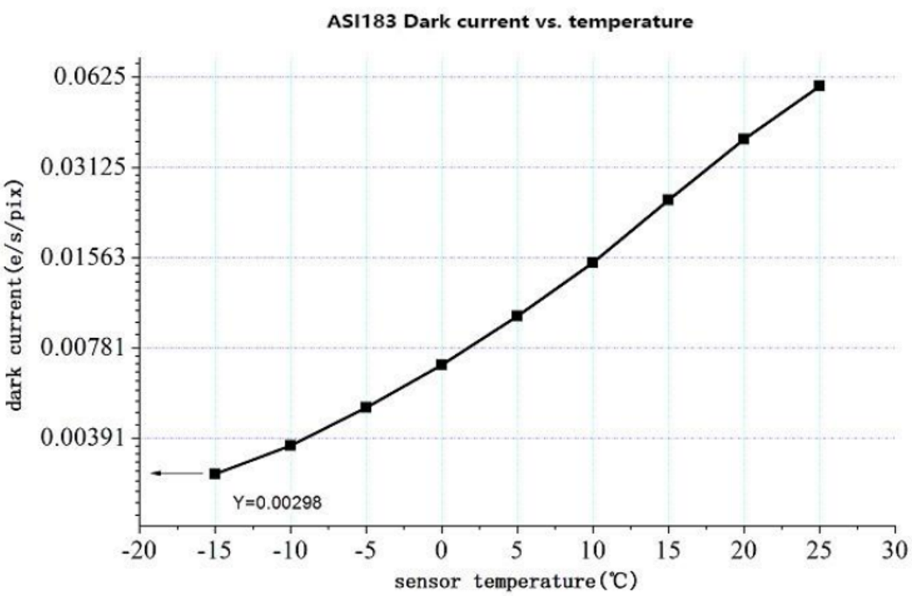


Figure 4.6.1: Dark current through the camera at various temperatures.

As an example, the SNR as affected by dark current at -10 °C versus 10 °C is

$$\text{SNR(-10 °C)} = \frac{(6.16\,\text{photons/pixel/sec})\times(0.84)\times(300\,\text{s})}{\sqrt{(6.16\,\text{photons/pixel/s})\times(0.84)\times(300s)+(0.003\,91\,\text{e/pixel/s})\times(300\,\text{s})+(1.6\,\text{e})^2}}$$

SNR(-10 °C) = 39.35

$$\text{SNR(10 °C)} = \frac{(6.16\,\text{photons/pixel/sec})\times(0.84)\times(300s)}{\sqrt{(6.16\,\text{photons/pixel/s})\times(0.84)\times(300\,\text{s})+(0.015\,63\,\text{e/pixel/s})\times(300\,\text{s})+(1.6\,\text{e})^2}}$$

SNR(10 °C) = 39.31

Optothermal stability Another important effect will be the how thermal stresses and subsequent deflections can affect the optics of the camera, in particular the index of refraction, and hence the quality of the collected data. Variation of solar flux over the time of flight and from the heat signatures of the BEXUS module will need to be considered. A thermoelastic analysis should be conducted in finite element analysis software to evaluate the effects of the thermal environment, and the implication of those results on the validity of the data should be investigated.

Condensation Condensation may occur if air heated by the camera heating elements is able to condensate on the cold surfaces of the optics. This will deteriorate the quality of the detections and must also be mitigated.

4.6.2 Thermal environment

Atmosphere ambient conditions IRISC will ascend to and float in the stratosphere at an altitude of between 25 and 30 km, after which it will experience altitude fluctuations of no more than 200 m. This is the phase of flight during which the infrared camera will be operational and hence thermal control most necessary in ensuring sound optical performance. This part of the atmosphere is also characterised by relatively low temperatures. Based on the flights of number previous BEXUS missions seen in the graph of the atmosphere, it can be assumed that the atmospheric temperature during float will range between -70 °C and -50 °C.

Flight phase	Expected temperature	Duration
Preparation	15 – 25 °C	4 hours
Launch pad wait	-15 – 0 °C	3 hours
Ascent phase	-80 – 0 °C	1.5 hours
Float phase (25-30km)	-70 – -50 °C	1 – 5 hours
Descent phase	-80 – 0 °C	30 minutes
Post-flight phase	-15 – 0 °C	1 – 2 days

Solar flux The extent of solar irradiance is characterised by several factors, including the sun's height above the horizon, typically low for the polar latitudes that the balloon will be flying at, and the height in the atmosphere and atmospheric conditions, which will cause absorption and scattering of light.

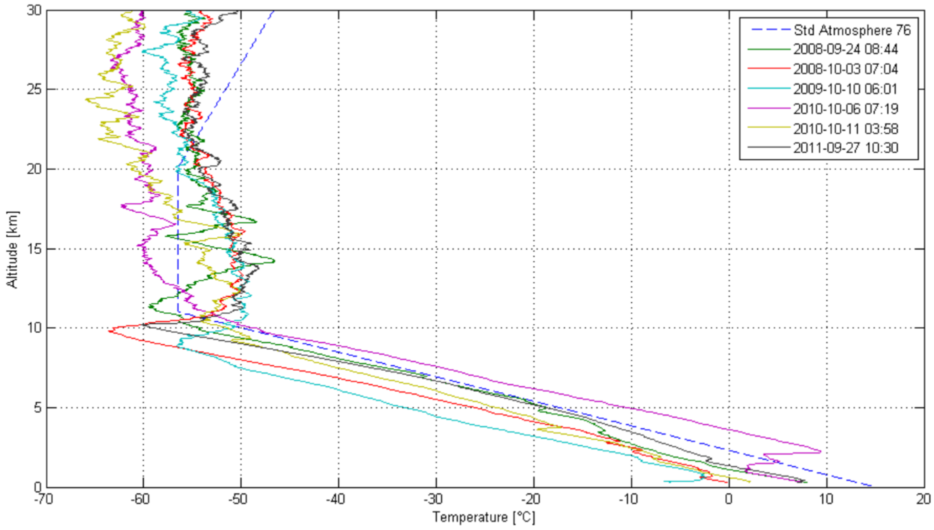


Figure 4.6.2: Temperature profile of the atmosphere.

The total solar irradiance, neglecting atmospheric effects, at the Esrange latitude of 68° and assuming a launch date of the 15th of October is demonstrated in the following graph of direct solar radiation, with a peak of 500 kW/m^2 at noon.

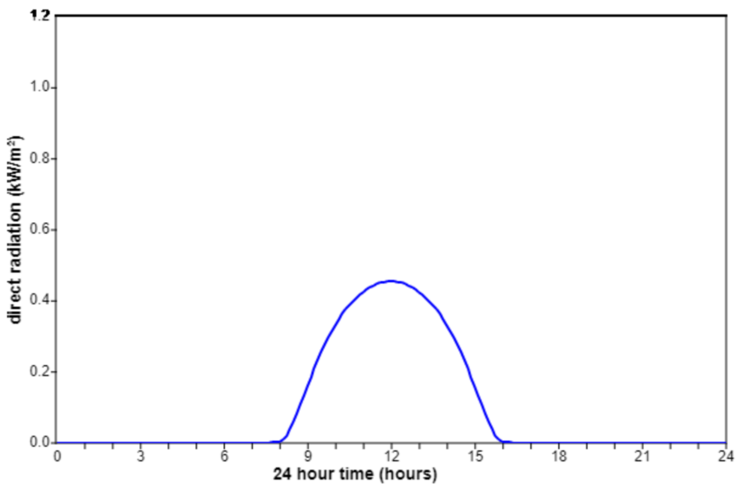


Figure 4.6.3: Estimate of direct solar radiation at the top of the atmosphere.

The degree of attenuation of solar radiation through the atmosphere can be described using the Beer–Lambert law, which relates the transmittance of radiation to optical depth. For an atmosphere with properties that change exponentially with respect to altitude, the optical depth can be estimated to also change exponentially with respect to altitude.

4.6.3 Temperature requirements

Component	Operating temperature
ASI183 camera	-5 – 45 °C
Camera module for Raspberry Pi 5MP 1080P	-20 – 80 °C
Igarashi DC Gearmotor 33GN2738-132-GV-5 312:1	0* – 60 °C
GYRO / ACCELEROMETER 3-AXIS MPU-3050	-20 – 105 °C
Electronics	-5 – 60 °C

*0 °C required to prevent condensation and subsequent freezing on the motors

As the ambient conditions are likely to be very cold, many of the components will need to be heated so that the electronics are able to operate. If the ambient conditions are assumed to be -70 °C, and the desired temperature for the components of 0 °C, heating will be needed to increase the temperature of components by up to 75 °C, a tolerance of 5 °C below the minimum operating temperature for the motors.

4.6.4 Thermal control

In order to heat the electronics to the desired temperature, Polyimide Thermofoil Heaters supplied by Minco can be used, as they are lightweight, and commonly used to protect electronics from cold at high altitudes. A heater will be supplied for each of the three motors, for the camera, and for the electronics box. The heaters can be used to generate temperatures of up to 200 °C. Temperature sensors will be included next to the heaters to provide feedback that will allow the temperature to be controlled to the desired operating point.

The motor is 37.8 mm long with a diameter of 33 mm, so the 5572 heater with dimensions 12.7 mm x 12.7 mm and a resistance of 26.5 Ω is selected.

$$P = \frac{5\,\mathrm{V}^2}{26.5\,\Omega} = 0.95\,\mathrm{W}$$

The camera is 73.5 mm long with a diameter of 78 mm, so the 5587 heater with dimensions 31.8 mm x 31.8 mm and a resistance of 13.1 Ω is selected.

$$P = \frac{5\,\mathrm{V}^2}{13.1\,\Omega} = 0.95\,\mathrm{W}$$

The electronics box is 100 mm x 100 mm x 100 mm, so the 5592 heater with dimensions 44.5 mm x 44.5 mm and a resistance of 26.3 Ω is selected.

$$P = \frac{5\,\mathrm{V}^2}{26.3\,\Omega} = 0.95\,\mathrm{W}$$

4.7 Power System

A 28.8V (13 Ah) battery package can be provided by the gondola, according to the BEXUS user manual. One constrain is that the continuous maximum current is 1.8 A. Thus buck-converters will be needed to step down the voltage, while stepping up the current, so that the power needed will be delivered to the instrument. The voltage levels of the buck converters are:

- 28.8 V –> 3.3 V, with the power 1.65 W.
- 28.8 V –> 5 V, with power 15 W.
- 28.8 V –> 12 V, with power 15 W.

A schematic of the power system can be found in the appendix C.

The estimated power consumption of the components are shown in table 4.7.

Component Name	**Supply Voltage [V]**	**Input Current [A] (MAX)**	**Power [W] (MAX)**	**Quantity**
Raspberry Pi CM3 Lite	5	2	10	1
DC Motors	12	0.35	4.2	3
Gyroscope	3.3	6.1m	0.02013	2
Magnetometer	3.3	8m	0.0264	1
GPS	3.3	10m	0.033	1
Encoders	5	8m	0.04	2
Heater Motors	5	0.188	0.94	3
Heater Camera	5	0.382	1.91	1
Heater Electronics	5	0.19	0.95	1
Camera	5	0.3	1.5	1
Sanity Camera	3.3	0.25	0.825	1
Guiding Camera	5	0.3	1.5	1
Accelerometer	3.3	0.000155	0.000558	1
Temperature sensors	3.3	1.5m	0.00495	5
Buck Converter 3.3V	28.8	0.5(output)	0.18333	1
Buck Converter 5V	28.8	5(output)	6.25	1
Buck Converter 12V	28.8	1.25(output)	3.75	1
TOTAL	-	**4.946855**	**38.0099545**	

Table 4.7.1: The estimated power consumption of the components in active mode.

The BEXUS manual recommends the instrument to be prepared to have power supplies for 2 hours of testing, 2 hours on ground and for a flight time of 6 hours as a minimum. The instrument therefore needs to be in active mode for at least 8 h, because on ground the instrument will be in sleep mode. The instrument will also be in sleep mode for ascending and descending of the gondola.

The total estimated power for the instrument:

- Active mode: 38.02 W –> 304 Wh (8h)
- Sleep mode: 15 W –> 45Wh (3h)

Thus the instrument will require at least 349 Wh. The maximum power provided by the gondola will be 375 Wh, which should satisfy the instruments needs.

4.8 Software Design

4.8.1 Purpose

The purpose of the On-Board Software consists of:

- Controlling the tracking and choosing of targets to observe.
- Ensuring that the camera is not oriented towards the sun.
- Reading data from sensors and controlling actuators when needed.
- Processing and storing images taken by camera.
- Logging housekeeping data.
- When possible, send images and housekeeping data to ground station.

4.8.2 Design

a) Process Overview

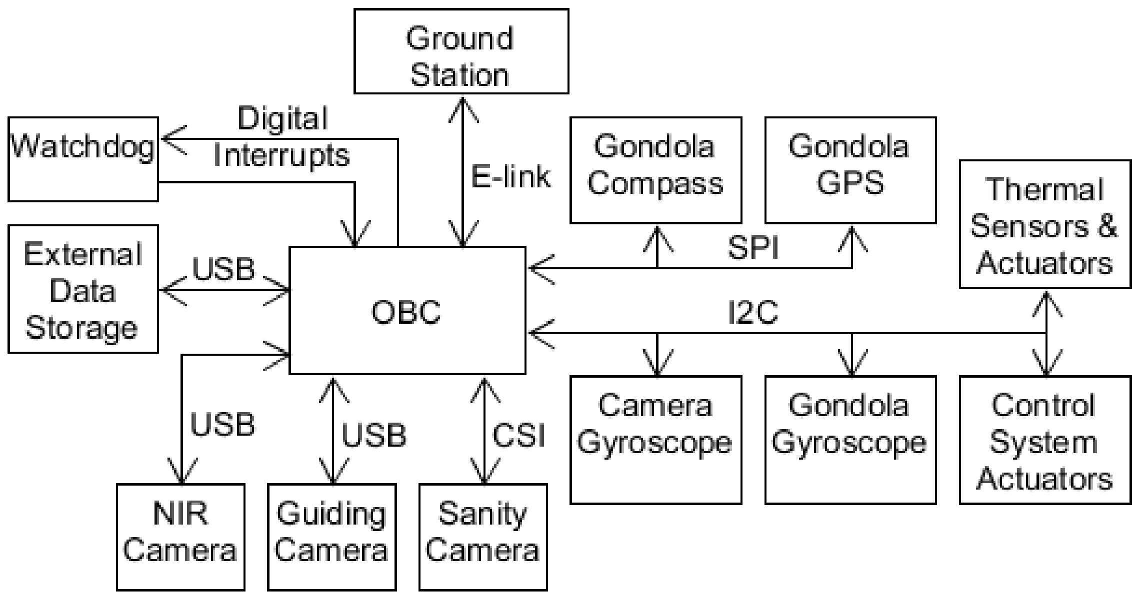


Figure 4.8.1: Relations between On-Board Computer and connected components.

All external components connected to the On-Board Computer and their interface are displayed in figure 4.8.1.

b) General and safety related concepts

To ensure that the software is not erroneous rigorous testing will be done during development and after completion. A watchdog timer will be used to avoid software freezing. This timer will reset the On-Board Computer if it is not itself reset by the software within a certain period.

c) Interfaces

If connection to ground is available, images compressed with a lossless compression will be sent down over the E-link over the course of the experiment. If the storage were to fail on touchdown for any reason, this would mean that not all data is lost.

Component	Interface
Ground Station	E-link
External Data Storage	USB
NIR Camera	USB
Guiding Camera	USB
Sanity Camera	CSI
Watchdog	Digital Interrupts
Gondola GPS	SPI
Compass/Magnetometer	SPI
Gondola Gyroscope	I2C
Camera Gyroscope	I2C
Controller Actuators	I2C
Thermal Sensors & Actuators	I2C

Table 4.8.1: Table showing the interface that each external component is connected with. This is also visually represented in figure 4.8.1.

d) Data acquisition and storage

The main bulk of data handled is the images taken by the camera. Housekeeping data such as positioning, camera direction, time, etc will also be stored along with the images.

As the camera has a resolution of $5496 * 3672$ and a colour depth of 12 bits, the raw image size will be 30.27 MB. For a 4 hour float phase and an exposure time of 30 s a total of 14.53 GB is required in on-board data storage for the images.

With a maximum of 1 Mbit per second data transfer rate to ground it takes at least 145.5 s to transfer one image compressed losslessly to 60 % of original size. This means that with little down time between observations and for most exposure times, not all images can be transmitted to ground.

e) Process Flow

Pre-launch tests shall be conducted to ensure that all systems work as expected. Afterwards the system shall enter a sleep mode with the camera in a safe launch position. When the float phase is reached, the system will wake. After wake-up the system shall find its orientation and the position of the sun. Finally tracking and observation can start.

Astronomical targets are prioritised. The software shall track and observe the highest priority target within the field of view with varying camera settings until one of the following events happen:

- Current target leaves operational field of view.
- Target moves too close to the sun for observation.
- A higher priority target enters the field of view.

If one of the aforementioned events happen, the software will switch current target following prioritisation. While observing targets, the On-Board Software shall store images and housekeeping data. If connection to ground is available this data shall be compressed using a lossless compression method and sent to ground.

At the end of the floating phase the camera shall be oriented in a landing position and the system shall shut down. Figure 4.8.2 shows the complete process flow. Figure 4.8.3 shows a simple state diagram for the experiment. Observations are done in the Normal state. In the rare case of a software freeze, it will be reset without entering sleep mode.

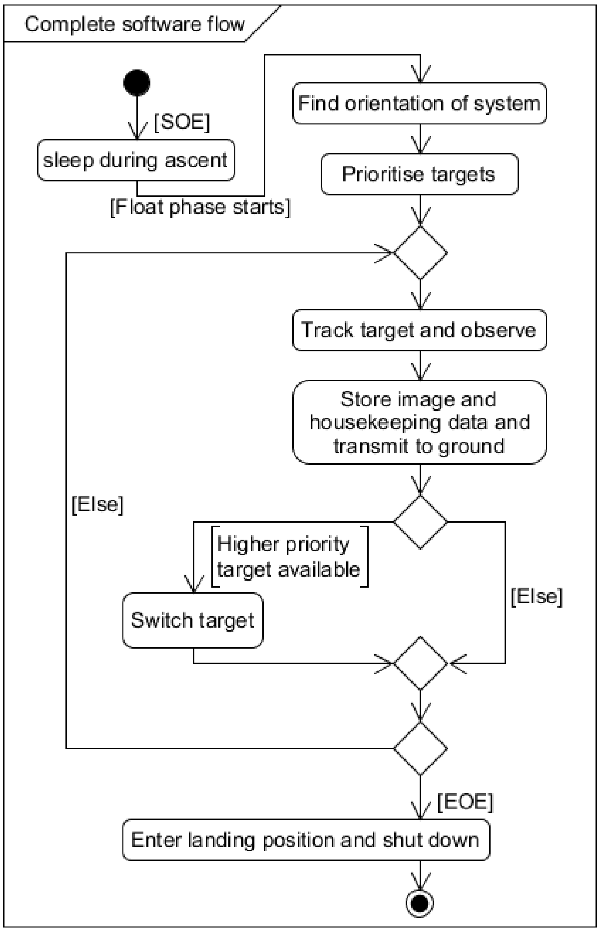


Figure 4.8.2: Activity diagram describing the complete software flow.

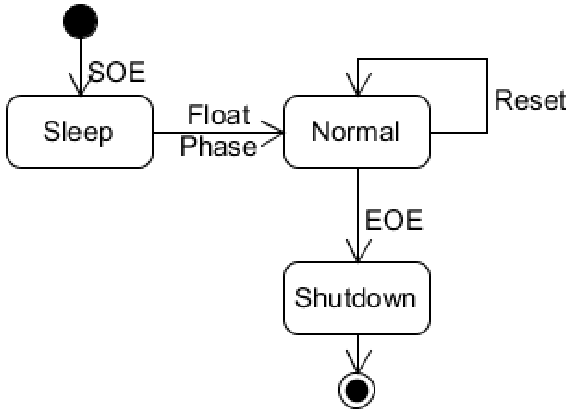


Figure 4.8.3: State diagram for On-Board Software

f) Modularisation and pseudo code

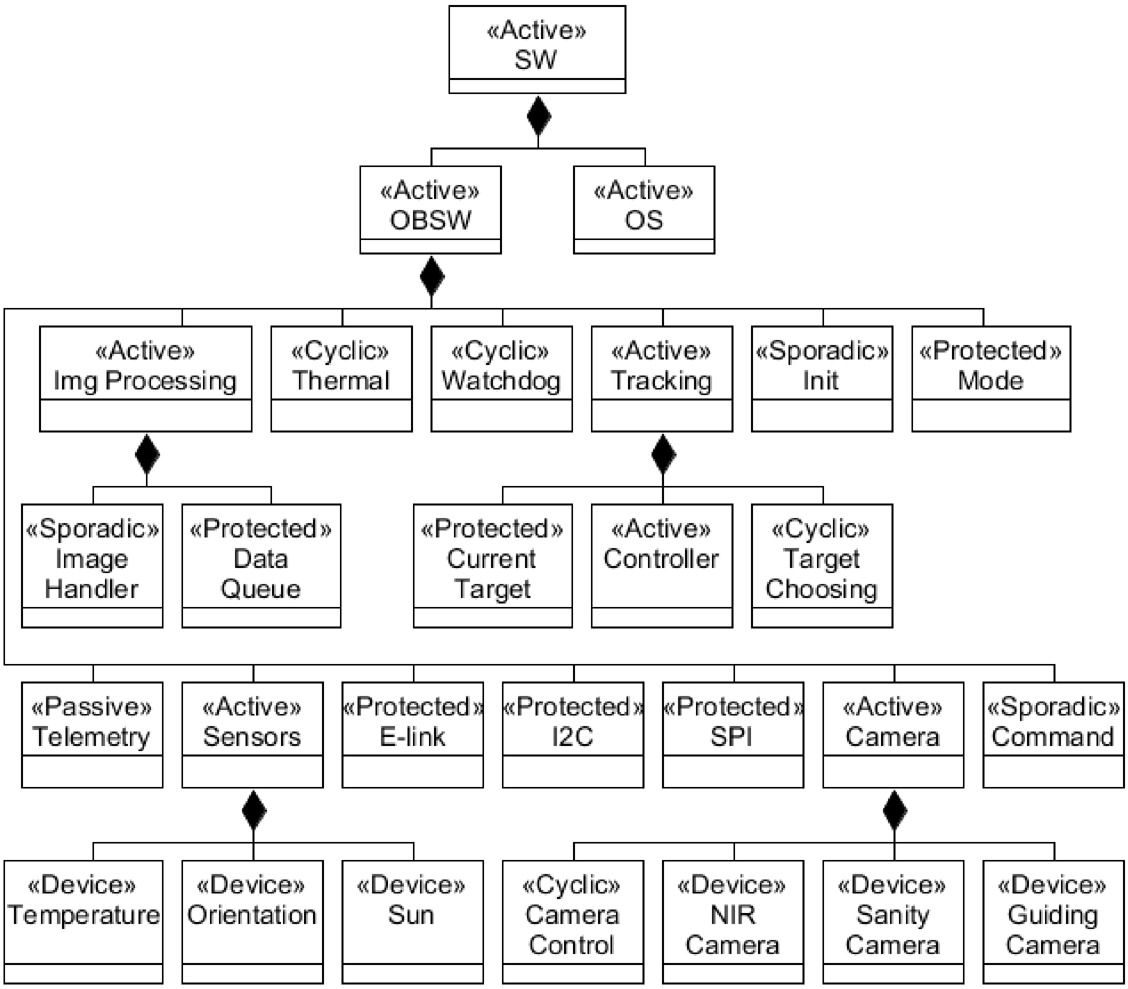


Figure 4.8.4: Composition tree of On-Board Software.

Figure 4.8.4 shows how the complete software is modularised. Each component is described below.

- Img Processing: Image processing, parent
  - Image Handler: Module processing and storing images taken by camera.
  - Data Queue: Buffer to hold camera data until Handler is ready
- Thermal: Module responsible for active thermal control
- Watchdog: Timer to reset external watchdog.
- Tracking: parent
  - Current Target: Module holding the current target to be observed.
  - Controller: Module responsible for keeping camera on target.
  - Target Choosing: Module responsible for keeping track of target prioritisation.
- Init: Module initialising each component.
- Mode: Module responsible for the current state of the software.
- Telemetry: Module responsible for sending telemetry to ground.
- Sensors: parent
  - Temperature: Thermal sensors.
  - Camera Orientation: Module keeping track of camera orientation and location.
  - Sun: Module keeping track of position of the sun.
- E-link: Module responsible for communications over the E-link interface.
- I2C: Module responsible for communications over the I2C bus.
- SPI: Module responsible for communications over the SPI bus.
- Camera: Parent
  - Camera Control: Module responsible for selecting target, camera settings and capturing images.
  - NIR Camera: Communication link to the NIR camera.
  - Sanity Camera: Communication link to the sanity camera.
  - Guiding Camera: Communication link to the guiding camera.
- Command: Module responsible for handling incoming commands from ground.

4.8.3 Implementation

The code for the On-Board Software shall be implemented in C. An operating system will be used to enable the modularisation required. Additional libraries may be needed.

4.8.4 Control system

The main task of the control system is selecting and tracking the astronomical targets and stabilising the telescope during exposure. Other tasks include minor tasks like the thermal control of the CMOS sensor and the electronics box as well as control of the actuators.

Selecting and tracking targets The selection and tracking of targets is done by using the current time, position (GPS) and orientation (compass/magnetometer) of the gondola. Once a suitable target in the operational field of view is selected, it is tracked during exposure. This includes the compensation of the following motions:

- Time-dependent rotational motion of the astronomical targets in the sky. This will be continuously compensated during exposure using models and/or interpolation of tables.
- Position-dependent rotational motion of the astronomical targets in the sky. This will be corrected once for every picture, using the GPs data.
- Rotation of the gondola in the z-axis; can be corrected during exposure using a gyroscope sensor.

Due to the nature of the motion of astronomical targets, it is necessary to use a 3-axis gimbal.

Stabilisation of the gimbal The stabilisation of the gimbal only needs to be active during exposure in order to avoid blurred pictures. It is responsible for compensating all kinds of small-scale, unpredicted movements of the gondola. In order to achieve this, an active feedback loop that requires information about the gondola movements is needed. This information is gathered by using accelerometers and gyroscopes for all 3 axis.

4.9 Ground Support Equipment

A computer on the ground will be connected to the experiment via the E-Link. The ground support software will include a simple GUI which will enable an operator to issue commands to the experiment such as reset, target selection, and moving to landing position. Low resolution pictures will be received by the ground support software, which can be examined to verify nominal operation. The ground support software shall be written in C or MATLAB.

5 Experiment Verification and Testing

5.1 Verification Matrix

The verification matrix is made following the standard of *ECSS-E-10-02A*. [4].

There are four established verification methods:
A - Verification by analysis or similarity
I - Verification by inspection
R - Verification by review-of-design
T - Verification by testing

ID	Requirement text	Method	Reference	Status	Verification result
F.1	The telescope shall successfully track the celestial bodies of interest.	A, T	Tests: 4, 5, 9, 10	A: to be done T: to be done	Not verified
F.2	The camera shall take images in the near infrared (NIR) spectrum.	R	Test: 1	R: to be done	Not verified
P.1	The gimbal stabilization system shall point the telescope towards the celestial body with an accuracy of at least 1 arc seconds.	A, T	Tests: 3, 4, 5, 9, 10	A: to be done T: to be done	Not verified
P.2	The optics shall be cable of making pictures of 0.5-1.5 x 0.3-1 degrees.	R, T	Test: 1	R: to be done T: to be done	Not verified
P.3	The NIR camera shall make images in the range of 720-850 to 1200 nm.	R	Test: 1	R: to be done	Not verified
P.4	The NIR camera shall have a resolution of at least 16 MP.	R, T	Test: 1	R: to be done T: to be done	Not verified
P.5	The NIR camera shall be able to make images with exposure times between 0.5 and 150 seconds.	R, T	Test: 1	R: to be done T: to be done	Not verified
P.6	The experiment shall measure the location and orientation of the gondola.	A, T	Tests: 3, 4, 5, 9, 10	T: to be done	Not verified
D.01	The experiment shall be able to operate in the temperature profile of the BEXUS environment.	T	Test: 2	T: to be done	Not verified
D.02	The experiment shall be able to operate in the pressure profile of the BEXUS environment.	T	Test: 2	T: to be done	Not verified

D.03	The experiment shall be able to operate in the vibration profile of the BEXUS environment.	T	Tests: 8, 10	T: to be done	Not verified
D.04	The absolute position of the telescope relative to the gondola shall be known with a accuracy of 0.1 degrees.	T	Tests: 3, 4, 9, 10	T: to be done	Not verified
D.05	The supporting structure shall not twist by more than 0.1 degrees.	T	Tests: 9, 10	T: to be done	Not verified
D.06	The experiment shall never be pointed directly at the sun $\pm$ 27 degrees.	T	Tests: 4, 9, 10	A: to be done T: to be done	Not verified
D.07	The experiment shall be able to fly during the entire day.	T	Tests: 9, 10	T: to be done	Not verified
D.08	The temperature of the NIR camera shall be held at $0 \pm 5\,^{\circ}$C.	T	Tests: 9, 10	T: to be done	Not verified
D.09	The images obtained shall be send to a ground station by the E-link system with a maximum data rate of 1000 kilo bits per second.	T	Test: 6	T: to be done	Not verified
D.10	The experiment shall be mounted at the side of the gondola.	T	Tests: 9, 10	T: to be done	Not verified
D.11	The experiment shall not consume more power than 250 Wh.	T	Tests: 9, 10	T: to be done	Not verified
D.12	The mass of the experiment shall not exceed 20 kg.	I	Test: 7	I: to be done	Not verified
D.13	The experiment shall be able to run for at least 2.5 hours.	T	Tests: 9, 10	T: to be done	Not verified
D.14	The experiment shall be able to function autonomously.	T	Tests: 4, 9, 10	T: to be done	Not verified
D.15	The data stored in the experiment shall be able to survive the landing.	T	Test: 8	T: to be done	Not verified
O.1	The experiment shall be able to be controlled by the ground station when requested.	T	Tests: 4, 10	T: to be done	Not verified
O.2	The experiment shall rotate to a 'safe' position while descending.	T	Tests: 4, 9, 10	T: to be done	Not verified

Table 5.1.1: Verification Matrix.

5.2 Test Plan

5.2.1 Planned Tests

The planned tests are as follows:

Test 01: Optics & Camera;

Test 02: Thermal & pressure test;

Test 03: Electronics;

Test 04: Software with electronics;

Test 05: Control system;

Test 06: Data transfer;

Test 07: Mass & Volume;

Test 08: Drop test (without optics and camera);

Test 09: Gimbal mounted on replicated gondola;

Test 10: Gimbal mounted on a car.

5.2.2 Test Descriptions

Test Number	1
Test Type	Optics & Camera
Test Facility	LTU (outside), Kiruna
Tested Item	Optics & Camera
Test Level/ Procedure and Duration	Verify the design that pictures are only able to be made in the specified NIR spectrum range, with the specified resolution and angular size. Then put the selected optics with camera on a tri-pod and make picture of all the selected targets. For these tests the NIR filter may be temperately removed (if possible). But all targets should be photographed at least in the NIR spectrum. Test duration: 8 hours (at night).
Test Campaign Duration	1 day
Test Campaign Date	April
Test Completed	NO
Requirements verified	NO

Table 5.2.1: Test 1: Optics & camera ground tested.

Test Number	2
Test Type	Vacuum & freezer
Test Facility	IRF/ EISCAT, Kiruna
Tested Item	Electronics, optics and camera
Test Level/ Procedure and Duration	The electronics, optics and camera should be placed in a vacuum and freezer to test the components functionality with a simulated environment based on the one we expect to encounter. The pressure should be <5 mbar and temperature -80 °C (or atleast colder than -40 °C if not possible) The components may be tested separately, but should function during the test. Test duration: 15 minutes per test on the specified pressure and temperature.
Test Campaign Duration	1 day
Test Campaign Date	Beginning of June
Test Completed	NO
Requirements verified	NO

Table 5.2.2: Test 2: Vacuum and freezer test of atleast the electronics, optics and camera.

Test Number	3
Test Type	Electronics
Test Facility	LTU, Kiruna
Tested Item	Sensors and Actuators
Test Level/ Procedure and Duration	The sensors should first be read out one by one, without the other sensors connected. If multiple sensors or actuators are located on the same PCB, there should also be a test PCB available with each sensor and actuator separated from the prototype phase. Afterwards, the same is done for each actuator. Then, one by one, each sensor and actuator is added to the system to test the system as a whole. Test duration: 5 hours.
Test Campaign Duration	1 day
Test Campaign Date	Beginning of June
Test Completed	NO
Requirements verified	NO

Table 5.2.3: Test 3: Sensors and actuators test.

Test Number	4
Test Type	Software
Test Facility	LTU, Kiruna
Tested Item	Raspberry pi software with electronics connected.
Test Level/ Procedure and Duration	This test should be done after the functionality of the electronics is verified. Then all sensors and actuators should be tested integrated with the software. Let the gimbal be targeting 4 specific points with a separation of 90 degrees. Test if the gimbal stabilize the system when moved and switches targets based on the field of view. The targets should also be able to be switched on the groundstation. Then add a 5th target which it may never look directly at and repeat the test. Test duration: 5 hours.
Test Campaign Duration	1 day
Test Campaign Date	Beginning of June
Test Completed	NO
Requirements verified	NO

Table 5.2.4: Test 4: Software (onboard and ground) with electronics connected test.

Test Number	5
Test Type	Control system
Test Facility	LTU, Kiruna
Tested Item	Control software.
Test Level/ Procedure and Duration	This test is done in a simulation program. The program verifies that the control system is able to track moving targets realtime in the sky without looking directly at the sun. Test duration: 2.5 hours (real time, simulation might be speed up).
Test Campaign Duration	1 day
Test Campaign Date	Beginning of June
Test Completed	NO
Requirements verified	NO

Table 5.2.5: Test 5:Control system simulation.

Test Number	6
Test Type	Data transfer
Test Facility	LTU, Kiruna
Tested Item	Controller
Test Level/ Procedure and Duration	Send the pictures, made in test 1, over the telemetry channel and monitor the data packages with the program 'Wireshark' or similar. Write down the telemetry data rate including headers and footers. During the test the connection should be resetted and the buffer should make sure all data will be transferred after the connection comes online again. Test duration: 30 minutes.
Test Campaign Duration	0.5 Day
Test Campaign Date	Beginning of June
Test Completed	NO
Requirements verified	NO

Table 5.2.6: Test 6: Telemetry testing.

Test Number	7
Test Type	Mass & Volume
Test Facility	LTU, Kiruna
Tested Item	Entire system
Test Level/ Procedure and Duration	Weigh the project on a measuring scale and write down the total weight. All components that are also included on the BEXUS balloon should be added. The subsystems may be measured individuality or as a whole. Then measure the volume of the project and write down the volume. Test duration: 30 minutes.
Test Campaign Duration	1 hour
Test Campaign Date	Beginning of June
Test Completed	NO
Requirements verified	NO

Table 5.2.7: Test 7: Check mass and dimensions of entire system.

Test Number	8
Test Type	Drop test
Test Facility	LTU, Kiruna
Tested Item	Electronics and gimbal
Test Level/ Procedure and Duration	Get the electronics and gimbal and put them off. Put them on the replicated gondola in the preferred positions with the attachment material that will also be used during the BEXUS flight. Drop the experiment from 1, 2 and 3 meters high. After every test the functionality of the system should be tested. At least the data logger should survive. Test duration: 1 hour.
Test Campaign Duration	0.5 day
Test Campaign Date	Beginning of June
Test Completed	NO
Requirements verified	NO

Table 5.2.8: Test 8: Drop test of entire system except optics and camera.

Test Number	9
Test Type	Gimbal performance
Test Facility	LTU, Kiruna
Tested Item	Gimbal, software and electronics
Test Level/ Procedure and Duration	Put the entire system in the replicated gondola and montage the system as would be montaged on the BEXUS flight. Let the system in sleep mode for atleast 2 hours (waiting) plus 1.5 hours (ascending) and simulate that the floating phase is reached. Then let the system work for at least 2.5 hours. Move the system around during the floating phase. Then simulate that the descending phase has started. Monitor the power and data usage during this test. Test duration: 6 hours.
Test Campaign Duration	1 week
Test Campaign Date	End of June
Test Completed	NO
Requirements verified	NO

Table 5.2.9: Test 9: Gimbal with all subsystems mounted on a replicated gondola.

Test Number	10
Test Type	Gimbal vibration test
Test Facility	LTU (outside), Kiruna
Tested Item	Gimbal, software and electronics
Test Level/ Procedure and Duration	Then let the system make images for at least 2.5 hours while being mounted on top of a car. Drive with the slowly car around on a mostly flat survive. Test duration: 5 hours.
Test Campaign Duration	1 week
Test Campaign Date	End of June
Test Completed	NO
Requirements verified	NO

Table 5.2.10: Test 10: Gimbal mounted on a car to test entire system with vibrations.

5.3 Test Results

The results shown here provide the key information obtained from testing. A full report for each test can be found in Appendix **??**.

Verification Number	1
Test Type	Optics & Camera
Facility	LTU (outside), Kiruna
Verified item	Sampling System
Verification description	The camera should make pictures in the NIR spectrum with the specified resolution and angular size. This test is also used to obtain ground made pictures from the targets of interest.
Expected results	The camera makes NIR images from the targets of interest.
Obtained results	
Conclusions	Not verified.

Table 5.3.1: Results test 1: Optics & camera ground tested.

Verification Number	2
Test Type	Vacuum & freezer
Facility	IRF/ EISCAT, Kiruna
Verified item	Electronics, optics and camera
Verification description	The electronics, optics and camera withstand a pressure of <5 mbar and a temperature of atleast -40 °C.
Expected results	The system controls the temperature if the temperature almost gets below the minimum temperature specified. The system is also able to survive in a <5 mbar environment.
Obtained results	
Conclusions	Not verified.

Table 5.3.2: Results test 2: Vacuum and freezer test of atleast the electronics, optics and camera.

Verification Number	3
Test Type	Electronics
Facility	LTU, Kiruna
Verified item	Sensors and actuators
Verification description	The specified range and accuracy of each sensor and actuator are being met, even after integration. The sensors are read out by the same board that is used for the onboard control system and read out on a display.
Expected results	Each sensor and actuator works separated and integrated together within the specified accuracy.
Obtained results	
Conclusions	Not verified.

Table 5.3.3: Results test 3: Sensors and actuators test.

Verification Number	4
Test Type	Software
Facility	LTU, Kiruna
Verified item	Raspberry Pi software with electronics connected.
Verification description	Program four targets of interest and move the gimbal around. Determine if the targets are being followed. Then add a 5th point that the gimbal should never point, or around with the specified angle, and determine that this never happens. Connect the ground station and check if the system can be controlled remotely.
Expected results	The gimbal is able to chose targets and keeps it tracked and a specific target will never be looked directly at or nearby.
Obtained results	
Conclusions	Not verified.

Table 5.3.4: Results test 4: Software (onboard and ground) with electronics connected test.

Verification Number	5
Test Type	Control system
Facility	LTU, Kiruna
Verified item	Control software
Verification description	In a simulation program the control system is verified. The targets with movement are inserted in this simulation.
Expected results	The gimbal is able to chose the specified targets and keeps it tracked and a specific target (sun) will never be looked directly at or nearby.
Obtained results	
Conclusions	Not verified.

Table 5.3.5: Results test 5: Control system simulation.

Verification Number	6
Test Type	Data transfer
Facility	LTU, Kiruna
Verified item	Controller
Verification description	The data packages will be monitored by 'Wireshark' or a simular program and the data rate is below the specified data rate. The data gets buffered while being connection is lost.
Expected results	The data rate is below the specified data rate and the data gets buffered while the connection is lost.
Obtained results	
Conclusions	Not verified.

Table 5.3.6: Results test 6: Telemetry testing.

Verification Number	7
Test Type	Mass & Volume
Facility	LTU, Kiruna
Verified item	Entire system
Verification description	The mass and volume of the experiment gets measured.
Expected results	The mass and volume are below the specified values.
Obtained results	
Conclusions	Not verified.

Table 5.3.7: Results test 7: Check mass and dimensions of entire system.

Verification Number	8
Test Type	Drop test
Facility	LTU, Kiruna
Verified item	Electronics and gimbal
Verification description	The electronics and gimbal get droped, mounted on a replicated gondola, from a height of 1, 2 and 3 meters and atleast the data logger survives.
Expected results	The data logger survives but the gimbal might break depending on the impact.
Obtained results	
Conclusions	Not verified.

Table 5.3.8: Results test 8: Drop test of entire system except optics and camera.

Verification Number	9
Test Type	Gimbal performance
Facility	LTU, Kiruna
Verified item	Gimbal, software and electronics
Verification description	The test is run for atleast 6 hours. The system is slightly moved during the last 2.5 hours, while the images are made. The power and data usage is monitored during the test.
Expected results	The system is able to work for atleast 6 hours with the specified power and data usage. The images are the same as made from a static point.
Obtained results	
Conclusions	Not verified.

Table 5.3.9: Results test 9: Gimbal with all subsystems mounted on a replicated gondola.

Verification Number	10
Test Type	Gimbal vibration test
Facility	LTU (outside), Kiruna
Verified item	Gimbal, software and electronics
Verification description	The entire system including the replicated gondola is mounted on top of a car and the images takes are compared to the images taken while being static.
Expected results	The system is able to work with the vibrations and movement from the car, the images obtained are the same.
Obtained results	
Conclusions	Not verified.

Table 5.3.10: Results test 10: Gimbal mounted on a car to test entire system with vibrations.

6 Launch Campaign Preparations

6.1 Input for the Campaign / Flight Requirements Plans

6.1.1 Dimensions and Mass

The data shown in Table 6.1.1 below is based on the design presented in Section 4.4.

	Telescope	Electronics	Gimbal	TOTAL
Experiment mass [kg]	5	1.5	5	13
Experiment dimensions [m]	0.222x0.651	0.1x0.1x0.1		
Experiment footprint area [m^2]	0	0.1		
Experiment volume [m^3]	0.0123	0.1		
Experiment expected COG position	$X = cm$ $Y = cm$ $Z = cm$	$X = 5cm$ $Y = 5cm$ $Z = 5cm$	$X = 32.5cm$ $Y = 11.1cm$ $Z = cm$	

Table 6.1.1: Experiment Summary Table.

6.1.2 Safety Risks

Table 6.1.2 contains the risks of all stages of the whole campaign and project.

Risk	Key Characteristics	Mitigation
Moving telescope lens	A telescope is stabilized in three axis. Therefore there is the risk that the motor will start turning uncontrollable.	Adding additional components that at least a double component failure should occur before there is any risk.
Sharp edges, machines aluminum	Sheet and tubing, some sharp edges exist after machining.	Deburr edges where possible. Contain sharp edges in tough material. During transportation, use protective gloves when handling if sharp edges are still present.
Massive bulky structure	The mass of the assembly poses risk of trapped and damaged fingers or feet being crushed.	Order of assembly should be well thought out and practiced. At least two people are present during assembly and that there is a dedicated space for assembly.
Parts dropping from gondola	Parts are heavy enough to cause harm if they fall onto people.	All parts sufficiently fastened. Testing conducted to ensure fastening is able to hold all parts in place in case of turbulence. Where possible, add assurance by adding additional fixations.

Table 6.1.2: Experiment safety risks.

6.1.3 Electrical Interfaces

During the launch campaign, the telemetry system needs to be checked in order to ensure that the data that's intended to be sent from the gondola to our ground station is within the capabilities of the E-link system.

6.1.4 Launch Site Requirements

Prior to launh, in the case that ice has appeared on the experiment prohibiting free motion for the controller, a small electric heater fan will be needed to remove the ice.

Post launch a laptop PC will be used to send and receive data to the experiment. For this a desk and chair will be needed, along with a power outlet and ethernet cable for E-link connection.

6.1.5 Flight Requirements

The flight requirements for the IRISC experiment are stated below.

- **Desired float altitude:** A height of >20 km is adequate for this experiment. However, a higher altitude will improve the signal to noise ratio.
- **Desired float duration:** We need a floating time of at least 90 min in order to collect sufficient amount of data. A longer floating time would desirable.
- **Required launch time:** A partial night flight would be preferable because there is less interference with the sun and a wider range of view. However, the system will be designed to be able to function during the entire day.

6.1.6 Accommodation Requirements

Assuming that the experiment is able to be mounted to an outer side of the gondola as shown in figure 6.1.1, the objective end of the telescope *must* be able to point outside of the gondola for the entirety of the float phase, preferably to an angle of 60 degrees above the horizontal. Additionally, it should be able to move such that it has a viewing angle of 45 degrees horizontally in either direction. The telescope requires a "slewing area" of approximately 650 mm wide, 350 mm deep and 350 mm high within the gondola.

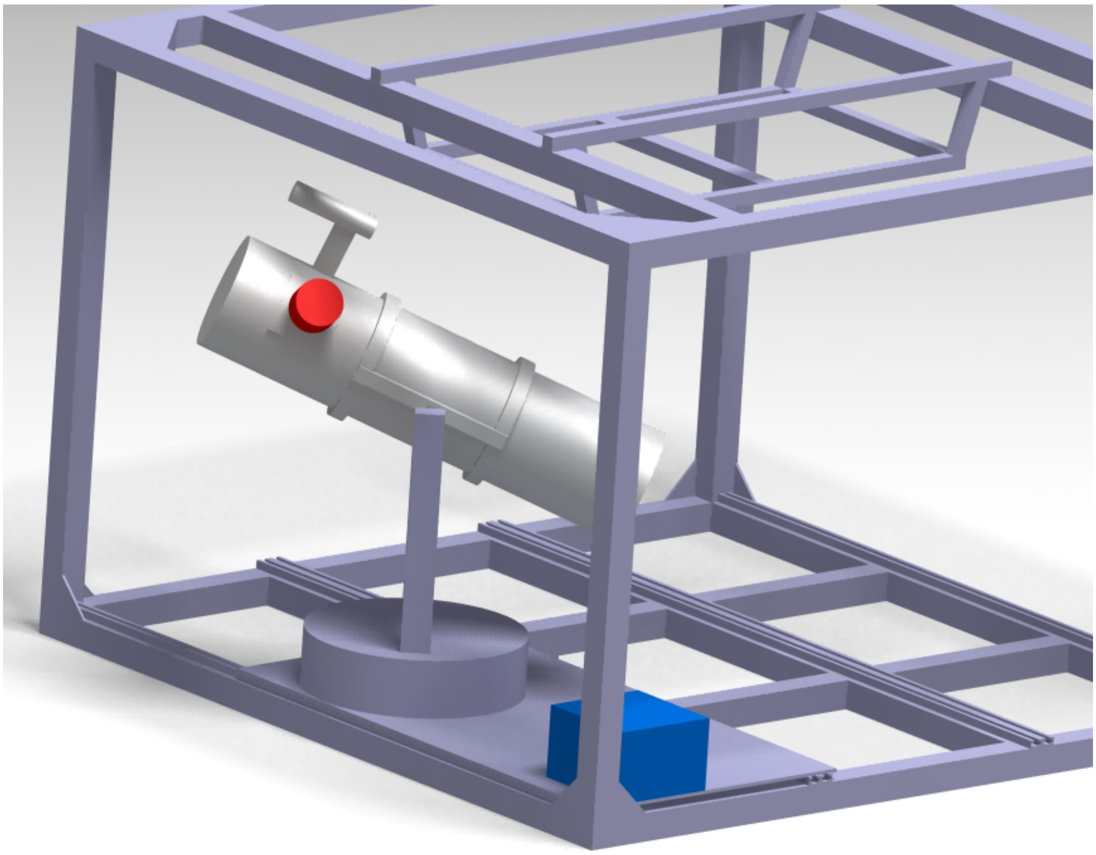


Figure 6.1.1: Instrument position on gondola

6.2 Preparation and Test Activities at Esrange

When arriving at Esrange the the ground station and e-link will be set up and tested. The control system will be checked, and a picture will be sent in order to ensure functionality of all components. The experiment will then be stowed and a protective cap will cover the lens.

6.3 Timeline for Countdown and Flight

Table 6.3.1 is the estimated timeline during countdown and flight.

Time	Altitude	Events
T-3H	0m	Perform pre-flight system check according to system checklist
T-2.5H	0m	System check complete
T-1H	0m	Lens cover is removed
T-1H	0m	Experiment is switched on
T-1H	0m	Experiment goes to standby mode
T=0	0m	Lift-off
T+1s	∼5 m	Experiment is stowed and not operational during ascent.
T+∼1.5H	∼25 km	Float Phase, experiment starts operating autonomously.
CUT-OFF-5MIN	∼25 km	Data collection stops and experiment moves to safe position.
CUT-OFF	∼25 km	Cut-off, experiment returns to safe stowage position.
Touchdown	0m	Experiment recovery begins.

Table 6.3.1: Countdown and Flight Estimated Timeline.

6.4 Post Flight Activities

As no component of the experiment is hazardous, no special precautions are needed for recovery. If possible, the whole experiment should be collected as is.

If it is not possible to collect the whole experiment due to external damage or otherwise, then the on-board data storage SD-card shall be collected. The experiment will be designed with this as a consideration, and the data storage unit will be removable in a non-invasive manner. Instructions will be provided on securing that the gimbal is locked in the stowage position, and that no actuators are powered. Manual shutdown will be possible, should the automated shutown have failed.

The data will then be taken off site for further analysis.

7 Data Analysis and Results

7.1 Data Analysis Plan

In a best-case scenario, where there are no pointing errors, the CMOS sensor experiences no malfunctions and all astronomical targets are imaged as planned with images delivered in RAW, then the only data analysis to be done is to compare the SNR of the control images to the flight images, and then to images of the given targets in the same wavelength from other instruments, if applicable. Images to be processed and analysed are expected to be delivered in RAW and at full resolution for a size of 20-30 MB each, and will therefore require substantial computing power to stack and process.

7.1.1 Control Images

A set of control images is necessary to establish a baseline SNR to compare to the flight images. To obtain these control images, the entire apparatus should be functional in order to as closely simulate the BEXUS gondola inertial environment as possible (temperature and pressure conditions do not need to be the same). In order to image the same targets as will be available during the BEXUS campaign, daylight constraints and the positions of the targets require that attempts begin 4-6 weeks before the experimental instrumentation needs to be completed in full. Should this window be missed, imaging attempts after the launch (provided that the instrumentation survive the landing) can continue for another 6-8 weeks before the targets move out of sky view.

7.1.2 Image Processing and SNR Determination

In astrophotography, there are four main kinds of images that contribute to a final image:

- **Light Frames:** the image of the target itself, with no modifications or corrections yet applied.
- **Dark Frames:** images taken at the same settings and under the same conditions as the light frames, but with the aperture blocked of light.
- **Flat Frames:** these determine the brightness balance of the sensor– a lot of sensors are 'brighter' toward the middle of the frame and 'darker' toward the edges.
- **Bias Frames:** these are taken at as fast an exposure time as possible, with the lens cap on, to remove the readout noise due to the sensor.

These four kinds of images need to be sequentially divided and subtracted from the light image to remove as much noise as possible from the final image. Quantitative determination of the SNR of each image will occur once all frames have been processed through appropriate software, e.g. SIPS, Deep Sky Stacker or RegiStax.

7.2 Launch Campaign

7.2.1 Flight preparation activities during launch campaign

The flight preparations can be found in Section 6.2.

7.2.2 Flight performance

7.2.3 Recovery

7.2.4 Post flight activities

7.3 Results

No results have been produced yet. More information will be provided following the launch campaign in a later version of the SED.

7.3.1 Expected Results

It is expected that since atmospheric interference is a large contributor to the reduction of target light intensity and increased noise in the final images, flight images will display increased clarity and finer detail, as well as an increased SNR as compared to images taken on the ground.

7.4 Lessons Learned

7.4.1 Management

- Increased familiarity with organizational tools
- Increased familiarity with LaTeX

7.4.2 Scientific

- Increased familiarity with astrophotography systems and instrumentation
- Increased familiarity with CMOS sensors and infrared detection

7.4.3 Electrical

- Friendship
- Sleep deprivation

7.4.4 Software

- Friendship
- Sleep deprivation

7.4.5 Mechanical

- Friendship
- Sleep deprivation

7.4.6 Thermal

- Fans don't work as a cooling mechanism without air
- Sleep deprivation

8 Abbreviations and References

8.1 Abbreviations

ASC	Air Sampling Control
ANSYS	ANalysis SYStem
BEXUS	Balloon Experiment for University Students
CAD	Computer Aided Design
CDR	Critical Design Review
CFD	Computational Fluid Dynamics
CH_4	Methane
CLK	Serial Clock
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COG	Center of Gravity
CRDS	Cavity Ring Down Spectrometer
DC	Direct Current
DFM	Design for Manufacturability
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EB	Electronic Box
EBASS	Esrange BAlloon Service System
ECTS	European Credit Transfer System
EOE	End of Experiment
EPDM	Ethylene Propylene Diene Monomer
ESA	European Space Agency
FCS	Frame Check Sequence
FEA	Finite Element Analysis
FMI	Finnish Meteorological Institute
GC	Ground Control Station
GPIO	General Pins Input Output
GPS	Global Positioning System
GUI	Graphical User Interface
H_20	Water
HOOD	Hierarchic Object-Oriented Design
I2C	Inter-Integrated Circuit
IDE	Integrated Software Environment
I/O	Input/Output
IR	Infra-Red
IRF	Institutet för rymdfysik (Swedish Institute for Space Physics)
LED	Light Emitting Diode
LTU	Luleå University of Technology
MATLAB	MATrix LABoratory
MB	Mega Byte
MISO	Master Input Slave Output
MORABA	Mobile Rocket Base
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MOSI	Master Output Slave Input

MSc	Master of Science
NOAA	National Oceanographic and Atmospheric Administration
OBC	On-Board Computer
OBSW	On-Board Software
ppb	parts per billion
ppm	parts per million
PCB	Printed Circuit Board
PDR	Preliminary Design Review
REXUS	Rocket Experiment for University Students
RJ45	Registered Jack 45
RTOS	Real-time operating system
SAFT	Société des Accumulateurs Fixes et de Traction
SCP	Serial Clock Pin
SD	Secure Digital (Storage)
SDP	Serial Data Pin
SED	Student Experiment Documentation
SNSA	Swedish National Space Agency
SOE	Start of Experiment
SOP	Standard Operation Procedure
SPI	Serial Peripheral Interface
SSC	Swedish Space Corporation
STP	Standard Temperature Pressure
SW	Software
TBC	To Be Confirmed
TBD	To Be Determined
TCP	Transmission Control Protocol
TT&C	Telemetry, Tracking, and Command
UDP	User Datagram Protocol
VC	Valve Center
ZARM	Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation

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Appendix A Experiment Reviews

Appendix B Outreach

Website and social media pages:

- Official Website : irisc.space
- Facebook: facebook.com/IRISCBexus
- Instagam: instagram.com/irisc-bexus
- Twitter:

Figure B.0.1 shows the IRISC Loggo.

Figure B.0.1: IRISC loggo.

Appendix C Additional Technical Information

Appendix D Standard Operation Procedures