SED

Student Experiment Documentation

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Team Name: IRISC

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

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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 Board (SNSB). 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.

Acknowledgements

1 Introduction

1.1 Scientific Background

1.2 Mission Statement

1.3 Experiment Objectives

1.4 Experiment Concept

1.5 Team Details

The IRISC Team consists of twelve people of a number of different educational and personal backgrounds. All team members are studying at the LuleåUniversity 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)

Responsibilities: experiment scientific background and overall objectives; defining experimental parameters; contacting and collaborating with industry partners that manufacture off-the-shelf optics components; data analysis; interpreting and documenting images; 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.

Harald Magnusson - Software

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

Previous Education:

Responsibilities: Software (onboard & ground station).

Niklas Ulfvarson - Software

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

Previous Education:

Responsibilities: Software (onboard & ground station).

Sabina Björk - Electrical

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

Previous Education: -

Responsibilities: Energy technology, electrical engineering.

William Eriksson - Software

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

Previous Education:

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 measure the location and orientation of the gondola.

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 experiment shall never be pointed directly at the sun $\pm$ 27 degrees.

D.07 The experiment shall be able to fly during the entire day.

D.08 The temperature of the NIR camera shall be held at $0 \pm 5\,^{\circ}$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 65 x 40 x 40 cm.

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 shall be able to function autonomously.

D.16 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 while descending.

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

3.2 Schedule

3.3 Resources

3.3.1 Manpower

3.3.2 Budget

Category	**Total Mass [g]**	**Total Price [EUR]**
Structure	0.00	00.0
Electronics Box	000.0	0.00
Cables and Sensors		
CAC		
AAC		
Tools	–	
Travel	–	
Contingency	–	
Total without Error Margin		
Shipping Costs and Error Margin		
Total with Error Margin		

Table 3.3.1: Mass and Cost Budget.

3.3.3 External Support

3.4 Outreach Approach

3.5 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)

1. Negligible – Minimal or no impact
2. Significant – Leads to reduced experiment performance
3. Major – Leads to failure of subsystem or loss of flight data
4. Critical – Leads to experiment failure or creates minor health hazards
5. 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	Gears get jammed	B	4	Low	Gear will be oiled on the day of the launch.
MS30	Damage to the system on landing	D	1	Low	Optics will move inside a frame for protection.
MS40	Damage to the storage unit on landing	C	2	Low	Data will be send over telemetry
MS50	Storage unit full during flight	A	3	Very Low	Sufficient modeling will be done to decrease the probability.
MS60	BEXUS balloon power failure	A	4	Very Low	-
MS70	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 3.5.1: Risk Register.

4 Experiment Design

4.1 Experiment Setup

I know this is more like the SUNBYTE structure and not so much like the EXIST one, but in this particular case I prefer the readability of SUNBYTE

The experiments mounts a telescope with an attached CMOS sensor inside the gondola, looking out as shown in figure CAD-model of experiment setup. The telescope is mounted on a gimbal system that provides stabilisation along two axis (three if required, 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 individual sections of the experiment are described below.

4.1.1 Telescope and CMOS sensor

The telescope chosen is a Skywatcher BKP 130 DS, 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), 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 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:

$$\mathrm{FoV}_{\mathrm{horizontal}} = \arctan \frac{13.2\,\mathrm{mm}}{650\,\mathrm{mm}} = 1.16^\circ \tag{1}$$
$$\mathrm{FoV}_{\mathrm{vertical}} = \arctan \frac{8.8\,\mathrm{mm}}{650\,\mathrm{mm}} = 0.757^\circ \tag{2}$$
$$\mathrm{FoV}_{\mathrm{diagonal}} = \arctan \frac{15.86\,\mathrm{mm}}{650\,\mathrm{mm}} = 1.382^\circ \tag{3}$$

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

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

4.1.2 Electronics

The onboard processor/microcontroller 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, only applicable if there is no real-time access to the GPS data from the BEXUS gondola), 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.

The CMOS sensor data is transmitted to the onboard processor/microcontroller 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 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.

currently not included: guiding scope & camera

4.2 Experiment Interfaces

4.2.1 Mechanical Interfaces

4.2.2 Thermal Interfaces

4.2.3 Electrical Interfaces

4.2.4 Radio Frequencies (Optional)

4.2.5 Thermal (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

4.4.2 Inside

4.4.3 etc

4.5 Electrical Design

4.5.1 Block Diagram

4.5.2 Critical Component/Part A

4.5.3 Critical Component/Part B

4.5.4 Critical Component/Part C

4.5.5 Schematic

4.5.6 PCB Layout

4.6 Thermal Design

4.6.1 Thermal Environment

4.6.2 The Critical Stages

4.6.3 Overall Design

4.6.4 Internal Temperature

4.6.5 Calculations and Simulation Reports

4.7 Power System

A 28.8V/1mA battery package can be provided by the gondola, according to the BEXUS user manual. Which should satisfy IRISCs power needs. One constrain is that the continuous maximum current is 1.8 A. Thus a buck-converter will be needed to step down the voltage, so that the power system will be able to provide the right voltages for the rest of the subsystems.

4.8 Software Design

4.8.1 Purpose

4.8.2 Design

4.8.3 Implementation

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.

5 Experiment Verification and Testing

5.1 Verification Matrix

The verification matrix is made following the standard of *ECSS-E-10-02A*. [1].

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 volume of the experiment shall not exceed 65 x 40 x 40 cm.	I	Test: 7	I: to be done	Not verified
D.13	The mass of the experiment shall not exceed 20 kg.	I	Test: 7	I: to be done	Not verified
D.14	The experiment shall be able to run for at least 2.5 hours.	T	Tests: 9, 10	T: to be done	Not verified
D.15	The experiment shall be able to function autonomously.	T	Tests: 4, 9, 10	T: to be done	Not verified
D.16	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' location 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 tripod 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.

	xxx	xxx	TOTAL
Experiment mass [kg]			
Experiment dimensions [m]			
Experiment footprint area [m^2]			
Experiment volume [m^3]			
Experiment expected COG position	$X = cm$ $Y = cm$ $Z = cm$	$X = cm$ $Y = cm$ $Z = cm$	$X = cm$ $Y = cm$ $Z = cm$

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 digits 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

Please refer to Table 6.1.3 for details on the electrical interfaces with the gondola.

BEXUS Electrical Interfaces		
E-link Interface:		
	Number of E-link interfaces	
	Data rate - Downlink	
	Data rate - Uplink	
	Interface type (RS232, Ethernet)	
Power system: Gondola power required?		
	Peak power (or current) consumption:	
	Average power (or current consumption)	
Power system: Experiment includes batteries?		

Table 6.1.3: Electrical Interface Table.

6.1.4 Launch Site Requirements

Prior to launcch, 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

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.

Time	Altitude	Events
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 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 secured in safe stowage position.
Touchdown	0m	Experiment recovery begins.

Table 6.3.1: Countdown and Flight Estimated Timeline.

6.3 Timeline for Countdown and Flight

Table 6.3.1 is the estimated timeline during countdown and flight.

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 or SSD) 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

7.1.1 Analysis Strategy

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 for now. More will come after the launch campaign in an updated version of the SED.

7.3.1 Expected Results

7.4 Lessons Learned

7.4.1 Management

- Friendship
- Sleep deprivation

7.4.2 Scientific

- Friendship
- Sleep deprivation

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

- Friendship
- Sleep deprivation

8 Abbreviations and References

8.1 Abbreviations

8.2 References

[1] ECSS Secretariat. *Space Engineering: Verification*. ESA-ESTEC, Requirements & Standards Division, ESTEC, P.O. Box 299, 2200 AG Noordwijk, The Netherlands, Nov 1998.

Appendix A Experiment Reviews

Appendix B Outreach

Appendix C Additional Technical Information

Appendix D Checklists