INFINITY MISSION: A MICROSATELLITE SPACE TELESCOPE FOR AMATEUR ASTRONOMICAL OBSERVATIONS

Alfredo Locarini[1], Dario Modenini[1,2], Paolo Tortora[1,2], Franco Cappiello[3]
[1] Alma Mater Studiorum – Università di Bologna, Interdepartmental Center for Industrial Research in Aerospace, Via B. Carnaccini 12, 47121 – Forlì, Italy, alfredo.locarini@unibo.it
[2] Alma Mater Studiorum - Università di Bologna, Department of Industrial Engineering, Via Fontanelle 40, 47121, Forlì, Italy, {dario.modenini, paolo.tortora}@unibo.it
[3] BFC Space S.r.l. Via M. Gioia 55, 20124, Milan, Italy, franco.cappiello@gmail.com

ABSTRACT

Amateur astronomy can represent a valuable resource to support professional astronomical research and promote celestial observation. The "INFINITY" mission has been conceived to provide an orbital telescope, hosted on board a small satellite platform, which aims at becoming a reference point for the global amateur astronomical community. As an ambitious project and with scarce literature behind it, this mission presents several critical design and technological issues, considering that the mission will be carried out using a micro-satellite platform, with an approximate mass between 50 kg and 100 kg. In this study we addressed the "INFINITY" mission and spacecraft preliminary architecture definition, focusing on the design and technological solutions adopted to achieve the mission goal. The mission concept was characterized from orbital, operational and data delivery perspectives and some of the system main aspects were preliminary investigated.

The mission timeline is subject to the identification and procurement of the critical technology represented by the focal plane piezoelectric control stage, needed to stabilize the payload during image acquisition, currently not available in Europe. It is therefore being developed as an R&D internal activity, with a strong interest also in its possible adaptation to Earth observation missions.

1 INTRODUCTION

Amateur astronomy is practiced all over the world by a large number of people, coming from any type of background or professional field. Current estimates see between 200,000 to 500,000 amateur astronomers around the world, often equipped with sophisticated expensive equipment and connected to each other with dedicated networks, with the aim of planning coordinated observation sessions, facilitating communication, data sharing and dissemination.

Although amateur astronomy often provide a valuable contribution to observation campaigns coordinated by the professional research, scheduling optical astronomy sessions is generally not an easy task for non-professional astronomers, due to unpredictable weather conditions, logistic issues and personal commitments.

In this context, the possibility offered by the INFINITY mission to have a space-based platform carrying an imaging telescope dedicated to celestial body observation would represent a unique opportunity for the community to easily access astronomy equipment, to perform rapid on-demand observation sessions of major celestial bodies, and to share the data with the scientific and amateur community. The telescope will be hosted by a small satellite platform, with a mass in the range 50 kg – 100 kg, whose reduced overall cost would allow the service to be economically affordable by non-professional astronomy community. Based on the heritage from previous microsatellite projects, a spacecraft volume in the order of 320 x 320 x 640 mm^3 was considered, with approximately half of it dedicated to the payload and the others half to the bus subsystems.

Additionally, INFINITY would also represent a valuable resource for observations run by universities and research centers, outside large observation campaigns. The mission goal is to offer a service that allows exclusive access to the telescope orbiting in LEO, through a dedicated booking system, with fixed length observation slots, to target one celestial object, chosen from a catalogue of those visible during every observation session.

The INFINITY mission astronomical target are galaxies, nebulae, variable stars, comets and asteroids. For every targeted celestial object, the mission must be able to allocate observation sessions of 30 minutes length each, slew manoeuvres excluded and the concept of operations should be designed to accommodate two observation sessions per orbit. Final processed images of celestial bodies shall be delivered to the final user, who submitted the observation request, within 36 hrs from the observation.

To meet the typical needs of the astronomical amateur community, for each 30-minute observation slot, the spacecraft will perform a pointing maneuver on the target and will take a series of photos, in the order of tens, of the same body, with a sensor exposition of a few seconds and maintaining an adequate pointing stability over the shutter opening period. Following the in-orbit results of the JPL's Asteria project [1], Infinity will feature a sophisticated pointing mechanism that aims at ensuring a pointing accuracy in the arcsecond range with long-term stability. A first stage, based on reaction wheels and magneto-torquers, will be in charge of the spacecraft bus attitude control to obtain the target within the field of view of the imaging sensor, and a finer second stage, which will take care of maintaining the stability of the target within the picture, using piezoelectric actuators placed on the sensor plane.

The mission expected lifetime is 5 years. At the time of writing, the identification of the industrial partner for the platform development is still on-going, while the critical payload stabilization technology is currently being investigated as internal research at the Università di Bologna.

In the following, an overview on the outputs of the preliminary mission study carried out by the Università di Bologna is presented, organized thematically in three main sections: mission architecture definition, including orbital, data delivery and concept of operations; payload investigation, aiming at defining the preliminary engineering and operational aspects; brief overview on other subsystems analysis.

The mission is run and funded by BFC Space Srl, which also performed a preliminary economic sustainability assessment of the INFINITY service and provided the mission requirements.

2 MISSION ARCHITECTURE

2.1 INFINITY orbit

A Sun-Synchronous Orbit (SSO) was found being the most suitable orbital solution for the INFINITY mission, as it offers a constant angular offset between the Sun-Earth direction and the orbital plane and facilitates the payload phases allocation, allowing a highly repeatable operational workflow. The mission performance would benefit from this configuration as the observability of the complete celestial sphere is possible over 1 year period and due to the possibility to observe, each orbital revolution, a portion of the sky with very well determined and fixed geometry between the Sun, the spacecraft and the Earth, allowing for an easier allocation of observable targets for every period of the year. Moreover SSO orbits present very good coverage by polar ground stations, which is of great value for data-intensive missions, like the INFINITY case.

The target orbit height will be between 500 km and 600 km, as a trade-off between the launch opportunities, the mission performances, the size of the Earth exclusion angle, the bus subsystems performances, the environmental interaction and the end of life disposals.

The selected SSO is a Dawn-Dusk (LTAN 06:00), i.e. with the spacecraft always orbiting above the terminator line. This orbit choice is advantageous from attitude, thermal and energy perspectives:

- With a proper subsystems physical allocation within the INFINITY platform, the solar array can always be oriented towards the Sun by simply maintaining its axis direction parallel to the orbit normal. There will still be an offset between the solar array normal and the Sun direction due to the variable Sun declination.
- One of the spacecraft body axes maintains a constant Nadir-Pointing orientation, suggesting a preferable face for antennas mounting and allowing consistent contact for the onboard telecom subsystem;
- The Sun-spacecraft-Earth geometry allows to perform the spacecraft tasks allocation along the orbit based only on convenience and not dictated by orbital conditions, e.g. like the eclipse.
- More stable on-board temperatures and faster convergence to equilibrium temperatures since the entire orbit trajectory is always illuminated by Sun for most of the year.
- Easier electrical power system design, given the theoretical 100% solar energy collection capability during the orbit period.

The orbital scenario details are resumed in Table 1.

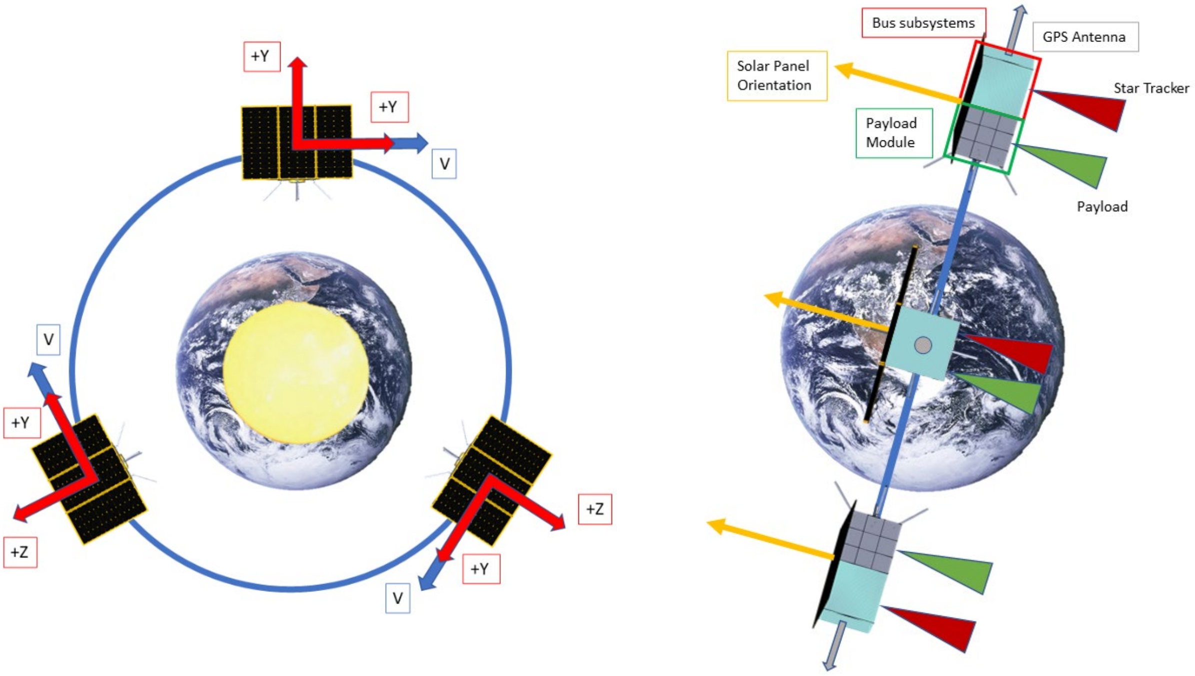

Figure 1: Spacecraft attitude and orbital representation

Table 1: INFINITY orbital scenario

Altitude	~600 km
e – Eccentricity	Very Low eccentricity
Orbit Type	Sun-Synchronous
LTAN	06:00 (Dawn-Dusk)
i – Inclination	~97°
Orbit Period	~96.5 min
Nominal attitude	Nadir-Pointing with orbit-normal constraint

2.2 Concept of Operations (CONOPS)

A cartoon of the CONOPS in the assumed Dawn-Dusk SSO is shown in Figure 2.
The orbital period is split into three operational phases, each connected to the other through a slew manoeuvre, see Table 2. Based on the INFINITY service requirements, two phases are allocated to observation sessions, lasting 30 minutes each. The remaining one is devoted to S/C maintenance operations, i.e. solar energy harvesting plus TM-TC and data-delivery operations (in case of G/S visibility).
The two observation sessions foresee inertial pointing. To guarantee a minimum predictable level of energy input, a different priority level is assigned to the two observation sessions, with the secondary session subject to additional energy-related pointing constraints:

- Primary observation session; no constraints on the payload pointing angles are foreseen, apart from the exclusion cones related due to the stray light coming from the Sun, the Earth, and the Moon, i.e. payload pointing is independent from any solar panels exposure consideration.
- Secondary observation session; it must contribute to solar energy harvesting. For this reason, celestial targets are selected among those whose pointing allow keeping the angle between the solar panels normal and the Sun direction smaller than 30°.

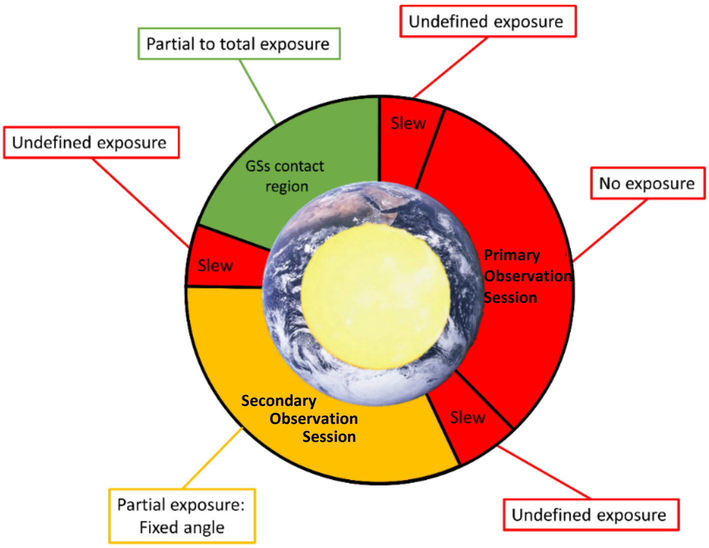

Figure 2: Exposure levels of the solar panels to the Sun in every part of the Dawn-Dusk orbit.

Thanks to chosen Dawn-Dusk SSO and the assumed S/C configuration featuring an angle of 90° between the solar panels normal and the antennas boresight, the region of orbit dedicated to data downlink will also contribute to the energy generation. The orbital phasing for the three operational phases is set to ensure that the telecommunication operations take place over the high Earth latitudes, where the INFINITY ground stations are located.
The three slew manoeuvres connecting the operational phases are allocated 6 minutes each, leading to a required slew-rate up to 0.5 deg/s.

Table 2: Dawn-Dusk SSO operations allocations

Mission operational time windows	Length	% of the orbital period	Solar energy harvesting
Orbital period	~96.5 min	/	/
Primary Observation slot	30 min	31.1 %	No
Secondary Observation slot	30 min	31.1 %	Yes (up to 30° offset)
Slew manoeuvre slots	3 x 6 min	18.6 %	No
Residual Telecommunication Window	~18.5 min	19.2 %	Yes (offset depending on Sun declination)

2.3 Data delivery strategy

The proposed data delivery scenario for the INFINITY mission was conceived to allow the complete download of the products of each observation sessions in the 24 hours following the observation, to satisfy the 36 hours mission requirement between the image acquisition and the delivery of the final product to the user.

The INFINITY ground segment involves two stations with well separated functions (Table 3):

- Italy Station (44° N, 12°E): this facility placed in central Italy will include the Mission Control Centre (MCC) and the Payload Operations Control Centre (POCC). This facility will offer the telemetry and telecommands station and a backup payload data station, which will be used for payload data downlink only in case of unavailability of the Main station.
- Polar Station (67° N, 27° E): several companies offering high data rate downlink services exist, with stations typically distributed at very high latitudes. As a tentative solution, a KSAT station was considered [2], to be used as primary payload data station and mission support during LEOP.

For the analytical/simulative assessment of the contacts, an elevation mask equal to 5° was applied. Table 3 reports the results of the contacts assessment simulations in terms of length and number of contacts between the spacecraft and each ground station.

Table 3: Average and total length and number of passages per day

Station Location	Max. length	Avg. length	Min. # of passages/day	Max. # of passages/day	Avg. # of passages/day
TM & TC Station	10.3 min	8.0 min	4	6	4.7
Payload Data Station	10.3 min	8.2 min	10	12	10.2

3 OPTICAL PAYLOAD

The tasks that the INFINITY payload must be able to execute are: i) taking a batch of pictures of celestial bodies of astronomical interest, like galaxies, nebula, variable stars, comets and asteroids; ii) dynamically adjust the sensor placement in the focal plane to maintain the target object within the stability requirements margin; iii) saving and storing the raw batch of pictures internally; iv) processing the group of images taken from a single observation and merge them into one final high-quality product.

The payload architecture encompasses a group of functional components, including the electronics for data storage and processing, integrated within a single opto-mechanical assembly:

- a CMOS monochromatic sensor coupled with a H-alpha filter, needed for nebula observation.
- Optics in a catadioptric configuration, with spherical lenses (Schmidt-Cassegrain), capable to generate more compact solutions, best suitable for small satellite missions. The selected optical configuration is in the small optical ratio range, between f/2.1 and f/5.
- Sensor linear actuators, meant to be used as fine focal plane control stage, to reach the desired level of pointing stability.
- A processing computer that hosts an implementation of astrophotography algorithms, allowing an on-board preliminary processing of the raw batch of pictures for every observation session.
- A memory unit, needed to save the batch of raw photos taken during the observation sessions and the ones generated as output of the processing algorithm hosted by the processing PC.

Several sensors suitable for this application have been considered for the payload and mission preliminary study presented hereafter: AMV's CMV4000 and CMV12000, both radiation-tested; Fairchild Imaging's Cis2521, used in the astro-photography payload of the JPL Asteria mission; Canon's 35MMFHDXS, with flight heritage from previous missions; Sony IMX294CJK, widely used

in ground-based astrophotography; Teledyne's Emerald 67M, from Teledyne, as a high end of the resolution range.
Some further details are available in Table 4.

Table 4: Sensors main technical features

	35MMFHDX	**CMV4000**	**Cis2521**	**IMX294CJK**	**CMV12000**	**Emerald 67M**
Pixels	2160x1280	2048x2048	2592x2192	4144x2822	4096x3072	8192x8192
Size [mm]	36.5 x 20.5	11.3 x 11.3	16.9 x 14.2	19.2x13.1	22,5 x 16,9	20.5 x 20.5
Pixel size	19 μm	5.5 μm	6.5 μm	4.63 μm	5.5 μm	2.5 μm
ADC [bits]	16	8/10/12	22	14	8/10/12	8/10/12

To limit payload complexity and enhance its reliability we expect fixed optics with a frozen focal length and thus FOV. To size the FOV, a trade-off has been performed based on the angular size of a subset of objects of the most interest for the amateur astronomy community in the Messier catalogue (see Figure 3).

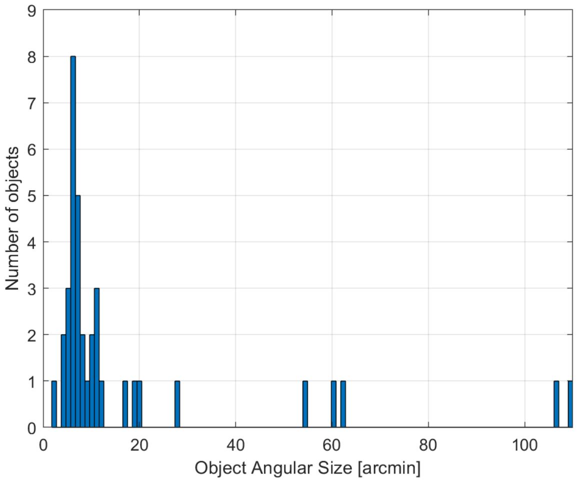

Figure 3: Target objects average angular size distribution

Based on this analysis, the 83.8% of the objects have an angular dimension between 0 and 20 arcmins. So 20 arcmins is used as a lower end of the range of FOV to size the payload optics, while the angular dimension of the largest object in the catalogue, the Pleaides, of 110 arcmins (~1.83°) width, were taken as upper end FOV.
Assuming a microsatellite platform with a payload volume for in the order of 320 x 320 x 320 mm^3 and constraining the maximum optical aperture to 280 mm, a series of potential focal lengths and focal ratios have been derived and reported in Table 5 for FOV=110 arcmin, since sizing around the narrower FOV leads to focal ratios exceeding the identified range F/2.1 to F/5.

Table 5: Imager/optics coupling parameters for FOV=110 arcmin

Sensor	Total FOV[arcmin]	Pixel scale [arcsec]	Focal length [mm]	Focal Ratio
35MMFHDXS	195.55 x 110.00	5.16 x 5.16	645.44	F/2.3
CMV4000	110.00 x 110.00	3.22 x 3.22	354.18	F/1.3
Cis2521	130.07 x 110.00	3.01 x 3.01	448.23	F/1.6
IMX294CJK	161.51 x 110.00	2.34 x 2.34	411.11	F/1.5
CMV12000	146.45 x 110.00	2.15 x 2.15	531.58	F/1.9
Emerald 67M	110.00 x 110.00	0.80 x 0.80	644.19	F/2.3

3.1 Payload Operations and Data Volume

The payload operations are organized in a series of observation sessions lasting 30 minutes each. Within this interval, the payload is asked first to perform a series of “support” pictures, that will be used to calibrate and process the observation session products, and then the actual batch of raw images of the target body. Within each observation session, only one celestial body will be targeted at a time. The post-acquisition processing activities will be executed by the processing computer in the intervals between the observation sessions. The processing pc will host astrophotography algorithms which will preliminary process the batch of raw pictures into a single final product.

Due to the orbital and attitude dynamics, space-based astro-photography suffer from a reduced amount of time available to perform a continuous exposure of the sensor to the light source, if compared with ground-based observation sessions. The principle of the long-exposure photography is based on the capability of the imager to collect the light and to sum it for long time periods, allowing to detect and acquire celestial objects way better than at naked eye. The strategies proposed for the INFINITY mission, are based instead on the short-exposure photography, also called “lucky imaging”, which compensate the short shutter time with a high number of pictures obtained in sequence of the same object. Combining these pictures with dedicated astro-photography algorithms, which perform a correlation between consecutive pictures taken of the same target, it is in principle possible to obtain a final picture of a quality comparable with the traditional ground-based long exposure technique, drastically reducing the sensor exposure from 30 minutes to a series of shots of a few seconds. This means that there is no need to extend the pointing stability requirements to the entire observation session, only within the single sensor exposure time.

Exposure time depends on a series of variables, like telescope aperture, focal length, optics luminosity, and the type of target. It is practically impossible to determine a single exposure time that fits all possible target objects: for this reason the exposure time on-board will be an adjustable parameter during the mission, whose value will be changed based on pre-programmed payload internal assessments or external command from ground.

The two types of “service pictures” that must be taken within each observation session are:

- «Dark» frames: with exposure times typical of astrophotography, the imager heats up and some “burned” (”hot”) pixels appear, i.e. pixels detecting light even if they are not actually hit by the light coming from the target object. To remove this noise effect from the final products, a series of so called “Dark Frames” are necessary and can be obtained by closing the shutter and taking some pictures with the same exposure time of the regular pictures.
- «Bias» frames: they contribute to the removal of the sensor electronic noise. They can still be obtained by taking a series of pictures while the «black cover» of the shutter is in place. In this case the noise to be eliminated is not dependent on the exposure time and the Bias Frames can be obtained with exposures in the order of fractions of a second.

The amount of payload data generated each revolution is given by:

$$Data\ Volume = \left(N_{px} \cdot bits_{ADC}\right)_{Mb} \cdot n_{pics} \cdot n_{obs}, \qquad \text{Eq. 1}$$

where N_{px} is the number of pixels for each sensor, $bits_{ADC}$is the amount of bits used to converts the signal from analog to digital, $n_{pics}$is the number of pictures taken for each batch (including also 5 "full exposure" dark frames and 5 "fast" bias frames) and n_{obs} is the number of observation session. The data volumes collected in 1 orbit with each sensor, expressed in Mbit, are displayed in Figure 4 as a function of the variable shutter time, in the range 1 sec to 60 sec.

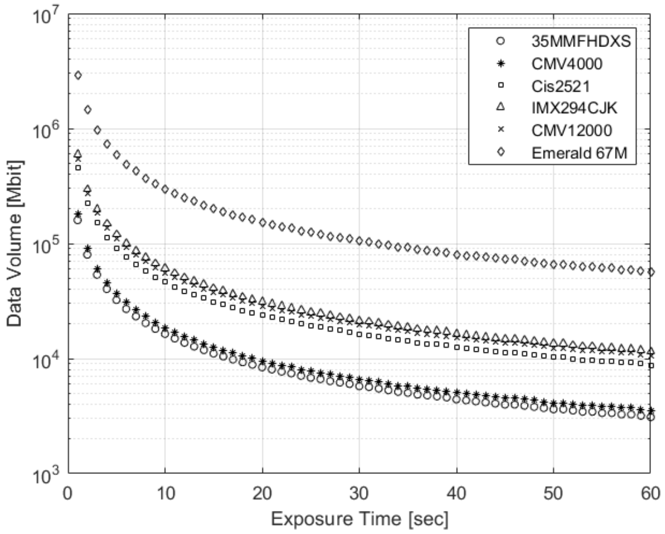

Figure 4: Payload data volume collected in 1 orbital period

3.2 Payload stabilization technology

The pointing accuracy and stability requirements are mainly dictated by the need for locking the payload LOS onto the celestial target within 1 IFOV (i.e. 1 pixel angular aperture) during the exposure time, and can be summarized as follows:

- The payload orientation control and knowledge shall be accurate enough to acquire the target object in the field of view.
- The payload shall be operated maintaining the target object within the same group of pixels field of view for the entire image acquisition interval.

Before the beginning of the observation session, the spacecraft attitude control system will perform a pointing maneuver to acquire the selected celestial object in the payload field of view. Due to the nature of the targets to be pointed, the attitude control strategy will be purely inertial. Once the reference attitude is obtained for a given celestial target, during the 30 minutes observation the spacecraft maintains the fixed attitude, by applying correction maneuvers, at system and payload level, to contrast the effect of the environmental torques. The effect of external disturbances would result into a displacement of the targeted celestial body in the image plane while the shutter is open, an effect that must be minimized to ensure a good image quality.

To this end, a two-stage attitude control mode is envisaged for INFINITY during the observation sessions: at bus level, using reaction wheels, and at payload level, using a set of actuators/sensor, independent from the bus attitude control (Figure 5).

Following the successful approach implemented by JPL ASTERIA mission [1], the aforementioned pointing requirements could be fulfilled using a dedicated "Fine" attitude control at payload level, which will stabilize the focal plane of the payload. It will exploit a copy of the sensor used for astrophotography placed in the same focal plane, but operating at higher frame rate to detect the displacement of the target in the sensor FOV. It will then contrast the displacement using a dual-axis piezoelectric linear actuator in closed loop to maintain the target within the same pixels group.

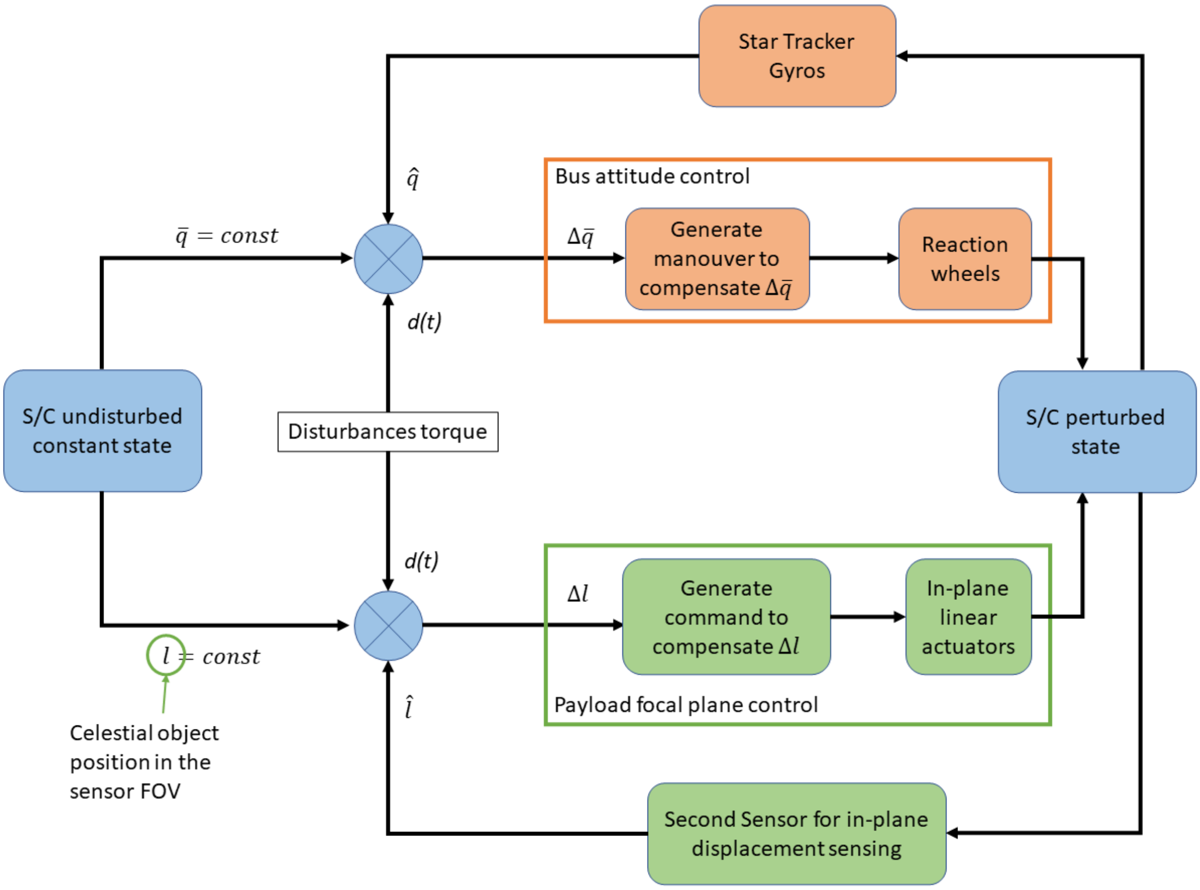

Figure 5: Payload pointing control logic at bus level and at payload level

4 BUS SUBSYSTEMS ANALYSIS

4.1 ADCS

The need of high pointing accuracy and maneuverability suggests for INFINITY a 3-axis zero-momentum attitude control strategy.

The attitude determination will be performed using a couple of star sensors in cold redundancy coupled with a three-axis gyroscope. Additionally 2 sun sensors and 1 triaxial magnetometer will be included as a back-up sensor suite in case of unavailability of the star-trackers. The control hardware includes 4 reaction/momentum wheels and 3 magnetorquer rods for wheels desaturation.

As described in Section 3.2, the pointing requirements will be partially handled by the bus control system and partially by the payload sensor plane positioning through a piezoelectric stage, with different levels of accuracy.

According to such dual-stage approach, the top-level objective of the bus-level ADCS is that of guaranteeing, during the exposure time, a pointing stability compatible with the maximum stroke of the sensor plane fine positioning control. In particular, three main pointing requirements for the bus ADCS have been identified, which are expressed as a function of the sensor characteristics (size and number of pixels) and FOV:

- Pointing Error: below +/-25% of the total payload FOV;
- Pointing Knowledge: below +/-10% of the total payload FOV;
- Pointing Stability: 1 IFOV over the sensor exposure time.

As discussed in Section 3.1, the pointing stability is expressed over the length of the single exposure time (e.g. a few seconds), rather than the entire observation session length. The expression of the pointing requirements with absolute values can be found in Table 6 and in Table 7, based on the sensors and FOV analyses previously discussed.

Table 6: Pointing Error and Knowledge absolute requirements for FOV=110 arcmin

Pointing Error	Pointing knowledge
±27.5 arcmin	±11 arcmin

Table 7: Pointing Stability absolute requirements for FOV=110 arcmin

35MMFHD	CMV4000	Cis2521	IMX294CJ	CMV12000	Emerald67M
5.16 arcsec	3.22 arcsec	3.01 arcsec	2.34 arcsec	2.15 arcsec	0.80 arcsec

4.2 Telecommunication subsystem

Based on the estimation of the data volume generated by the payload presented in Chapter 3, here the INFINITY communication subsystem architecture is discussed. Preliminary data rate and link budget are estimated, given the selected data delivery strategy. The INFINITY mission will implement two telecommunication segments:

- Segment for TM&TC operating in UHF frequencies. Data rate expected in the range 4.8 kbps – 154.3 kbps for telemetry downlink and 4.8 kbps – 77.2 kbps for telecommands uplink.
- Segment for payload data downlink operating in X-Band with a maximum data rate of 100 Mbps.

Given the estimations of daily averaged contacts length and number with the high-latitude Payload Data Station considered, provided in Chapter 2, the daily averaged preliminary data rate value can be obtained as:

$$Data\ Rate|_{avg\_day} = \frac{Data\ Volume|_{orbit} \cdot N_{orbits\_per\_day}}{N_{contacts\_per\_day} \cdot Contact\ length|_{average}} \qquad \text{Eq. 2}$$

This represents the minimum data rate value to be achieved by the on board telecommunication apparatus in order to satisfy the 24hrs downlink latency requirement: the assumption is that the spacecraft must be able to transfer the entire data volume collected in one day within the contacts available in a 24hrs window. The requested data rate values are computed for each investigated sensor and with a variable shutter time in the range 1 second to 60 seconds. The computed data rate values are based on an a preliminary estimation of the raw data volume, without considering any loss-less on-board compression, which may contribute to significantly reduce the size of the data package to be downloaded and the data rate.

For the on-board segment a commercial patch antenna specifically designed for small satellites was selected [3], while for the ground antenna a commercial X-Band parabolic reflector dish was selected, with a diameter D=3.7 m and G/T=27 dBK [2]. A transmission power at HPA output equal to 2W was considered [4] and a downlink frequency of 8200 MHz. Figure 6 displays the Eb/N0 values for different sensors as a function of the sensor exposure time.

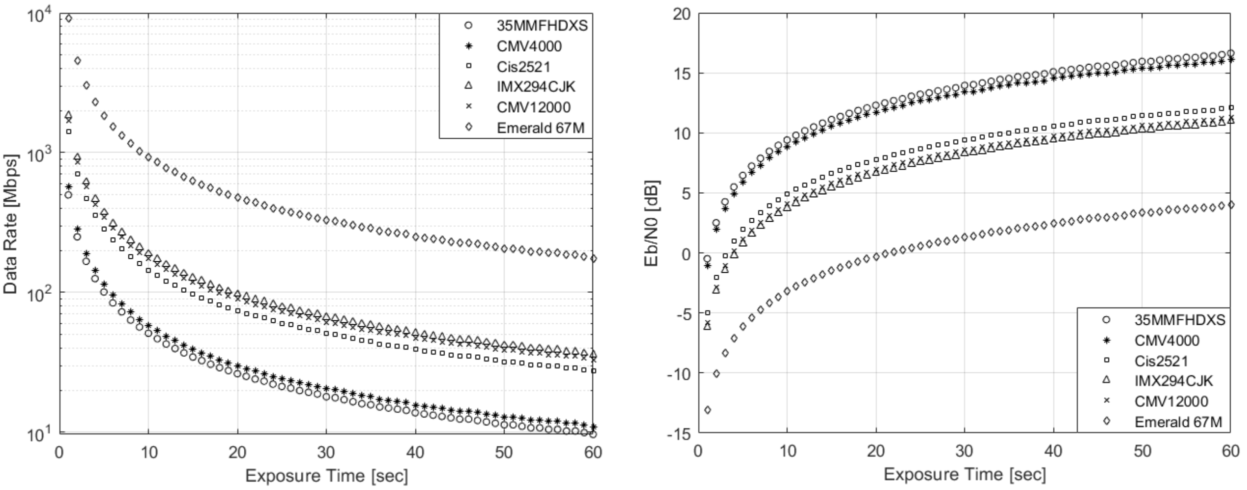

Figure 6: Link assessment expressed in terms of data rate (left) and Eb/N0 (right) as functions of shutter time, computed for each sensor

4.3 EPS

As discussed in Chapter 2, the only operational phase which is guarantee to contribute to collecting solar energy is the Secondary Observations Session, set to be operated with a maximum offset angle of 30° with respect to the Sun, and the telecommunication region. For this last, the sun-exposure angle of the solar panels varies in a year from 0°, when the so-called beta angle[1] is maximum, and 31.23°, when the beta angle is minimum. These values were obtained from geometrical considerations, based on the orbit inclination and precession dynamics and the Sun declination yearly variation.

Table 8 shows the preliminary energy budget obtained from COTS components or data from previous missions.

Table 8: Preliminary Energy Budget

Subsystem (with power margin)		**Power on time [sec]**	**Expected power consumption [W]**	**Expected energy consumption [J]**	**Source**
Payload (30%)		3600	13.8	49608	[9]
ADCS	Star tracker (10%)	5789	1.65	9551.85	[6]
	Gyros (20%)	5789	1.8	10420.2	[4]
	Reaction wheels (slew) (10%)	1080	6.6 x 4 wheels	28512	[6]
	Reaction wheels (nominal) (10%)	4709	3.3 x 4 wheels	62158.8	[6]
	Magnetorquers (10%)	4341	0.96 x 3 rods	12463.011	[8]
	Magnetometers (10%)	868	1.1	954.8	[7]
OBC (10%)		5789	0.55	3183.95	[10]
Telecomm – UHF (beacon mode) (10%)		4741	2.53	11994.73	Heritage
Telecomm – UHF (TM and TC mode) (10%)		625	9.9	6187.5	Heritage
Telecomm – X Band (20%)		625	14.4	9000	[4]
GPS Receiver (10%)		600	3.3	1980	[5]
Thermal Control (30%)		2189	13.8	30164.42	Thermal analysis
Total				**236179.06**	

---

[1] The beta angle is defined as the angle between the orbital plane and the Earth-to-Sun vector.

By assuming a microsatellite configuration with an external volume of 32x32x64 cm, a total solar array surface of 0.614 m^2 can be obtained, composed of 3 aligned panels of 32x64 cm^2 each. The energy request is composed of:

- a contribution that will be stored and supplied by the battery pack, during primary observation session and the slew maneuvers;
- a contribution supplied to the equipment directly by the solar array, during secondary observation and the telecommunication window.

The sum of the energy of the two power profiles, scaled by their respective conversion efficiency, is $Energy_{req} = 320.6\ kJ$. The energy that can be collected by the solar surface in an entire orbit, in the worst case beta min scenario, given the exposure assumptions discussed before, is $Energy_{available} = 408.9\ kJ$.

It is now possible to compute the actual margin for the worst case “beta min” scenario:

$$Energy\ margin_{beta\ min} = \frac{Energy_{available} - Energy_{requested}}{Energy_{available}} = 22\ \% \quad \text{Eq. 3}$$

This result demonstrate the feasibility and energetic sustainability of a concept of operations designed to satisfy the demanding INFINITY requirements in terms of payload duty cycle and data delivery: it is theoretically possible to allocate two 30-minutes long observation sessions and downlink operations every orbit.

5 FUTURE DEVELOPMENTS: FINE OPTICAL STABILIZATION APPLIED TO EARTH OBSERVATION

The line-of-sight (LOS) stabilization through piezo-electric actuation is the main enabling technology for INFINITY. Nonetheless, it can find application beyond that of astronomical observations, most notably in Earth Observation (EO) missions based on micro/nano-satellite platforms.

Ultra-fine pointing control for EO can be even more demanding, as it must compensates not only for the attitude jitter, but also for the payload-to-ground LOS variation due to the orbital motion. Indeed, the so-called *forward motion compensation* (FMC), is a well-known issue in airborne and space-borne imagery, which is regaining attention due to the increasing interest on small satellites for high quality EO missions [11],[12]. The requirement is still that of maximizing the time frame during which the LOS motion is maintained below 1 IFOV, to allow for longer exposure times, thereby increasing the image signal-to-noise ratio. Failing to fulfill such constraint results into a significant *motion blur*, thus degrading image quality.

As a spin-off of the INFINITY study, we are currently undertaking the conceptual design of a FMC system based on piezoelectric focal plane stabilization. The working principle consists of actuating the focal plane with a periodic motion having the same frequency of the frame-rate and with suitable amplitude and profile, to create a time window in which the relative ground motion of the LOS is practically canceled. Such window, which is repeated at the sensor motion frequency can then be used for image acquisition. The concept of FMC via periodic LOS motion has been recently applied in [12], there applied using voice-coils actuation following a fairly complex calibration procedure.

The choice of the piezo-stage motion profile and of its amplitude depends both on the ground scan-rate of the instrument (thus, on the orbit, the observation latitude, the platform attitude profile) and on the swath-area and resolution, which determines the apparent image motion in pixels. The study and optimization of the motion profile is the subject of the ongoing development.

6 CONCLUSIONS

The main objective of this work is the description of the INFINITY microsatellite mission concept, highlighting the technical challenges that were addressed to satisfy the ambitious mission requirements. The mission goal is to perform celestial objects photography from an orbital platform achieving a quality of the final product comparable with the one obtainable with ground based long exposure techniques and equipment, with the advantage of providing an access to the observation sessions that is only dependent on the payload booking availability.

First, the spacecraft operational workflow was characterized, by identifying a suitable orbital solution, a concept of operations fulfilling the service requirements and the ground segment architecture.

The payload technical characterization was then investigated with a series of trade off studies involving a selection of sensors suitable for this application and different FOV sizing approaches, starting from a focal ratio requirement and an optical aperture constraint dictated by the limited volume available on board of the targeted microsatellite platform. The critical technology aimed at guaranteeing the payload pointing stability was also investigated, highlighting how an unconventional approach based on two pointing control stages is needed to achieve high quality images.

A preliminary sizing and architecture discussion were provided for some spacecraft subsystems, demonstrating the feasibility of such a complex mission with the typical small satellite limited technical resources and by exploiting mainly commercial technologies.

The possible future employment of the INFINITY payload stabilization technology in the field of Earth observation was also discussed, describing the possible operational and technological concept currently under investigation as an internal research project at the University of Bologna.

7 REFERENCES

[1] Pong, C. “On-Orbit Performance & Operation of the Attitude & Pointing Control Subsystems on ASTERIA”, 32nd Annual AIAA/USU Conference on Small Satellites, 2018.

[2] https://www.ksat.no/

[3] http://www.anywaves.eu/wp-content/uploads/2020/02/ANYWAVES-Technical-Data-Sheet-X-Band-Antenna-2020-V1-1.pdf

[4] https://www.endurosat.com/cubesat-store/cubesat-communication-modules/x-band-transmitter/

[5] Locarini. A. “Design, development and testing of a GPS-based navigation subsystem for microsatellites missions”, PhD Thesis, 2017

[6] https://www.bluecanyontech.com/static/datasheet/BCT_DataSheet_Components_ReactionWheels.pdf

[7] http://www.spacequest.com/attitude-determination-control/mag-3

[8] http://www.newspacesystems.com/wp-content/uploads/2020/04/NewSpace-Magnetorquer-Rod_7b.pdf

[9] Optical Payloads for small satellites: a sector overview. Available online at: https://blog.satsearch.co/2020-03-25-optical-payloads-for-small-satellites.

[10] https://www.cubesatshop.com/product/isis-on-board-computer/

[11] Haslehurst, A., Bird, R., Wood, T., Whiting, C., Mero, B., Rana, H., ... & Sweeting, M. (2021). DarkCarb: An Innovative Approach to Infrared Imaging.

[12] Linden, P., Smith, N., & Rohrbach, T. (2021). Automatic Optical Image Stabilization System Calibration, Validation, and Performance for the SkySat Constellation.