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TIRA – a compact Thermal InfraRed imager for Asteroids
Technical Proposal

Submitted by: VITO (Belgium)

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V1.0	10/10/2018		Final version for submission
V1.1	25/01/2019		New version after descoping instrument to TIR

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LIST OF TERMS, DEFINITIONS AND ABBREVIATIONS

ARR	Assembly Readiness Review
CDR	Camera Detailed Review
CHIB	Compact Hyperspectral Imager Breadboard
CHIEM	Compact Hyperspectral Imager Engineering Model
CMOS	Complementary metaloxide semiconductor
COSI	COmpact Spectral Imaging solution
COTS	Commercial Off The Shelf
CPR	Camera Preliminary Review
DR	Design Review
DN	Digital Number
EGSE	Electrical Ground Support Equipment
FIDELHEO	Filter DEposition on chip for Lightweigth Hyperspectral Earth Observers
FM	Flight Model
FPA	Focal Plane Array
FP	Final Presentation
FR	Final Review
GNC	Guidance, Navigation and Control
GSE	Ground Support Equipment
GSTP	General Support Technology Programme
HW	Hardware
TIRA	compact Thermal infrared Imager for Asteroids
I/F	Interface
ITT	Invitation to tender
KO	Kick-off
LVF	Linear Variable Filter
MAIT	Manufacturing, Assembly, Integration and Tests
MRR	Mission and Requirements Review
MRTD	Minimum Resolvable Temperature Difference
NEO	Near-Earth Object
NIR	Near InfraRed
OGSE	Optical Ground Support Equipment
RD	Reference Document
ROD	Review Of Design
SoW	Statement of Work
SW	Software
SWIR	Short-Wave InfraRed
TIR	Thermal InfraRed
VITO	Flemish Intitute for Technological Research
VNIR	Visible-Near-InfraRed

CHAPTER 1 INTRODUCTION

1.1. PURPOSE OF THIS DOCUMENT

This document is the technical proposal submitted by VITO and its subcontractors in reply to the ESA ITT AO/1-9522/18/NL/AR [AD3] with its SOW [AD2]. The project will be referred to as the “TIRA” project.

1.2. APPLICABLE DOCUMENTS

[AD1]	The General Clauses and Conditions for ESA Contracts (herein referred to as GCC), reference ESA/REG/002, rev. 2 not attached hereto but known to both Parties and available on http://emits.sso.esa.int/emits/owa/emits.main) “reference documentation” – “administrative documents”, as amended by this Contract
[AD2]	The Statement of Work “BREADBOARD OF AN HYPERSPECTRAL CAMERA FOR DUAL USE AS SCIENTIFIC PAYLOAD AND GNC SENSOR”, reference: ESA-GSTP- TECMMO-SOW-010535, issue 1, dated 26/07/2018
[AD3]	The VITO Proposal reference TAP/HYPTIRA/16498/TECH dated 10/10/2018
[AD4]	MOM of clarification telco of the evaluation outcome concerning AO1-9522 (14/12/2018)
[AD5]	Revised requirements (email by Alessandro Zuccaro Marchi, 19/12/2018 [GSTP CHYTI] requirements with descoping to TIR_v2)

Table 1: List of Applicable documents

1.3. REFERENCE DOCUMENTS

[RD1]	FIDELHEO (Filter DEposition on chip for Lightweight Hyperspectral Earth Observers) – final report 19/01/2015, ESA contract 4000107525/13/SFe
[RD2]	ButterflEYE LS S199 datasheet: “Real-Time Spectral Imaging: Introducing the ButterflEYE LS” Cubert GmbH
[RD3]	Compact Hyperspectral Imager Breadboard Final Report". CHIB.TR.AMO.003 – TN4. ESA contract 22859/09/NL/VS
[RD4]	ESA AO/1-7793/14/NL/SW: ITT: “Technologies and key components for Compact Hyperspectral Instruments”
[RD5]	Hera: Mission Requirements Document (23/05/2018; ESA-TECSP-RS-009704)

Table 2: List of Reference documents

1.4. OTHER REFERENCES

Gil-Fernandez, Jesus, and Guillermo Ortega-Hernando. 2018. "Autonomous Vision-Based Navigation for Proximity Operations Around Binary Asteroids." CEAS Space Journal, February. Springer Vienna, 1–8. doi:10.1007/s12567-018-0197-5.
M. Marshall, P. Thenkabail, Advantage of hyperspectral EO-1 Hyperion over multispectral IKONOS, GeoEye-1, WorldView-2, Landsat ETM+, and MODIS vegetation indices in crop biomass estimation, ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 108, Pages 205–218, Oct. 2015

Michel, P., A Cheng, M Küppers, P Pravec, J Blum, M Delbo, S F Green, et al. 2016. "Science Case for the Asteroid Impact Mission (AIM): a Component of the Asteroid Impact & Deflection Assessment (AIDA) Mission." Advances in Space Research, April. COSPAR, 1–19. doi:10.1016/j.asr.2016.03.031

Okada, Tatsuaki, Tetsuya Fukuhara, Satoshi Tanaka, Makoto Taguchi, Takeshi Imamura, Takehiko Arai, Hiroki Senshu, et al. 2017. "Thermal Infrared Imaging Experiments of C-Type Asteroid 162173 Ryugu on Hayabusa2." Space Science Reviews, June. The Author(s), 1–32. doi:10.1007/s11214-016-0286-8

Tsuchiyama, A. 2014. "Asteroid Itokawa a Source of Ordinary Chondrites and a Laboratory for Surface Processes." Elements 10 (1): 45–50. doi:10.2113/gselements.10.1.45.–63. doi:10.2458/azu_uapress_9780816532131-ch003.

CHAPTER 2 UNDERSTANDING OF THE TECHNICAL REQUIREMENTS

2.1. PROJECT BACKGROUND

Hera – named after the Greek goddess of marriage – is a candidate ESA mission planning to rendezvous with a binary asteroid system, a little understood class making up around 15% of all known asteroids. Hera would fly to the Didymos pair of Near-Earth asteroids: the 780 m-diameter main body is orbited by a 160 m moon, informally called 'Didymoon'.

The smaller Didymoon is Hera's main focus: the spacecraft would perform high-resolution visual, laser and radio science mapping of the moon, which will be the smallest asteroid visited so far, to build detailed maps of its surface and interior structure.

By the time Hera reaches Didymos, in 2026, Didymoon will have achieved historic significance: the first object in the Solar System to have its orbit shifted by human effort in a measurable way. A NASA mission called the Double Asteroid Redirection Test, or DART, is due to collide with it in October 2022. The impact will lead to a change in the duration of Didymoon's orbit around the main body. Ground observatories all around the world will view the collision, but from a minimum distance of 11 million km away.

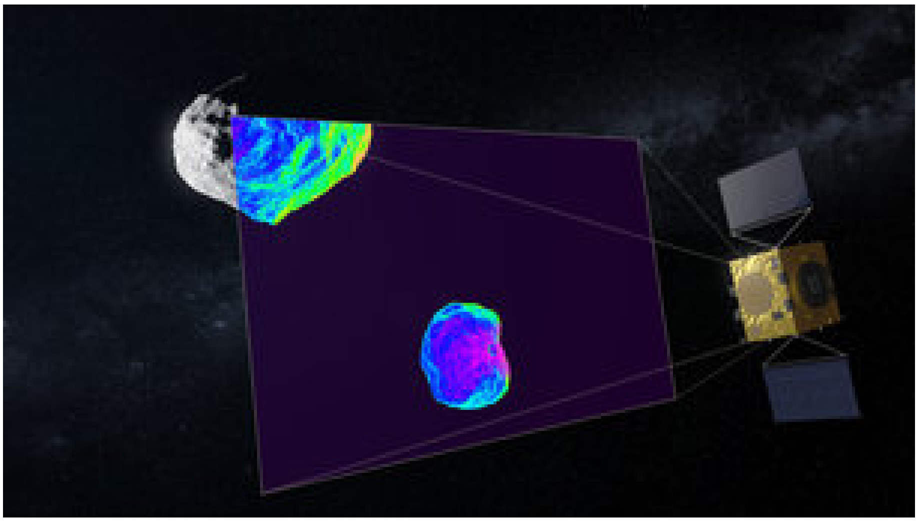

Figure 1 Infrared imaging of the impact crater by the HERA satellite

The goal with Hera is to determine the mass of Didymoon, the shape of the impact crater, as well as physical and dynamical properties of Didymoon. This experiment is essential to investigate the planetary defence technique in order to stop an incoming asteroid if needed. The Hera mission will host different instruments for science and navigation, amongst which the one covered in this proposal: a compact Thermal InfraRed (TIR) imager.

Surface characteristics can be obtained through thermal imaging from which thermo-physical properties of the uppermost surface can be deduced. Surface and near subsurface composition and in particulur grain size and porosity affects the thermal behaviour. Low surface thermal inertia indicates typically high porosity or fine sands as those observed on the surfaces of Ceres and Moon respectively. On the other hand, denser materials similar to those found on Itokawa rough terrain typically have higher thermal conductivity and have higher thermal inertia. Thermo-physical properties of the uppermost planetary surface can be obtained from thermal emission but direct observations are limited despite recent explorations. Hayabusa 2 carries a TIR imager in the range of 8-12 µm to obtain a precise map of the thermal behaviour of the surface (Okada et al., 2017). Temporal and spatial variability of surface thermal signature allow to deduce physical properties of the regolith including the cohesion mechanism, grain size distribution, formation of surface sedimentation as well as Yarkovsky/YORP effects. In addition, thermo-physical properties of boulders (originates from parent body interior) and crater interior (indicator of current interior structure) provide constrains on the interior density structure. The TIR imager has the potential to increase the science return significantly. TIRA would also assit near- surface operations providing vision-based navigation.

Small body missions require higher level of autonomy in the Guidance, Navigation and Control (GNC) system for higher scientific return and lower operational costs (Gil-Fernandez and Ortega-Hernando 2018). The trajectories for the proximity operations shall be intrinsically safe to avoiding collision in case of operational system failures and maneuver execution errors as well as unmodelled perturbations due to irregular gravity field. The trajectory relative to the asteroid can be determined using a vision-based navigation algorithm with an onboard camera. A TIR imager could be in particular very useful for this purpose during close proximity operations, provided that it can allow with high precision to determine the centre-of-brightness, limb extraction (allowing distance-from-size estimation) as well as as well as pattern recognition and tracking several surface features simultaneously under all illuminations conditions including the night side.

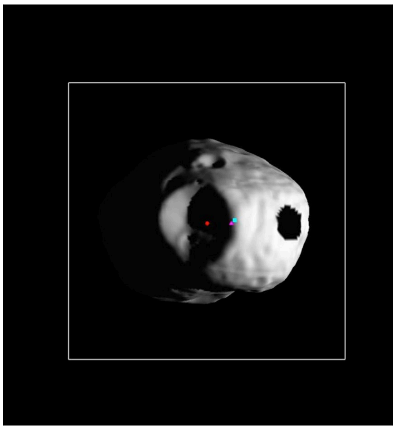

Figure 2: Image processing results showing window size, true Center of Mass (circle), IP-computed Center of Body (triangle) and estimated Center of Body (light square). Image shows shadows on primary due to its non-convex shape and the secondary asteroid (Gil-Fernandez and Ortega-Hernando 2018).

Thermal InfraRed imager – uncooled bolometers

Particularly interesting for the development of a compact TIR imager are the microbolometer arrays which can operate in uncooled conditions. One of our partners, OIP, has years long experience with the development and production of TIR cameras for defence applications (see OIP company description). Based on the heritage related to the development of small cameras for use in space (navigation and monitoring), OIP have the knowledge to adapt the TIR cameras for use in a space environment.

The OIP product portfolio contains TIR cameras making use of an uncooled sensor from ULIS. This camera family is called “EOPTRIS”. The main optical characteristics of EOPTRIS are summarized in Table 3. EOPTRIS contains a dual fixed field of view (WFOV and NFOV) and has image stabilization provisions (focusing mechanism).

OIP has the relevant experience and equipment to test this TIR camera.

Specification	**Value**
Sensor type	Uncooled LWIR sensor from ULIS
Sensor pitch	17 µm
Number of pixels	640 x 480
Focal length (NFOV)	135 mm
NFOV	4.6° x 3.5°
Functionality & features	- Digital zoom x2 and x3 - Video polarity change - Manual focus control (near / far), focus to infinity, auto focus on request of the operator. - Non uniformity correction at start-up for both FOV and manual non uniformity correction on request. - Gain and level control (auto and manual) - Gamma control

Table 3 characteristics of TIR camera for breadboard

2.2. PROJECT OBJECTIVES

The overall rationale of the TIRA project is to implement the camera design and develop the breadboard of a TIR imager to be used within the Hera mission. Such an instrument should address two aspects: the characterisation of small bodies of the Solar system (such as Didymos asteroid) and its use for spacecraft navigation purposes, especially in proximity operations.

2.3. CHALLENGES OF THE STUDY

In this section we list and describe the main challenges for the TIRA study. They are based on the description of the instrument as given in the SOW [AD2] and the requirements imposed on the instrument as described in the Hera MRD [RD5].

Challenge 1: Compatibility (engineering budgets [mass, volume, power, data link,..] and concept of operation of instrument) of the TIRA instrument with S/C
In the study we will investigate the constraints imposed by the mission in respect to the instrument development.

Challenge 2: Overall performance of the TIR channel
The performance of the camera needs to be evaluated through simulations and testing and then confronted with the Hera mission requirements.

Challenge 3: Image product generation on-board of the platform
The GNC demands rapid on-board image processing for position determination. Because of the limited datalink to Earth, it will be important to reduce the total data amount by on-board data processing and obtain final science data products for down link

Challenge 4: Instrument performance and end product quality (scientific + navigation)
The study will obtain relevant image data through execution of performance testing and simulation to investigate the performance of the instrument and obtain data as input for the data processing.

Challenge 5: Calibration of uncooled TIR imager (navigation and or scientific use)
The temporal responsivity behavior of the uncooled micro-bolometer array will be investigated. If needed a blackbody calibration source will be included in the design. Special care needs to be taken because of the compactness of the instrument.

ID	Challenge	Verification method
1	Compatibility (engineering budgets [mass, volume, power, data link,..] and concept of operation of instrument) of the TIRA instrument with S/C	ROD
2	Overall performance of the TIR channel	Analysis and testing
3	Image product generation on-board of the platform	Analysis
4	Instrument performance and end product quality (scientific + navigation)	Analysis and testing
5	Calibration of uncooled TIR imager (navigation and or scientific use)	Analysis and testing

Table 4 List of challenges for the study and how they will be investigated.

CHAPTER 3 PROPOSED ACTIVITIES AND STUDY PLAN

3.1. PROPOSED CONCEPT

The goal of the project is to make a detailed design of a compact TIR imaging instrument for the Hera mission. The instrument will work as a GNC sensor but will also perform scientific measurements. It will be part of this study to investigate how the instrument needs to be operated and to establish the needs for (on-board) data processing. A representative breadboard will be provided and used for testing the performance of the camera. Simulated images will be used to investigate the on-board data processing algorithms.

3.2. TIR SENSOR

The TIR sensor that we propose for the flight camera is the 1024 x 768 pixel, 17 µm pitch uncooled microbolometer from ULIS.

In order to fit within the time constraints of the project, the breadboarding activities will be done with an existing EOPTRIS camera from OIP. This TIR camera contains a 640 x 480 pixel ULIS microbolometer with 17µm pitch.

3.3. TIR OPTOMECHANICAL DESIGN

The design of the TIR camera will be based on the use of the abovementioned uncooled microbolometer.
It will be part of this study to investigate wether the requirements on SNR and spatial resolution can be met with a reflective telescope. If with such an objective the minimum achievable f number is too big to meet these requirements, an a-thermalized objective will be designed instead.
The optical performance parameters will be derived, and a ghost straylight analysis will be performed. A more detailed straylight analysis will be performed during the next project phase, as these analyses cannot be done within the time and cost boundaries of the present project.
The mechanical housing of the camera will be designed, taking into account the tolerance analysis of the optical design and the thermal aspects. Thermo-mechanical and structural analyses will be performed during the succeeding phase of the project.

3.4. ROE

During this project the design activities of the FPA-ROE of the TIR camera will include:

- Perform schematics design
- Define preliminary Firmware architecture (Risk and feasibility analysis, functional block diragram)
- Prepare preliminary electrical ICD

Within the available time and budget constraints, the following design tasks are not yet included:

- Lay-out of the PCBs
- FPGA FW.

For breadboarding testst, the ROE electronics from EOPTRIS will be used. The ROE contains an FPGA to control and readout the ULIS sensor, to perform image processing and to generate a digital camera link output. For the proposed breadboarding activities, it is the intention to connect the camera link output (30 frames/sec) with a framegrabber to capture the digital images. This ROE for the BB 640 x 480 pixels detector will not be modified during this project.

3.5. IMAGE PROCESSING SW

VITO has ample experience with the data processing of imagery from radiometrically calibrated thermal cameras with an uncooled microbolometer (e.g. Workswell WIRIS 2 and similar cameras equipped with a FLIR 640 sensor with 17 µm pixel pitch, measuring in the 7.5 – 13.5 µm band). These camera's are operated on Remotely Piloted Aircraft Systems (RPAS). During pre-processing, the collected data are validated using quality checks on the raw images and the flight and camera metadata (including onboard GPS data for georeferencing). Thermal images are processed through a structure from motion (SfM) photogrammetry workflow encompassing tie-point extraction and matching, outlier detection and bundle adjustment, optional measurement of additional manual tie-points and ground control points (GCPs), geometric camera calibration, colored dense point cloud generation, point cloud classification into terrain, above ground and noise points, raster digital surface model (DSM) and digital terrain model (DTM) generation, and true orthophoto projection onto the DTM. The resulting 16 bit thermal orthomosaic has pixel values expressed as digital numbers (DN) scaled to temperature (K). This can be done using open-source or commercial SfM photogrammetry software packages on Linux, for which VITO extensively tailored the processing workflow and parameters to handle the thermal data characteristics. Thermal imagery can also be used in a per-frame analysis workflow based on a live image feed using direct georeferencing. In the framework of the H2020 MONOCLE project, VITO developed a workflow running on a portable Linux computer (Raspberry Pi) carried by the RPAS to integrate a live multispectral VNIR image feed together with GNSS/IMU measurements from the RPAS platform and sensor gimbal, enabling real-time on-the-ground image analysis, stitching and camera feedback (e.g. adjusting image acquisition parameters). This system can easily be adjusted to handle a thermal imagery feed. It is our intention to modify the above technique to the conditions expected in the Hera mission concerning the different operations of the instrument and the expected images which are, unlike for the remote sensing on Earth, not covering the whole FOV of the camera.

The IMAGE processing system must be fully compliant with the navigation and scientific performance requirements. A software simulator to render scenes observed by the camera, which can then be used for the assessment of navigation (large distances and close encounters) and scientific performance will be developed. Realistic image simulation will use asteroid and spacecraft trajectory information, a camera model with appropriate radiometric scaling for the Didymoon environment, and 3-D shape models including the thermal properties and response over the asteroid surface. The trajectories will be extracted from the SPICE toolkit[1], including camera positioning and orientation on the spacecraft. Rendering of the scene in 3-D can be done using open-source software, such as Cosmographia[2] and Blender[3]. ROB has experience with both, and early on will weight their advantages to decide between them. The influence of thermo-physical properties will be determined

[1] https://www.cosmos.esa.int/web/spice/spice-for-hera
[2] https://www.cosmos.esa.int/web/spice/cosmographia
[3] https://www.blender.org

by a 1-D thermal model applied across the asteroid surface, which gives the surface temperature resulting from equilibrium between insolation heat flux and radiative losses, taking into account time lag due to thermal inertia. The final simulation software will be able to produce images that consider various thermal inertia values, rock size and shape distributions, and HERA trajectories.

The data processing will need to be performed on board of the Hera satellite before being downlinked to Earth. Different aspects of the data rate, necessary data storage will be included in this analysis. This information will be used as input for the development for an ICU developmemt plan by DELTATEC.

Thanks to its knowledge of Payload Data Handling Unit (PDHU), DELTATEC will support the consortium during the mission requirements and ICU sub-system requirements.
Based on the information received from VITO and OIP, DELTATEC will specify the ICU.
In order to provide the specification, expected inputs (non-exhaustive list) are:

- Electrical HW interfaces (front-end and back-end)
- Data rate at the input, data rate at the output.
- Expected Data storage capacity
- Processing to be performed, and expected computing speed.
- Contribution to the development plan (ICU related tasks)

Based on those inputs, DELTATEC will specify the ICU. In parallel a short survey of existing high-performance Instrument Control Units (ICU) will be performed. Preliminary evaluation of mass, power, volume and processing performances will be part of the study.
If available ICU wouldn't fit the project requirement, DELTATEC could propose existing design tailoring and/or suggest a specific design for the mission.

3.6. "BREADBOARD" ACTIVITIES PLAN

With the testing of the breadboard we aim to obtain relevant data to investigate the requirements imposed on the instrument and for the navigation and scientific purposes. The outcome, together with the detailed design analysis, will be used for the FM development plan.

The effect of the f number of the camera objective will be simulated during breadboarding tests making use of the existing OIP TIR camera, equipped with an a-thermilized refractive COTS objective and 2 different apertures.

As mentioned above, the tests will be done with the ROE that is available at OIP.

Another aspect that will be included in the test campaign is the calibration of the TIR sensor response to investigate the need for an on-board calibration source.

The breadboard tests will be performed with the test equipment is available at OIP:

- MRTD measurement equipment (collimator, various targets & uniform black body source)
- Uniform black body source with 175 x 175 mm clear aperture
- General optical alignment equipment.

The following breadboard tests are foreseen:

MRTD:

The minimum resolvable temperature difference will be derived as follows:

- o The TIR camera is placed in front of a collimator. The collimator is equipped with:
  - A set of bar targets in the collimator focal plane. Each bar target consists of a metal plate with 4 rectangular slits in the horizontal direction and 4 rectangular slits in the vertical direction. There are multiple bar targets, each with a different spatial frequency. (see picture). When looking into the collimator, the targets have an angular resolution of 0.5, 1, 2 and 3 cycles / mrad.
  - Behind the bar targets is a uniform black body source with adjustable temperature.
- o For each target, the following sequence is followed:
  - Set black body temperature to room temperature => no contrast visible
  - Reduce black body temperature until the bar target is just visible on the screen. This temperature is Tminus
  - Increase the black body temperature until the bar target is just visible on the screen. This temperature is Tplus
  - (Tplus – Tminus)/2 is the MRTD for this target
- o As such a curve can be drawn with the on the x-axis the angular resolution and on the y-axis the MRTD.

Non-uniformity calibration:
In this test the TIR camera is placed in front of a uniform black body source with adjustable temperature. A such, a perfect camera would show a uniform image. During this calibration, the offset and gain for each pixel is determined in order to make the image uniform. This calibration is executed for different scene temperatures.

SNR:
The signal to noise ratio can be measured using the MRTD measurement equipment described above. The target with a large clear area should be chosen. The noise present in the system can be measured with the background black body at room temperature. Multiple frames are stored and the variation in the signal on each pixel is a measure of the noise.
The background black body can then be set to a pre-defined temperature. The difference in pixel response with the previous measurement is a measure of the signal.

Optics MTF:
The optics MTF will be derived from the system MTF using the detector MTF values as provided by the detector supplier.

System MTF:
The system MTF can be determined using the MRTD measurement equipment described above. The target with a large clear area and a sharp, straight edge should be chosen.
When looking at this target, the response of the system is a black to white transition across the image. The better the system MTF, the sharper the transition is. By accurately analysing this image, the system MTF can be retrieved.
If a high accuracy is required, it can be considered to record multiple images, each one with the TIR camera slightly rotated (at sub-pixel resolution). This is not a standard working method however.

NeDT:
The noise equivalent temperature can be determined from the MRTD measurement procedure described above, along with knowledge of the f-number of the lens and temperature of the observed scene.

	TIR breadboard
Optical system	Refractive COTS
Detector	640 x 480 pixel ULIS
ROE	EOPTRIS
EGSE	Framegrabber + PC + power supplies

Table 5 Overview breadboard

We do not foresee testing in appropriate radiation or thermal environment conditions within this project.

3.7. STUDY PLAN

The work flow and the different milestones are given in Figure 3. The tasks in the different workpackages are described in the management proposal. In a first phase we plan to review requirements of the Hera instrument and define a compact camera for thermal imaging and GNC purposes. In this phase we will also assess the usage of a reflective versus refractive optics in terms of volume, mass and performances.
After the MRR the preliminary camera design will happen with the definition of the different subsystems and a performance analysis. In this phase the breadboard of the instrument will be defined and assessed in respect to the FM baseline design.
After the CPR meeting, the detailed design activities will start. The optical design of the camera will be made, including a tolerance and image performance analyses. A ghost straylight analyses will be made. The opto-mechanical design of the camera will be made, including the thermal and tolerance constraints impose by the optical design. The ROE design will be performed, including the preparation of a preliminary ICD. In parallel, the image processing algorithms for the GNC and scientific measurements will be defined. This will be used as a first input to define the ICU.
After the CDR meeting, the breadboarding activities will start. The COTS objective will be implemented in the EOPTRIS camera and the breadboard test set-up will be prepared.
With the test campaigns we will investigate the performance of the instrument and compare with the requirements imposed.
Simulated images, based on the asteroid and spacecraft trajectory information, will be used as input for the on-board data processing.
As we are facing a very tight schedule in this project we leave open the option to continue work on the detailed design of the camera and definition of the ICU in parallel to the ongoing test campaign. We would then present those modifications at the FR. The results from the analysis of the design and the testing of the camera will be used in the final phase with the development plan towards a FM instrument.

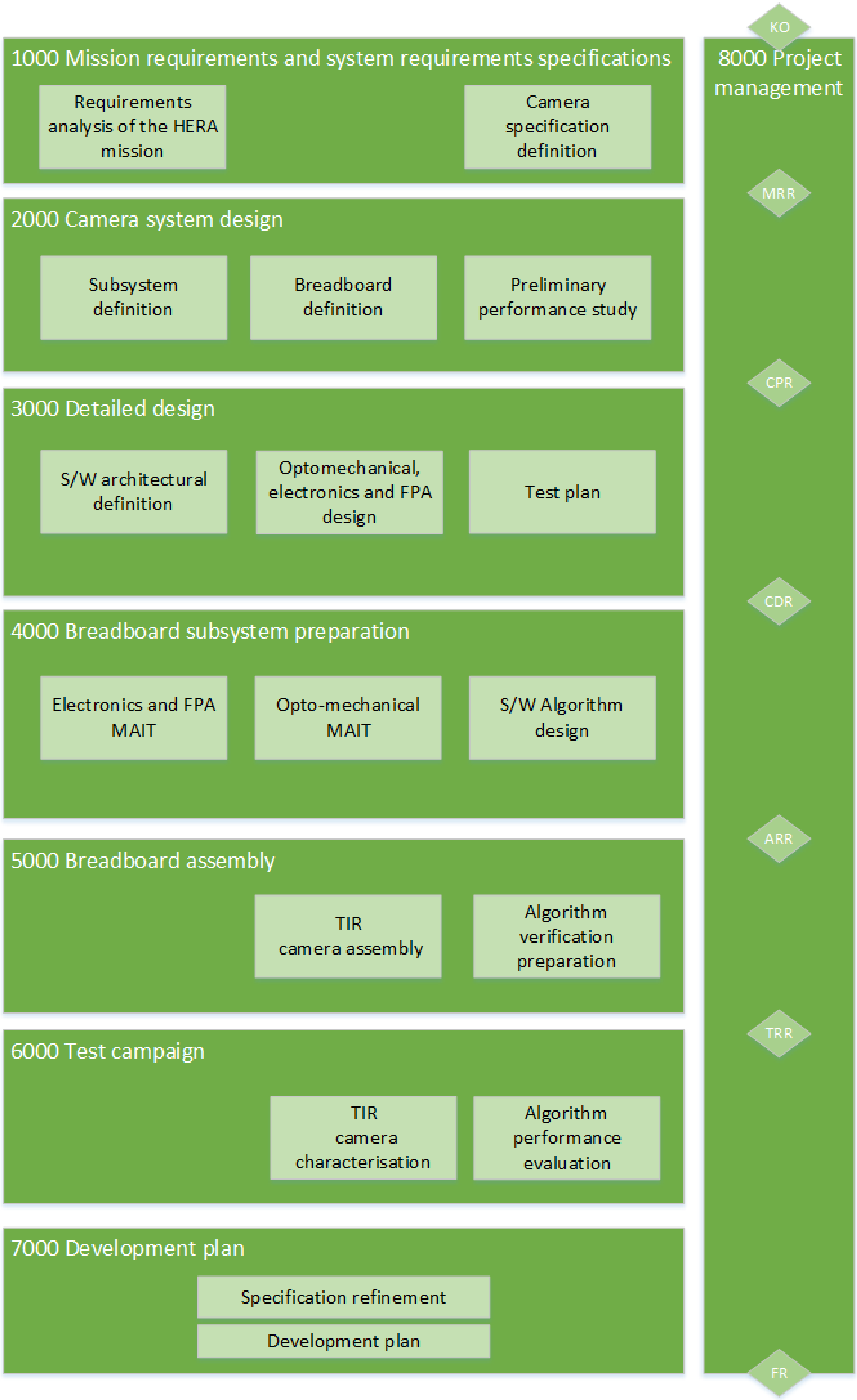

Figure 3 Overview of project flow and work breakdown structure

CHAPTER 4 COMPLIANCE MATRIX

Functional and performance requirements (based on revised version provided by Alessandro Zuccaro Marchi; email 19/12/2018 [GSTP CHYTI] requirements with descoping to TIR_v2).

Functional and Performance Requirements					
ID	**Definition**	**Requirement**	**Notes**	**Compliance**	**Comment**
	TIR CHANNEL				
R_TEL_01	Telescope	Reflective (TBD)	Tradeoff with refractive solution is needed.	c	Before the MRR a trade-off between reflective and refractive will be made
R_TEL_02	FoV (deg x deg)	> 7 ACT x 5.5 ALT (with rectangular detector array)	FoV > AFC camera's FoV (i.e. 5.5 x 5.5).	c	By design
R_T_SYS_01	GSD	< 2 m @ 10 km	Similar to AFC camera's	c	By design
R_T_SYS_02	Spatial Resolution	< 3 m @ 10 km		c	This resolution is met at 8 µm
R_T_SYS_03	Spectral band	8 – 14 µm		c	
R_T_SEN_01	Pixel pitch (µm)	17 µm (TBC)		c	
R_T_SEN_02	NeDT (mK)	<50 @300K @ F/1	Temperature and f/# are for reference	c	
R_T_SEN_03	Detector size	1024 x 768 px	Goal: 1024 x 1024 px	pc	NC for breadboard, larger array exists
R_T_SEN_04	Frame rate	>1Hz[1] (TBC)		C	
R_T_SYS_02	Signal-to-Noise Ratio	>16 (TBC)		TBD	

[1]To be related to the thermal relaxation rate of the chosen detector and trade-offs for noise reduction.

A2.2. Interface Requirements

The following preliminary interface needs between HYPTIRA and the Hera Spacecraft platform shall be accounted for ([AD2], Section 6.3.3):

INTERFACE REQUIREMENTS

ID	Definition	Requirement	Note		
R_INT_01	Mass (Kg)	<6 (TBC)	Estimated value, to be iterated with HERA platform	TBD	
R_INT_02	Volume (WxLxH, mm3)	200 x 300 x 130 (TBC)	Instrument aperture on WxH side Estimated values, to be iterated with HERA platform	TBD	
R_INT_03	Power consumption in Nominal Mode (W)	< 25 (TBC)		TBC	
R_INT_04	Operation Temperature Ranges (in power-off, Stand-by and Nominal modes) (°C)	-30 to +70 (TBC)		TBC	

Note:
Requirements regarding:
- Pointing Accuracy (APS, AKE, RPE, RKE, reconstructed)
- Power Supply

- Power consumption in stand-by mode
- Power dissipations in both modes
- Data interfaces
- Data rates in both modes
- Clock synchronisation

are still TBD. They shall be implemented and agreed in parallel with the development of Hera activity.

A2.3. Environmental Requirements

R_ENV_01	The CHYTI Camera breadboard shall be compatible with and fulfil the functional and performance requirements in a standard laboratory environment (to reach TRL 4) and the critical functions in a relevant environment, i.e. one that represents the expected operational environment (to reach TRL 5).	NC	We will investigate the BB in a standard lab environment

A2.4. Configuration & Implementation Requirements

R_CON_01	The software for optical design must be chosen between Zemax and Code V.	C

Zemax will be used

A2.5. Verification & Testing Requirement

The tests to be performed shall at least include the following:

Verification & Testing Requirement

ID	Definition	Compliance	Comment
	FOREOPTICS		
R_TST_01	Optical quality of optical components	C	
R_TST_03	Focal length	C	
R_TST_04	Entrance Pupil Diameter	C	
R_TST_05	FoV ACT and ALT	C	
	TIR CHANNEL		
R_TST_24	SNR	C	
R_TST_25	Optics MTF	C	
R_TST_26	System MTF	C	
R_TST_27	NeDT	C	
	CAMERA		
R_TST_28	Volume	C	Verification by review of design
R_TST_29	Mass	C	Verification by review of design

CHAPTER 5 USE OF BACKGROUND INTELLECTUAL PROPERTY OR THIRD PARTY PRODUCT/RIGHTS

The BIPR is listed in the MGT proposal.