JANUS on JUICE: A Camera to Investigate Ganymede, Europa, Callisto and the Jovian System.

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Introduction: The detailed investigation of three of Jupiter's Galilean satellites (Ganymede, Europa, and Callisto), which are believed to harbour subsurface water oceans, is central to elucidating the conditions for habitability of icy worlds in planetary systems. The study of the Jupiter system and the possible existence of habitable environments offer the best opportunity for understanding the origins and formation of the gas giants and their satellite systems. The JUpiter Icy moons Explorer (JUICE) camera system JANUS (Jovis, Amorum ac Natorum Undique Scrutator) will determine the formation and characteristics of magmatic, tectonic, and impact features, relate them to surface forming processes, constrain global and regional surface ages, and investigate the processes of erosion and deposition. Global medium resolution imaging of Ganymede and important parts of the surface of Callisto better than 400 m/pixel will provide context information. While the resolution capability of the instrument would allow to provide global coverage at a resolution of 75m/pixel, the achievable resolution during the mission will be limited by mission data volume. Selected targets will be investigated with high-resolution imaging with spatial resolution from 30 m/pixel down to <10m/pixel. The camera system has 14 panchromatic, broad- and narrow-band filters in the 0.36 µm to 1.1 µm range, and provides stereo imaging capabilities. JANUS will also allow relating spectral, laser and radar measurements to geomorphology and thus will provide the overall geological context.

The JANUS experiment's science objectives:
Outstanding questions that will be addressed by JUICE Imaging [1]: What are the relative roles of tectonism and cryovolcanism in shaping the dark and bright terrains on Ganymede? What does the distribution of craters on the Galilean satellites tell us about the evolution of the impactor population in the Jovian system through time? How is the geological evolution of Ganymede and Europa related to the impact, tectonic and cryovolcanic history and how is the geological evolution correlated with differentiation processes and stages? What are the ages of specific geological units on Ganymede and Europa, and how will these findings contribute to our understanding of the origin and evolution of the Jupiter system? What is the rheological response of ices and ice/salt/clathrate mixtures w.r.t. tectonic stress? To what extent are surfaces altered by cosmic weathering and what are the major exogenic surface alteration processes (micrometeorites, radiation, charged particles)? What are the fine-scale characteristics of non-ice materials on Callisto? By which intriguing mechanisms is CO2-replenishment taking place on Callisto?

Further science objectives of JANUS are to

- Characterize the exospheres of the Galilean satellites and search for potential water plumes;
- Characterize and study the physical properties of other satellites of the Jupiter system, including Io, the irregular and inner satellites;
- Perform a physical characterization of the ring system;
- Study the Jupiter troposphere, imaging the active dynamical processes, cloud systems, waves, vortices, and other instabilities, determining cloud structure in discrete features, and detecting lightning;
- Observe Jupiter stratospheric variations due to vigorous water meteorology and disturbances from large vortices, such as the Great Red Spot;
- Investigate the Jupiter upper atmosphere by imaging auroral activity and particle precipitation in the form of polar hazes;
- Contribute to the study of the interaction between the Jupiter magnetosphere and the bodies embedded in it.

Required Performance of the Instrument to Satisfy the Objectives:
JANUS is the next logical step after the impressive successes of the imaging studies by Voyager, Galileo and Cassini of the Jovian system. JANUS will allow orders-of-magnitude steps ahead in terms of coverage and/or resolution and/or time evolution on many targets in the Jupiter system. The JANUS camera's spatial resolution ranges from 400 m/pixel to < 10m/pixel for the three main Galilean satellites, and from a few km/pixel to few tens of km/pixel for Jupiter and the other targets in the Jovian system. Based on current best assumptions on the available data volume, JANUS

observations will cover about 100% of Ganymede in 4 colours at 400 m/pixel. About 3% of the surface of Ganymede will be covered with resolutions better than 30 m/pixel down to 7.5m/pixel during the 500 km circular orbit. Stereo imaging at Ganymede is doable at resolutions between 5 to 10 m/pixel and around 25 m/pixel. Stereo images will be acquired both in nadir pointing and by tilting the spacecraft in a subsequent orbit. Medium-resolution stereo coverage of Ganymede will be acquired during the flybys. For Callisto, assuming only nadir pointing, JANUS will cover 100 % of the surface at ≤2 km/pixel, 41 % at ≤1 km/pixel, 14 % at ≤ 400 m/pixel, 6.5% at ≤ 200 m/pixel, and some targets at resolutions ~ 10 m/pixel, with 4 colour imaging at medium resolutions. 55% of Europa's surface can be covered at ≤ 3 km/pixel, 35 % at ≤1 km/pixel, 30% at ≤ 500 m/pixel, 1% at≤ 100 m/pixel and about 0.2% at ~ 10 m/pixel. Low- to medium-resolution imaging (i.e. km to ~100 m-range) is obtained in four colours. Spatial resolutions at Io will reach 6 to 20 km/pixel with long monitoring times also at NIR wavelengths. The rings and minor satellites can be observed at maximum resolutions of ~7km/pixel. The resolution at Jupiter's atmosphere will reach 9km/pixel. The SNR > 100 can be maintained in almost all observational scenarios.

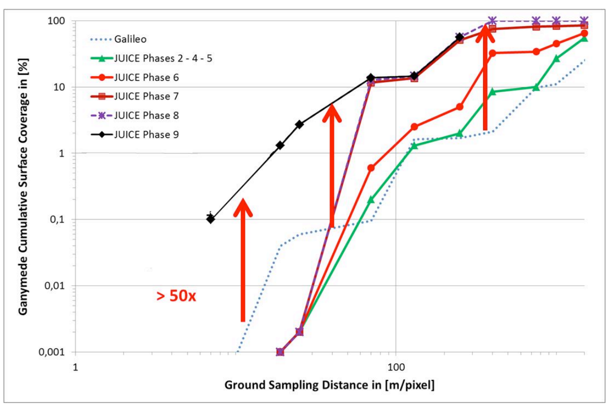


Figure 1: Expected ground resolution and surface coverage for Ganymede by JANUS compared to Galileo

JANUS instrument design:

General design concept A trade-off between different design solutions, performed by the JANUS team in order to satisfy all JUICE mission's scientific requirements, has led to the following architectural choices:

- a catadioptric telescope is coupled with a framing detector, avoiding a scanning mechanism and any operational requirement on the S/C;
- a fine tuning of instrument parameters coupled with the mission design allows to have an instrument designed to be fully compliant with both the high- and low-resolution imaging requirements of the mission;
- instrument operations are flexible enough to optimize the acquisition parameters with respect to the many different observation requirements and conditions that JANUS will face. The instrument design will allow to adjust the resolution through binning, the field of view through windowing, the signal levels and SNR through integration time and the instrument calibration parameters through in-flight calibration and data pre-processing.

The JANUS design concept has been optimized to have the highest probability to guarantee a scientific success of the mission by the best usage of the resources allocated to imaging through the implementation of a single NAC channel, with WAC capabilities, with high reliability due to the redundancy philosophy. The JANUS concept has also the advantage to obtain the low to medium resolution Ganymede global coverage early during the mission, allowing an informed choice of observation targets for the high-resolution phase.

The JANUS camera consists of three units with physical I/F with the JUICE spacecraft: a) the optical head including the telescope and mounting structure, the aperture cover, the filter wheel, and the focal plane; b) the proximity electronics; c) the main electronics including camera control, data handling, compression and power supply.

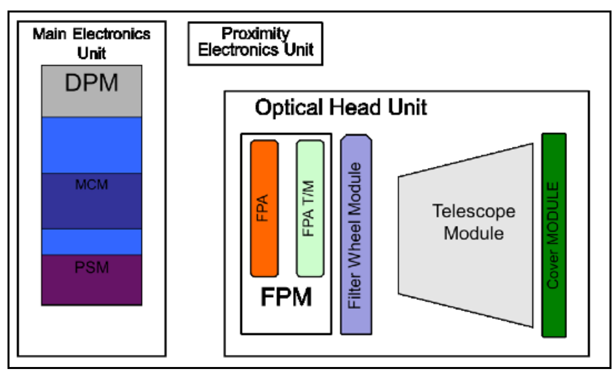


Figure 2: JANUS overall configuration

Optical Head: The Optical Head Unit will be integrated on a stable platform together with star- tracker and other remote sensing instruments in order to allow co-alignment stability. It includes the optics, the external baffle, the mechanisms (filter wheel and cover) and the thermo-mechanical module supporting and conditioning the Focal Plane Assembly (FPA). Iso-static mountings are foreseen to cope with S/C thermal and mechanical constraints.

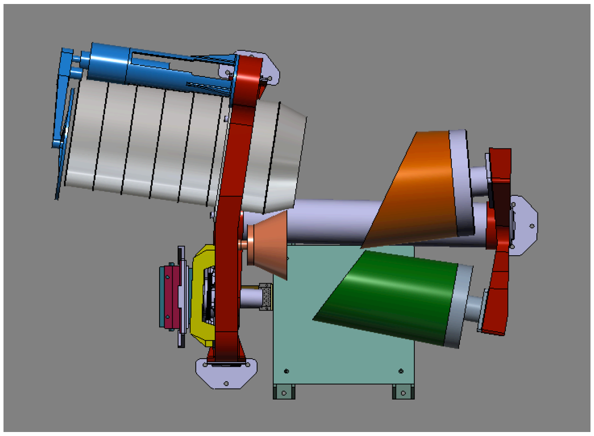
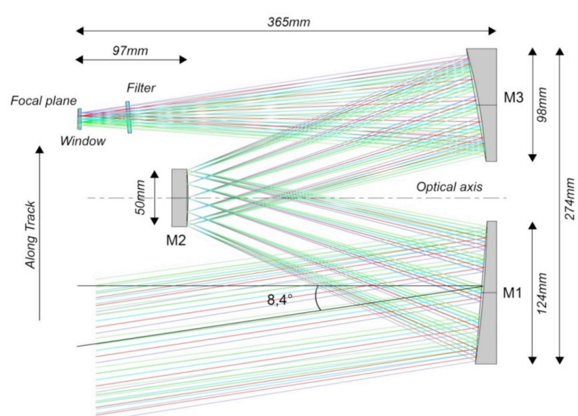


Figure 3: JANUS Optical Head Unit with main optical and functional elements (design details are under review)

The optical solution adopted as JANUS camera baseline is a Three Mirror Anastigmat (TMA). The camera is composed by three mirrors sharing the same optical axis. The first mirror is a concave off-axis hyperboloid, the secondary mirror is convex with a spherical shape, while the tertiary mirror is a concave off-axis oblate ellipsoid [2]. The optical system has an on-centered unobstructed virtual entrance pupil and an off-centered field of view, similarly to the OSIRIS Narrow Angle Camera on Rosetta [3].



Specification	Value
Entrance pupil diameter	100 mm
Effective focal length	467 mm
F/#	4.67
Field of View	1.72 x 1.29 degree^2
Detector format	2000 x 1504
Pixel size	7 µm
Pixel scale	15 µrad/pixel
Spectral range	350 – 1050 nm

Figure 4: JANUS optical design and main parameters

For multispectral observations, a set of 14 optical filters is implemented in a filterwheel. **Figure 5** lists the different bandwidths and central wavelengths for 13 of them.

Filter id.	**λ / width [nm] (tbc)**	**Note**
FPAN	650/500	Panchromatic – monochromatic imaging
FBLUE	450/60	Blue – satellite colours
FGREEN	530/60	Green, background for Na – satellite colours
FRED	656/60	Red, background for Ha– satellite colours
CMT medium	750/20	Continuum for strong Methane band on Jupiter, geology
Na	590/10	Sodium D-lines in exospheres
MT strong	889/20	Strong Methane band on Jupiter
CMT strong	940/20	Continuum for medium Methane band on Jupiter, Fe^{2+} on satellites
MT medium	727/10	Medium Methane band on Jupiter
Violet	410/80	UV slope of satellites surfaces
NIR 1	910/80	Fe^{2+}, Io lava spots
NIR 2	1000/ 150	Fe^{2+}, Io lava spots
Ha	656/10	Hα-line for aurorae and lightnings
tbd	tbd	tbd

Figure 5: JANUS filter central wavelengths and bandwidths for 13 filters (fine-tuning still ongoing)

The JANUS Focal Plane Module consists of the focal plane baseplate carrying the detector PCB, the Cold-Finger (CF) I/F to the spacecraft radiator, and a radiation cover for the detector. The baseline detector is the CIS115 from e2V. Am alternative detector option is the SOLOHI- detector from SRI. Both options are currently under investigation. Analog signal conditioning, FPM driving, and the focal plane control will be performed by the Proximity Electronics Unit (PEU). The PEU will be integrated on the S/C close to the OHU. The PEU provides all the clocks and biases required by the focal plane and digitizes (nominal 14 bits) the image sensor data. Preamplifiers are located on the Focal Plane Module (FPM) to minimize the capacitive loading of the sensor's analog output(s) and to drive the short length of cable between the FPM and PEU. The PEU will have only a very limited number of active electronics in order to provide a high level of radiation tolerance. The key components are 14 bit ADCs and a radiation hard FPGA.

Mechanisms: Two mechanisms are part of the Optical Head Unit: the Filter Wheel Module (FWM) and the Cover Module (COM). The FWM positions the optical filters in front of the image sensor with high accuracy. The present design consists of a support structure and a single filter wheel with 14 positions, driven by a stepper motor-gear combination.

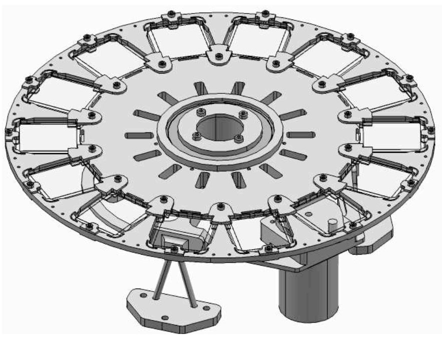


Figure 6: FWM preliminary design

The cover module was included in the design in order to mitigate the contamination risk for the optics during the non-operational phases of the mission. Moreover, the cover allows to protect the instrument from direct sunlight, provides a mean for calibration checking through an internal light source, and limits the heat dissipation during non-operative phases. The cover mechanism includes the cover door, a sealing ring that attaches to the baffle to ensure proper sealing, an opening mechanism driven by a redundant stepper motor and a single-shot emergency (fail-safe) opening system.

Main Electronics: The Main Electronics Unit (MEU) is designed fully cold-redundant and consists of:

- the Data Processing Module (DPM) with a processor that controls the complete instrument and manages the interface to the spacecraft: reception of TeleCommands (TCs), synchronization with the On Board Time (OBT), formatting and transmission of TeleMetry (TM) packets (data and housekeeping). The DPM includes the interfaces to the PEU and a real-time, seamless lossless to lossy data compression of the acquired image data according to the CCSDS 122.0-B-1 standard. It is based on a three-level two-dimensional Discrete Wavelet Transform (DWT) that performs decorrelation, followed by a Bit Plane Encoder (BPE) that encodes the decorrelated data and provides simple and efficient data rate control.

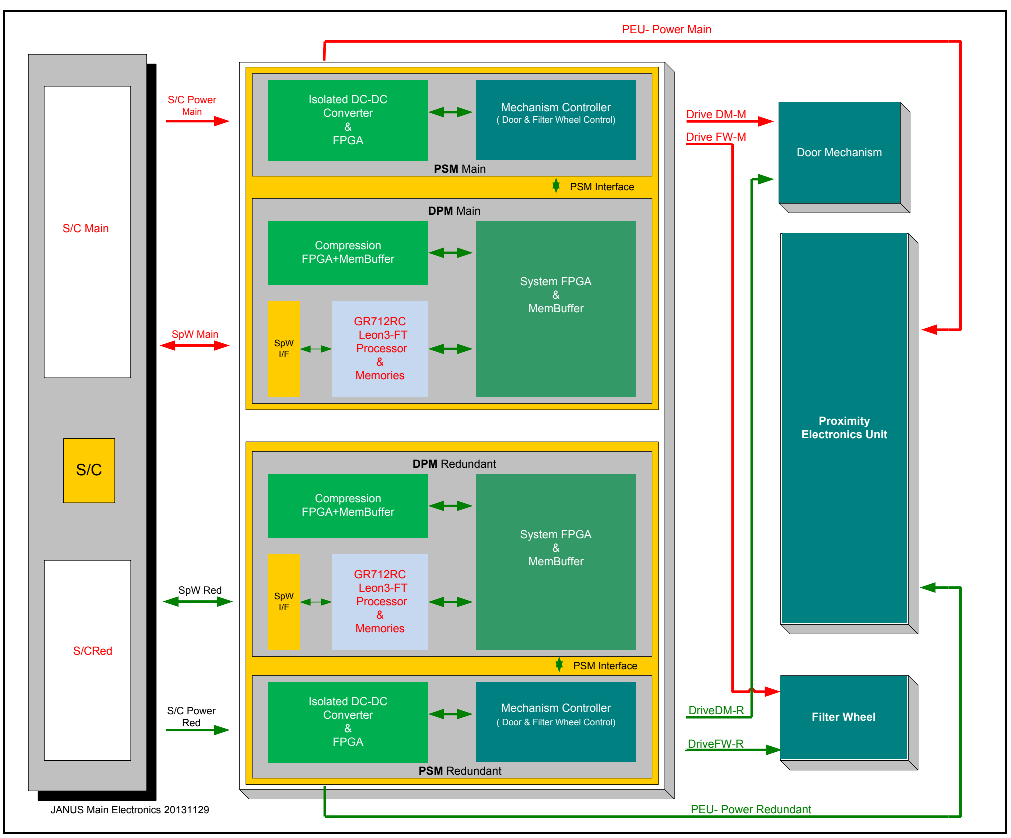


Figure 7: MEU block diagram

- A Power Supply Module (PSM), equipped with power line input filters and DC/DC converters to provide the needed voltages. The Filter Wheel and Door Controllers are integrated on the PSM PCB.

Figure 7 shows a block diagram of the MEU architecture and its external and internal signal interfaces.

JANUS Instrument Performances: During the low-latitude circular orbit GCO500, JANUS will concentrate on panchromatic imaging of targeted areas at high spatial resolutions. The operative conditions during GCO500 are very demanding, due to the high S/C relative velocity and β angle. Nevertheless, the JANUS performance is very good. Figure 8d shows SNR evaluation results for imaging with an integration time of 2.5 ms and a 2 × 2 binning (pixel scale is 15 m/pixel). The thin lines represent the beginning and the end of the phase (β angle ranging from 62.5° to 78°), the bold line is the SNR for the phase-typical β angle (β = 70°).

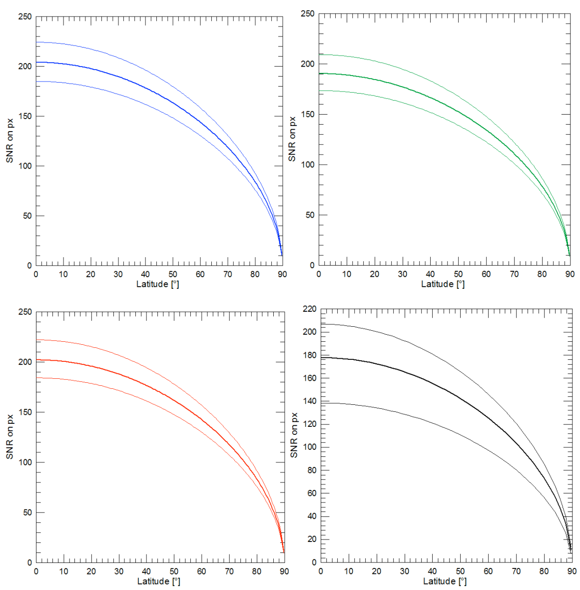


Figure 8: Predicted SNR during GCO5000 (a,b,c) with RGB filters, and during GCO500 (d, monochromatic)

JANUS spatial resolution and coverage capabilities: **Figure 9** shows an overview of the ground sampling distances and resulting image swaths in comparison with the mission analysis results. The available data downlink capacity of JUICE (i.e., 1.4 Gbit per day) represents a major constraint for JANUS, because it will limit the coverage and/or spatial resolution capabilities. Thus, the JANUS data rate and volume is defined by a multi-parameter matrix which not only depends on instrument-internal parameters like data compression (i.e., nominal compression ratio of 3.5:1) and resolution, but also on mission-related parameters like distance-to-target, dwell time and illumination conditions. The most important measure to optimize data volume and coverage within the given constraints are data compression and modification of the spatial resolution by pixel binning. The coverage achievable during the JUICE mission has already been discussed above.

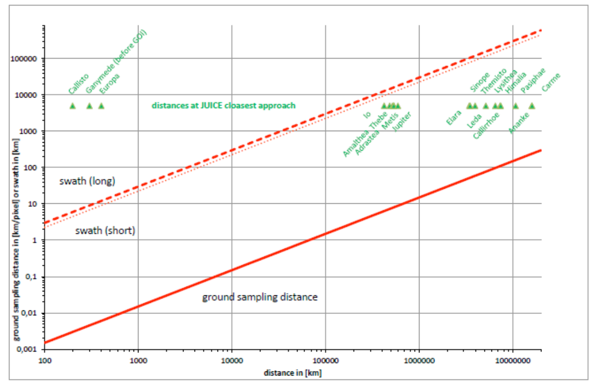


Figure 9: JANUS spatial resolution and image swaths as a function of distance from target. Triangles mark the distances to the surface (not center) at closest approach to Jupiter and several satellites based on the existing JUICE orbit predict

References:

[1] Grasset, O., et al., JUpiter ICy moons Explorer (JUICE): An ESA mission to orbit Ganymede and to characterise the Jupiter system, PSS, Volume 78, 1-21 (2013). [2] Greggio, et al., A preliminary optical design for the JANUS Camera of ESA's space mission JUICE, SPIE. [3] Dohlen, et al., Optical designs for the Rosetta narrow-angle camera, Optical Engineering, 35, 1150 (1996).