PANGU version v8: Event-based sensor simulation for space applications in real-time

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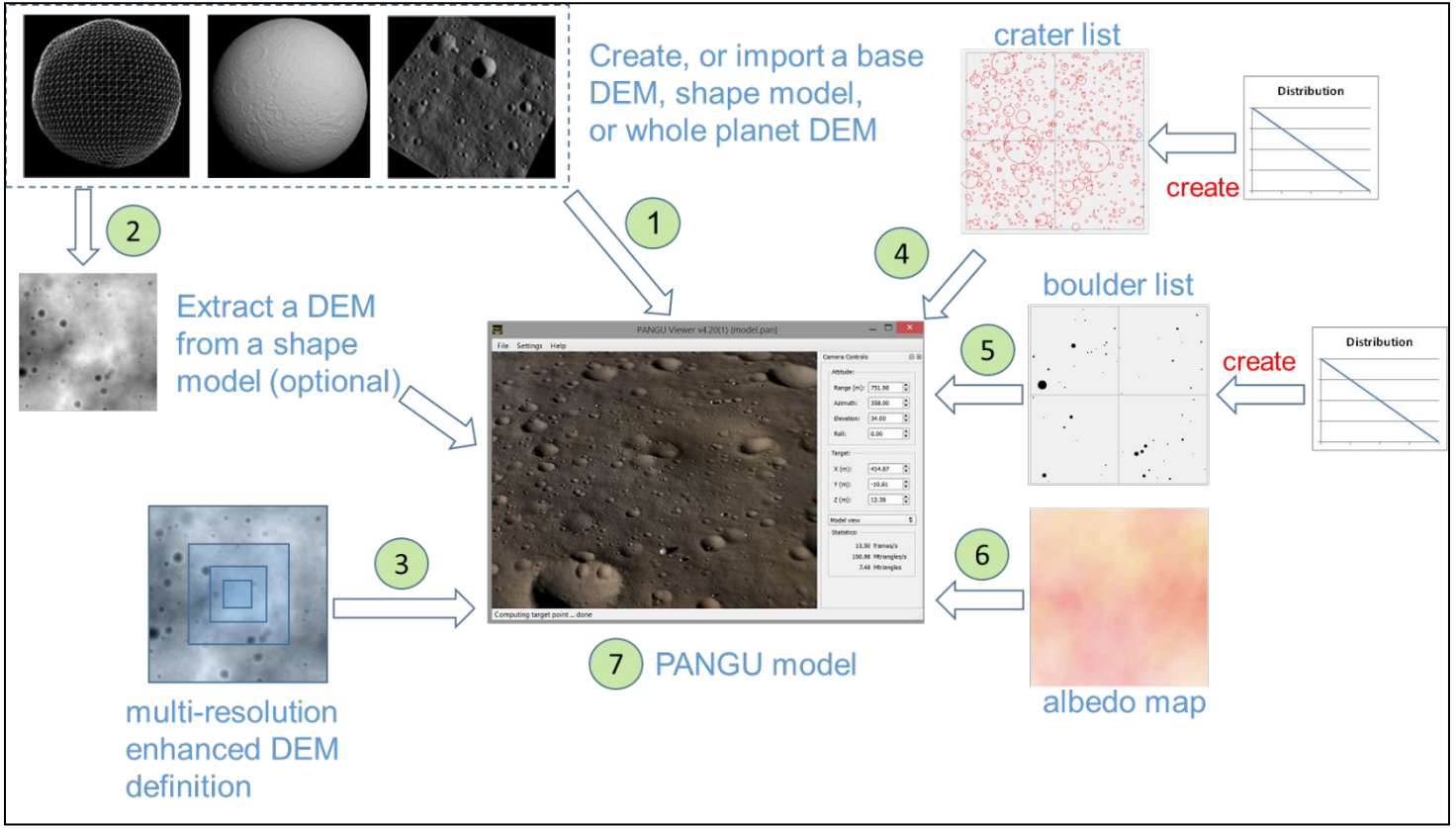
PANGU: Planet and Asteroid Natural Generation Utility

- What is PANGU?
- How does it work
- Examples / videos
- Functionalities (existing / new)
- Event-Based Cameras simulation / “Image” (event) data set generation
- PANGU in the Vision-Based Navigation (VBN) roadmap
- PANGU in the Eco-system of Image Renderers

PANGU: What is PANGU?

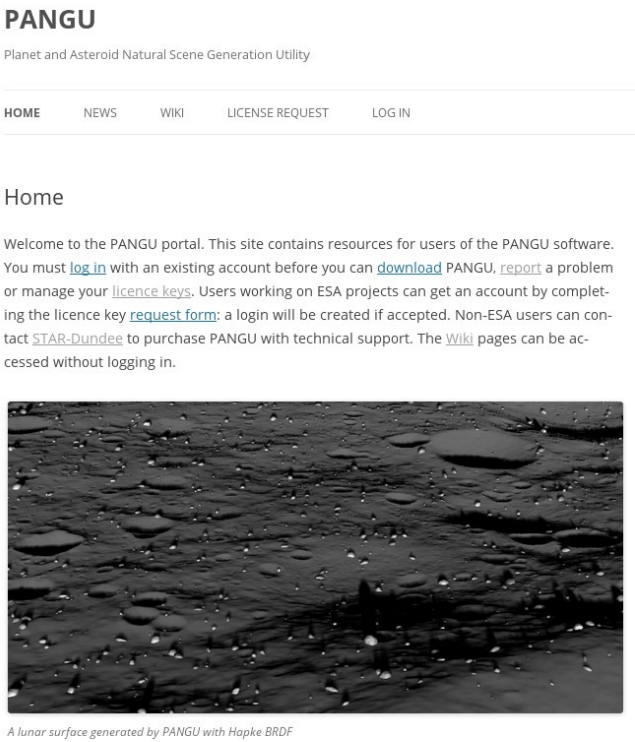
- Synthetic Image Generation tool:
  - Allows for generation of a Digital Elevation Model (DEM, i.e. terrain) from scratch
  - Accepts (opens and converts for further model modification/refinement) a variety of File formats
- Used in Vision-Based Navigation simulations (open-loop and closed-loop, e.g. HW-in-the-Loop (HIL)) in real-time and faster than real-time (SW-in-the-Loop (SIL))
- Radiometrically calibrated
- Physically representative parameters (space context, camera, sensor, etc)
- Validated over the years
- User community in European Space industry (free of charge for ESA projects)

PANGU: How are PANGU models created from DEMs (Digital Elevation Models)



How PANGU works: SW development / SW licensing /

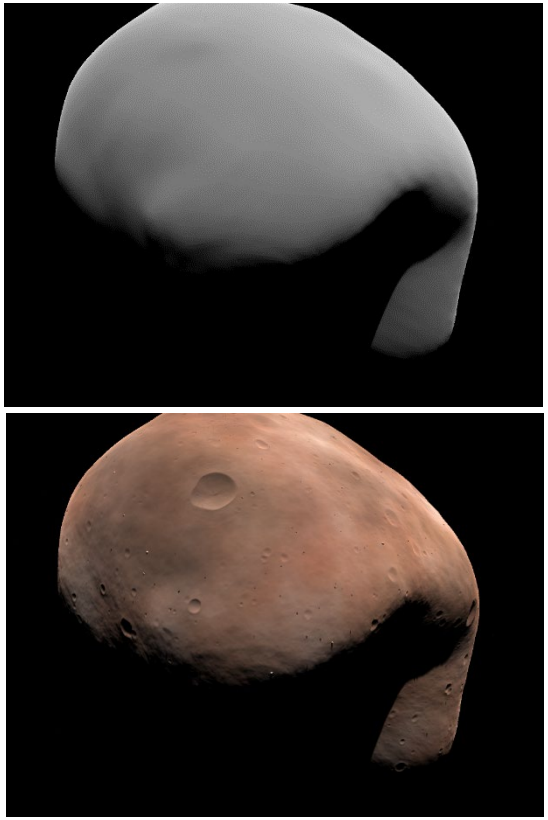
- Agile SW development (intermediate branches / versions if needed)
- PANGU website: https://pangu.software
  - Simplified SW license request
  - Access to SW (current and previous versions)
  - NCR/SPR report



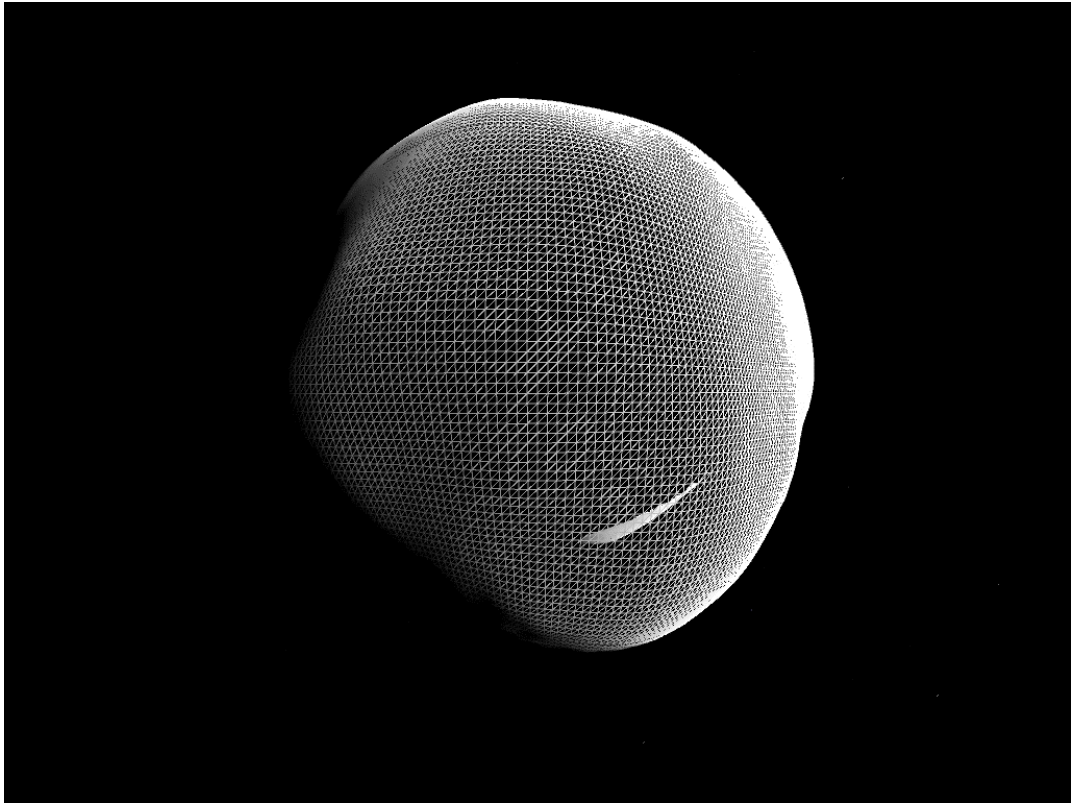
How PANGU works: enhancing a Low Resolution model

PANGU v5 example scenario:

- Starts with a low-res OBJ model→ICQ (InterConnected Quadrilaterals)
- Enhance the resolution
- Add craters
- Generate and apply a synthetic albedo map
- Define boulders with different BRDFs (BiDirectional Reflectance Distribution Function, modelling optical properties of the surface)
- Define a relative flight path
- Generate a video

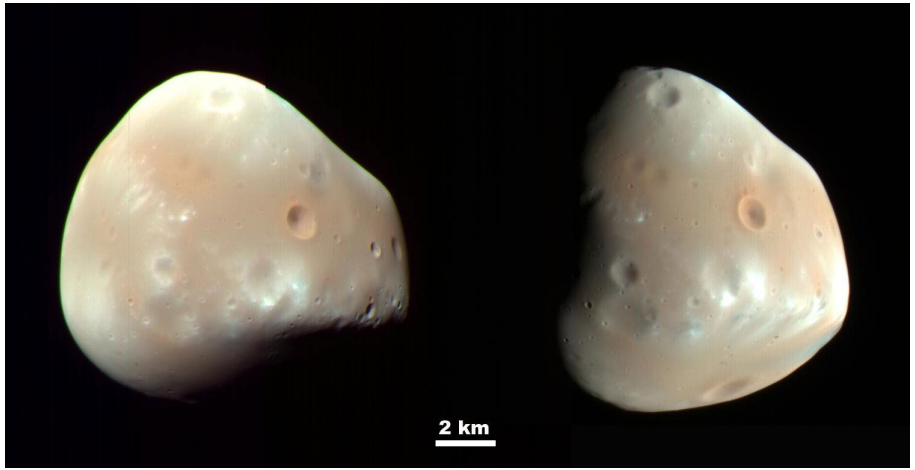


How PANGU works: enhancing a Low Resolution model

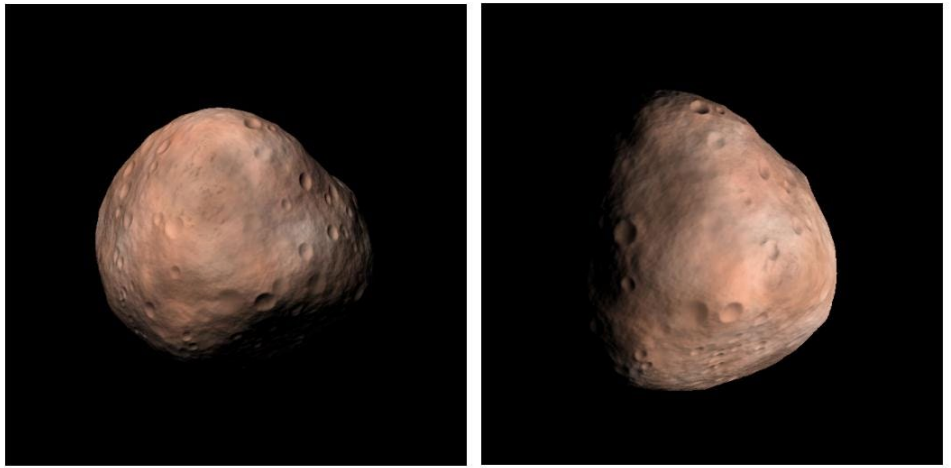


How PANGU works: MRO/HiRISE image of Deimos

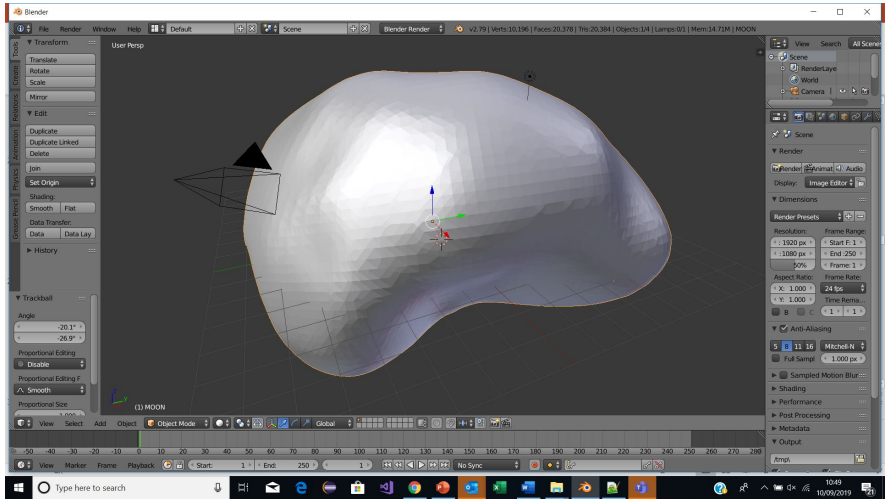
MRO/HiRISE image of Deimos



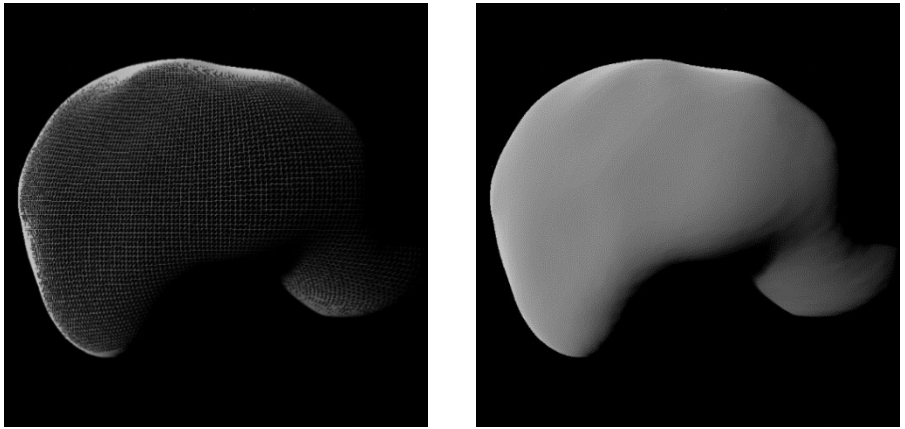
PANGU simulation of MRO/HiRISE image of Deimos (also to test variability / sensitivity of Vision-Based Navigation algorithms to albedo maps)



How PANGU works: Interoperatibility with other Image renderer SW

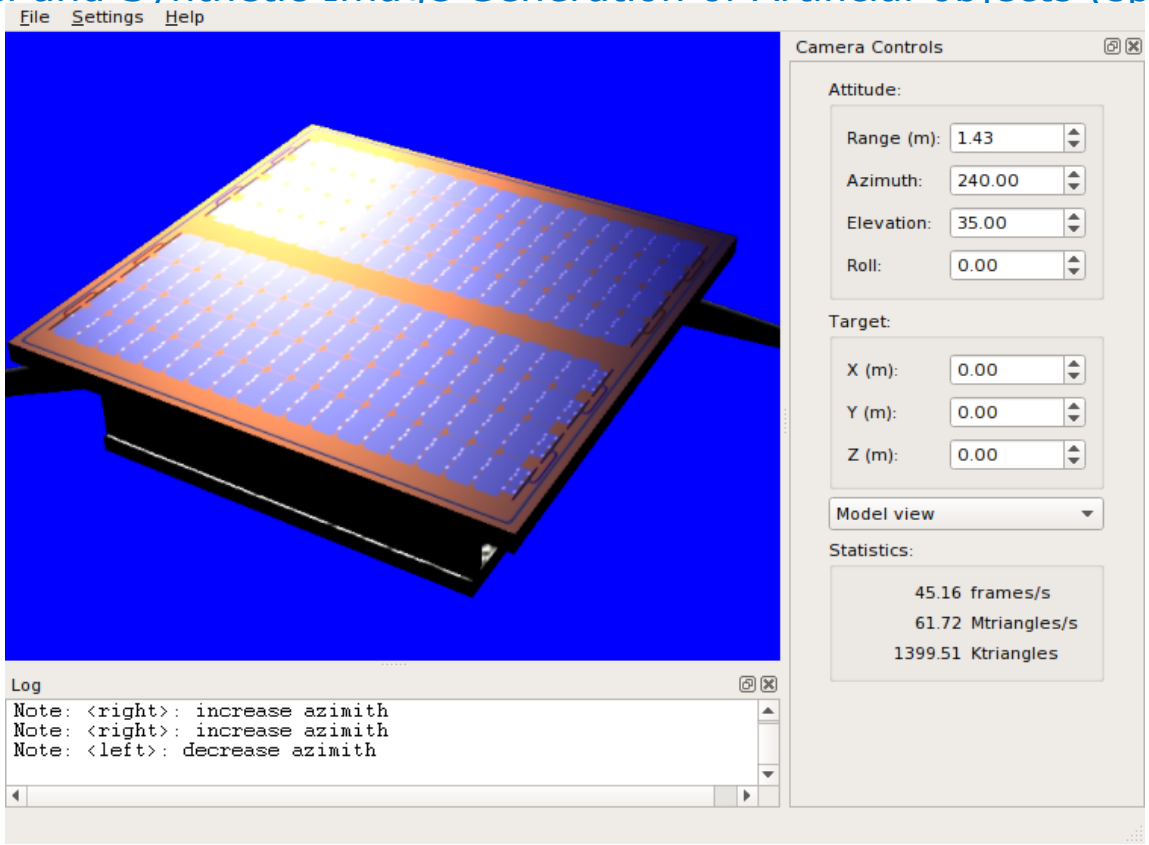


WaveFront (OBJ) IN Blender

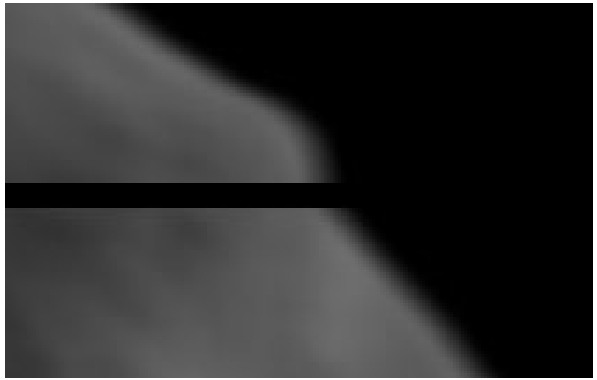


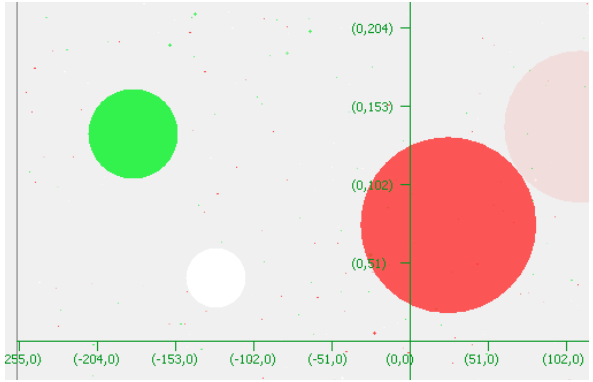
Wire-frame (left) and solid Hapke view (right)

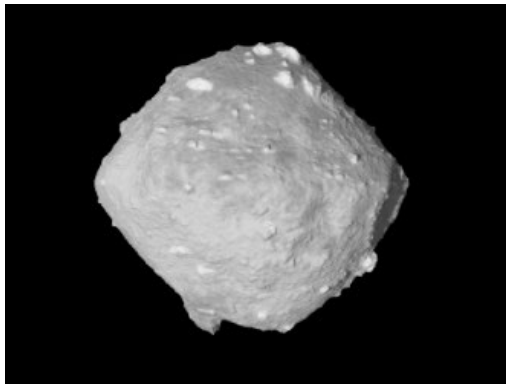
How PANGU works:
Camera model and Synthetic Image Generation of Artificial objects (spacecrafts)

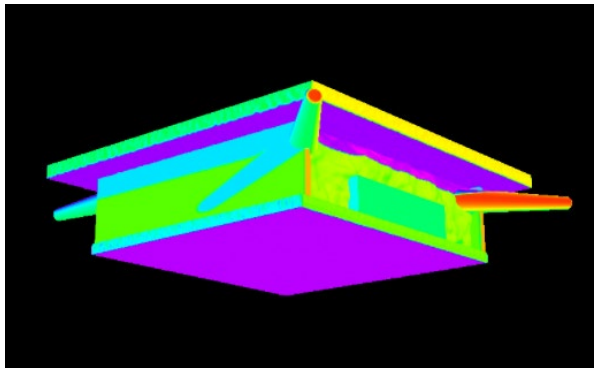


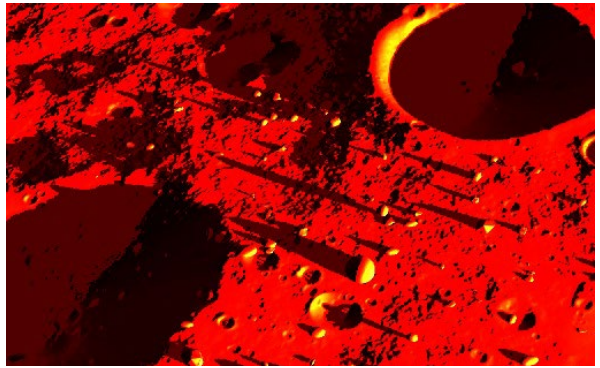
How PANGU works: Overview of new features in PANGU v6 (thermal Infrared, communication errors, etc)

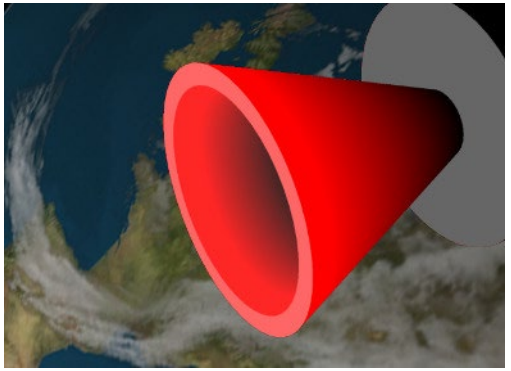






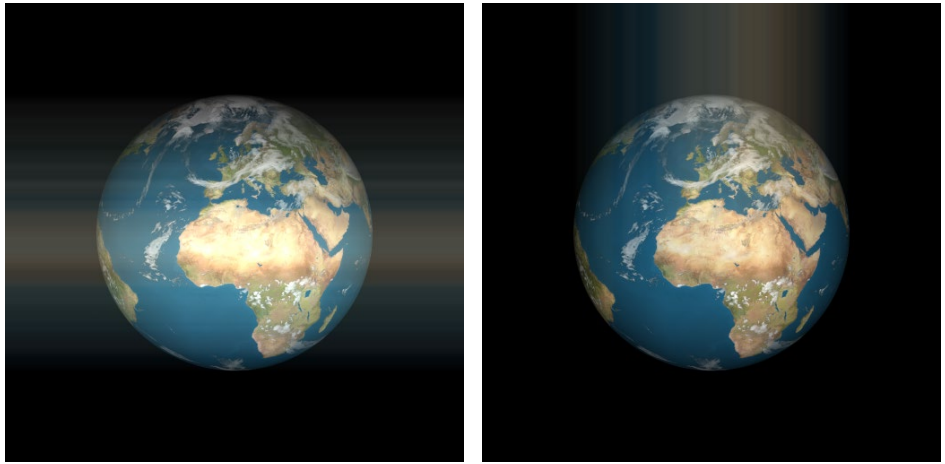




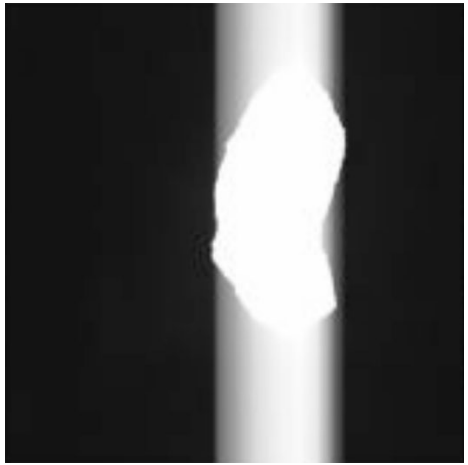


How PANGU works: Camera and sensor effects
Reset and read-out smear

Earth image

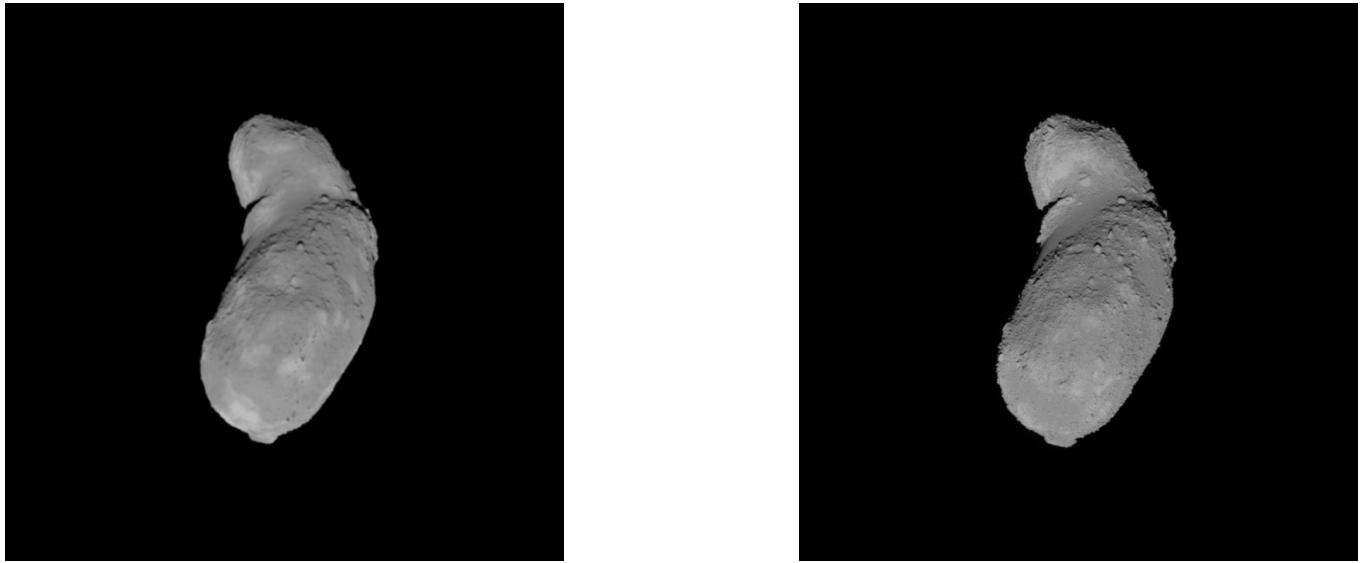


Low-res COSPAR Image with smear



PANGU v5 AMICA simulation

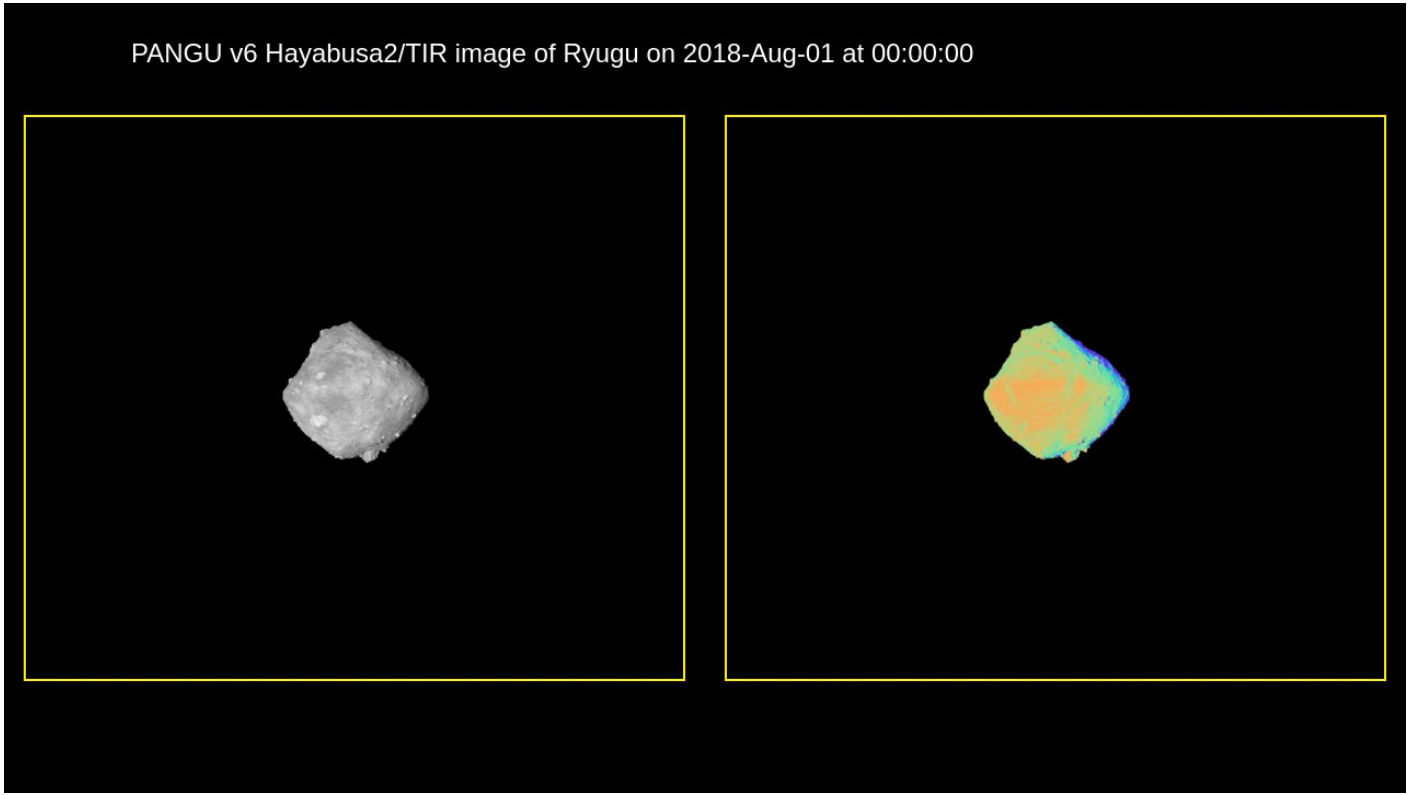
PANGU examples: Asteroid albedo maps (Itokawa comparison)



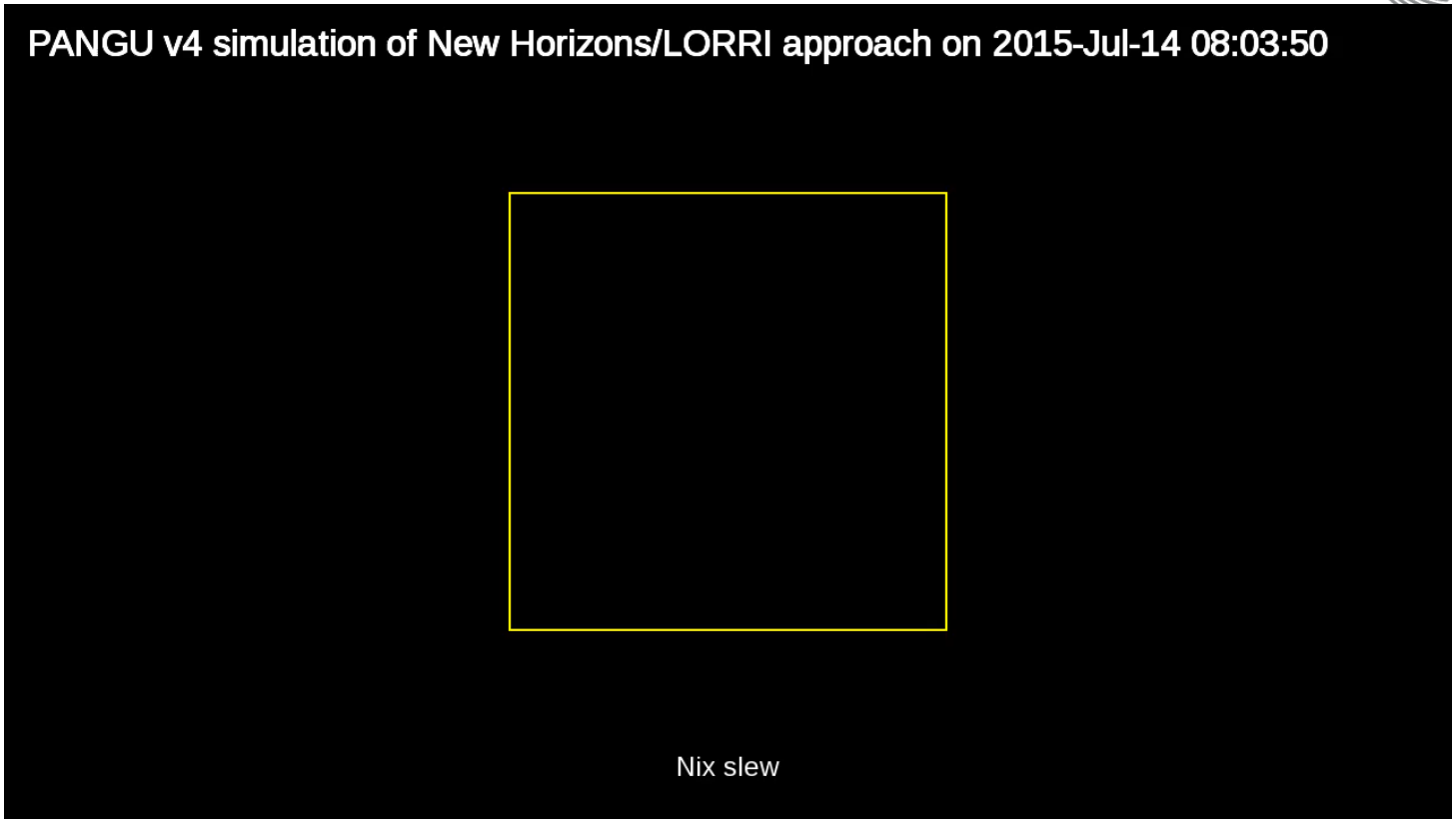
PANGU Itokawa model with synthetic albedo compared with real AMICA image

PANGU example: Malapert Moon landing

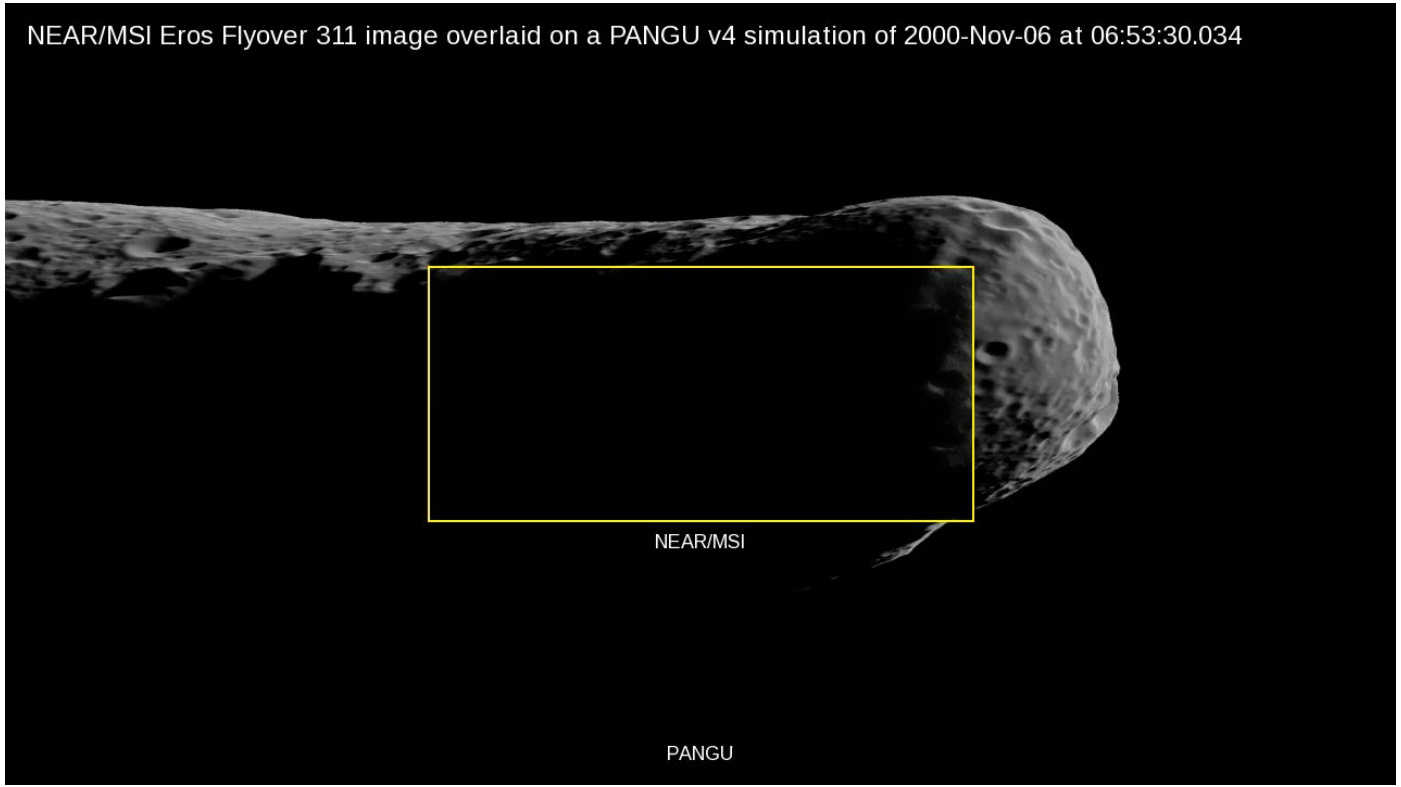
PANGU example: Ryugu / Hayabusa2



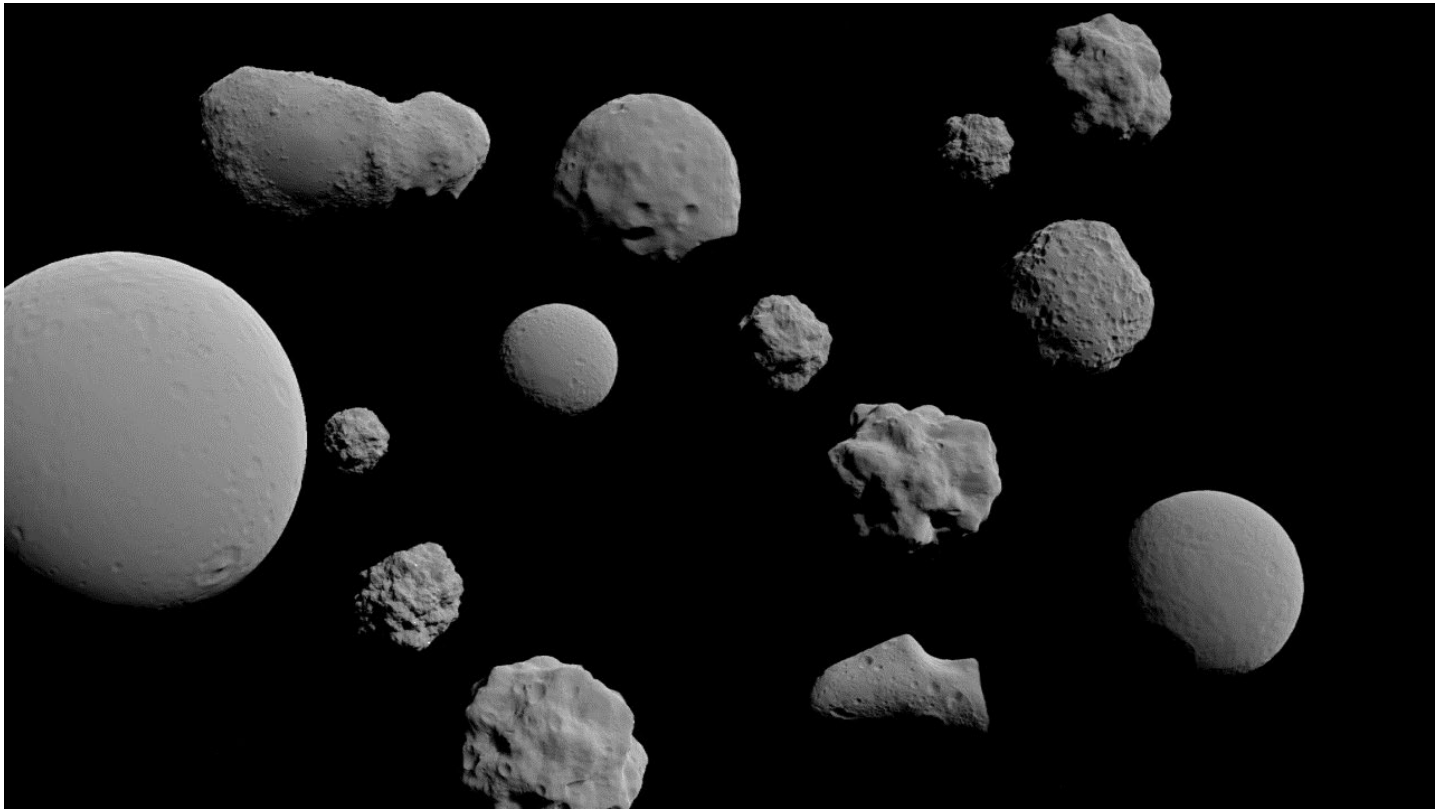
PANGU example: New Horizons/Lorri approach Pluto



PANGU example MP4 video overlaid from PANGU

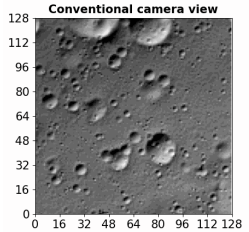


PANGU: Example “Too many asteroids”



PANGU: Functionalities (existing/new)

- PANGU developed over the years (15+) in visible
- Thermal infrared introduced in version v6
- **Real-time (for HW-in-the-Loop simulations) Thermal Infrared synthetic image generation** was need to validate other developments (HW/SW) in MultiSpectral Cameras, for instance:
    - MuLaN (**Multispectral camera Engineering Model**, GSTP ESA Project)
    - Use for Vision-Based Navigation as application for instance of Thermal Infrared camera under development by Jena-Optronik (JOP)
- PANGU used to emulate **Plenoptic cameras**
- New functionalities in version v8 following user requests (depth of field for rover navigation) and to support on-going innovative activities (potentially disruptive technologies):
    - **Event-Based cameras**
        - Advanced Concept Team (ACT): https://www.esa.int/gsp/ACT/projects/event_camera/
        - Event Camera for Planet Landing (in collaboration with ETH Zürich)
    - **GAN/Deep Learning**: To improved realism of Moon crater rim aging



PANGU: Event-based cameras simulation

- Event-based camera pixels independently respond to changes in brightness (from reference value to the current one) for the intensity arriving to each pixel, with instantaneous response.
- Advantages:
  - Temporal resolution
  - Dynamic range over the complete Field-of-View
  - Pre-processing and selection of relevant changes in image for pose estimation (Vision-Based Navigation), computationally efficient
- Difficulties (operational/simulation):
  - Noise filtering (tuneable thresholds)
  - Development/adaptation of algorithms for pose estimation (change of paradigm)

- Temporal representation of the signal (asynchronous) is not trivial, behaviour of electronics is dependent on manufacturer's implementation
- Intensity triggering representation of signal: Logarithmic/other (triggering function could result in other types of intensity change functions depending on the camera's design and the intended application)
- Noise models in event-based cameras (spatial and temporal structure) not necessarily the same as for conventional frame cameras
- Other previous work to be used for cross-comparison/cross-validation (ETH_Zurich, Hu's toolbox (v2e), etc)

TEC-SAG activities on Vision-Based Navigation for Small Body Navigation / Rendezvous Multispectral cameras (Visible + Thermal Infrared)

TRP | GSTP | MREP/ETP | Other ESA Programs | Non-Programmatic

NPI/OSIP | NMS Romania | Small Activities | GNC Test Facilities | HRE/ CleanSpace

2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024

IRPN (Image Recognition and Processing for Navigation) Vis/IR/LiDAR ADR

IRPN (CCN) FPGA

Navigation on a Chip

Multispectral Camera for Relative Navigation (MSRN-NL) Cosine/GMV

Multispectral Camera for Relative Navigation (MSRN-TAS-F/DMS/PT)

Automated Transfer Vehicle (ATV) to ISS

Generic VB Tech Building Blocks for landing & Rendez Vous (GENEVIS; Rendezvous use case for In-Orbit Servicing) (ADS-TLS)

OSIPs on VBN (Verification methods Image renderers)

AI/Deep Learning for VBN

VBN / IP for RvD using Deep Learning TBC (up to TRL 4-5)

VBN/IP for RvD using Deep Learning TBC (for/from TRL 5-6)

Validation Spicam using Flight Images (comparison with PANGU)

GENEVIS CCN

GNC Design

Event-Bsaed cameras

TIRVOA Thermal Infrared images in Vacuum (comparison with open air)

Multispectral Camera EM SSV (MuLaN)

Breadboard Multispectral camera Rendezvous Lagrangian Orbit (Heracles / Cosine/GMV) TRL 5

AstroTIR (JOP) / TEC-SAS

Visnav (ADS-TLS)

Visnav-EM (TAS-I)

Visnav-EM 1 (TAS-I)

Marco Polo

Autonomous GNC Tech for NEO Land. (NEO-GNC) (GMV-SP)

NEO-GNC 2(GMV-SP)

PhootPrint

GNC for Phootprint Descent & Landing(GMV-PO)

VBN camera Elegant Breadboard Phobos (CAM-PHOR-VNAV) (GMV-SP)

MultiPurpose Camera Navigation System / Small-Body Nav & Rendezvous (TBC - from Multispectral Camera EM SSV) **Optics B**

Multispectral camera EQM/FM for Rendezvous (TBC) (for CleanSpace / Space Gateway) TRL 8-9

SW & HW

Flight opportunities (COTS thermal_IR camera, Space Ride experiments, etc)

VisiLab

LIRIS in ATV-5 (In-Orbit_Demonstration

LIRIS data analysis (ESA in-house, ADS, Sodern, Jena-Optronik)

GRALS

RT Verification and testing facilities (ASTOS)

PANGU CCN MSR_SFR cover support (TBC)

PANGU versions developed through v3.10 (U. Dundee)

PANGU enhancement (v4.0)(Dundee)

PANGU v5.0 (U. Dundee) Maintenance/Upgrade

PANGU v6.0 Thermal IR (planets /asteroids/S/C

PANGU v7.0 PIL/High-Fidelity

PANGU v8.0 Event-Based Cameras GAN Deep Learning Image enhancement Mission Support (Argonaut, HERA, etc)

V & V

PANGU in the Eco-System of Synthetic Image Renderers

- Several **other image renderers developed by other companies** (SurRender (Airbus), SpiCam (TAS), ASTOS CameraSimulator (ASTOS), etc) with complementary functionalities
- Benchmarking for cross-validation and evaluate them against reference scenarios (TEC-SAG activities)
- PANGU validated over years with strong community of users
- PANGU provided free-of-charge to ESA projects (HERA, Argonaut, MuLaN (selected for thermal Infrared validation), etc)
- PANGU commercialization agreement with STAR-Dundee in niche market. PANGU licences issued worldwide (North America, Japan, South Korea, India, South Africa, etc) but mostly limited to national space agencies and large aerospace organisations
- New functionalities (thermal Infrared, Event-Based cameras, etc), for identified and potential needs in projects, after feasibility tested at proof of concept, need a push for initial technology development / industrialization
- PANGU contributes to Verification & Validation (existing and new camera technology in different types of missions)
- Functionalities like **real-time Thermal Synthetic Image Generation** not trivial, gradually improved for realism and specially for difficult scenarios and conditions (**transients in eclipse** with different material behaviour, etc)

PANGU_v8

Questions / comments /suggestions?

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