School of Science
and Engineering
University of Dundee

Real-time image rendering for simulation of thermal infrared cameras with application in Space Debris Removal

(2021 CSID: DEBRIS REMOVAL AND SERVICING)

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Overview

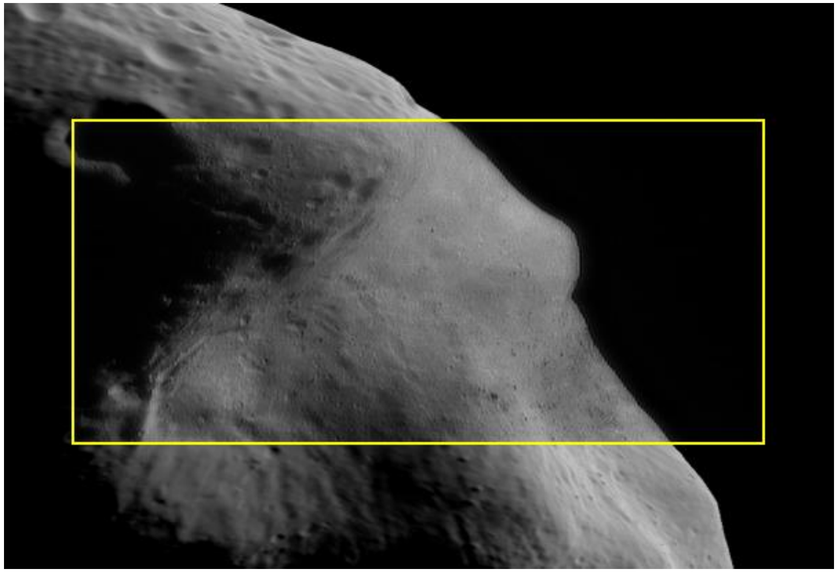
1) GNC sensors for Space Applications
2) PANGU: Planet and Asteroid Natural Scene Generator Utility
3) Real-time thermal image generation
4) Results

1: GNC sensors for Space Applications

Simulating GNC Sensors

Simulated images have been used for GNC testing for many years:

- Planetary landers (surface relative navigation, hazard detection and landing)
- Interplanetary navigation
- Asteroid approach and landing
- Spacecraft rendezvous and docking
- Sample return canister capture

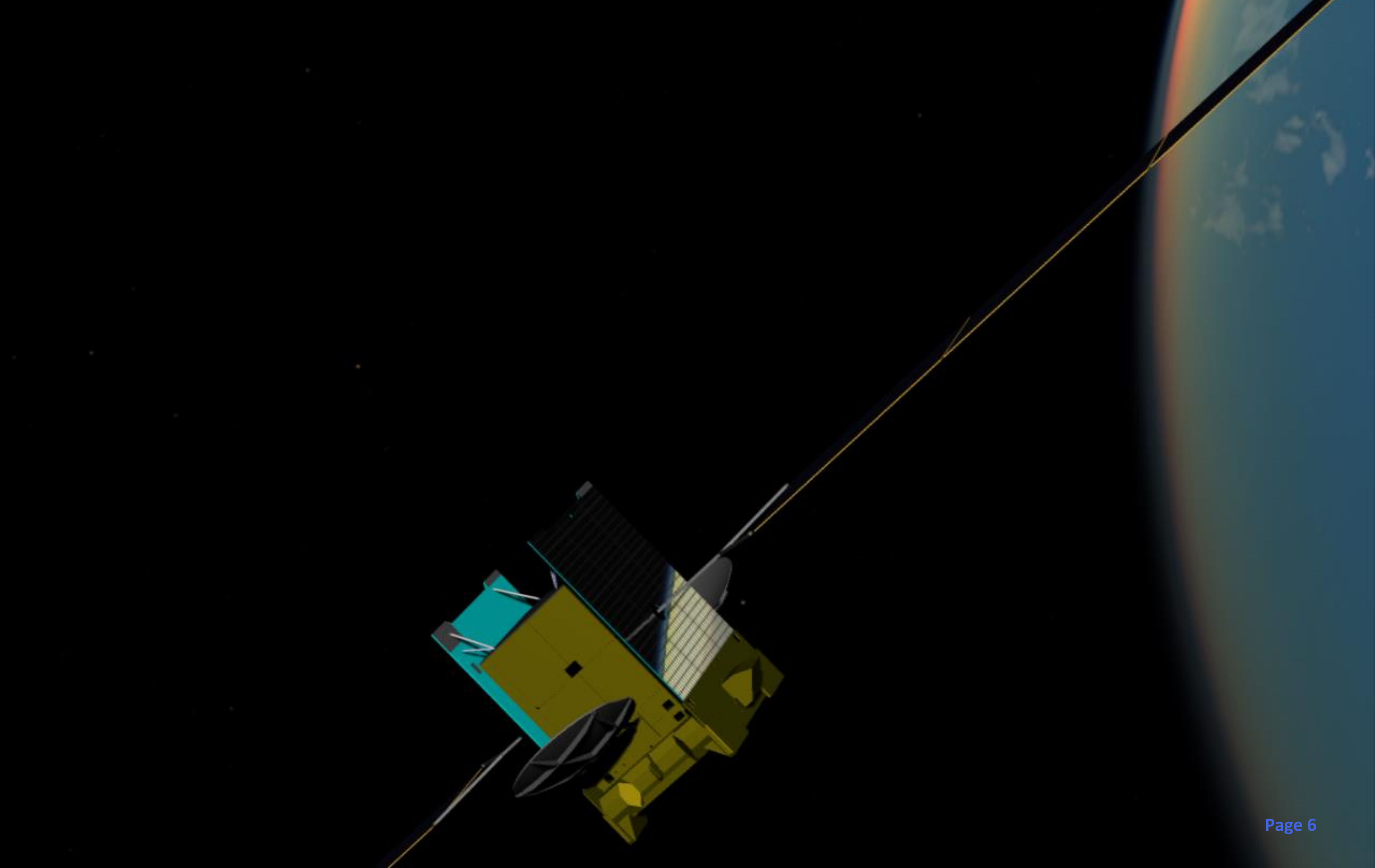


Multiple types of sensors can be simulated:

- Cameras (VIS/visual), LiDAR, RADAR
- Cameras in thermal infrared (TIR) considered for future missions

2: PANGU:
Planet and Asteroid Natural Scene Generation Utility

Low Earth orbit uncooperative spacecraft rendezvous



PANGU v4 simulation of an uncooperative spacecraft rendezvous in low Earth orbit

Created: 2016-Jun-17

Modelling: Iain Martin/PANGU v4.00
Rendering: Martin Dunstan/PANGU v4.00

With thanks to ESA

3: Real-time thermal image generation

Real-time rendering considerations (1/2)

What are the *visible* effects for TIR camera images:

- external surfaces (*e.g.* MLI) are being observed not internal structures:
    - internal temperatures typically designed to be fairly stable
- how does the temperature/radiance change during an orbit?
    - solar input (direct and indirect/albedo), enter/leave eclipse
    - planetary emission (is a constant temperature sufficient?)
    - internal heat dissipation (passive/active thermal control)
    - background emission (space *vs* room temperature lab experiments)

Real-time rendering considerations (2/2)

What are the *visible* effects for TIR camera images:

- how fast do external spacecraft surface temperatures change?
  - MLI ought to change rapidly; what about solar panel surfaces?
  - instantaneous response feasible for real-time rendering:
    - can use a "stateless" zero-capacitance model
  - slower response (thermal inertia effects) is much harder:
    - need to propagate thermal model over time (high cost/settling time)

- Solar Orbiter thermal test video shows fast response to temperature:
  - https://www.esa.int/ESA_Multimedia/Images/2020/01/Solar_Orbiter_thermal_testing

- For natural bodies (*e.g.* the Moon) can use local time/LUT-based model

Solar Orbiter thermal test (steep gradients)

Screen-cap of Solar Orbiter thermal rotation test (Ti MLI shield)

PANGU v6 (per-pixel) thermal modelling

Several models without runtime calculations:

- None (no emission), constant, external (temperature baked into PANGU model)

Look-up table-based (*per* LRO/Diviner) with diurnal, seasonal, thermal inertia LUTs:

- For natural bodies *e.g.* planets, moons, asteroids

Equation-based using zero-capacitance/zero-conductance model:

- For spacecraft; based on thermal balance equations [**Savage**]
- Direct solar, reflected solar (albedo), planet emission, internal heat

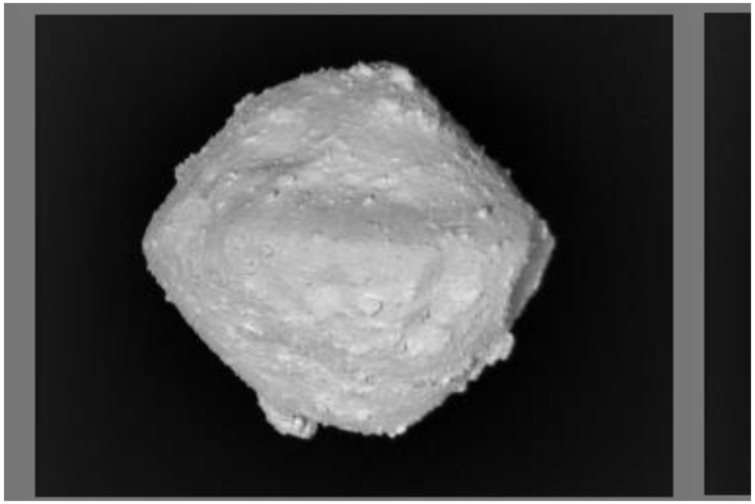
Temperatures are converted to thermal radiance using Planck's law:

- Computed *per*-pixel with spectral (RGB) emissivity

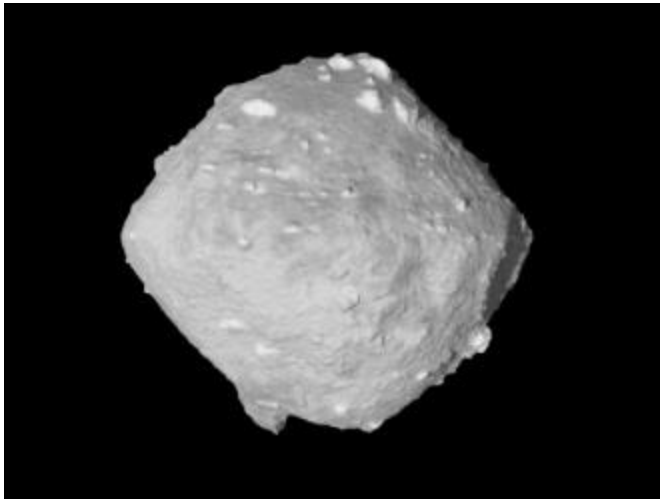
Savage, C., J., *Spacecraft Systems Engineering*, 3rd Edition, Chapter 11 "Thermal control of spacecraft", Wiley, 2003.

4: Results

Hayabusa2/TIR *vs* PANGU LUT and equation models



hyb2_tir_20180801_174744_l1



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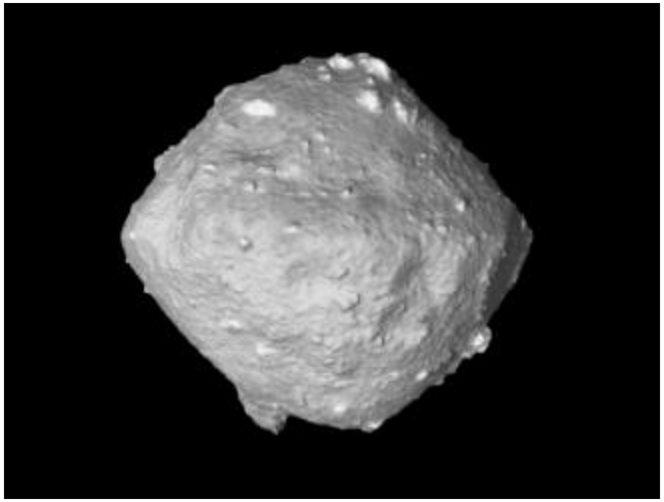
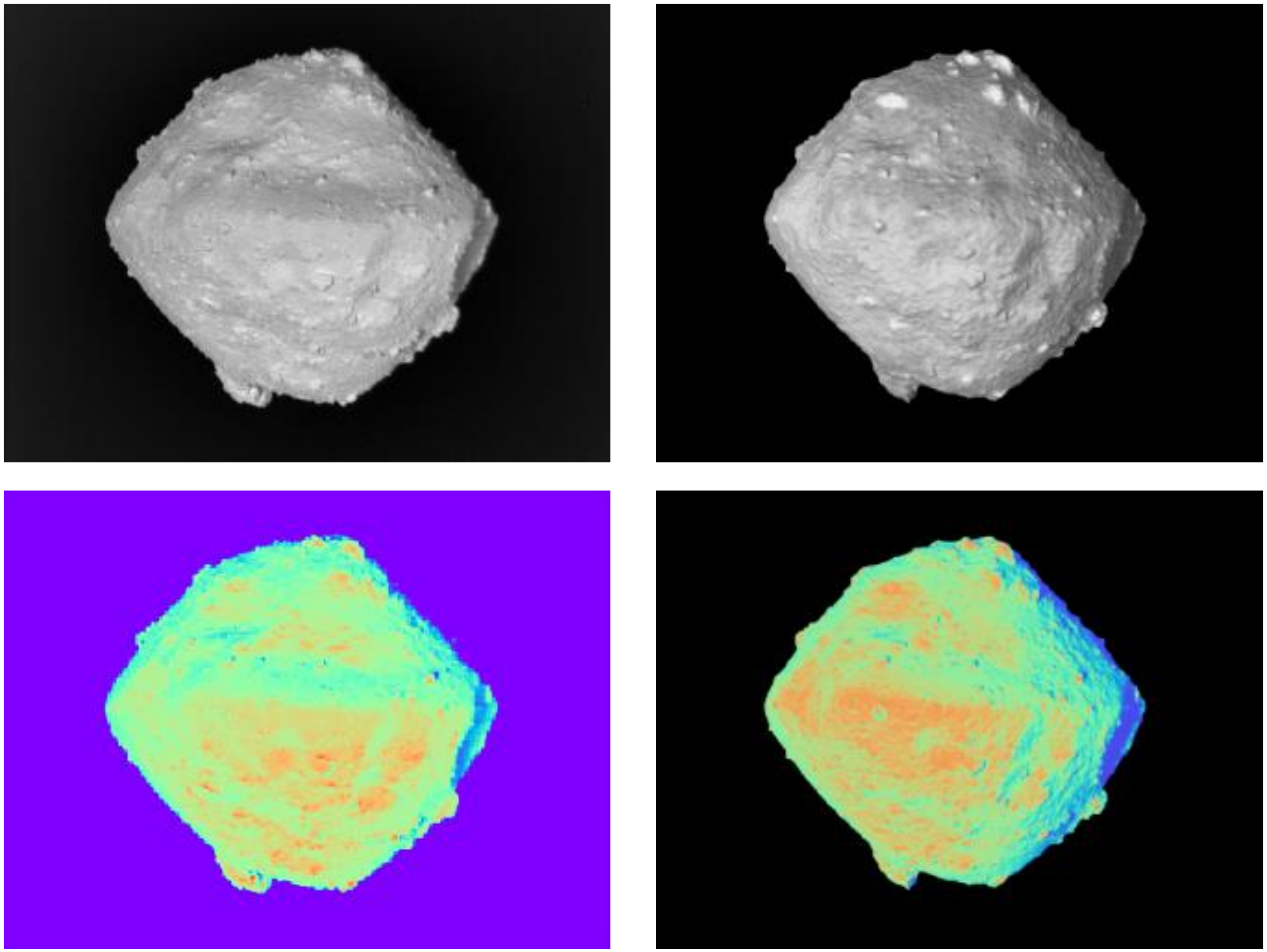


eqn_20180801_174744

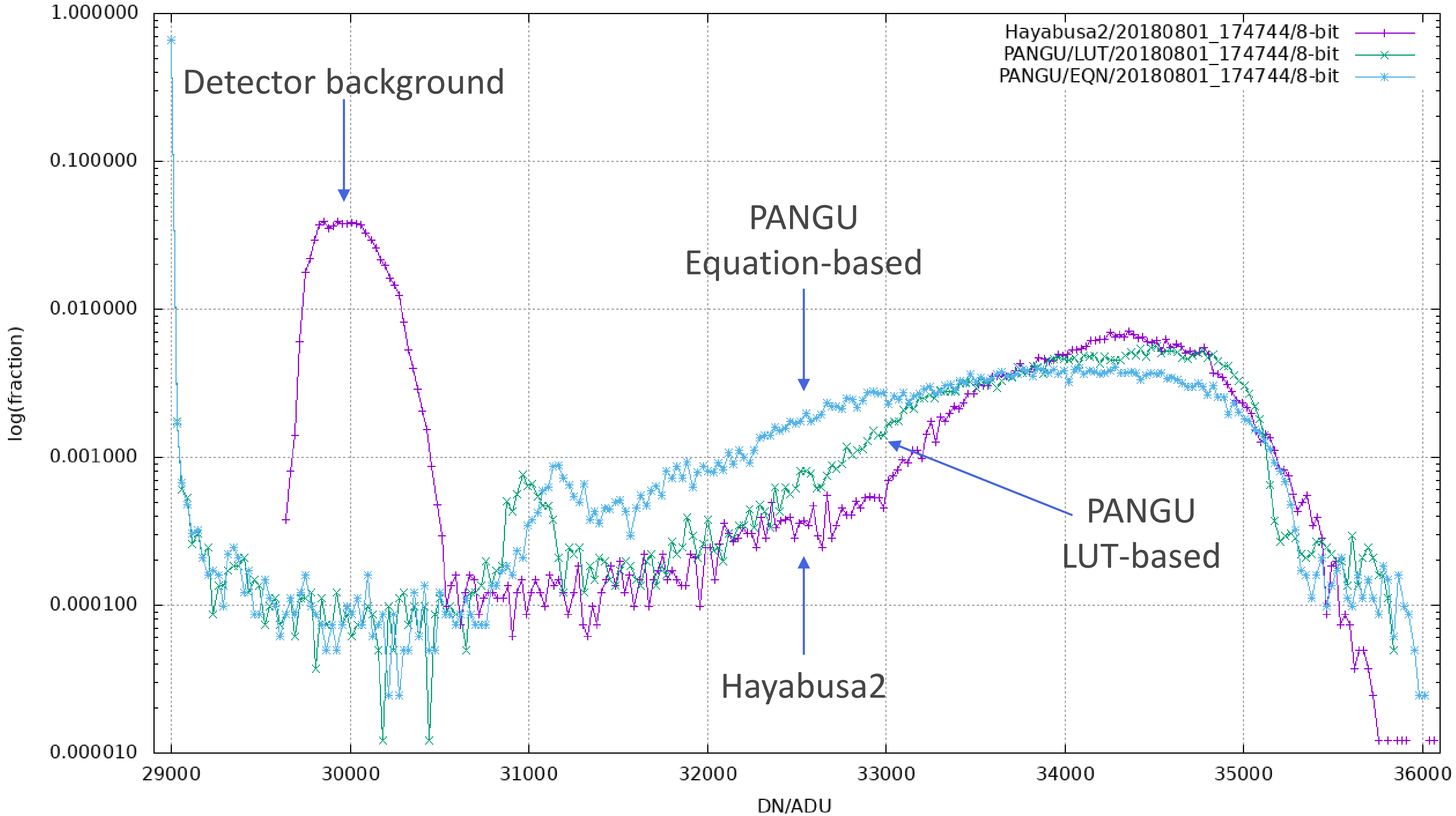
Ryugu *vs* PANGU equation-based model



Hyb2/TIR/20180801T174744

PANGU/TIR/20180801T174744

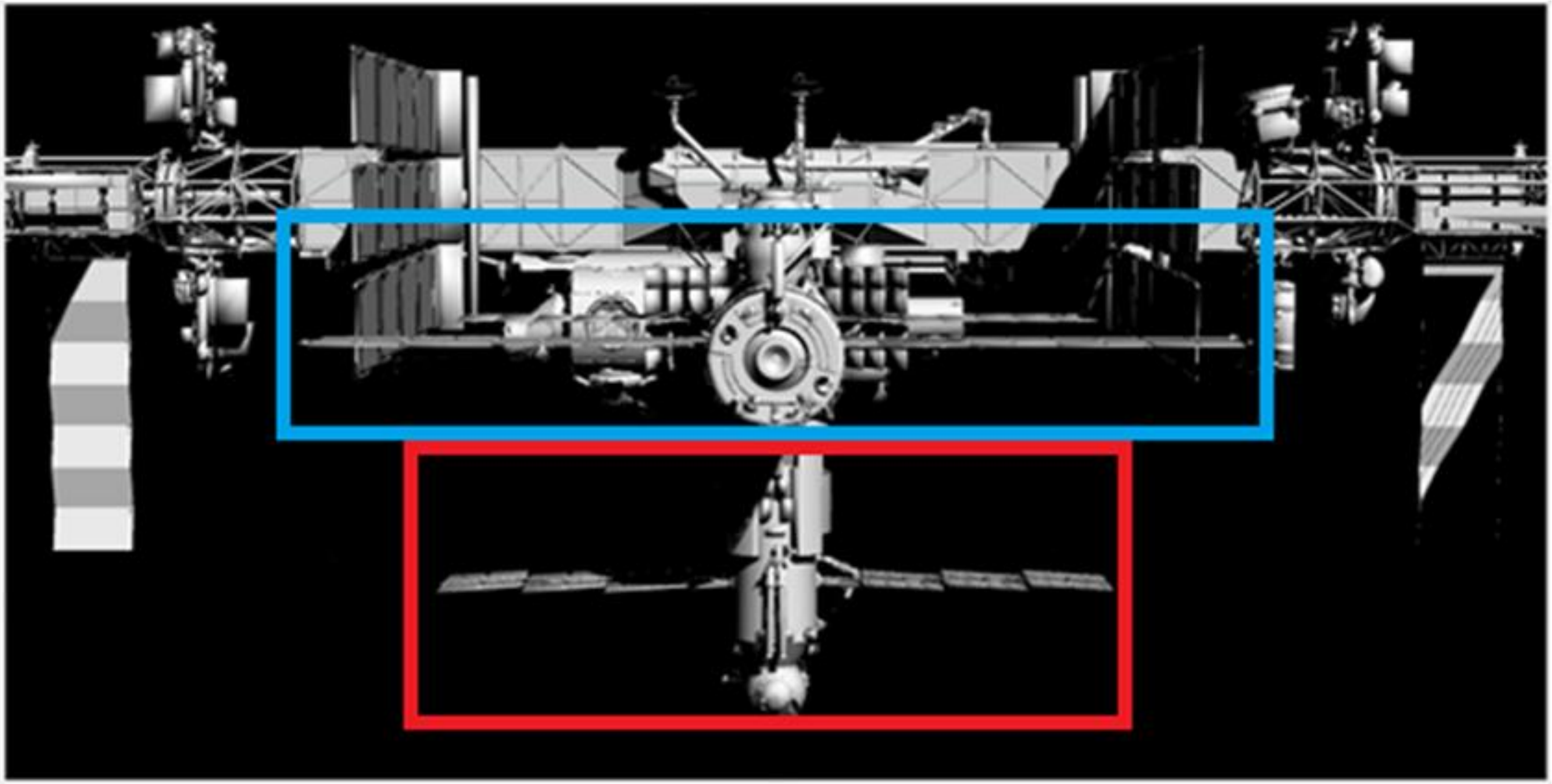
Ryugu/PANGU grey-level histograms



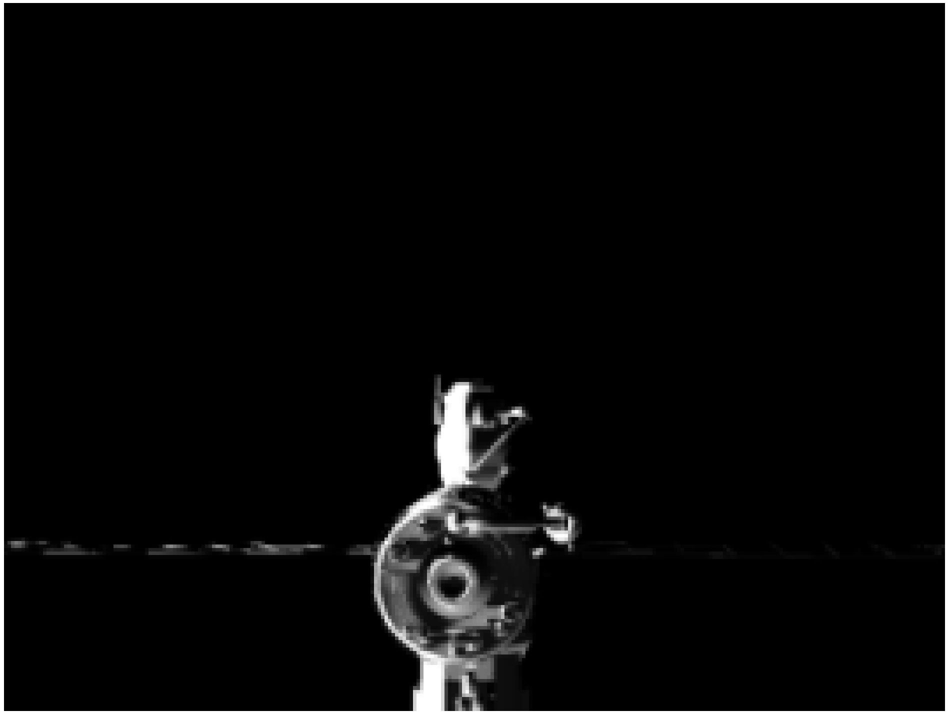
ATV/LIRIS image of the International Space Station

LIRIS TIR image of ISS from 17 m range

LIRIS PANGU thermal simulation geometry

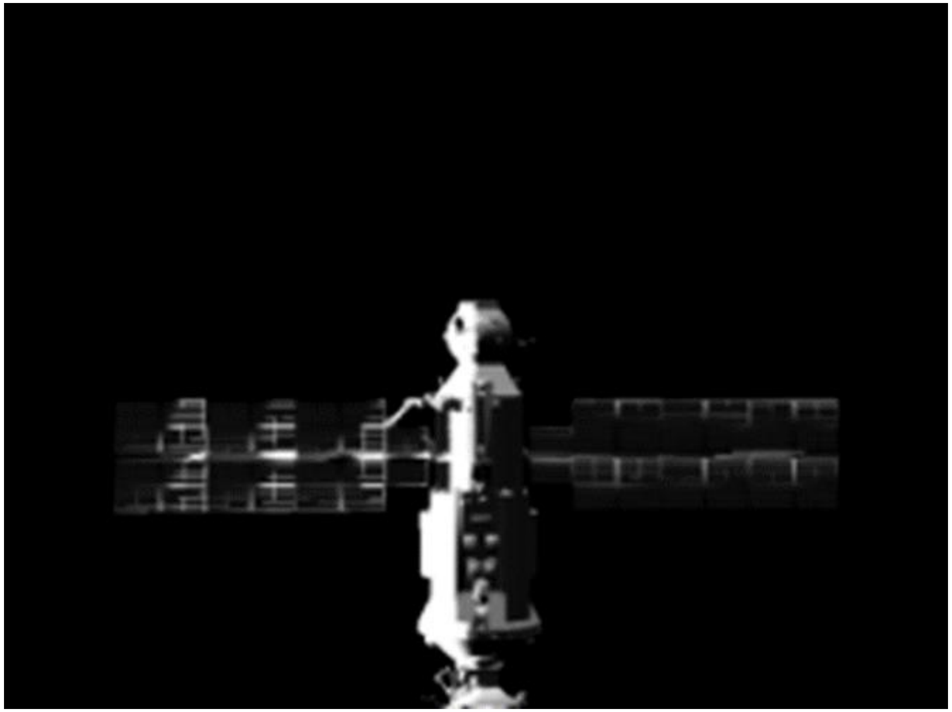


LIRIS image (left) and PANGU simulation (right)



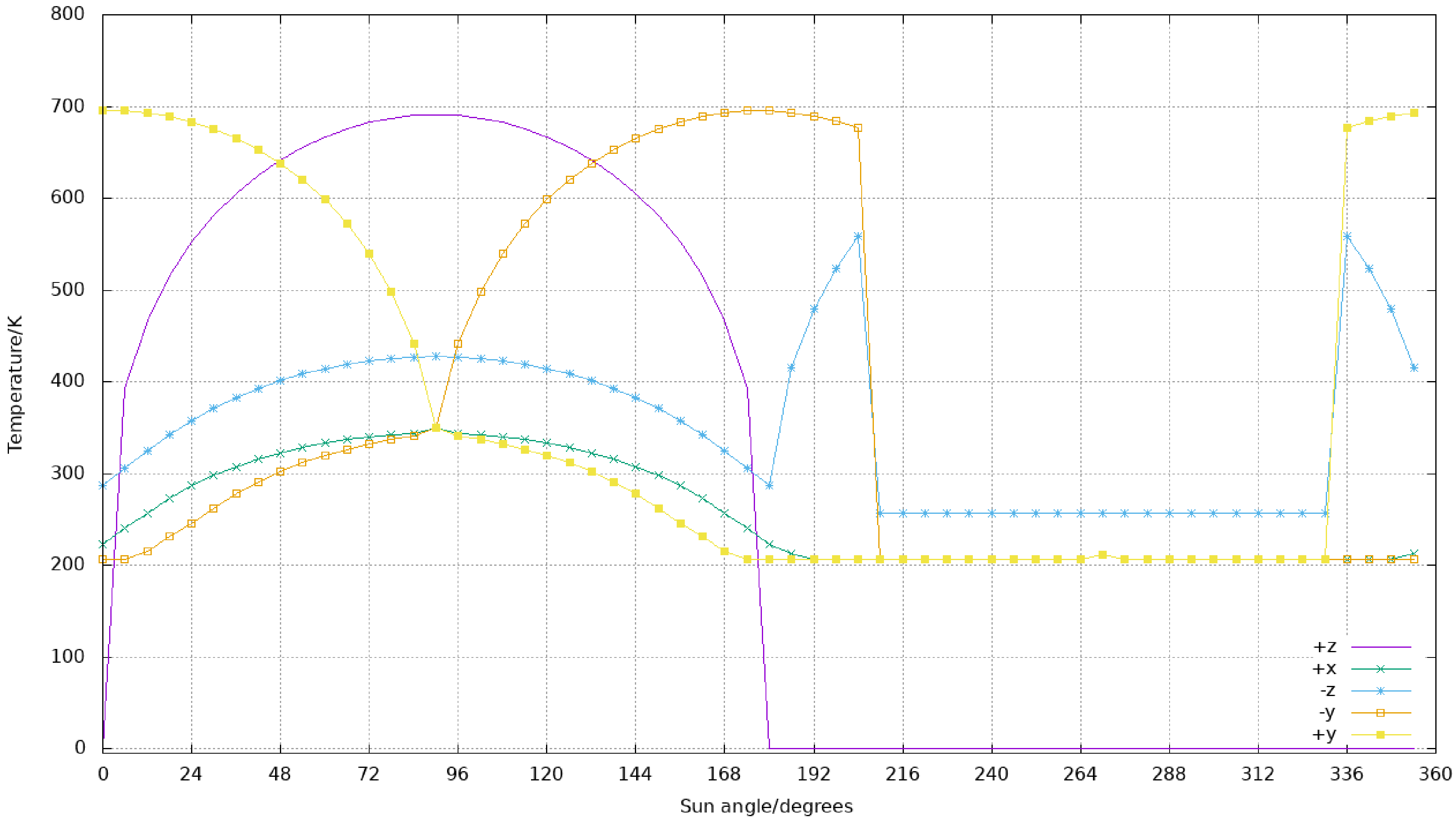
PANGU thermal simulation of the docking port in the centre of LIRIS image.
Unknown local time of day (*e.g.* direct/indirect solar).

LIRIS image (left) and PANGU simulation (right)

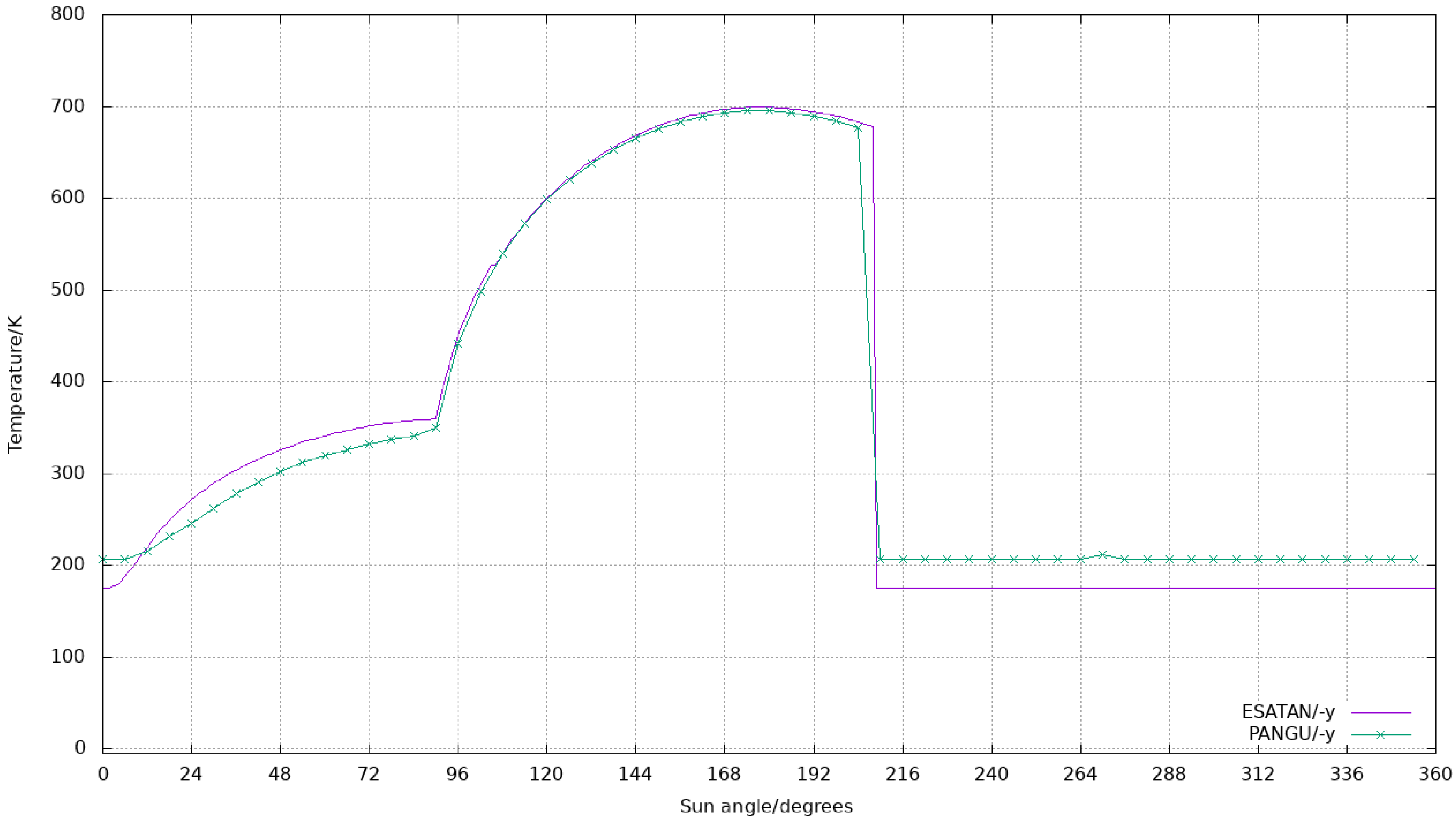


PANGU thermal simulation of the Soyuz/Progress craft in LIRIS image.
Unknown local time of day (*e.g.* direct/indirect solar).

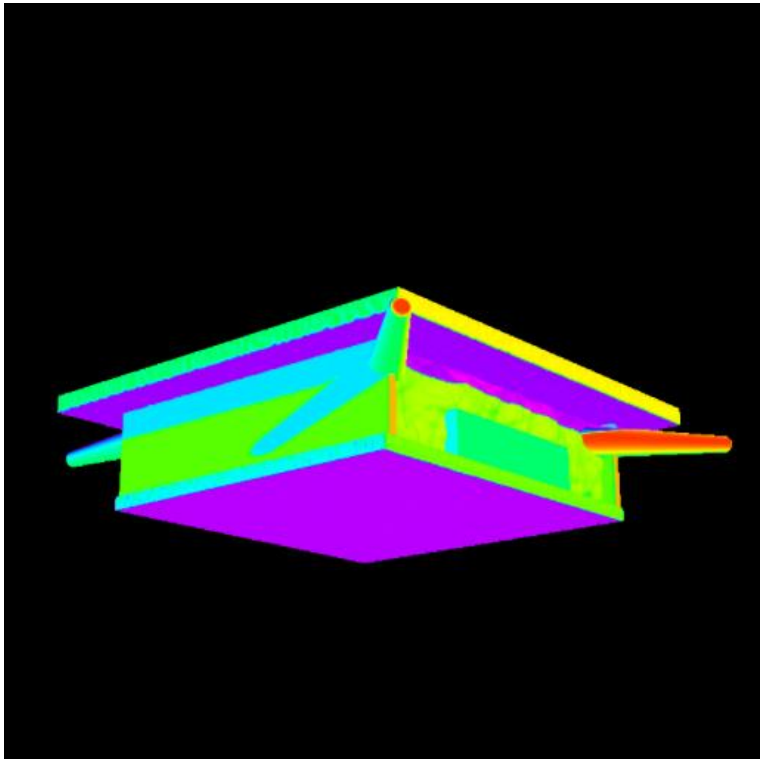
MLI cube (α/ε=9.5) face temperatures (PANGU)

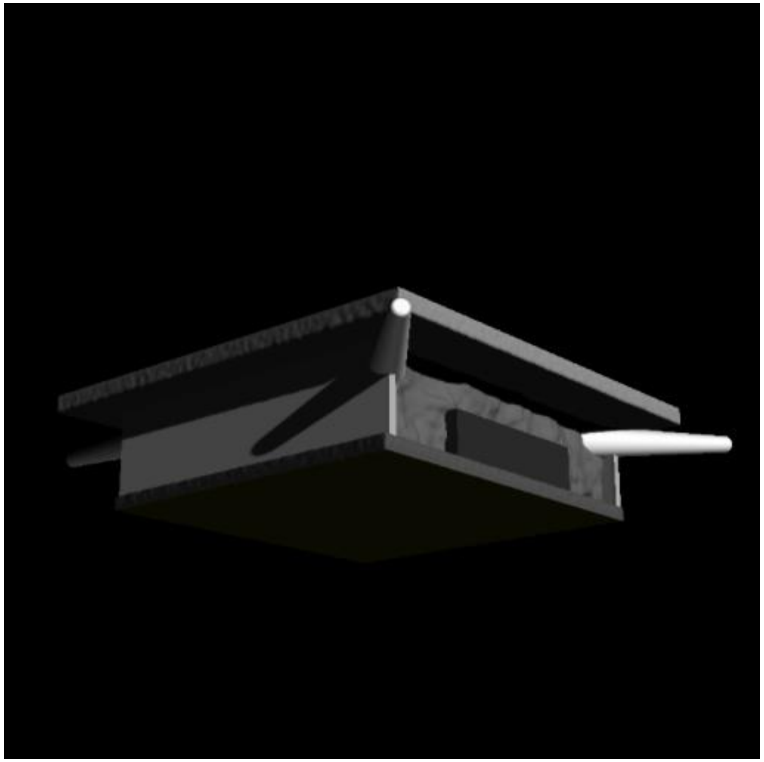


MLI cube satellite temperature (PANGU *vs* ESATAN)



Thermal image simulation: PRISMA/Tango

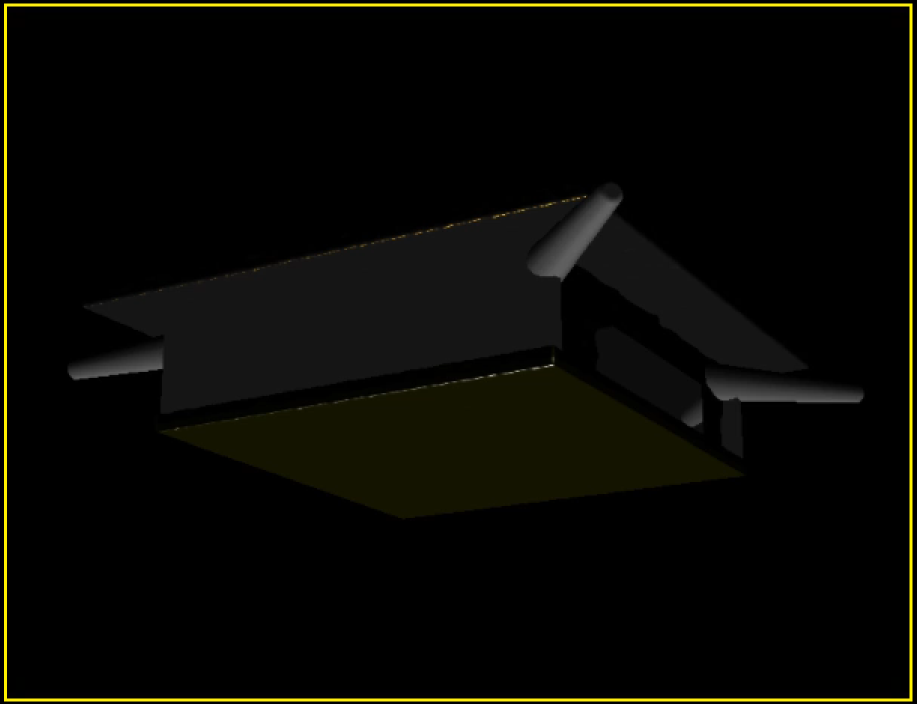


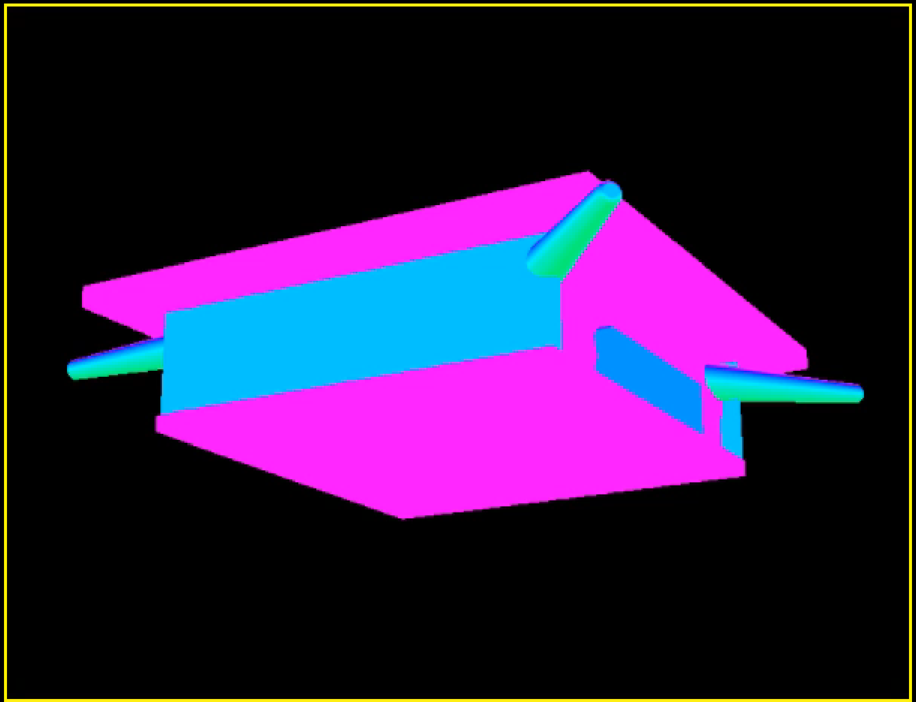


Simulated false colour and thermal radiance images of PRISMA/Tango model

- includes direct solar, background, albedo and planetary emission

PANGU v6 TIR/12µm image of a spacecraft in 773km Earth orbit (Sun elevation -90.0°)





Thank you for your attention

PANGU and PANGU was developed by the University of Dundee for ESA.
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