An overview of Jason-2 radiation force model development work at UCL

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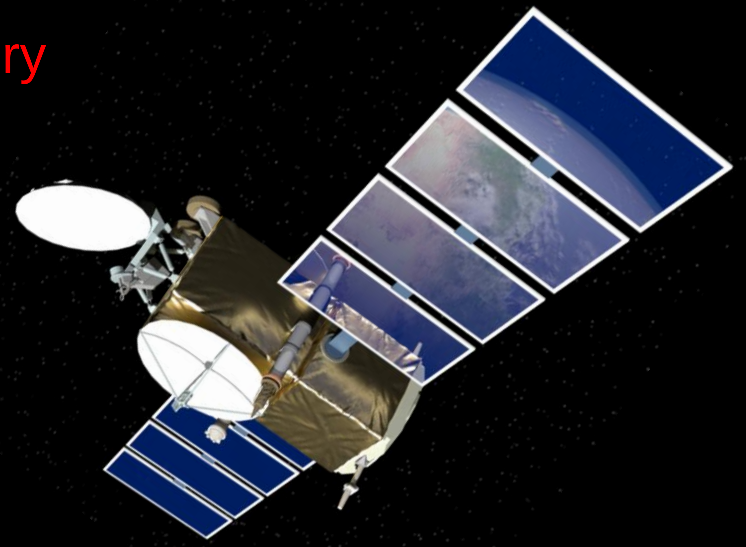
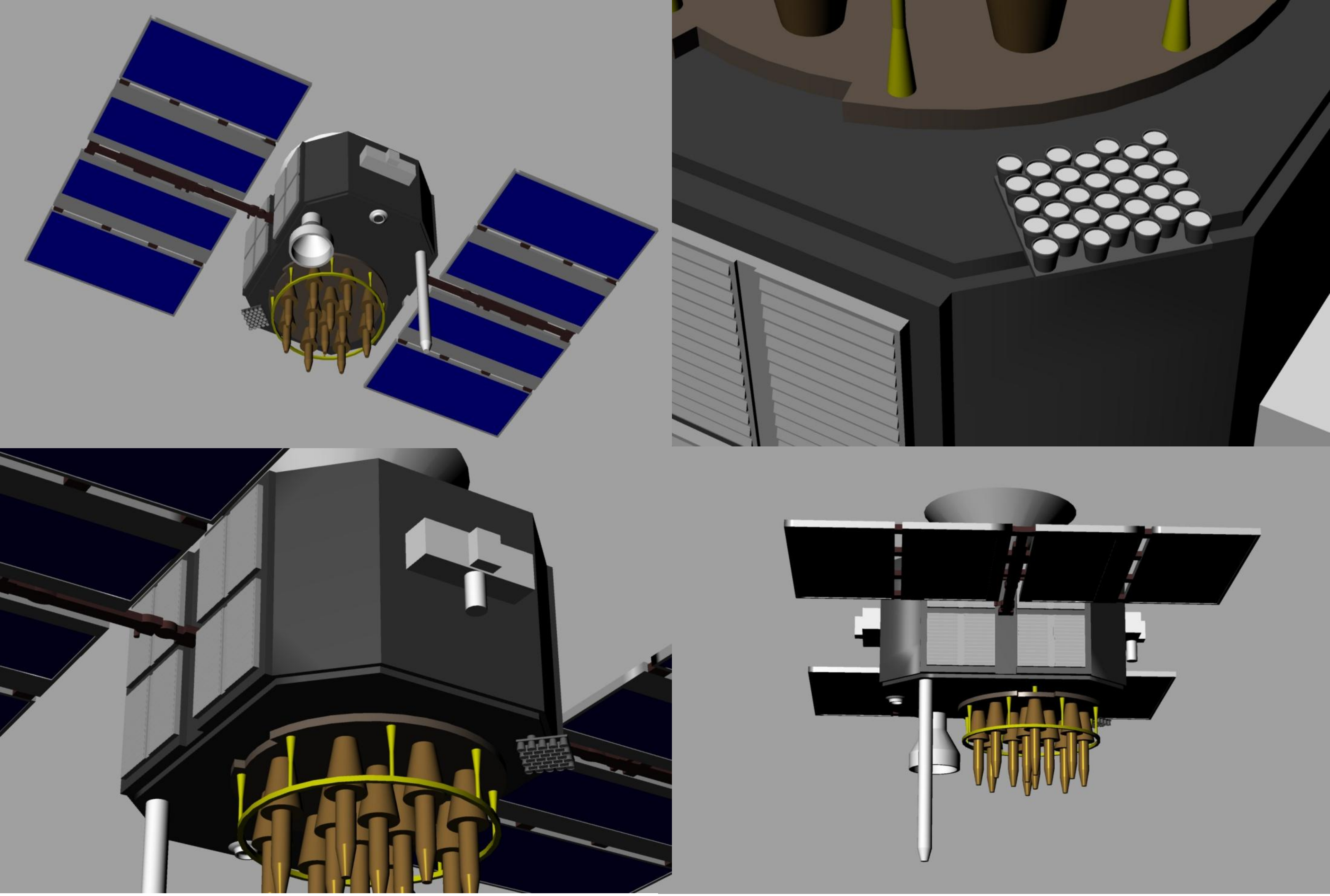


IDS Analysis Working Group Meeting, Delft, Holland

Executive Summary

- UCL has developed a new photon pressure model for Jason-2, and is ready to carry out implementation and testing
- The Jason-2 model features several advances over the existing, 'proven' Jason-1 model
- New features:
  - Very detailed structural data (superior to Jason-1 model)
  - Enhanced grid file calculation method (higher resolution, better mathematical stability)
  - Details of anti-sun facing solar panel construction and properties
  - Solar panel thermal gradient force
  - Mass history model

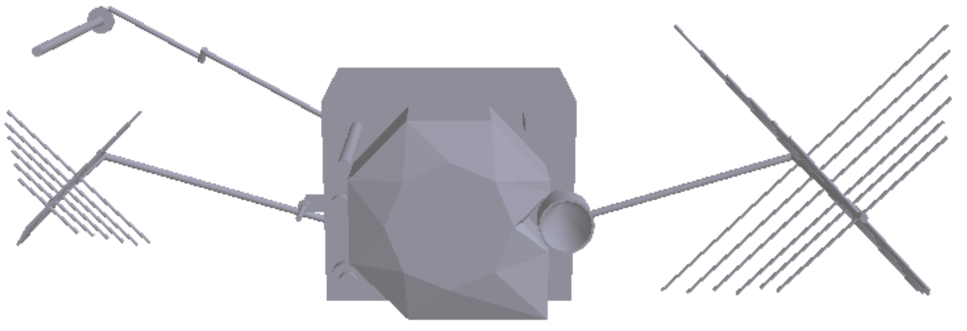


We develop a detailed structural computer model of the spacecraft

Ray Tracing - 1

Geometry

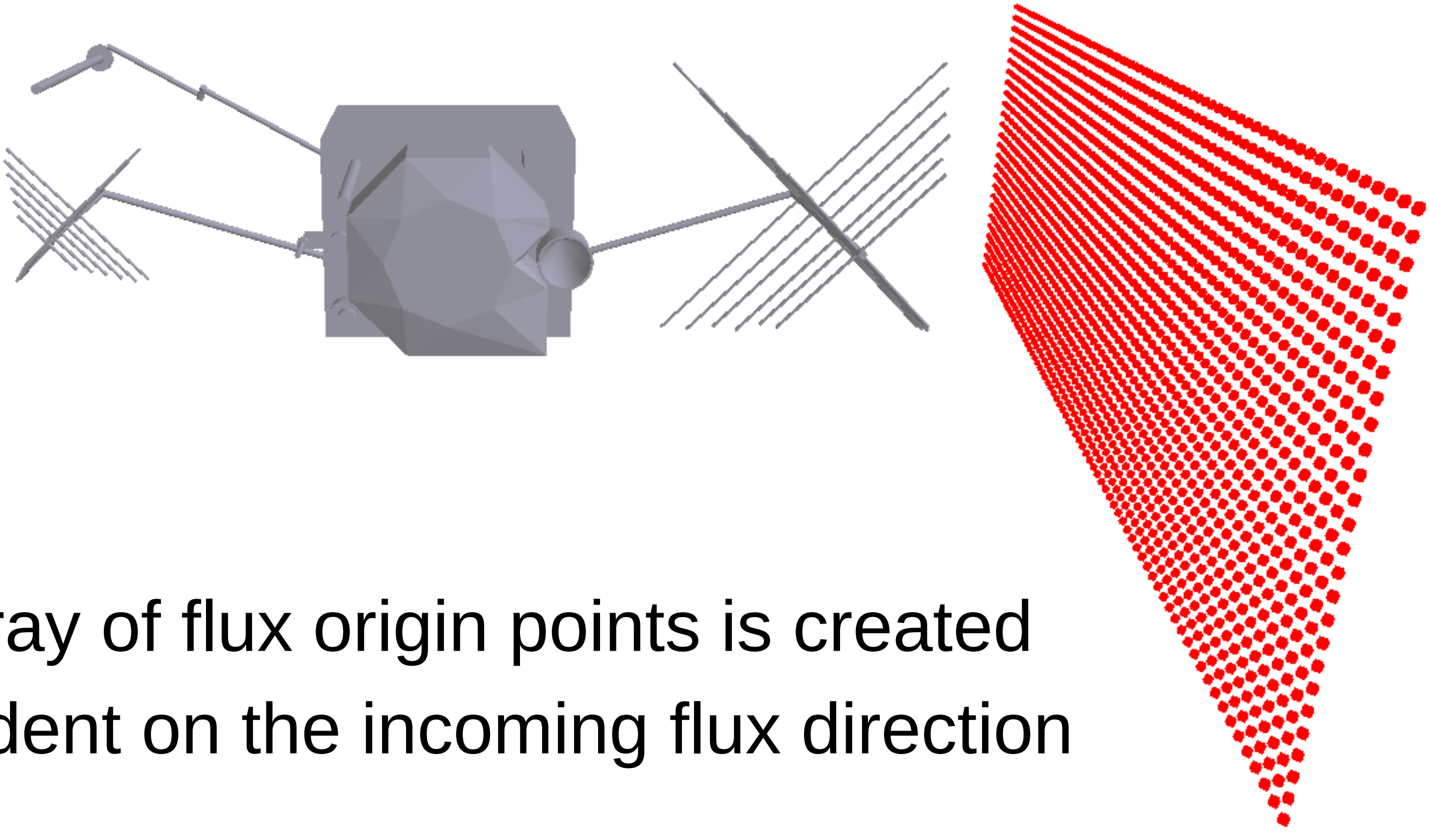
Material types



Optical and thermal properties

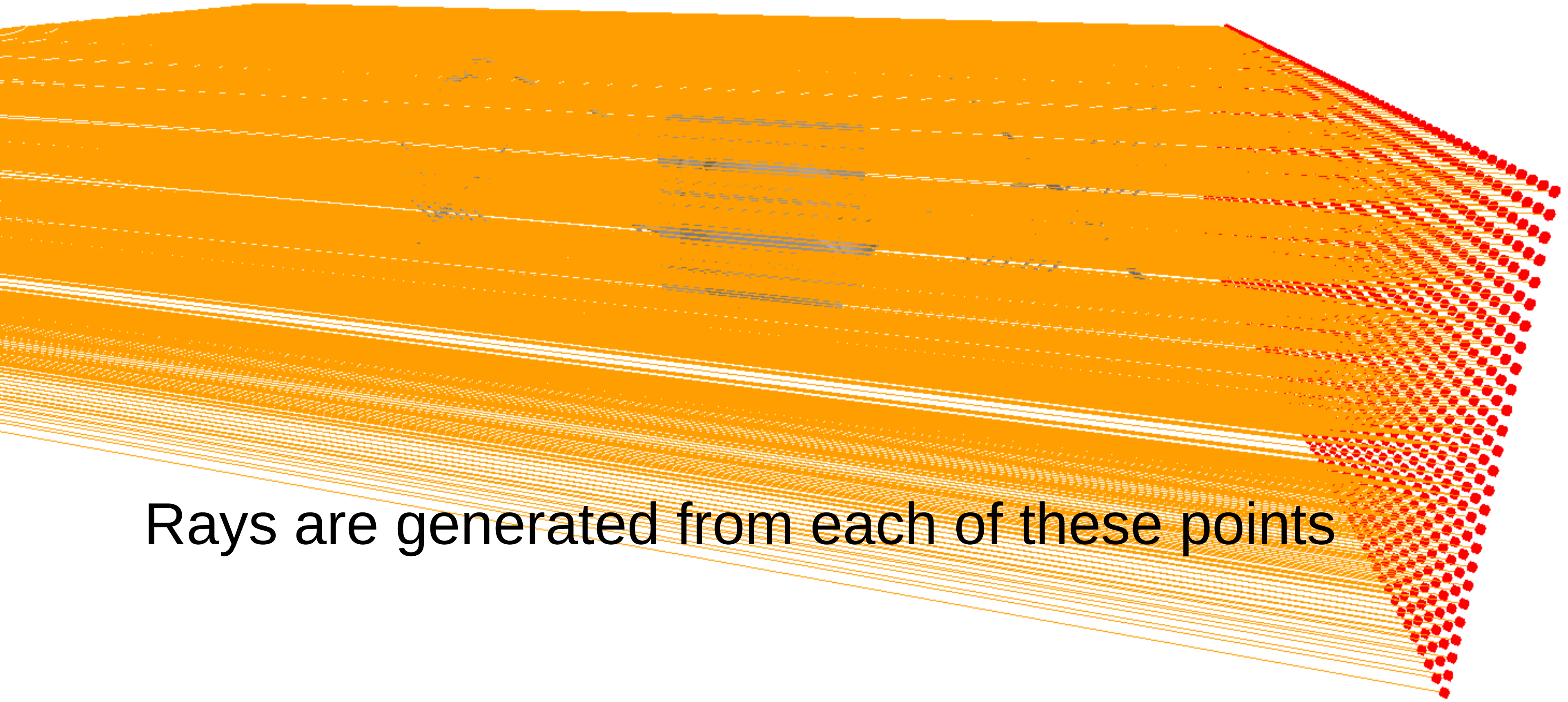
Spacecraft model represented in the SV body frame

Ray Tracing - 2



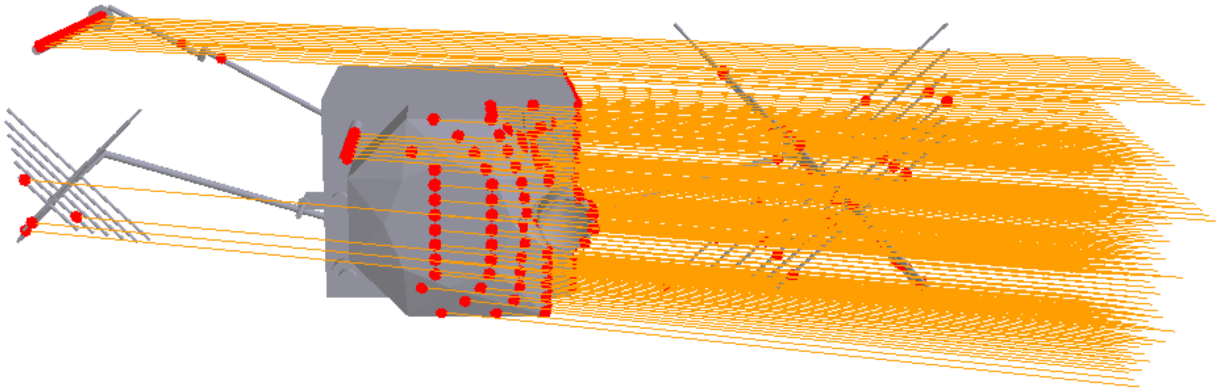
An array of flux origin points is created
Dependent on the incoming flux direction

Ray Tracing - 3



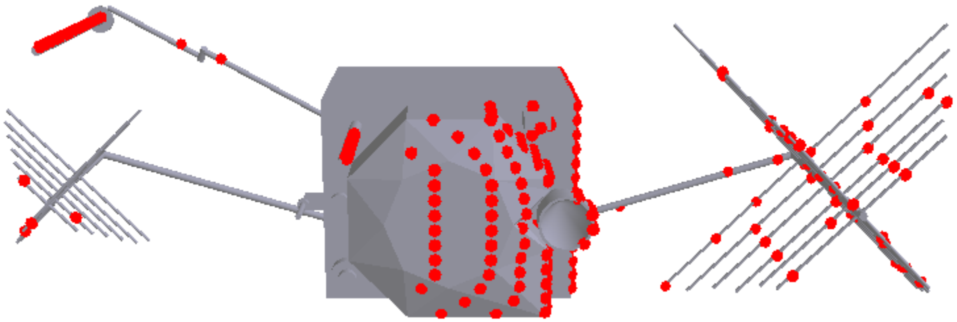
Rays are generated from each of these points

Ray Tracing - 4



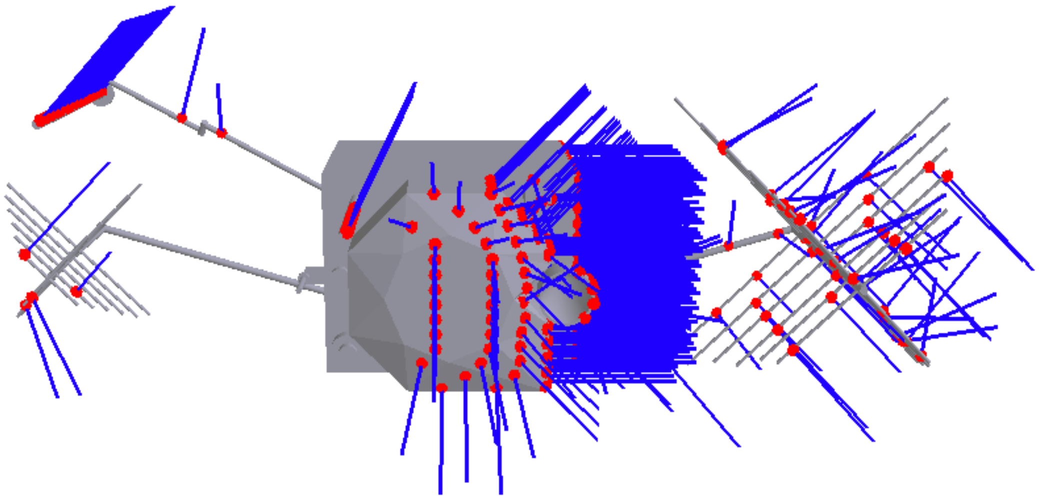
The intersection between each ray and the spacecraft is computed

Ray Tracing - 5



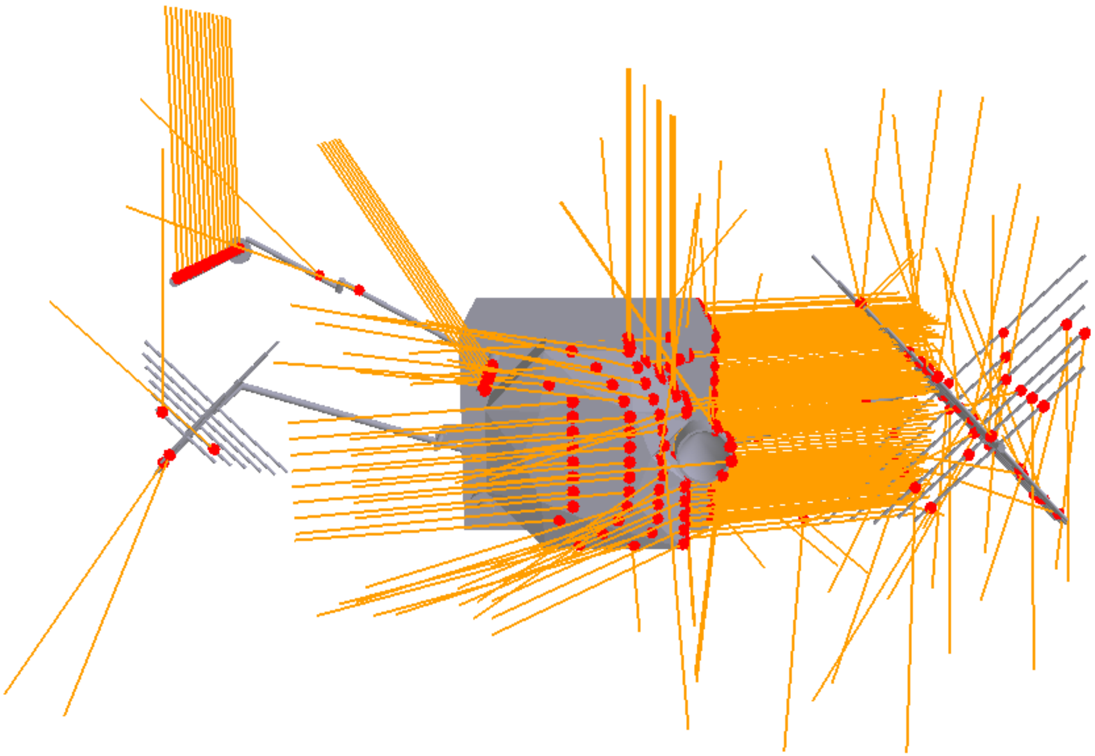
The material properties of the surface are known at each of these points

Ray Tracing - 6



The surface normal is calculated at each of these points for planar or **curved** surfaces

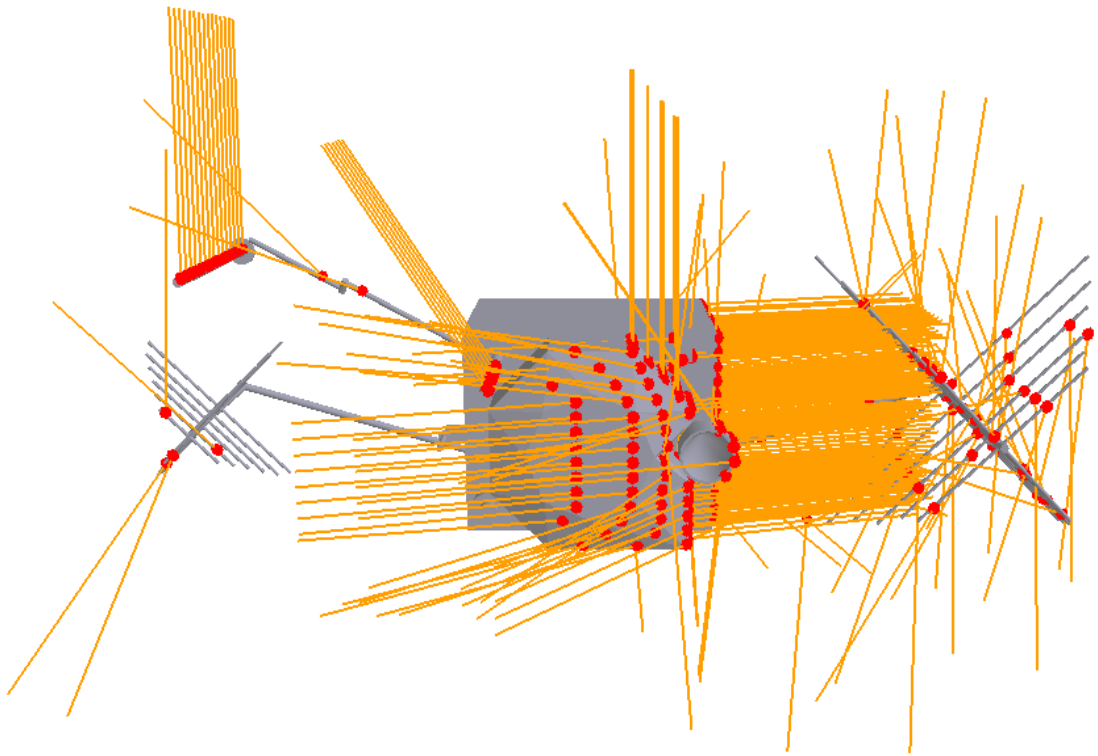
Ray Tracing - 7



New rays are generated for each reflection and the intersection and reflection step repeated:

Secondary intersections

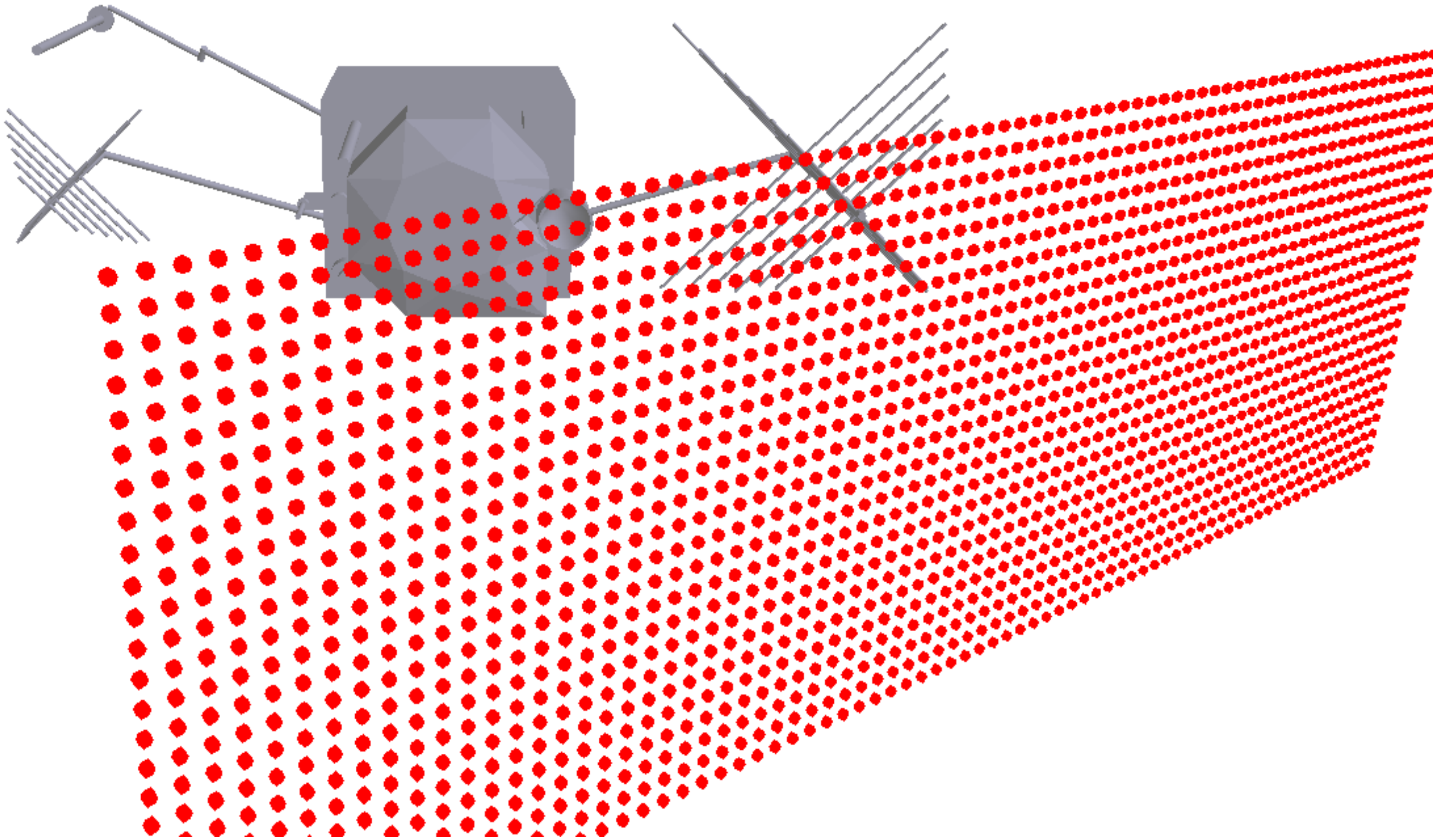
Ray Tracing - 8

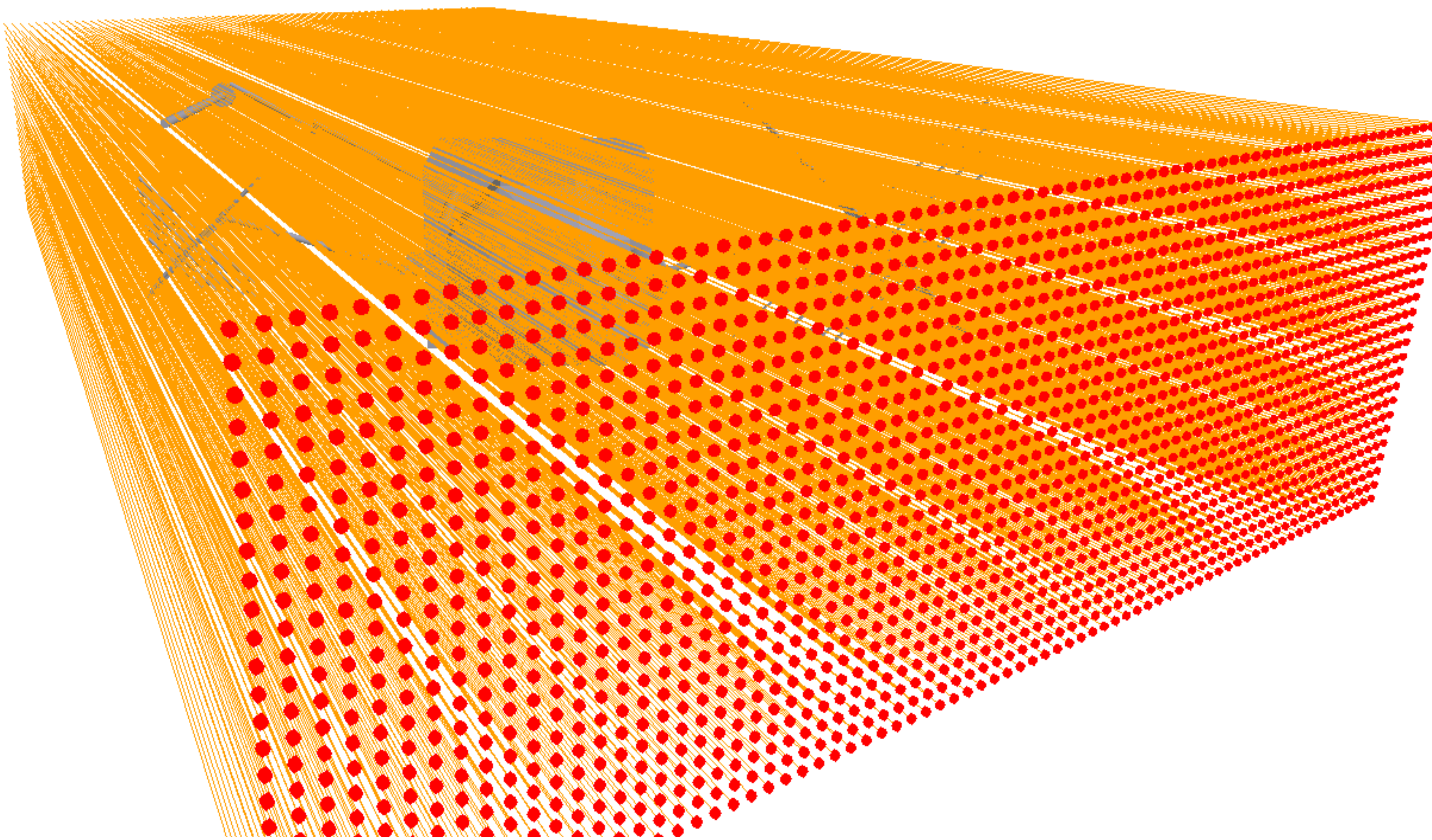


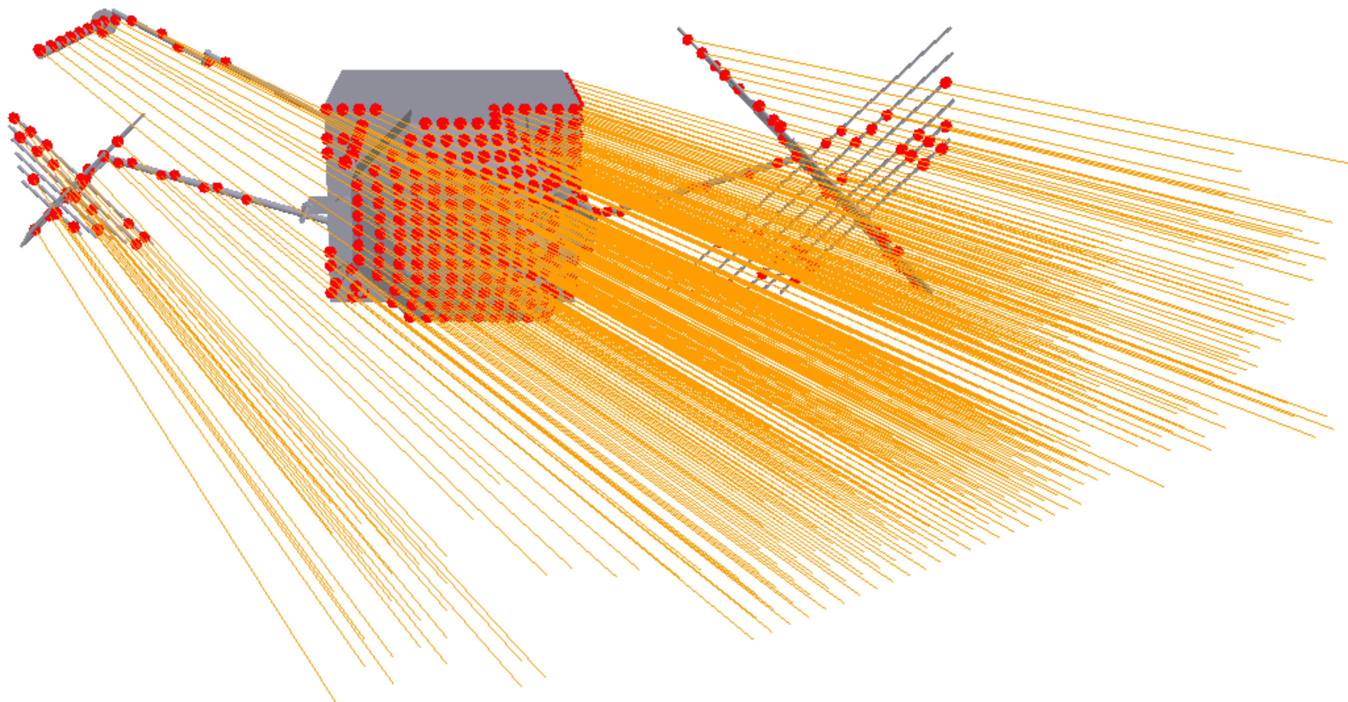
The acceleration data for all rays (primary and secondary) is collected:

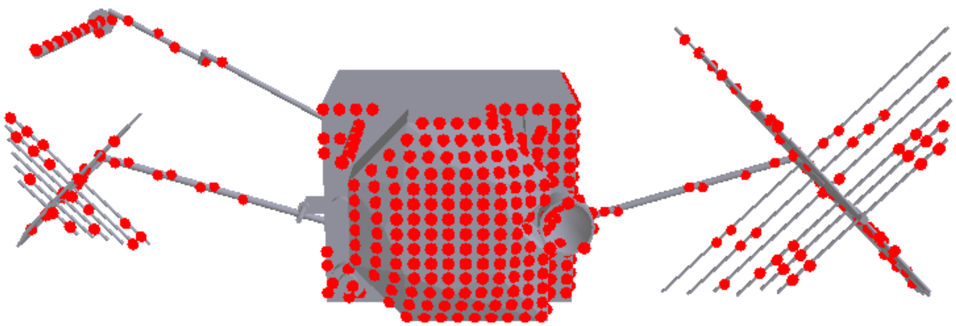
Resultant acceleration computed for that radiation source direction

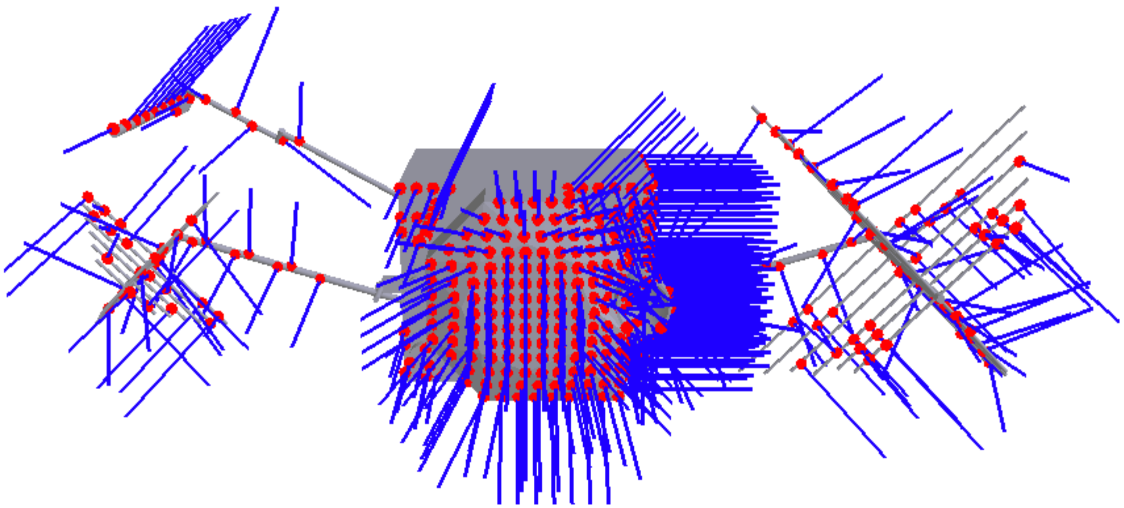
Process is repeated for other incoming flux directions

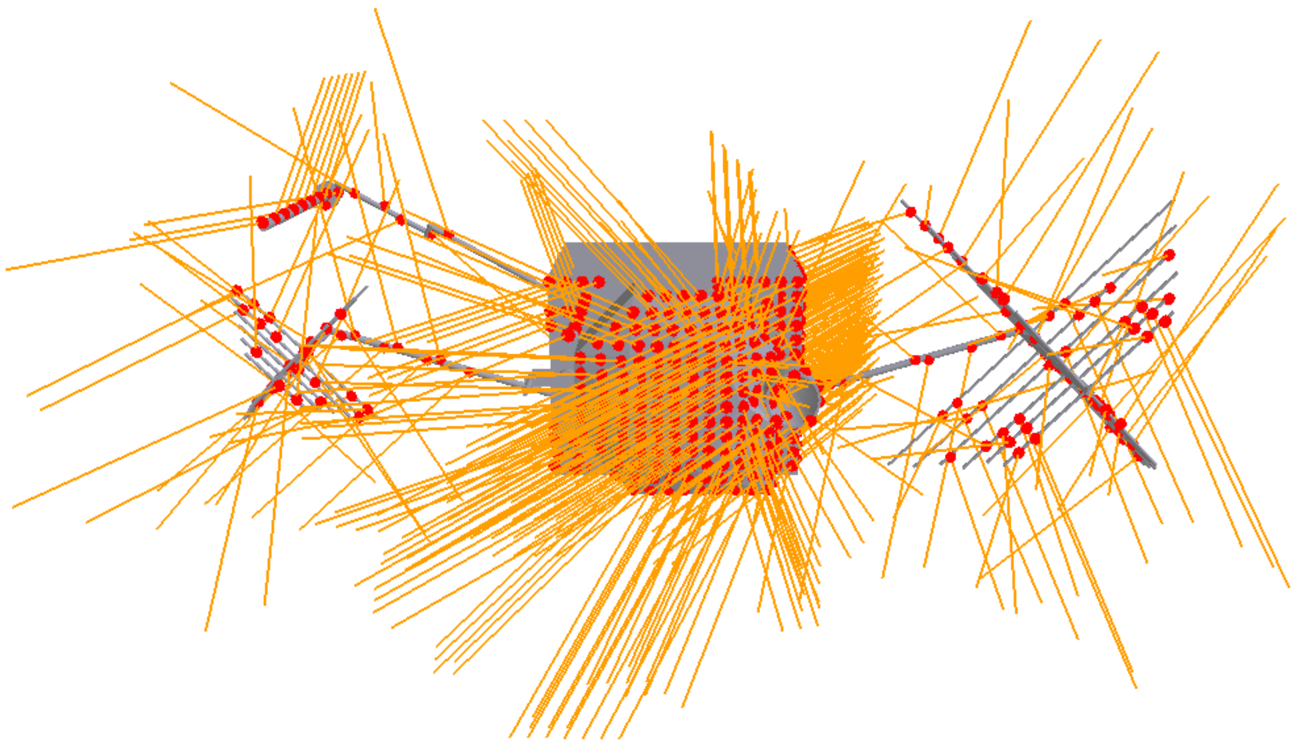






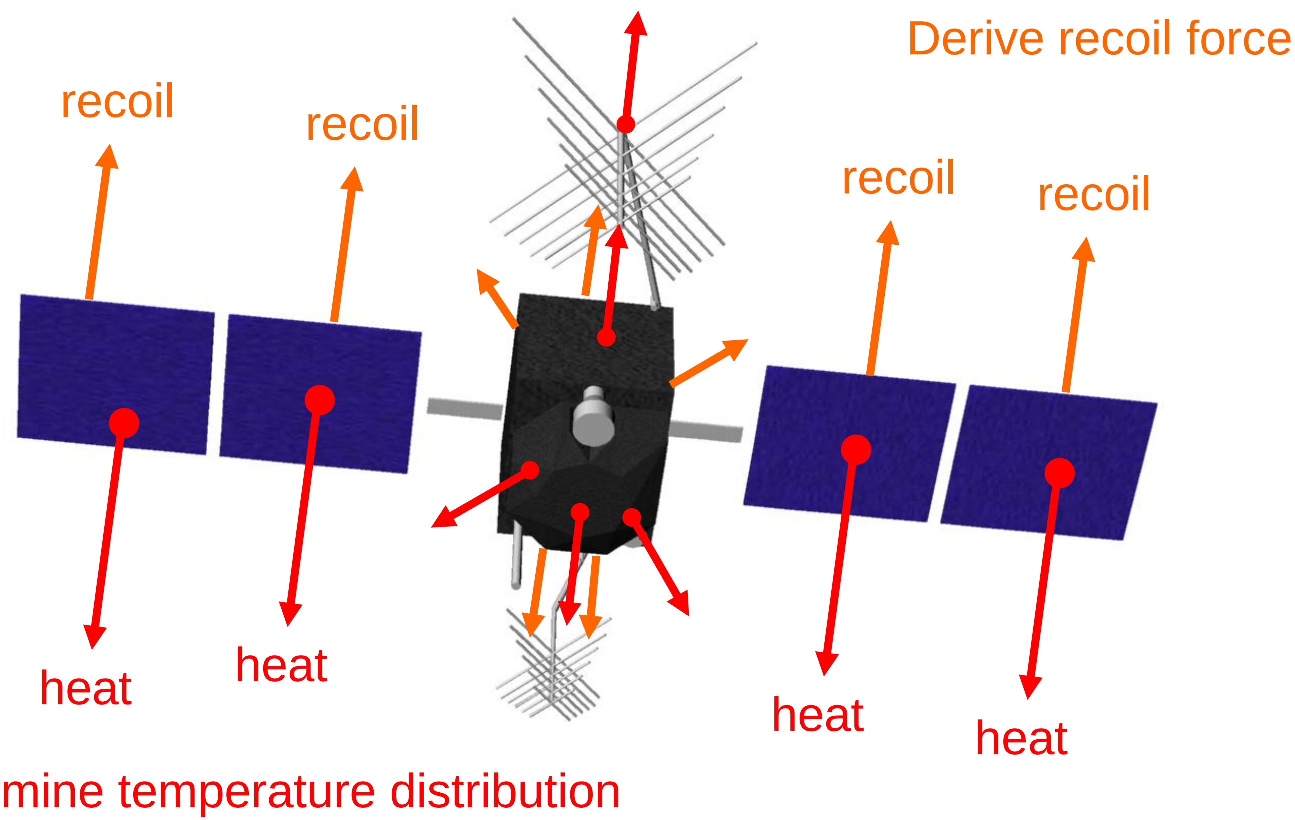






Thermal modelling:

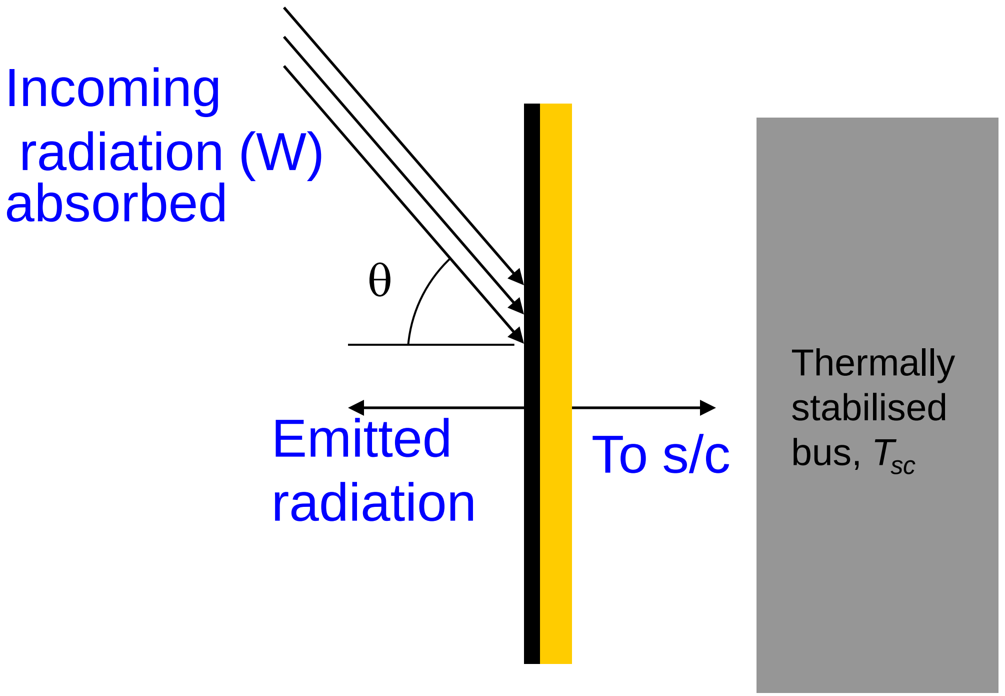
Anisotropic thermal emission from spacecraft results in a net acceleration



Multilayer Insulation (MLI)

- Pixel array algorithm determines insolation of MLI
- 'Effective emissivity' (ε_{eff}) parameter governs heat transfer to bus
- MLI blackened, α=0.94 $\Rightarrow$ large thermal force

Energy balance:



$$T_{MLI}^4 = \frac{\alpha W \cos\theta + \varepsilon_{eff}\sigma T_{sc}^4}{\sigma(\varepsilon_{MLI} + \varepsilon_{eff})}$$

Solar Panel Thermal Analysis

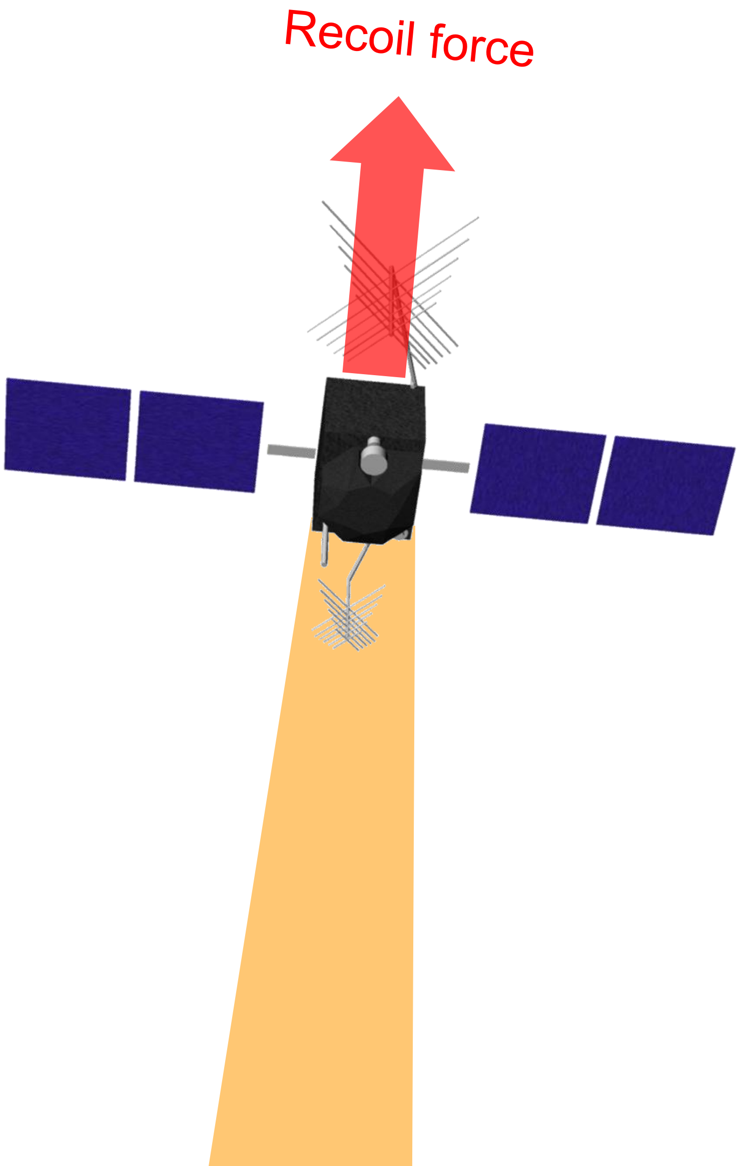
- Steady state and transient models (during eclipse) developed to yield temperatures and forces

- Input data : thicknesses and conductivities of panel composite layers, surface emissivities and absorptivities, power draw

- Model verification by comparison with telemetered surface temperatures

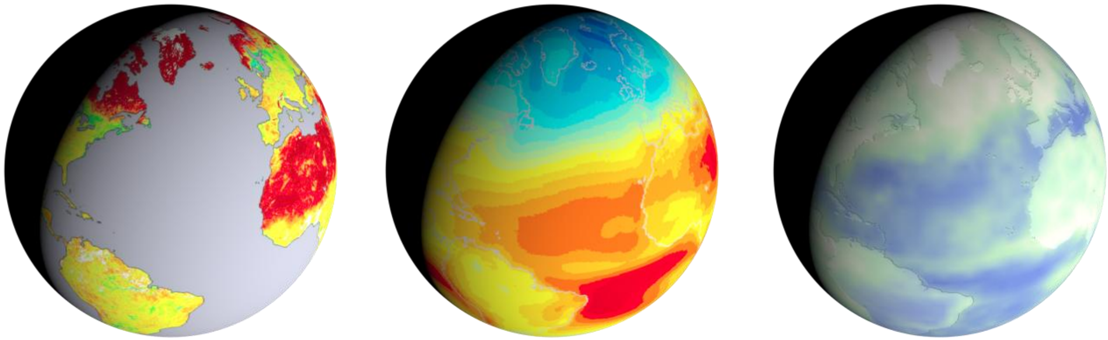
Antenna Thrust

- Recoil force on satellite due to transmitted signals
- Systematic and observable effect
- Requires knowledge of power transmission of satellites



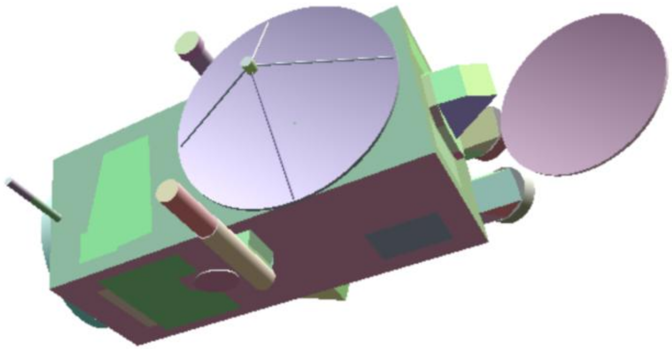
Planetary Radiation Pressure (PRP) models using space based observations of emission and reflectance.

*Earth textures courtesy of NASA Blue Marble: Next Generation. Earth radiation data courtesy of CERES and MODIS.

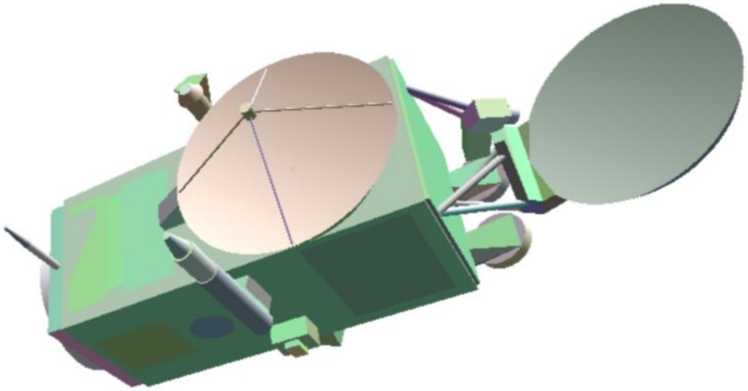


UCL structural model comparison

Jason-1



Jason-2



Jason-2 structural model has far better detail compared to the Jason-1 data we used at the time

The UCL Jason-2 structural model

Model visualisation

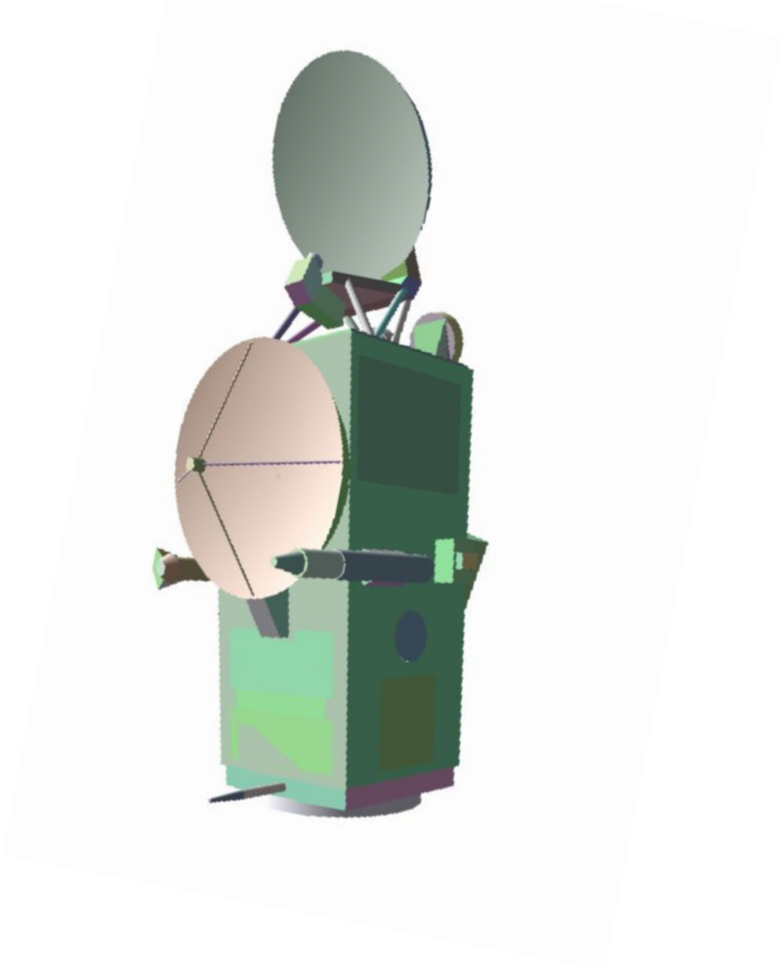
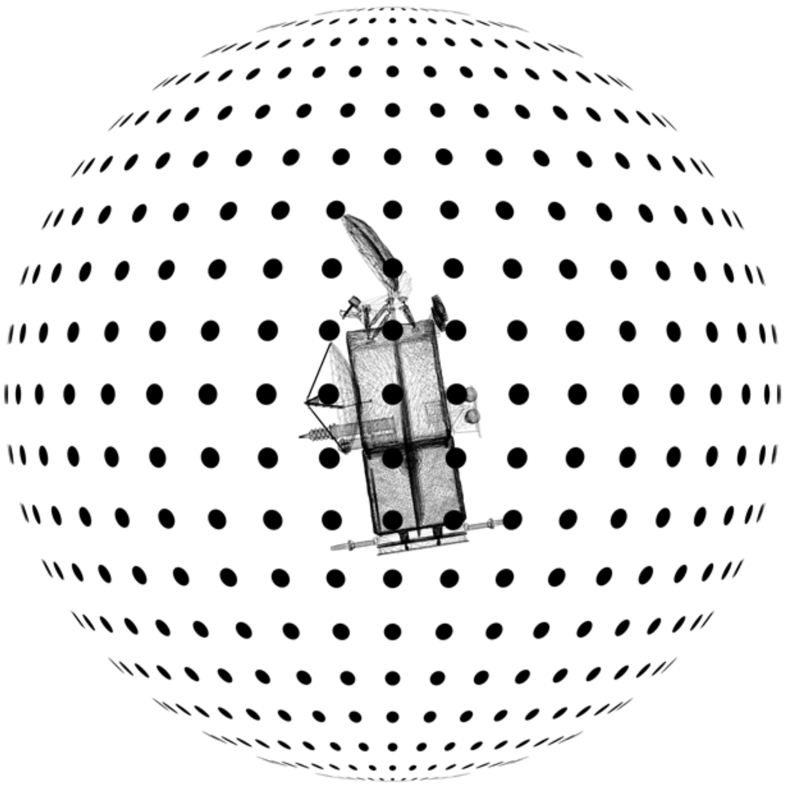


Image taken during ground tests

Structural models, SRP/TRR(MLI) computations, and grid files

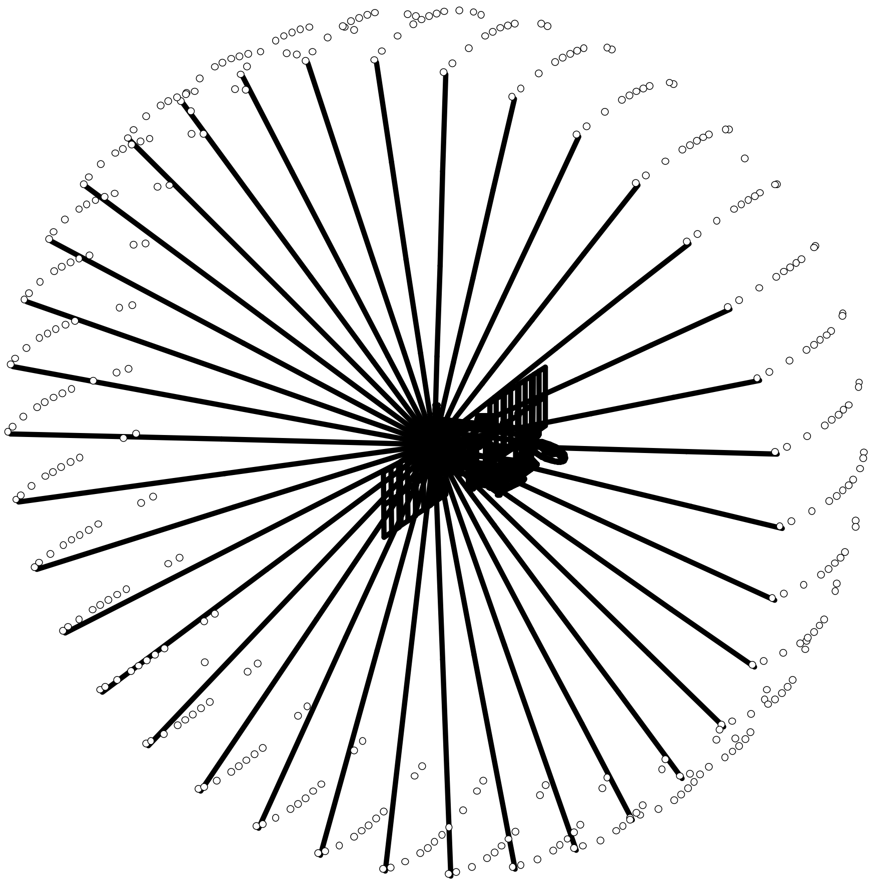
BUS MODEL

Spiral points computation



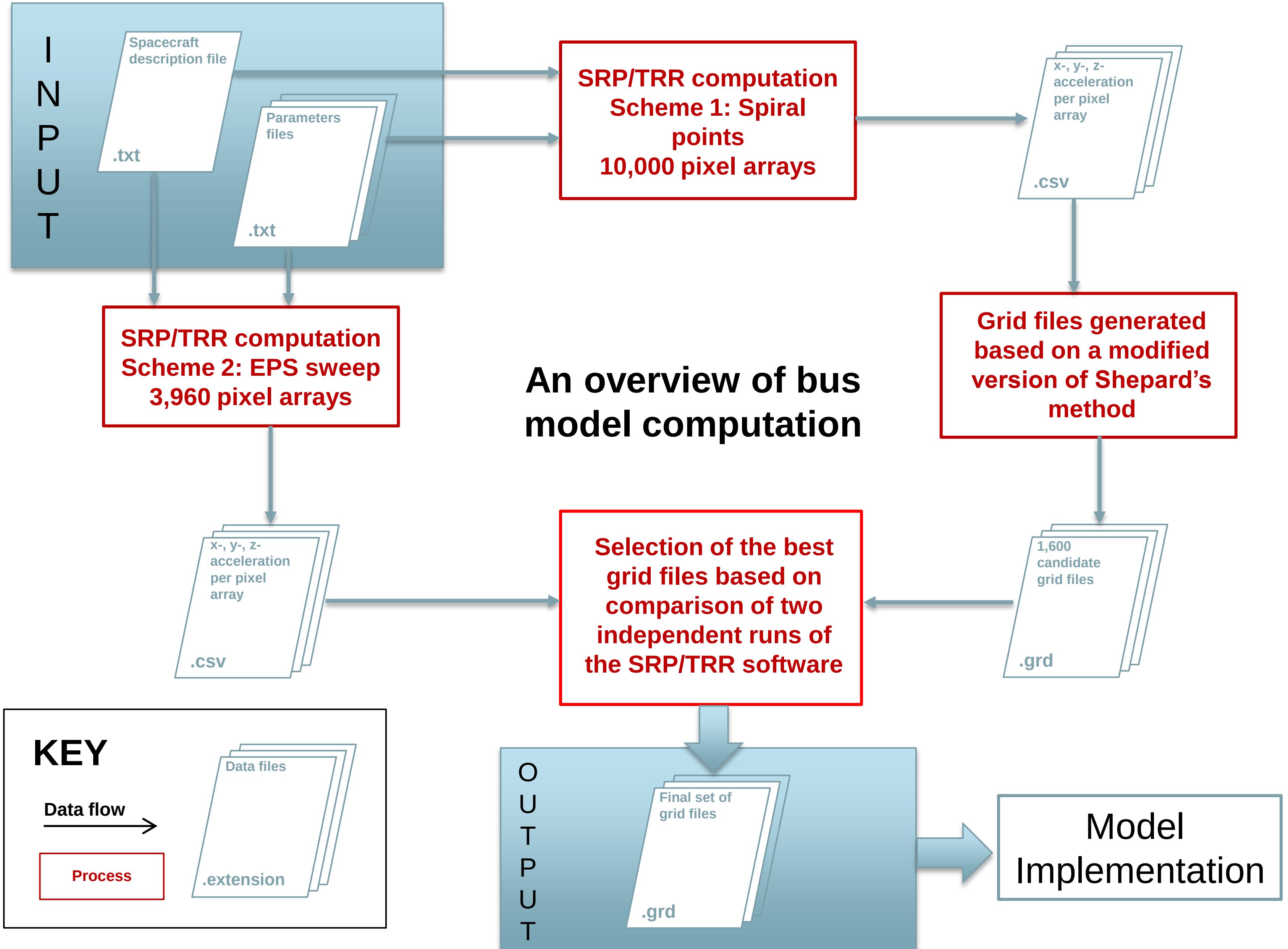
- 10,000 pixel arrays distributed evenly over a sphere centred on the S/C bus
- 1mm pixel resolution
- Each pixel array position yields a resultant radiation force vector in body-frame components
- Primary data set from which the grid file calculation is derived
- The grid file allows for interpolation to create a continuous acceleration surface, modelled in the S/C body frame
- Grid file computation and selection involves a subsequent pixel array data set called an ‘EPS Sweep’ (see next slide)

EPS (Earth-probe-Sun) sweep



- 3,960 separate pixel arrays positioned in a band within +/-10˚ of the SC X-Z plane
- 1mm pixel resolution
- Each pixel array position yields a resultant radiation force vector in body-frame components
- Higher resolution distribution of pixel arrays compared to the spiral points algorithm
- Represents the primary parts of the body frame space within which the Sun moves
- Used in the method to select an optimal set of grid files derived from the spiral points calculations

An overview of bus model computation



Back face of the panel, solar radiation pressure and thermal gradient analysis

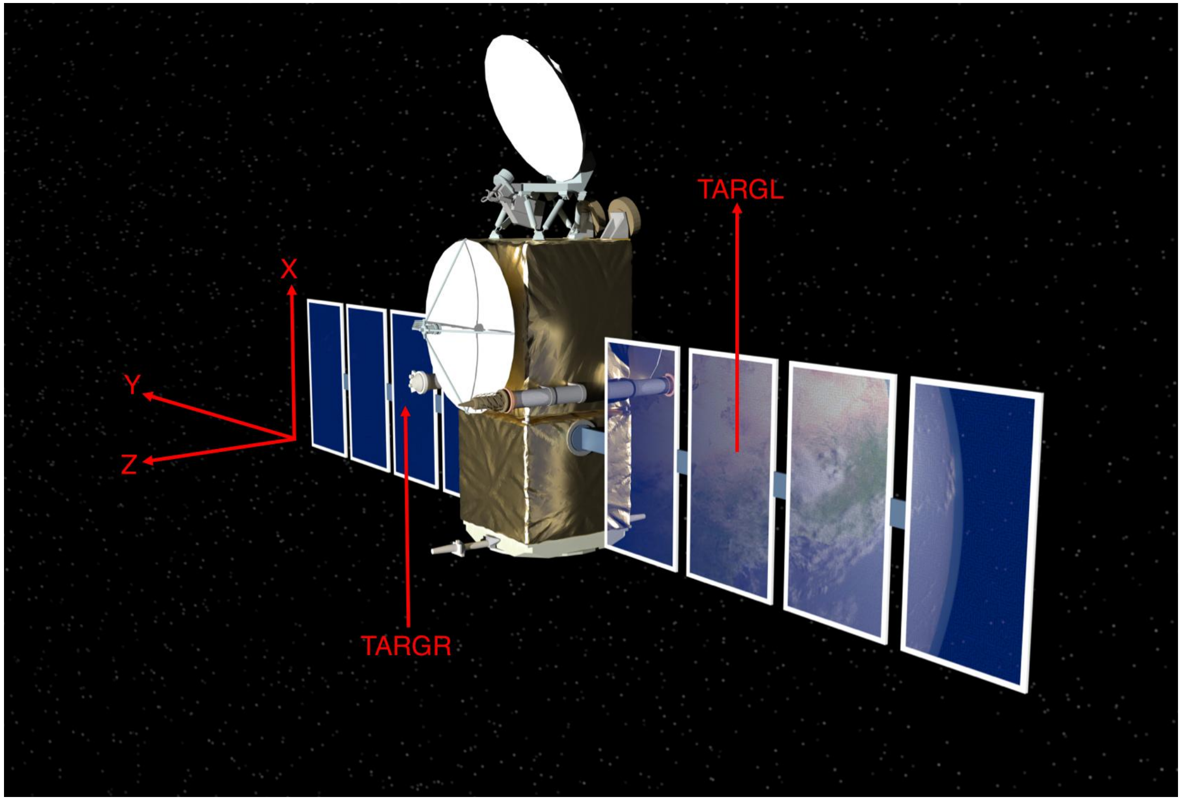
SOLAR PANEL MODEL

Investigations into the Jason-2 solar panel properties

- Area: Documentation suggests an area of 9.8 m^2 – however it is unclear whether this value includes the area of the solar panel yoke arms.

- Rear face material properties: seems rear face composed of three separate surface materials

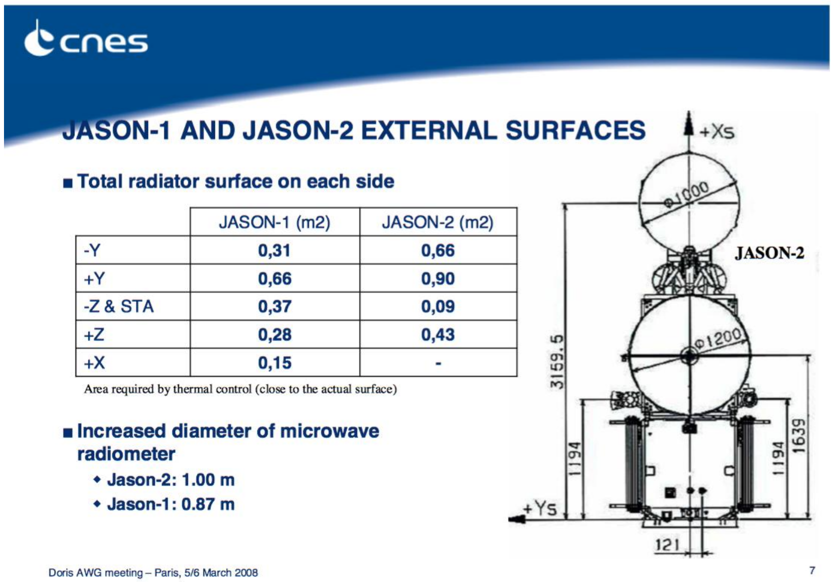
- Developments in thermal gradient analysis



Investigating solar array surface area

Surface area data

Area of solar array + yoke arms



cnes

JASON-1 AND JASON-2 EXTERNAL SURFACES

- Total radiator surface on each side

	JASON-1 (m2)	JASON-2 (m2)
-Y	0,31	0,66
+Y	0,66	0,90
-Z & STA	0,37	0,09
+Z	0,28	0,43
+X	0,15	-

Area required by thermal control (close to the actual surface)

- Increased diameter of microwave radiometer
  - Jason-2: 1.00 m
  - Jason-1: 0.87 m

Doris AWG meeting – Paris, 5/6 March 2008

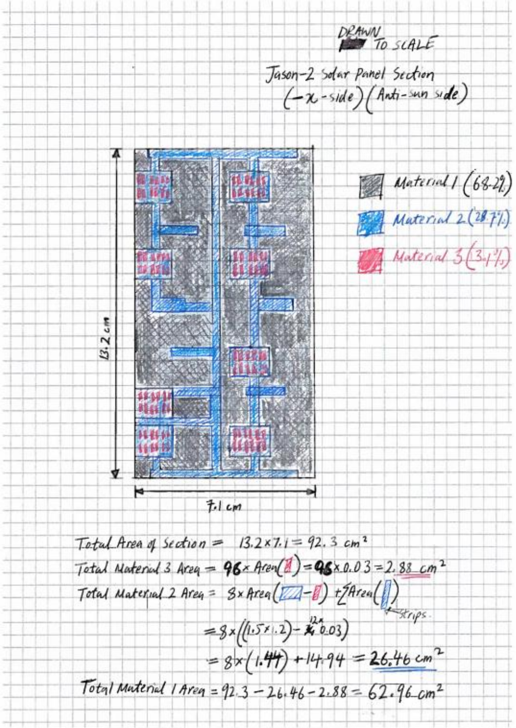
7

Question: Does the quoted value for the total solar array area (9.8 m^2) include the yoke arms? We are developing our own values for this

Solar array rear surface materials

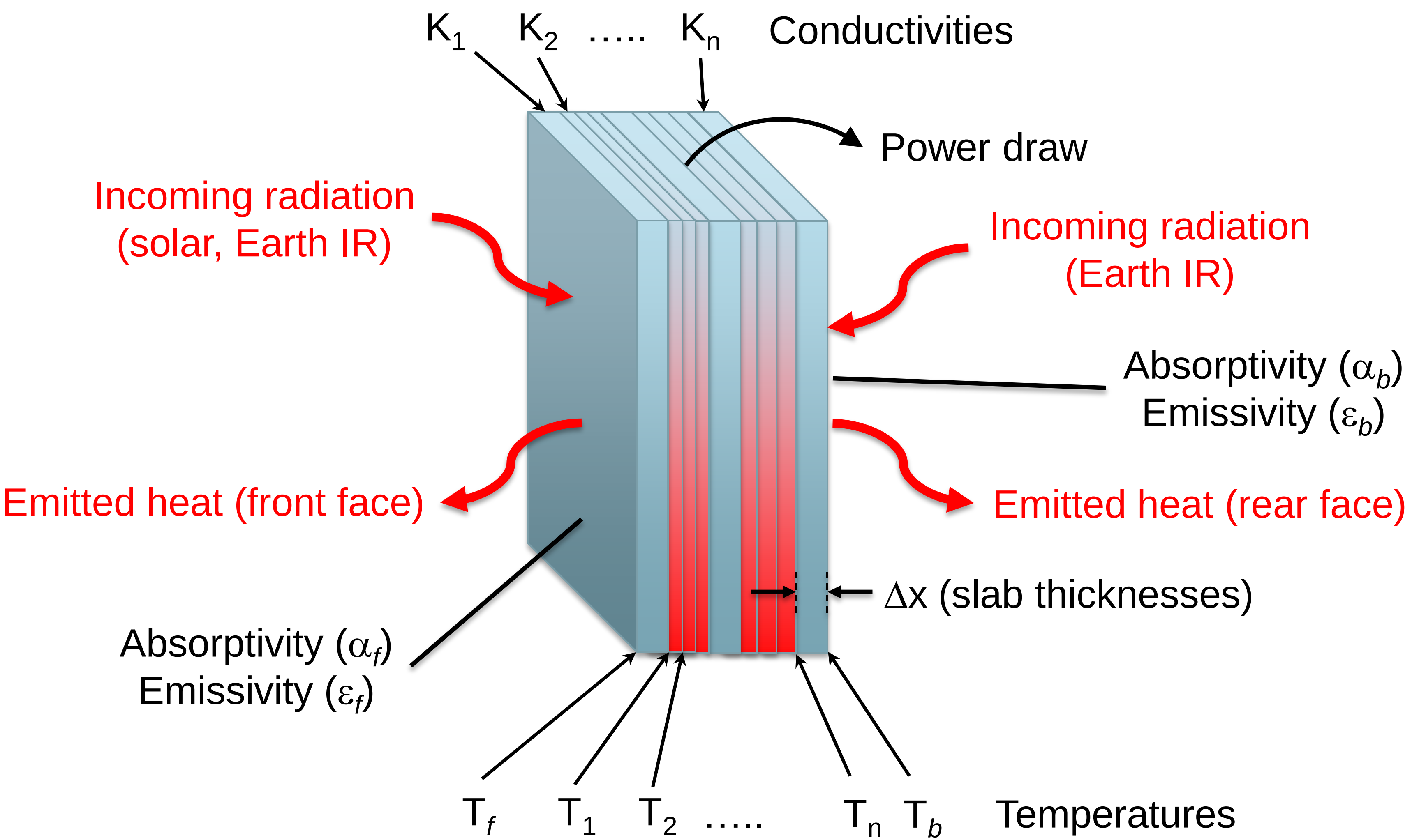
Cleanroom image of the rear face of one solar array section

Determining the composition of solar array rear surface



- Material 1: 68.2%
- Material 2: 28.7%
- Material 3: 3.1%

Solar panel thermal gradient force: system



Solar panel thermal gradient force: Inputs and outputs

Inputs:

- Incident radiation fluxes
- Panel attitude in inertial space
- Absorptivity and emissivity (front and back)
- Slab thicknesses and conductivities
- Power draw

Outputs:

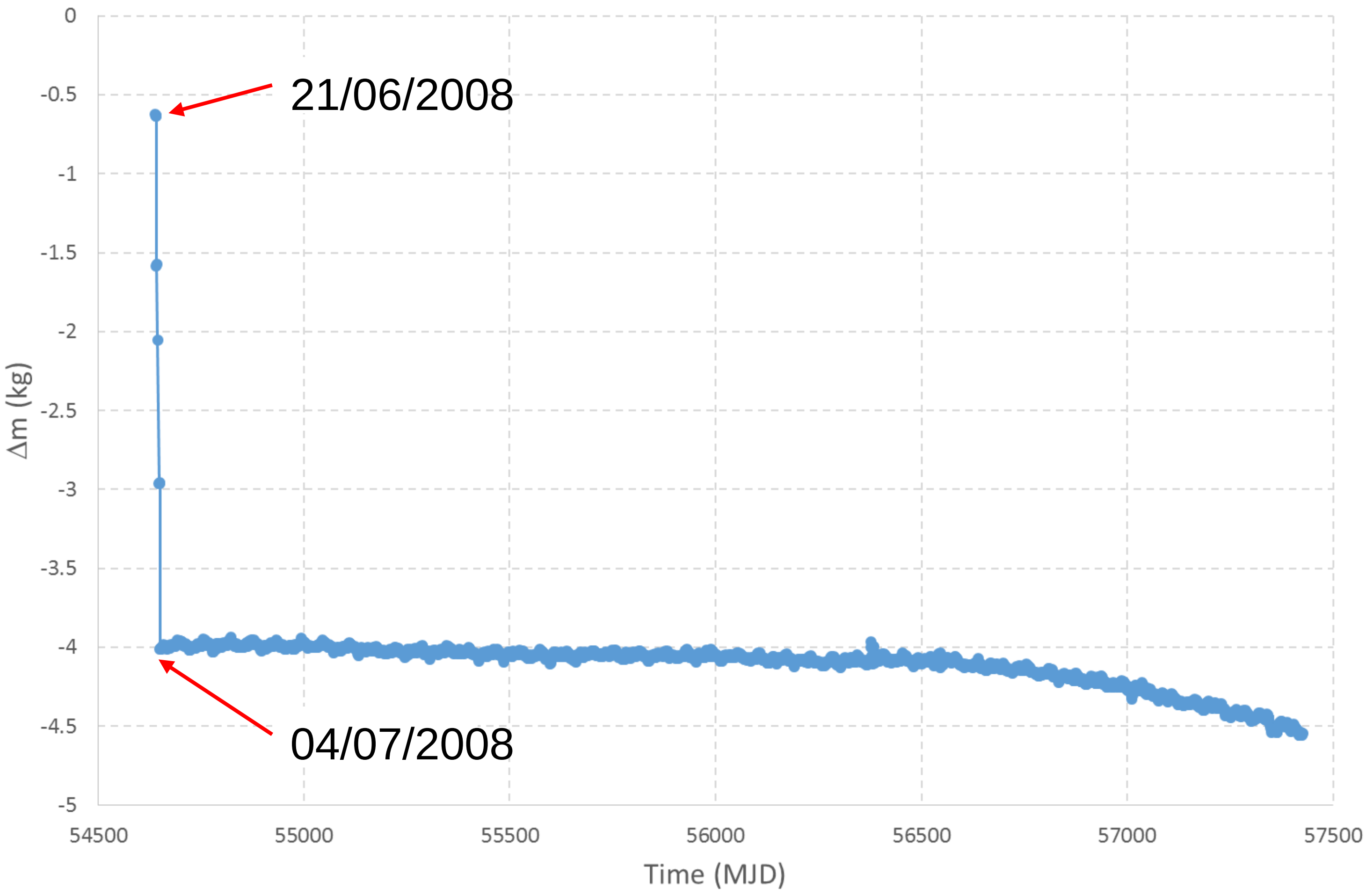
- Intermediate:
  - Temperatures at slab interfaces
  - Net thermal gradient
- Final:
  - Accelerations due to thermal emission (front and back)

Thermal gradient analysis

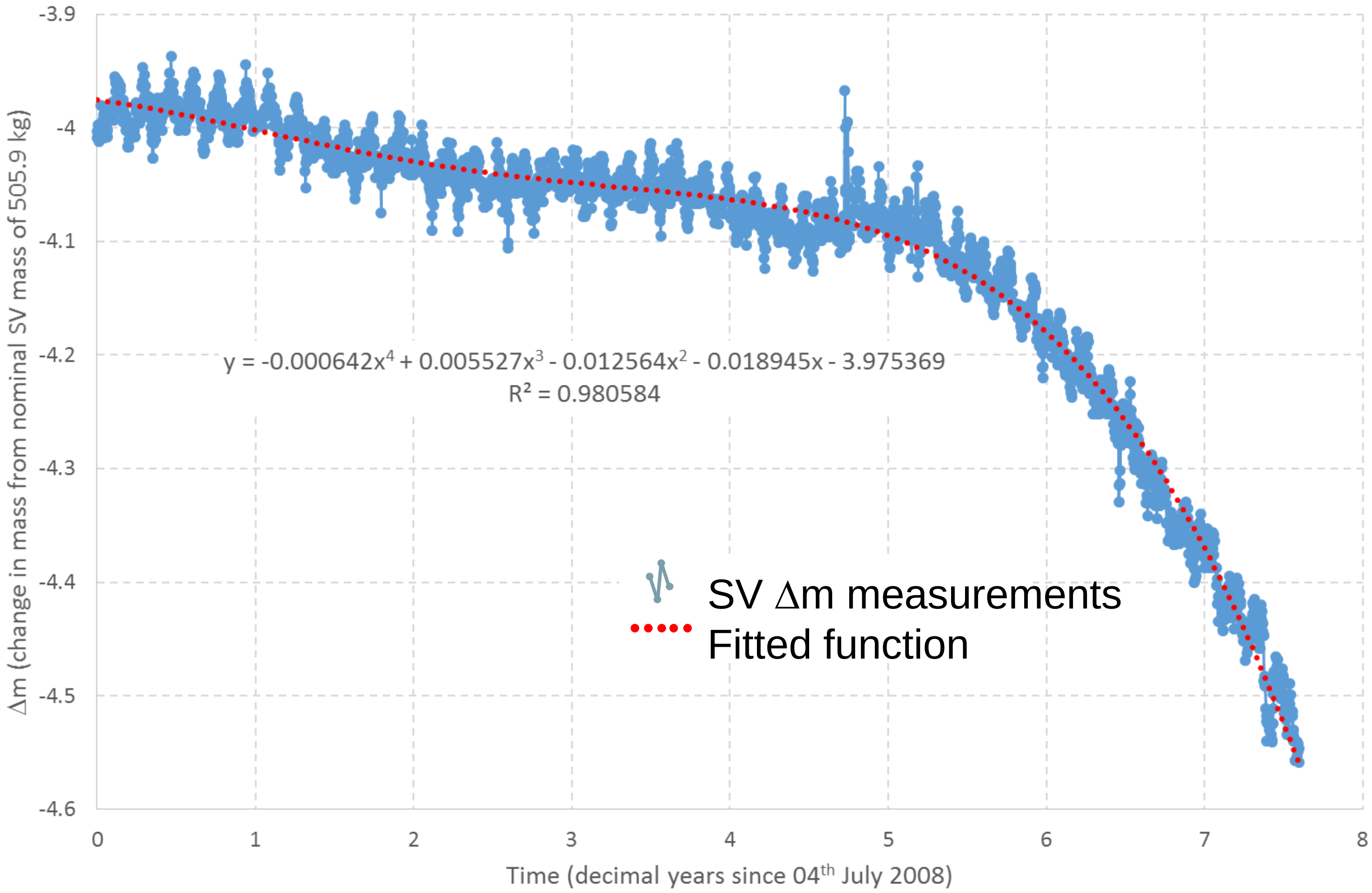
- Wish list: solar absorptivity coefficient of surface materials, thermal conductivity, emissivity, thickness individual layers, power draw – we have these values from Jason-1.
- To-do: Adaptation of the GPS IIR two-panel solar panel gradient analysis tool for Jason-2.

MASS HISTORY MODEL

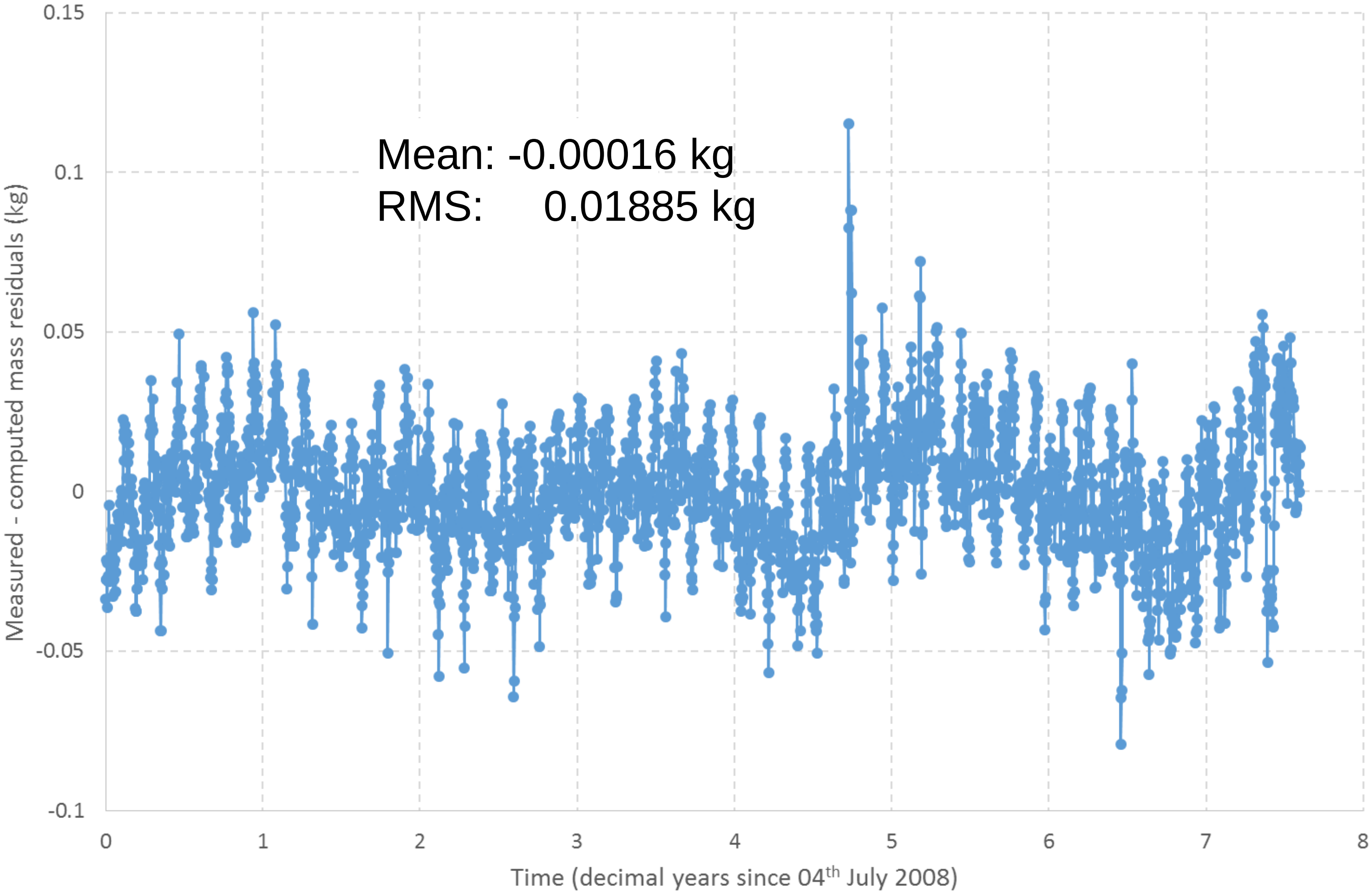
Mass change history data from CNES file:



UCL Jason-2 mass history model (main operational phase)



UCL mass history model residuals



Next steps….

- UCL supplies draft documentation and source code to Goddard
- Conversion of all C++ code to Fortran (UCL and GSFC depending on context)
- Visit to GSFC to carry out implementation
- Discussions concerning tests and experiments

Summary

- UCL has developed a new photon pressure model for Jason-2, and is ready to carry out implementation and testing
- The Jason-2 model features several advances over the existing, 'proven' Jason-1 model
- New features:
  - Very detailed structural data (superior to Jason-1 model)
  - Enhanced grid file calculation method (higher resolution, better mathematical stability)
  - Details of anti-sun facing solar panel construction and properties
  - Solar panel thermal gradient force
  - Mass history model

Back up slides

Other DORIS missions (1) – Spot-4

UCL model for Spot-4

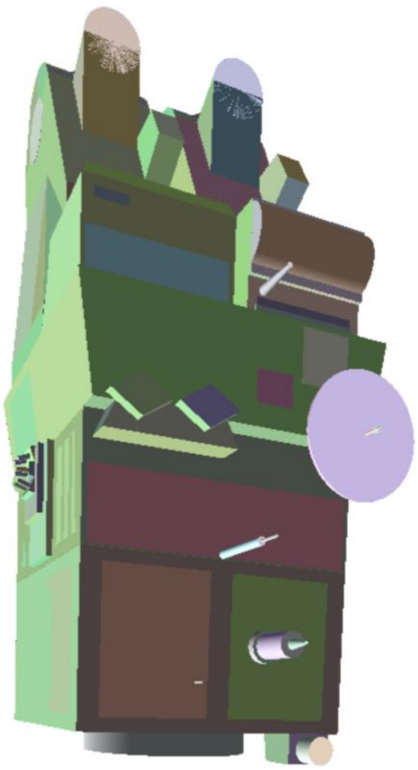


Image taken during ground tests

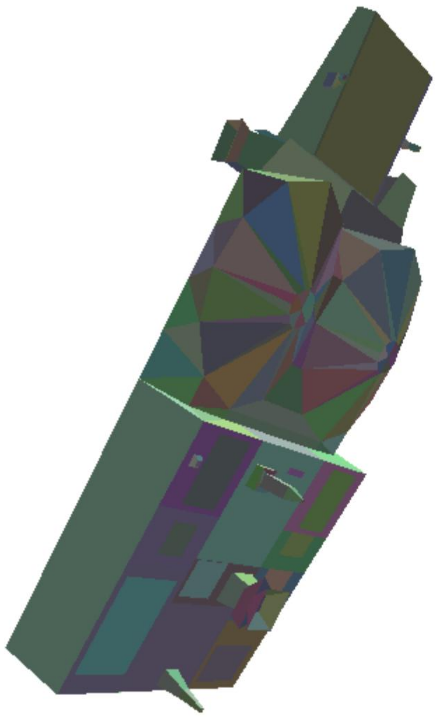
Other DORIS missions (2) – Spot 5

UCL model for Spot-5

Prelaunch image

Other DORIS missions (3) – Cryosat-2

UCL model for Cryosat-2



Cleanroom image

UCL modelling philosophy

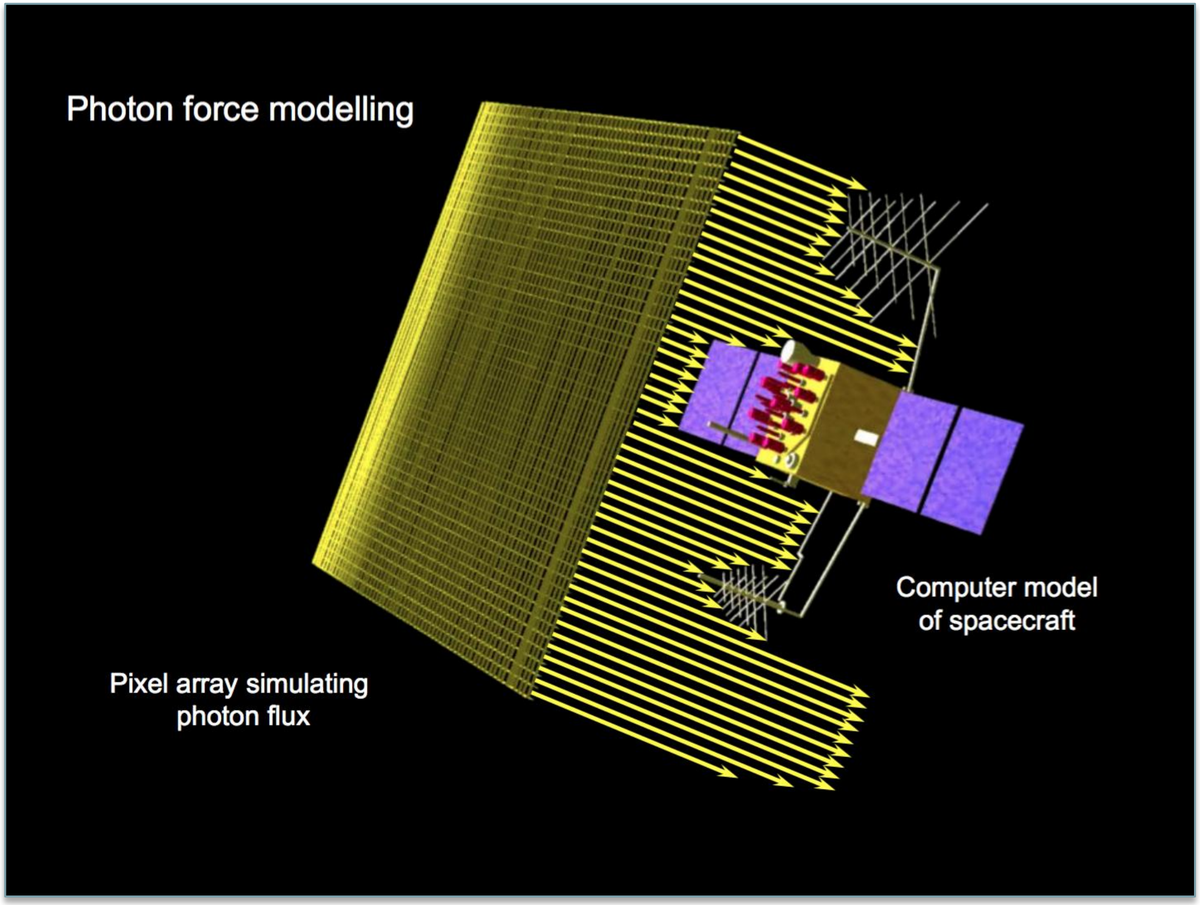
- Use all available physical and engineering data in model computation
- Avoid simplifying assumptions and embrace complexity
- Avoid any empirical (soak-up estimation)
- Output models that *capture complexity*, but are *simple to implement* and *run fast*

The elements of the UCL approach

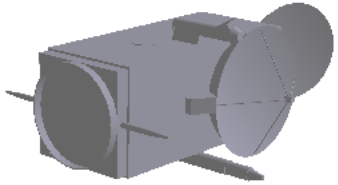
- Separate SV model into bus and solar panels components
- Bus models (pixel array computation, grid file approach, radiation forcing, thermal re-emission)
- Solar panel models (radiation forcing, thermal gradient force)
- Four main pillars:
  - SRP: solar radiation pressure
  - TRR: thermal re-radiation (radiators, MLI)
  - ERP: earth radiation pressure,
  - AT: antenna thrust
- Mass history model
- Detailed, straightforward documentation, source code

The pixel array method[1]

- Uses fundamental physical principles to account for the interaction of photons with the spacecraft bus
- Used to compute SRP and thermal forces on the Jason-2 bus.
- The computation is done as pre-processing step. The output is a look-up table of accelerations, given the position of the radiation source in the BFS.

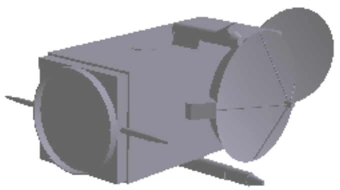


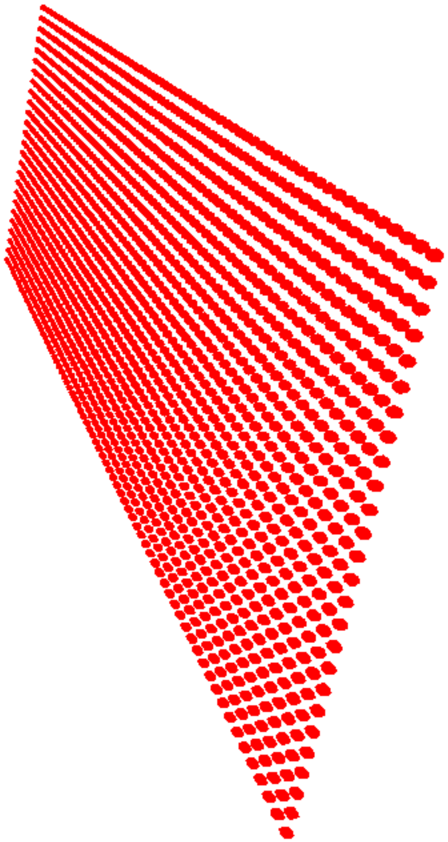
1) Ziebart,M.,(2004) Generalised Analytical Solar Radiation Pressure Modelling Algorithm for Spacecraft of Complex Shape, Journal of Spacecraft and Rockets, Vol.41, No.5, pp 840-848(9)



Bus SRP/TRR computation algorithm – 1

- The input to the algorithm is the UCL spacecraft description file
- The UCL spacecraft description file is built using information about the geometry and of the properties of the surface materials

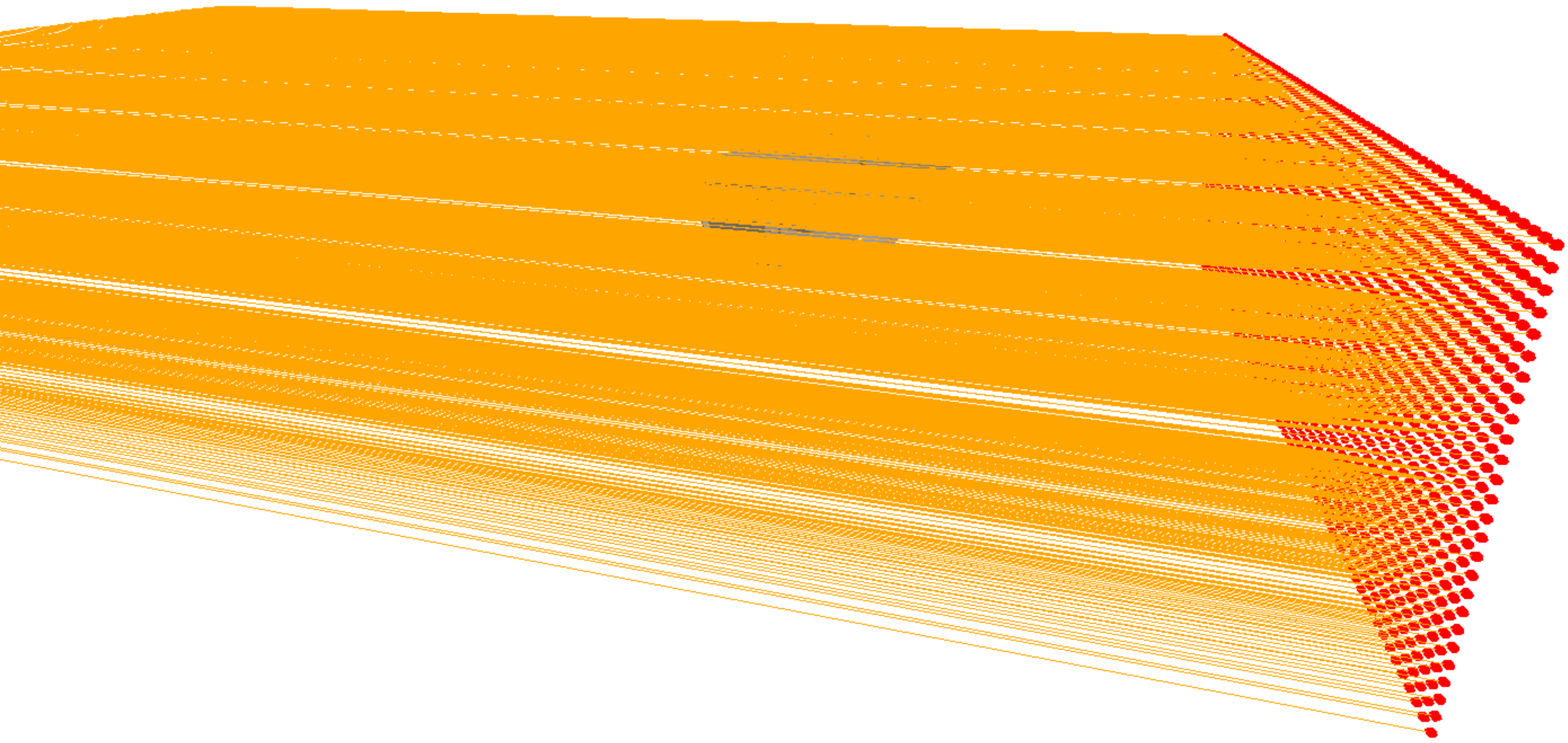




Bus SRP/TRR computation algorithm – 2

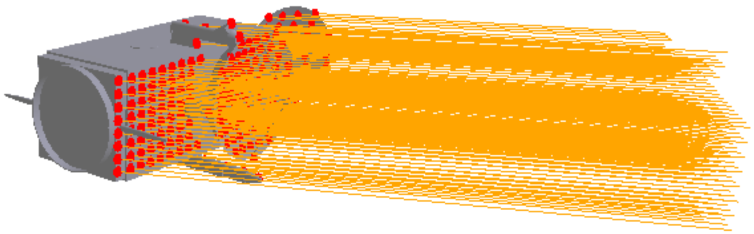
- For a specific orientation of the radiation source with respect to the spacecraft, the photon flux is simulated by a pixel array

- Jason-2 bus model computation uses 1mm spacing for the pixel array



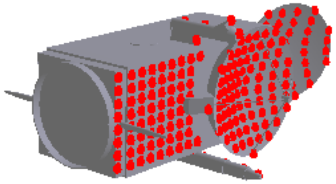
Bus SRP/TRR computation algorithm – 3

- Rays are generated from the center of each pixel array grid



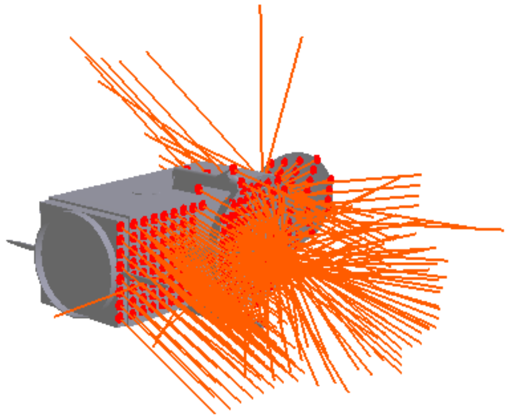
Bus SRP/TRR computation algorithm – 4

- The rays intersect with the surface of the spacecraft
- Regions of shadow are computed automatically – the rays can not reach them



Bus SRP/TRR computation algorithm – 5

- At each intersection point, a number of computations are made to account for the shear force, the normal force and the thermal force
- This requires a knowledge of the material properties of the surface at each point



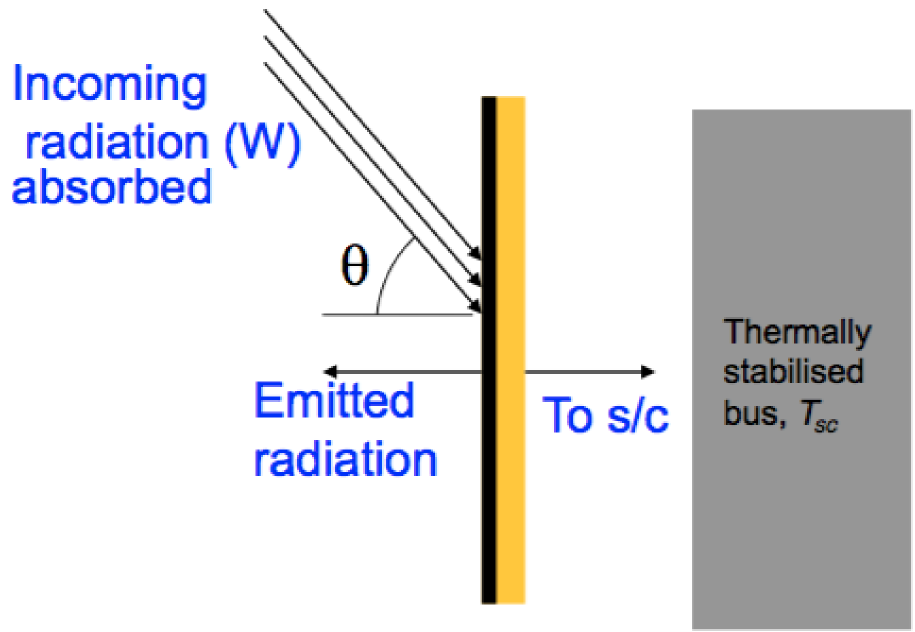
Bus SRP/TRR computation algorithm – 6

- Each intersection point is used as an origin point for a secondary ray
- Forces are computed at each point where the secondary rays intersect with the spacecraft surface

Multilayer Insulation (MLI)

- Pixel array algorithm determines insolation of MLI
- 'Effective emissivity' (ε_{eff}) parameter governs heat transfer to bus
- MLI blackened, α=0.94 $\Rightarrow$ large thermal force

Energy balance:



$$T_{MLI}^4 = \frac{\alpha W \cos\theta + \varepsilon_{eff}\sigma T_{sc}^4}{\sigma(\varepsilon_{MLI} + \varepsilon_{eff})}$$

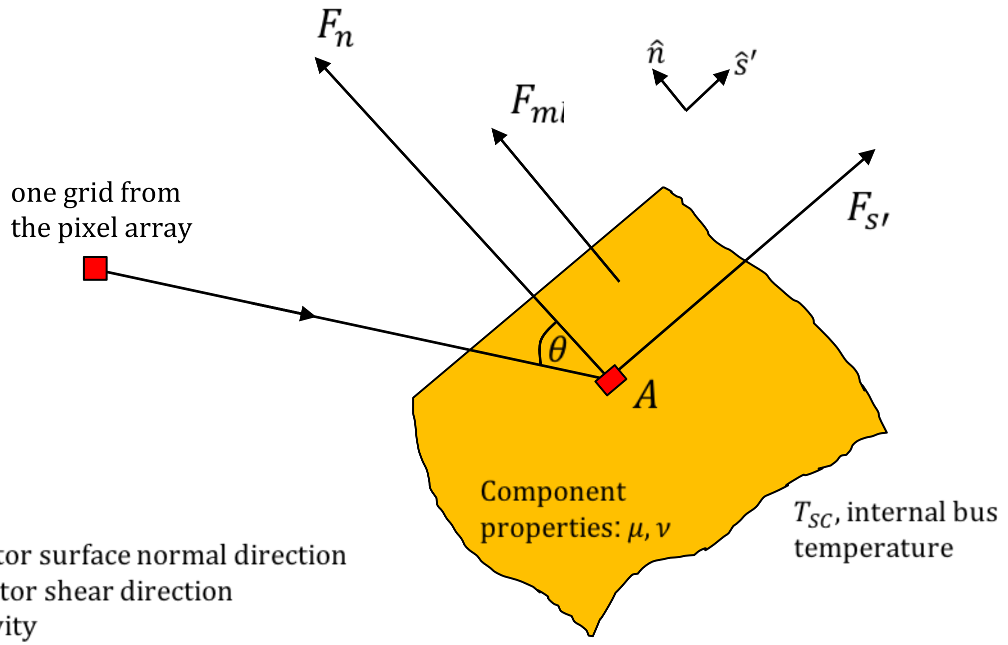
Momentum exchange at each intersection point computed according to:

$$\overrightarrow{F_n} = -\frac{AW\cos\theta}{c}\left[(1+\mu\nu)\cos\theta + \frac{2}{3}\nu(1-\mu)\right]\hat{n}$$

$$\overrightarrow{F_{s\prime}} = \frac{AW\cos\theta}{c}\left[(1-\mu\nu)\sin\theta\right]\hat{s}'$$

$$\overrightarrow{F_{mli}} = -\frac{2}{3}\frac{\sigma\varepsilon T_{mli}^4}{c}A\hat{n}$$

T_{SC}



$\hat{n}$: unit vector surface normal direction
$\hat{s}'$: unit vector shear direction
μ : reflectivity
ν: specularity

Computation

- 2.5×10^7 rays per incoming flux direction
- 1×10^4 different directions to give full coverage in the spacecraft body frame
- 2.5×10^{11} ray/spacecraft intersections takes approximately 3 days to compute on UCL supercomputer ~2000 cores
- We crunch the numbers so you don’t have to!

What is the output?

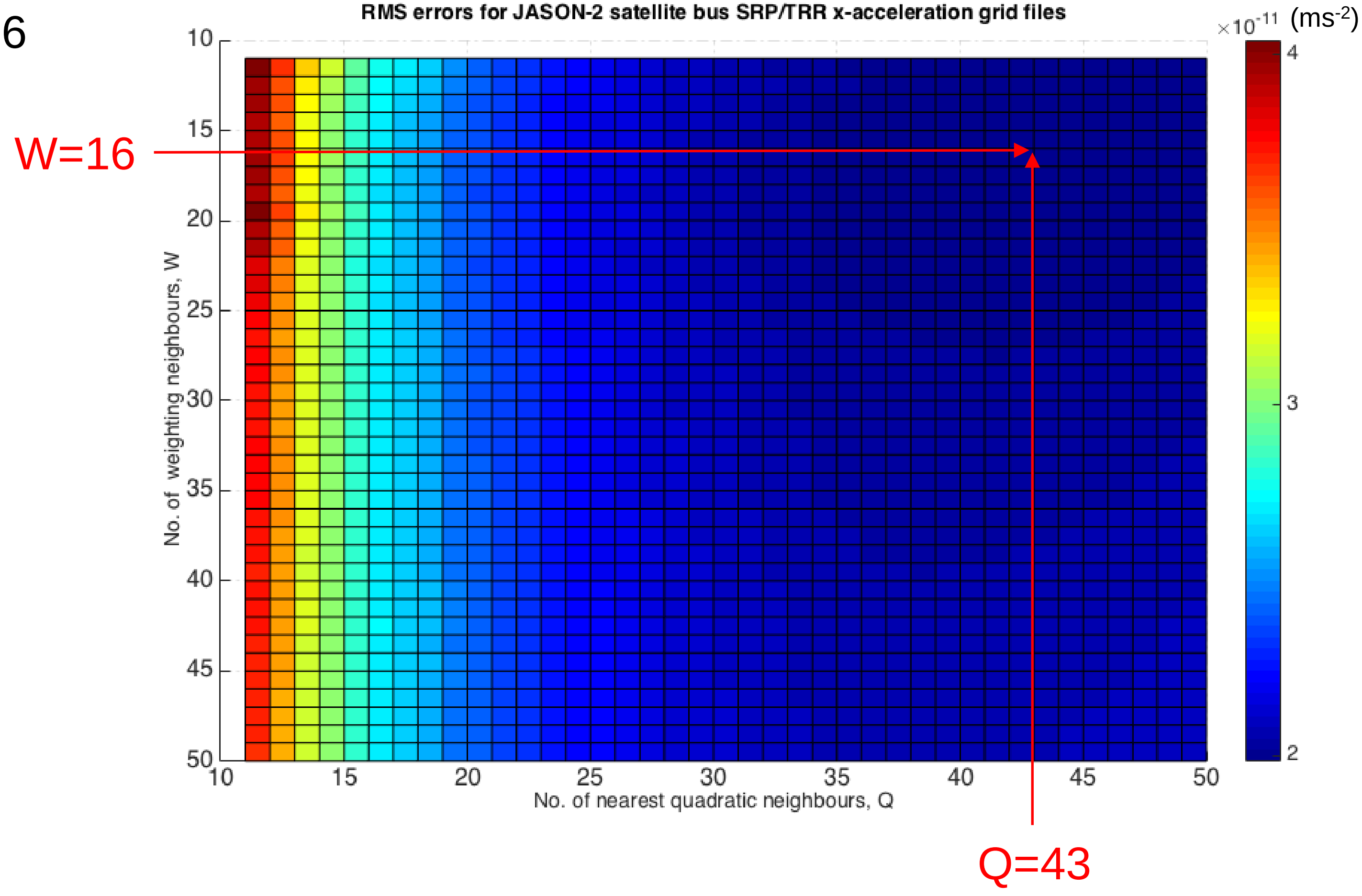
- Acceleration due to incident flux (normalised) is calculated at each intersection
- These accelerations are summed to give a total acceleration in the body frame for a given direction
- These values are calculated for many different directions in the body frame (lat/lon)
- The output is a lookup table describing the acceleration in the X,Y or Z axes for a given lat and lon of incident flux

A gridding process is required because…

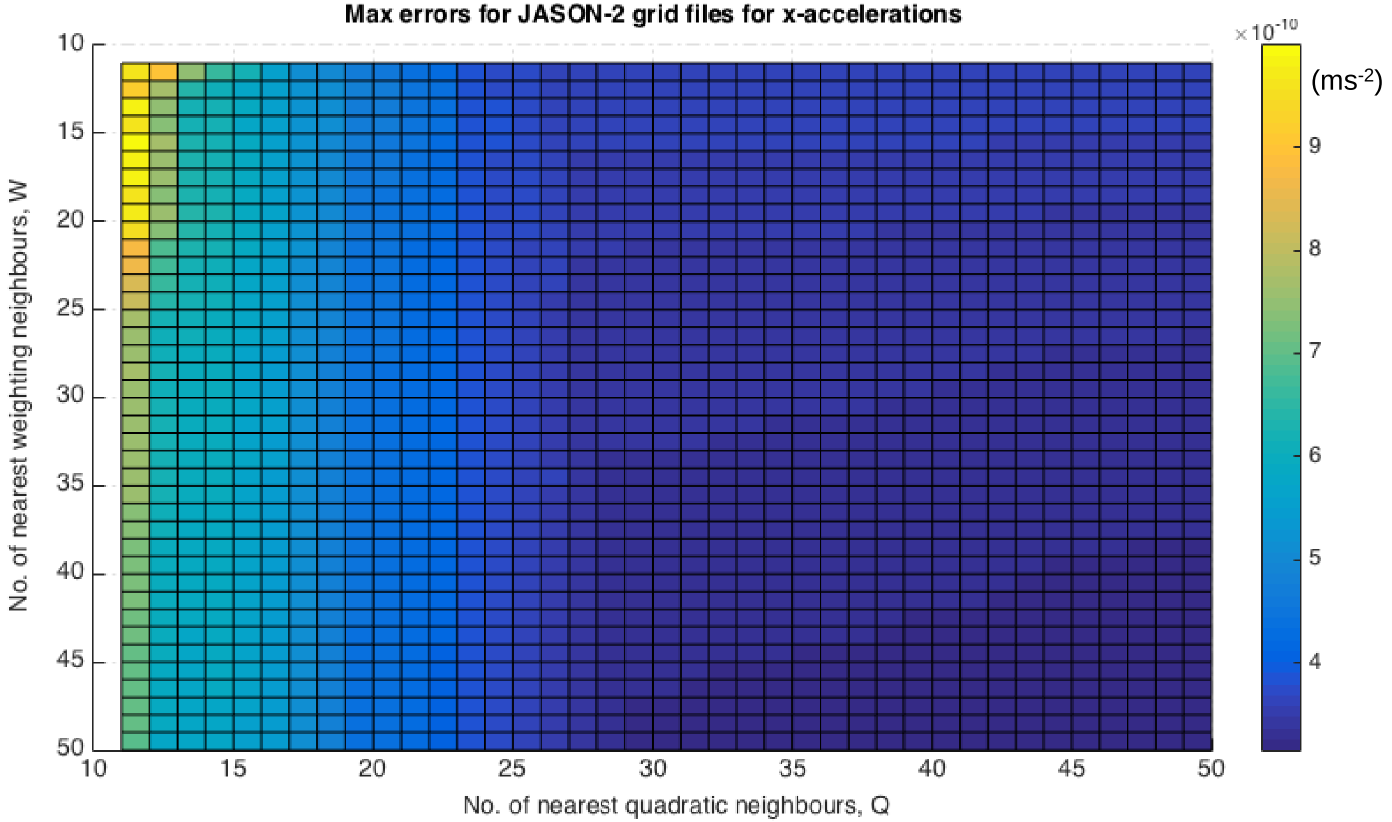
- The spiral points orientation scheme is an efficient way to provide optimal coverage in terms of pixel-array orientations covering the whole 4π steradians around the bus
- But the spiral points are not uniformly spaced in a lat/lon system
- Uniformly spaced grid in lat/lon easier to implement – interpolation is easier
- We use Modified Shepard's method to compute the SRP/TRR bus grid files
- Search through a total of 1600 candidate grid files to find the optimal one – the one that minimises RMS errors in a comparison with the results of the EPS sweep job

Grid file selection for x-accelerations – RMS errors

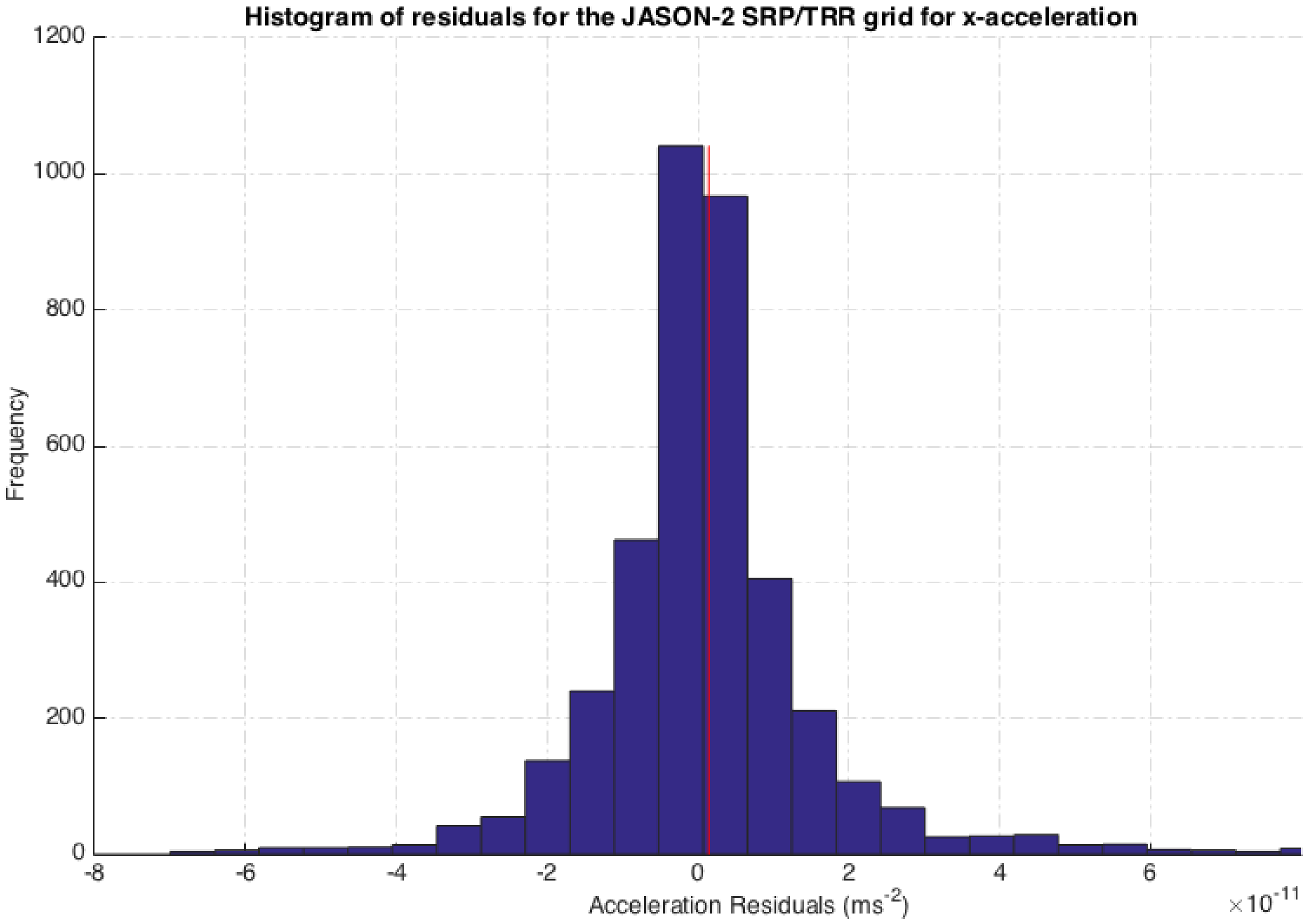
For the chosen grid file:
Q=43, W=16



The x-accelerations grid file – max errors



The chosen x-accelerations grid file – residuals



Work on other DORIS missions, how grid files are computed, etc.

BACKUP SLIDES

Other DORIS missions (1) – Spot-4

UCL model for Spot-4

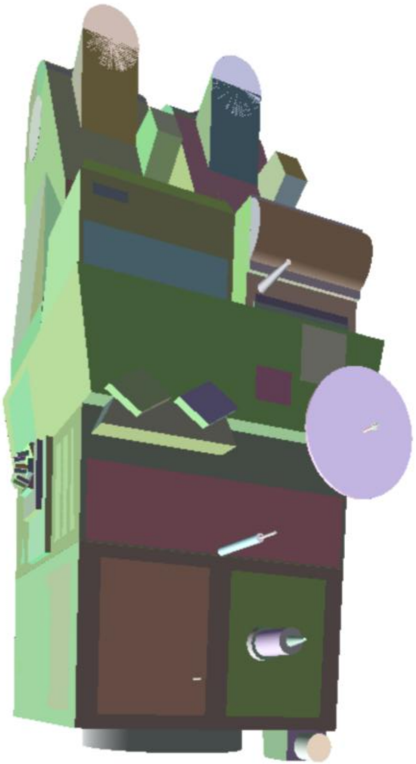


Image taken during ground tests

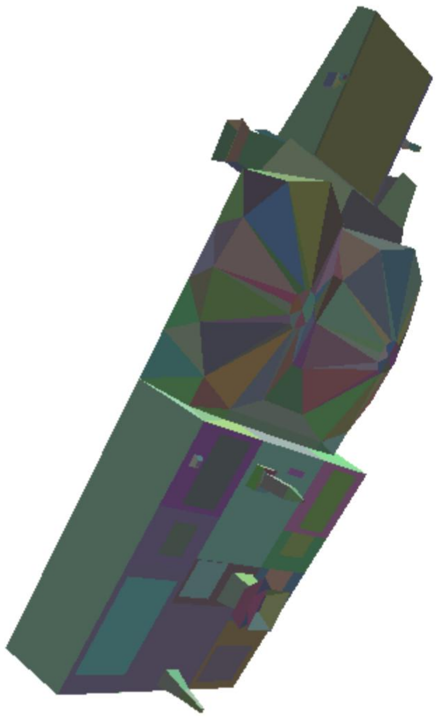
Other DORIS missions (2) – Spot 5

UCL model for Spot-5

Prelaunch image

Other DORIS missions (3) – Cryosat-2

UCL model for Cryosat-2



Cleanroom image