Next Generation Radiation Pressure Modelling for GNSS Space Vehicles:

Grid File Model Tests on GPS IIR

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The Maths…….

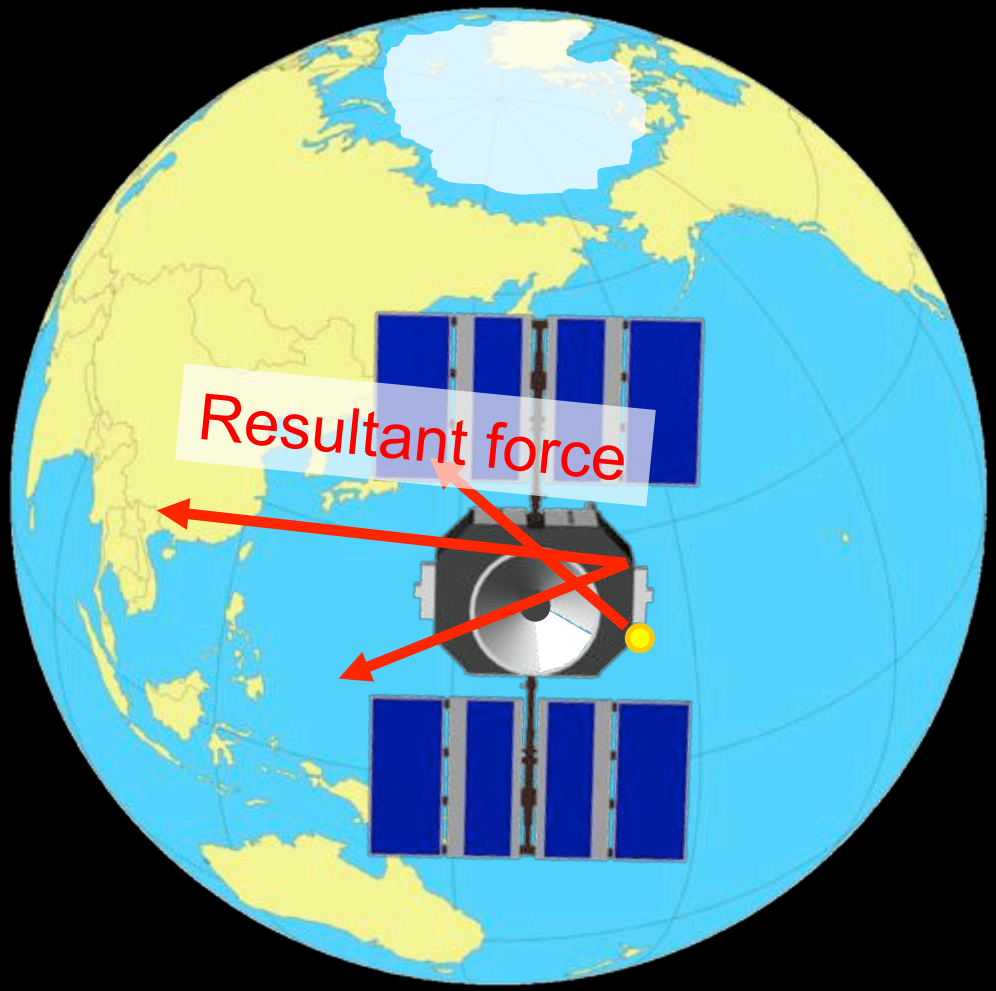
$$E = mc^2$$

For Photons:

$$\rho = E/c$$

Momentum = Energy/speed of light

Radiation Pressure



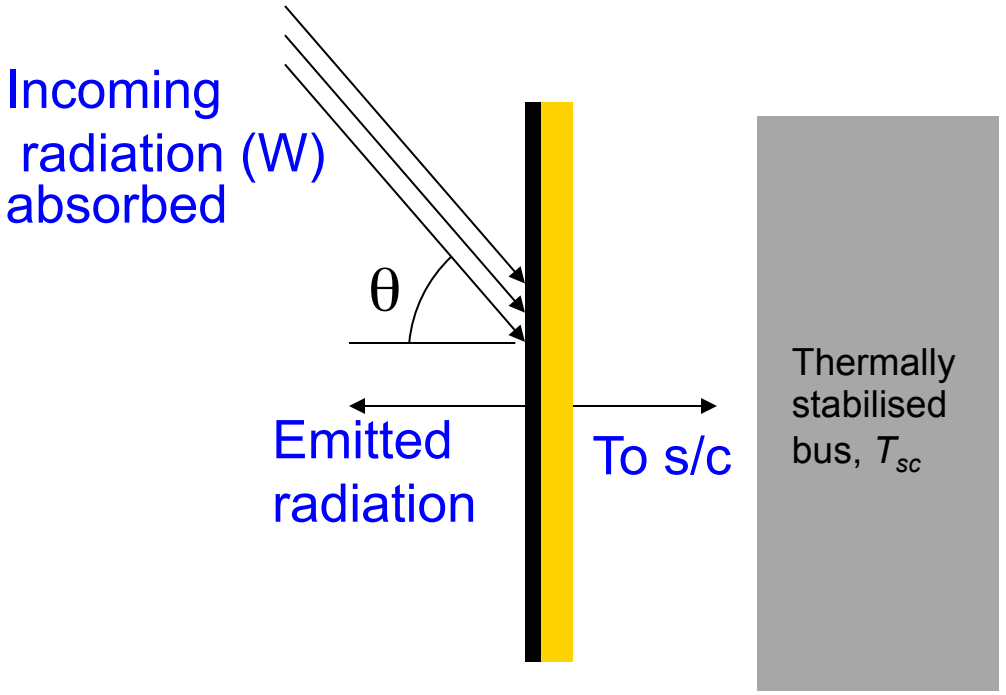
Multilayer Insulation (MLI)

- Pixel array algorithm determines insolation of MLI

- 'Effective emissivity' (ε_{eff}) parameter governs heat transfer to bus

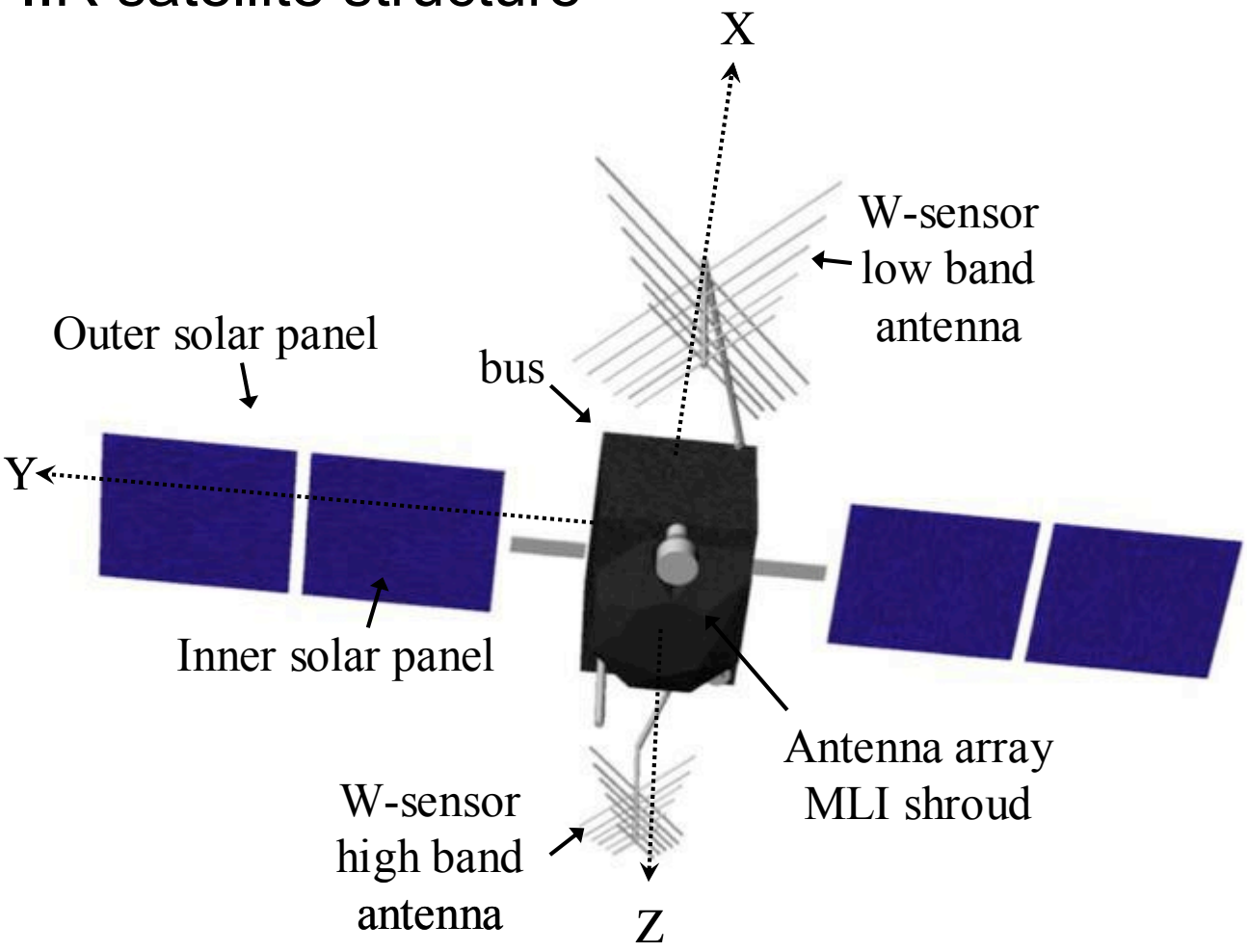
- MLI blackened, α=0.94
  $\Rightarrow$ large thermal force

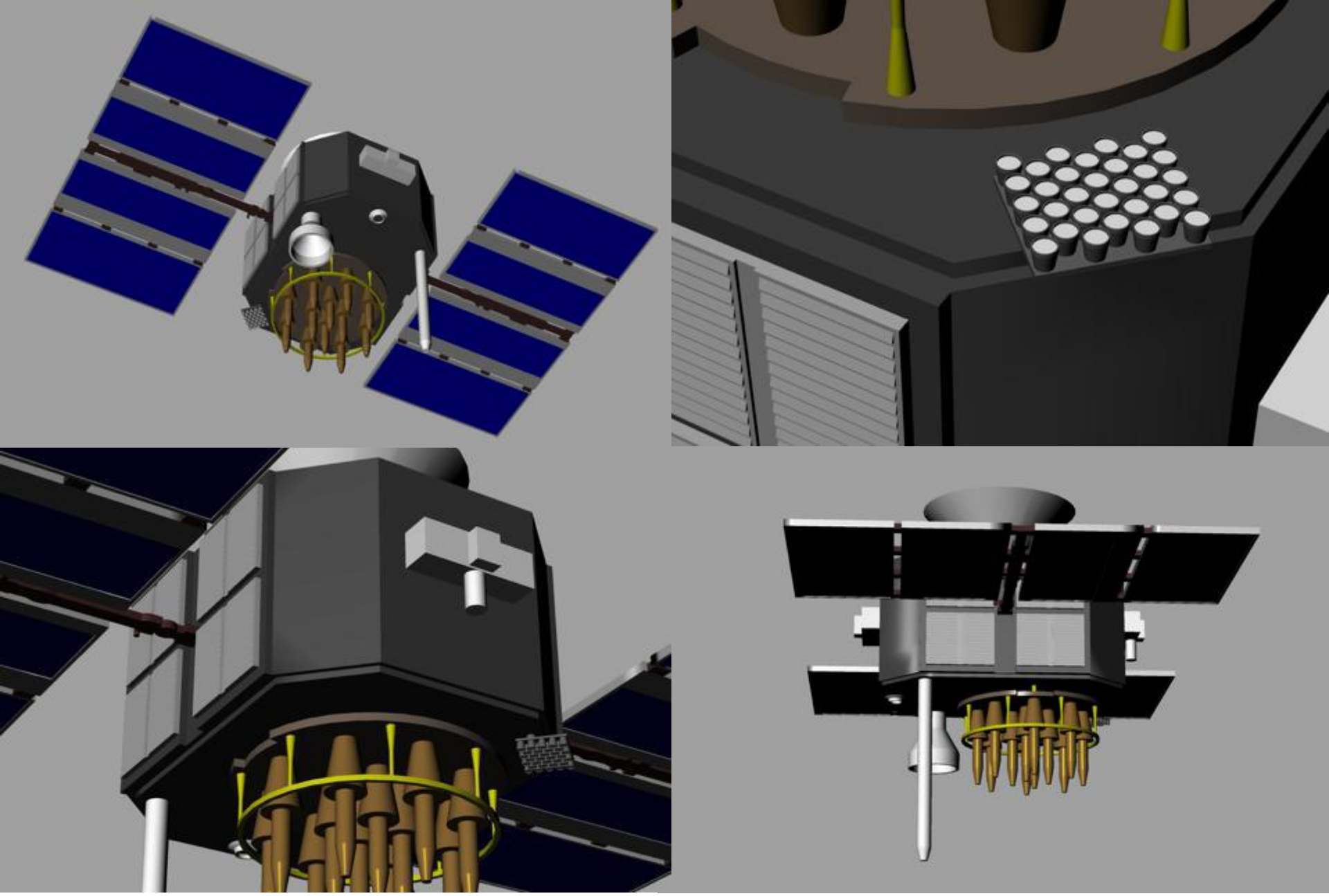
Energy balance:



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

GPS IIR satellite structure



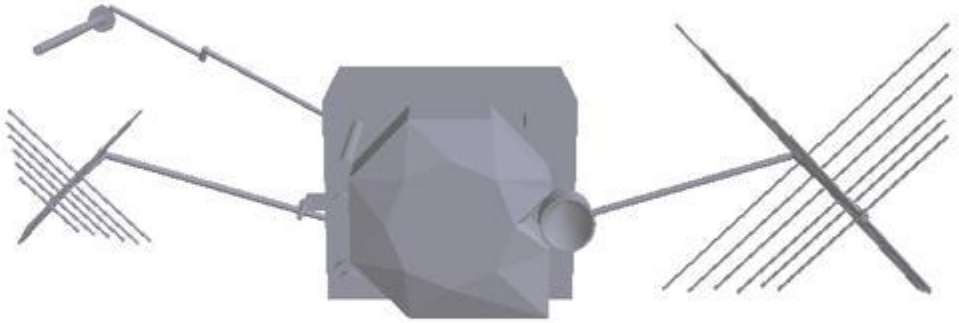


We develop a detailed structural computer model of the spacecraft

Ray Tracing - 1

Geometry

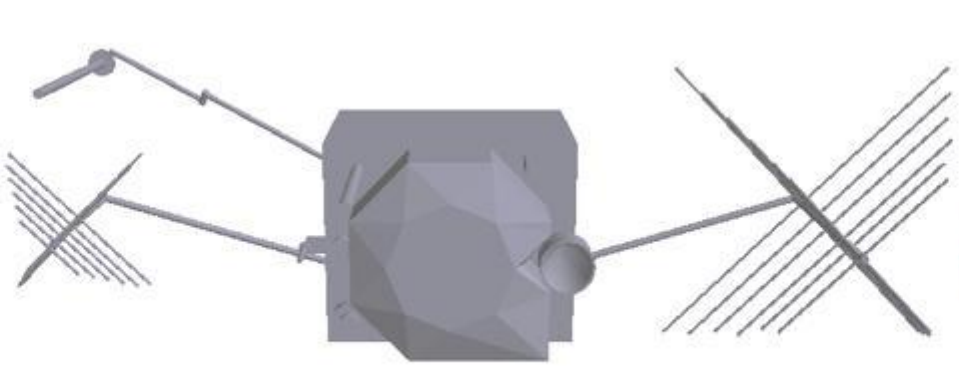
Material types

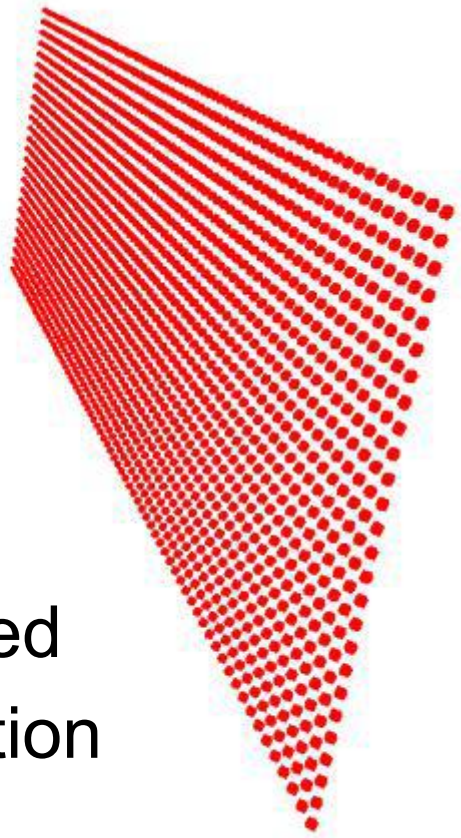


Optical and thermal properties

Spacecraft model represented in the SV body frame

Ray Tracing - 2

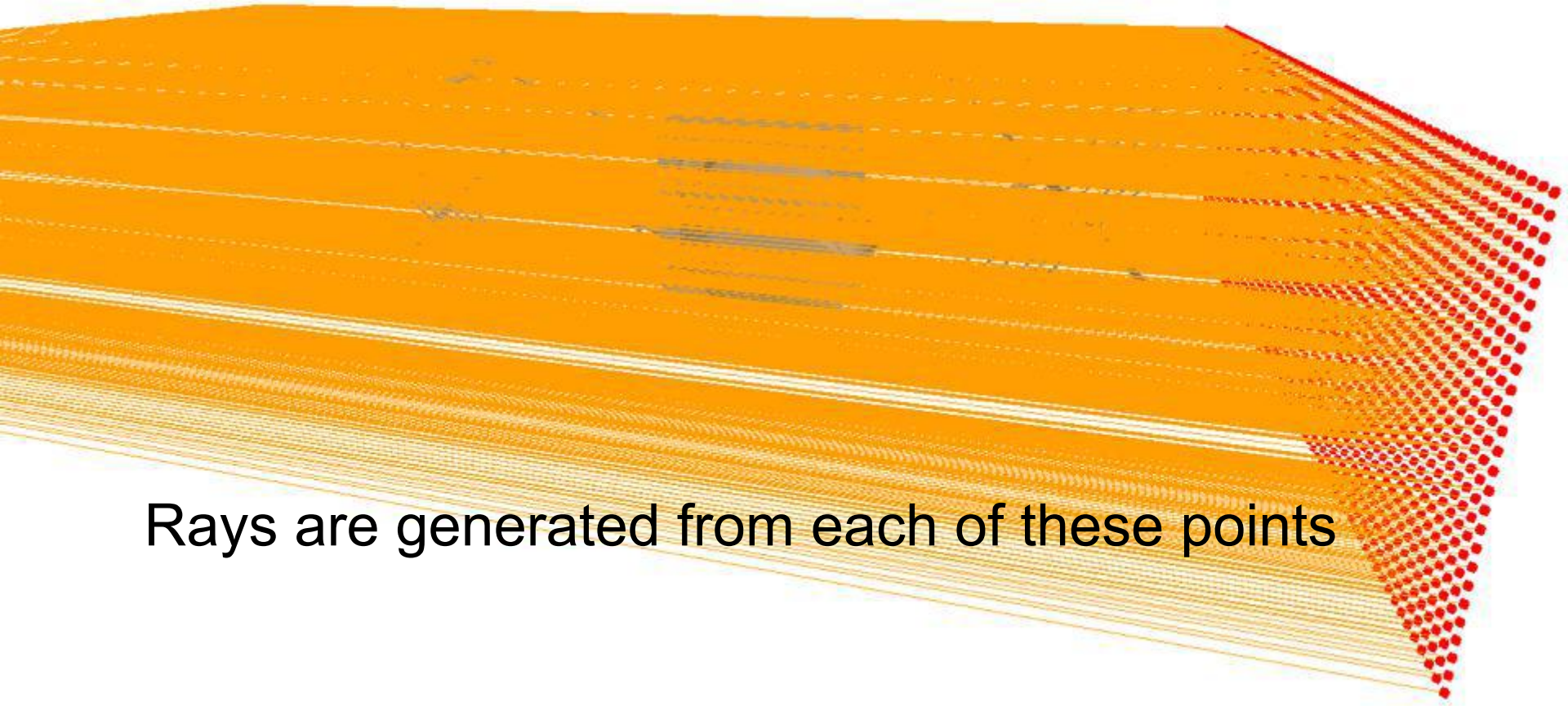




An array of flux origin points is created

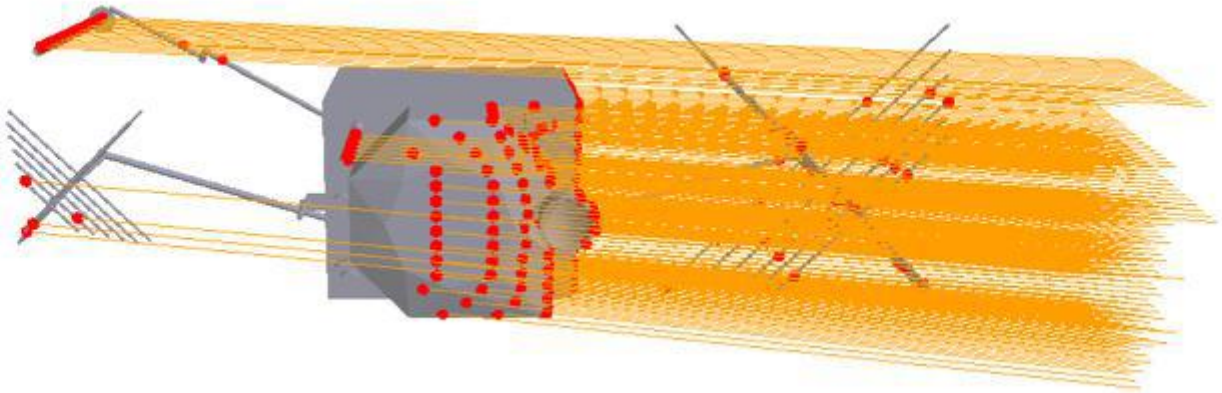
Dependent on the incoming flux direction

Ray Tracing - 3



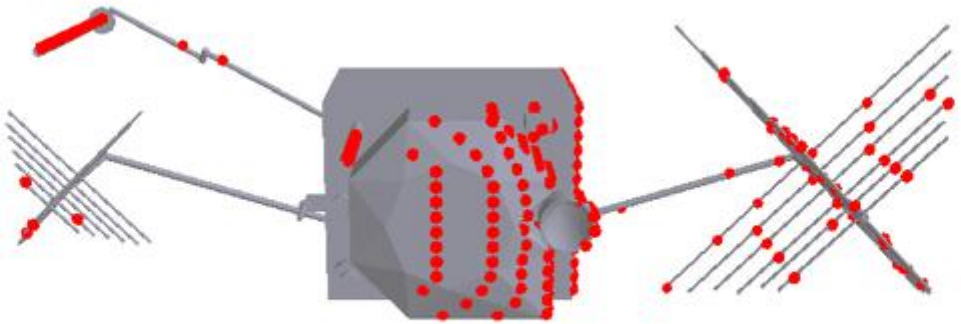
Rays are generated from each of these points

Ray Tracing - 4



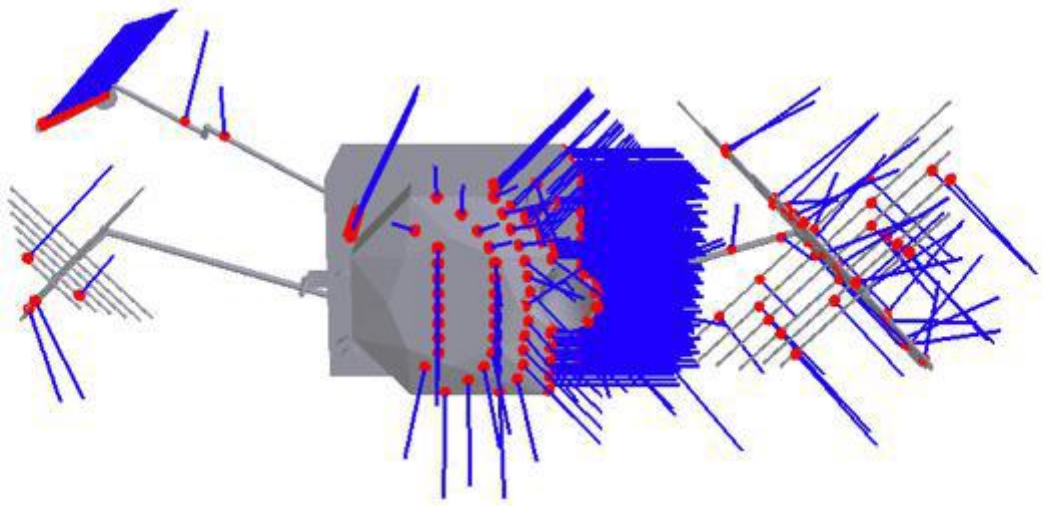
The intersection between each ray and the spacecraft is computed

Ray Tracing - 5



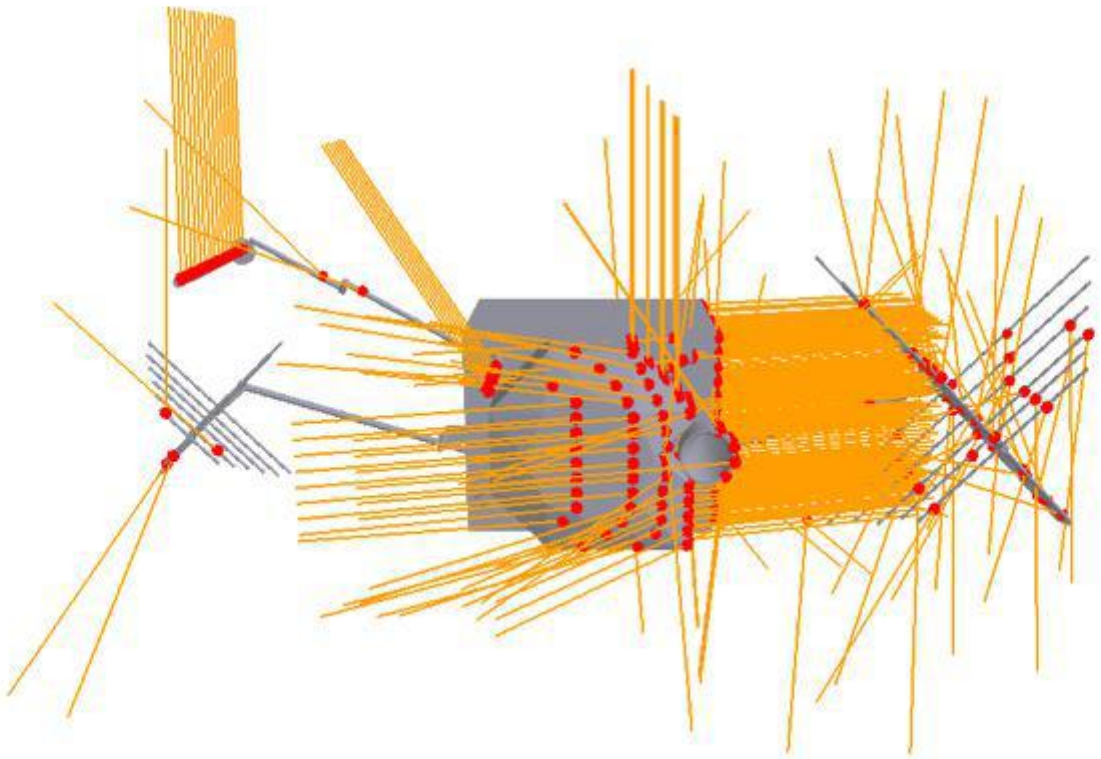
The material properties of the surface are known at each of these points

Ray Tracing - 6



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

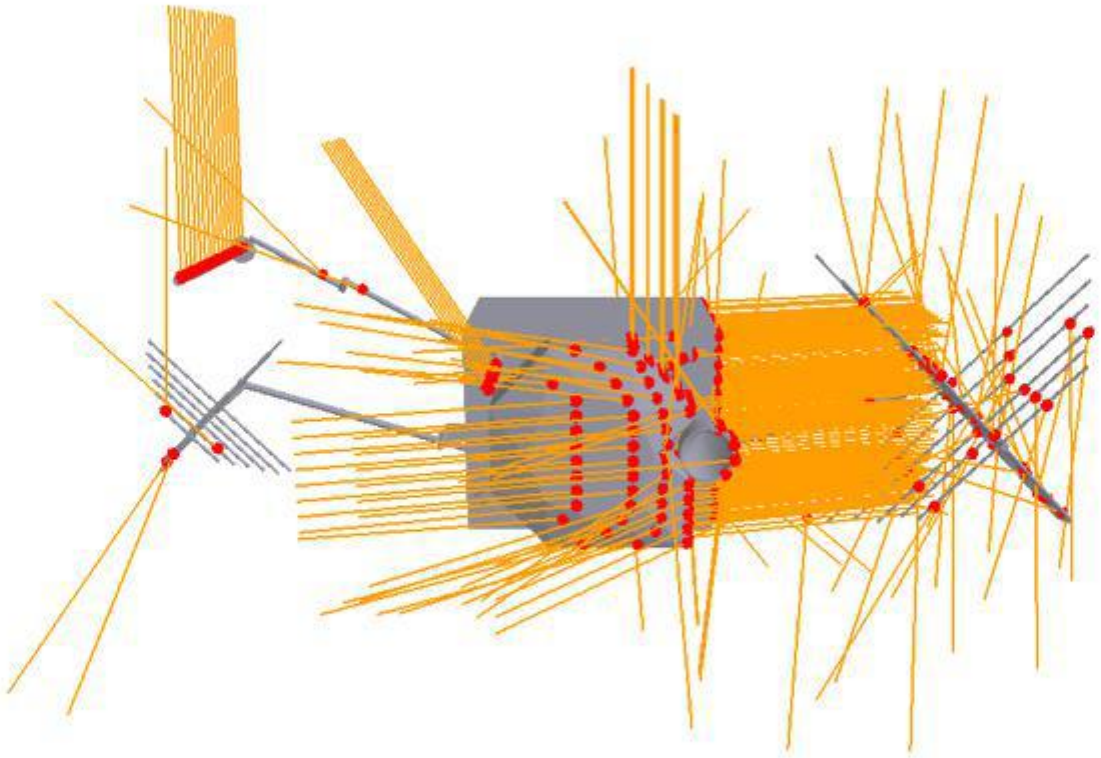
Ray Tracing - 7



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

Secondary intersections

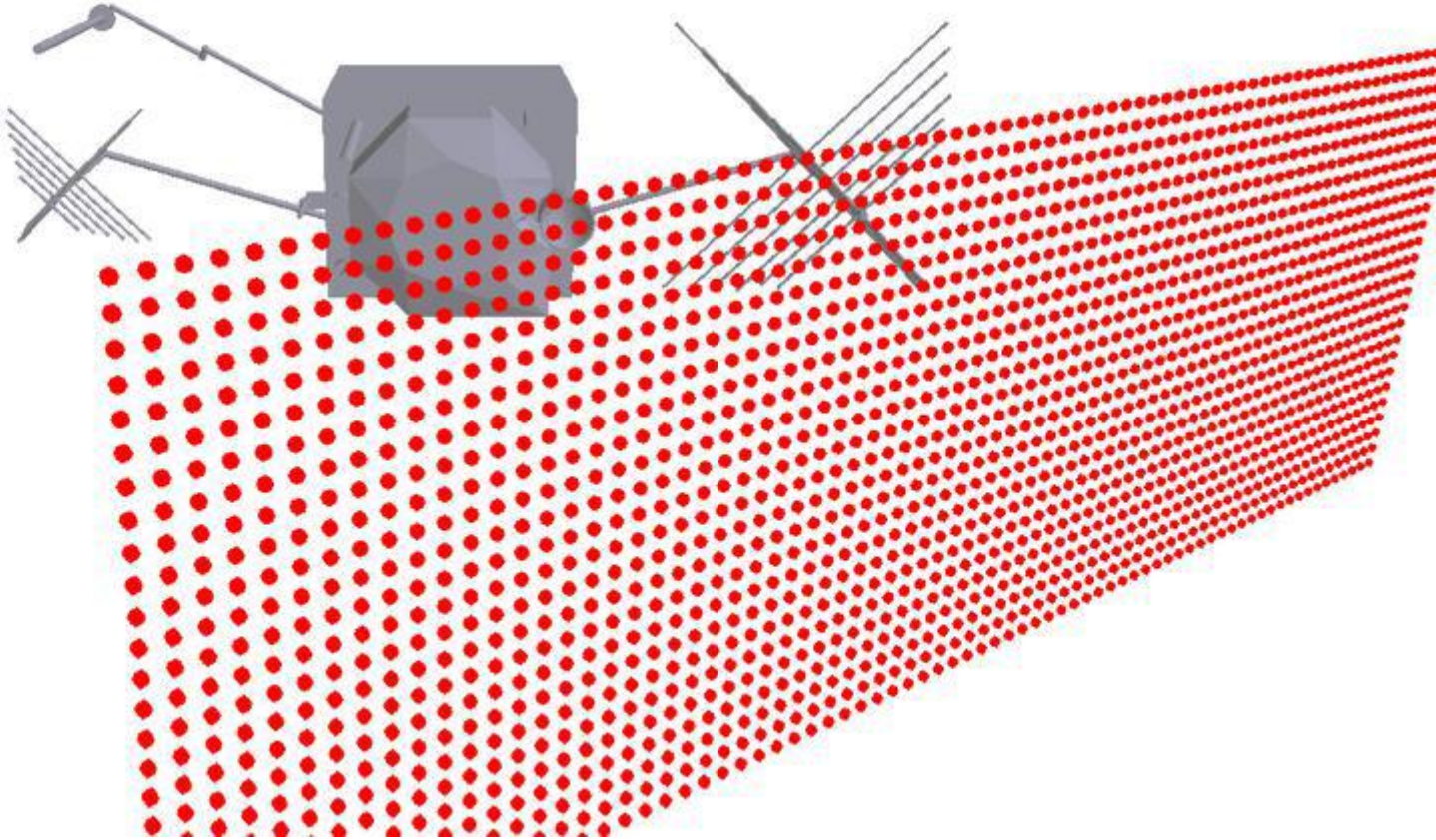
Ray Tracing - 8

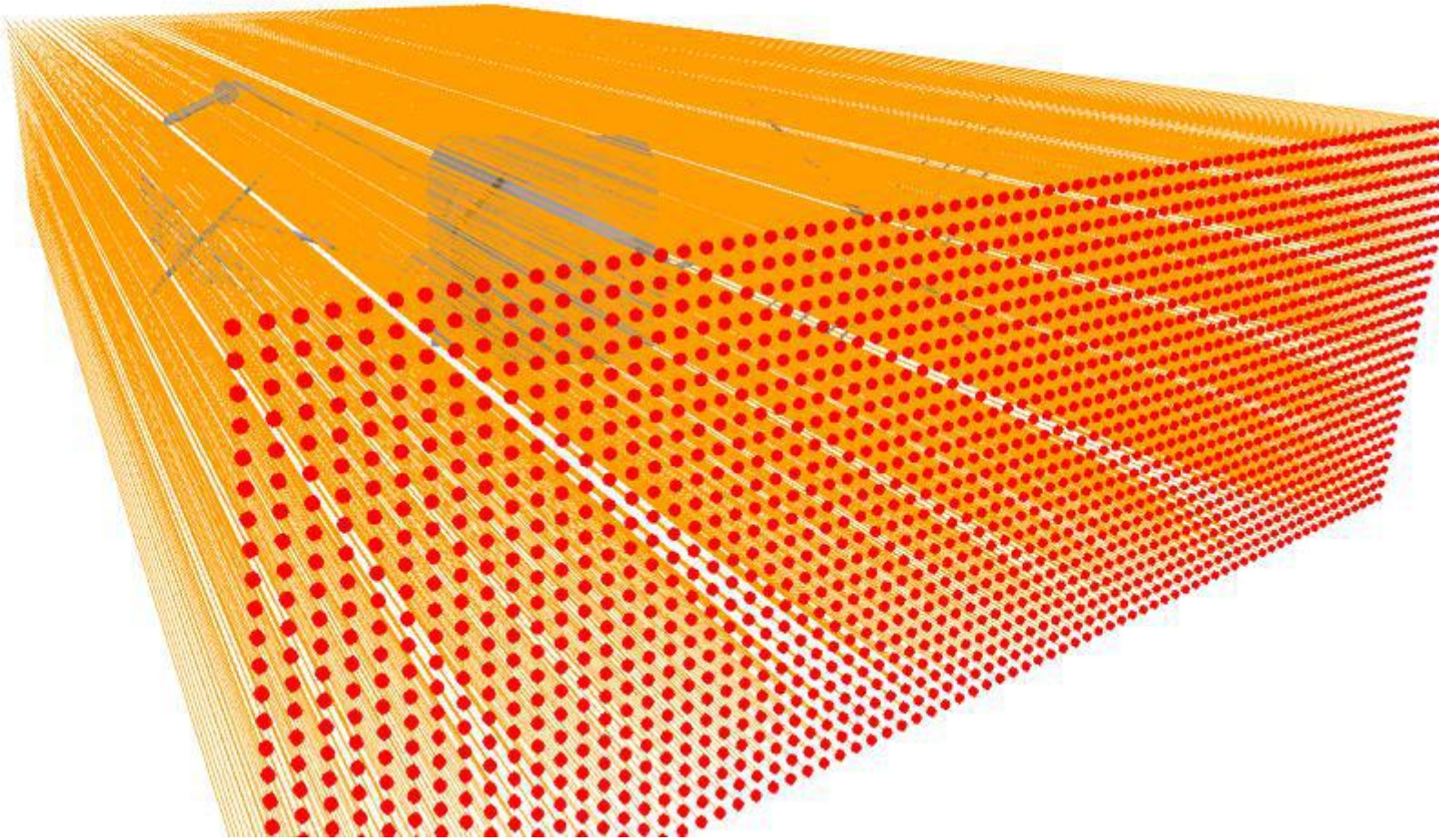


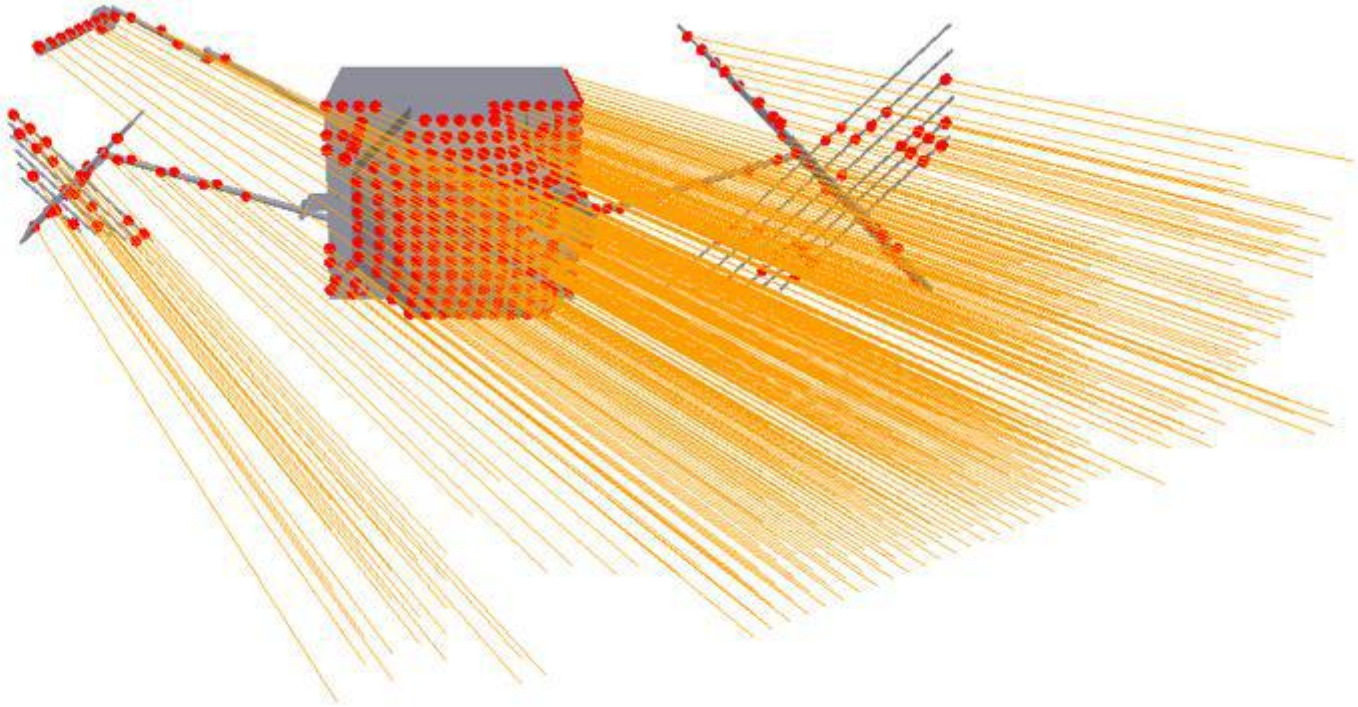
The acceleration data for all rays (primary and secondary) is collected:

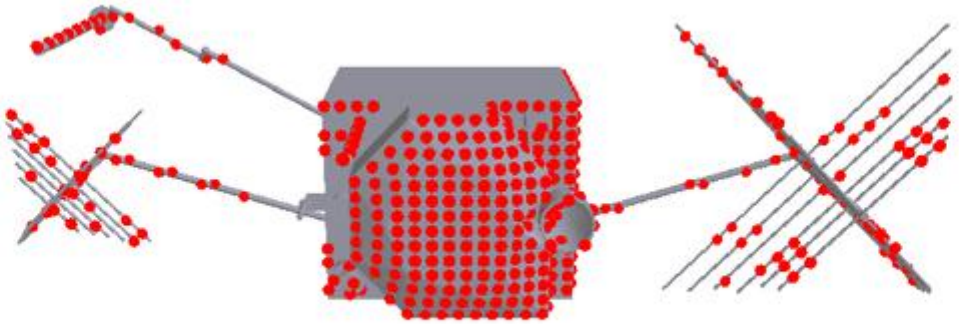
Resultant acceleration computed for that radiation source direction

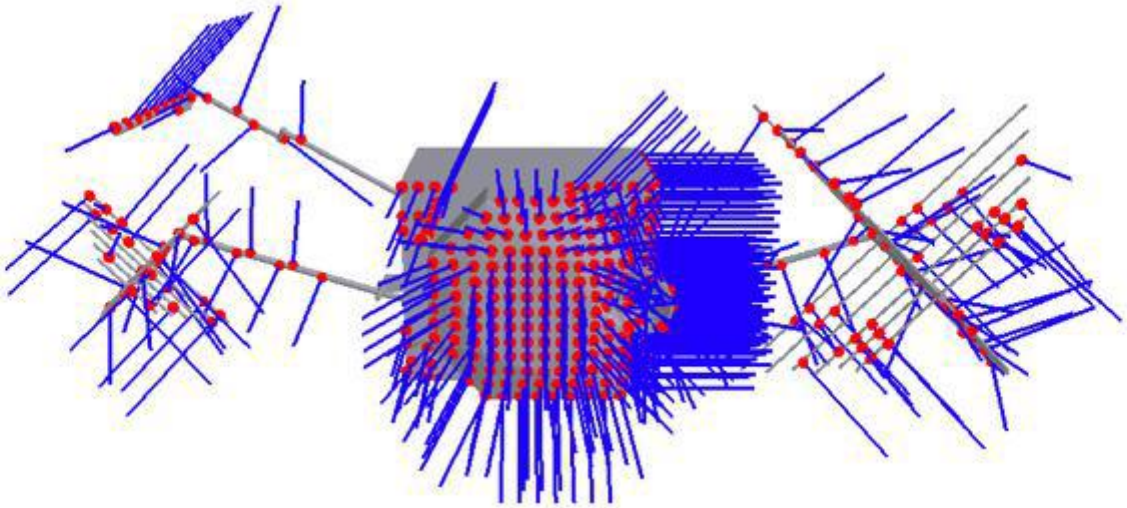
Process is repeated for other incoming flux directions

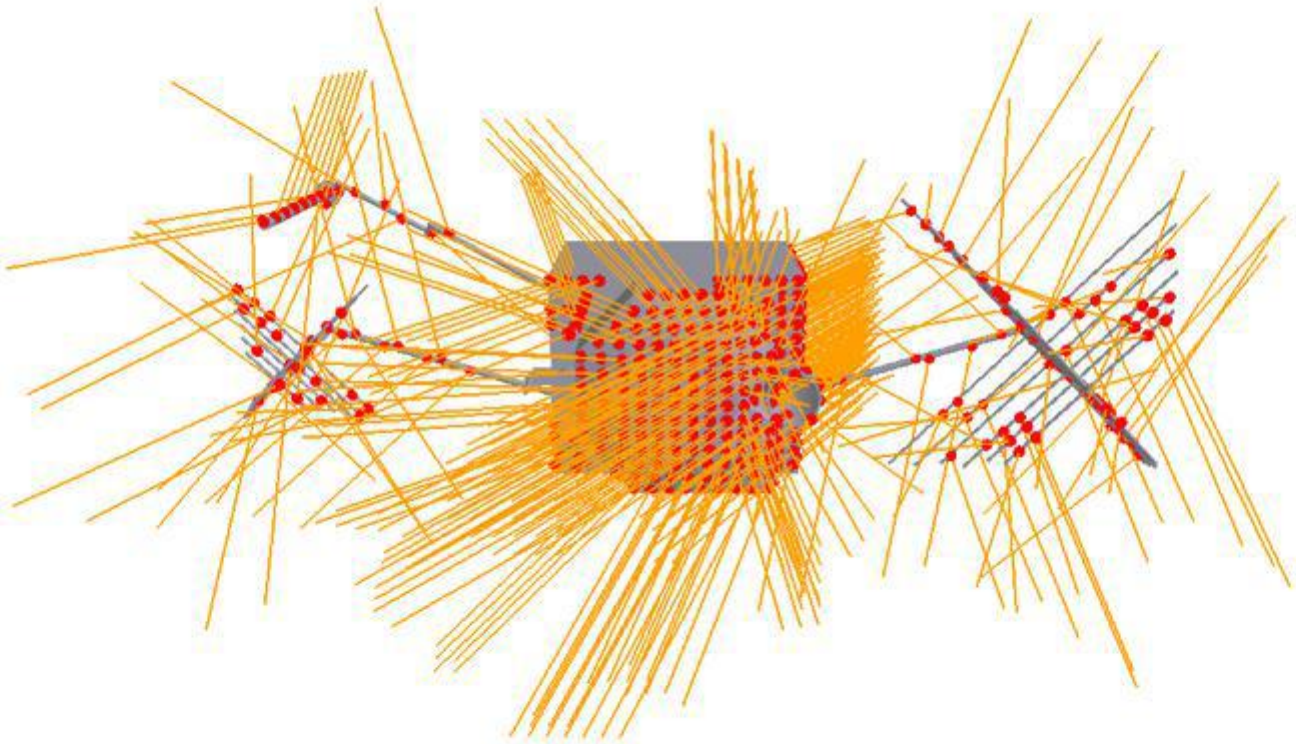




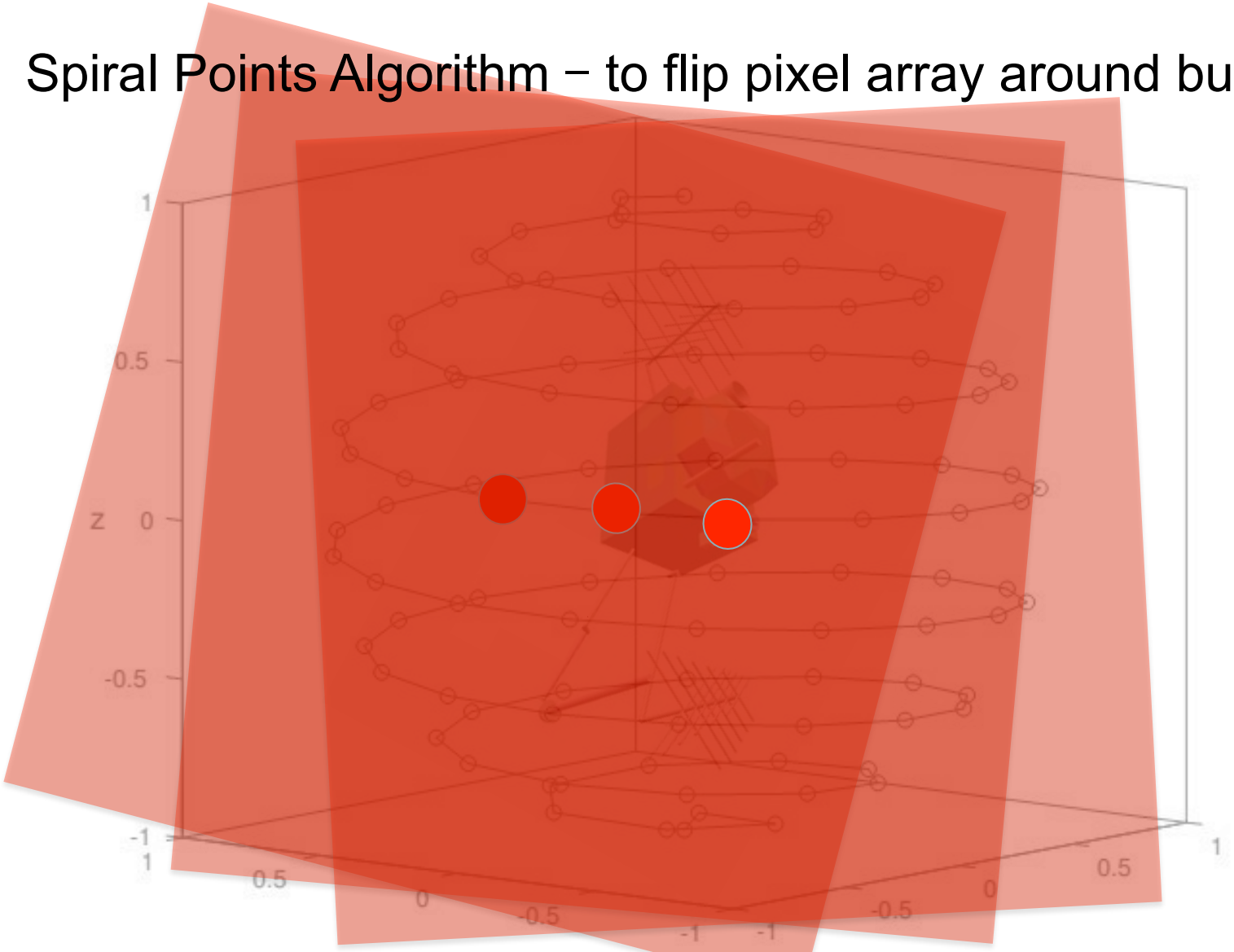




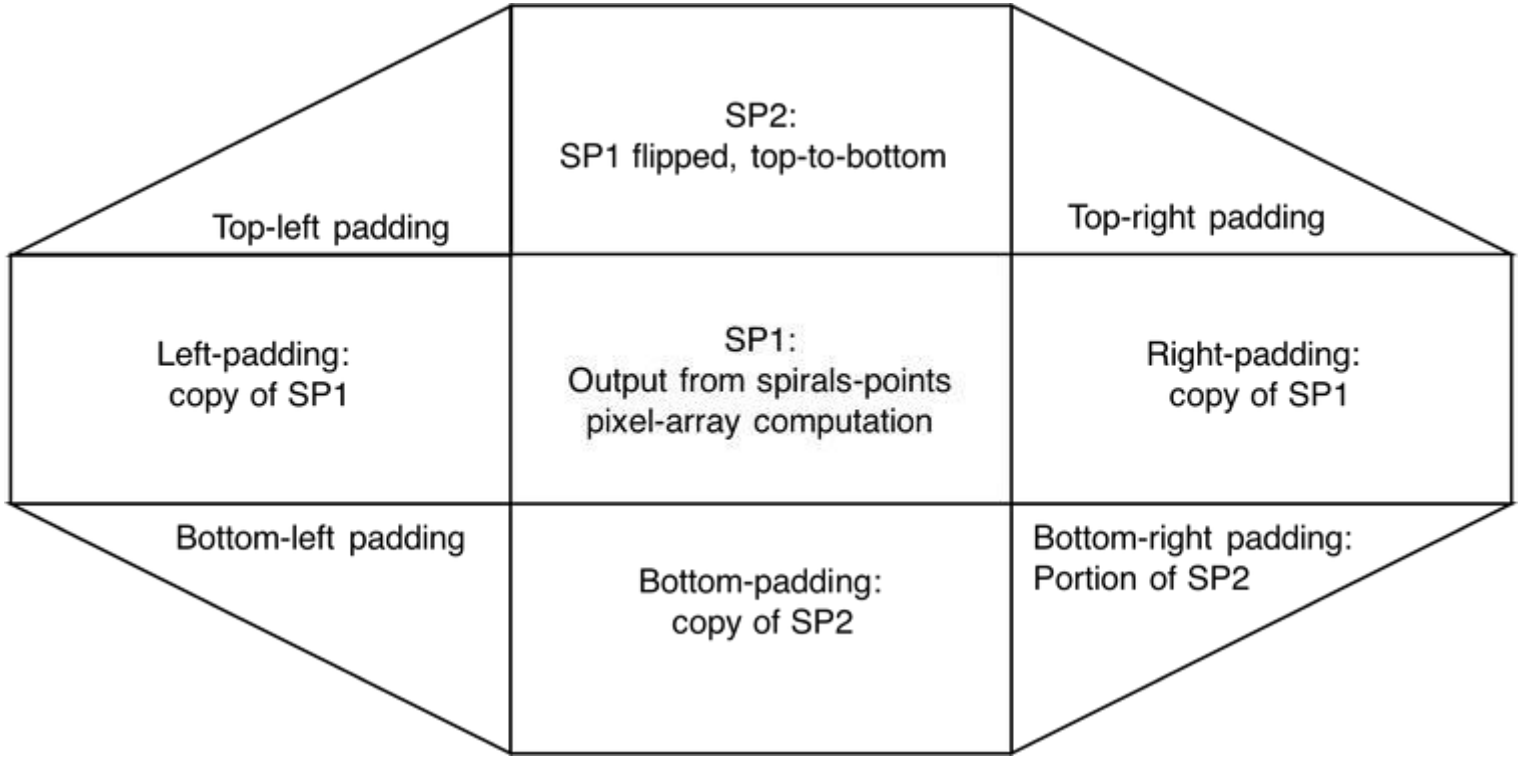




Spiral Points Algorithm − to flip pixel array around bus

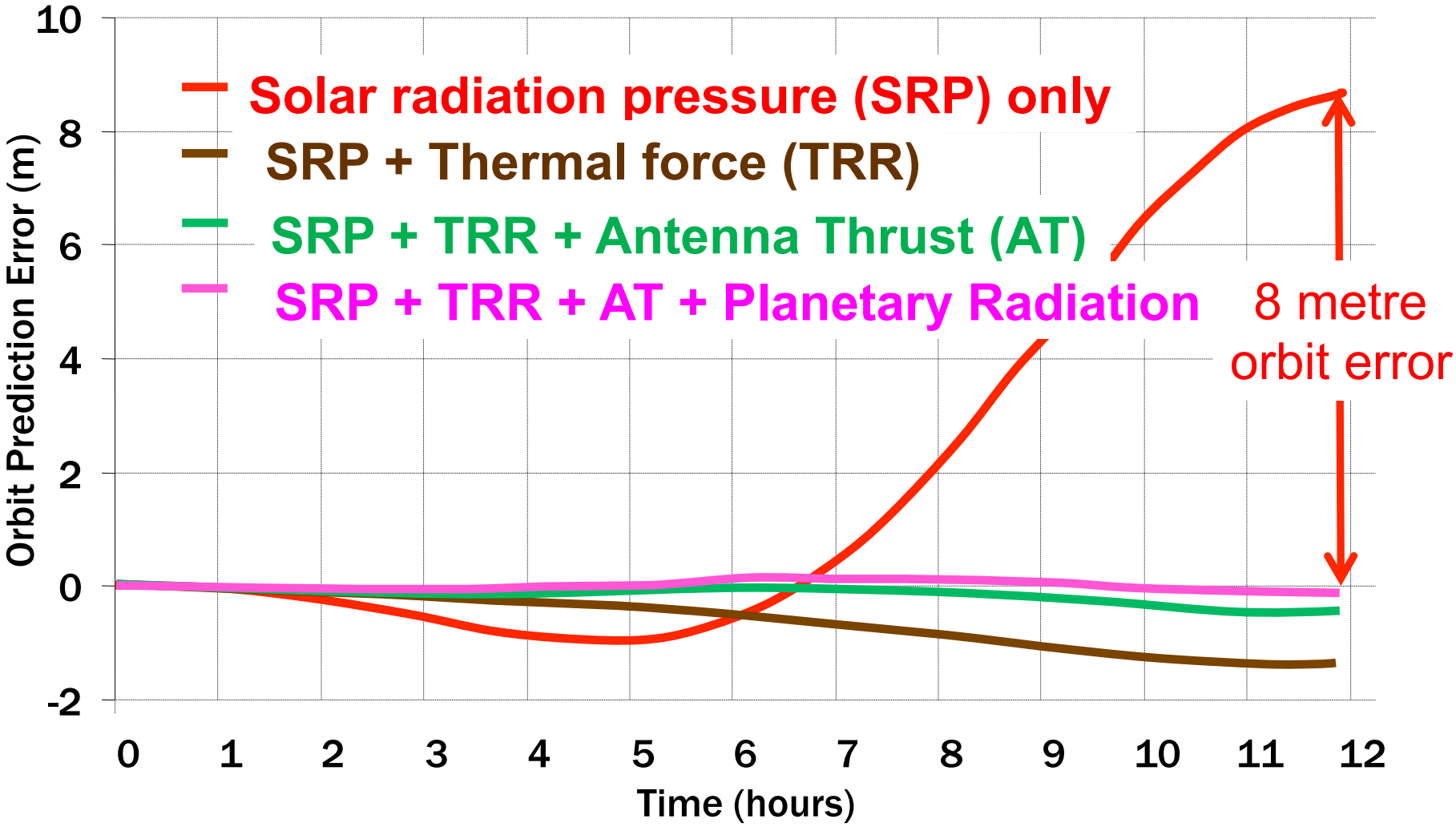


A priori model computation uses 10,000 spiral points, at 1mm pixel resolution



- Schematic representation of the padded spiral points data set used to avoid discrepancies at the grid edges during the grid file production
- Technical paper in submission to explain process

Along-track orbit prediction errors over 12 hours for one GPS IIR satellite with different photon-based force models

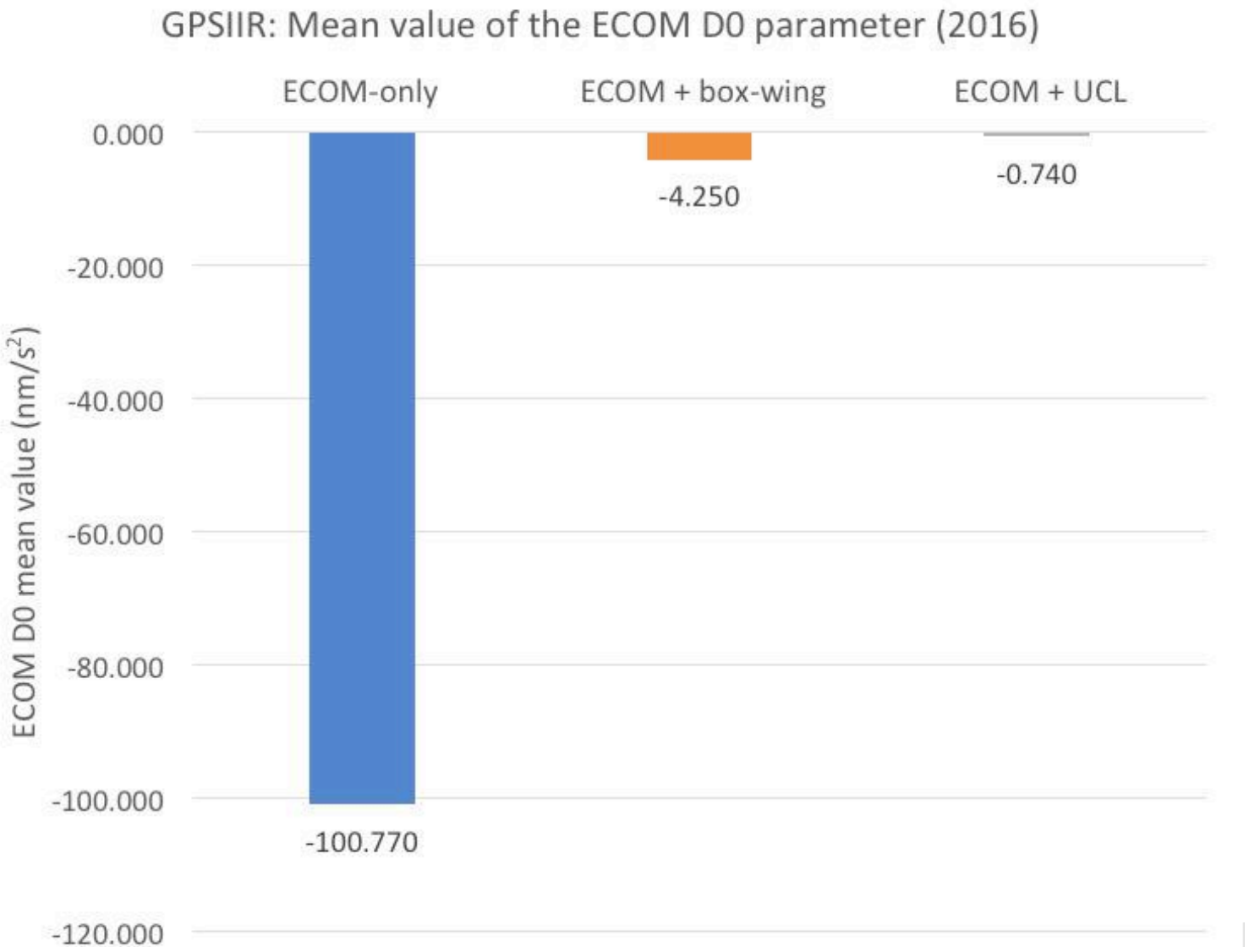


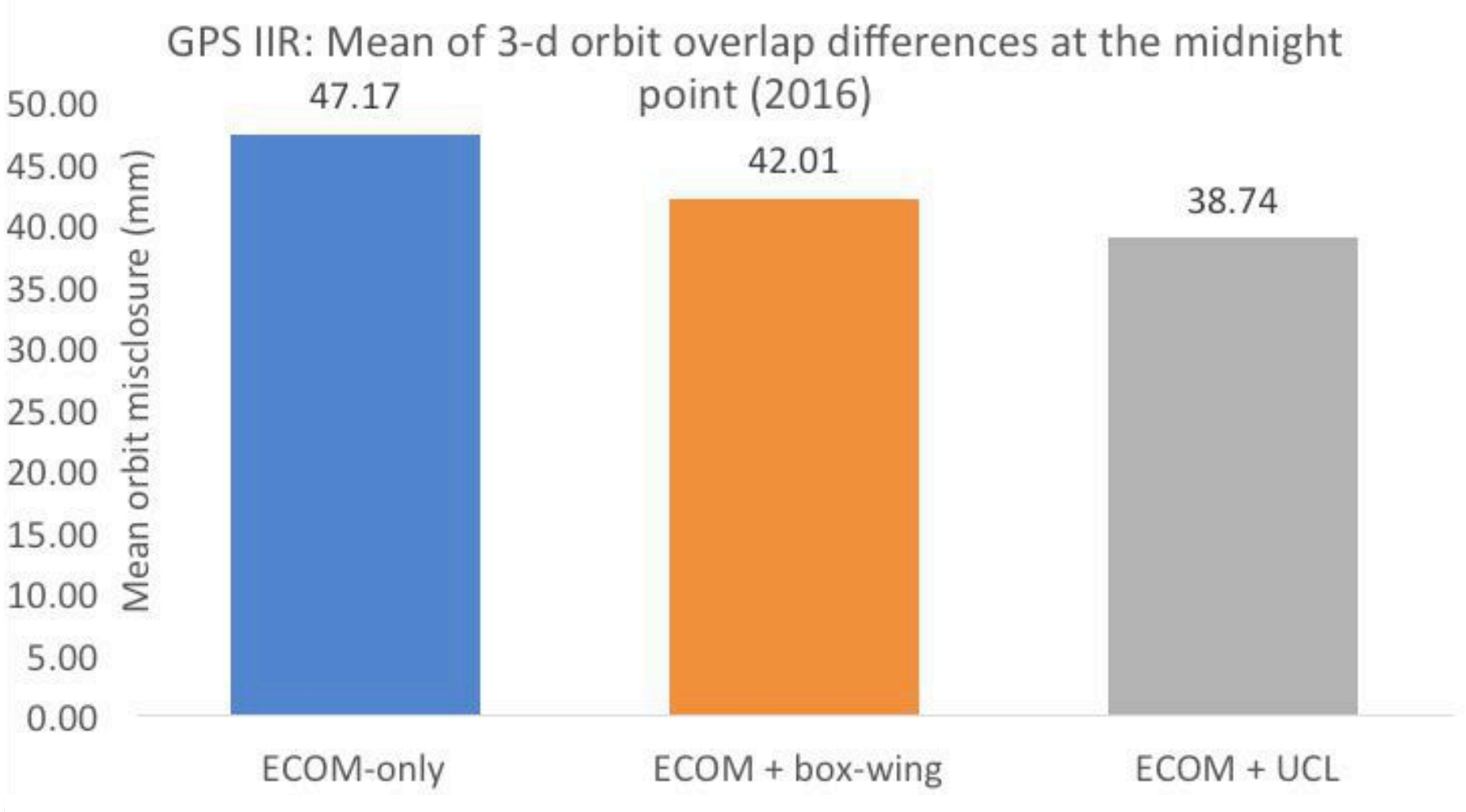
Description of Experiment

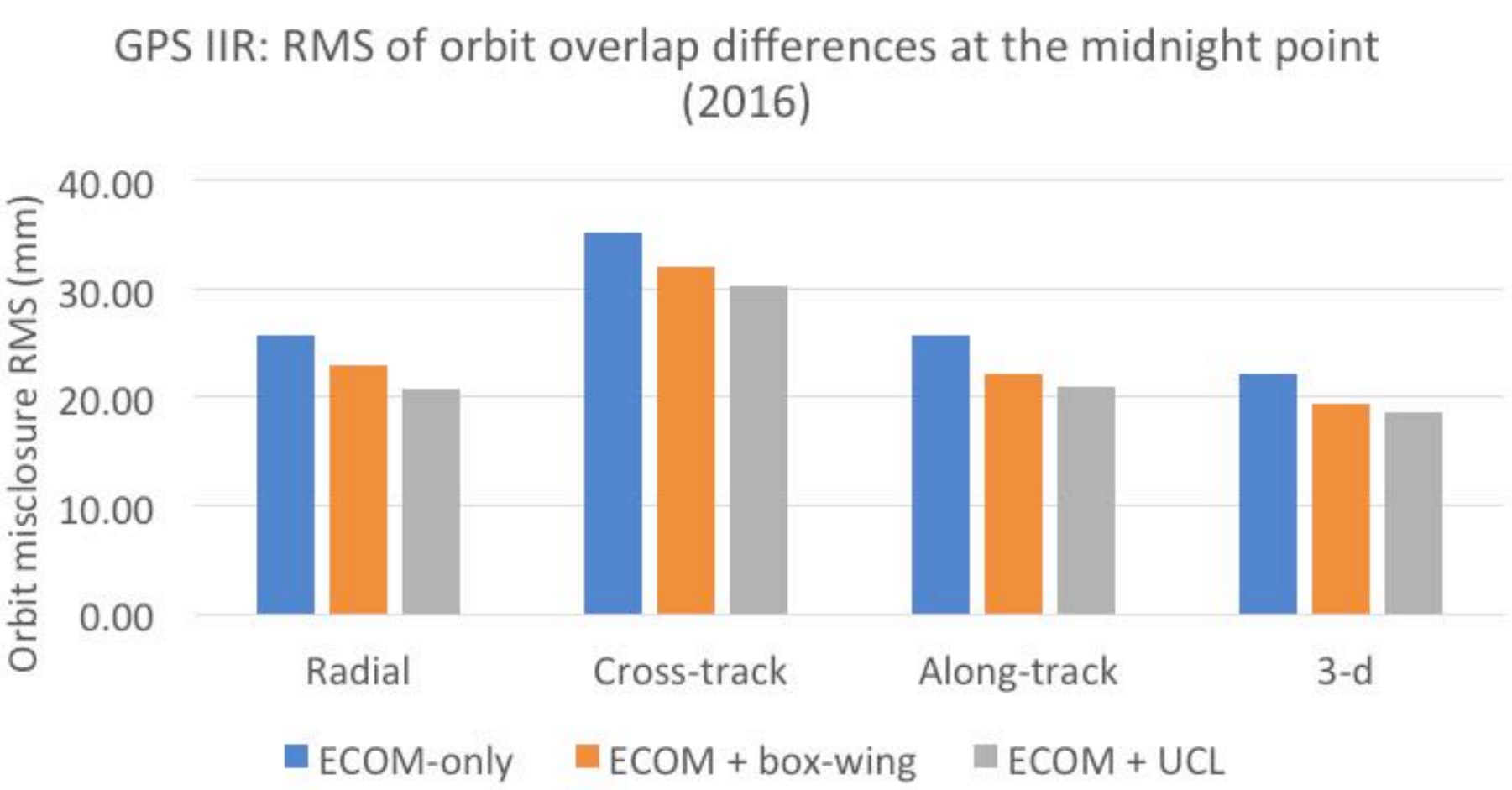
- Software: NAPEOS
- 100 station global network
- One year of daily orbits
- Three contrasting force model parameterizations
- Analysis: values of empirical parameters, orbit overlaps

Force model parameterizations

1. ECOM: No *a priori* model, 5 ECOM parameters (constants D0, Y0, B0, and the cosine and sine terms in the B-direction) and 3 constrained along-track parameters (constant and cosine and sine with argument of latitude as period).
2. ECOM + Box-wing: Same estimation strategy as ECOM-only, but with an *a priori* box-wing model.
3. UCL model: the only difference with strategy 2 is that the box-wing model is replaced by the UCL bus 'grid file' model + solar panels SRP force.


GPSIIR: Mean value of the ECOM D0 parameter (2016)
ECOM-only
ECOM + box-wing
ECOM + UCL
0.000
-20.000
-40.000
-60.000
-80.000
-100.000
-120.000
ECOM D0 mean value (nm/s²)
-100.770
-4.250
-0.740


GPS IIR: Mean of 3-d orbit overlap differences at the midnight point (2016)
Mean orbit misclosure (mm)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
47.17
42.01
38.74
ECOM-only
ECOM + box-wing
ECOM + UCL


GPS IIR: RMS of orbit overlap differences at the midnight point (2016)
Orbit misclosure RMS (mm)
40.00
30.00
20.00
10.00
0.00
Radial
Cross-track
Along-track
3-d
ECOM-only
ECOM + box-wing
ECOM + UCL

Conclusions

- UCL's grid file bus modelling has been applied successfully to LEO spacecraft (JPL, GSFC) but has not been tested on GNSS by the IGS
- Tests show encouraging results for orbit improvements in accuracy of physical modelling and orbit overlaps
- UCL/Positim/GMV/ESTEC are applying this technique to Galileo IOV and FOC right now
- We have demonstrated improved precision − the aim of this workshop!