Current Status of Non-conservative Force Modelling:

Interface to REPRO2

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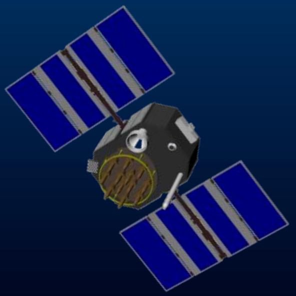
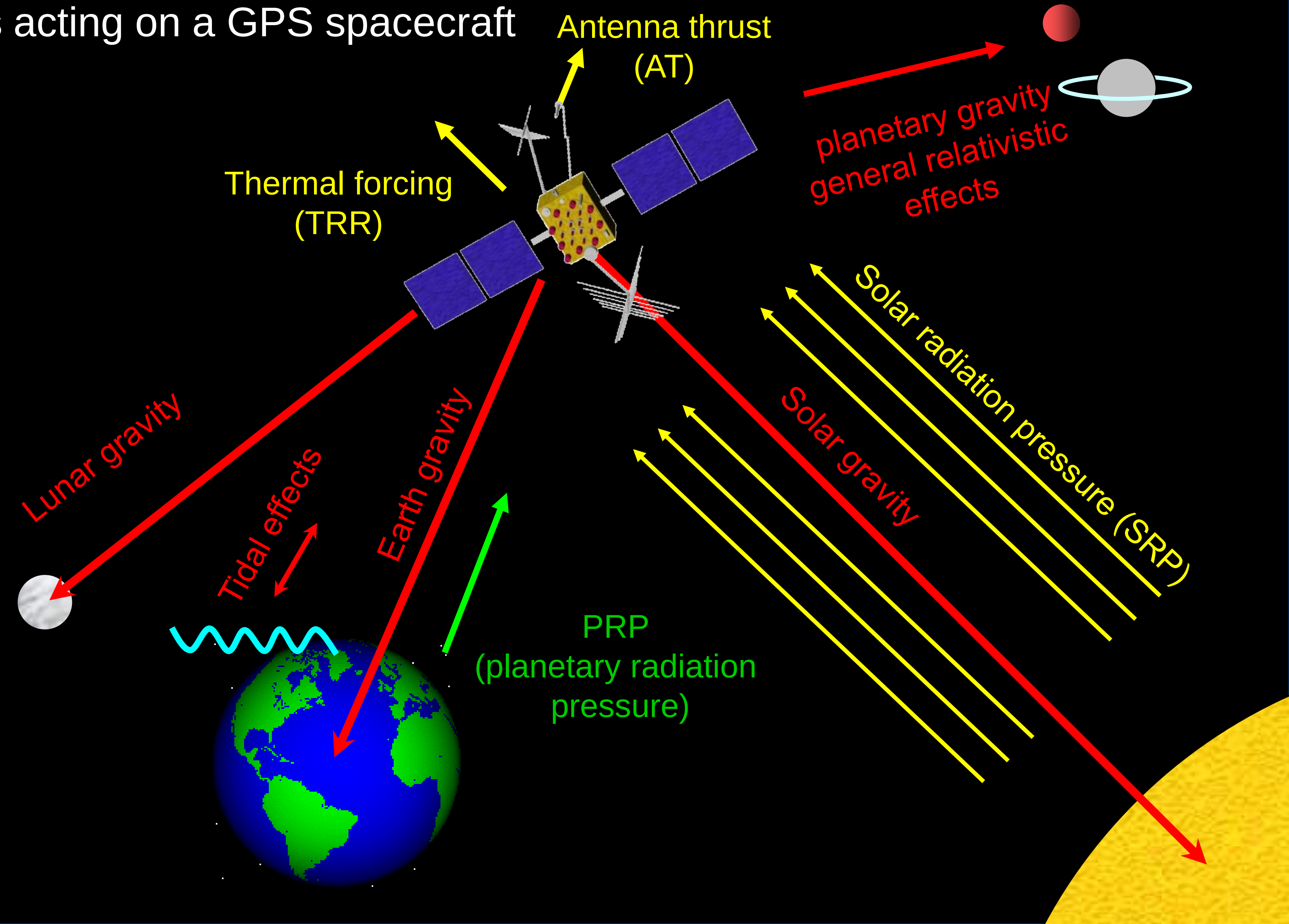
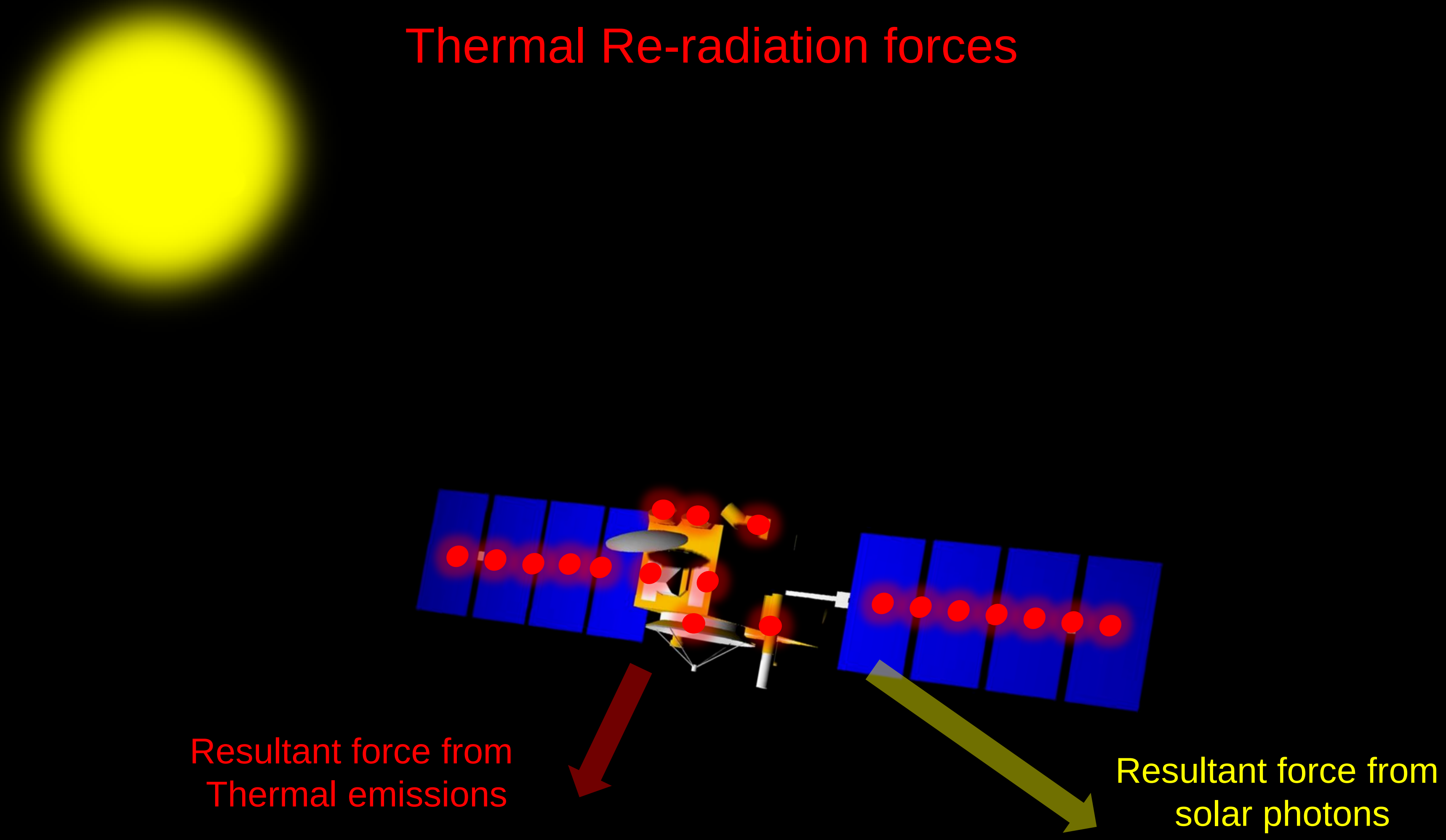


IGS Workshop 2012 University of Warmia and Mazury in Olsztyn, July 2012

Forces acting on a GPS spacecraft



Solar radiation pressure

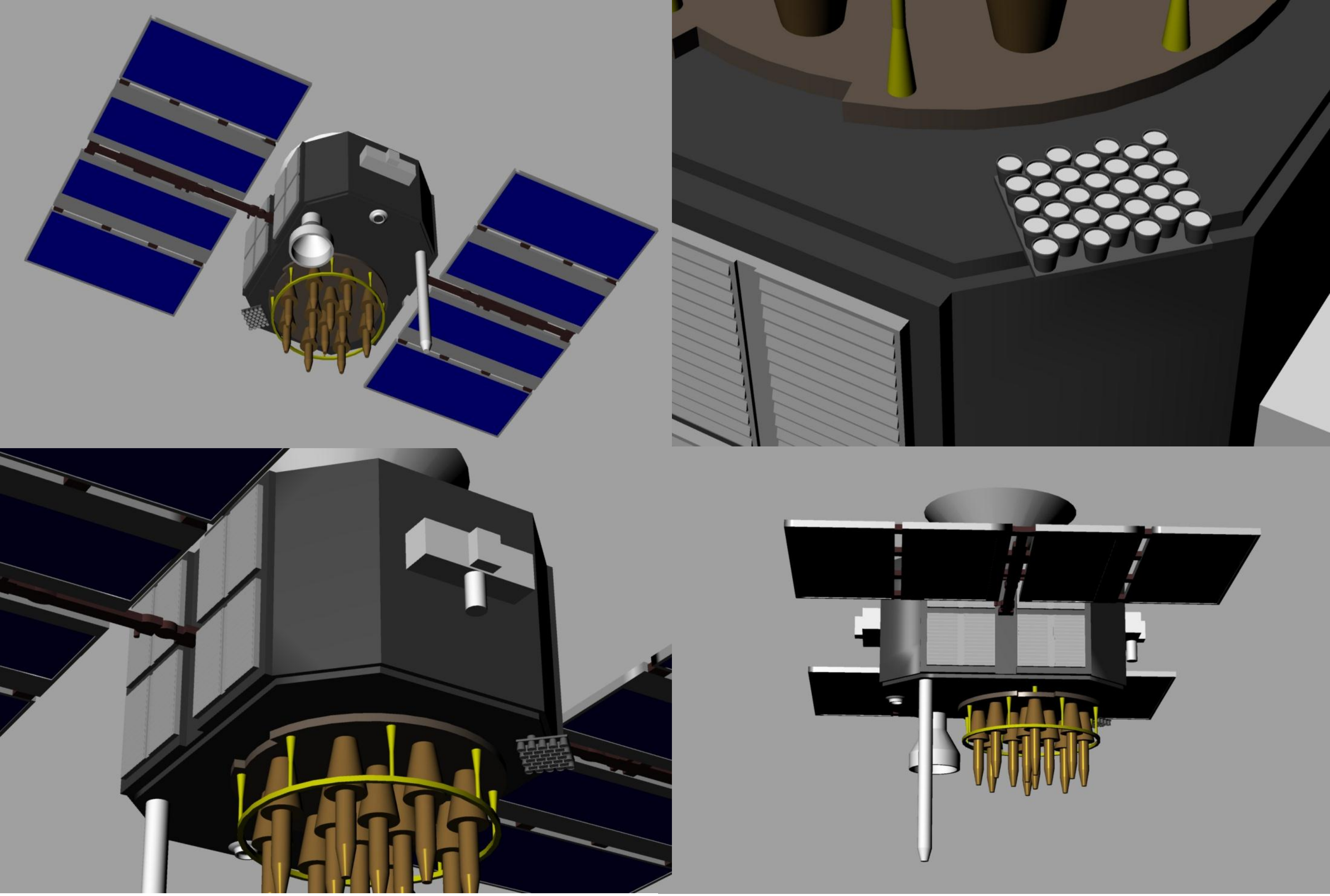


Existing 'solar radiation pressure' modelling approaches

- Typically empirical models estimated from tracking data
- Some movement towards physical components (Earth radiation pressure, antenna thrust)
- Some development of 'box and wing' approaches
- There are alternatives

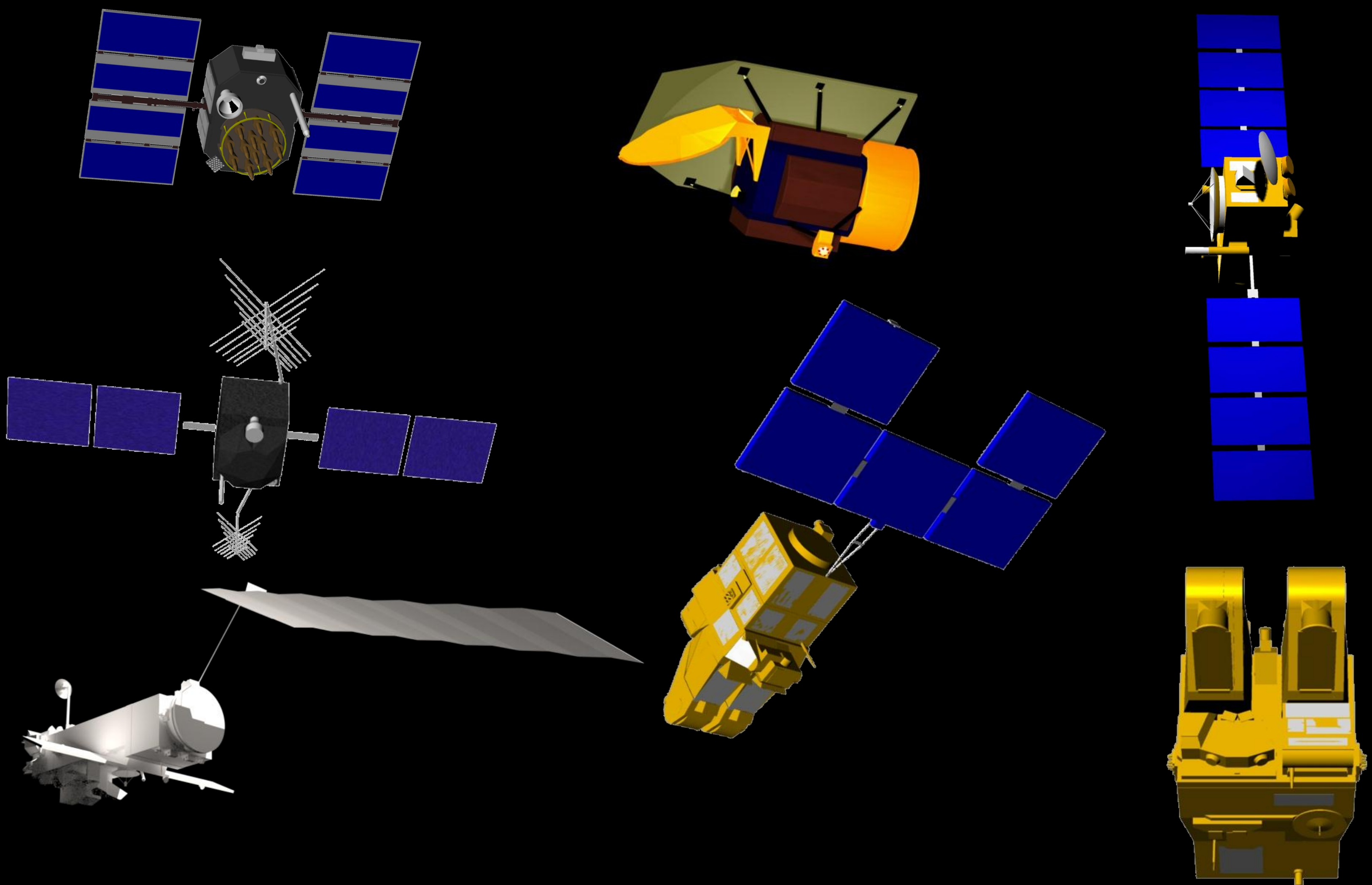
UCL Modelling Philosophy

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

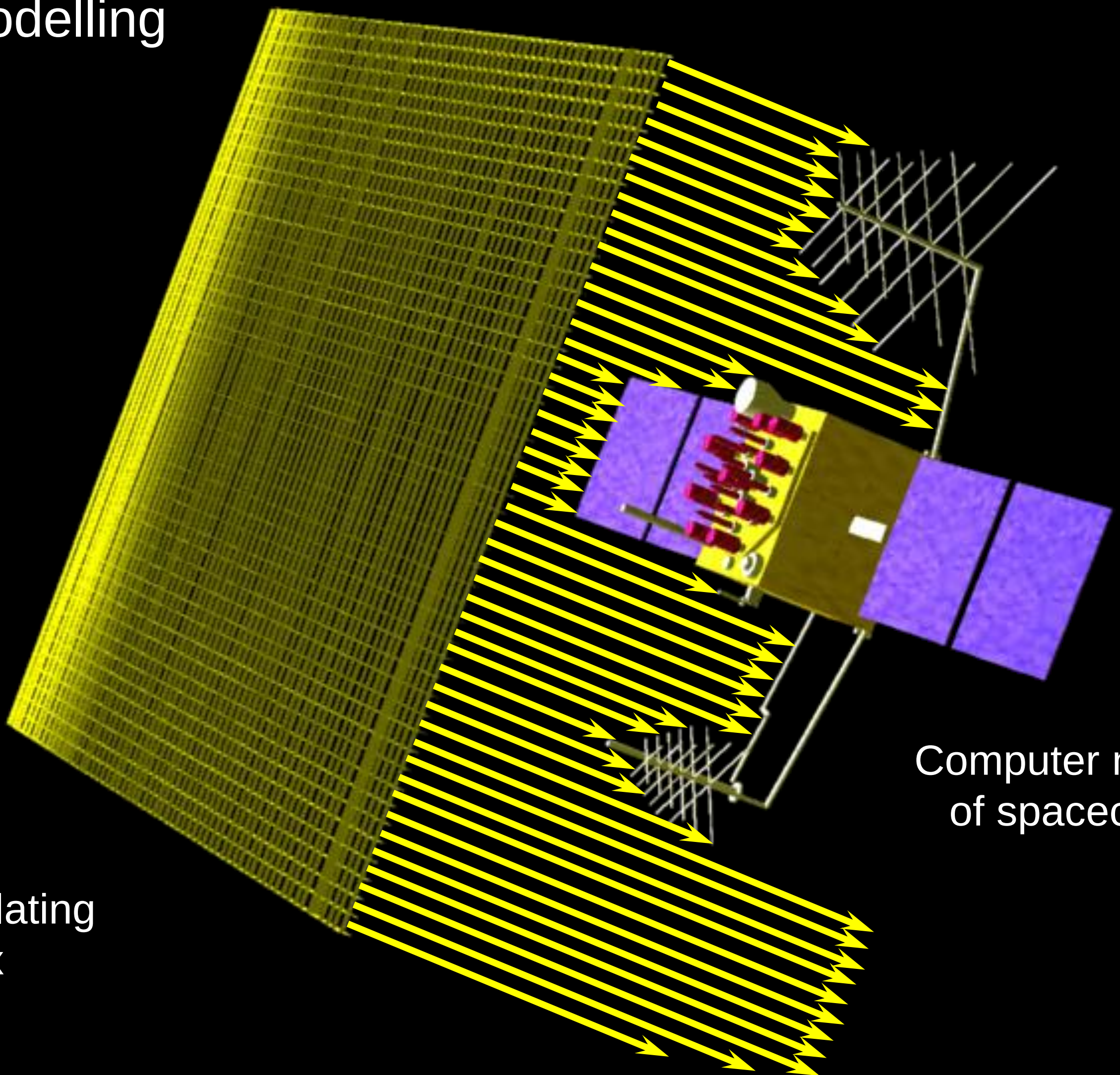


We develop a detailed structural computer model of the spacecraft

Many space vehicles studied by my group

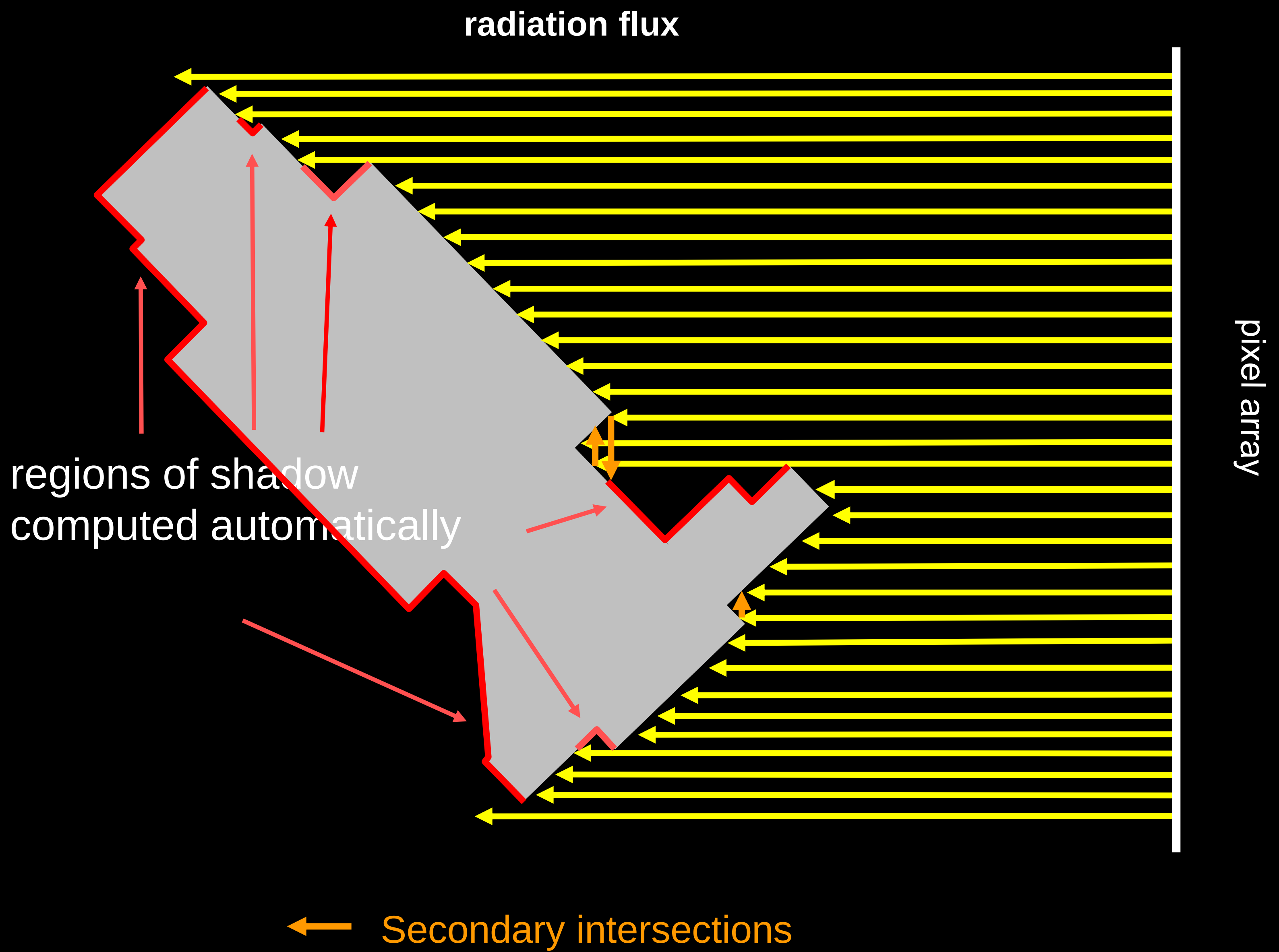


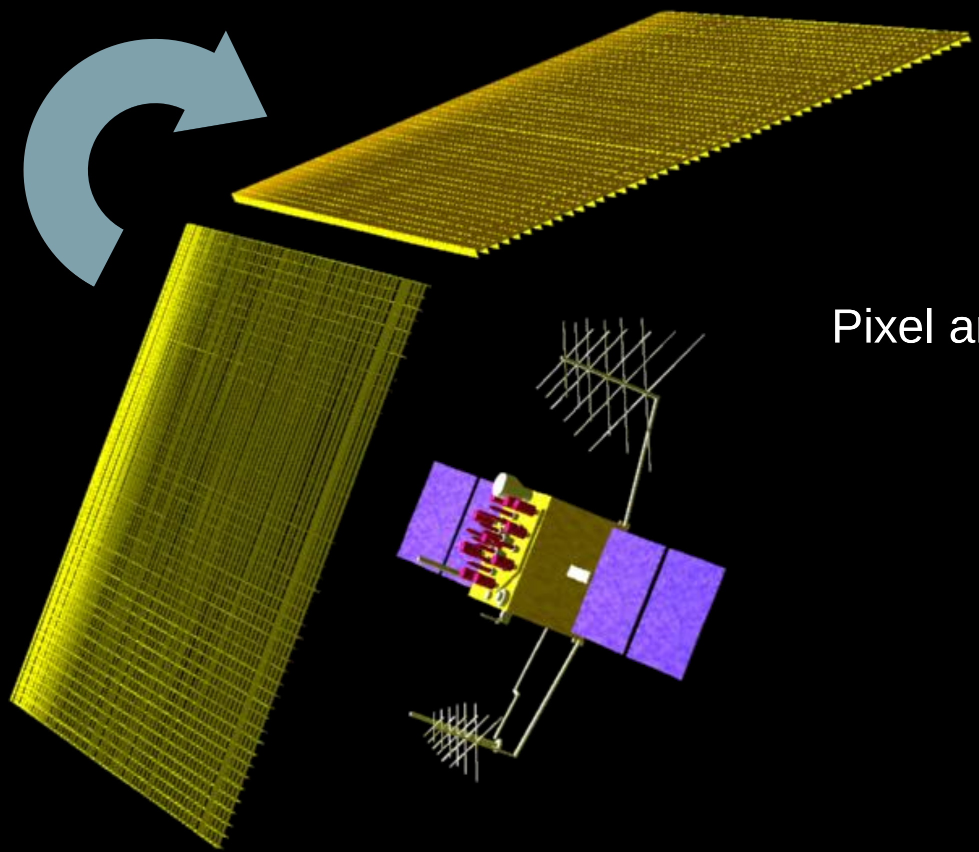
Photon force modelling



Computer model
of spacecraft

Pixel array simulating
photon flux


radiation flux
pixel array
regions of shadow
computed automatically
Secondary intersections



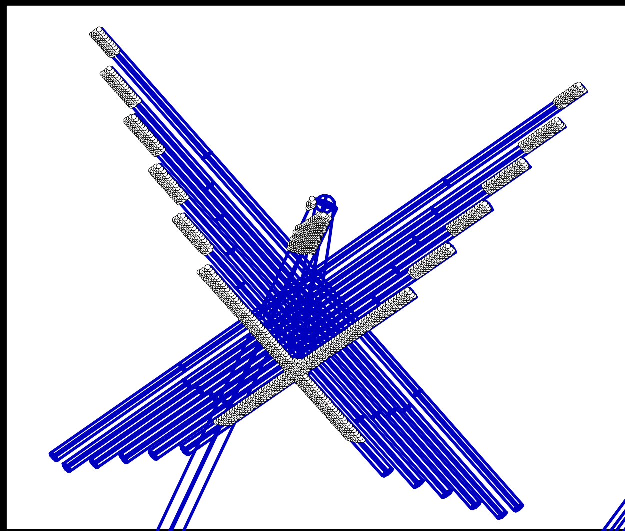
Pixel array rotated around spacecraft,
solar panels adjusted

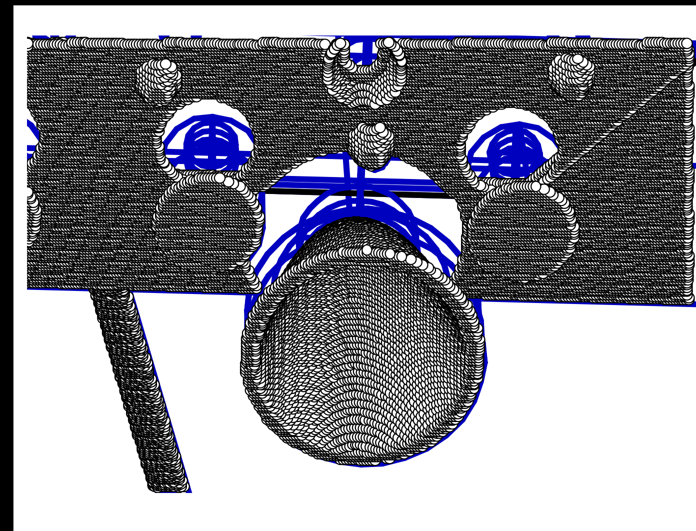
Publications:

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)

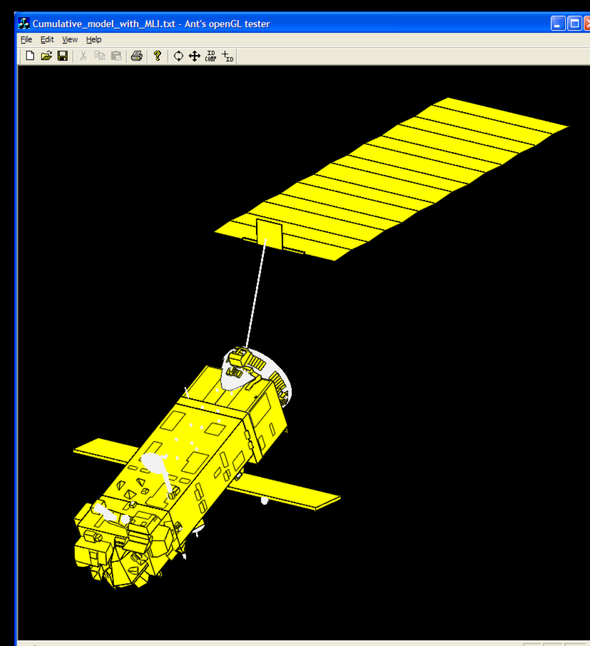
Ziebart,M., Adhya, S., Sibthorpe, A., and Cross, P., (2003) GPS Block IIR Non-conservative Force Modelling: Computation and Implications, Proceedings of ION GPS/GNSS 2003, Portland, Oregon, US (***winner of best paper award***, Science/timing application session)

Quality control: Rasterisation test



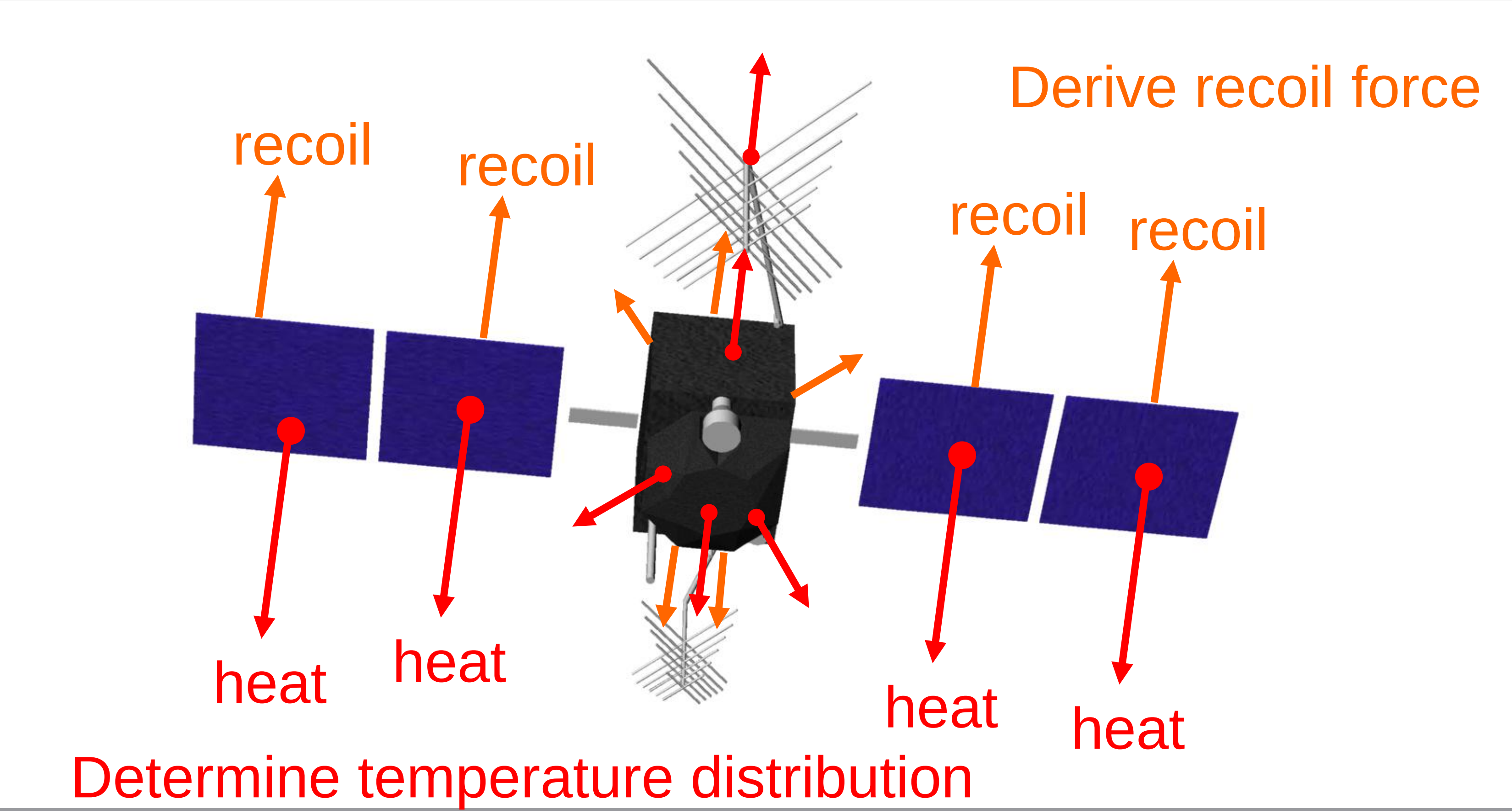


Quality control: Graphical User Interface to database



Thermal modelling:

Anisotropic thermal emission from spacecraft results in a net acceleration



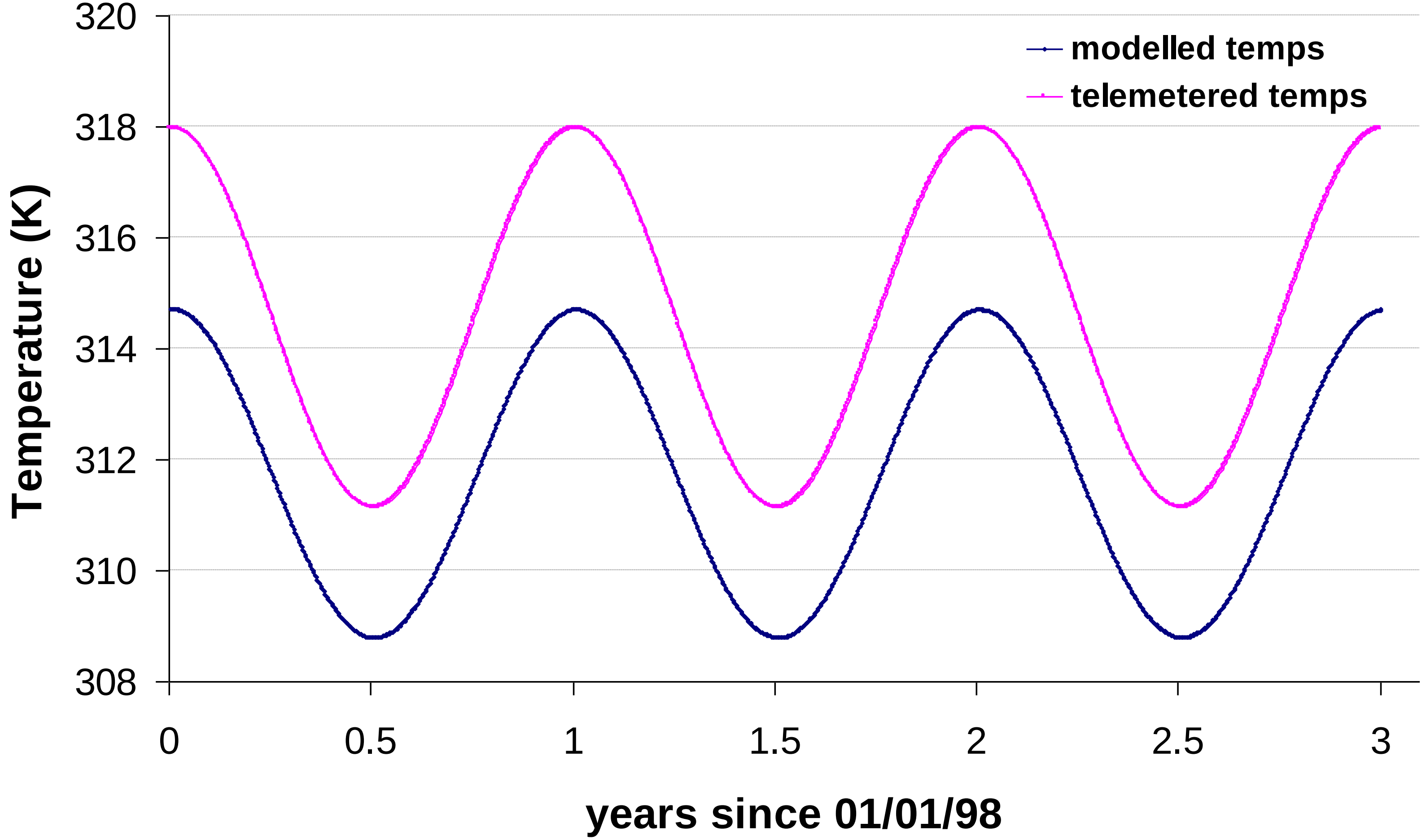
Solar Panel Analysis

- 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

- Model verification by comparison with telemetered surface temperatures

Modelled and telemetered temperatures of GPS Block IIR solar panel

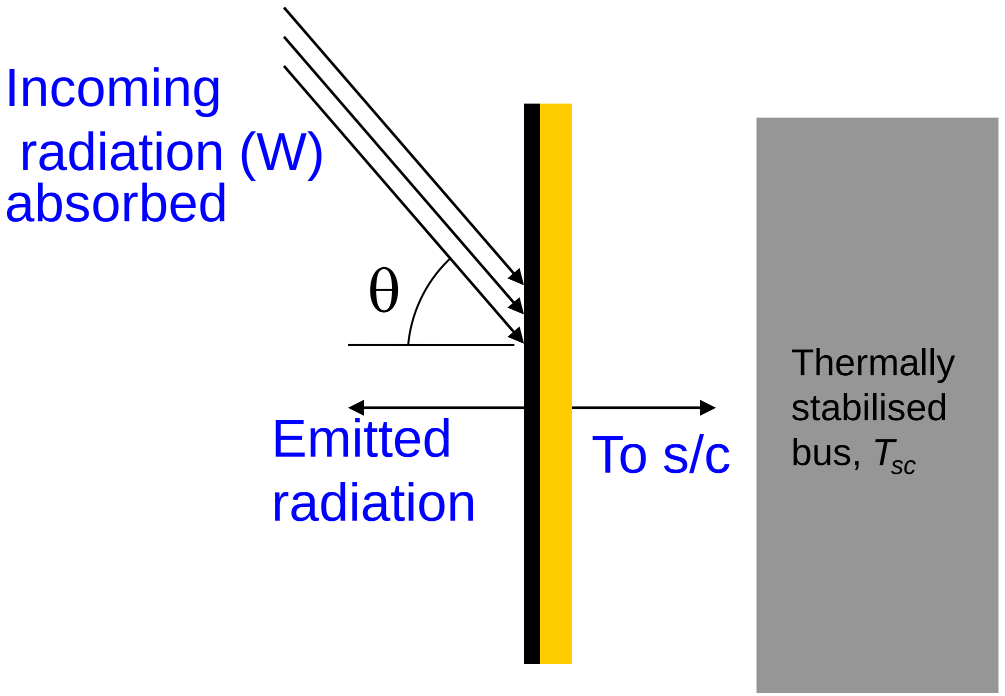


Modelled surface temperatures within noise band of telemetry surface temperatures

Multilayer Insulation (MLI)

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

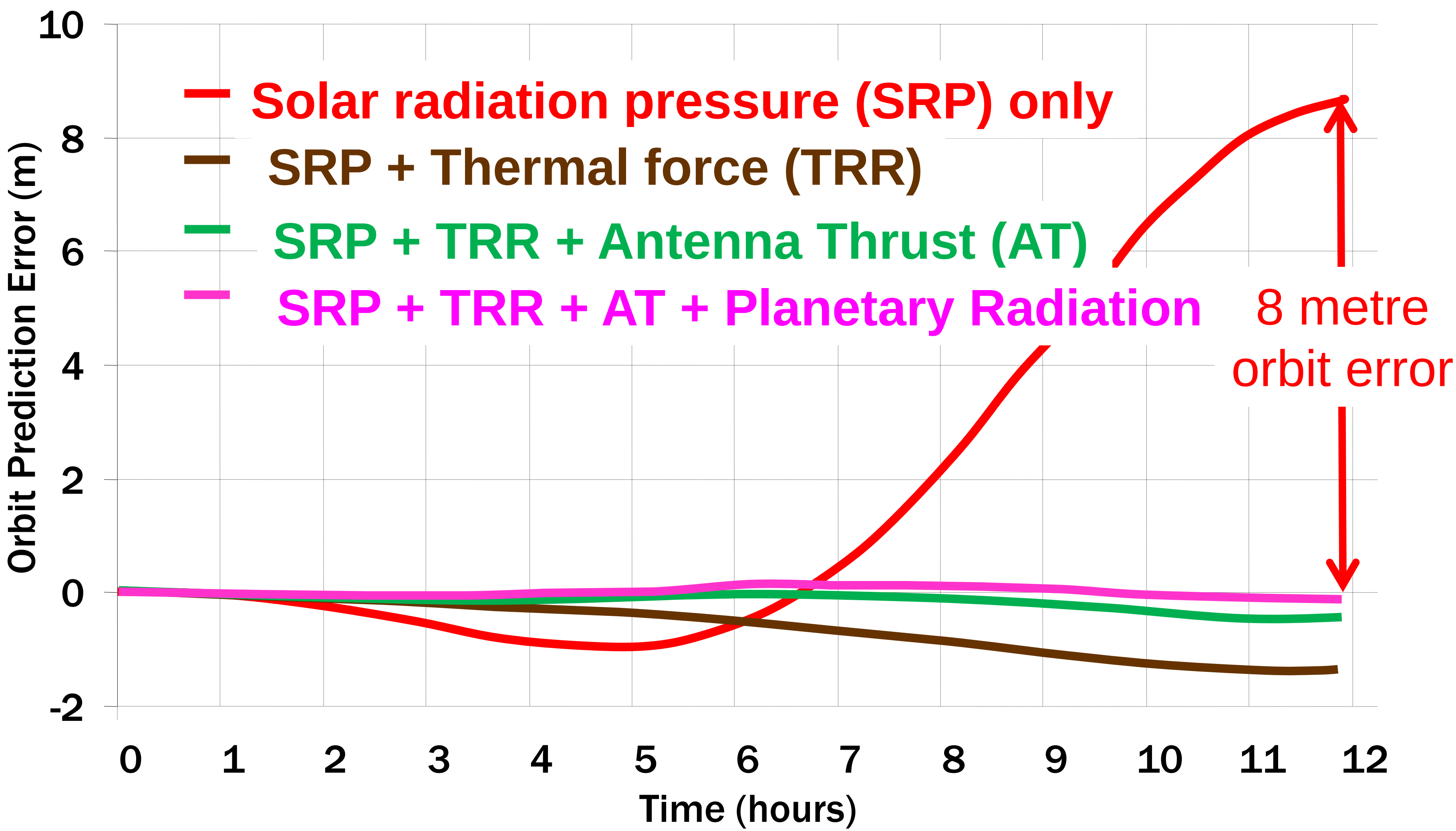
Energy balance:



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

Crude test of model fidelity

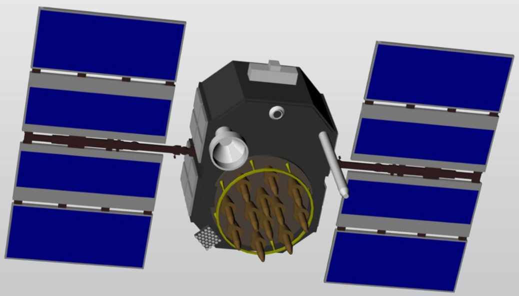
Along-track orbit prediction errors over 12 hours for one GPS satellite with different photon-based force models

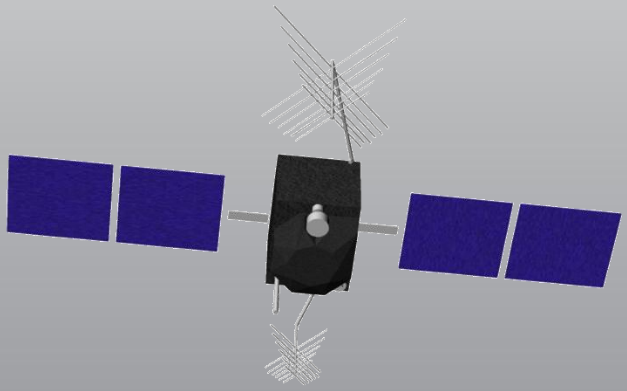


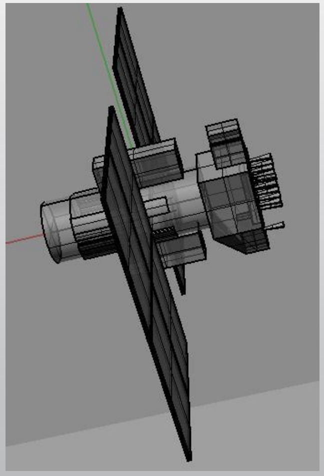
Models, formats, implementation

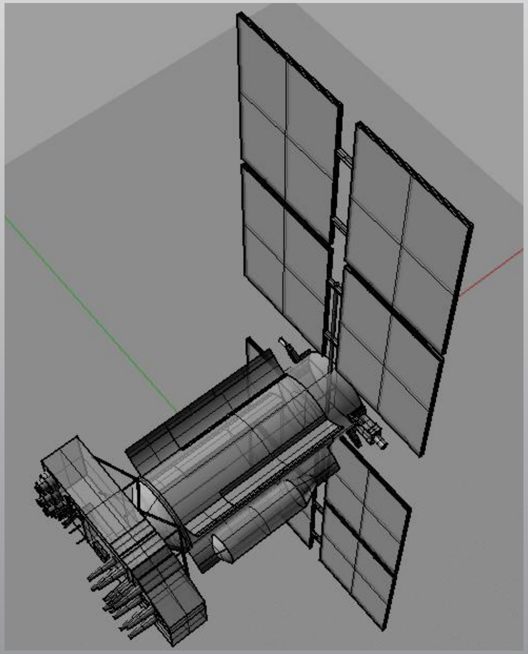
- Models supplied as Fourier Series or grid files
- Models designed to run fast without compromising accuracy/precision
- Models coded in C++, Fortran90 or Fortran77 according to user choice
- Implementation requires knowledge of sun position, and spacecraft attitude

High resolution analytical SRP/TRR models: Block IIA, Block IIR, GLONASS IIν, GLONASS IIM



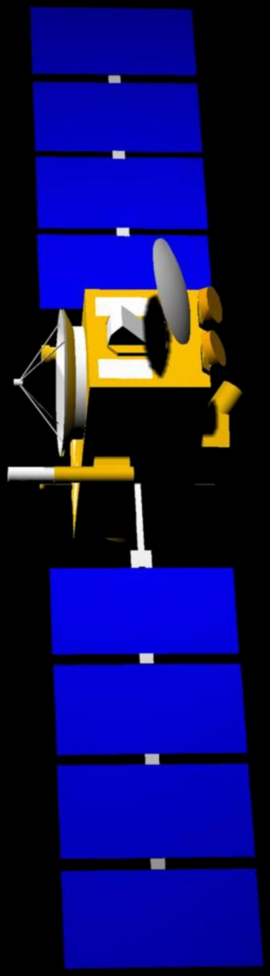






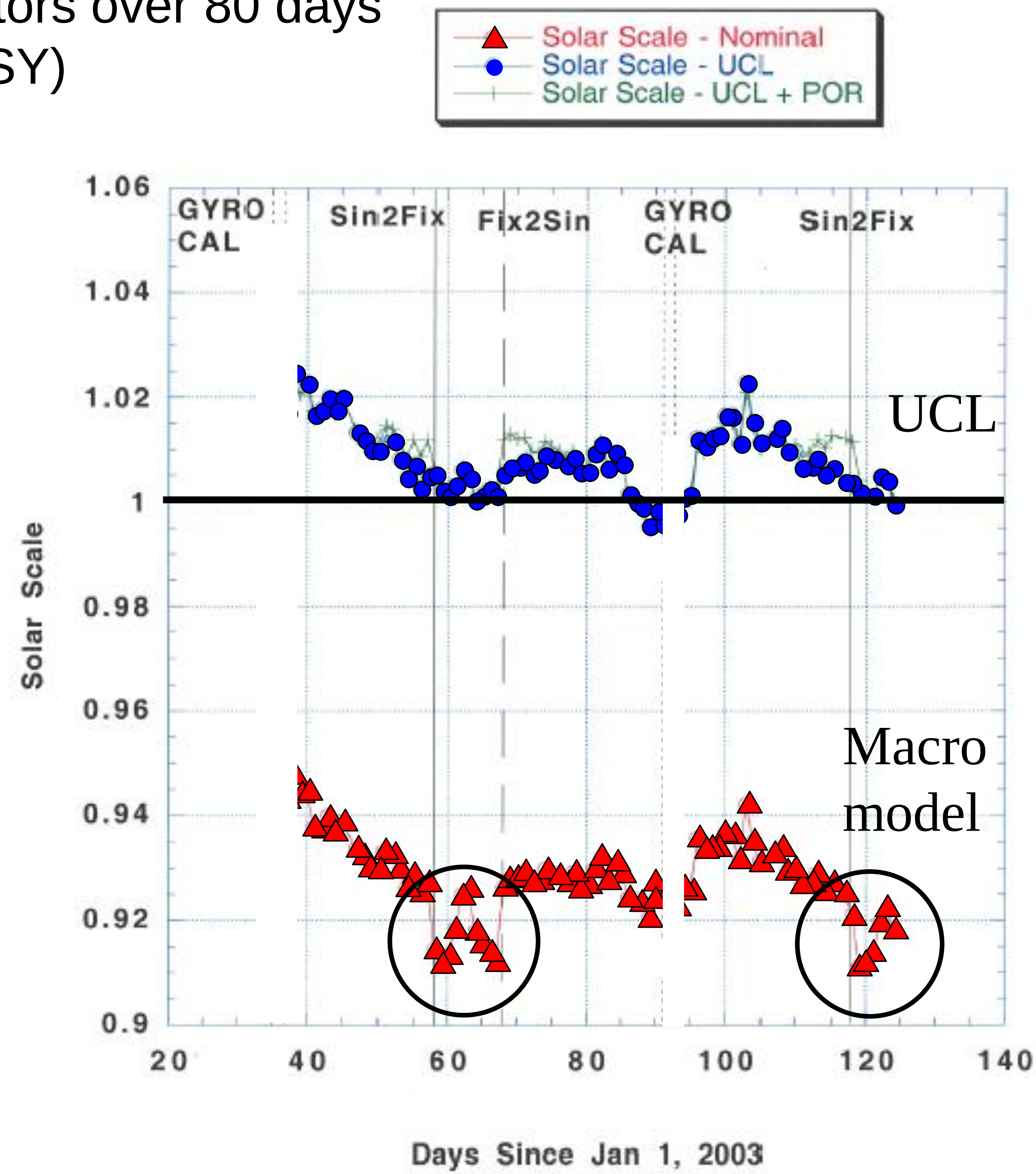
Jason-1 modelling (SRP and TRR)

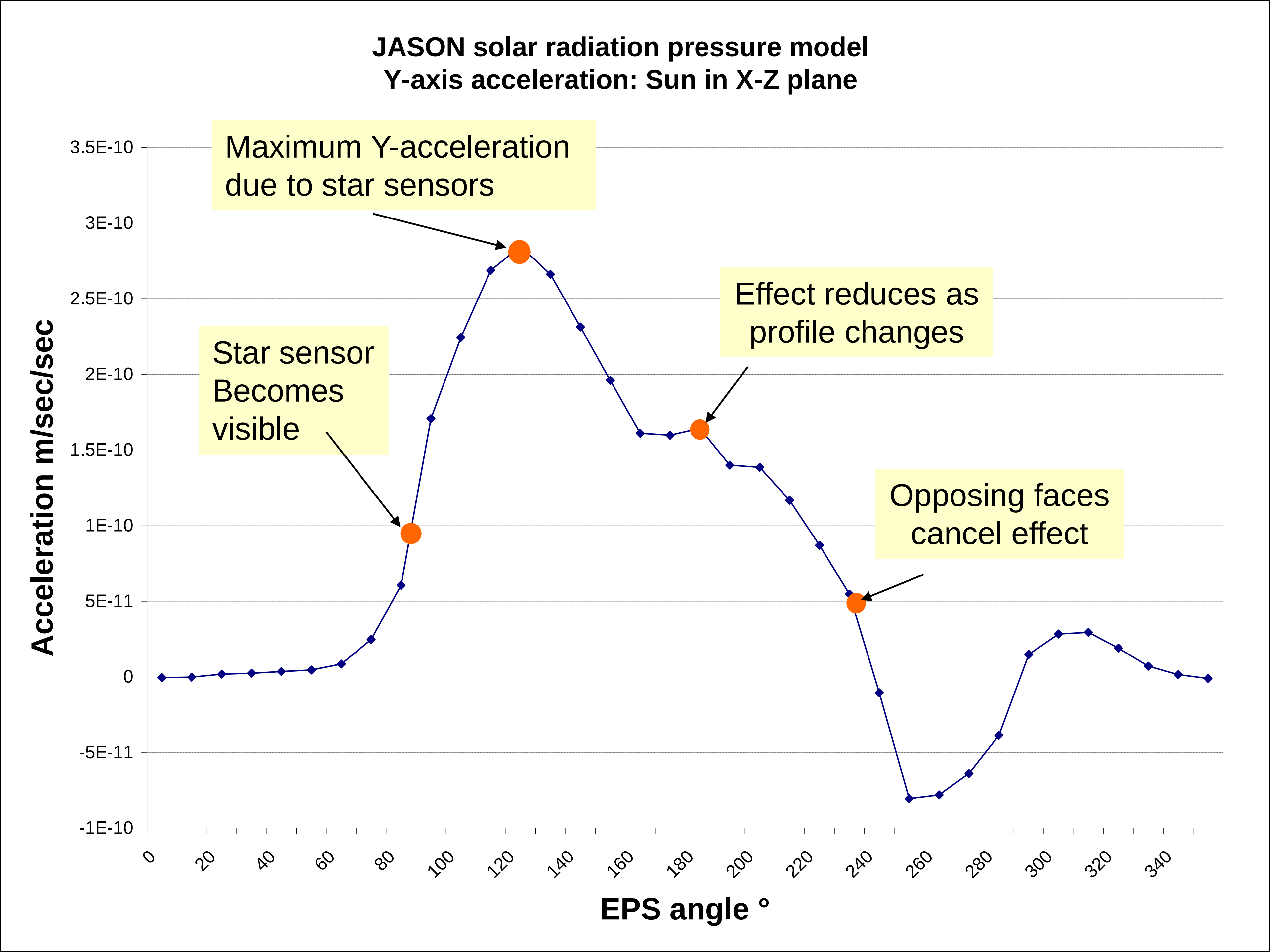
- Extensive tests carried out at JPL
- Dynamic orbit improvements in cross overs, SLR residuals, orbit overlaps and scale factors
- Model subsequently tested by Goddard Space Flight Centre
- Strong improvement in solar scale empirical term
- Model adopted by NASA as operational standard for Jason-1
- Models in development for Jason-2



Solar pressure scale factors over 80 days (JPL, GIPSY)

Note:
- UCL model scale ~ 1.007
- More stable behaviour
- Macro-model bias ~7%




JASON solar radiation pressure model
Y-axis acceleration: Sun in X-Z plane
Maximum Y-acceleration due to star sensors
Star sensor Becomes visible
Effect reduces as profile changes
Opposing faces cancel effect
Acceleration m/sec/sec
EPS angle °
3.5E-10
3E-10
2.5E-10
2E-10
1.5E-10
1E-10
5E-11
0
-5E-11
-1E-10
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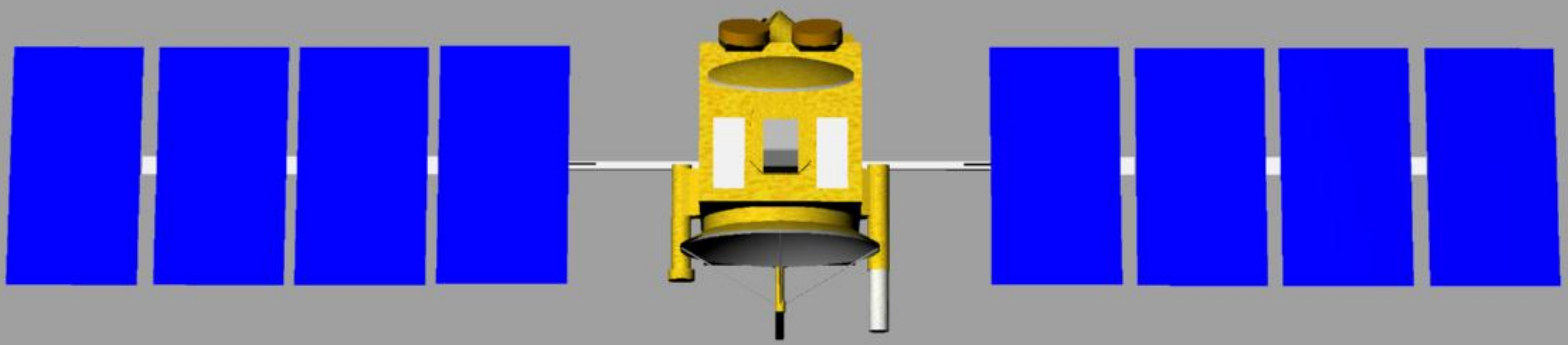
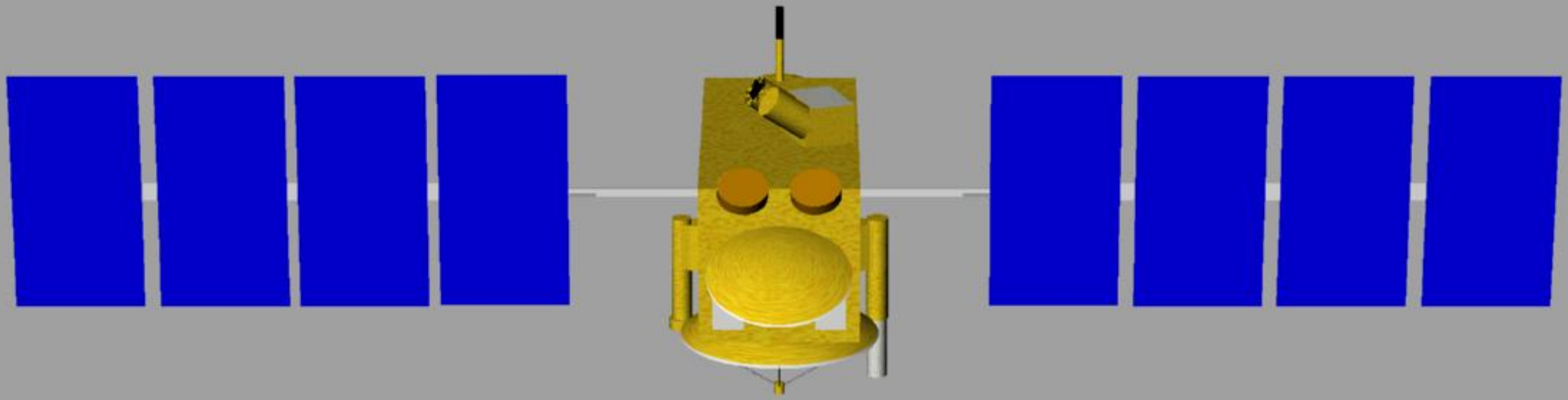
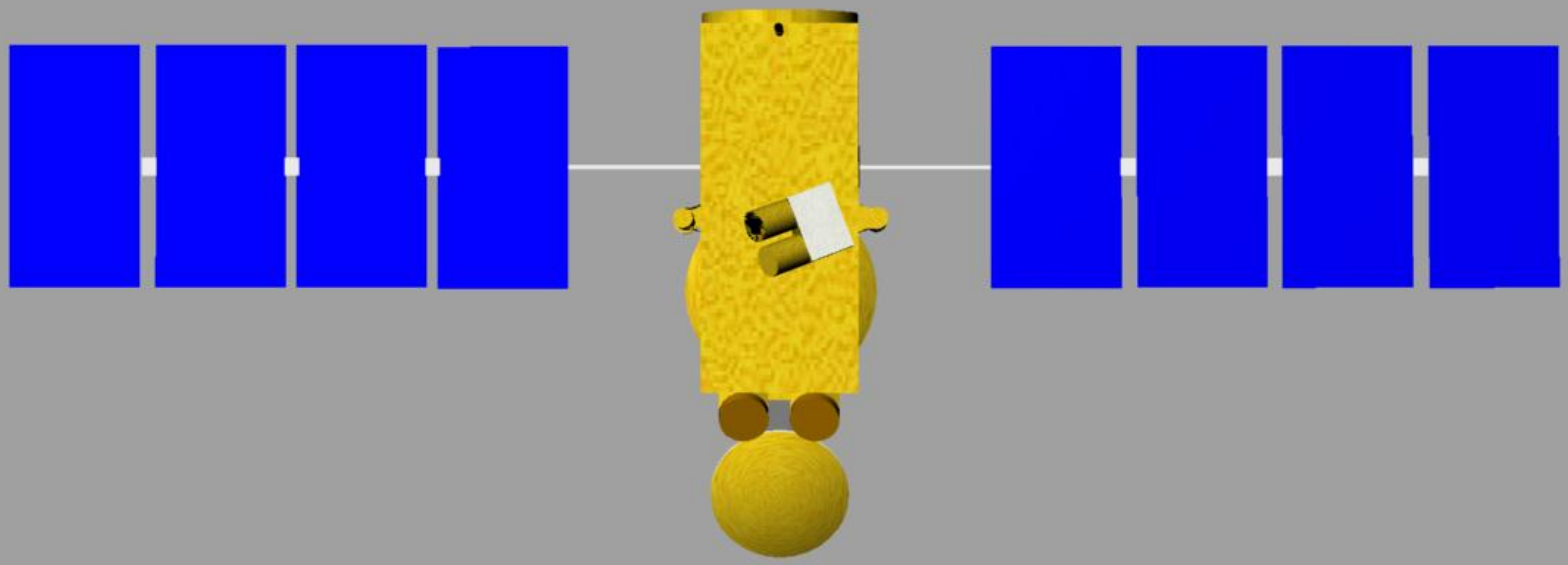
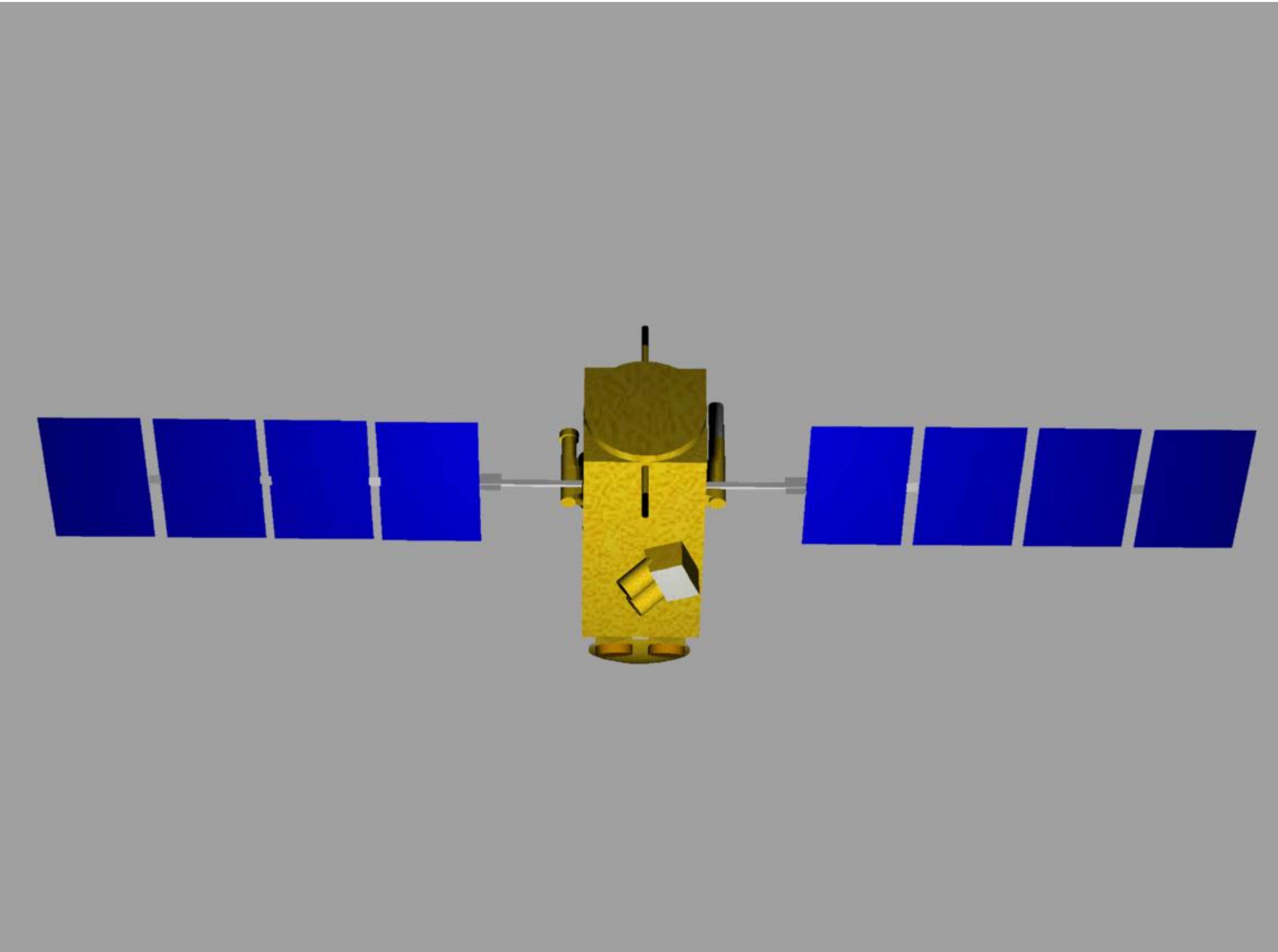
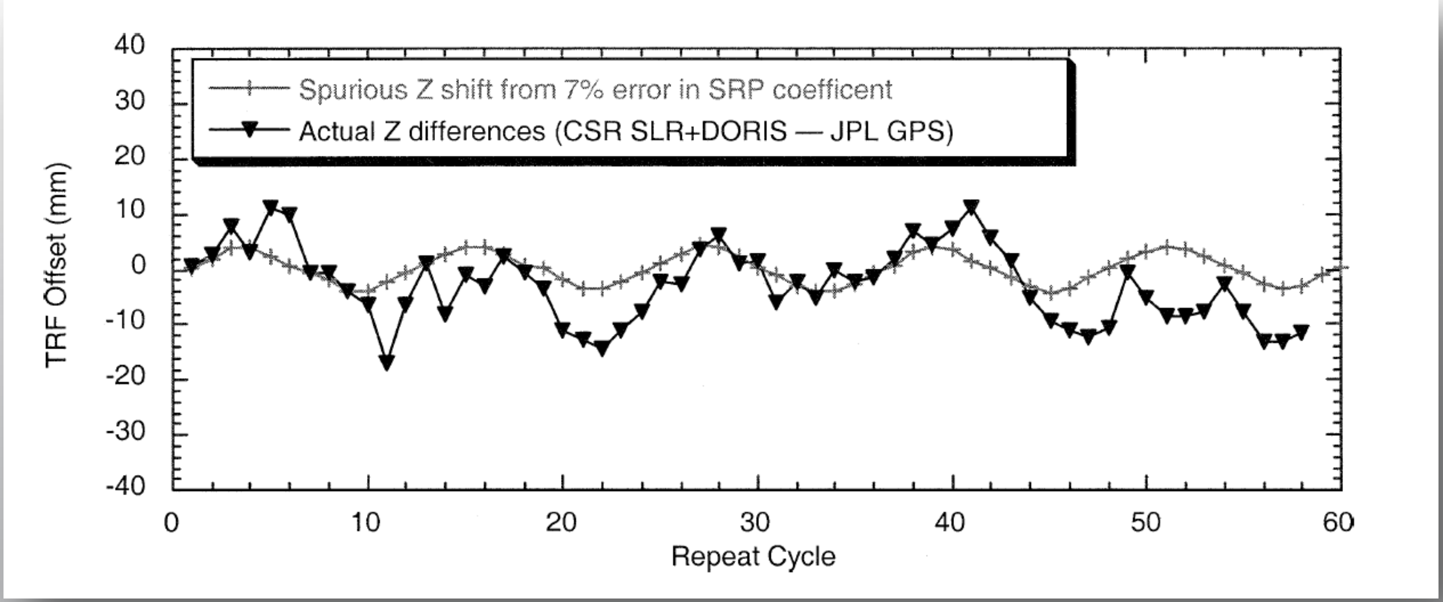








JASON-1 tests using differing solar radiation pressure scale factors (Bruce Haines, JPL)

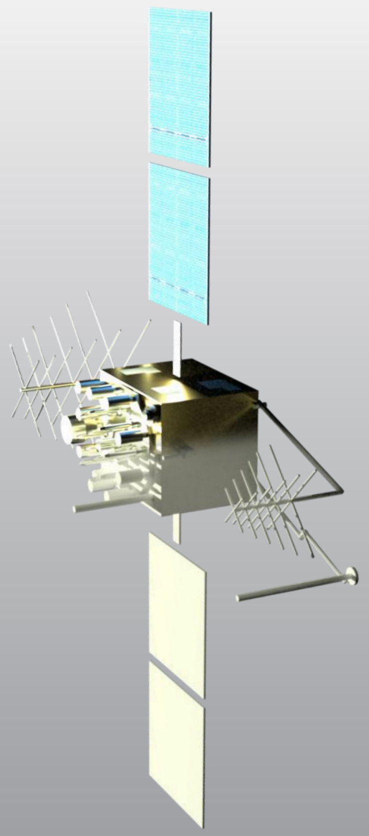


Key points:

1. Estimating radiation pressure scale factor leads to correlation with other parameters – can lead to instability (cf. early CNES experiments)
2. Significant scale errors (~5%) cause spurious Z-axis variations in orbit
3. John Ries (Centre for Space Research, Texas) showed similar effect
4. Box and wing model scale error ~8% => spurious Z-shift
5. UCL Jason-1 scale error <1%

Why use a physical model of the spacecraft?

- We know a lot now about the satellites – why not use it?
- Testing physical models tests our understanding
- Residuals and performance metrics can be interpreted logically and physically
- Use empirical terms to test what we <u>don't yet understand</u>

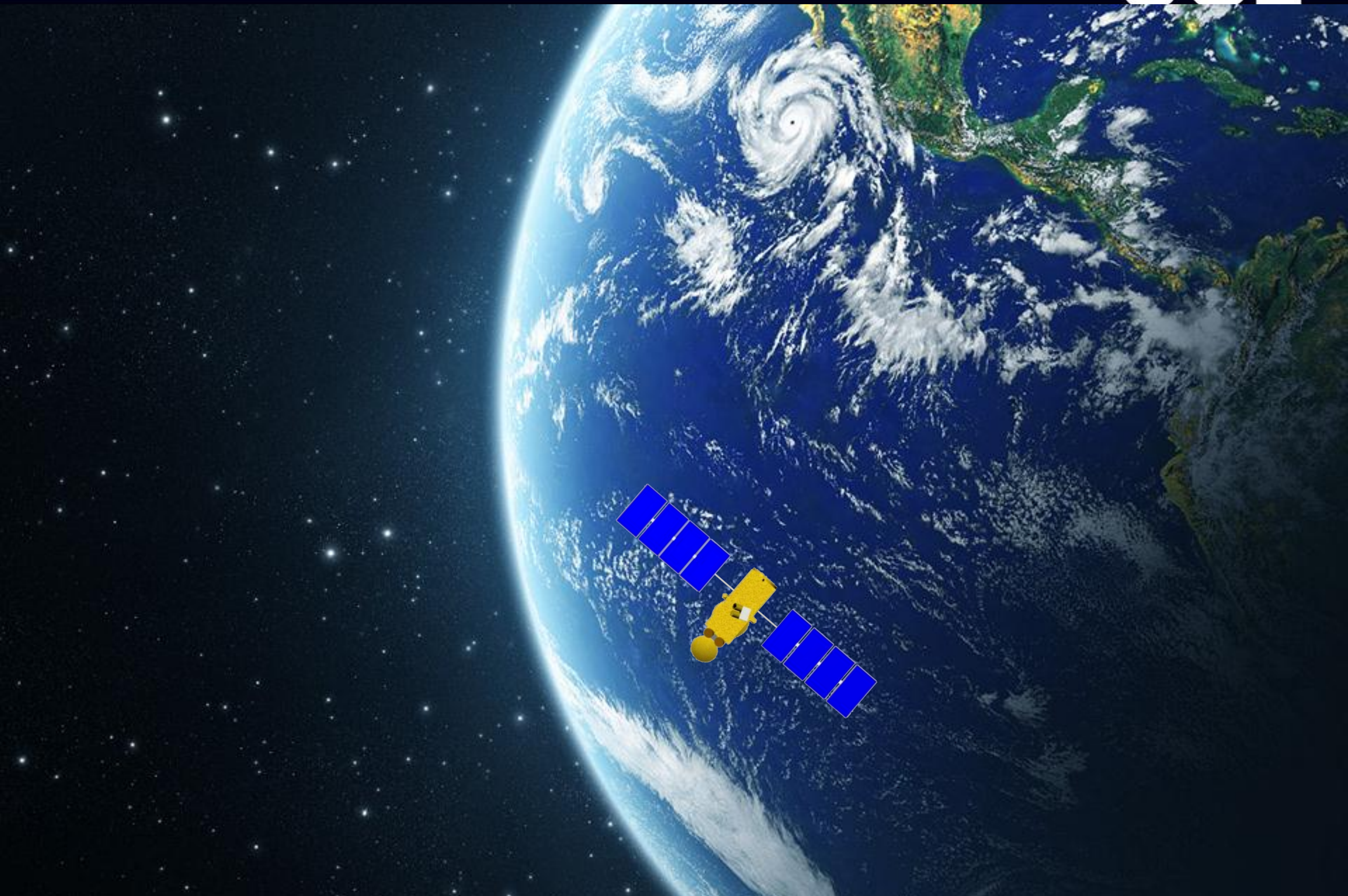


Barriers to progress

- Time (we are all busy)
- Willingness to experiment (approach is well tested – JPL, GSFC, commercial companies)
- Speed of execution (models are designed to execute fast)
- Development of interfaces
- Space vehicle attitude uncertainties
- Additional effects (mass history, aging of materials, change in centre of mass)
- Optimal empirical parameterisation

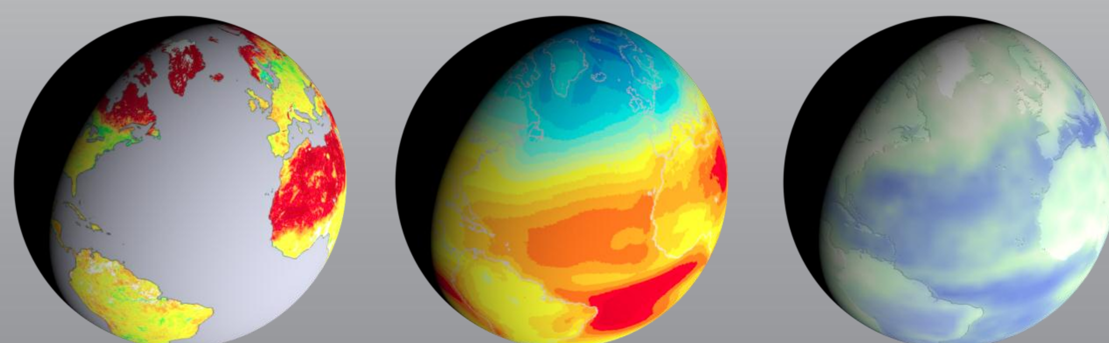
Conclusions

- IGS orbit products are dominated by empirical radiation pressure models
- Empirical models have known correlations with geophysical parameters
- We know much about the real spacecraft
- Detailed photon-pressure modelling techniques are mature and well tested
- Using the best available physical model gives you insight into what you do not yet understand
- This is not an academic exercise: there are practical scientific and engineering advantages in using these physical models



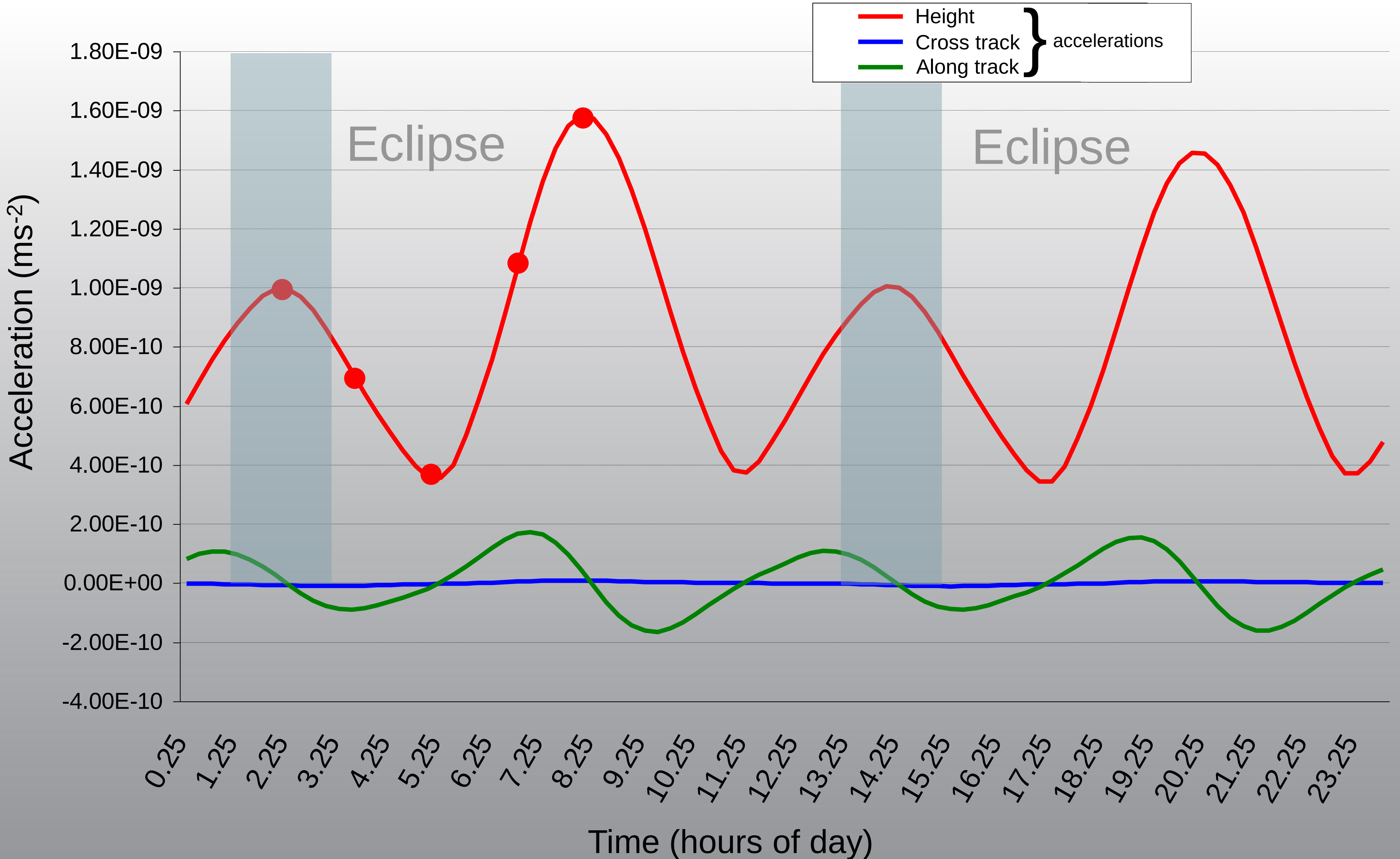
Planetary Radiation Pressure (PRP) models are being developed using space based observations of emission and reflectance.

Forces due to PRP are calculated using the same UCL ray tracing approach.



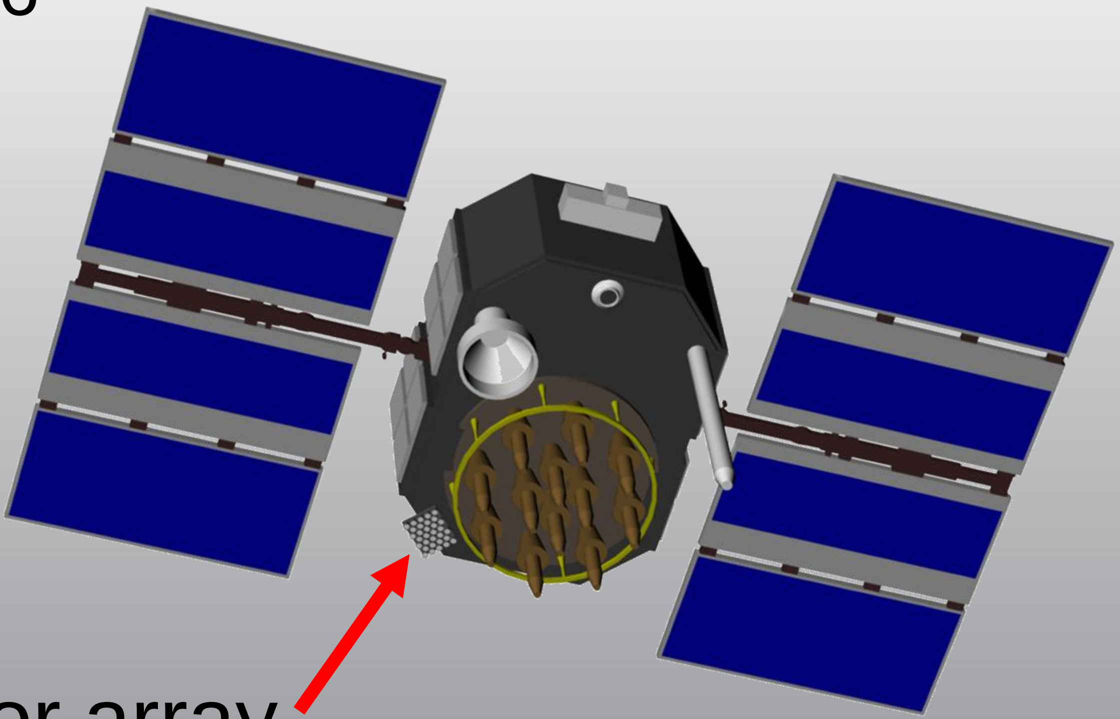
*Earth textures courtesy of NASA Blue Marble: Next Generation. Earth radiation data courtesy of CERES and MODIS.

Modelled Earth Radiation pressure (SVN35, UCL ADM model



GPS satellites carrying retro-reflectors

- 2 Block IIA spacecraft
- PRN05, PRN06



Retro-reflector array

Laser Retro-reflector Array (LRA) offset

- LRA position in s/c body frame required for analysis of laser ranging
- New data suggests LRA offset further from centre of mass than previously understood
- Shim corrections: +11 mm (PRN05), +13 mm (PRN06)