ESA Space Environments and Effects: The Role of Spenvis & Some Perspectives

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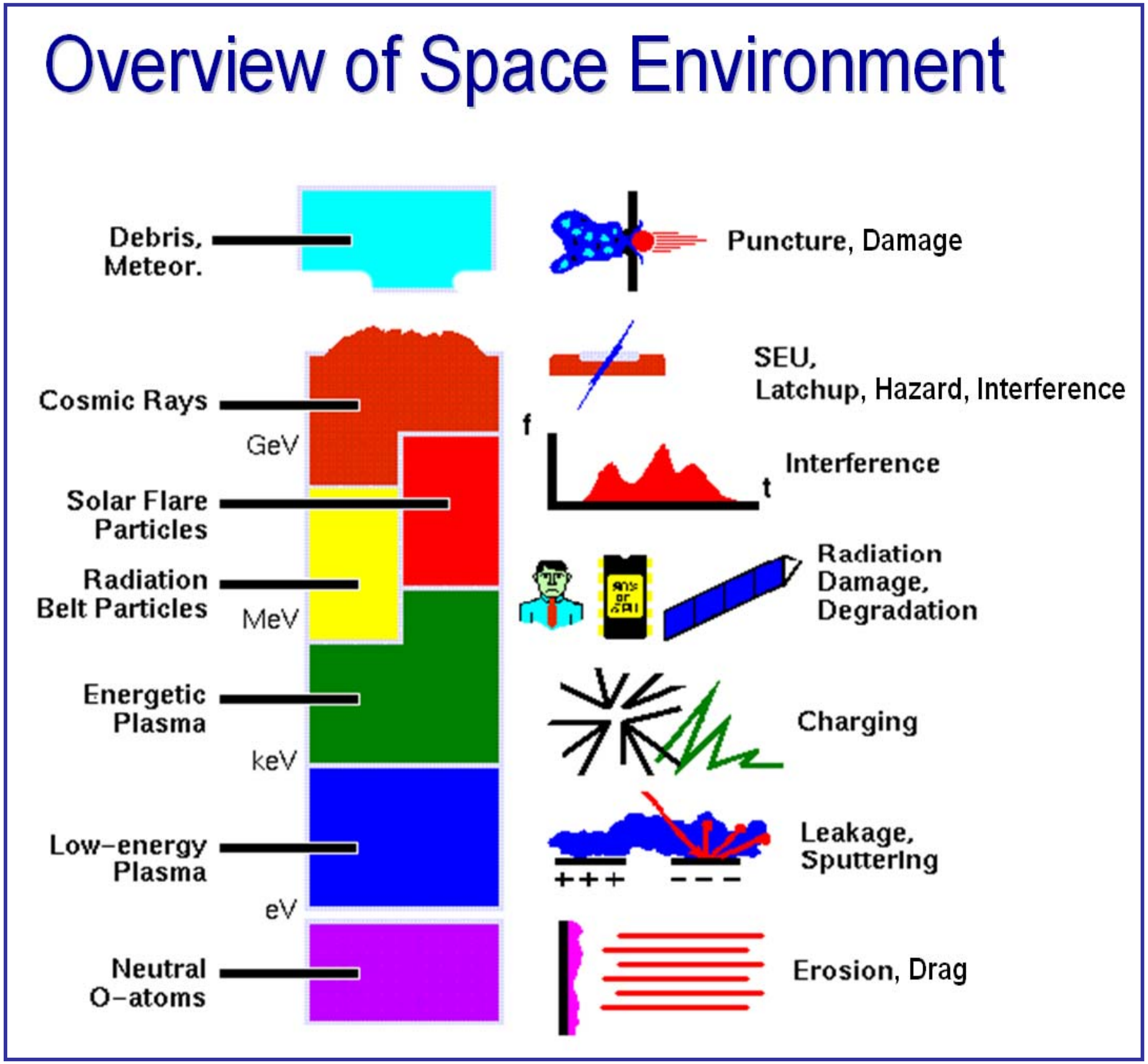
ESA Space Environments and Effects Section

Space Environments & Effects Section
Primary Function is Project Support

- Evaluation of space environments and effects
  - Starts pre-phase A
    - Environment specifications
    - Tailoring of standards
    - Concurrent Design
  - More detailed support in later phases
  - In-orbit behaviour evaluations

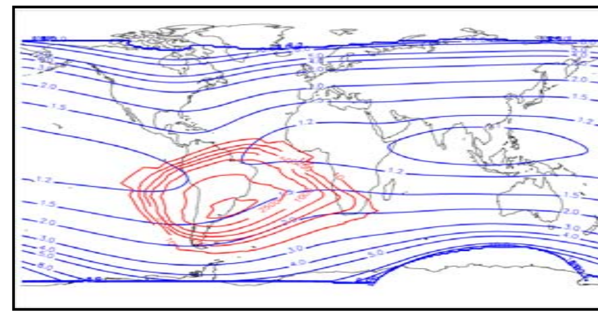
- Supporting activities:
  - R&D
  - Standardisation
  - Collaboration

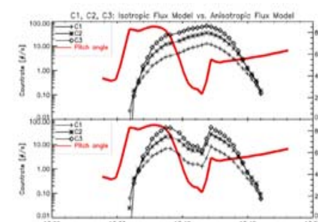


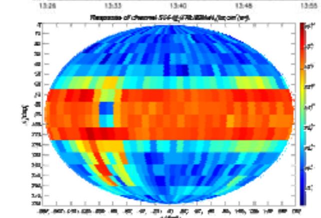
Environment	*Effect*	***Analysis Necessary***
Radiation (cosmic rays, solar energetic particles; radiation belts; secondary radiation)	Degradation, damage, SEU, background, electrostatic charging, health hazards	Environment predictions; SEU/dose computation; Interactions and background analysis; "Transport" simulations
Plasmas (hot at high alt., cold at low alt.)	Electrostatic charging, Instrument interference, Current collection, Contamination	Electrostatic charging simulation; spacecraft-plasma interaction simulation & analysis
Atmospheres and neutrals	Erosion (Atomic Oxygen); Drag; Planetary weather effects; Contamination; Glow	Titan, Mars, etc. planetary atmosphere Models; expected atmospheric conditions, operations in the atmosphere
"Microparticles" (micro-meteoroids and small-sized debris)	Damage: catastrophic; degrading, pinholes, etc.	Damage risk analysis; Probability of penetration

- Affected ESA missions
  - Science; Earth Observation; Navigation; Communications; Human Spaceflight; Launchers;

- Technology/Engineering work for mitigation
  - Day-to-day project support
    - environment definition (starts early);
    - effects “prediction” (interactions);
    - data analysis (from instruments);
    - post launch support (effects, etc.)
  - R&D programmes (develop engineering methods, models, instruments)
  - Space Weather element of ESA Space Situational Awareness preparatory programme

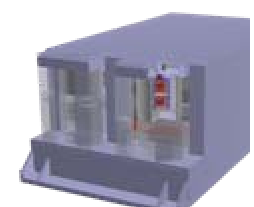






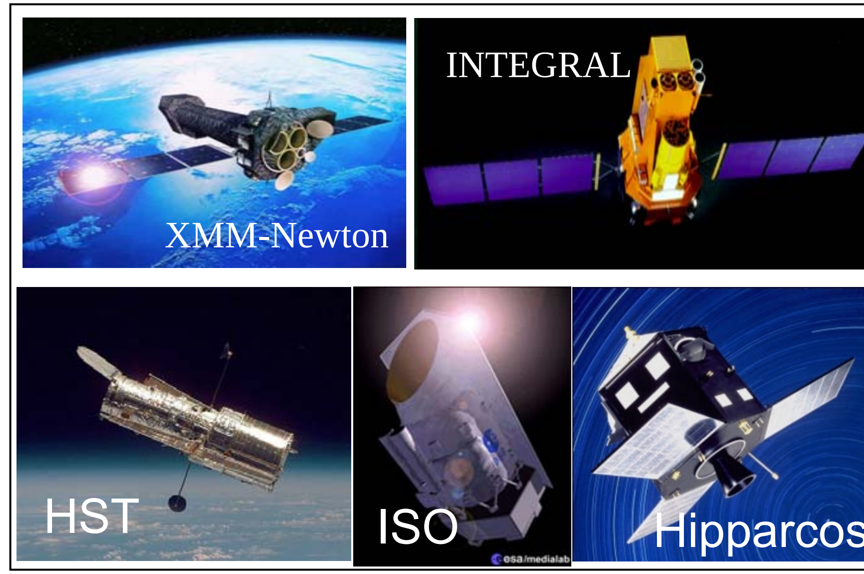
- Standardisation
  - ECSS, ISO

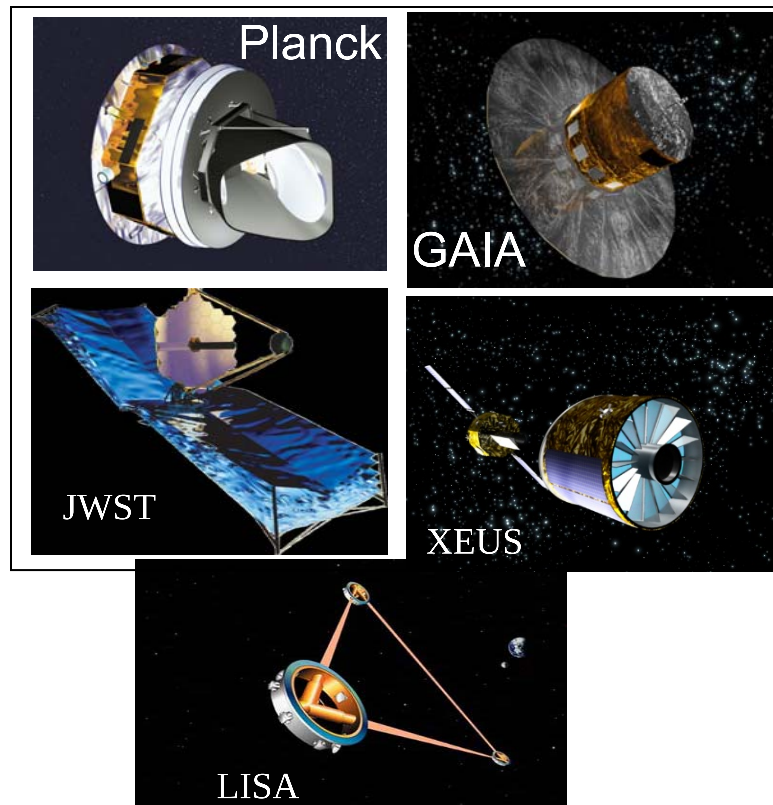
- Broader collaborations
  - SEENoTC, SWWT, SPINE, Geant4,…



Astrophysics Missions

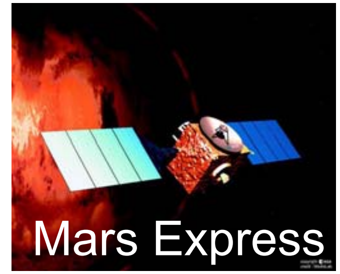
- γ , X, UV, IR, sub-mm missions, past & future →
- Each special measurement technique responds to the radiation environment in a different way
- Problems include
  - "background"
  - detector damage
- **past** missions: often in orbits passing through the **radiation belts**
- next generation of major missions take place at **L2**:
  - JWST (IR), Herschel (Far-IR), Planck (sub-mm), GAIA (visible) and XEUS (X-ray)
- radiation exposure minimization
  major mission design driver
- "**fundamental physics**" missions to detect gravitational waves & test relativity are planned.:
  - Sensitive measurement systems susceptible to radiation induced interferences.
  - E.g LISA mission to detect gravitational radiation: triangular formation of spacecraft separated by **$5x10^6$ km**
    - sensing elements free of disturbances to a level of **1.8 nm $Hz^{-1/2}$**.

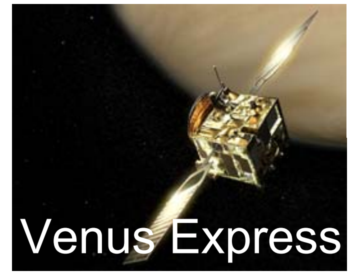


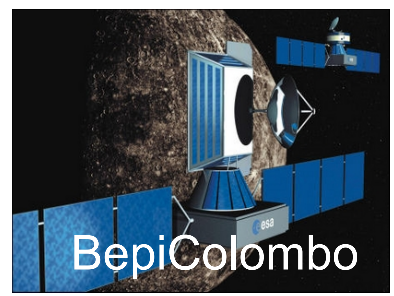


Solar System Science & Exploration Missions

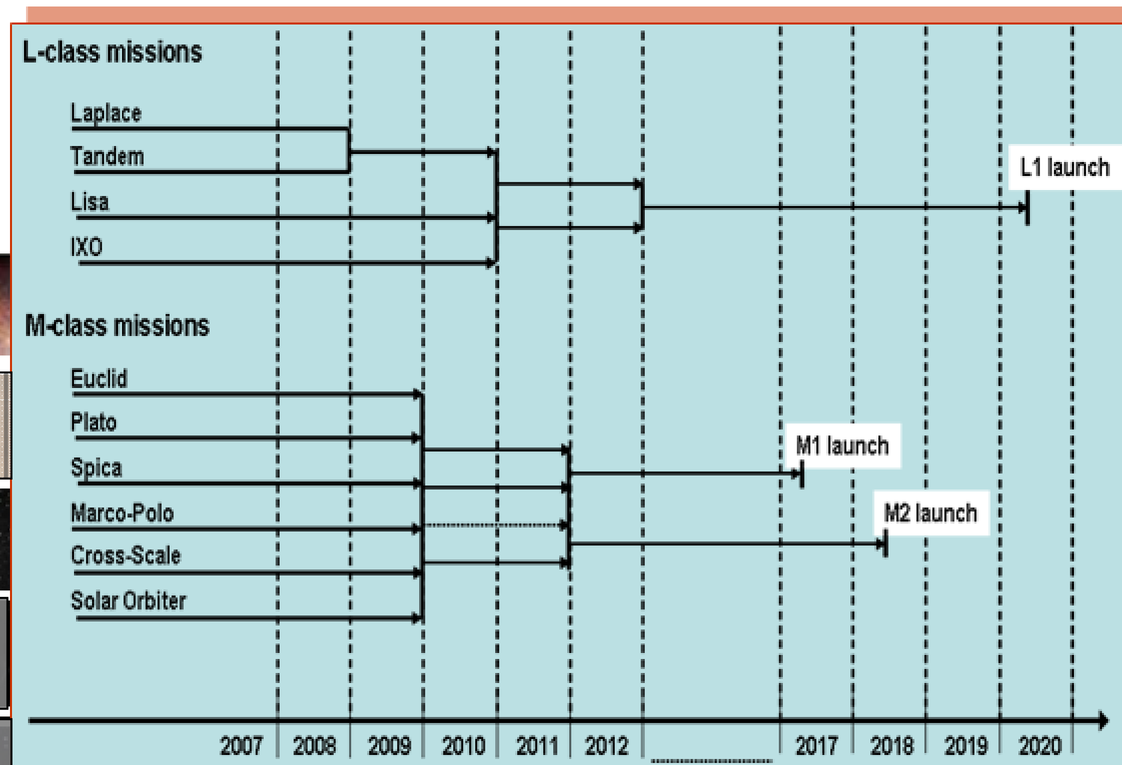
- Exomars 2016 & 2018
  & Next mars mission ~2020
- Missions to other planets need to take account of local environments
  - **Jupiter:** severe radiation & plasma env;
  - Venus, Mars: no magnetosphere;
  - Mercury: weak magnetosphere;
- But:
  - ✓ concern that **solar particle events could be significantly stronger at Mercury** (~0.3AU from Sun) than at Earth;
  - ✓ operations on **surfaces of planets** (Mars, Moon) need to take account of the modifying effects of the atmosphere and surface material on the primary radiation.
- Plasma interactions:
  - Interference with instruments
  - Electric propulsion
- Atmospheric Interactions:
  - Mars entry descent & landing, aerobraking







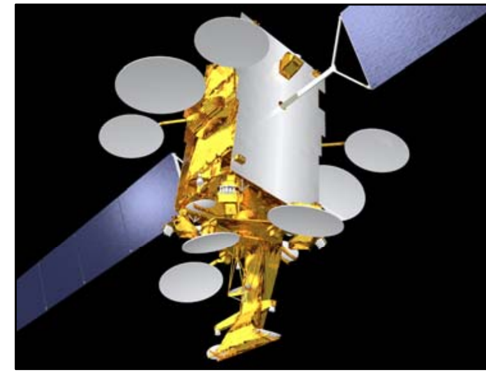
Selecting the next science missions



All future science missions have difficult environment issues to solve

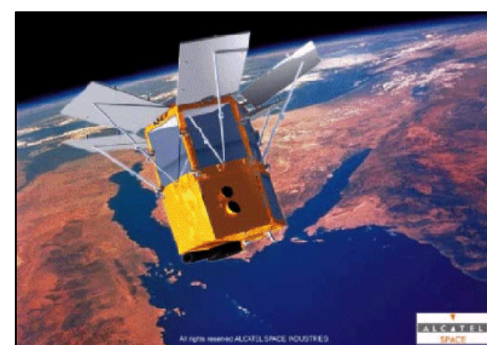
Commercial, Applications & Earth Observation Missions

- **Telecommunications** spacecraft in GEO:
  - environment dominated by energetic e^- of the outer radiation belt;
  - High lifetime dose
  - Spacecraft charging



- Low altitude constellations (e.g. **Globalstar** at 1400km)
  - Mixed environment; High lifetime dose

- **Earth observation** and Earth science:
  - “sun-synchronous” polar orbit ~600-900 km; Mixed environment
  - Many ESA Earth Science and “Sentinel” projects
  - Atmospheric interactions (ATOX,…)



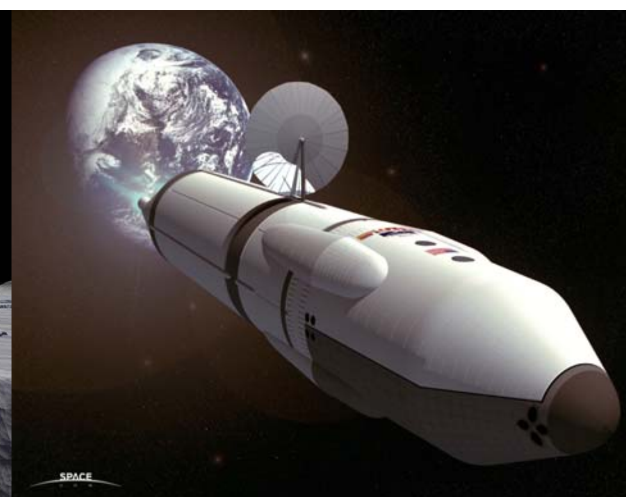
- **Navigation** systems
  - medium altitude, highly inclined, circular orbits.
  - Galileo at ~25000km and ~55º incl. → heart of the radiation belts.
  - Spacecraft charging

Trends have major implications

- ↑ complexity of on-board systems;
- ↑ spacecraft size in GEO;
- ↑ power in GEO → large lightweight solar arrays,
- ↓ procurement costs;
- minimization of operations;
- ↑ on-board processing;
- long-term reliability;
- extensive use of commercial off-the-shelf components (COTS):
  - ↓ radiation hard or poorly characterized
  - ↑ on-chip complexity.

Manned Missions

- Manned missions have their own special radiation issues.
- Radiation exposure on long duration missions is one of the main mission design drivers
  - *design of habitats should minimize doses from Cosmic Rays*
  - *special measures to warn and protect from solar particle events will also be necessary*
- Electronic and other systems supporting manned missions also have to have high reliability & radiation hardness.

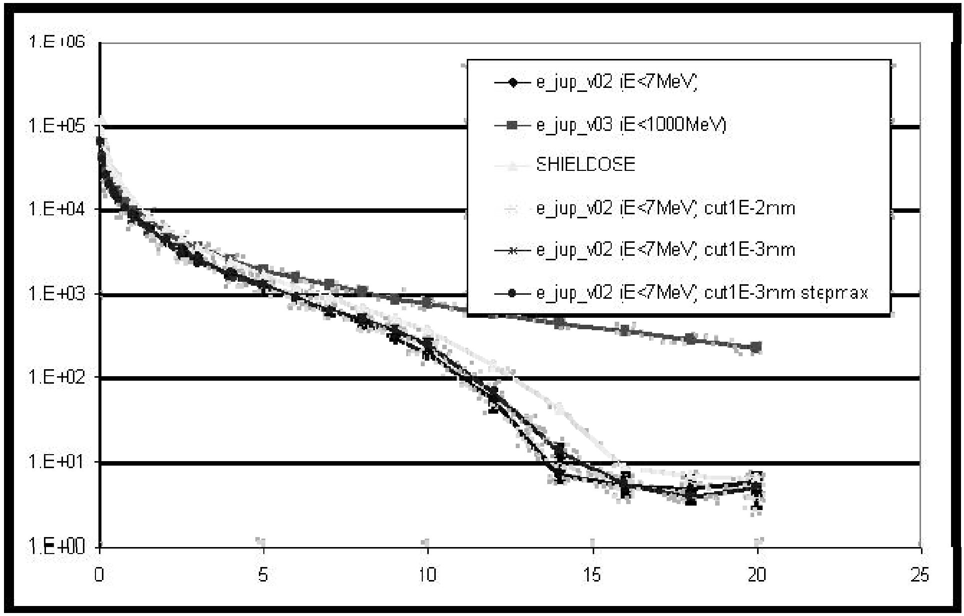


(some) Environment Issues

Dose and non-ionizing damage

- Ionizing dose is the traditional concern for spacecraft electronics
  - Continuing effort to improve accuracy and speed of analysis
  - Reduce margins and “over-design”
  - Validation of sectoring approach
  - Cope with special high dose conditions (Galileo, Jupiter)

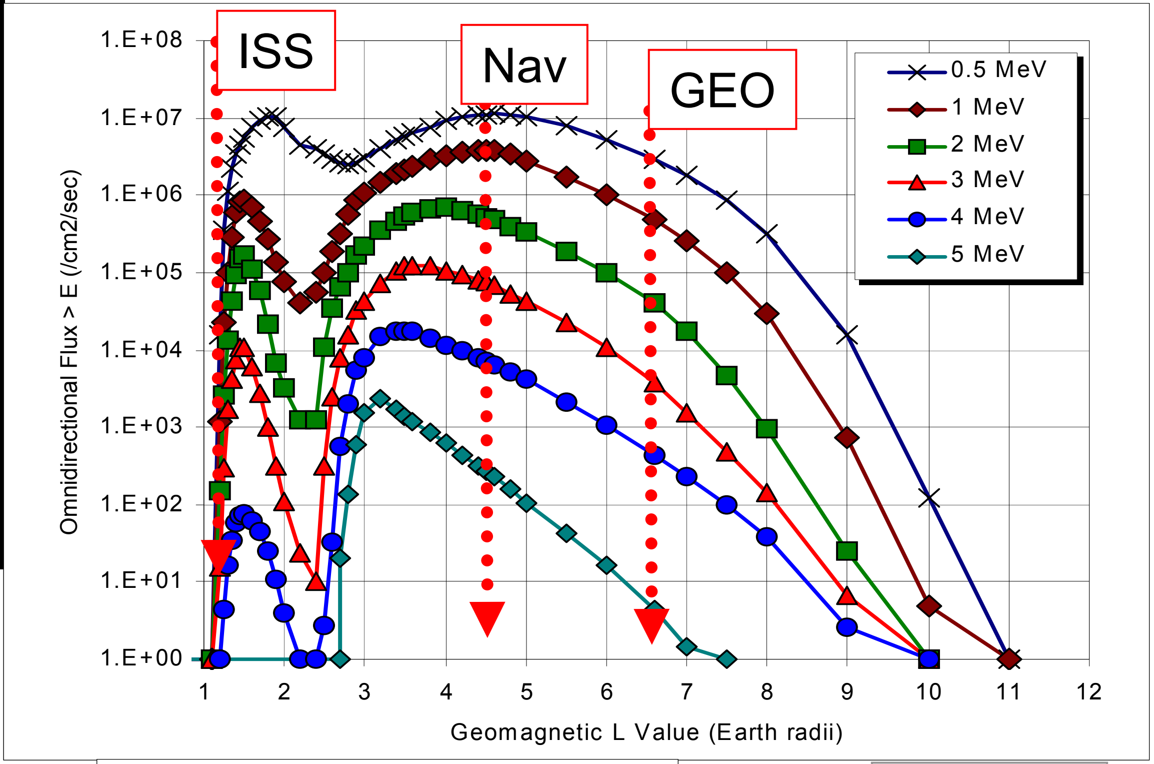
- Non-ionizing dose effects important for some components (e.g. sensors)
  – issue in proton belts and during SPEs



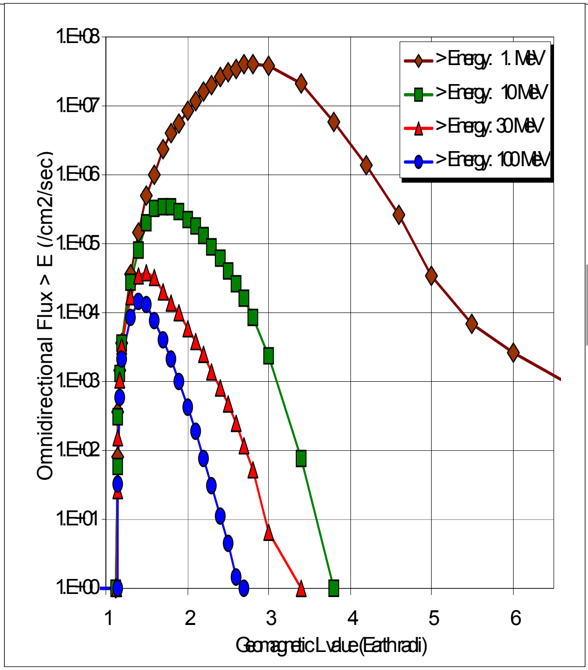
ESA JURA CDF study (2008)

- Models need improvements and effort has focused on the priorities
  - MEO
  - Jupiter
  - Dynamics of environment (extremes, statistics)
  - Modelling of shielding

Models of Radiation Belts provide Engineers with Quantitative Data



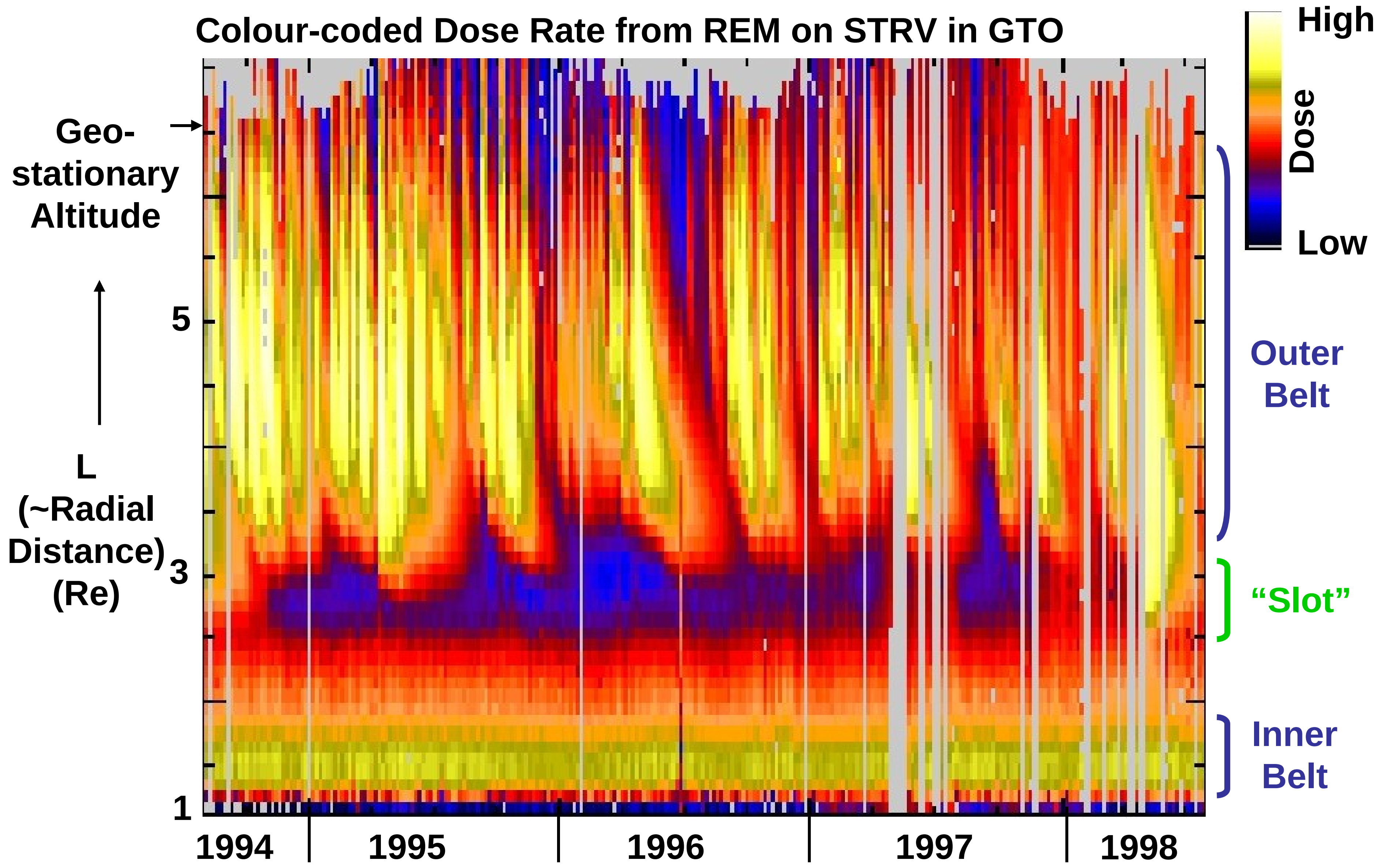
electrons



protons

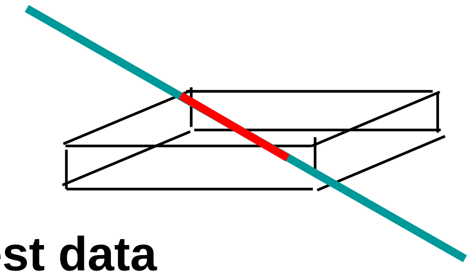
- Based on data from 1960's-1970's
- Work on-going to update them
- Long-term averages; but the outer belt is very stormy

A Radiation Monitor Crossing the Belts for ~5 Years



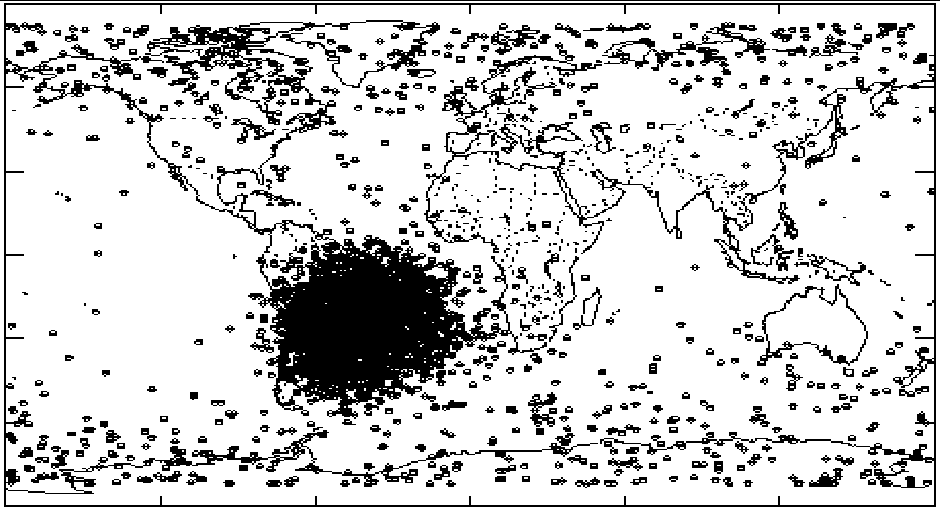
Single Event Effects

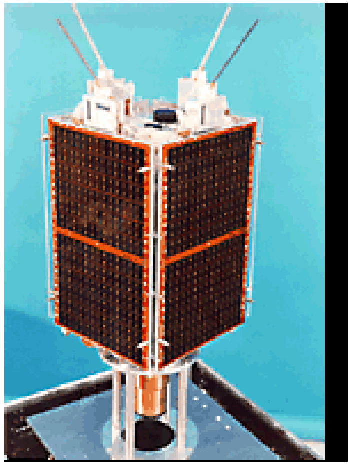
- The CREME codes for SEE rate prediction were developed to model both the environment (proton, ion) and interactions
- The cosmic ray environment is quite well known and modelled.
- For **solar particle events** CREME-96 uses worst case conditions
  - **not necessarily worst;** can be exceeded; is no information on the probability of such conditions; one might not want the worst case…
- CREME uses a simple procedure.
  - Sensitive volume is assumed a **rectangular parallelepiped**
  - Device characterized by unique **critical charge**
  - **Testing** is used to derive the "critical charge" and the parallelepiped dimensions.



- For both proton and heavy ion predictions, **good quality test data** are required and test techniques may break down if device is not close to "ideal"
- **The assumptions underlying CREME are progressively more questionable (shape, LET).**
- **New methods in development**
- **Drawbacks**: analysis timescales and complexity increase, need geometry of sensitive nodes

SEUs on UoSAT-3 microsatellite memory

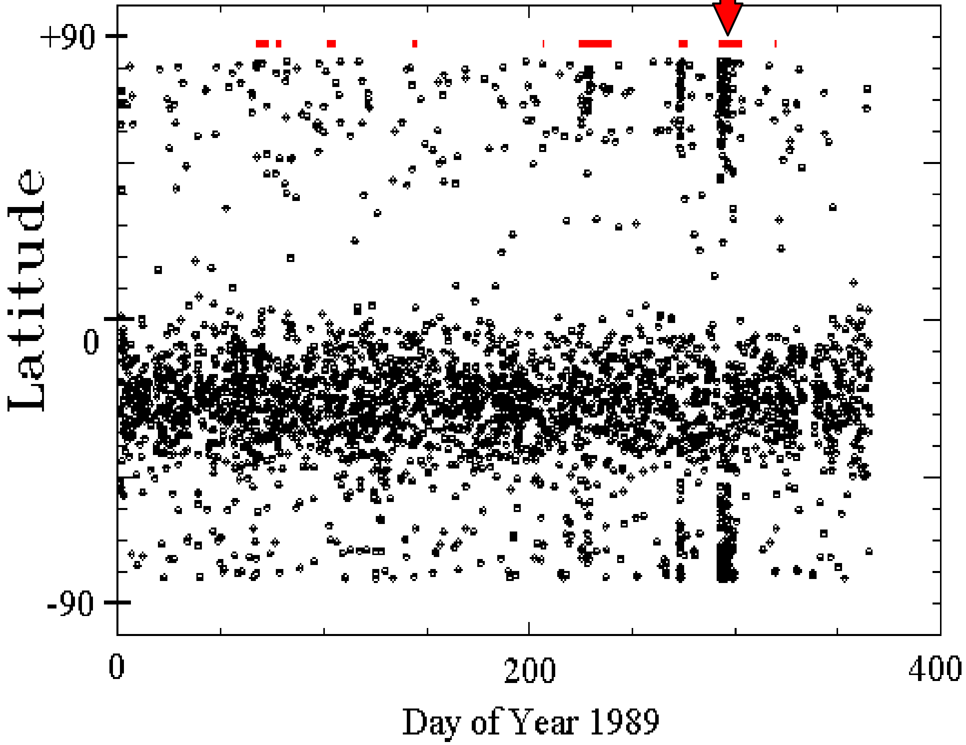




Oct '89

Mapped

Time behaviour



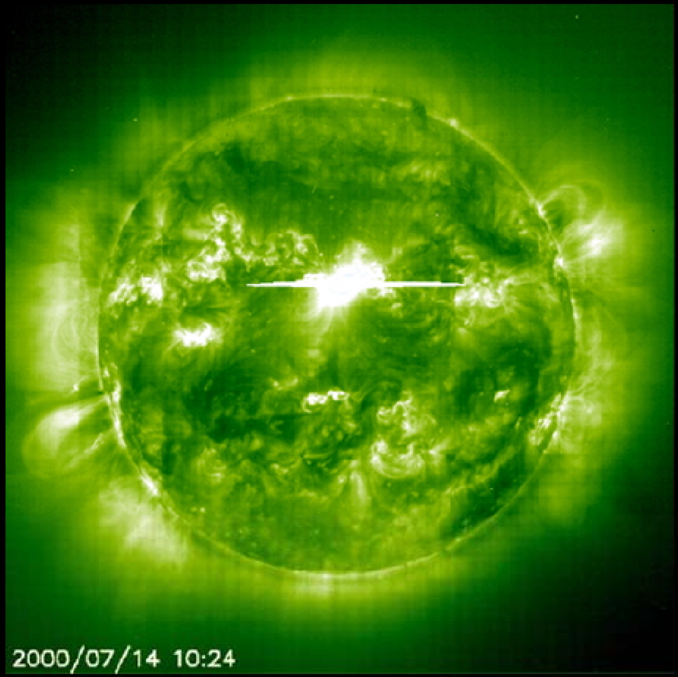
SEUs are from:

- Cosmic rays and solar ions at high latitude
- Radiation belt proton nuclear reactions in south Atlantic

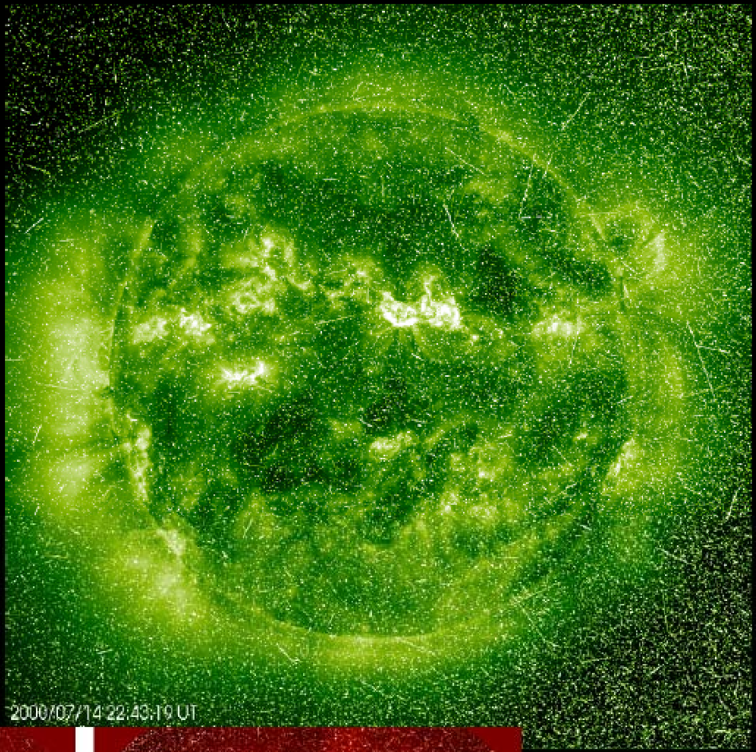
Radiation Background

- Specific to a particular measurement system.
- From
  simple single-event type processes:
  direct ionization in a detector induces a signal in addition to the signal from the target
- To
  highly complex interactions…
- Often radiation background can be "rejected" by taking advantage of the sizes of the signals induced, or some other feature.

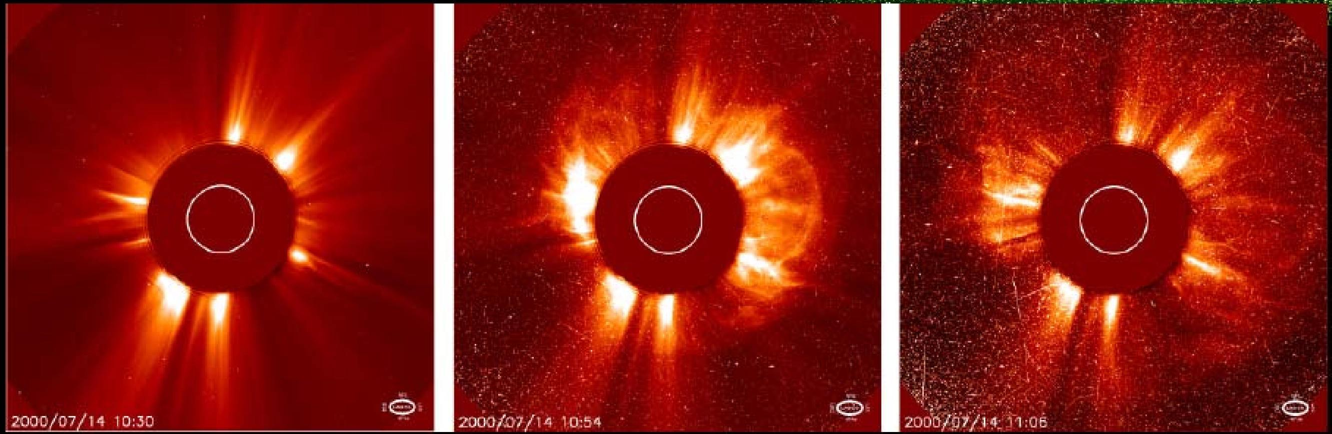
A strong solar flare triggers the largest particle storm of this solar cycle near solar maximum



A powerful flare flashes . . .



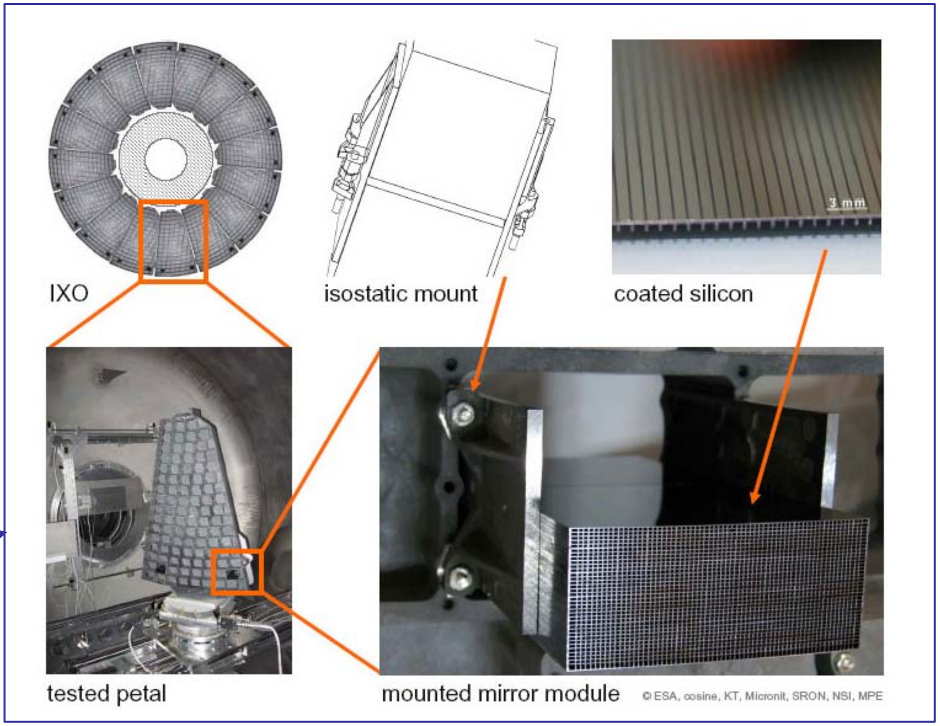
and hours (even days) later high-energy protons were still smacking SOHO

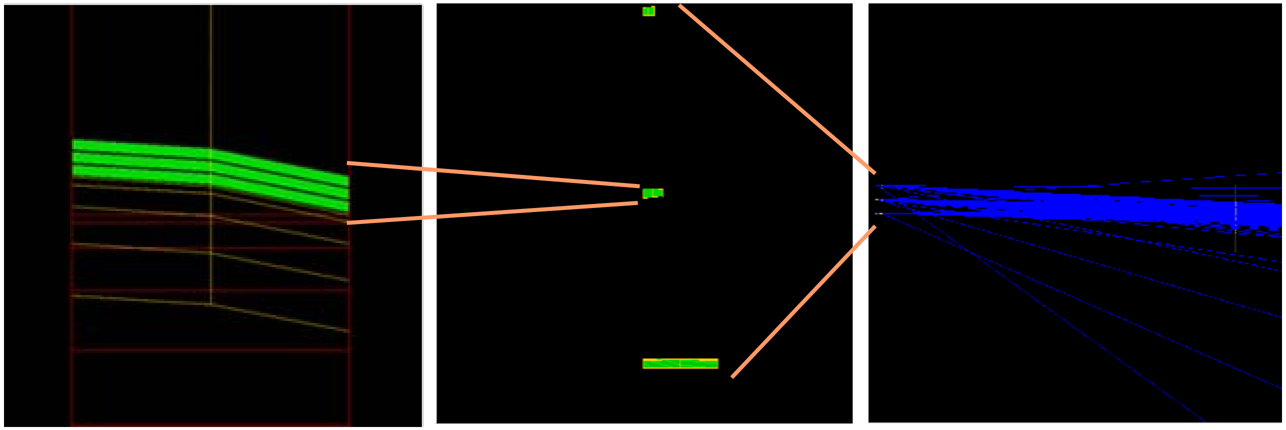


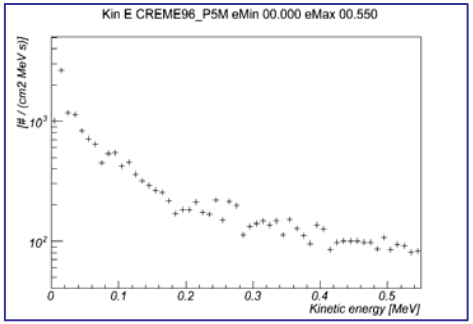
Protons unleashed by the flare begin striking SOHO in minutes

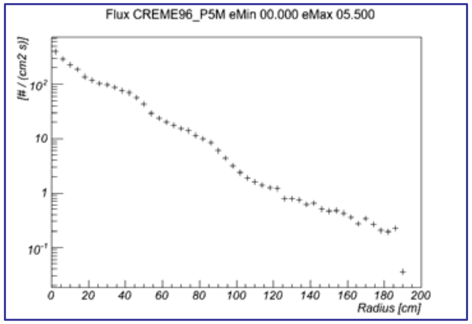
IXO
Environment Analysis

- Support to mission design process
- Learning lessons from XMM and (NASA's) Chandra (proton scattering through X ray optics seriously damaged CCDs)
- New technology optics (Silicon Pore Optics)
- Also looking at puncture of telescope "tube" by micrometeoroids → stray light









Images courtesy Giovanni Santin (RHEA/ESA)

“Internal” electrostatic charging

MeV electrons penetrate material and build up an electrostatic charge

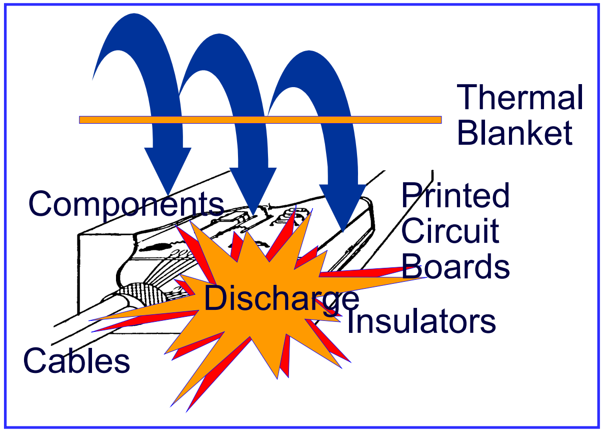
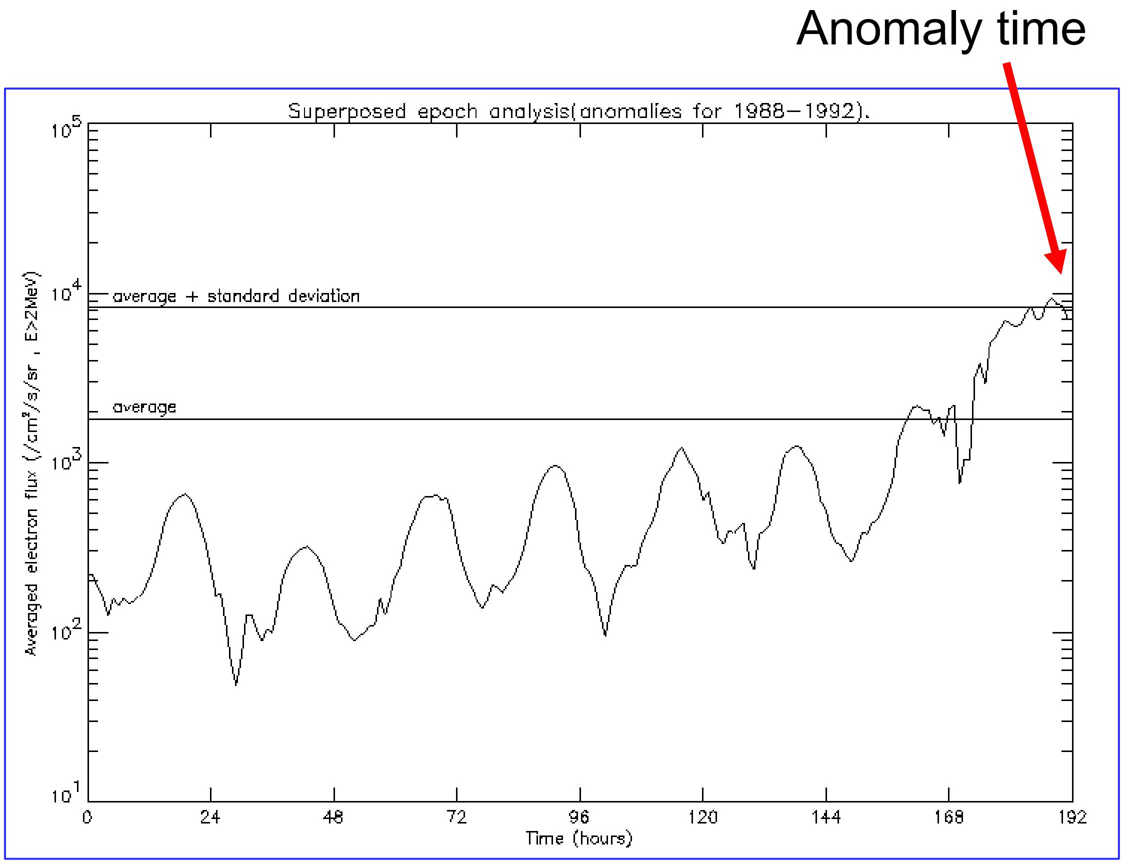
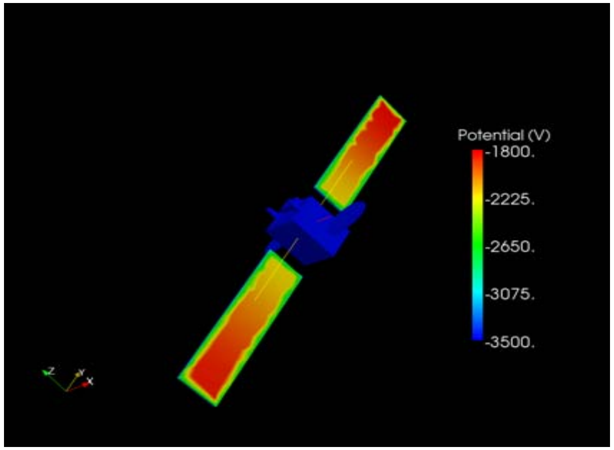


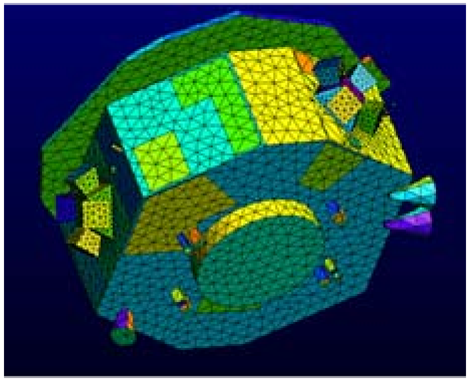
Figure courtesy of QinetiQ

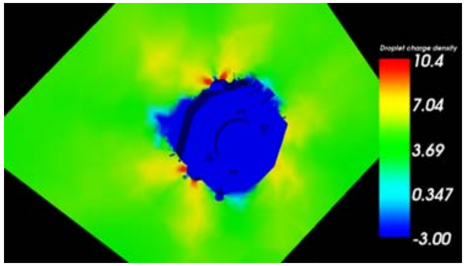


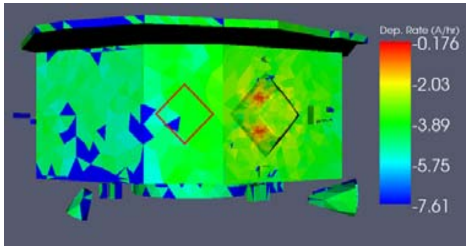
- Meteosat 1,2,3 (1988-1992) had many (~200) disturbances
- On average, environment was seen to get severe before an anomaly
- Discharges around the radiometer mirror

“Low-Energy” Spacecraft-Plasma Interaction Simulations:



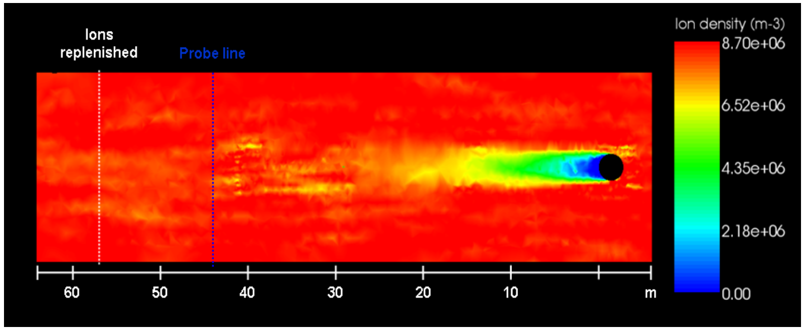






<u>Examples</u>

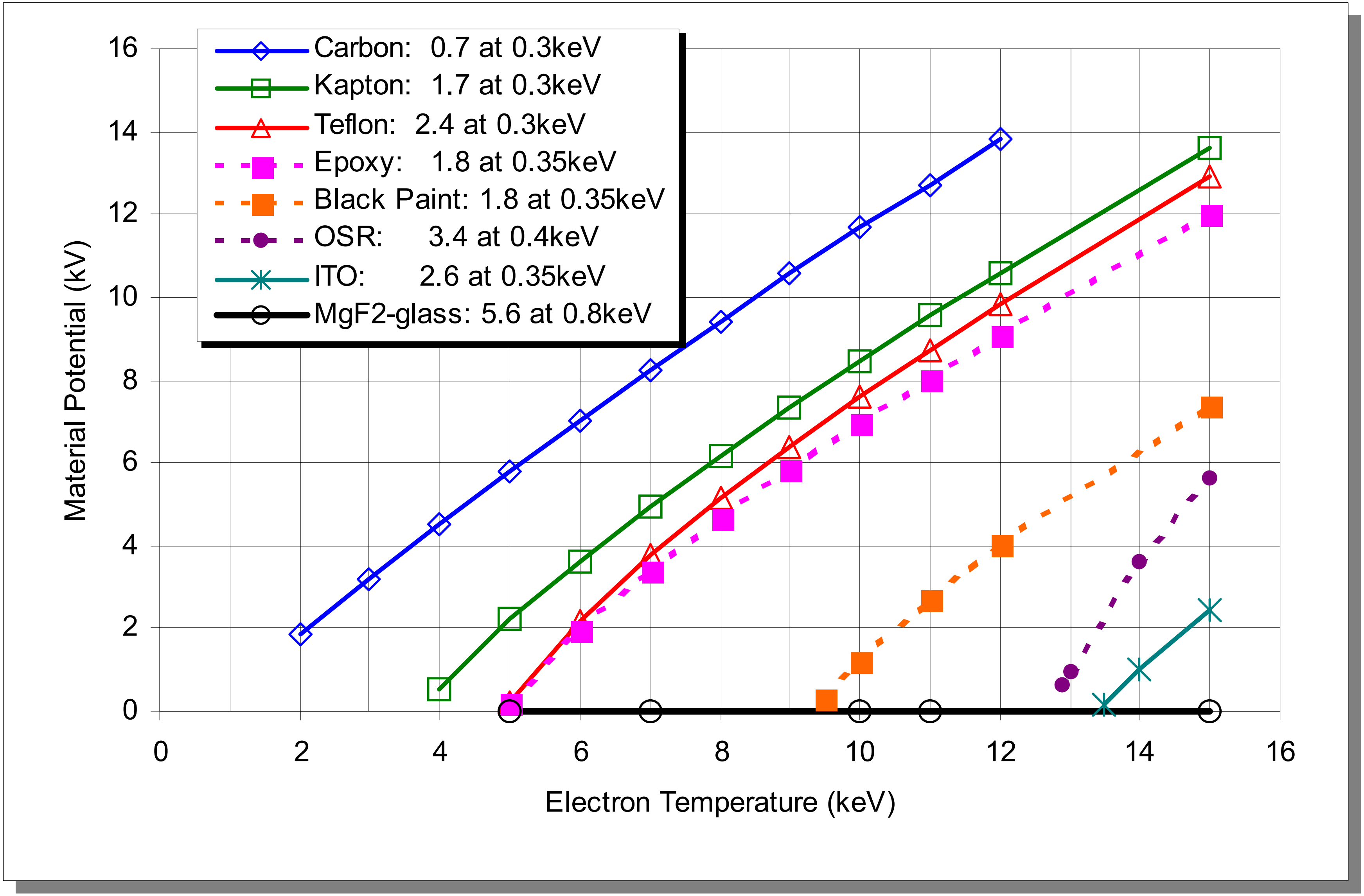
- Telecommunications satellite electrostatic charging in GEO
- LISA Pathfinder Contamination
  - electric thrusters produce neutral & charged contaminants;
  - Charge exchange occurs → neutrals become charged & re-attracted



- Plasma wakes in the solar wind

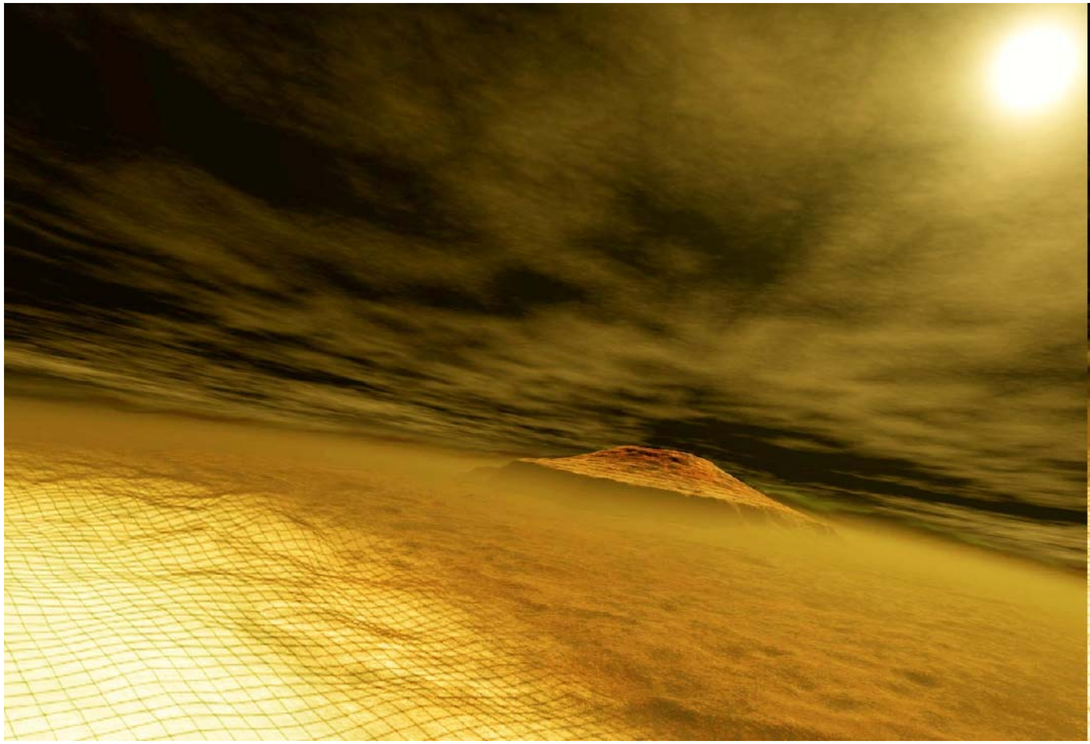
Images courtesy Simon Clucas (RHEA/ESA)

Sensitivity of Charging Potential to Material

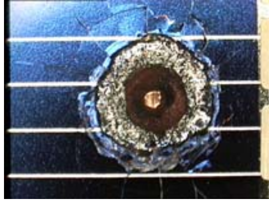


Atmospheres

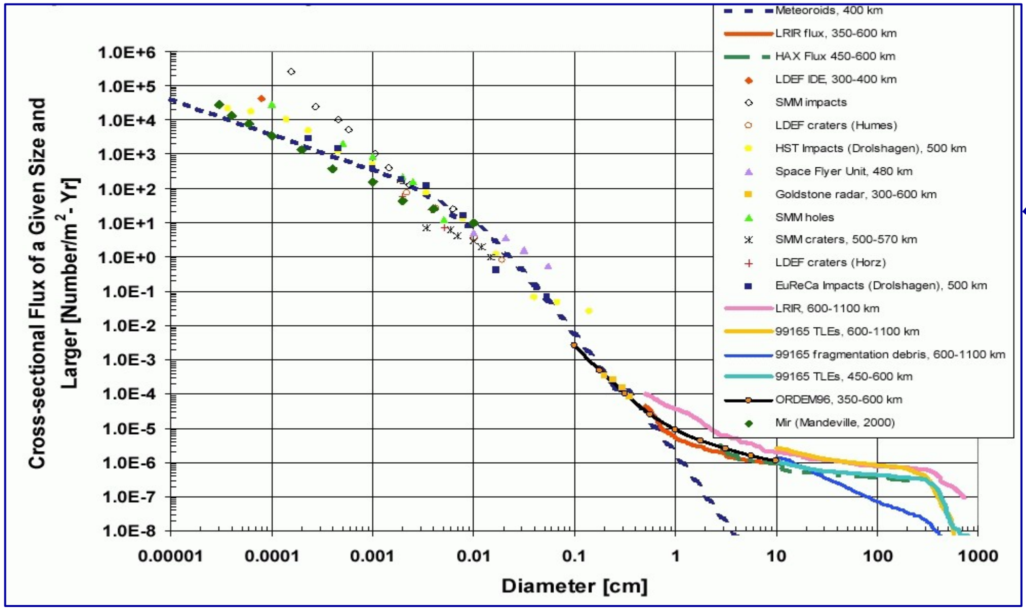
- European Mars Climate Database
  - Key resource for mission design
  - Based on in-situ data and climate modelling with a global circulation model
- Earth's thermosphere
  - Tools for atomic oxygen impact and erosion



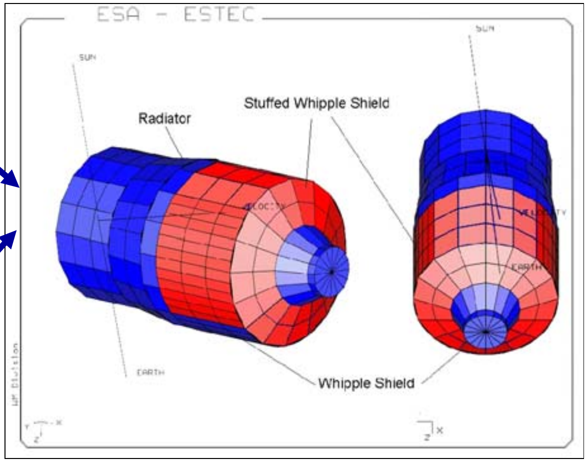
Analysis of Meteoroids & Debris Risks



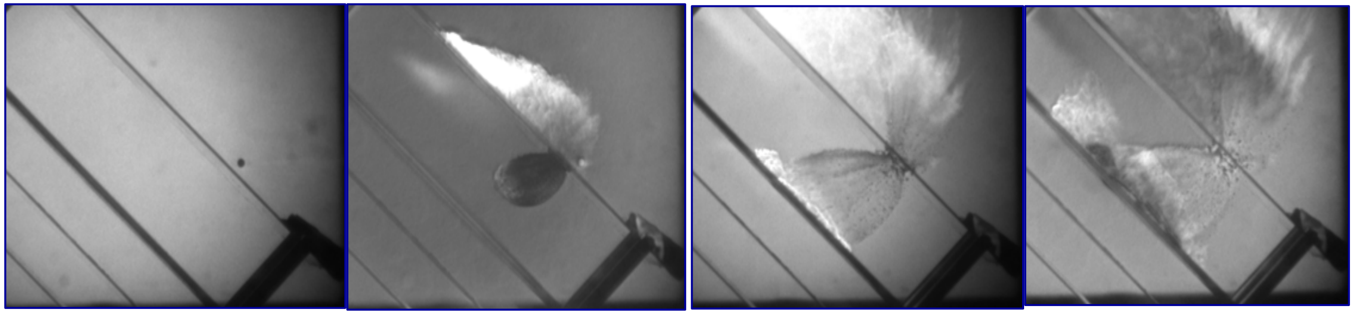
Population models



"Risk of damage" assessment (e.g. ATV)

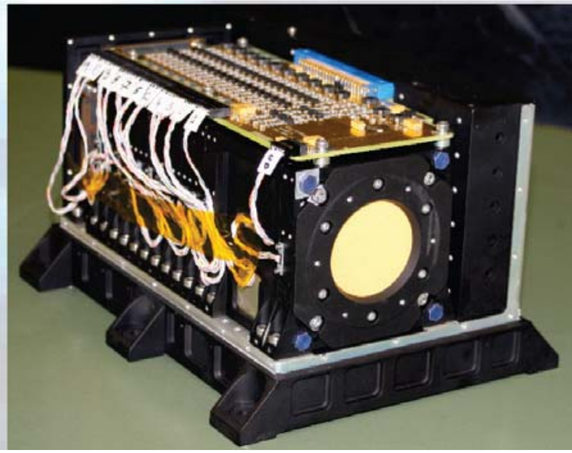


Damage characteristics (test, simulation)



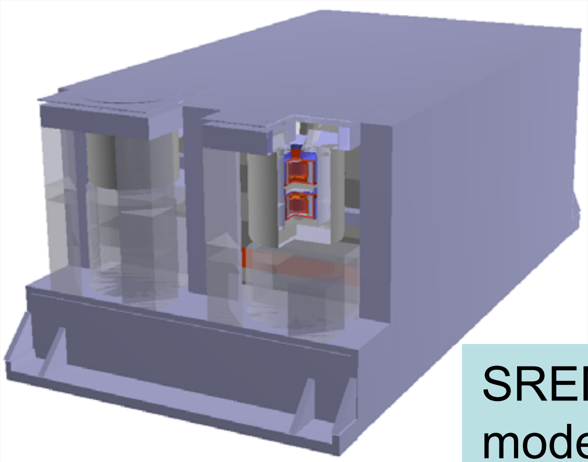
In-orbit monitoring

- Radiation Monitors
  - past: REM, SREM
  - Future: EPT, MFS, EMU, NGRM, HMRM, 3DEES,…
- Microparticle detectors
  - Debie-2 recently returned from ISS (EuTEF)
- Plasma monitors
  - SEPS
  - Other R&D



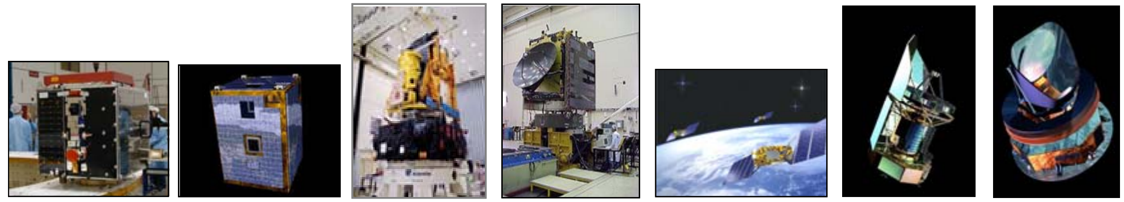
EPT Picture courtesy CSR

NASA picture

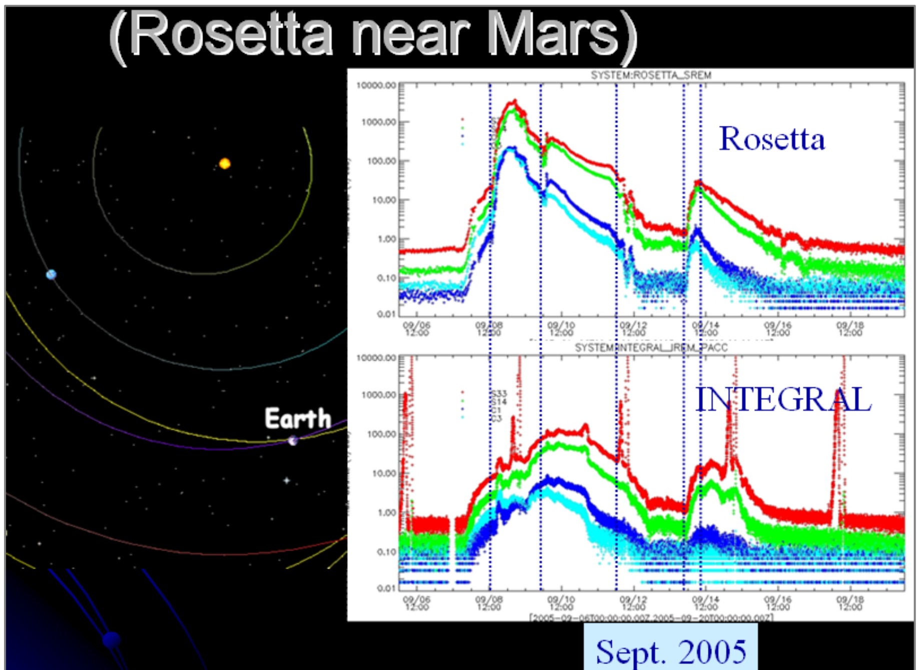


SREM Geant4 model

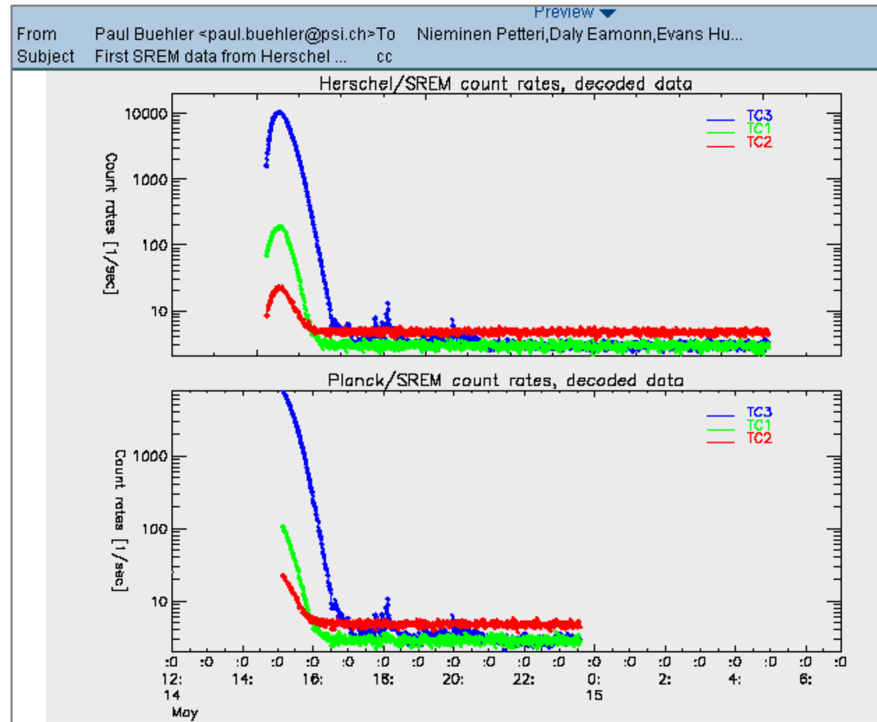
Image courtesy Martin Siegl (ESA)



STRV-1c 2000 | PROBA-1 2001 | INTEGRAL 2002 | ROSETTA 2004 | GIOVE-B 2006 | HERSCHEL 2009 | PLANCK 2009



SREM on Rosetta



SREMs on Herschel and Planck

Image courtesy Paul Buehler and PSI

Standards for Space Environments & Effects

- Standards are needed to aid the development process; ensure people work in the same way and account properly for all issues
- ECSS
  - E-ST-10-04c
    Space Environment – update
  - E-ST-20-06c
    Spacecraft Plasma Interactions
  - E-ST-10-12c
    Methods for Calculation of Radiation Effects
  - E-HB-10-12
    Handbook on Methods for Calculation of Radiation Effects
  - Q-ST-60-15c
    Radiation Hardness Assurance
- ISO
  - TC20 SC14 WG4 Space Environment
    (WG on Space Debris)

Place of Spenvis in ESA

- Main resource for:
  - Specifications (early project phase)
  - First-step analyses
  - Quick answers (“deadline is yesterday” type requests)
- Complemented by
  - Detailed toolkits (SPIS, G4,…) where physics, genoetries are more complex
  - But boundaries are blurring
- Use of Spenvis by partners ensures:
  - validity of tools and approaches
  - mutual understanding of inputs/outputs

Future

- There will be important developments in models and tools themselves
- New or updated:
  - environment models (GEO, MEO, Jupiter,…)
  - effects tools (e.g. SEE, solar cells,…)
- Two important evolutionarily opportunities:
  - SSA will try to reuse existing “assets” rather than re-invent them (Alexi’s talk)
  - Approved development contract “Next Generation Space Environment Information System”
    - Open, Distributed
    - Allows geographically separated resources (models, data, tools) to be in a virtual system
    - Partners can provide models or access
    - Delegation of responsibilities

Conclusions

- Strong growth in most future ESA programmes
- Many missions strongly affected by environmental interactions
- Environmental effects are becoming more complex, problematic, expensive
- Tools and methods deployed are improving and need to improve further
- Spenvis will play a vital, developing role