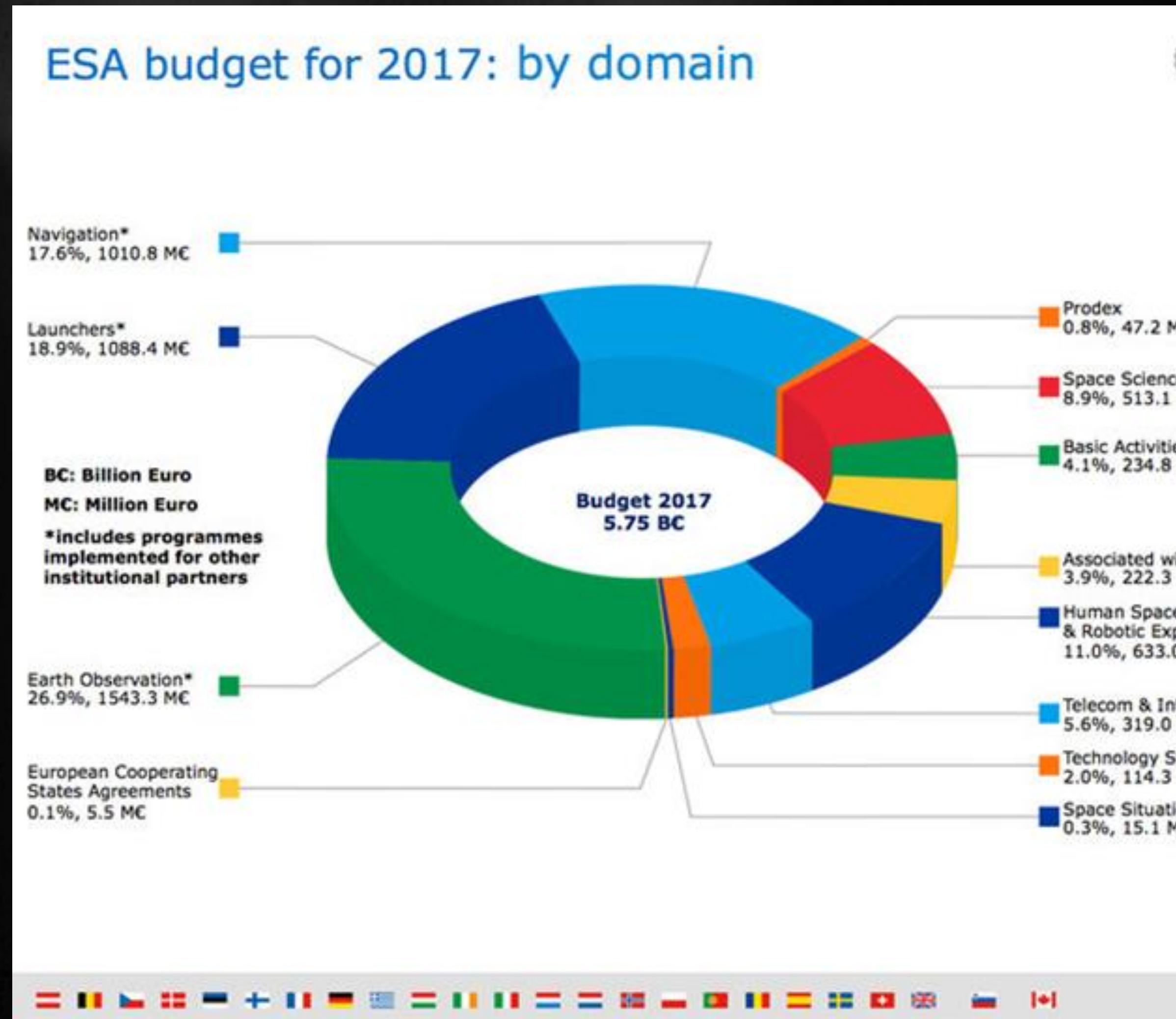
Radiation Environments, Effects and Needs for ESA Missions

Eamonn Daly
European Space Agency
ESTEC, Noordwijk, The Netherlands

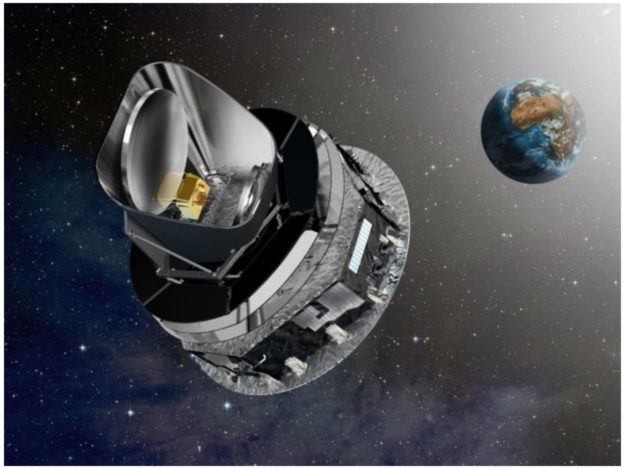
Space Environment Engineering and Science Applications Workshop
5 September 2017

- Technology, Engineering and Quality
- Science
- Human Spaceflight and Robotic Exploration
- Earth Observation
- Telecommunications
- Navigation
- Space Transportation
- Space Situational Awareness

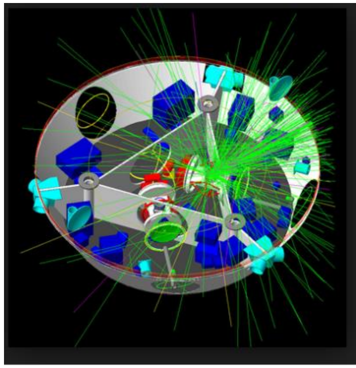


Radiation effects trends

- Single event effects (proton RB, cosmic rays)
  Trend: increasing complexity (EO, Telecom)
- "Total dose"(Ionizing dose, non-ionizing dose)
  Trend: COTS/low cost components/standard units
- Payload interference
  Trend: more complex, sensitive payloads
- Solar array degradation
  Trend: high power, light weight
- Internal charging
  Trend: hazardous mission scenarios
- Human spaceflight
  Trend: beyond LEO: Deep Space Gateway, Moon village, Mars
- ->**Radiation hardness assurance** / Testing / Analysis



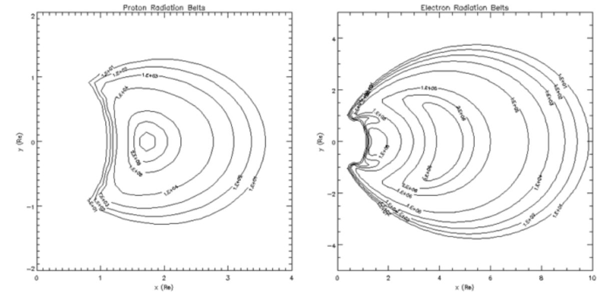
Mitigation:
- Testing
- Shielding
- "By design"

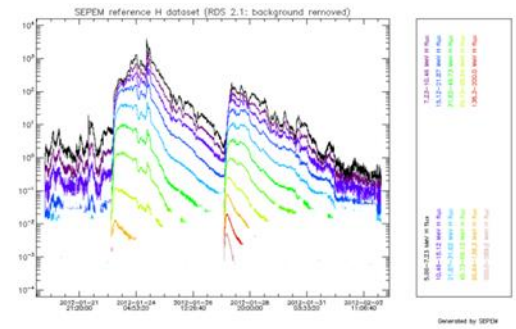


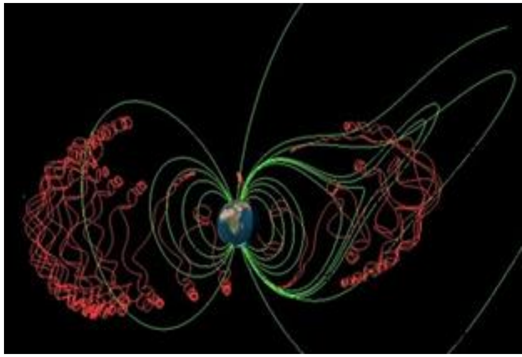
Prerequisite:
- Knowledge:
  - Environment
  - Effects

Environment Specification

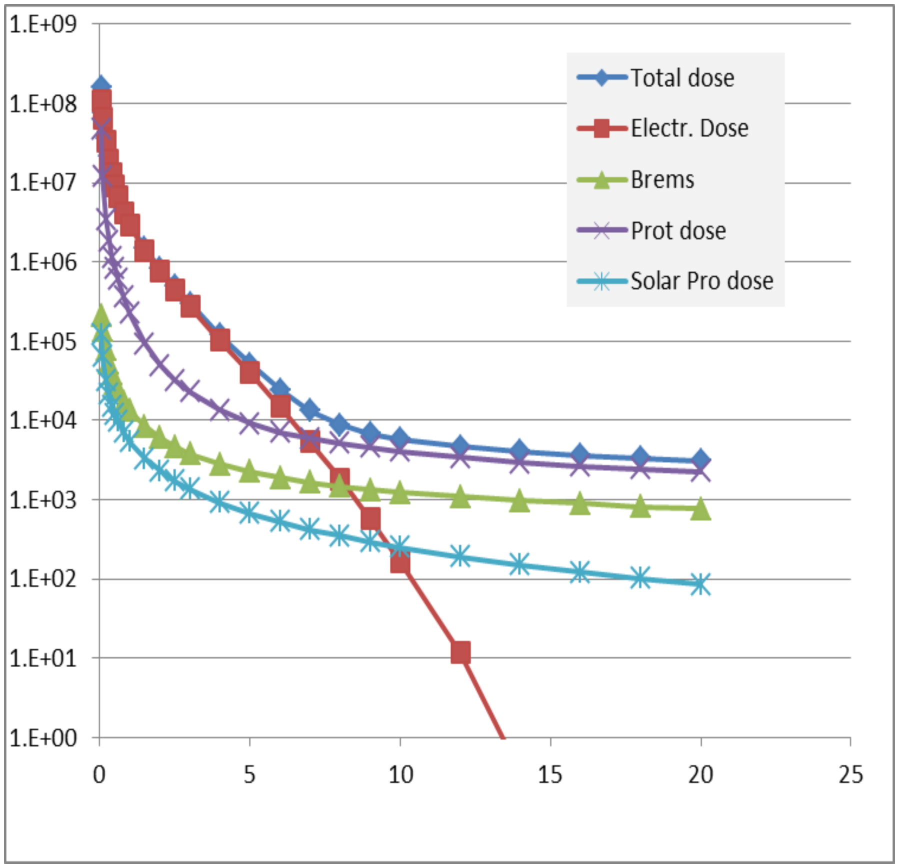
- Established early in a project’s development, based on the orbit or location.
- Specification is based on **standard** models that represent:
    i. long-term averages of radiation belt proton and electron fluxes;
    ii. short term enhancements of electron fluxes;
    iii. statistics of deviations from the long-term average (e.g. as described in most recent AE-9 models);
    iv. risk assessment of solar particle event proton/ion fluences and peak fluxes;
    v. worst case plasma charging environment;
    vi. low energy ion long term fluxes for evaluation of surface degradation;
    vii. solar cycle modulated GCR fluxes;
    viii. geomagnetic modulation of (iv) and (vii) if required by the orbit.

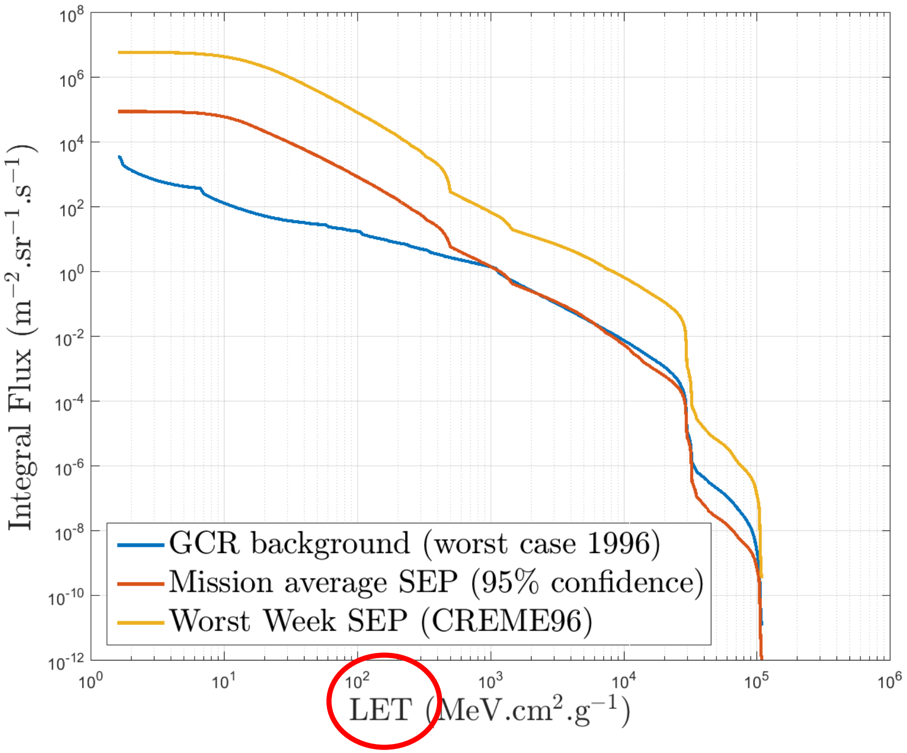






Annual radiation dose (rads) within shielding

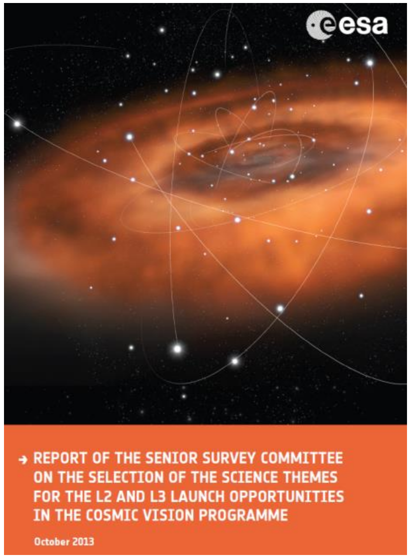




Flux of ions as a function of Linear Energy Transfer can be used to quantify the SEE rate (with test data)

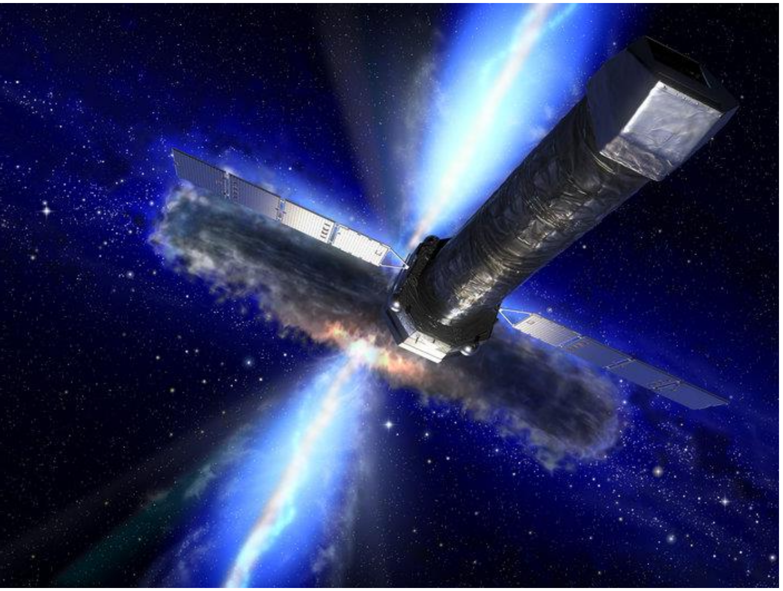
Science Missions

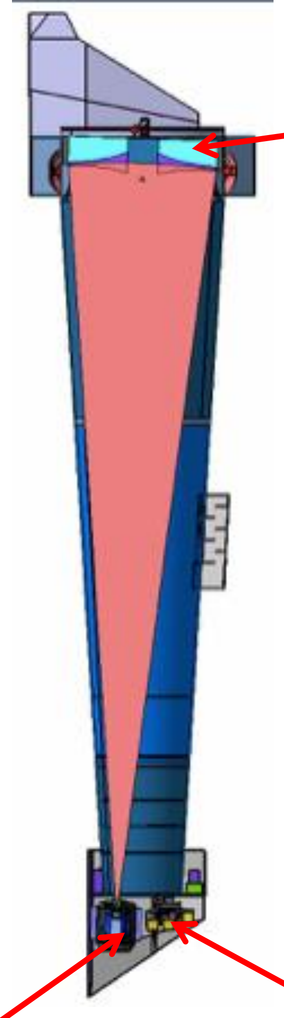
- JUICE Mission to Jupiter requires intensive work on environment specification and radiation transport
- The next 2 “L” (large) missions after L1 (JUICE)
  - L2 Theme: The Hot and Energetic Universe: ***Athena*** X-ray observatory
  - L3 Theme: The Gravitational Universe: gravitational wave mission ~”***eLISA***”

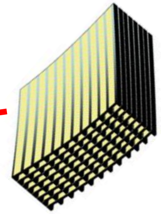


- Based on past experience, intensive analysis is/ will be performed on radiation issues for payloads
  - XMM-Newton: “soft proton” damage; background from soft protons and fluorescence (more than expected)
  - Planck
  - GAIA
  - Lisa Pathfinder

Athena

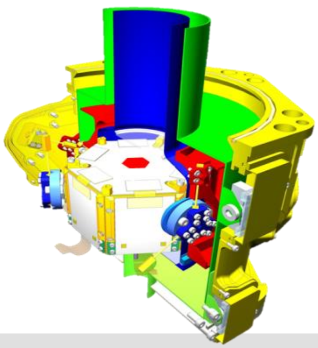


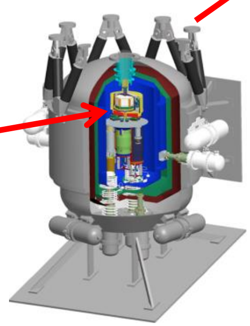


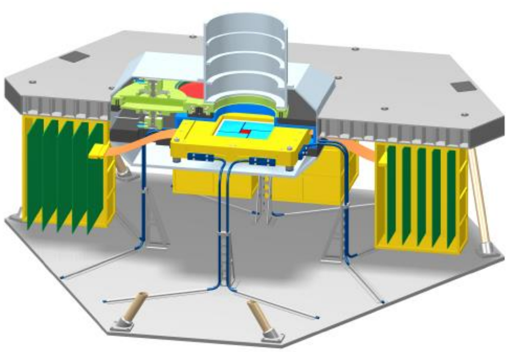


- High resolution imaging and spectroscopic X-ray observatory
- **Very low background required**
- Novel Si pore X-ray optics
- 2 focal plane (FP) instruments:
  - X-IFU: spatially resolved high resolution spectroscopy
    - cryo bolometer;
    - rear anti-coincidencing
  - WFI: wide field imager with spectroscopy
    - DEPFET APS arrays

- Current phase: A/B1;
  Adoption: 2019;
  Launch: 2028

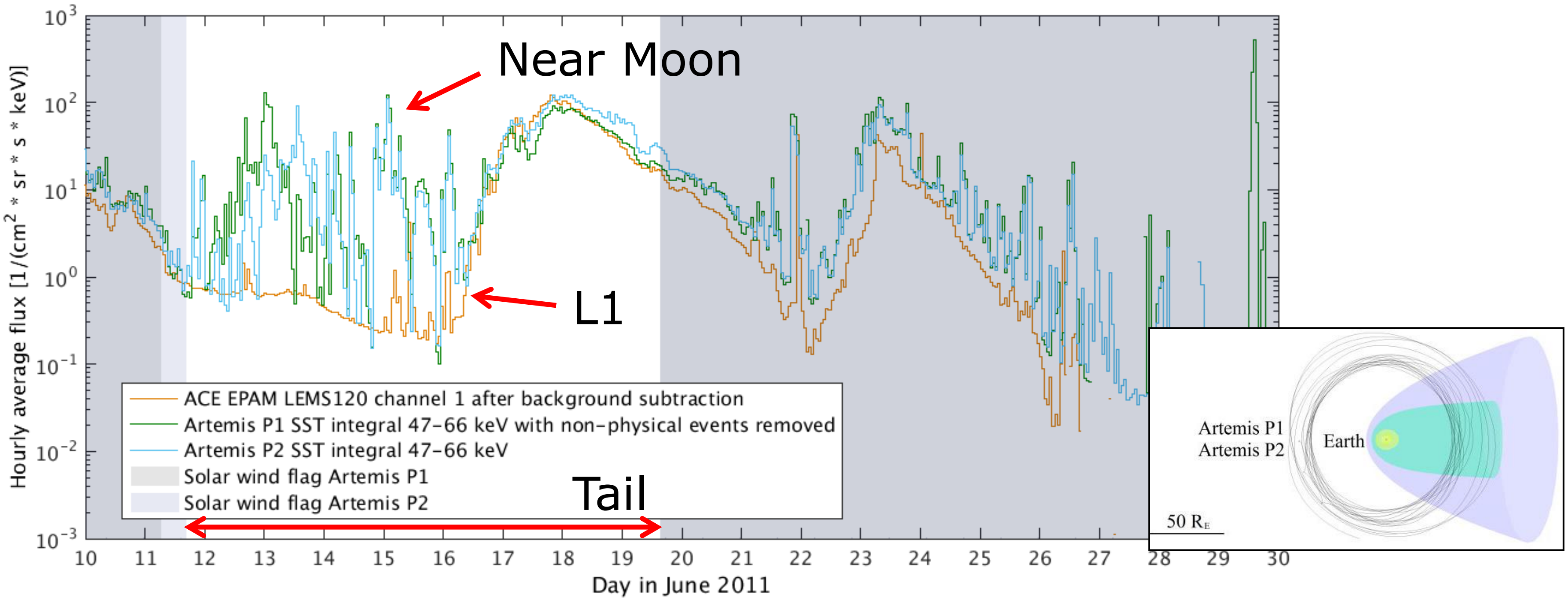






Environment Assessment for Athena

- L2 is not well characterised (in contrast to L1), especially for low E populations
- Likely effects of magnetosphere/tail processes on particle populations

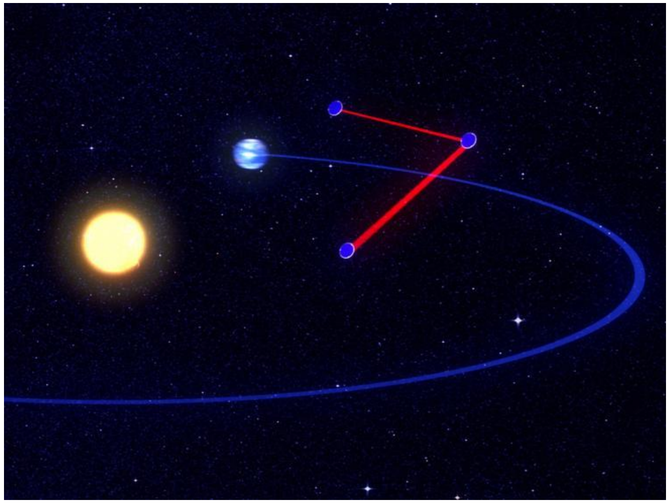


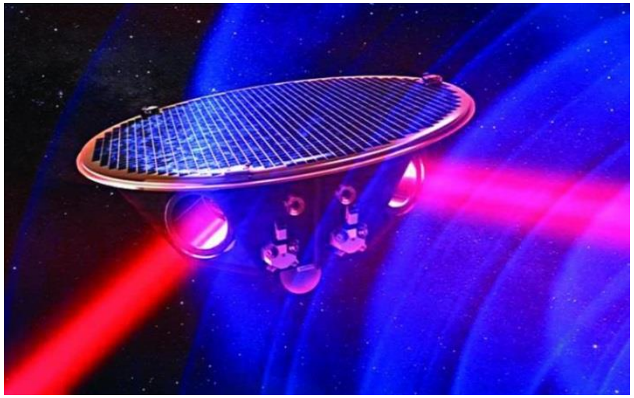
- Analyses of relevant datasets (GEOTAIL, ARTEMIS, etc.) have been done but they emphasise the limited data availability/ applicability

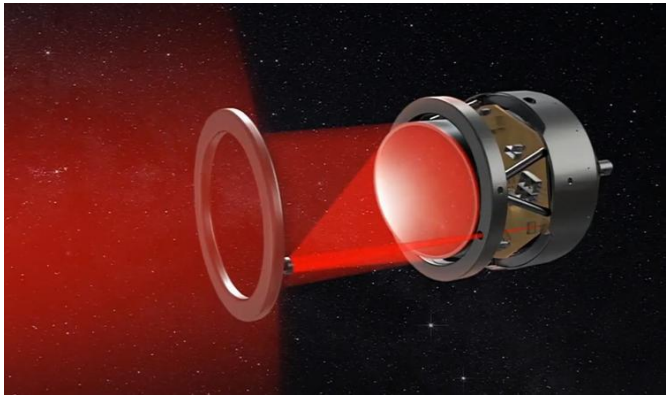
Budjáš et al., *Soft Proton Fluxes in and around Earth's Magnetotail*, submitted to IEEE Trans. Plas. Sci., 2016

The Gravitational Universe: gravitational wave mission LISA

- LISA concept for detection of LF gravitational waves at 100μHz-100mHz
- Triangular formation with arms 1Mkm
- Sensitivity to displacement of ~ 5×10^{-11} m
- 46mm free-falling cubes
- Laser transmitters/receivers
- "Noise" sources need careful auditing, as with LISA pathfinder
- Cosmic ray induced test-mass electrostatic charging is one contributor
- Intensive simulation will be performed
- Charging alleviation with UV lamps
- 2034 launch (?)







Credit: AEI/MM/exozet

The Cosmic Vision program

Missions in the Cosmic Vision 2015-2025 Programme		Launch
L1 mission	**JUICE**	2022
L2 mission	**Athena**	2028
L3 mission	**Gravitational wave observatory**	2034
M1 mission	**Solar Orbiter**	~~2018~~
M2 mission	**Euclid**	2020
M3 mission	**PLATO**	2024
S1 mission	**CHEOPS**	2018
S2 mission	**SMILE**	2021
M4 candidates	**ARIEL, THOR, XIPE**	2025
M5 selection	**Call for proposals closes Oct. '16; selection June '17**	2029

Possibly earlier

2019

+ BepiColombo (Mercury mission) 2018

Issues in other Programs

EO: growth in on board complexity – detectors and processing

proton SEE important

Telecom:

Electric orbit raising hazards + consuming TID budget at BoL;

Growth of on board processing and shortened procurement times

Megaconstellations – reliability concerns

Navigation: hot and variable environment in MEO;

solar cycle variations and short term enhancements;

internal and surface charging

Human spaceflight: human hazards at DSG

also high reliability requirements

Space Situational Awareness:

tools and missions to address end user needs

ESA R&D actions

Various R&D programs used to fund R&D; **often program driven**

- Targeted environment modelling
  - Special locations – Jupiter, MEO, L2, Mars,…
  - Investigation of APE9/Irene
- Solar Particle Environment data analysis and modelling
- Shielding tool developments,
  - e.g. Geant4 related tools
  - Interfacing (tool-tool, user)
  - Comparative investigations of methodologies
- Radiation effects research and facilities
  - Single event prediction methodology
  - Very high energy facility experiments (GSI, CERN)
- Space Environment Information System (Spenvis)
- Detectors and instruments; also in-flight effects (DM, net)
- Surface and internal charging tools and measurements

Standardization

European Cooperation on Space Standards – a join venture between agencies, experts and industry

E-10-04 Environment; first issued in 2000
(next update in 2018)

E-10-12 Methods for Calculation of Radiation Effects
Also an associated handbook

E-20-06 Spacecraft Charging

Note also the activities of
ISO TC10/SC14/WG4 Space Environment

Some Final Points

- A **quiet sun** means higher GCRs and SAA protons:
    - **increased risk** to electronics (and humans)
- Some missions require knowledge of **electron belt enhancements**: electric orbit raising, GPS/Galileo, etc.
- Engineering **margins**: much debate: how good are the data?, the models?, the analysis?; hidden margins
- **Standards** are the basis for design: progress with models and methods need to be implemented through consensus
- Growing appreciation of on-board monitoring (env,, effects)
- Lessons learned and return on experience – **not only anomalies**
- Far more effort is devoted to **space climate** specification and hardening, rather than space **weather**:
    - GCR; Proton belts; long term effects
    - Testing; mitigation (shielding…); analysis
- Space Weather products are so far most useful in **post-anomaly analyses**
    - what happened and why?