Geant4 in Space

selected recent investigations

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European Space Agency
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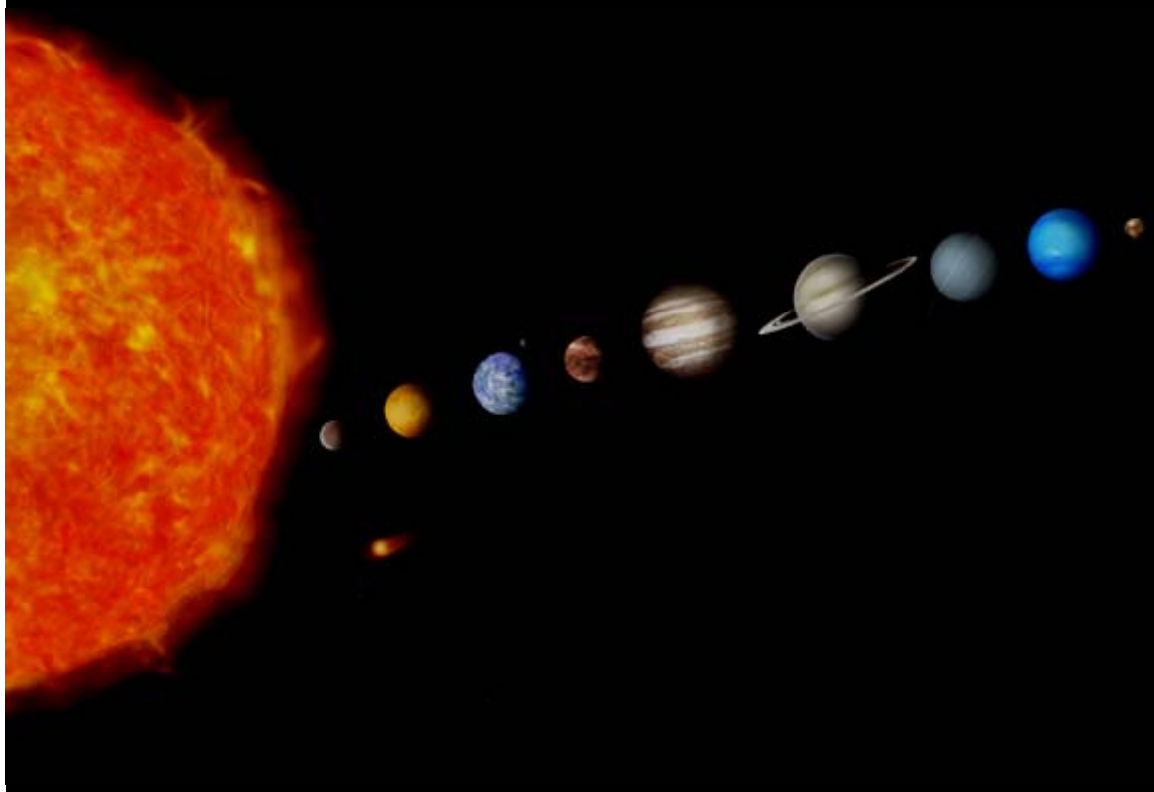
Geant4 '07
Hebden Bridge, 13-19 Sep 2007

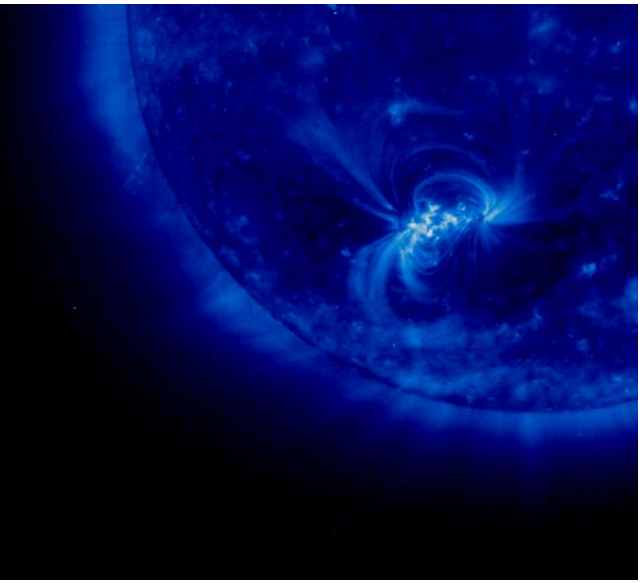
Outline

1. Planetary exploration
2. Looking outside the solar system
3. Geant4 usability: Tools and Engineering aspects
4. Space Users' community

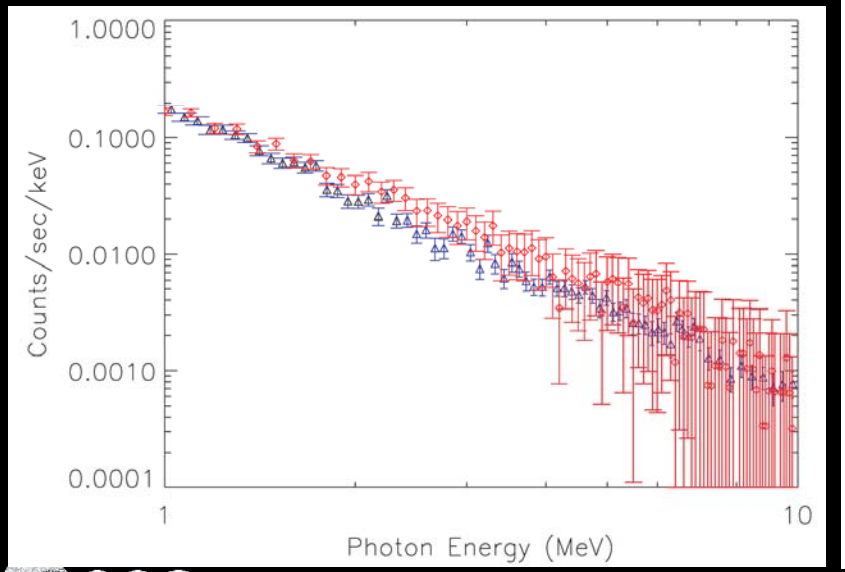
2. Planetary exploration



Solar event gamma-rays



- Electron Bremsstrahlung – induced gammas in solar flares
- Compton back-scattering
  → observable gamma-ray spectrum much softer than predicted by simple analytic calculations



Effects of Compton scattering on the Gamma Ray Spectra of Solar flares

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National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, JAPAN
junichi.kotoku@nao.ac.jp
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and
Mitsuhiro KOHAMA, Yukikatsu TERADA and Toru TAMAGAWA
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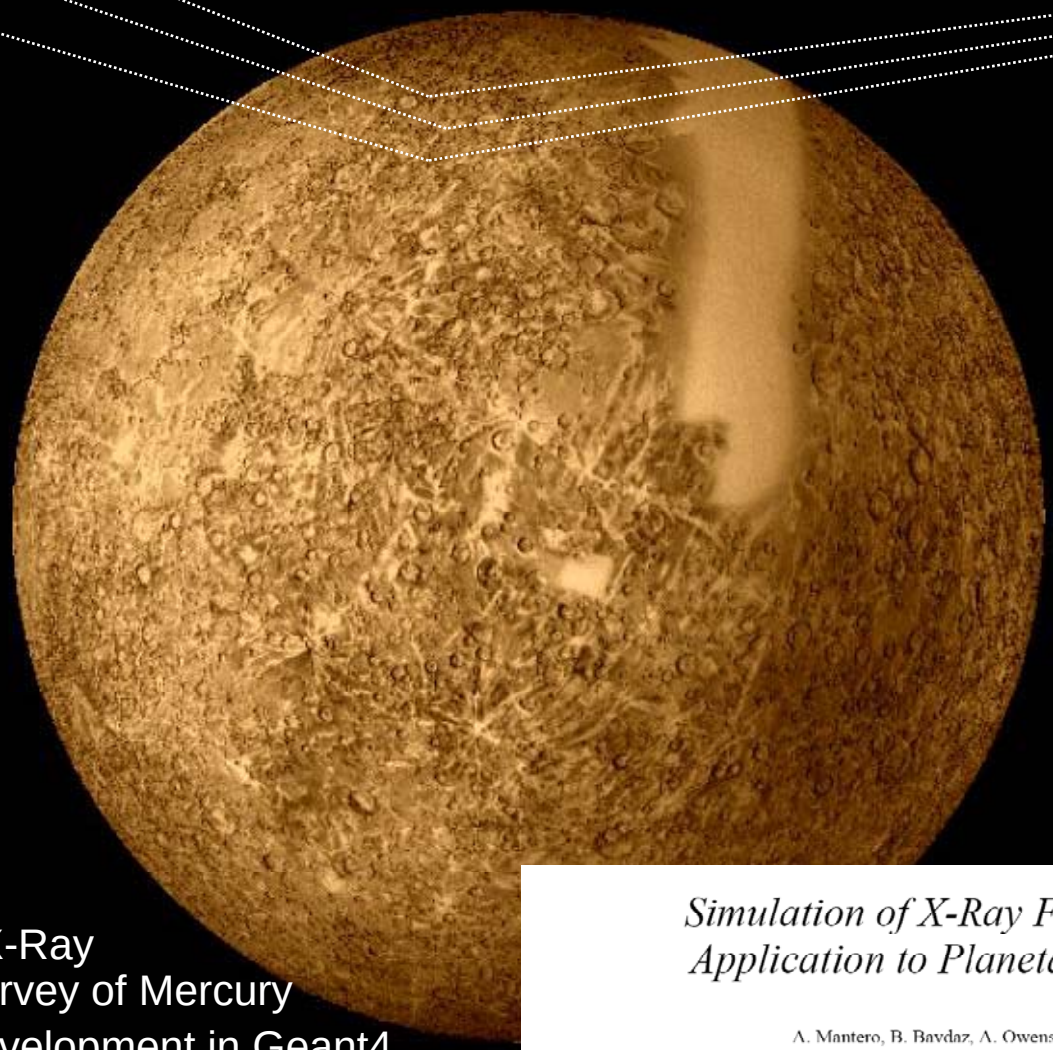
[1]*Also at RIKEN*
[2]*Present address: Mitsubishi Electric Co., Ltd.*

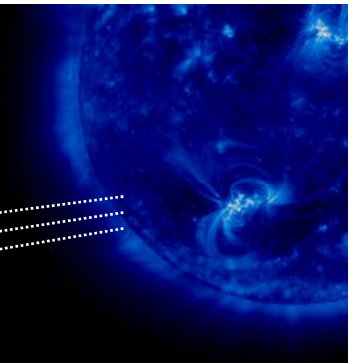
(Received ; accepted)

Abstract

Using fully relativistic GEANT4 simulation tool kit, the transport of energetic electrons generated in solar flares was Monte-Carlo simulated, and resultant bremsstrahlung gamma-ray spectra were calculated. The solar atmosphere was ap-

Mercury surface ?



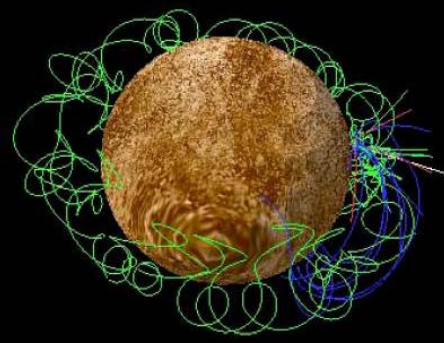


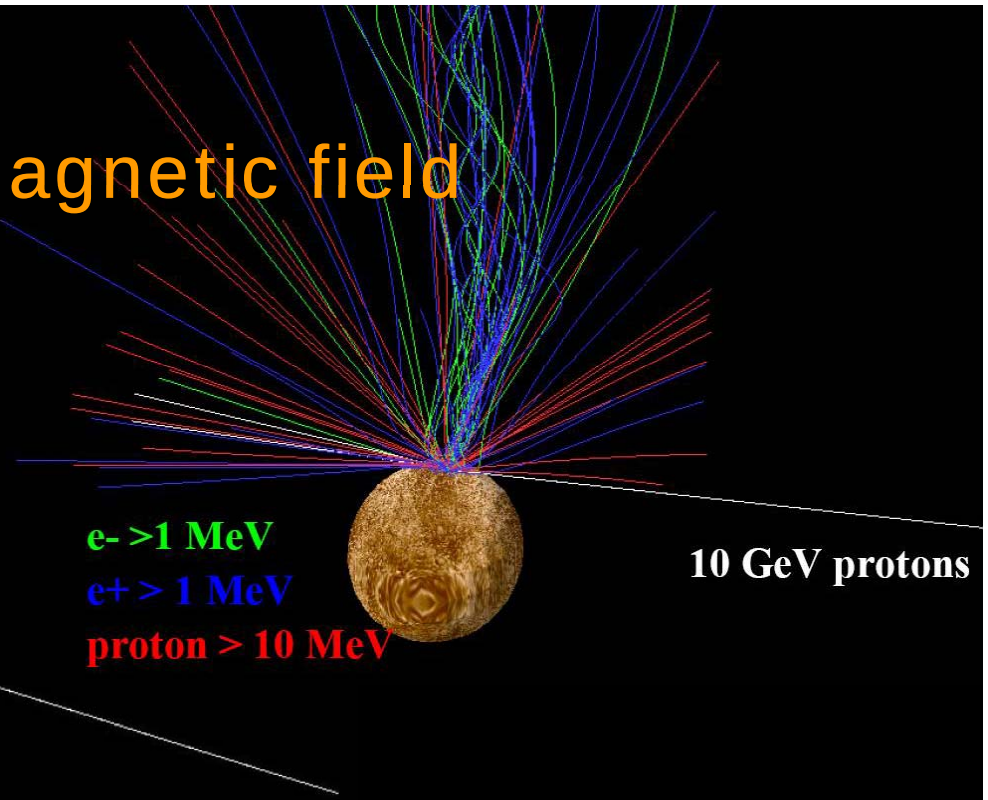
- Bepi Colombo: X-Ray Mineralogical Survey of Mercury
- Fluorescence development in Geant4

Simulation of X-Ray Fluorescence and Application to Planetary Astrophysics

A. Mantero, B. Bavdaz, A. Owens, T.Peacock, M.G.Pia

PlanetoCosmics
Mercury soil and magnetic field





e- >1 MeV
e+ > 1 MeV
proton > 10 MeV

10 GeV protons from dayside

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Advances in Space Research 37 (2006) 1759–1763

ADVANCES IN SPACE RESEARCH
(a COSPAR publication)

www.elsevier.com/locate/asr

A Geant4 application to simulate the interaction of space radiation with the Mercurian environment

M. Gurtner *, L. Desorgher, E.O. Flückiger, M.R. Moser

Physikalisches Institut, Space Research and Planetary Sciences, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland

Received 3 November 2004; received in revised form 15 December 2004; accepted 15 December 2004

- Mercury soil
  + Dipole B0 = 300 nT

Detectors for Mercury (and Mars)

- High-Purity Germanium detectors (HPGe) used in astrophysics / planetary exploration gamma-ray spectrometers
- GCR and secondary fast neutrons → degradation of energy resolution, normally recovered by annealing (e.g. Mars Odyssey, INTEGRAL)
- For missions to inner solar system (Mars Observer, Messenger, BepiColombo) solar protons becoming major source of degradation (NIEL)

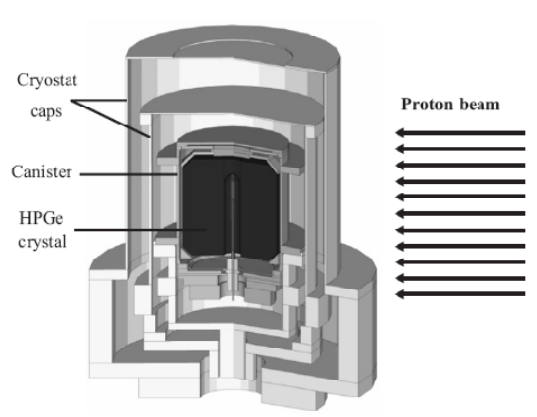

Fig. 2. Layout of the first detector (crystal, canister and cryostat caps).

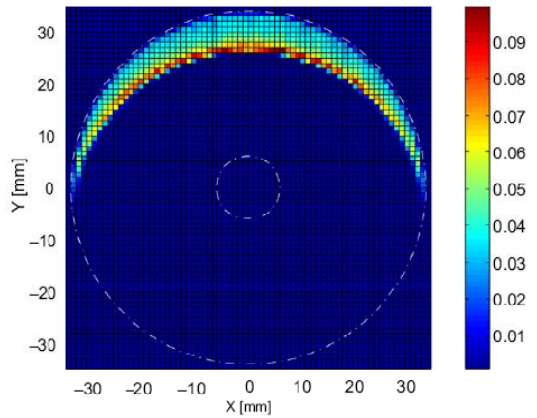

Fig. 4. Ionizing energy deposits in the crystal of the first detector. Dose

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Nuclear Instruments and Methods in Physics Research A 572 (2007) 698–707

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

Solar proton damage in high-purity germanium detectors

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[b]*Center for Space Radiations, University of Louvain, 2 Chemin du Cyclotron, B-1348 Louvain-la-Neuve, Belgium*
[c]*Max-Planck-Institut für Chemie, P.O. Box 3060, D-55020 Mainz, Germany*

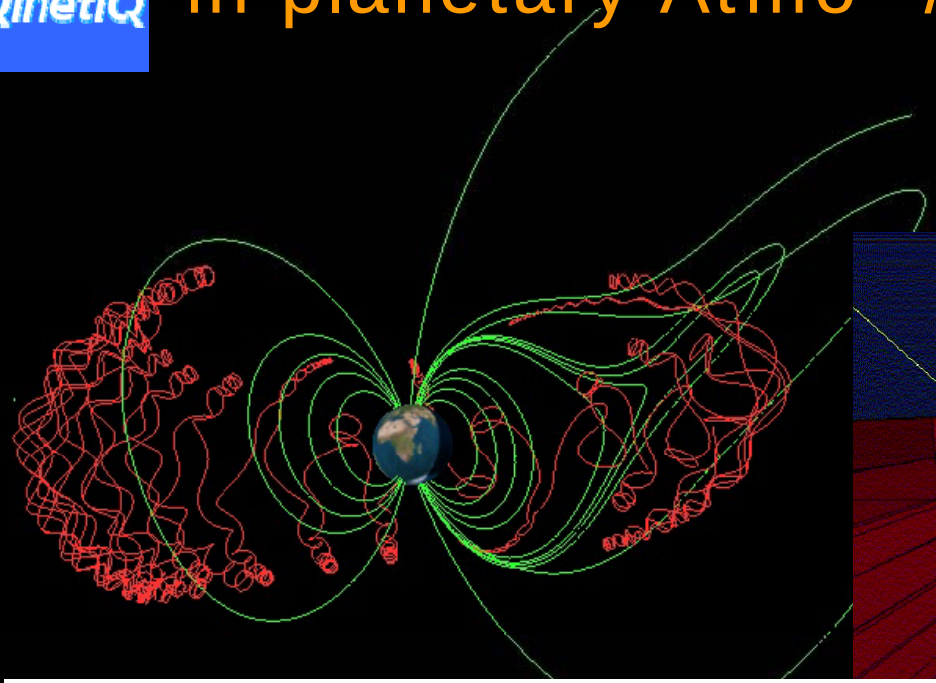
Received 1 June 2006; received in revised form 16 October 2006; accepted 14 November 2006
Available online 13 December 2006

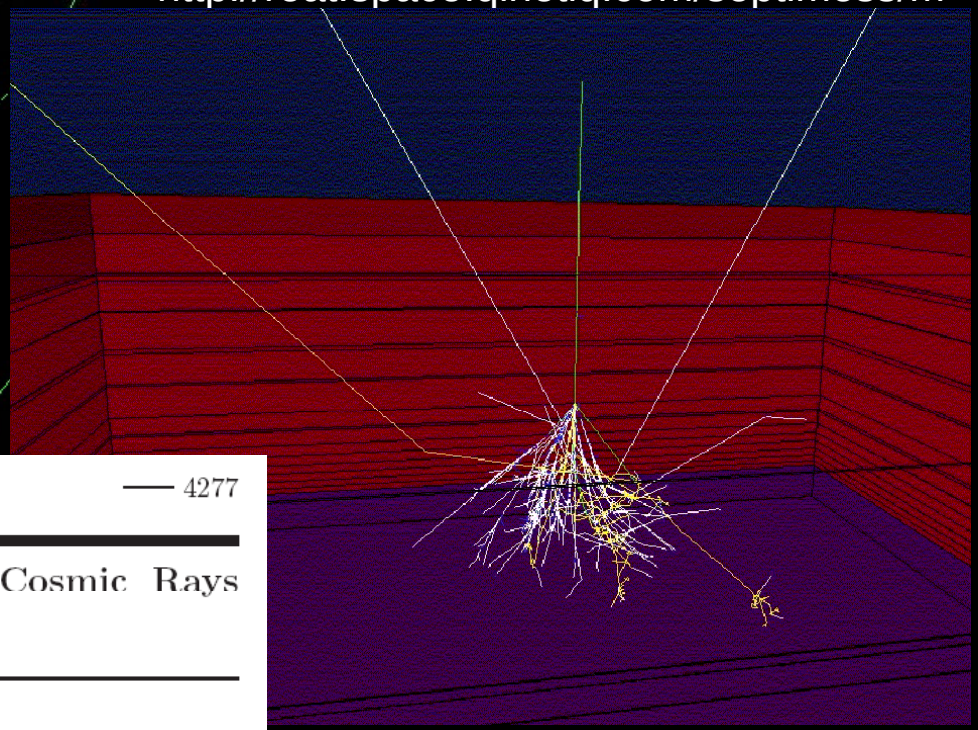
PlanetoCosmics

Geant4 simulation of Cosmic Rays in planetary Atmo- / Magneto- spheres

- Laurent Desorgher, University of Bern

http://reat.space.qinetiq.com/septimess/m





28th International Cosmic Ray Conference — 4277

Geant4 Simulation of the Propagation of Cosmic Rays through the Earth's Atmosphere

L. Desorgher, E. O. Flückiger, M. R. Moser, and R. Bütikofer
Physikalisches Institut, University of Bern, CH-3012 Bern, Switzerland

DESIRE

Dose Estimation by Simulation of the ISS Radiation Environment

http://www.particle.kth.se/desire/

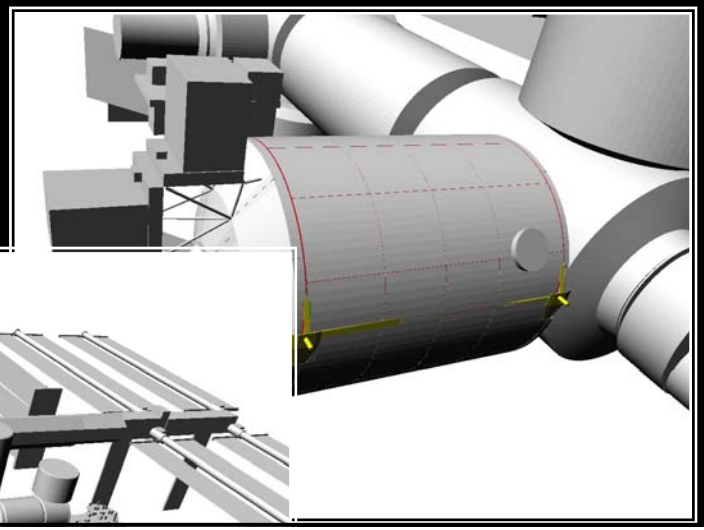
T. Ersmark[1], P. Carlson[1], E. Daly[2], C. Fuglesang[3], I. Gudowska[4], B. Lund-Jensen[1], R. Nartallo[2], P. Nieminen[2], M. Pearce[1], G. Santin[2], N. Sobolevsky[5]

[1]Royal Institute of Technology (KTH) (Stockholm), [2]ESA-ESTEC (Noordwijk), [3]EAC/JSC (Cologne/Houston), [4]Karolinska Institutet (Stockholm), [5]Institute for Nuclear Research (Moscow)

GOAL

Accurate Monte Carlo calculations (Geant4) of the radiation fields and doses to astronauts inside the European Columbus module of the International Space Station.

ISS AND COLUMBUS



INCIDENT RADIATION

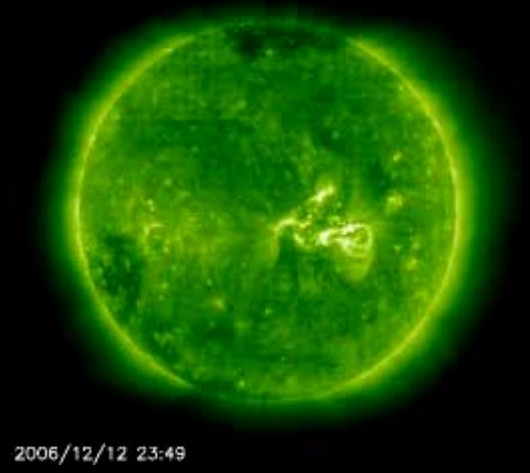
- Trapped protons
- Galactic cosmic rays
- Solar particle events
- Earth albedo neutrons

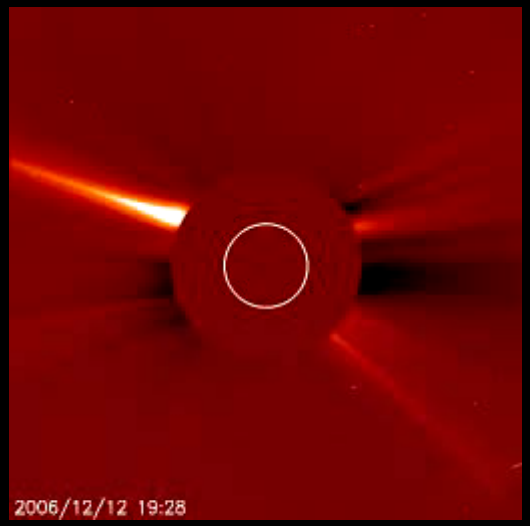
Geant4 Monte Carlo Simulations of the Belt Proton Radiation Environment On Board the International Space Station/Columbus

Ersmark, T. Carlson, P. Daly, E. Fuglesang, C. Gudowska, I. Lund-Jensen, B. Nieminen, P. Pearce, M. Santin, G.

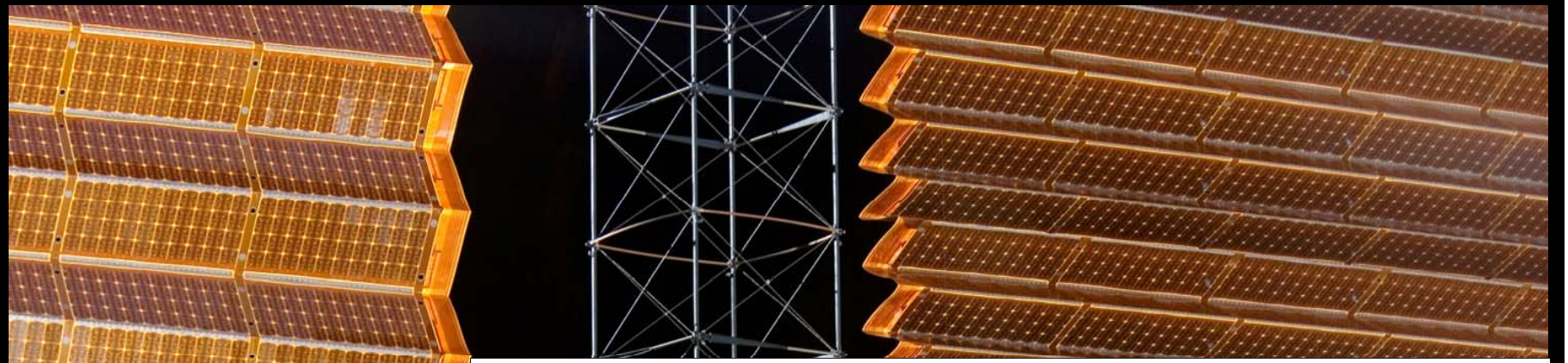
This paper appears in: Nuclear Science, IEEE Transactions on
Publication Date: Aug. 2007
Volume: 54, Issue: 4, Part 3
On page(s): 1444-1453

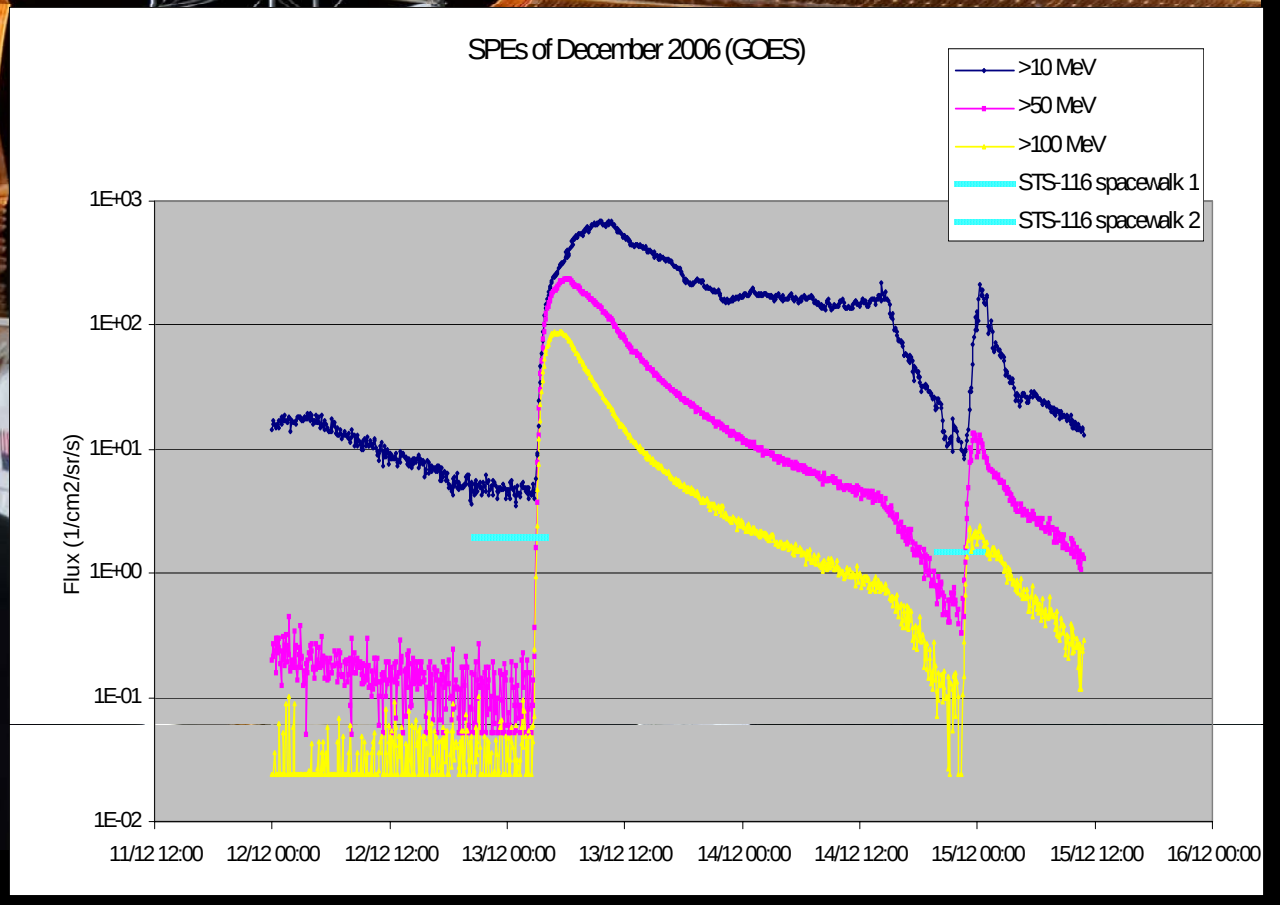
Solar event of 13 December 2006





STS-116 mission to ISS





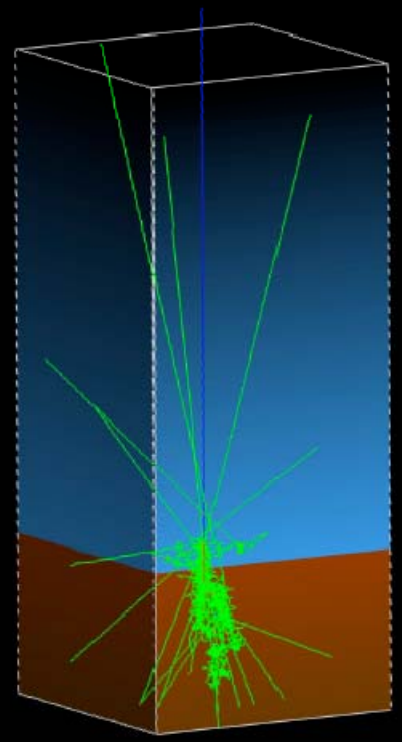
Life on Mars?

GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L02207, doi:10.1029/2006GL027494, 2007

Modelling the surface and subsurface Martian radiation environment: Implications for astrobiology

L. R. Dartnell
Centre for Mathematics and Physics in the Life Sciences and Experimental Biology (CoMPLEX), University College London, London, UK

L. Desorgher
Physikalisches Institut, University of Bern, Bern, Switzerland



Biogeosciences, 4, 545–558, 2007
www.biogeosciences.net/4/545/2007/

Biogeosciences

Martian sub-surface ionising radiation: biosignatures and geology*

L. R. Dartnell[1], L. Desorgher[2], J. M. Ward[3], and A. J. Coates[4]
[1]CoMPLEX (Centre for Mathematics & Physics in the Life Sciences and Experimental Biology), University College London, UK
[2]Physikalisches Institut, University of Bern, Switzerland
[3]Department of Biochemistry and Molecular Biology, University College London, UK
[4]Mullard Space Science Laboratory, University College London, UK

*Invited contribution by L. R. Dartnell, one of the Union Young Scientist Award winners 2006.

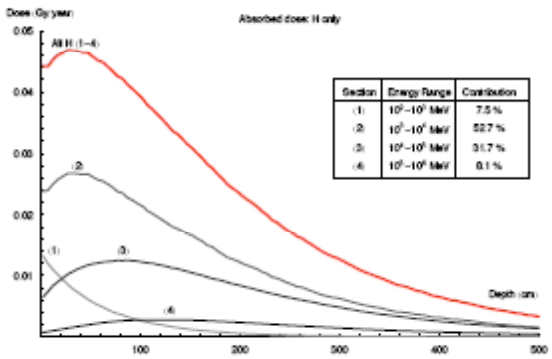
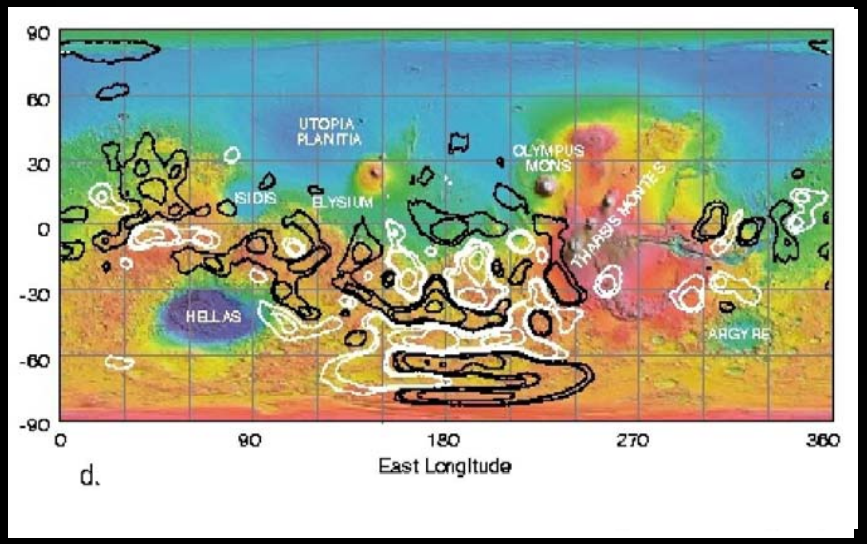
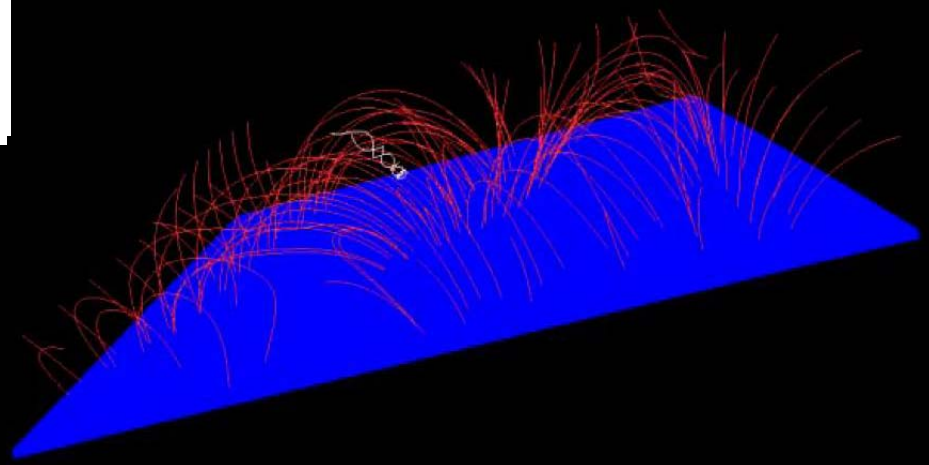


Fig. 8. Dose contributions from different energy bands of the primary GCR proton spectrum. Section numbers correspond to the energy ranges indicated in Fig. 1.

PlanetoCosmics
Mars field and atmosphere



- MGS observation Br @ 400 km
- Connerney et al., Geophys.Res.Let. 28, 21, 4015-4018, 2001
- Cain 50-degree spherical harmonic model (2003)

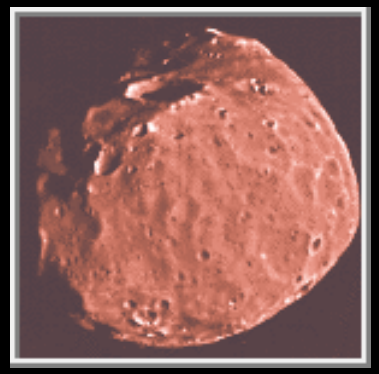


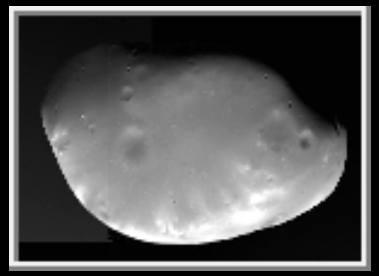
- NASA Mars-GRAM2001 model
  - p,n, T in function of :
    - Lat., long. (topography from MOLA)
    - Altitude, season, local time, F10.7
    - Dust models
  - Based on :
    - Nasa MGCM 0-80 km
    - Univ. of Arizona MTGCM 80-170 km

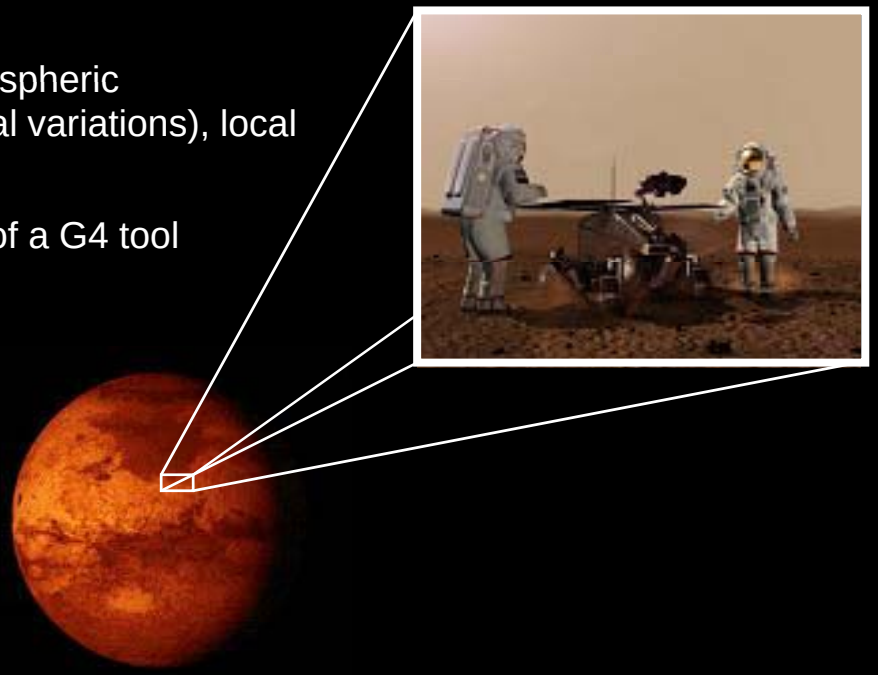
Geant4 implementation courtesy L. Desorgher, University of Bern

MarsREM

- Models for Mars, Phobos and Deimos
- Surface topology and composition, subsurface, atmospheric composition and density (including diurnal and annual variations), local magnetic fields
- Active magnetic shielding: review and development of a G4 tool
- User-friendly engineering tool (QARM)
- New ion physics



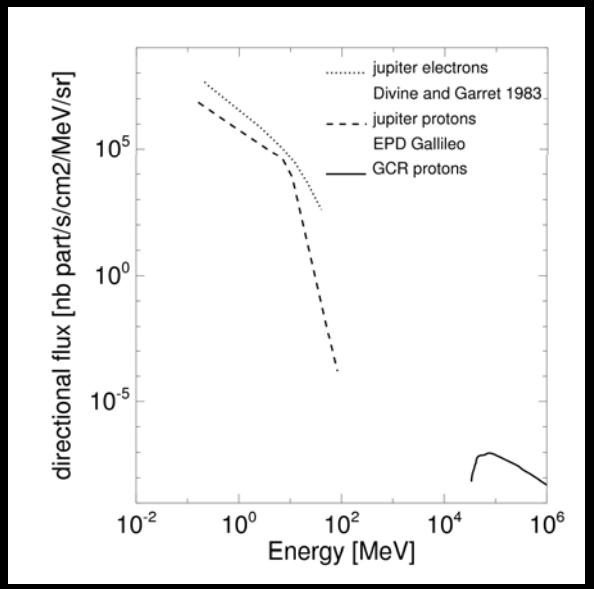




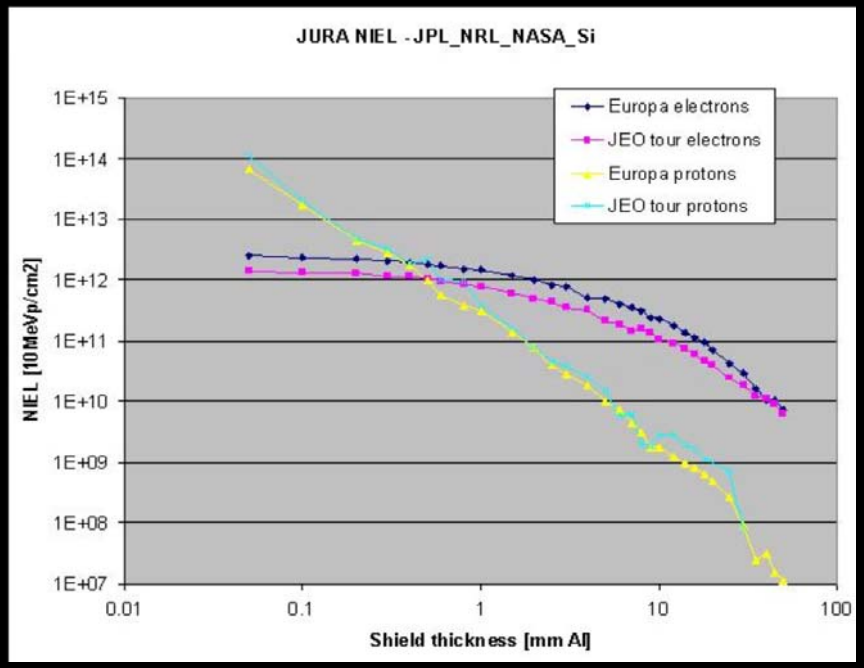
- Consortium led by QinetiQ. ESA funding
- See dedicated talk on Friday afternoon
  - Parallel Session 2- Aero/Space Applications

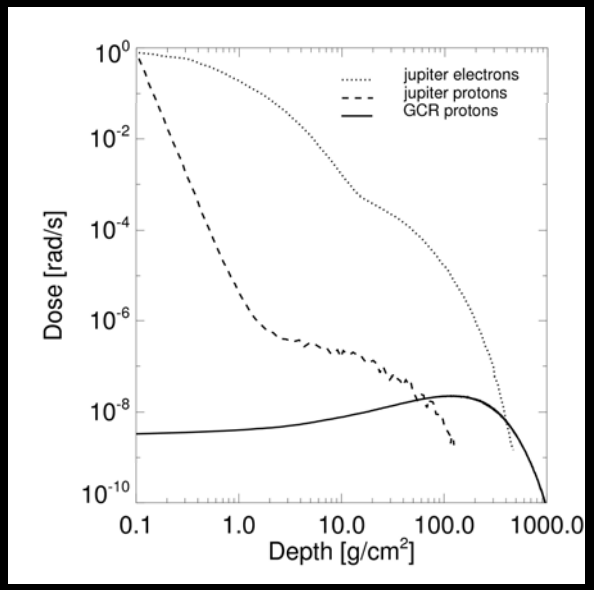
No humans on Jupiter

- Laurent Desorgher et al, Planetocosmics tool
  Environments and doses on Jupiter Europa

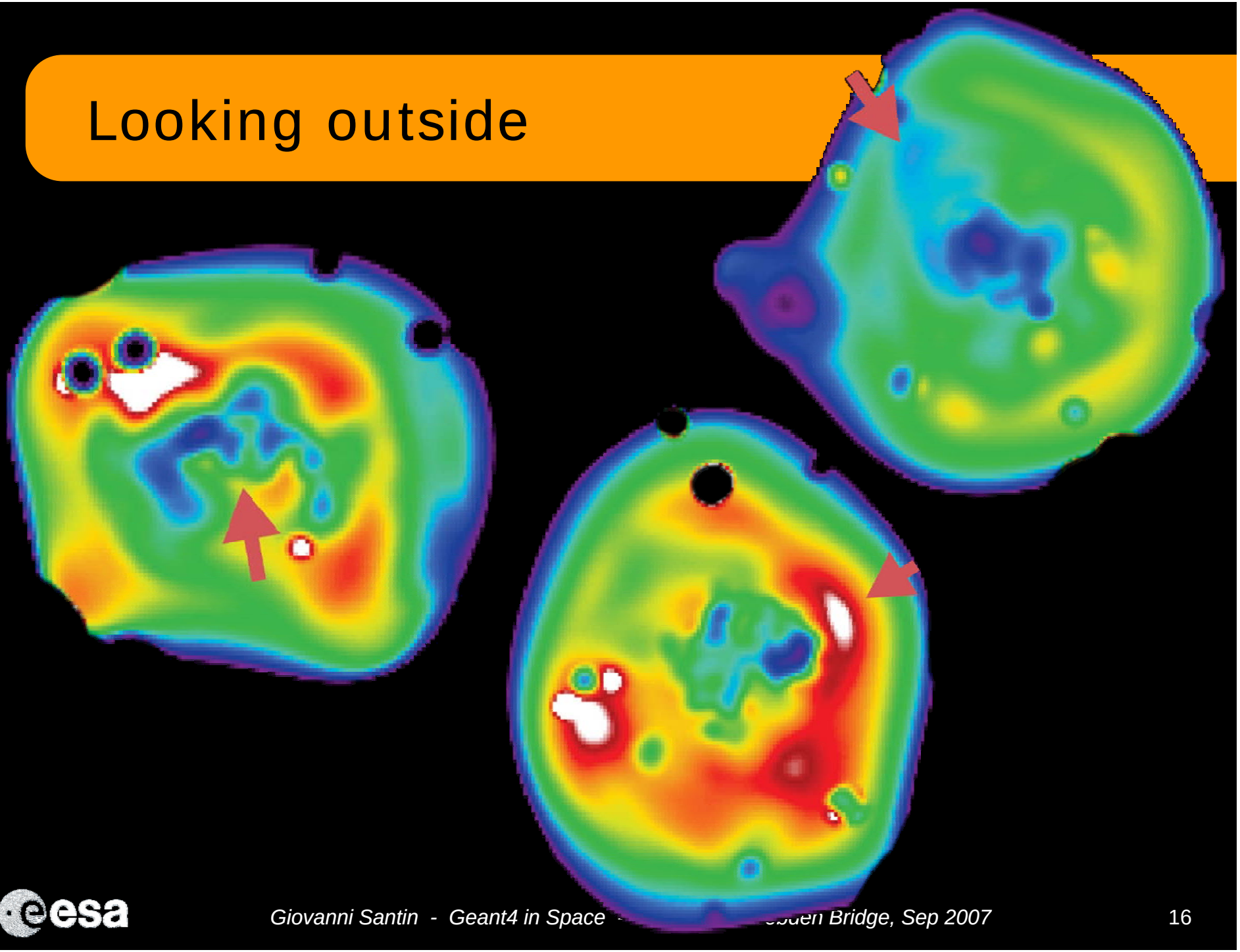


- ESA / ESTEC, GRAS tool
  JURA Jupiter mission feasibility study
  focusing on radiation





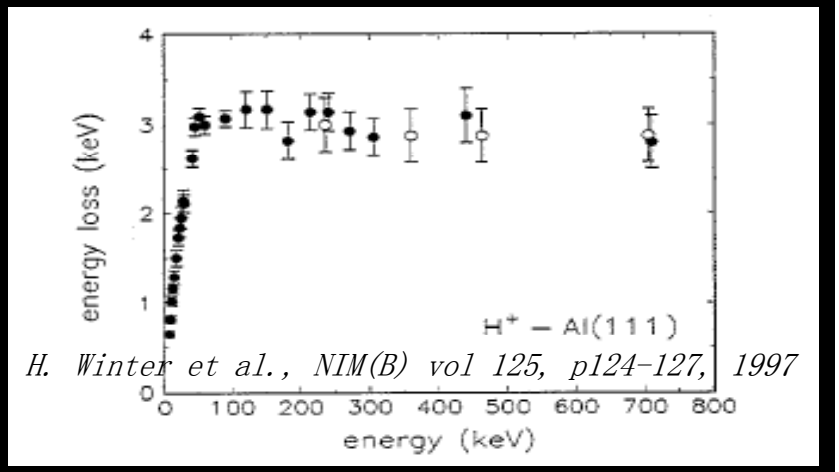
Looking outside



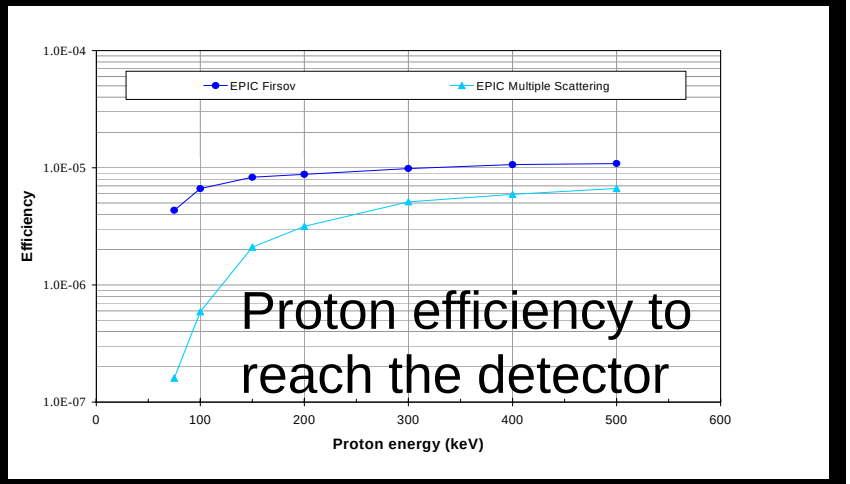
XMM

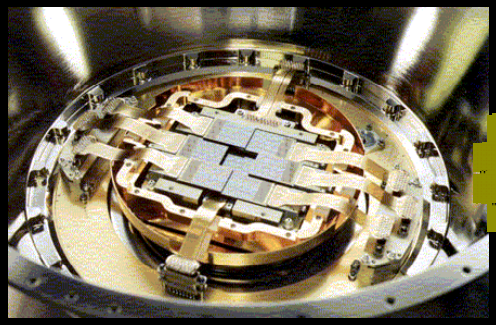
Firsov + multiple scattering

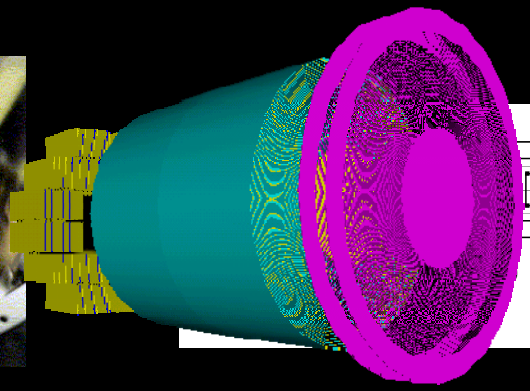
- DD induced CCD CTE loss observed on ACIS instrument on board Chandra
- Radiation belt low-energy protons scattering off X-ray mirrors
- Surface scattering: new physics in Geant4: proton scattering at very small angles

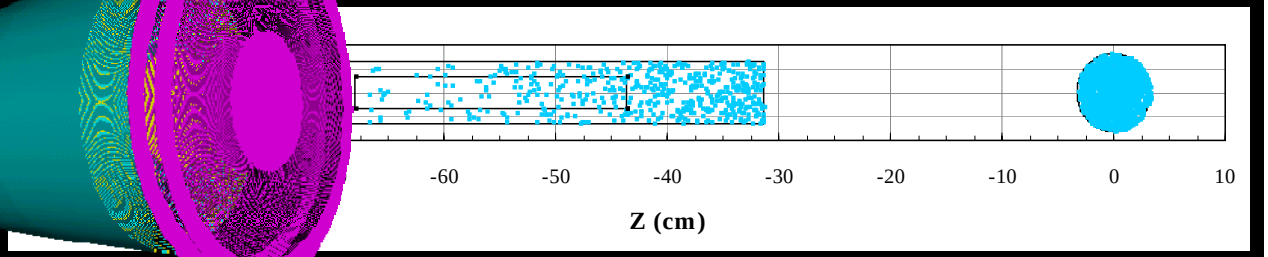


H. Winter et al., NIM(B) vol 125, p124-127, 1997









X- and Gamma-ray "Suzaku" Observatory

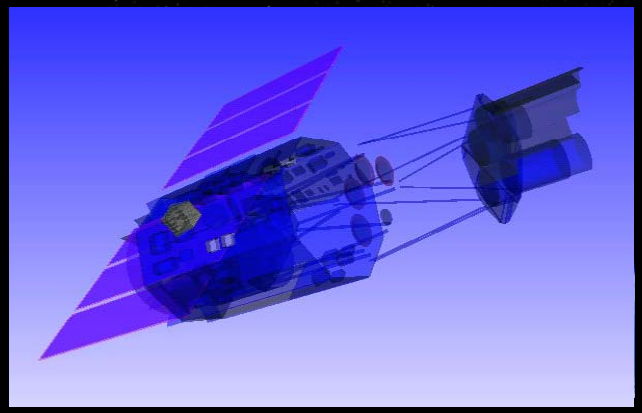
JAXA / NASA-GSFC, launched July 2005

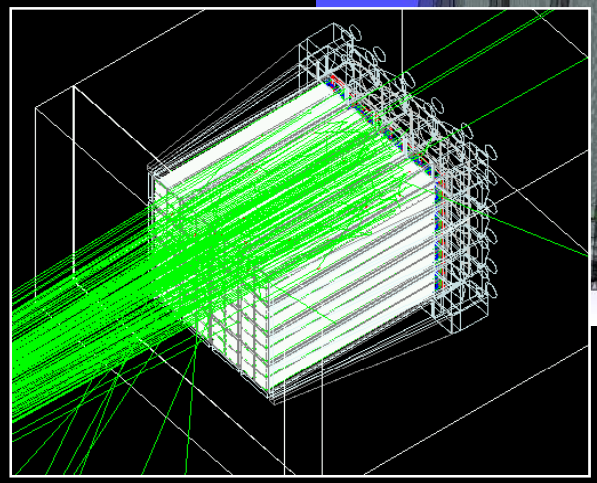
High-precision and Low-noise detector systems

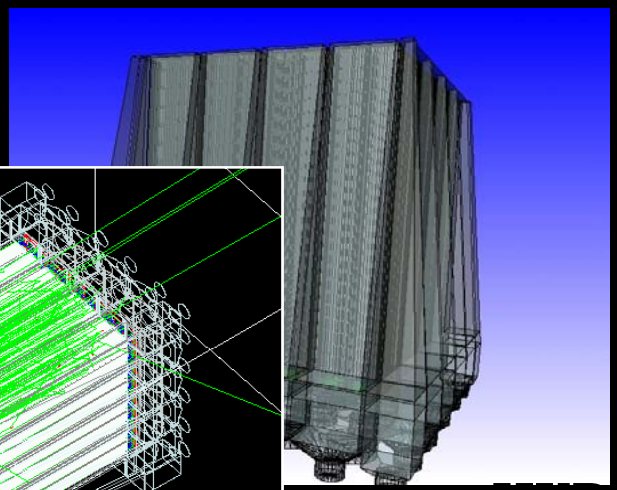
- XIS: X-ray [0.3—12 keV]
  - imaging spectrometer, 4 CCD
- HXD: Hard X-ray [10—600 keV]
  - GSO-BGO phoswich, embedded CCD

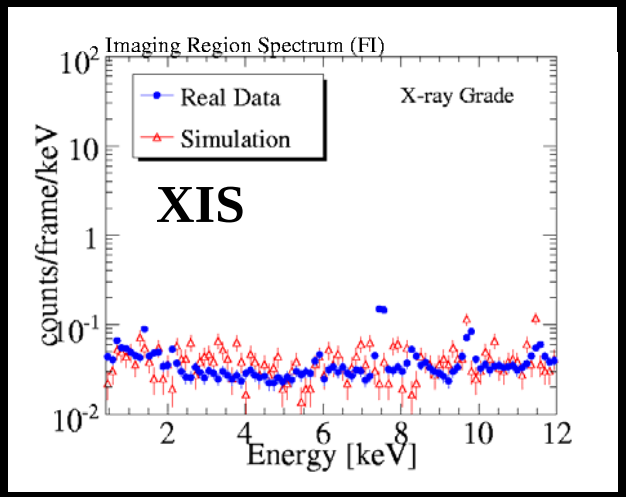
Geant4 simulation:

- Energy deposition
- + Charge-diffusion in CCD





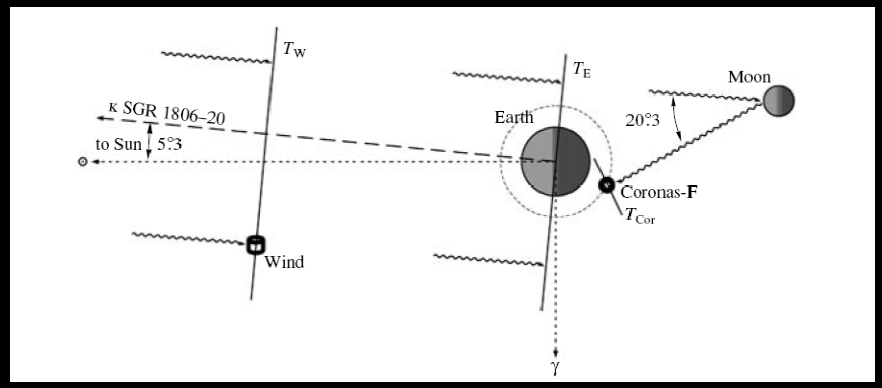




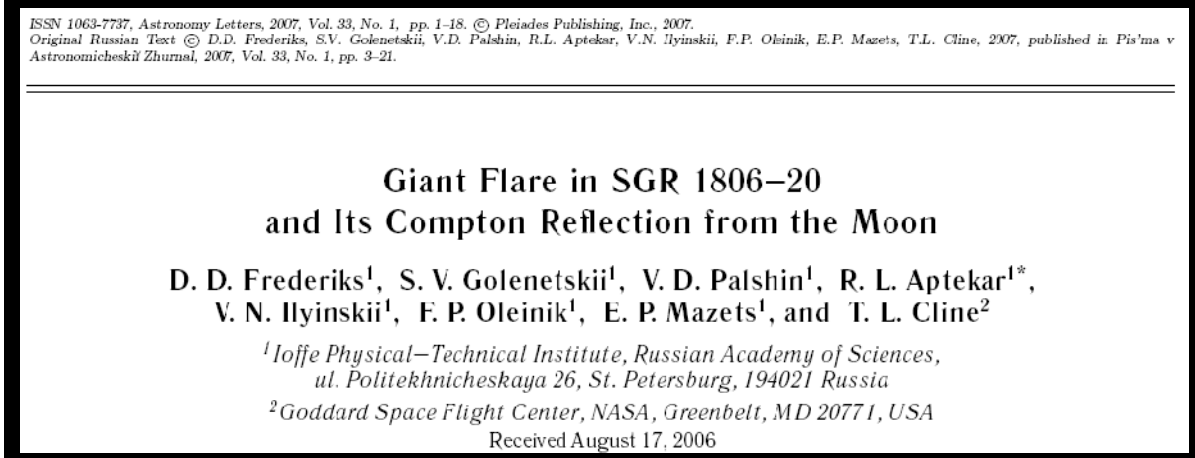
Succeeded in representing the BGD spectrum and resolving the BGD generation mechanism

Courtesy of Masanobu Ozaki (ISAS/JAXA and JST/CREST)

Gamma-rays from neutron stars



- December 27, 2004
  - One of the biggest explosions ever observed by humans
- Saturation in Konus-Wind direct observation
- Compton gammas from Moon surface detected by Helicon-Corona-F
  - response matrix computed with Geant4


ISSN 1063-7737, Astronomy Letters, 2007, Vol. 33, No. 1, pp. 1–18. © Pleiades Publishing, Inc., 2007.
Original Russian Text © D.D. Frederiks, S.V. Golenetskii, V.D. Palshin, R.L. Aptekar, V.N. Ilyinskii, F.P. Oleinik, E.P. Mazets, T.L. Cline, 2007, published in Pis'ma v Astronomicheskiĭ Zhurnal, 2007, Vol. 33, No. 1, pp. 3–21.

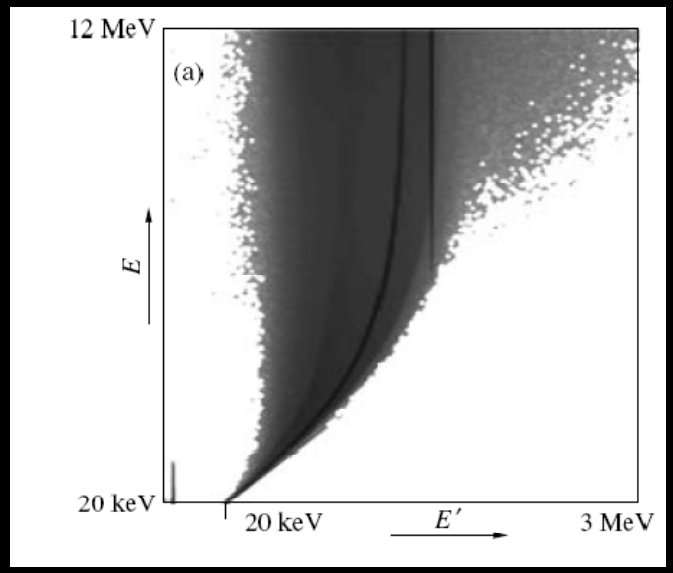
Giant Flare in SGR 1806–20
and Its Compton Reflection from the Moon

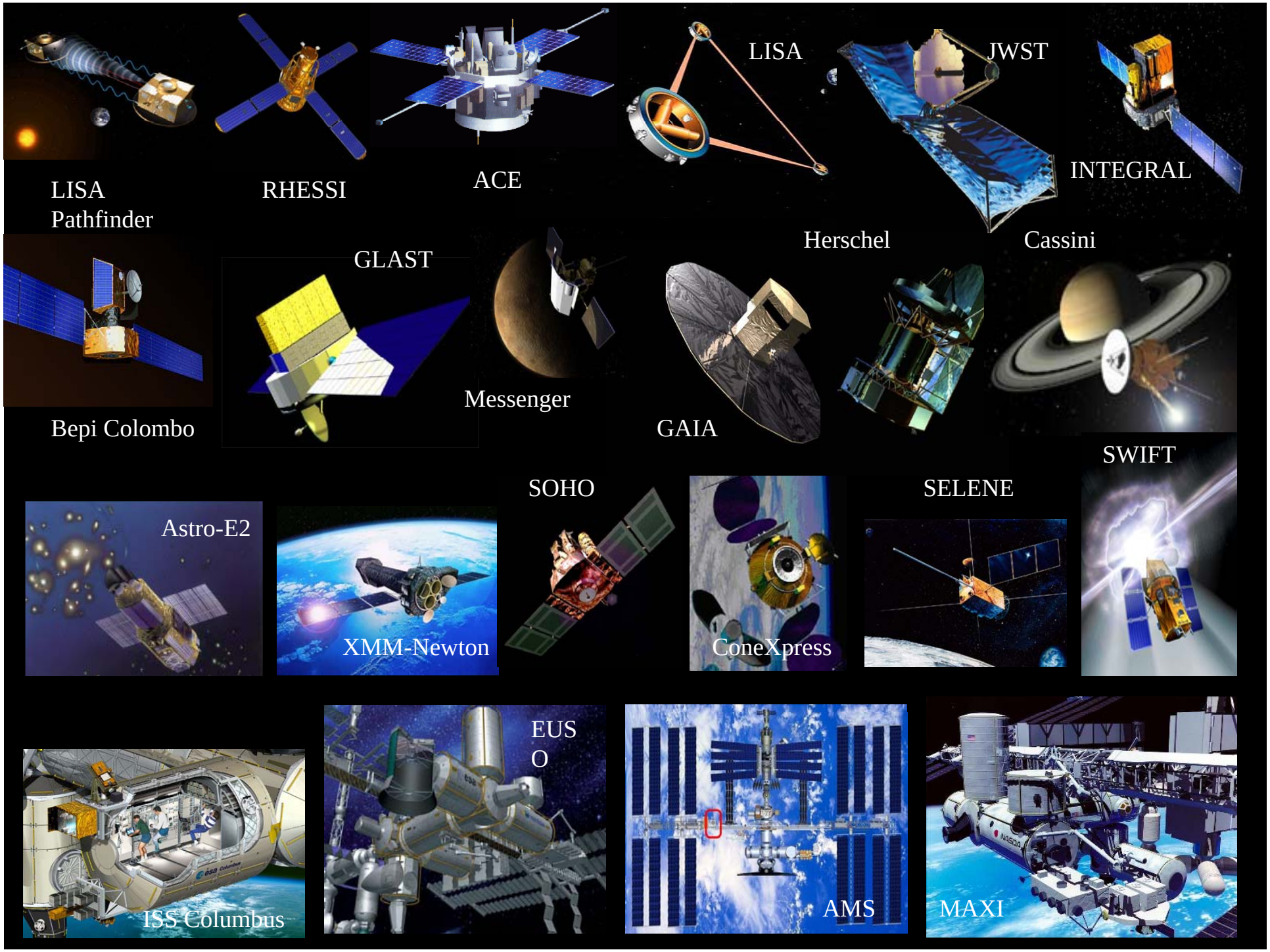
D. D. Frederiks[1], S. V. Golenetskii[1], V. D. Palshin[1], R. L. Aptekar[1*], V. N. Ilyinskii[1], F. P. Oleinik[1], E. P. Mazets[1], and T. L. Cline[2]

[1] Ioffe Physical–Technical Institute, Russian Academy of Sciences, ul. Politekhnicheskaya 26, St. Petersburg, 194021 Russia

[2] Goddard Space Flight Center, NASA, Greenbelt, MD 20771, USA

Received August 17, 2006




LISA Pathfinder
RHESSI
ACE
LISA
JWST
INTEGRAL
Herschel
Cassini
GLAST
Bepi Colombo
Messenger
GAIA
SWIFT
SOHO
SELENE
Astro-E2
XMM-Newton
ConeXpress
ISS Columbus
EUSO
AMS
MAXI

Geant4 usability

- Developments oriented to both science and engineering

- Interfaces / Geometry
  - Formats, interfaces: Geometry: GDML, STEP-SPE
  - CAD Geometry modelling: FASTRAD, ESABASE2
  - Geometry model database

- Tools
  - Detector / Shielding :SSAT, MULASSIS, GRAS
  - Planetary environments: PLANETOCOSMICS
  - Microdosimetry: GEMAT (QinetiQ), RADSAFE (Vanderbilt)

- Reverse MC
  - Prototype successful implementation - ongoing
    Laurent Desorgher, ESA REAT-MS project

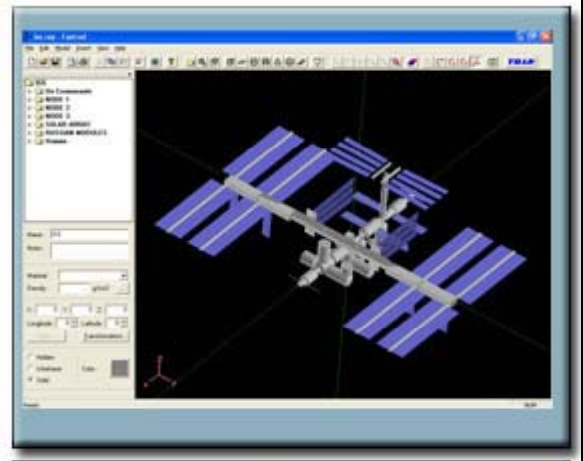
See talks by
Fan Lei - Friday Plenary session
TRAD – Aerospace Parallel session

CAD geometry interface
(and 3D modelling GUI)

- ESA REAT-MS contract
- CAD
  - Using G4TessellatedSolid by P.Truscott (ESA REAT_MS1)
  - Prototype used to require ST-Viewer commercial S/W (~300 USD)
    - GDML module reads ST-Viewer files
  - New: Direct GDML output from 3D modelling tools tools (ESA REAT_MS2)
    CAD STEP interface (and normal 3D models)

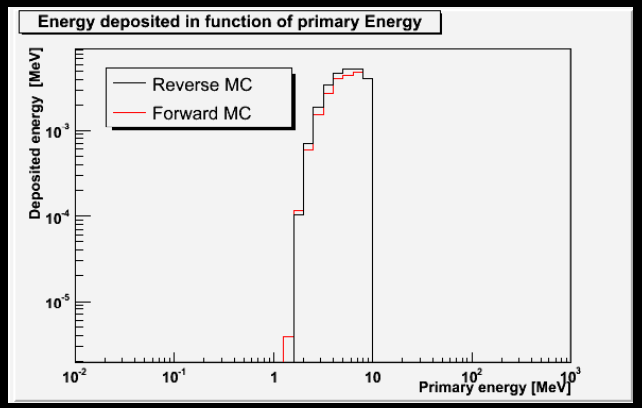
    FASTRAD and ESABASE2
- GDML (Witek Pokorski)
  - Tessellated shape, modular (multi-file) models, loops
- FASTRAD, ESABASE2
  - GUI for 3D modelling
  - GDML output

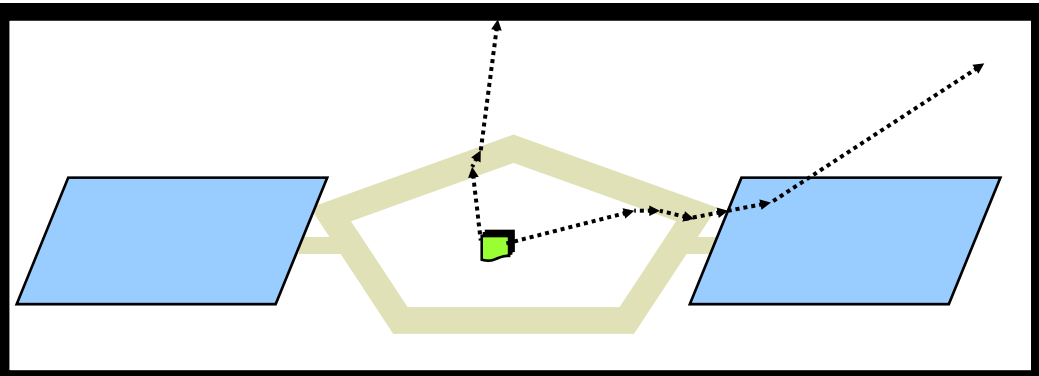
See FASTRAD talk in Aerospace parallel session



Modèle de la station internationale sur FASTRAD

Geant4 Reverse MC





Laurent Desorgher

Space IT and Uni. Bern

"Adjoint" technique [see e.g. Kalos, 1968]

- Transport analogous to the forward one, but backward
  - successive points are higher in energy, earlier in time

Feasibility study (REAT_MS 1)

- Only continuous energy loss and simple multiple scattering

Full implementation (REAT_MS 2)

- RMC in G4 for fast e- dose computation
- Backward simulation of :
  - e- ionisation with delta production, continuous energy loss and multiple scattering
  - Bremstrahlung, compton scattering, photo-electric effect
- Ongoing development

Proposed to be included in Geant4 release

Space community

- Geant4 Space Users' web page
  - Users, publications, news
  - http://geant4.esa.int
  - Feedback appreciated
- Space Users' Workshop
  - Tokyo University, Japan, 12-15 Feb 2008