Results from MARIE

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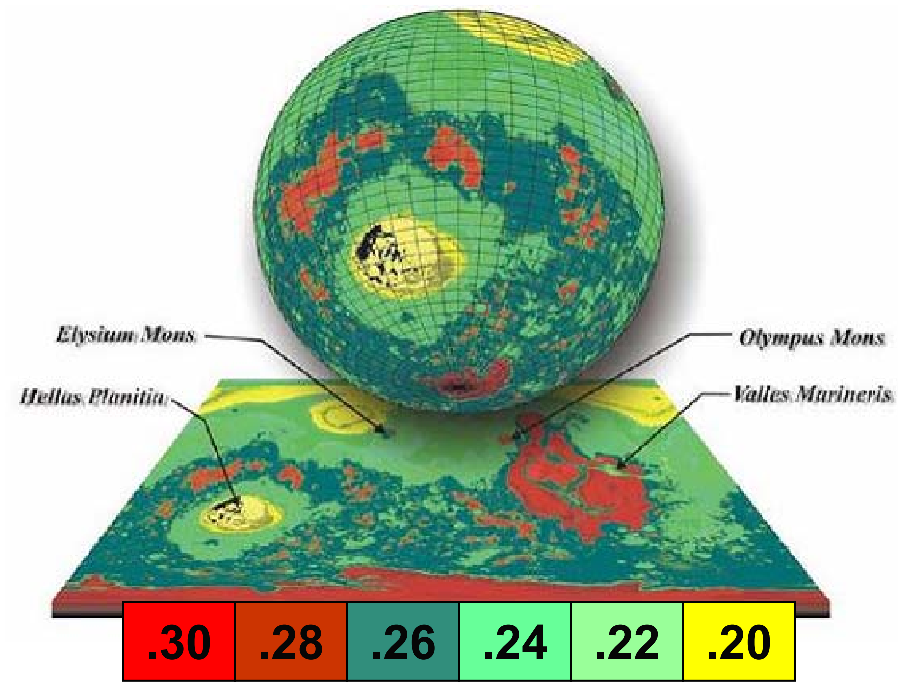
Odyssey Mission

- Launched April ‘01, reached Mars Oct. ‘01.
- Two-hour circular, polar mapping orbit established by Feb. 2002 – 5 p.m. day/5 a.m. night
  - THEMIS and GRS turned on.
- MARIE turned on March 2002, recovered after anomaly in cruise.

Mars Radiation Map – GCR

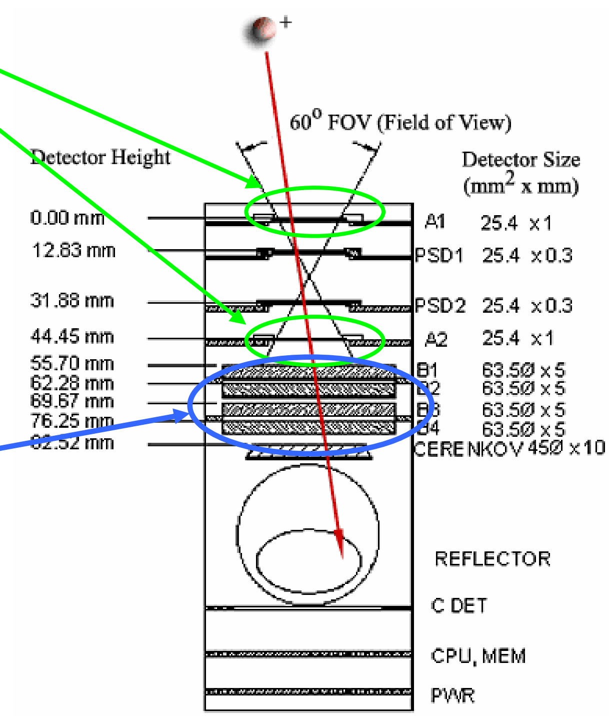
- Calculated skin dose on surface, using HZETRN model.
- Unshielded doses ~ 1000 times greater on Mars than Earth's surface.

Annual dose-equivalent (Sv/yr)



MARIE Silicon Detector Stack

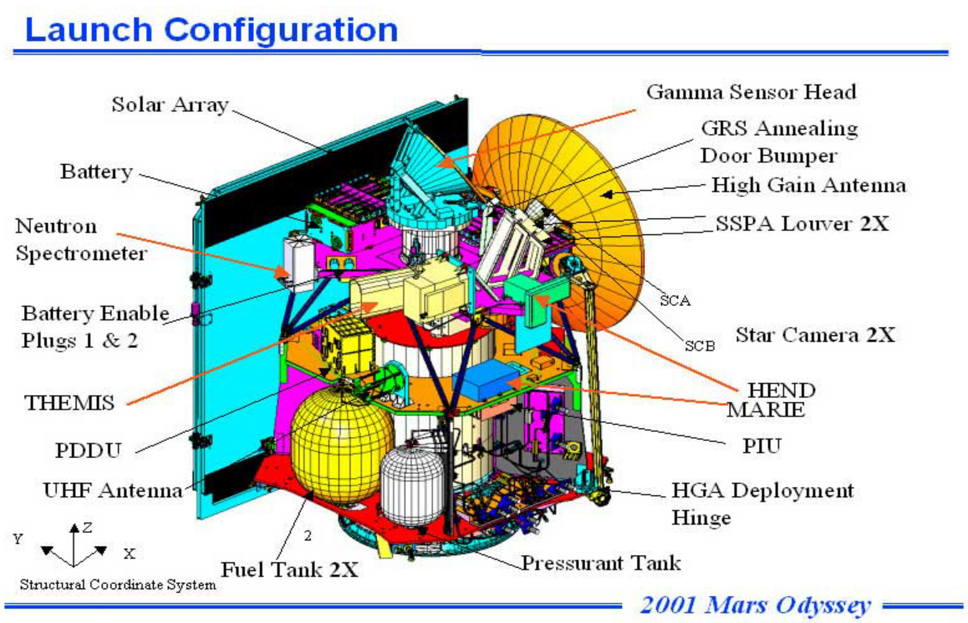
- 1-mm Si detectors A1 & A2 define trigger, 30° FOV cone, proton E > 30 MeV to reach A2.
  - No forward/backward distinction w/o Cerenkov.
  - On trigger, read all detectors.
- 5-mm thick Si detectors B1-B4 provide high-resolution dE/dx measurements.
- At these energies, dE/dx in silicon ∝ tissue dose.
- Counts in A1, A2, B1, B2 recorded, stored per minute.



MARIE's Dirty Laundry

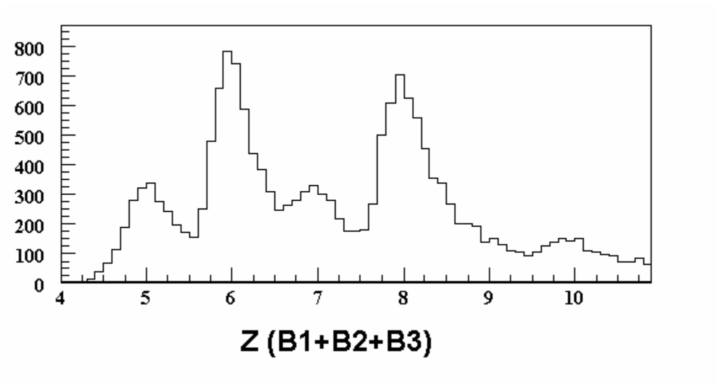
- Instrument has many problems
  - PSD's noisy, unreliable
  - Trigger threshold not well understood.
  - Cerenkov not quite dead but close (might be fixable)
  - Preamplifier gains too high, saturation at ~ 60 MeV deposited in A's & at ~ 320 MeV for B's.
  - Can only handle about 3 events/second.
    - Require Δt between events > 0.4 sec in analysis.
    - Substantial deadtime corrections especially for SPEs.
  - Only possible gain adjustment: very limited changes to bias voltages (lose-lose on signal:noise).
- Some improvements possible w/new software

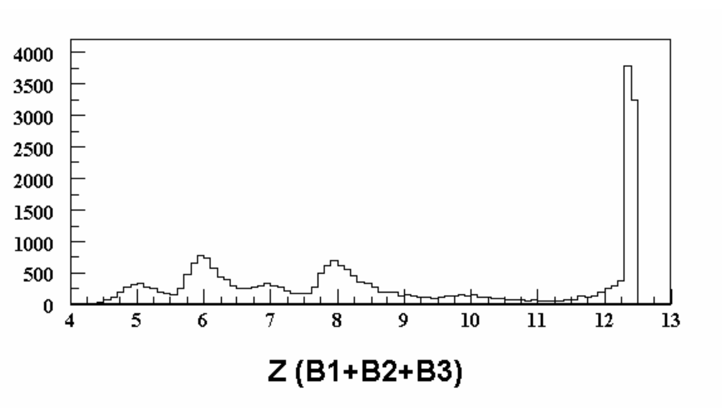
Orientation



- MARIE bore-sight in s/c anti-velocity direction.
- FOV perpendicular to nadir vector, does not include Mars.
- Positioning & orientation non-critical for isotropic radiation.
- Considerable mass (> 100 g cm^{-2}) behind.

Detection of GCR HZE





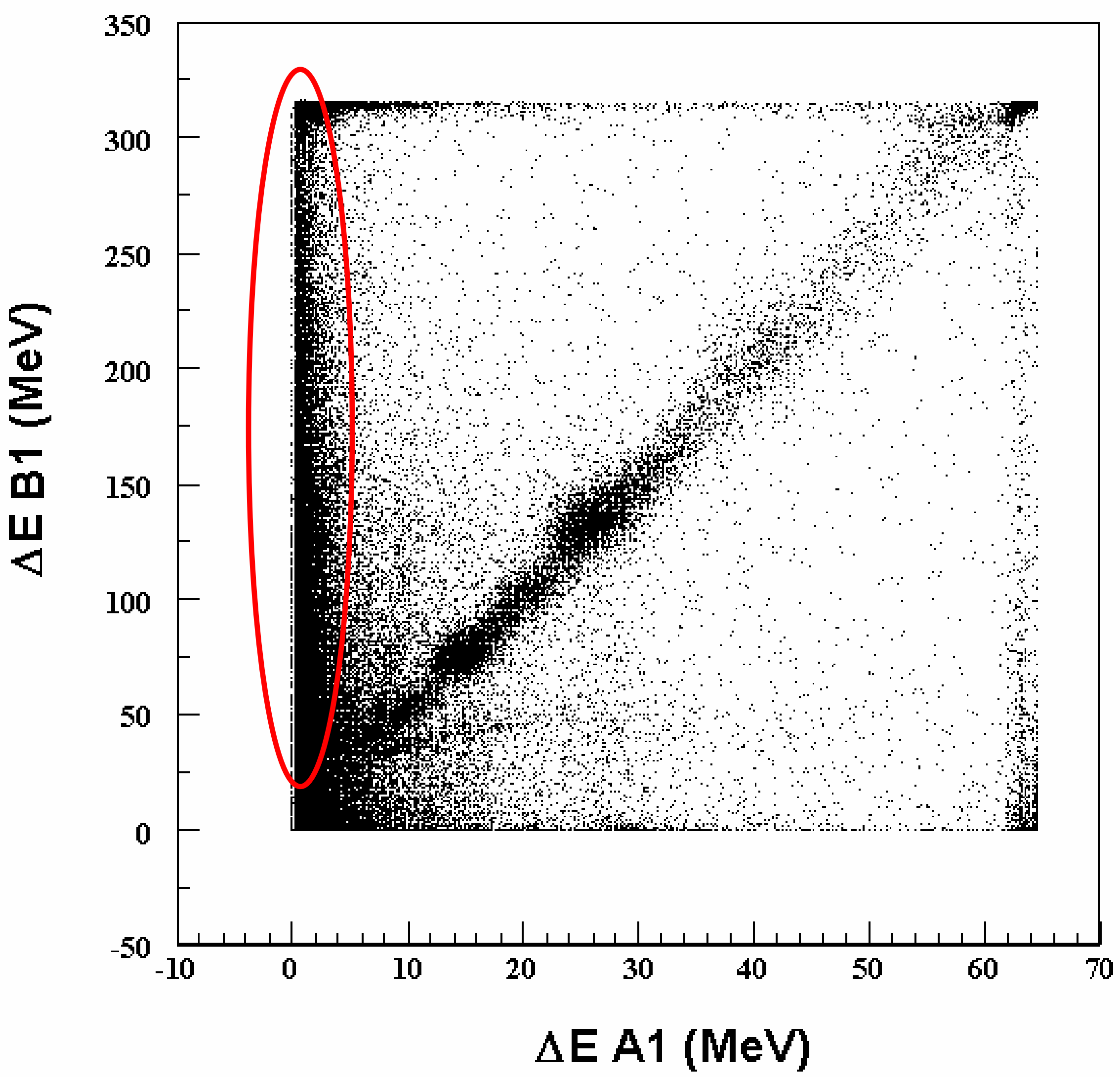
- See 1:2:1:2 ratio of B:C:N:O at “high” E (~1 GeV/amu)
- Upper limit for GCR ~ charge 11-12 for high E.
  - Higher Z or lower energy → saturation.
  - Stopping particles saturate if Z > 3.
  - Result: dose & dose equivalent systematically underestimated.
  - HZETRN predicts ~ 15% of dose due to Z > 12

Comparison with ACE/CRIS

- ACE/CRIS in near-Earth orbit. ACE reports flux of protons with E > 30 MeV, good match.
- Recent quiet-time flux ~ 0.57 cm^{-2} sr^{-1} s^{-1}
- MARIE " " " ~ 0.35 cm^{-2} sr^{-1} s^{-1}
  - Need to characterize MARIE geometry, trigger threshold, etc., better
- Can't yet directly compare heavy-ion fluxes due to different E sensitivity.
  - MARIE identifies high-E ions, ACE/CRIS low-E

Flux & Geometry Factor Issues

- Probable explanation for low flux result from MARIE: A1 & A2 have large “edge” regions of inefficient charge collection.
  - Test of A efficiency: select heavy ions in B1+B2, look at A.
  - Result – 40% of these events have small ΔE in A1 (poor correlation w/B signals).
  - Similar for A2, 30% bad.



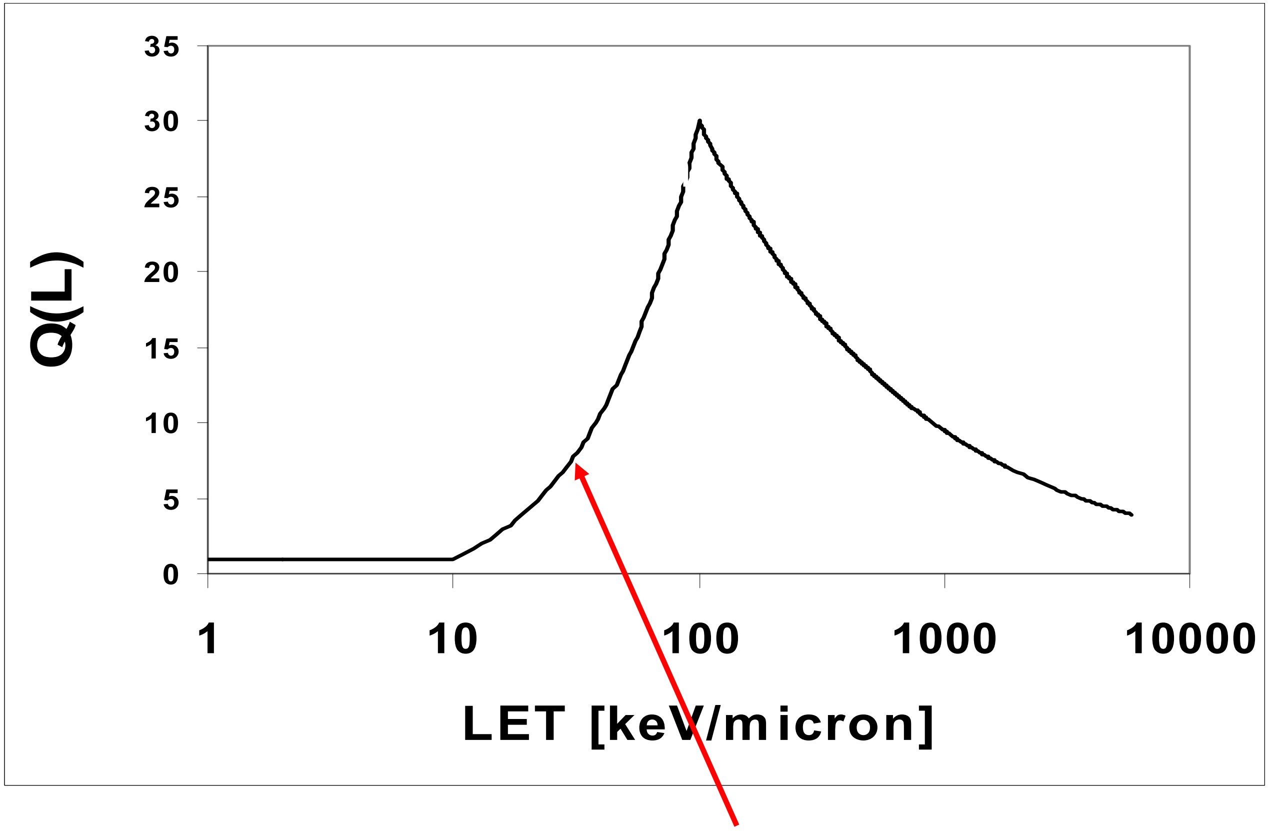
Selected Z > 4 in B2 vs. B1 scatter plot.

~40% of events in indicated region.

Flux & Geometry Factor, more

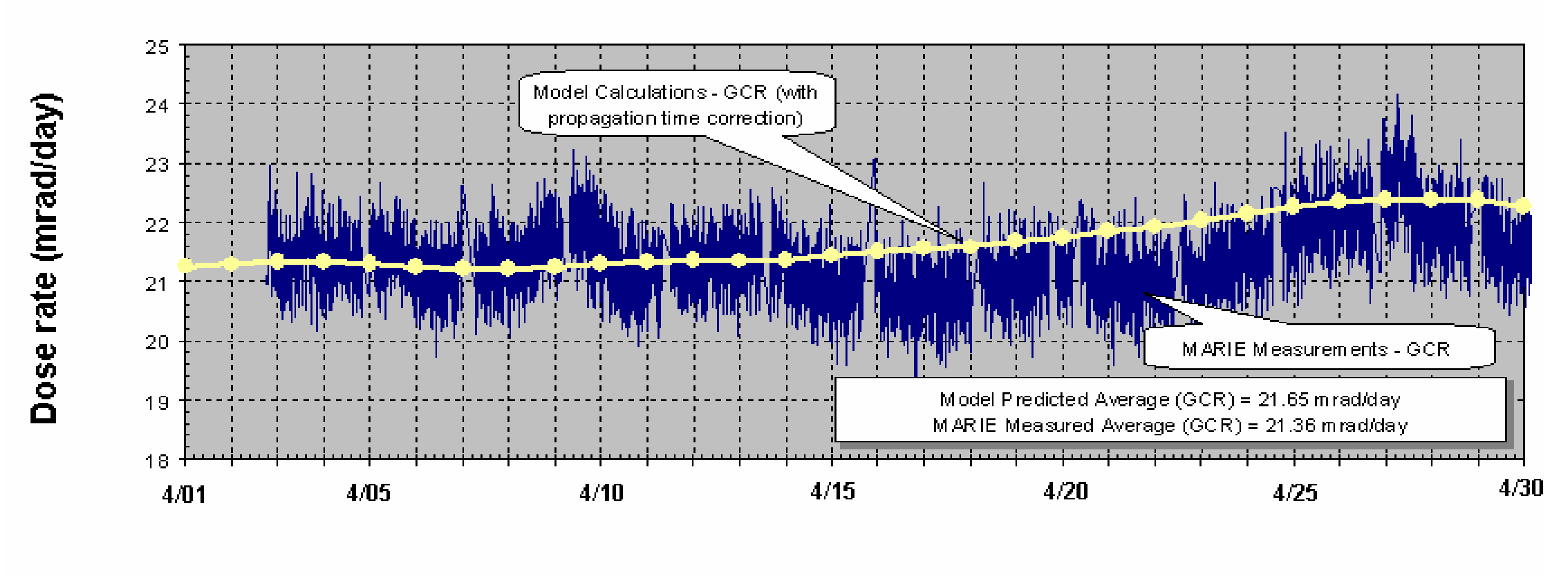
- Possibly, significant numbers of protons are missed due to trigger threshold.
  - Recent study suggests we see protons up to 1 GeV or higher energy.
  - Threshold was set by trial-and-error to get acceptable data rate.
  - No ground data to tell us correlation between digital control value & true energy.

Q And Saturation Problem



Everything above charge 12 (LET > 30 keV/μm) registers as charge 12 (LET = 30 keV/μm).

Measured Dose Rate vs. HZETRN



- Quiet-time dose agrees well w/model.
- Data normalization uncertain to ±20%.

GCR Dose Equivalent

- GCR dose ~ 210 μGy/day
- 16-month avg. → 0.39 ± 0.14 Sv/yr.
  - ~ 10% from SPEs.
- Used <Q> = 5 from HZETRN.
  - Data <Q> = 3.5 due to saturation problem.
  - Can bracket <Q> w/data*, find 3.5 < Q < 7.
    - * All events with LET > 30 keV/μm assigned LET=100 keV/μm.

First Detailed SPE Data From Mars

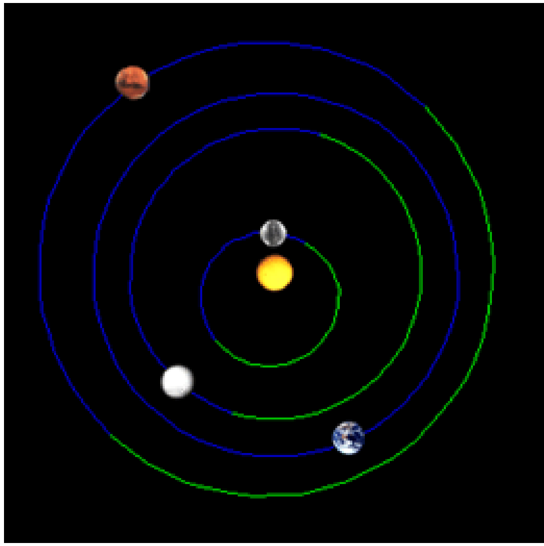
- Several SPE's since March 2002.
- Earth-Sun-Mars angle has varied, was 100° to 180° for 2002.
  - Observation of "back-sided" SPEs.
- Later in '03, Earth & Mars magnetically connected to same region on sun.
- Compare timing, intensity to GOES.

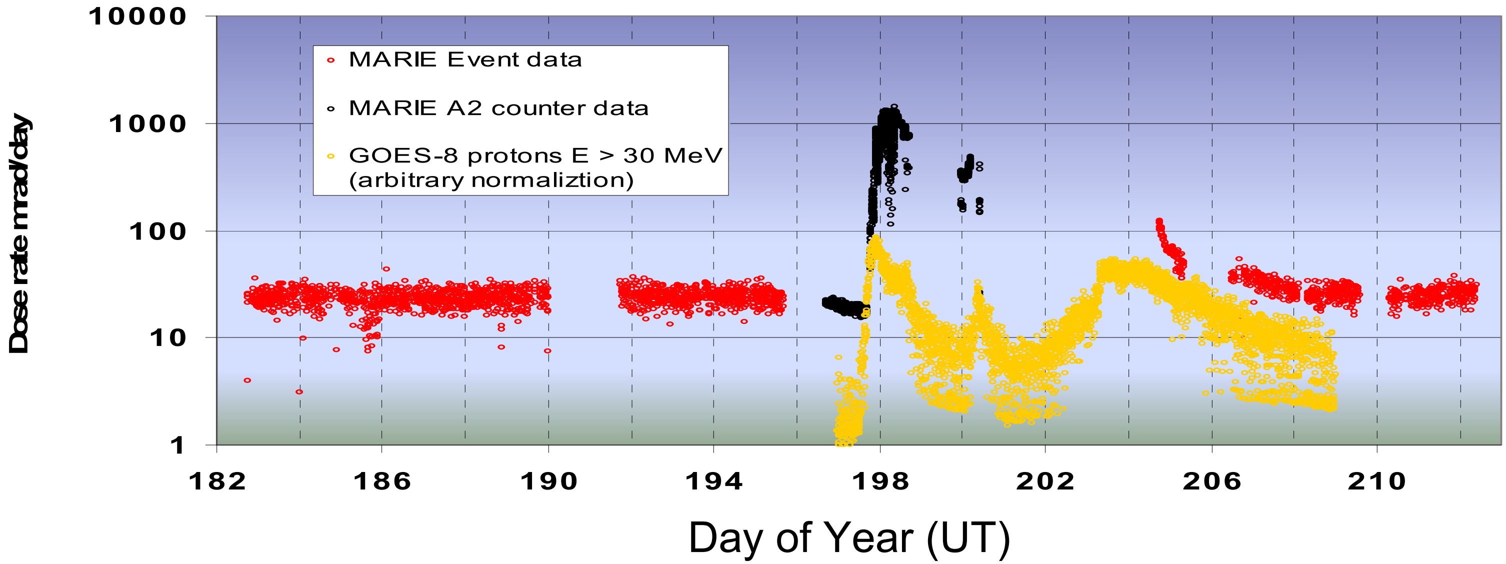
Earth-Mars Comparisons

- MARIE has seen:
  - Events when nothing was seen at Earth.
  - Events well-correlated w/near-Earth observations.
  - Times of no enhancement when an event was observed near Earth.

July 2002 Event

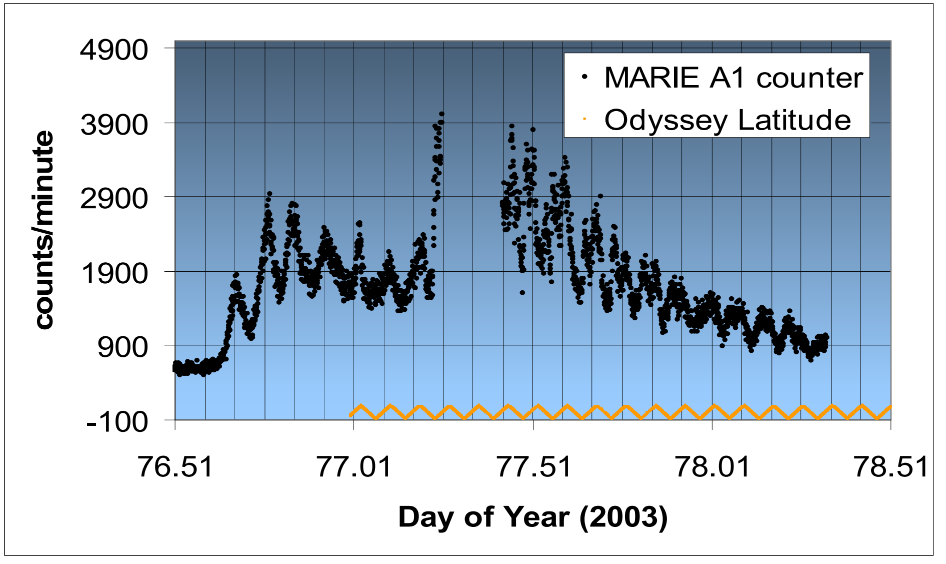
- MARIE & GOES-8 correlated despite nearly 180° Earth-Sun-Mars angle. Dose rate up ~ factor of 50.
- MARIE data acq swamped (counters o.k.).



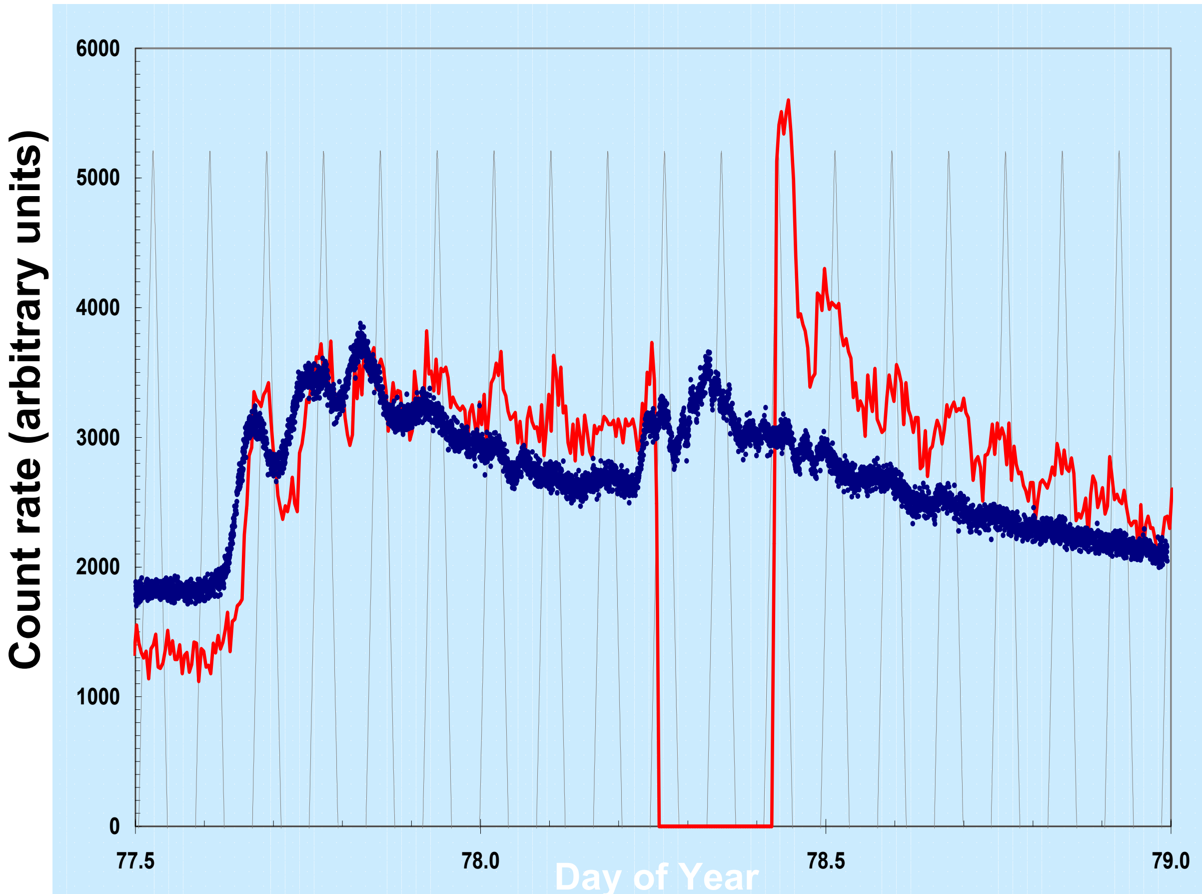


Two-hour Structure in SPE Intensity

- Periodic structure related to Odyssey's orbit – regular peaks North Pole + a few others.
- Not yet understood.
- Also seen by GRS & Mars Global Surveryor electron reflectometer.

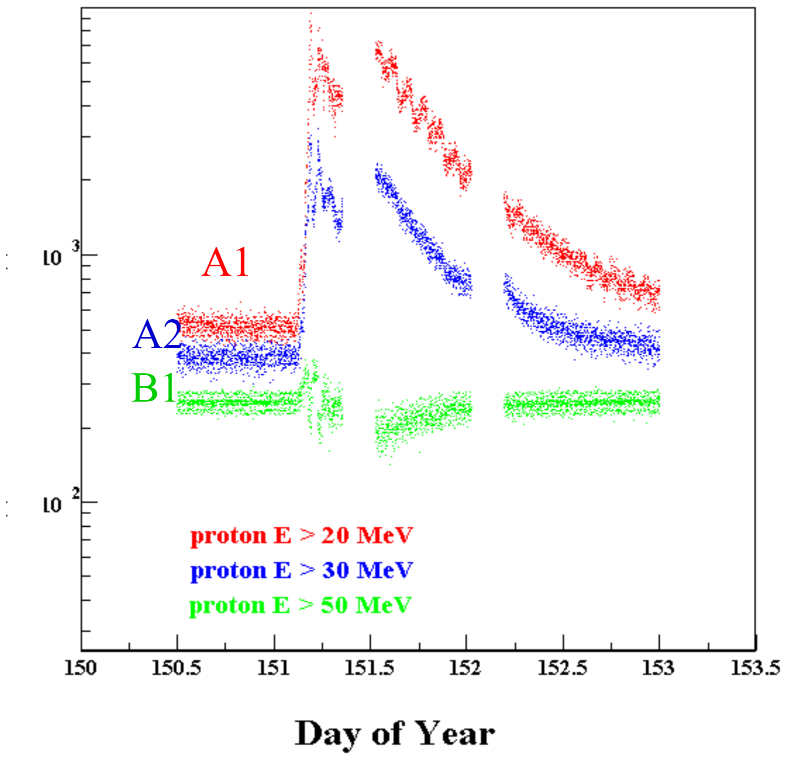


MARIE & GRS ULD



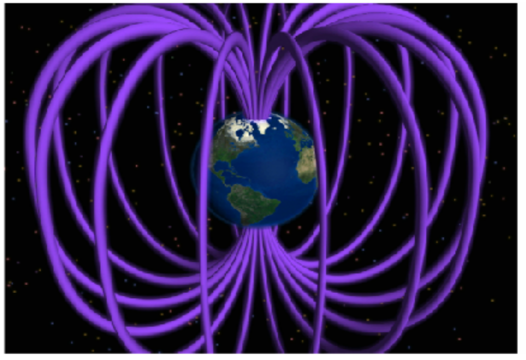
- ULD = GRS gamma crystal upper level discriminator.
- Threshold energy unknown.

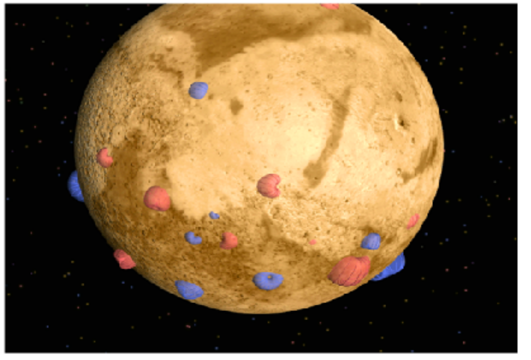
Oscillations vs. energy



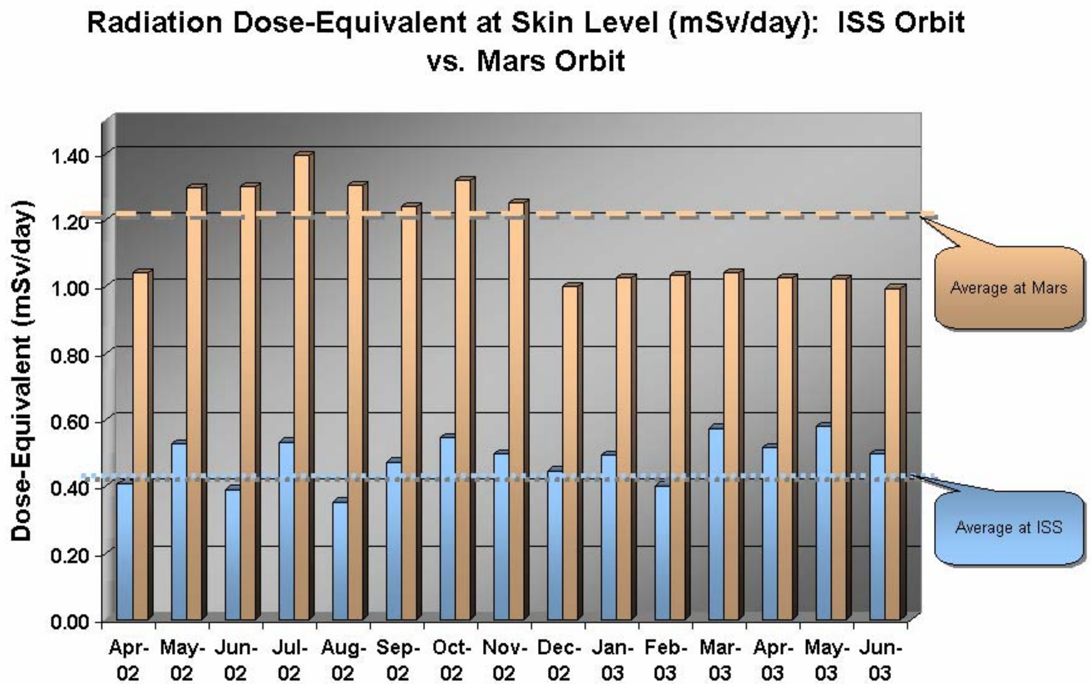
- A1 counter requires proton E > 20 MeV.
- A2 requires E > 30 MeV.
- Oscillations strongest in 20-30 MeV protons, esp. later in event.

Relation to Magnetism?



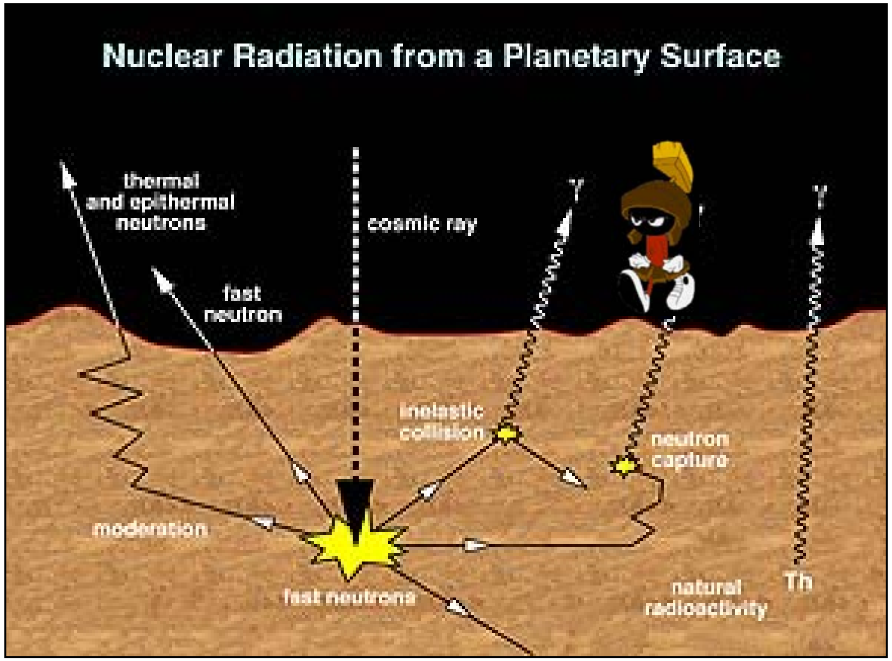


- Martian magnetism is complicated.
- Field lines from surface extend to high altitudes, strength comparable to IMF.
  - Mars Global Surveyor magnetometer – superb data set thanks to extended aerobraking campaign.



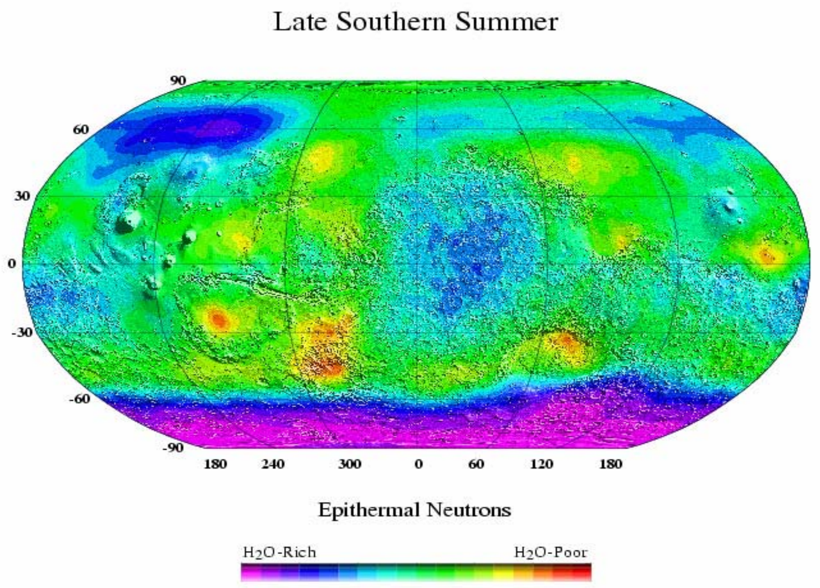
- H ~ 2.5× larger in Mars orbit than ISS.
  - ISS orbit inside geomagnetosphere + shielding.
- July ’02 SPE contributed only ~ 35% to H.
  - Q=1 for protons.
  - Contribution even less w/shielding.

GRS Physics



- Measure γ-rays & neutrons coming up.
- Made by nuclear interactions of incident protons.
- Combined γ + neutron data reveals elemental composition of top meter of soil.

GRS discovery of polar water ice



- H signal in γ-ray spectrum correlates w/lack of neutrons.
- Don't see H at north pole due to CO_2 cap.
- Seasonal, reverses in Northern Summer.

Neutron dose

- Neutrons on surface from below & above.
  - GCR + soil → nuclear interactions produce a neutron flux (upward-going).
  - GCR + atmosphere → nuclear int’s produce neutrons (downward-going).
- GRS data w/model (MCNP) can be used to estimate dose of upward neutrons.
- NASA-LaRC model predicts ~ 0.02 Sv/yr.
- Detector on lander should have neutron sensitivity – possibilities for ’07, ’09.

Mars Mission Risk Assessment

- Scenario: 1 yr. transit, 2 yrs. on Mars.
- Mitigating factors on surface:
  - Charged particles from above only (4π in transit).
  - Atmosphere provides some shielding, esp. from SPE.
- Worst exposure is in transit.
- Total ~ 1 to 1.5 Sv, dominated by GCR.

Summary

- MARIE is working well, returning first detailed radiation data from Mars.
  - Improvements planned (event rate, C det., etc.).
- Good agreement between HZETRN and dose rate during quiet time.
  - Data normalization still uncertain to ± 20%.
- Nominal mission ends 8/04, extension likely.
  - Spacecraft in great shape, lots of fuel.
  - Solar activity declining, minimum in ’06-07, GCR increase expected.
  - Mission could go into ’08.