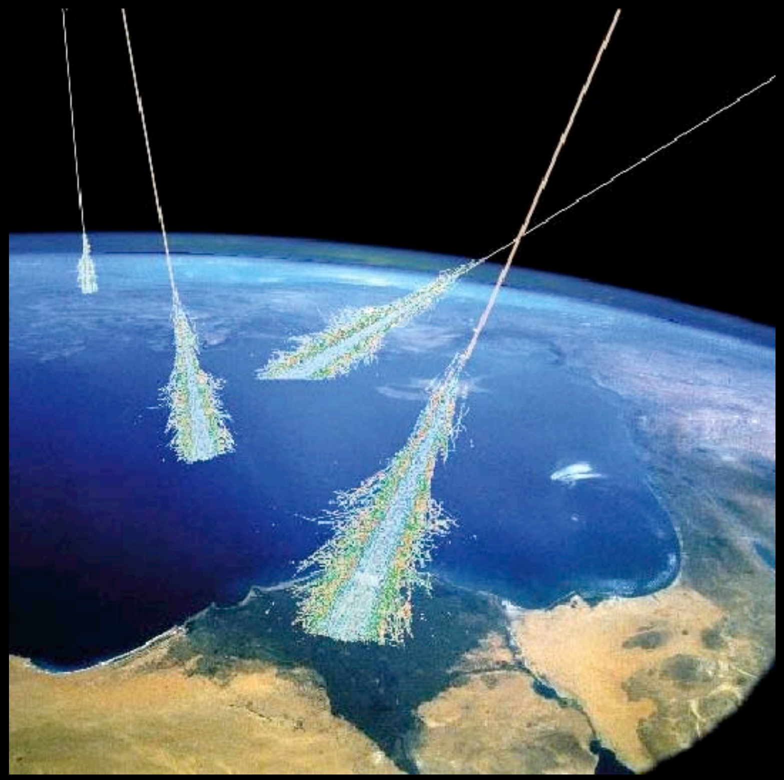
Atmospheric Effects of High Energy Cosmic Rays



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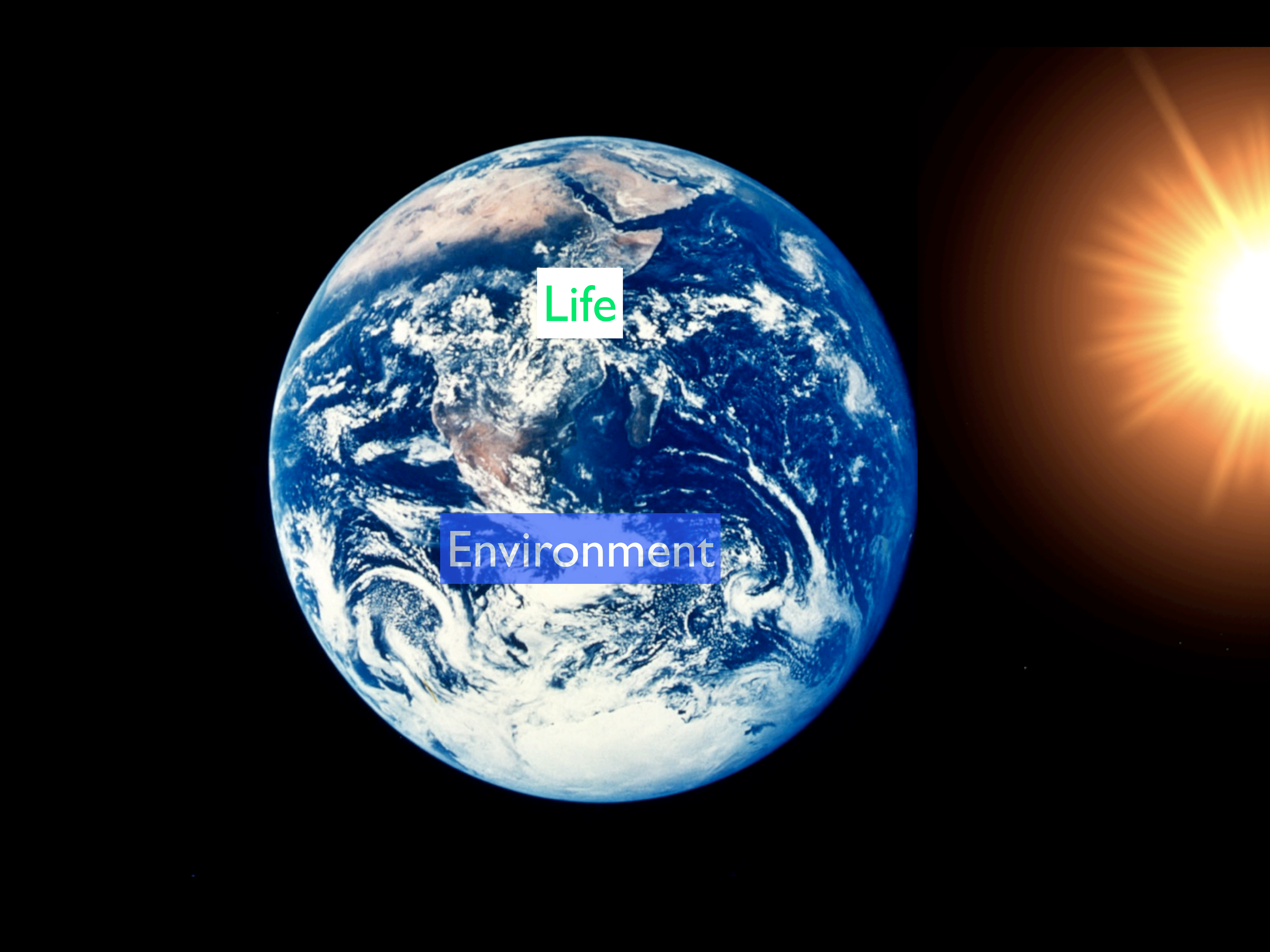
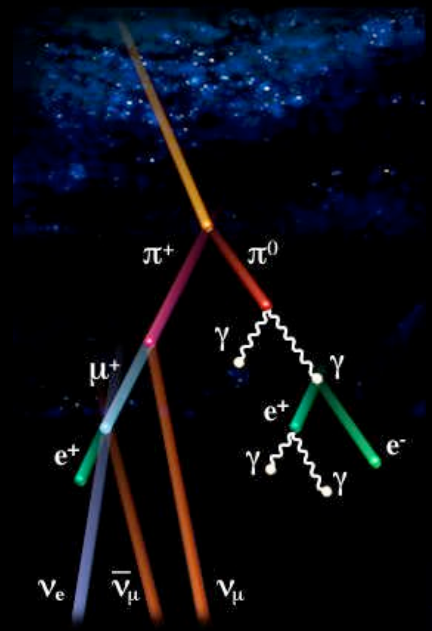
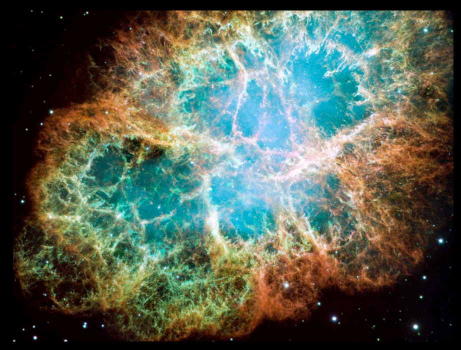
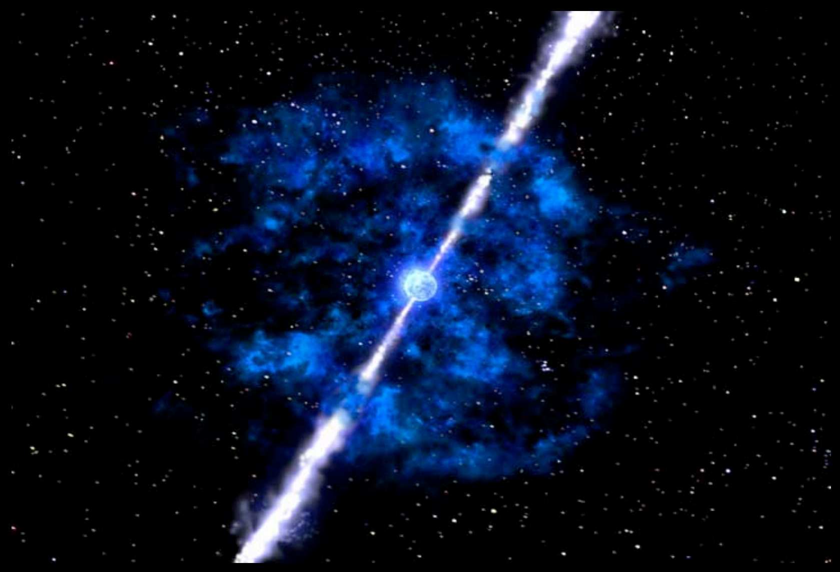
Life
Environment


Life
Environment

Environment





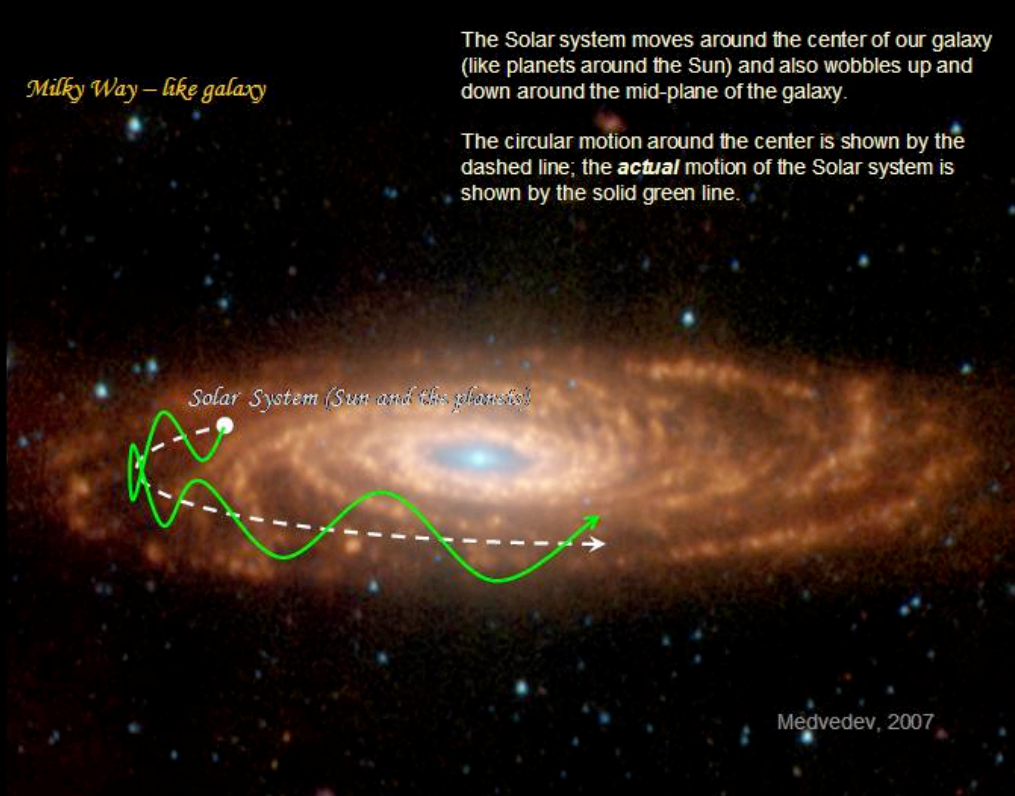


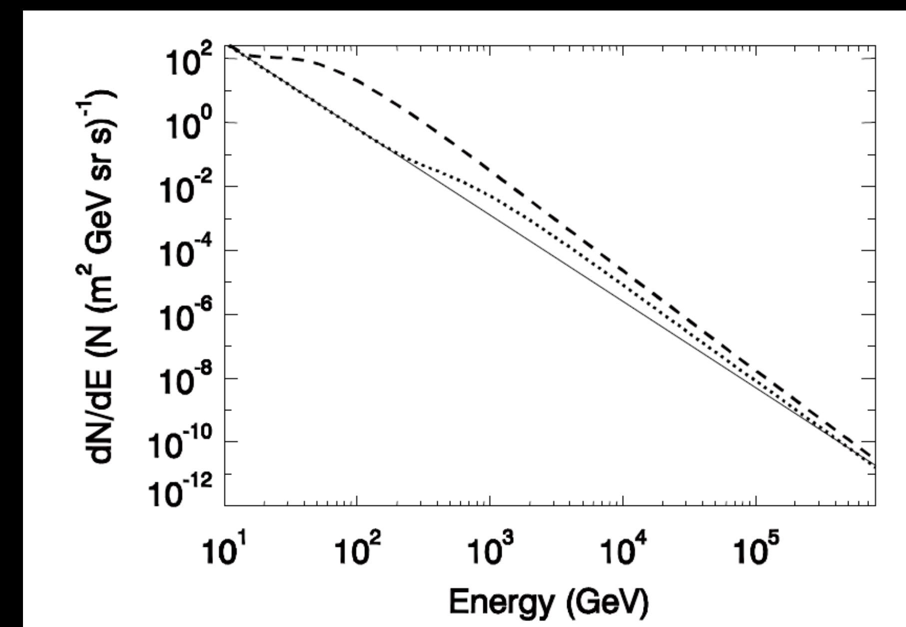
- SN ~ 10^{44} J, CR upto 10^{15} eV. ^{60}Fe evidence of a nearby SN. Incorrect CR treatment.

- GRB ~ 10^{47} J, CR upto 10^{18} eV. Once every 170 My. A 3 kpc burst. Previous modeling with only photons.

- Extragalactic Shock Model - Enhancement between 10 GeV - 1 PeV. Periodicity: 62 Myr.

Periodicity in terrestrial biodiversity





Enhanced spectra in the extragalactic shock model (Medvedev and Melott, 2007).

Melott and Bambach, 2010, "An ubiquitous ~62 Myr periodic fluctuation superimposed on general trends in fossil biodiversity: Part I, Documentation", in press at Paleobiology.

Melott A., "Long-term cycles in the history of life: Periodic biodiversity in the Paleobiology database" PLoS ONE, 2008. 3(12).

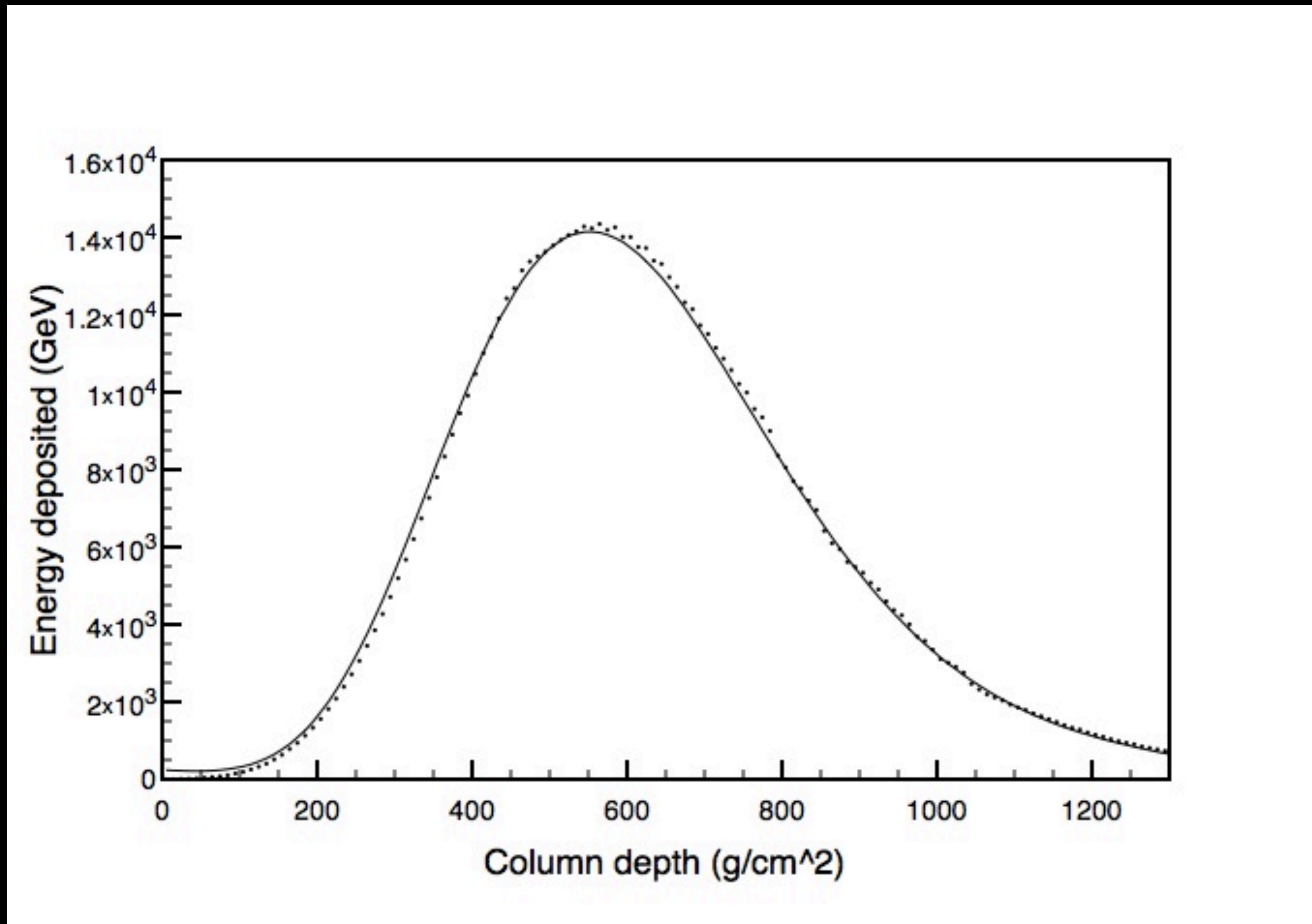
Rohde, R. and R. Muller, "Cycles in fossil diversity". Nature, 2005. 434(7030): p. 208-210.

Medvedev M., Melott A., "Do extragalactic cosmic rays induce cycles in fossil diversity?" Astrophysical Journal (2007)

CORSIKA Simulations

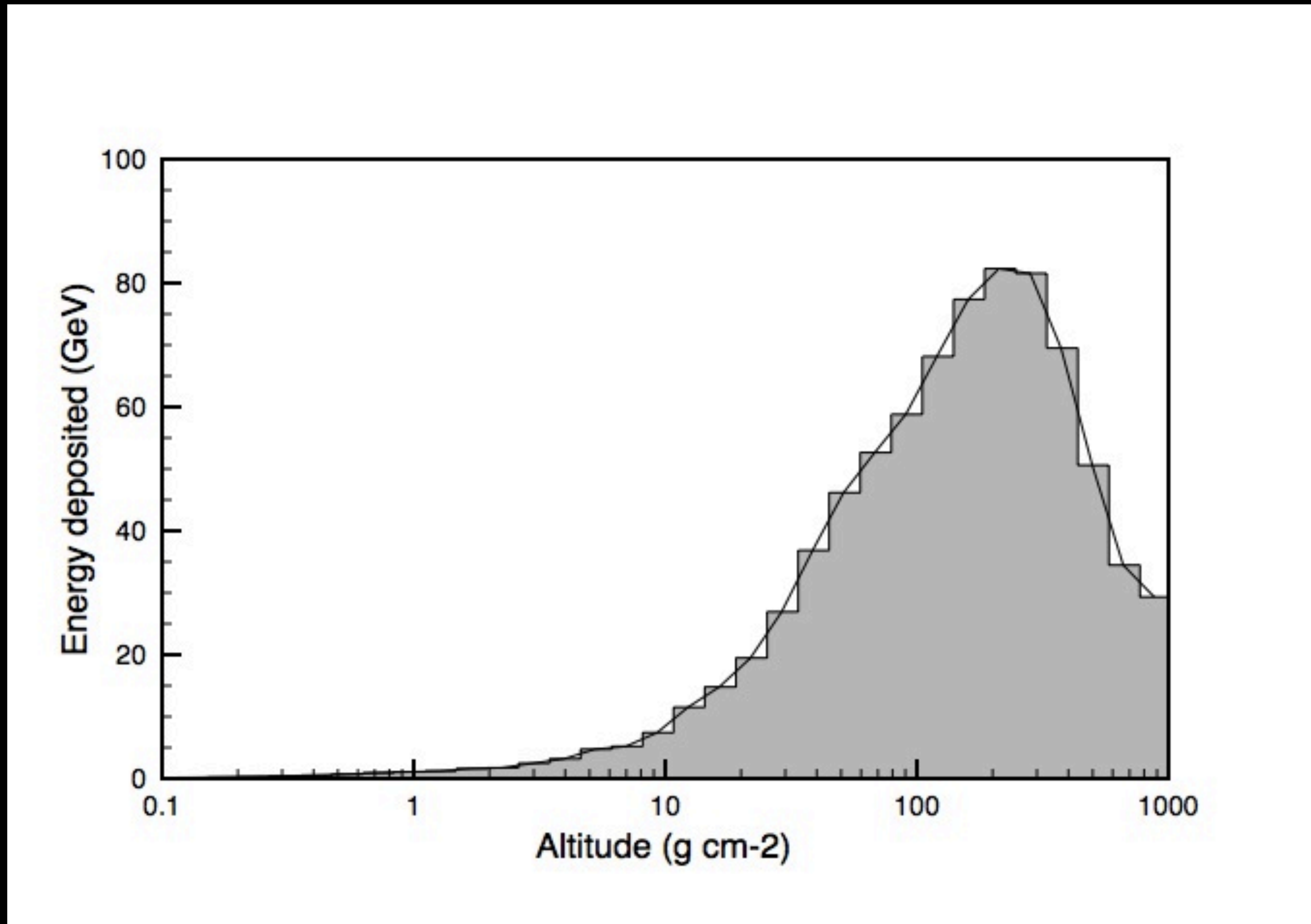
~ 7×10^5 showers

134,000 hours of supercomputer time

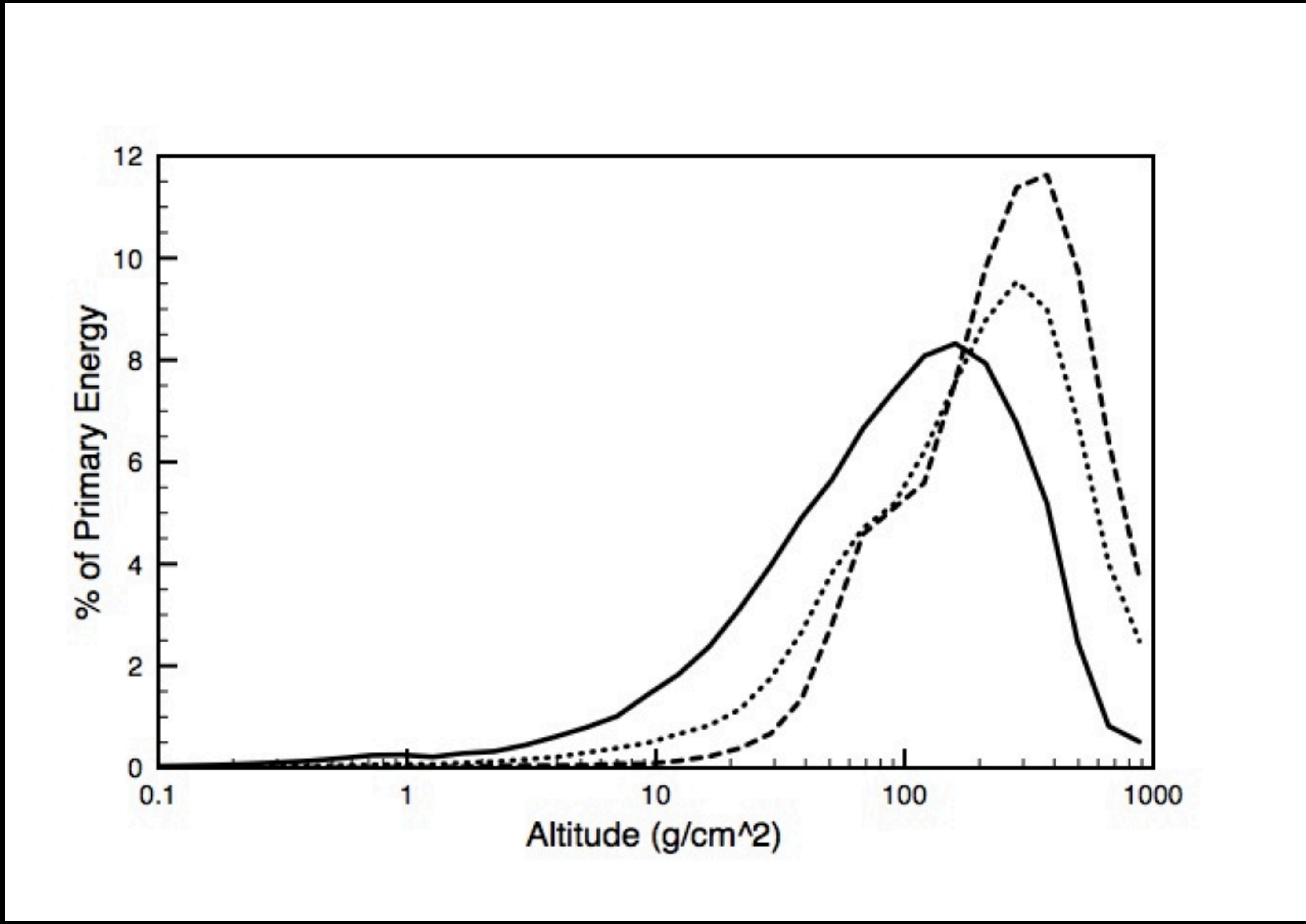


1 PeV shower: Energy deposition as a function of column depth.

Atri D., et al., "Lookup Tables to Compute High Energy Cosmic Ray Induced Atmospheric Ionization and Changes in Terrestrial Atmospheric Chemistry" (Journal of Cosmology and Astroparticle Physics, 2010).



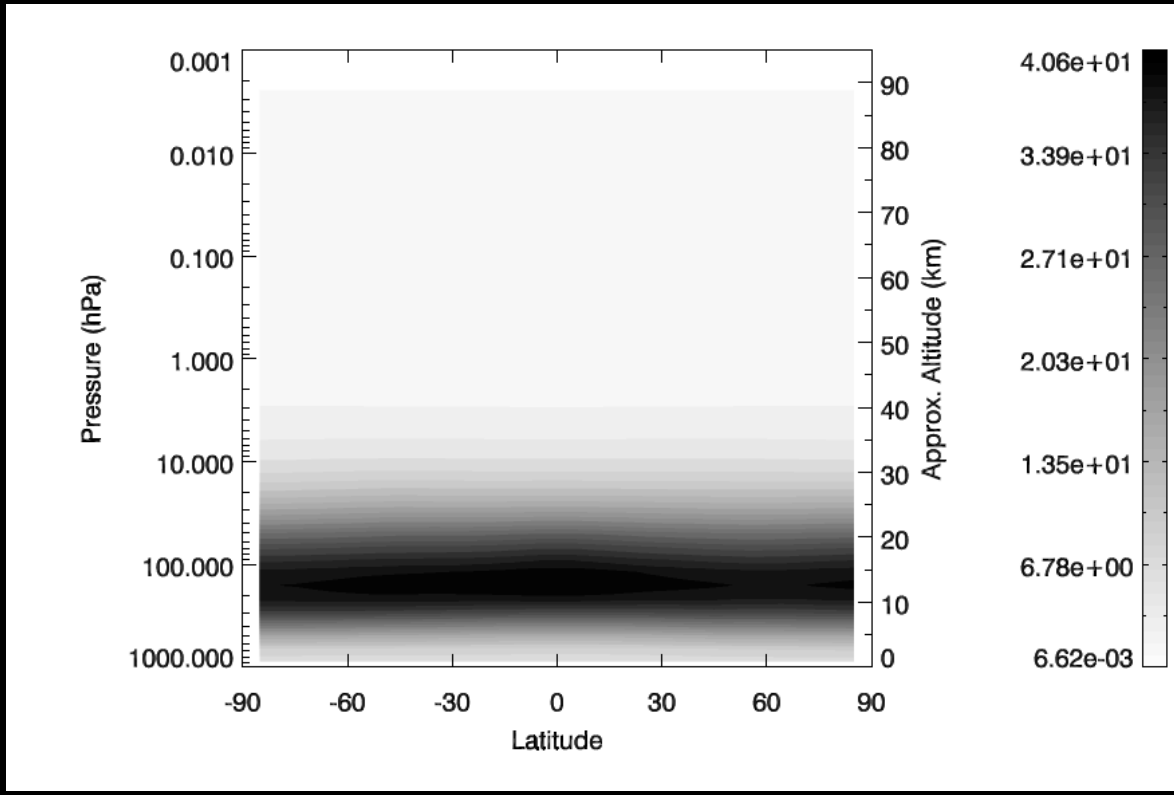
The averaged energy deposition profile is interpolated to work as an input in the NASA GSFC 2D atmospheric modeling code.



Energy deposition due to primaries of energy 100 GeV (solid) and 10 TeV (dotted) and 1 PeV (dash). [Atri et al. 2010, JCAP]

Horizontal axis is the altitude in g cm^{-2} and the vertical axis gives the energy deposition in % of primary energy.

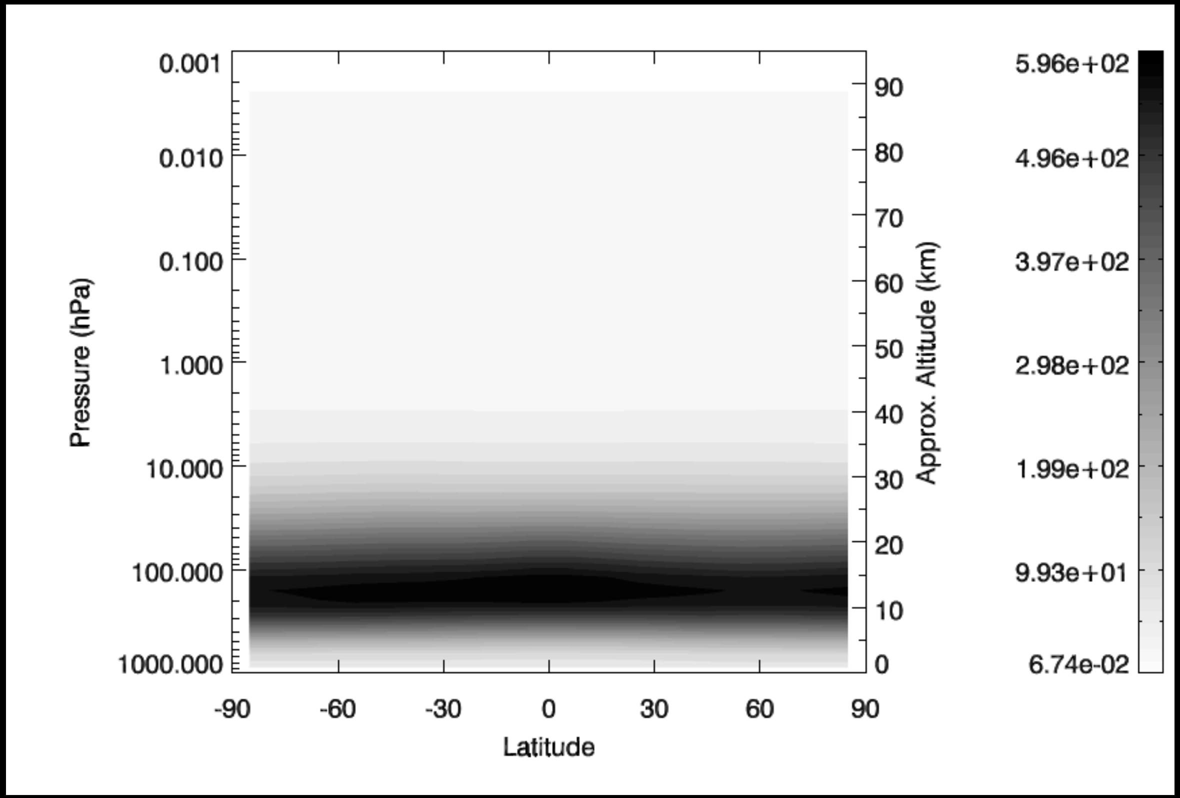
As expected, the peak of the energy deposition profile of the higher energy primary is deeper in the atmosphere.



Case 1

Global enhancement by a factor of ~3.

Ion pairs per cubic cm per sec



Case 2

Global enhancement by a factor of ~30.

Atmospheric Chemistry

NASA GSFC 2D photochemical code.

NOx compounds catalyze the conversion of O_3 to O_2. This leads to ozone depletion, which makes way to the harmful UVB (280-315 nm) radiation which is known to damage DNA and proteins.

$$NO + O_3 \rightarrow NO_2 + O_2$$
$$NO_2 + O \rightarrow NO + O_2$$
$$O_3 + O \rightarrow O_2 + O_2$$

- Harmful effects of UVB also include erythema (sunburn), skin cancer and mutations leading to other diseases.

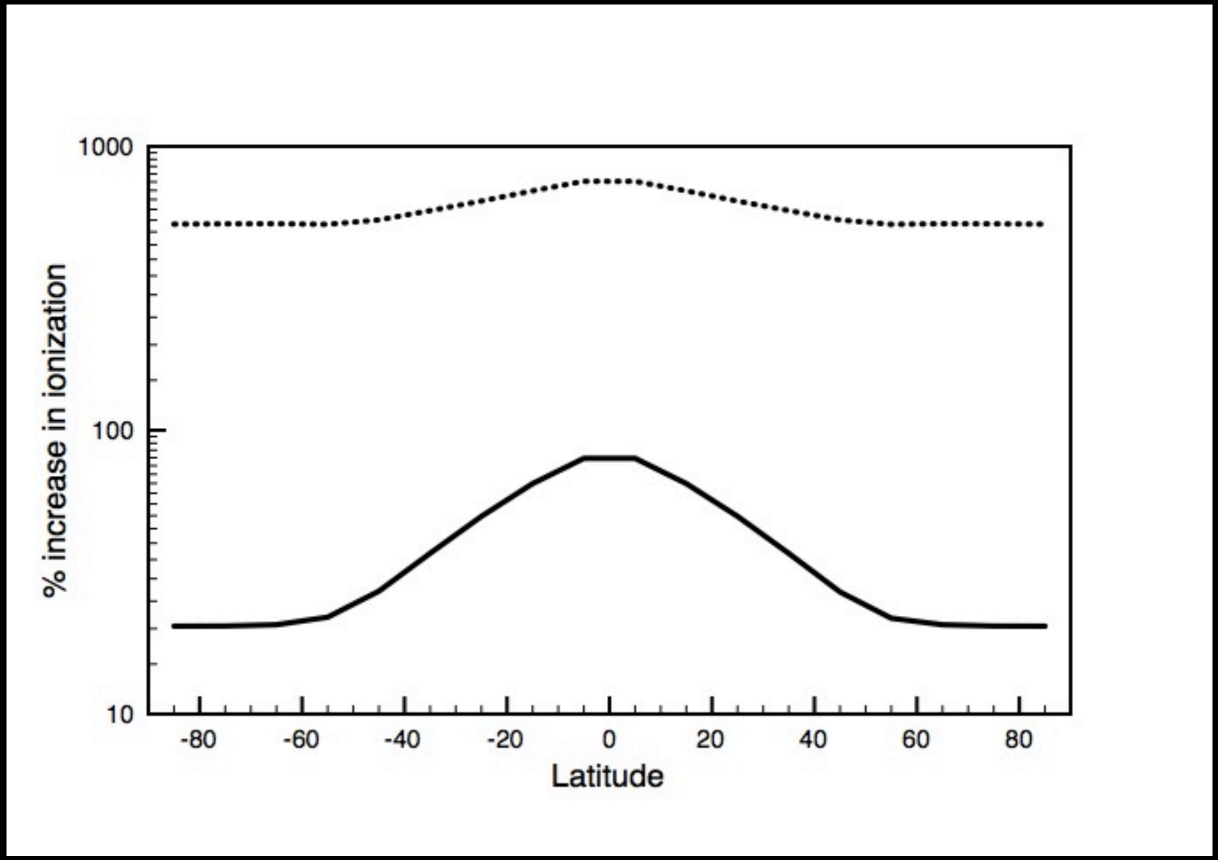
- An increase in flux of UVB can be harmful to a variety of organisms such as phytoplanktons which form the base of the food chain.

Ozone depletion

- Case 1: The magnitude of the stratospheric O_3 depletion and resulting enhanced solar UVB is smaller than that experienced now from anthropogenic causes.
- Case 2: The effect is greater, with a globally averaged fractional depletion of about 6% in O_3 with localized maxima up to 48%.
- The reduced O_3 allows more UVB, 280-315 nm to reach the surface. The levels we find in the case 2 simulation are larger than those noted from current anthropogenic O_3 depletion (3% global average).
- UVB has a wide variety of damaging effects on organisms. (DNA gamage, skin diseases etc.)

Melott, A. L. et al. "Atmospheric consequences of cosmic ray variability in the extragalactic shock model: II Revised ionization levels and their consequences" Journal of Geophysical Research, in press.

Changes in the low altitude cloud cover?



Percent increase in atmospheric ionization for case 1 (solid) and case 2 (dotted) at 3 km altitude. The enhancement is greater at the equator than the poles because many normal cosmic rays are guided toward the poles by the geomagnetic field, while the cosmic rays in the extra- galactic model are typically too energetic to be redirected.

Case 1: 40 %
Case 2: x 6

Atri D. et al. 2010 “Can periodicity in low altitude cloud cover be induced by cosmic ray variability in the extragalactic shock model?” (Submitted)

Calculating terrestrial effects from any astrophysical source

1. Atmospheric ionization from primaries in the 10 GeV - PeV range.

2. Extending this work up to EeV range.

3. Flux of secondaries on the ground up to PeV.

4. Analysis of exposure from other sources.

5. Data available to the community.