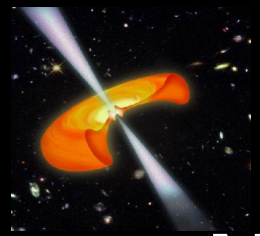

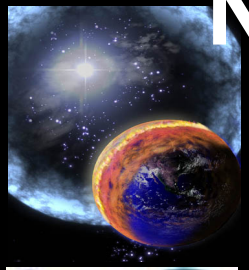

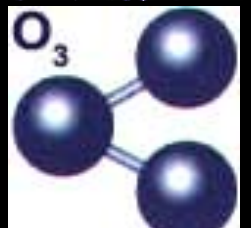

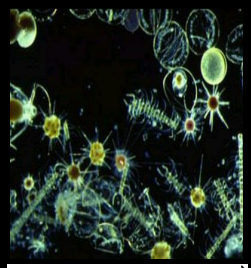

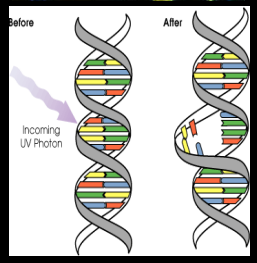

Astrophysics and Extinctions: New rate estimates for potentially lethal ionizing radiation events

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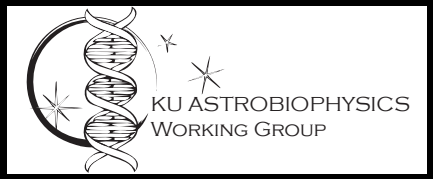


Work supported by NASA grant No. NNX09AM85G

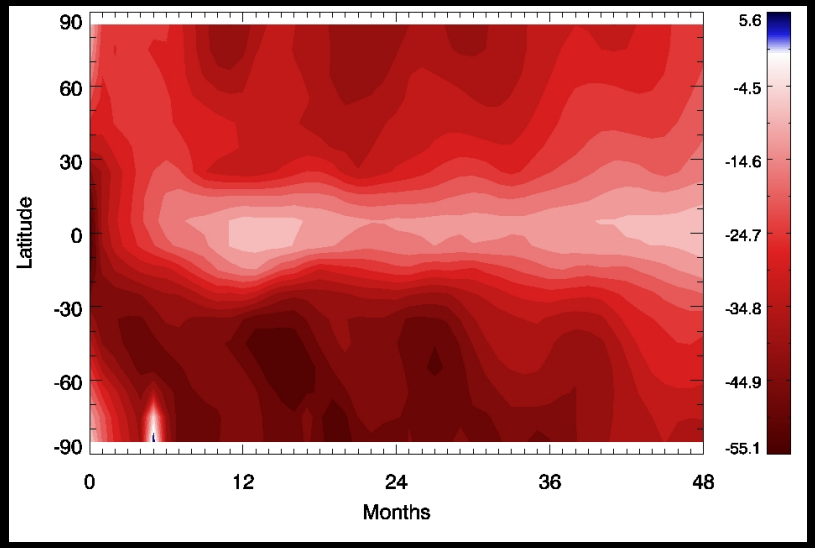
Astrophysical Radiation & Earth

- High energy radiation:
  - X-rays, gamma-rays
  - Cosmic rays – charged particles (protons)
- Effects:
  - Atmospheric chemistry changes
    - Nitrogen dioxide “smog”
    - Stratospheric Ozone depletion
  - High-E CRs => energetic muons

Long-Term Consequences

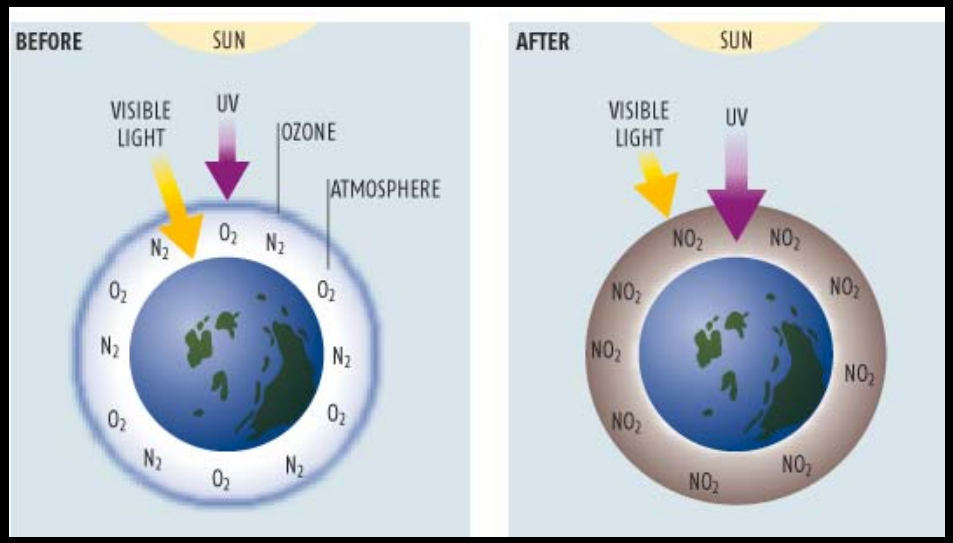
- Life at the surface sees enhanced UV for years
  - Phytoplankton and other surface dwellers hit hardest
  - Food-web impact
  - Mass Extinction?

O_3 depletion, latitude v. time



Thomas et al. 2005, ApJ, 634, 509

Cooling due to opacity of NO_2 ?

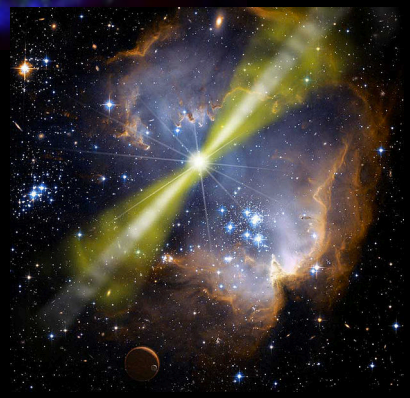


New Scientist, Sept. 2003

A Range of Sources

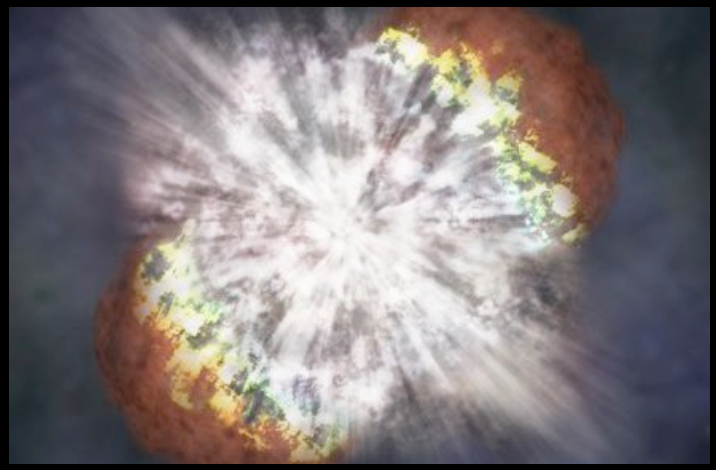
In order of *increasing* energy and *decreasing* frequency:

- Solar flares & CMEs
  - Primarily protons
  - Up to 10^{25} J total
- Supernovae (various types)
  - X- and gamma-ray photons
  - CRs (partly location dependent)
  - Up to 10^{46} J
- Gamma-Ray Bursts (2 types)
  - X- and gamma-ray photons
  - Up to 10^{47} J

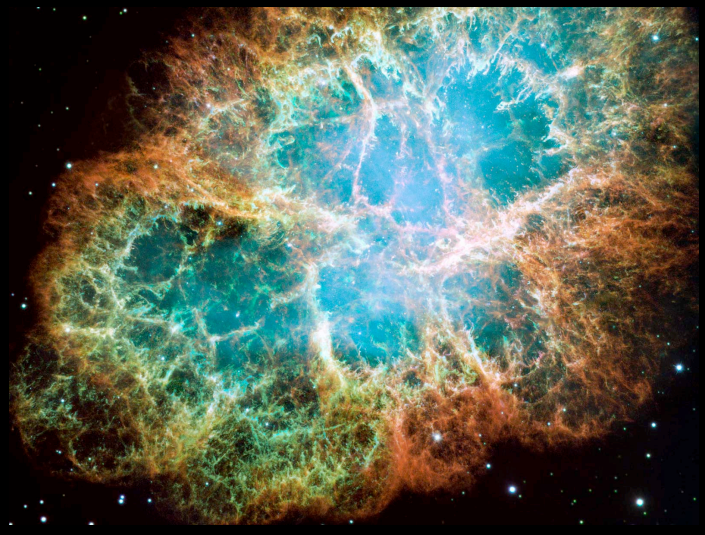


Supernova at 30 light years

- Photons for ~ 1 year
  - Global average O_3 depletion up to 35%, lasting several years

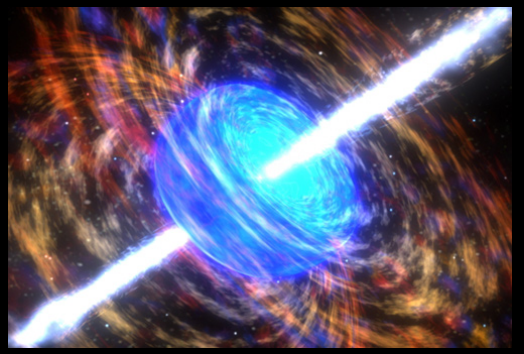


- Cosmic ray enhancement ~ thousand years
  - Also causes O_3 depletion
  - High energy CRs => penetrating muons

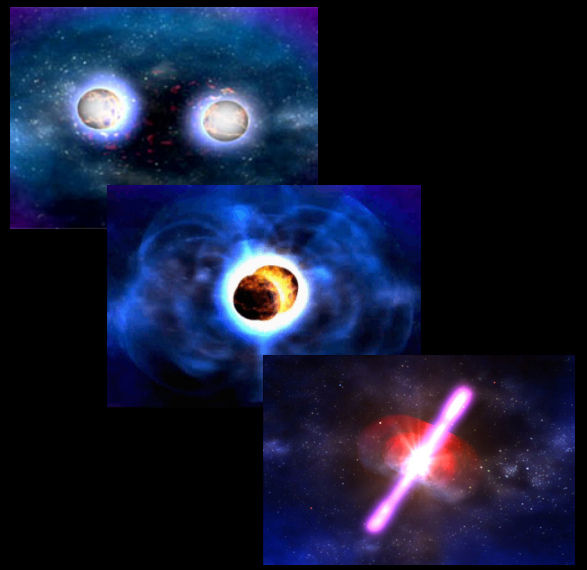


Source: Gamma-Ray Bursts

- Two main types, both strongly beamed.
  - Long-soft GRB
    - Duration: > 2 s (typical ~ 10 s)
    - Softer spectrum (peak ~ 180 keV)
    - Special case of core-collapse SN (?)



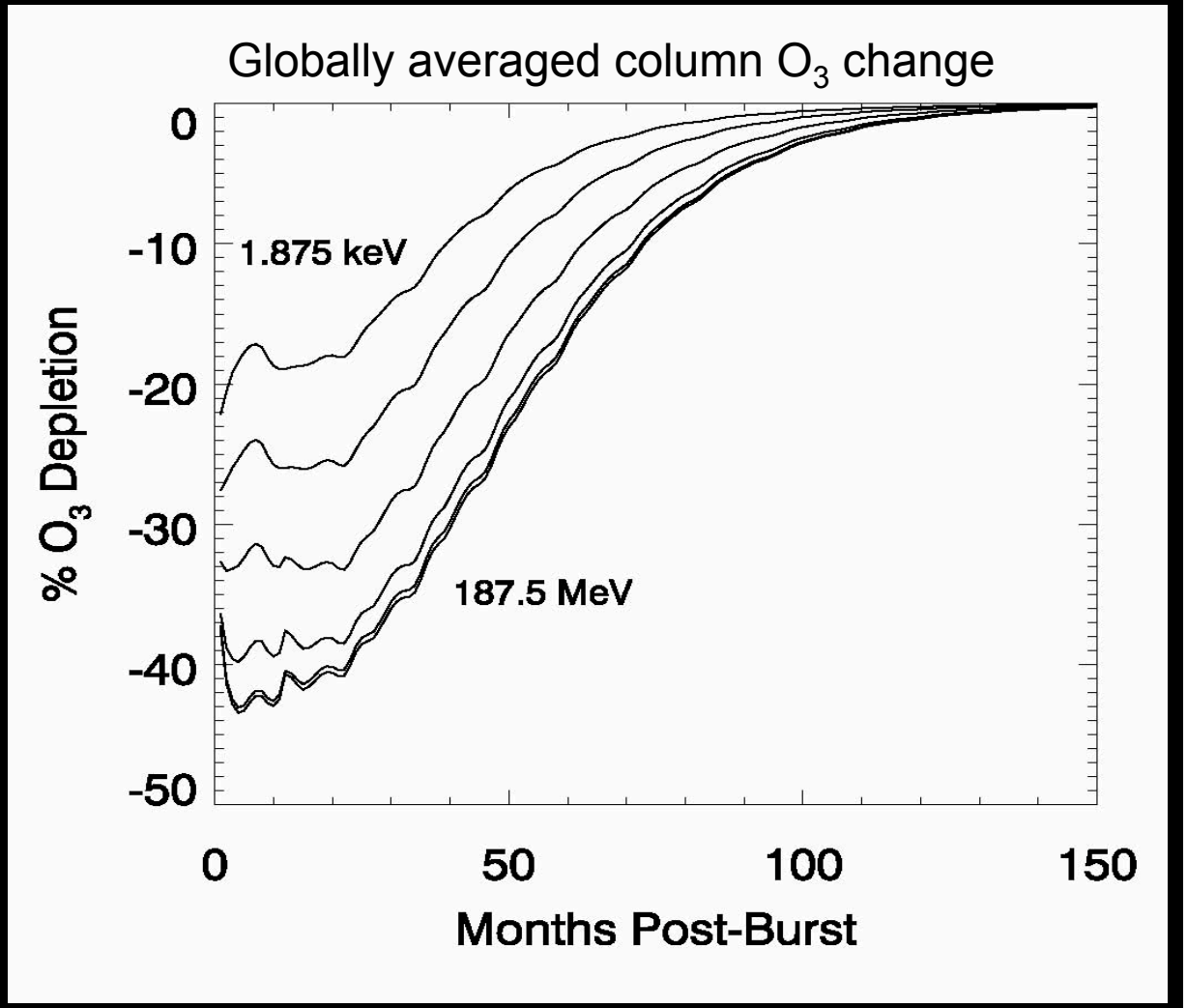
  - Short-hard GRB
    - Duration: < 2 s (typical ~ 0.1 s)
    - Harder spectrum (peak ~ few MeV)
    - Compact-object merger (?)



Varying Event "Hardness" in Photons

- Same total energy received.
- Vary the relative number of high energy photons
- Broadly,

  Harder = worse

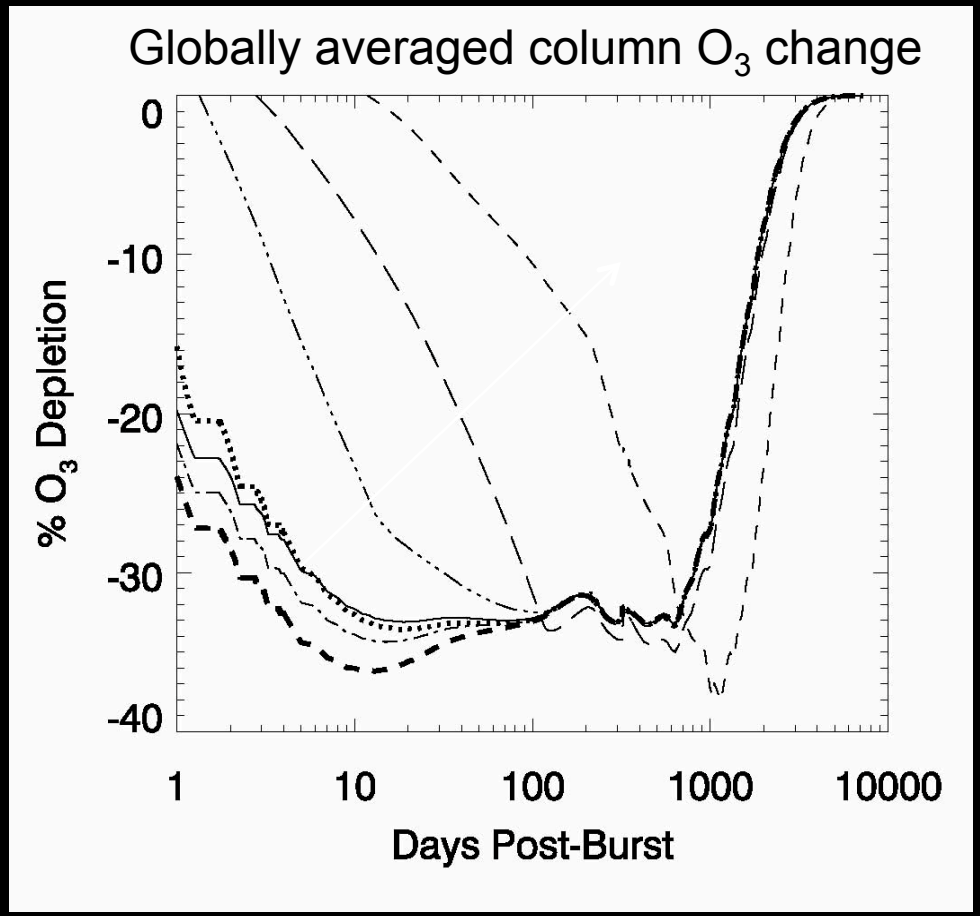


Ejzak et al. 2007, ApJ, 654, 373

Varying Event Duration

- Constant spectrum and energy received.
- Duration from 0.1 to 10^8 s

- Broadly,
  - Variation in timing
  - But, similar total depletion



Ejzak et al. 2007, ApJ, 654, 373

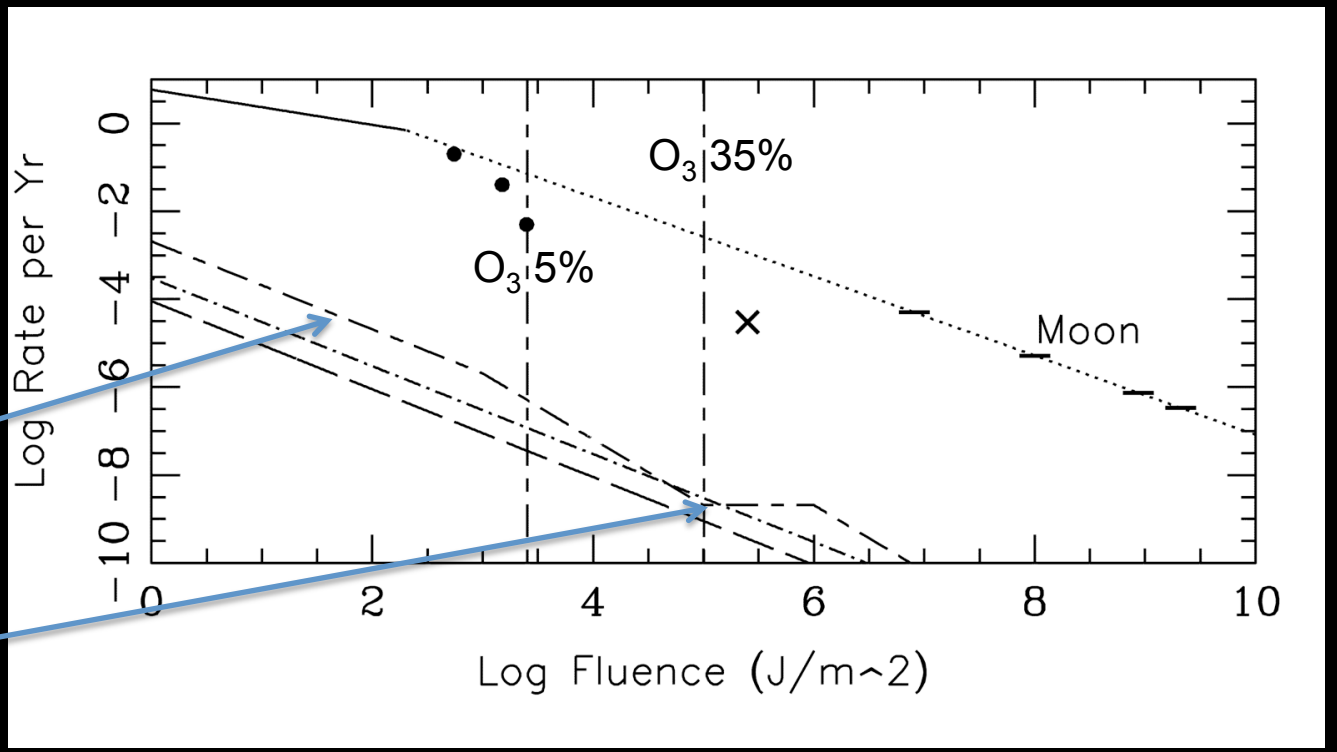
Putting it all together: Rates

- Rate vs. Fluence (energy per unit area)
  - *Fluence convolves total energy and distance*
- Solar, SN, Short-Hard GRBs, Long-Soft GRBs
- O_3 global average depletion thresholds:
  - 1) ~5%: current, 1859 SPE
    - noticeable bio effect
  - 2) ~35%: 100 kJ m^{-2} fluence (GRB, SN)
    - major bio impact – mass extinction?

Rate vs. Fluence

- Solar: Line, Recent SPE; Dots, historical SPE
- “Moon” upper limits on cumulative exposure rates from lunar radionuclides (x=goal; isotopes, ice cores)
- SN
- SHGRB
- LSGRB

SN:
From D^{-2} to D^{-3}
Inside remnant



Estimated Rates

- For events that yield ~ 35% globally averaged O_3 depletion:
  - Short-Hard GRBs: 1 per 300 million years
  - Supernovae: 1 per 500 million years
  - Long-Soft GRBs: 1 per billion years

Extinctions

- 35% global O_3 depletion expected to have severe impact for several years.
- We have previously identified correlations in late Ordovician extinction:
  - Depth and latitude dependence (Melott et al. 2004, Thomas et al. 2005, Melott & Thomas 2009)
- Work in progress to better quantify impact on marine primary producers.
- Future work investigating ecological impact?

Resources and Acknowledgements

- "Astrophysical Ionizing Radiation and Earth: A Brief Review and Census of Intermittent Intense Sources"
  - Melott & Thomas, *Astrobiology,* v.11 (2011)
- "Late Ordovician geographic patterns of extinction compared with simulations of astrophysical ionizing radiation damage"
  - Melott & Thomas, *Paleobiology*, v.35, p.311 (2009)
- "Gamma-Ray Bursts as a Threat to Life on Earth"
  - Thomas, *Int. J. of Astrobiology*, v.8, p.183 (2009)

Pre-prints available at arXiv.org

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