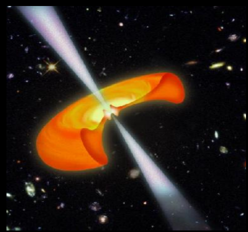
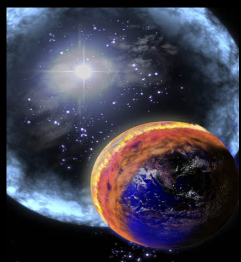
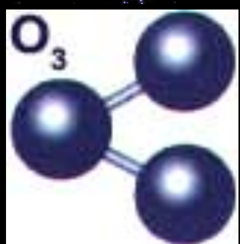


Terrestrial Effects of Ionizing Radiation Events

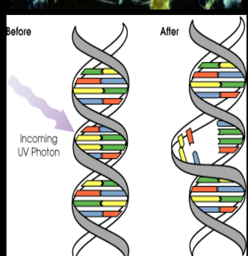




Brian C. Thomas
Dept. of Physics and Astronomy
Washburn University

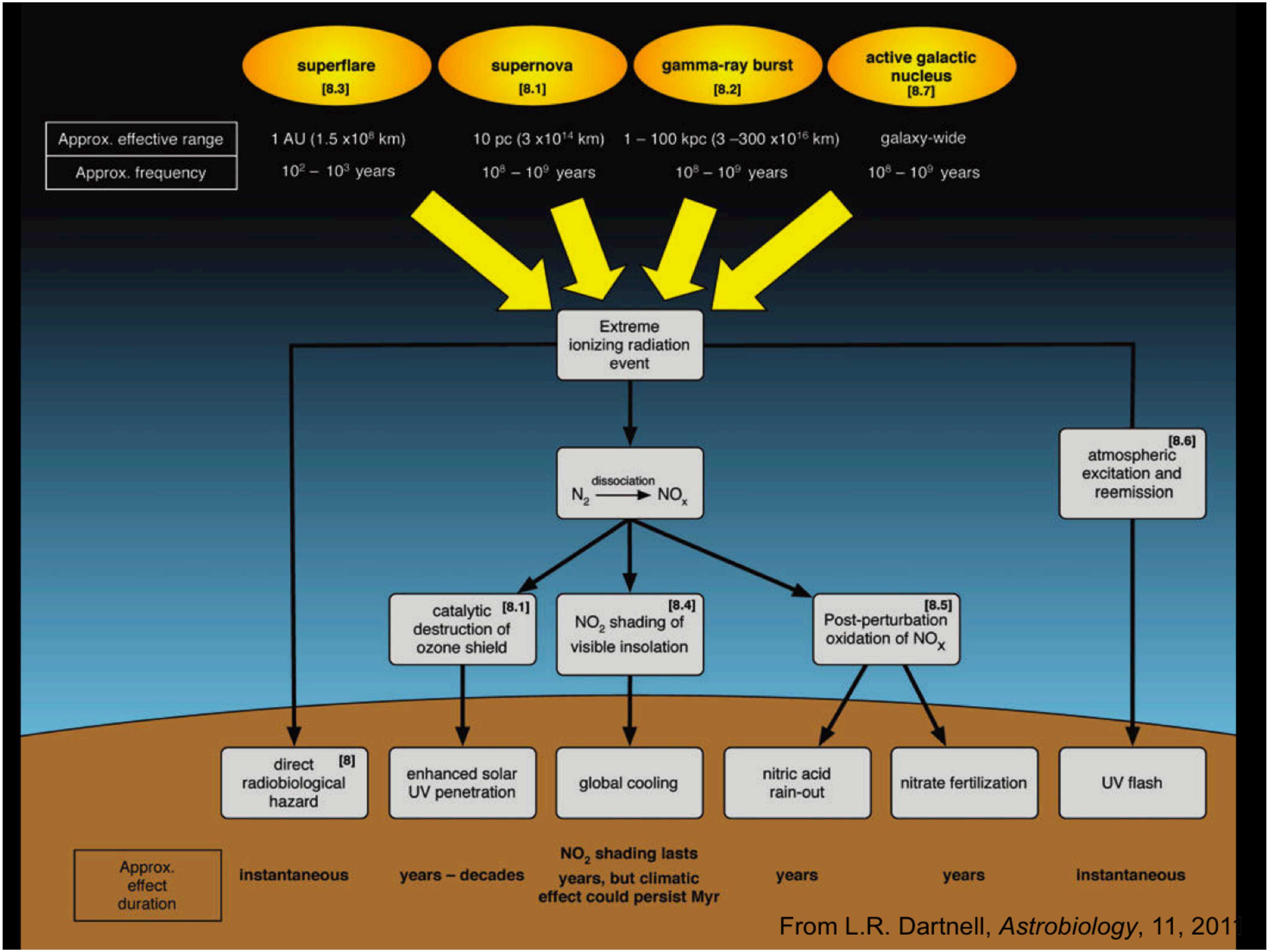
Adrian L. Melott
University of Kansas

Patrick J. Neale
Smithsonian Environmental Research Center

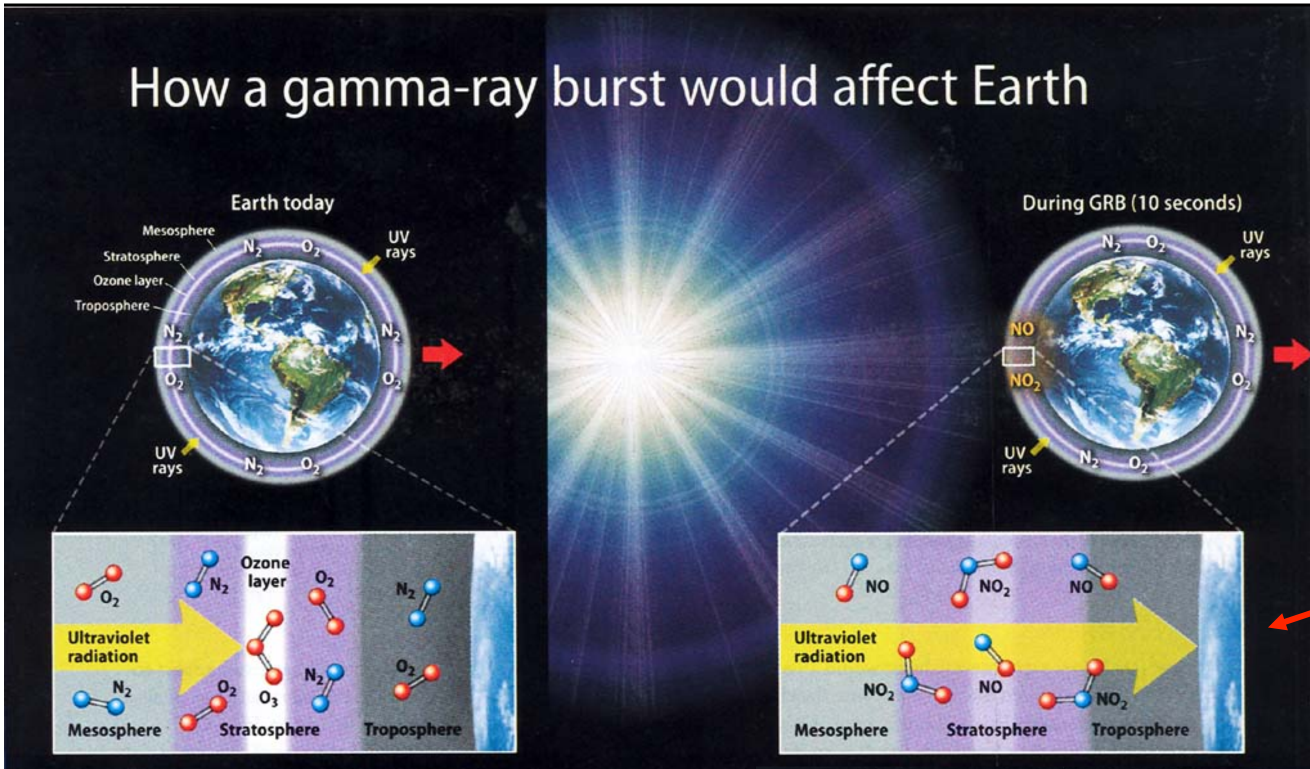


Effects of Ionizing Radiation

- Direct effects are limited:
  - Redistributed photon energy (γ -> UV)
    - High energy primaries -> GRBs (10 s, hemisphere)
  - High energy CRs: direct and/or secondaries
    - But, flux is small
- Atmospheric effects are more important:
  - Ionization creates NO_x compounds (NO, NO_2)
  - Catalytically destroy O_3 -> Enhanced Solar UV
  - Recovery takes years (up to a decade)



From L.R. Dartnell, *Astrobiology*, 11, 2011



AFTER:
Solar UV reaches surface,
NO_2 haze darkens

BEFORE: UV blocked by O_3

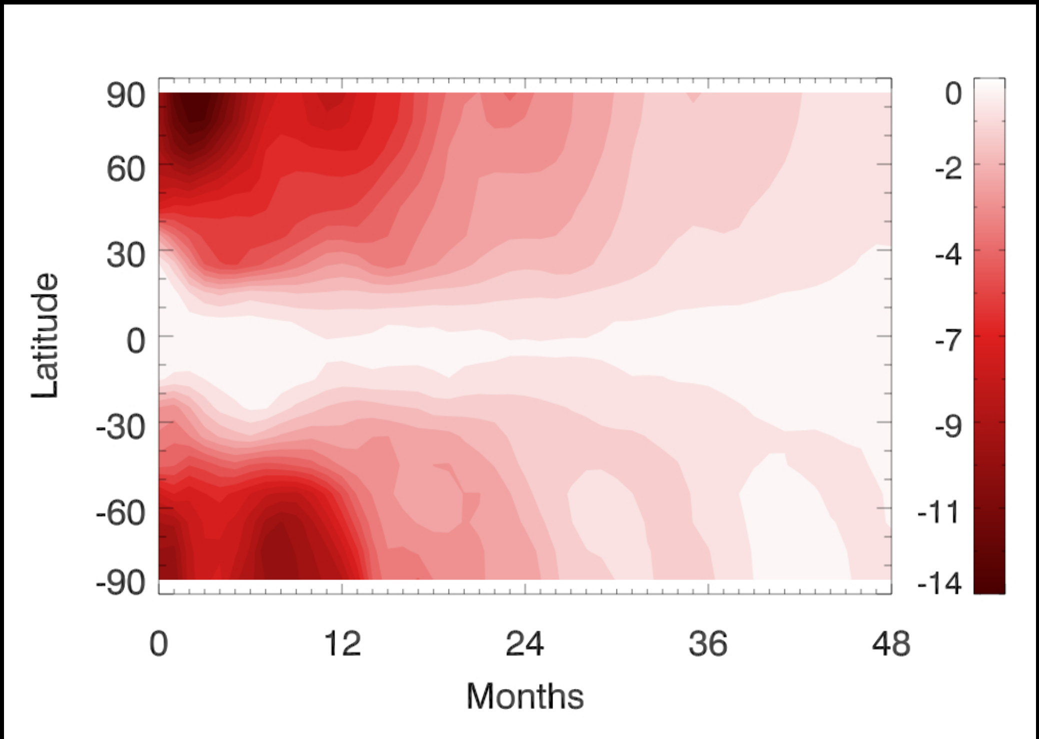
Astronomy Magazine,
Oct. 2005

Modeling Atmo Effects

- Compute atmospheric ionization from primaries (photons and/or CRs)
- Ionization is a source of NO_x
  - NASA GSFC 2D atmo chemistry & dynamics model
- Run the model with pre-industrial conditions.
- Analyze changes in O_3
  - Compute enhanced surface UV, bio impact

Atmo Effects: 1859 Solar Proton Event

- O_3 depletion:
  - Max 5% global avg.
  - Similar to current
  - Recovery ~ 4 yrs



Thomas et al. 2007, GRL, 34, L06810

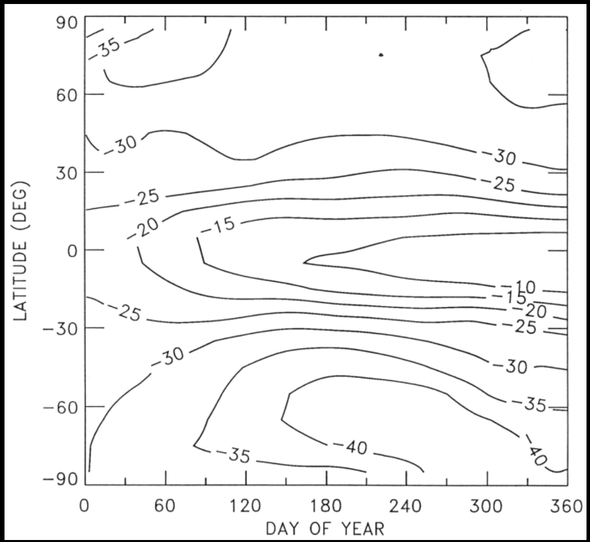
Atmo Effects: SN 1987A scaled

- Most complete modeling from Gehrels et al. 2003 (ApJ):
  - Photon spectrum input; CRs just turned up GCR
  - Based on 1987A observations

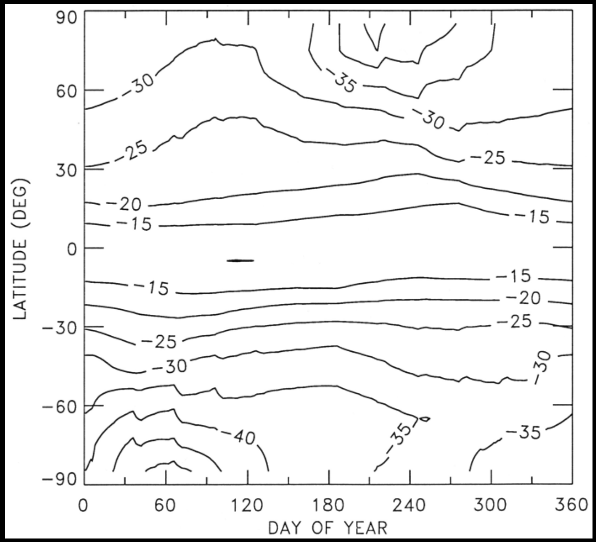
Depletion is similar for each component separately.

Up to 50-60% locally, 25% globally averaged

Photons @ 10 pc

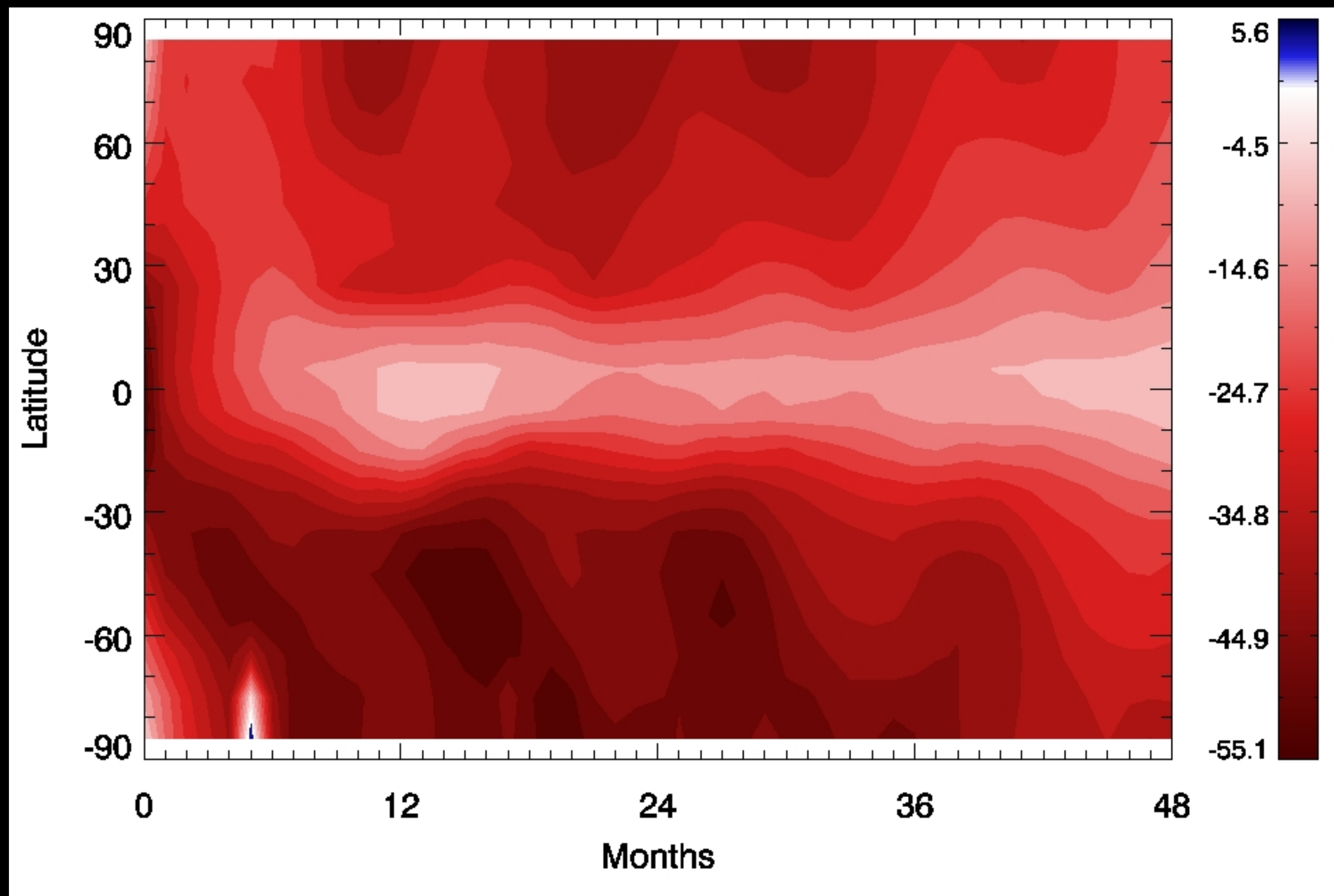


CRs @ 10 pc



Atmo Effects: Long GRB

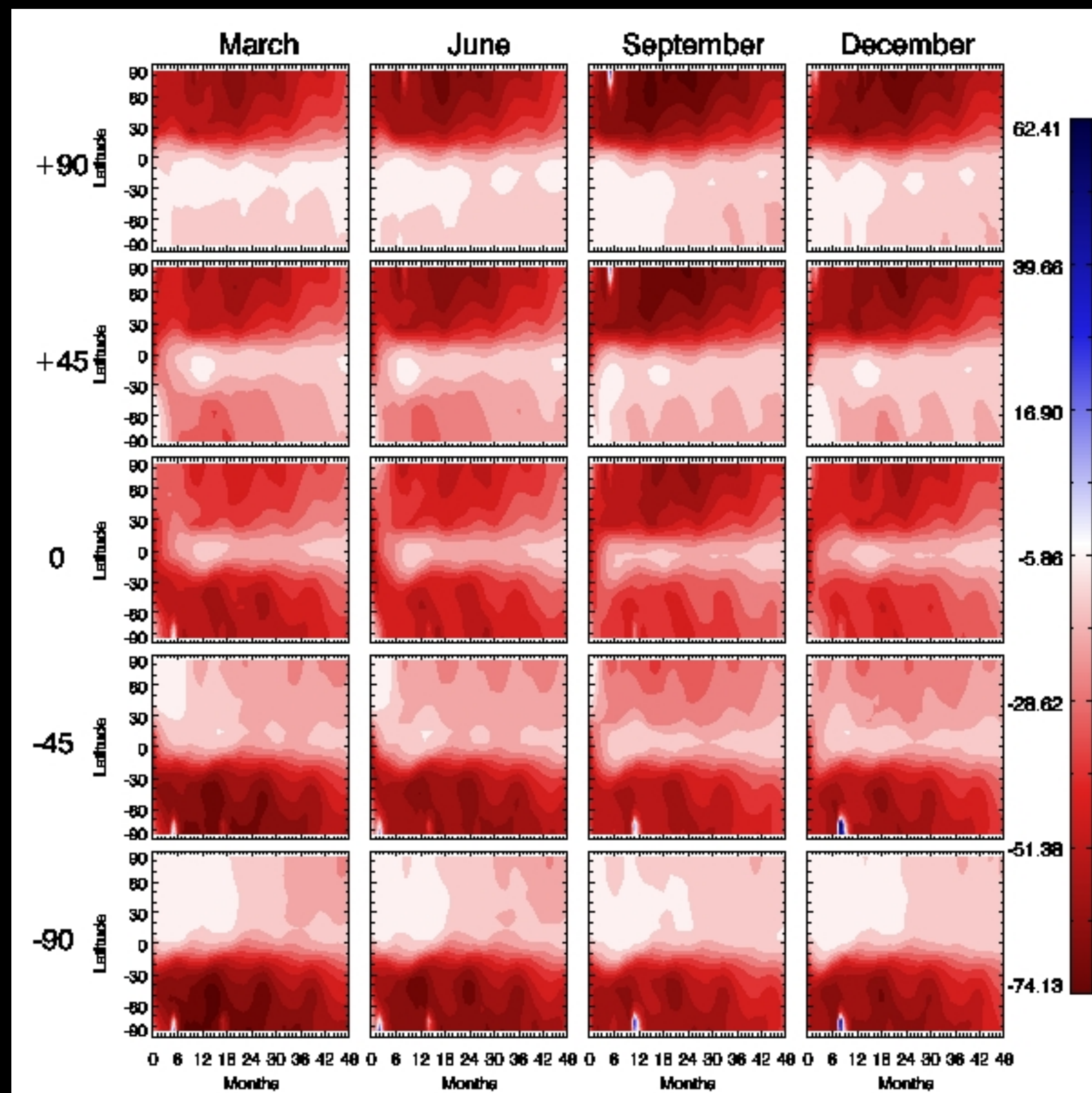
- O_3 depletion for burst over Equator, in March, at 2 kpc



Thomas et al. 2005, ApJ, 634, 509

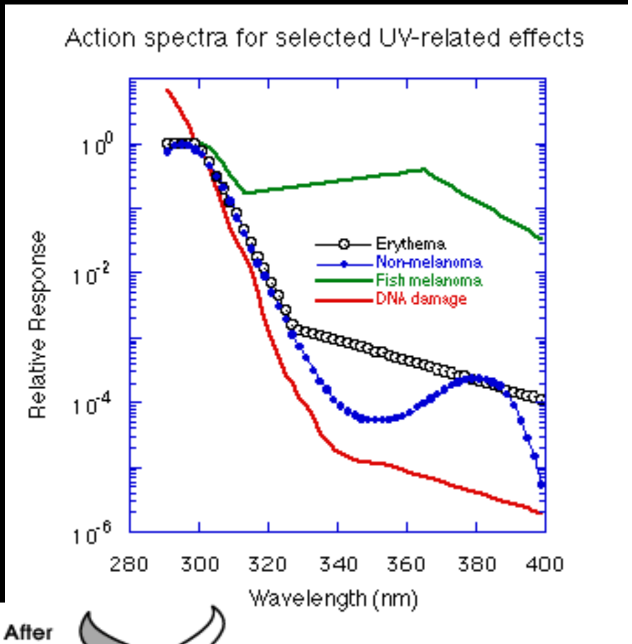
Atmo Effects: Long GRB

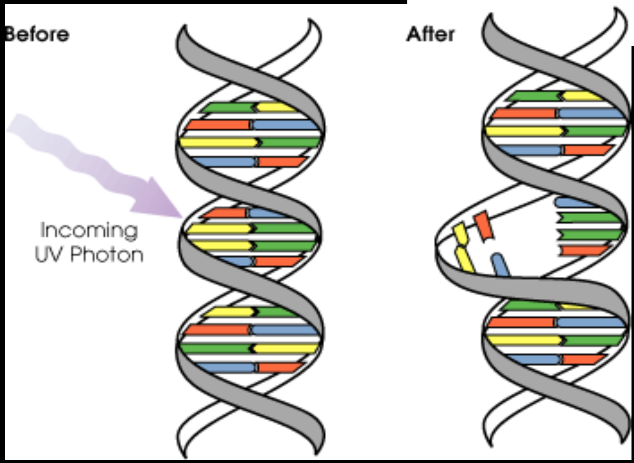
- Location and season of burst affect intensity and geographic distribution of impact.
- Globally averaged depletions up to 35%



Solar UV and Biological Effects

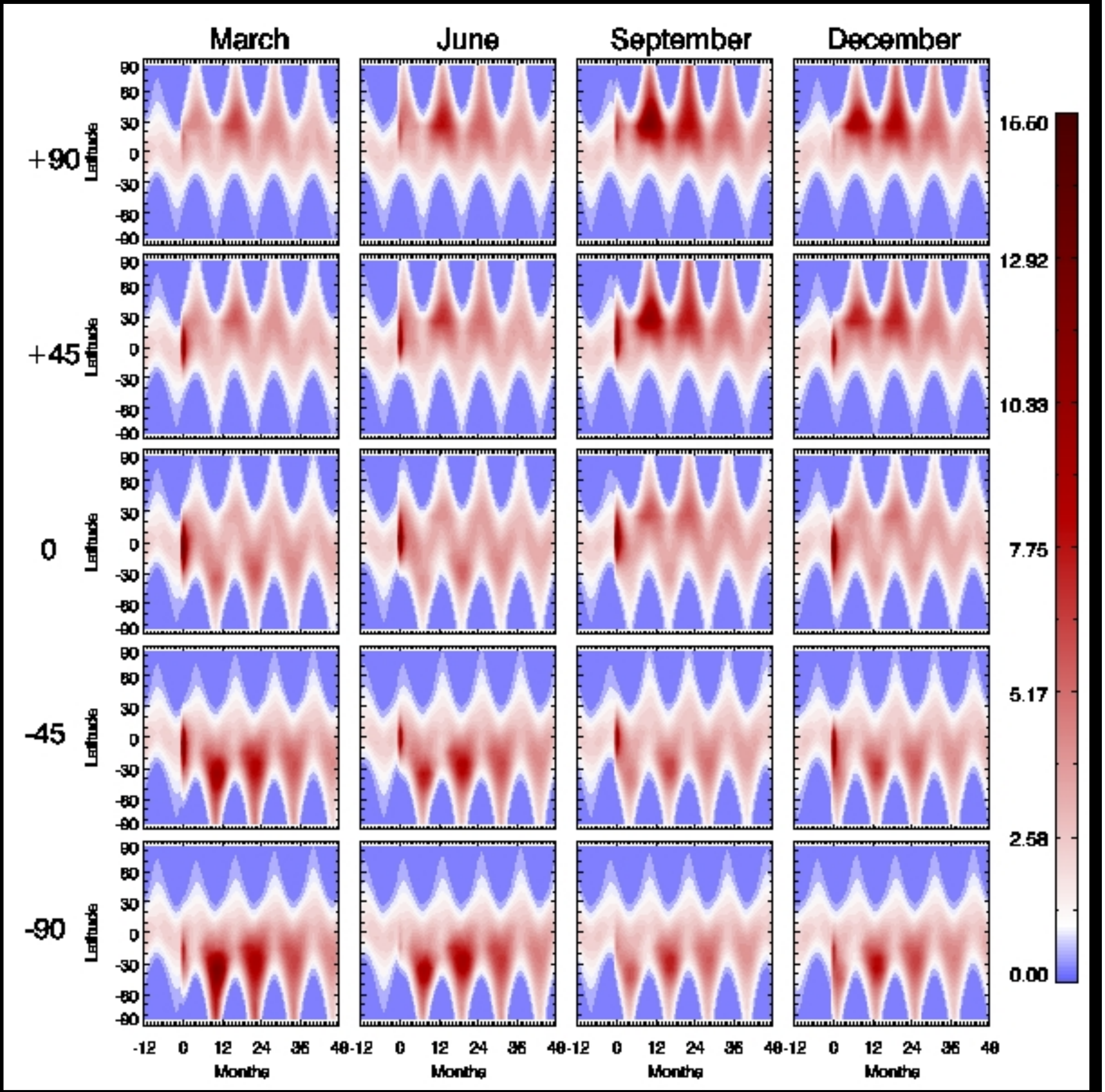
- Surface UVB (280-315 nm)
  - Solar UVB attenuated by O_3 column
  - Simple approach (no scattering, etc.)
- DNA damage
  - Computed using a *weighting function* (Setlow 1976) and solar UVB irradiance.





Relative DNA damage (normalized by annual global average pre-burst)

Note primarily mid-low latitudes affected.



Steps toward Improvement

- To get more realistic damage estimates:
  1. Use a full radiative transfer model to get *spectral irradiance* at surface
     - And, use a *variety* of weighting functions
  2. Compute transfer of light into water
  3. Use weighting functions for the impact on phytoplankton primary productivity, integrated over the water column population.
     - In particular, newly measured BWFs for picophytoplankton species *Synechococcus* and *Prochlorococcus*

Atmo Radiative Transfer Modeling

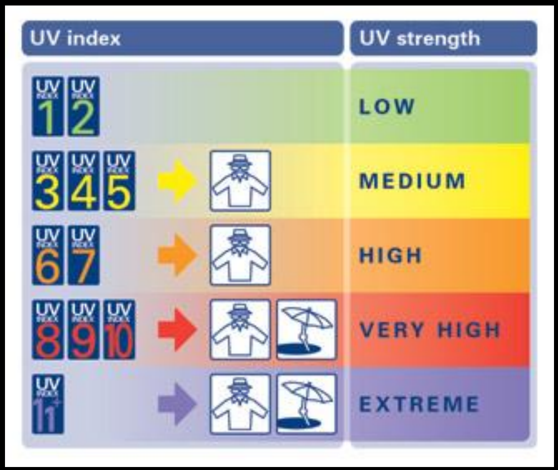
- TUV is a freely available atmo-RT model
  - Modified to read in O_3 and NO_2 profiles from atmo chemistry/dynamics modeling
- Output surface values:
  - Spectral irradiance from 280-700 nm
  - Total irradiance in UVB, UVA
  - Relative effects measured by various built-in weighting functions

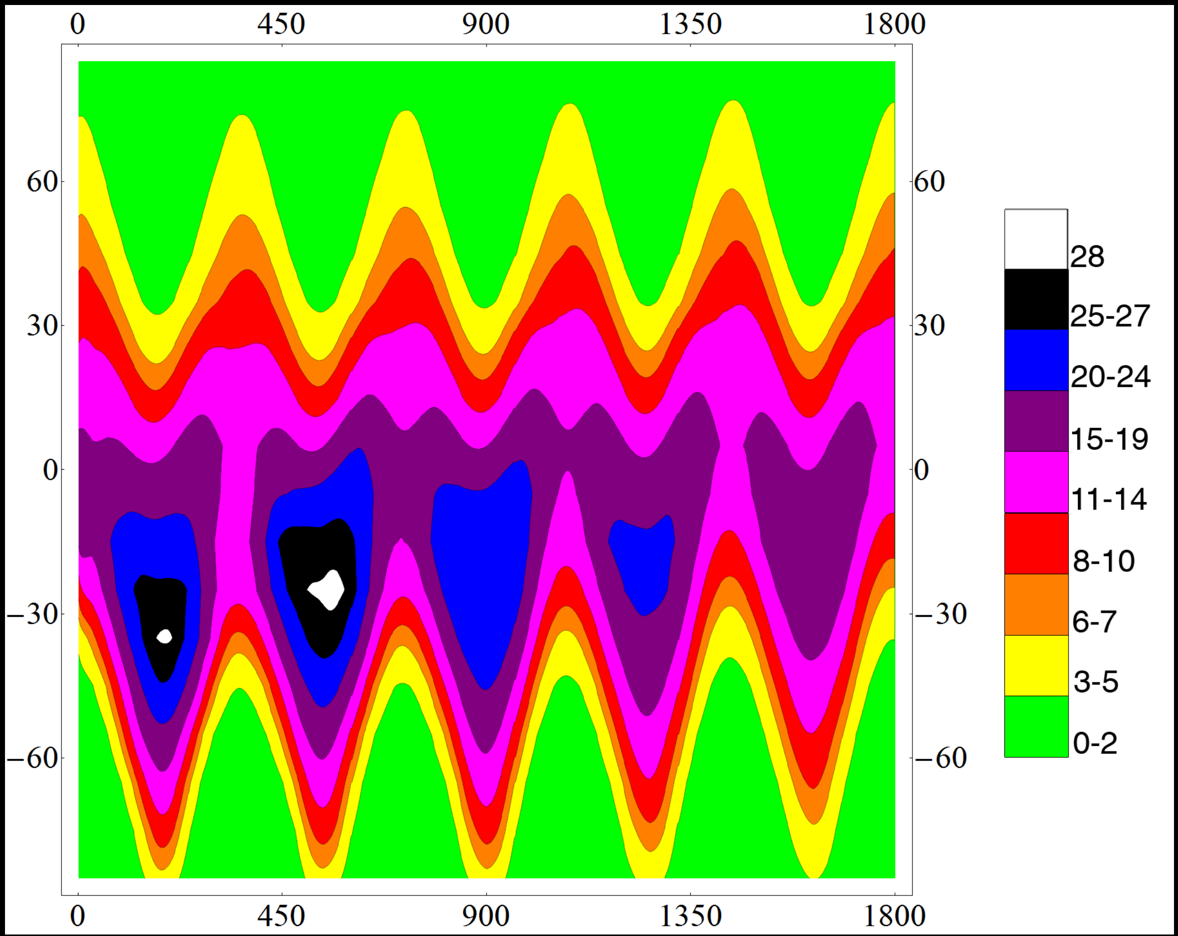
Some Results

GRB over S.Pole, in June

(candidate for the end-Ordovician extinction)

- UV Index





More Results
GRB over S.Pole, in June

- At 25 deg South, 560 days (1.6 years) after burst (Jan. 16)

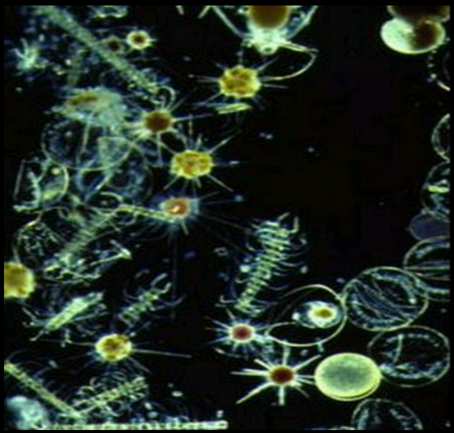
Quantity	% Change (GRB vs. Normal)
O_3 column density	-52
NO_2 column density	+2517
UV index (WMO, 1994)	+128
UVB irradiance	+66
UVA irradiance	-2
Erythema, humans (Anders et al., 1995)	+137
Phytoplankton (Boucher et al., 1994)	+83
Phytoplankton, *Phaeodactylum sp.* (Cullen et al., 1992)	+26
Phytoplankton, *Prorocentrum micans* (Cullen et al., 1992)	+40
Cataract, pig (Oriowo et al., 2001)	+100
Plant damage (Flint & Caldwell, 2003)	+49
DNA damage, in vitro (Setlow, 1974)	+310

Primary Productivity

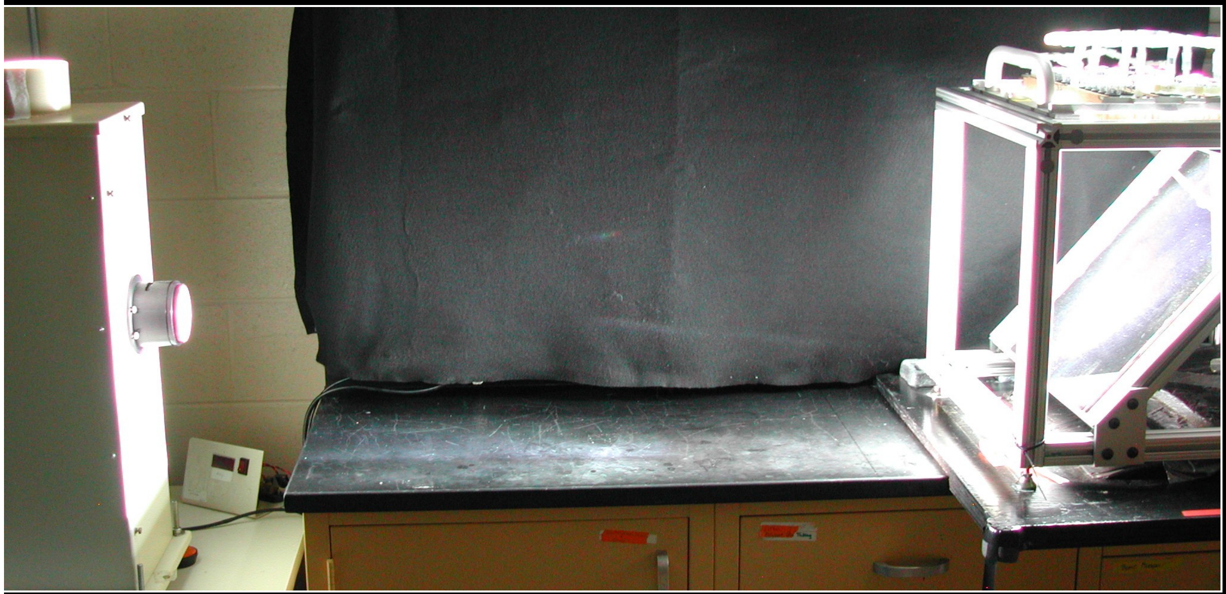
- Computing the impact on primary productivity in the water column gives us an *integrated value*
- Removes most of the bio issues we had:
    1. Organisms aren't bare DNA
    2. Marine organisms live in and under the water, not just on surface (UV attenuated)
    3. Primary producers have repair mechanisms, and can move up and down in the water column

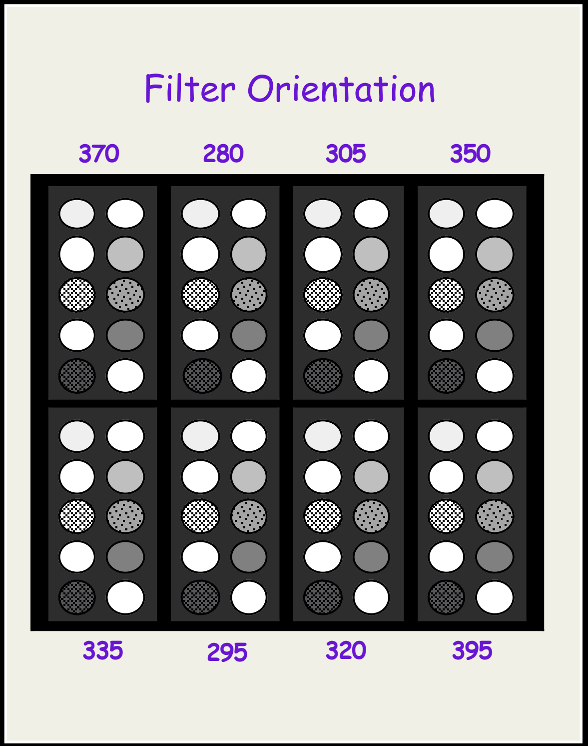
Why Phytoplankton?

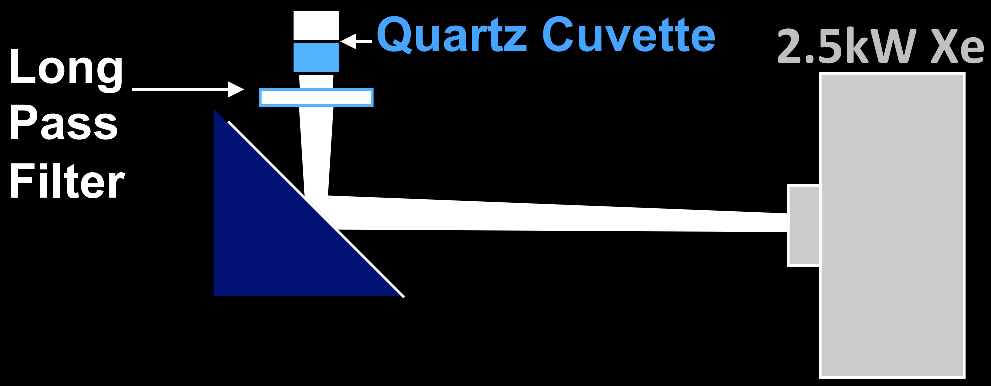
- Live in oceans, lakes, etc.
- Form the base of the food chain in these bodies of water
  - *Synechococcus* and *Prochlorococcus* are prevalent in mid-latitudes
- Produce half the world's O_2 supply
  - And consume CO_2 in the process
- Potentially vulnerable to increases in UV



The Photoinhibitron

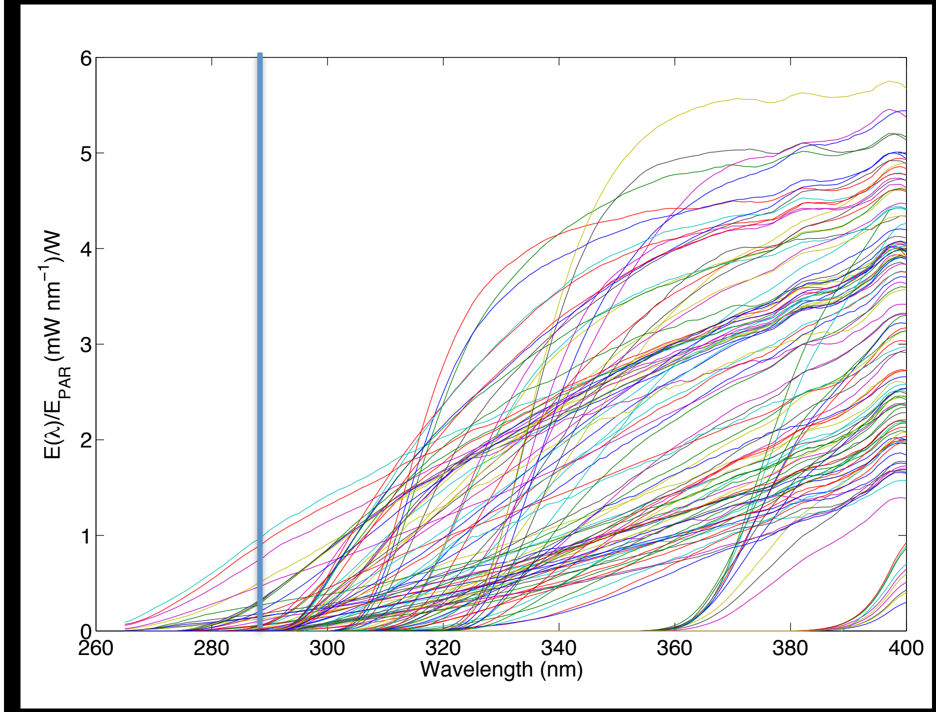


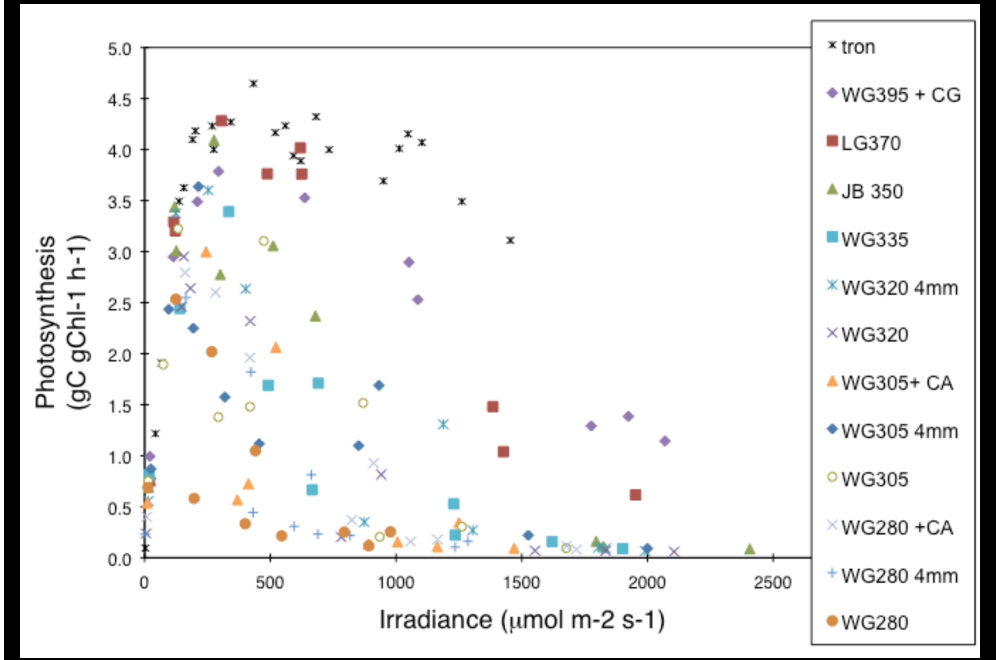




A Polychromatic Incubator for Experimental UV Exposures

Photoinhibitron
Exposure - Response

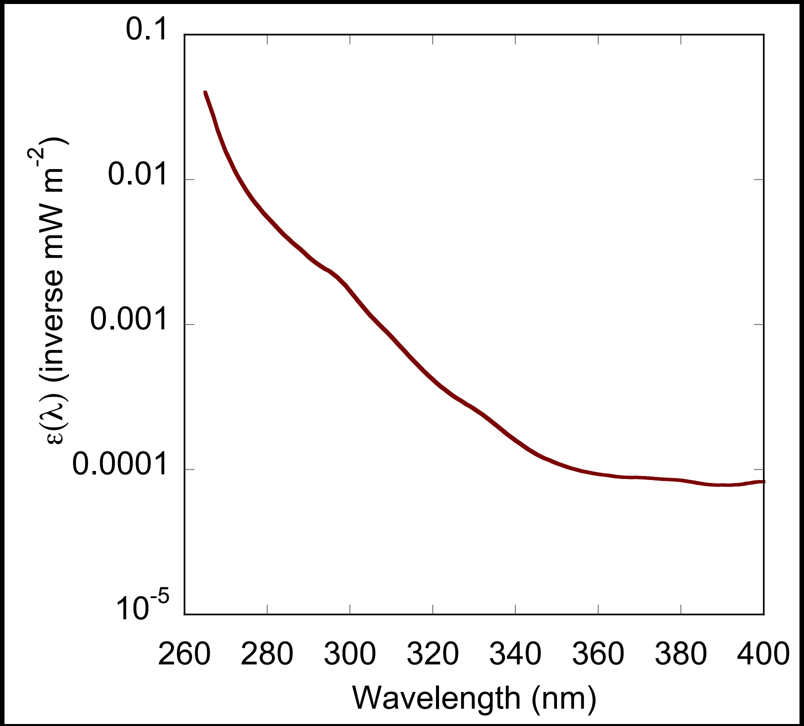


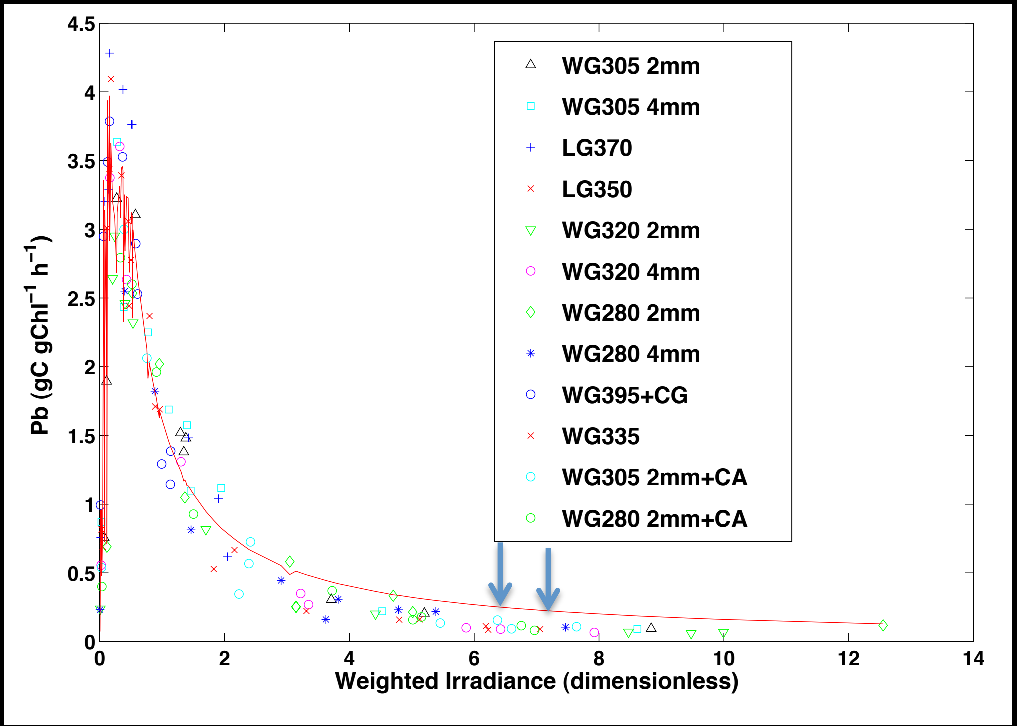


120 Spectral Treatments – some exposures extend below 290 nm

12 Cutoff filters x 10 Exposure Levels

BWF – Photosynthesis Model





Preliminary Observations from Model Results:

-Ambient Conditions have Strong Effects – Surface UV inhibits Photosynthesis by ~80%

-Modest Effect of Additional UV from GRB

Further Decrease in Photosynthesis Generally < 10% at Surface

Resources and Acknowledgements

- Short review article on terrestrial effects of GRBs
  - "Gamma-Ray Bursts as a Threat to Life on Earth" Thomas, *Int. J. Astrobiology*, vol. 8, 2009
- Recent review article on various kinds of events
  - "Astrophysical Ionizing Radiation and Earth: A Brief Review and Census of Intermittent Intense Sources" Melott and Thomas, *Astrobiology*, vol. 11, 2011

- These and other papers available at arXiv.org
  - Or, email me: brian.thomas@washburn.edu

- Thanks again to all my various collaborators and students!
- Current work supported by NASA grant No. NNX09AM85G