γ-Ray Bursts: Extinction and Survivability

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Introduction

There is an ongoing debate on whether Gamma Ray Bursts (GRBs) might lead to Life threatening scenarios, i.e. complete extinctions:

- Paper I [1] claims that such an event could prove deadly to Earth's life, and possibly explains why no life has been found in the galaxy.
- Paper II [2] argues such an event will not bring about total extinction on an Earth-like planet, due to the survival of extremophiles.

Our goal is to better understand the threat that GRBs can impose, while using quantities that are agreed upon between both papers and avoiding extreme scenarios or assumptions.

In addition to complete extinctions, we examined the possibility that GRBs could limit or impede advanced Evolution.

Long GRB (LGRB) Probability per Flux

P(LGRB)	$O_3 \downarrow$	t < 5Gyr	t < 1Gyr	t< 0.5Gyr
10kJ/m^2	68	99.8	98.7	95
100kJ/m^2	91	90	60	50
1000kJ/m^2	98	25	7	4

Table 1 (Based on Paper I [1]): for each scale of flux of a long γ-Ray Burst, the first column gives the fraction (%) of the Ozone depleted following the event. The next 3 columns show the probabilities (%) of at least one such LGRB within each time frame.

Attenuation of EM radiation in typical Media by λ and E

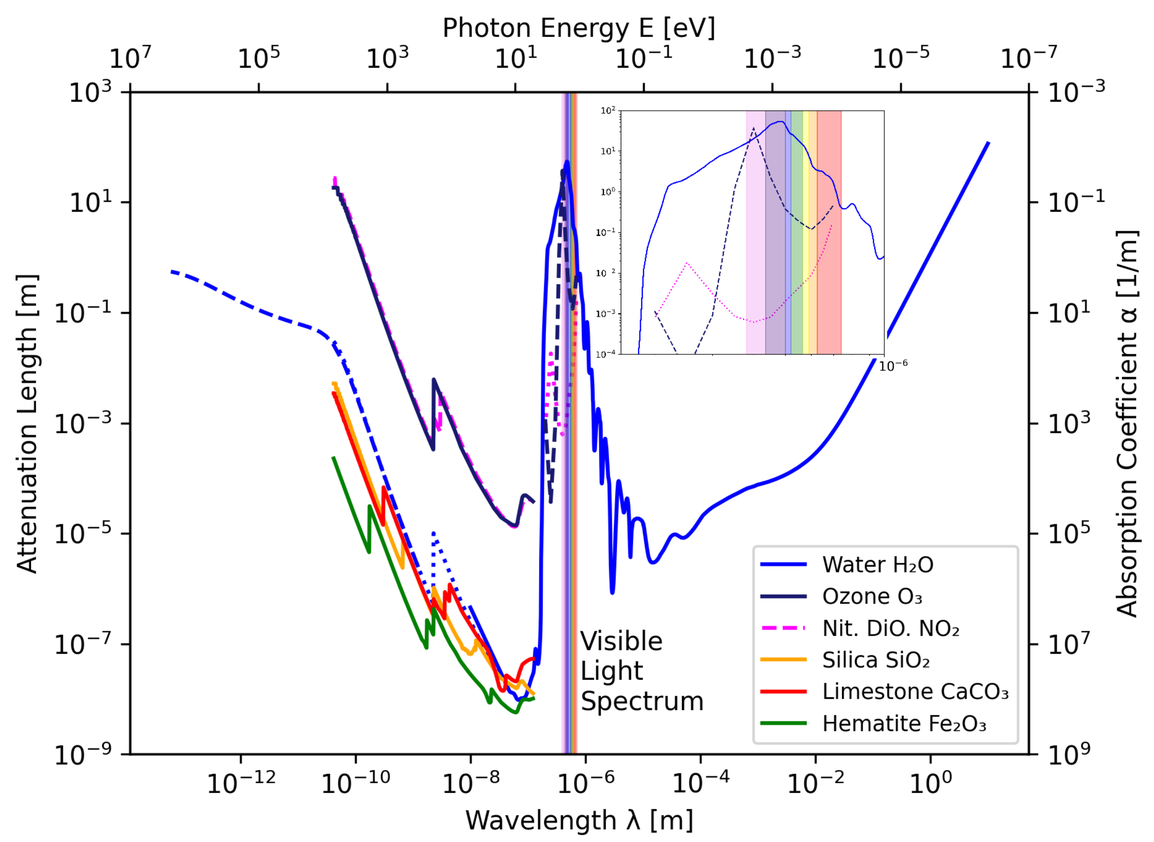


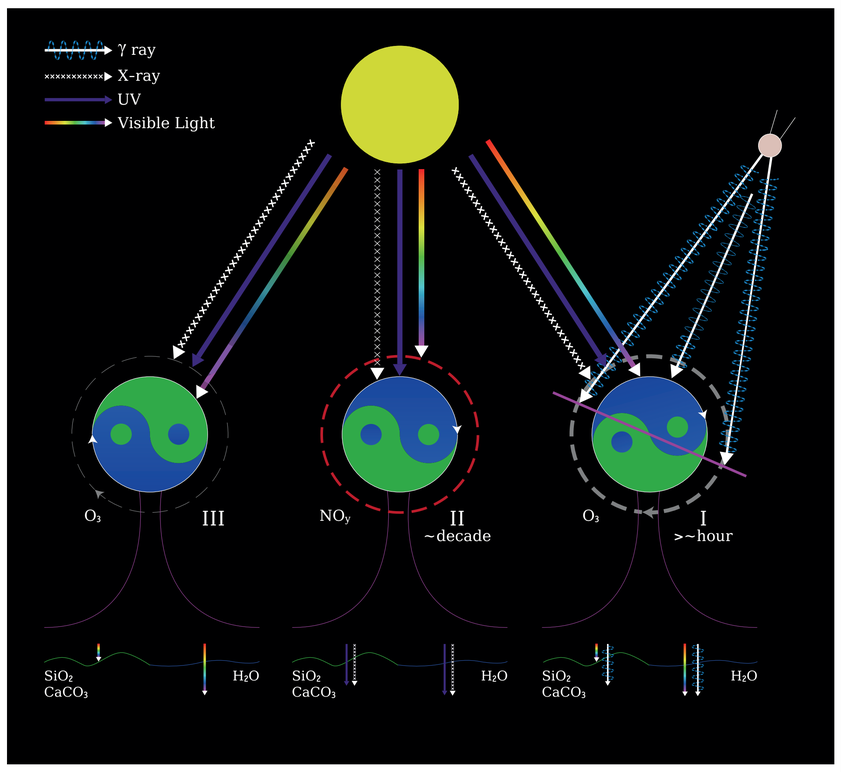
Fig. 1: All X-ray data taken from CXRO. Shorter wavelengths (for water) taken from NIST. UV, visible and IR for water from Segelstein; for Nitrous DiOxide from Schneider.

The Stages of Damage and Recovery

- **Stage I**: initial γ burst
  - lasts up to $\lesssim$ 1 hour [3]
  - kills off air & surface life, over $\gtrsim$ $1/2$ the planet
  - breaks atmospheric $N_2 \Rightarrow$ recombine to NOy
- **Stage II**: atmospheric NOy break O_3
  - parent star's UV & X-ray reach surface
  - NOy limits visible light to surface
  - decades until NOy washed away, O_3 restored
- **Stage III**: back to normal
  - O_3 filters UV & X-ray
  - lasts eons, until next catastrophe

Can/which species survive?

- $\lesssim$ $1/2$ planet survives Stage I (opposite side)
- Deep underwater or underground species could survive Stage II
- Depth depends on species' radiation durability



Assumptions

- We assume an "Earth-like Planet", i.e. a rocky planet in the habitable zone around a G-type star of Population I. This implies a similar **length year**, a similar **length day**, a similar **composition**, and a similar **lifetime**.
- As the main sustained effect of a GRB comes through Ozone depletion and replenishing, we assume irrelevance of GRBs prior to oxygenation to recent levels (~ 0.5 Gyr) [4].

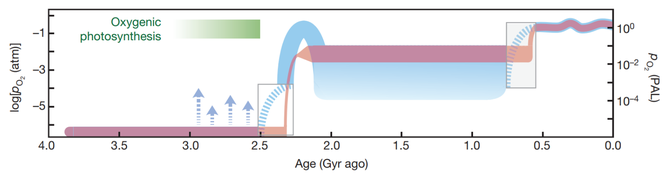


Fig. 2: A timeline of Earth's atmosphere from [4]. The areas marked in gray highlight oxygenation events, incidents where Earth's atmospheric oxygen grew by orders of magnitude.

Discussion

- The GRB's flux diminishes with distance $\Rightarrow$ the rate of powerful nearby GRBs declines with the rise in flux
- Organism's durability to ionizing radiation differs: we note humans (rep. mammals) can sustain 5-8 Gy, while the resilient Tardigrades [2] can sustain up to 8 KGy. Most surface complex organisms thus expected to die.
- A 1000kJ/m^2 GRB would have killed our ancestors up to the Tiktaalik, about 375 Myr ago [5]. The average rate for such GRBs here is 1/500 Myr (Table 1). Thus, while on Earth subterranean fauna were unnecessary in evolution towards intelligent life, on planets with more frequent GRBs they might be relevant.

Future Work: Survivability beyond the single organism

- Extinction vs. Survival of groups and species, looking into regional distributions
- Ecosystems and their possible collapse or successions; in particular, effects of photosynthesis changes
- Impact on evolutionary lines, trees, fallbacks and alternatives

Remarks

Table 1 shows only long GRBs, and Fig. 1 assumes that the GRBs are in fact LGRBs; the full corresponding table in [1] shows that these dominate the threats (both longer and more energetic).

Acknowledgements

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