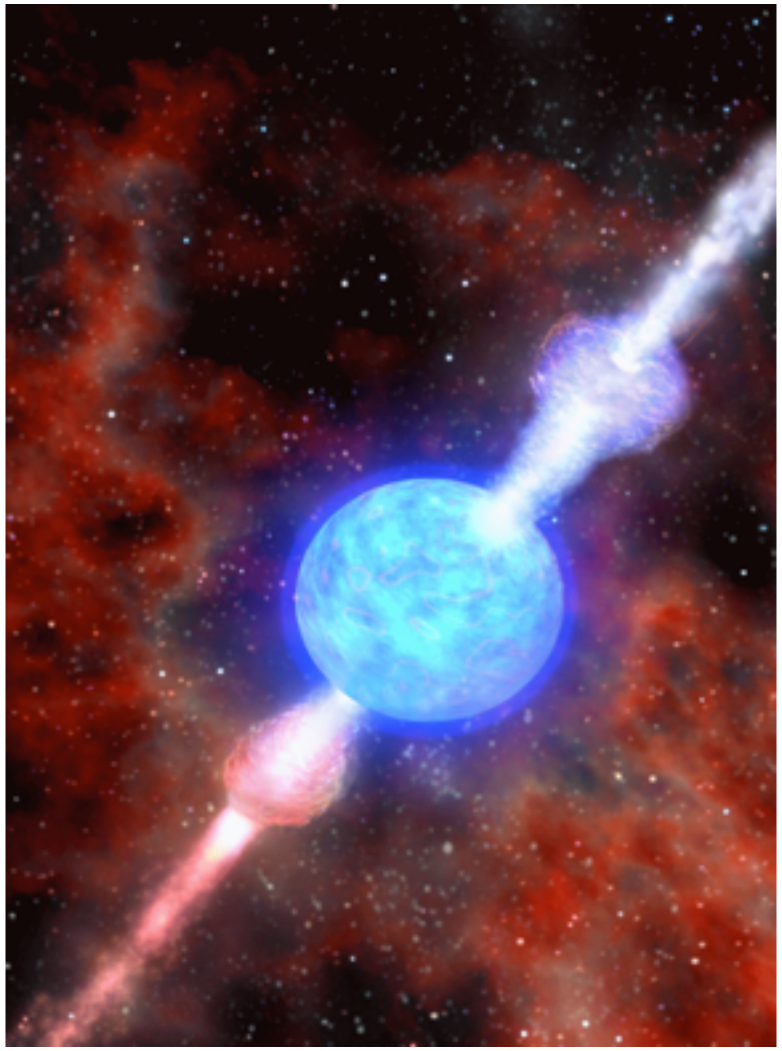
Astronomy 150: Killer Skies
Lecture 26, March 28

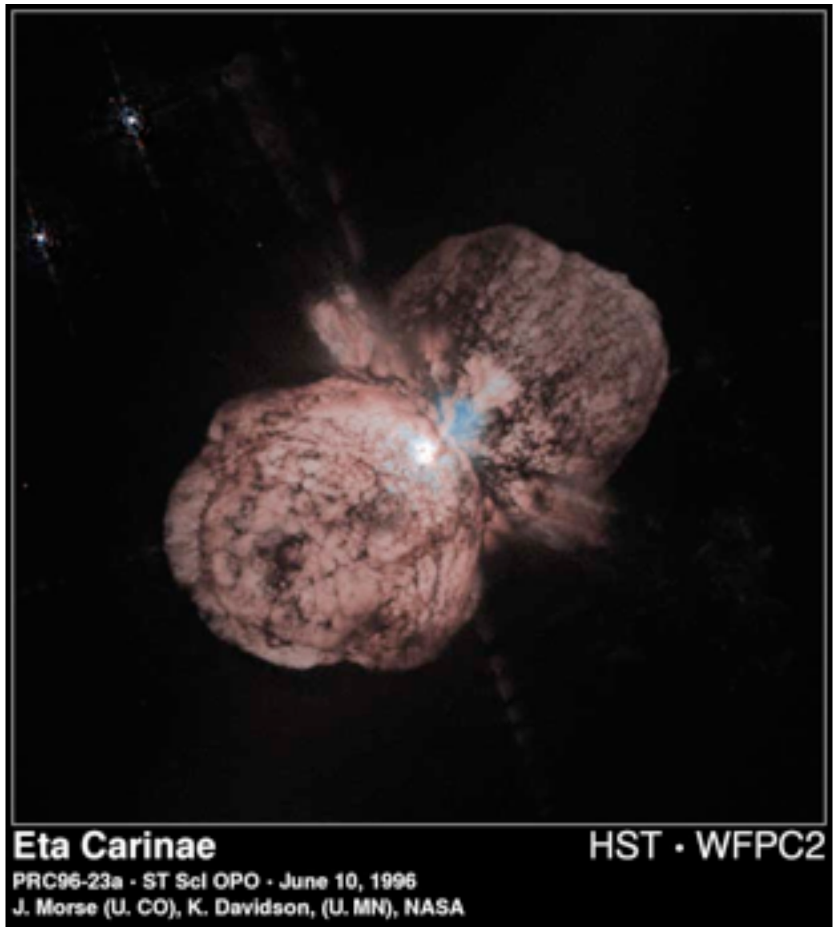
Assignments:

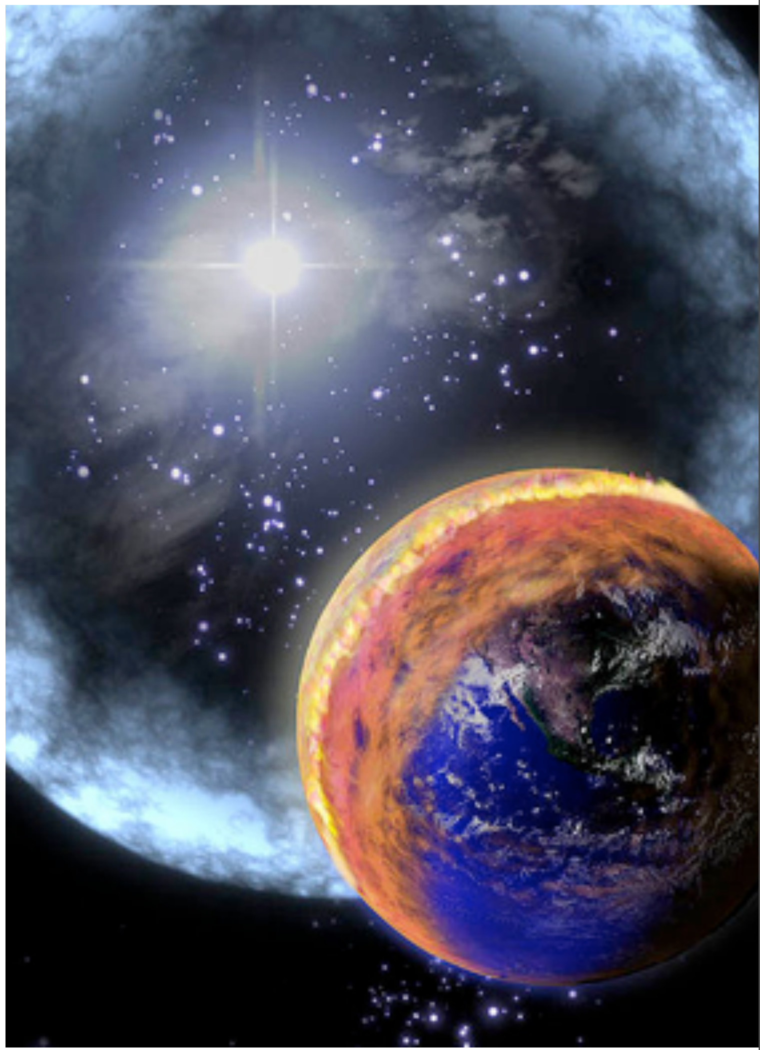
- HW8 due Friday
- Office Hours: immediately after class today

Last time: Gamma-Ray Bursts

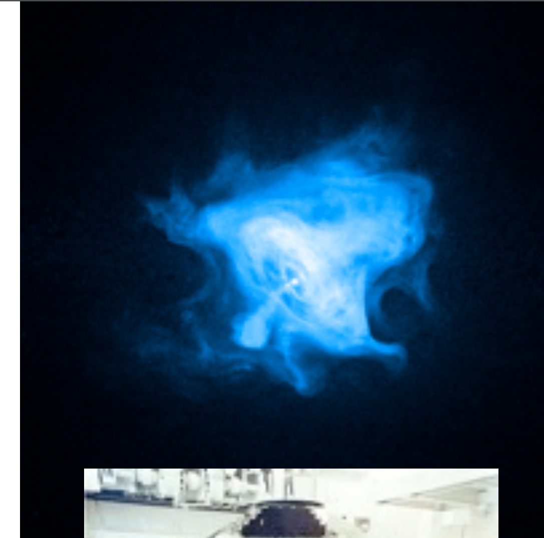
Today: Killer Gamma-Ray Bursts

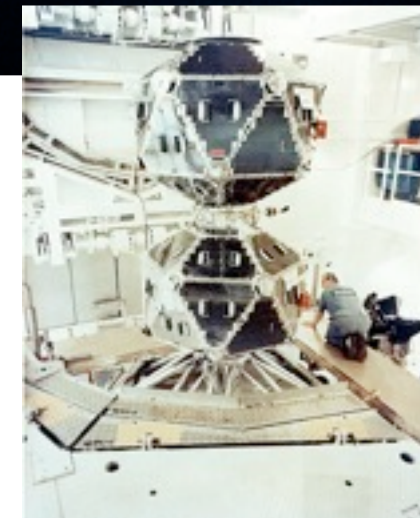






Gamma-Ray Bursts: Recap



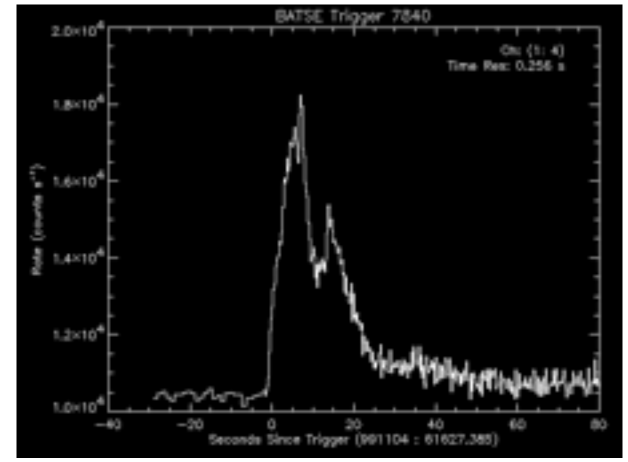


Massive star deaths not only lead to supernova explosions

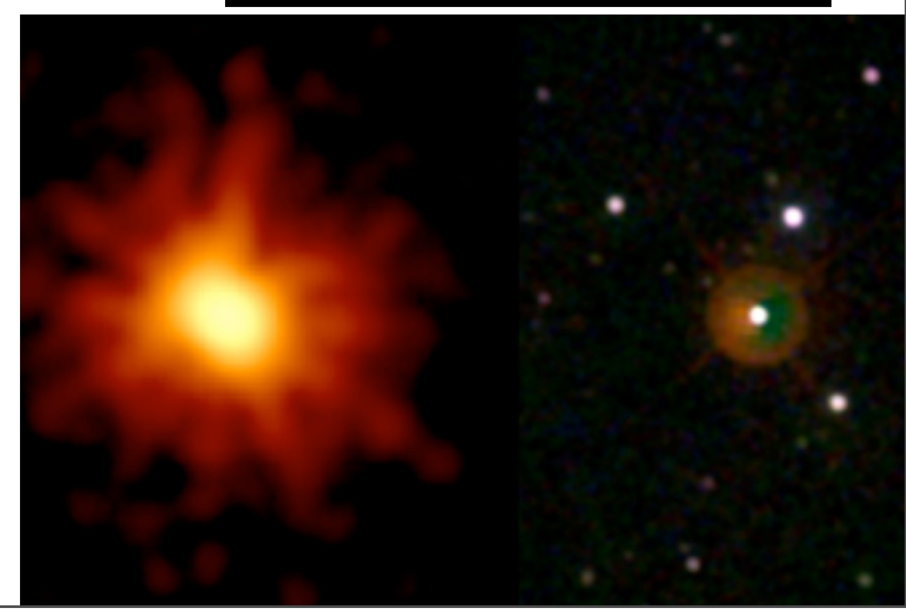
but also give birth to compact objects: huge mass in tiny region

- stars <30(?)M_{sun}: neutron stars
  - some seen as pulsars: rapidly spinning
- stars >30(?)M_{sun}: black holes

Gamma-Ray Bursts (GRBs)



- discovered accidentally by Vela military satellites looking for Soviet nuclear explosions
- what are they? short intense bursts of gamma rays -- highest energy light (photons)
- come from beyond Solar System, beyond our Galaxy
  - most distant GRB is the farthest known object in the Universe
- afterglows seen with some bursts: radiation at other wavelengths, X-rays through radio
  - dim rapidly over timescales of days
  - allow us to pinpoint sources ("hosts")
- GRB hosts always galaxies, mostly very distant galaxies, and usually the burst arises in regions of star formation
  - often when afterglow dims, can see evidence of supernova explosion
- bursts are beamed: radiation does not go in all directions but focussed in narrow cone: cosmic blowtorches!



CSI GRB:
What are Gamma-Ray Bursts

The Evidence:

- GRBs seen from huge distances:
  emit huge amounts of energy
- GRB hosts are star-forming galaxies
- GRBs trace the stellar distribution (in distance from galaxy center)
- GRBs occur in dense environments (probably star forming regions)
- some GRB afterglows show supernova explosion

The Culprit:

- huge, non-repeating, explosive source of energy needed
- found in regions of star birth: GRBs connected with star formation

  but recall: massive stars live very short lives

  die soon after born--don't ever leave star-forming regions

  likely GRBs connected with deaths of some massive stars

  indeed sometimes see supernovae with GRB
- supernova on steroids! "collapsar" or "hypernova" model

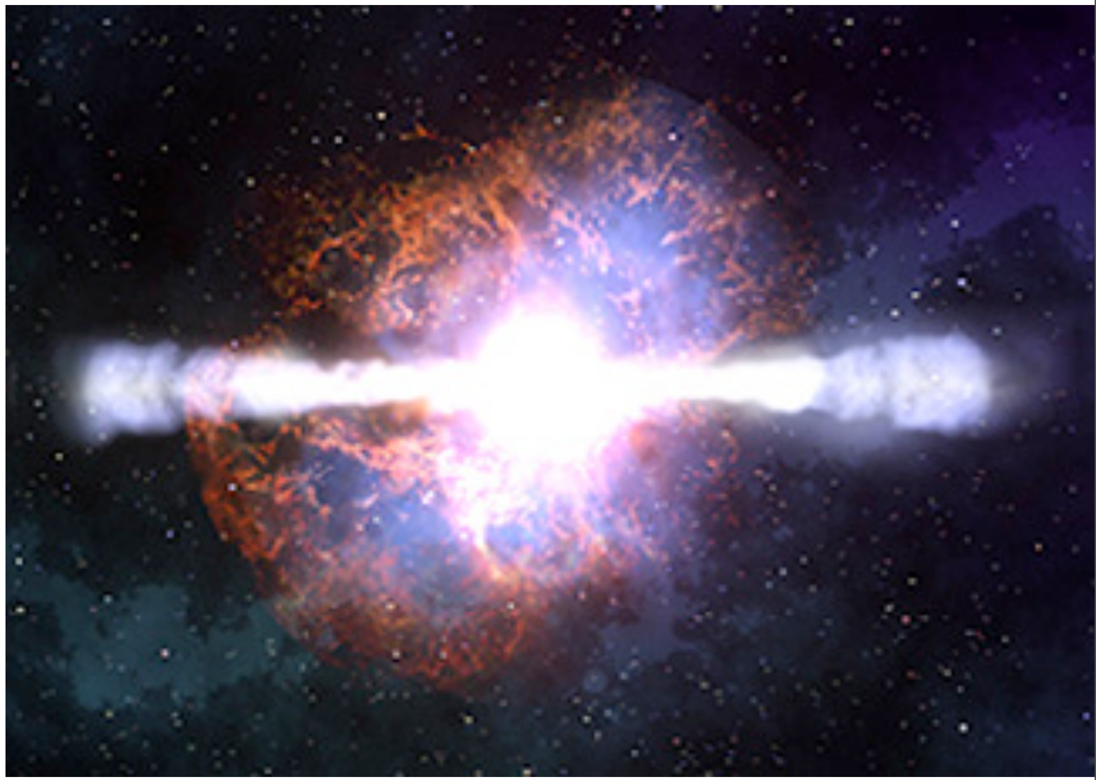
Artist's impressions of different models for GRBs: collapsar, supernova, NS/NS merger, hypernova
http://www.youtube.com/watch?v=npzgasXkHtk

Hypernova or Collapsar

- The death of an exceptionally massive star, >$50M_{sun}$!
- The core quickly collapses down to a black hole.
- The star must be rapidly rotating.

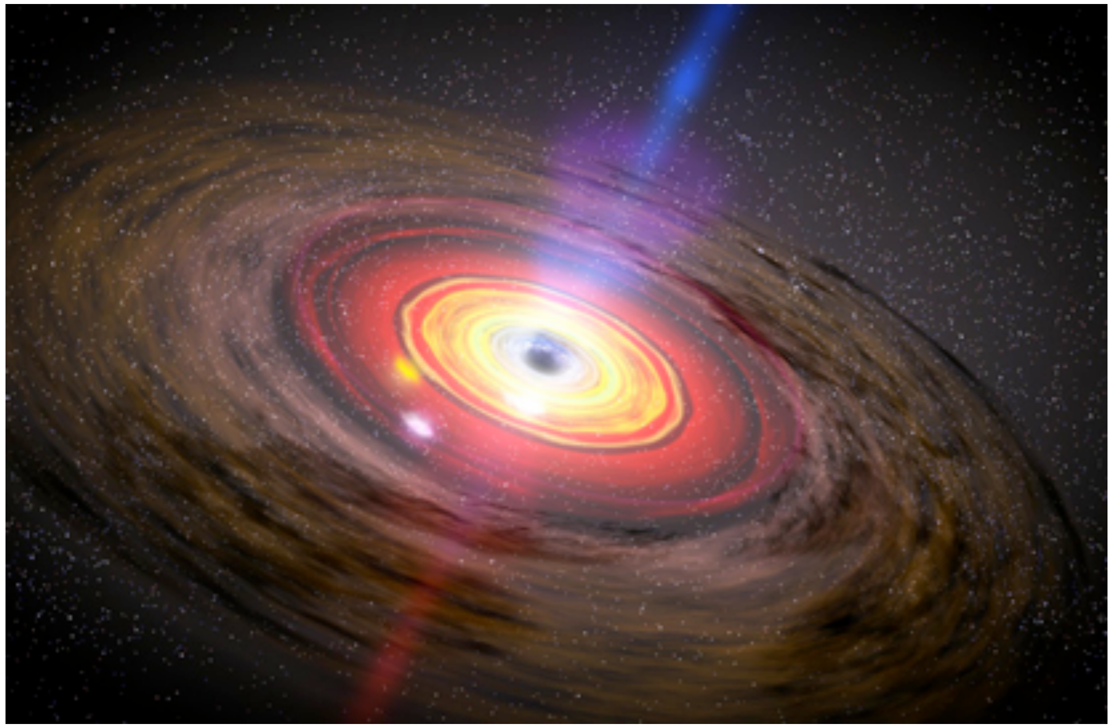
Hypernova or Collapsar

- But GRB is addition to normal supernova blast, and must be highly beamed
- need to create high energy, tightly focussed “jet”
- For the jet to make it out of the star, most of the hydrogen envelope should have been lost during the earlier evolutionary stages.
- Combination of magnetic field and temperature create a strong gamma-ray beam.



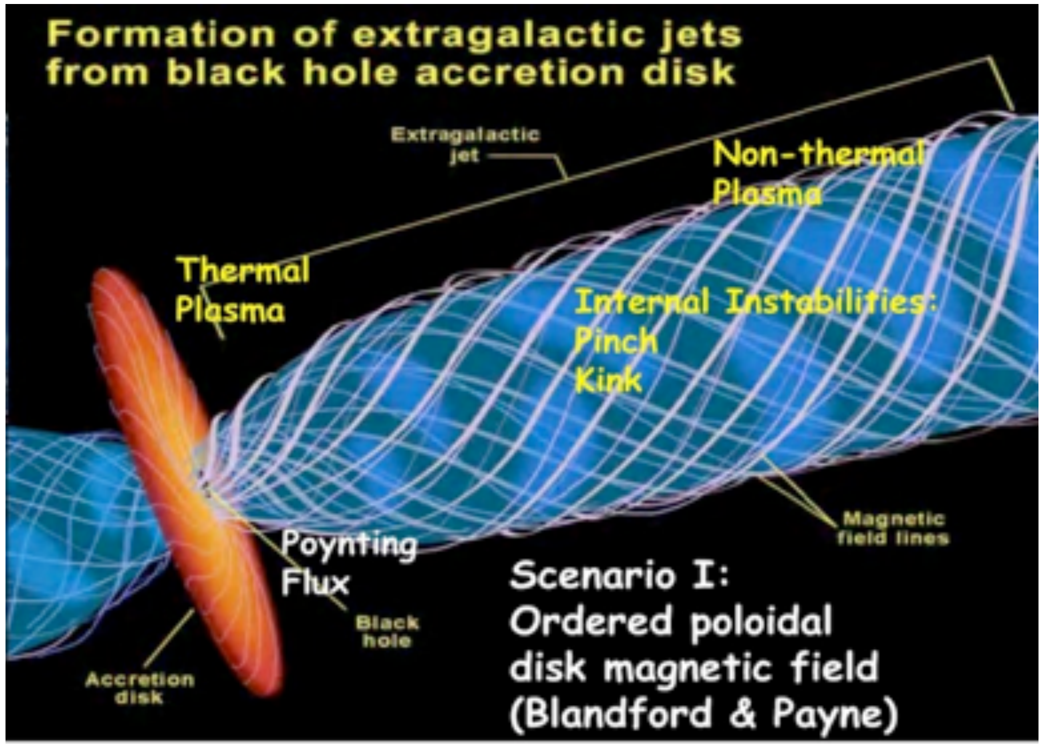
Blackhole Traffic

- Material falls into the revolving black hole is revolving around it, like water in a sink.
- Material is pulled toward the star by gravity ("accretion")
- but accreted material is also orbiting--closer orbits are faster (Kepler's laws!)
- This creates a "traffic jam" and leads to the formation of an accretion disk around the black hole. (Everyone loves disks!)
- Freaky high friction, heats up disk.
- Friction causes orbiting material to slowly spiral into the black hole



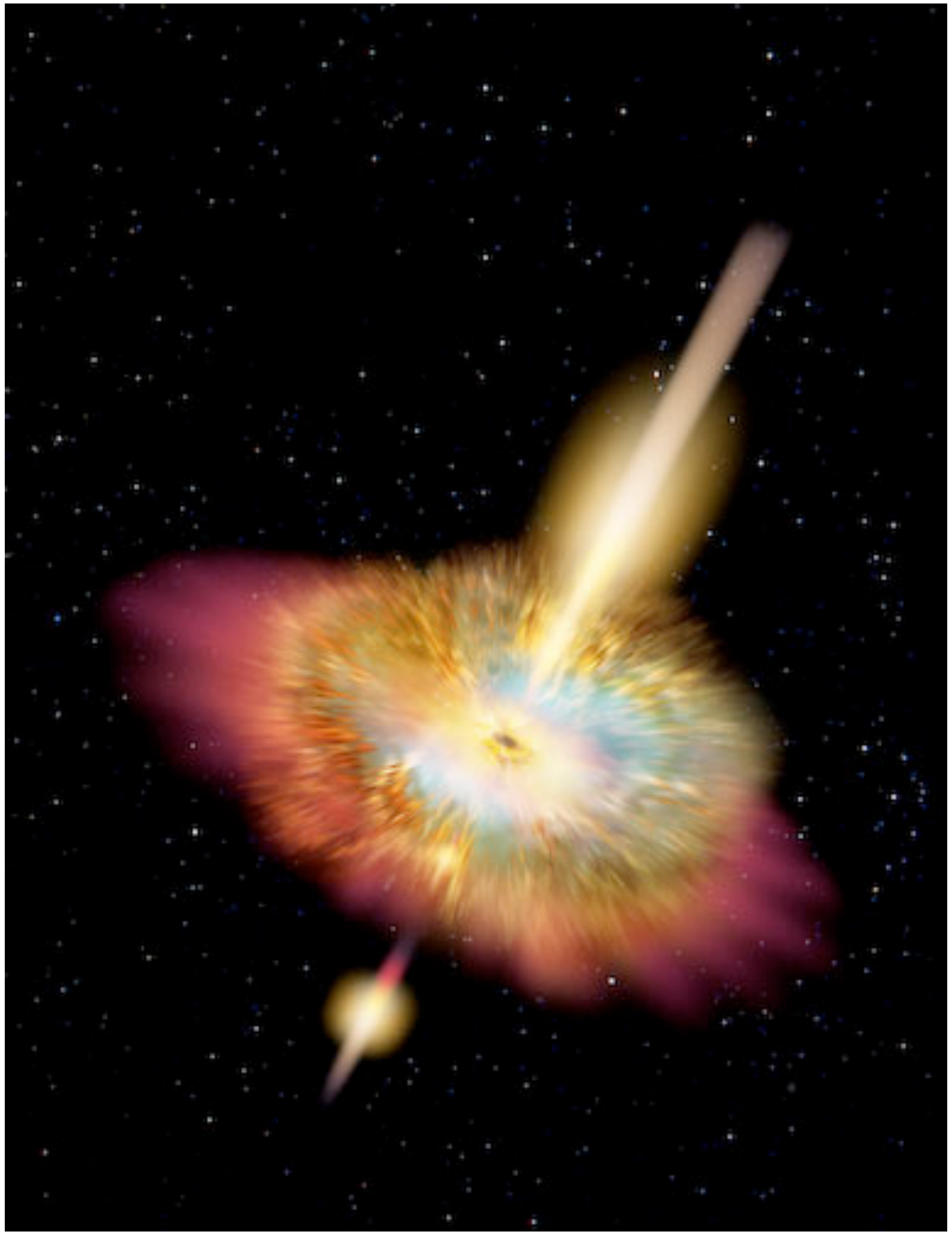
The Jet: So it Starts

- As in the case of neutrons stars, during the collapse the magnetic field strength increases.
- This combined with the hot temperatures tend to drive material away from the black hole
- It can’t move in disk plane, but above and below is open!
- Particles get accelerated, causing a pair of tight beams coming out of the magnetic poles.



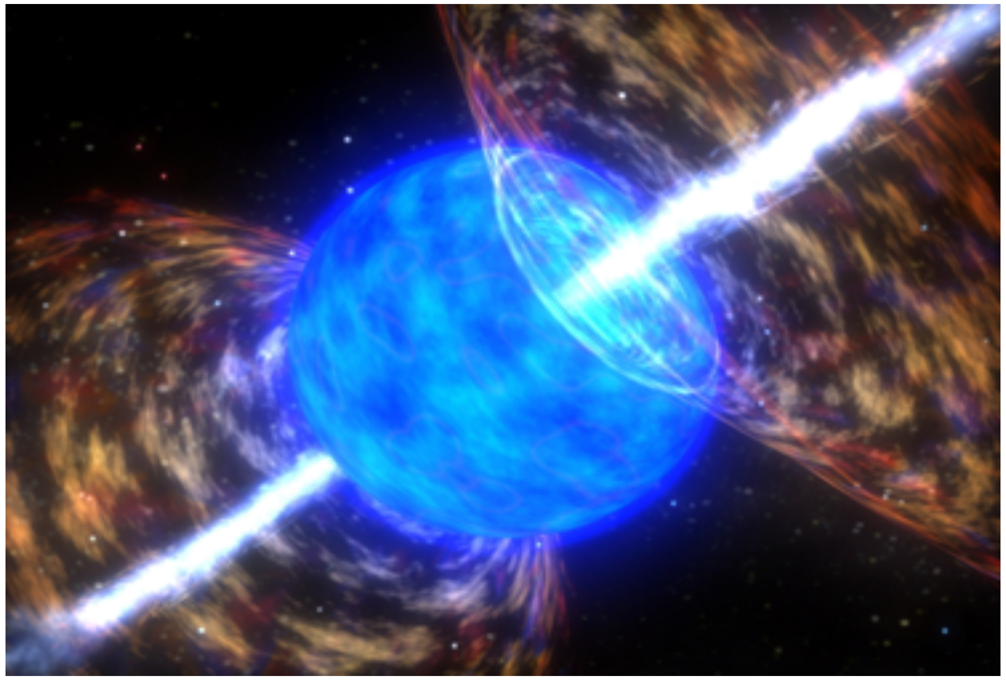
The Jet: So it Starts

- In the hypernova, all of this is happening fast!
- Moments after the black hole forms, an accretion disk forms
- and all that energy, a billion billion times the Sun's output, is focuses into twin back-to-back beams of destruction.
- The beams chew their way through the star to the surface, then erupt
- blast into space where they are free!



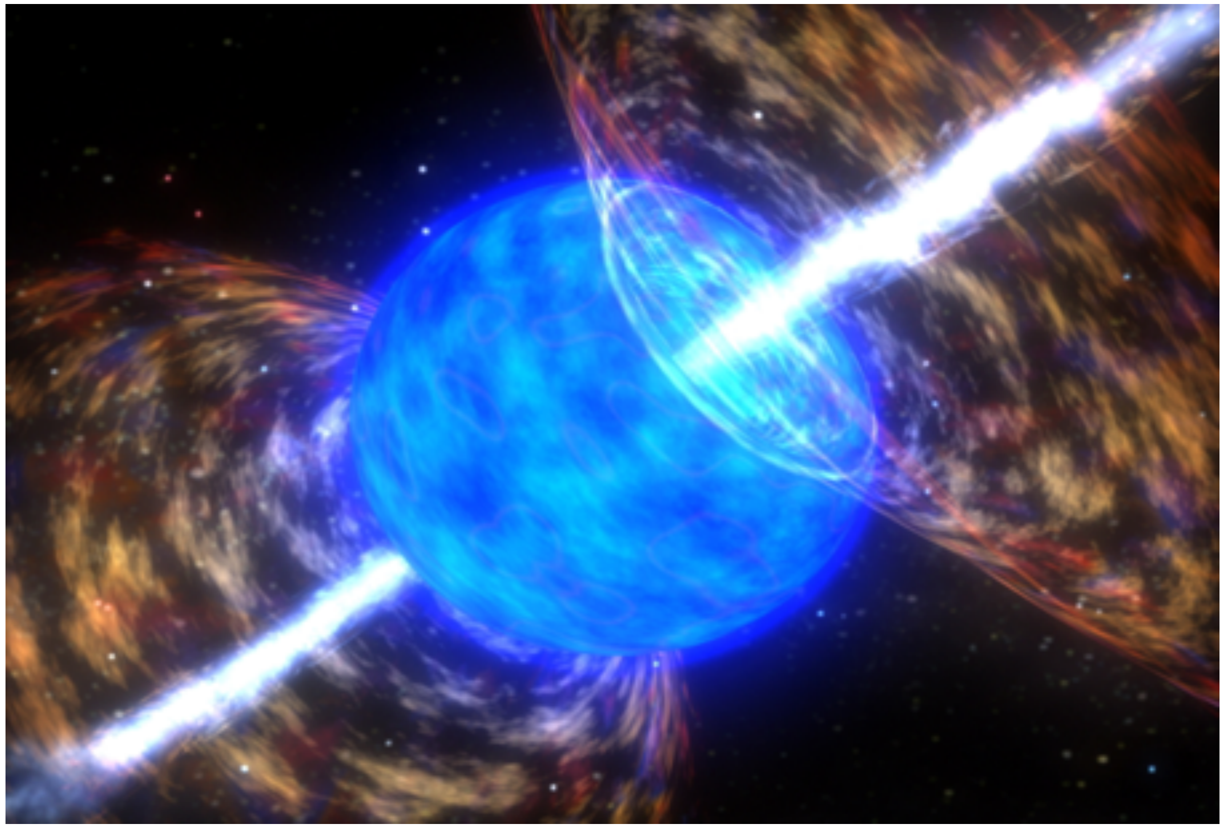
The Jet Goes Universal

- Ironically, the beam does not have too much stuff in it- only a few Earth masses.
- Matter can be accelerated to crazy speeds, almost the speed of light!
- But region surrounding the exploding star is filled with debris blown off by powerful winds during the stars life
- the high-energy beam rams into the surrounding matter



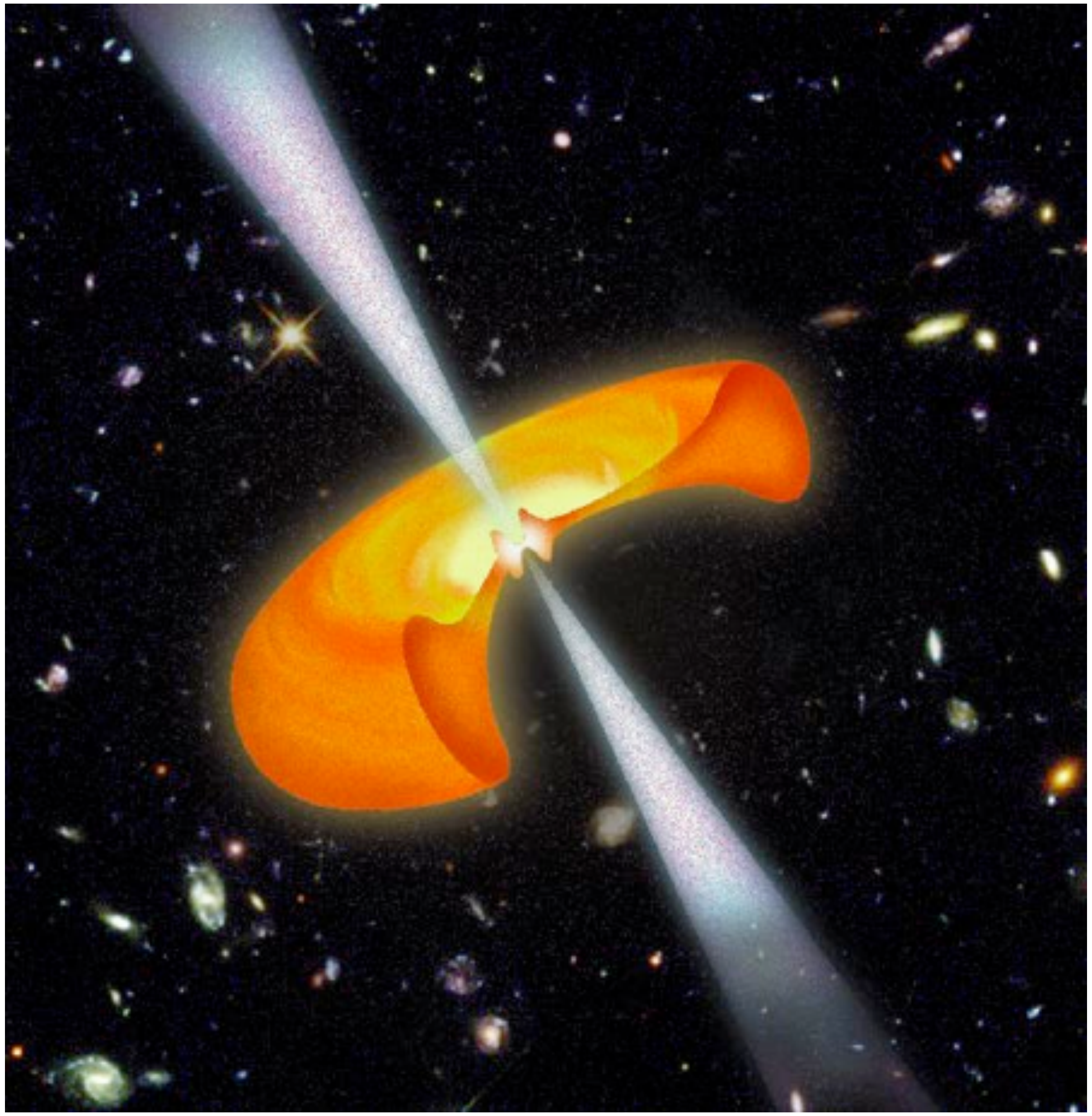
The Jet Goes Universal

- These collisions of gas at high speed produce shocks that heat the gas up to huge temperatures
- and shocks in the jet itself emit copious amounts of gamma-rays; a GRB is born!



The End

- Beams continue on to the edge of the Universe.
- Since the explosion is beamed, we only see a small fraction of them.
- So much rarer than normal core collapse supernova, or we'd see more.
- After the beam is gone, the supernova is still going on, which is where the optical afterglows come from.

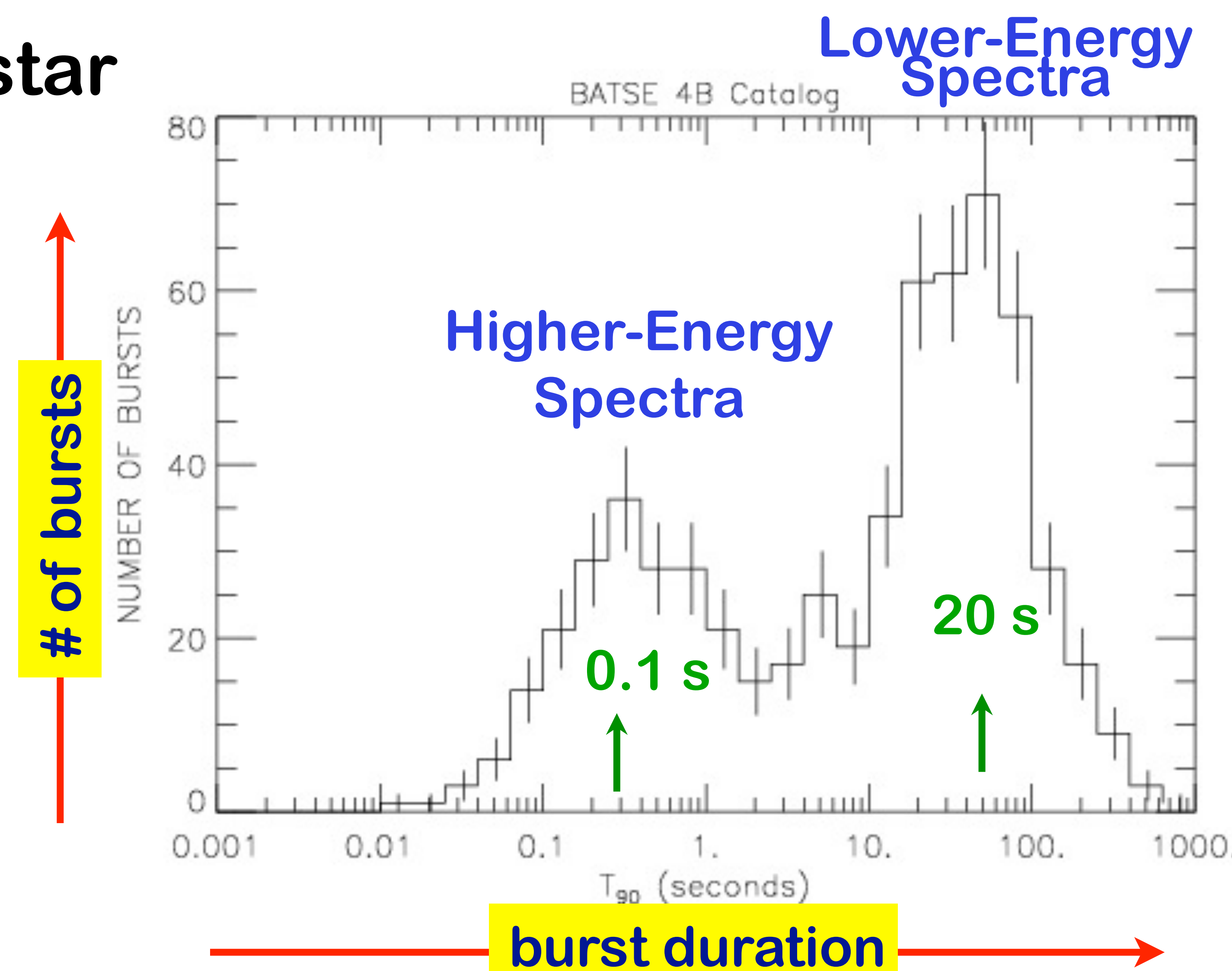


http://www.youtube.com/watch?v=X6PLcM2dXmw&feature=fvw

2:25+

More Than One Way

- Gamma-ray bursts seem to come in two varieties:
  - shorter-lasting and higher-energy
  - longer-lasting and lower-energy
- Hypernovas or collapsars explain the long gamma-ray bursts, but what about the short ones?
- These are not seen in star forming galaxies.
- Seen in outskirts of galaxies or in old elliptical galaxies, which are no longer making stars.
- No supernova like emission afterglow.

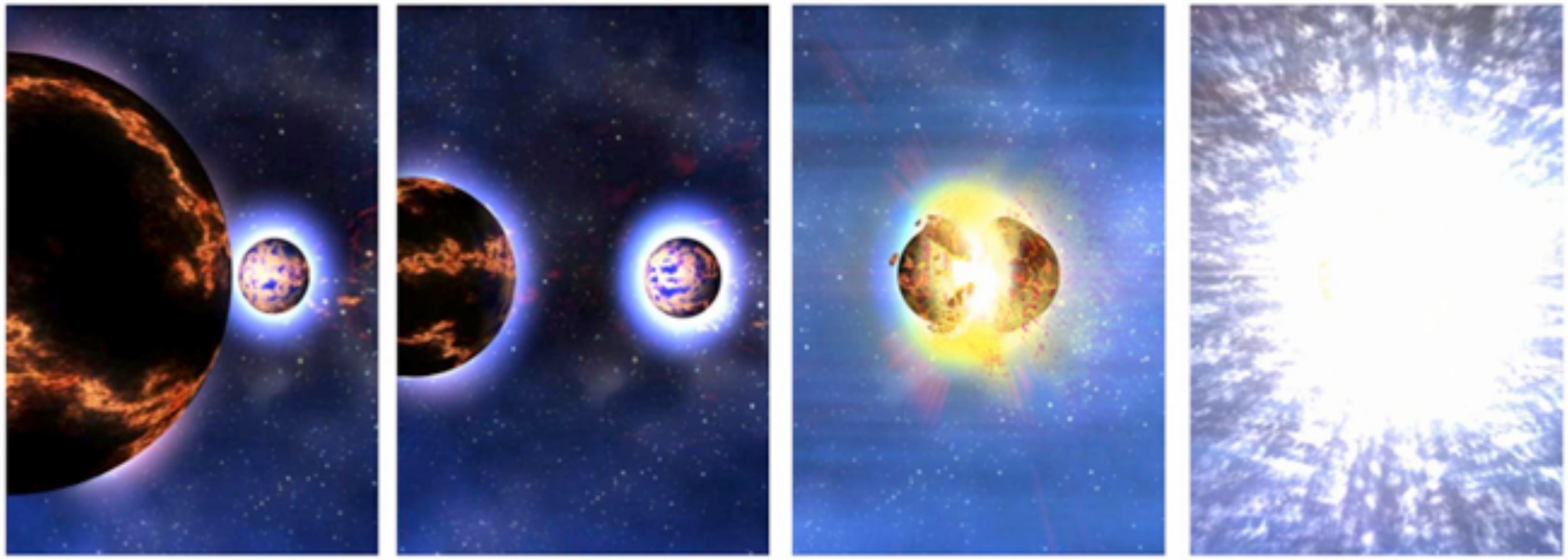


More Than One Way

- Although, astronomers are not actually sure, the most popular idea is an neutron star-neutron star merger or neutron star-black hole merger.
- Multiple systems are common, so we need a binary system with two 10-30 solar mass stars,
- The most massive star goes supernova, then the next.
- We're left with two compact objects in orbit.

Double Neutrons

- Over billions of years, the orbits decrease.
- The neutron stars get closer and closer together
- They quickly rip apart and merge with enough mass to turn into a blackhole.
- If enough material left over, it can form a black hole with accretion disk too.



- Fast and no supernova light expected.

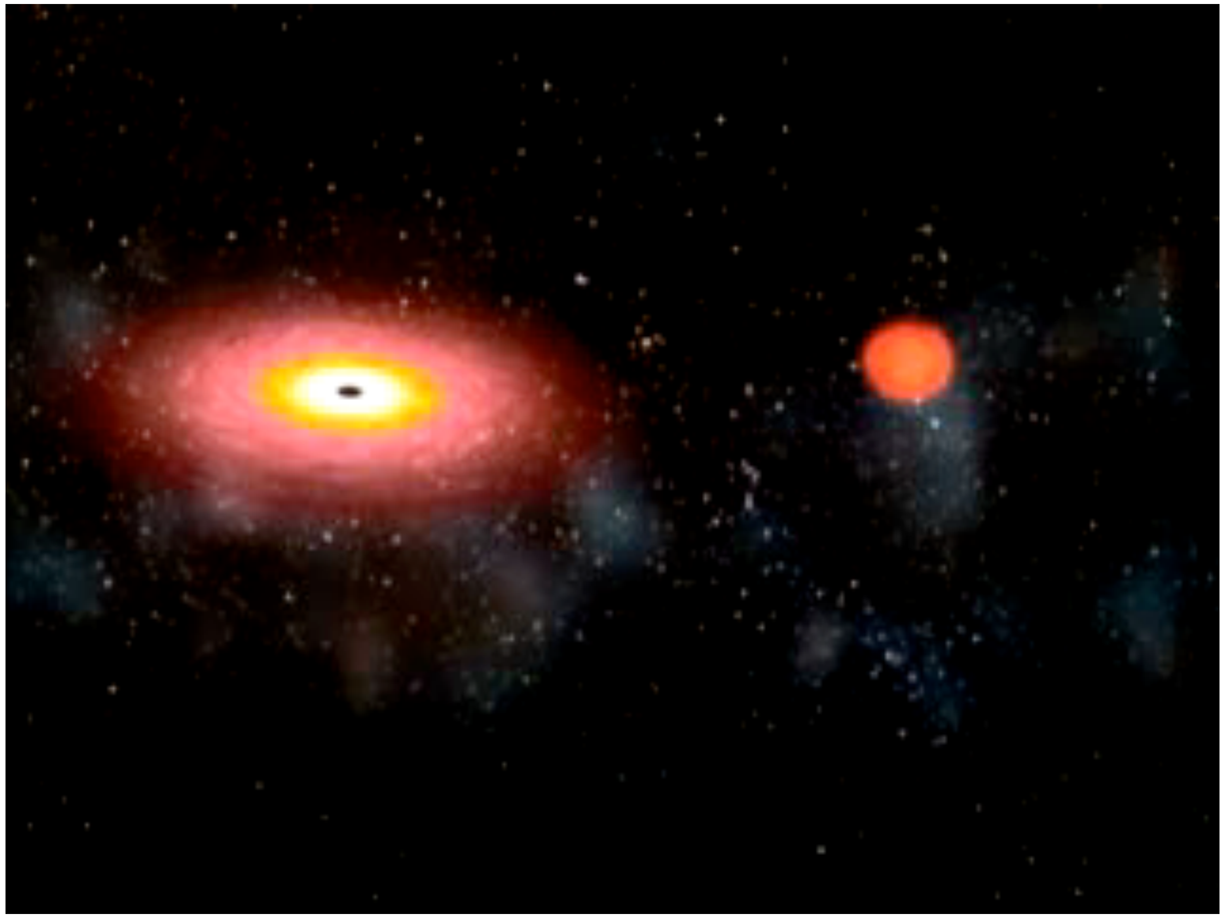
Double Neutron Stars

- Very similar to the hypernova
- Accretion disk, magnetic fields, powerful gravity creates twin beams of death.
- Expected to be shorter and higher-energy gamma-rays, and that is seen.

- Although hard to detect and rare, we do know of existing examples of close pairs in our Galaxy.

Neutron/Black Hole Merger

- Or, similarly, a neutron star mergers with a black hole.
- Again, accretion disk with possibility of GRB.
- We don't know of any, but rare and very hard to detect.
- Good news is that the total energy in all of these objects is smaller as they are so short in time.



iClicker Poll:
Merging neutron stars

Why does colliding/merging two 2 solar mass neutron stars create a black hole?

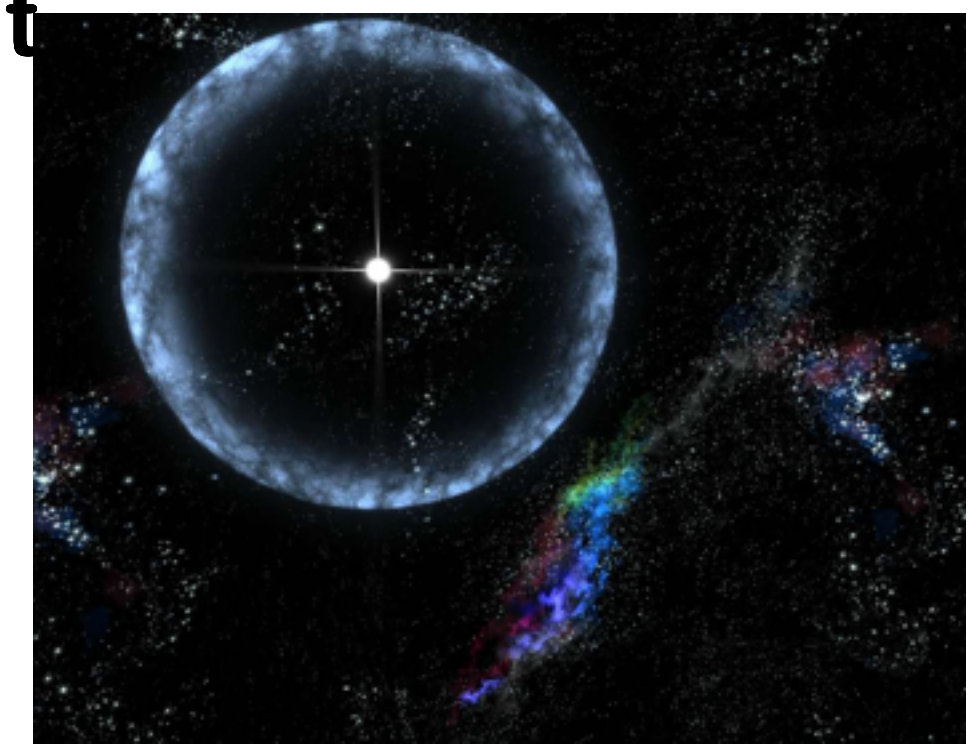
a) The total mass leads to gravity that is stronger than what can be supported by neutron degeneracy.

b) It doesn't.

c) The temperature at impact is so hot that only a black hole can be created.

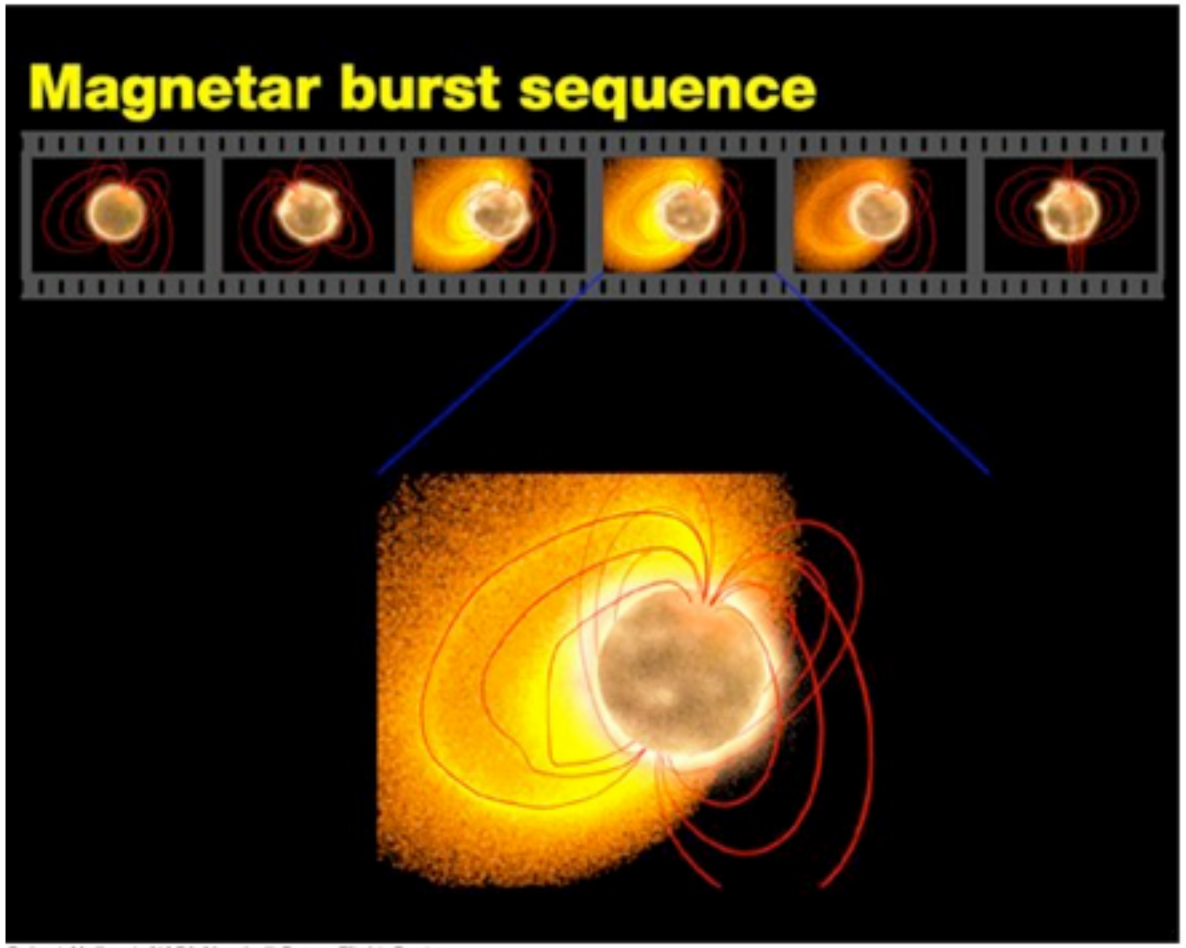
Magnetars

- Magnetars (neutron stars with ultrahigh magetism) also can produce GRB-like bursts, called magnetar flares.
- Stellar quakes from the twisting magnetic fields similar to solar flares.
- In Dec 2004, one was so bright (equal to 100,000 yrs of Sun output) that it blinded all gamma-ray satellites.
- It impacted the Earth's atmosphere, puffing up the Earth's ionosphere.



Magnetars

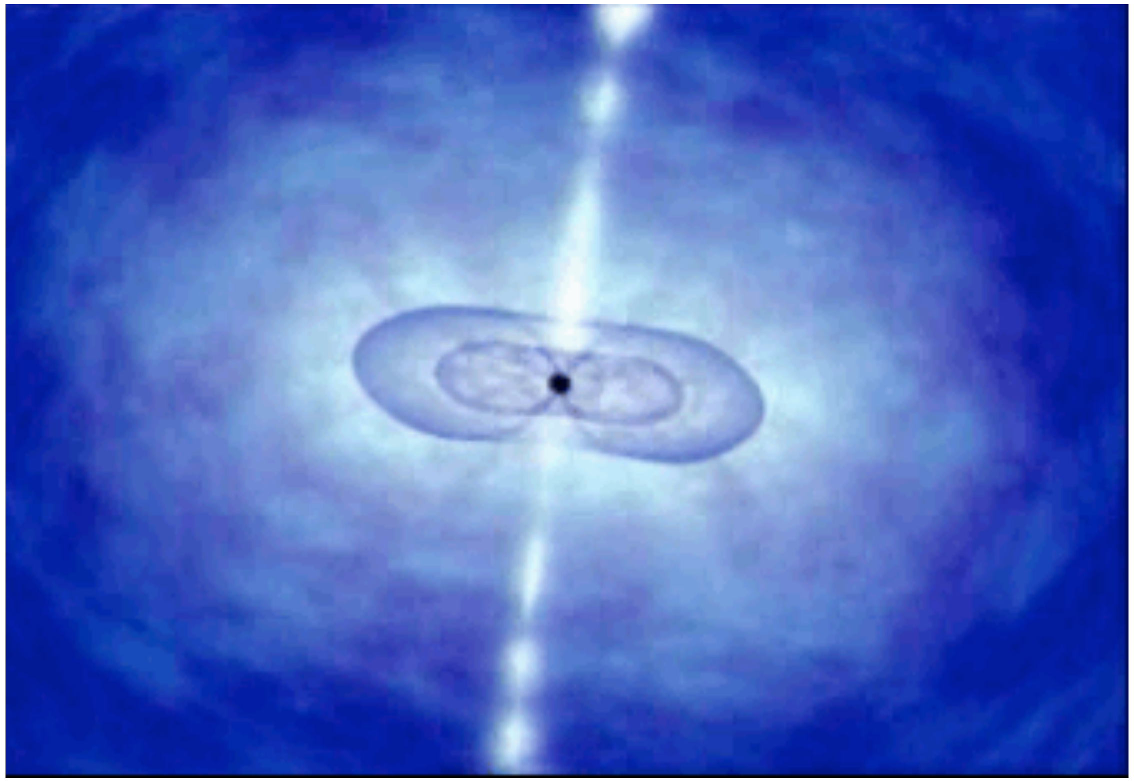
- The Dec 2004 magnetar was 50,000 light years away!
- If it was within 10 light years, it would have destroyed our ozone layer.
- No known magnetars within 13,000 light years.



Robert Mallozzi, NASA Marshall Space Flight Center

GRB Damage

GRBs are similar to supernova, BUT they can be dangerous from further away, much further away.



Let's play with a GRB beamed at the Earth from only 100 light years away.

- that is, 30 parsecs

The beam will encompass the entire Solar System, but it will only last about 10 seconds.

On the Earth, only one hemisphere will be in danger a first.

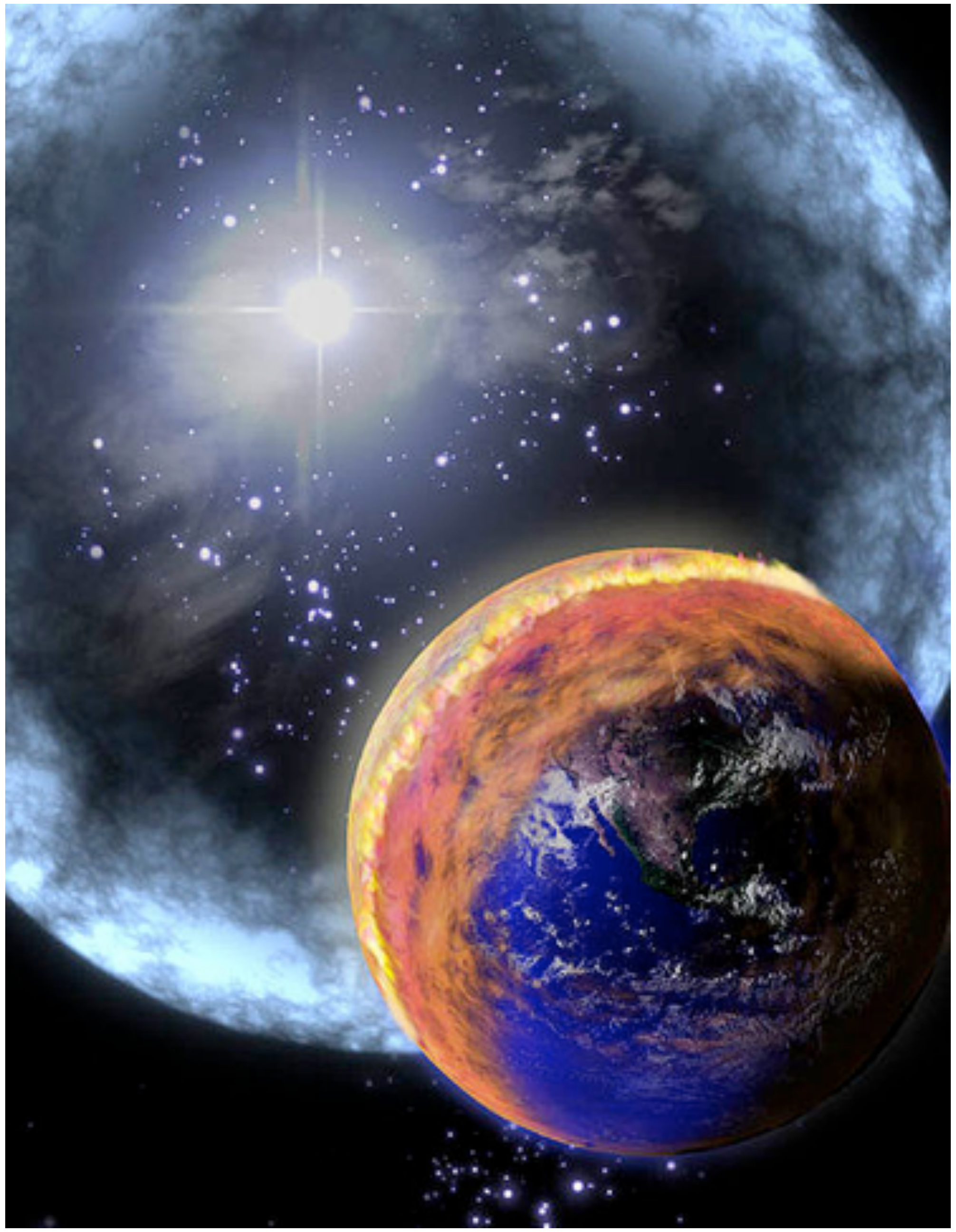
GRB Damage

The energy dumped on the Earth's surface is staggering.

It's like blowing up a 1 megaton nuclear bomb on every square mile of the surface.

Probably not enough energy to boil away the ocean or strip away the Earth's atmosphere.

But, this is still something that is 600 trillion miles away!

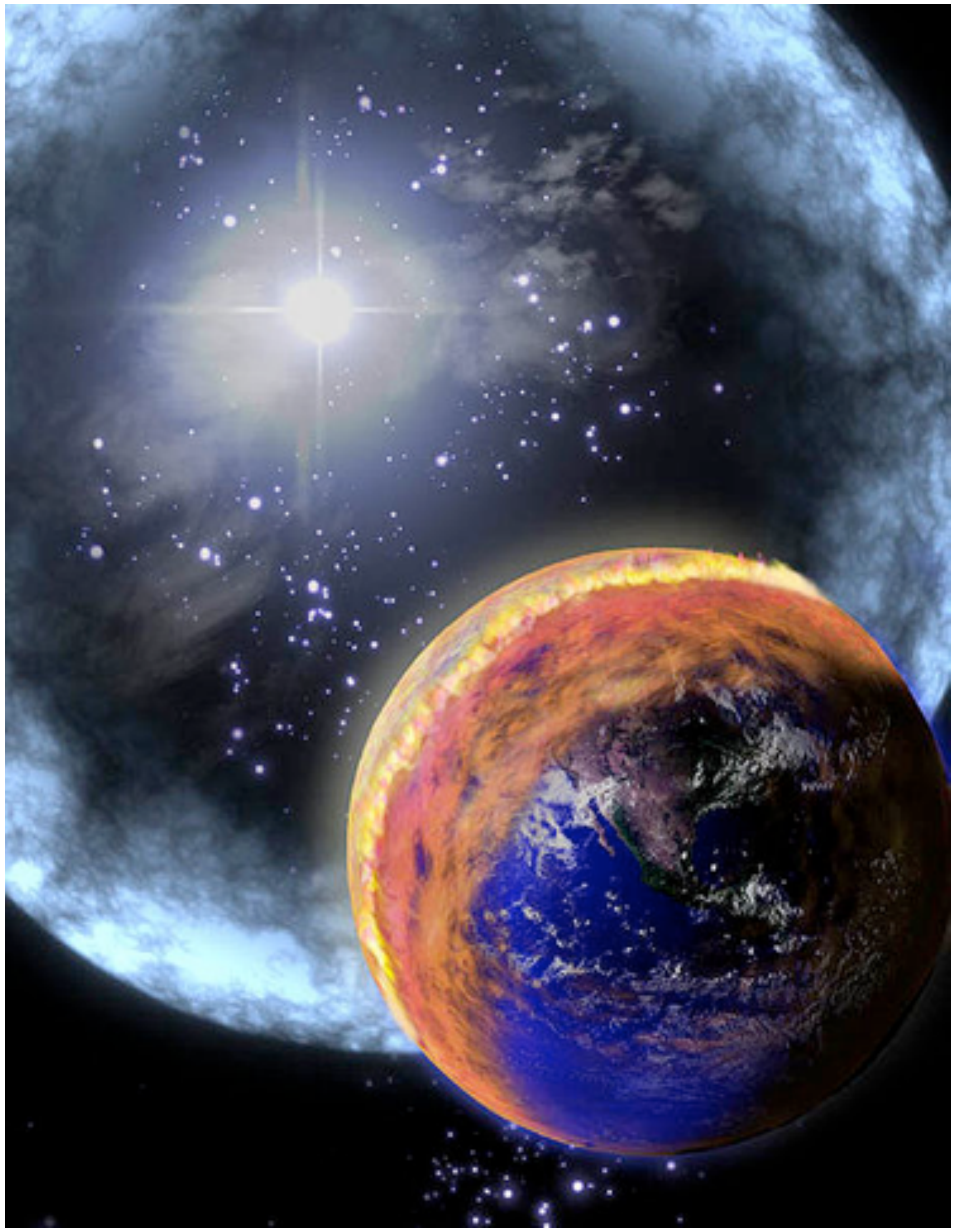


GRB Damage

For a GRB that close, if you looked at the burst, you would be blinded.

Outside, the heat would roast you.

Then influx of UV would give you lethal sunburn

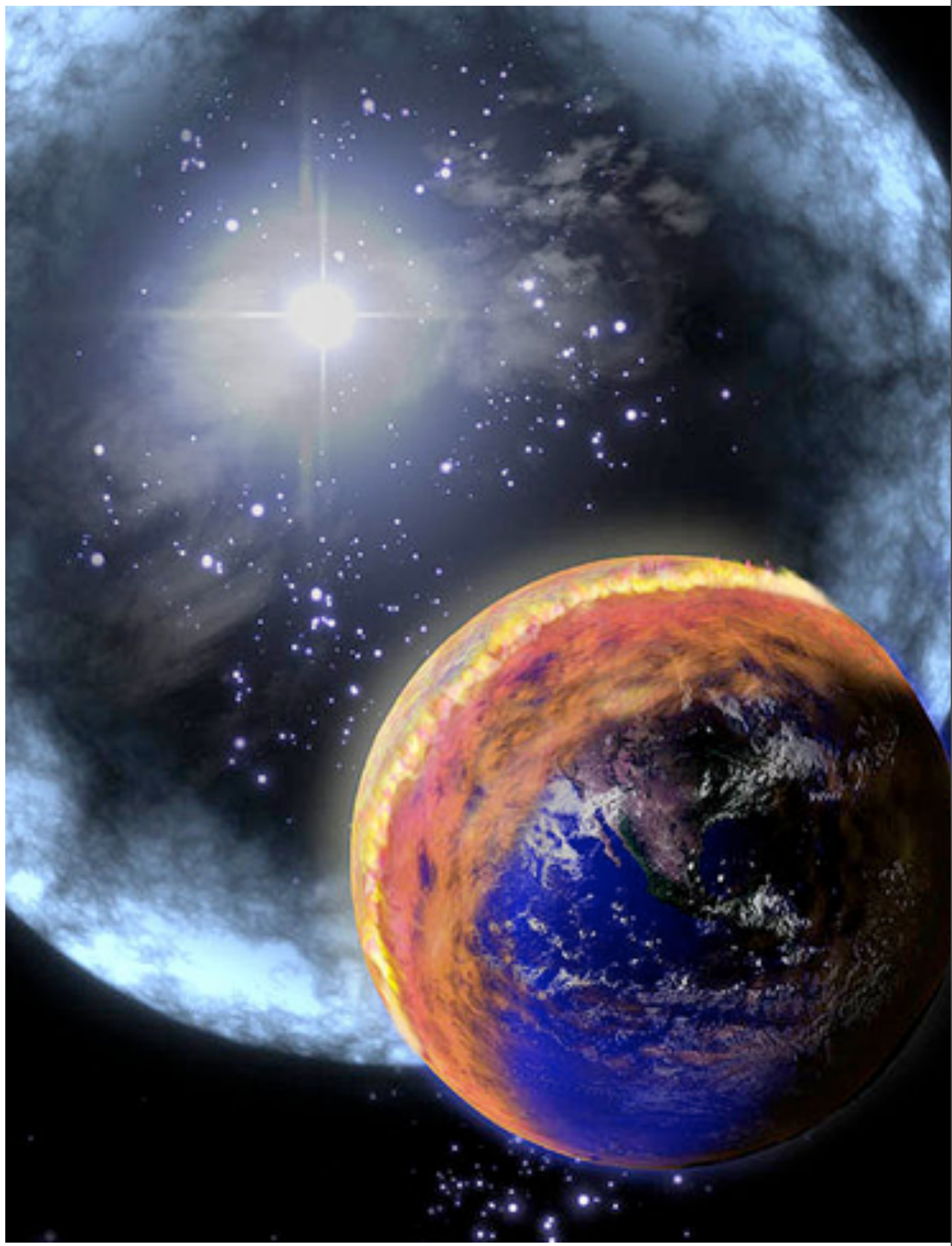


GRB Damage

The ozone layer instantly destroyed.

The Earth's surface would be sterilized, even underwater to a few meters.

Perhaps best not to mention x-rays and gamma-ray exposure.



What's Nearby

Okay, that was fun to speculate, but no likely candidates for GRB that close.

They are more rare than supernova.

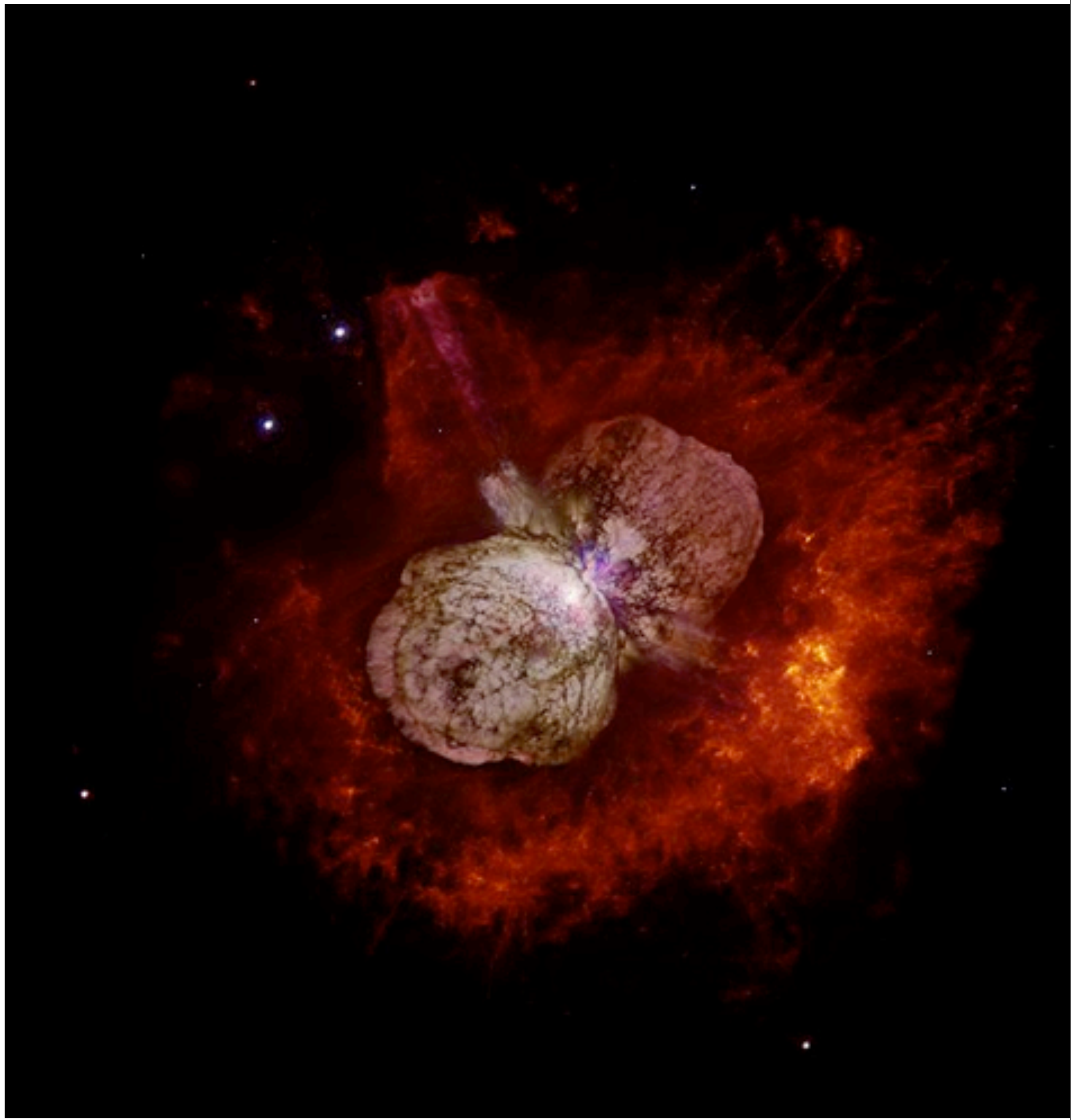
So what is the possible nearest GRB candidate?

One of the most massive stars in our Galaxy
Eta Carinae, about
7500 light years away,

- that is, 2500 pc

located in Southern Sky

- so can't seeit from Urbana.



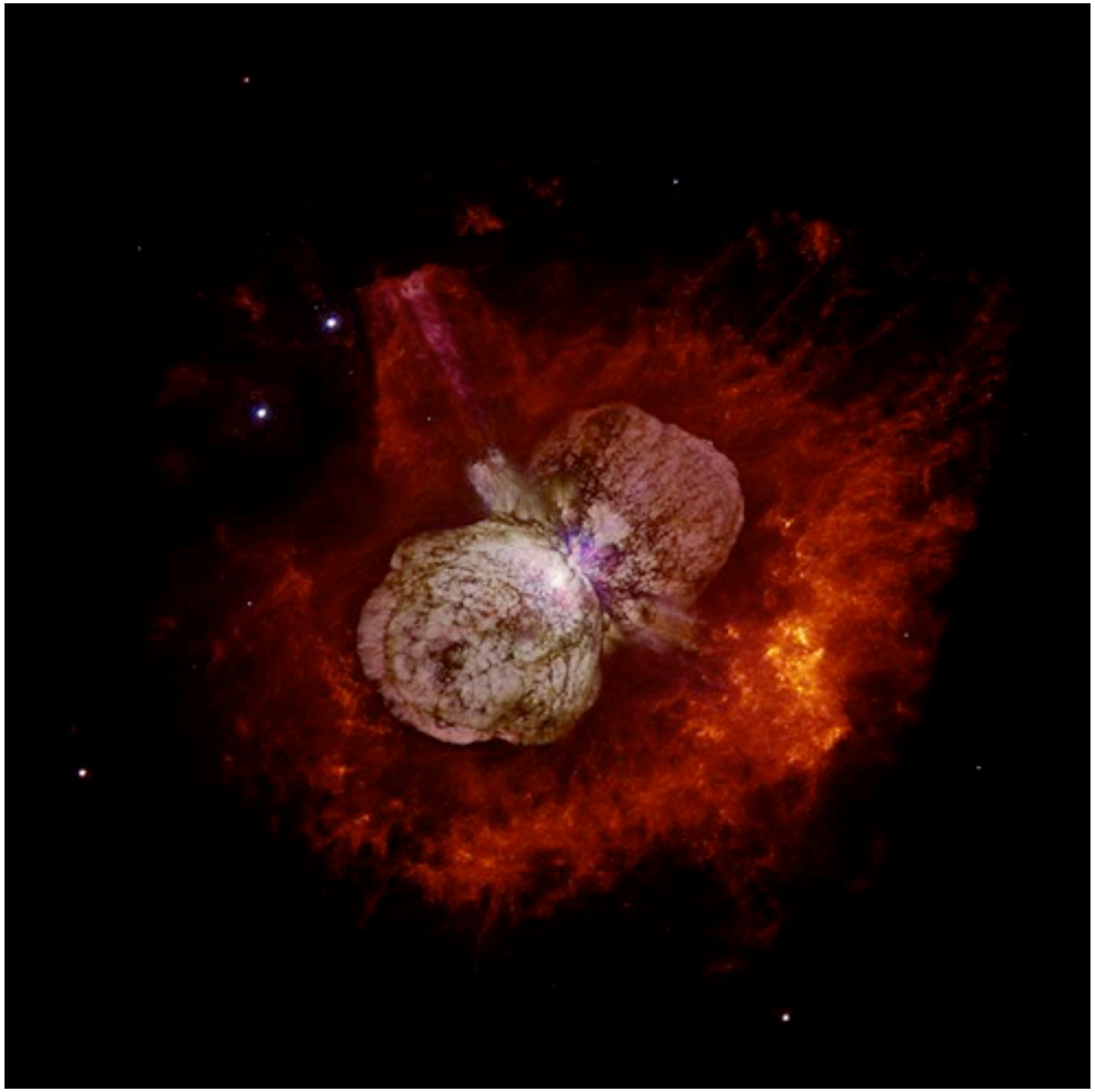
Eta Carinae

Binary system, the most massive component of which is 4 million times brighter than the Sun!

It give off more energy in one second as the Sun does in 2 months!

About 100 solar masses!

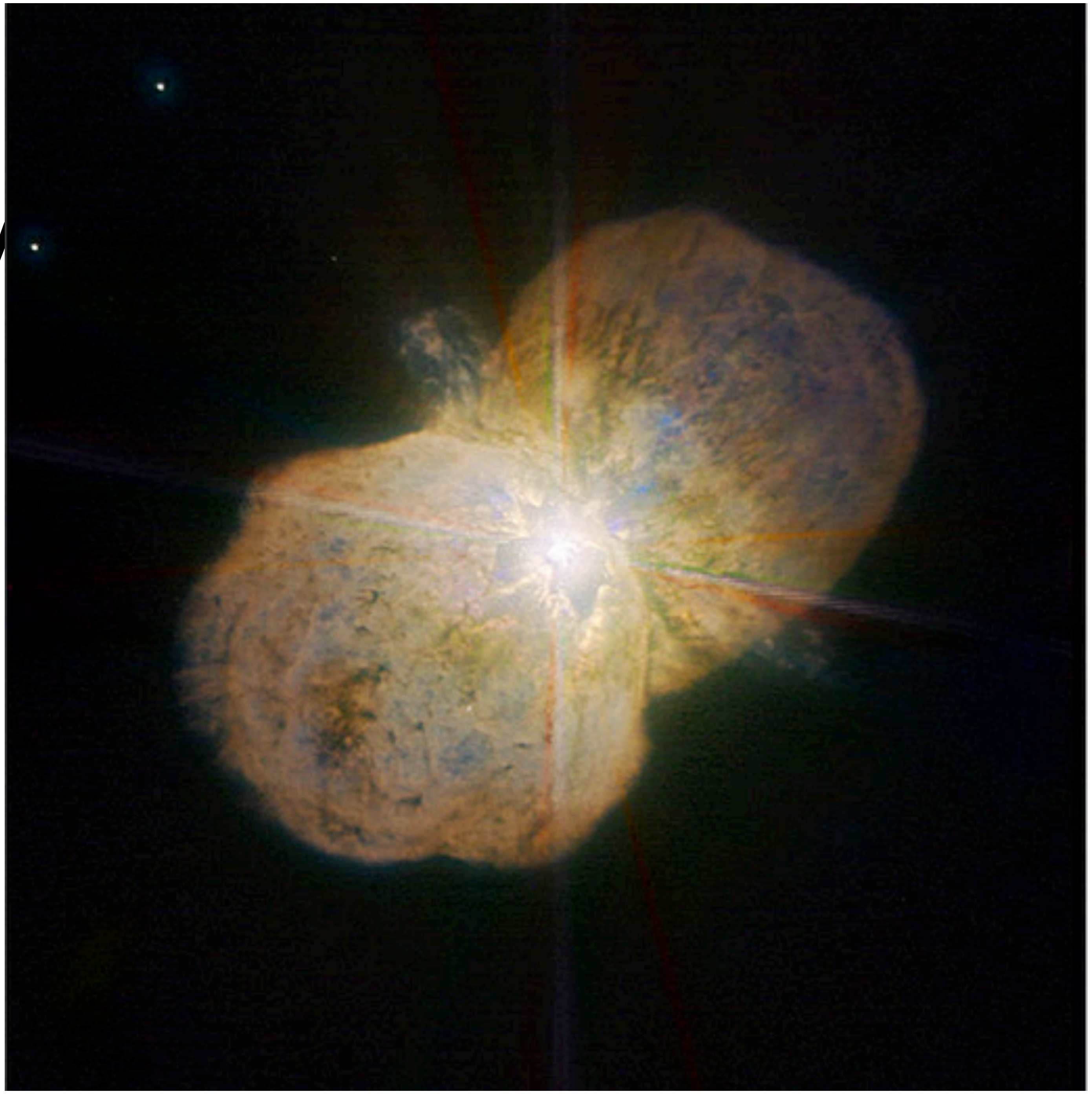
In 1843, Eta Carinae did something weird.



Eta Carinae

It had a violent spasm, blowing off huge amounts of material, almost as powerful as a supernova!

It was the second brightest star in the sky



It lost about 10 times the mass of the Sun, moving at a million miles per hour.

Today, we see two huge lobes of material, possibly the aftermath of this outburst.

Eta Carinae

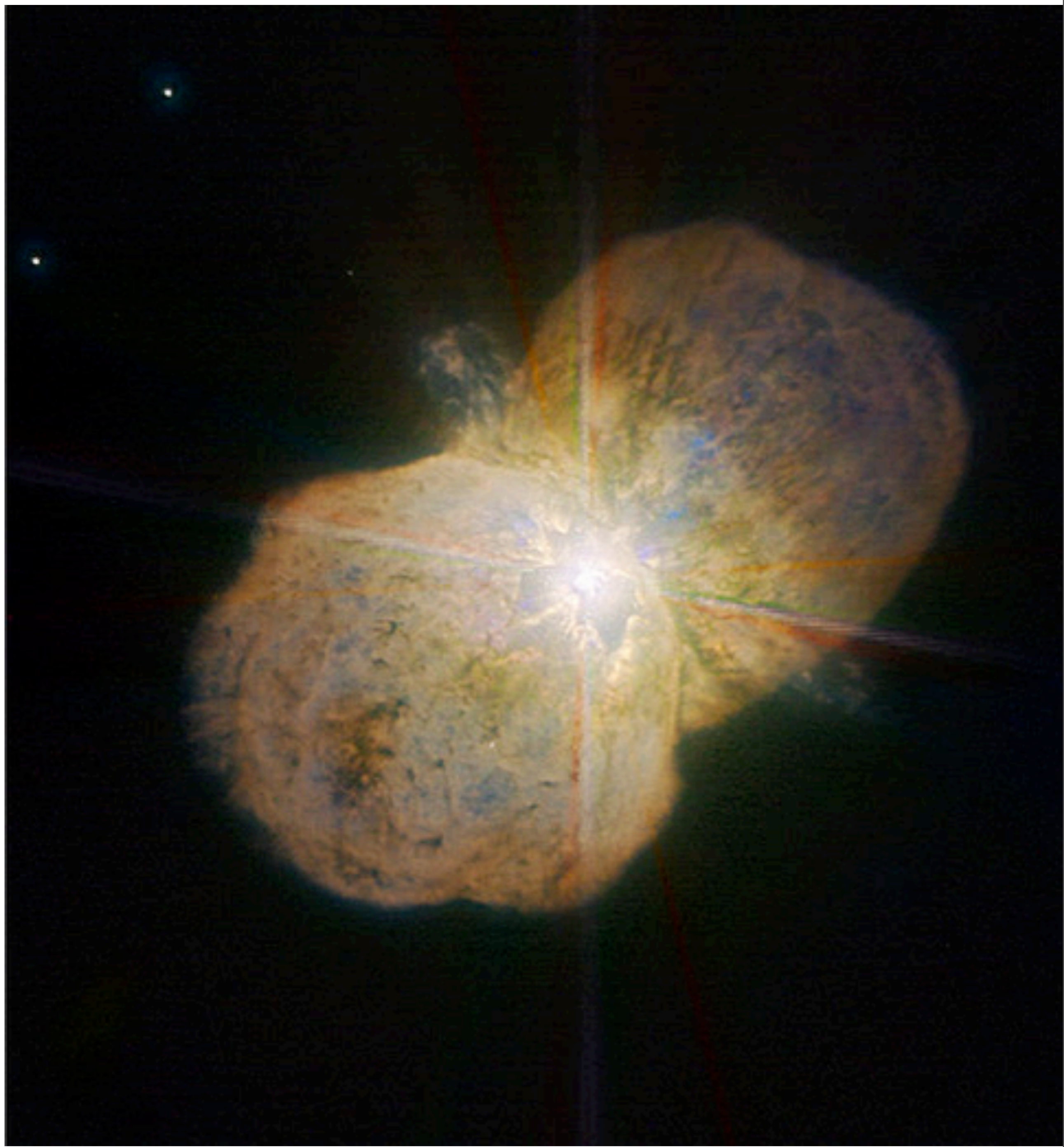
These supernova impostors are seen in other galaxies too.

We don't know when it will blow– today or in a million years.

It might be a hypernova, or GRB, but maybe not.

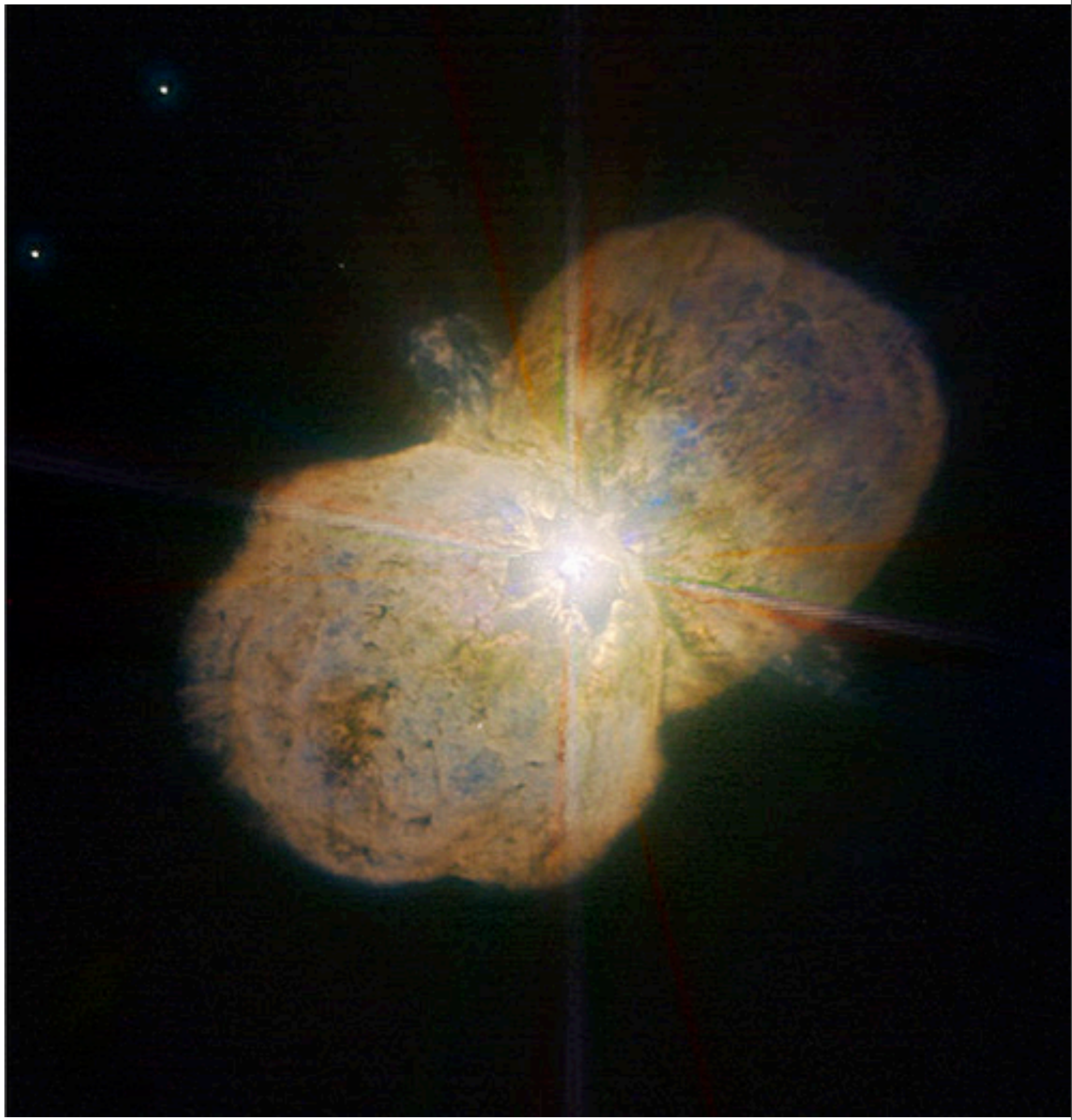
Regardless, the current orientation of the star (note, the lobes) suggests that it will miss the Earth.

Can change though.



Eta Carinae Damage

Let's play with what would happen if Eta Carinae did hypernova with the Earth in the beam.



Even at 7,500 light years bad things will happen.

Would be about 10 times brighter than the full Moon.

The UV light from it would probably give a sunburn.

Eta Carinae Damage

But the gamma-rays and X-rays?

Absorbed by the atmosphere, but worse affects than nearby supernova.

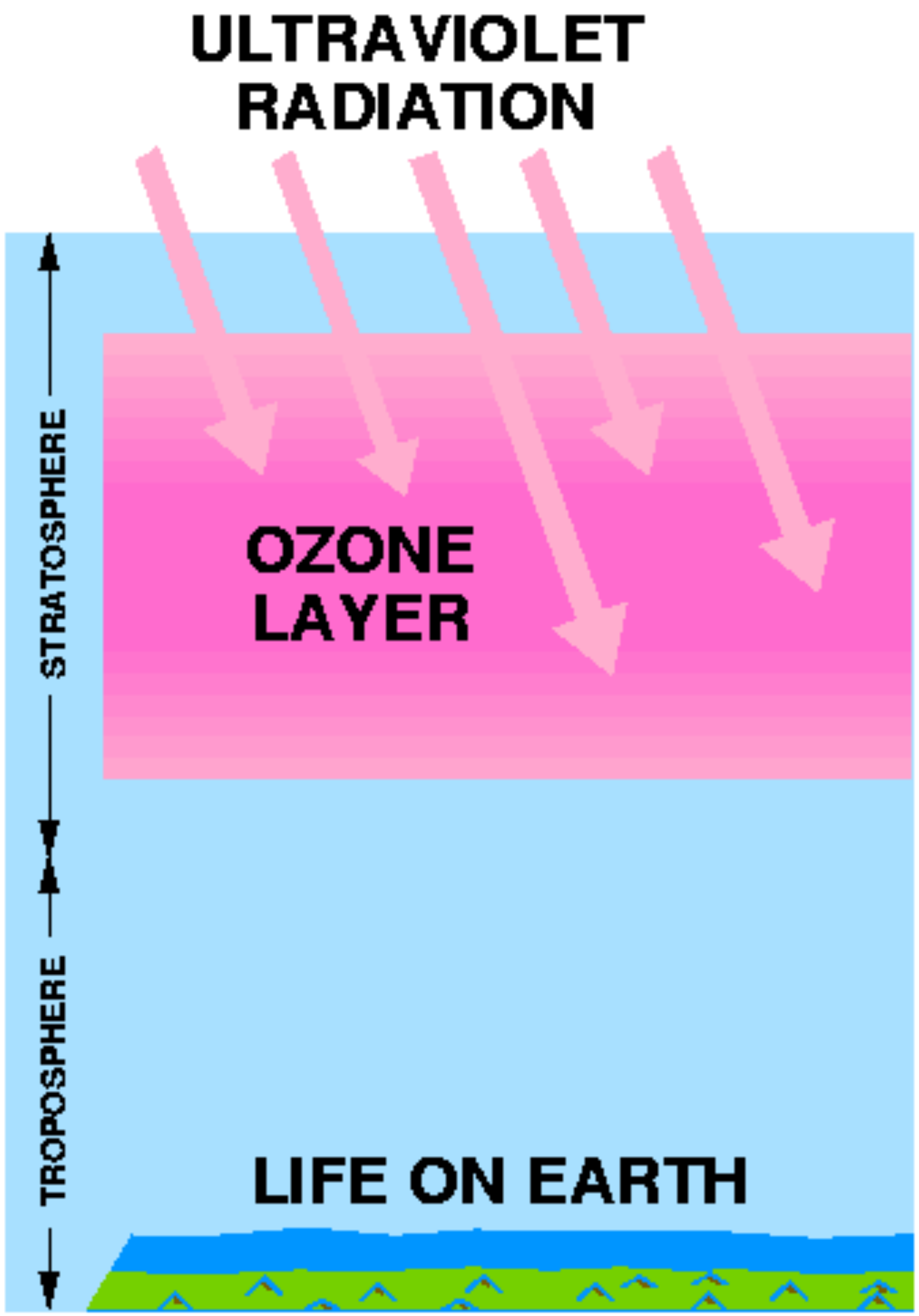
There would be a strong EMP (electromagnetic pulse) that would wipe out electronic devices for facing hemisphere

- Computers
- Power grids
- Airplanes
- Cars (emergency vehicles too)

All fried!

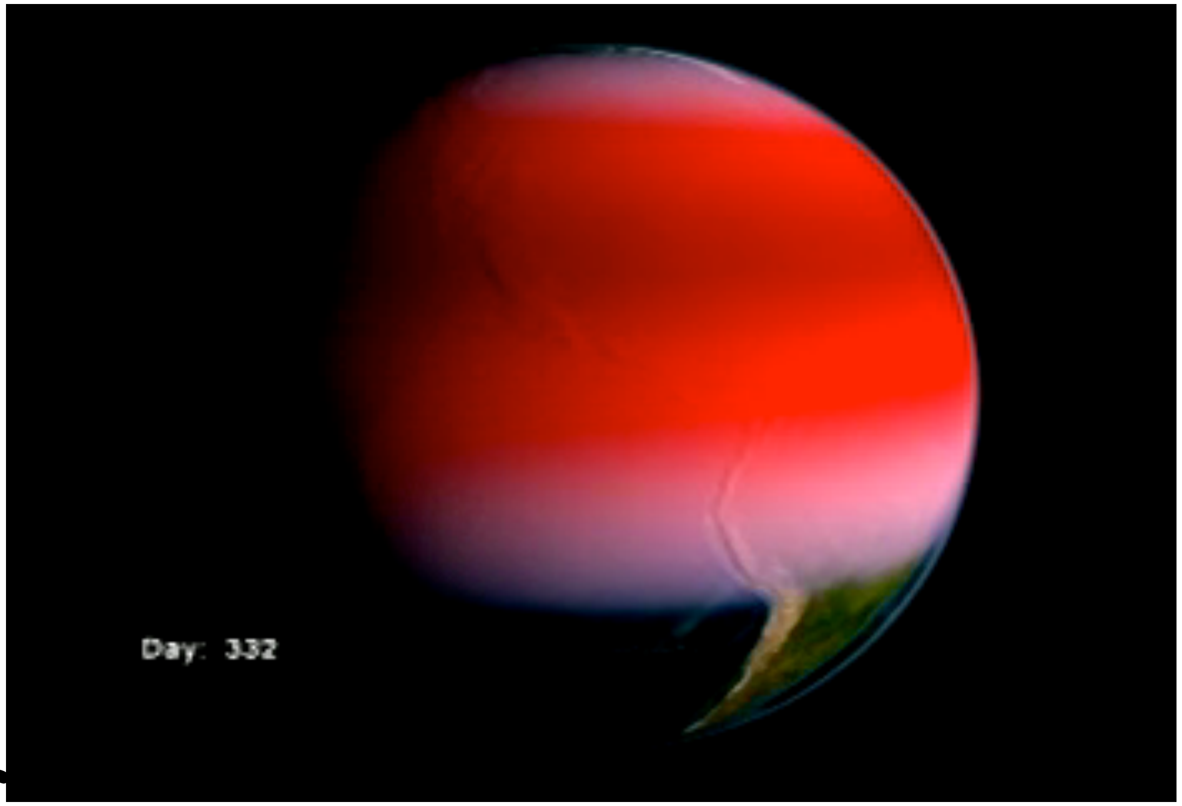
Ozone Layer is Devastated

- Gamma-rays convert N2 and O2 into NOx (N, NO, NO_2)
- NO, NO_2: catalysts to destroy ozone
- Up to half the ozone layer destroyed
- Takes years to recover
- Solar UV at the surface increases



Increased solar UV a threat to life

- UV radiation can damage DNA
- Risk of cancer, death, infertility
- Surface-dwelling plankton and other life near the surface, would not survive
- Water blocks UV, so deeper ocean life would be protected



Threat of Ice Age?

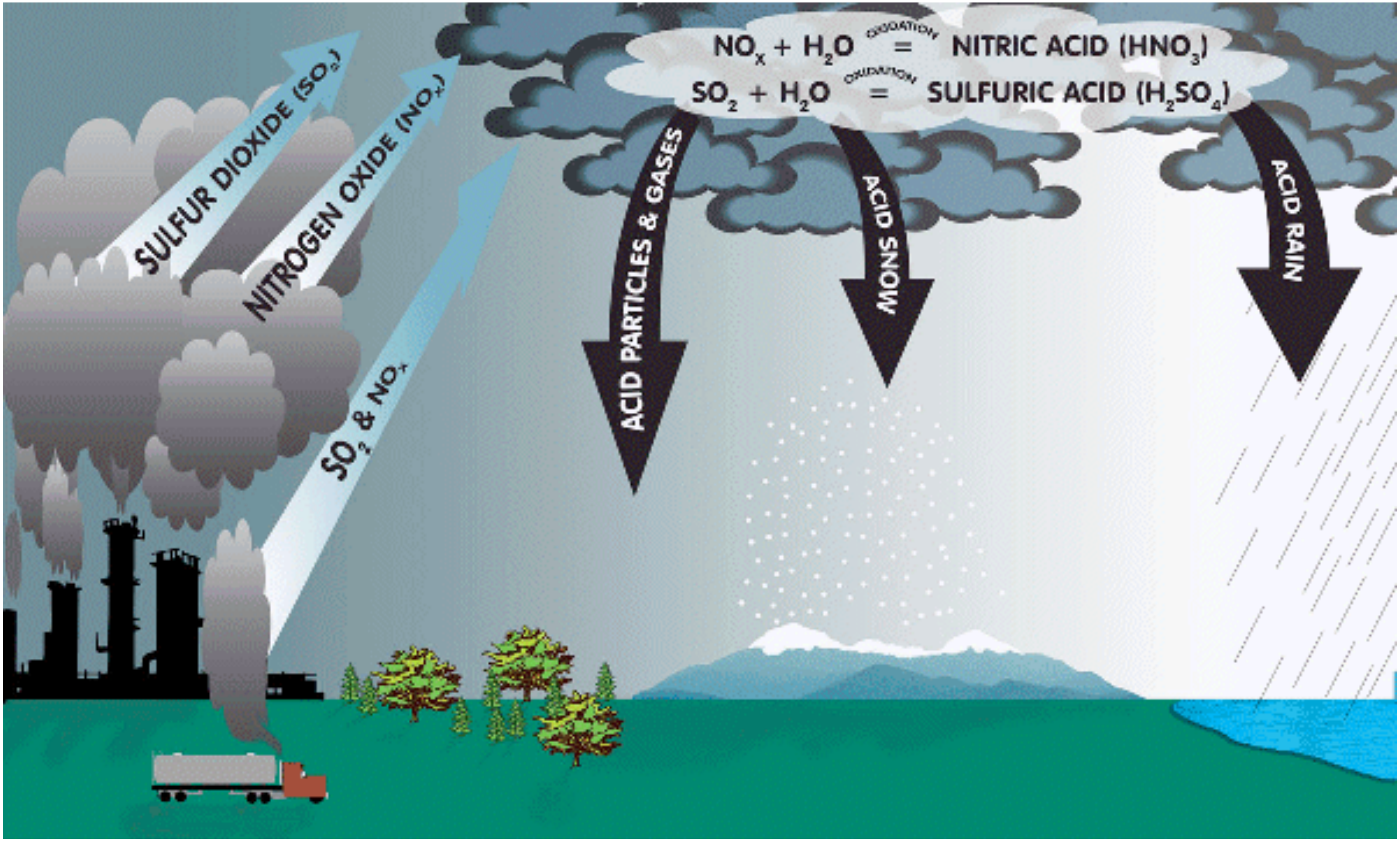
NO_2 is a reddish-brown gas

Its opacity also reduces the visible light from the Sun reaching the ground

Less solar energy leads to reduction in global temperatures

Trigger an ice age?

Nitrogen oxides also cause acid rain!



So how bad is it?

If

- eta Carinae leads to a GRB
- and is aimed at the Earth
- and is as powerful as typical GRBs

Then

- it would be unpleasant for all
- and deadly for some (air travellers etc)
- but not the end of humanity
- if you trust these guys

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Rapid Communication

Superluminous Supernovae: No Threat from η Carinae

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and BARBARA J. ANTHONY-TWAROG[2]

i>clicker question

Why is it thought that Eta Carinae will probably not kill us all?

A. It doesn’t have a gun.
B. It will not go hypernova.
C. We don’t think the lobes are pointed our direction.
D. It will likely turn into a planetary nebula.
E. Its too far away to be a danger.

GRB Rates?

Based on the observed Universal rate of 1/day, we can estimate the GRB rate in the Milky Way.

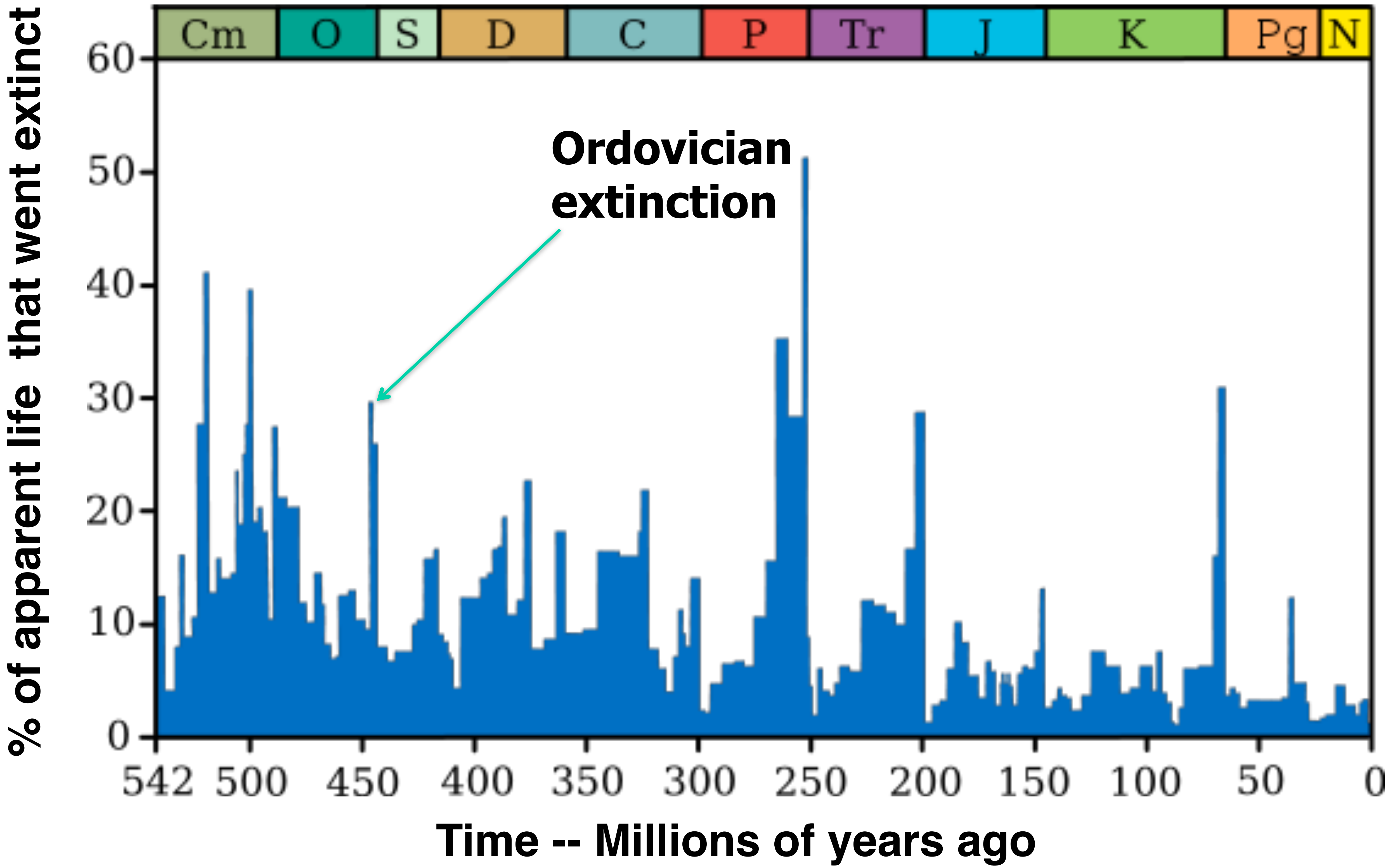
We expect about 1 burst per 100,000 or million years

Most not beamed at Earth

So about 1/billion years within 5000 light years

We have had ozone for two billion years, so any observable affect?

Extinction Events -- Are any due to GRBs?



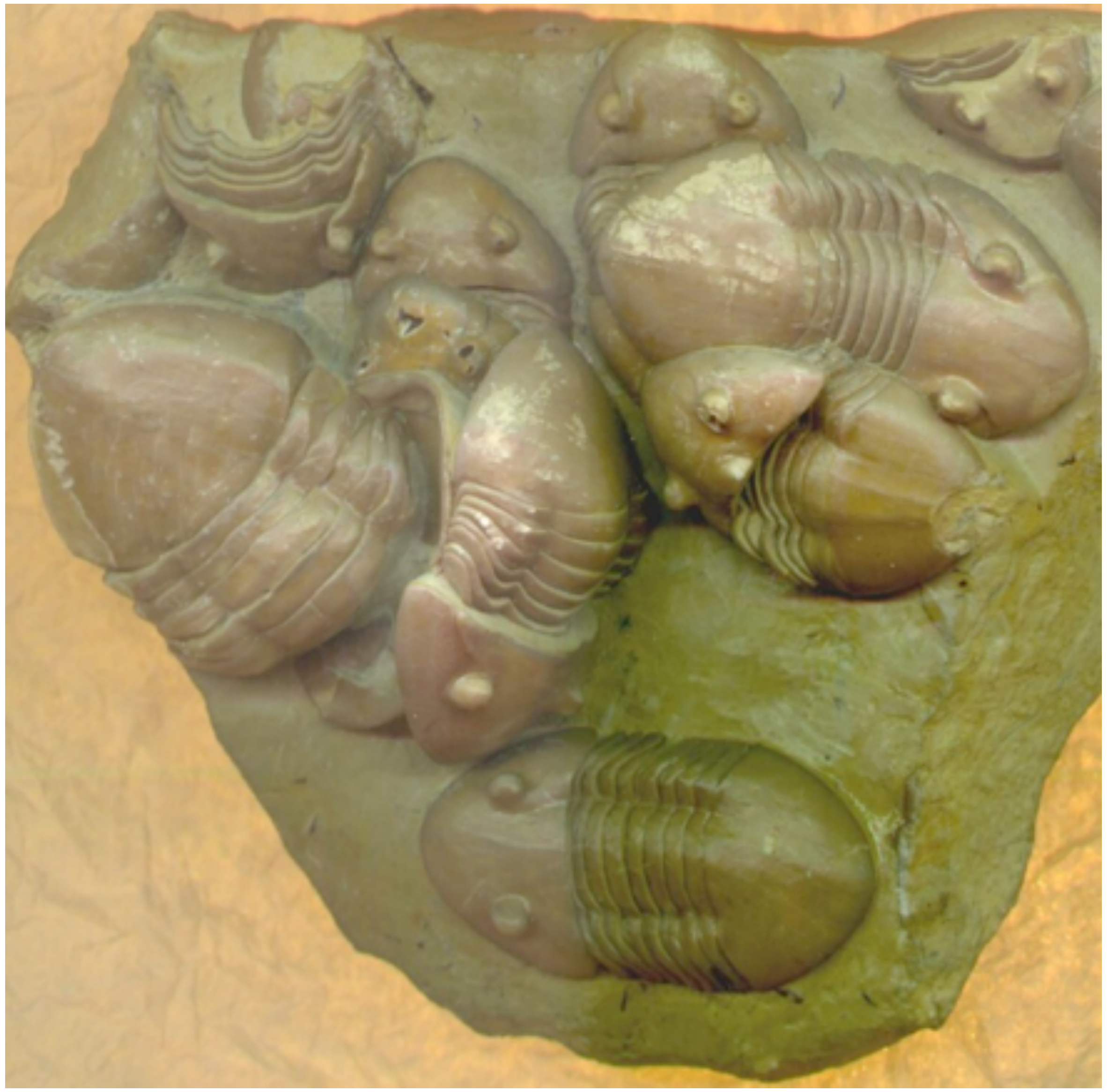
http://upload.wikimedia.org/wikipedia/commons/0/06/Extinction_intensity.svg

Patterns of Ordovician Extinction

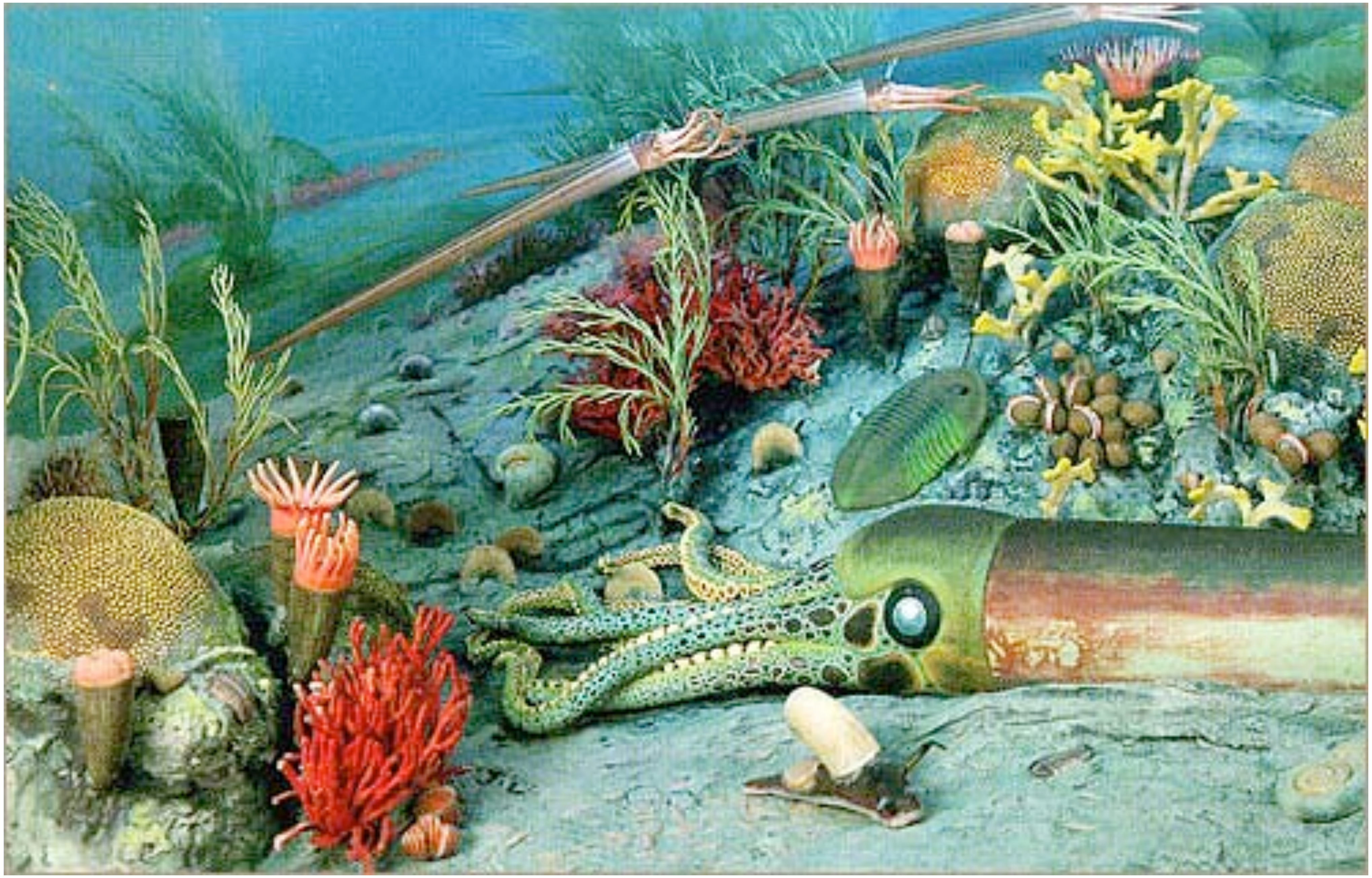
- Third-largest of the five major extinction events in Earth's history in terms of percentage of genera that went extinct
- Second largest in the overall loss of life
- More than 60% of marine invertebrates died

Trilobite Extinction

- In the Ordovician, trilobites were wide-spread and abundant
- Yet, they went extinct while more restricted groups persisted
- This is counter-intuitive
  - Abundant groups should be more extinction resistant



Extinction Patterns: Depth



During the late Ordovician, species dwelling in shallow water were more likely to go extinct than species dwelling in deeper water

Global Cooling and the Ordovician Extinction

Extinction has been linked to global cooling, glaciation, and sea-level fall

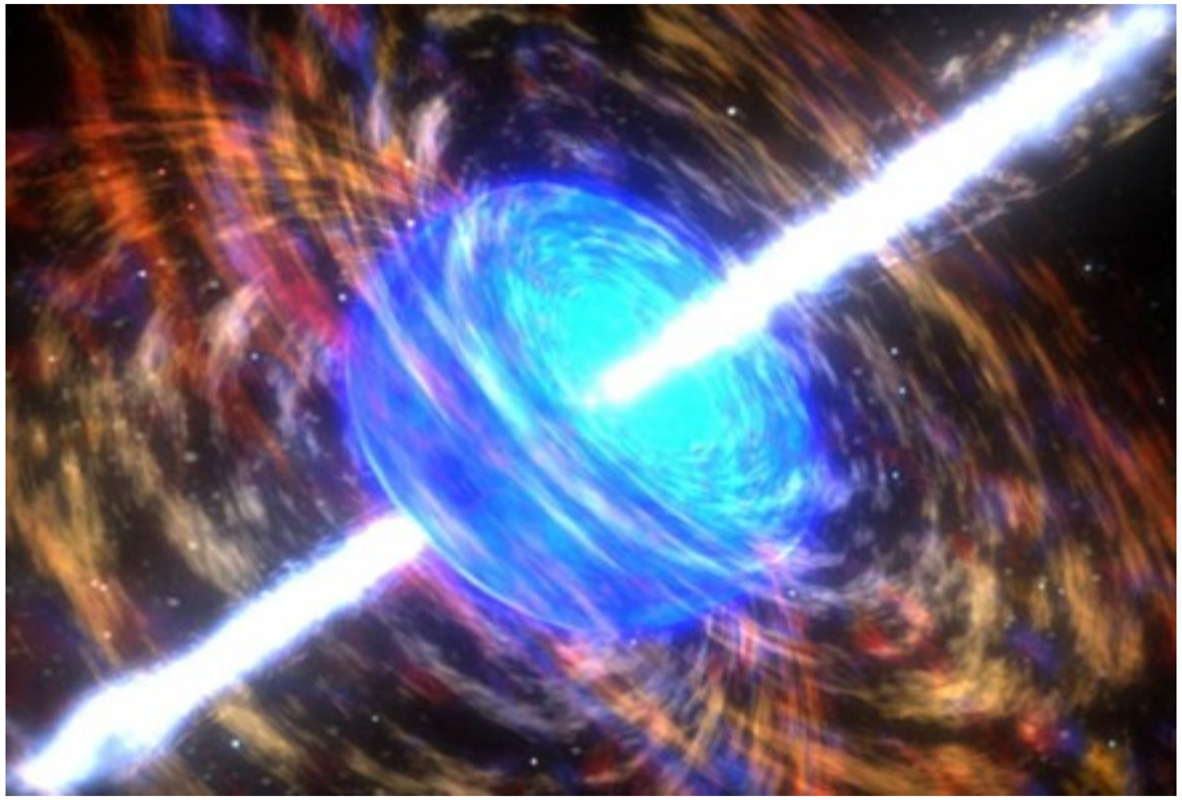
Climate models of the Ordovician show that it is difficult to initiate glaciation without a forcing impulse, such as a period of reduced sunlight

Ordovician/GRB Connection?

A GRB would have...

- Destroyed ozone layer, leading to increased solar UV
- produced NO_2, triggering global cooling

A one, two punch for life on the planet - initiates mass extinction



Predicted as GRB Effects	Observed in late Ordovician
Extinction of shallow (not deep) water organisms	Yes
Extinction of surface floaters (plankton) and organisms with planktonic larval forms	Yes
Reduction of solar radiation – cooling	Yes – glaciation needed “kick”

But... the evidence is all circumstantial

NO SMOKING GUN!

(i.e. no direct evidence of a GRB)