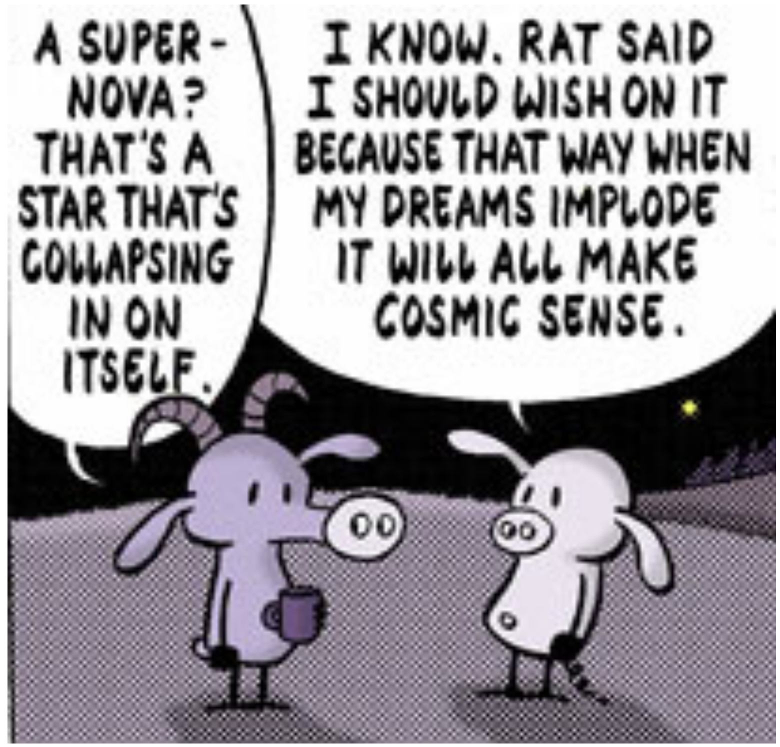
Killer Skies

- Homework 6 due tonight
- Night Observing-- first clear night M-W 7-9pm (Report due Nov 15th)
- Last time: Nature of Stars 2
- Today: Death of High Mass Stars

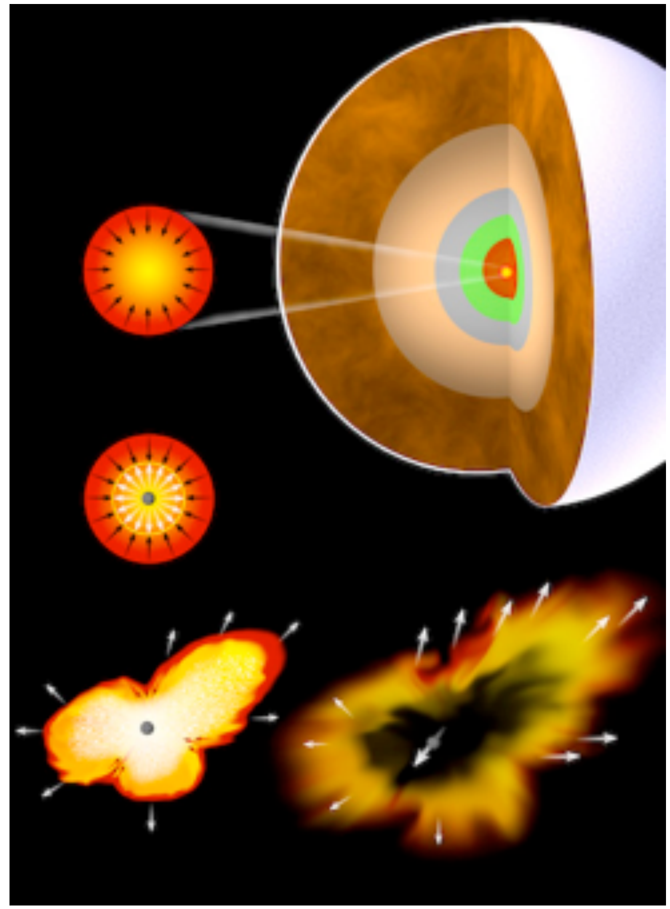


Music: *Princes of the Universe* – Queen

Massive Star Death: Recap

the life of a star is a struggle against gravity

- massive star death begins when core of star stops generating heat
- gravity overcomes pressure
- core of star collapses under its own weight



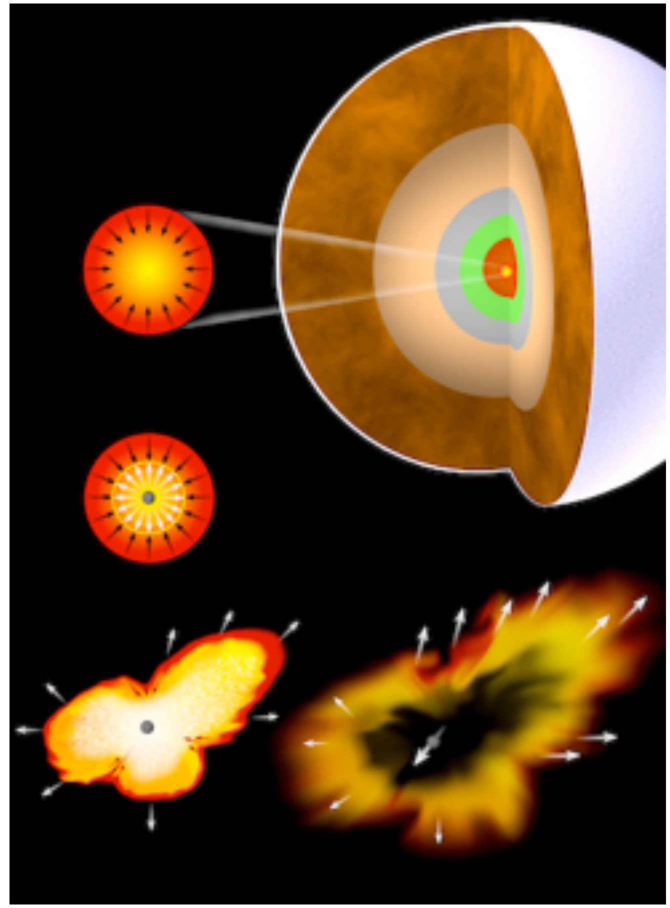
fate of core?

- during collapse: nuclei and electrons compressed to enormous density
- first: electrons squeezed into protons, making neutrons
  - (and neutrinos)
- neutrons compressed until touching
  - neutron core forms a solid supported by “degeneracy pressure”
  - touching neutrons ordinarily only exist in atomic nuclei
- core becomes a giant nucleus made of 10^{57} neutrons

Massive Star Death: Recap

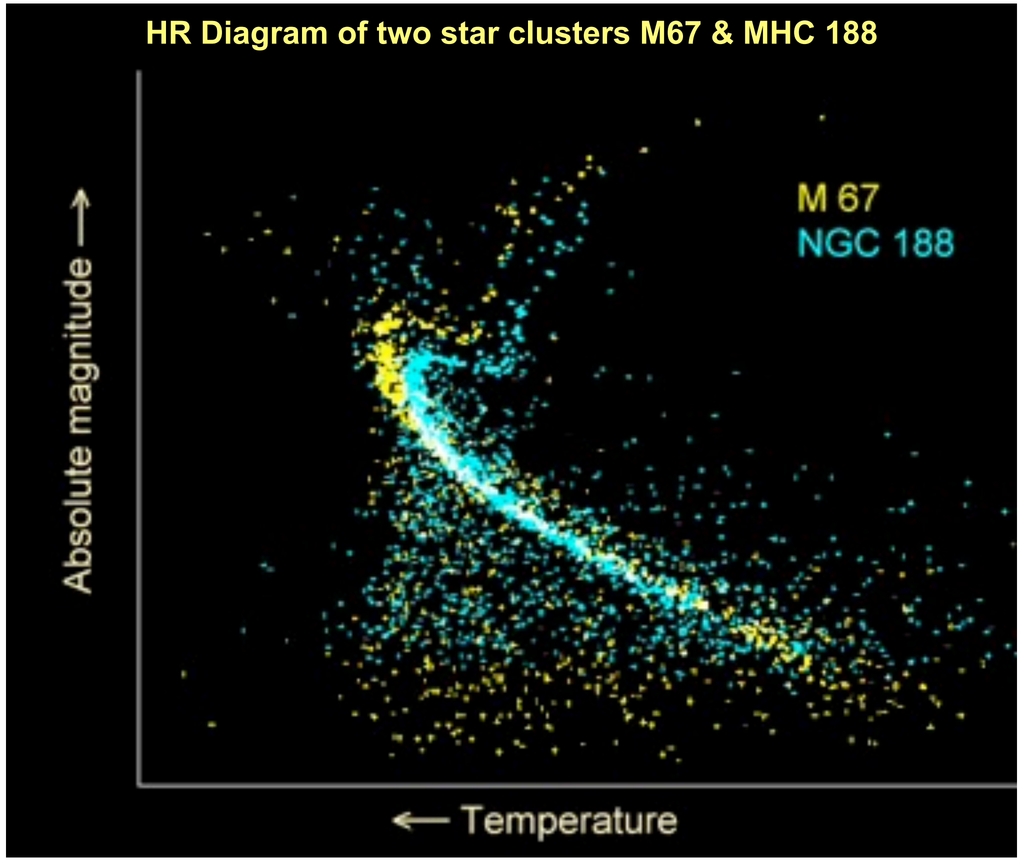
And then?

- if star mass < 30 M_{sun} or so (highly uncertain), this newborn "neutron star" remains stable, cools off, remains as "corpse" of massive star
- if star mass larger than this: neutron star driven to become unstable--leads to black hole



Clusters make stellar evolution visible

- Star cluster forms at the same time
- More massive stars die sooner
- Lifetime of most massive stars still on main sequence tells us a cluster's age!
- Called **main sequence turnoff**

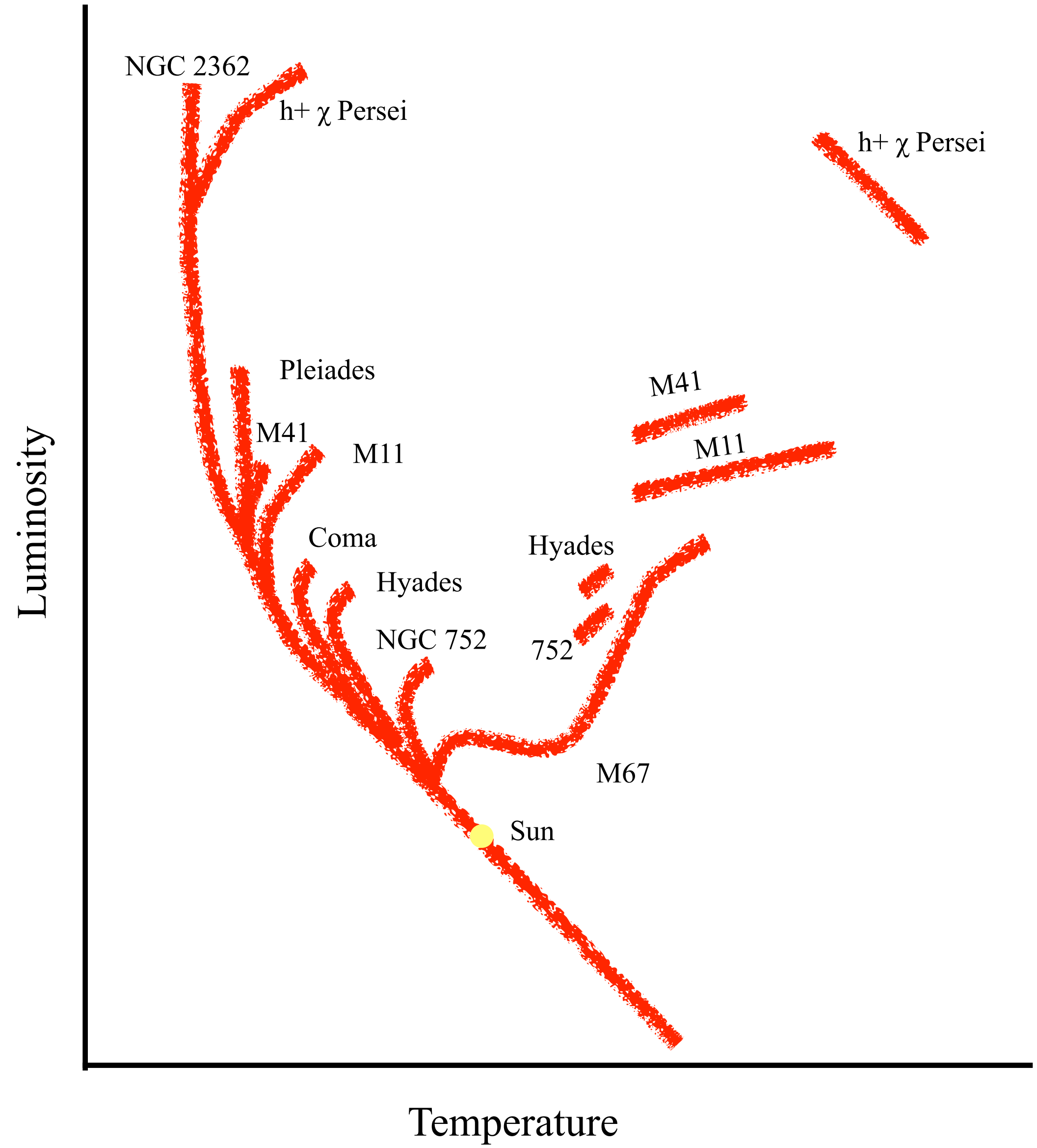


Since M67 has more high mass stars on the main sequence, it must be the younger of the two.

You can see the stars that have recently left the main sequence.

Visualizing stellar evolution

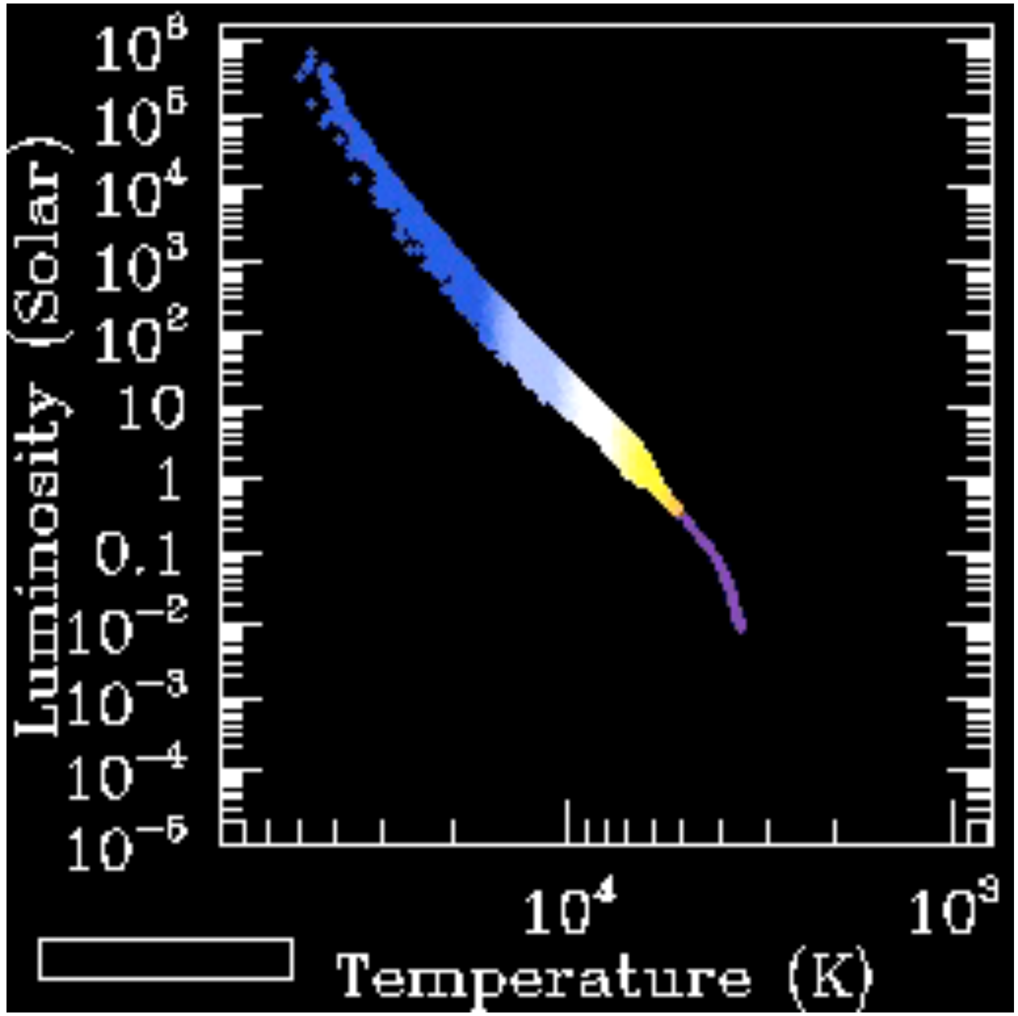
By comparing clusters of different ages, we can visualize how stars evolve



Cluster NGC 2362 has many high mass main sequence stars and supergiants – ~5 million years old. Pleiades has lost O stars, but still has B type MS stars – ~100 million years old. Hyades only has A type MS stars, no supergiants, just red giants – ~625 million of years old. M67 Sun-like stars are the most massive on the MS, many red giants – ~5 billion years old. Almost like watching a film of a star cluster evolving over billions of years. Were it not for star clusters, astronomers would have little confidence in the theories of stellar evolution. Star clusters make that evolution visible and assure astronomers that they really do understand how stars are born, live, and die

Visualizing stellar evolution

Simulation of a cluster evolving. Note how the massive stars die quickly, then the lower mass stars evolve into white dwarfs.



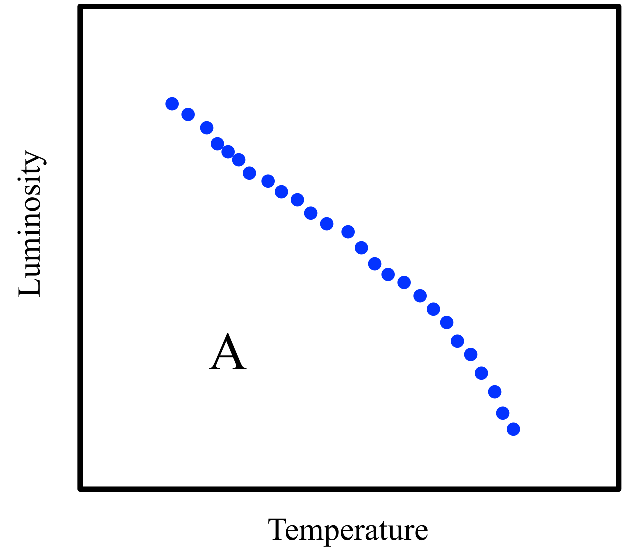
Thought Question

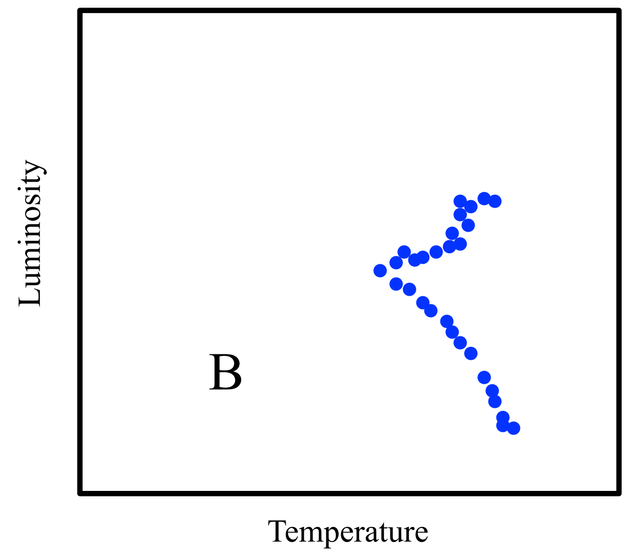
H-R diagrams for two star clusters, A and B, are shown at right. Which of the clusters is older?

A. Cluster A

B. Cluster B

C. It is impossible to tell with the information given





Answer B, because more stars have evolved off the main sequence.

Supernovae and the Census of Stars

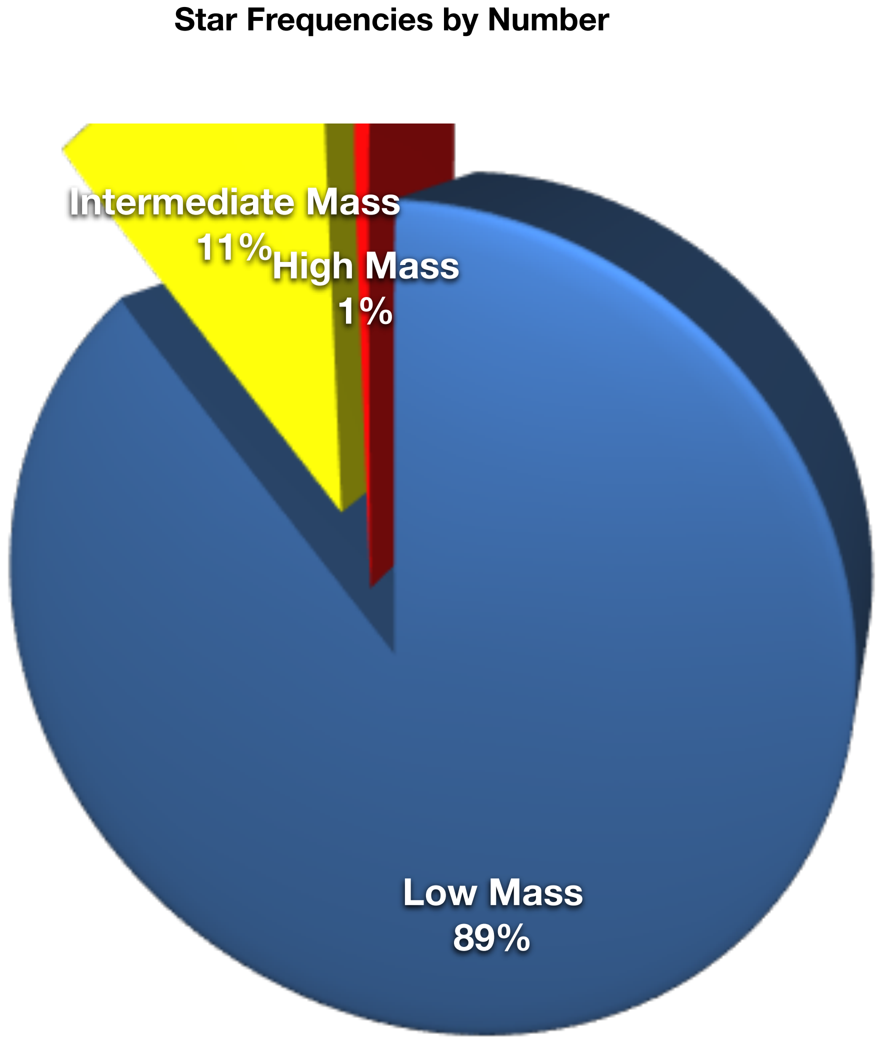
Supernovae are spectacular but rare:

- last recorded event in our Milky Way Galaxy of 100 billion stars: 300 years ago!
- typically: 1 to few supernovae per century in a big galaxy like ours

Why?

Supernovae mark the deaths of massive stars

- and most stars are not massive!



Predicting Supernova Explosions

Clearly, we would like to know when a massive star will explode!

Good news:

- massive stars are the most luminous
- can go up to 100,000 L_{sun}
- very obvious, can't "sneak up" on us

Bad news:

- massive stars evolve rapidly
- main sequence: 90% of lifetime, lasts few million years
  - star is blue
- after main sequence: He burning through Si burning and explosion
  - takes a few 100,000 years
  - star is red supergiant

Predicting Supernova Explosions

Problem is that most massive stars don't change appearance much once a supergiant

- luminosity, temperature remain same
- but that's all we can observe!
- so no warning before explosion!
- for all we know, any supergiant could explode today or 100,000 years from now
- can't predict when an explosion will occur
- explosions are effectively random!

Supernova Threat

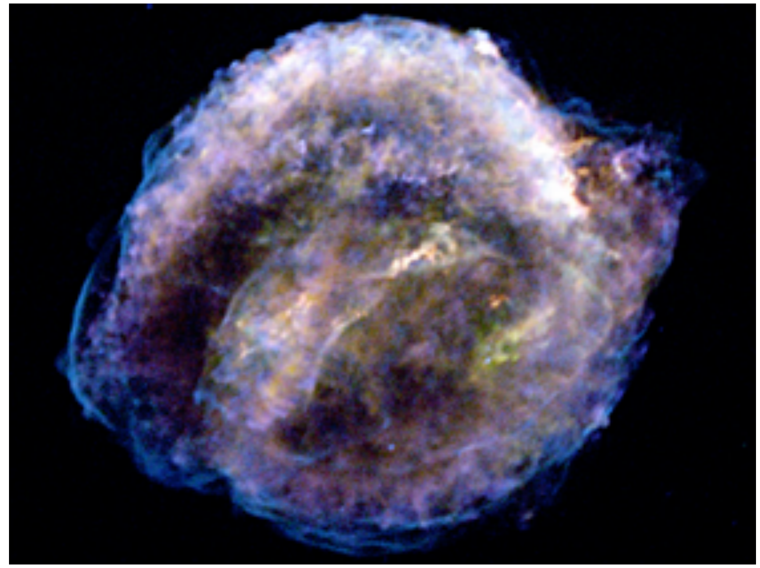
Massive star death is dangerous in several ways

- the supernova explosion itself is a cosmic bomb!
- this is where we will focus first

but leading to the explosion, the star's gravity crushes the star's core ultrahigh density

- leaves behind a "compact object" of enormous density and high gravity
- a neutron star or black hole!
- these pose their own threats: gamma-ray bursts, black hole digestion
- we'll get to these later...

Supernova Threat



Supernovae are like tigers

- beautiful and majestic from afar
- dangerous if too close
- but usually only a threat if you seek them out and provoke them

How is a supernova explosion dangerous to life on Earth or elsewhere?

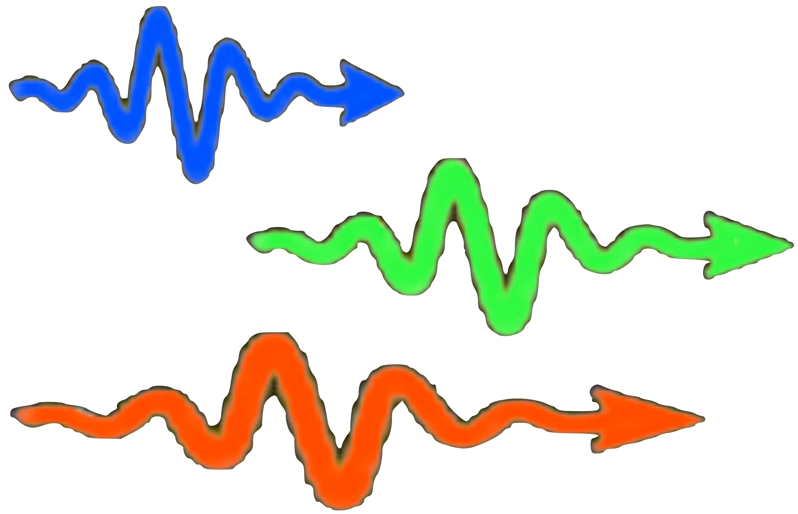
- blast impact
- neutrino zap!
- UV, X-ray, gamma ray exposure

Blast impact and neutrino zaps? You have to be really close. If you are that close other issues....

The Real Danger:
Supernovae produce lots of ionizing radiation

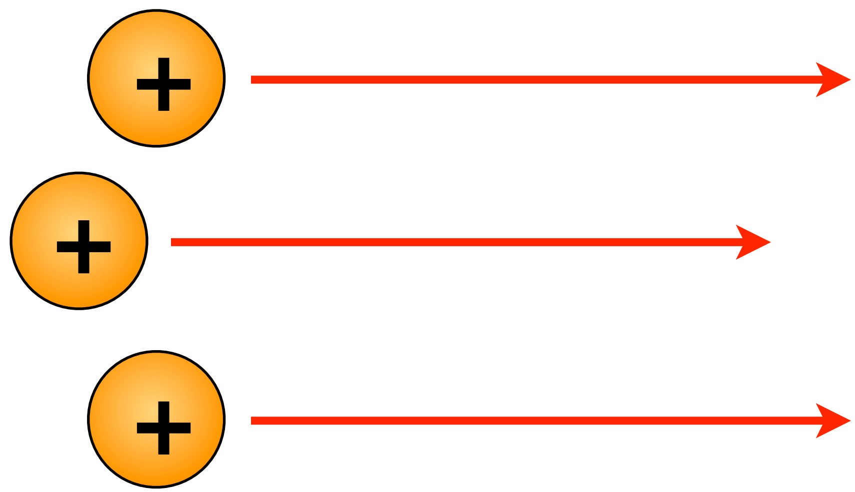
Ionizing radiation

- light or particles that have enough energy to ionize atoms: rip electrons away



1. Supernovae produce large amount of ionizing light

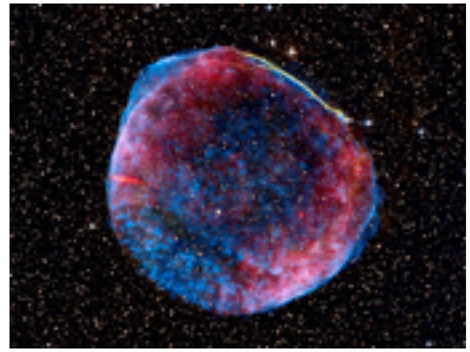
- ultraviolet (UV), X-ray, gamma-ray
- Health hazard if exposed directly



2. Supernovae also produce cosmic rays

- Energetic, charged subatomic particles
- Most are protons
- Travel at nearly the speed of light

Cosmic Rays

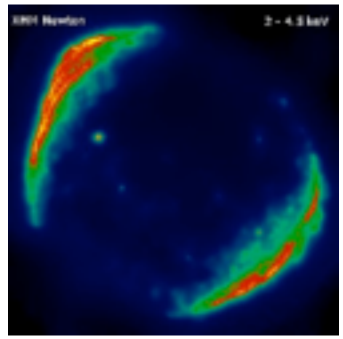


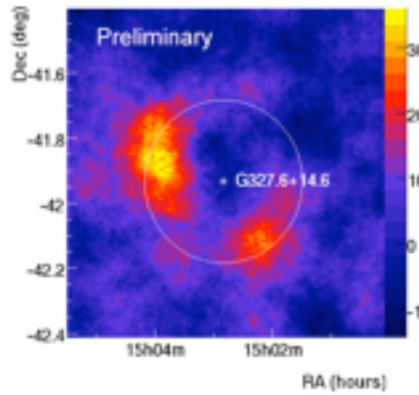
Cosmic rays are high-energy particles from space

- constantly bombard the Earth

Cosmic rays fill interplanetary and interstellar space

- energy content about the same as all of starlight!
- revved up to high energies in supernova explosions!
- supernovae are “cosmic-ray factories”
- so cosmic rays intense and dangerous near the explosion

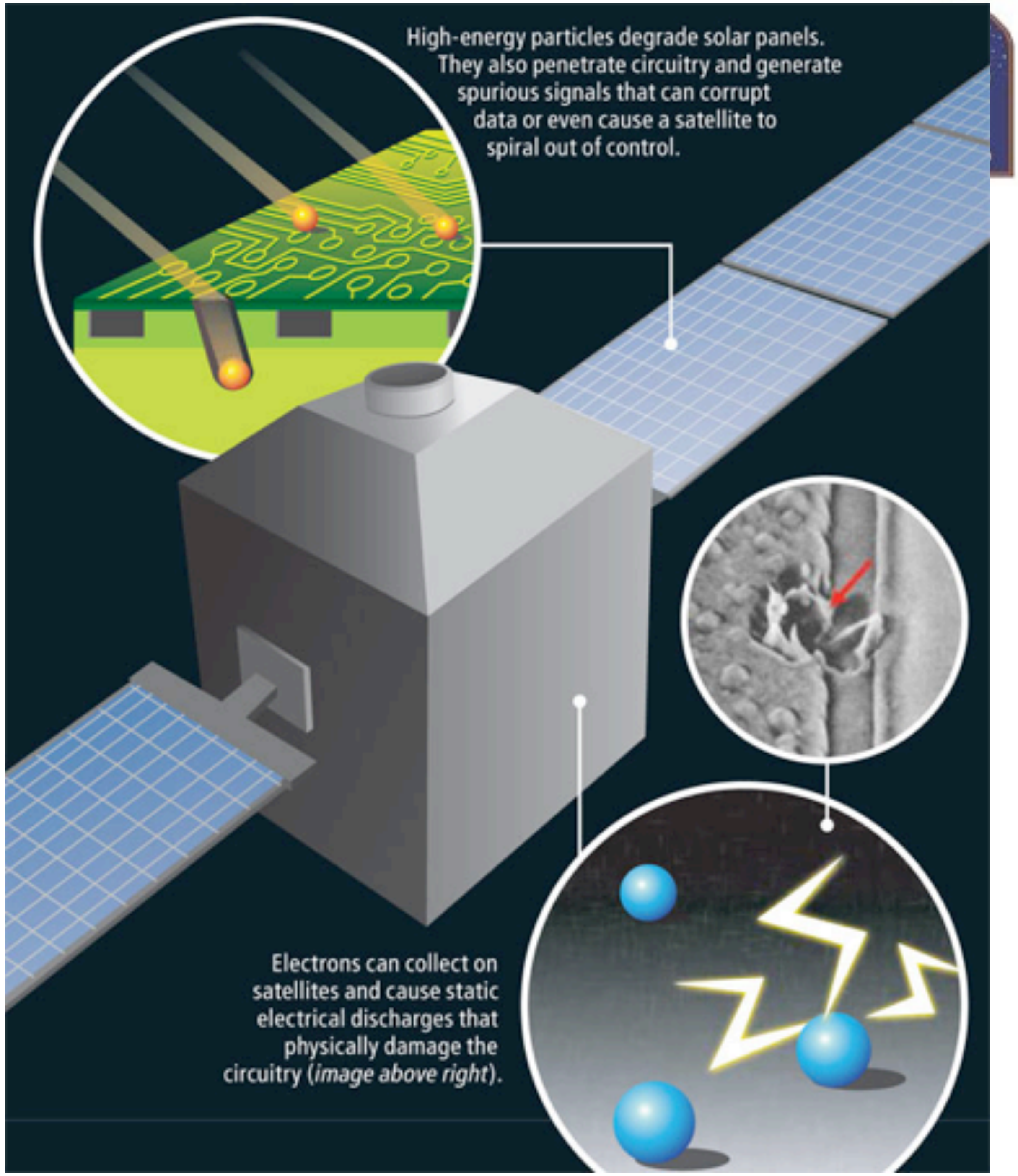




Supernova 1006

visible light: blast
X-rays: cosmic-ray electrons
gamma rays: cosmic-ray protons

Cosmic ray particles can damage satellites in orbit

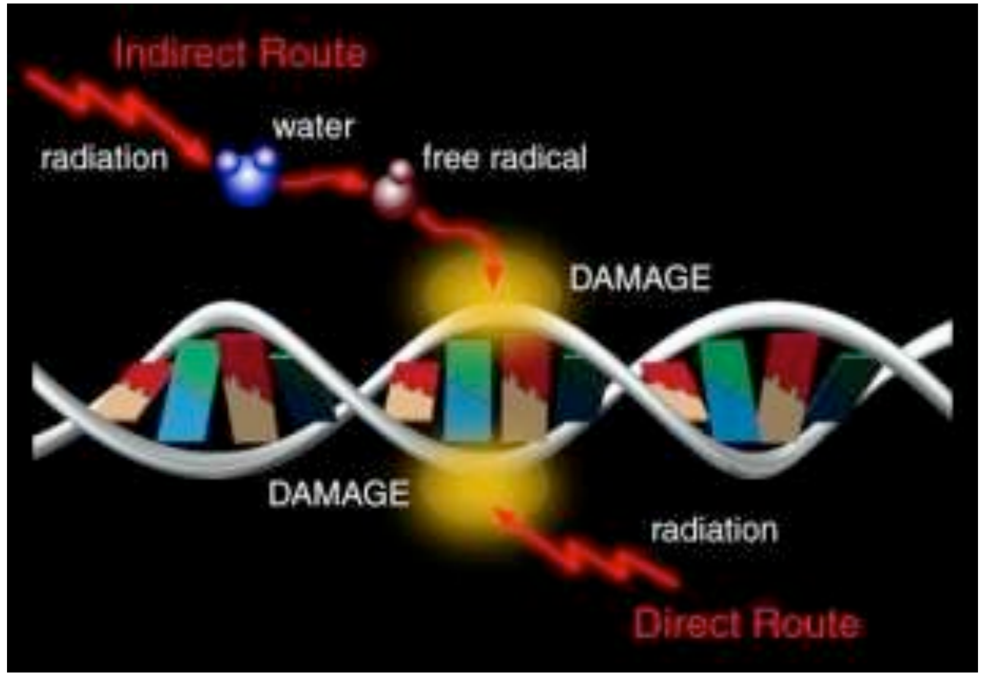


High energy particles impacting satellites can damage solar panels, penetrate circuitry, corrupt data, etc..

Can also build up static electricity on the exterior of the satellite and cause electric discharges that damage the circuitry

Radiation Hazard

- High-energy charged particles can damage DNA
- Increases risk of cancer
- People at greatest risk
  - Astronauts: Shuttle, International Space Station
  - Crew/Passengers in high-flying jets



Spacewalking astronauts might have only minutes after the first flash of light to find shelter from energetic solar particles following close on the heels of those initial photons. Their spacecraft would probably have adequate shielding; the key would be getting inside in time.

Electric grid overload

Supernova damage similar to solar storms

Sudden ionization of upper atmosphere leads to sudden spike of electric force

- why?
- electrons freed by ionization move in Earth's magnetic field
- "in-synch" motion of electrons acts like huge antenna, creating electromagnetic pulse (EMP)
- note: similar damage caused by (and discovered in) high-altitude nuclear blasts

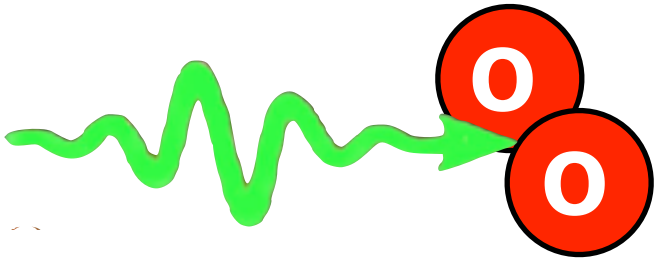
pulse signal so strong that all electrical electrical wires and equipment are destroyed

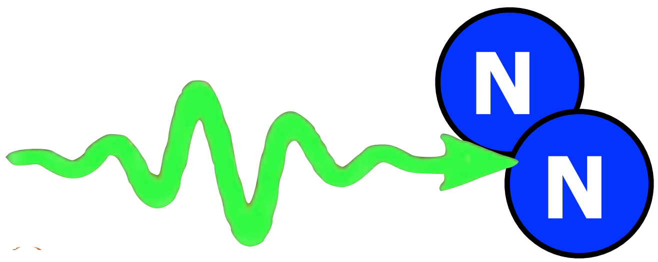
- "fried" by voltage spikes

But this is just a sideshow...not the real problem

Gamma rays and cosmic rays from a supernova create nitric oxide

Air is mostly made of N_2 and O_2





Gamma-rays and cosmic rays convert N_2 and O_2 into NO

Nitric oxide is a catalyst to destroy ozone!

Ozone: O_3

- molecule with 3 oxygen atoms
- O-O-O
- smell it if there is a spark or electrical arc

unhealthy to breathe

but good at absorbing ultraviolet light

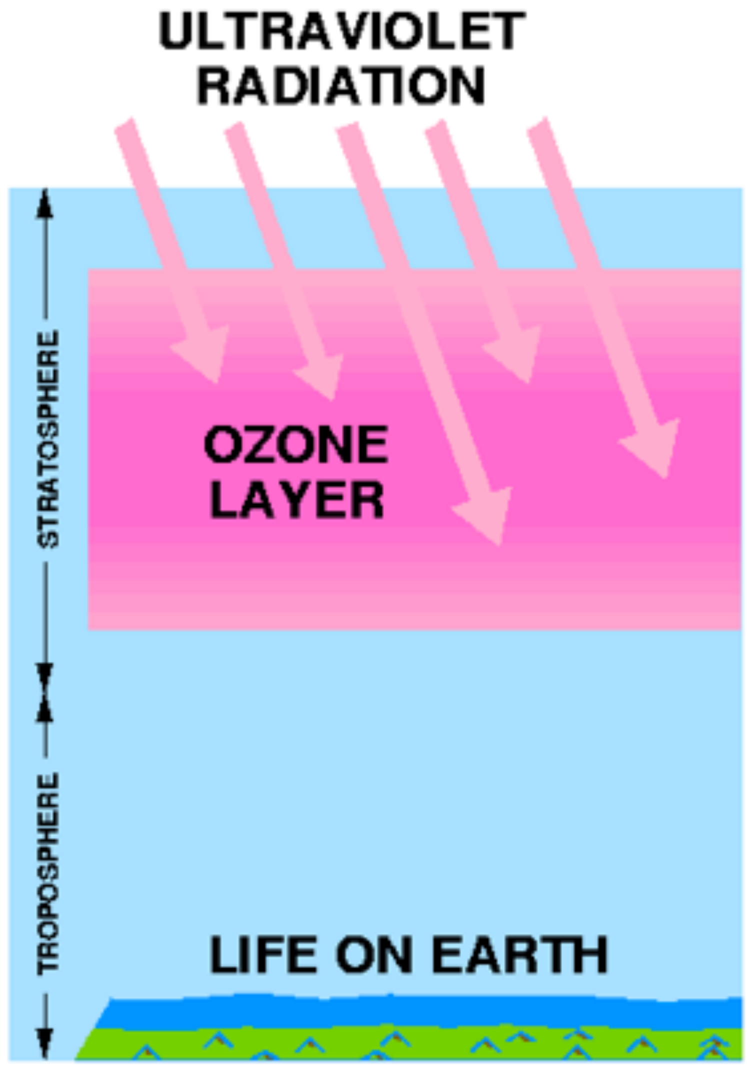
$$NO + O_3 \longrightarrow NO_2 + O_2$$

$$NO_2 + O \longrightarrow NO + O_2$$

$$\text{Net } O + O_3 \longrightarrow 2O_2$$

Most Dangerous Effect: Ozone Layer Depletion

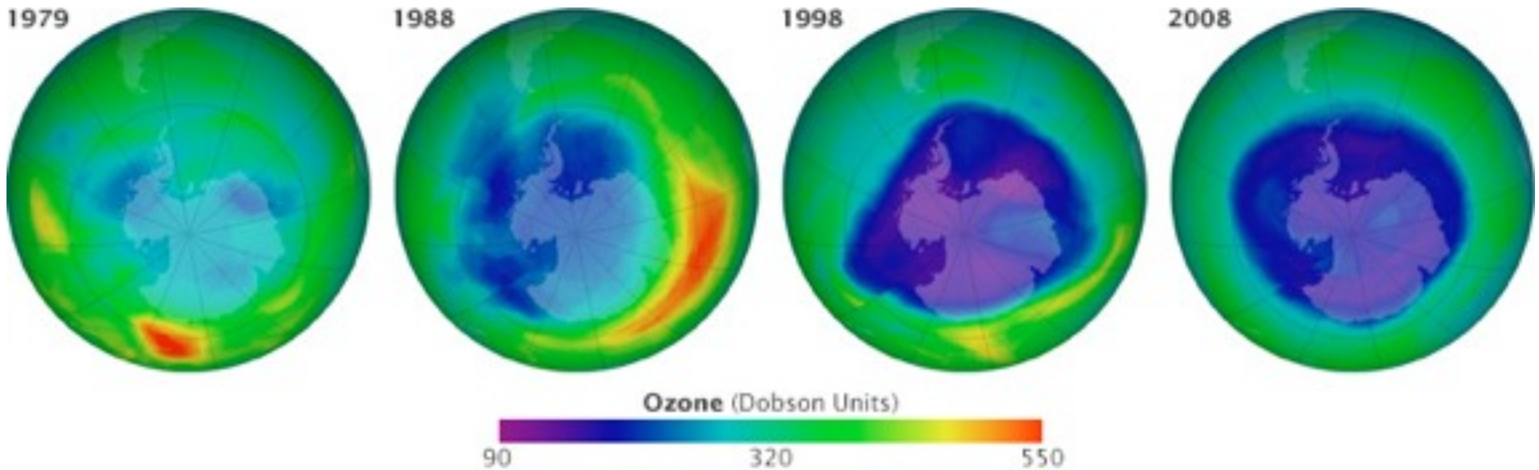
- Life on Earth's surface, as we know it, could not exist without the ozone (O_3) layer
- It shields us from ultraviolet (UV)radiation from the Sun, which is damaging to life
- Located ~30 km up in the stratosphere, warmed by the UV radiation absorption

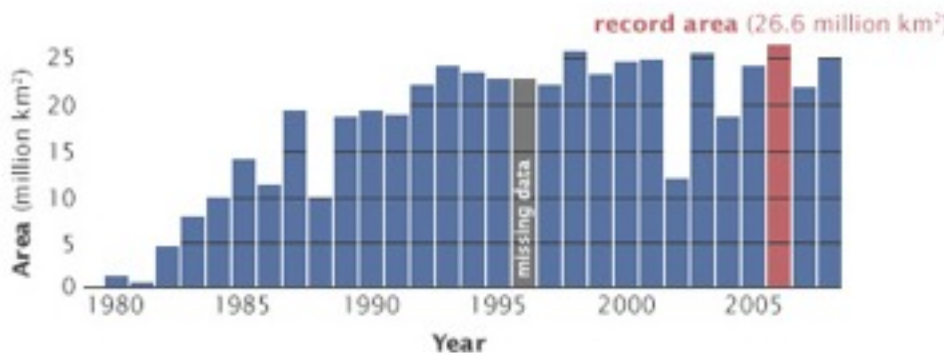


Early life on Earth was underwater for this reason. Life on the Earth's surface is only possible after oxygen happened in the atmosphere, causing ozone.

This layer absorbs 97–99% of the Sun's high frequency ultraviolet light, which is damaging to life on Earth. It is mainly located in the lower portion of the stratosphere from approximately 13 to 40 kilometres (8.1 to 25 mi) above Earth. Energy from solar UV absorbed by ozone, actually heats the stratosphere making it warmer that the upper layers of the troposphere (lowest layer of atmosphere).

The Ozone “Hole”





Man-made chemicals have been depleting the ozone layer for decades

We know the dangers of ozone depletion!

The ozone hole is not technically a “hole” where no ozone is present, but is actually a region of depleted ozone in the stratosphere over the Antarctic that happens at the beginning of Southern Hemisphere spring (August–October).
ozone levels at the south pole decrease by up to 60% in the spring!
Ozone depletions happen over north america/europe as well

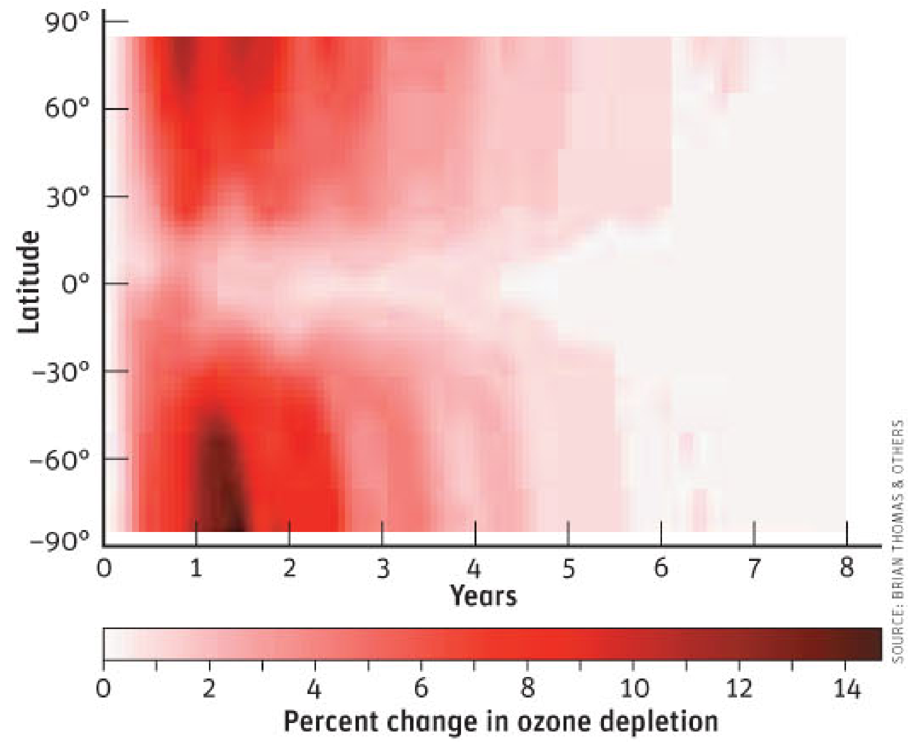
How much of the ozone layer would a supernova destroy?

Supernova damage depends on distance

- Why?
- Supernova apparent brightness = flux drops strongly with distance d
- inverse square law: $F = \frac{L}{4\pi d^2}$

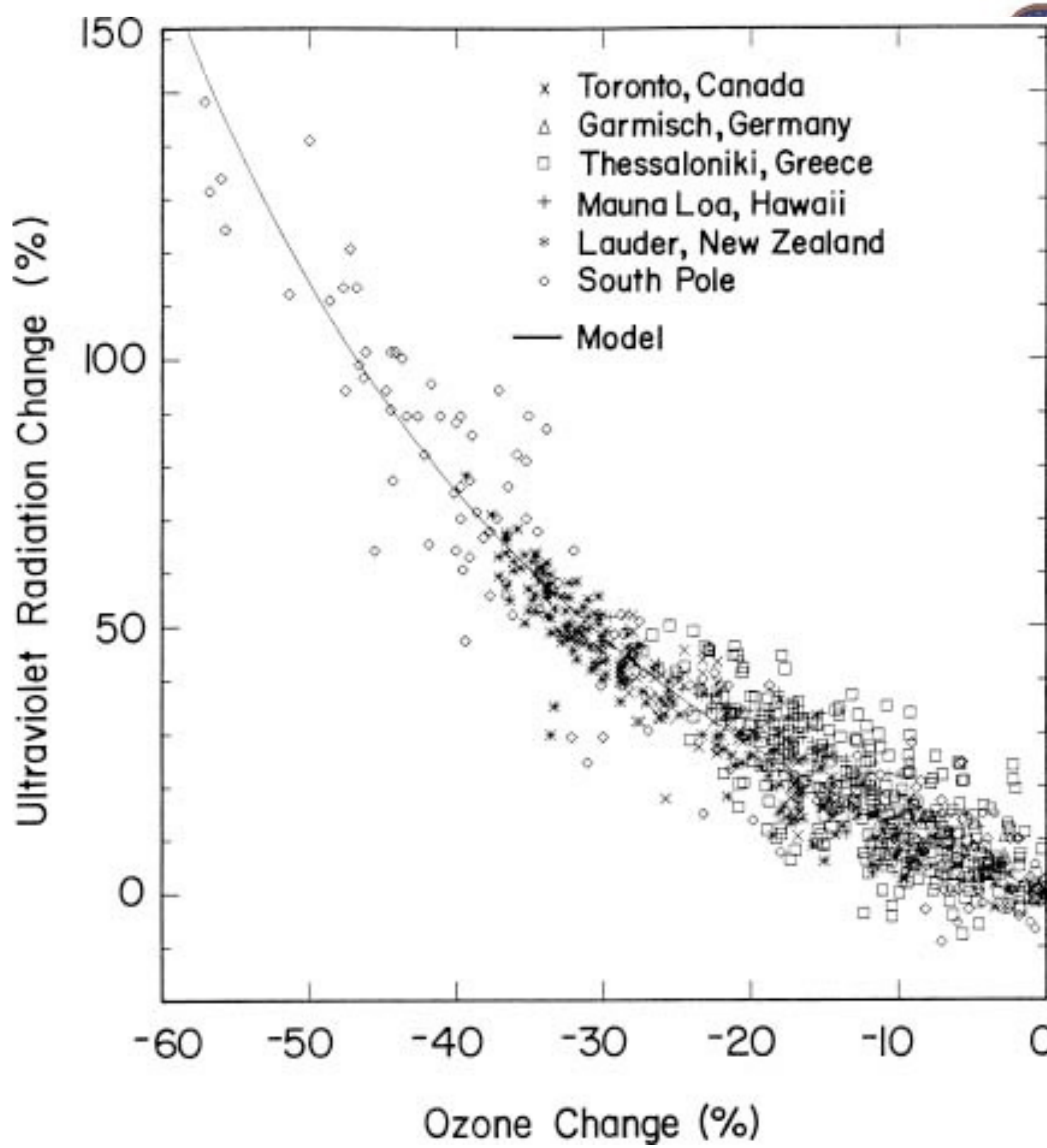
If supernova nearby, flux is intense, damage catastrophic

- At d = 25 light years: destroys 50% of ozone layer
- At d = 100 light years: 7-15% reduction of ozone layer



Ozone depletion from a Type II supernova at 100 light years

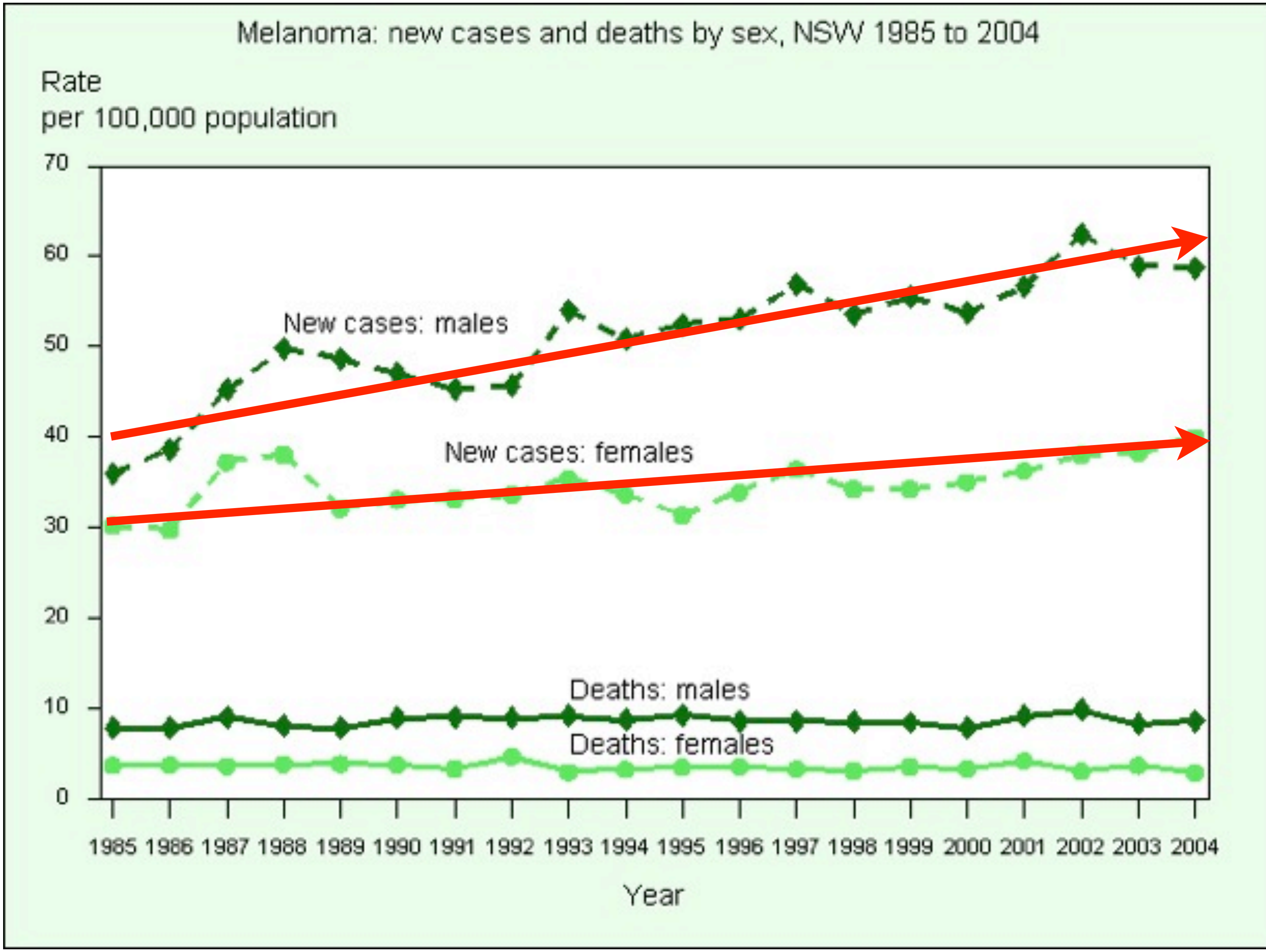
As ozone levels decrease, UV radiation level at the surface increases!



Data shows that cutting ozone levels in half doubles the UV radiation at the surface!

Increased solar UV leads to…

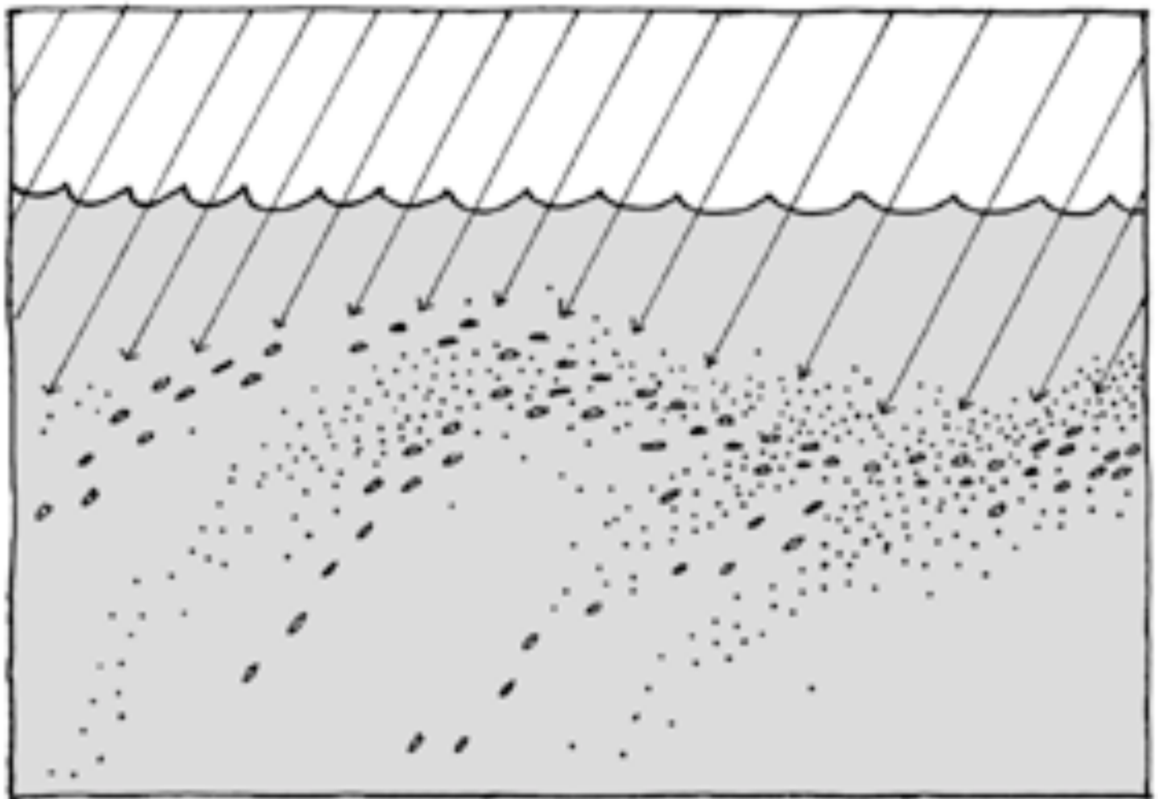
Severe sunburn!



Increased risk of skin cancer

Skin cancer rates are increasing

Damaging ultraviolet rays (UV-B) penetrate deep into the ocean



It has been estimated that a 16% ozone depletion would result in a 5% loss in phytoplankton

This would cause a reduction in fishery and aquaculture yields of about 7 % which equals a loss of about 7 million tons of fish per year

Phytoplankton are the base of the marine food chain

Plankton eaten by larger creatures

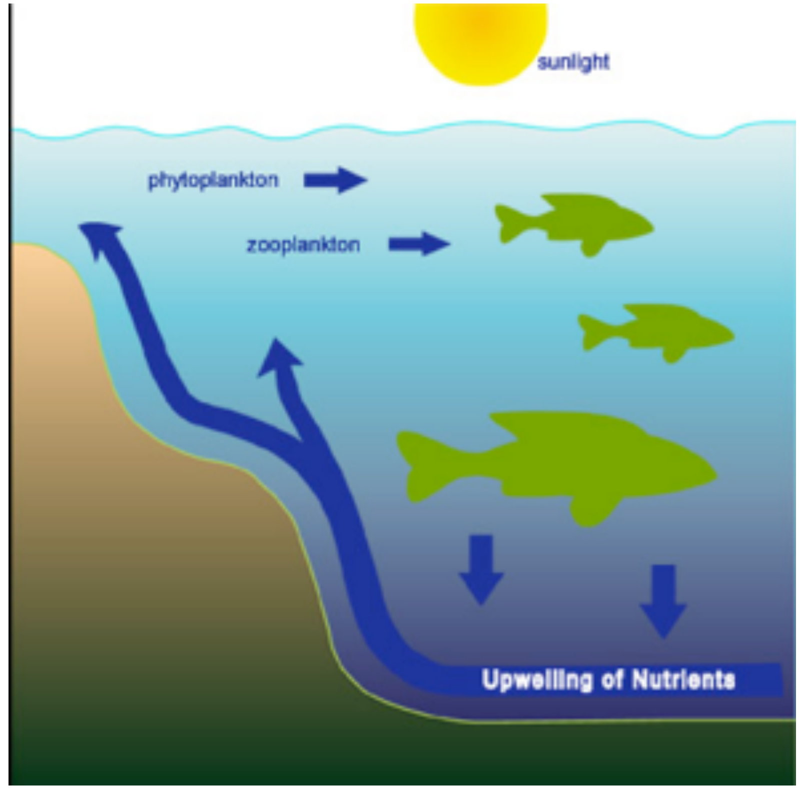
- which are eaten by larger creatures
- kill plankton, and much of marine life dies!

On land:

- similar story with plants

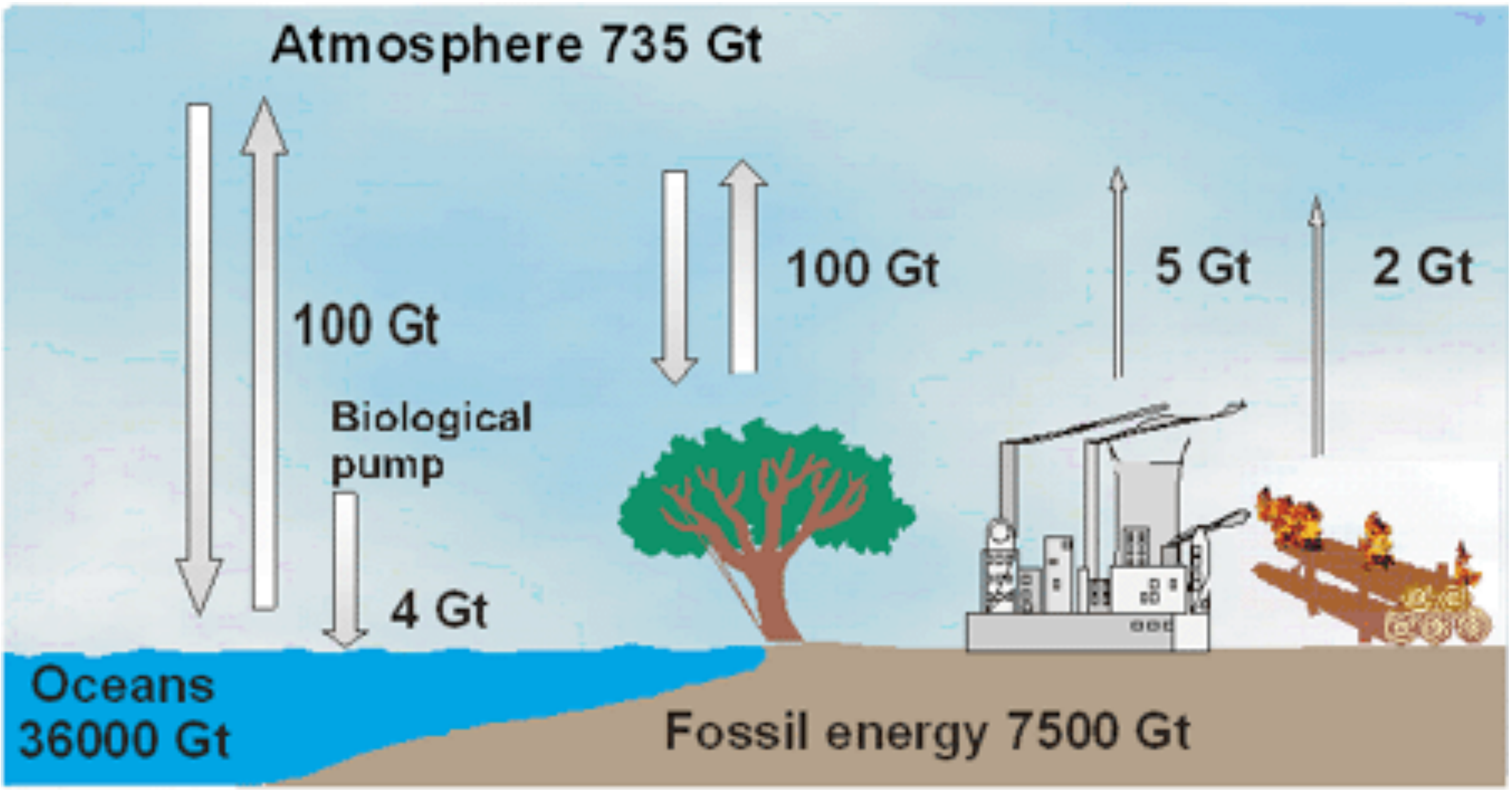
Effect of supernova:

- disrupt food chain, cause starvation



Phytoplankton are the primary producers. They are consumed by zooplankton which are, in turn, consumed by progressively larger aquatic organisms. The cycle completes as nutrients from decomposing organisms circulate to supply nutrition to phytoplankton.

Phytoplankton are also a major sink for atmospheric CO_2



Global carbon fluxes and reservoir. The figure shows production (up arrows) and consumption (down arrows) of carbon by (from left to right) aquatic organisms, terrestrial organisms, industrial activity and forest fires. The biological pump refers to carbon settling to the ocean bottom in the form of decaying small particulate organic matter.

Too close for comfort?

Supernova explosion damage depends on distance

if too close:

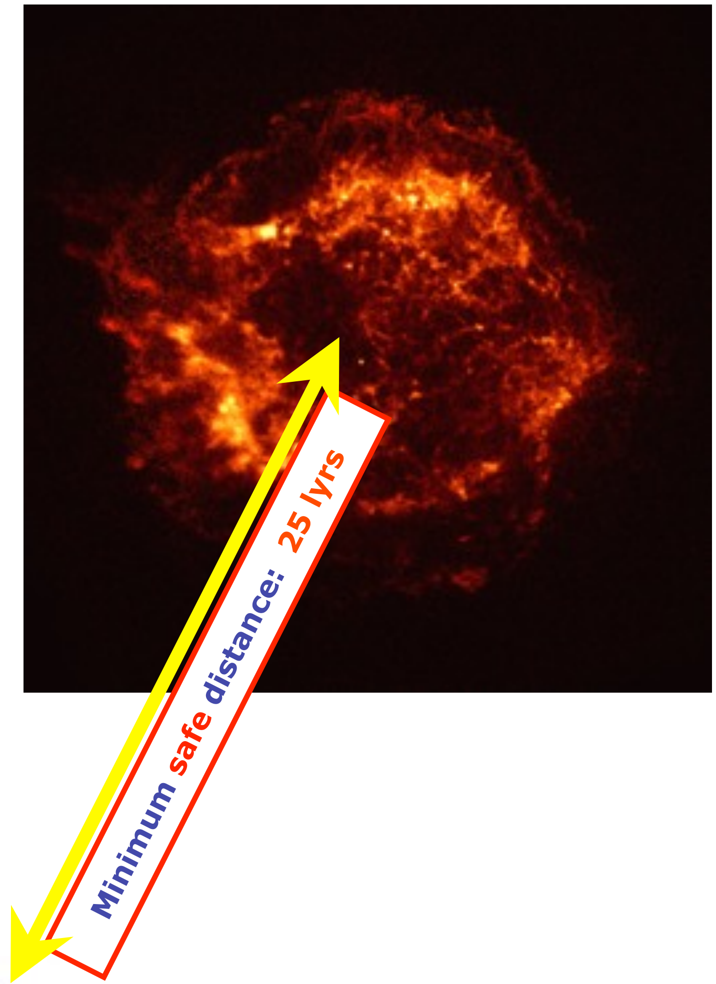
- large ionizing radiation dose
- catastrophic damage
- (un)holy grail: connect supernova with mass extinction
  - originally, supernova considered as source of dino-killing KT extinction

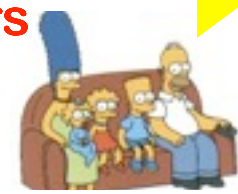
if far away:

- just beautiful, free cosmic fireworks

Minimum safe distance:

- ozone destruction severe if supernova is closer than about 25 light years





i>clicker question

Which of the following would NOT be a consequence of the destruction of the ozone layer on the Earth?

A. Large-scale (perhaps total) destruction of life on the Earth
B. Large-scale freezing of the oceans
C. Drastic increase in ultraviolet radiation at the Earth's surface
D. Elimination of the rise in temperature in the stratosphere

Answer B

iClicker Poll: Supernova Threat Today

The minimum safe distance to a supernova is about 25 light years

Vote your conscience:

Are there any future supernovae (massive stars) currently closer than this?

Hint: nearest star (alpha Cen) is at 4.2 light years

A. definitely yes. uh oh.
B. definitely no. whew!
C. no way to tell. gulp.

So is 25 lyrs close?

Supernova “kill radius” about 25 lyrs

Good news:

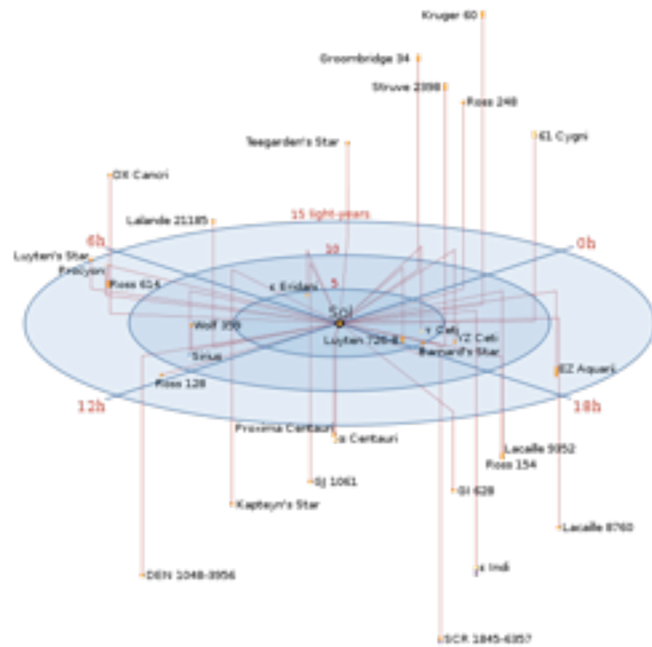
- massive stars are the most luminous of all stars
- easy to spot if nearby

before exploding, massive star is red supergiant

- at 25 lyrs, star would be > 100 times brighter than brightest star in sky today (Sirius)
- and 6 times brighter than Venus (brightest planet)
- you could see it during the day for > 100,000 years before the explosion!

But we know our local neighborhood well

- there is no such star in the sky now
- no supernova threat at present! sleep easy tonight!

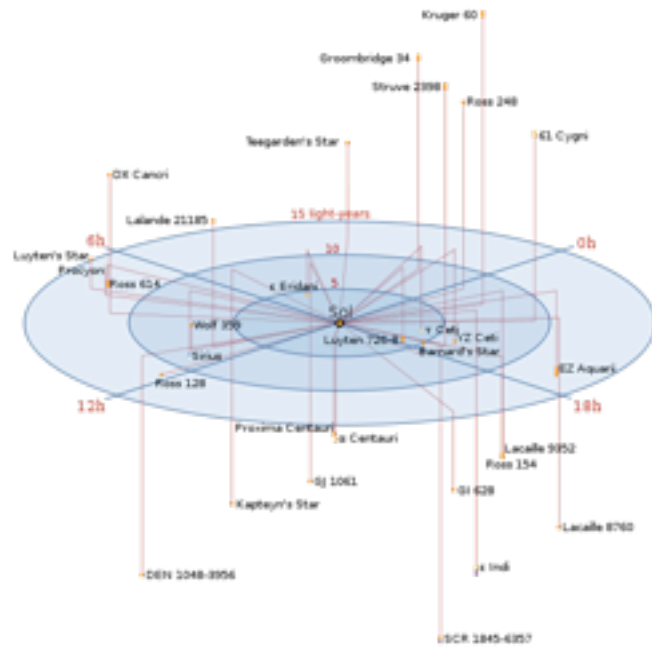


So is 25 lyrs close?

On the other hand:

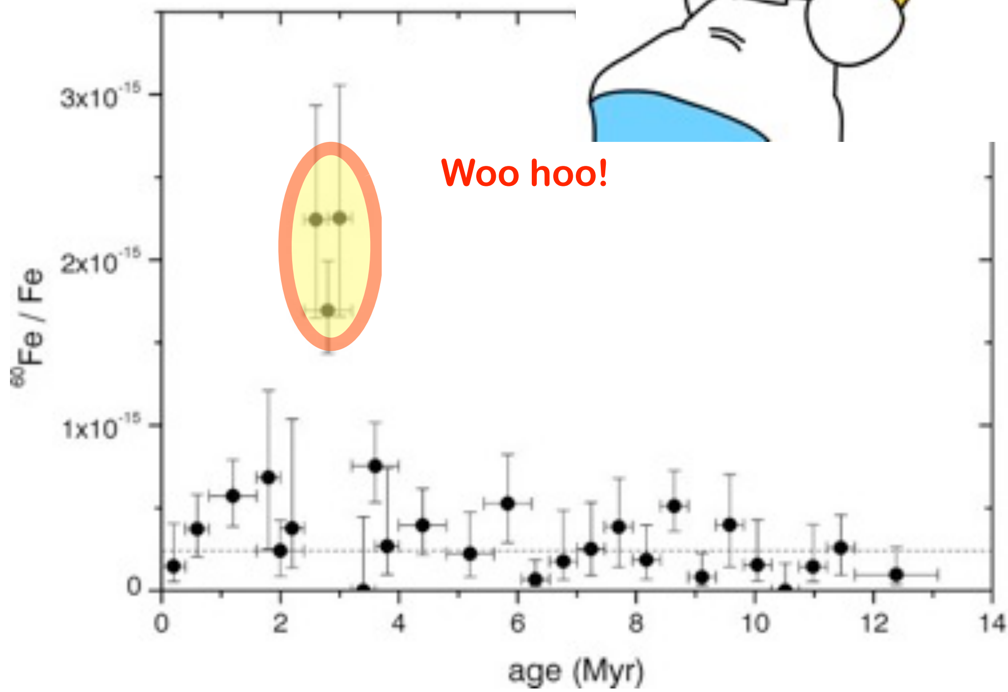
- many stars have been born throughout our Galaxy over its > 10 billion year history
- including massive stars
- it is overwhelmingly likely that one or more supernovae has exploded within 25 lyrs over the lifespan of the Earth
- in the past (and future) threat is real!

- We have proof!



^{60}Fe Confirmation

- ^{60}Fe, half-life 2 million years, is only produced in supernova
- If nearby supernova, expect to find some on the sea floor rocks in a small layer.



$$t = 2.8 \pm 0.4 \text{ Myr}$$

A Landmark Result

- Isolated pulse identified
- Epoch quantified

In 2004, big new result, same German group.

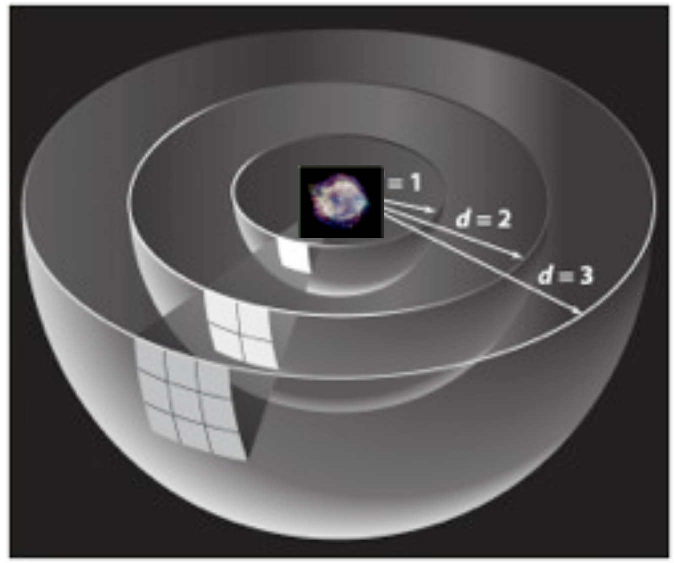
How far away was it?

When?

- iron not decayed: had to be within last few million years (half-life)
- from layering of rock: ~3 million years ago

Where?

- amount of iron (number of atoms) set by amount made in supernova but also distance to supernova
- farther away, iron more spread out, less for us
  - in fact, it's an inverse square law!
- So from measured iron, can infer distance
  - result: SN between 60 to 300 lyrs away



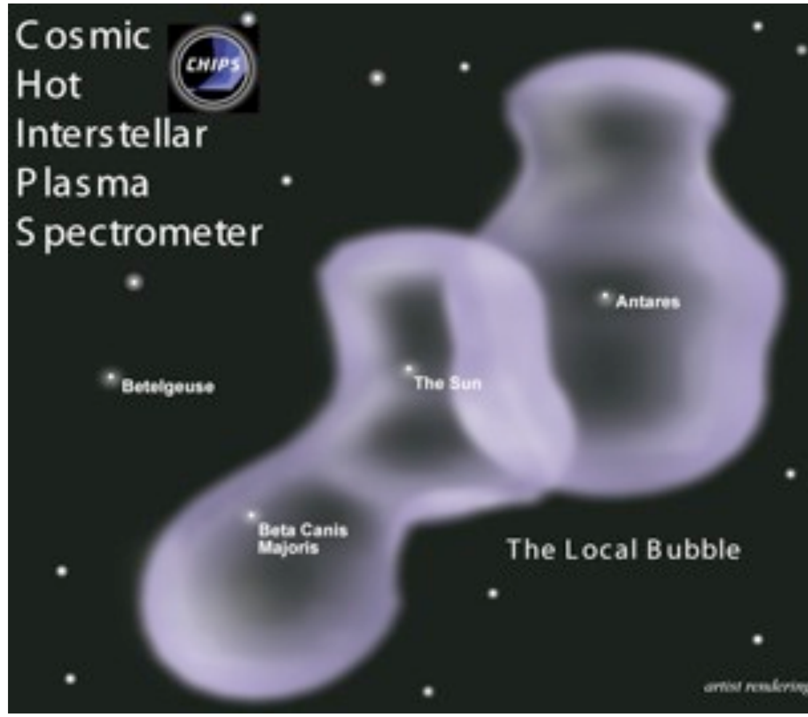
Aftermath: The Local Bubble?

The Sun lives in region of hot, rarefied gas

- The Local Bubble
- hot cavity ~150 lyrs ⇒ huge
- seen via foreground absorption in nearby starlight

Nearby SN needed

- we live inside SN remains
- bubble models require >> 1 SN in past 10 Myr
- ^{60}Fe event from nearest massive star cluster?



A Near Miss?

^{60}Fe suggest ~30 lyrs
...so barely missed us:
"near miss"

- cosmic ray winter?
- bump in extinctions?

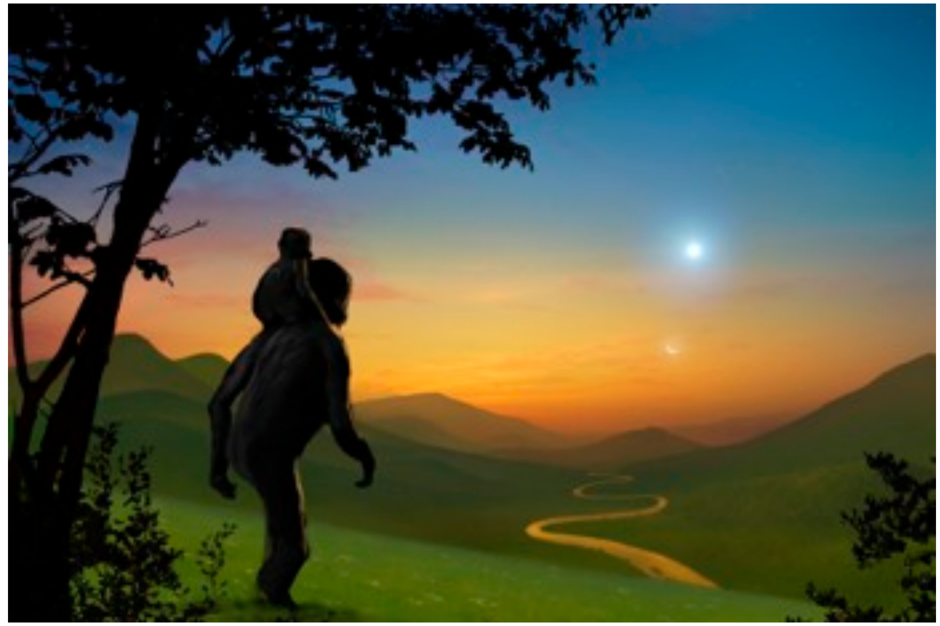


Image: Mark Garlick
www.markgarlick.com

If true:

possible effects on prehistoric environment and maybe human evolution?

Supernova Attack: Mitigation

Q: what do you think?

Not much can be done!

- Try not to live too close to a massive star near the end of its life.
- With time, our species should one day travel to the stars.
- We could monitor nearby candidates.
  - recall: surface luminosity, temperature do not change much near death--no hints of when the end is near
  - but if nearby supernova, neutrino signal very large, and changes violently during late stages: early warning!
  - could measure with large detector

Imagine

- Astronomers are the first to know.
- Neutrino detectors around the world are overwhelmed by the blizzard of signals
- Gamma and x-ray telescopes are quickly blinded by the bright light from the object
- Then in the night sky a star gets brighter and brighter, easily seen with the naked eye and still getting brighter.
- Can easily be seen during the daytime!
- The first supernova in 400 years!

Imagine

- The power grid collapses
- The sky around the star is blue!
- Gamma Rays have already destroyed the ozone layer, we just don't know it yet.
- Severe sunburn, but UV radiation will kill off phytoplankton, the base of the food chain
- A new mass extinction is happening!
- As you die blissfully, you wonder what Leslie was going to talk about this week.

Safe?

Okay, so no supernova nearby... so you feel safe again...

Is there any nova that can be bigger than super?

Well.... now you asked.... there is something that can kill from farther away

Imagine

- The beam comes without warning.
- You're walking downtown, hanging out, suddenly, an incredibly bright light in the sky!
- It hurts to look at it at first, then it begins to dim.
- Hours later, silent subatomic particles slam into the Earth's atmosphere.
- No matter if people are inside or not, a large fraction of the Earth is exposed to lethal radiation.
- 60% of the population of the world starts dying from the high dose.

Imagine

- The ozone layer has been dramatically damaged, and solar UV radiation will kill off the food chain.
- A thick layer of smog forms and the sky turns a dark reddish-brown. Plants begin to die, then the acid rain starts.
- A new ice age begins.
- Survivors realize that the supermassive star Eta Carinae exploded.
- As you die, you wonder how a star trillions of miles away killed you, and why didn’t Leslie talk about it in class?

Gamma Ray Burst

http://www.youtube.com/watch?v=6ZnHO0B0hfA