Astronomy 150: Killer Skies
Lecture 23, March 14

Assignments:

- HW7 due next time at start of class
- Night Observing

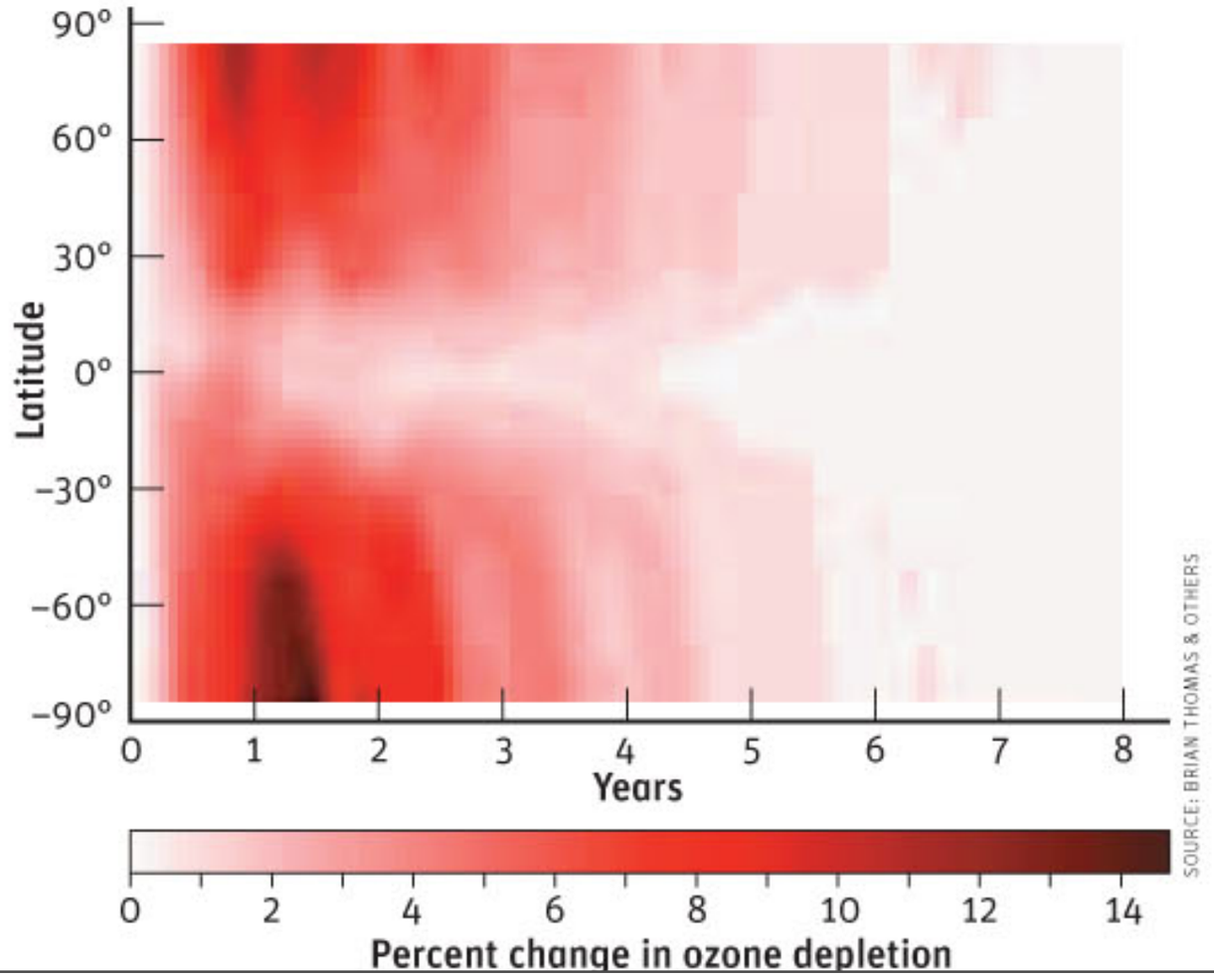
  report also due on or before Friday

Last time: Supernova Explosions

Today: When Stars Attack!

- warning: this is a research topic for your instructor!

Supernova 1006
Exploded 1006 years ago



Last Time: Supernova Explosions

Supernovae mark the rare and spectacular deaths of massive stars

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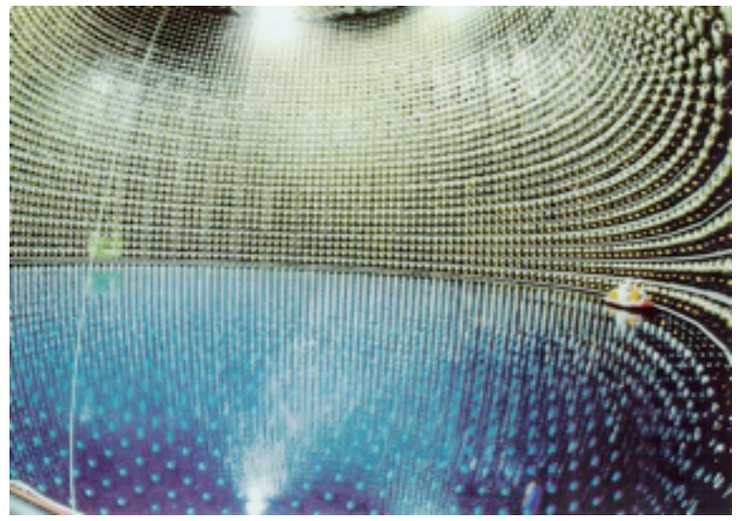

Supernovae mark the rare and spectacular deaths of massive stars

Neutrino burst

- carries away most of supernova energy invisibly!
- supernovae are “neutrino bombs”

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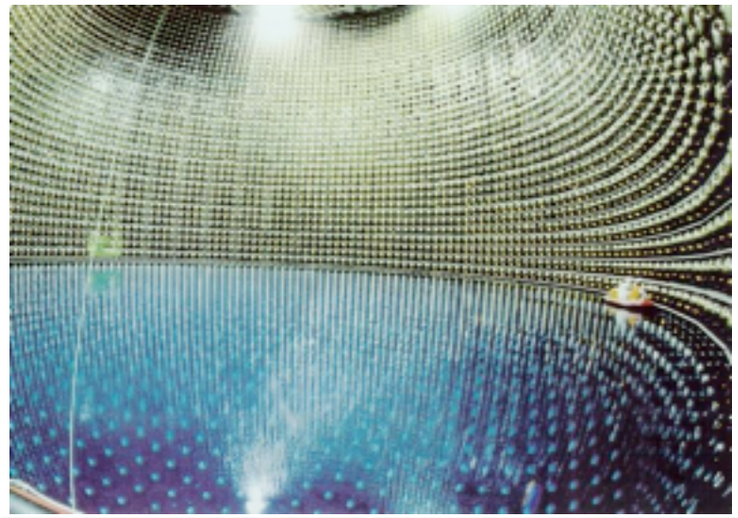
- very luminous at all wavelengths
- large output of UV, X-rays, gamma rays



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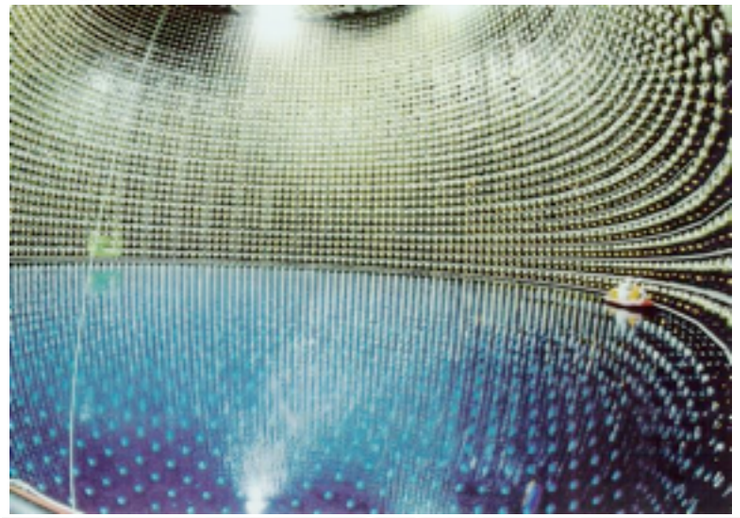
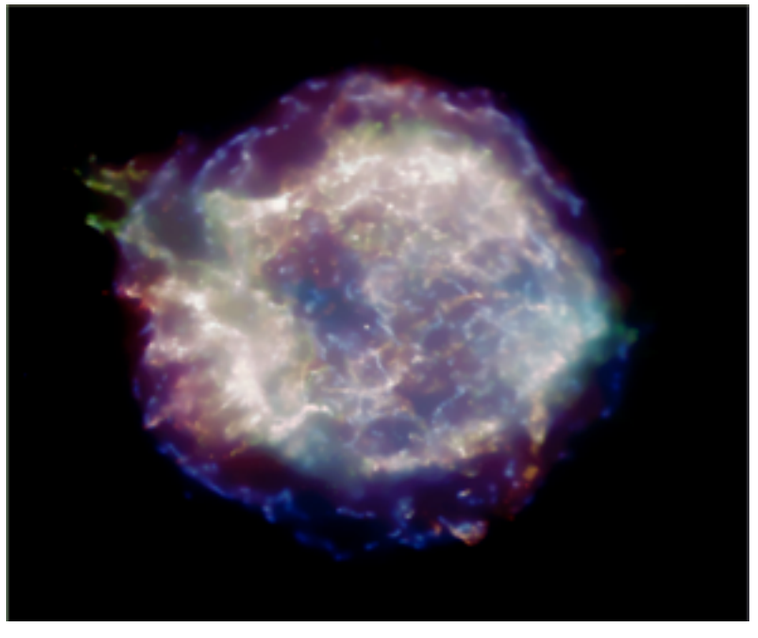
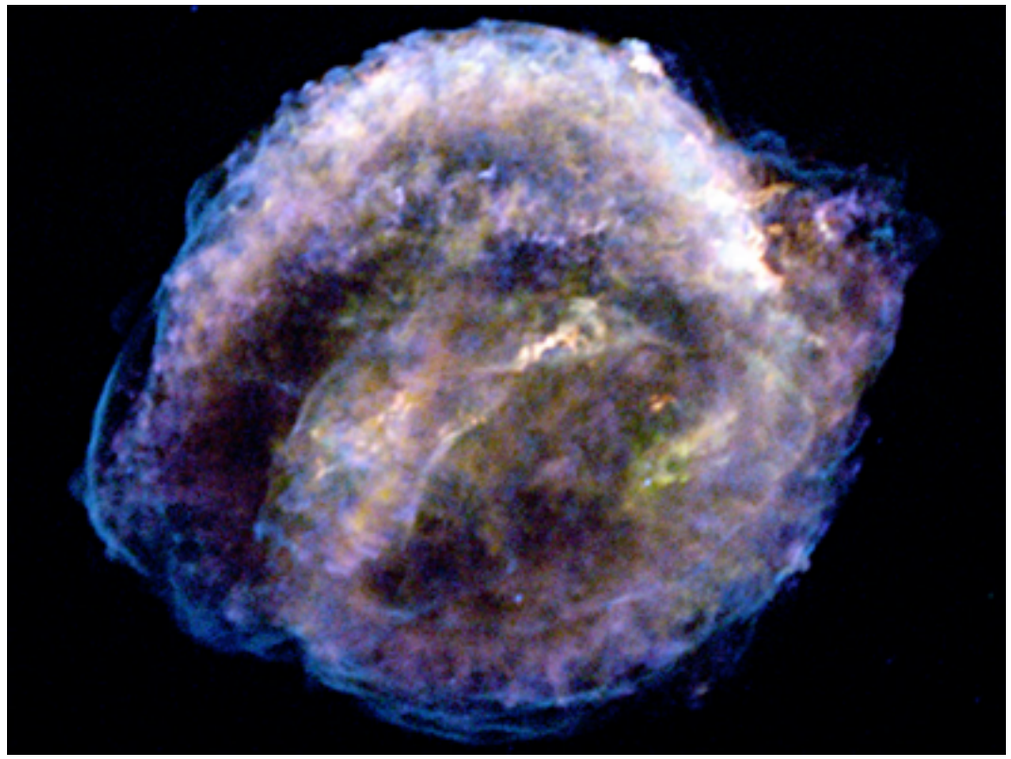
Blast:

- >90% of star’s mass ejected
- fast: highest initial speeds up to 10% c
- hot: millions of degrees, blackbody radiation is X-ray
  - high T: also high pressure
- carries all new heavy elements made during and before supernova explosion
  - including some radioactive elements





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

Supernova Blast Impact

Blast initially high-speed, high pressure

- plows into interstellar gas
- sweeps up dense shell

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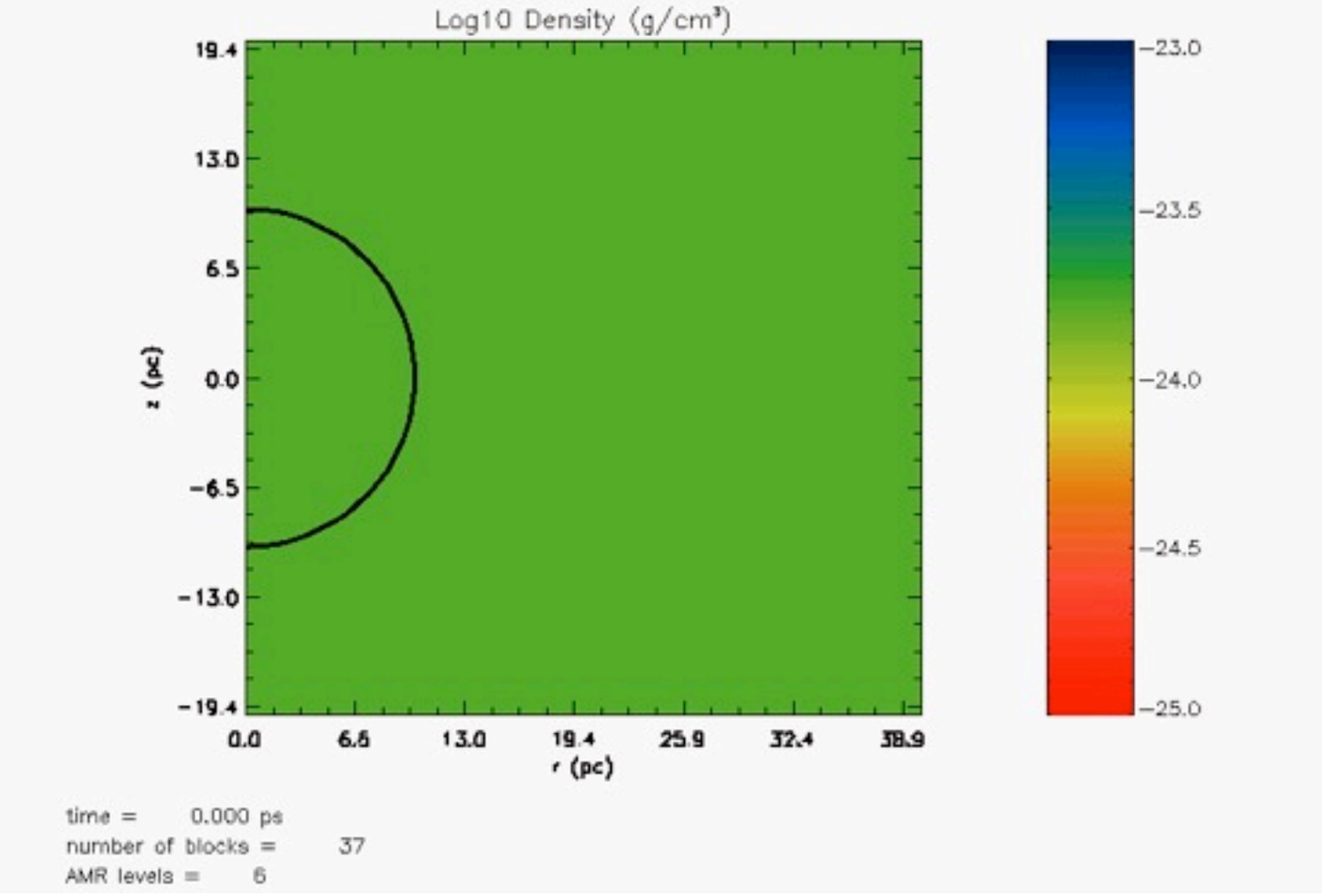

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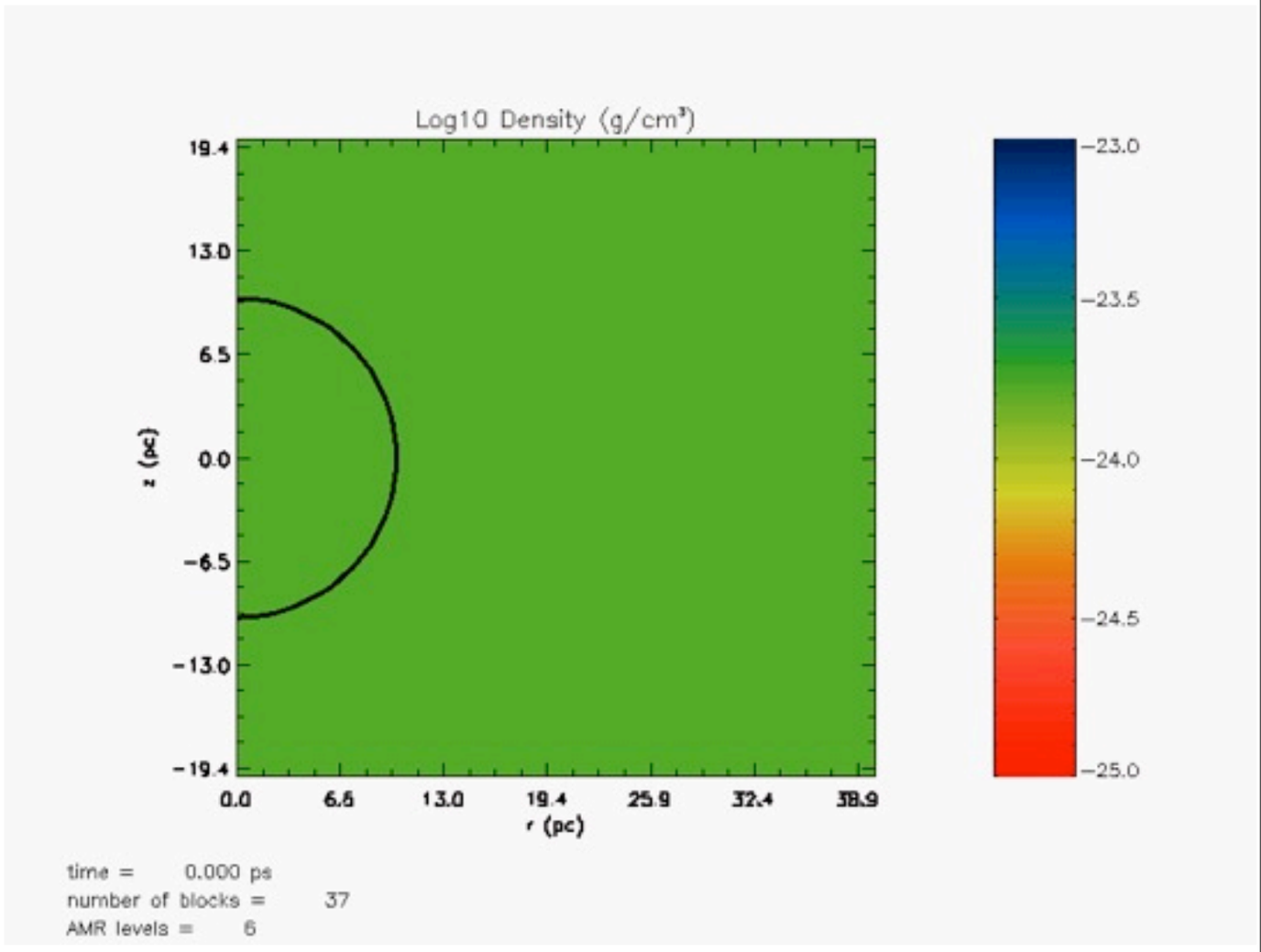

simulated supernova blast
"big picture" view
circle drawn at 10 pc
red: low density
green: medium density
blue: high-density

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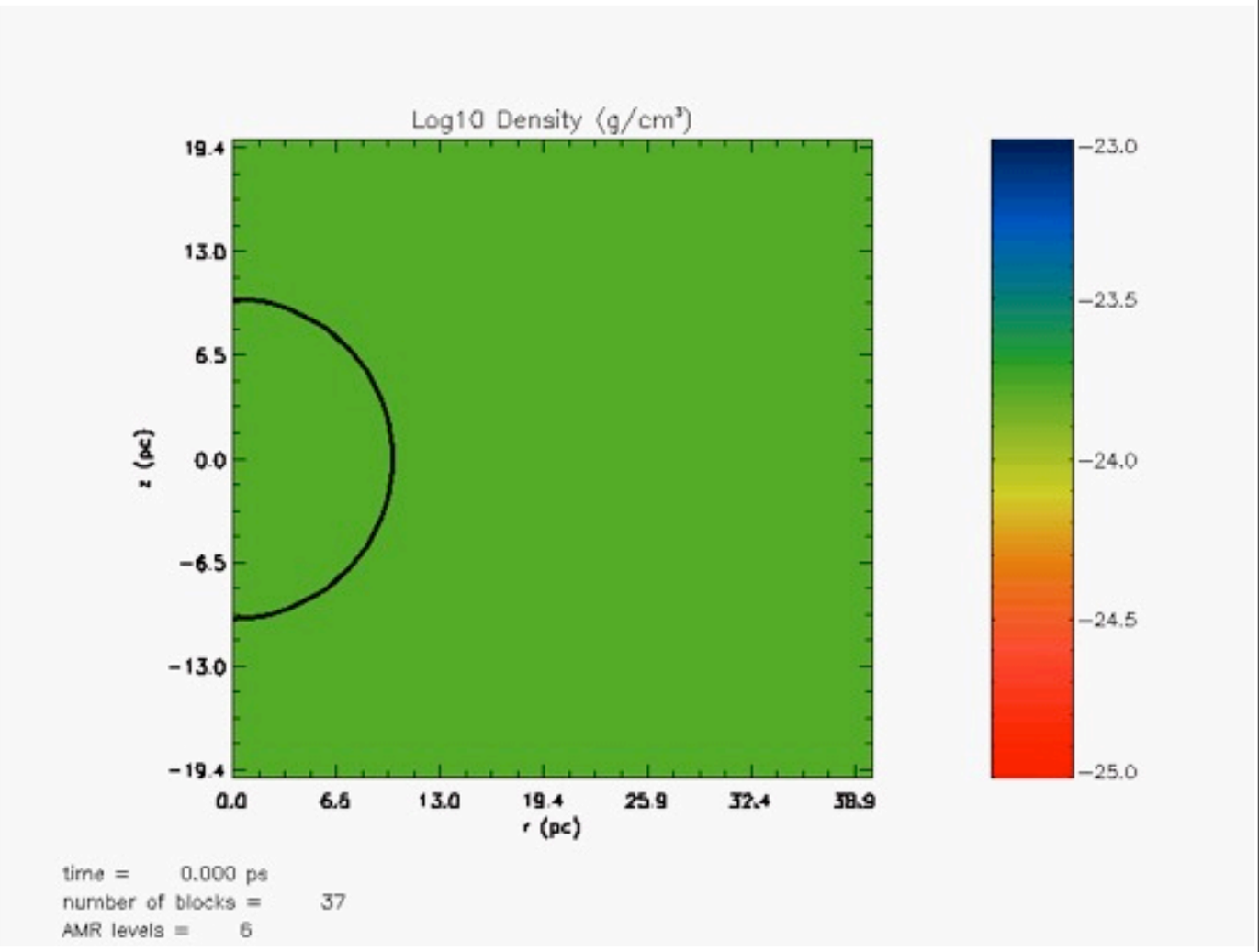
- yikes!



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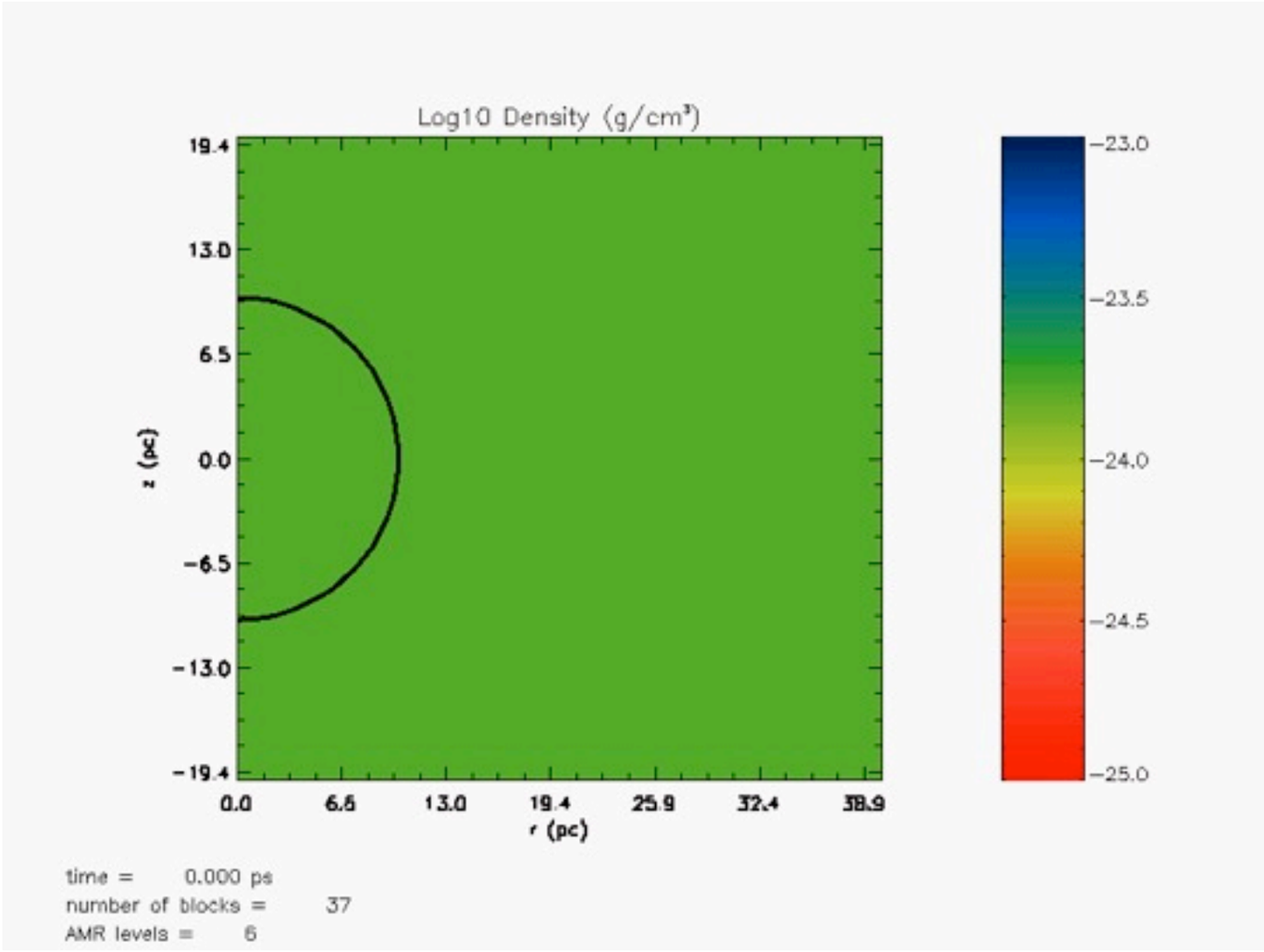
But it turns out:

- if close enough to do this, other effects will have killed us already
- at realistic distances, pressure similar to that of Solar wind today -- which does not strip our atmosphere!



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- also damages DNA: smaller dose can still cause mutations and cancer

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Good news: neutrinos only interact weakly

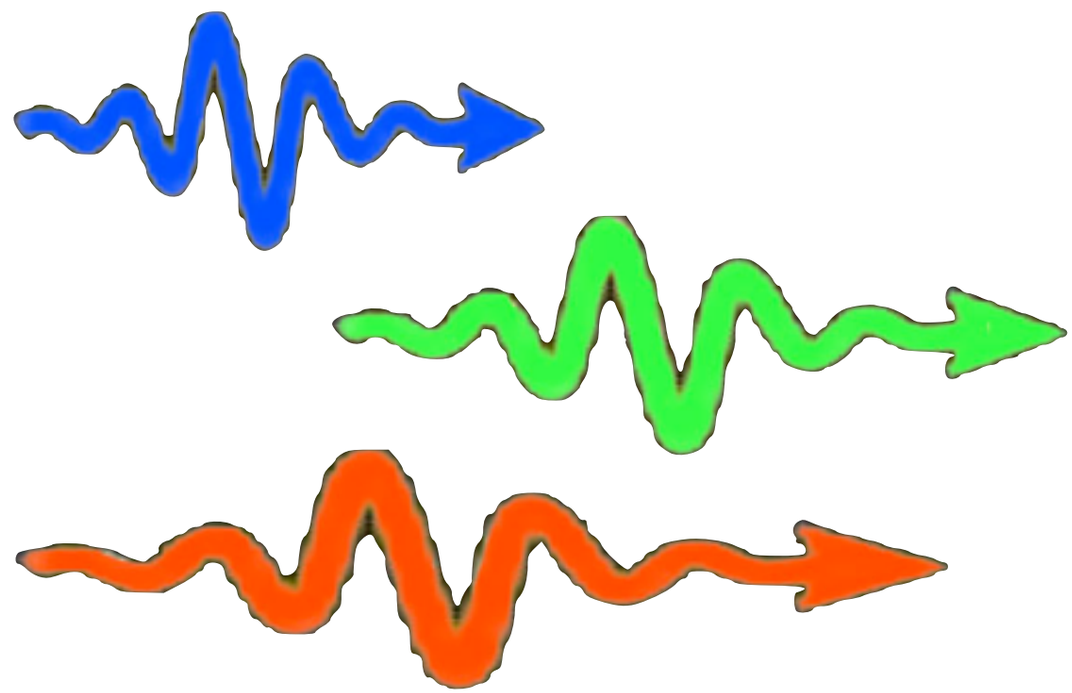
- meaning that these ionizing events are rare and few
- unless the supernova is really close, but then other problems are worse!
- this is fortunate, because there is no way to shield against neutrinos

  you can't run, you can't hide

The Real Danger:
Supernovae produce lots of ionizing radiation

Ionizing radiation

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

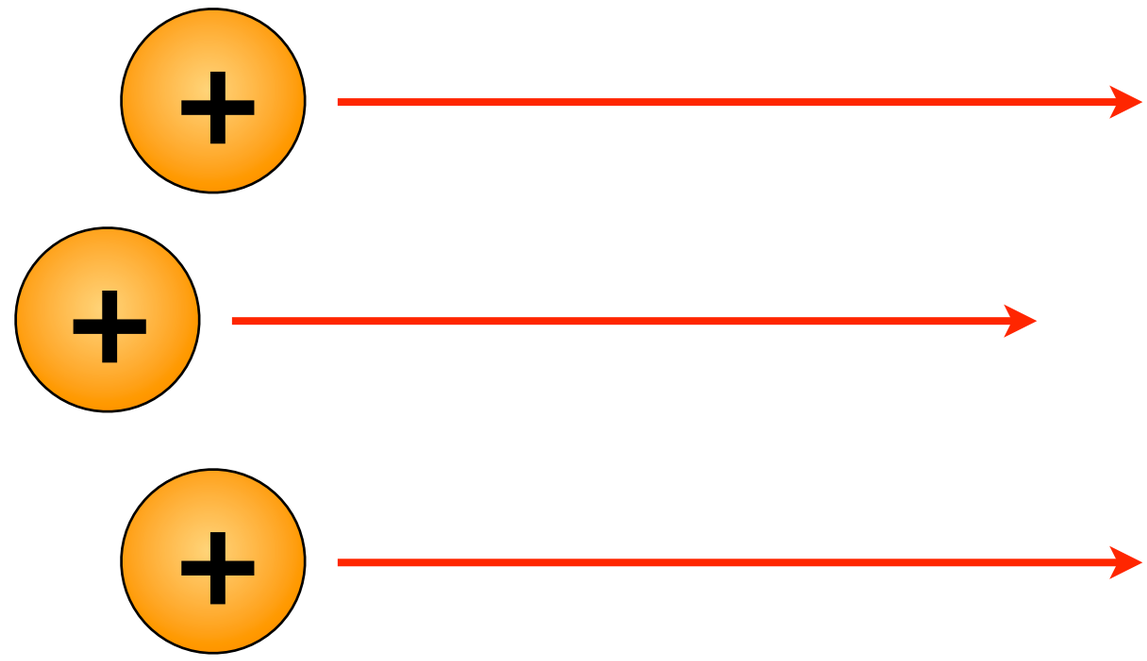


Supernovae produce large amount of ionizing light

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

Supernovae also produce cosmic rays

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



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- Gieger counter experiment
  - about 10% of clicks are due to cosmic rays

Victor Hess 1912
100 years ago!
Nobel Prize 1936

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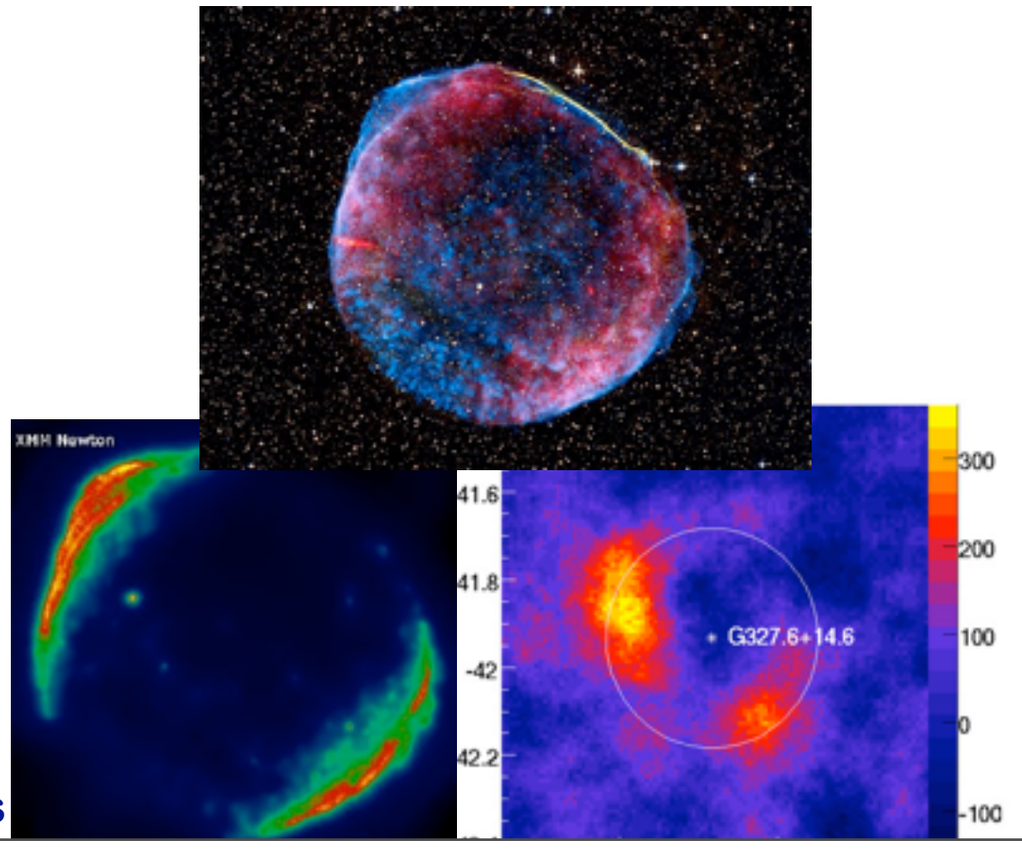
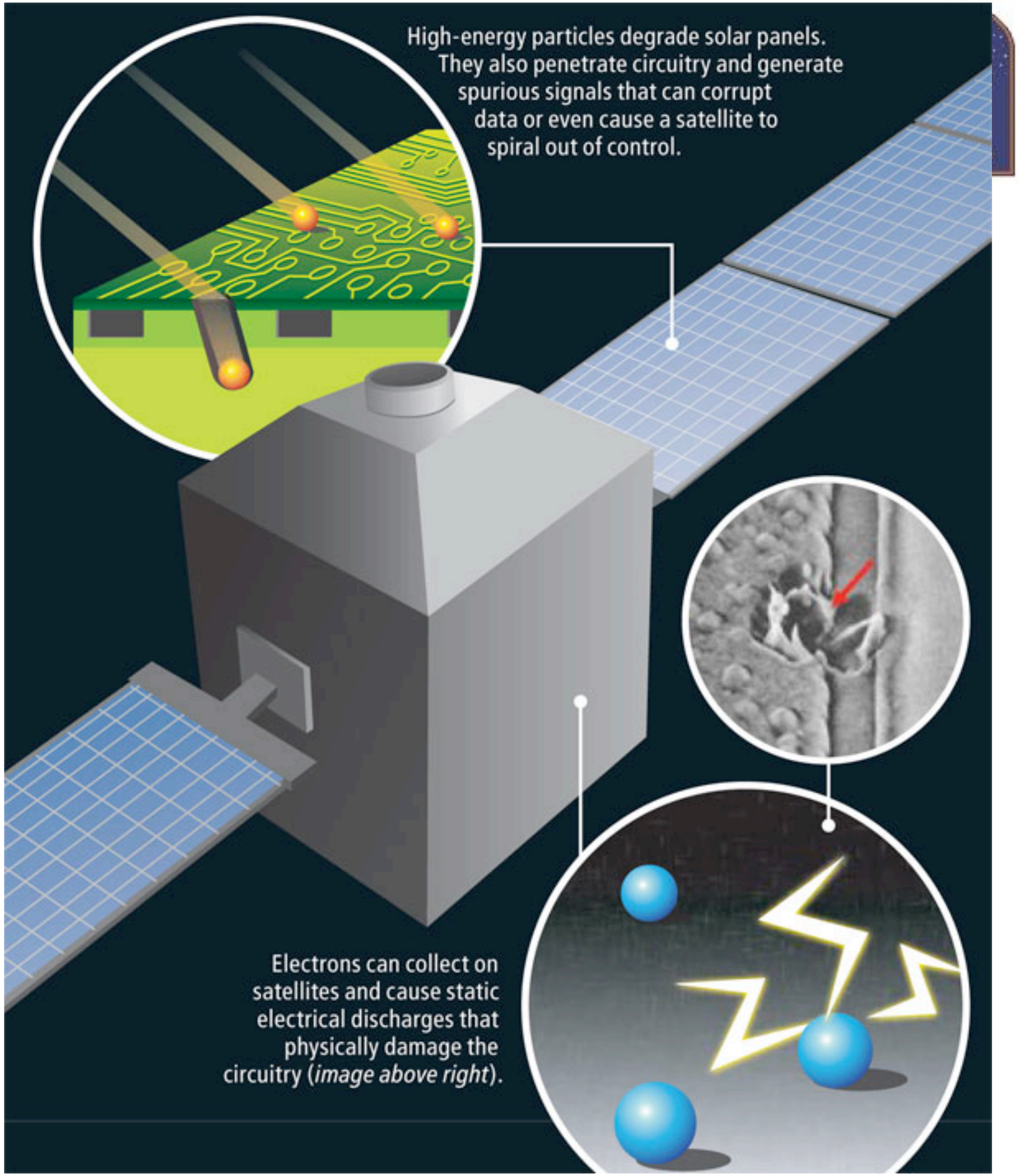
Cosmic rays fill interplanetary and interstellar space

- 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



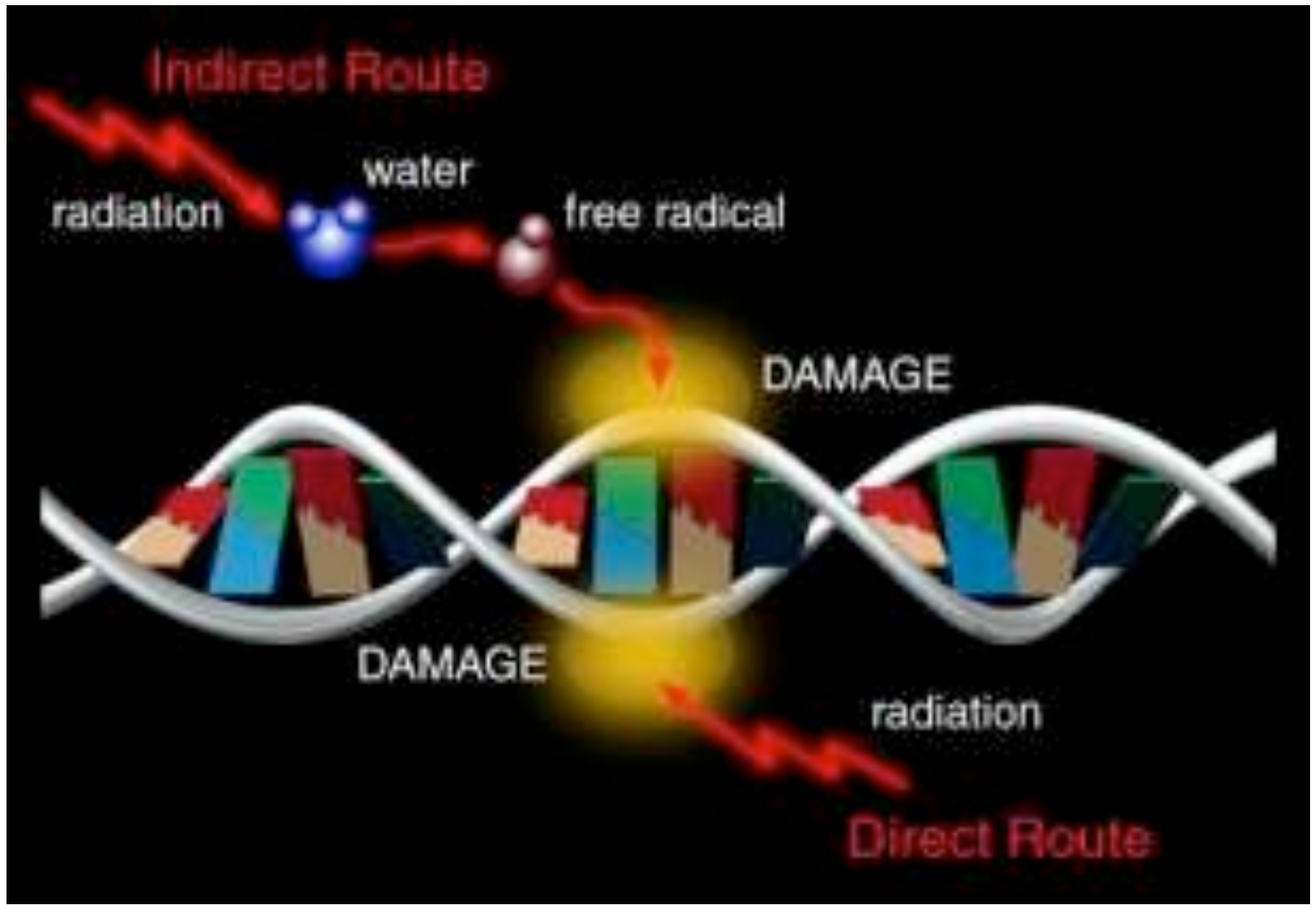
Radiation Hazard

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



Electric grid overload

Supernova damage similar to solar storms

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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

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- "fried" by voltage spikes

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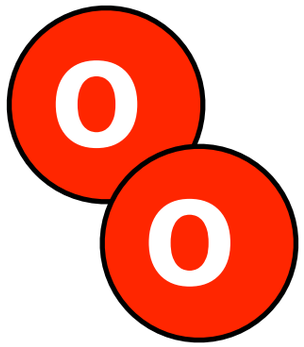
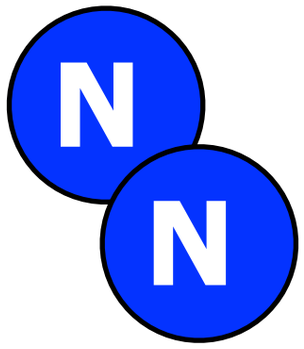
But this is just a sideshow...not the real problem

Gamma rays and cosmic rays from a supernova create nitric oxide

Air is mostly made of N_2 and O_2





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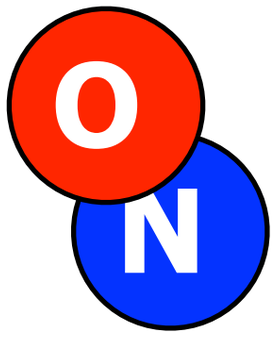
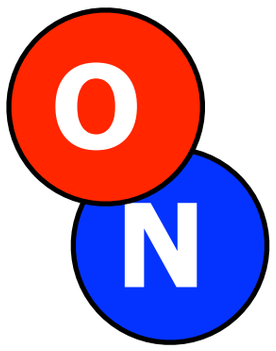




Gamma-rays and cosmic rays convert N_2 and O_2 into NO

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

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

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

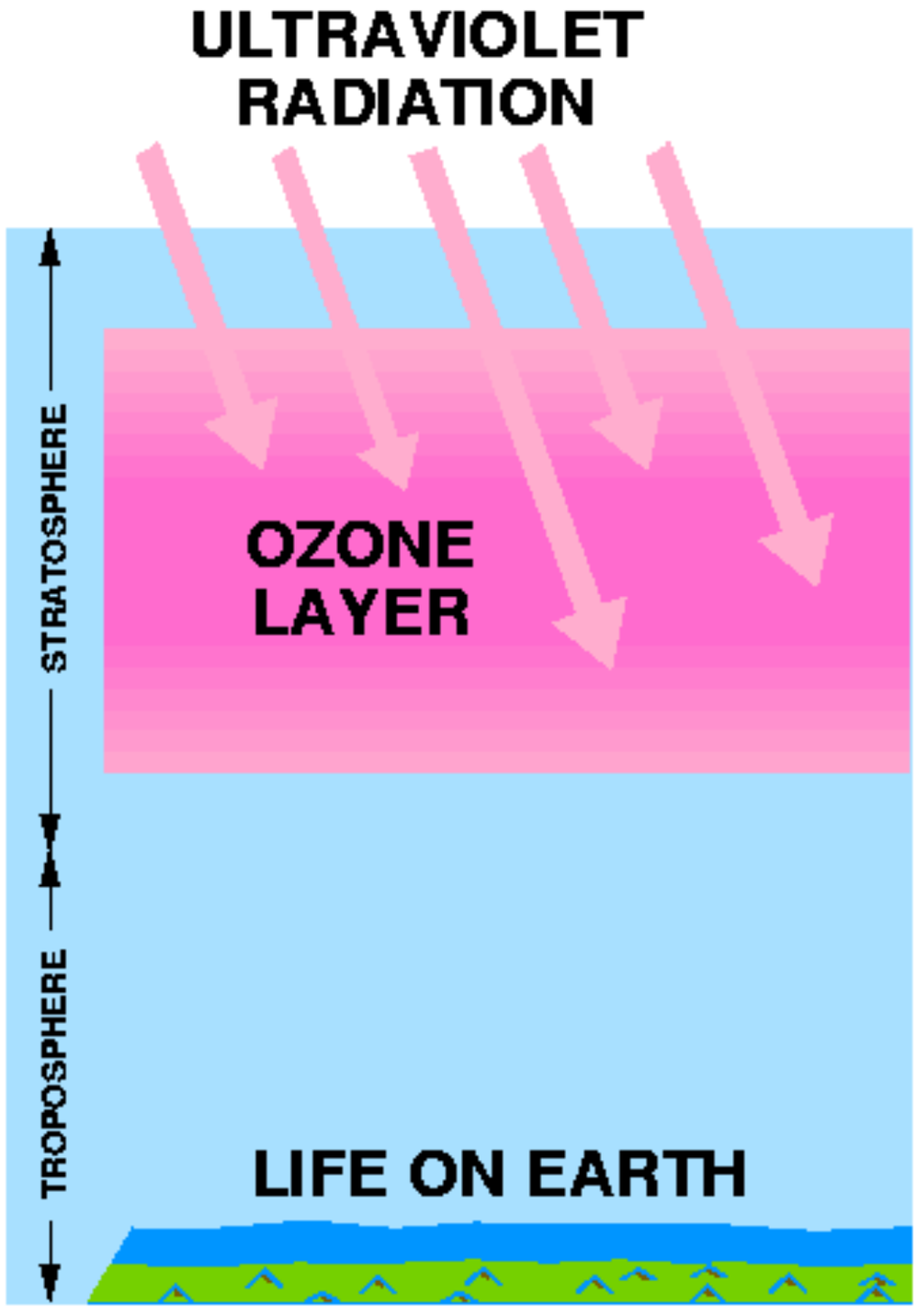
$$\text{Net } O + O_3 \longrightarrow 2O_2$$

Most Dangerous Effect: Ozone Layer Depletion

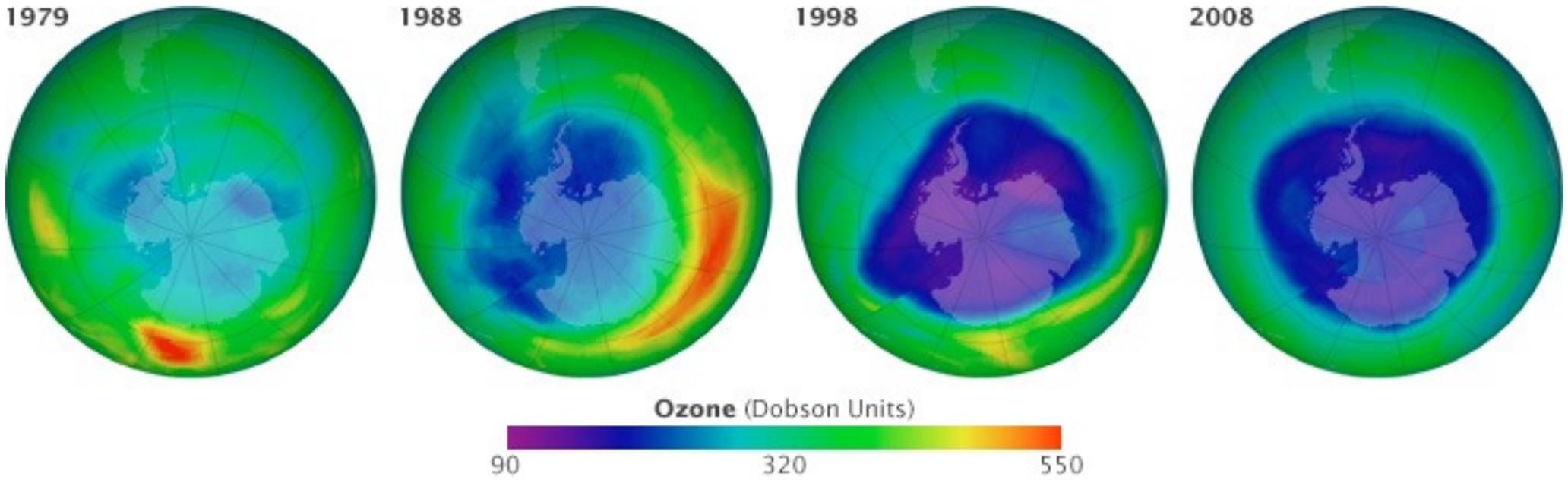
Life on Earth, as we know it, could not exist without the ozone (O_3) layer

It shields us from ultraviolet (UV)radiation from the Sun, which is damaging to life

Located ~30 km up in the stratosphere



The Ozone "Hole"



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

We know the dangers of ozone depletion!

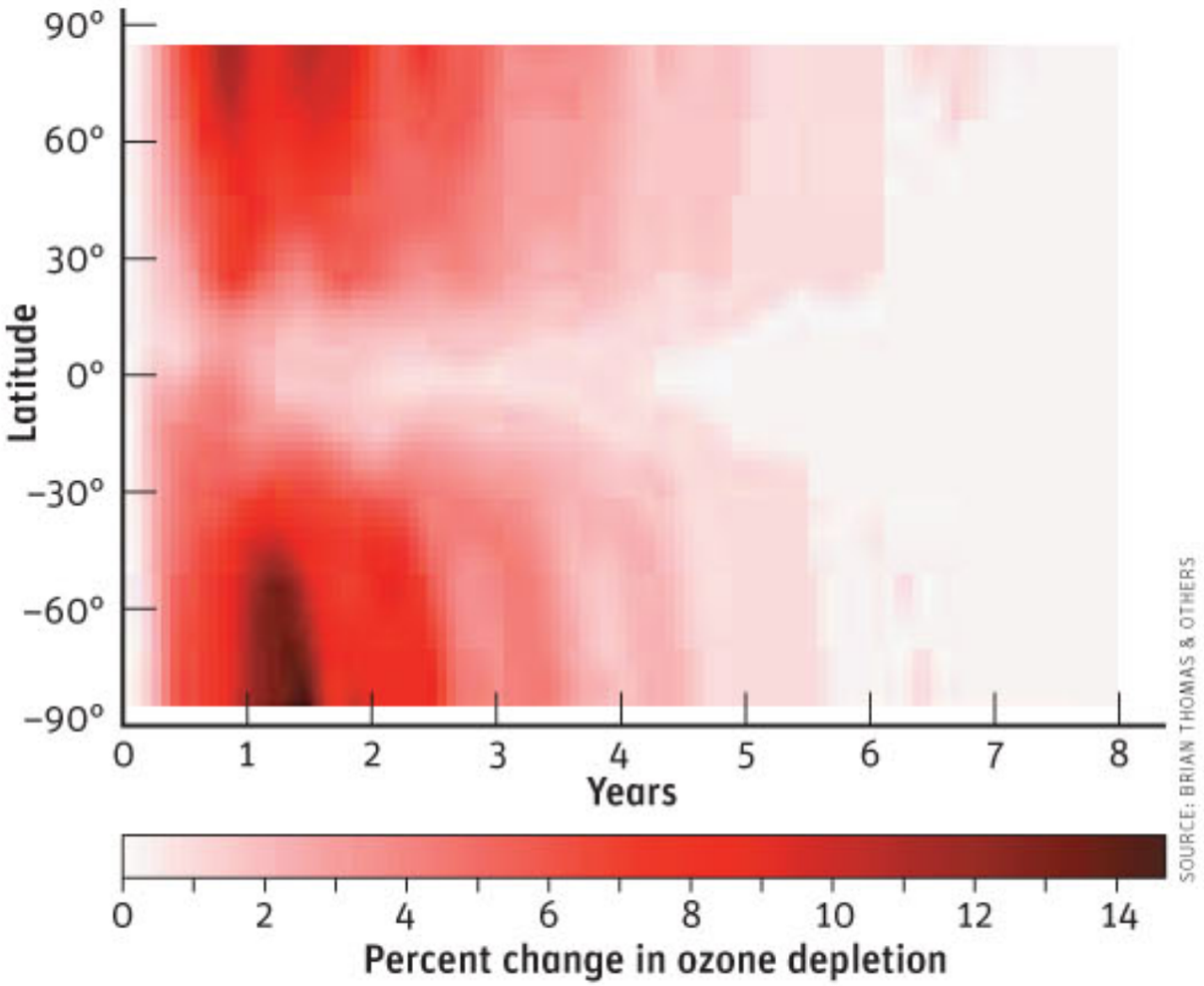
How much of the ozone layer would a supernova destroy?

Supernova damage depends on distance

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

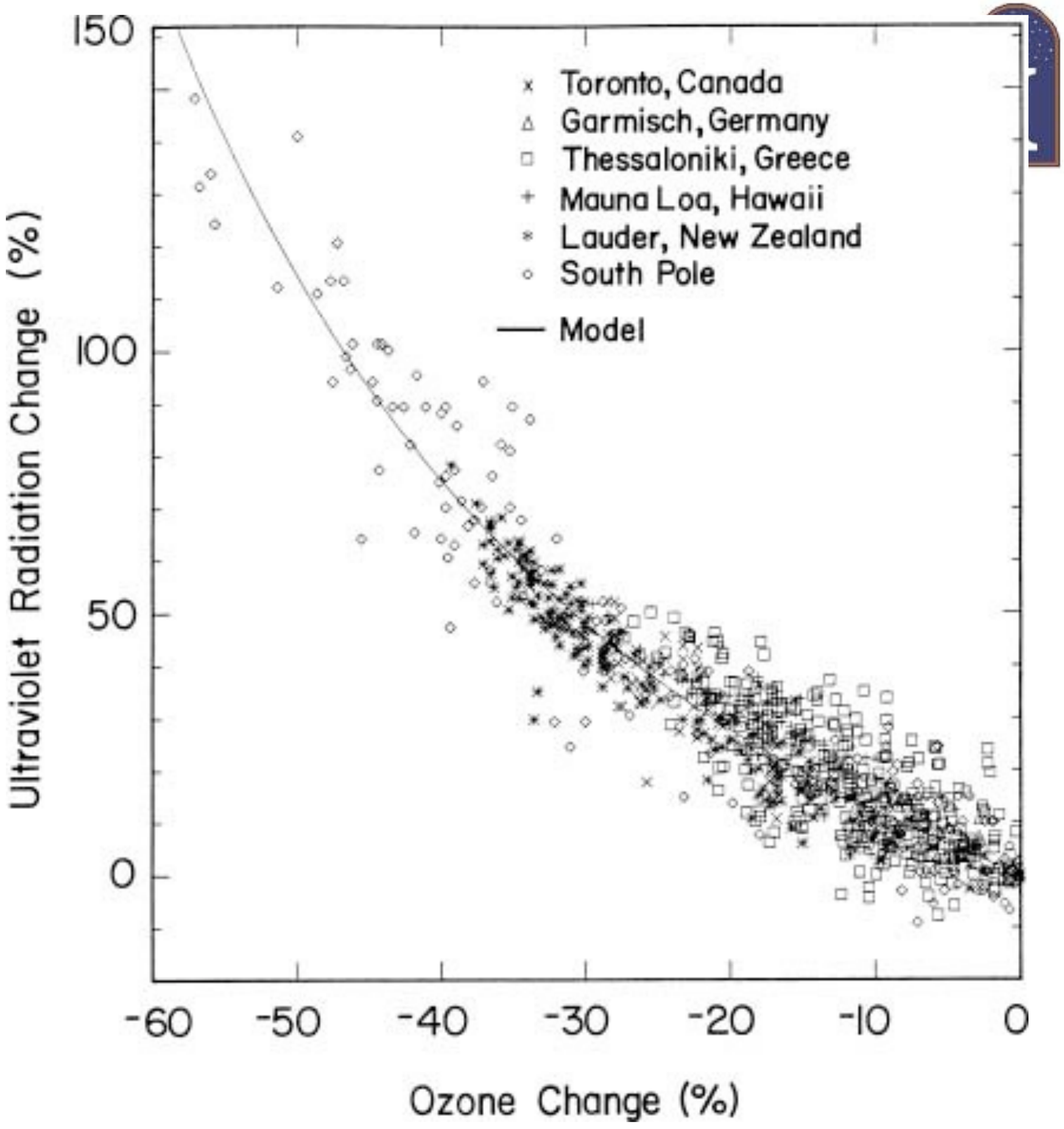
If supernova nearby, flux is intense, damage catastrophic

- At d = 25 light years = 6 pc: destroys 50% of ozone layer
- At d = 100 light years: 7-15% reduction of ozone layer



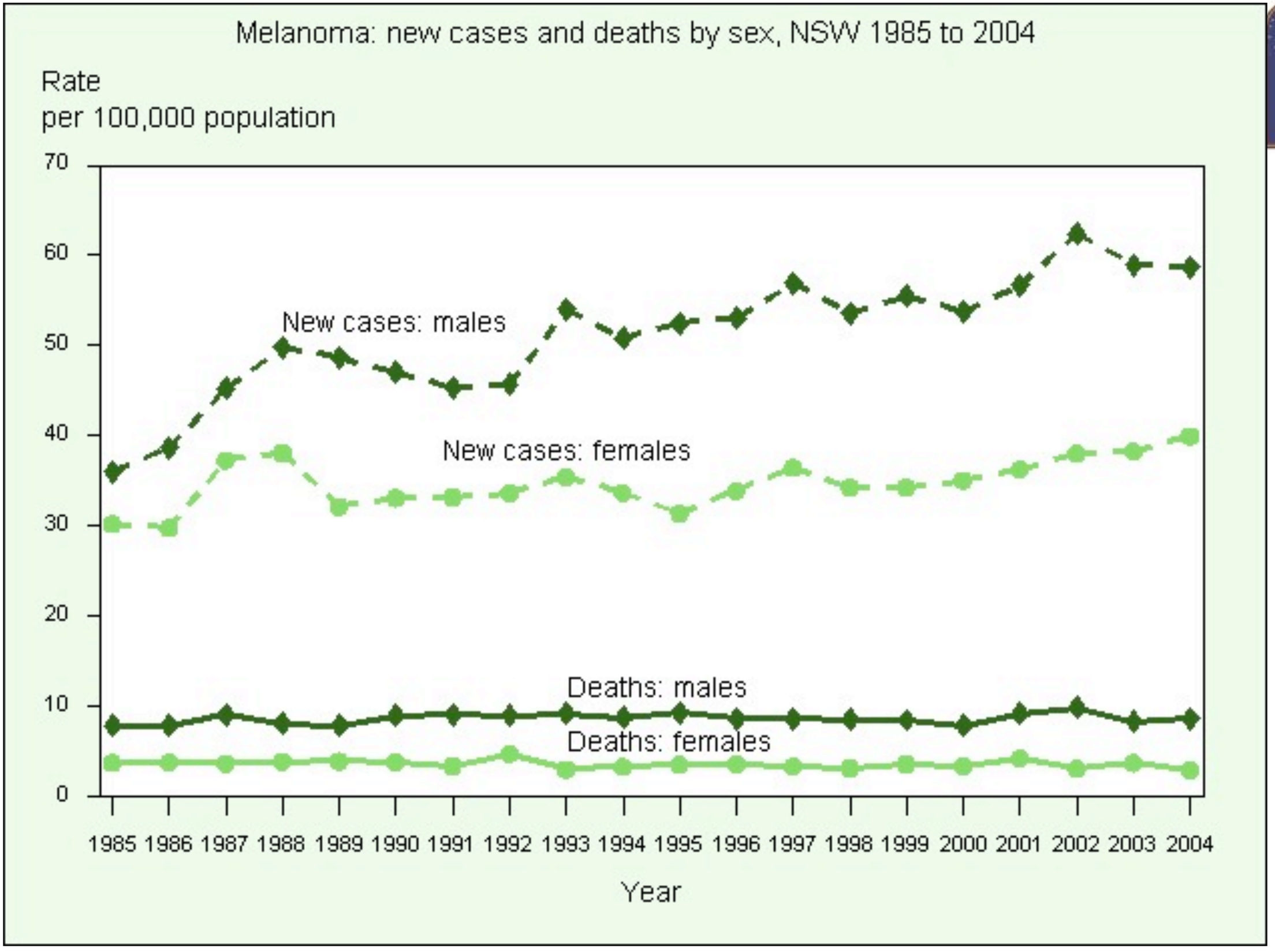
Ozone depletion from a Type II supernova at 100 light years

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

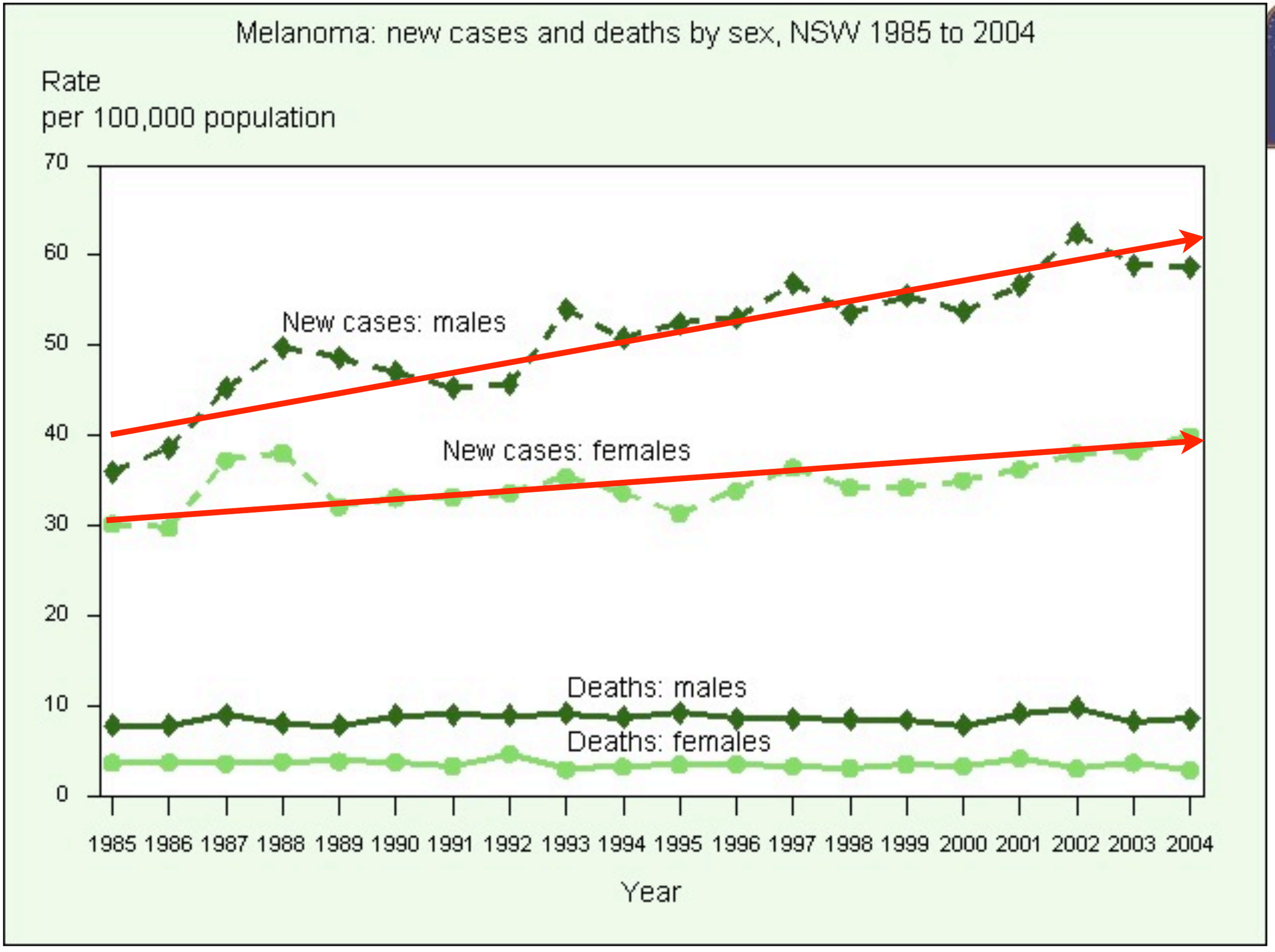


Increased solar UV leads to…

Severe sunburn!

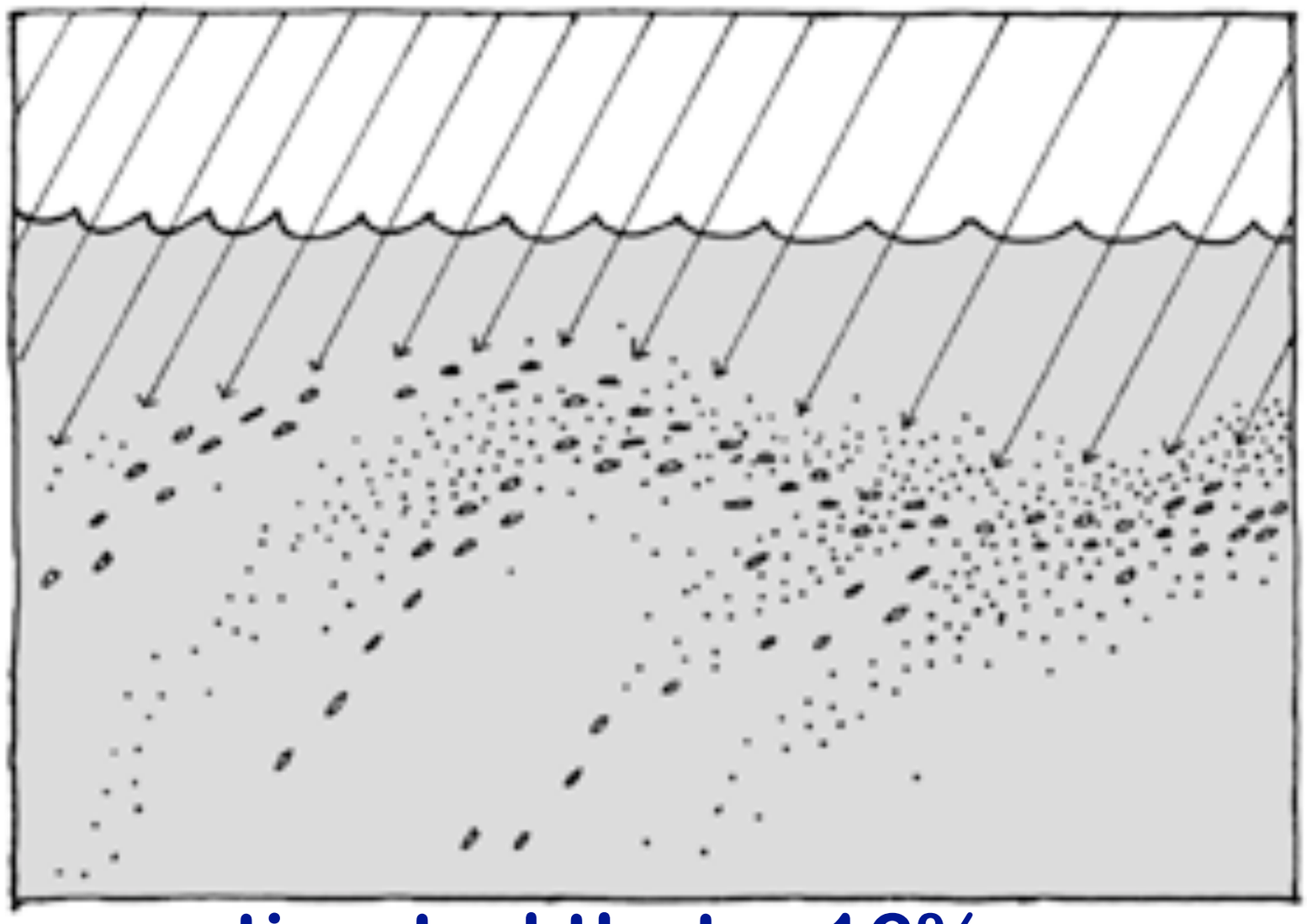


Increased risk of skin cancer



Increased risk of skin cancer

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

Phytoplankton are the base of the marine food chain

Plankton eaten by larger creatures

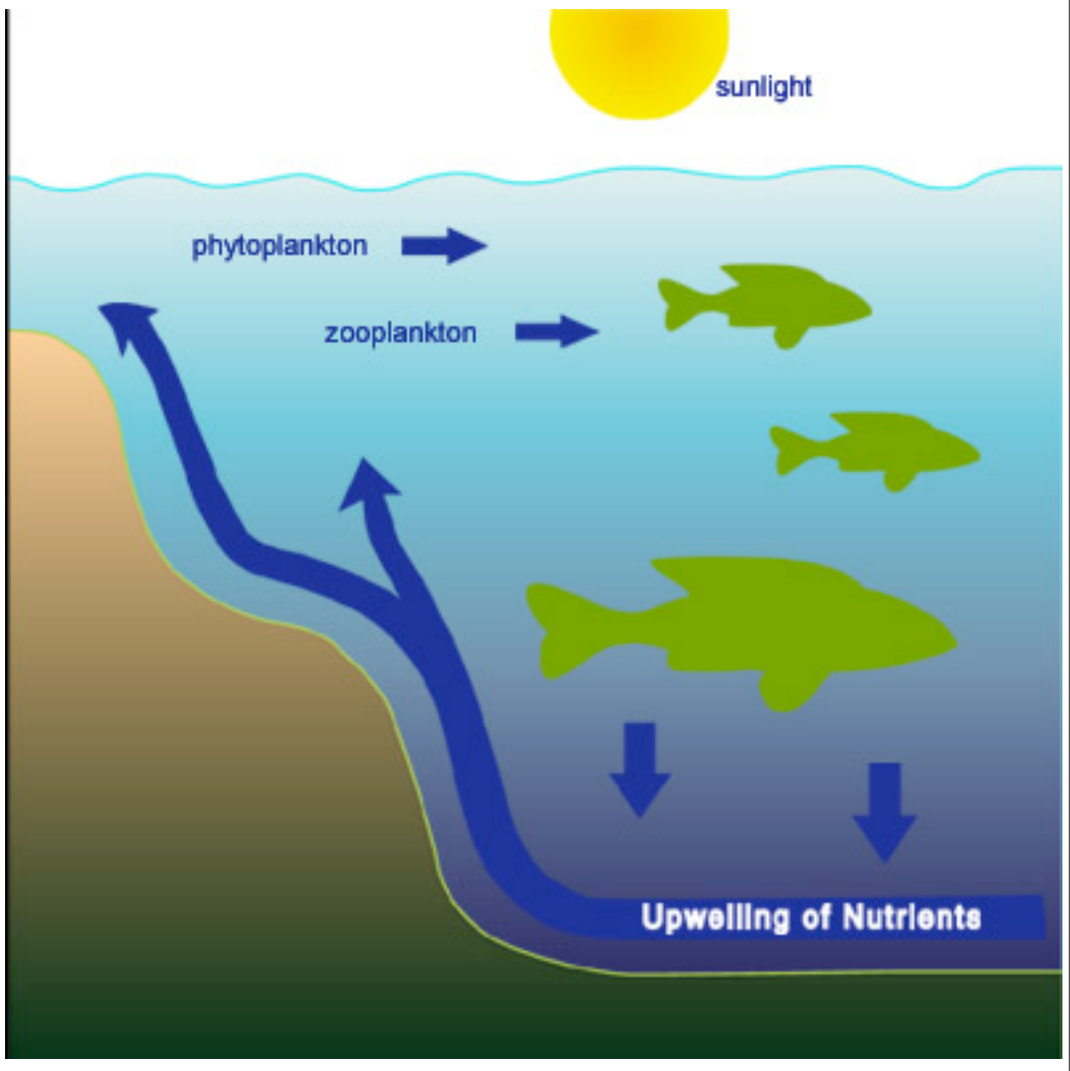
- which are eaten by larger creatures
- kill plankton, and much of marine life dies!

On land:

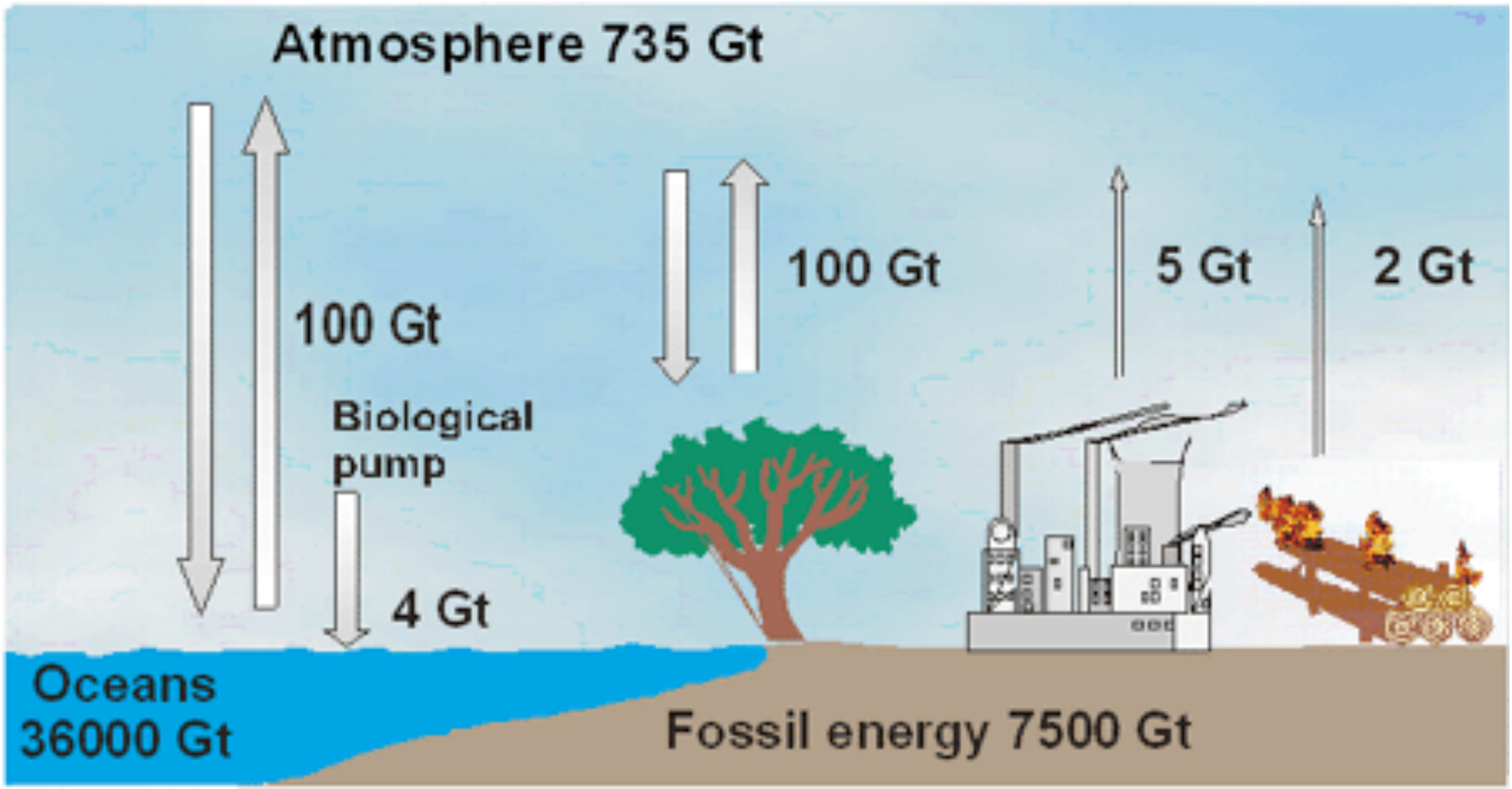
- similar story with plants

Effect of supernova:

- disrupt food chain, cause starvation



Phytoplankton are also a major sink for atmospheric



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 8 pc = 25 light years

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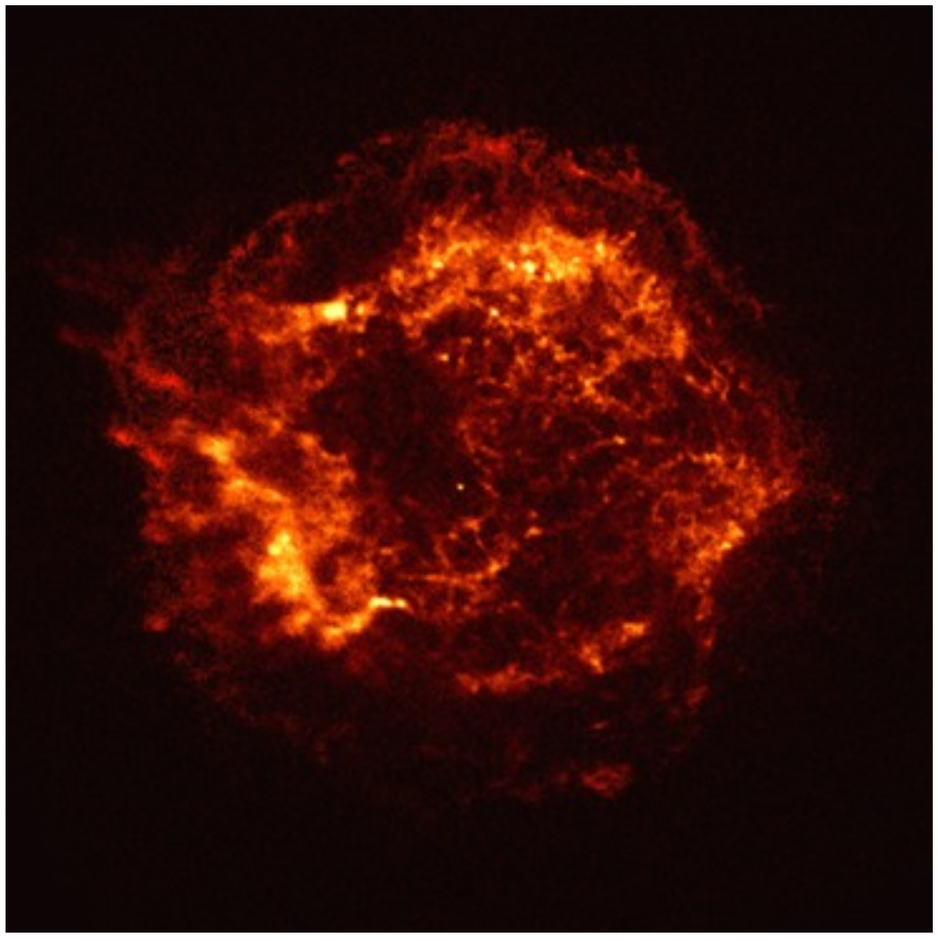

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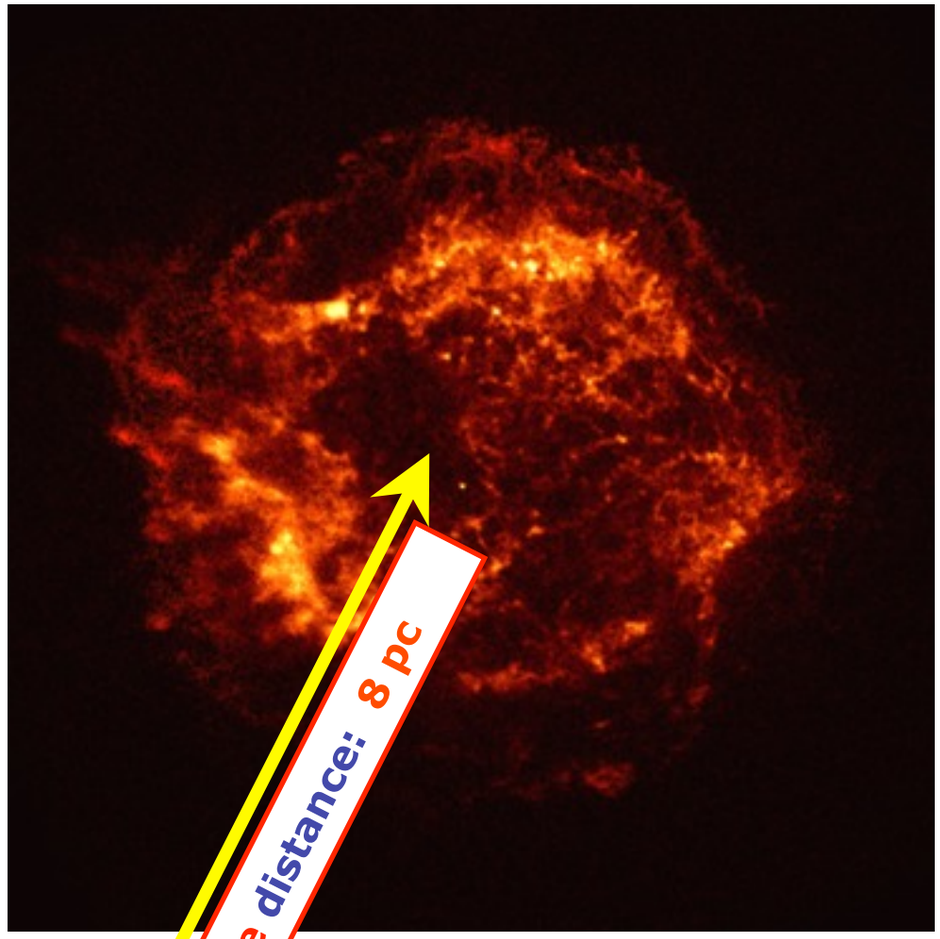

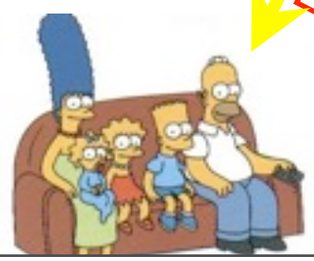

iClicker Poll:
Supernova Threat Today

The minimum safe distance to a supernova is about 8 parsecs

Vote your conscience:

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

Hint: nearest star (alpha Cen) is at 1.3 pc

A. definitely yes. uh oh.

B. definitely no. whew!

C. no way to tell. gulp.

So is 8 parsecs close?

Supernova “kill radius” about 8 pc

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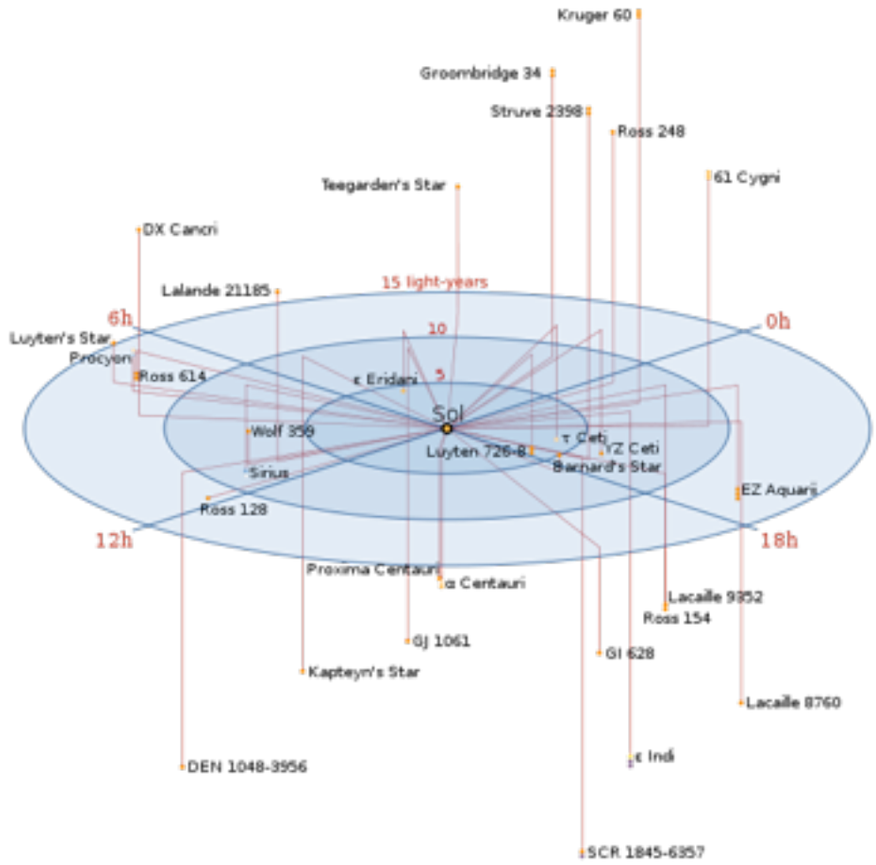
But we know our local neighborhood well

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



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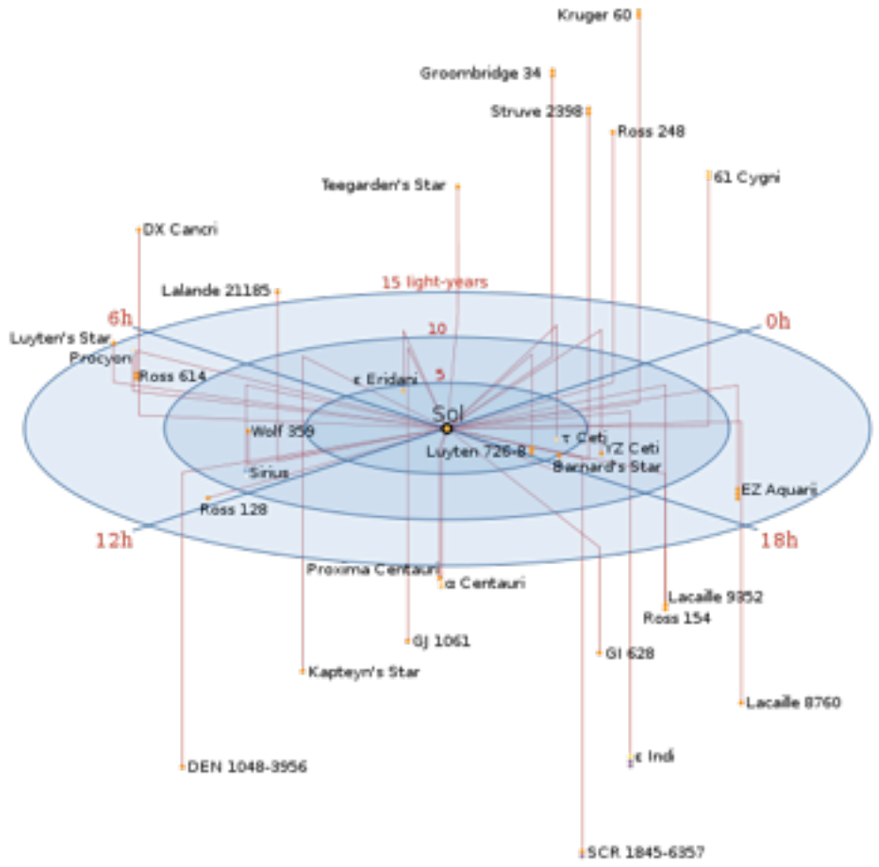
On the other hand:

- 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 8 pc over the lifespan of the Earth
- in the past (and future) threat is real!



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The Smoking Gun: Supernova Debris on the Earth

Ellis, BDF, & Schramm 1996

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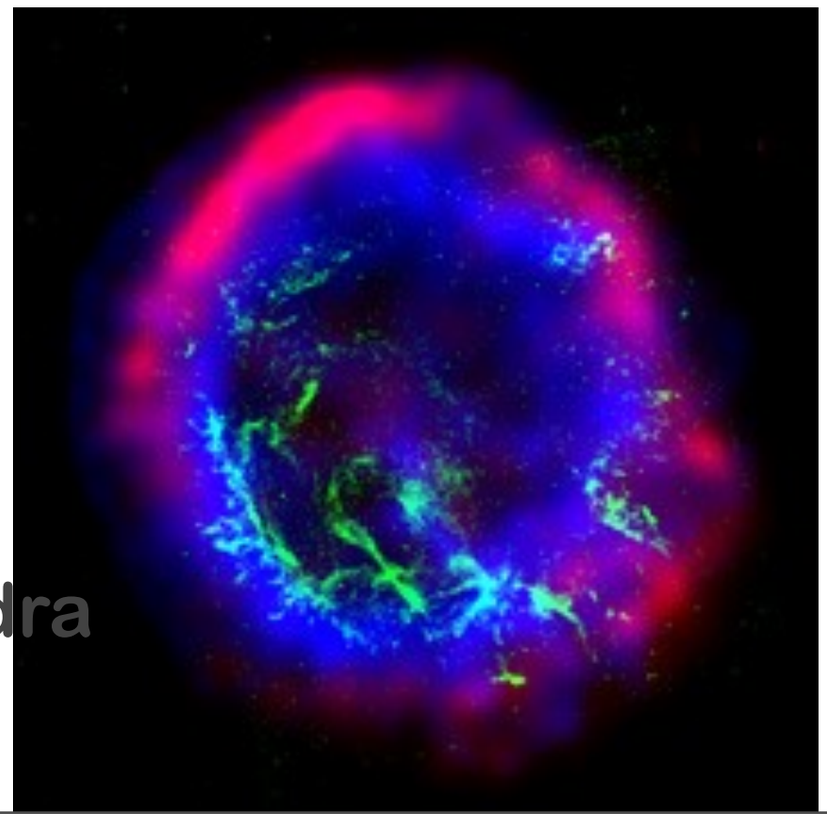

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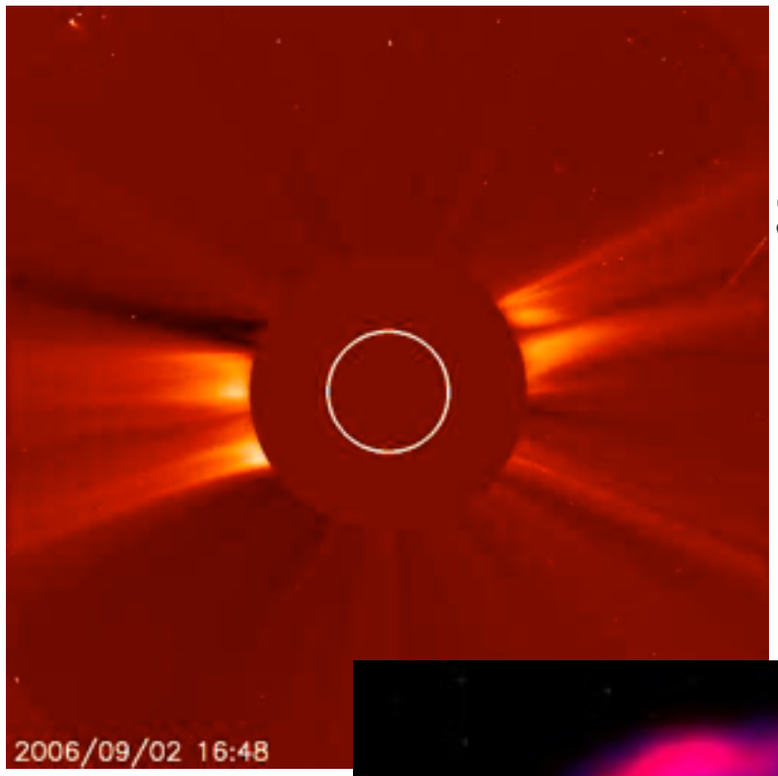
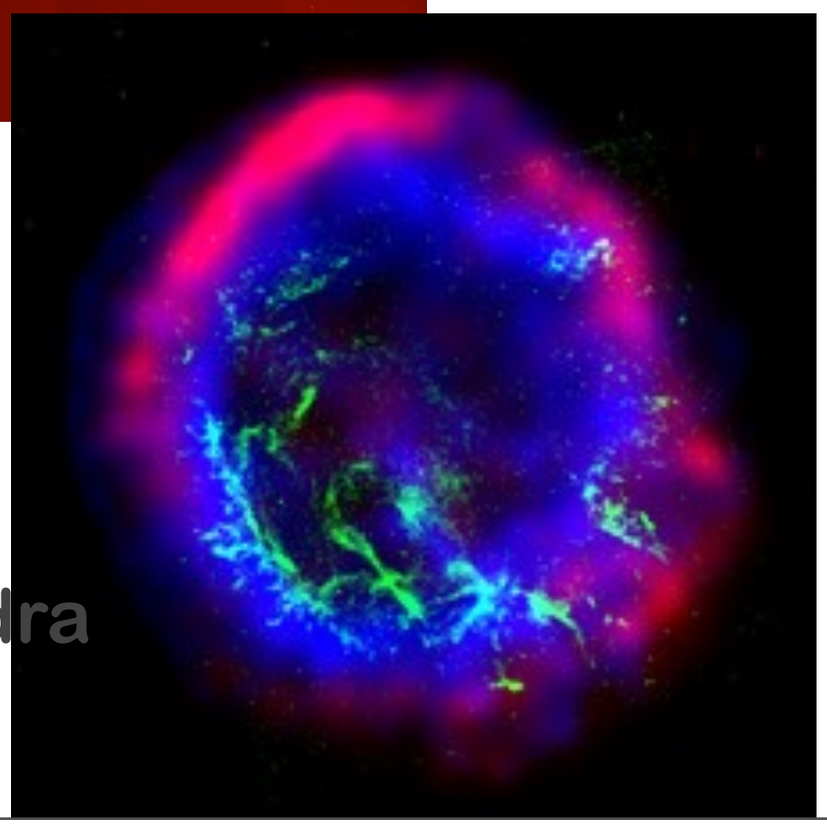


SOHO



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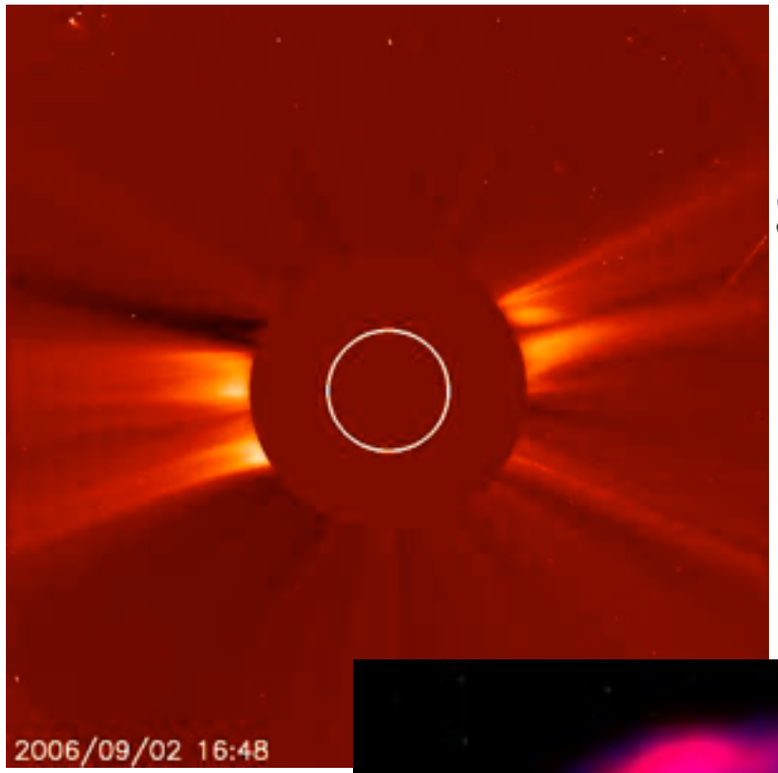

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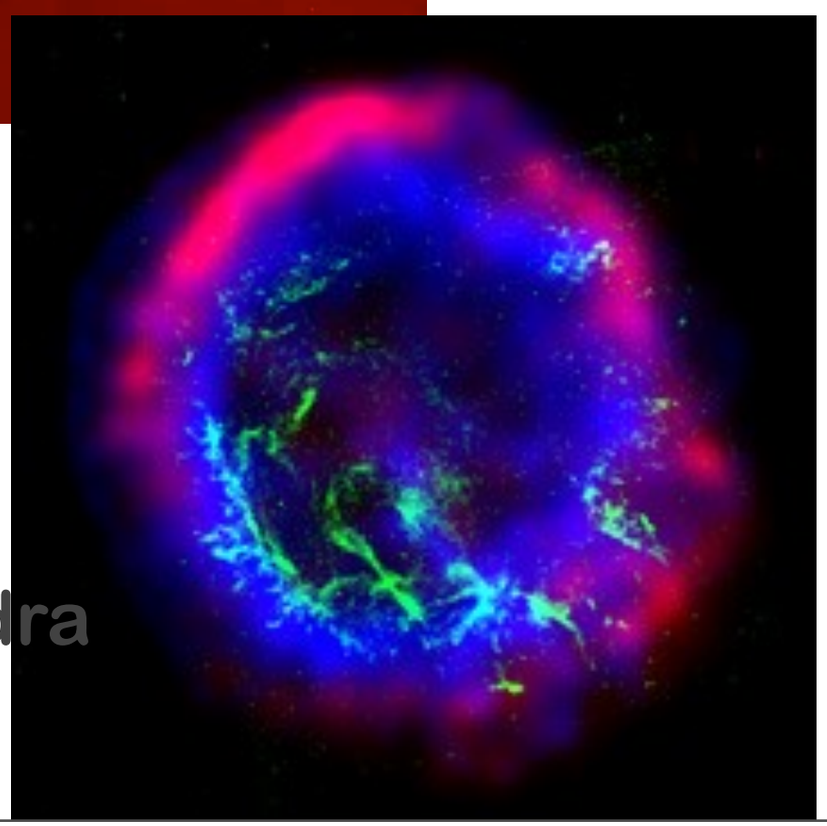

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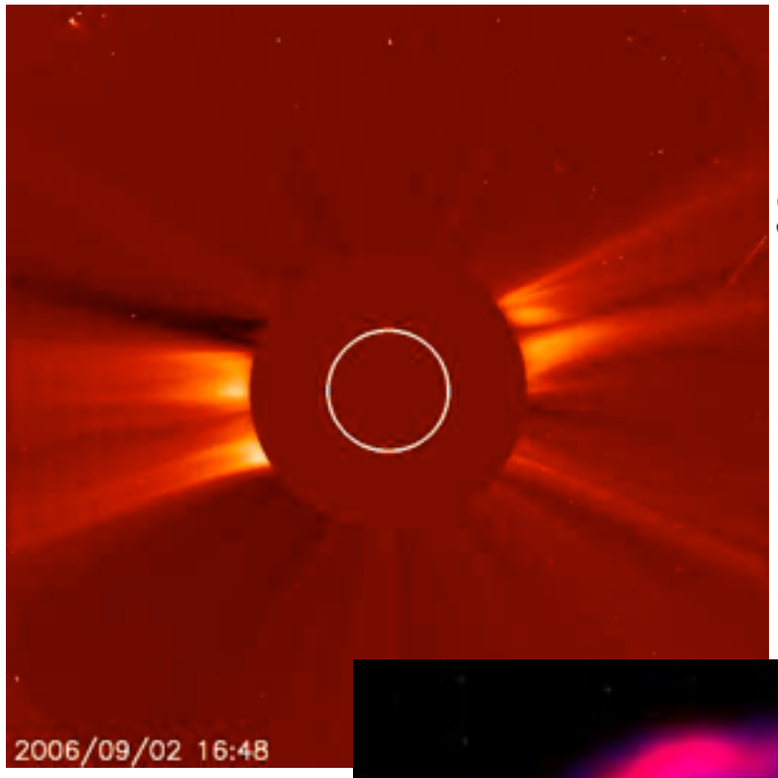

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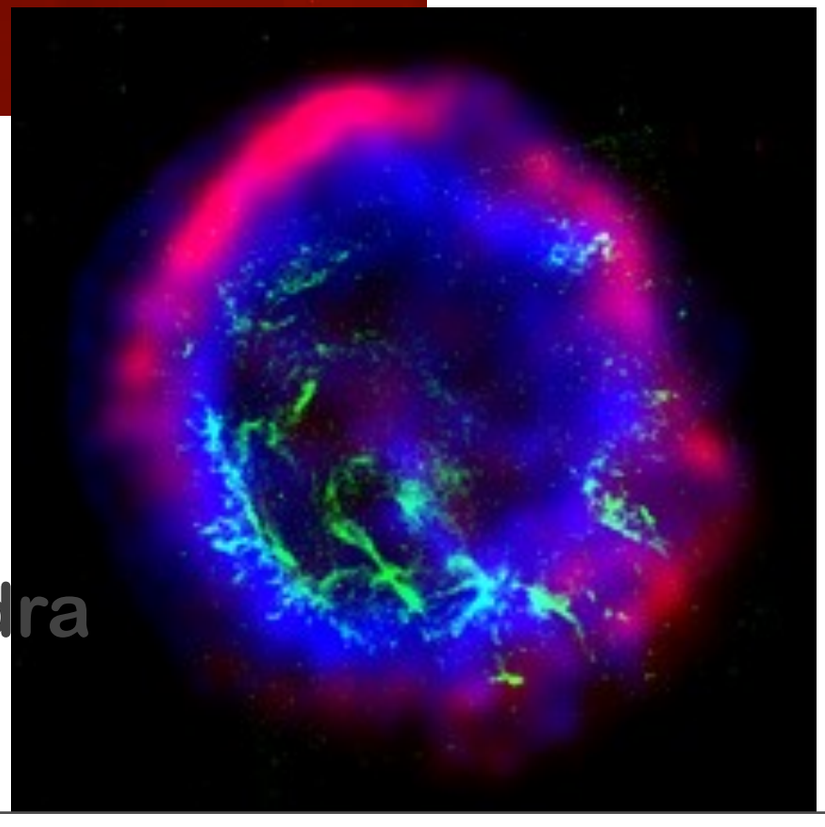

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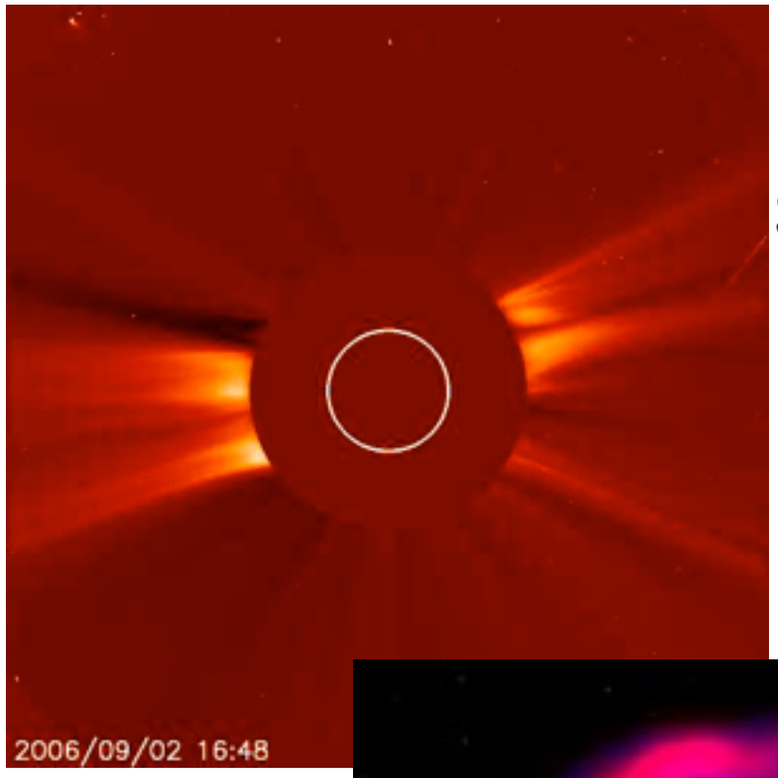

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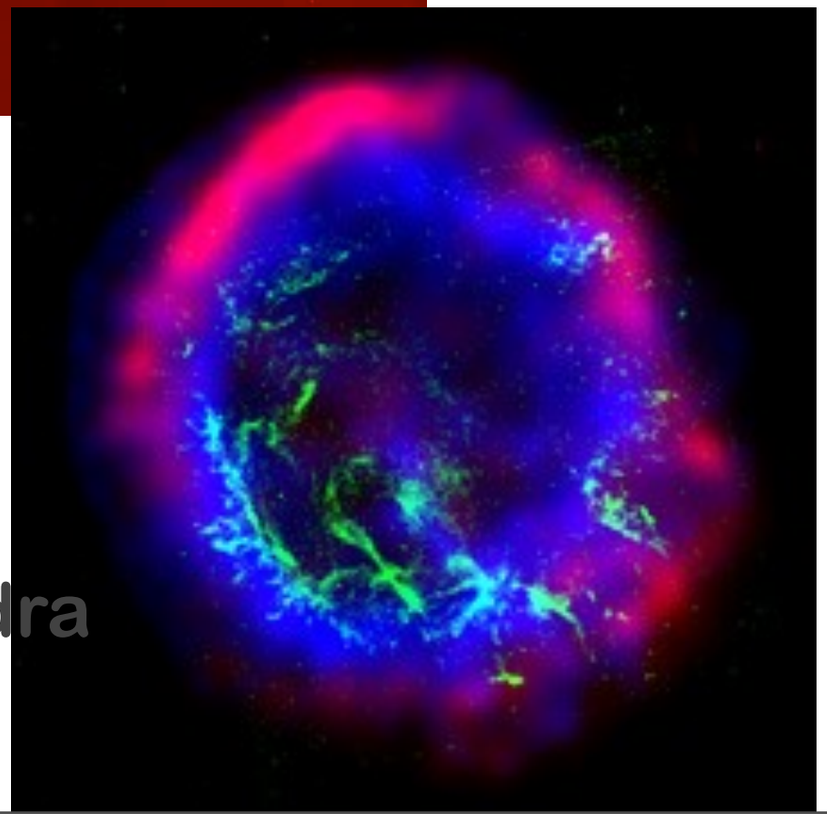

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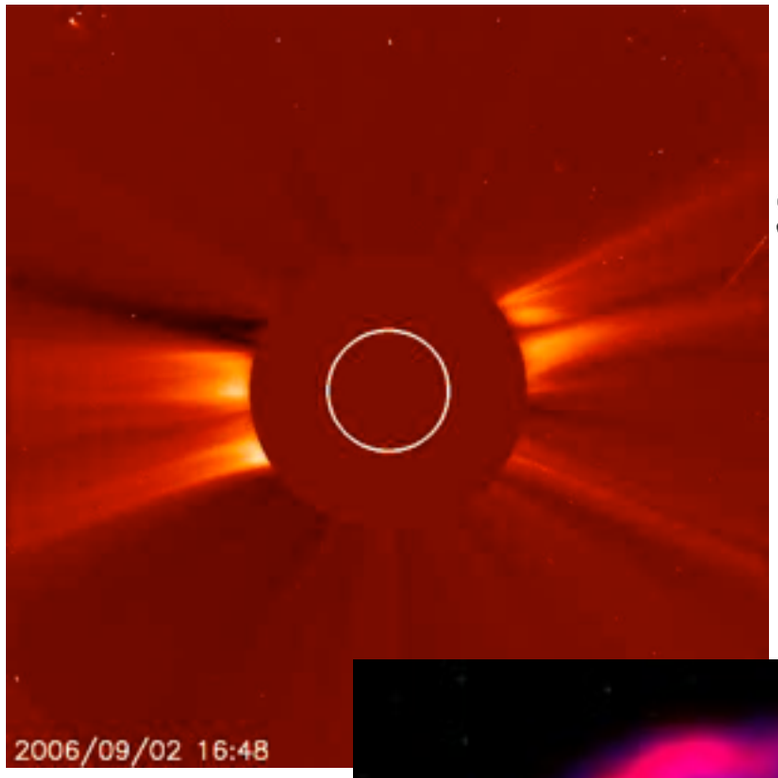

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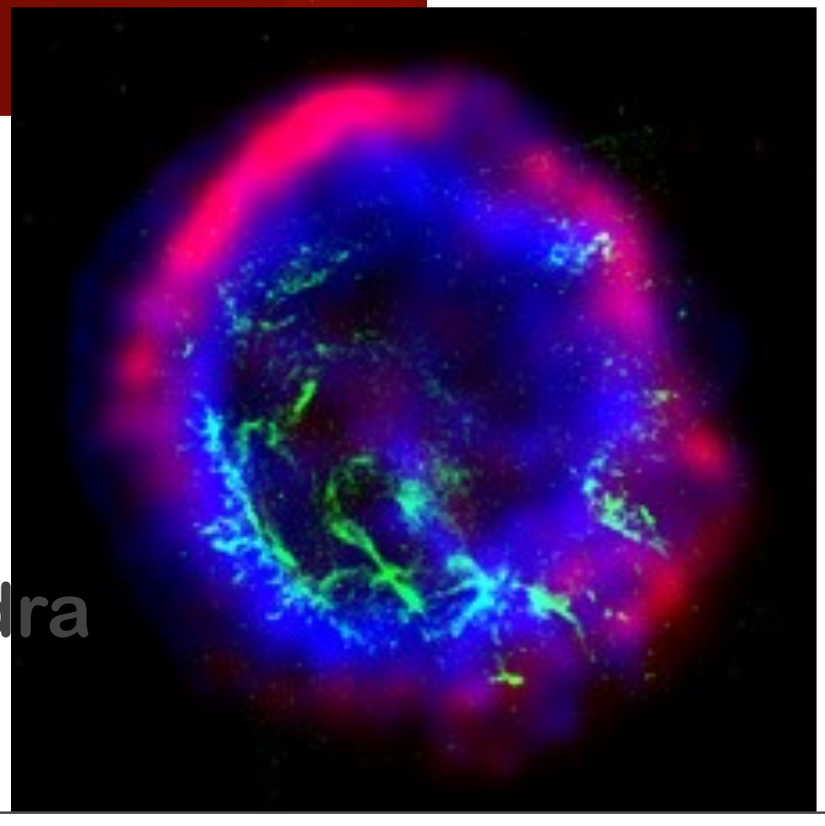

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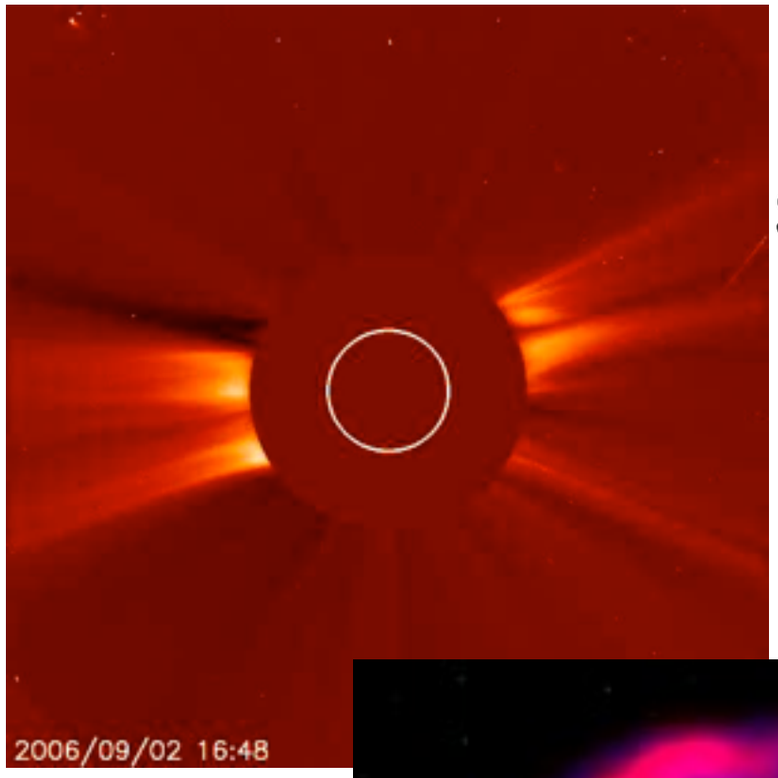

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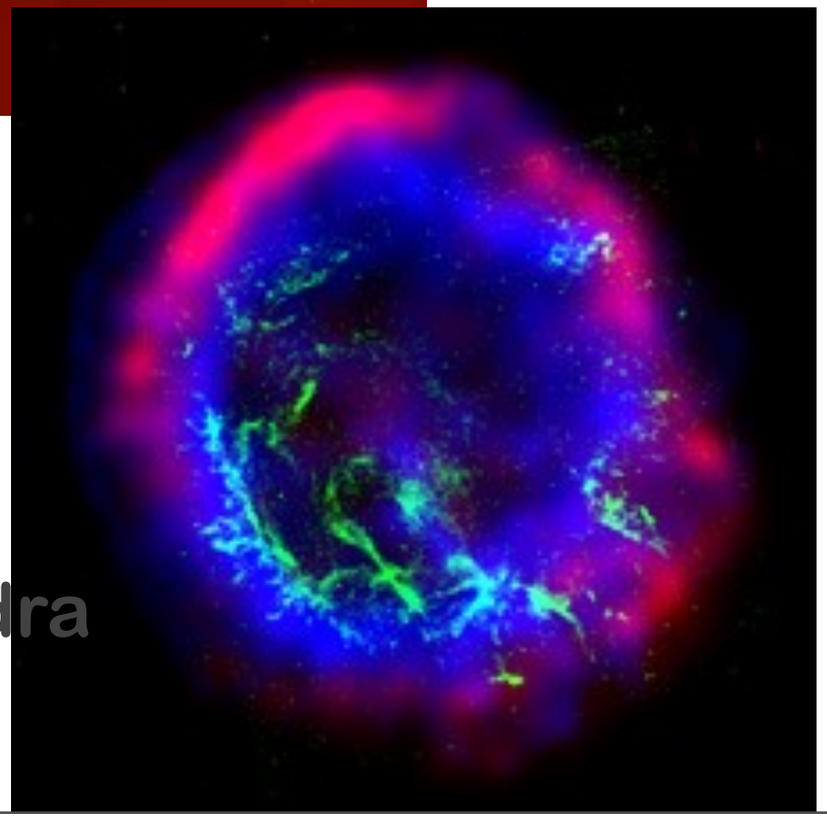

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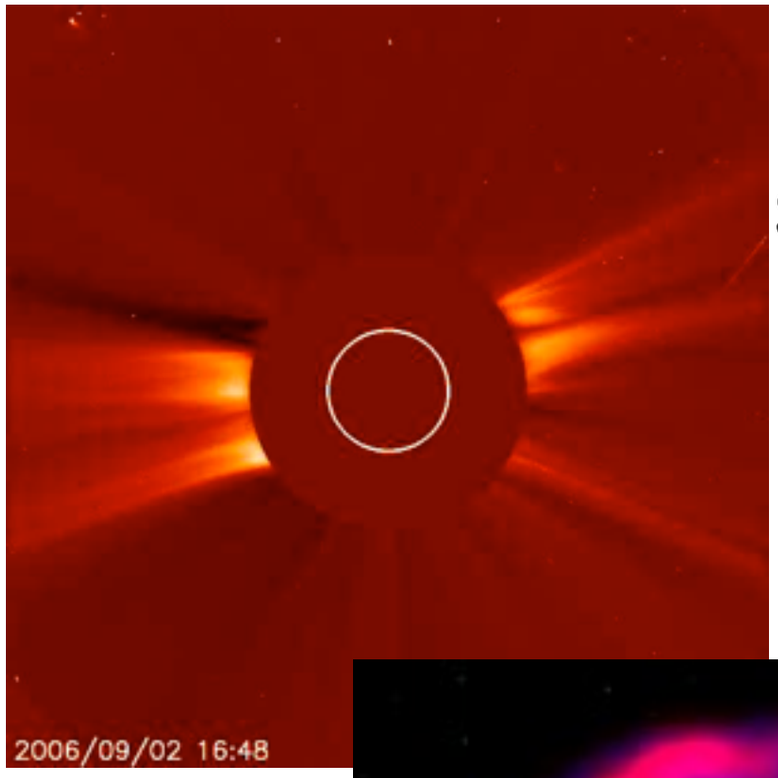

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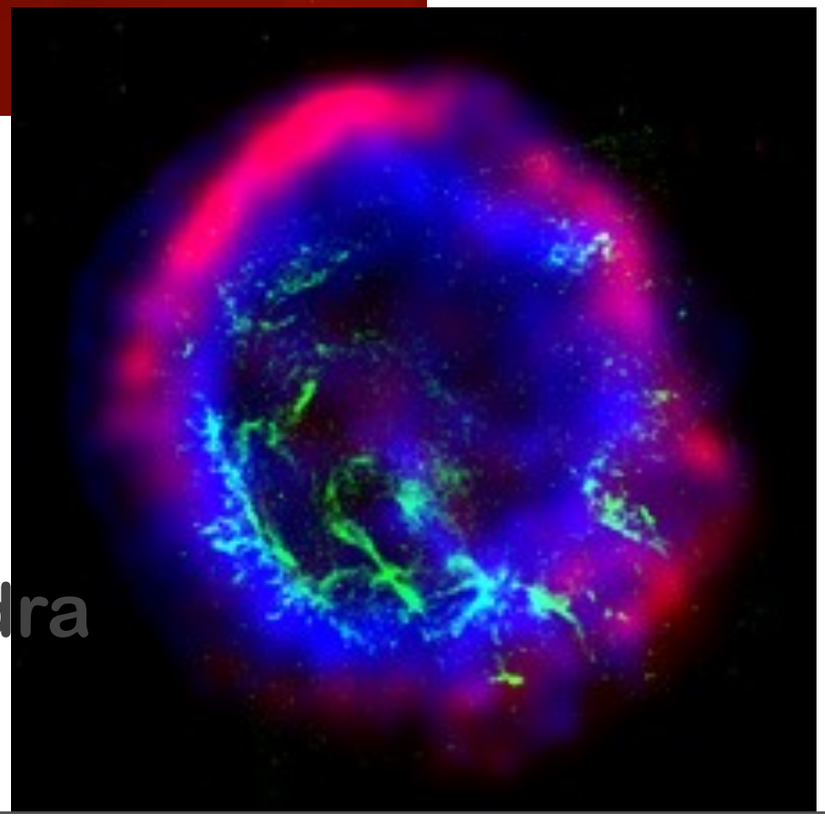
✓ Live radioactive elements, with half-lives << age of Earth

Will decay after a few half-lives

No leftovers today if any on early Earth

If found, must come from SN!



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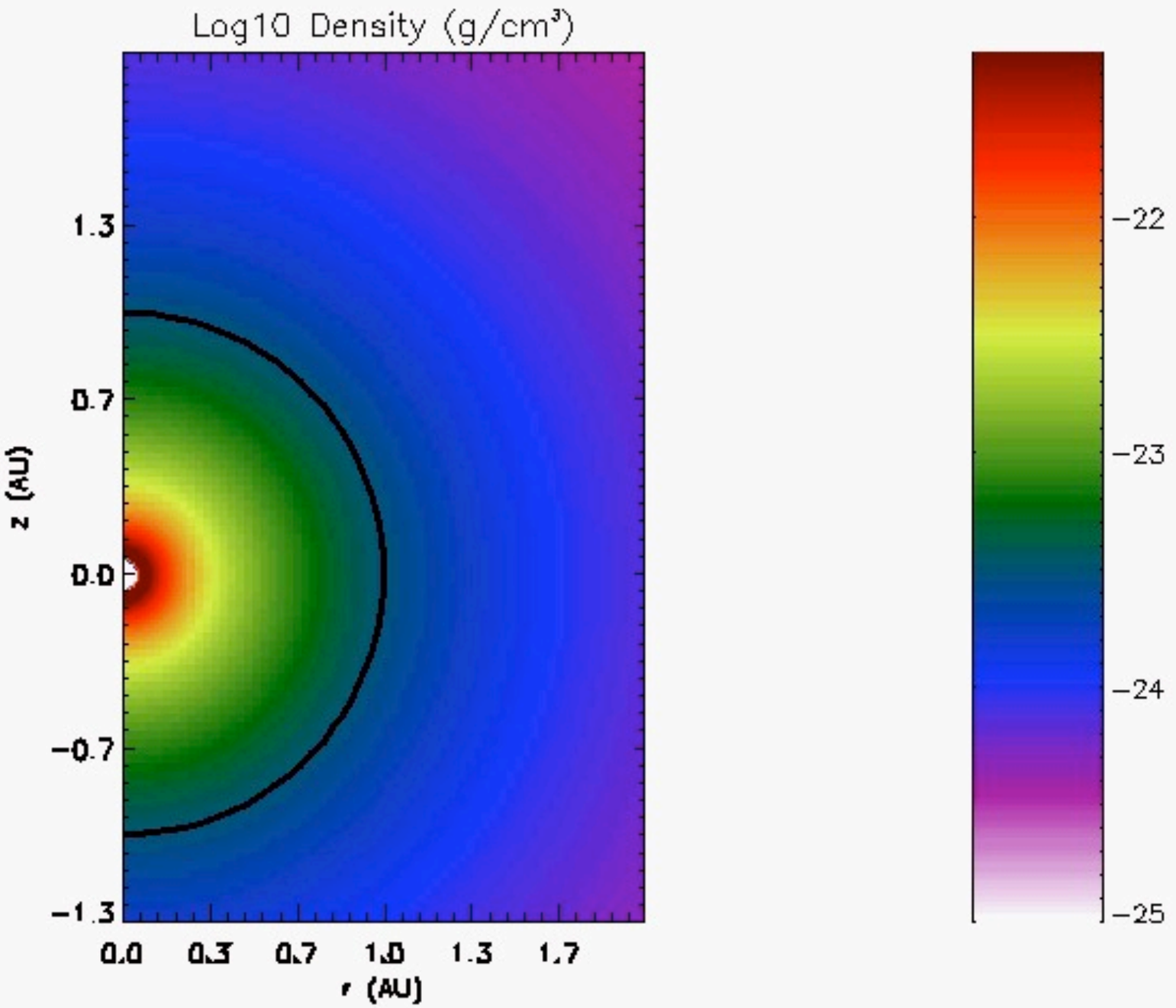

time = 0.000 ps
number of blocks = 240
AMR levels = 3

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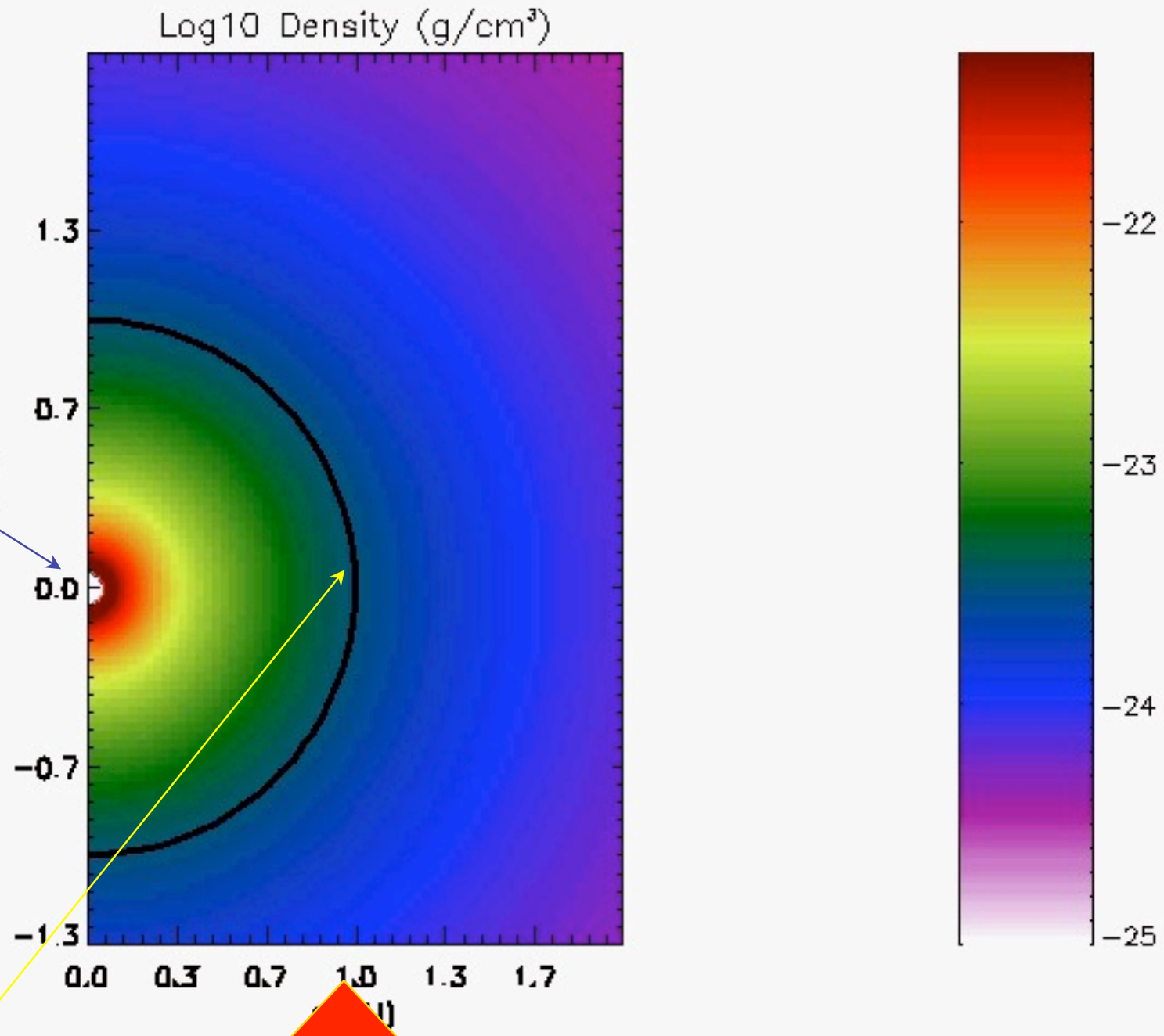

Sun

1 AU = Earth's orbit

Incoming blast

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formed by slowly growing layers, mostly made of iron and manganese

layers like tree rings: deeper = older

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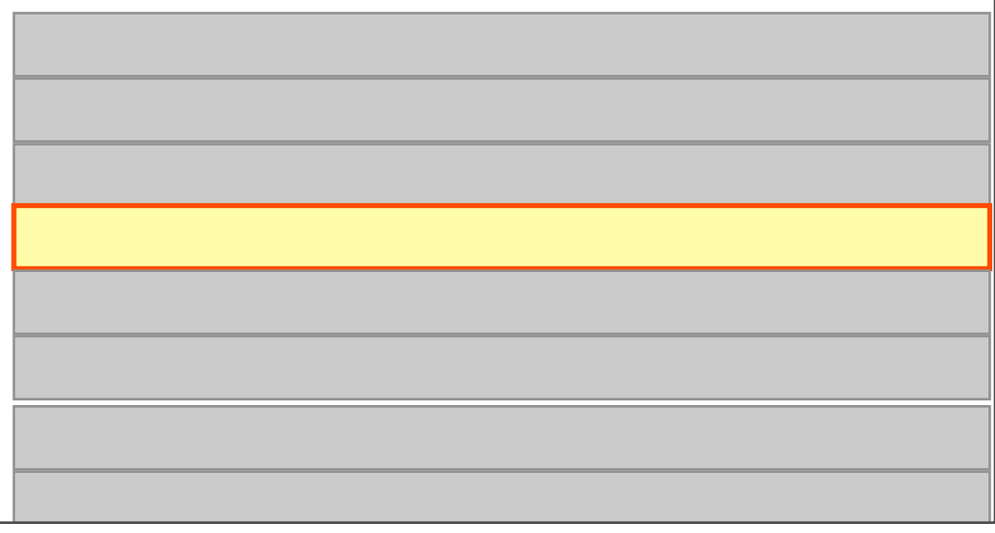

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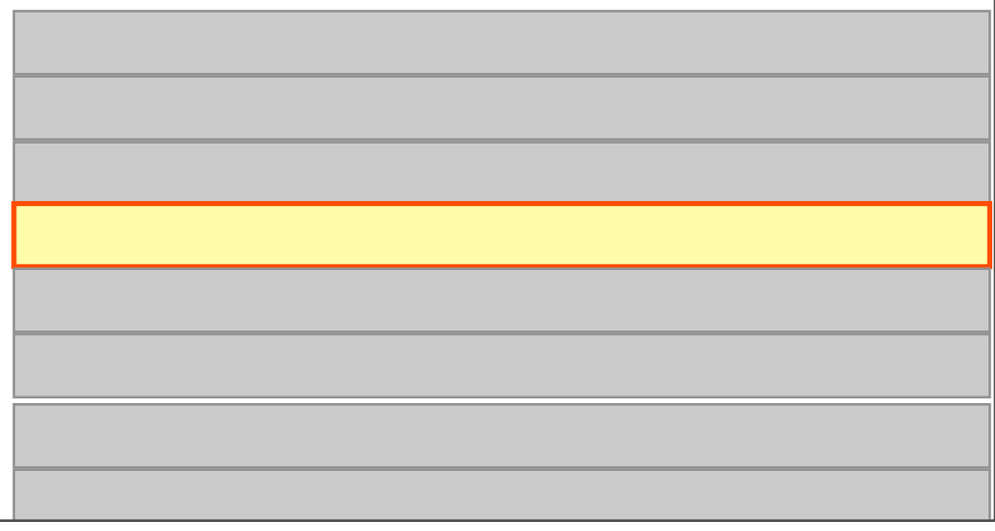

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✓Better geometry (planar)

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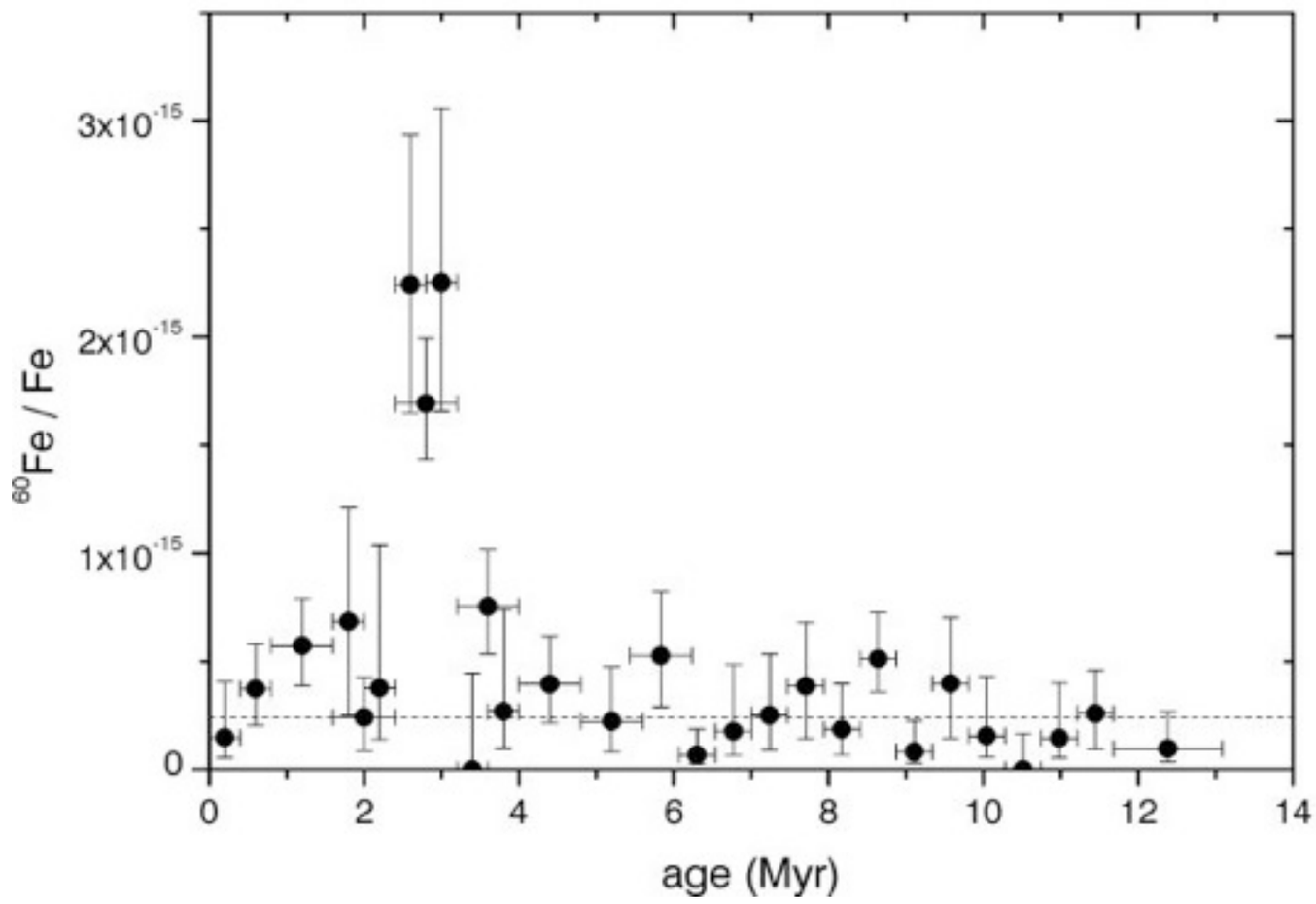

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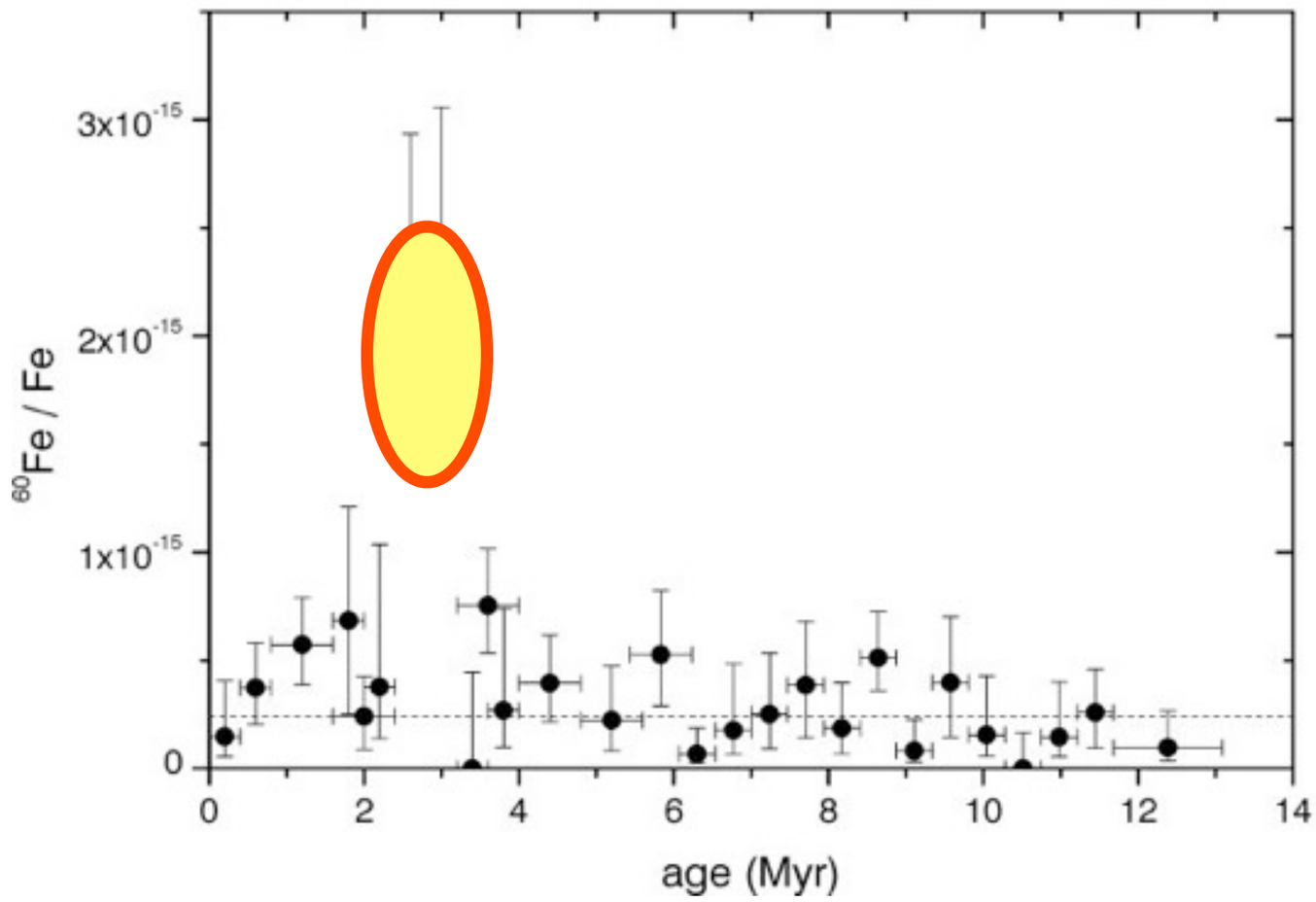

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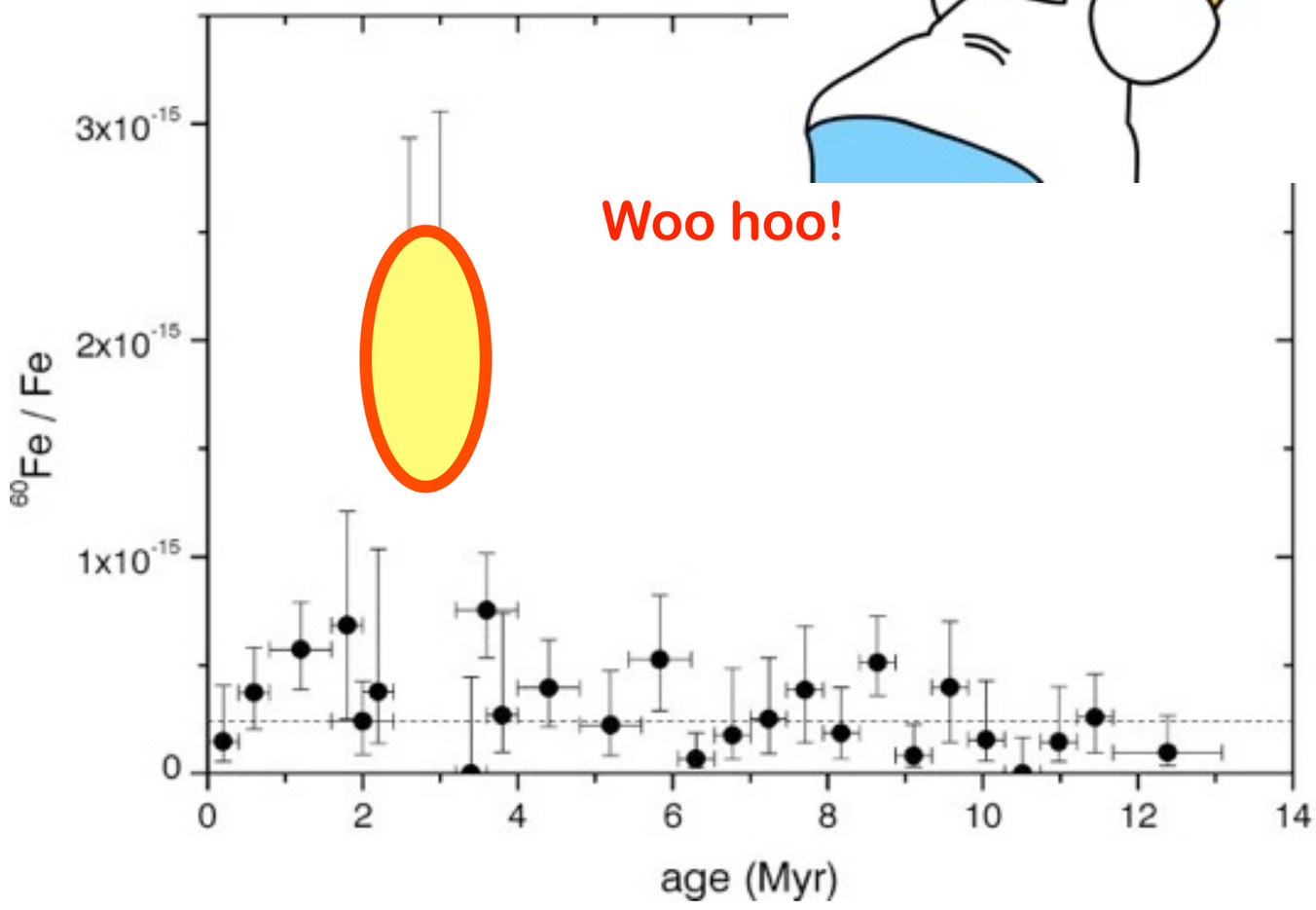

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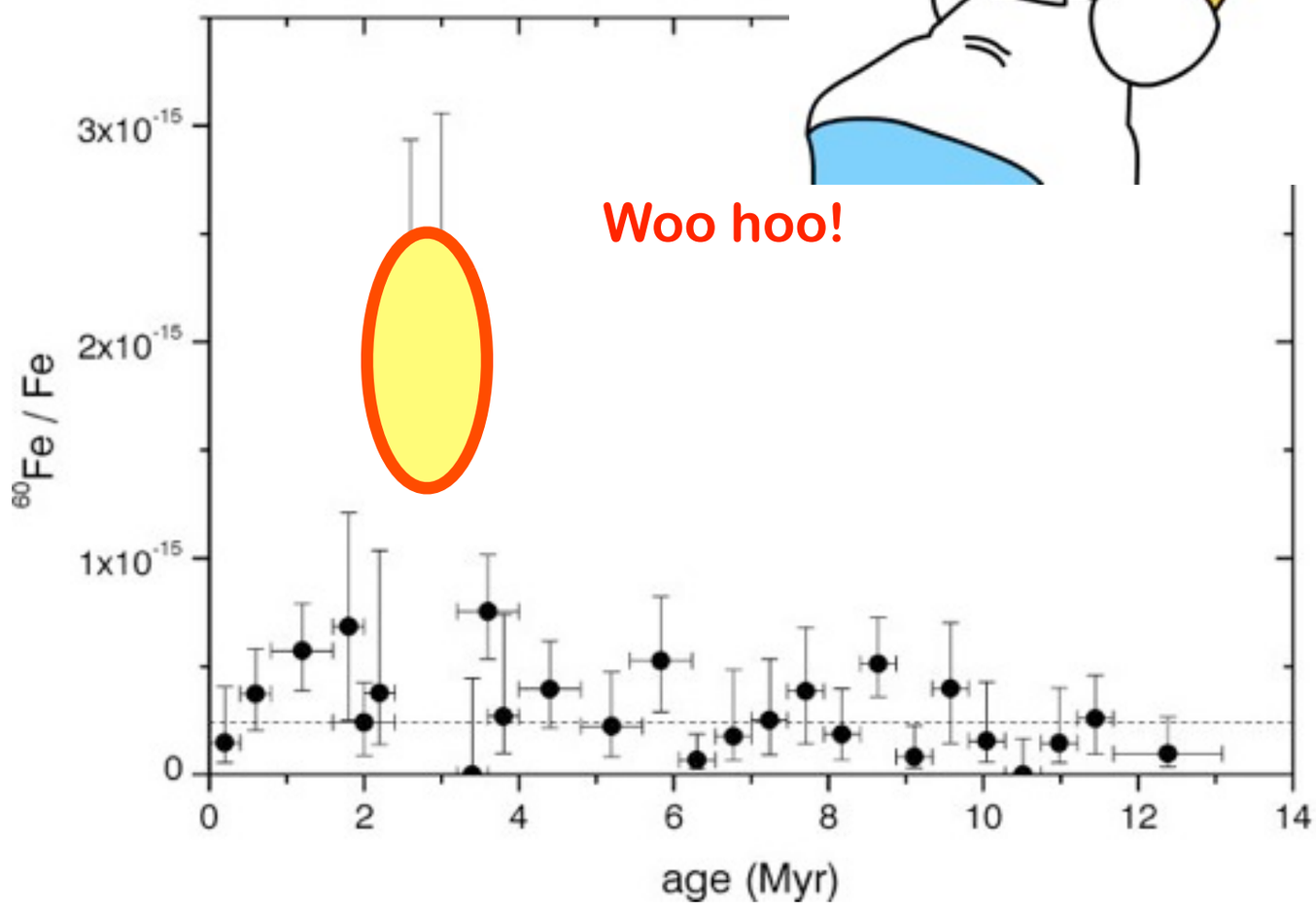

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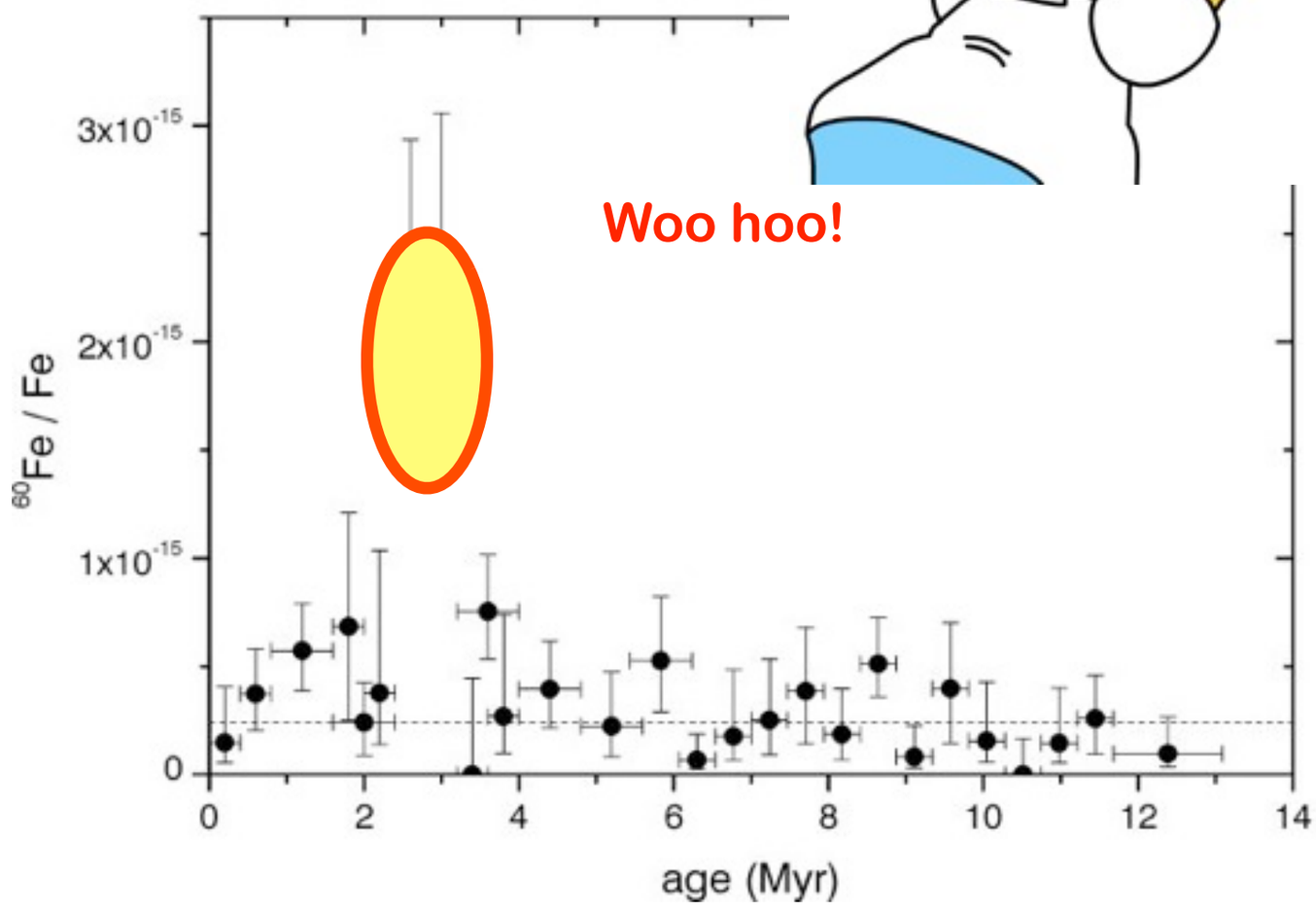

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How far away was it?

Live radioactive iron tells us about the nearby supernova

When?

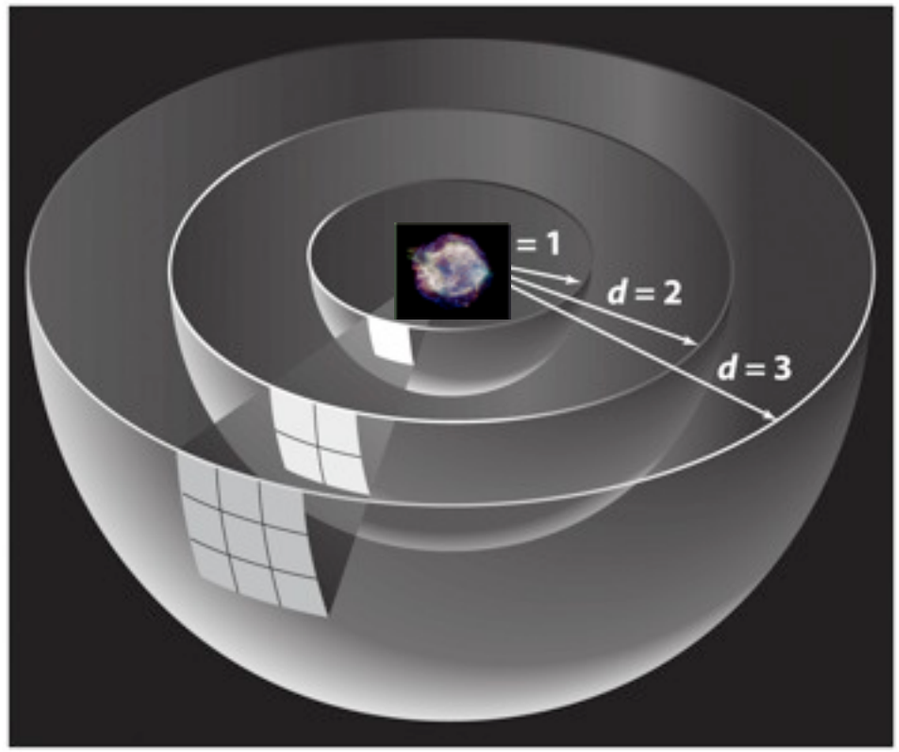
- iron not decayed: had to be within last few million years (half-life)
- from layering of rock: 2-3 million years ago

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 20 to 100 pc away



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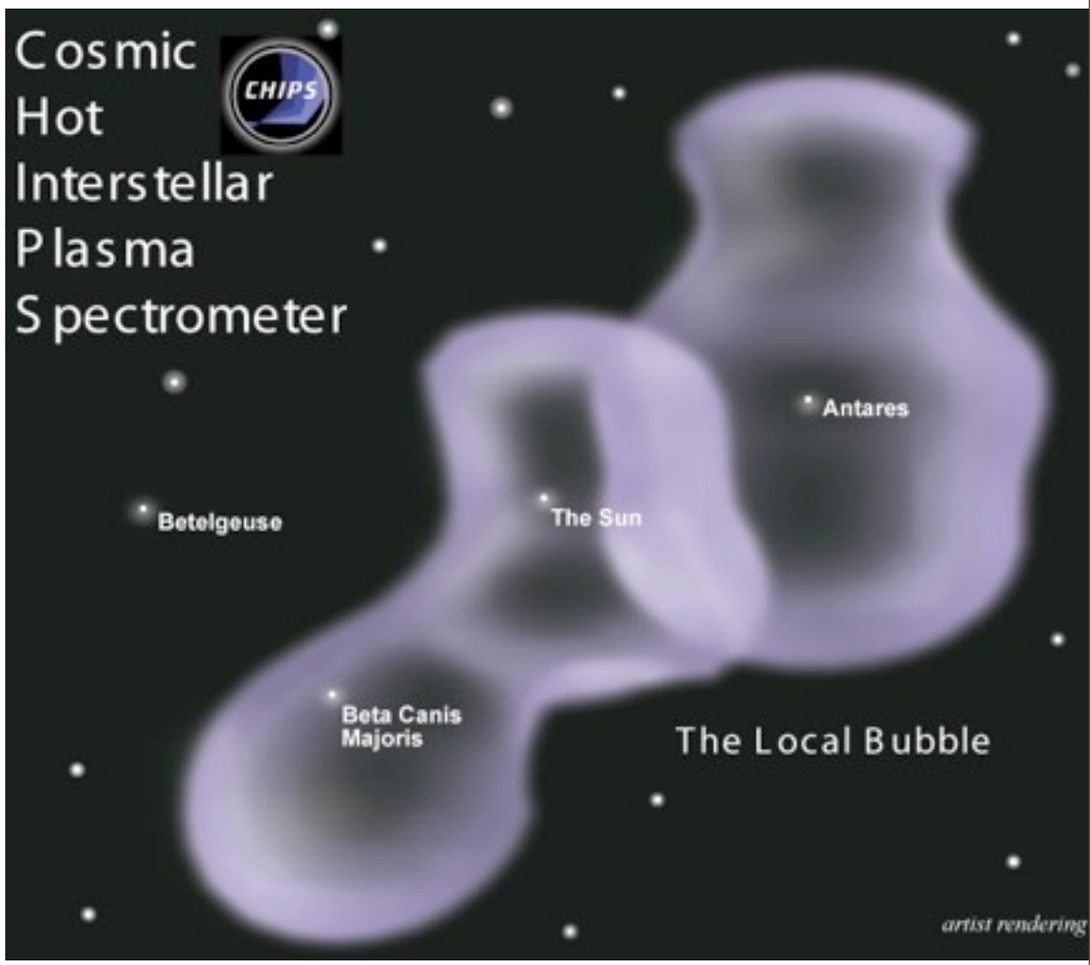

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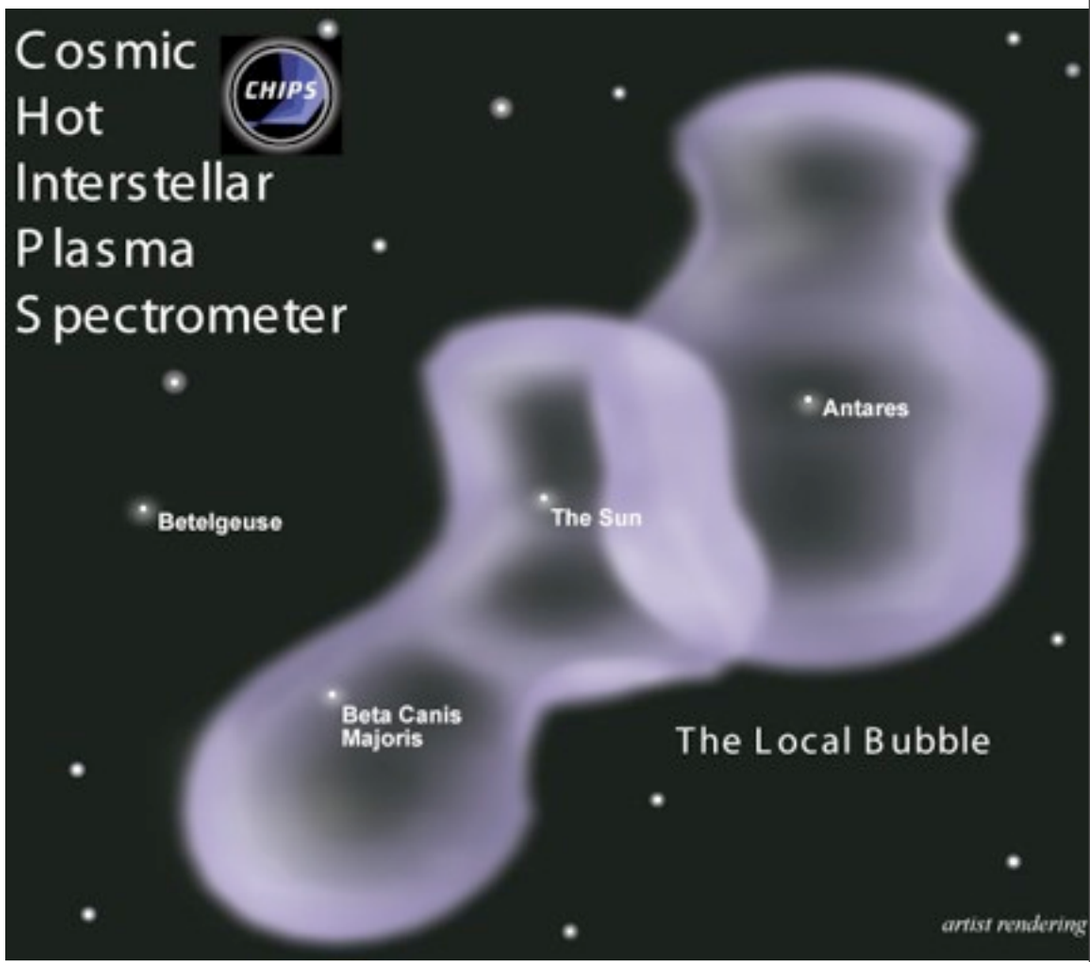

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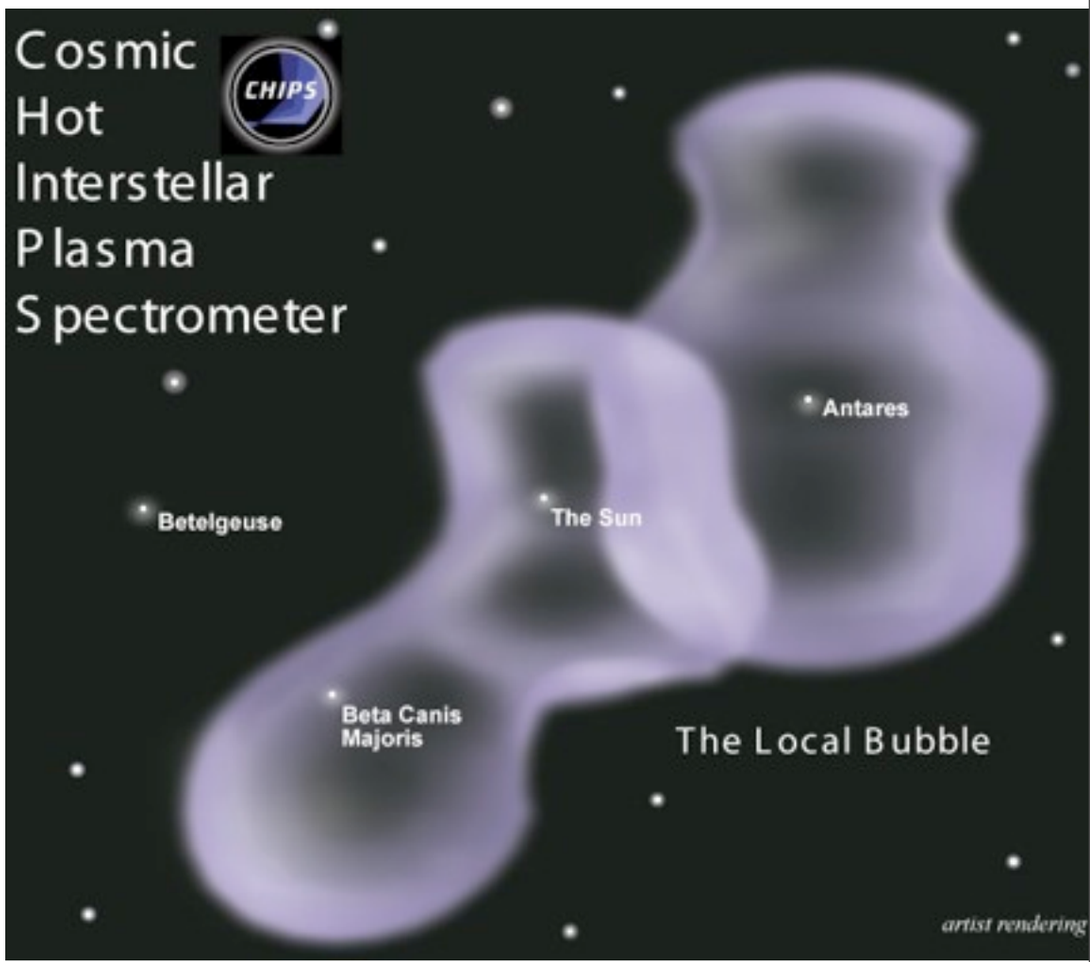

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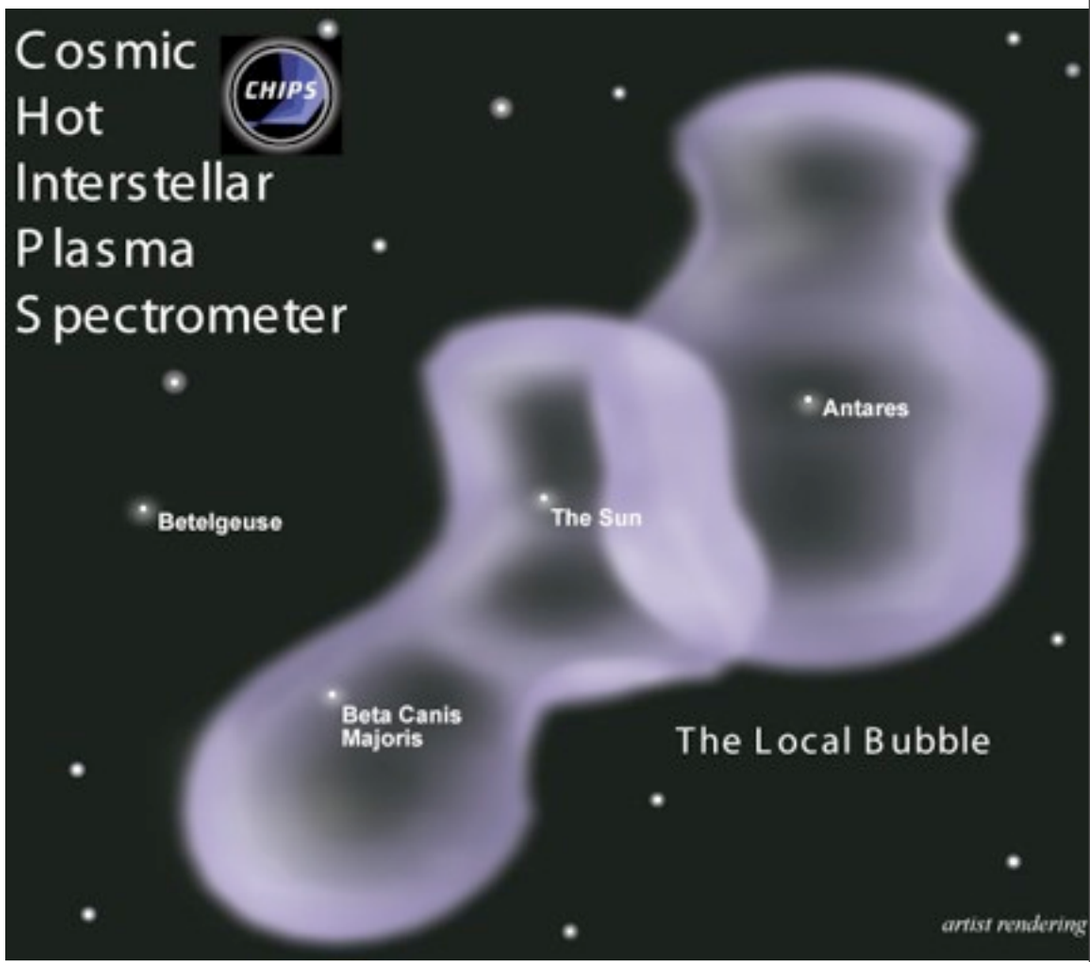

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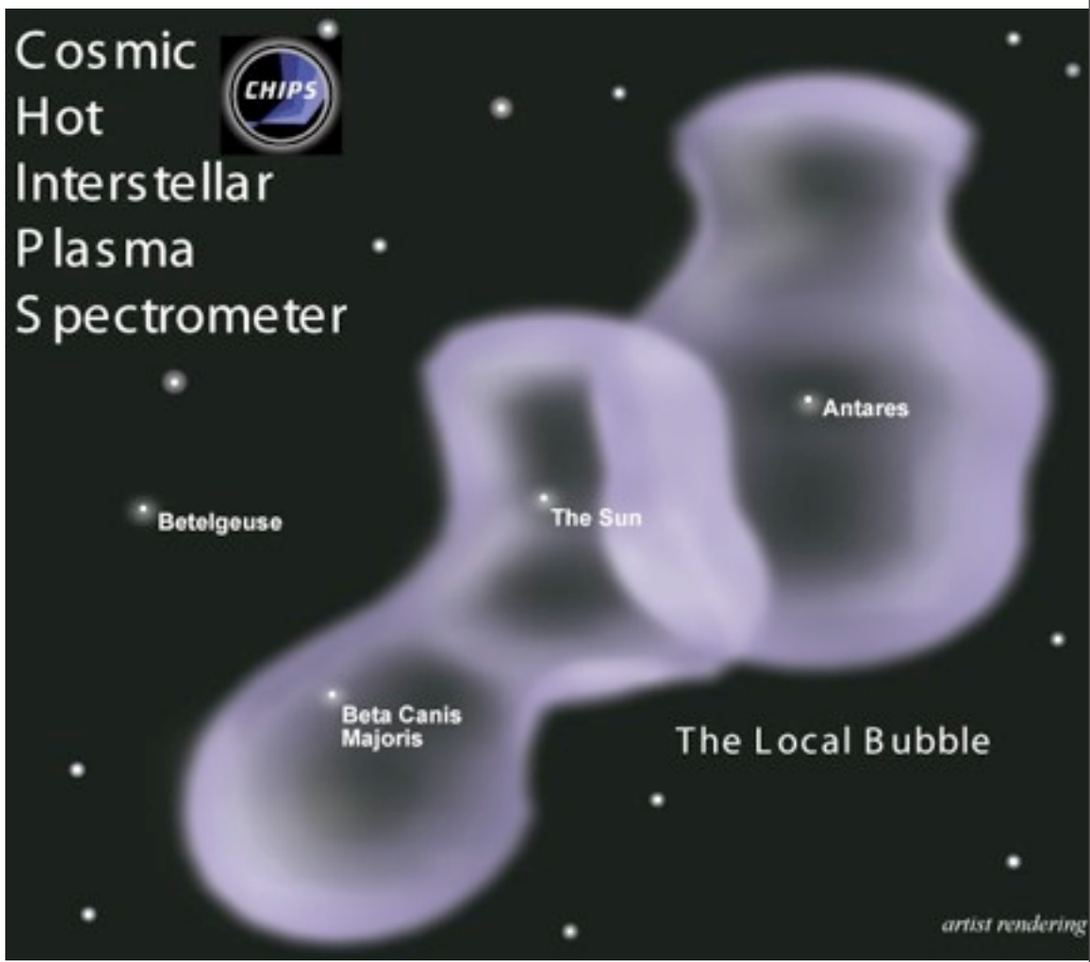

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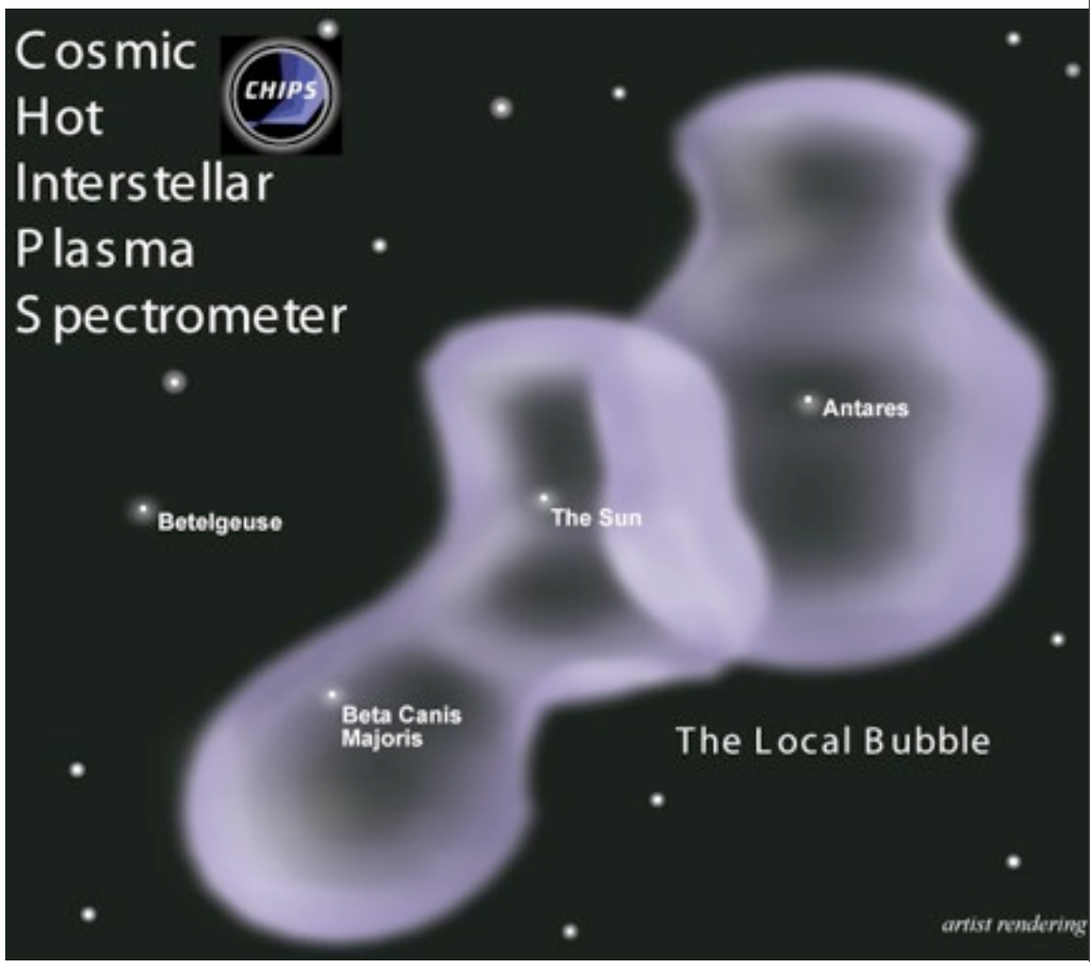

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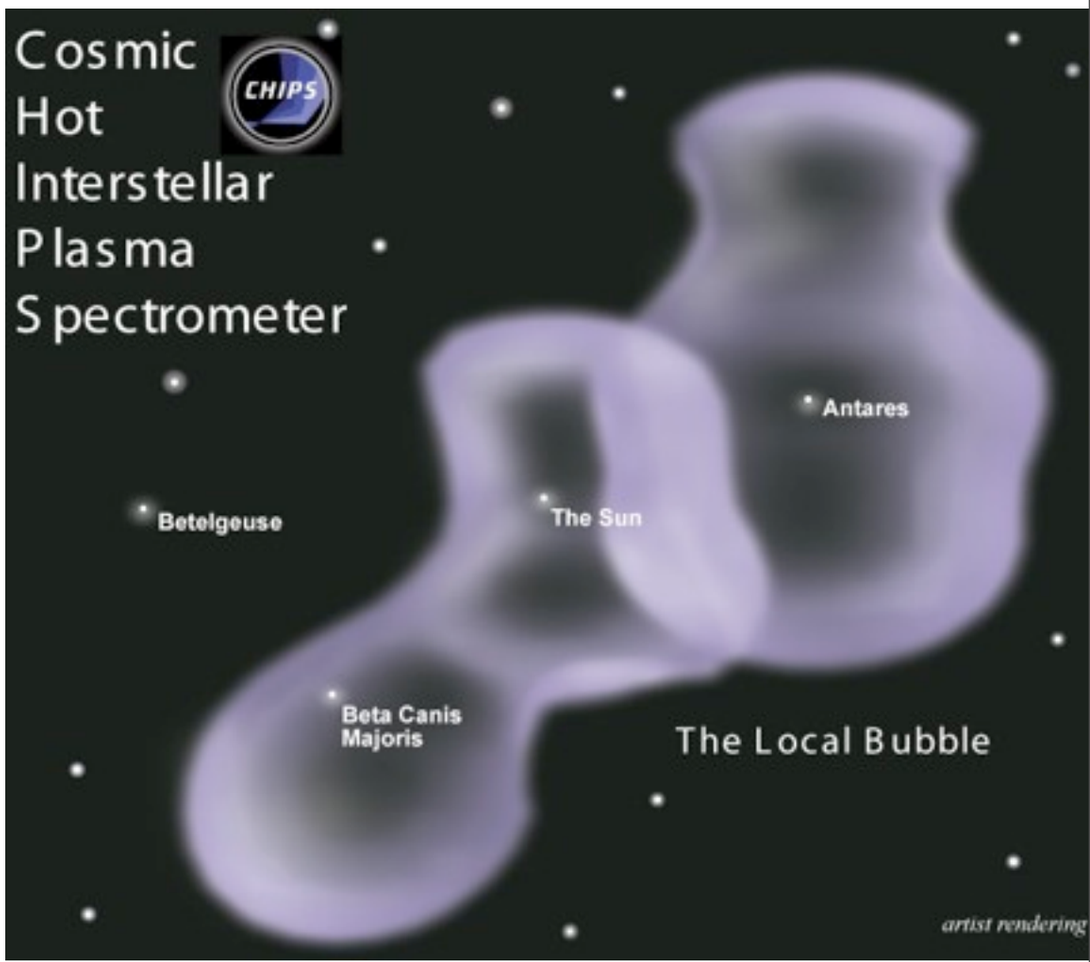

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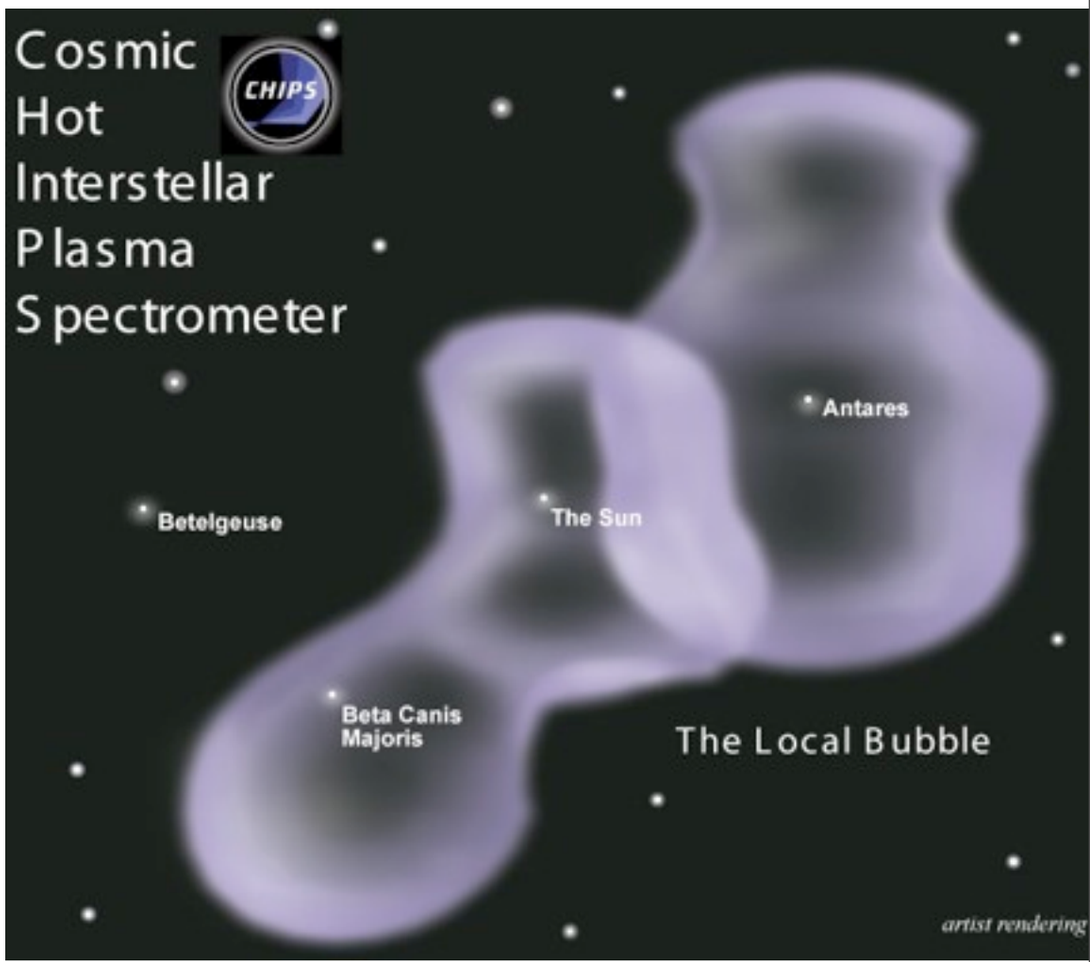

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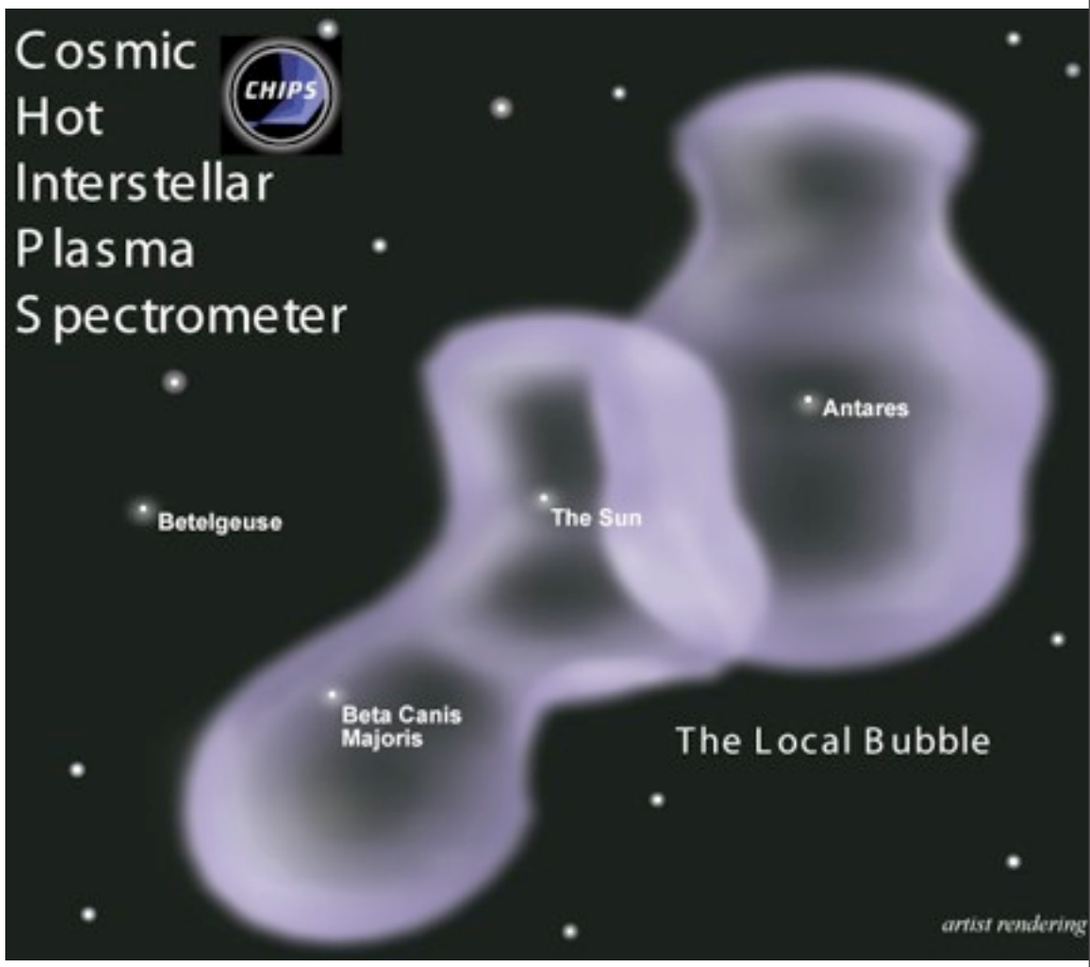

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- ^{60}Fe event from nearest massive star cluster? Benitez et al 00

Other Signals?

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- **Lunar Soil**
  - consistency check for deep-ocean signal
  - if supernova can put debris on Earth, should also put debris on Moon (and elsewhere in solar system)
  - but: have to worry about radioactivity created by cosmic ray bombardment of lunar surface

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Alan Bean, Apollo 12 (1969)

A Near Miss?

$d > d_{\text{kill}} \sim 10$ pc...but barely: "near miss"

¿ cosmic ray winter?

¿ bump in extinctions?

If true:

possible effects on prehistoric environment and maybe human evolution?

Image: Mark Garlick
www.markgarlick.com