Astronomy 150: Killer Skies
Lecture 22, March 12

Assignments:

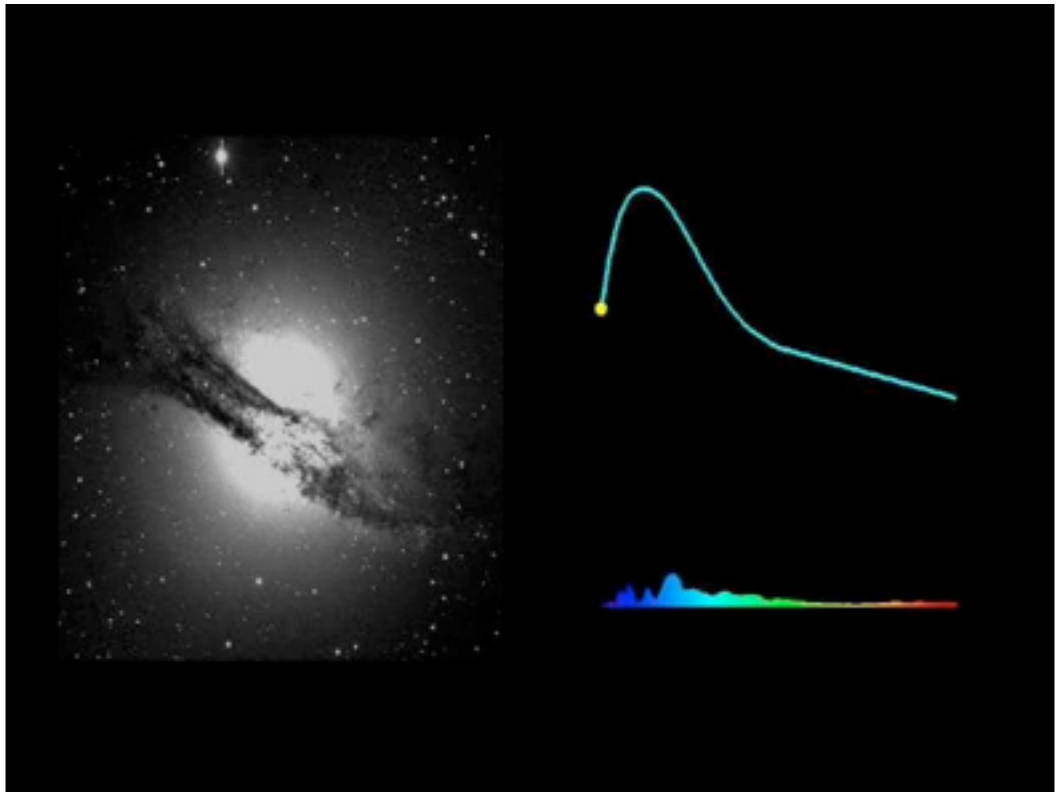
- HW7 due next Friday at start of class
- Night Observing

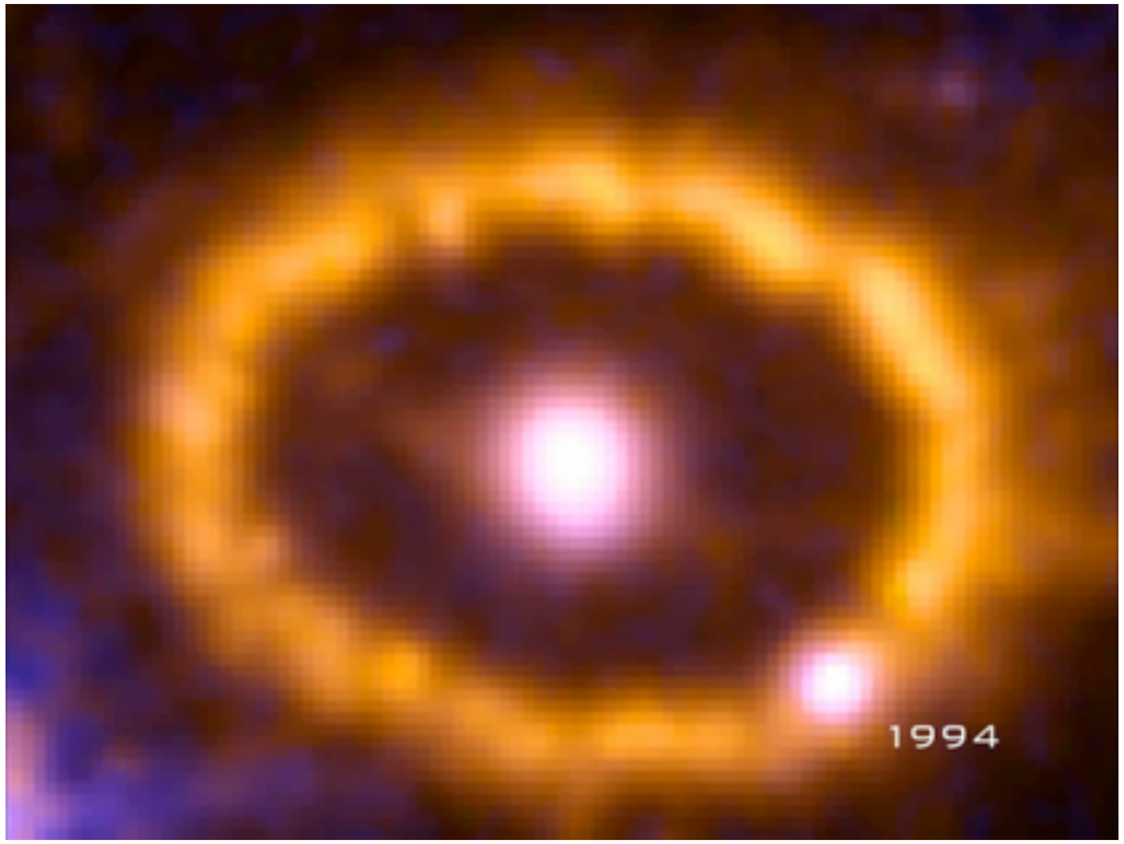
  report also due on or before Friday

  last-chance extra session: 8-9 pm Tuesday, weather permitting

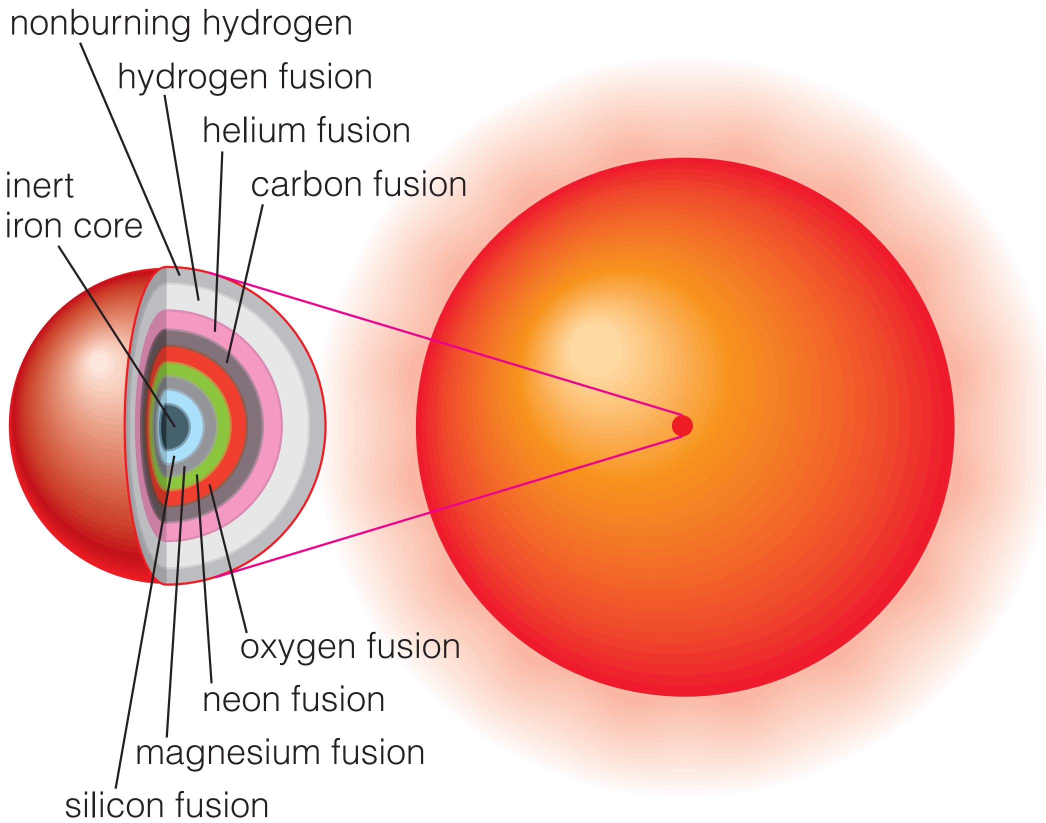
Last time: Stellar Evolution

Today: Supernova Explosions



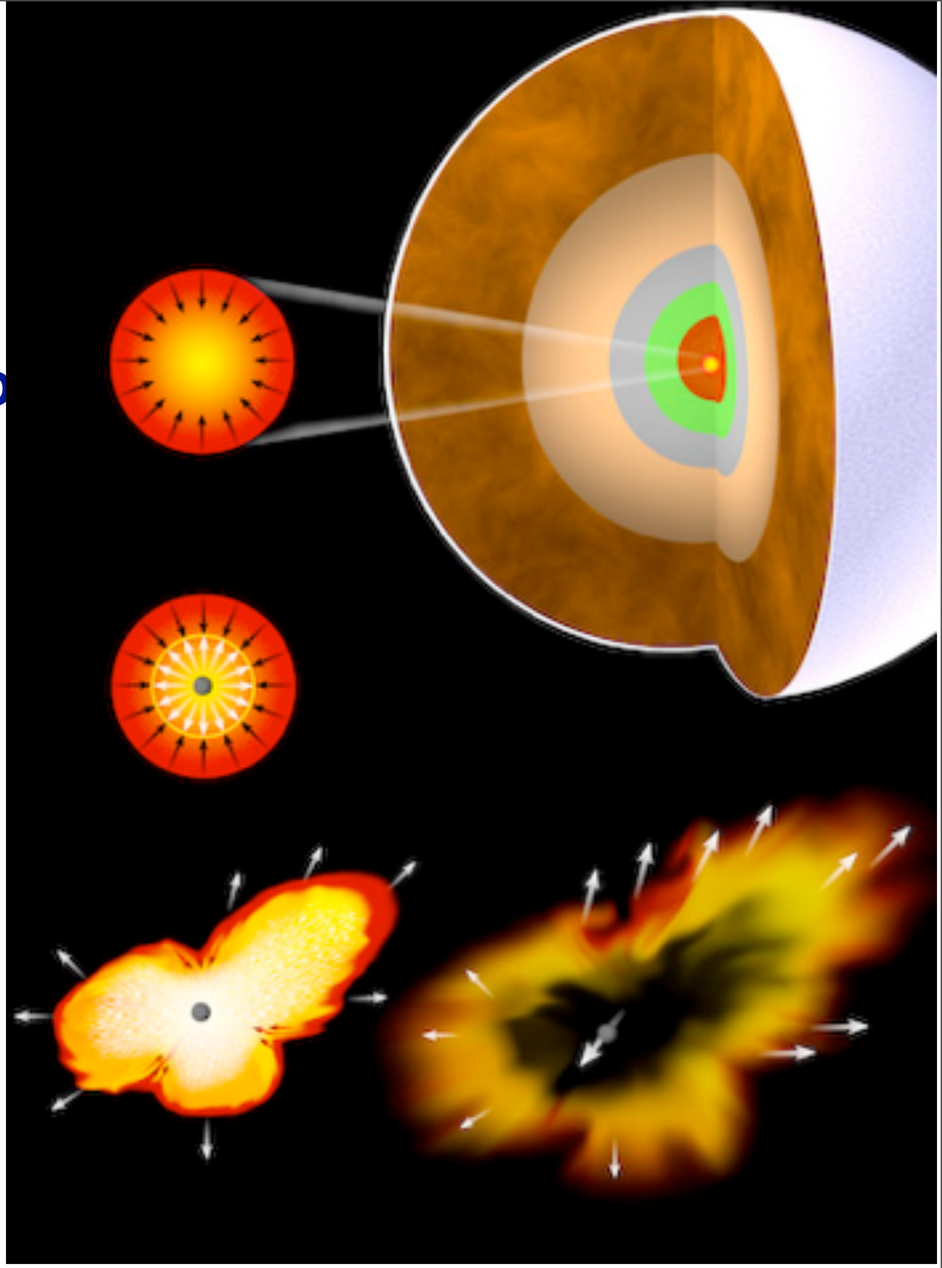


Last Time:
Massive Star Life & Death



When iron core too massive:

- unstable
- core collapses under its own gravity
- compresssed to ultradense solid
- infalling gas layers rebound violently



Massive stars:

- burning phases ever hotter,
- ever faster,
- making ever heavier elements
- until iron...

Result: Supernova explosion

plural: supernovae (Latin!)

- most (>90%) of star mass ejected into space
- ultradense central object remains

Supernova Explosions in Recorded History

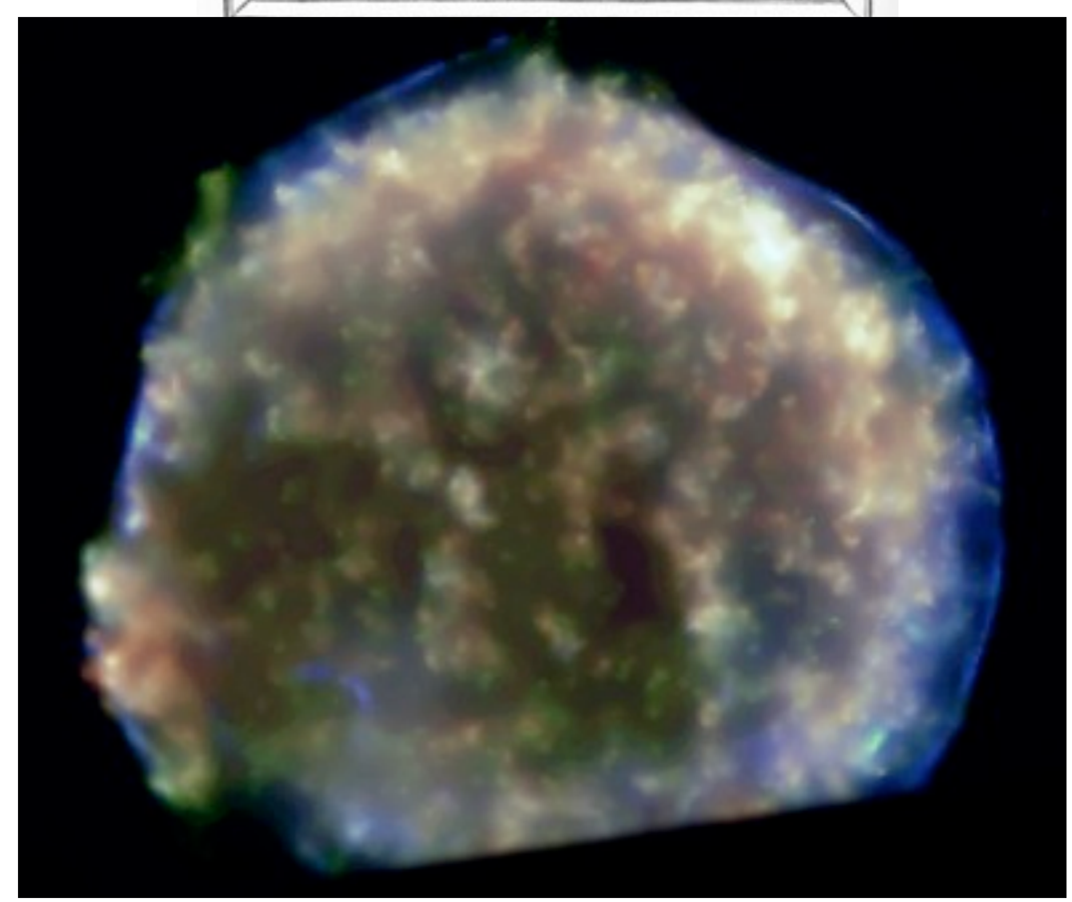
November 11, 1572

Tycho Brahe

A “new star”
(“nova stella”)

Modern view (X-rays):

remains of a supernova explosion



November 11, 1572
Tycho Brahe

On the 11th day of November in the evening after sunset … I noticed that a new and unusual star, surpassing the other stars in brilliancy, was shining … and since I had, from boyhood, known all the stars of the heavens perfectly, it was quite evident to me that there had never been any star in that place of the sky …

I was so astonished of this sight … A miracle indeed, one that has never been previously seen before our time, in any age since the beginning of the world.

What did Tycho get right?

Where was he wrong?

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

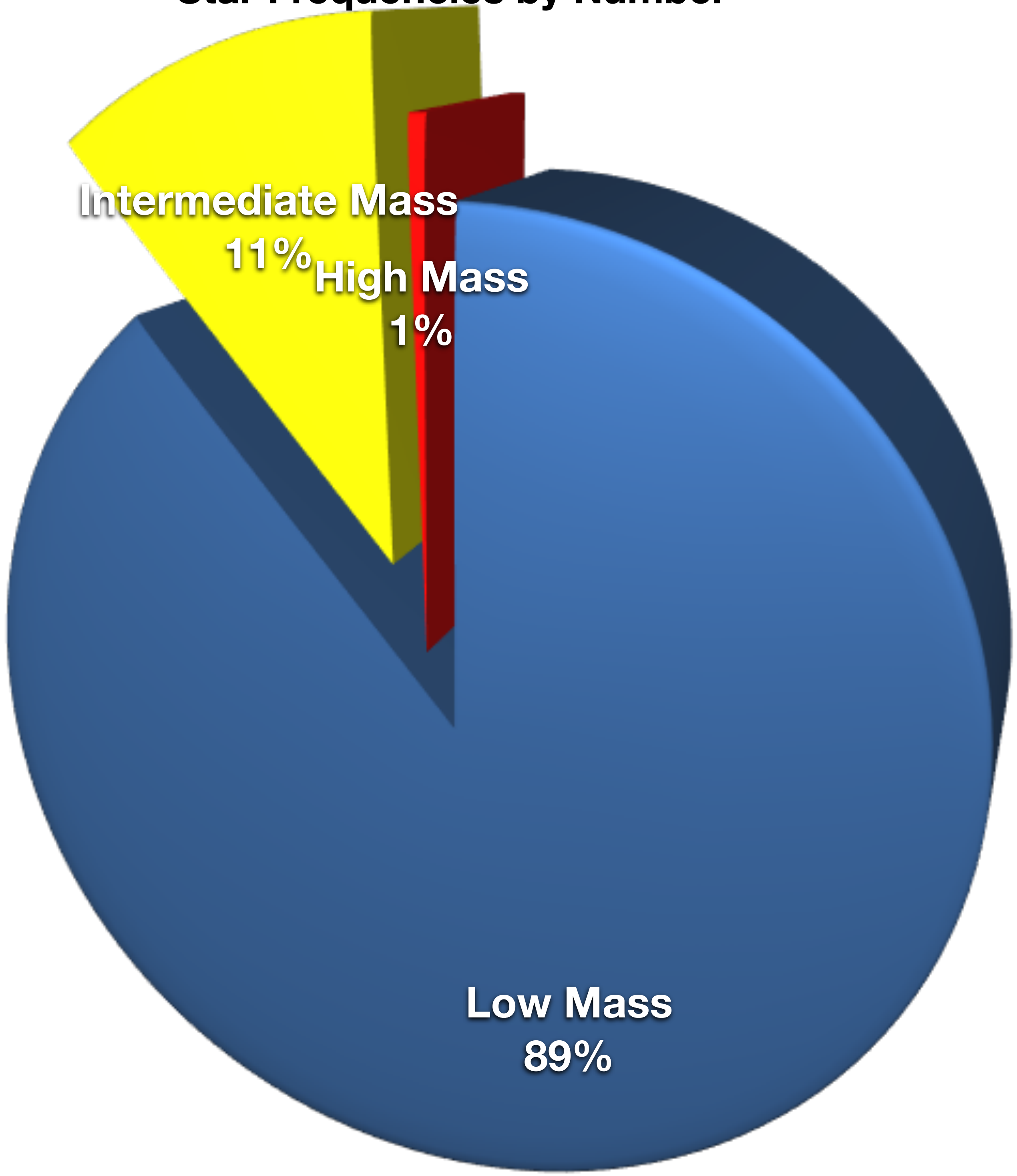
- and most stars are not massive!

A Census of Stars

in a fair sample of stars:

low mass much more common than high mass

- more low mass stars formed in stellar nurseries
- low mass stars live longer once born
- < 1% of stars are massive, become supernovae
- but since so massive, represent 10% of all mass in stars



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

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!

Q: so how do we see them?

Supernova Detection

Supernova explosions are random

So finding them involves luck

Strategy I: Patience

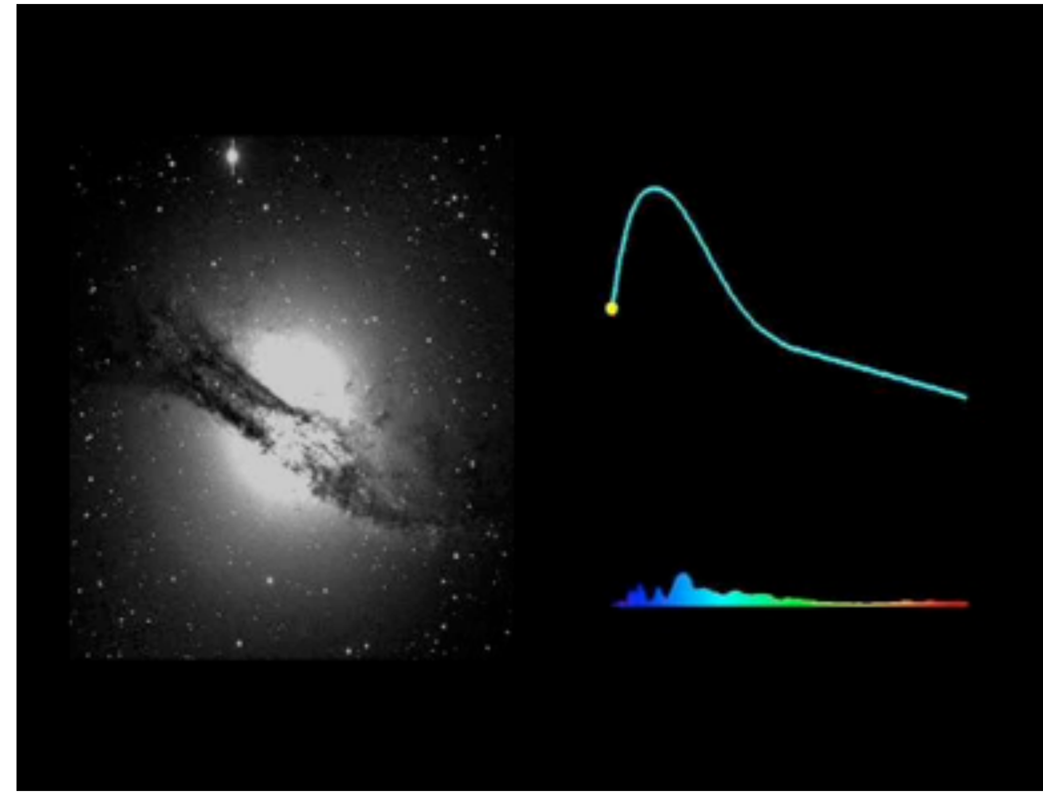
- wait.
- if few events per century per galaxy
- then if watch one galaxy, expect explosions about every few decades
- to date: about 5000 supernovae seen in all galaxies in 1000 years of recorded history
- but: if monitor 100 galaxies, expect few events per year, so...

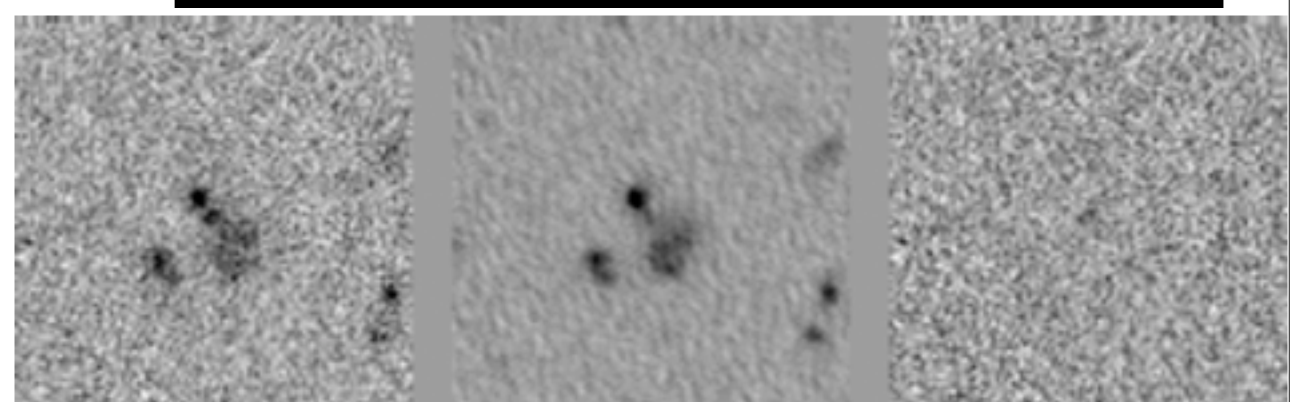
Strategy II: Overwhelming telescope power

- digitally monitor huge numbers of galaxies
- subtract old images from new ones, find difference
- automatically discover many supernovae!

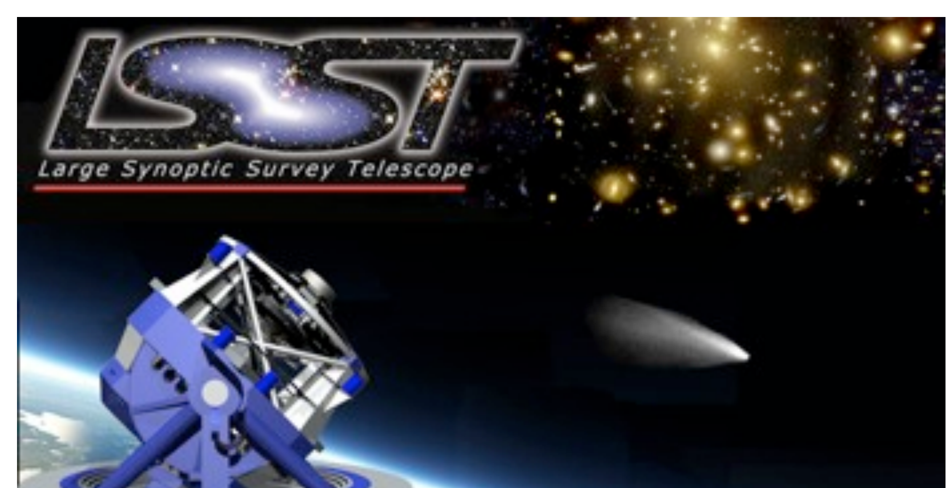
Large Synoptic Survey Telescope (LSST)

- new telescope, being built now
- operational in 2018 or 2019
- can scan entire sky in 3 nights
- repeated scans: movie of sky
- will monitor galaxies over much of observable universe
- will discover nearly 1 million supernovae per year!
- Illinois will play a key role!





SN Legacy Survey ~4 month scan



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 next...

Supernova Blast

Supernova ejects >90% of star's mass

Ejecta are

- hot
- fast -- initially move up to 10% speed of light!
- enriched with products of nuclear fusion before and during explosion
  - a "blizzard" of nuclear reactions produces:
  - heavy elements: lots of oxygen (O), silicon (Si), iron (Fe),
  - and probably all the way to the very heaviest elements

most of the elements in the periodic table (i.e., most of the diversity of the elements) originate in supernova explosions

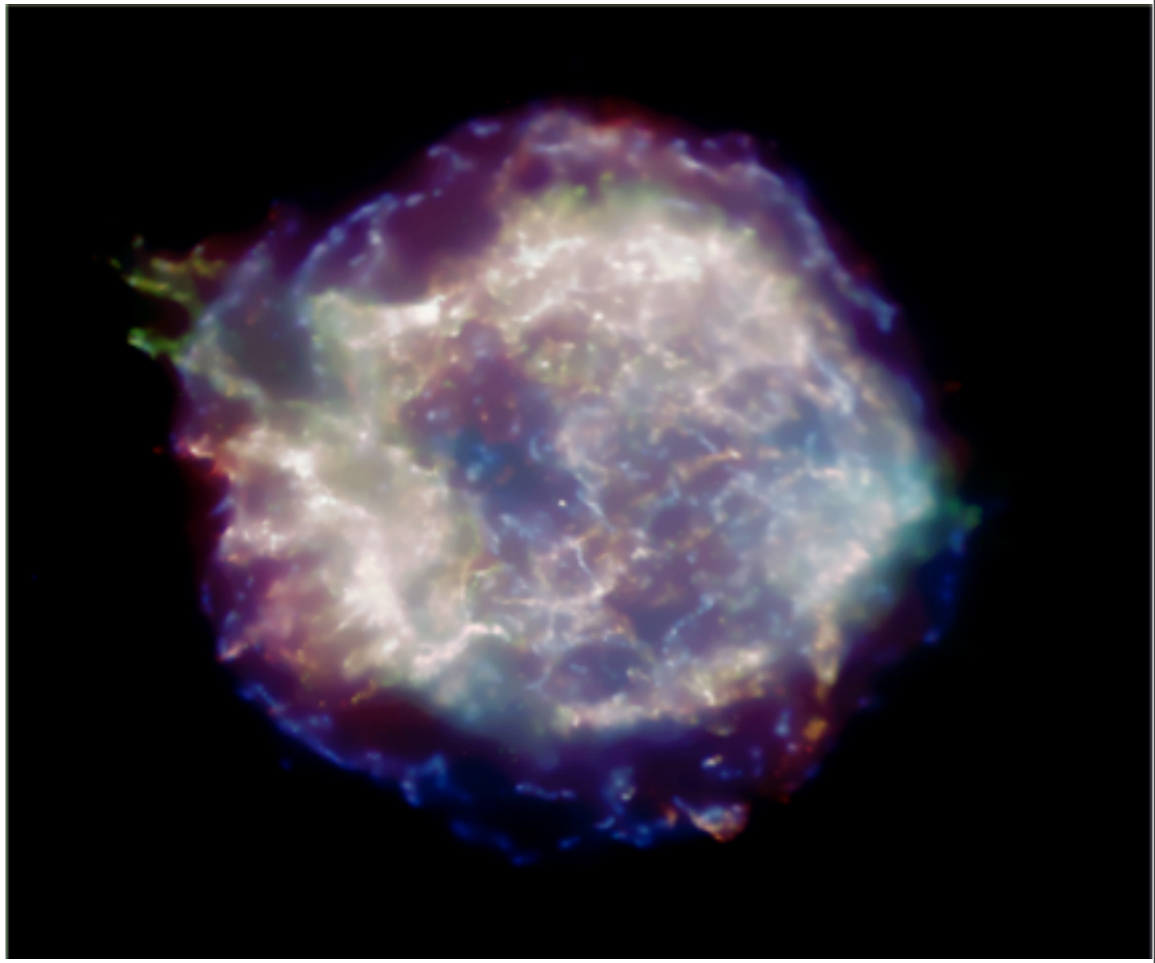
- we are made atoms once in exploding stars!

new elements (new nuclei) can only be made in nuclear reactions

- these don't happen naturally on Earth, so
- all elements were made elsewhere in the cosmos!
  - http://www.youtube.com/watch?v=9DO5ej8u-gU&feature=player_embedded#!

Nucleosynthesis: study of how and where the elements were made

- low-mass stars are source of C (carbon, from helium burning!)
- Supernovae are source of O, Si, Fe ...



X-ray Image of Supernova
different colors = different heavy elements

Ashes of Nuclear Furnaces

Most nuclear reactions in stars produce healthy, stable atoms

But…

Some unstable, radioactive atoms are always produced

- then decay after a certain time

For example:

- The solar system was born 4.5 billion years ago with traces of radioactivity
- Today, our Galaxy contains a small amount of radioactivity

…which c
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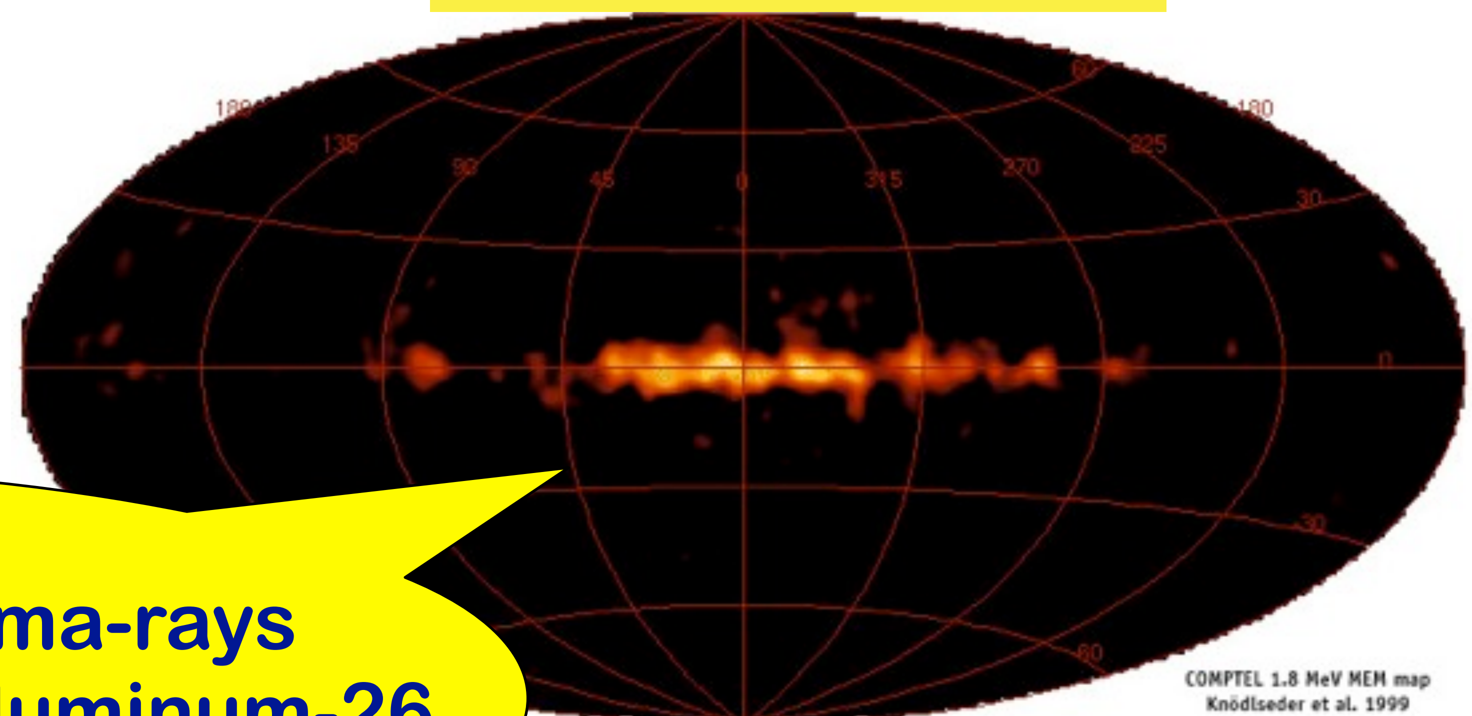


The radioactive sky: gamma-rays from decays of unstable aluminum-26 atoms

iClicker Poll:
Supernova Neutrinos

We saw that the Sun is a confirmed source of neutrinos

in fact: a few percent of the Sun's luminosity (energy release) is in neutrinos rather than light

Now consider a massive star, exploding as a supernova and vote your conscience:

Which best describes a supernova's energy release?

A. $< 1\%$ of energy released in neutrinos, $> 99\%$ in light

B. $\approx 50\%$ of energy released in neutrinos, $\approx 50\%$ in light

C. $> 99\%$ of energy released in neutrinos, $< 1\%$ in light

Supernova Neutrinos

In supernova explosion, core compressed to tiny region

- huge density
- also huge temperature: $>10^9$ K!

particles in core have random motions with speeds near c!

- huge particle energies
- typical kinetic energy $> m_{electron}c^2$!

in this energetic environment, neutrinos produced abundantly

- much moreso than in the Sun
- also: supernova core so dense that even neutrinos interact in it
- scatter repeatedly before leaving core

theoretical predictions:

- huge burst of neutrinos created in explosion
- > 99% of supernova energy release is in neutrinos!
- scatterings in dense core → signal spread over several seconds

Q: how to test this prediction?

Supernova 1987A

Most recent supernova in our "neighborhood"

- Feb 24, 1987 (25 years ago!)
- supernova seen in nearby galaxy
  - Large Magellanic Cloud (LMC)
  - small satellite galaxy orbiting Milky Way

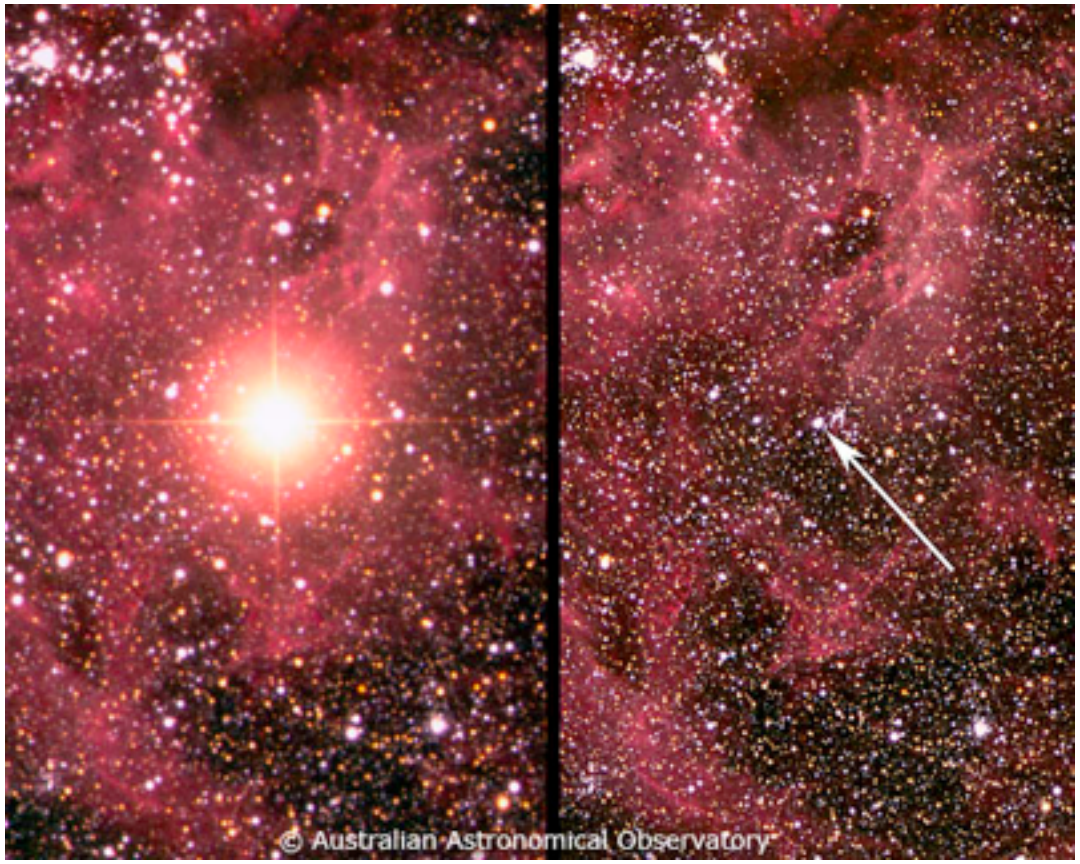
Outburst peaked in a week or so

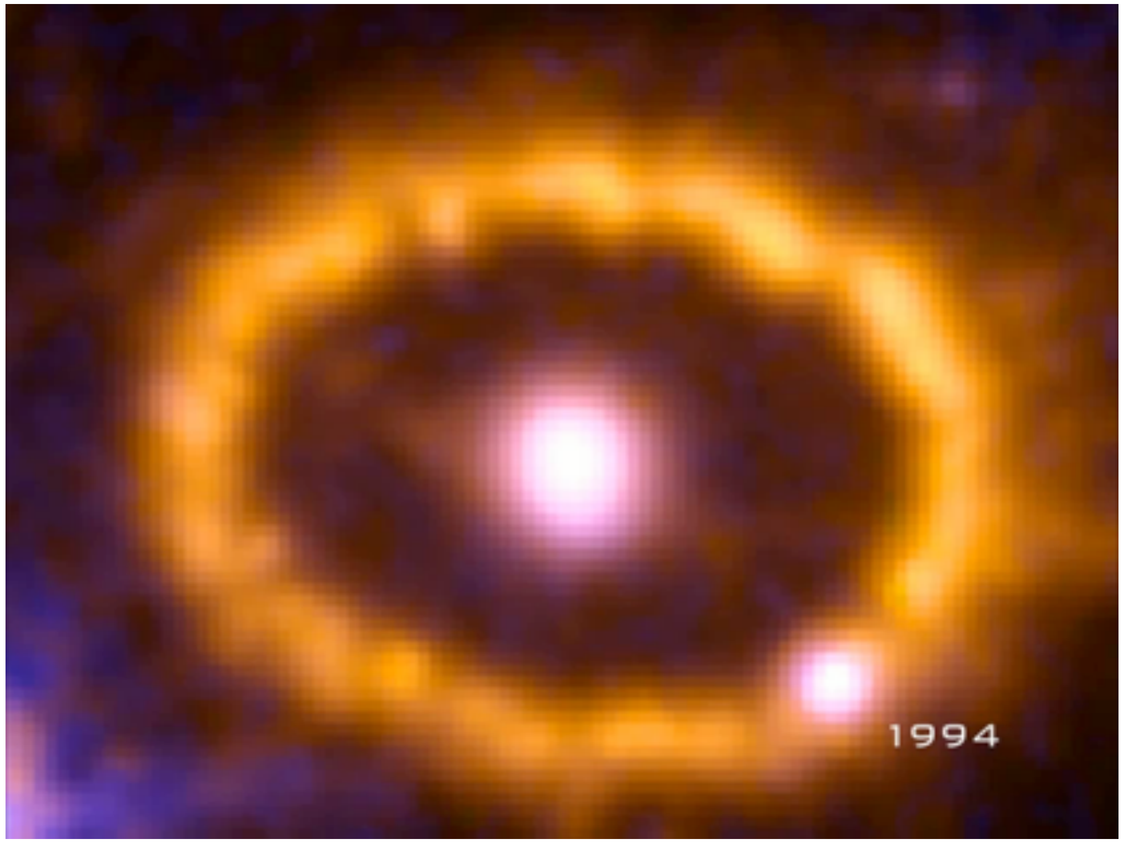
- dimmed over months
- blast wave tracked by Hubble

Detected at all wavelengths

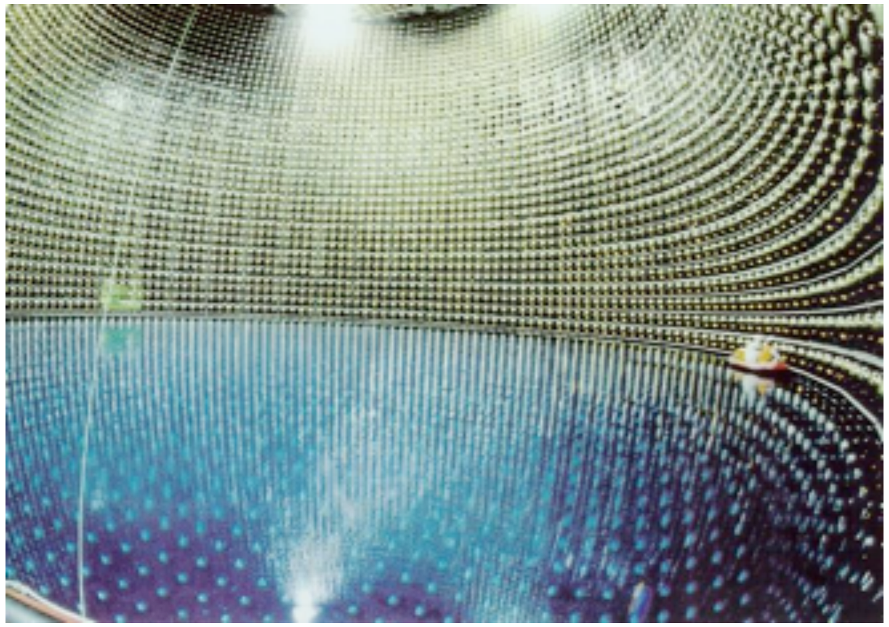
- visible light ("optical")
- ultraviolet
- X-ray
- gamma-ray

a lucky "experiment" to test our ideas about supernovae





Supernova 1987A: Neutrinos



Super-Kamiokande Neutrino Detector

Crown Jewel:

supernova neutrinos detected on Earth!

- signal was about 20 neutrinos
- spread over about 10 sec
- but came from exploding star 50 kpc = 150,000 lyr away!

2002 Nobel Prize in Physics:

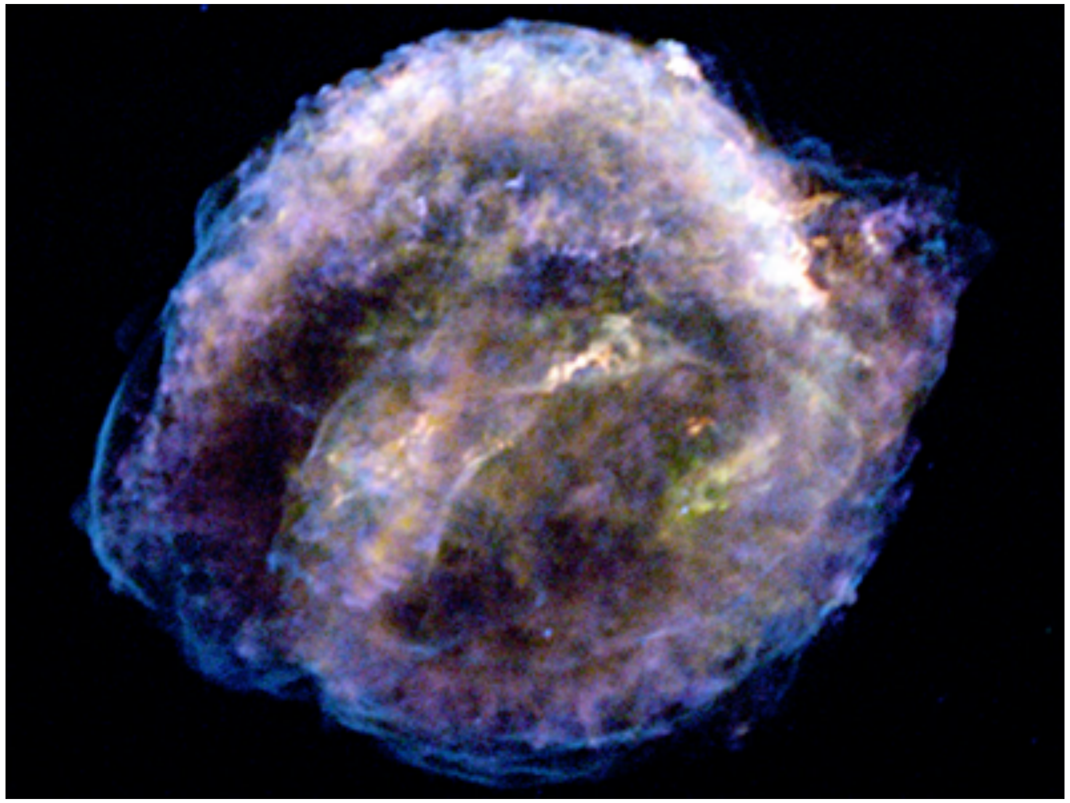
- Masatoshi Koshiba and SuperK

Neutrino detection confirms:

- most (> 99%!) of explosion energy carried by ν’s

  visible energy only 1% of total!
- supernovae are really “neutrino bombs”!
- 10 sec signal: neutrinos slowly leak out of dense star core

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?

- more than one reason
- think of some with your neighbors
- click A when done