# White Dwarves Mass vs Radius

- In WD, gravity is balanced by pressure due to degenerate electrons
- White Dwarves are about the size of Earth and have a mass about that of our Sun
- A heavier WD will have smaller radius. Counter-intuitive but “easily” calculated using senior level physics. First determined by an Indian graduate student S. Chandrashekar in 1930s using Einstein special theory of relativity

# Degenerate electrons

**not on tests**

same as Pauli exclusion - two electrons which are "close" to each other can not occupy the same quantum state. Causes:

- Periodic table and different chemical properties for different atoms
- why metals conduct electricity
- interior of stars and planets, white dwarves

electrons are forced to higher energy states and so exert more pressure than normal

# Degenerate electrons DON'T NEED TO KNOW

Being "close" depends on electrons energy. Easier for lower energy to be close (wavelength = h/p) DON'T NEED TO KNOW. A "Fermi gas" is when the particles in a gas are very close to each other.

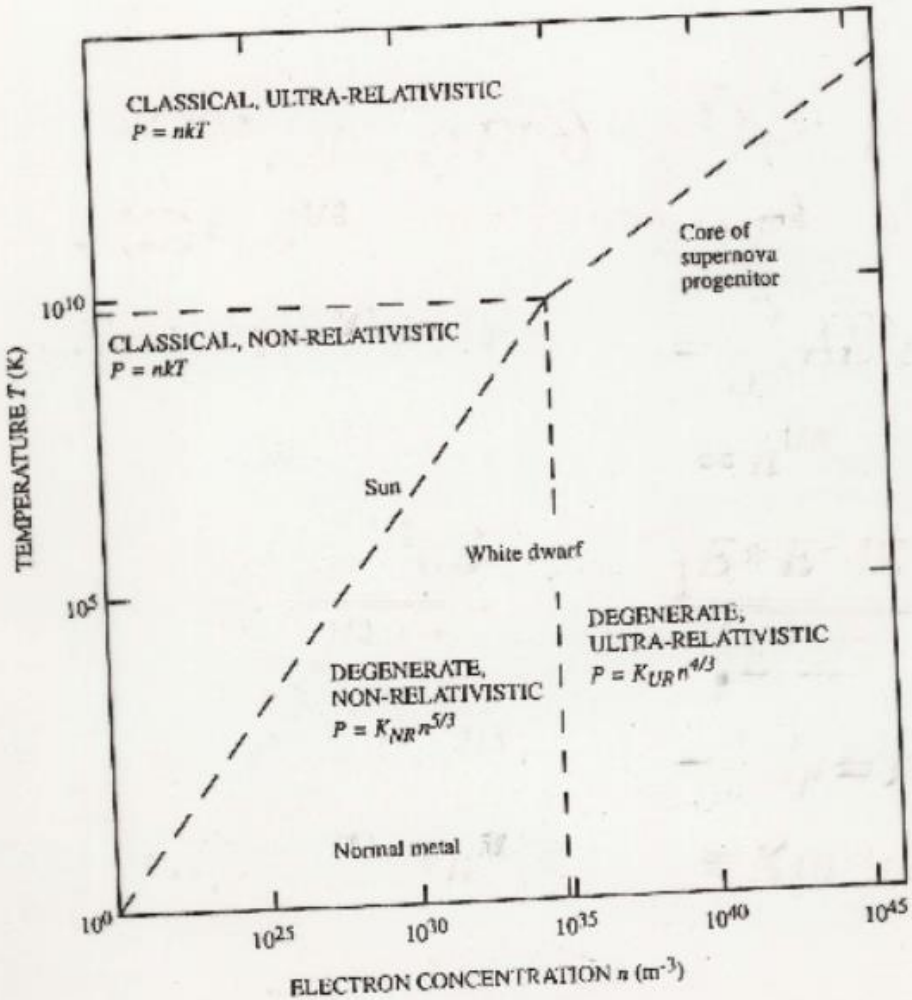
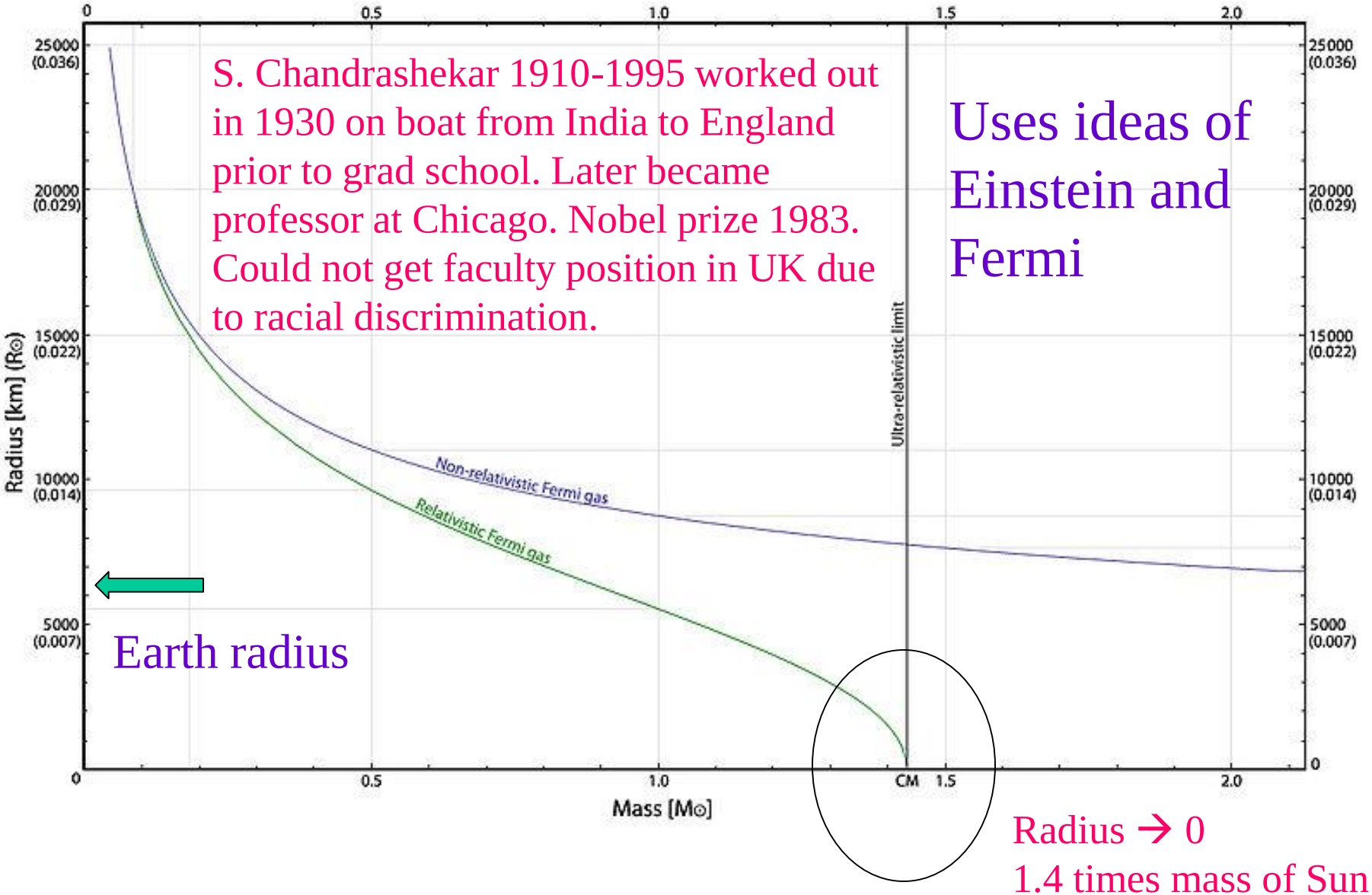



Fig. 2.2 Equation of state regimes for an ideal electron gas at a temperature $T$ and at a density of $n$ electrons per $m^3$. Typical values are shown for the temperature and density for electrons in a normal metal, in the sun, in a white dwarf and in the iron core of an evolved star just prior to a supernova.

# White Dwarves Mass vs Radius




S. Chandrashekar 1910-1995 worked out in 1930 on boat from India to England prior to grad school. Later became professor at Chicago. Nobel prize 1983. Could not get faculty position in UK due to racial discrimination.

Uses ideas of Einstein and Fermi

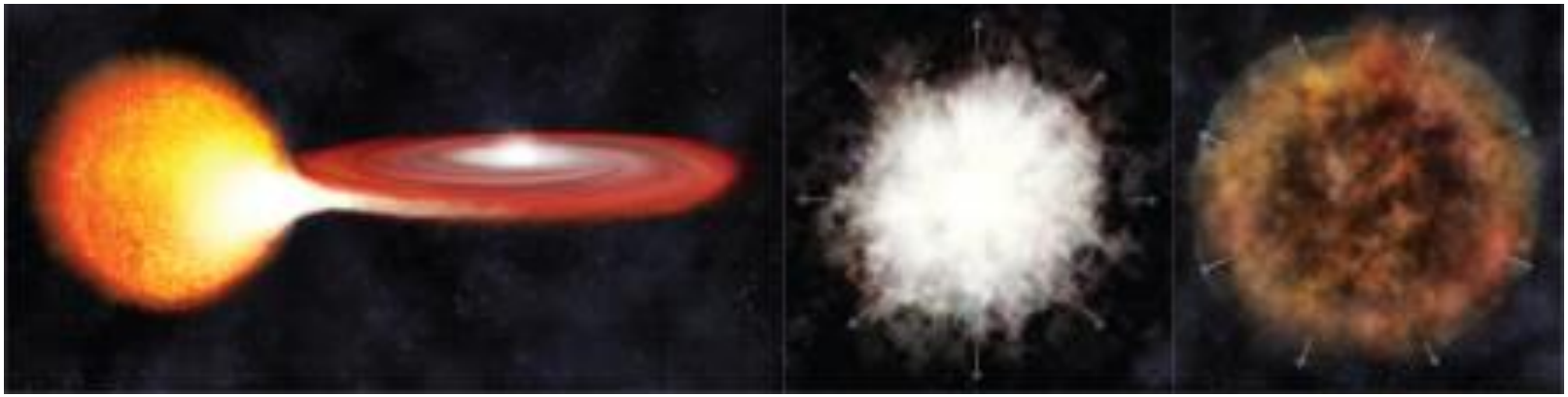
Earth radius

Radius → 0

1.4 times mass of Sun

# White Dwarves Mass vs Radius

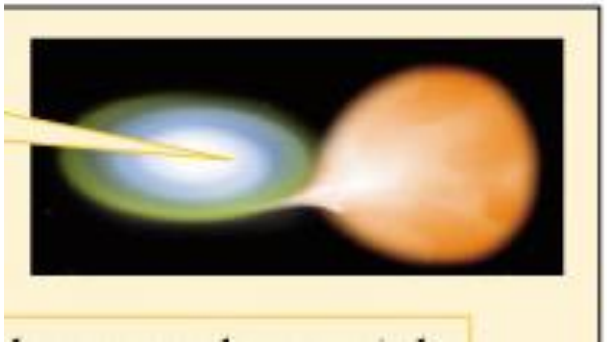
- if Mass(WD) > 1.4 M(Sun) degenerate electrons can not resist gravity → called Chandrasekhar limit and no WD has a mass greater than this
- If WD can acquire mass from companion star and goes over this mass limit then the white dwarf will collapse and have radius go almost to 0 → Type I Supernova and (usually) produces a Neutron Star with ~20 km radius



# Stellar Supernova Explosions – Two Types

For heavy white dwarves with a companion star

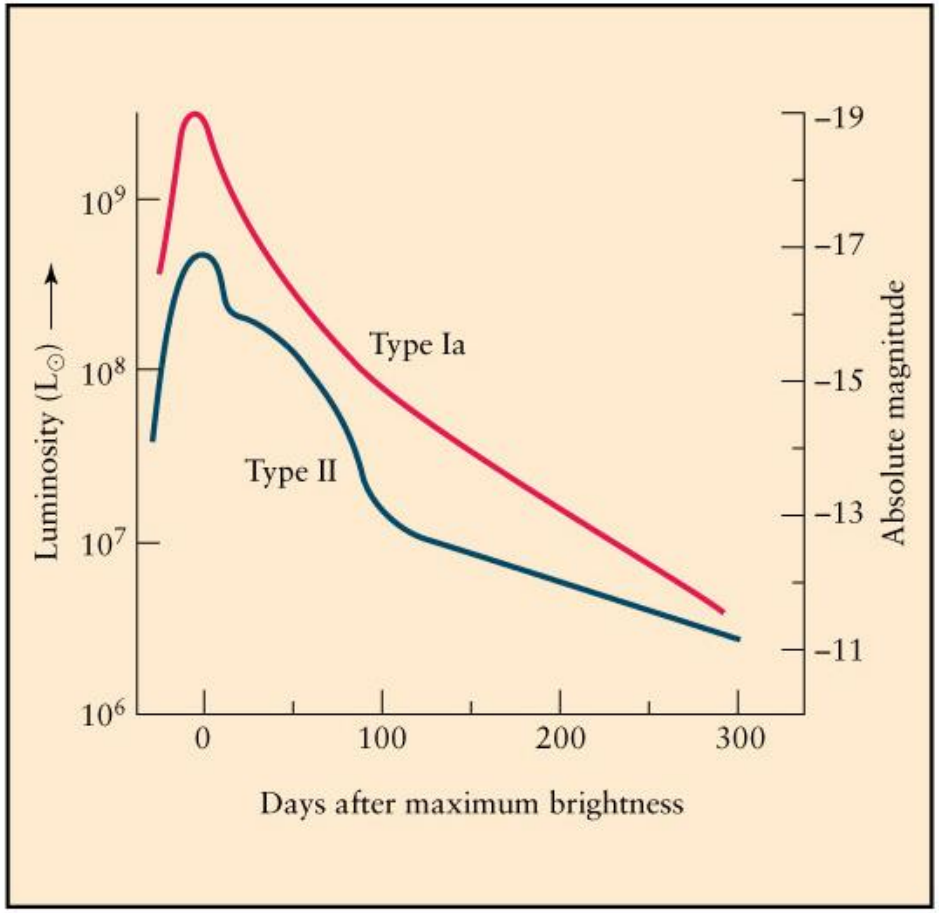
- acquire mass, if becomes > 1.4 M(Sun) SUPERNOVA (Ia). p + e → n + neutrino
- Usually leaves neutron star.



For high mass stars

- fusion continues beyond C,O
- core of degenerate electrons builds up - opposes gravity
- if Mass(core) > about 1.4 M(Sun) core collapses in SUPERNOVA (II).
- leaves either Neutron Star or Black Hole. Produces many heavy elements

# Supernova Explosions




1 billion times brighter then the Sun for a few months

Two Types

Ia = White Dwarf collapse

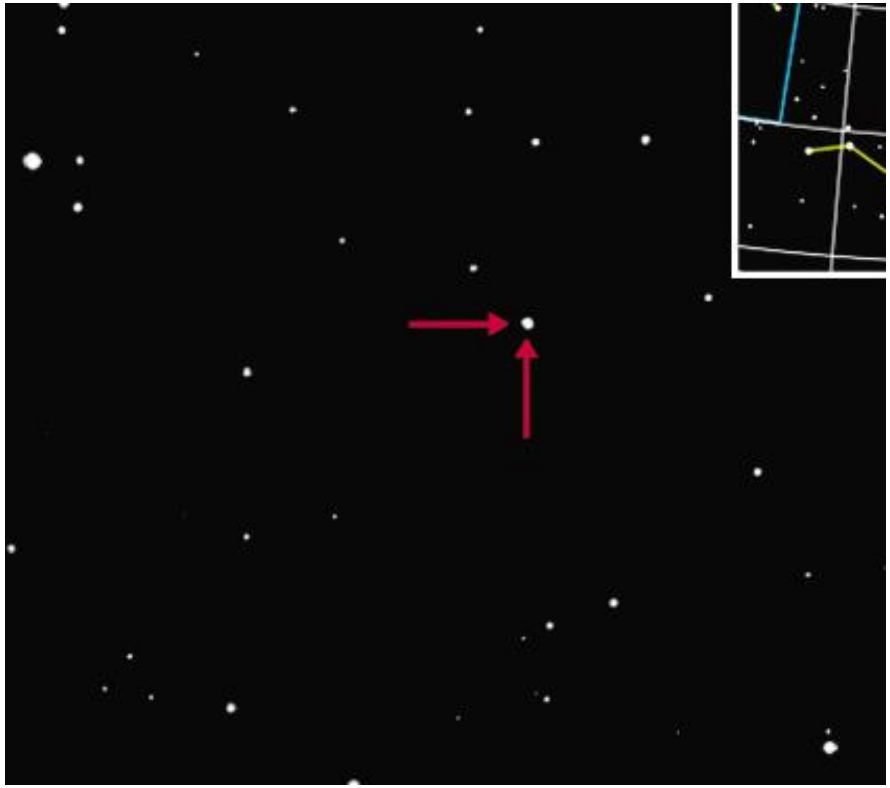
II Massive star has inner core collapse

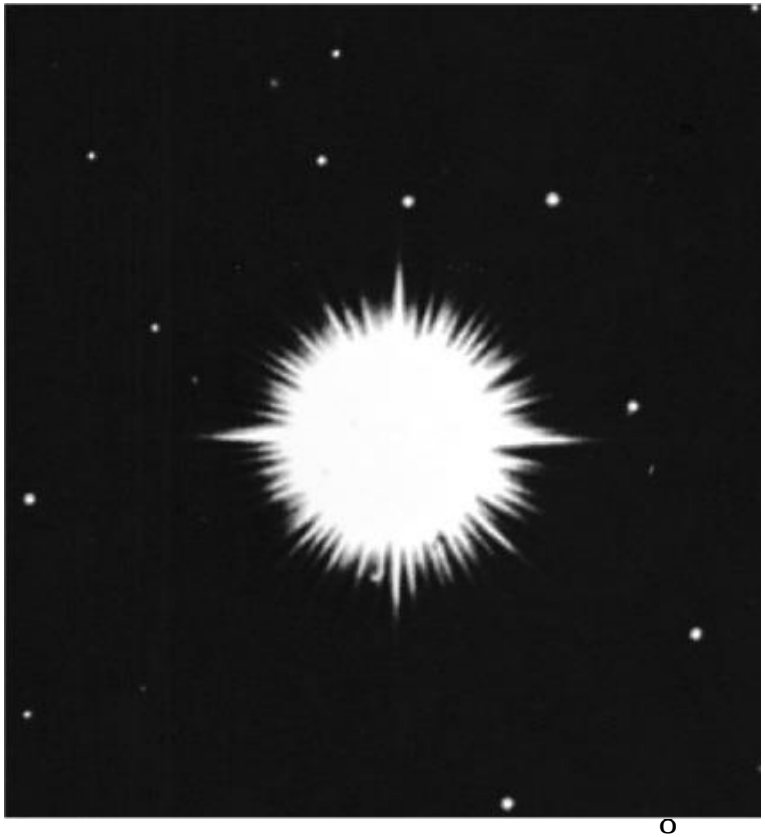
Ia are ~10 times brighter

Decay in intensity over years (decay time due to lifetime of radioactive nuclei)

# Supernova Explosions

1 billion times brighter then the Sun for a few months. Can outshine all other stars in a galaxy. Before on left and during supernova on right. Note the position and brightness of the other stars which do not change between photos





# Supernovas

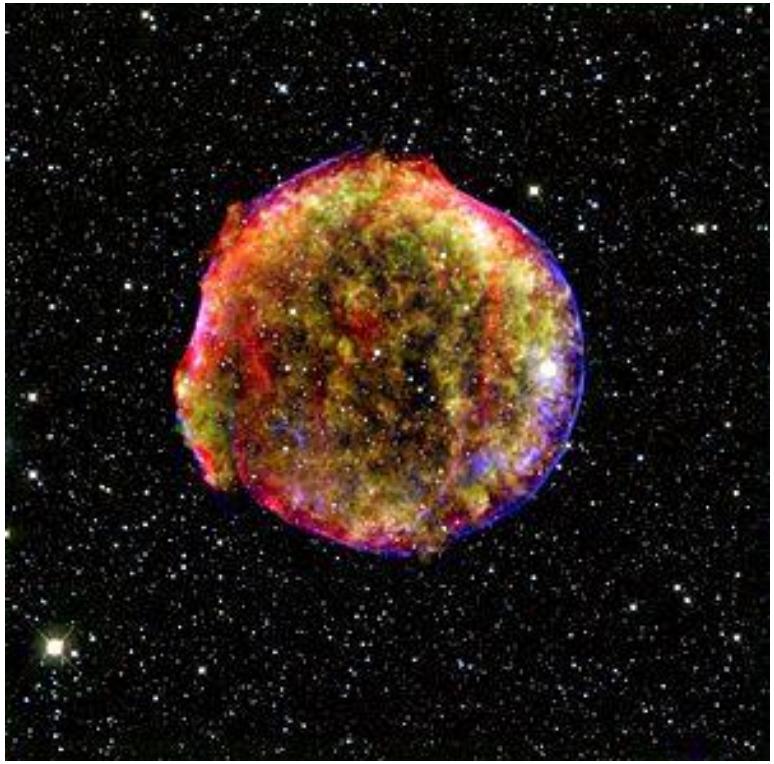
- 10-20 supernovas occur every1000 years in a galaxy the size of the Milky Way (~400 billion stars) with ~15% being type Ia
- 8 observed in last 2000 years (185, 386, 393, 1006, 1054, 1181, 1572, 1604); every 250 years or so
- Hard to observe if on "opposite" side of Milky Way → all recent observed SN are in other galaxies
- Can be observable during the day
- All astronomers waiting for next "close" supernova

# 1572 (Tycho Brahe) and 1604 (Kepler)

In Milky Way both probably Type Ia. Can now see and study remnants for a few thousand years. Can tell what atoms are present from spectrum, measure velocity of ejected material

1572: in Cassiopeia 9,000 LY away. Has companion star similar to Sun. Brahe became famous as stated was “far away” (outside solar system)

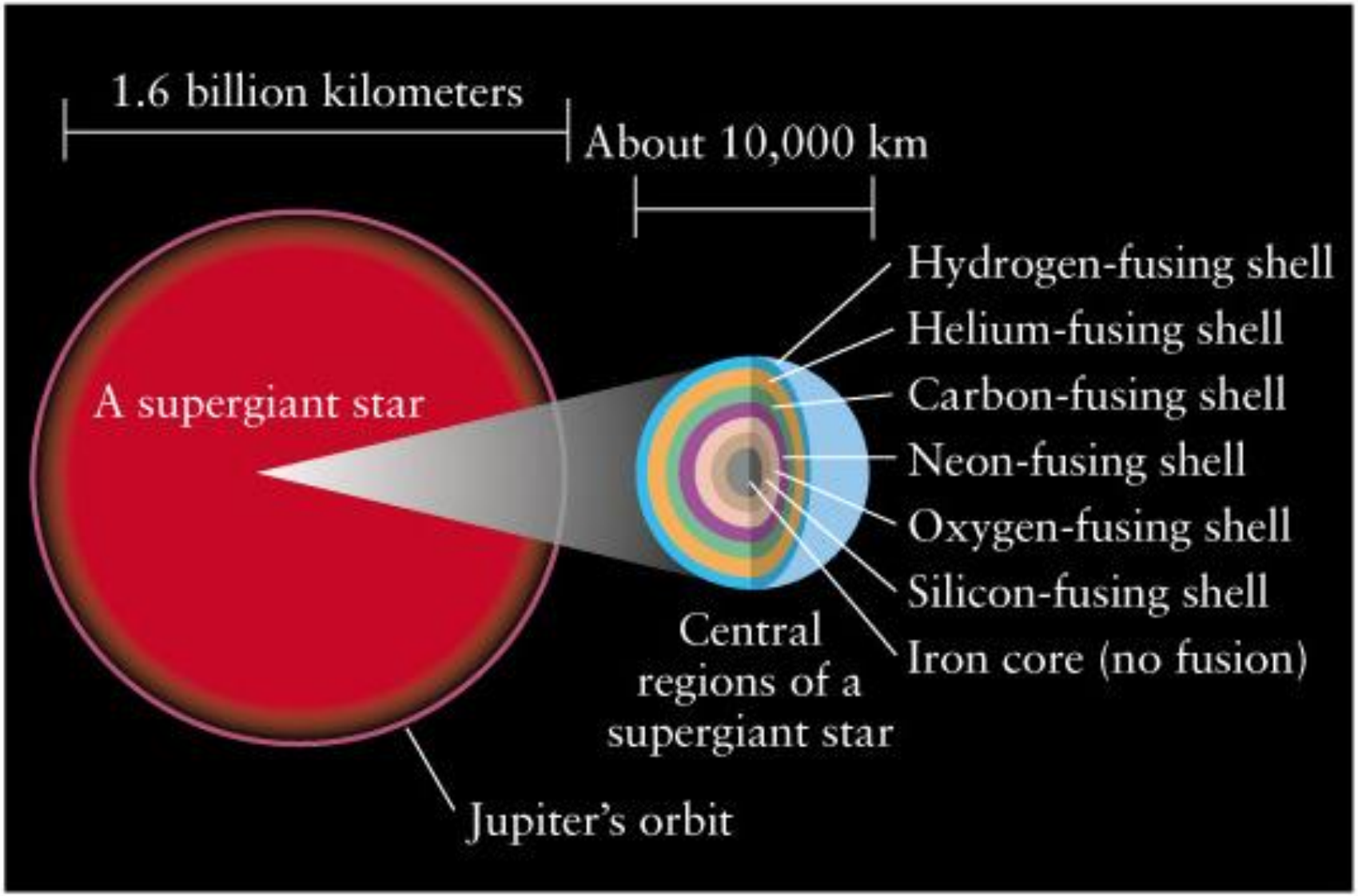
1604: in Ophiuchus about 20,000 LY away



# Type II Supernovas and Core Collapse

- massive stars have fusion to heavier nuclei (Neon, Silicon, Sulpher, etc)
- end up with core of Iron nuclei plus 26 unbound “free” electrons for every Fe
- electrons are “degenerate” as so close together. This causes them to provide most of the pressure resisting gravity
- enormous stress. If electrons “give way” leaves “hole” in center of star

# Supergiant → Iron Core

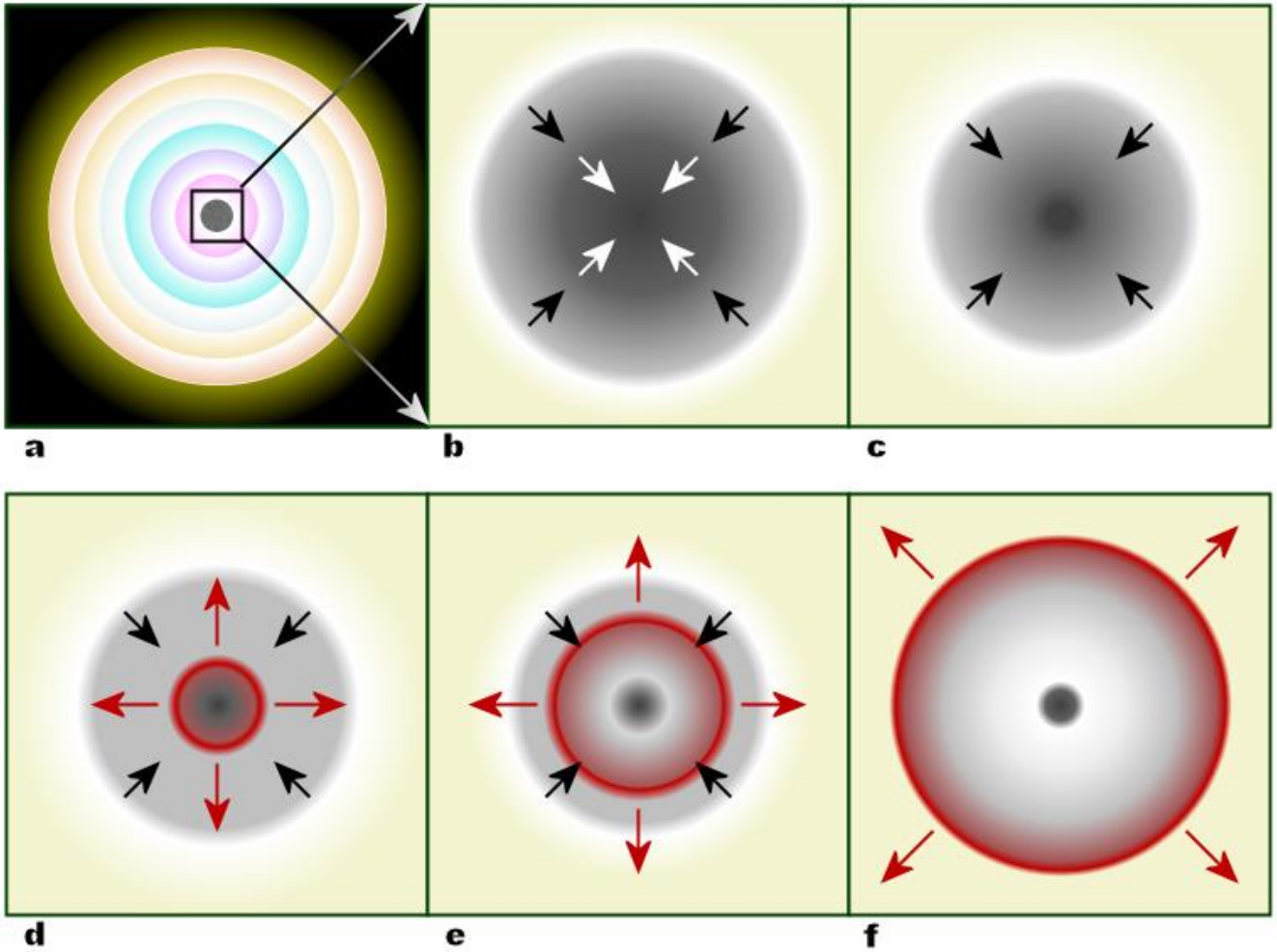


# Core Collapse

core collapses into mostly neutrons – very hot

outer layers rush into “hole” smashing into shock wave from core

happens when mass of core about > 1.4 Mass Sun. similar to Chandrashekar limit



# During Supernova

- core collapse gives 200 billion degrees → energetic photons
- breaks up many nuclei

  Fe → 26p + 31n  O → 8p + 8n
- new nuclei form → photons, n, and p strike shell around core. One way Universe makes heavy elements
- p + e → n + neutrino. Due to large electron energy

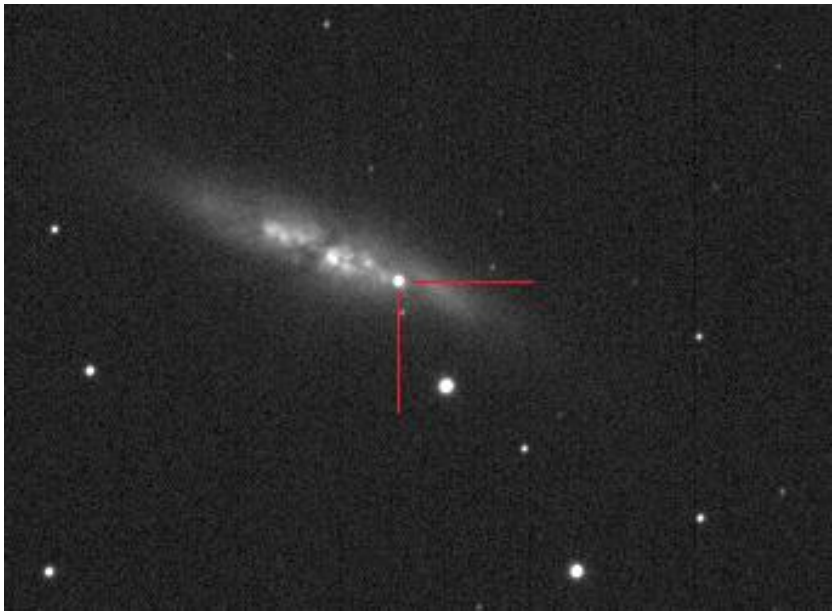
1. Burst of neutrinos. 1000 times more energy than from light (photons) during supernova
2. Leftover neutron star

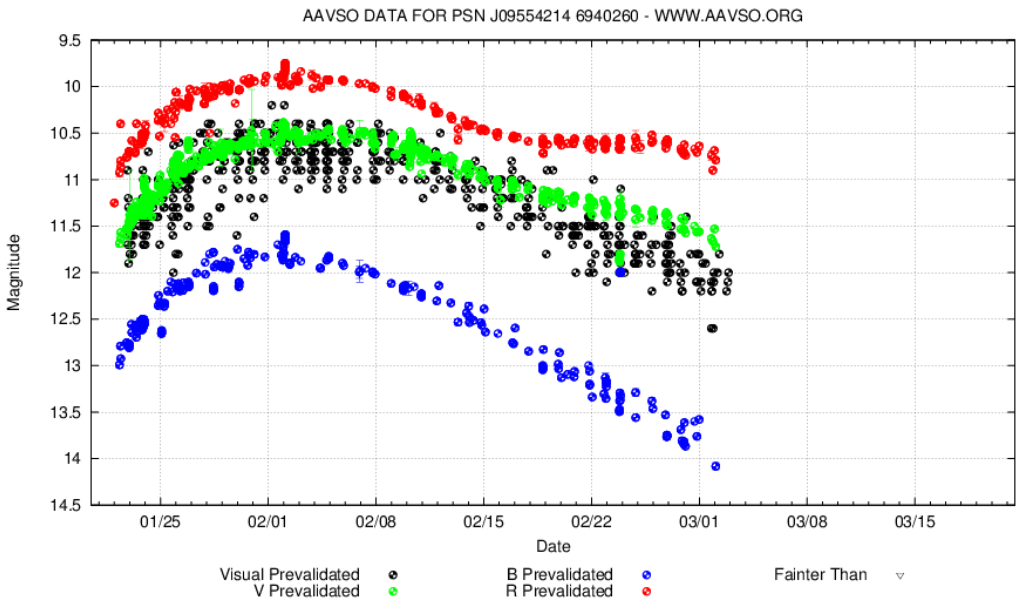
# Nearby Supernovas?

- if Sirius B, a white dwarf with mass=Sun, acquired mass from Sirius A with mass=2*Sun **(it won't),** it would be a Type Ia supernova and would be about 1% the apparent brightness of the Sun. It is 8.6 LY away.
- If Betelgeuse, a Red Giant, has a core collapse Type II supernova (it will, or it already has and the light is travelling towards us), it would have an apparent brightness about 1/millionth = 0.000001 that of the Sun, which will be about 10,000 times brighter than the brightest star Sirius. It is 427 LY away.

# Supernova 2014j – Jan 2014

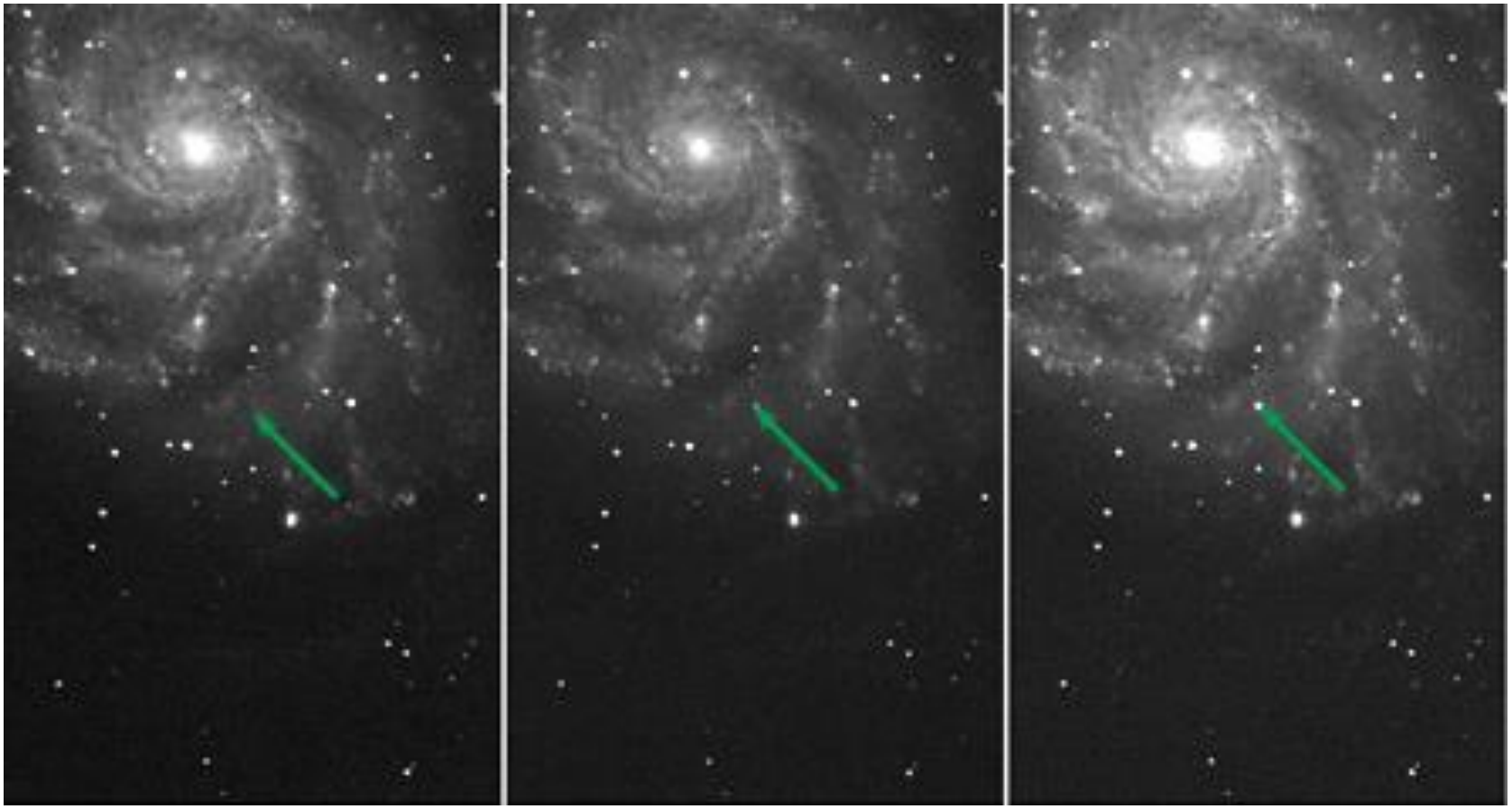
In M82 Galaxy (Ursa Major). Type Ia. Closest of this type observed in modern times. 11.5 million LY away. Discovered at undergrad session Univ College London (SN1972 e was 11 MLY but pre “modern”)





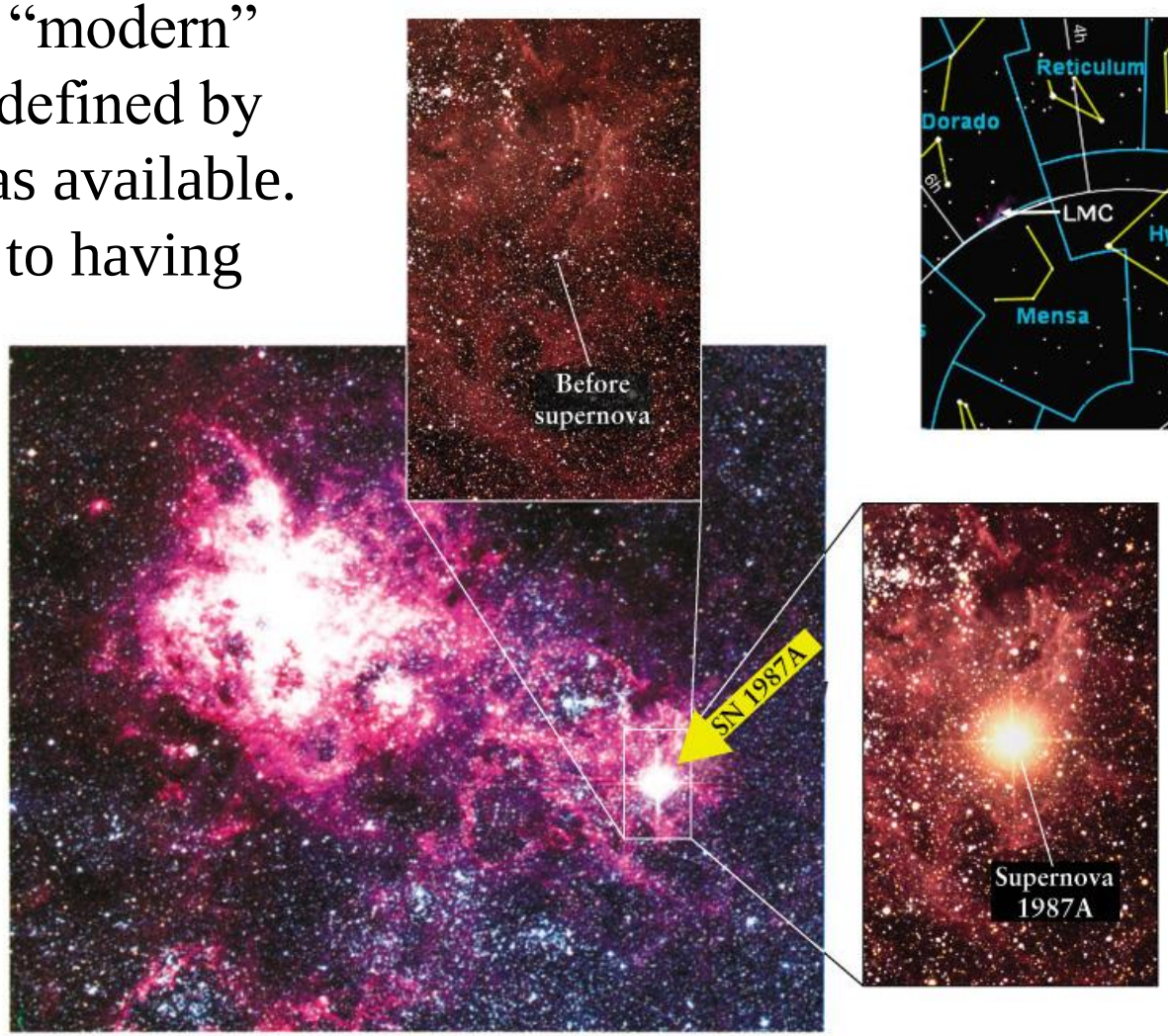
# Supernova PTF 11kly – Sept 2011

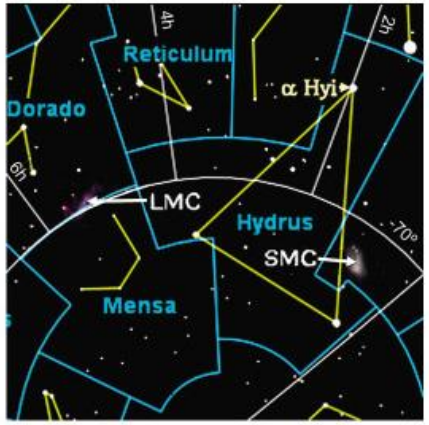
In Pinwheel Galaxy. Type Ia. 2nd closest Ia observed in modern times. 21 million LY away



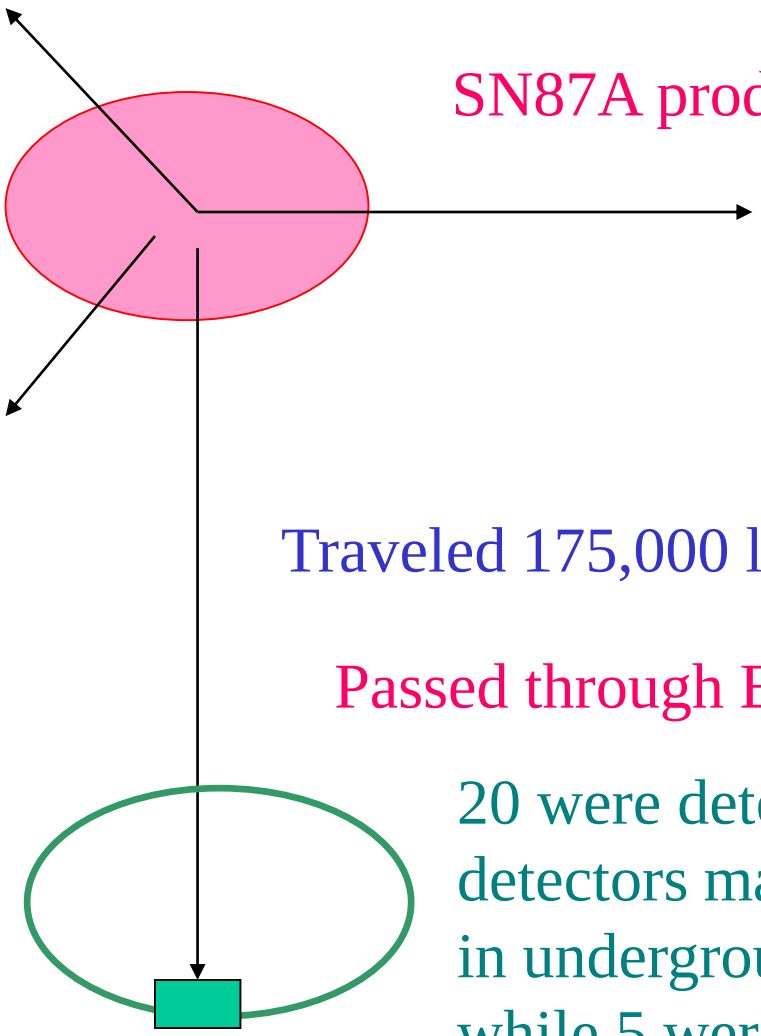
# Type II Supernova 1987a

Large Magellanic Cloud
180,000 LY away
Closest in not quite “modern” times. “modern” is defined by what technology was available. 1987 was just prior to having digital cameras and the internet



# Detection of neutrinos from SN1987A



SN87A produced $10^{58}$ neutrinos

$10^{15}$ $\nu/cm^2$ at Earth

$10^{18}$ neutrinos from SN1987a passed through every person's body

Traveled 175,000 light years to Earth

Passed through Earth

20 were detected (mostly antineutrinos) in detectors made from 100 tons of water located in underground mines in Ohio and Japan, while 5 were observed in a tank of scintillator in the USSR (pre Soviet collapse)

# Supernova 1987a – 2/23/1987

Was first seen by eye by Oscar Dehalde while on a coffee/cigarette break while working as an operator at the Las Campanas observatory in Chile. He didn't realize what he had seen. A postdoc from Canada, Ian Shelton, took an exposure on a photographic plate using a smaller (and broken) telescope. He then developed the plate before going to bed and noticed a "new star" in the Large Magellanic Cloud and realized it was a probable supernova. The next day he went down the mountain and sent a telex to Boston stating a supernova was probably discovered. Afterwards, it was realized that an amateur astronomer had taken a photo of the LMC a few hours earlier but had gone to bed without developing it. That was the first "light" from SN87a observed on Earth and helped to understand how this star had exploded.

The neutrinos and antineutrinos were detected in experiments that had been built by particle physicists to look for evidence of proton decay.

Not really modern as did not have digital cameras or the internet.

# Supernovas and Luck

- Astronomers have to get lucky to observe a supernova which is close enough to make detailed measurements
- Today there are many telescopes with “fast analysis” of their digital camera data which are continuously automatically looking for supernovas. One will not have to rely on the luck that gave the first observation of SN87a. The pre-observation data will also be available to better study the evolution of the supernova
- Today there are many large neutrino detectors (Minnesota, Antarctica, Italy, Japan, China, Canada, etc) which also continuously look for a burst of neutrinos in their data coming from a supernova.
- Just have to wait. Large stars like Deneb, Betelguese or Rigel will probably supernova anytime in the next 100,000 years. Or they already have and the light is now travelling towards Earth.

# Supernovas and Technology

- Much has changed since 1987 for astronomers which allow them to do much, much more in general, and will allow significant better measurements of future “close” supernovas, and as we will see has opened up the use of very distant supernovas for cosmology studies

- We have discussed modern digital cameras, and the new observatories in Chile, Hawaii, plus many more on land and in satellite orbits.

- Disk storage: in 1987 the first disk I purchased at NIU was a 500 Mbyte disk, about 2 feet in diameter, which cost $25,000. A 32 GB thumbdrive now costs about $9. That is an improvement in cost/byte of about 250,000, which allows astronomers to store very large catalogs (and you to store photos and tunes on your phone)

# Supernovas and Technology - Internet

- Much of astronomy data is now stored in online databases which are accessed remotely via the internet/WWW
- In 1987 astronomers like Ian Shelton did not have access to the internet and so sent a telegram or made a phone call. The internet was developed in the 1970s primarily by the US government (good use of federal research funds), and in 1982 the TCP/IP protocol was established. I sent my first e-mail in 1982, and by 1983 was accessing remote computers through the internet as the high energy physics community which had labs in Europe and the US (like Fermilab) was the first big user. In 1985 I carried a "laptop" to spend time with family in Tucson. The laptop had a 700 baud (not mega or giga) modem, a keyboard, and (essentially) a typewriter. I would phone Fermilab, connect to computers there and at Brookhaven on Long Island. Reading an e-mail took about 5 minutes per paragraph as so slow. When applying to NIU in 1986, no one at NIU had the capability of receiving an e-mail. In 1987, at NIU, I leased a phone line from my house to NIU ($2000/yr) and a faster phone line from NIU to Fermilab ($10,000/yr) paid by my grants in order to have good access to the internet to do my research. I kept these phone lines until 2000 when I switched to a commercial provider which I then paid for myself.

# Supernovas and Technology - WWW

- The world wide web was developed at CERN in Switzerland in 1991 with Fermilab and SLAC (in California) having the first non-CERN pages in 1992. I started using in 1993 but the first browser, LYNX, was terrible, and the Web did not “take off” until after UIUC released its browser Mosaic in 1993. The NIU physics department had NIU’s first web page in 1995; we got our IP address by me having my system manager phone Fermilab. The first PHYS 162 web page was in 1999 (I think this was a first for a course at NIU). If you look at our course’s web page (in Firefox this is ctrl U or view source), it is written in base html as easier for me than using any web design app as I “grew up” writing code in base html. The web as we know is completely a product of government funded R&D in Europe and the US.