Supernova 1987A

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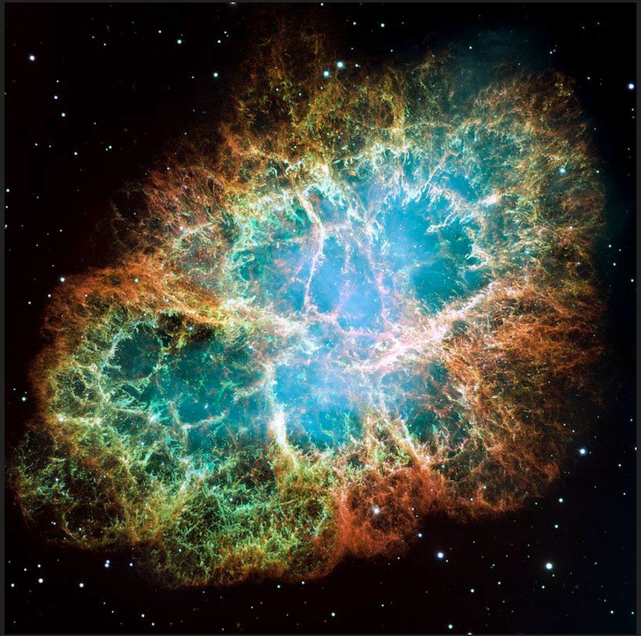
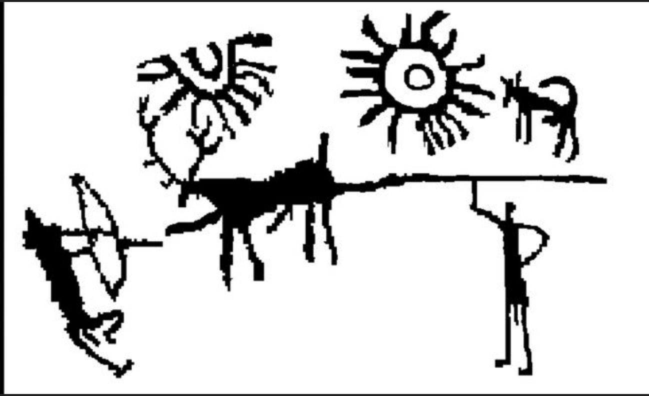
Supernovae

- powerful and luminous stellar explosions
- expels several solar masses of material at high speed
- typically 10^{44} J of energy is released (≈ energy released by the Sun during its whole lifetime)
- their peak optical luminosity can be comparable to that of an entire galaxy before fading over several weeks or months
- they occur in the Milky Way on average about three times every century
- most supernovae are triggered by one of two basic mechanisms:
  - the sudden re-ignition of nuclear fusion in a degenerate star such as a white dwarf
  - the sudden gravitational collapse of a massive star's core
- major source of heavy elements in the interstellar medium from oxygen through to rubidium



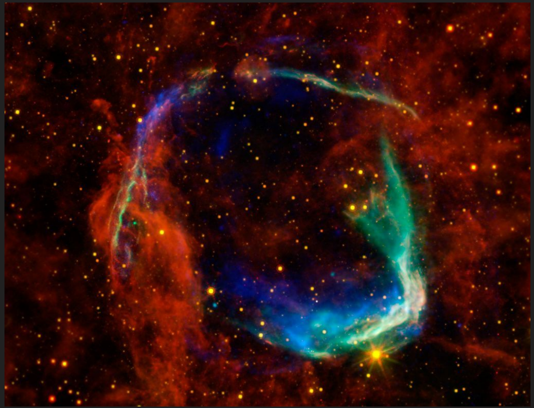
The Crab Nebula, a supernova remnant from the 1054 supernova. Source: https://en.wikipedia.org/wiki/Supernova#/media/File:Crab_Nebula.jpg

Earliest supernovae



The earliest possible recorded supernova, known as HB9, could have been viewed and recorded by unknown Indian observers in 4500±1000 BC.

Image source: https://index.hu/tudomany/2018/01/09/otezer_eves_sziklarajz_orzi_a_legkorabbi_szupernovat/

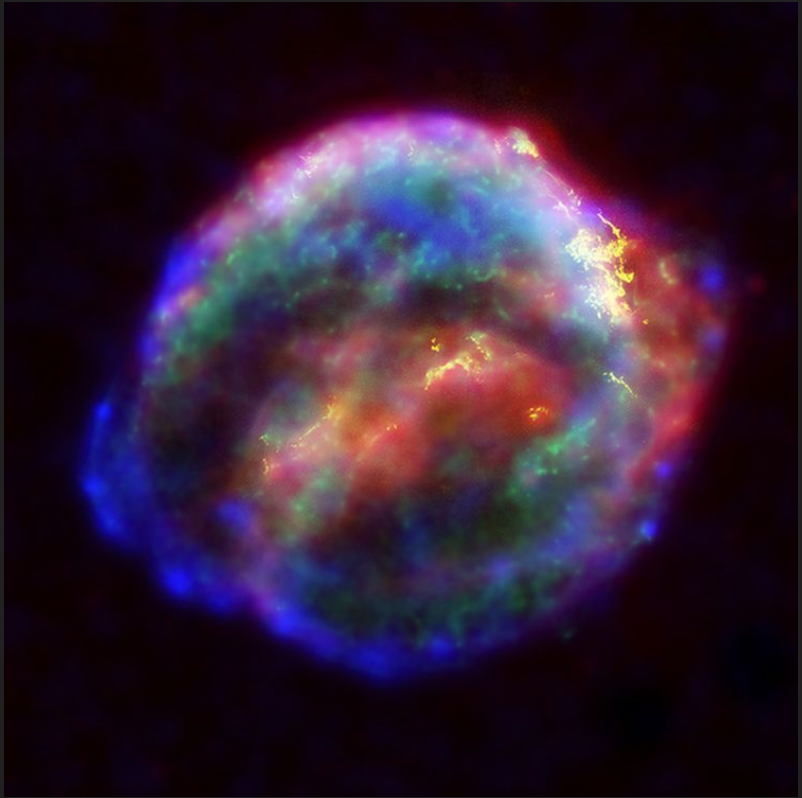


In the year 185 AD, astronomers recorded the appearance of a bright star in the sky, and observed that it took about eight months to fade.

The gaseous shell RCW 86 is probably the supernova remnant of this event.
Source: https://en.wikipedia.org/wiki/SN_185#/media/File:RCW_86.jpg

Kepler’s Supernova

- the last observed supernova in our galaxy (cause: interstellar gas and dust)
- SN 1604
- type Ia supernova
- brighter at its peak than any other star in the night sky, with an apparent magnitude of −2.5
- it was visible during the day for over three weeks



X-ray, Optical & Infrared Composite of Kepler's Supernova Remnant. Source: https://en.wikipedia.org/wiki/Kepler%27s_Supernova#/media/File:Keplers_supernova.jpg

Classification

<table>
<tr><td rowspan="3">Type I
No hydrogen</td><td colspan="3">Type Ia
Presents a singly ionised silicon (Si II) line at 615.0 nm, near peak light</td><td>Thermal runaway</td></tr>
<tr><td rowspan="2">Type Ib/c
Weak or no silicon absorption feature</td><td colspan="2">Type Ib
Shows a non-ionised helium (He I) line at 587.6 nm</td><td rowspan="6">Core collapse</td></tr>
<tr><td colspan="2">Type Ic
Weak or no helium</td></tr>
<tr><td rowspan="4">Type II
Shows hydrogen</td><td rowspan="3">Type II-P/-L/n
Type II spectrum throughout</td><td rowspan="2">Type II-P/L
No narrow lines</td><td>Type II-P
Reaches a "plateau" in its light curve</td></tr>
<tr><td>Type II-L
Displays a "linear" decrease in its light curve (linear in magnitude versus time)</td></tr>
<tr><td colspan="2">Type IIn
Some narrow lines</td></tr>
<tr><td colspan="3">Type IIb
Spectrum changes to become like Type Ib</td></tr>
</table>

SN 1987A

Tarantula nebula in the Large Magellanic Cloud in the (image made by ESO Schmidt telescope). Source: https://www.csillagaszat.hu/wp-content/uploads/2017/02/20170214_harminc_ev_elteltevel_is_tartogat_titkot_az_sn_1987a_szupernova_1.jpg

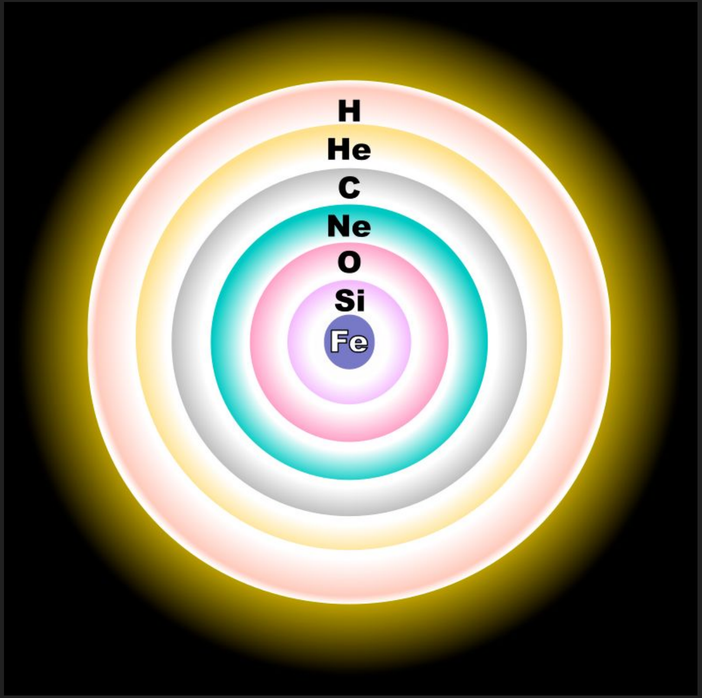
Discovery

- February 24, 1987
- Chile, Ian Shelton and Oscar Duhalde
- later, independently
  - Albert Jones in New Zealand
  - Colin Henshaw in Zimbabwe
- brightness peaked in May, with an apparent magnitude of ~3
- 4 days after the event was recorded, the progenitor star was tentatively identified as Sanduleak −69° 202
  - blue supergiant
  - located on the outskirts of the Tarantula Nebula in the Large Magellanic Cloud
- Type II supernova

The Large Magellanic Cloud before and after the appearance of SN 1987A. (ESO)

Type II supernovae

- rapid collapse and violent explosion of a massive star (8-50 $M_\odot$)
- presence of H in the spectrum
- when core's mass exceeds the Chandrasekhar limit, electron degeneracy is no longer sufficient to counter the gravitational compression
- cataclysmic implosion of the core within seconds (0.23c)
- sudden compression increases the temperature (~100 billion K)
- neutrons and neutrinos are formed via reversed beta-decay, releasing about 10^{46} J in a 10-second burst
- collapse is halted by neutron degeneracy
- stellar material is accelerated to escape velocity
- for a brief period of time the production of elements heavier than iron occurs
- depending on initial mass of the star, the remnants of the core form a neutron star or a black hole



The layers of a massive, evolved star just before core collapse. Source: https://en.wikipedia.org/wiki/Supernova#/media/File:Evolved_star_fusion_shells.svg

Core collapse

(a) via fusion a nickel-iron core is formed

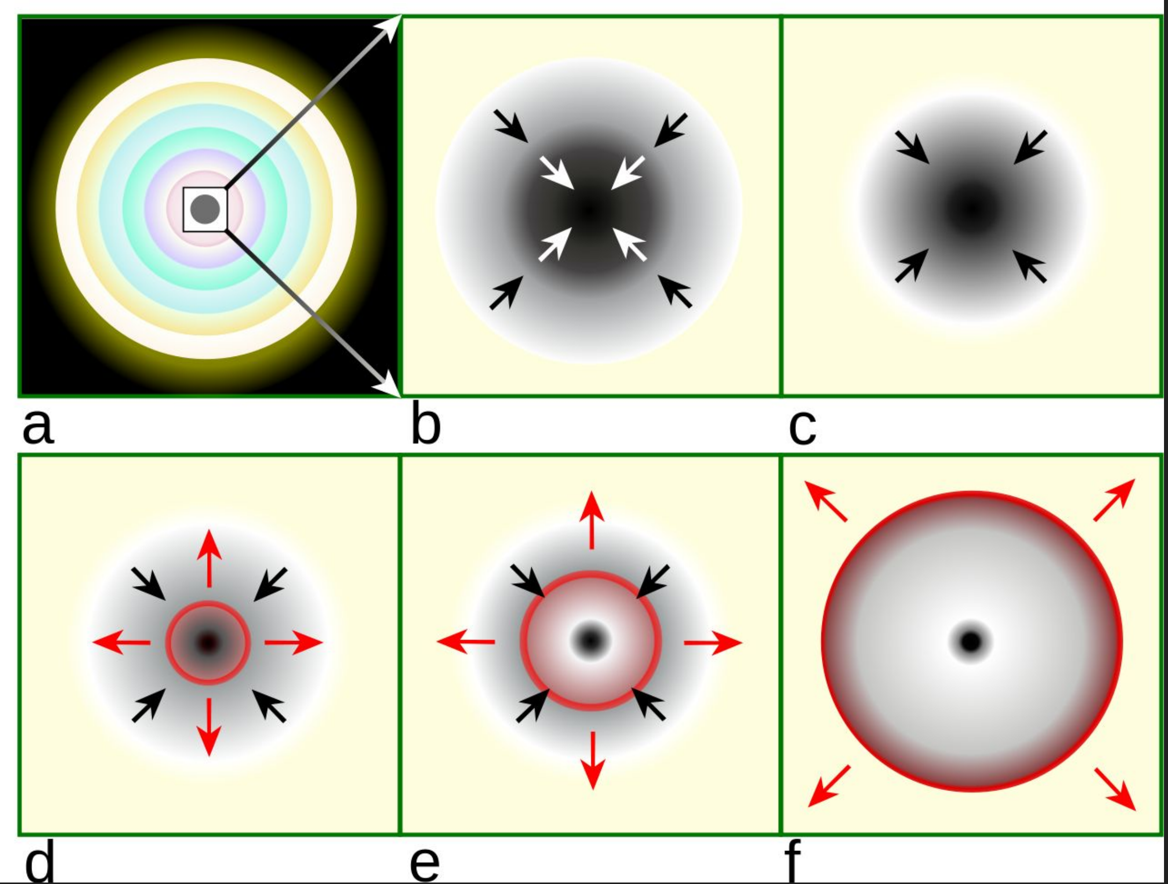
(b) when the core's mass reaches the Chandrasekhar limit, collapse starts

(c) the inner part of the core is compressed into neutrons

(d) infalling material bounces back and forms an outward-propagating shock front (red)

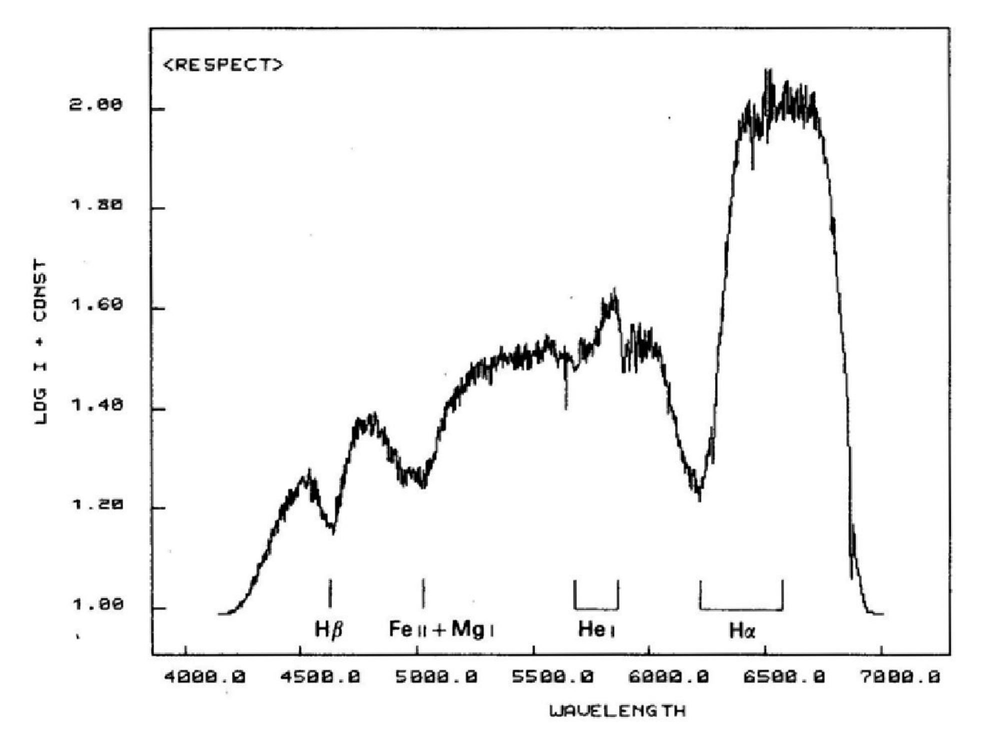
(e) the shock starts to stall, but is revived by a process that may include neutrino interaction

(f) the surrounding material is blasted away, leaving only a degenerate remnant



Neutrino emissions

- as the density of the core increases
  - protons and electrons combine to form neutrons by electron capture, electron neutrino is produced
  - 100 billion K → 'thermal' neutrinos form as neutrino-antineutrino pairs of all flavors
- these 2 mechanisms convert the gravitational potential energy of the collapse into a 10-second neutrino burst, releasing about 10^{46} J
- 2-3 hours before the visible light from SN 1987A reached Earth, a burst of neutrinos was observed at three neutrino observatories:
  - Kamiokande II detected 12 neutrinos
  - IMB: 8 neutrinos
  - Baksan: 5 neutrinos
- observations were consistent with theoretical supernova models in which 99% of the energy of the collapse is radiated away in the form of neutrinos



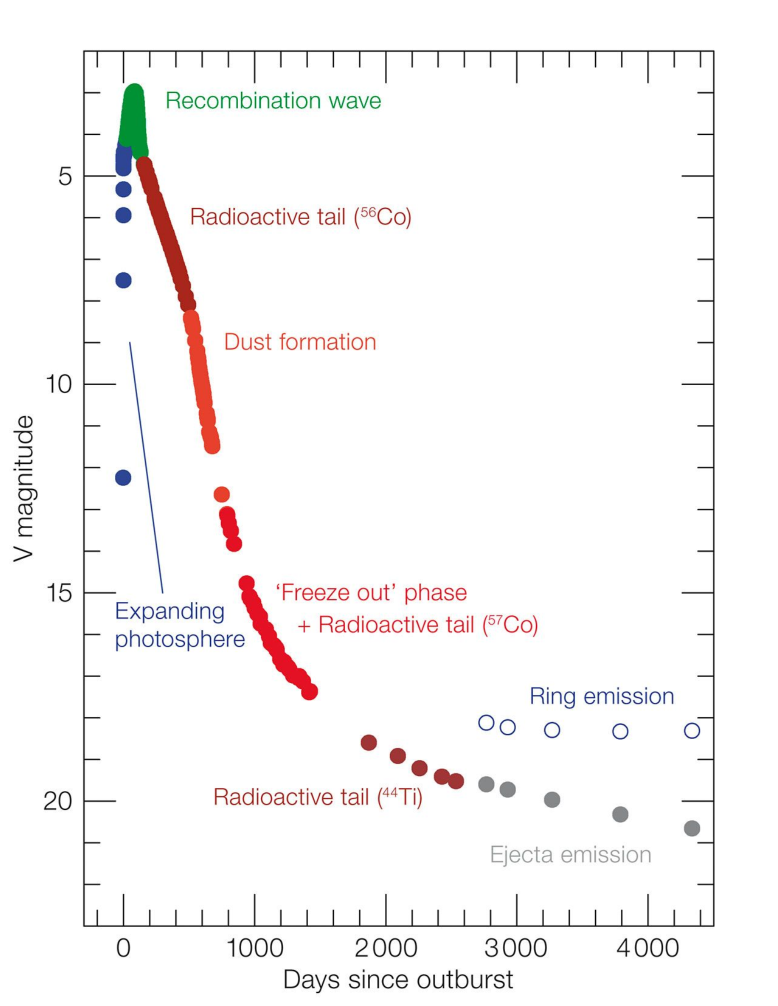
The spectrum of SN 1987A recorded on 1987 February 26.63 at 110 Å mm^{-1}. The sharp feature at λ=5650 is a plate flaw. The correction for instrumental response has not been applied.

Light curve

- graph of luminosity as a function of time
- subsequent radioactive heating of the rapidly expanding ejecta
- radioactive decay produces gamma-ray photons that are absorbed and dominate the heating and thus the luminosity

Light curve of SN 1987A over the first 12 years. The figure marks some of the most important events in the history of the supernova.

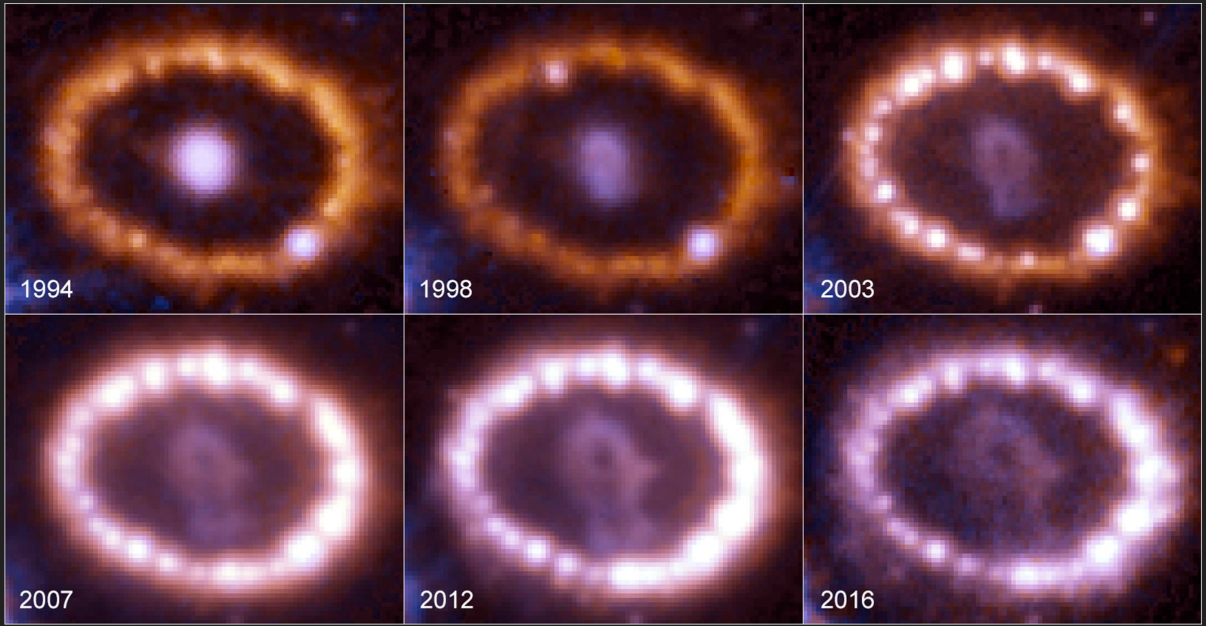
Source:
https://www.eso.org/public/ireland/images/eso0708c/?lang



Neutron star

- SN 1987A should result in a neutron star given the size of the original star. The neutrino data indicate that a compact object did form at the star's core.
- Hubble Space Telescope has taken images of the supernova regularly since August 1990 without a clear detection of a neutron star.
- Possible causes of the missing neutron star:
  - the neutron star is enshrouded in dense dust clouds so that it cannot be seen
  - a pulsar was formed, but with either an unusually large or small magnetic field
  - large amounts of material fell back on the neutron star, so that it further collapsed into a black hole
  - there is a compact object in the supernova remnant, but no material to fall onto it, so it is too dim to be detected
- 2019: evidence presented that a neutron star was inside one of the brightest dust clumps close to the expected position of the supernova remnant
- 2021: X-ray emission from SN 1987A — does not indicate a neutron star, but rather a heated mass of dust and gas which may hide the neutron star behind it

Material from the stellar wind of the progenitor

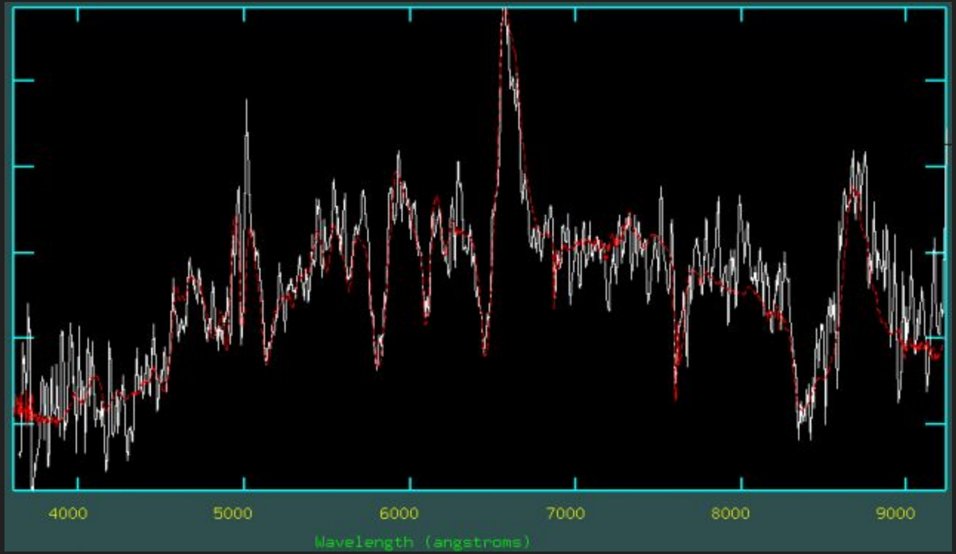


These images, taken between 1994 and 2016 by NASA's Hubble Space Telescope, chronicle the brightening of a ring of gas around an exploded star.

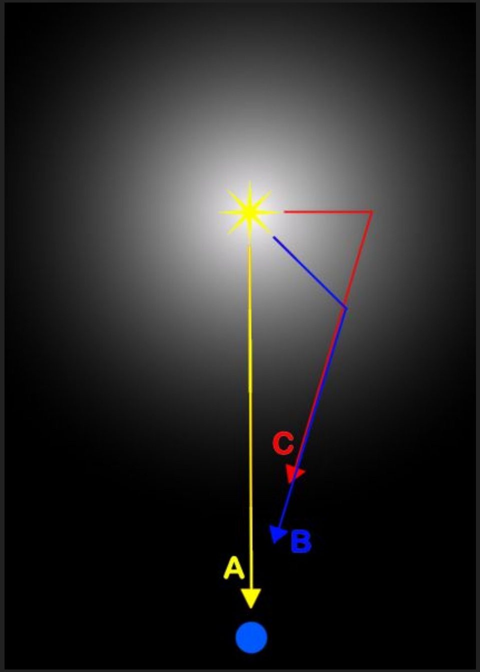
Credits: NASA, ESA, and R. Kirshner (Harvard-Smithsonian Center for Astrophysics and Gordon and Betty Moore Foundation), and P. Challis (Harvard-Smithsonian Center for Astrophysics)

AT 2019xis

- in 2019 ESO discovered a transient named AT 2019xis
- position and redshift (z=0,001) indicated its from LMC (z=0,00092)
- problem : 17 magnitudes dimmer than 1987A



Spectrum of AT 2019xis (white) and the spectrum of SN 1987A 70 days after explosion (red). Almost a perfect match, but the former spectrum had to be upscaled by 17.2 magnitudes.



Reflected light following path B arrives shortly after the direct flash following path A but before light following path C. B and C have the same apparent distance from the star as seen from Earth.

References

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