THE 82ND ARTHUR H. COMPTON LECTURE SERIES

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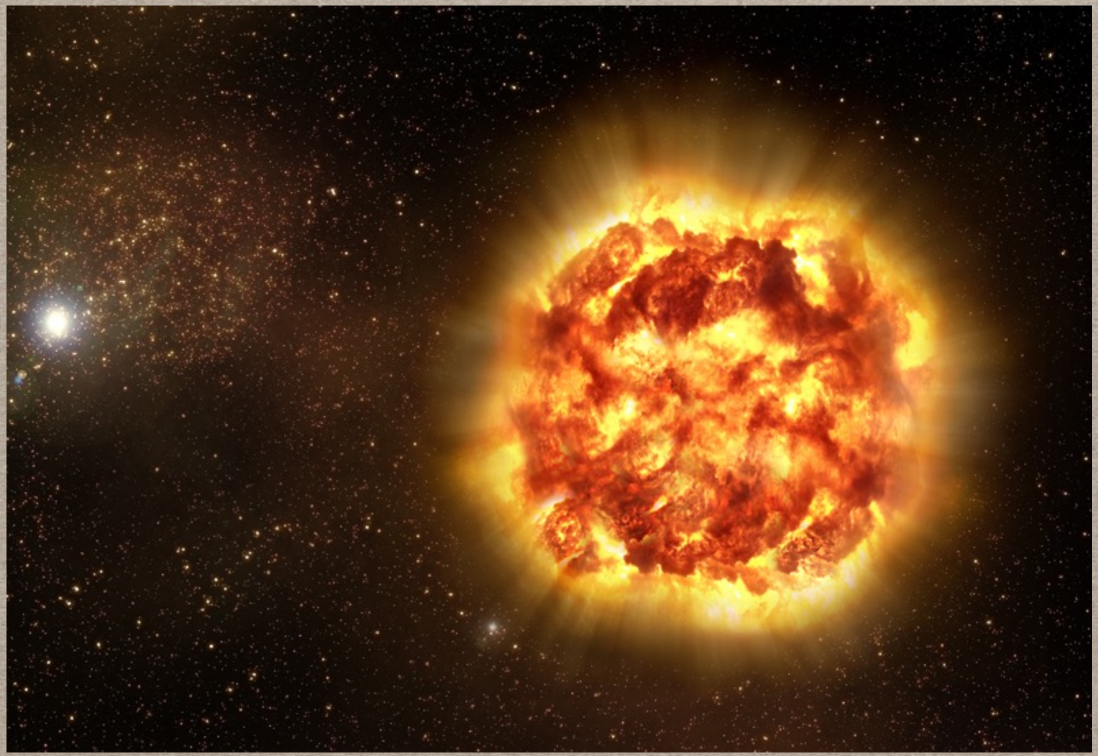
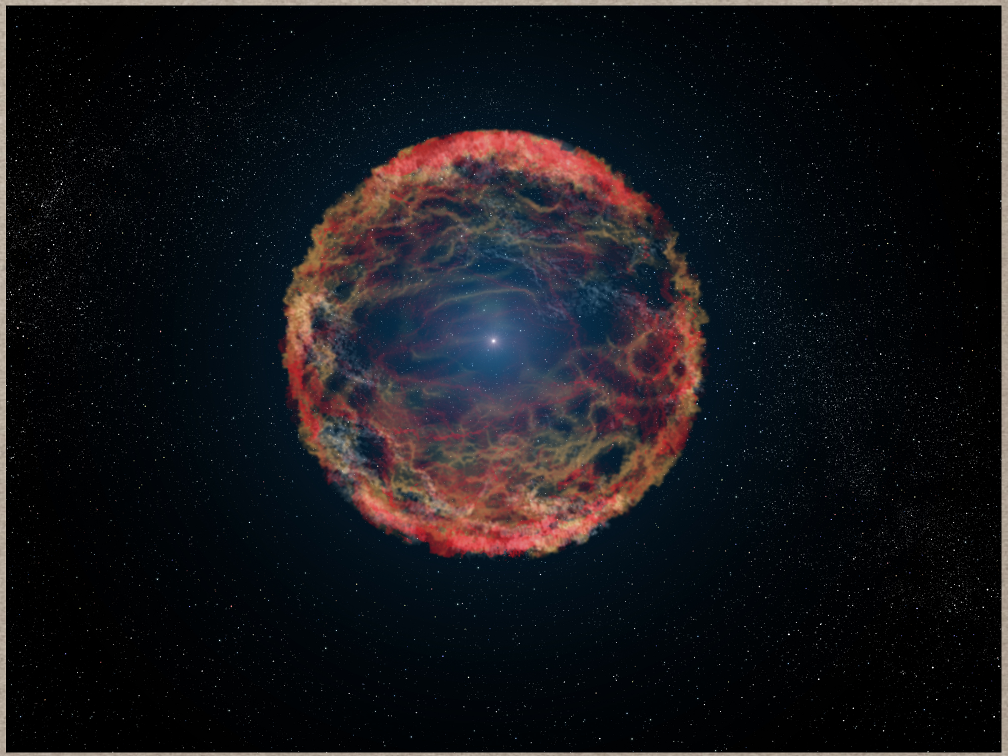




LECTURE 2

SUPERNOVA "ASTROZOOLOGY": THE DIFFERENT TYPES OF SUPERNOVA EXPLOSIONS

10/10/2015

SUPERNOVAE: ENDPOINTS OF SOME WHITE DWARFS AND ALL MASSIVE STARS

In the previous lecture we learned how different the evolution of massive stars is from that of sun-like stars.

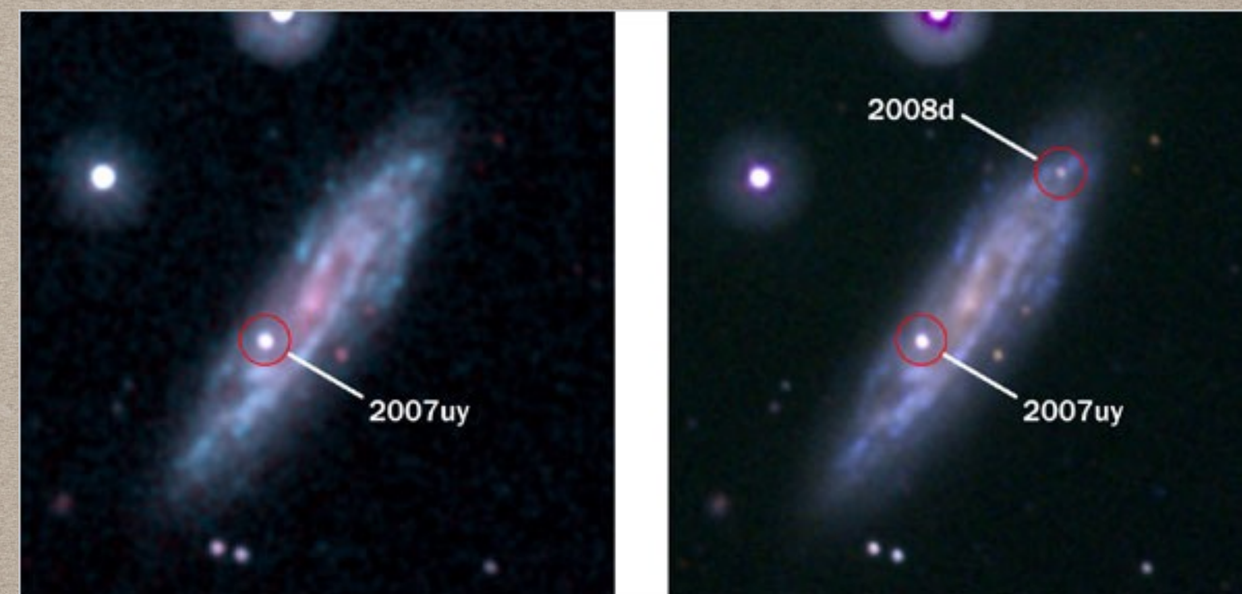
Regardless, stars end their lives either leaving a compact remnant behind, **most times a white-dwarf**, or violently explode as **supernovae**.

A large fraction of stars (> 50%) are not actually single, but rather live in binary or multiple star systems. Given that a large fraction of them is actually of low-mass, there are a lot of binary systems composed of two stars with slightly different masses, yet still "low-mass".

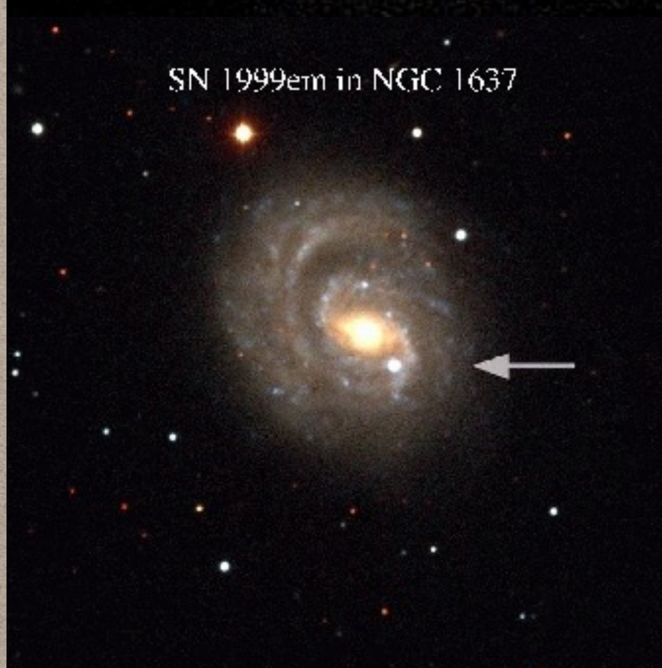
Mass transfer in binary stellar systems can also make some white-dwarfs explode, under the right conditions: Supernovae all over the place! Or not?

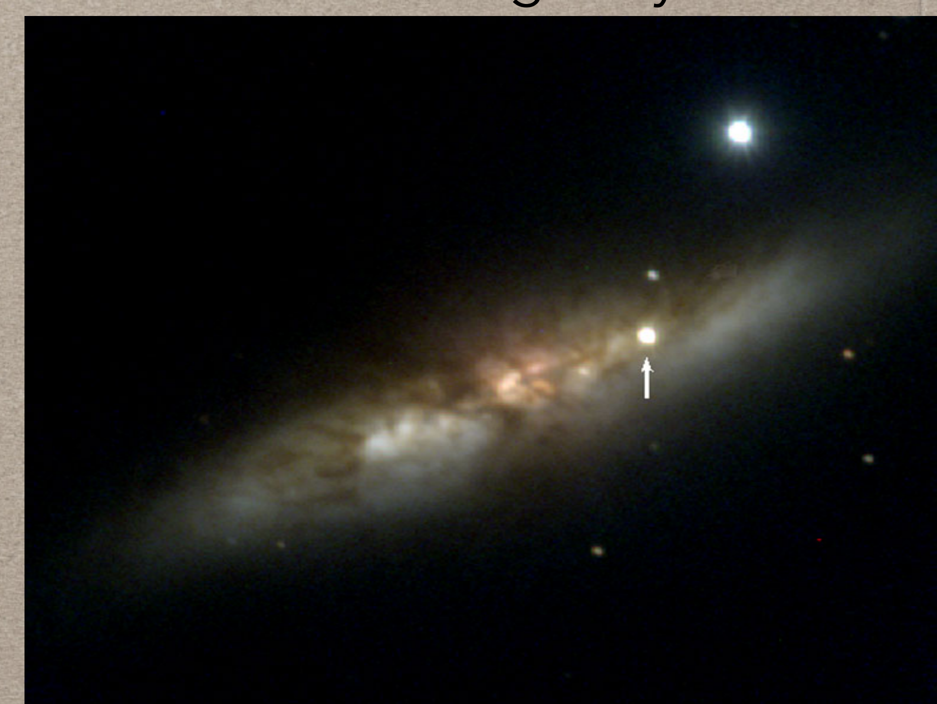
THEY ARE ALL "TRANSIENTS" AFTER ALL…

This is what we really see through our telescopes: a bright-spot appearing in a distance galaxy where there was nothing before…a spot that gets brighter for some time and then eventually fades away, usually after 1-2 weeks.



Some supernovae outshine their entire host galaxy!

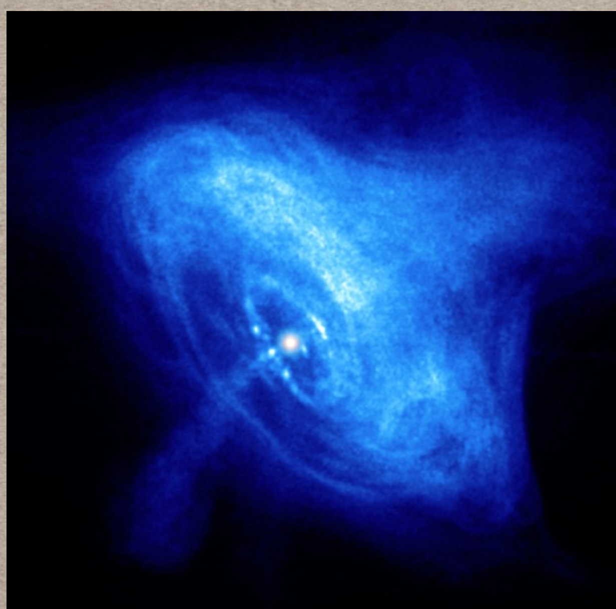


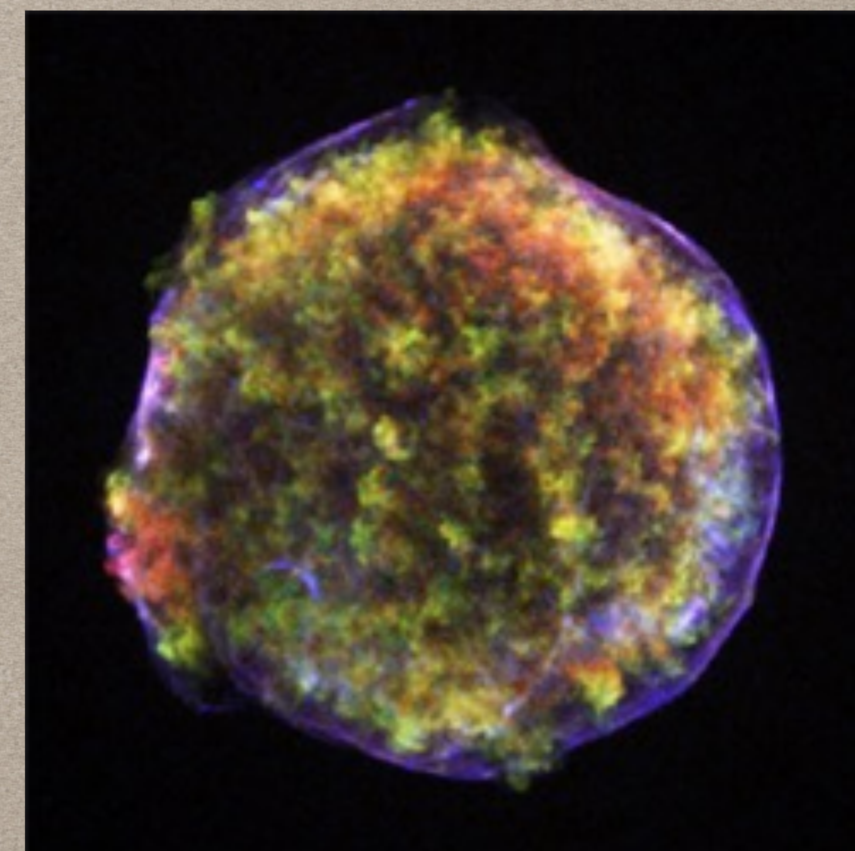


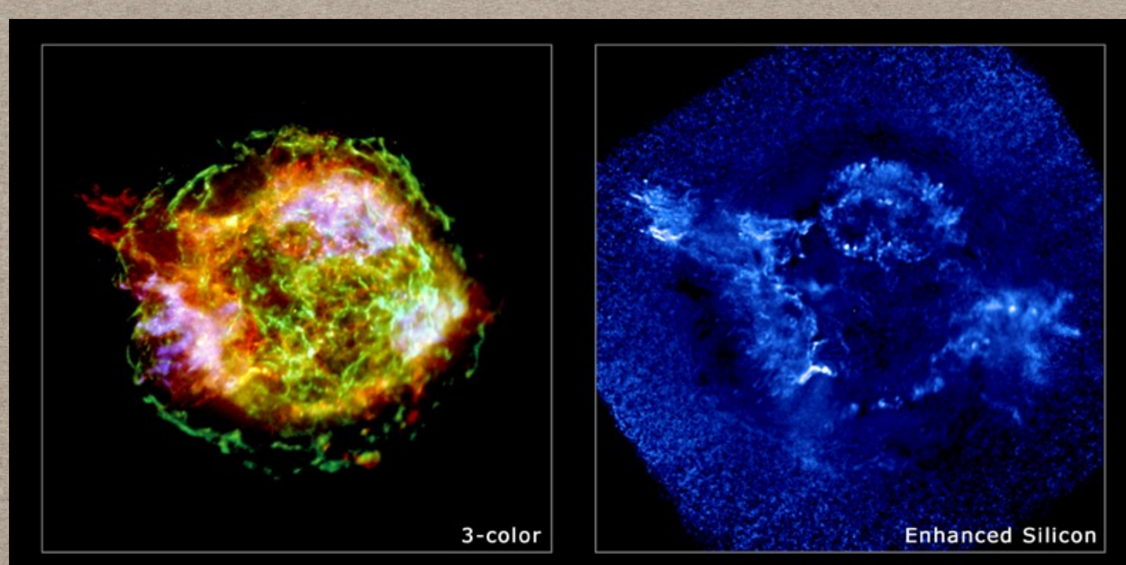
So how do we learn more things about them?

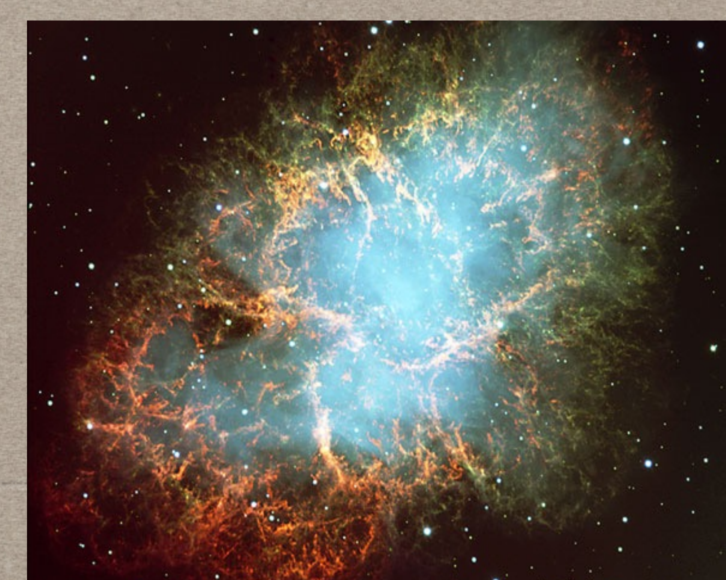
A CLOSER LOOK...

Studying **supernova remnants** from SN explosions that happened in our galactic neighborhood help us understand more things about how these events occur. We see complex three-dimensional structures of **different compositions**, **geometries**, some having **compact remnants**…





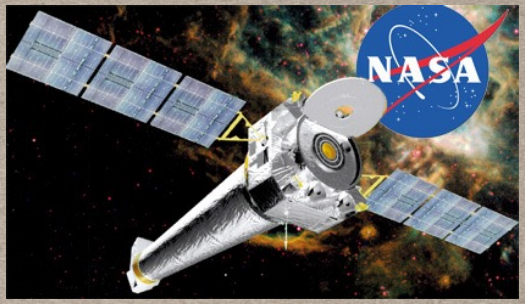




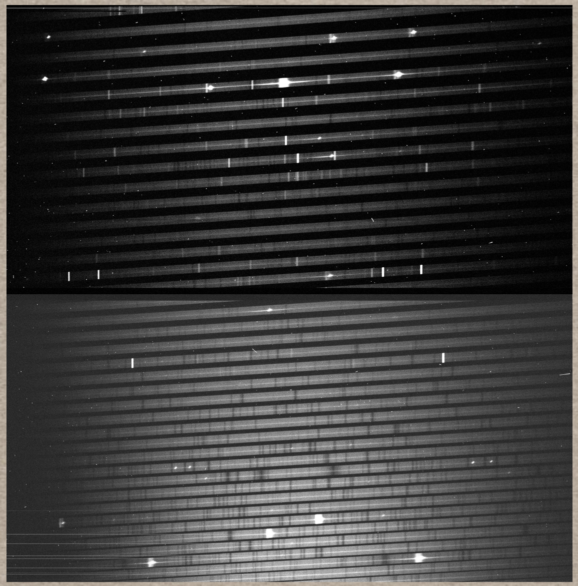
LIGHT IS ALL WE HAVE!

Hubble Space Telescope

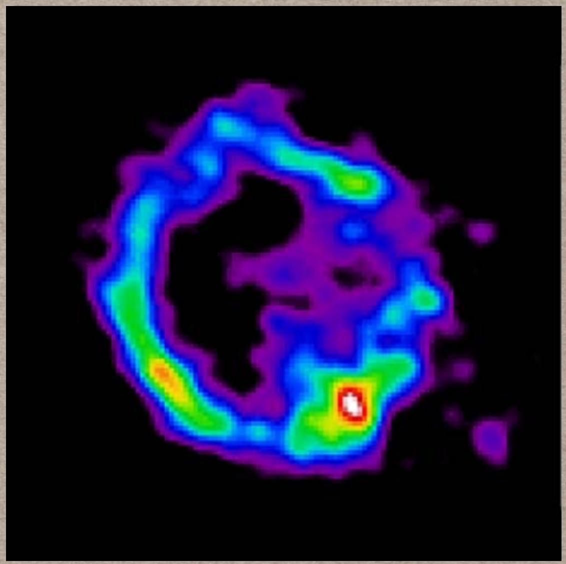
Chandra X-ray observatory



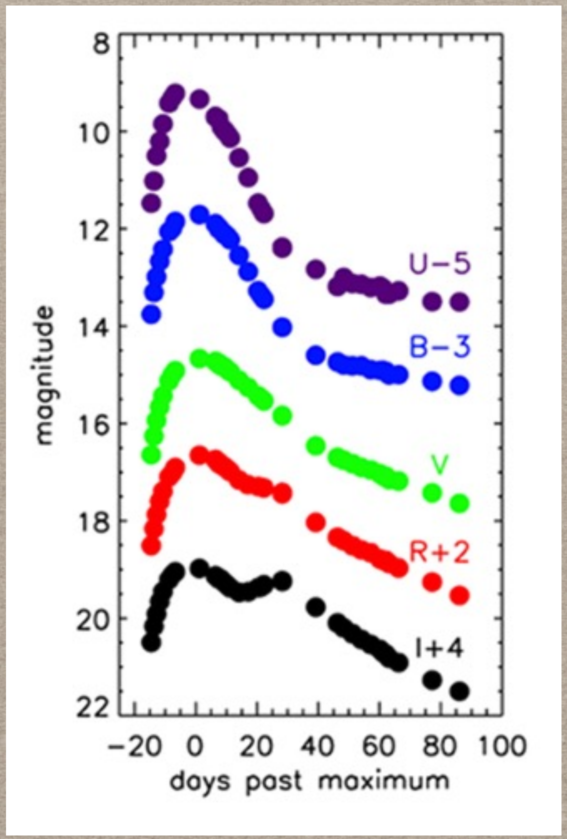
Raw spectrum



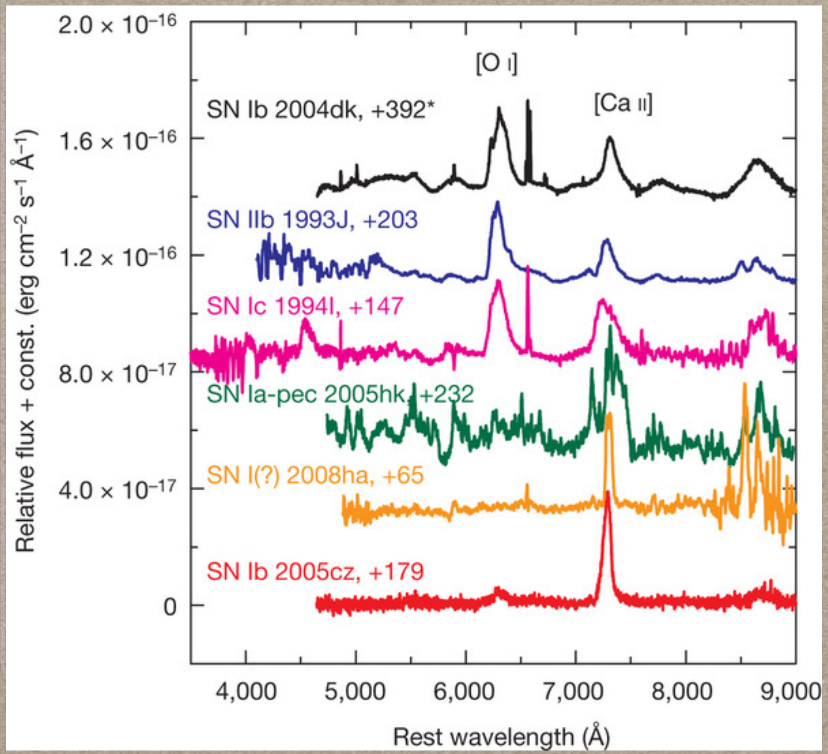
X-ray imaging



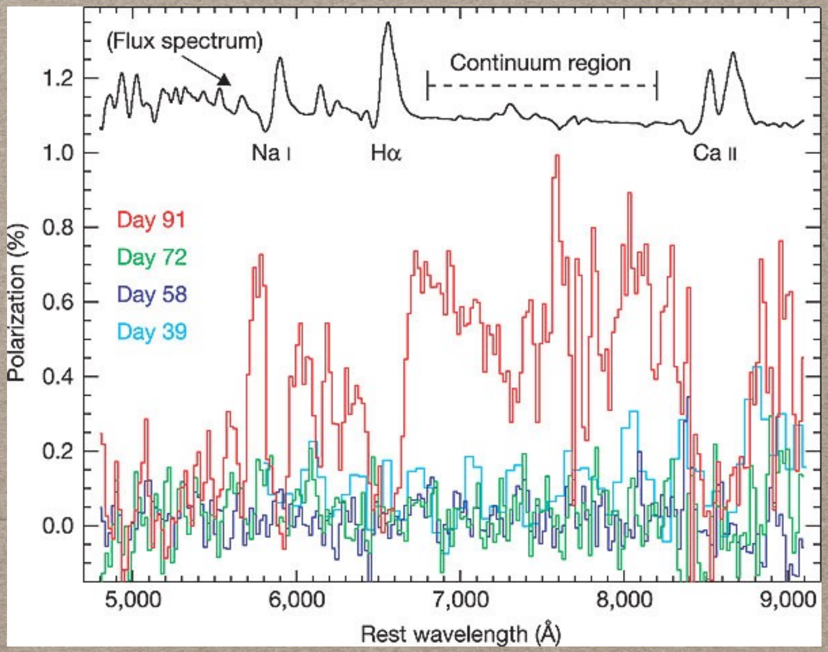
Multi-band light curves



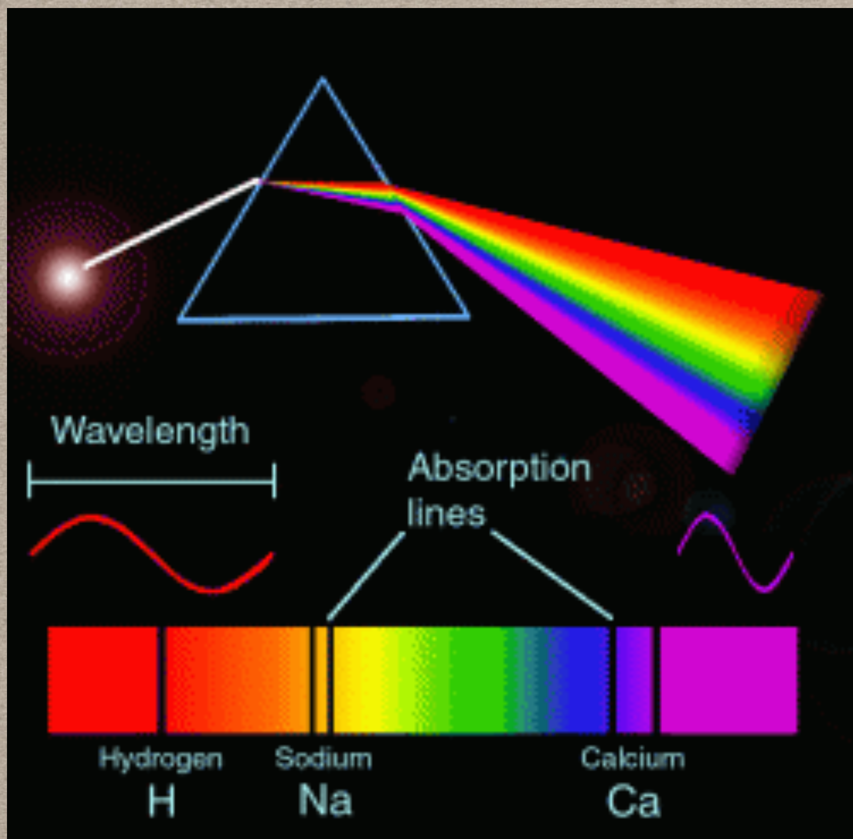
Processed spectra



Polarization



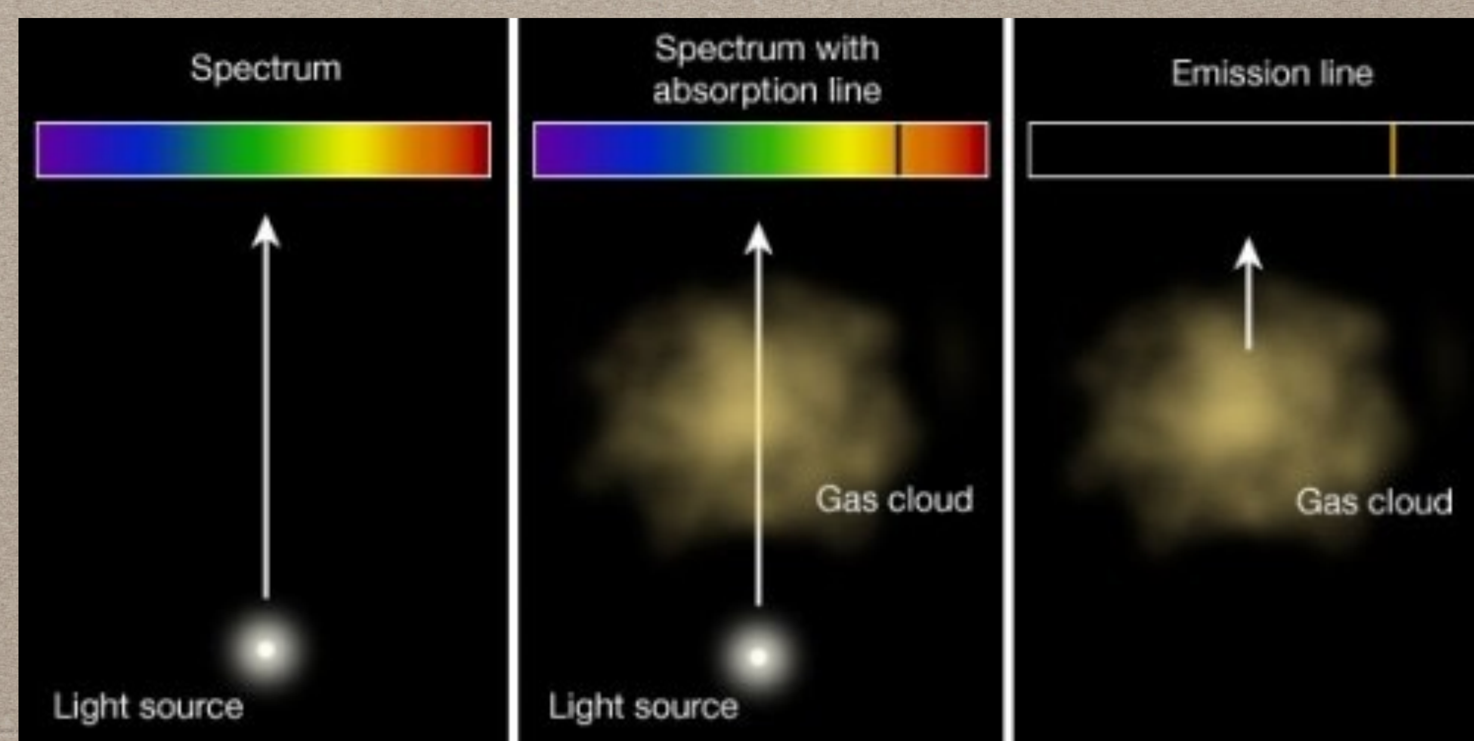
A QUICK REVIEW OF SPECTROSCOPY



1. When light passes through a prism it can be broken down to it's components or "colors" that make up the **spectrum**.

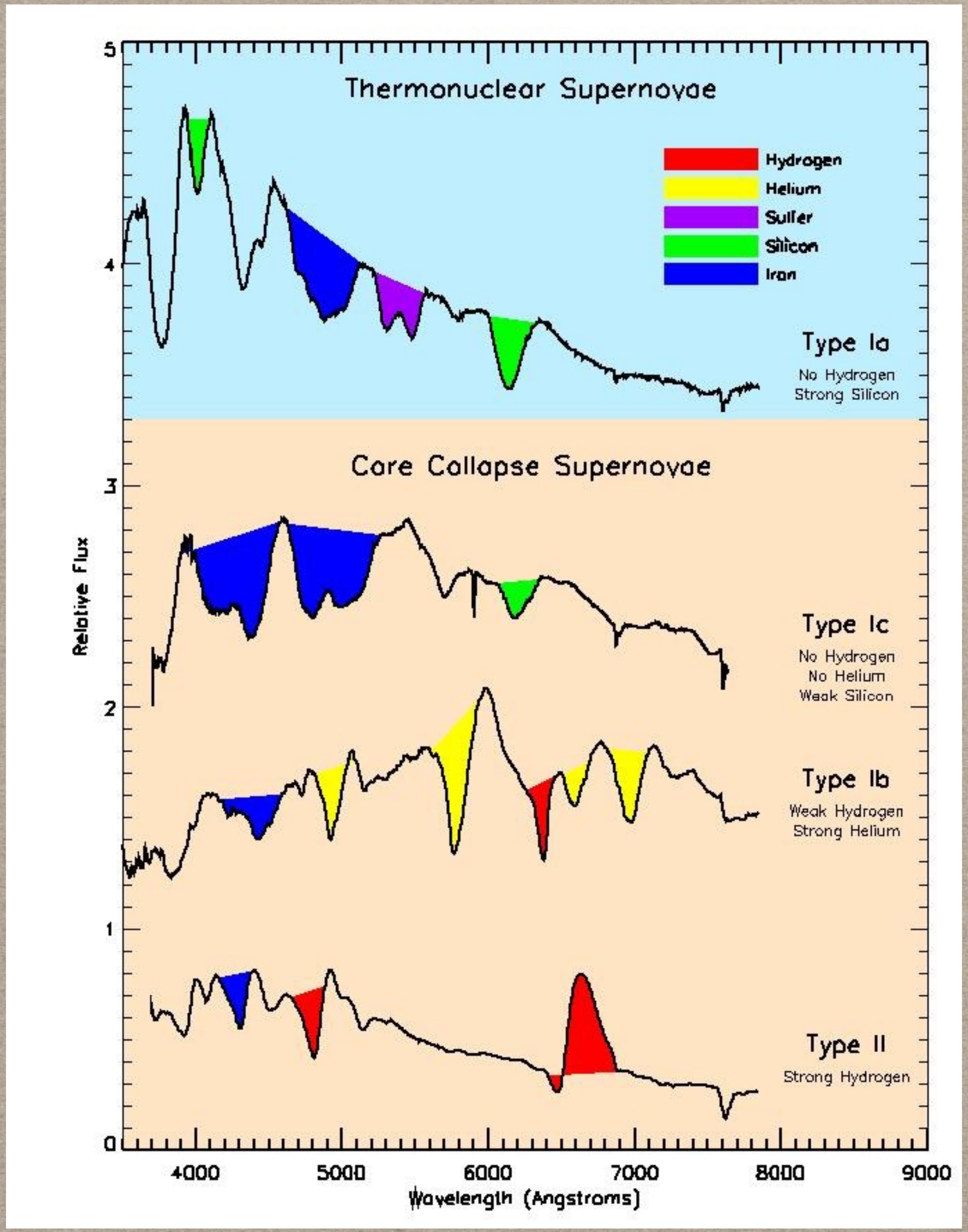
2. If the incoming light has passed through matter prior to reaching us, the "signatures" of that intervening matter are seen as **absorption lines** in the spectrum that give us insights on its **composition**.

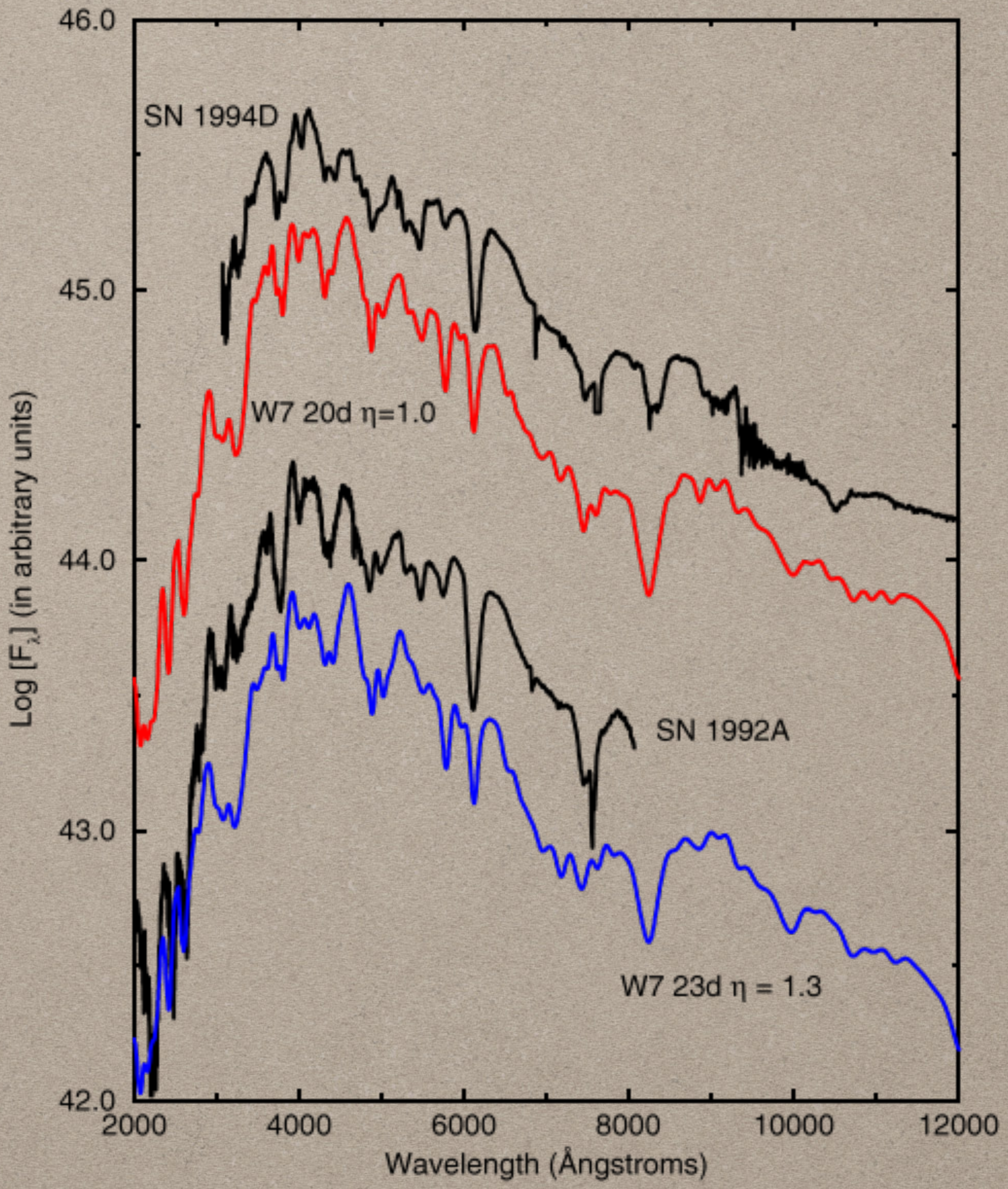
3. If matter is hot enough it can emit it's own radiation and produce **emission lines** that also tell us about its composition.



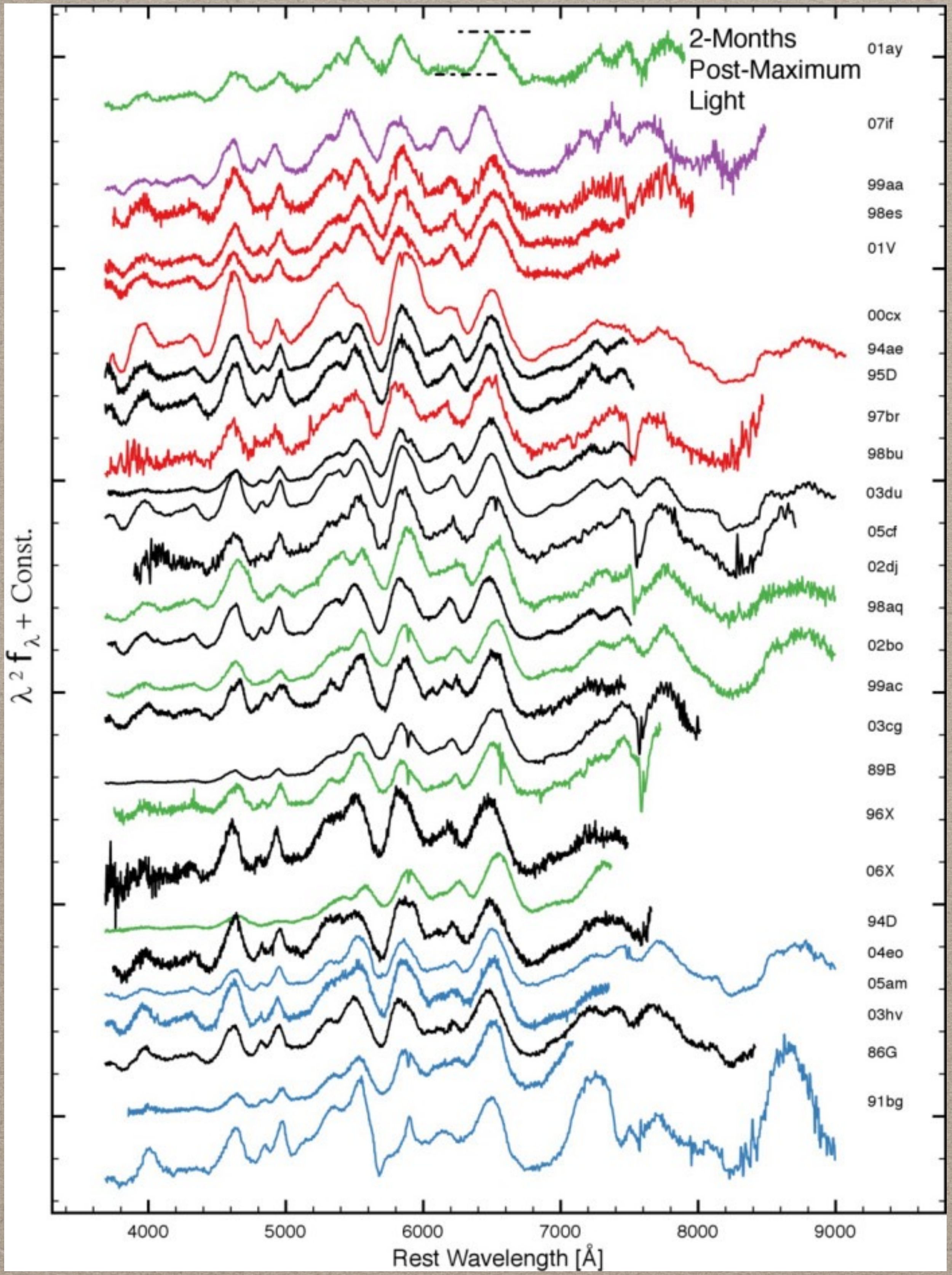
SUPERNOVA SPECTRA

A function of "intensity" or "flux" versus "wavelength" or "frequency"





SUPERNOVA TYPES: SN IA



1st category discovered

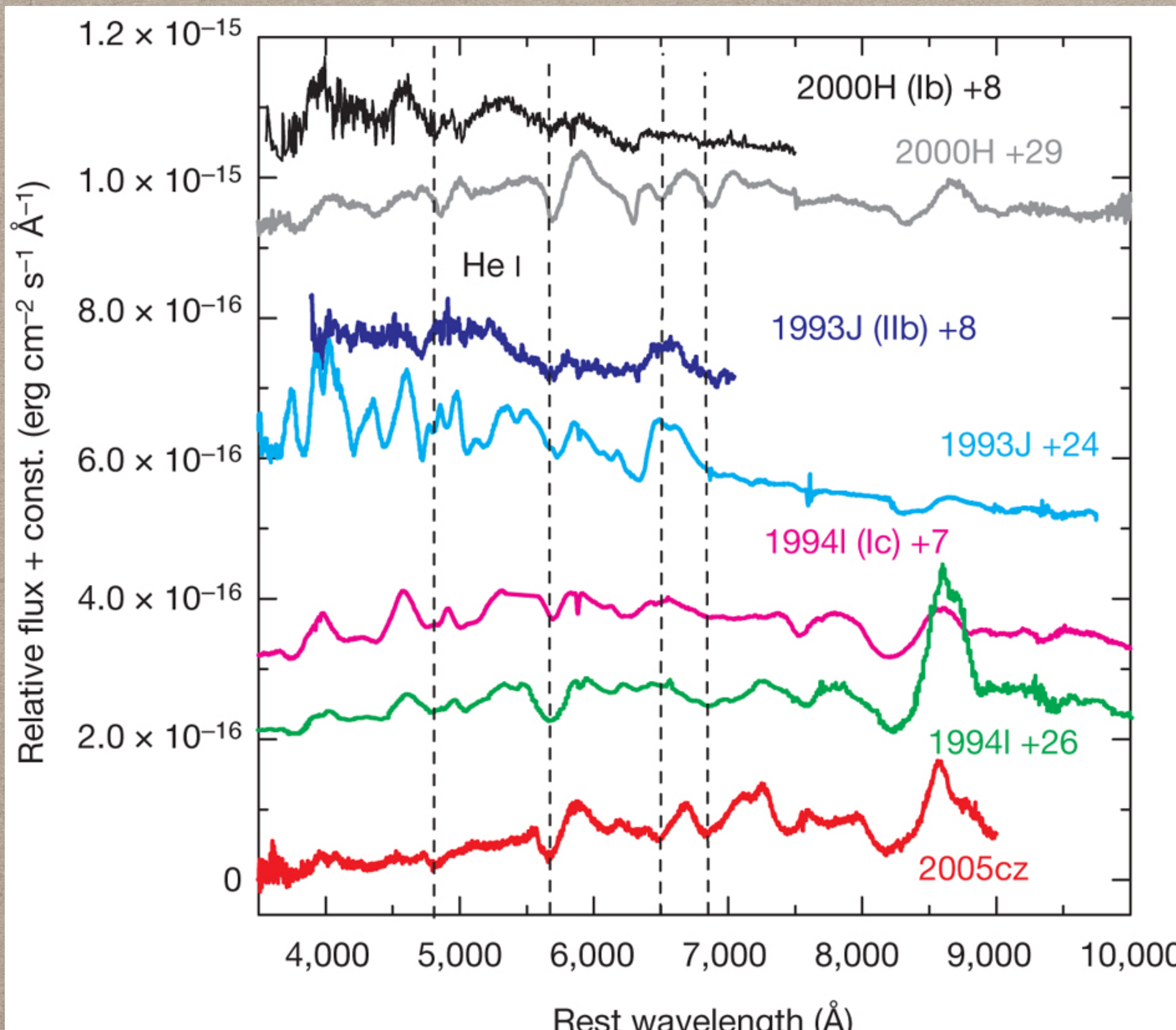
Type Ia – near peak light, no detectable Hydrogen or Helium in the spectrum, rather "intermediate mass elements" such as oxygen, magnesium, silicon, sulfur, calcium. Iron appears later as the light fades.

Type Ia occur in all galaxy types:
In **spiral galaxies** they tend to avoid the spiral arms, they have had time to drift away from the birth site → ***the star that explodes is old***

In **elliptical galaxies** where star formation is thought to have ceased long ago → ***the star that explodes is old, billions of years***

T***he progenitor that explodes must be long-lived, not very massive, suggesting a white dwarf.*** Sun is long-lived, but won't explode

SUPERNOVA TYPES: SN II



Type II Supernovae - "other" type discovered early in the study of supernovae, show Hydrogen in the spectrum early, Oxygen, Magnesium, Calcium, later

Most occur in spiral galaxies, *in the spiral arms*, ***they have no time to drift from the birth site***

never in elliptical galaxies (no young stars)

Stars with more mass have more fuel, but they burn it at a prodigous rate, live a shorter time!

→***The progenitor stars are young, short-lived (millions to tens of millions of years) massive stars***

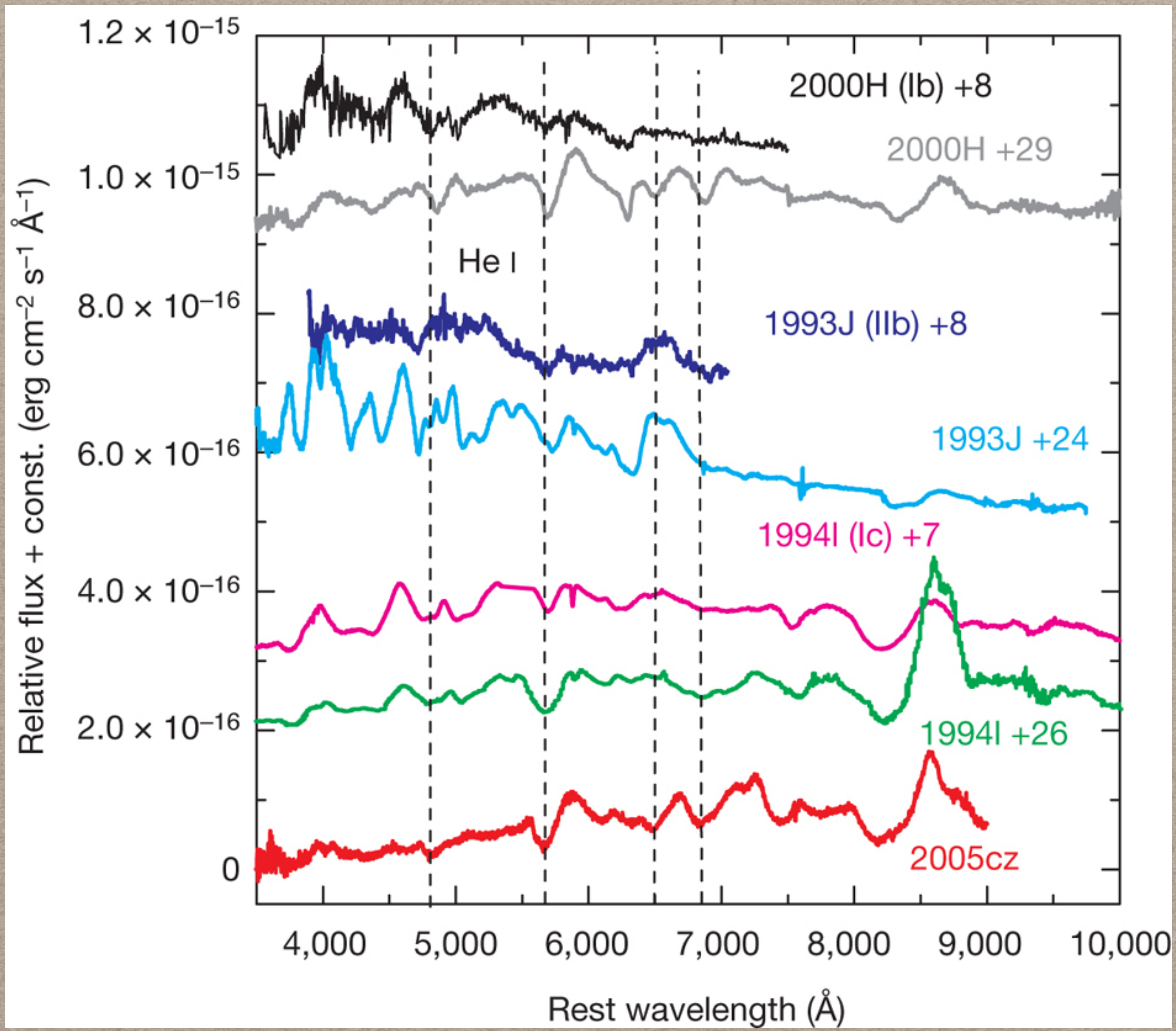
We expect such stars to evolve to form iron cores and collapse to a neutron star or black hole (physics to come)

SOME SUPERNOVA SUB-TYPES

Stripped-envelope SN Ib/c

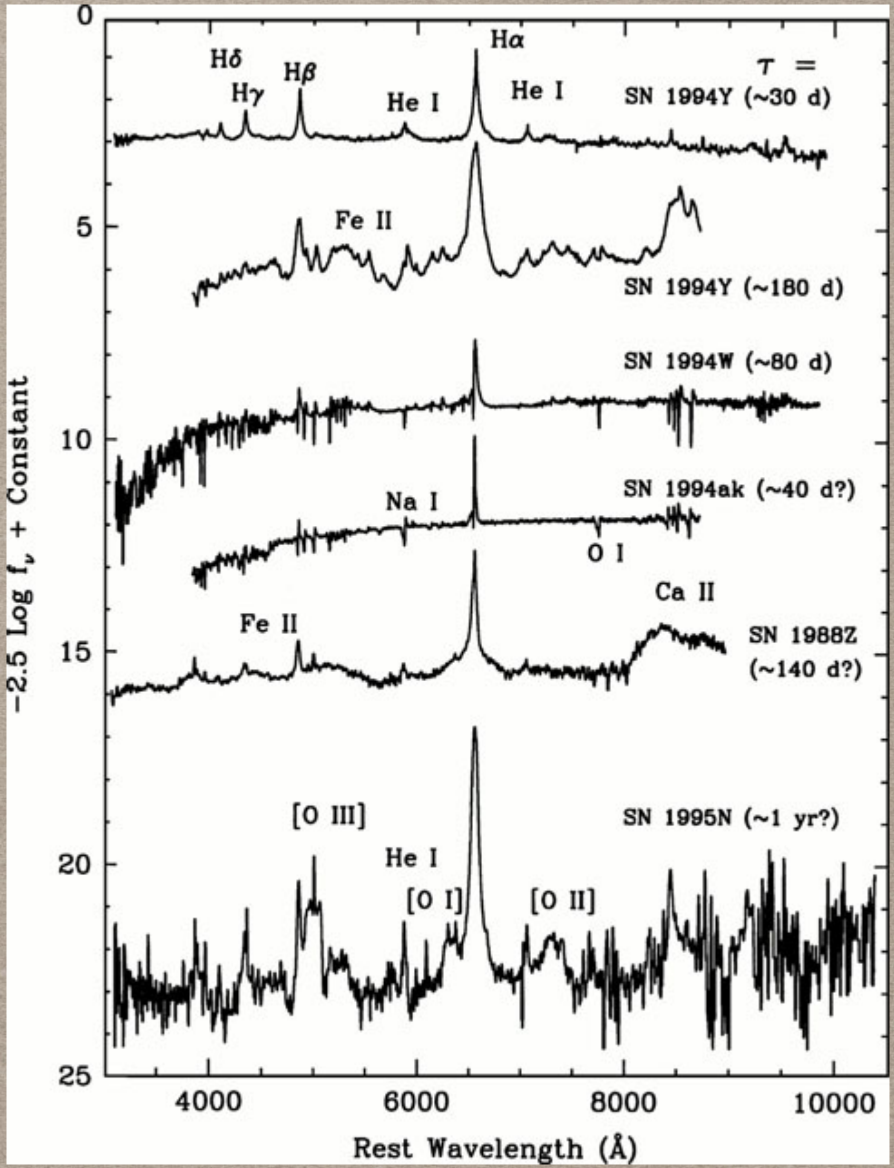
Ib: *He present in the spectra but H absent. Lost their H-envelope. Some turn into type II at later times (Type IIb).*

Ic: *Neither H or He present in the spectra. Lost both H/He layers. Some turn into Ib at later times (Type Ibc).*



Interacting SN IIn

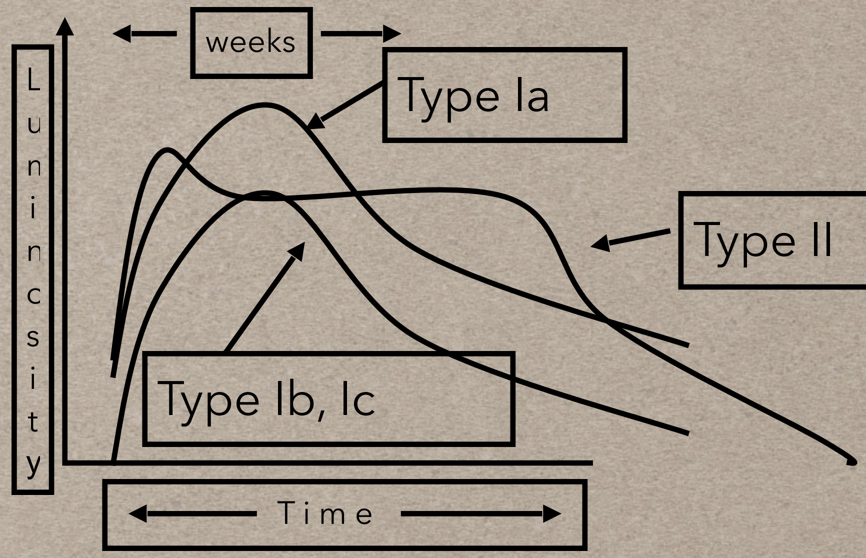
Show strong emission lines of H and/or He due to interaction with "circumstellar" matter.



SUPERNOVA LIGHTCURVES

Ejected matter must expand and dilute before photons can stream out and supernova becomes bright: ***must expand to radius ~ 100 × Earth orbit***

Maximum light output ~ 2 weeks after explosion

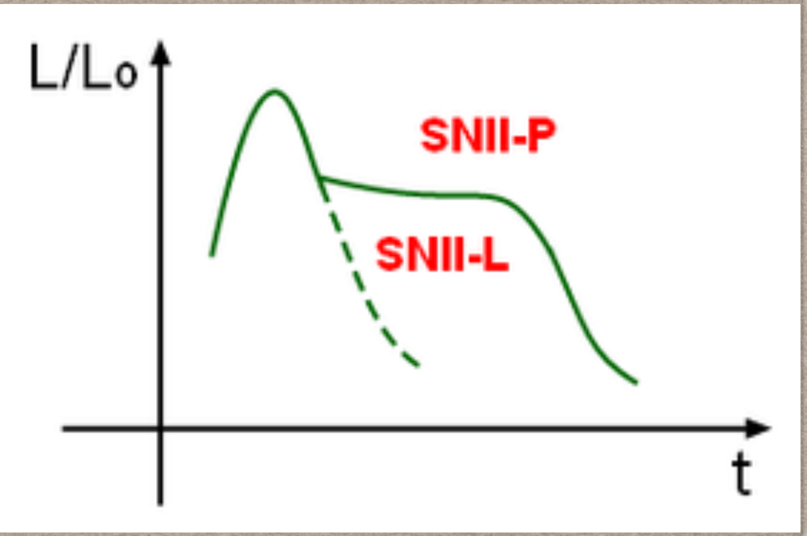


Type II in red giants have head start, radius already about the size of Earth's orbit; light on plateau comes from *heat of original explosion*

Ejected matter cools as it expands: for white dwarf (Type Ia) or bare core (Type Ib, Ic) tiny radius about the size of Earth, must expand huge factor > 1,000,000 before sufficiently transparent to radiate.

All heat of explosion is dissipated in the expansion
By time they are transparent enough to radiate, there is no original heat left to radiate
Need another source of energy for Type I a, b, c to shine at all!

Type II-"Pleteau" and Type II-"Linear" SNe



AND WHAT EXACTLY MAKES THEM SHINE?

Fast explosion of C/O in Type Ia and shock hitting layer of Si in Type Ib, Ic make element closest to iron (with same total p + n), but with #p = #n, **Nickel-56.**

Nickel-56: 28p, 28n total 56 -- Iron-56: 26p, 30n total 56

Ni-56 is unstable to **radioactive decay**

Nature wants to produce iron at bottom of nuclear "valley"
Decay caused by (slow) weak force p → n

Nickel -56	γ-rays heat	**Cobalt-56**	γ-rays heat	**Iron-56**
28p	"half-life"	27p	"half-life"	26p
28n	6.1 days	29n	77 d	30n

Secondary heat from radioactive decay γ-rays makes Type I a, b, c shine

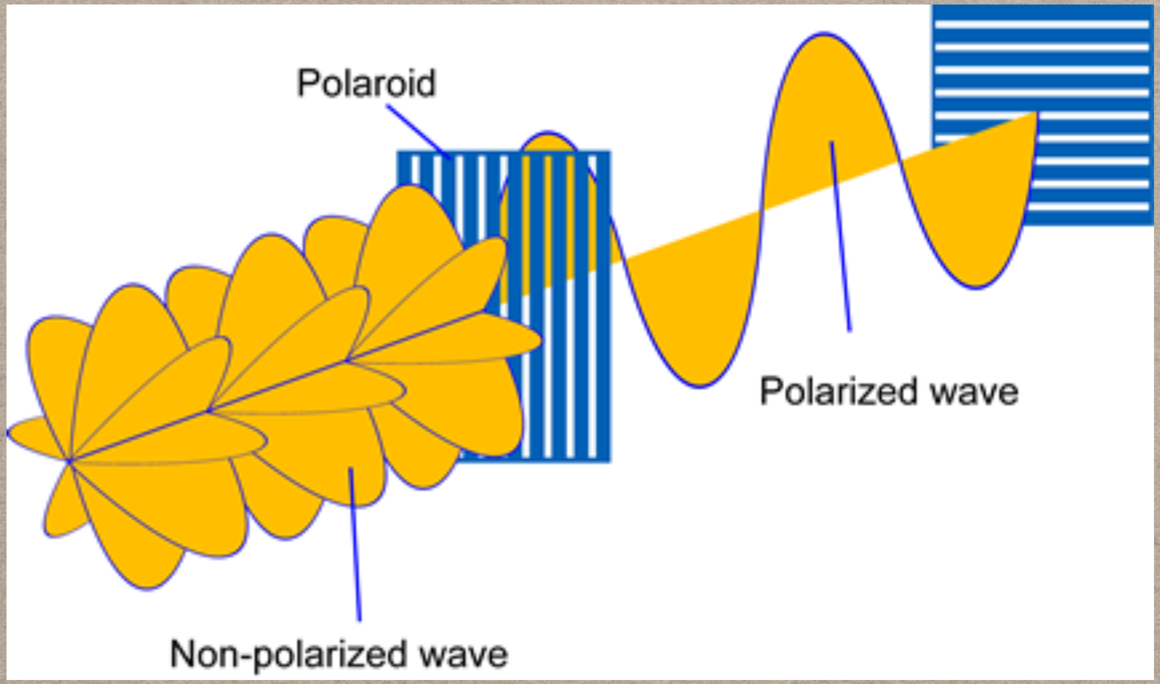
Type Ia are brighter than Type Ib and Ic because they produce more nickel-56 in the original explosion.

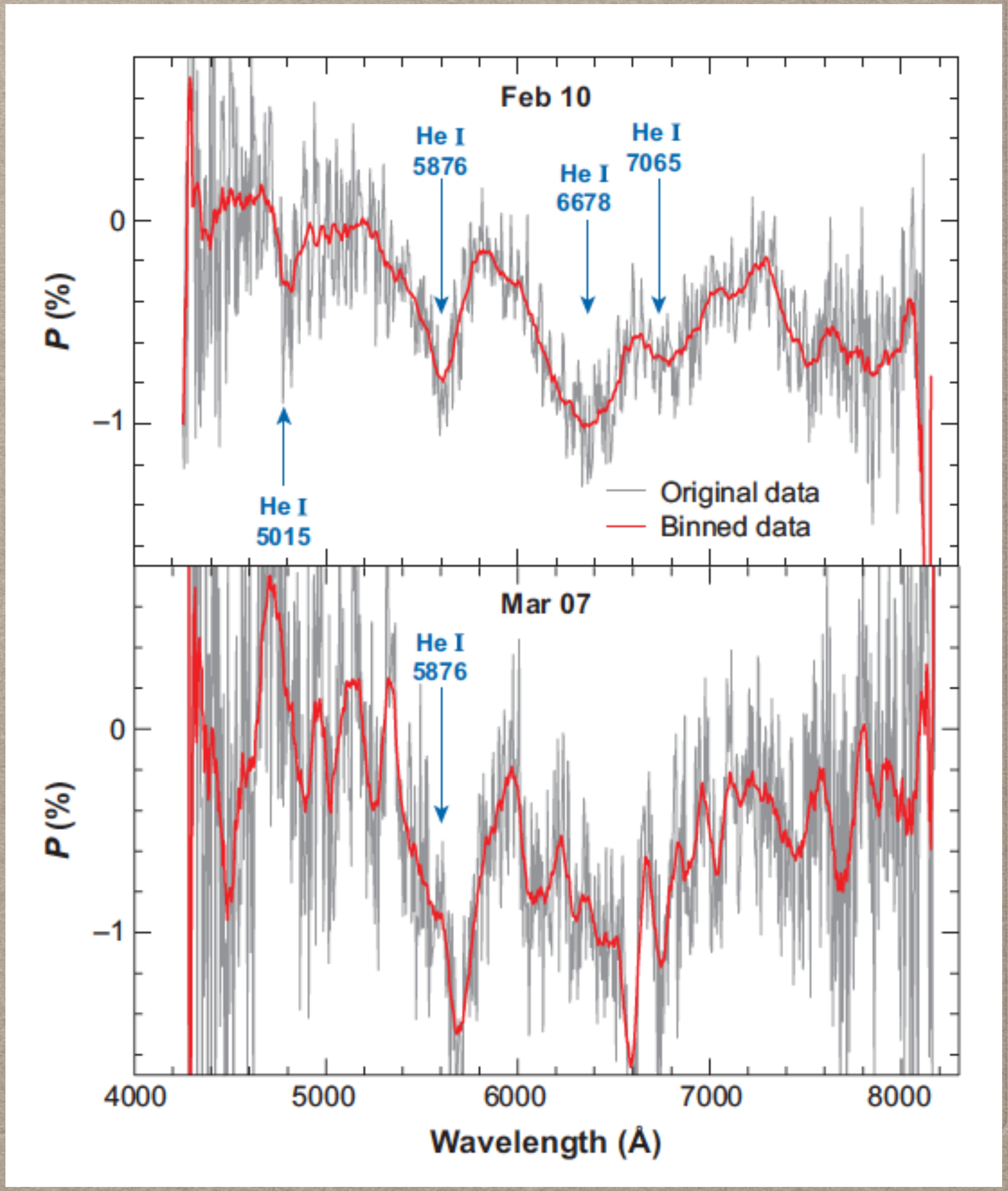
The thermonuclear burning of C and O in a white dwarf makes about 0.5 - 0.7 solar masses of Ni-56. A core-collapse that blasts the silicon layers makes about 0.1 solar masses of Ni-56.

POLARIZATION

Normal light is made up of electro-magnetic waves oscillating perpendicular to each other. If passed through a filter, the oscillation plane is forced constant and light oscillates in a fixed direction -> polarized light.

Looking at supernova polarization using "polarimeters" help us understand a lot about the shape of supernova ejecta!

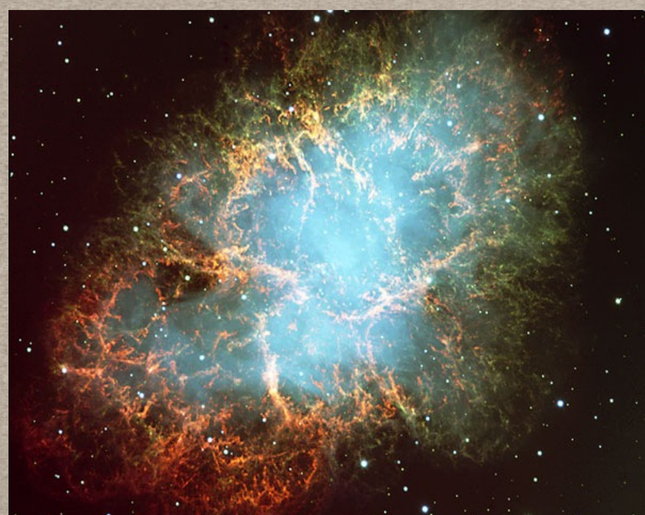




EXAMPLES OF SUPERNOVA TYPES

TYPE II

SN 1054 (Crab nebula)

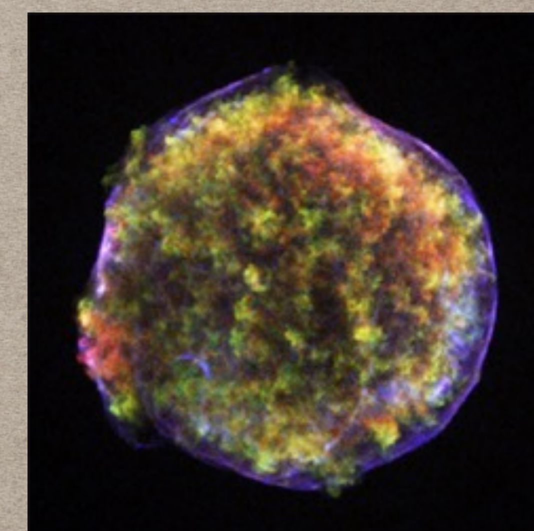


SN1987A

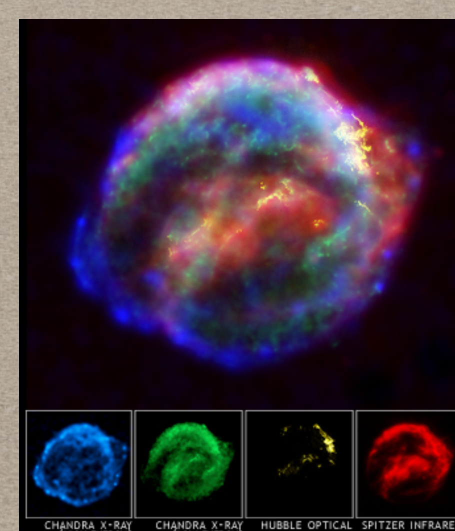
TYPE Ia

SN 1006

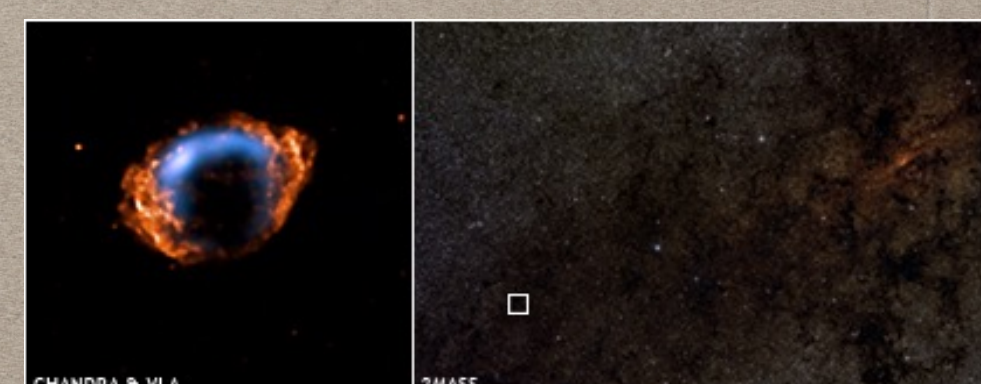
SN 1572 (Tycho)



SN 1604 (Kepler)



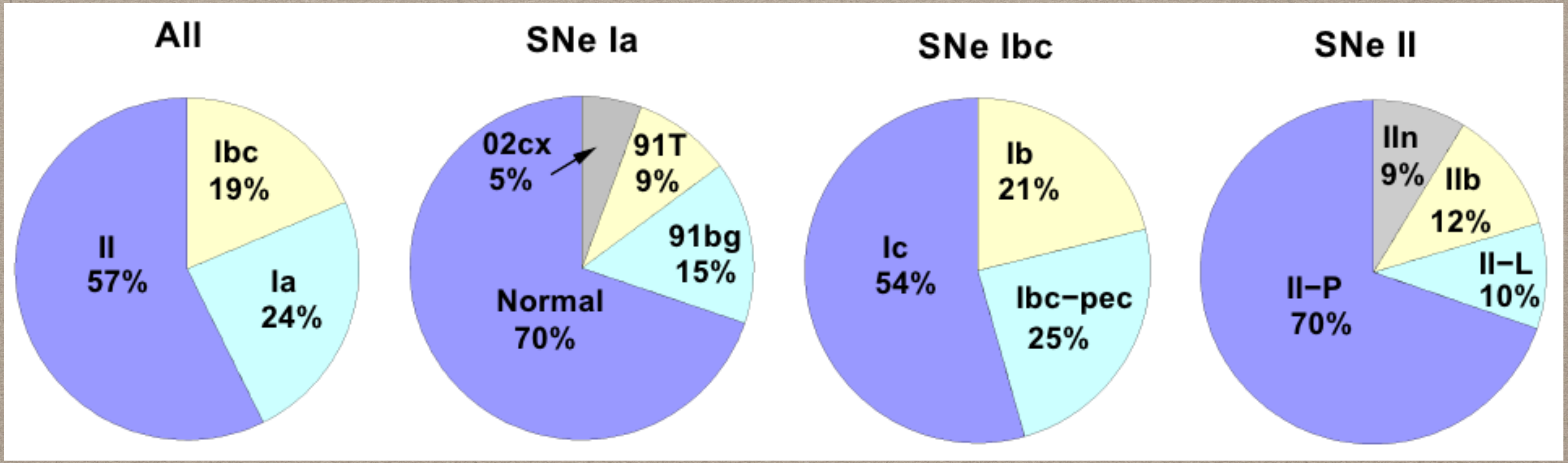
G1.9+0.3



SUPERNOVA DEMOGRAPHICS & RATES

Host galaxy type	Rate
Spiral	*~ 1 in 20 years*
Irregular	*~ 1 in 2 years*
Elliptical	*~ 3 in 100,000 years*

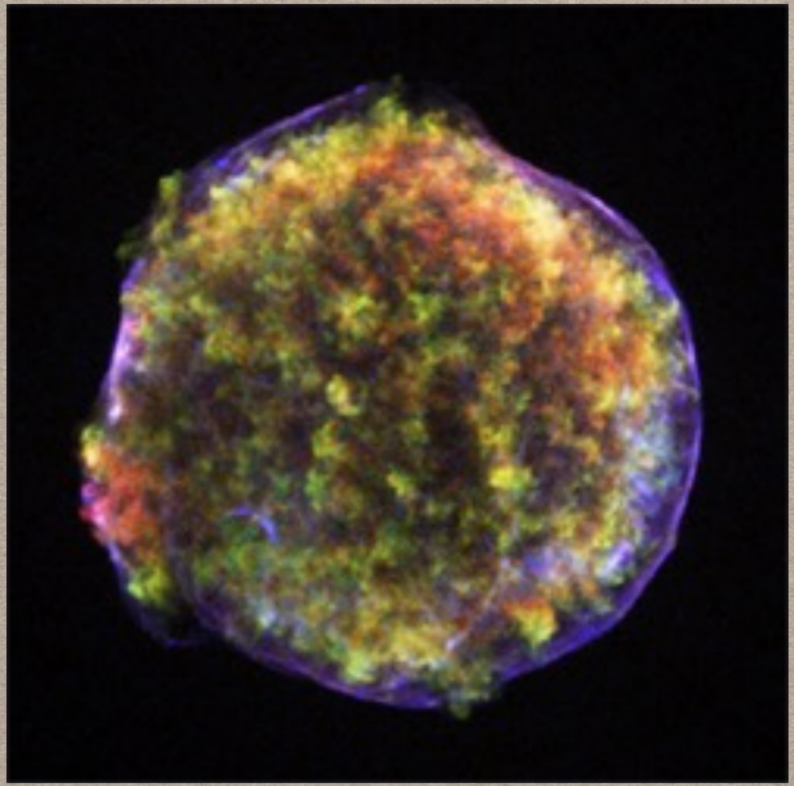
We are well overdue a SN here in the Milky Way galaxy! Keep looking up…



WHAT'S LEFT BEHIND?

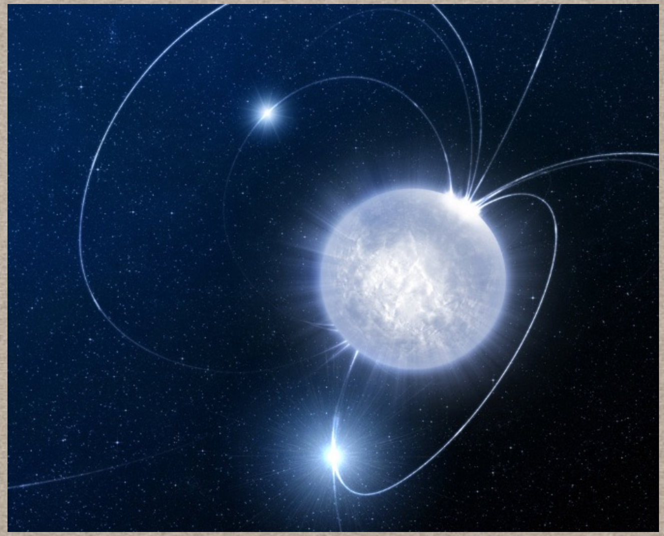
TYPE Ia

No remnant…people are still looking for the companion star however!



TYPE II

Compact "neutron star" or pulsar.



Black hole

SUMMARY

- Everything we learn about supernova comes from analyzing their light (spectra, polarization) and measuring how it's intensity evolves over time (light curves).
- Type Ia SNe come from explosions of white dwarfs in binary systems and do not show signs of He, but strong Si absorption.
- Type II SNe show H in the spectra. Subtypes are IIP, IIn, IIL.
- Type Ib/c SNe have lost their H (Ib) and sometimes also He (Ic) envelopes.
- Most supernova light curves are consistent with being powered by the radioactive decays of nickel-56 and cobalt-56 to iron-56.
- Supernovae are rare in Elliptical galaxies but more frequent in irregular and spiral galaxies.
- Type Ia supernova leave no remnants behind; Type II (core-collapse) supernova leave compact remnants such as neutron stars and black holes.