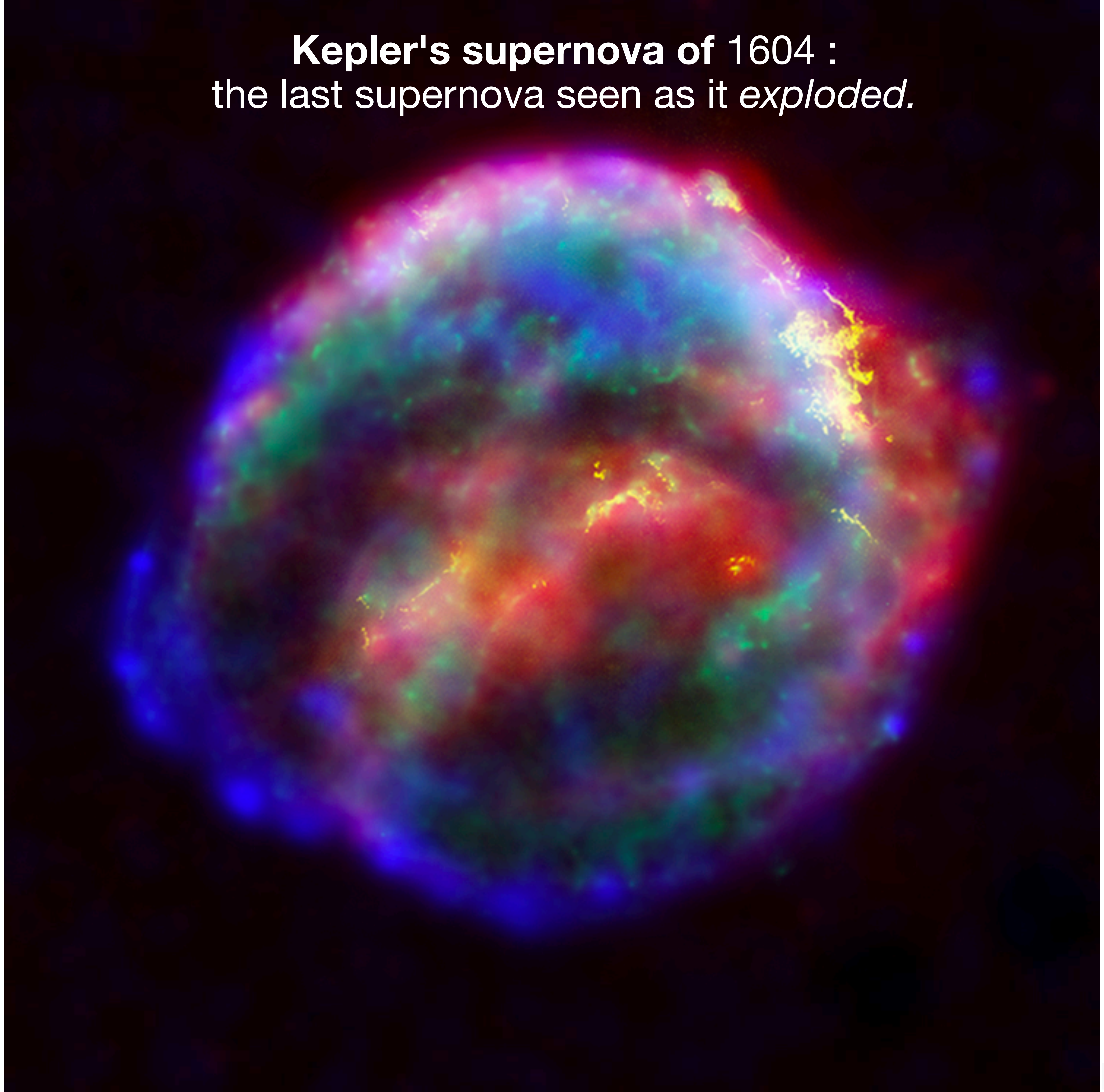
SUPERNOVAE

Part D (complement
to Thomas Janka’s slides)

Supernovae have been seen and documented by humans for over 2000 years.

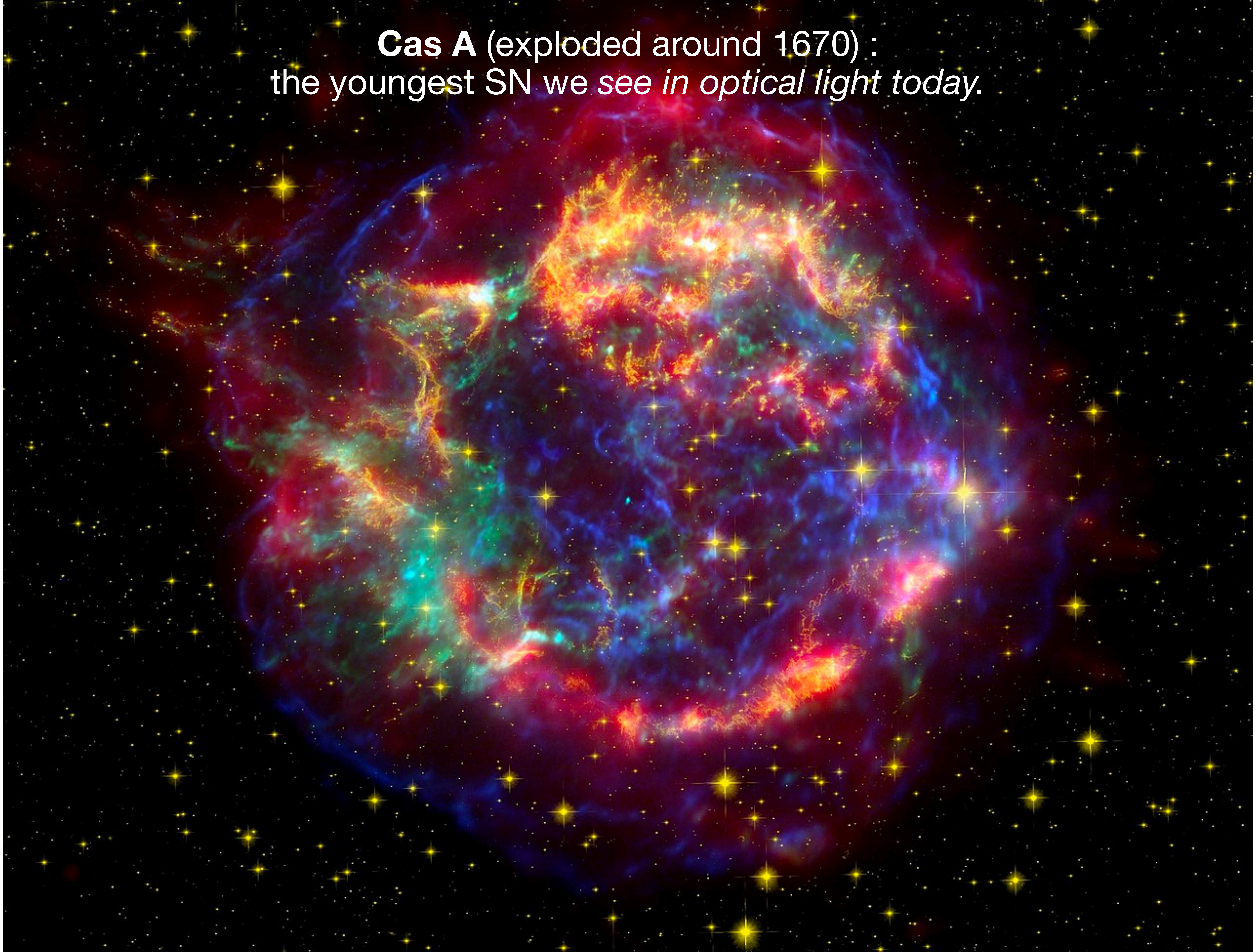
Drawing of when **Tycho Brahe** observed **Supernova 1572** from Herrevad’s Kloster in Skåne.

Kepler's supernova of 1604 :
the last supernova seen as it *exploded.*



NASA/ESA/JHU/R.Sankrit & W.Blair

Cas A (exploded around 1670) :
the youngest SN we *see in optical light today.*



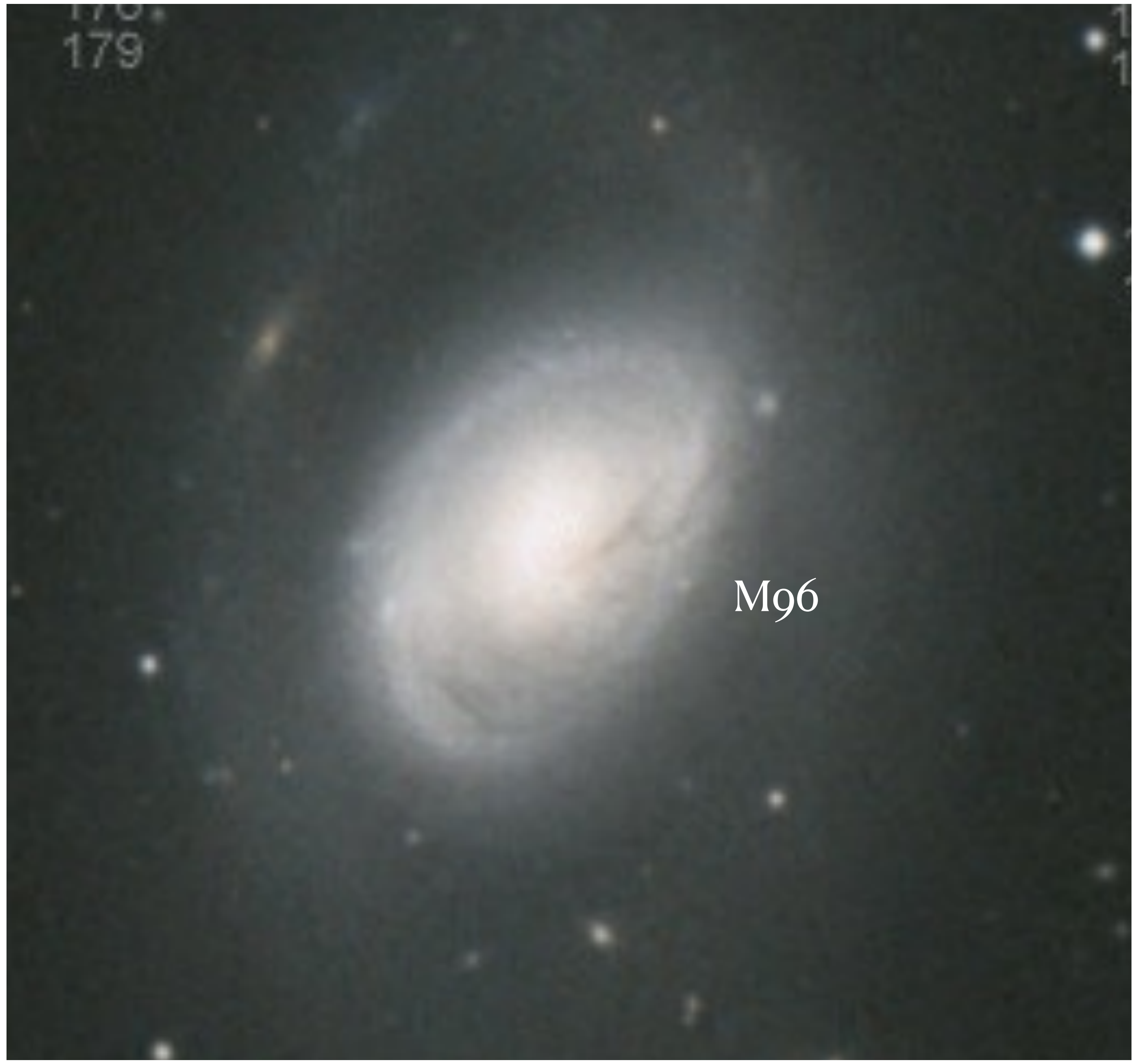
NASA/JPL-Caltech

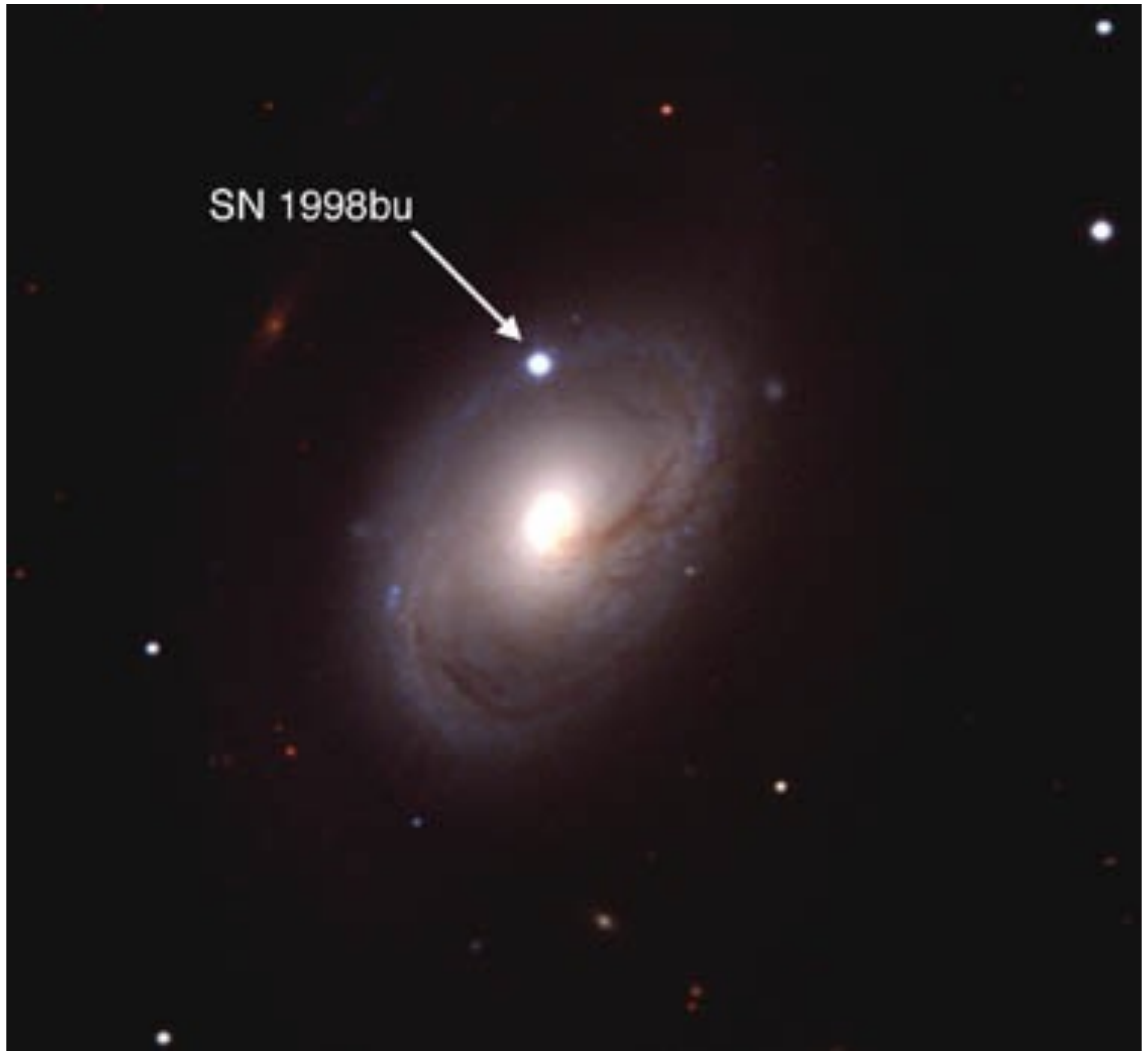
G1.9+0.3 (exploded around 1900) :
the youngest SN we see at *any waveband (radio, X-rays,..) today.*

NASA/CXC/NCSU/S.Reynolds et al.

SNe are so bright we can see them in other galaxies

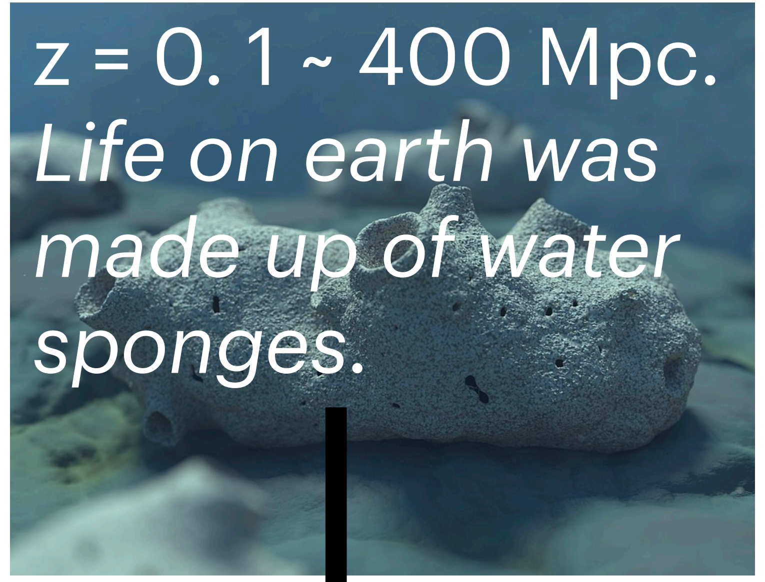
Under a few months/weeks they are as bright as a whole galaxy.

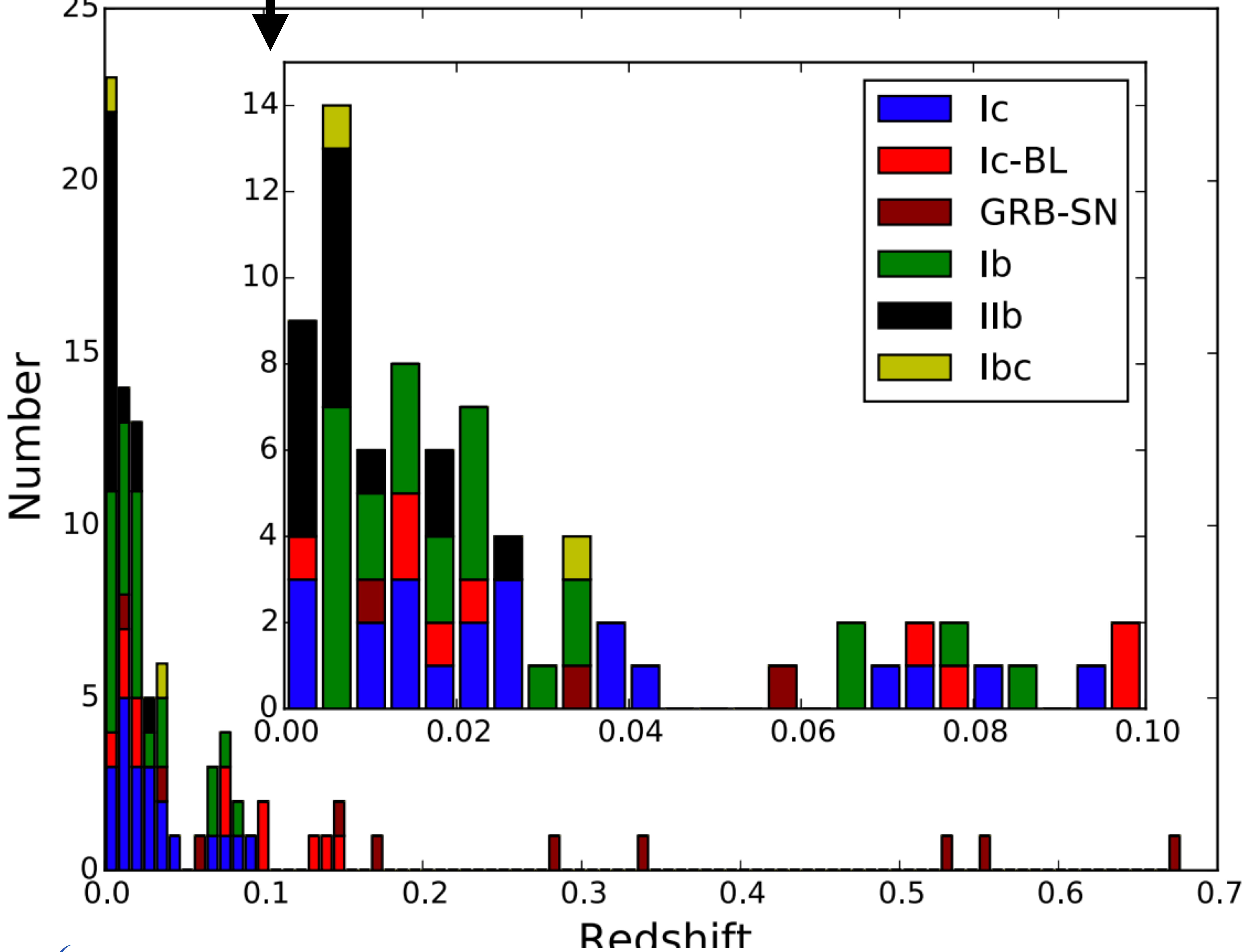




Credit: O.Trondal/N Suntzeff.

The distances to SNe

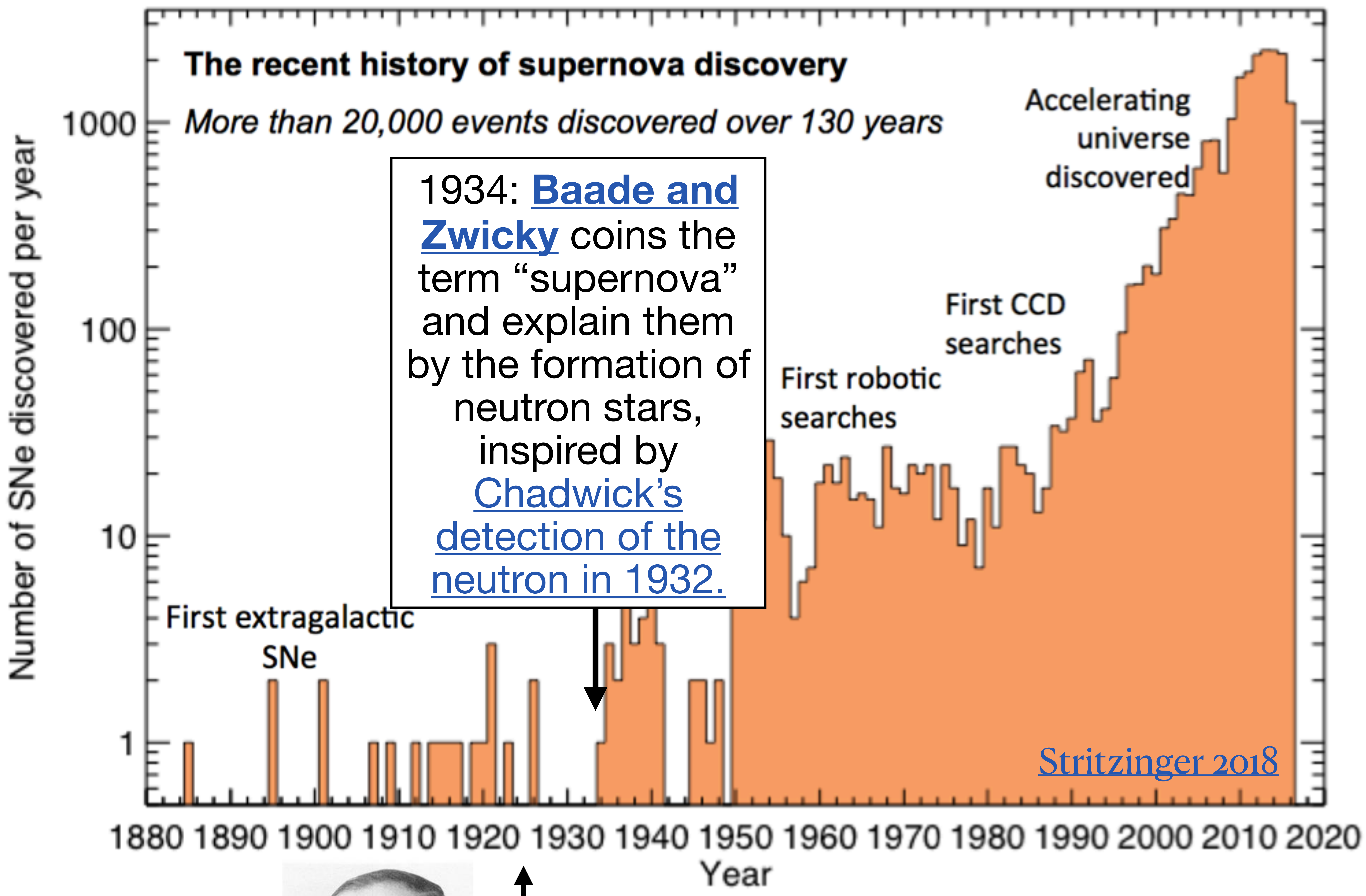




- Most detected SNe within redshift z ~ 0.05 (~200 Mpc). (Andromeda is 0.8 MPc away).
- Discoveries beyond z ~ 0.15 (~600 Mpc) usually following a Gamma Ray Burst (GRB) trigger.

Prentice 2016

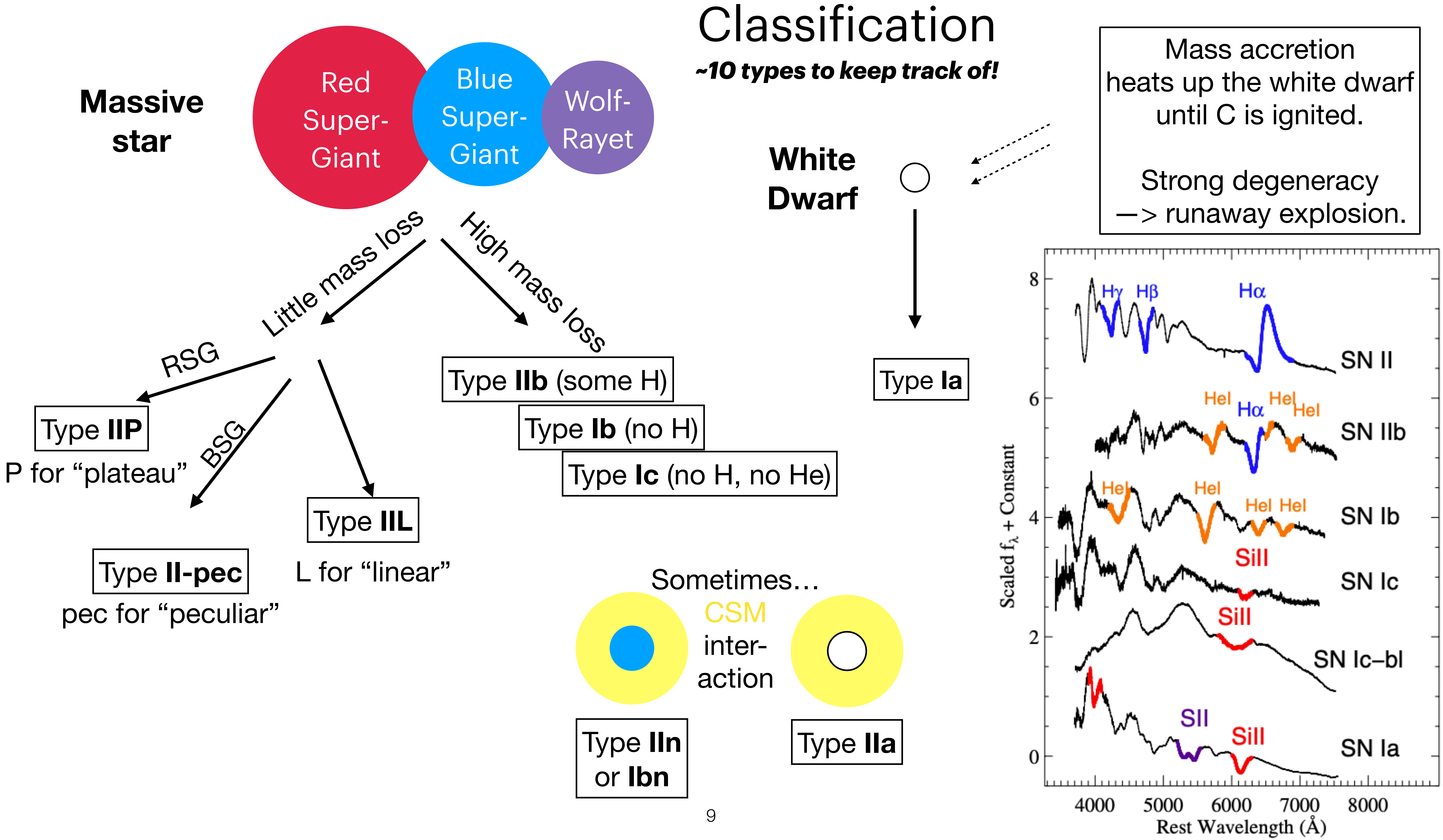
Supernova discoveries



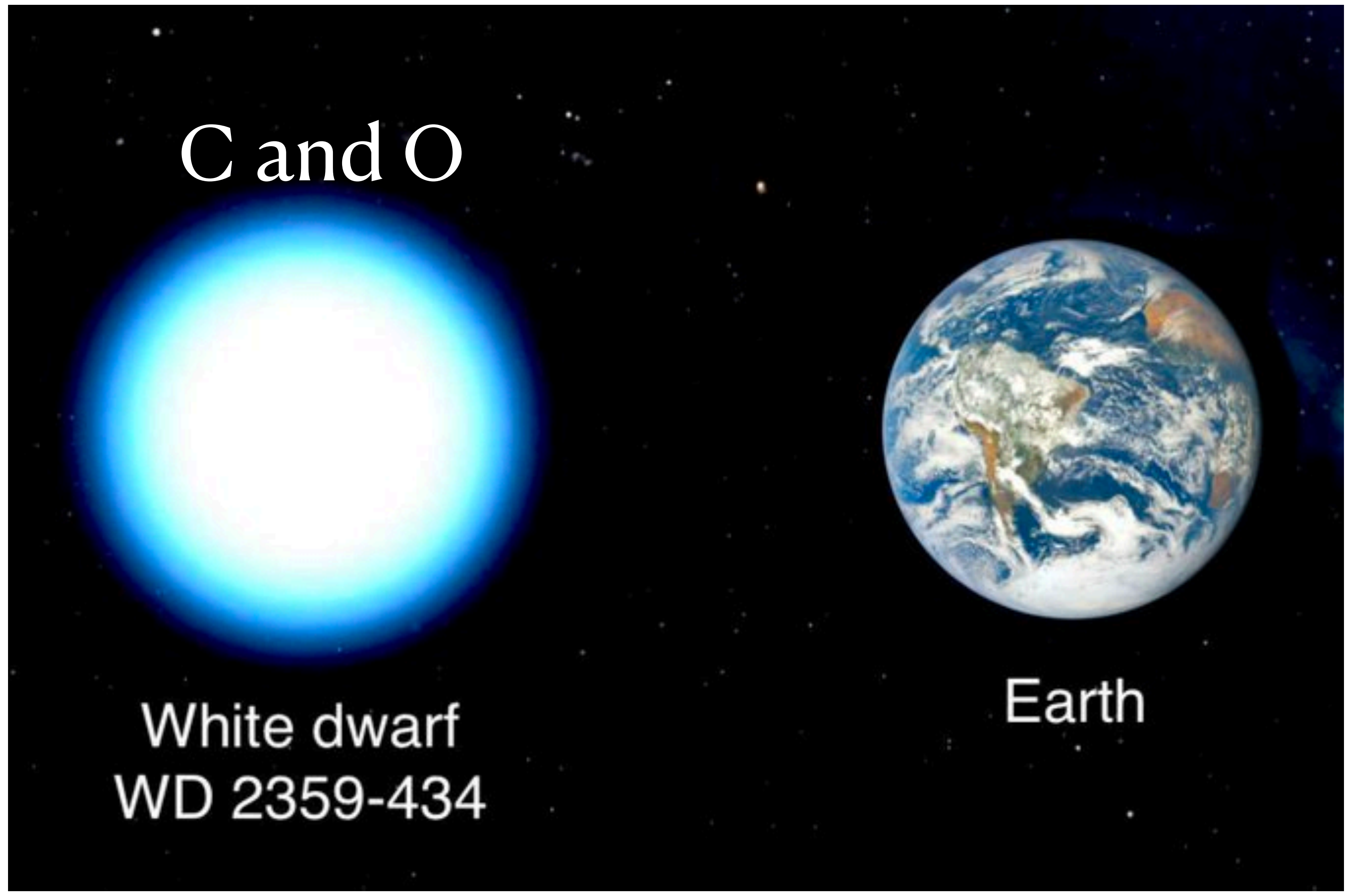
1934: **Baade and Zwicky** coins the term “supernova” and explain them by the formation of neutron stars, inspired by Chadwick’s detection of the neutron in 1932.

- Today several 1000 discovered per year : automated survey telescopes have revolutionised.
- About 1 SN occurs per second in the universe : vi discover about 1 in 30,000 of these.

1925 : **Knut Lundmark** is the first person to realize SNe are something different to novae.


Classification
~10 types to keep track of!
Massive star
Red Super-Giant
Blue Super-Giant
Wolf-Rayet
Little mass loss
High mass loss
RSG
BSG
Type IIP
P for "plateau"
Type II-pec
pec for "peculiar"
Type IIL
L for "linear"
Type IIb (some H)
Type Ib (no H)
Type Ic (no H, no He)
White Dwarf
Type Ia
Mass accretion heats up the white dwarf until C is ignited.
Strong degeneracy —> runaway explosion.
Sometimes…
CSM inter-action
Type IIn or Ibn
Type IIa
Hγ Hβ Hα
SN II
HeI Hα HeI HeI
SN IIb
HeI HeI HeI HeI
SN Ib
SiII
SN Ic
SiII
SN Ic–bl
SII SiII
SN Ia
Scaled f$_\lambda$ + Constant
Rest Wavelength (Å)
0
2
4
6
8
4000
5000
6000
7000
8000

Type Ia supernovae



- 1931 : **Chandrasekhar** derives upper mass limit for WDs (~1.4 M_{sun}). *What happens if such a star accretes more mass?*

1) Nuclear potential energy available (if you burn 1 solar mass of C och O to Fe) : $2*10^{51}$ erg
2) Gravitational binding energy : $3*10^{50}$ erg
3) Degenerate conditions

1+2+3 —> *explosive disruption, no remnant.*

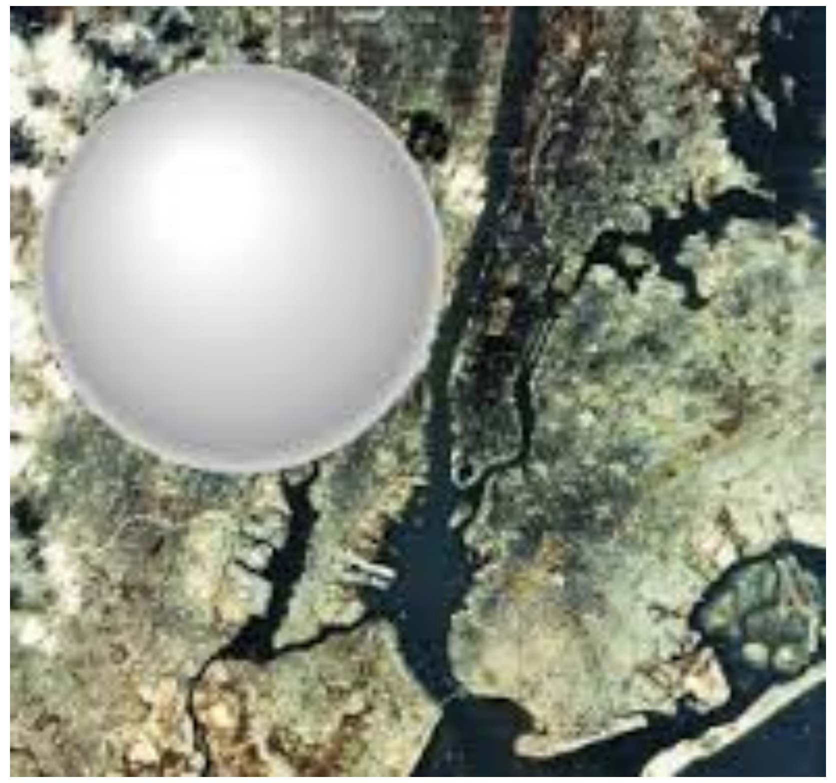
- Produce mostly iron-group elements: about half the cosmic production from here (other half from core-collapse SNe).

- Most events probably due to 2 WDs merging.

- Can be used as standard candle to measure distances —> Discovery of cosmic acceleration and dark energy in 1998.

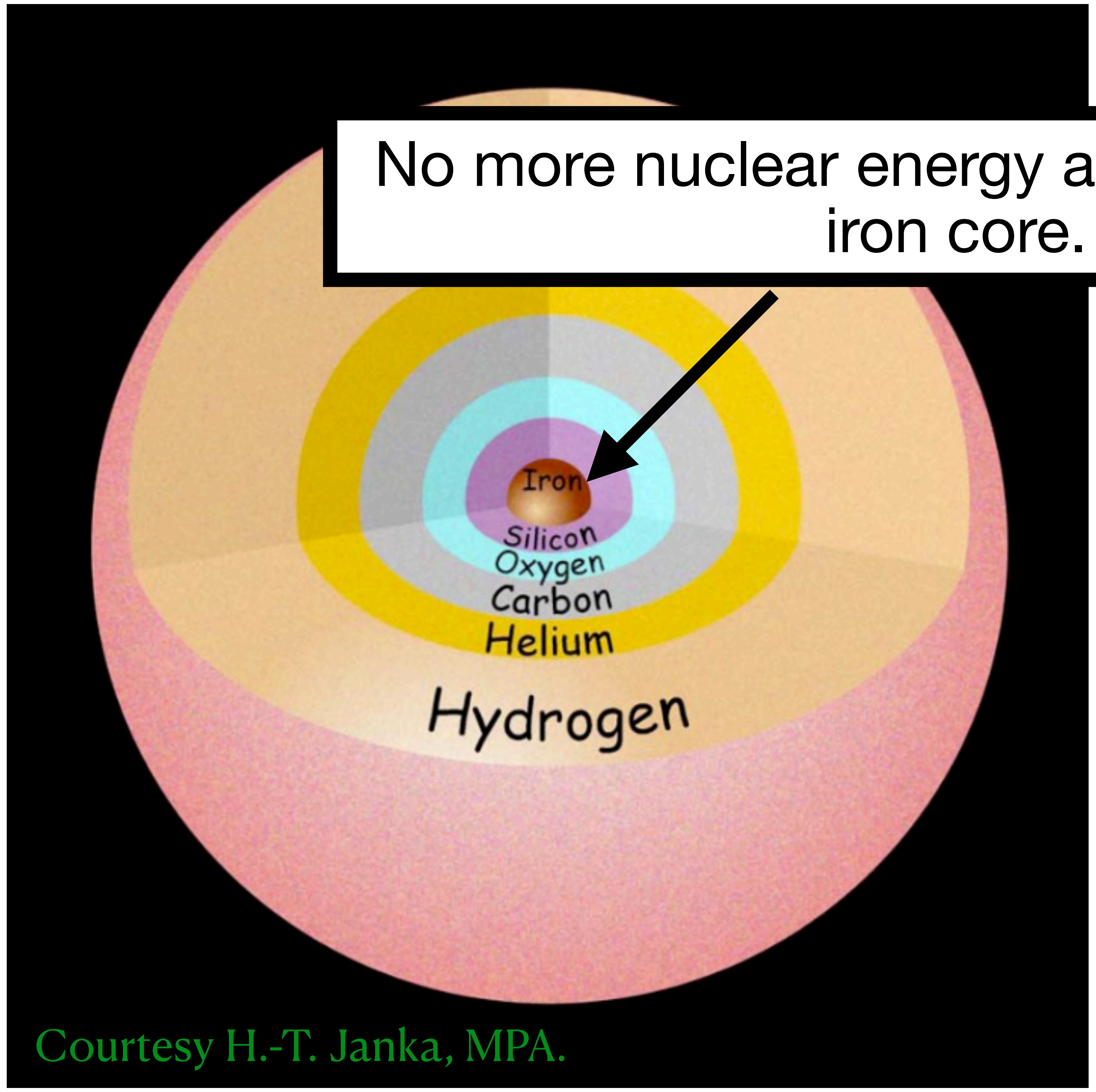
Supernovae from massive stars

Fuel	Duration	T (K)	Cooling	T_{surf} (K)	HR
H	10^7 yr	10^7	photons	20,000-40,0	O,B
He	10^6 yr	10^8	"	3,000-4,000	K,M
C	10^3 yr	$8*10^8$	neutrinos	3,000-60,00	O-M
Ne	1 yr	$1.8*10^9$	"	"	"
O	1 yr	$2.1*10^9$	"	"	"
Si	1 day	$3.7*10^9$	"	"	"

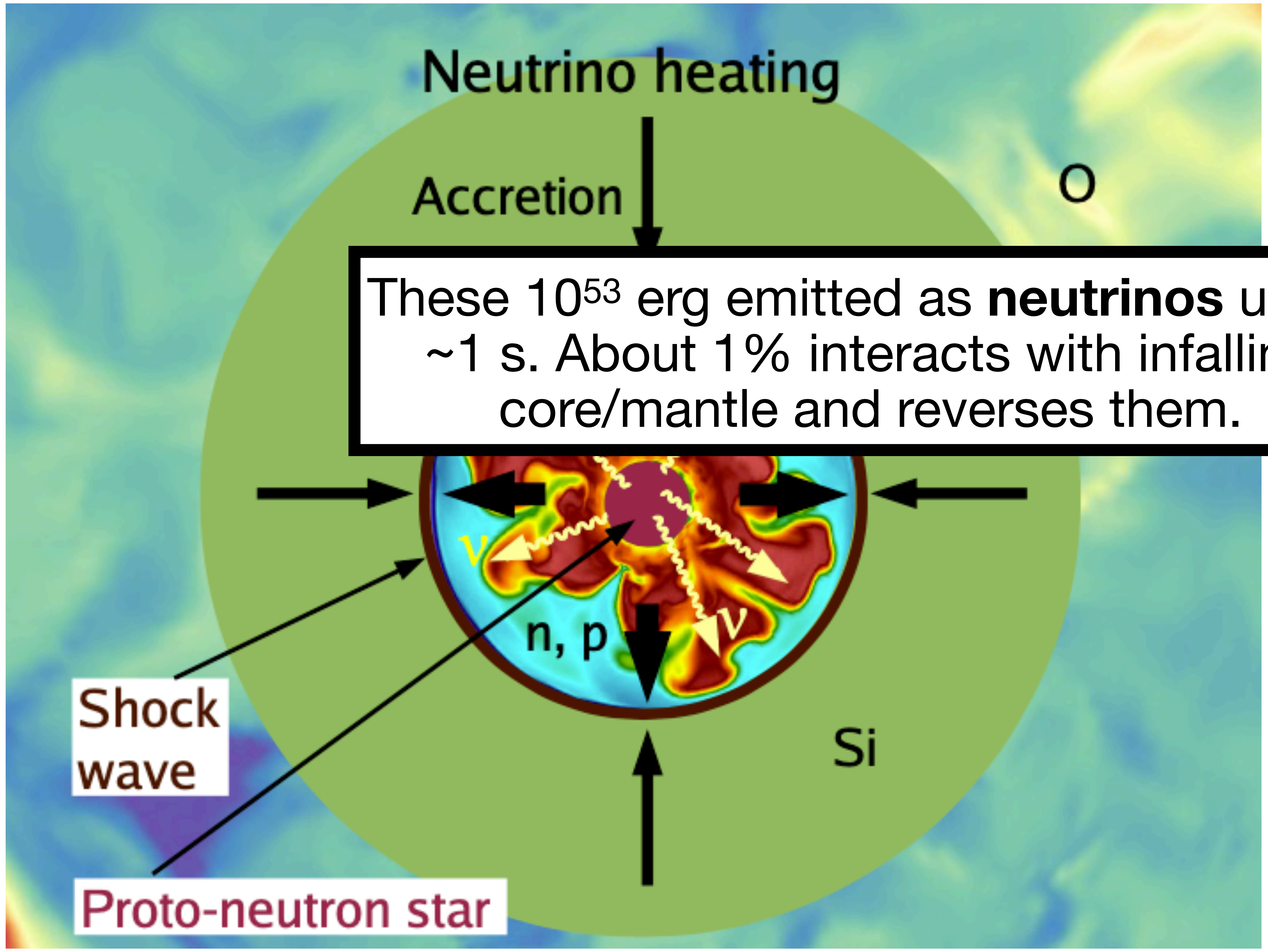


The core collapses to a **neutron star.**

Binding energy released: E ~ GM^2/R ~ 10^{53} erg

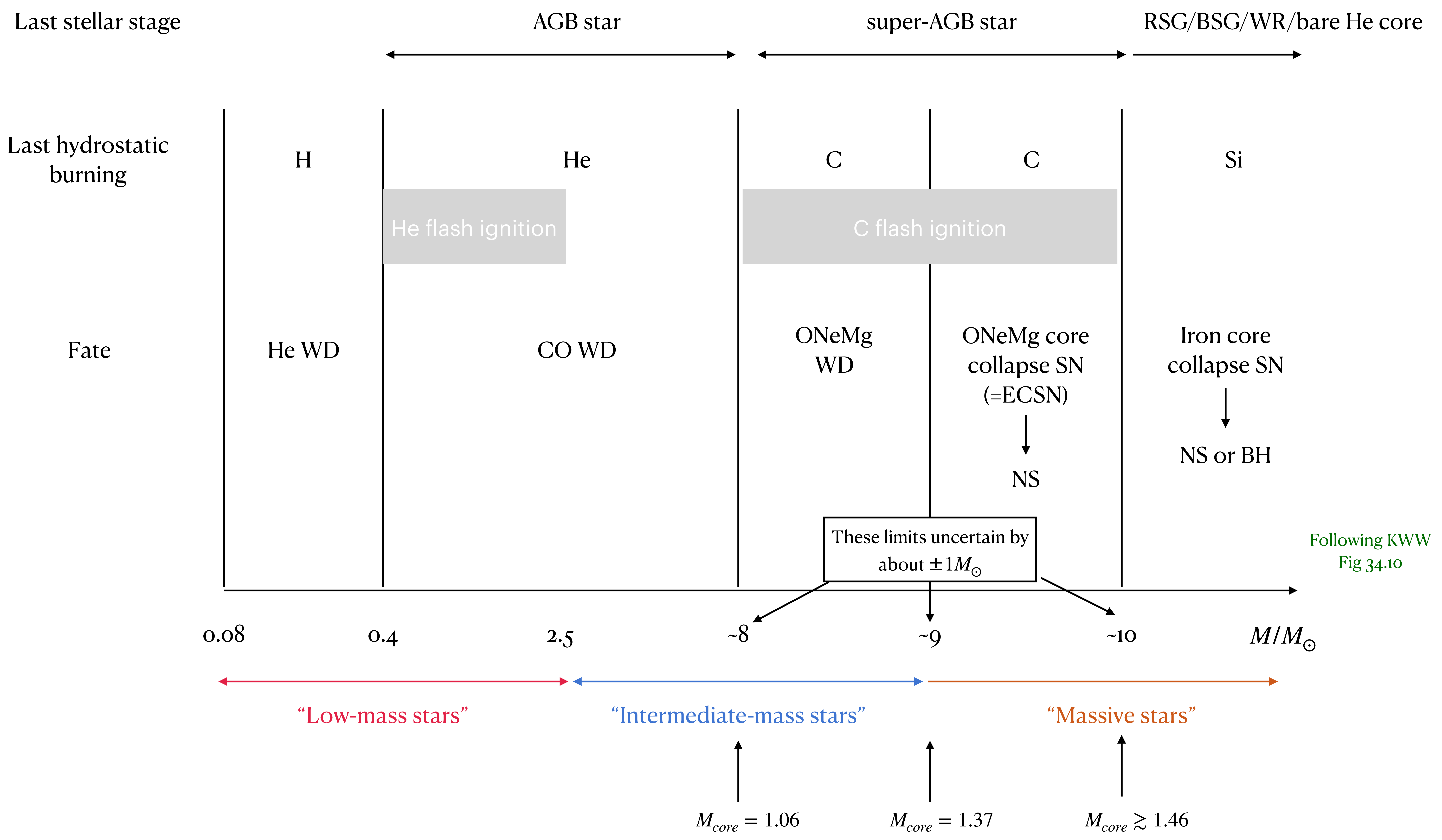


No more nuclear energy available from an iron core.



These 10^{53} erg emitted as **neutrinos** under ~1 s. About 1% interacts with infalling core/mantle and reverses them.

Stellar fates versus M_{ZAMS}



Two types of collapse initiation

ONeMg core

Density is high and degeneracy pressure important for support.

Efficient electron capture reactions on ^{20}Ne at $M_{ONeMg} \geq 1.37 M_{\odot}$ causes catastrophic loss of the supporting electrons.
(M_{Ch} rapidly decreases)

Expected only for M_{ZAMS} $9 - 10 M_{\odot}$ range, and this range may be even smaller or even non-existent.

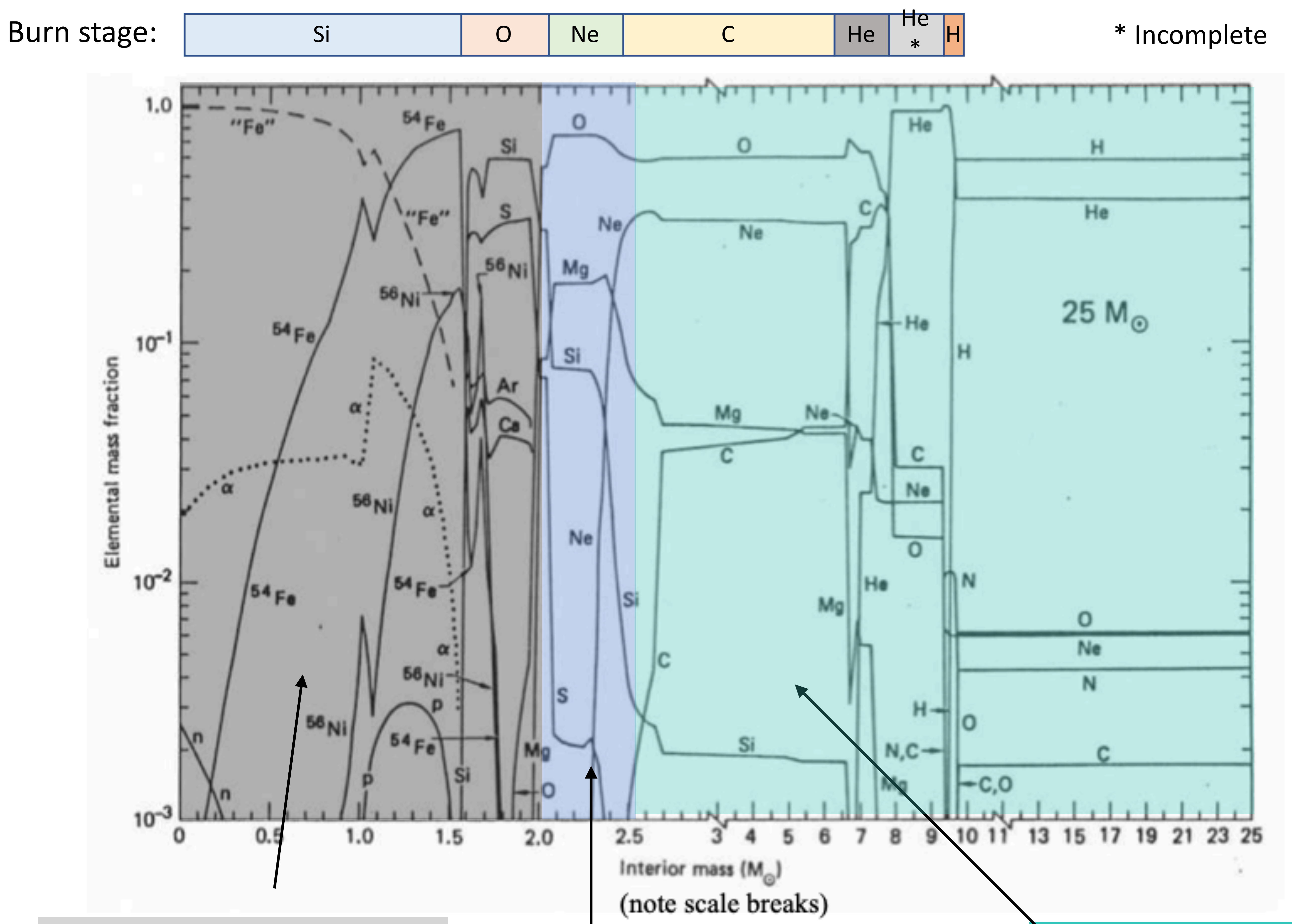
Iron core

Density is lower and radiation pressure important.

Efficient photo-disintegration processes causes catastrophic loss of supporting photons.

Expected for $M_{ZAMS} \sim 10 - 100\ M_{\odot}$

Explosive nucleosynthesis



S. Woosley

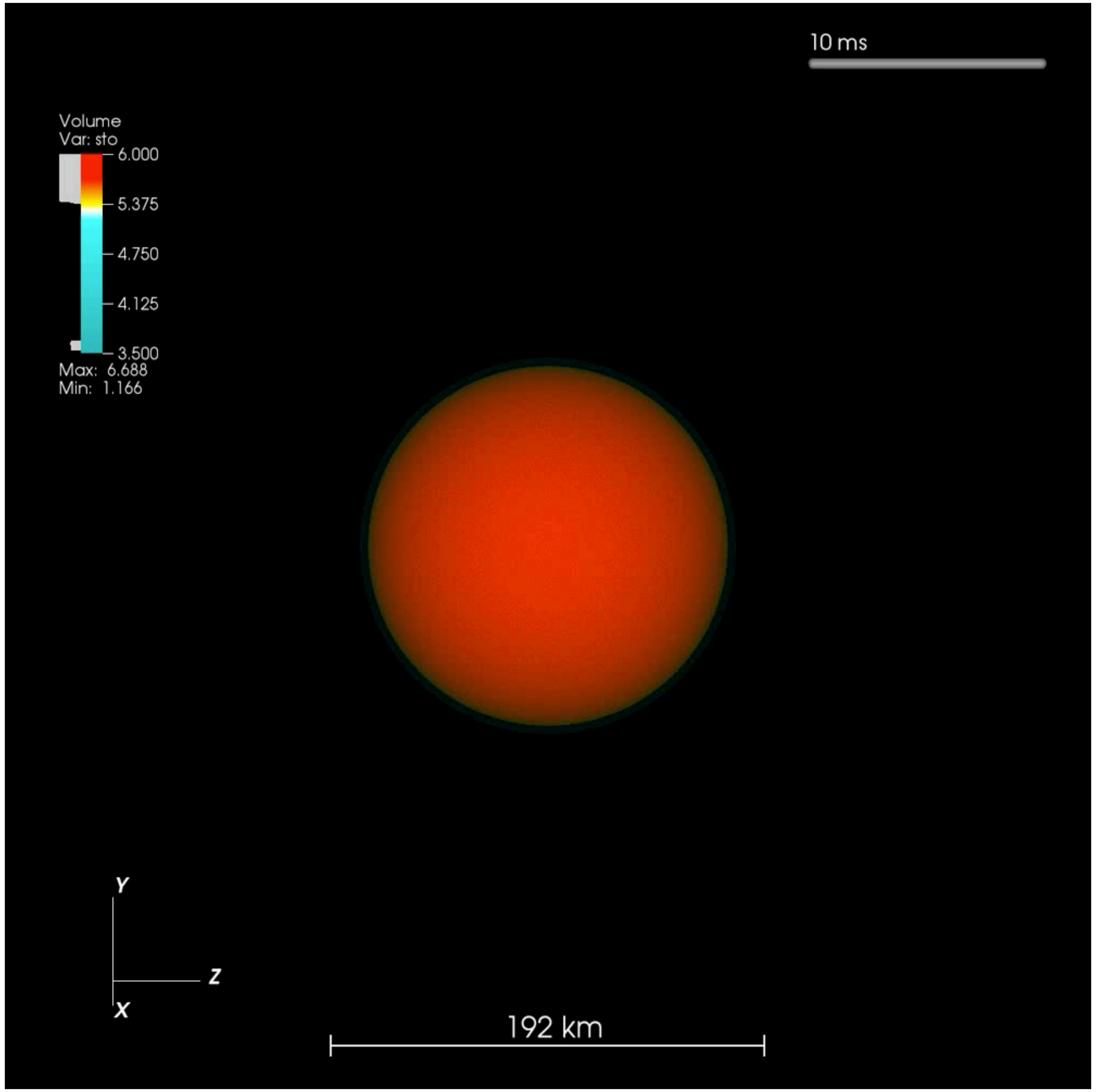
- Fuel for explosive burning is O, Ne, Mg, Si —> no explosive C burning.
- Main explosive burning stages are Si burning and O burning.
- Because the fuel layers have small neutron excess ($\eta \sim 10^{-3}$), the explosive Si burning makes ^{56}**Ni**, and roughly solar proportions of iron-group elements.
- Explosive O burning makes **Si, S, Ca**, also in good agreement with solar abundances.
- Elements up to Mg are typically made in the pre-SN star, Si and up by explosive burning.

This region forms NS or BH

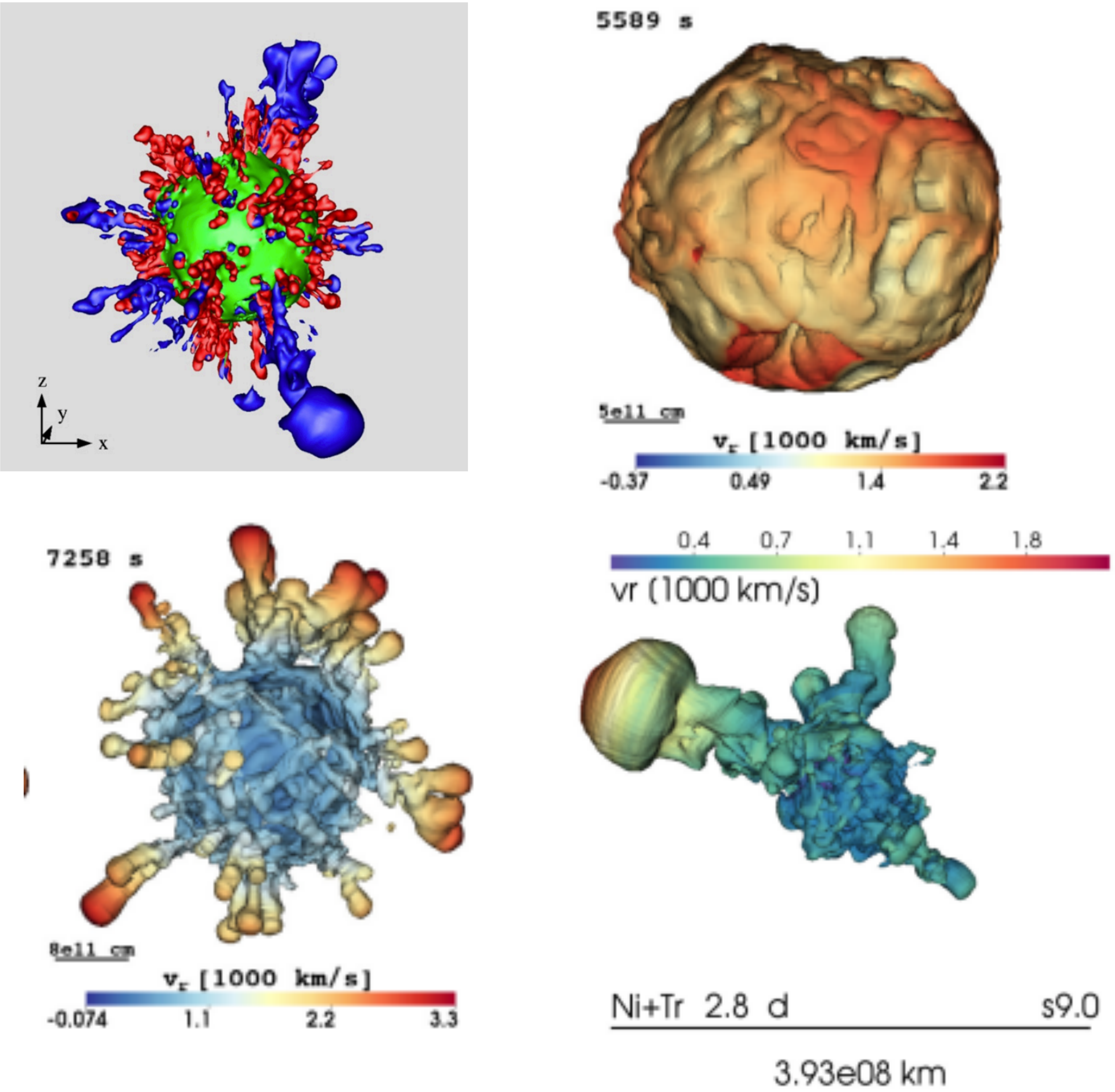
In this region T > 5E8 and explosive nucleosynthesis in a few 0.1 $M_\odot$ of material occurs

These layers are ejected without any changes in composition by the explosion (when the shock reaches them it is too cool to burn anything)

Supernovae from massive stars i 3D



Melson 2015



Wongwathanarat 2015, Stockinger 2020.