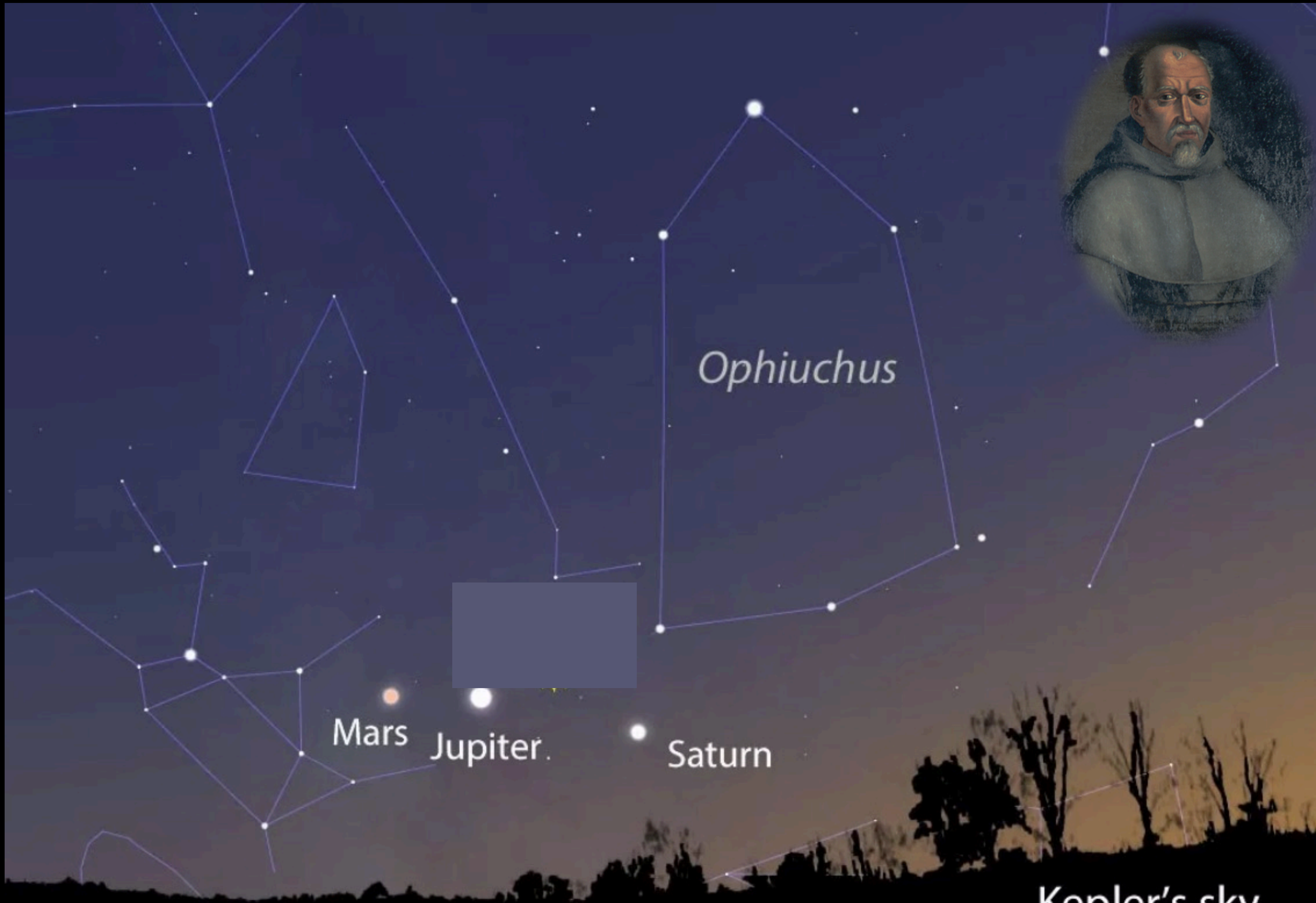
From Kepler's Supernova to the naked-eye GRB 080319B

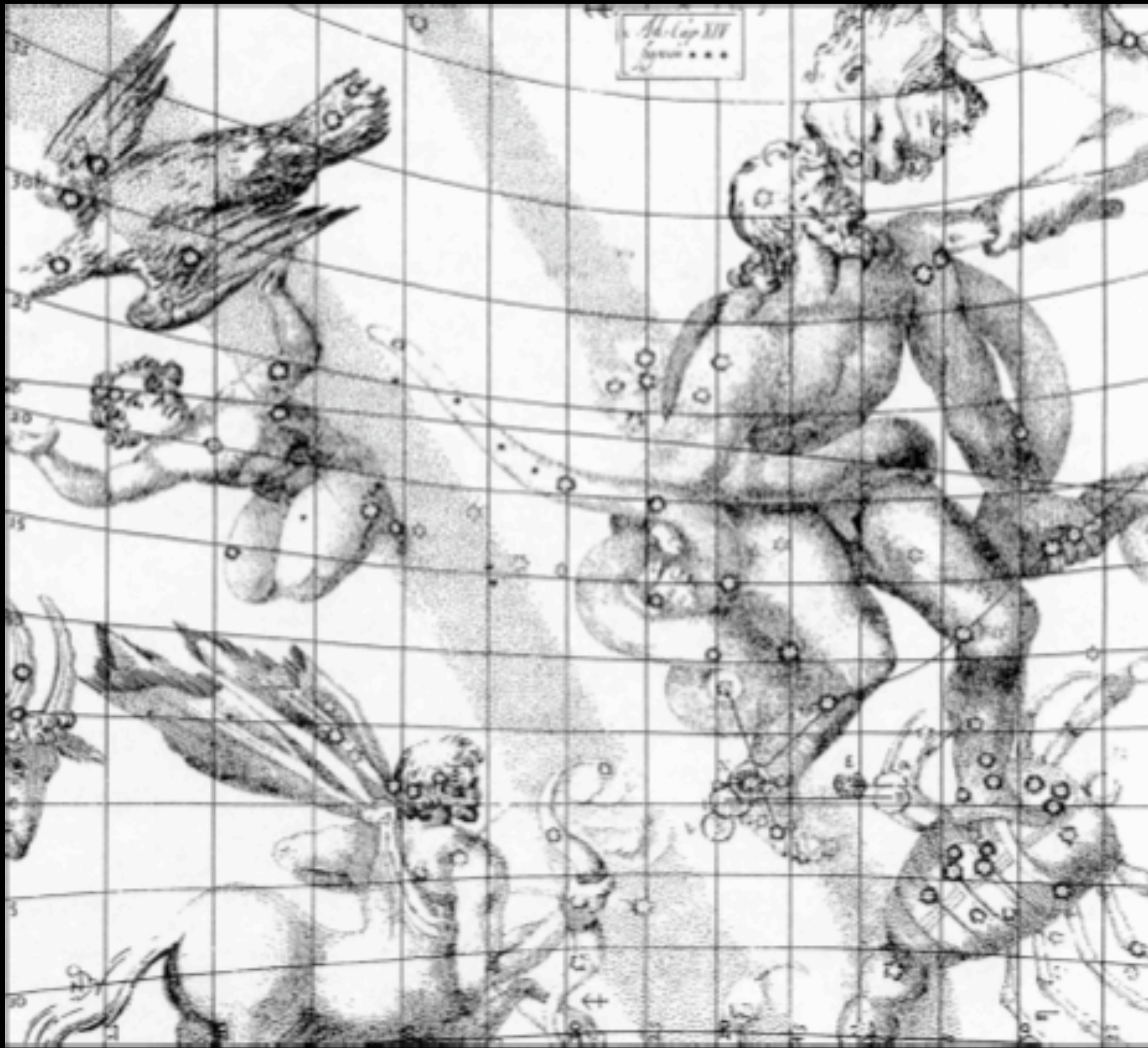
Massimo Della Valle
Capodimonte Observatory, INAF-Naples

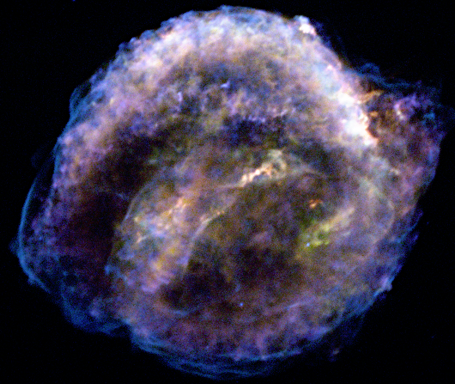
SIF-Verona 13-17 Settembre



S.West

Kepler's sky
Oct. 17, 1604





De Stella Nova *"in pede Serpetarii"* 1606

I cieli di "cristallo" di Aristotele e Tolomeo sono andati in frantumi grazie all'osservazione di una "stella nova"

"Guest Stars"

Date (AD)	Type	m_{max}	Naked Visibility	Discovered by	Remnant
185?	I?	-8	?	Chinese	RCW86
393	?	-1	?	Chinese	
837	?	-8?	?	Chinese	IC 443
1006	I	-9	> 2yrs	Chinese/Arabs	SN 1006
1054	II	-6	~2yrs	China/Japan/ Chaco Canyon	Crab Nebula
1181	II?	+1	0.5yrs	China/Japan	3C58
1572	I	← -1	1.5 yrs	Tycho Brahe	Tycho
1604	I	-3	1 yr	Kepler/Galilei	Kepler
ca. 1667	II	+5?	missed	Flamsteed	Cas A
1870	I	~ +6	missed	Hartwig	M31
1987	II	+2.9	~1 yr	Ian Shelton	SN1987A

What Supernovae?

SUPERNOVA	=	super	-	nova
		very bright		new star

(Baade & Zwicky 1934)

With all reserve we advance the view that a super-nova represents the transition of an ordinary star into a neutron star consisting mainly of neutrons. Such a star may possess a very small radius and extremely high density (Baade & Zwicky 1934)

Fritz Zwicky illustrating the concept of "Supernova"

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Supernovae from Palomar

18 inches ~ 1950 ~ 20 SNe/yr

Supernova Classification

SPECTRA OF SUPERNOVAE

PASP 1941

BY R. MINKOWSKI

(*Abstract*)

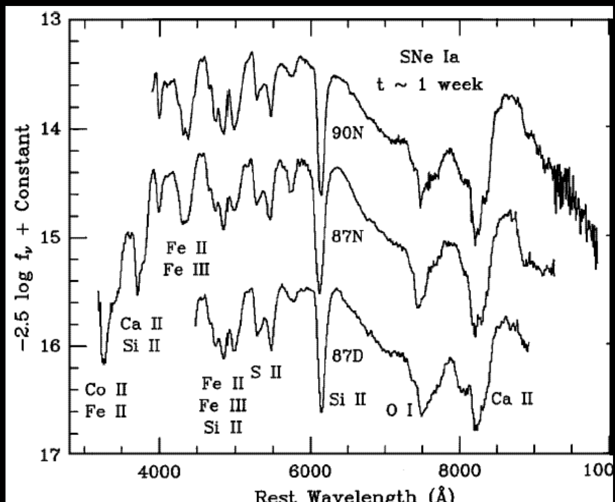
Spectroscopic observations indicate at least two types of supernovae. Nine objects (represented by the supernovae in IC 4182 and in NGC 4636) form an extremely homogeneous group provisionally called "type I." The remaining five objects (represented by the supernova in NGC 4725) are distinctly different; they are provisionally designated as "type II." The individual differences in this group are large; at least one object, the supernova in NGC 4559, may represent a third type or, possibly, an unusually bright ordinary nova.

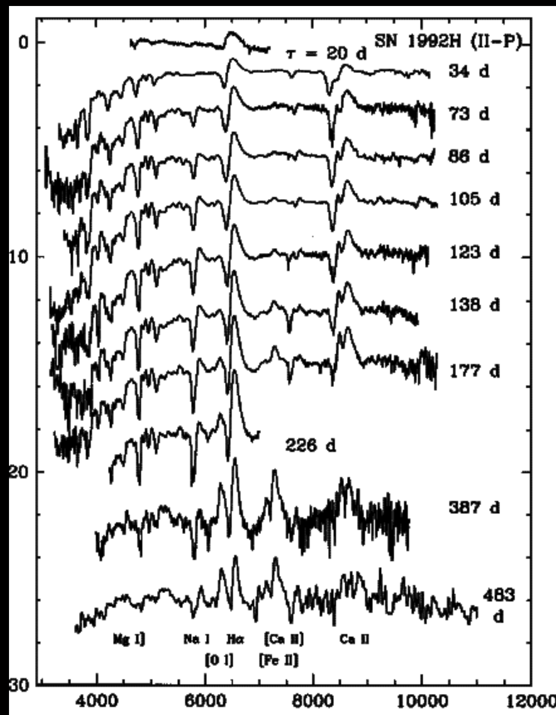
Supernova taxonomy

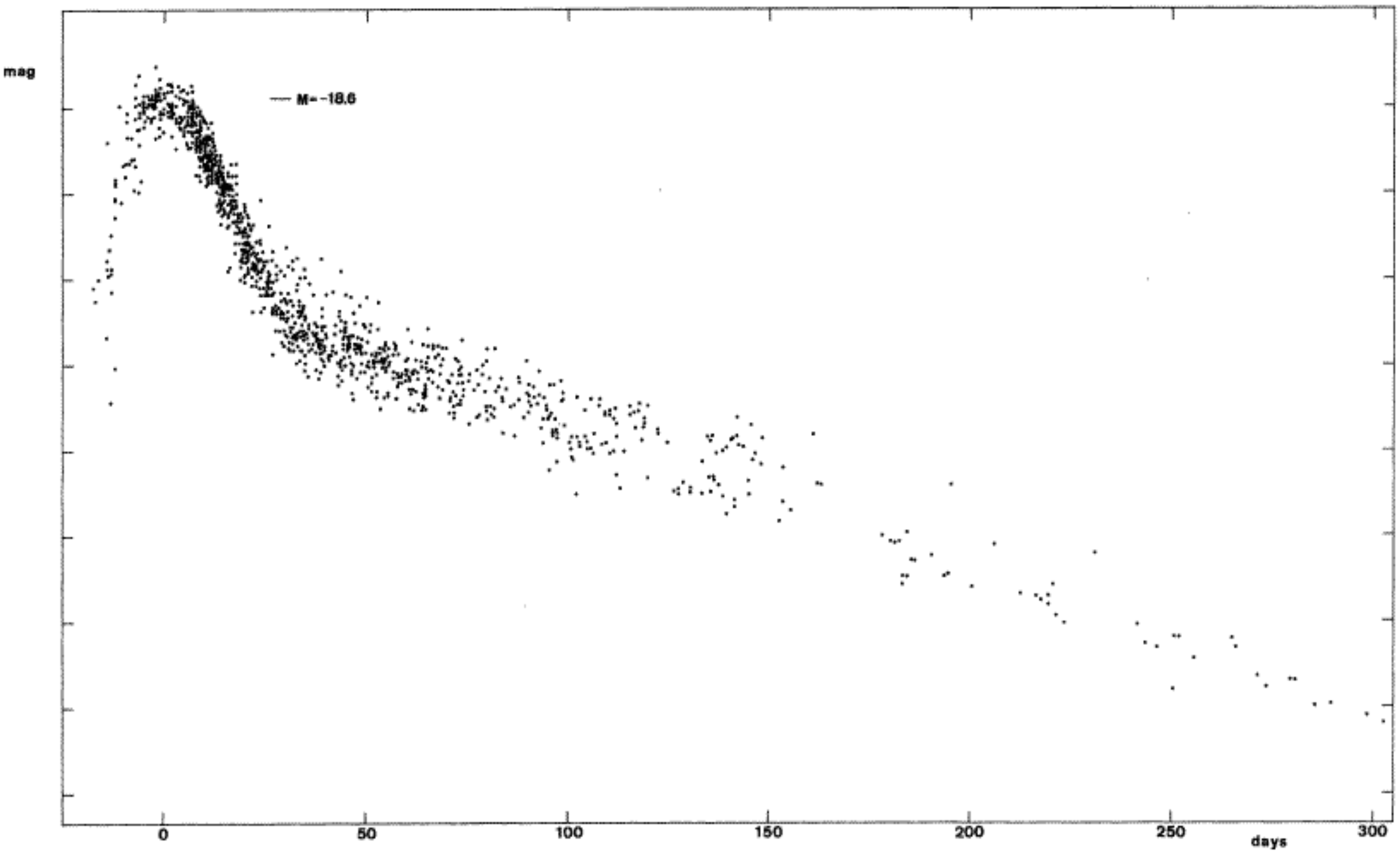
H

I

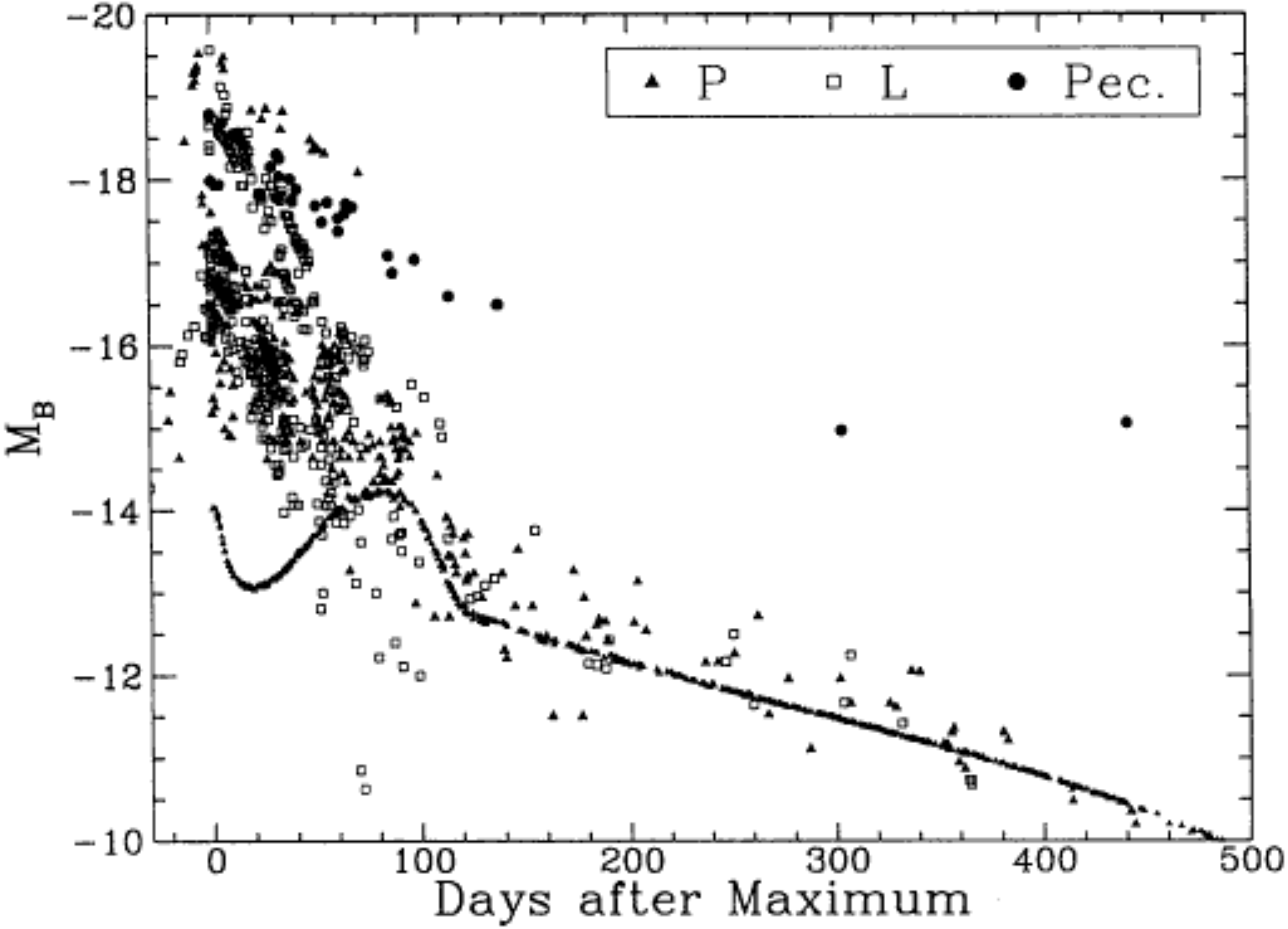
II





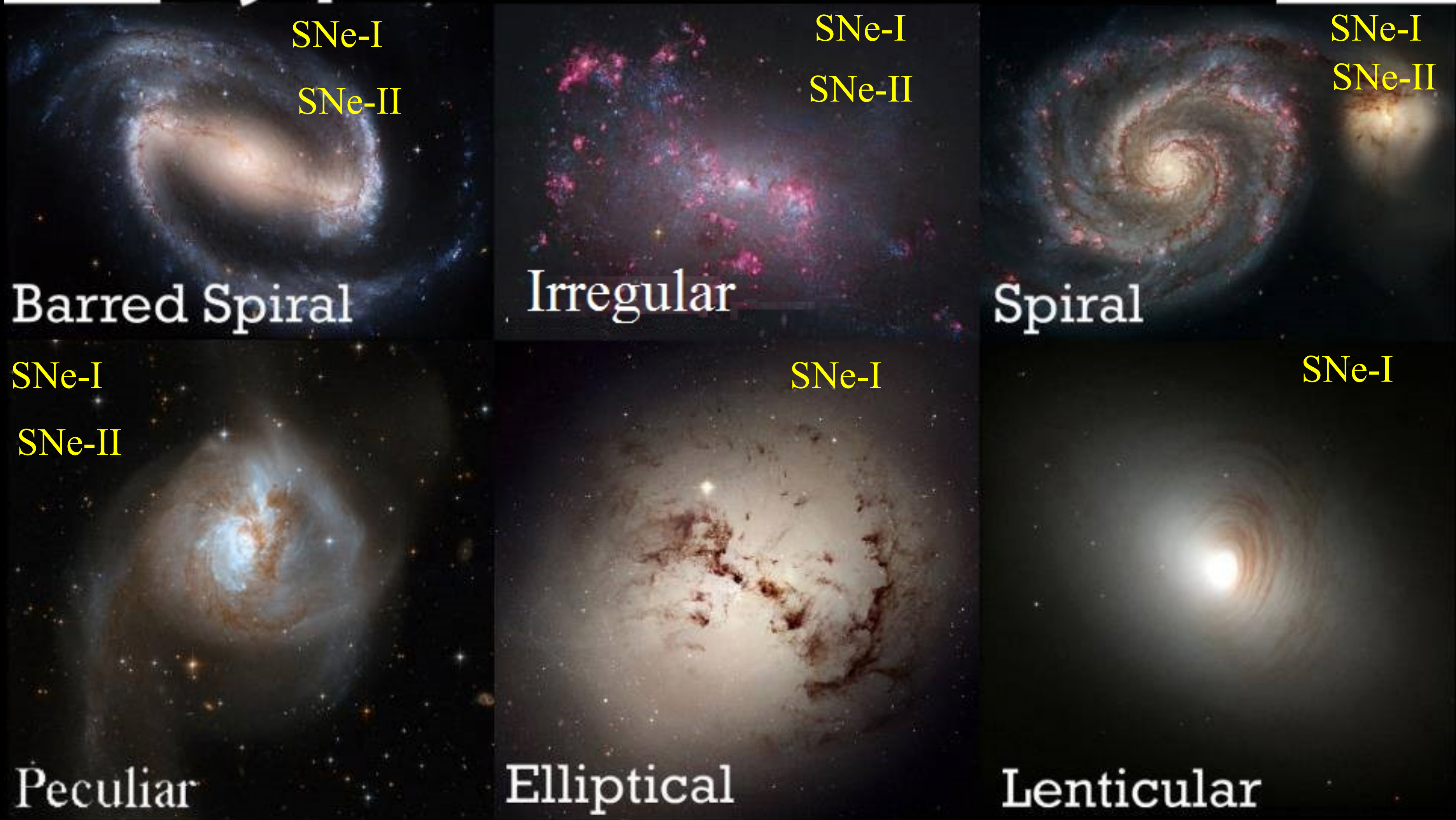


Barbon, Ciatti & Rosino 1973



Patat et al. 1995

Types of Galaxies



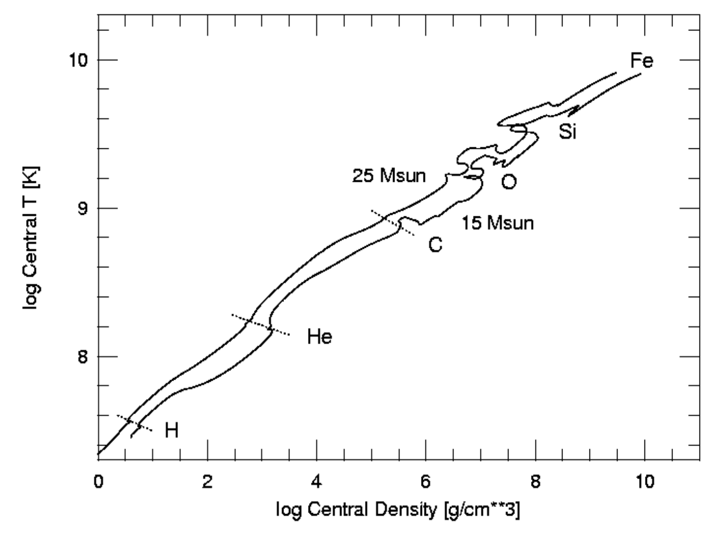
With all reserve we advance the view that a super-nova represents the transition of an ordinary star into a neutron star consisting mainly of neutrons. Such a star may possess a very small radius and extremely high density (Baade & Zwicky 1934)

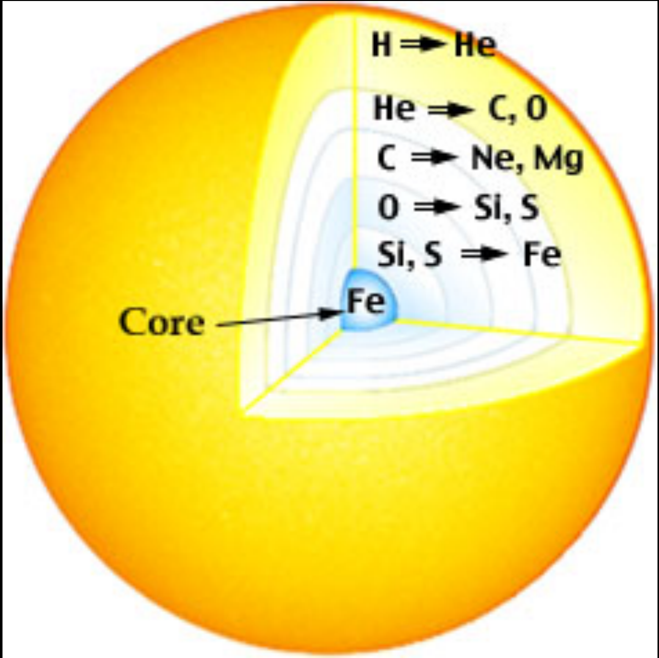
Fritz Zwicky illustrating the concept of "Supernova"

30 Dor Nebula before SN 1987A explosion

30 Dor Nebula after SN 1987A explosion

What would cause a massive star to explode?





Stars are gravitationally confined thermonuclear reactors.

Each time one runs out of one fuel, contraction and heating ensue, unless degeneracy is encountered. The burning is transferred to a shell about the core while further contraction of the core will lead to a higher temperature and the next stage of fusion. For star > 8 $M_{\odot}$ the core temperature will rise to a value high enough ($T \sim 10^9/10^{10}$) to burn O and Ne to form Si, S and Mg, via: $^{16}O + ^{16}O \rightarrow ^{28}Si + a$; $^{16}O + ^{16}O \rightarrow ^{32}S$; $^{20}Ne + a \rightarrow ^{24}Mg$.

A particular important reaction is $^{28}Si + ^{28}Si \rightarrow ^{56}Ni$
Since Ni decays to Co via $^{56}Ni \rightarrow ^{56}Co + e^{+} + n$ and Co to Fe via $^{56}Co \rightarrow ^{56}Fe + e^{+} + n$

The decay chain ends here because Fe is stable. When the core has exhausted its supply of Si the Si+Si channel shuts off and the core of the star contracts until we get burning in a shell around the Fe core. This short summary explains the well known 'onion' structure.

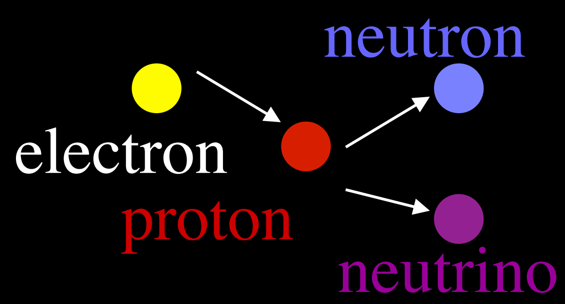
What would cause a massive star to explode? (cont'd)

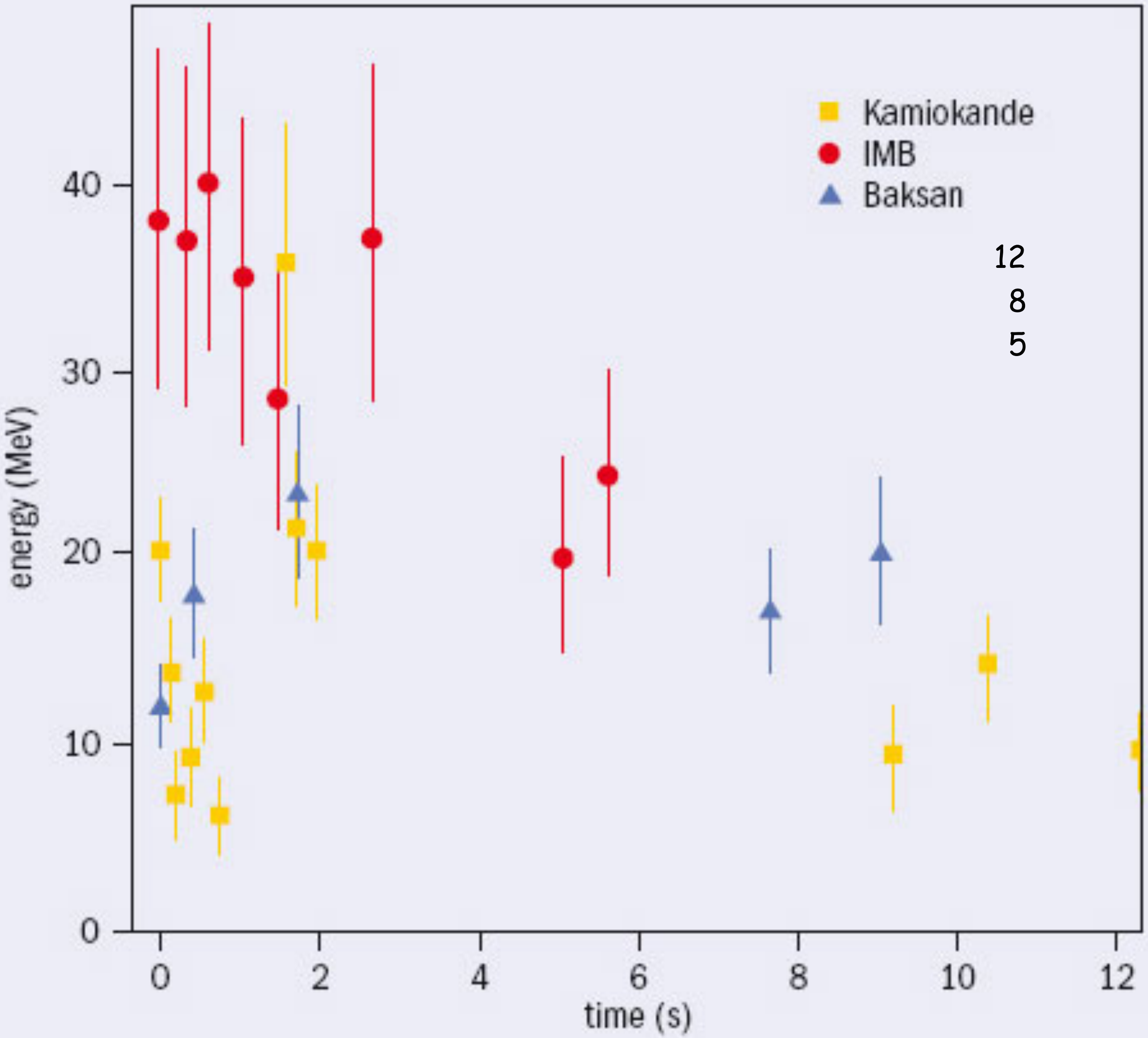
The Fe core (about $1M_{\odot}$) cannot support itself and starts to contract and its T rises. What happens as the T further increases in the Fe core?

Fe is at the top of the average binding energy curve, so that Fe can only decompose into elements of lower binding energy, which means a net absorption of energy and the ultimate collapse of the core: at about 6×10^9 K the photodisintegration of the Fe gives

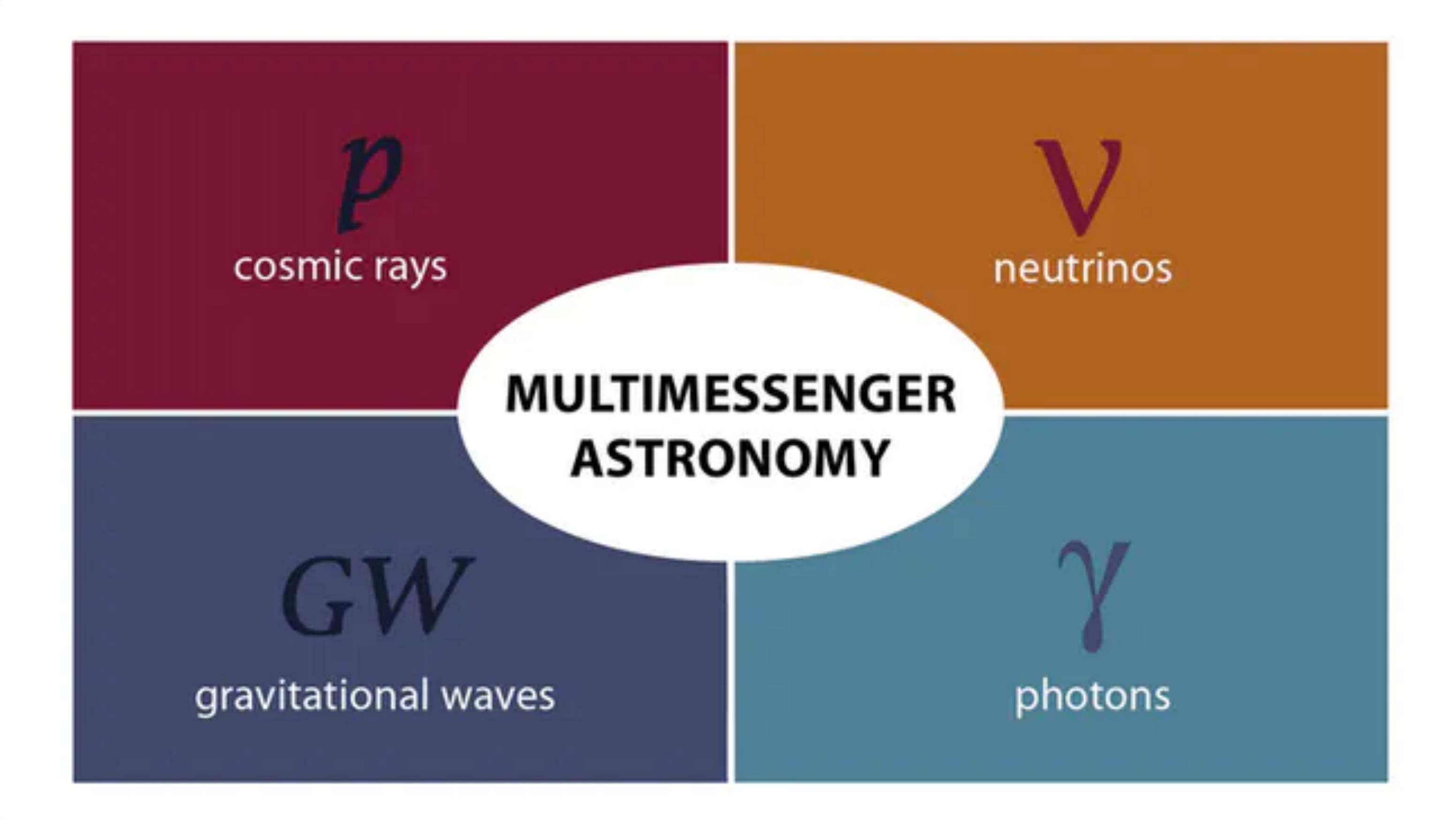
$\gamma + {}^{56}Fe \rightarrow 13\ {}^{4}He + 4n$ (it requires about 124 MeV or 1.5×10^{-5} erg/nucleon). With 2×10^{57} protons in M_{CH}, this corresponds to a total energy loss of 3×10^{52} erg $\rightarrow$ the core contracts more rapidly

Due to high density electrons are squeezed into the protons to form neutrons and creating more neutrinos: $p + e^- \rightarrow n + v$ converts the core to a degenerate neutron gas (=NS)– a neutron ‘’ pudding” ($\rho \sim 10^{14}$ g/cm^3; e^- and p < 1%). This is a degenerate neutron gas that stops the collapse, unless the mass of the core is > $3M_\odot$





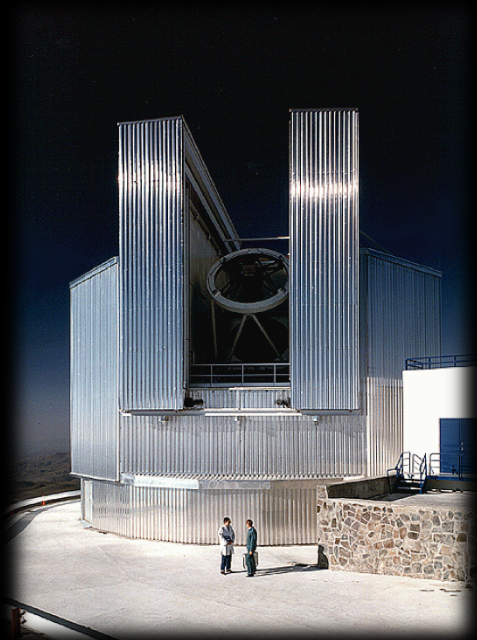
Neutrinos detection confirms that a NS is the residual of a CC SN explosion.

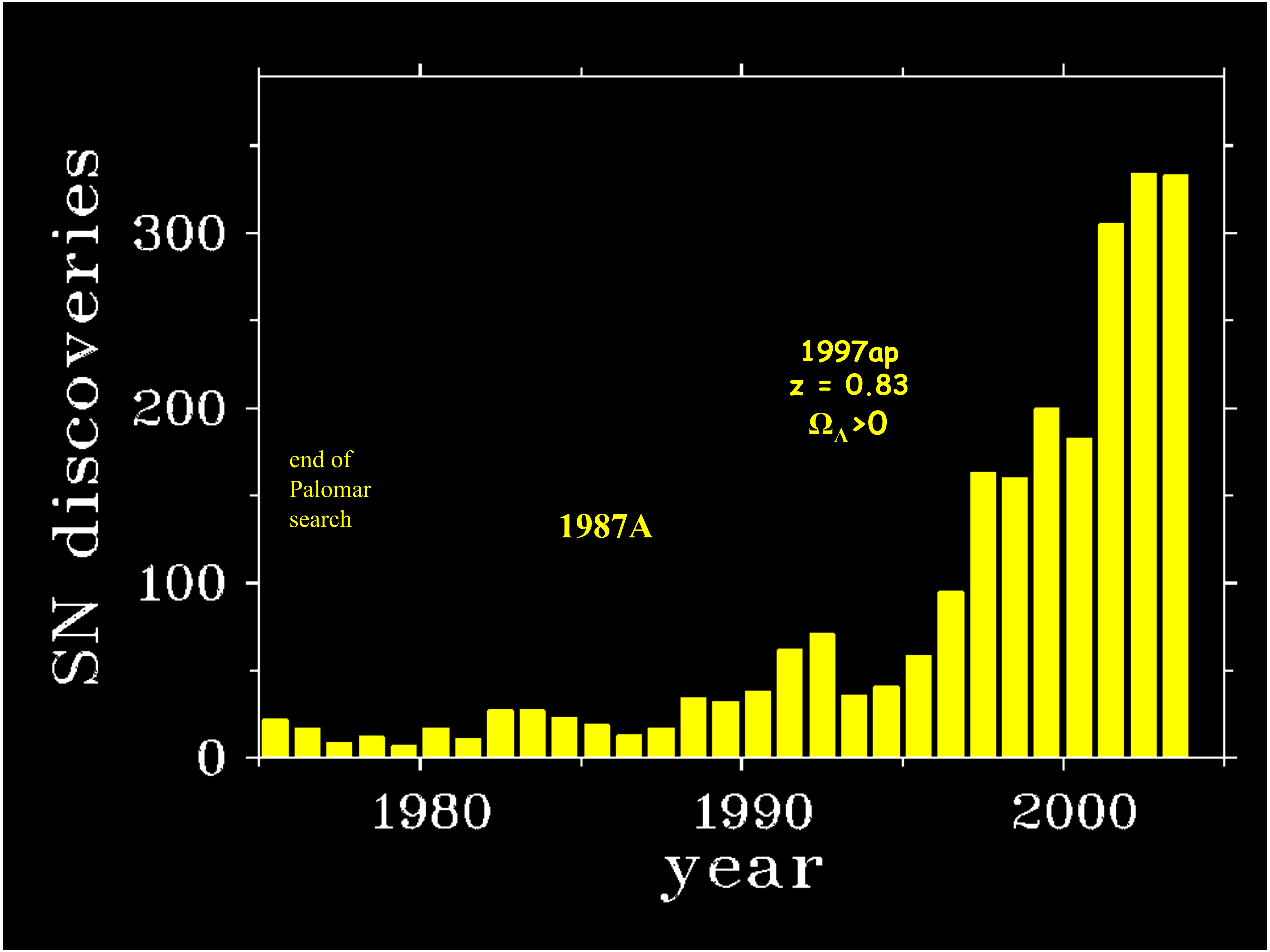


p
cosmic rays
ν
neutrinos
MULTIMESSENGER
ASTRONOMY
GW
gravitational waves
γ
photons


4m telescopes

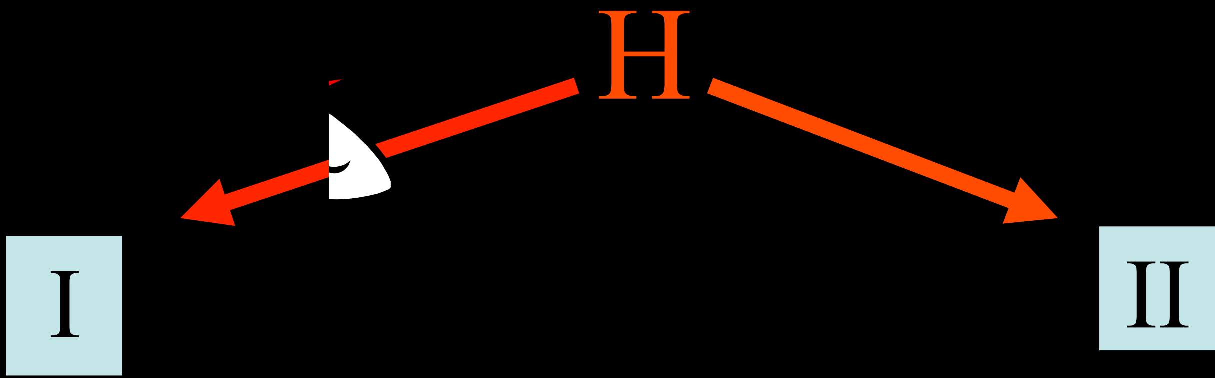

18 inches

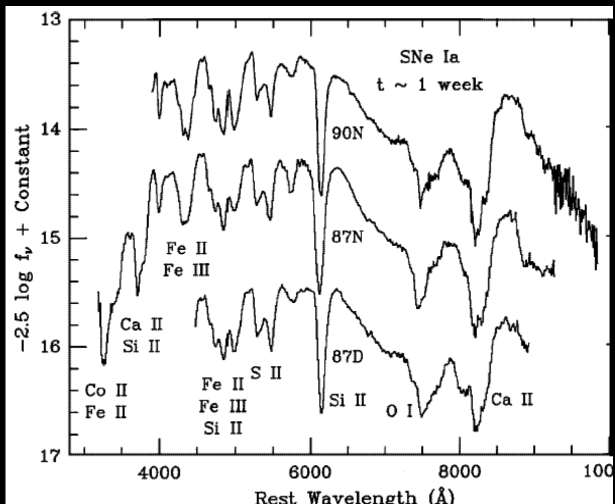


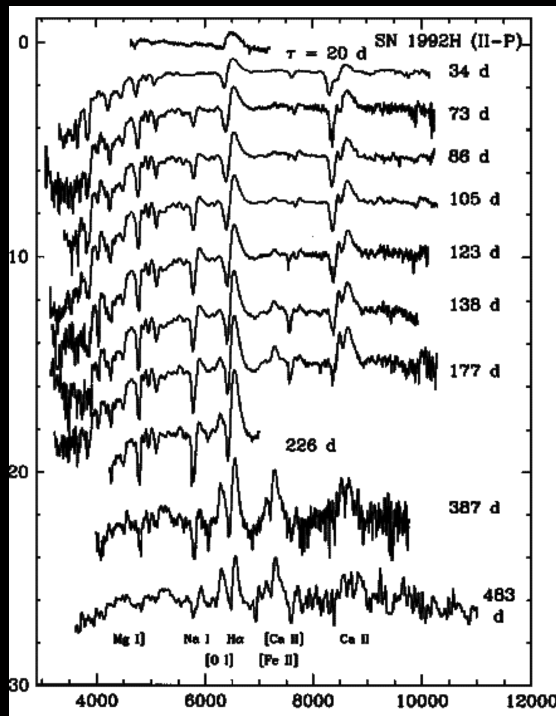


SN discoveries
300
200
100
0
1980
1990
2000
year
end of
Palomar
search
1987A
1997ap
z = 0.83
Ω_Λ>0

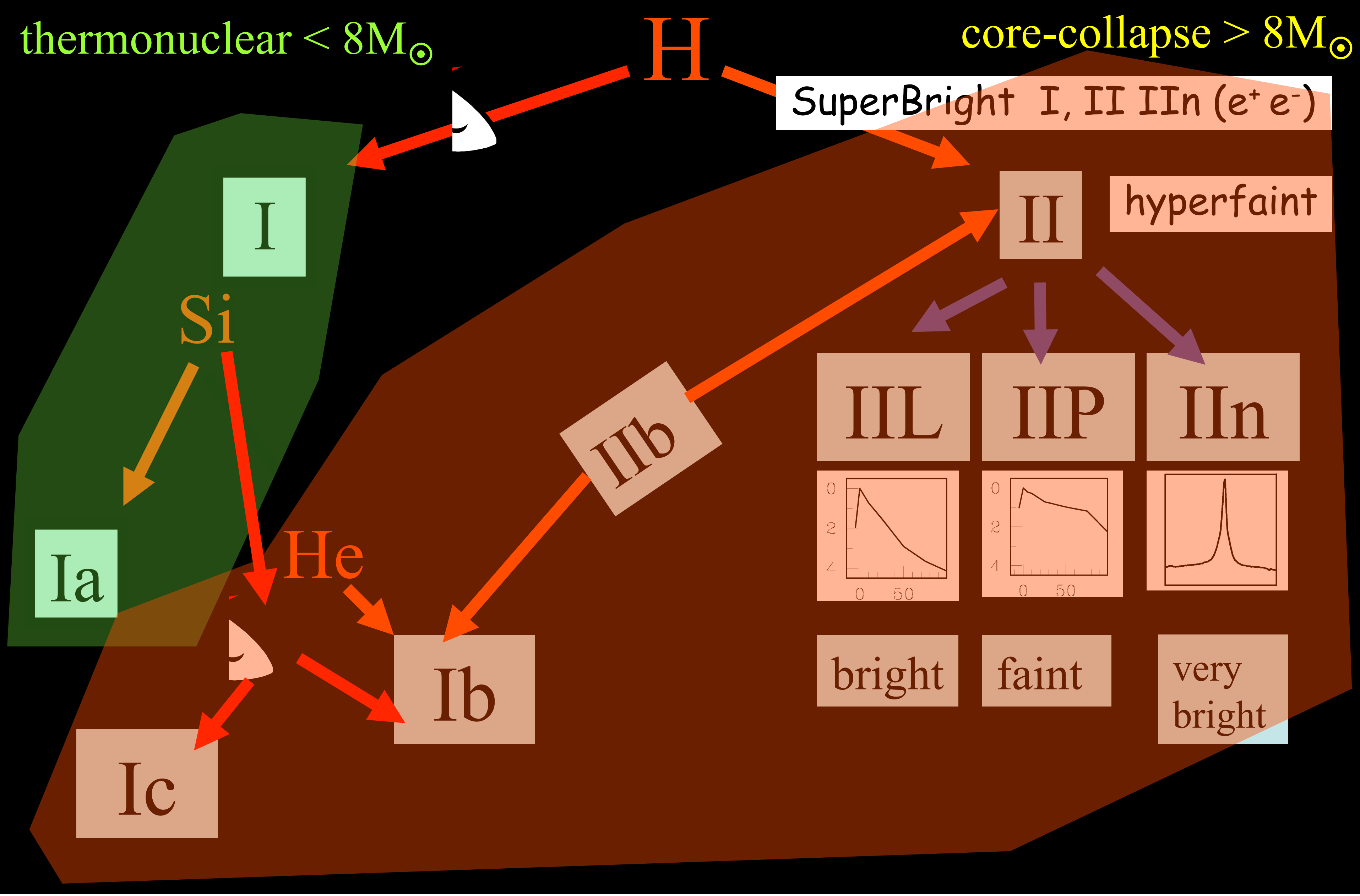
Supernova taxonomy







Supernova taxonomy



Discovery of a supernova explosion at half the age of the Universe

S. Perlmutter[1,2], G. Aldering[1], M. Della Valle[3], S. Deustua[1,4], R. S. Ellis[5], S. Fabbro[1,6,7], A. Fruchter[8], G. Goldhaber[1,2], D. E. Groom[1], I. M. Hook[1,10], A. G. Kim[1,11], M. Y. Kim[1], R. A. Knop[1], C. Lidman[12], R. G. McMahon[5], P. Nugent[1], R. Pain[1,6], N. Panagia[13], C. R. Pennypacker[1,4], P. Ruiz-Lapuente[14], B. Schaefer[15] & N. Walton[16]

The ultimate fate of the Universe, infinite expansion or a big crunch, can be determined by using the redshifts and distances of very distant supernovae to monitor changes in the expansion rate. We can now find[1] large numbers of these distant supernovae, and measure their redshifts and apparent brightnesses; moreover, recent studies of nearby type Ia supernovae have shown how to determine their intrinsic luminosities[2–4]—and therefore with their apparent brightnesses obtain their distances. The >50 distant supernovae discovered so far provide a record of changes

Perlmutter et al. 1998

Riess at al. 1998

Schmidt et al. 1998

Perlmutter et al. 1999

Riess et al. 2001

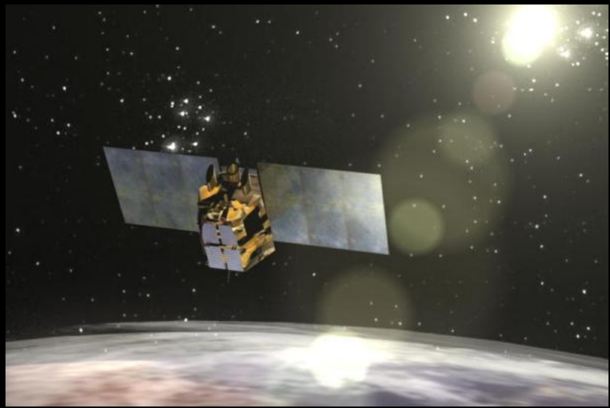
Tonry et al. 2003

Knopp et al. 2003

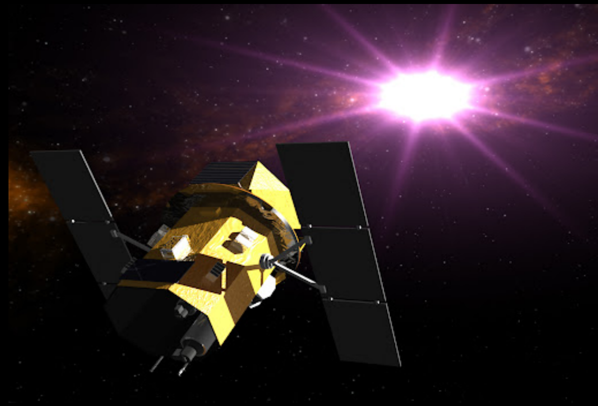
Riess et al. 2004

Astier et al. 2006

……..and more

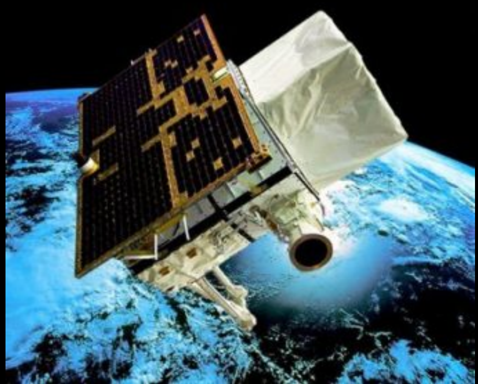


Bepposax 1996



Swift 2004

Integral 2002



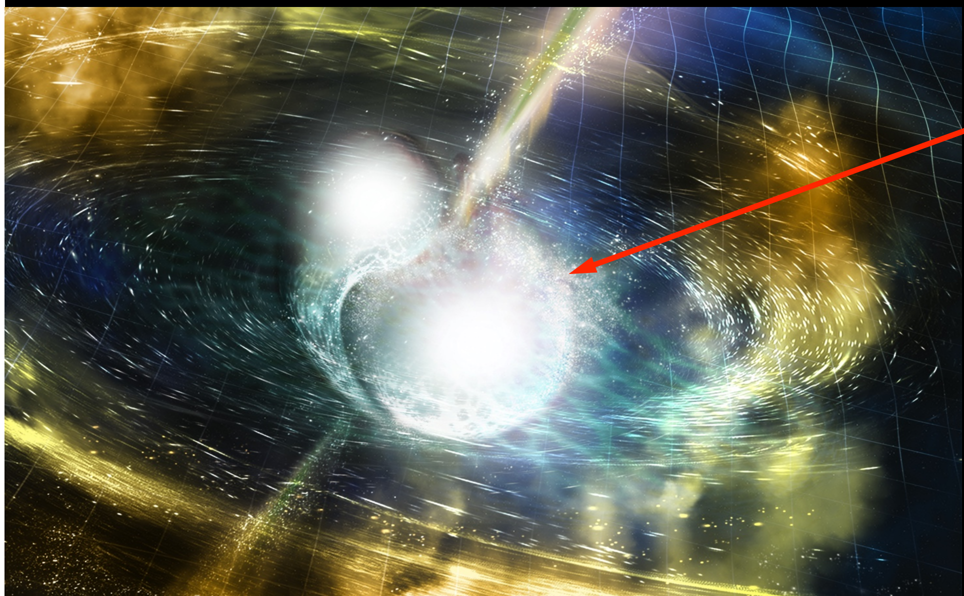
Agile 2007

Hete-2 2000

Fermi 2008

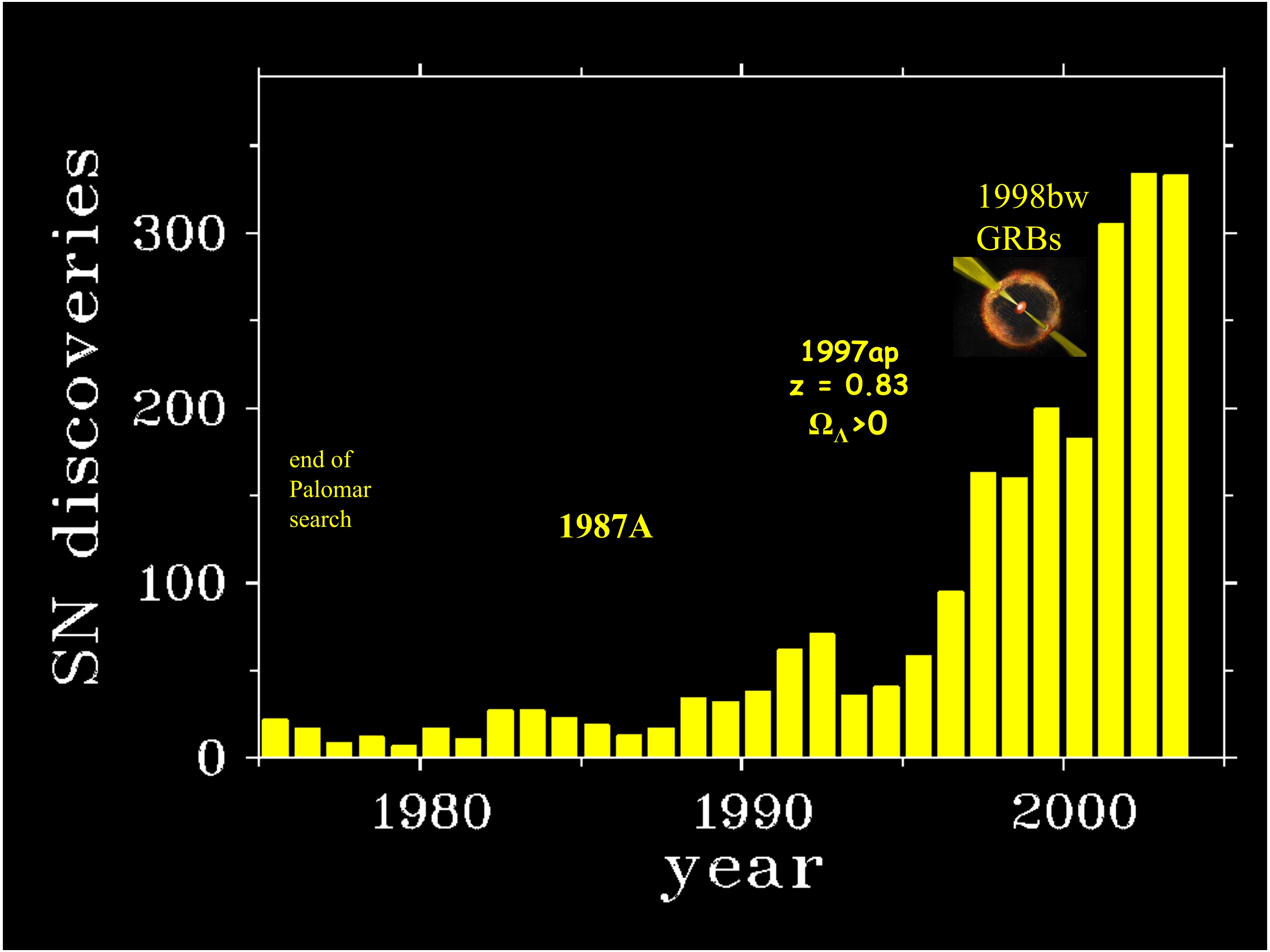
LONG GRBs

* Association with HNe
* Star-forming host galaxies
* ΔT~10s-1000s



SHORT GRBs

* Differentiated host galaxies (early types and spirals)
* Normally **not** associated with recent star formation
* Binary compact object mergers **(NS+NS; BH+NS)**
* ΔT <2s


SN discoveries
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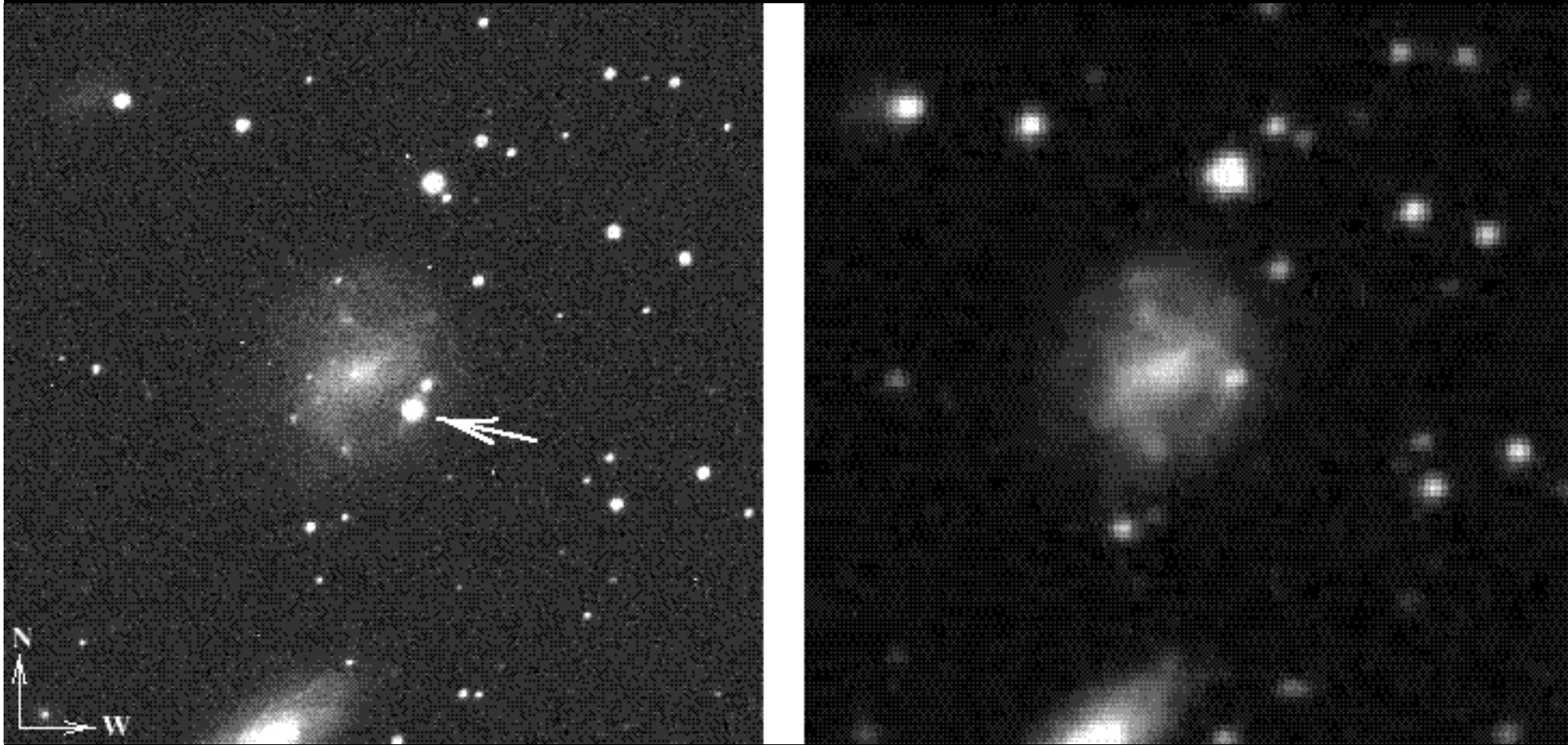
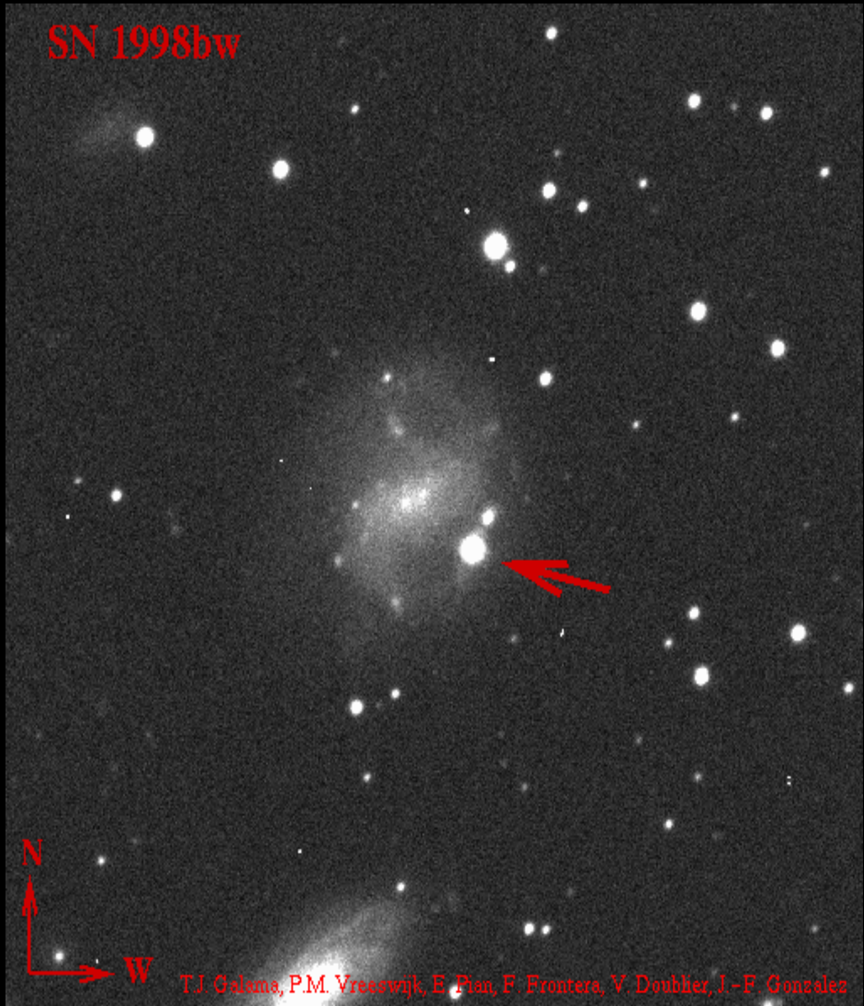
GRBs



N
W

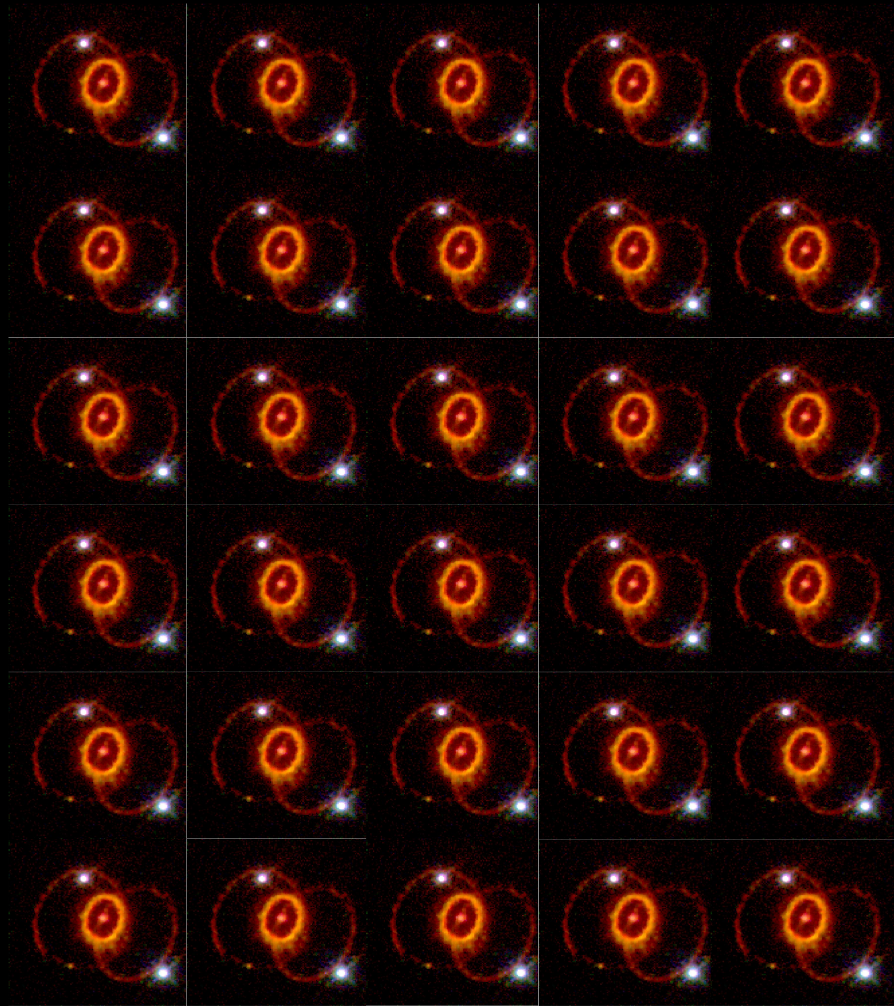
SN 1998bw



$E_K \sim 30 \times 10^{51}$ erg

=

SN 1987A

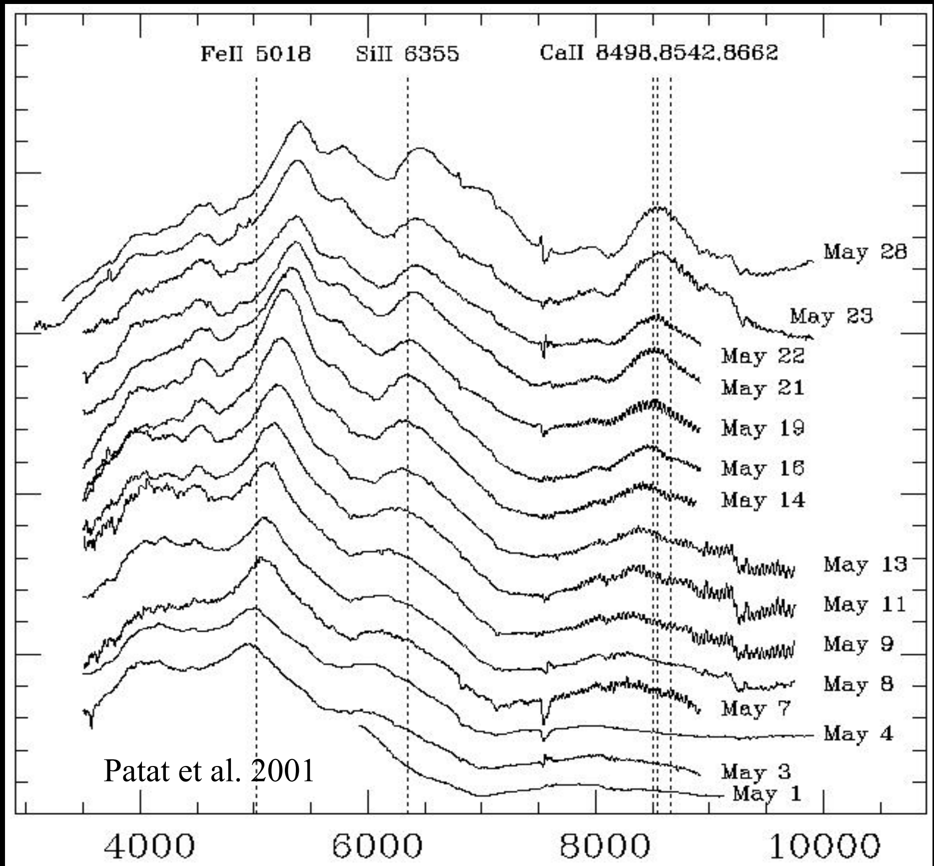


$E_K \sim 1 \times 10^{51}$ erg

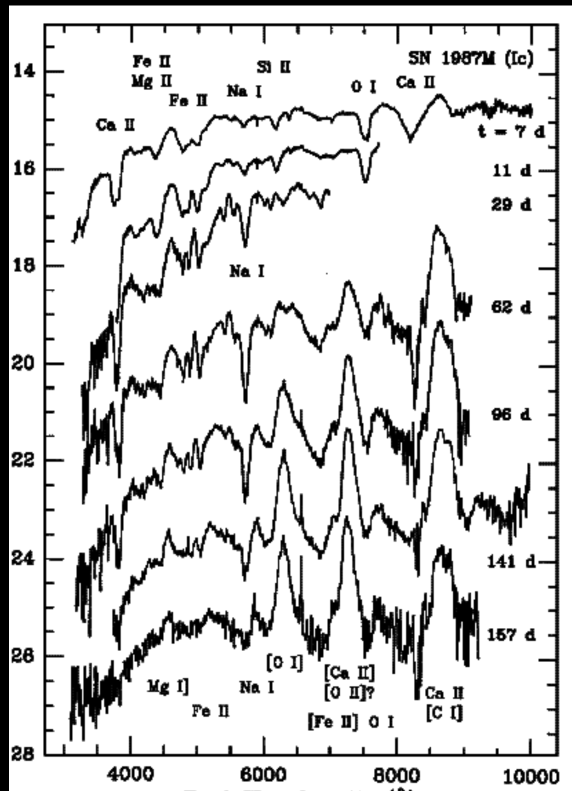
Properties of GRB-SNe (broad-lined SNe-Ic)

Lack of H and He in the ejecta: SNe-Ic

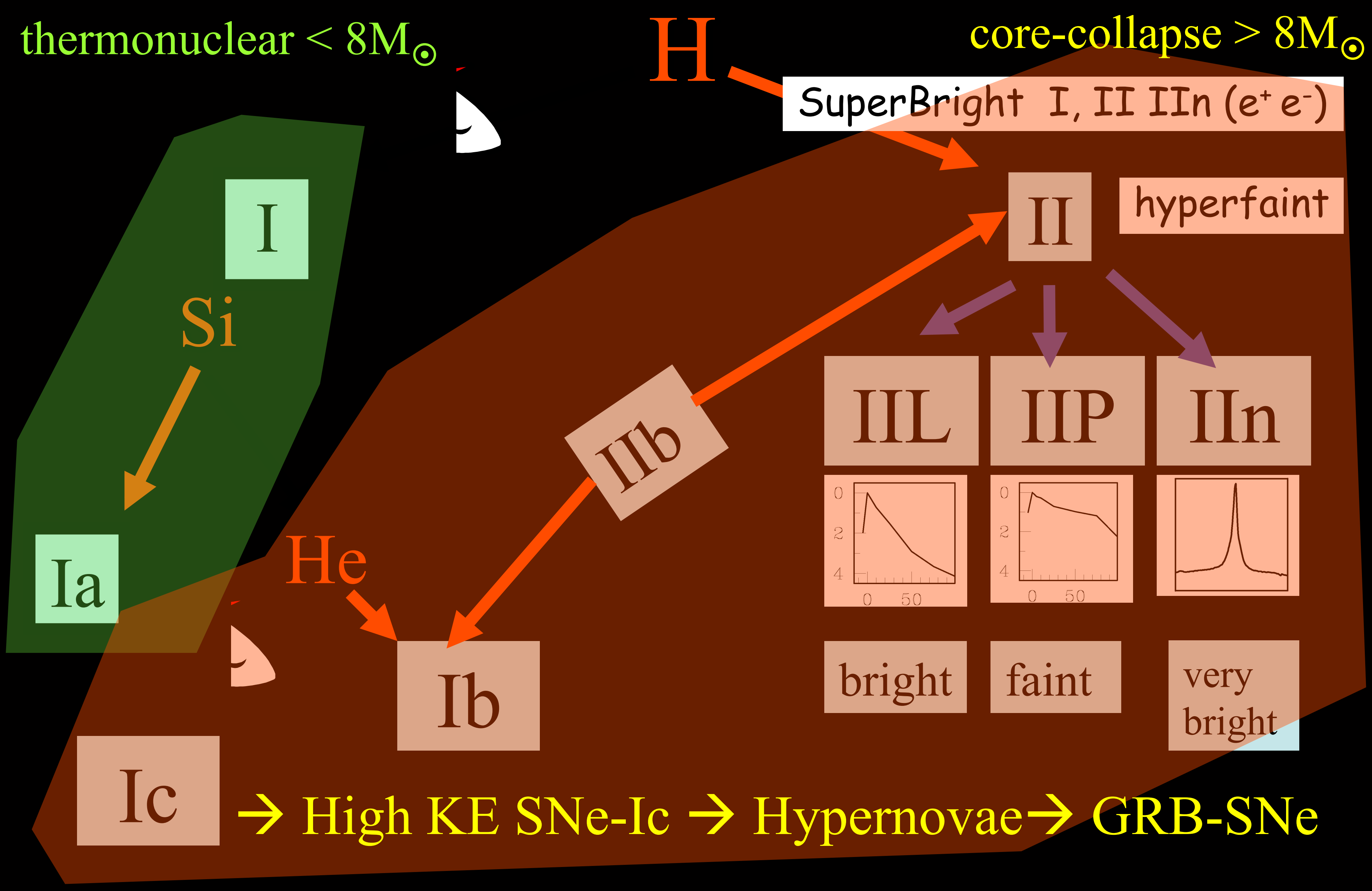
Very broad features: large expansion velocity (> 0.1c)



Patat et al. 2001



Supernova taxonomy



SNe-CC size progenitors

Red Supergiant

$R \sim 4 \times 10^{13}$ cm

Blue Supergiant

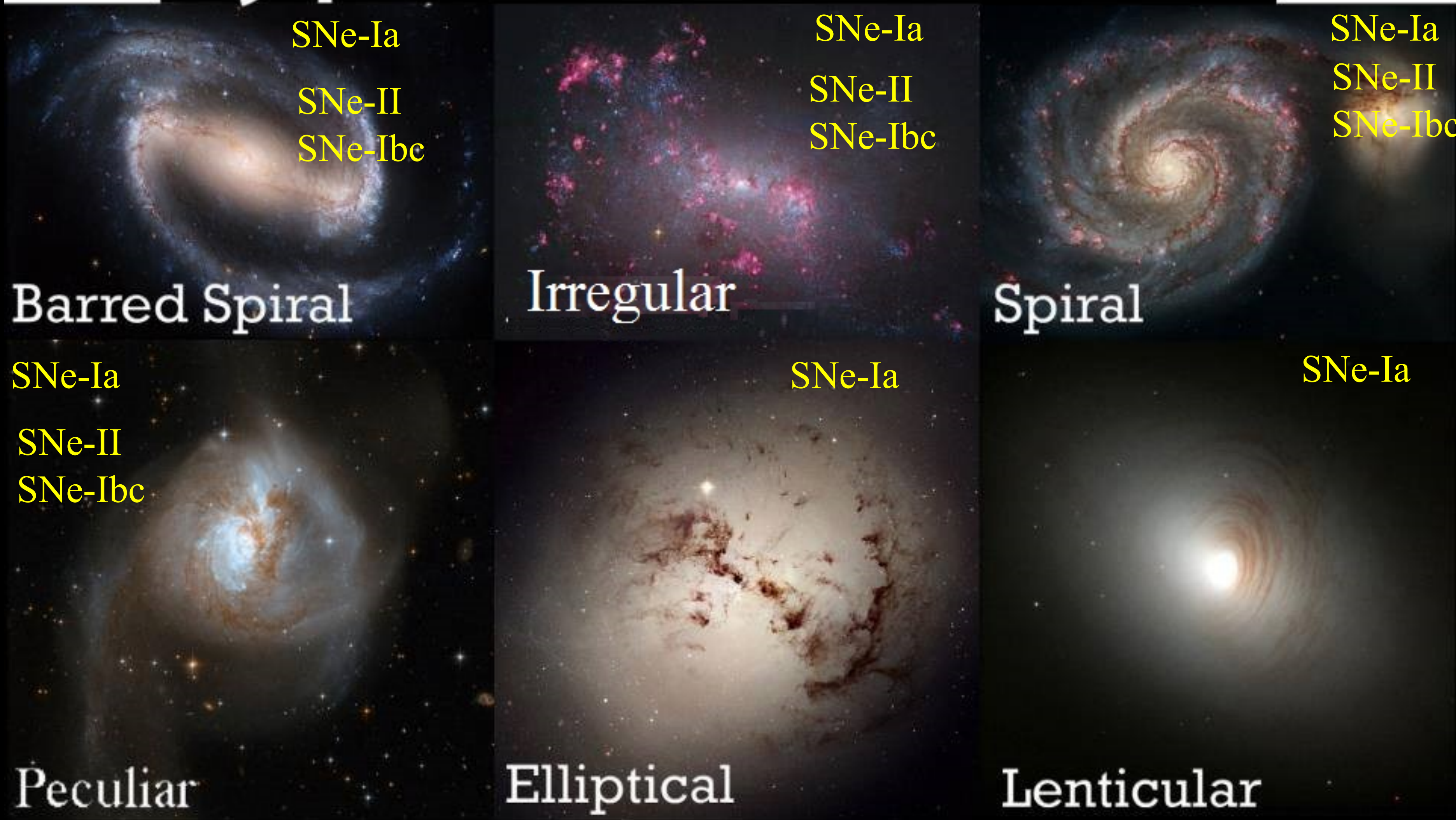
$R \sim 4 \times 10^{12}$ cm

The radius of the progenitor

W-R Star

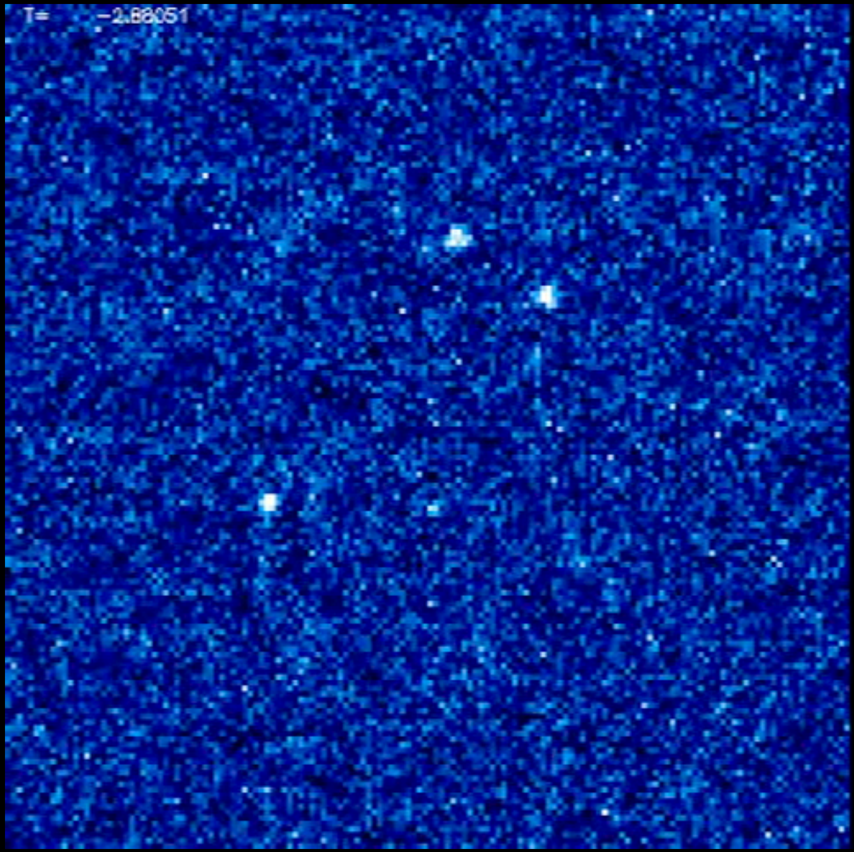
- $R \sim 4 \times 10^{11}$ cm

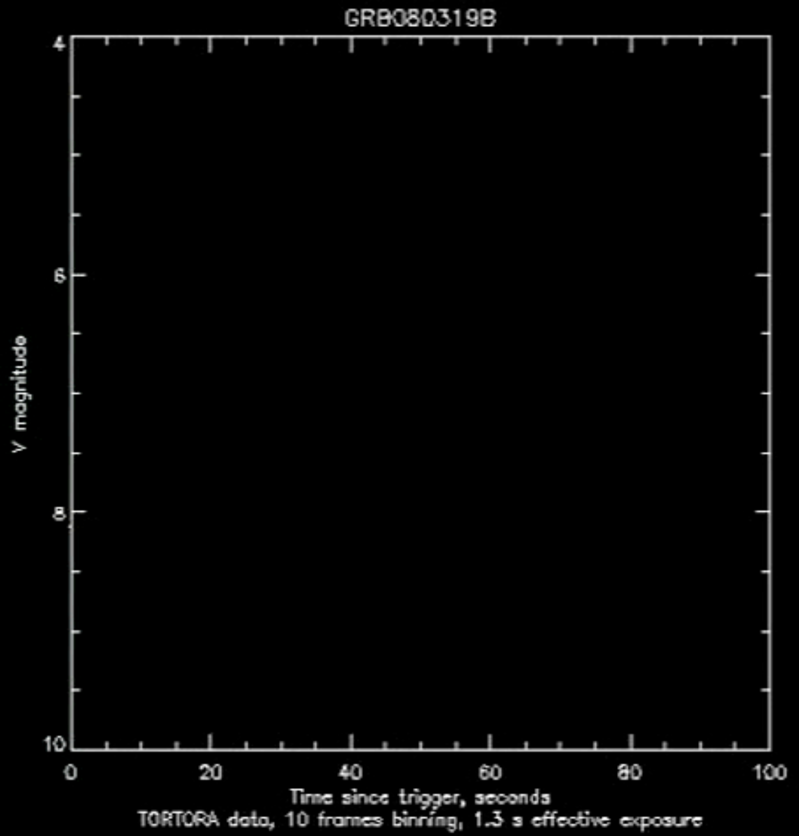
Types of Galaxies



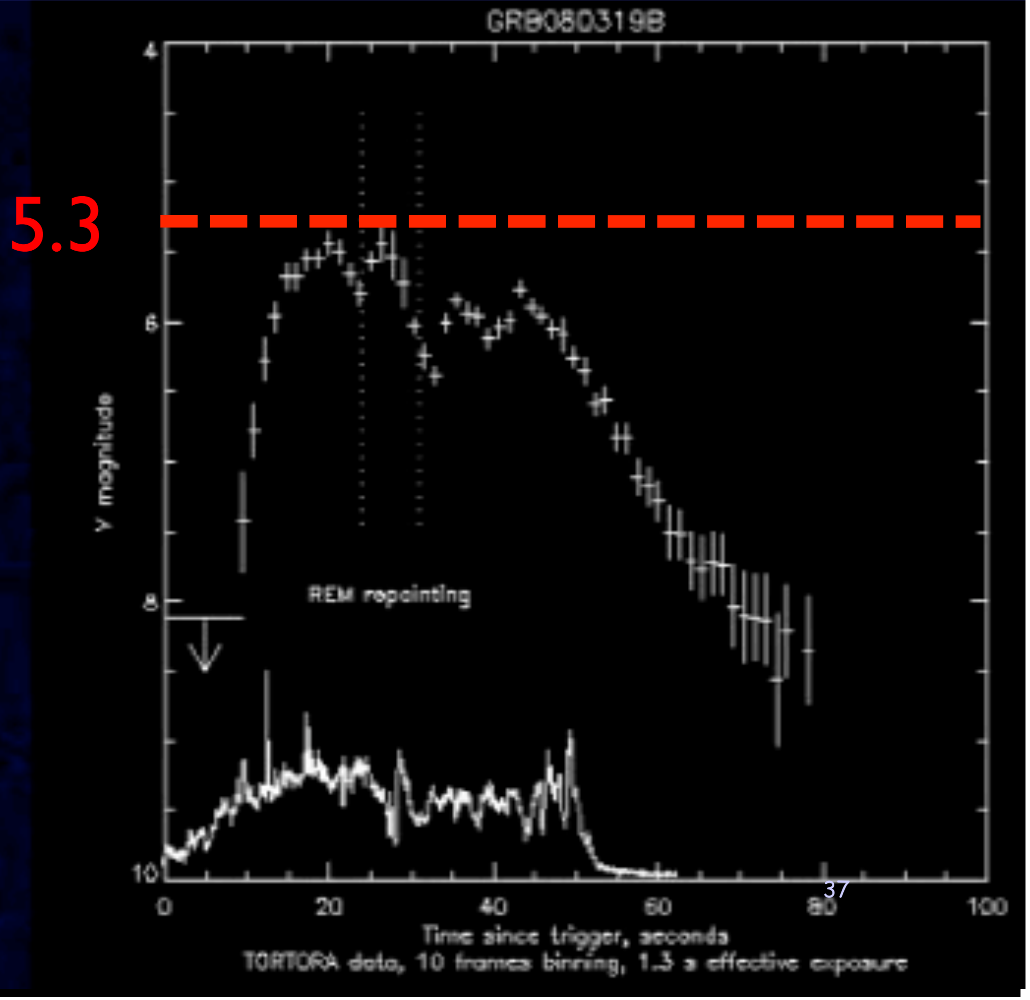
The location of GRB 080319B in the sky was just ~10° away from the previously discovered (about 30min earlier) GRB 080319A

This means that TORTORA which was already observing the field of GRB 080319A had GRB 080319B in the field of view before the delivery of the high-energy alert

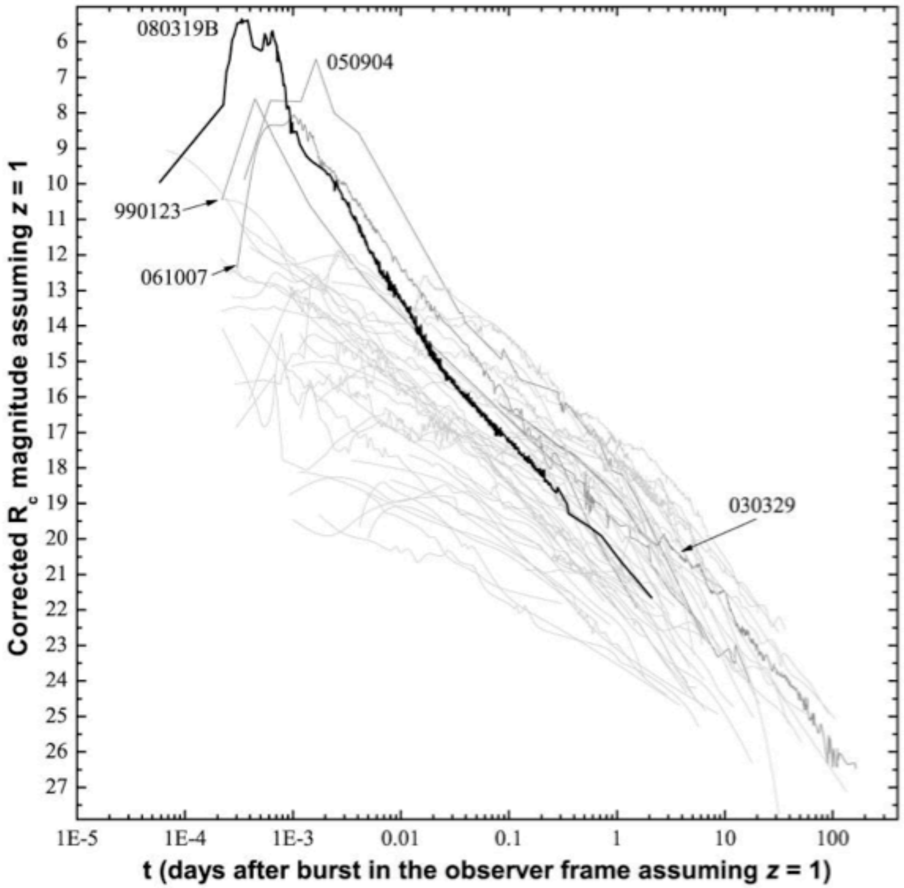


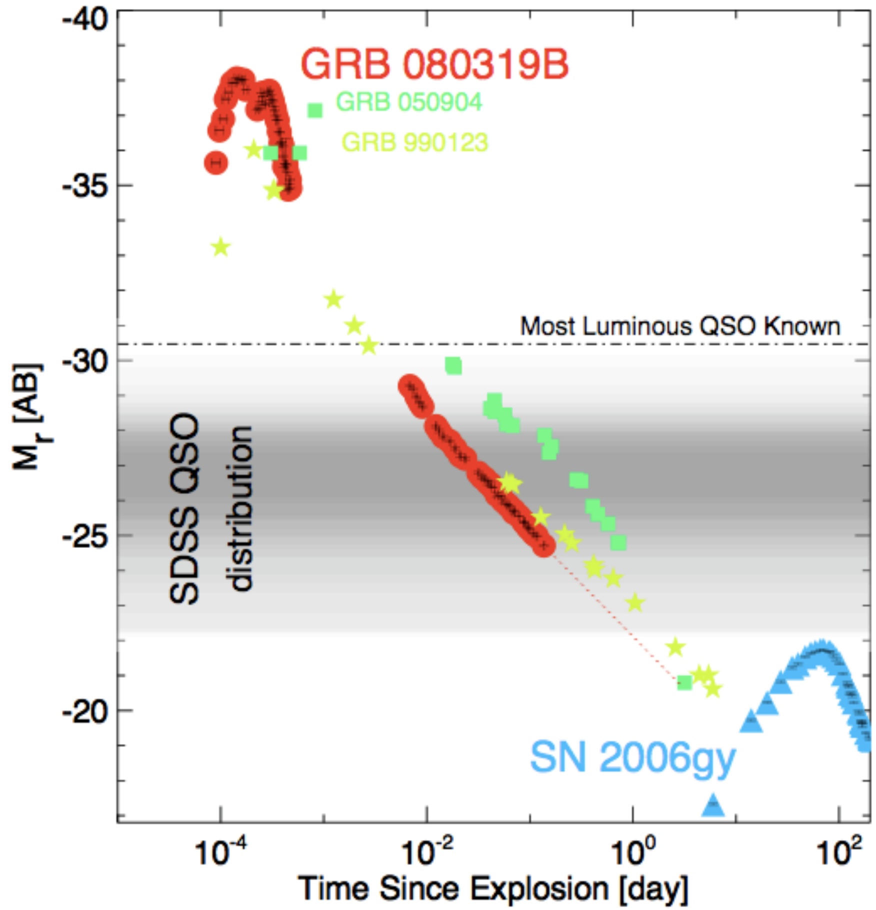


The apparent magnitude

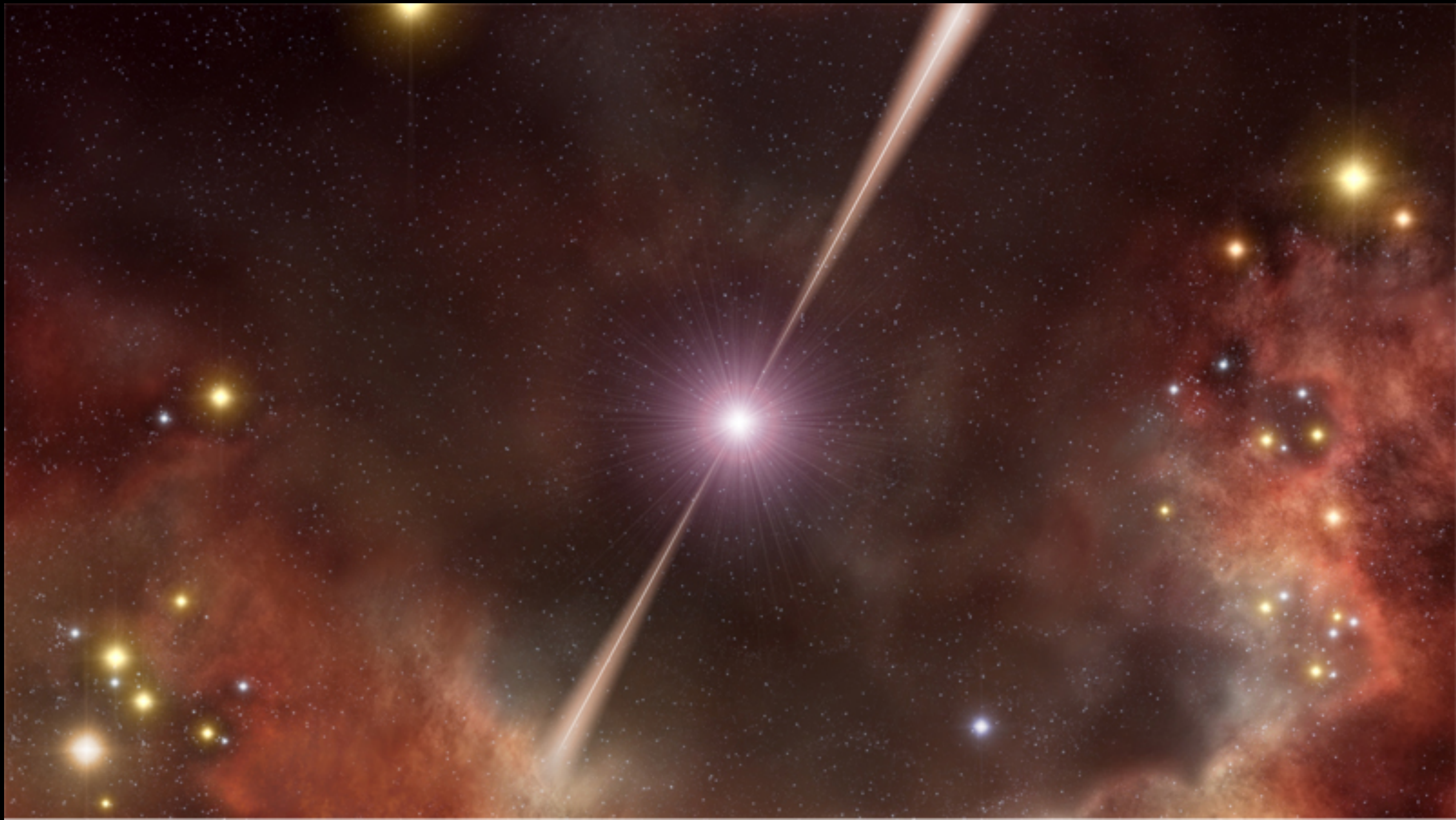


GRB 080319B compared to other GRBs or cosmological sources (Bloom et al. 2008)

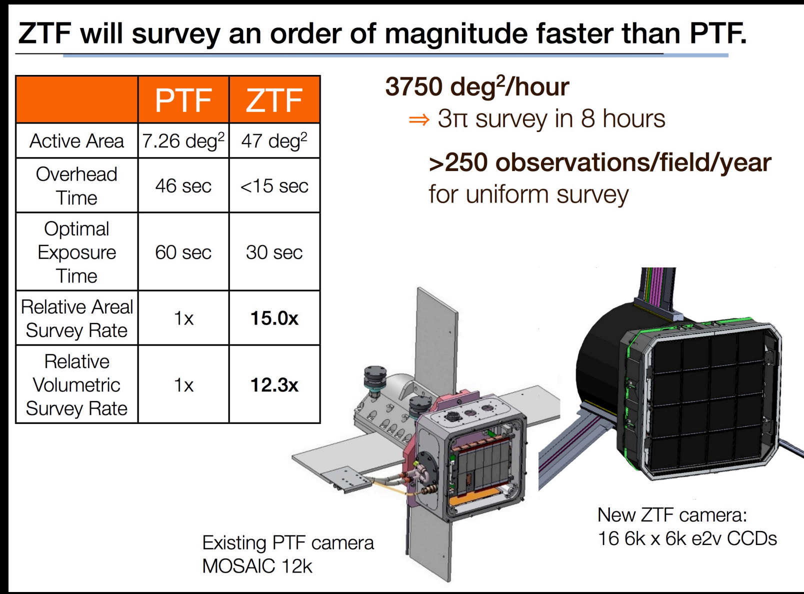




The apparent magnitude of the Moon is -12.6 and the apparent magnitude of the Sun is -26.7, cfr. to ~ -38



PAN-STARRS



ZTF will survey an order of magnitude faster than PTF.

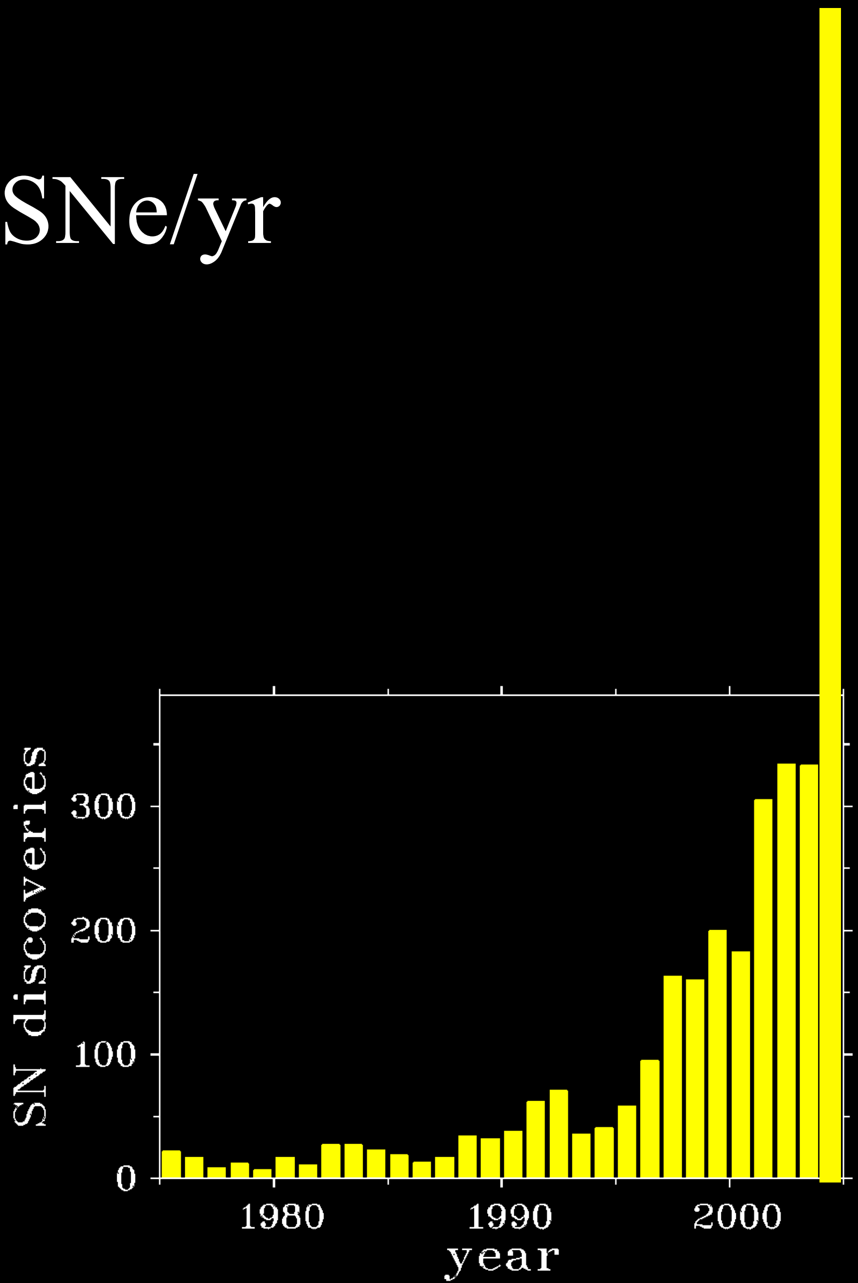
	PTF	ZTF
Active Area	7.26 deg^2	47 deg^2
Overhead Time	46 sec	<15 sec
Optimal Exposure Time	60 sec	30 sec
Relative Areal Survey Rate	1x	**15.0x**
Relative Volumetric Survey Rate	1x	**12.3x**

ASASSN
SDSS and DES
ATLAS
ESSENCE SN survey
DLT40
SUDARE @ VST

SkyMapper

Chile, Hawaii, Texas, South Africa

~ 1000 SNe/yr



Astrophysics with SNe

- Explosive Death of Stars — *-Physics of compact objects*
- Metal Enrichment — *-Galaxies Nucleosinthesis*
- Energy Injection
- Tracers of SFRs — *-Evolution of stellar populations and galaxies*

- Distance Indicators
- Tracers of cosmological models — *-Cosmology*

- Bright Background Sources — *-CBM/IGM Studies at high z*

  -exploring the RE

- Bright Echoes — *-3D Structure of ISM*
- Cosmic Rays — - SN Remnants
- GWs (GW170817)
- Neutrinos (1987A) — *-Multi-Messenger*