SUPERNOVAE

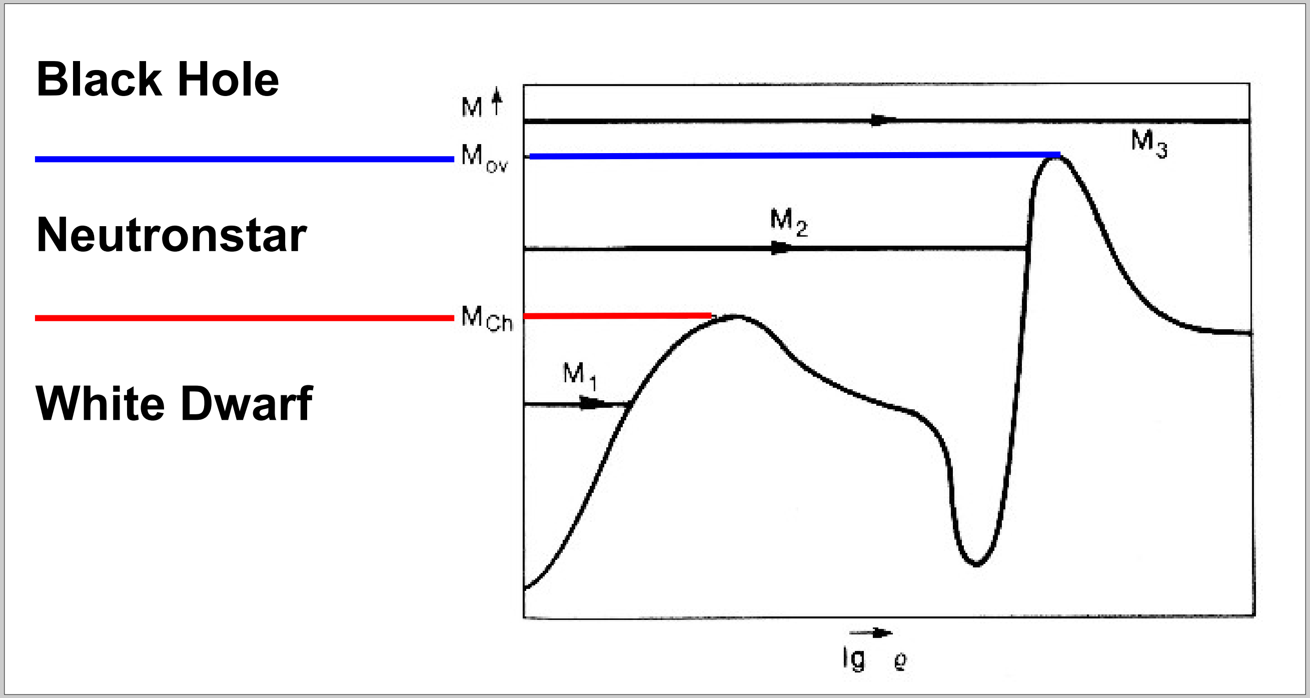
SUPERNOVAE

Stellar evolution – The End

The mass determines the final product of a star

Oppenheimer Volkoff mass
M_{OV} ~ 2 $M_\odot$

Chandrasekhar mass
M_{Ch} ~ 1.4 $M_\odot$



Massive star → Supernova plus ↗ Black Hole
↘ Neutronstar

Low mass star → white dwarf
BUT white dwarf in binary system
accretion M > 1.4 $M_\odot$ → Supernova Ia

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Supernova

Historic Supernovae

Tycho Brahes Supernova
November 1572

450 years ago

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Historic Supernovae

Tycho Brahes Supernova
November 1572

450 years ago

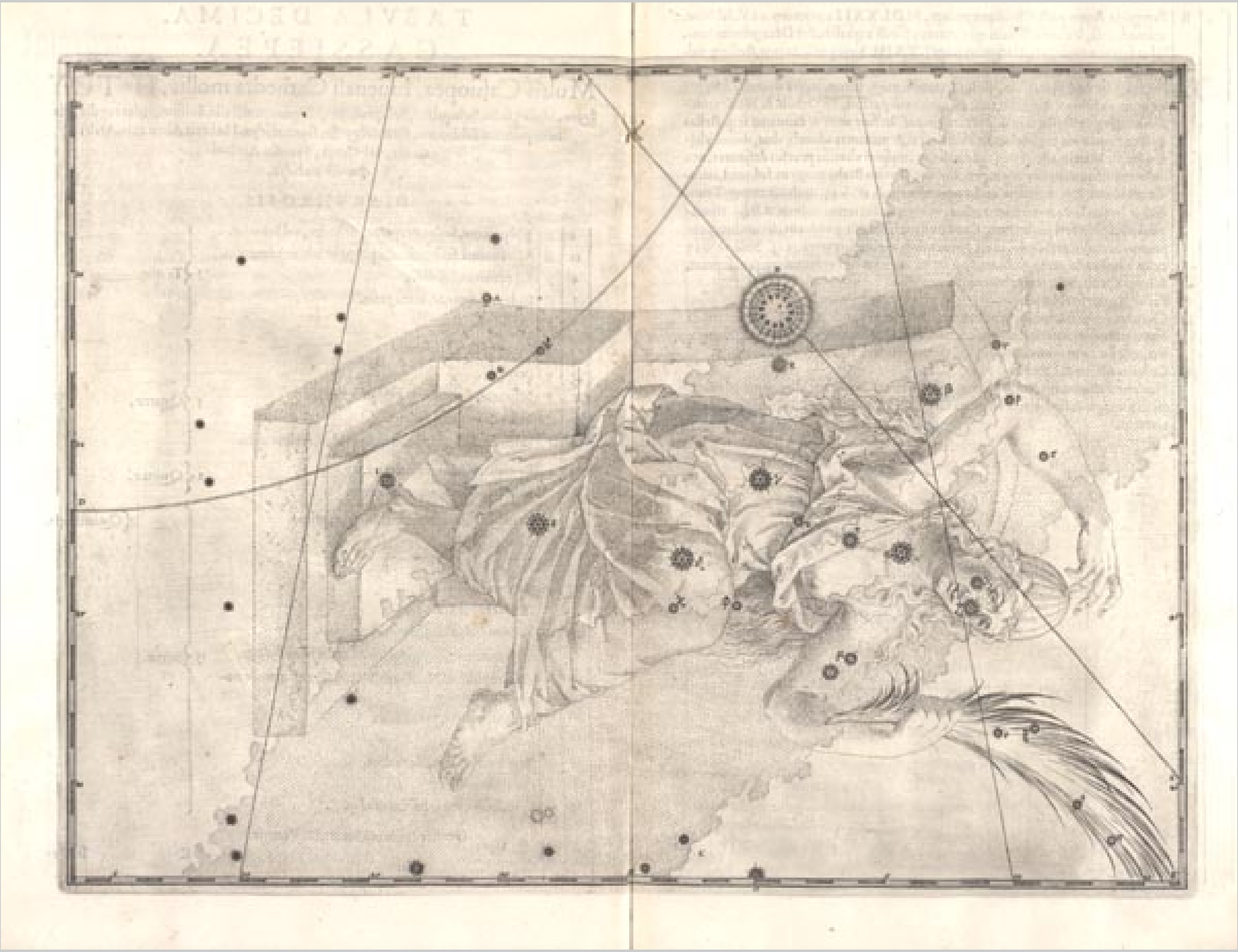
Tycho Brahe used the term

NOVA STELLA

believing he had just seen the birth and not death of a star

→ that further developes into SUPERNOVA

Historic Supernovae



Johann Bayer , Uranometria, 1603

Historic Supernovae in the MW

Supernova	remnant	constellation	distance pc	brightness V mag
SN 1006	G327.6+14.5	Lupus	1000	-9
SN 1054	Crab nebula	Taurus	2000	-5
SN 1181	3C58	Cassiopeia	2600	+1
SN 1572	Tychos SN	Cassiopeia	3050	-4
SN 1604	Keplers SN	Ophiuchus	5000	-2.6
SN 1680	Cas A	Cassiopeia	2800	+6

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History – the first Supernovae

The first person known to have seen a supernova was **Hipparchus** (**135 BC, Scorpio**).
From Rhodes, Hipparchus made very precise observations of the positions of the stars and noted them down. He then writes in December in the year 135 BC a new star appeared → a supernova ?

There is also evidence from **Chinese** records that supernovae have been seen:

SN185 was described in **Han's book**:
In the 2nd year of the Zhongping epoch in the 10th month on the day of Kwei Hae ↔ December 7 in185 a "**guest star**" appeared. It showed variable colors and gradually faded. In the 6th month it disappeared.

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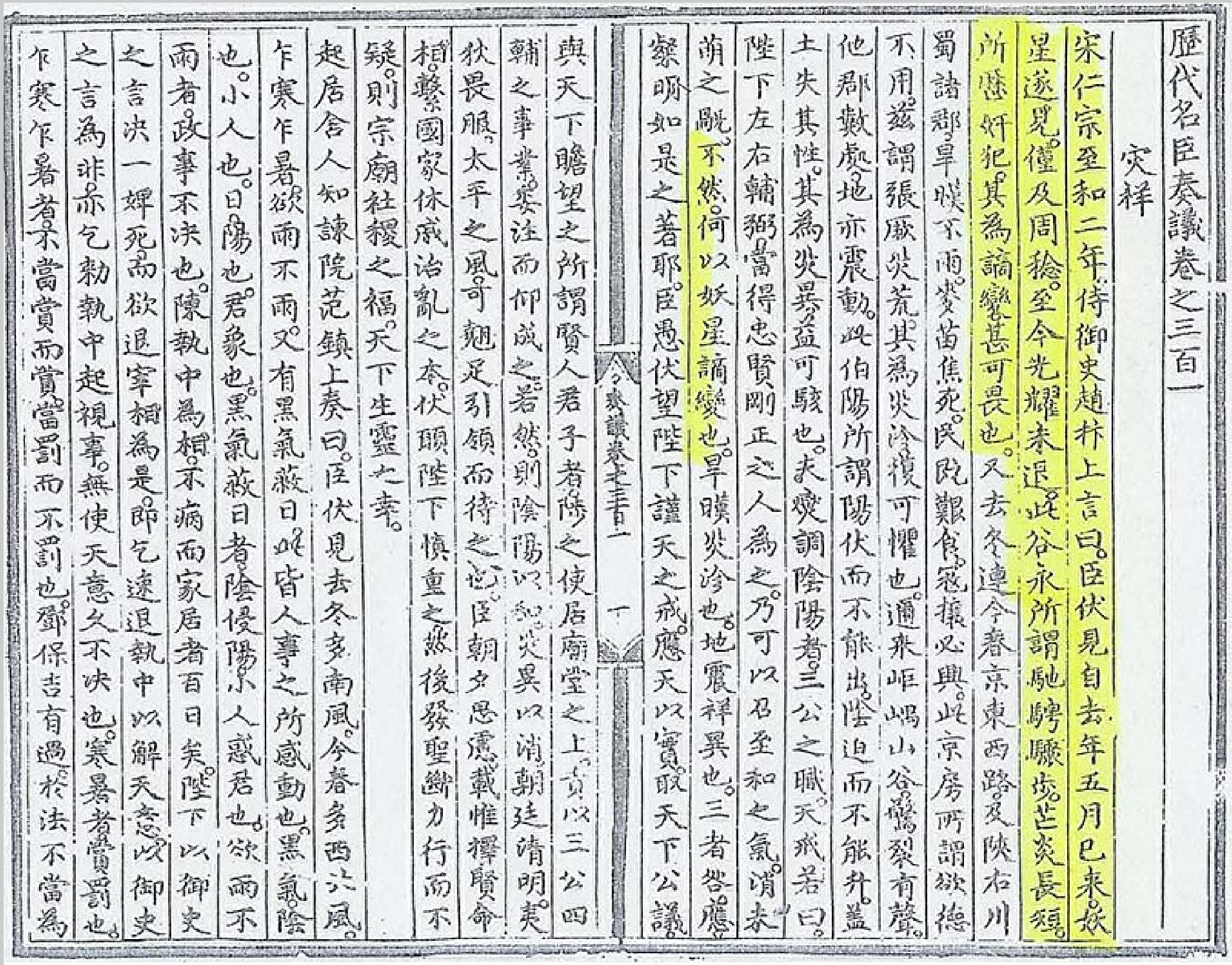
History – the first Supernovae

Other Chinese records exist for SN1006 and SN1054



歷代名臣奏議卷之三百一
災祥
宋仁宗至和二年侍御史趙抃上言曰臣伏見自去年五月已來妖
星遂見僅及周稔至今光耀未退此谷永所謂馳騁驟步芒炎長彗
所歷奸犯其為譎變甚可畏也又去冬連今春京東西路及陝右川
蜀諸郡旱暵不雨麥苗焦死民既艱食寇攘必興此京房所謂欲德
不用茲謂張厥災荒其為災沴複可懼也邇來岷峨山谷驚裂有聲
他郡數處地亦震動此伯陽所謂陽伏而不能出陰迫而不能升蓋
土失其性其為災異益可駭也夫燮調陰陽者三公之職天戒若曰
陛下左右輔弼當得忠賢剛正之人為之乃可以召至和之氣消未
萌之禍不然何以妖星譎變也旱暵災沴也地震祥異也三者咎應
繫晰如是之著耶臣愚伏望陛下謹天之戒應天以實敢天下公議
奏議卷之三百一 一
與天下瞻望之所謂賢人君子者俾之使居廟堂之上責以三公四
輔之事業委注而仰成之若然則陰陽以和災異以消朝廷清明夷
狄畏服太平之風可翹足引領而待之也臣朝夕思慮載惟擇賢命
相繫國家休戚治亂之本伏願陛下慎重之然後發聖斷力行而不
疑則宗廟社稷之福天下生靈之幸
起居舍人知諫院范鎮上奏曰臣伏見去冬多南風今春多西北風
乍寒乍暑欲雨不雨又有黑氣蔽日此皆人事之所感動也黑氣陰
也小人也日陽也君象也黑氣蔽日者陰侵陽小人惑君也欲雨不
雨者政事不決也陳執中為相不病而家居者百日矣陛下以御史
之言決一婢死而欲退罷相為是耶乞速退執中以解天意以御史
之言為非耶乞勅執中起視事無使天意久不決也寒暑者賞罰也
乍寒乍暑者不當賞而賞當罰而不罰也鄧保吉有過於法不當為

History – Tycho's Supernovae

But Tycho Brahe's supernova from November 1572 was seen in Europe and one for which maps and records were made **that still exist !**

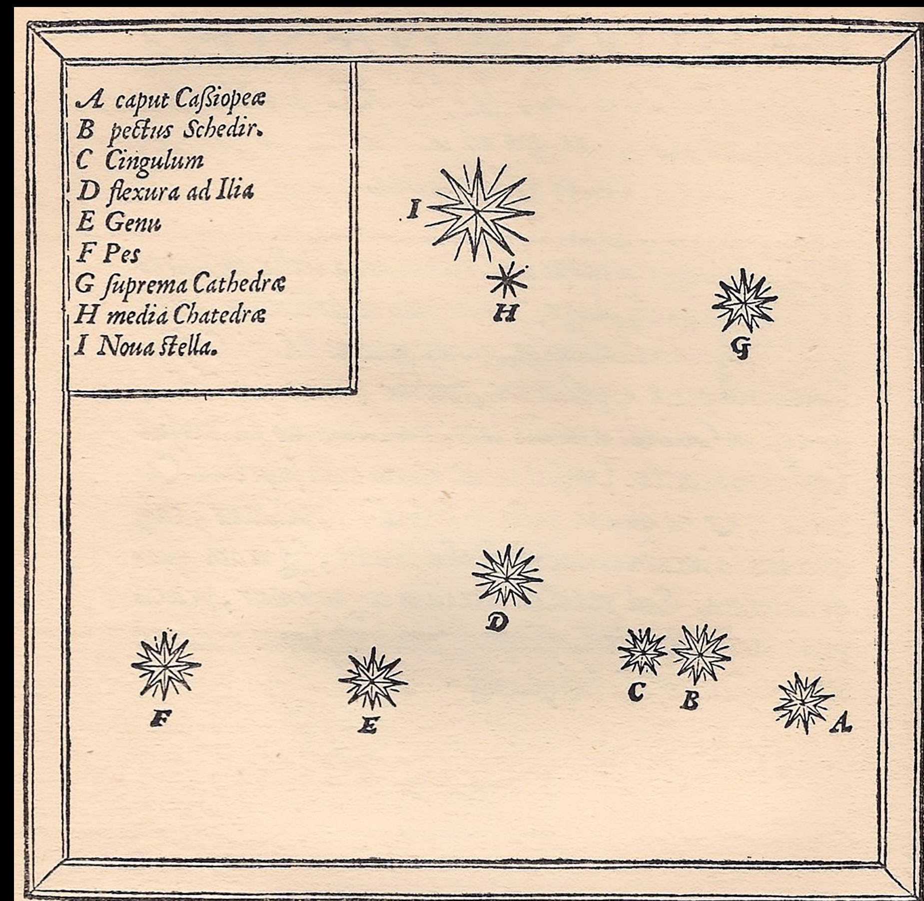
Tycho Brahes notes/booklet: De Nova Stella

TYCHONIS BRAHE DANI

DE NOVA STELLA

REGIA SOCIETAS SCIENTIARUM DANICA

HAUNIÆ



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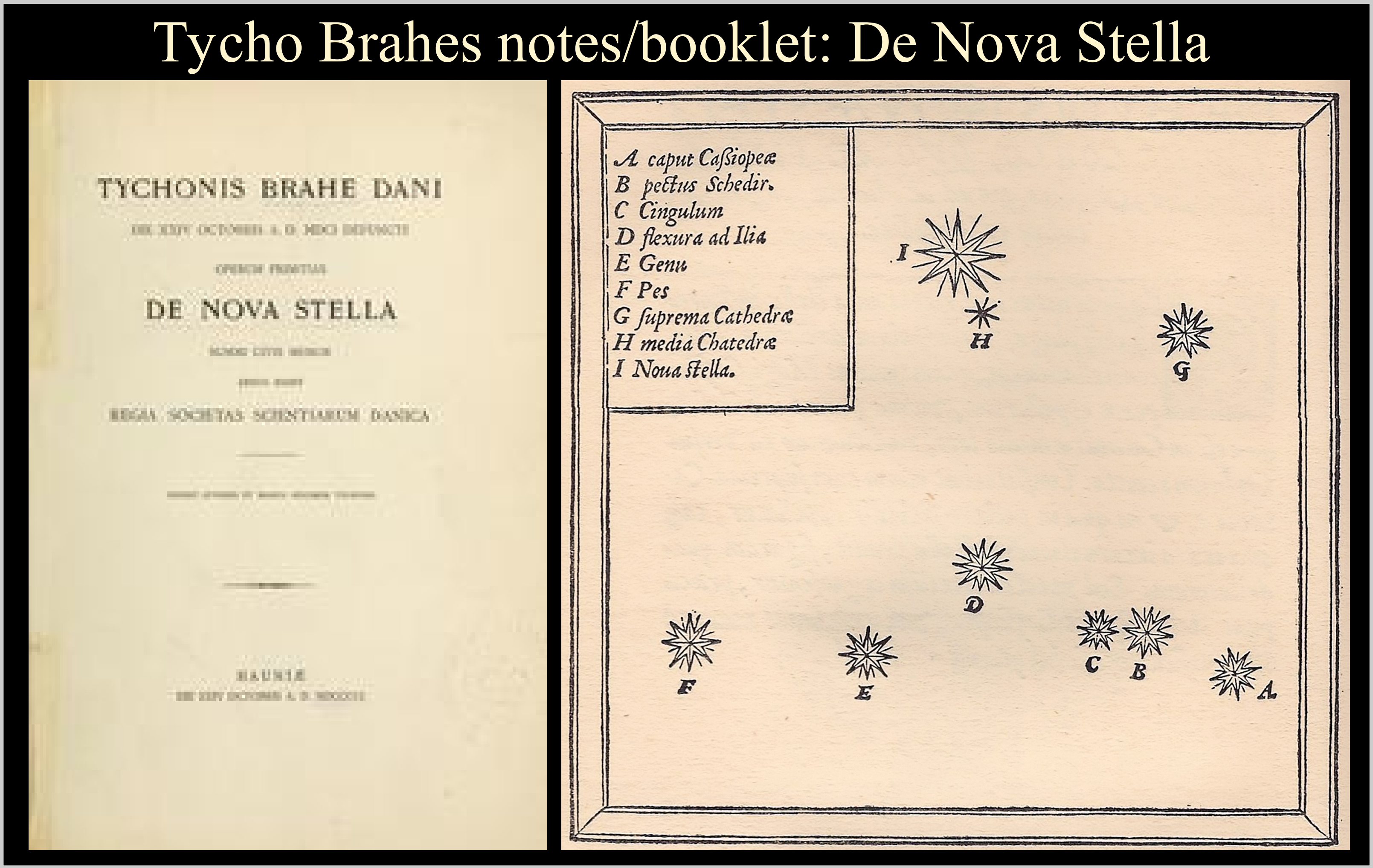
History – Tycho's Supernovae

But **Tycho Brahe's supernova?** from November 1572 was seen in Europe and one for which maps and records were made **that still exist !**



One of the first to see this explosion was **Paul Hainzel** from Augsburg (Germany) he notices it on Nov 7, Tycho Brahe saw it on the 11th.

Paul Hainzel

*1527 †May 12 1581)

German astronomer and mayor of Augsburg.

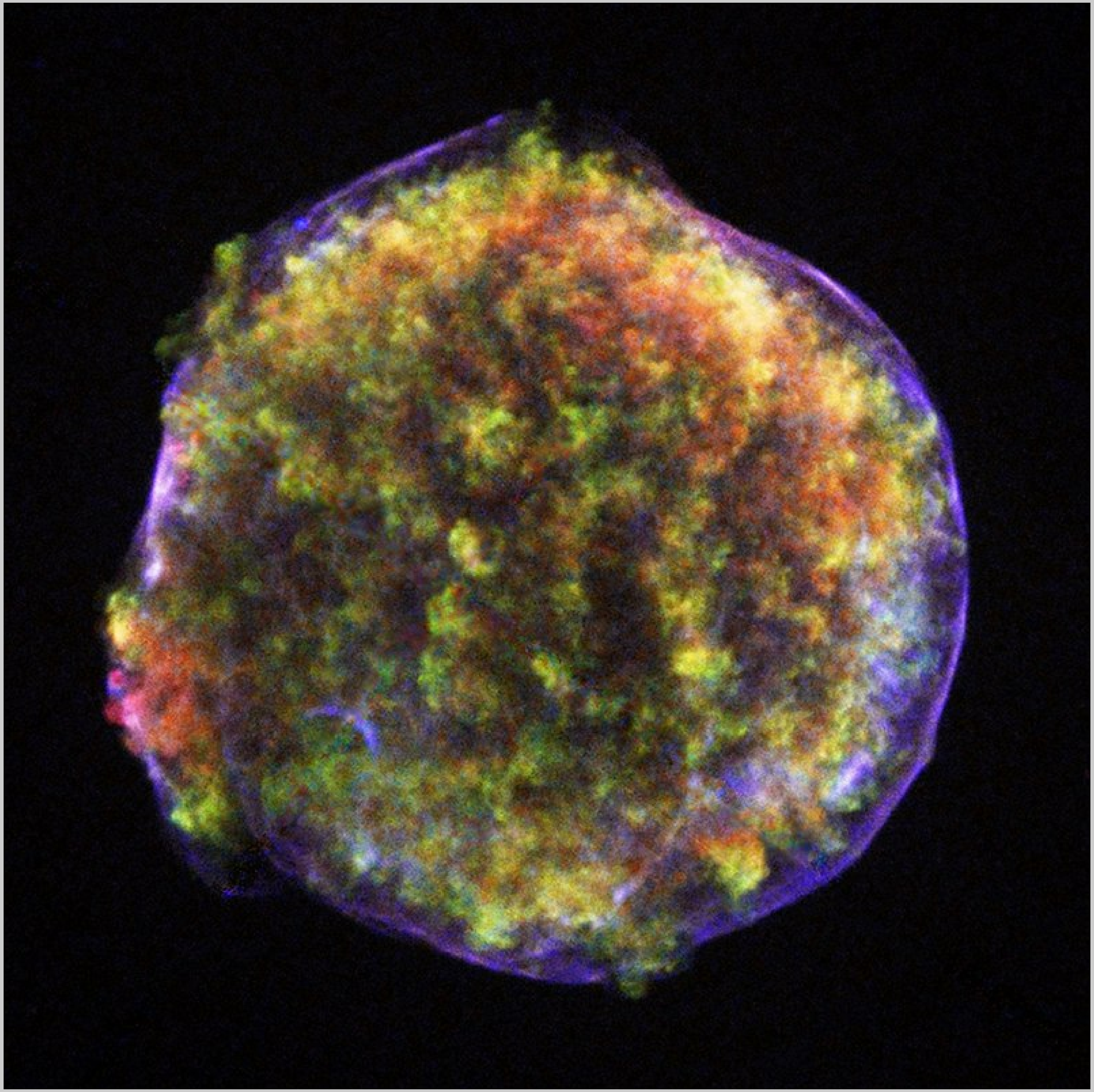
He studied in Basel, Tübingen,Wittenberg and 1545-1549 in Italy.

In 1569, Paul Hainzel helped his friend Tycho Brahe design and construct a large quadrant. The quadrant, which was 19 feet in radius and built on Hainzel's estate, was used for measuring the height of stars. However, it was destroyed five years later by fire or wind, before it could make significant observations. It was destroyed by a storm in December 1574. With the quadrant, Hainzel was able to determine the geographical latitude of his location at 48 degrees and 22 arc minutes in 1572, about two kilometers from the actual value.

History – Tycho's Supernovae

Tycho Brahes Supernova today

… the remnant



X-ray: NASA/CXC/SAO;

Infrared: NASA/JPL-Caltech;

Optical: MPIA, Calar Alto, O. Krause et al.

SUPERNOVA

ABC

Supernova – official naming

The name are given in chronologic order :

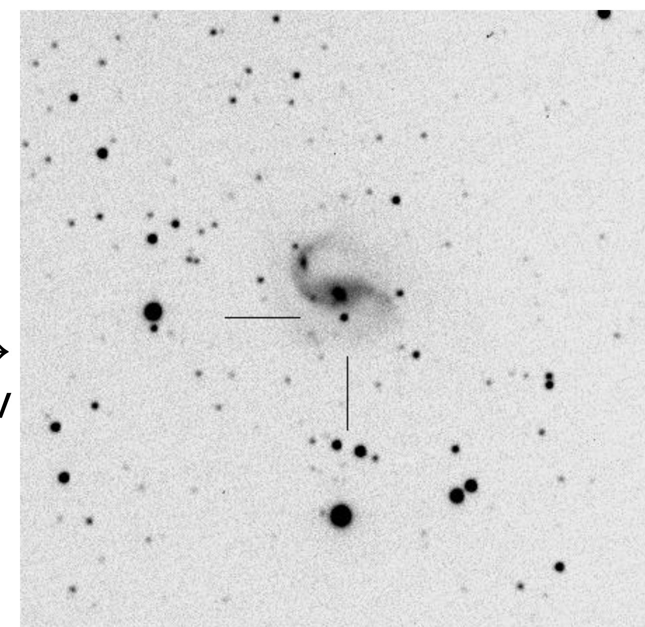
SN year

Since there are more than one in a years → further distinction
It starts with alphabetically capital letters: A B C ...
Exp. SN 1987A → which was the first SN detected in 1987

Then alphabetically with double lowercase letters: aa,ab,.. az, ba, bb ...
Exp. SN2004 bv → was the 74th in 2004
followed by <u>triple</u> lowercase letters and now <u>quadruple</u> lowercase letters

→ SN2004bv

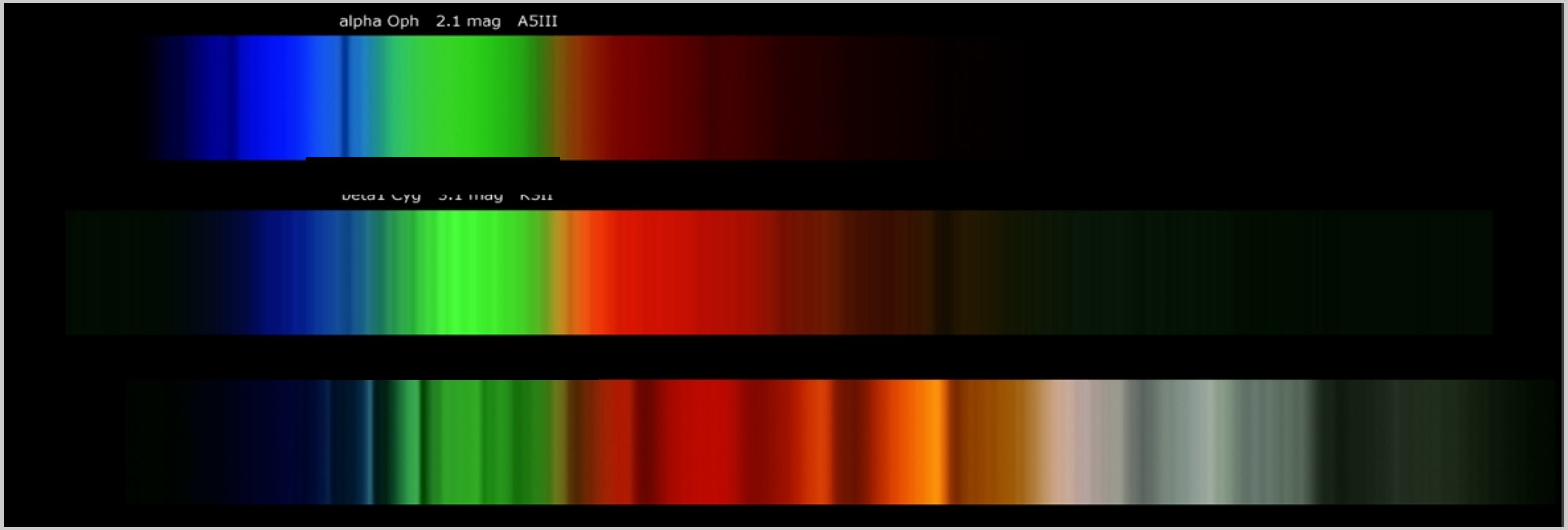
← SN1987A



classification of SN

Classification based on only

spectra and light curves



A lightcurve by Villeroy & Boch

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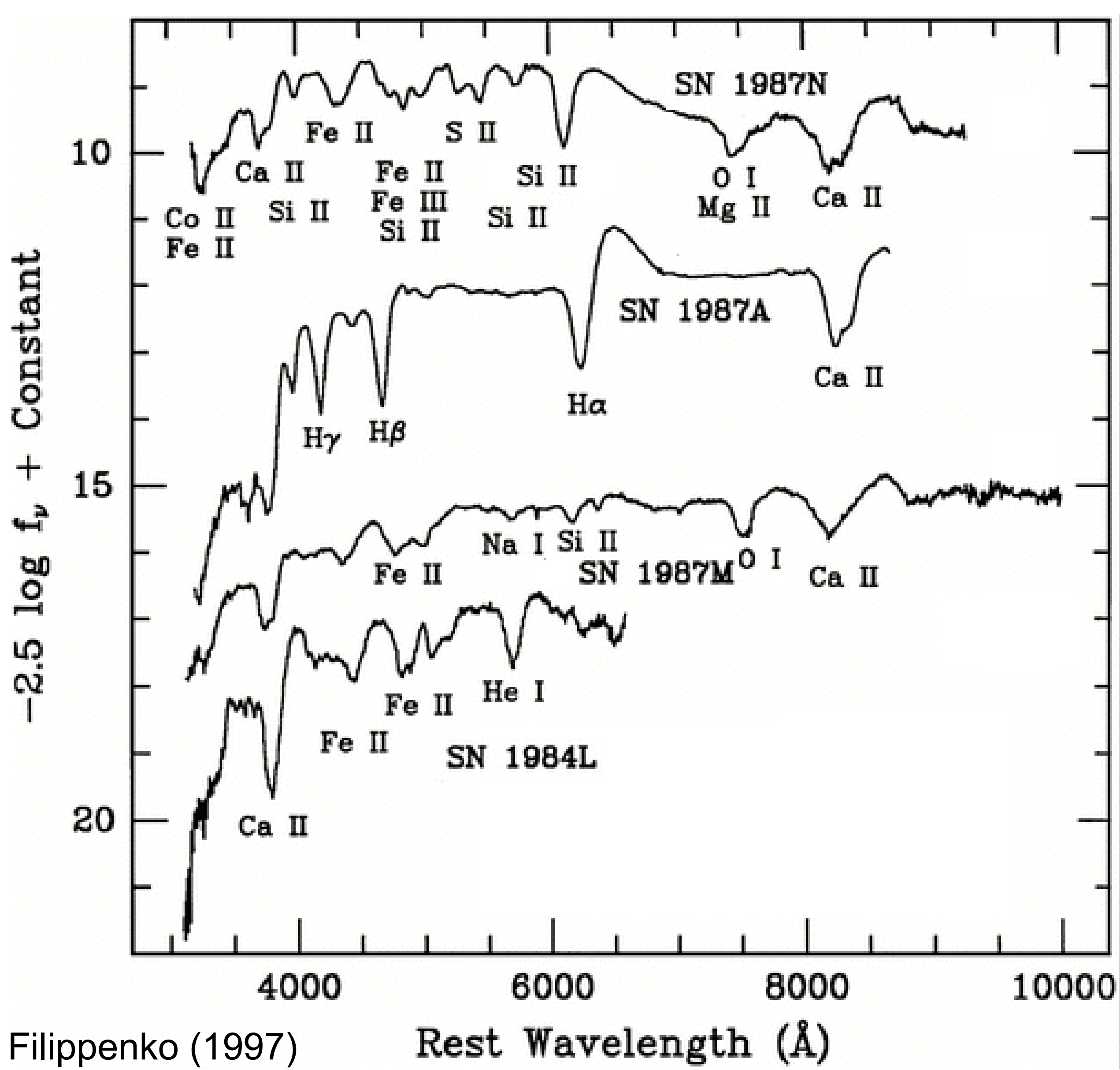
Supernova – Spectra



Filippenko (1997)

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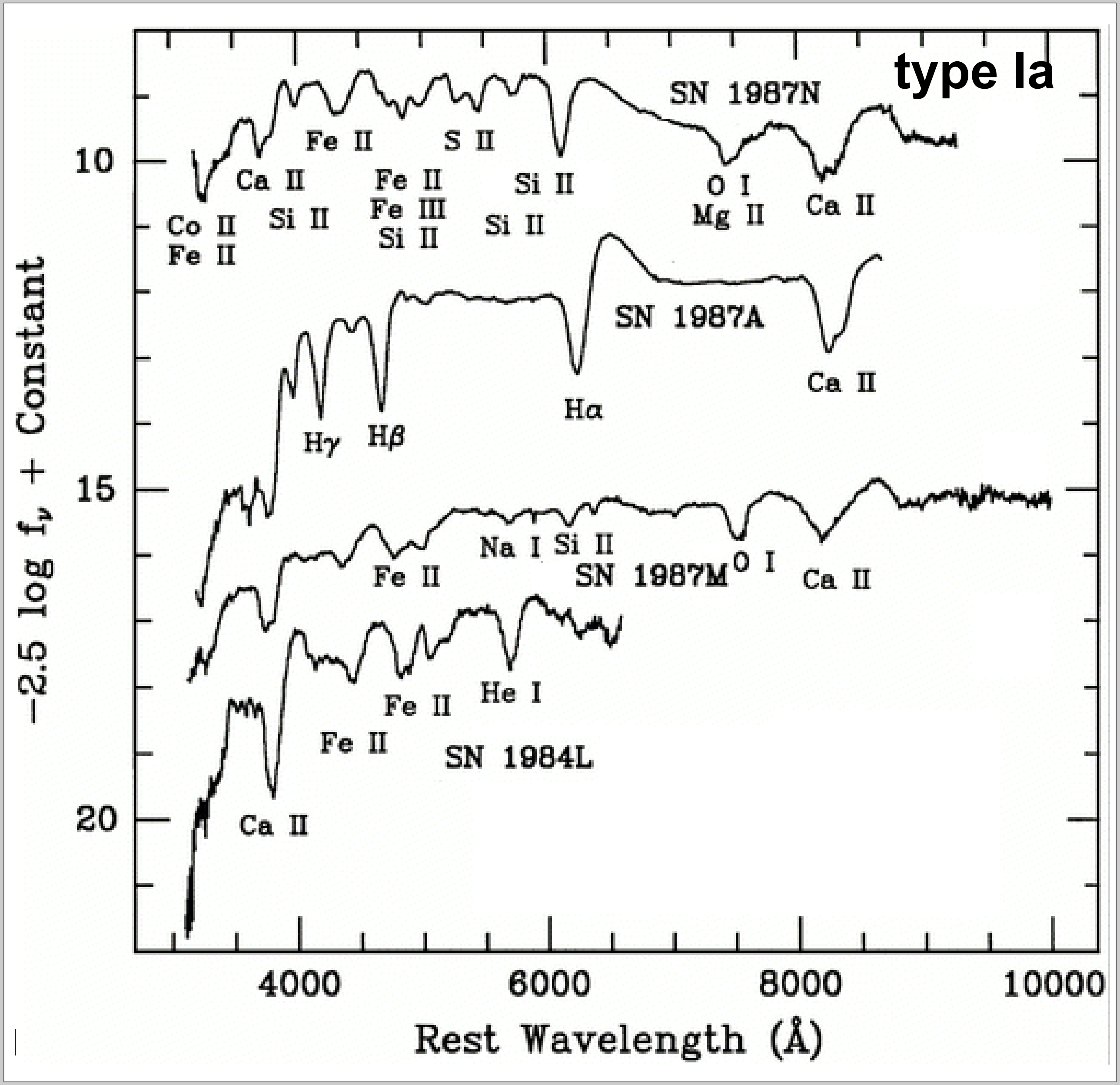
Supernova – Spectra

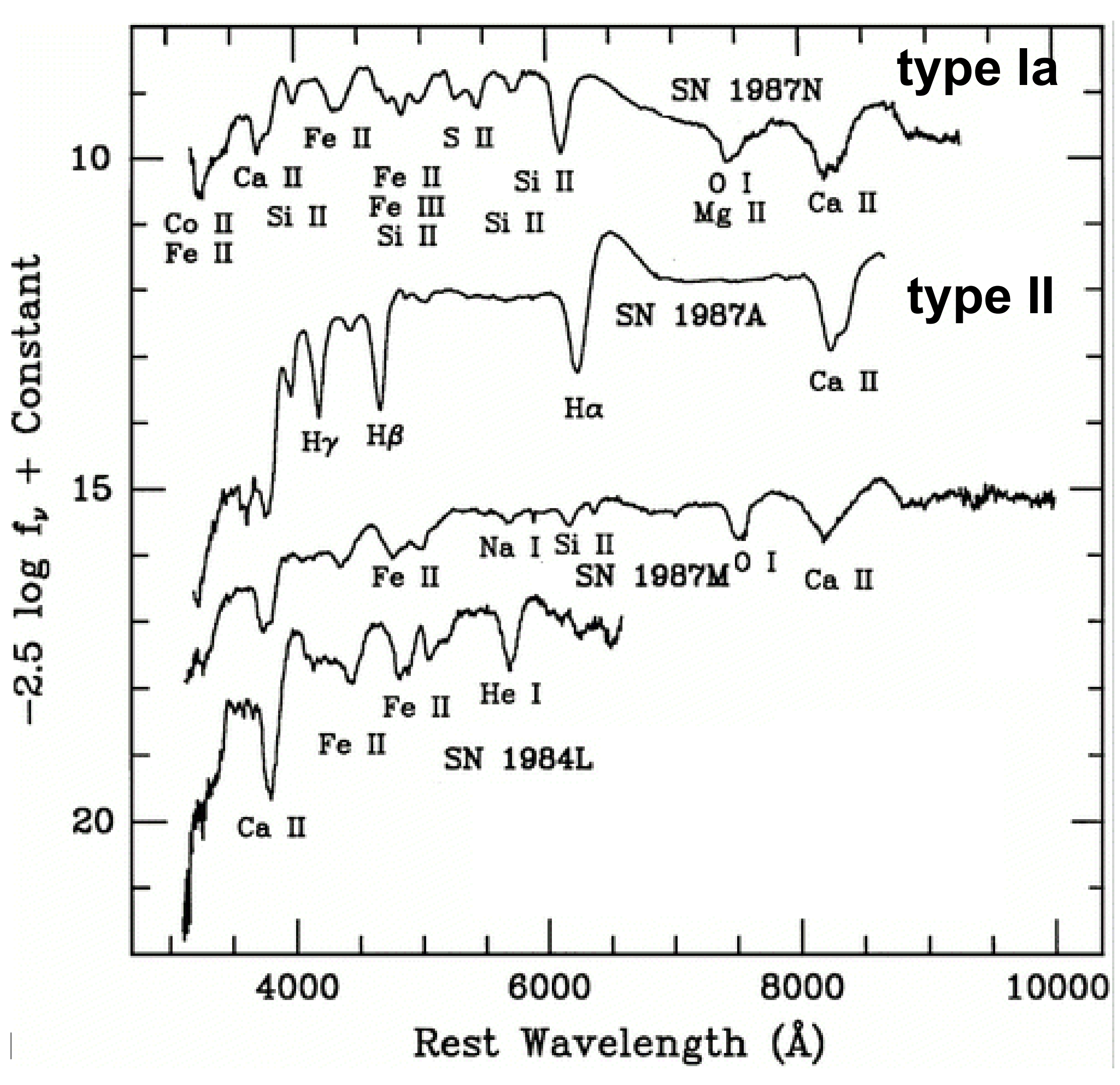
Typ Ia ↔ H ✘ Si ✓



Supernova – Spectra

Typ Ia ↔ H ✘

Typ II ↔ H ✓

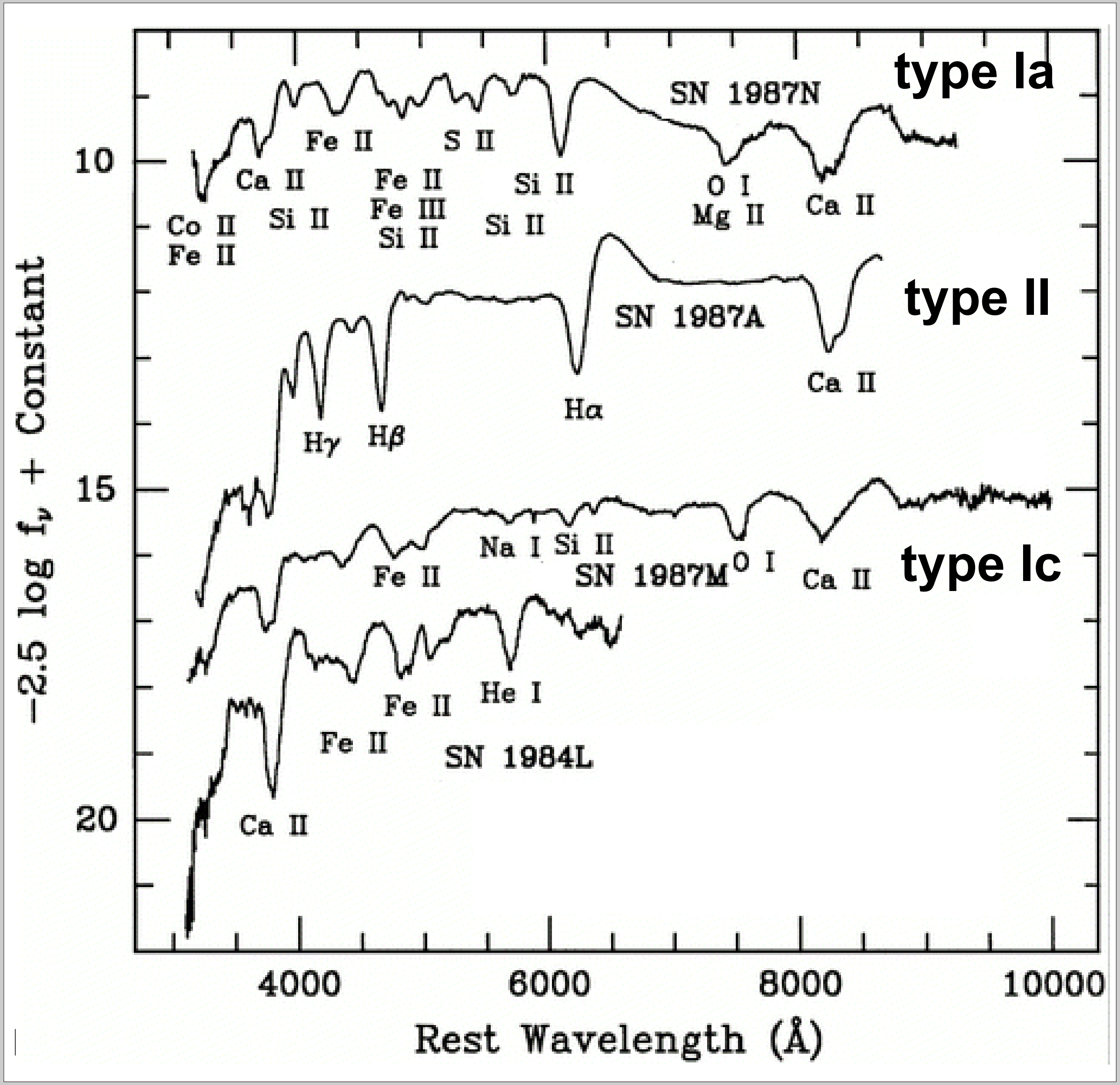


Supernova – Spectra

Typ Ia ↔ H ✘ Si ✔

Typ II ↔ H ✔

Typ Ic ↔ H ✘ He ✘



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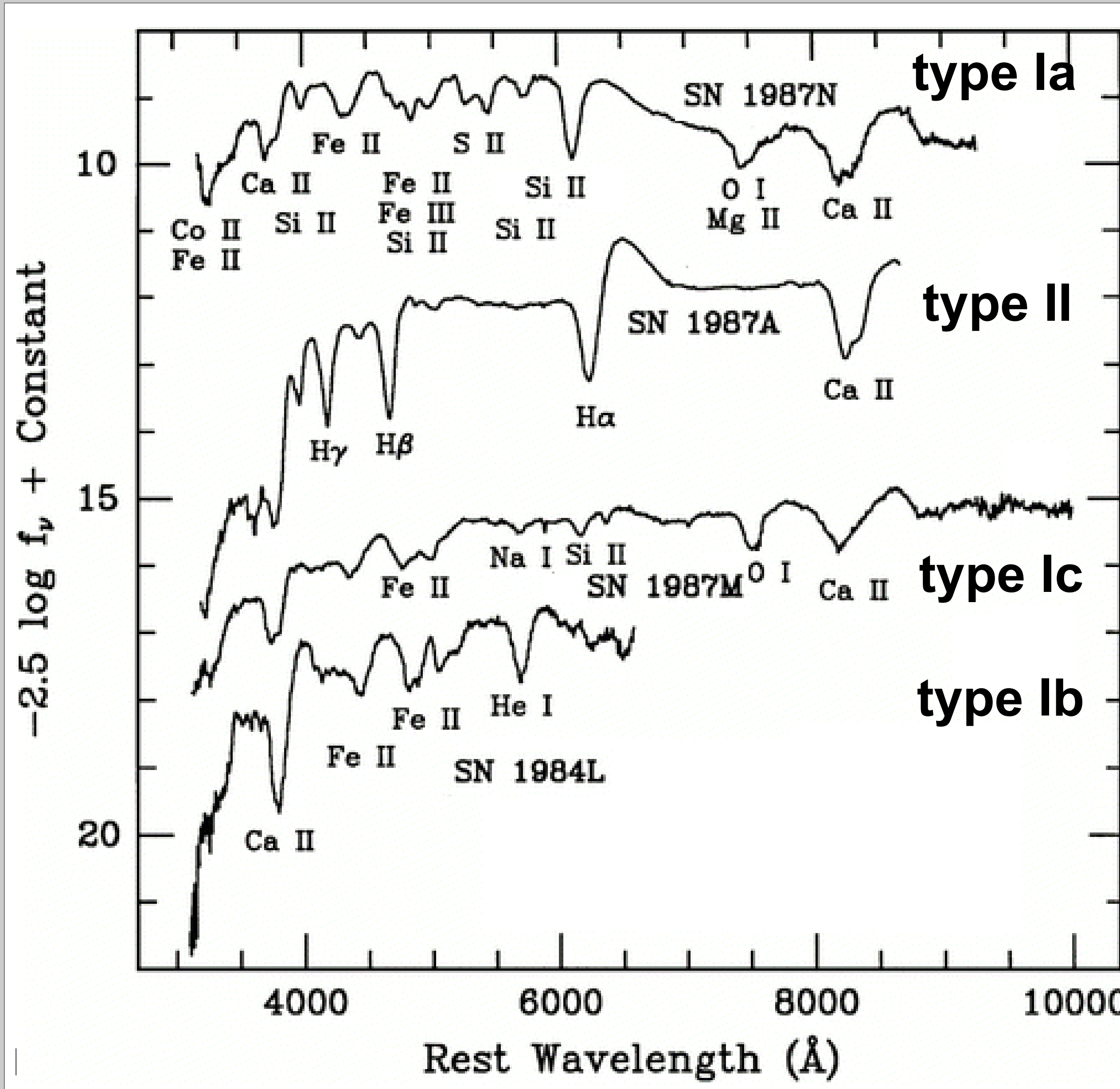
Supernova – Spectra

Typ Ia ↔ H ✘ Si ✔

Typ II ↔ H ✔ Si ✘

Typ Ic ↔ H ✘ He ✘ Si ✔

Typ Ib ↔ H ✘ He ✔ Si ✘



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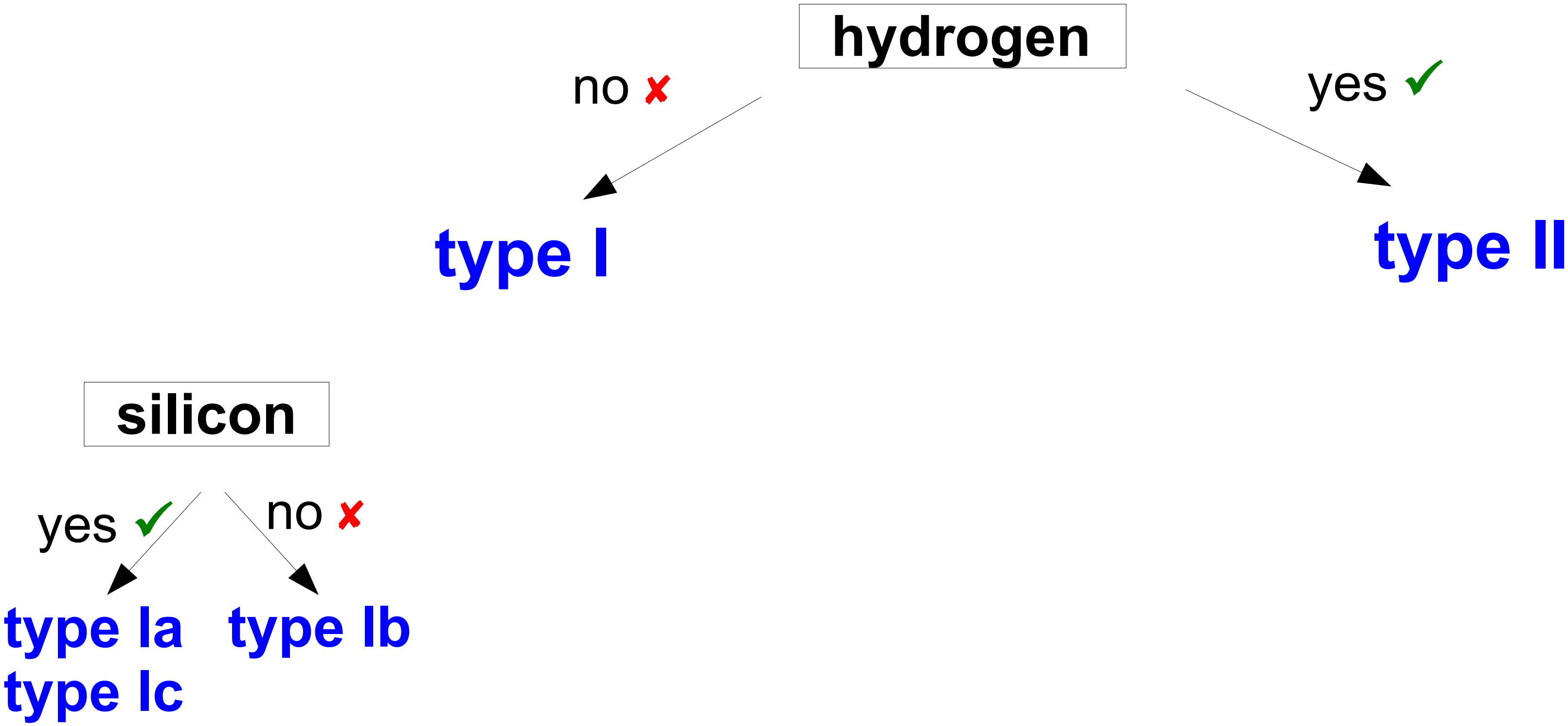
Supernova – Spectra & Lightcurves

hydrogen

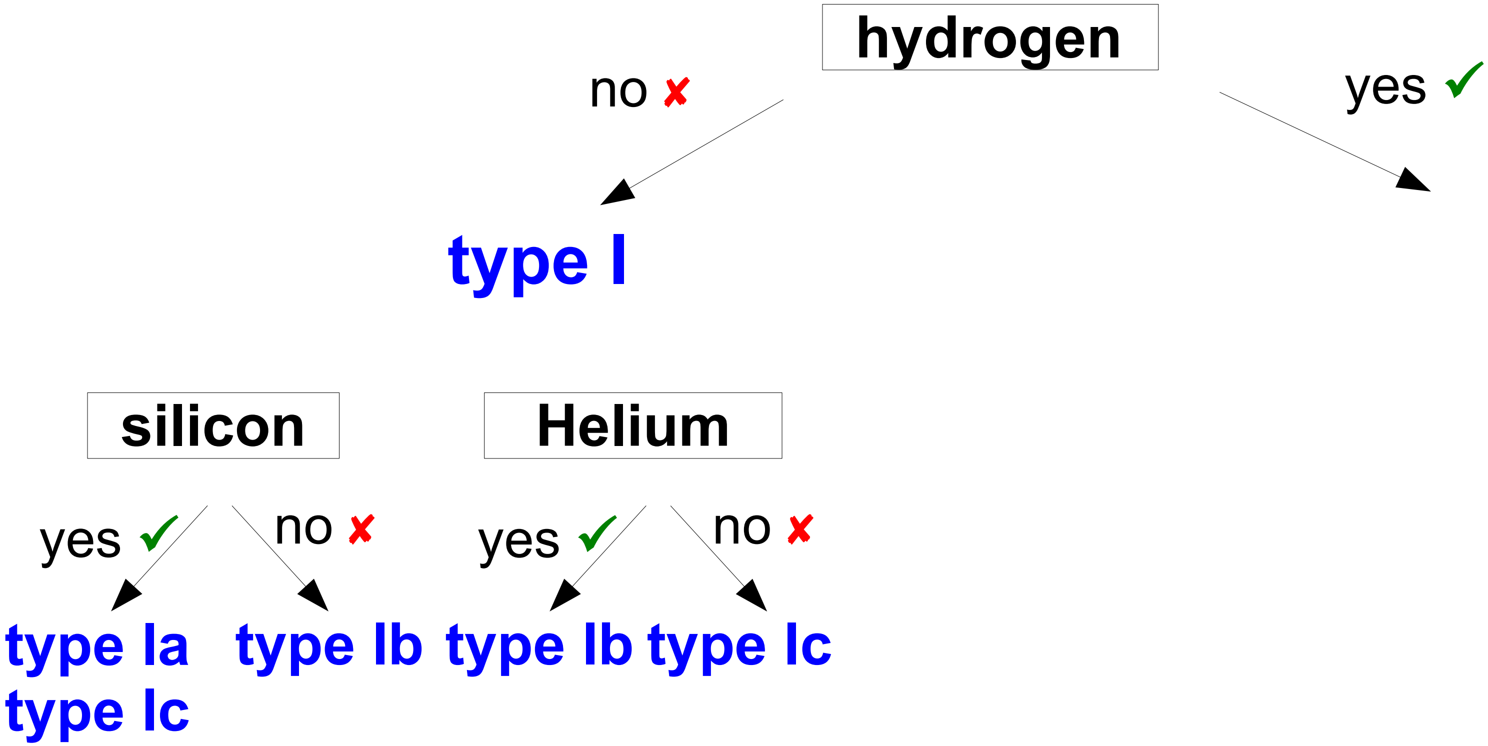
no ✘ → **type I**

yes ✓ → **type II**

Supernova – Spectra & Lightcurves

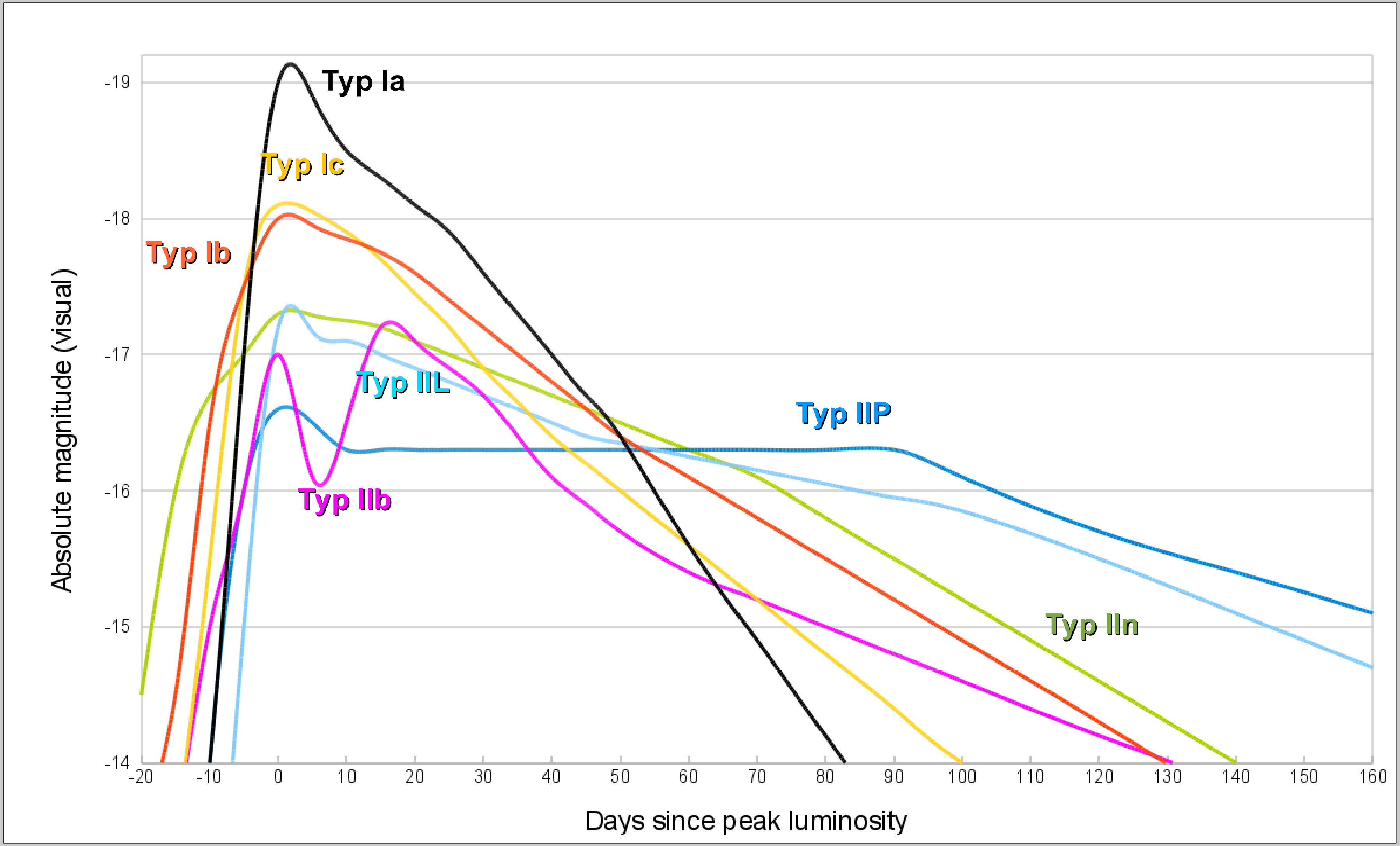


Supernova – Spectra & Lightcurves



Supernova – Lightcurves

Adapted from Filippenko (1997)



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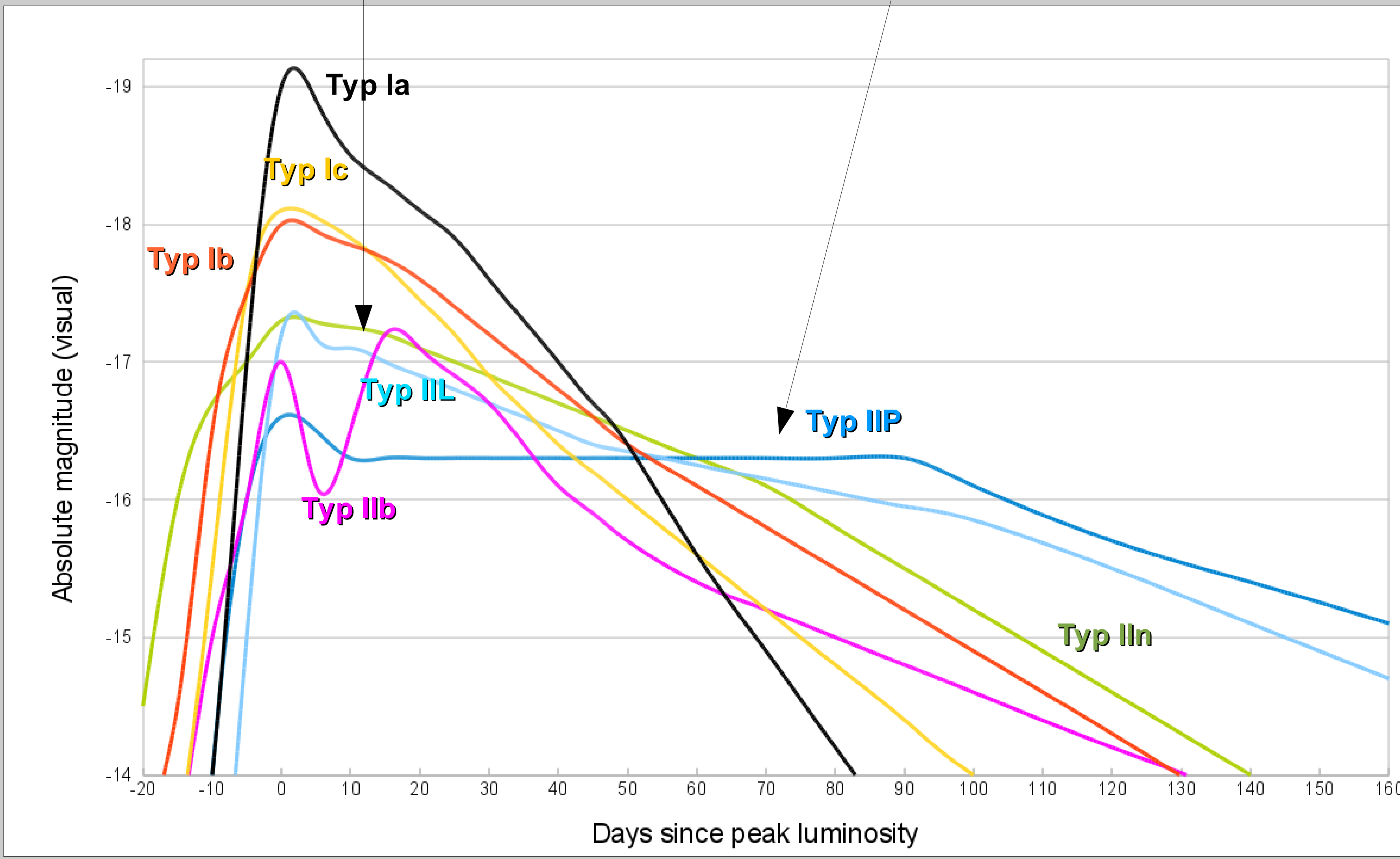
Supernova – Lightcurves

Light curves → with type II further subdivision into SN IIL and SN IIP

Light curve decline **linear → SN IIL** Light curve has **Plateau → SN IIP**



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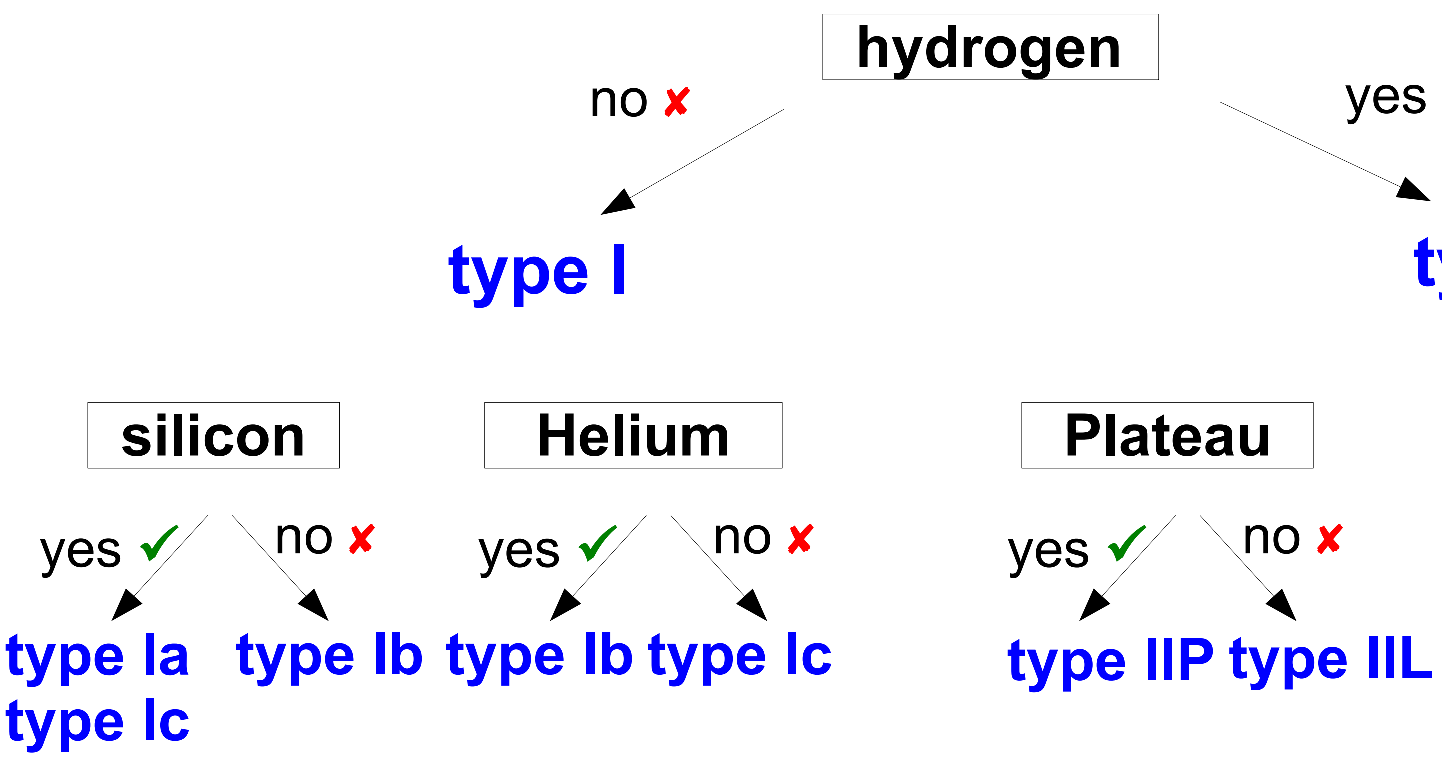
Supernova – Spectra & Lightcurves

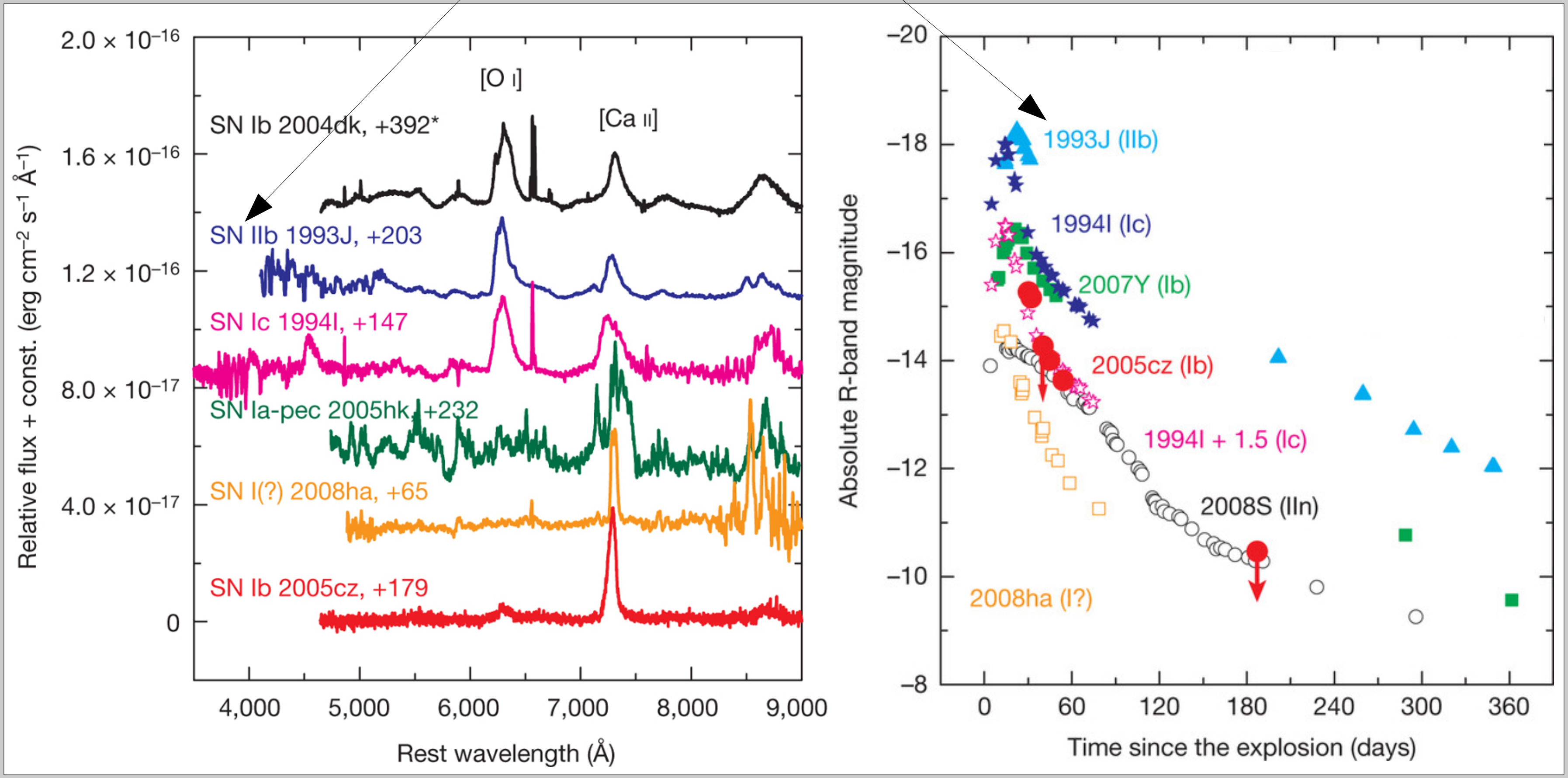


Supernova – Typ IIb

Type IIb

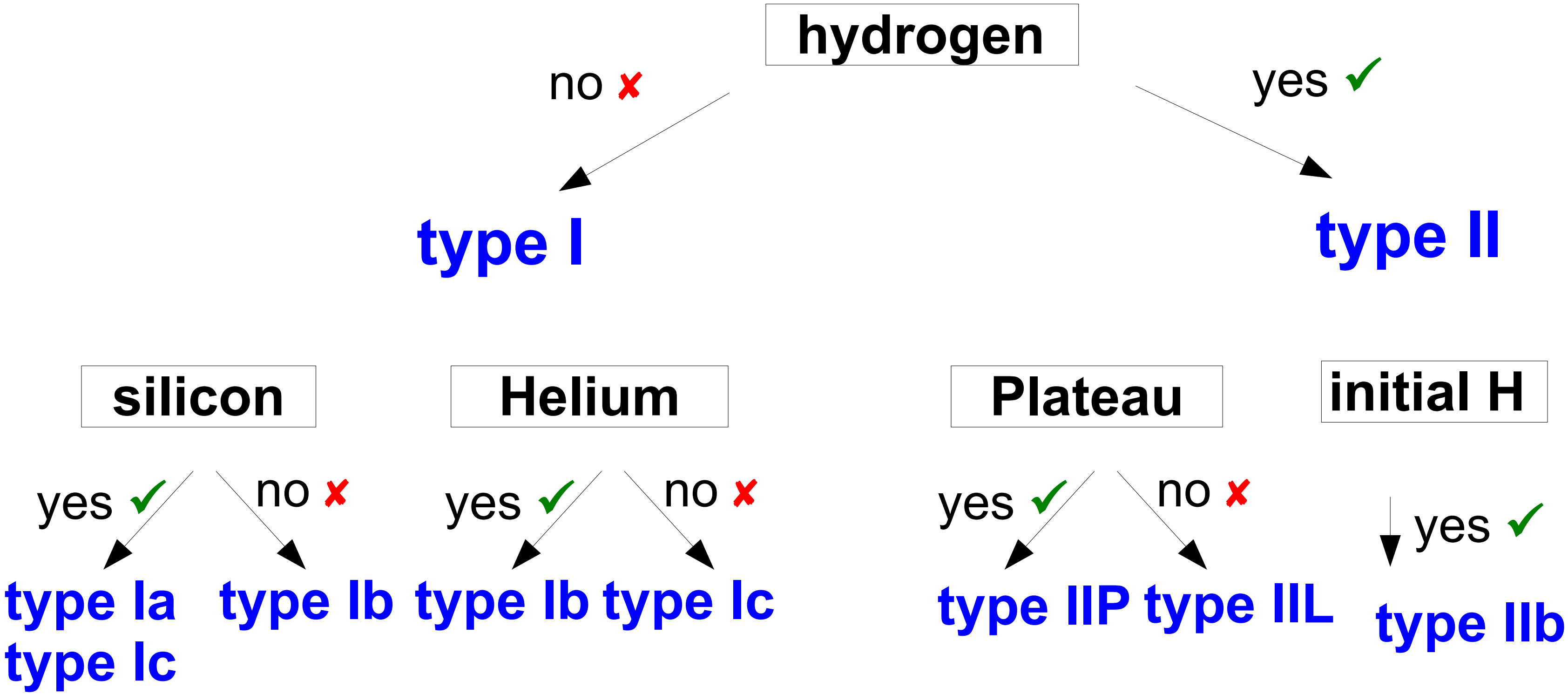
Spectrum **initially shows hydrogen in the spectrum** (→ hence II) which then **<u>disappears</u>**. The **light curve** is similar to type **Ib**.

→ new **Type IIb supernova**



Kawabata et al. (2010)

Supernova – Spectra & Lightcurves



Supernova – Typ IIn

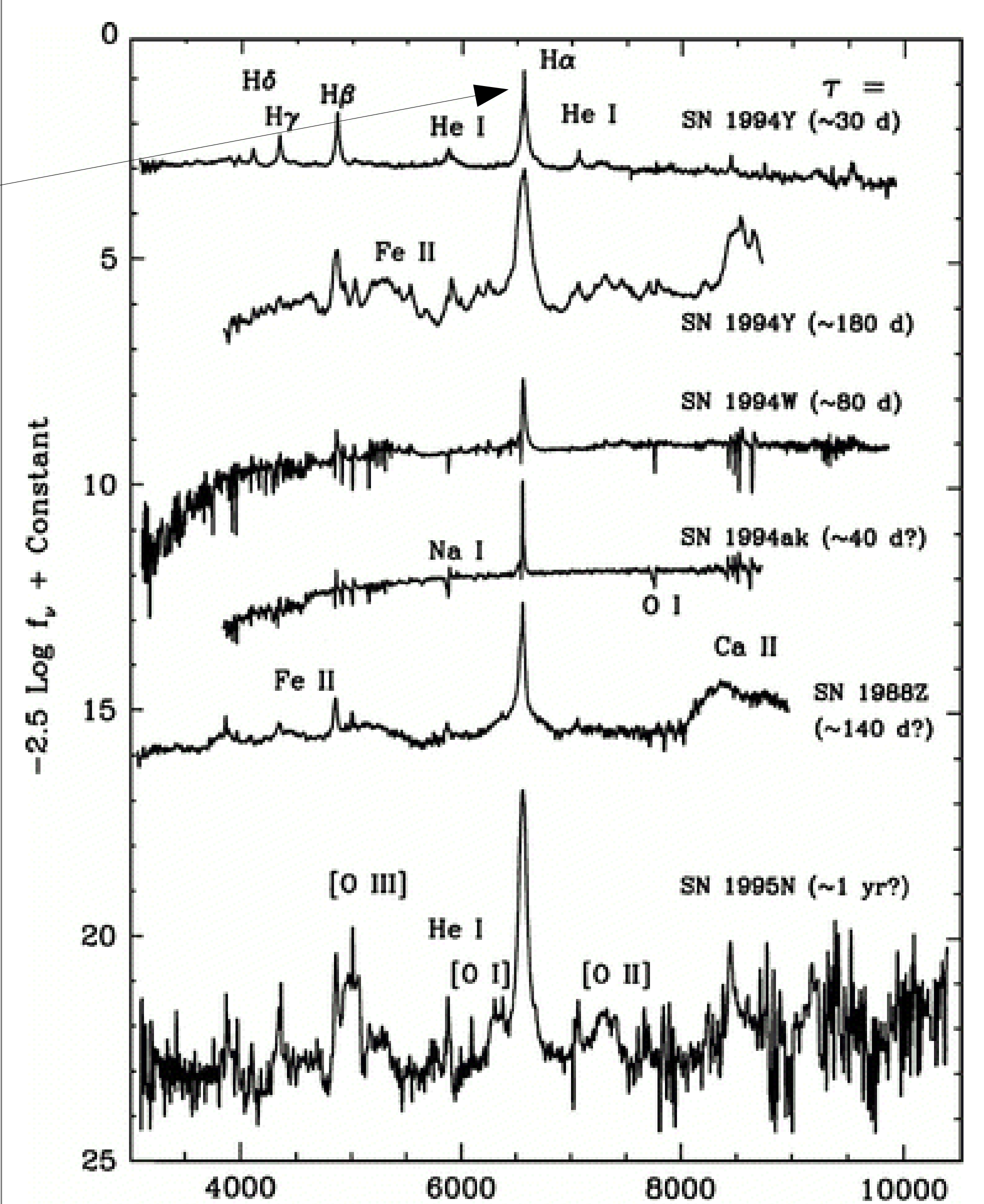
Typ IIn

Spectrum shows narrow emission lines (→ n)

(typically ~100 km/s)

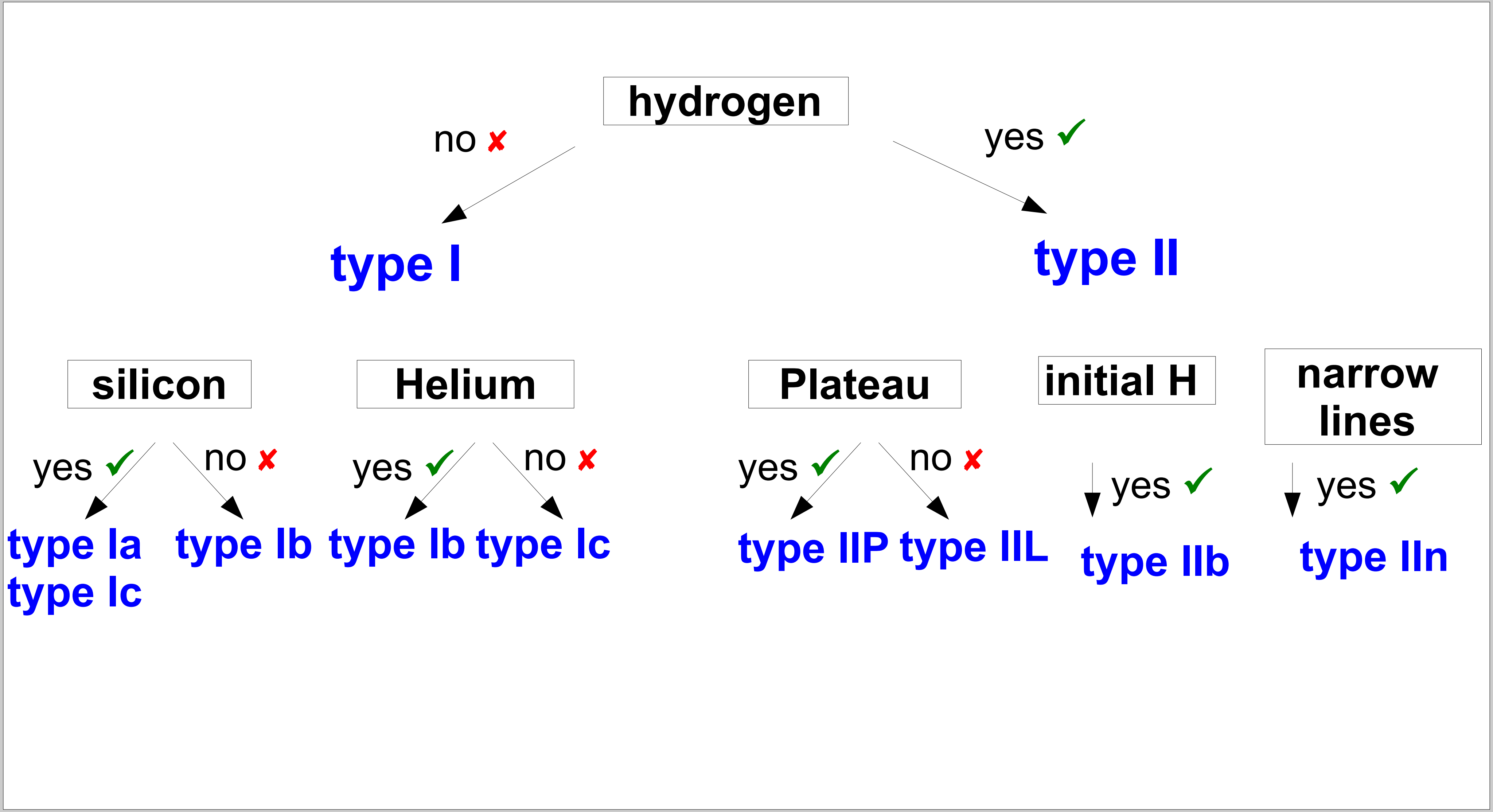
→ indication for circumstellar material/nebula around the progenitor

→ Examples: LBV or WR Nebulae



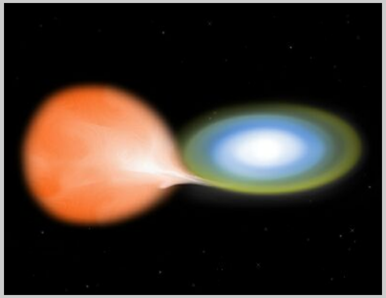
Filippenko (1997)

Supernova – Spectra & Lightcurves



Supernova – Szenarios

Type Ia



Binary System: Main sequence or giant star
with a white dwarf

→ constant mass accretion
→ the mass of the White Star increases until
it **exceeds the Chandrasekhar limit of 1.4 $M_\odot$**

→ **explosive ignition of the accreted and degenerate material**
→ **supernovae**

→ The process always happens under roughly the same conditions
→ SN with always the same maximum brightness and light curve
→ good standard candle for distance measurements

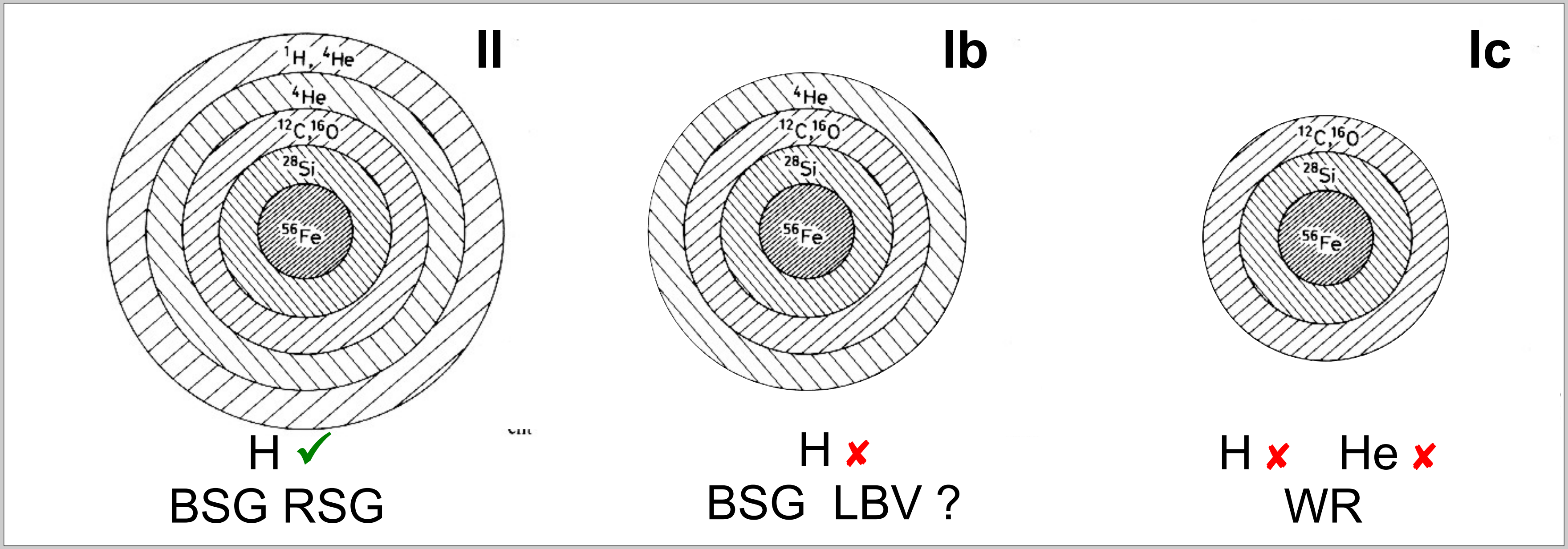
Supernova – Szenarios

Typ II   Ib   Ic

II explosion of a massive stars
IIP still larger envelope → explosion more damped ↔ M lower
IIL not much envelope = more wind→ explosion not damped ↔ M higher

Ib Explosion of a massive star that almost completely lost hydrogen shell

Ic Explosion of a massive star that almost completely lost hydrogen and Helium shell → high mass loss/wind for example WR



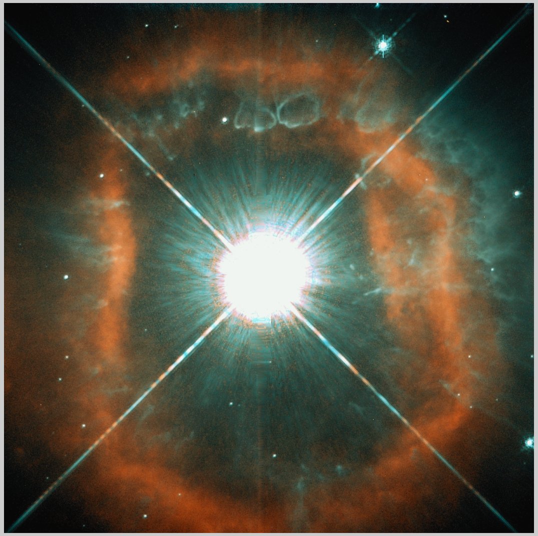
Supernova – Szenarios

Typ IIb IIn

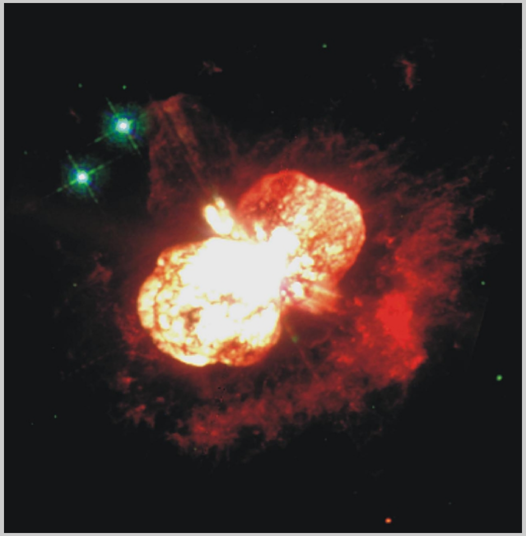
IIb Explosion of a massive star of with only a very small (nearly no) hydrogen shell. Idea: binary system where the companion has Large accreted parts of the shell.

IIn Explosion of a massive star that has circumstellar material/nebula. Best / most likely examples are LBV and WR stars.

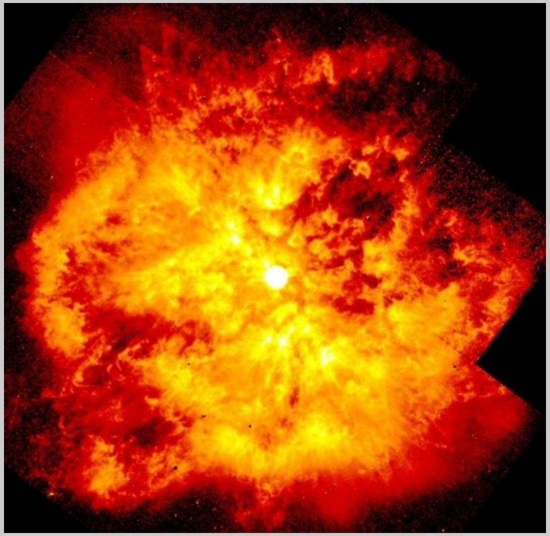
AG Car



η Car



M1-67



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SN 1987A – do you find it ?

LMC without SN 1987A

LMC with SN 1987A

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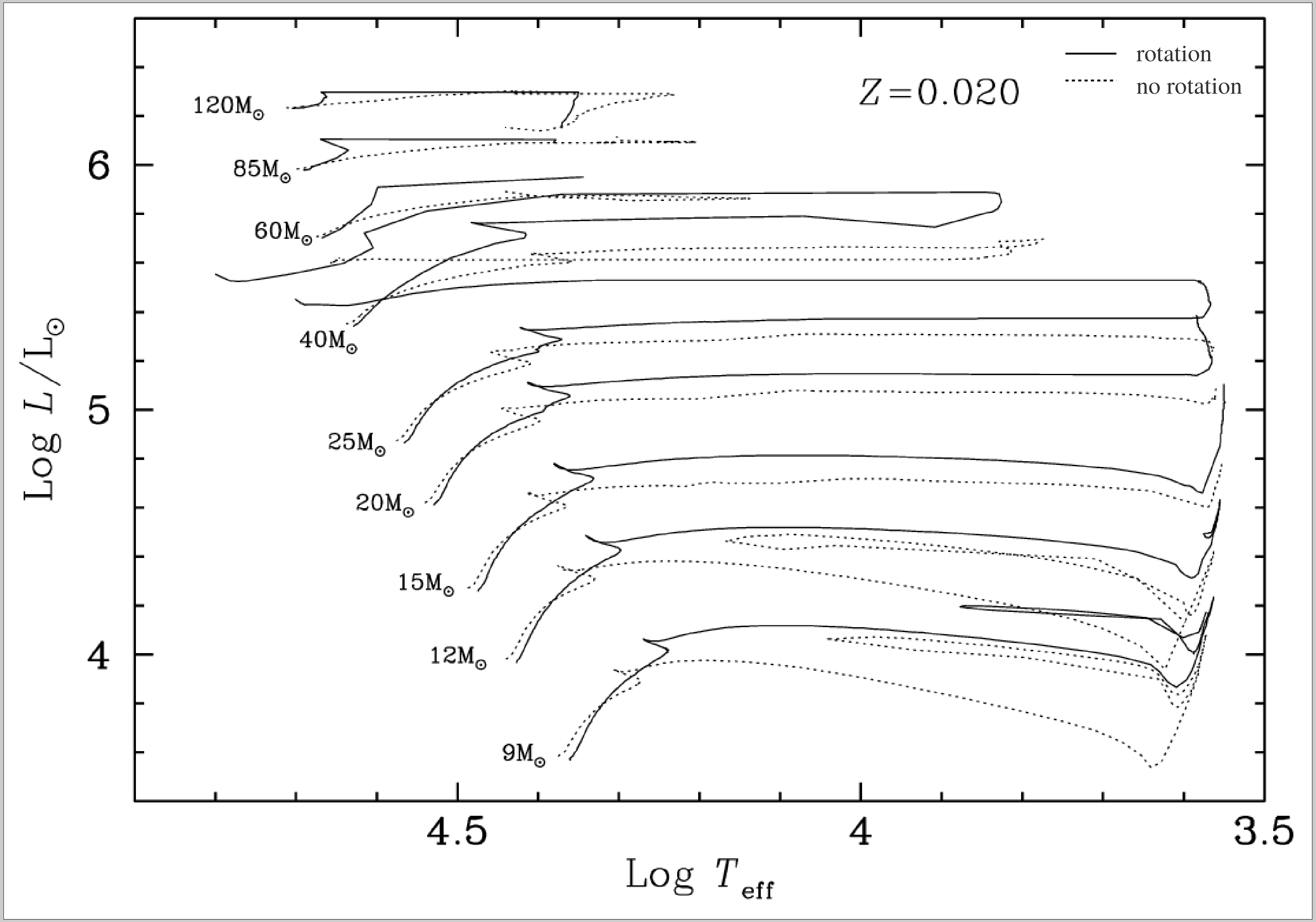
SN 1987A: first SN with known progenitor

SN1987A in LMC

February 24 1987

SN 1987A: first SN with known progenitor

Supernova types – progenitors im HRD

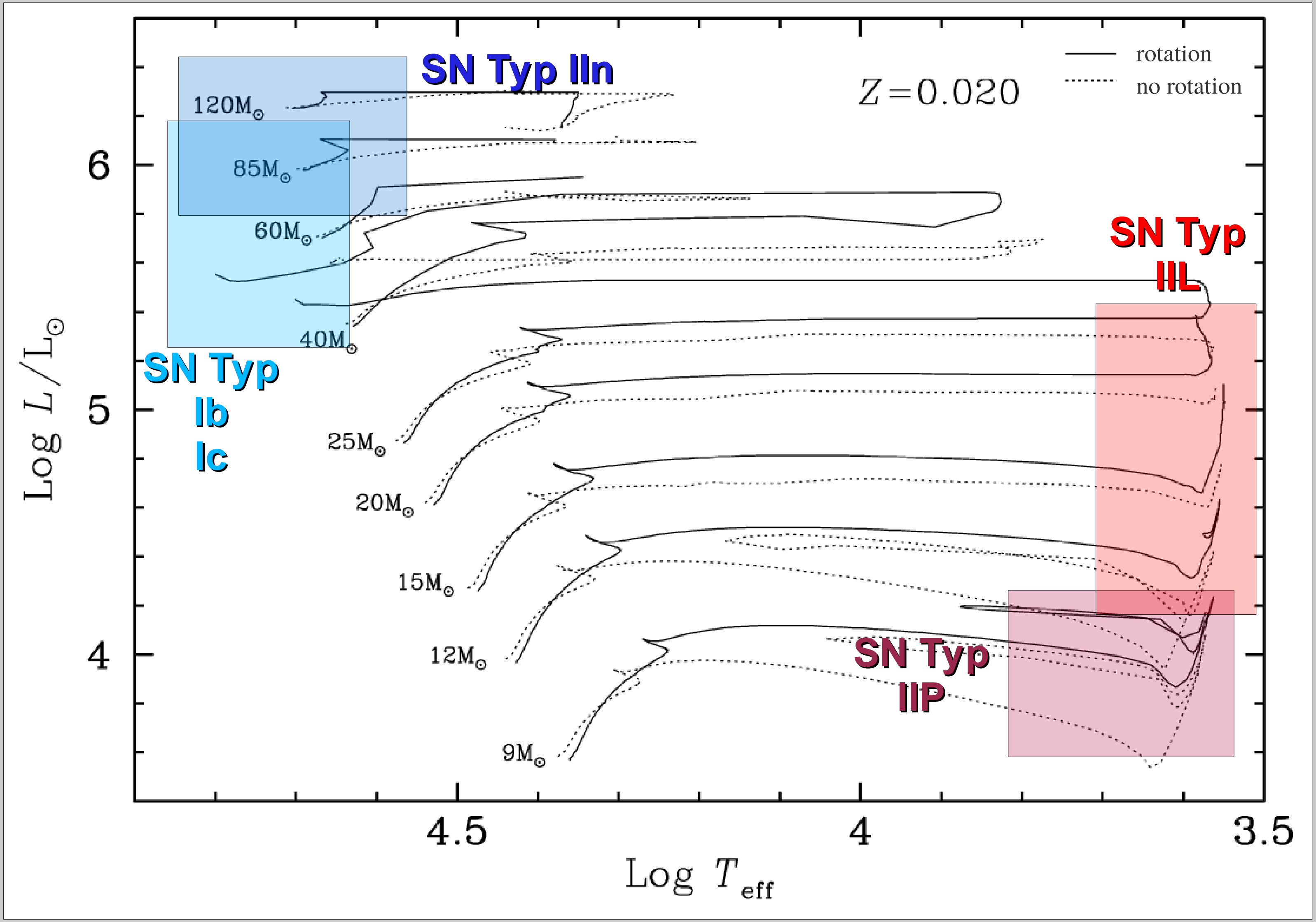


Genfer Modelle Maeder 2005

Supernova types – progenitors im HRD

"rough position for SN types"

...without SN Ia



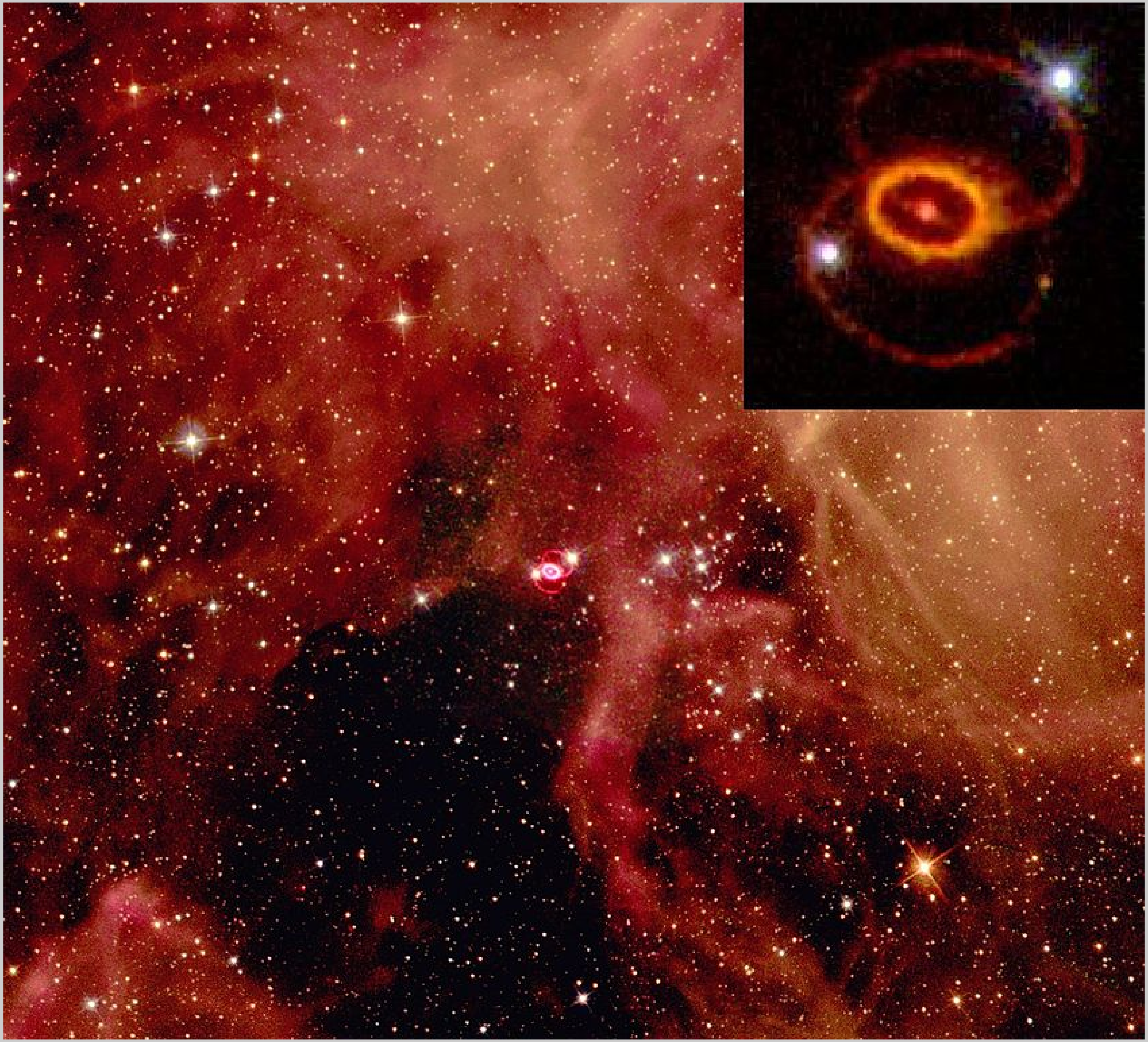
Genfer Modelle Maeder 2005

SN 1987A – Details

SN 1987A

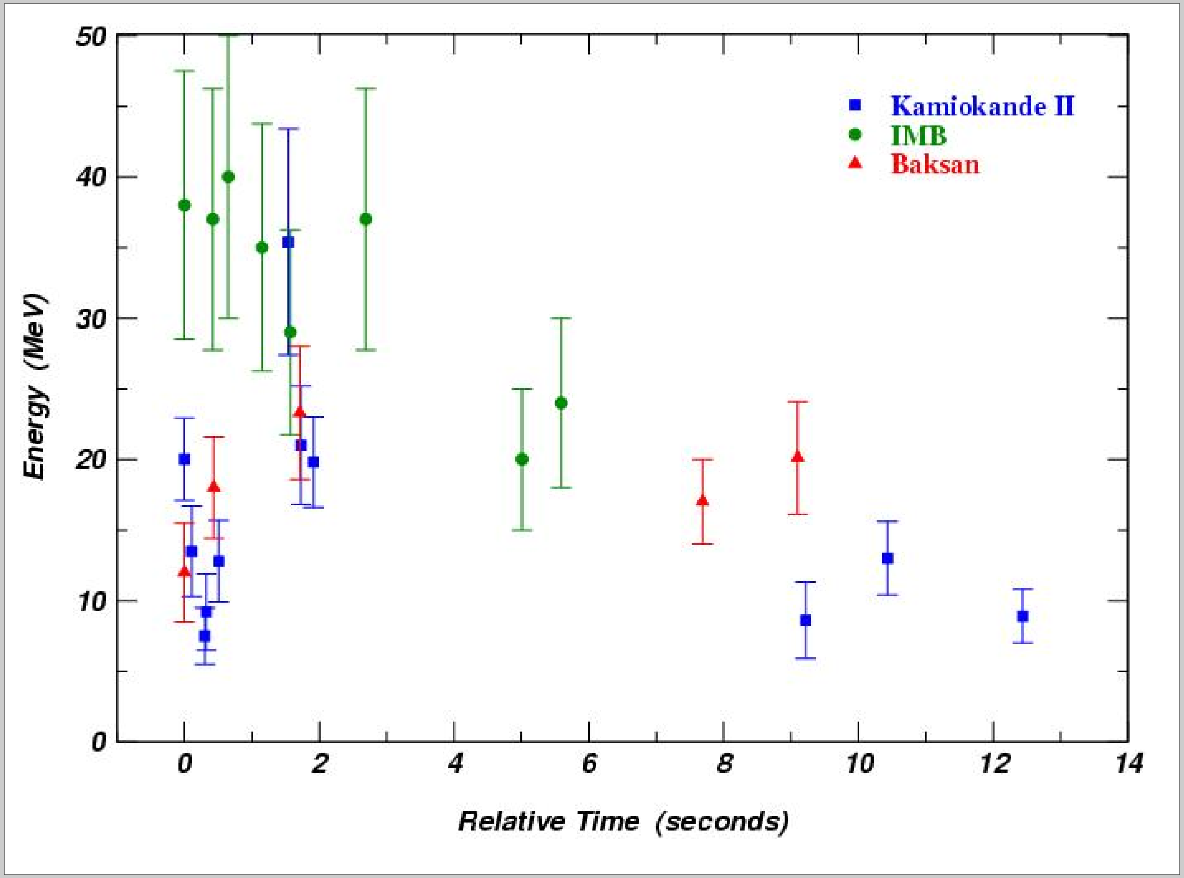
circumstellar material

→ old winds



SN 1987A – Details

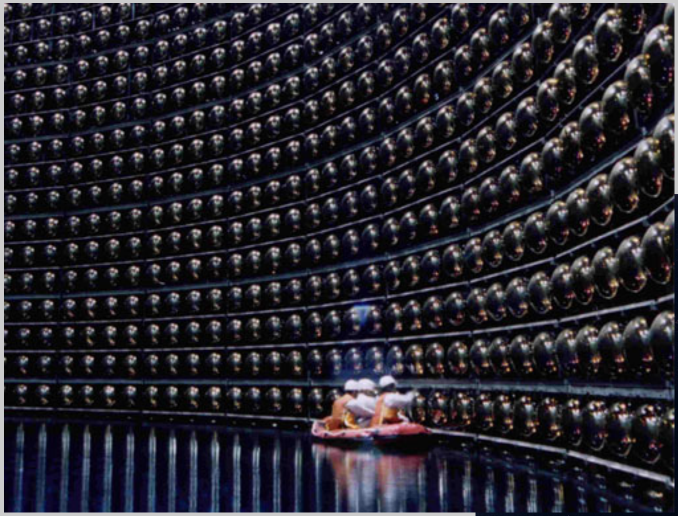
First SN for which neutrino were detected

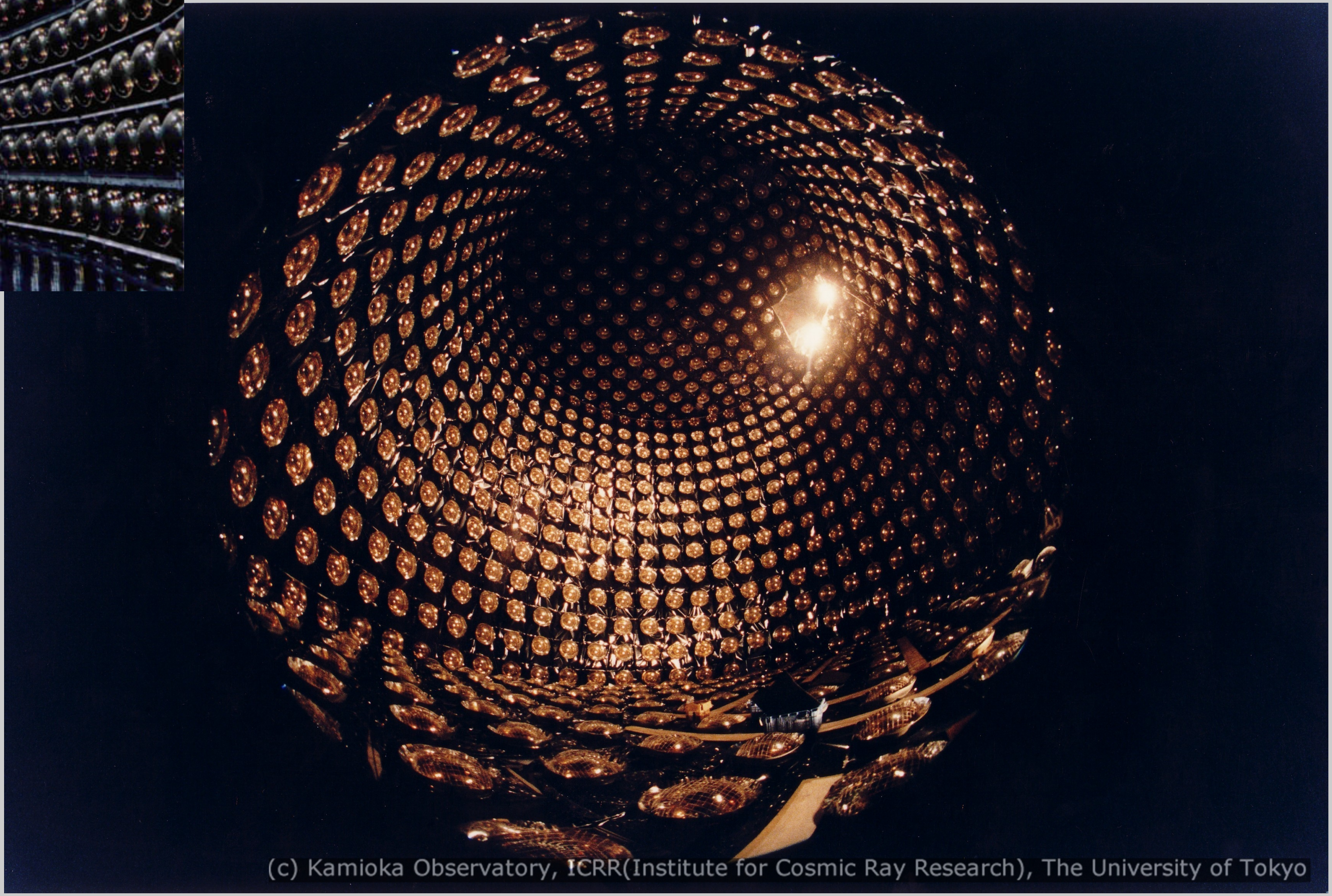


SN 1987A – Details

Neutrinodetector Kamiokande (Japan)

Water (↔ Protons) + ν
→ Cherenkov Strahlung





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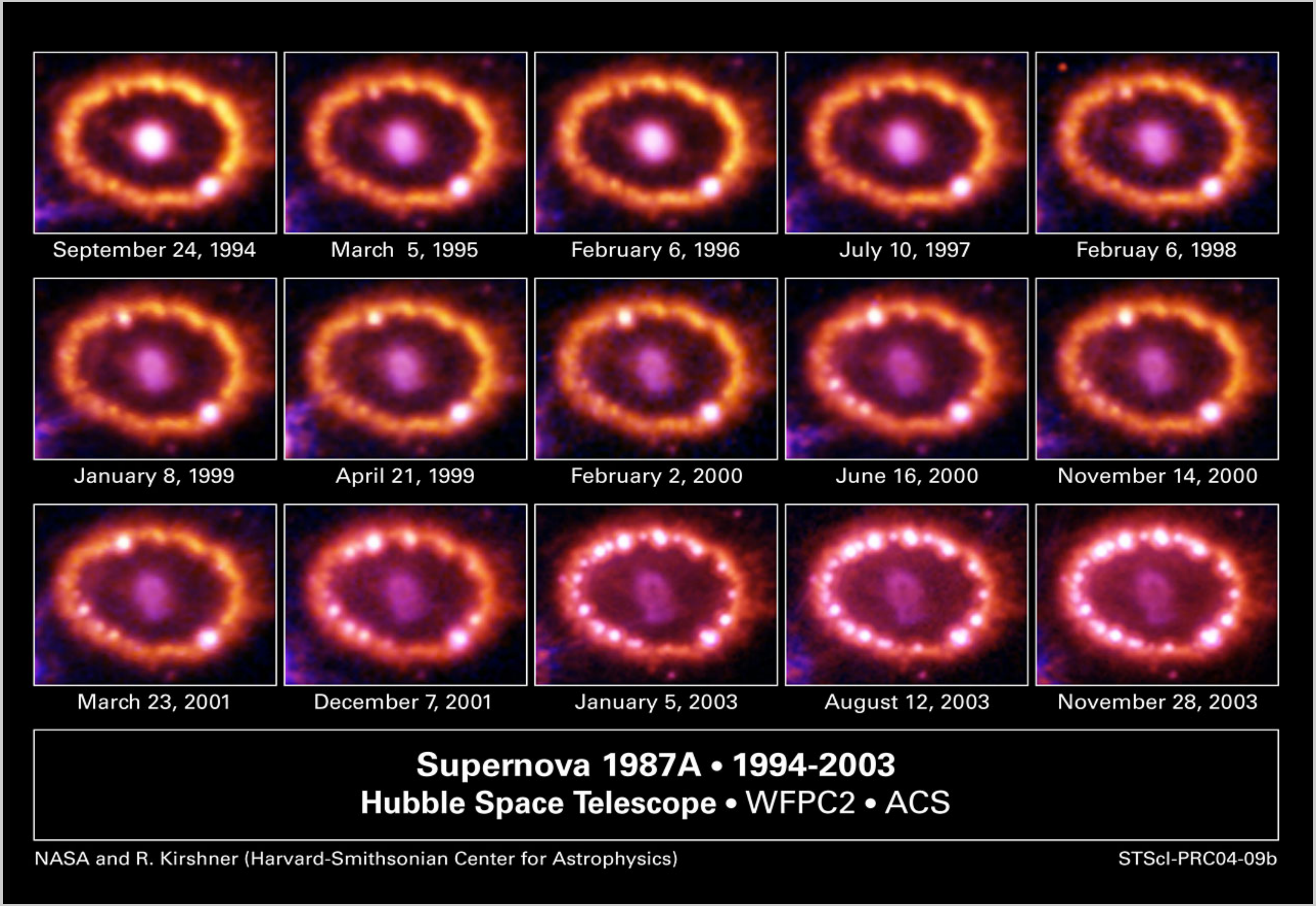
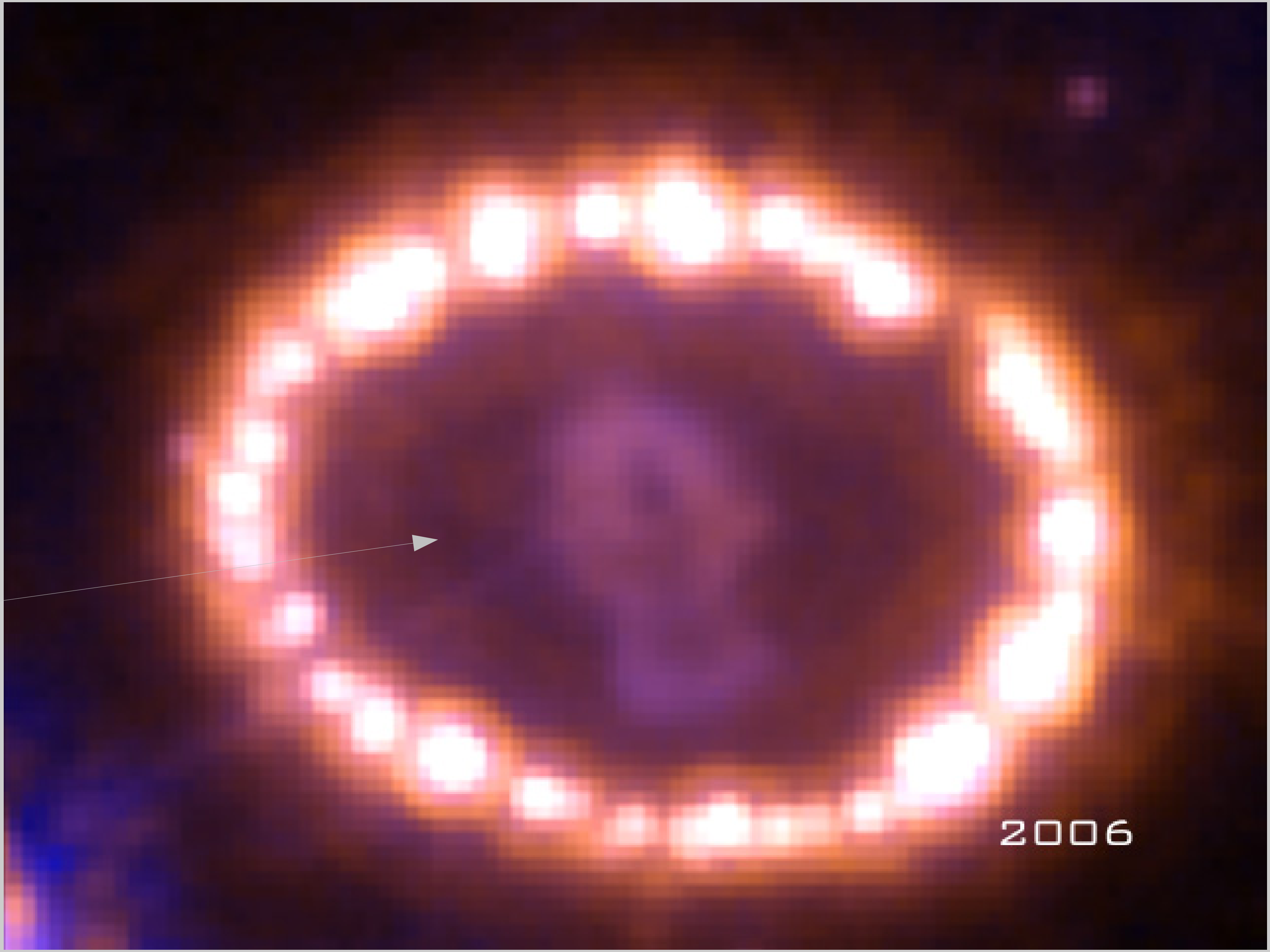
SN 1987A – Details

UV rdiation of SN reaches the trifft inner ring → brightens/ionizes



SN 1987A – Details



Schock
SNR

SN 1987A and the Bochum Teleskop

Bochum 0.61-m- Teleskop

Name: Bochum 0.61-m-Telescope
Ort: La Silla / 2375 m
System: Cassegrain Reflector
Primary M1: 0.61 m
Secondary M2: 0.15 m
Equatorial Mount

FirstLight
7. September 1968

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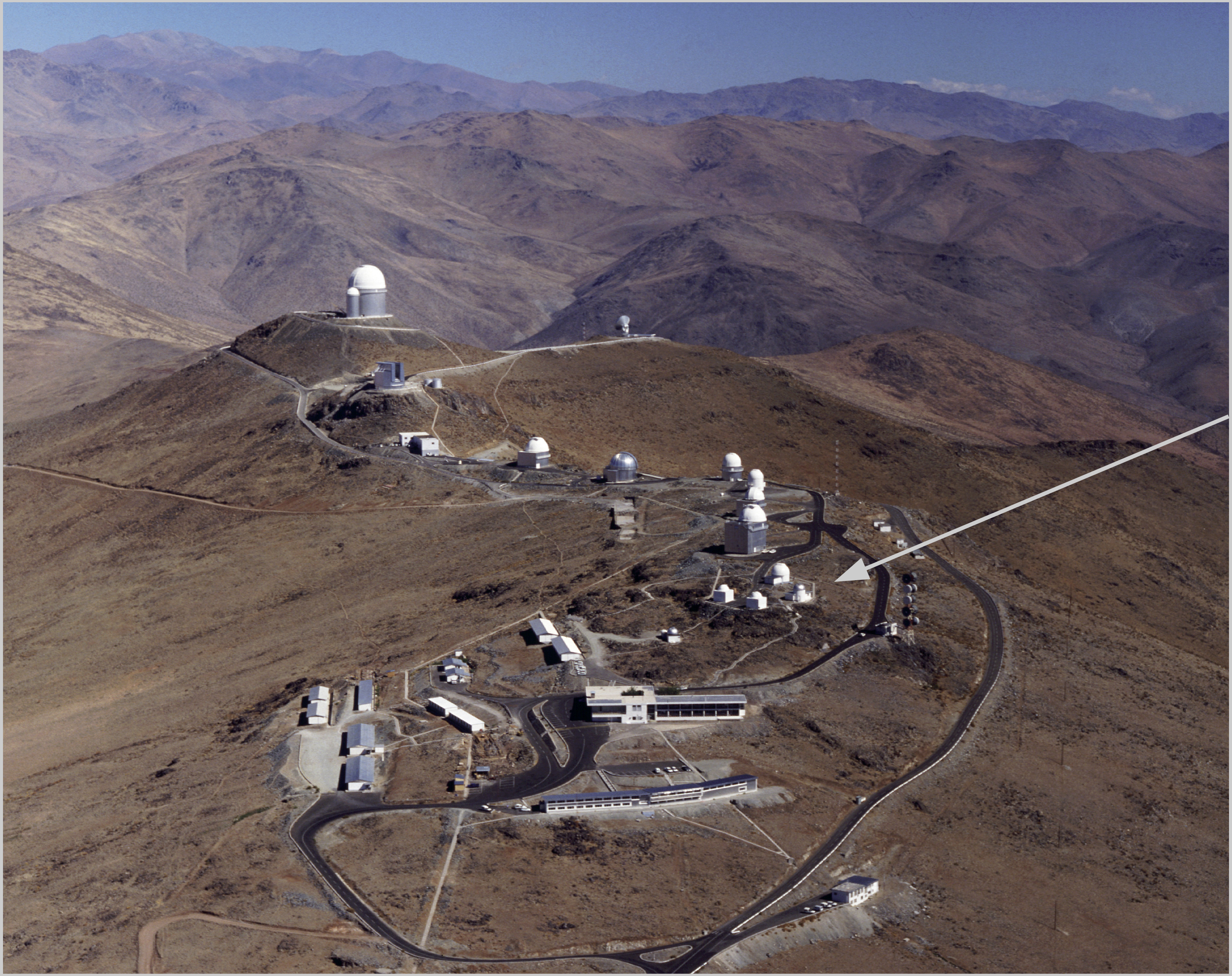
SN 1987A and the Bochum Teleskop



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SN 1987A and the Bochum Teleskop

"Ironically, the supernova (SN 1987A) was too bright for the state-of-the-art 4m-class telescopes and most of them had to be stopped down (half-closed covers) or could not observe at all" says Jason Spyromilio (ESO).

Some of the smaller telescopes took their chance. T<u>he 61cm Bochum telescope on La Silla was used</u>, on a nearly daily basis for more than a year, to measure optical spectroscopy with photometric accuracy.

SN 1987A and the Bochum Event !!!

Absolute Spectrophotometry of SN 1987A and the Hα Bochum Event

Reinhard W. Hanuschik, *Ruhr-Universität, Bochum, Federal Republic of Germany*

Abstract: Spectrophotometric optical fluxes of SN 1987A have been measured at high accuracy with the 61cm telescope equipped with a rapid spectrum scanner. This highly homogeneous data set covers the wavelength range 3200-8700Å at 10Å resolution. Selected wavelength regions, e.g. around Hα, have also been measured at 3Å resolution. The Hα line shows an undisturbed P Cygni-type profile until March 15, superimposed by variable fine-structure thereafter, developing within a few days into a blue-shifted, peak-like flux excess and a red-shifted flux deficiency. This fine-structure is intrinsic to Hα. Similar fine-structure is also observed in Na I-D, in Paschen-α and possibly in Hβ. We discuss our observations in terms of the 'mystery spot', and of models involving a jet and interactions with surrounding pre-existing material, and we propose density inhomogeneities, or occupation number deficits due to NLTE effects, within the inner regions of the envelope as origin.

Spectrophotometric Bochum Fluxes for SN 1987A

Starting on 1987 February 25.1, absolute spectrophotometric fluxes of SN 1987A at 10Å resolution have been measured by numerous observers with the 61cm University of Bochum telescope located on La Silla, Chile, and equipped with a rapid spectrum scanner (Haupt *et al.* 1976). These fluxes have been obtained by comparison with bright spectrophotometric standard stars (Tüg 1980 a,b). Fluxes are presently reduced until day 157, the first 50 days are going to be published (Hanuschik and Dachs 1988). The typical accuracy of these fluxes is generally better than 5%, essentially limited by the internal errors of the Tüg standard system. Time coverage is almost 1 spectrum/day within the first two months, and ≈ 1 spectrum/2 days thereafter.

The Hα Region

Measurements of the Hα region have been additionally obtained at 3Å resolution, rather often twice per night, and have been fluxed using the spectrophotometric data. The measurements presented here cover the period 1987 March 12 to June 14, with additional data at 10Å resolution before March 12 taken from Hanuschik and Dachs (1988).

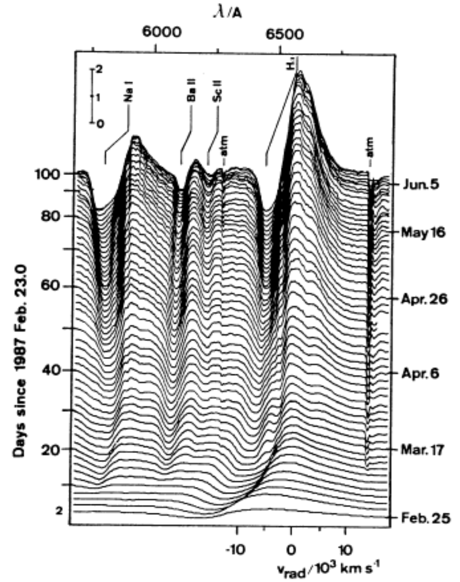

Figure 1 – Hα tracings of SN 1987A between 1987 February 25 and June 14. Flux F(λ) is plotted vs. radial velocity relative to λ_0 = 6568.9Å (bottom scale), and vs. wavelength (top scale). The bar symbolizes 2×10^{-10} erg s^{-1} cm^{-2} $Å^{-1}$. Only every second day is shown. For comparison, the lines of Ba II-2 λ6142, ScII-28 λ6245 and Na I-D λ5890/96, together with two atmospheric absorption lines, are also shown.

The spectral and temporal evolution of the Hα line in SN 1987A is illustrated in Figure 1, where we show a set of Hα tracings in a flux, F(λ), vs. radial velocity plot. After exhibiting a classical P-Cygni profile until March 14, resulting from scattering of photons in a spherically symmetric expanding medium, the Hα profile suddenly begins to show complex fine-structure (the 'Bochum event', cf. also Hanuschik and Dachs 1987 a,b):

1. Within one day (March 14.07 - 15.06), a very weak hump (called blue-shifted fine-structure = BFS in the following) appears in the transition between minimum and maximum flux, further developing into a well-visible hump within another day (until

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Absolute Spectrophotometry of SN 1987A and the Hα Bochum Event

Reinhard W. Hanuschik, *Ruhr-Universität, Bochum, Federal Republic of Germany*

Abstract: Spectrophotometric optical fluxes of SN 1987A have been measured at high accuracy with the 61cm telescope equipped with a rapid spectrum scanner. This highly homogeneous data set covers the wavelength range 3200-8700Å at 10Å resolution. Selected wavelength regions, e.g. around $H\alpha$, have also been measured at 3Å resolution. The $H\alpha$ line shows an undisturbed P Cygni-type profile until March 15, superimposed by variable fine-structure thereafter, developing within a few days into a blue-shifted, peak-like flux excess and a red-shifted flux deficiency. This fine-structure is intrinsic to $H\alpha$. Similar fine-structure is also observed in Na I-D, in Paschen-α and possibly in $H\beta$. We discuss our observations in terms of the 'mystery spot', and of models involving a jet and interactions with surrounding pre-existing material, and we propose density inhomogeneities, or occupation number deficits due to NLTE effects, within the inner regions of the envelope as origin.

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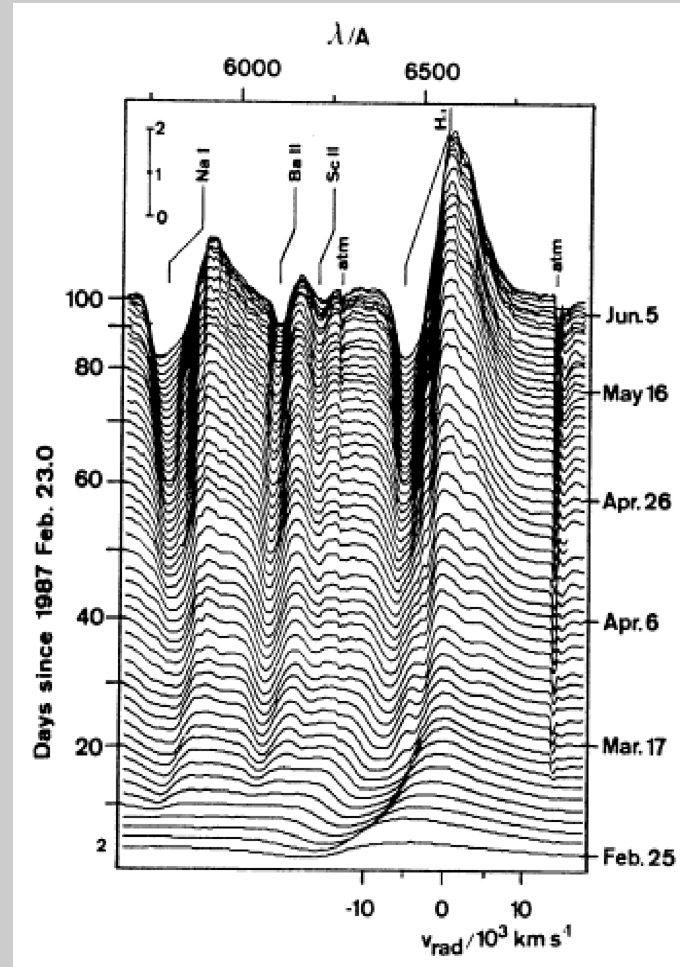

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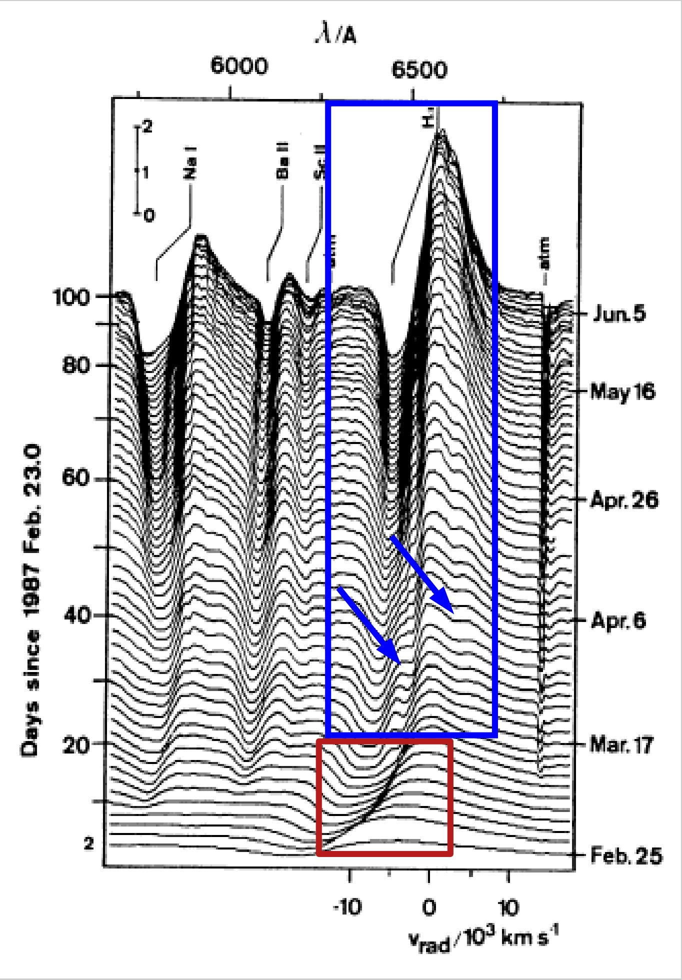

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The optical light curve of SN 1987A was rather different from those of previously observed core-collapse supernovae. The old models of spherical explosions had to be revised. The spectroscopic evolution provided further evidence for asymmetries in the explosion. The 'Bochum event' was a rapid change in the line profile observed with the Bochum telescope on La Silla.

It is the signature of a radioactive blob rising from the inner ejecta to the surface. "The picture emerging from the observations of the first several weeks was certainly more complex than what had ever been assumed of supernovae before," says Bruno Leibundgut (ESO).

Supernova Remnants

- compacter n-Stern or black hole
- a lot of gas = former stellar envelop

For more
→ see lecture on stars winds and nebulae

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