Types of Variability

I. Intrinsic Variability

Star variable "by itself" → variability caused by physical changes of star

- **pulsation variable ✔**
- **Eruptive**
- **Rotationally induced variables**

II. Extrinsic variability

Star not variable by “itself”→ variability generated by external influences

- **Binary stars ↔ eclipsing variables**
- **Accretion disks ↔ like T Tauri**
- **binary+accretion disk ↔ cataclysmicvariables, novae**

Luminous Blue Variables

LBV
Landesamt für Bauen
und Verkehr

LBV

lbv
landesbetrieb **verkehr**

LBV
Lohnsteuer-Beratungs-Verein e.V.
Lohnsteuerhilfeverein


Load-Bearing Vest

**Landesamt
für Besoldung und Versorgung**

LBV

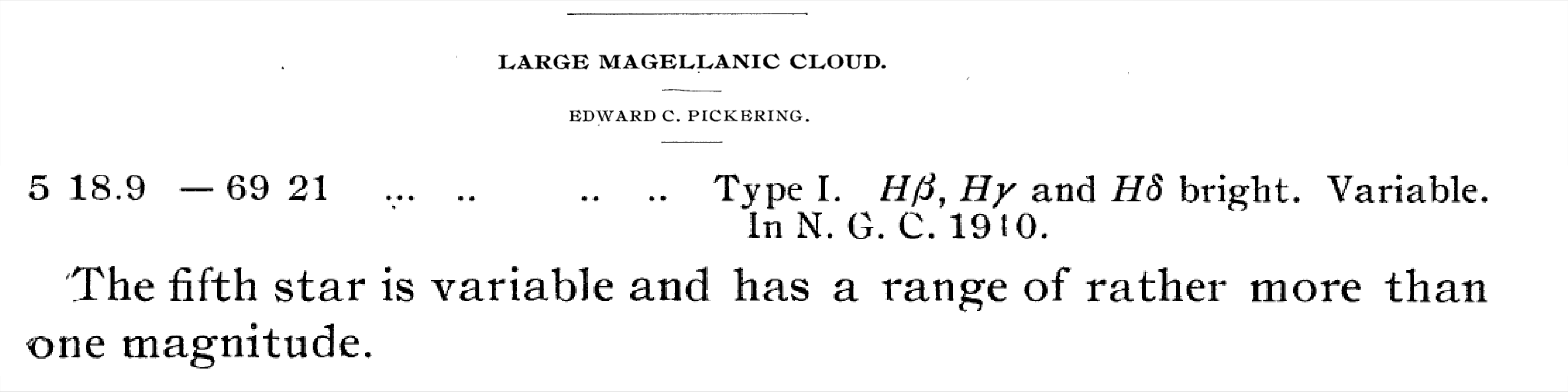
LBV
Lokaler Bildungsverbund
Tiergarten-Süd/Berlin
LERNEN IM NETZWERK

LIPPSTÄDTER BILLARDVEREIN
1984 E.V.

LBV
Wir sind auf Ihrer Seite.

Oberfinanzdirektion Niedersachsen
Landesweite Bezüge- und Versorgungsstelle

LBVs – how it all started



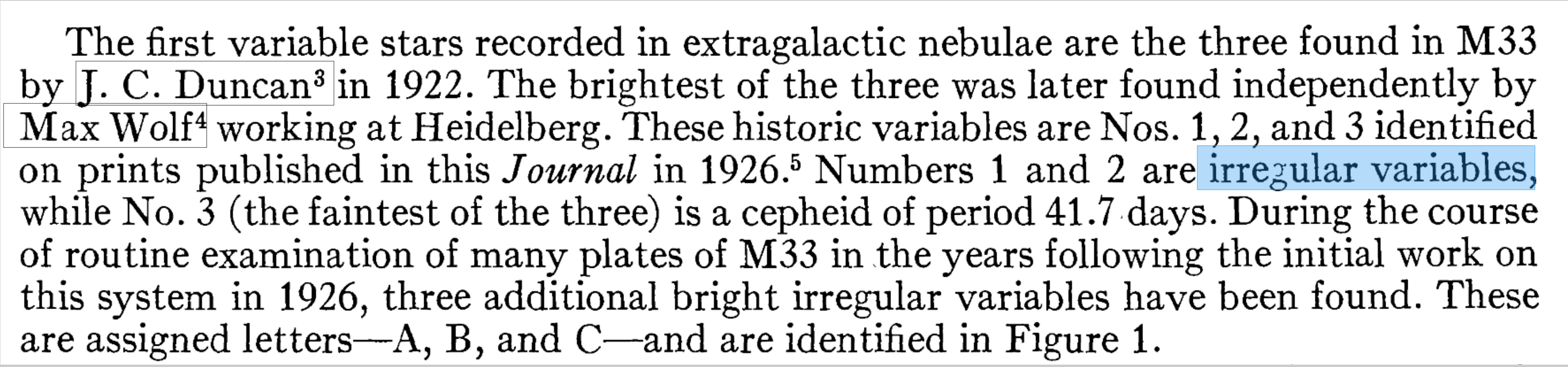
LARGE MAGELLANIC CLOUD.

EDWARD C. PICKERING.

5 18.9 — 69 21 ... . Type I. Hβ, Hγ and Hδ bright. Variable. In N. G. C. 1910.

The fifth star is variable and has a range of rather more than one magnitude.

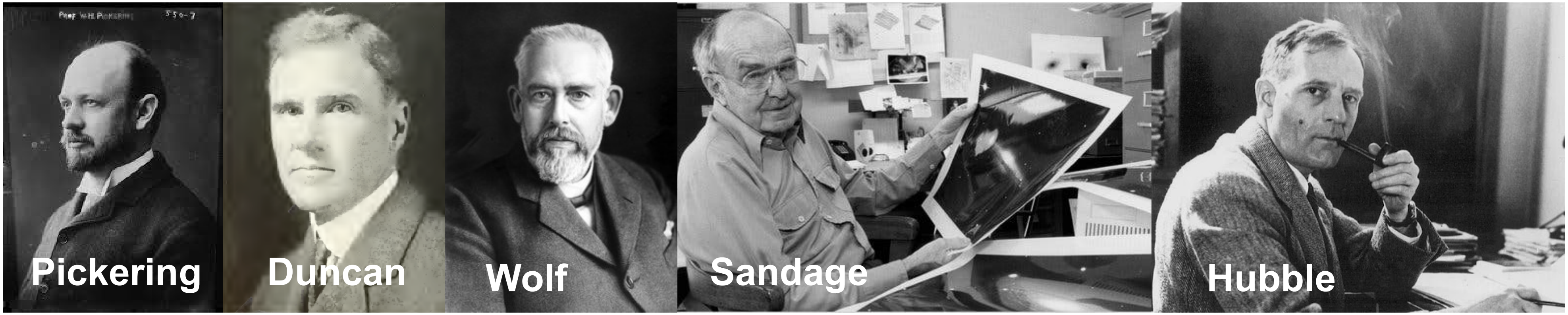
(Pickering 1897)



The first variable stars recorded in extragalactic nebulae are the three found in M33 by J. C. Duncan[3] in 1922. The brightest of the three was later found independently by Max Wolf[4] working at Heidelberg. These historic variables are Nos. 1, 2, and 3 identified on prints published in this *Journal* in 1926.[5] Numbers 1 and 2 are irregular variables, while No. 3 (the faintest of the three) is a cepheid of period 41.7 days. During the course of routine examination of many plates of M33 in the years following the initial work on this system in 1926, three additional bright irregular variables have been found. These are assigned letters—A, B, and C—and are identified in Figure 1.

(Hubble & Sandage 1953)

LBVs – how it all started



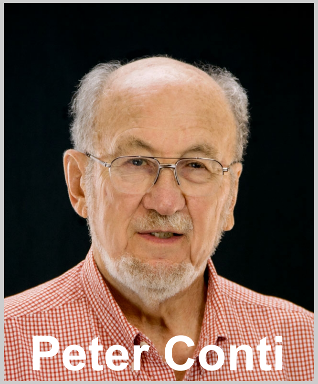
Irregular Variables

Luminous Variables

Wolf's Variables

Sandage Variables

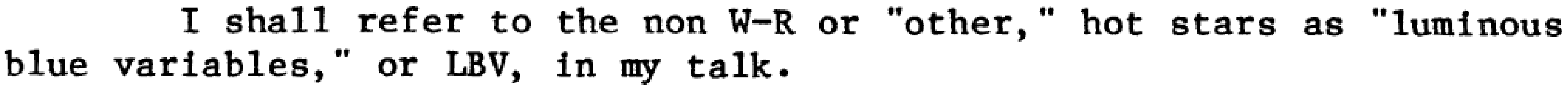
Hubble-Sandage Variables



Peter Conti at a confernce talk1984:

> I shall refer to the non W-R or "other," hot stars as "luminous blue variables," or LBV, in my talk.

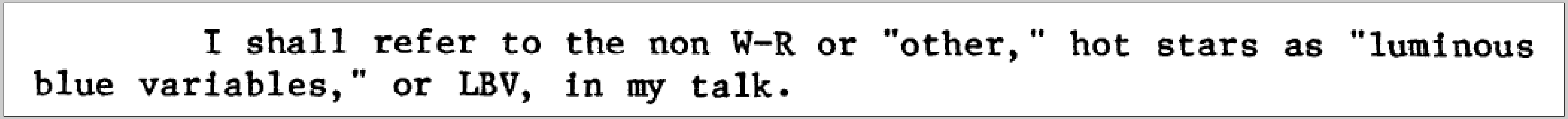
LBV – Introduction of the class by Conti in 1984



I shall refer to the non W-R or "other," hot stars as "luminous blue variables," or LBV, in my talk.

Luminous Blue Variables

Definition/Classification of an LBV



I shall refer to the non W-R or "other," hot stars as "luminous blue variables," or LBV, in my talk.

… this really is the first and one and only definition and rather <u>precise</u> definition ☺ !

Conti 1984

<u>It did exclude</u>

- classical main-sequence O stars
- Wolf-Rayet stars

<u>restricted that sample to</u>

- **luminous** ↔ massive not a big deal
- **blue** ↔ hot not a big deal given massive
- **variable** ↔ variable maybe **a big deal !**

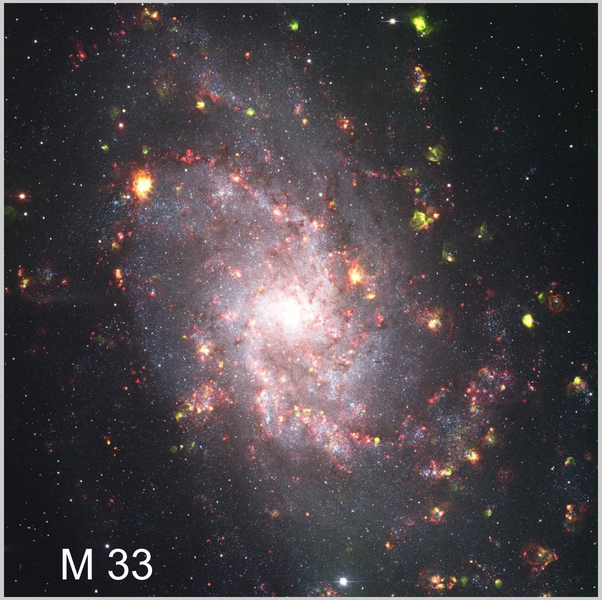
<u>included and united the already known</u>

- **Hubble Sandage Variables** and **S Dor Variables**
- **P Cygni type stars**

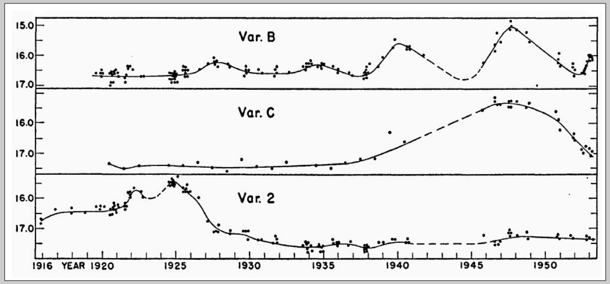
LBV – Introduction of the class by Conti in 1984

→it united these already known classes

Hubble-Sandage variables

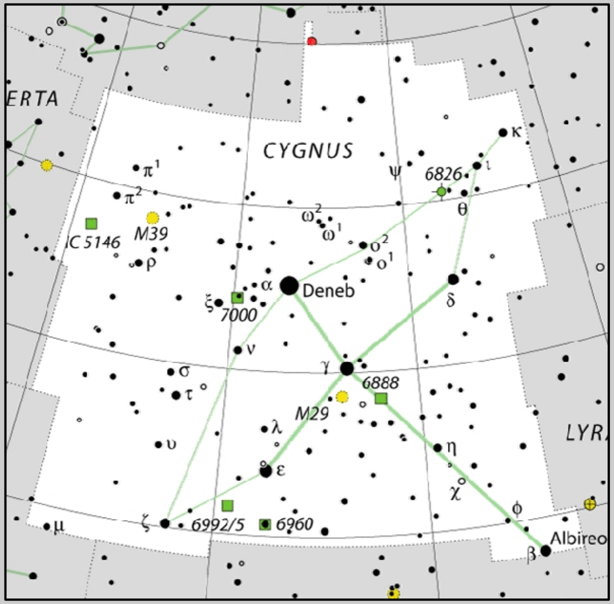


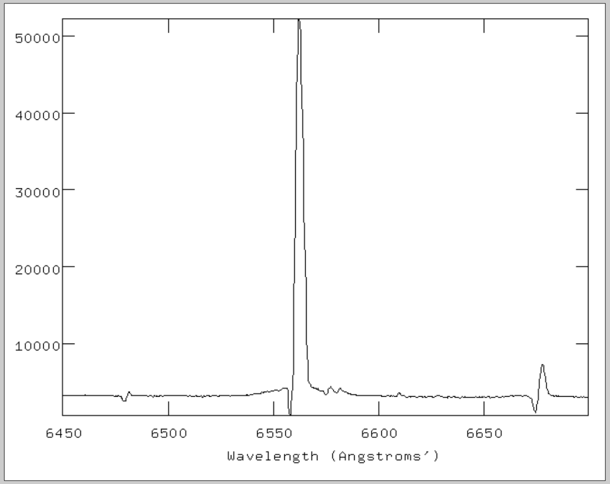
(Burggraf)



(Hubble & Sandage 1953)

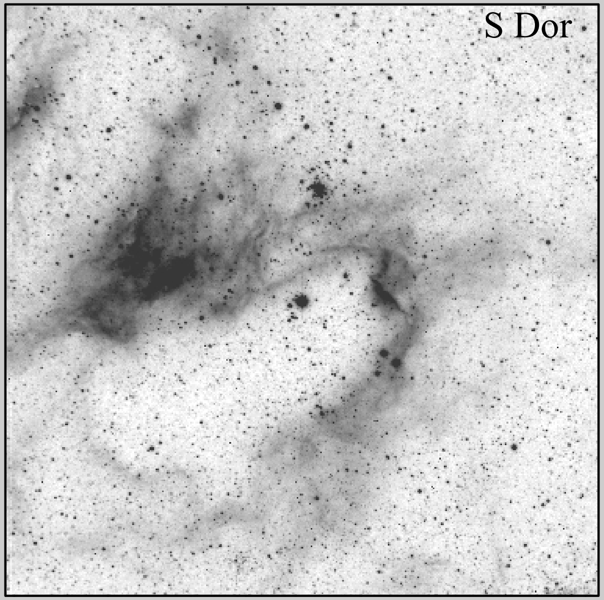
P Cygni Type stars



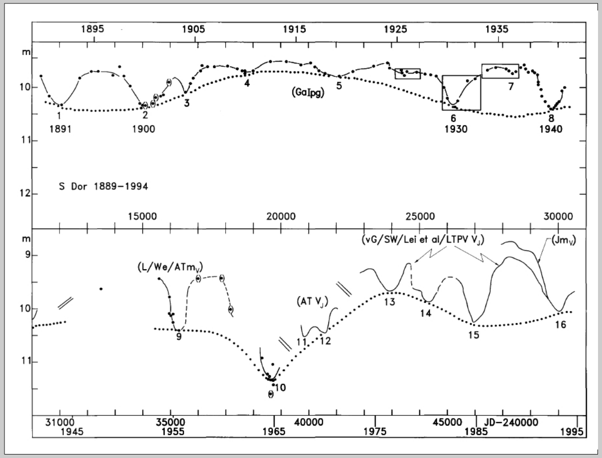


(Weis 1999)

S Doradus variables



(Weis 2003)

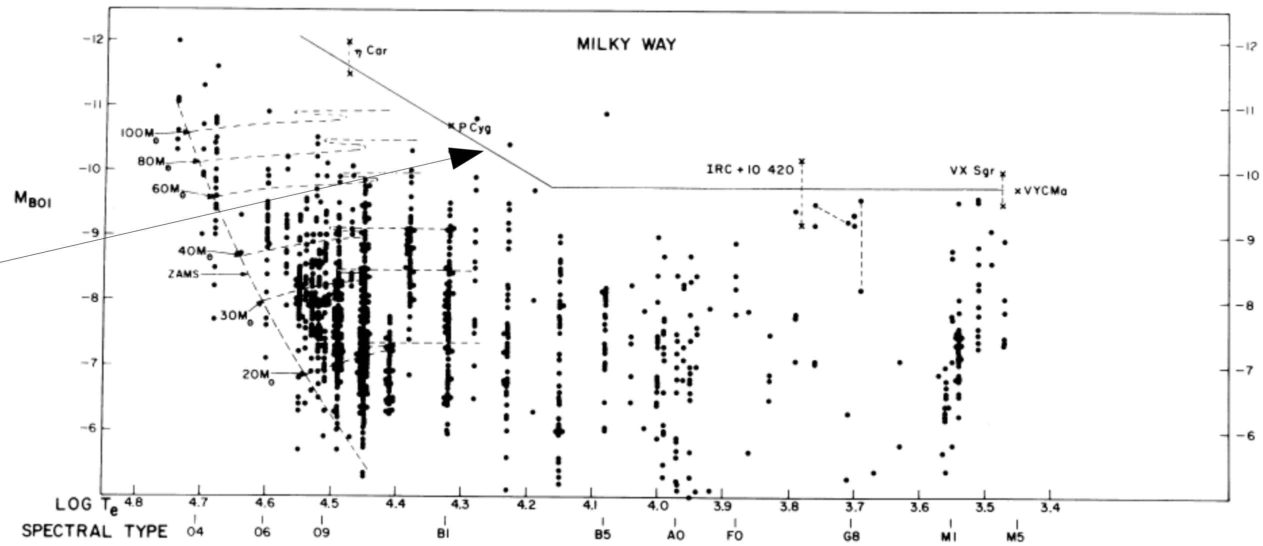


(van Genderen 1997)

The Humphreys-Davidson Limit

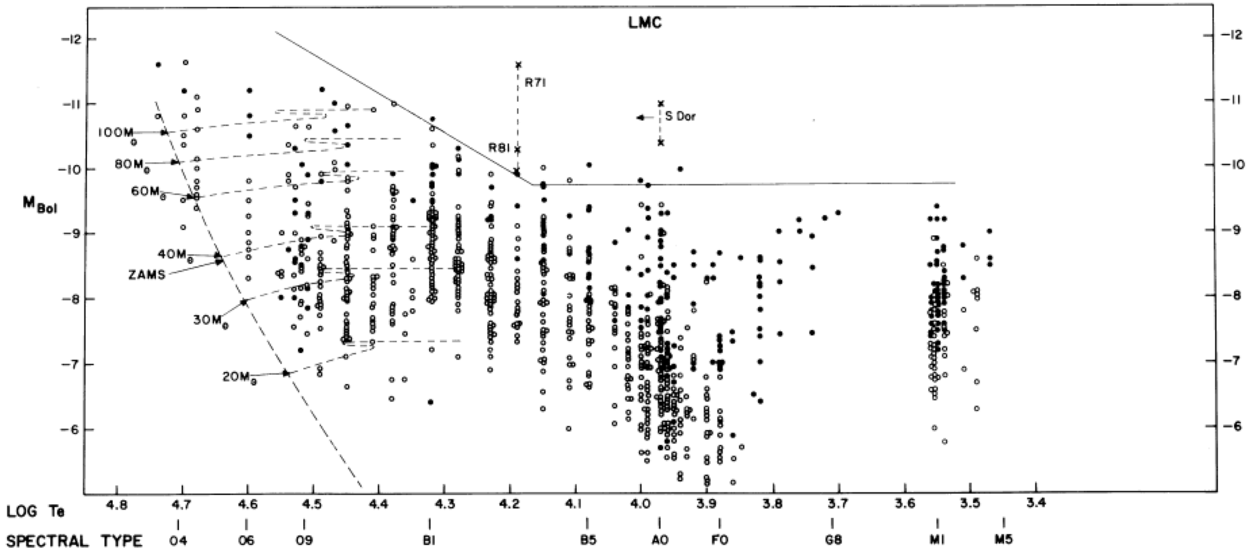
Humphreys and Davidson find empirical limit

No stars seem to exist beyond this line



Milky Way

FIG. 3.—The "theoretical" H-R diagram, M_{bol} versus log T_e, for the galactic supergiants. The position of the ZAMS and evolutionary tracks with mass loss are shown. The solid line defines the approximate upper boundary of the supergiant luminosities. The positions of two peculiar stars, η Car and P Cyg, and three supergiant infrared sources are also indicated.

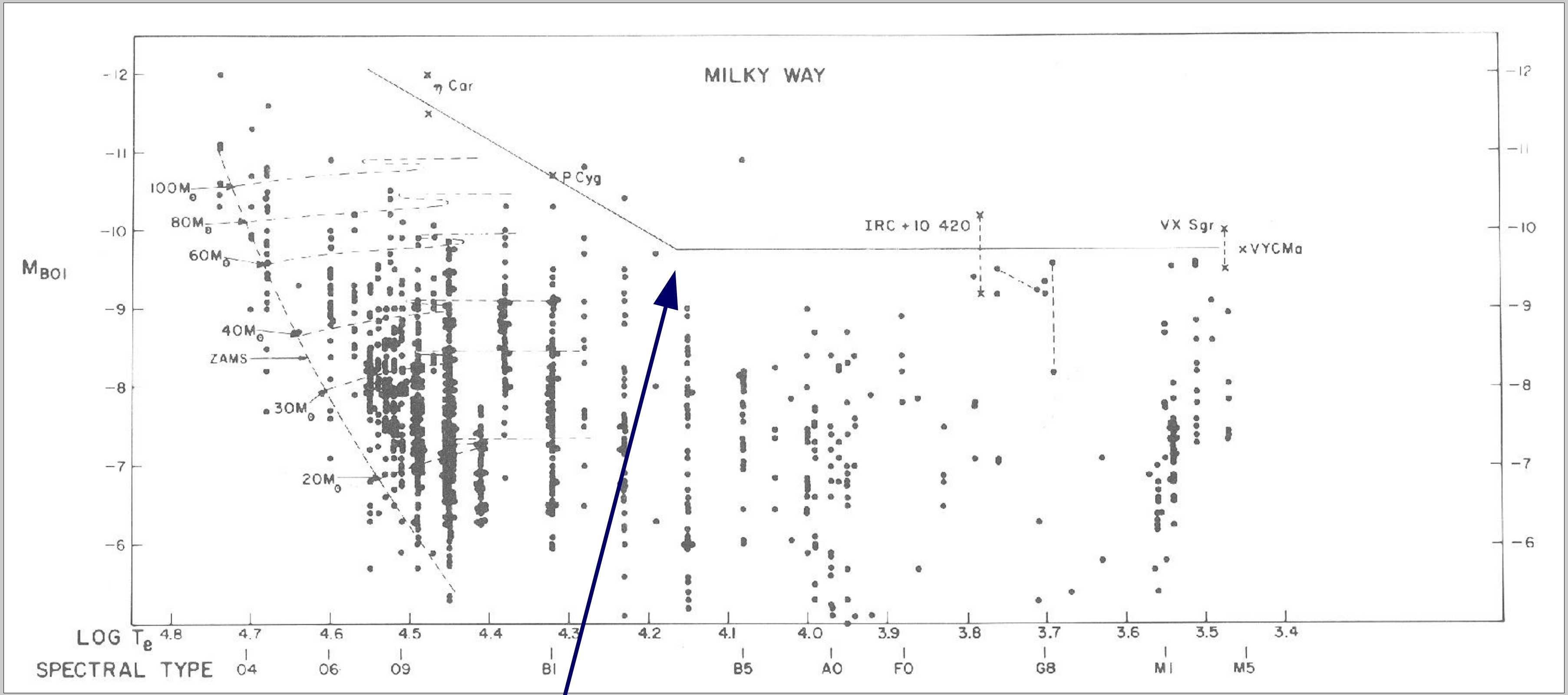


LMC

FIG. 4.—Same as Fig. 3 for the LMC supergiants. The positions of S Dor and two other peculiar stars are indicated.

(Humphreys & Davidson 1979)

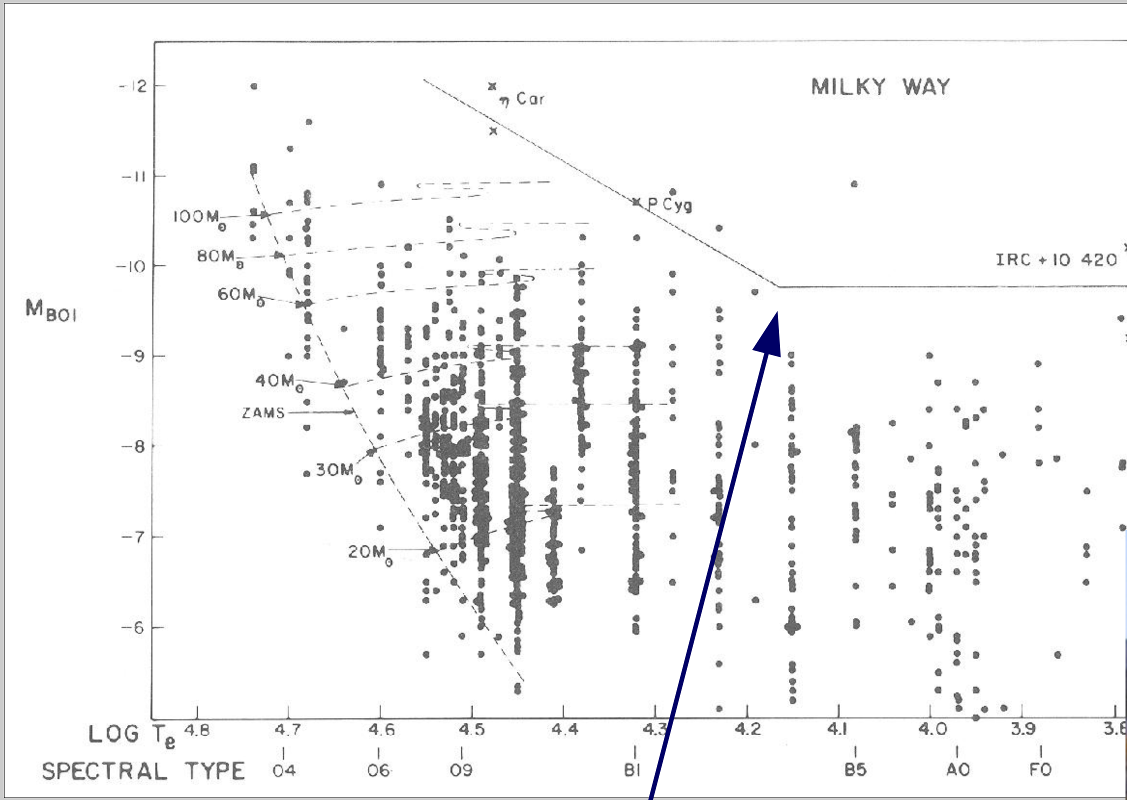
The Humphreys-Davidson Limit



(Humphreys & Davidson 1979)

**Roberta Humphreys &
Kris Davidson**

The Humphreys-Davidson Limit



(Humphreys & Davidson 1979)

Roberta Humphreys &
Kris Davidson

Astronomisches Institut
RUHR-UNIVERSITÄT BOCHUM

Stellar evolution – massive stars – ROTATION

Four major **scenarios** for the **post main** sequence evolution of massive stars.

$> 90\ M_\odot$

→ **WR – SN**

$45 - 90 M_\odot$

→ **BSG – LBV – WR – SN**

$22\text{-}45 M_\odot$

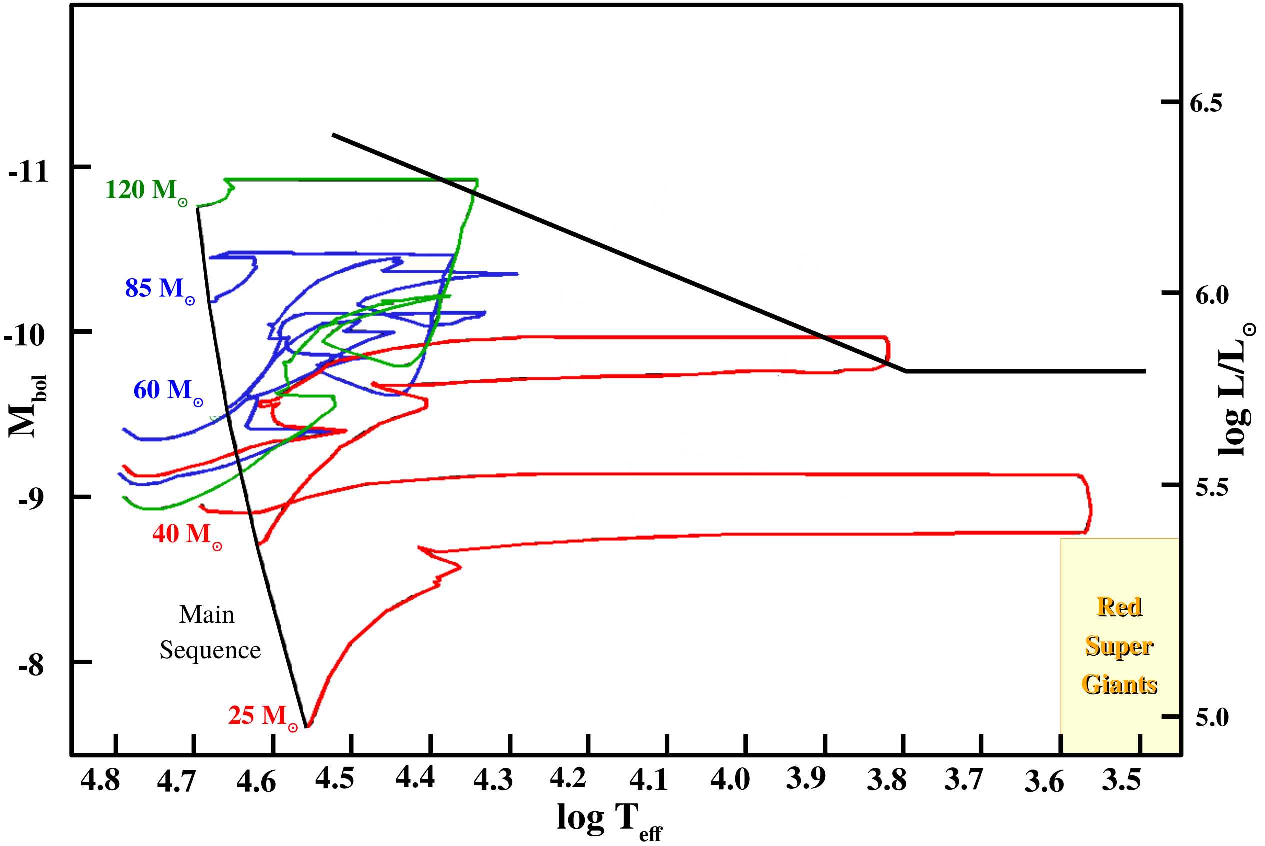
→ **BSG – LBV – SN**

or

→ **RSG – BSG – SN**

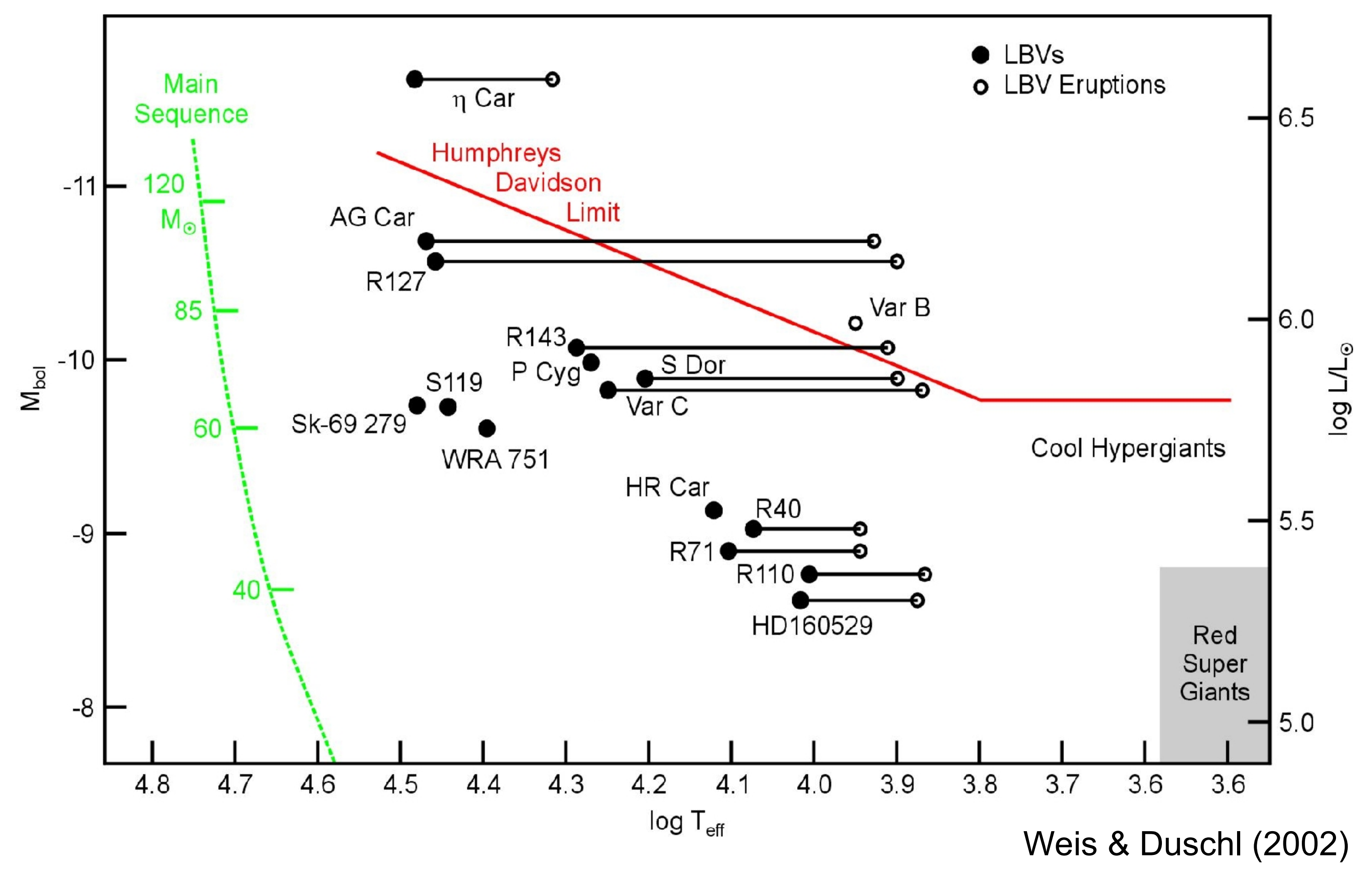
$< 22\ M_\odot$

→ **RSG – SN**



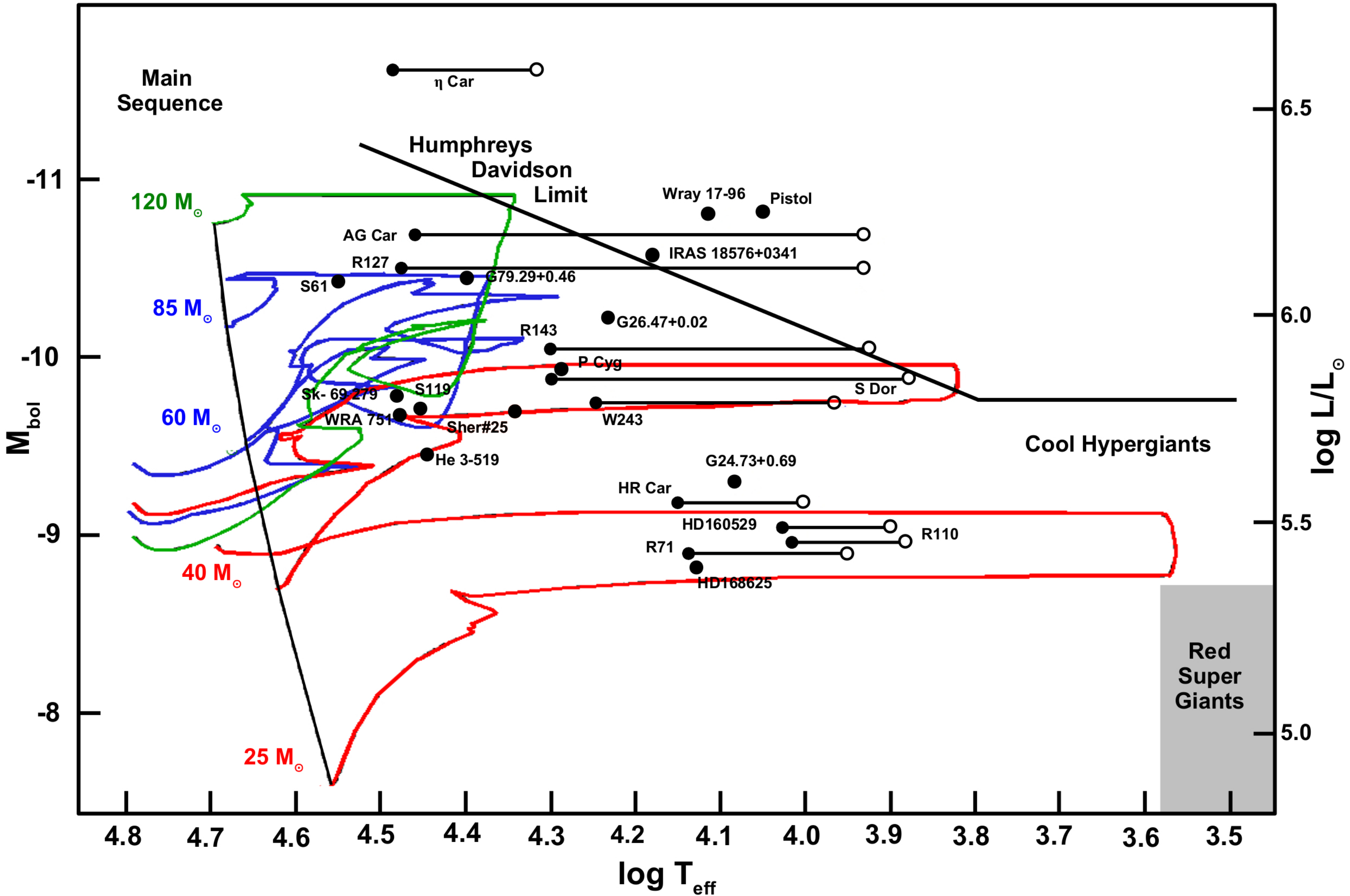
LBVs $M_{ini} > 22\ M_\odot$

LBVs and the Humphreys-Davidson Limit



Weis & Duschl (2002)

LBVs and tracks in the HRD



Weis & Bomans (2020)

Eddington Limit ↔ Γ-Limit

stable Star ↔ forces from radiation pressure and Gravitation are balanced – if not the star becomes unstable, that is the case if the star reaches the Eddington limit. In the HRD this limit coincides with the **HD-Limit** !!!

$$\frac{dP}{dr} = G\frac{M\rho}{r^2} \qquad \frac{dP}{dr} = F_{rad}\frac{\kappa\rho}{c} \qquad L = 4\pi R^2 F_{rad}$$

κ opacity
ρ density

$$\frac{\text{forces from radiation pressure}}{\text{Gravitation}} = \Gamma = \frac{\kappa L}{4\pi c G M}$$

Sir Arthur Eddington
(1882-1944)

Γ = 1 Eddington Limit

> 1 outward force from radiation pressure dominates → <u>instable</u>

Eddington Limit ↔ Γ-Limit

stable Star ↔ forces from radiation pressure and Gravitation are balanced – if not the star becomes unstable, that is the case if the star reaches the Eddington limit. In the HRD this limit coincides with the **HD-Limit** !!!

$$\frac{dP}{dr} = G\frac{M\rho}{r^2} \qquad \frac{dP}{dr} = F_{rad}\frac{\kappa\rho}{c} \qquad L = 4\pi R^2 F_{rad}$$

κ opacity
ρ density

$$\frac{\text{forces from radiation pressure}}{\text{Gravitation}} = \Gamma = \frac{\kappa L}{4\pi\, c\, G\, M}$$

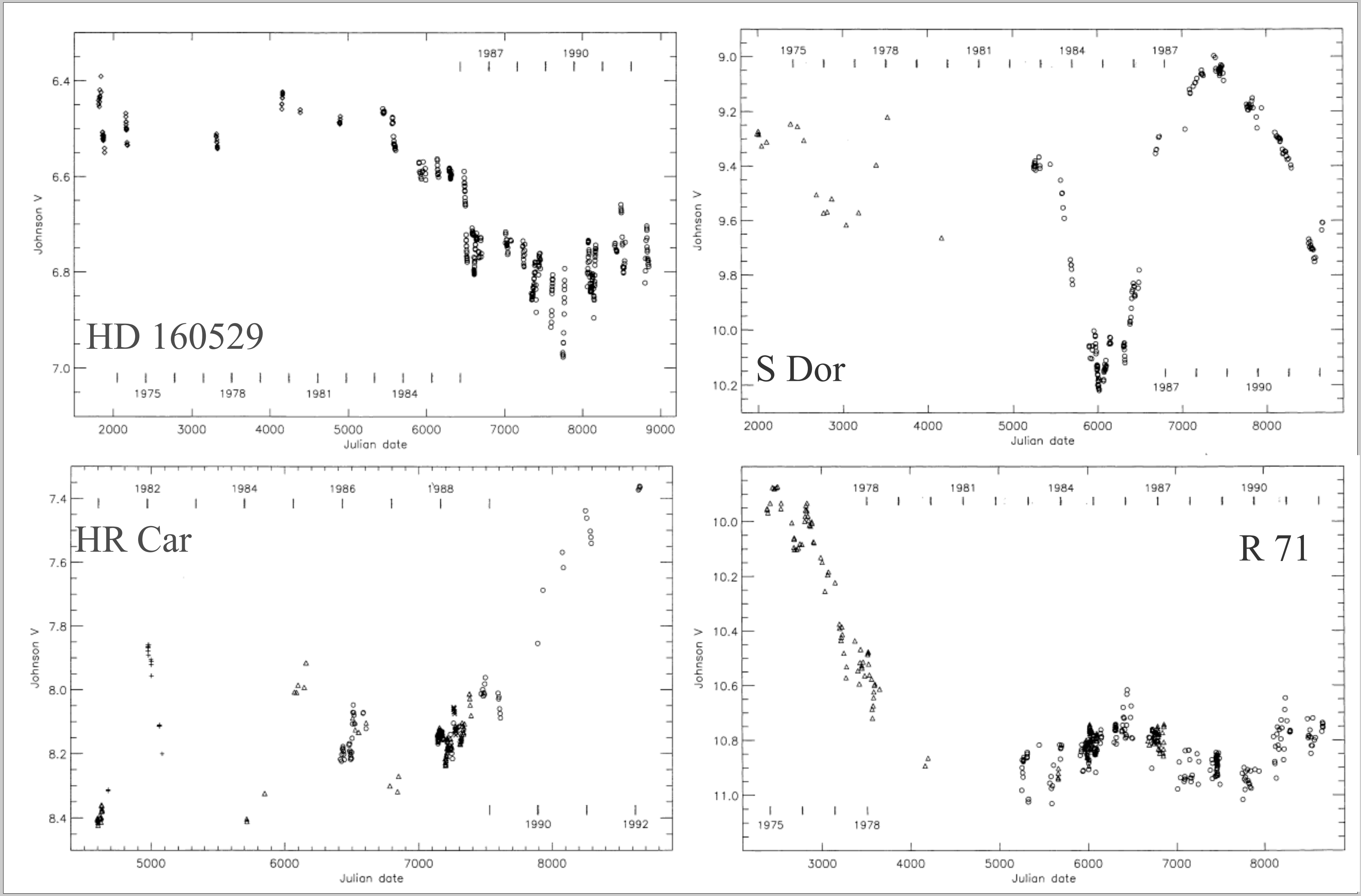
Sir Arthur Eddington
(1882-1944)

Rotation additional terms or use the reduced mass (centrifugal force)
→ **rotating** stars reach the Eddington Limit **earlier**
and with **lower** initial mass

Metallicity lower metallicity means κ smaller (e.g. less Fe)
→ hence **metal-poor** stars reach the limit **later**
and with **higher** initial masses

LBVs – V for Variability

LBVs show mostly irregular photometric variability



(Spoon et al. 1994)

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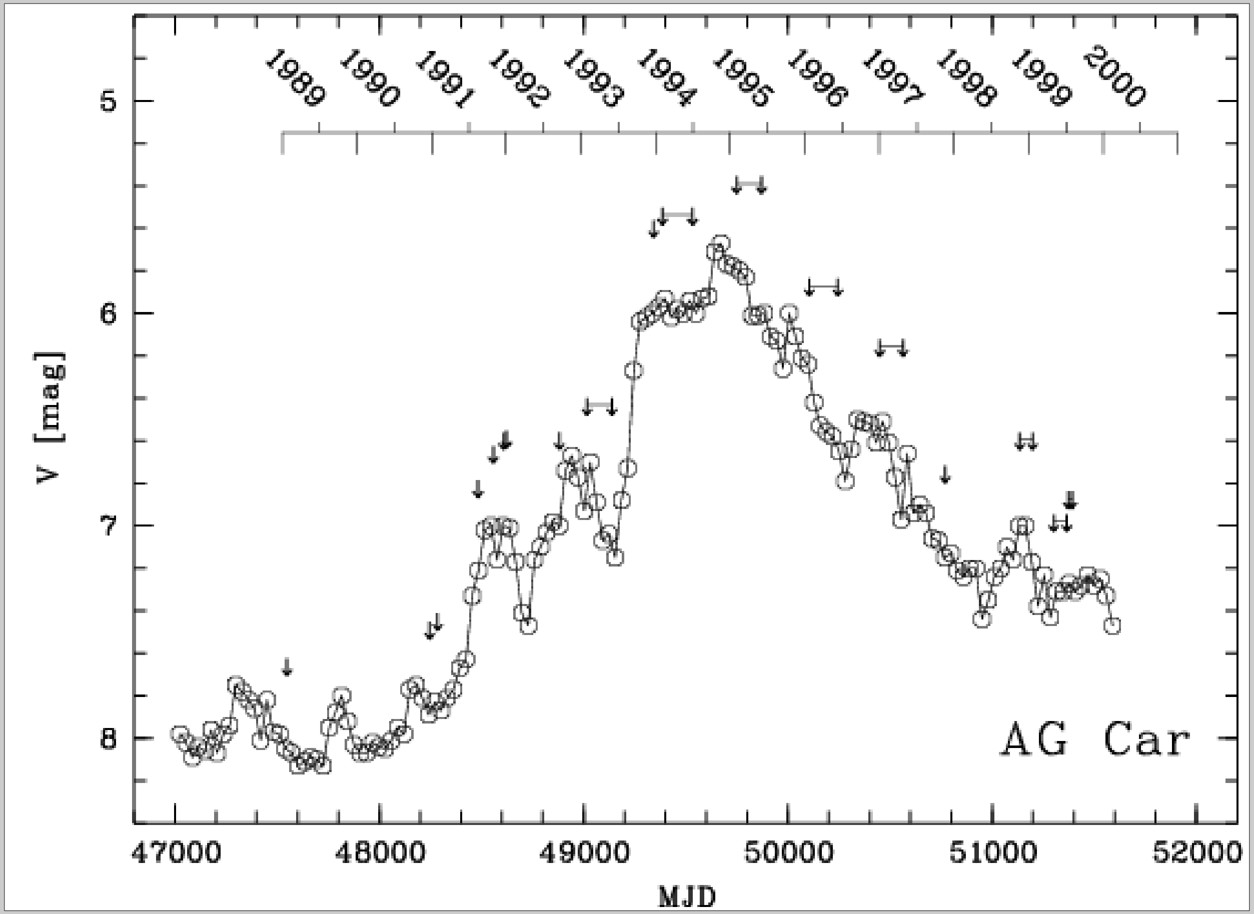
Defining a Luminous Blue Variable

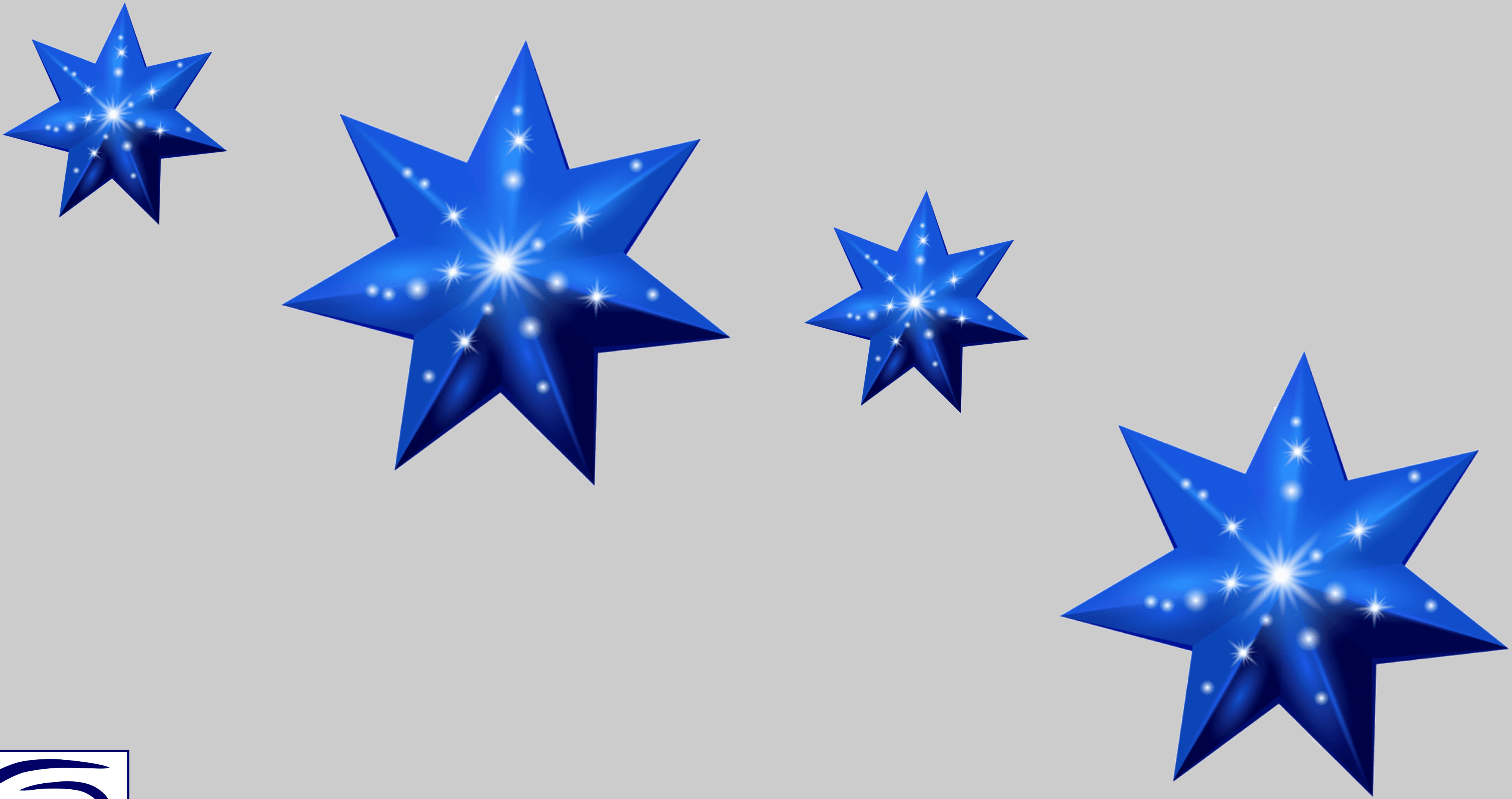
First of all it nees to be variable **photometric variability**



(Stahl et al. 2001)

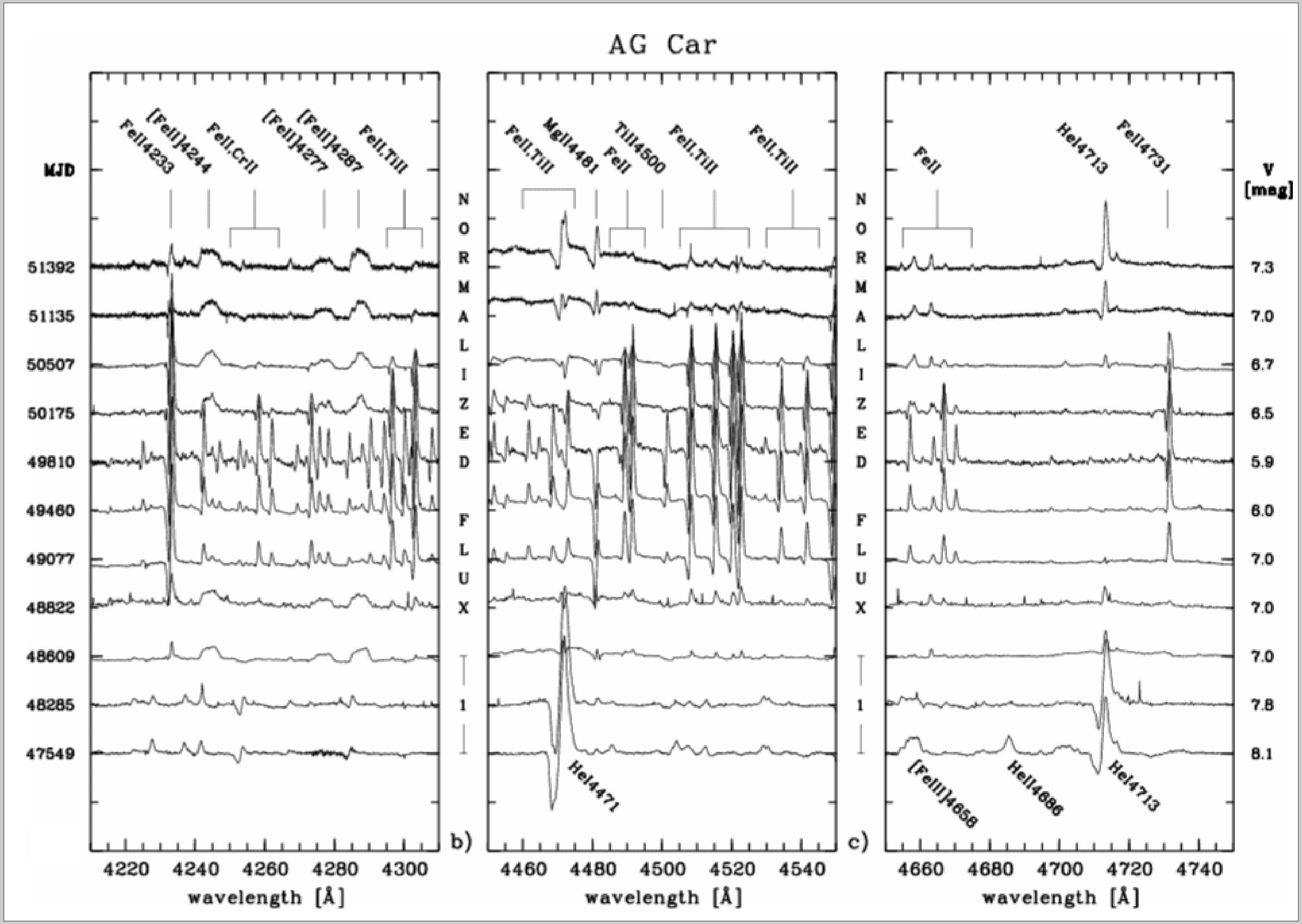
Defining a Luminous Blue Variable

First of all it nees to be variable



Defining a Luminous Blue Variable

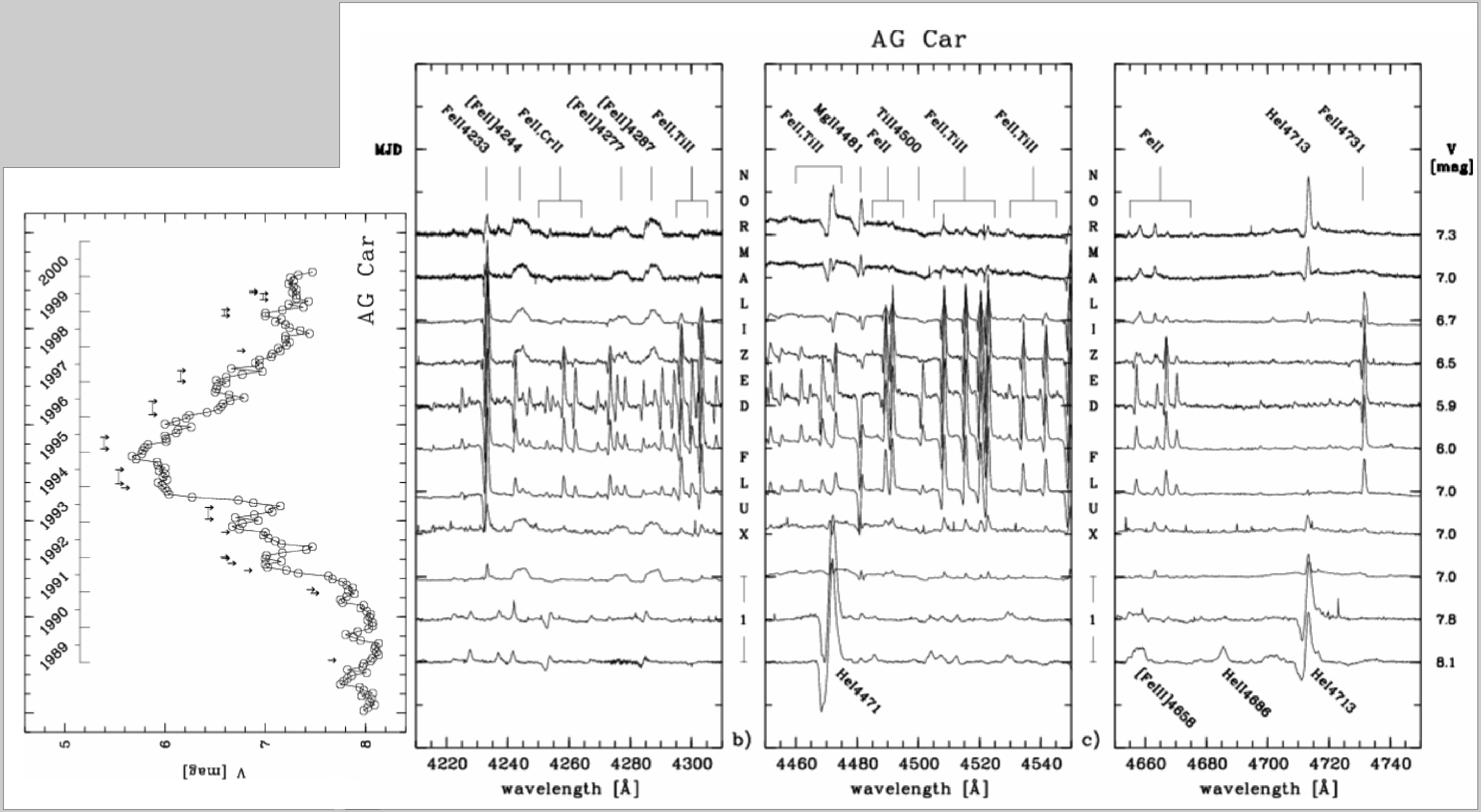
First of all it nees to be variable **spectroscopic variability**



(Stahl et al. 2001)

Defining a Luminous Blue Variable

First of all it nees to be variable **photometric & spectroscopic variability**



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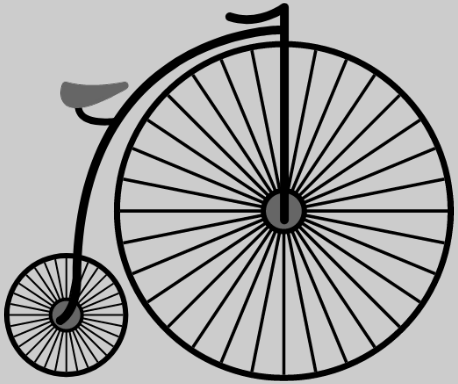
(Stahl et al. 2001)

Defining a Luminous Blue Variable

A **photometric variability** that is **coupled** to a **change** in the **spectrum**

S Dor Variability ↔ S Dor cycle

↔ (minor) eruption



- **hot** spectrum → maximum in UV and blue
  → **visually faint**

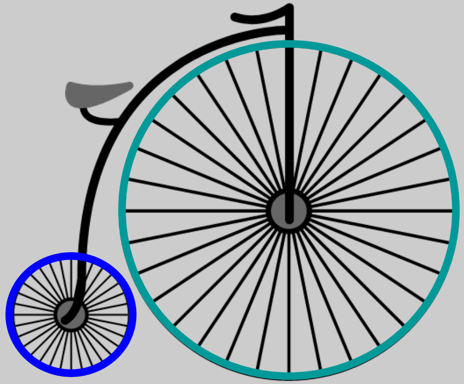
- **cooler** spectrum → maximum in visual and red
  → **visually bright**

- variability in general **irregular** variation 1-2 mag in 10-40 years
  van Genderen (2001) further subdivided this into
  S-SD (<10-20 a, **short**) and
  L-SD (>20 a, **long**) , as well as an
  ex-/dormat (no variability last 100 a years)

LBVs – S Dor cycle

Changing the brightness by changing the spectrum

WHAT CHANGES THE SPECTRUM ?



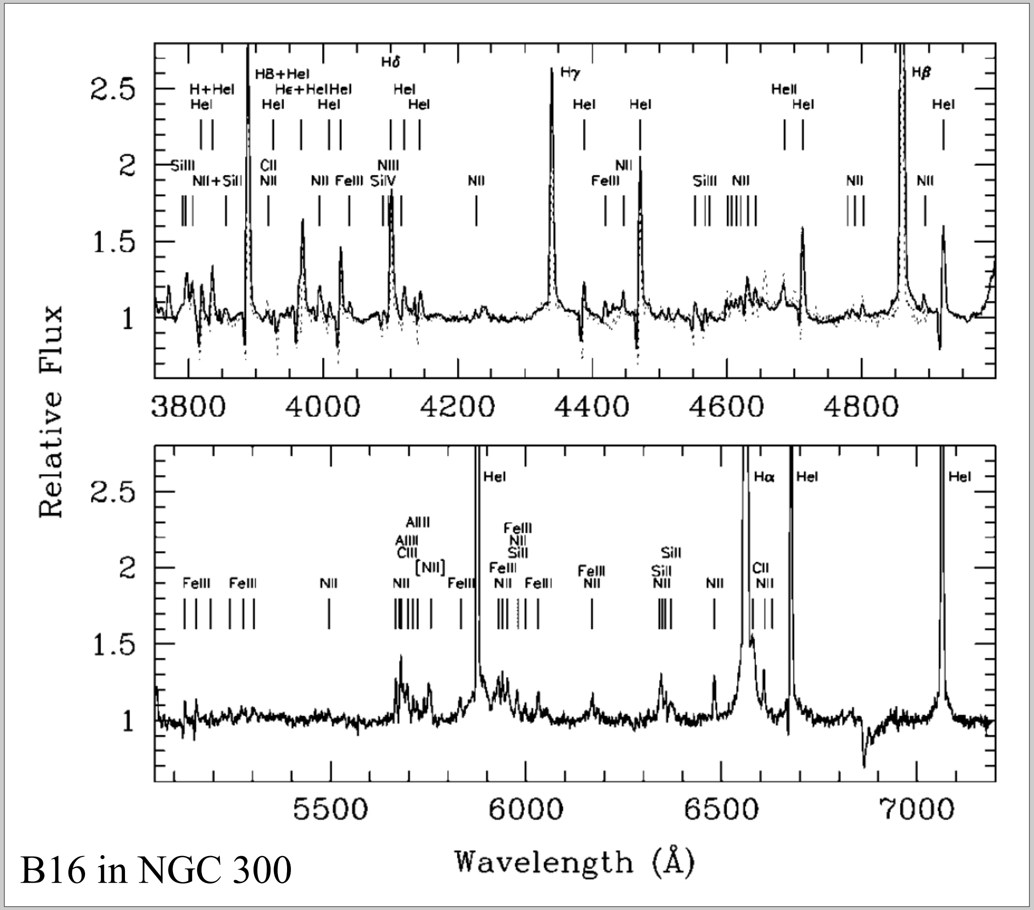
The spectrum of a star originates in the photosphere
inflating the radius
↔ changes the photosphere
↔ changes the spectrum of the star

LBVs inflate their
radius → **spectrum** appear **cooler** or **hotter**

LBVs – Spektraltypes

- Spectral type is variable (S Dor cycle)
- O, B types in hot phase and A, F types in cool phase
- P Cygni lines (↔ strong wind) in e.g. Balmer series, He, Fe II, [Fe II]
- Emission line spectrum (but partly from the nebula)
- in hot phase type **Ofpe/WN9**
  Of → O with emission lines
  WN → WR with a lot of N
  ↔ CNO

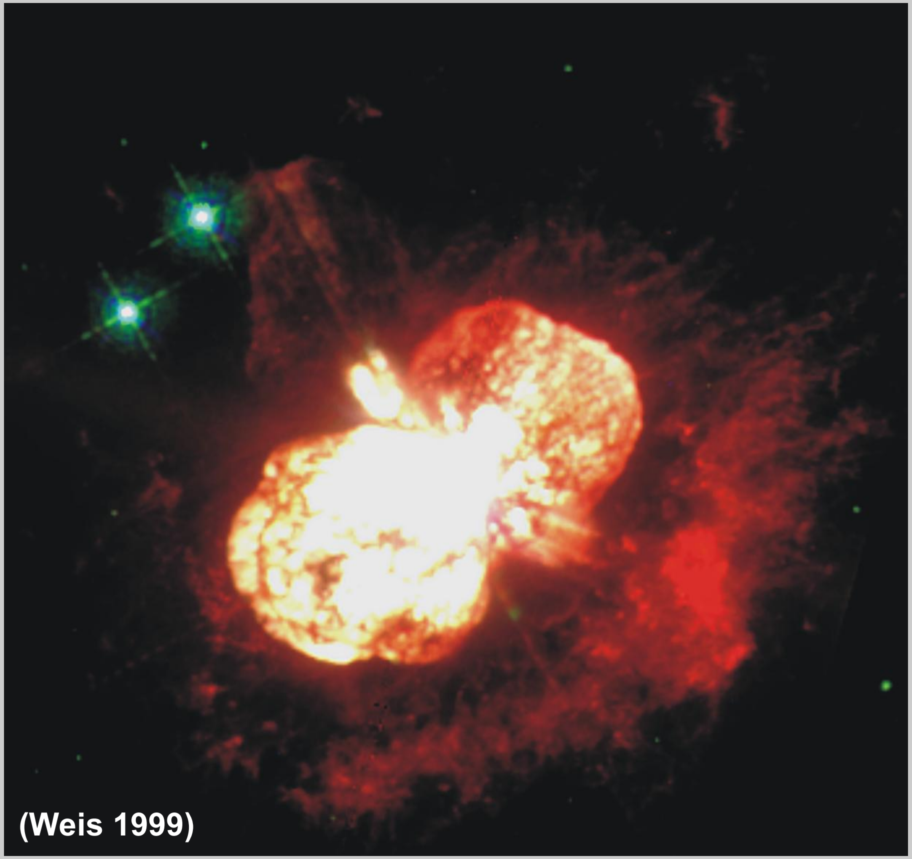
Ofpe/WN9 Spektra→



B16 in NGC 300

Security advice
Do not leave your LBV unattended!

… it could erupt !!!



(Weis 1999)

LBVs – Giant Eruptions

LBVs can have giant eruptions (e.g. η Car)

Variability spontaneous, change 2-5m in V

time scale ? Multiple ?

Energy output 10^{49} erg/s

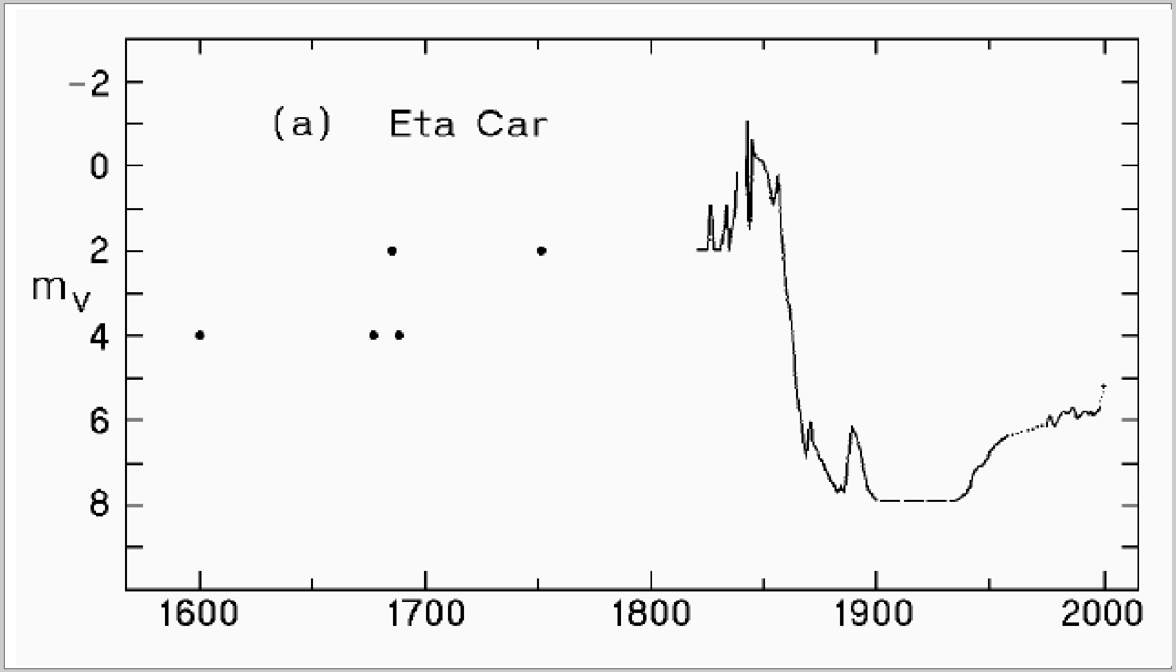
Most likely caused by κ-mechanism (Fe) coupled with the proximity to the Eddington limit → opacity (κ) Fct. of T → LBVs sometimes show structural changes → like radius change

classic examples

η Carinae
P Cygni
SN 1961V
SN 1954J (V12)

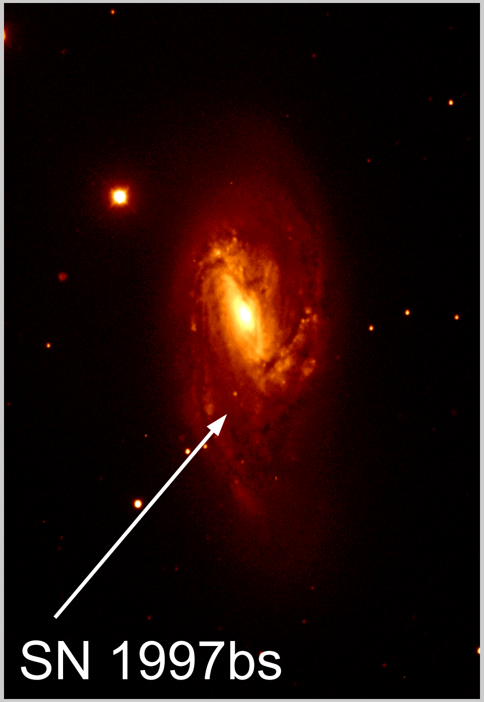
→ direct classification criterion

(Humphreys et al. 1999)



LBVs – Giant Eruptions – SN imposters

Now a lot are found in Supernova search programs
Find events that only appear as if they are SNe.
they are called **supernova imposters**.



LBVs – Giant Eruptions – SN imposters

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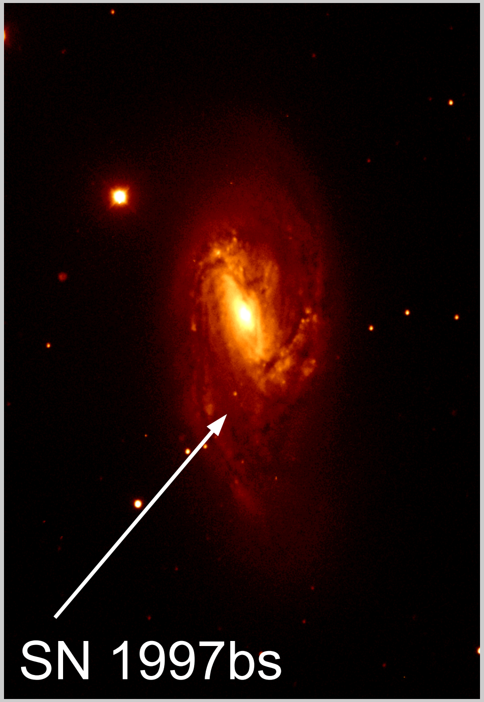
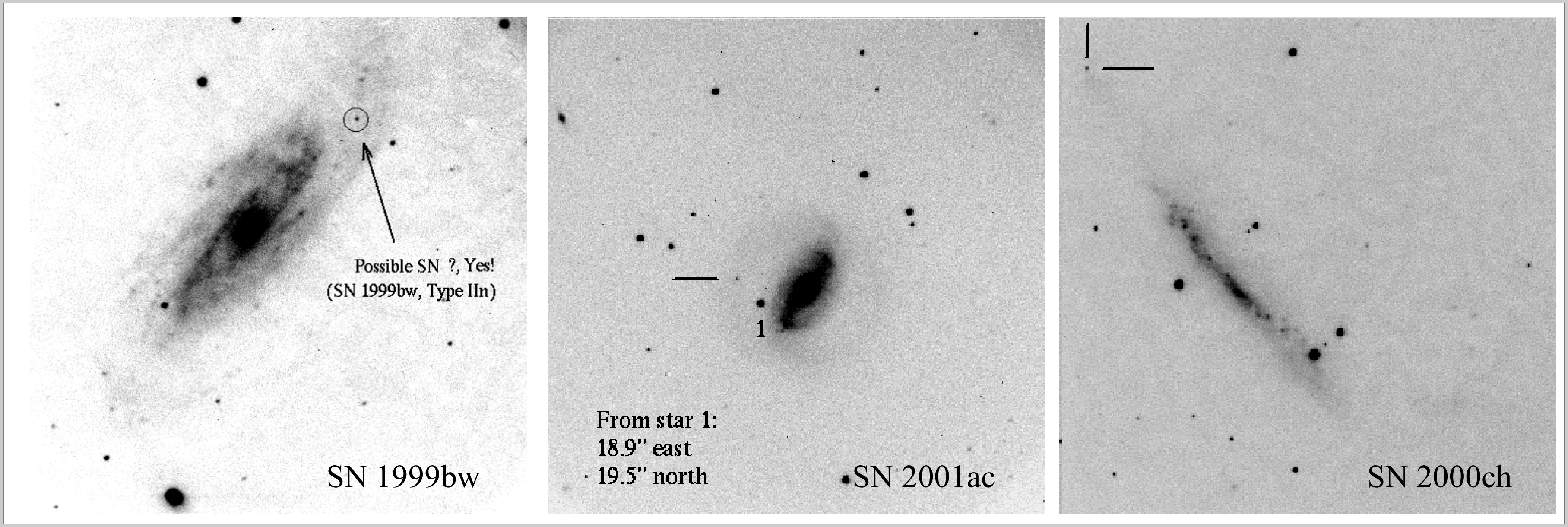
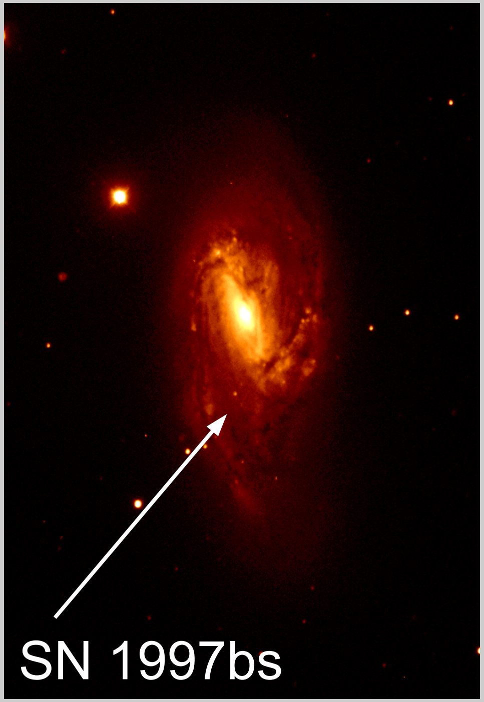


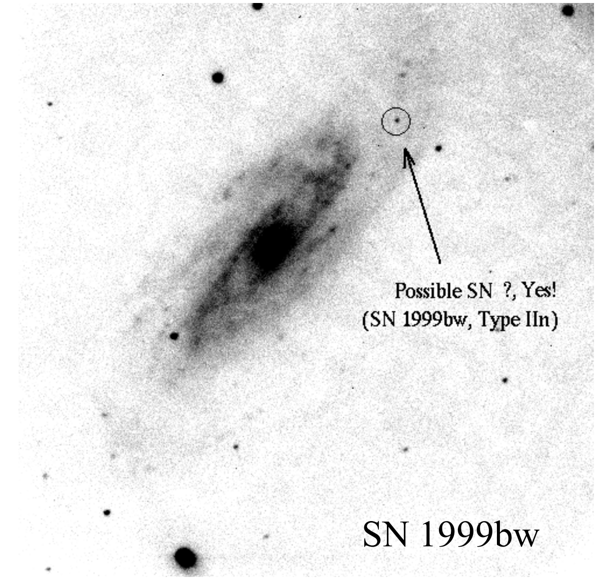


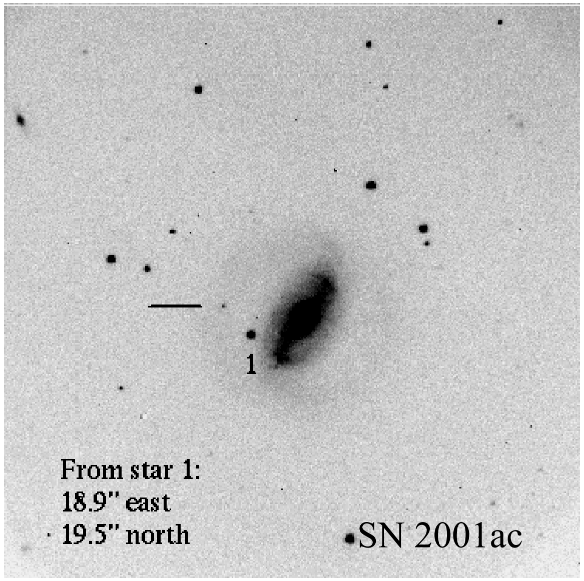
LBVs – Giant Eruptions – SN imposters

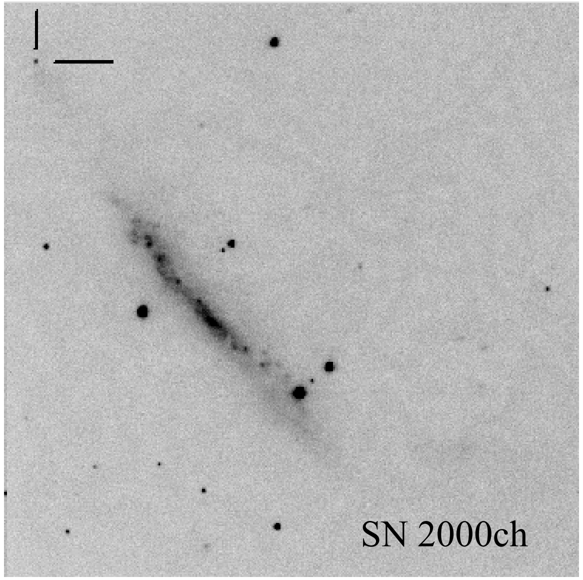
Now a lot are found in Supernova search programs
Find events that only appear as if they are SNe.
they are called

supernova imposters
giant eruptions look like SN imposter







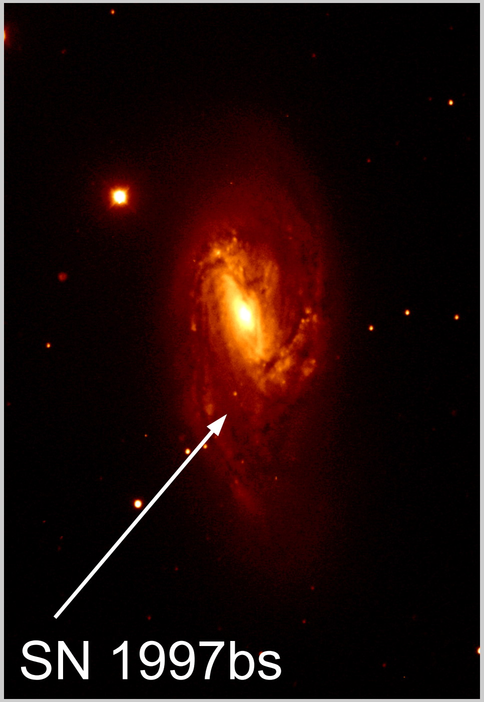


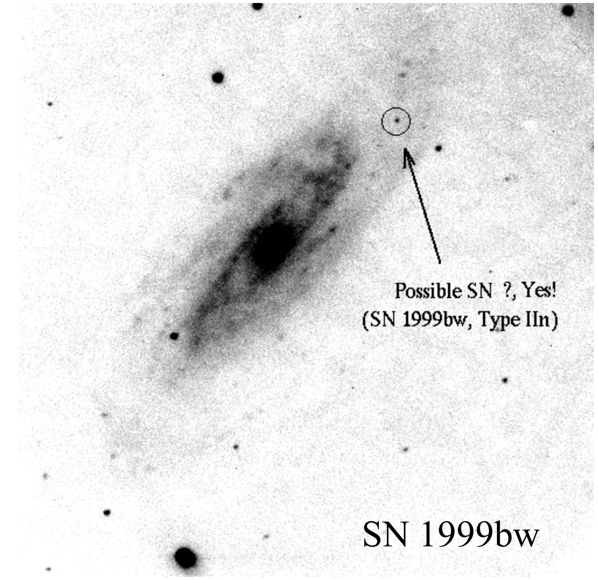
LBVs – Giant Eruptions – SN imposters

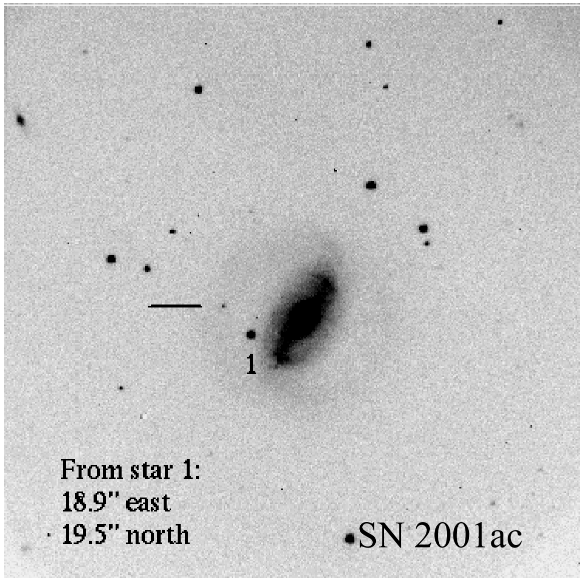
Now a lot are found in Supernova search programs
Find events that only appear as if they are SNe.
they are called

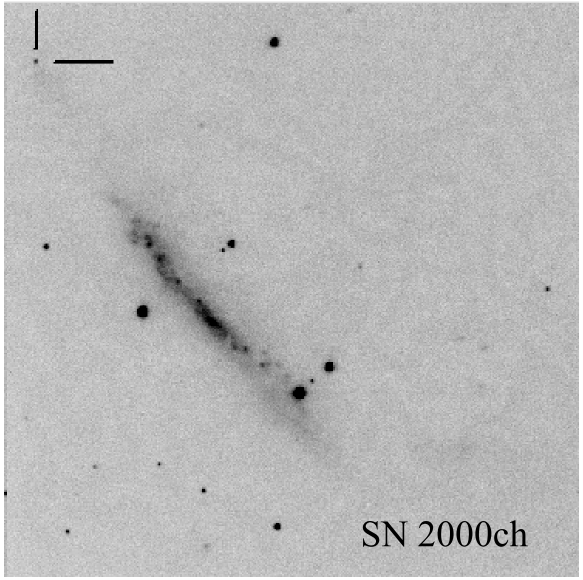
supernova imposters
giant eruptions look like SN imposter

but not all SN imposters are giant eruptions !!!









Definition/Classification of an LBV

Peter Conti
1984

I shall refer to the non W-R or "other," hot stars as "luminous blue variables," or LBV, in my talk

Bruce Bohannan
1997

Remember what is said about ducks:
it may look like a duck, walk like a duck,
but is not a duck until it quacks .

An LBV can only be classified as an LBV if it has 'quacked'
→ scientific that means

- clear evidence for a **S Dor cycle**

and / or

- clear evidence for a **giant eruption**

Origin of the LBV Variability – mechanism

What could initiate the S Dor cycle ?
What triggers giant eruption ?

from theoretical considerations two scenarios

- a kind of heat accumulation → poor energy transport
  → Pressure build-up → Radius increase or shell ejection

- increased energy production and temperature increase
  → Pressure build-up → Radius increase or shell ejection

Origin of the LBV Variability – mechanism

What could initiate the S Dor cycle ?
What triggers giant eruption ?

from theoretical considerations two scenarios

- a kind of heat accumulation → poor energy transport
  → Pressure build-up → Radius increase or shell ejection

we already know a mechanism that can do that
the **κ mechanism**

- increased energy production and temperature increase
  → Pressure build-up → Radius increase or shell ejection

Here we need ...

Lets go to the

Epsilon Camp

the

Epsilon Mechanism

ε Mechanism

Energy production in the star $\frac{dL}{dr} = 4\pi r^2 \rho \varepsilon \qquad \varepsilon \propto T^n$

CNO-cycle

$\varepsilon \propto T^{20}$

Helium or Triple-α burning

$\varepsilon \propto T^{30\text{-}40}$

Carbon burning

$\varepsilon \propto T^{40}$

Oxygen burning

$\varepsilon \propto T^{>40}$

Silicon burning

$\varepsilon \propto T^{>40}$

Energy production have
T dependence of

$\varepsilon \propto T^{20\ldots>40}$

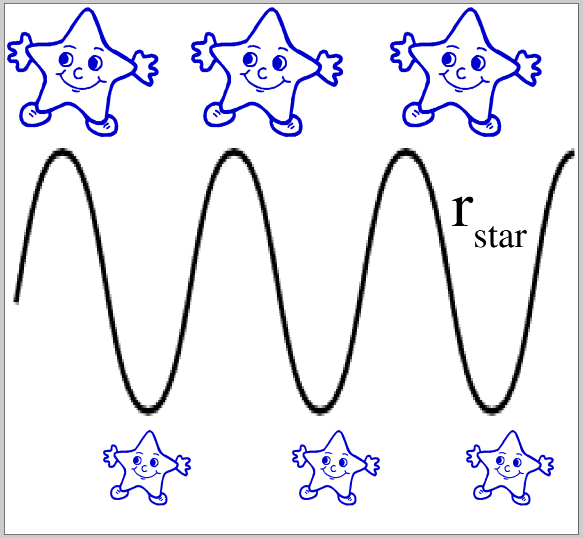
ε Mechanism

energy production in the star
extremely temperature dependent !!!

$$\boxed{\varepsilon \propto T^{20...>40}}$$

small temperature change → large change in energy production

T rises a bit
↓
energy increases highly
↓
T increases
↓
Expansion so r increases →
T decreases
↓
Contraction → T rises



Not unlike in κ-Mechnismus, radius and therfore
Luminosity changes → pulsation or cycle OR...

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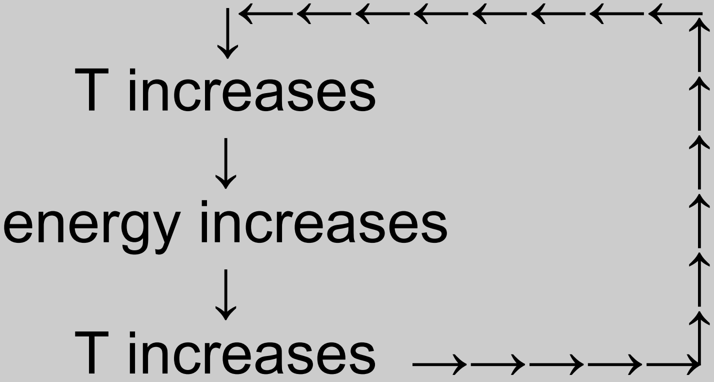
ε-Mechanismus

energy production in the star
extremely temperature dependent !!!

$$\boxed{\varepsilon \propto T^{20\ldots>40}}$$

small temperature change → large change in energy production



T increases
↓
energy increases
↓
T increases

Expansion too slow due to large/heavy envelope
→ run-away process → until pressure becomes too high
↓
eruption

Origin of the LBV Variability – mechanism

What could initiate the S Dor cycle ?
What triggers giant eruption ?

from theoretical considerations two scenarios

- a kind of heat accumulation → poor energy transport
  → Pressure build-up → Radius increase or shell ejection

we already know a mechanism that can do that
the κ **mechanism** could trigger the **S Dor Cycle** or **giant eruption**

- increased energy production and temperature increase
  → Pressure build-up → Radius increase or shell ejection

enlarged energy production due to changes in the temperature
ε **mechanism** increases the pressure now either a pulsation starts
S Dor Cycle or the outer layer are ejected in an **giant eruption**

What really happen is still unclear
so far no reliable detection/test methods

LBVs and LBV Nebulae

Stellar Winds

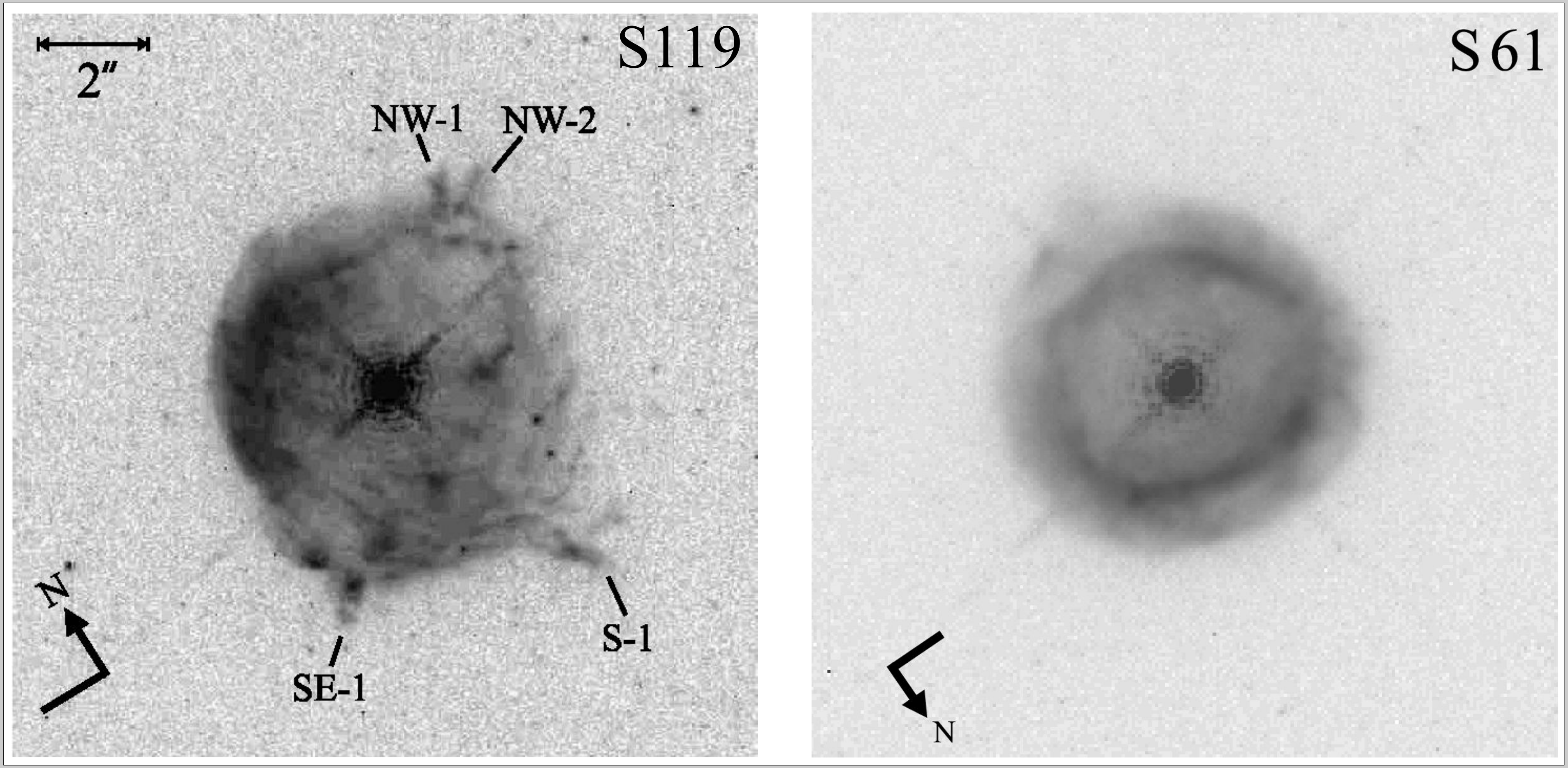
LBVs have **stellar Winds with** extremely high rate of mass loss $\sim 10^{-6...-3}\,M_\odot\,a^{-1}$

Velocities between fast (~1000 km/s) and slow (~100 km/s) due to the S dor cycle → Wind-wind interaction

And several solar masses of material are ejected/ejected in LBV Giant Eruption

→ both can lead to the formation of **LBV nebulae**

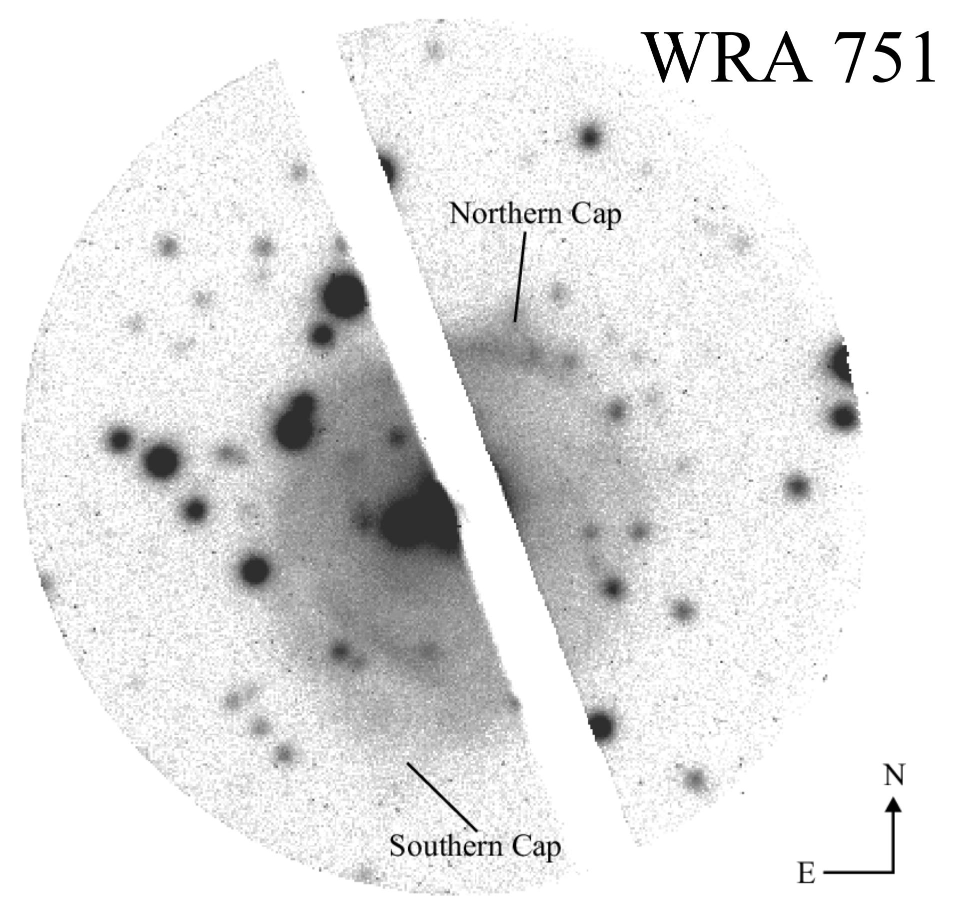
LBV Nebulae – round LMC LBV Nebulae



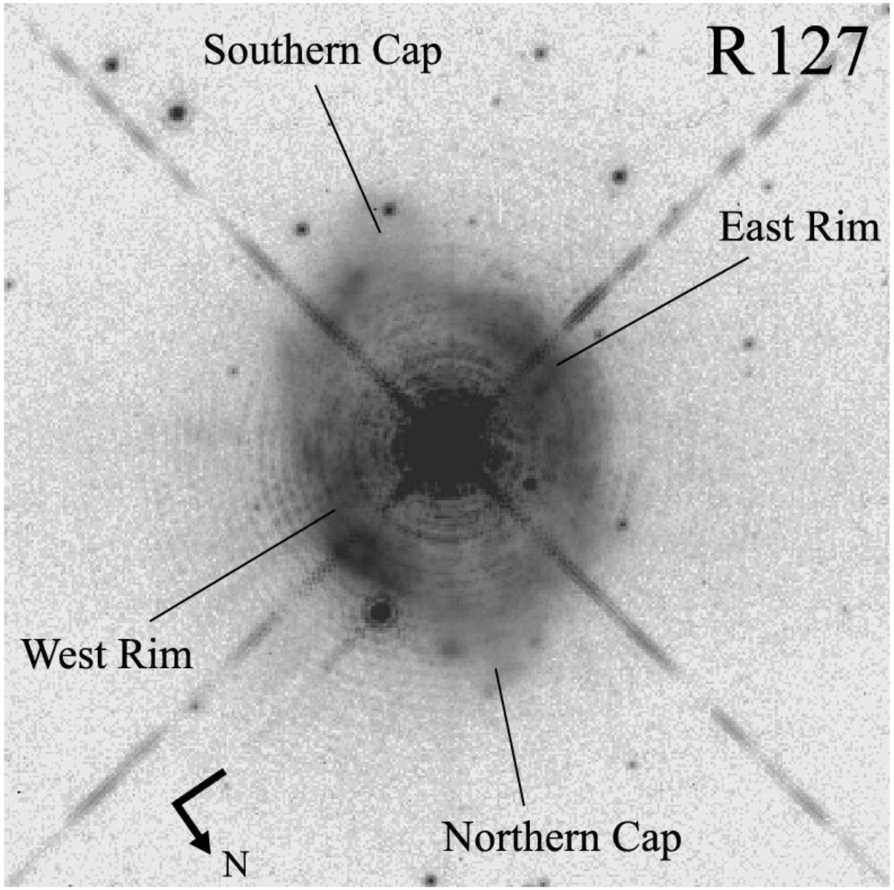
HST Bilder F656N = (H_α)

(Weis 2003)

LBV Nebulae – round with bipolar caps



(Weis 2000)



(Weis 2003)

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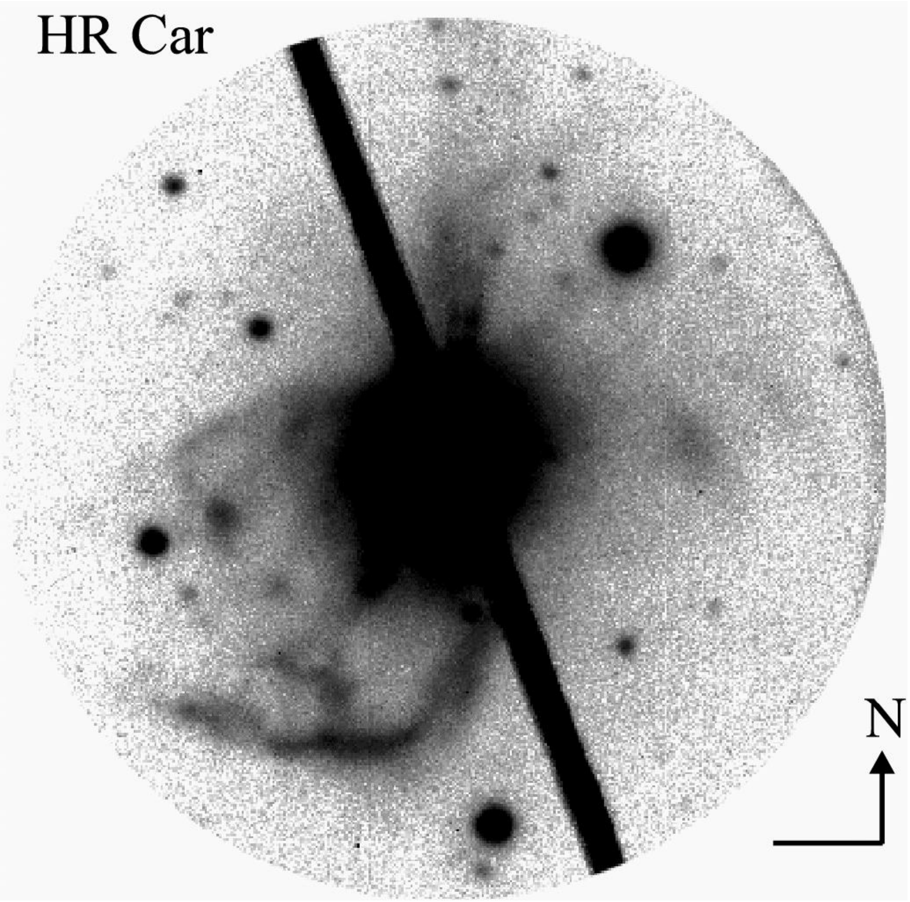
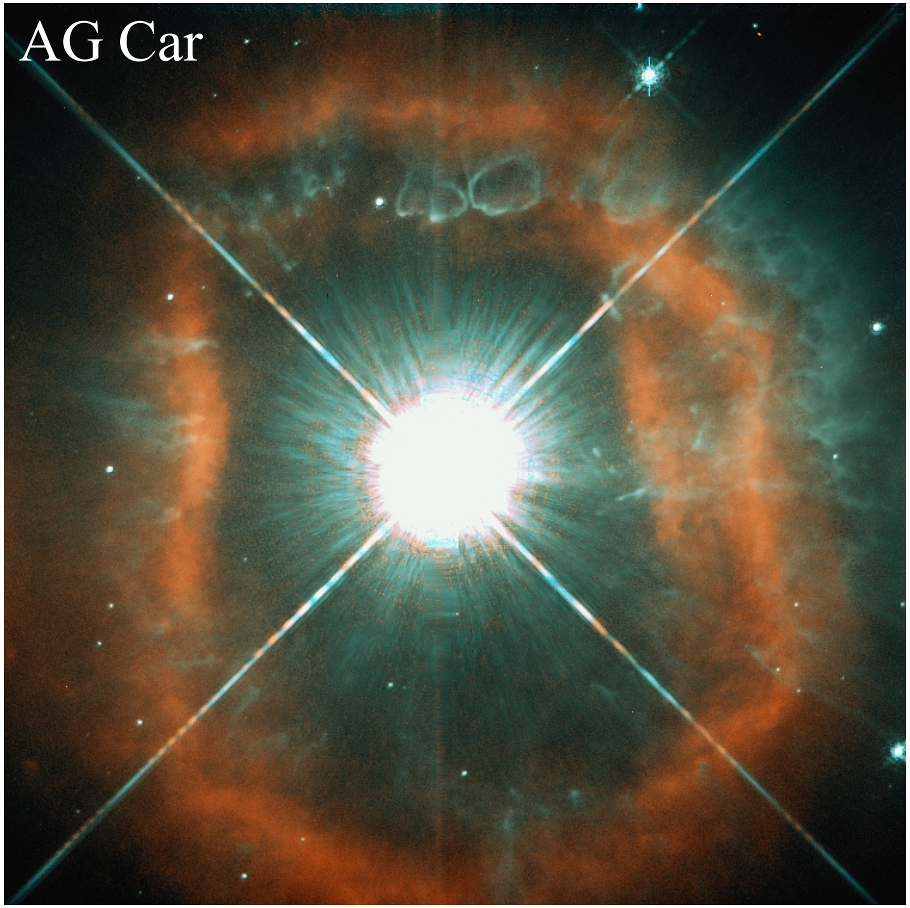
LBV Nebulae – Bipolar Nebulae

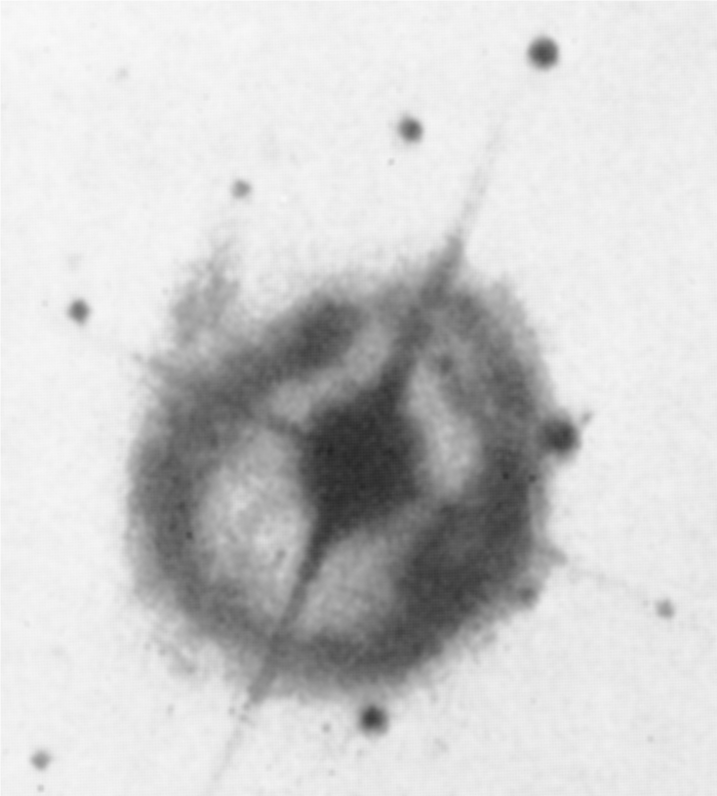


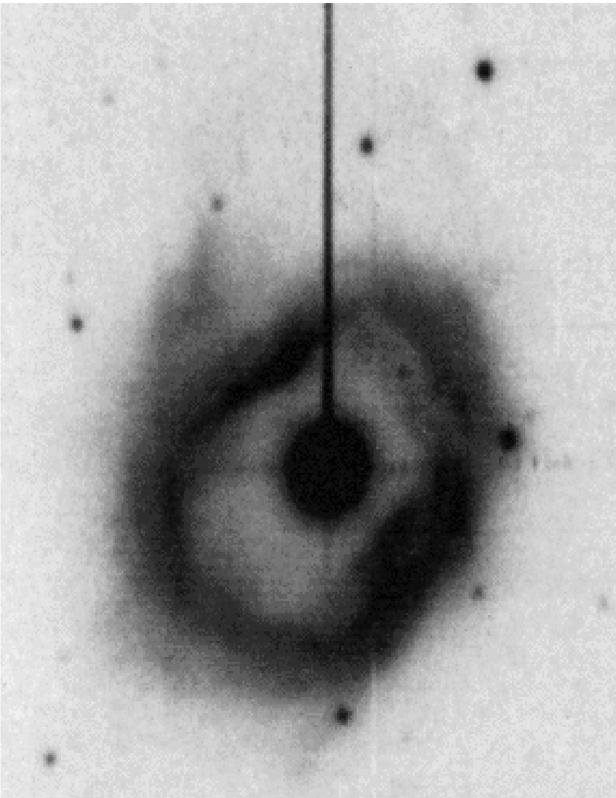
(Weis 1997)

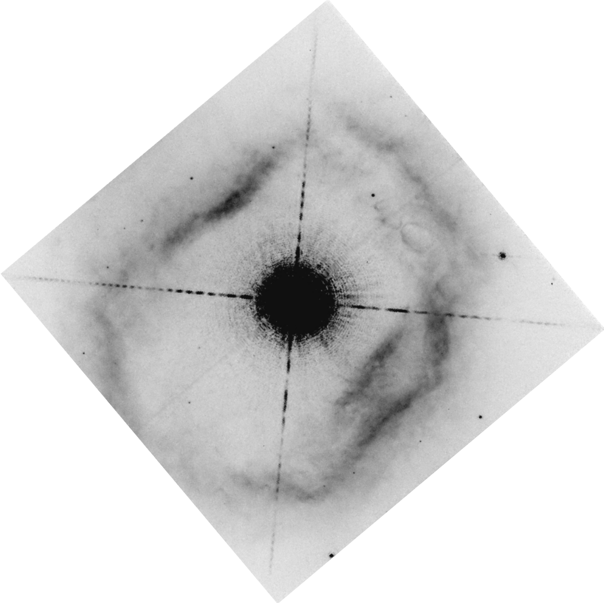


(Weis 2009)

LBV Nebulae – AG Carinae


(Thackeray 1950)


(Stahl 1987)

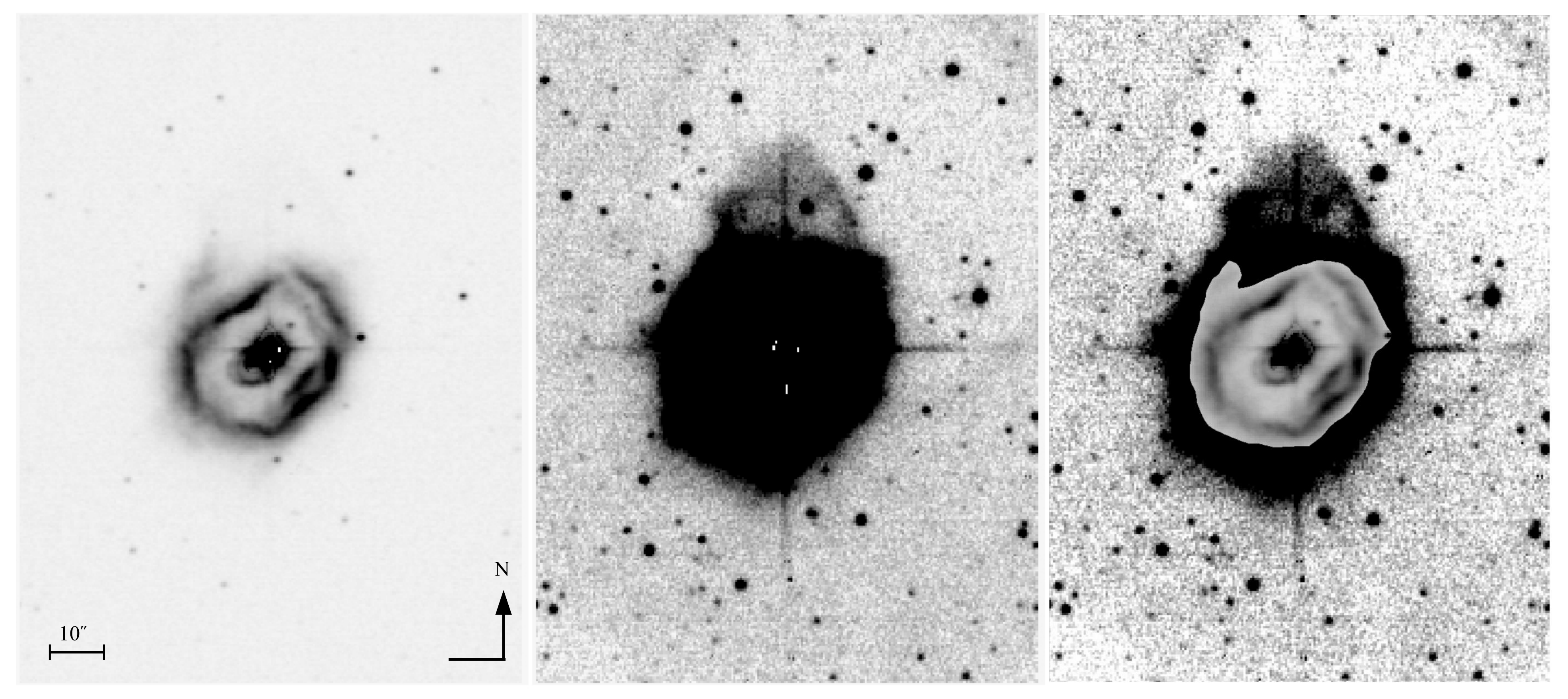

(Weis 2008)

AG Carinae is – if something like that really exists – probably the most typical and currently also the best-studied LBV.

… and yet

LBV Nebel – AG Carinae

SURPRISE !!! ☺

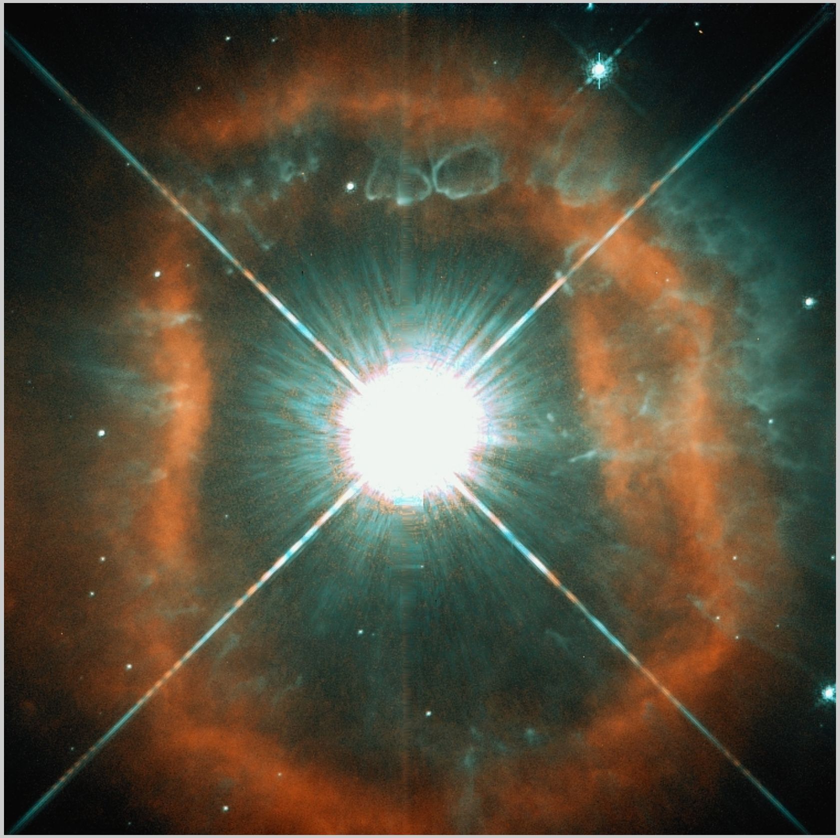


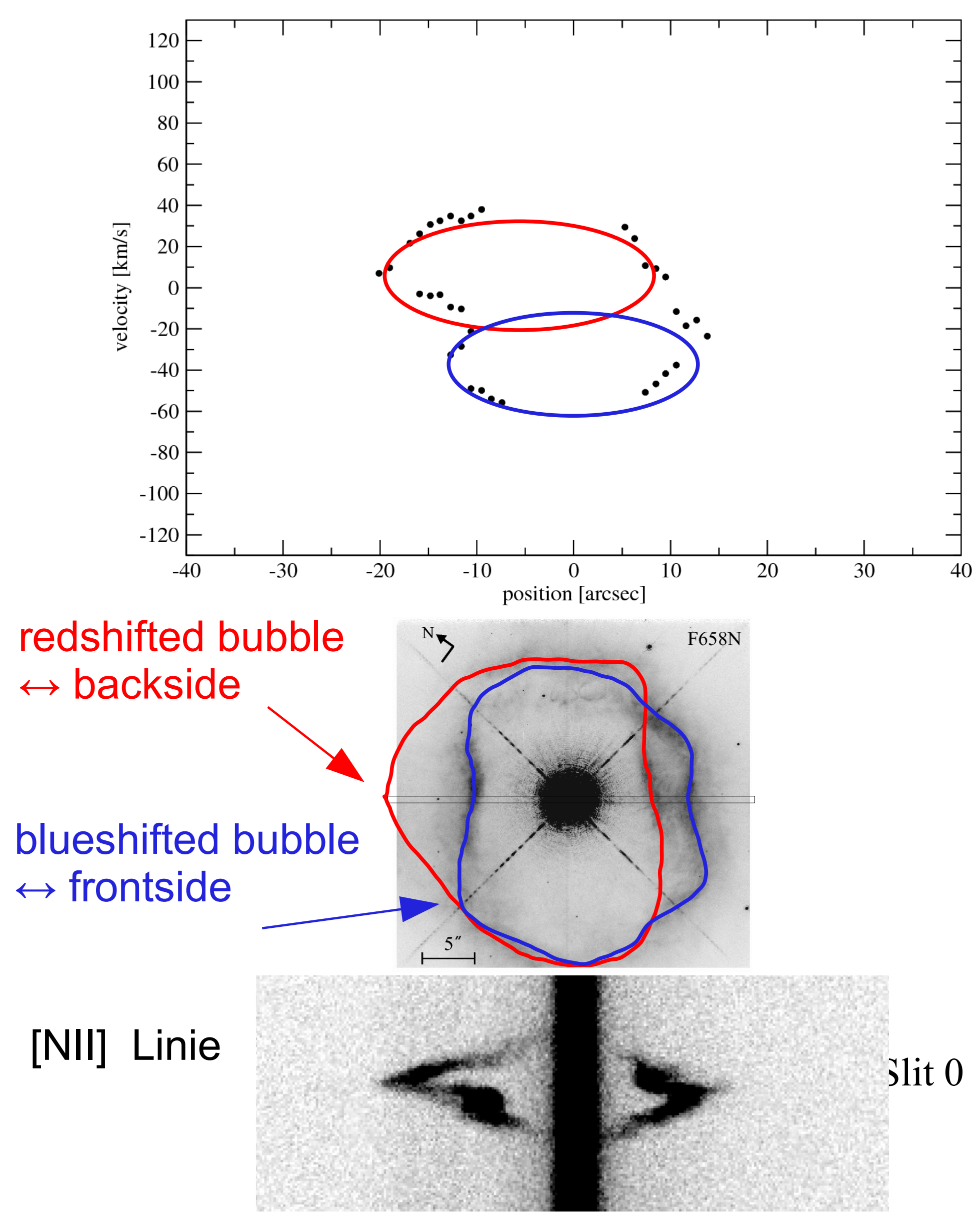
(Weis in prep.)

The nebula around AG Carinae is considerably **larger** than previously thought! not just 1 pc → but a whole 1.4 x 2 pc.

<ins>Size has doubled!!!</ins> ☺

AG Carinae – making a box bipolar





redshifted bubble
↔ backside

blueshifted bubble
↔ frontside

[NII] Linie

The nebula around **AG Carinae** is not elliptical or 'box-like' but → **really bipolar !!!**

☺

(Weis in prep.)

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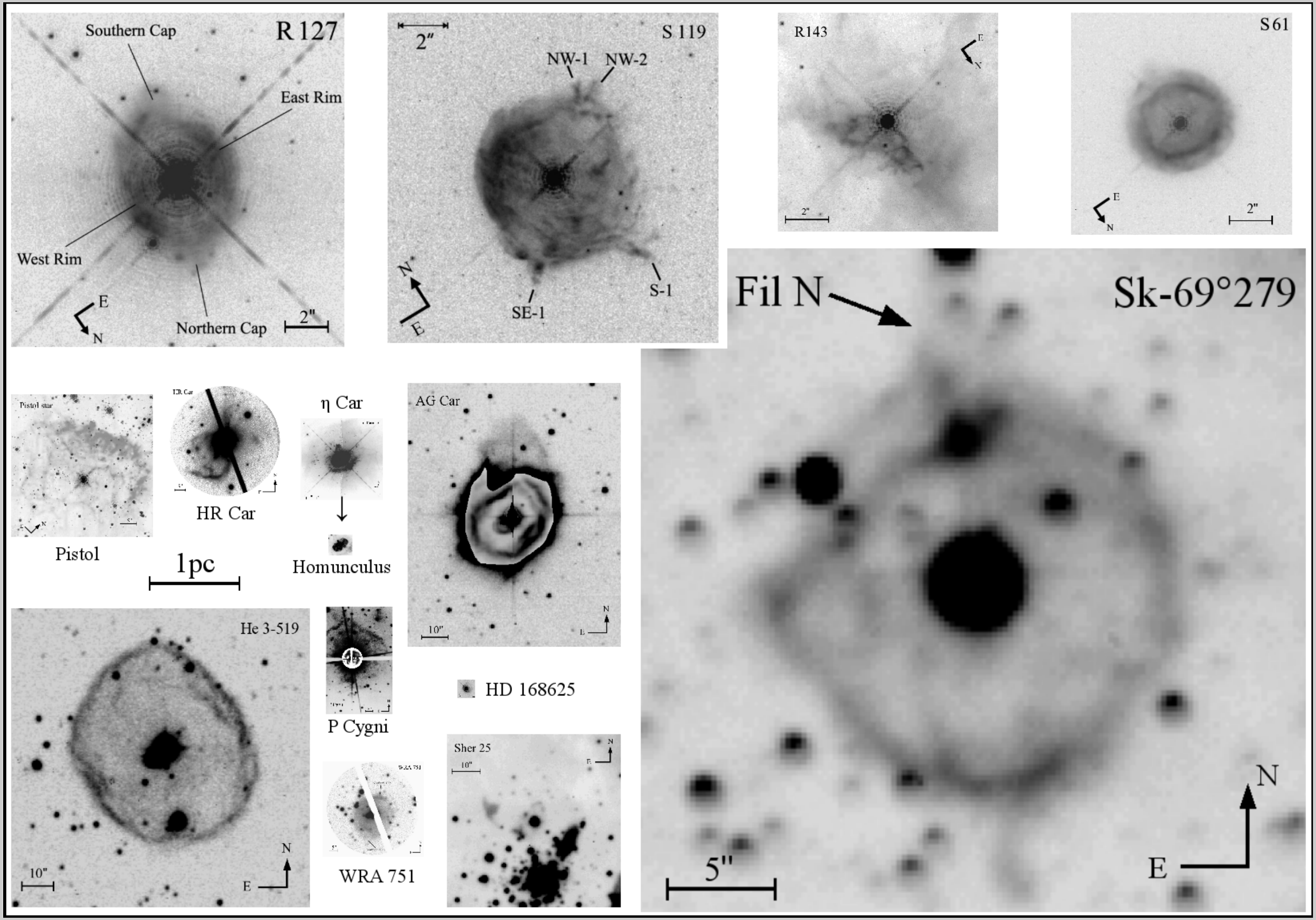
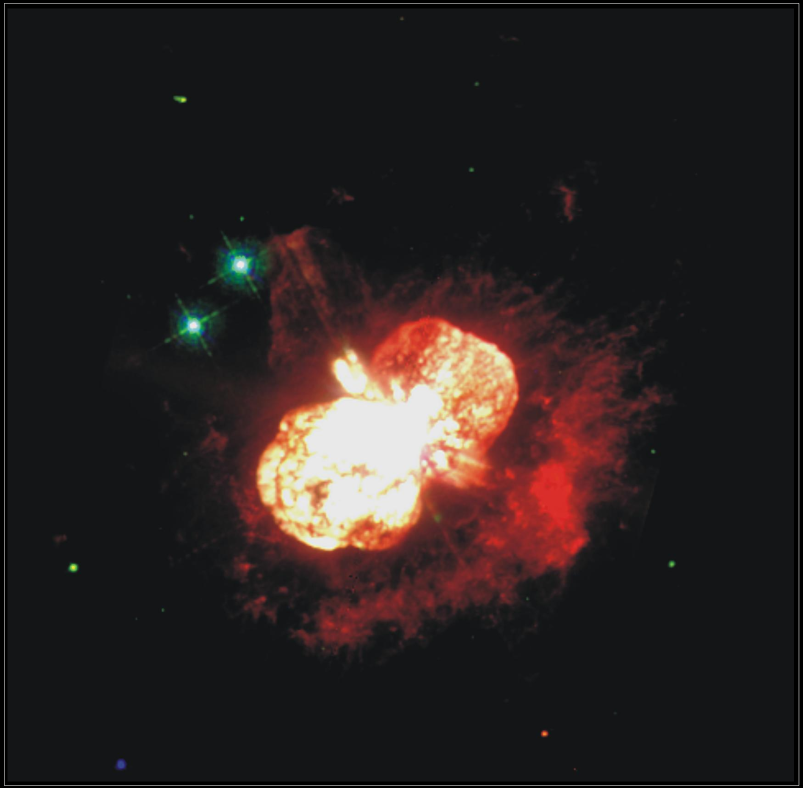
LBV Nebulae – scaled !



(Weis 2012)

Don't let this happen to you !!!



Have you checked your radiation pressure lately ?

National Association for the Prevention of Giant Eruptions

Types of Variability

I. Intrinsic Variability

Star variable "by itself" → variability caused by physical changes of star

- **pulsation variable ✔**
- **Eruptive ✔**
- **Rotationally induced variables**

II. Extrinsic variability

Star not variable by “itself”→ variability generated by external influences

- **Binary stars ↔ eclipsing variables**
- **Accretion disks ↔ like T Tauri**
- **binary+accretion disk ↔ cataclysmic variables, novae**