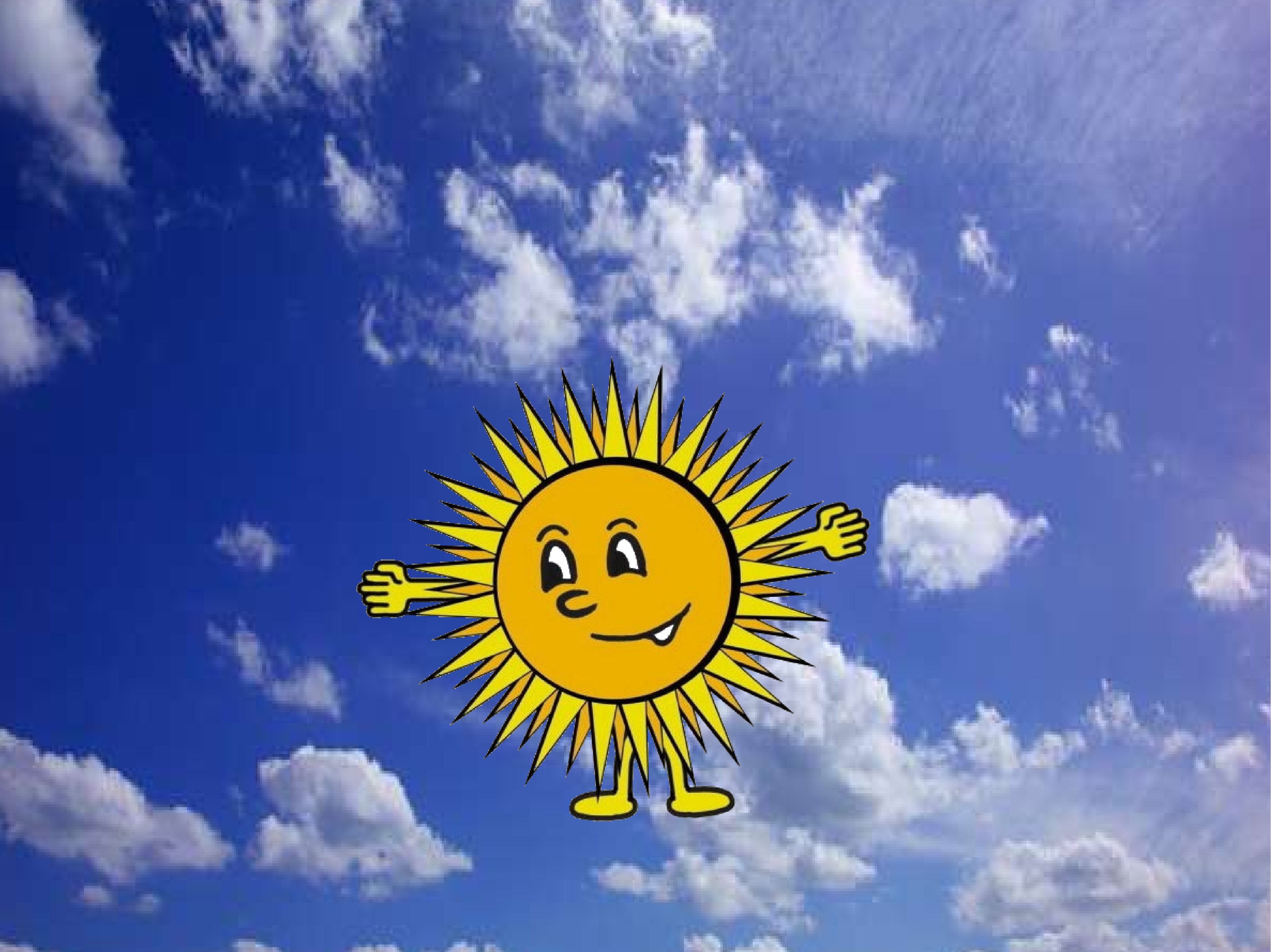
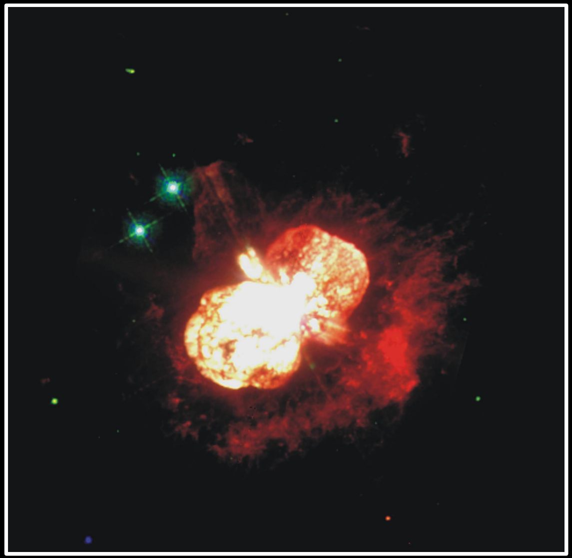


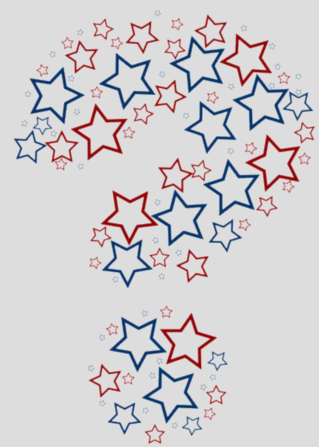
LBVs – Variabilities and the Formation of Nebulae

Kerstin Weis

Astronomisches Institut
Ruhr-Universität Bochum
Bochum, Germany



Let us start simple:
What defines a Luminous Blue Variable ?



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Defining a Luminous Blue Variable

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

Conti 1984

… this is a quite broad definition but at least excluded

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

...and restricted that sample to more evolved objects that

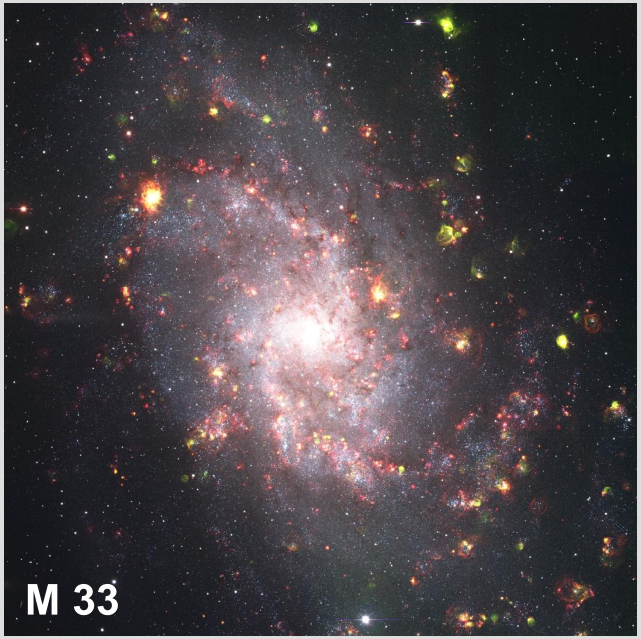
→ need to be **luminous** ↔ massive
→ need to be **blue** ↔ hot
→ need to be **variable**

at that time already three classes were known to fulfill these criteria

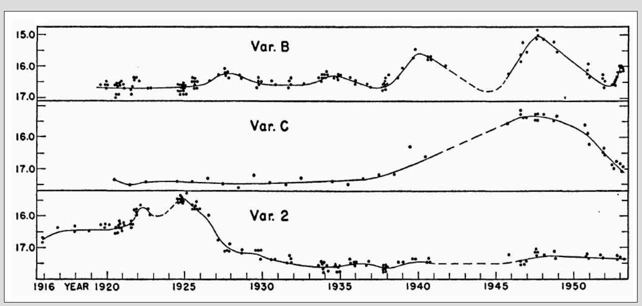
Hubble Sandage Variables
P Cygni typ stars
S Doradus Variables

LBVs – a grand unification of

Hubble-Sandage Variables

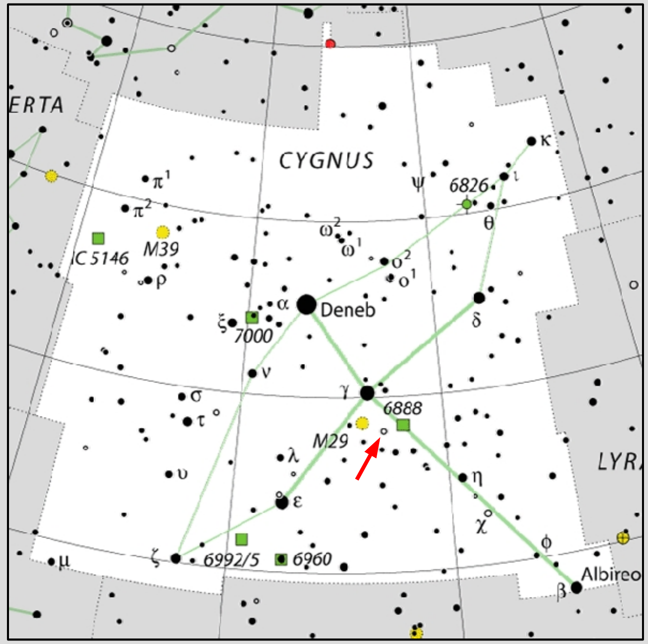


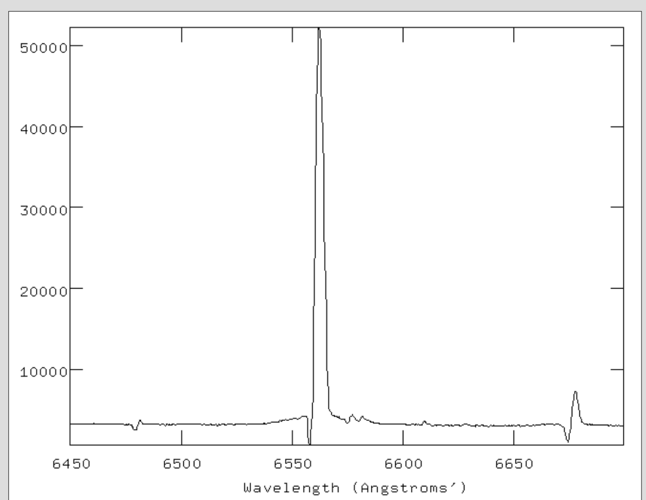
(Burggraf 2005)



(Hubble & Sandage 1953)

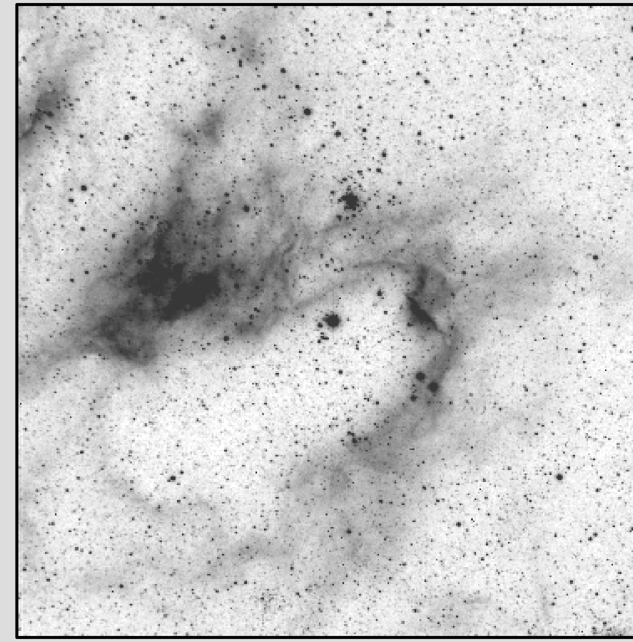
P Cyg type star



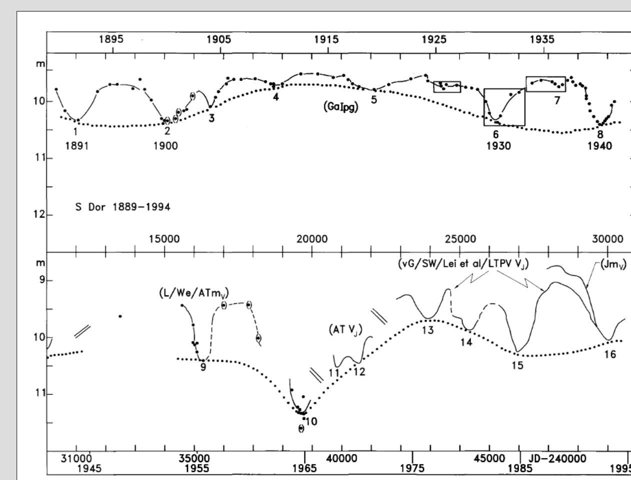


(Weis 1999)

S Dor Variables



(Weis 2003)



(van Genderen 1997)

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Defining a Luminous Blue Variable

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

Conti 1984

↓

LBV = Hubble-Sandage Variables + P Cygni-typ stars + S Dor Variables

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Conti 1984

LBV = Hubble-Sandage Variables + P Cygni-typ stars + S Dor Variables

...13 years later ...

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The terminology has stuck and it is now appropriate, given the occasion of this very energetic Workshop, to ask whether or not revisions or a redefinition might be in order. First of all, I think most of us would agree that the term "variable" really means, within the context of the LBV phenomena, an "outburst" (but I do not propose changing LBV to LBO, especially since the latter already has significance within the financial field). It also appears clear that outbursts are either "major" or "minor". The former has occurred to only three stars so far as the historical record is concerned: η Car, P Cyg and SN 1961v.

Conti 1997

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Defining a Luminous Blue Variable

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Conti 1997

Defining a Luminous Blue Variable by Variability

Photometric Variability

"minor outburst"

"major outburst"

- **minor fractions of magnitudes,**
  on timescales of days and weeks

many magnitudes,
more or less instantly

- **fractions to a few magnitudes**
  on timescales of several years

Defining a Luminous Blue Variable by Variability

Photometric Variability

"minor outburst"

- **minor fractions of magnitudes,** on timescales of days and weeks

micro-variations

seen in LBVs and many other massive stars

- **fractions to a few magnitudes** on timescales of several years

LBV in eruption
↕
S Dor Cyclus

→ stars changes T_{eff} and **Radius**

"major outburst"

many magnitudes, more or less instantly

LBV with a giant eruption

→ stars **instable,** in the HRD close to de Jager-/ Humphreys-Davidson-/ Eddington- / ΩΓ -limit*

SN imposter

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*** pick whatever is you favorite ☺**

Defining a Luminous Blue Variable by Variability

minor outburst (Conti 1997)

↕

small scale variation

micro-variations

LBV in eruption ↔ S Dor cycle

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Microvariations of Luminous Blue Variables

- typical amplitudes are 0.1-0.5^{mag}
  typical timescales few days to several weeks

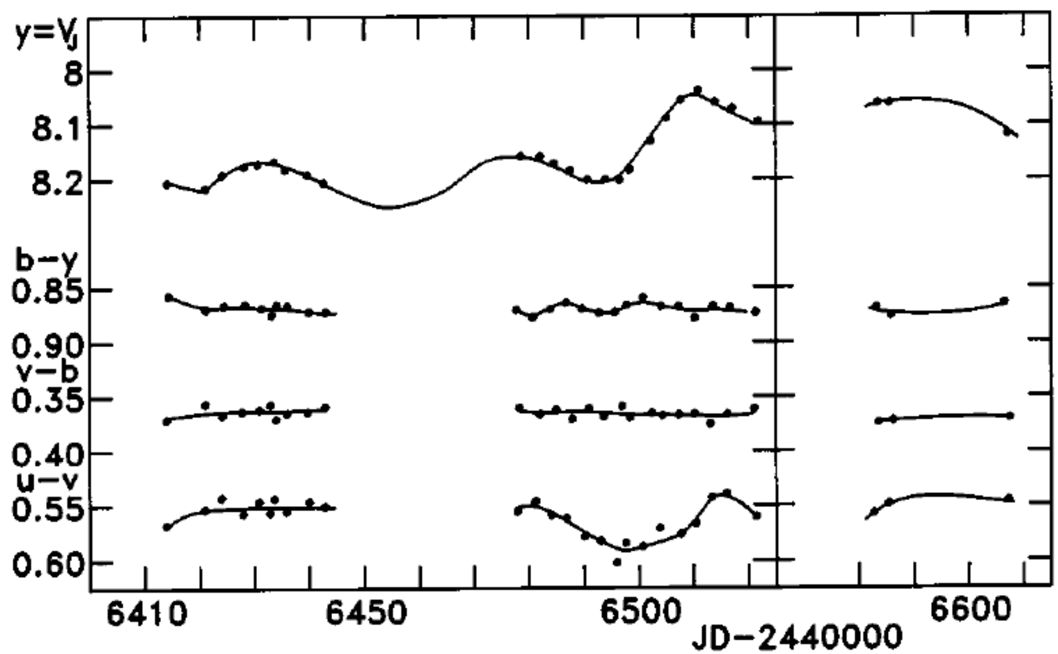

Fig. 2. Detailed light and colour curves of the ~ 40 d micro variations in the hump of the descending branch of HR Car's normal SD phase (with a maximum at JD 2446250). Note that the magnitude scales for the colour curves are twice that for the light curve

example of **micro-variations** in the lightcurve of the LBV **HR Carinae**

(van Genderen et al.1997)

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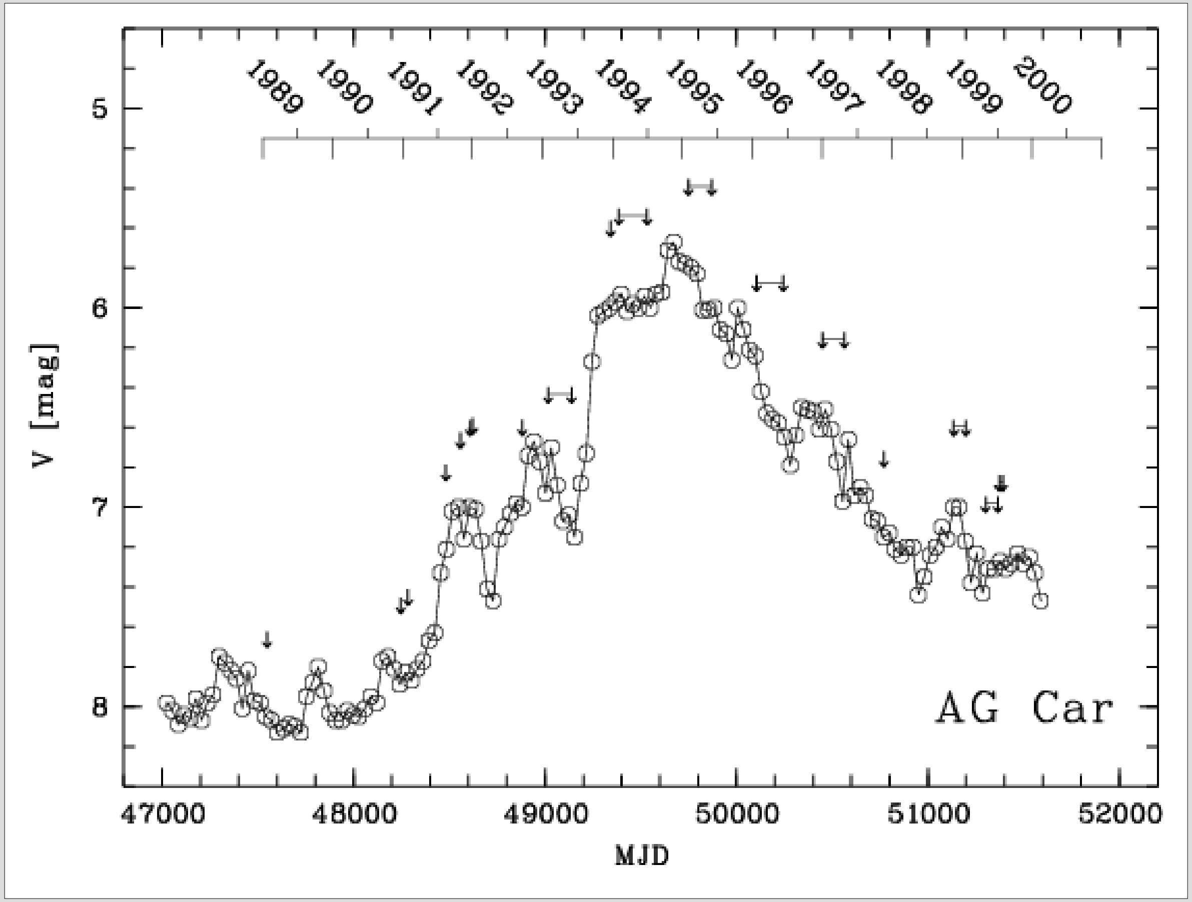
Defining a LBV – minor outburst ↔ S Dor cycle

photometric variability

S Dor Cycle



(Stahl et al. 2001)

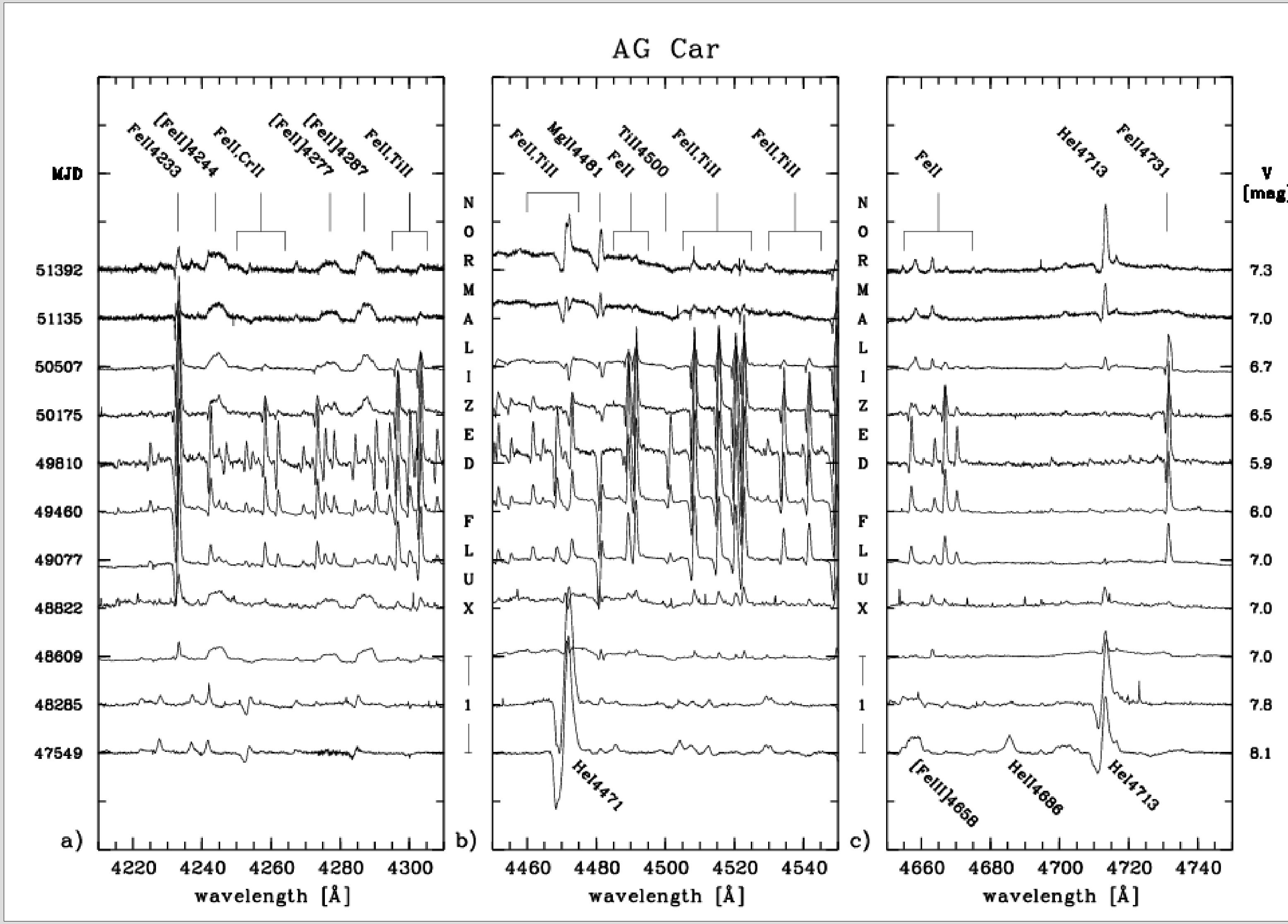
Defining a LBV – minor outburst ↔ S Dor cycle

spectral variability

S Dor Cycle

2000

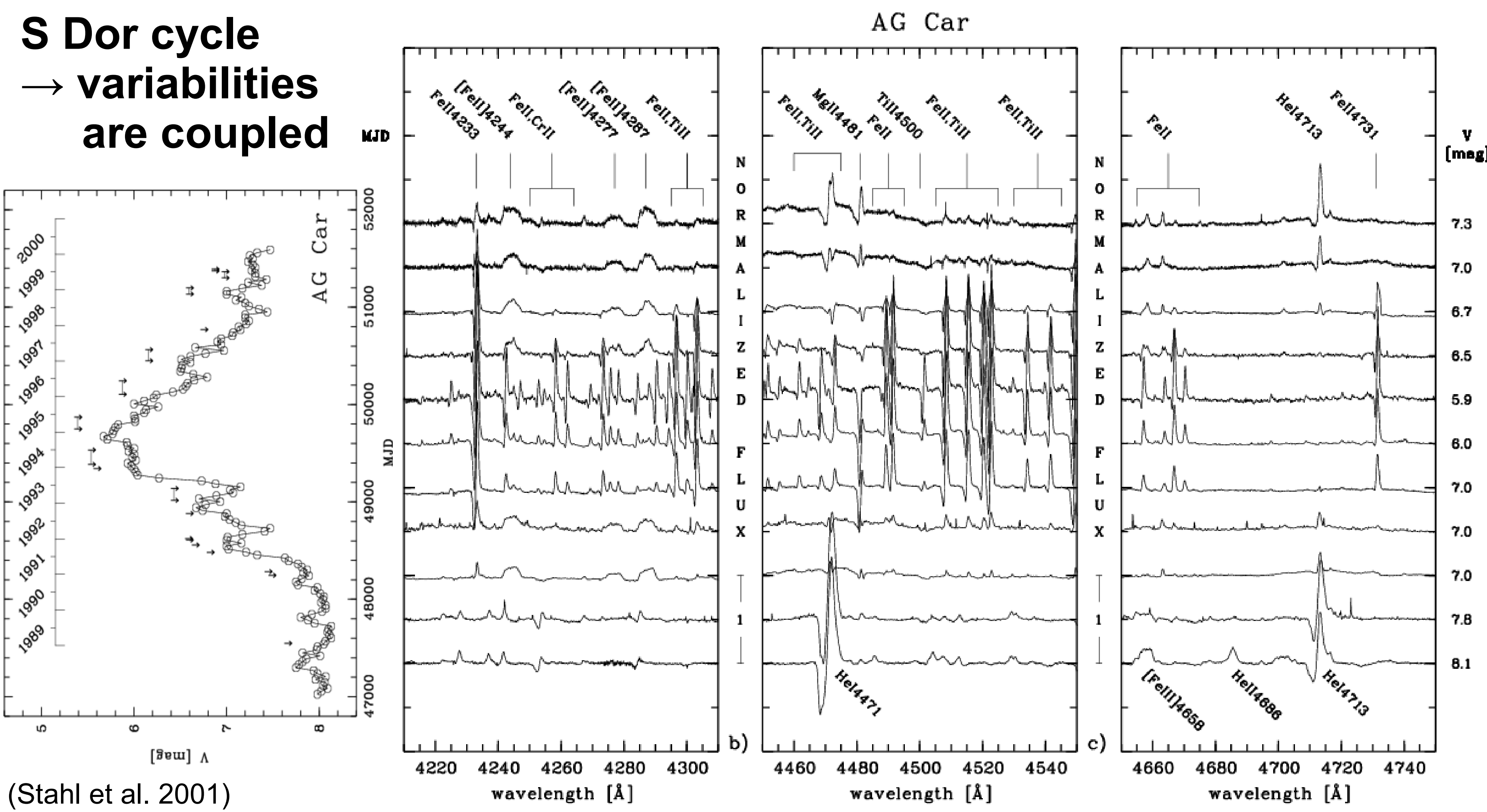
1989



(Stahl et al. 2001)

Defining a LBV – minor outburst ↔ S Dor cycle

S Dor cycle
→ variabilities are coupled



(Stahl et al. 2001)

T_{eff} changes ↔ spectrum changes ↔ flux in filter band changes

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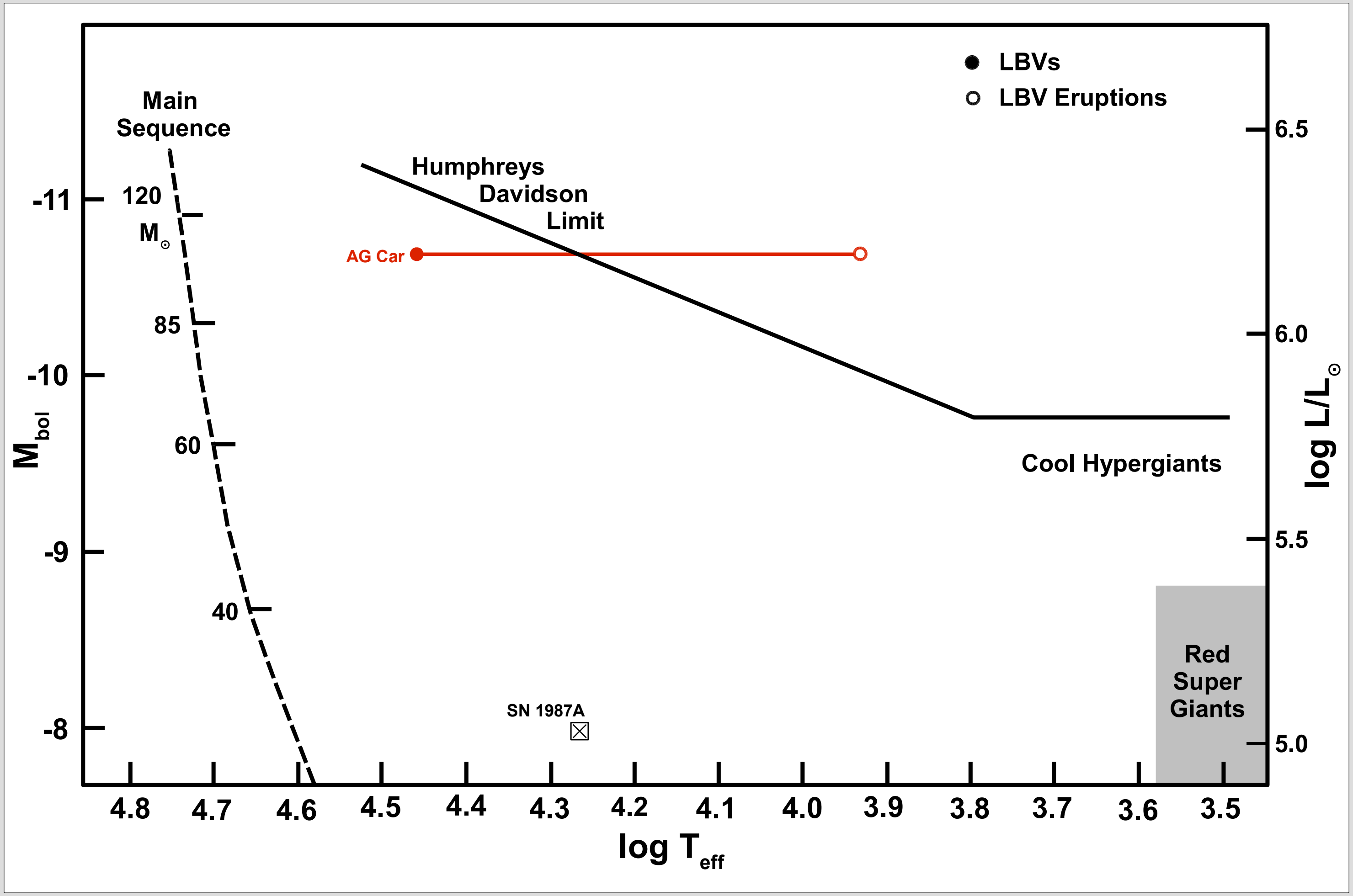
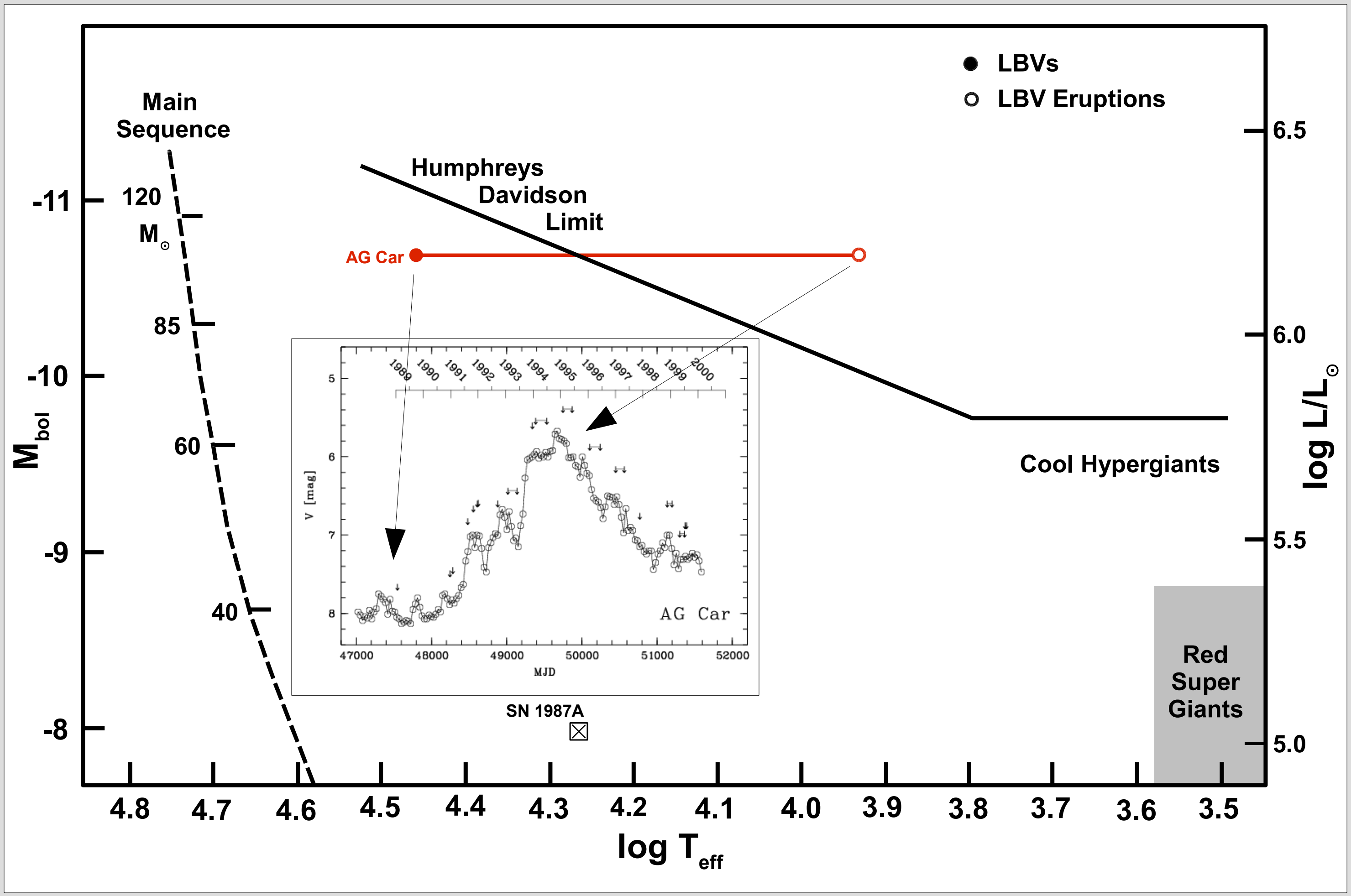
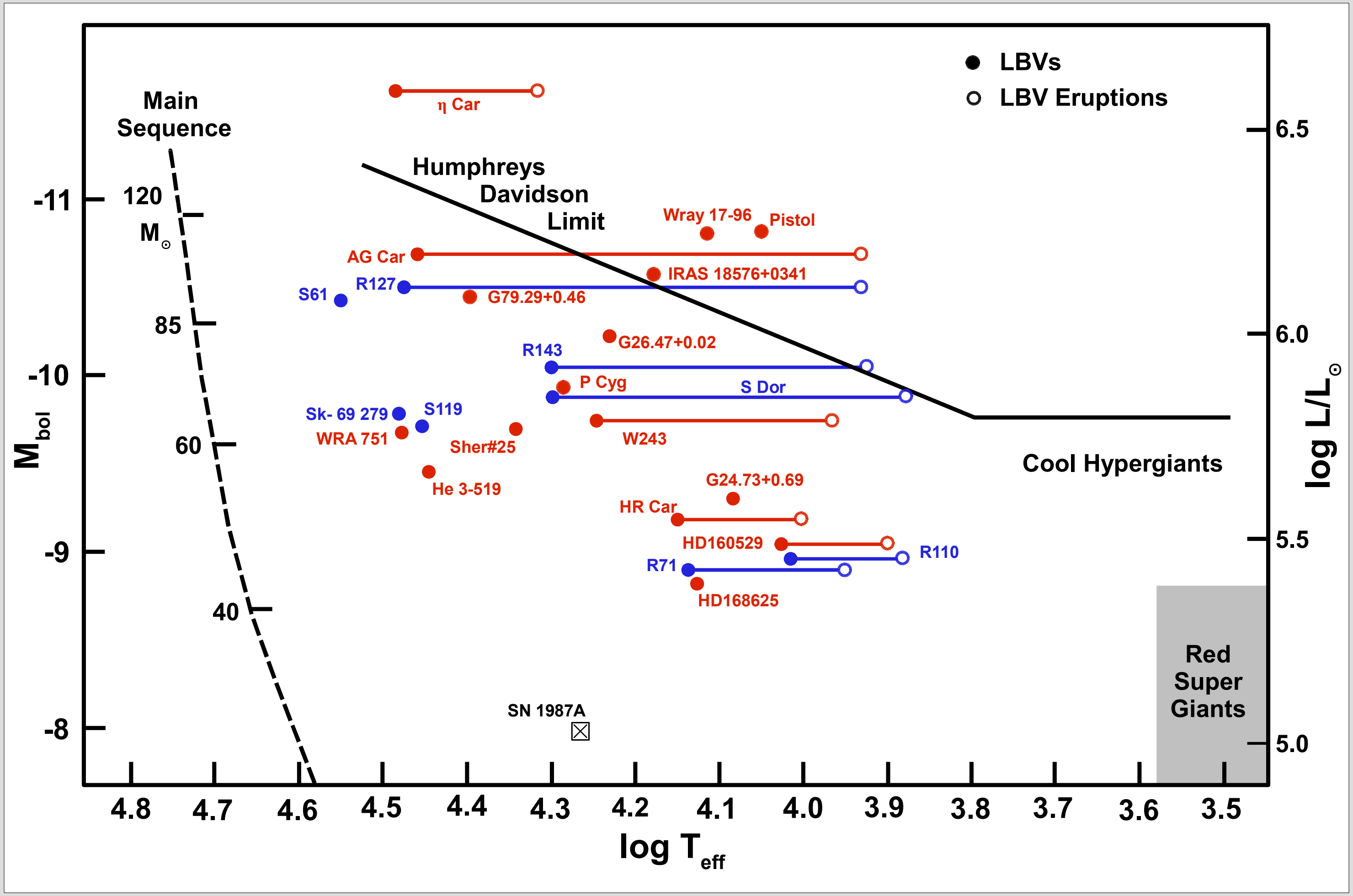
Defining a LBV – minor outburst ↔ S Dor cycle



Defining a LBV – minor outburst ↔ S Dor cycle



Defining a LBV – minor outburst ↔ S Dor cycle



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Classification of various S Dor subtypes

I. By the stars activity

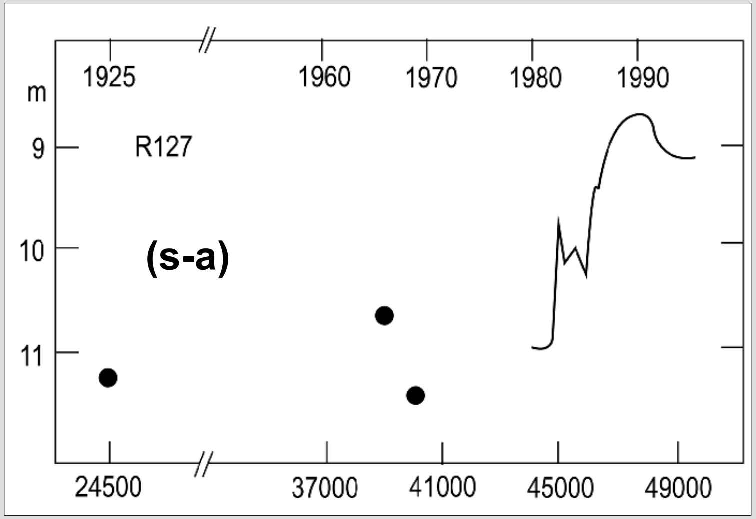
strong-active (s-a)
light amplitudes > 0.5 ^{mag}
e.g.: AG Car, HR Car, HD 160529, WRA 751, R127,
S Dor, R71, R110, R143...

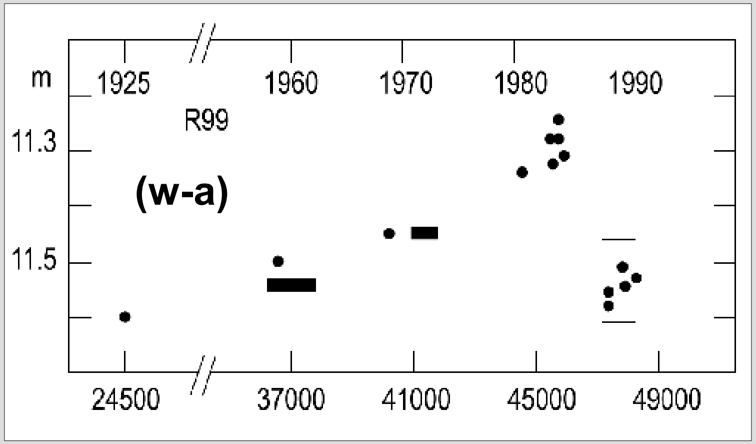
weak-active (w-a)
light amplitudes < 0.5 ^{mag}
e.g.: η Car, P Cyg, HD 168607, CygOB2#12, R99,
R123, R74, R81, R149...

ex- and dormant (ex/dormant)
no variations detected in the 21st century (given the data present)

candidate
divided into
- positive (+)
- negative (-)
- non-candidates (0)

less to no evidence





(van Genderen 2001)

Classification of various S Dor subtypes

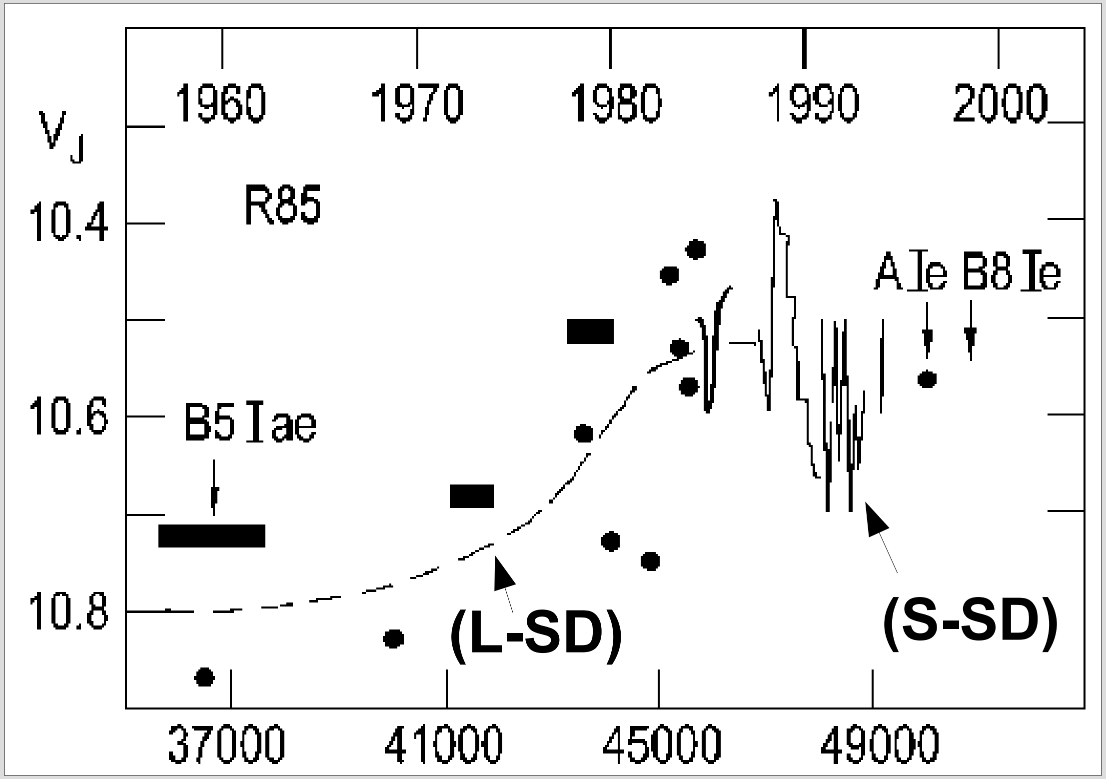
II. By timescale

short-S Dor (S-SD)
S Dor cycle shorter as 10 yr

long-S Dor (L-SD)
S Dor cycle longer as 20 yr

it also exists a
very-long-term-S Dor (VLT-SD)
S Dor cycle 20-50 yrs
→ now in L-SD

see poster by Burggraf et al.
on Var C in M33



(van Genderen 2001)

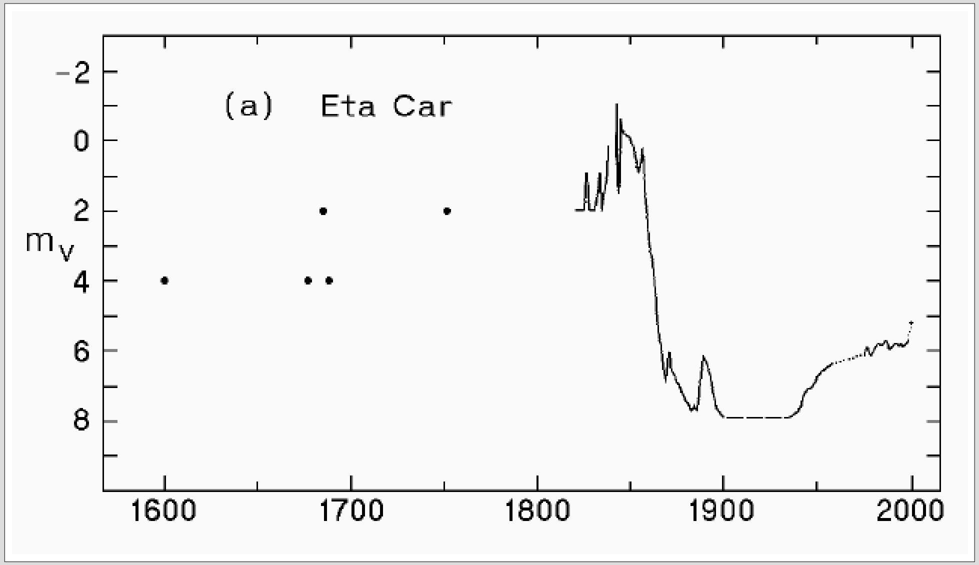
Is the S Dor cycle and its timescales different for different metalicities ?

Maybe !
see talk/poster Bomans et al. on transients at very low Z

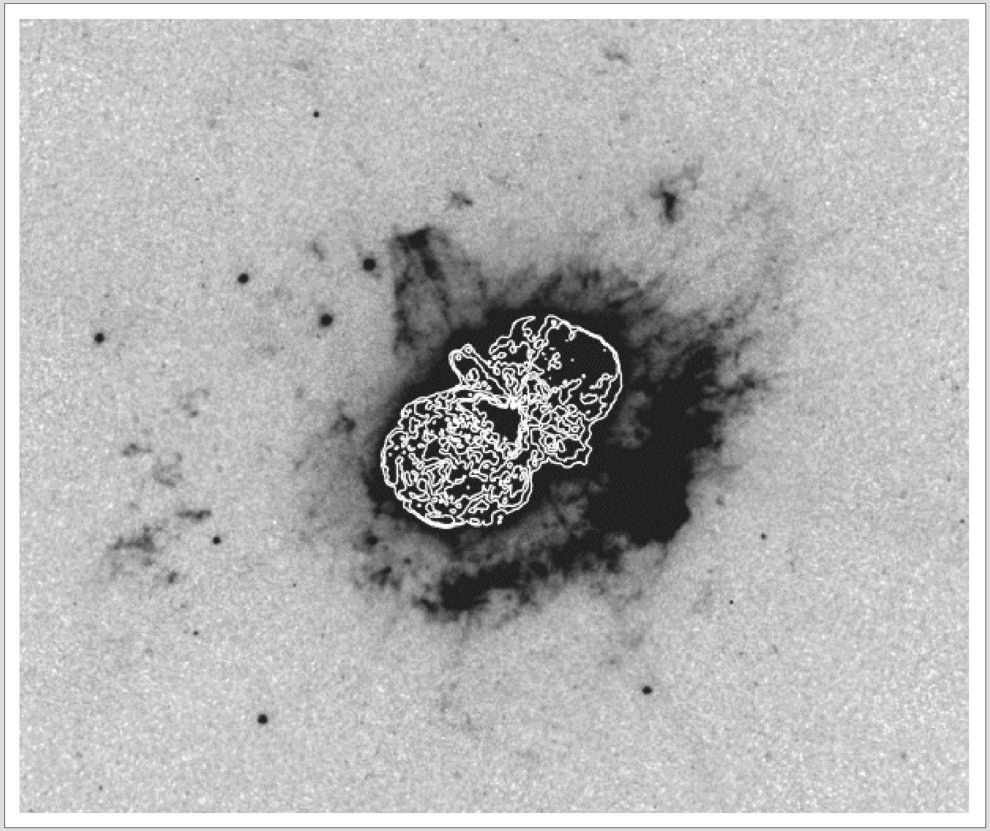
Security advise !

Security advise !
Don't leave your LBV unattended !

Security advise !
Don't leave your LBV unattended !



(Humphreys et al. 1999)



(Weis et al. 2001)

giant eruption

Defining a Luminous Blue Variable by Variability

major outburst

(Conti 1997)

$\updownarrow$

LBV giant eruption

$\updownarrow$

η **Car variables**

$\updownarrow$

SN imposters

Defining a Luminous Blue Variable by Variability

major outburst

(Conti 1997)

↕

LBV giant eruption

↕

η Car variables

↕

SN imposters

η Carinae

P Cygni

SN 1961V

SN 1954J

(Humphreys 1999)

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Defining a Luminous Blue Variable by Variability

Warning !!!

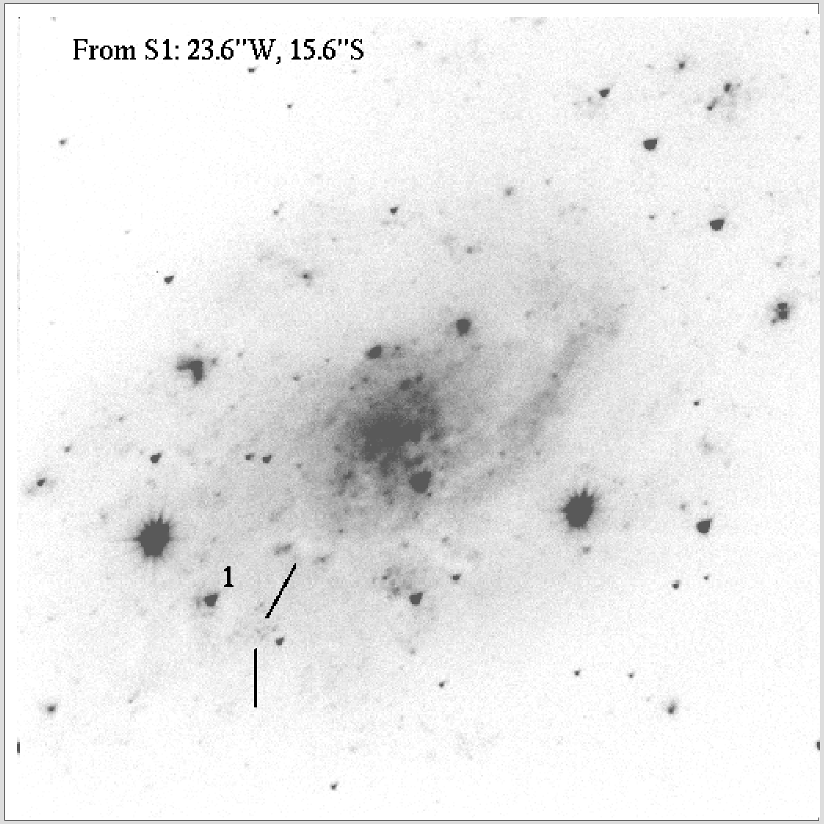
What looks like giant eruption may not always be one !

The case of SN 2002kg

SN2002kg is was detected in NGC2403

“The object was at mag 19 +/- 0.3,
and possibly showed a brightening trend,
from **2002 Oct. 26** to 2003 Jan. 1.”

Schwartz et al. ,IAUCircular No. 8051



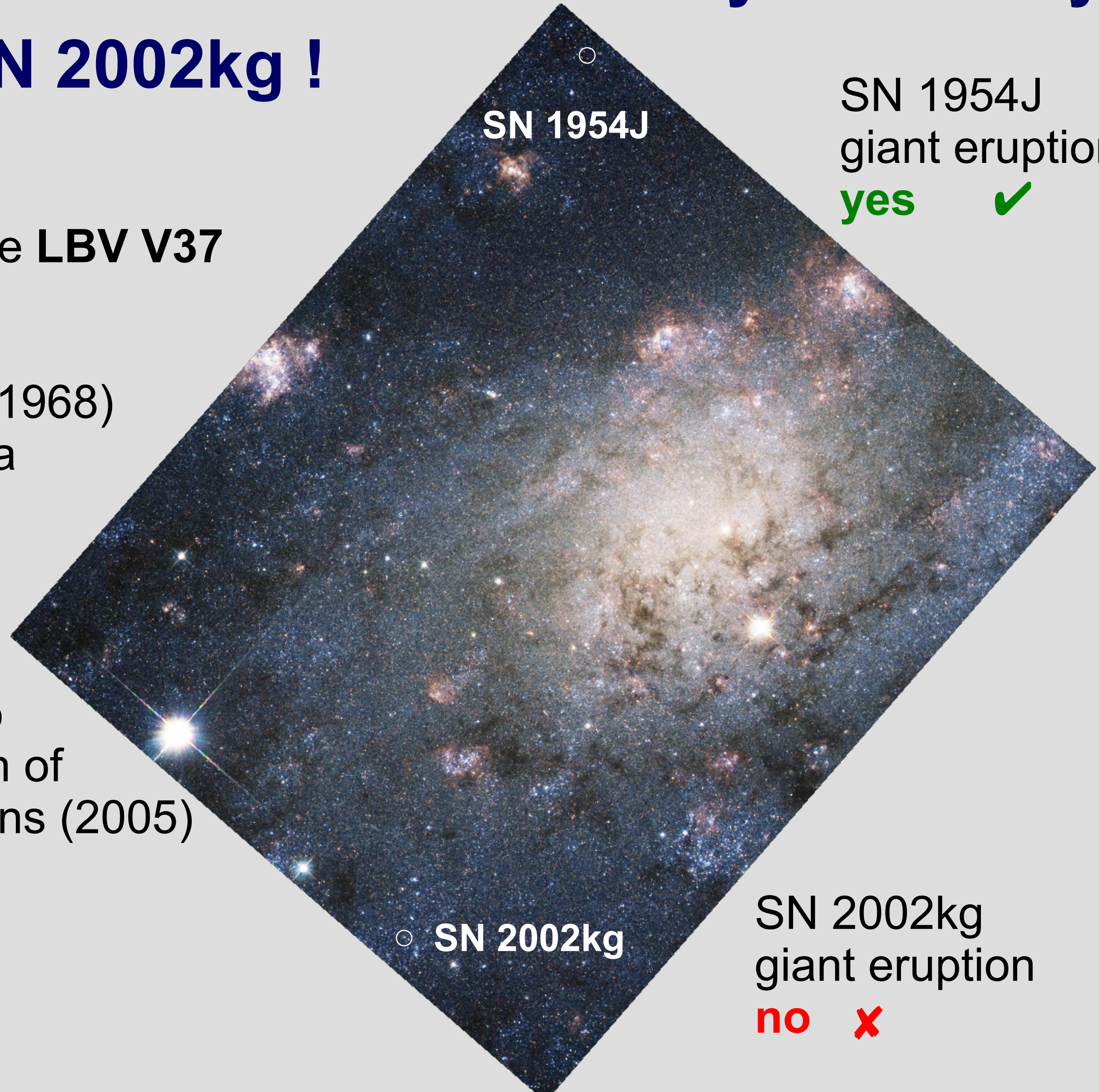
Defining a Luminous Blue Variable by Variability

The case of SN 2002kg !

SN 2002kg
= the brightening of the **LBV V37** in NGC 2403

Tamman & Sandage (1968) first identified V37 as a blue irregular variable star ↔ fitting to LBV

SN 2002kg is found to agree with the position of V 37 by Weis & Bomans (2005) and Van Dyk (2005)



SN 1954J
giant eruption
yes ✔

SN 2002kg
giant eruption
no ✘

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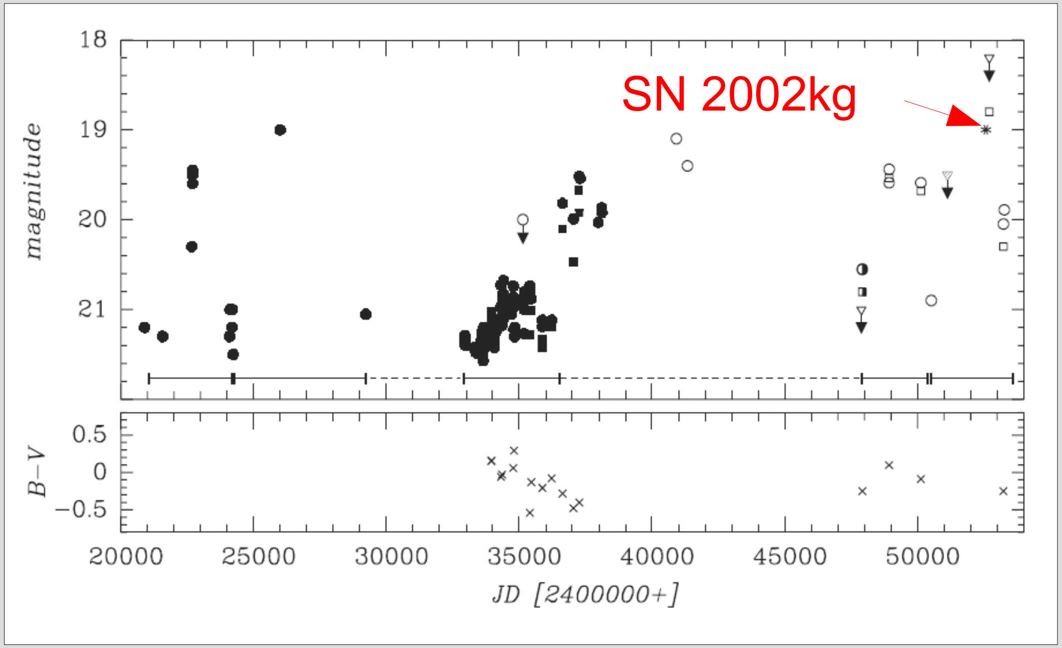
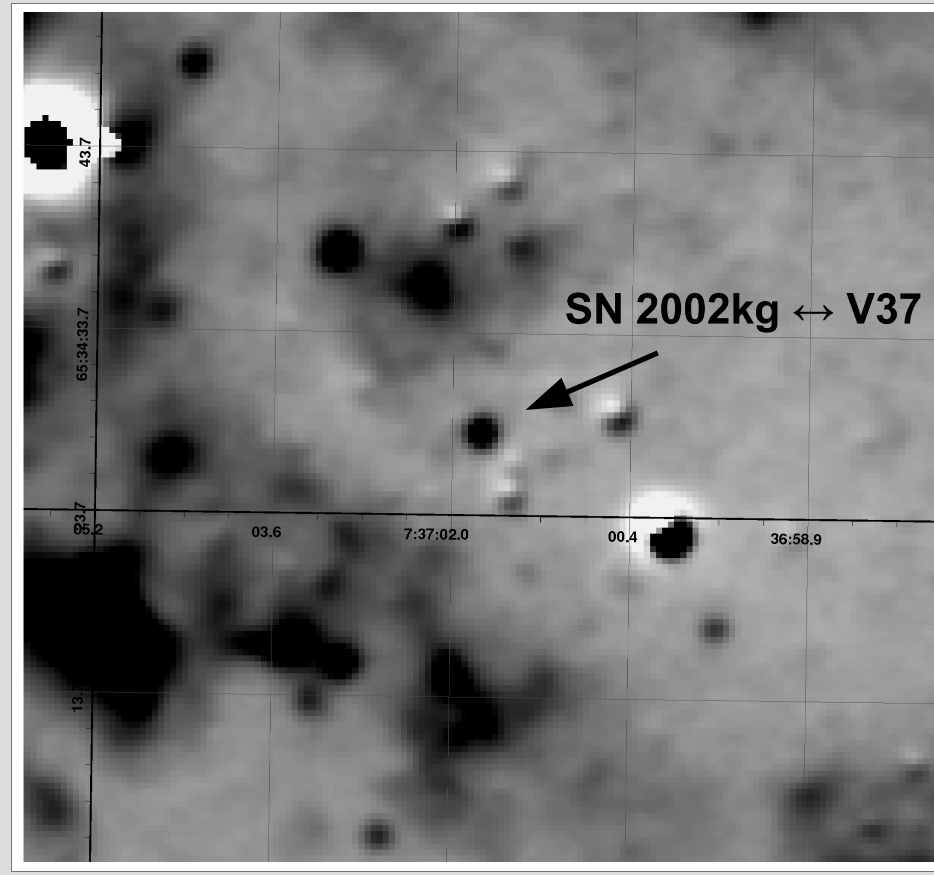
The LBV eruption of V37 ↔ SN2002kg



Lightcurve of V37 with the SN 2002kg detection → the star brightend but it was **neither a giant eruption nor a classical S Dor cycle**



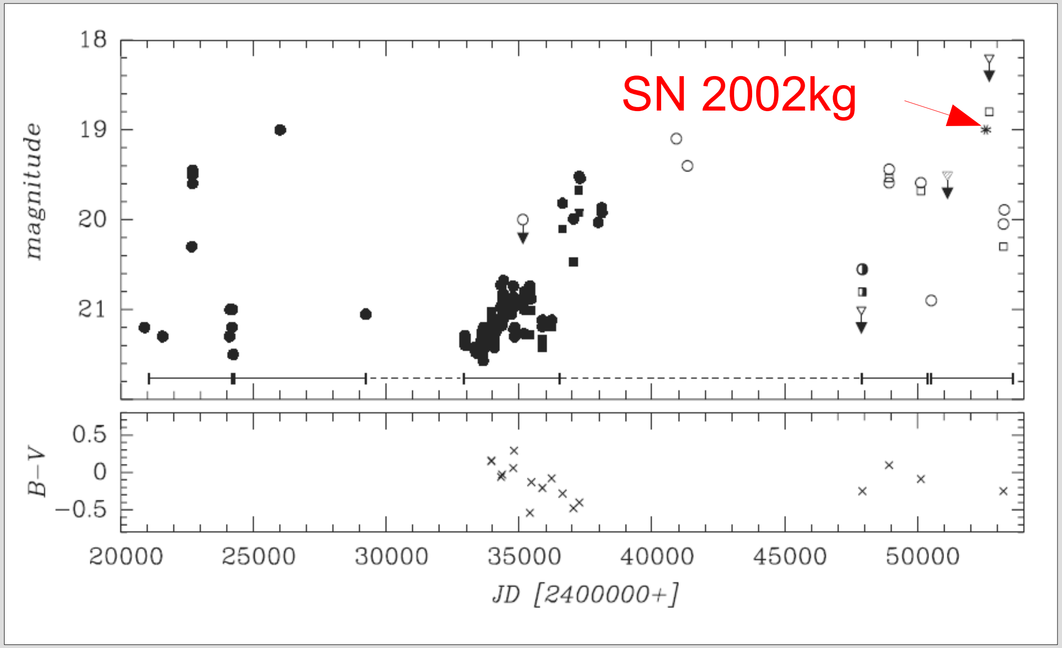
H_α image of the area and V37 taken before the SN 2002kg. Here V37 is found in bright H_α emission.

→ strong **emission line star**

→ indications for a **nebula**

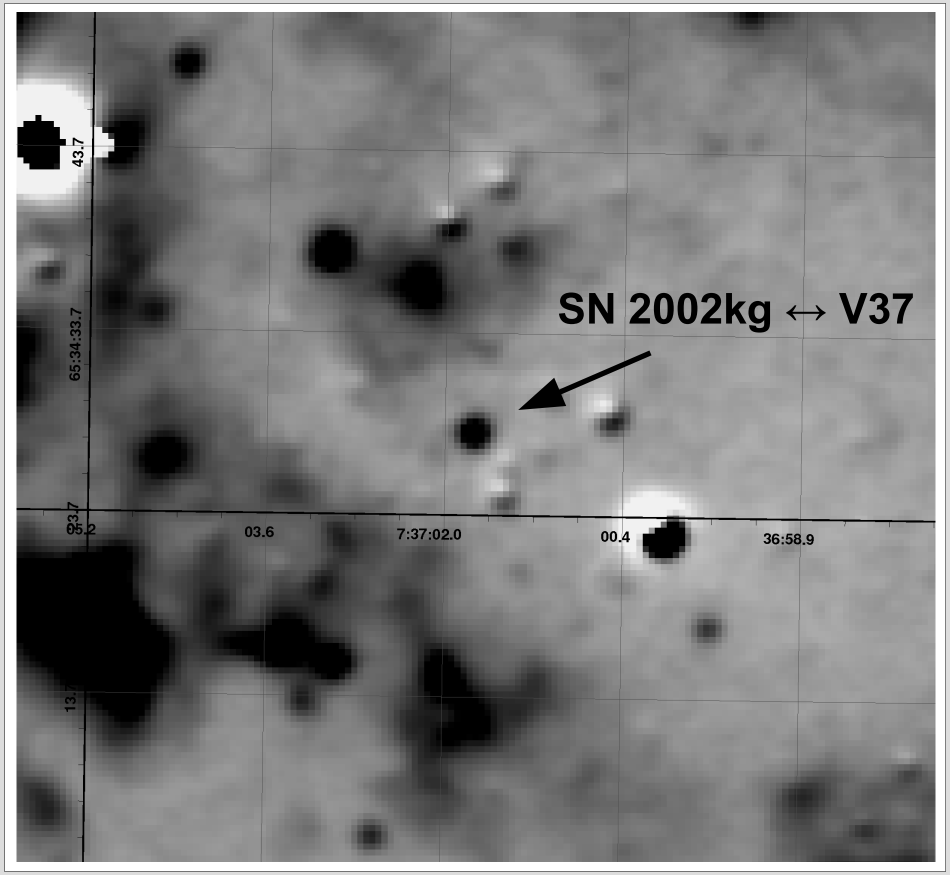
(Weis & Bomans 2005)

The LBV eruption of V37 ↔ SN2002kg



Lightcurve of V37 with the SN 2002kg detection → the star brightend but it was **neither a giant eruption nor a classical S Dor cycle**

Is V37 a giant eruption imposter ?



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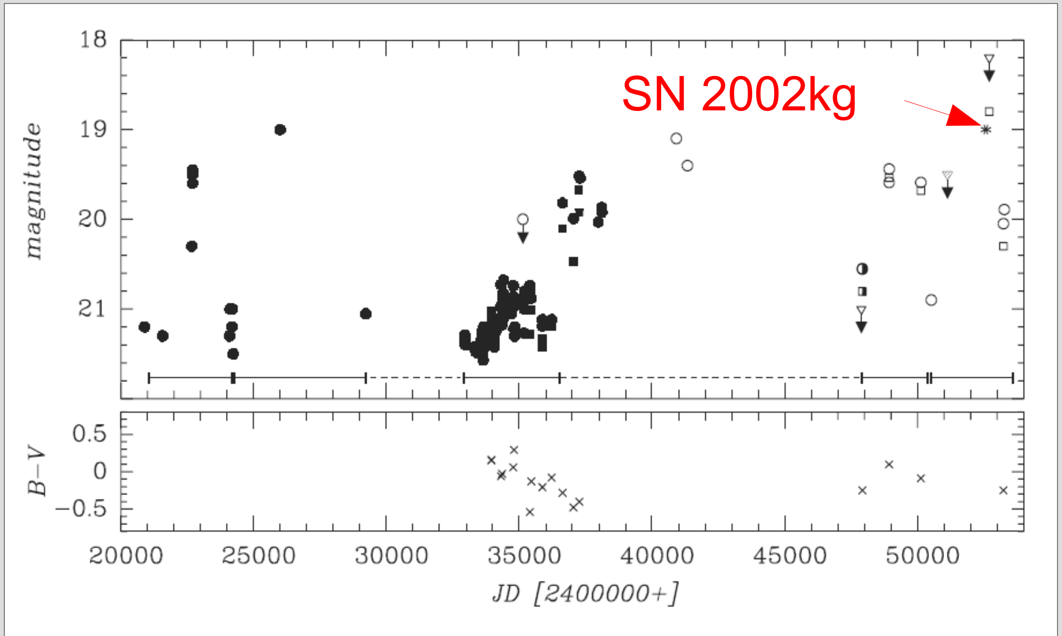
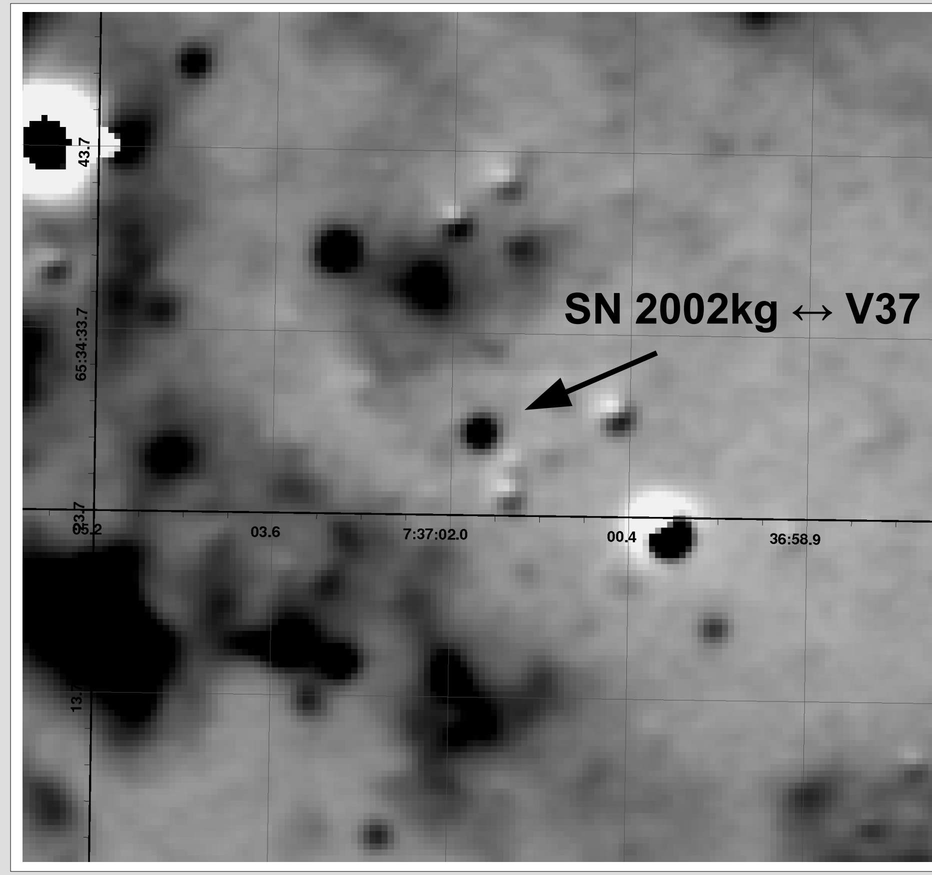


Lightcurve of V37 with the SN 2002kg detection → the star brightend but it was **neither a giant eruption nor a classical S Dor cycle**

Is V37 a giant eruption imposter ?
...No not again a new acronym...

(Weis & Bomans 2005)



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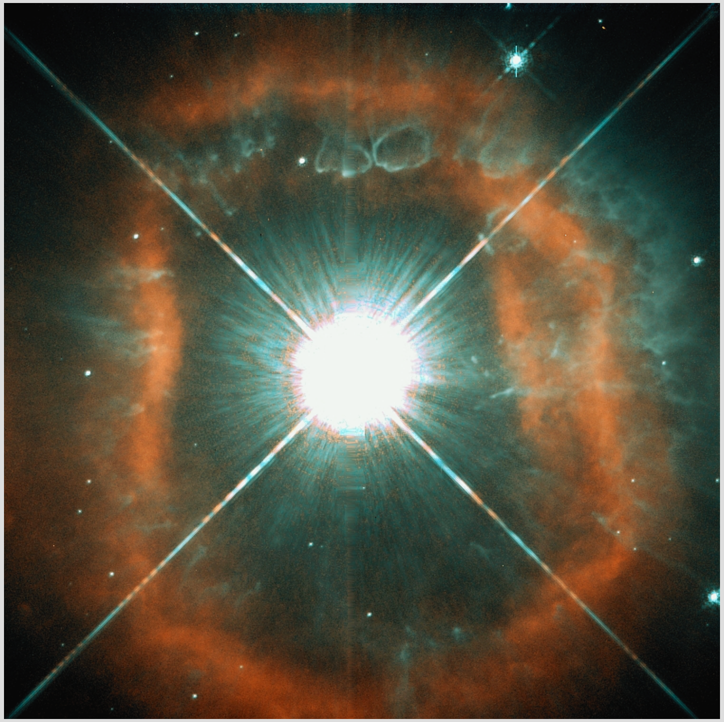
→ strong **emission line star**

→ indications for a **nebula**

LBVs – The nebula basics

Variable stellare winds and giant eruptions
→ ideal conditions to creat **circumstellar nebulae**

- strong N lines ↔ CNO processed material

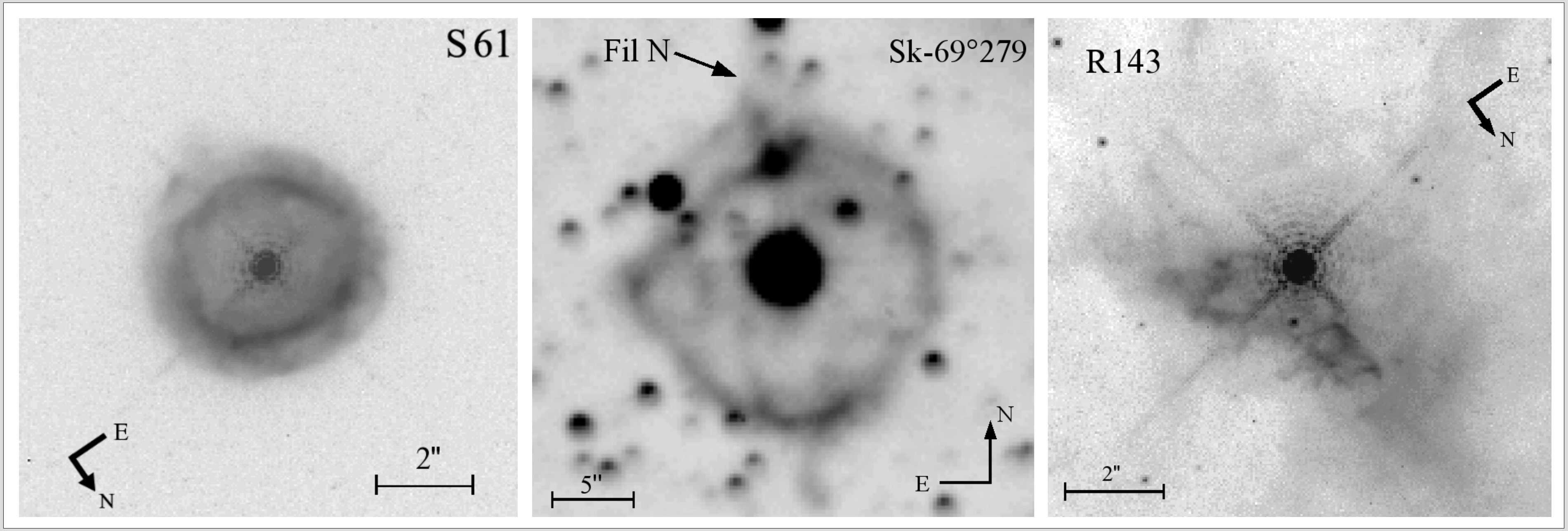


(Weis 2009)

Morphology of LBV nebulae

Morphology

- several are quite spherical (e.g. S 61)
- a few do show outflows or convexity (e.g. Sk -69° 279)
- rarely irregular (best example R 143)

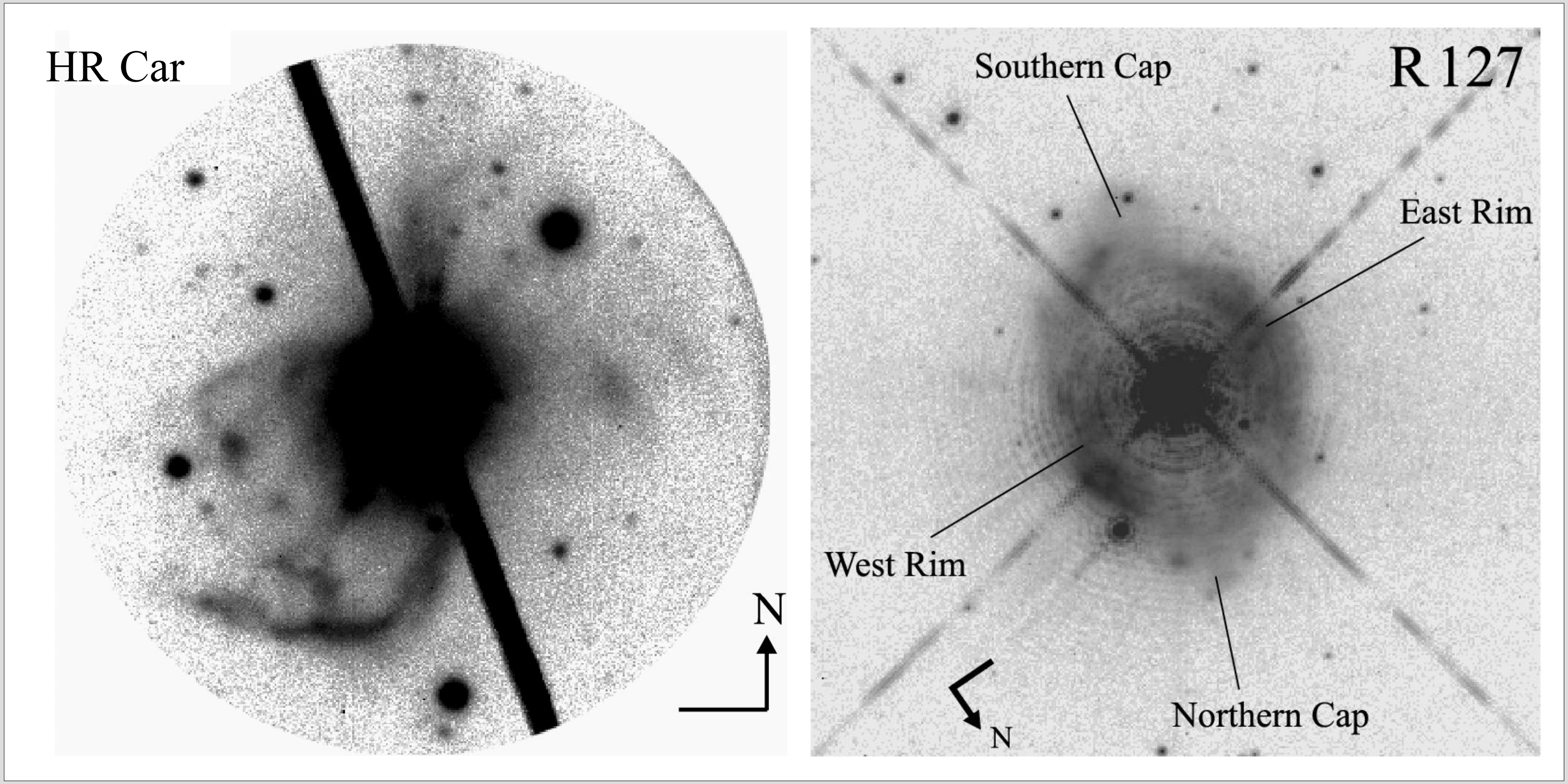


(Weis & Duschl 2002, Weis 2003)

Morphology of LBV nebulae

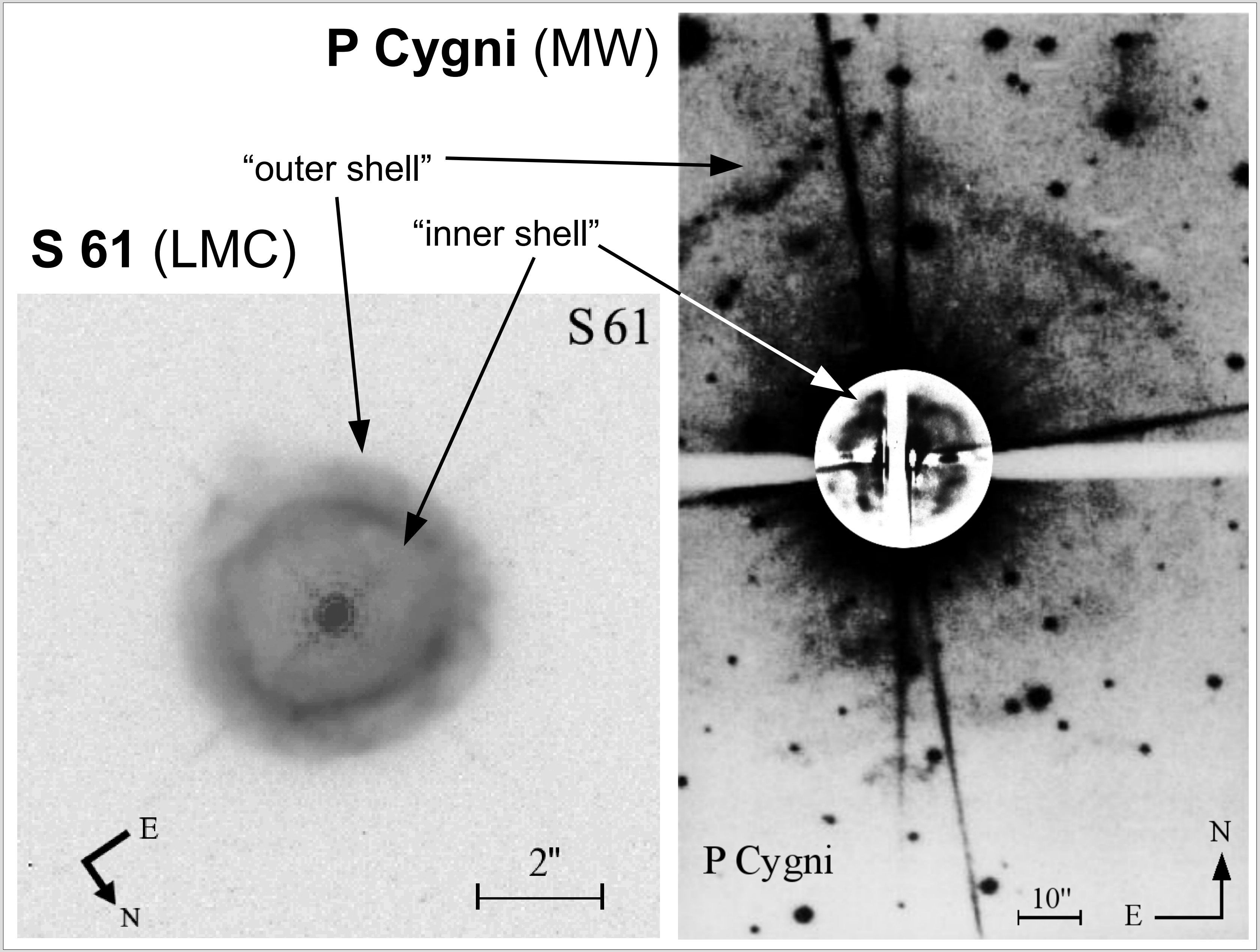
Morphology

- a quite large number are **bipolar**
  → either like **hourglass** shaped nebulae (e.g. η Car, HR Car)
  → or as bipolar attachments → **caps** (e.g. WRA 751, R 127)



(Weis et al. 1997 & Weis 2003)

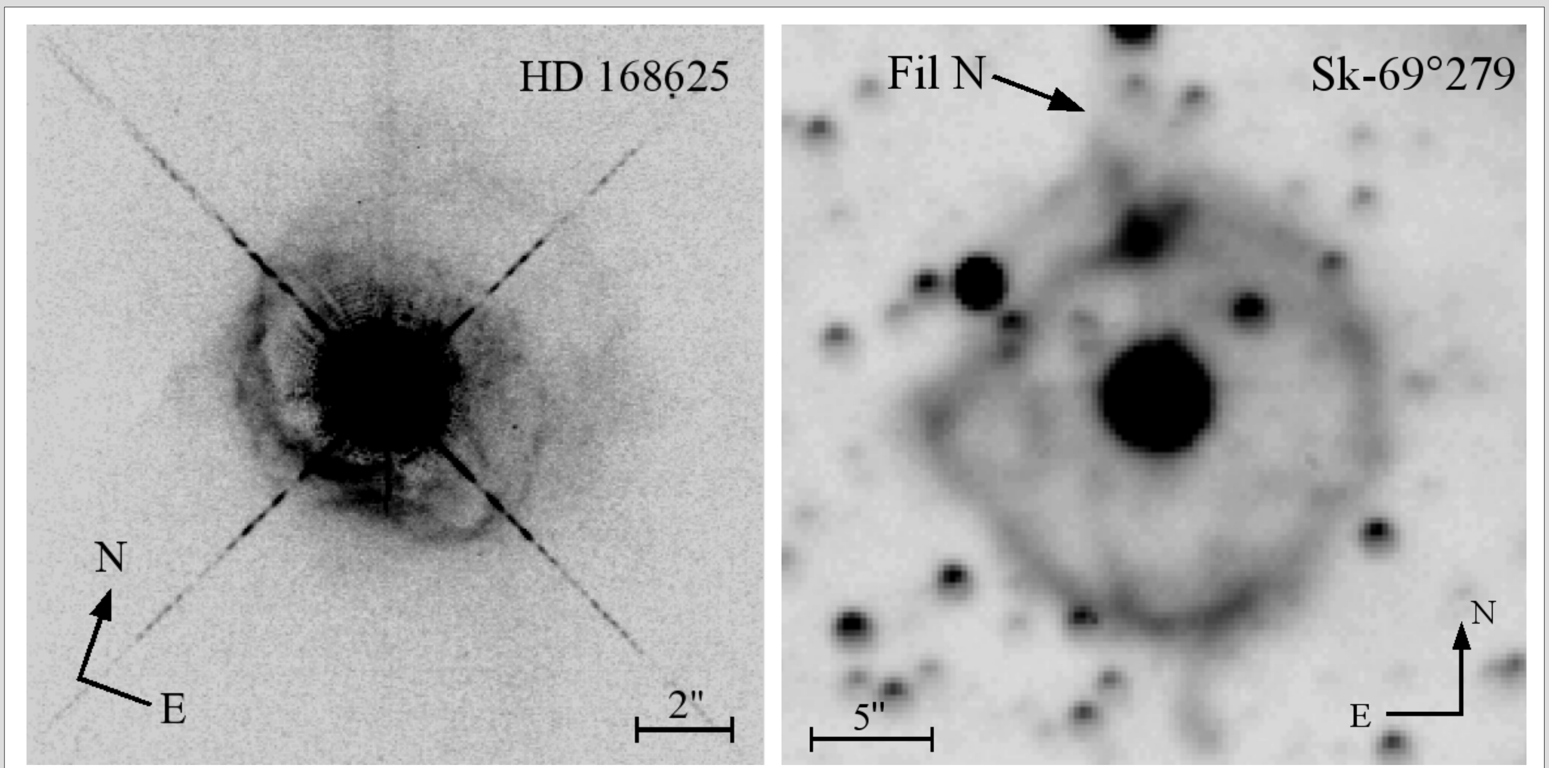
Multi-shell nebulae – several phases ?



Sizes of LBV nebulae

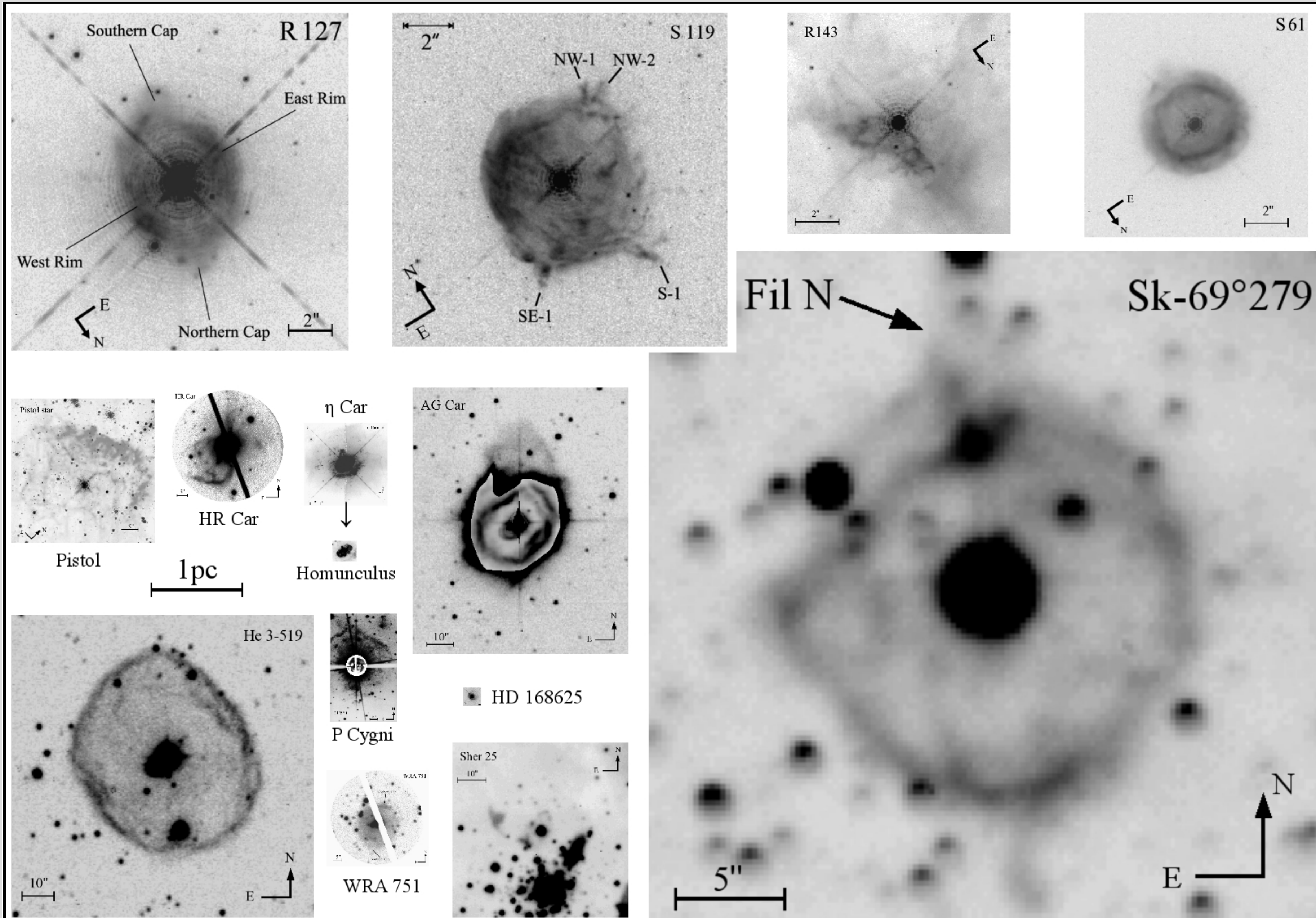
Sizes

- the **smallest** are the Homunculus and HD168625 both Ø ~ **0.2 pc**
- the **largest** is Sk -69° 279 with Ø ~ **4.5 pc** or 6.2 pc (with Fil N)
- the **majority** has a size between **1-2 pc**
- the **LMC** nebulae are **larger** compared to the **Galactic**



(Weis 2009, Weis & Duschl 2002)

LBV nebulae – on scale !



(Weis 2009)

Kinematics of LBV nebulae

Expansion velocities

- the slowest is Sk -69°279 with **14 km/s**
- the fastest is η Carinae with up to at least $\geq$ **3200 km/s**
- the average is around **50 km/s**
- **LMC LBVs** have in general a **slower** expansion velocity

Outflows

- some have **outflows** that move **faster** (e.g. S 119)

Bipolarity

- is detected **kinematically**
  - either as two expansion ellipses (e.g. AG Car)
  - or the bipolar expansion of the attached caps (e.g. WRA 751)

LBV nebulae in numbers

LBV	host galaxy	maximum size [pc]	radius [pc]	v_{exp} [km/s]	kinematic age [10^3 yrs]	morphology
η Carinae	Milky Way	0.2/0.67	0.05/0.335	$300^*/10-3200$		bipolar
AG Carinae	Milky Way	1.4×2	0.4	$\sim25^*$	~30	bipolar
HD 168625	Milky Way	0.13×0.17	0.075	30	1.8	bipolar ?
He 3-519	Milky Way	2.1	1.05	61	16.8	spherical/elliptical
HR Carinae	Milky Way	0.65×1.3	0.325	75^*	4.2	bipolar
P Cygni	Milky Way	0.2/0.84	0.1/0.42	$110-140/185$	0.7/2.1	spherical
Pistol Star	Milky Way	0.8×1.2	0.5	60	8.2	spherical
Sher 25	Milky Way	0.4×1	0.2×0.5	$30-70$	$6.5-6.9$	bipolar
WRA 751	Milky Way	0.5	0.25	26	9.4	bipolar
R 71	LMC	<0.1?	<0.05?	20	2.5 ?	?
R 84	LMC	<0.3 ?	<0.15?	24 (split)	6 ?	?
R 127	LMC	1.3	0.77	32	23.5	bipolar
R 143	LMC	1.2	0.6	24 (split)	49	irregular
S Dor	LMC	<0.25?	<0.13?	<40 (FWHM)	3.2 ?	?
S 61	LMC	0.82	0.41	27	15	spherical
S 119	LMC	1.8	0.9	26	33.9	spherical/outflow
Sk $-69°$ 279	LMC	4.5×6.2	2.25	14	157	spherical/outflow

* expansion velocity per lobe

JUST OUT

Weis 2012 in *Eta Car and the Supernova Impostors* A&A library (eds. Davidson & Humphreys)

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The case of bipolarity

LBV	host galaxy	maximum size [pc]	radius [pc]	v_{exp} [km/s]	kinematic age [10^3 yrs]	morphology
η Carinae	Milky Way	0.2/0.67	0.05/0.335	300*/10 – 3200		bipolar
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R 71	LMC	< 0.1?	< 0.05?	20	2.5 ?	?
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R 127	LMC	1.3	0.77	32	23.5	bipolar
R 143	LMC	1.2	0.6	24 (split)	49	irregular
S Dor	LMC	< 0.25?	<0.13?	< 40 (FWHM)	3.2 ?	?
S 61	LMC	0.82	0.41	27	15	spherical
S 119	LMC	1.8	0.9	26	33.9	spherical/outflow
Sk $-69°$ 279	LMC	4.5×6.2	2.25	14	157	spherical/outflow

* expansion velocity per lobe

JUST OUT

Weis 2012 in *Eta Car and the Supernova Impostors* A&A library (eds. Davidson & Humphreys)

About **50 %** of the **all LBV nebulae** show signs of **bipolarity**!
Taking only the **galactic LBVs** the **fraction** is about **70%**.
Hints for **stellar rotation** ? Hints for a **metalicity** effect ?

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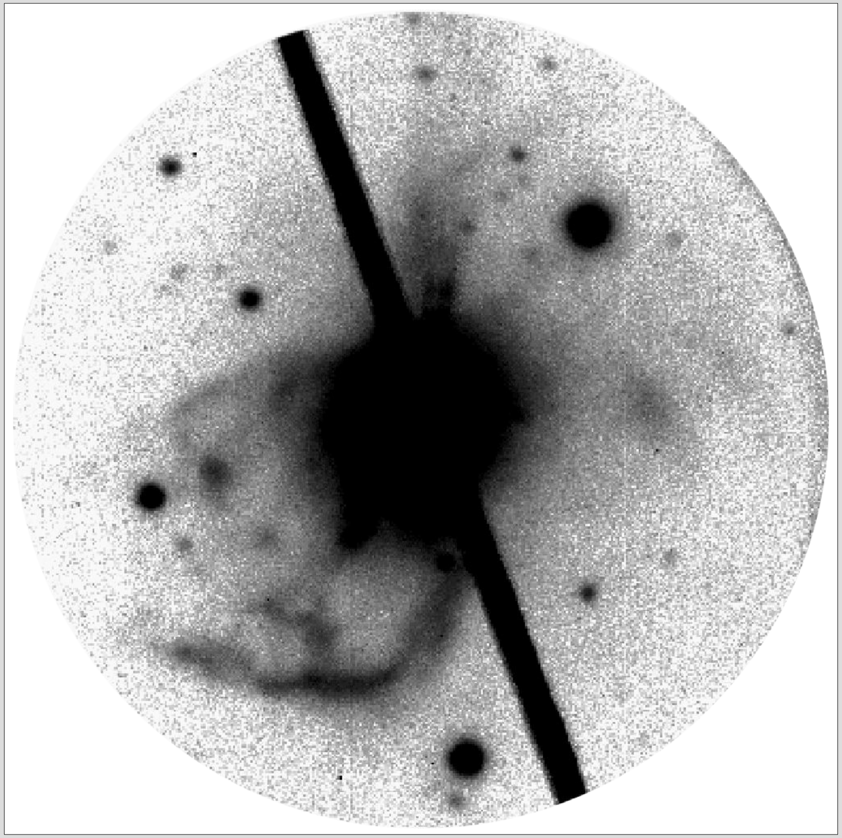
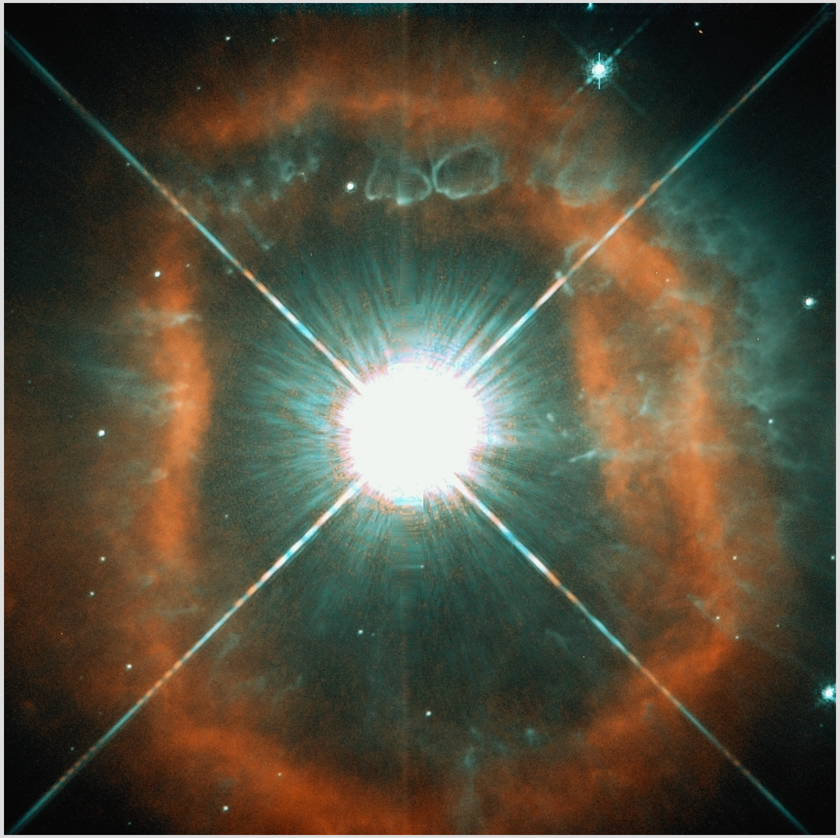
The cause of bipolarity → Rotation ?

HR Car



(Weis et al. 1997)

AG Car



(Weis 2009)

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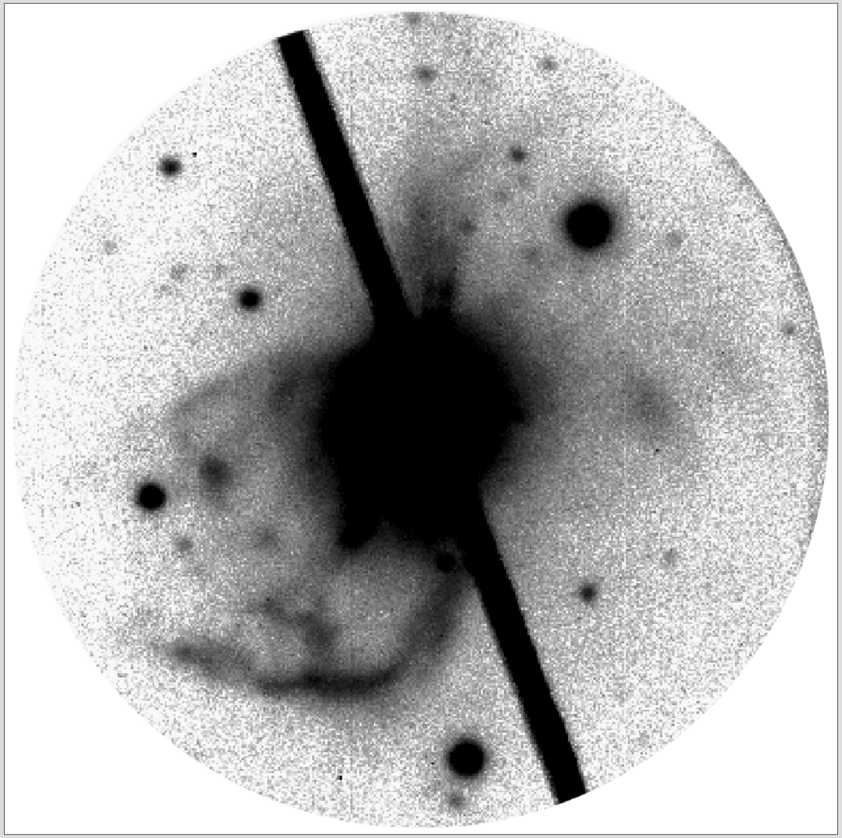
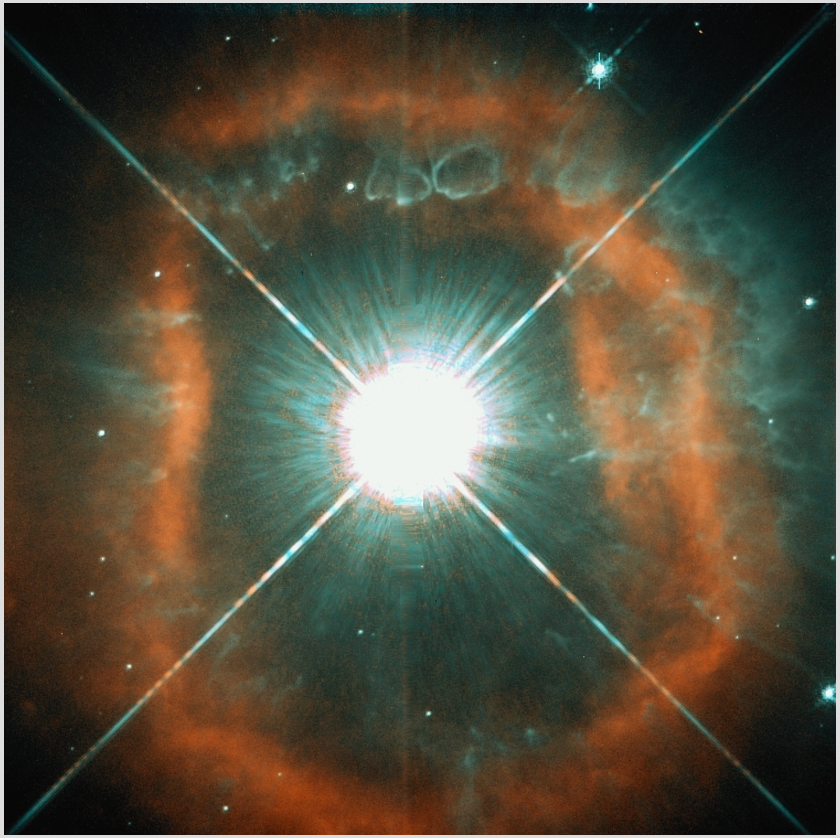
The cause of bipolarity → Rotation ?

HR Car



(Weis et al. 1997)

AG Car



(Weis 2009)

v sin i = 150 km/s

v sin i = 85-190 km/s

both are fast rotating stars !

☺

velocities from Groh et al. 2006, 2009

What we know and learn from LBV nebulae

LBV nebulae facts

- morphologies are **spherical**, **elliptical** to **irregular**
- a **large fraction** (50-75%) shows **bipolarity**
- **LMC** nebulae are generally **larger** as those in the **Milky Way**
- expansion velocities range typically between **10-150 km/s** with the exception of η **Carinae ($\geq$ 3200 km/s)**
- **LMC** nebulae are generally **slower** as those in the **Milky Way**
- some LBV nebulae show **multiple shells**

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What we know and learn from LBV nebulae

- **bipolar** nebulae (see → AG Car & HR Car)

  → result of the **faster rotation** of the central stars

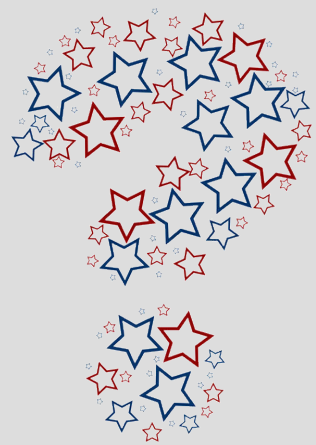
- **lower** metalicity LBVs (LMC) have **larger, slower** expanding and **fewer bipolar nebulae**

  → **metalicity depend mass loss** and **ejecta mechanism**
  → **coupling** of **metalicity** and **faster rotation**

- **multiple shell structures** in the **nebulae**

  → **various wind ↔ S Dor phases**
  → **multiple eruptions**

So back to the start, what do we know defines a Luminous Blue Variable ?



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LBVs – The observational background

- photometric and spectroscopic variable
- S Dor variability is a photometric ↔ spectroscopic ↔ T
- may undergo a giant eruption
- variability in general irregular !
- close to Humphreys-Davidson limit

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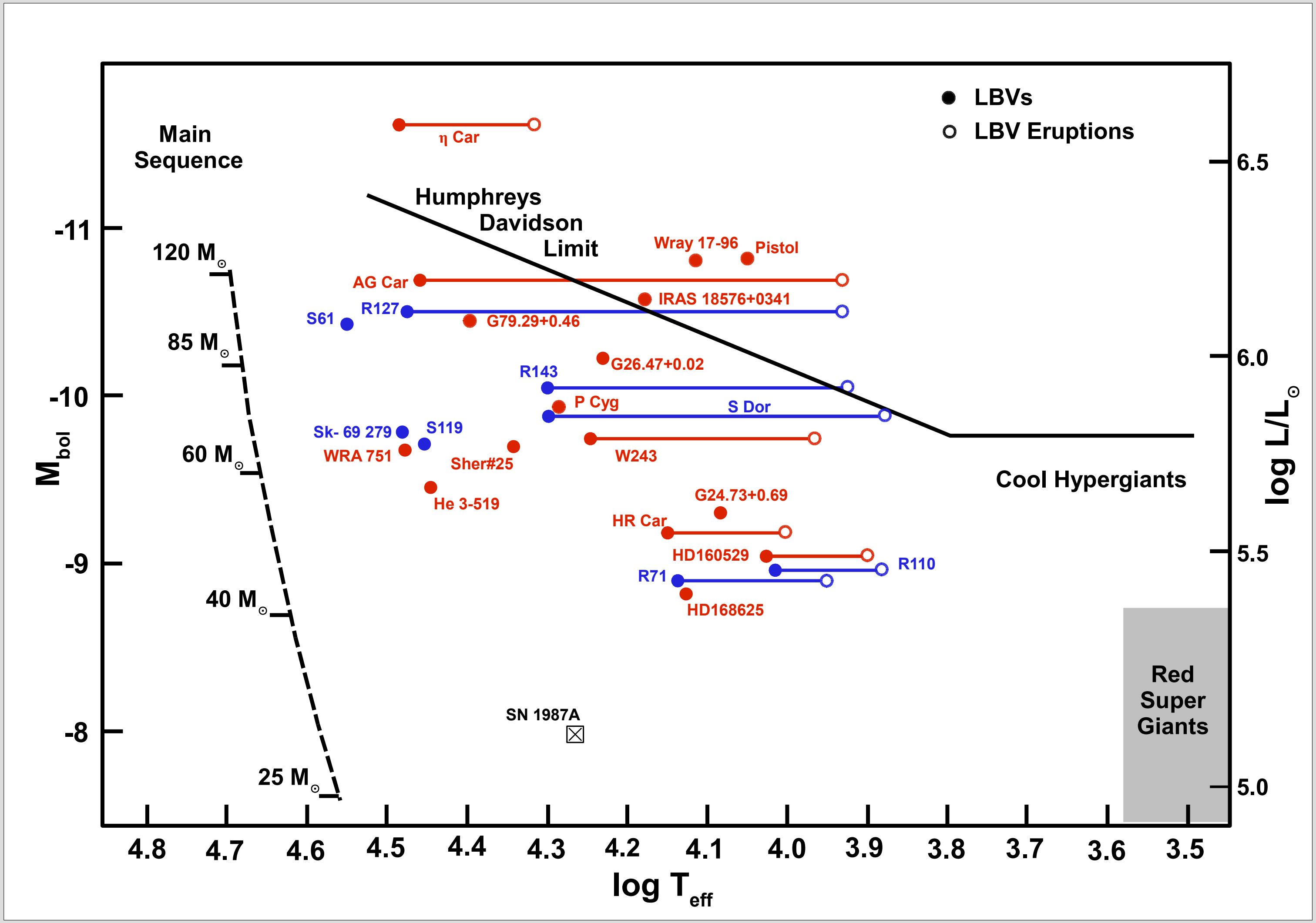
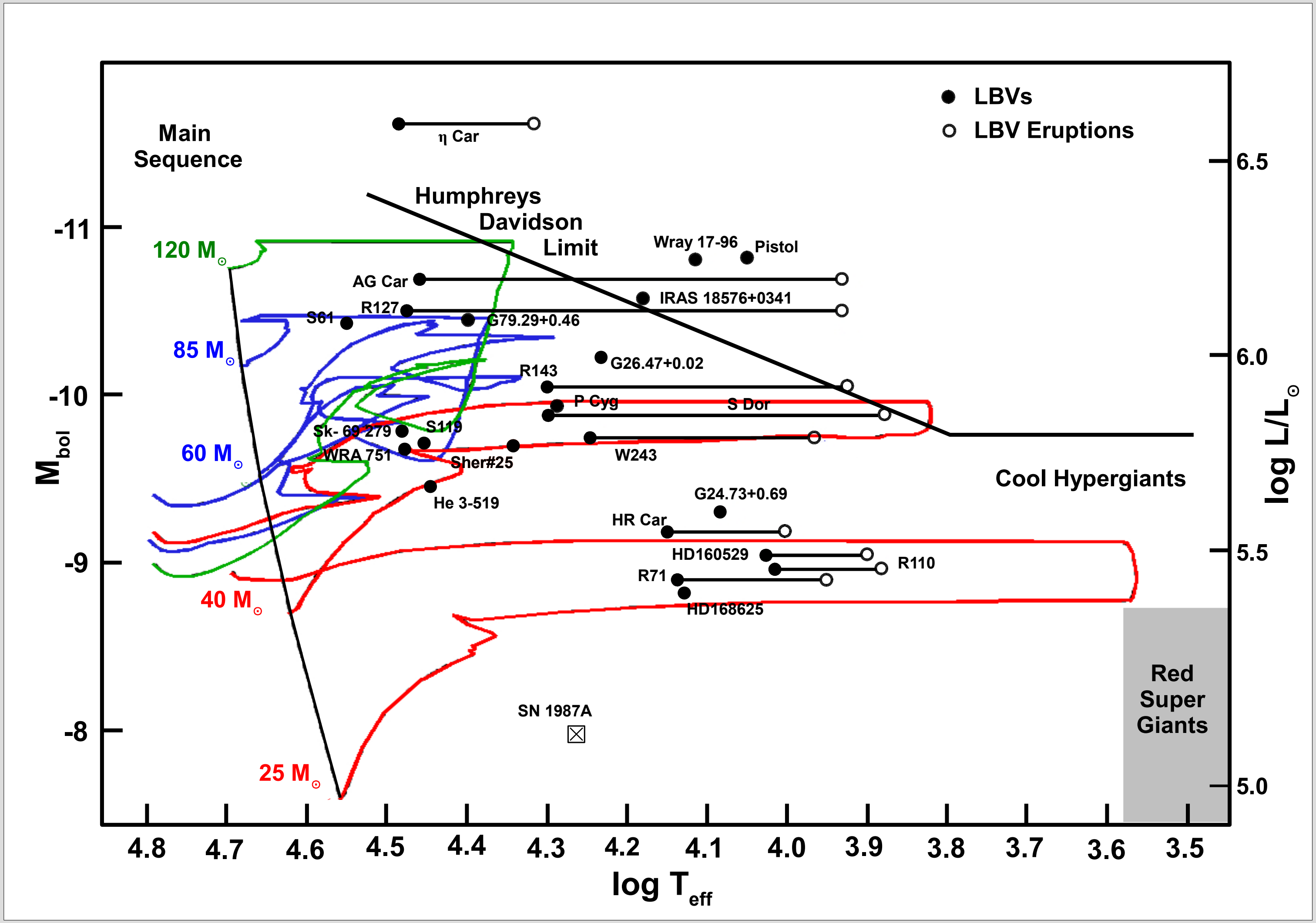
The LBVs in the HRD – the theory side



The LBVs in the HRD – the theory side



Geneva Modells
Z=0.02
V_{rot} = 300 km/s

The LBVs in the HRD – the theory side

- evolved massive star
- comparison with rotation models → M_{ini} as low as 22 $M_\odot$
- high mass loss ~ $10^{-6...-3}\ M_\odot\ yr^{-1}$
- LBV phase short ~ 2 10^4 yrs → is it ?
- close to Eddington or if rotating $\Omega\Gamma$-limit

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There is no unique LBV feature → therefore no unique classification scheme !

giant eruptions

a fitting log $L_\odot$ and log T_{eff}

irregular photometric variations

...?

spectral variations

nebula

Proximity to instability limit

S Dor cycle

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How many do we have to check with yes ✓ to classify it as LBV ?

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How many do we have to check with yes ✓ to classify it as LBV ?

To be or not to be a LBV. That is the question.

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