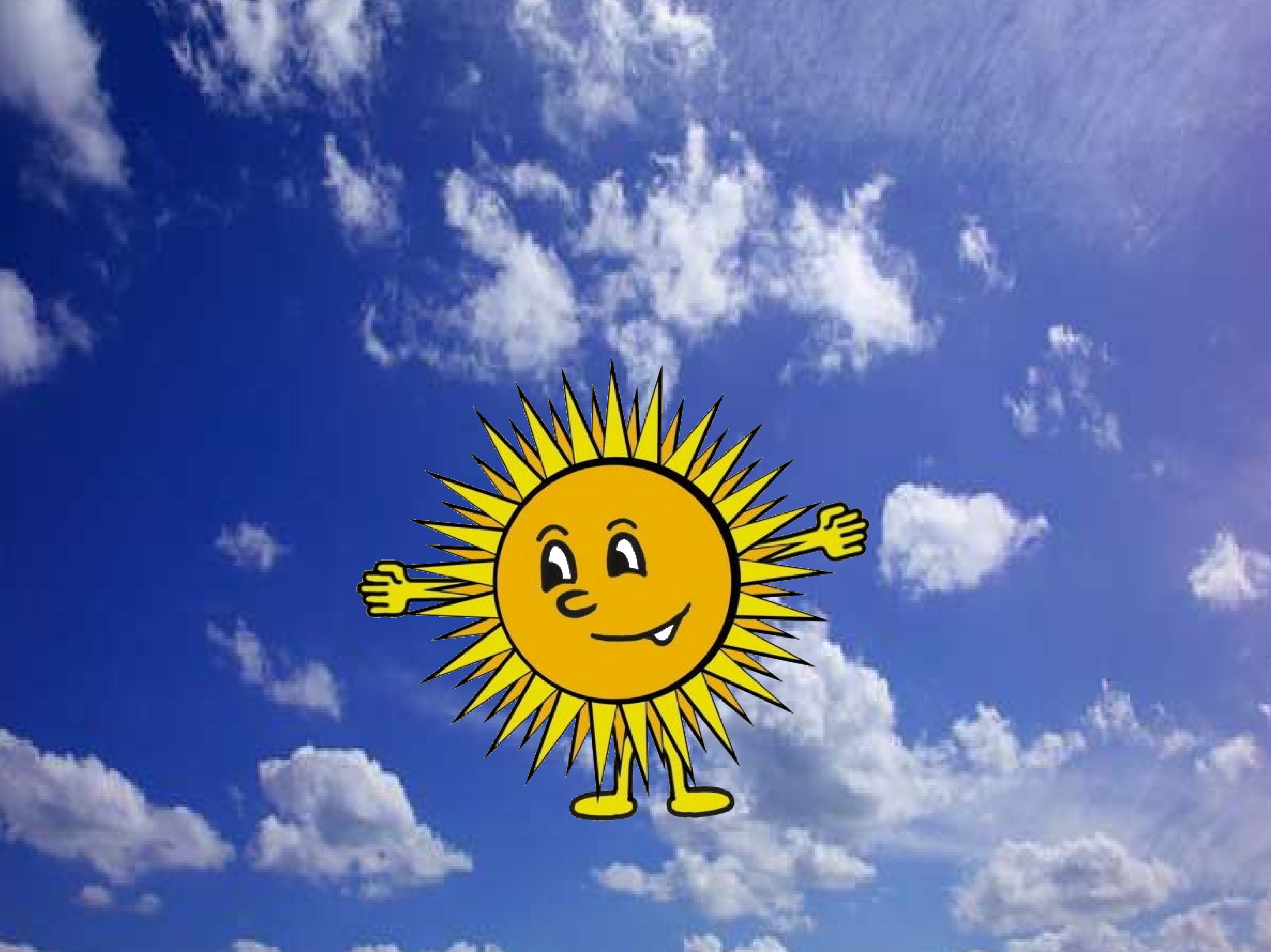
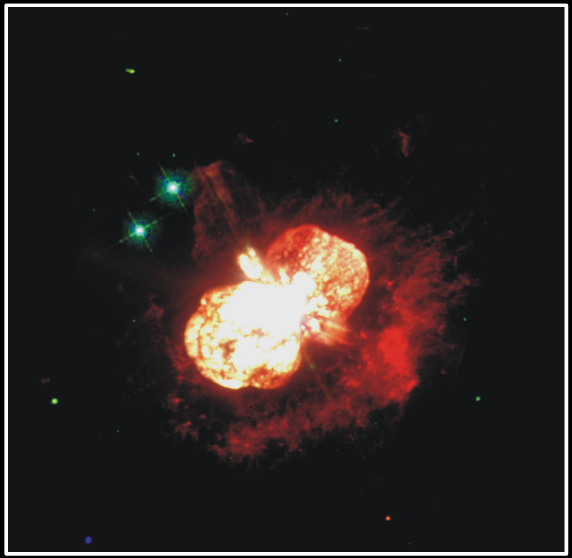


LBVs – Variabilities and the Formation of Nebulae

Kerstin Weis

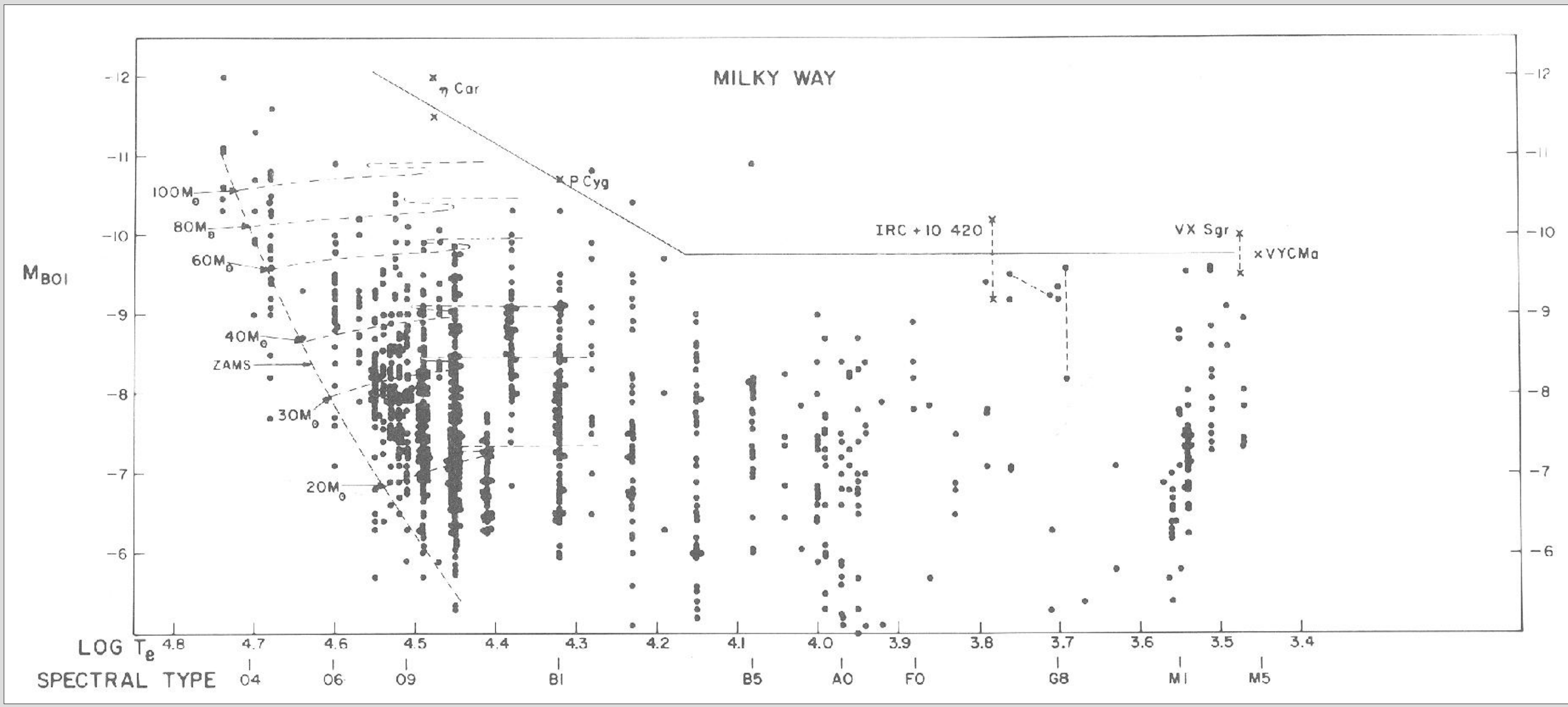
Astronomisches Institut
Ruhr-Universität Bochum
Bochum, Germany



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

Where are they and where not?

The original plot for LBVs … don't leave home without it !



(Humphreys & Davidson 1979)

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

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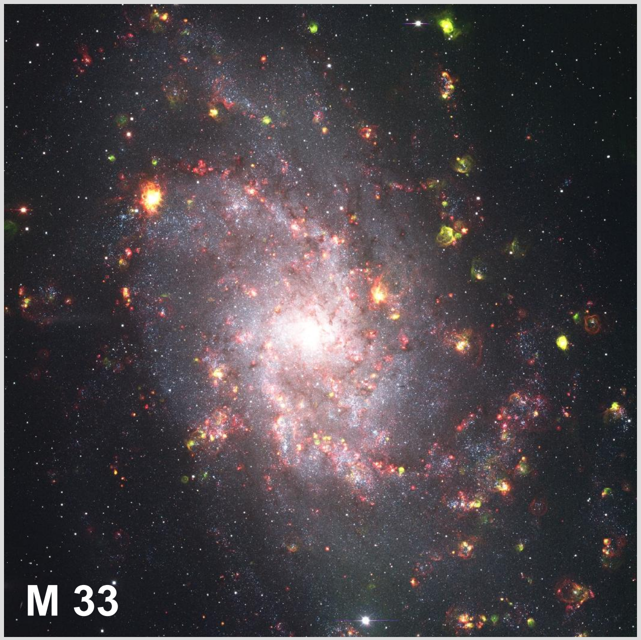
LBVs – a grand unification of

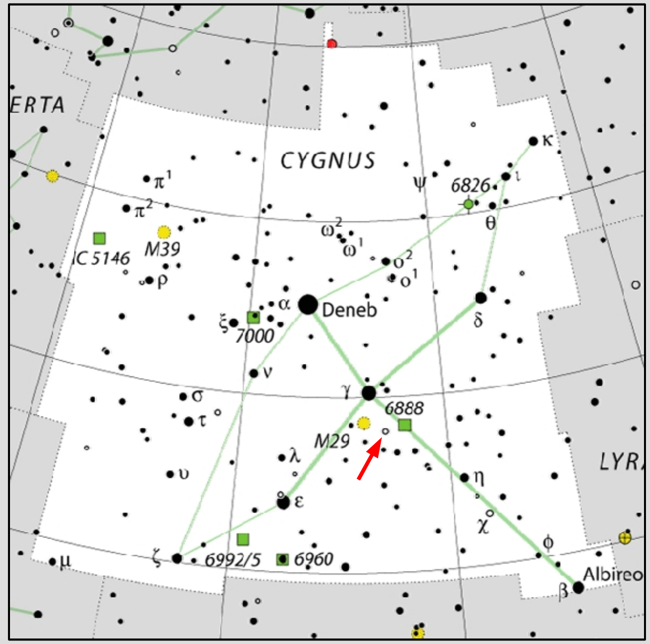
Hubble-Sandage Variables

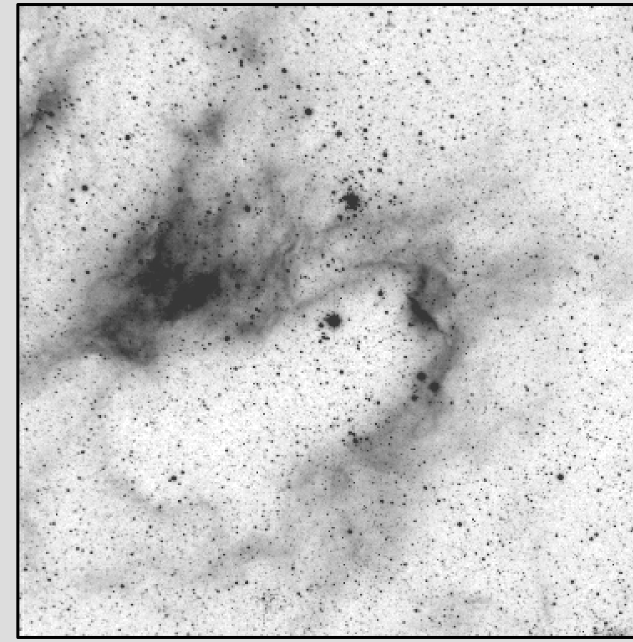
P Cyg type star

S Dor Variables

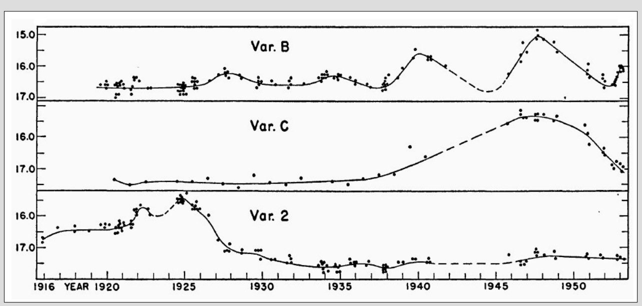


(Burggraf 2005)

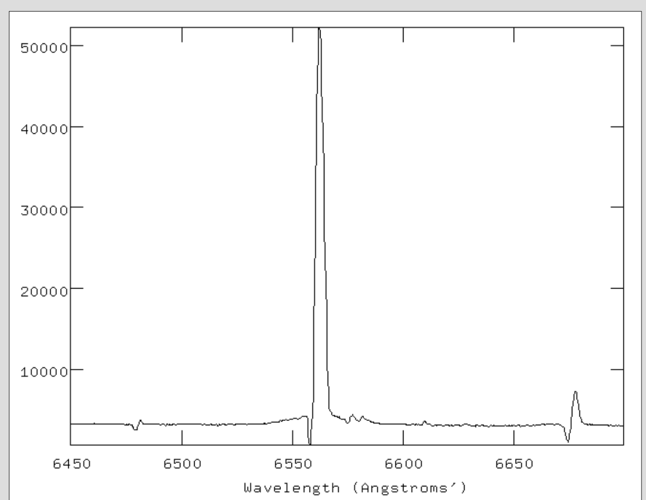




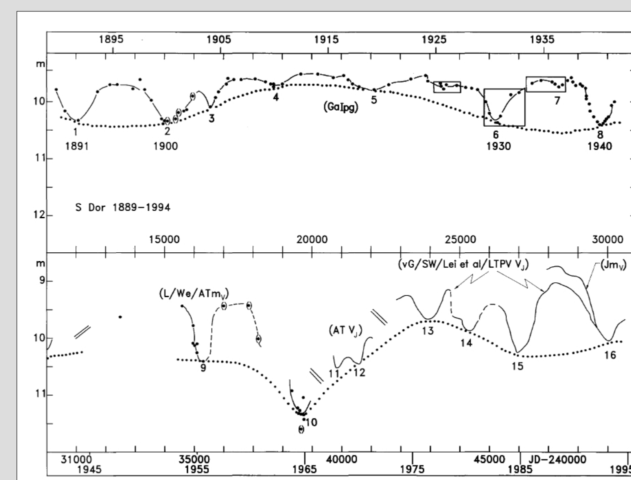
(Weis 2003)



(Hubble & Sandage 1953)



(Weis 1999)



(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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Conti 1997

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Conti 1997

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Defining a Luminous Blue Variable by Variability

Photometric Variability

“minor outburst”

“major outburst”

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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	

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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 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- / $\Omega\Gamma$ -limit*

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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

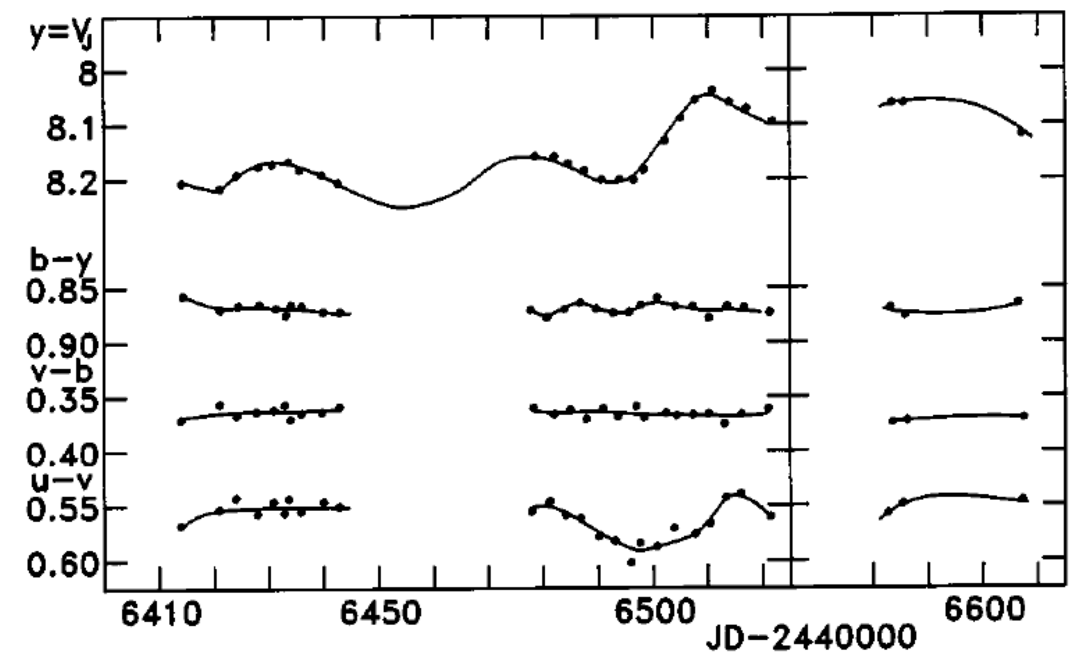


Fig. 2. Detailed light and colour curves of the ~ 40 d micro variations in the hump of the descending branch of HR Car's normal SD phase (with a maximum at JD 2446250). Note that the magnitude scales for the colour curves are twice that for the light curve

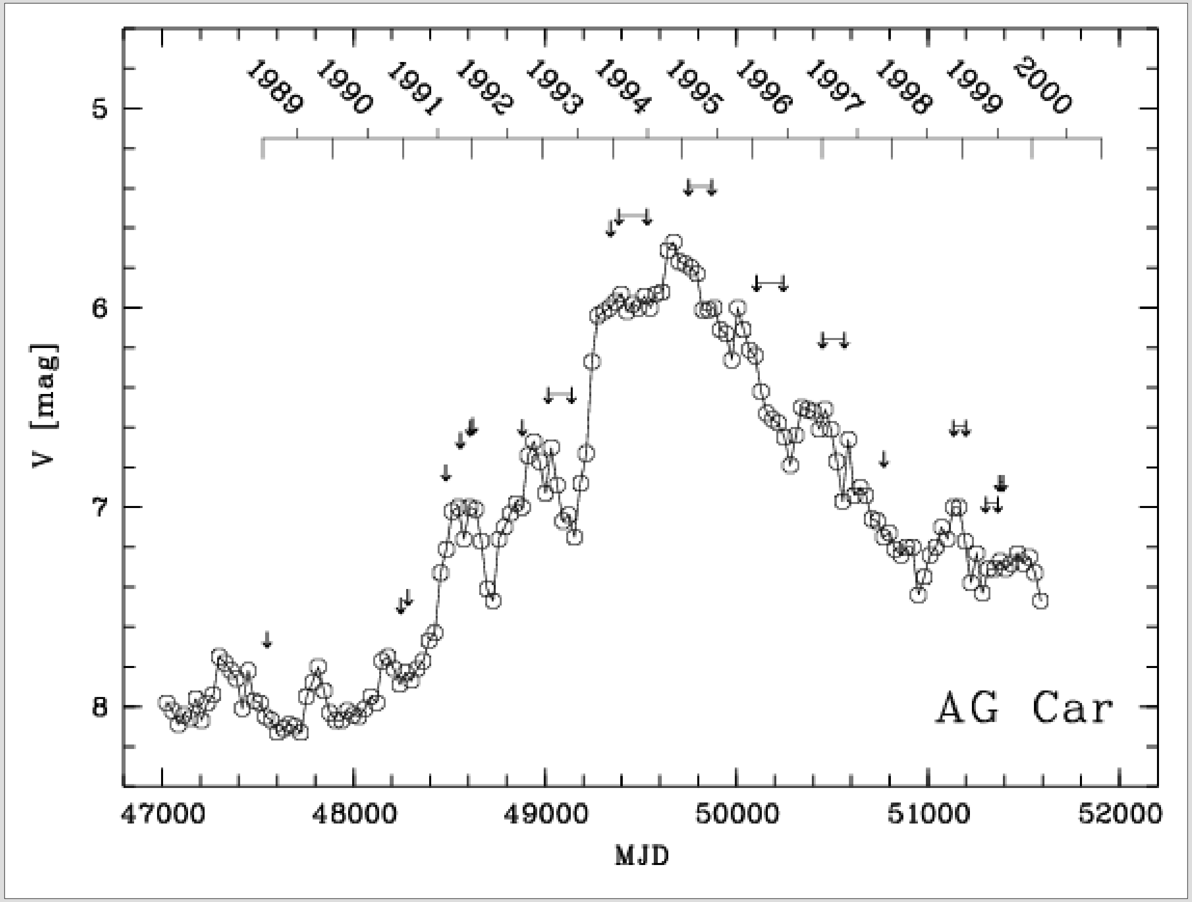
example of **micro-variations** in the lightcurve of the LBV **HR Carinae**

(van Genderen et al.1997)

Defining a LBV – minor outburst ↔ S Dor cycle

photometric variability

S Dor Cycle



(Stahl et al. 2001)

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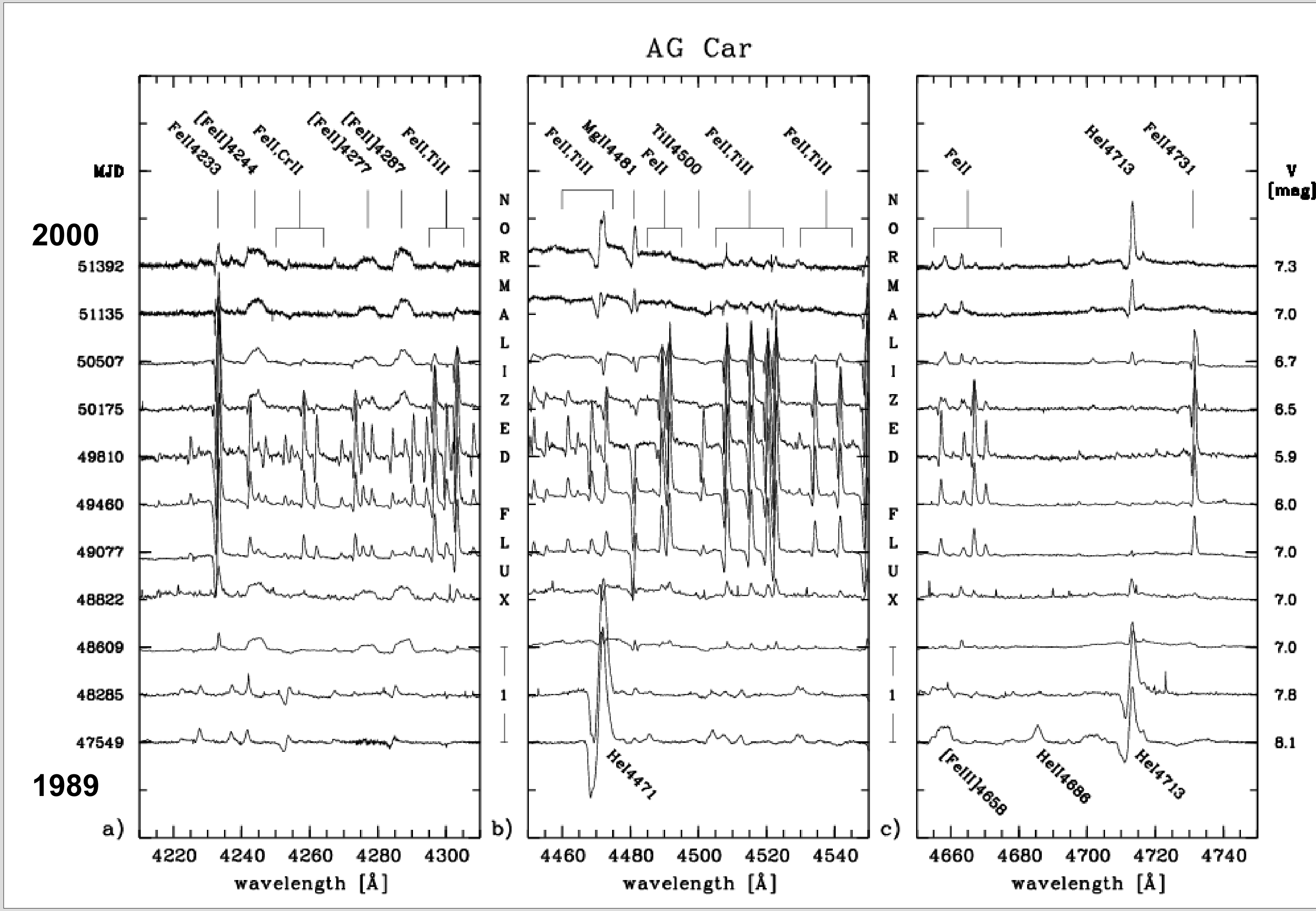
Defining a LBV – minor outburst ↔ S Dor cycle

spectral variability



(Stahl et al. 2001)

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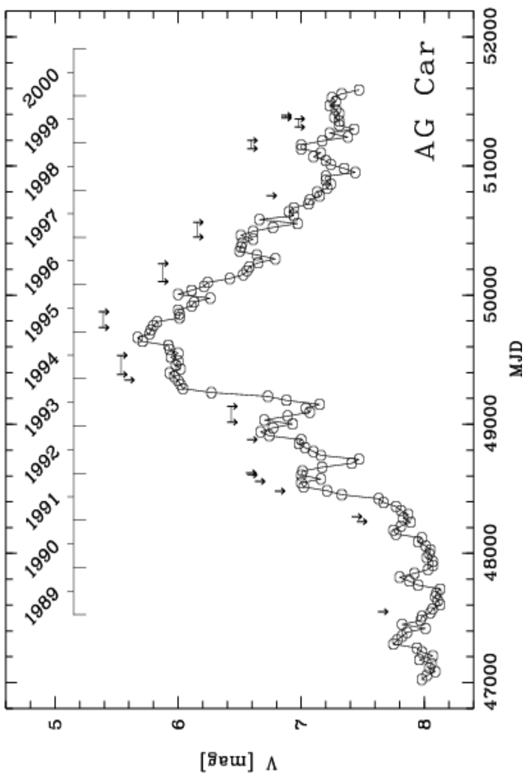
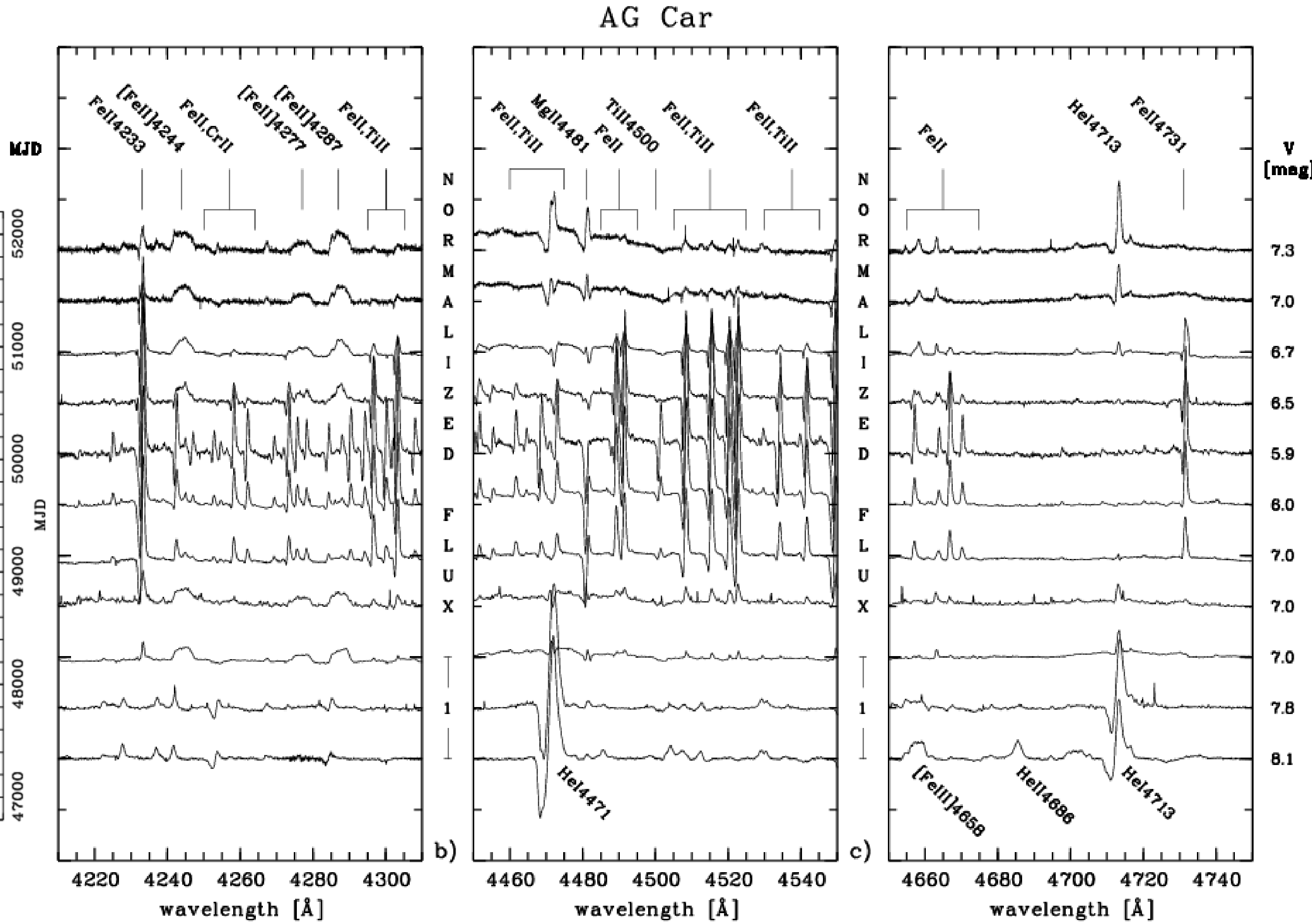
Defining a LBV – minor outburst ↔ S Dor cycle

S Dor cycle
→ variabilities are coupled





(Stahl et al. 2001)

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

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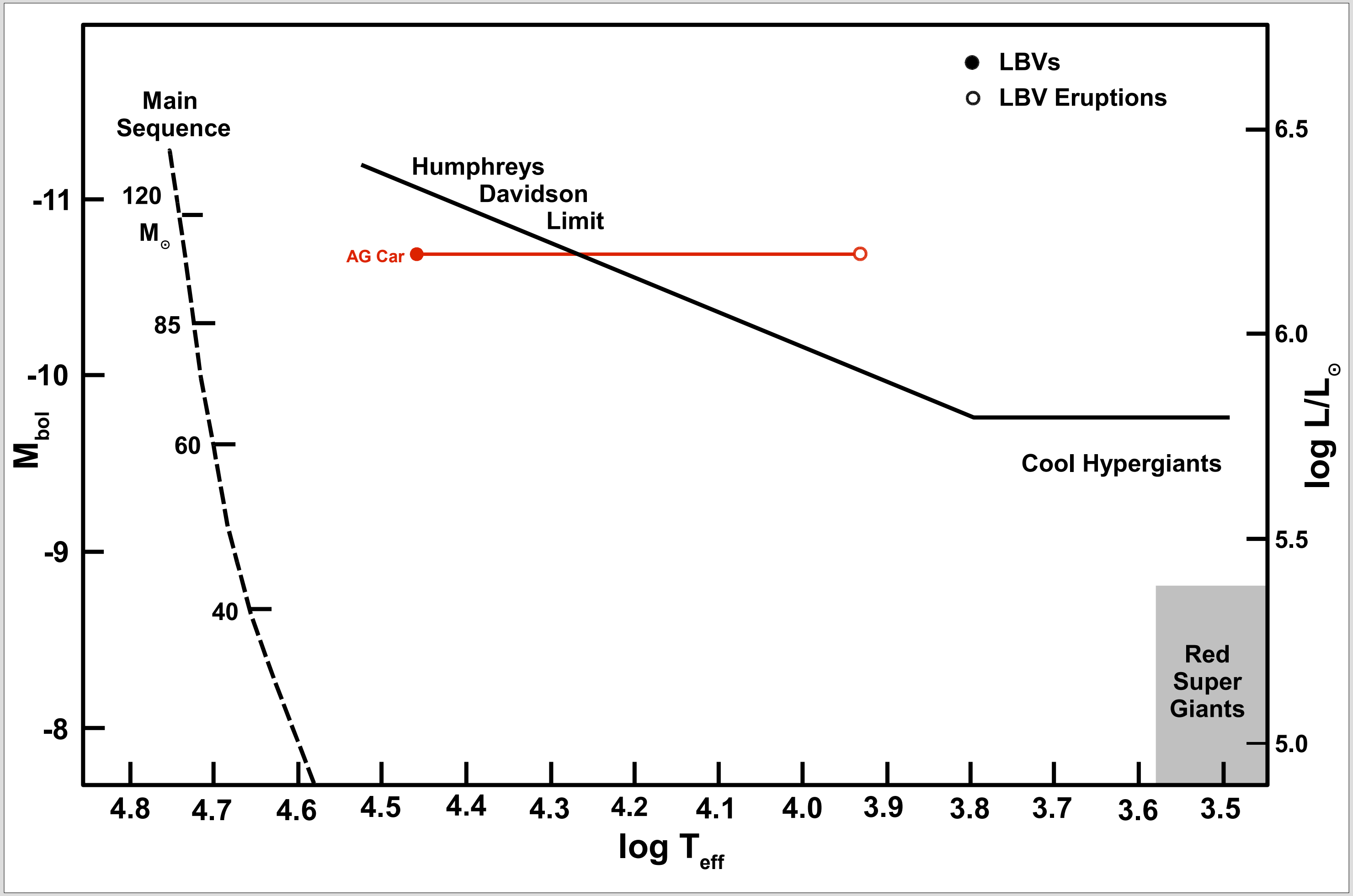
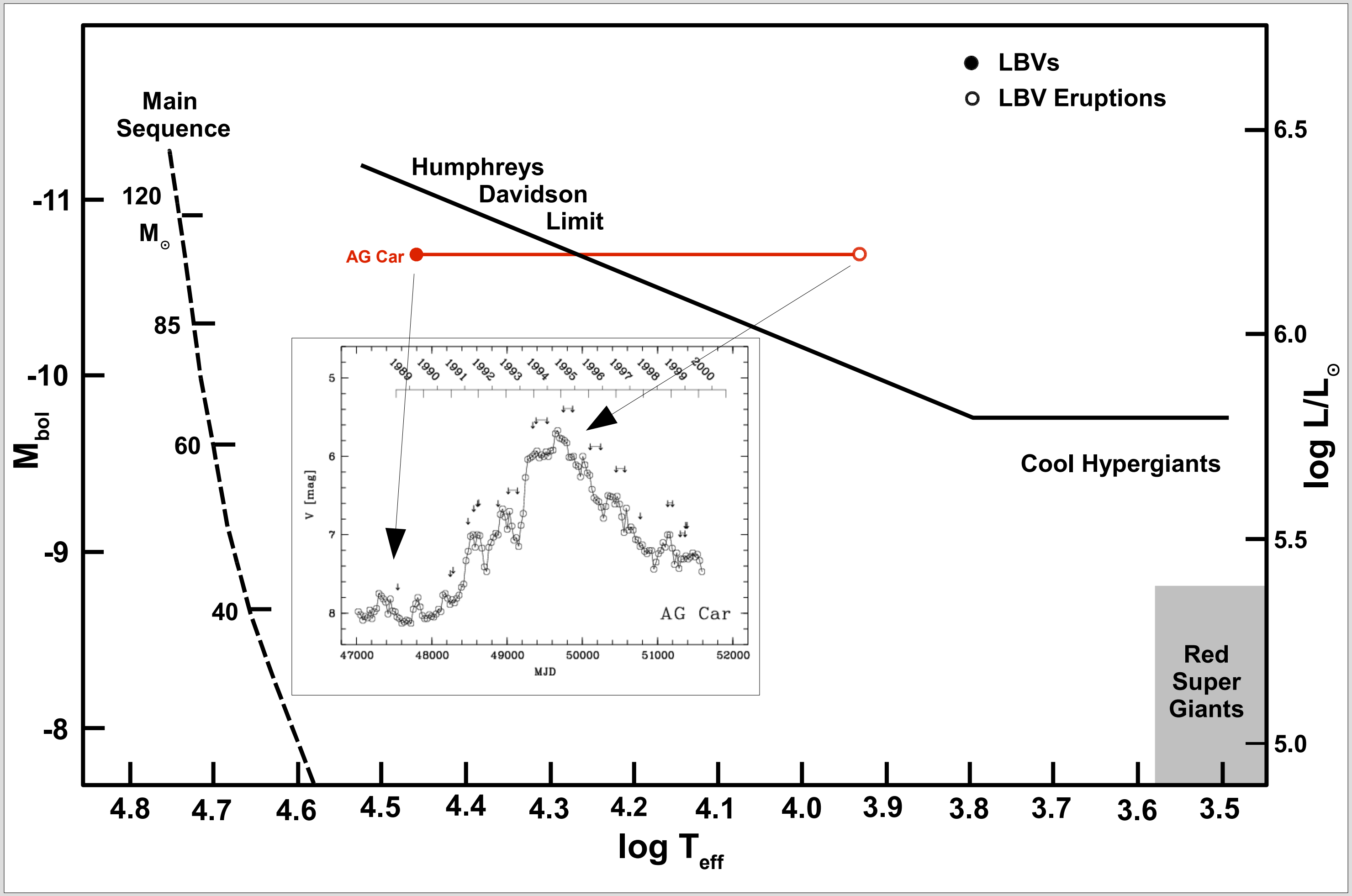
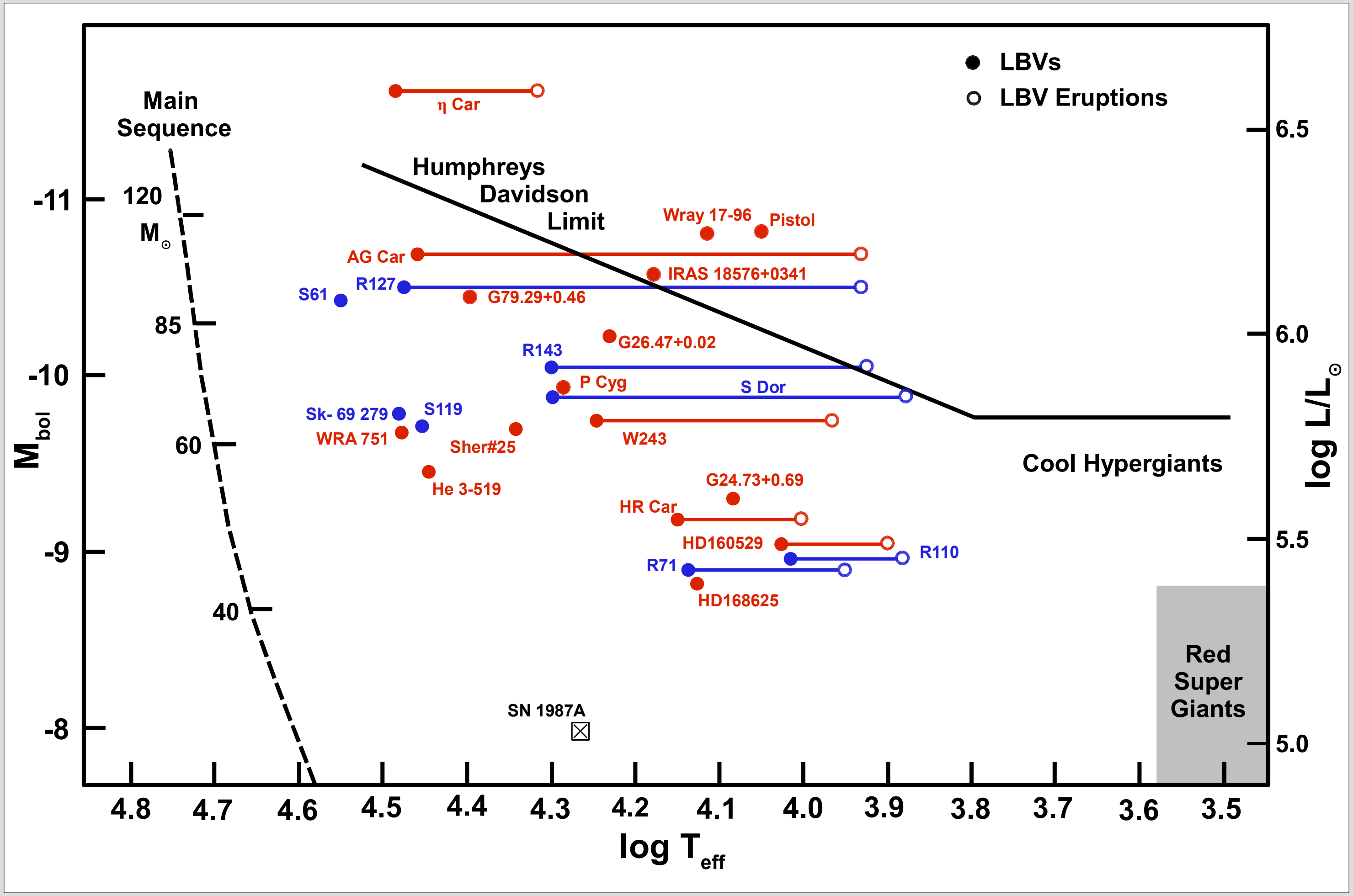
Defining a LBV – minor outburst ↔ S Dor cycle



Defining a LBV – minor outburst ↔ S Dor cycle



Defining a LBV – minor outburst ↔ S Dor cycle



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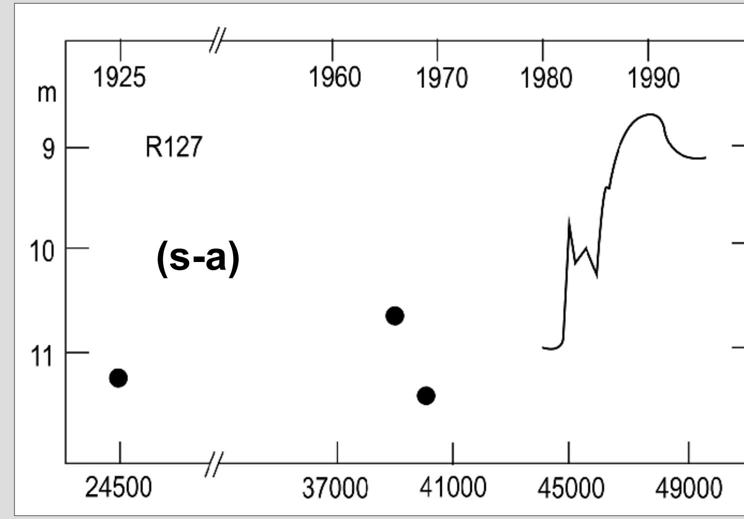
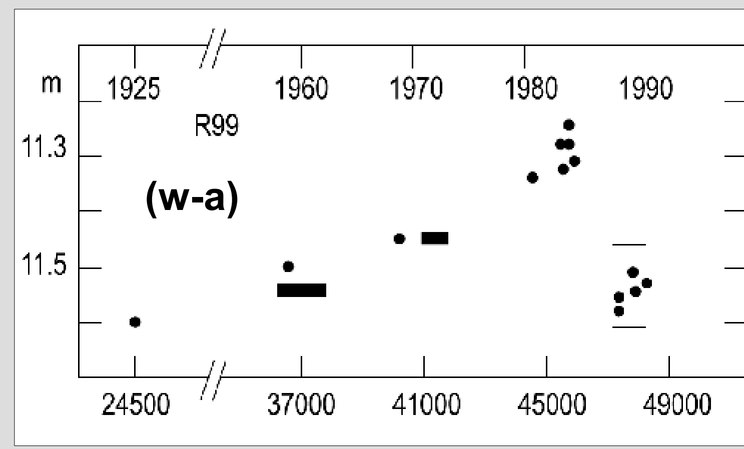
Classification of various S Dor subtypes

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...



(van Genderen 2001)

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

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Classification of various S Dor subtypes

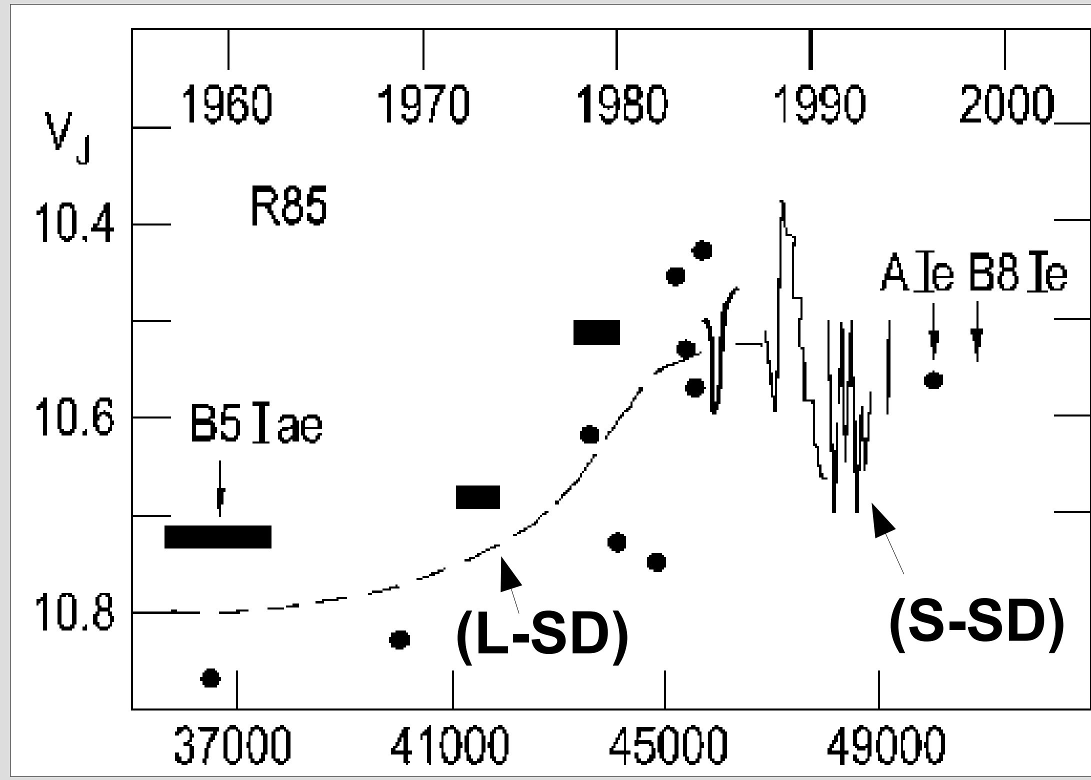
II. By timescale

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

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Security advise !

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Security advise !
Don't leave your LBV unattended !

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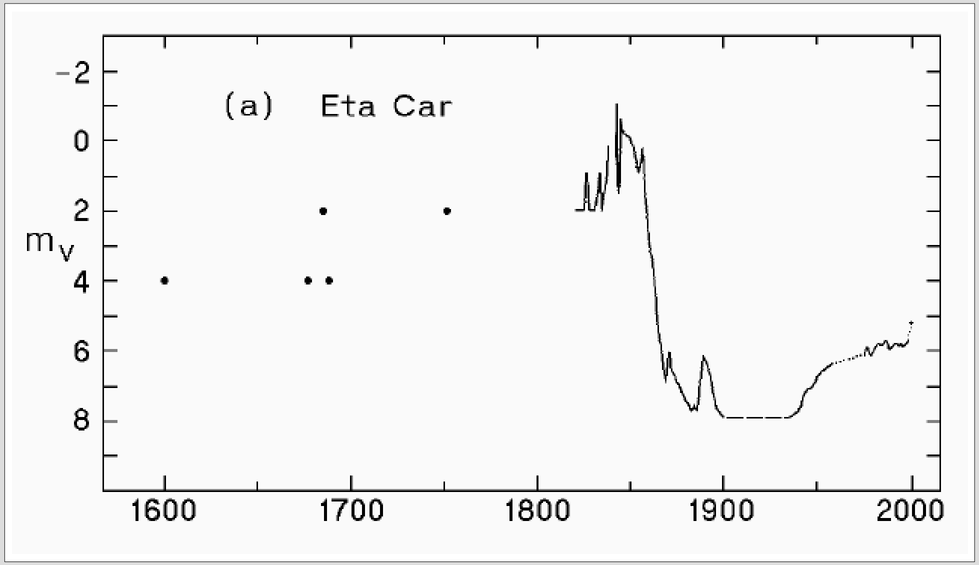
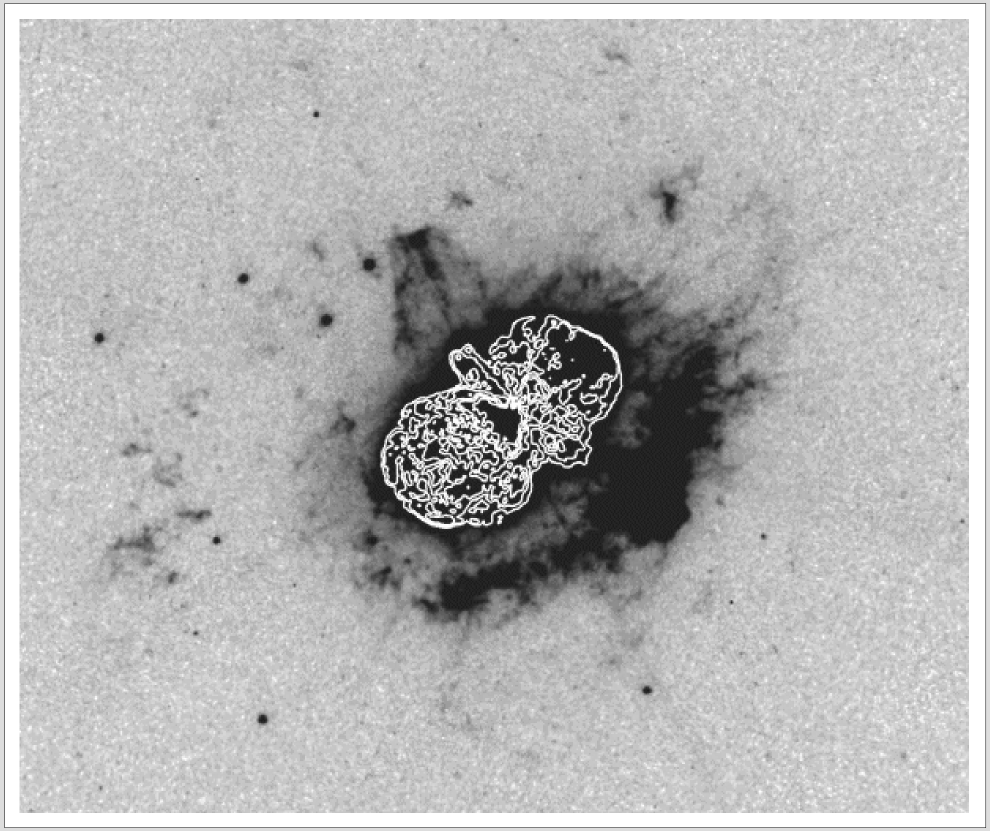


(Humphreys et al. 1999)



(Weis et al. 2001)

giant eruption

Defining a Luminous Blue Variable by Variability

major outburst
(Conti 1997)

↕

LBV giant eruption

↕

η Car variables

↕

SN imposters

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Defining a Luminous Blue Variable by Variability

major outburst

(Conti 1997)

↕

LBV giant eruption

↕

η Car variables

↕

SN imposters

η Carinae

SN 1961V

P Cygni

SN 1954J

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Conti 1997

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Defining a Luminous Blue Variable by Variability

Warning !!!

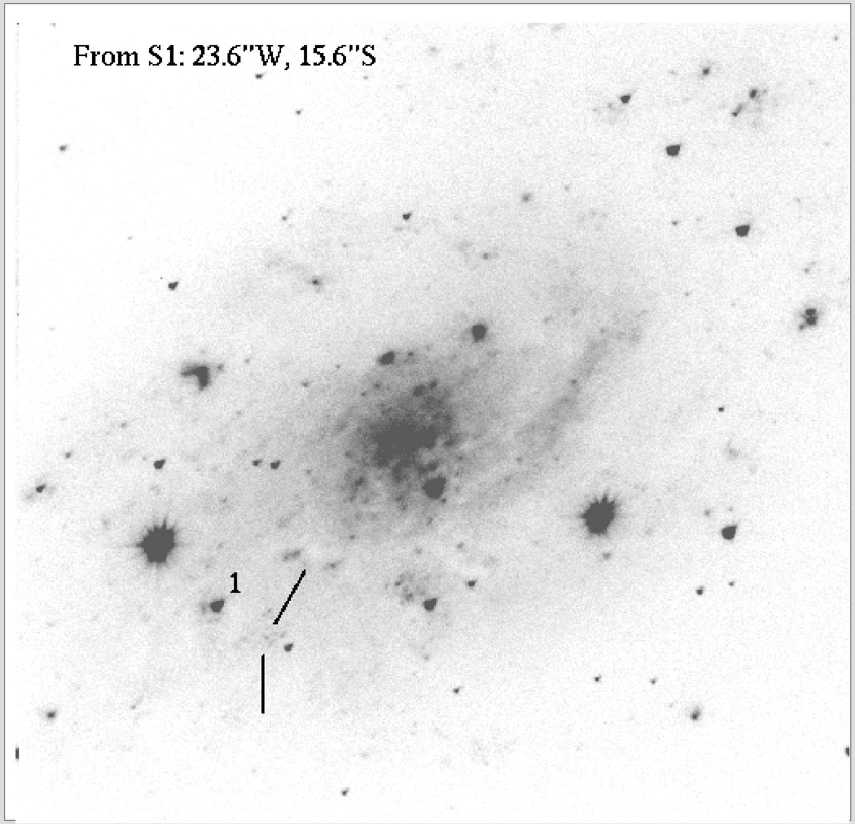
What looks like giant eruption may not always be one !

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



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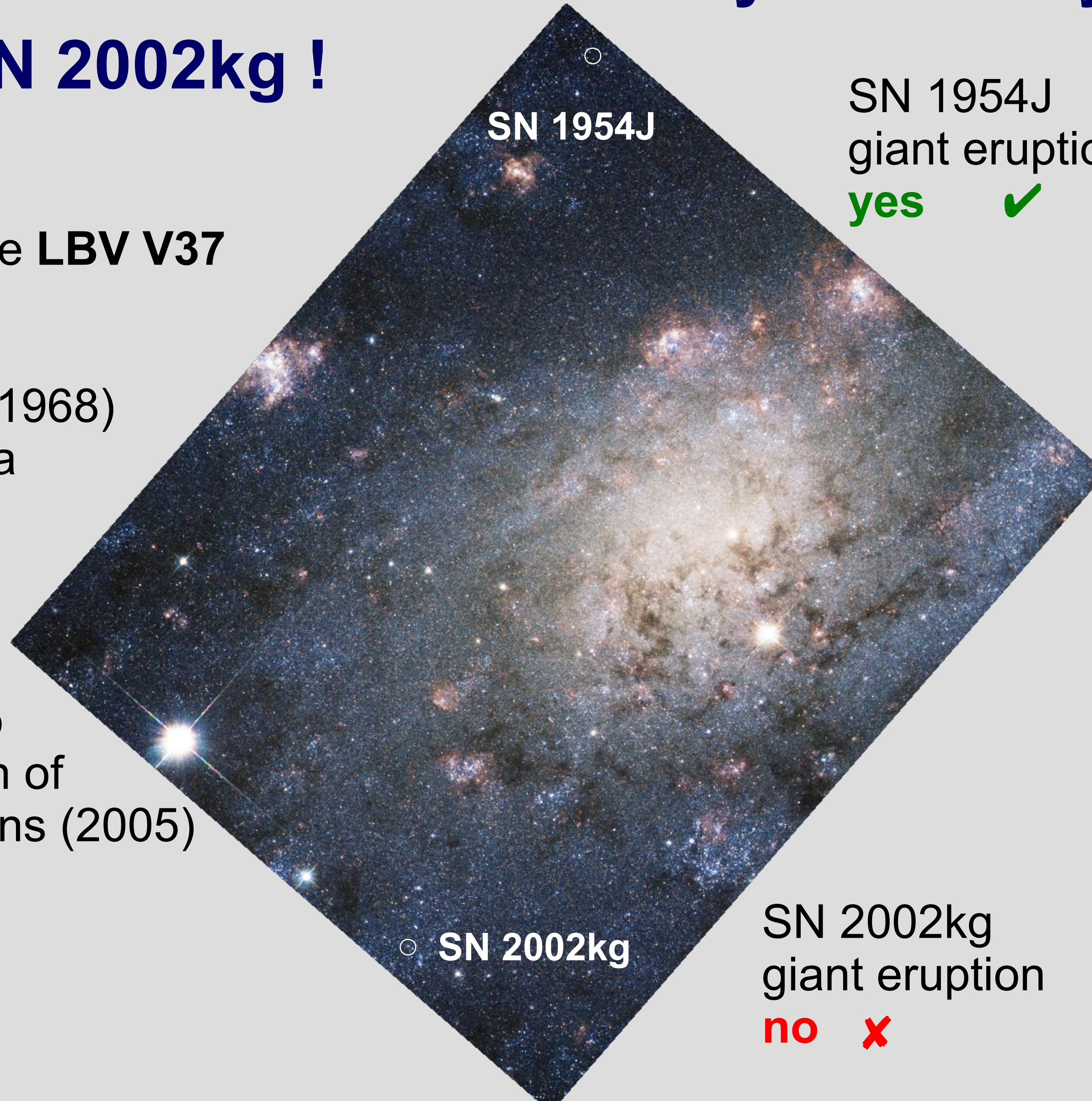
Defining a Luminous Blue Variable by Variability

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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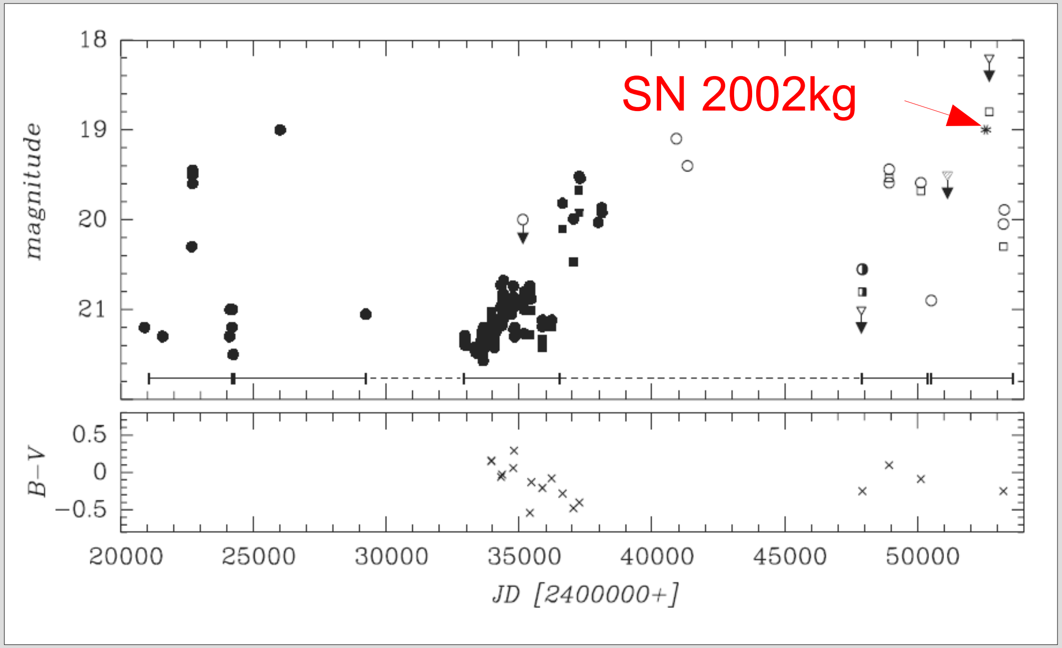
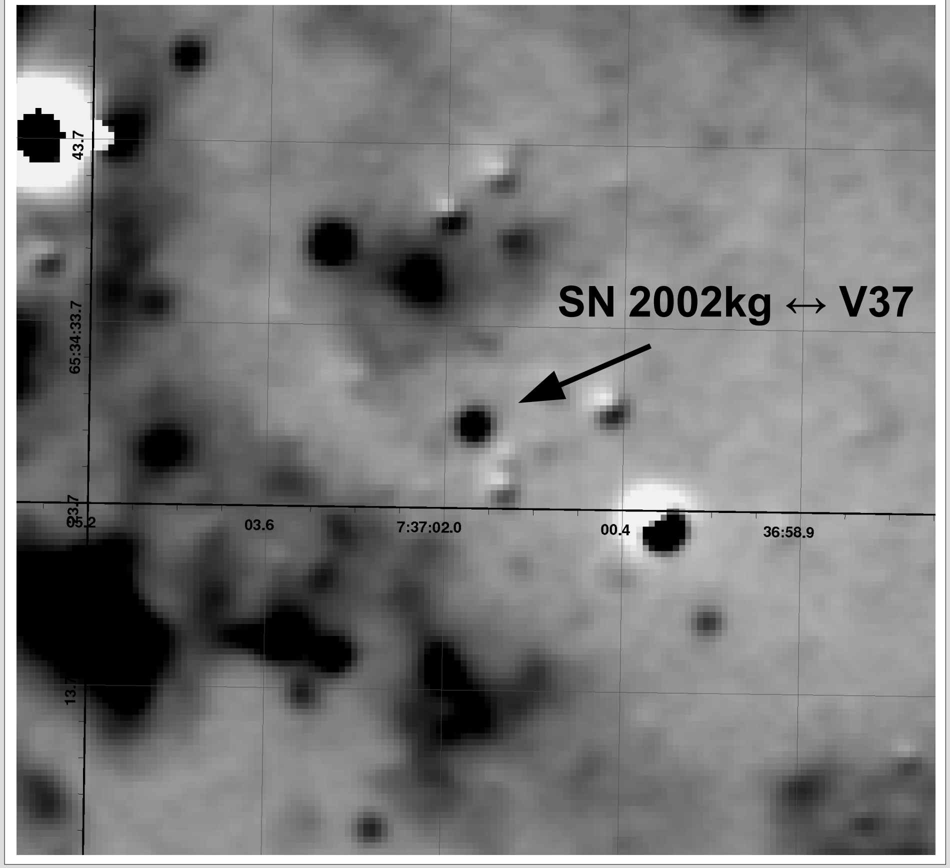
The LBV eruption of V37 ↔ SN2002kg



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)

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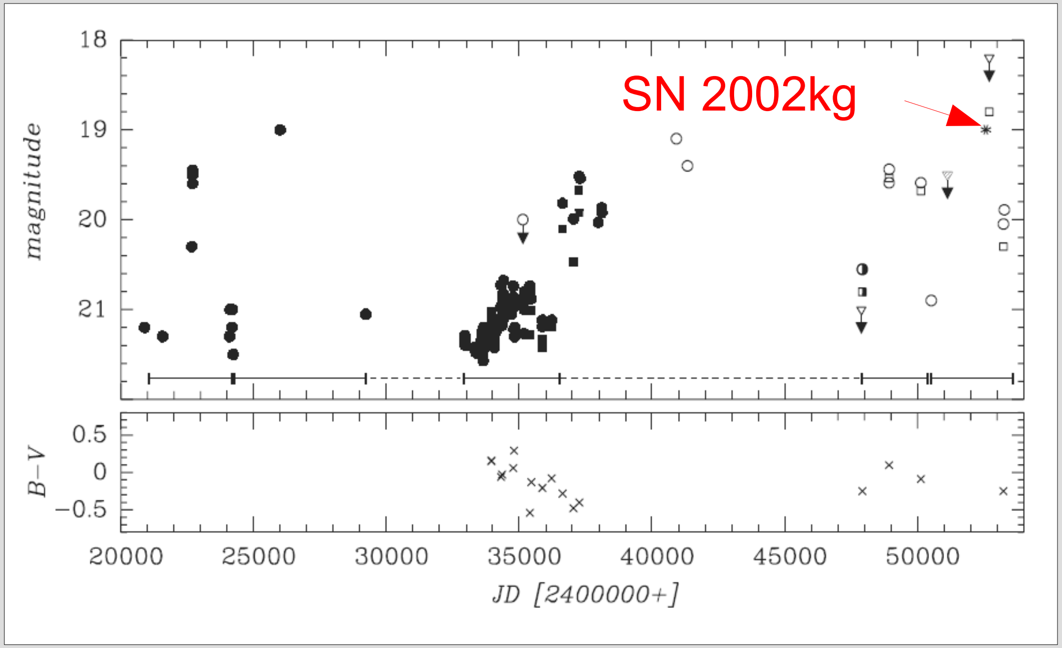
The LBV eruption of V37 ↔ SN2002kg



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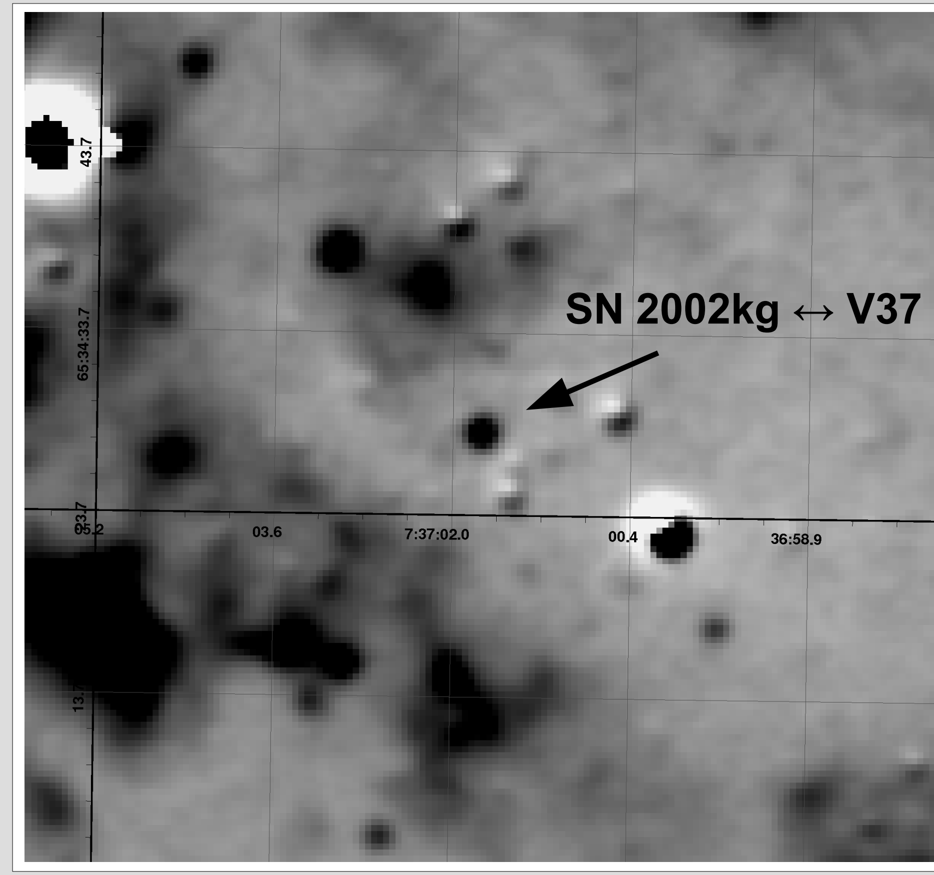
Is V37 a giant eruption imposter ?



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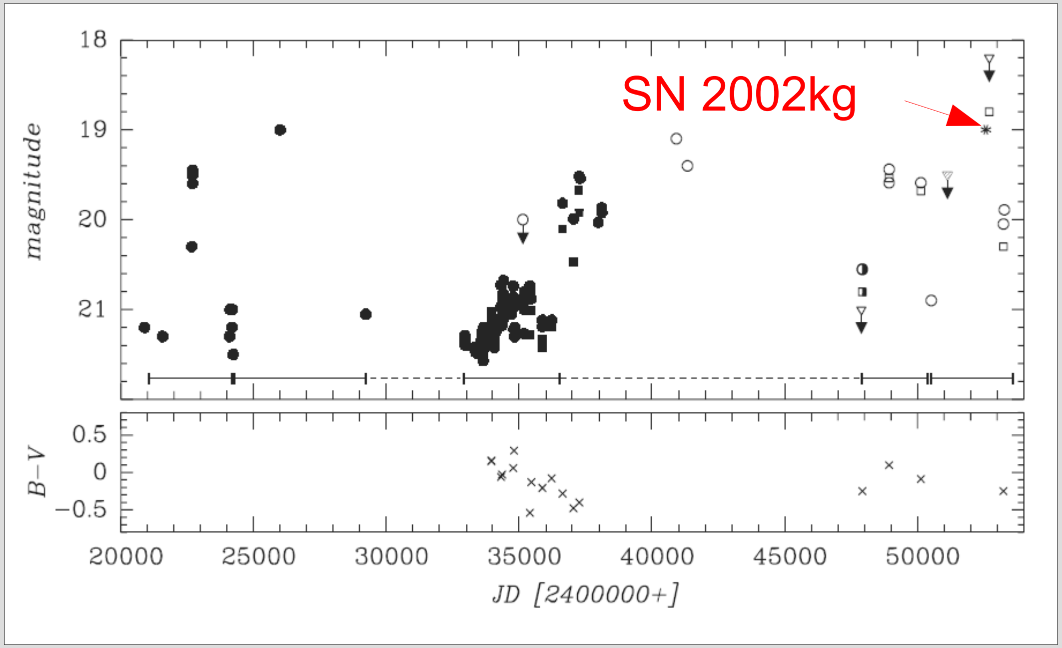

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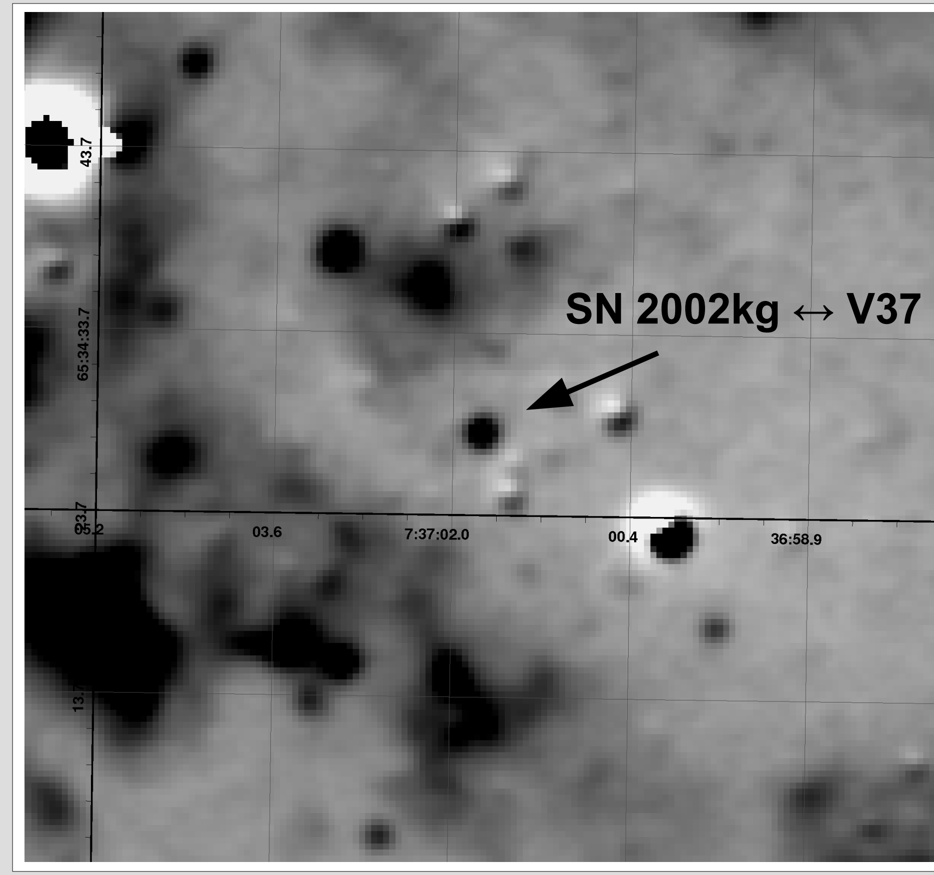
Is V37 a giant eruption imposter ?
...No not again a new acronym...



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→ strong **emission line star**

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(Weis & Bomans 2005)

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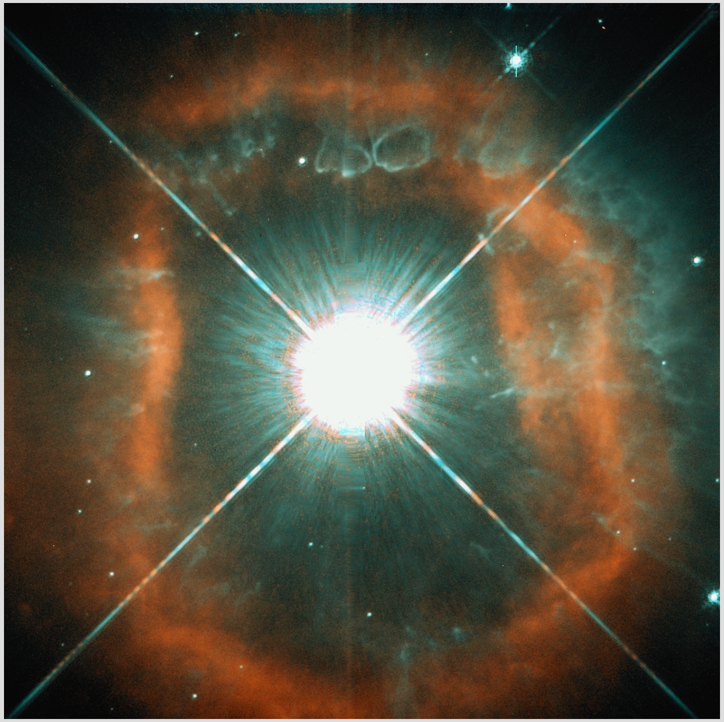
LBVs – The nebula basics

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

- strong N lines ↔ CNO processed material

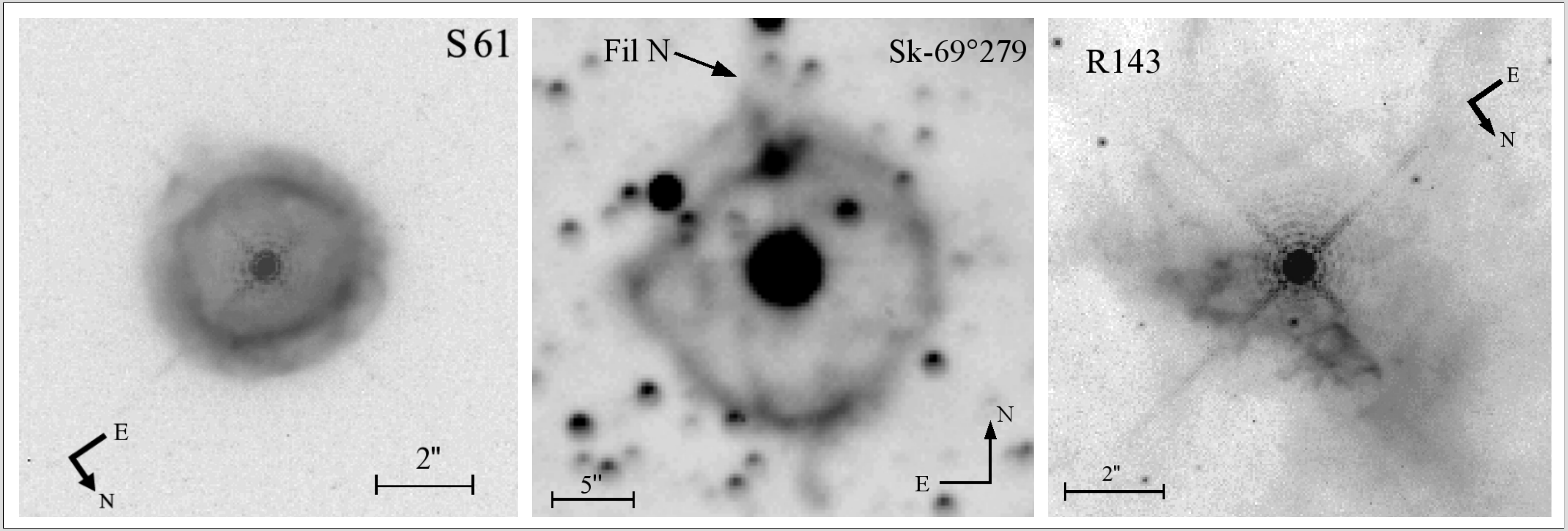


(Weis 2009)

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)

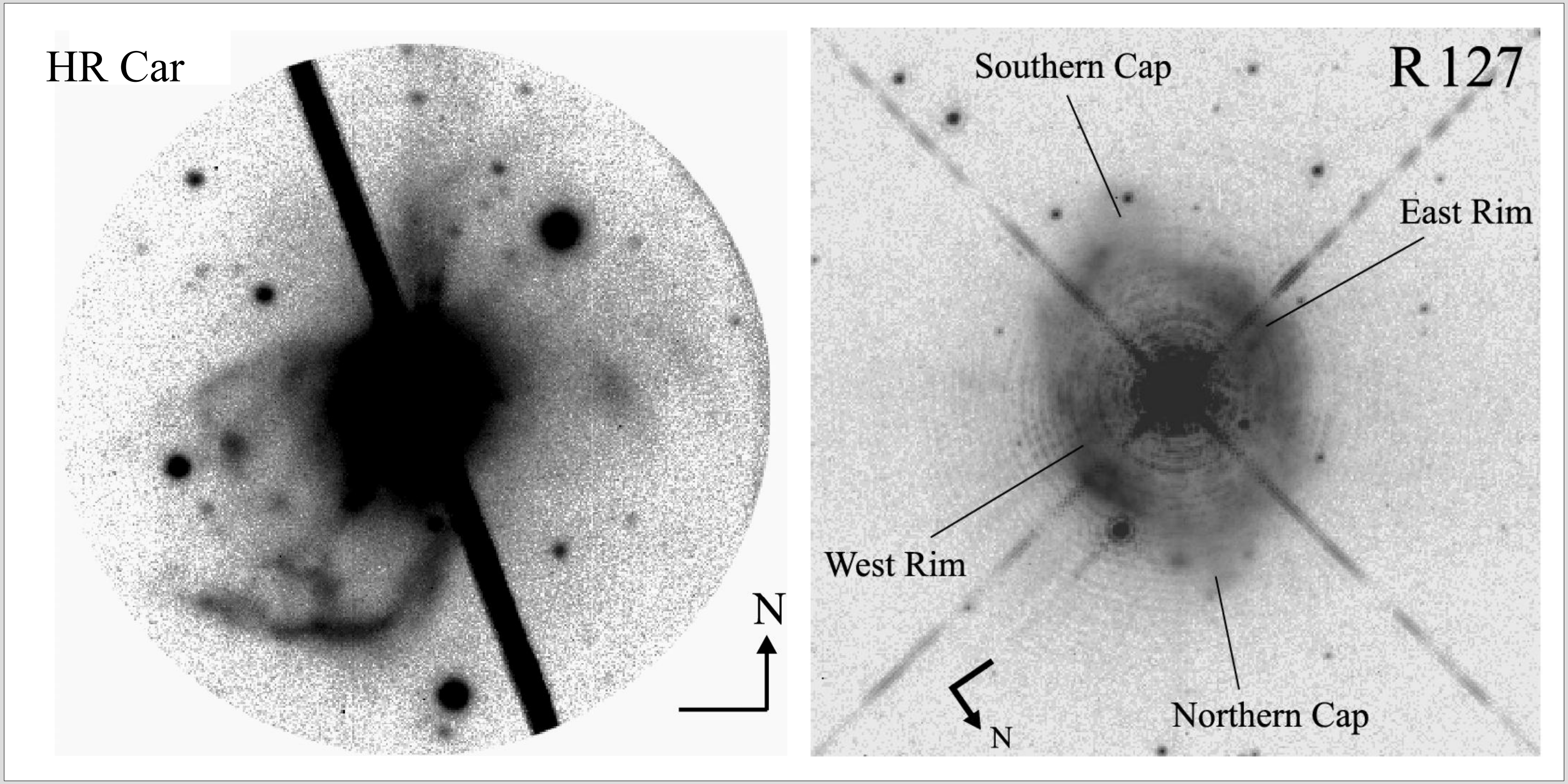


(Weis & Duschl 2002, Weis 2003)

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)

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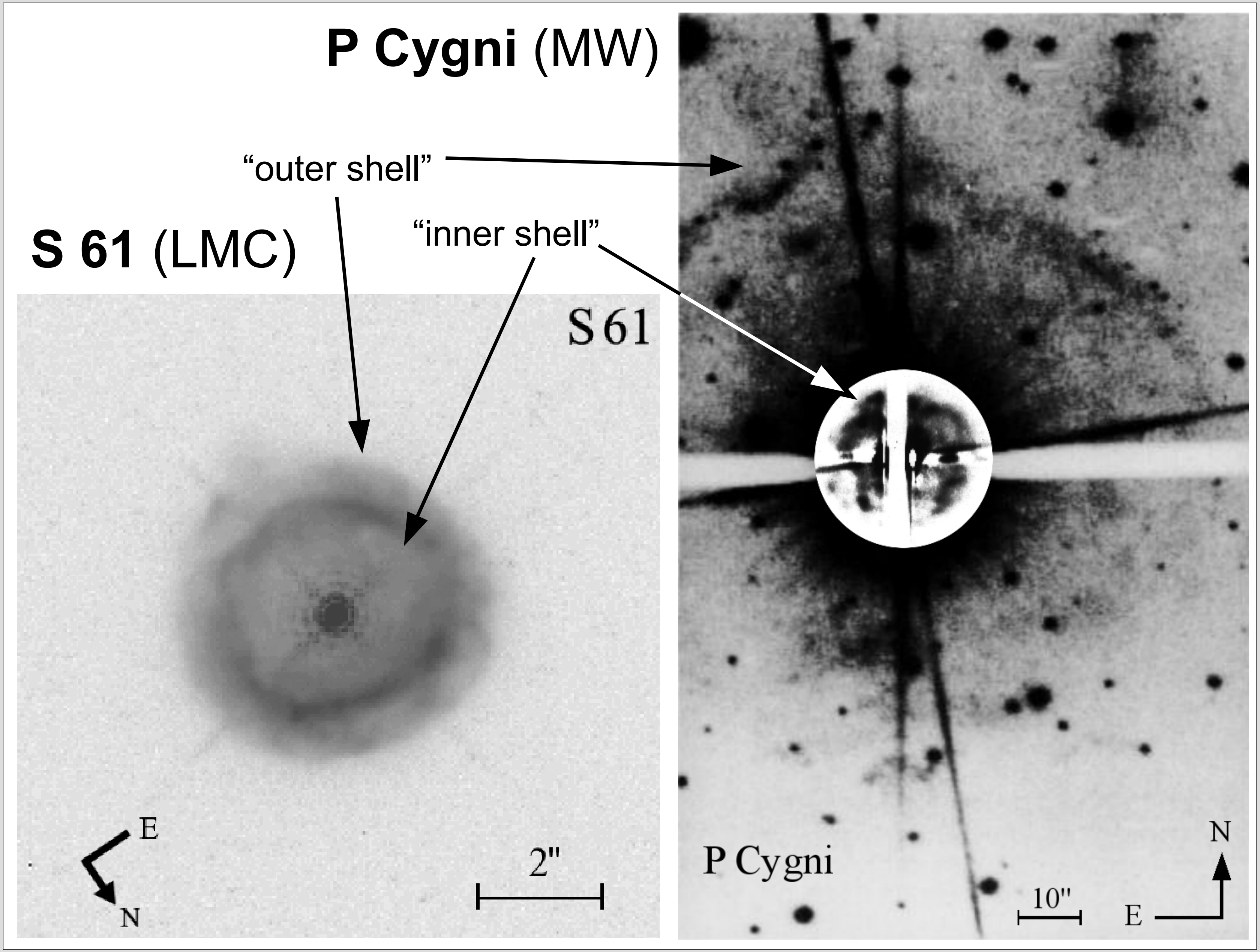
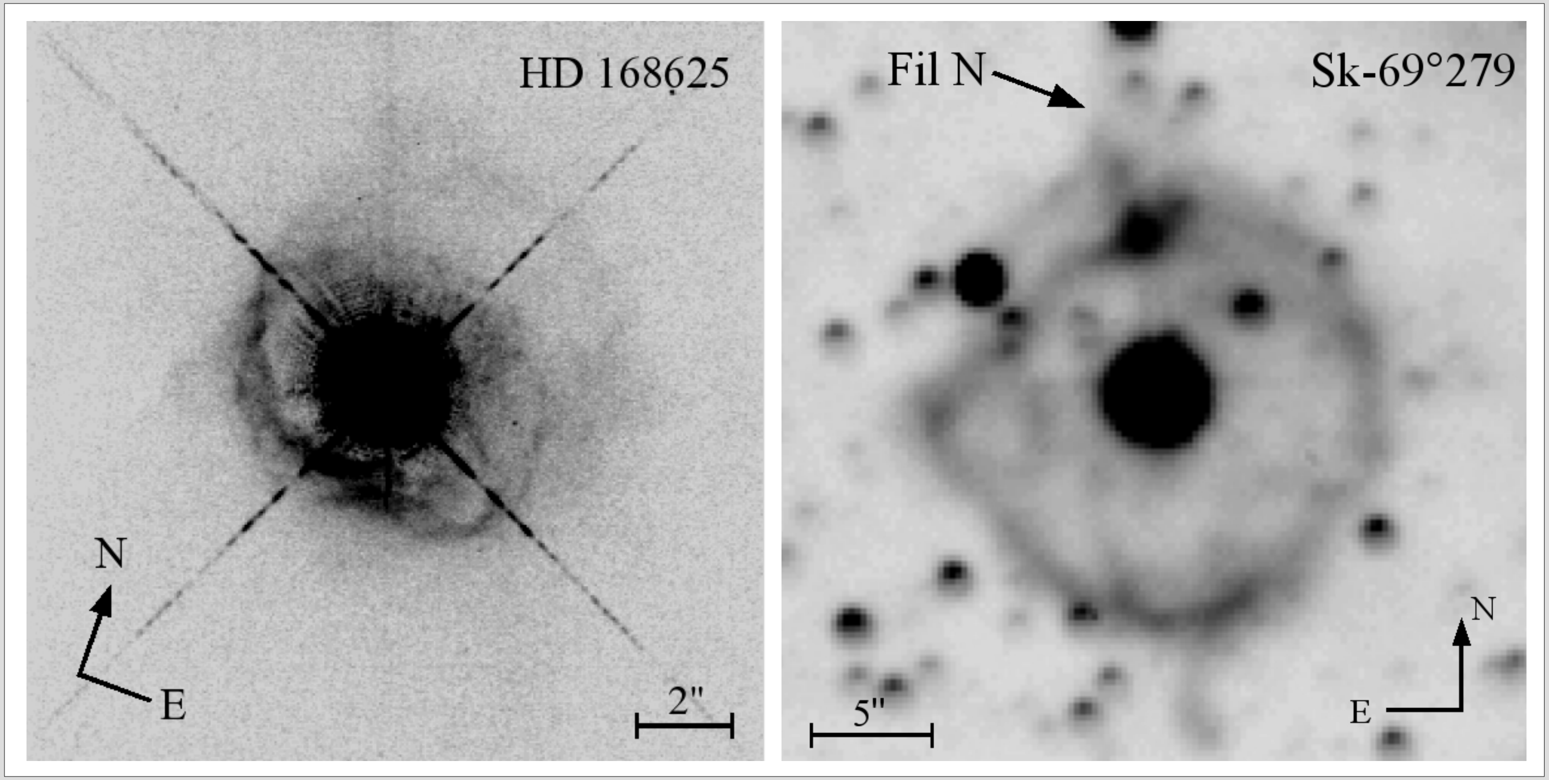
Multi-shell nebulae – several phases ?



Sizes of LBV nebulae

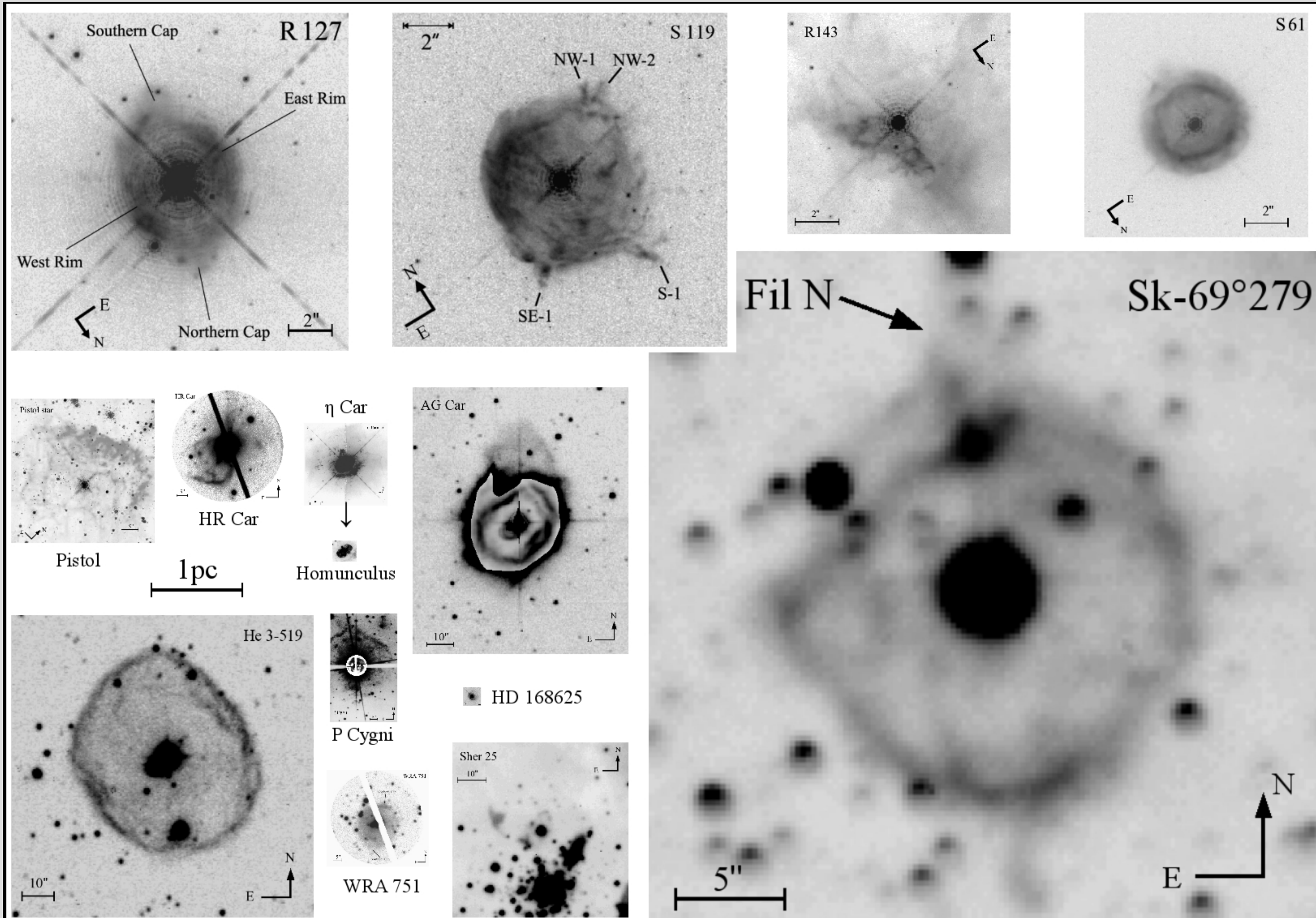
Sizes

- 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)

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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)

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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	$\sim 25^*$	~ 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
AG Carinae	Milky Way	1.4×2	0.4	~ 25*	~ 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

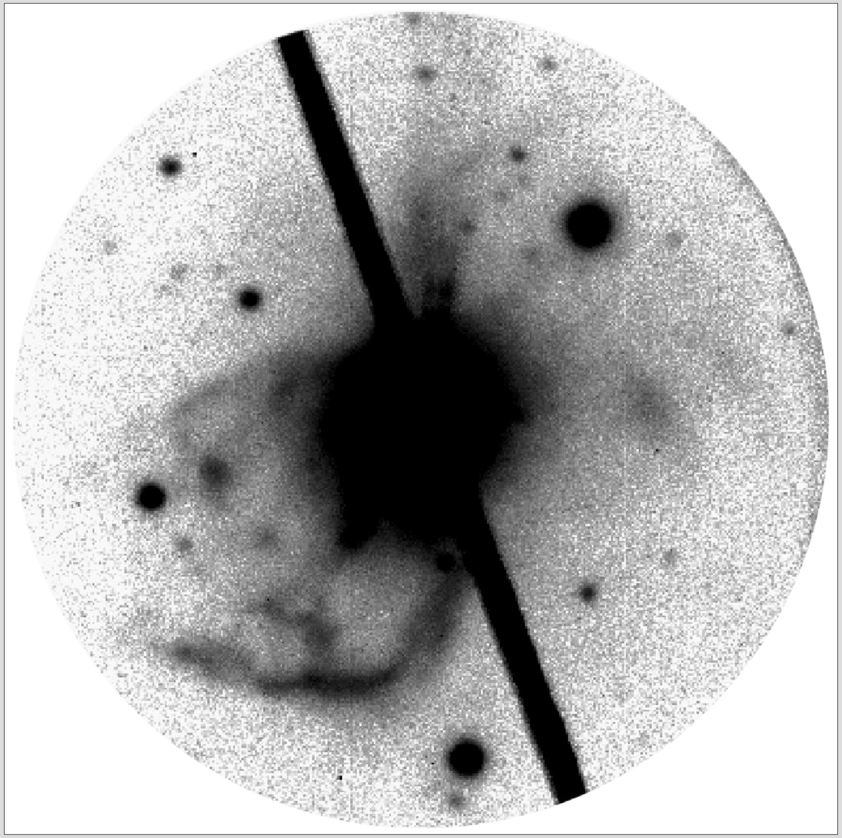
JUST OUT

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

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 ?

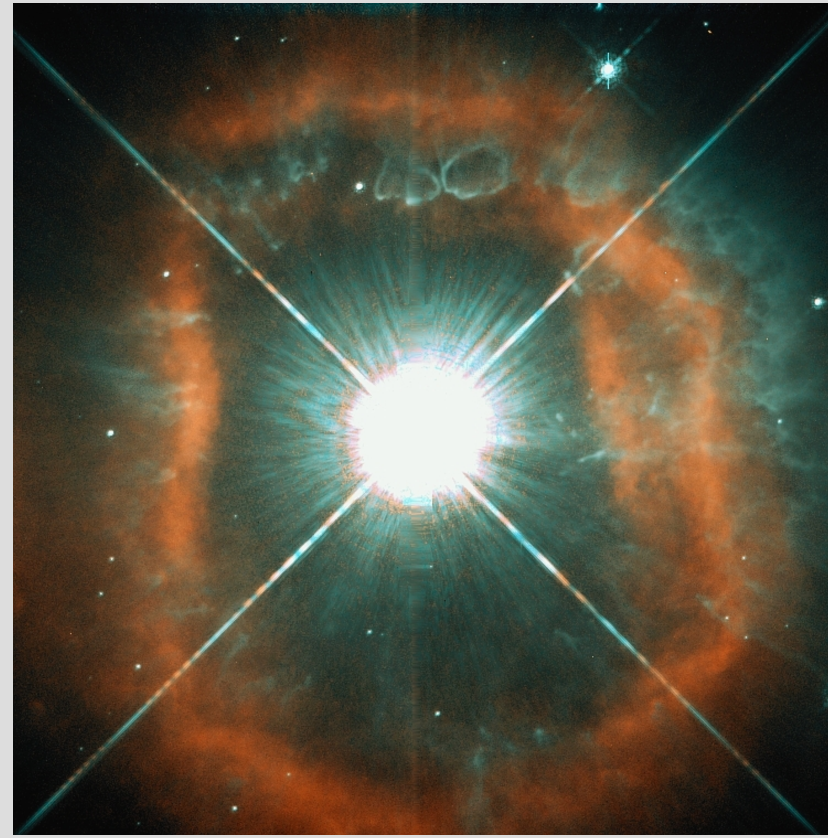
The cause of bipolarity → Rotation ?

HR Car



(Weis et al. 1997)

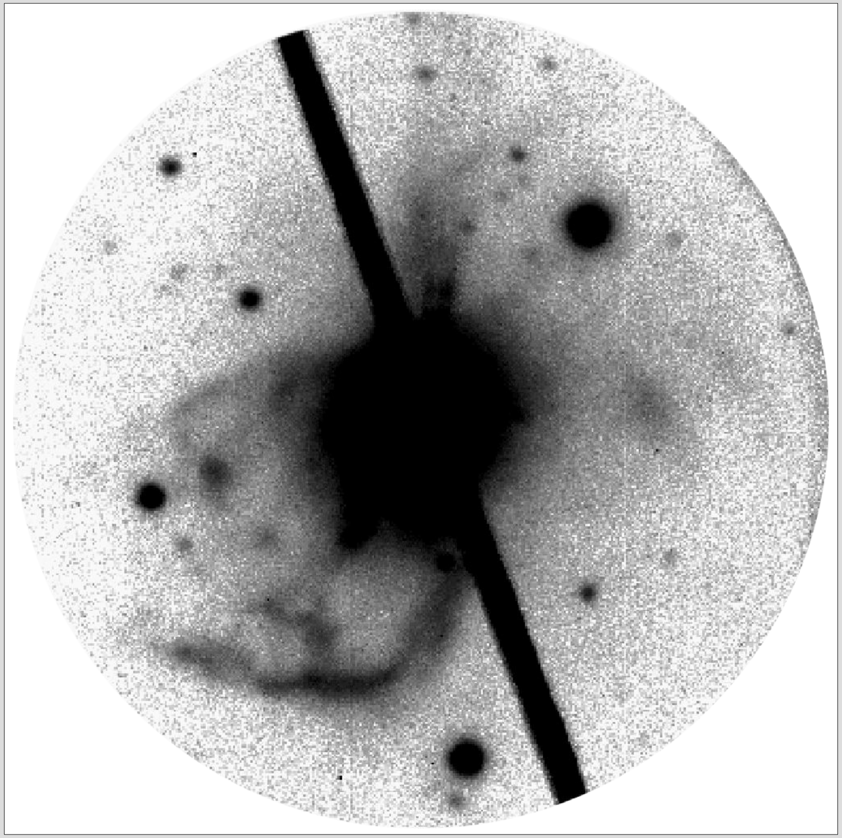
AG Car



(Weis 2009)

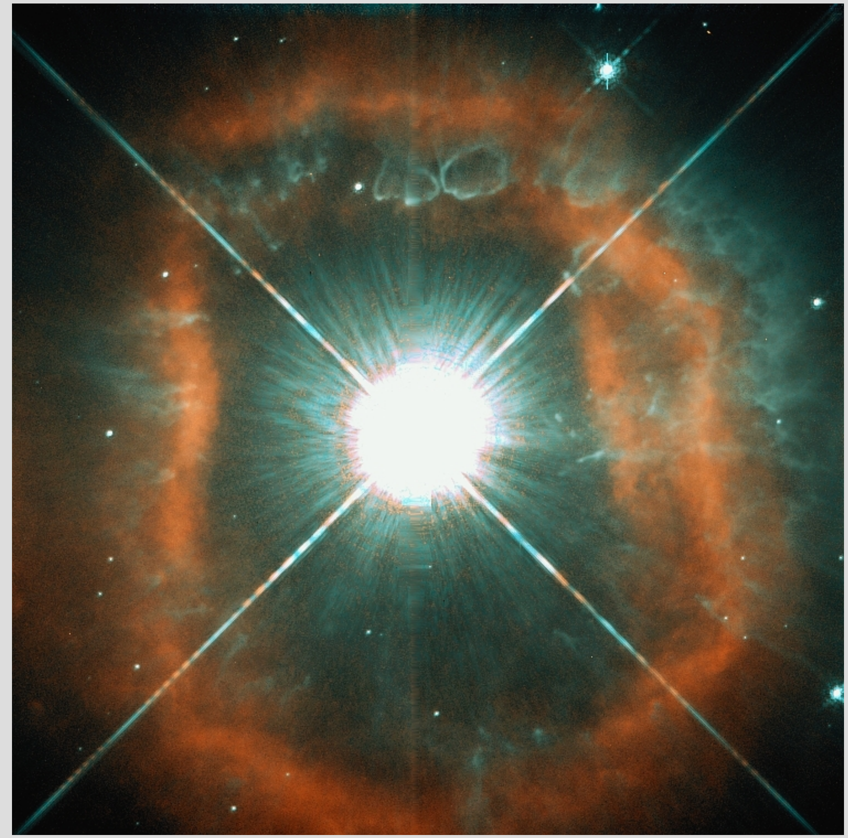
The cause of bipolarity → Rotation ?

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

Conclusions 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**

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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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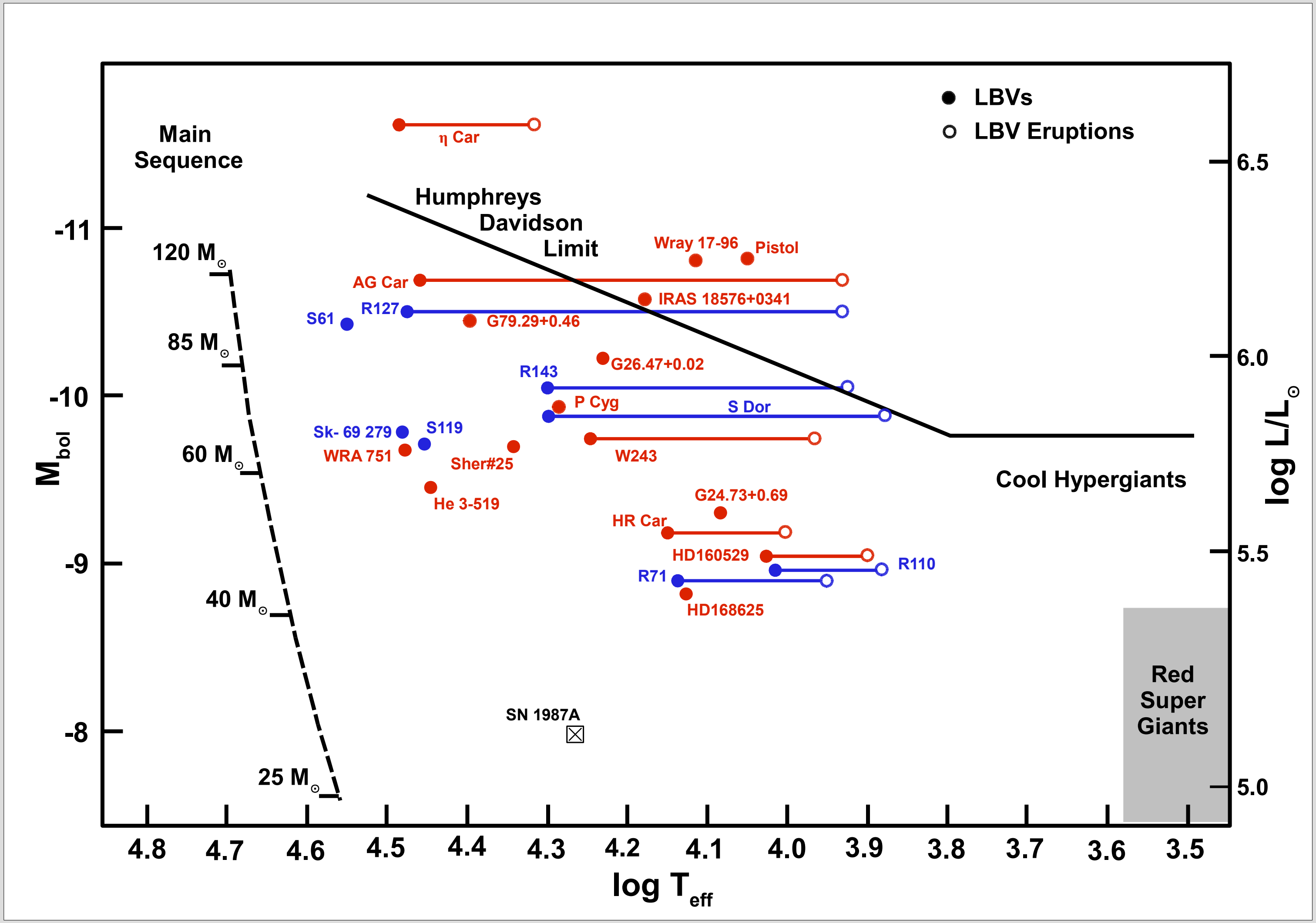
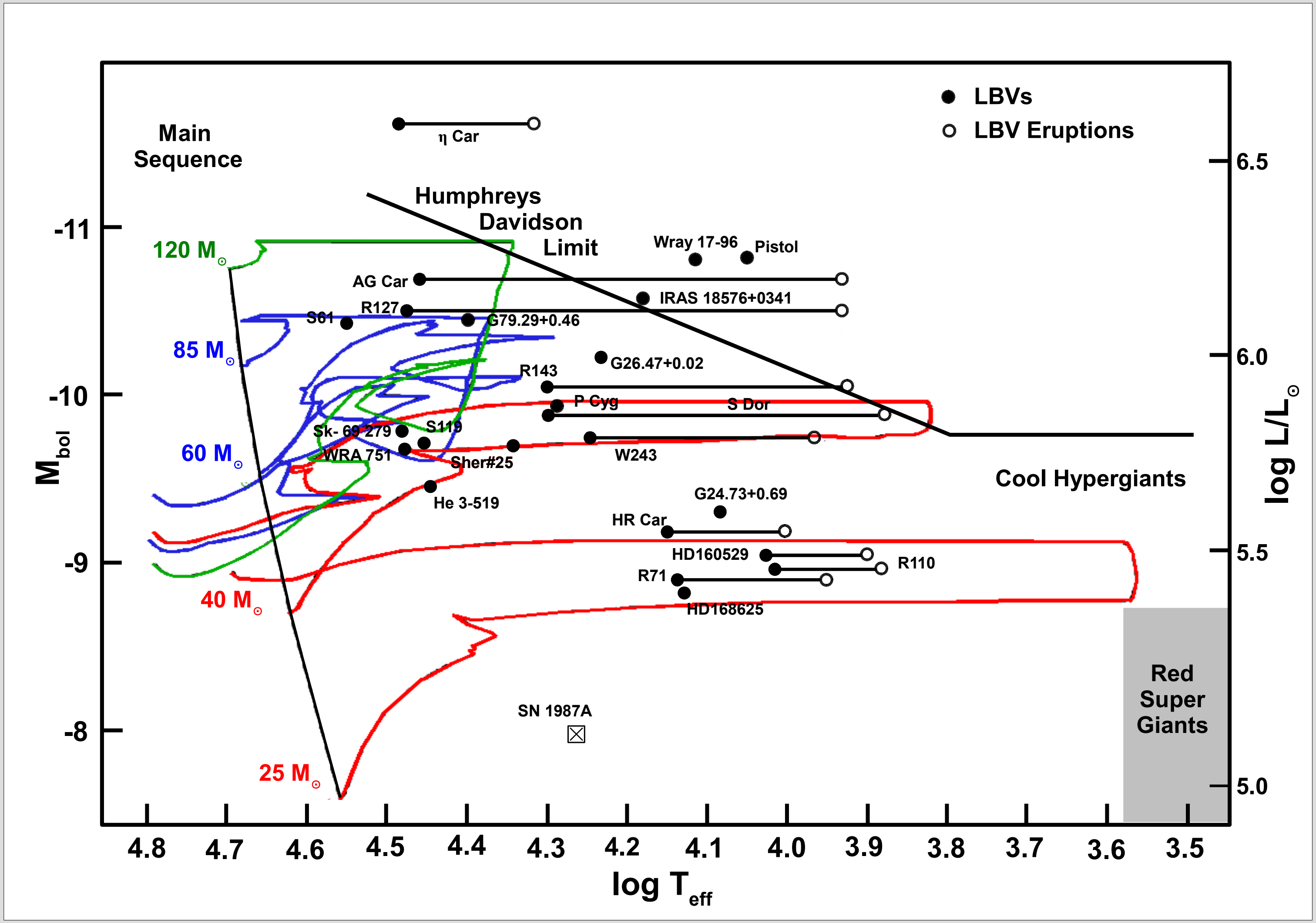
The LBVs in the HRD – the theory side



The LBVs in the HRD – the theory side



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

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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

S Dor cycle

Proximity to instability limit

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S Dor cycle

Proximity to instability limit

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

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There is no unique LBV feature →
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...?

spectral variations

nebula

Proximity to instability limit

S Dor cycle

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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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 **Galaxy**
- 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 **Galaxy**
- some LBV nebulae show **multiple shells**

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