STAR
Space sciences, Technologies and Astrophysics Research

LIÈGE université

Observations of massive stars with the ILMT: what can we learn from (variability) studies using the ILMT?

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Outline

I. What are we talking about ?

1. A few words about massive stars
2. The multiplicity of massive stars

II. What can we expect to do ?

1. Analysis of photometric light curves
2. Long term variability of evolved massive stars
3. Spectral classification of Wolf-Rayet stars
4. Expectations and challenges

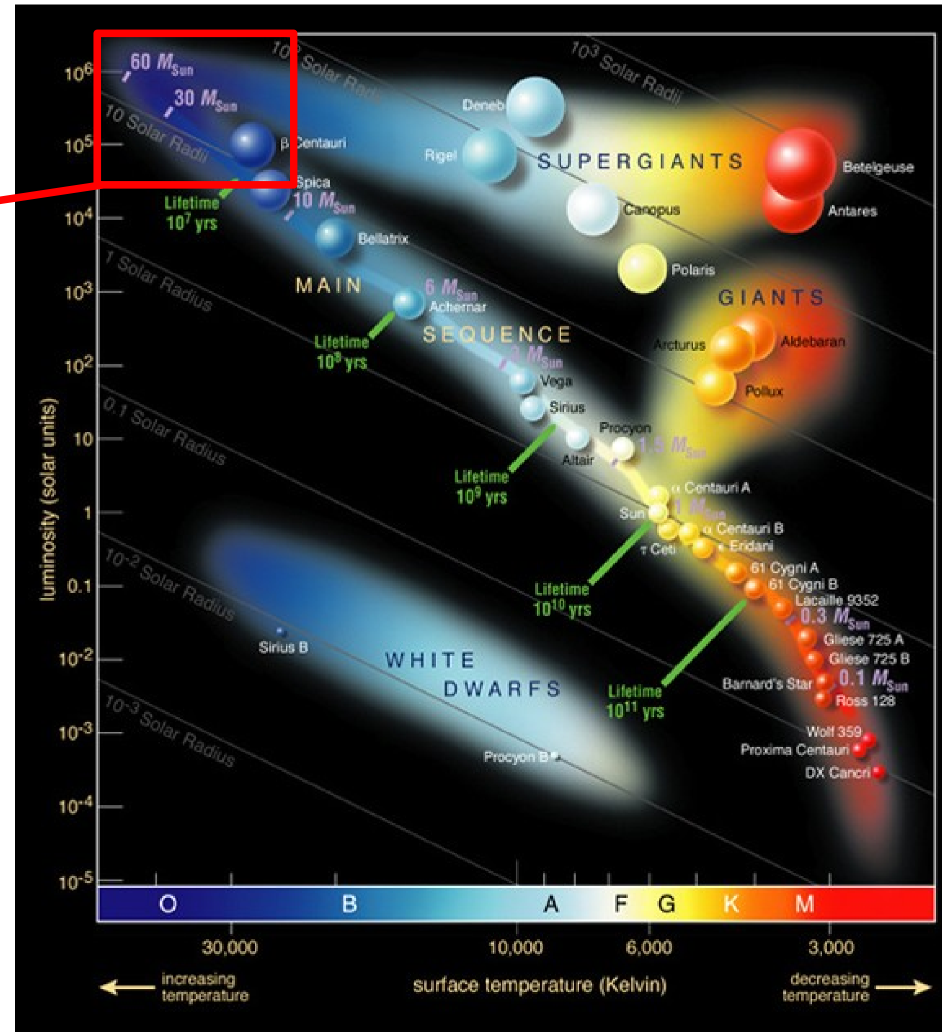
III. Concluding remarks

What are we talking about ?

1. A few words about massive stars

[Hertzsprung-Russel diagram]

Most massive stars in the upper left corner



Mass:

Typically larger than 8 – 10 M_{sol}

(focus on $M > 16\ M_{sol}$)

Luminosity:

Larger than $10^4\ L_{sol}$ (most frequently in the range $10^5 – 10^6\ L_{sol}$)

Temperature:

Larger than 20000 K (up to ~10^5 K)

Evolution time-scale:

A few/several Myr (up to ~10 Myr)

1. A few words about massive stars

A crucial feature of massive stars: the **stellar wind**!

Conversion of radiative energy into mechanical energy!

Consequence of the high luminosity
→ **strong radiation pressure**
→ massive stars lose large amounts of material during their evolution time
→ **influence the evolution (WR, ...)**

- Depending on the spectral type/evolutionary stage, typical **mass loss rates** are in the range **10^{-7} – 10^{-5} M_{sol}/yr**
  (mass loss rate of the solar wind ~10^{-14} M_{sol}/yr)

- Ejected material can reach quite high speeds:
  Terminal velocities typically of the order **1000 – 3000 km/s**

As a result, a huge amount of kinetic power is ejected into the interstellar medium

$$P_{kin} = \frac{1}{2}\dot{M}\,V_\infty^2 \longrightarrow P_{kin} \approx 3.16 \times 10^{35}\,\dot{M}_{usual}\,V_{\infty,usual}^2 \quad \text{(erg / s)}$$

Important for energy budget considerations and for their feedback on the ISM !

[Usual units are M_{sol}/yr and km/s]

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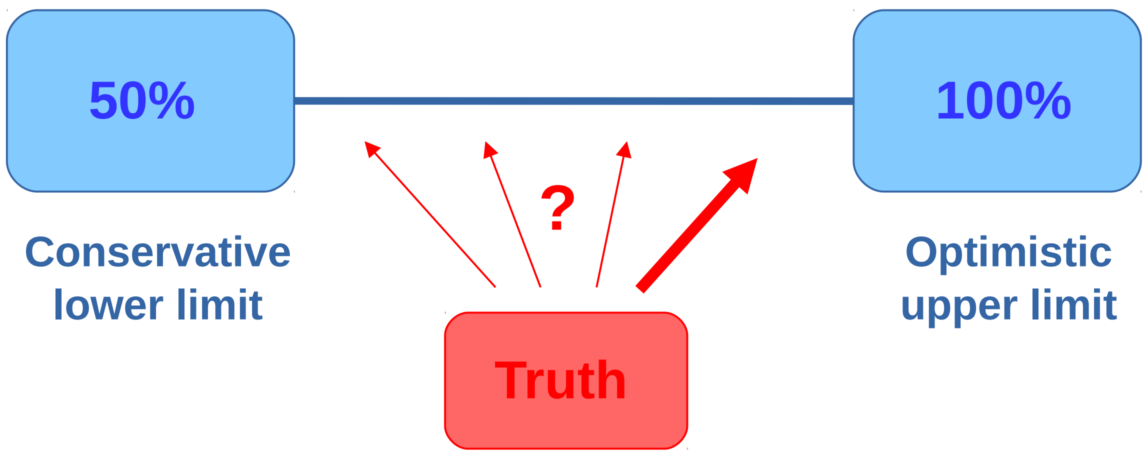
2. Multiplicity of massive stars

Binary and higher multiplicity systems

What is the fraction of binaries among massive stars?



Binarity is not a rare feature among massive star populations

Some references:

Sana & Evans 2010, IAU Symp. 272, 474

Sana et al. 2012, Science, 337, 444

2. Multiplicity of massive stars

Binary and higher multiplicity systems

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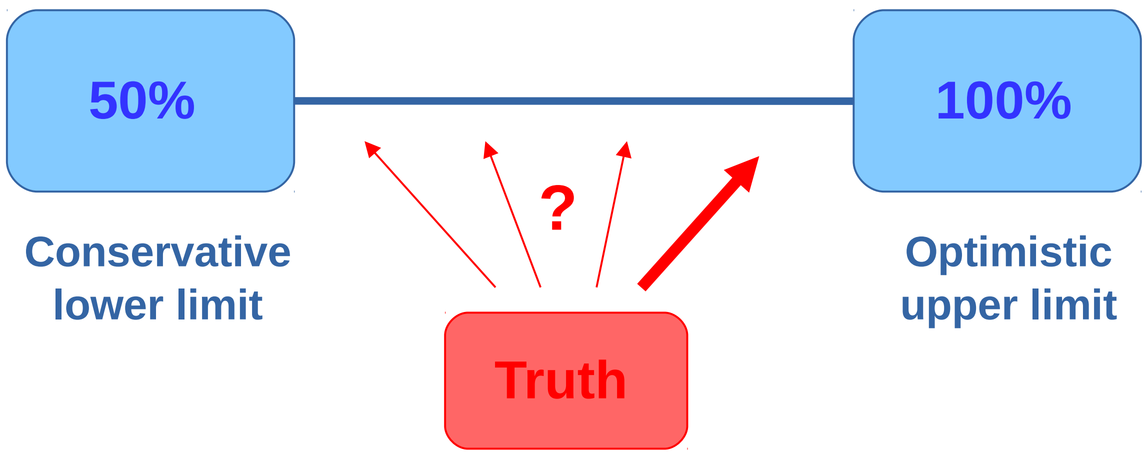

Binarity is not a rare feature among massive star populations

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→ multiplicity is a crucial feature of massive star populations, and it constitutes an obvious source of periodic variability

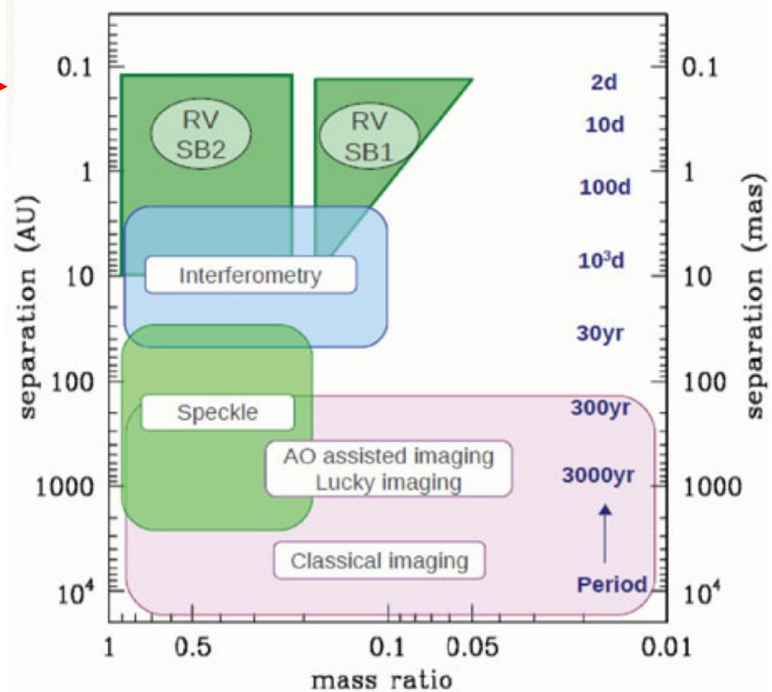
2. Multiplicity of massive stars

Binary and higher multiplicity systems

Period:
From a few days up to centuries...
Eccentricity:
From 0.0 (short period) up to ~0.9 (long period)
Circularization occurs on time scales much shorter than the evolution time scale for short period systems.

Photometric variations induced by an orbital motion (eclipse, ellipsoidal variations...) will be associated to short period systems, whose orbits are most probably circular.

Identification of binary systems:
Various techniques are used, and are more or less adequate depending on the period, inclination, mass ratio...



Sana & Evans 2010, IAU Symp. 272, 474

Photometry adequate for short period systems (the most abundant ones)

What can we expect to do ?

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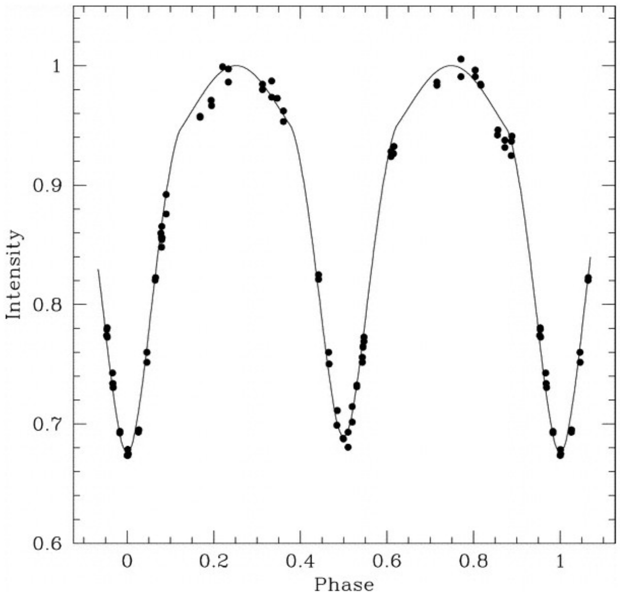
1. Analysis of photometric light curves

What is the outcome of LC analysis?

Investigation of eclipsing binaries :
→ characterization of the shape of eclipses
→ determination of the inclination (i)
→ minimum masses (M $\sin^3 i$) can be converted into *absolute masses (M)*



Bonanos et al. 2004, ApJ, 611, L33

WR20a: one of the most massive binaries that benefited of spectroscopic and photometric measurements

Minimum masses determined by the RV curve analysis
→ $M_1 \sin^3 i = 74\ M_{sol}$ and $M_2 \sin^3 i = 73.3\ M_{sol}$

Determination of the period and inclination thanks to the photometric light curve
→ P = 3.686 d   i = 74.5°

→ Absolute masses:
$M_1 = 82.7\ M_{sol}$ and $M_2 = 81.9\ M_{so}$

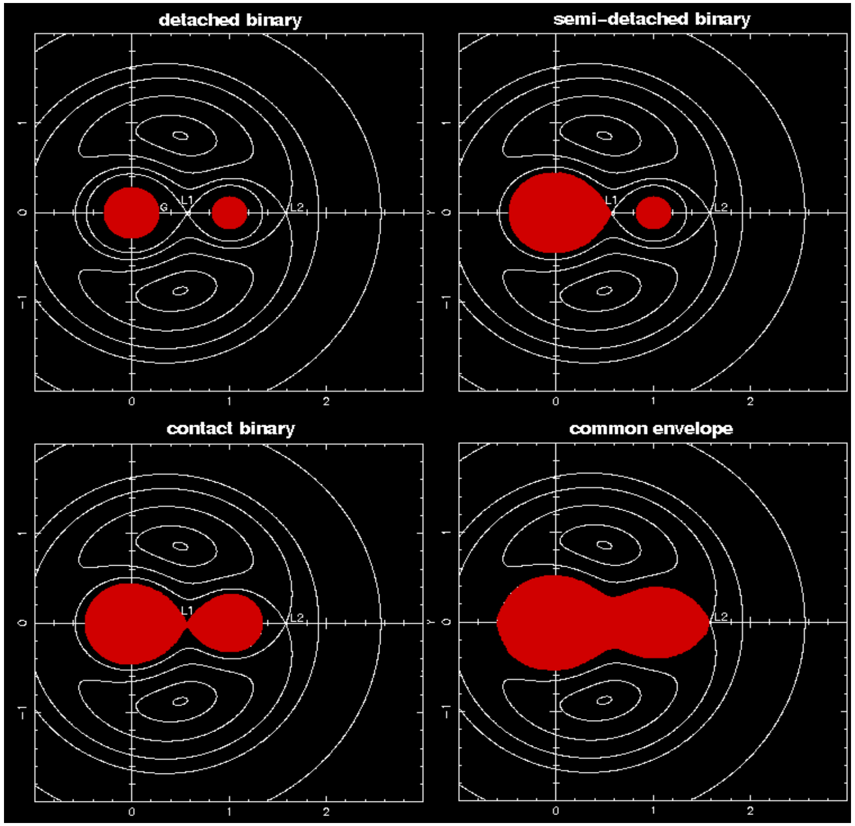
Photometric light curves used in complementarity with radial velocity curves (←spectroscopy) allow us to determine absolute stellar masses.

1. Analysis of photometric light curves

What is the outcome of LC analysis?

Among massive binaries, many are in short period systems
→ likely to adopt various configurations depending on the filling of the Roche lobes

- detached
- semi-detached
- contact
- common envelope



Photometric light curves offer the opportunity to characterize the shape of such systems
→ establish their configuration and derive physical parameters
→ insight into their evolution

Sana et al. 2012, Science, 337, 444

1. Analysis of photometric light curves

What is the outcome of LC analysis?

VFTS 352 : overcontact binary

Simultnanous fit of photometric light and RV curves

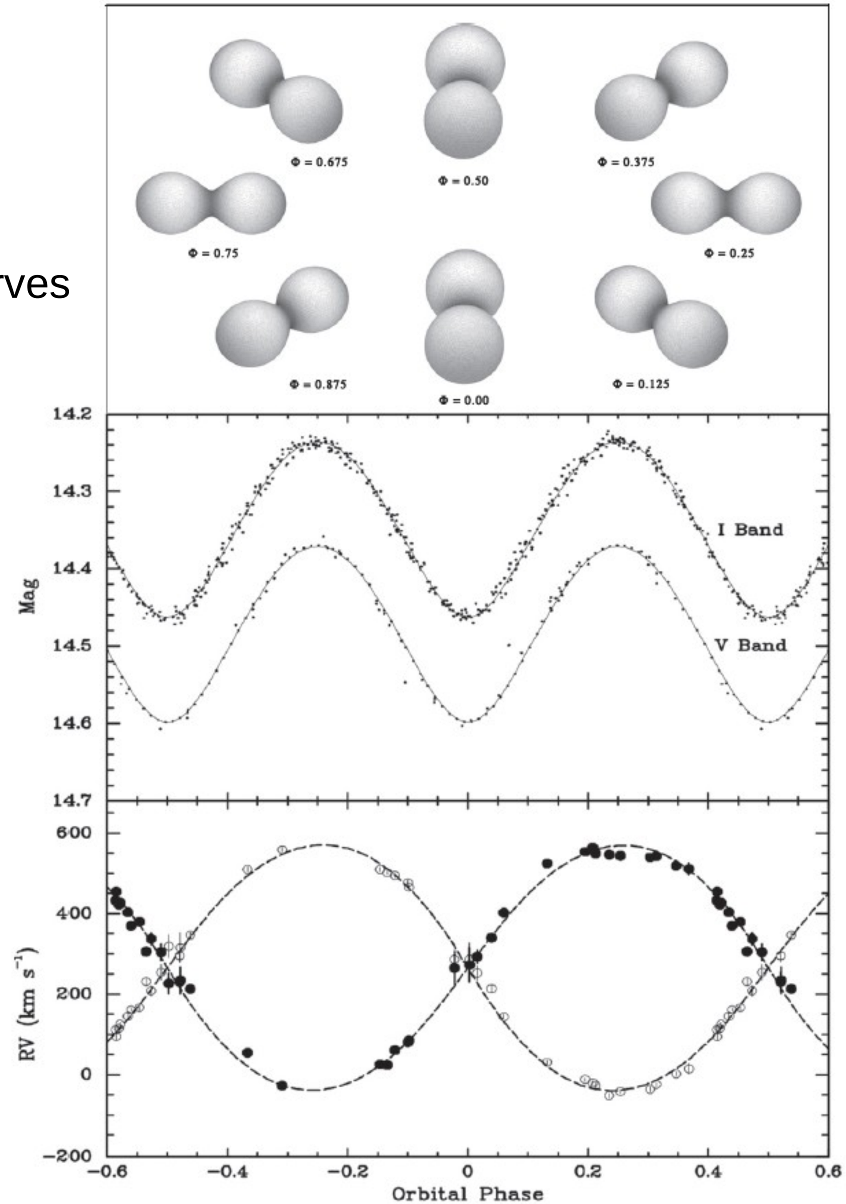
→ various parameters

P = 1.12 d   i = 55.6°

M_1 = 28.63 M_{sol} M_2 = 28.85 M_{sol}

+ other parameters (g, T_{eff} , …)

And... *shape of the system*



High importance of the complementarity between photometric and spectroscopic measurements to derive a full set of system parameters!

Almeida et al. 2015, ApJ, 812, 102

1. Analysis of photometric light curves

What is the outcome of LC analysis?

Survey of many objects in the field of view of the ILMT
→ identification of new massive binaries
→ better statistics on the *binary fraction*
→ relevant *input for stellar population synthesis* modelling

Complementarity with other techniques (spectroscopy, high angular resolution imaging...)
→ identification of short binaries in wider multiple systems
→ better statistics on the *fraction of high multiplicity systems* in stellar populations
→ relevant *input for stellar population synthesis* and *cluster dynamical interaction* modelling

Beside individual studies, a survey approach over an extended sky strip with the ILMT would be insightful for population studies (keeping in mind multiplicity is a crucial feature of massive star populations)!

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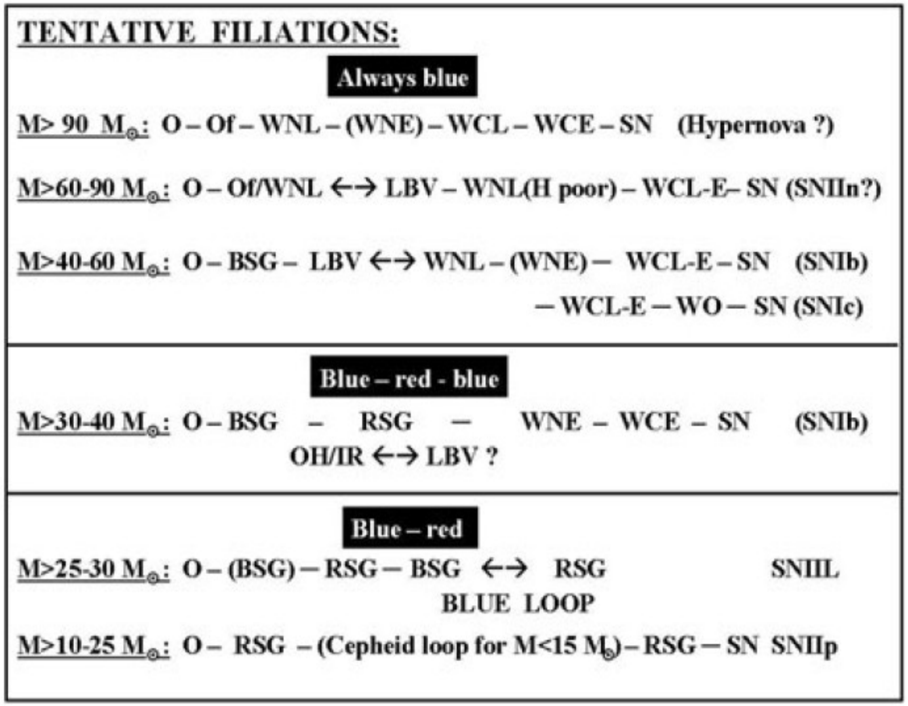
2. Long term variability of evolved stars

Evolved massive stars, in transition somewhere between the main sequence and the Wolf-Rayet stages
→ Luminous Blue Variables (LBV)

Short duration evolution stage : ~ 10^4 years
→ only a few objects are currently in that phase, and only a small subset is known
→ poorly understood evolution phase, challenging for current models

Humphreys & Davidson. 1994, PASP, 106, 1025



Maeder et al. 2007, IAU Symp. 250, 3

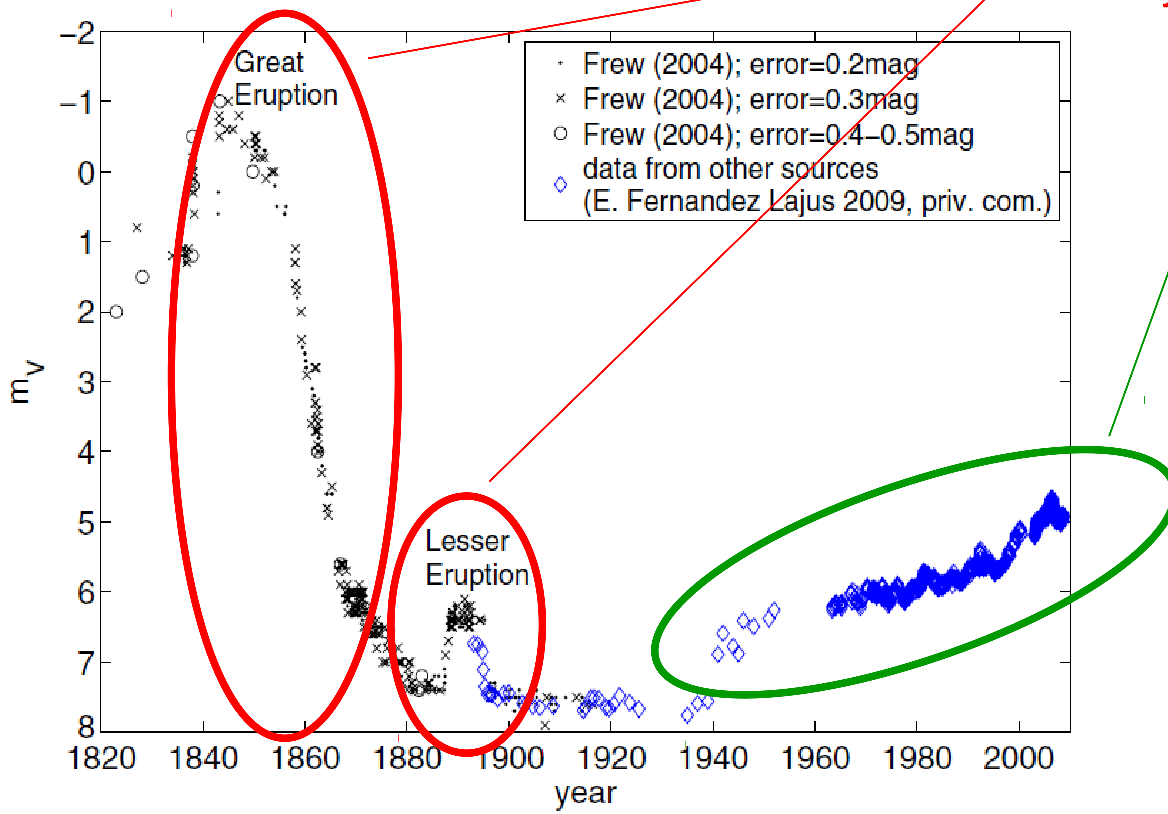
What could be expected from ILMT obervations?

1. A monitoring of stellar populations may reveal new objects in this category. This is a scarce group → *any new member is significant*
2. Very good photometric time sampling → high quality light curves for *detailed analysis*

2. Long term variability of evolved stars

Example of LBV: Eta Car

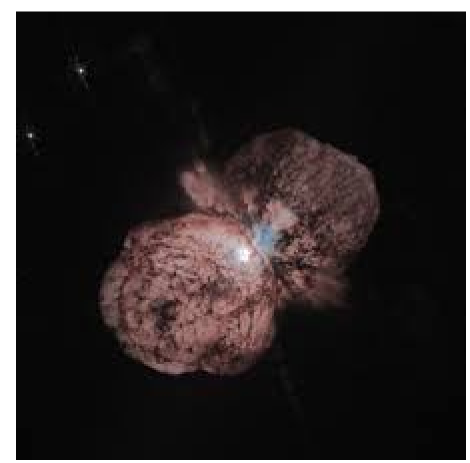
Major events in the 19th Century, GE and LE



Kashi & Soker 2010, ApJ, 723, 602

Shallower evolution in the 20th Century

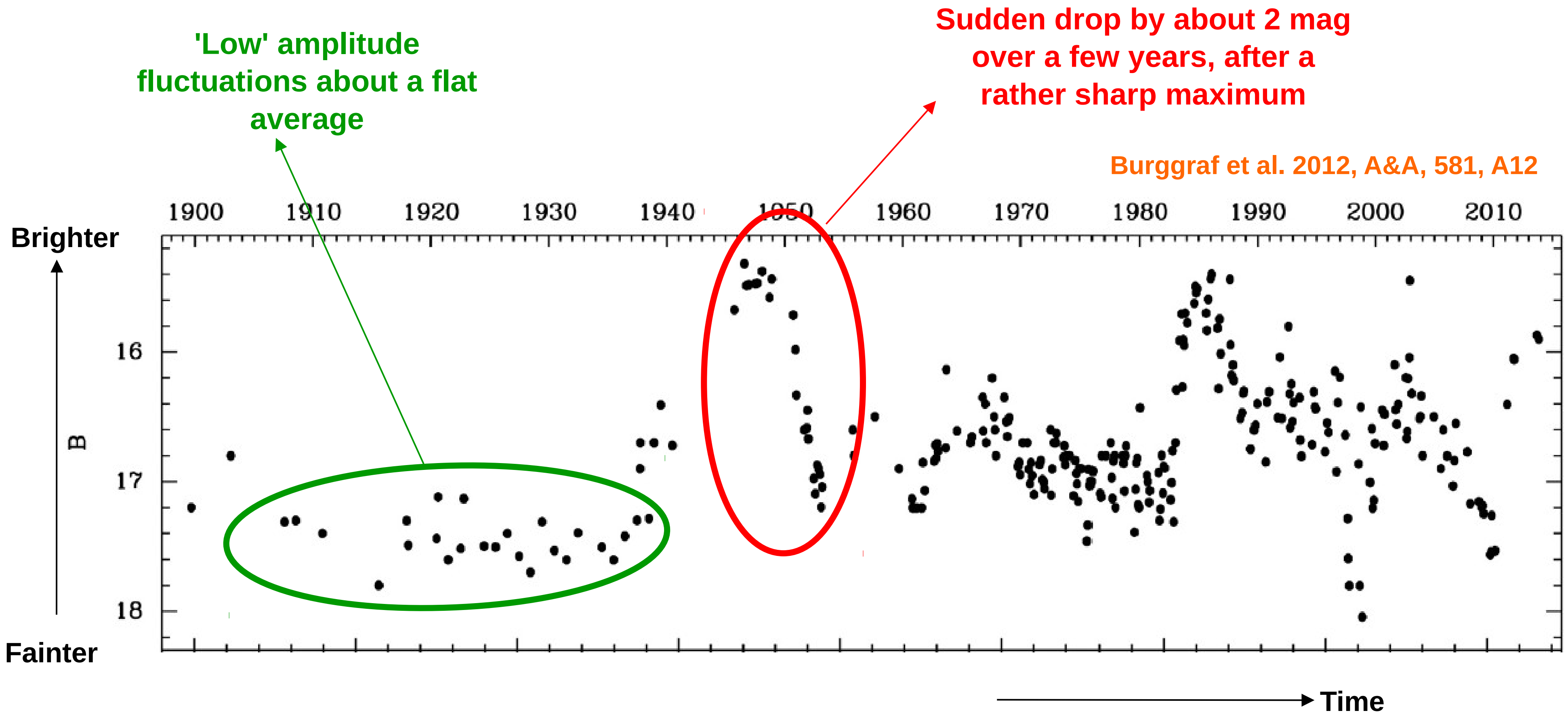
Extreme object, binary system with a period of 5.54 yr, very massive primary, surrounded by a dense nebula



2. Long term variability of evolved stars

Example of LBV: Var C (in nearby galaxy M33, 2.7 Mly)

Strong variations with ΔB up to 2, sometimes over time scales of a few years only
Time analysis → no specific period, potentially multi-periodic



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3. Spectral classification of WR stars

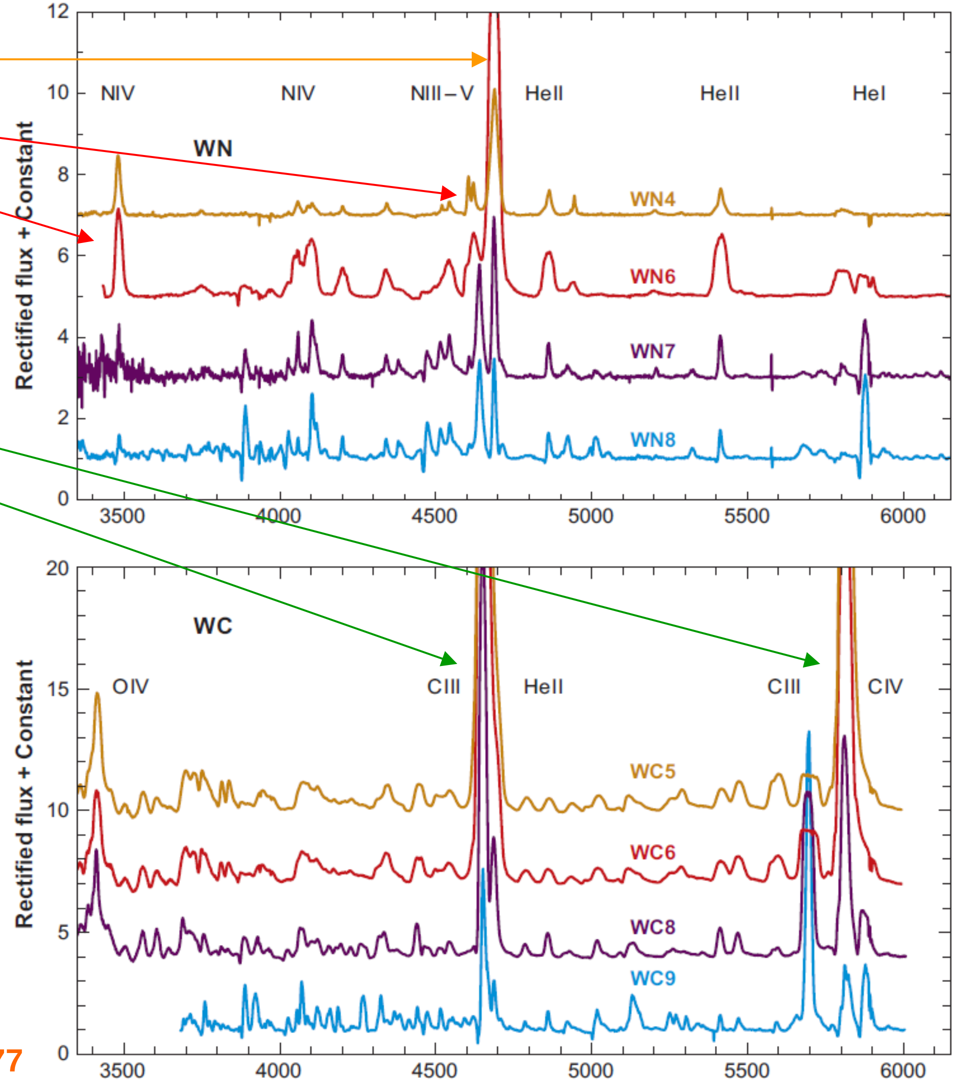
Wolf-Rayet stars: evolved counter parts of O-type stars

WN: enhancement in **N** and in **He**, depletion in H

WC: enhancement in **C**, depletion in He (no more N)

→ narrow band filters are appropriate for the spectral classification

Such a set of filters is not present on the ILMT, but equivalent filters exist: (continuum windows, C IV, He I, He II...)
→ It may be worth to consider such narrow band filters for the ILMT



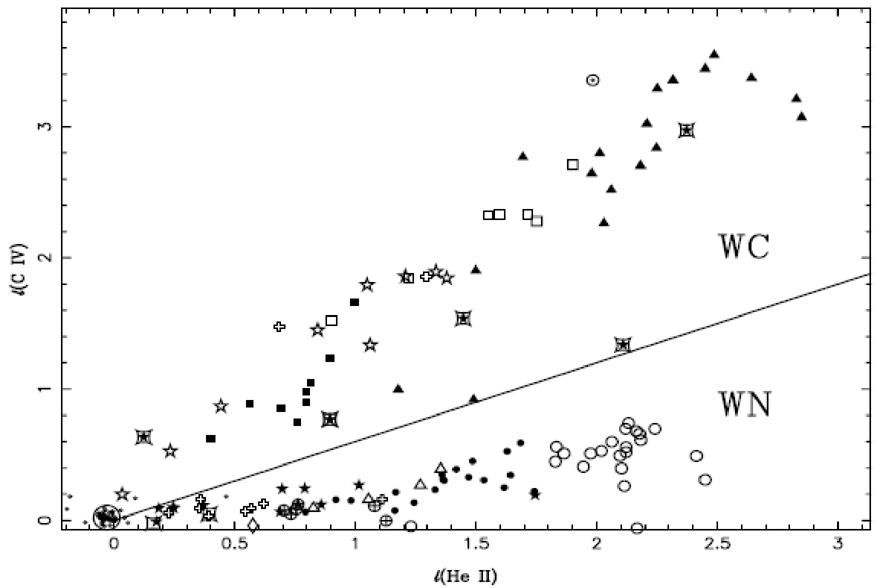
Crowther 2007, ARAA, 45, 177

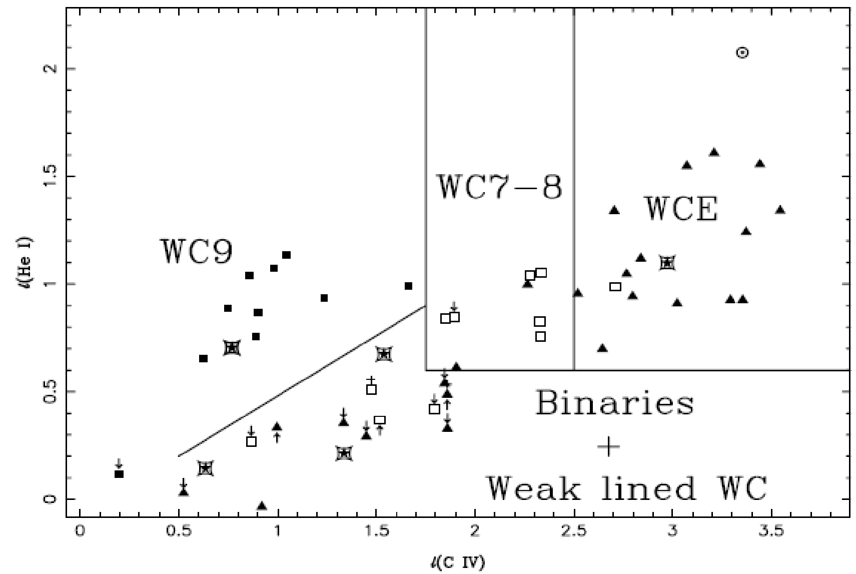
3. Spectral classification of WR stars

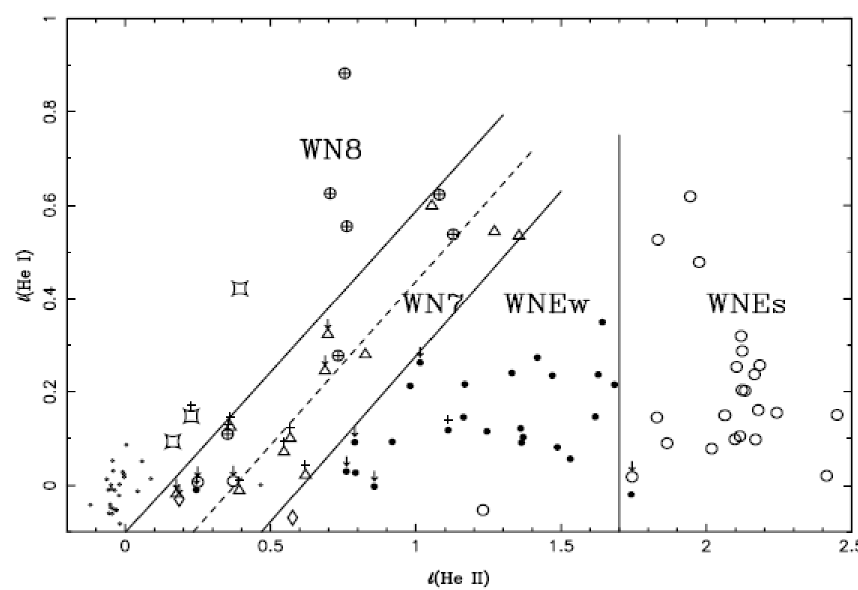
Wolf-Rayet stars: evolved counter parts of O-type stars

→ *spectral classification* of WR stars even in crowded regions where spectroscopic investigations are not always easy

Royer et al. 1998, A&ASS, 130, 407







→ investigation of a *crucial part of the evolution* of massive stars

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4. Expectations and challenges

Positive points:

Very good time sampling : very adequate for variability studies: very important to investigate many time scales (short period binaries, long term variations)

Long time series : accuracy on variability periods, monitoring of slow changes, better chance to catch a sudden change...

→ **highly efficient tool for variability studies on various time scales**

Difficulties:

Galactic massive stars → problem of saturation (?)

… and ...

Massive stars in nearby galaxies → problem of angular resolution (?)

→ **the actual population of objects likely to be investigated is not determined at this stage**

4. Expectations and challenges

→ **Recommendations**

1. A census of nearby galaxies in the sky strip monitored by the ILMT shoud be established

2. A census a galactic open clusters and OB associations falling in the sky strip should be established

3. The relevance of alternative filters (Hα, prominent lines...) should be investigated to optimize observations of massive stars

4. The trade-off between nearby/bright and distant/poorly resolved populations must be addressed in detail

Concluding remarks

Concluding remarks

Sciences cases in relation with the most massive stars may be split into three main categories :

1. Science cases related to their multiplicity :

- Determination of fundamental parameters (M, R, …) → *Important for their evolution !*
- Characterization of their configuration in close binaries (detached, semi-detached, contact, common enveloppe) → *Important for their evolution !*
- Identification of new eclisping binaries (or short period components in higher mutliplicity systems) → *Important for population studies !*

2. Long term variability of evolved objects :

- Identification of additional transition objects such as Luminous Blue Variables → *Important for stellar evolution !*
- Production of detailed light curves with high quality time sampling → *Better characterization of their behaviour !*

3. Classification of massive star populations

- Use of narrow band filters for *objects with prominent emission lines* → *Spectral classification !*
- Stellar populations including Wolf-Rayet stars → *Insight into stellar evolution !*

Concluding remarks

The *International Liquid Mirror Telescope* will constitute a very nice opportunity to investigate massive stars (among other topics), keeping in mind that…

1. The high quality, dense and long term time sampling constitutes the most important asset of ILMT observations

2. The complementarity with spectroscopic studies constitutes a significant requirement for these science cases. This should motivate further to push for the installation of a spectrometer at the *Devasthal Optical Telescope*.

3. Preliminary studies of the massive star population that will actually be monitored in the ILMT field are highly recommended.

4. The possibility to equip the ILMT with alternative filters also deserves to be investigated.

Thank you !