Binary star interactions: periastron events and evolution

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Nidiafest
2018 Nov 5

Collaborators

- Nidia Morrell (Las Campanas, The Carnegie Observatories)
- John Hillier (University of Pittsburgh)
- Edmundo Moreno (IA-UNAM)
- Rodolfo Barbá (Universidad de la Serena)
- Roberto Gamen (Universidad Nacional de la Plata)
- Norbert Langer (Argelander Institüt, Universität Bonn)
- Frédéric Masset (ICF-UNAM)

Connections shared with Nidia

- Nolan, Phil,Virpi, Miguel Roth

Massive star – SN connection

Structure of the SN progenitor

- How did it get to have that structure?

Structure of the CSM at time of SN

- Wind mass loss
- LBV eruption events

Massive star – SN connection

Structure of the SN progenitor

- How did it get to have that structure?

Variable H, He content

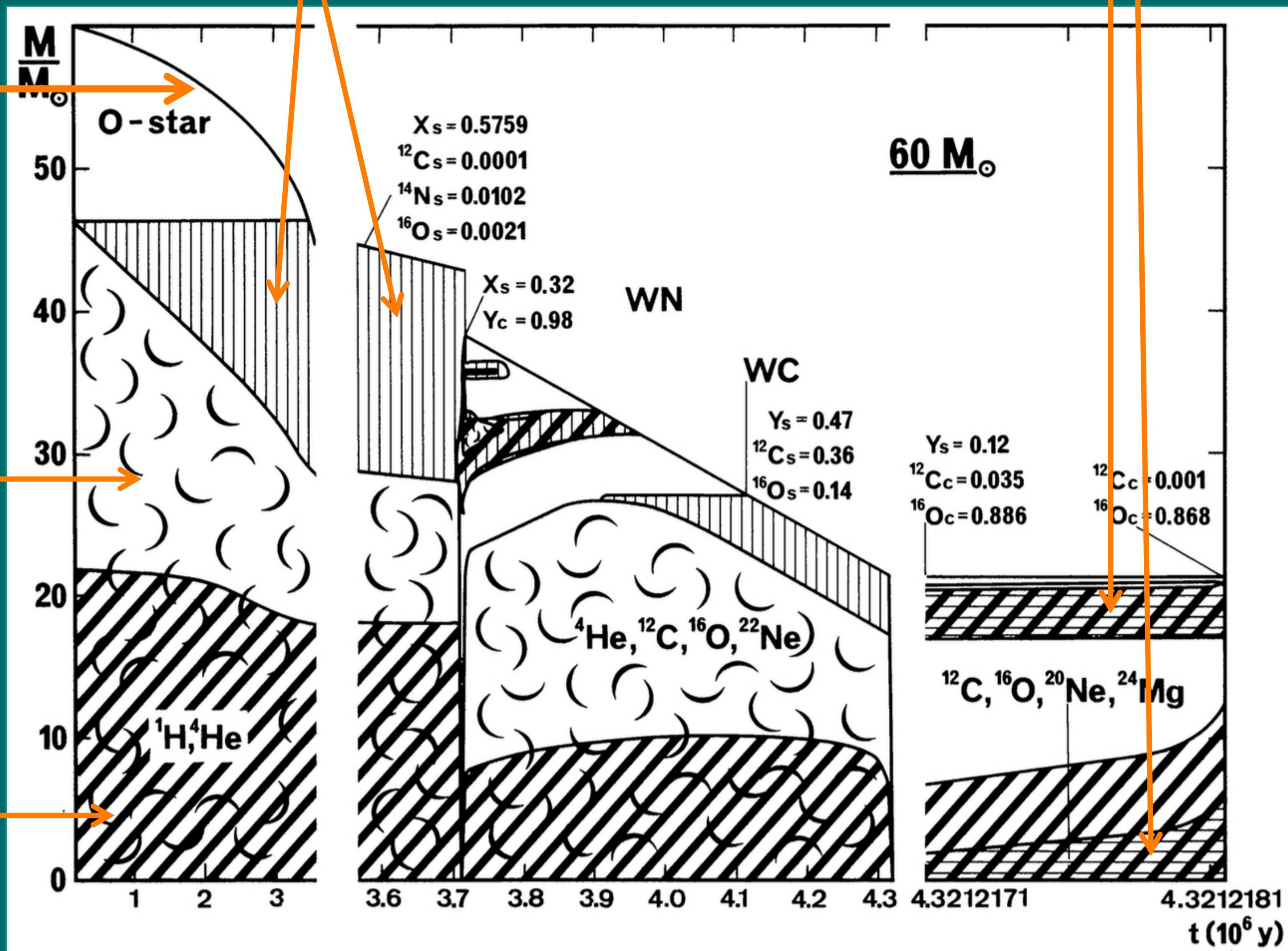
$V_{rot}=0$

Variable C, O, Ne content

Photosphere

Convection

$\varepsilon > 10^3$ ergs/s-gram



H-burning

He-burning

End of C-burning

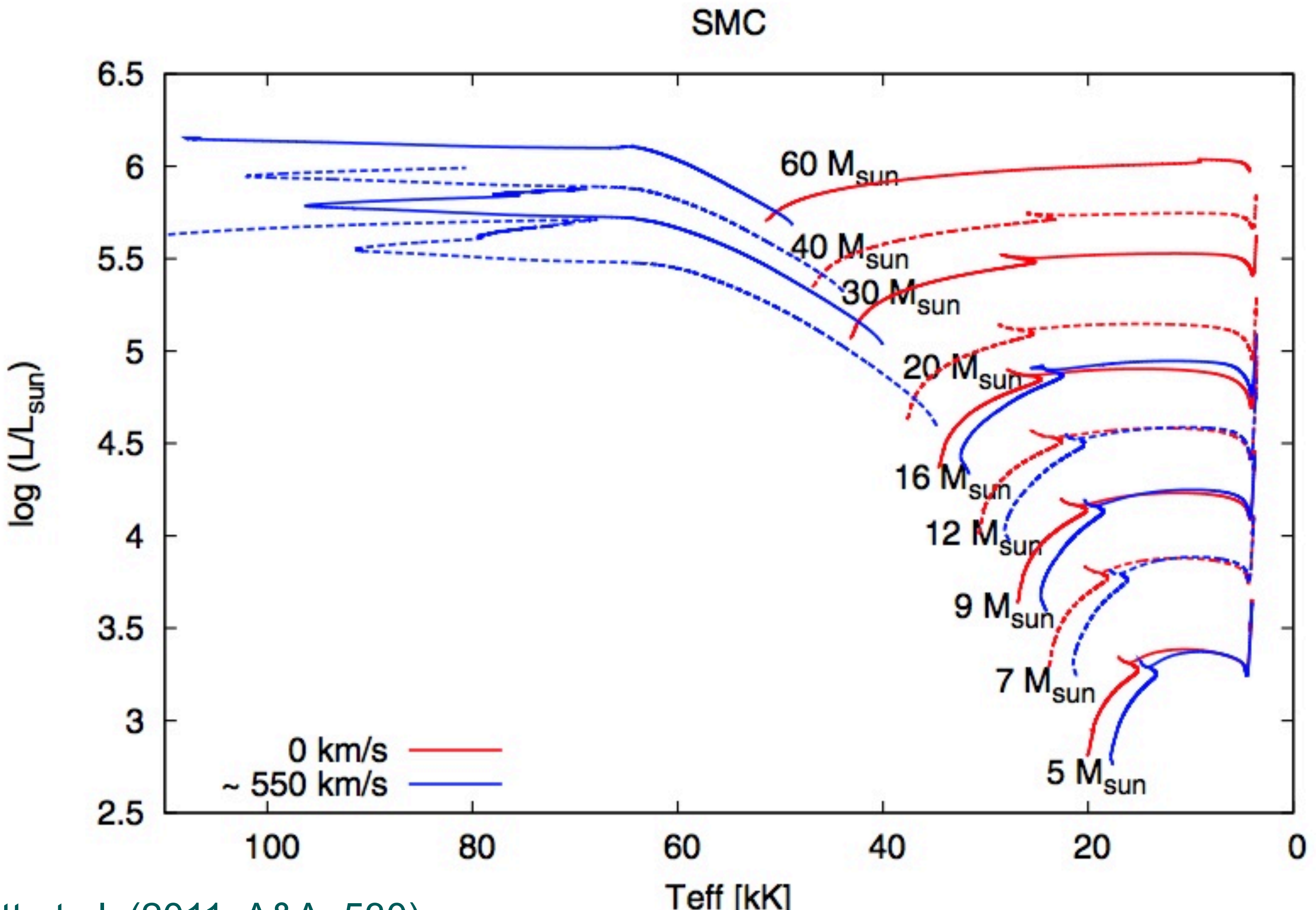
Reference: Maeder & Meynet 1987

Structure

As time passes, structure is determined by

- a. Mass loss
    - Wind
    - Eruptions
    - RLO
- b. Degree of internal mixing
    - Differential rotation

More mixing larger core longer life



Brott et al. (2011, A&A, 530)

Highly mixed, larger core; Rotation is a proxy for mixing

Stellar Structure

Single stars

Complex problem

Binaries ?

“The evolution of binary stars does not differ from that of single stars unless they get in each other’s way”

Hurley, Tout & Pols (2002)

When does a companion get in the way?

Standard scenario: Roche Lobe Overflow

Hypothesis:

But even long before RLO phase is reached

tidal perturbations

could affect the structure

Outline

- Case study: HD 5980
- Perturbing effect of a binary companion
- Suggestions for further progress

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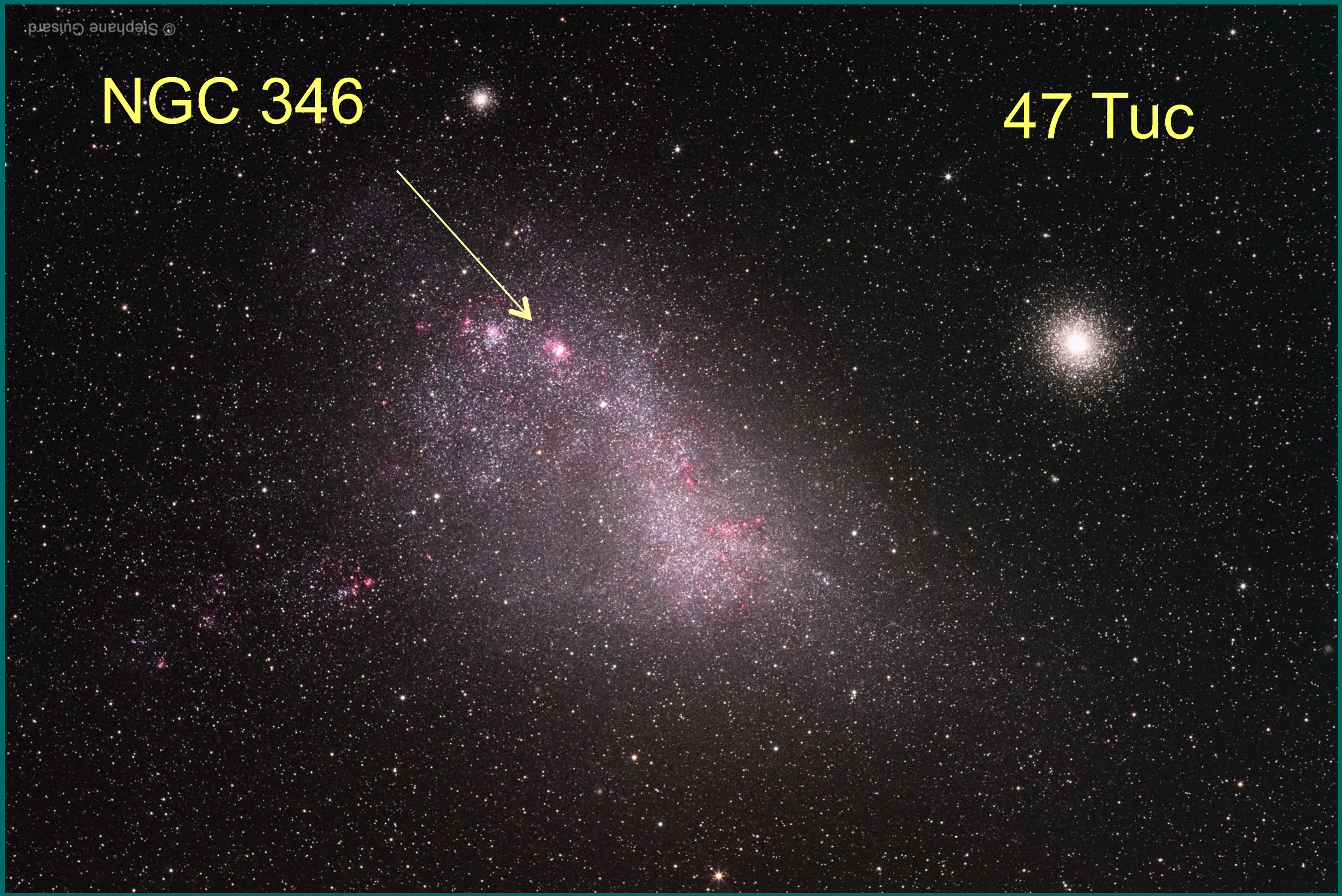
SMC



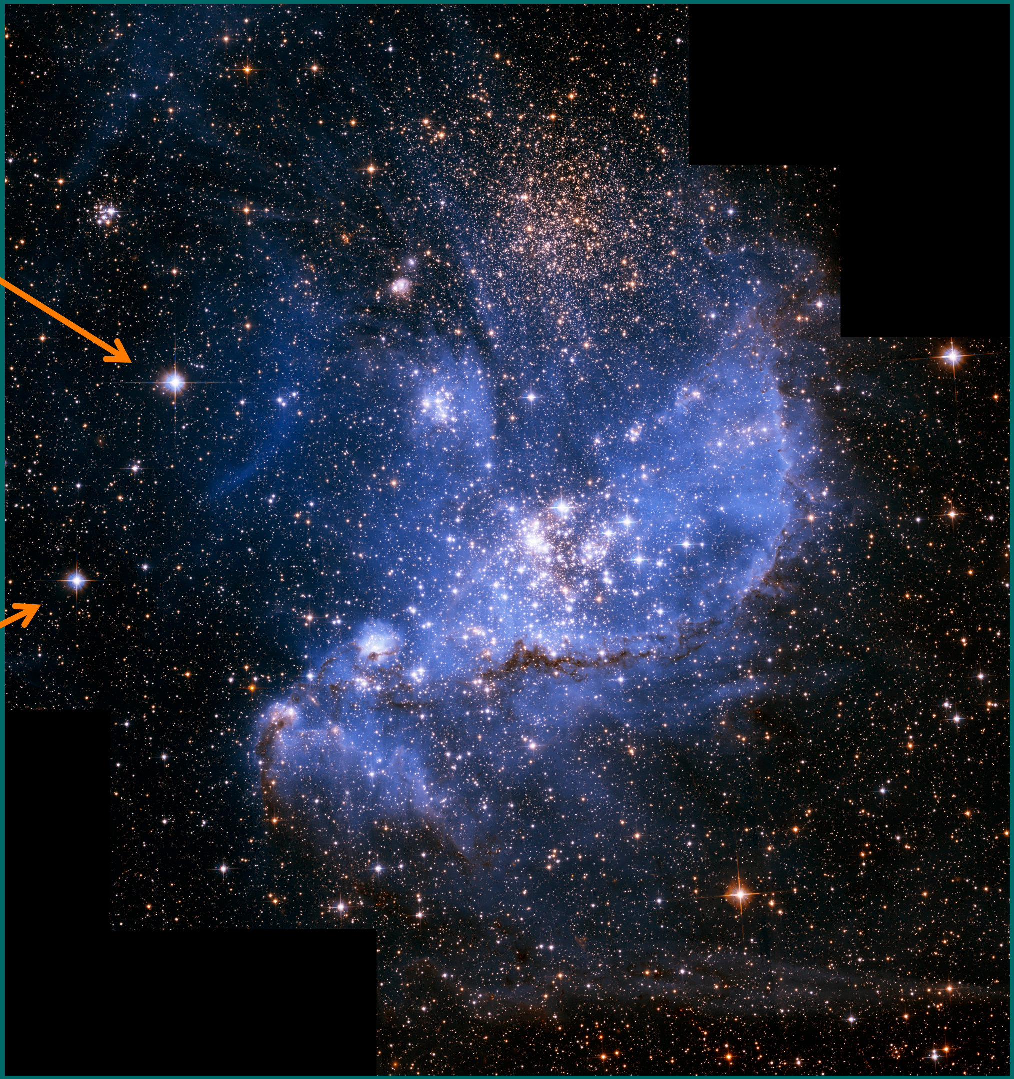
Guisard, APOD

NGC 346 HST

HD 5980

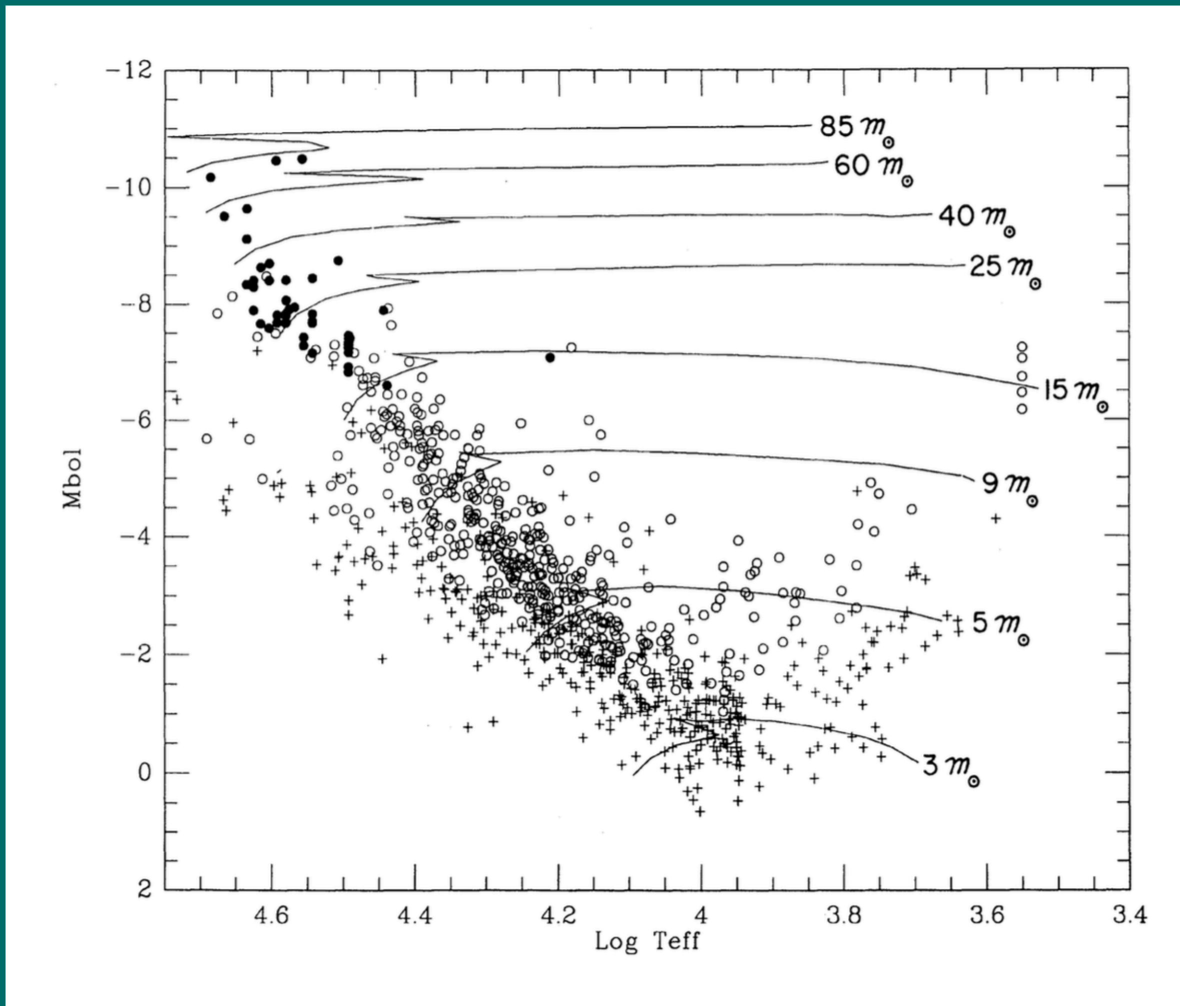
Age: 2-3 Myrs (Mokiem et al. 2007)

Sk 80
O7If



Nota et al.

NGC 346 HRD

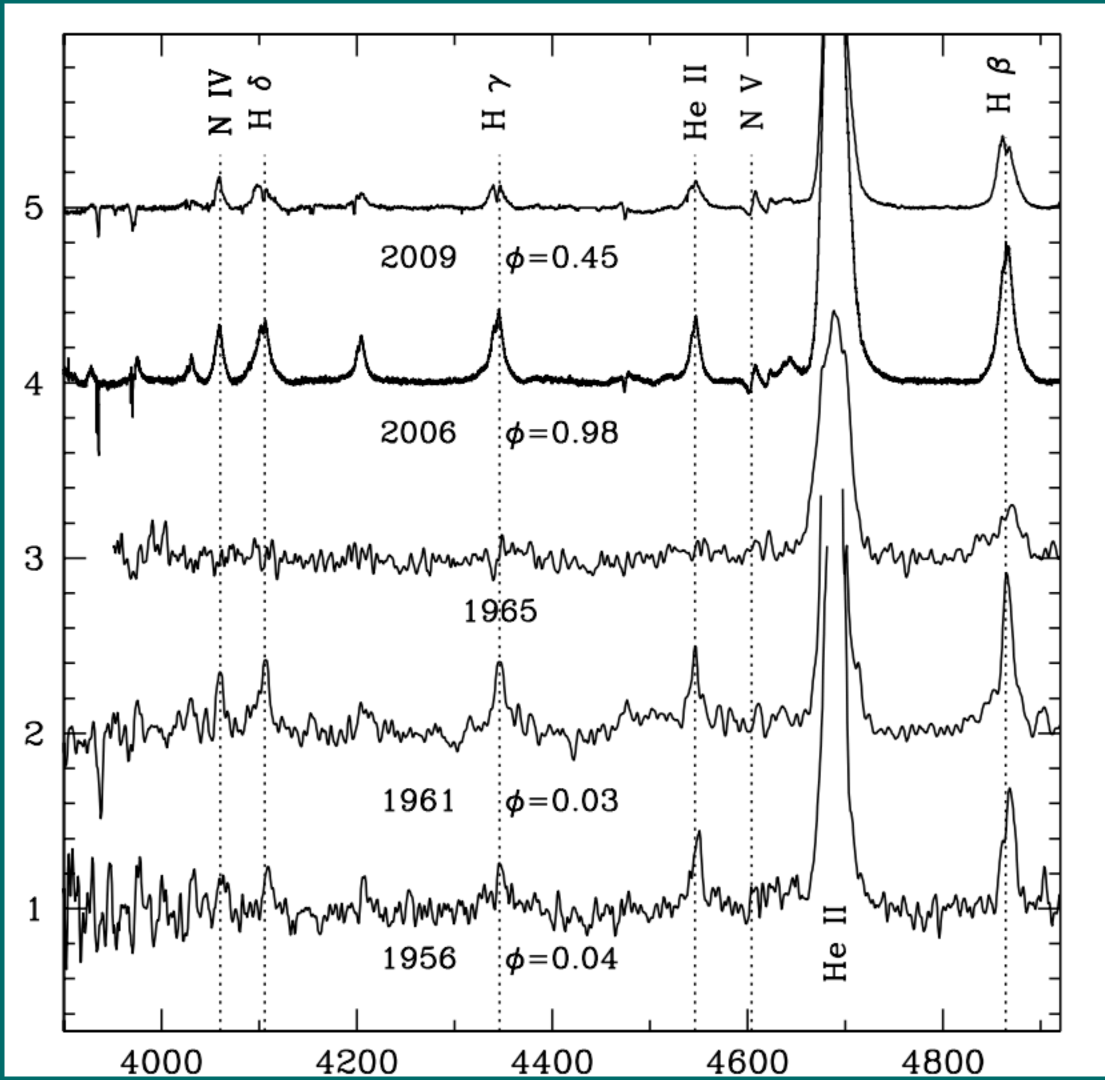


Massey et al. 1989

Stellar content:

876 stars measured
33 O-type stars
~11 with >35 M_o
1 WR (binary)

Optical spectra since 1956: WR



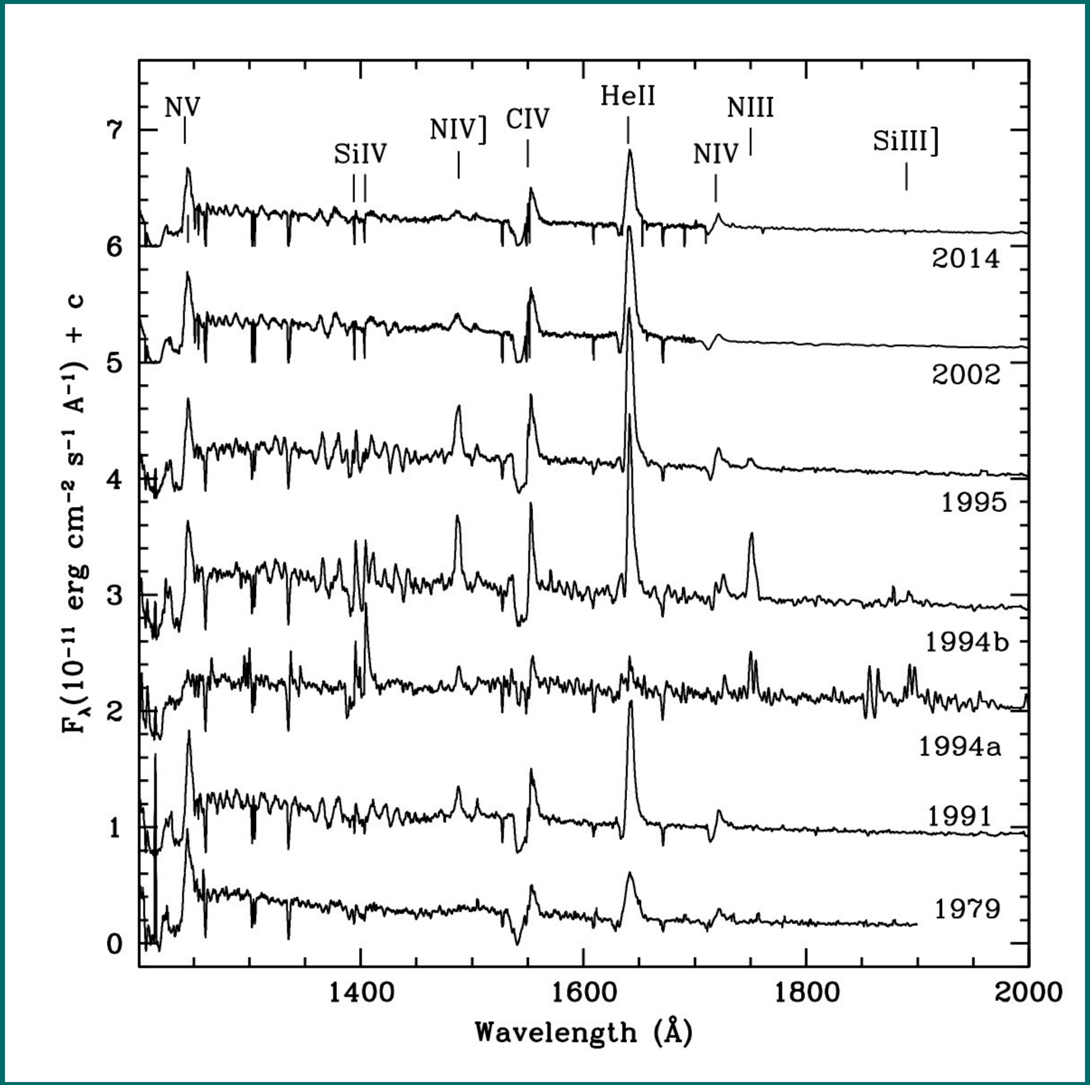
Koenigsberger et al. 2010

UV spectra since 1979

2009

1994

1979

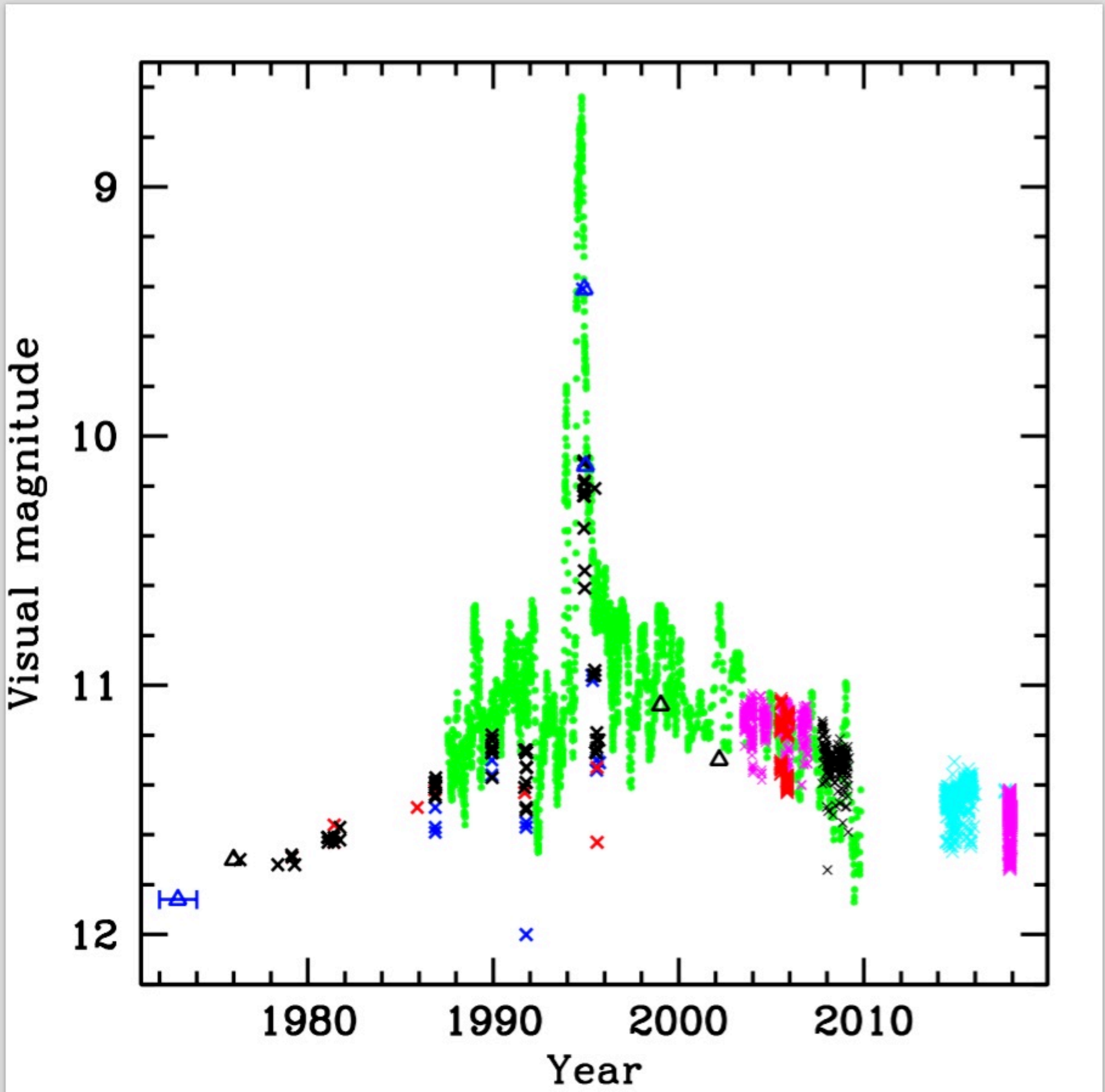


WN6

WNL

Eruption

WNE


Visual magnitude
9
10
11
12
1980
1990
2000
2010
Year

What we know thus far

A+B system	WR + WR	19.3d	e=0.3
	61 + 66 M_o		
	~20 R_o		
C system	Of + ?	96.4d	e=0.8

Star A erupted

Parameters from *CMFGEN* fits

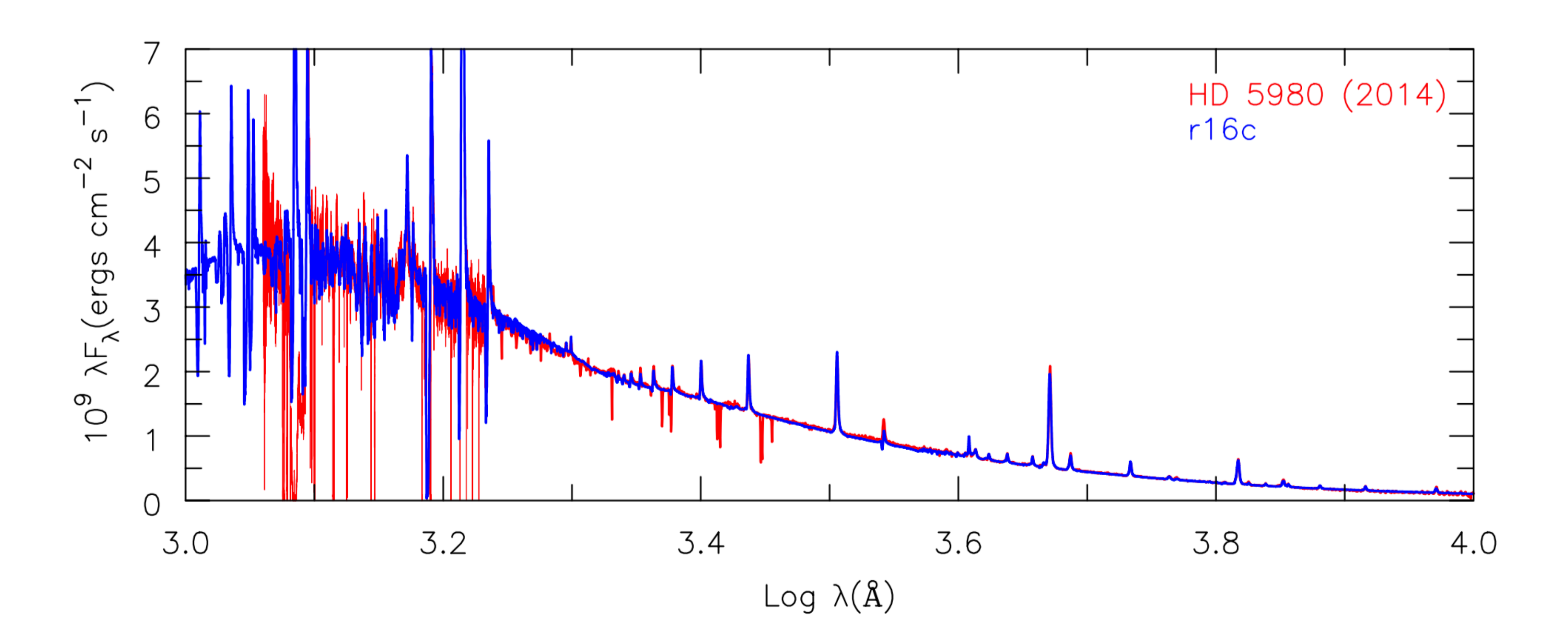
Star A parameters

	1994	2000	2002	2009	2014
R_{10}/R_o	28	20	21	19.3	19
$R_{2/3}/R_o$	124	34	32	28	24.2
T_{eff}/kK	23	37	40	43	43
T_*/kK	47	48	50	47	48
M_{dot} 10^{-5} M_o/yr	17.5	5.5	4.0	3.6	2.2
$\log(L/L_o)$	6.6-7	6.3	6.4	6.4	6.2
v_∞ /km/s	460	2100	2100	2500	3000:
v_{esc}/km/s	460	740	730	760	910:
Γ	0.75	0.53	0.53	0.53	0.33
He/H by number	0.75	M_A=61 ±10 M_o M_B=66±10 M_o			

Drissen et al. 2001; Koenigsberger et al. 1998; 2014; Georgiev et al. 2011; Shenar et al. 2016; Hillier et al. 2019

Parameters: CMFGEN model fits

HST/STIS: 2014

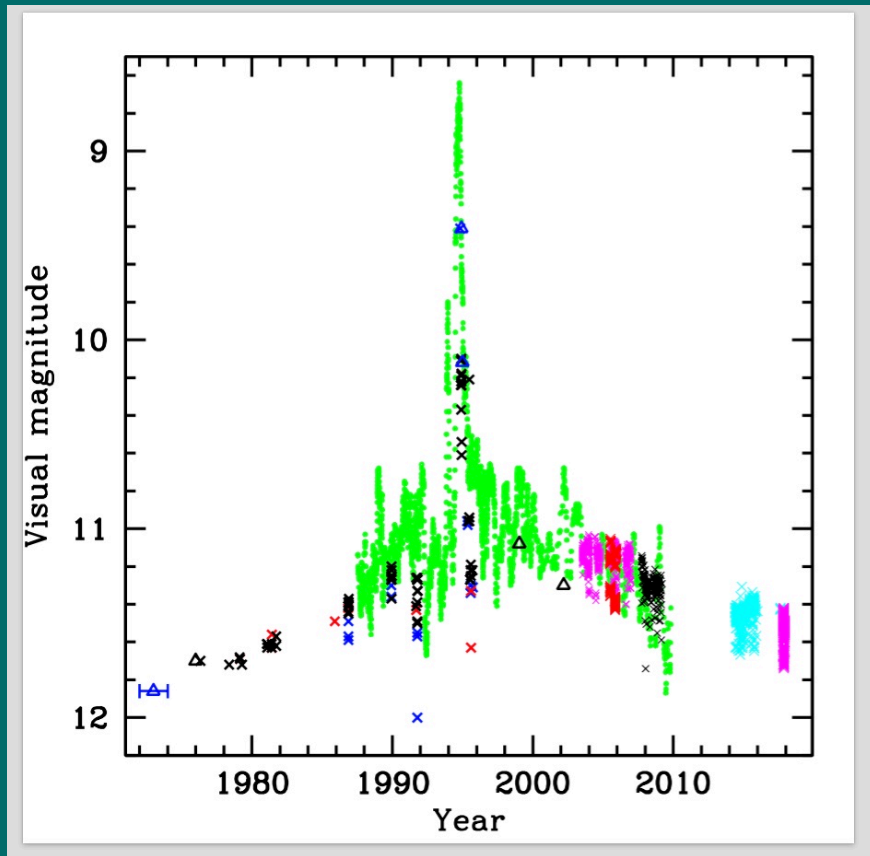


Hillier et al. 2019

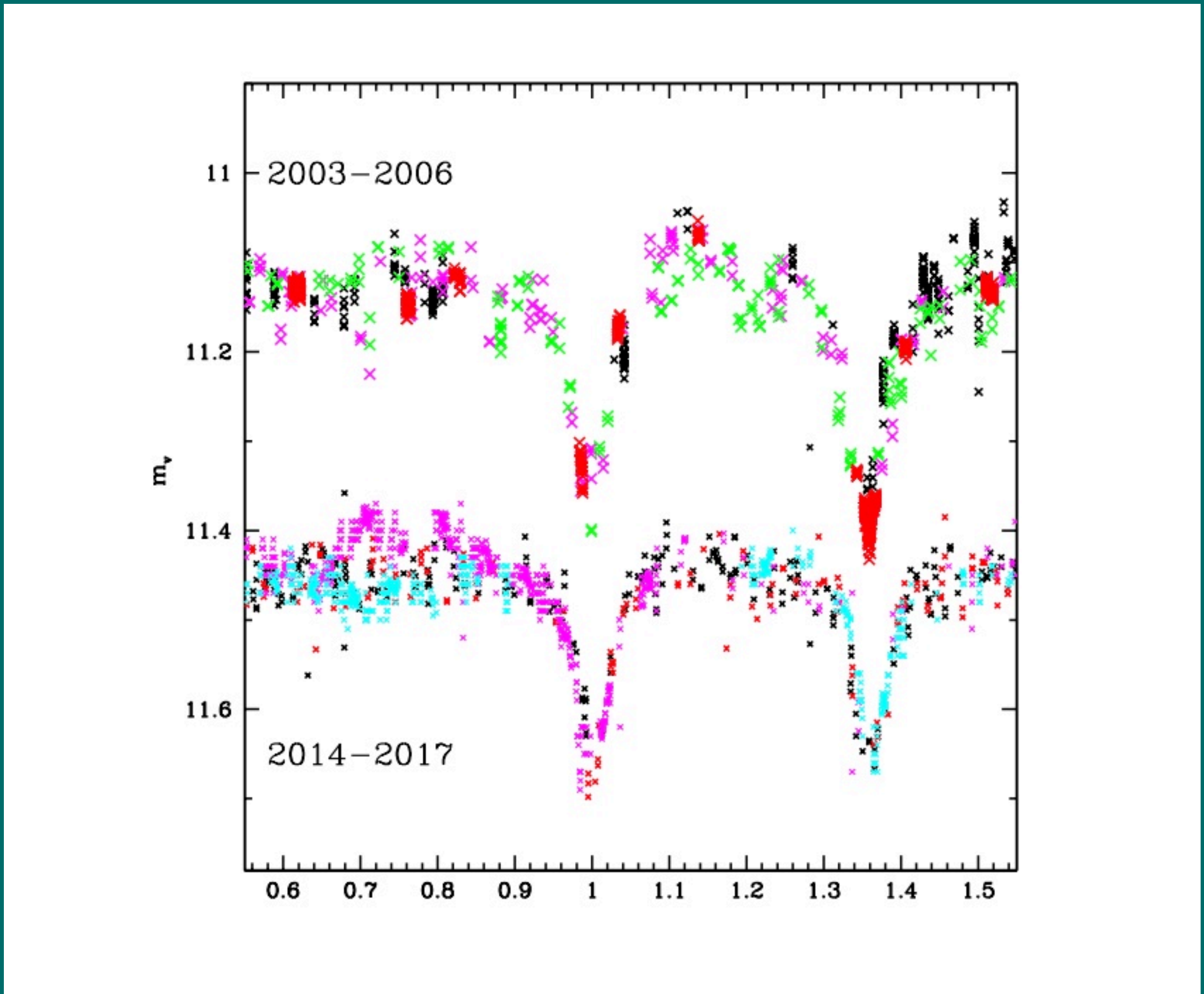
What caused the eruption?

What caused the eruption?

How is the slow rise related to the eruption?



HD5980 contains an eccentric binary



Gamen et al. 2019

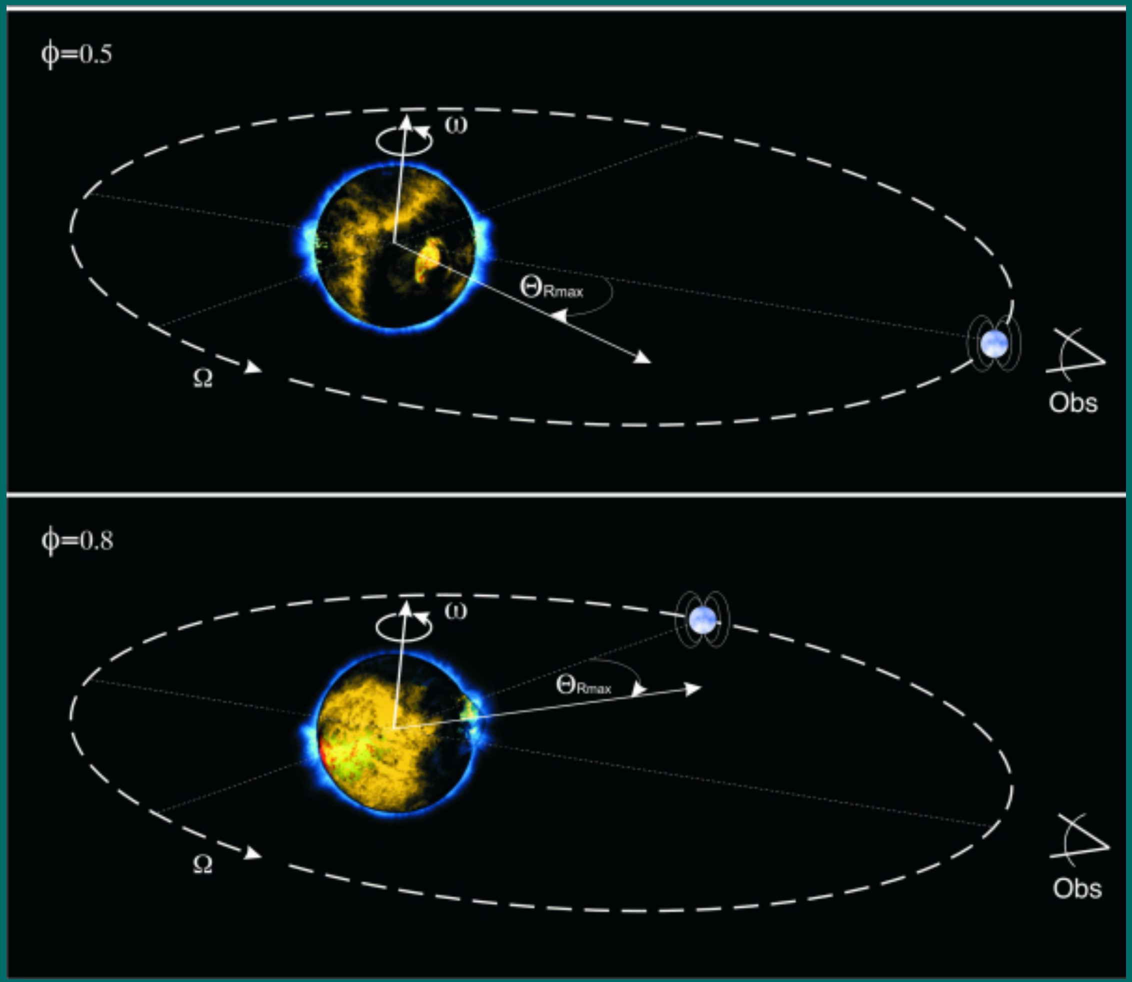
What caused the eruption?

Could the binary companion possibly induce an instability leading up to the eruption?

Speculation: each periastron passage inputs energy part of which does not escape before the next periastron passage making the star bloat.

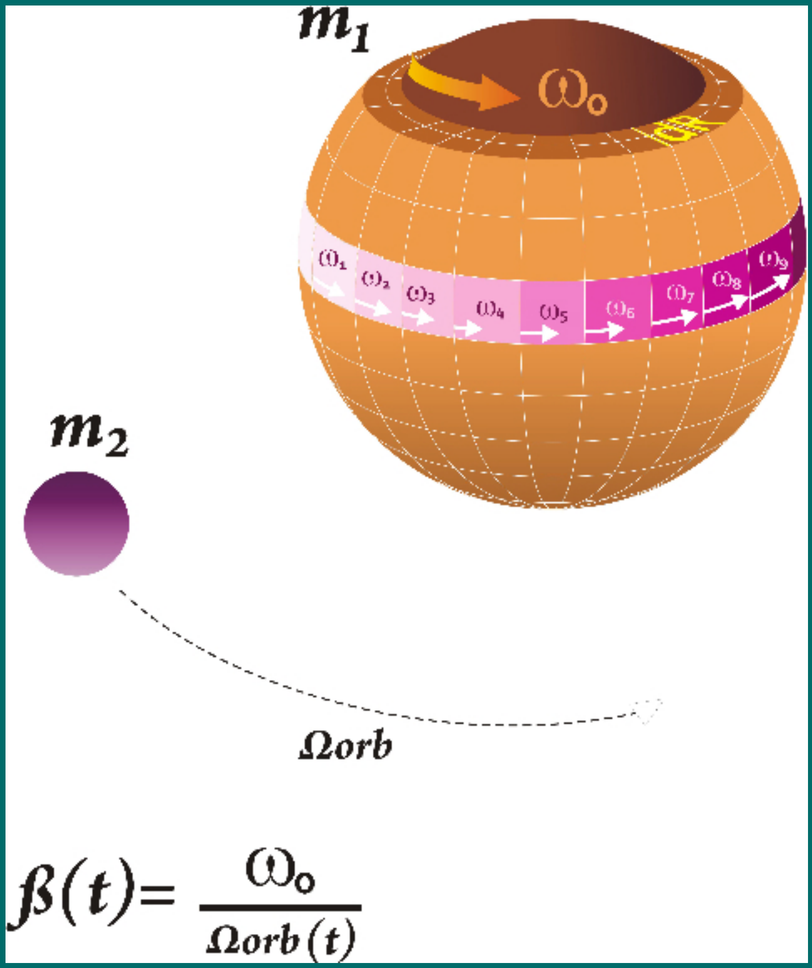
Inspiration: Io and Europa

Asynchronous rotation



Birth of the TIDES code (Moreno & Koenigsberger 1999)

TIDES* Code



INPUT PARAMETERS

m_1, m_2, R_1, P_{orb}, e, v_{rot}
i, ω_{per}

v : kinematical viscosity
n : polytropic index

N_r: number of layers
dR: layer thickness
N_{Az},N_{lat}: grid size

OUTPUT
velocities
energy dissipation
absorption line profiles

Tidal Interactions with Dissipation of Energy through Shear (Moreno et al. 2011)

Tidal shear energy dissipation

$$\dot{E} \simeq \eta \left\{ \frac{4}{3} \left(\frac{\partial \omega'}{\partial \varphi'} \right)^2 + \left[r'^2 \left(\frac{\partial \omega'}{\partial r'} \right)^2 + \left(\frac{\partial \omega'}{\partial \theta'} \right)^2 \right] \sin^2 \theta' \right\} .$$

Note: I'm an observer .....

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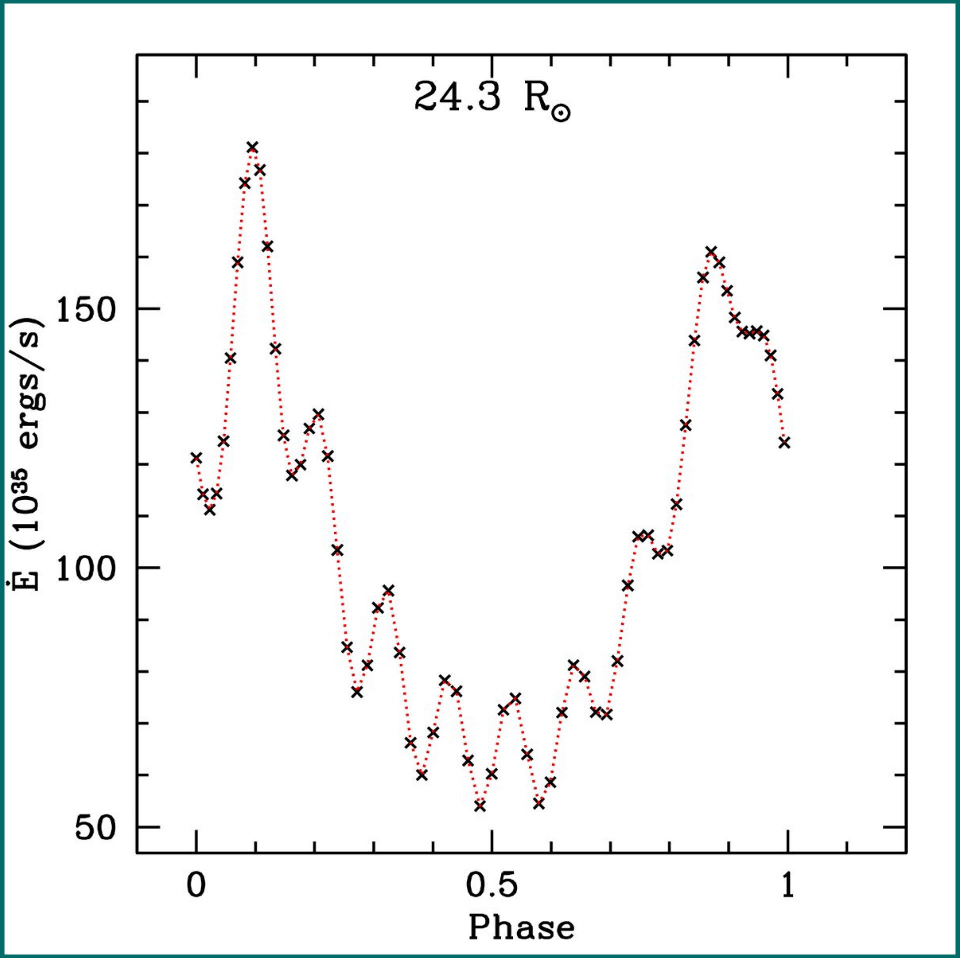
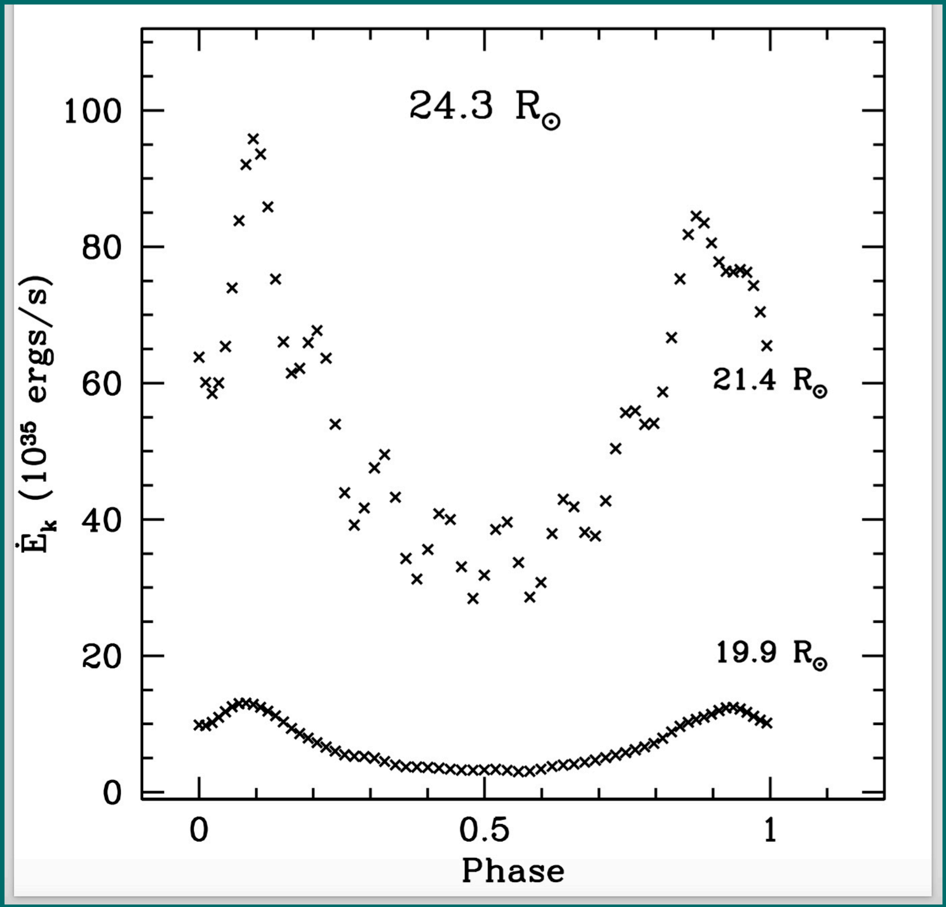
Variable R_{10}, luminosity and Eddington gamma-factor

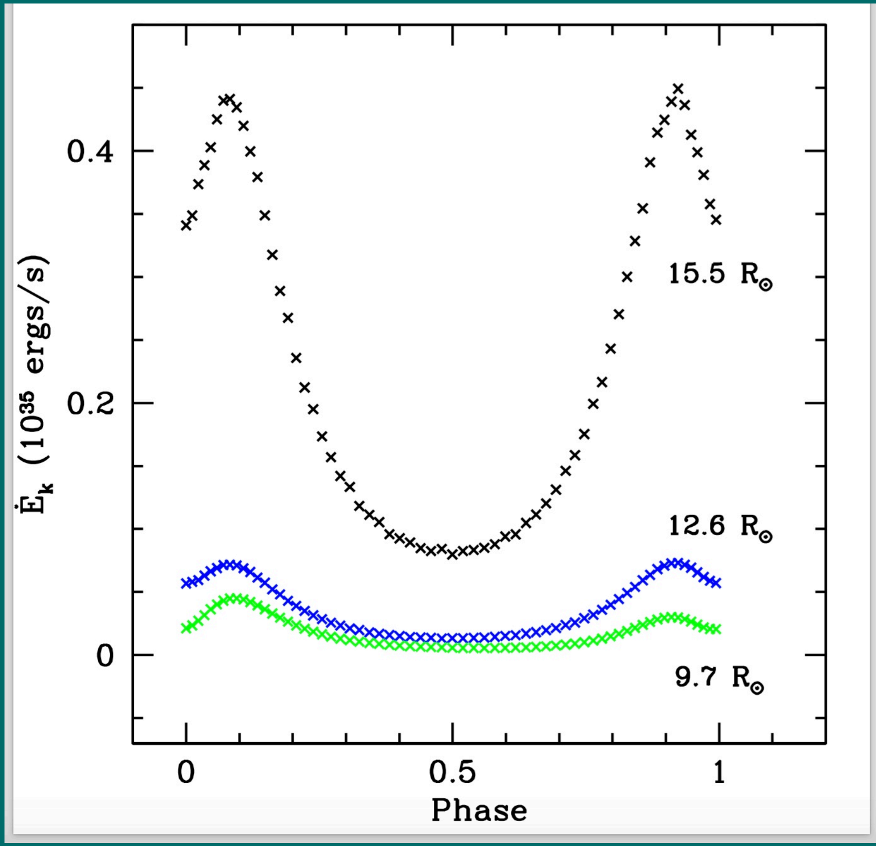
Results of TIDES calculation

Tidal shear energy dissipation rate

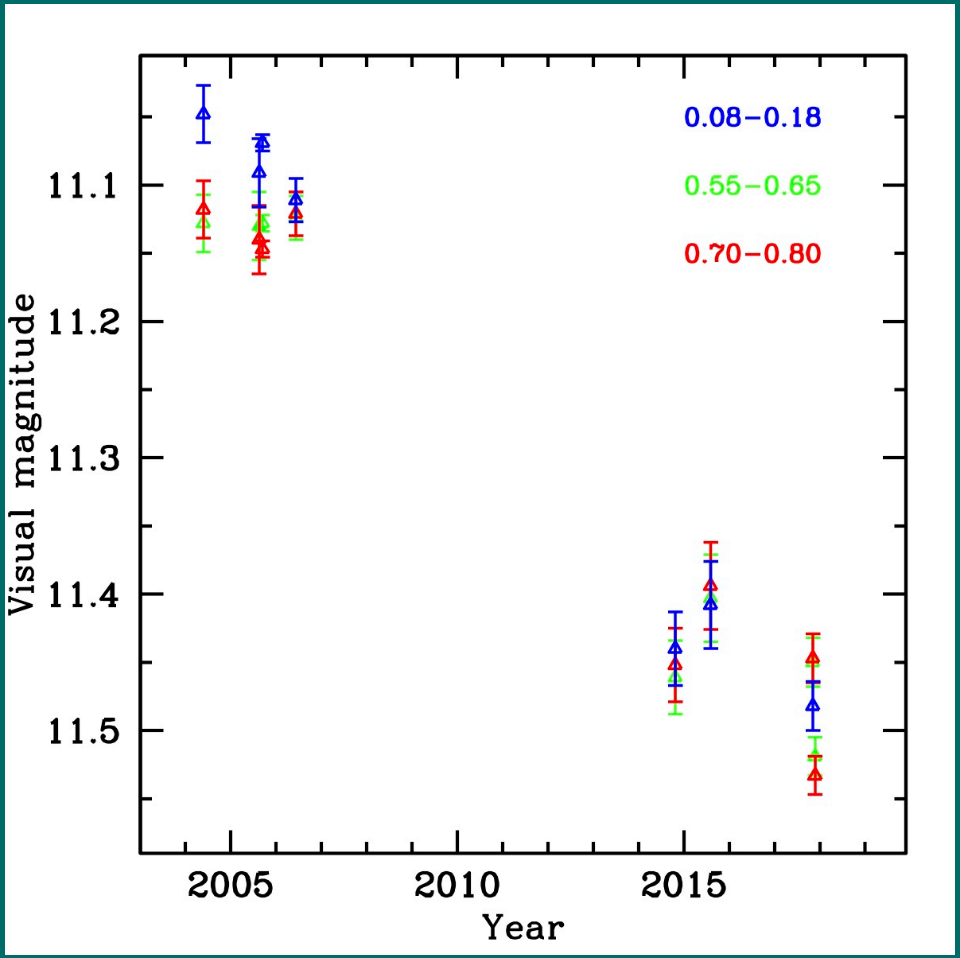


Periastron is at phase 0


24.3 R☉
21.4 R☉
19.9 R☉
$\dot{E}_k$ (10^{35} ergs/s)
Phase
0
20
40
60
80
100
0
0.5
1


15.5 R☉
12.6 R☉
9.7 R☉
$\dot{E}_k$ (10^{35} ergs/s)
Phase
0
0.2
0.4
0
0.5
1

Photometric data



Slight brightening after peri in 2005-2006

Hypothesis

a) Tidal shear energy dissipation causes R to increase **

b) When $R=R_{crit}$, dE/dt is sufficient to drive $L>L_{Eddington}$

Effect (a) causes the long term trend, Effect (b) the sudden eruption

Rough calculation: $R=24.3\ R_o$ model
$M=66\ M_o$
$\Delta M=10^{-4}\ M_o$

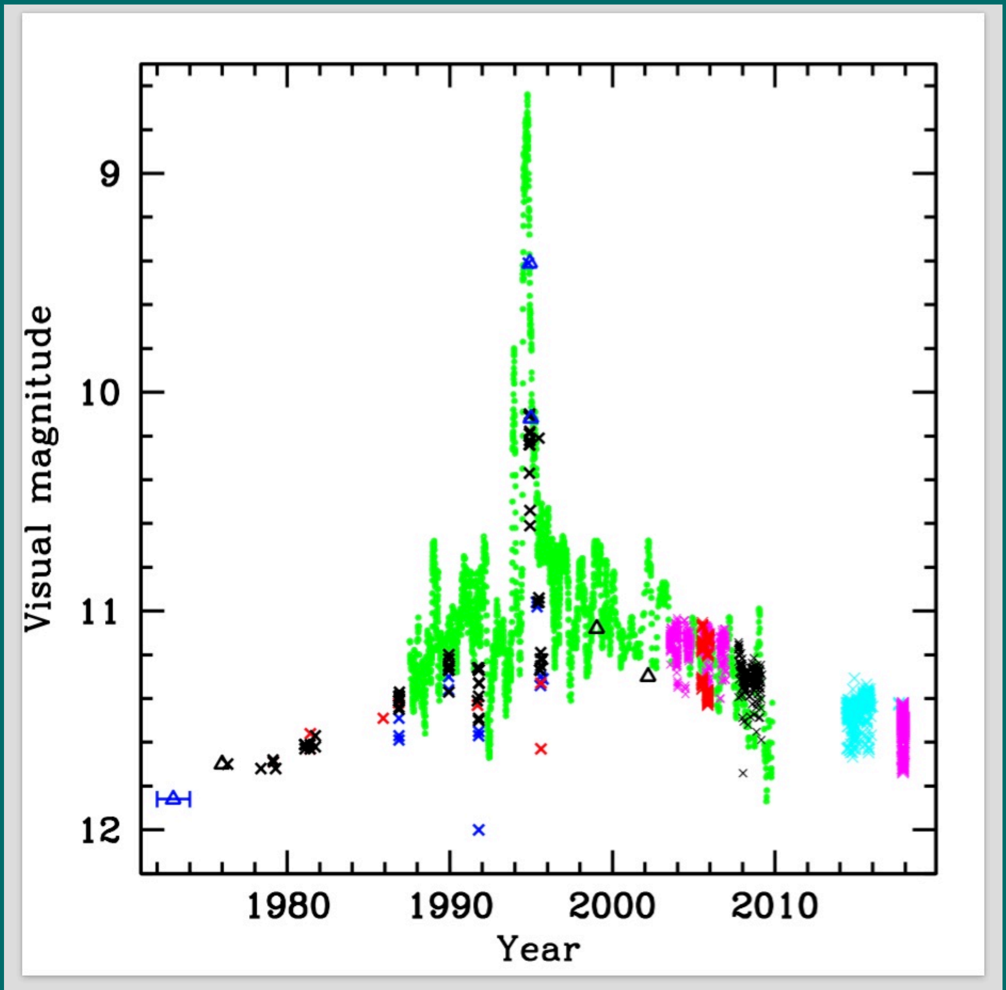
Binding energy: $dU=-GM\ \Delta M/R = 10^{45}$ ergs

TIDES gives: $dE/dt \sim 10^{37}$ ergs/s over the orbit

Assume 50% accumulates as internal energy, $|dU|/0.5\ dE/dt \sim 16$ years

** see computation for V1309 Sco in Koenigsberger & Moreno (2016)

Timescale for slow rise: 16 yrs



Further progress needs:

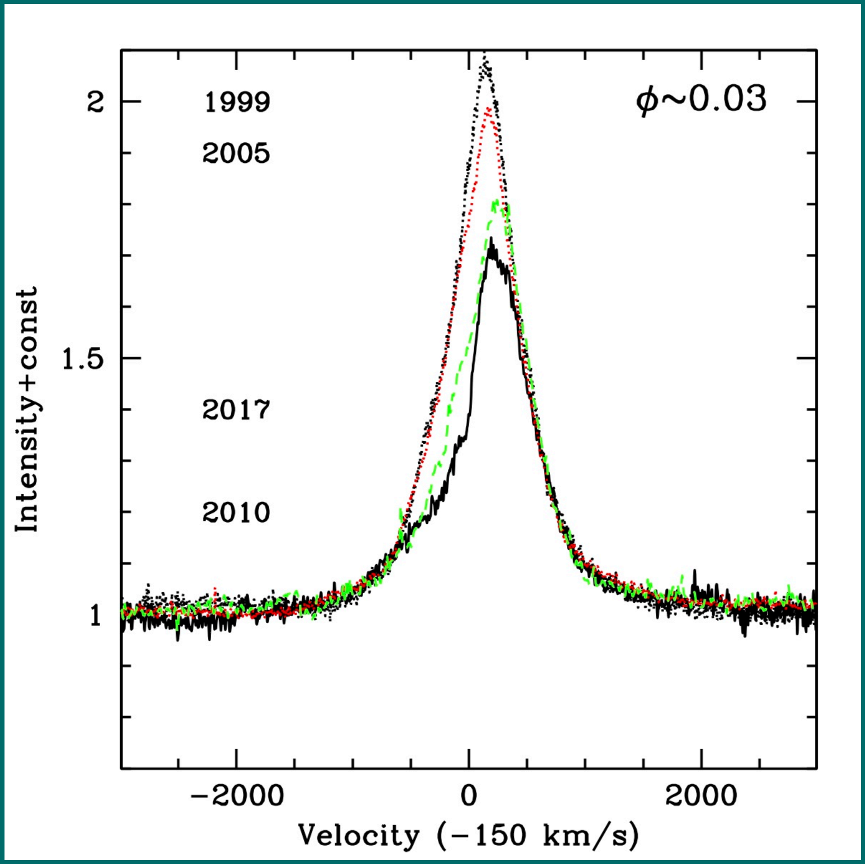
Combine a stellar structure code with a TIDES-like code

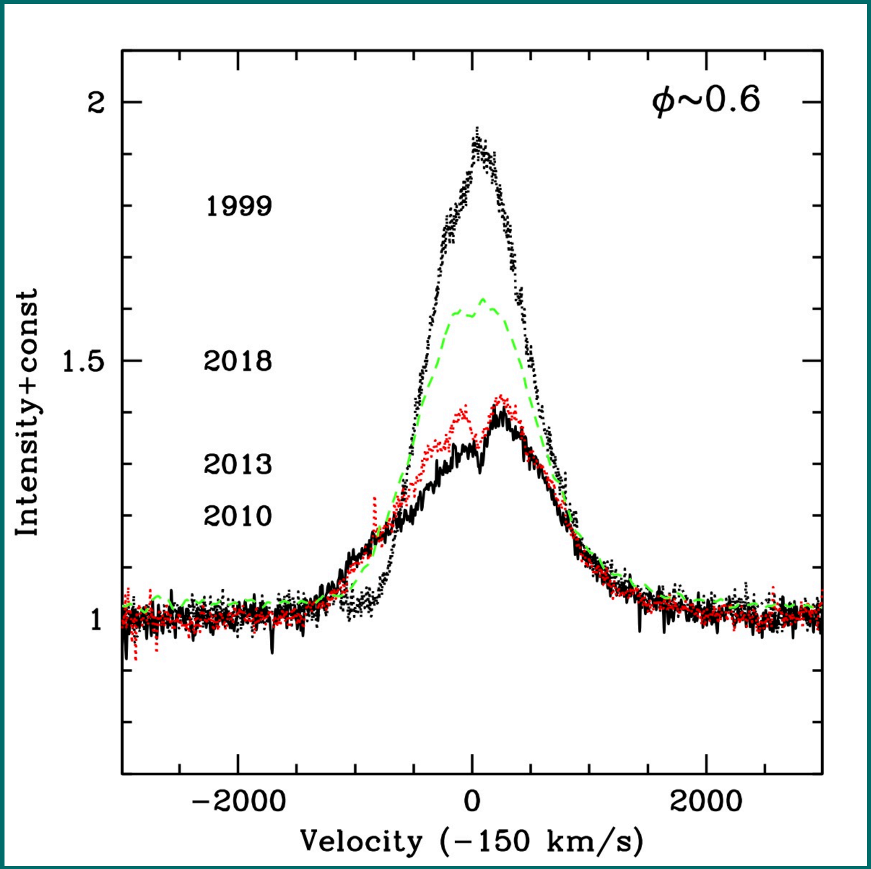
- Realistic stellar structure *vs* polytrope
- Feedback from TIDES:
  - angular momentum and energy
- Effect of energy injection on structure?
- Effect on wind structure?

Anyone interested ..... ?

Also, huge data set ....

Increasing activity since 2013





Thanks to our *Querida Hada de la Montaña*!

When does binarity matter?

Binaries may modify

- a. Observational diagnostics
- b. Mass loss
  - Wind
  - Eruptions
  - RLO
- c. Degree of internal mixing ?
  - Differential rotation ?

These phenomena are intertwined

there they are
living an impossible love
reaching out... finding each other
but unable to touch
only proximity...
periastron

Pablo Peña 2002

hope is not lost, however
from proximity to contact
a first touch
then rapid merger
transformed and united
they become and remain
forever together

G. Koenigsberger
2018