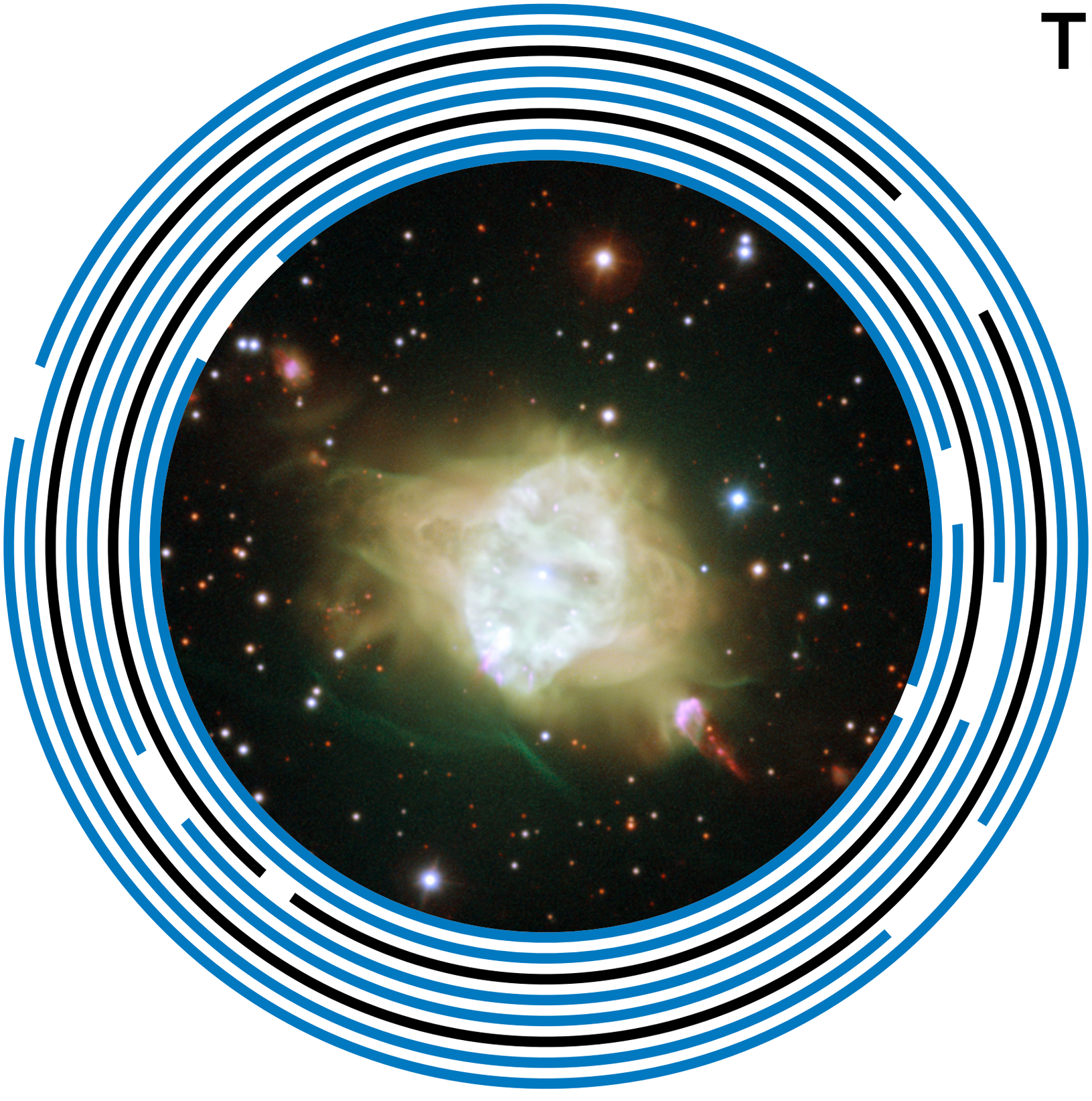


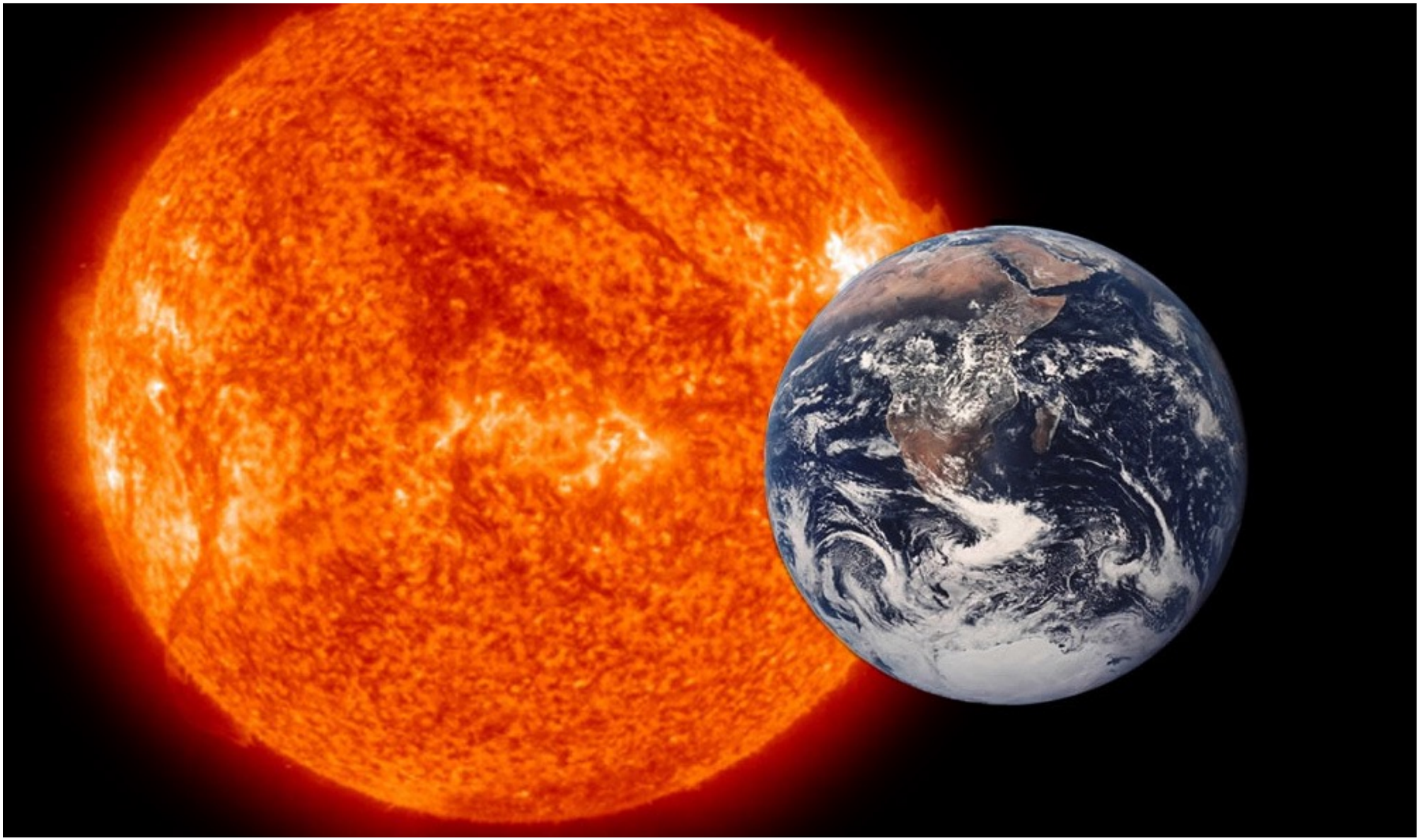
THE IMPACT OF BINARIES ON STELLAR EVOLUTION

INTRODUCTION

Henri Boffin

03 July 2017

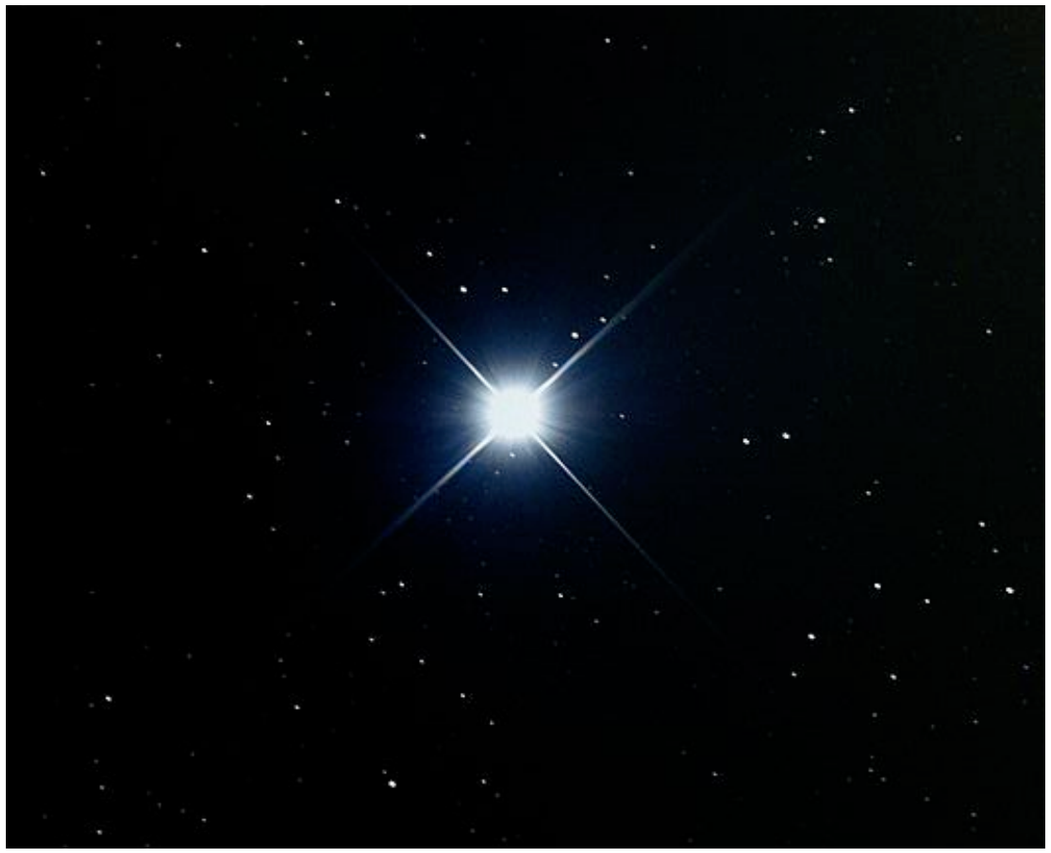
The Sun is single…



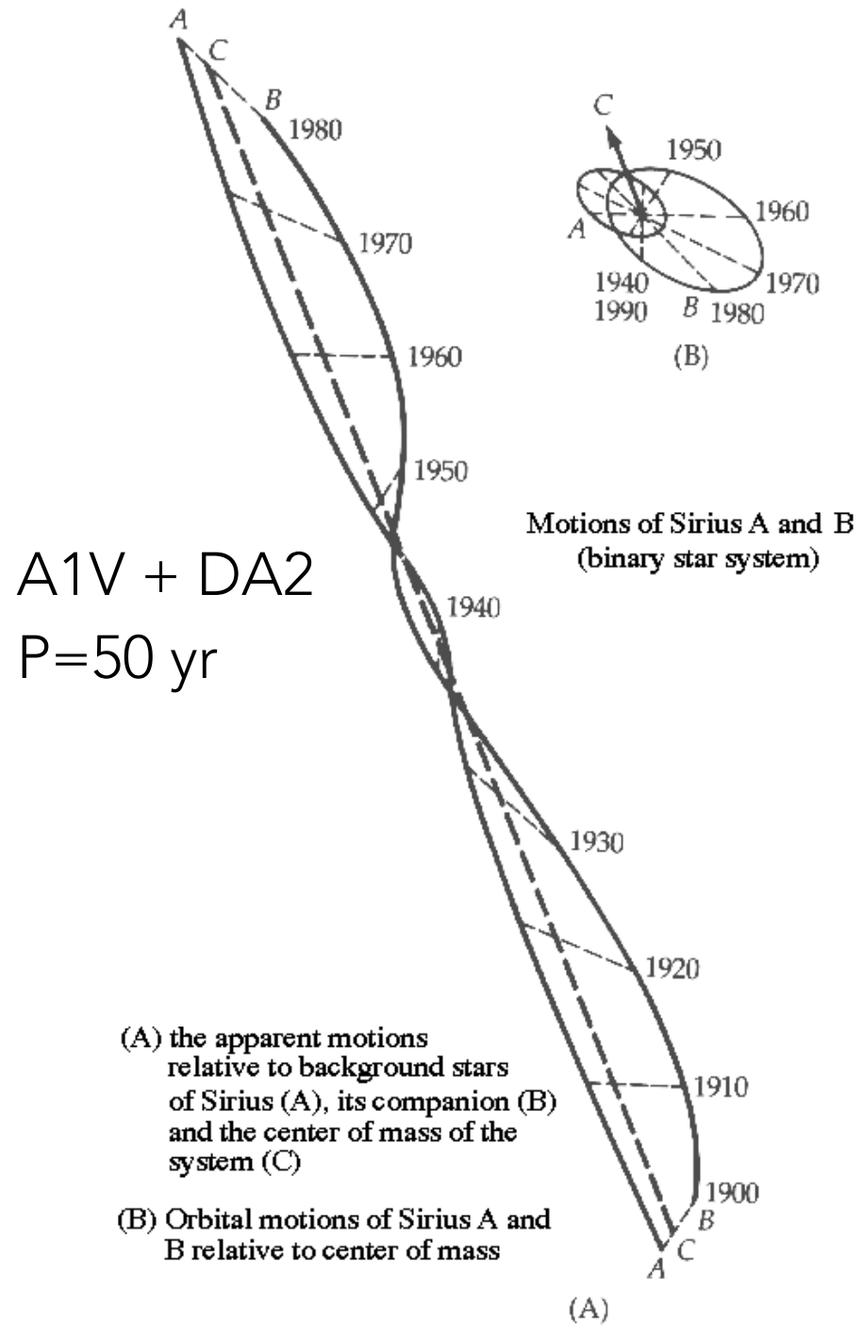
…but most stars aren't

© Star Wars Episode IV: A New Hope.

The brightest star in the night sky is a binary



© Mellostorm



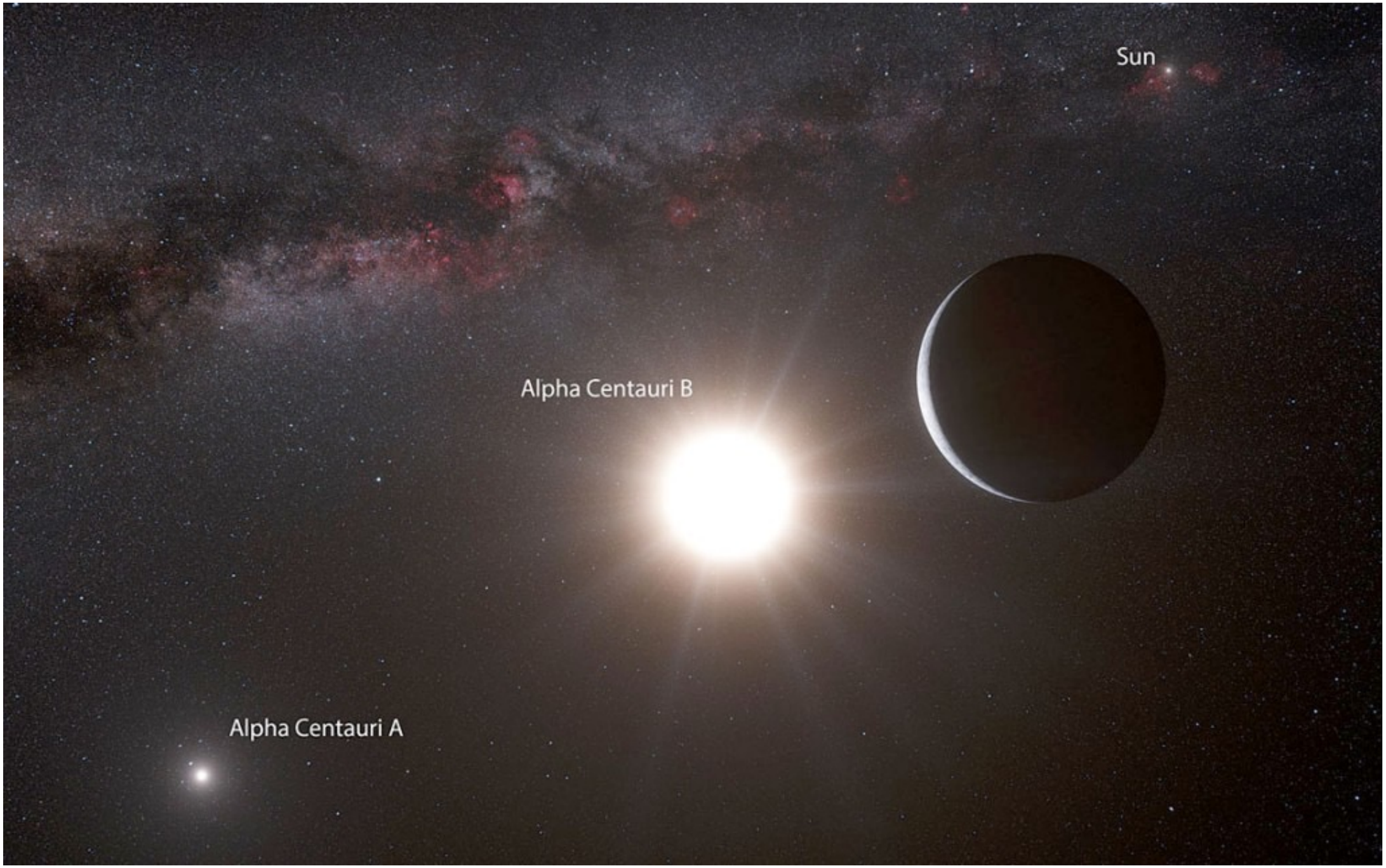
A1V + DA2

P=50 yr

The presence of Sirius B was first detected by observing the wobble in the motion of Sirius A

…an Astrometric Binary

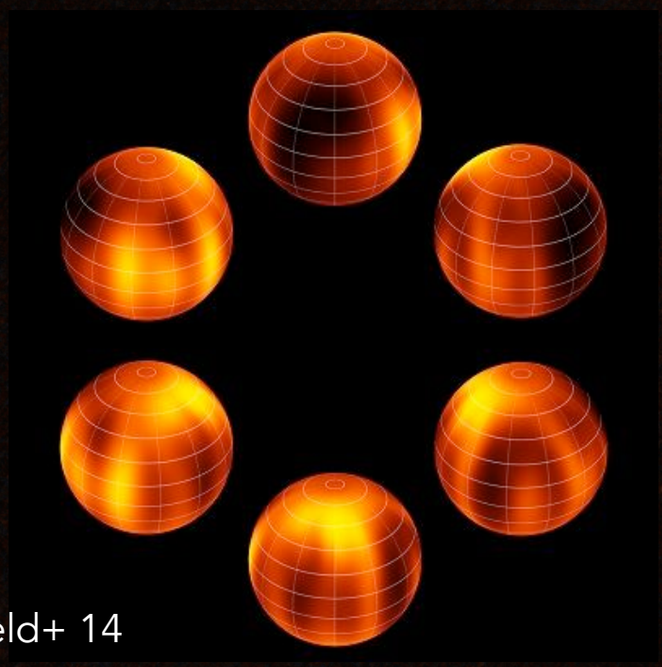
Among the closest ones …



Luhman-16

Binary Brown dwarfs
2 pc away
separation ~ 3 au

Boffin+ 14
Bedin+ 17



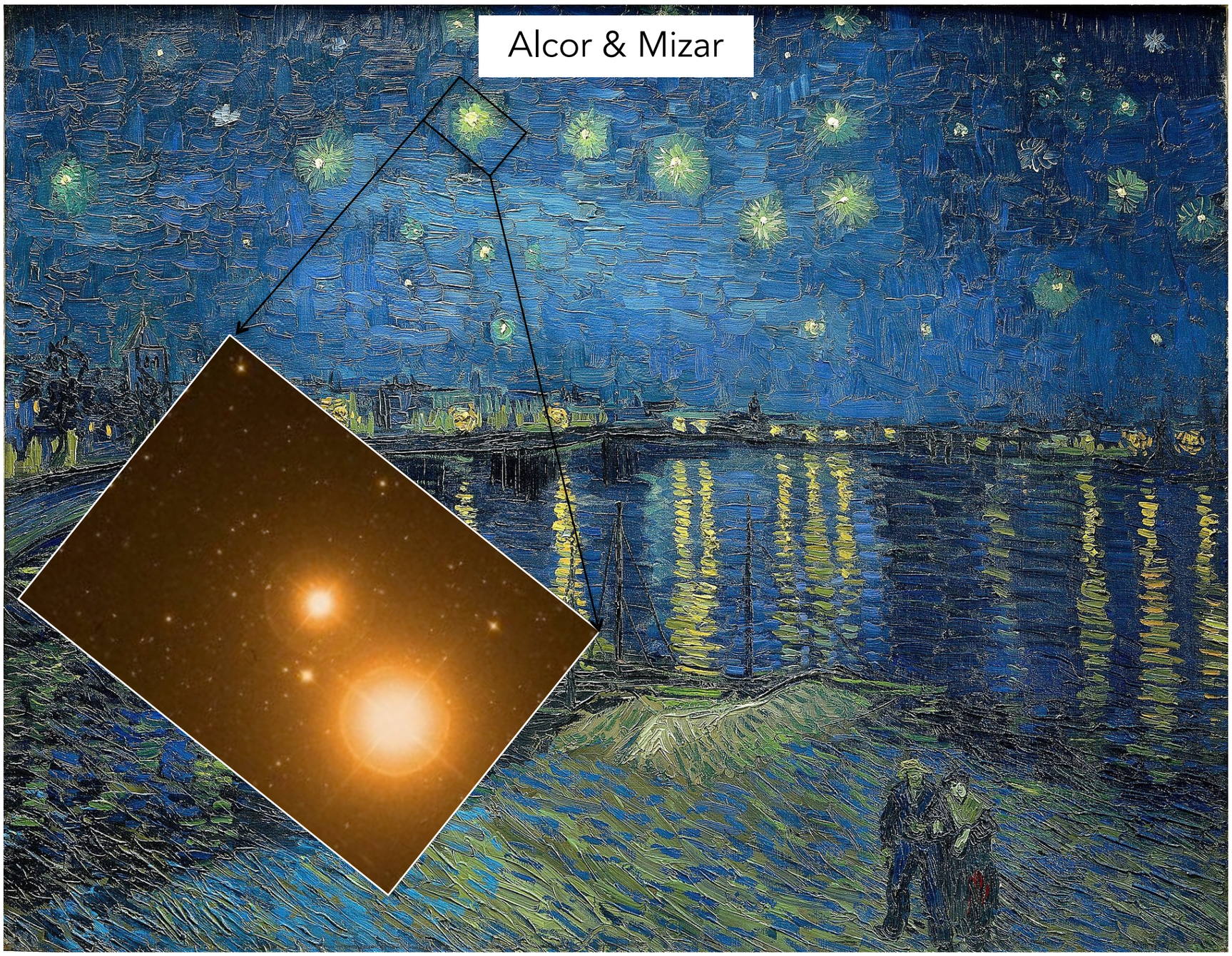
Crossfield+ 14

Another famous multiple

Musee d'Orsay, Paris, France

Starry night - Van Gogh

Another famous multiple

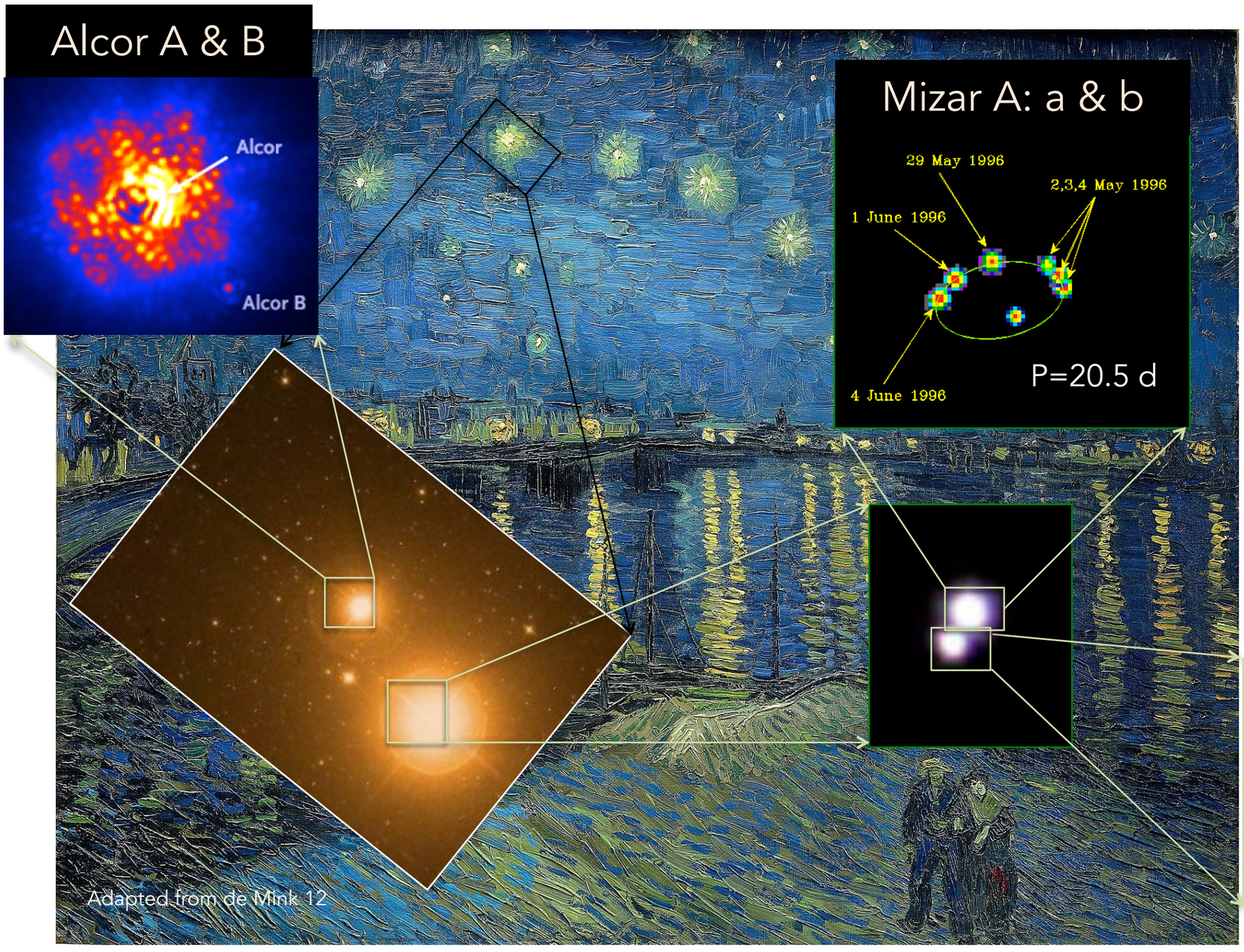


Starry night - Van Gogh

Lifespan star
or "jumyouboshi" (寿命星)

Married couple in
Indian astronomy

Another famous multiple

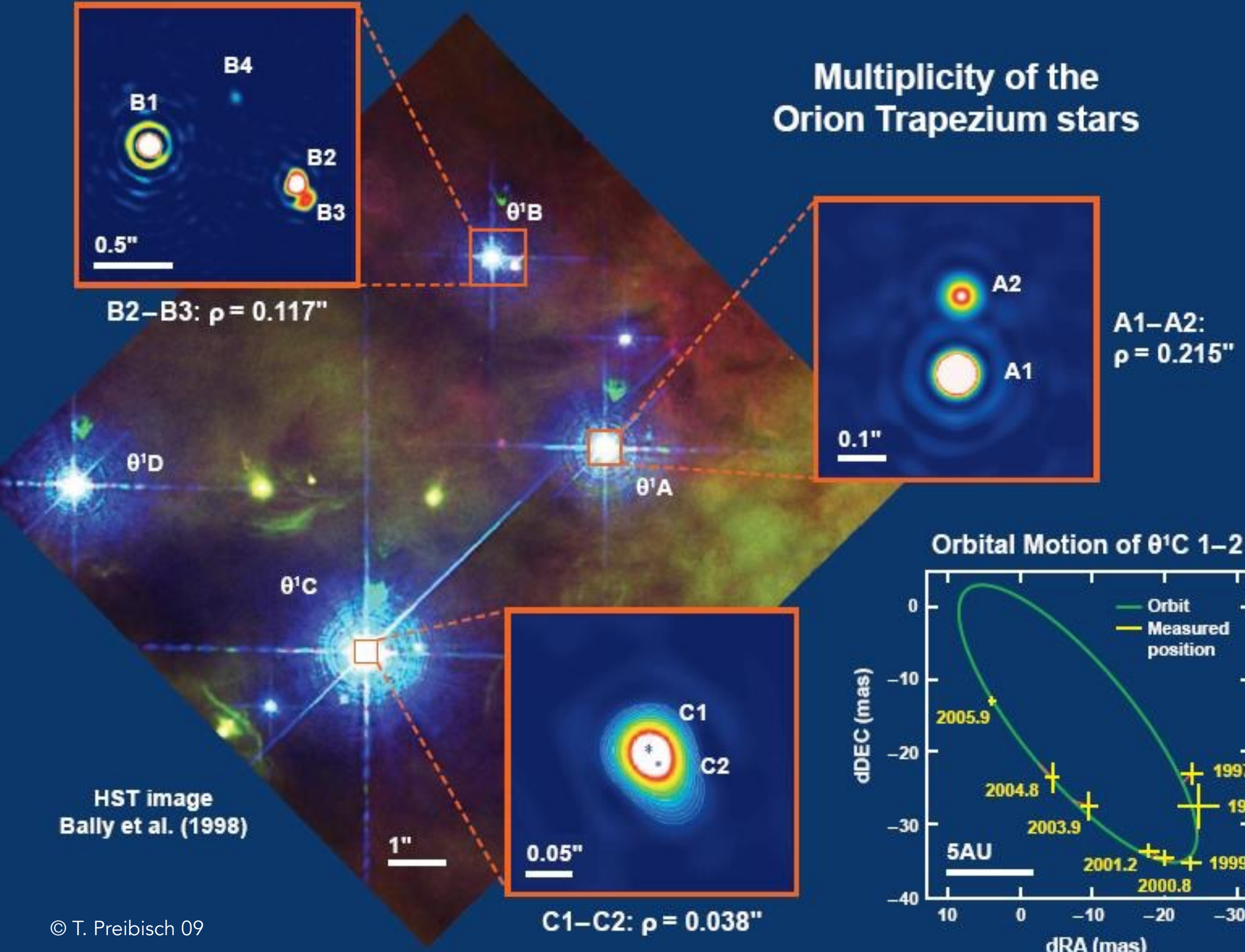


3 binaries forming a sextuple system

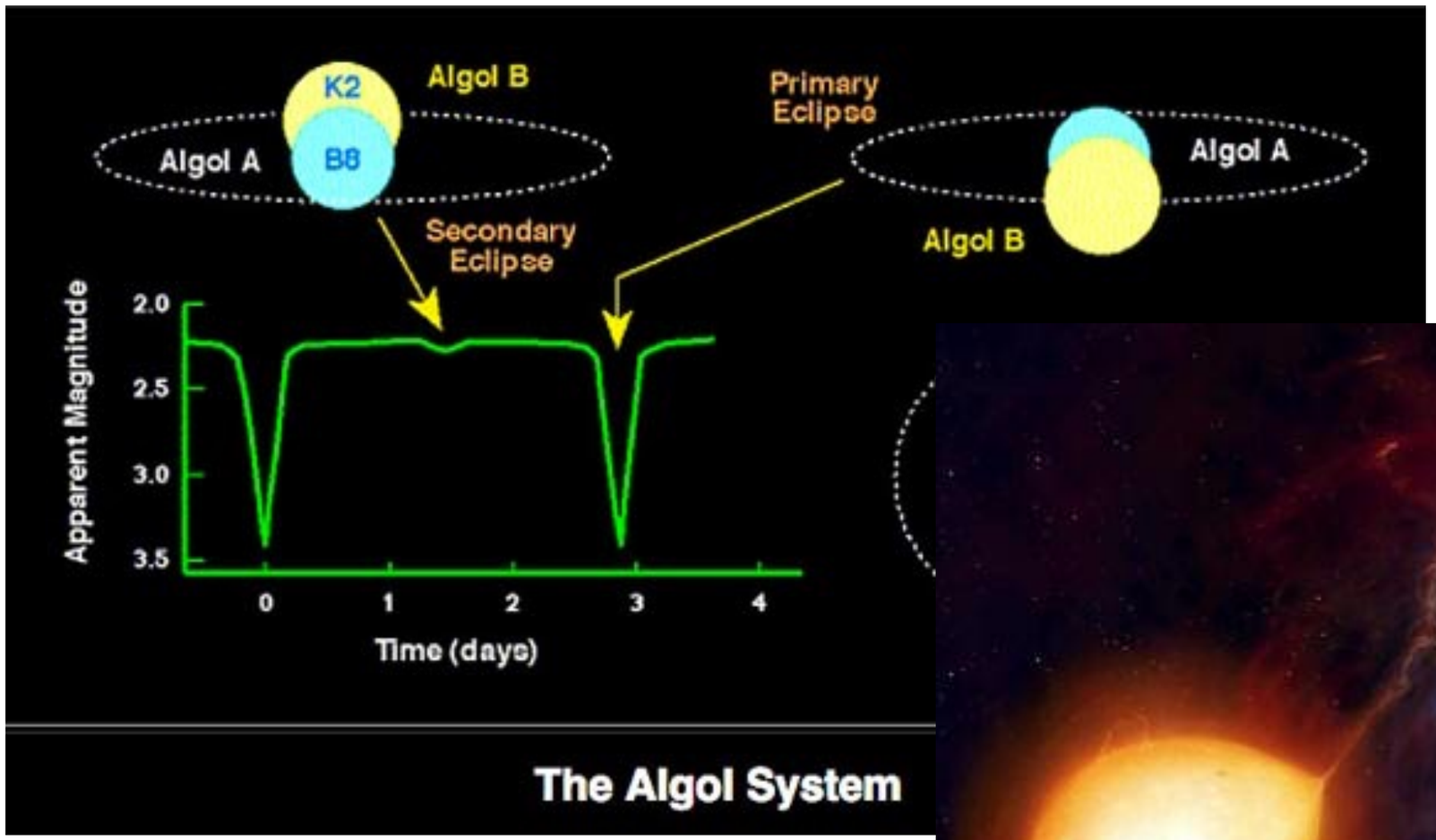
Mizar B: a & b

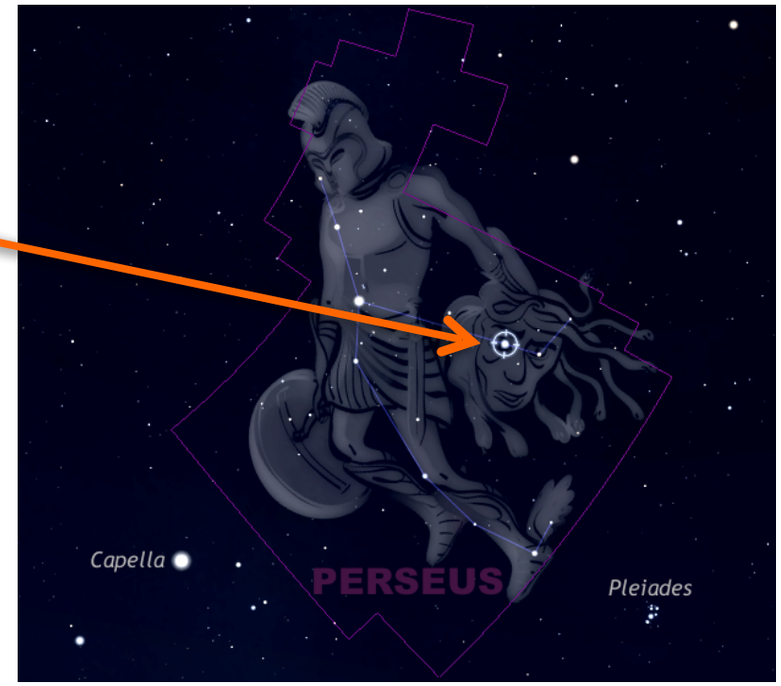
Spectroscopic binary
P~6 months

Multiplicity of the Orion Trapezium stars



Algol (The Daemon)





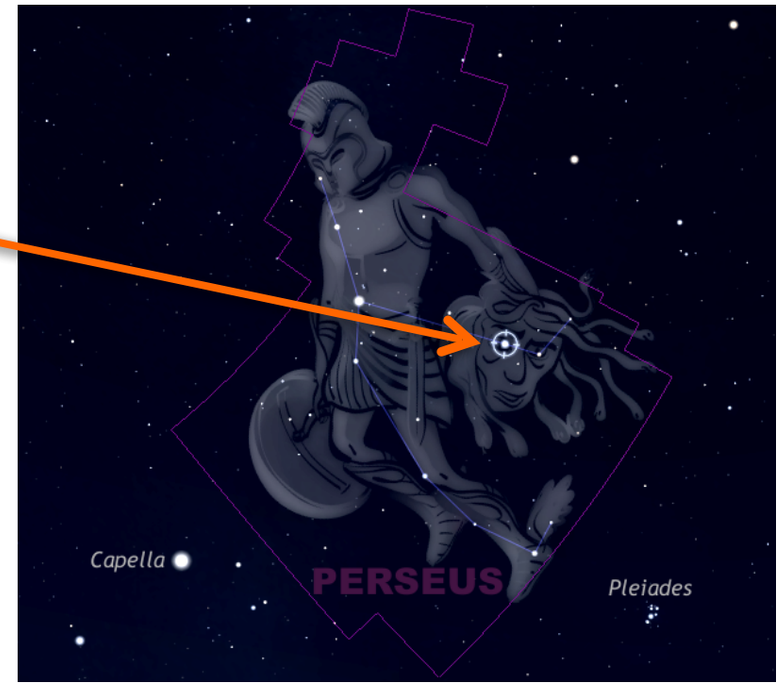
Ade Ashford / Stellarium

Credit: Mark Garlick

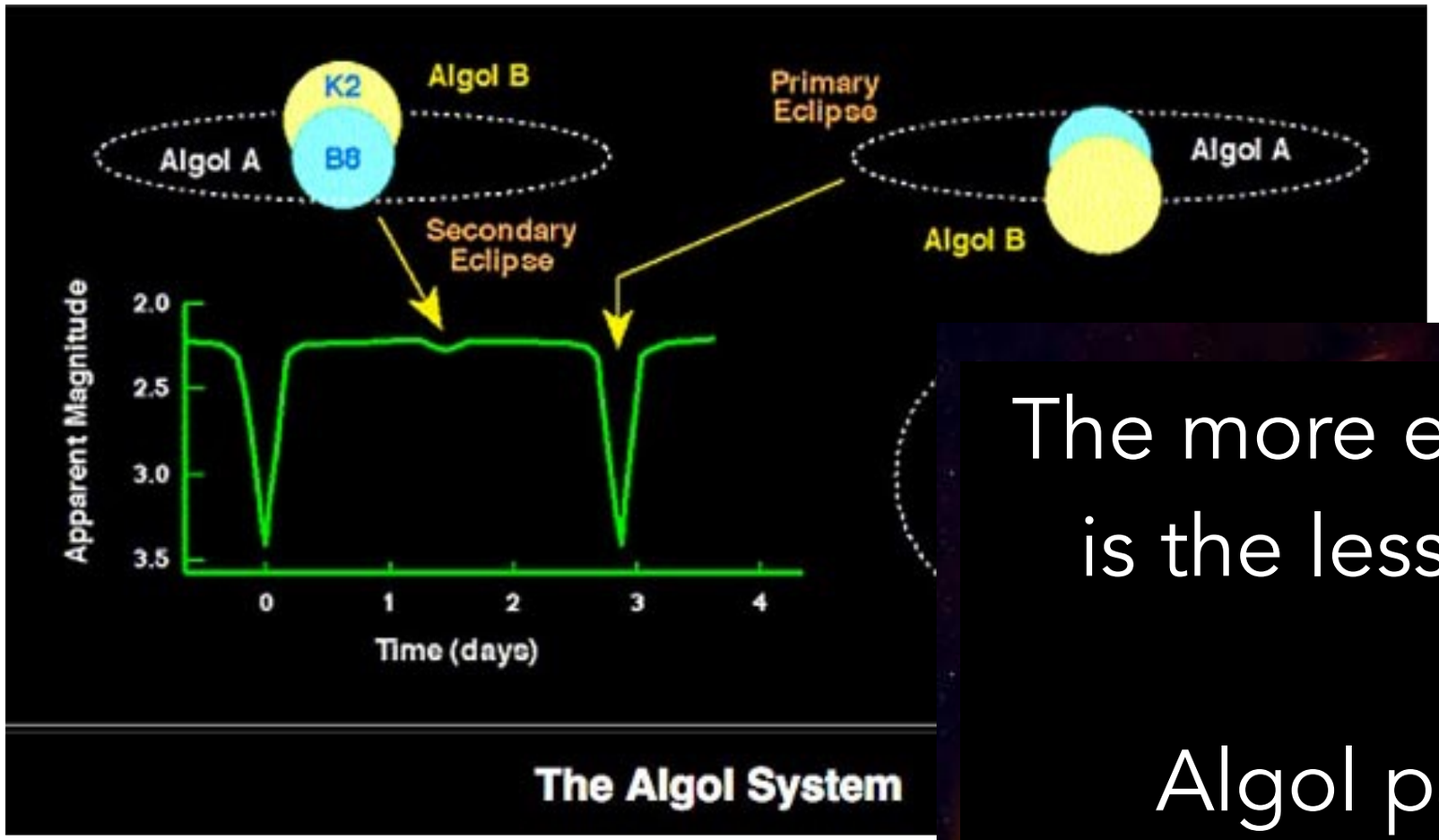
Primary: B8 V, 3.7 $M_\odot$

Secondary: K2 IV, 0.8 $M_\odot$

Algol (The Daemon)



Ade Ashford / Stellarium



Primary: B8 V, 3.7 $M_\odot$

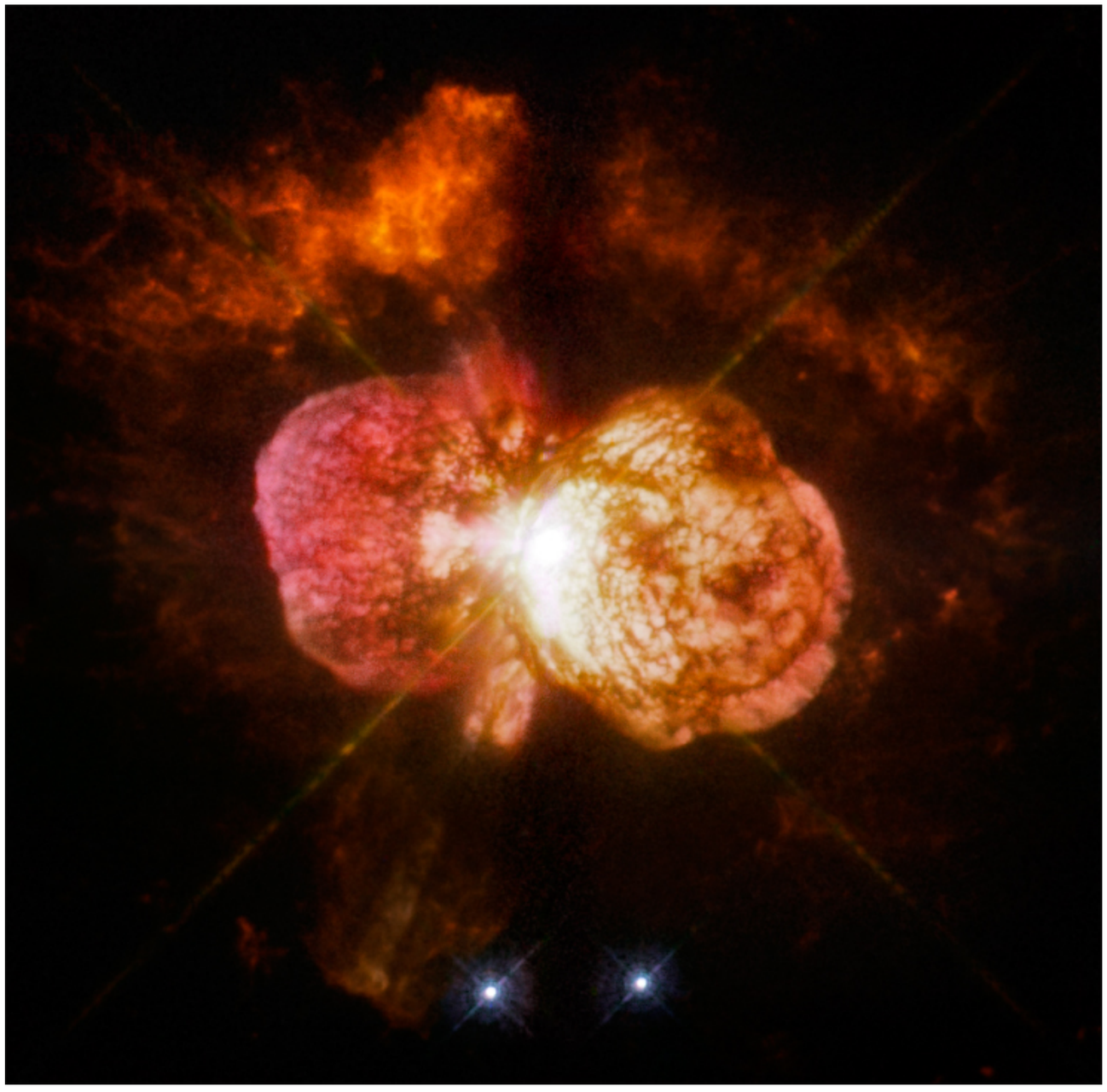
Secondary: K2 IV, 0.8 $M_\odot$

The more evolved star is the less massive!

Algol paradox!

Mass Transfer!

Another extreme: Eta Carinae

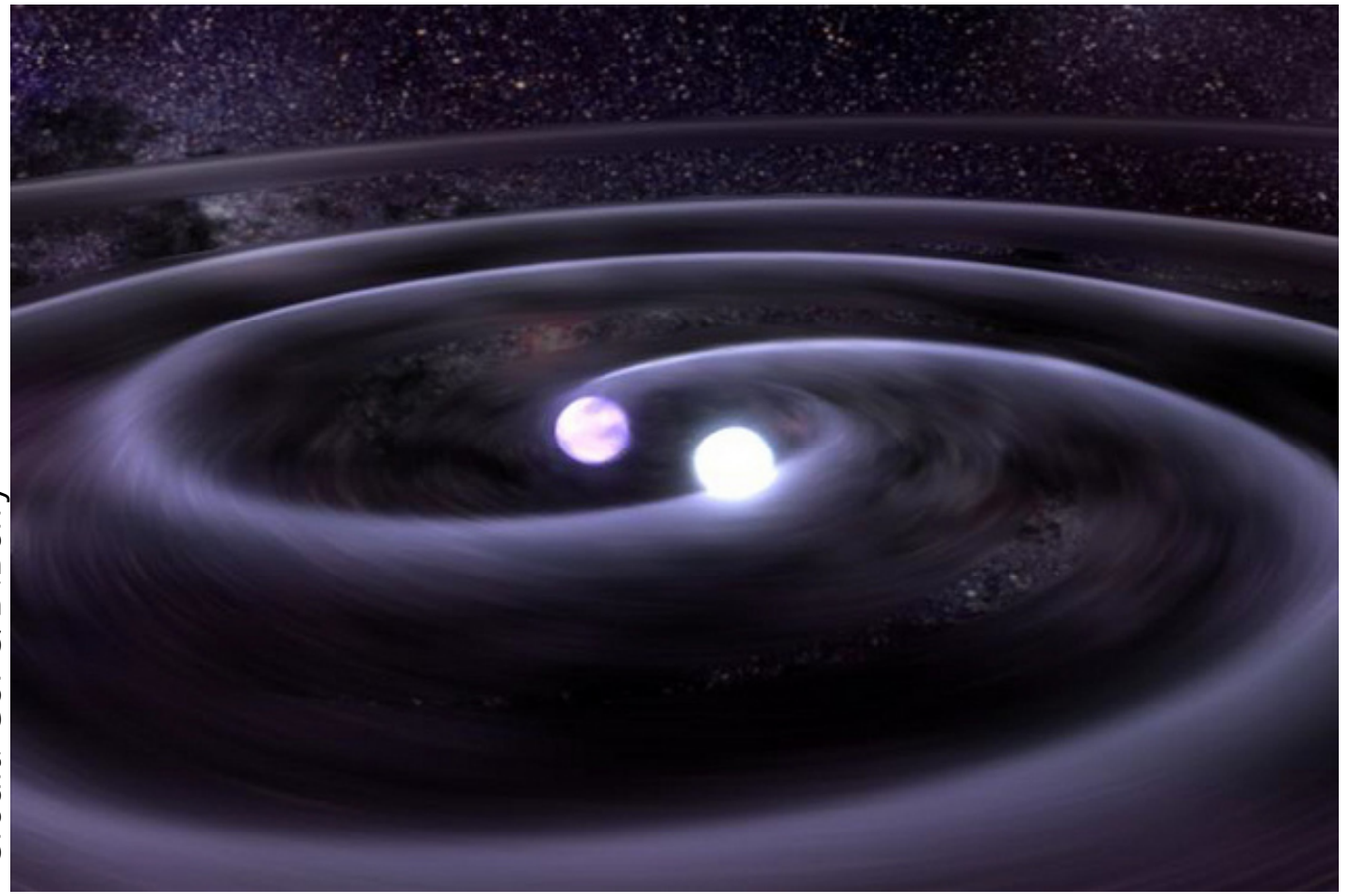


NASA/ESA/HST

- LBV 120 $M_\odot$ + 30 $M_\odot$ companion
- Eccentric system
- P = 5.5 years
- Undergo outburst

- The next Supernova in our Galaxy?

SDSSJ010657.39-100003.3



Credit: GSFC/D.Berry

Kilic+ 11

Detached binary

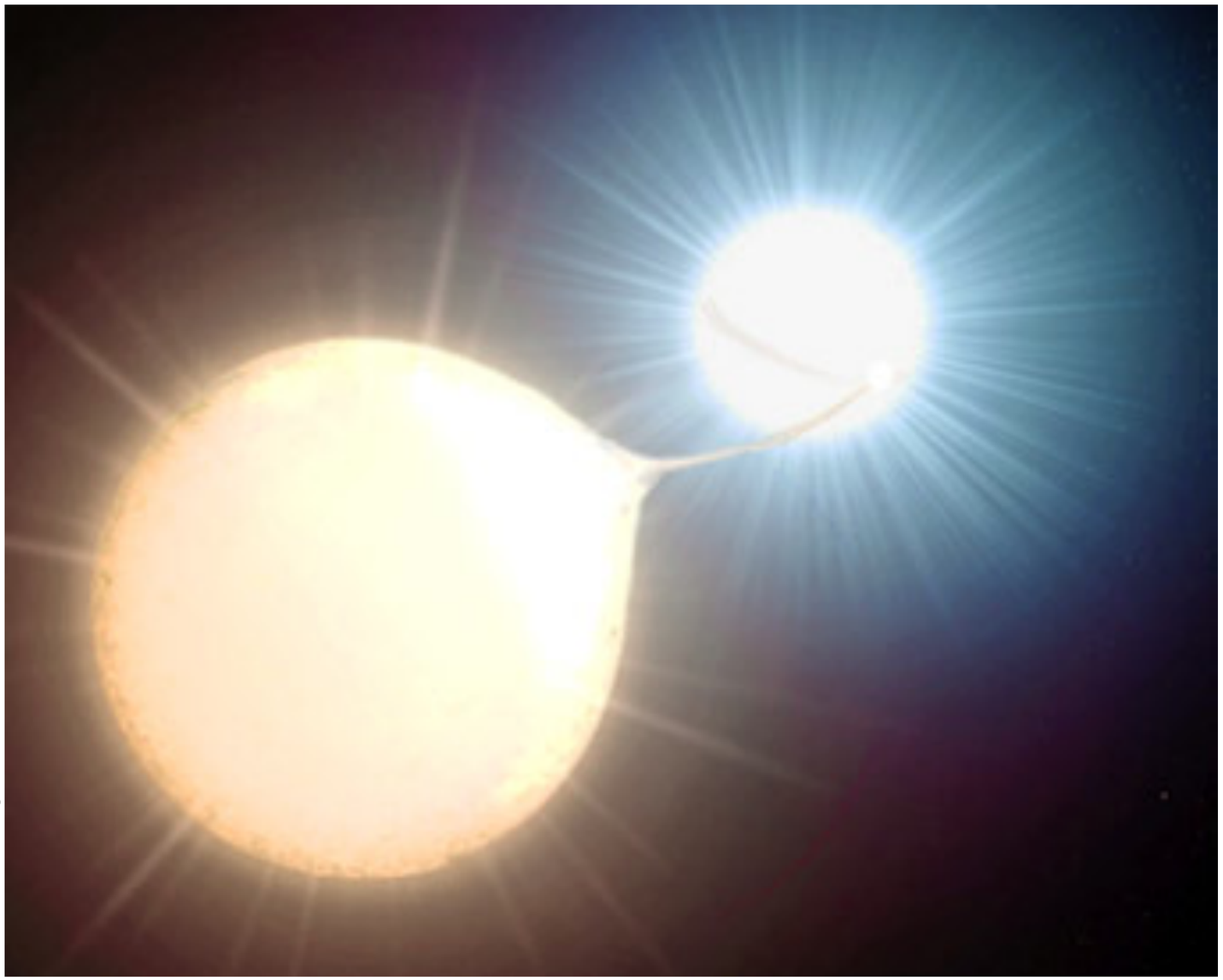
P = 39.1 min

2 WDs

A = 0.32 $R_\odot$

Will merge in 37 Myr to become a sdB star

HM Cancri



S&T: Casey Reed

Roelofs+ 10

Two white dwarfs

One is transferring mass to the other!

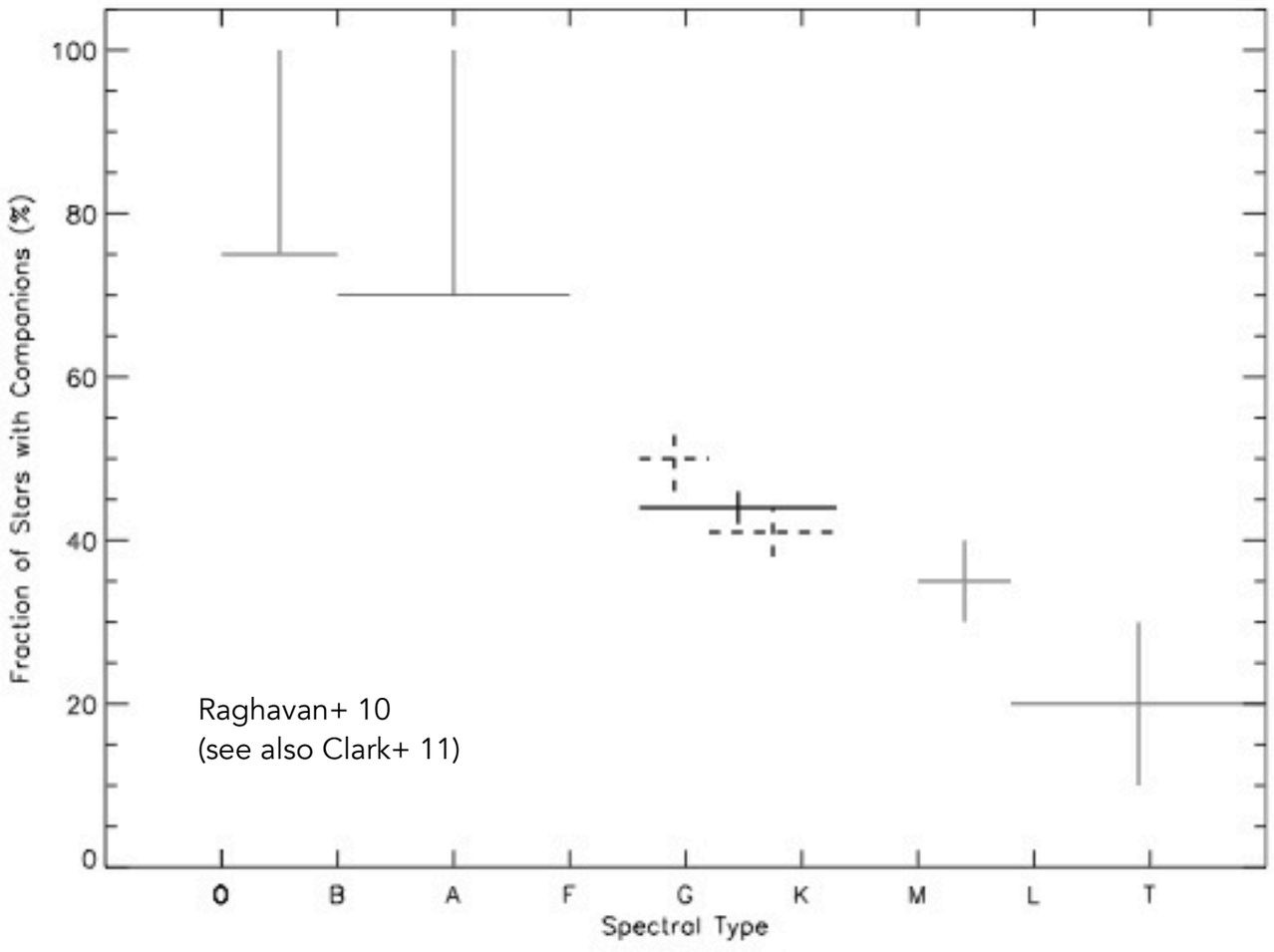
Orbital period 321 seconds!

Distance between stars:
<100 000 km

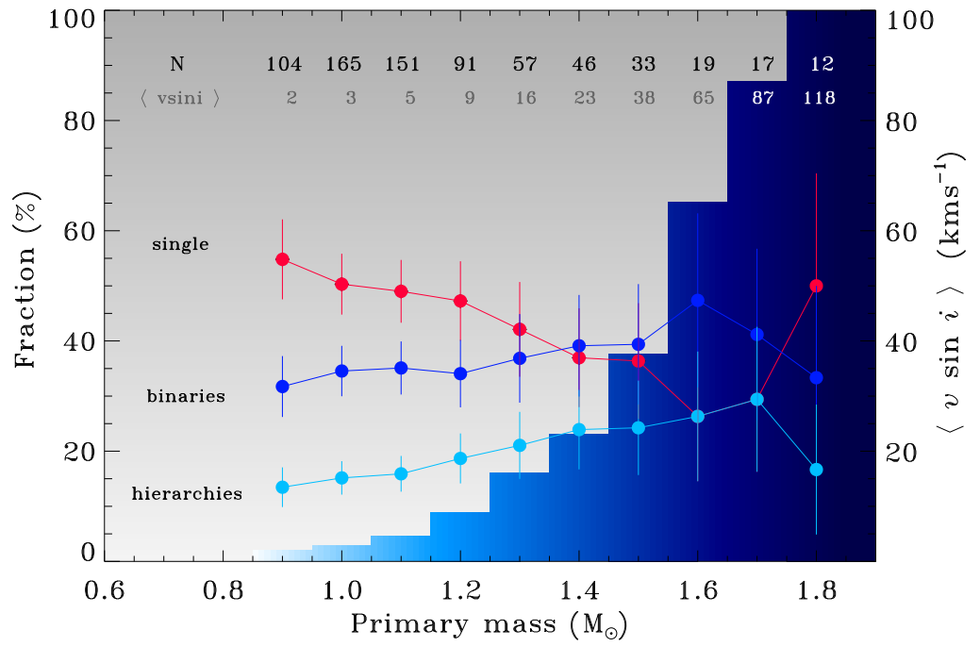
Orbital velocity > 10^6 km/h

Masses: 0.27 and 0.55 $M_\odot$

Multiplicity is function of primary mass, M_A



Mass of primary, M_A



Fuhrmann + 17

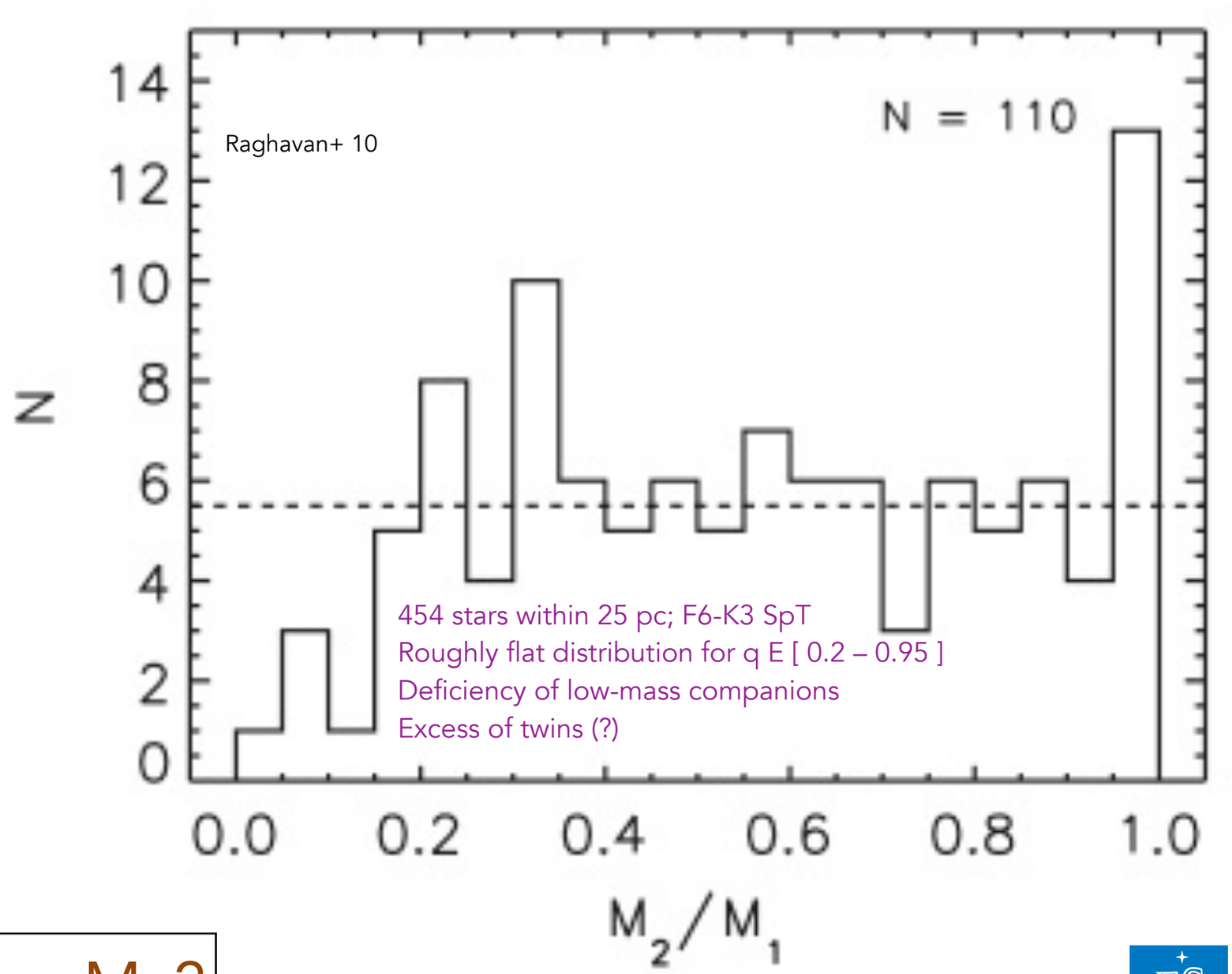
But is this the full story?

What about stars that are secondaries?

What about the mass ratio distribution?

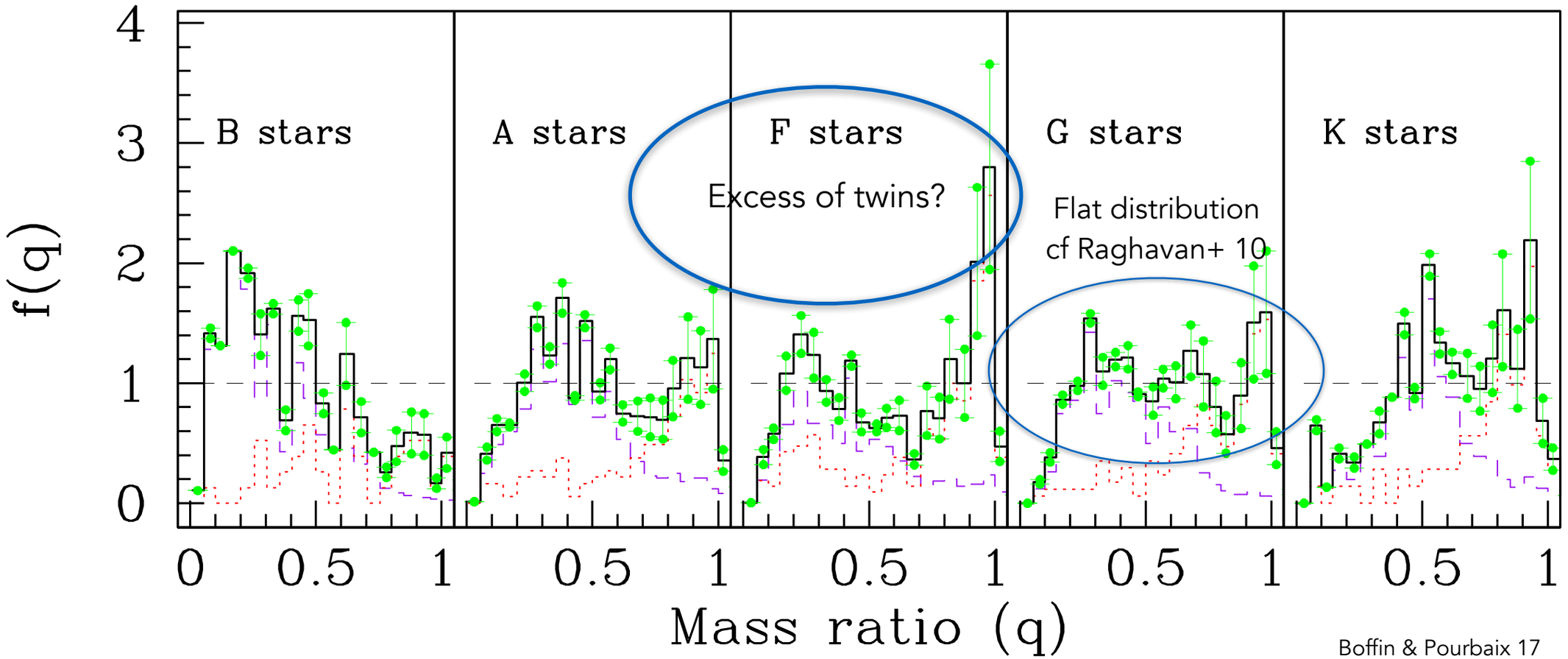
Binary formation mechanisms?
e.g. random pairing, f(q) constant

Evolution of binary systems? e.g. twins population?



Does f(q) depend on M_A?

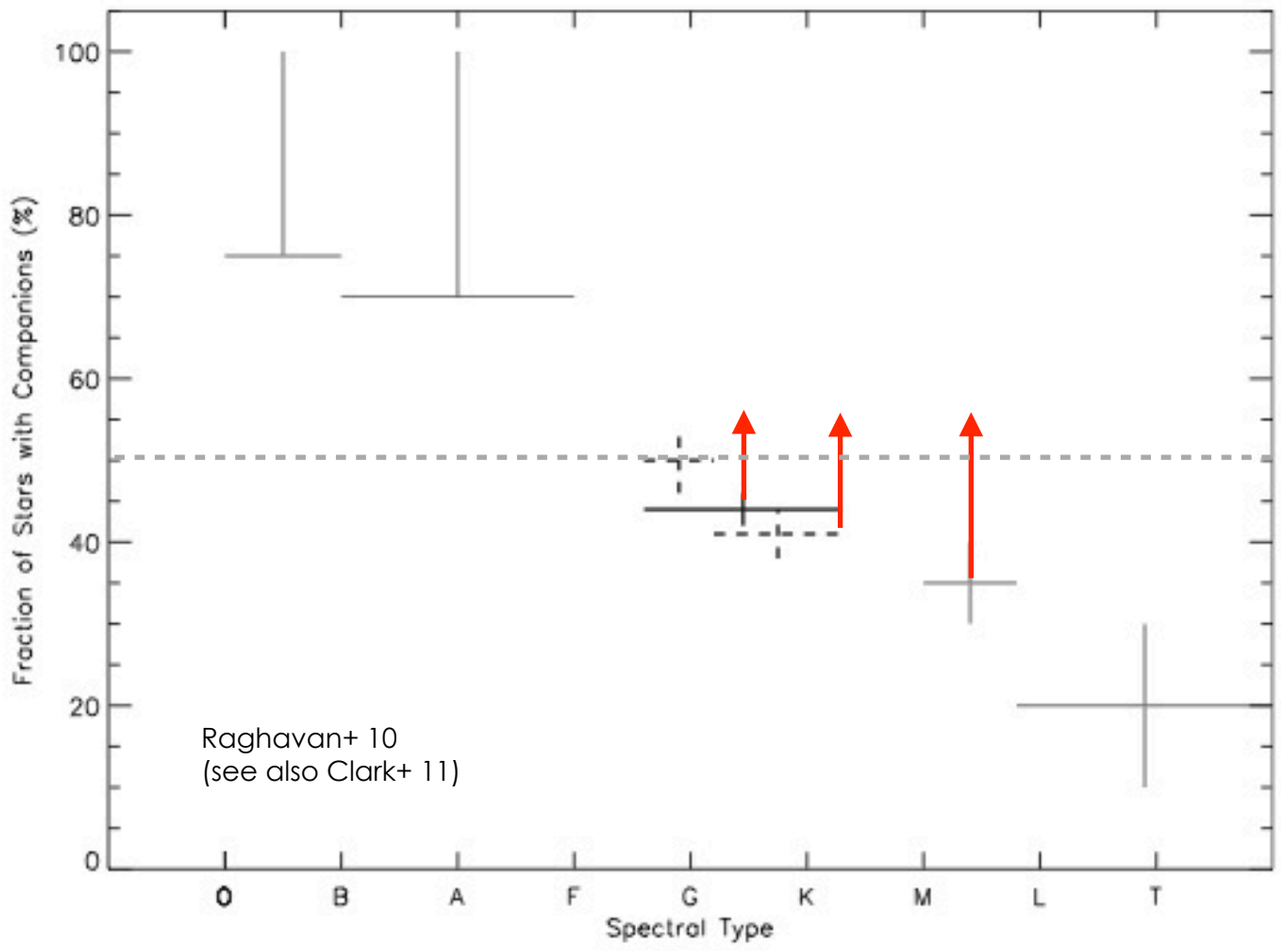
S_B^9 sample: Mass ratio distribution



Boffin & Pourbaix 17

Continuous distribution?

Multiplicity is function of primary mass, M_A



Mass of primary, M_A

Majority of solar-like stars are in binaries!

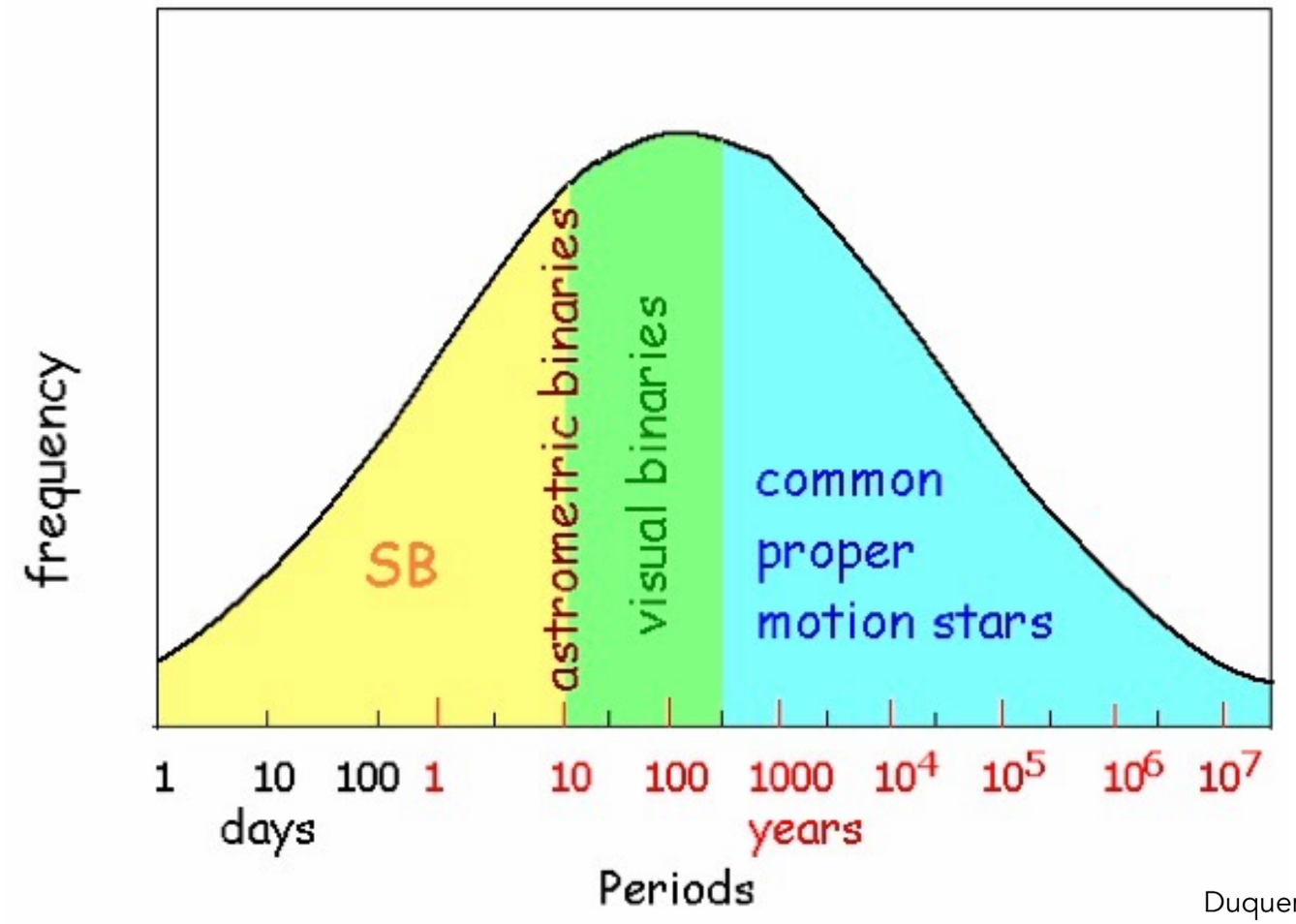
Binarity of G, K, M stars may be similar and above 50%

Boffin & Pourbaix 17
See also Whitworth & Lomax 15

Ackerl, Clarke, Kroupa, Moe, Winters

Period distribution

F7-K dwarfs



Log-Normal distribution from 1 day to 10 million years

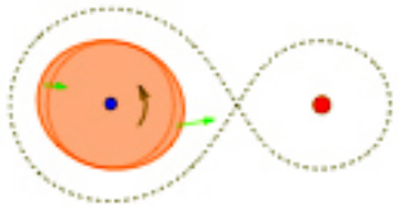
$\langle \log P_{days} \rangle = 4.8$

$\sigma_{\log P} = 2.3$

Duquennoy & Mayor 91
Halbwachs+ 10

Close Binaries

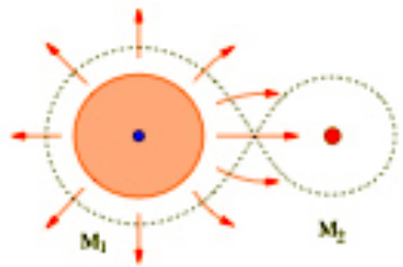
stars in binaries can interact in various ways:



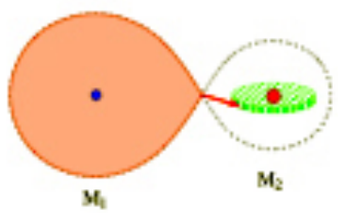
tidal interaction

e–log *P* diag., mixing

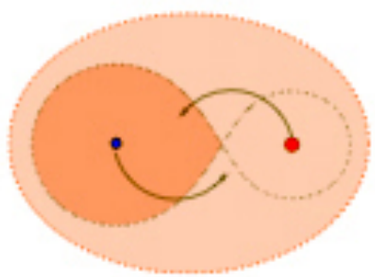
Beck



wind accretion

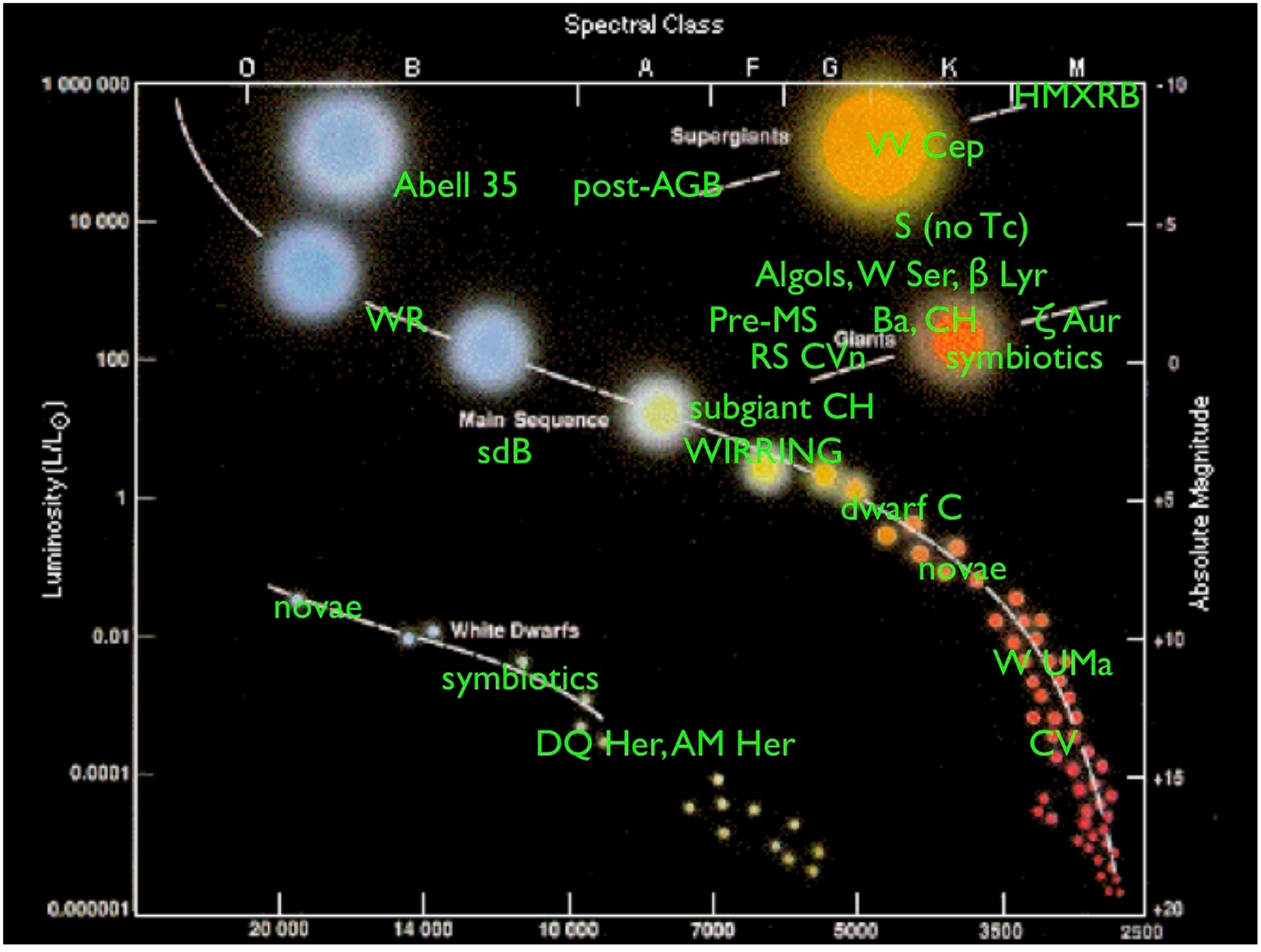


Roche-lobe overflow



common envelope evolution

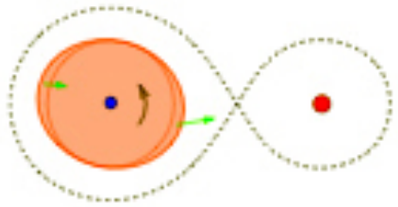
O. Pols


Spectral Class
O
B
A
F
G
K
M
1 000 000
10 000
100
1
0.01
0.0001
0.000001
Luminosity (L/L⊙)
-10
-5
0
+5
+10
+15
+20
Absolute Magnitude
20 000
14 000
10 000
7000
5000
3500
2500
Supergiants
Giants
Main Sequence
White Dwarfs
HMXRB
VV Cep
Abell 35
post-AGB
S (no Tc)
Algols, W Ser, β Lyr
WR
Pre-MS
Ba, CH
ζ Aur
RS CVn
symbiotics
subgiant CH
sdB
WIRRING
dwarf C
novae
novae
W UMa
symbiotics
DQ Her, AM Her
CV

Credit???

Close binaries

stars in binaries can interact in various ways:



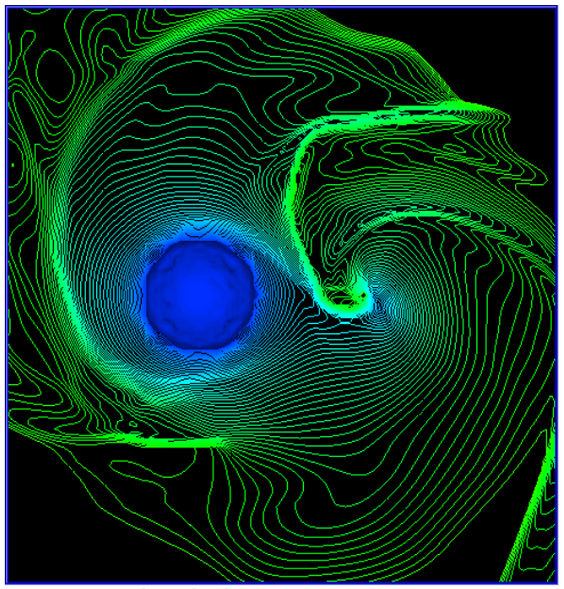
tidal interaction

wind accretion

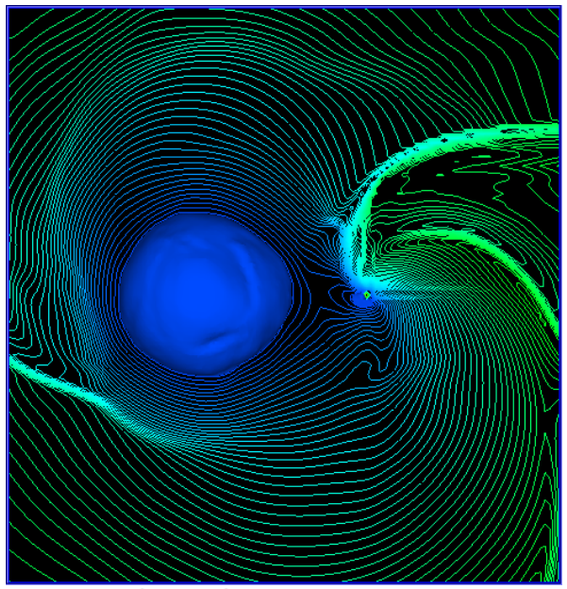
Detached systems

PRGs, symbiotic stars, novae, SN Ia

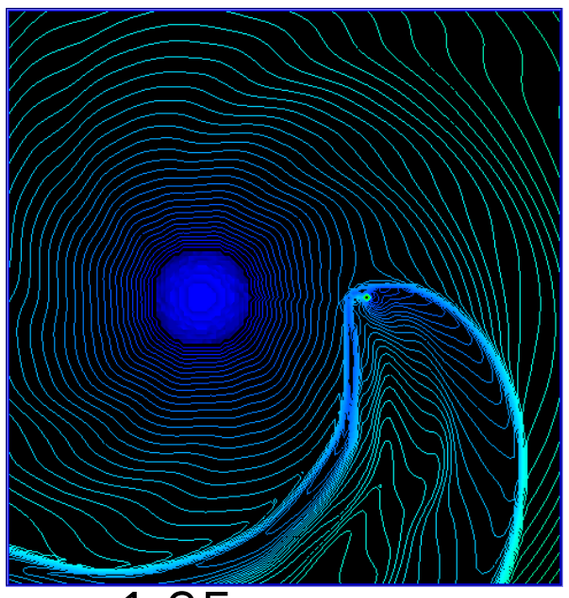
Wind accretion



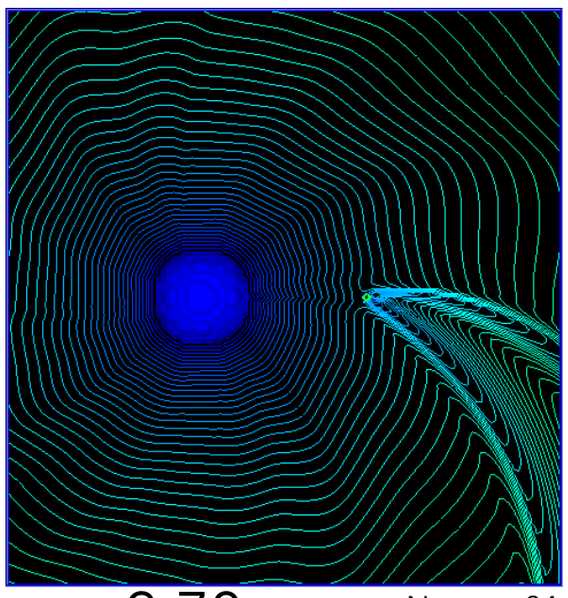
$v_w = 0.03$



$v_w = 0.10$



$v_w = 1.35$



$v_w = 3.78$

Nagae+ 04

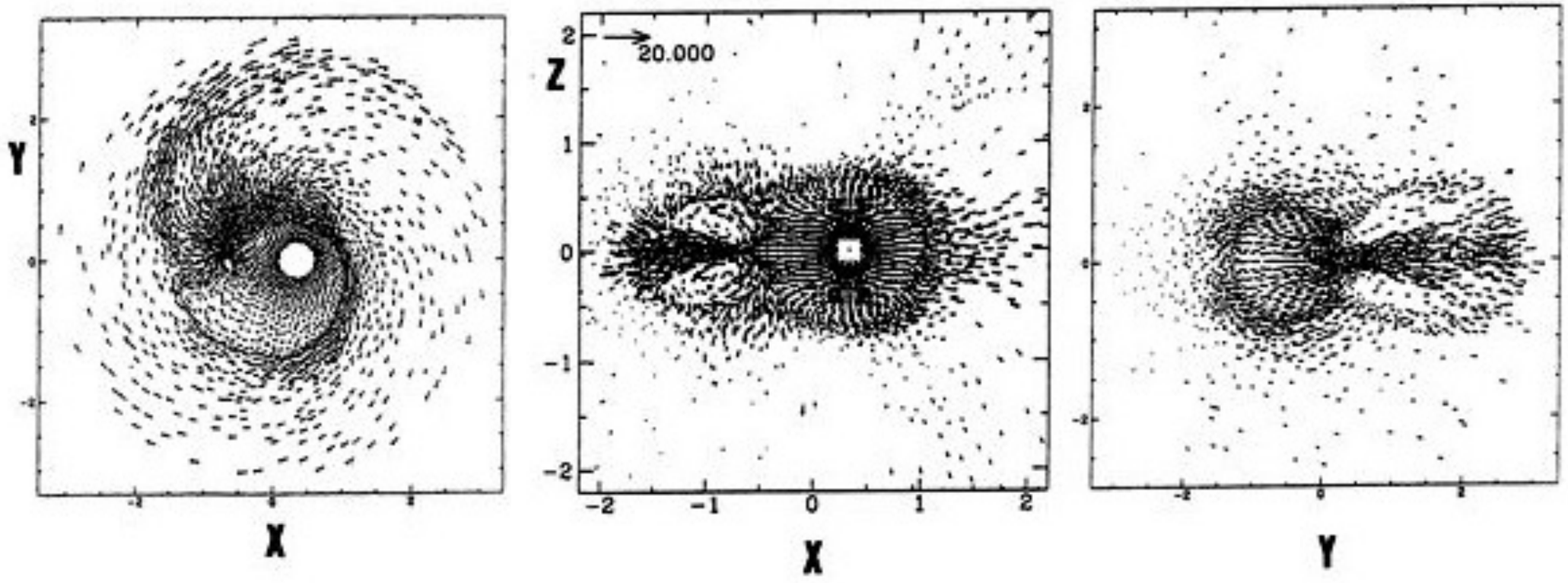
Flow structure depends on the ratio of the wind velocity with respect to orbital speed.

Flows very different: from Bondi-Hoyle type (but with asymmetry) to very complex ones.

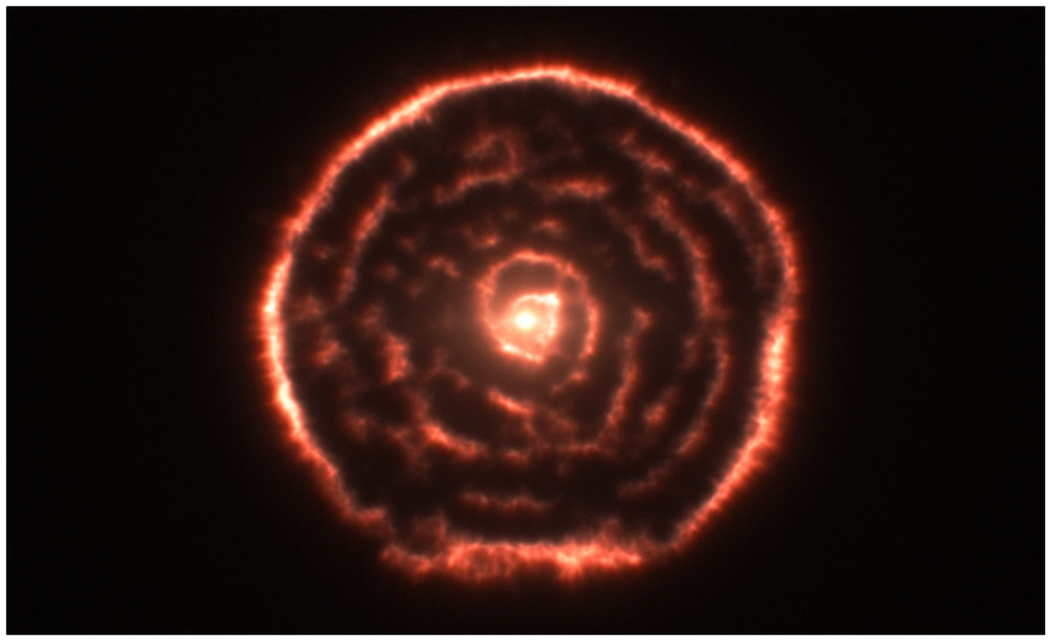
Wind accretion with an AGB

- In AGB stars binaries of interest, the wind speed is smaller or comparable to the orbital velocity
- v_w = 5–15 km/s $< v_{orb}$ = 20–30 km/s
- Not a Bondi-Hoyle (even modified) type flow
- Coriolis and centrifugal forces play a vital role

Boffin+ 94, Theuns+ 96

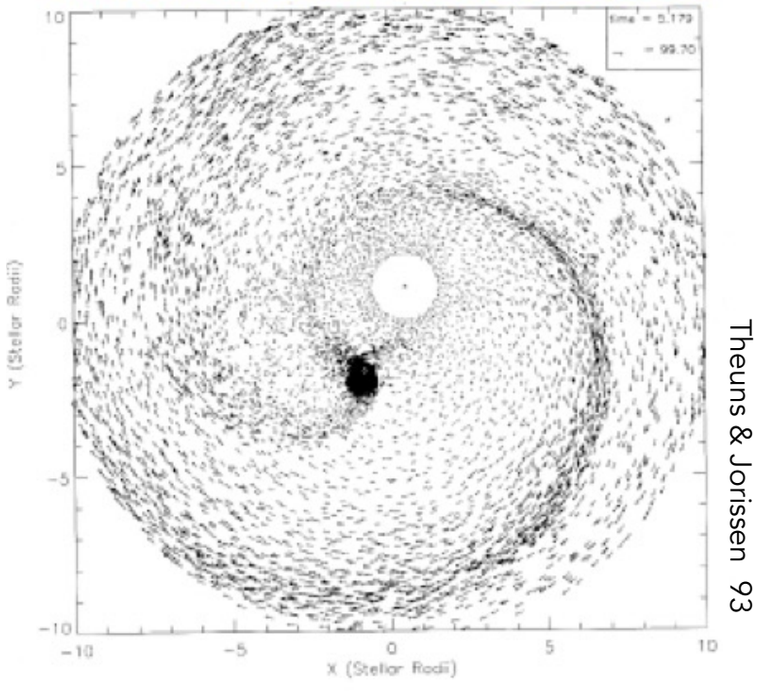


AGB star: R Scl



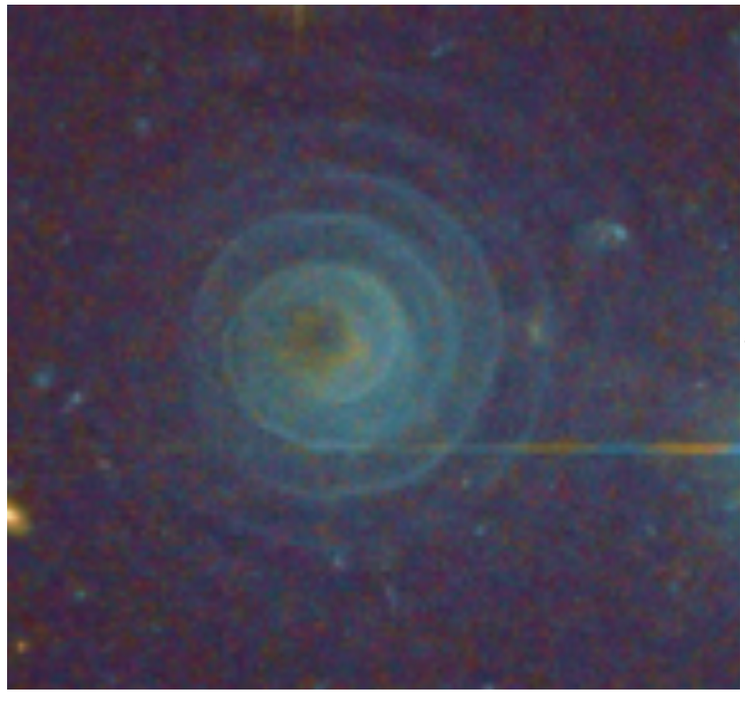
Maercker+ 2012 (ALMA)

a = 60 AU
P = 350 years (!)
$M_1+M_2 = 2\ M_\odot$
M_1 suffered a thermal pulse event about 1800 years ago that lasted for about 200 years



Theuns & Jorissen 93

Carbon star AFL 3068



© ESA/NASA & R. Sahai, Morris et al. 2006

Barium stars

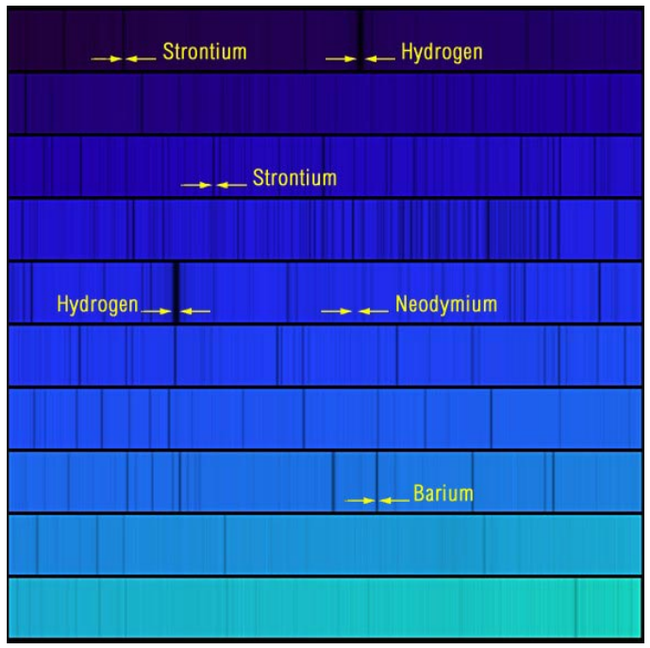
~1% of all G- and K-type giants which present overabundances of nucleosynthesis s-process (e.g., Ba) elements on their surface.

THE *Ba* II STARS*

WILLIAM P. BIDELMAN AND PHILIP C. KEENAN
Yerkes, McDonald, and Perkins Observatories

Received July 16, 1951

Since then, also Ba dwarfs, extrinsic S stars, CH-giants and dwarfs, CEMP-s, etc.



Astron. Astrophys. 205, 155–163 (1988)

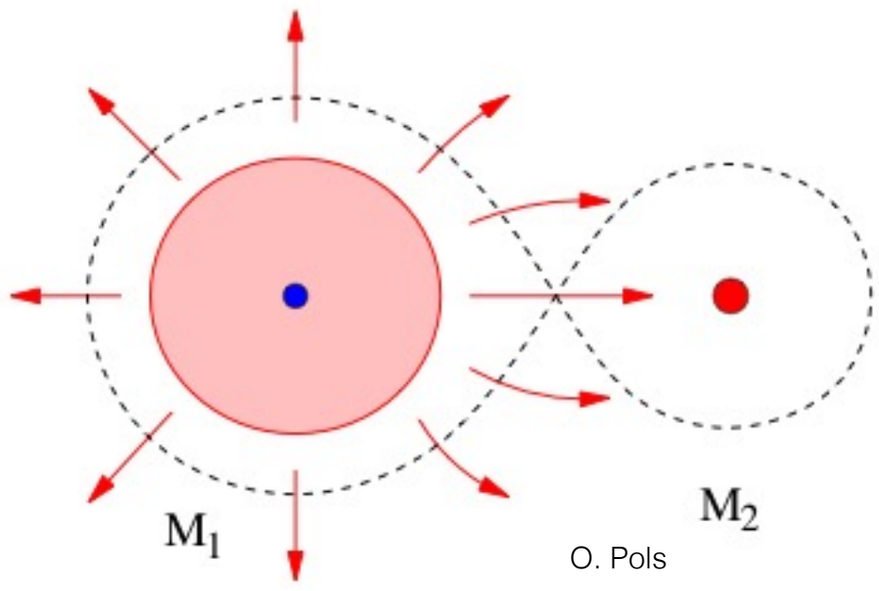
ASTRONOMY AND ASTROPHYSICS

Can a barium star be produced by wind accretion in a detached binary?

H.M.J. Boffin* and A. Jorissen*

Institut d'Astronomie, d'Astrophysique et de Géophysique, Université Libre de Bruxelles, C.P. 165, Av. F. Roosevelt 50, B-1050 Bruxelles, Belgium

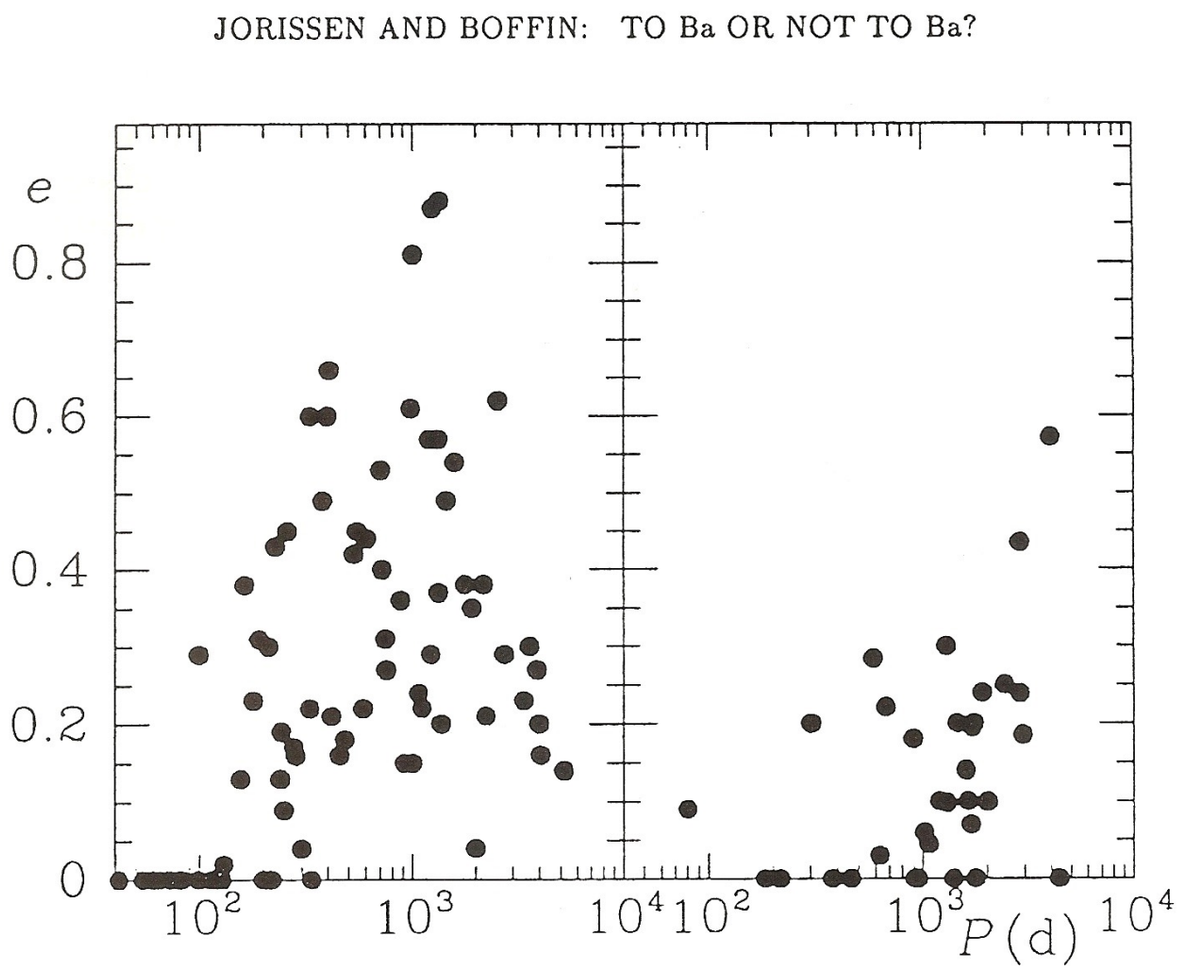
Received January 29, accepted May 18, 1988



O. Pols

Master thesis done in 1987
30th anniversary!

Barium stars



Jorissen & Boffin 92

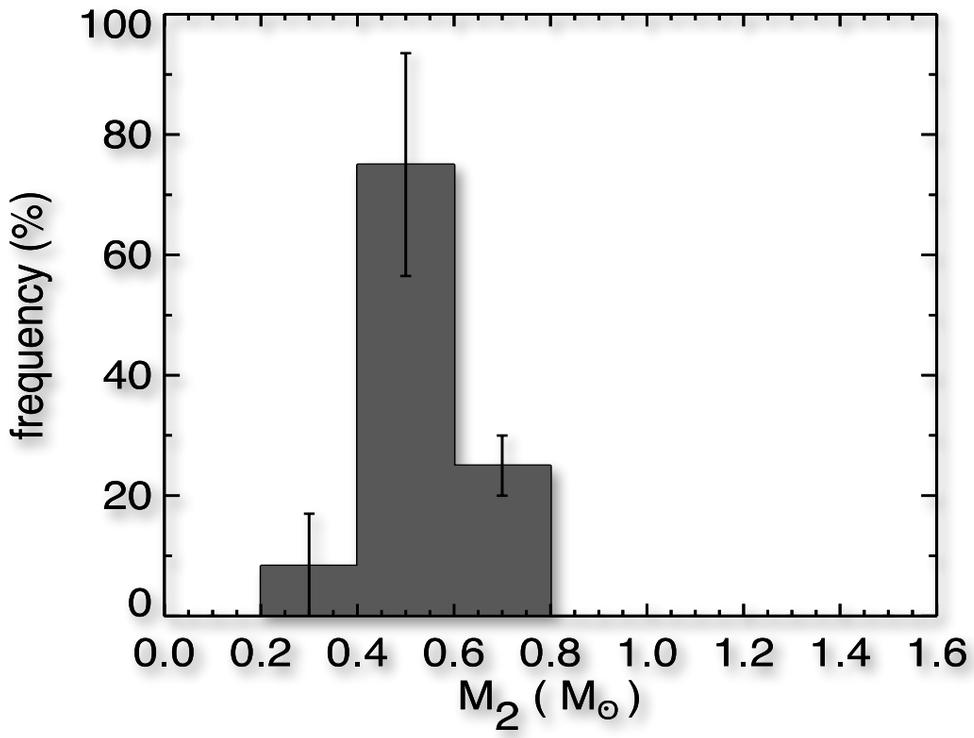
Confirmation of model:
Period of Ba stars are longer than those of normal giants

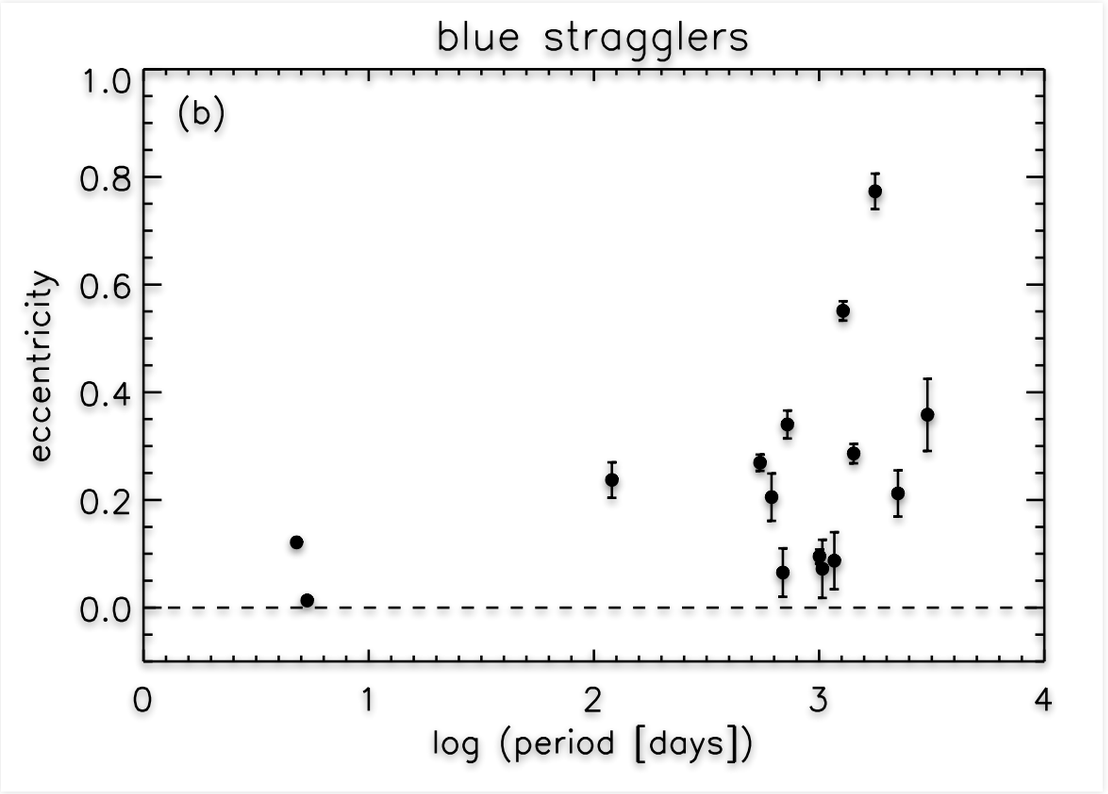
But eccentricity?

And can we really avoid RLOF?

Kamath, Escorza, Karinkuzhi, Pols, Whitehouse

NGC 188 blue stragglers





Mathieu & Geller 2009

Same properties as Barium stars!

These are also post-mass transfer stars, the result of wind mass transfer from an AGB that is now a white dwarf

Ferraro, Mapelli, Mathieu, Ramirez-Tannus, Yakut

Symbiotic Stars

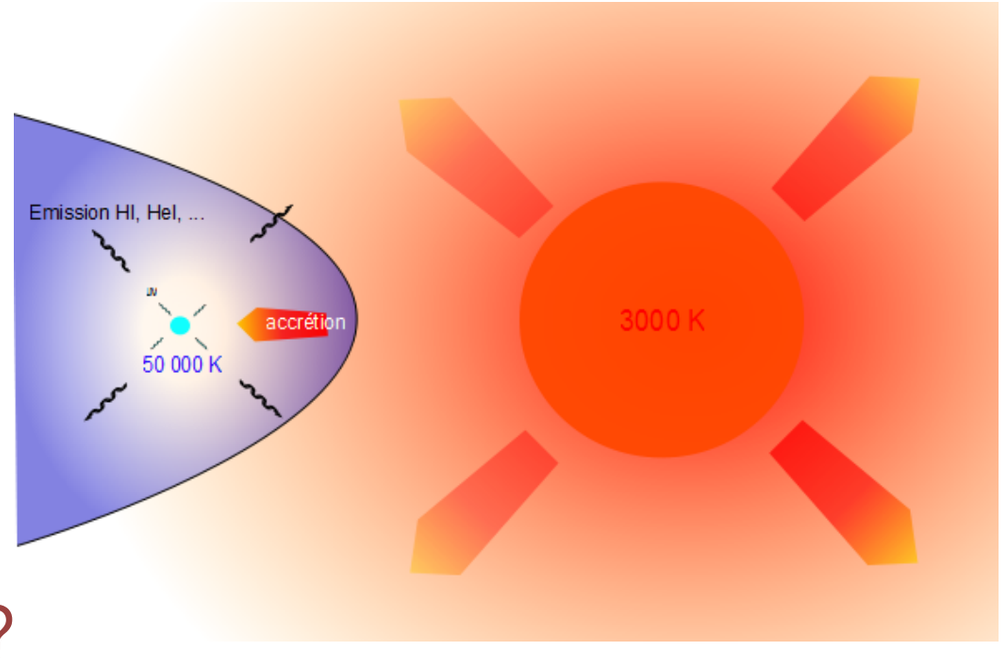
a cool red giant and a small hot companion seem to live in general harmony

Oxpeckers eat the parasites off of large animals like this African buffalo. But they're also parasites themselves, keeping wounds open and picking at scabs.
Natphotos/Digital Vision/Getty Images
howstuffworks.com

variety. The inference, while not necessarily correct, is obvious enough. Physically associated with such objects as Z *Andromedae,* T *Coronae,* R *Aquarii,* R W *Hydrae,* and others is an extremely faint O-type star, too faint to be seen, inclosed by a small surrounding nebular shell of high excitation. Binary motion and the proximity of a nebular shell may account for the irregular light variations commonly observed, as well as for the complex changes in the bright line spectrum. Instances where the intensity gradient of the bright hydrogen lines is not rapid whenever ionized helium appears would hardly be favorable to this viewpoint.[1] Visual confirmation of this hypothesis might be sought for by examining these objects for possible duplicity with a powerful instrument.

LOUIS BERMAN

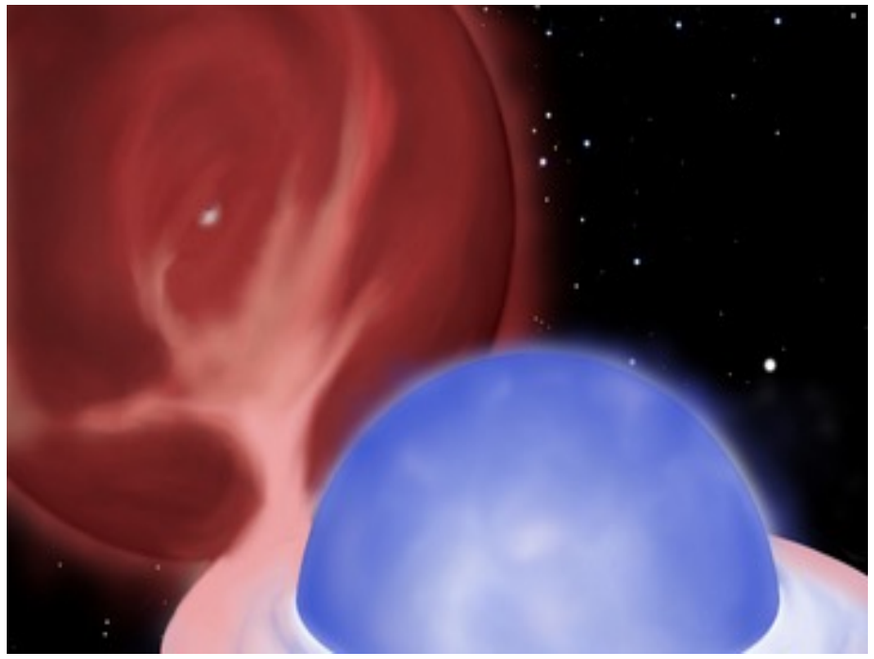
LICK OBSERVATORY
MOUNT HAMILTON, CALIFORNIA
September, 1932



Nature of Mass Transfer?

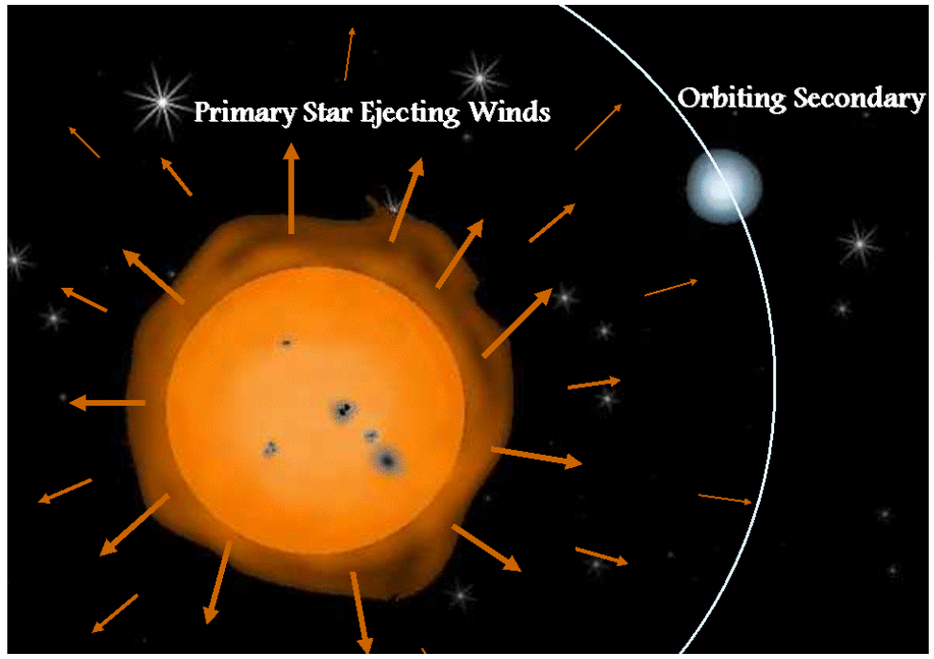
Symbiotic stars

Using VLTI data, symbiotic stars can be divided into two categories based on the nature of the components:



(a) a lobe-filling giant and a A-F main sequence star

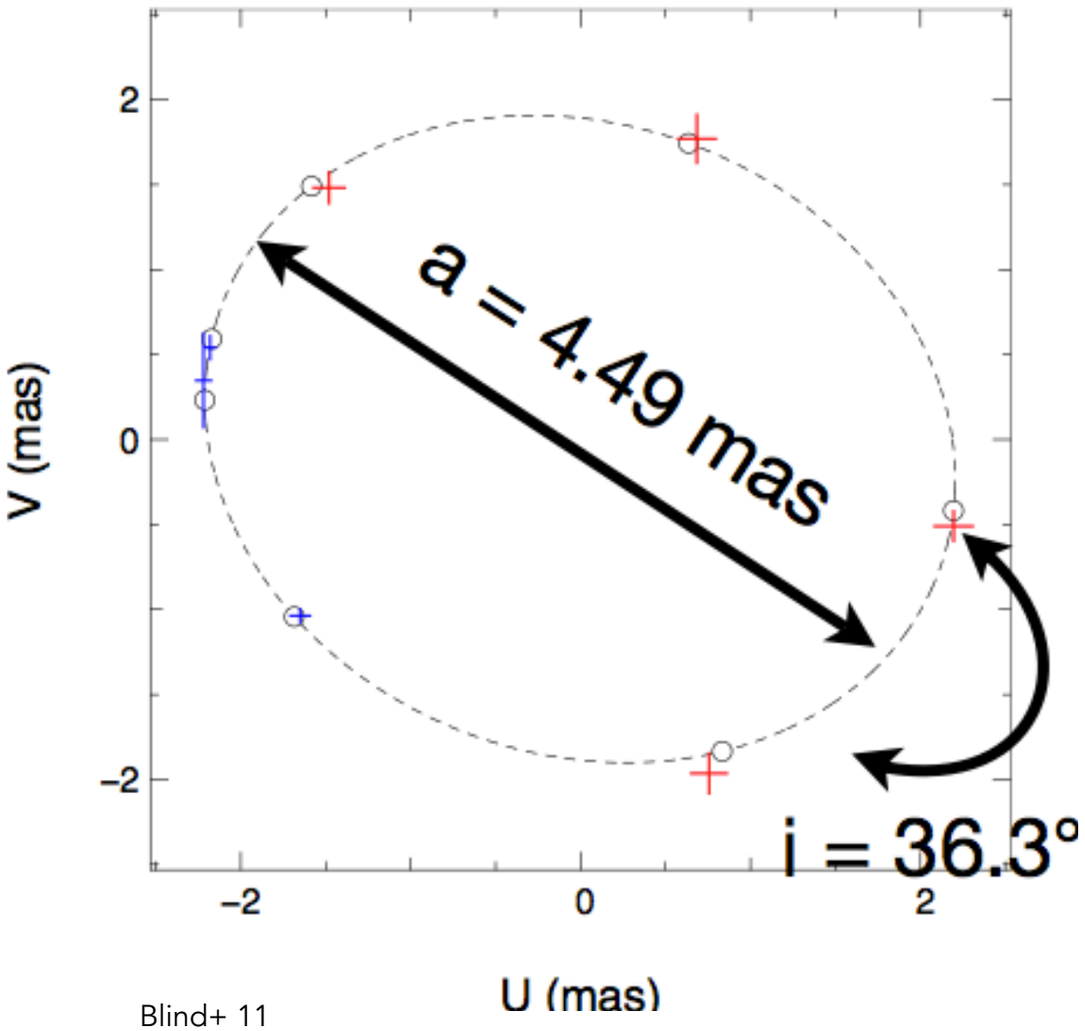
Boffin+ 14



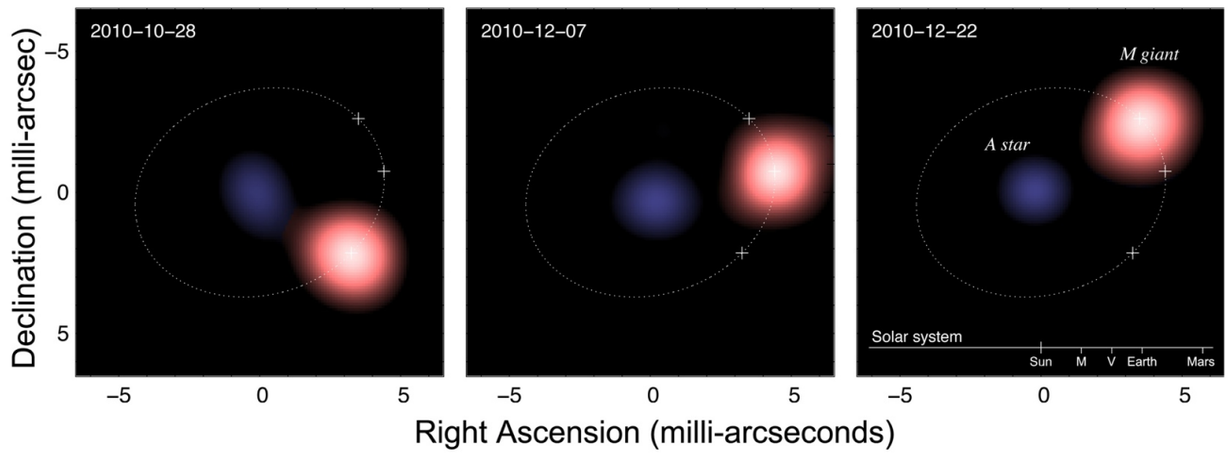
(b) a white dwarf or subdwarf and a red giant losing mass in a stellar wind

Chen, Griffin, Pala, Saladino, Sokoloski

The Symbiotic Star 17 Lep



Blind+ 11



P = 260 days

Resolve both components

No RLOF

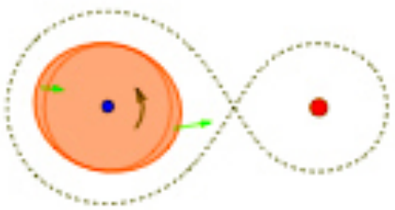
No model can explain such system!

Precursor of **post-AGB stars**?

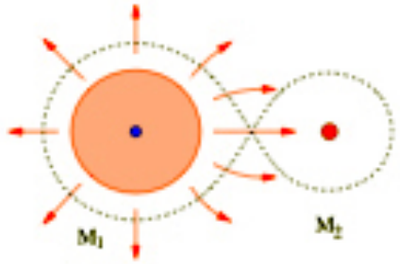
Kamath, van Winckel

Close binaries

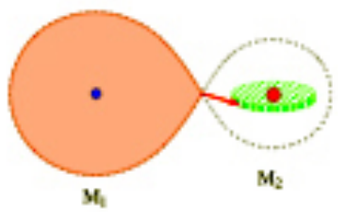
stars in binaries can interact in various ways:



tidal interaction



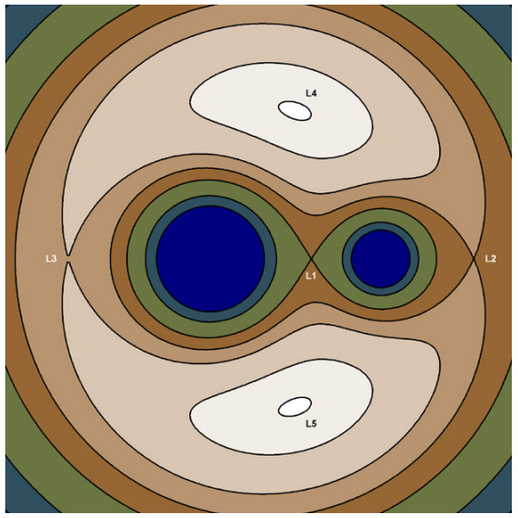
wind accretion

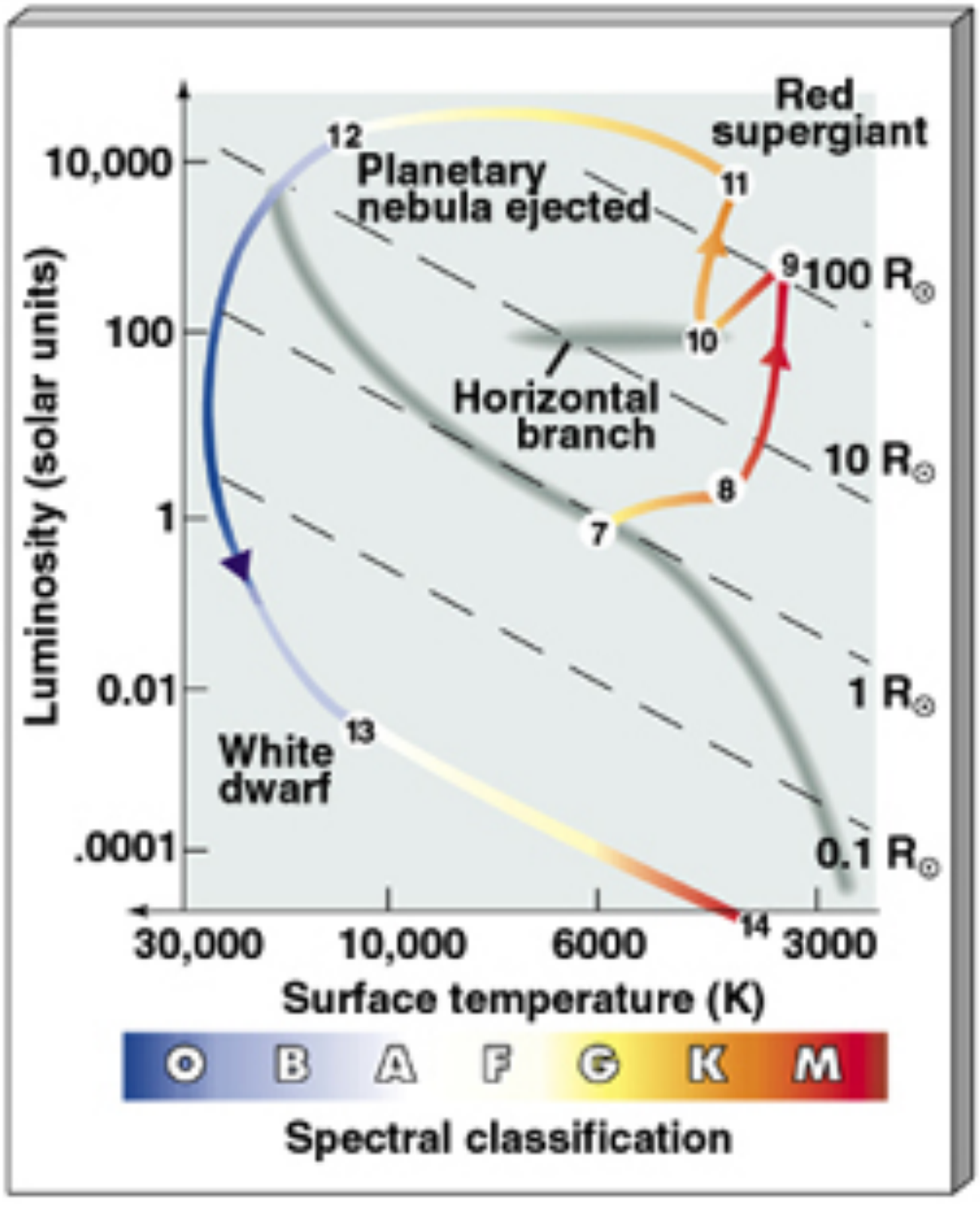


Roche-lobe overflow

Semi-detached systems

CVs, Algols





Roche lobe overflow if

a ~ 1.3 au; P ~ 1 yr

a ~ 0.13 au; P ~ 12 d

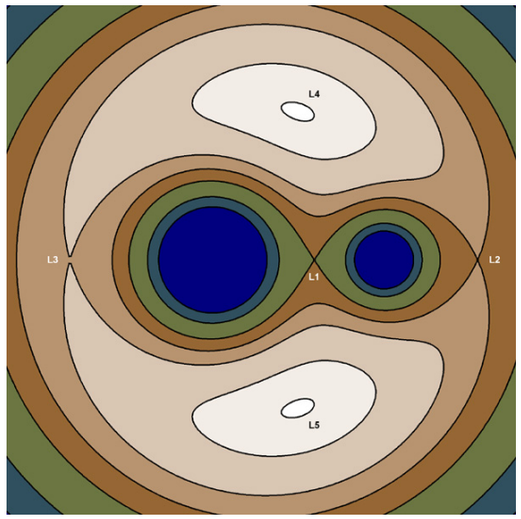
a ~ 2-3 $R_\odot$; P ~ 5-6 h

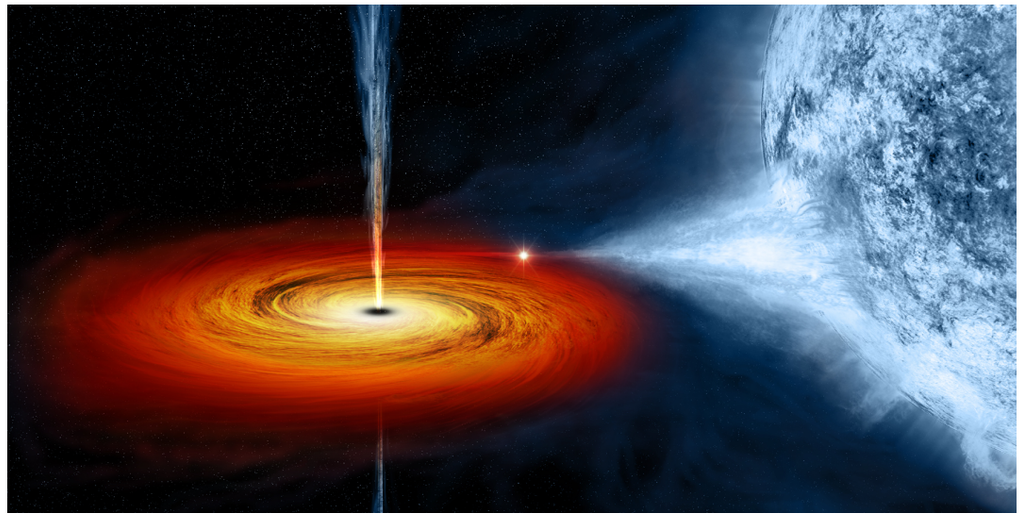
a ~ 0.25 $R_\odot$; P ~ 30 min

Different kind of systems → a Zoo!

Roche lobe overflow

- If $R_{circ} > R_*$, a disc forms, and sometimes jets
- This is the case when accretor is WD (CV), NS (LMXB), BH (HMXB)
- Or even a MS if system is wide (e.g. symbiotic star)
- If MS and short period, then direct impact (Algol)

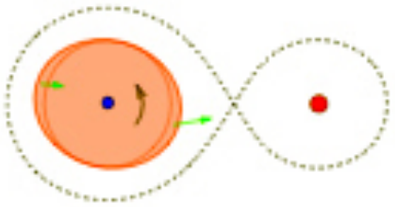




Chaty, Dervisoglu, Garofali

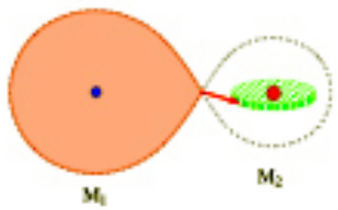
Close binaries

stars in binaries can interact in various ways:

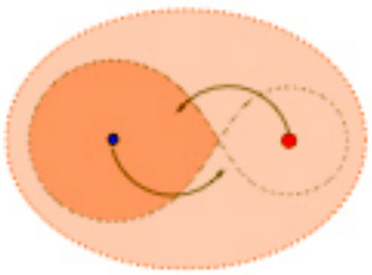


tidal interaction

wind accretion



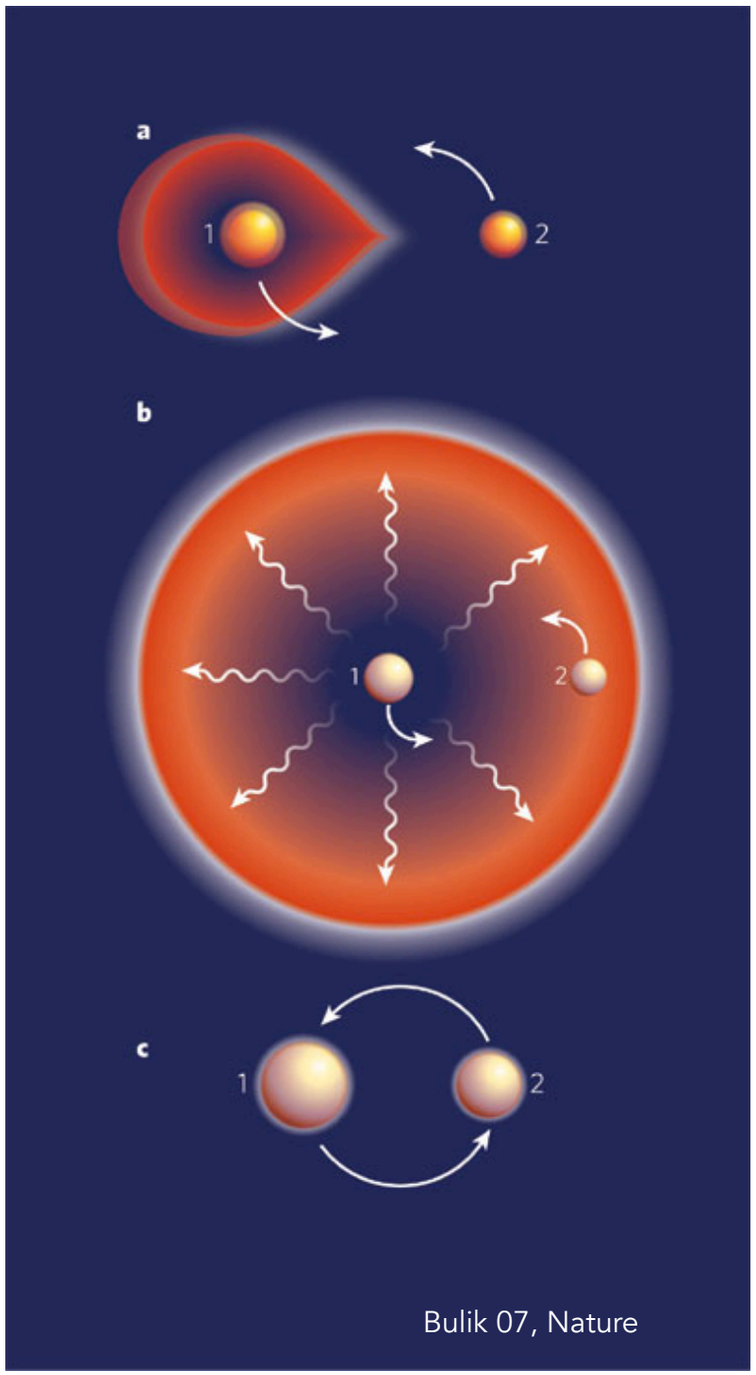
Roche-lobe overflow



common envelope evolution sdB, Bin. CSPNe

Common envelope

Paczynski 76

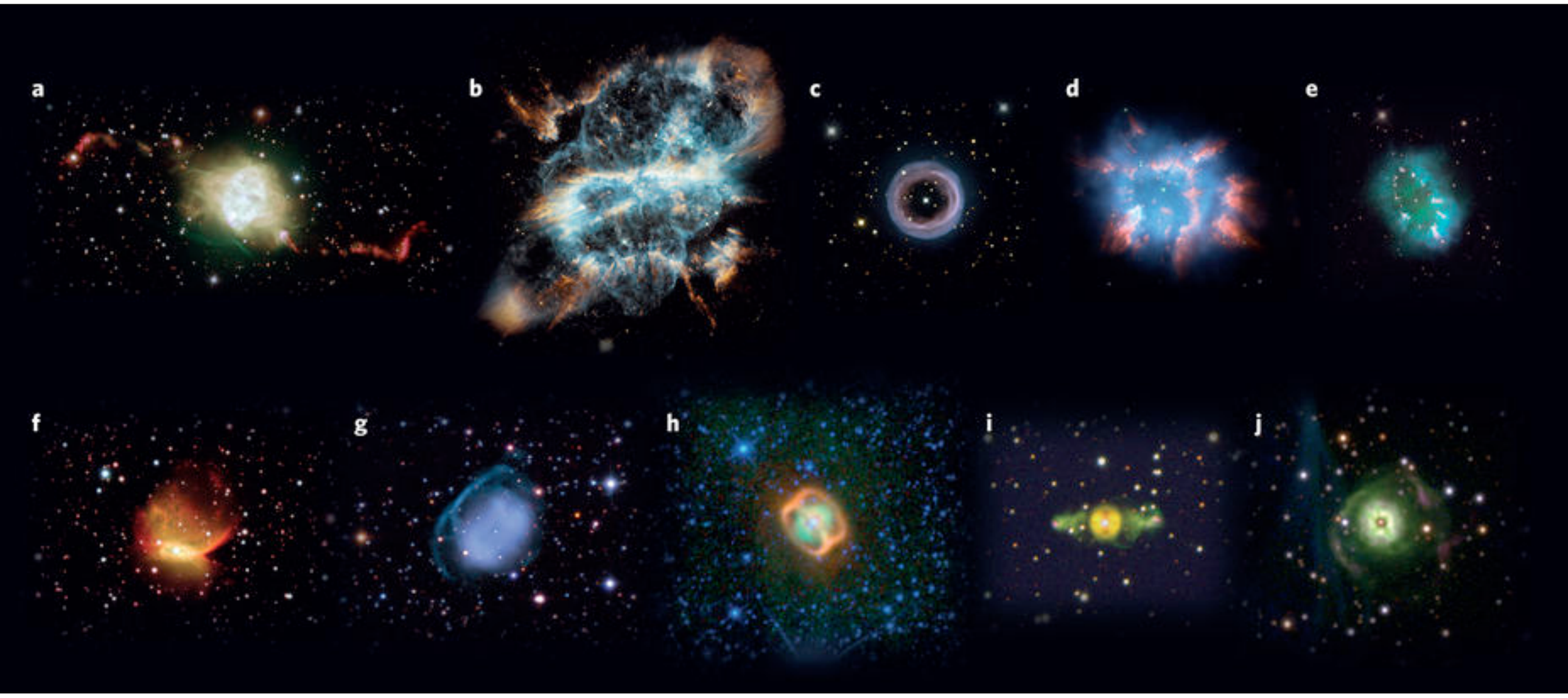


Bulik 07, Nature

Credit: NASA/ESA/Hubble

The Butterfly Nebula

Planetary Nebulae



Jones & Boffin 17, Nature Astronomy

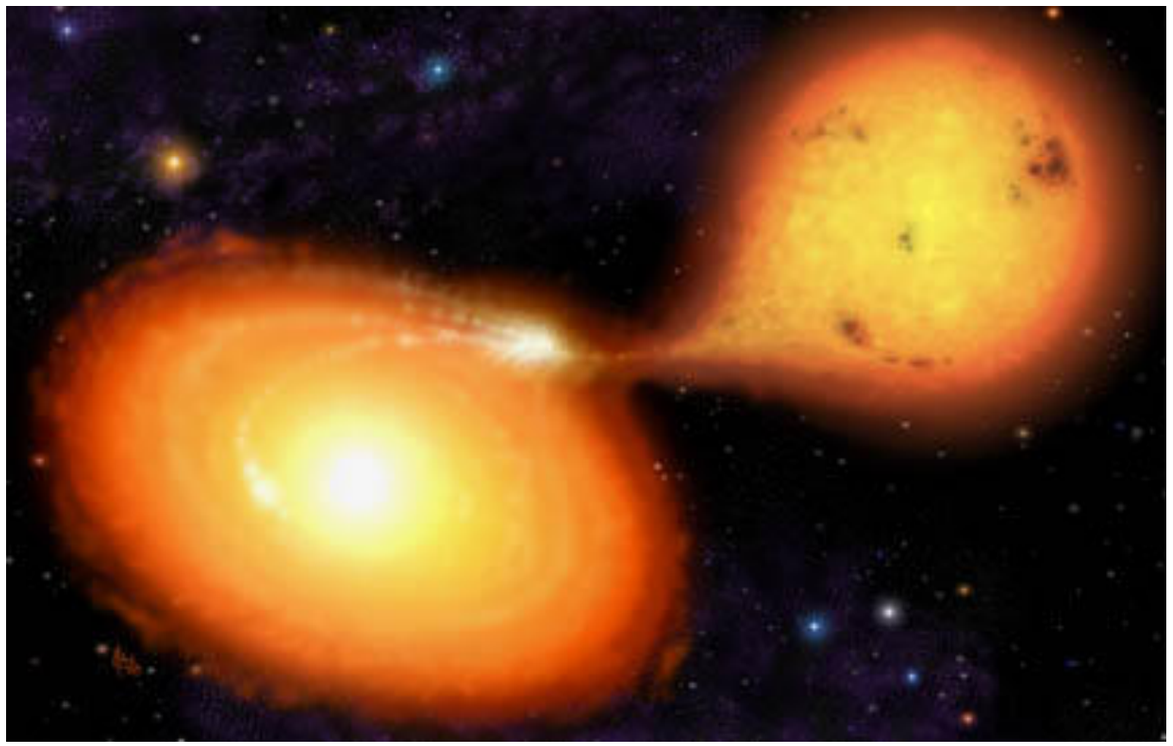
Textbooks need most likely to be rewritten!

Binary Central – Stars of PNe

Boffin et al., Science, 2012
ESO press release 1244

Jones, Sowicka

Cataclysmic variables



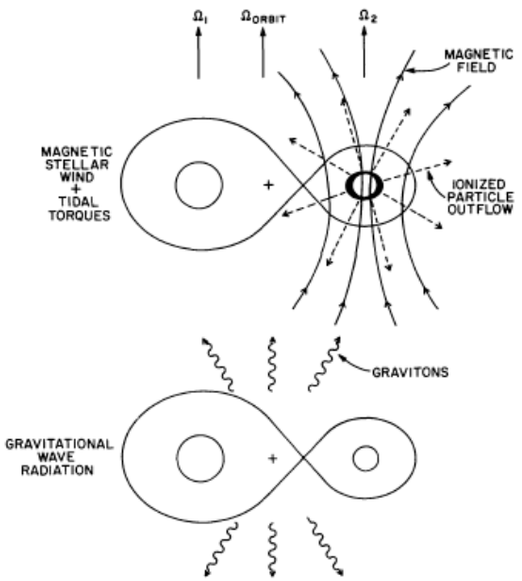
Mark Garlick, http://www.space-art.co.uk/

Contains a main sequence star filling its Roche lobe and a white dwarf

Orbital period ~ few hours
Separation ~ 1 solar radius

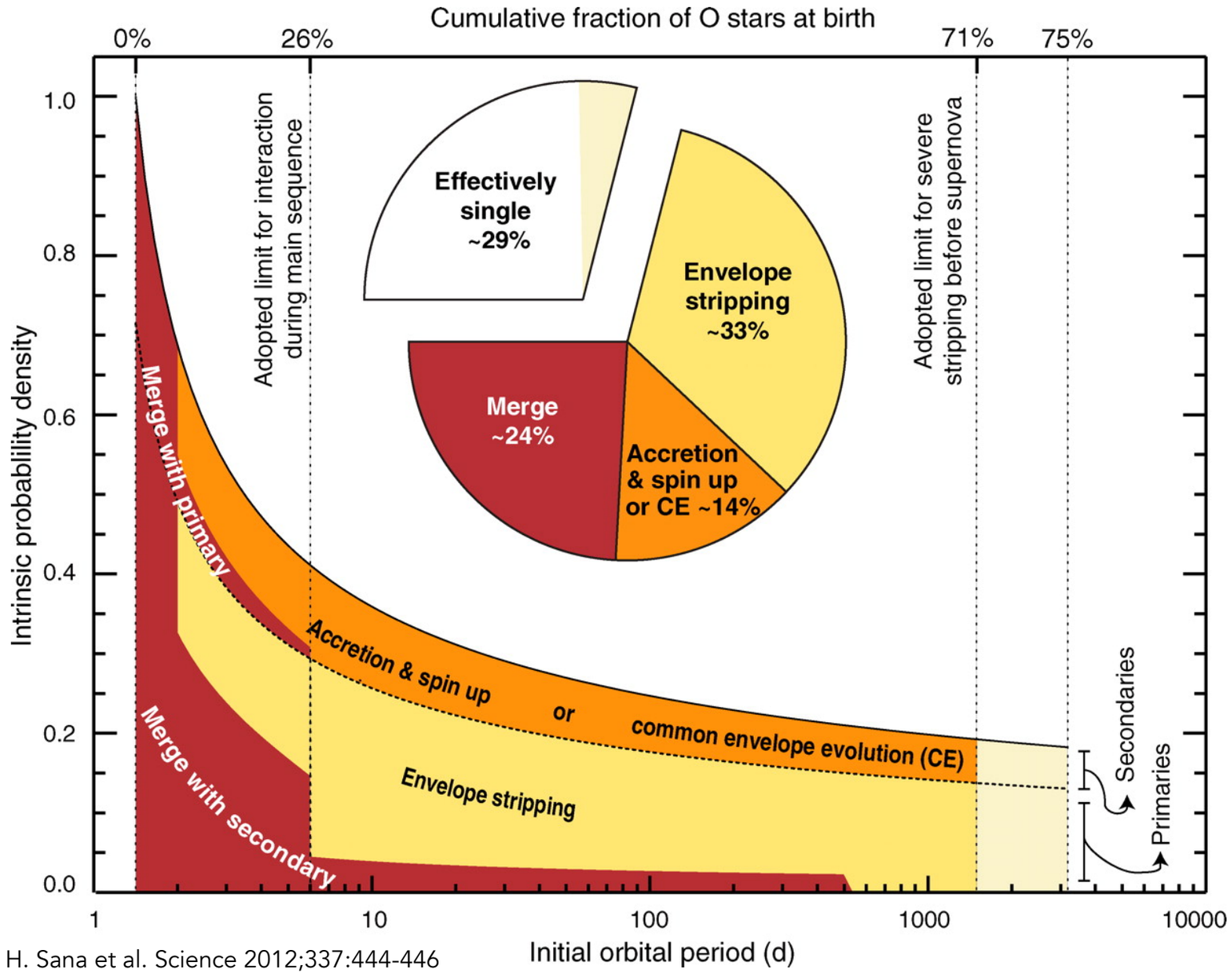
Angular momentum evolution:
- magnetic fields
- gravitational waves

May lead to mergers



Kaminski, Pala

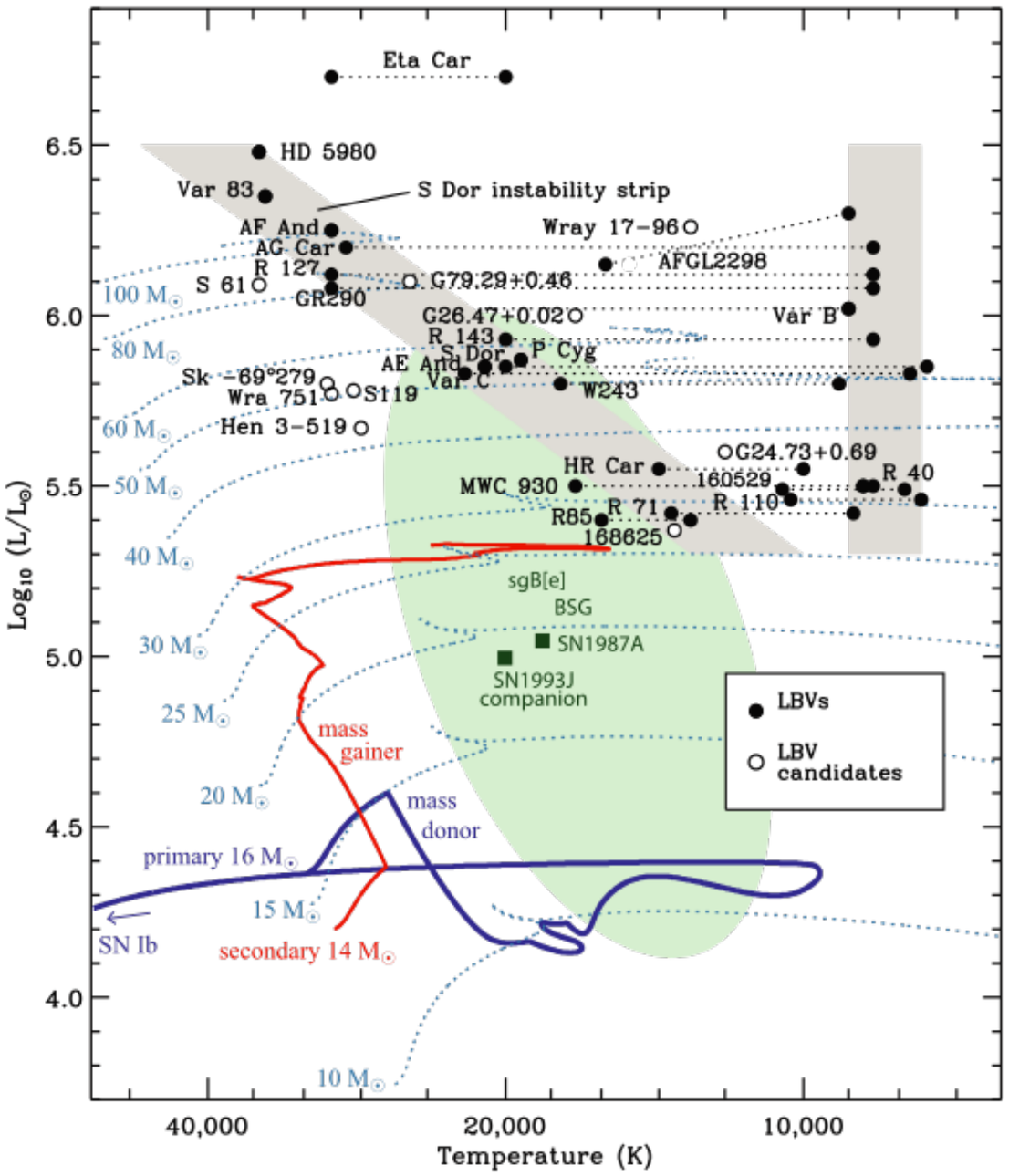
Massive stars interact!



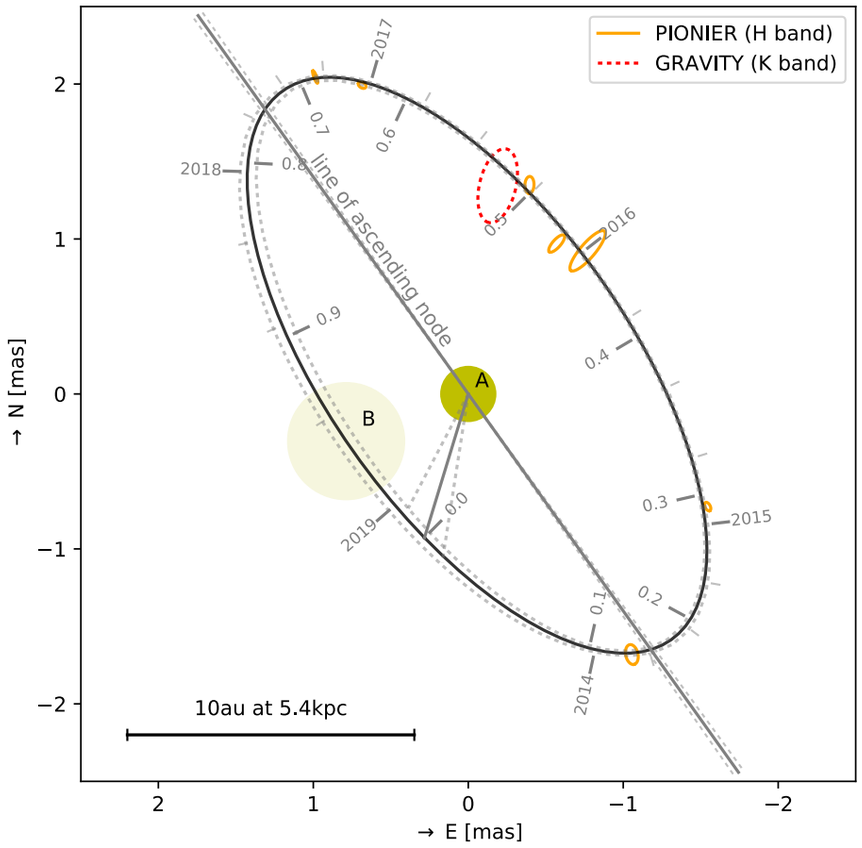
H. Sana et al. Science 2012;337:444-446

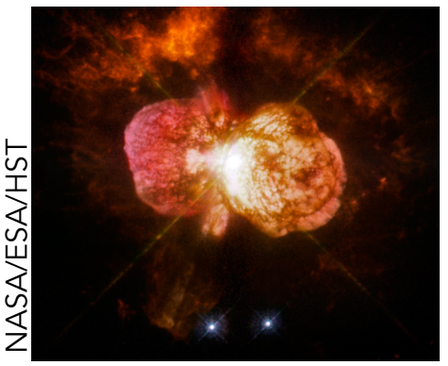
Alecian, Goetberg, Langer, Ohlmann, Rauw, Sana

Luminous blue variables



Smith & Tombleson 15



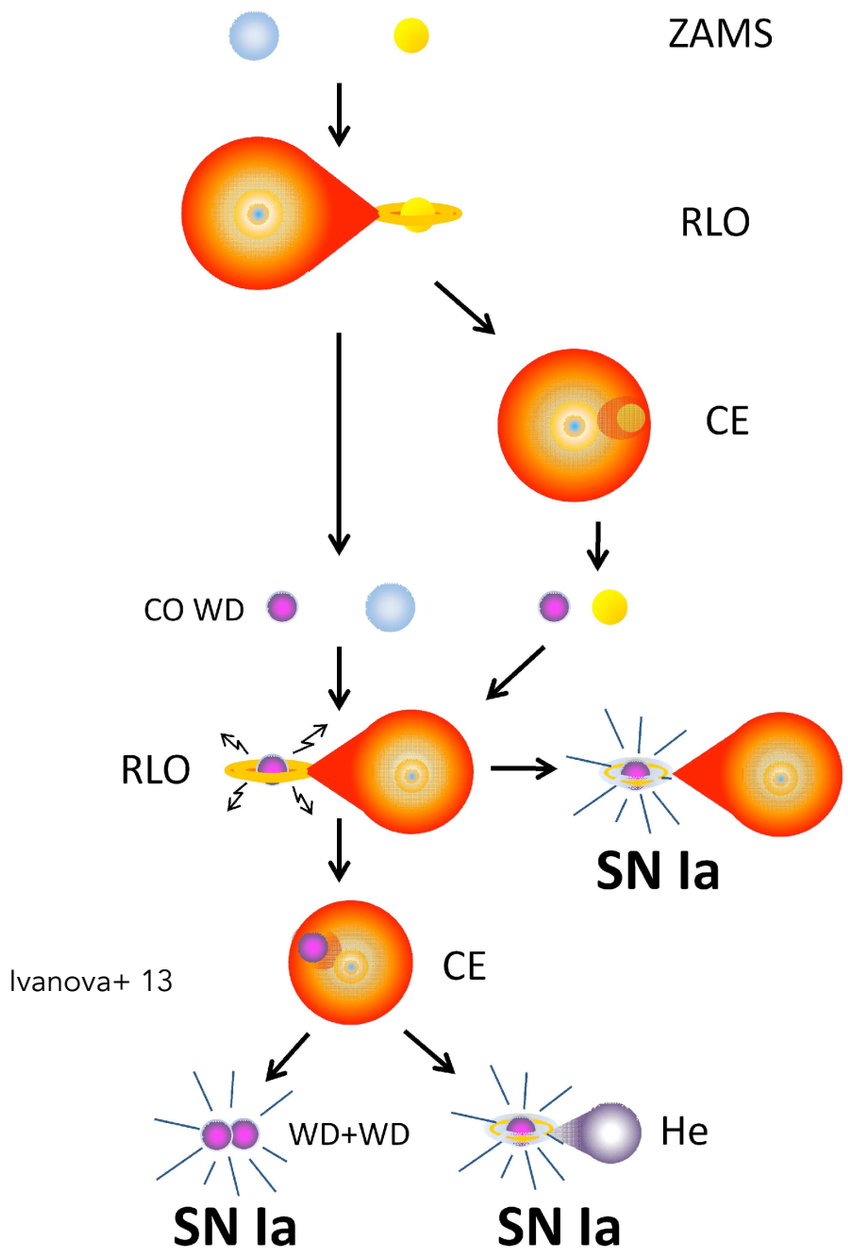


Boffin+ 16, 17

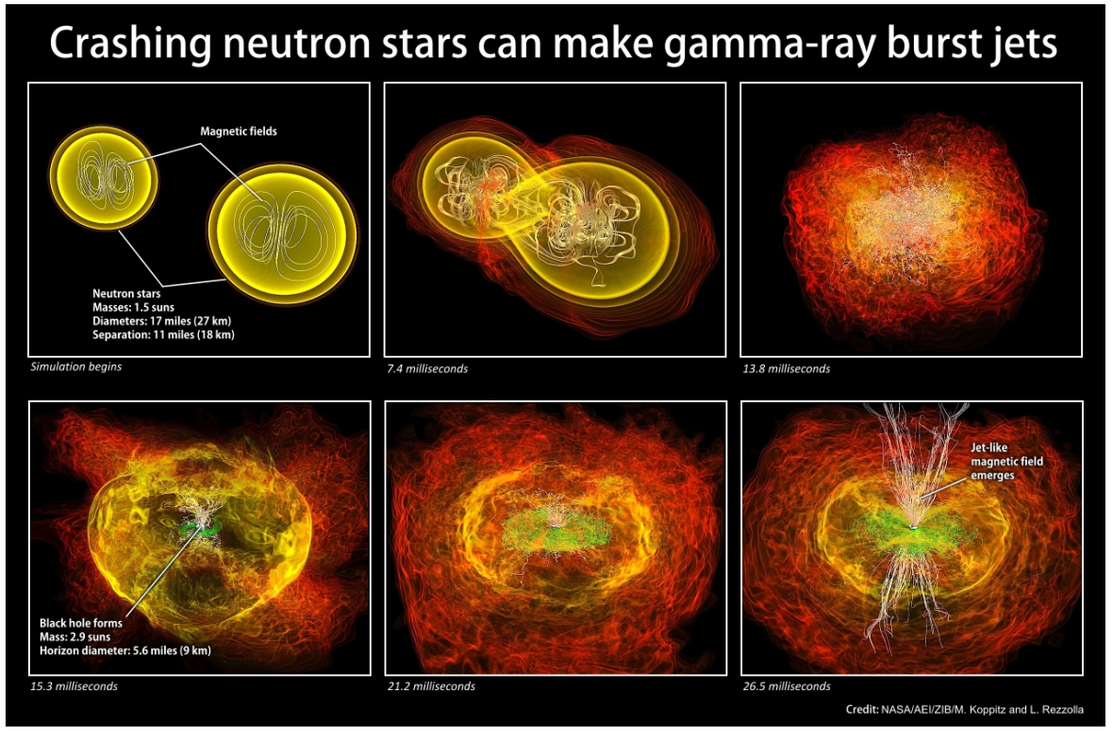
HR Car is a binary!

Kashi, Pakull, Sanchez Bermudez, Smith

Exploding events



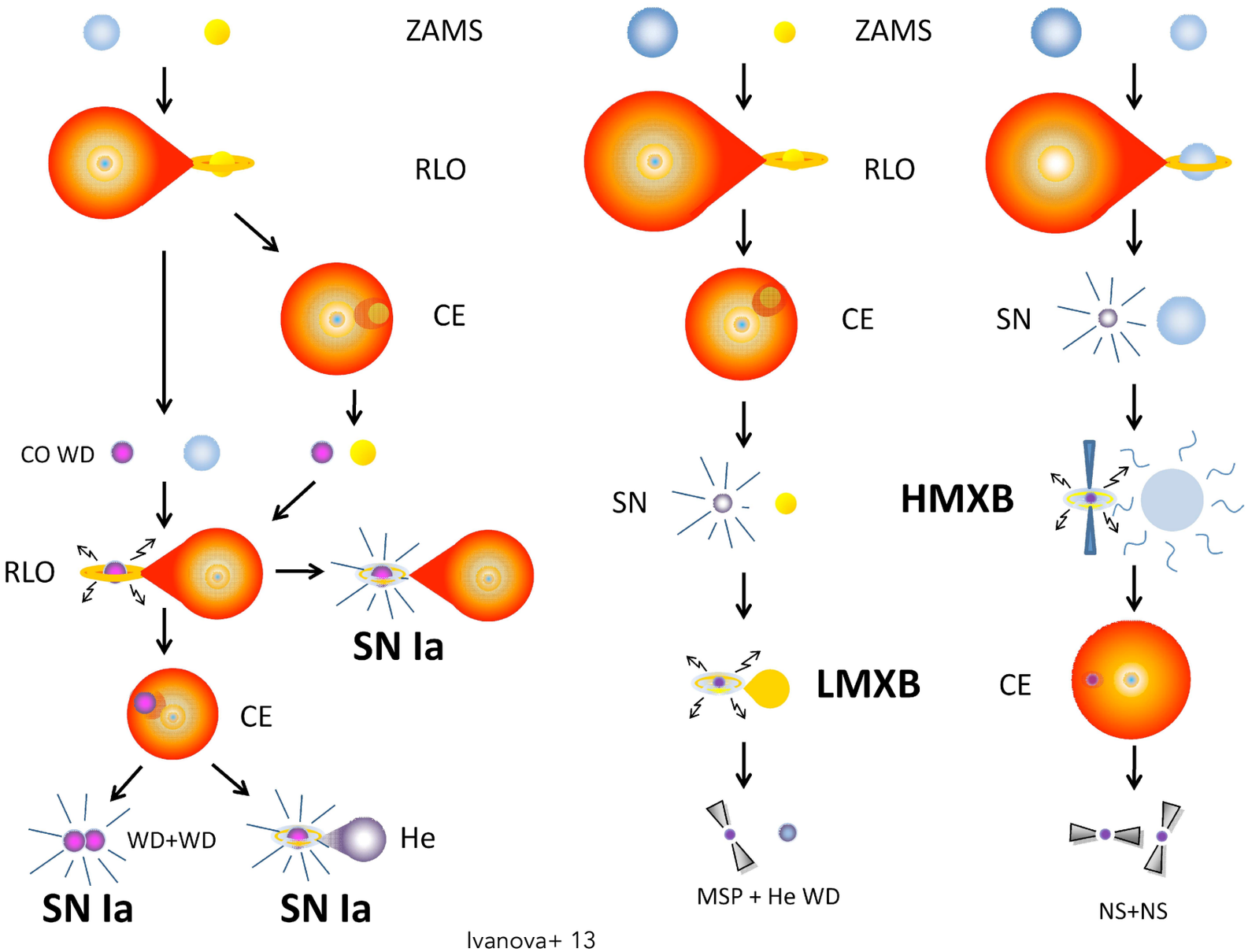
Ivanova+ 13



Hallakoun, Patat, Pritchett, Ruiter, Tanvir

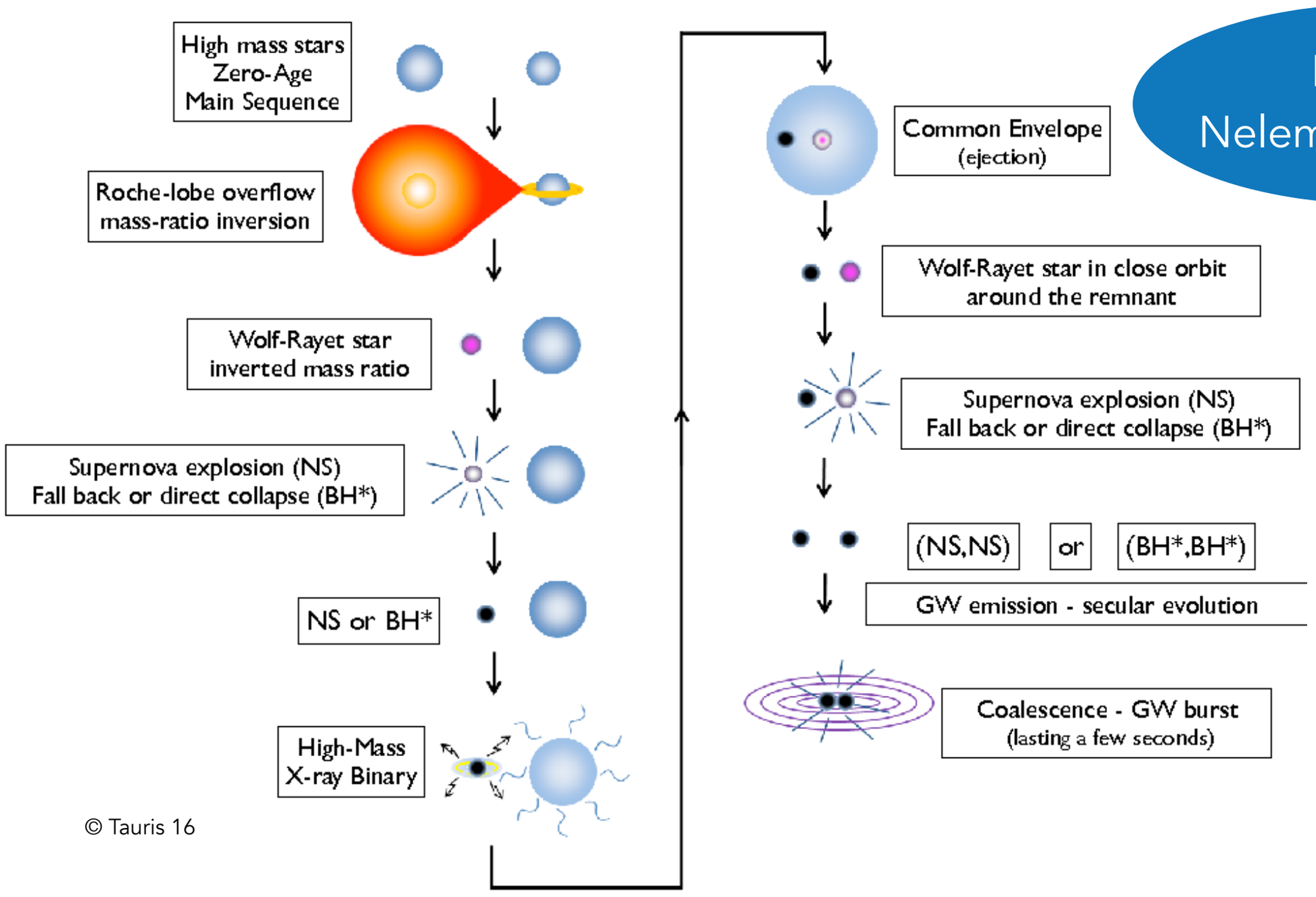
At Various Scales

Chaty, Garofali, Pallanca



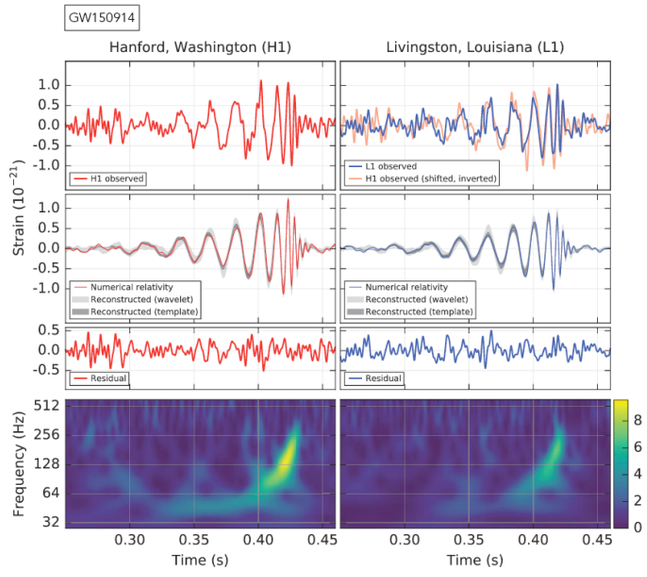
Ivanova+ 13

Neutron stars, black holes, gravitational waves…

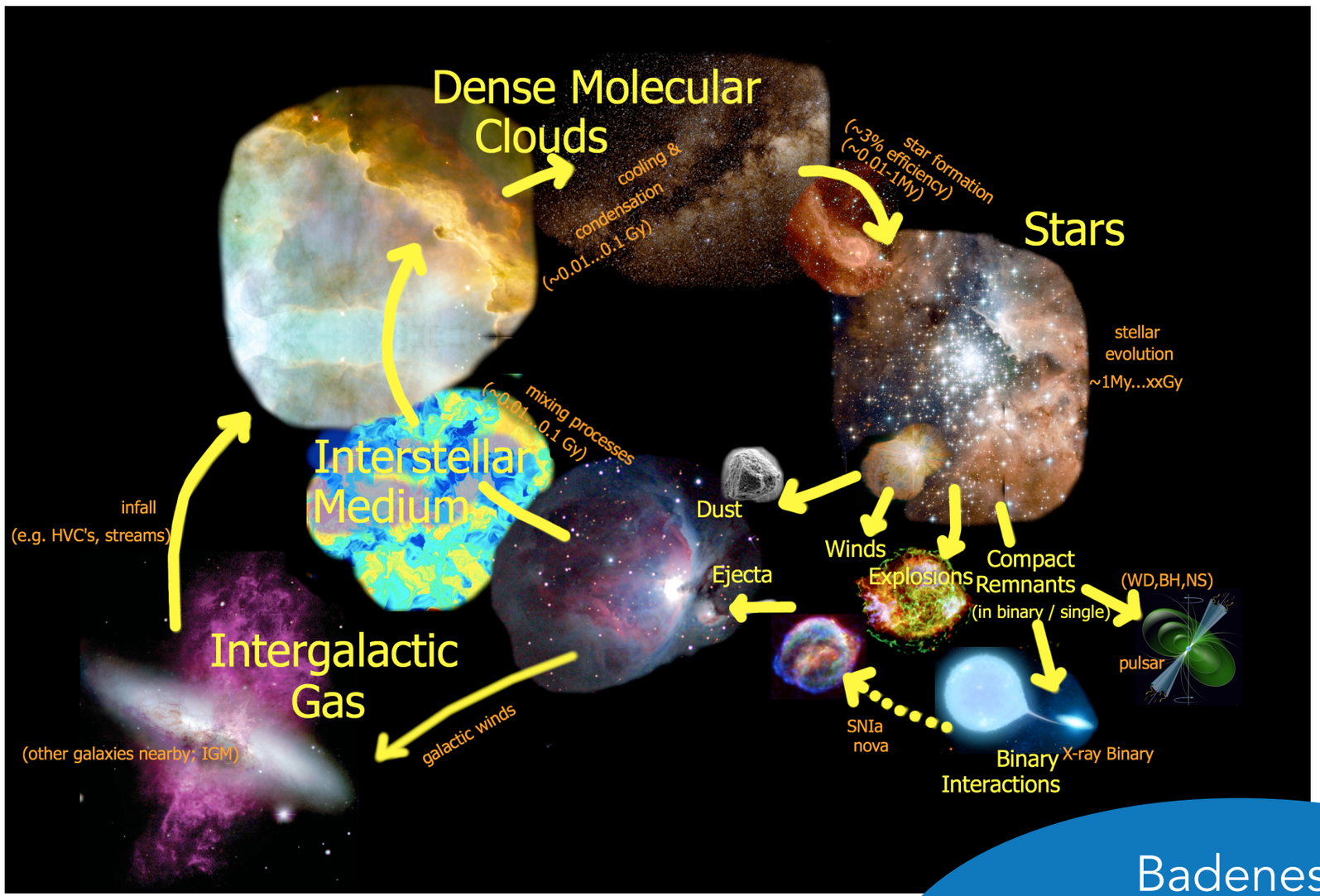


© Tauris 16

Klencki,
Nelemans, Neijssel



And there is also….



R. Diehl 10

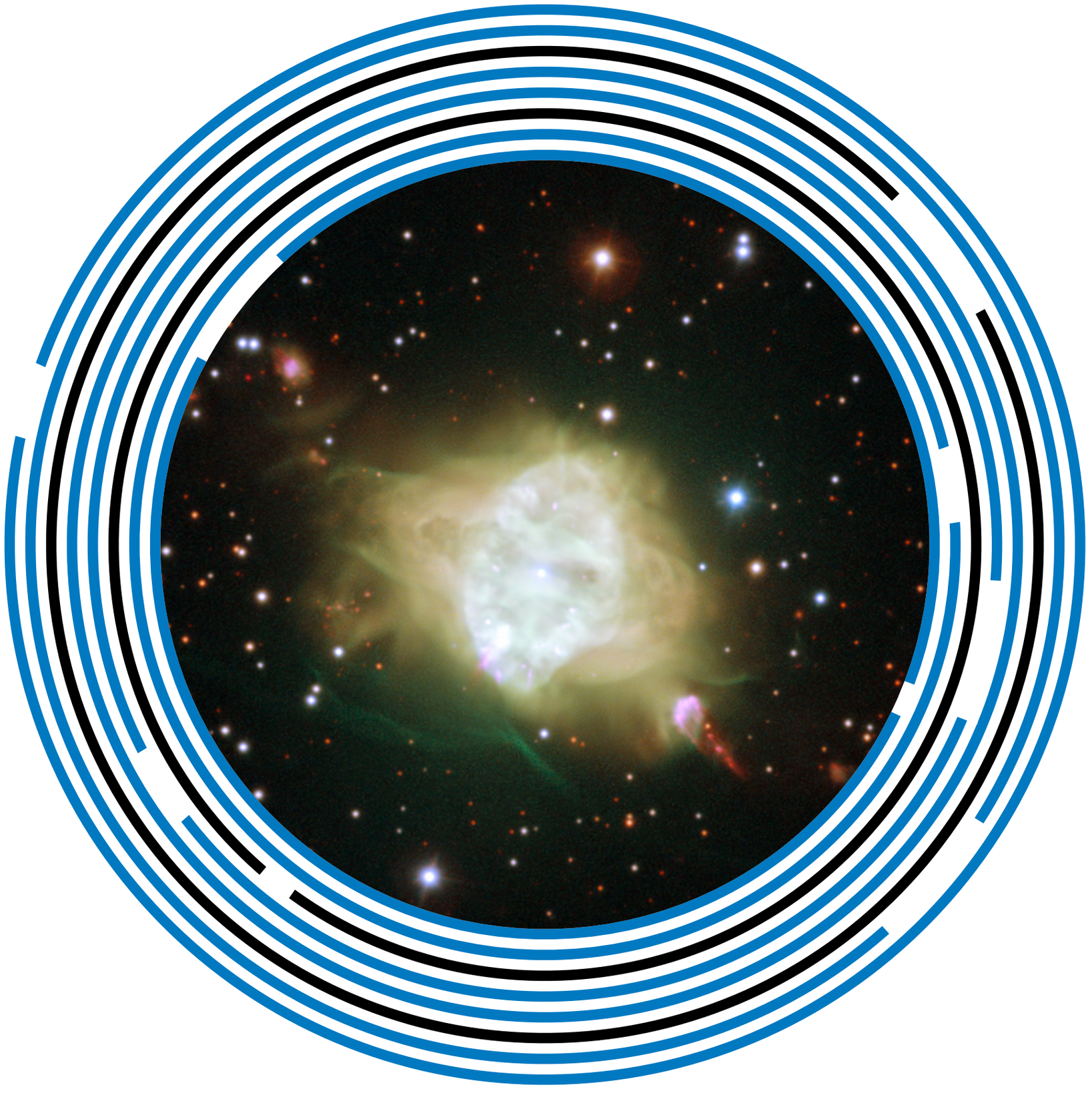
- Stellar evolution
- Chemical composition
- Chemical evolution of galaxies
- Population synthesis
- Large surveys
- …

Badenes, Eldridge, Eyer, Kroupa, Lucatello, Nowlavi, Salaris, Starkenburg

As well as….

No less than 98 posters!

Don’t miss them during the week, and the 2 poster sessions.



Welcome to ImBaSE17!