The Importance of binary stars

Henri M.J. Boffin

Twinkle twinkle little star,
I don't wonder what you are,
What you are I know quite well,
For your light changes will tell.

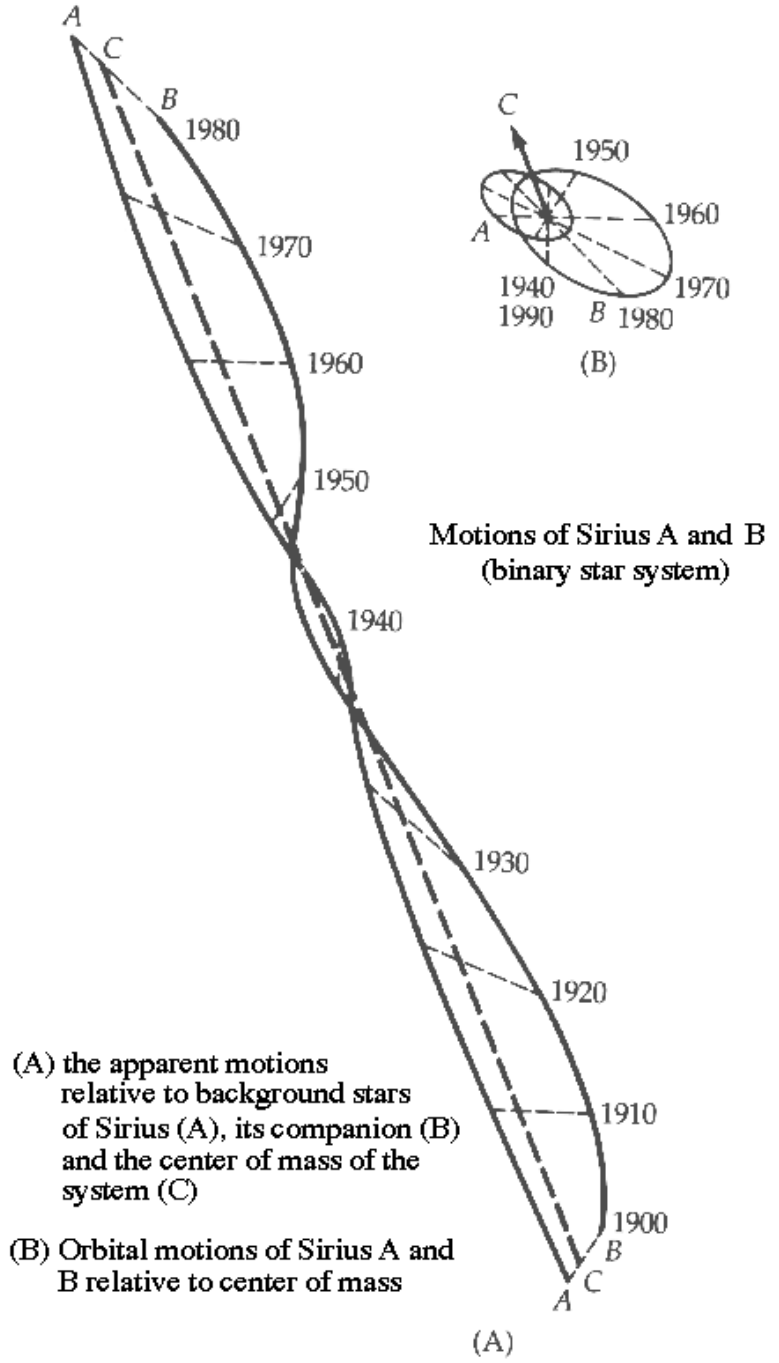
Z. Kopal

The brightest star in the night sky is a binary

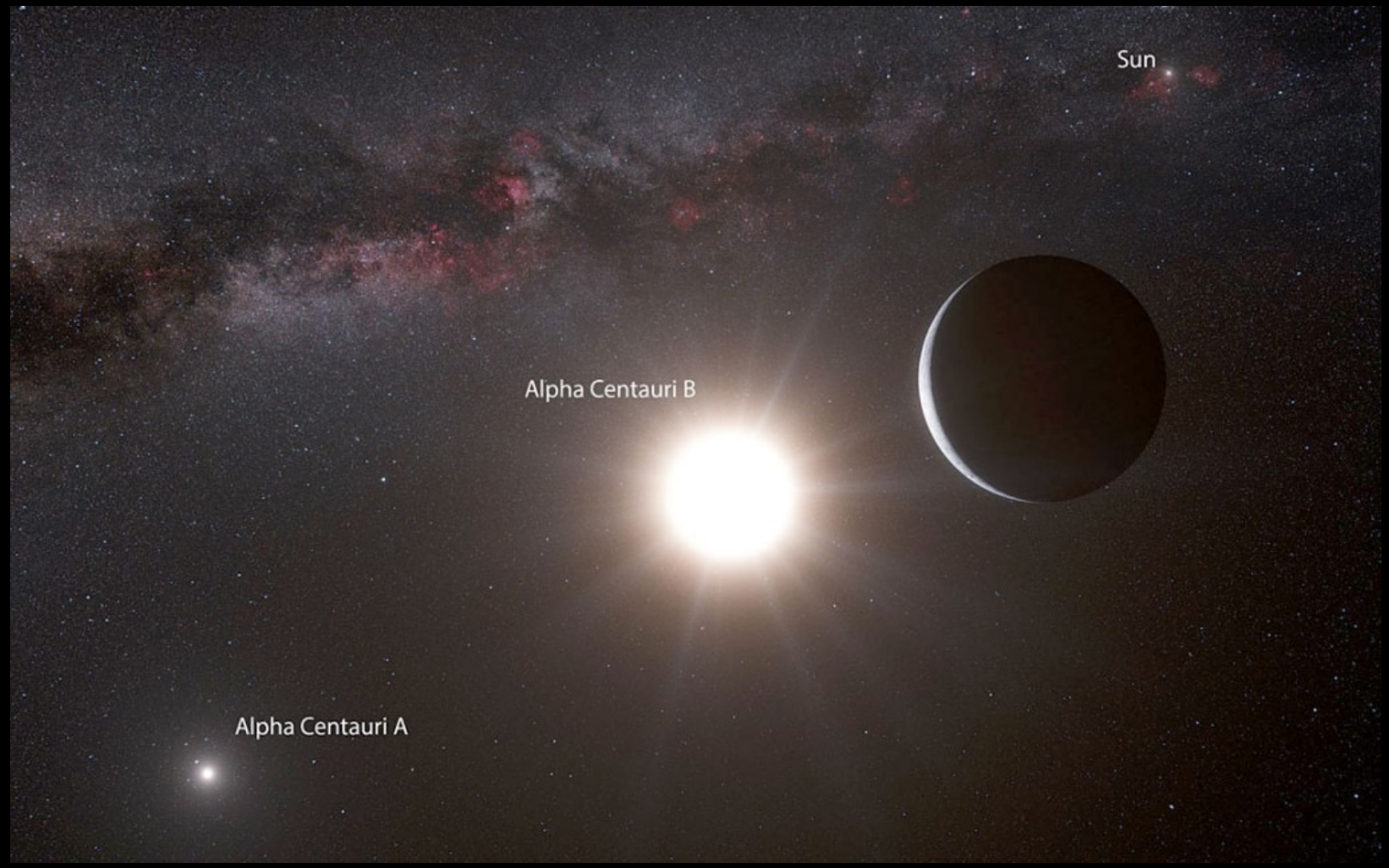
A1V + DA2
P=50 yr

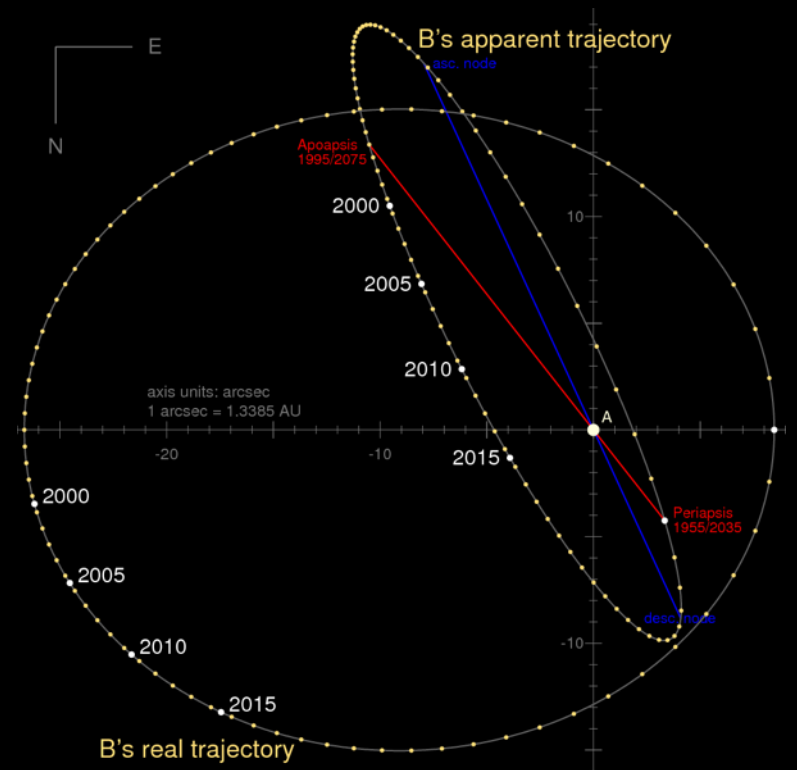
The presence of Sirius B was first detected by observing the wobble in the motion of Sirius A
→ unseen companion – a white dwarf!

Bessel 1844; see also Liebert+ 13, Bond+ 17



Among the closest ones ...





4.37 ly (1.34 pc) away

1.1 $M_\odot$ + 0.9 $M_\odot$

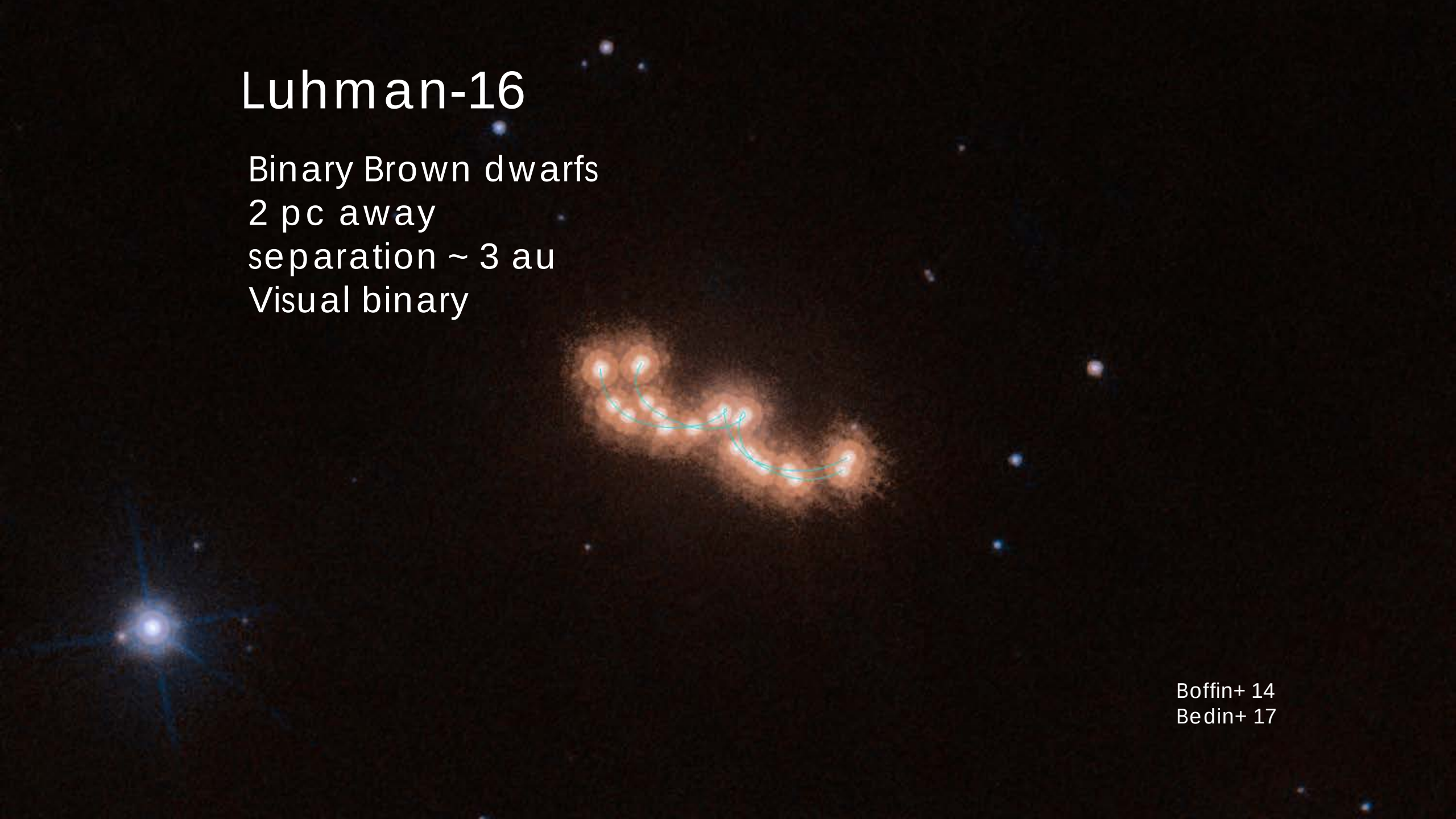
P = 79 years

Visual binary

Triple system with Proxima Centauri

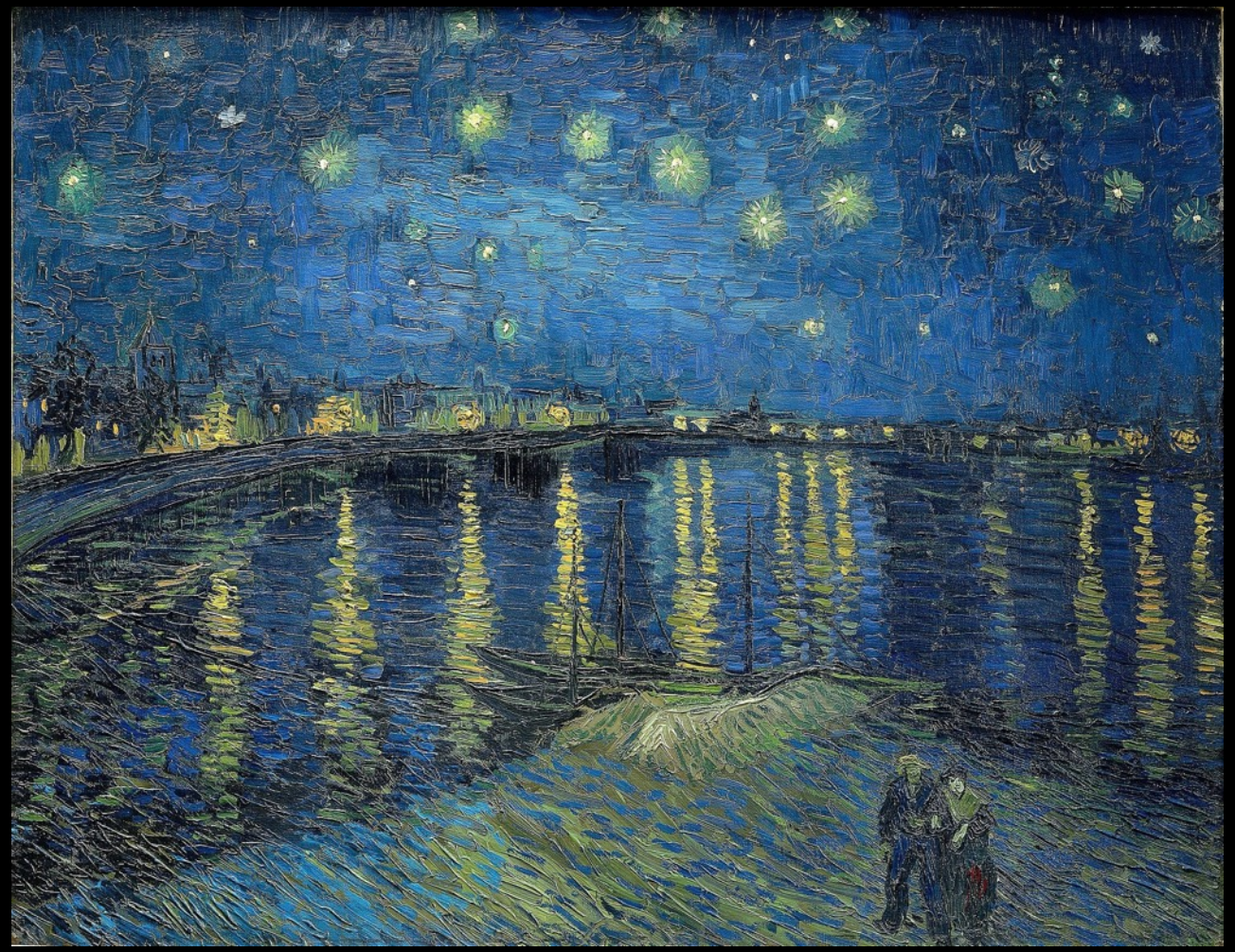
Luhman-16

Binary Brown dwarfs
2 pc away
separation ~ 3 au
Visual binary



Boffin+ 14
Bedin+ 17

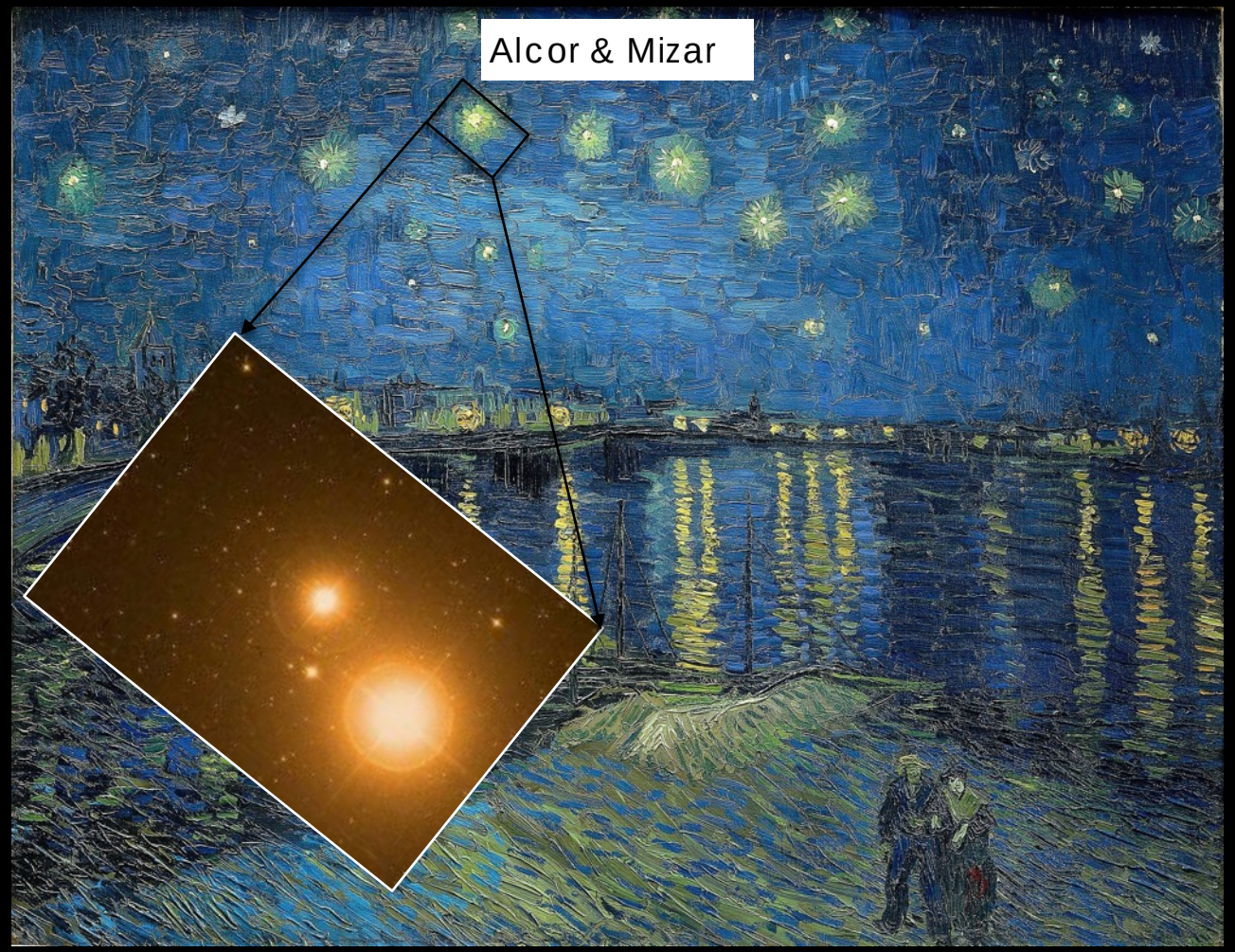
Another famous multiple



Starry night - Van Gogh

Adapted from
de Mink 12

Another famous multiple



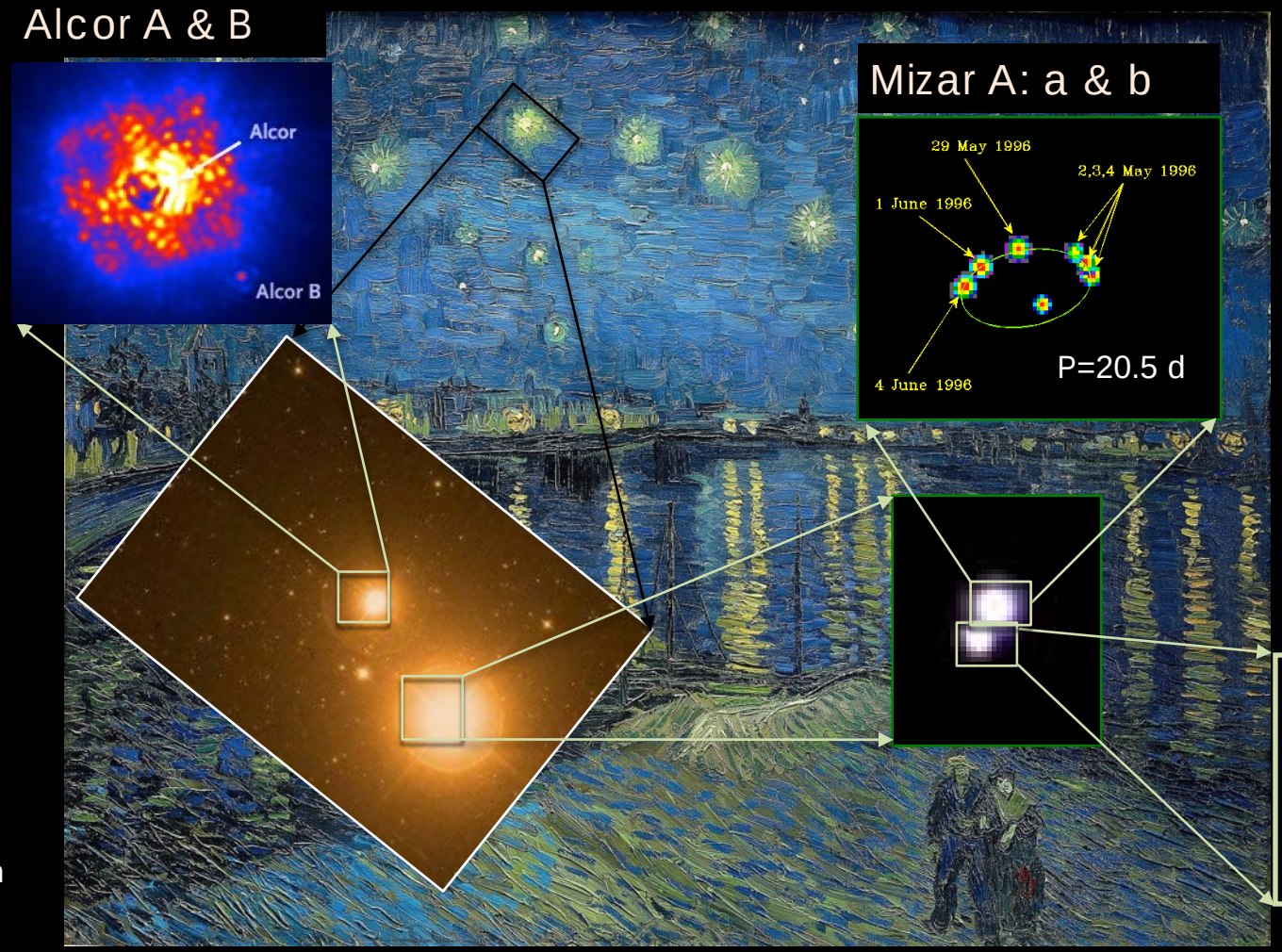
Starry night - Van Gogh

Lifespan star
or "jumyouboshi" (寿命星)

Married couple in
Indian astronomy

Adapted from
de Mink 12

Another famous multiple



3 binaries forming a sextuple system

Adapted from de Mink 12

Importance of binaries

Cultural aspects

Accurate stellar masses, radii, luminosities

Constrain models: stellar evolution, star formation, gravity, ...

Galactic evolution: SNe, novae

Help understand a zoo of strange objects, e.g., PNe, novae, short gamma-ray bursts, Type Ia SNe, chemically peculiar stars, blue stragglers

XII. Extract from the Translation of a Letter from Professor Bessel, dated Konigsberg, 10th of August, 1844. On the Variations of the Proper Motions of *Procyon* and *Sirius*. Communicated by Sir J. F. W. Herschel.

The subject which I wish to communicate to you, seems to me so important for the whole of practical astronomy, that I think it worthy of having your attention directed to it. I find, namely, that existing observations entitle us without hesitation to affirm that the proper motions, of *Procyon* in declination, and of *Sirius* in right ascension, are not constant; but, on the contrary, that they have, since the year 1755, been very sensibly altered. If this be so, the

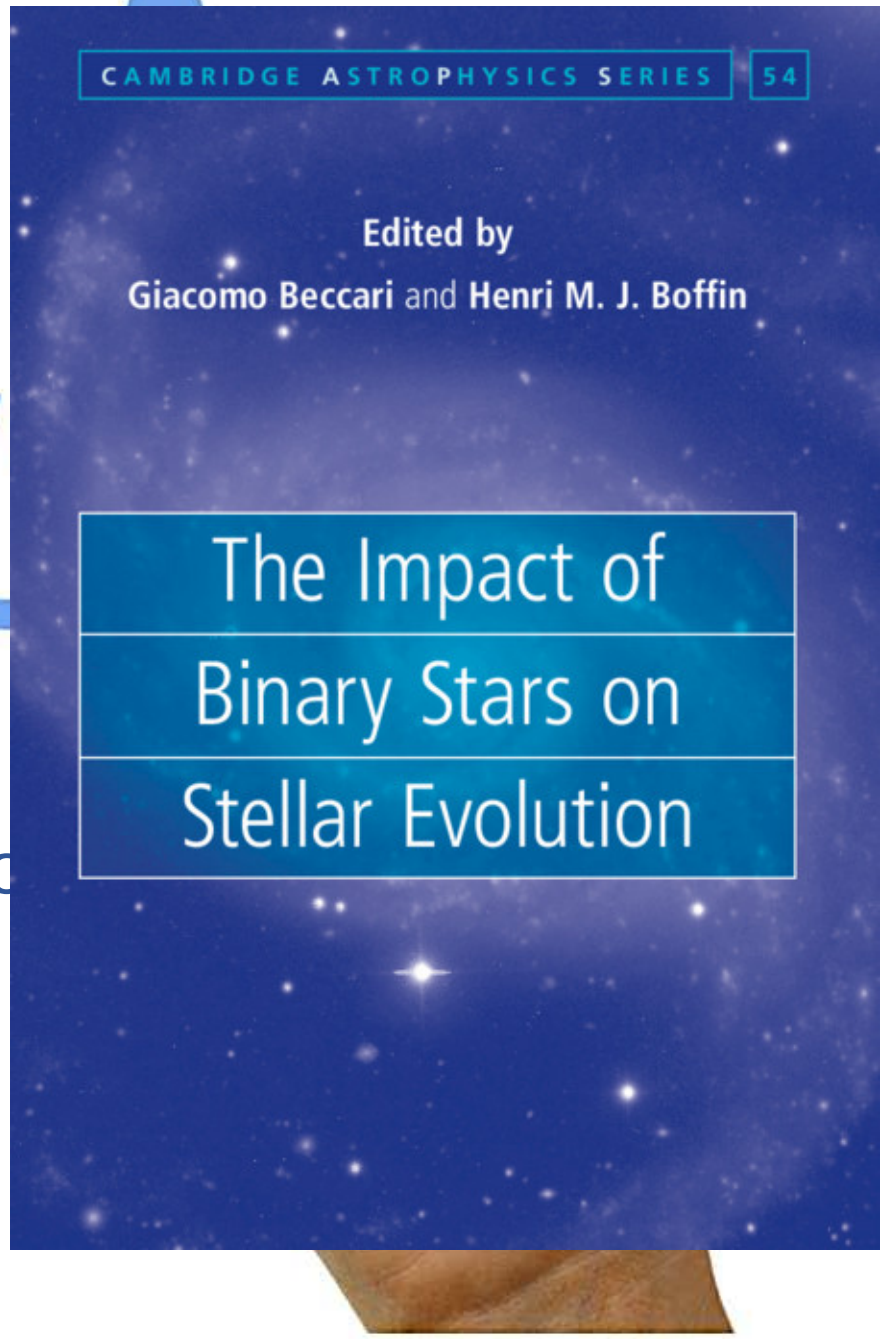
Bessel 1844

"To understand galaxies, we need to understand stars, but since most are members of binary and multiple star systems, we need to study and understand binary stars...

...And sometimes binary stars are the only way to understand single stars ..."

–R. Izzard (2009)

CAVE



Very biased and limited presentatio

No triples, no multiples...

Binaries span a wide range of separations

HM Cancri; P= 321 seconds!

S&T: Casey Reed

Roelofs+ 10

CPM pair; P= Myr!

Binaries span a wide range of separations

HM Cancri; P= 321 seconds!

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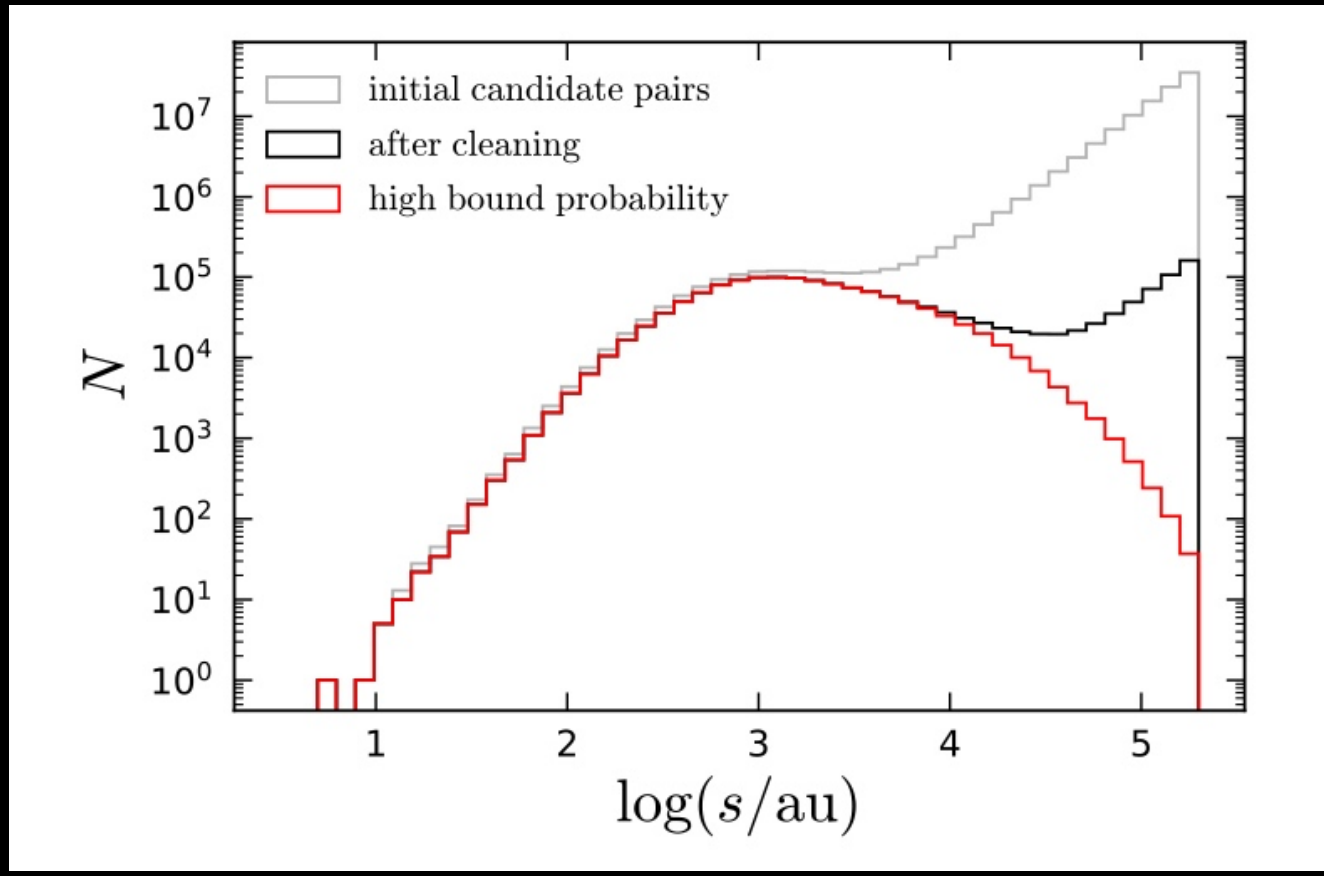
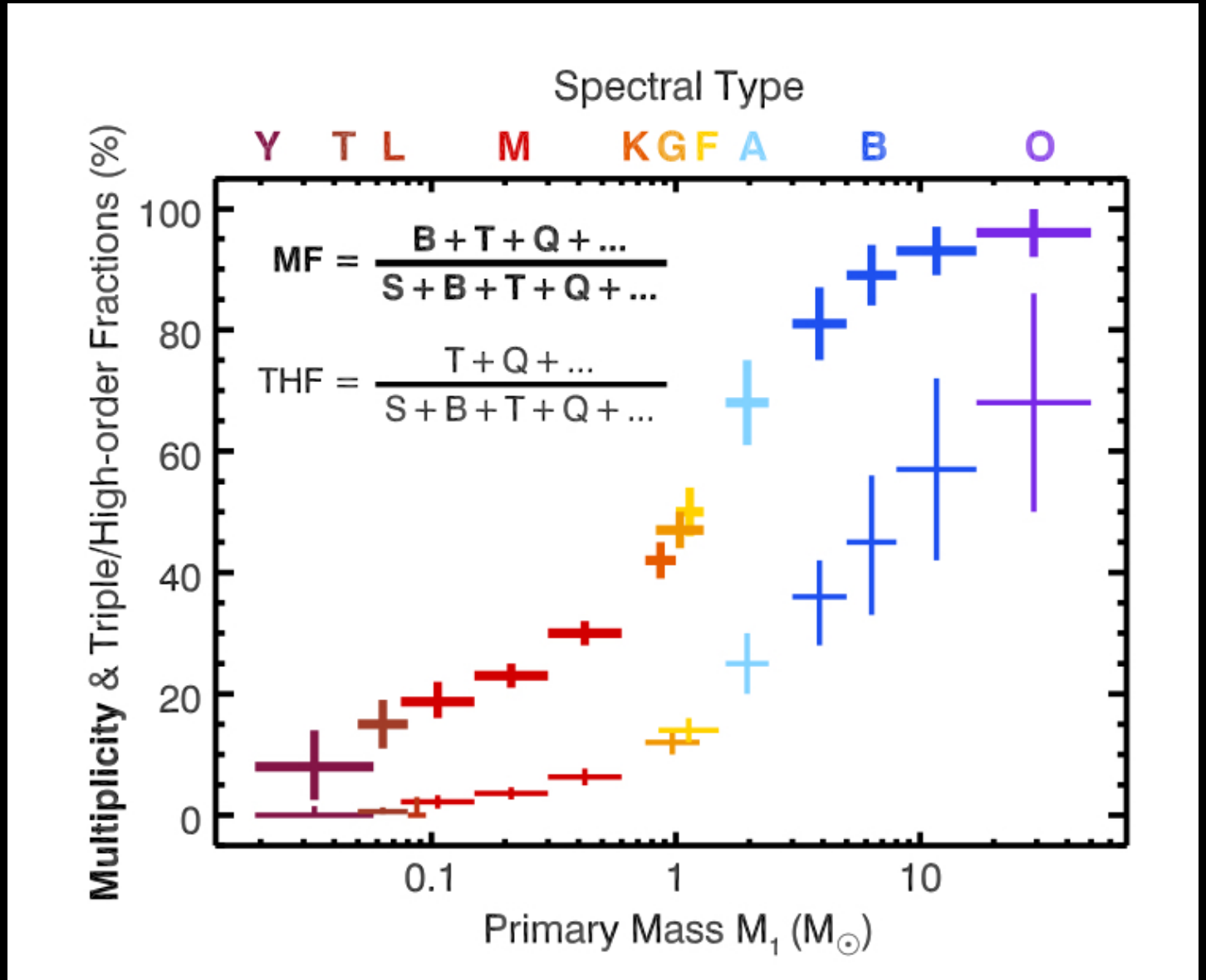
Roelofs+ 10



El-Badry+ 21

Many stars are in binaries/multiples



Offner+ 23

Ignoring binarity can affect distance estimate

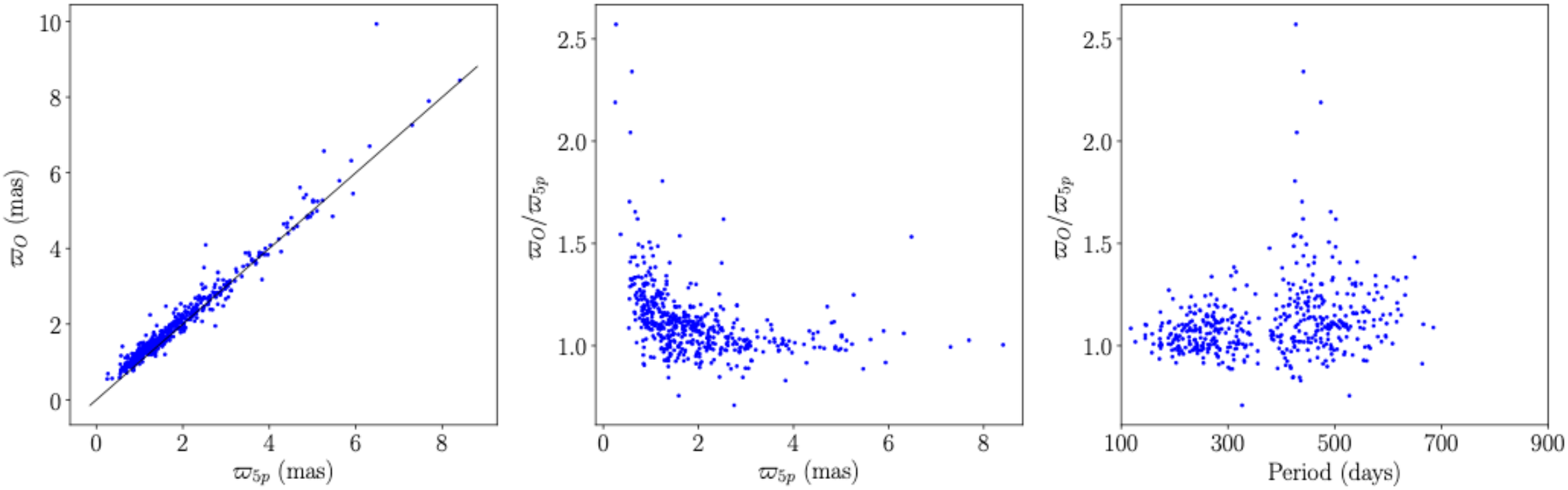
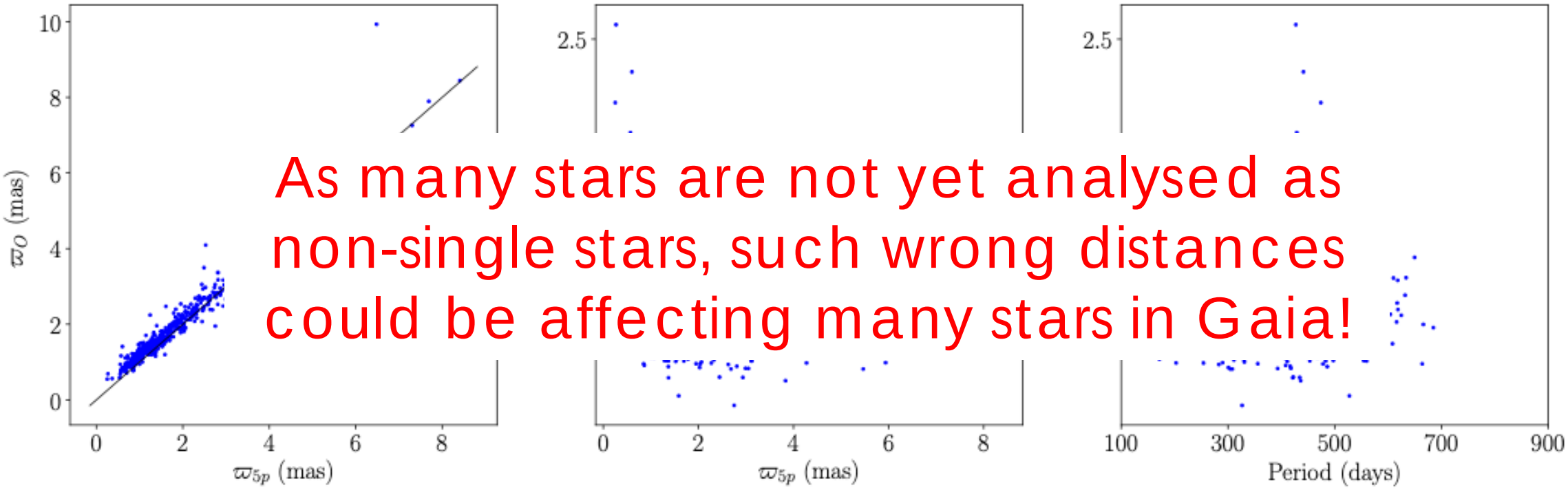


Fig. 3. Effect of adopting the orbital model on the parallax.

Ignoring binarity can affect distance estimate

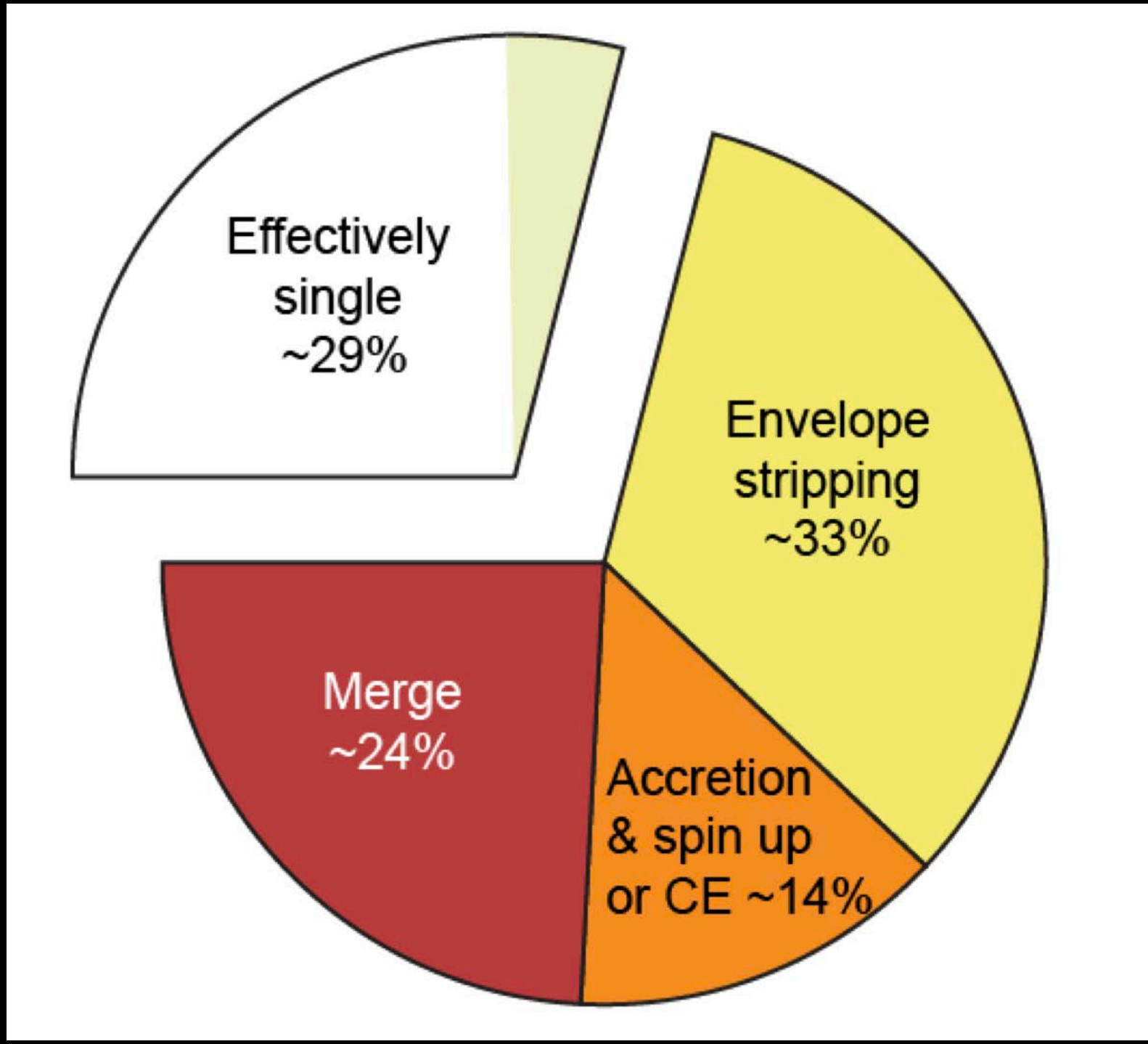


As many stars are not yet analysed as non-single stars, such wrong distances could be affecting many stars in Gaia!

Fig. 3. Effect of adopting the orbital model on the parallax.

70% of all massive stars will interact in their lifetime!

Stellar evolution of massive stars needs to take this into account



Sana+ 12

Importance of binaries

"Even though a star may be single now, it may well have been a member of a binary system in the past.

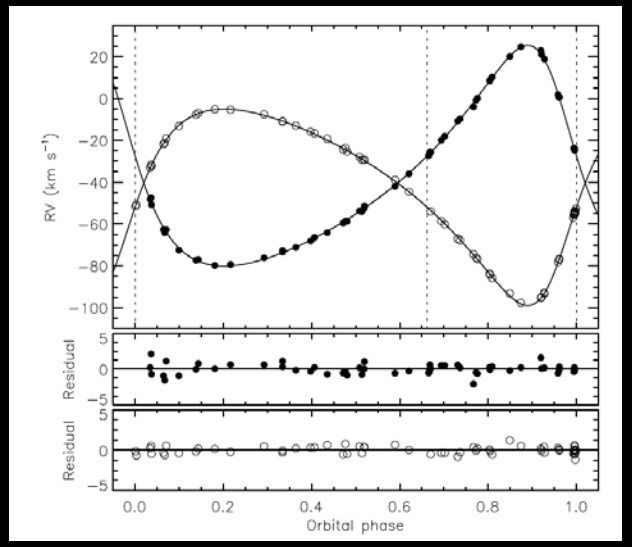
Indeed, whenever one is confronted with a new stellar phenomenon, it is probably advisable to first thoroughly explore the possibility of a binary interaction as a cause of the phenomenon before starting to adjust the input physics in the stellar calculation."

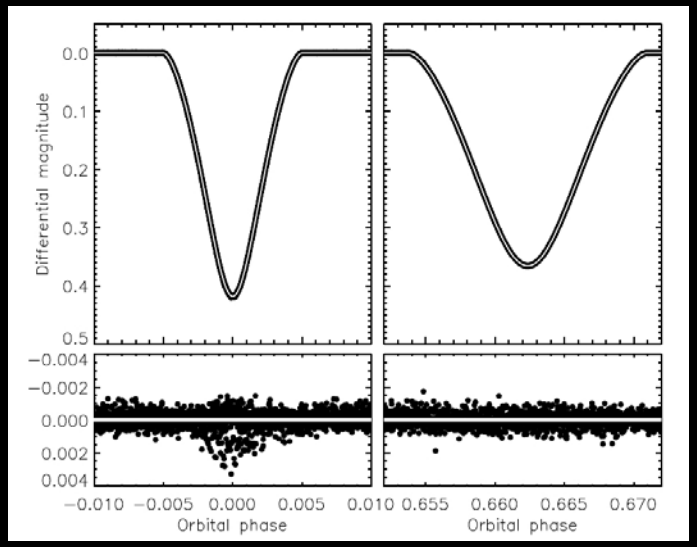
–P. Podsiadlowski

Binaries – accurate radius, masses, and luminosities

This can thus be used to constrain stellar models

Best cases are double-eclipsing binaries with spectroscopic and photometric orbits

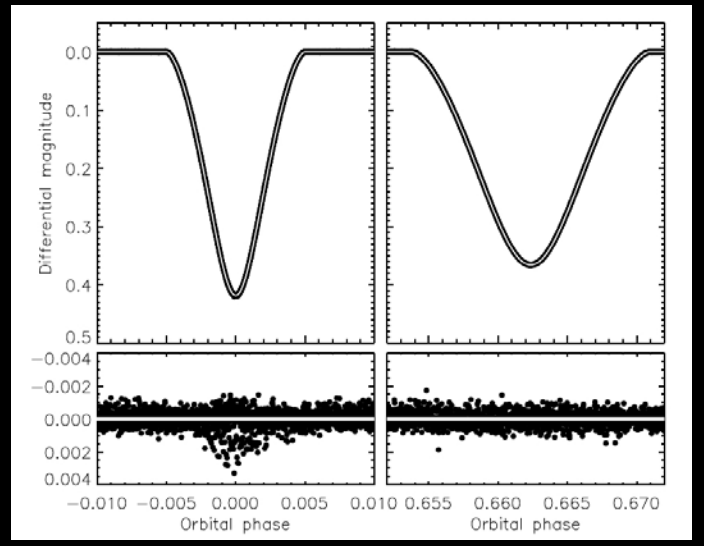




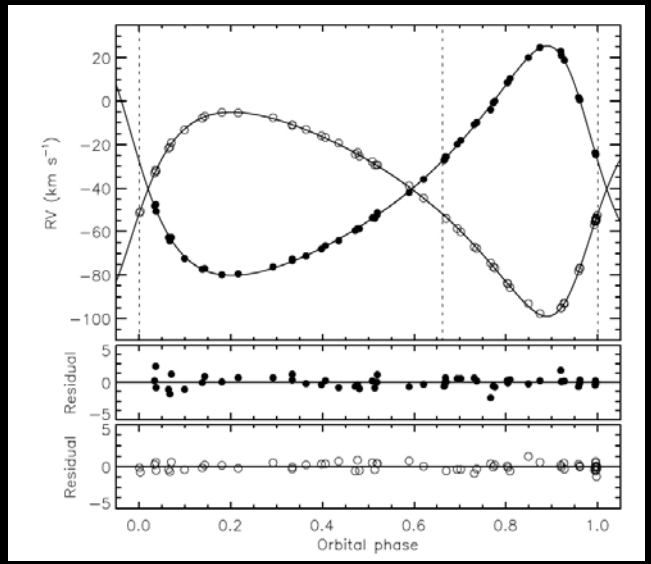
Southworth 24
See also Serenelli+ 21, Hinse+ 24

A case in point: V454 Aur

Parameter	*Star A*	*Star B*
Mass ratio $M_{\rm B}/M_{\rm A}$	1.1235 ± 0.0045	
Semimajor axis of relative orbit ($\mathcal{R}_\odot^{\rm N}$)	49.24 ± 0.10	
Mass ($\mathcal{M}_\odot^{\rm N}$)	1.0336 ± 0.0059	1.1612 ± 0.0081
Radius ($\mathcal{R}_\odot^{\rm N}$)	0.9787 ± 0.0027	1.2105 ± 0.0025



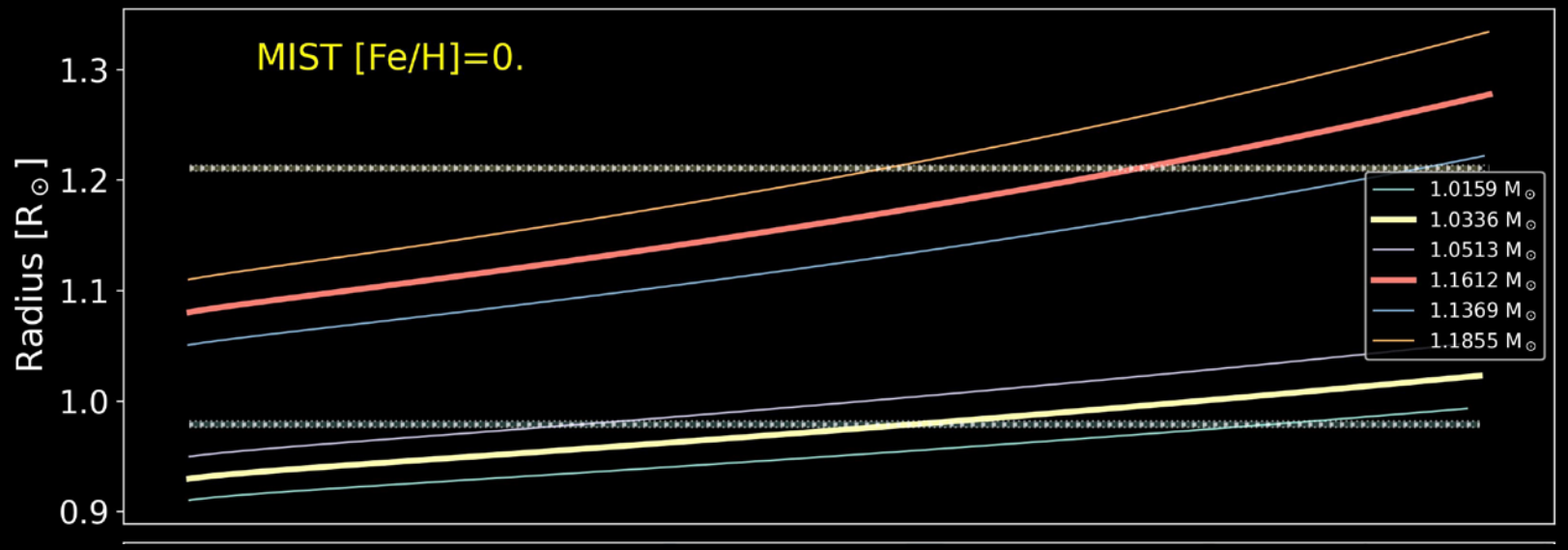
0.6% precision on mass!
0.2% precision on radius!



This is in principle a model-independent test of stellar models

Southworth 24

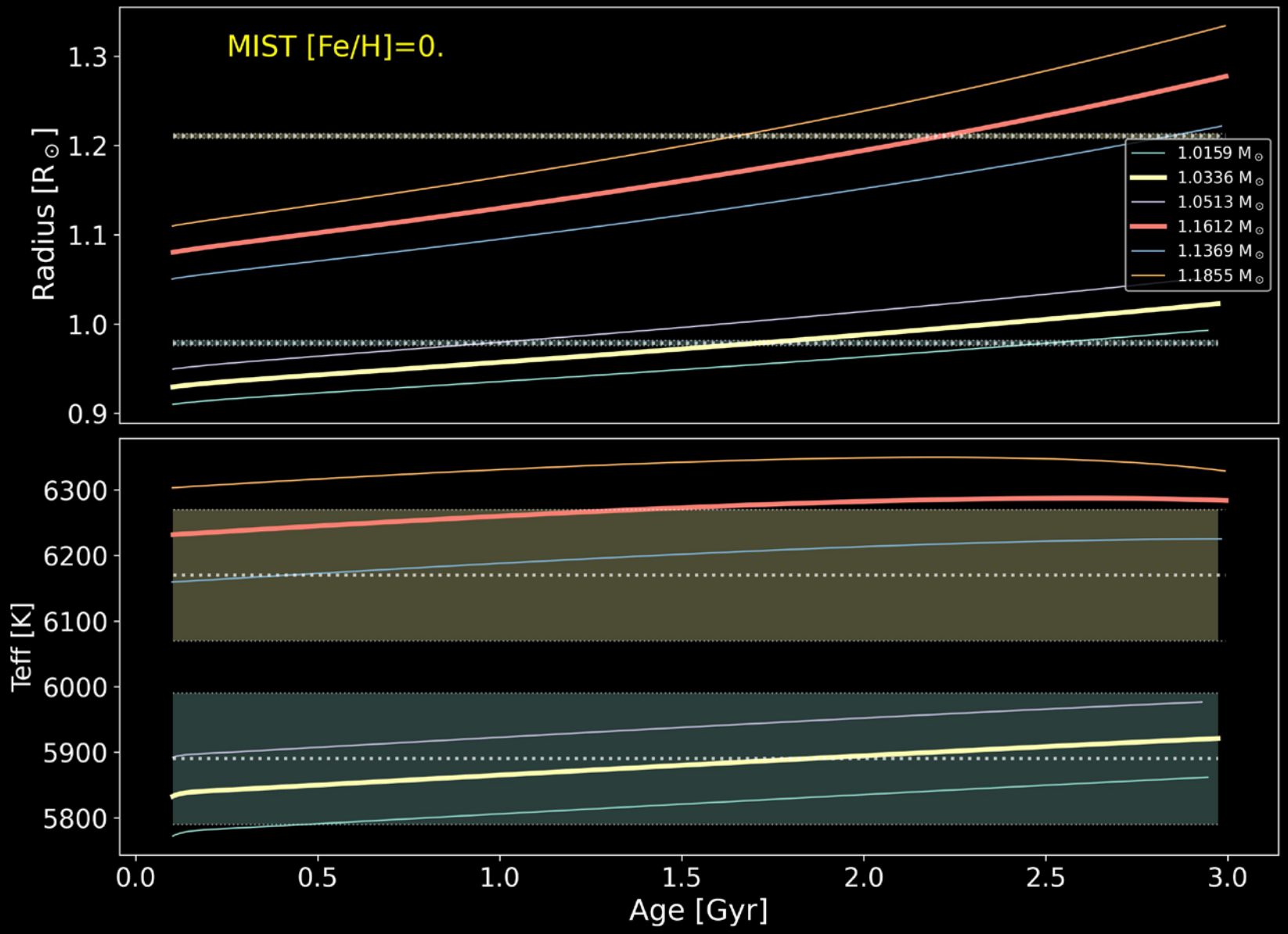
Comparing with models



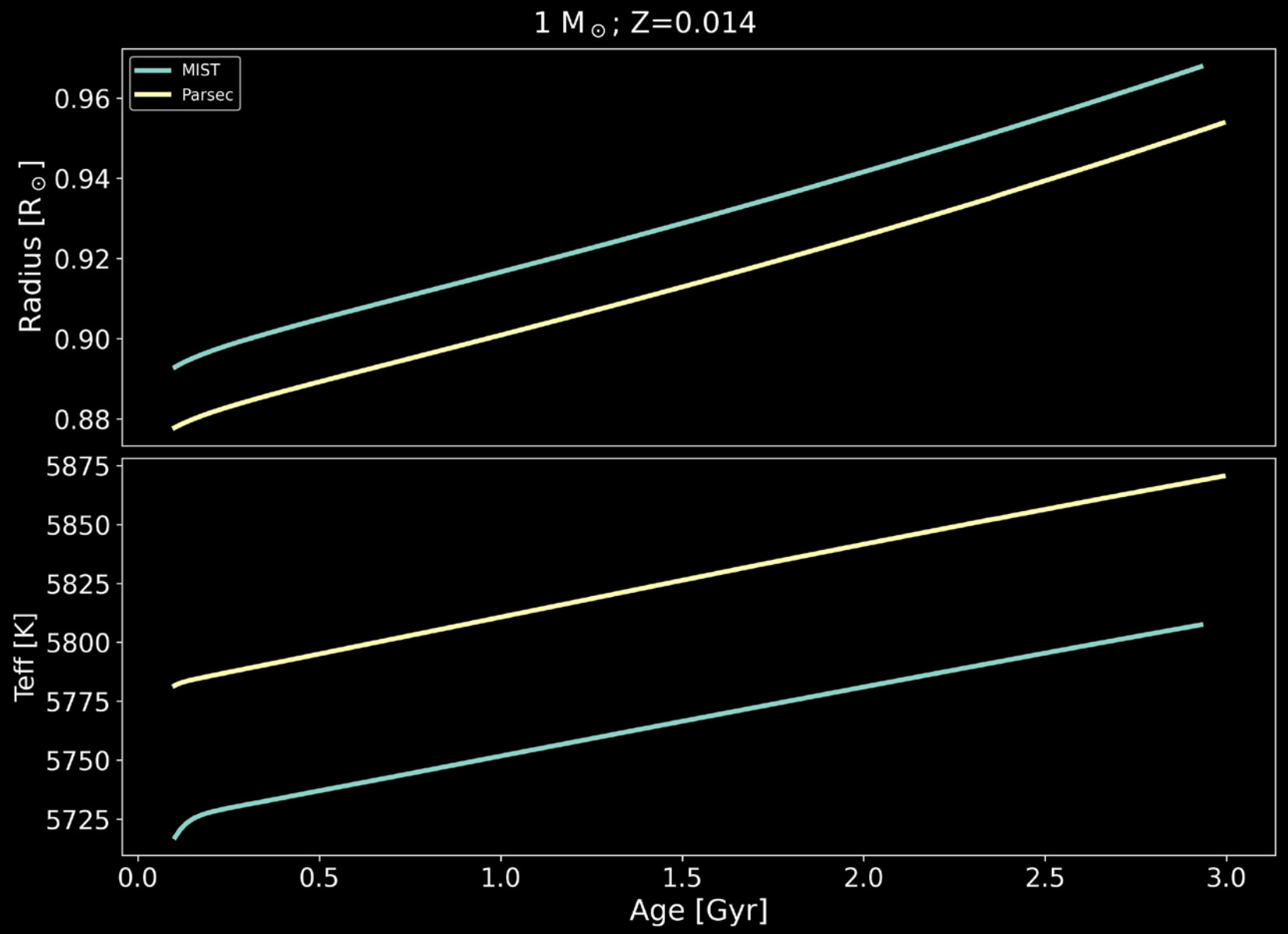
Can in principle infer age of stars if assume coeval

Note: This can also be done with wide binaries, especially those that contain a WD and a MS star (see Fouesneau+ 19; Martin+ 21, Moss+ 22)

Comparing with models



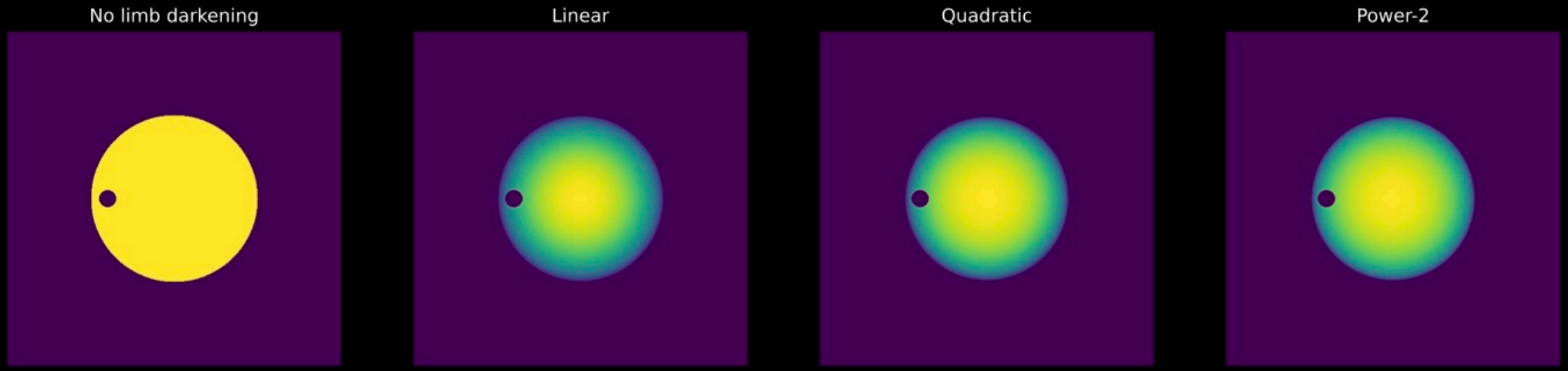
Can in principle infer age of stars if assume coeval and constrain models



Difference between MIST and PARSEC tracks...

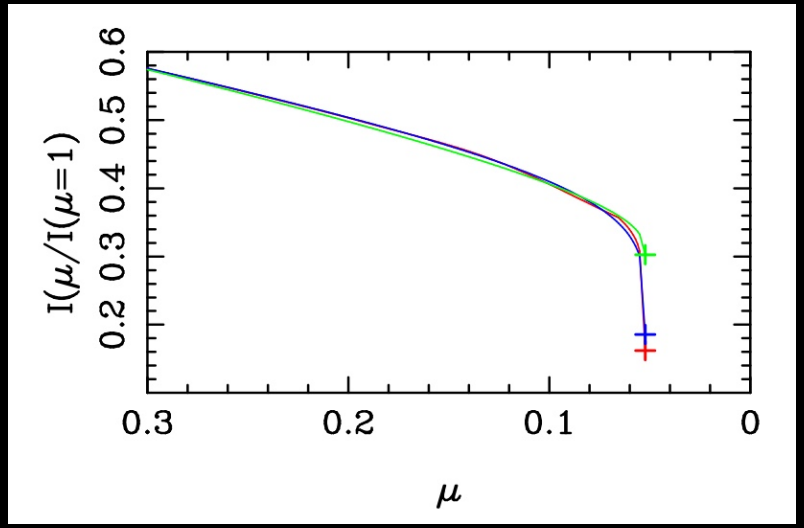
We are now with a level of precision that can in principle test this!

Totally model-independent?



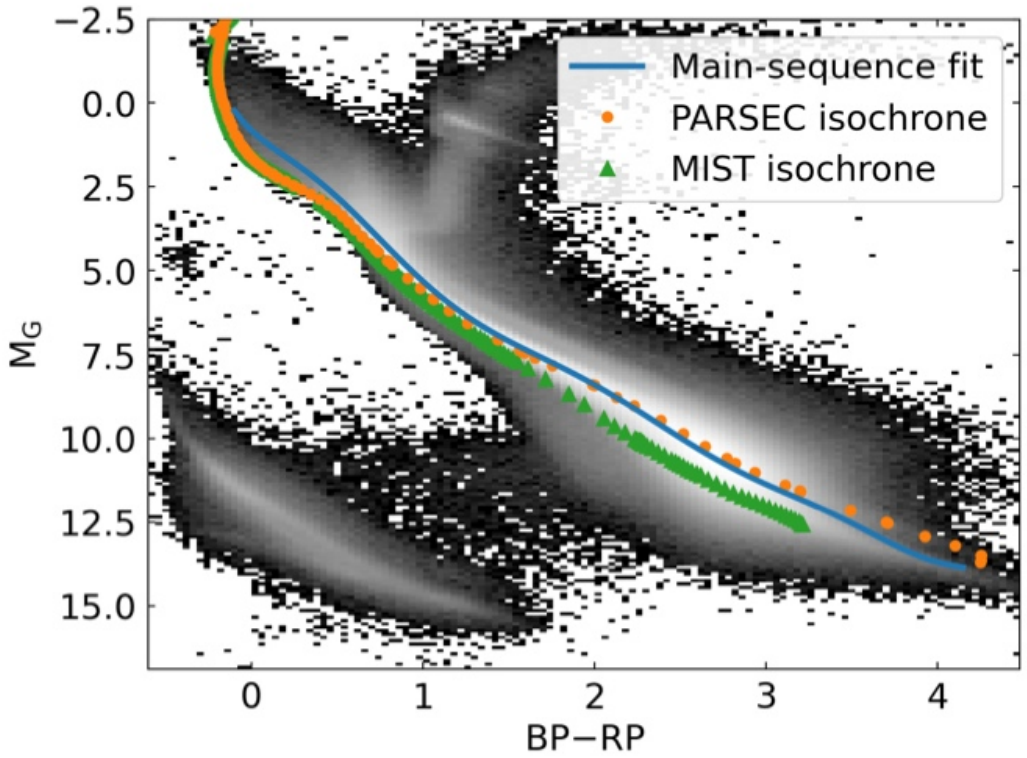
Analysis of light curve depends on limb-darkening law

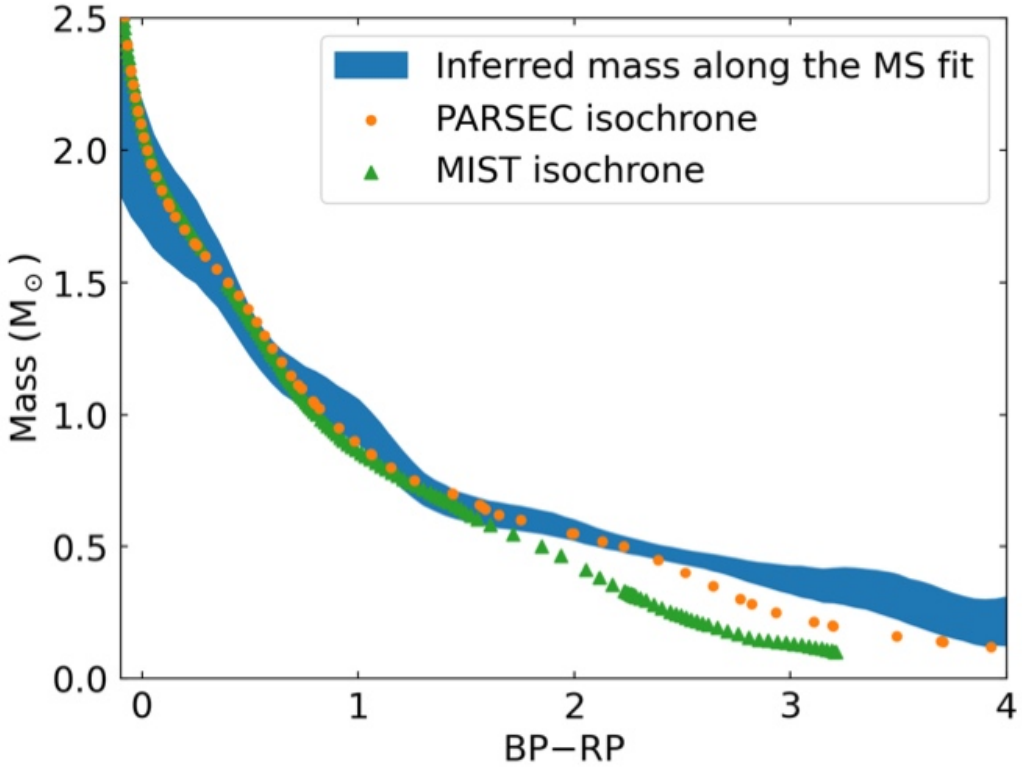
Coefficients are derived from models!



Claret & Southworth 23

Mass-luminosity relation

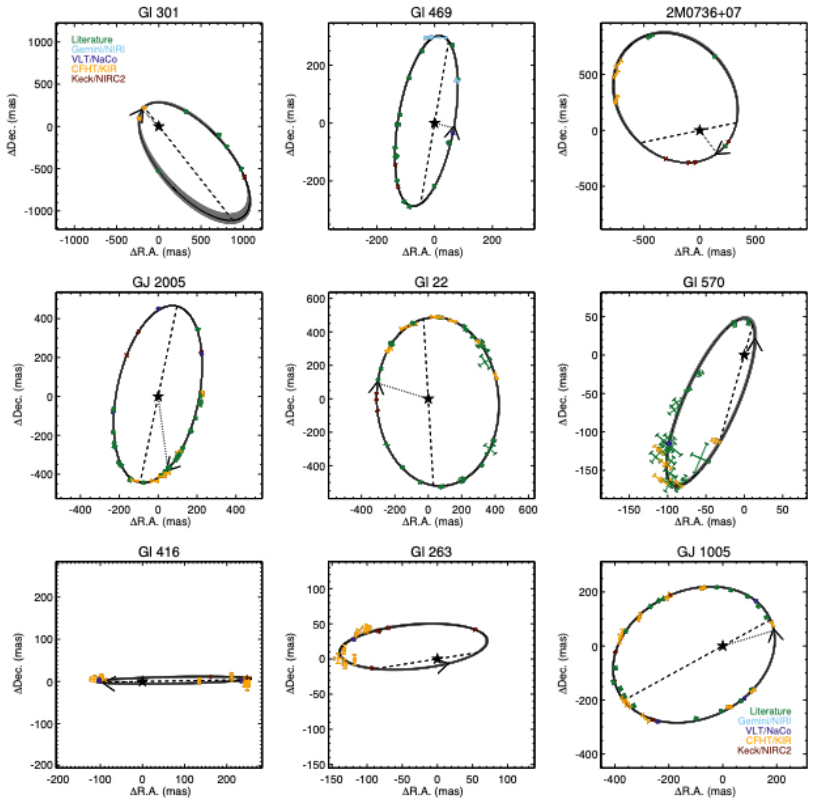




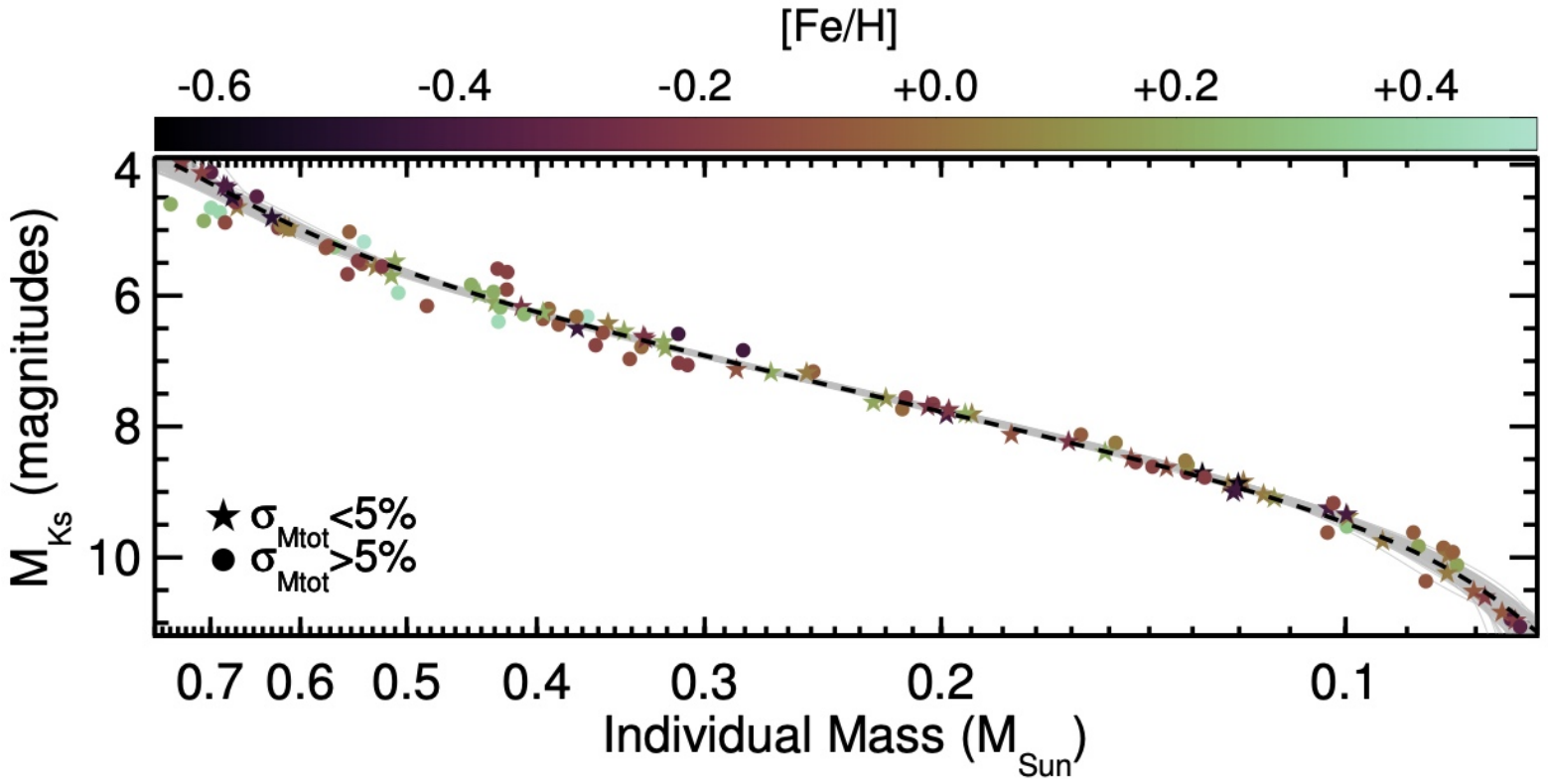
Hwang+ 23

Differences between models can be checked

Mass-luminosity relation

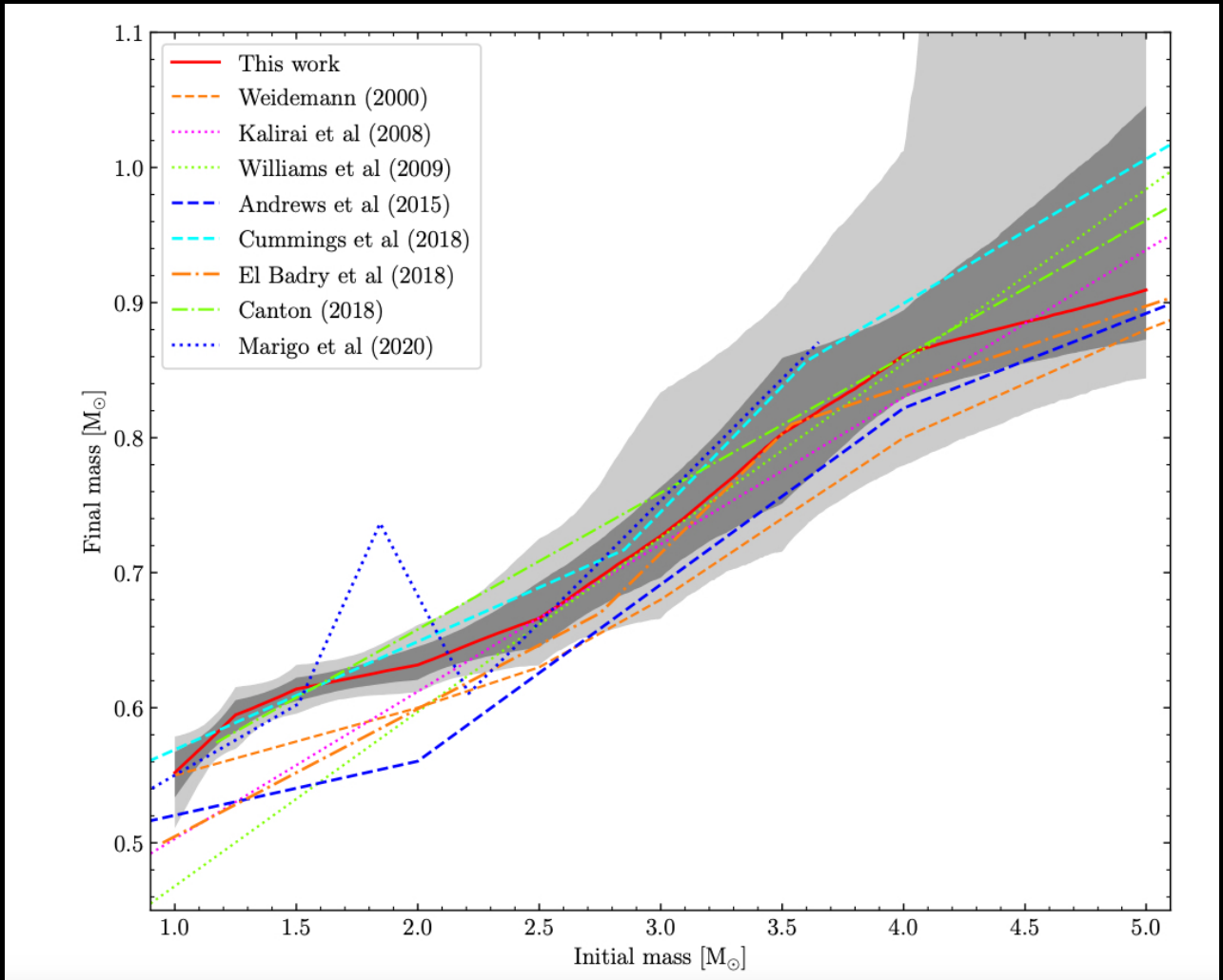


Mann+ 19



Initial-Final mass relation for WDs

90 Gaia double white dwarfs using FORS2 on the VLT



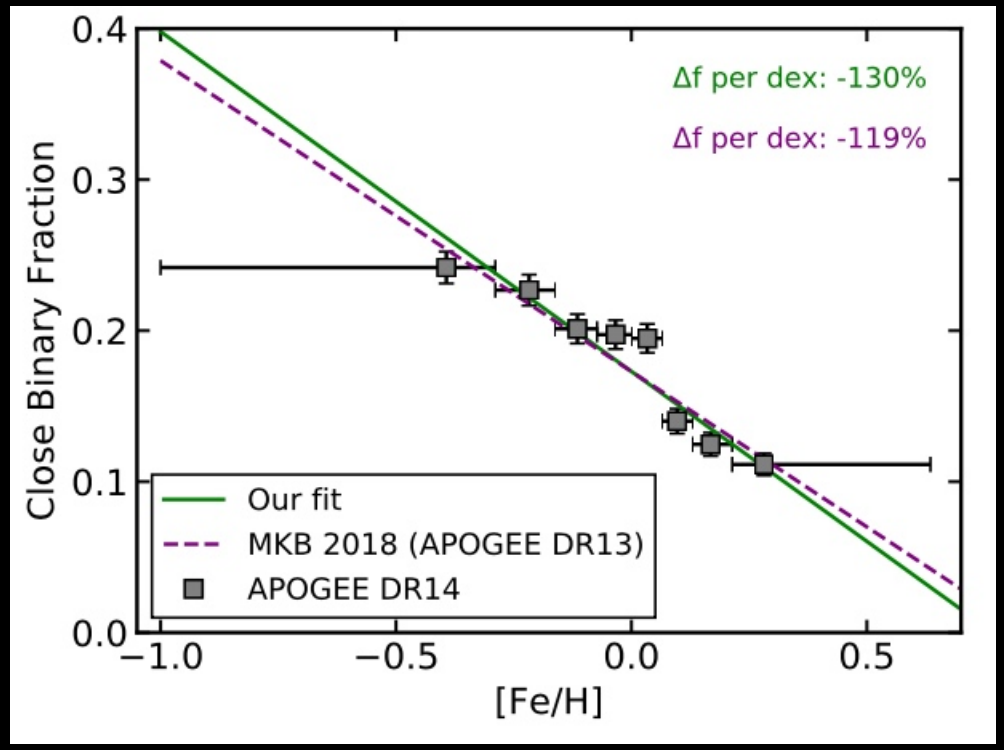
Hollands+ 24
See also Heintz+ 22

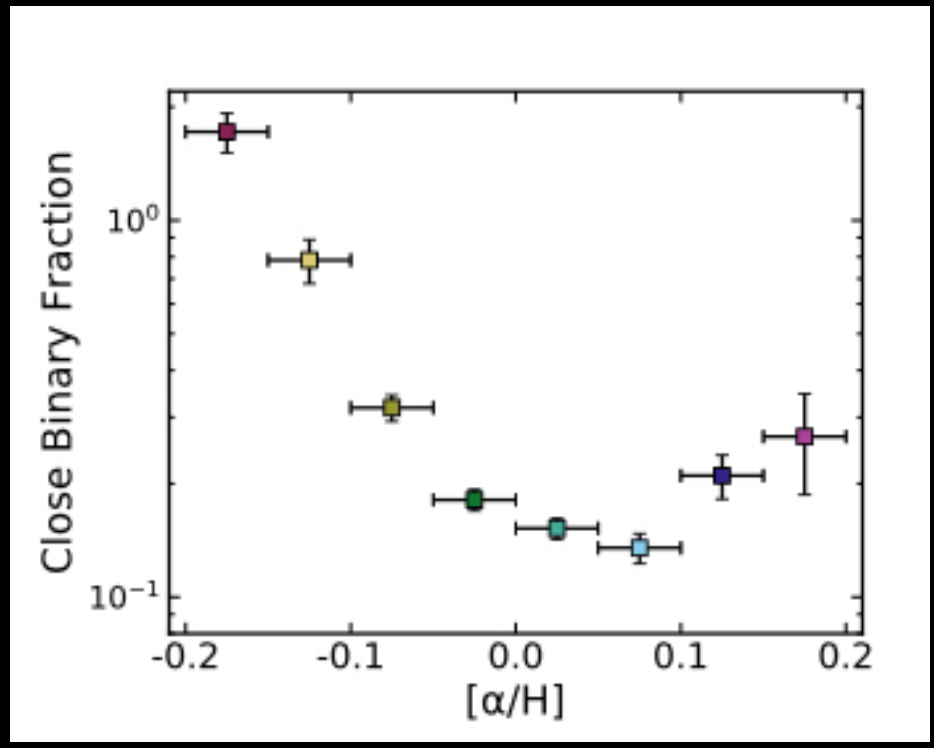
Test of star formation models

Many stars form as binaries

Binaries can tell us about the formation

Test of star formation models





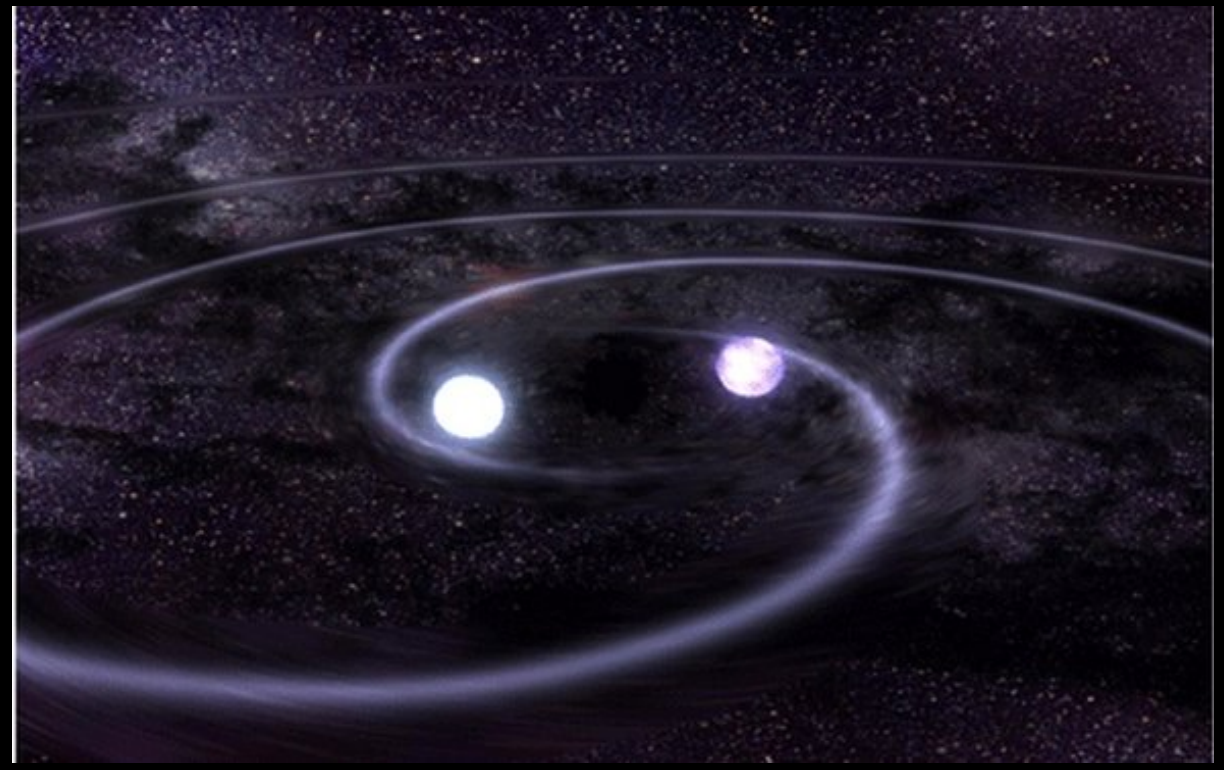
Fraction of binaries anti-correlated with metallicity and with alpha-element abundance
(cf. importance C, O, Si in the form of dust and ices)

→ most binaries form by disc fragmentation

Mazzola+ 20; see also Badenes+ 18; Moe+ 19; El-Badry & Rix 19; Tokovinin & Moe 20

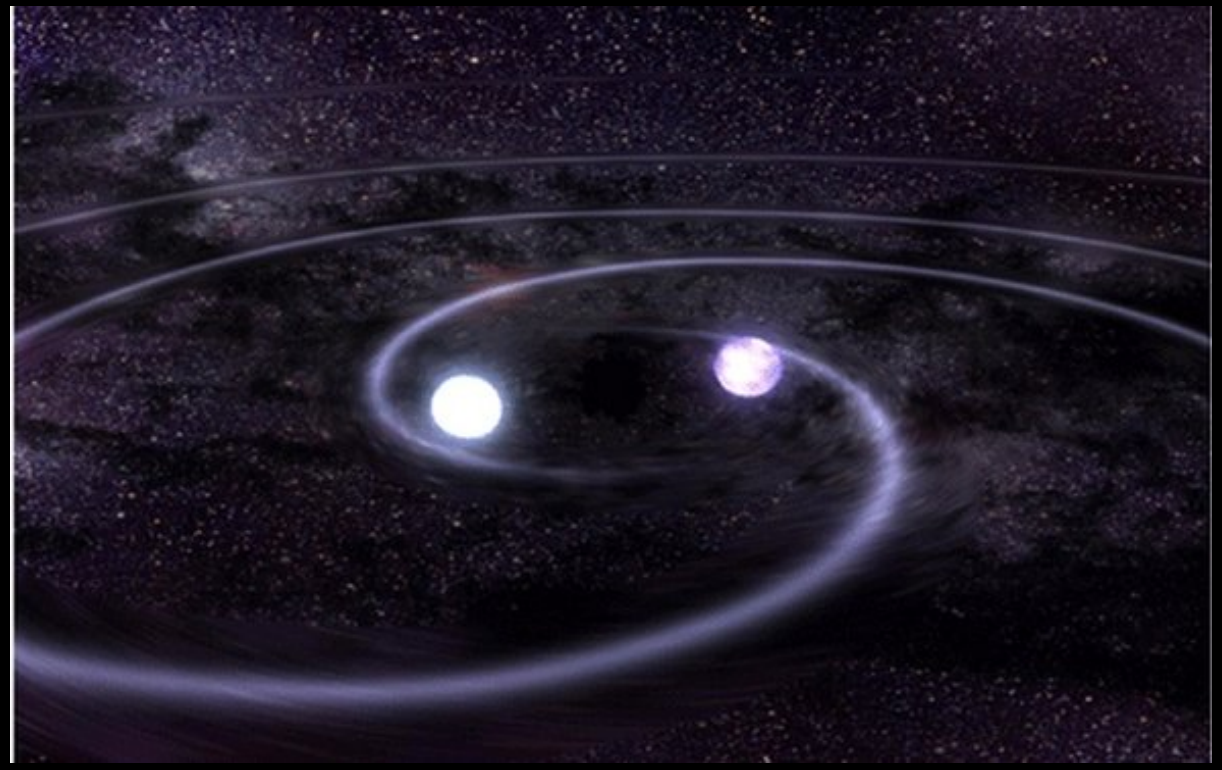
Testing general relativity

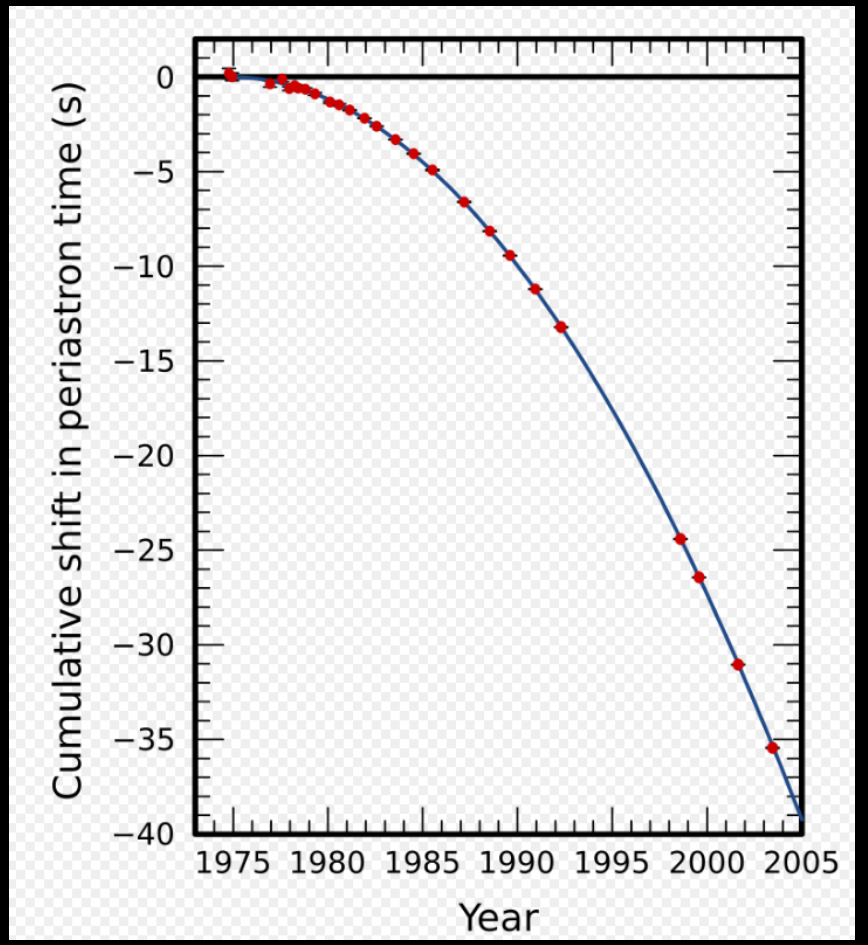
Hulse–Taylor pulsar



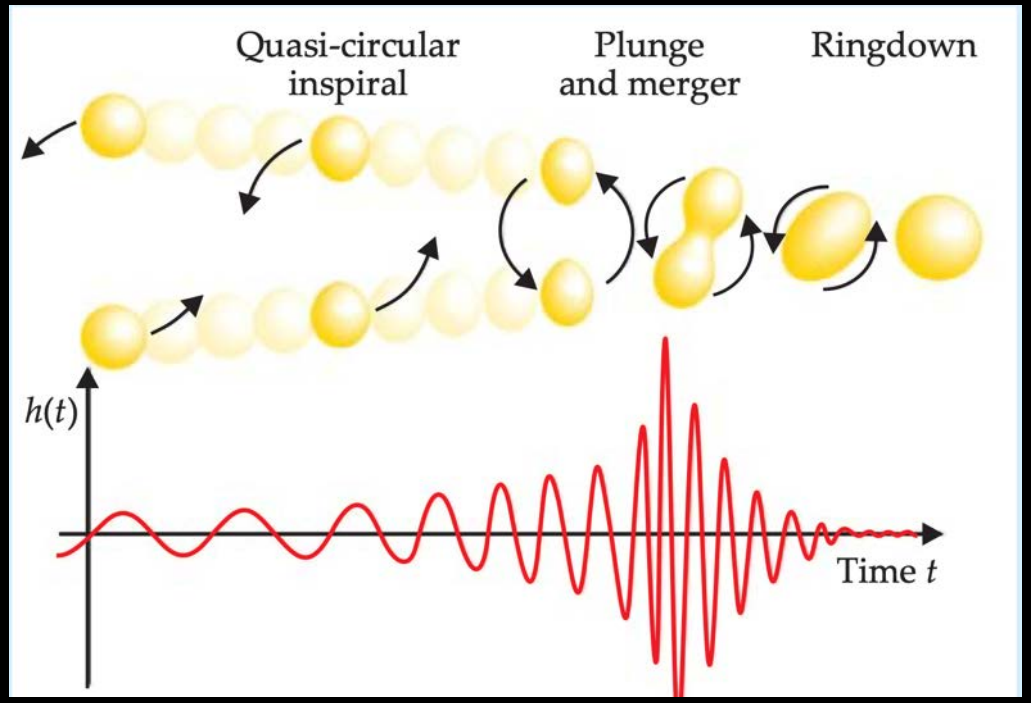
Testing general relativity

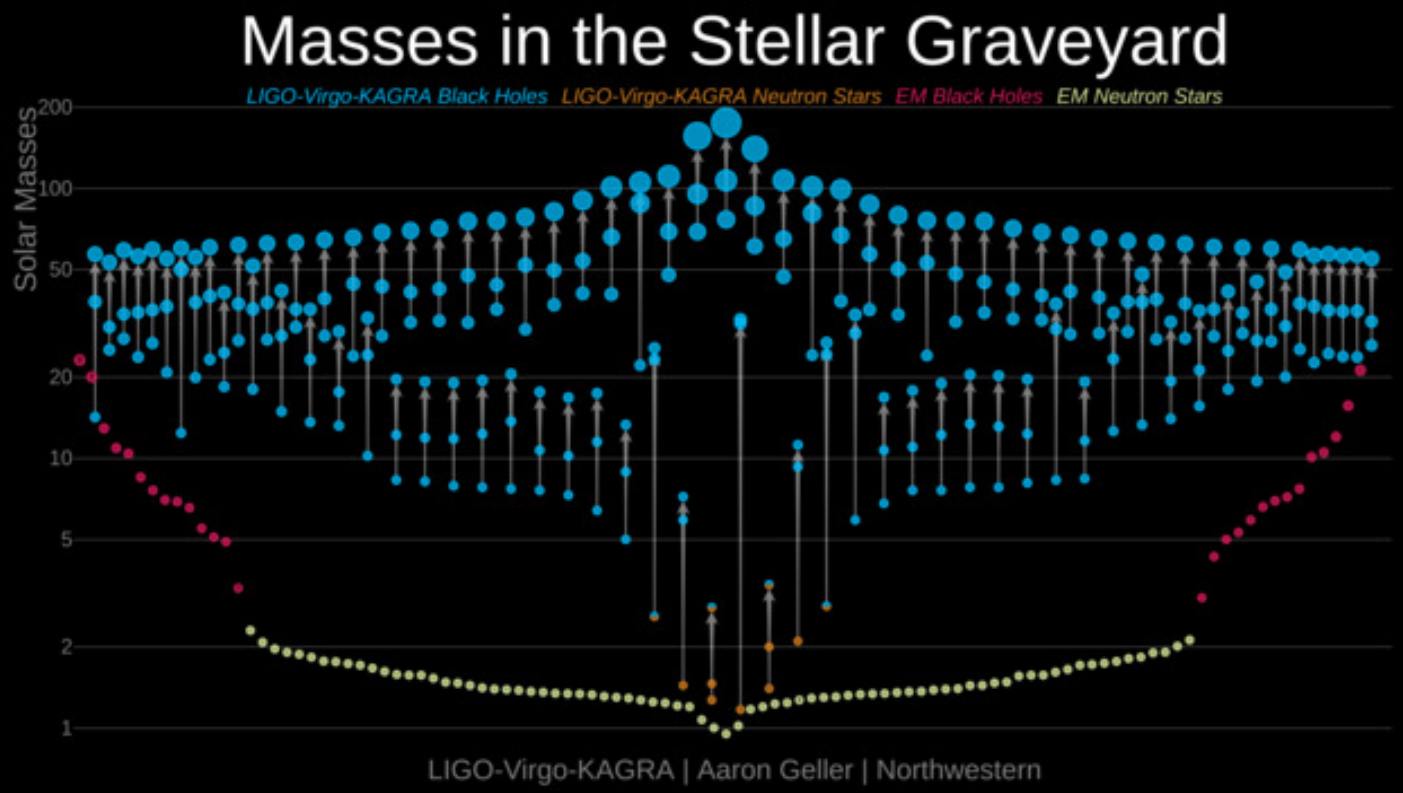
Hulse–Taylor pulsar



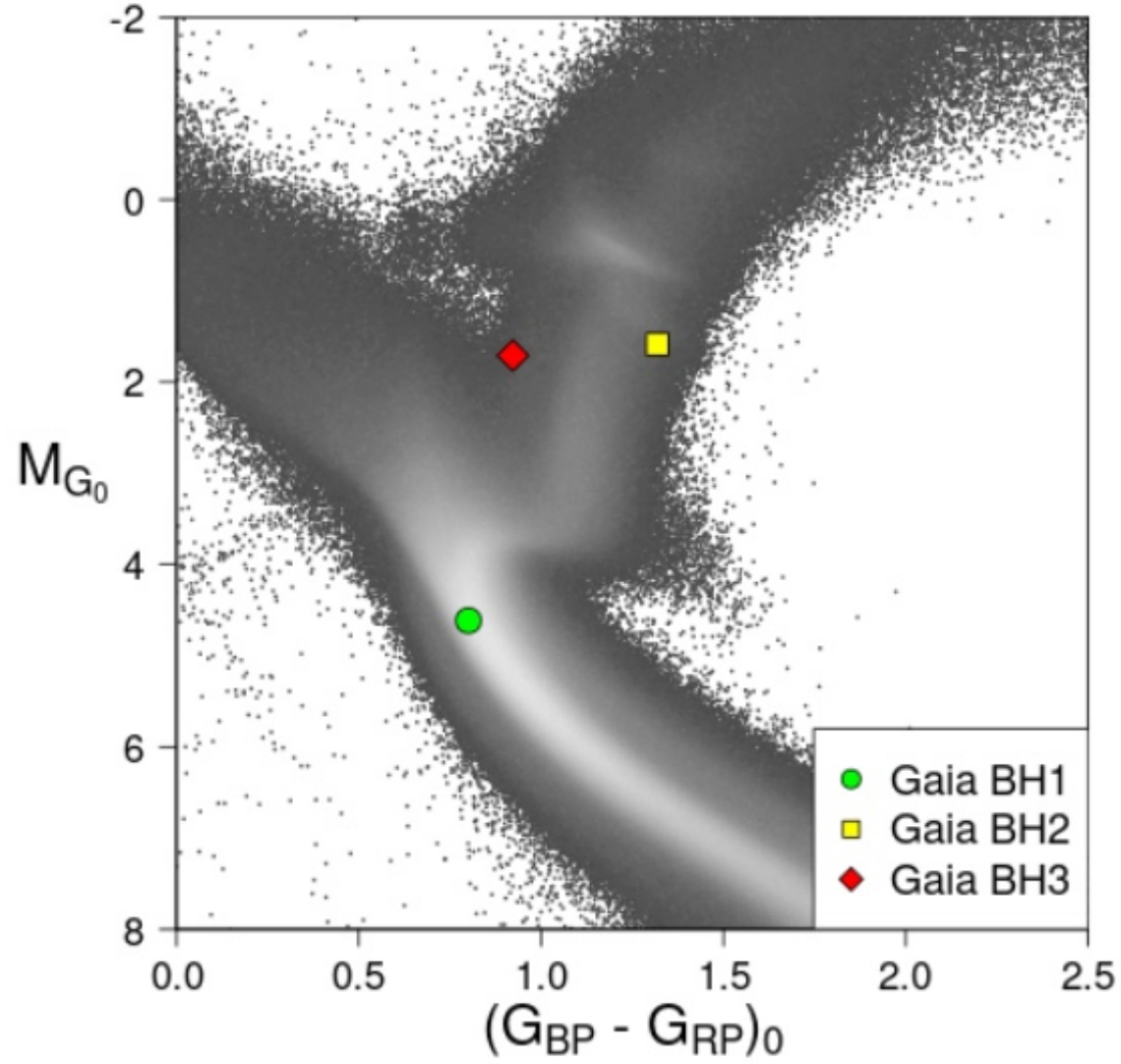


Mergers of NS or BH will lead to GW emission





Gaia quiescent black holes



Gaia BH3

Most massive stellar BH in the MW

On par with BHs discovered by GW

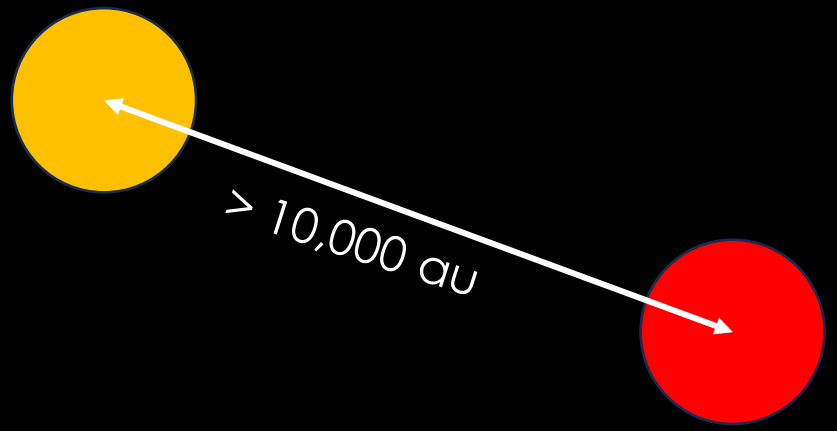
[Fe/H] = -2.56 !
→ high-mass BHs are the remnants of metal-poor stars

Likely formed through dynamical exchanges in clusters

Rastello+ 23; Tanikawa+ 24; Marin Pina+ 24; many more…

Testing gravity theory

Wide binaries as tests of MOND



If large separation → MOND predicts higher orbital velocities than Newton

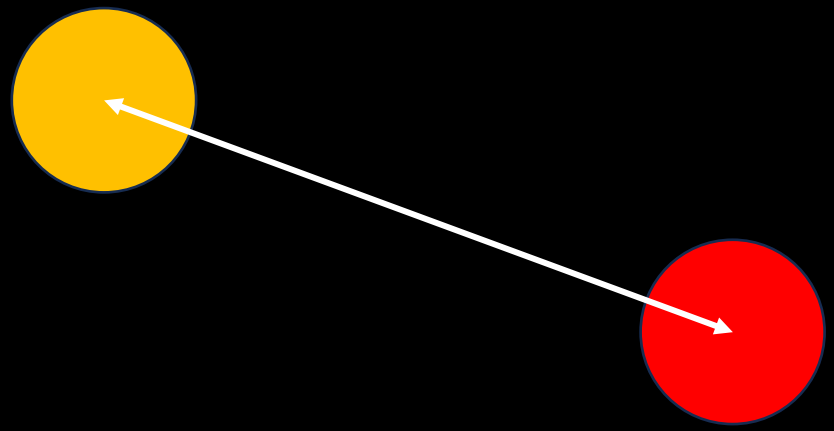
→ Potentially very interesting

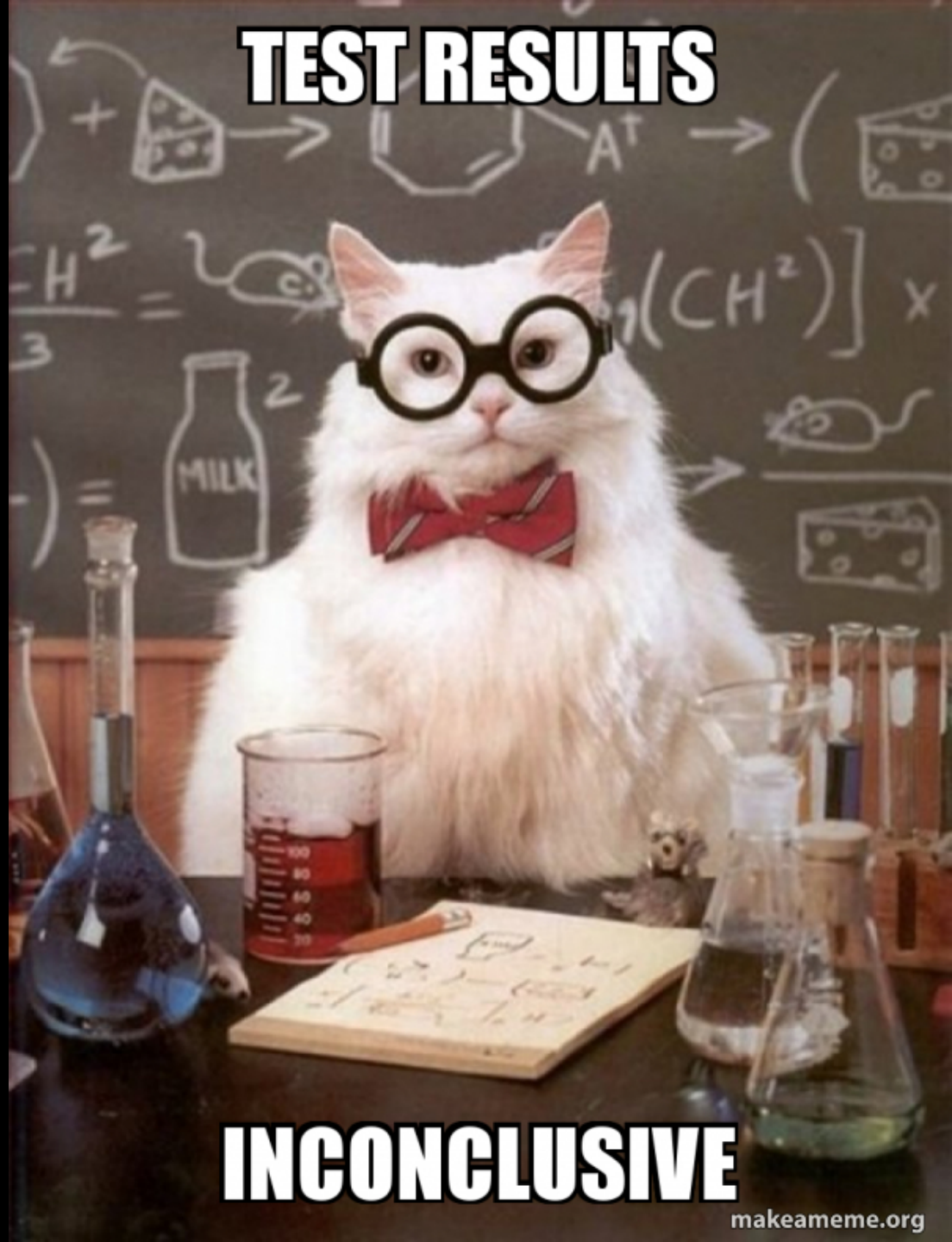
→ Many attempts: Hernandez+ 23; Pittordis & Sutherland 23; Banik+ 24; Chae 23, 24
see El-Badry 24 for a discussion

Caveats:
Effect less severe in Galactic plane
Need 3D velocities
Correct for projection effects

Testing gravity theory

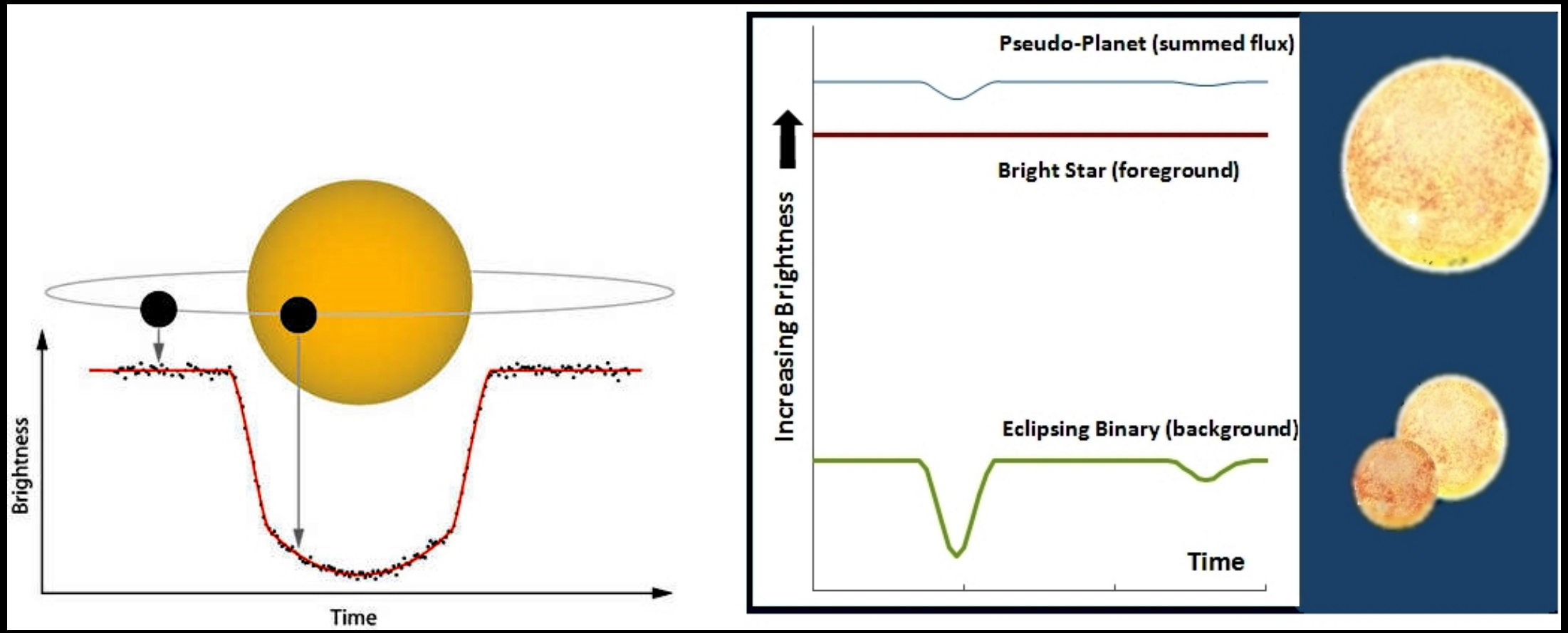
Wide binaries as tests of MOND





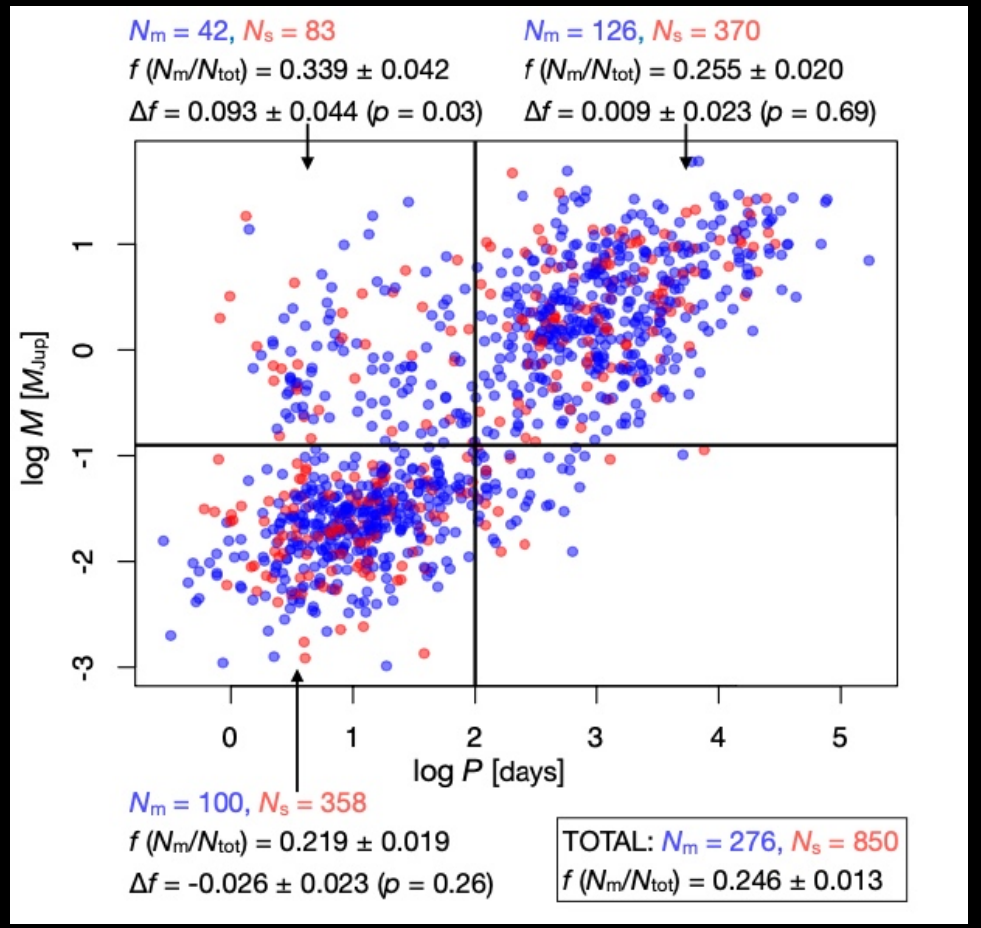
Binaries and planets

Binaries as contaminant



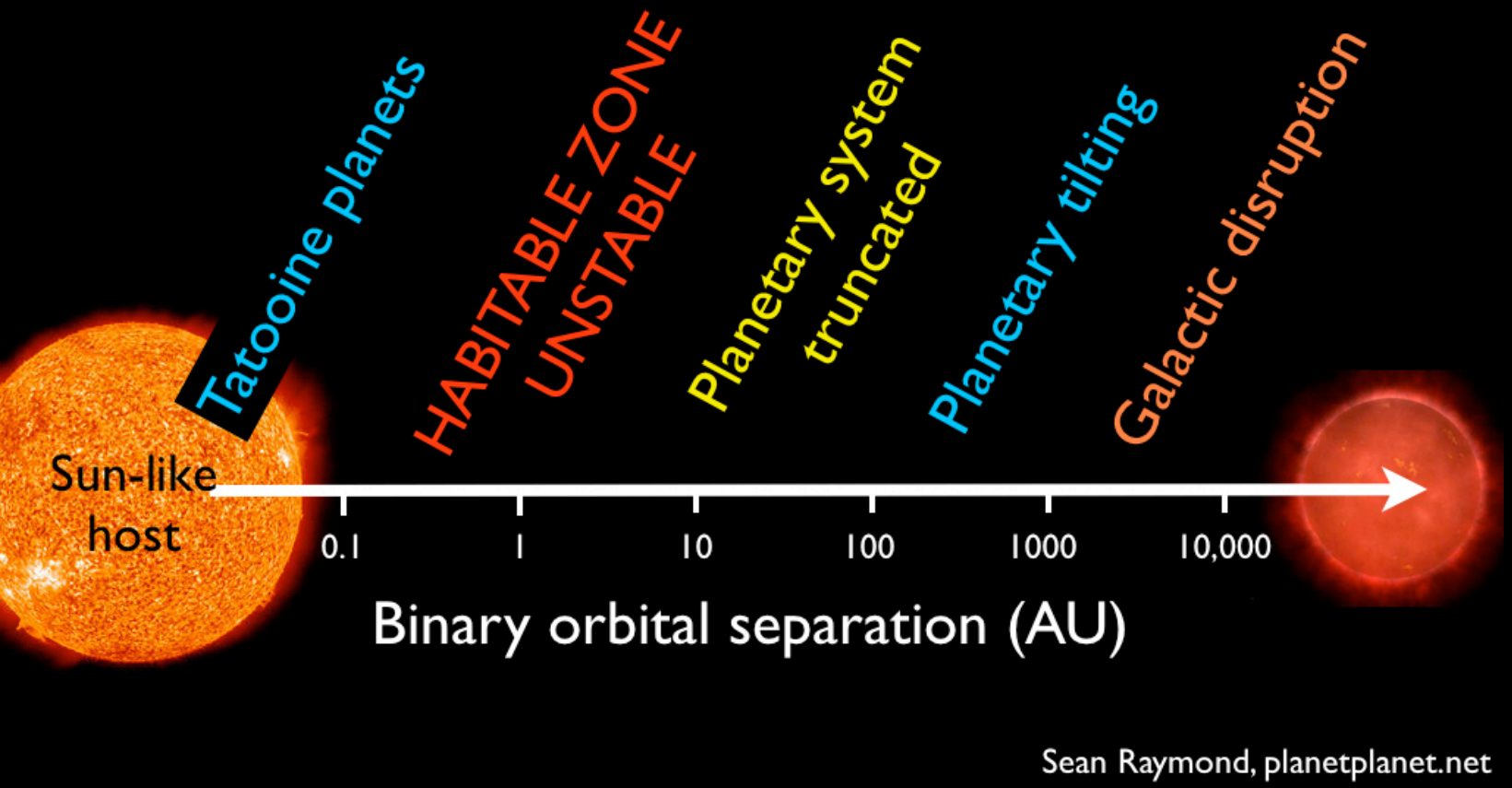
Planets in multiple systems

No significant statistical differences as far as their number is concerned



González-Payo+ 24

Binary stars: friends or foes?

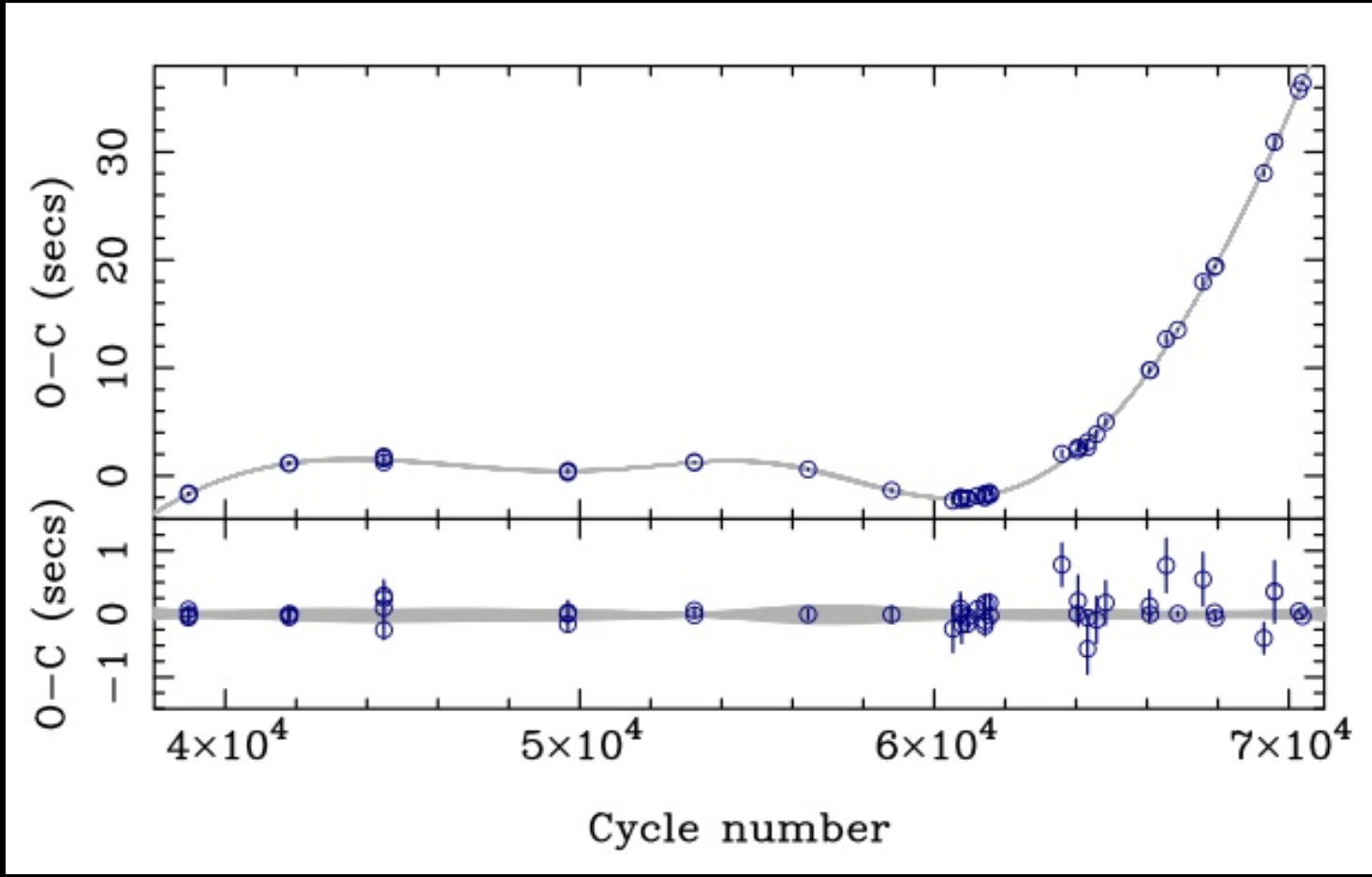


Sean Raymond, planetplanet.net

Effect of a binary star on planets in the habitable zone orbiting a Sun-like host star for the full range of binary orbital separations

Blue outcomes are OK for life

Planet around close binary



11 years of eclipse times around NN Ser

Binary: WD + M star, P = 0.13 d

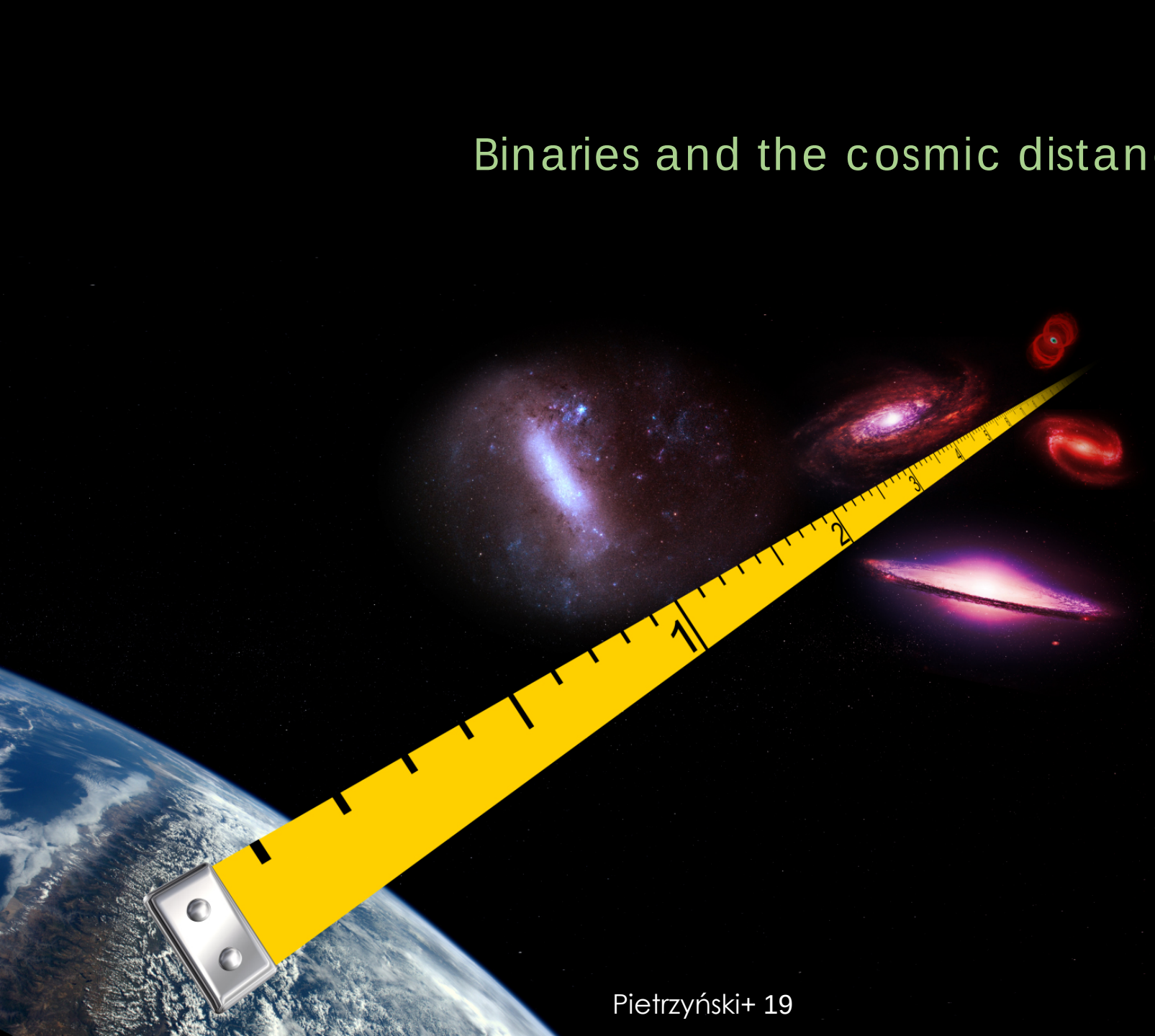
One, possibly two planets

First or second generation?

Or something else?

Marsh+ 13; see also Özdönmez+ 23

Binaries and the cosmic distance ladder

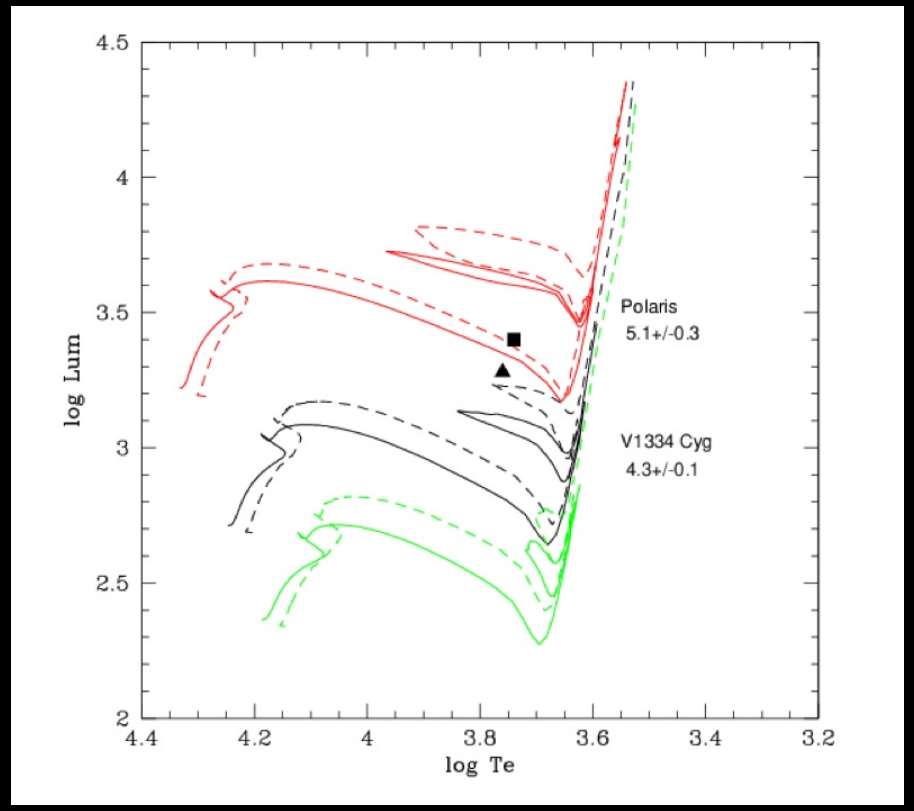


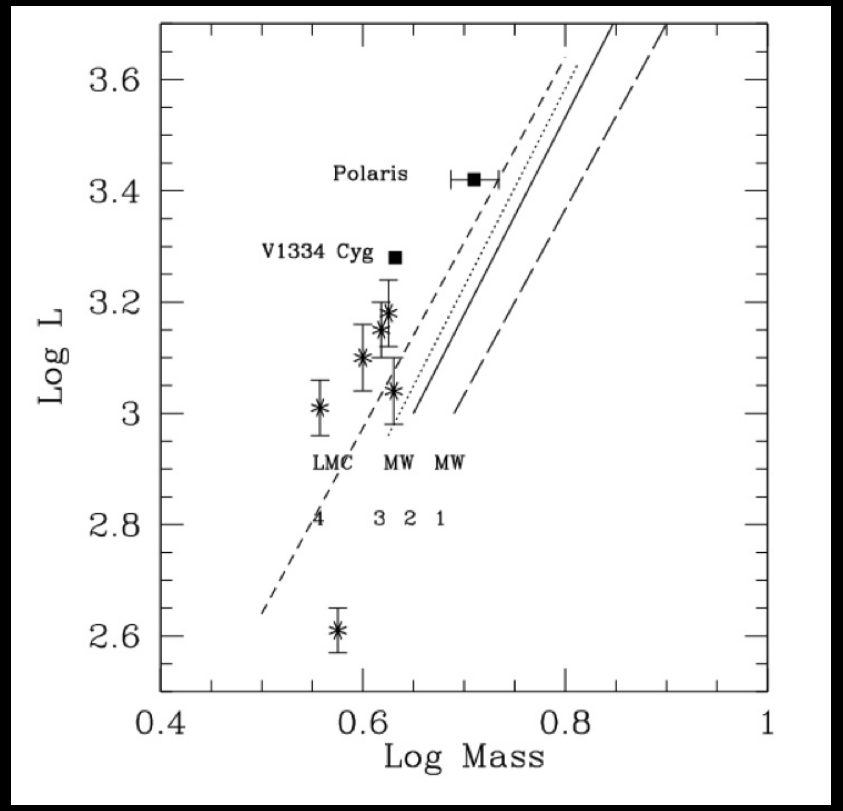
Eclipsing binary systems offer the most precise and accurate way to measure the distance to the Large Magellanic Cloud, the first step on the ladder

Also to SMC, Andromeda and Triangulum galaxy

Pietrzyński+ 19

Cepheids





Evans + 24; Gallenne+ 18; see also Pilecki+ 24

Cepheids in binary systems seem to be over luminous compared to models

Cepheid companions in binary systems are a significant source of a systematically positive photometric bias to the Cepheid fluxes, as well as contributors to the scattering of the P–L relations

On the other end of the ladder

SN Ia

Binary stars!
Several possible scenarios

Also…

Binary origin of blue straggler stars in Galactic star clusters

M. J., Rain[1], M.S., Pera[3,4], G.I., Perren[2,4], O.G., Benvenuto[2,5], J.A., Panei[2,5], M.A. De Vito[2,5], G. Carraro[6], and S. Villanova[7]

Searching for new observational signatures of the dynamical evolution of star clusters

B. Bhat,[1,2] B. Lanzoni,[1,2] F. R. Ferraro,[1,2] and E. Vesperini[3]

Double Blue Straggler sequences in GCs: the case of NGC 362[1]

E. Dalessandro[2], F. R. Ferraro[2], D. Massari[2], B. Lanzoni[2], P. Miocchi[2], G. Beccari[3], A. Bellini[4], A. Sills[5], S. Sigurdsson[6], A. Mucciarelli[2], L. Lovisi[2]

The impact of binary stars on the dust and metal evolution of galaxies

Robert M. Yates,[1,2★] David Hendriks,[2] Aswin P. Vijayan,[3,4] Robert G. Izzard,[2] Peter A. Thomas[5] and Payel Das[2]

The impact of stars stripped in binaries on the integrated spectra of stellar populations★

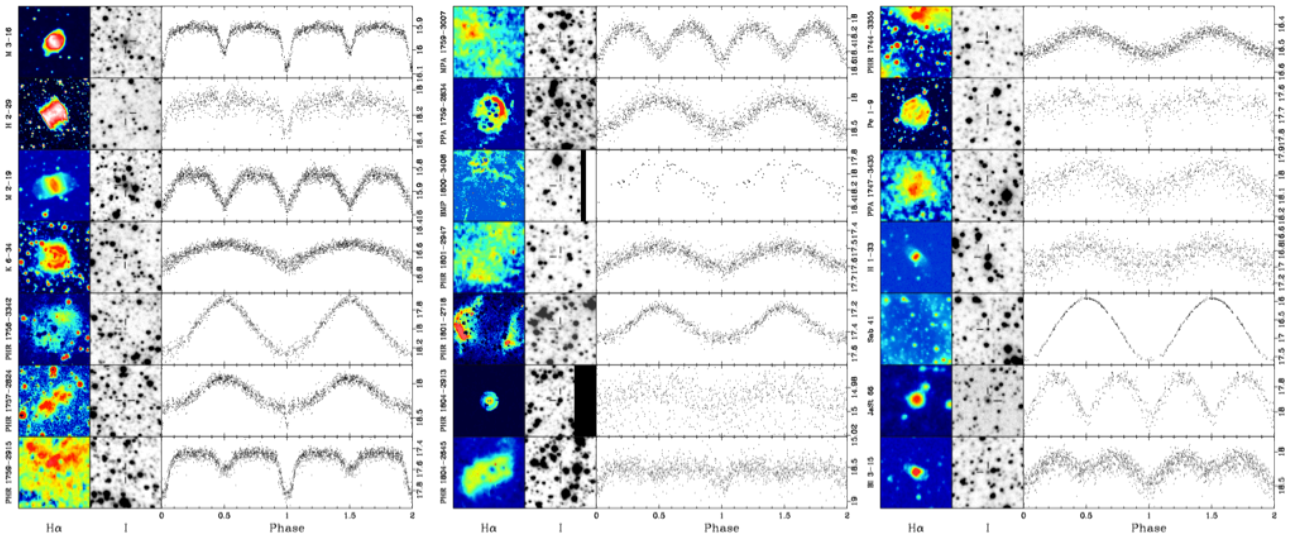
Y. Götberg[1,2], S. E. de Mink[1,3], J. H. Groh[4], C. Leitherer[5], and C. Norman[6]

A brief and biased view at the zoo

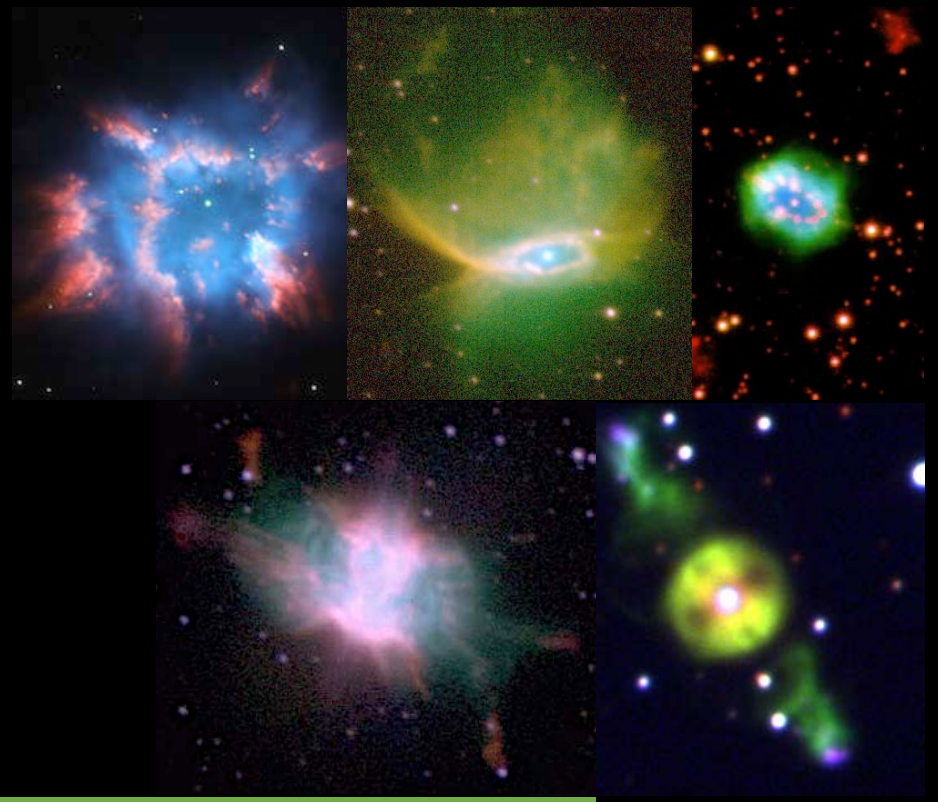
PLANETARY NEBULA

CLOSE BINARIES

Close binary fraction: 17 ± 5% Miszalski+ 08, 09



Bias towards small periods → lower limit!



We now know about 100 close binaries CSPN!

drdjones.net

> 80% of all PNe are likely binaries

→Is binarity a necessary condition for the formation of PNe?

→Will the Sun become a PN?

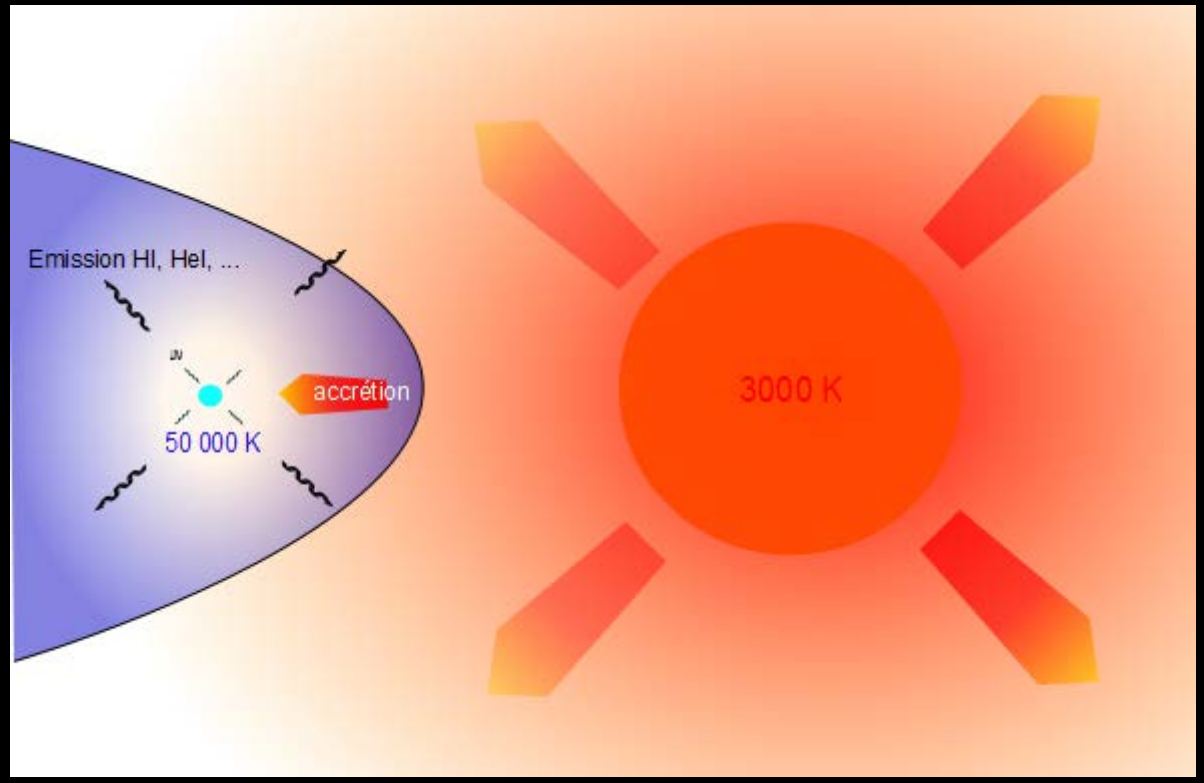
→We need to rewrite textbooks!

See Boffin & Jones 19

Symbiotic Stars

Stars initially discovered as showing the signatures of a cool and hot star!

→ binaries!

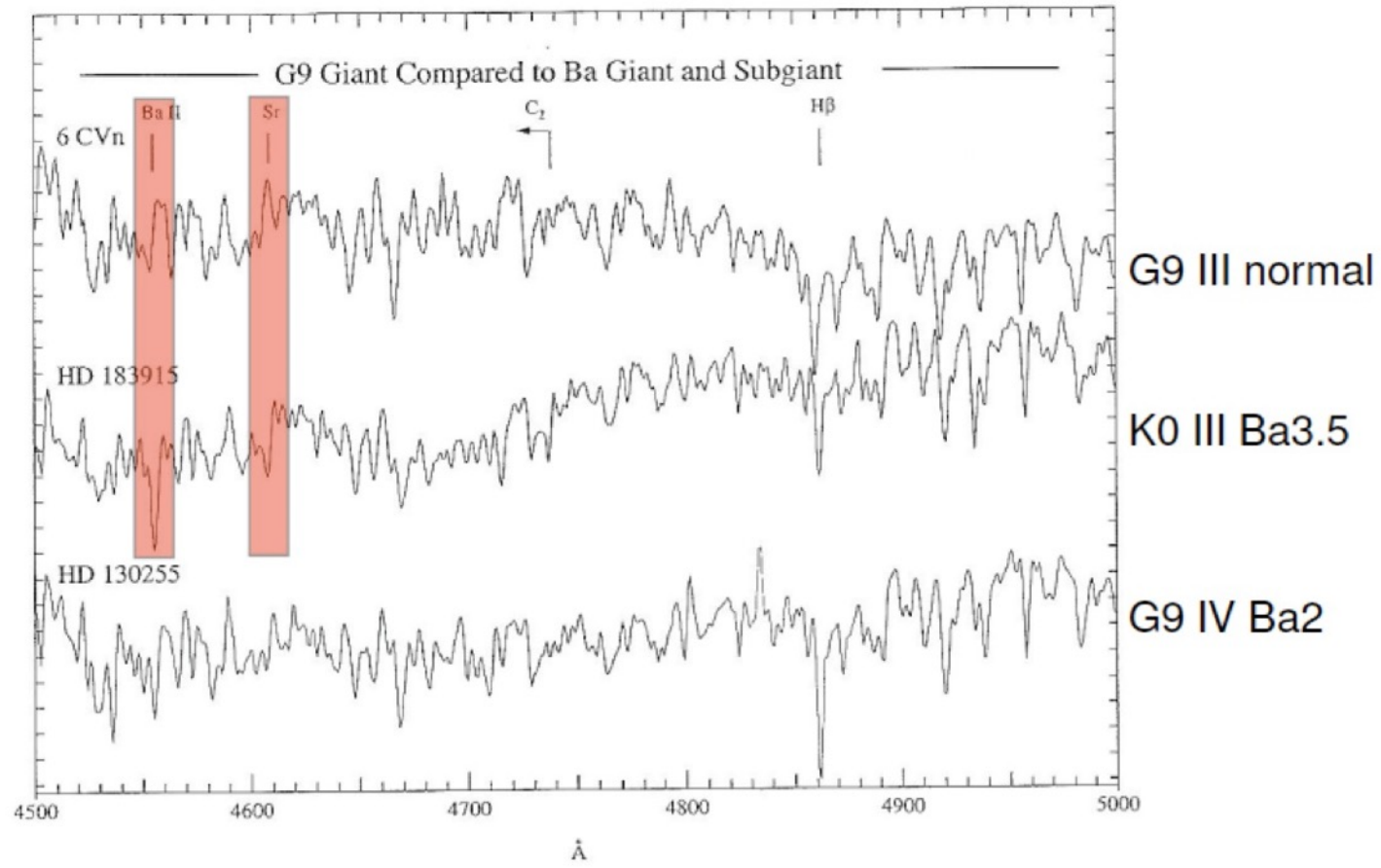


Oxpeckers eat the parasites off of large animals like this African buffalo. But they're also parasites themselves, keeping wounds open and picking at scabs.
Natphotos/Digital Vision/Getty Images
howstuffworks.com

Nature of Mass Transfer?

Barium stars

Ba stars: A class of chemically-peculiar giants known since the 50's



Barnbaum (1996), ApJS 105, 419

Red giant enriched in s-process elements and carbon

Not evolved enough to have produced these elements

A case in point: Barium stars

THE BARIUM STARS*

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Received 1983 October 15

Ba stars are formed through binary interaction

The barium stars are Population I G–K giants that have enhanced abundances of carbon and *s*-process elements, and are probably related in their peculiarities to several other carbon enhanced red-giant types such as CH, R, N, and S stars. Since the abundance anomalies in the barium stars are likely the result of mixing of processed material from deep within a stellar interior, and since they are numerous with many bright examples suitable for detailed observations, these stars provide very valuable information on nucleosynthesis, and the advanced stages of stellar evolution. A clue to the origin of the anomalous abundances in the barium stars is the recent discovery that they are likely all members of binary systems.

Key words: barium stars—carbon stars—nucleosynthesis—stellar evolution

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

ASTRONOMY AND ASTROPHYSICS

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

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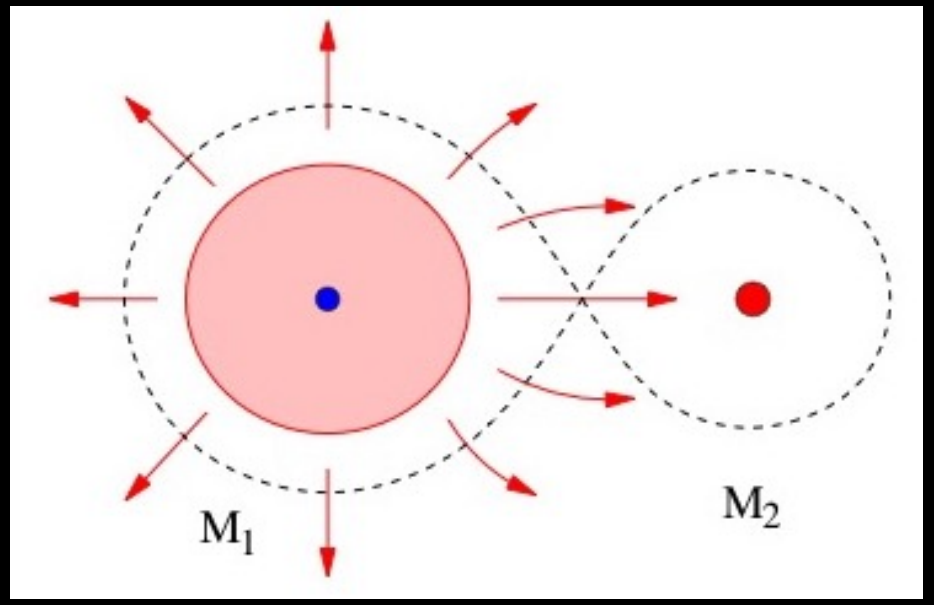
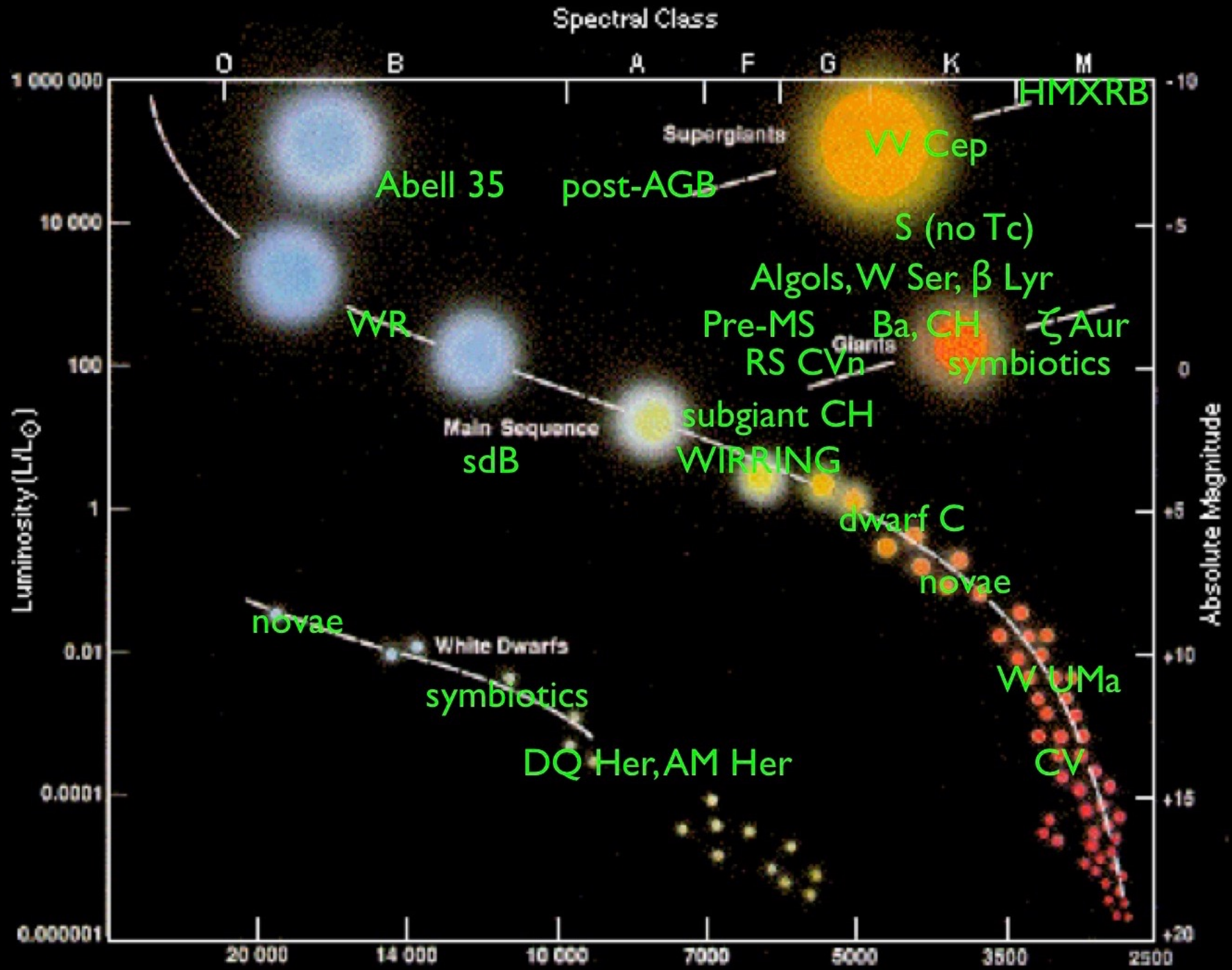
Master thesis done in 1987



O. Pols



Binaries are everywhere!

Different kind of systems → a Zoo!

A. Jorissen

Enjoy the conference!

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