Credit: Fabian Bodensteiner

HD 45166: the first magnetic Wolf-Rayet star

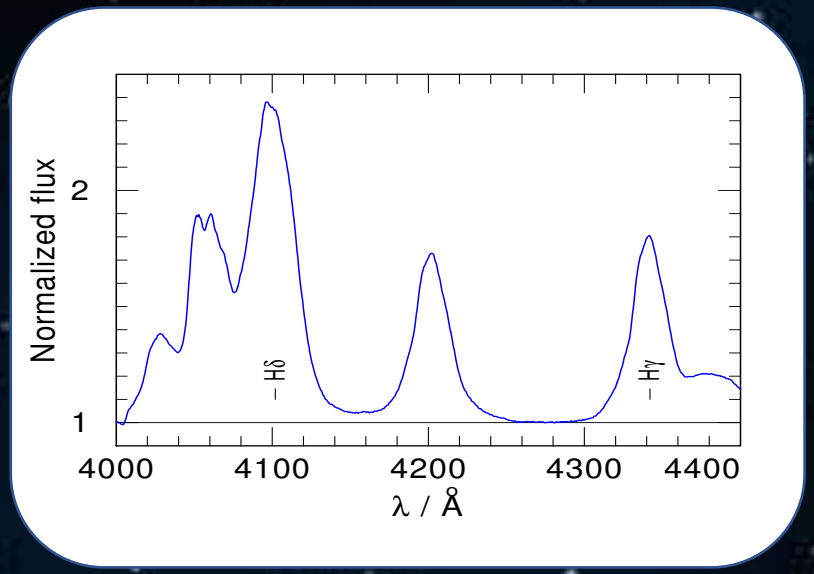
Tomer Shenar
University of Amsterdam, NL

Collaborators: **Gregg Wade**, Pablo Marchant, Stefano Bagnulo, Julia Bodensteiner, Dominic Bowman, Avishai Gilkis, Norbert Langer, Andre Nicholas-Chene, Lidia Oskinova, Timothy Van Reeth, Hugues Sana, Nicole St-Louis, Alexandre Soares de Oliveira, Helge Todt, Silvia Toonen

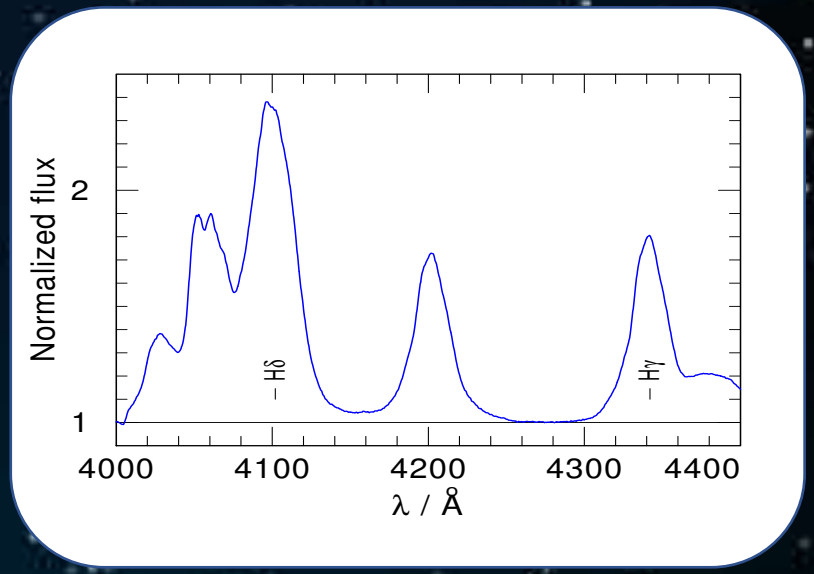
European Commission
Marie Skłodowska-Curie Actions

What are Wolf-Rayet stars?

Wolf-Rayet stars



Classical Wolf-Rayet stars



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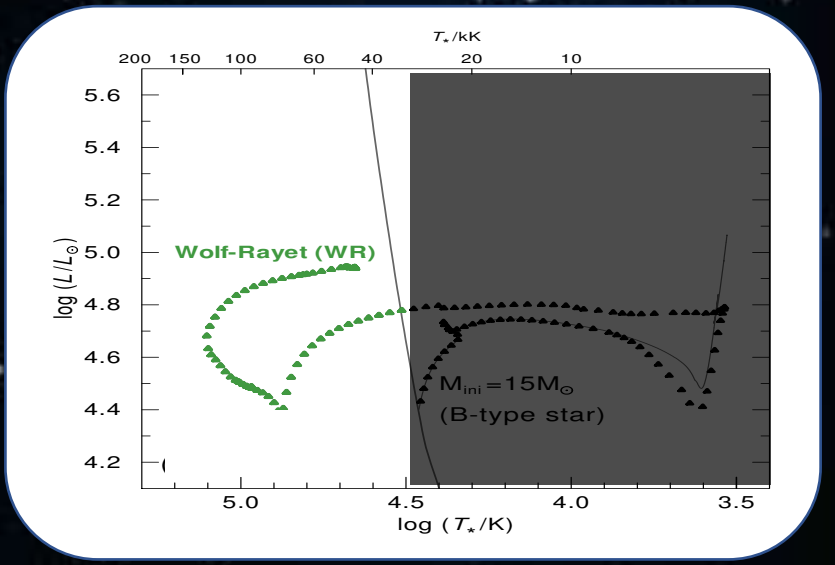
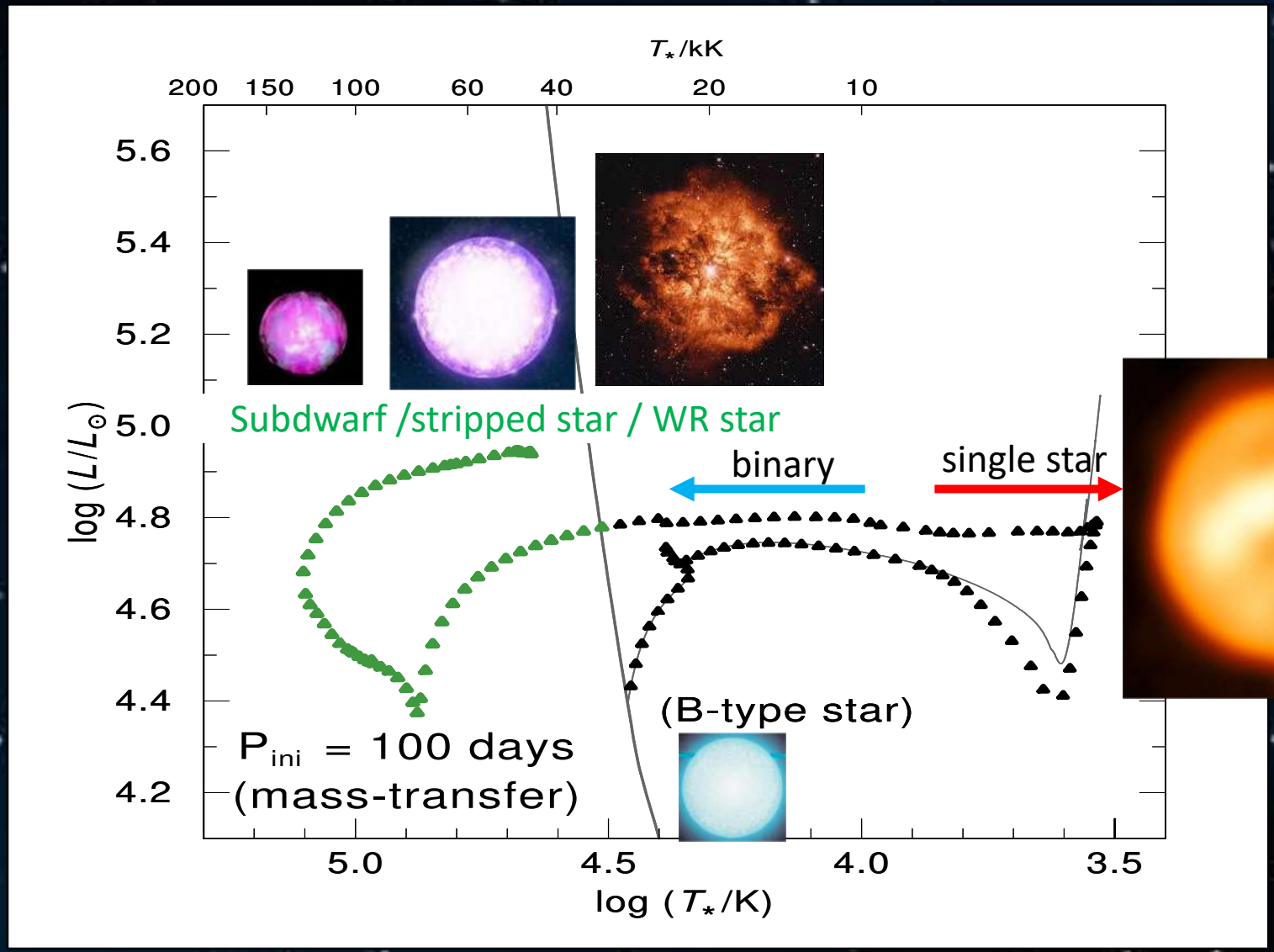
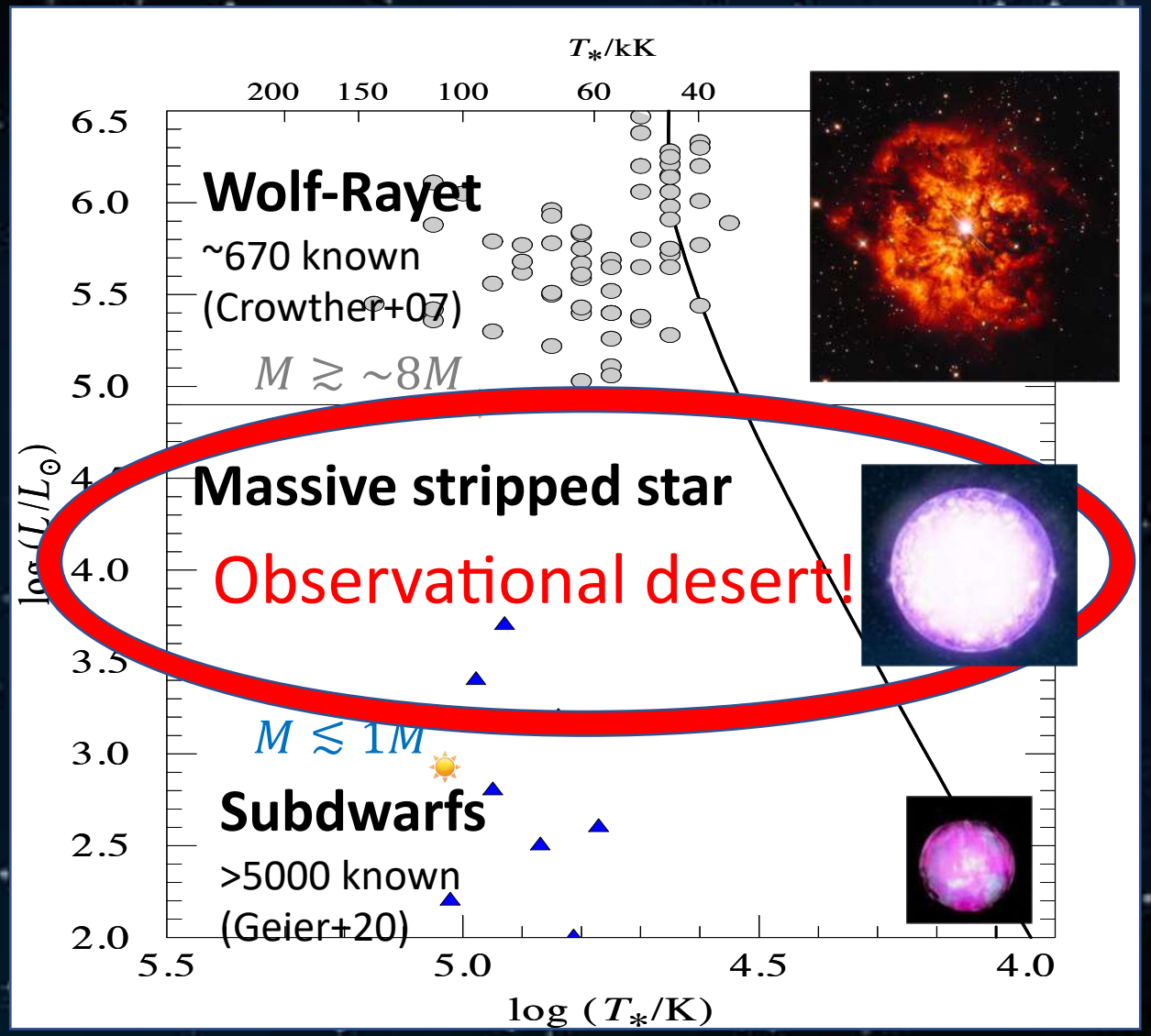


Binary stripping



An observational dearth of stripped stars

Sample found in the Magellanic Clouds
→ Götberg + Ludwig



Quasi-WR?
Groh+07

Dionne+ 07, Goetberg+17, 18, Hamann+06,19, Heber+10, Schootemeijer+ 18, Shenar+16, 19, 20, Wang+20, Klement+21

An observational dearth of stripped stars

Only two objects reported in the Galaxy

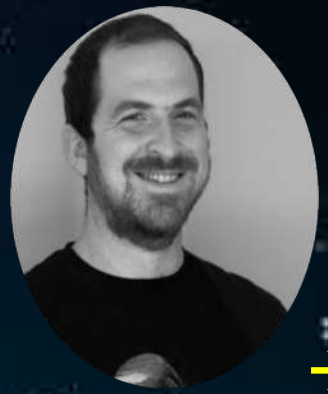
Ups Sgr
(H-deficient giant, binary)

~~1~~ ~$M_\odot$ bloated stripped star?
(Dudley & Jeffery 1990)

HD 45166
("quasi Wolf-Rayet", qWR, binary)

~4$M_\odot$ hot stripped star?
(Steiner & Oliviera 1990)

Sample found in the Magellanic Clouds
→ Götberg + Ludwig



Gilkis & Shenar+22,
"Ups! I did it again"
MNRAS, in press

→poster by Avishai Gilkis

Today's talk

Quasi-WR?
Groh+07

A history of classifications…

Wolf-Rayet (WN7)

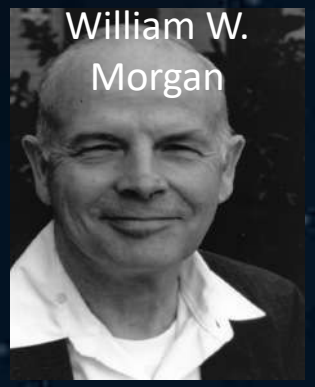
Jane Anger

Note on a Variable O-Type Spectrum. —

The only conspicuous feature on MC18388, January 25, 1922, is a strong line at about 4686; a bright line at 4059 is the next most prominent, and there may also be a trace of emission at 4640.

Anger 1933; Neubauer & Aller 1948

Be star



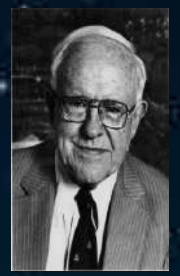
William W. Morgan

426	44743	18.3	-17	54	B1 II-III	1.99	- .18
427	44811	18.8	+19	45	07.5 V		- .03 (1)
428	44965	19.6	+11	45	B3 II		
429	45166	20.8	+ 8	3	B pe	9.7	- .15
430	45314	21.6	+14	57	09? pe	7.09	- .06

Morgan, Code & Whiteford 1955

"quasi WR" (qWR) + B7 binary?

W. Hiltner

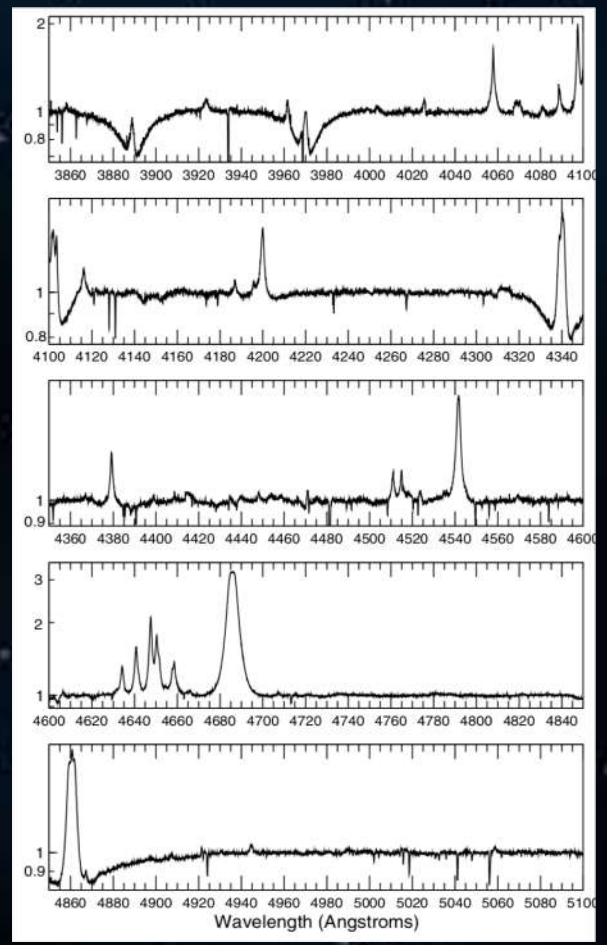


L. Aller

S. Heap

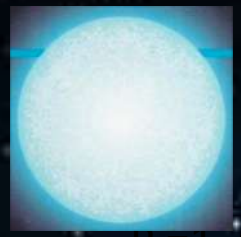
Although sometimes classed as a Wolf-Rayet star, except for the presence of emission lines in its spectrum, HD 45166 differs from true Wolf-Rayet stars in all its physical parameters. Since the spectrum also contains absorption lines characteristic of a late B-type star, Heap and Aller suggest that HD 45166 is a binary system composed of a normal late B star and what they term a "quasi Wolf-Rayet star" (qWR).[1]

Van Blerkom+ 78; Hiltner+ 56; Heap & Aller, unpublished



From Steiner & Oliviera 2005

The elusive orbital period of HD 45166



B7 V

P = 1.6d

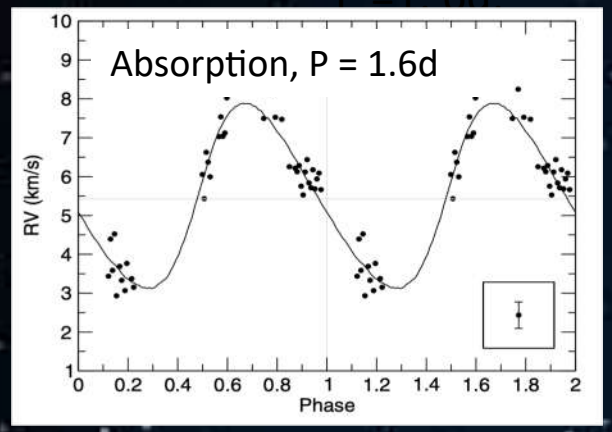
The qWR star HD 45166★,★★

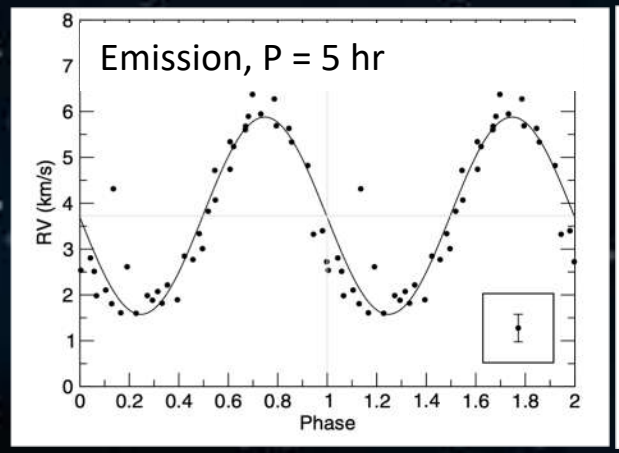
I. Observations and system parameters

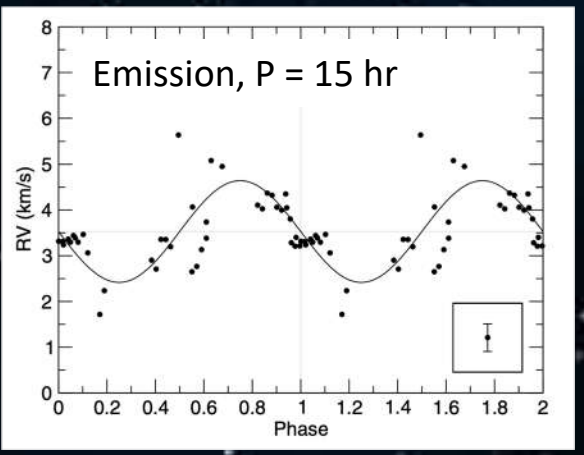
J. E. Steiner[1] and A. S. Oliveira[2,3]

2005

qWR

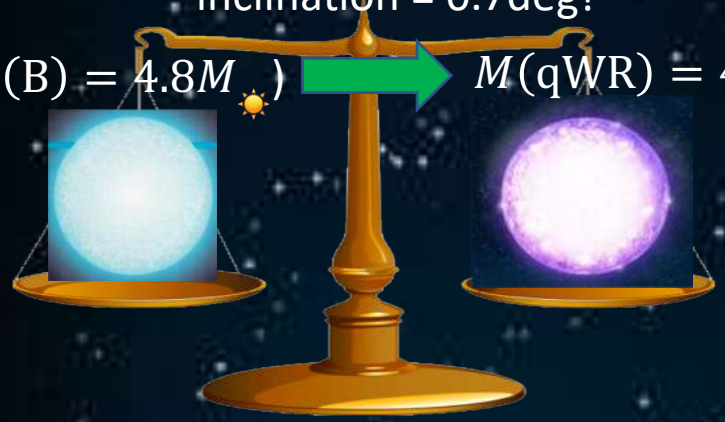




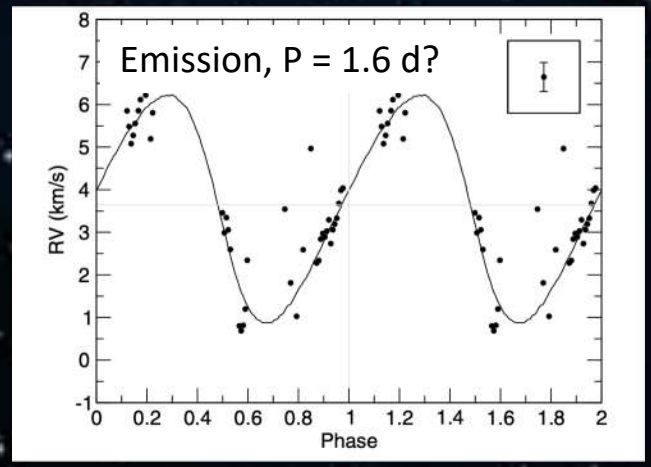


inclination = 0.7deg!

$M(\mathrm{B}) = 4.8M_\odot$ $M(\mathrm{qWR}) = 4.2M_\odot$



After subtracting the 5hr and 15hr periods



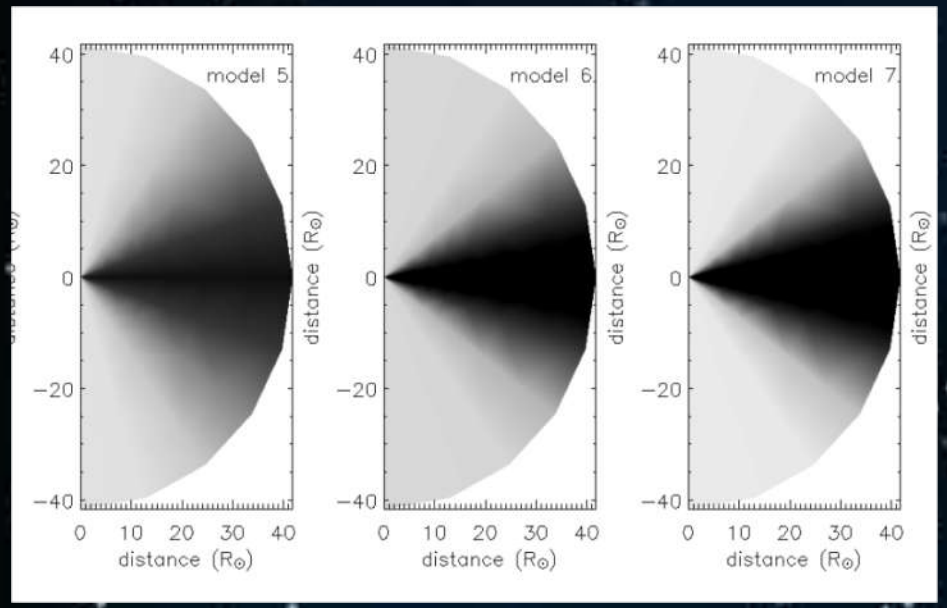
Latitude-dependent wind?

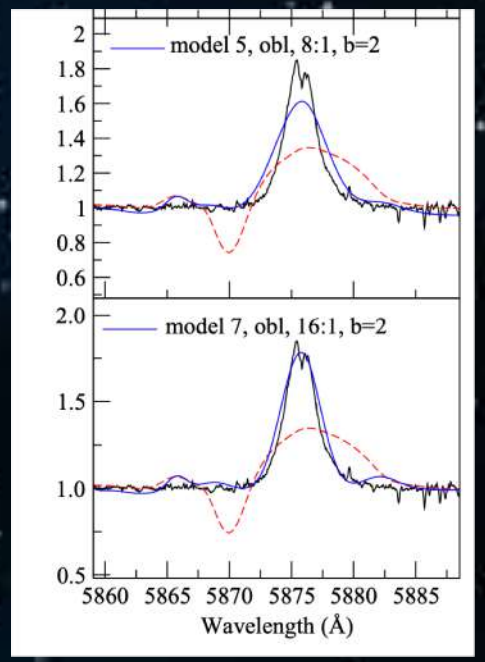
The qWR star HD 45166⋆

II. Fundamental stellar parameters and evidence of a latitude-dependent wind

J. H. Groh[1,2,⋆⋆], A. S. Oliveira[3,4], and J. E. Steiner[2]

P =1. 6d,





Parameter	Value
$\log (L_\star/L_\odot)$	3.75 ± 0.08
$T_\star$ (K)	70000 ± 2000
$T_{\rm eff}$ (K)	50000 ± 2000
$R_\star/R_\odot$ ($\tau = 100$)	0.51
$R_{\rm phot}/R_\odot$ ($\tau = 0.67$)	1.00
$\dot{M}$ ($M_\odot yr^{-1}$)	2.2×10^{-7}
v_∞ (km s^{-1})	425
β	4.0
f	0.5
v_c (km s^{-1})	100

Mass-loss rate lies orders of magnitude above expectation (e.g., Vink+ 17; Sander & Vink 20)

If massive stripped stars look so "obvious", why haven't we found more?

Why is the mass-loss rate so high?

Why should the "only massive stripped star" known be seen at pole-on inclination?

Why is the wind latitude-dependent?

Could the star be magnetic?!

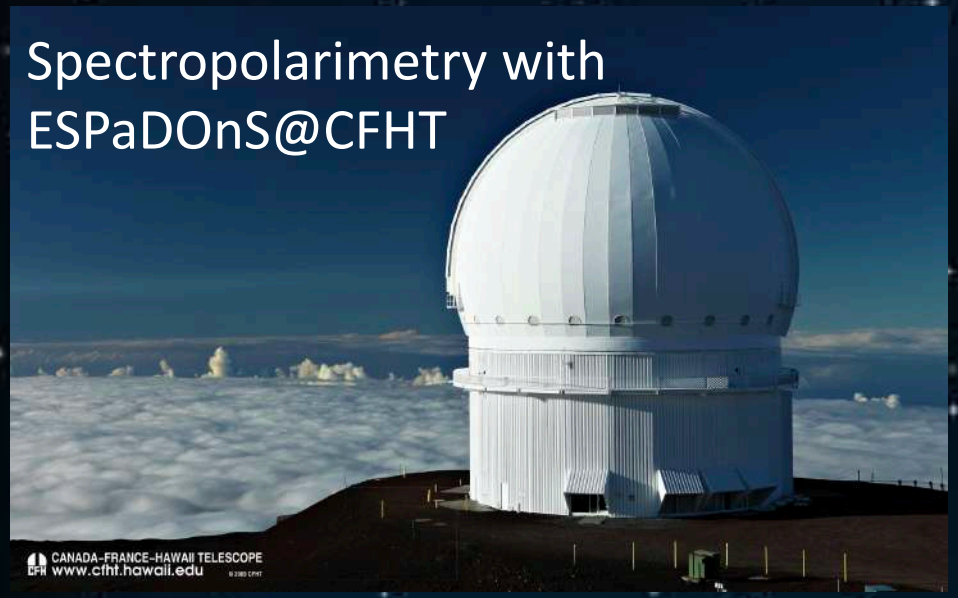
HD 45166 magnetic?

Tomer Shenar
Mon 5/17/2021 7:18 PM

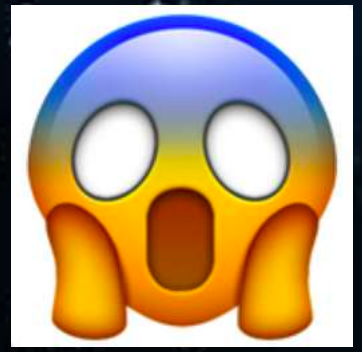
To: gwade@queensu.ca;

Gregg Wade

I checked all of the spectropolarimetric databases and there are no existing magnetic observations of this star. I agree that the 4650 complex looks like an

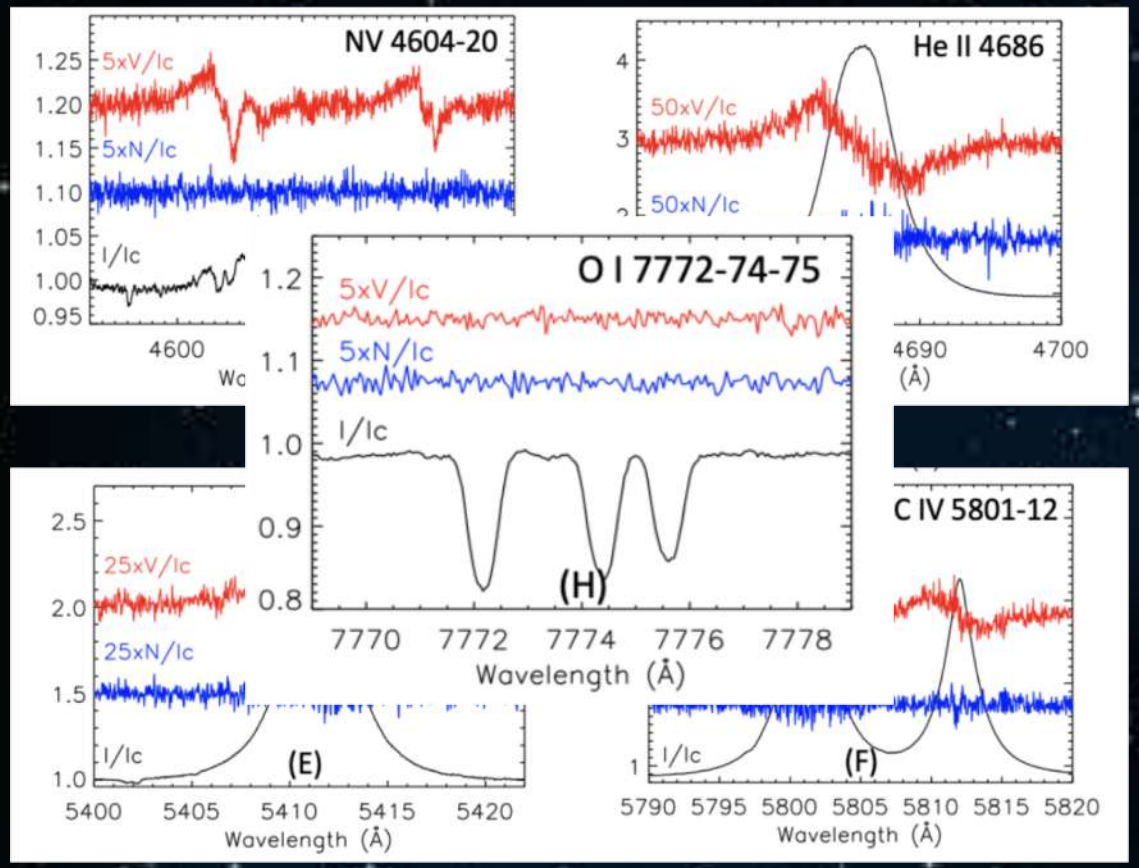


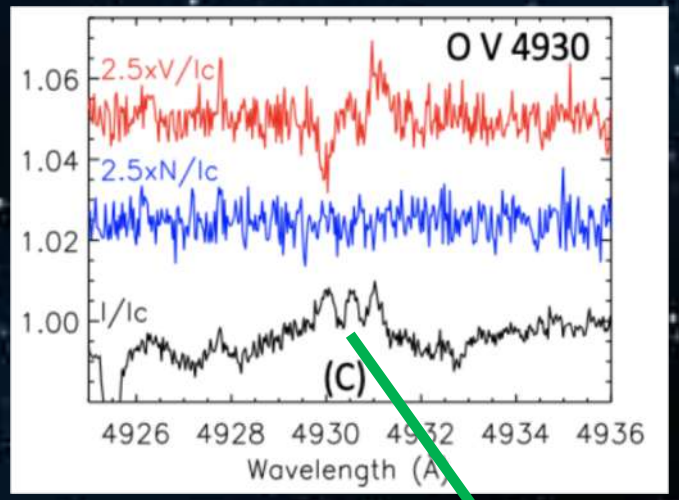
Well my friend... whatever this thing is, it's magnetic!

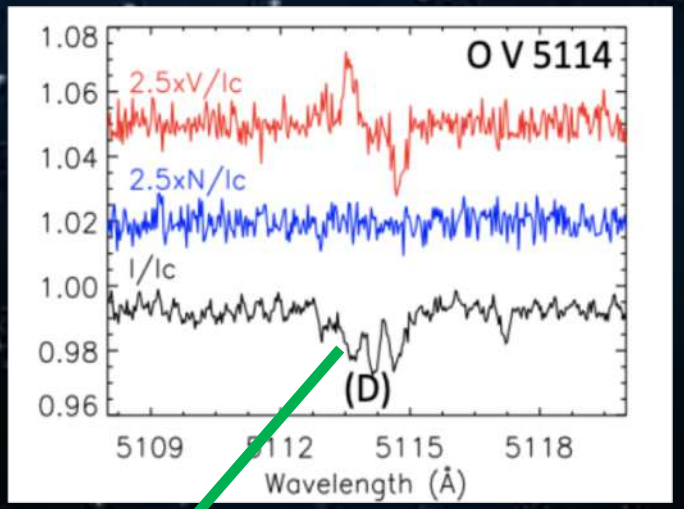


An extraordinary magnetic field

Shenar, Wade, Marchant et al. 2022, under review







Zeeman-split O V lines!

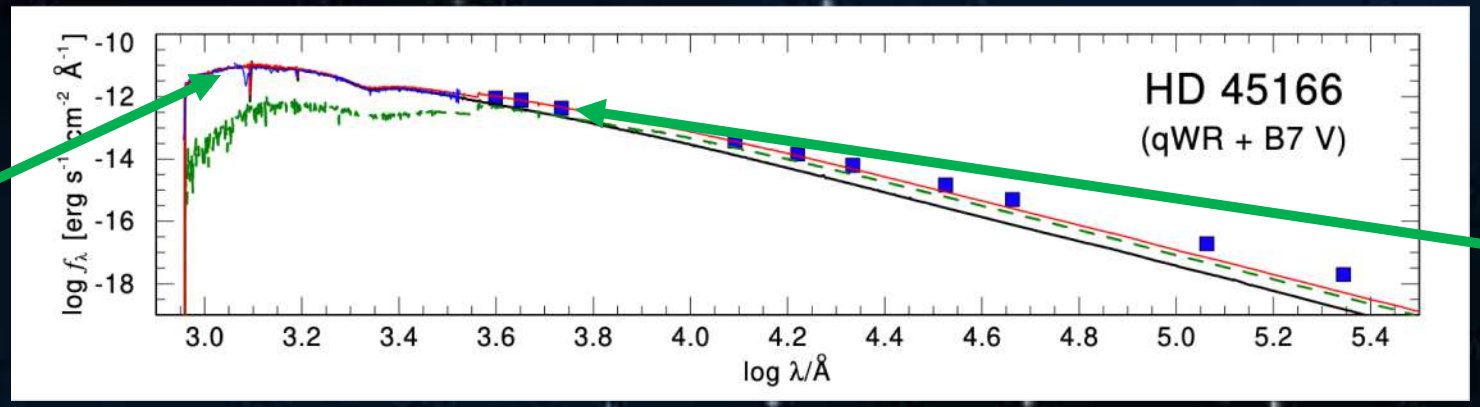
$$< B > = 43 \pm 1.5 \text{ kG}$$

qWR = magnetic;
B7 V = not magnetic

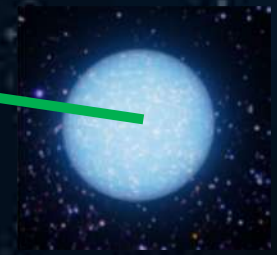
Strongest magnetic field in a pre-explosion star
First “magnetic Wolf-Rayet” star…

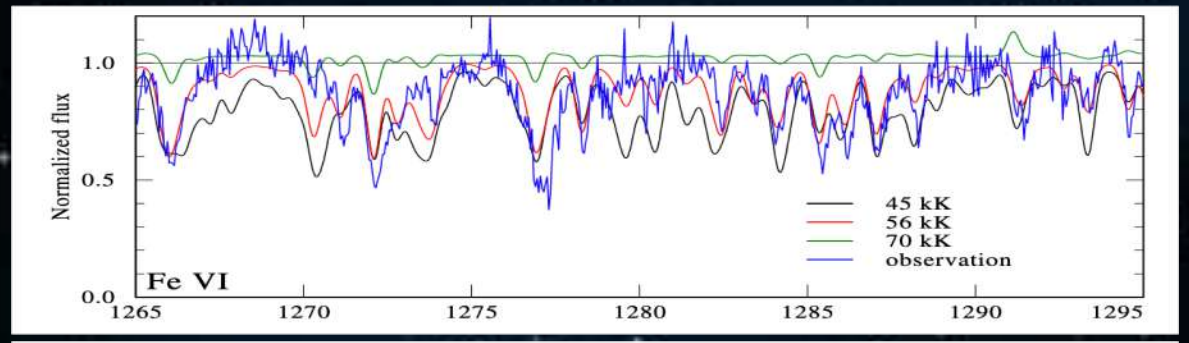
Physical parameters of companions

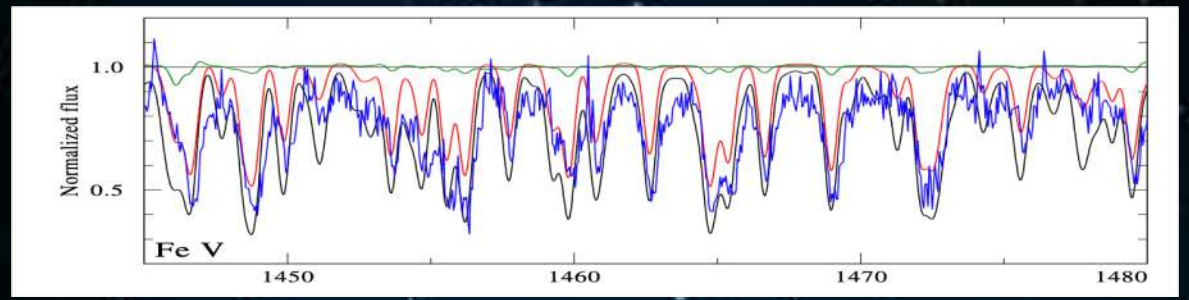
Fully dominates UV

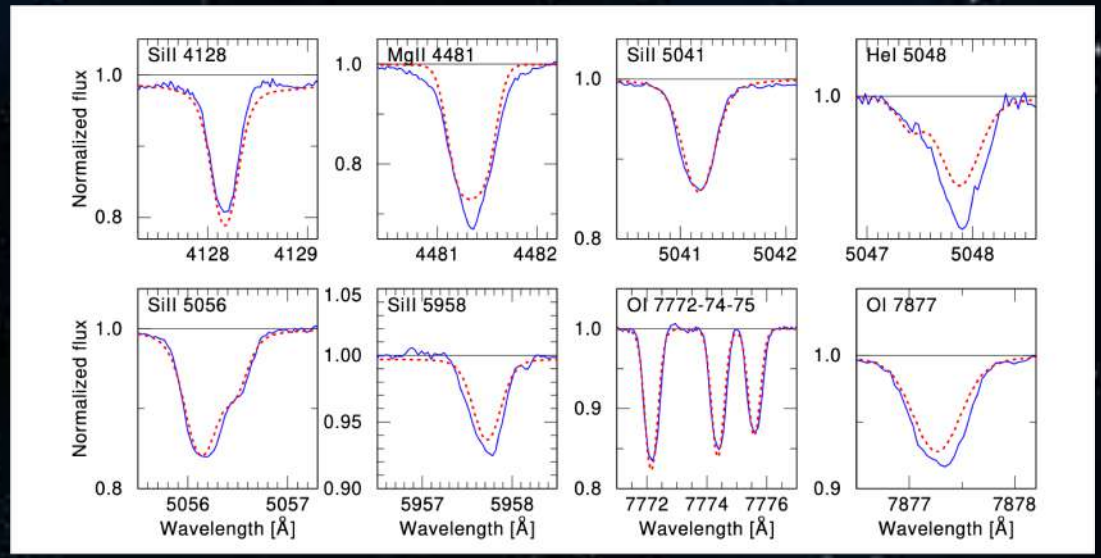


~50% in VIS
Dominates IR



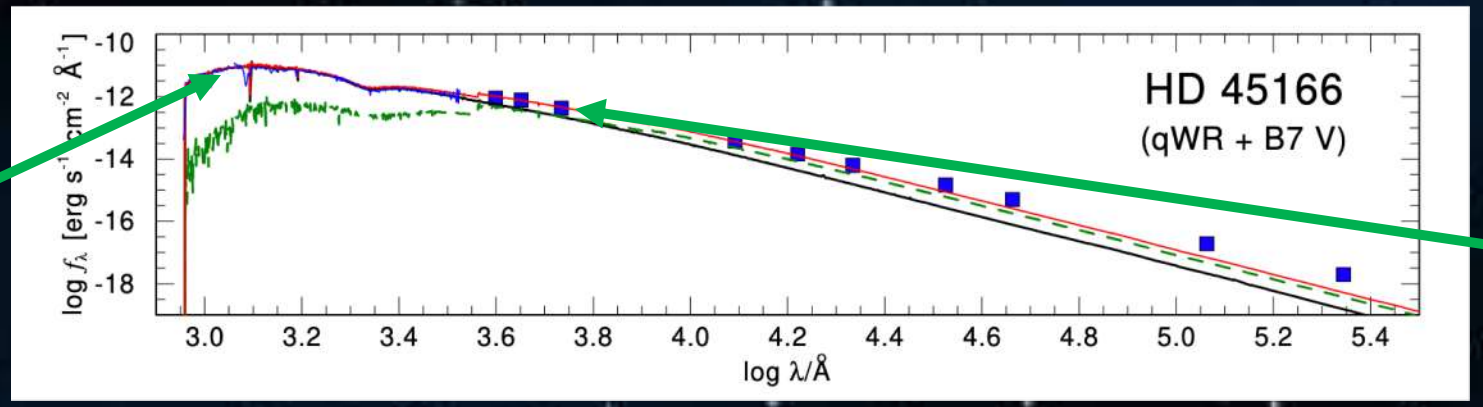




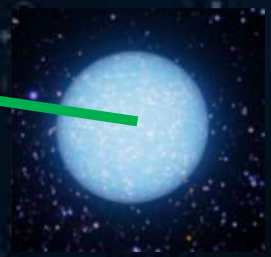


Physical parameters of companions

Fully dominates UV



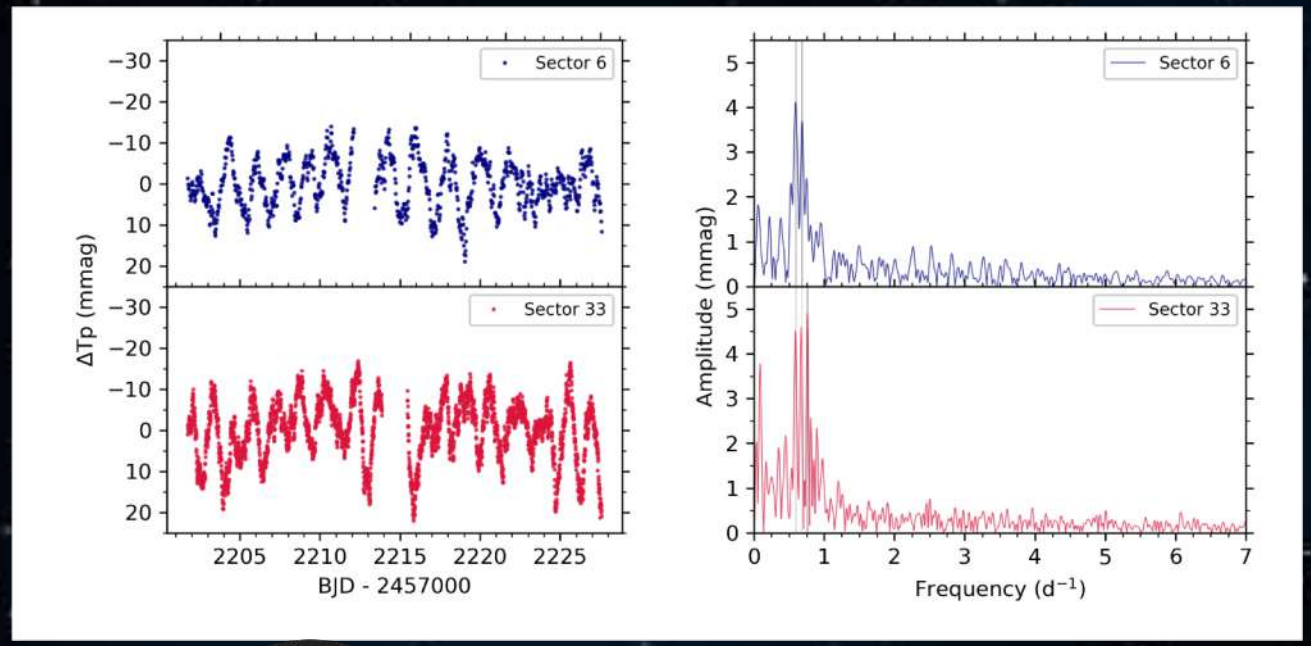
~50% in VIS
Dominates IR

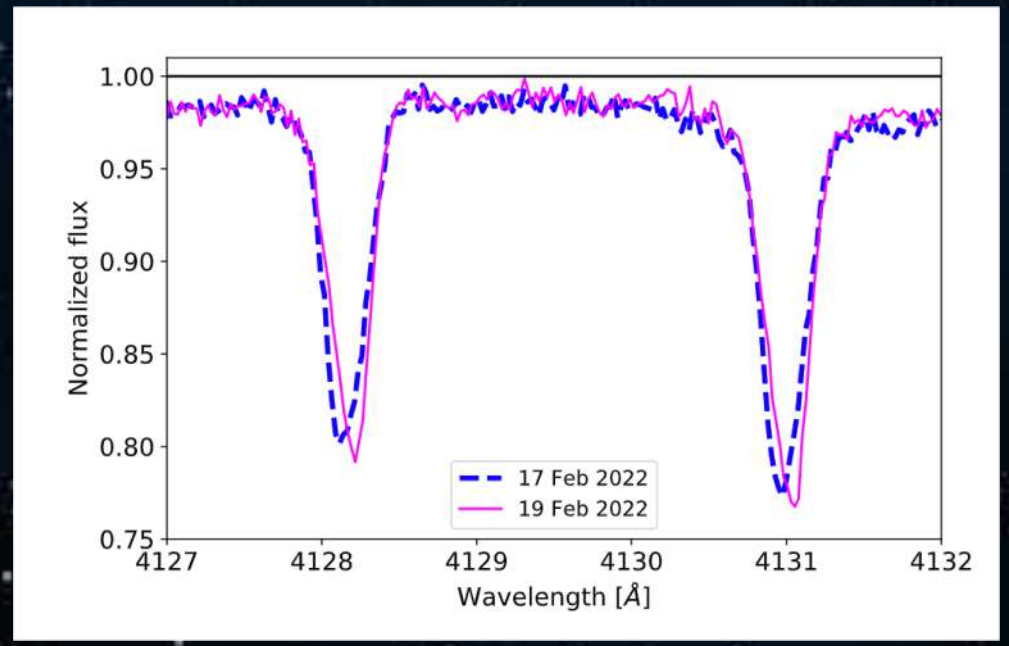


$T_{\rm eff}$ (base) ~ 55-60 kK
$\log L = 3.83 \pm 0.05\ [L_\odot]$
$R = 0.9\ \pm 0.1\ R_\odot$

$T_{\rm eff}$ ~ 12-13 kK
$\log L = 2.25 \pm 0.05\ [L_\odot]$
$R = 2.6\ \pm 0.4\ R_\odot$
M (evo.) $= 3.4 \pm 0.1\ M_\odot$
Age ~ 105 ± 35 Myr

Short 1.6d period confused with pulsations from B star!

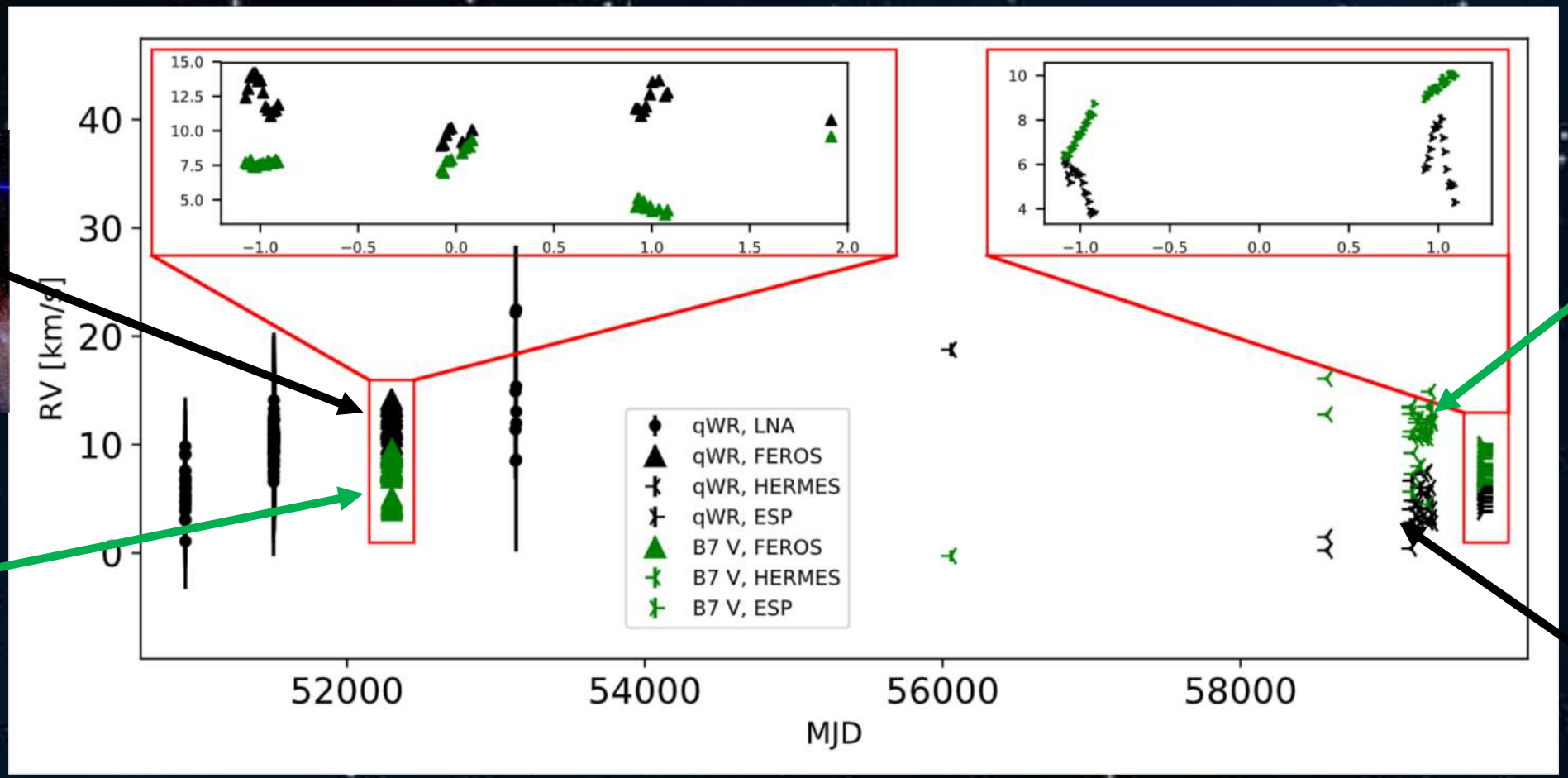




Dominic Bowman

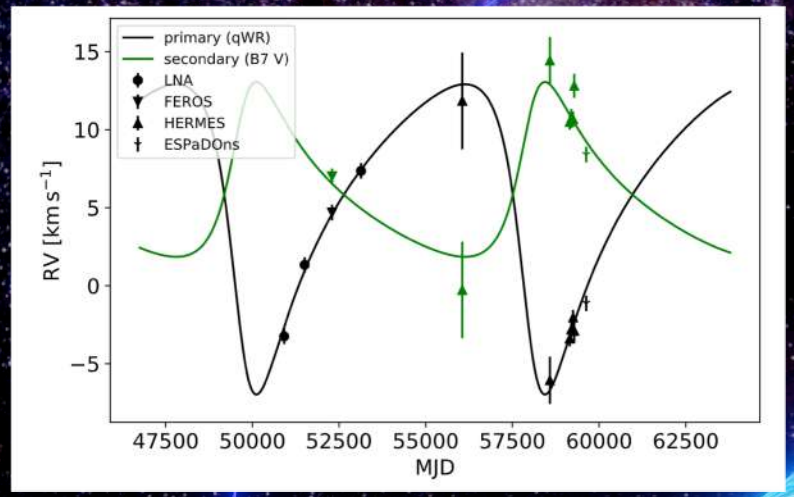
Timothy Van Reeth

Indication for a (very) long orbit!



24 yr of data coverage (LNA, FEROS, HERMES, ESPaDOnS)

Credit: Fabian Bodensteiner



M (evo.) $= 3.4 \pm 0.1\ M_{\odot}$

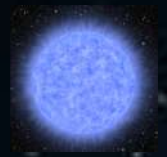
Orbital inclination ~ 50 deg

M (dyn.) $= 2.0 \pm 0.5\ M_{\odot}$

q $= M_{qWR}/M_B$ $= 0.59 \pm 0.12$

Period = 22.5 yr,
e = 0.46 ± 0.17

Evolution scenario: we propose a merger in a triple!



$\sim 3.5 M_\odot$

$\sim 0.6 M_\odot$ $\sim 3 M_\odot$ $\sim 7.4 M_\odot$

1. Stable mass transfer

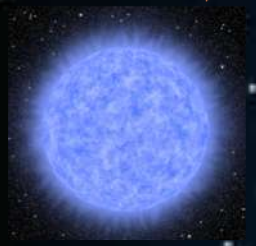
Ferrario+ 2009, Schneider+ 18

Evolution scenario: we propose a merger in a triple!

$\sim 3.5M_\odot$

$\sim 3.5M_\odot$

$\sim 5M_\odot$ $\sim 3M_\odot$



1. Stable mass transfer

$\sim 0.6M_\odot$ ~ 1.5–$7.4M_\odot$

2. Unstable mass transfer and merger

Ferrario+ 2009, Schneider+ 18

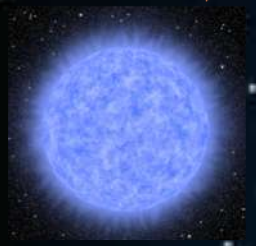
Evolution scenario: we propose a merger in a triple!

$\sim 3.5M_\odot$

$\sim 3.5M_\odot$

$\sim 3.5M_\odot$

$\sim 5M_\odot$

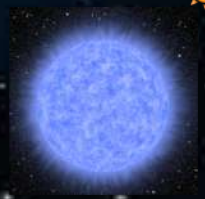


$\sim 3M_\odot$

1. Stable mass transfer

$\sim 0.6M_\odot$

$7.4M_\odot$



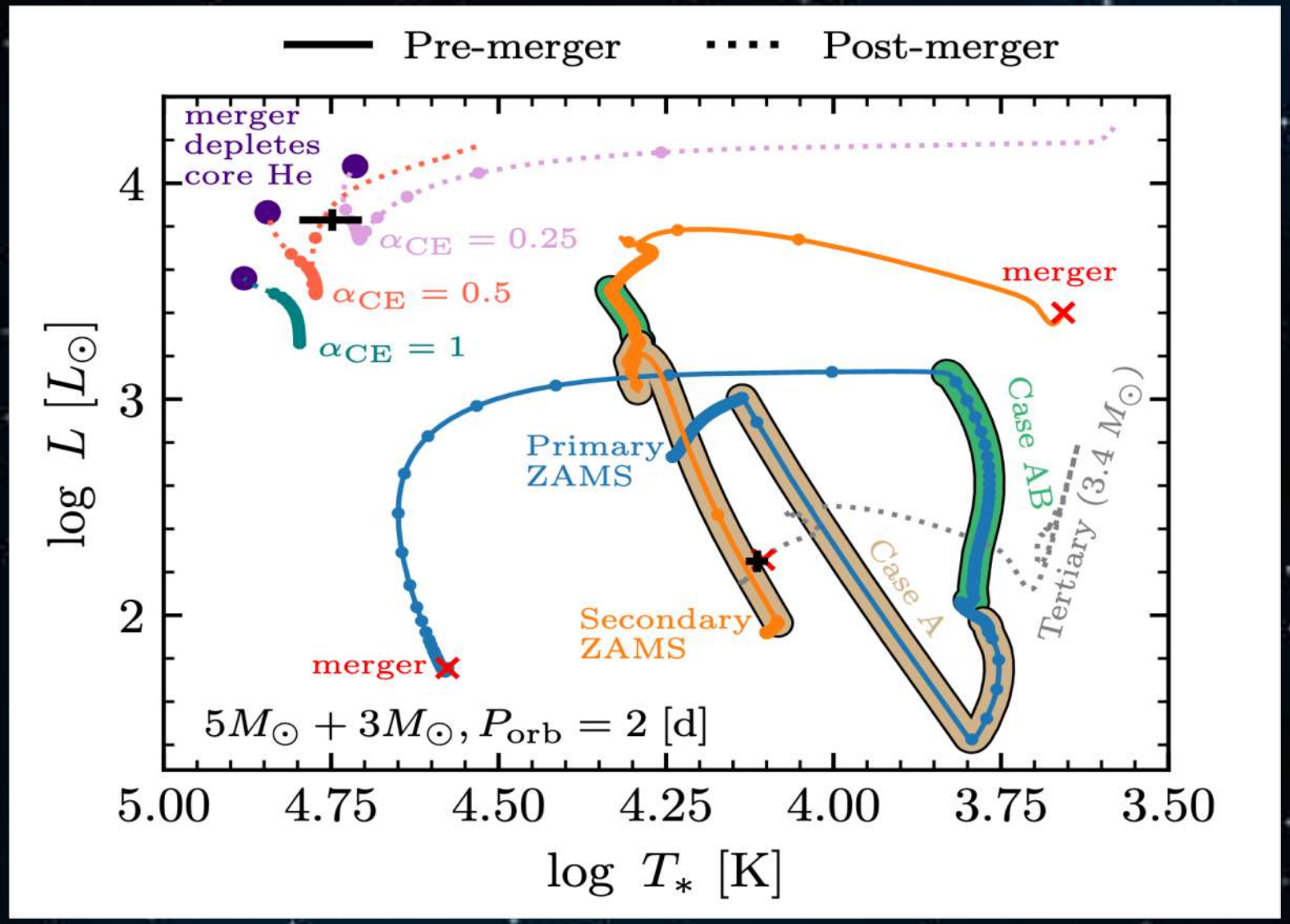
2. Unstable mass transfer and merger

$\sim 1.5 - 2.5M_\odot$

3. Current day

Ferrario+ 2009, Schneider+ 18

Evolution scenario: we propose a merger in a triple!

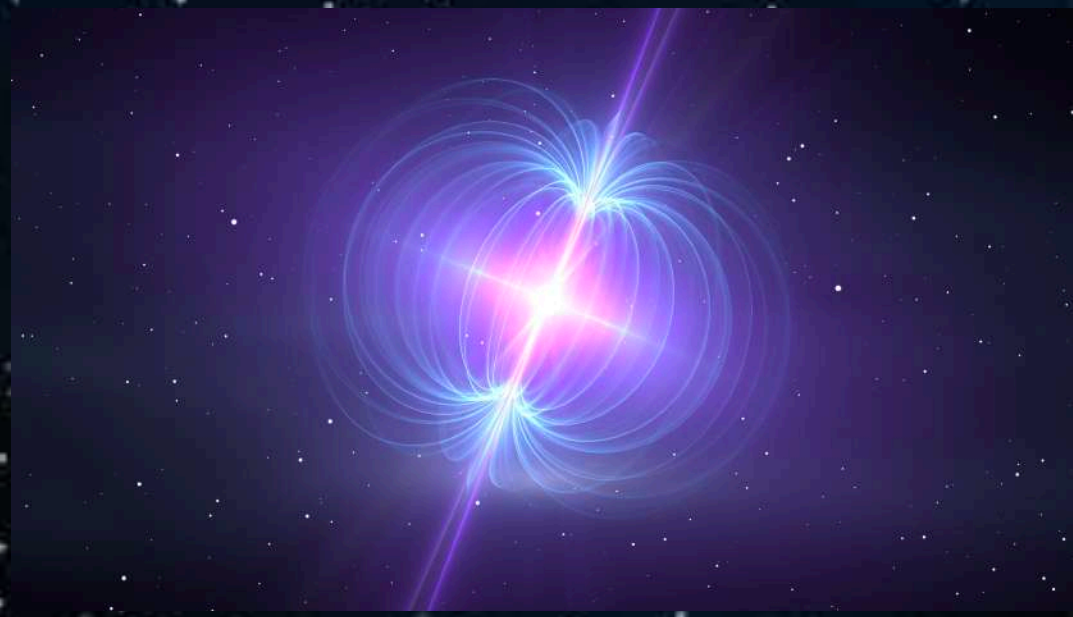


Pablo Marchant

A promising magnetar progenitor!

$< B > = 43 \pm 1.5$ kG

$R = 0.9 \pm 0.1\ R_{\odot}$

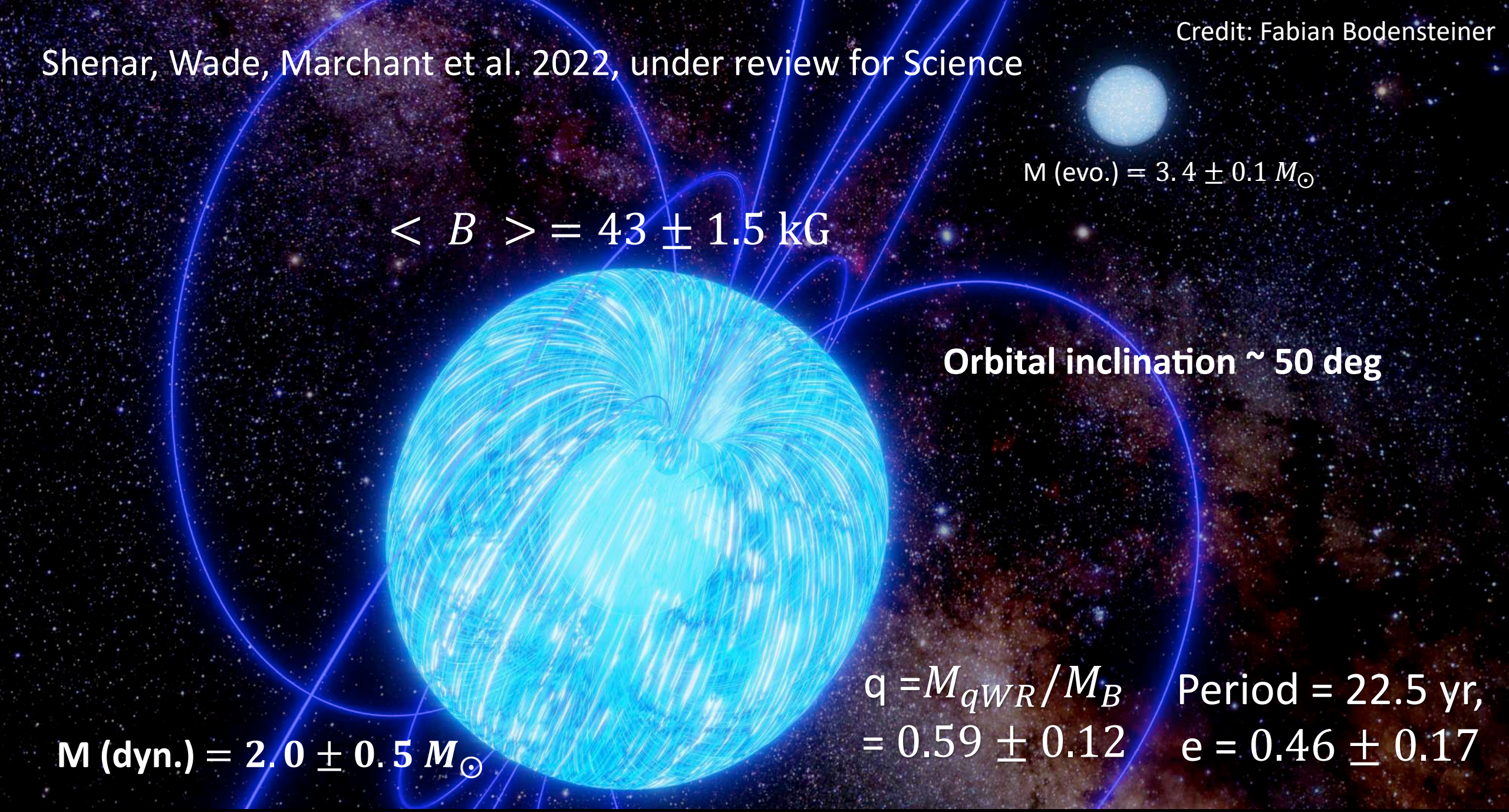


$< B > \sim 10^{14}$G

$R = 12$ km

Shenar, Wade, Marchant et al. 2022, under review for Science

Credit: Fabian Bodensteiner



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