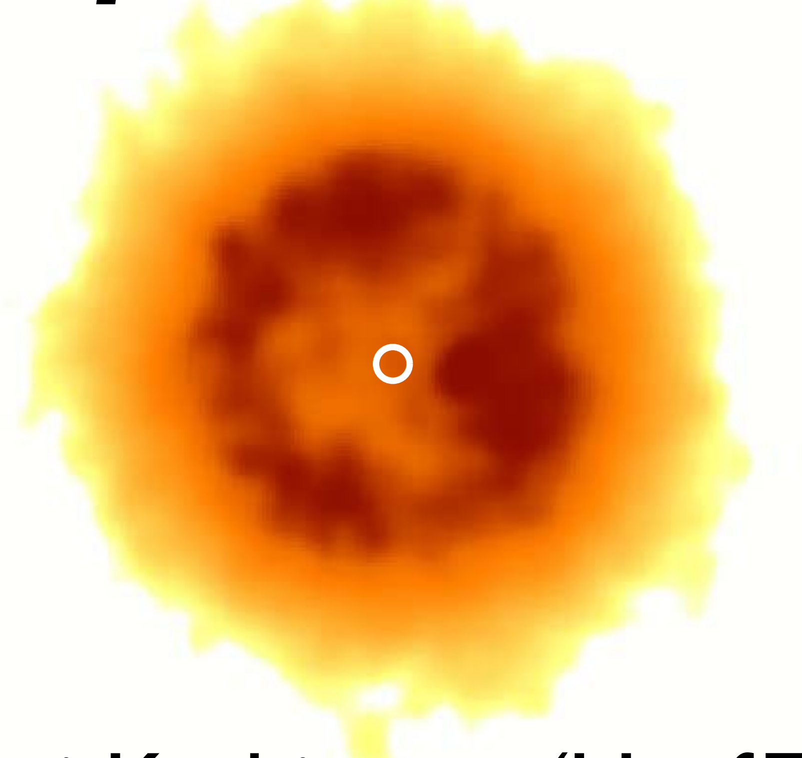
White dwarf merger remnants (and fast radio bursts)



Kazumi Kashiyama (U. of Tokyo)

arXiv:1907.12317

Type Ia supernova?

Highly magnetized massive white dwarf?

...

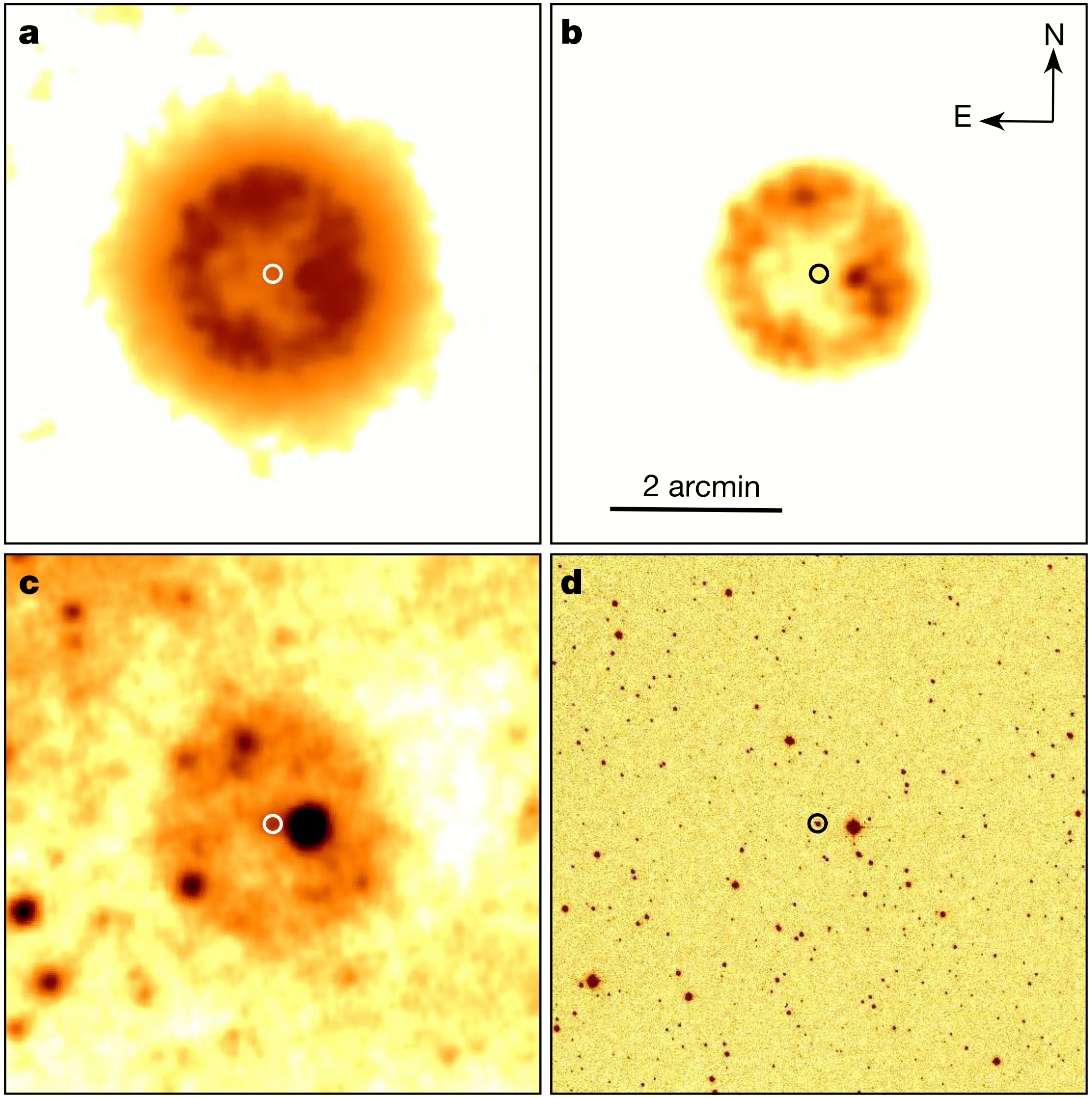
Collapse into neutron star?

GRB? FRB?

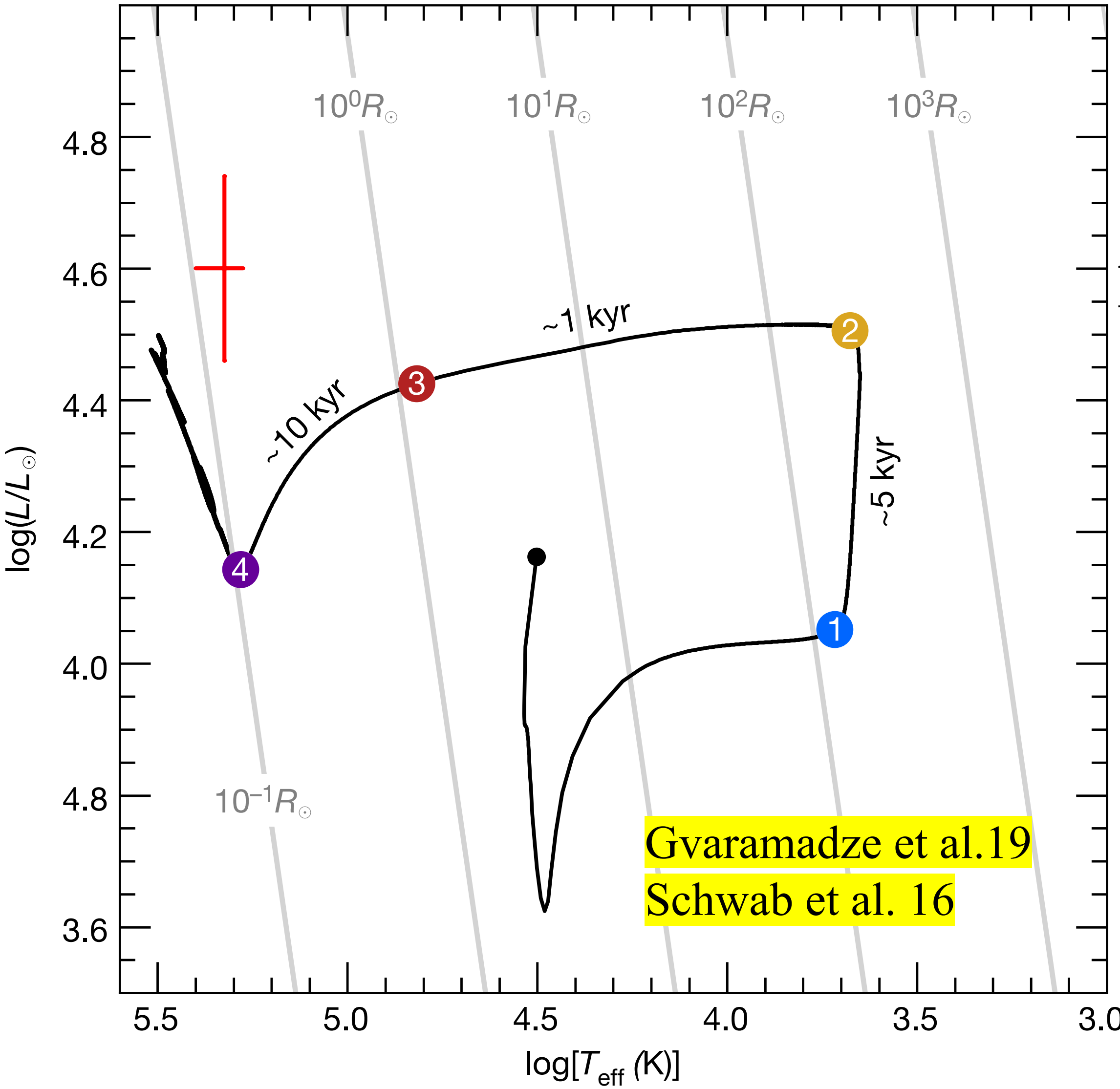
...

Gvaramadze et al.19

A pale blue dot in an infra nebula WS35 (= J005311)



The pale blue dot on the HR diagram



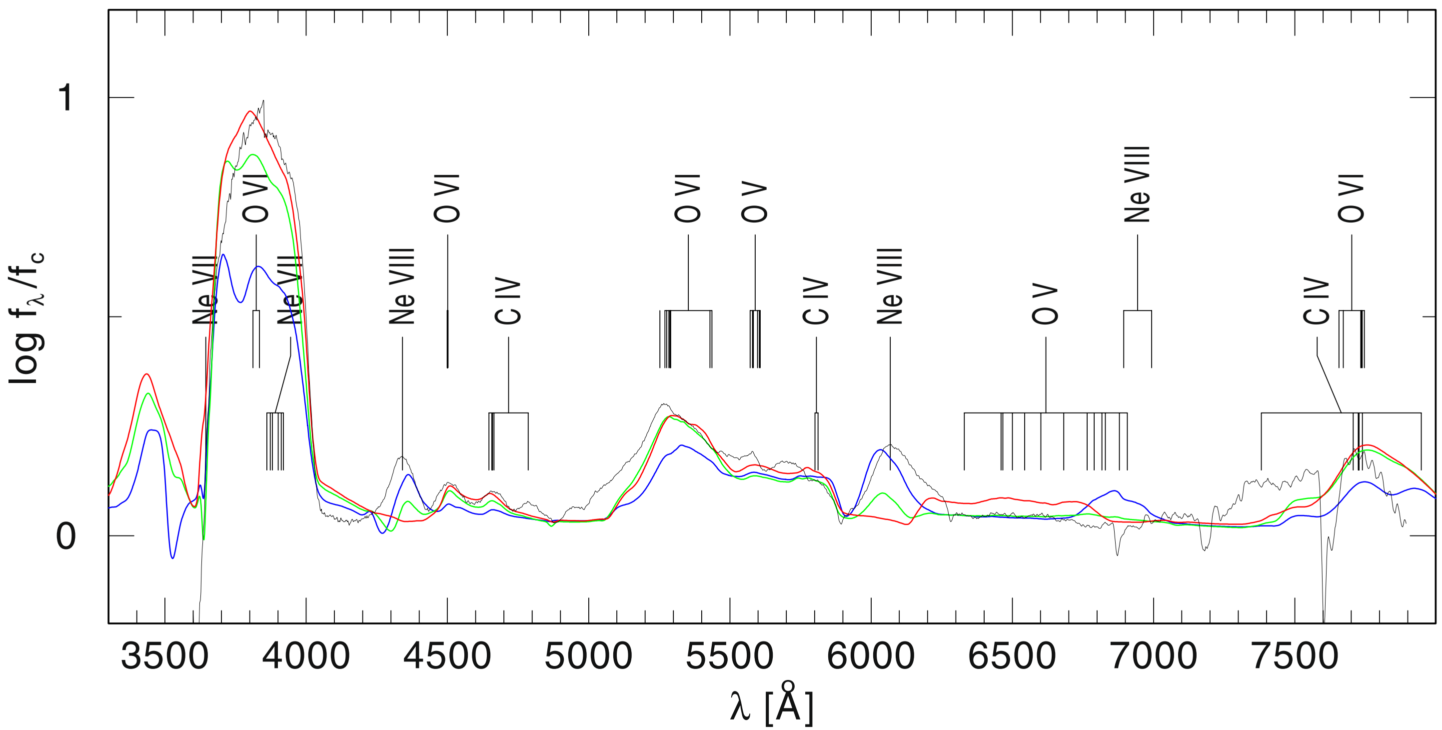
$$T_{\rm eff} = 211,000^{+40,000}_{-23,000}\,{\rm K}$$

$$\log(L_{\rm rad}/L_\odot) = 4.60 \pm 0.14$$

$$r_{\rm ph} = 0.15 \pm 0.04\,R_\odot$$

Ne enriched C/O dominated wind

Gvaramadze et al.19



$X_{\rm C} = 0.2 \pm 0.1$

$X_{\rm O} = 0.8 \pm 0.1$

$X_{\rm Ne} = 0.01$

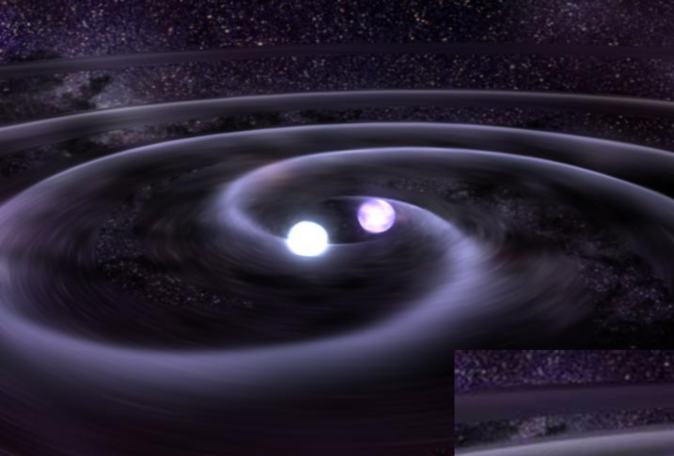
Line width & height ⇒

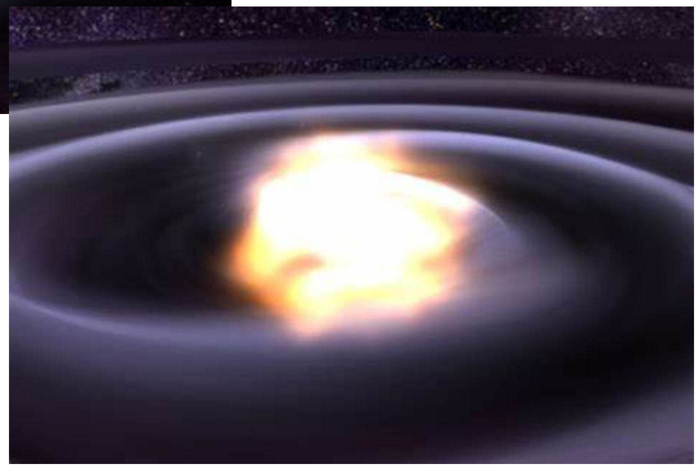
$$\dot{M} = (3.5 \pm 0.6) \times 10^{-6}\, M_\odot\, {\rm yr}^{-1}$$

$$v_\infty = 16,000 \pm 1,000\, {\rm km\, s}^{-1}$$!?

A white dwarf merger product with a super-Chandrasekhar mass

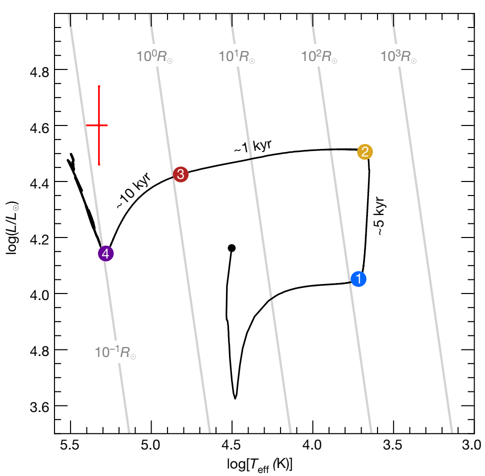
Gvaramadze et al.19

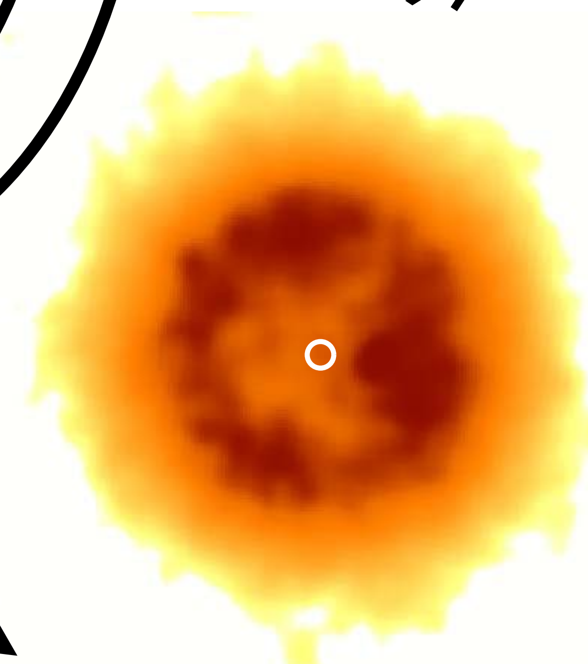




time

~10 kyr



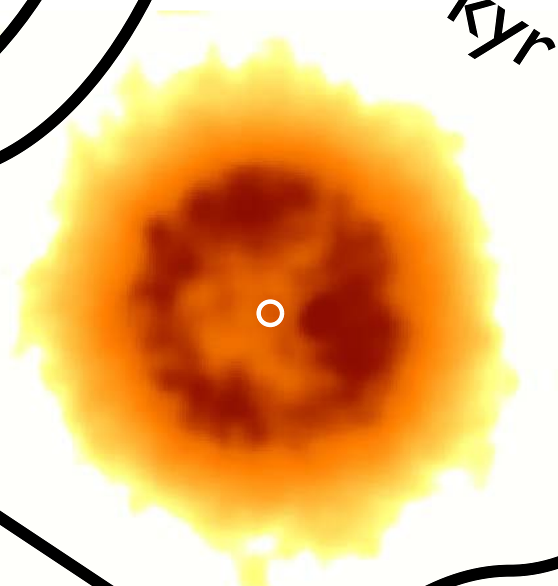


will finally collapse into a neutron star

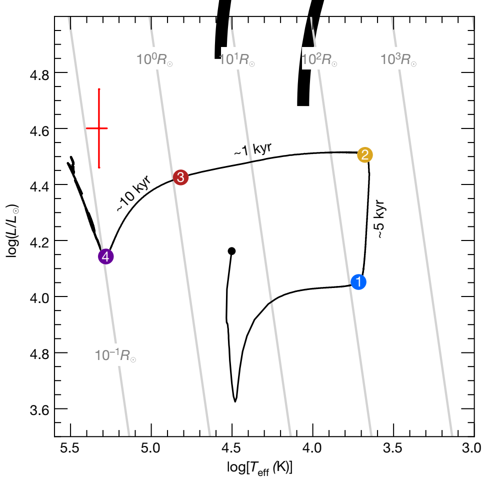
Gvaramadze et al.19

~10 kyr

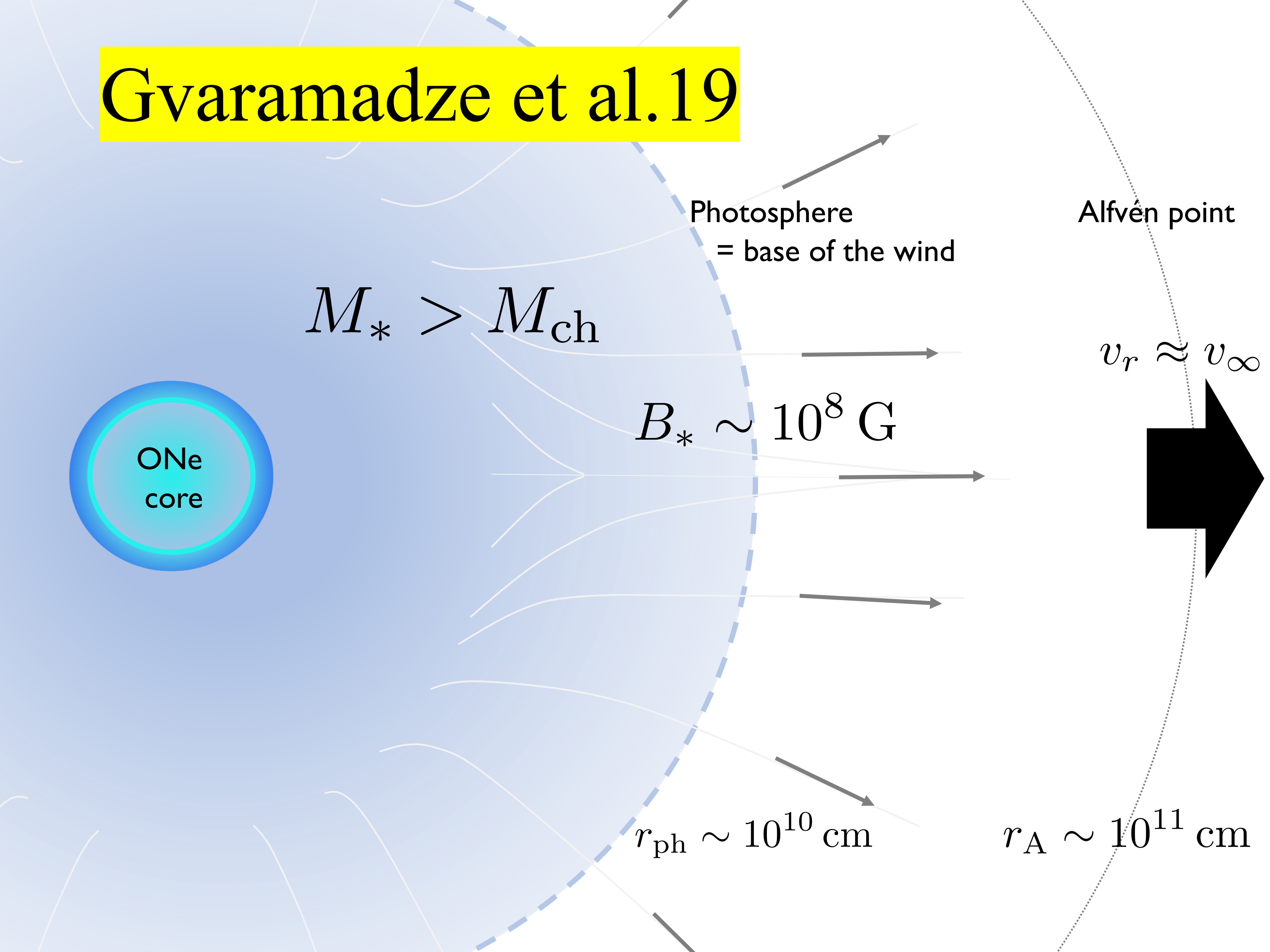
time



a few kyr



Gvaramadze et al.19



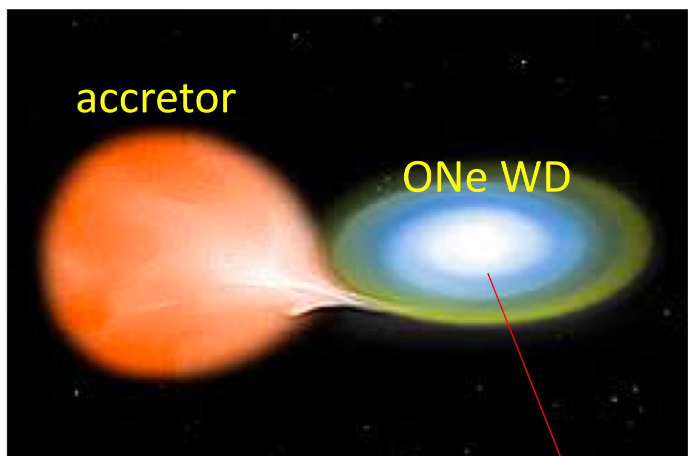
Our model

The launching mechanism

- $X_C = 0.2$, $X_O = 0.8$, $X_{Ne} = 0.1$
  (but $X_{Fe} = 1.6\times10^{-3}$ similar to the solar abundance)

≈

"Neon novae"



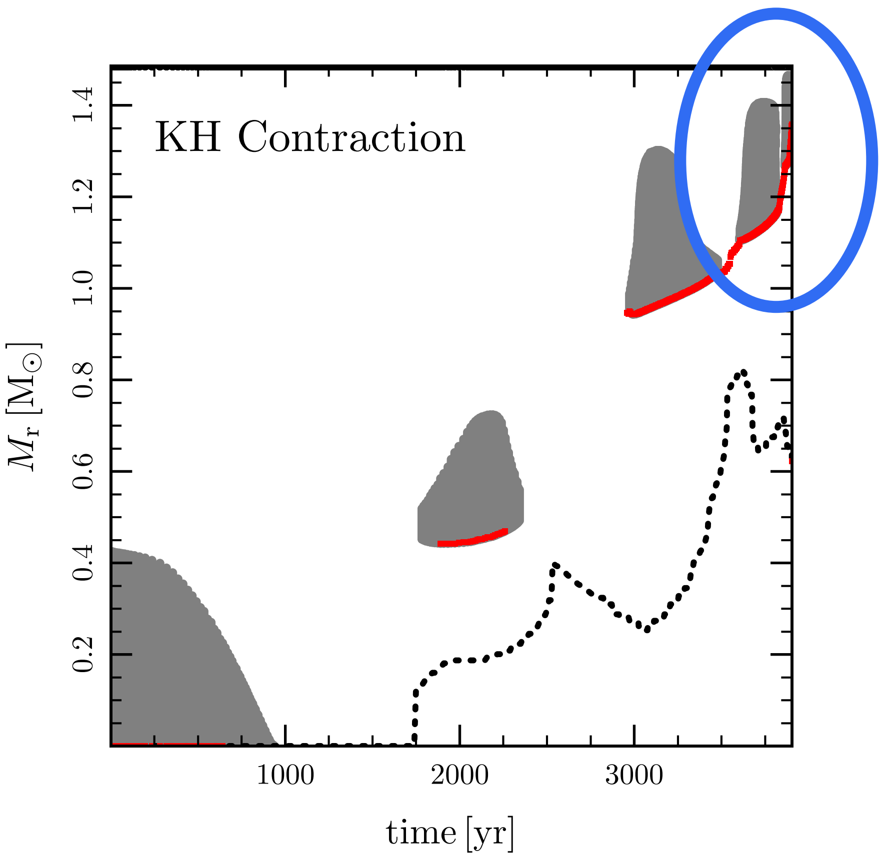
The ONe mantle is dredged up

e.g.,
Truran & Livio 86
Hachisu & Kato 16

The launching mechanism

- A similar situation can be realized on the surface of a carbon/oxygen white dwarf merger remnant

Schwab et al. 16



In the merged CO WD, C is ignited off-center and the C-burning flame propagates into the interior.

The flame reaches the center in ~ 10 kyr after the merger, neutrino cooling leads to the Kelvin-Helmholtz contraction of the ONe core and a series of off-center C flashes occur.

The timing is consistent with the nebula age of J005311!

OPTICALLY THICK WINDS IN NOVA OUTBURSTS

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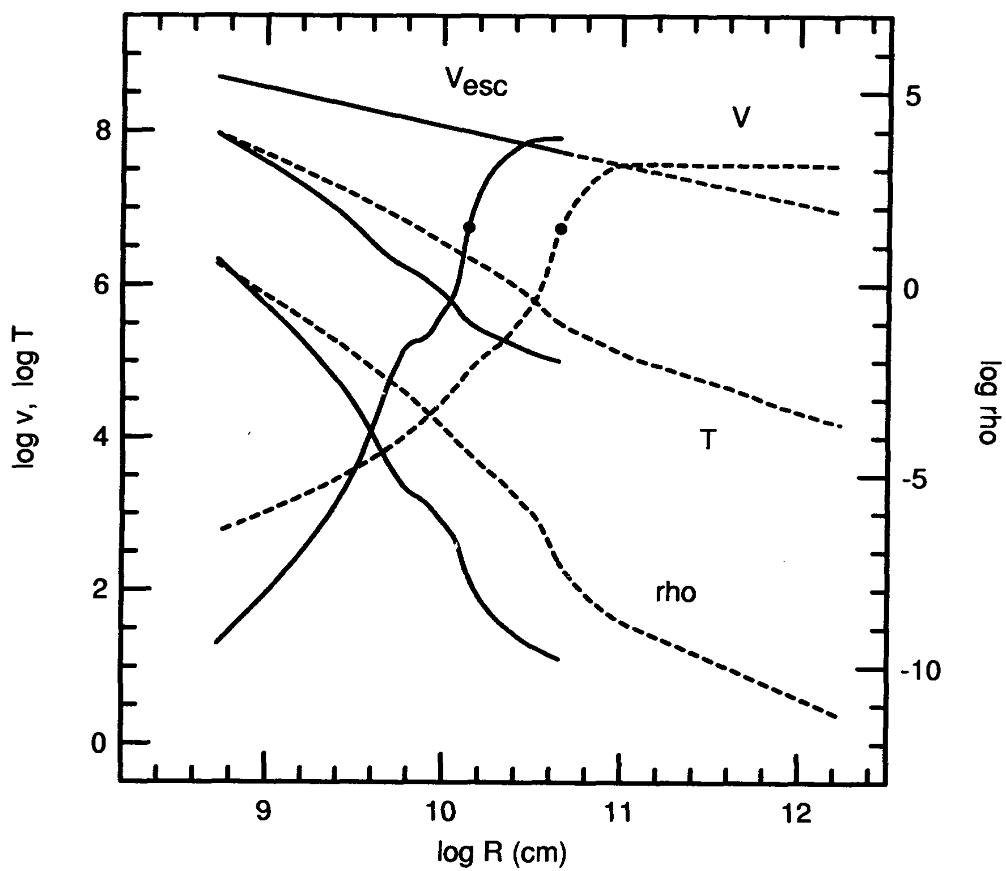
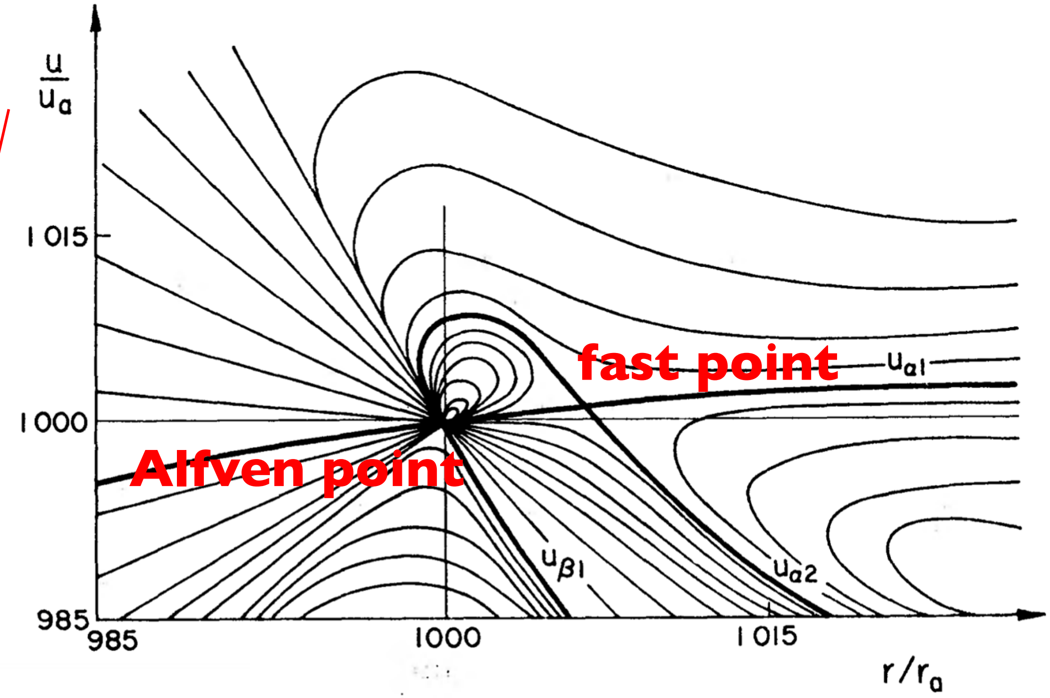
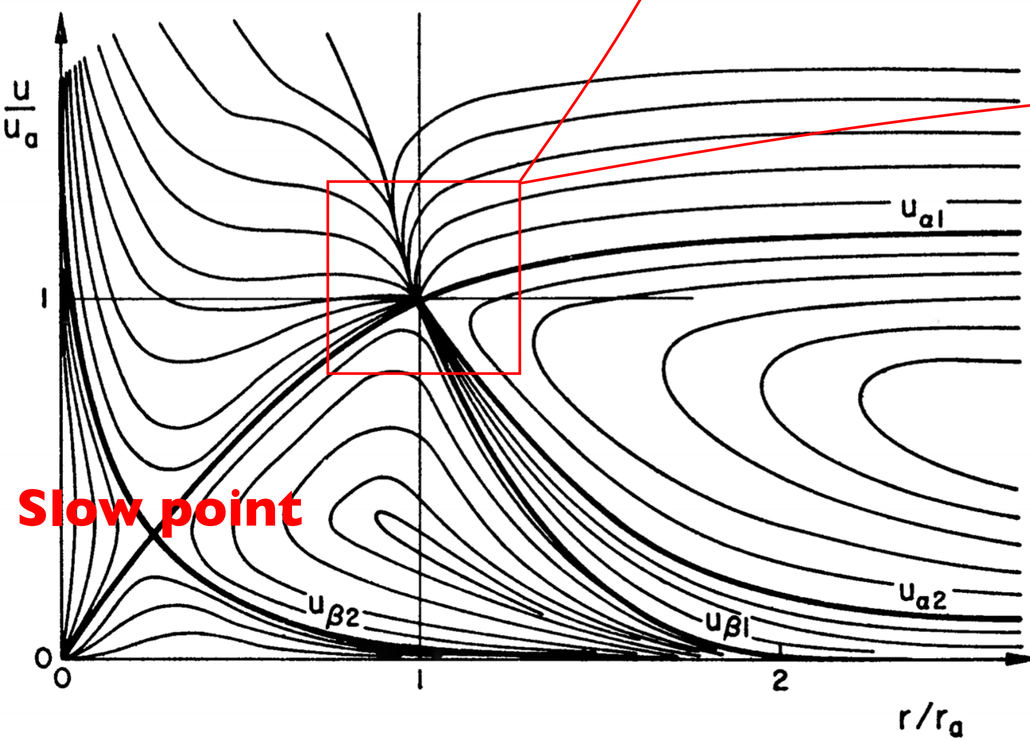
Received 1994 February 7; accepted 1994 June 28



Weber & Davis 67





The rotating magnetic wind in the equatorial plain

4 constraint equations

$$\mathcal{F}_B = r^2 B_r = const$$

$$\frac{B_\phi}{B_r} = \frac{v_\phi - r\Omega}{v_r}$$

$$\rho v_r r^2 = \frac{\dot{M}}{4\pi}$$

$$\mathcal{L} = r v_\phi - \left(\frac{r B_r B_\phi}{4\pi\rho v_r}\right) = const$$

3 evolution equations

$$v_r \frac{dv_r}{dr} + \frac{1}{\rho}\frac{dP_{\rm g}}{dr} - \frac{\kappa L_{\rm rad}}{4\pi r^2 c} + \frac{GM_*}{r^2} - \frac{{V_\phi}^2}{r} + \frac{B_\phi}{4\pi\rho r}\frac{d}{dr}(rB_\phi) = 0$$

$$v_r \frac{d\varepsilon_{\rm g}}{dr} + P_{\rm g} v_r \frac{d}{dr}\left(\frac{1}{\rho}\right) = -\frac{1}{4\pi r^2 \rho}\frac{dL_{\rm rad}}{dr}$$

$$\frac{dT}{dr} = -\frac{\kappa\rho L_{\rm rad}}{16\pi ac\lambda T^3 r^2}$$

3 evolution equations

$$\left(v_r^2 - \frac{k_\mathrm{B}T}{\mu m_\mathrm{u}} - \frac{A_\phi^2 v_r^2}{v_r^2 - A_r^2}\right)\frac{r}{v_r}\frac{dv_r}{dr} = \frac{\kappa L_\mathrm{rad}}{4\pi r c} + \frac{k_\mathrm{B}}{\mu m_\mathrm{u}}\left(\frac{dT}{d\log r} + 2T\right) - \frac{GM_*}{r} + v_\phi^2 + 2v_r v_\phi \frac{A_r A_\phi}{v_r^2 - A_r^2};$$

$$\text{with} \qquad A_r = \frac{B_r}{\sqrt{4\pi\rho}}, \quad A_\phi = \frac{B_\phi}{\sqrt{4\pi\rho}}$$

$$\frac{d\bar{\varepsilon}}{dr} = \frac{\kappa L_\mathrm{rad}}{4\pi r^2 c}$$

$$\text{with} \qquad \bar{\varepsilon} = \frac{L_\mathrm{rad}}{\dot{M}} + \frac{1}{2}({v_r}^2 + {v_\phi}^2) + \frac{5}{2}\frac{kT}{\mu m_u} - \frac{GM_*}{r} - r\Omega v_\phi + \mathcal{L}\Omega$$

$$\frac{dT}{dr} = -\frac{\kappa\rho L_\mathrm{rad}}{16\pi a c \lambda T^3 r^2}$$

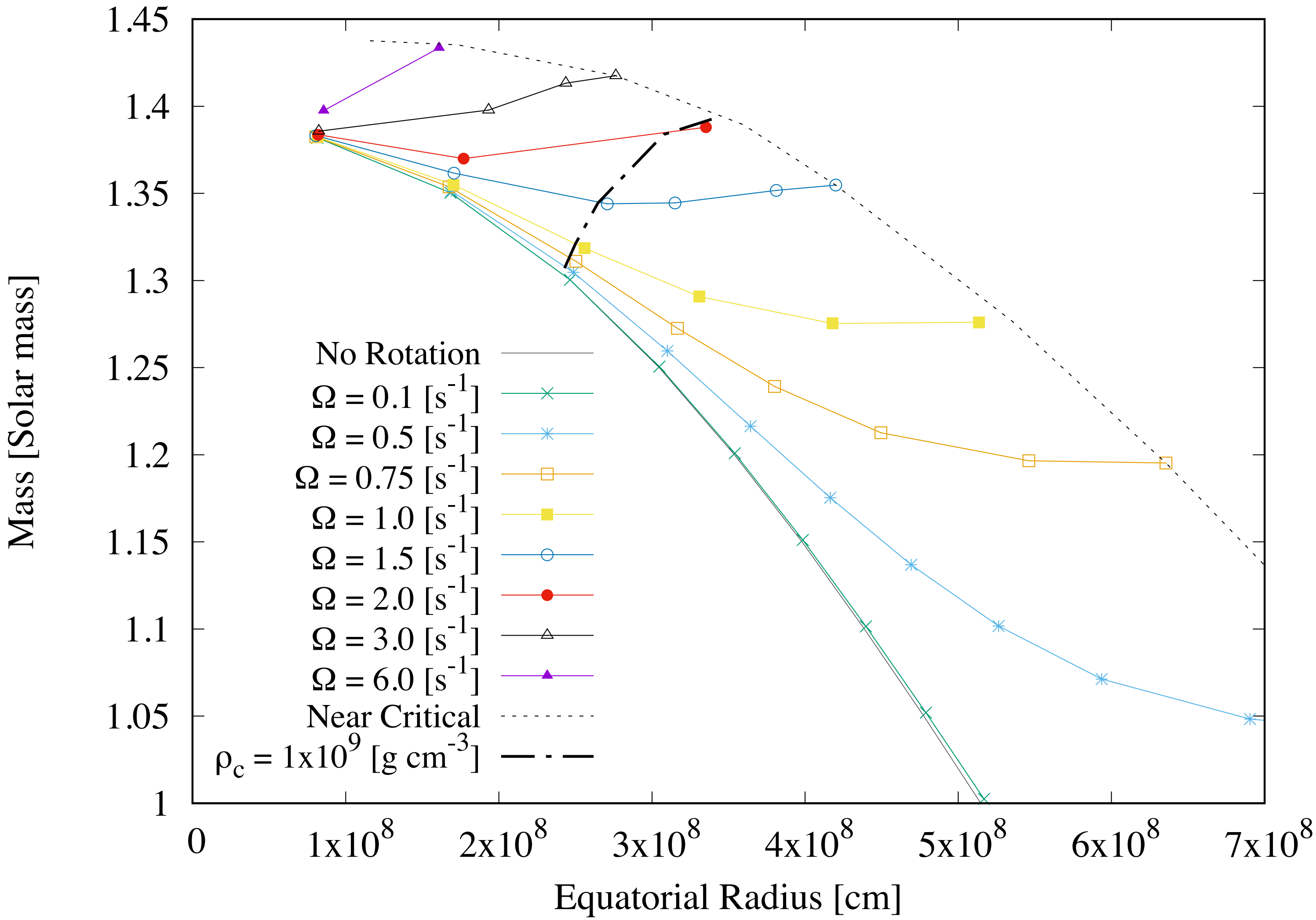
7 variables

$$(\rho, v_r, v_\phi, B_r, B_\phi, T, L_{\rm rad})$$

7 boundary conditions

- Go through the slow point
- Go through the fast point
- $\dot{M} \gtrsim \dot{M}_{\rm obs}$
- $v_r(\infty) \gtrsim v_{\infty,\rm obs}$
- $T(r_{\rm ph}) \sim T_{\rm eff,obs}$
- $L_{\rm rad}(r_{\rm ph}) \sim L_{\rm rad,obs}$
- $L_{\rm n}(R_*) \approx L_{\rm rad}(R_*)$
- The M_*-R_* relation of rotating ONe core

The M_*-R_* relation of uniformly rotating ONe core



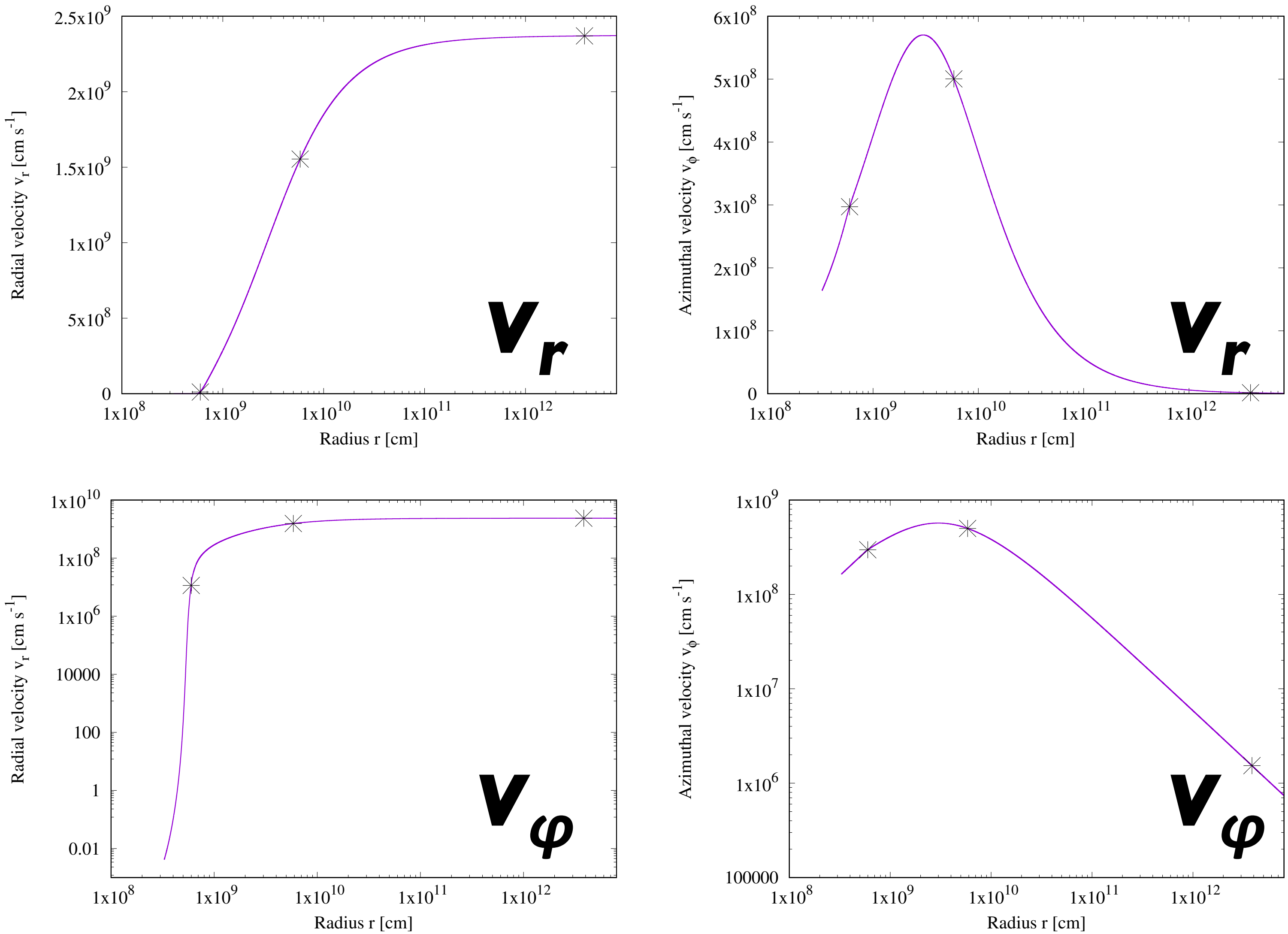
Fujisawa 15

Results

The WD J005311 wind : v_r & v_φ

Liner scale

Log scale

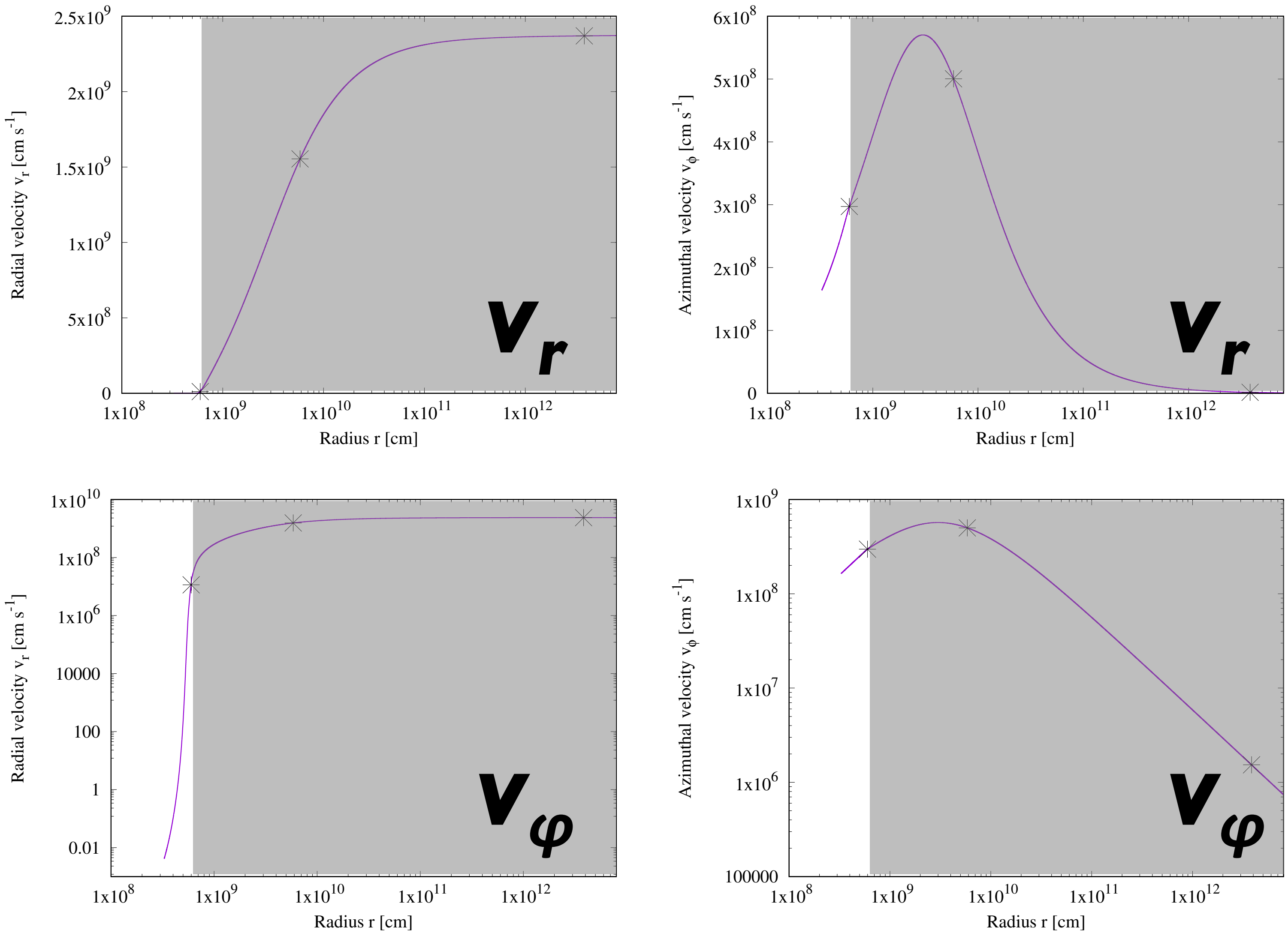


$$M_* = 1.25\,M_\odot,\ R_* = 3.3\times10^8\,\mathrm{cm},\ B_* = 4.2\times10^7\,G,\ \Omega = 0.5\,\mathrm{s}^{-1},\ \text{and}\quad \dot{M} = 6\times10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$$

The WD J005311 wind : v_r & v_φ

Liner scale

Log scale

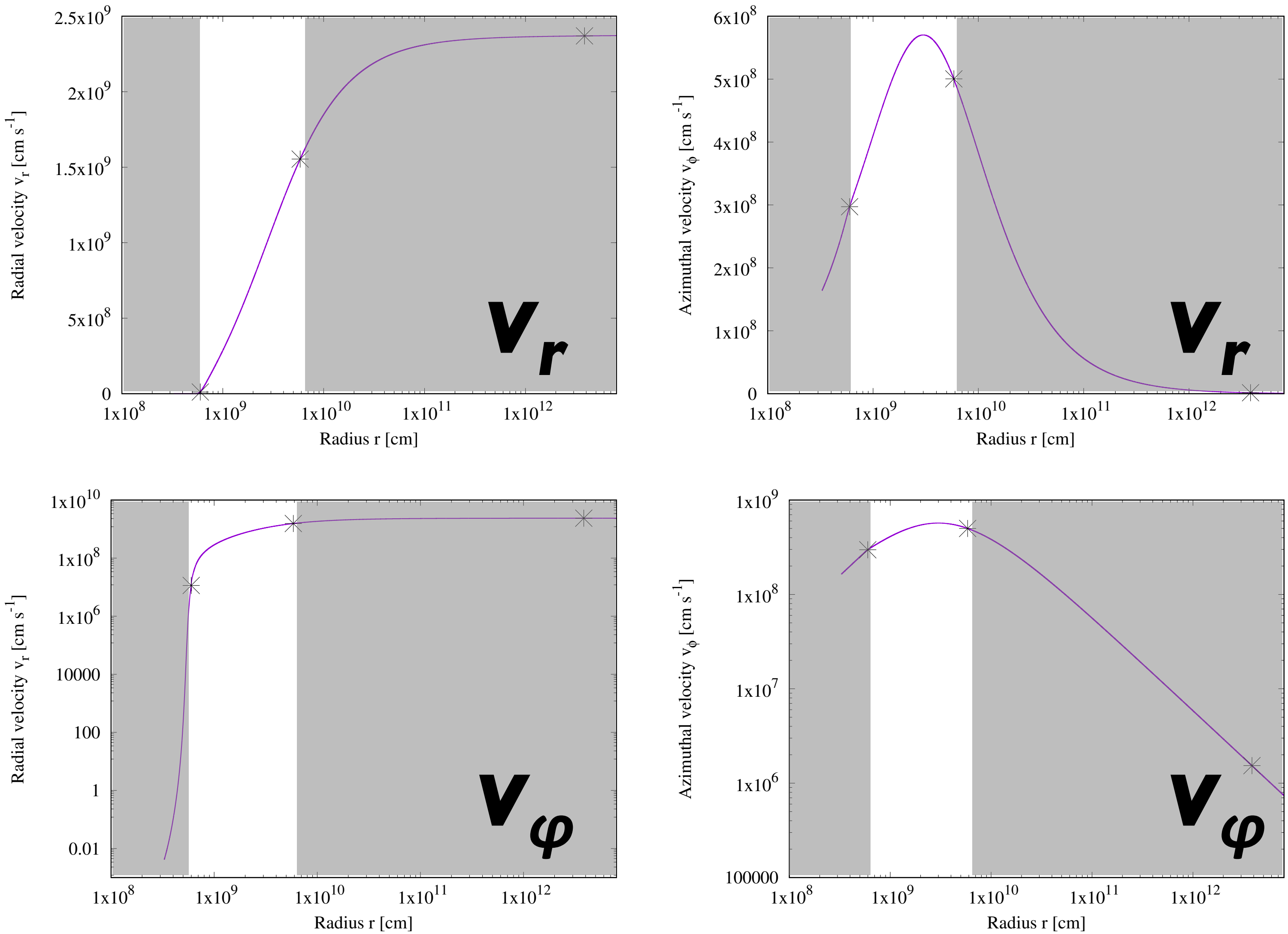


$$M_* = 1.25\,M_\odot,\ R_* = 3.3\times10^8\,\mathrm{cm},\ B_* = 4.2\times10^7\,G,\ \Omega = 0.5\,\mathrm{s}^{-1},\ \text{and}\quad \dot{M} = 6\times10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$$

The WD J005311 wind : v_r & v_φ

Liner scale

Log scale



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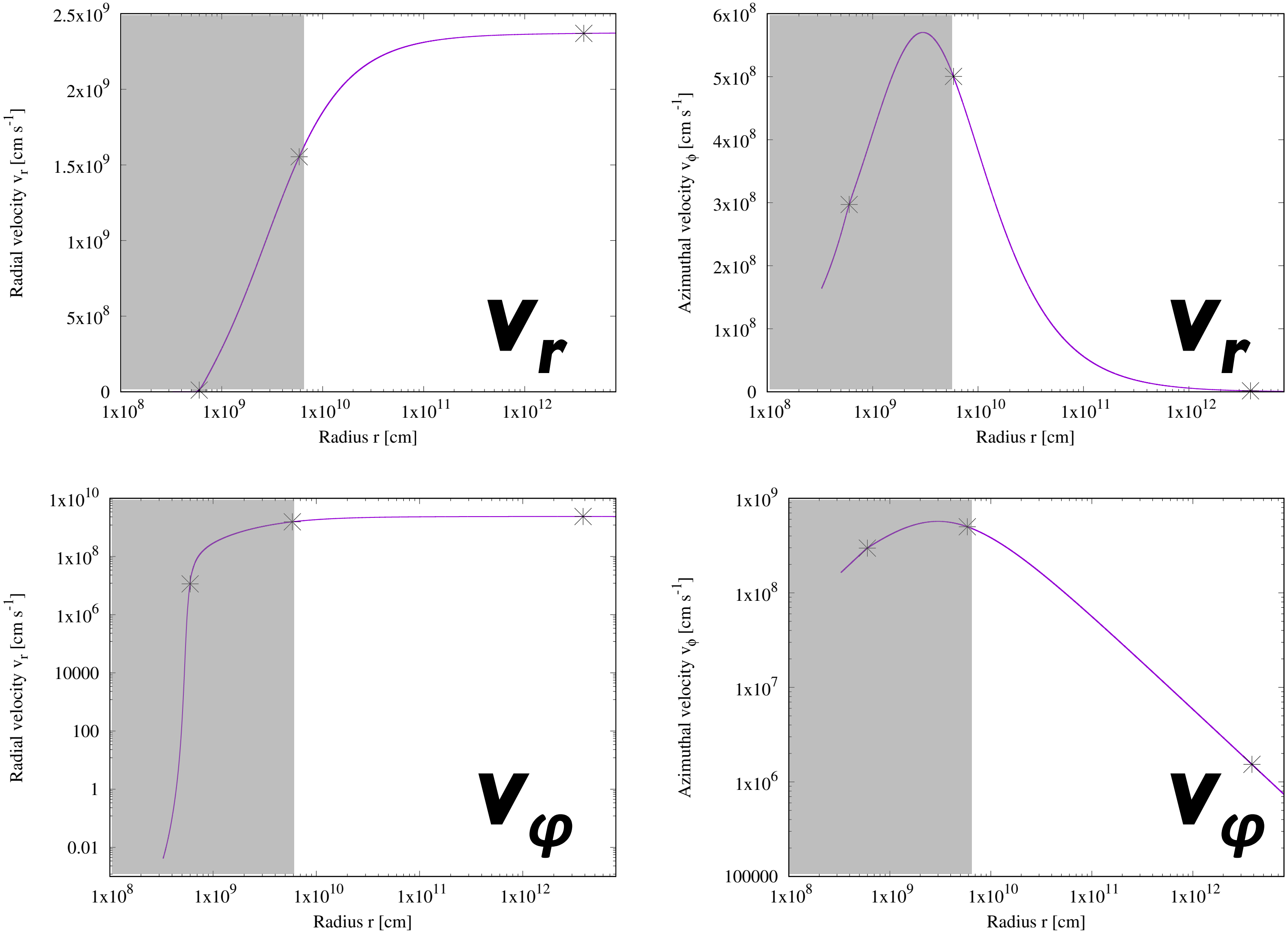
The WD J005311 wind : v_r & v_φ

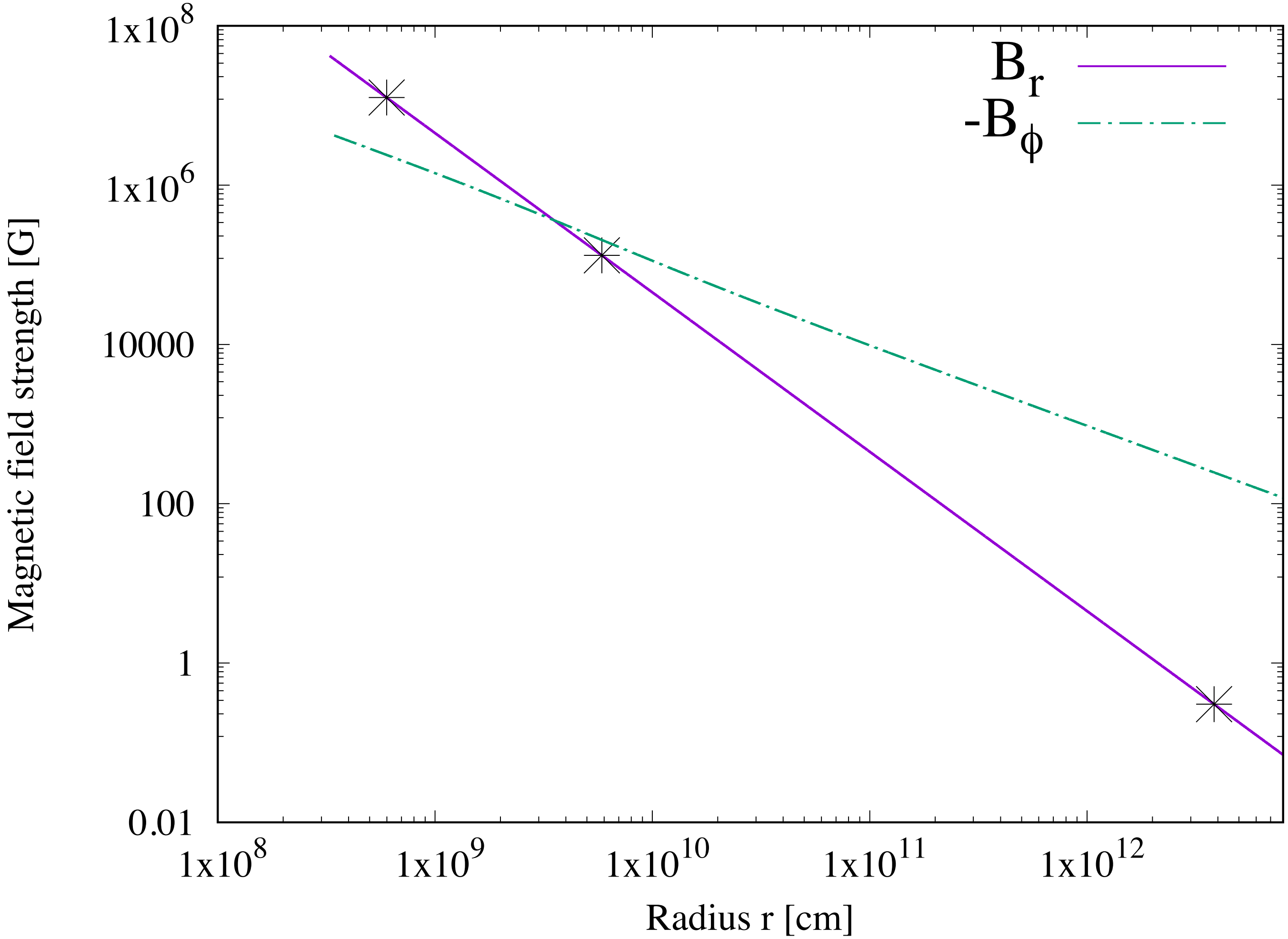
Liner scale

Log scale



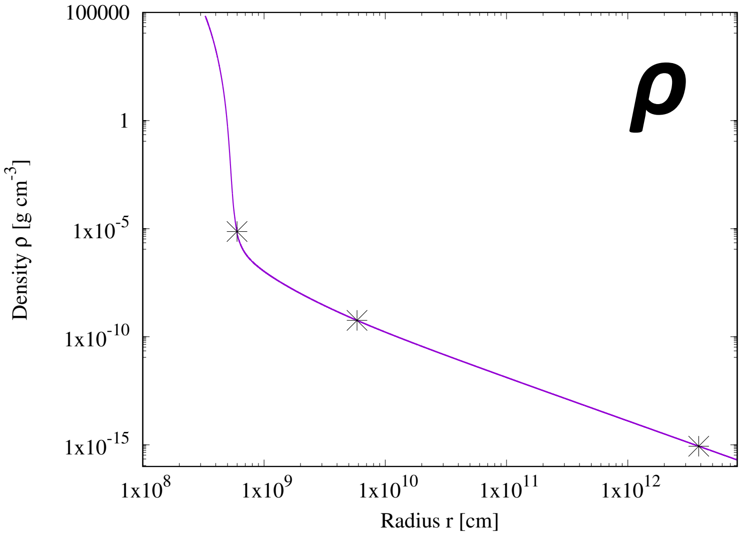
$M_* = 1.25\,M_\odot,\ R_* = 3.3\times10^8\,\mathrm{cm},\ B_* = 4.2\times10^7\,G,\ \Omega = 0.5\,\mathrm{s}^{-1}$, and $\dot{M} = 6\times10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$

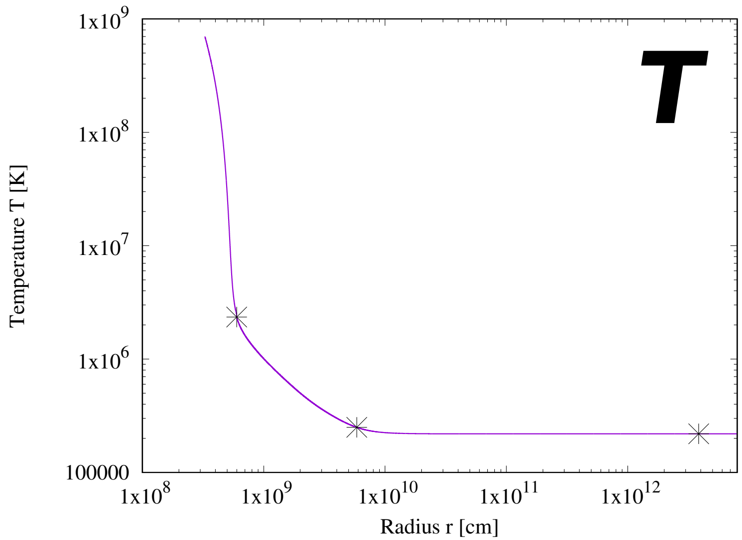
The WD J005311 wind : B_r & B_φ

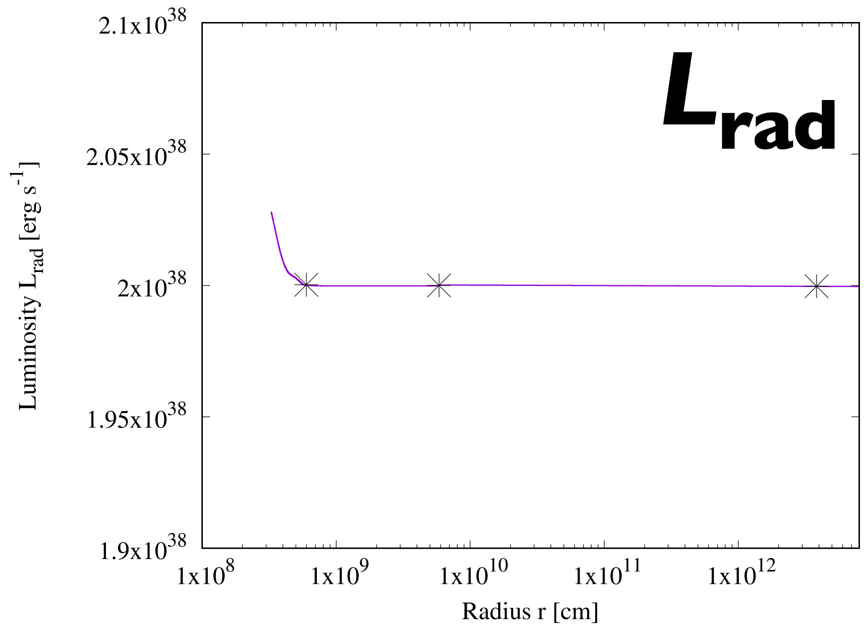


$M_* = 1.25\,M_\odot,\ R_* = 3.3\times10^8\,\mathrm{cm},\ B_* = 4.2\times10^7\,G,\ \Omega = 0.5\,\mathrm{s}^{-1}$, and $\dot{M} = 6\times10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$

The WD J005311 wind : ρ, T, L_{rad}







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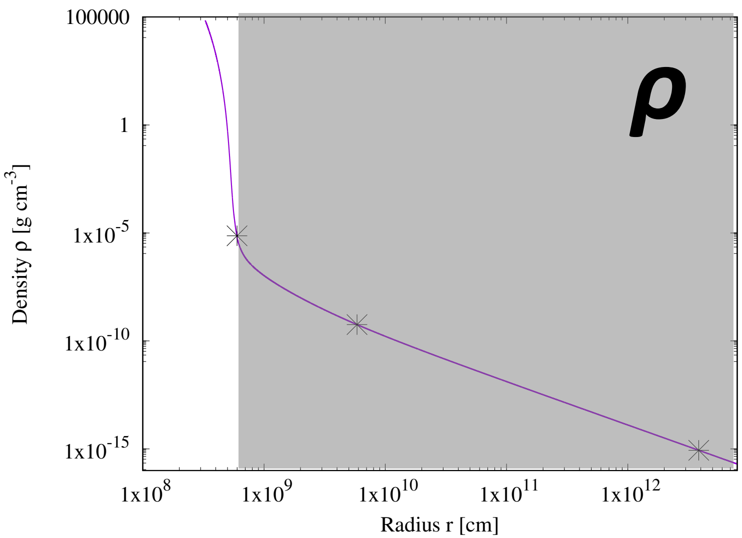
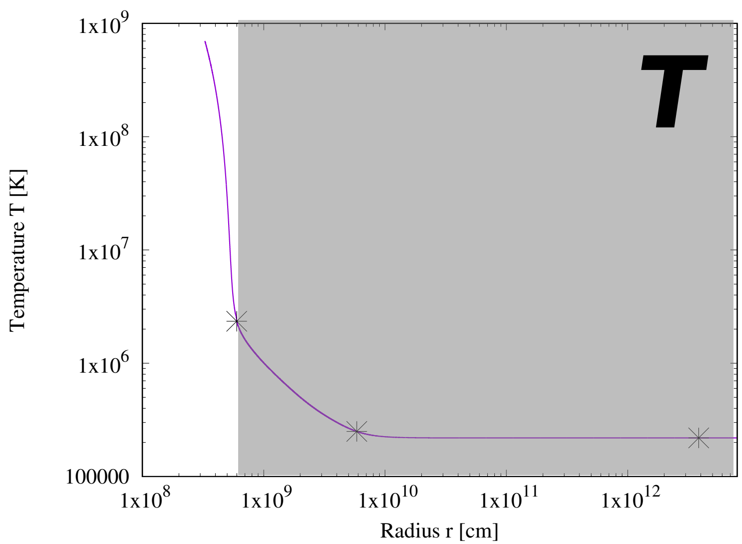
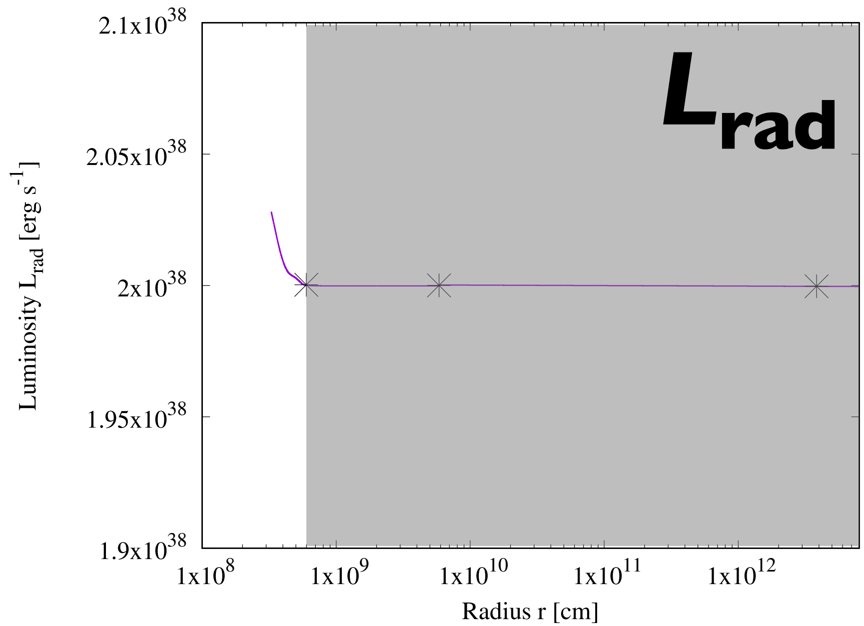
The WD J005311 wind : ρ, T, L_{rad}







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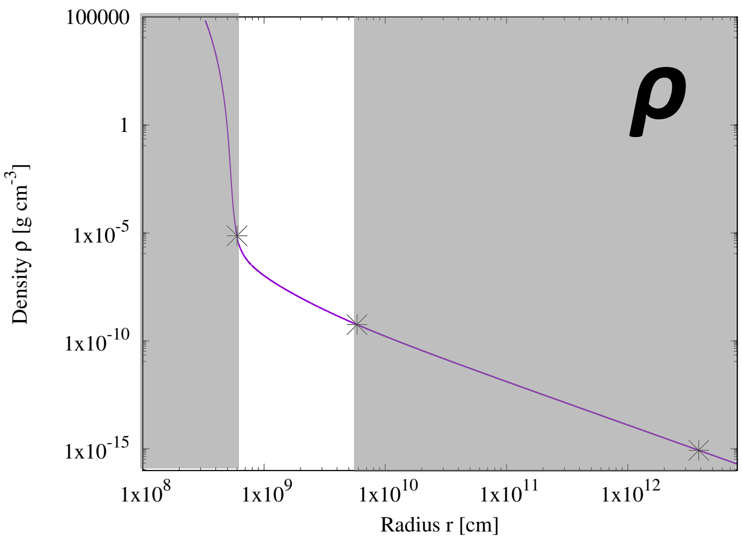
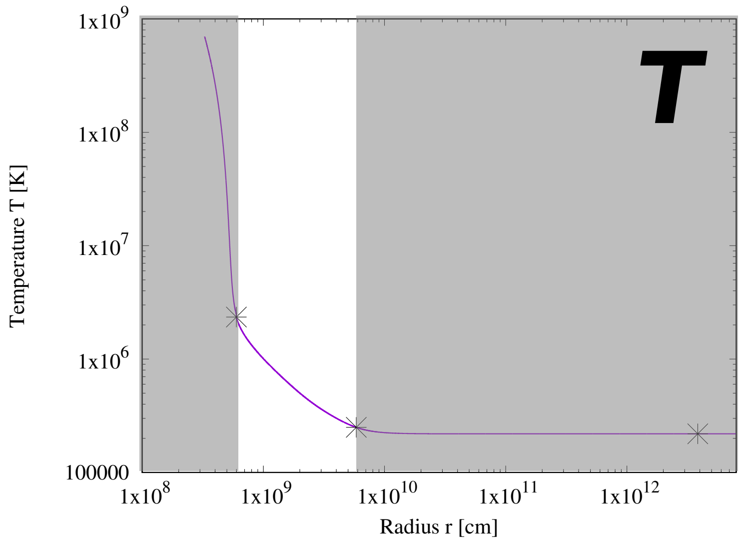
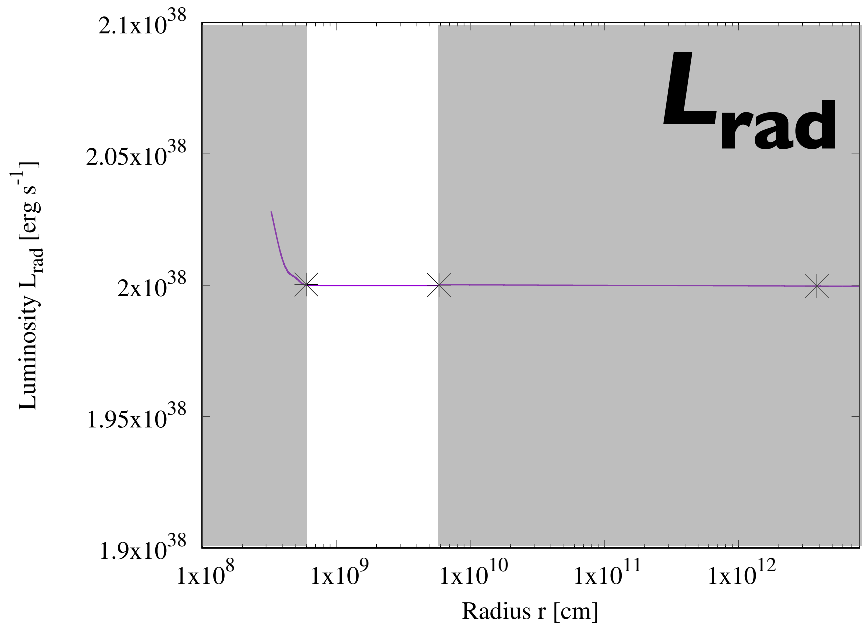
The WD J005311 wind : ρ, T, L_{rad}







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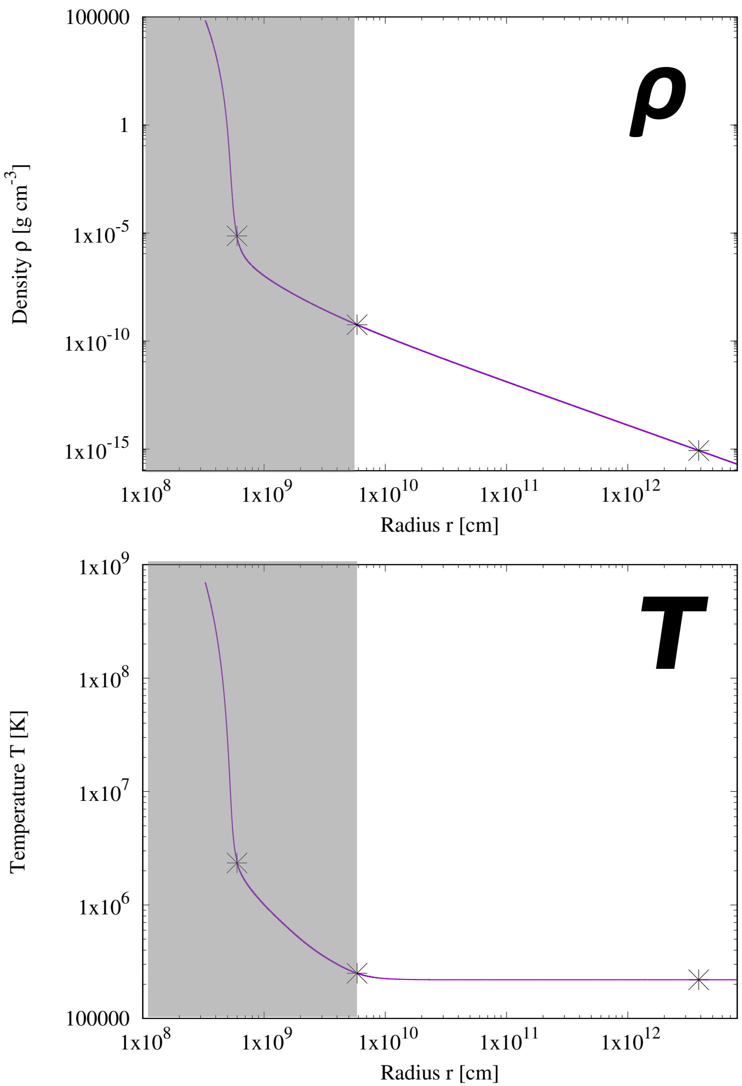
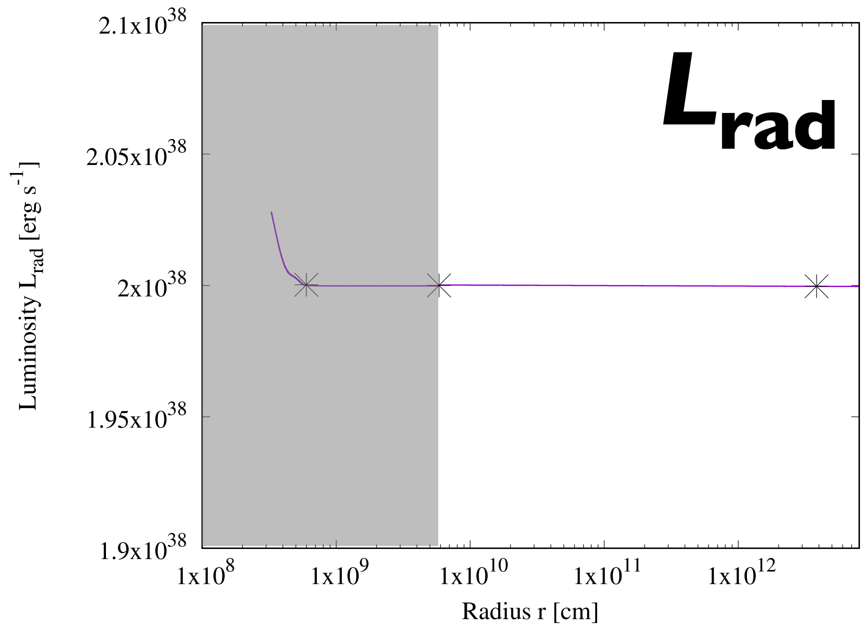
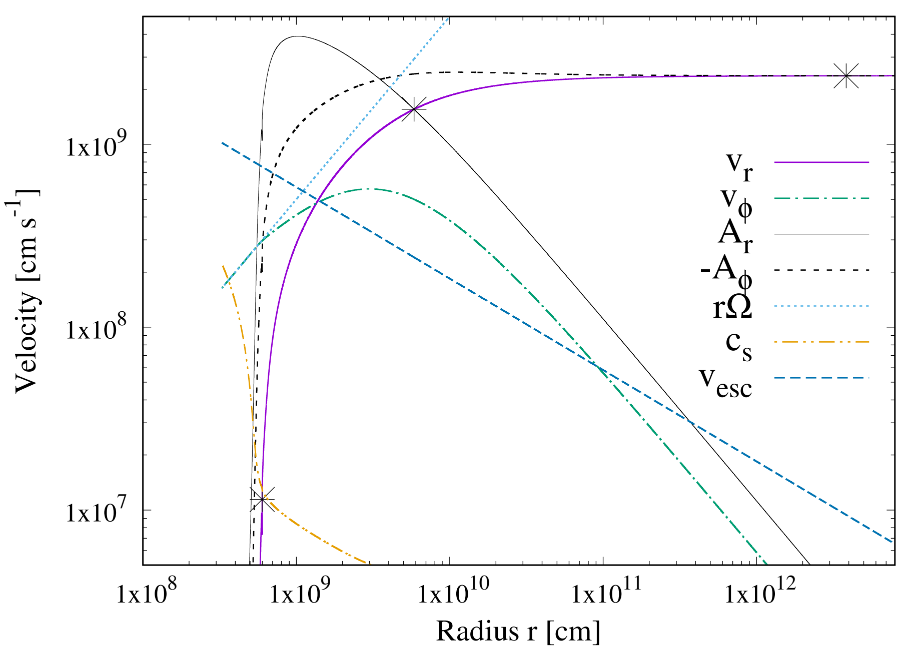
The WD J005311 wind : ρ, T, L_{rad}

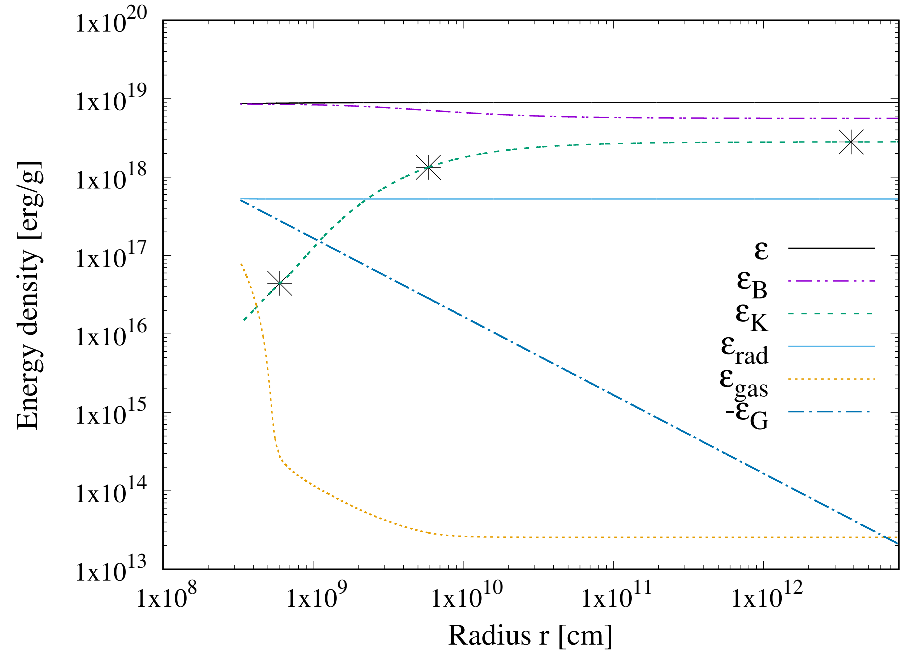




$M_* = 1.25\,M_\odot,\ R_* = 3.3\times10^8\,\mathrm{cm},\ B_* = 4.2\times10^7\,G,\ \Omega = 0.5\,\mathrm{s}^{-1}$, and $\dot{M} = 6\times10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$

The WD J005311 wind : How is it accelerated?





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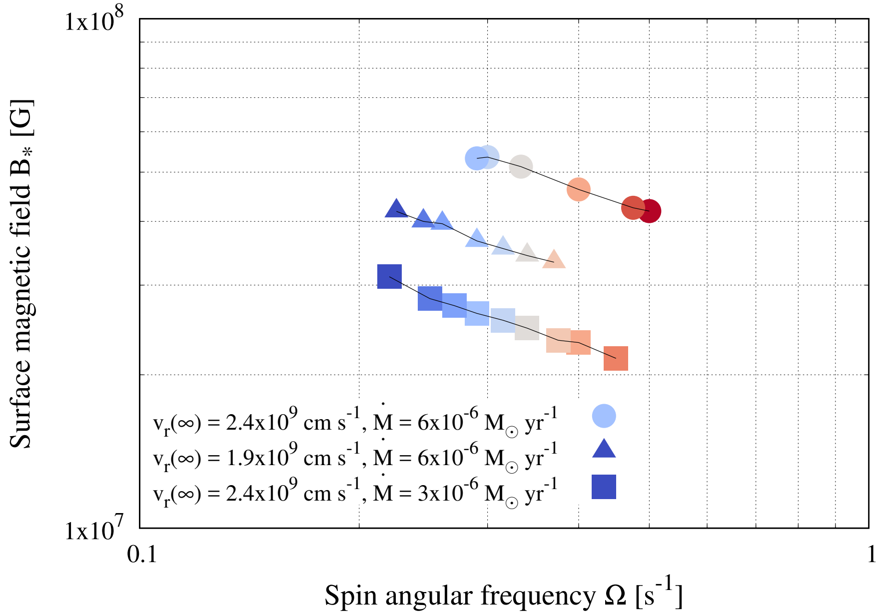
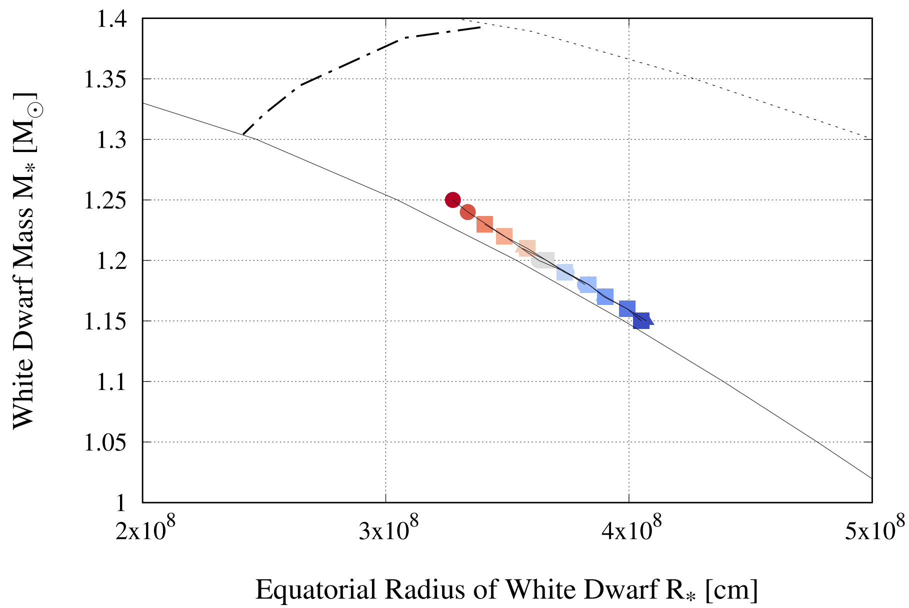
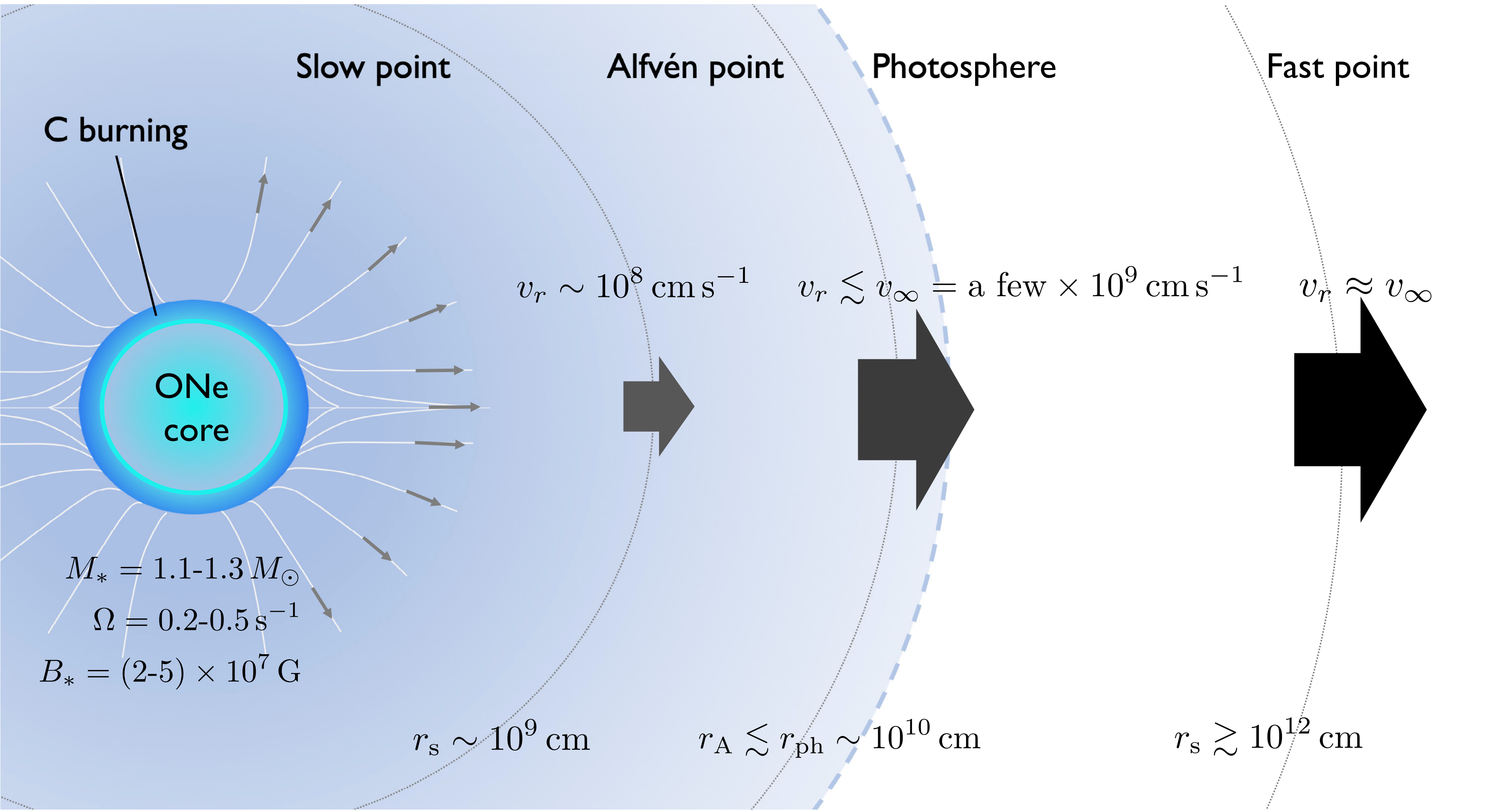
The WD J005311 wind : Allowed parameter region





The observed properties of WD J005311 can be explained by the rotating magnetic wind from an ONe WD with $M_* = 1.1\text{-}1.3\ M_\odot$, $B_* = (2\text{-}5) \times 10^7$ G, and $\Omega = 0.2\text{-}0.5 \mathrm{s}^{-1}$.

Kashiyama, Fujisawa, Shigeyama 19



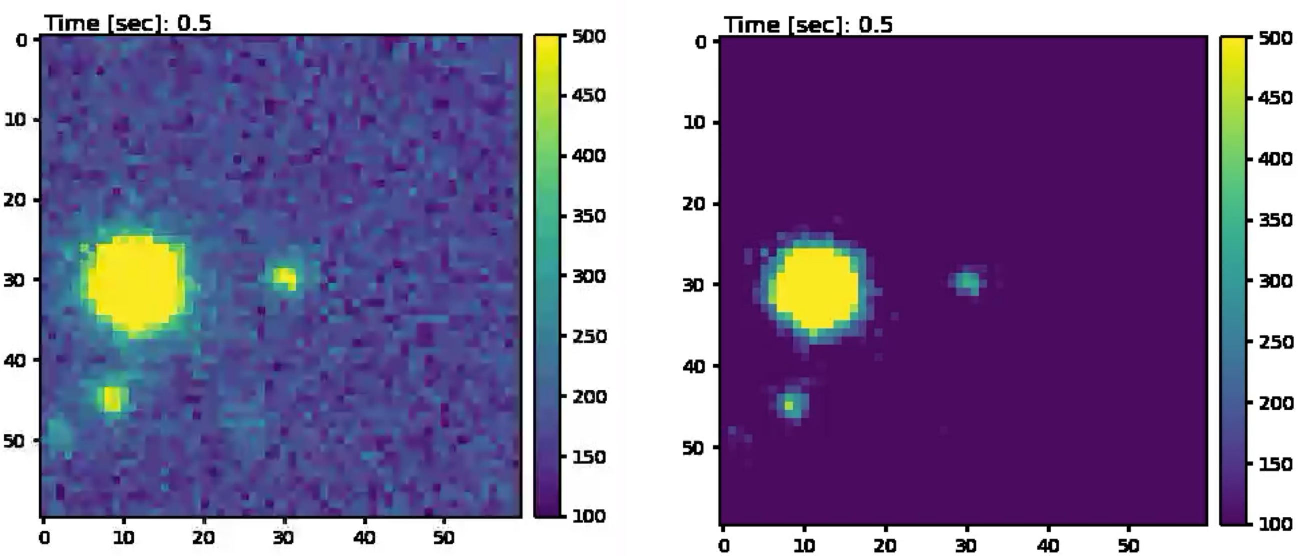
arXiv:1907.12317

Discussion

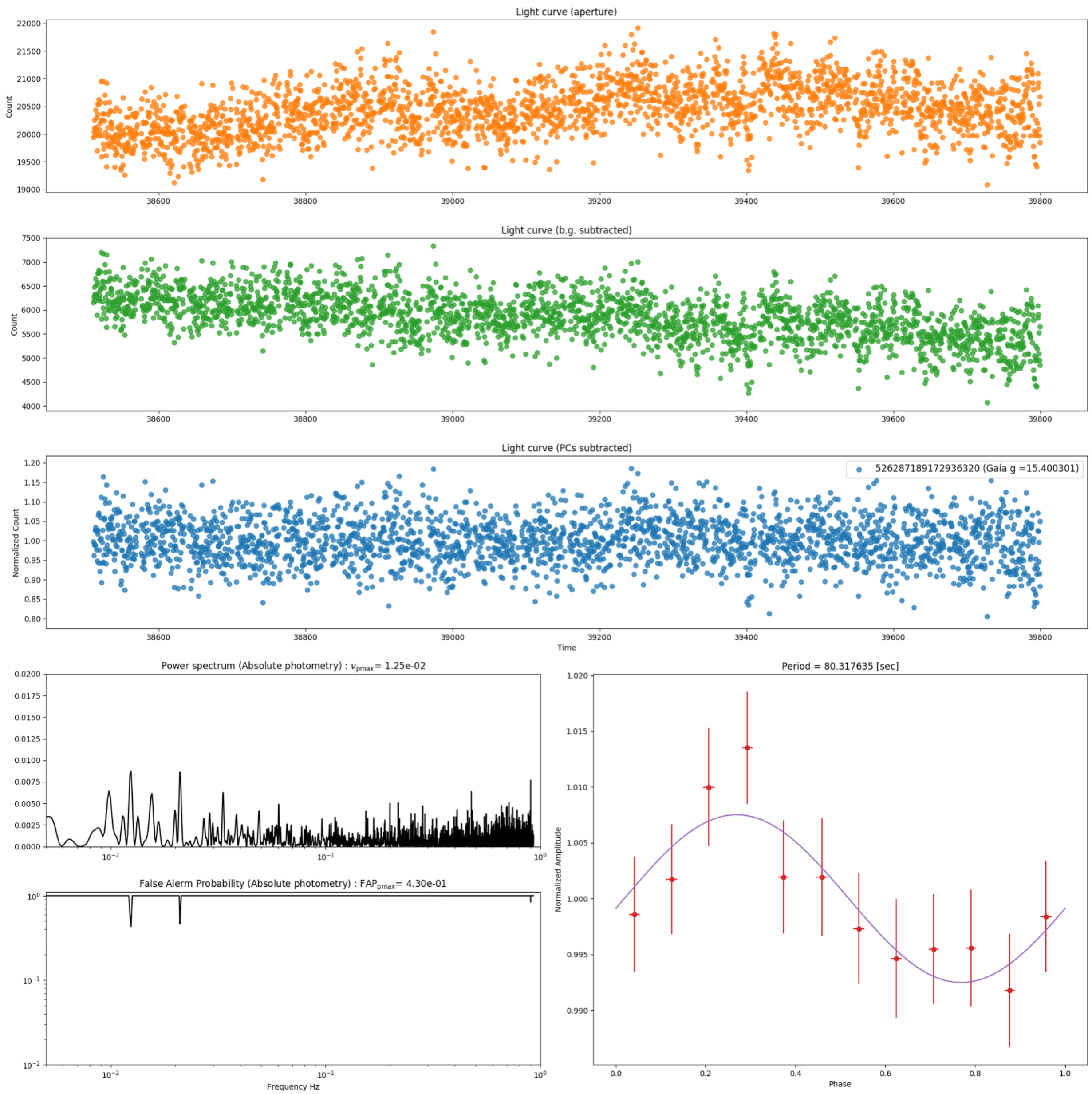
- WD J005311 will neither explode as type Ia supernova nor collapse into neutron star.
- If the wind continues to blow another a few kyr, WD J005311 will spin down significantly and join to the known sequence of slowly-rotating magnetic WDs.
- Otherwise it may appear as a fast-spinning magnetic WD and could be a new high energy source.
- The photosphere spins with a period of ~min.

J005311 with Tomo-e

トモエゴゼン



Timing analysis of J005311



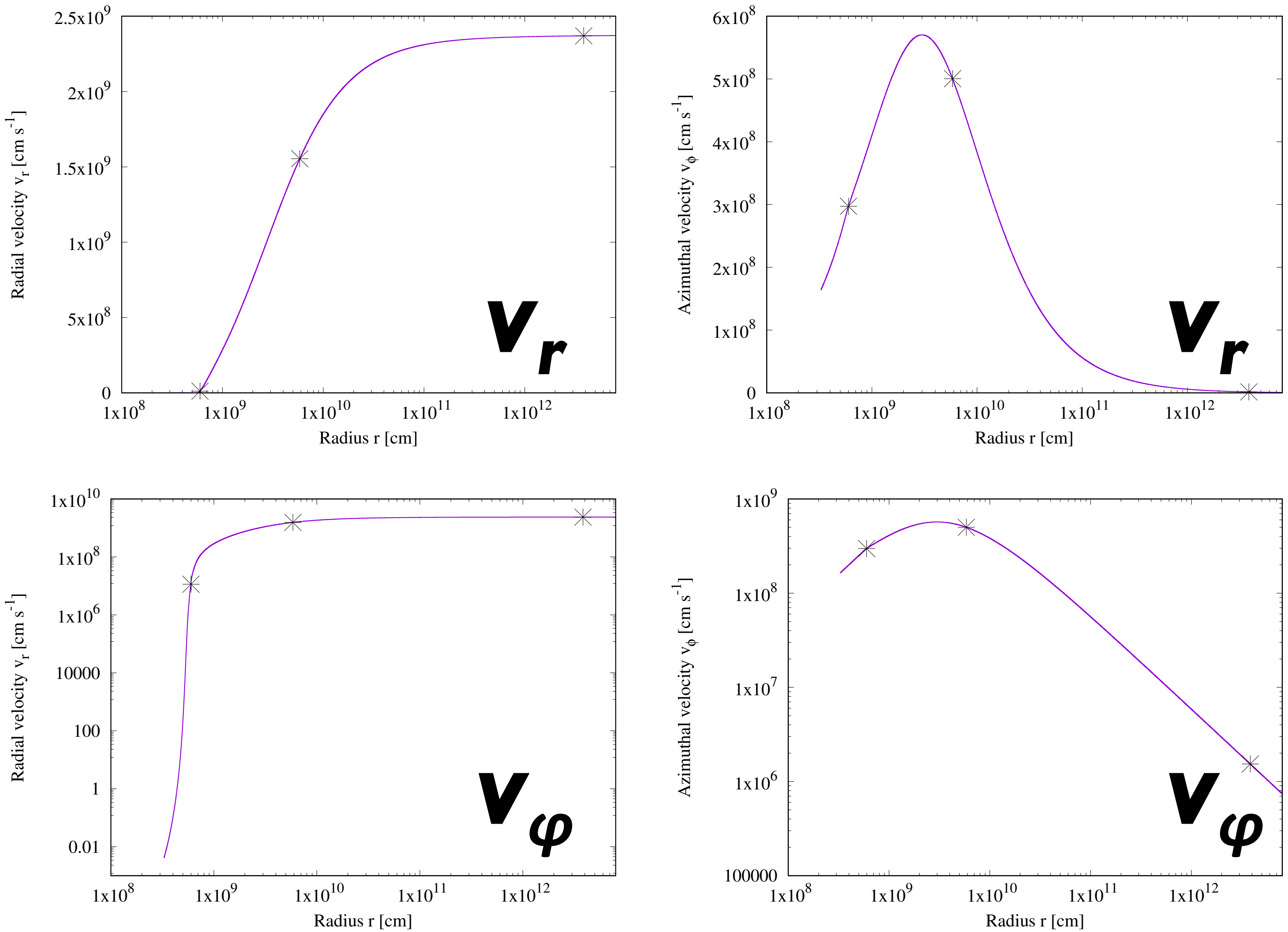
Appendix

Results

The WD J005311 wind : v_r & v_φ

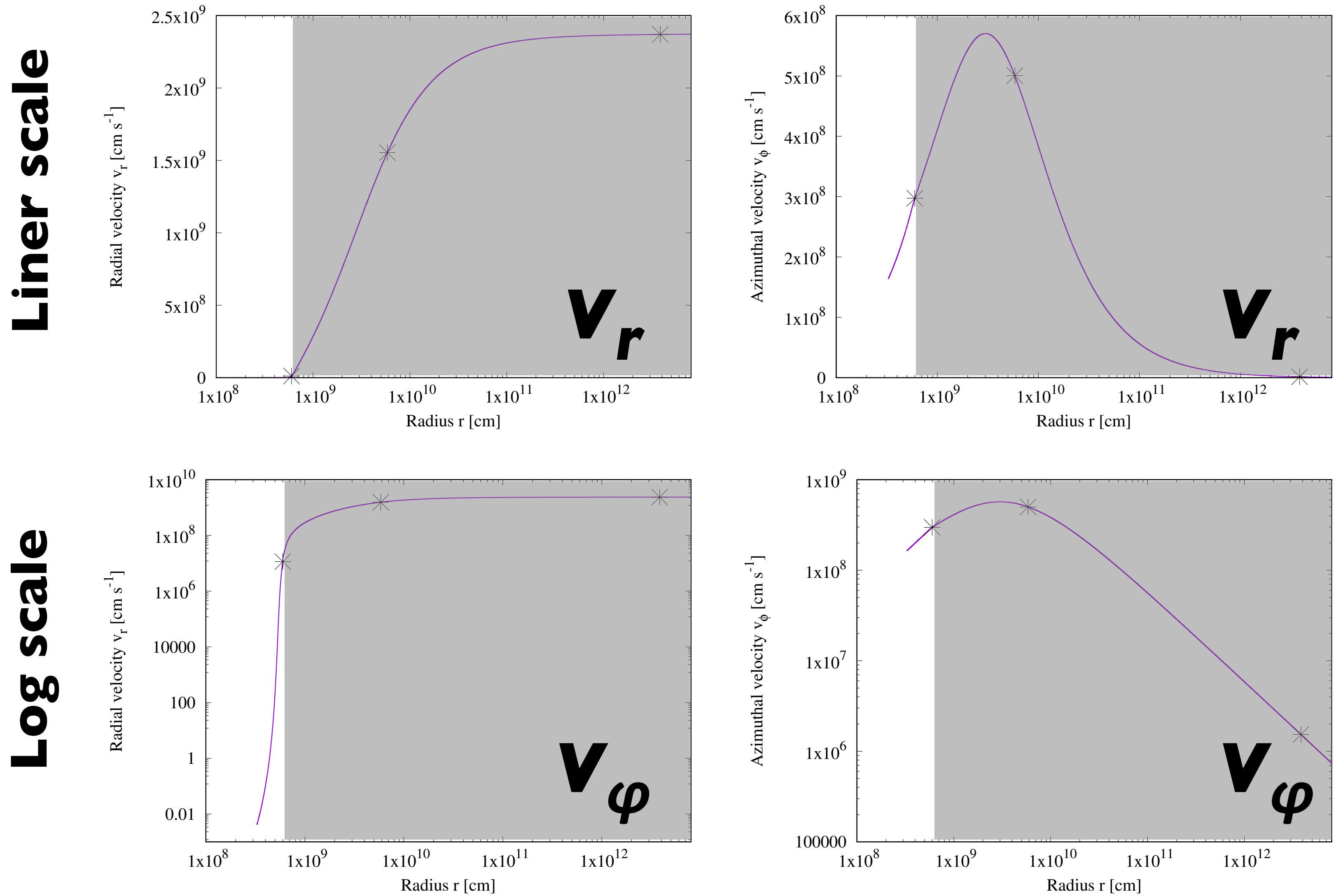
Liner scale

Log scale



$$M_* = 1.25\, M_\odot,\ R_* = 3.3\times 10^8\,\mathrm{cm},\ B_* = 4.2\times 10^7\, G,\ \Omega = 0.5\,\mathrm{s}^{-1},\ \text{and}\quad \dot{M} = 6\times 10^{-6}\, M_\odot\,\mathrm{yr}^{-1}$$

The WD J005311 wind : v_r & v_φ



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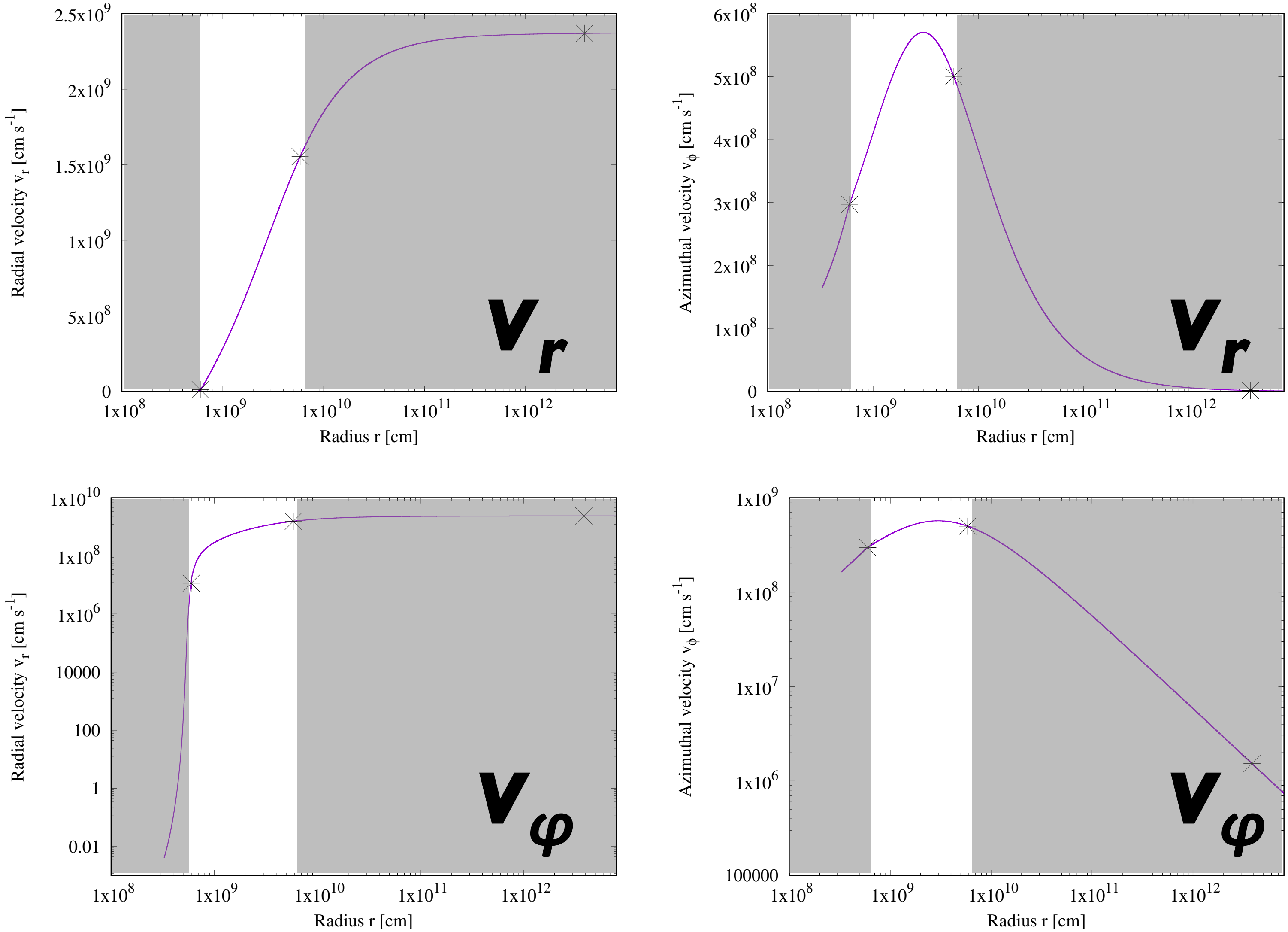
The WD J005311 wind : v_r & v_φ

Liner scale

Log scale



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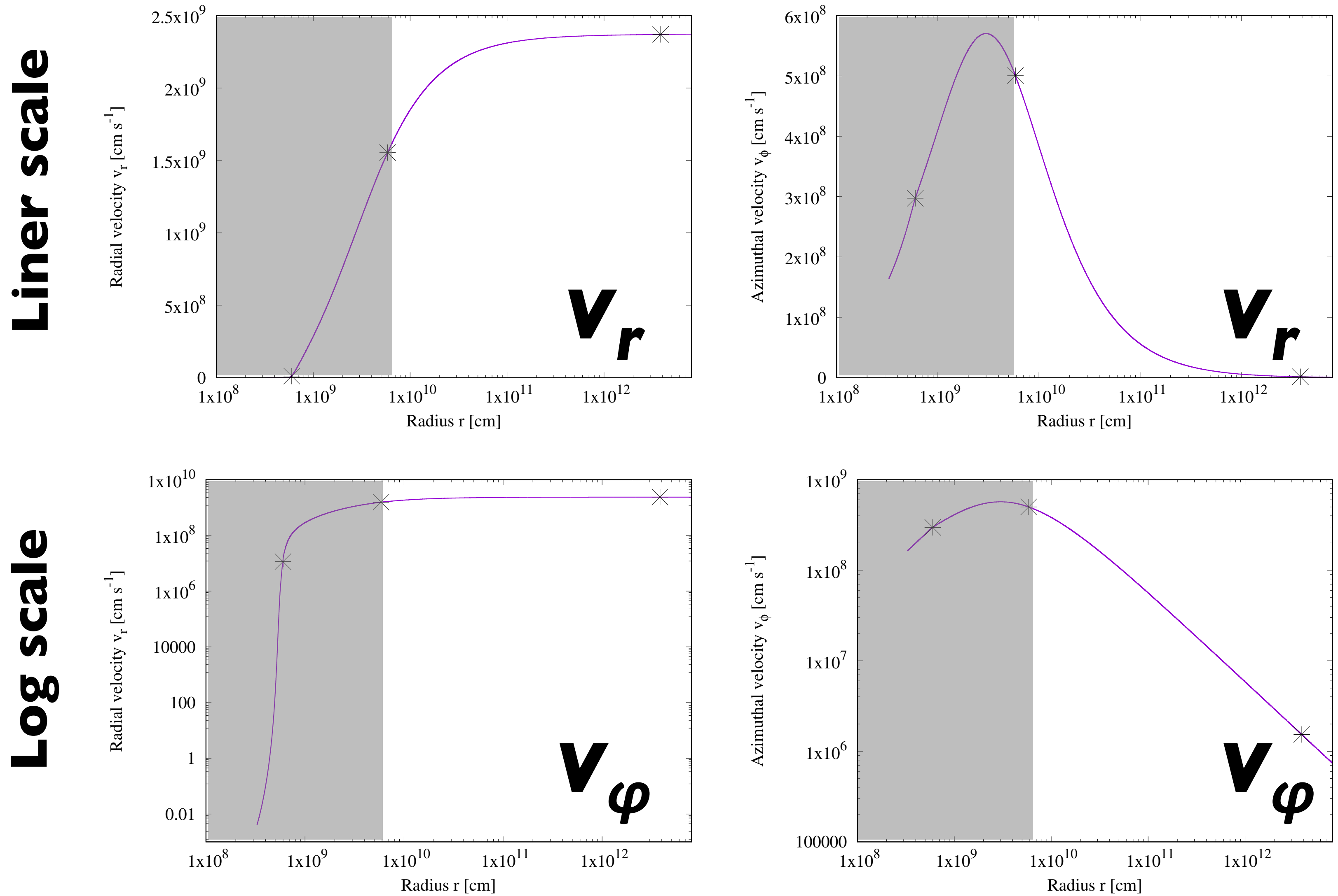
The WD J005311 wind : v_r & v_φ



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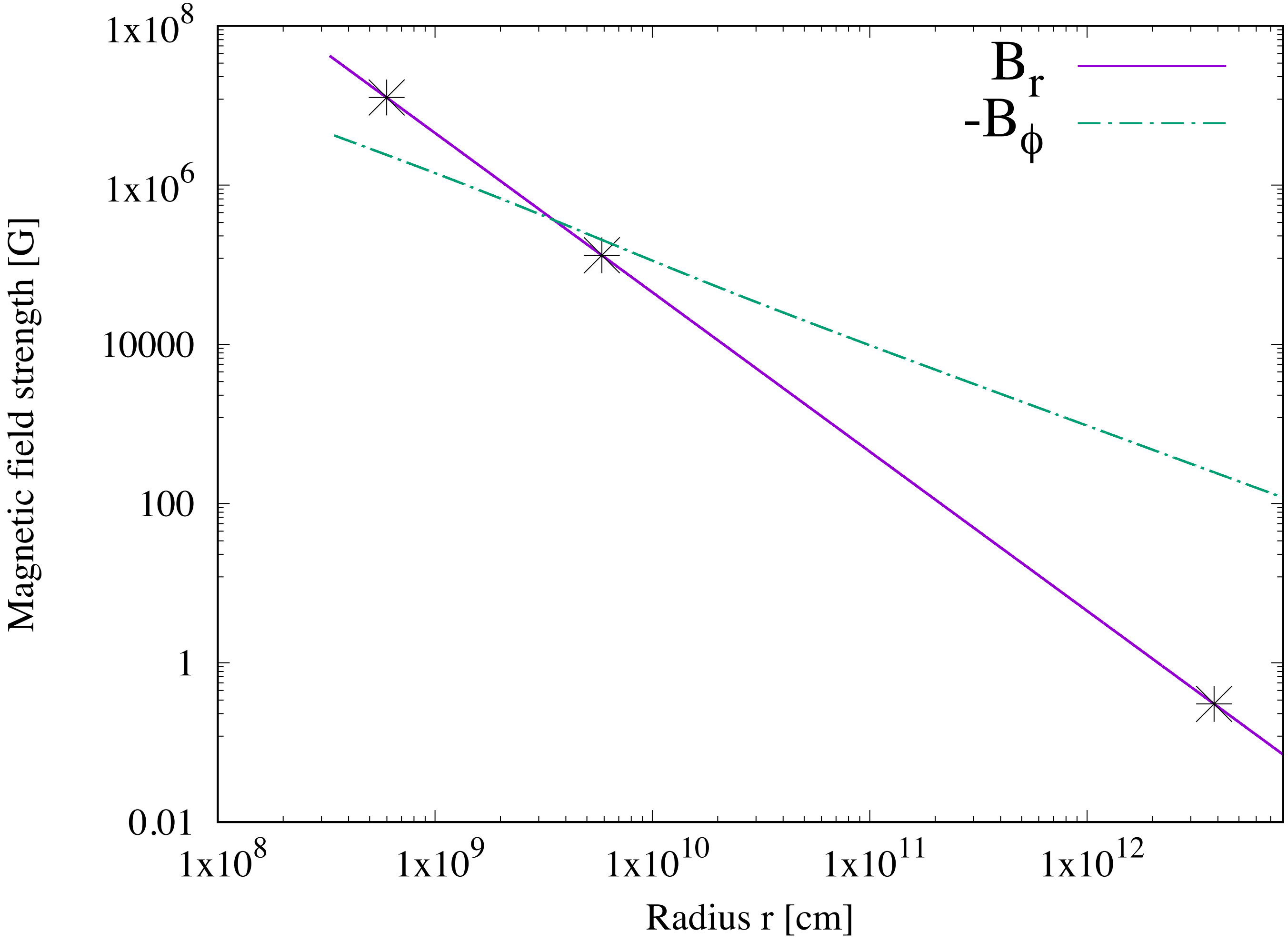
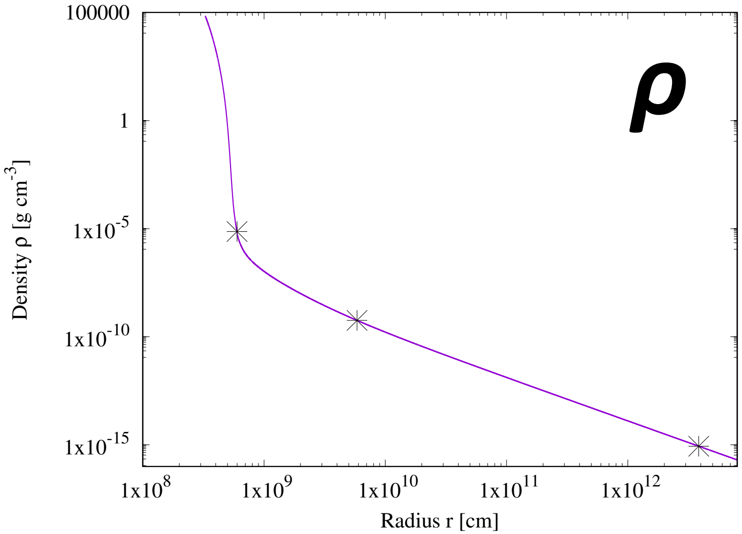
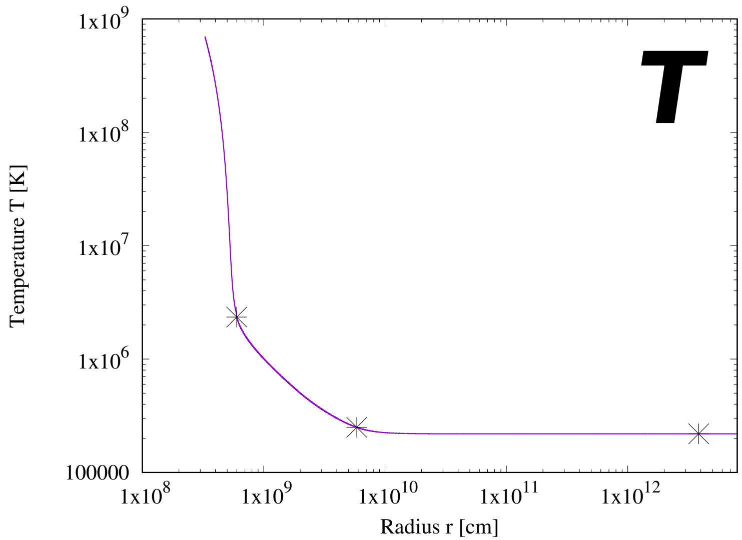
The WD J005311 wind : B_r & B_φ

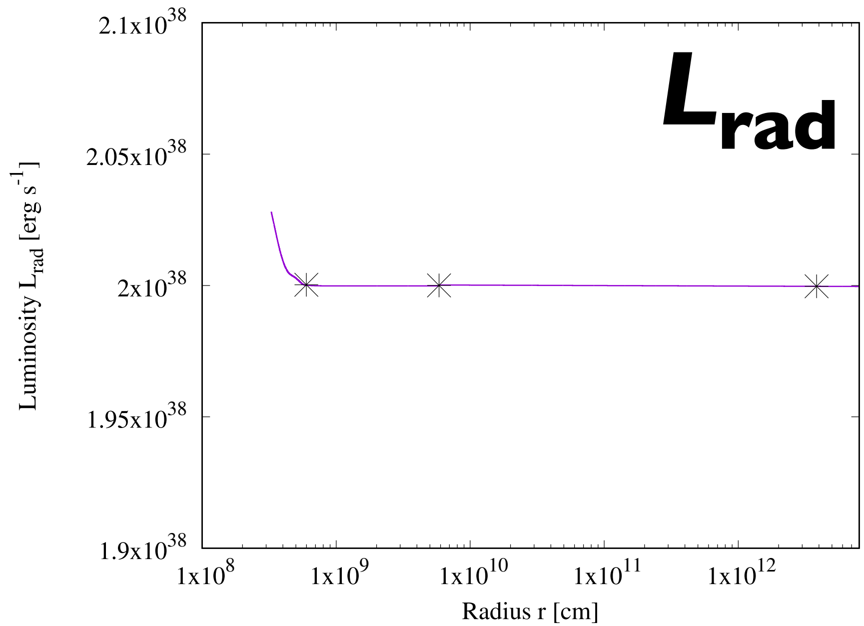


$M_* = 1.25\, M_\odot,\ R_* = 3.3 \times 10^8\,\mathrm{cm},\ B_* = 4.2 \times 10^7\, G,\ \Omega = 0.5\,\mathrm{s}^{-1}$, and $\dot{M} = 6 \times 10^{-6}\, M_\odot\,\mathrm{yr}^{-1}$

The WD J005311 wind : ρ, T, $L_{\rm rad}$

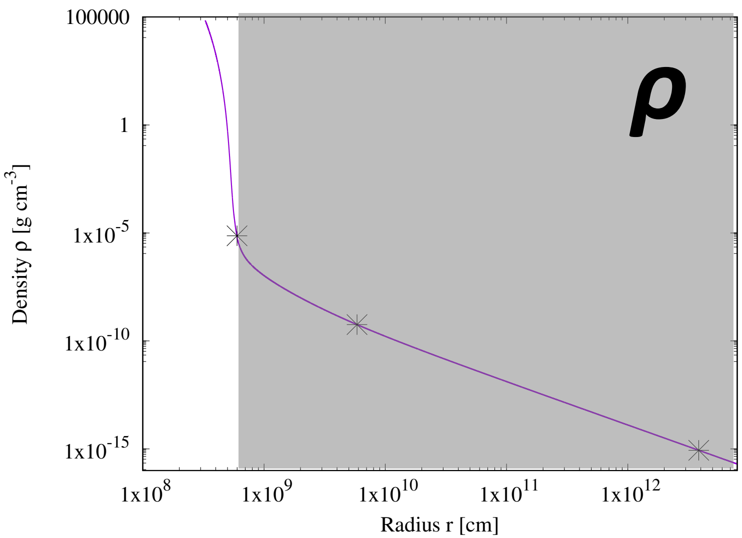


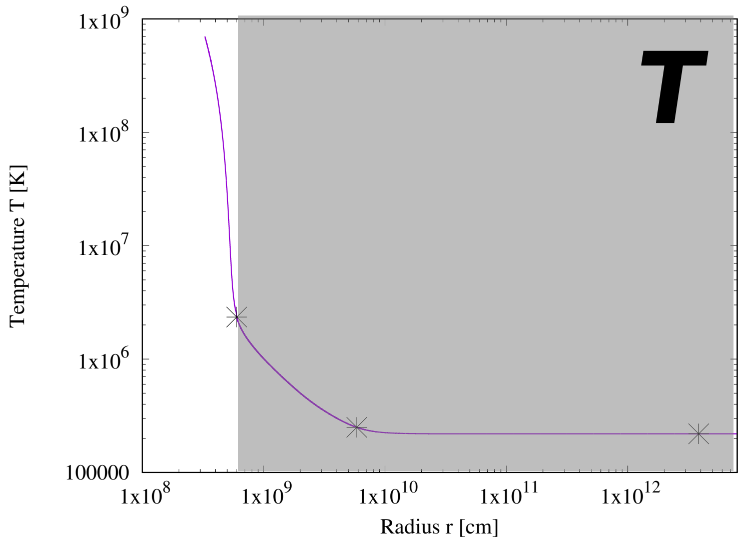


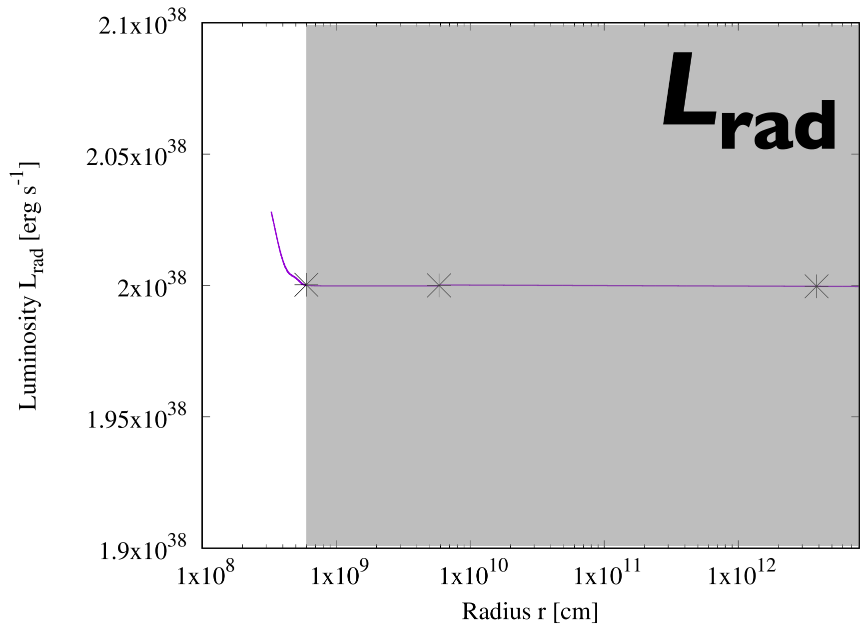


$$M_* = 1.25\,M_\odot,\ R_* = 3.3\times10^8\,\mathrm{cm},\ B_* = 4.2\times10^7\,G,\ \Omega = 0.5\,\mathrm{s}^{-1},\ \text{and}\quad \dot{M} = 6\times10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$$

The WD J005311 wind : ρ, T, L_{rad}







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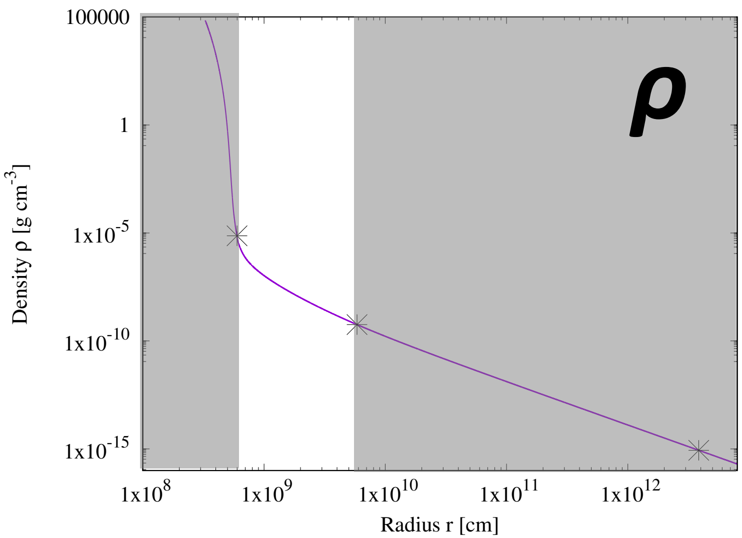
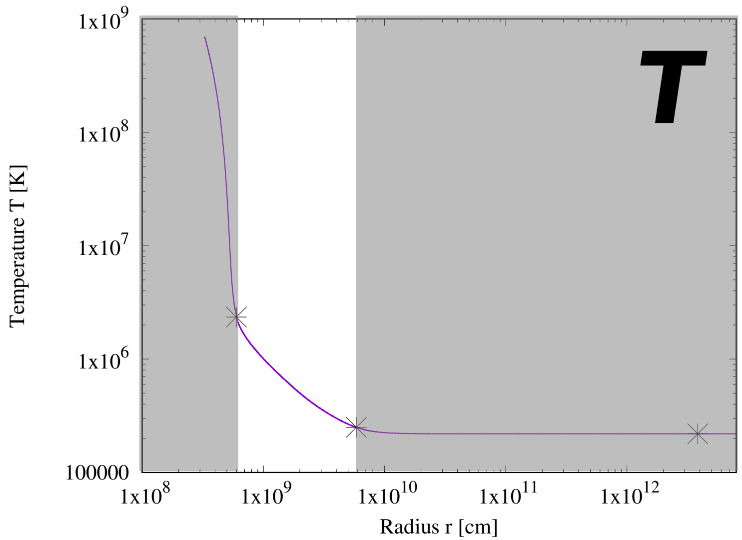
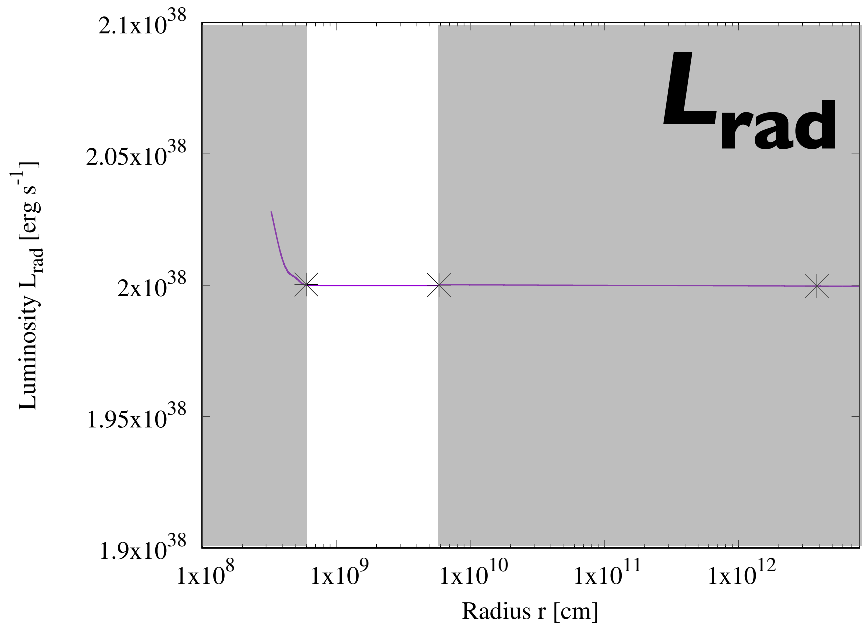
The WD J005311 wind : ρ, T, L_{rad}

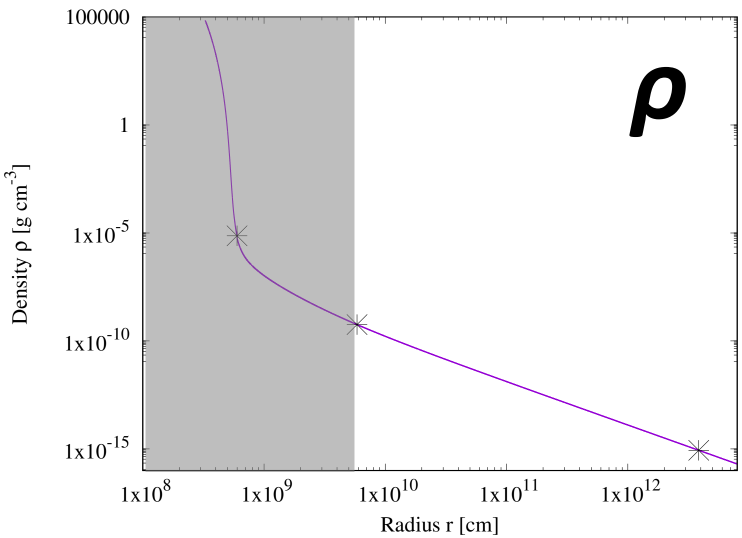


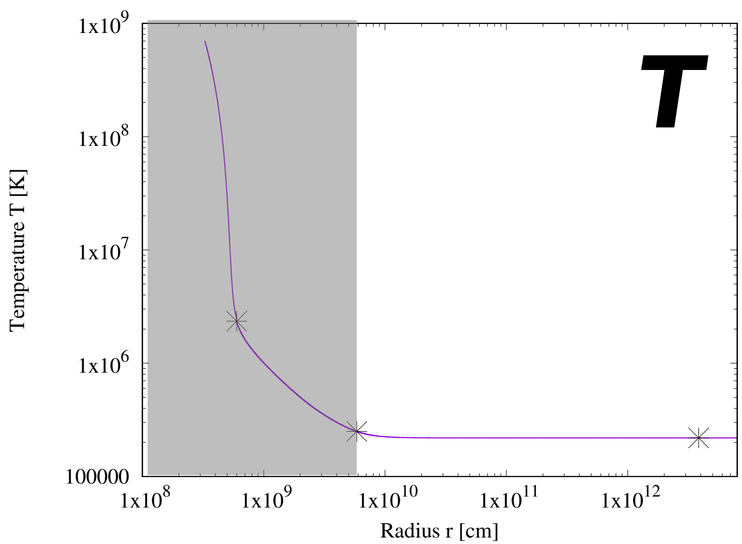


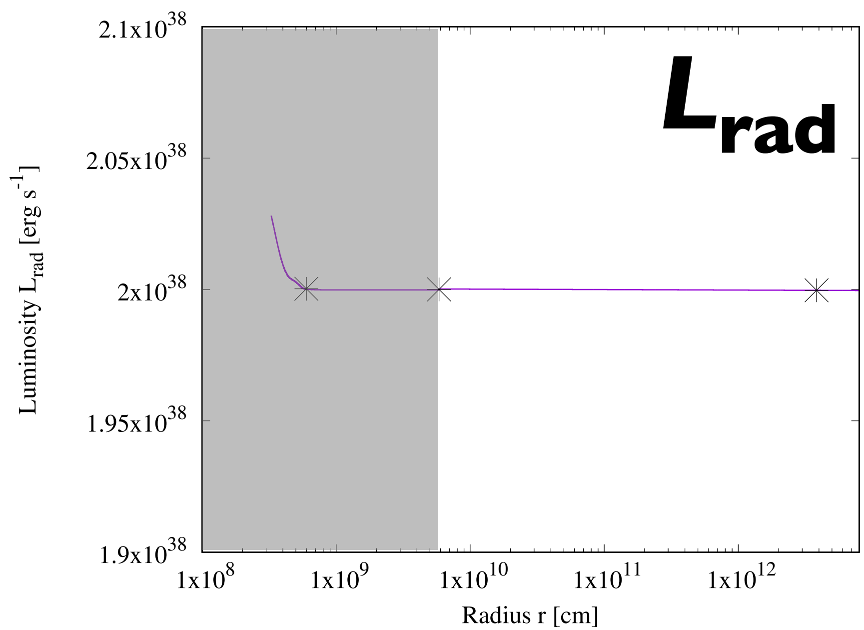


$$M_* = 1.25\, M_\odot,\ R_* = 3.3 \times 10^8\, \text{cm},\ B_* = 4.2 \times 10^7\, G,\ \Omega = 0.5\, \text{s}^{-1},\ \text{and} \quad \dot{M} = 6 \times 10^{-6}\, M_\odot\, \text{yr}^{-1}$$

The WD J005311 wind : ρ, T, L_{rad}

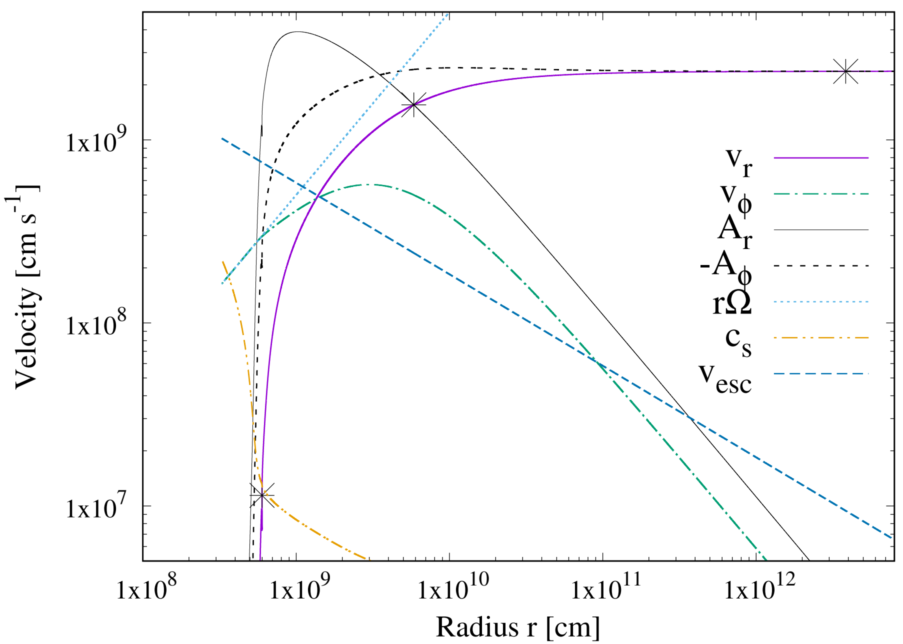


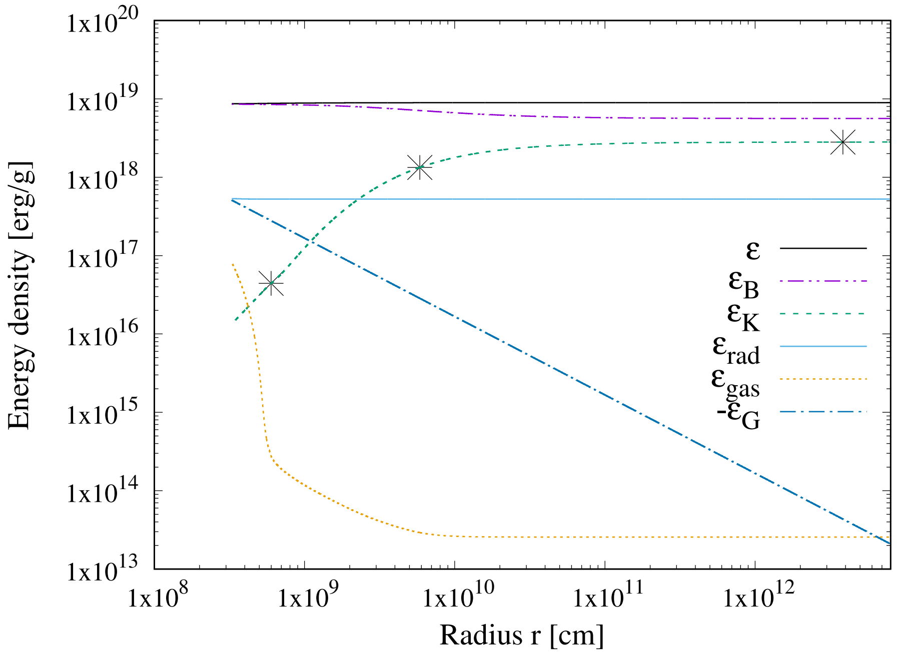




$M_* = 1.25\,M_\odot,\ R_* = 3.3 \times 10^8\,\mathrm{cm},\ B_* = 4.2 \times 10^7\,G,\ \Omega = 0.5\,\mathrm{s}^{-1}$, and $\dot{M} = 6 \times 10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$

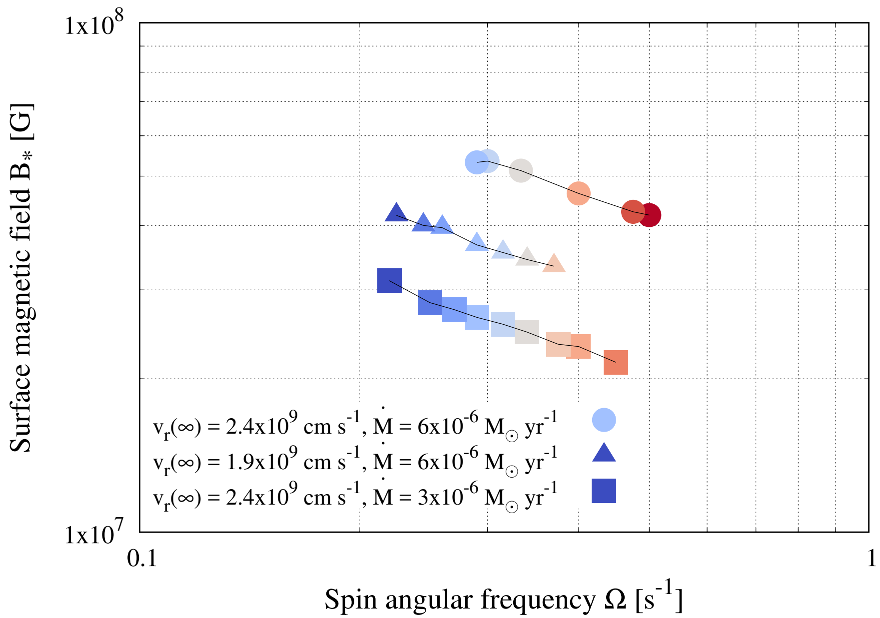
The WD J005311 wind : How is it accelerated?

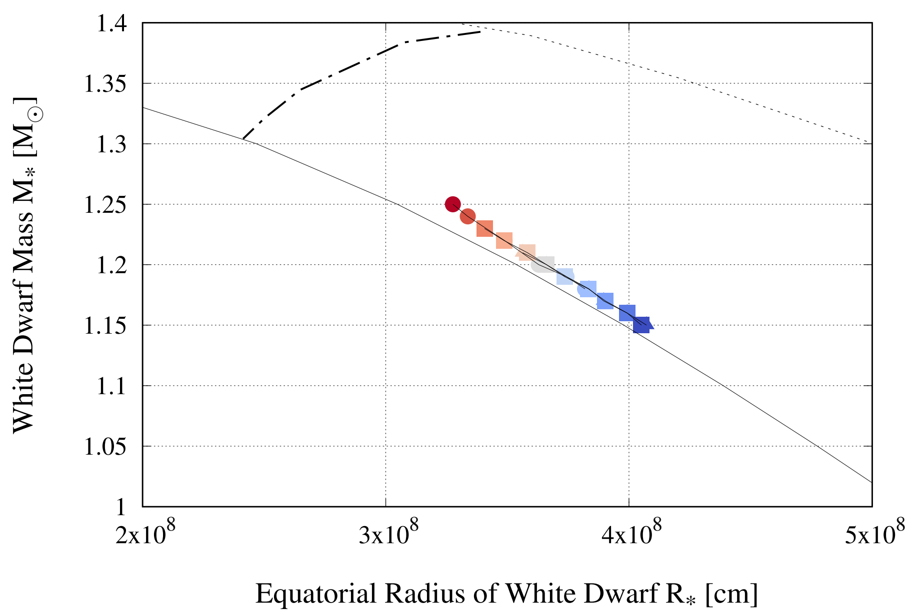




$M_* = 1.25\,M_\odot,\ R_* = 3.3\times10^8\,\mathrm{cm},\ B_* = 4.2\times10^7\,G,\ \Omega = 0.5\,\mathrm{s}^{-1},$ and $\dot{M} = 6\times10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$

The WD J005311 wind : Allowed parameter region





The observed properties of WD J005311 can be explained by the rotating magnetic wind from an ONe WD with $M_* = 1.1\text{-}1.3\ M_\odot$, $B_* = (2\text{-}5) \times 10^7$ G, and $\Omega = 0.2\text{-}0.5 s^{-1}$.

Table 1 | Stellar parameters and surface abundances of J005311

Parameter	Value
$\log(L_*/L_\odot)$	4.60 ± 0.14
T_* (K)	$211{,}000^{+40{,}000}_{-23{,}000}$
R_* ($R_\odot$)	0.15 ± 0.04
$\dot{M}$ ($M_\odot$ yr^{-1})	$(3.5 \pm 0.6) \times 10^{-6}$
D	10
v_∞ (km s^{-1})	$16{,}000 \pm 1{,}000$
β	1.0
d (kpc)	$3.07^{+0.34}_{-0.28}$
$E(B-V)$ (mag)	0.835 ± 0.035
R_V	3.1
He mass fraction	<0.1
C mass fraction	0.2 ± 0.1
O mass fraction	0.8 ± 0.1
Ne mass fraction	0.01
Fe group mass fraction	1.6×10^{-3}

The given uncertainties are an indicator of the obtained fit quality as a function of stellar parameters, on the basis of the criteria described in Methods. Owing to the nature of this analysis they do not represent statistical error distributions. Parameters without error estimates were adopted in the model. *D*, wind clumping factor; β, acceleration parameter; *d*, distance to J005311; R_V, total-to-selective absorption ratio.

Q. How can the wind be so fast?

- Radiation pressure?

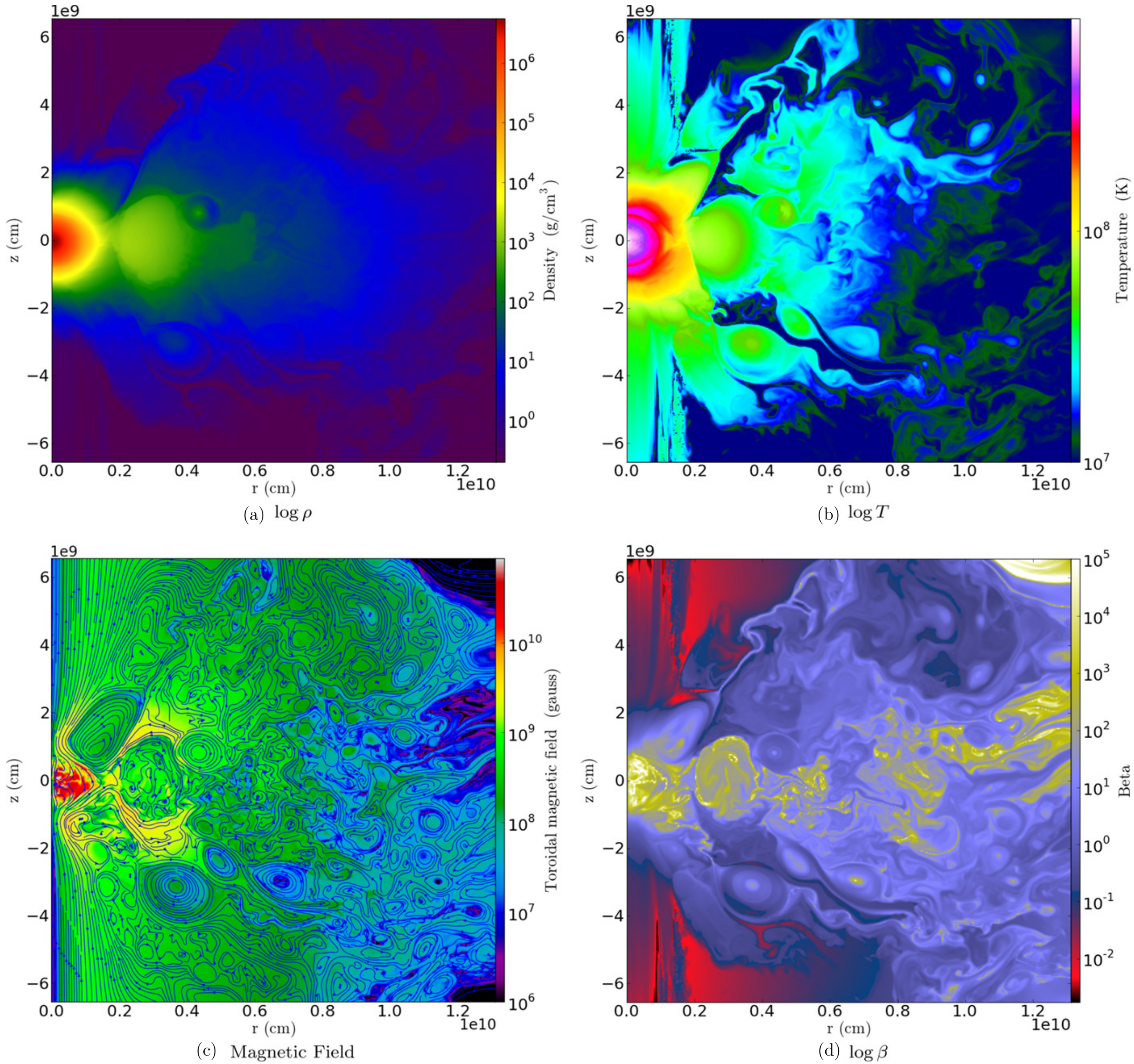
→ wind velocity $\sim$ escape velocity @ photosphere

$\sim$ O(1,000) km s^{-1} for a ~ solar mass obj.

<< 16,000 km s^{-1} …

- Rotating magnetic field?

→ wind velocity ↑↑ for *a larger B field and a faster spin*



(a) $\log\rho$

(b) $\log T$

(c) Magnetic Field

(d) $\log\beta$

Ji et al.13

Gvaramadze et al.19

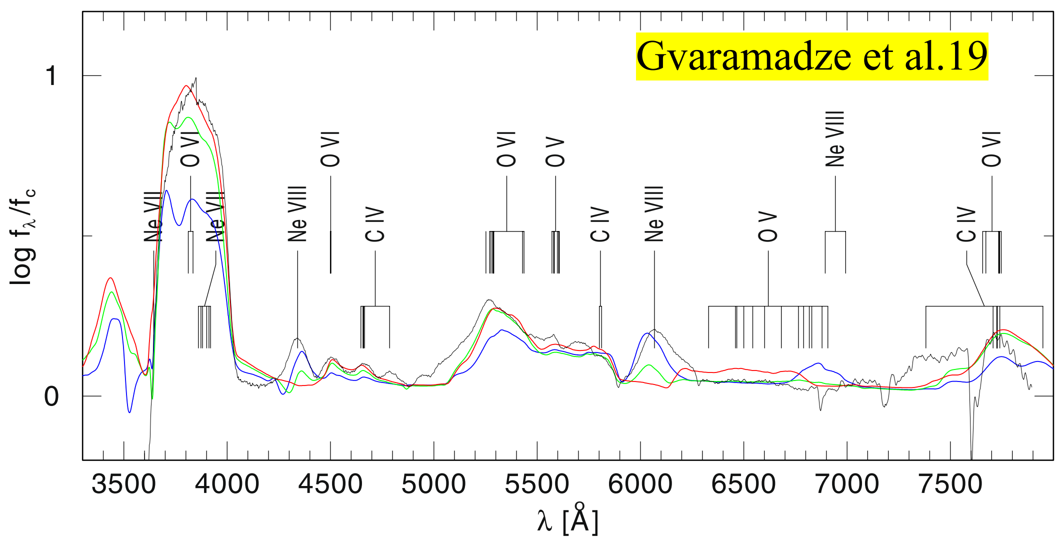
- *" … this extremely high velocity can be explained in the framework of rotating magnetic wind models."*

- *" We find that a co-rotation speed of 16,000 km s^{-1} at the Alfvén point in J005311, where the inertia force starts to dominate over the magnetic forces, requires an Alfvén radius of about 10 stellar radii (about $1.5R_{\odot}$), which is achieved with a magnetic field strength of about 10^8 G. "*

???

- If the bulk acceleration occurs beyond the photosphere, a P Cygni profile should be detected, but the emission lines in the observed spectrum lacks blue-shifted absorption components …

→ A sub-photospheric acceleration may be required.



???

- If the bulk acceleration occurs beyond the photosphere, a P Cygni profile should be detected, but the emission lines in the observed spectrum lacks blue-shifted absorption components …

  → A sub-photospheric acceleration may be required.

- How fast the star rotates?
- How the wind is launched?
- Does it need to have a super-Chandrasekhar mass?