連星白色矮星合体とその後の進化について

樫山和己（東大理）

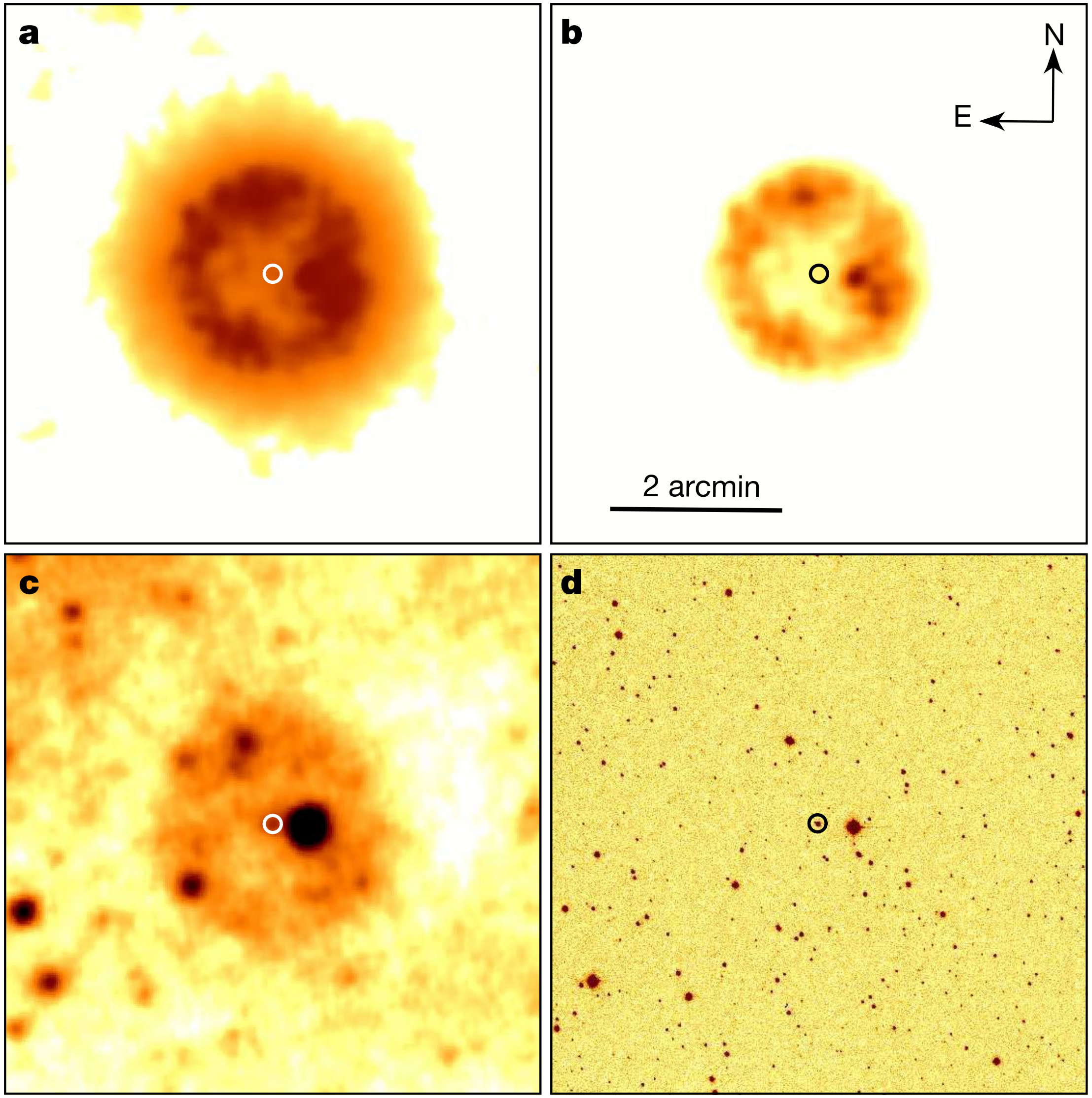
Type Ia supernova?

Highly magnetized massive white dwarf?
WD pulsar? ...

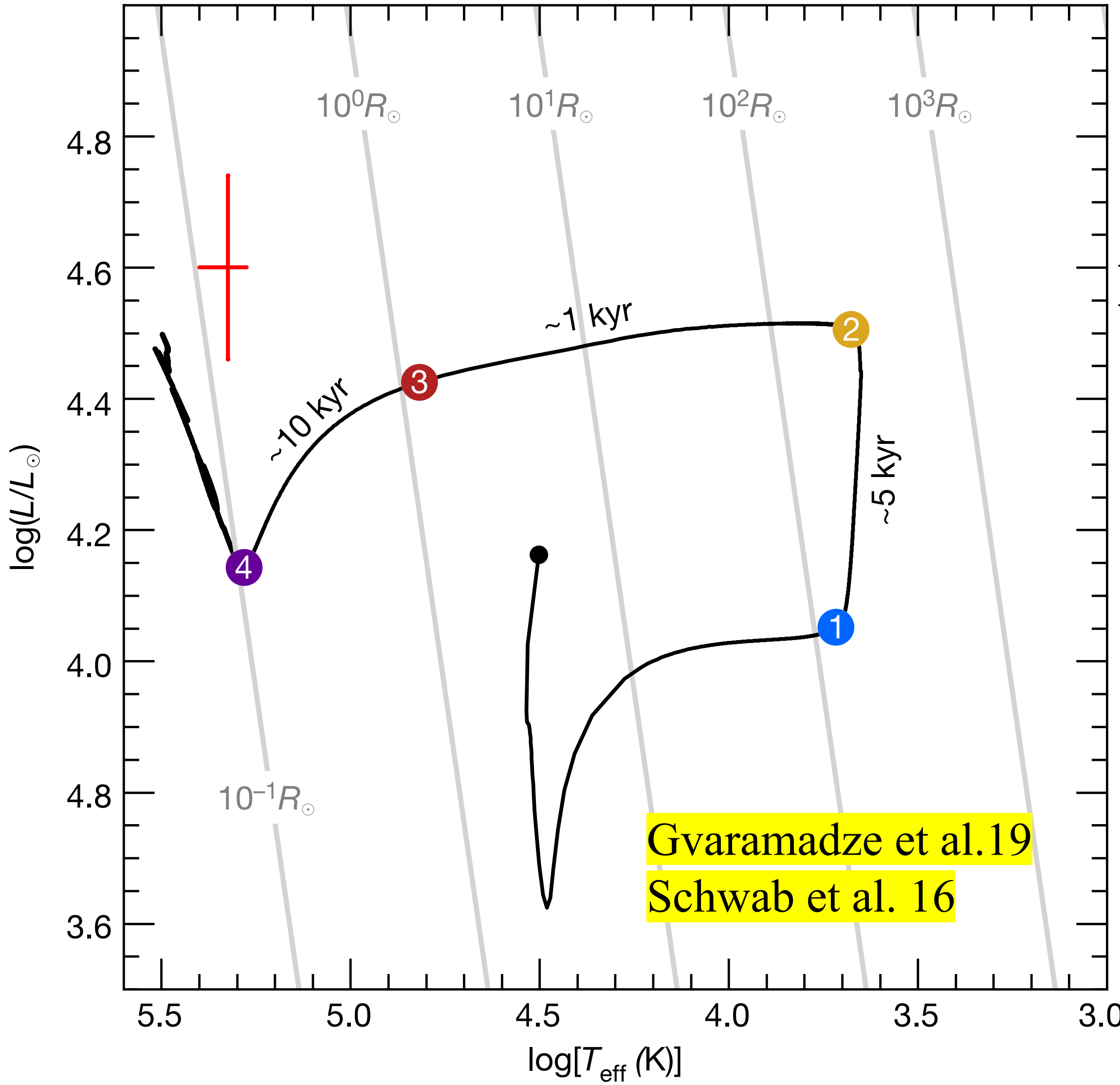
Collapse into neutron star?
GRB? FRB?
...

Gvaramadze et al.19

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



The pale blue dot on the HR diagram



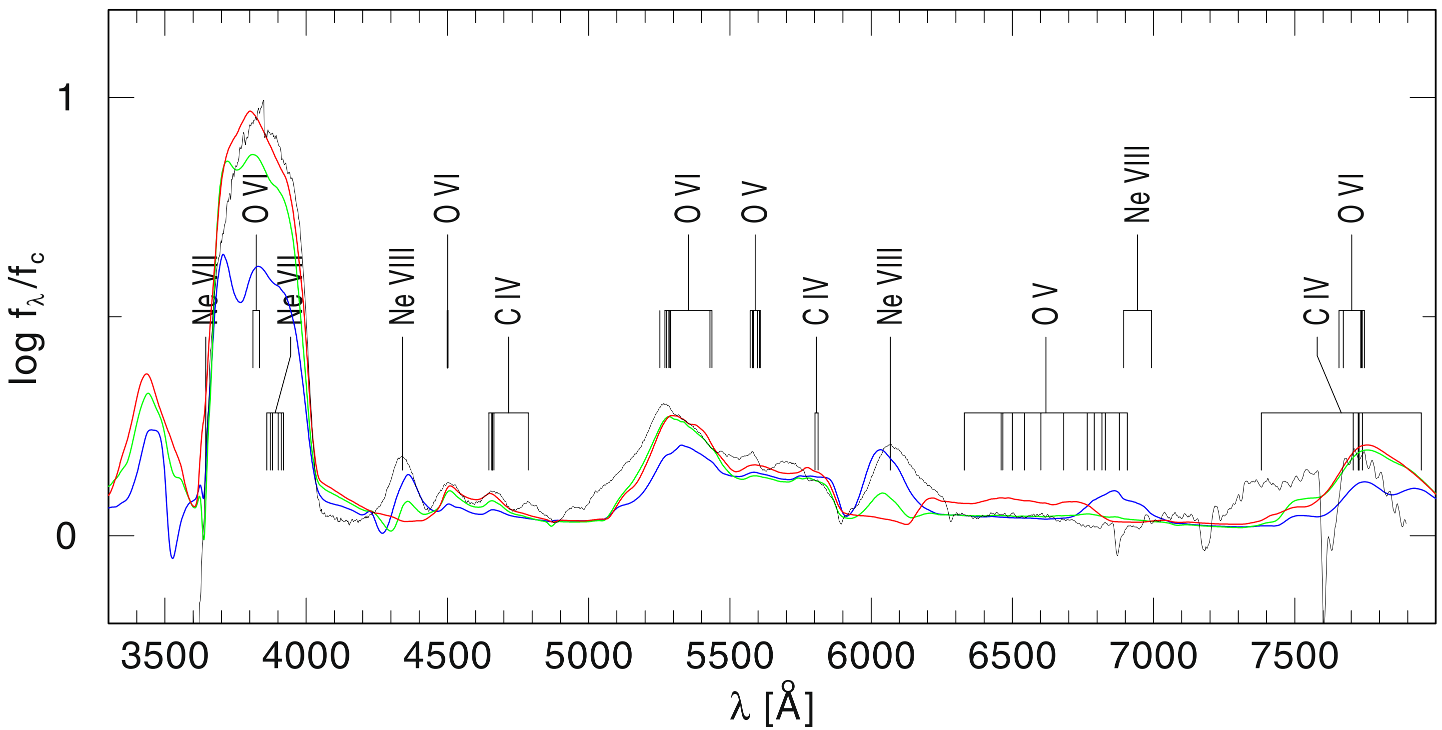
$$T_{\rm eff} = 211,000^{+40,000}_{-23,000}\,{\rm K}$$

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

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

Ne enriched C/O dominated wind

Gvaramadze et al.19



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

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

$X_{\mathrm{Ne}} = 0.01$

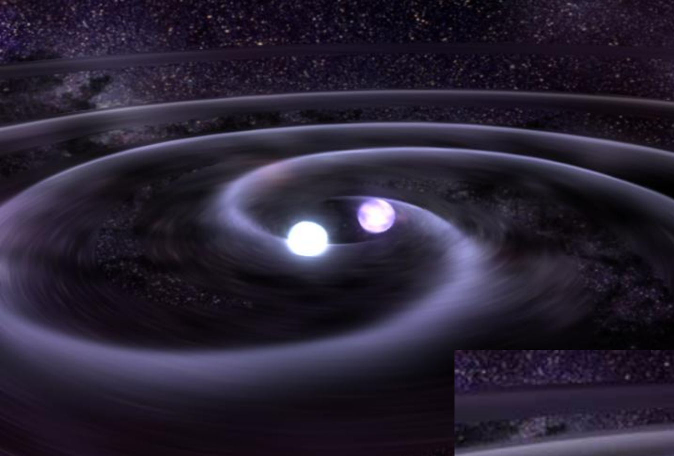
Line width & height ⇨

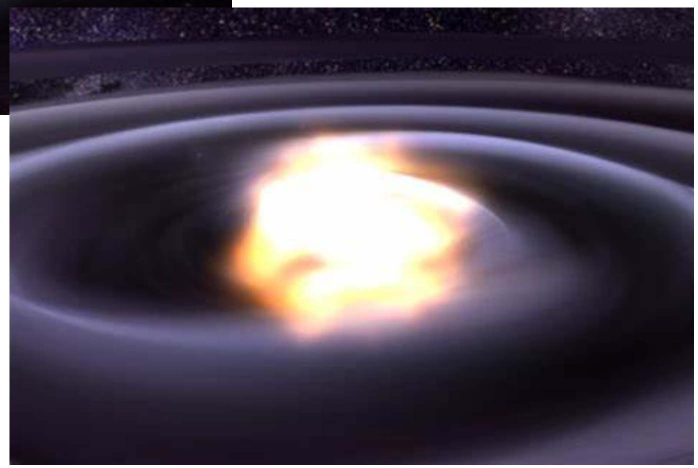
$$\dot{M} = (3.5 \pm 0.6) \times 10^{-6}\, M_{\odot}\, \mathrm{yr}^{-1}$$

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

A white dwarf merger product with a super-Chandrasekhar mass

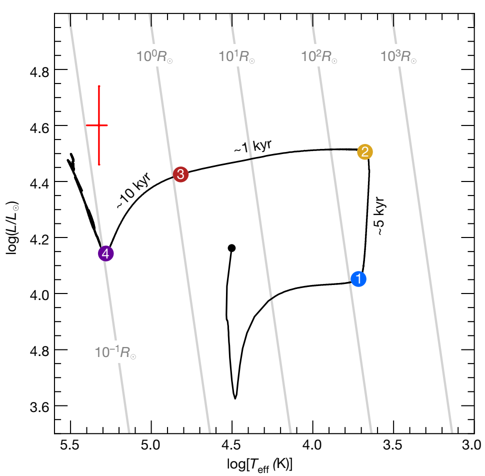
Gvaramadze et al.19

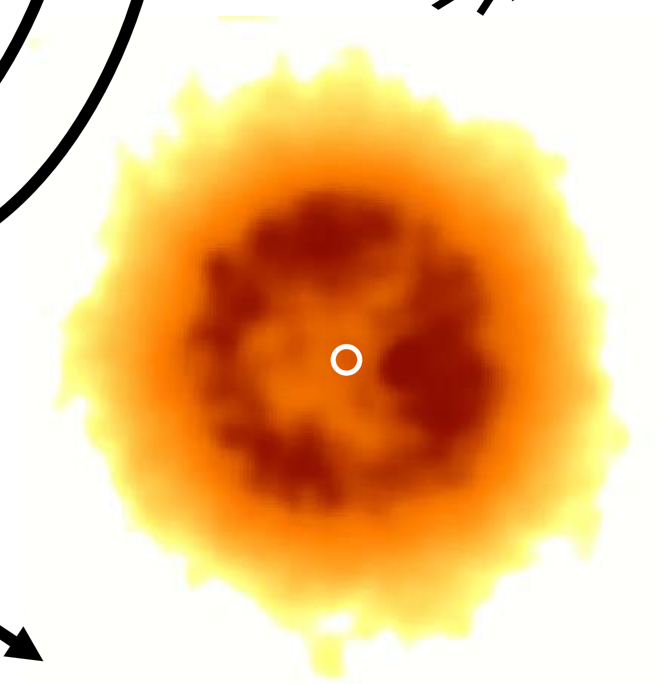




time

~10 kyr

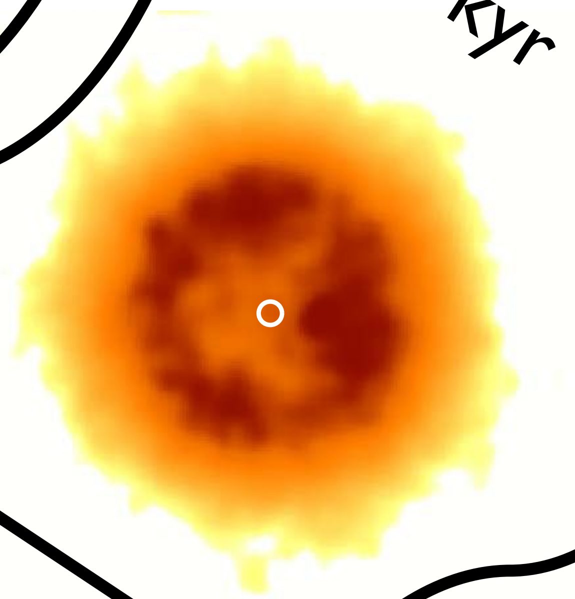




will finally collapse into a neutron star

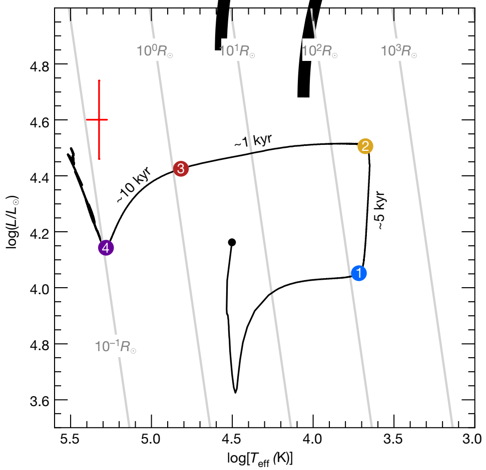
Gvaramadze et al.19

~10 kyr

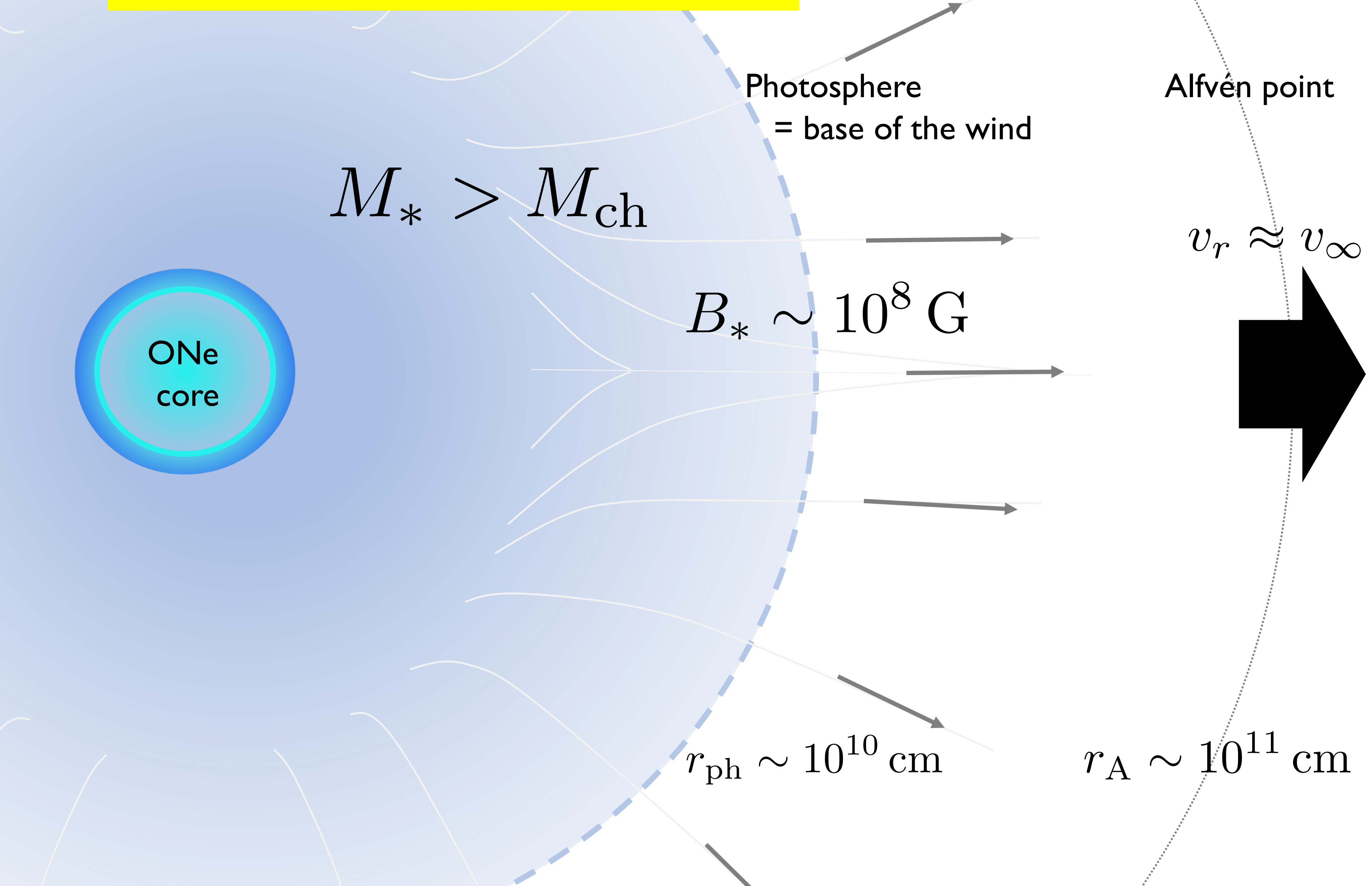


time

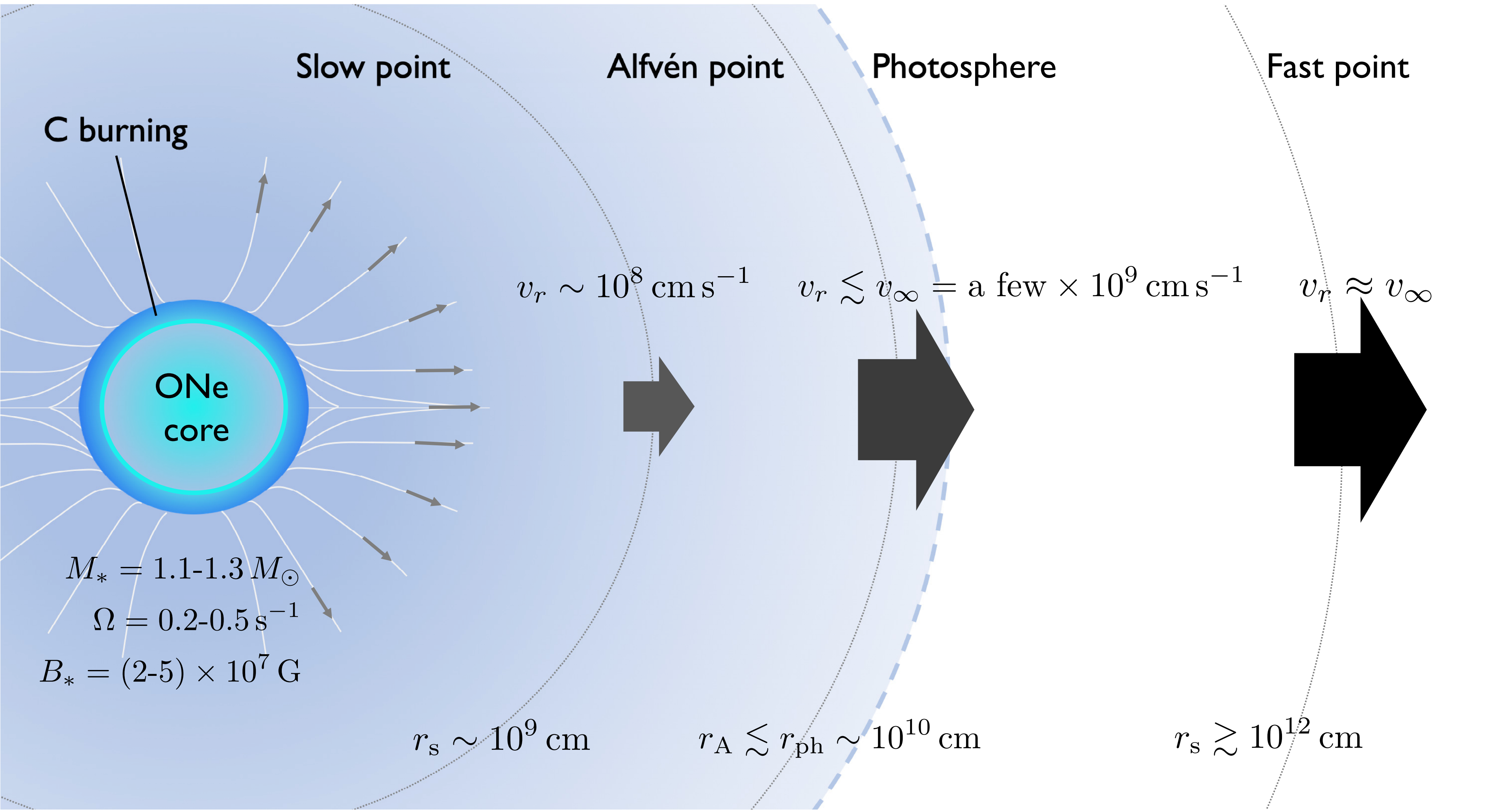
a few kyr



Gvaramadze et al.19



Kashiyama, Fujisawa, Shigeyama 19



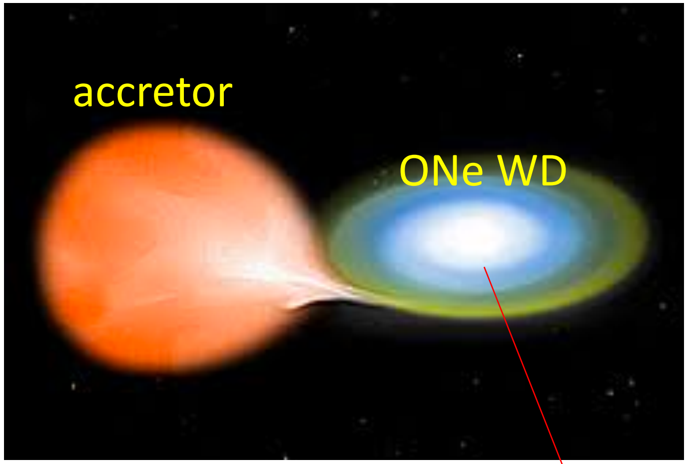
arXiv:1907.12317

The launching mechanism

- $X_C = 0.2, X_O = 0.8, X_{Ne} = 0.1$
  (but $X_{Fe} = 1.6 \times 10^{-3}$ similar to the solar abundance)

$\wr\wr$

"Neon novae"



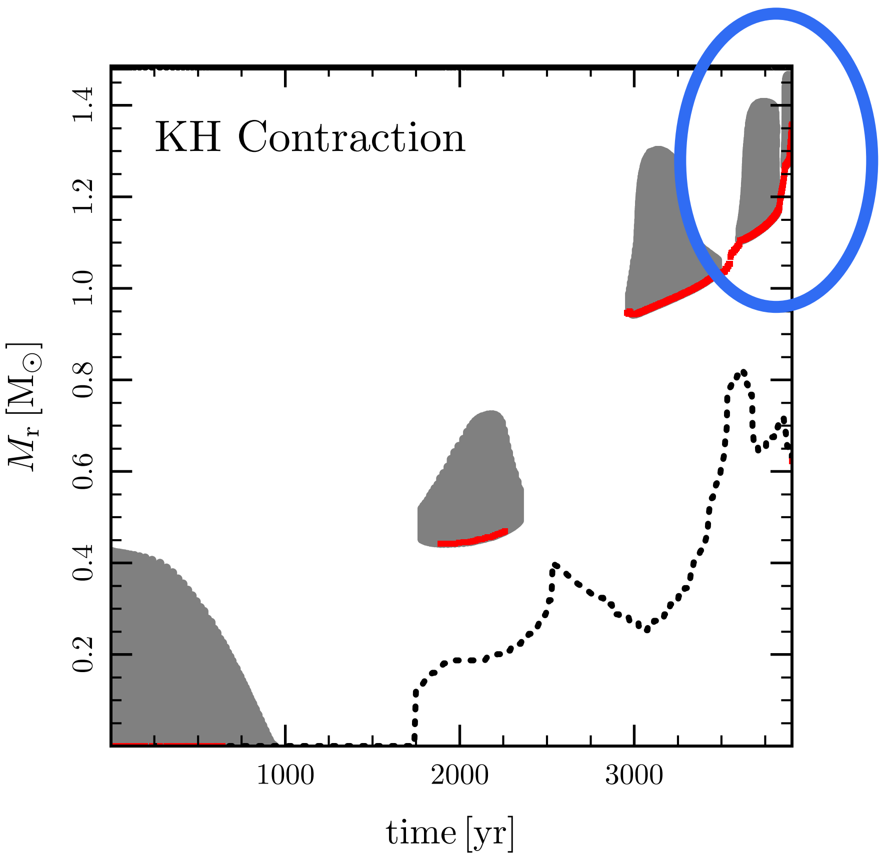
e.g.,
Truran & Livio 86
Hachisu & Kato 16

The ONe mantle is dredged up

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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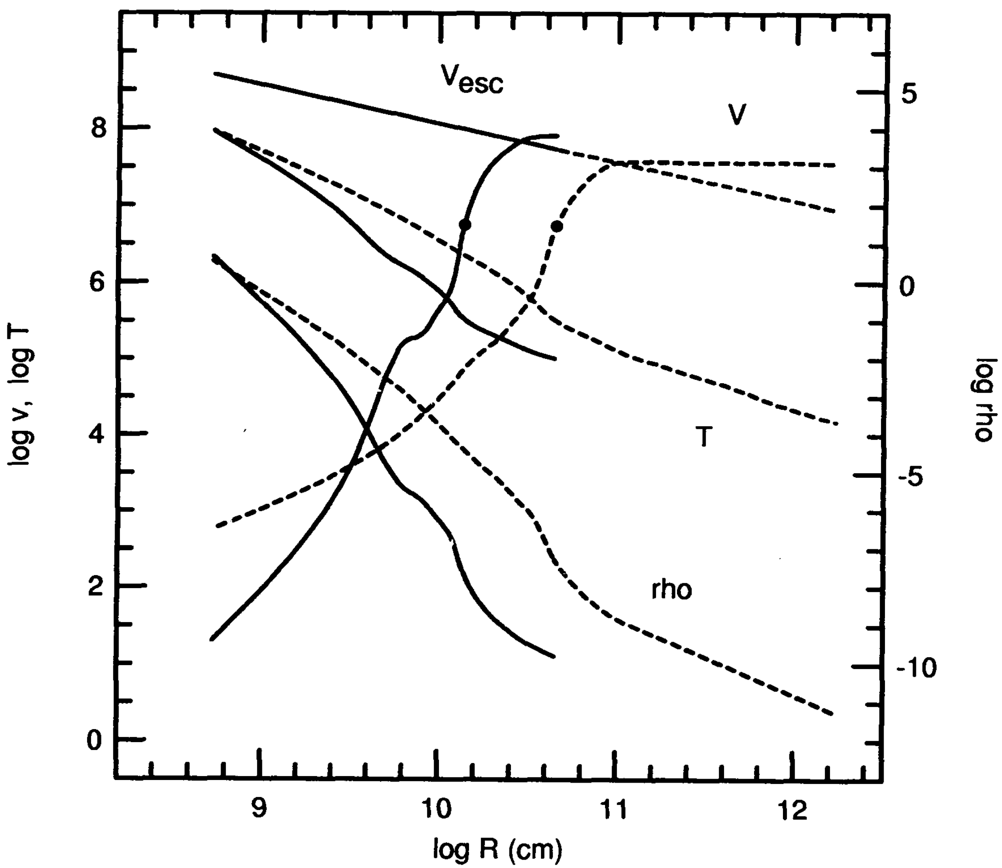
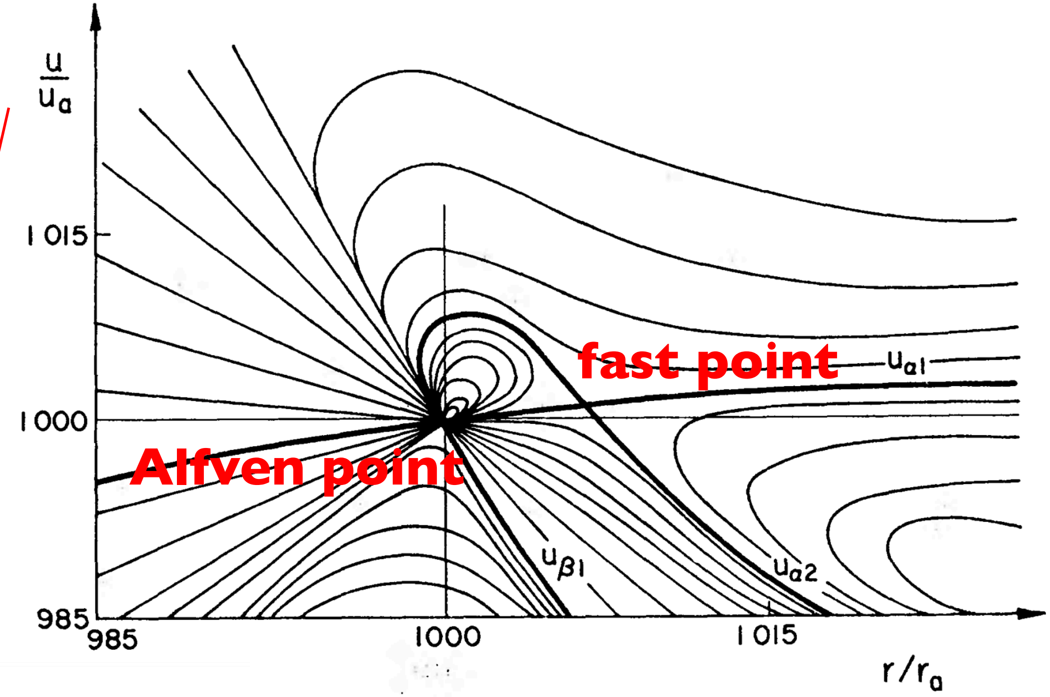
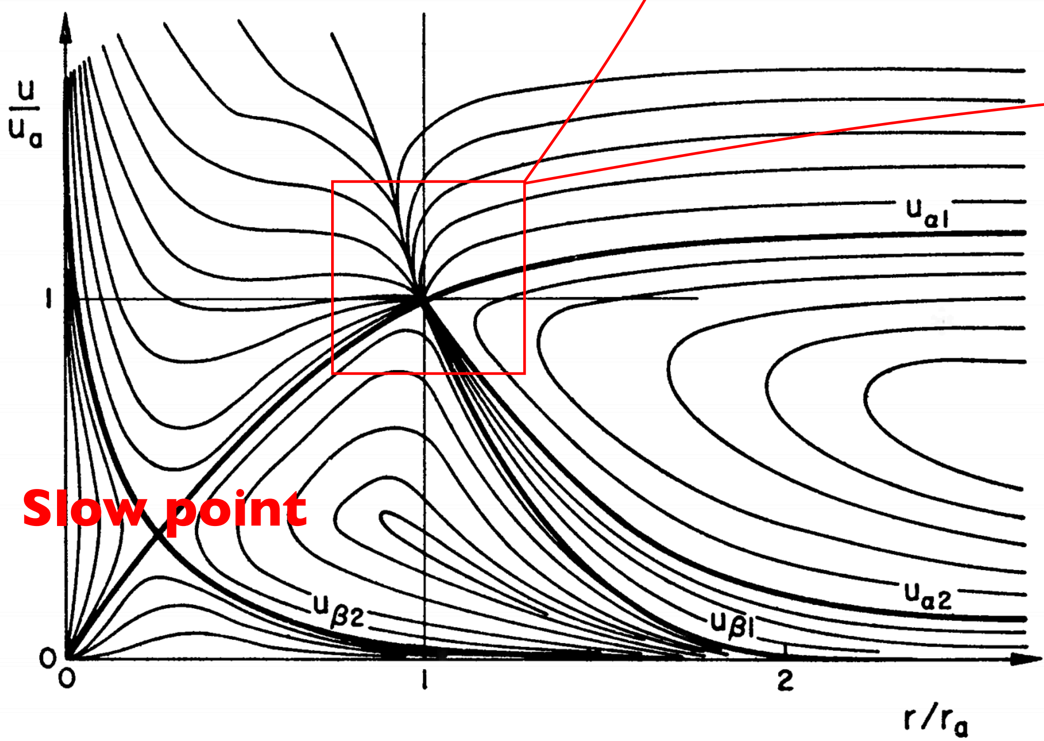


Weber & Davis 67





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

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

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

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

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

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

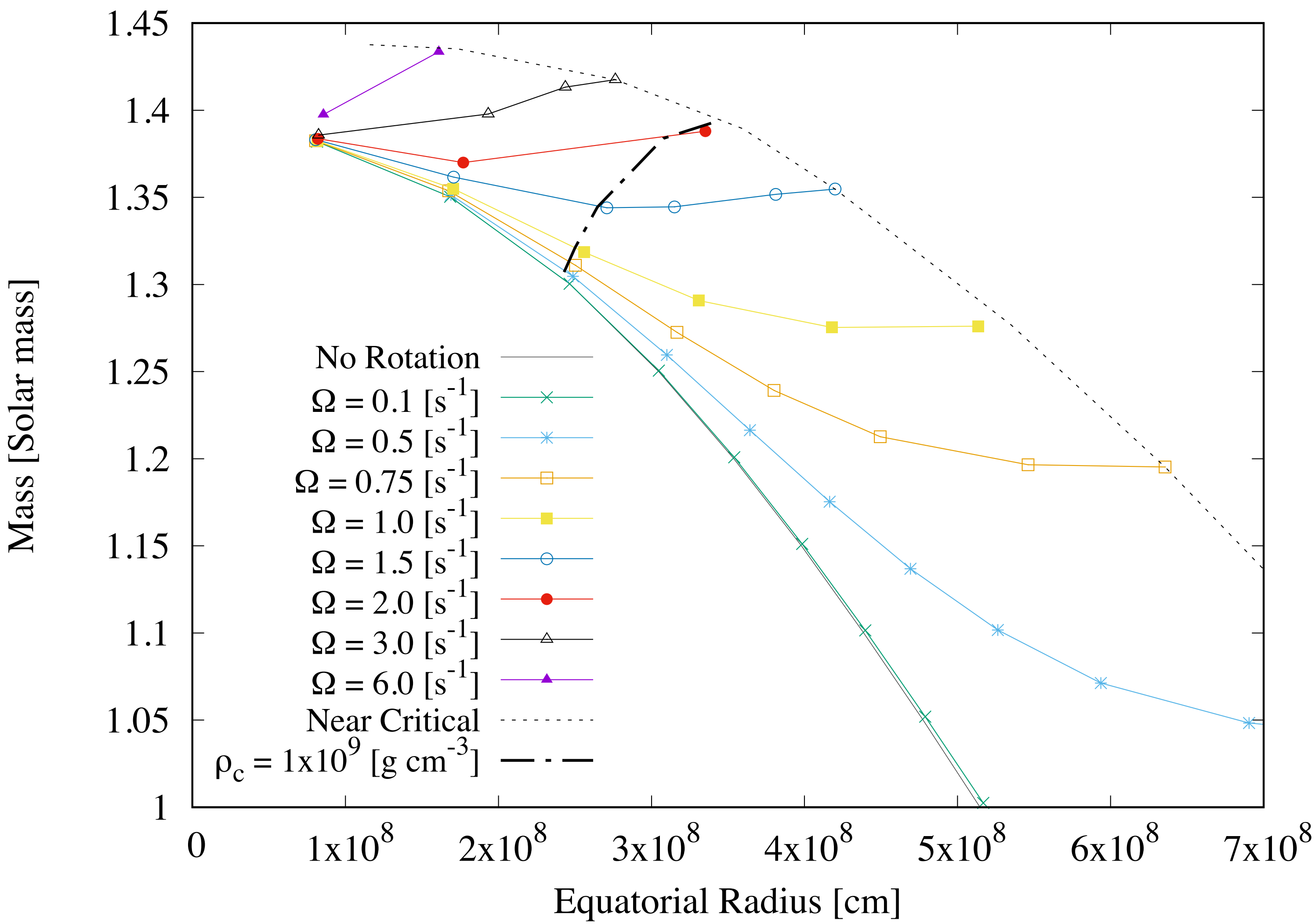
7 variables

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

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

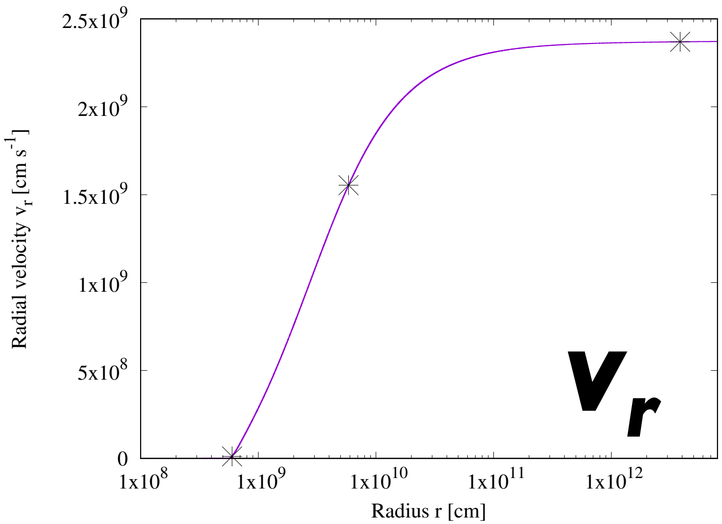


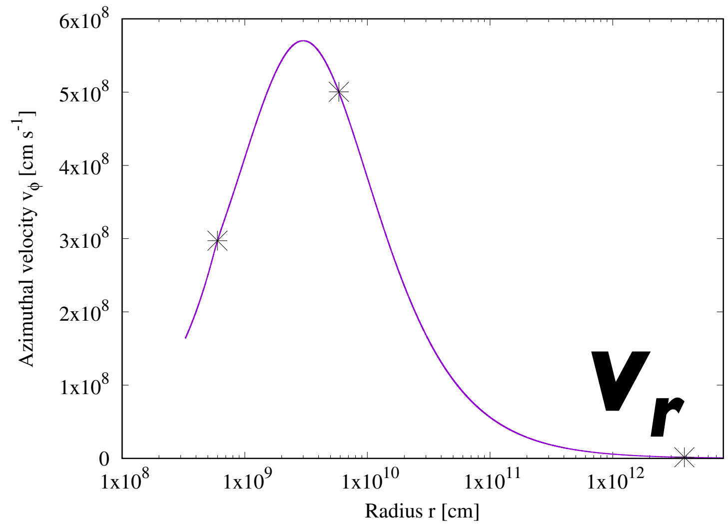
Fujisawa 15

Results

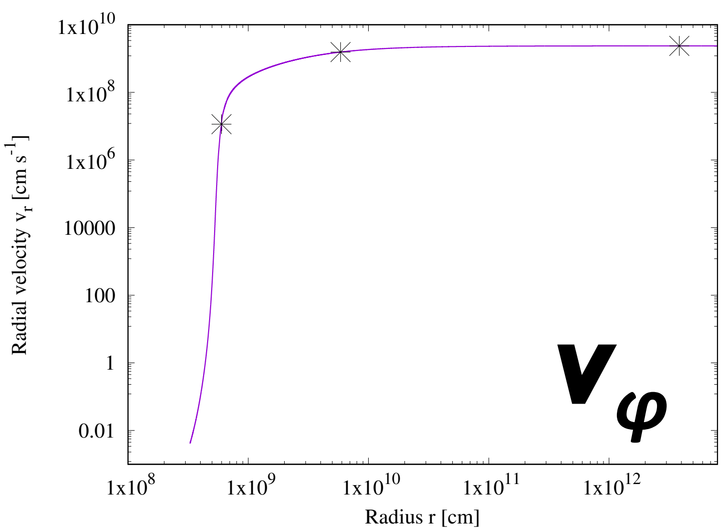
The WD J005311 wind : v_r & v_φ

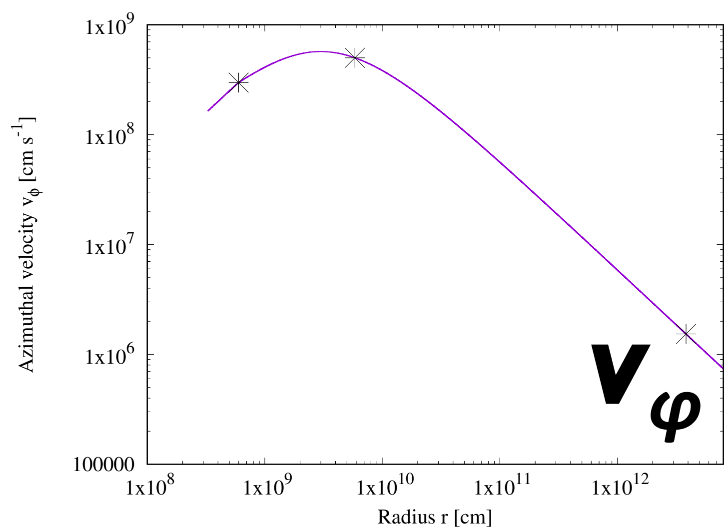
Liner scale





Log scale



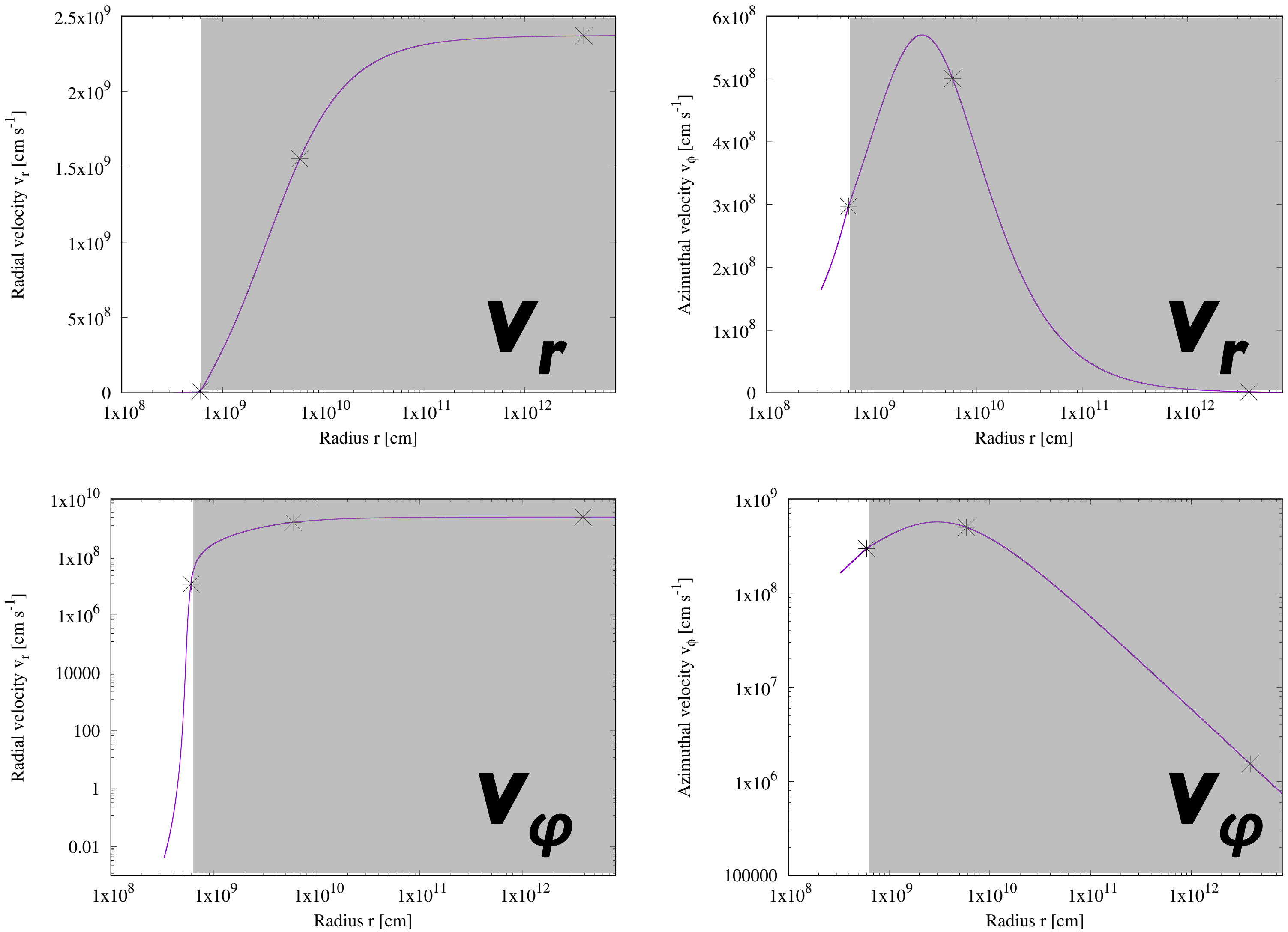


$M_* = 1.25\, M_\odot,\ R_* = 3.3 \times 10^8\,\mathrm{cm},\ B_* = 4.2 \times 10^7\, G,\ \Omega = 0.5\,\mathrm{s}^{-1},$ and $\dot{M} = 6 \times 10^{-6}\, M_\odot\,\mathrm{yr}^{-1}$

The WD J005311 wind : v_r & v_φ

Liner scale

Log scale



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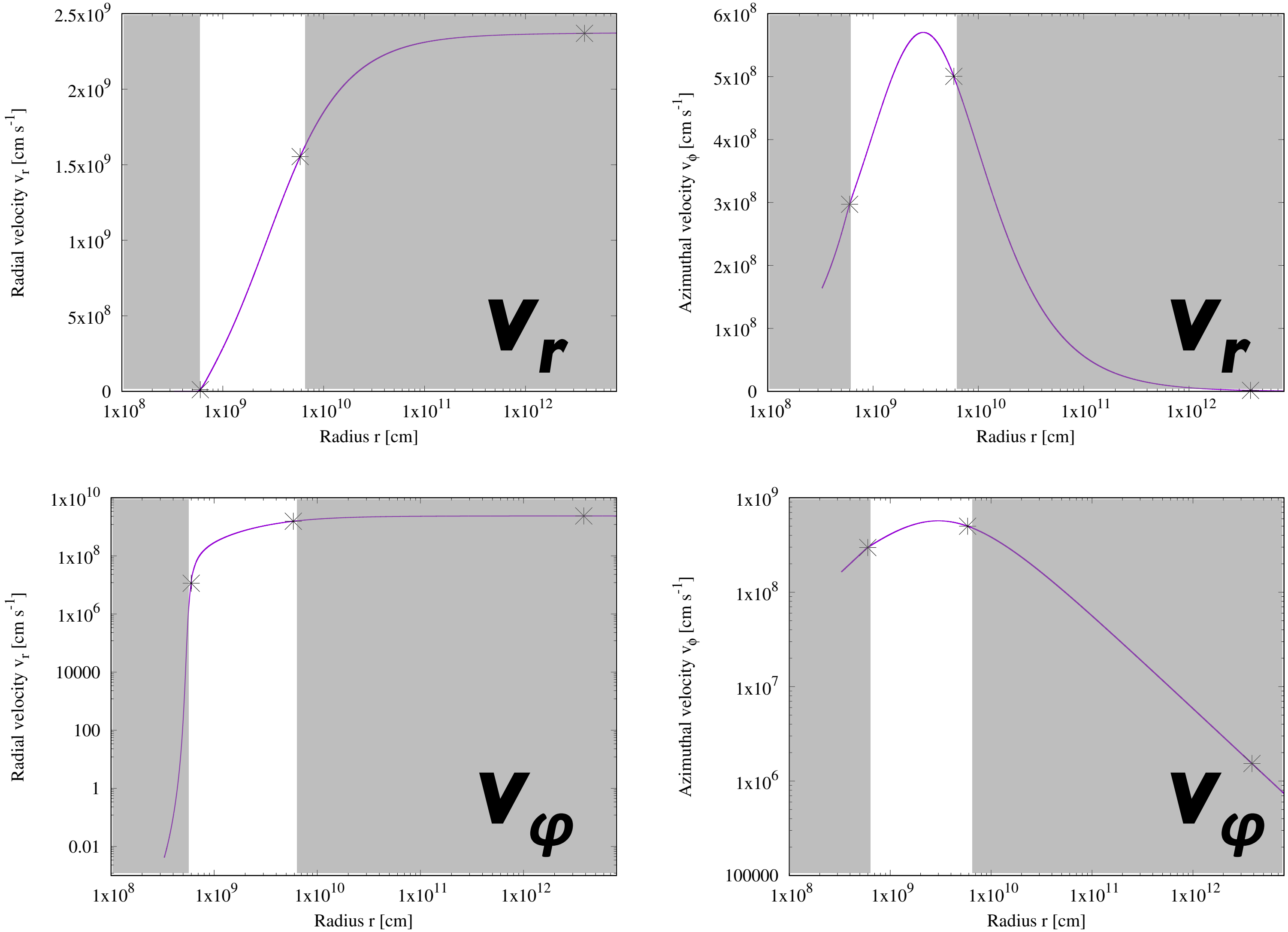
The WD J005311 wind : v_r & v_φ

Liner scale

Log scale

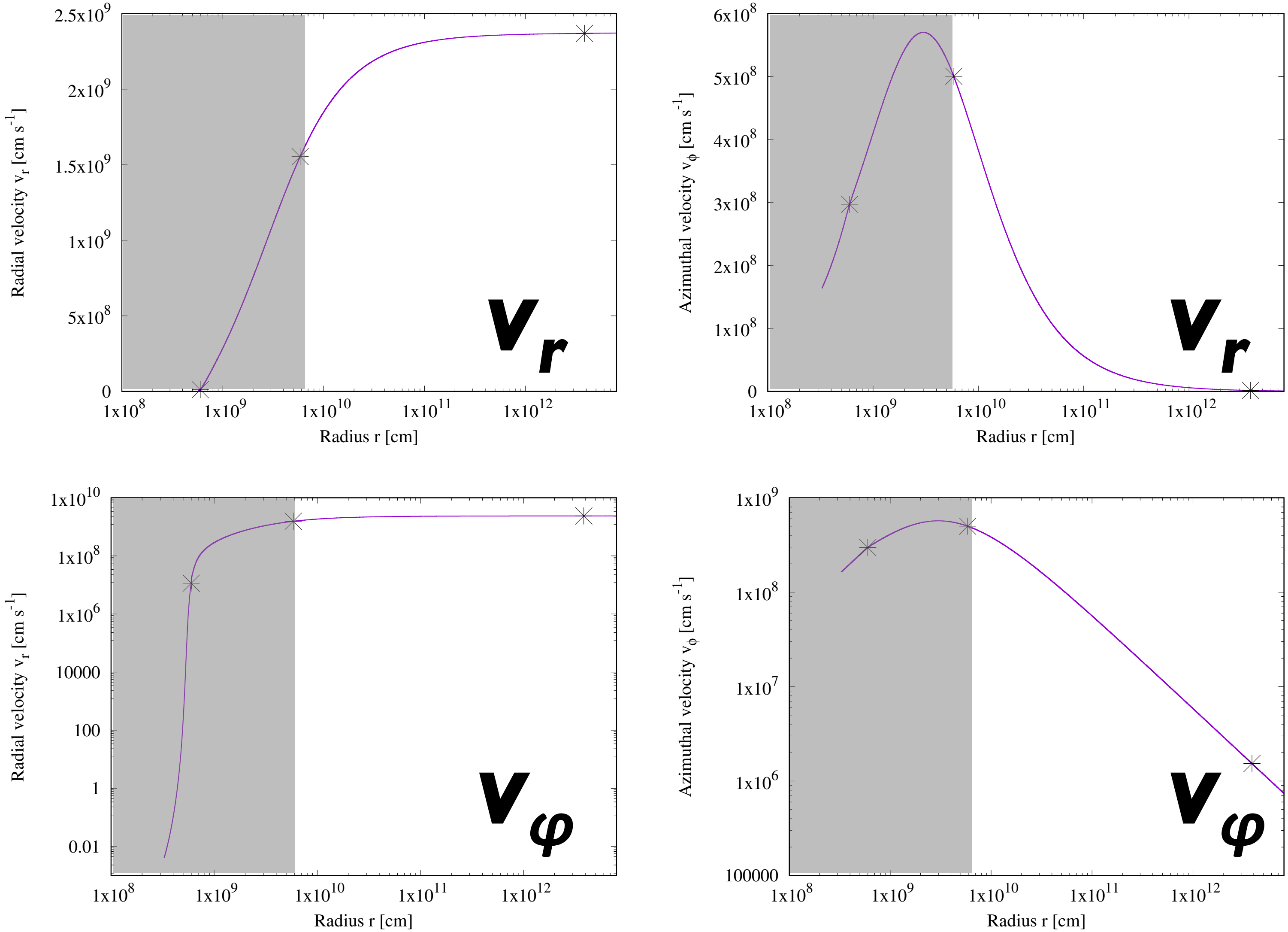


$$M_* = 1.25\, M_\odot,\; R_* = 3.3\times10^8\,\mathrm{cm},\; B_* = 4.2\times10^7\,G,\; \Omega = 0.5\,\mathrm{s}^{-1},\ \text{and}\quad \dot{M} = 6\times10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$$

The WD J005311 wind : v_r & v_φ

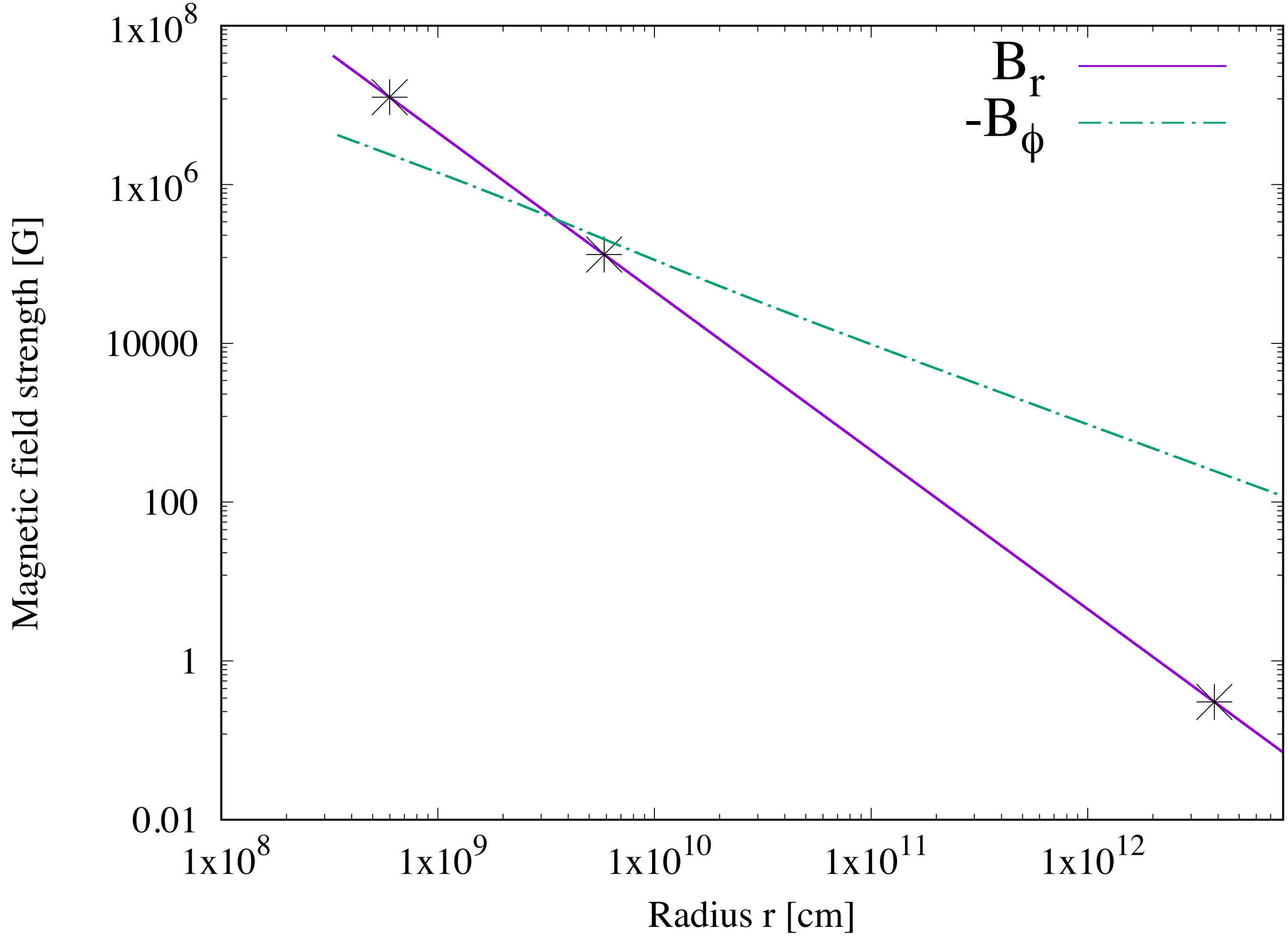
Liner scale

Log scale



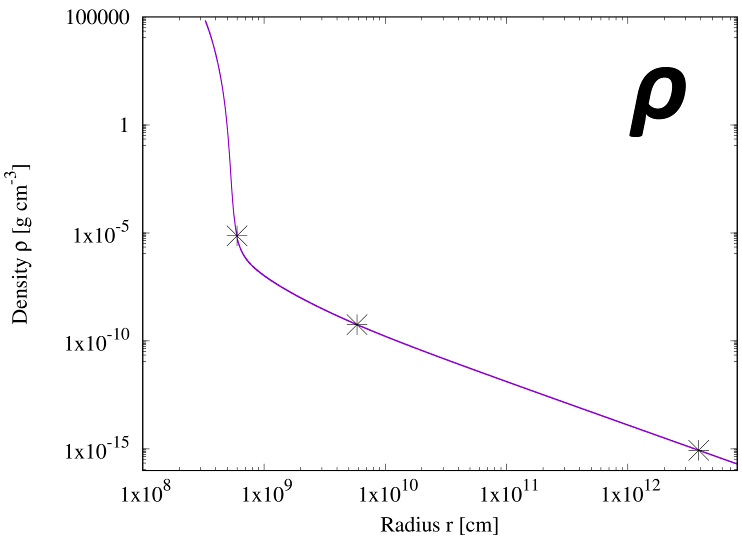
$$M_* = 1.25\, M_\odot,\ R_* = 3.3 \times 10^8\,\mathrm{cm},\ B_* = 4.2 \times 10^7\, G,\ \Omega = 0.5\,\mathrm{s}^{-1},\ \text{and} \quad \dot{M} = 6 \times 10^{-6}\, M_\odot\,\mathrm{yr}^{-1}$$

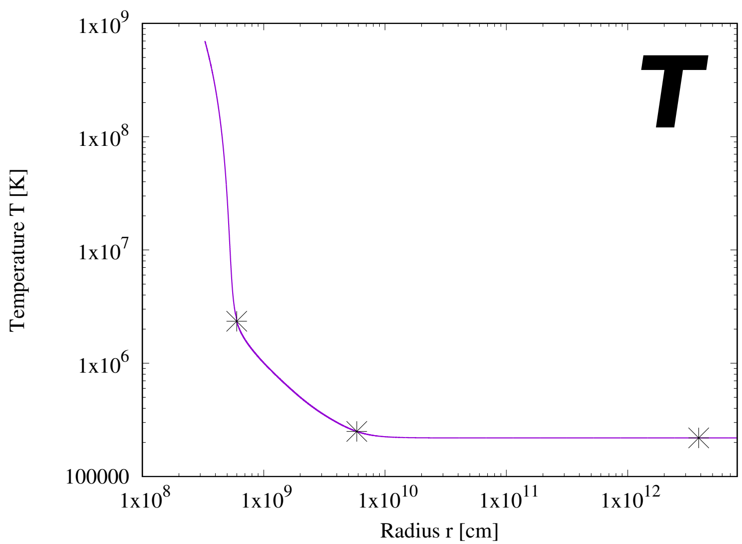
The WD J005311 wind : B_r & B_φ

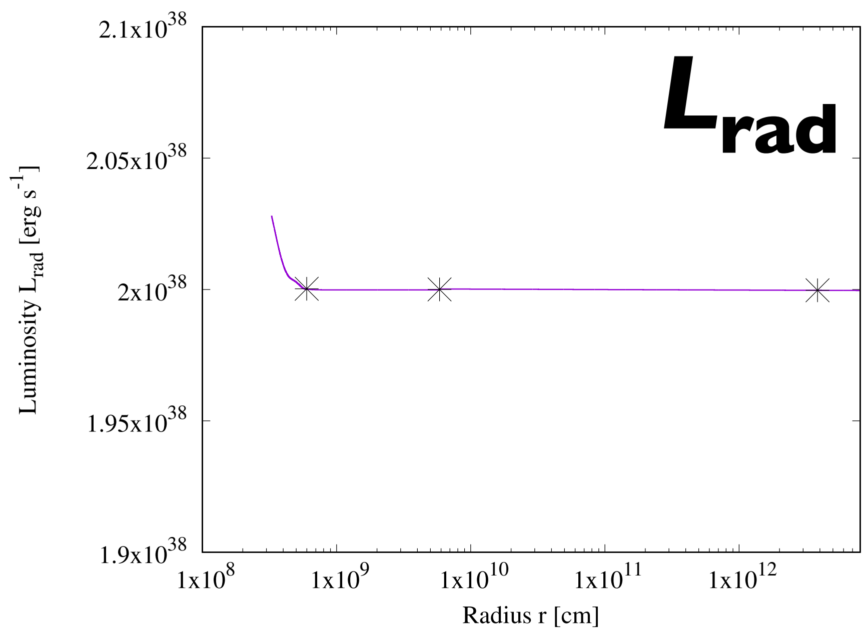


$M_* = 1.25\, M_\odot,\ R_* = 3.3 \times 10^8\,\mathrm{cm},\ B_* = 4.2 \times 10^7\, G,\ \Omega = 0.5\,\mathrm{s}^{-1}$, and $\dot{M} = 6 \times 10^{-6}\, M_\odot\,\mathrm{yr}^{-1}$

The WD J005311 wind : ρ, T, L_{rad}

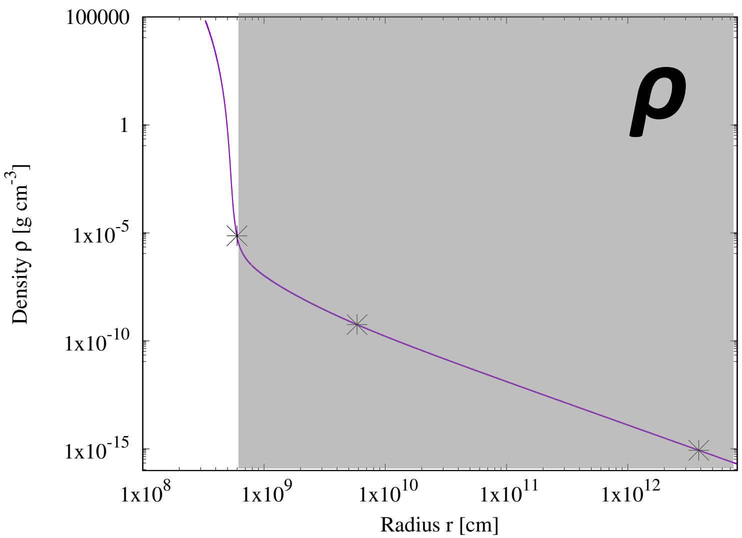


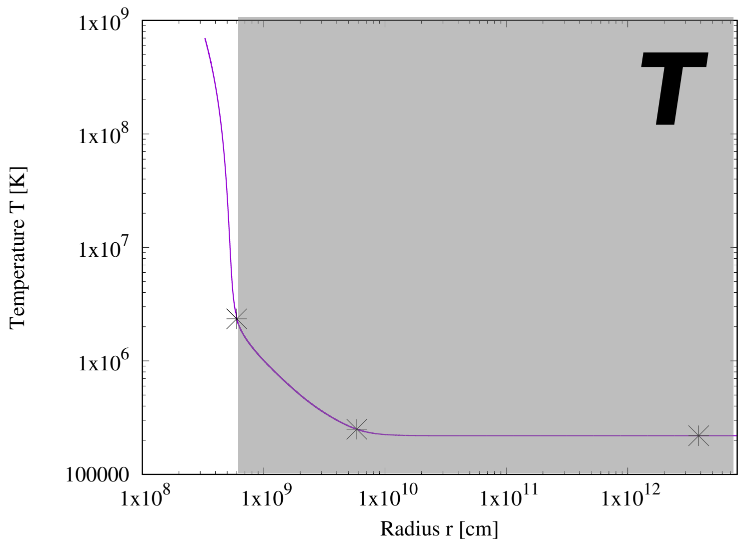


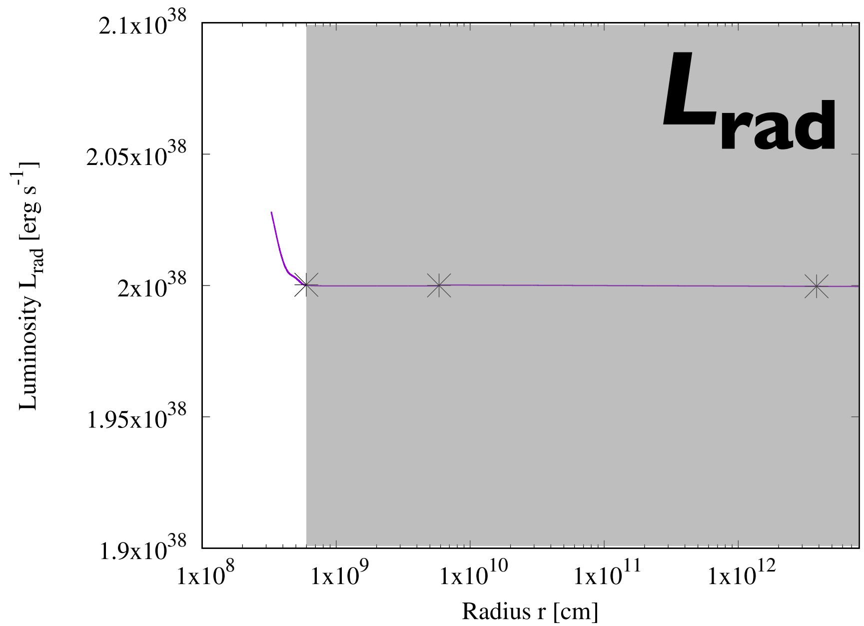


$M_* = 1.25\,M_\odot,\ R_* = 3.3\times10^8\,\mathrm{cm},\ B_* = 4.2\times10^7\,G,\ \Omega = 0.5\,\mathrm{s}^{-1},$ and $\dot{M} = 6\times10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$

The WD J005311 wind : ρ, T, L_{rad}







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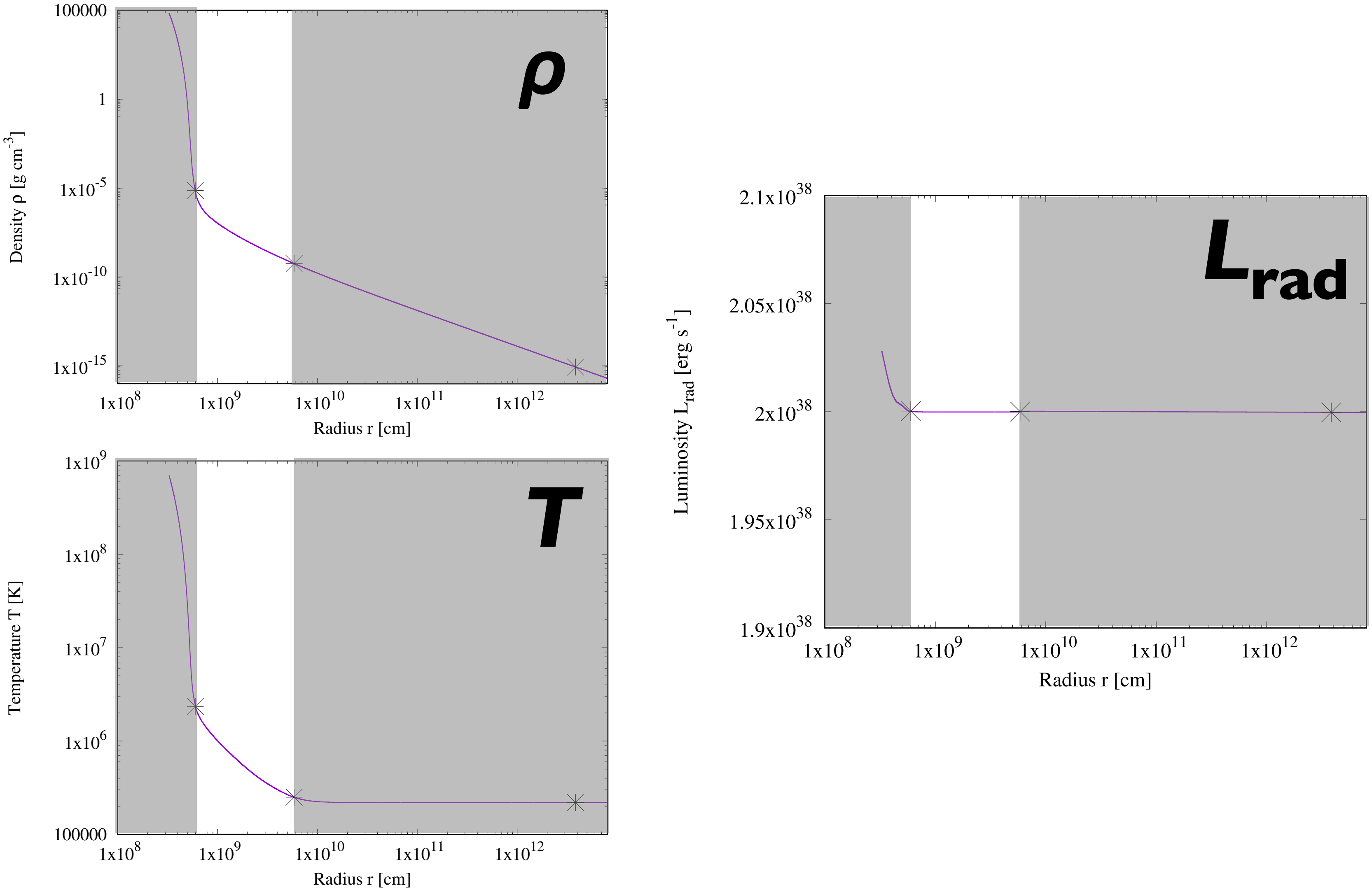
The WD J005311 wind : ρ, T, L_{rad}



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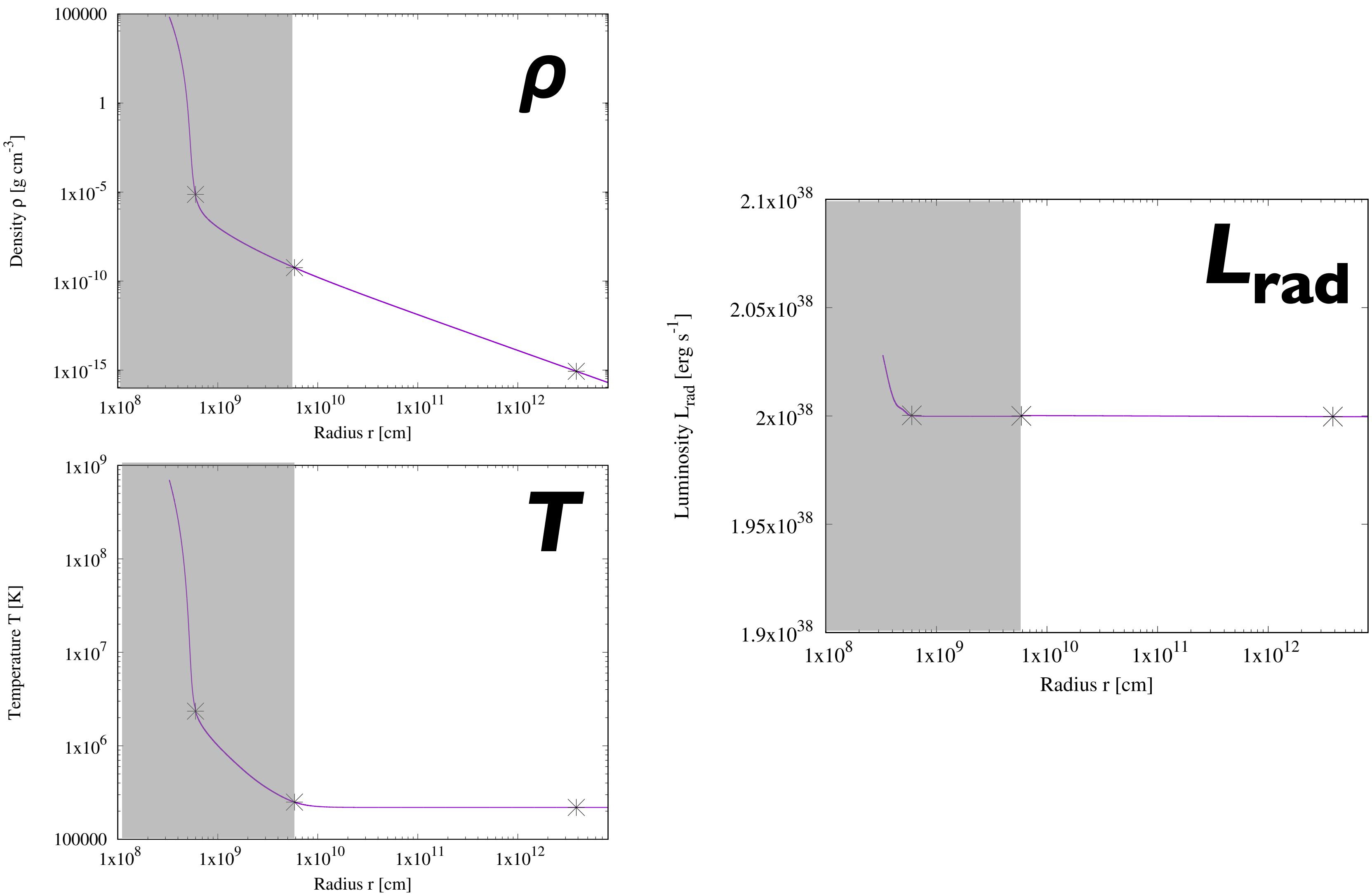
The WD J005311 wind : ρ, T, L_{rad}



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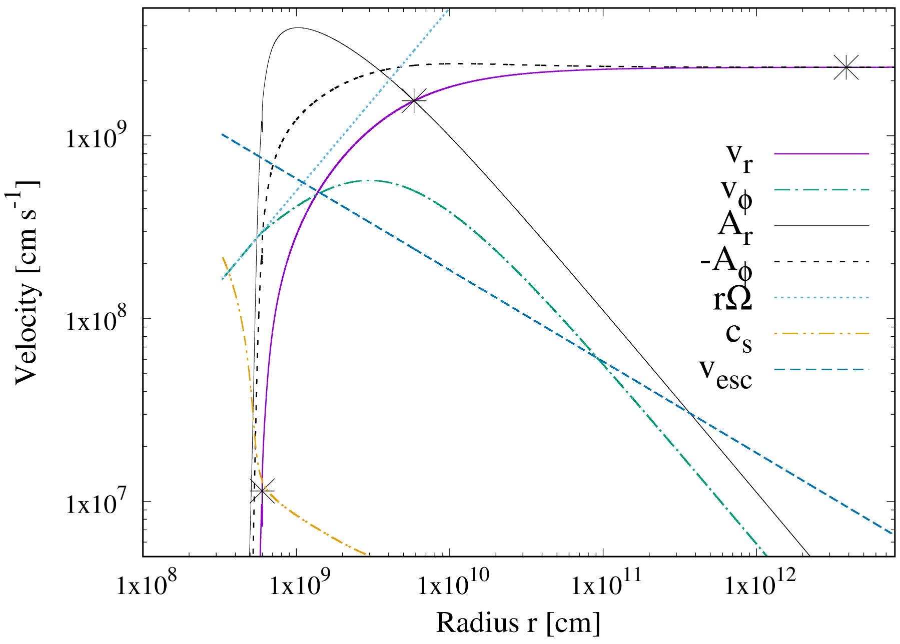
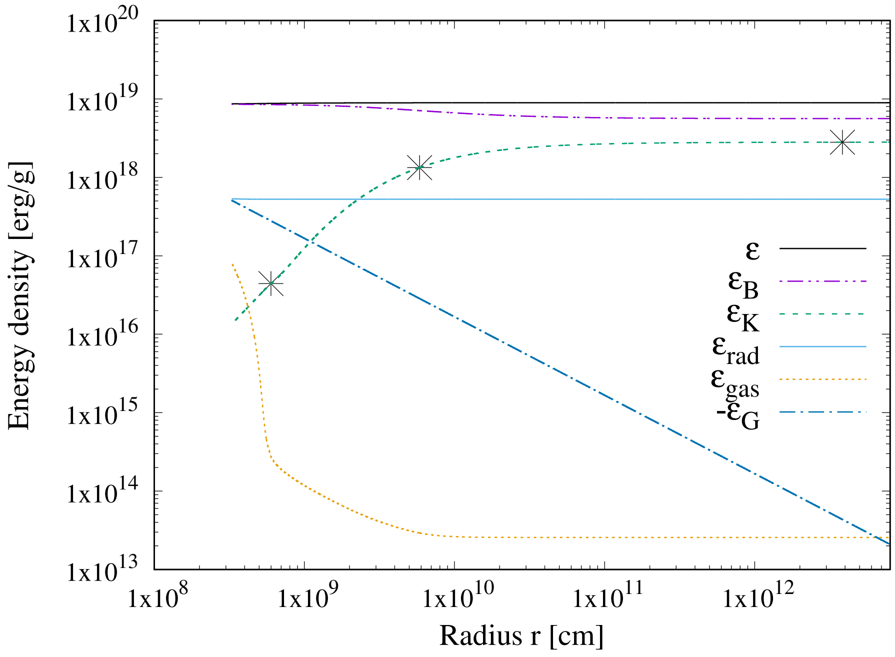
The WD J005311 wind : How is it accelerated?





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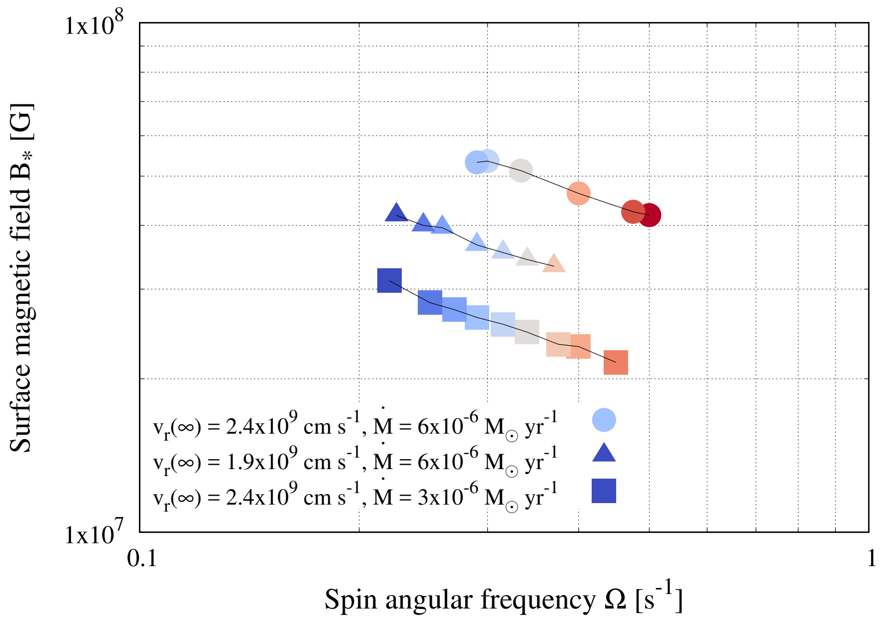
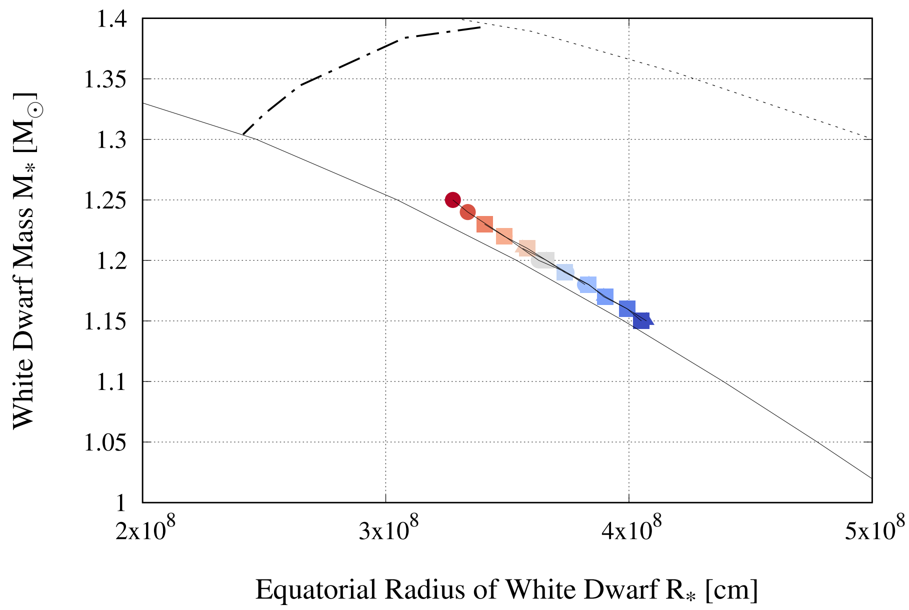
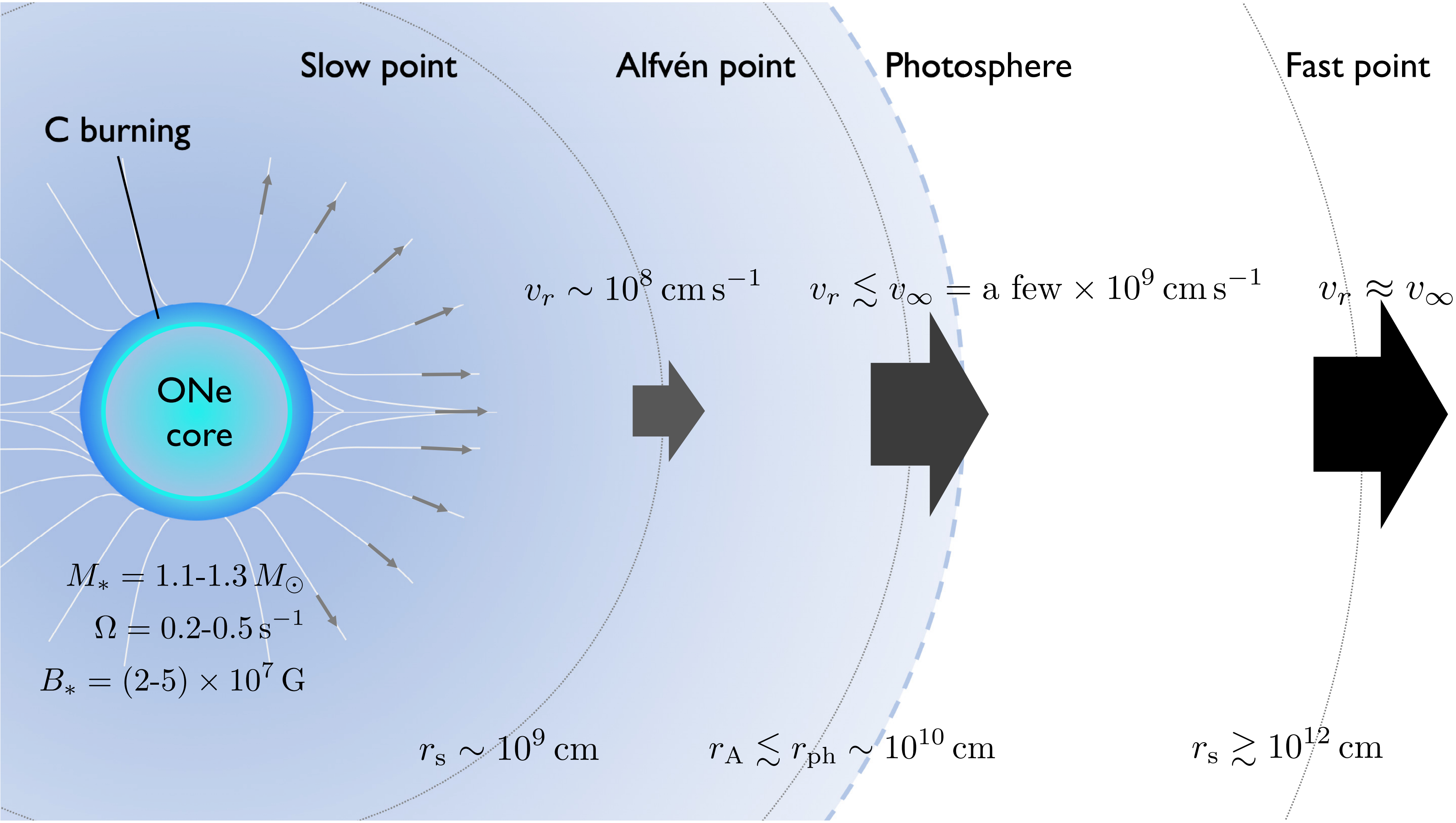
The WD J005311 wind : Allowed parameter region





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

Lessen learned

- 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.

Still, there should be ~ 100 of massive WD merger remnants in the Galaxy…

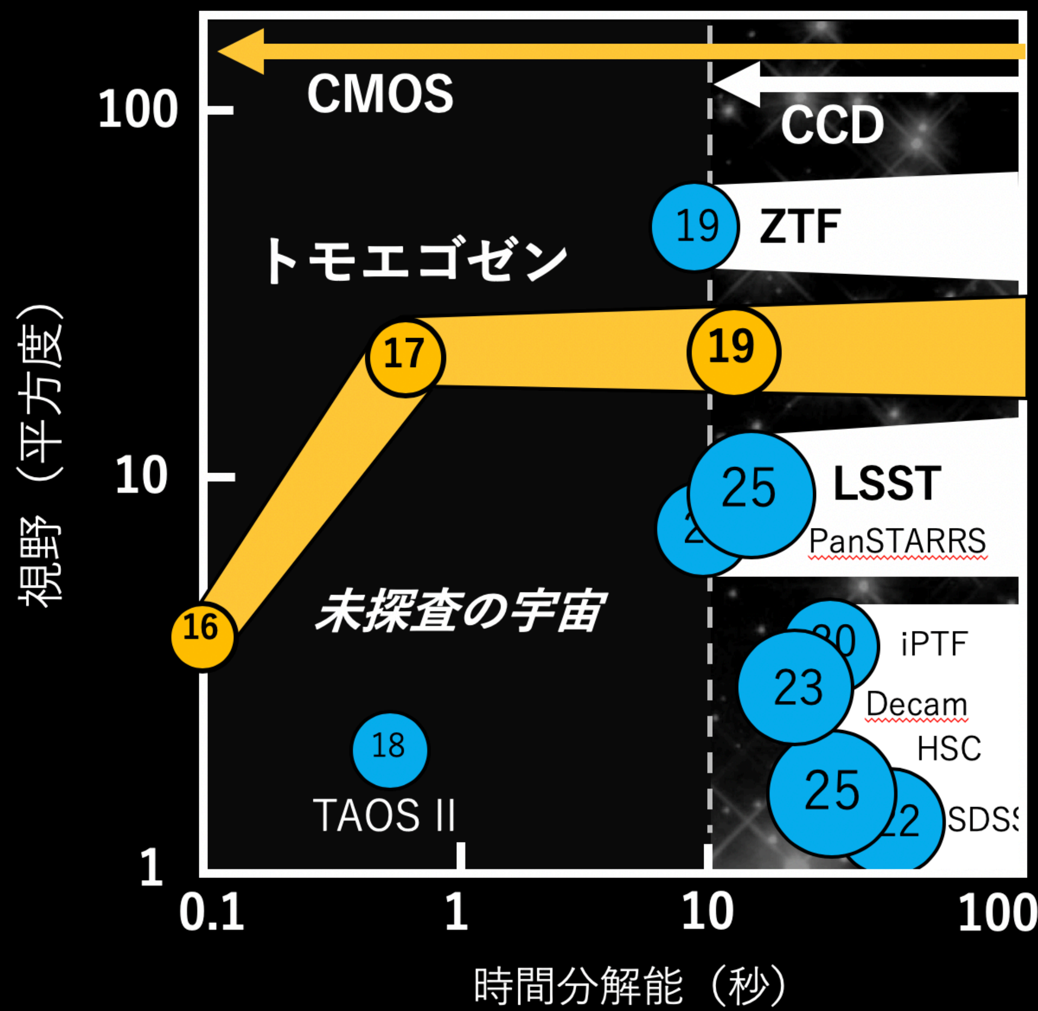
HeSO

(the Hertz Spinning Object survey)

with

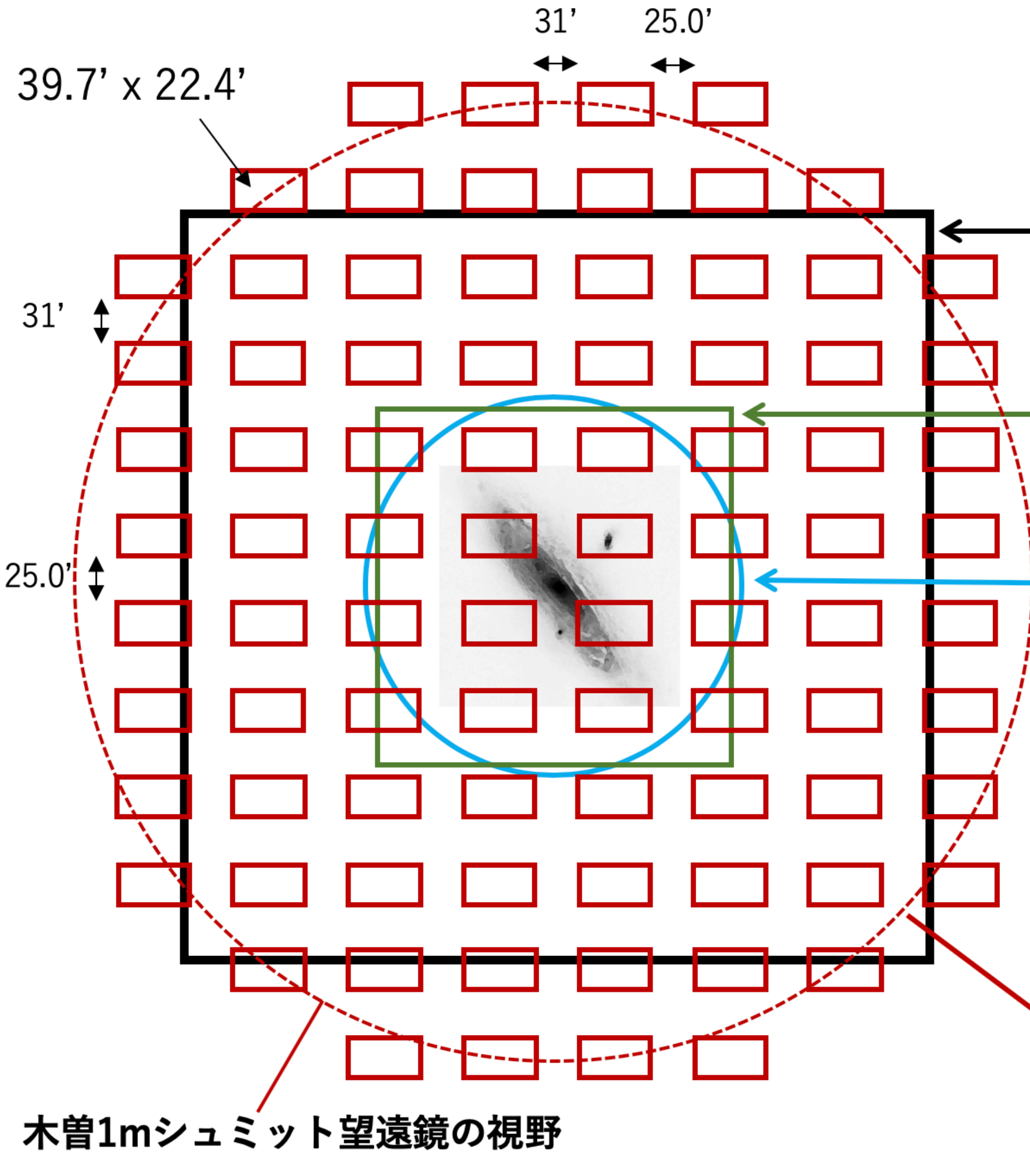
TOMO·E GOZEN

突発現象の探査能力の比較



丸の中の数字は検出限界等級

広視野装置の視野の比較



ZTF (1.2m) , 47平方度, 2018-
,
AΩ ＝ 40 , Δ τ ～ 1日, **CCD**

Pan-STARRS (1.8m), 9平方度,
AΩ ＝ 15 , Δ τ ～1日, **CCD**

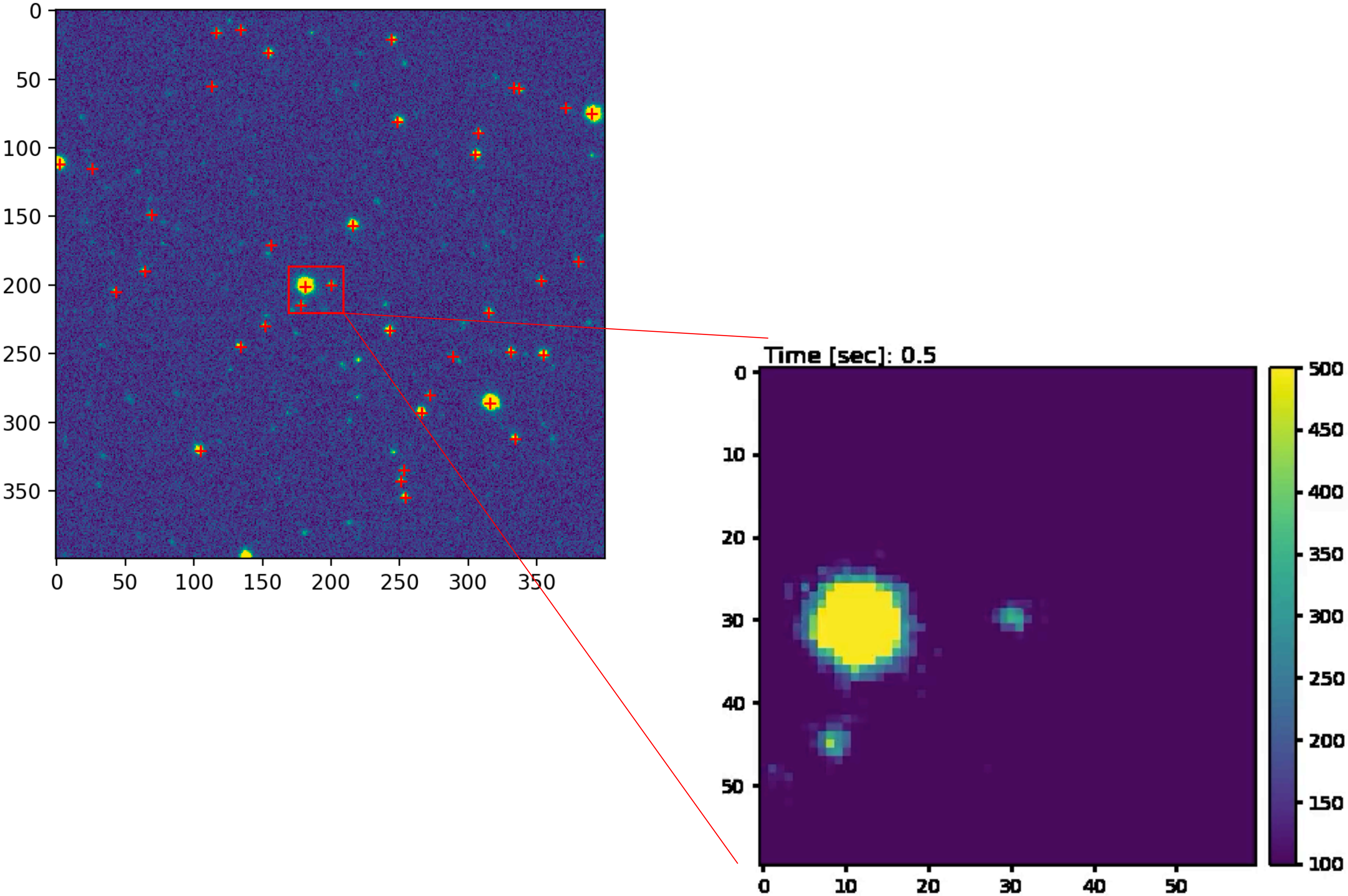
LSST (8.4m), 9.6 平方度, 2023-
,
AΩ ＝ 320 , Δ τ ～ 1時間,
CCD

トモエゴゼン
Φ9度内の20平方度
AΩ ＝ 28, Δ τ ～サブ秒
CMOSセンサ

Searching for yet-to-be-discovered sub-minute variability of white dwarfs

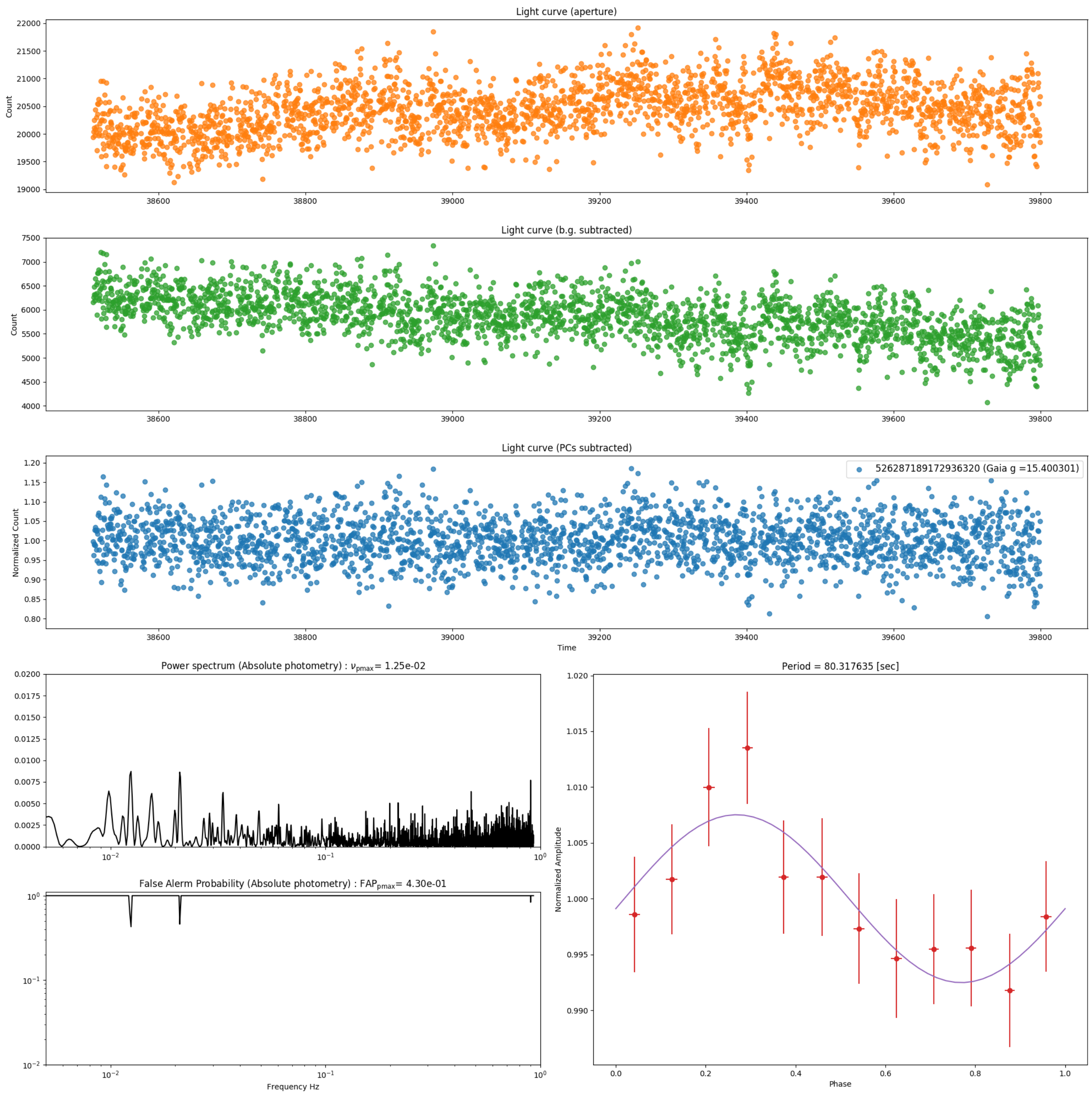
- Spin (close to the mass shedding limit)
  - ✓ (Magnetohydro)dynamics of formation and merger
  - ✓ A new class of high energy source
- (p-mode) oscillation
  - ✓ New asteroseismology to probe the interior
- Tidal disruption (of asteroids)
- Transits (of "habitable" planets)
  - ✓ Future of our solar system?

HeSO

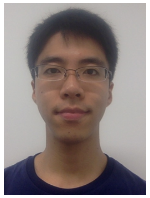


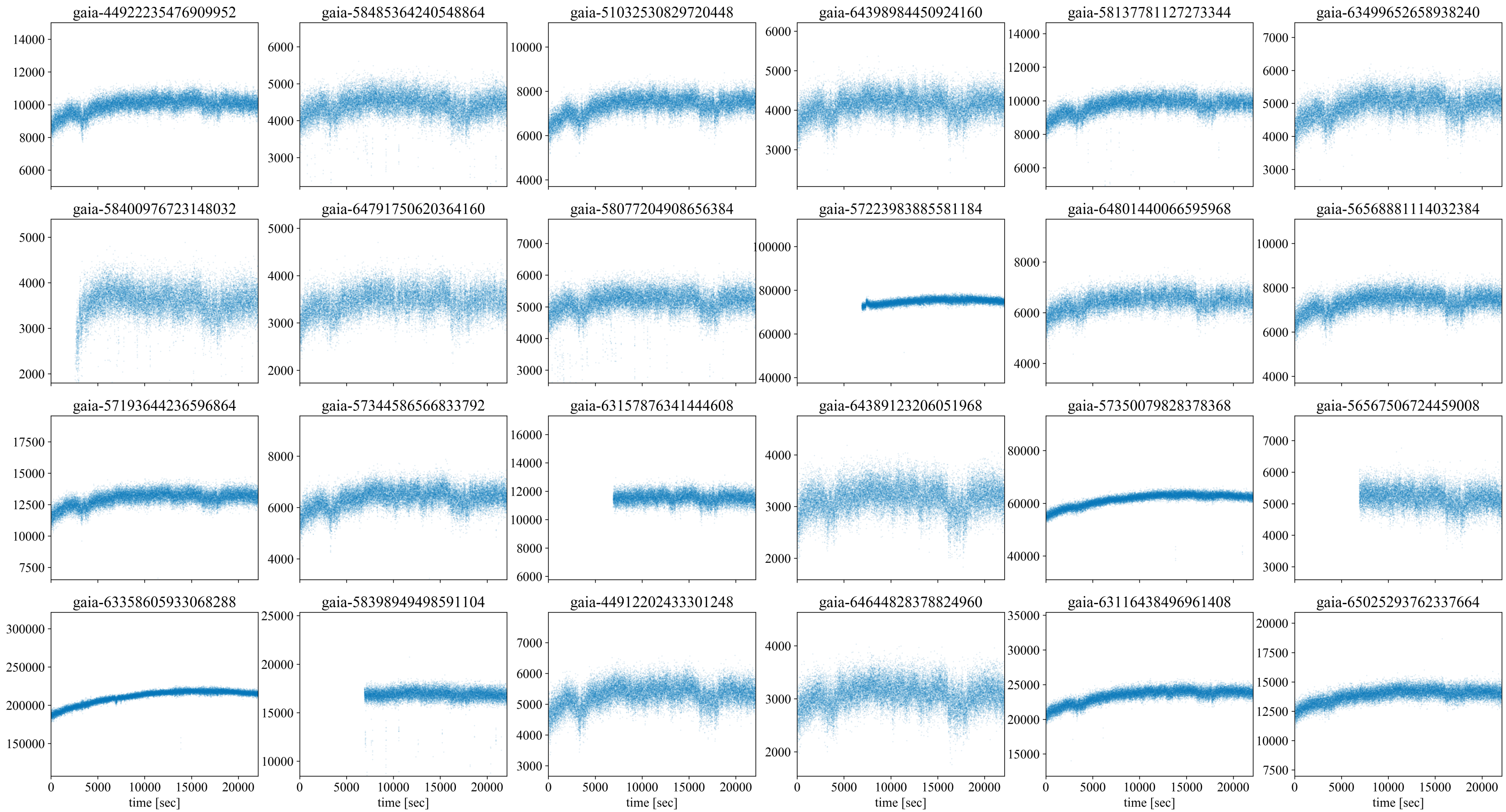
Tomo-e observation of J005311

Timing analysis of J005311



The survey has started (~50TB/night). The pipeline construction underway …





We need more people. If you are interested in the data, please let me know!