Winds of hot subdwarfs: metallicity is the key

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Stellar wind of hot stars

Puls et al. (2008):

- supersonic flow from hot stars
- accelerated due to the absorption of radiation mainly in the resonance lines of heavier elements (C, N, O, or Fe)
- found in OBA stars, WR stars, CSPNs, and sdO stars

Stellar wind of hot stars

Puls et al. (2008):

- most important wind parameters are mass-loss rate $\dot{M}$ and terminal velocity v_∞
- wind mass-loss rate $\dot{M}$ depends on
  - the stellar luminosity L

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- the terminal velocity v_∞ proportional to the escape velocity v_{esc}

$$v_\infty \sim v_{\mathrm{esc}}$$

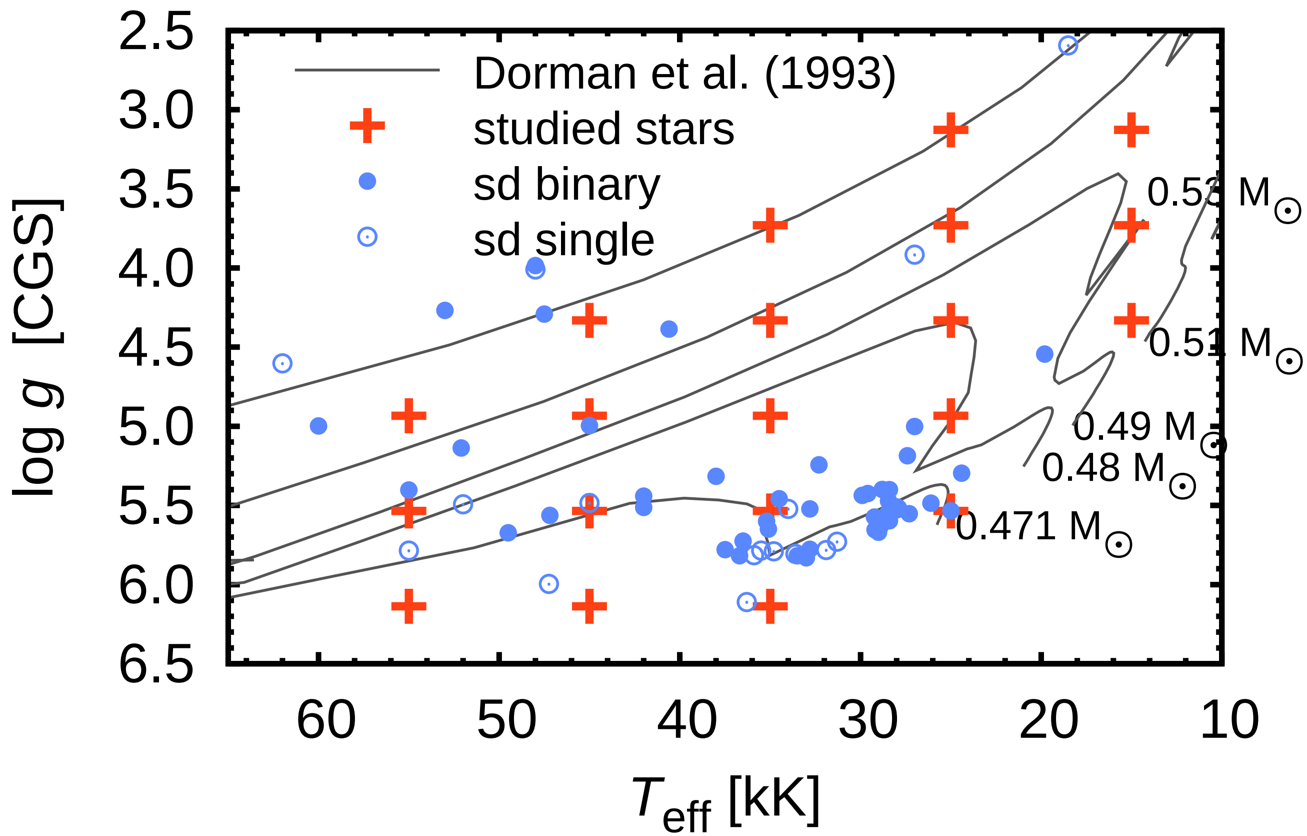
NLTE wind models

(Krtička & Kubát 2010)

- spherically symmetric stationary wind models
- level populations derived from kinetic equilibrium (NLTE) equations
- radiative force calculated using the comoving frame (CMF) radiative transfer equation
- wind density, velocity and temperature structure derived from hydrodynamical equations

$\Rightarrow$ enable to predict wind mass-loss rate $\dot{M}$, and terminal velocity v_∞

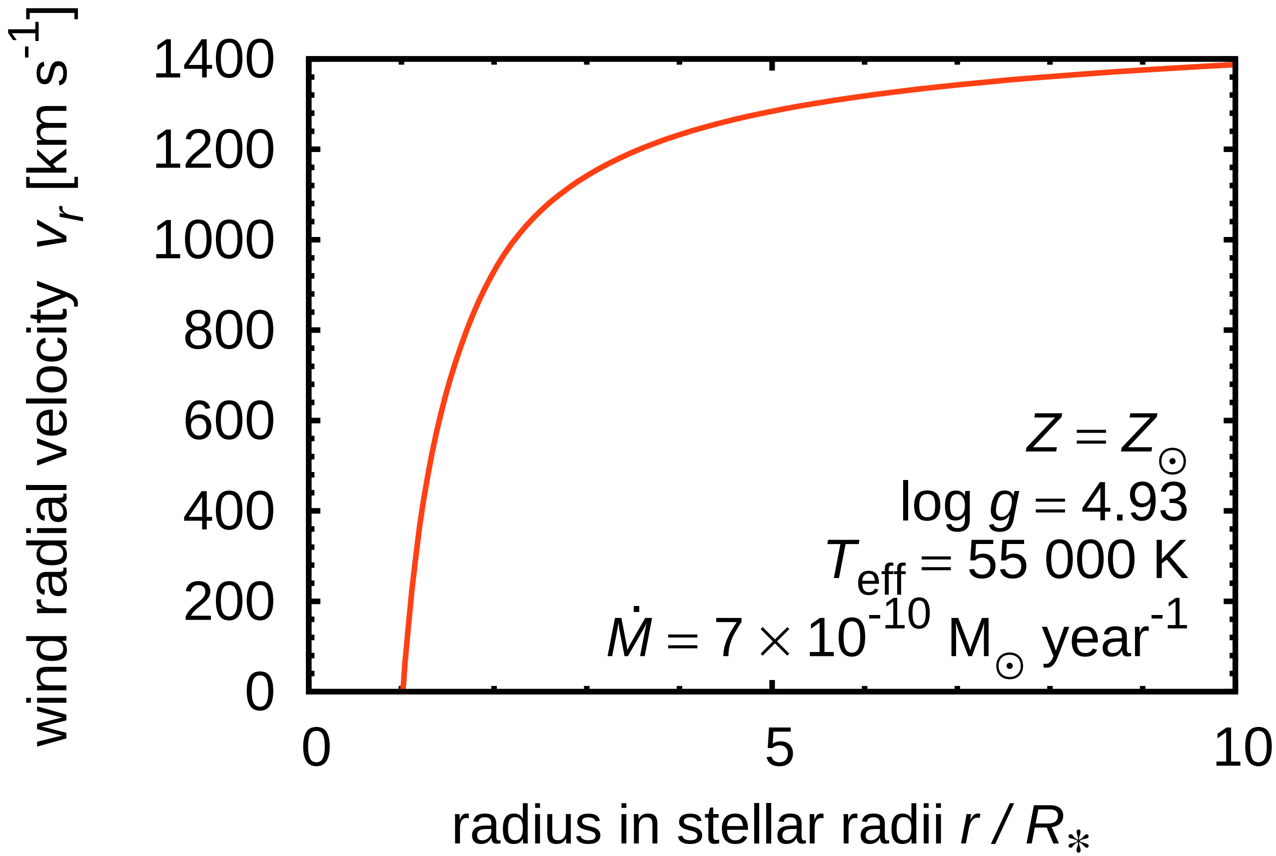
Model stars: log g vs. T_{eff}



- stellar mass $M = 0.5\,\mathrm{M}_\odot$
- metallicity Z: $0.1\,Z_\odot$, $Z_\odot$, $10\,Z_\odot$
- helium content $N(\mathrm{He})/N(\mathrm{H})$: 0.085

Example of wind model

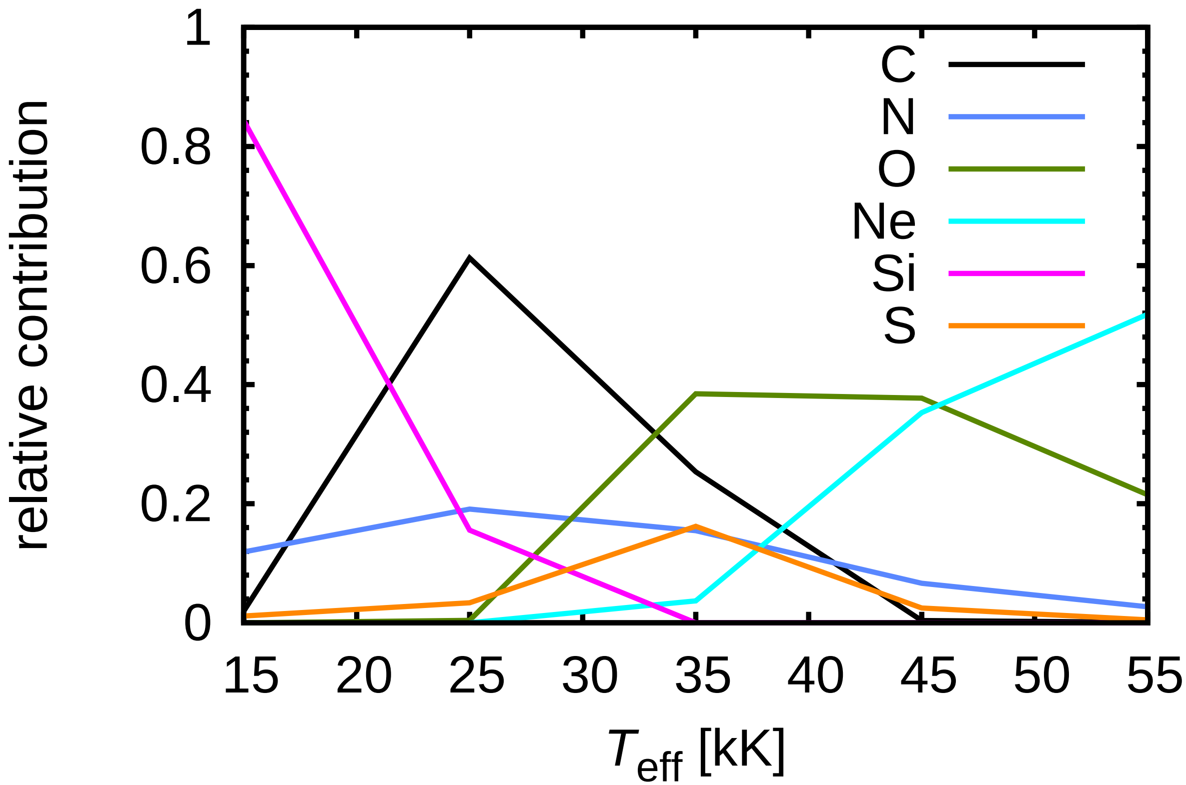
- wind radial velocity



- low luminosity ⇒ low mass-loss rate

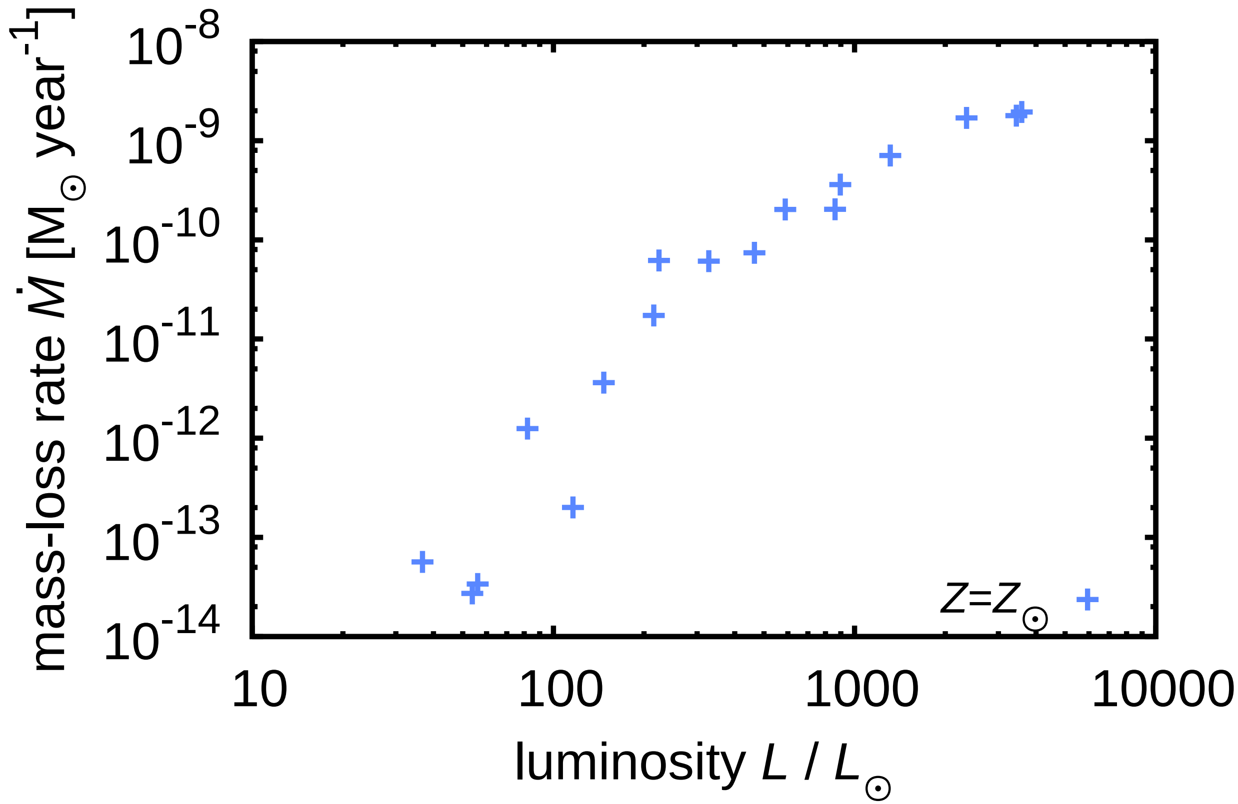
Contribution of different elements

- relative contribution of individual elements to the radiative force for $Z = Z_\odot$



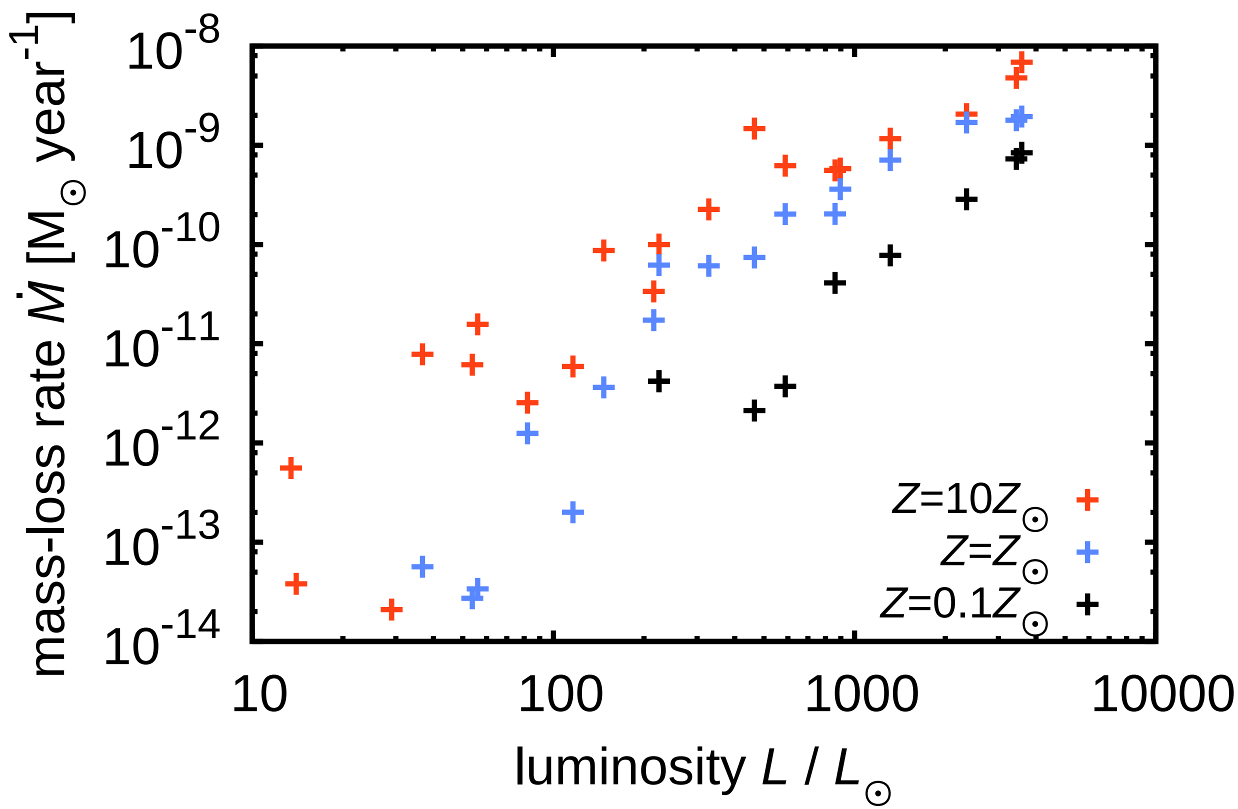
- different elements contribute at different $T_{\rm eff}$
- mass-loss rate sensitive to the composition

Wind mass-loss rate



- mass-loss rate scales with stellar luminosity

Wind mass-loss rate



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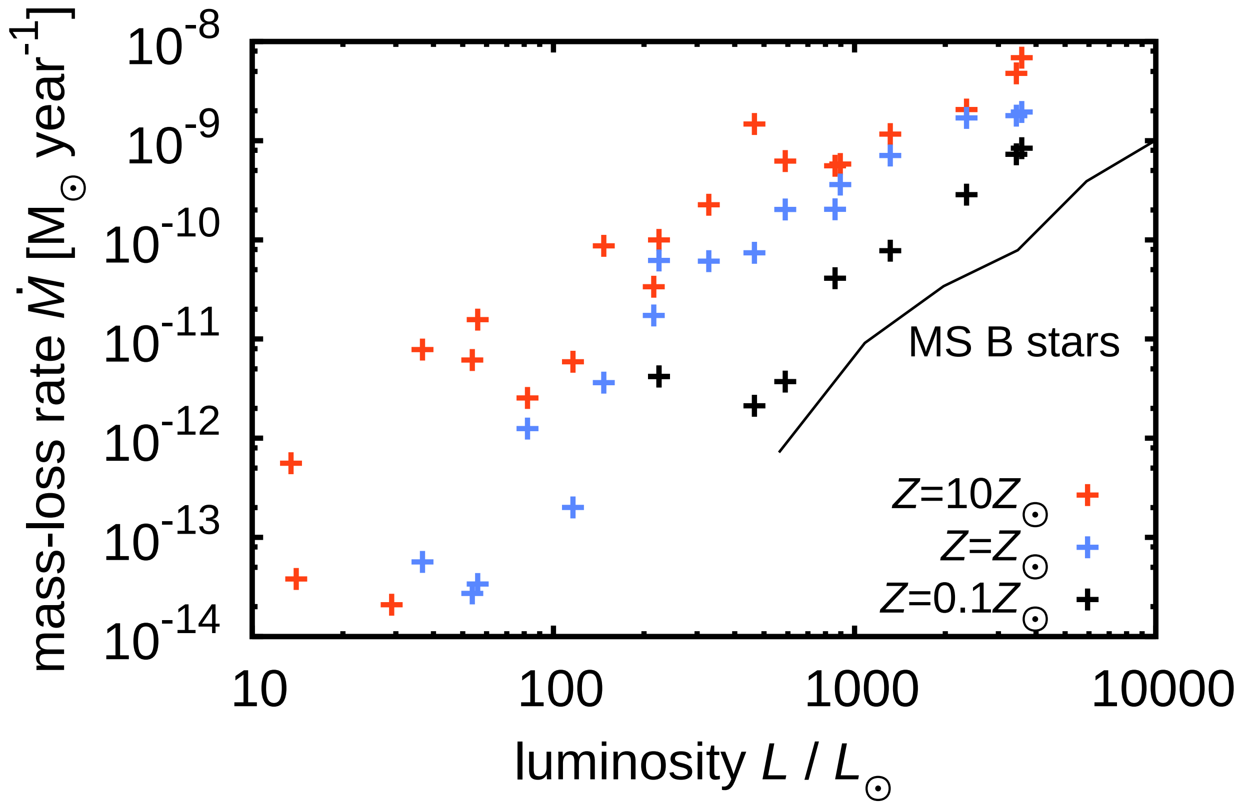


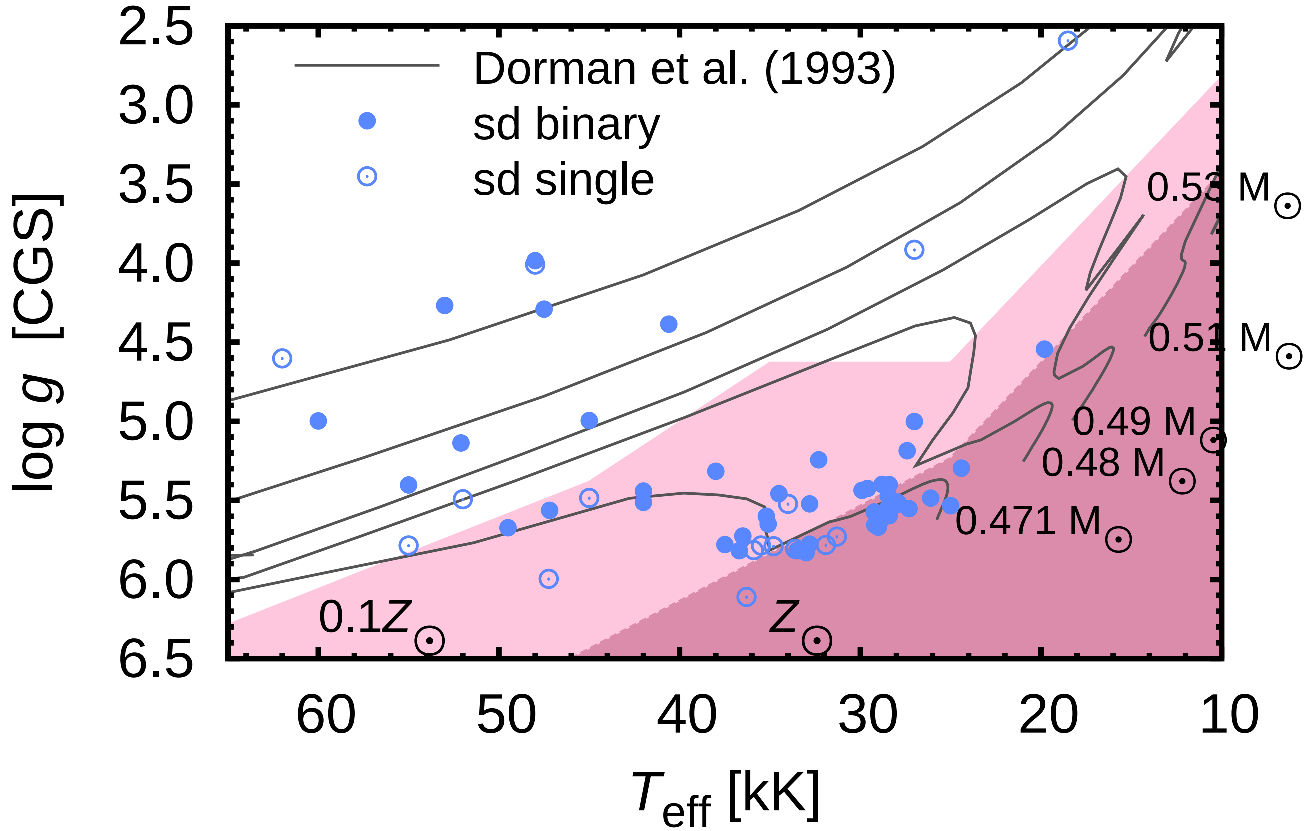
- mass-loss rate scales with stellar luminosity
- mass-loss rate depends on metallicity
- higher than for main-sequence B stars with the same luminosity

Wind mass-loss rate

- mass-loss rate recipe

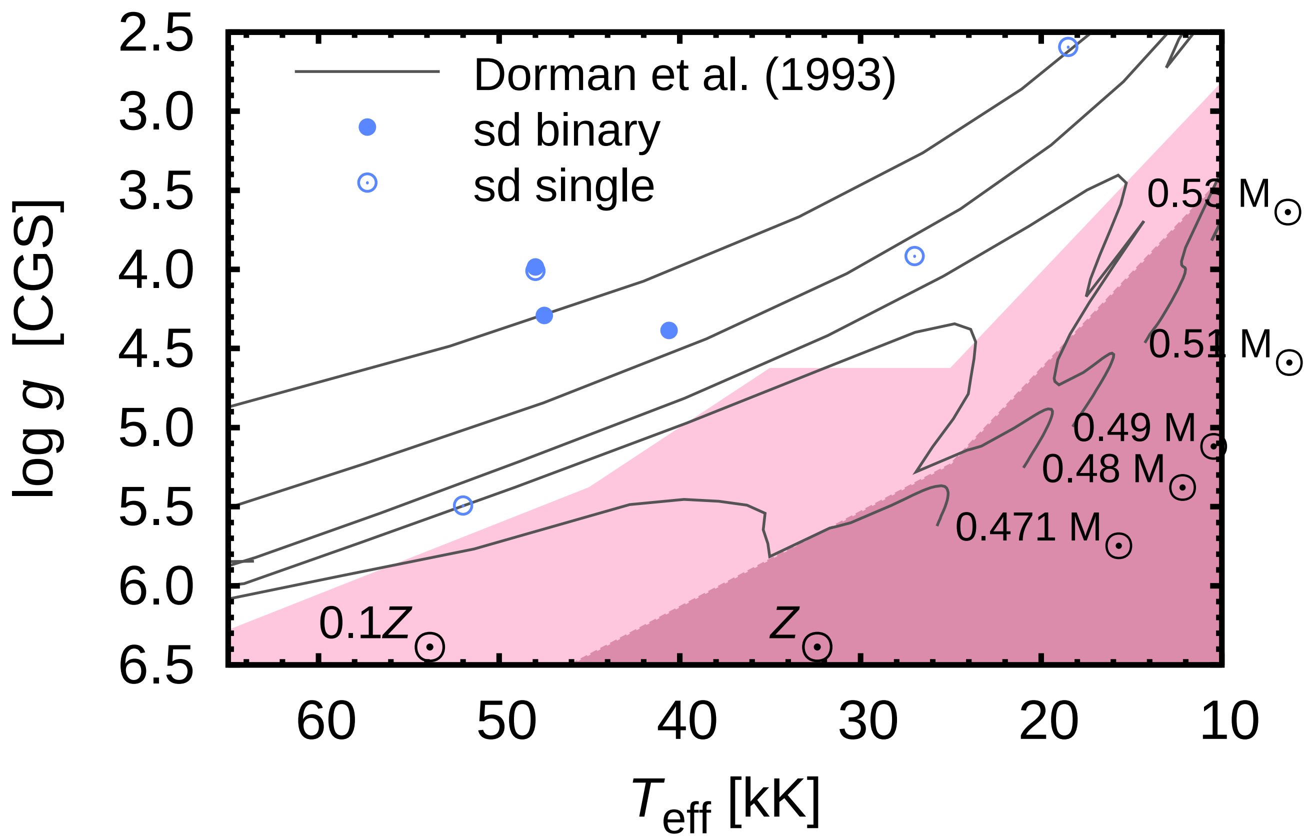
$$\log\left(\frac{\dot{M}}{1\,\mathrm{M}_\odot\,\mathrm{year}^{-1}}\right) = -12.6 + 1.4\log\frac{Z}{Z_\odot} + \\ + \left(3.8 - 1.4\log\frac{Z}{Z_\odot}\right)\log\left(\frac{L}{10^2 L_\odot}\right) + \\ + \left(-1.1 + 0.6\log\frac{Z}{Z_\odot}\right)\log^2\left(\frac{L}{10^2 L_\odot}\right) + \\ + 1.1\log\left(\frac{T_\mathrm{eff}}{10^4\,\mathrm{K}}\right)$$

Wind domains: log g vs. $T_{\rm eff}$



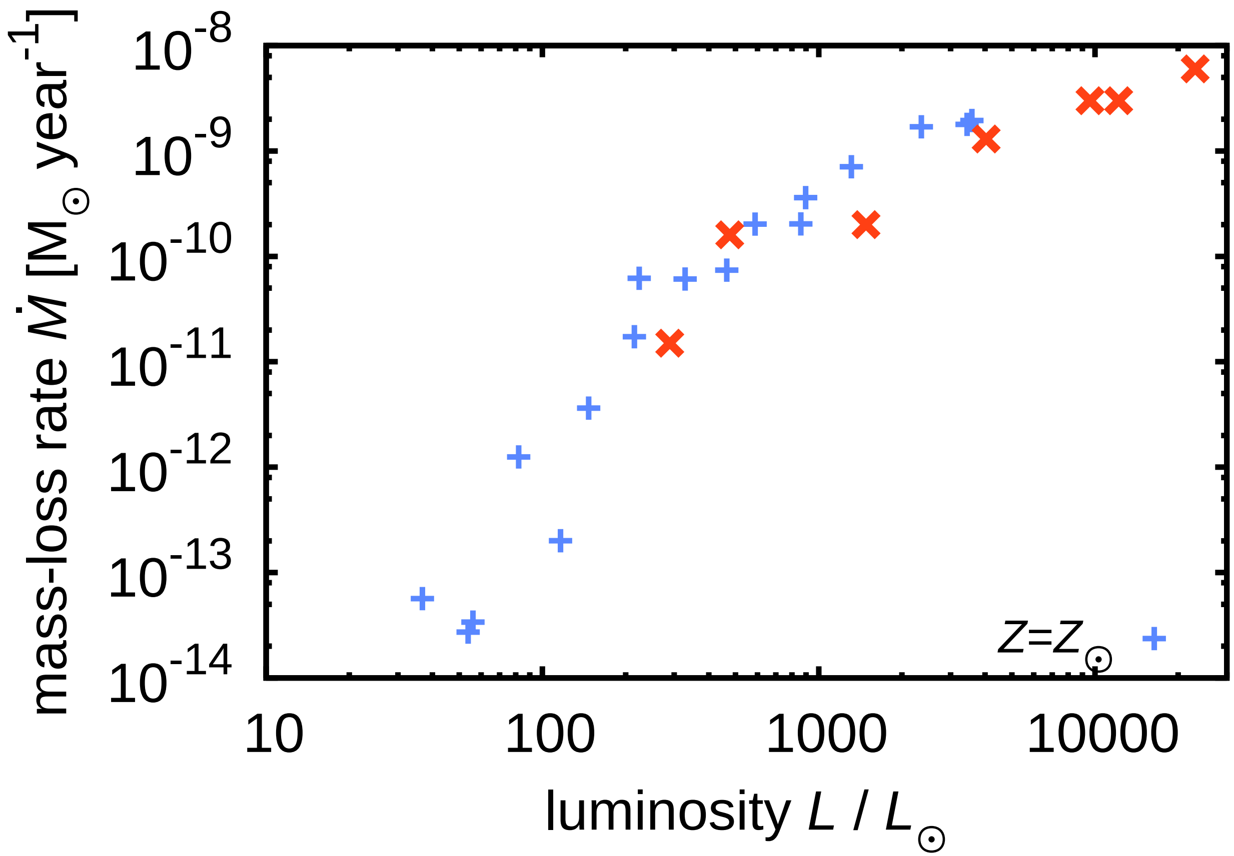
- wind possible only in white areas ($g^{\rm rad} > g$)
- forbidden (red) region with $g^{\rm rad} < g$

Stars with winds: $T_{\rm eff}$ vs. log g



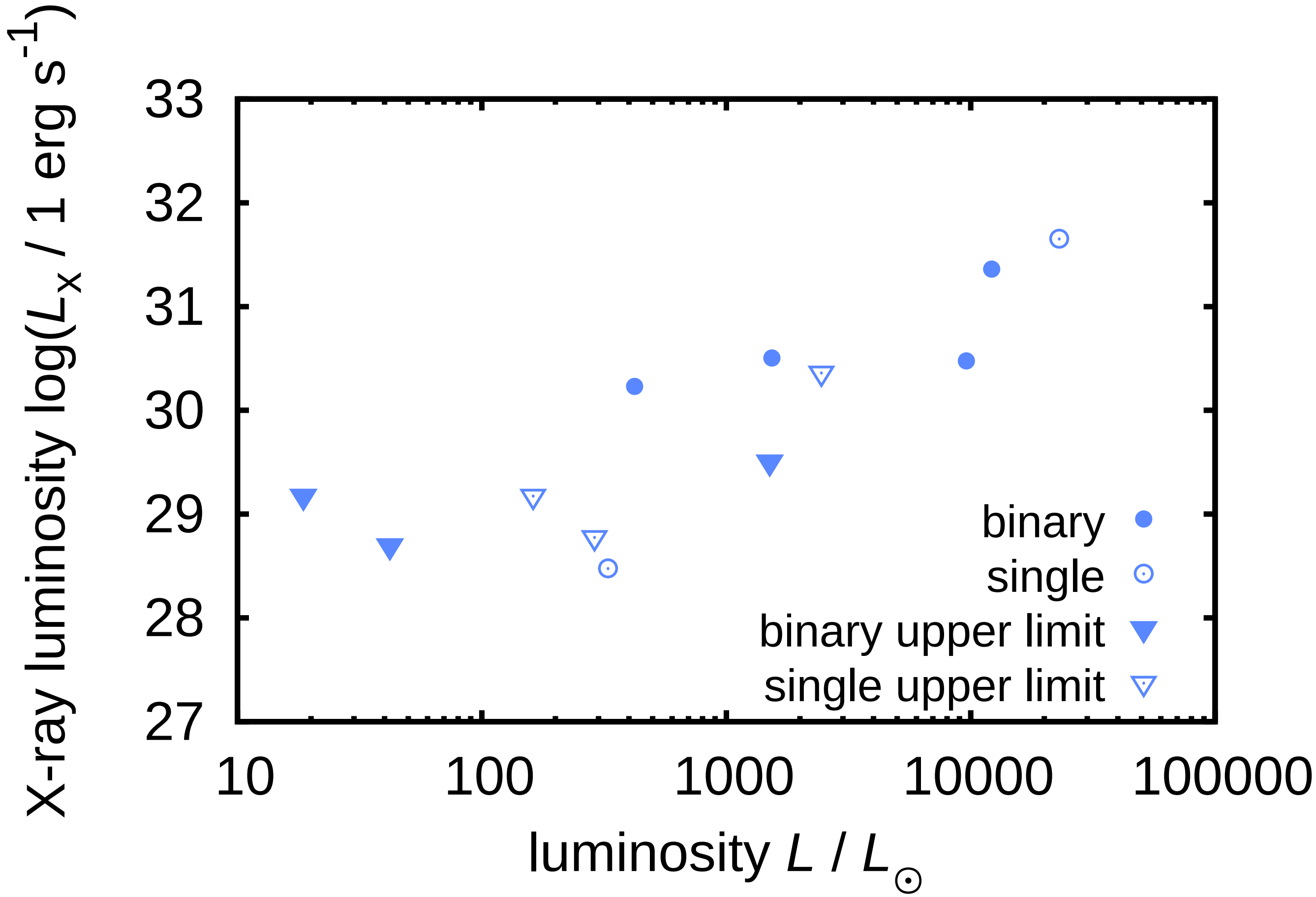
- stars with observed wind in the allowed region

Test against observations: $\dot{M}$



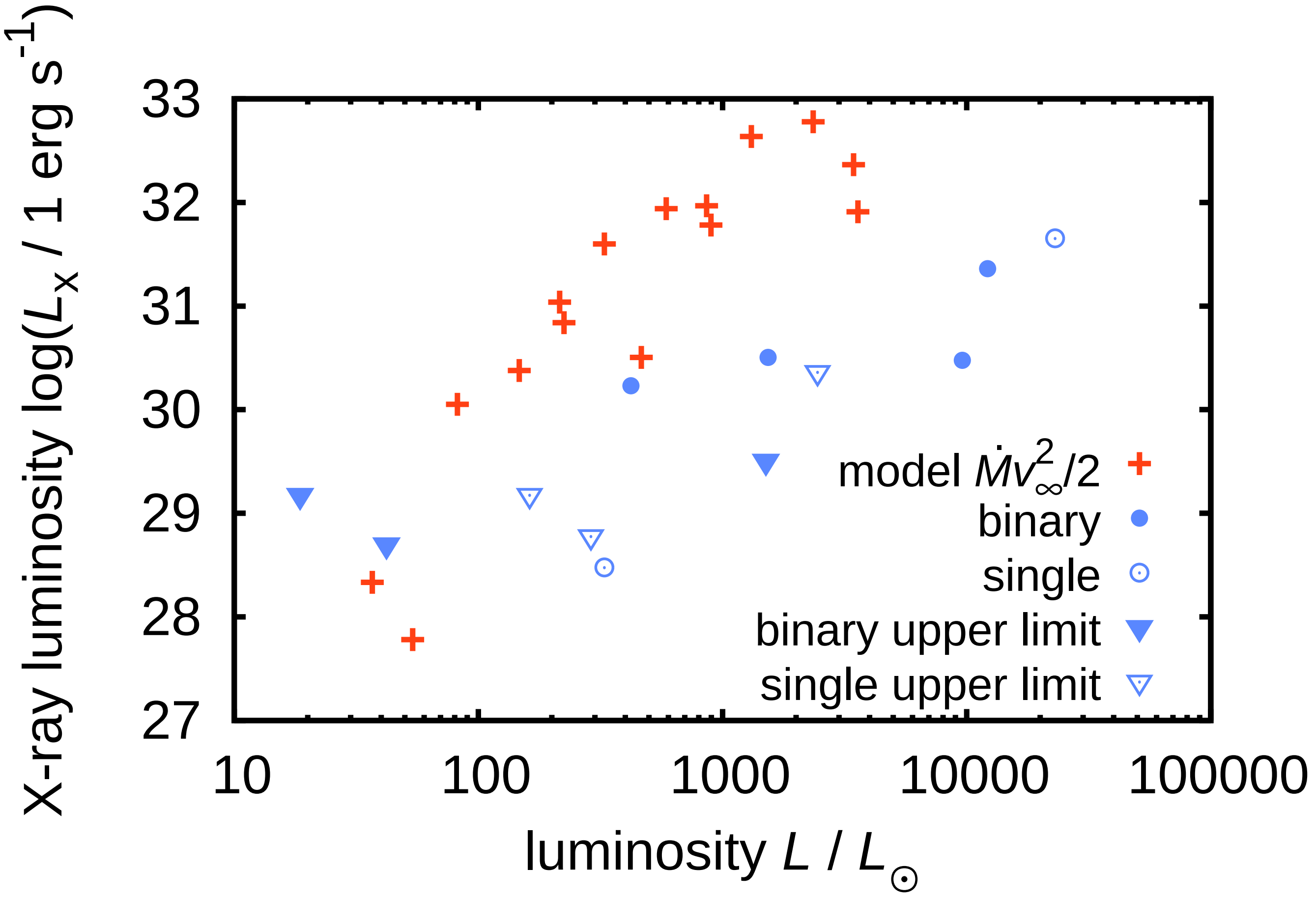
- mass-loss rates: Jeffery & Hamann (2010), Lanz et al. (1997), Gruschinske et al. (1983)

Test against observations: L_X



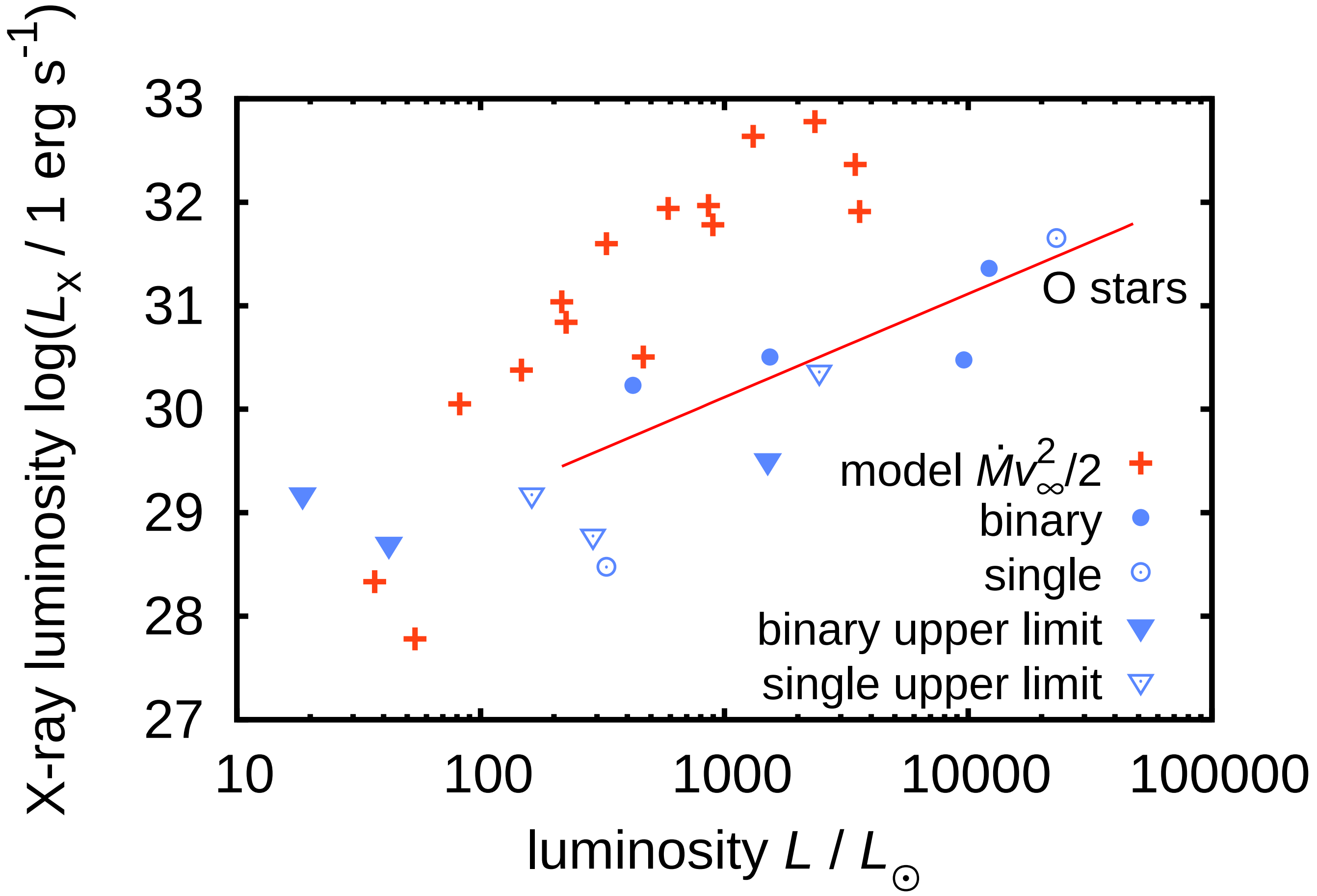
- X-ray luminosities: La Palombara et al. (2012), Montez et al. (2010), Mereghetti et al. (2013), La Palombara et al. (2014)

Test against observations: L_x



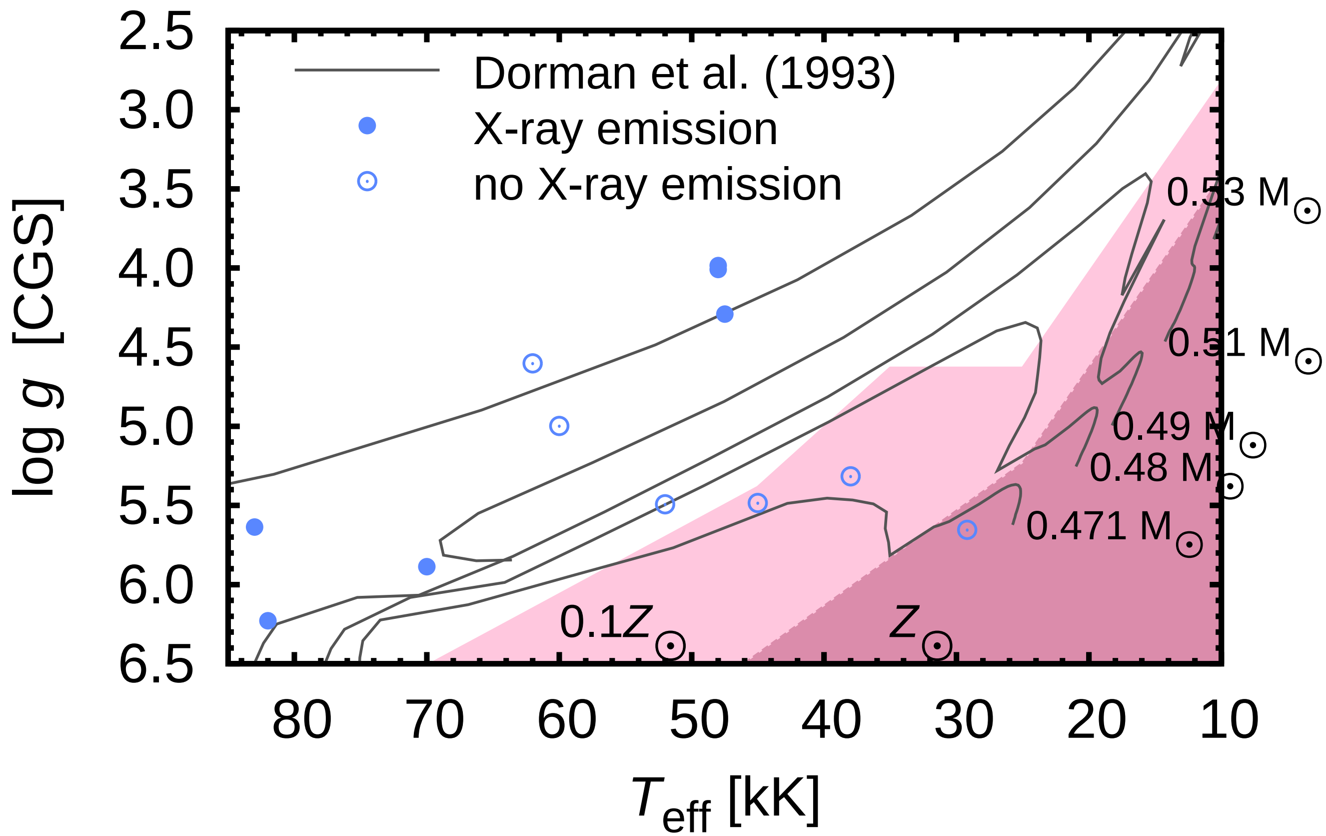
- X-rays may be produced in the wind ($\frac{1}{2}\dot{M}v_\infty^2 > L_x$)

Test against observations: L_x



- X-ray luminosity corresponds to O stars (Nazé 2009)

X-ray emission: log g vs. $T_{\rm eff}$



- X-ray emission only in the wind domain

No X-ray emission: CD –30° 11223

- CD –30° 11223: sdB+WD binary
- Bondi-Hoyle-Lyttleton accretion of the wind on WD companion
- X-ray luminosity (a is the orbital separation)

$$L_\mathrm{x} = G\frac{M_\mathrm{WD}\dot{M}_\mathrm{acc}}{R_\mathrm{WD}} = \frac{1}{4}\frac{GM_\mathrm{WD}}{R_\mathrm{WD}}\dot{M}\left(\frac{r_\mathrm{acc}}{a}\right)^2,$$

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(Mereghetti et al. 2014)

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  the accretion radius is $r_{\rm acc} = 2GM_{\rm WD}/v^2$
- no X-rays detected from CD –30° 11223: $L_x < 1.5 \times 10^{29}\,{\rm erg\,s^{-1}}$
- upper limit for the mass-loss rate $\dot{M} < 3 \times 10^{-13}\,{\rm M_\odot\,year^{-1}}$

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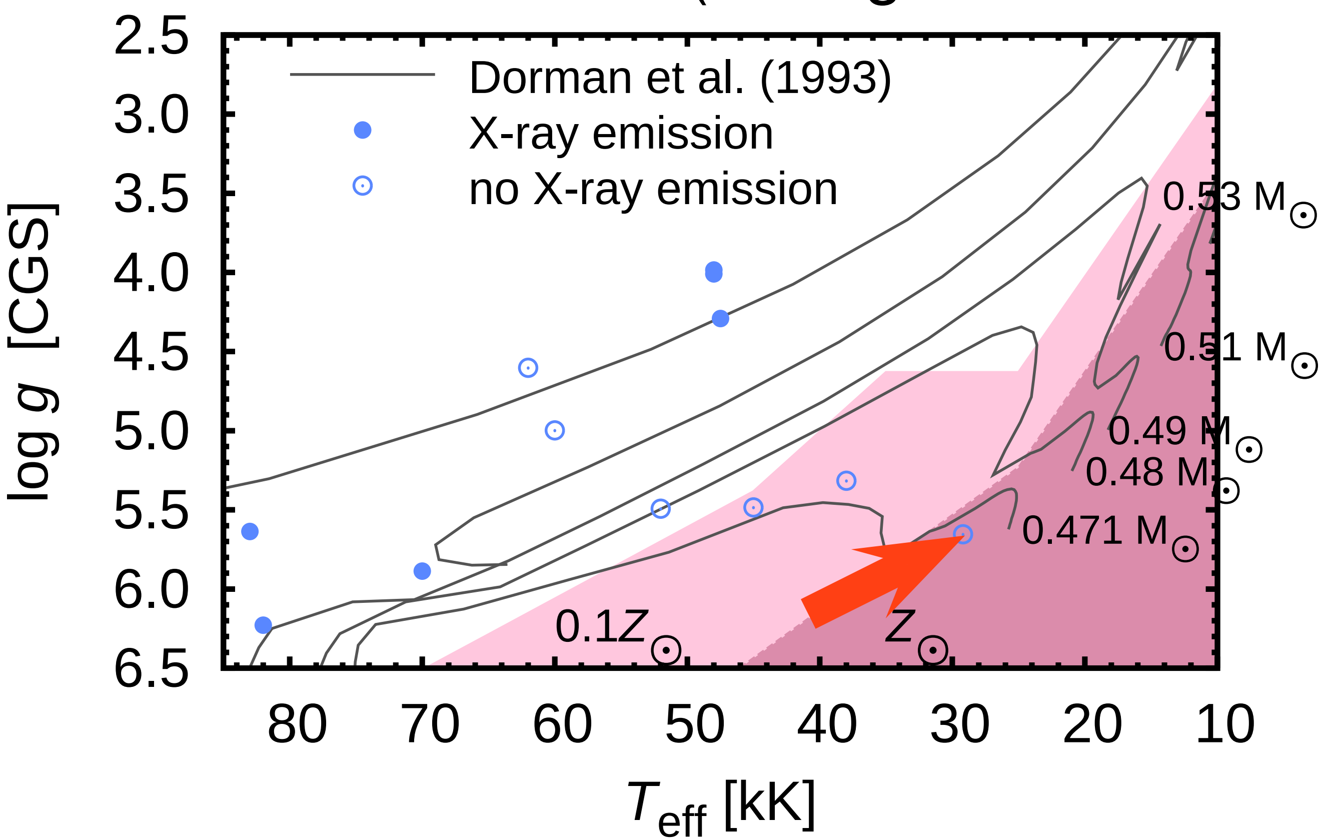
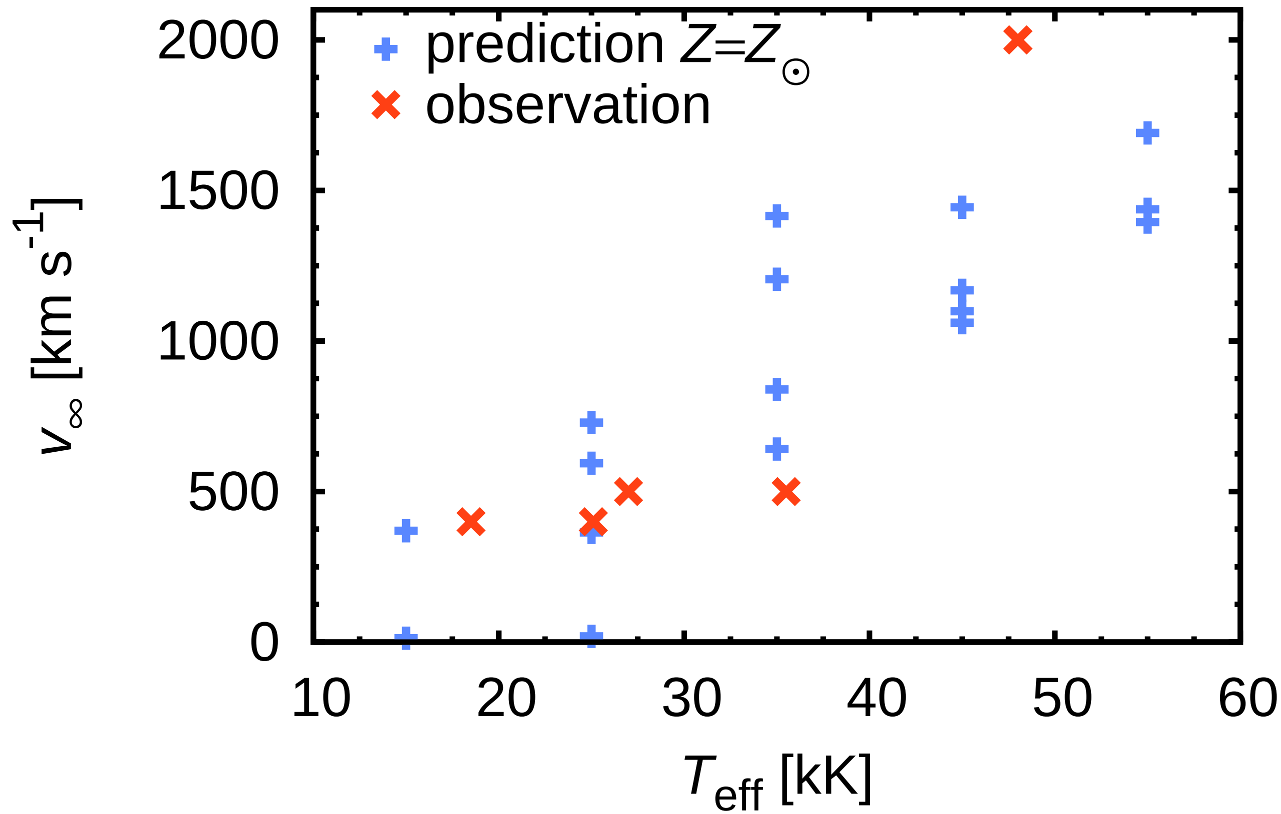


- no wind from the simulations

Test against observations: v_∞



- wind terminal velocity v_∞ proportional to v_{esc}
- decreases with T_{eff} due to decrease of v_{esc}
- observations: Jeffery & Hamann (2010)

Cherry on top: φ Per

- member of a rare group of sdO+Be binaries (Gies et al. 1998, Koubský et al. 2014)
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- member of a rare group of sdO+Be binaries (Gies et al. 1998, Koubský et al. 2014)
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- sdO star mass-loss rate $1.1 \times 10^{-9}\,\mathrm{M}_\odot\,\mathrm{year}^{-1}$
- Be star disk mass-loss rate $10^{-9}\,\mathrm{M}_\odot\,\mathrm{year}^{-1}$ (Granada et al. 2013)
- the disk and wind collide: momentum condition

$$\rho_{\mathrm{disk}} v_{\mathrm{disk}}^2 = \rho_{\mathrm{wind}} v_{\mathrm{wind}}^2$$

- this occurs at $0.1 - 0.3\,a$ (orbital separation)

$\Rightarrow$ radiative and mechanical interaction

Conclusions: subdwarf winds

- driven by lighter elements (similarly to early B stars)
- stars with low effective temperatures and high surface gravities do not have any wind
- metallicity is one of the key wind parameters
- fair agreement with observations (mass-loss rates, X-ray luminosities, terminal velocities)