Multicomponent stellar wind and chemical peculiarity in A stars

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Acceleration of hot star winds

Hot star winds are accelerated mainly by absorption of radiation in resonance lines:

1. absorption of radiation by C, N, O, Fe, etc. (minor wind component), light scattering by free electrons
2. transfer of obtained momentum to the major wind component (H, He)
   - *high density winds* – no multicomponent effects (e.g. stellar winds of galactic O stars)
   - *low density winds* – frictional heating, possible decoupling of wind components, etc.

Multicomponent model equations

Stationary spherically symmetric hydrodynamic equations for multicomponent radiatively driven stellar wind (Krtička & Kubát 2001):

- *continuity equation* for each component a

$$\frac{\mathrm{d}}{\mathrm{d}r}\left(r^2\rho_a v_{r\,a}\right) = 0,$$

  - ρ_a is the density of component a
  - $v_{r\,a}$ is the radial velocity of component a

Multicomponent model equations

- *momentum equation* for each component a

$$v_{ra}\frac{\mathrm{d}v_{ra}}{\mathrm{d}r} = g_a^{\mathrm{rad}} - g - \frac{1}{\rho_a}\frac{\mathrm{d}}{\mathrm{d}r}\left(a_a^2\rho_a\right) + \frac{q_a}{m_a}E + \sum_{b\neq a} g_{ab}^{\mathrm{fric}}$$

  - g_a^{rad} is the radiative acceleration either due to the lines in the CAK approximation (Castor, Abbott & Klein 1975) or due to free electrons
  - g is the gravity acceleration
  - a_a is the isothermal sound speed
  - E is the electric polarization field
  - g_{ab}^{fric} is the frictional acceleration

Multicomponent model equations

- *energy equation* for each component a

$$\frac{3}{2} v_{r\,a} \rho_a \frac{\mathrm{d} a_a^2}{\mathrm{d} r} + \frac{a_a^2 \rho_a}{r^2} \frac{\mathrm{d}}{\mathrm{d} r} \left(r^2 v_{r\,a} \right) = Q_a^{\mathrm{rad}} + \sum_{b \neq a} \left(Q_{ab}^{\mathrm{ex}} + Q_{ab}^{\mathrm{fric}} \right)$$

  - Q_a^{rad} is the radiative heating/cooling calculated using the thermal balance of electrons method (Kubát et al. 1999)
  - Q_{ab}^{ex} is the heat exchange
  - Q_{ab}^{fric} is the frictional heating
  - we neglect Gayley-Owocki heating (Gayley & Owocki 1994)

Important simplifications

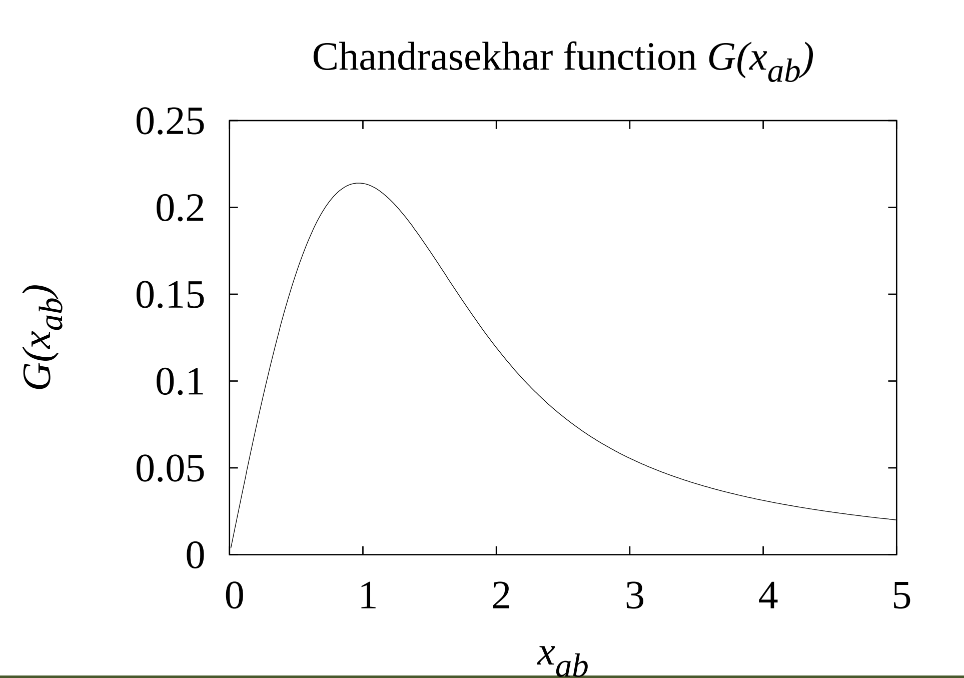
- radiative force in the CAK approximation with force parameters after Abbott (1982) $\Rightarrow$ possibly incorrect wind parameters
- ionization equilibrium approximated using “nebular approximation” (Mihalas 1978) $\Rightarrow$ significantly influences the frictional force
- neglected wind instabilities (Owocki & Puls 1999)
- neglected magnetic fields (ud-Doula & Owocki 2002)
- only Coulomb collisions accounted for the calculation of the frictional force

The frictional force

The frictional force depends on the velocity difference via the Chandrasekhar function

$$G(x) = \frac{\Phi(x) - x\frac{\mathrm{d}\Phi(x)}{\mathrm{d}x}}{2x^2},$$

$$x = \frac{|v_{rb} - v_{ra}|}{\alpha_{ab}}.$$



- for $x \gtrsim 1$ is $G(x)$ decreasing function, this behaviour enables *decoupling* of wind components

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- decoupling of wind components in the atmosphere
  - helium decoupling $\Rightarrow$ helium-free wind, possible helium overabundance in the atmosphere
  - hydrogen and helium decoupling $\Rightarrow$ metallic stellar wind only

Helium decoupling

- proposed by Hunger & Groote (1999) as the explanation of chemical peculiarity of Bp stars

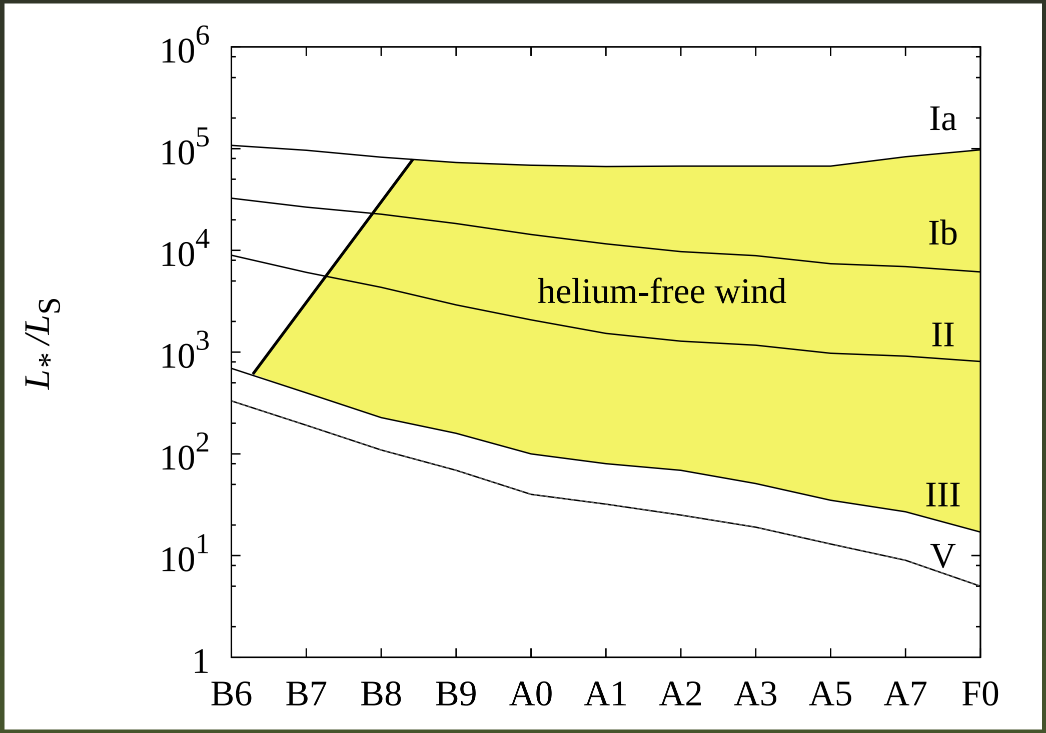
Helium decoupling in the atmosphere – the frictional acceleration lower than the gravity acceleration:

$$g_{\alpha\mathrm{p}}^{\mathrm{fric}} < g,$$

$\Rightarrow$ for solar metallicity stars helium decouples when the mass-loss rate is lower than

$$\dot{M} \lesssim 2 \cdot 10^{-16}\,\mathrm{M}_\odot\,\mathrm{year}^{-1} \left(\frac{M}{\mathrm{M}_\odot}\right) \left(\frac{T_\mathrm{eff}}{10^4\,\mathrm{K}}\right)^{3/2} z_\alpha^{-2}$$

Helium decoupling in HR diagram



- due to its low charge z_α helium is not present in the stellar wind of A stars (Kubát & Krtička 2003)
- helium may be overabundant in A star atmospheres

Frictional heating

The multicomponent effects are found to be important when the velocity difference is comparable with the thermal speed (Krtička et al. 2003),

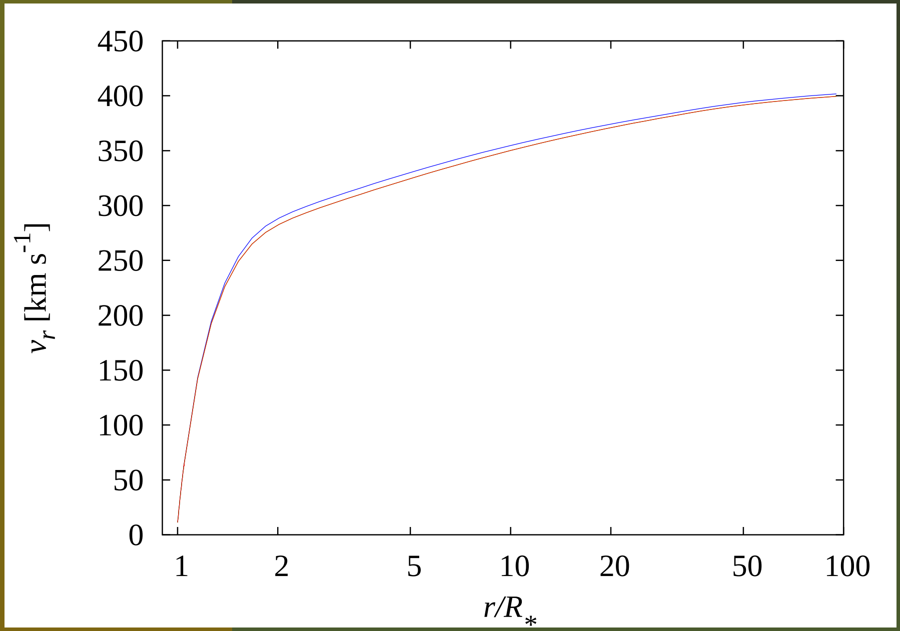
$$\frac{v_{r\mathrm{i}} - v_{r\mathrm{p}}}{\sqrt{\frac{2kT}{m_\mathrm{p}}}} \gtrsim 0.1.$$

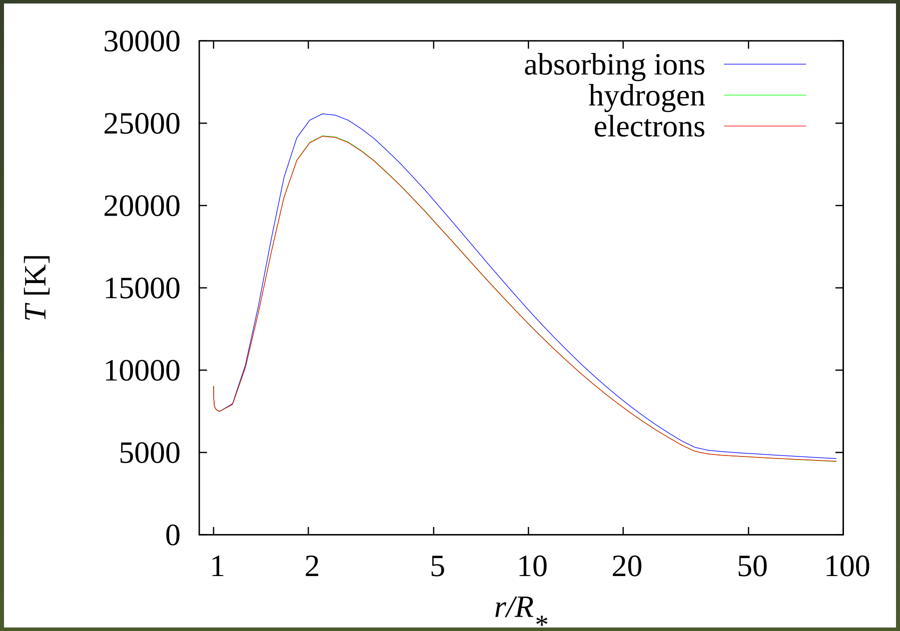
For solar metallicity stars the multicomponent effects become important for mass-loss rates lower than

$$\dot{M} \lesssim 10^{-10}\,\mathrm{M}_\odot\,\mathrm{year}^{-1} \left(\frac{v_\infty}{10^8\,\mathrm{cm\,s}^{-1}}\right)^3 \left(\frac{R_*}{\mathrm{R}_\odot}\right) \left(\frac{T_\mathrm{eff}}{10^4\,\mathrm{K}}\right) \frac{1}{z_\mathrm{H}^2 z_\mathrm{i}^2}.$$

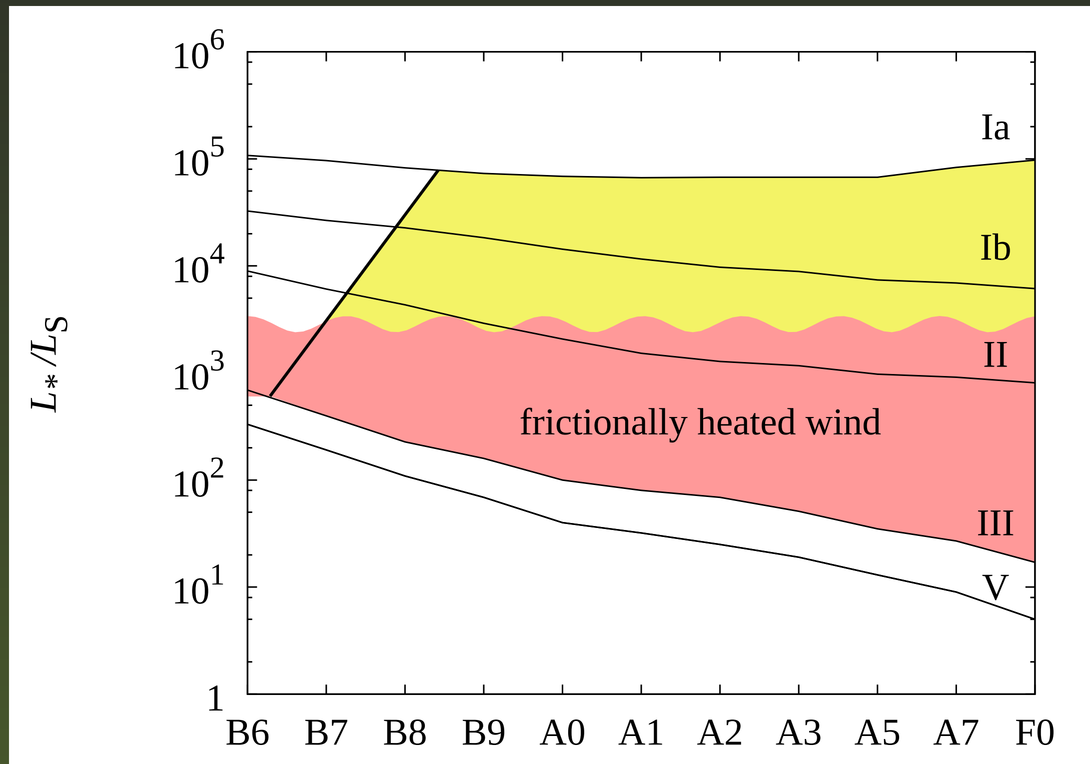
Frictional heating in the stellar wind

Example of the frictionally heated wind of A5II star ($T_{\mathrm{eff}} = 8\,300\,\mathrm{K}$, $M_* = 5.5\,\mathrm{M}_\odot$, $R_* = 15.1\,\mathrm{R}_\odot$)





Frictional heating in HR diagram



- stellar wind of bright giants is heated by friction

Hydrogen decoupling

Hydrogen decoupling occurs when the velocity difference is equal to the thermal speed,

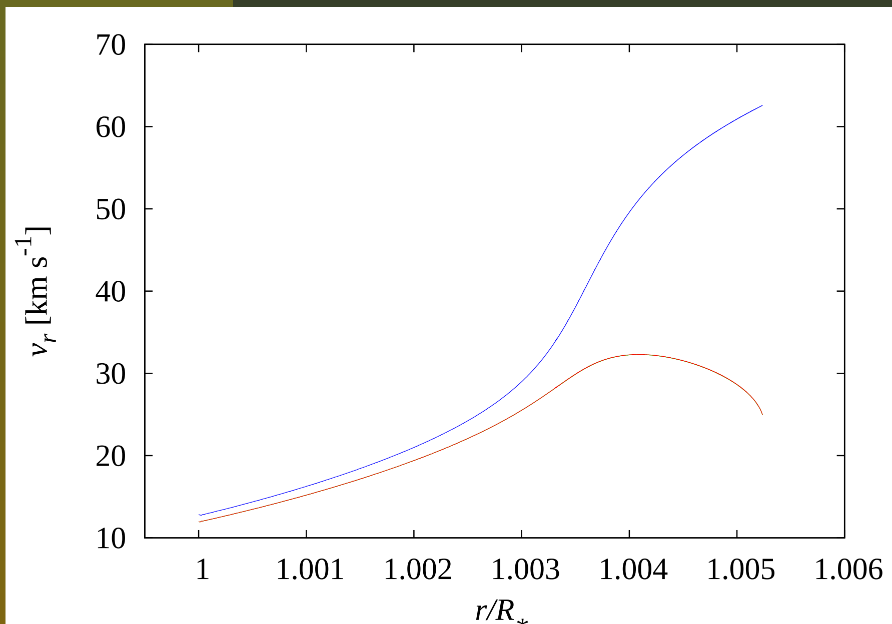
$$\frac{v_{r\mathrm{i}} - v_{r\mathrm{p}}}{\sqrt{\frac{2kT}{m_\mathrm{p}}}} \approx 1.$$

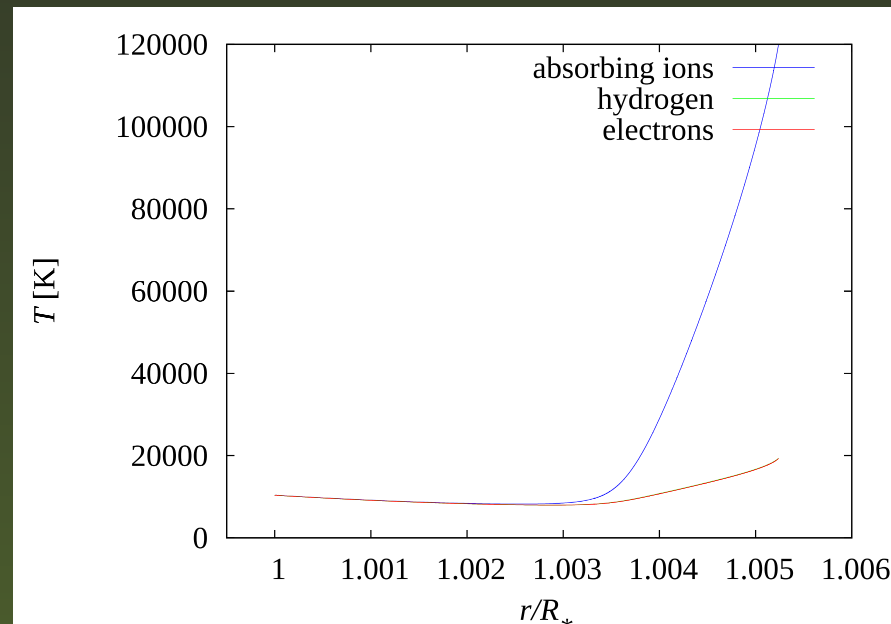
After decoupling

- hydrogen leaves the star if $v_\mathrm{H} > v_\mathrm{esc}$,
- hydrogen falls back onto the stellar surface or forms clouds above the surface (Porter & Skouza 1999),
- hydrogen decouples in the atmosphere, only pure metallic wind exist (Babel 1995, Babel 1996).

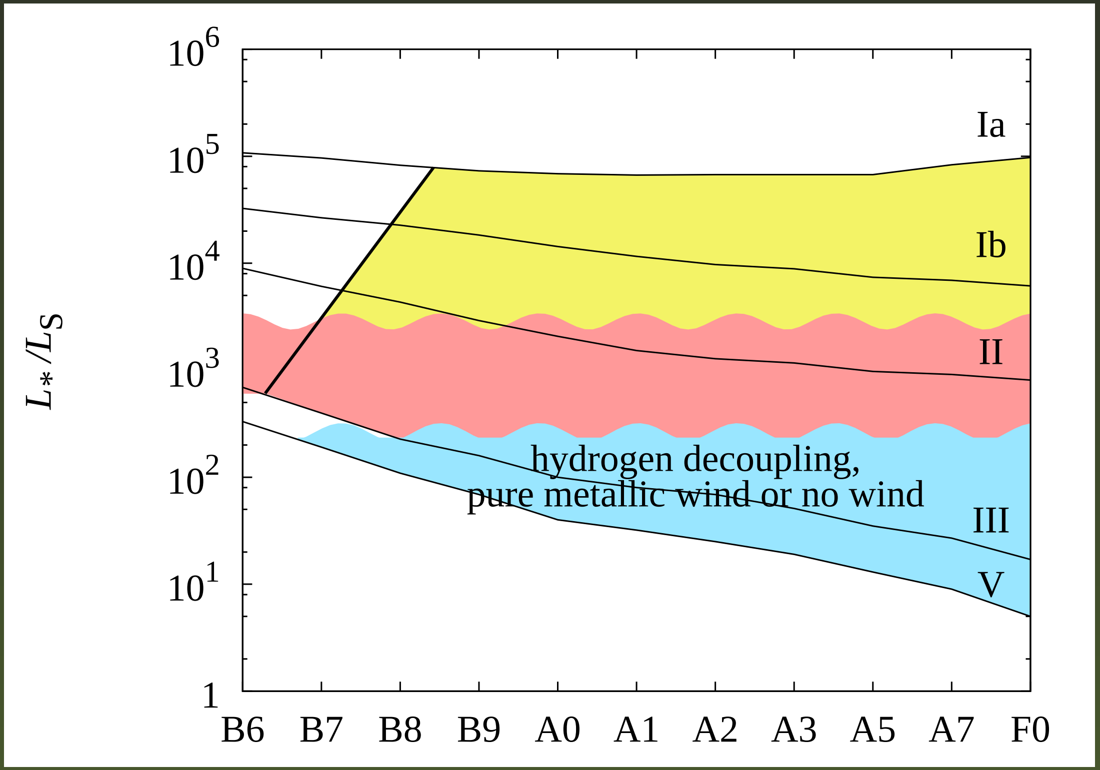
Hydrogen decoupling

Hydrogen decoupling in the wind of A0III star
($T_{\rm eff} = 9\,600\,{\rm K}$, $M_* = 2.7\,{\rm M}_\odot$, $R_* = 3.63\,{\rm R}_\odot$)



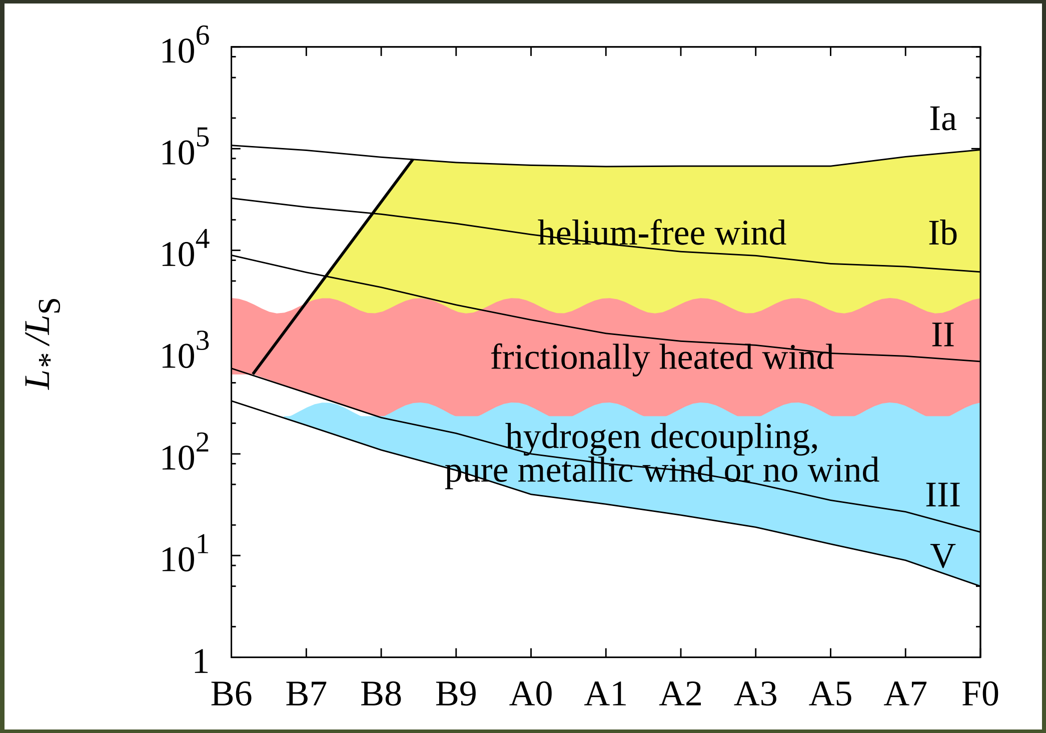


Hydrogen decoupling in HR diagram



- hydrogen decouples in the stellar wind of A giants or A giants may have pure metallic wind

Conclusions



- multicomponent effects *may* be important for those A stars which have stellar wind
- more advanced (NLTE) models are necessary to study these effects in detail