Stellar parameters of PNe
Old fashioned or trendy?

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Overview

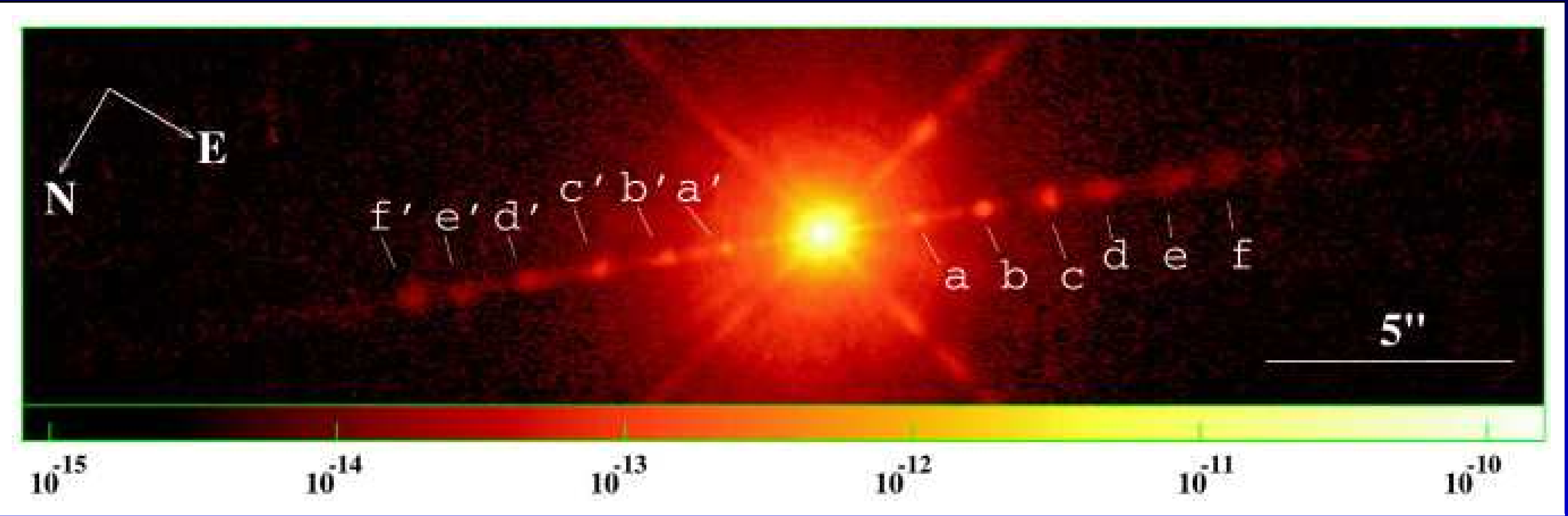
- Motivation
- Hen 2-90
- Determination of stellar parameters
- Results
- Conclusions & Outlook

Motivation

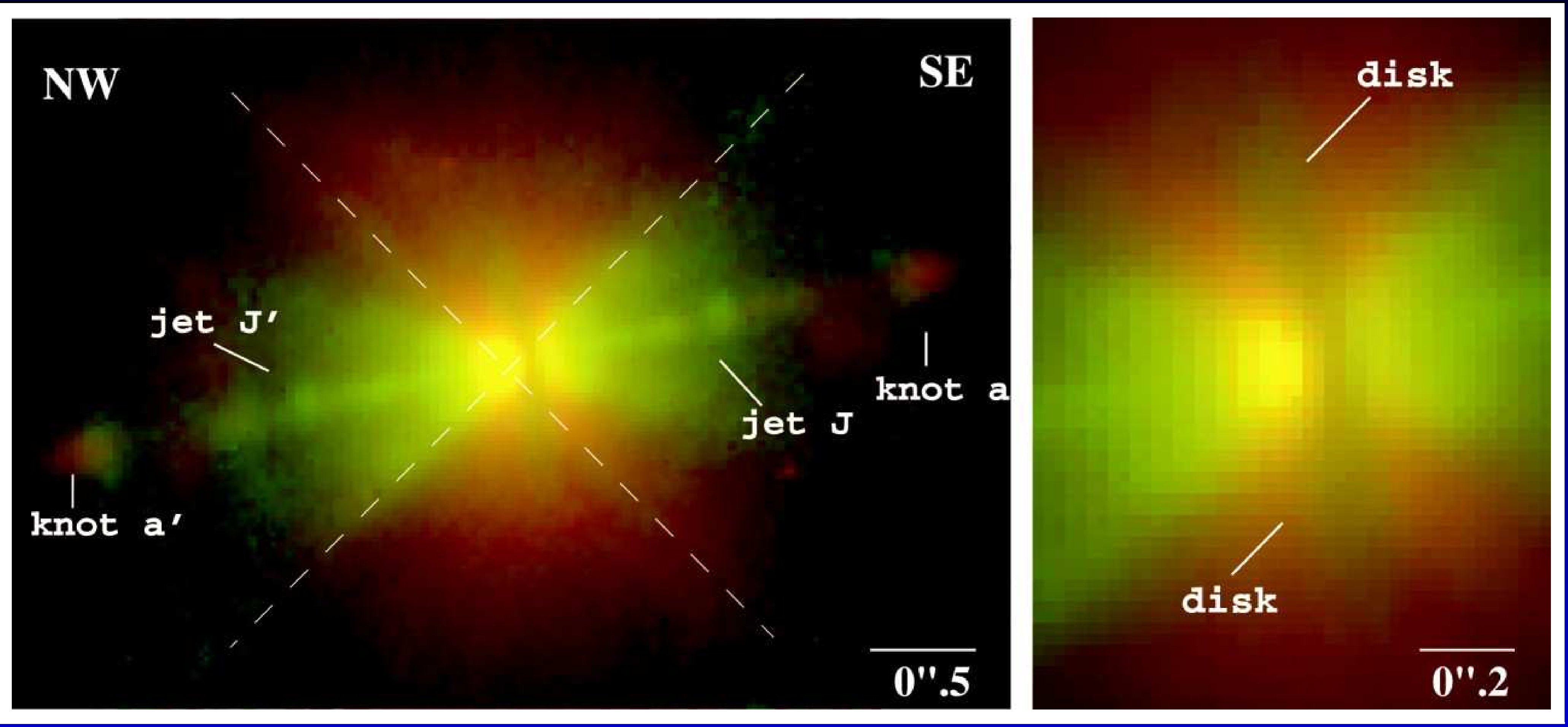
- Study of B[e] stars: Subclass compact planetary nebulae
- In particular: Hen 2-90
- Aim: investigating the mass loss history of the central star
- Stellar parameters: taken from literature
- Assumptions for derivation of the stellar parameters:
  - spherical symmetry
  - constant electron density

Hen 2-90

HST observations (from Sahai & Nyman 2000)



HST observations (from Sahai et al. 2002)



Spherically symmetric?? constant density??

Determination of the stellar parameters

We make use of 2 different models which have the following assumptions in common:

- spherically symmetric fully ionized nebula or wind
- constant electron temperature fixed at 10 000 K
- all optical emission lines are optically thin
- Hydrogen follows case B recombination

The constant density nebula model (CDNM)

Additional assumptions:

- constant electron density
- star is a point source

The spherical wind model (SWM)

Additional assumptions:

- mass loss rate defines radial density distribution which can be parametrized as

$$N_e(r) = N_e(R_*) \frac{R_*^2}{r^2} \quad (1)$$

Set of model observations

Line	λ [Å]	observed line luminosities
H_α	6563	2.10×10^{-11} erg s^{-1} cm^{-2}
H_β	4861	1.80×10^{-12} erg s^{-1} cm^{-2}
[S II]	6731	6.75×10^{-13} erg s^{-1} cm^{-2}
[S II]	6716	3.00×10^{-13} erg s^{-1} cm^{-2}
continuum	4861	2.50×10^{-15} erg s^{-1} cm^{-2} Å^{-1}

Results

1. Effective temperature

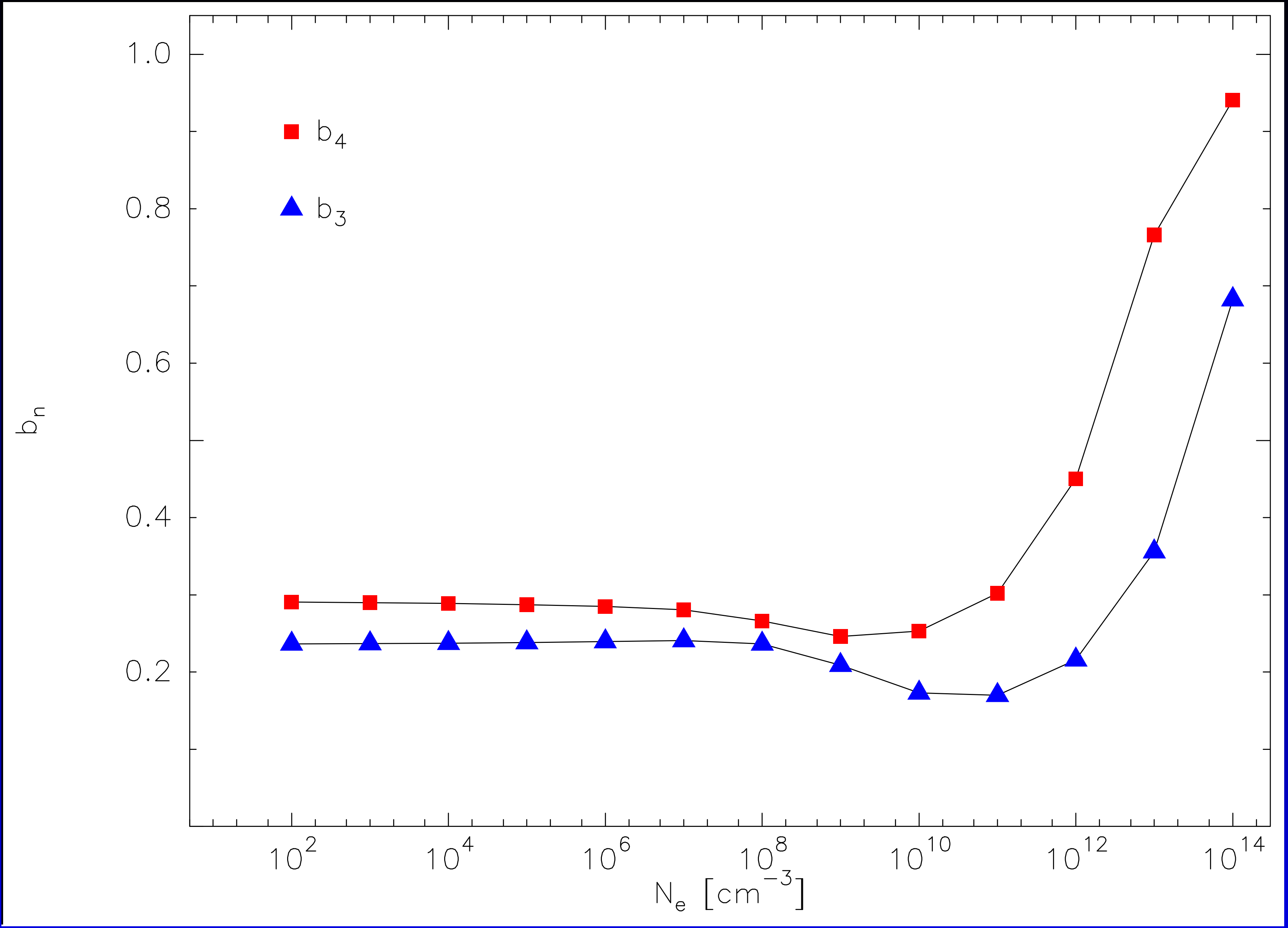
- Method used: Zanstra temperature for H

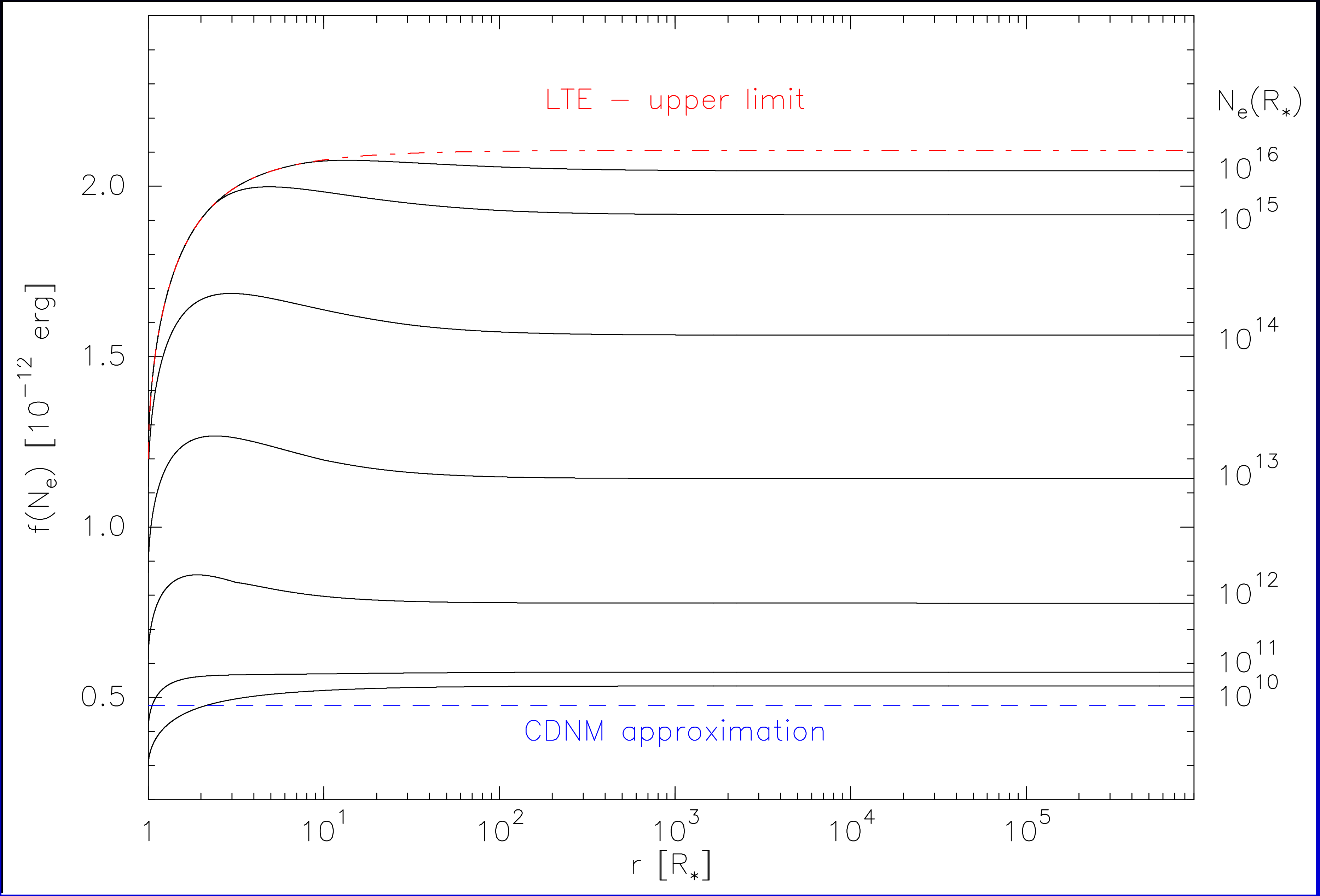
(2)
$$f(T_{\rm eff}) = \frac{L_\nu}{\int_{\nu_0}^{\infty} \frac{L_\nu}{h\nu} d\nu} = h\nu_{\rm H\beta} \frac{F_\nu^{\rm obs}}{F_{\rm H\beta}^{\rm obs}} \; f(N_{\rm e})$$

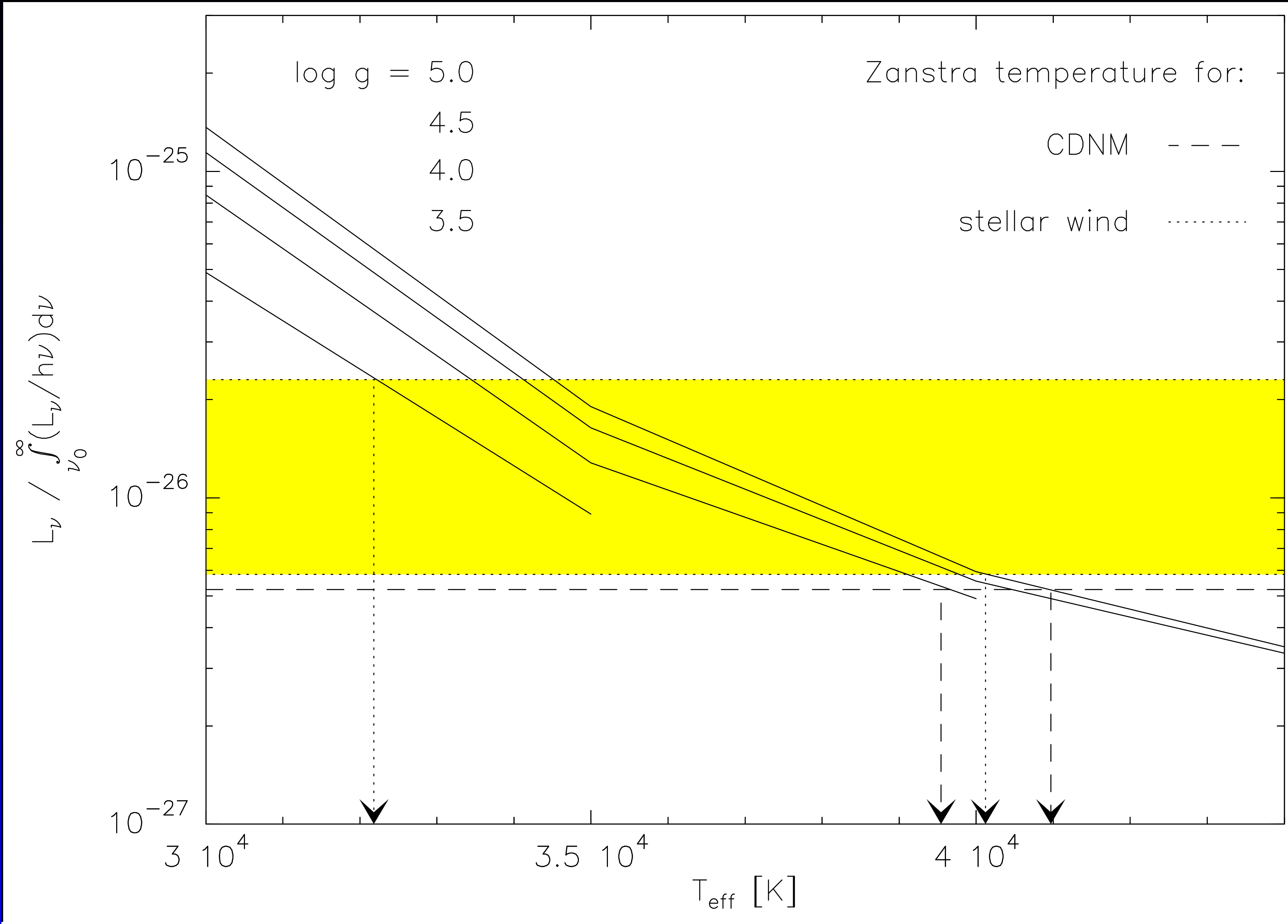
with

(3)
$$f(N_{\rm e}) = \frac{\int N_{\rm e} N_{\rm p} b_4(N_{\rm e})(1-W(r))\tilde{\alpha}_{\rm H\beta}^{\rm eff} dV}{\int N_{\rm e} N_{\rm p} \alpha_{\rm B}({\rm H}^0, T) dV}$$

- Problem: $b_{\rm n}$ factors are for high $N_{\rm e}$ not constant !


1.0
0.8
0.6
0.4
0.2
b_4
b_3
b_n
10^2
10^4
10^6
10^8
10^{10}
10^{12}
10^{14}
N_e [cm^{-3}]


LTE – upper limit
$N_e(R_*)$
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
CDNM approximation
$f(N_e)$ [10^{-12} erg]
2.0
1.5
1.0
0.5
1
10^1
10^2
10^3
10^4
10^5
r [R_*]


log g = 5.0
4.5
4.0
3.5
Zanstra temperature for:
CDNM
stellar wind
10^{-25}
10^{-26}
10^{-27}
$L_\nu / \int_{\nu_0}^{\infty}(L_\nu/h\nu)d\nu$
3 10^4
3.5 10^4
4 10^4
T_{eff} [K]

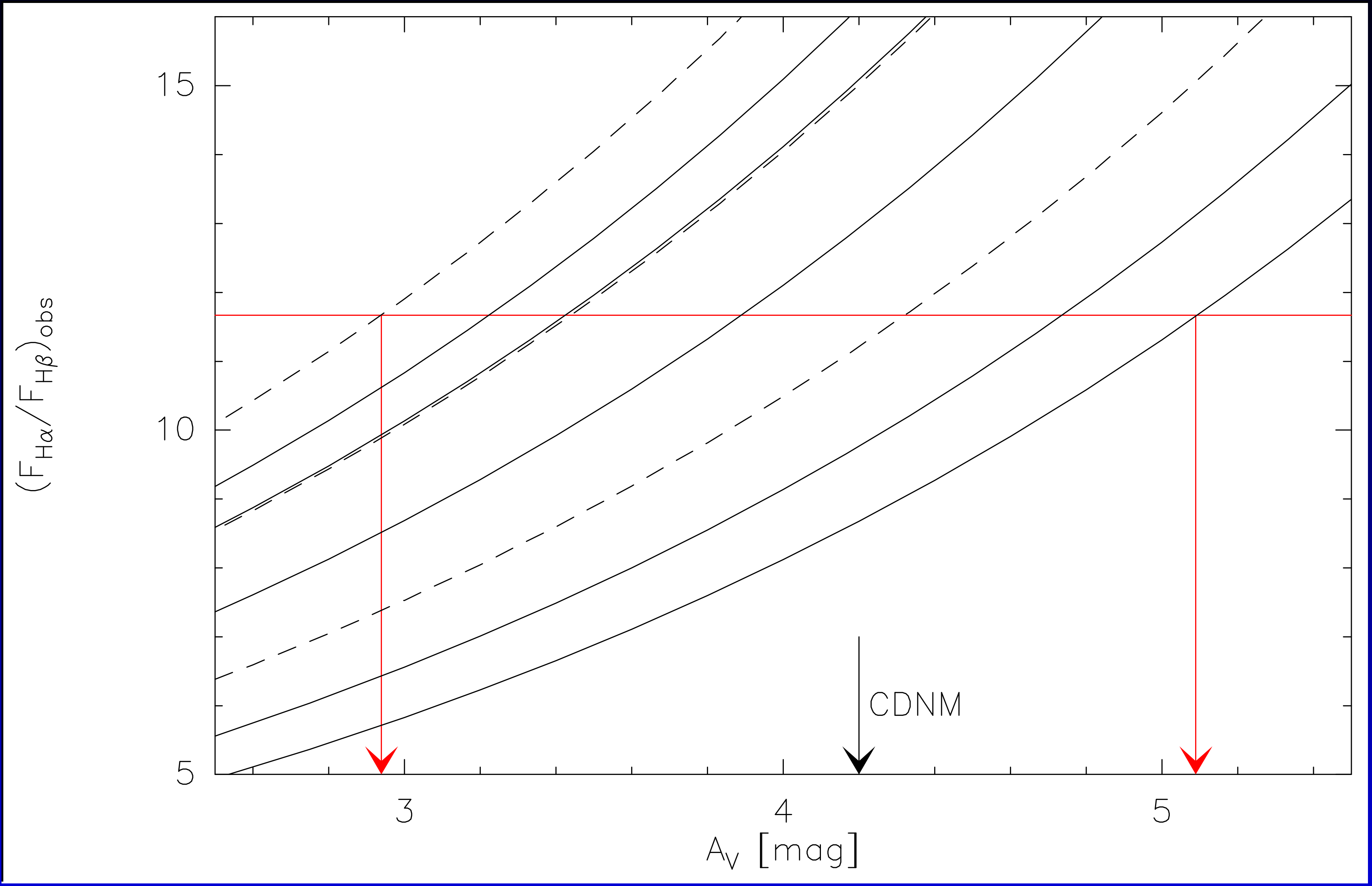
2. Interstellar extinction

- Method used:

$$\left(\frac{F_{\lambda_1}}{F_{\lambda_2}}\right)^{\text{obs}} = \left(\frac{F_{\lambda_1}}{F_{\lambda_2}}\right)^{0} e^{-CA_{\text{V}}} \qquad (4)$$

- Ingredient: H_β line, H_α line

- Problem: Ratio of b_3 and b_4 is a function of N_e !



15
10
5
3
4
5
$(F_{H\alpha}/F_{H\beta})_{obs}$
A_V [mag]
CDNM

3. Nebular abundances

- Method used (e.g. Pottasch et al. 2003):

$$\frac{N_{\rm ion}}{N_{\rm p}} = \frac{I_{\rm ion}}{I_{\rm H\beta}} N_{\rm e} \frac{\lambda_{\rm ul}}{\lambda_{\rm H\beta}} \frac{\alpha_{\rm H\beta}}{A_{\rm ul}} \left(\frac{N_{\rm u}}{N_{\rm ion}}\right)^{-1} \quad (5)$$

- Ingredient: constant $N_{\rm e}$ as the only unknown

- But: difficult to compare with stellar wind model, therefore

- use forbidden emission lines of [S II]

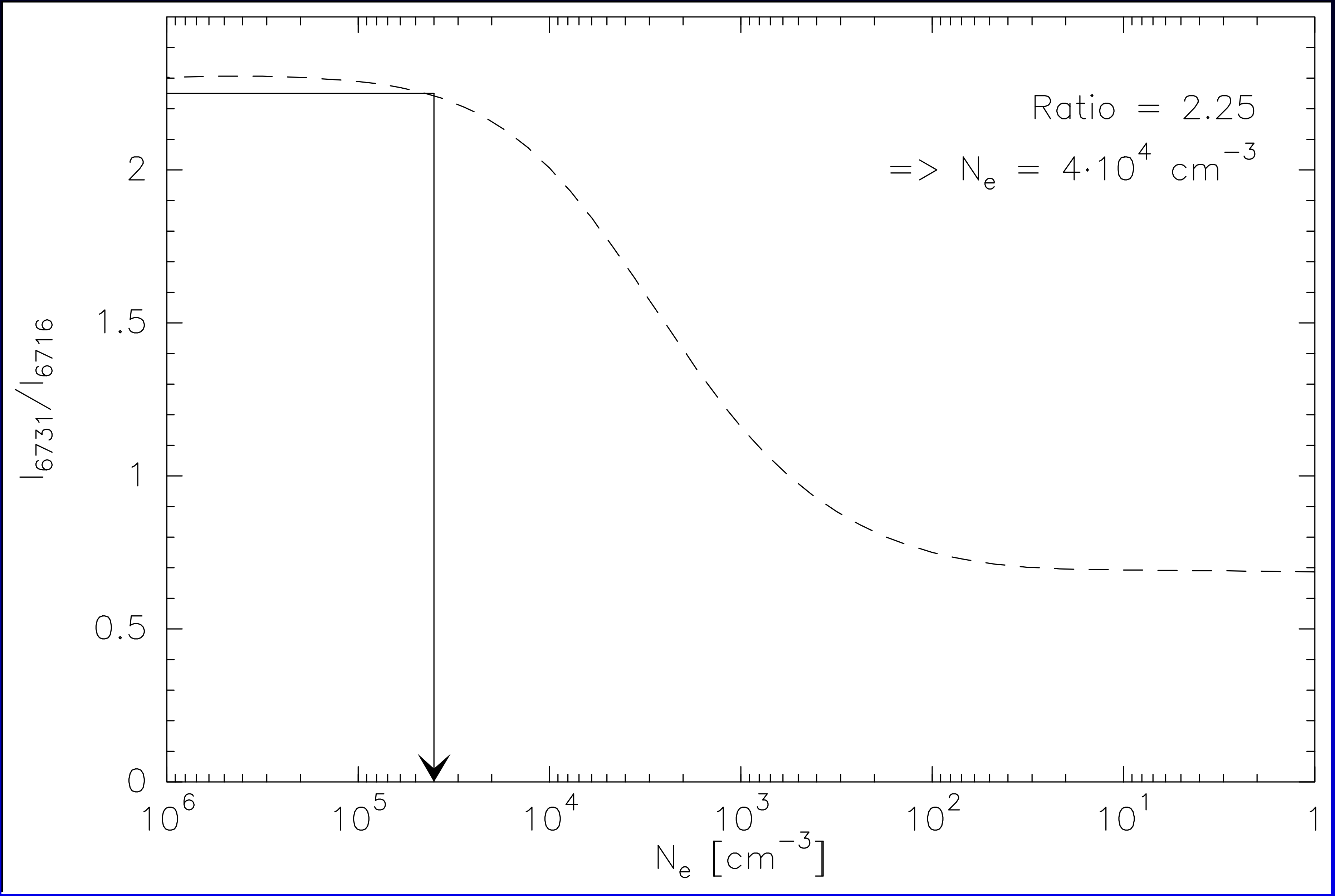
- re-write equation for CDNM

$$\frac{I_{[\mathrm{S\,II}]}}{I_{\mathrm{H}_\beta}} = \frac{\lambda_{\mathrm{H}_\beta}}{\lambda_{\mathrm{ul}}} \frac{A_{\mathrm{ul}}}{\alpha_{\mathrm{H}_\beta}} \frac{N_{\mathrm{S\,II}}}{N_{\mathrm{p}}} \frac{1}{N_{\mathrm{e}}} \frac{N_{\mathrm{u}}}{N_{\mathrm{S\,II}}} \tag{6}$$

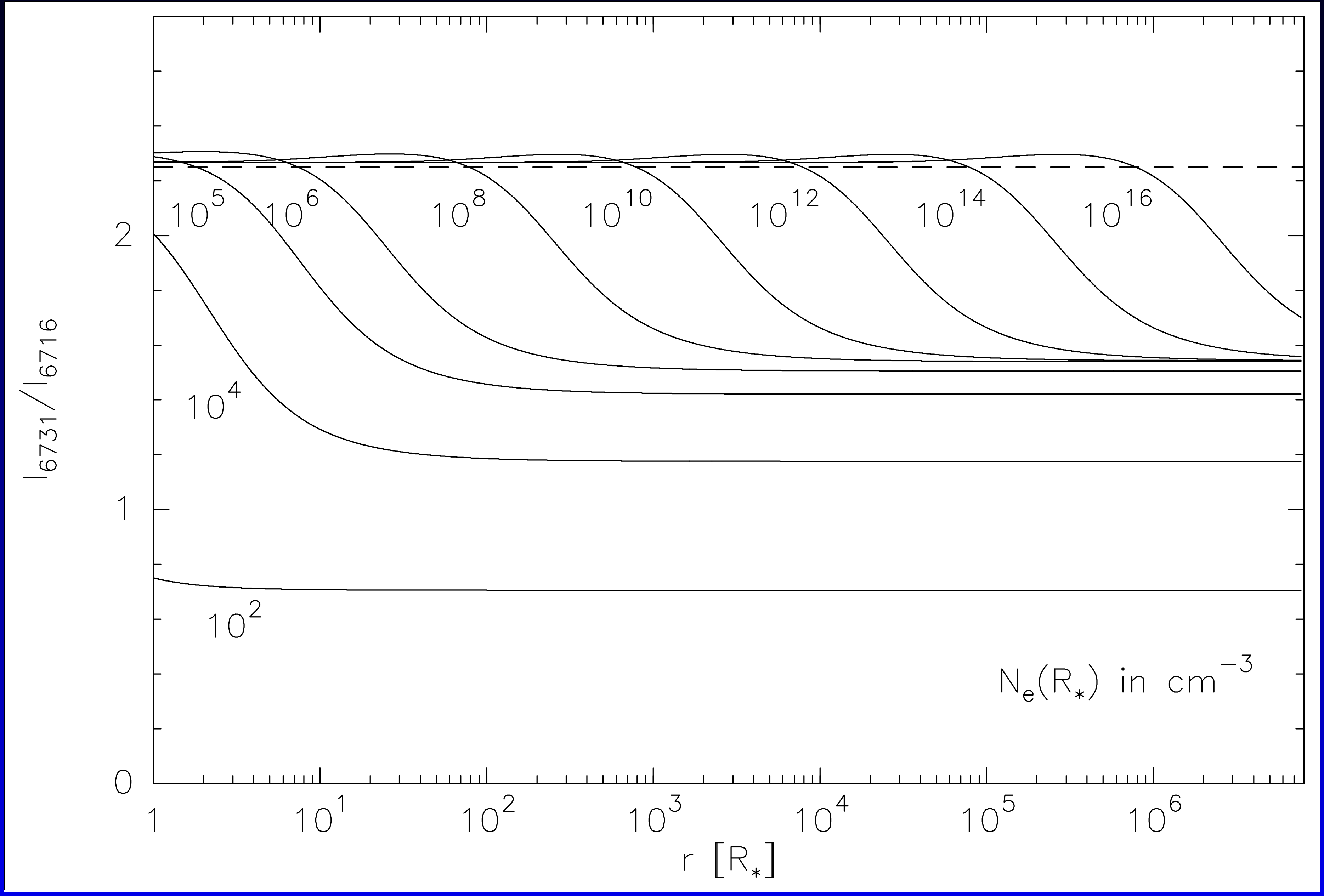
- and for stellar wind

$$\frac{I_{[\mathrm{S\,II}]}}{I_{\mathrm{H}_\beta}} = \frac{\lambda_{\mathrm{H}_\beta}}{\lambda_{\mathrm{ul}}} \frac{A_{\mathrm{ul}}}{\tilde{\alpha}_{\mathrm{H}_\beta}} \frac{\int N_{\mathrm{u}}(r)(1-W(r))dV}{\int N_{\mathrm{e}}(r)N_{\mathrm{p}}(r)b_4(N_{\mathrm{e}})(1-W(r))dV} \tag{7}$$

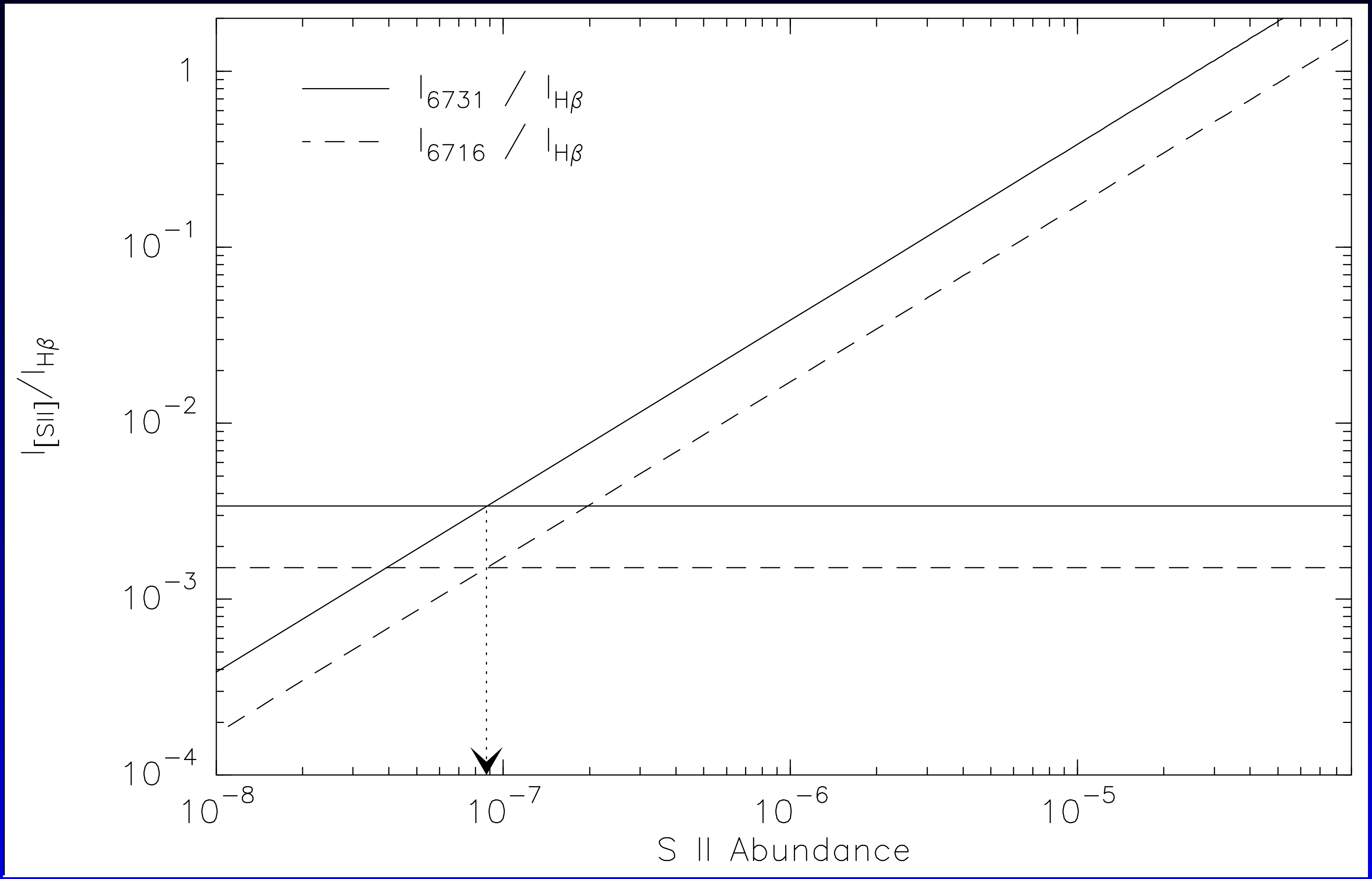
Sulfur line ratio in case of CDNM



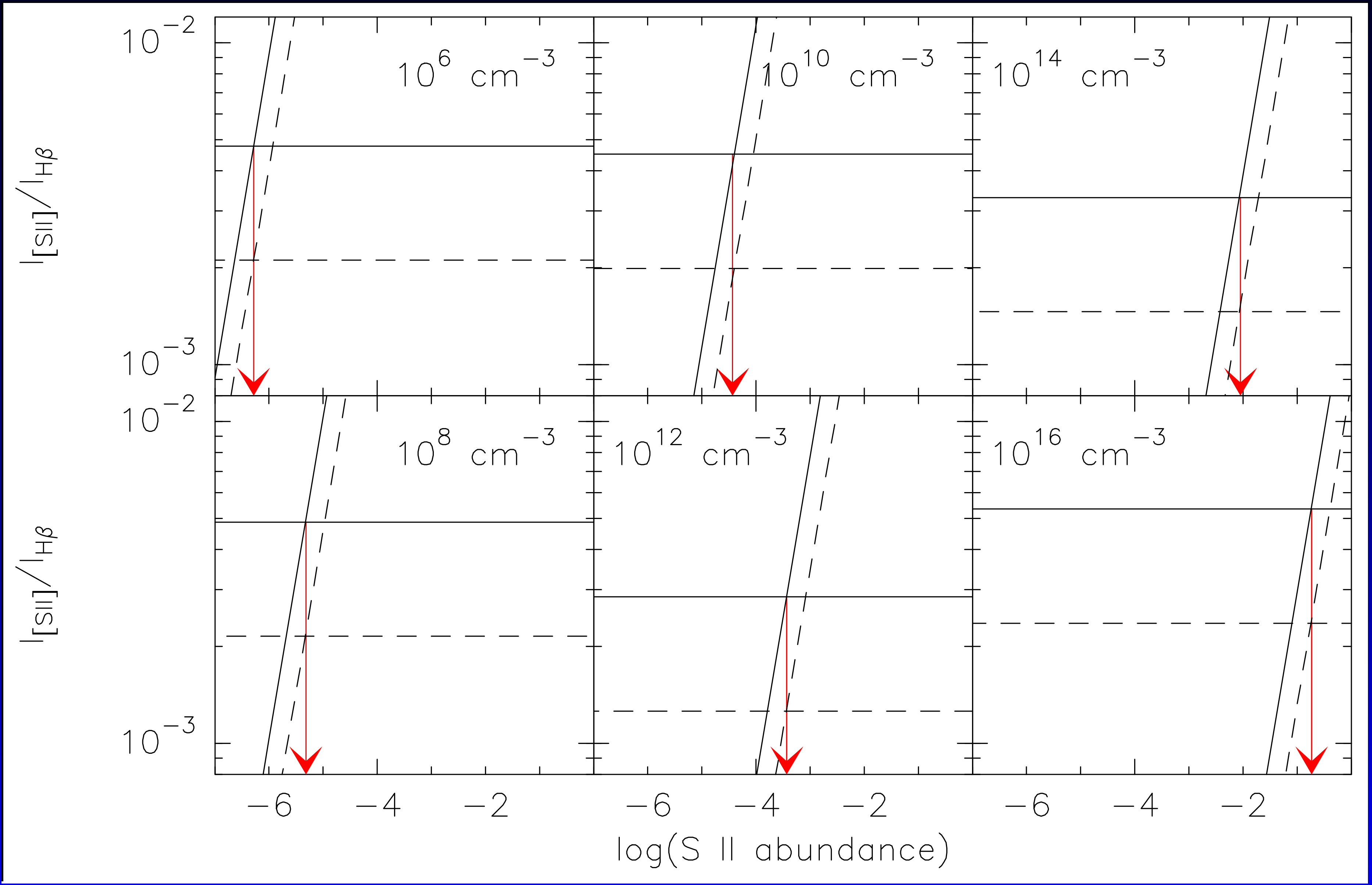
Sulfur line ratio in case of SWM



SII abundance in case of CDNM



SII abundance in case of SWM



Summary of results

	CDNM	Costa et al. ('92)	SWM
$T_{\rm eff}$ [K]	40 000	51 000	$\sim$ 38 000
$\log g$	4.0–5.0		4.0–5.0
$A_{\rm V}$ [mag]	4.2	4.0	4.7
$\log(N_{\rm SII}/N_{\rm p})$	$\sim 10^{-7}$	2×10^{-6}	3×10^{-4}
d [kpc]		1.5 ($\theta = 6''$)	7.5
L_* [$L_\odot$]		10^3	5×10^5
R_* [$R_\odot$]		0.38	16
$R_{\rm out}$ [AU]			600
$N_{\rm e}(R_*)$ [cm^{-3}]	4×10^4	2×10^5	10^{12}
$\dot{M}$ [$M_\odot$yr^{-1}]		10^{-7}	3×10^{-6}

Conclusions

- Comparison of CDNM with SWM results in different values for some stellar parameters
- Observations used were from Hen 2-90 which has clearly non-spherical CSM
- Of special interest : SWM gives much higher nebular abundances than CDNM !

Outlook

- Inclusion of velocity and temperature structure of the wind
- Extension to non-spherical wind models (disk + bipolar wind)