Non-LTE line formation for trace elements in stellar atmospheres,
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Departures from LTE in chemically stratified atmospheres

Lyudmila Mashonkina
Institute of Astronomy, Russian Academy of Sciences

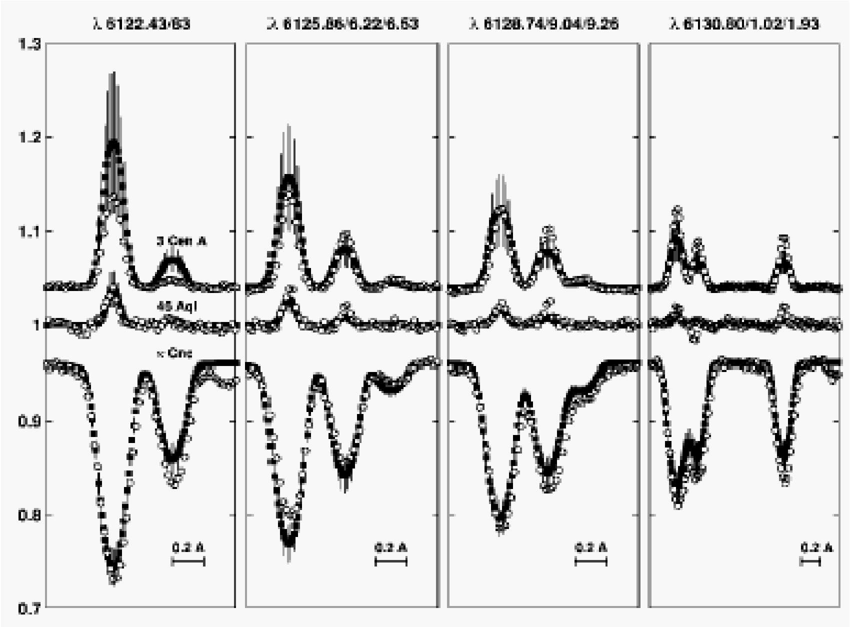
Chemical peculiarity

- Abundances of some individual elements do not follow overall metallicity.
  - Non-LTE line formation is similar to that in non-peculiar stars.
  - SE calculations with a right value of the element abundance.
  - Non-LTE abundances are determined iteratively.

- There are evidences for a non-uniform vertical distribution of the selected elements.

  How does this affect line formation?

I. ^{3}He star 3 Cen A (B5 III-IVp), HgMn stars 46 Aql (B9 III) and κ Cnc (B8 III).



- 3 Cen A and 46 Aql,
  Mn II 6122 – 6132 in emission,
- κ Cnc
  Mn II 6122 – 6132 in strong absorption

(observations are shown by open circles).

LTE cannot predict an emission in the line if the line is of photospheric origin.

Sigut (2001): Non-LTE line formation for Mn II.

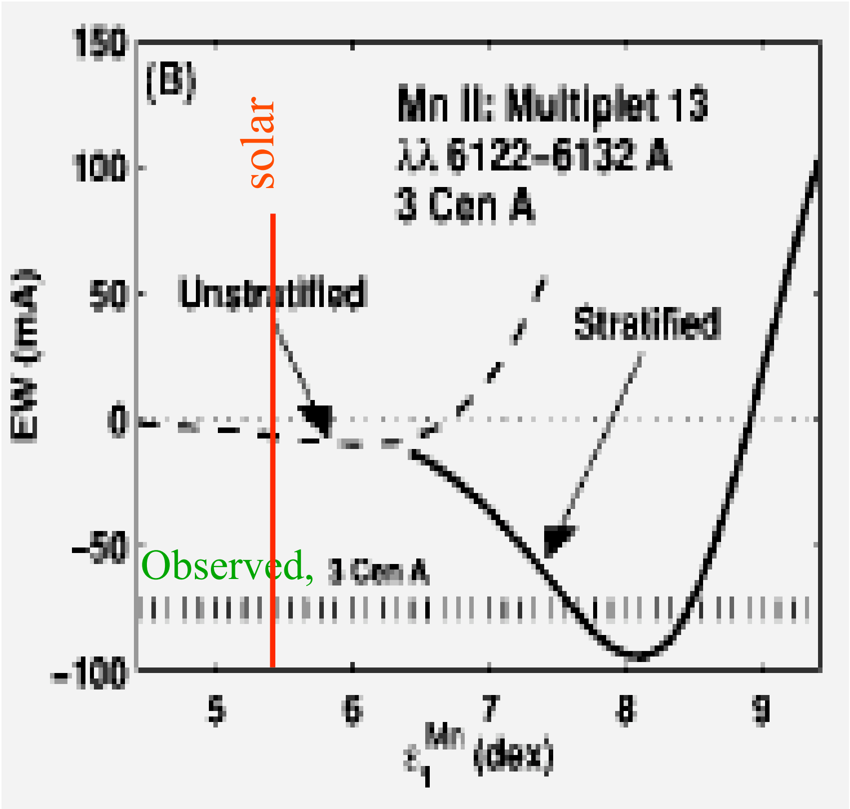
$b_j/b_i > 1 \rightarrow S_\nu/B_\nu$ rises toward the surface leading to an emission line.

Effect depends on the abundance of Mn.

Stratification of the Mn abundance

- 3 Cen A:
  – Uniform Mn abundance.
    Weak emission at [Mn/H] < 1.
  – Mn is concentrated above
    log τ = -2 with [Mn/H] ≈ 2.5.

  This distribution matches the strengths of both emission and weak absorption lines.



Predicted equivalent widths for 3 Cen A depending on the Mn abundance.

- 46 Aql:

Mn II emission is weaker due to lower T_{eff} and less sensitivity of the correction for stimulated emission to departures from LTE.

- κ Cnc:

A large Mn abundance forces mult.13 into absorption.

II. roA p (*rapidly oscillating*) stars

- photometric variability, ~10^{-3} mag
- radial velocity variations:

} with the same period

e.g., γ Equ, P = 12.3 min.;

amplitudes: 25 m/s to 800 m/s from different lines

- slow rotators, e.g. γ Equ, T = 76 years
- magnetic field, e.g. γ Equ, B = 4 kG

- a violation of LTE ionization balance
  - *Cowley & Bord,* 1998:
    log ε (Nd III) – log ε (Nd II) = 1.5 dex (γ Equ)
  - *Ryabchikova et al*., 2001: the sample of 31 roAp and Ap stars

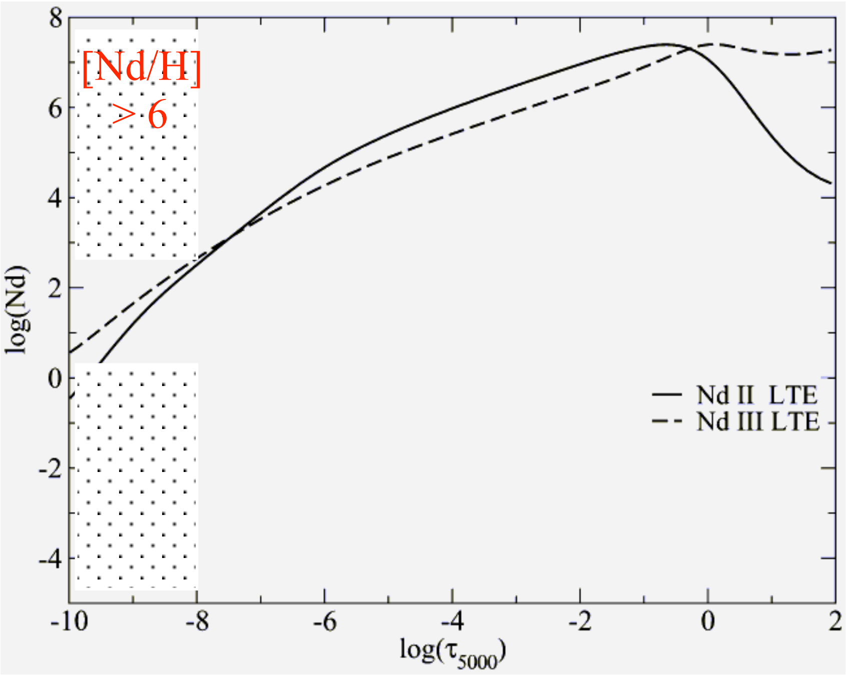
In <u>all</u> roAp stars, log ε (Nd III) > log ε (Nd II)

log ε (Pr III) > log ε (Pr II)

(up to 2 dex!)

Empirically derived Nd distribution in the atmosphere of γ Equ.

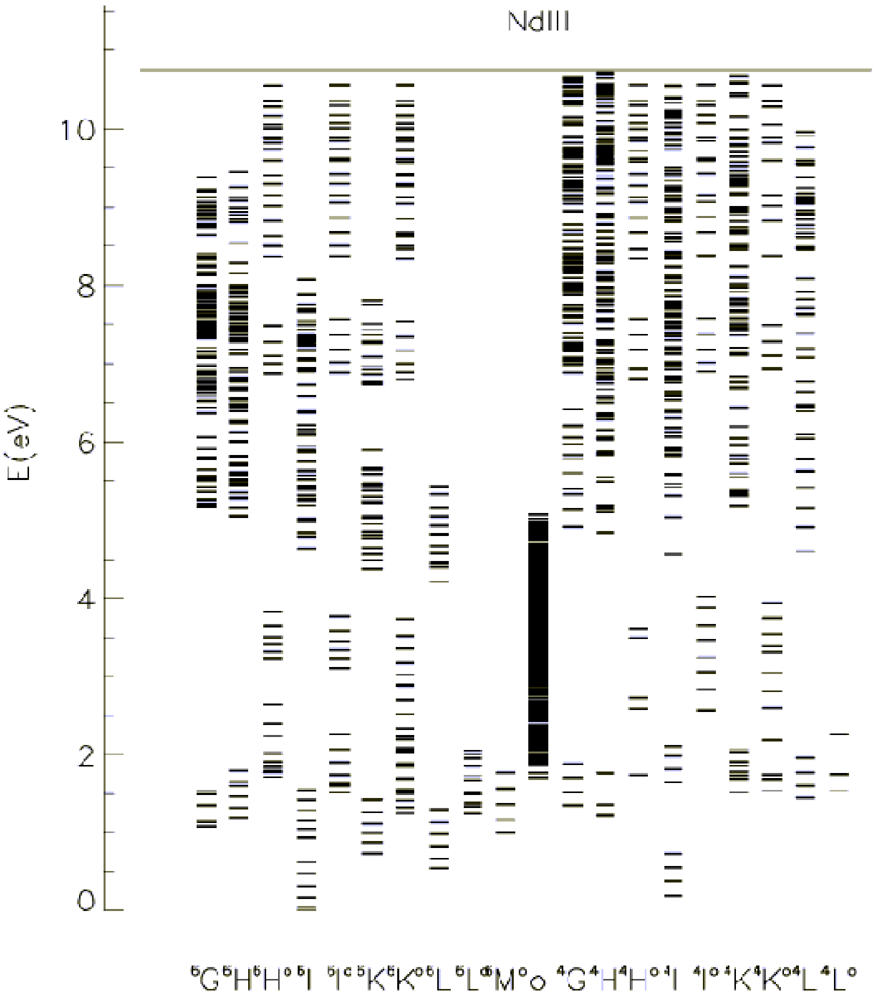
(*Ryabchikova et al.* 2002, LTE analysis)



Nd is concentrated above log τ = -8 with [Nd/H] > 6.

The LTE assumption is not valid in so high atmospheric layers.

Non-LTE line formation for Nd II/III



Model atom of Nd II

(*Mashonkina et al.* 2005)

Nd II:
658 measured levels +
993 predicted levels (A.Ryabtsev)
Nd III: 883 levels

- Uniform Nd distribution

(T_{eff} = 7250 K)

Δ_{NLTE} = (-0.12) – (+0.03) dex (Nd II)

Δ_{NLTE} = (-0.26) – (-0.42) dex (Nd III)

We fail to remove the disparity between ε(Nd II) and ε(Nd III)

Nd stratification from non-LTE analysis

- Stratified Nd distribution.

  γ Equ:

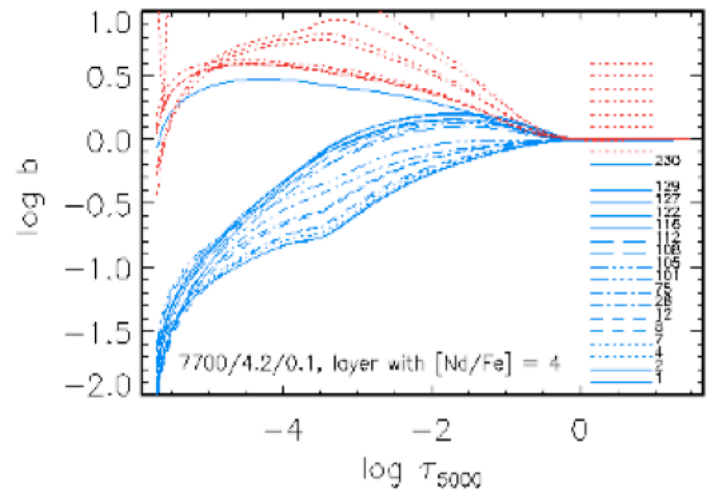
  [Nd/H] = 4 at $\log \tau_{5000} < -3.5$

  HD 24712:

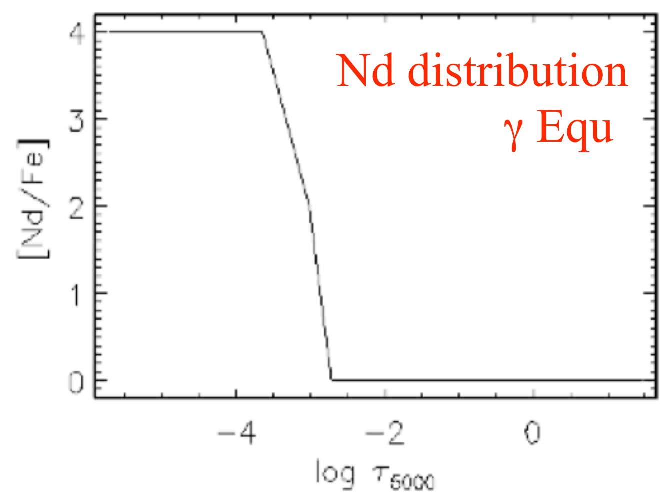
  [Nd/H] = 4.5 at $\log \tau_{5000} < -4.5$

  (empirically from analysis of 4 Nd II and 4 Nd III lines)

b-factors for the stratified Nd distribution



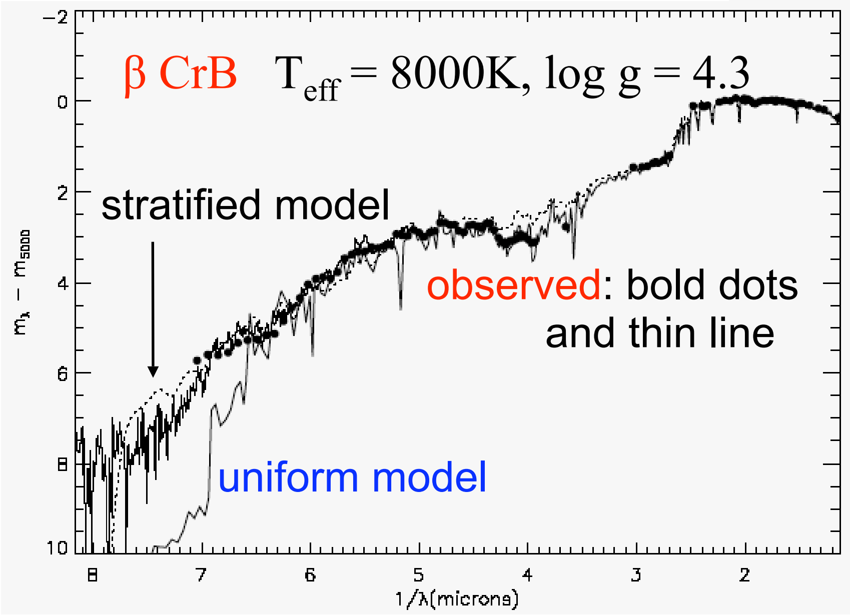
(!) Δ_{NLTE} = (+0.97) – (+1.42) dex (Nd II)
Δ_{NLTE} = (-0.27) – (-0.51) dex (Nd III)



- NLTE calculations were performed also for Pr II/III (*Mashonkina et al.* 2007, in preparation).

The sources of the uncertainties of non-LTE modelling

1) We use stationary homogeneous (!) LTE (!) model atmospheres assuming non-uniform distribution of the REE .



At λ > 1600 Å stratified and uniform models provide the same radiation field.

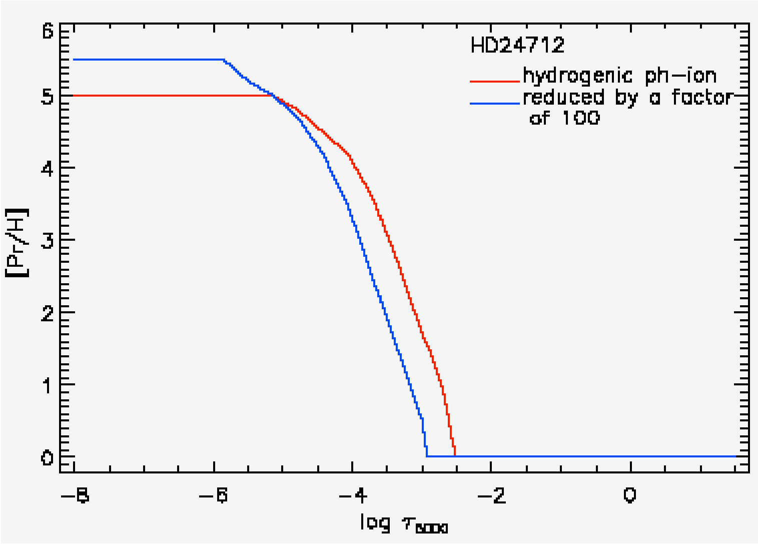
The sources of the uncertainties of non-LTE modelling

2) The lack of accurate atomic data.

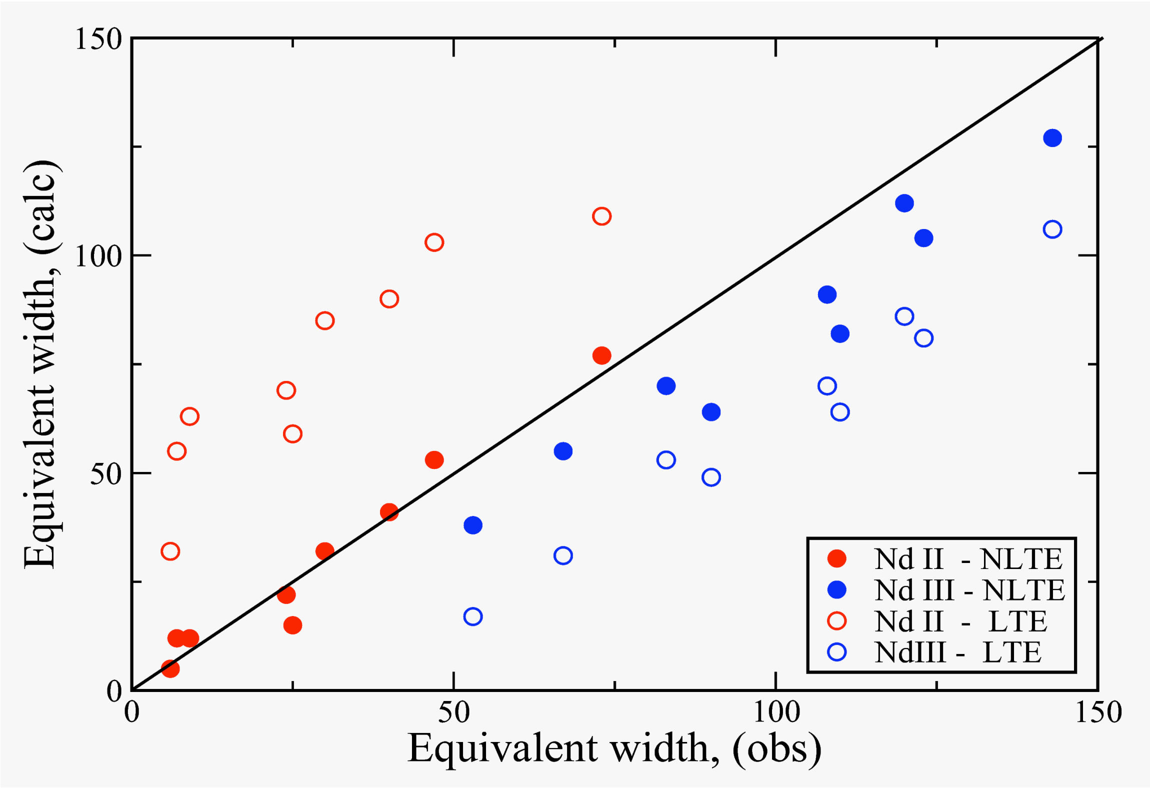
– Collisional cross-sections.
  Effect is minor for the uppermost layers.
– Photoionization cross-sections.
  We use the hydrogenic cross-sections.

Test calculations for $0.01\sigma_{ph}$ and $100\ \sigma_{ph}$:

Δ_{NLTE} decrease/increase by 0.5 / 0.1 dex, the layer of enhanced Nd and Pr is shifted upward by $\Delta\log\tau_{5000} \cong 0.5$.



NLTE and LTE equivalent widths in the stratified model compared to the observed ones in roAp star γ Equ



The found Nd distribution is supported by the later observations

γ Equ: 9 Nd II and 9 Nd III lines

HD 24712: 21 Nd II and 20 Nd III lines

Method: NLTE calculations

model atom: energy levels from laboratory measurements (NIST) and calculations (A.Ryabtsev)

Nd II (1651 levels) + Nd III (607 levels)