Two Experimental Techniques Yielding Different Descriptions of Quenching

a very personal view by

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with real work done by:

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and a lot of help by

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Air Fluorescence Workshop, Karlsruhe 2011

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„Communities“

Molecular Physics

Potential curves, energy levels, QM calculations, disentangle vibr. rot. spectra etc.

Gas Kinetics

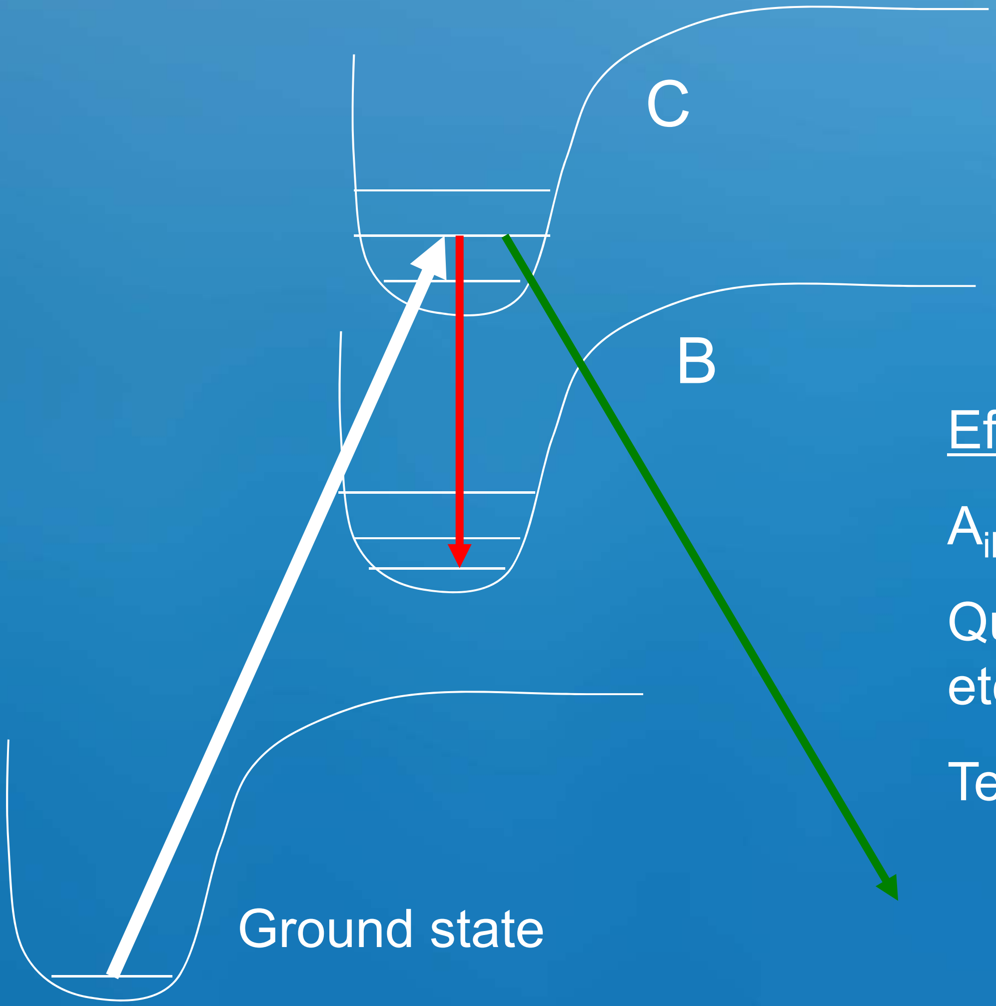
Population and depopulation of levels, energy transfer, light emission, laser schemes etc.

Particle and Astro- Particle Physics

Energy loss in matter, particle tracks, particle identification, “quenching factors” etc.

Air Fluorescence: A bit of all of these subjects!

Fluorescence of Nitrogen Molecules



Effects of:

A_{ik} Lifetime

Quenching by N_2, O_2, H_2O etc. - Density

Temperature

This picture leads to the following analysis of the fluorescence:

Measurement of p’ using dc excitation

$$I \propto A_{ik}\, n$$

$$\frac{dn}{dt} = R_p - A_{ik}\, n - \sum k_q N_q n$$

$$const.\ pumping\ \ rate$$

$$R_p = const \quad \Rightarrow \quad \frac{dn}{dt} = 0$$

$$I \propto \frac{R_p}{A_{ik} + \sum k_q N_q}$$

$$I_0 = \frac{R_p}{A_{ik} + 0} \qquad I = \frac{R_p}{A_{ik} + \sum k_q N_q} \qquad \frac{I}{I_0} = \frac{1}{1 + \frac{\sum k_q N_q}{A_{ik}}}$$

Just one “quencher” of density N_q

$$\frac{I}{I_0} = \frac{1}{1 + \frac{k_q N_q}{A_{ik}}} = \frac{1}{1 + \frac{p}{p'}} \quad ; \quad p' = \frac{A_{ik}}{k_q} \frac{p}{N_q}$$

$$p \propto N_p$$

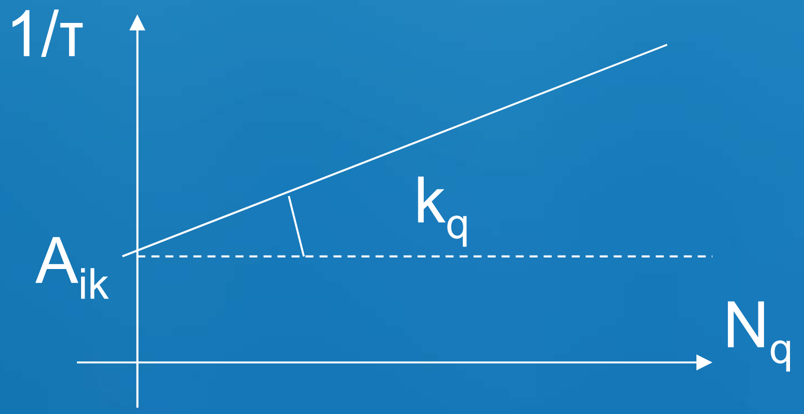
$$p' = const\, \frac{A_{ik}}{k_q}$$

Measurement of quenching rate constants using pulsed excitation:

After the pulse:

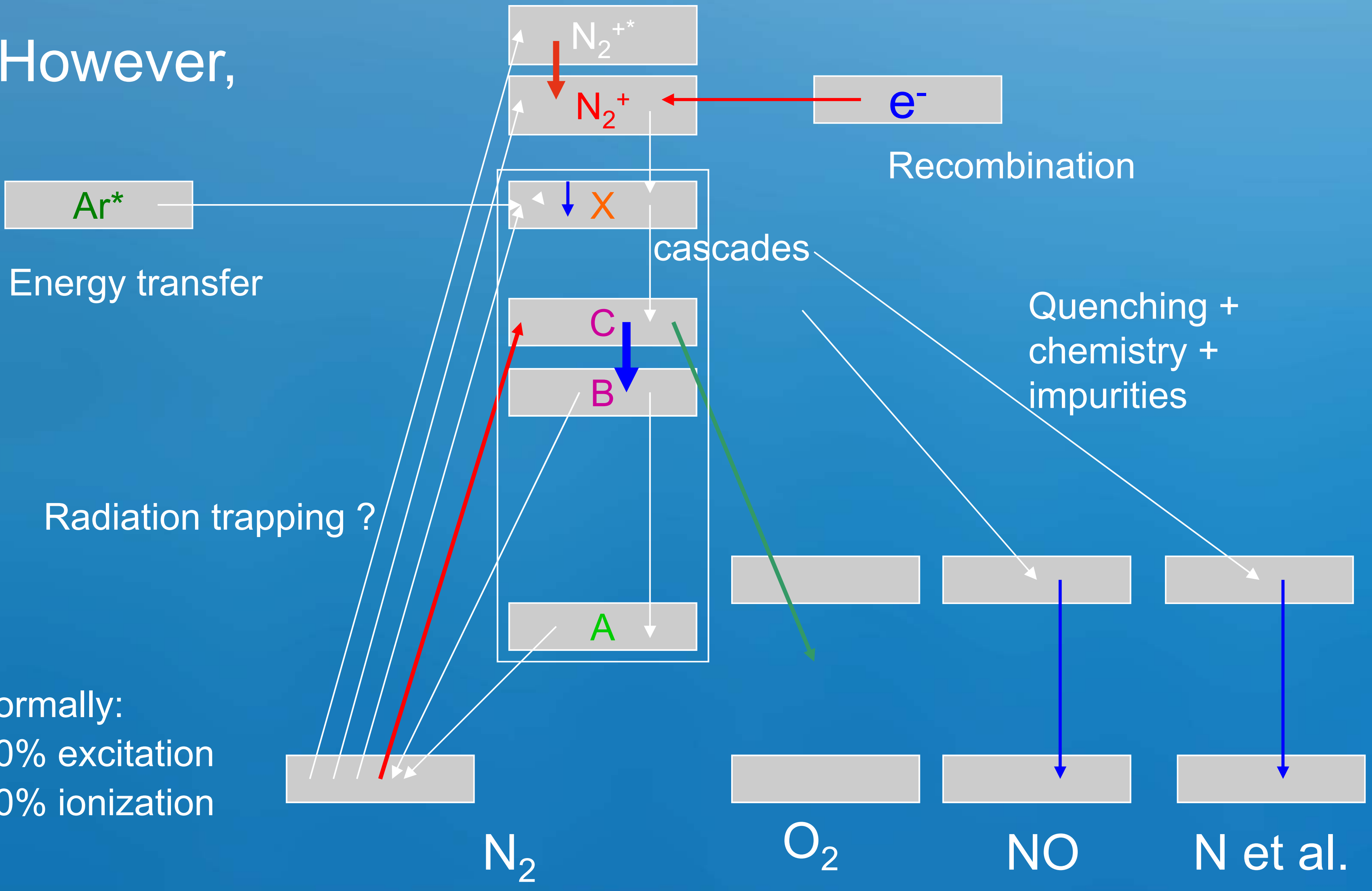
$$\frac{dn}{dt} = 0 - A_{ik} n - \sum n k_q N_q \qquad n(t) \propto I(t) \propto n_0 \, e^{-(A_{ik} + k_q N_q)t}$$

$$\frac{1}{\tau} = A_{ik} + k_q N_q$$



$$p' = const \frac{A_{ik}}{k_q}$$

However,

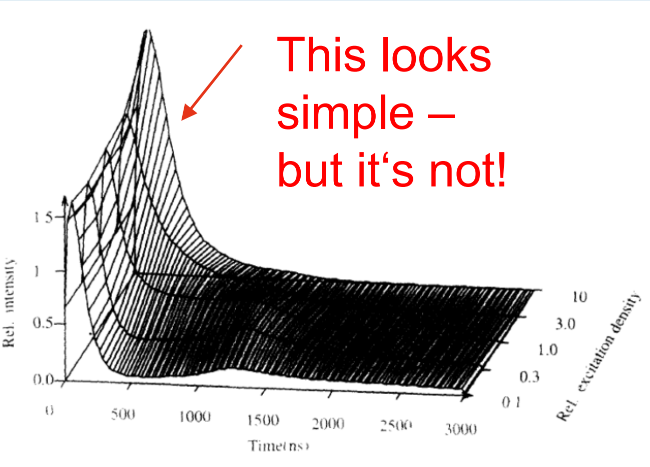


normally:
50% excitation
50% ionization

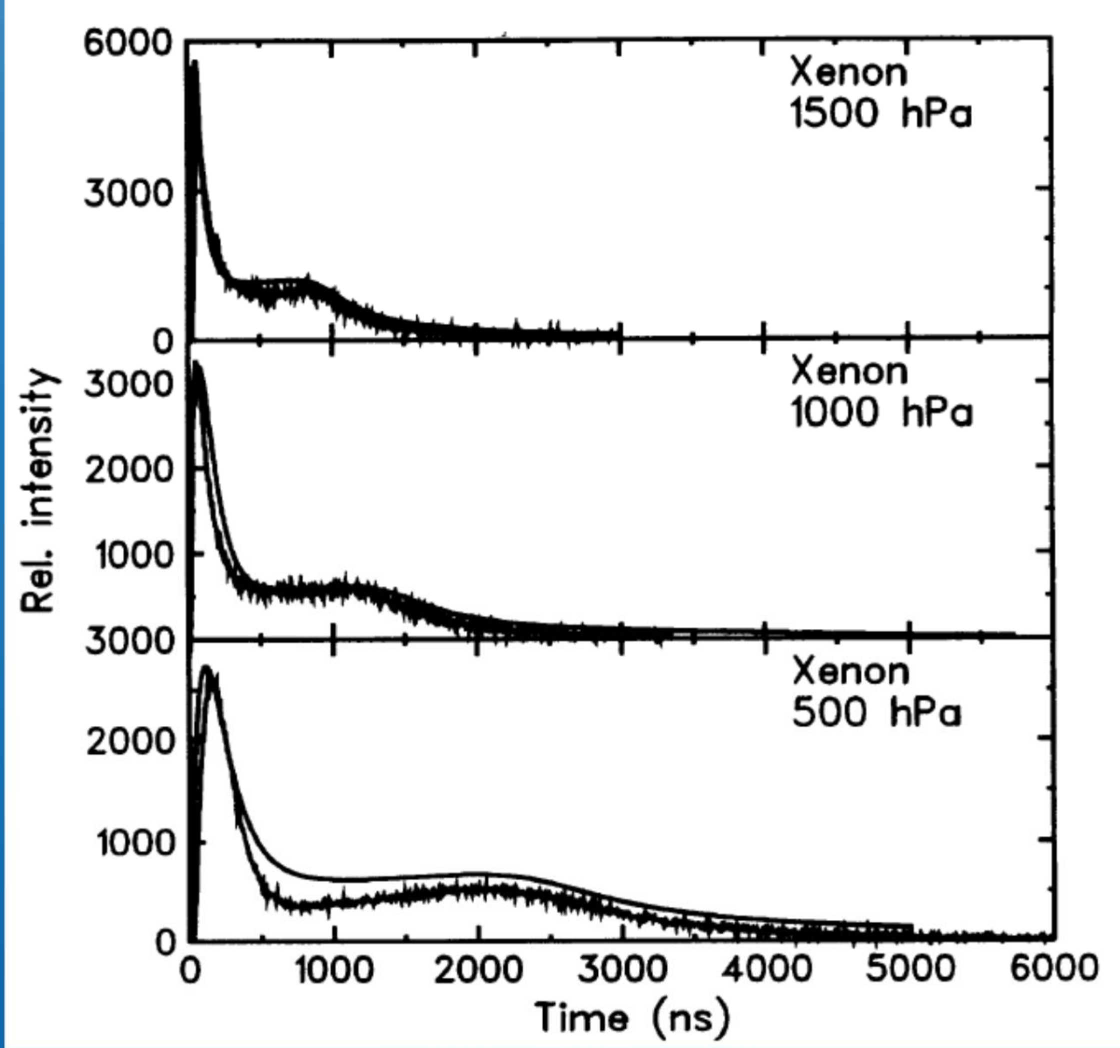
A complex gas kinetics is normally the case

See rare gases:

172nm excimer light following a 2 ns ion beam excitation pulse



This looks simple – but it‘s not!



G. Ribitzki et al, Phys. Rev. E **50**,3973 (1994)

W. Krötz et al. Hyperfine Interactions **88** 193 (1994)

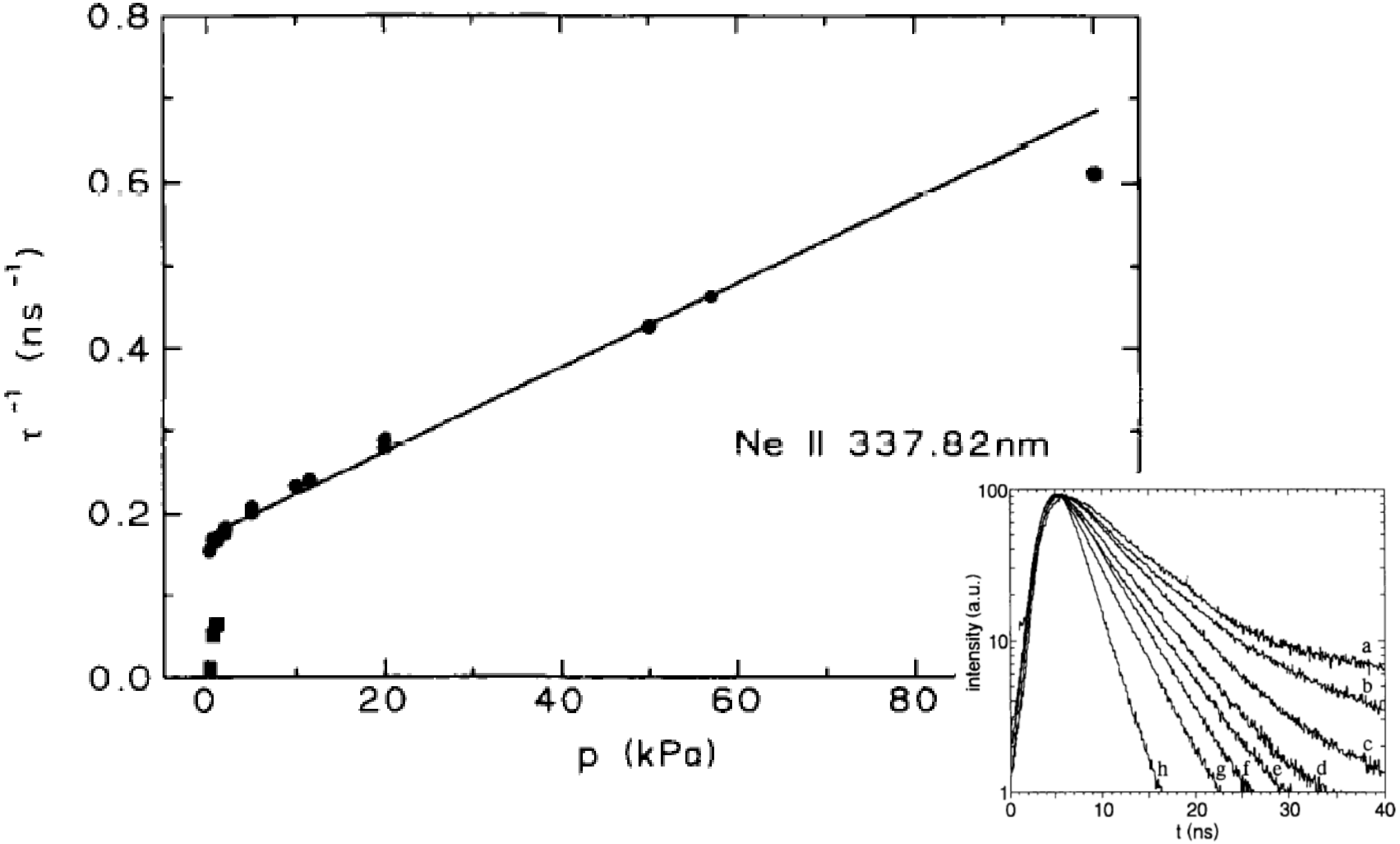
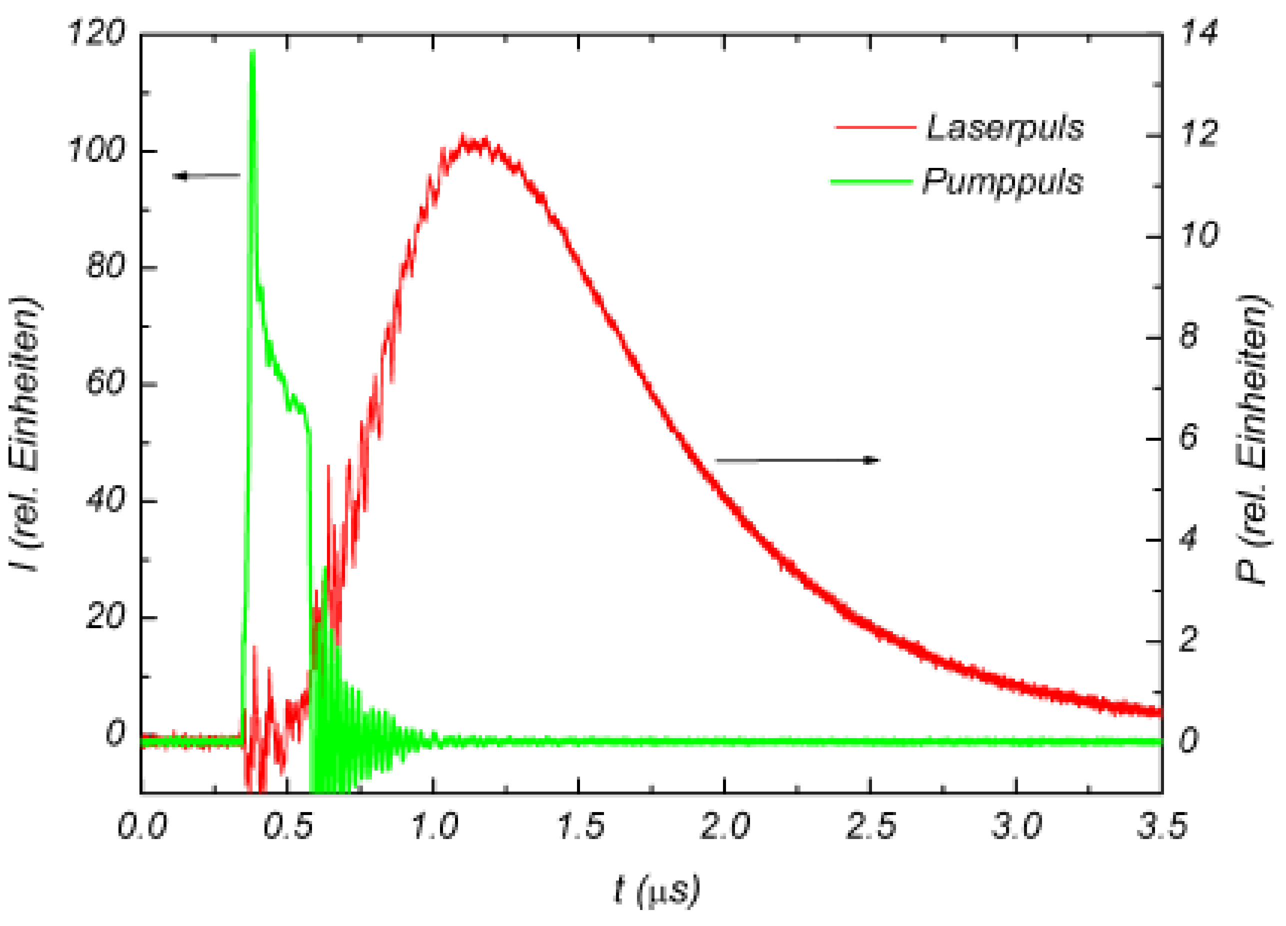


Fig. 8. The inverse of observed lifetimes of the Ne II emission at 337.82 nm is plotted versus the target pressure *p*. The straight line is a least-squares fit to the data. A second time constant is observed at low pressures.

An extreme case: Recombination laser – Diploma thesis C. Skrobol



This is, by far, too complicated for the air fluorescence data analysis?

What can be done?

We have to identify what is

- “purely academic and irrelevant” or
- <u>“relevant for our goal”</u>

and focus on air instead of nitrogen?

So one has to identify relevant processes.

My personal feeling at the moment:

(based on some of the data described below)

I think it is important to be aware how data were obtained!

Excitation	Nitrogen	Air
Individual particles		where to put an extended air shower ???
Particle beam		

b) Measurements with air should be more relevant than with “pure” nitrogen

c) Recombination may be relevant

d) Cascades may be important

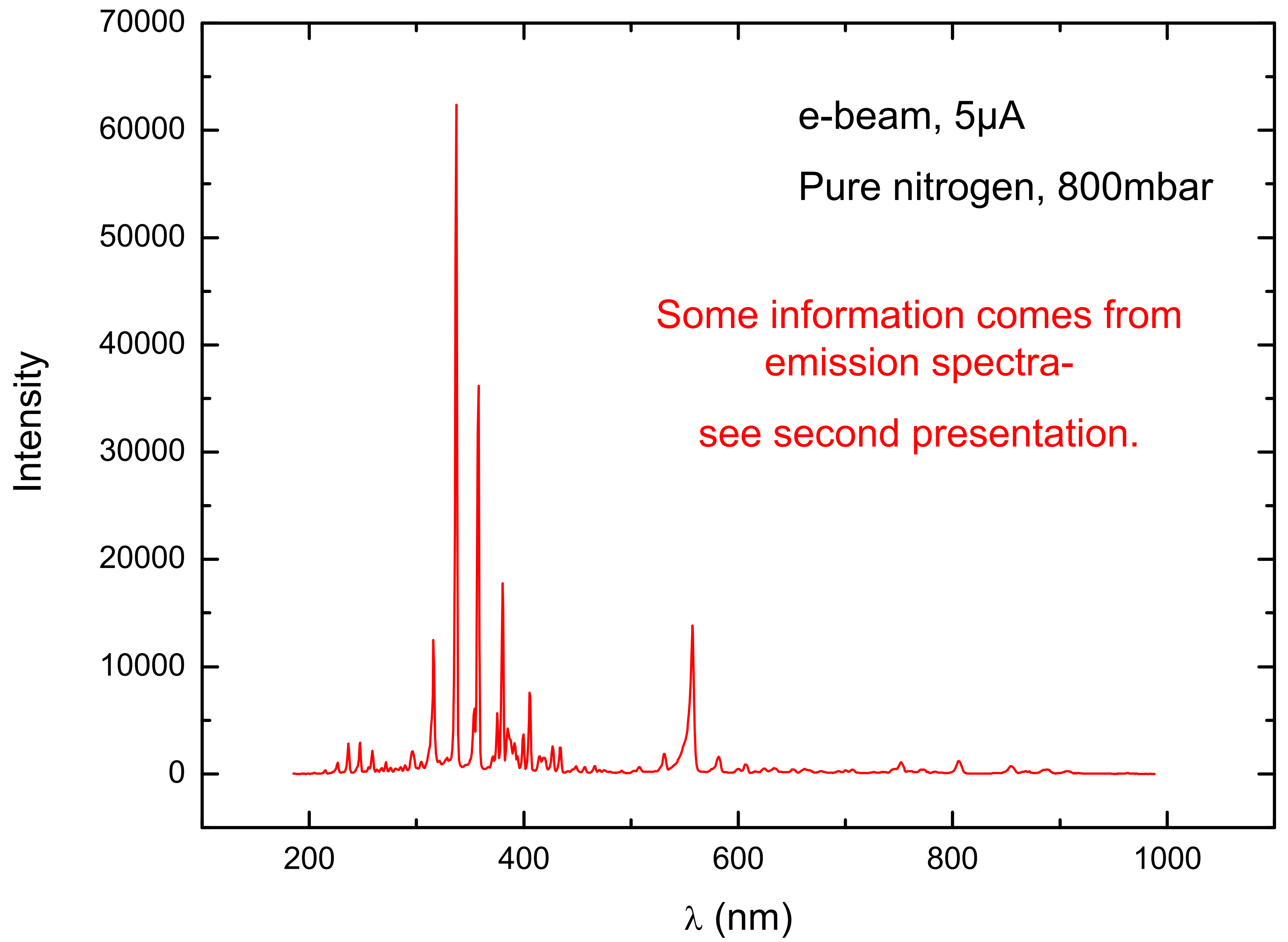
e) I would guess that Ar, N and NO are not important

f) The p’ concept is conceptually wrong but may be “ok” as an approach in air

g) **Deviations between p’ and k_q measurements reveal other mechanisms**

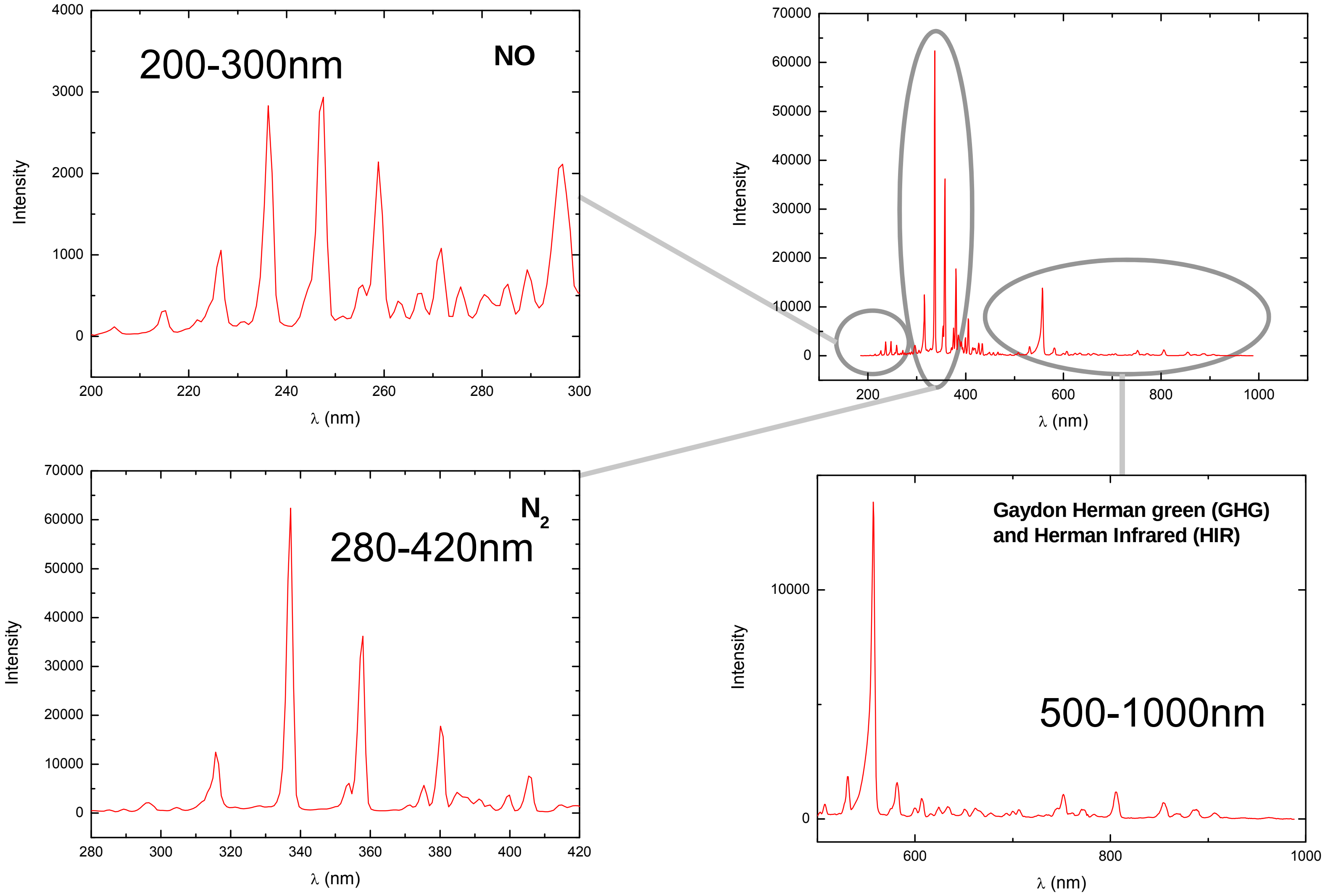
How can I dare to make such
strong statements ?

Some observations:

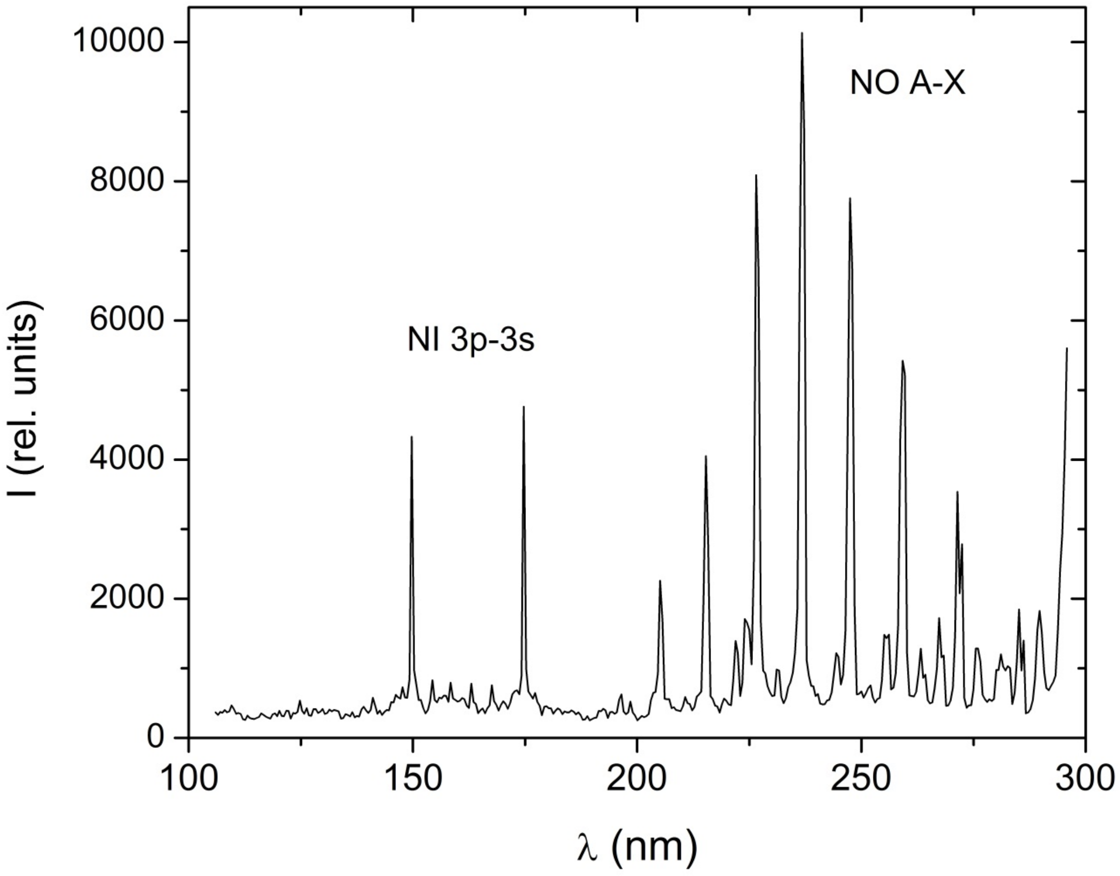


Some information comes from emission spectra-

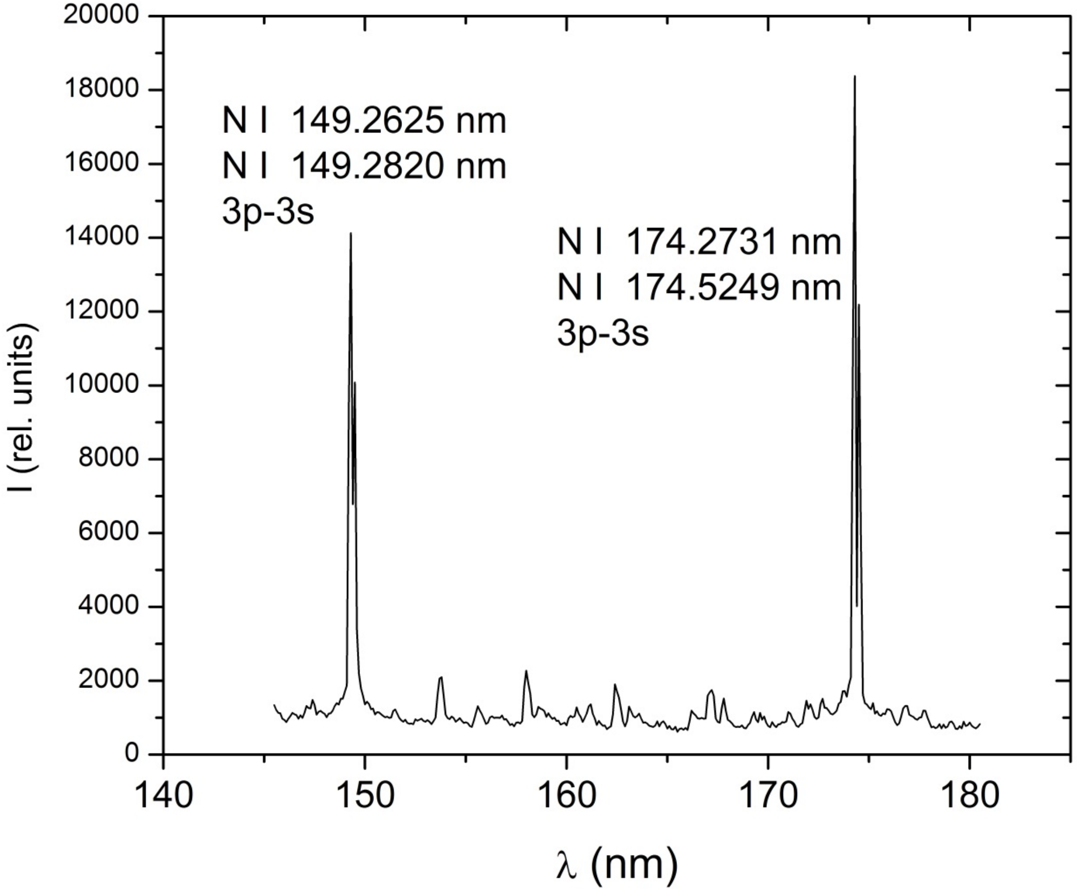
see second presentation.


200-300nm
NO
Intensity
4000
3000
2000
1000
0
200
220
240
260
280
300
λ (nm)
Intensity
70000
60000
50000
40000
30000
20000
10000
0
200
400
600
800
1000
λ (nm)
N_2
280-420nm
Intensity
70000
60000
50000
40000
30000
20000
10000
0
280
300
320
340
360
380
400
420
λ (nm)
Gaydon Herman green (GHG)
and Herman Infrared (HIR)
500-1000nm
Intensity
10000
0
600
800
1000
λ (nm)

Extension into the VUV shows N I lines ! (nitrogen spectrum)

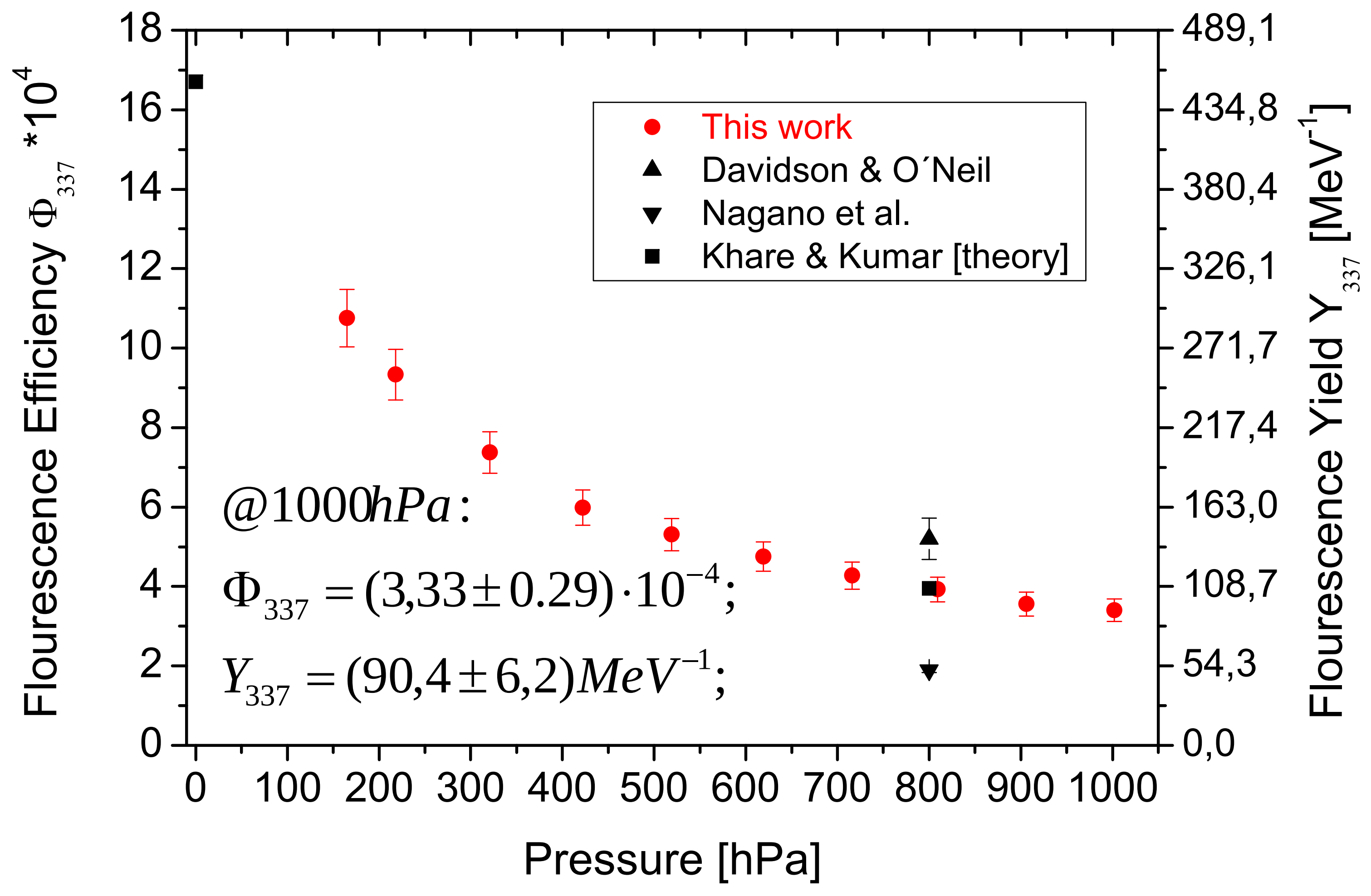


Atomic nitrogen shows up in the VUV spectral range



Emission of the 337nm C-B transition from pure (?) nitrogen

N_2 Absolute Fluorescence Efficiency

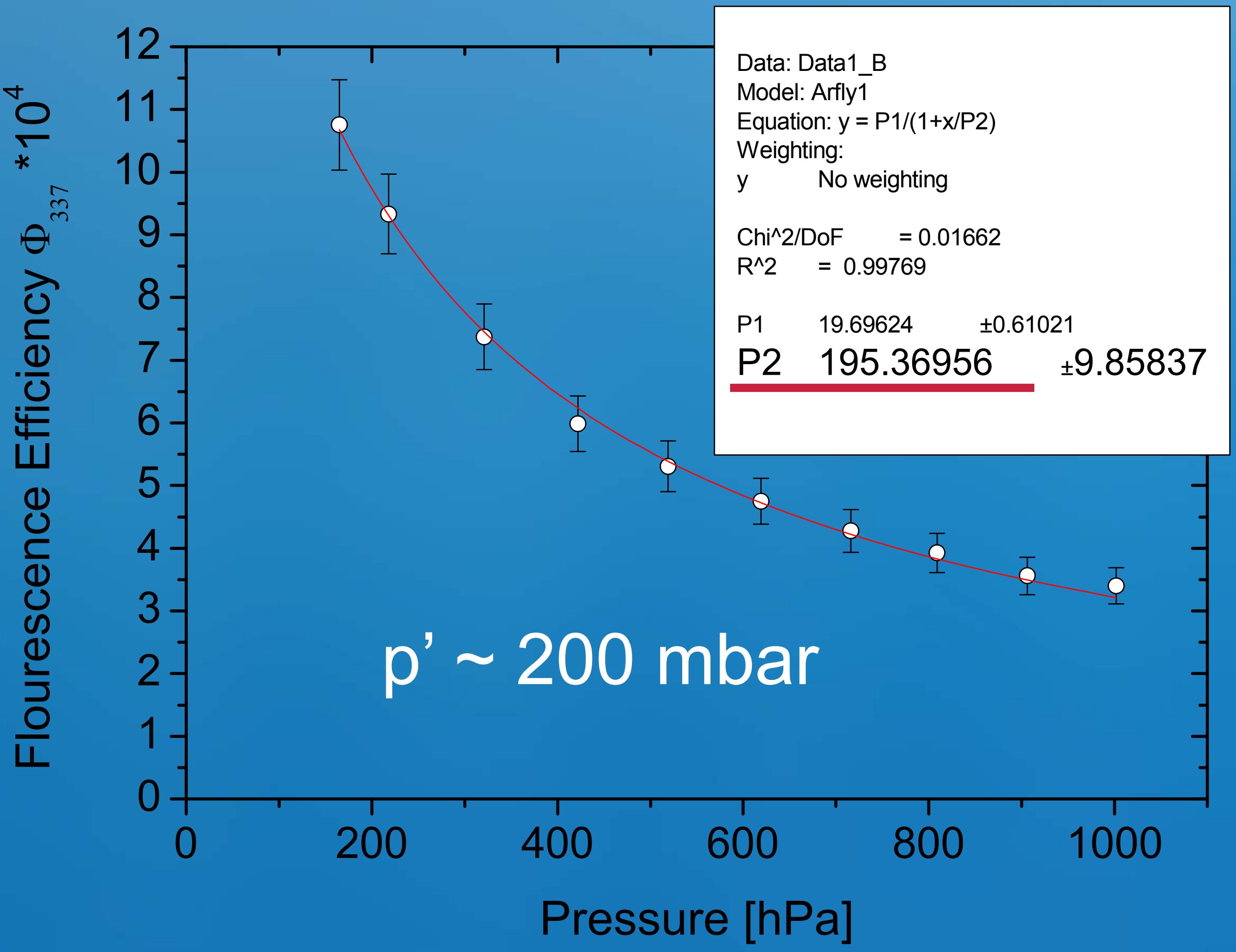


$$@1000hPa:$$

$$\Phi_{337} = (3,33 \pm 0.29) \cdot 10^{-4};$$

$$Y_{337} = (90,4 \pm 6,2) MeV^{-1};$$

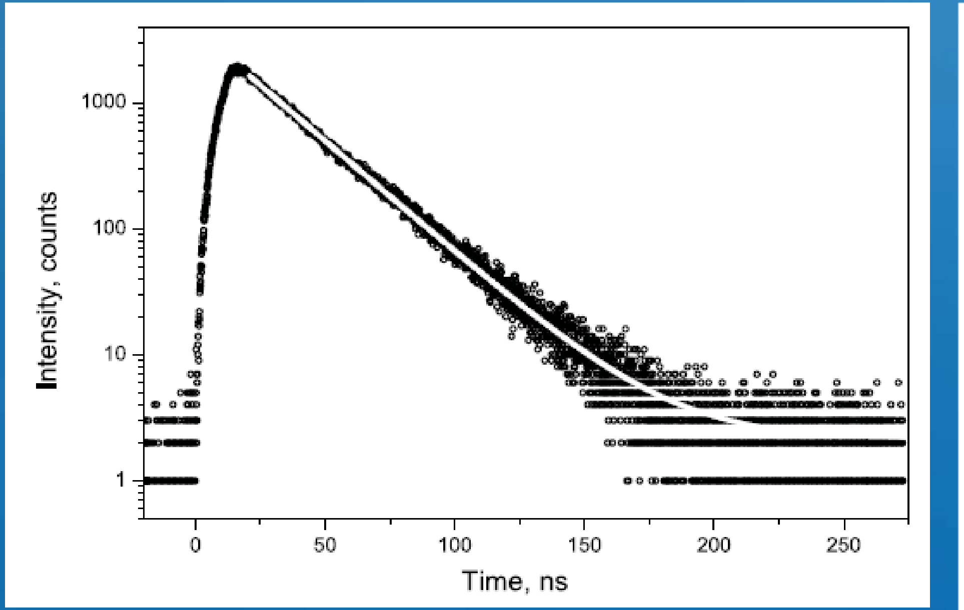
Problem with Efficiency Data – Fitting P'



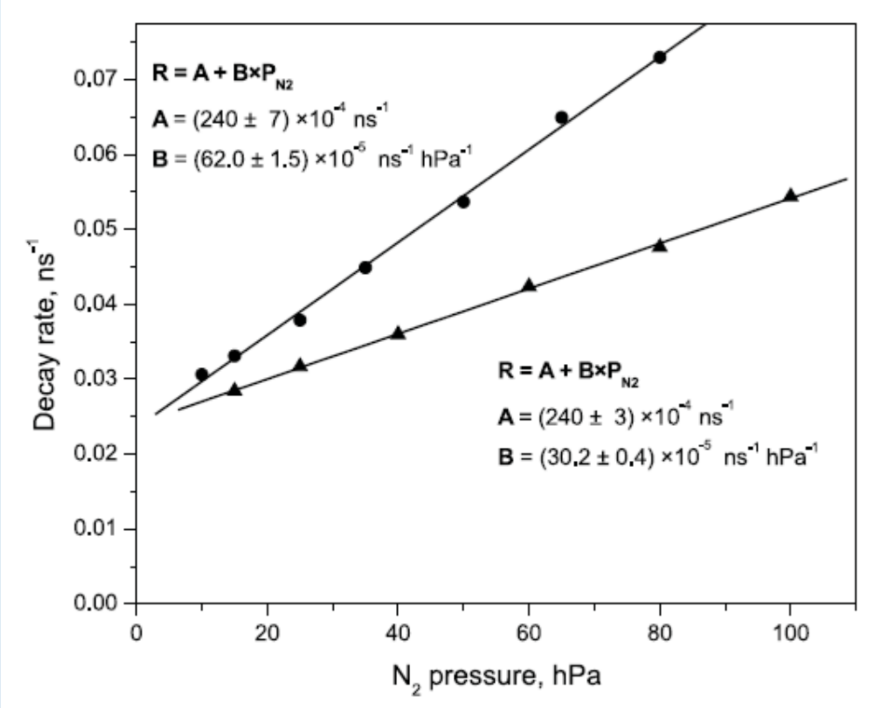
```
Data: Data1_B
Model: Arfly1
Equation: y = P1/(1+x/P2)
Weighting:
y          No weighting

Chi^2/DoF        = 0.01662
R^2      =  0.99769

P1       19.69624          ±0.61021
P2    195.36956          ±9.85837
```

p' ~ 200 mbar

Correlation with lifetime and quenching data:



Eur. Phys. J. D **33**, 207–211 (2005)



- vibrational level 0: $\tau = 41.7 \pm 1.4$ ns,

  $$Q_{N_2} = (3.0 \pm 0.2) \times 10^5\ \mathrm{s}^{-1}\,\mathrm{hPa}^{-1}$$
  $$\to (1.2 \pm 0.1) \times 10^{-11}\ \mathrm{s}^{-1}\,\mathrm{cm}^3$$

p’ = 74.4 mbar ???

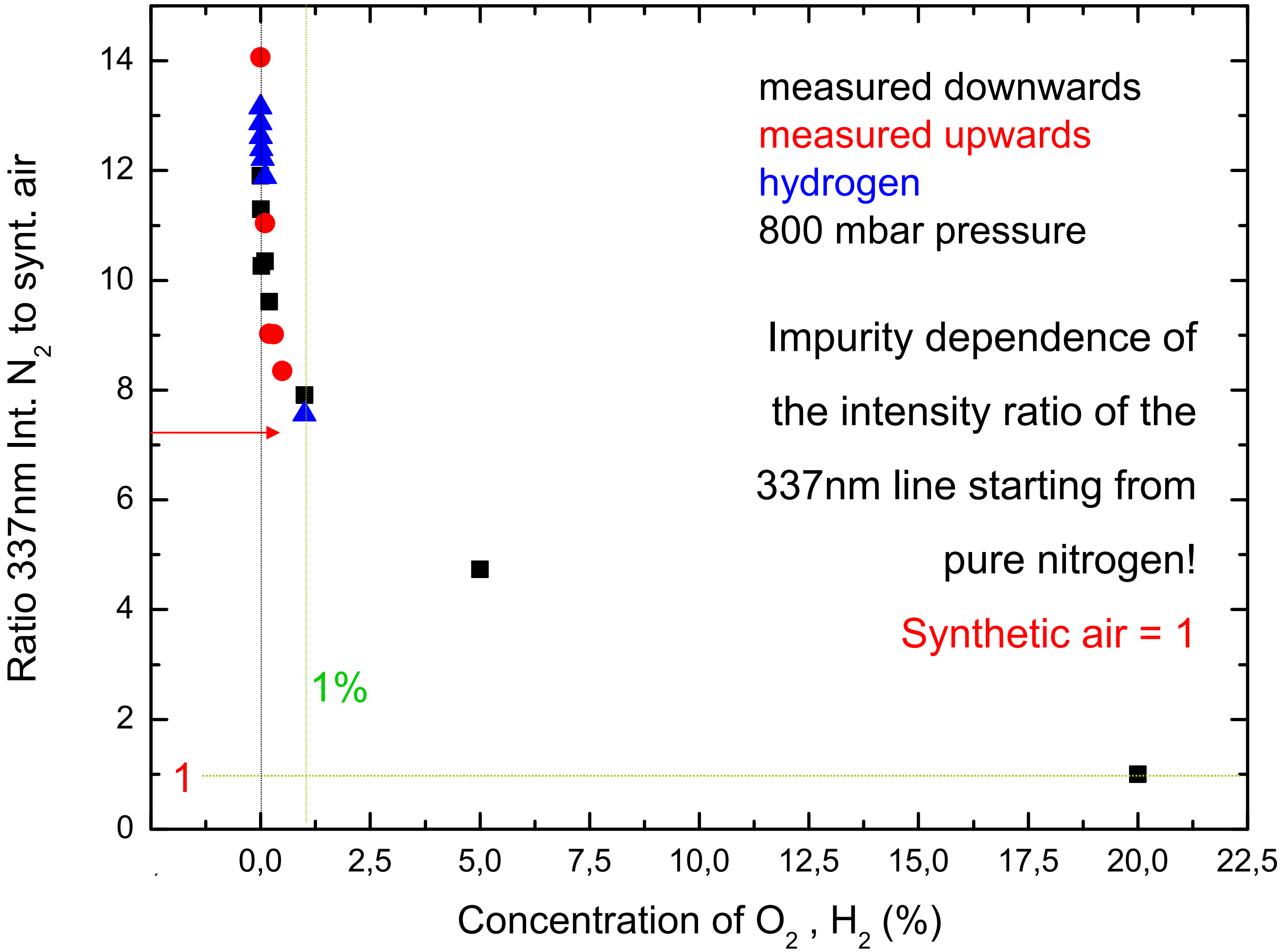
Another test:

337nm emission intensity –

nitrogen vs. air

Quenching rate constants of nitrogen and oxygen are involved !

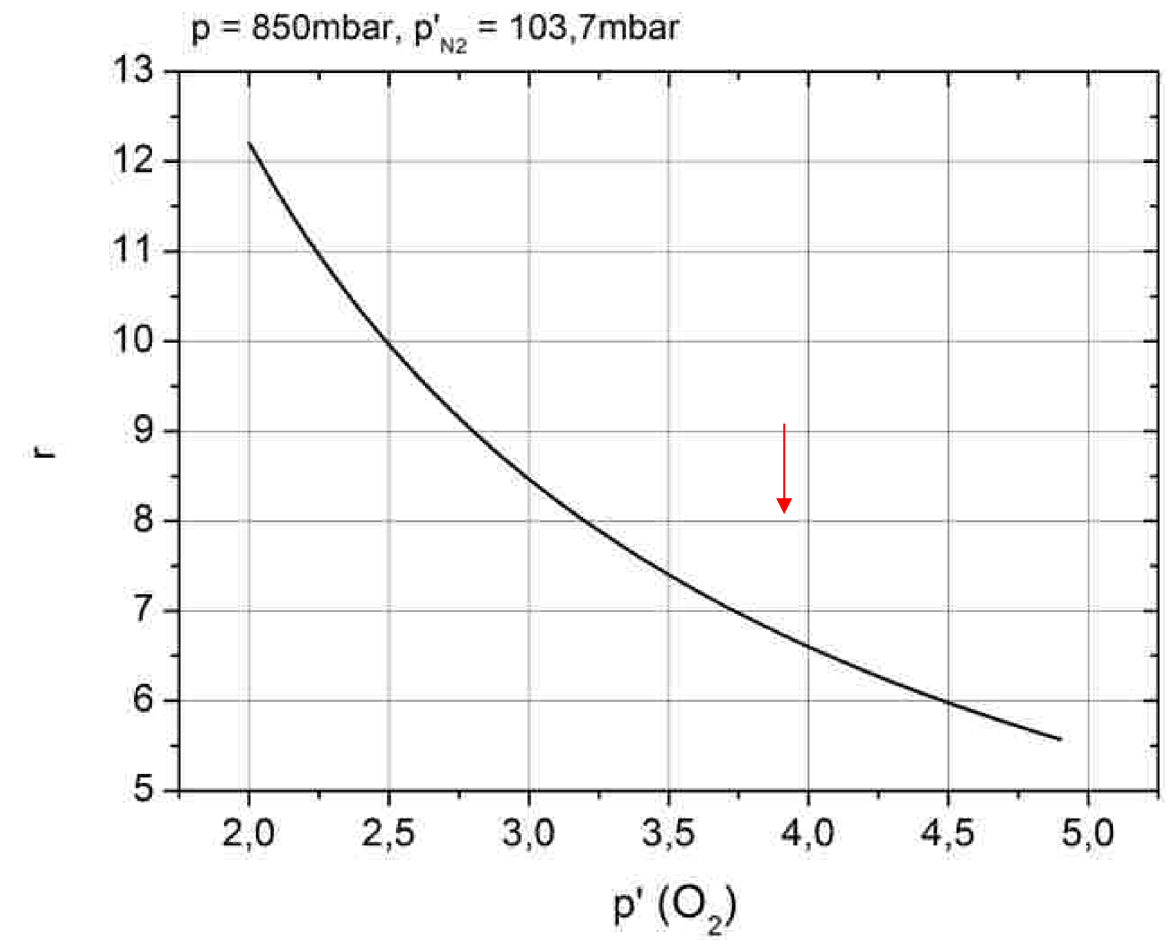
Int. ratio nitrogen / air

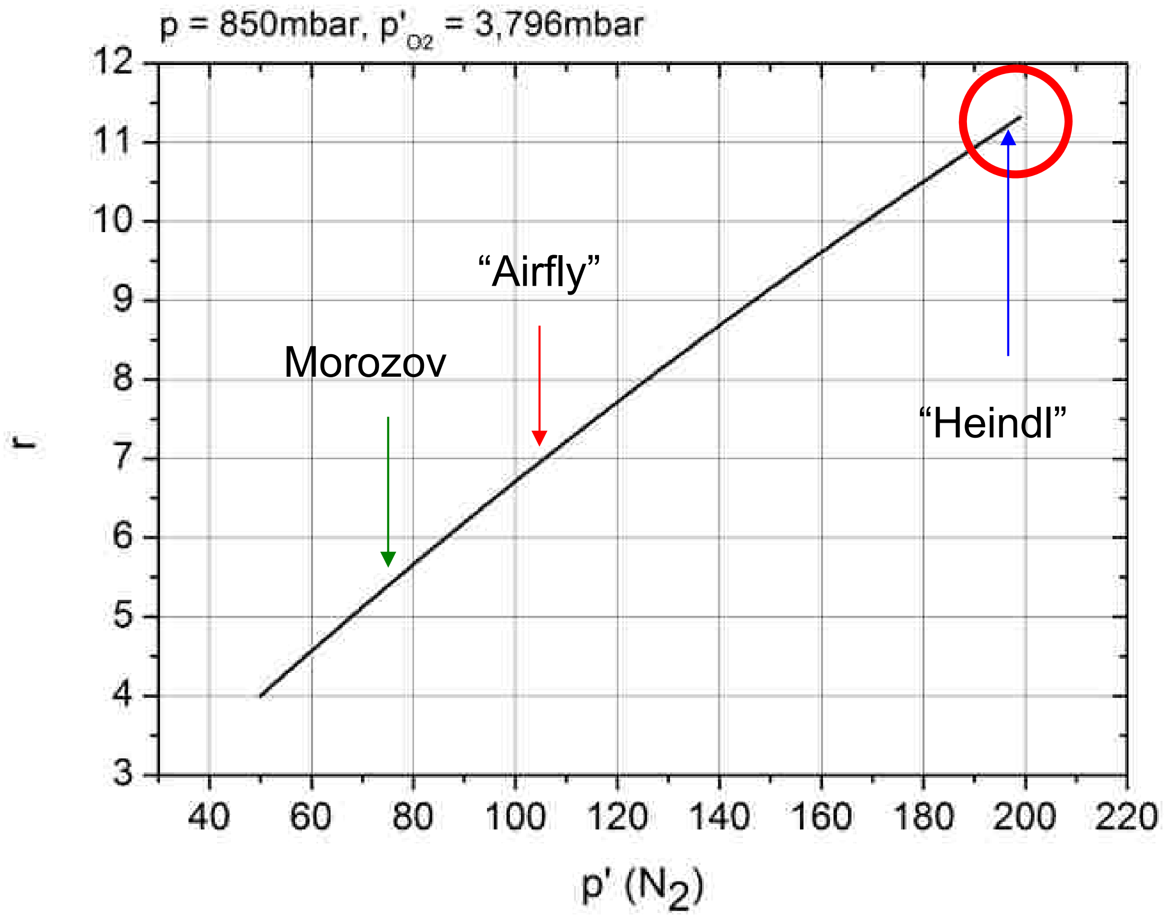


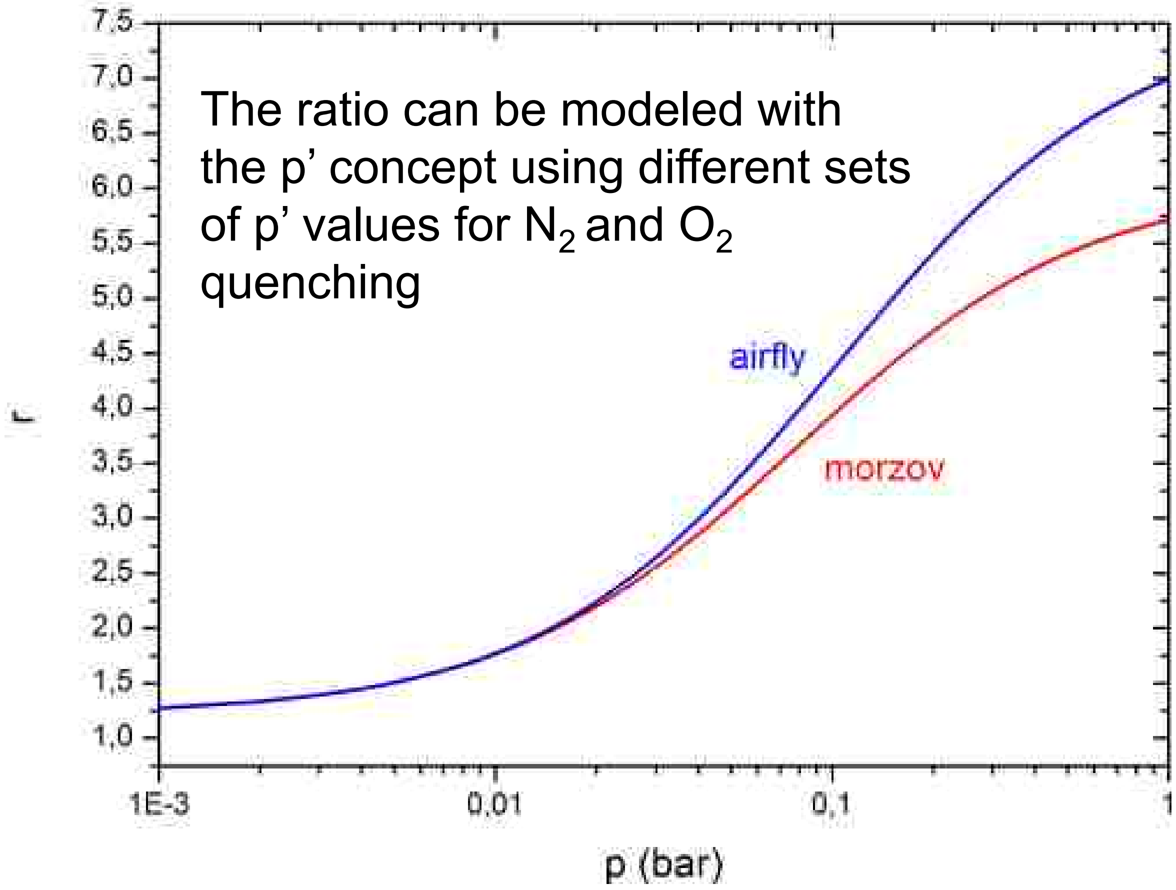
Impurity dependence of the intensity ratio of the 337nm line starting from pure nitrogen!

Synthetic air = 1

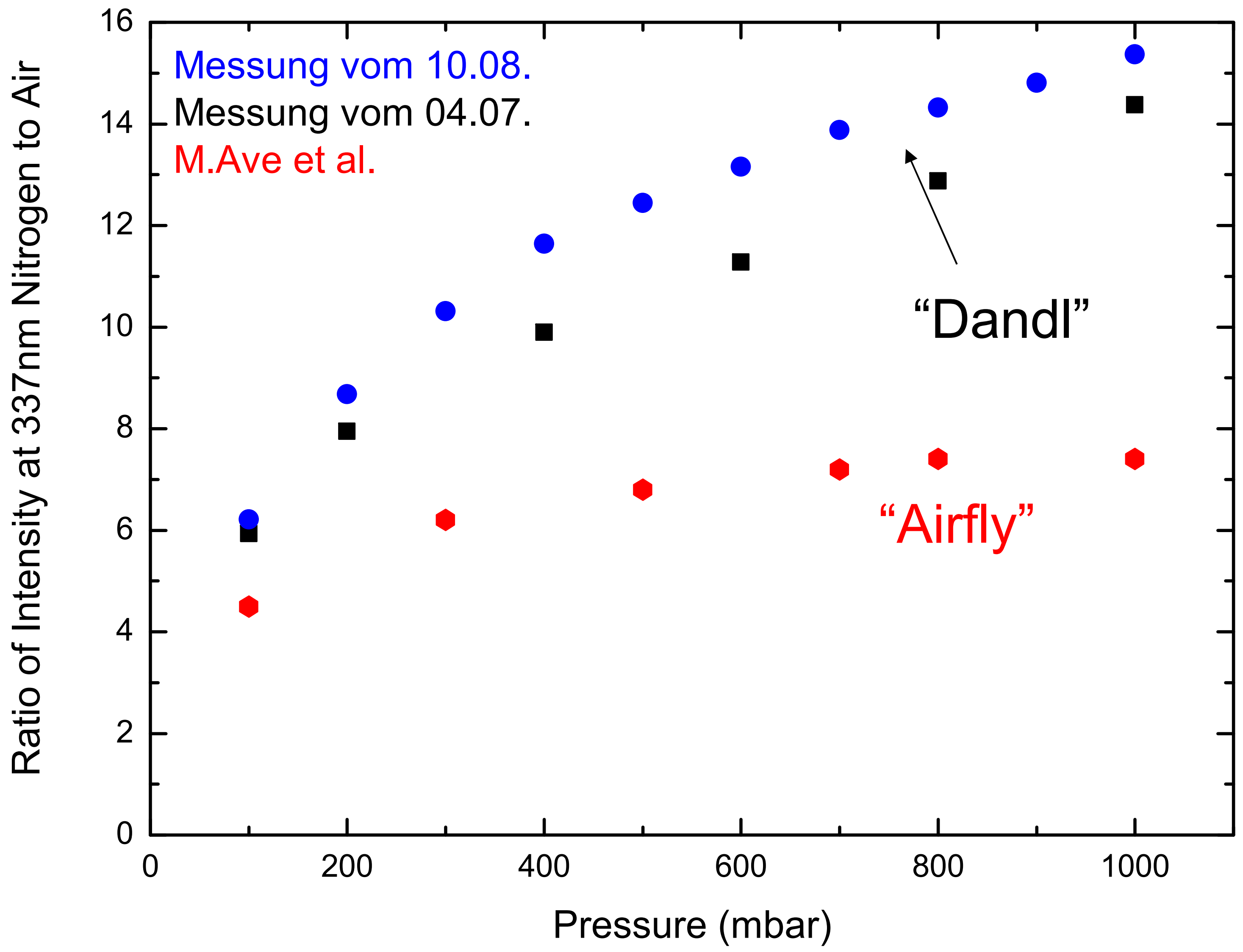
How does the intensity ratio depend on p’ O_2 and p’ N_2 ?




p = 850mbar, p'$_{O2}$ = 3,796mbar
r
3
4
5
6
7
8
9
10
11
12
40
60
80
100
120
140
160
180
200
220
p' (N$_2$)
Morozov
“Airfly”
“Heindl”



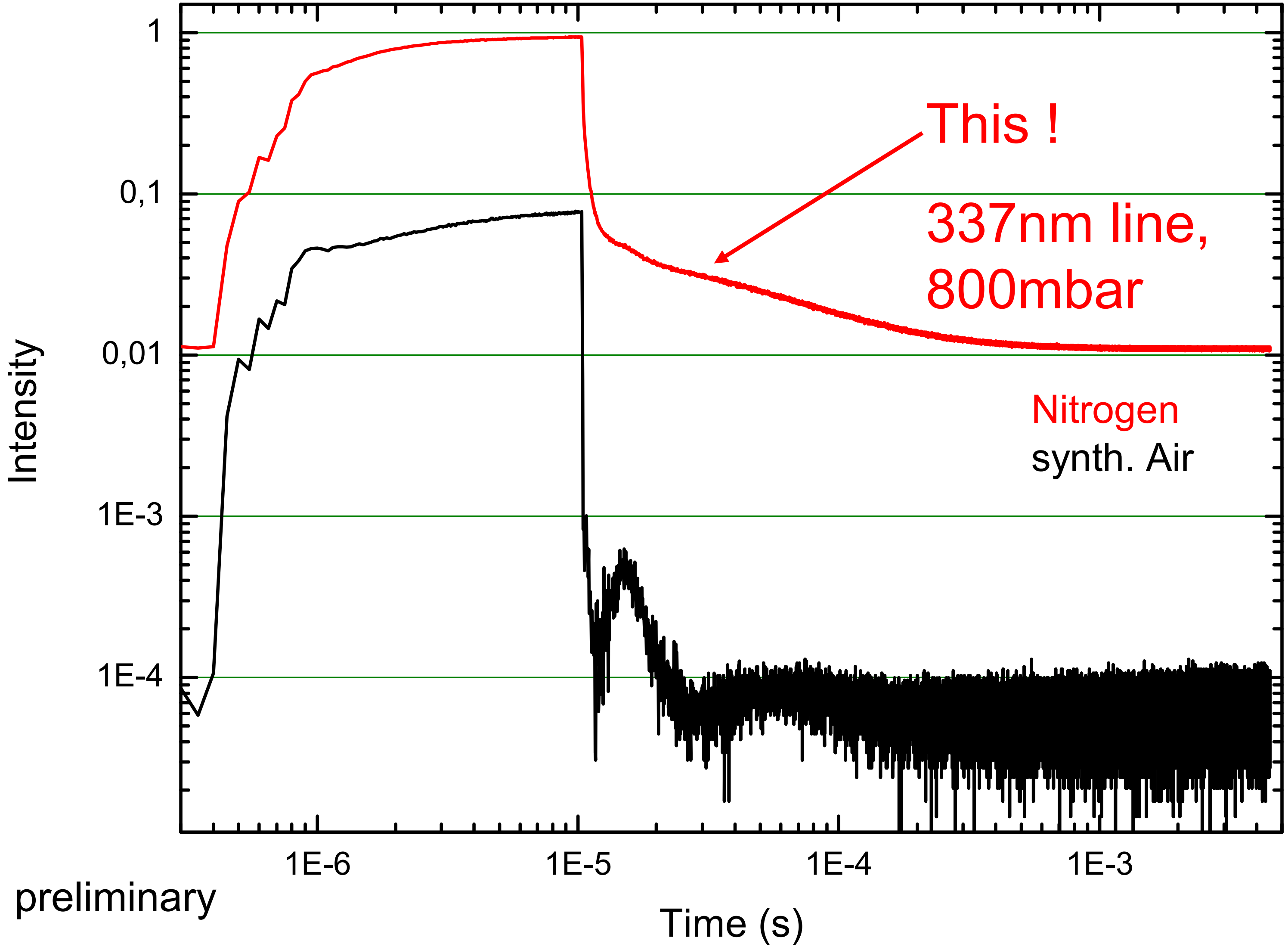
The ratio can be modeled with the p' concept using different sets of p' values for N_2 and O_2 quenching


Messung vom 10.08.
Messung vom 04.07.
M.Ave et al.
"Dandl"
"Airfly"
Ratio of Intensity at 337nm Nitrogen to Air
Pressure (mbar)
0
2
4
6
8
10
12
14
16
0
200
400
600
800
1000

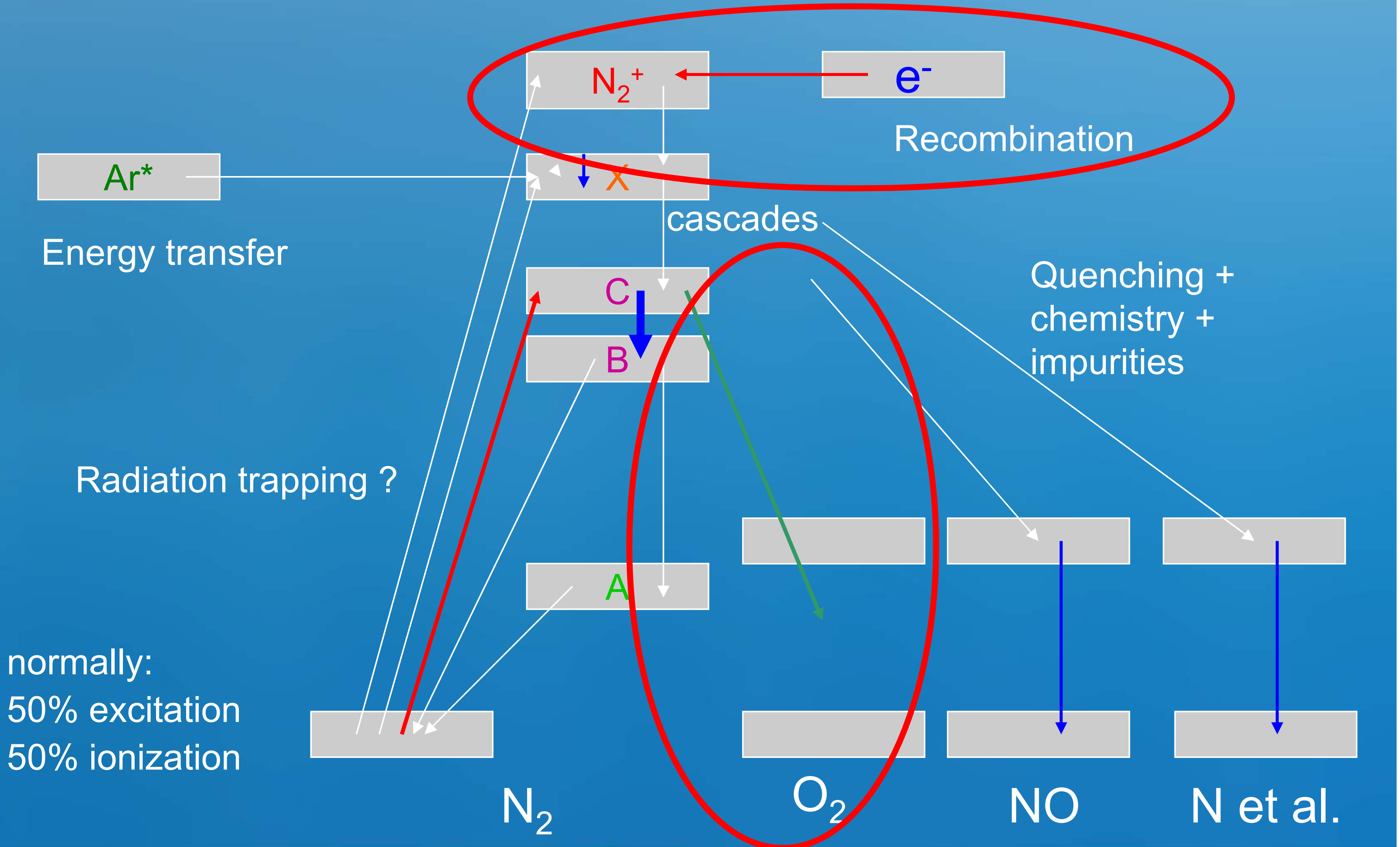
For the comparison of nitrogen and air the p’ concept fails → there must be other important processes involved !!

I suspect due to the factor of 2:

Recombination!



preliminary



Recombination

Energy transfer

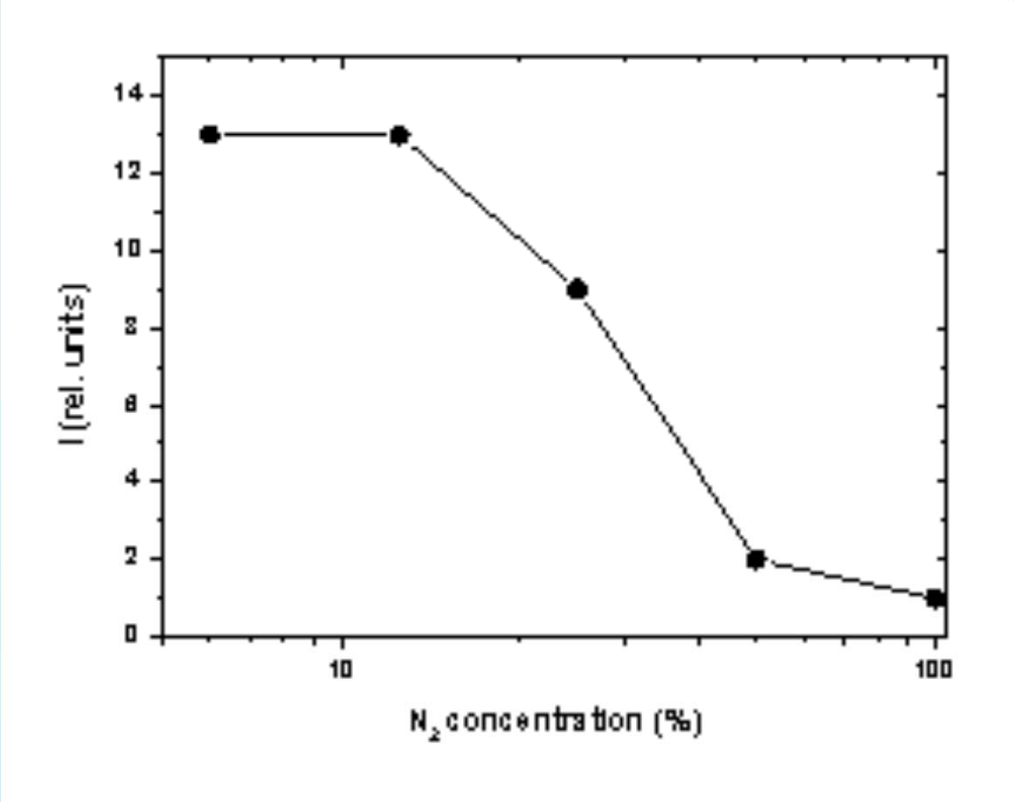
cascades

Quenching + chemistry + impurities

Radiation trapping ?

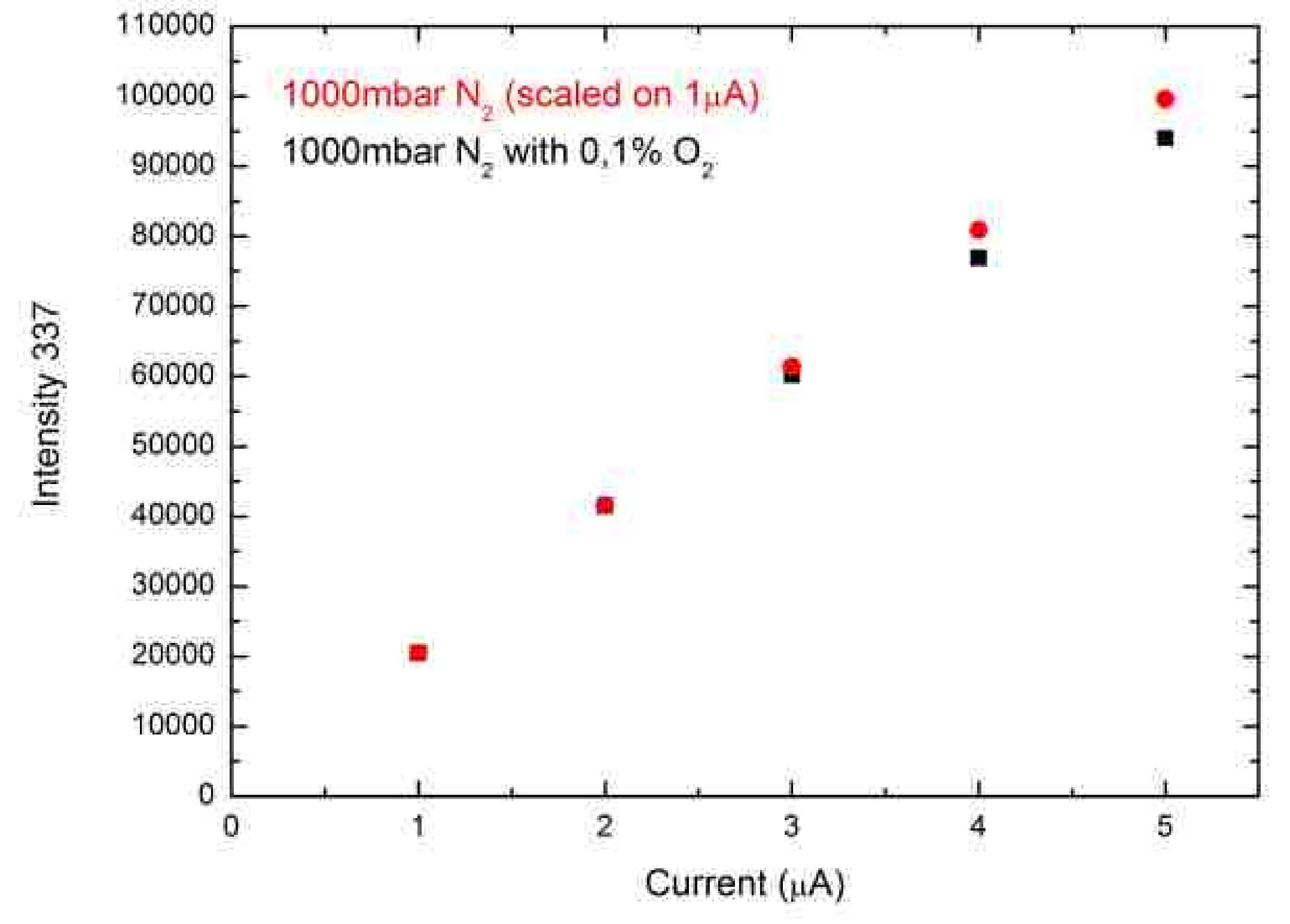
normally:
50% excitation
50% ionization

Comment: Ar N_2 mixtures lead to 13x increase in (358nm) intensity



So: going from air to Ar-N_2 means 16x13 ~ 200 x intensity increase !!!! With the same power deposition

Comment: how to study beam vs. single particle excitation



Conclusion:

- p’ is conceptionally wrong (but may be ok in air (O_2) ?)
- Transfer from nitrogen to air is probably too complicated for the air fluorescence data analysis.
- Oxygen quenching should be measured again.
- What type of excitation is an “extended air shower” ???
- How can p, T, humidity be included if not from “first principles” from nitrogen measurements ???

Sorry for the long and somewhat smart-alecky presentation!

Happy End !!!

Reading a draft of an AIRFLY paper this weekend

Now, if I think I understand the problems and discrepancies I find a photon yield for air at 1000 hPa of

5.594 ± 0.37 Phot. /MeV (from Y Heindl and r Dandl)

Compared with the AIRFLY averaged value at 1013 hPa of

5.61 ± 0.06 Phot. /MeV

Thank you for your attention !