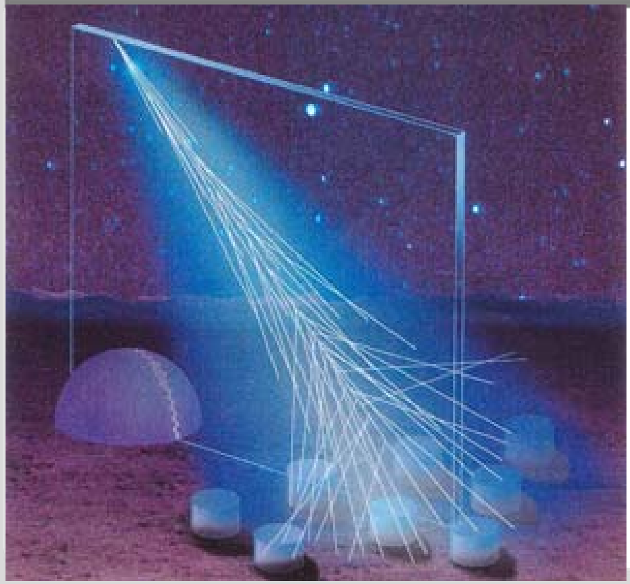
8th Air Fluorescence Workshop

12. – 14. September 2011



Ingredients for a common fluorescence description

- The fluorescence yield is NOT a “name” (e.g. Nagano, Kakimoto, ..) but a set of parameters:

1) Absolute value (e.g. Y_{337} , $Y_{\Delta\lambda}$) ⟶ **Main source of uncertainty**
2) Wavelength spectrum
3) Pressure dependence in dry air (P'_{λ})
4) Humidity dependence (P'_{w})
5) Temperature dependence (α)

Non-negligible contribution

F. Arqueros (UCM) 8th Air Fluorescence Workshop, Karlsruhe 3

Possible strategies

„fluorescence community"- point of view

- Understand almost all underlying processes
- Find best physical values for
  1. Absolute calibrated yield
  2. Pressure dependence
  3. Temperature-dependent collisional cross sections
  4. Humidity quenching
  5. Spectrally resolved intensities
- Find an average value for all items
  AND / OR
  provide all ingredients by individual experiments

„cosmic ray community"- point of view

- A convincing, commonly accepted fluorescence description is needed for comparison of CR observations and fluorescence experiments
- Have reasonable estimate as intermediate solution for
  - Absolute calibrated yield
  - Pressure dependence
  - Temperature-dependent collisional cross sections
  - Humidity quenching
  - Spectrally resolved intensities

Possible strategies

„fluorescence community"- point of view

- Understand almost all underlying processes
- Find best physical values for
  1. Absolute calibrated yield
  2. Pressure dependence
  3. Temperature-dependent collisional cross sections
  4. Humidity quenching
  5. Spectrally resolved intensities
- Find an average value for all items AND / OR provide all ingredients by individual experiments

In about 1 year?

„cosmic ray community"- point of view

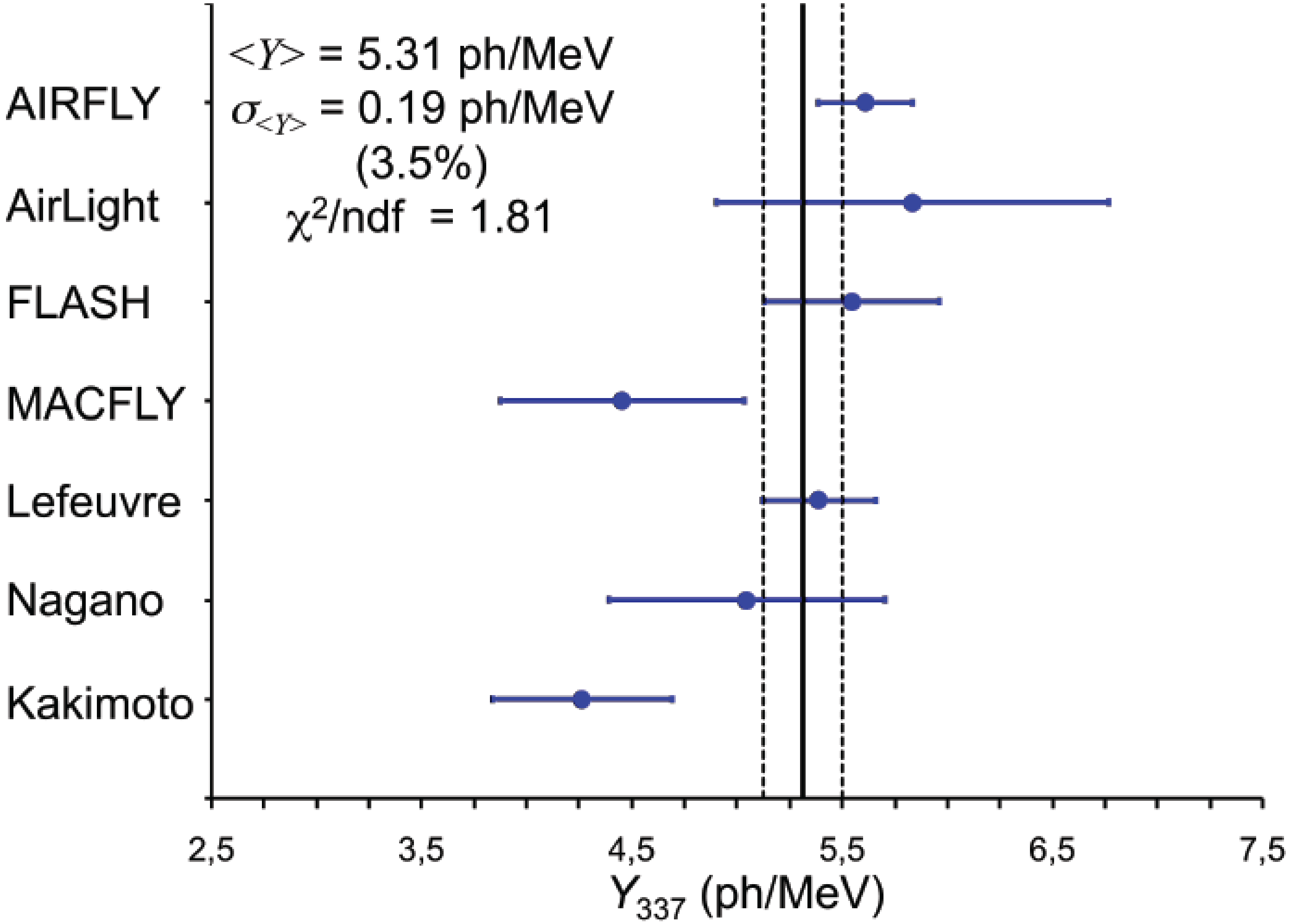
- A **convincing, commonly accepted** fluorescence description is needed for comparison of CR observations and fluorescence experiments
- Have reasonable estimate as intermediate solution for
  - Absolute calibrated yield
  - Pressure dependence
  - Temperature-dependent collisional cross sections
  - Humidity quenching
  - Spectrally resolved intensities

Can be defined today!

Proposal of a reference fluorescence yield for comparing cosmic ray experiments

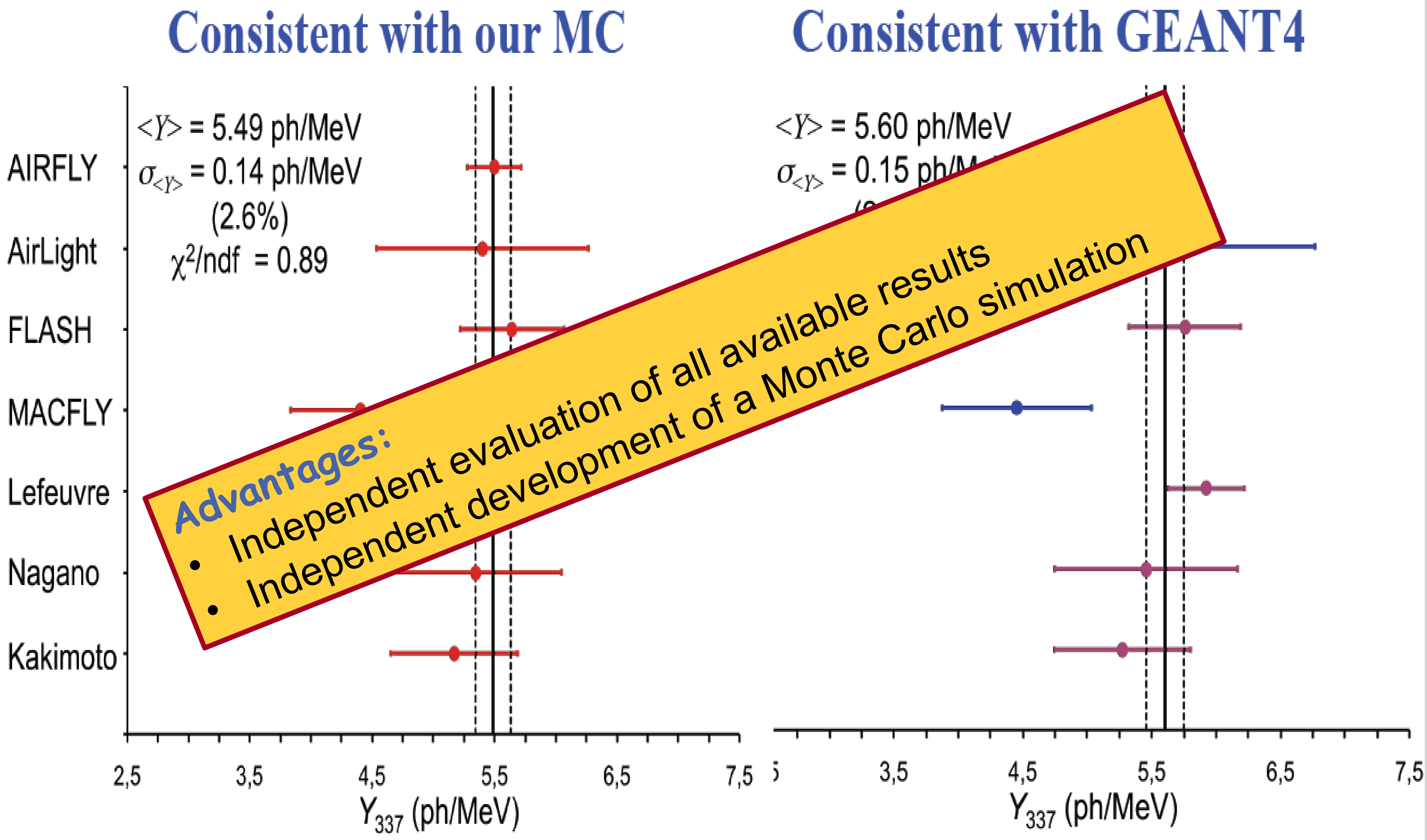
1. Absolute yield – suggestion A

Uncorrected sample



J. Rosado *et al.*, 8th AFW, Karlsruhe, Germany, September 2011

1. Absolute yield – suggestion A



J. Rosado *et al.*, 8th AFW, Karlsruhe, Germany, September 2011

Advantages:

- Independent evaluation of all available results
- Independent development of a Monte Carlo simulation

1. Absolute yield – suggestion B

Three Measurements with different systematics

AIRFLY

performed in Nitrogen to increase the statistics

Ratio Nitrogen/Air (337nm)

- *Measured at AWA Argonne* r = 7.35±0.08
- *Confirmed in Fermilab setup*

Fluo/Cere ratio

$$Y_{air} = \frac{(R_{N2} / r)}{(R_{air})_{MC}}$$

$(Y_{air})_{F/C} = 5.64 \pm 0.12_{stat}$ photons$_{337}$/MeV

2.4 % statistical unc.

Mylar mirror $(Y_{air})_{F/C} = 5.48 \pm 0.25_{stat}$ photons$_{337}$/MeV

Laser calibration

$$Y_{air} = \frac{(L_{N2} / r)}{(L_{air})_{MC}}$$

$(Y_{air})_{LAS} = 5.73 \pm 0.08_{stat}$ photons$_{337}$/MeV

1.3 % statistical unc.

Combined result

$$(Y_{air})_{Airfly} = 5.61 \pm 0.06_{stat} \pm 0.21_{syst} \text{ photons}_{337}\text{/MeV}$$

(dry air, 1013 hPa, 293 K)

1. Absolute yield – suggestion B

Three Measure...

differ...

perform... the statistics

Ratio N...

...onne r = 7.35±0.08

...milab setup

Fluo/Cere ratio

$\frac{(R_{N2} / r)}{(R_{air})_{MC}}$

Mylar mi...

$Y_{air} = \frac{(L_{N2} / r)}{(L_{air})_{MC}}$

$(Y_{air})_{Airfly}$

Advantages:

- Consistent measurements with different setups
- Thorough investigation of systematics

AIRFLY

Systematic uncertainties

AIRFLY

Fluo/Cere ratio		*Laser calibration*	
- sphere efficiency	~ 0.9 %	- laser probe calibration	~ 5.0 %
- PMT quantum efficiency	~ 1.0 %	- calibration sphere Transmission	~ 0.8 %
- Monte Carlo statistics	~ 1.0 %	- Monte Carlo statistics	~ 1.0 %
- N_2/Air ratio	~ 1.0 %	- N_2/Air ratio	~ 1.0 %
- sphere λ dependence	~ 1.0 %	- sphere efficiency	~ 0.9 %
- filter transmittance	~ 2.0 %	- background subtraction	~ 1.0 %
- background subtraction	~ 1.0 %	- energy deposit	~ 2.0 %
- energy deposit	~ 2.0 %	- geometry	~ 0.3 %
Total	*3.7 %*	*Total*	*5.8%*

2. Pressure Dependence – suggestion A

M. Nagano et al. / Astroparticle Physics 22 (2004) 235–248

Table 4
Average p' values in different radiative systems in nitrogen gas and in air

Transition state	Gas	p' (hPa at 20 °C)
$2P(0, v'')$	N_2	144.7 ± 3.1
	Air	18.1 ± 0.6
$2P(1, v'')$	N_2	74.5 ± 2.8
	Air	25.6 ± 1.4
$2P(2, v'')$	N_2	36.2 ± 8.0
	Air	7.9 ± 1.8
$1N(0, v'')$	N_2	5.48 ± 0.46
	Air	4.83 ± 0.24

2. Pressure Dependence – suggestion A

M. Nagano et al. / Astroparticle Physics 22 (2004) 235–248

Table 4
Average p' values in different radiative systems in nitr[illegible]s and in air

Transition state	Gas	p' (hPa at 20 °C)
$2P(0, v'')$	N_2	144.7 ± [illegible]
	Air	[illegible]
$2P(1, v'')$	[illegible]	[illegible] ± 2.8
	[illegible]	25.6 ± 1.4
$2P(2, v'')$	N_2	36.2 ± 8.0
	Air	7.9 ± 1.8
$1N(0, v'')$	N_2	5.48 ± 0.46
	Air	4.83 ± 0.24

Advantages:
- Weighted averages for main band systems

2. Pressure Dependence – suggestion B

M. Ave et al. / Nuclear Instruments and Methods in Physics Research A 597 (2008) 41–45

Table 2
Collisional quenching reference pressures in dry air at 293 K

Band	λ (nm)	$p'_{air}(\lambda)$ (hPa)
2P(0,0)	337.1	15.89 ± 0.73
2P(0,1)	357.7	$15.39 \pm 0.25 \pm 0.72$
2P(0,2)	380.5	$16.51 \pm 0.48 \pm 0.72$
2P(0,3)	405.0	$17.8 \pm 1.5 \pm 0.8$
2P(1,0)	315.9	$11.88 \pm 0.31 \pm 0.62$
2P(1,1)	333.9	$15.5 \pm 1.5 \pm 0.7$
2P(1,2)	353.7	$12.70 \pm 0.34 \pm 0.64$
2P(1,3)	375.6	$12.82 \pm 0.45 \pm 0.62$
2P(1,4)	399.8	$13.6 \pm 1.1 \pm 0.6$
2P(1,5)	427.0	$6.38 \pm 0.68 \pm 0.43$
2P(2,0)	297.7	$17.3 \pm 4.0 \pm 0.8$
2P(2,1)	313.6	$12.27 \pm 0.78 \pm 0.64$
2P(2,2)	330.9	$16.9 \pm 3.5 \pm 0.76$
2P(2,3)	350.0	$15.2 \pm 3.7 \pm 0.7$
2P(2,4)	371.1	$14.8 \pm 1.9 \pm 0.7$
2P(2,5)	394.3	$13.7 \pm 3.3 \pm 0.7$
2P(2,6)	420.0	$13.8 \pm 4.0 \pm 0.7$
2P(3,1)	296.2	$18.5 \pm 5.0 \pm 0.8$
2P(3,2)	311.7	$18.7 \pm 3.8 \pm 0.8$
2P(3,3)	328.5	$20.7 \pm 2.6 \pm 0.8$
1N(0,0)	391.4	$2.94 \pm 0.58 \pm 0.31$
1N(0,1)	427.8	$2.89 \pm 0.64 \pm 0.30$
1N(1,1)	388.5	$3.9 \pm 1.7 \pm 0.3$
GH(0,4)	346.3	$21 \pm 10 \pm 1$
GH(0,6)	387.7	$7.6 \pm 1.6 \pm 0.5$

Quoted uncertainties are statistical and the propagated uncertainty of $p'_{air}(337)$, respectively.

2. Pressure Dependence – suggestion B

M. Ave et al. / Nuclear Instrume[illegible] in Physics Research A 597 (2008) 41–45

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Quoted uncertainties are statistical and the propagated uncertainty of $p'_{\mathrm{air}}(337)$, respectively.

Advantages:
- Most complete set of wavelengths
- Cross check / consistency within band systems

3. Temperature-dependent collsional cross sections – suggestion A

i) For some N_2 2P bands

v'	(v',v'')	λ (nm)	α_λ [1]
0	(0,0)	337.1	-0.35±0.01
0	(0,1)	357.7	-0.35±0.02
0	(0,2)	380.5	-0.34±0.03
0	(0,3)	405.0	-0.37±0.08
1	(1,0)	315.9	-0.19±0.03
1	(1,2)	353.7	-0.22±0.04
1	(1,3)	375.6	-0.17±0.05
1	(1,4)	399.8	-0.20±0.08
2	(2,1)	313.6	-0.13±0.05
2	(2,3)	350.0	-0.38±0.16
2	(2,4)	371.1	-0.24±0.13
2	(2,5)	394.3	-0.20±0.14

ii) For two N_2^+ 1N bands

v'	v''	λ (nm)	α_λ [1]
0	0	391.4	-0.79±0.03
0	1	427.8	-0.54±0.08

[1] M. Bohacova, 6th FW, L'Aquila, Italy, Feb. 2009

± 0.08 systematic error due to 337 ratio

3. Temperature-dependent collsional cross sections – suggestion A

i) For some N_2 2P bands

v'	(v',v'')	λ (nm)	α_λ [1]
0	(0,0)	337.1	-0.35±0.01
0	(0,1)	357.7	-0.35±0.02
0	(0,2)	380.5	-0.34±0.0[illegible]
0	(0,3)	405.0	[illegible]
1	(1,0)	31[illegible]	[illegible]
1	(1,[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]20±0.08
2	[illegible]	[illegible]	-0.13±0.05
2	[illegible]	350.0	-0.38±0.16
2	(2,4)	371.1	-0.24±0.13
2	(2,5)	394.3	-0.20±0.14

± 0.08 systematic error due to 337 ratio

ii) For two N_2^+ 1N bands

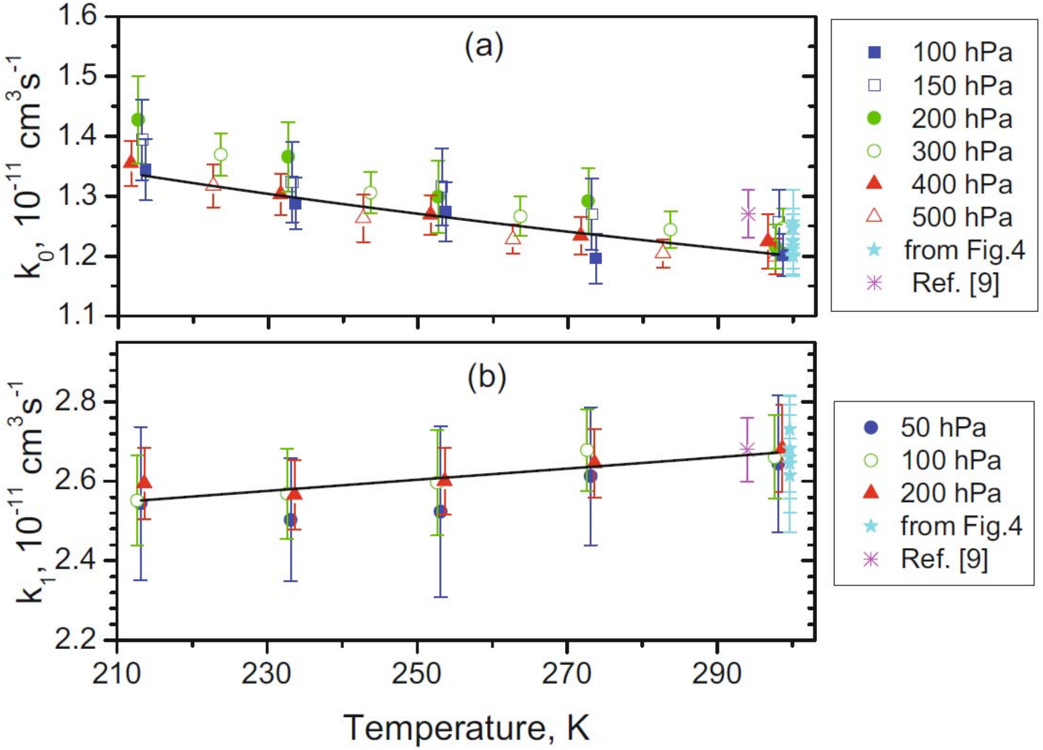
v'	v''	λ (n[illegible]	[illegible]1]
0	0[illegible]	[illegible]	[illegible]03
[illegible]	[illegible]	[illegible]	[illegible]3

[illegible]W, L'Aquila, Italy, Feb. 2009

Advantages:

- Most complete set of wavelengths
- Cross check / consistency within band systems
- Measurements directly in air

3. Temperature-dependent collsional cross sections – suggestion B



(Pereira et al., Eur. Phys. J D 56 (2010) 325)

k_0 increases by (13±3)% from 300 to 210 K,

k_1 decreases by (5±3)% from 300 to 210 K

$$k_0\,(T) = C(\frac{T}{300})^{\beta}$$

$$\beta_0 = -0.33 \pm 0.04$$

$$C = k_0(298K) = (1.2 \pm 0.2) \times 10^{-11}\,\mathrm{cm^3 s^{-1}}$$

$$\beta_1 = 0.14 \pm 0.08$$

$$C = k_1(298K) = (2.67 \pm 0.14) \times 10^{-11}\,\mathrm{cm^3 s^{-1}}$$

From $R_{v'}$ vs p, @ 298 K:

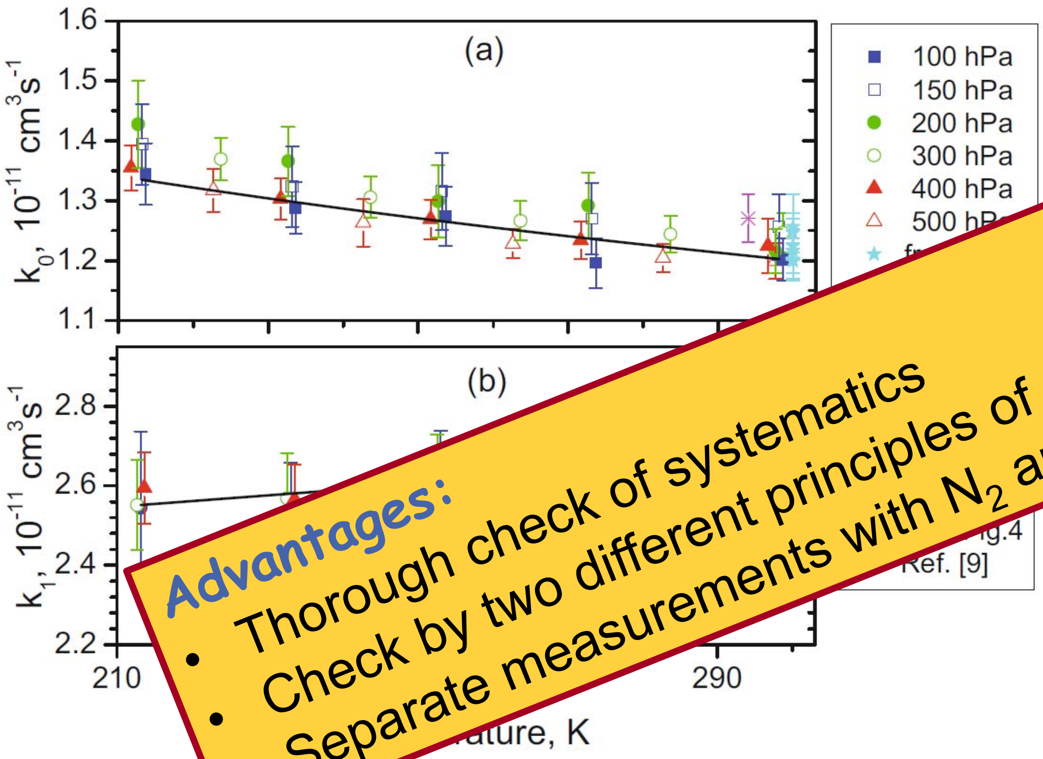
$$k_0(298\ K) = (1.24 \pm 0.04) \times 10^{-11}\,\mathrm{cm^3 s^{-1}}$$

$$k_1(298\ K) = (2.60 \pm 0.08) \times 10^{-11}\,\mathrm{cm^3 s^{-1}}$$

From intensity measurements:

$$\overline{\beta}_0^{LY} = -0.37 \pm 0.07$$

3. Temperature-dependent collsional cross sections – suggestion B



Advantages:

- Thorough check of systematics
- Check by two different principles of measurements
- Separate measurements with N_2 and O_2

(Pereira et al., Eur. Phys. J D 56 (2010) 325)

k_0 increases by (13±3)% from 300 to 210 K,

k_1 decreases by (5±3)% from 300 to 210 K

$k_0(T) = C(\frac{T}{\ldots})^{\beta}$

…4

$\ldots 10^{-11}\mathrm{cm^3s^{-1}}$

$\beta_1 = 0.14 \pm 0.08$

$C = k_1(298K) = (2.67 \pm 0.14)\times 10^{-11}\mathrm{cm^3s^{-1}}$

From $R_{v'}$ vs p, @ 298 K:

$k_0(298\ K) = (1.24 \pm 0.04)\times 10^{-11}\mathrm{cm^3s^{-1}}$

$k_1(298\ K) = (2.60 \pm 0.08)\times 10^{-11}\mathrm{cm^3s^{-1}}$

From intensity measurements:

$\bar{\beta}_0^{LY} = -0.37 \pm 0.07$

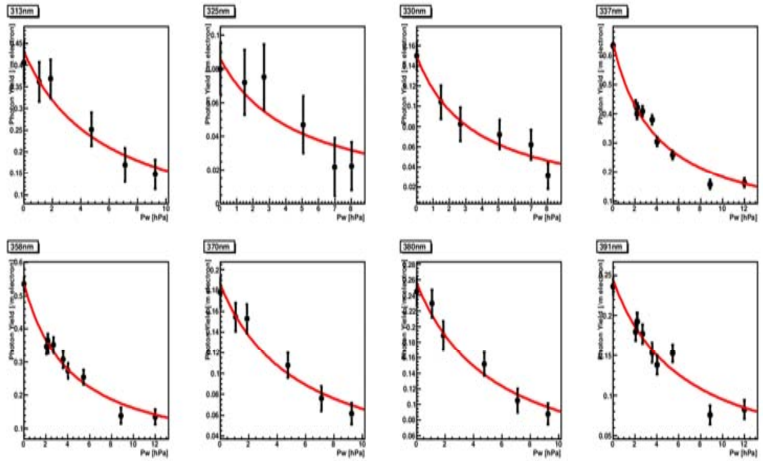
3. Temperature-dependent collsional cross sections – summary

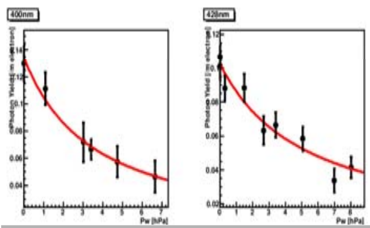
Molecular state	Quencher	α_λ (LYM)		α_λ (TRM)	
N_2 (C, v'=0)	N_2	-0.87±0.07	Coimbra	-0.83 ± 0.04	TUM
N_2 (C, v'=1)	N_2			-0.36 ± 0.04	TUM
N_2^+ (B, v'=0)	N_2	-0.82	Belikov et al.		
N_2 (C, v'=0)	O_2			-0.42 ± 0.05	TUM
N_2 (C, v'=0)	N_2+O_2	-0.35 ± 0.09	AIRFLY	-0.48 ± 0.05 (prediction)	
N_2 (C, v'=1)	N_2+O_2	-0.20 ± 0.11	AIRFLY		
N_2 (C, v'=2)	N_2+O_2	-0.22 ± 0.25	AIRFLY		
N_2^+ (B, v'=0)	N_2+O_2	-0.79 ±0.03	AIRFLY		

$$p'_{v'}(T) = p'_{v'}(T_0)\left(\frac{T_0}{T}\right)^{\alpha_{v'}-0.5}$$

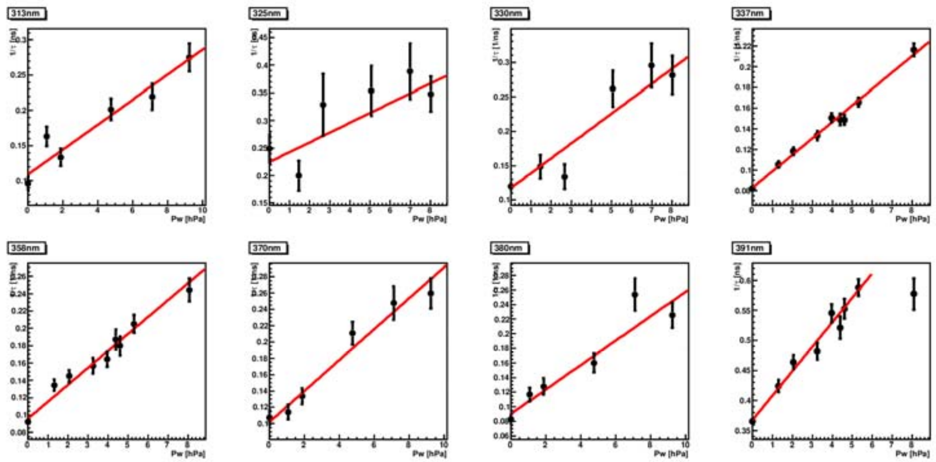
4. Humidity quenching – suggestion
average of these two sets of measurements

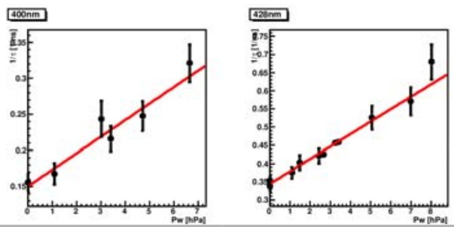
Results (Nagano & Sakaki)





Photon yield



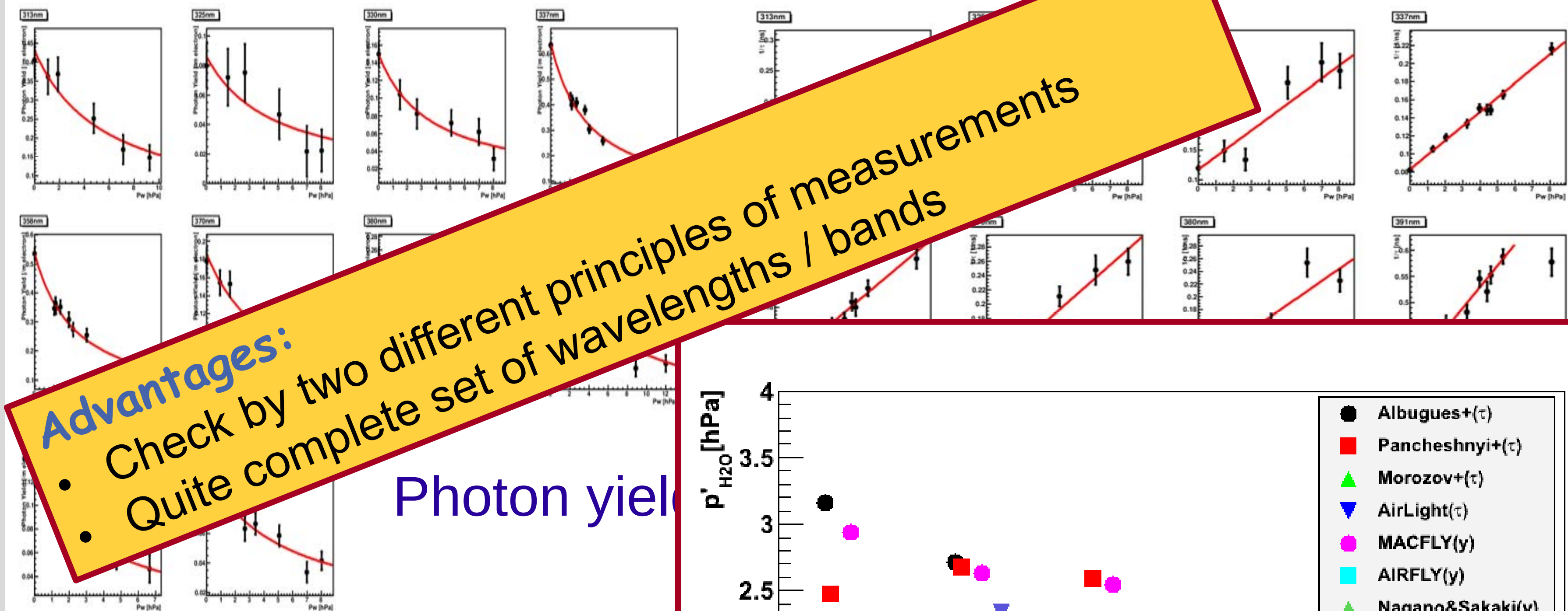


lifetime

	2P(0,0)	2P(0,1)	2P(0,2)	2P(1,0)	2P(1,4)
p’[hPa] (from yield)	1.36±0.07	1.23±0.12	2.08±0.34	2.23±0.54	1.30±0.29
p’[hPa] (from lifetime)	1.68±0.13	1.83±0.18	2.01±0.27	2.38±0.35	2.26±0.41
	2P(2,2)	2P(2,4)		1N(0,0)	1N(0,1)
p’[hPa] (from yield)	1.95±0.49	1.62±0.28		0.40±0.04	0.53±0.07
p’[hPa] (from lifetime)	2.88±0.39	1.59±0.2		0.42±0.03	0.89±0.07

4. Humidity quenching – suggestion
average of these two sets of measurements

Results (Nagano & Sakaki)

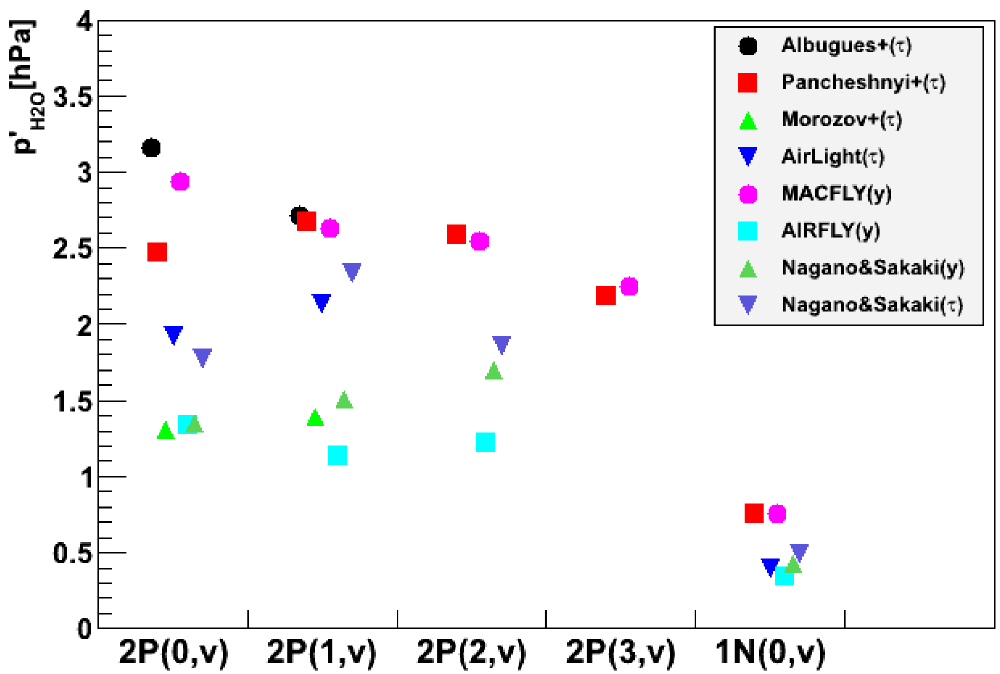


Advantages:

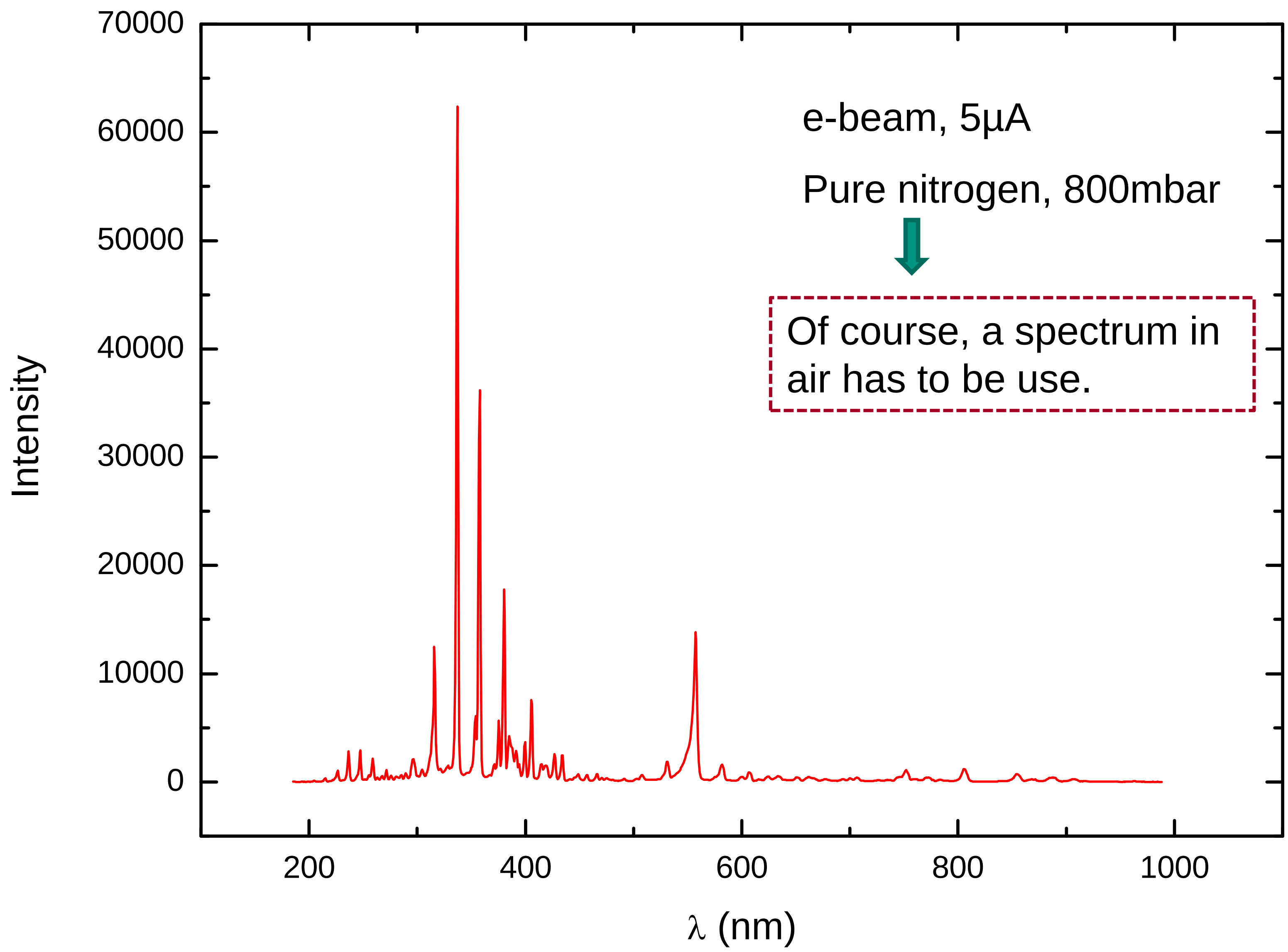
- Check by two different principles of measurements
- Quite complete set of wavelengths / bands

Photon yiel

	2P(0,0)
p'[hPa] (from yield)	1.36±0.07
p'[hPa] (from lifetime)	1.68±0.13
	2P(2,2)
p'[hPa] (from yield)	1.95±0.49
p'[hPa] (from lifetime)	2.88±0.39



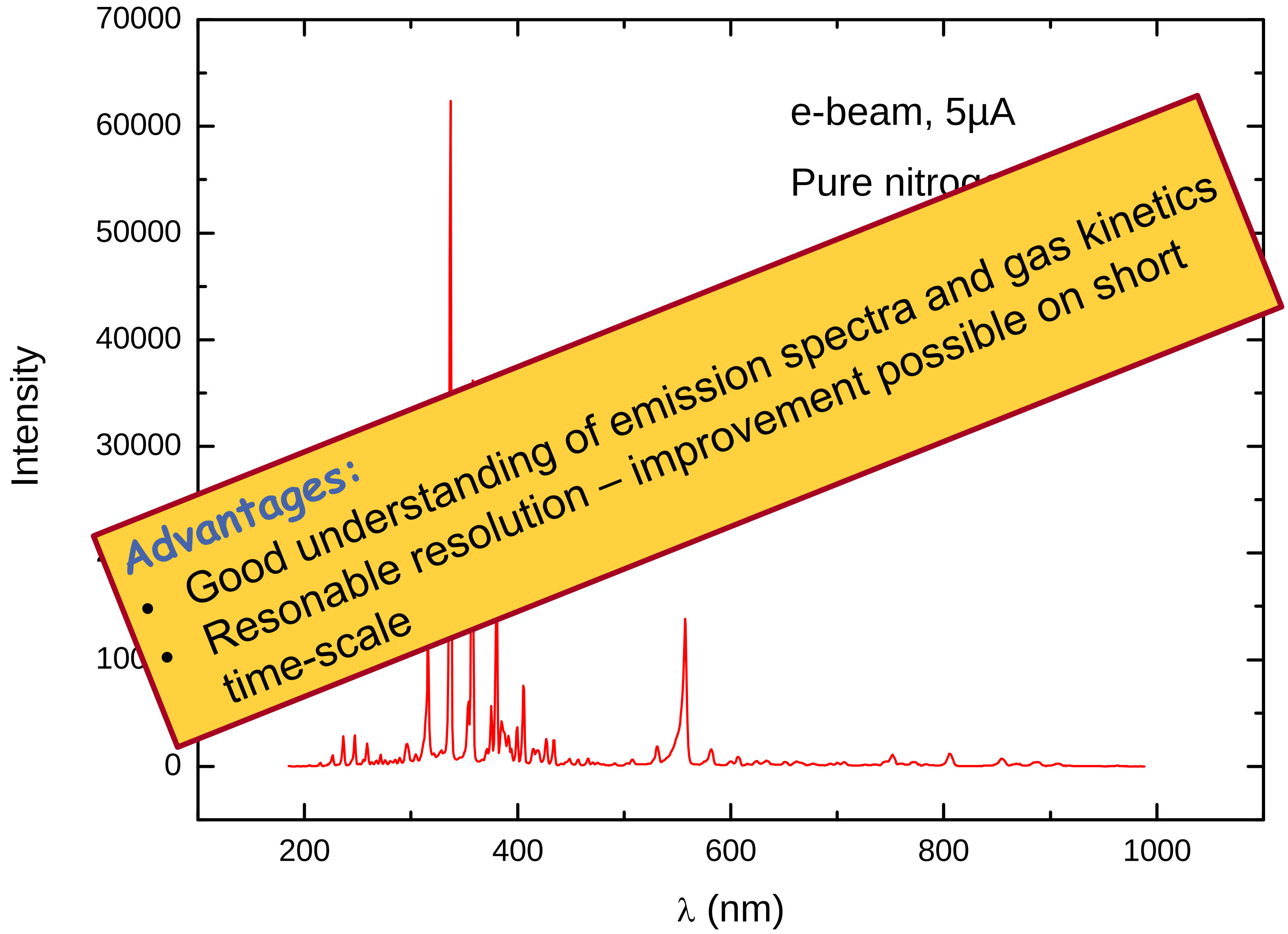
5. Spectral resolved intensities – suggestion A



Of course, a spectrum in air has to be use.

A. Ulrich et al., Air Fluorescence, Karlsruhe 2011

5. Spectral resolved intensities – suggestion A



Advantages:

- Good understanding of emission spectra and gas kinetics
- Resonable resolution – improvement possible on short time-scale

A. Ulrich et al., Air Fluorescence, Karlsruhe 2011

5. Spectral resolved intensities – suggestion B

Table 1
Relative intensities of observed band heads in air at 800 hPa and 293 K

Trans.	λ (nm)	I_λ (%)	Trans.	λ (nm)	I_λ (%)
2P(3,1)	296.2	5.16 ± 0.29	GH(0,5)	366.1	1.13 ± 0.08
2P(2,0)	297.7	2.77 ± 0.13	2P(3,5)	367.2	0.54 ± 0.04
GH(6,2)	302.0	0.41 ± 0.06	2P(2,4)	371.1	4.97 ± 0.22
GH(5,2)	308.0	1.44 ± 0.10	2P(1,3)	375.6	17.87 ± 0.63
2P(3,2)	311.7	7.24 ± 0.27	2P(0,2)	380.5	27.2 ± 1.0
2P(2,1)	313.6	11.05 ± 0.41	2P(4,7)	385.8	0.50 ± 0.08
2P(1,0)	315.9	39.3 ± 1.4	GH(0,6)	387.7	1.17 ± 0.06
GH(6,3)	317.6	0.46 ± 0.06	1N(1,1)	388.5	0.83 ± 0.04
2P(4,4)	326.8	0.80 ± 0.08	1N(0,0)	391.4	28.0 ± 1.0
2P(3,3)	328.5	3.80 ± 0.14	2P(2,5)	394.3	3.36 ± 0.15
2P(2,2)	330.9	2.15 ± 0.12	2P(1,4)	399.8	8.38 ± 0.29
2P(1,1)	333.9	4.02 ± 0.18	2P(0,3)	405.0	8.07 ± 0.29
2P(0,0)	337.1	100	2P(3,7)	414.1	0.49 ± 0.07
GH(0,4)	346.3	1.74 ± 0.11	2P(2,6)	420.0	1.75 ± 0.10
2P(2,3)	350.0	2.79 ± 0.11	1N(1,2)	423.6	1.04 ± 0.11
2P(1,2)	353.7	21.35 ± 0.76	2P(1,5)	427.0	7.08 ± 0.28
2P(0,1)	357.7	67.4 ± 2.4	1N(0,1)	427.8	4.94 ± 0.19

All lines are normalized to the 2P(0,0)-transition at 337.1 nm.

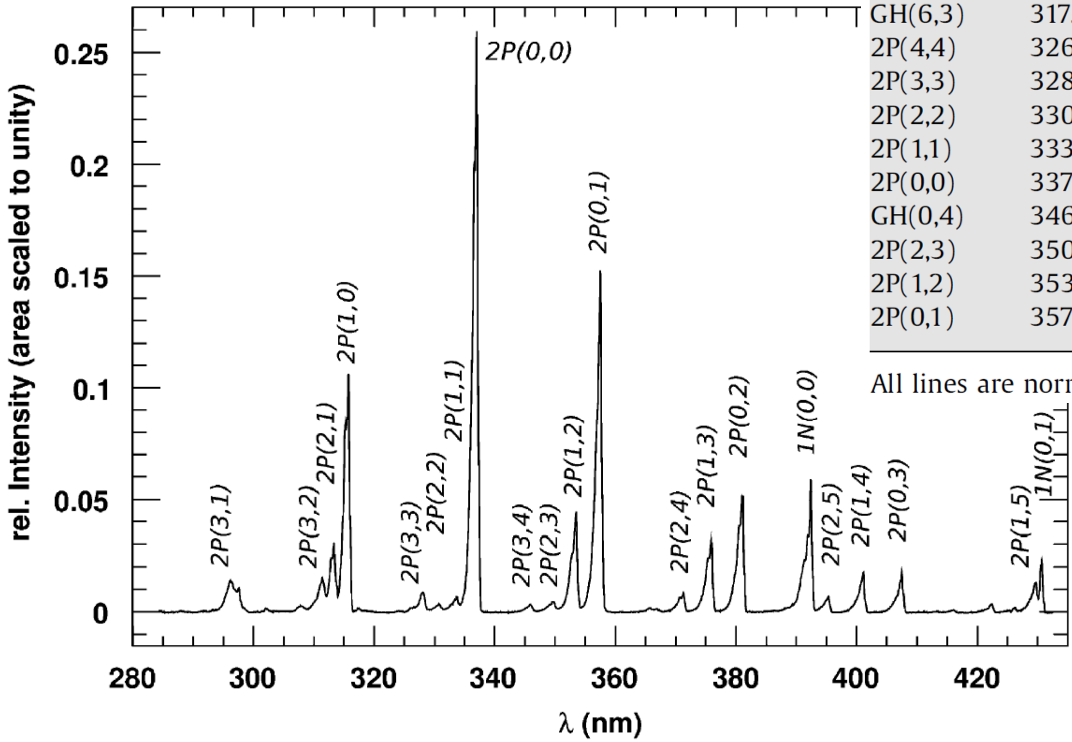


Fig. 1. Air fluorescence spectrum excited by 3 MeV electrons at 800 hPa. Labels indicate 21 major transitions.

M. Ave et al. / Nuclear Instruments and Methods in Physics Research A 597 (2008) 41–45

5. Spectral resolved intensities – suggestion B

Table 1
Relative intensities of observed band heads in air at 800 hPa and 293 K

Trans.	λ (nm)	I_λ (%)	Trans.	λ (nm)	I_λ (%)
2P(3,1)	296.2	5.16 ± 0.29	GH(0,5)	366.1	1.13 ± 0.08
2P(2,0)	297.7	2.77 ± 0.13	2P(3,5)	367.2	0.54 ± 0.04
GH(6,2)	302.0	0.41 ± 0.06	2P(2,4)	371.1	4.97 ± 0.22
GH(5,2)	308.0	1.44 ± 0.10	2P(1,3)	375.6	17.87 ± 0.63
2P(3,2)	311.7	7.24 ± [illegible]	2P(0,2)	380.5	27.2 ± 1.0
2P(2,1)	313.6	[illegible]	[illegible]P(4,7)	385.8	0.50 ± 0.08
2P(1,0)	315.9	[illegible]	[illegible](0,6)	387.7	1.17 ± 0.06
GH(6,3)	[illegible]	[illegible]	[illegible](1,1)	388.5	0.83 ± 0.04
2P(4,[illegible]	[illegible]	[illegible]	1N(0,0)	391.4	28.0 ± 1.0
[illegible]	[illegible]	[illegible] ± 0.14	2P(2,5)	394.3	3.36 ± 0.15
[illegible]	[illegible]	2.15 ± 0.12	2P(1,4)	399.8	8.38 ± 0.29
[illegible]	[illegible].9	4.02 ± 0.18	2P(0,3)	405.0	8.07 ± 0.29
[illegible]	337.1	100	2P(3,7)	414.1	0.49 ± 0.07
[illegible](0,4)	346.3	1.74 ± 0.11	2P(2,6)	420.0	1.75 ± 0.10
2P(2,3)	350.0	2.79 ± 0.11	1N(1,2)	423.6	1.04 ± 0.11
2P(1,2)	353.7	21.35 ± 0.76	2P(1,5)	427.0	7.08 ± 0.28
2P(0,1)	357.7	67.4 ± 2.4	1N(0,1)	427.8	4.94 ± 0.19

All lines are normalized to the 2P(0,0)-transition at 337.1 nm.

Advantages:
- Higher resolution of spectrometer

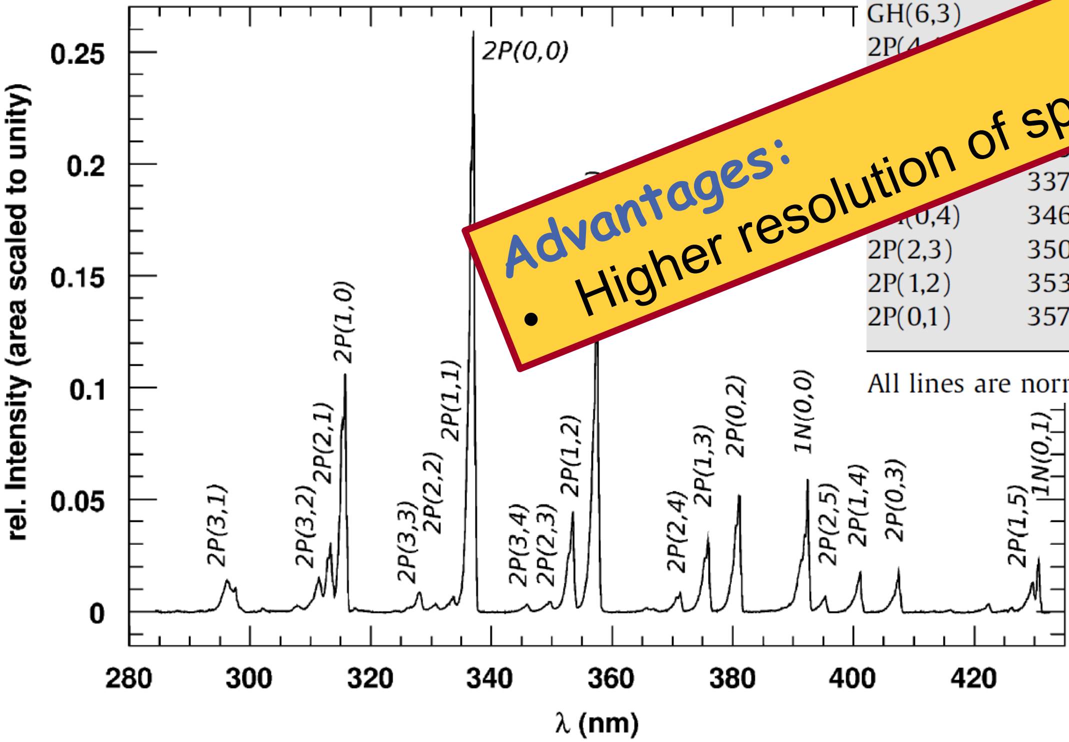


Fig. 1. Air fluorescence spectrum excited by 3 MeV electrons at 800 hPa. Labels indicate 21 major transitions.

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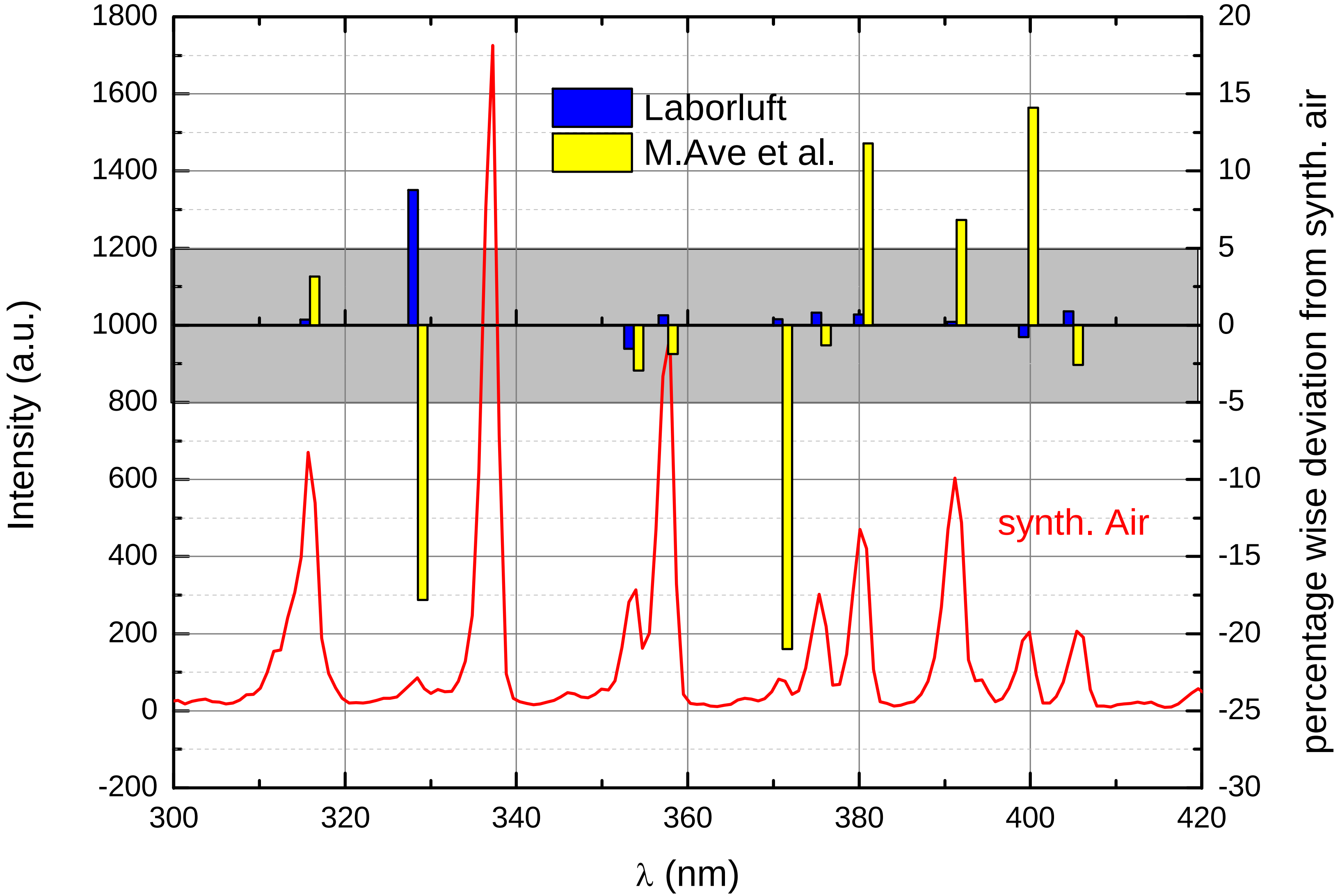
5. Spectral resolved intensities – summary



- An open discussion started........
- and the main aspects of it can be read at the next slide

Comments during Discussion

Short time scale:

- The aim should be to define a reference
- A reasonable reference fluorescence description has good chances to be used at the cosmic ray experiment, at least at Pierre Auger Observatory, Telescope Array and JEM-EUSO

Longer time scale:

- The aim should be to find the best physical description

- Build averages for relevant parameters for a reference where possible
- Building averages for all parameters is partly not feasible or sometimes would be physically wrong
- Try to address 4 out of the 5 items from slides 3 and 4, so excluding the absolute value of the fluorescence yield
- Some of the presented suggestions could be acceptable to all participants
- One should not forget older investigations and their results like Bunner, Davidson & O'Neil, …
- Try to get all PIs of the fluorescence experiments together for about 1 week to investigate the experimental systematics in order to evaluate a solution for averaging absolute fluorescence yield values

Final action items

- Build a small committee with representatives of all experiments
- Produce a draft / suggestion for a reference fluorescence description which is physically meaningful, and acceptable to all
- Suggestions for committee members will be solicited by the chair of the committee (B. Keilhauer)
- Circulate the draft in the community as fast as possible
- After iteration: Preparation of common publication in a dedicated journal with a comparison and discussion of all fluorescence yield data