Overview of Measurements of Humidity Quenching

Naoto SAKAKI
(Aoyama Gakuin University)

Contents

I. Introduction

Humidity Quenching

$$Y_{\mathrm{air}}(\lambda,p,T) = \Phi^0_\lambda \cdot \frac{\lambda}{hc}\rho_{\mathrm{air}} \cdot \left(1 + \frac{p}{p'_{\mathrm{air}}(\lambda,T_0)}\right)^{-1}$$

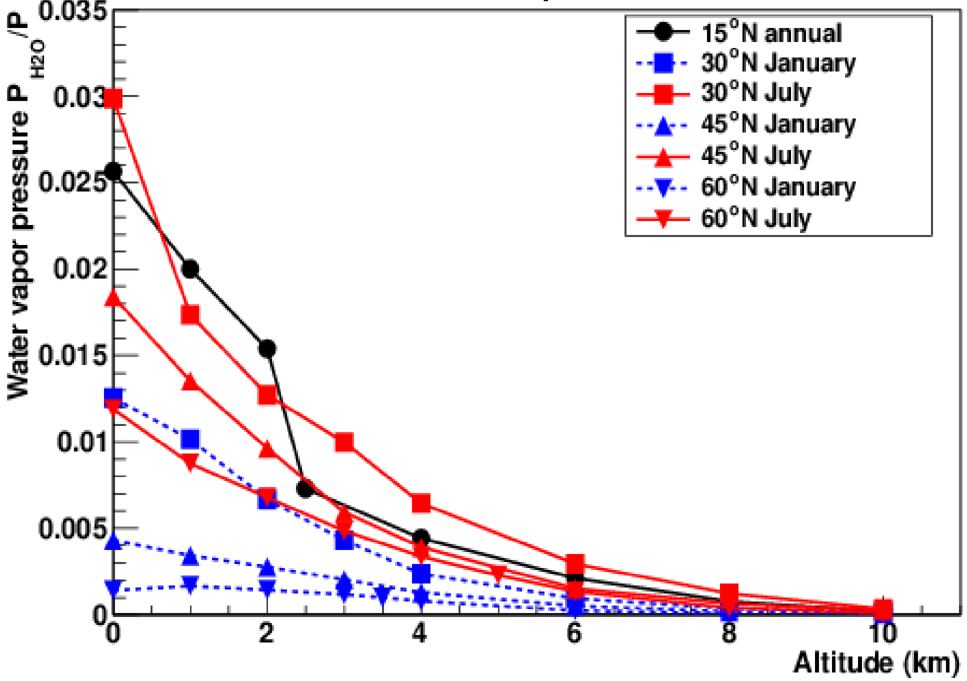
$$\frac{p}{p'_{\mathrm{air}}(\lambda,T_0)} = \frac{\tau_{0,\lambda}p_{\mathrm{air}}N_A}{RT} \cdot \sqrt{\frac{kTN_A}{\pi}} \times \left(4 \cdot C_v(\mathrm{N_2}) \cdot \sigma_{\mathrm{NN},\lambda}(T) \cdot \sqrt{\frac{1}{M_{m,\mathrm{N}}}}\right.$$

$$2 \cdot C_v(\mathrm{O_2}) \cdot \sigma_{\mathrm{NO},\lambda}(T) \cdot \sqrt{2(\frac{1}{M_{m,\mathrm{N}}} + \frac{1}{M_{m,\mathrm{O}}})} \quad (5)$$

$$\left. 2 \cdot C_v(\mathrm{H_2O}) \cdot \sigma_{\mathrm{NH_2O},\lambda}(T) \cdot \sqrt{2(\frac{1}{M_{m,\mathrm{N}}} + \frac{1}{M_{m,\mathrm{H_2O}}})}\right).$$

?

US standard atmosphere 1966



Humidity quenching is very important for space-based observation such as EUSO.

Quenching parameters

From photon yield

$$Y_{\mathrm{air}}(\lambda,p,T)=Y_{\mathrm{air}}(337\ \mathrm{nm},p_0,T_0)\cdot I_\lambda(p_0,T_0)\cdot\frac{1+\frac{p_0}{p'_{\mathrm{air}}(\lambda,T_0)}}{1+\frac{p}{p'_{\mathrm{air}}(\lambda,T_0)\cdot\sqrt{\frac{T}{T_0}}\cdot\frac{H_\lambda(T_0)}{H_\lambda(T)}}}$$

$$\frac{1}{p'_{\mathrm{air}}}\rightarrow\frac{1}{p'_{\mathrm{air}}}\left(1-\frac{p_h}{p}\right)+\frac{1}{p'_{\mathrm{H_2O}}}\frac{p_h}{p}$$

From lifetime

$$\frac{1}{\tau}=\frac{1}{\tau_{0,\lambda}}\left[1+\tau_{0,\lambda}p_{air}\{k_{N_2}C_v(\mathrm{N_2})+k_{O_2}C_v(\mathrm{O_2})+k_{H2O}C_v(\mathrm{H_2O})\}\right]$$

Quenching constant

$$k_i=2\sigma_{Ni,\lambda}(T)\sqrt{\frac{N_A}{\pi kT}}\sqrt{2\left(\frac{1}{M_{m,N}}+\frac{1}{M_{m,i}}\right)}$$

or

$$Q_i=k_ikT$$

$$\frac{1}{p'}=\tau_{0,\lambda}\{k_{N_2}C_v(\mathrm{N_2})+k_{O_2}C_v(\mathrm{O_2})+k_{H2O}C_v(\mathrm{H_2O})\}$$

II. Experiments

F. Albugues, et al.

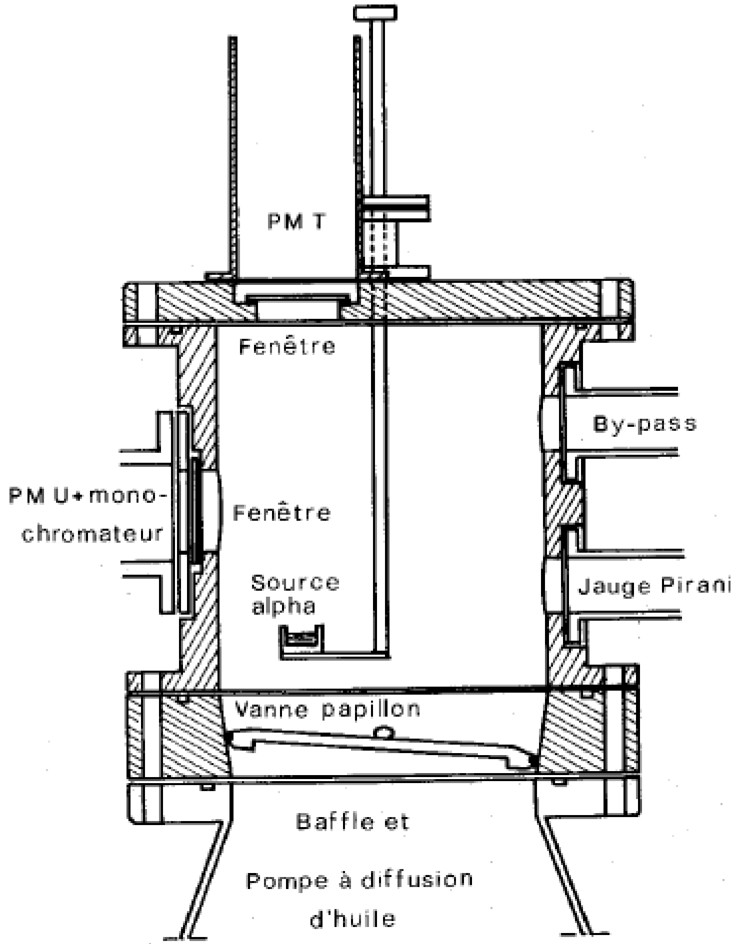


Figure I 25 : La Chambre de mesure

- 2.8MeV alpha particle
- 2P(0,0), 2P(1,0)
- Lifetime
- 50-700Torr N_2 + 0-3Torr H_2O

Results (Albugues et al.)

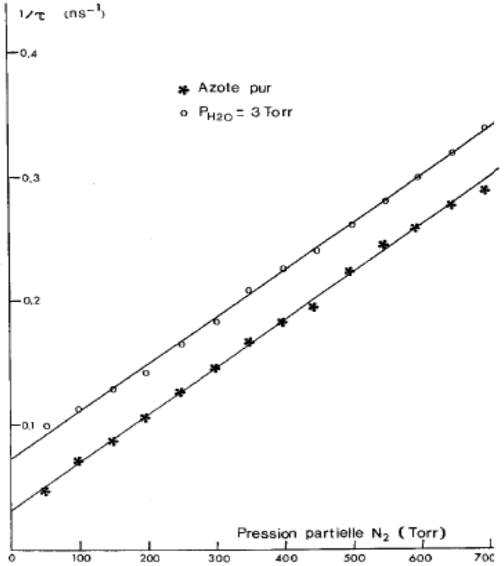


Figure IV.15 Bande 2p(0.0) Variation de 1/τ en fonction de P_{N2} (P_{H2O} = c^{te})

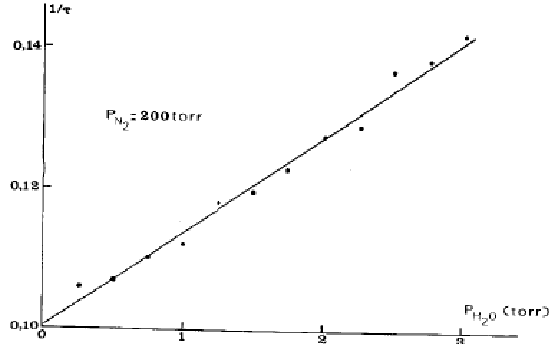


Figure IV 16 : Bande 2P(0-0). Variation de 1/τ en fonction de P_{H_2O} (P_{N_2} = 200 torr)

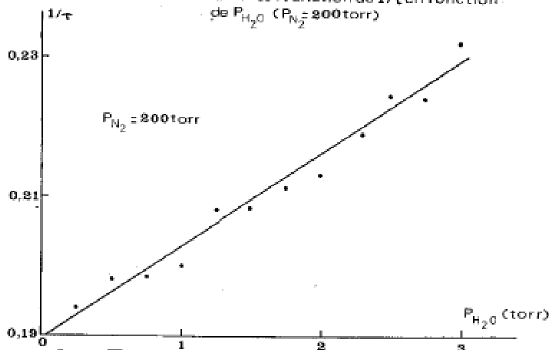


Figure IV 17 : Bande 2P(1-0). Variation de 1/τ en fonction de P_{H_2O} (P_{N_2} = 200 torr)

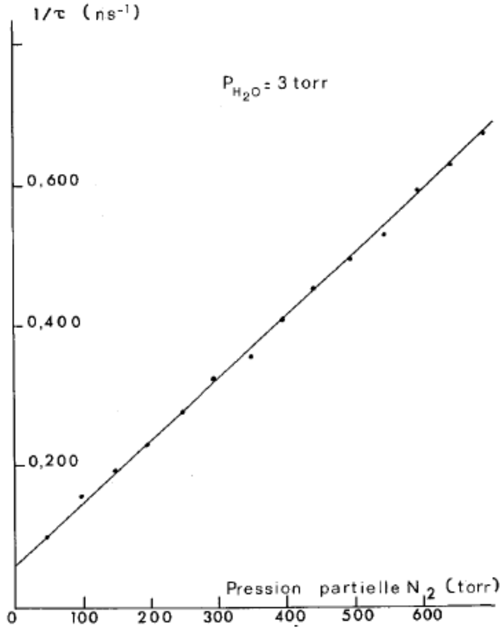


Figure IV 18. Bande 2P(1-0). Variation de 1/τ en fonction de P_{N_2} (P_{H_2O} = 3 torr)

	2P(0,0)	2P(1,0)	comment
k_{H2O}[/Torr ns]	1.38±0.36	1.32±0.53	p_{N2}=200Torr

S.V.Pancheshnyi et al.

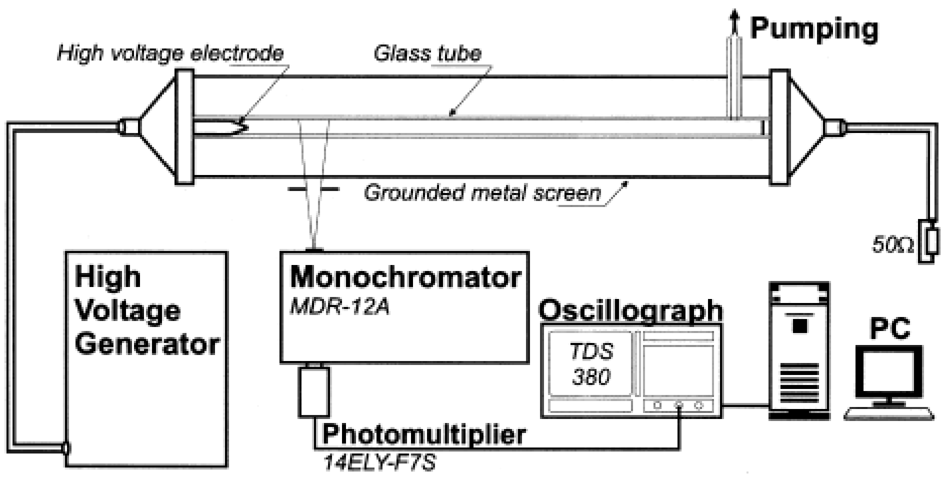


Fig. 1. Experimental setup.

- Discharge
- N_2+H_2O(0.05-30Torr)
- 295K
- 2P(0,0),2P(1,0), 2P(2,1),2P(3,7)

Results (Pancheshnyi et al.)

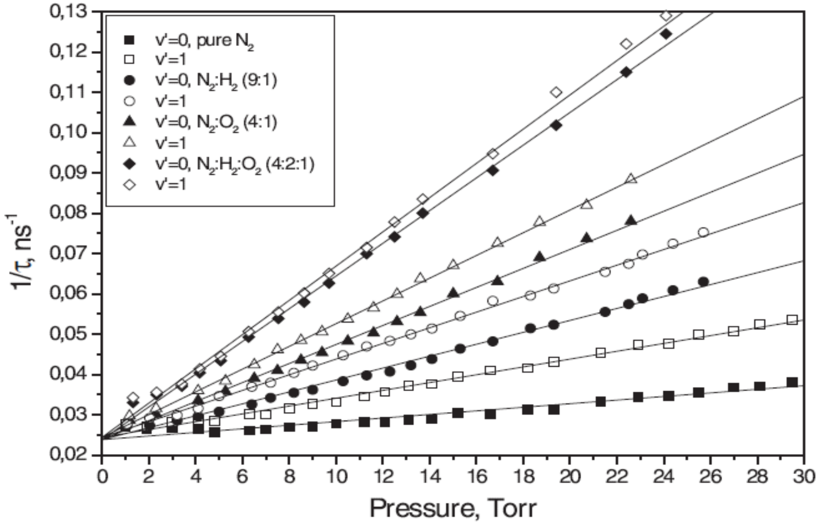


Fig. 3. Pressure dependence of observed lifetime of the levels $N_2(C^3\Pi_u, v=0)$ and $N_2(C^3\Pi_u, v=1)$ in various mixtures.

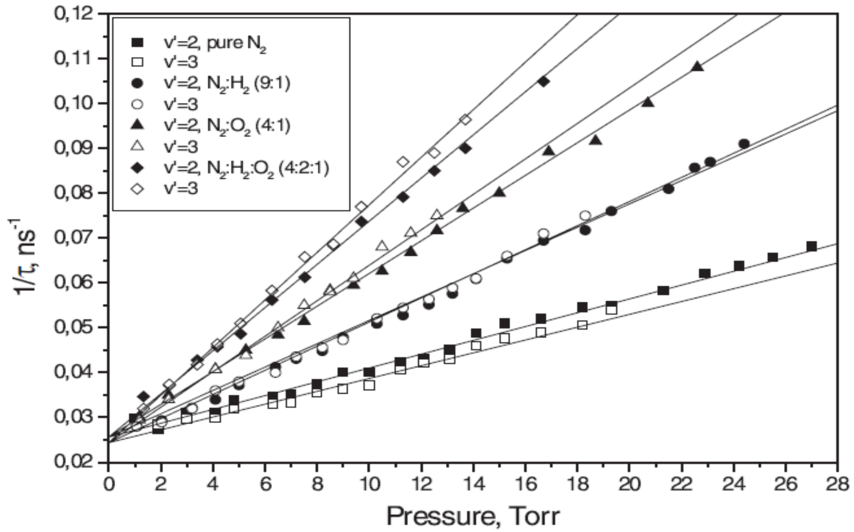
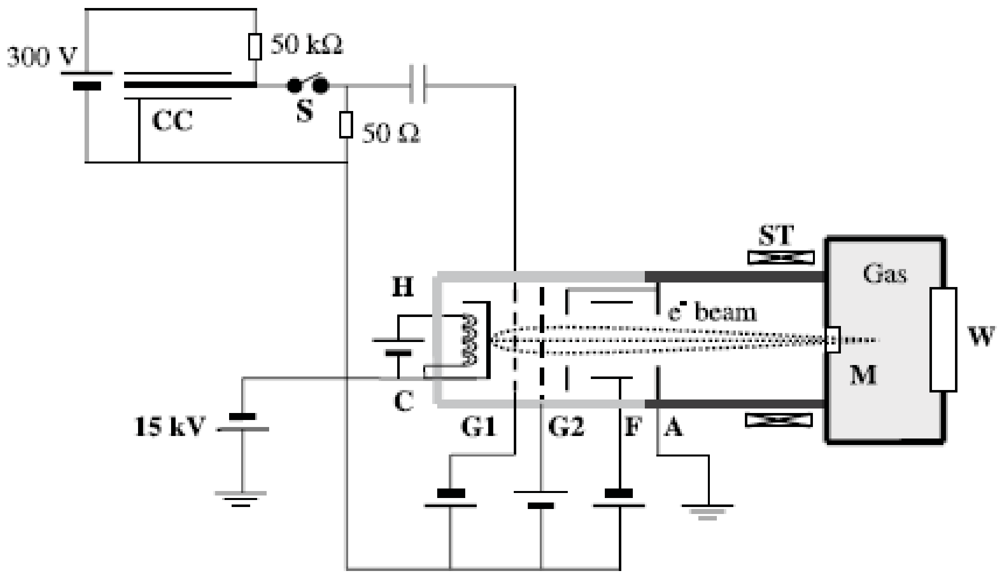


Fig. 4. Pressure dependence of observed lifetime of the levels $N_2(C^3\Pi_u, v=2)$ and $N_2(C^3\Pi_u, v=3)$ in various mixtures.

	1N(0,0)	2P(0,0)	2P(1,0)	2P(2,1)	2P(3,7)
$Q_{H2O}[10^{-10}cm^3s^{-1}]$	8.6±0.9	3.9±0.4	3.7±0.4	4.0±0.6	4.5±0.7

Morozov et al.



- ~10keV e- beam
- N_2(15,30hPa) +H_2O(0-1.4hPa)
- 2P(0,0),2P(1,0)
- 293K

Results (Morozov et al.)

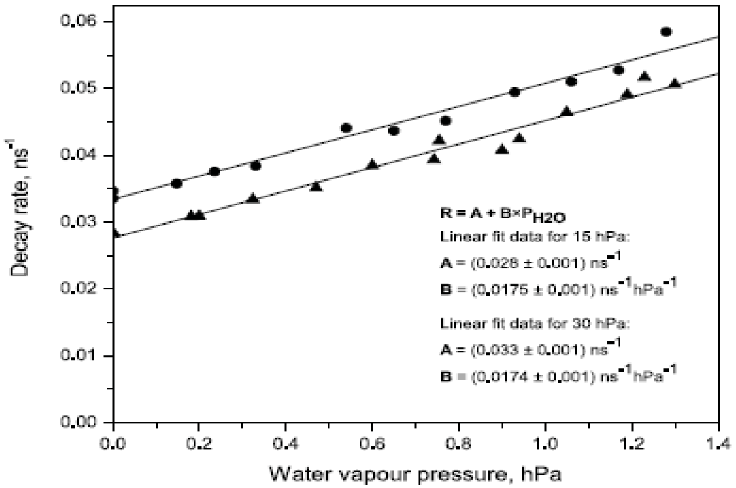


Fig. 5. Pressure dependence of the decay rate of the molecular nitrogen state C $^3\Pi_u$ ($\nu = 0$) in nitrogen water-vapour mixtures. Round and triangular dots show the results for mixtures with 30 hPa and 15 hPa nitrogen pressure, respectively. Linear fits (solid lines) as well as A and B parameter values are also shown.

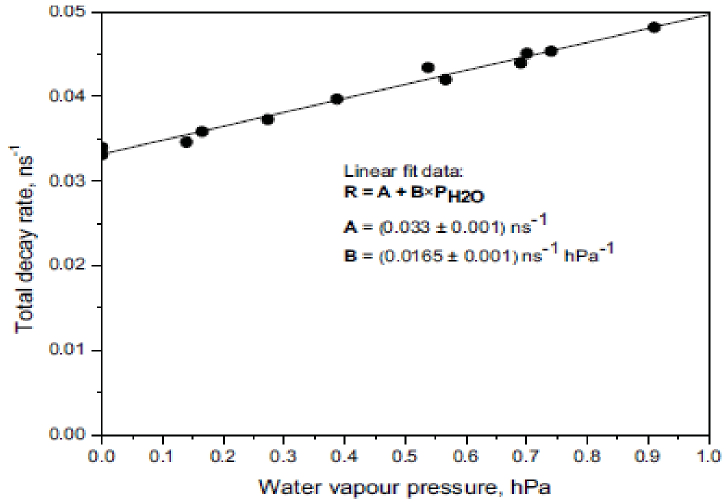
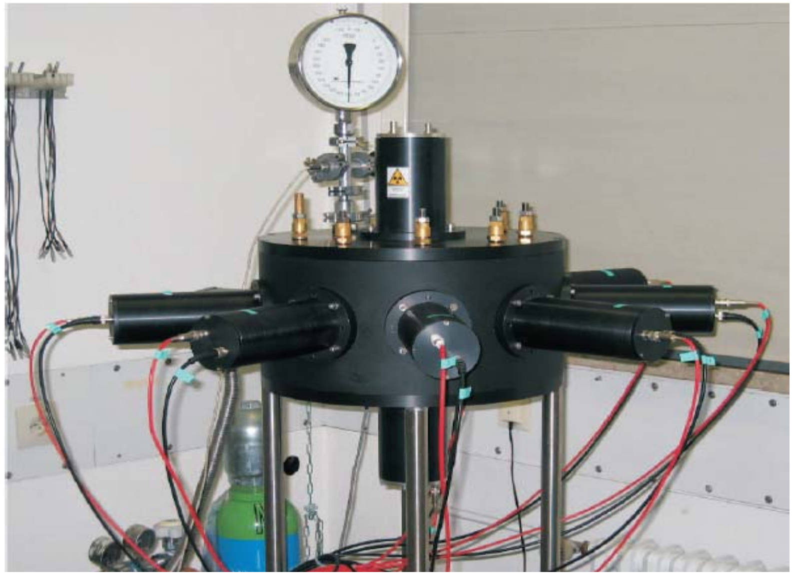
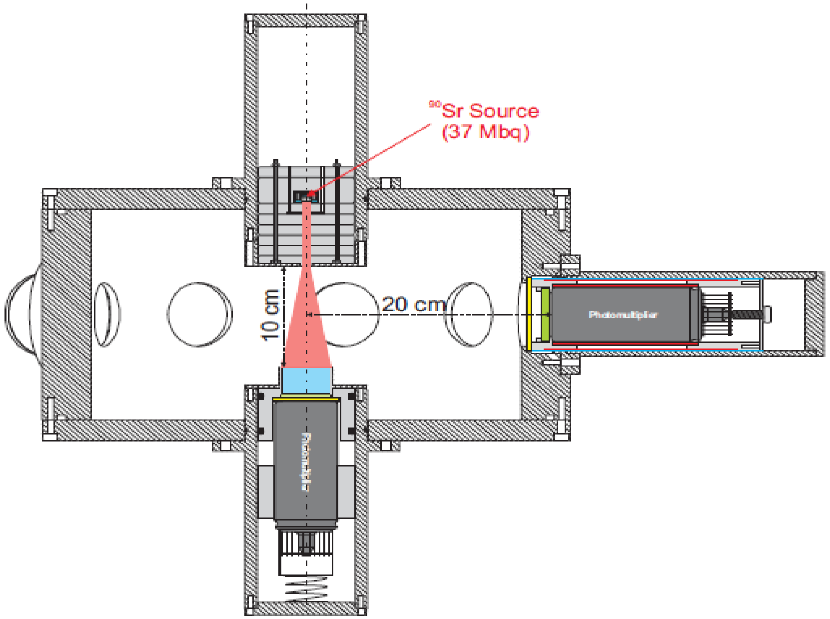


Fig. 6. Pressure dependence of the decay rate of the molecular nitrogen state C $^3\Pi_u$ ($\nu = 1$) in nitrogen–water vapour mixtures. The nitrogen pressure is 15 hPa. Linear fits (solid lines) as well as A and B parameter values are also shown.

	2P(0,0)	2P(1,0)
k_{H2O} [10^6/hPa s]	17.5±1.8	16.5±1.7

AirLight

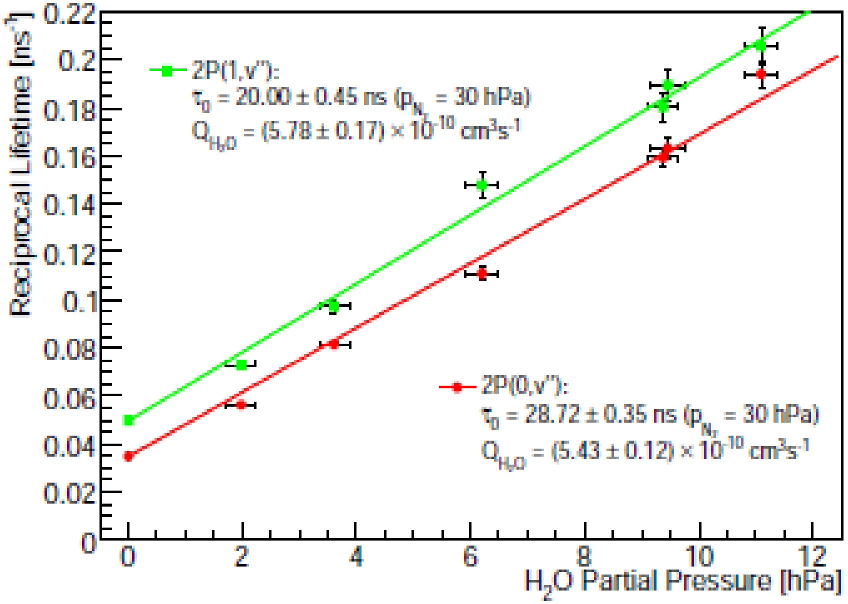




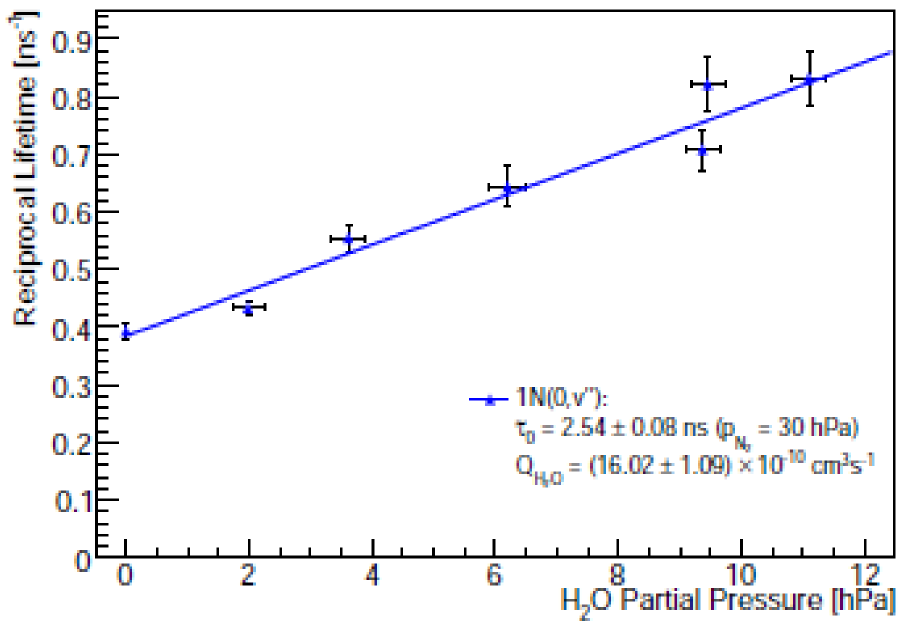
- Sr90 e- source
- N_2(30hPa)+ H_2O(0-12hPa)
- 2P(0,0),2P(1,0), 1N(0,0)
- ~290K
- Lifetime

Results (AirLight)

2P(0,v") and 2P(1,v")

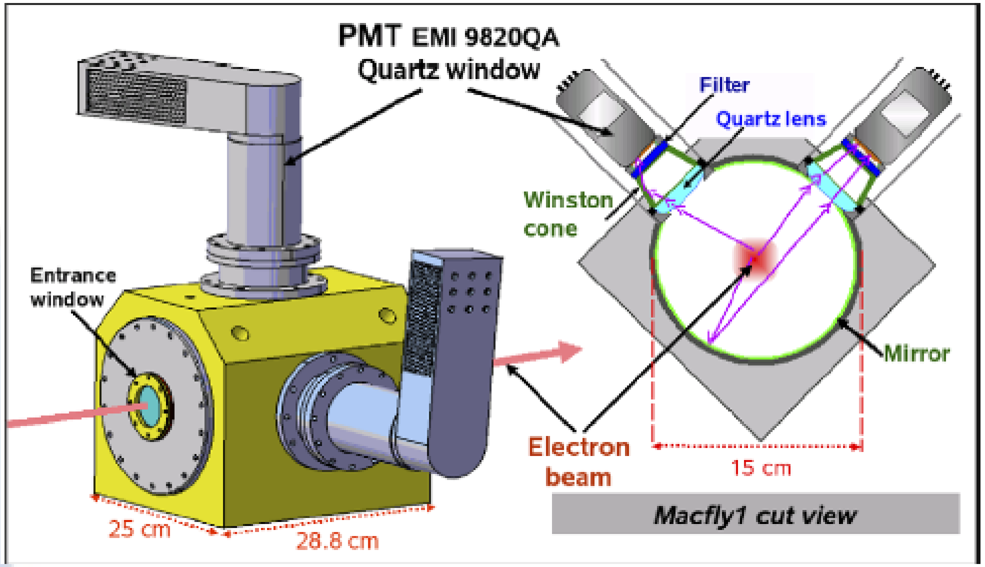


1N(0,v")



	2P(0,0)	2P(1,0)	1N(0,0)
Q_{H2O} [10^{-10}cm^{3}s^{-1}]	5.43±0.12	5.78±0.17	16.02±1.09

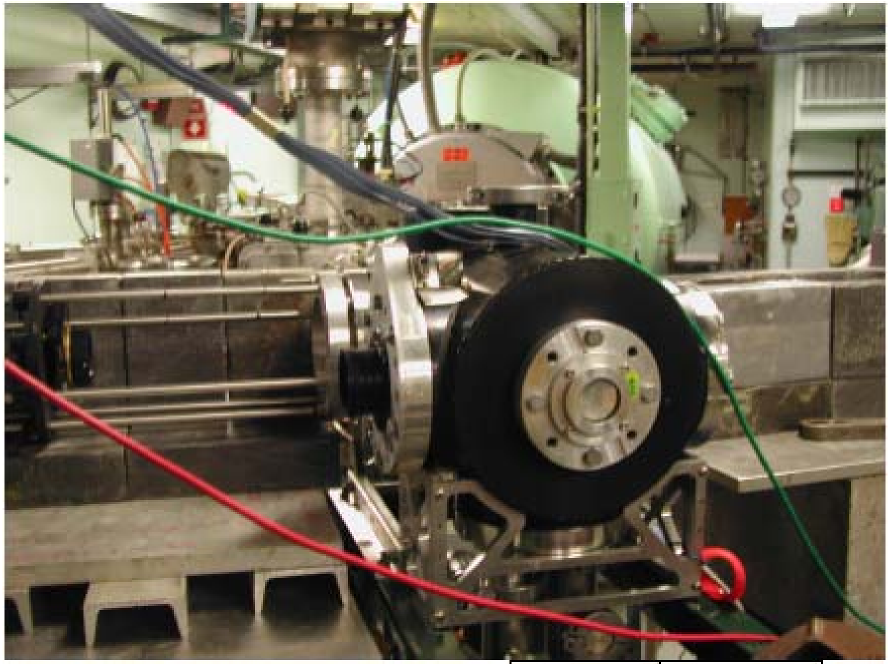
MACFLY



- Sr90 e- source
- 296K
- Real air (950hPa) at Humidity=35%
- Photon yield

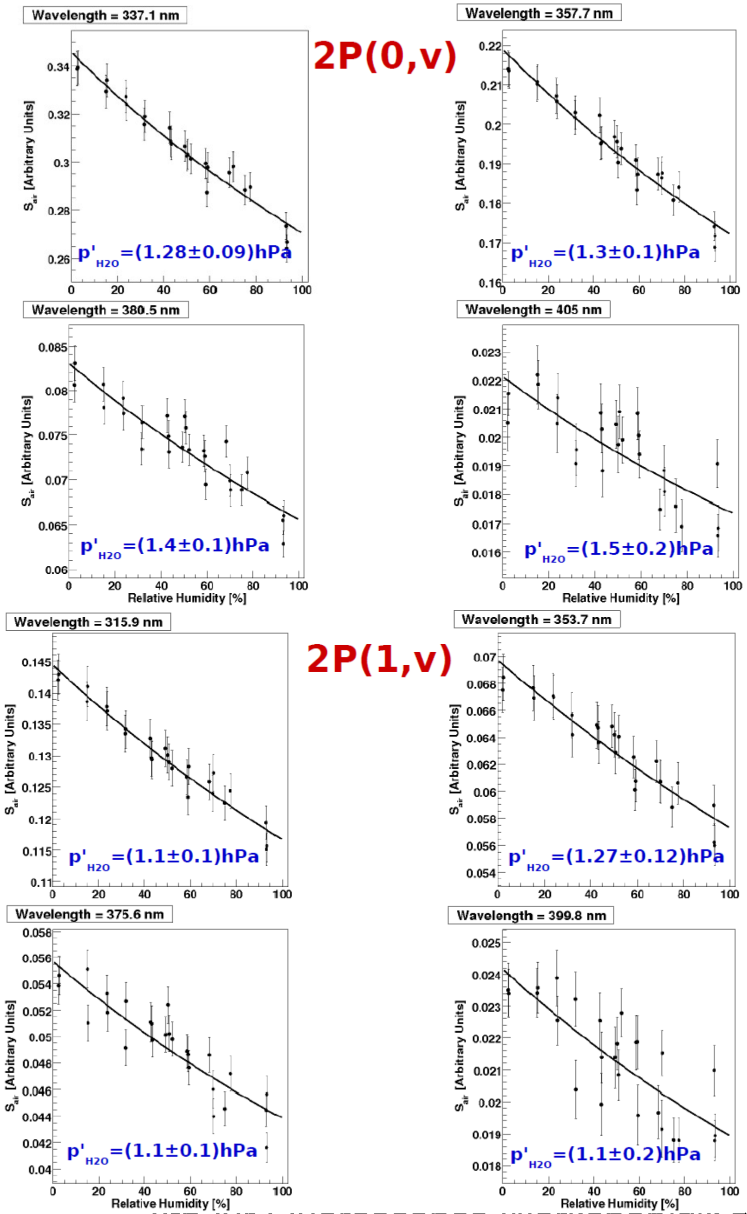
	2P(0,v)	2P(1,v)	2P(2,v)	2P(3,v)	1N(0,v)
k_{H2O} [/Pa ms]	92	95	98	111	211

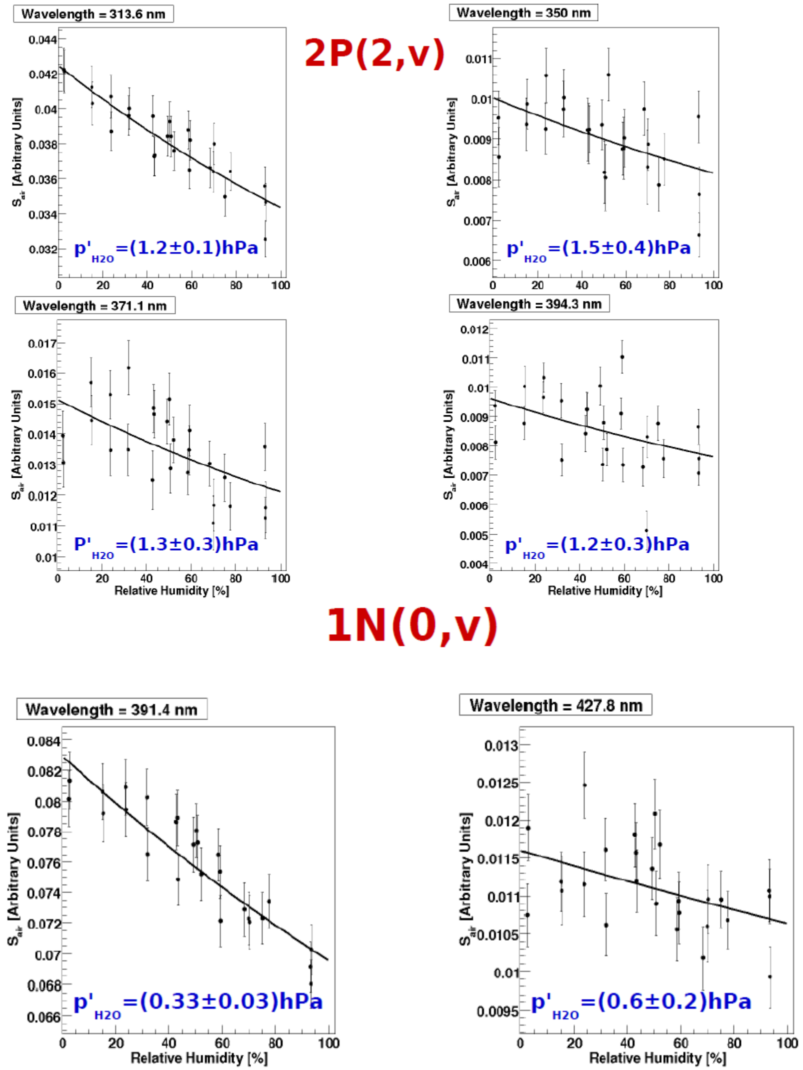
AIRFLY



- VdG 3MeV e-
- Air(N_2:O_2:Ar=78:21:1)+H_2O(0-25hPa)
- Atmospheric pressure
- Photon yield

Results (AIRFLY)



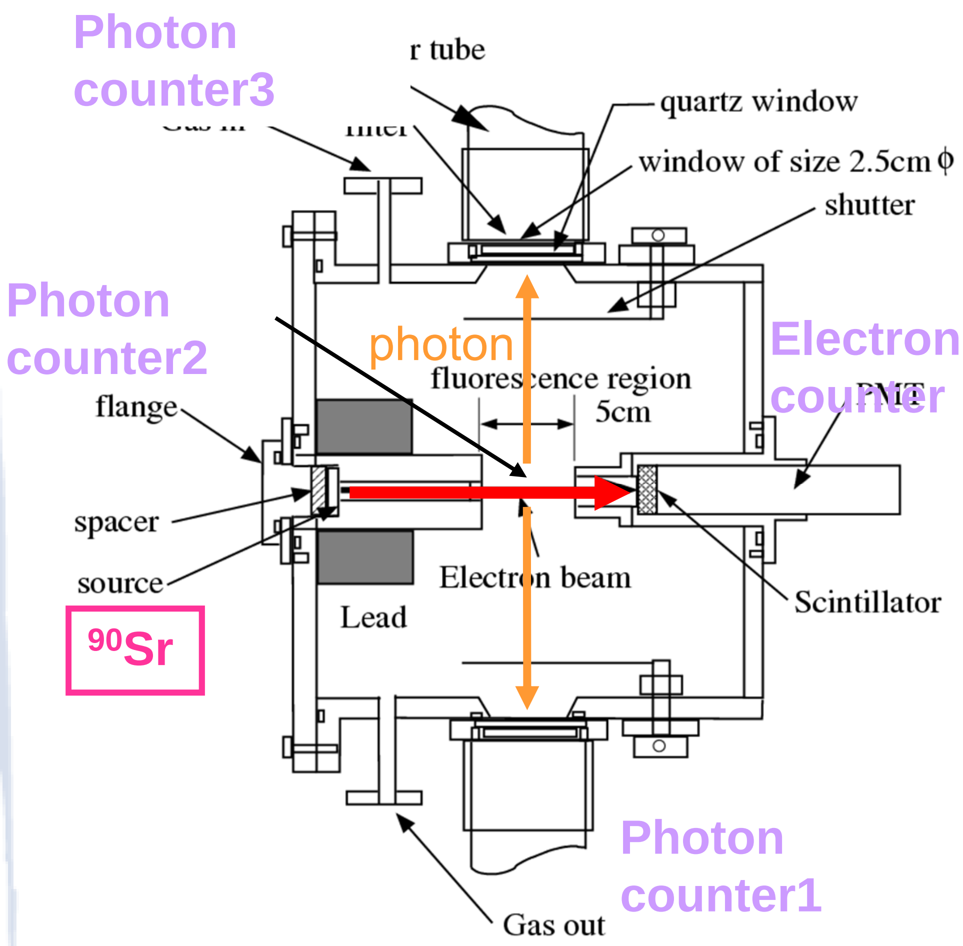


Bohacova (6th AFW, 2009)

Results (AIRFLY)

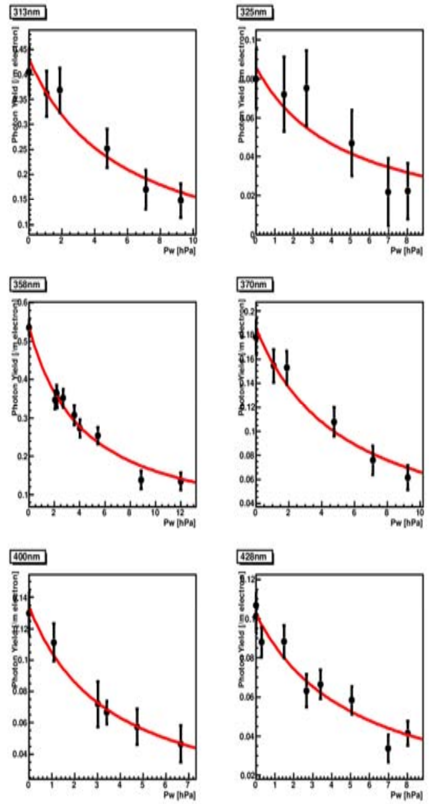
	2P(0,0)	2P(0,1)	2P(0,2)	2P(0,3)
p'_{H2O} [hPa]	1.28±0.09	1.3±0.1	1.4±0.1	1.5±0.2
	2P(1,0)	2P(1,1)	2P(1,2)	2P(1,3)
p'_{H2O} [hPa]	1.1±0.1	1.27±0.12	1.1±0.1	1.1±0.2
	2P(2,0)	2P(2,1)	2P(2,2)	2P(2,3)
p'_{H2O} [hPa]	1.2±0.1	1.5±0.4	1.3±0.3	1.2±0.3
	1N(0,0)	1N(0,1)		
p'_{H2O} [hPa]	0.33±0.03	0.6±0.2		

Nagano & Sakaki

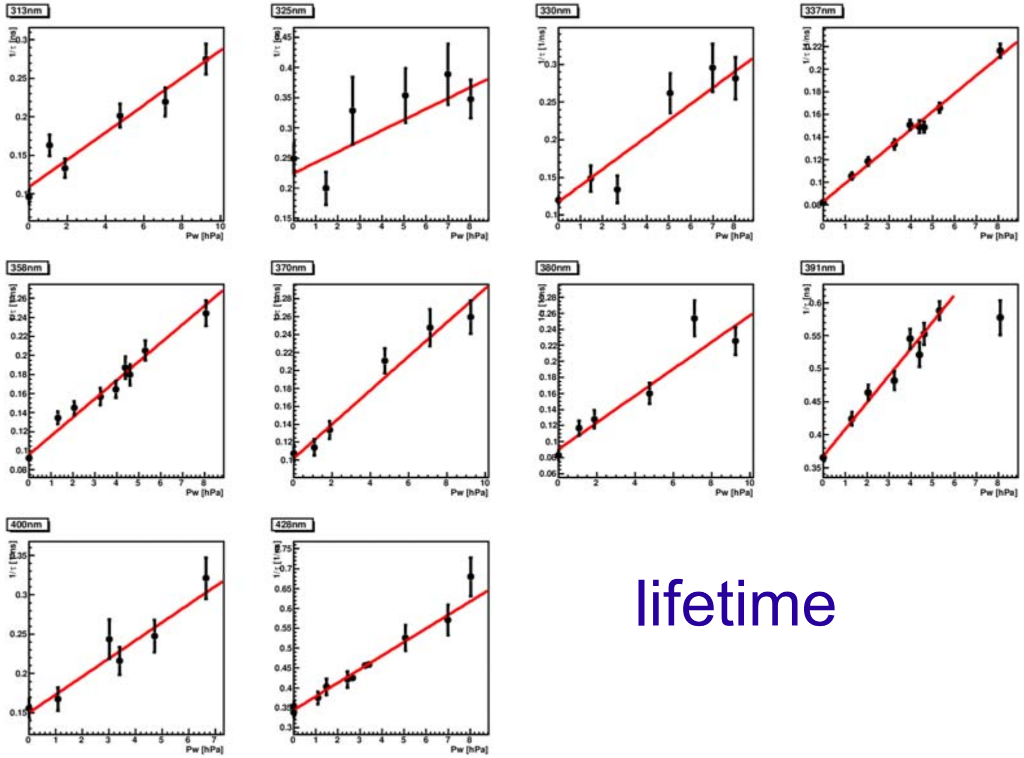


- Sr90 e- source
- Air(30,100,1000hPa)+ H_2O(0-10hPa)
- 293K
- Photon yield, lifetime

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

Summary of Humidity Quenching

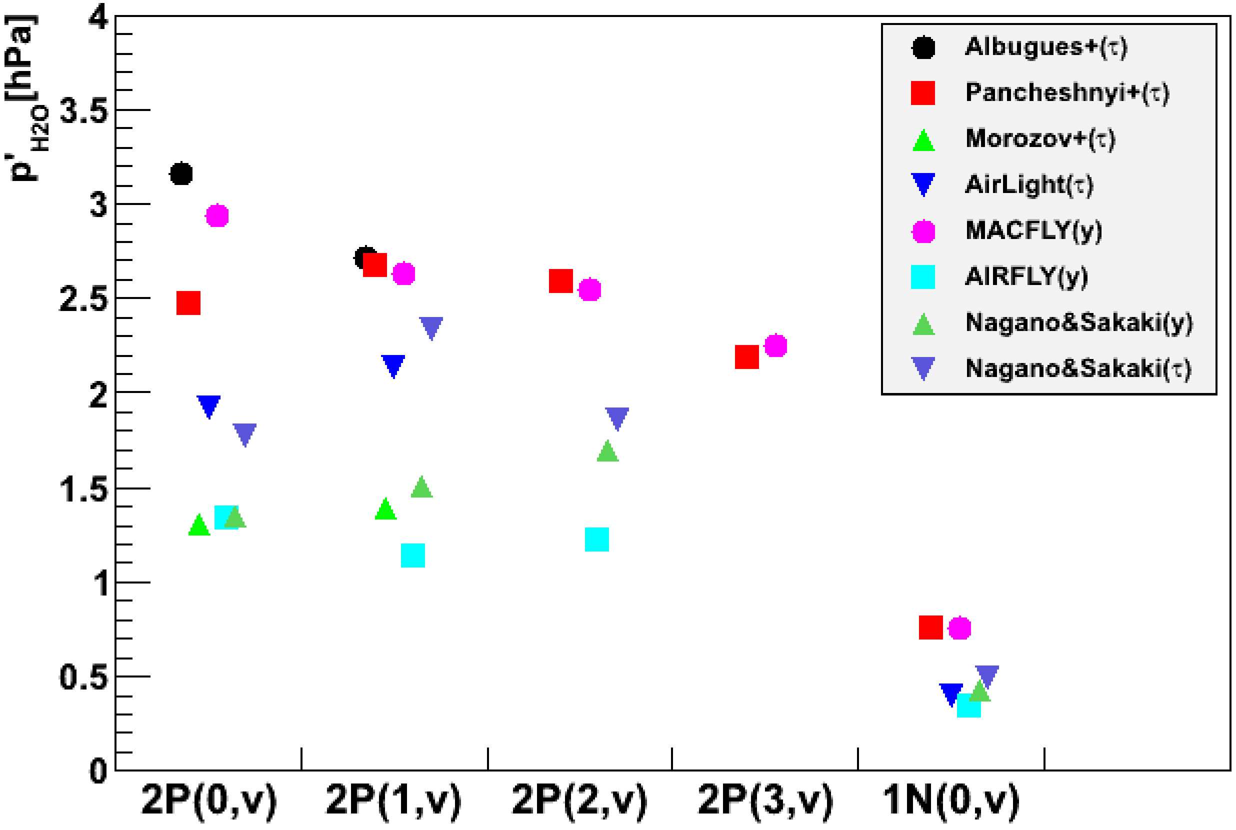
N2+H2O

p'_{H2O}[hPa]	Albugues(t)	Pancheshnyi(t)	Morozov(t)	AirLight(t)
2P(0,v)	3.16	2.47	1.31	1.92
2P(1,v)	2.72	2.67	1.39	2.13
2P(2,v)		2.59		
2P(3,v)		2.19		
1N(0,v)		0.76		0.39

Air+H2O

p'_{H2O}[hPa]	MACFLY(y)	AIRFLY(y)	Nagano& Sakaki(y)	Nagano& Sakaki(t)
2P(0,v)	2.94	1.34	1.35	1.77
2P(1,v)	2.63	1.14	1.51	2.33
2P(2,v)	2.55	1.22	1.70	1.86
2P(3,v)	2.25			
1N(0,v)	0.76	0.34	0.43	0.49

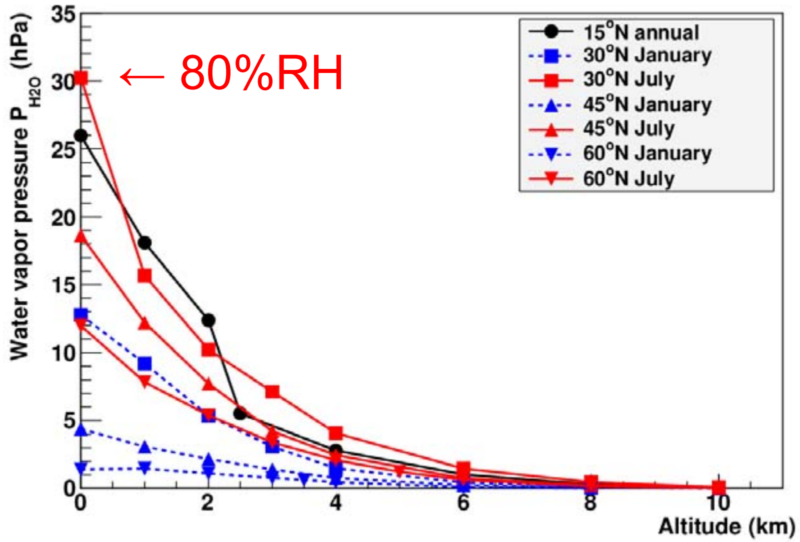
Summary of Humidity Quenching(2)



III. Application to UHECR observation

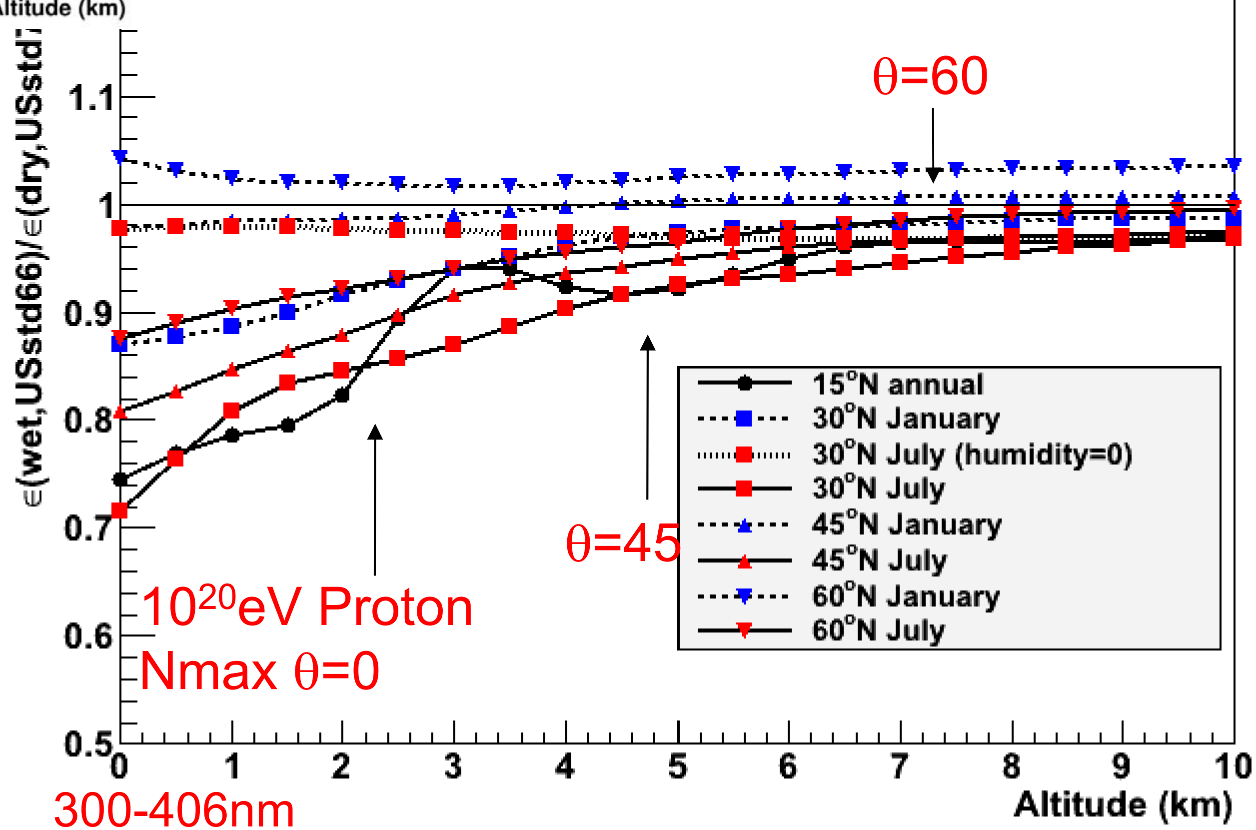
Photon Yield in atmosphere

(US standard atmosphere 1966)



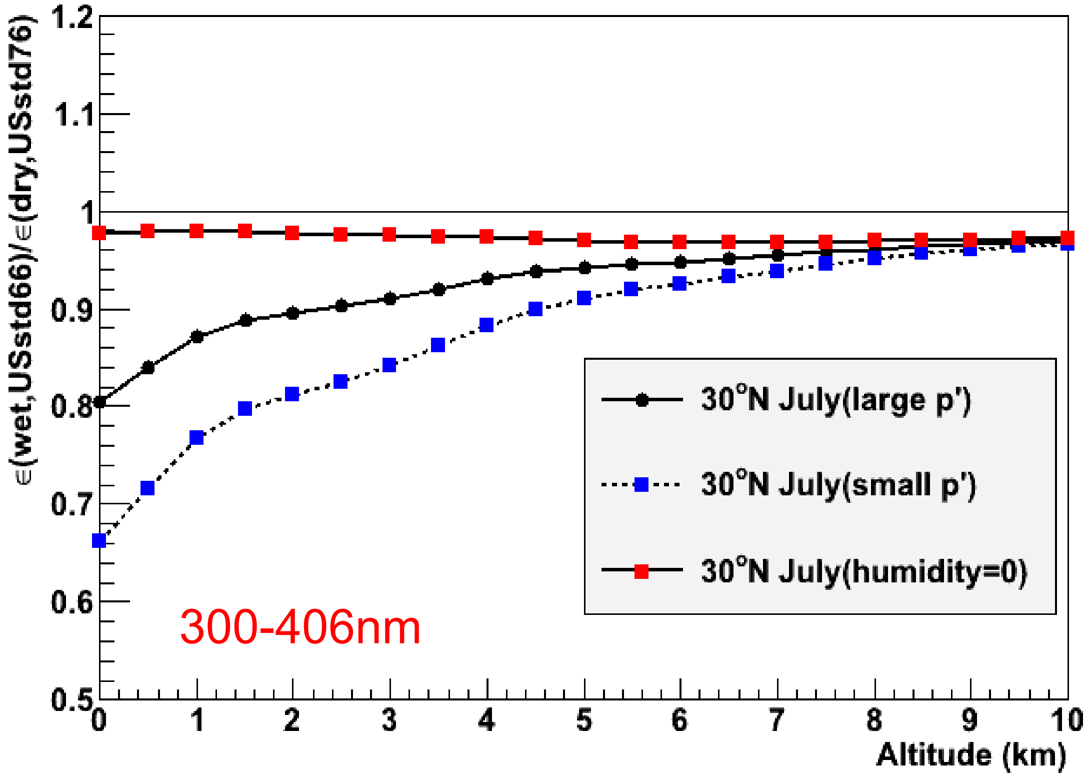
P': no T independence

$$\varepsilon = (\frac{dE}{dx})_{0.85MeV} \frac{\varphi^0 \rho_{N_2}}{h\nu(1+\rho R_g \sqrt{293T} / p'_{20})}$$



N.Sakaki+(ICRC2011)

Effect of Error in p'_{H2O}

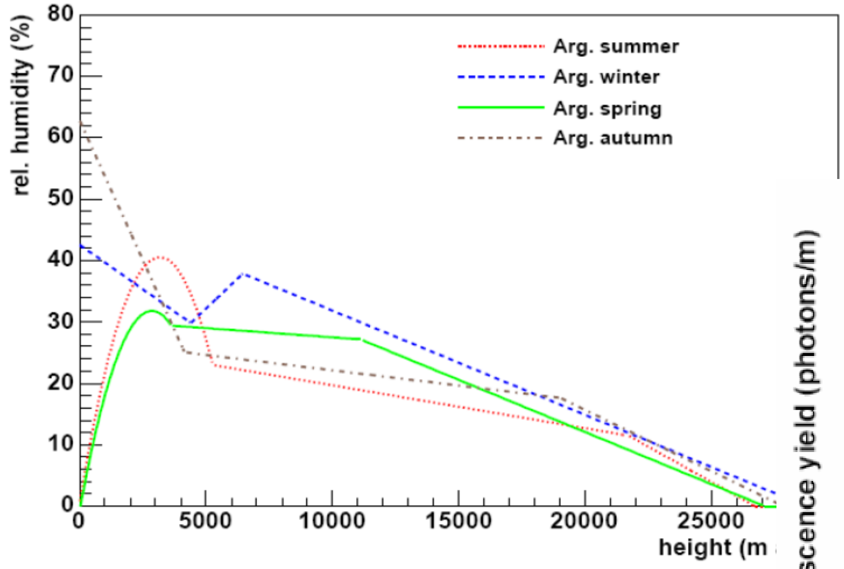


	2P(0,v)	2P(1,v)	2P(2,v)	2P(3,v)	1N(0,v)
Large p' model	3	2.7	2.7	2.3	0.7
Small p' model	1.3	1.3	1.3	1.3	0.35

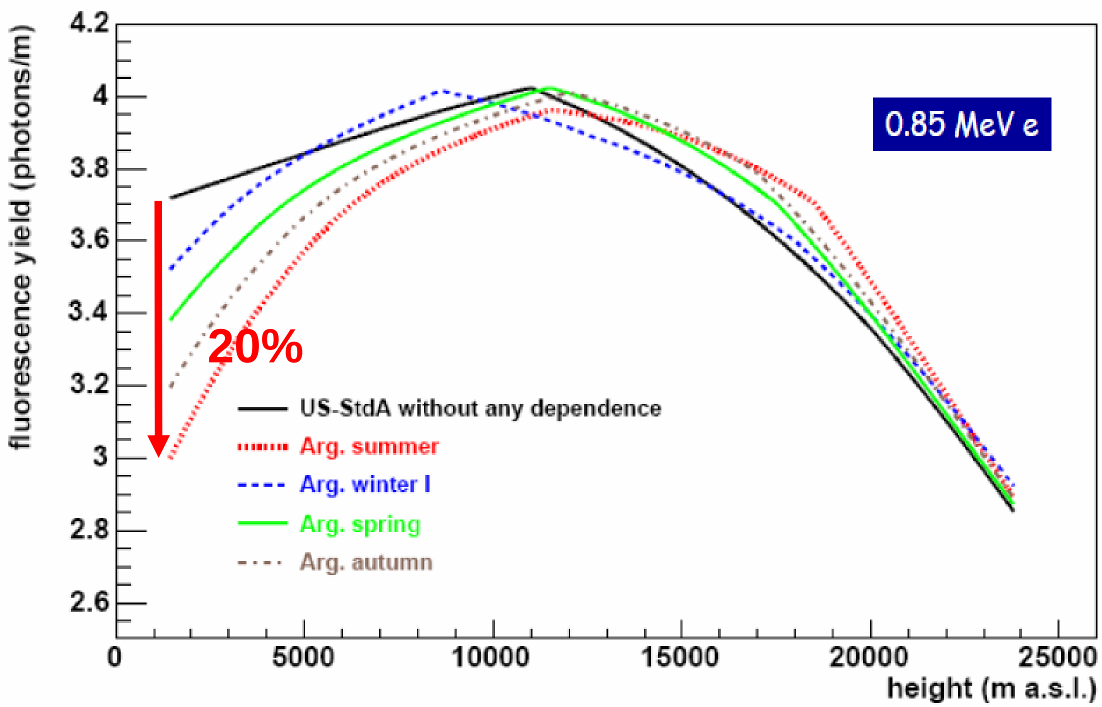
Humidity effect in TA atmosphere

- Fluorescence yield in TA atmosphere in July decreases by 3-6% compared to dry air (Ukai, master thesis (Yamanashi U.) 2010)

Humidity effect at Auger site



seasonal averages of relative humidity profiles at ni



model calculations including humidity profiles only (no T)

Keilhauer+ (5th AFW 2007,
NIM A597 (2008) 99)

Influence on reconstruction(1)

Fig. 2. Comparison of the effect of switching off σ_e and the collisional cross sections σ_T on E and X_{max} as well as the influence of different vapour quenching, σ_e^W [23] and σ_e^M [22].

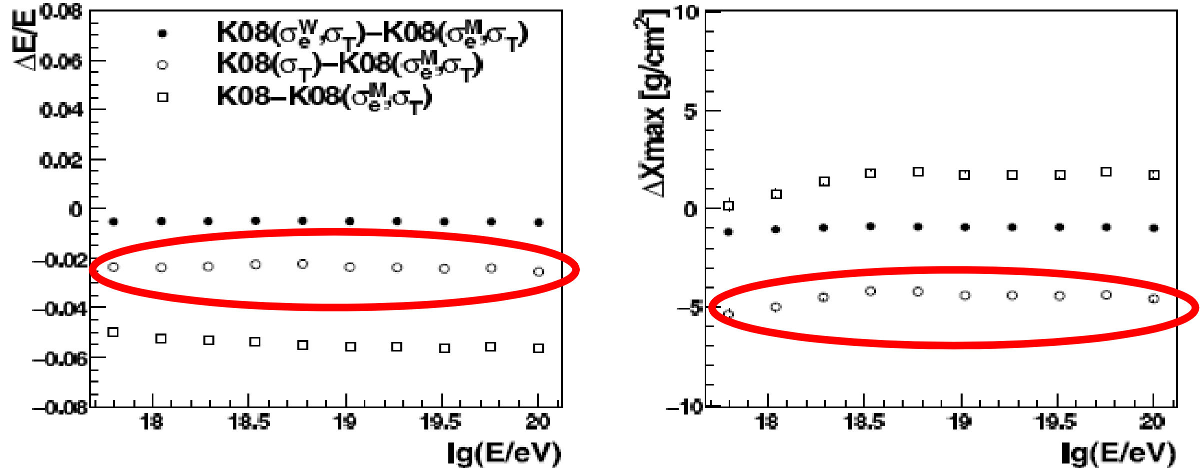
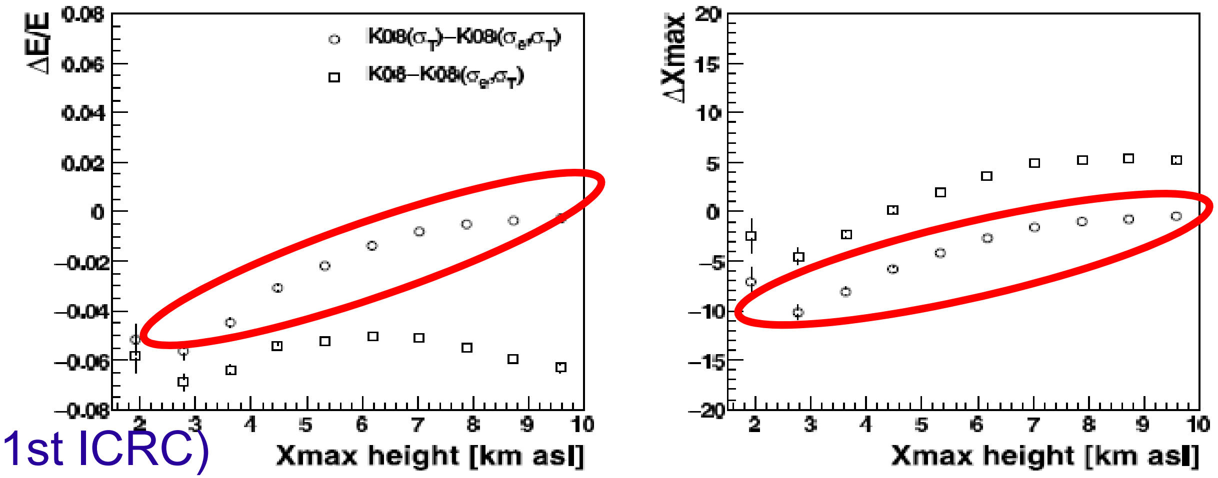
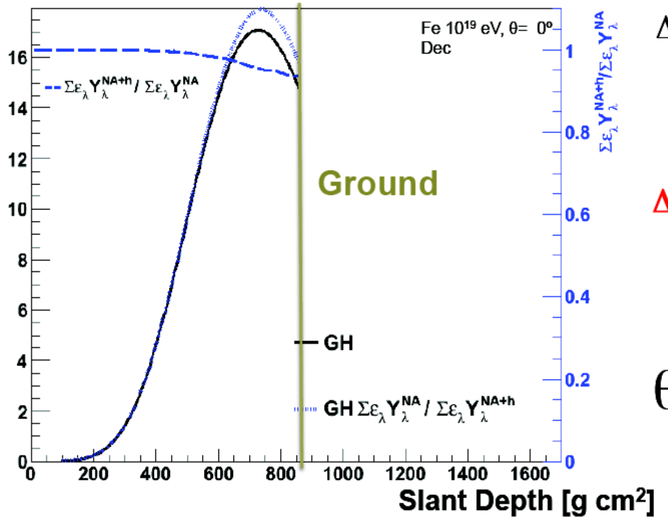


Fig. 3. Difference in reconstructed energy and X_{max} in dependence the vertical height of the shower maximum ($E = 10^{19}$ eV).



B.Keilhauer+2009(31st ICRC)

Influence on reconstruction(2)



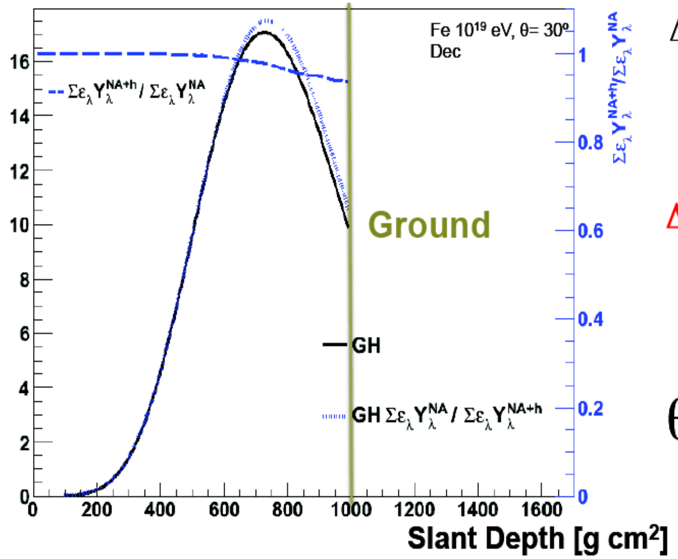
$\delta E = (E'-E)/E$

$\Delta X_{max} = X'_{max} - X_{max}$

δE = 6.1 %

ΔX_{max} = 10 g·cm^{-2}

$\theta = 0^o$



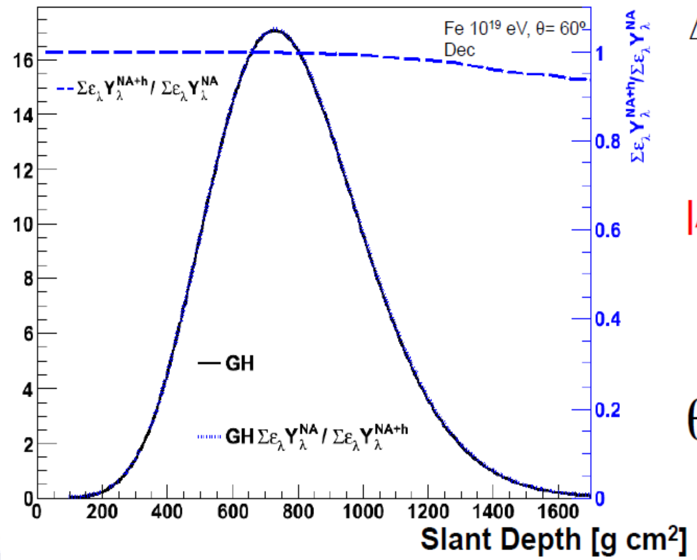
$\delta E = (E'-E)/E$

$\Delta X_{max} = X'_{max} - X_{max}$

δE = 4.3%

ΔX_{max} = 8 g·cm^{-2}

$\theta = 30^o$



$\delta E = (E'-E)/E$

$\Delta X_{max} = X'_{max} - X_{max}$

δE = 0.5%

$|\Delta X_{max}|$ < 1 g·cm^{-2}

$\theta = 60^o$

J. R. Vázquez+(7th AFW, 2010)

Summary

- Parameters for humidity quenching (p'_{H2O}) have been measured for 14 lines so far. But the difference among experiments is still large (factor ~ 2).
  ⇨ **should be improved!**
- This difference in p'_{H2O} causes ~10% difference in fluorescence yield on ground.
- Reconstructed UHECR energy may be underestimated by ~6%(@10^{19}eV) developed near ground for Auger case. Xmax may be shifted upward by several g/cm2.
- To be checked
  Is σ_{NH2O} really constant with temperature?

Thank you!

References

- F.Albugues et al.
  - F.Albugues et al., J. Chem. Phys. 61 (1974) 2695
  - H.Brunet, PhD thesis (1973)
- S.V.Pancheshnyi et al.
  - S.V. Pancheshnyi et al., Chm. Phys. 262 (2000) 349
  - S.V. Pancheshnyi et al., Chem. Phys. Lett. 294 (1998) 523
- Morozov et al.
  - A. Morozov et al., Eur. Phys. J. D 33 (2005) 207
- AirLight
  - T. Waldenmaier et al., Nucl. Instr. Meth. A597 (2008) 67
  - T. Waldenmaier, PhD thesis (2006) FZKA7209
- MACFLY
  - P. Colin et al., Astropart. Phys. 27 (2007) 317
  - P. Colin, PhD thesis (2005)
- AIRFLY
  - M. Ave et al., Nucl. Instr. Meth. A597 (2008) 50
  - M. Bohacova, presentation at 6th Air Fluorescence Workshop (L'aquila) (2009)
- Nagano & Sakaki
  - N. Sakaki et al., Nucl. Instr. Meth. A597 (2008) 88
  - N. Sakaki et al., Proc. 32nd ICRC (Beijing) (2011)