Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

# Optical detection of alpha-emitting radionuclides

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Department 6.3 "*Radiation protection dosimetry*"
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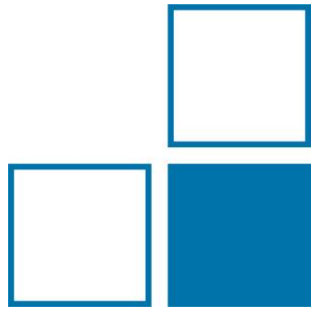

# Content

Motivation

Optical detection of alpha particles: concept and test measurements

EMPIR Joint Research Project RemoteALPHA

# Motivation: Emergency response plans

Safety standards for the protection against the dangers arising from the ionising radiation:
**The European Directive 2013/59/EURATOM**

**Article 97**

**Emergency Management System**

*-Member states should ensure that account is taken of the fact that emergencies may occur in their territory…*
*-The emergency management system shall provide for the establishment of emergency response plans…*

**Article 98**

**Emergency Preparedness**

*-Member States shall ensure that emergency response plans are established in advance for the various types of emergencies…*
*-Member States shall ensure that emergency response plans are tested and revised at regular intervals…*

**Article 99**

**International Cooperation**

*Member States shall cooperate with other Member States and with third countries in addressing possible emergencies on its territory which may affect other Member States or third countries…*

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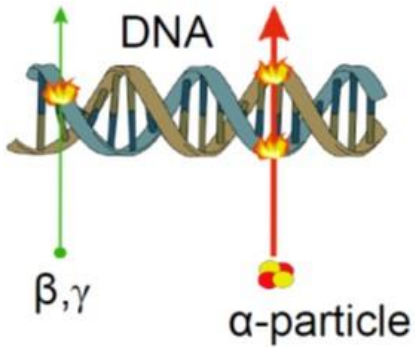
Possible radiological emergency:
**Accidental or deliberate dispersion of alpha emitting radionuclides in the environment**

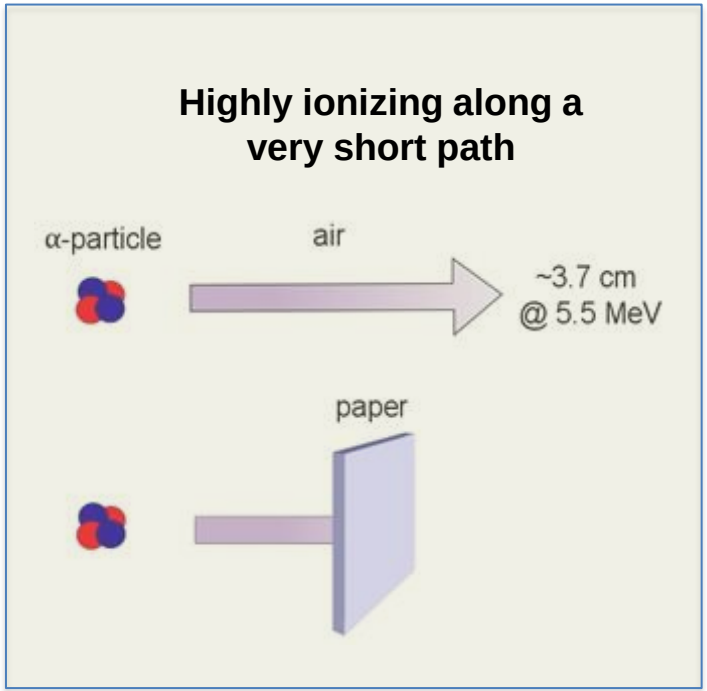
# Alpha particles

Single-strand DNA breaks:
"easy to repair"

Double-strand DNA breaks:
"hard to repair"




*DNA breaks caused by alpha, beta and gamma radiation.*



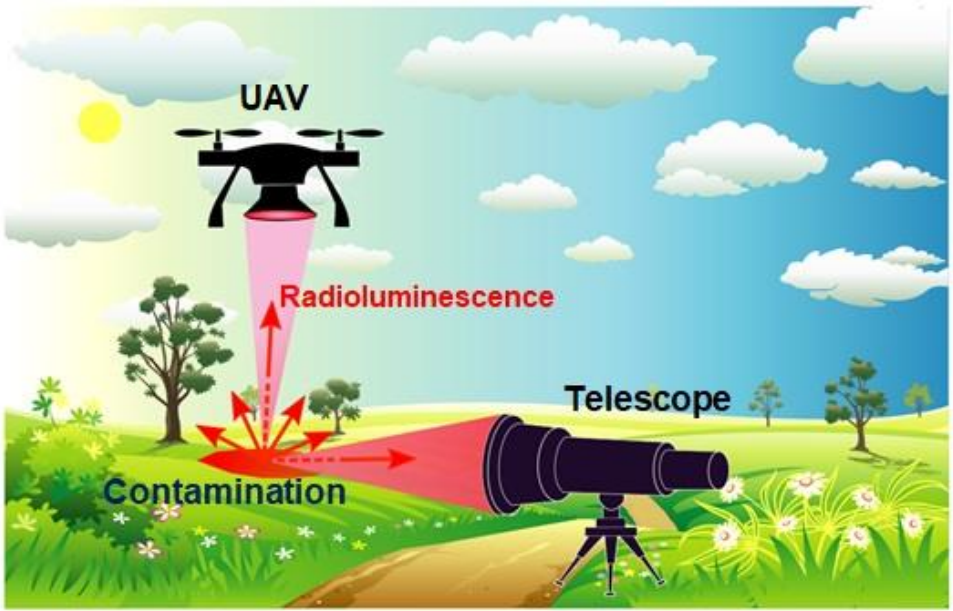
# Alpha particles. Close proximity detection

*Emergency response personnel checks for the radiation contamination. After U.S. National Archives, Public Domain Archive.*

Traditional detection methods (proportional counter, scintillator counter, PIPS detectors) are:

- involve **scanning very close to the surface** of the contaminated area,
- Expose the personnel to **other hazards and risks** (other types of radiation, fire, etc.),
- **time consuming and tedious,**
- require the use **personal protective equipment**.

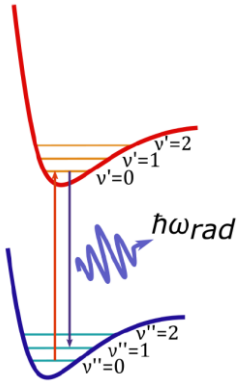
# Motivation: Remote detection of alpha particles




*Concept of remote detection of alpha particles.*

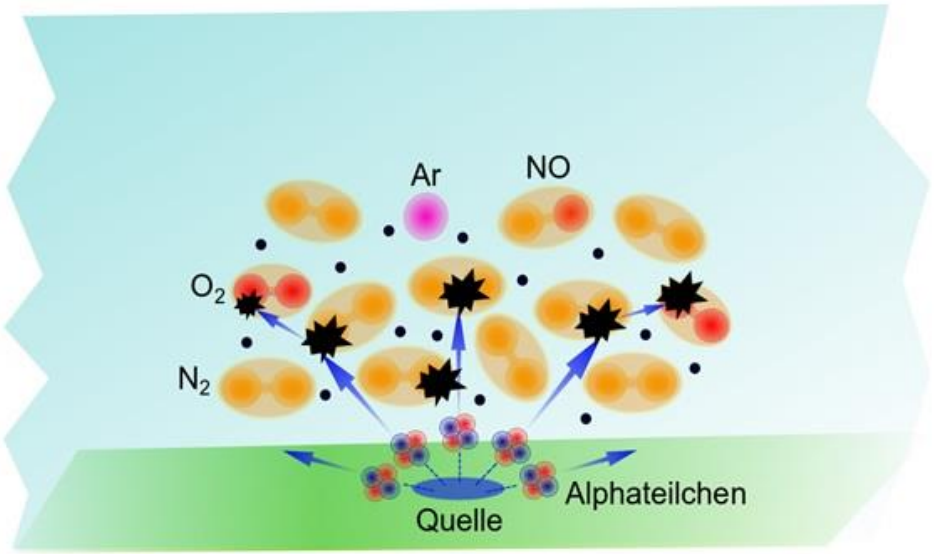
**Advantages:**

- Operators are kept out of the radiation field,
- Efficient scanning of large areas.




Use of optical transitions in gas molecules: **radioluminescence**

# Radioluminescence at a glance




*Schematic representation of air ionization by α-particles.*

High-energy alpha particles ionize air (predominantly molecular nitrogen).

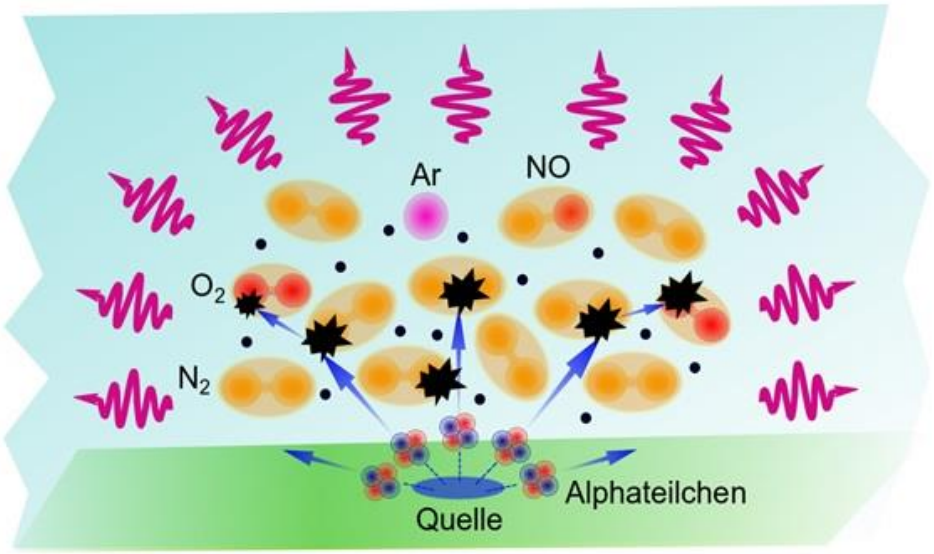
Secondary electrons excite the air molecules, e.g.,

$$e^- + \mathrm{N}_2\left(\mathrm{X}^1\Sigma_g^+\right) \rightarrow \mathrm{N}_2^*(\mathrm{C}^3\Pi_u) + e^-$$

$$e^- + \mathrm{N}_2^+\left(\mathrm{X}^2\Sigma_g^+\right) \rightarrow \mathrm{N}_2^*(\mathrm{C}^3\Pi_u)$$

$\mathrm{X}^1\Sigma_g^+, \mathrm{C}^3\Pi_u$ → Molecular levels

# Radioluminescence at a glance




*Schematic representation of air ionization by α-particles and radioluminescence.*

Air molecules emit fluorescent light (radioluminescence) in the UV range between 200 nm and 400 nm.

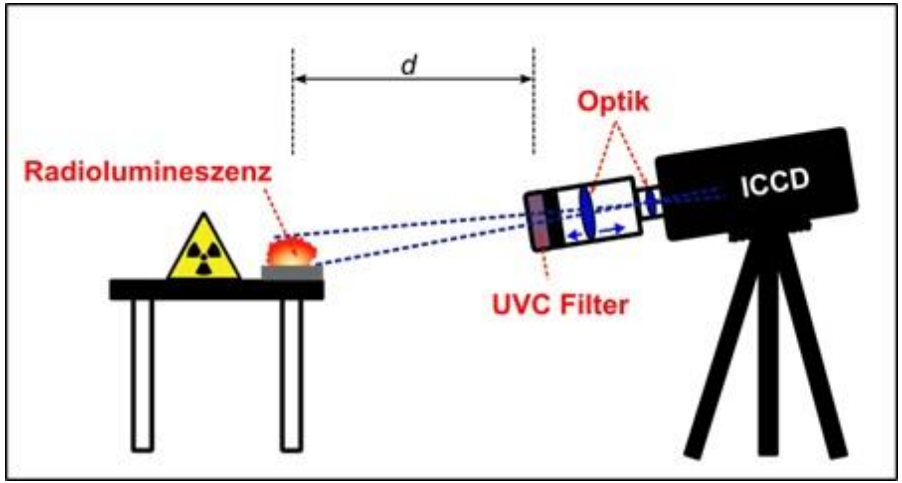
Range in air:

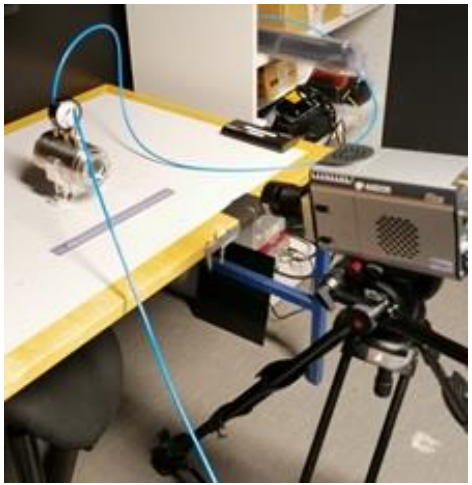
α-particles → 0,04 m
UV light → 500 m

# Imaging of alpha emitters in the UVC (solar-blind) spectral range

Experiments at the University of Tampere (Finland), Research Group of Prof. Juha Toivonen

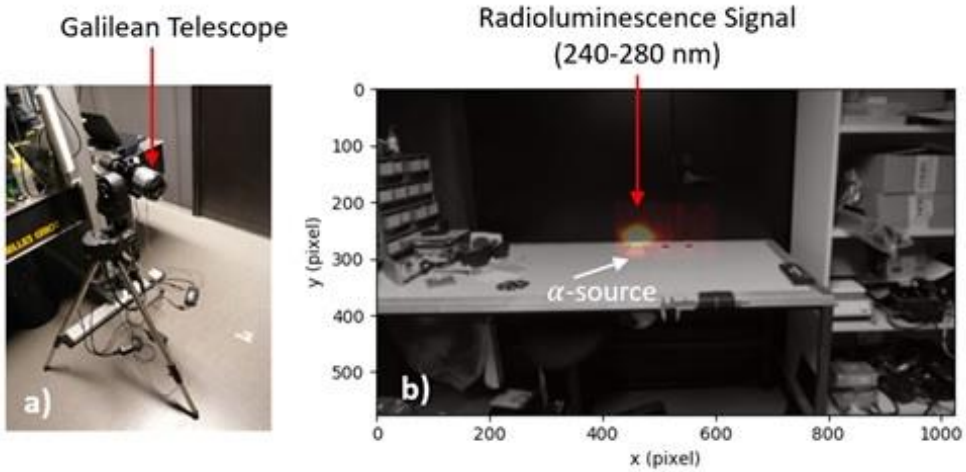
F. S. Krasniqi, T. Kerst, M. Leino, J.-T. Eisheh, H. Toivonen, A. Röttger, J. Toivonen,
Nuclear Inst. and Methods in Physics Research, A **987** (2021) 164821



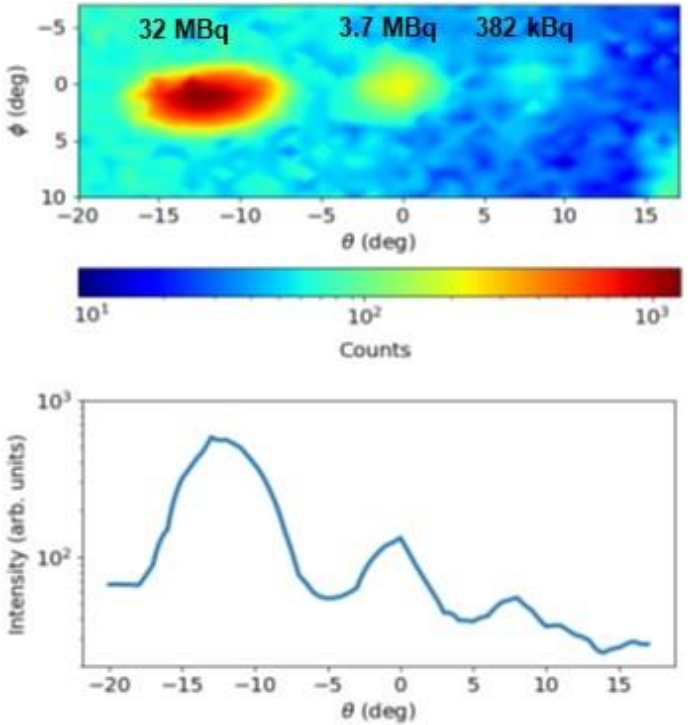



*Schematic representation of the UV-C test setup.*

# UV-C radioluminescence: Detection with telescope and PMT




*(a) A photo of the optical system for alpha particle detection. (b) Radioluminescence image of the Am-241 sample (32 MBq) in the UV-C spectral region.*

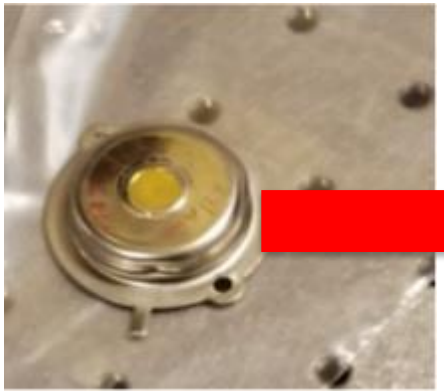


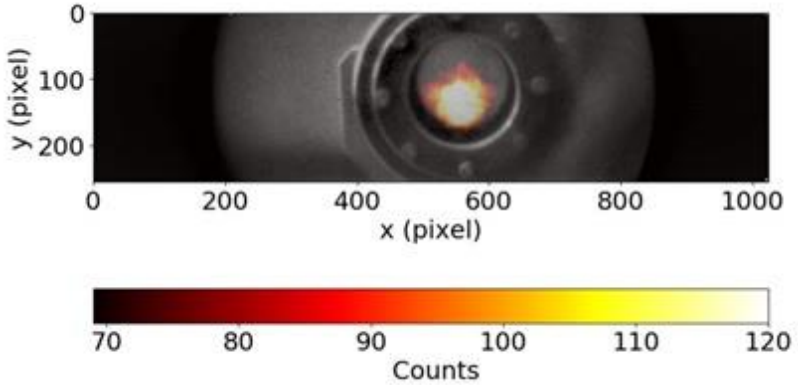

*Typical radioluminescence intensity distribution.*

# UV-C radioluminescence: Amplification with NO

By adding only 3 ppm NO to the air/$N_2$ amosphere,
**up to 500-fold increase of the radioluminescence signal**.

9.9 kBq Am-241
smoke detector ionizer



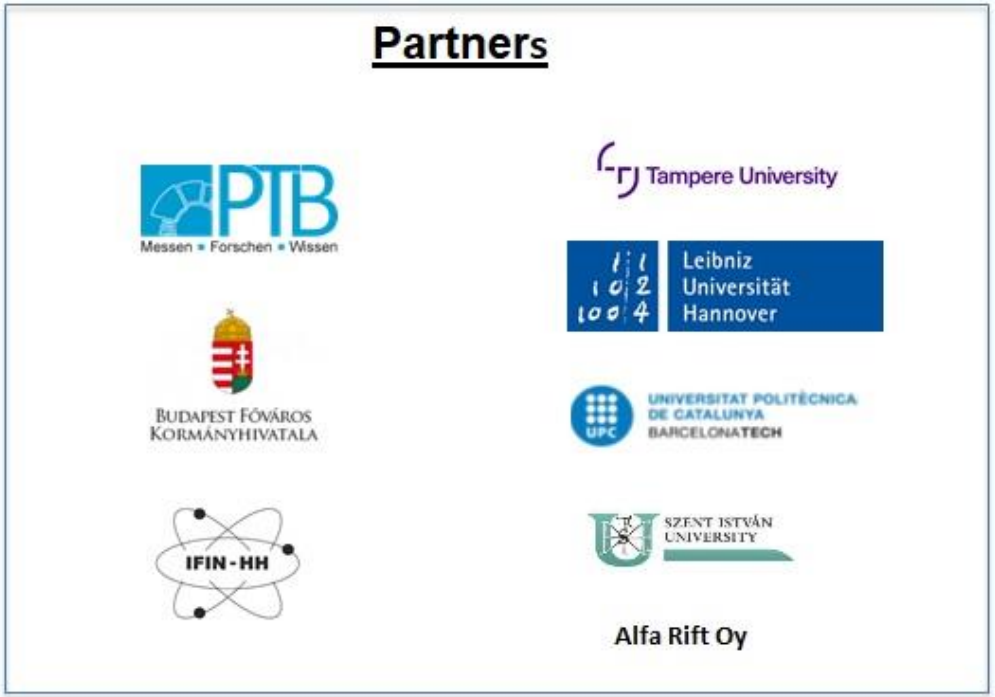



*UVC radioluminescence image of a 9.9 kBq source (right) and a photo of the sample in the experimental chamber (left).*

# EMPIR Project: RemoteALPHA

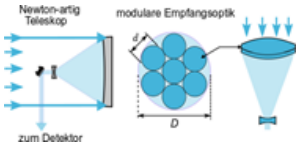
**Remote and real-time optical detection of alpha-emitting radionuclides in the environment**

(EMPIR≡ European Metrology Programme for Innovation and Research)

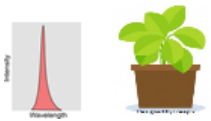



# Technical Workpackages

**RemoteALPHA: 01.09.2020 - 31.08.2023**

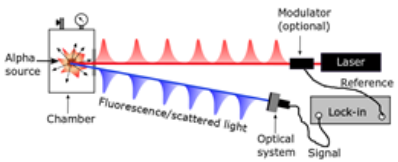



**WP1** New instruments for the optical detection of alpha emitters in the environment



**WP2** Calibration system for the novel radioluminescence detector systems

**WP3** Mapping alpha contamination in the environment using UAVs




**WP4** Feasibility study on laser-based techniques for alpha emitter detection

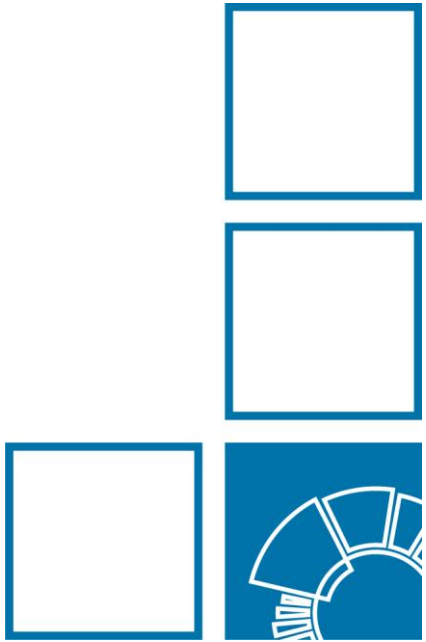
PTB Messen • Forschen • Wissen | Budapest Főváros Kormányhivatala | IFIN-HH | Alfa Rift Oy | Leibniz Universität Hannover | Tampere University | Universitat Politècnica de Catalunya BarcelonaTech | Szent István University

# Acknowledgments

*The project 19ENV02 RemoteALPHA has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.*

*19ENV02 RemoteALPHA denotes the EMPIR project reference.*

# Thank you!



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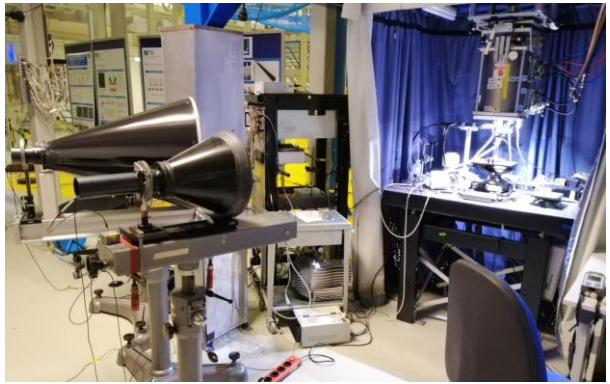
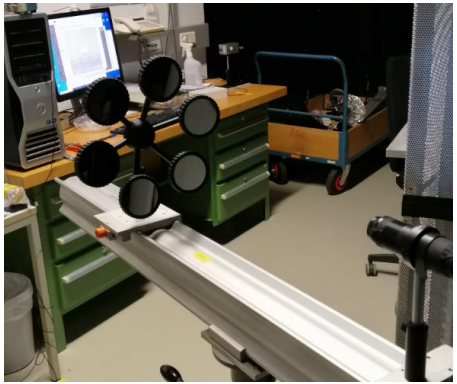
Dr. Faton S. Krasniqi
Telefon: 0531 592-6223
E-Mail: faton.krasniqi@ptb.de

www.ptb.de

# Optical setups: preliminary tests at the PTB Microbeam Facility



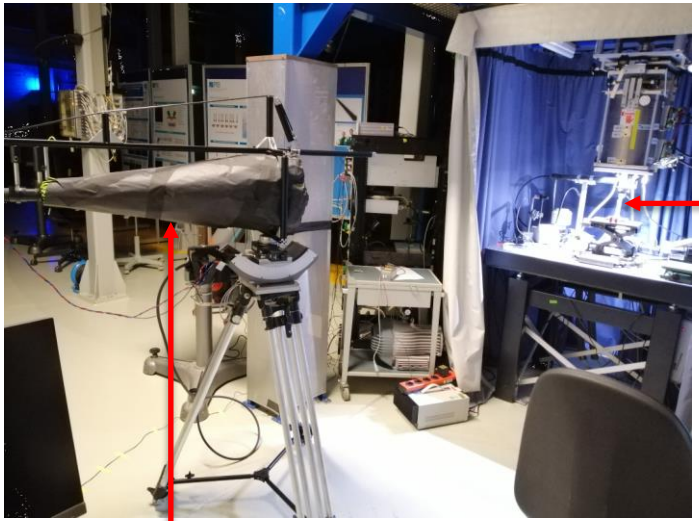
Fresnel lens-based systems (light weight)



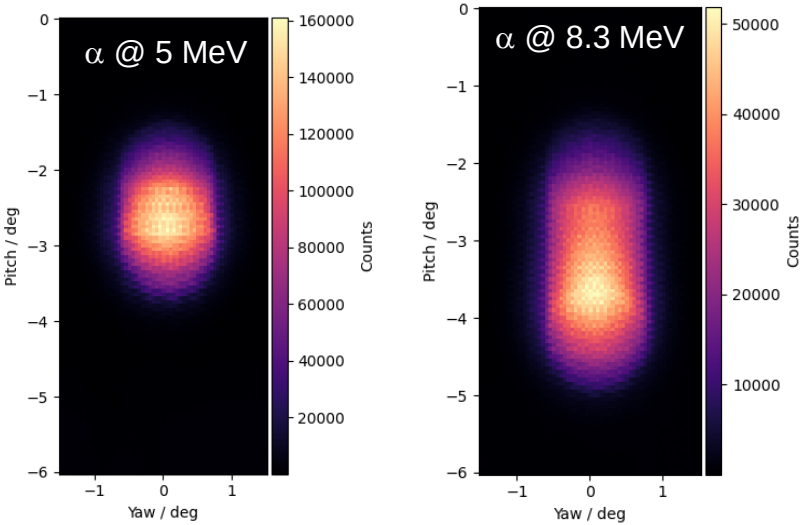
Modular-mirror systems

*M. Luchkov, V. Dangendorf, U. Giesen, K. Titelmeier, F. Langner, C. Olaru and F. Krasniqi*

# Optical setups: preliminary tests at the PTB Microbeam Facility



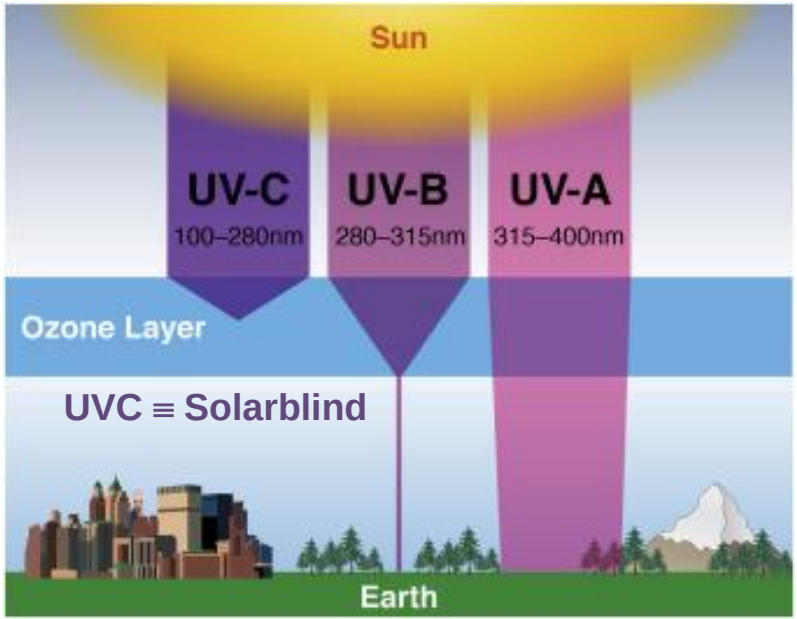

Scanning system based on ∅240 mm fused-silica lens



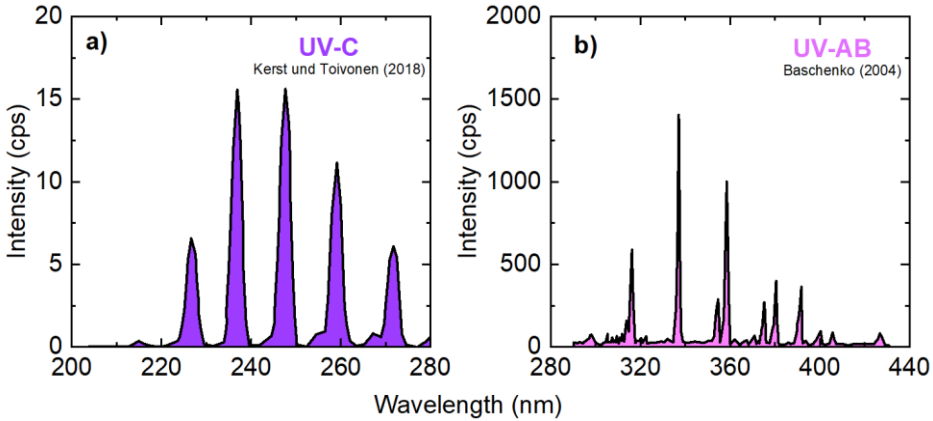

Radioluminescence mapping of accelerated alpha particles

*M. Luchkov, V. Dangendorf, U. Giesen, K. Titelmeier, F. Langner, C. Olaru and F. Krasniqi*

# UVC radioluminescence: Low disturbance by sunlight



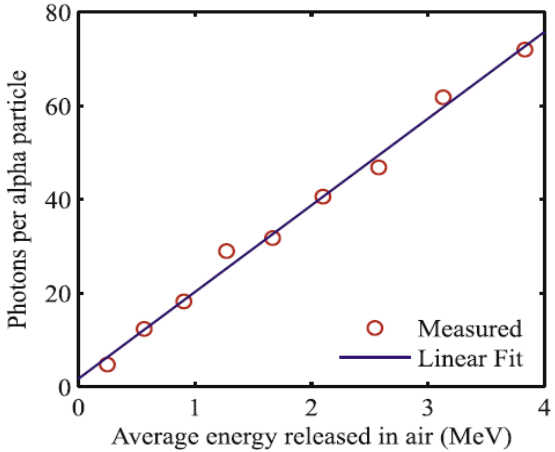

*D. W. Wilmouth et. al., Green Chemsitry, Ch. 3.3 (2018), https://doi.org/10.1016/B978-0-12-809270-5.00008-X*

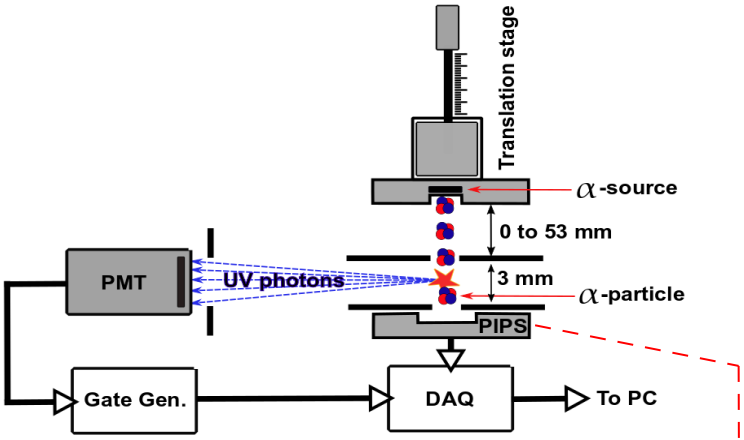



*Radioluminescence spectrum*

*a) T. Kerst und J. Toivonen, Optics Express **26**, 33764 (2018), und*
*b) S. M. Baschenko, J. Radiol. Prot. **24**, 27 (2004)*

# Number of UV Photons per Alpha Particle




*Alpha particles generate 19 ± 3 photons per one MeV of energy released in air at normal pressure (temperature 22 °C, relative humidity 43%). E. g.* ***a single 5 MeV alpha particle creates ~100 photons***.

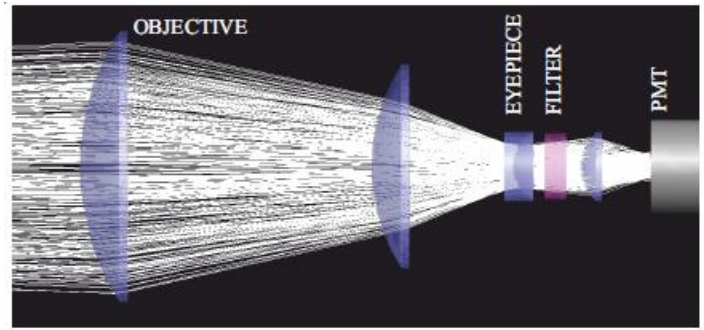
*PIPS detector measures the energy of α-particles (PIPS=Passivated Implanted Planar Silicon).*

J. Sand *et al.*, New Journal of Physics **16**, 053022 (2014).

# Radioluminescence Mapping of Alpha Emitters

*Radioluminescence mapping system based on a Galilean telescope built at Tampere University of Technology, Finland.*

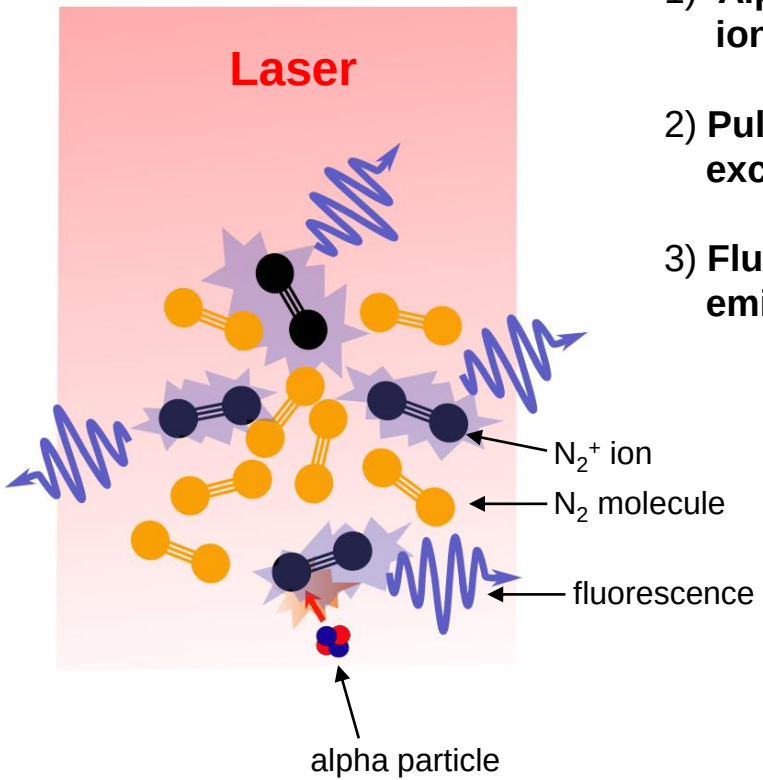
Objective lens diameter =100 mm




*The optical system (Galilean telescope) for collecting radioluminescent photons.*

J. Sand *et al*., IEEE Transactions on Nuclear Science **63**, 1777 (2016).

# Fluorescence/Resonant Raman Method at a Glance

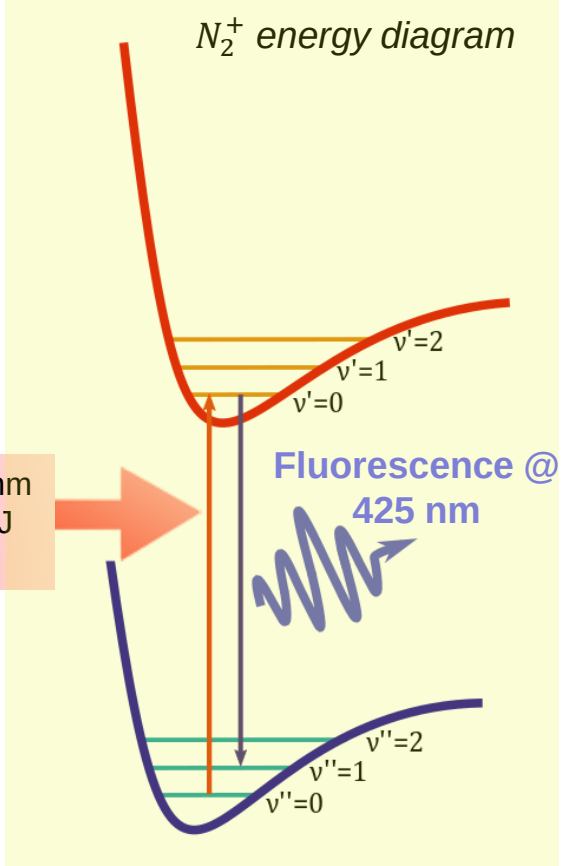



1) **Alpha particles ionize** $N_2$ molecules.

2) **Pulsed laser excites** $N_2^+$ ions at $\lambda_{las}$.

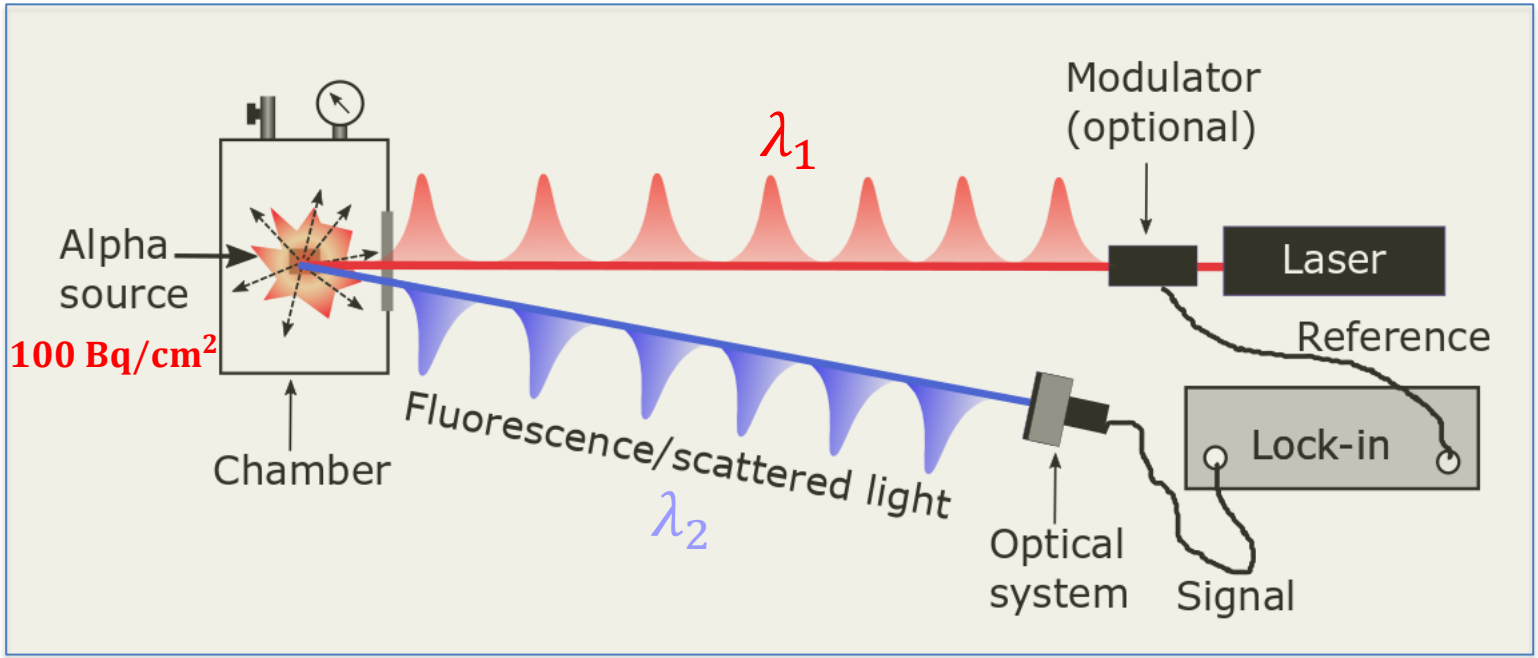
3) **Fluorescence is emitted at** $\boldsymbol{\lambda_{emission} \neq \lambda_{las}}$

Laser wavelength: 391 nm
Energy per pulse: 500 µJ
Rep. Rate: 10 Hz



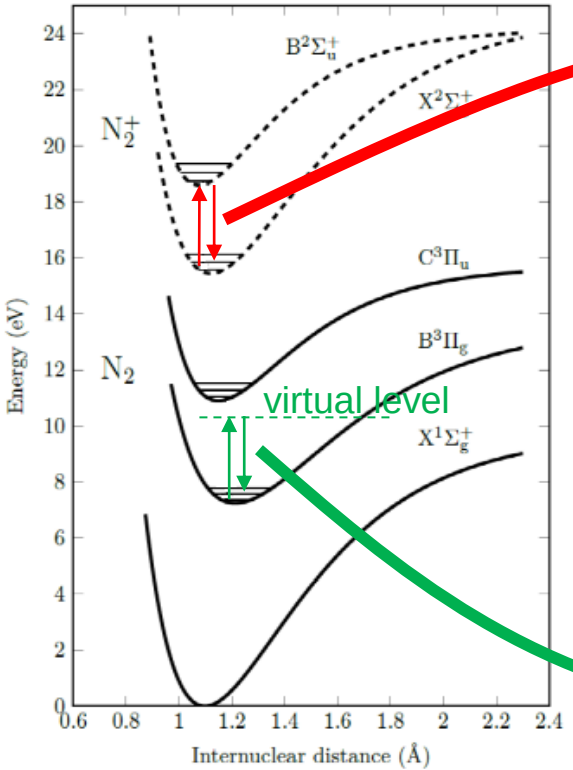
# Laser Lab Tests: Fluorescence/Raman LIDAR

**Supercontnuum fiber laser**
**Power: ~10 W**
**Rep rate: 20-320 MHz**
**Spectral coverage: 400 - 2400 nm**

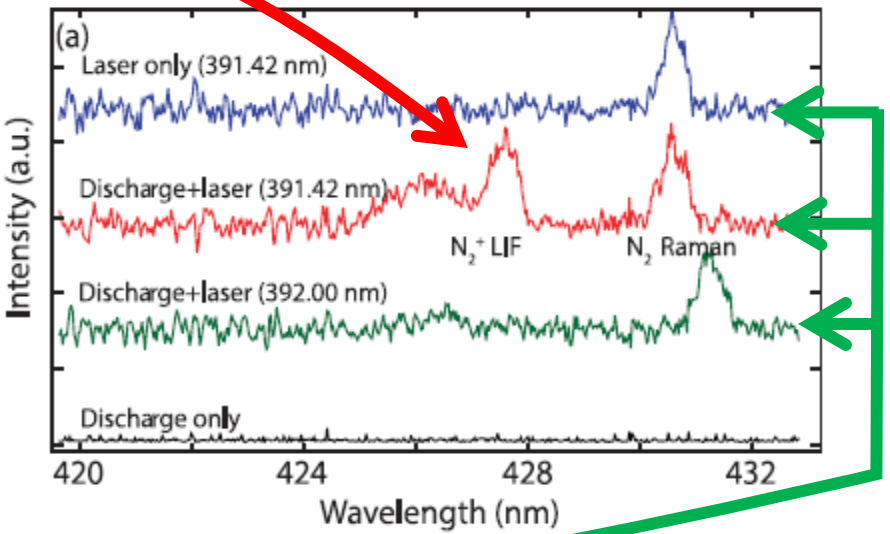


# Laser induced fluorescence in ambient air (corona discharge)

Ref.: Konthasinghe *et al*., Applied Spectroscopy **69**, 1042 (2015)




Resonant Raman from $N_2^+$ (Fluorescence)




Non-resonant Raman from $N_2$ (Stokes)

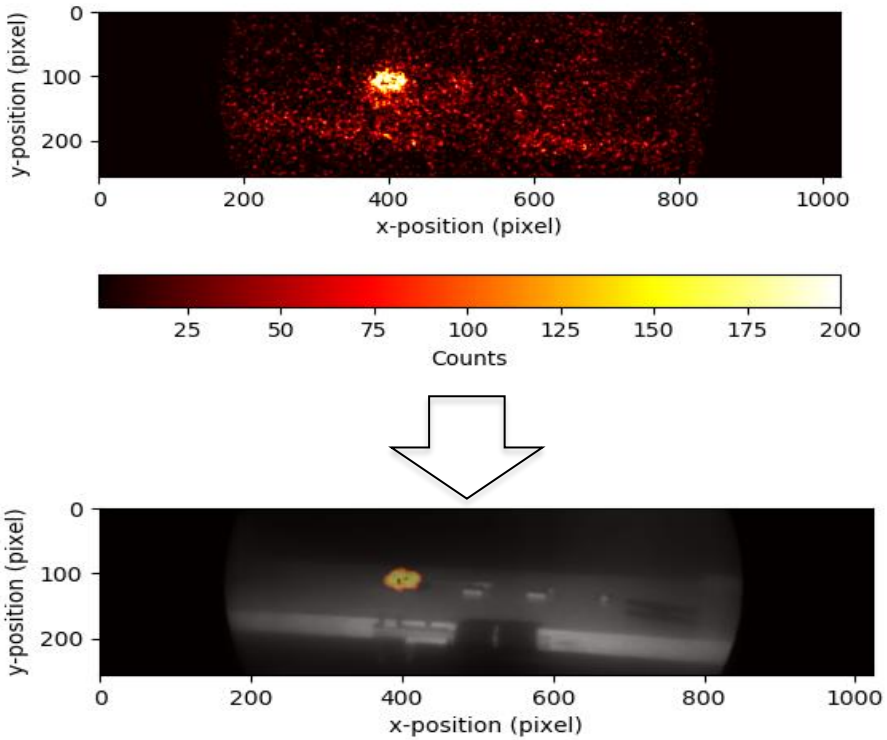
# Image filtering: removing „salt-and-pepper“ image noise

| | | | | | | |
|---|---|---|---|---|---|---|
| B11 | B12 | B13 | B14 | B15 | B16 | B17 |
| B21 | B22 | B23 | B24 | B25 | B26 | B27 |
| B31 | B32 | B33 | B34 | B35 | B36 | B37 |
| B41 | B42 | B43 | B44 | B45 | B46 | B47 |
| B51 | B52 | B53 | B54 | B55 | B56 | B57 |
| B61 | B62 | B63 | B64 | B65 | B66 | B67 |
| B71 | B72 | B73 | B74 | B75 | B76 | B77 |

the **pixel at the center** will be **replaced** by the **median of all pixel values inside the window**

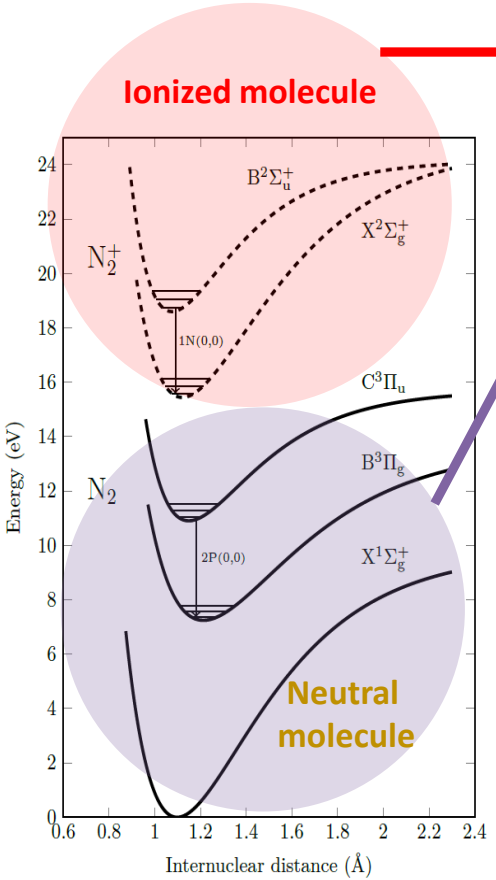
the window of a 2D median filter

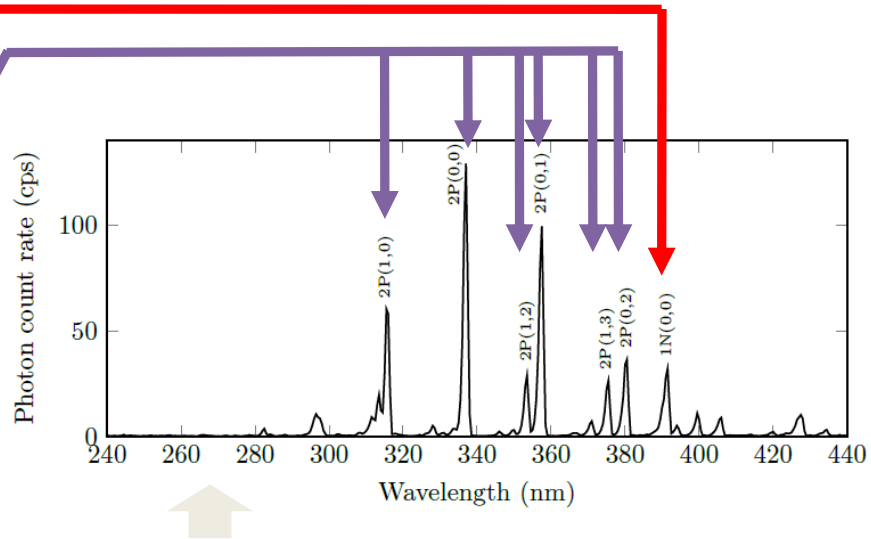
*Raw image*




*Filtered image + overlay*

# Energy Levels of $N_2$ Molecule

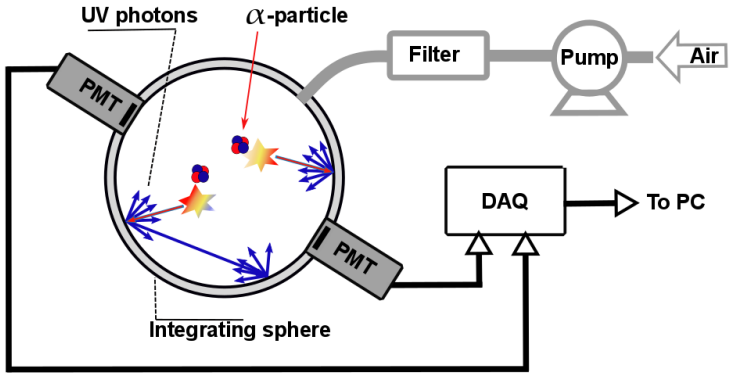


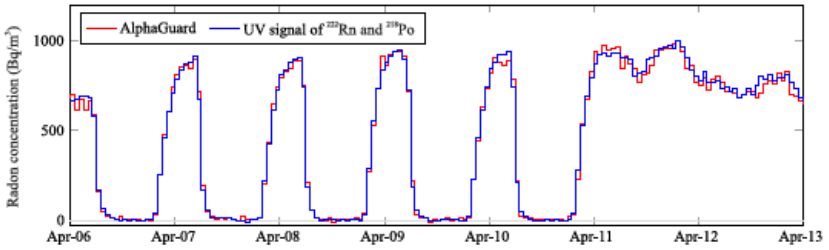

*Radioluminescence emission spectrum of air excited by Am-241 (32 MBq) alpha particles. The measurement was performed with a monochromator (Horiba iHR 550) and a low dark count rate photomultiplier tube (PMT) (Perkin Elmer, MP-1982P).*

[After Sand, J. (2016). *Alpha Radiation Detection via Radioluminescence of Air.* (Tampere University of Technology. Publication; Vol. **1449**)].

# Optical detection of radon decay in air




***Optical radon detection setup.*** *A pump (P) forces air into the detection volume through a filter which removes radon progenies from the incoming air. The sample leaves the detector through the PMT ports.*




*Comparison of the radon signal obtained from the radioluminescence to that measured using AlphaGuard.*

J. Sand *et al.*, Scientific Reports **6**, 21532 (2016).