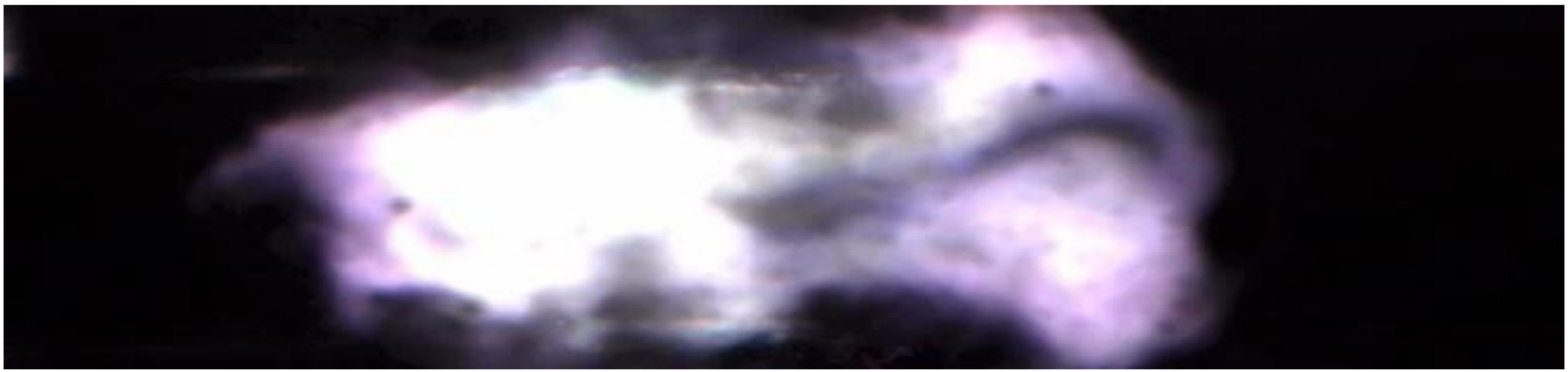
Emission Spectroscopy on Aluminum Wire Explosions in Different Atmospheres



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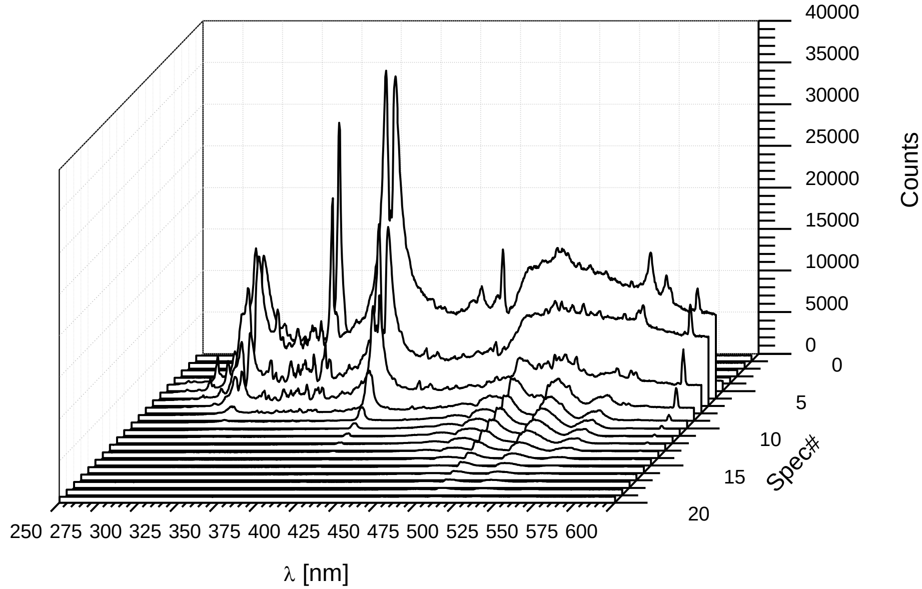
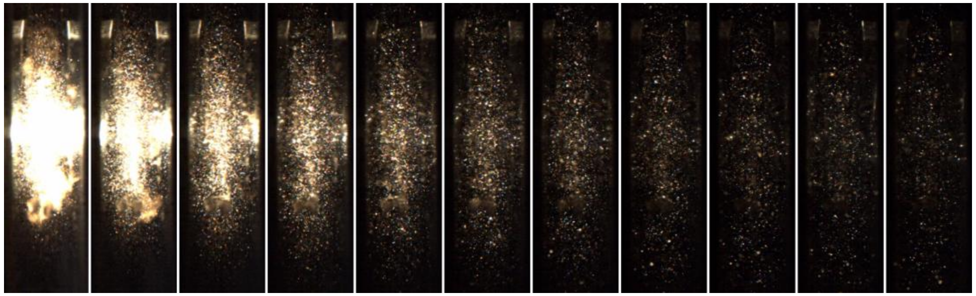
Outline

- introduction and motivation
- experimental setup
- visual observation
- I/U-characteristic
- spectra analysis
- temperature determination
- conclusion





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Introduction and Motivation

Investigation of wire explosions:

- Low temperature plasmas…

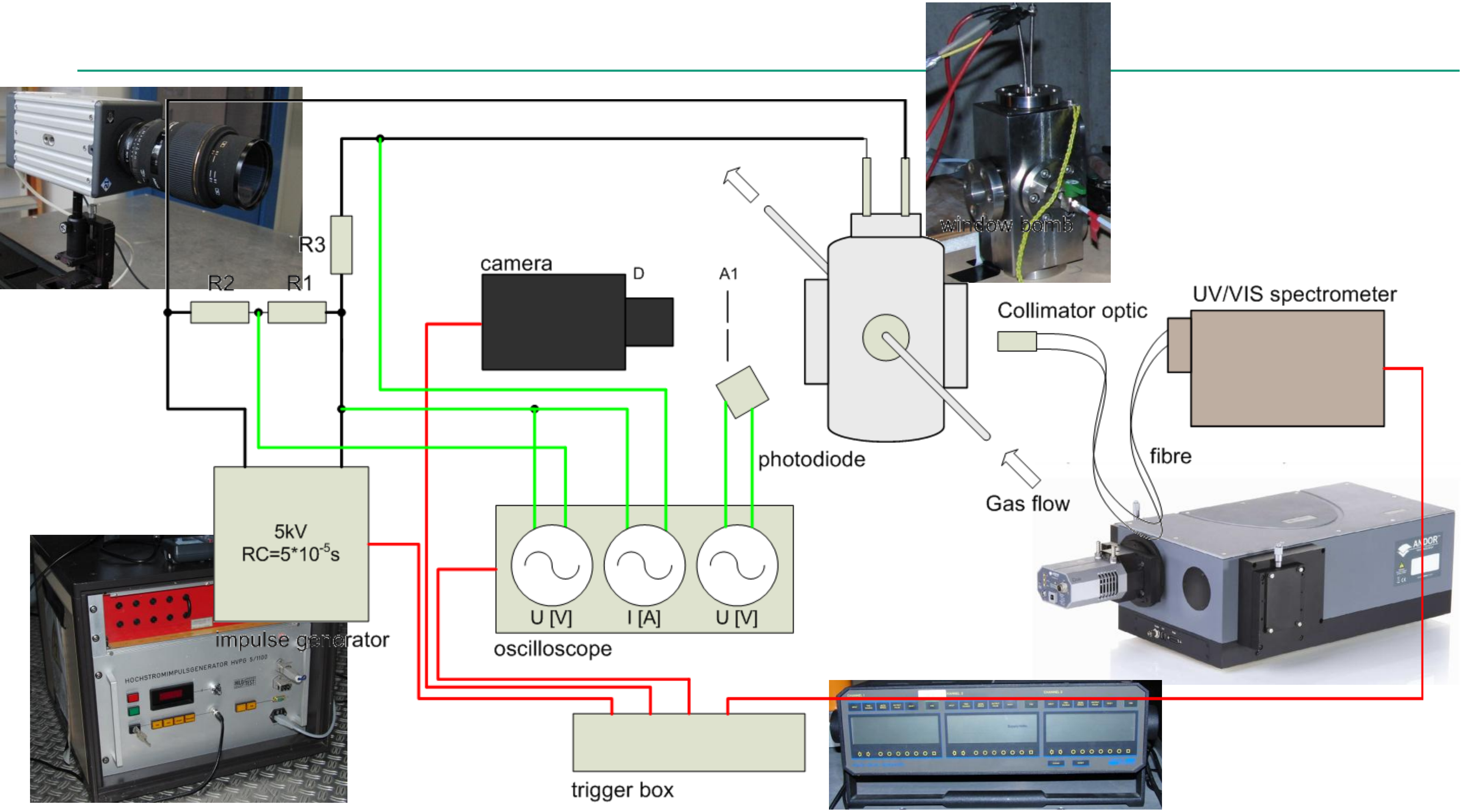
  … thermodynamic parameters reach extreme values

  … investigation of chemical reactions of metals in different atmospheres

  … spectroscopic investigation in absence of continuum radiation

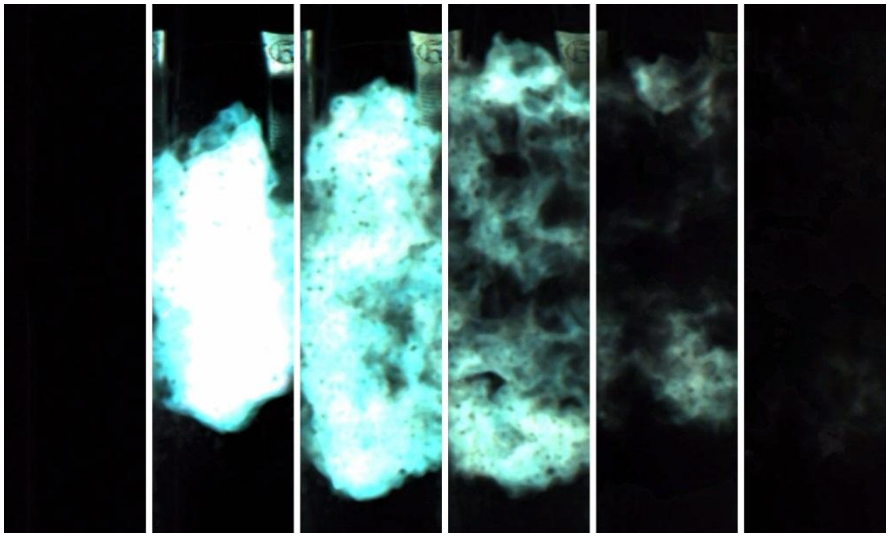
- Different applications…
- …plasma ignition of propellants
- …production of metal nano particles
- …creation of x-ray sources

Experimental Setup



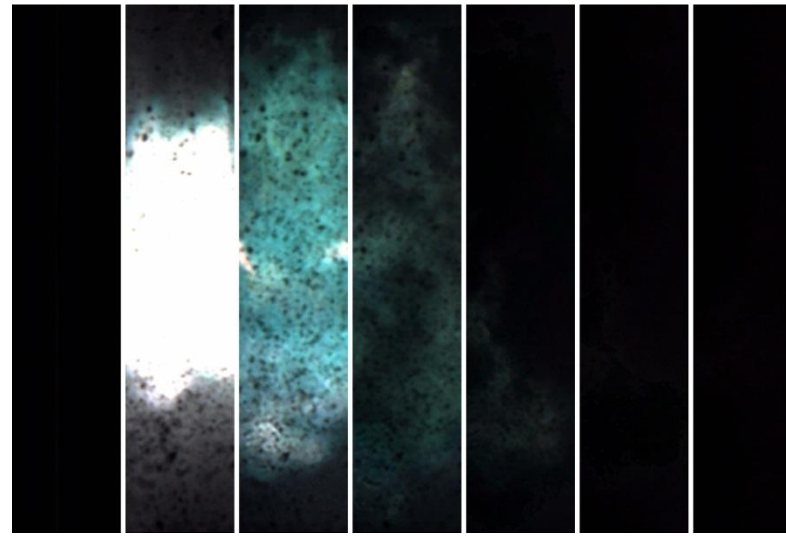
Visual Observation

Oxygen



- White cloud with green/blue zone at the border
- Could be an Indicator that AlO is formed
- Emission much brighter than in air

Carbon dioxide



- White cloud with a green/blue zone
- Turns into a green/blue one (AlO)
- Intensity decrease very fast

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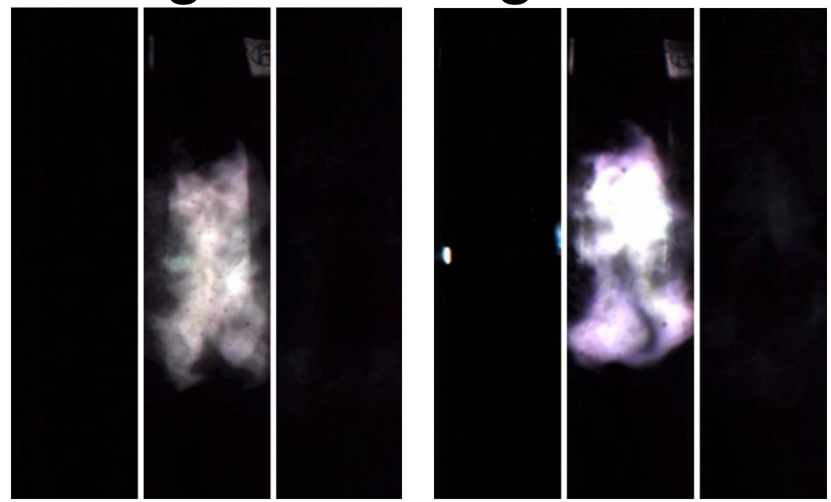
Visual Observation

Air

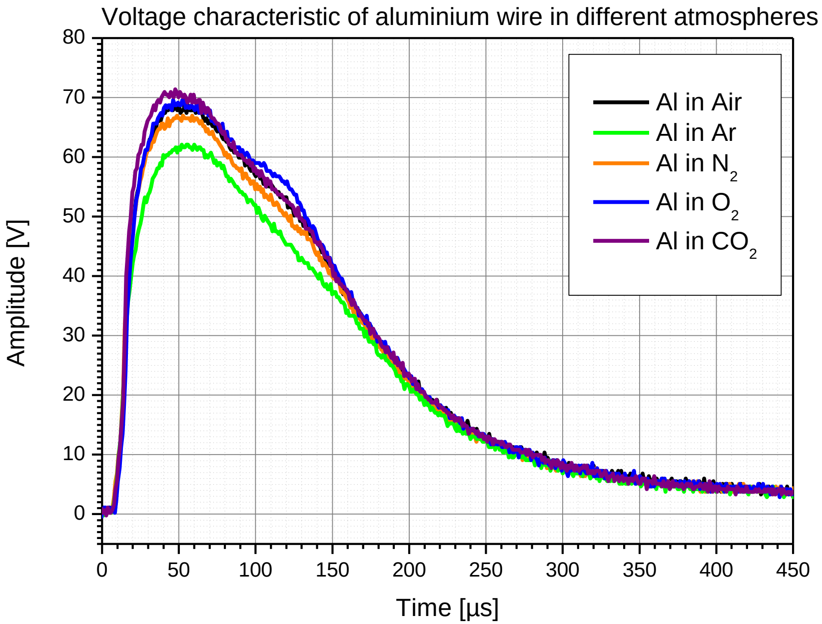
- White cloud turns in a green/blue one with great dimensions
- Emission is not so bright but it is visible for a long time

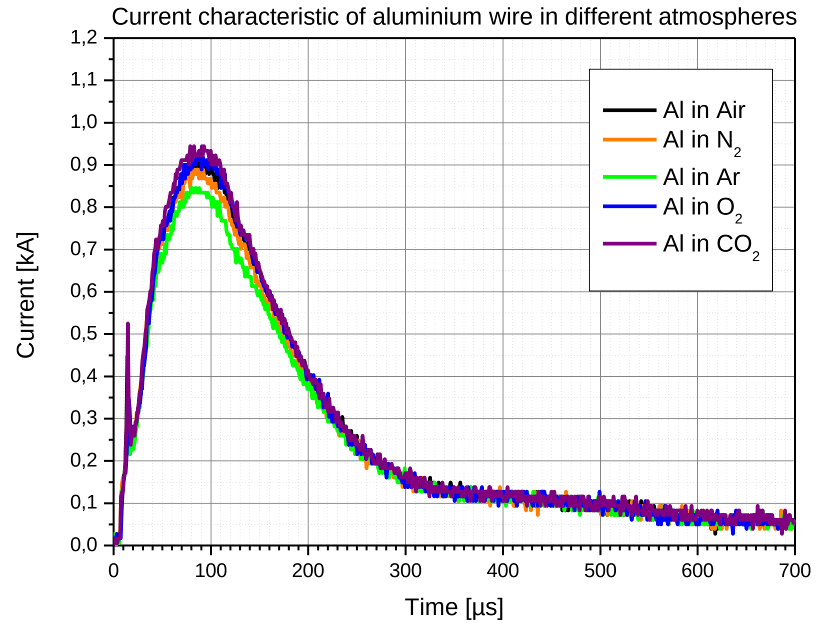
Nitrogen and Argon



- Very short process of light emission
- White cloud with purple border
- Originates from the excited aluminium atoms

I/U-characteristic
- energy input





- Shapes and amplitudes of the voltage and current curves nearly independent from the atmospheres and for all atmospheres identical
- Energy input for all atmospheres the same

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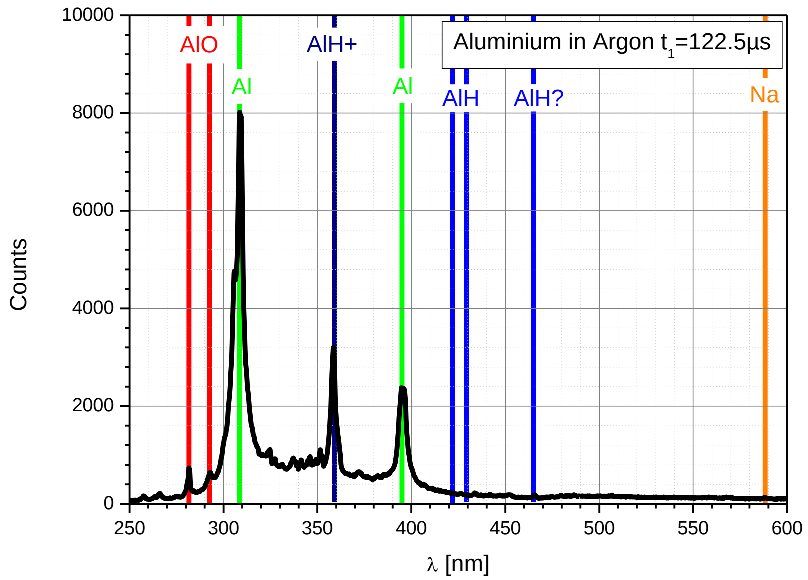
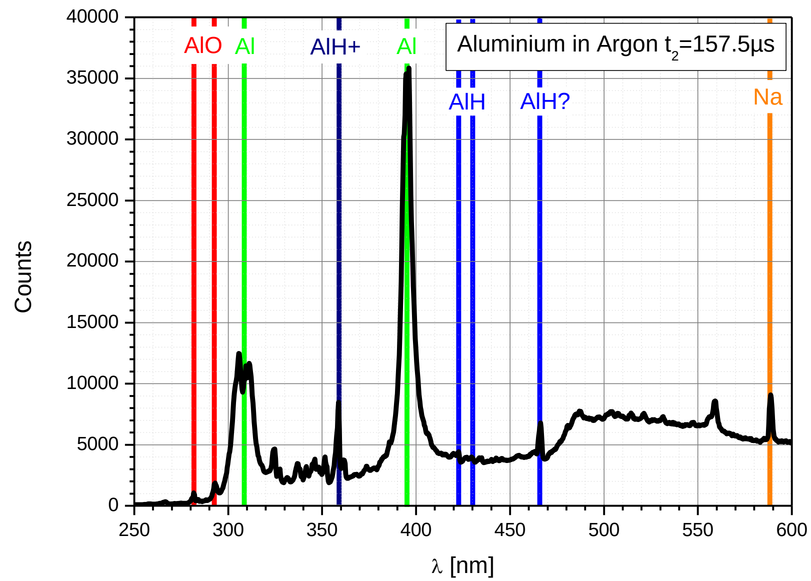
Spectra Analysis
- argon atmosphere





- All spectra show the strong atomic lines of aluminium
- No aluminium oxide except in the first few spectra from the oxide layer
- AlH+ appears in all spectra independent from the atmosphere

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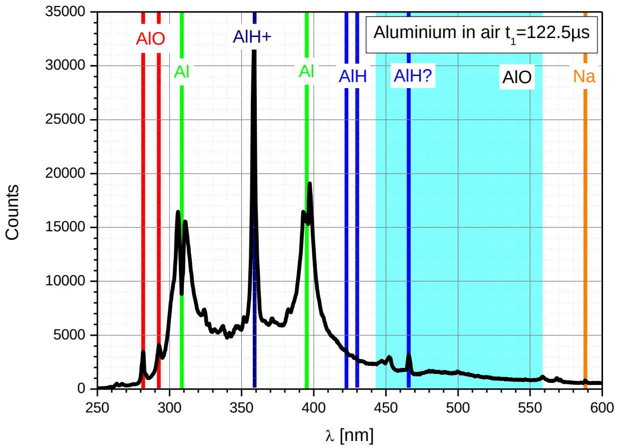
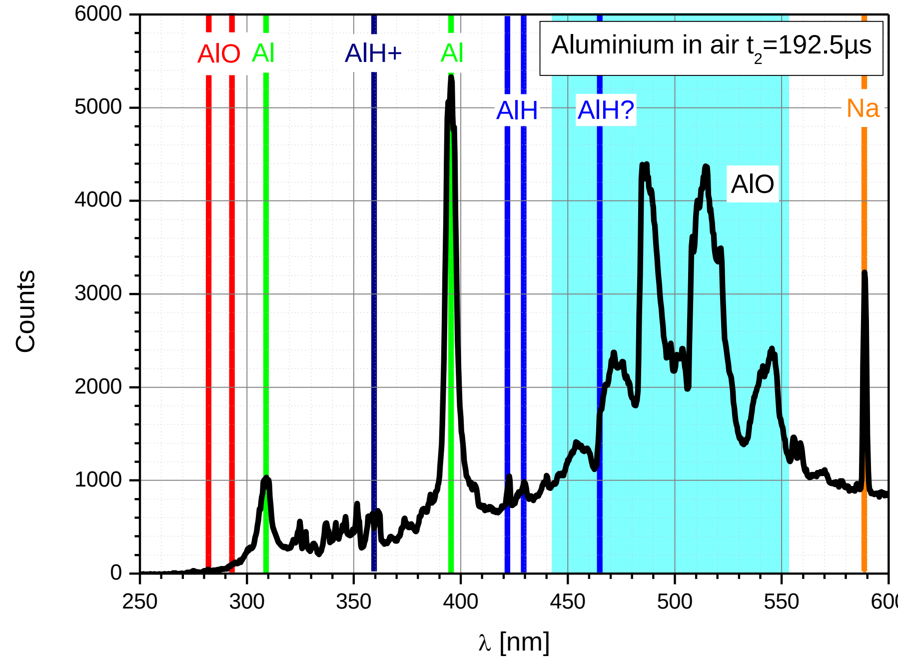
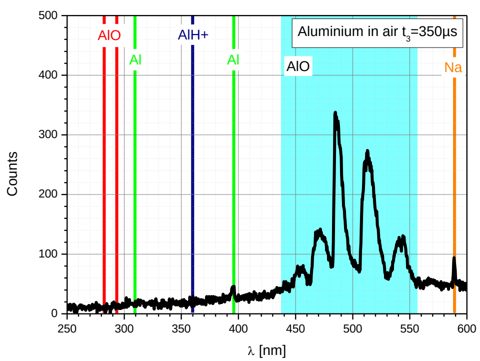
Spectra Analysis
- air atmosphere







- First spectrum shows AlO, AlH+, Al atomic lines similar to all other atmospheres
- The atomic aluminium lines are in absorption
- Later the AlO B-X system is visible for a long time

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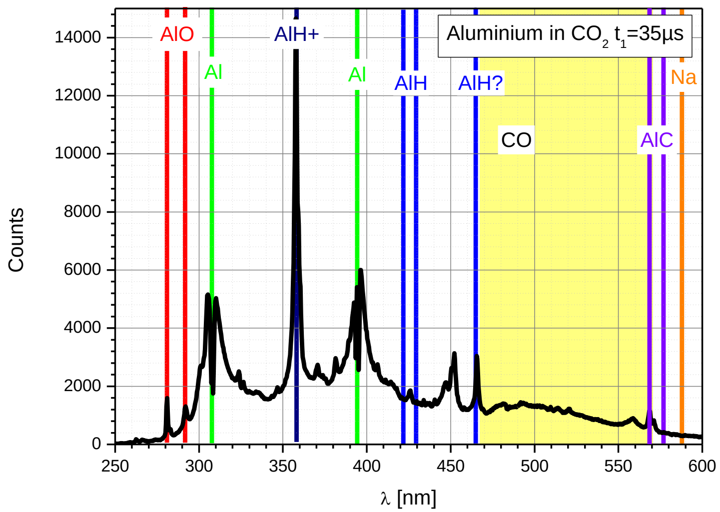
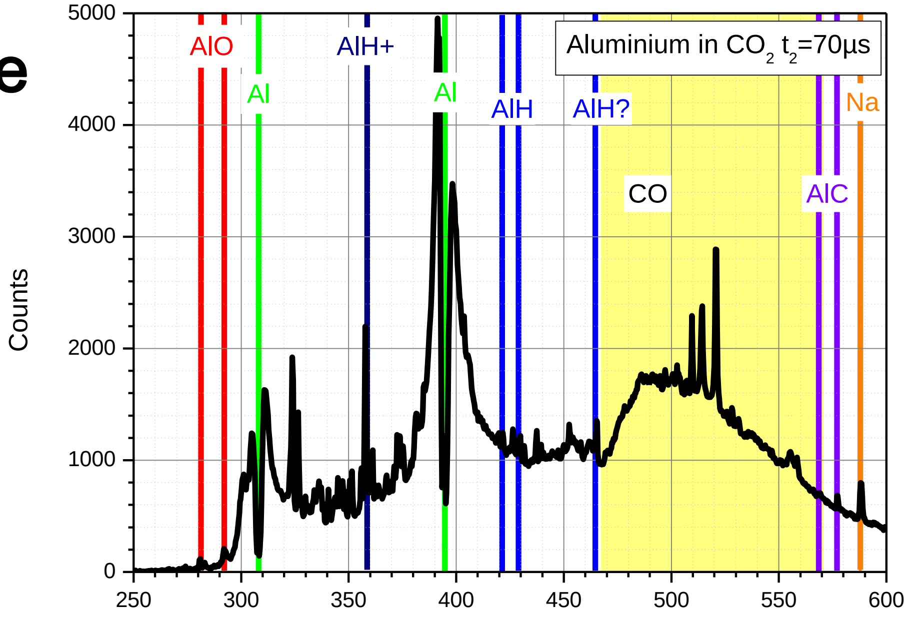
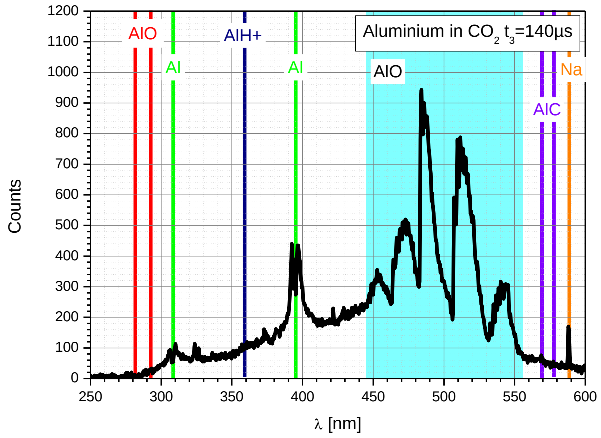
Spectra Analysis
- carbon dioxide atmosphere





- Atomic aluminium lines are in absorption
- CO system appears with unknown lines added
- Small signal of AlC at 570nm
- At the end of the process AlO B-X system is apparent



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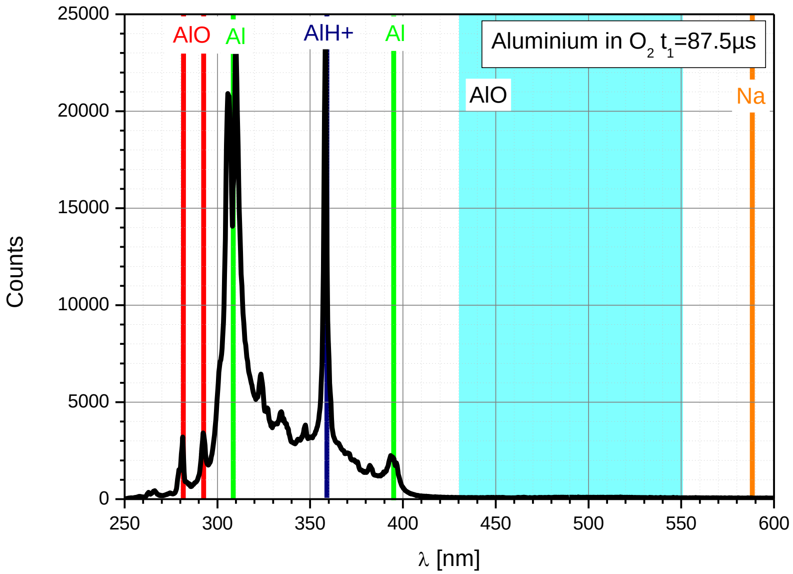
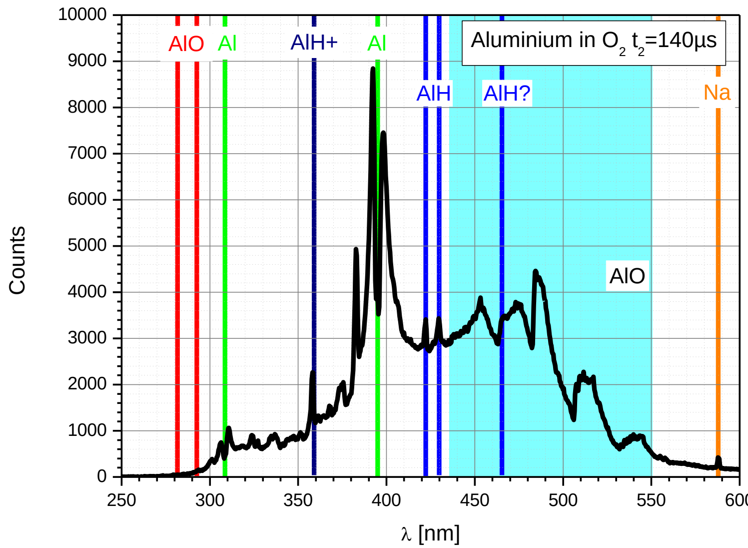
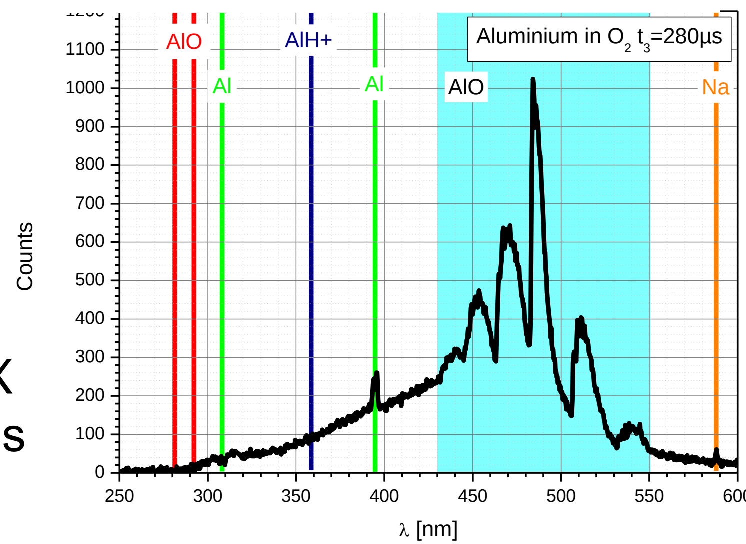
Spectra Analysis
- oxygen atmosphere







- First spectrum shows emission of atomic aluminium lines, AlO and AlH
- Al reaches absorption and the first AlO B-X system appears until the end of the process

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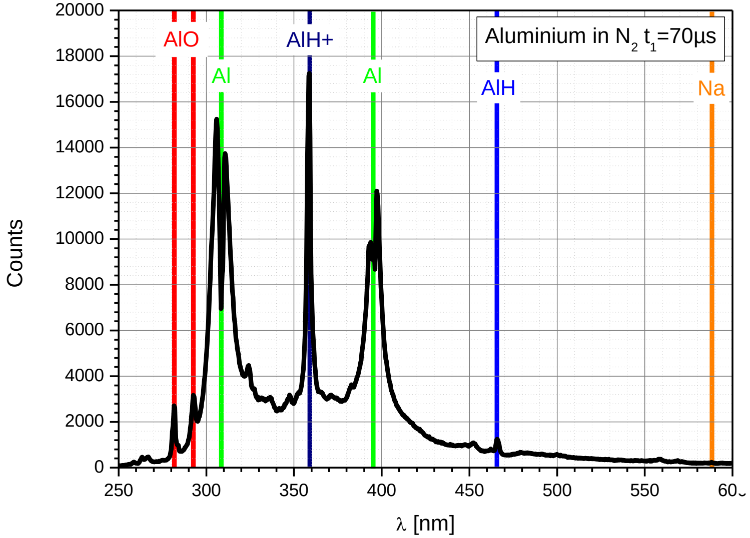
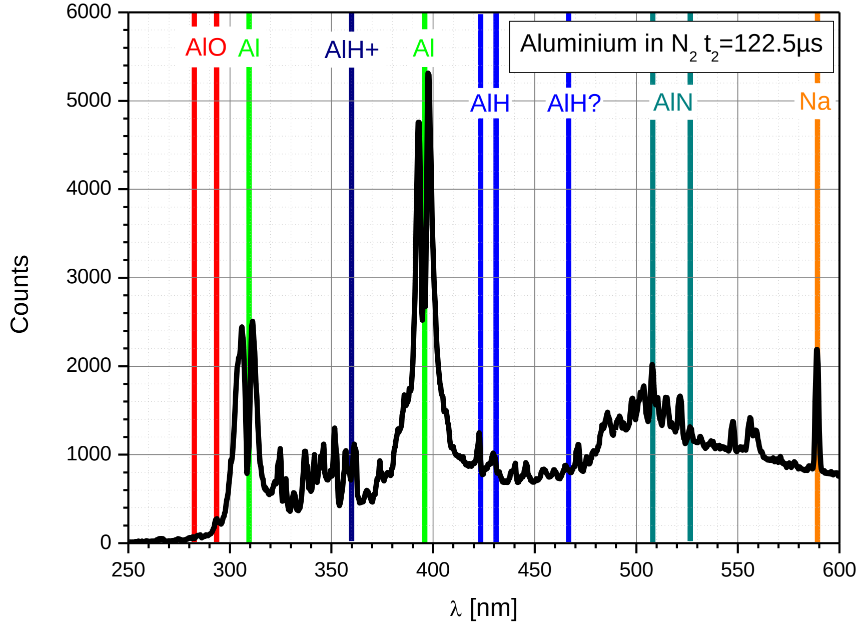
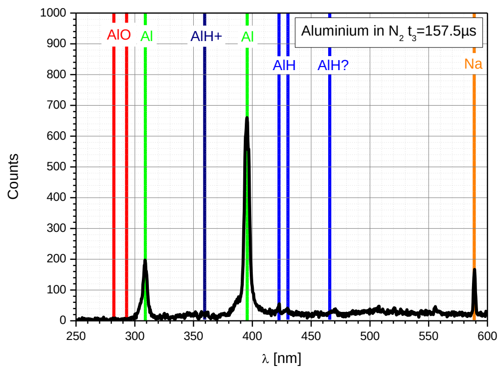
Spectra Analysis
- nitrogen atmosphere





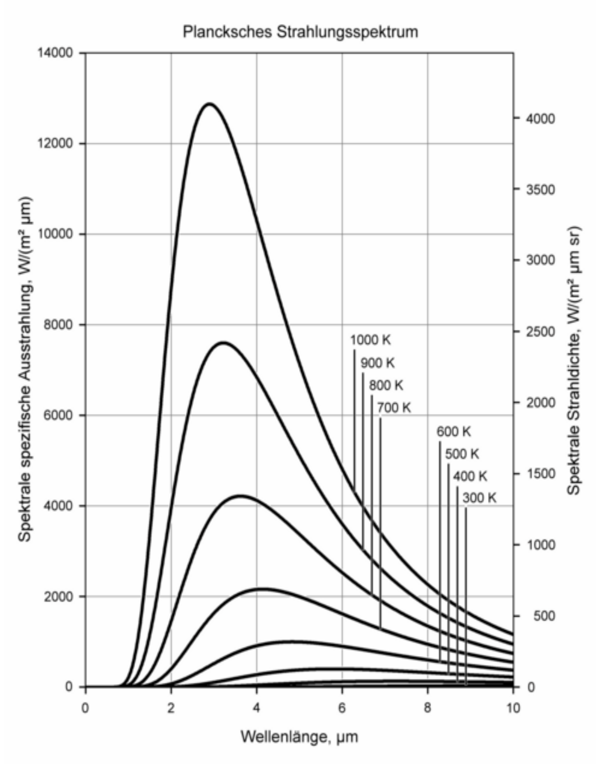


- First spectrum similar to the first spectrum in other atmospheres
- AlN molecule emission may be apparent

Temperature Determination
- continuum temperature

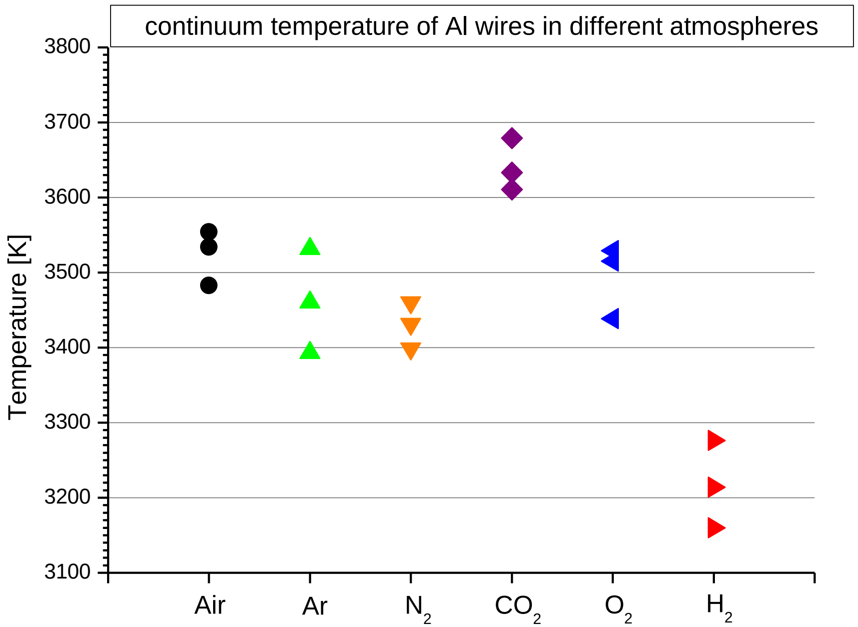
- Mainly emitted from
  - solid surfaces
  - glowing particles (soot, oxides, …)
- Theoretical description: Planck‘s law for black body radiation

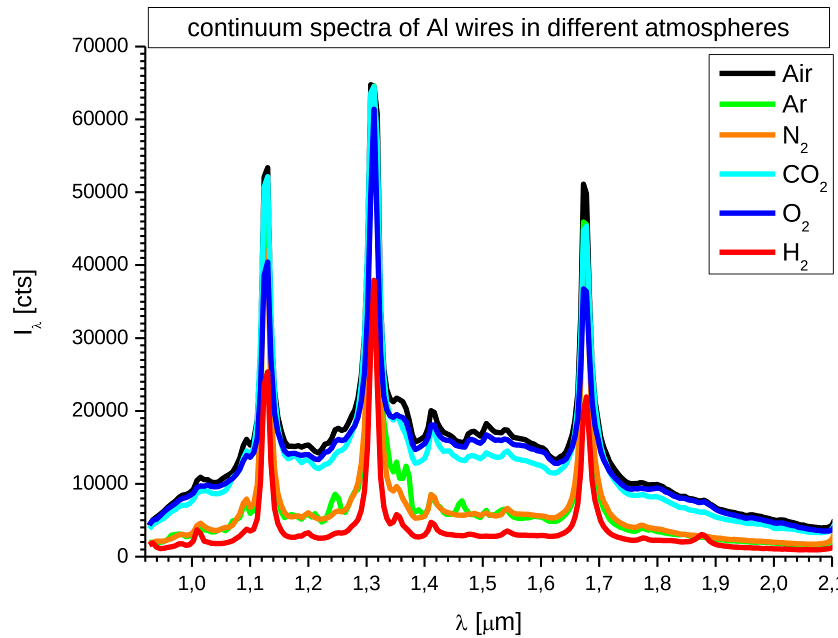
$$L_{\lambda S}(\lambda,T) = \varepsilon \frac{c_1}{\lambda^5\left(\exp\left(\frac{c_2}{\lambda T}\right)-1\right)} \frac{1}{\Omega_0}$$



- Simplest model: ε = const (grey body radiation)

Temperature Determination
- continuum temperature





- Grey body function was fitted to the spectra (ICT-BaM-Code)
- Integrated intensity distribution over the entire process
- Temperatures between 3400K and 3700K are a lower limit for gas phase temperature

Temperature Determination
- gas phase temperature - Calculation of Diatomic Molecules

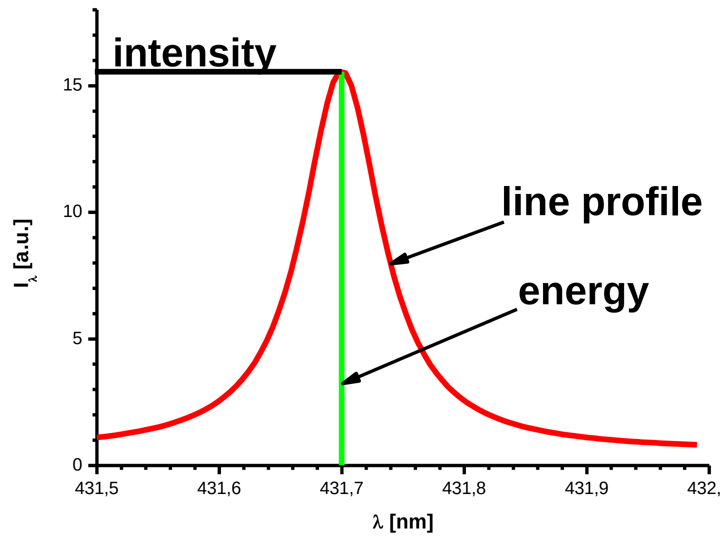
- wavelength = energy difference between excited and ground state
- intensity $\propto$ transition probabilities and Boltzmann-factor

➡ solution of Schrödinger-equation in Born-Oppenheimer-approximation

- line profile

➡ determined by the life time of the excited state

= Lorentz profile



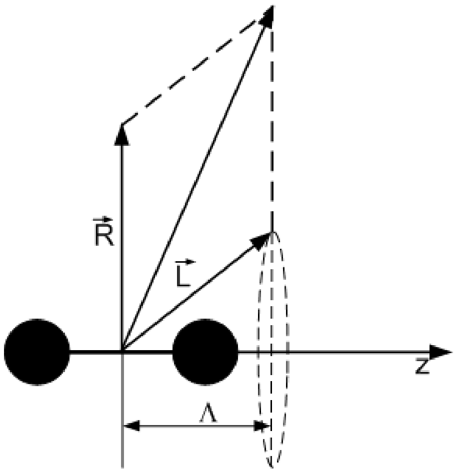
Calculation of Diatomic Molecules

- Calculation of the Energy Levels

- Born-Oppenheimer-approximation: $$E_{ges} = E_{el} + E_{vib} + E_{rot}$$

- electronic energy: constant for a given electronic transition
- vibrational energy: anharmonic model potential

$$G(v) = \omega_e\left(v+\frac{1}{2}\right) - x_e\omega_e\left(v+\frac{1}{2}\right)^2 + y_e\omega_e\left(v+\frac{1}{2}\right)^3 + \cdots$$



- rotational energy: symmetric top

$$F(J,\Lambda) = B_e J(J+1) - (A-B_e)\Lambda^2 - D_e J^2(J+1)^2 + H_e J^3(J+1)^3$$

Calculation of Diatomic Molecules

- Calculation of the Line Intensity

- line intensity:

$$I_{nm}^{em} = N_n hc\nu_{nm} A_{nm}$$

- population density:

$$N_n = \frac{N d_u}{Z} e^{-\frac{hcE'_{mol}}{k_B T}}$$

- energy of the transition:

$$E = hc\nu_{nm}$$

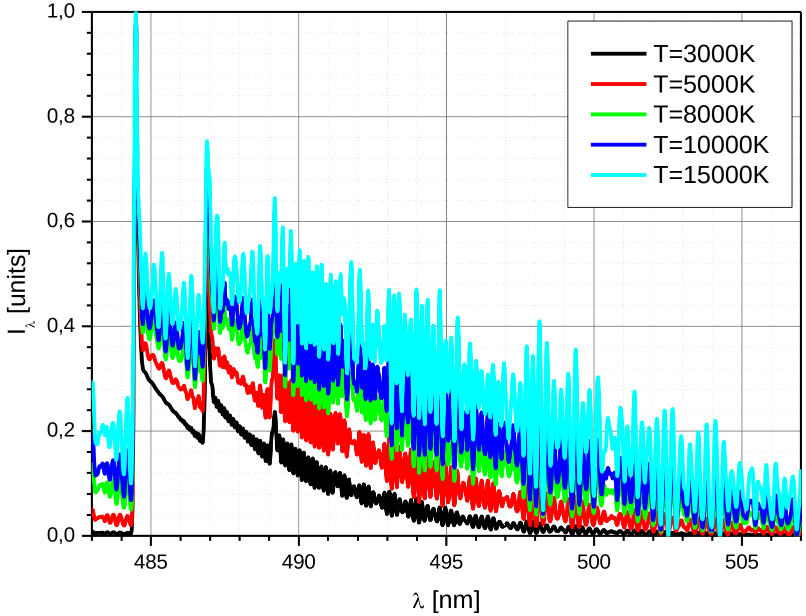
- Einstein-Coefficient for spontanous emission:

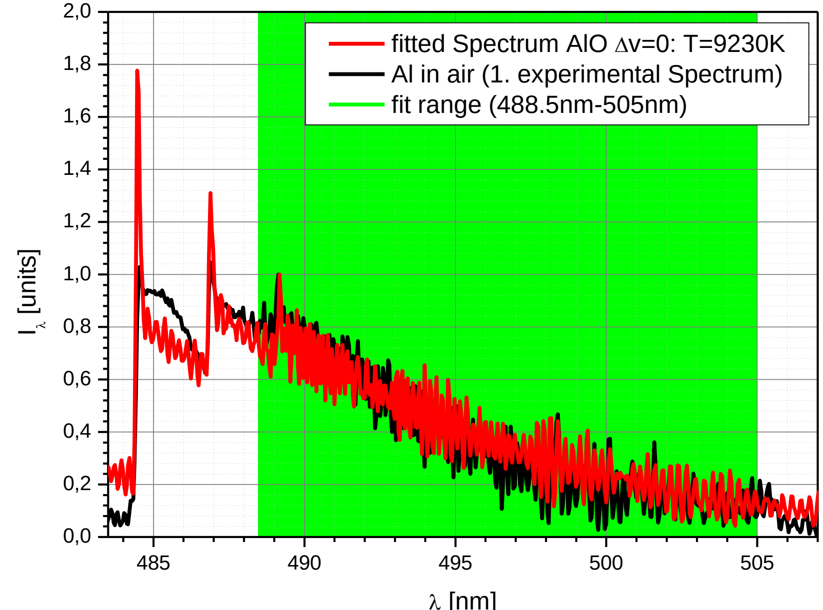
$$A_{nm} = \frac{2}{3} \cdot \frac{8\pi^3 \nu_{nm}^3}{\varepsilon_0 c^3 h} \cdot \left|D_{nm}\right|^2$$

- dipole operator matrix element:

$$\left|D_{nm}\right|^2 = \left|D_{mn}^{el}(R_{v'',v'})\right|^2 q_{v'',v'} S_{J'',J'}$$

Temperature Determination
- gas phase temperature





- Aluminium monoxide B-X system was analysed (fit calculated to experimental spectrum)
- The higher the temperature the more the rotational lines are excited and the slope between 490 nm and 507 nm is weaker

➡ It will be sufficient to fit only for this range because of self-absorption processes

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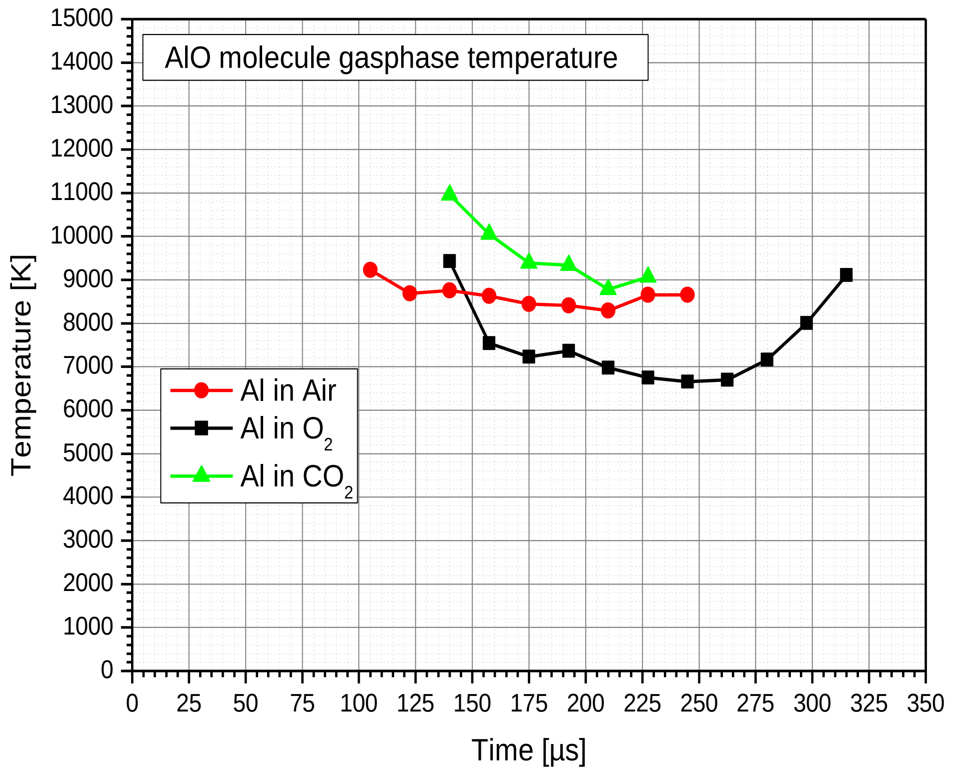
Temperature Determination
- gas phase temperature

- AlO was first formed in the middle of wire explosion process
- Temperatures were between:

  9500K and 6900K in oxygen

  9200K and 8600K in air

  11000K and 8800K in CO_2
- Temperature of the cool down phase
- Increase of temperature at the end



➡ calculated spectrum does not correspond well with the experimental spectrum

Conclusion

- aluminium wire explosions were investigated in different atmospheres

➡ First results of the experiments were presented

- High-speed videos give hints for the formation of aluminium monoxide
- I/U-characteristic shows that the input energy was independent from the atmosphere and equal for all measurements
- Analysed UV/VIS spectra show time resolved formation of atomic lines and diatomic molecules
- Continuum temperature was calculated but only for integrated intensity
- Gas phase temperature were determined for the cool down phase of the plasma

Thank you for your attention

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