A novel approach to imaging NO_2 in the atmosphere

The NO_2 camera based on Gas Correlation Spectroscopy

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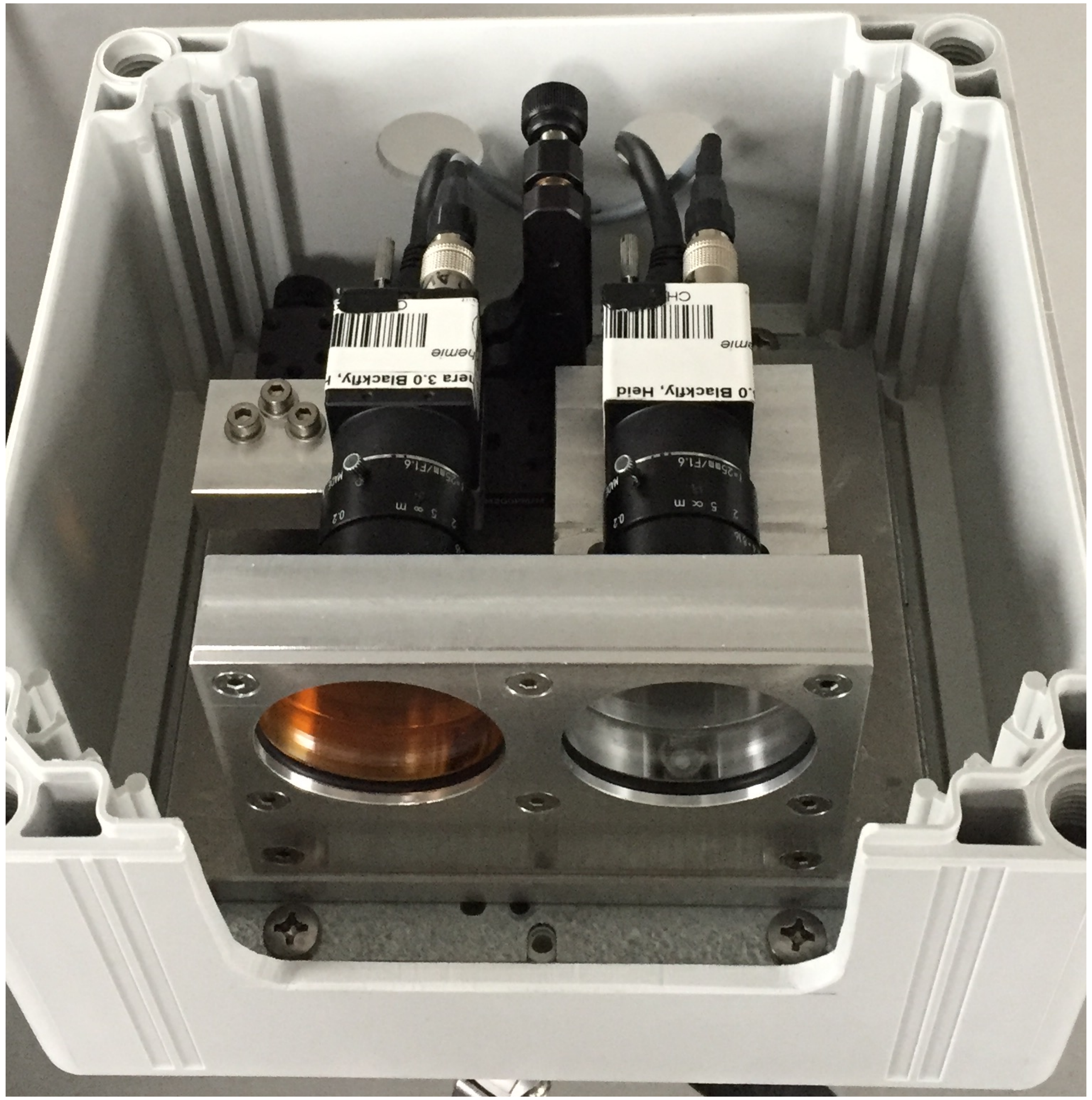
The NO_2 camera

- Motivation: Imaging measurements of atmospheric NO_2 with high spatiotemporal resolution are still a major challenge
- Our NO_2 camera works on the basis of gas correlation spectroscopy (GCS, see next slide)
- High spatiotemporal resolution of
  1 m × 1 m (at ~ 5 km object distance)
  1 frame per second
- Detection limit of ~ 10^{16} molec cm^{-2}
- Kuhn et al. 2022:
  The NO_2 camera based on gas correlation spectroscopy
  DOI: https://doi.org/10.5194/amt-15-1395-2022

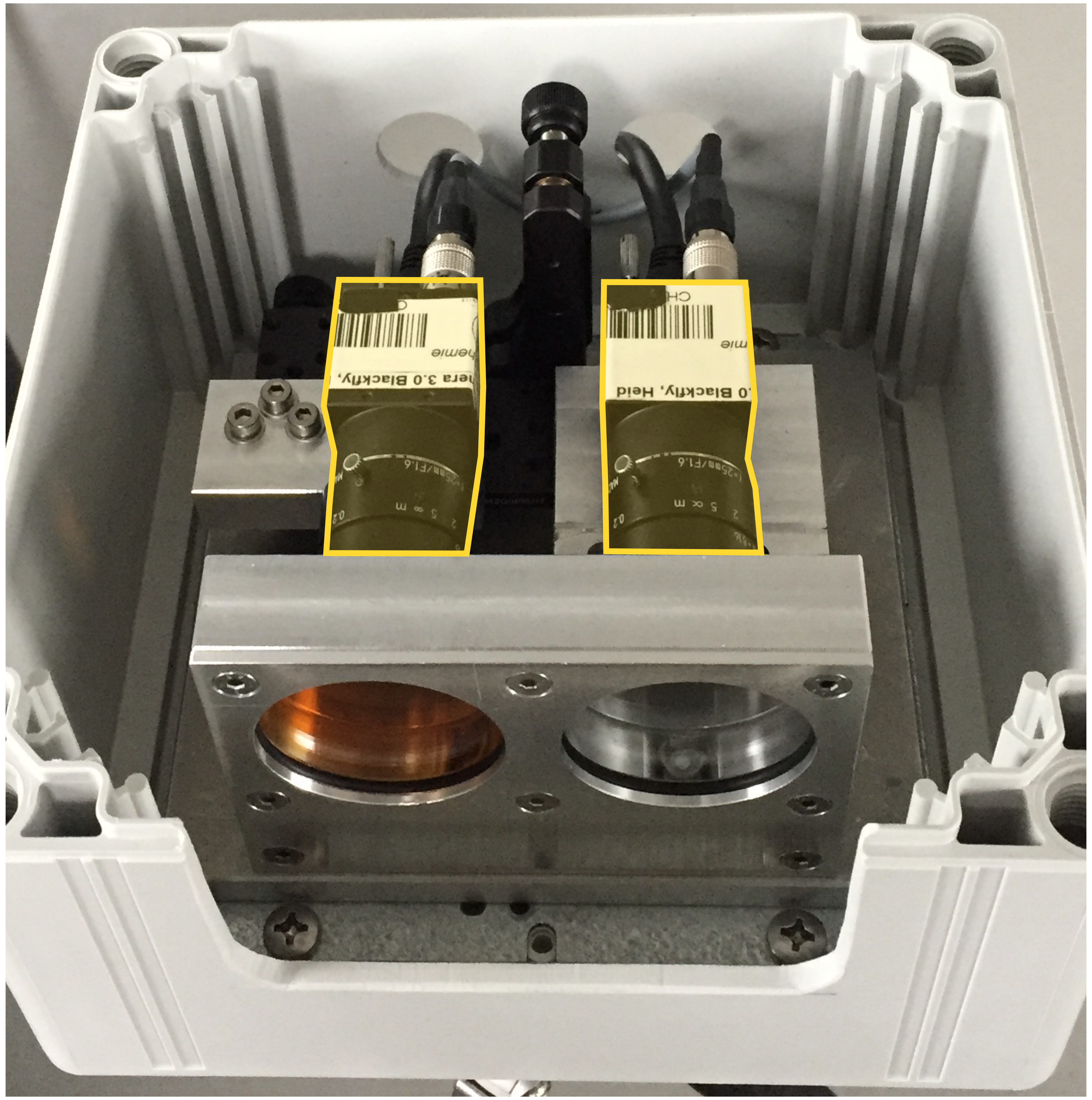


Photograph of the NO_2 camera

Instrumental setup

- The instrument uses two commercial camera modules

- Each camera is equipped with a lens and a bandpass filter (transmittance at 430 - 445 nm)

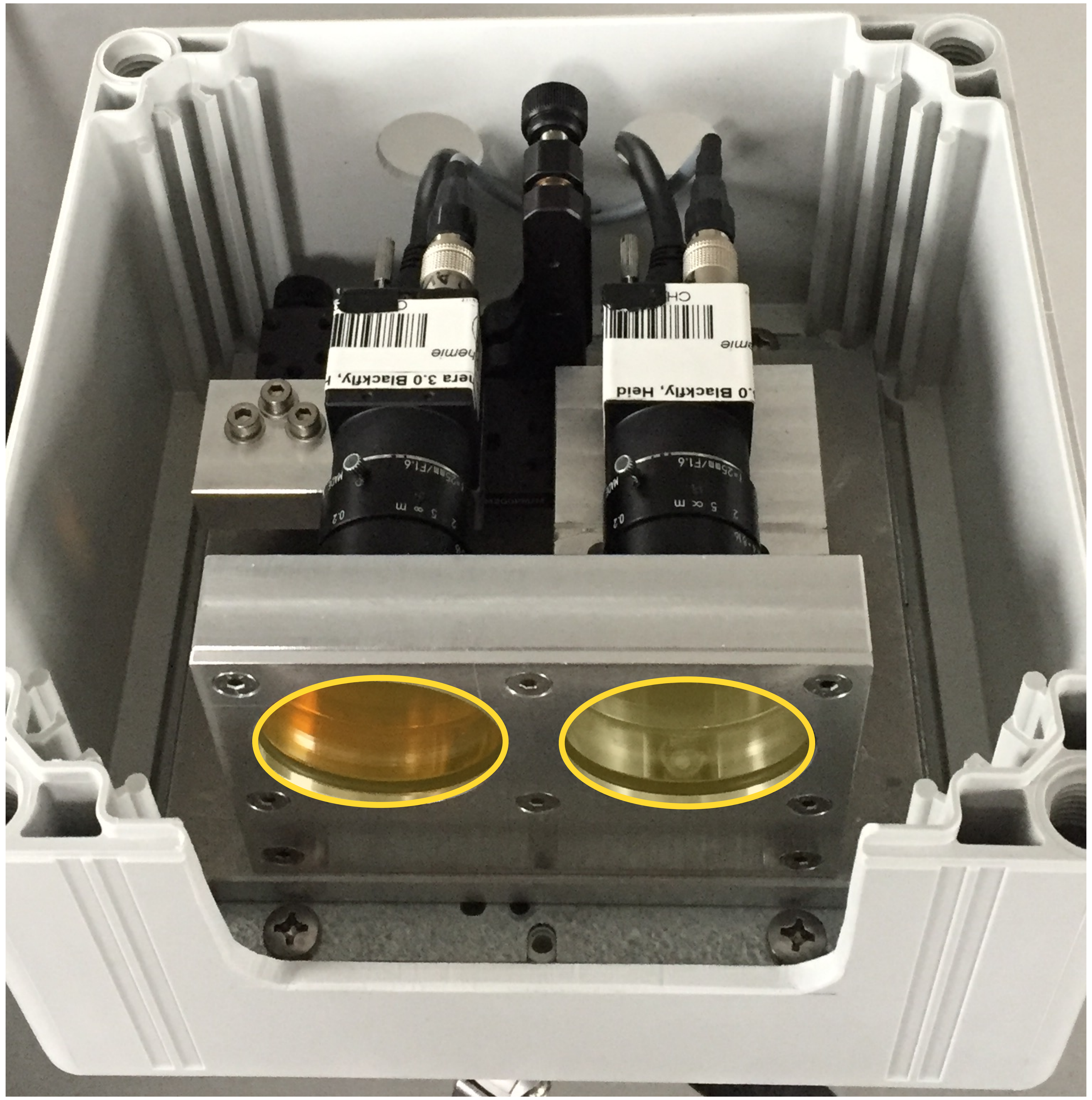


Photograph of the NO_2 camera

Instrumental setup

- The instrument uses two commercial camera modules
- Each camera is equipped with a lens and a bandpass filter (transmittance at 430 - 445 nm)
- Two gas cells are placed in front of the cameras:

  - One filled with a high amount of NO_2
  - One filled with air

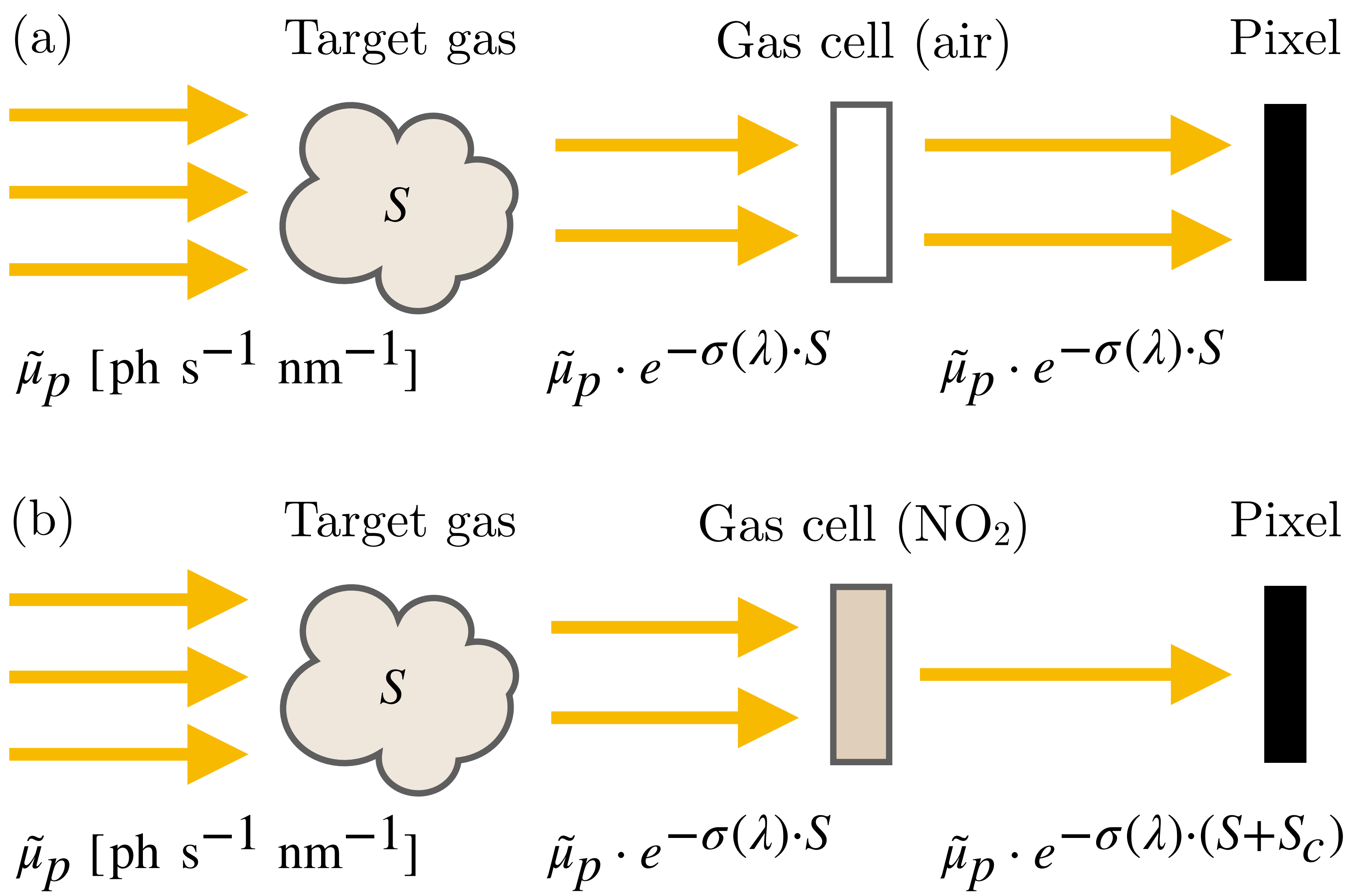


Photograph of the NO_2 camera

Measurement principle

- The instrument works on the basis of gas correlation spectroscopy
- Beer-Lambert law:

$$I(\lambda) = I_0(\lambda) \cdot \exp\left(-\sigma(\lambda) \cdot S\right)$$



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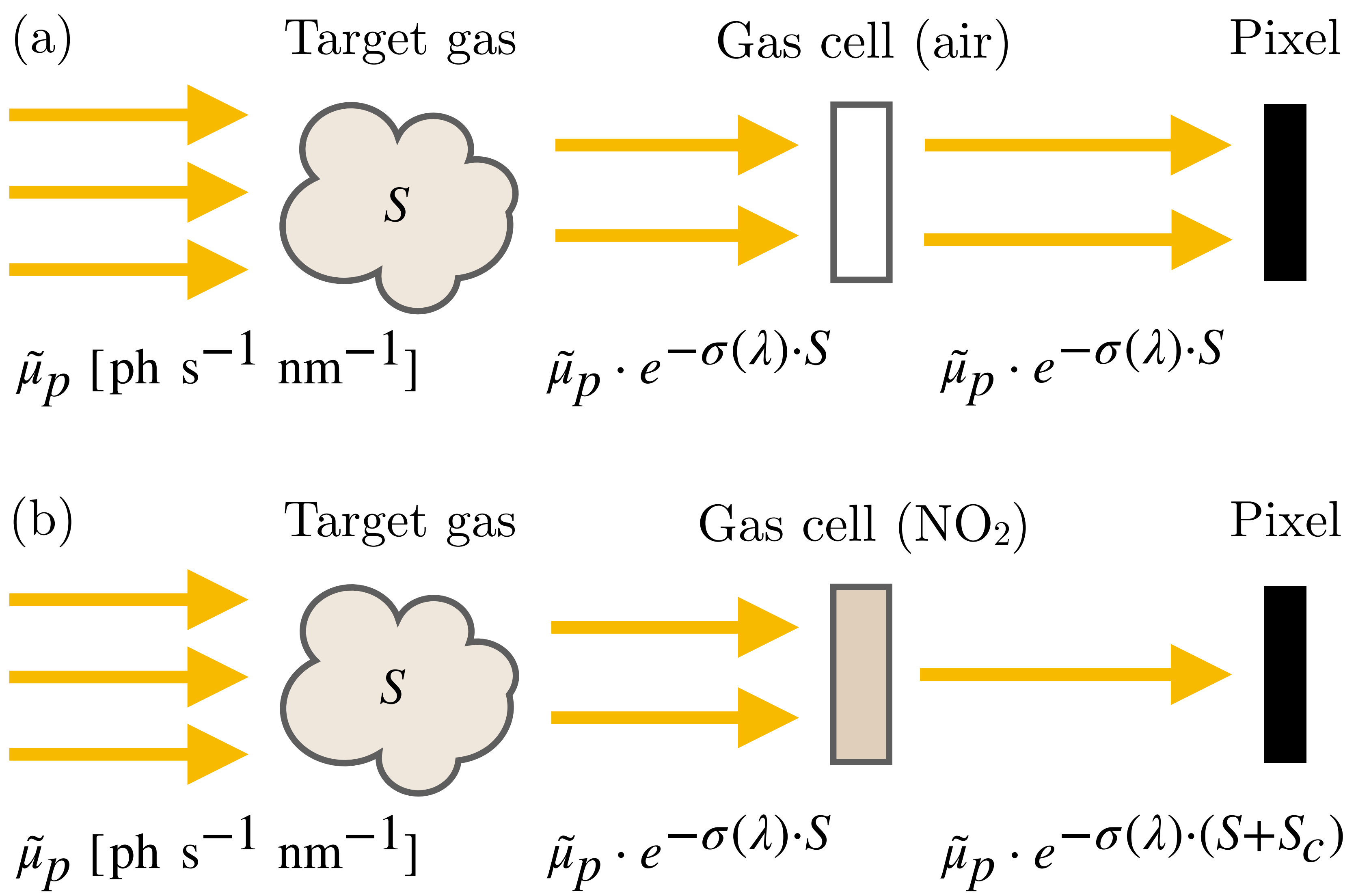
- Low (high) target gas concentration → gas cell has large (small) influence



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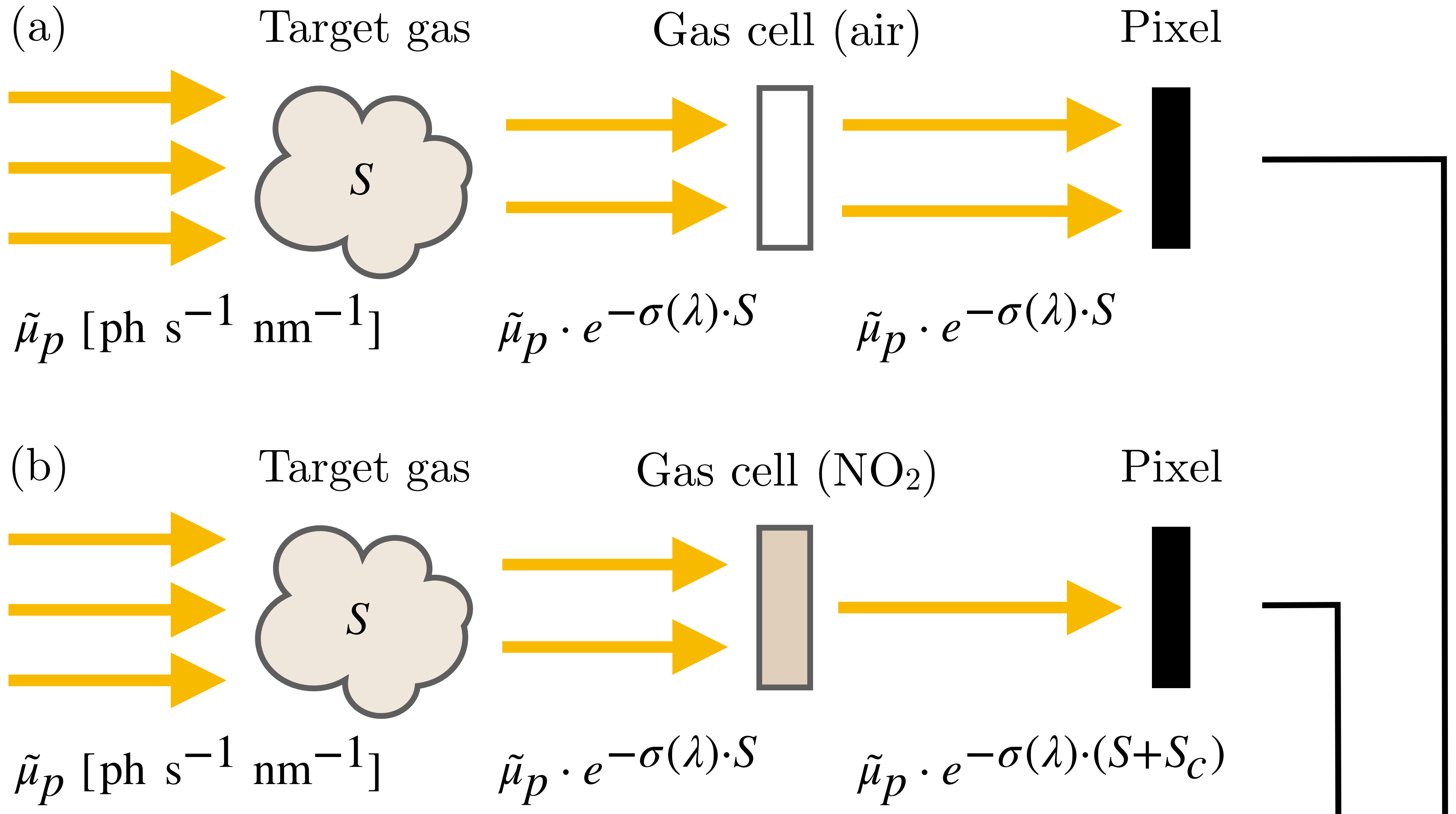


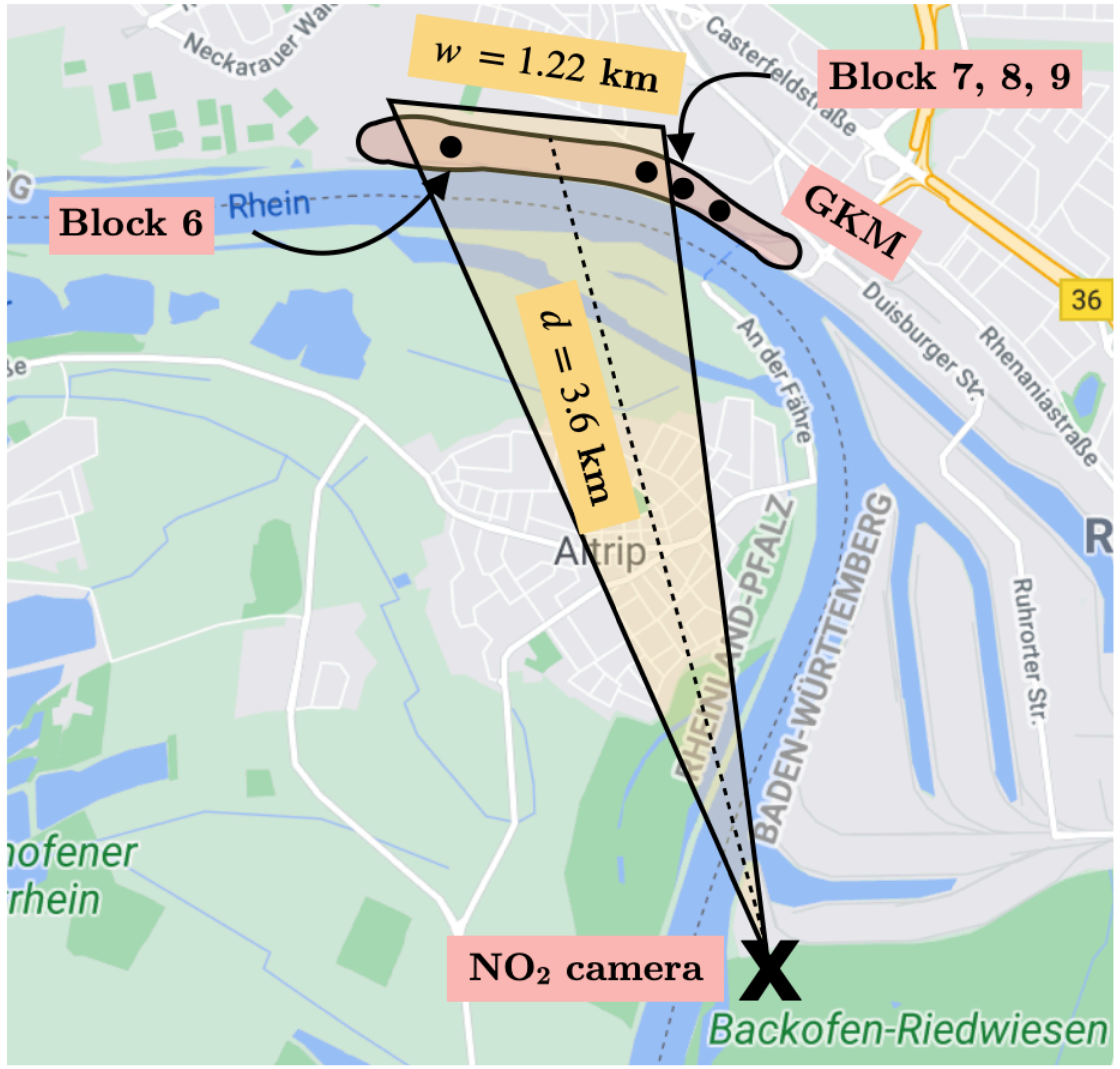
$$J_{c,(i,j)} = \int_{t_{\mathrm{exp}}} \int_{430\mathrm{nm}}^{445\mathrm{nm}} \eta(\lambda) \cdot \tilde{\mu}_p \cdot \exp\left(-\sigma(\lambda) \cdot S_{(i,j)+S_c}\right) \mathrm{d}\lambda \ \mathrm{d}t$$

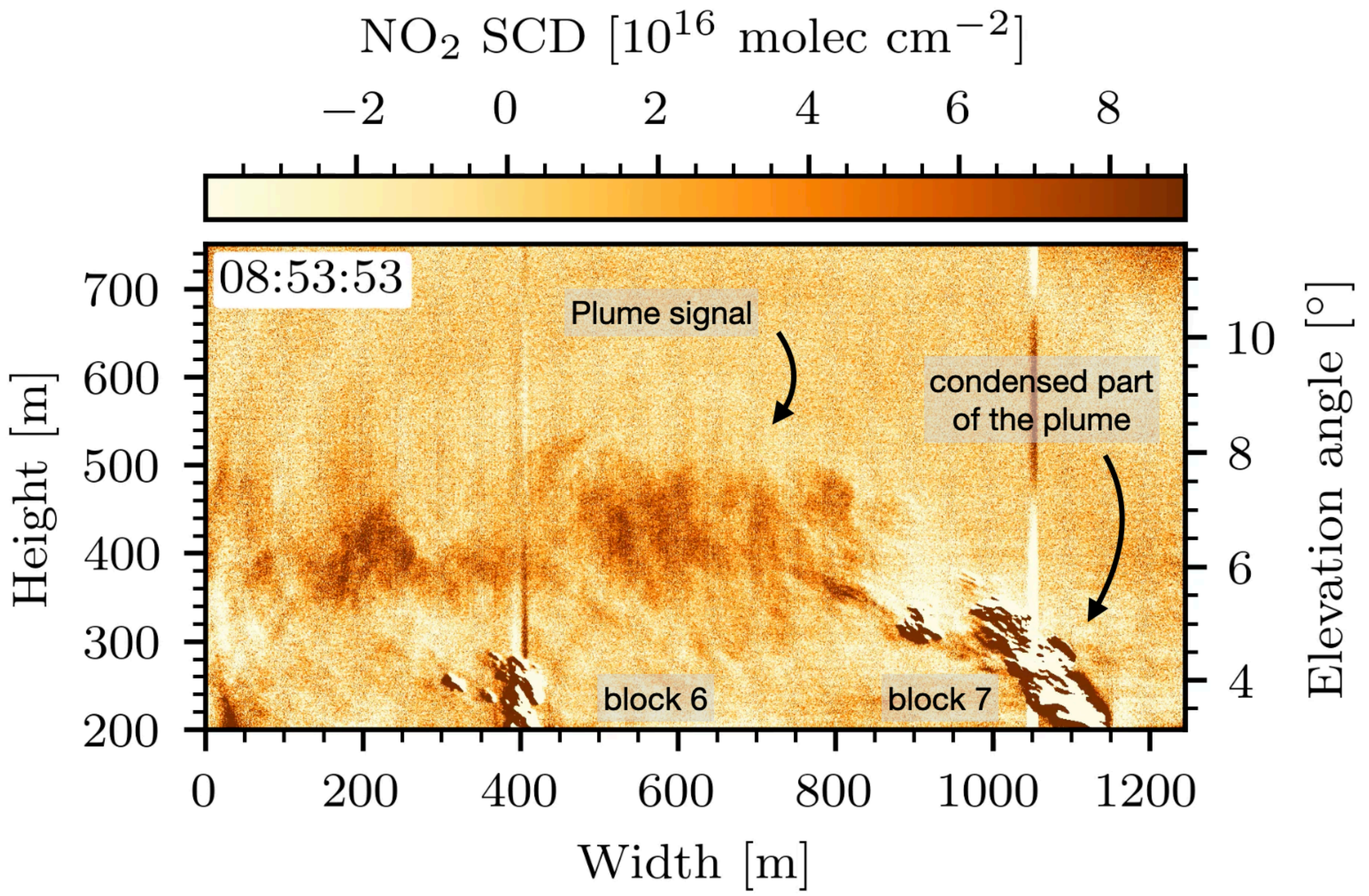
- Instrument signal $\tilde{\tau}_{(i,j)} = \ln\left(\frac{J_{c,(i,j)}}{J_{(i,j)}}\right)$

$$J_{(i,j)} = \int_{t_{\mathrm{exp}}} \int_{430\mathrm{nm}}^{445\mathrm{nm}} \eta(\lambda) \cdot \tilde{\mu}_p \cdot \exp\left(-\sigma(\lambda) \cdot S_{(i,j)}\right) \mathrm{d}\lambda \ \mathrm{d}t$$

Field measurements

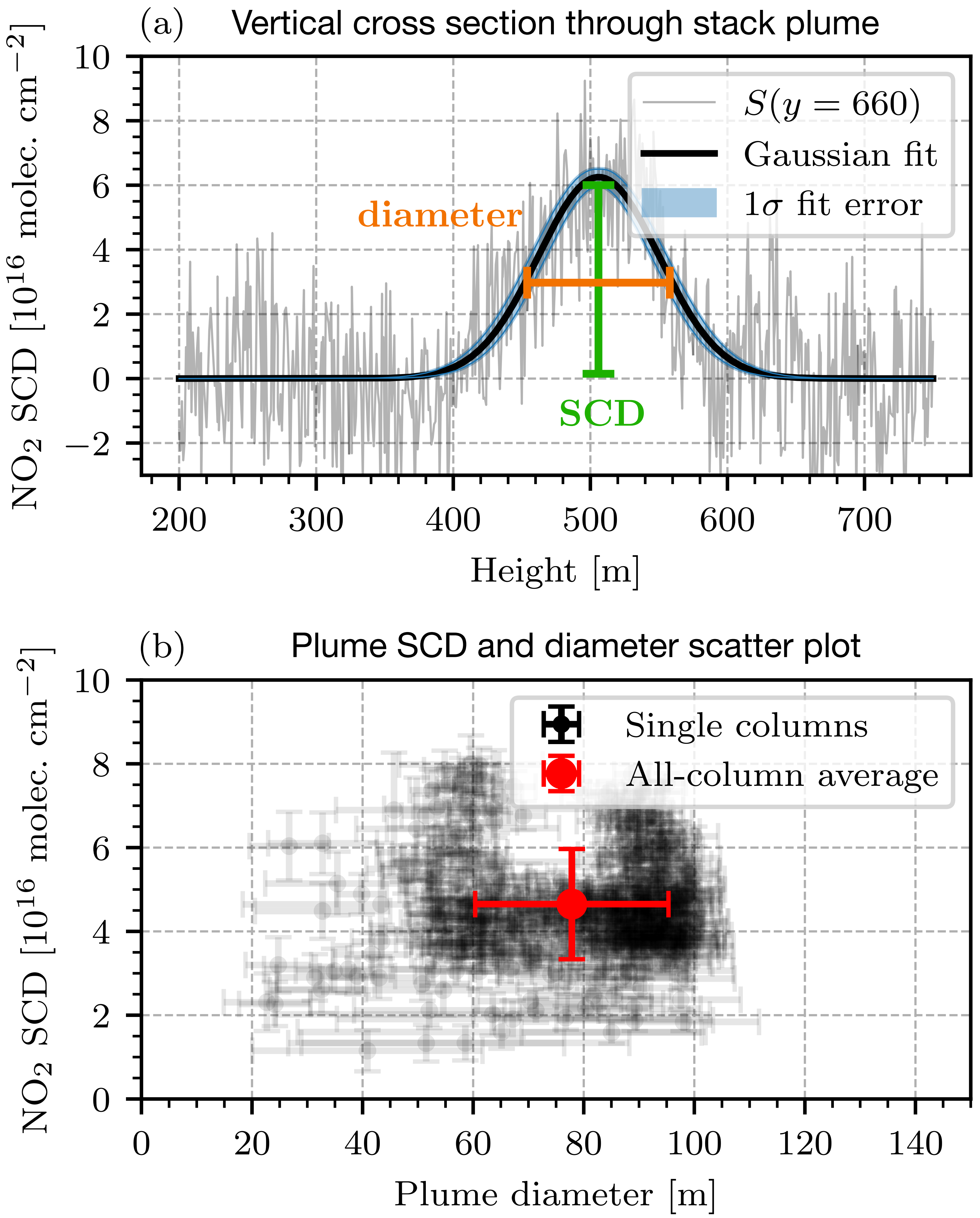
Images of a stack plume emitted by a German power plant (Großkraftwerk Mannheim)





New opportunities with the GCS-based NO_2 camera

- Plume SCD and geometry

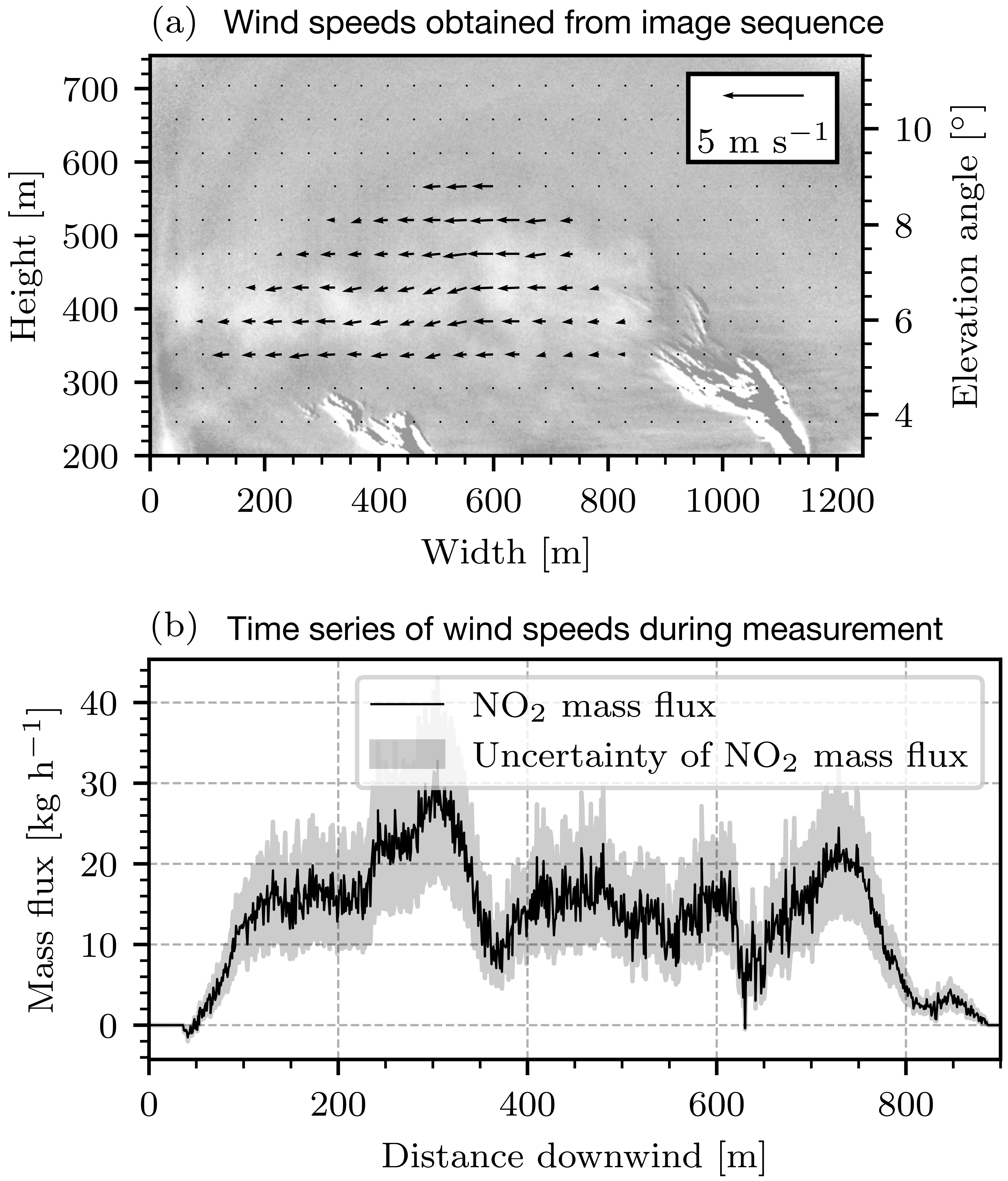


New opportunities with the GCS-based NO_2 camera

- Plume SCD and geometry
- Mass flux analysis

  - Compute wind speeds with Farnebäck algorithm*

  - Compute $F = \frac{M_{NO_2}}{N_A} \cdot v \cdot \int S(h)\, dh$



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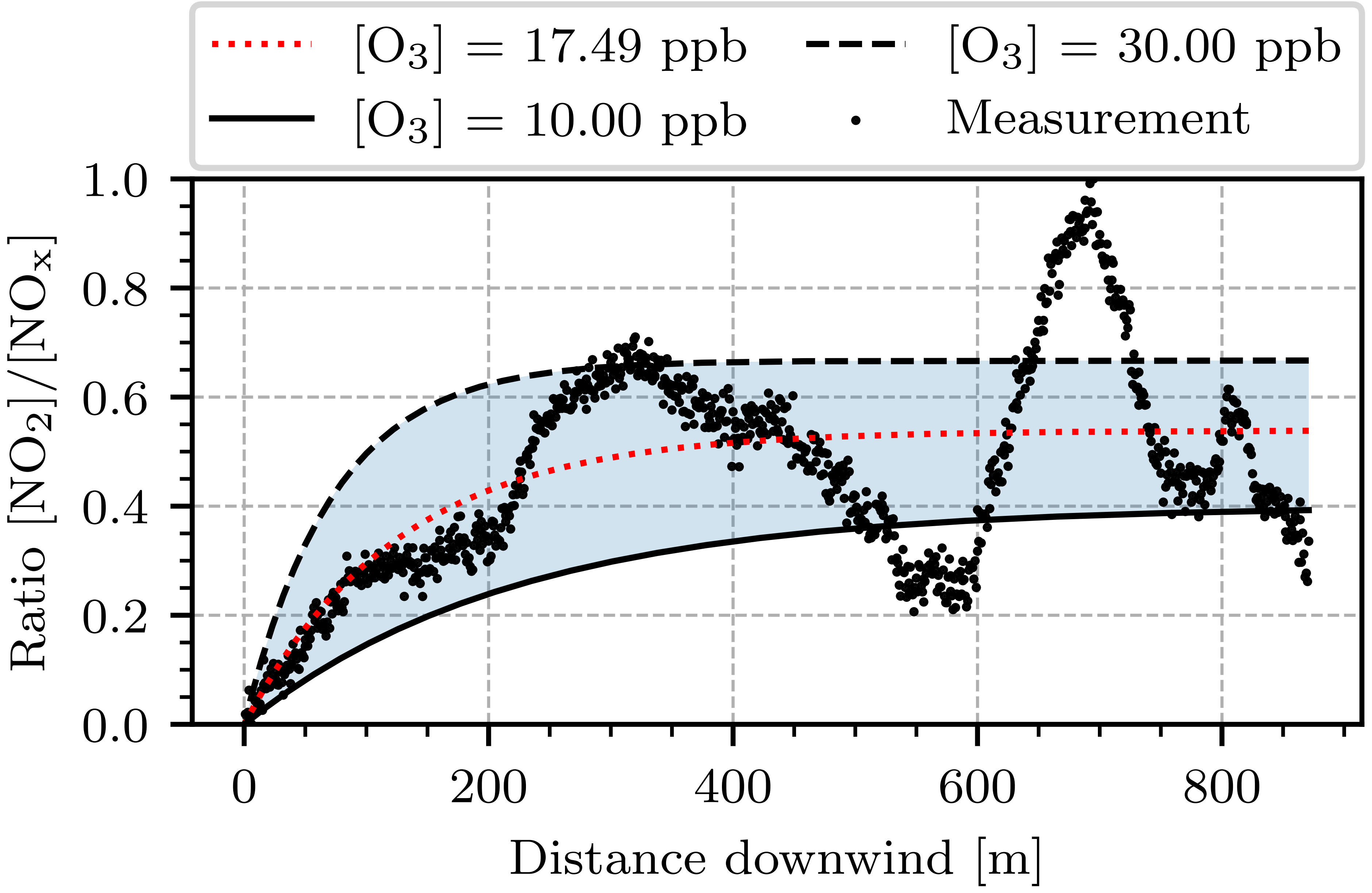
- Plume chemistry analysis

  - Compare NO_2/NO_x ratio to Janssen model**

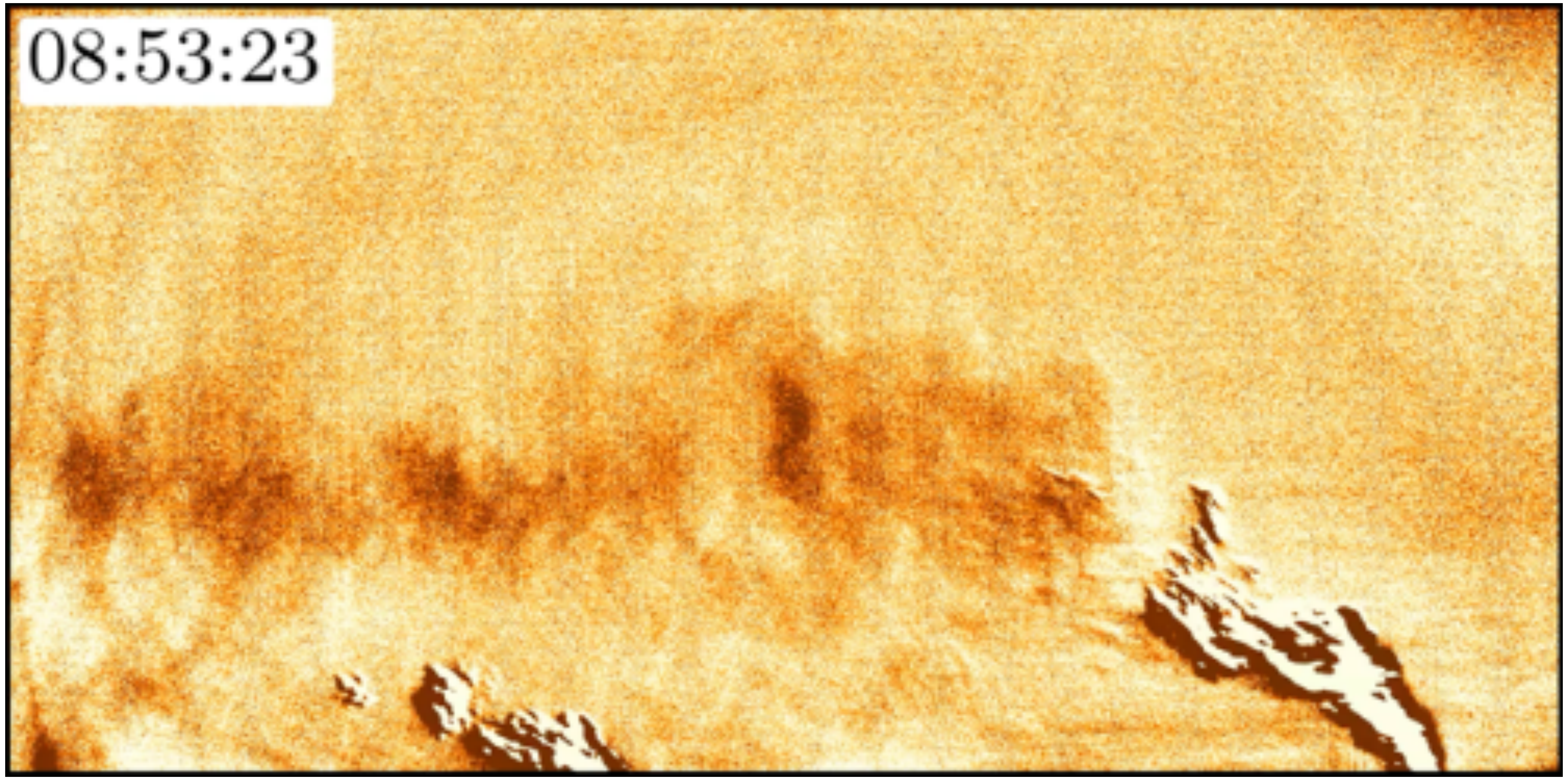
Comparison of measured $NO2/NO_x$ ratio and the Janssen plume model



*Gunnar Farnebäck: *Two-Frame Motion Estimation Based on Polynomial Expansion*. Scandinavian Conference on Image Analysis, 2003.

**Janssen et al.: *A classification of NO oxidation rates in power plant plumes based on atmospheric conditions*. Atmospheric Environment, 1988.

Thank you for your attention!



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