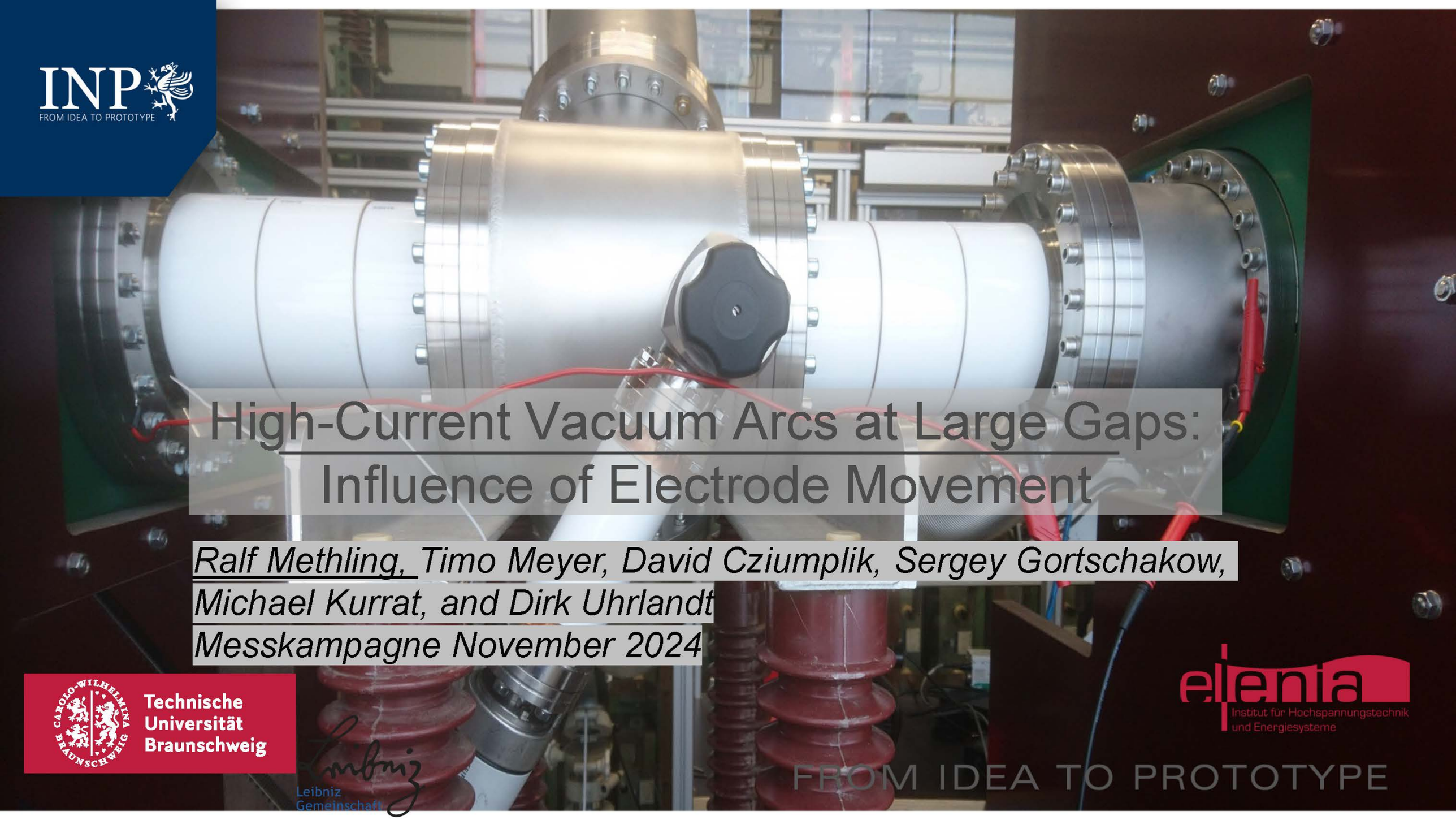

High-Current Vacuum Arcs at Large Gaps: Influence of Electrode Movement

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Messkampagne November 2024

INP
FROM IDEA TO PROTOTYPE

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FROM IDEA TO PROTOTYPE

Motivation

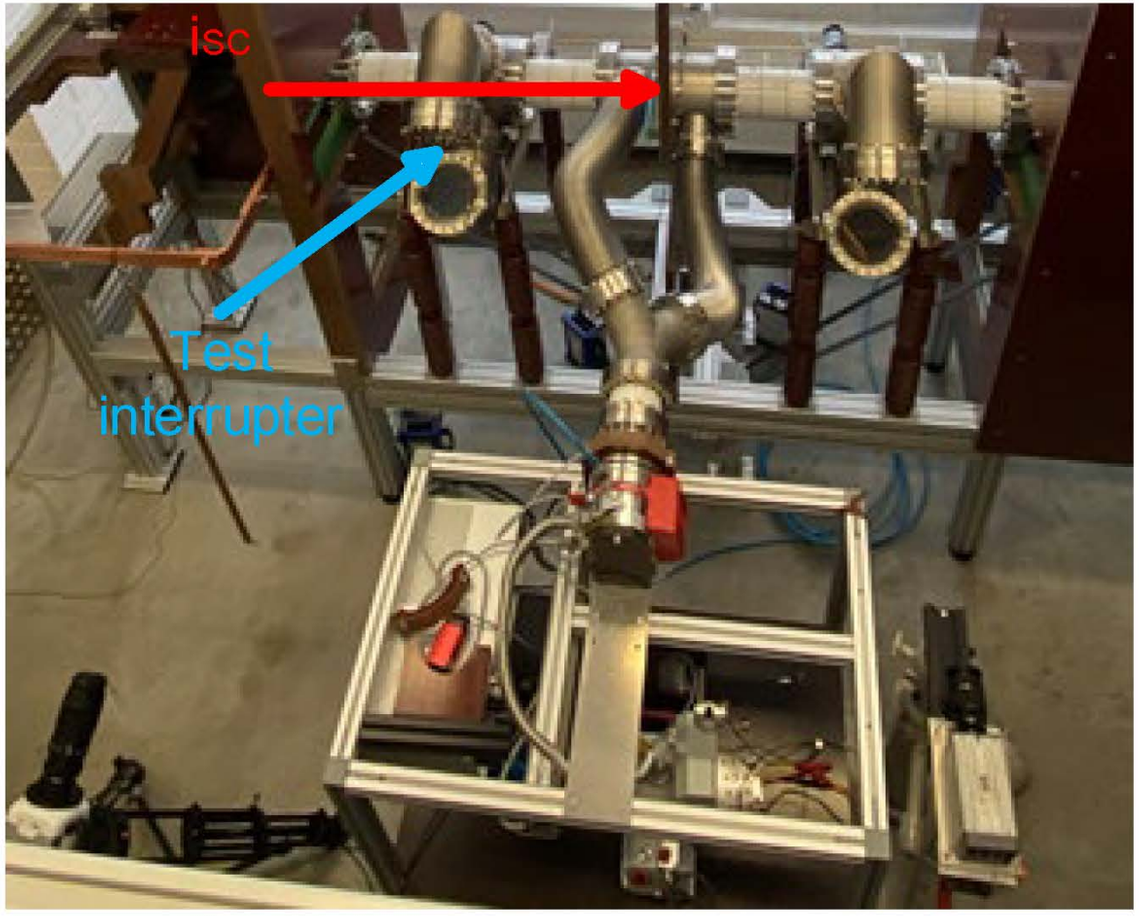
- Vacuum circuit breaker as alternative for SF6 breaker for high voltages

- New solutions are necessary:
  - Long gap distances
  - Double-break designs

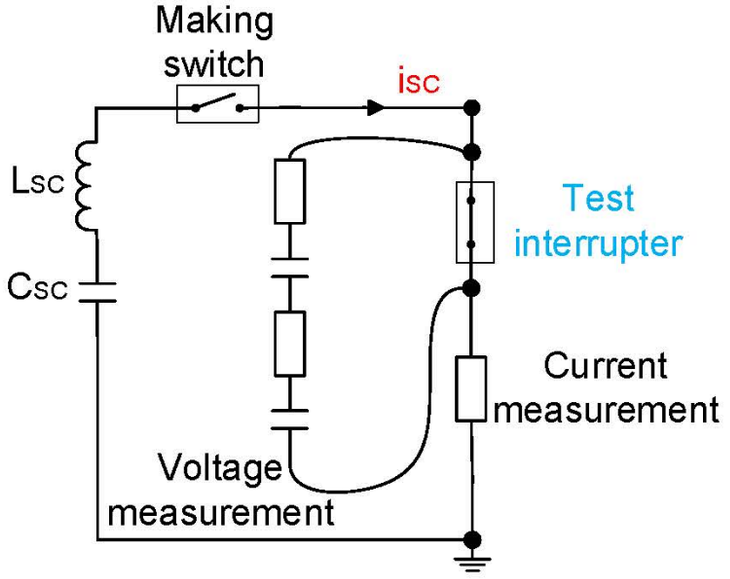
  → Impact on plasma properties if contact systems are opened @ high speed & long gaps?

- Research questions:
  - New arc modes visible?
  - Plasma distribution?
  - Current path formation?
  - Emission spectra characteristics?

Experimental setup

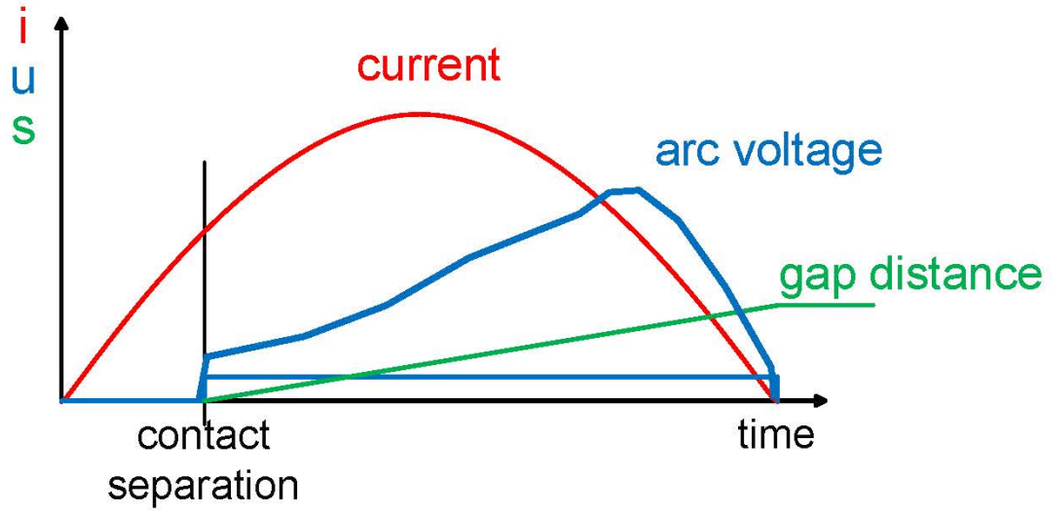


- Combine electric performance tests with
  - Model vacuum interrupter with digital actuator
  - Moving anode / moving cathode
  - High-speed imaging
  - Optical emission spectroscopy

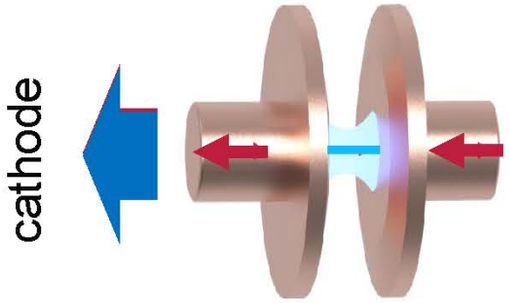


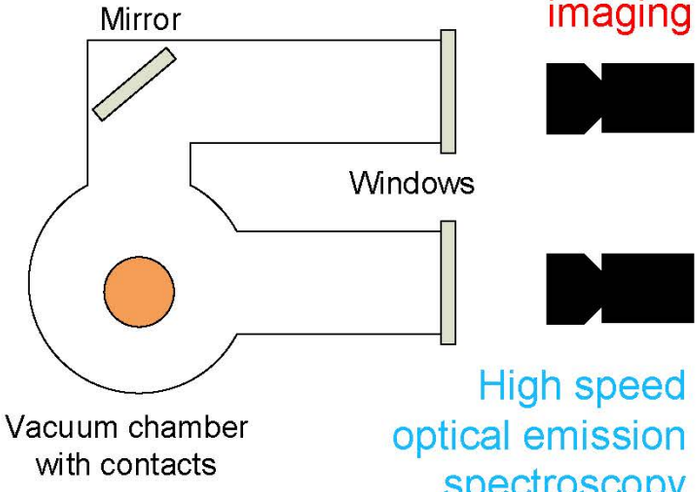
Experimental setup

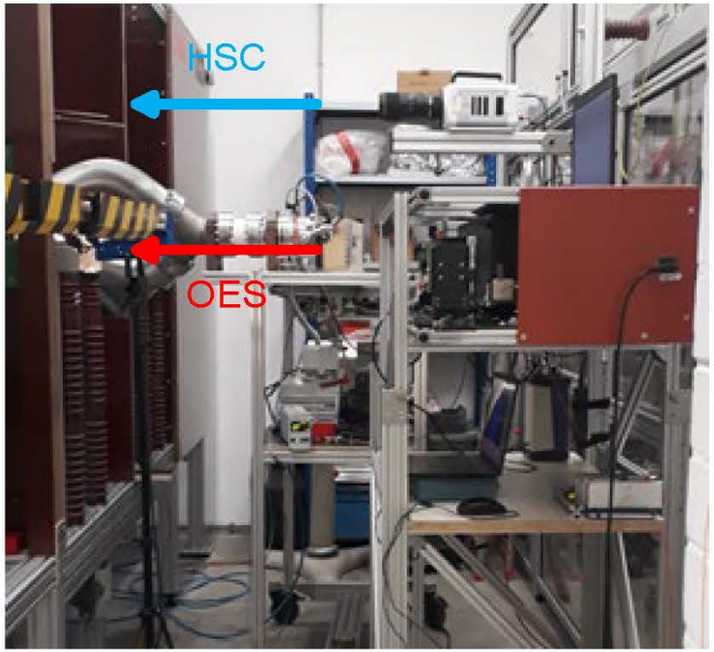
- Butt type contact (CuCr25, Ø 30 mm)
- Peak current 15 kA
- Current frequency 35 Hz,
  contact opening speed 3 m/s
  => gap of 30 mm at current zero
- Moved anode compared with moved cathode
- Optical methods:
  - High-speed camera (HSC)
  - Optical emission spectroscopy (OES),
  here: axial profile with 5000 frames per second



Change of current flow direction

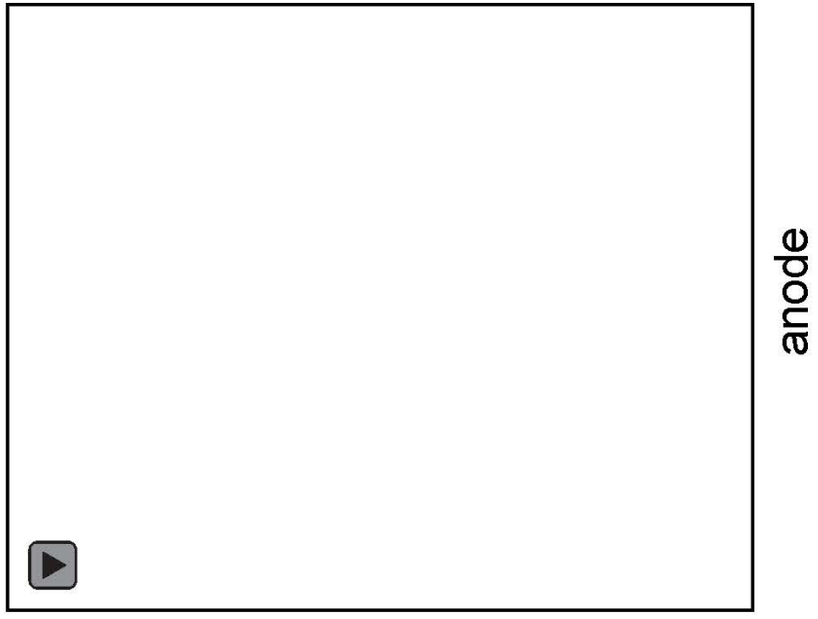




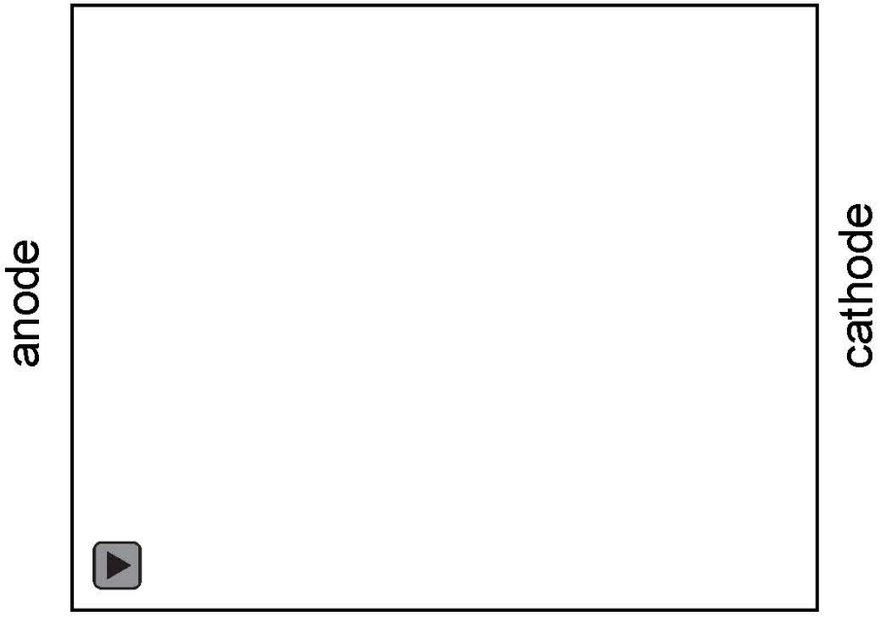


High-speed imaging

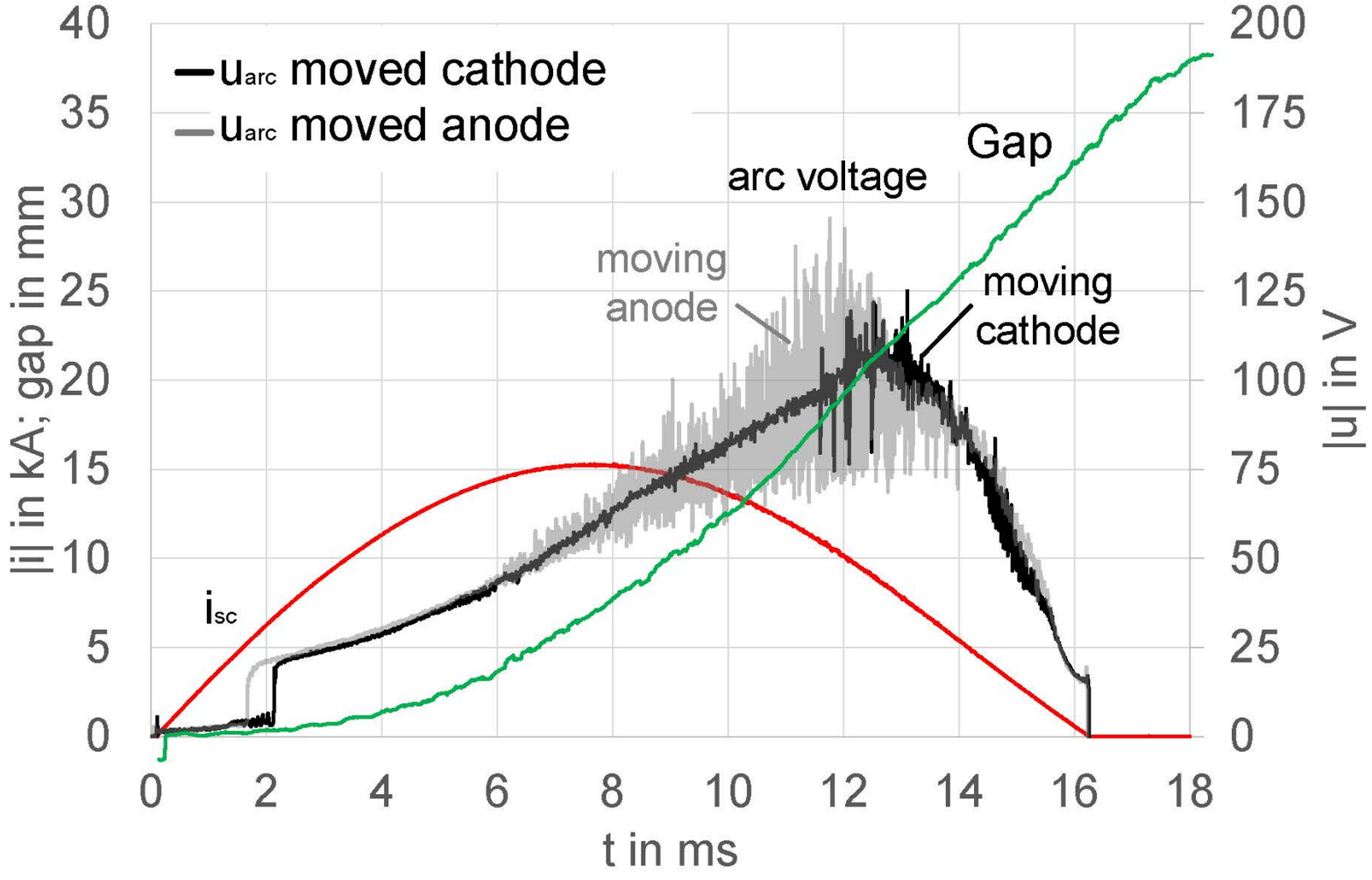
- Moving cathode
  - Columnar arc
  - Separation of anode and cathode plasma at about 20 mm gap distance
  - Evolution of active anode jet into the gap (strong anode spot type II followed by anode plume)



- Moving anode
  - Columnar arc
  - High frequency pulsing (vibration) of column around 10 mm gap distance
  - Separation of anode and cathode plasma at about 20 mm gap distance
  - Suppression of anode jet
  - Enhancement of cathode jet



Results: Electrical curves



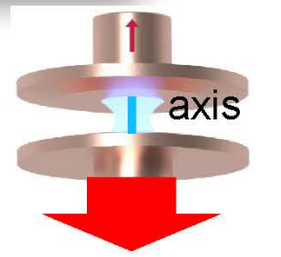
- **Moving cathode (black curve)**

  Relatively stable arc voltage with short time fluctuation events (voltage jumps indicating change of anode modes)

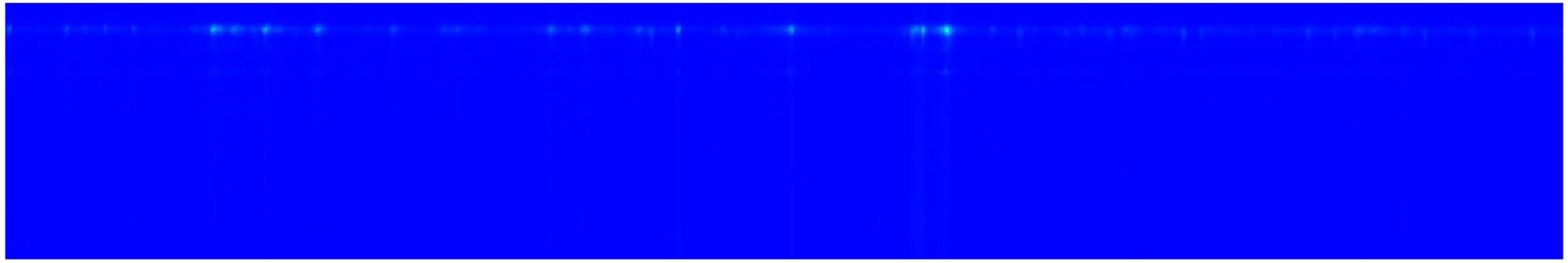
- **Moving anode (grey curve)**

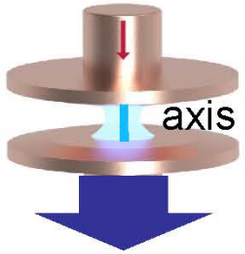
  Continuous arc voltage noise with fluctuation of arc voltage about +/- 25 % indicating highly frequent changes of modes

Optical emission spectroscopy along axis

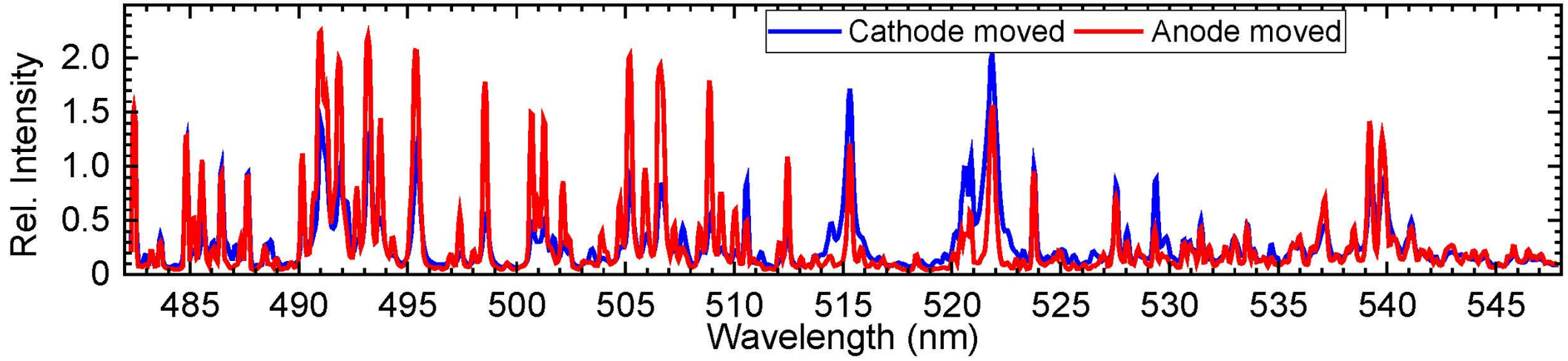


anode moved

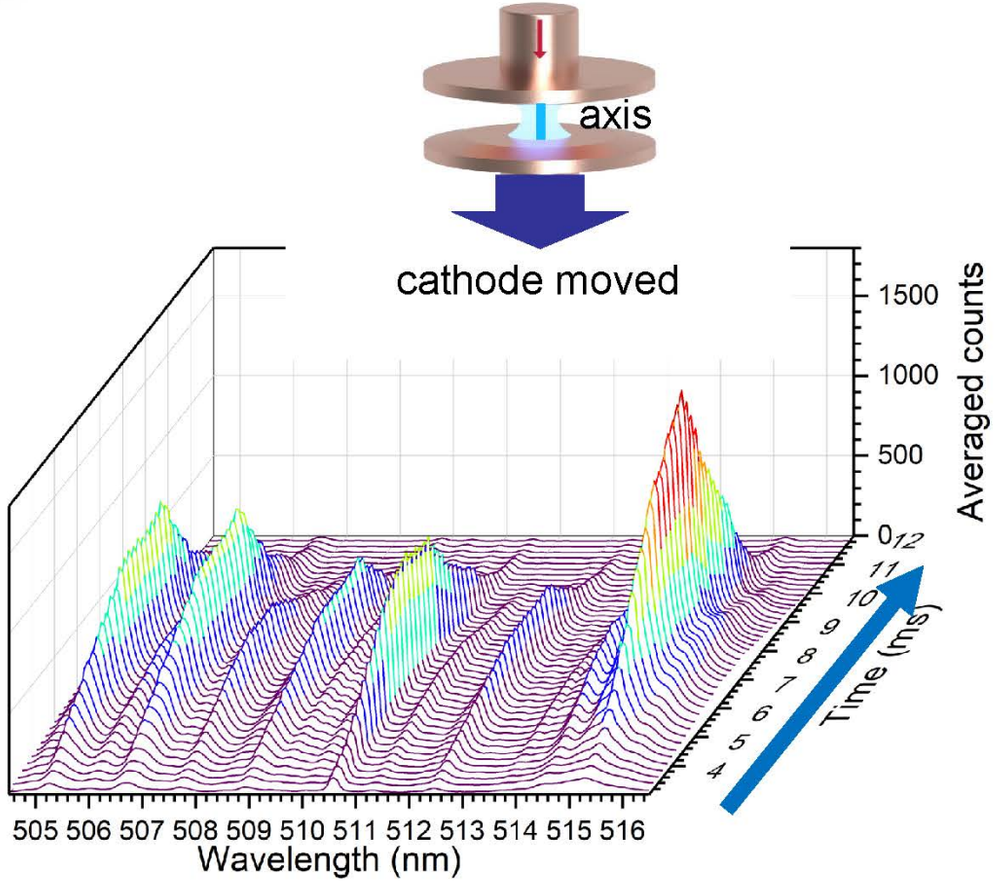


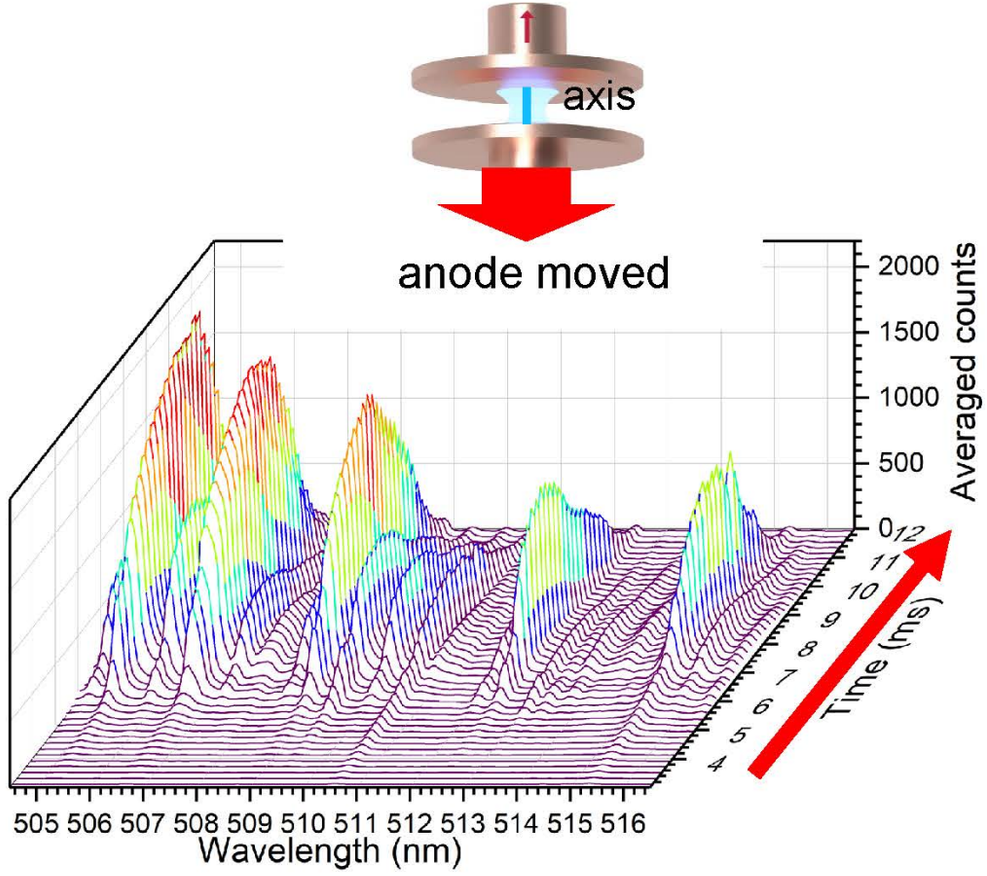


cathode moved

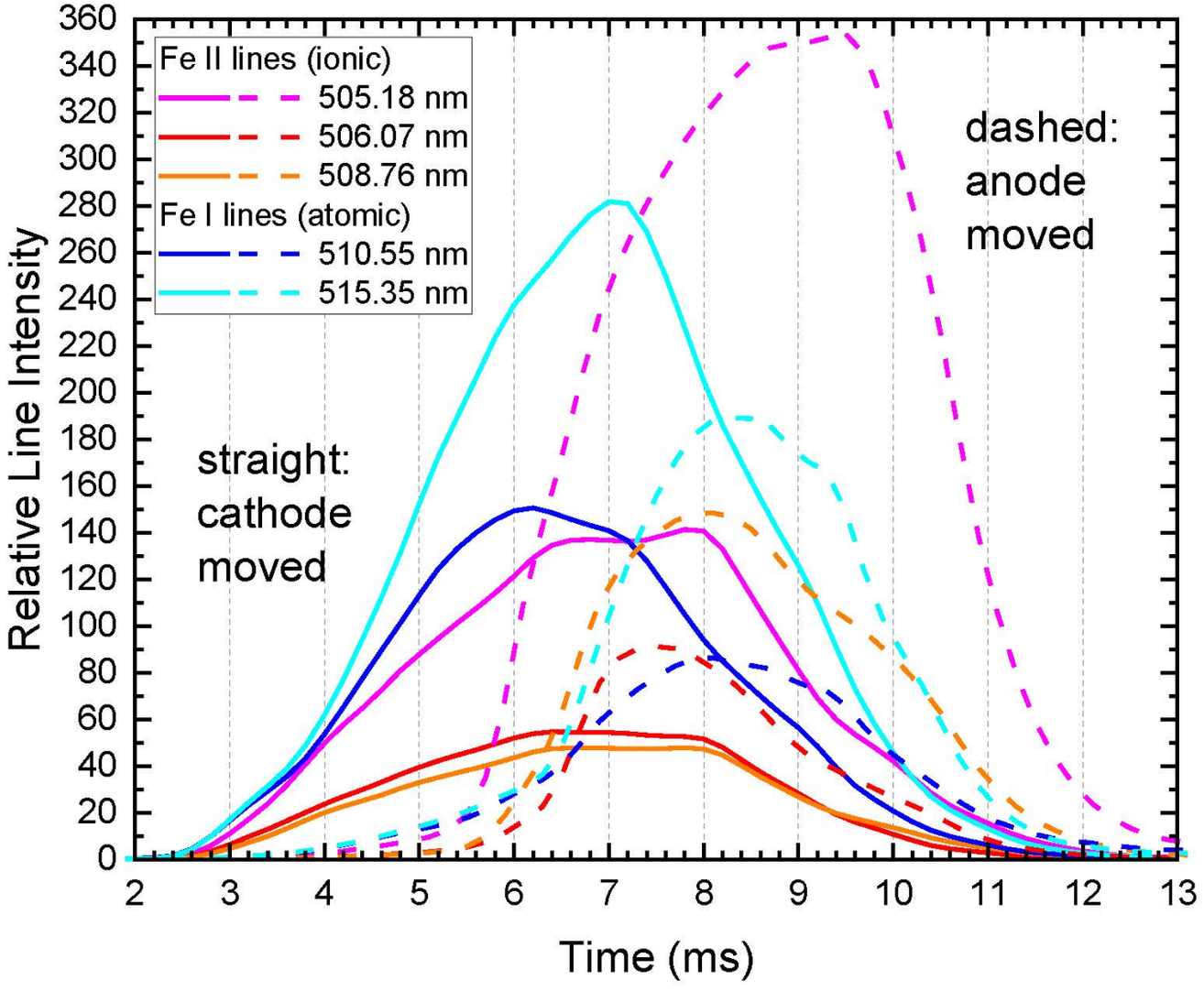


Spatially integrated optical emission spectra along the arc axis





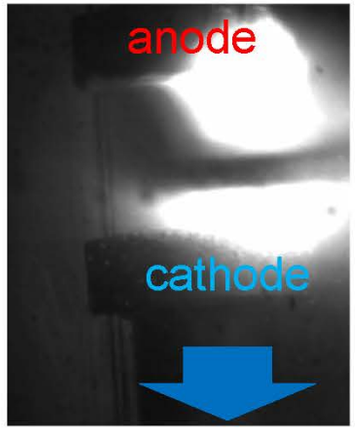
Temporal evolution of selected atomic and ionic lines

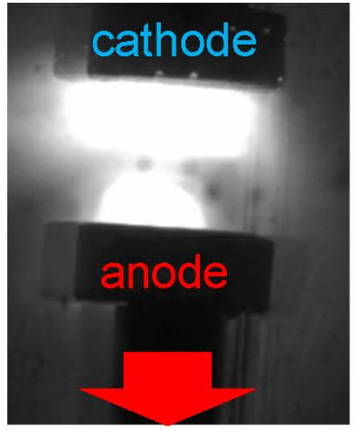


- In case of **moving anode** (straight lines):
  - **Emission rises** at 2-3 ms & peak at 6-7 ms → **earlier than in case of moving cathode** (dashed lines, start and peak 2-5 ms later)
  - **Atomic lines are stronger** (515 nm) or comparable (510 nm) to the strongest ionic lines (505 nm, 508 nm, 506 nm)
- In case of **moving cathode** (straight lines):
  - **Emission rises later**
  - **Ionic lines are often stronger** (505 nm) than atomic lines
- Although some lines with similar upper levels show similar temporal behavior, no general dependence can be found.
  → More sophisticated investigations necessary (2D-spatio-temporal resolution, simulation etc.)

Summary

- Moving cathode
  - Arc voltage: Relatively stable with only short time fluctuation
  - Jet modes
  - (Spatially integrated) emission dominated by ionic lines





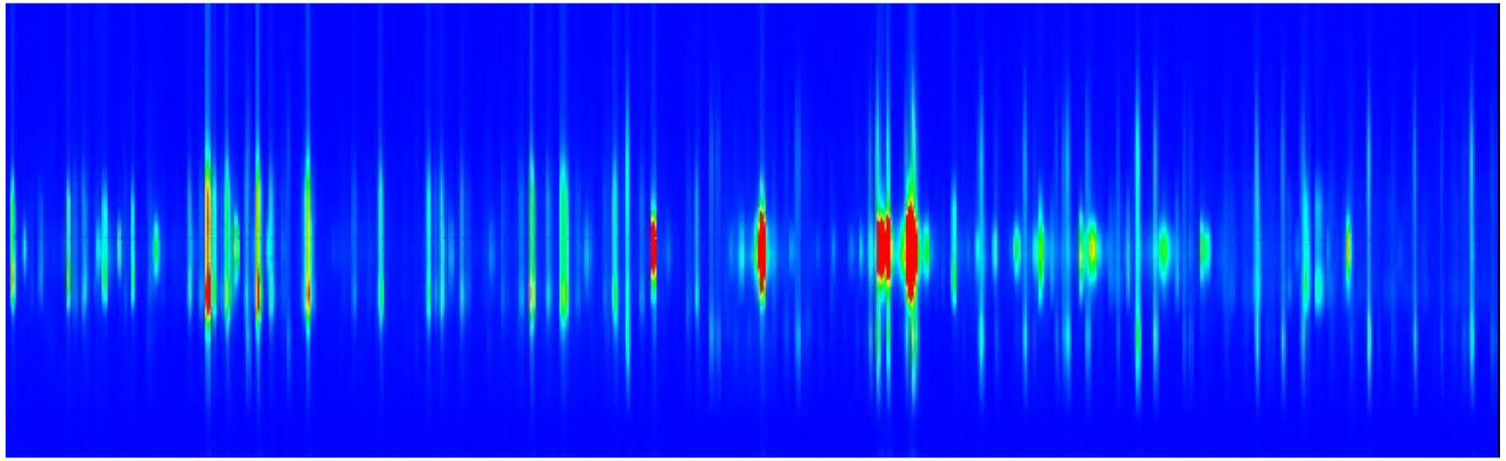
- Butt type contact pieces
- Contact **opening speed 3 m/s**
- **gap distance 30 mm** @ current zero
- Peak current 15 kA

- Moving anode
  - Arc voltage: Much stronger, continuous fluctuation indicating highly frequent changes of modes
  - Cathode activity
  - Anode jet suppression
  - (Spatially integrated) emission dominated by atomic lines

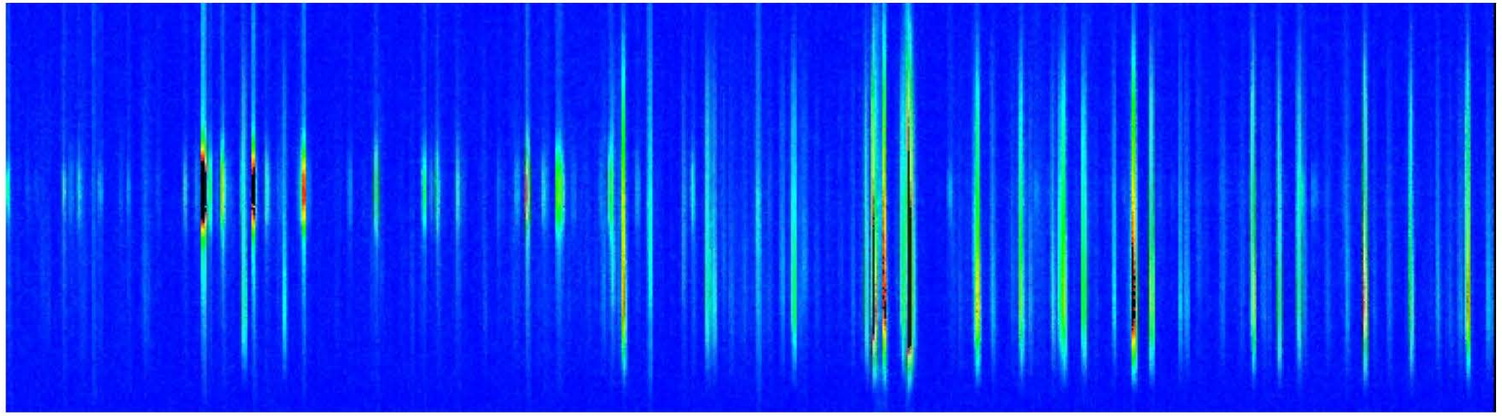
- For contact opening speed of 3 m/s and large contact gaps of up to 30 mm, the polarity of the moved contact is of high relevance.
- Many questions are still open (e.g, current path through vs. around the dense cloud in front of anode).
  → DFG project starting January 2027

Radial cross section

Anode moved
Observation near to cathode



16.6 ms



17.8 ms