Where to find the city of Darmstadt?

TECHNISCHE
UNIVERSITÄT
DARMSTADT

Darmstadt
~ 150,000 inhabitants
~ 40,000 students
> 30 research institutions

Source: thinkstock

RSM
Reaktive Strömungen + Messtechnik

TU Darmstadt in numbers

Students	~25,000
Professors	~300
Research associates	~2,150
Administrative and technical employees	~1,750

One focus: “energy conversion“

Engineering	~50%
Natural Sciences	~35%
Social Sciences	~15%

TU Darmstadt:
Dept. of Mechanical Engineering

Students	~3,000
Professors/institutes	28
Research associates	>400
Third party funding (2018)	46 Mio €

Institute Reactive Flows and Diagnostics
http://www.rsm.tu-darmstadt.de/rsm/index.en.jsp

- Prof. Dreizler (director),
- Prof. Votsmeier, Prof. Bauer
- Dr. Böhm, Dr. Wagner
- 22 Research associates (Ph.D.)
- 9 technical and administrative staff
- Third party funding in 2018 ~3 Mio €/a

→ **Focus on Turbulent Combustion**
→ **Advanced Laser Diagnostics**

Advanced Laser Diagnostics in Combustion

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TU Darmstadt, Germany
Dept. of Mechanical Engineering
Institute for Reactive Flows and Diagnostics

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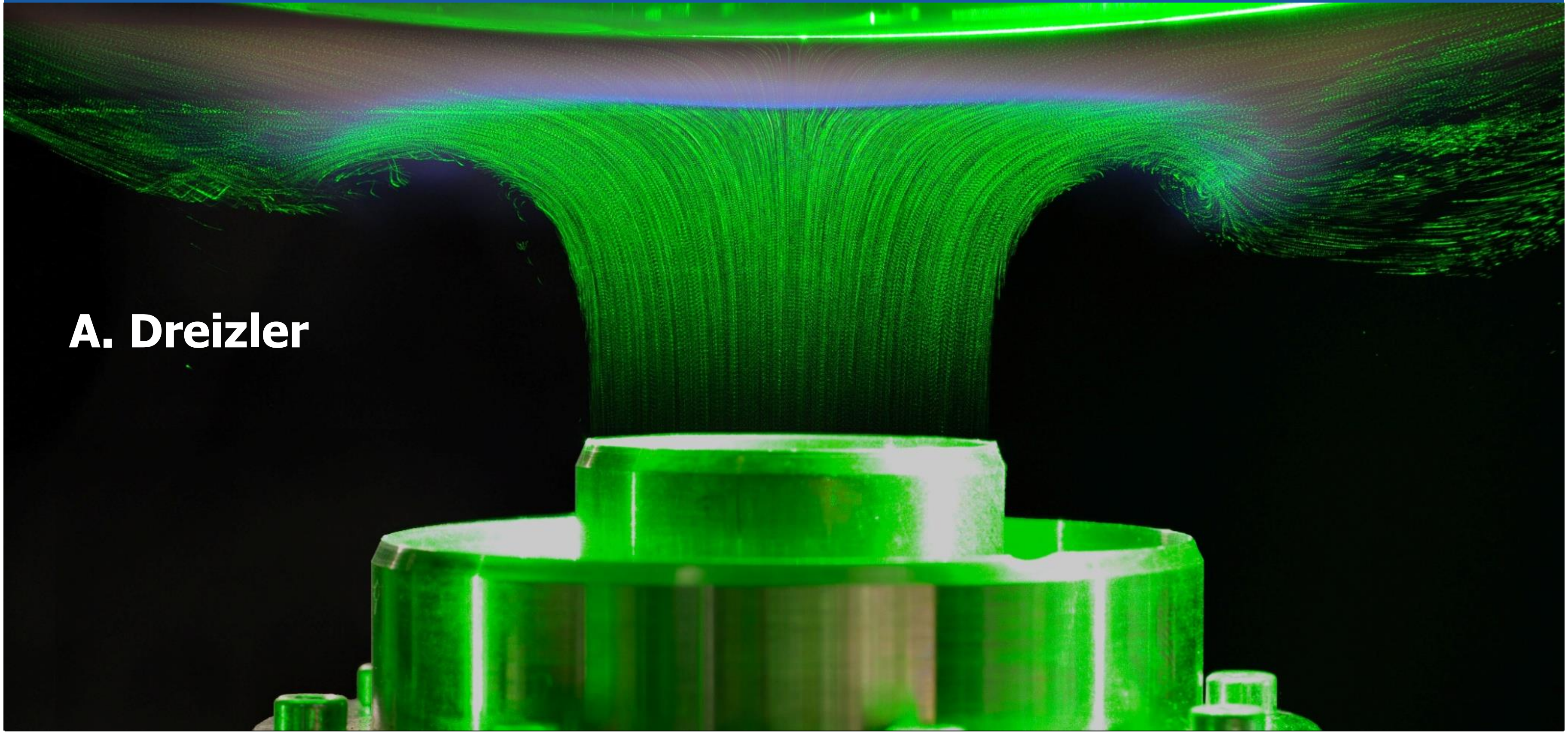
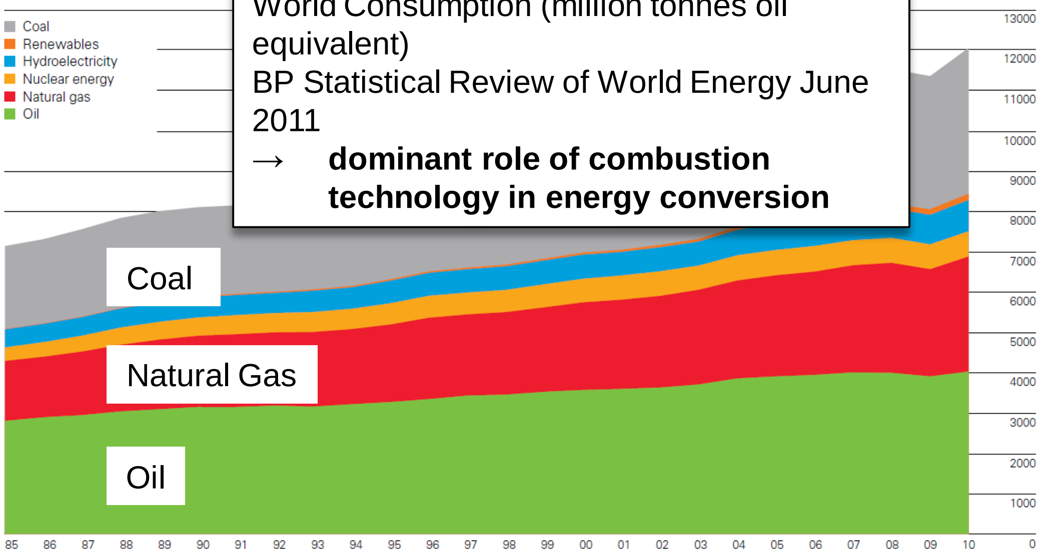


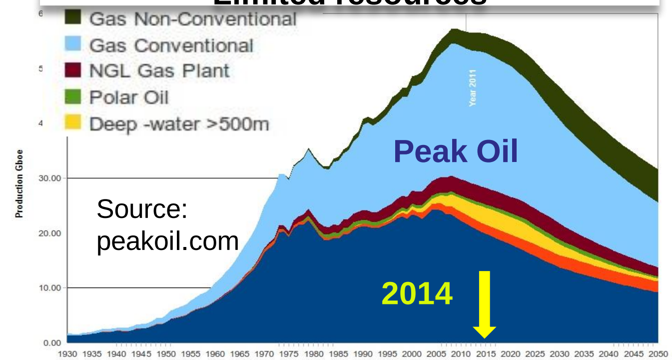
A. Dreizler

Challenges in combustion research

World Consumption (million tonnes oil equivalent)
BP Statistical Review of World Energy June 2011
→ **dominant role of combustion technology in energy conversion**



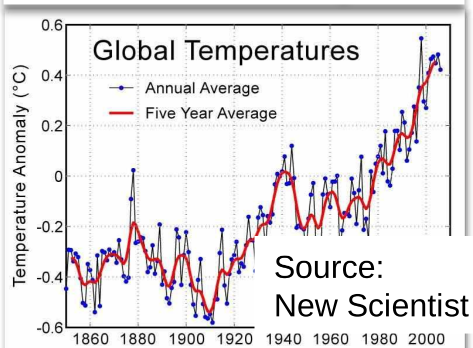
Limited resources



Pollutant emissions

Source:
World View of Global Warming

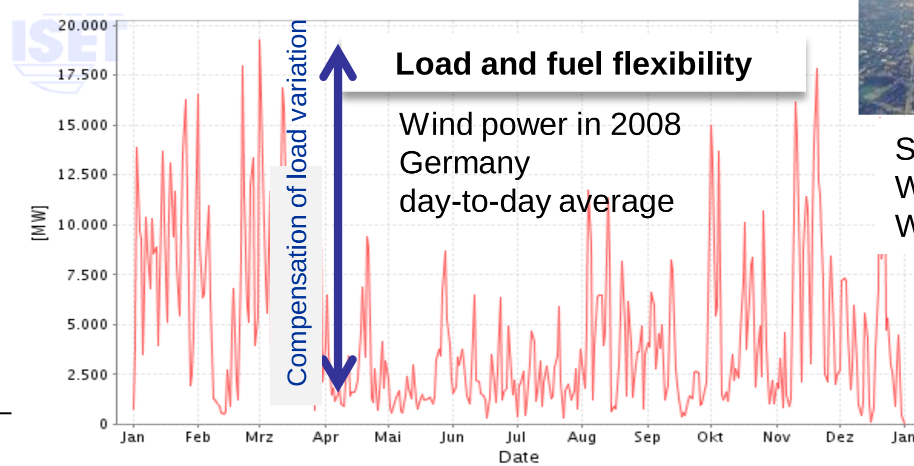
Global warming



Source:
New Scientist

Load and fuel flexibility

Wind power in 2008
Germany
day-to-day average



Source: ISET

Challenges in combustion research

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→ **Need for efficient, clean and flexible combustion technology**

→ **Coherent action of combustion-community: experiments, theory/modeling and simulation**

→ **Objective of this lecture series:**

- **Highlight role of combustion diagnostics**
- **Provide some basics of light – matter interaction**
- **Discussion of most important laser combustion diagnostic methods**
- **Present some topical application examples**

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Content

- Introduction
- Benchmark experiments
- General requirements for laser combustion diagnostics
- Particle-based velocimetry
- Gas-phase thermometry
- Surface thermometry
- Gas-phase concentration measurements
- Towards 4D-imaging
- Application examples
    - Flame-wall interactions in canonical configurations
    - Effusion cooling in gas turbine combustor
    - IC Engine: Technology development

Introduction
Laser diagnostics: contributions and context

Enabling Technologies

Cameras
Lasers
Optics
Signal Processing
Digital Image Processing
Applied Mathematics
Computer Sciences
Spectroscopy
Chemistry
Fluid Mechanics
Heat Transfer

Related Research Areas

Laser Diagnostics in Combustion →

Combustion System Tasks:

1. Phenomena
2. Validation data
3. Technology develop.
4. Robust sensing

Dreizler, Böhm. Proc. Combust. Inst (2015) 35:37-64

Quantities of primary interest in combustion

- **Flow field**
  - Mean velocities, fluctuations, Reynold-stresses
  - Strain, dilatation, vorticity
  - Integral length and time scales
  - Power spectral densities
- **Scalar field**
  - Means and fluctuation of temperature and chemical species concentrations
  - Structural information based on 2D- or quasi 3D-diagnostics
  - Scalar gradients
  - Wall/ nozzle temperatures
- **Inflow** conditions, boundary conditions
- Information on **unsteadiness**, temporal sequences of flow/ scalar fields

Using light – matter interaction for diagnostics

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Methods from physics

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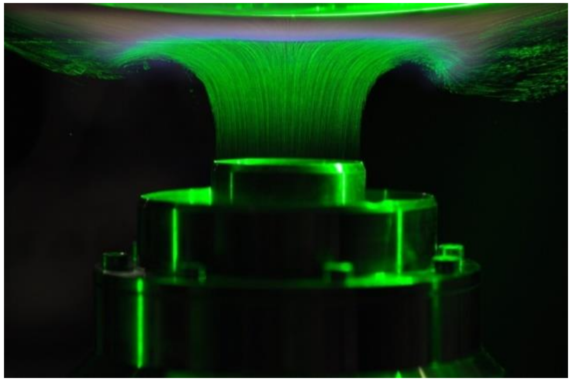
Engineering sciences

Transfer of methods

- Measuring by laser light
- Insitu-diagnostics → measuring inside combustors
- Non- or minimal intrusive
- High temporal resolution (~10^{-8}s)
- Reasonable spatial resolution (>10µm)



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Laser diagnostic methods

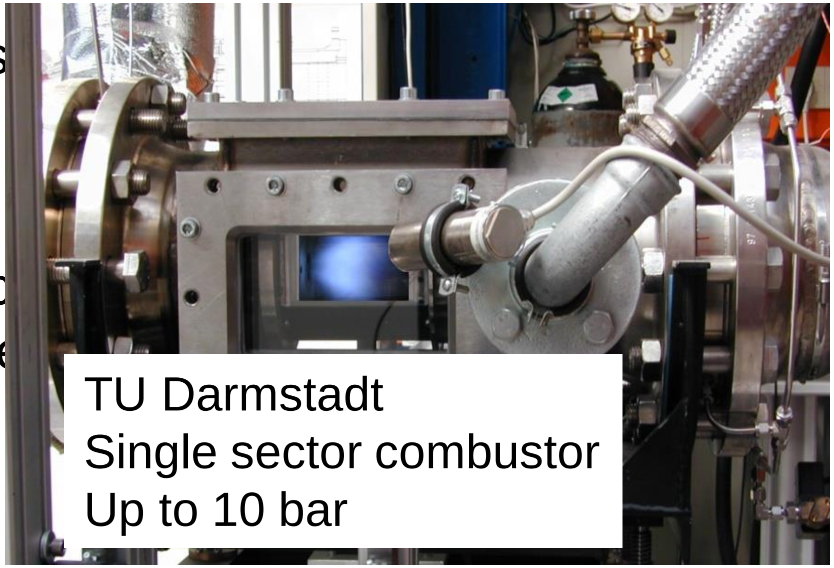
- Flow field
  - Laser Doppler Velocimetry (LDV), 1 to 3 components
  - Particle Image Velocimetry (10 Hz – 30 kHz)
    - 2 dimensional and 2 components (2D2C)
    - 2 dimensional and 3 components (2D3C – stereo PIV)
    - 3 dimensional and 3 components (3D3C – tomographic PIV)
- Two-phase flows
  - Mie scattering
  - Phase Doppler Anemometry (PDA)
- Scalar field
  - Mie scattering
  - Laser absorption spectroscopy (LAS) – but line-of-sight
  - Planar Laser-Induced Fluorescence (PLIF)
  - 1D Raman/Rayleigh scattering
  - Coherent anti-Stokes Raman Spectroscopy (CARS)
  - Thermographic Phosphors (TG)

Towards complex combustion systems

- Laser diagnostic methods have been used primarily in unconfined gaseous flames

Towards complex combustion systems

- Laser diagnostic methods have been used primarily in unconfined gaseous flames
- Additional challenges in practical combustion systems
  - Enclosure, high pressure → optical access
  - High turbulence levels → small length scales



Towards complex combustion systems

- Laser diagnostic methods have been used primarily in unconfined gaseous flames
- Additional challenges in practical combustion systems
  - Enclosure, high pressure → optical access
  - High turbulence levels → small length scales
  - Multiphase systems:
    - Droplets and sprays
    - Coal and solid fuel particles
    - Walls
  - Complex fuels → spectral interferences, unknown spectroscopic properties, sooty, high optical densities, …

Task 1: Studying phenomena by laser diagnostics

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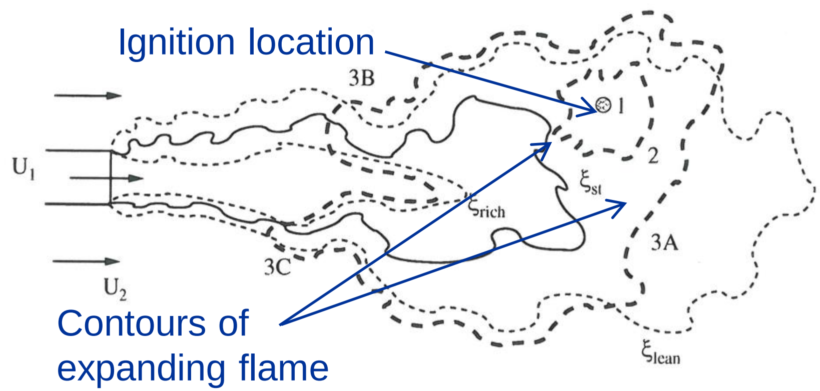
- Mimic specific properties of practical combustion systems in canonical configurations

Flame propagation in stratified mixtures



E. **Mastorakos**, PECS 2009: Schematic of flame kernel expansion following local ignition

UNIVERSITY OF CAMBRIDGE

Mastorakos. PECS (2009) 35:57–97

Task 1: Studying phenomena by laser diagnostics

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- Mimic specific properties of practical combustion systems in canonical configurations
- Adapt/develop laser diagnostics for monitoring of a specific property
- Exploit rapid developments in laser and camera technology to break new ground
  - From single-parameter to multi-parameter diagnostics
  - From 0-D towards 3-D measurements
  - From statistical independent measurements at low sampling rates towards high-speed diagnostics for statistically correlated measurements

→ Ultimate goal: summarize phenomenological understanding in physically consistent and predictive mathematical models

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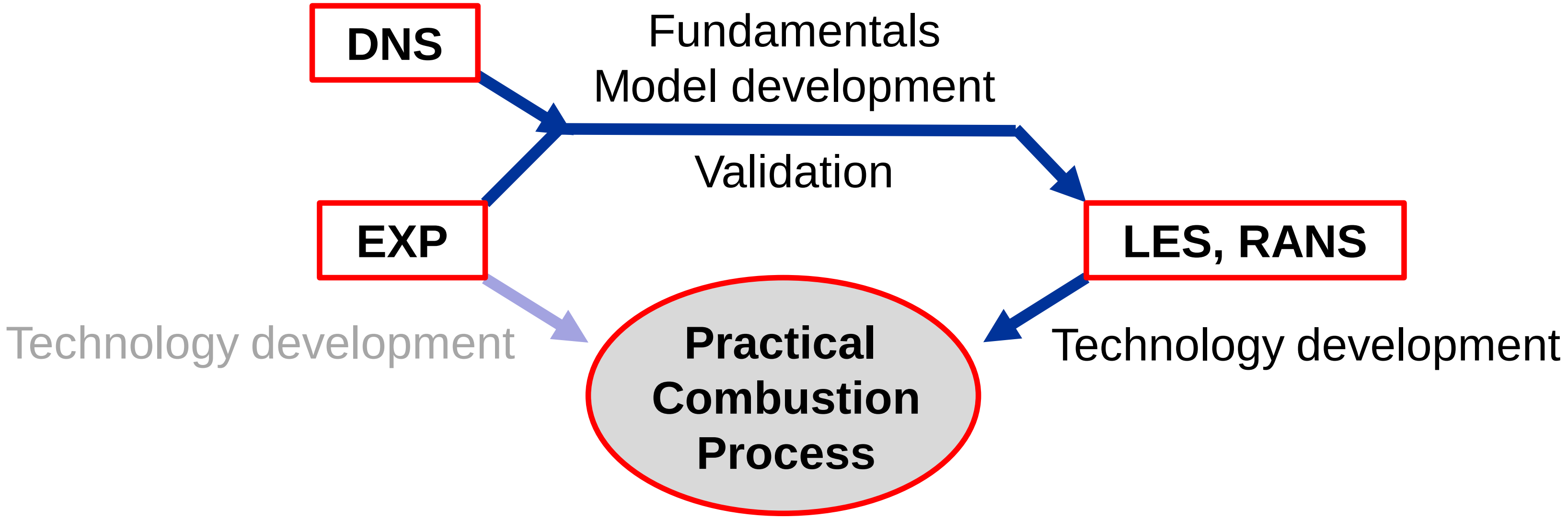
Task 2: Provide validation data

- Interplay of experimental and numerical methods for developing future combustion technologies



Task 2: Provide validation data

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- Validation sequence: from simple to complex
  - Stepwise approach: select specific sub-processes and build experiment to develop and validate models for this specific sub-process
  - Example:
    - Turbulence-chemistry interaction
    - Soot formation
    - Spray breakup
    - …

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Task 2: Provide validation data - from simple to complex, strategy at TUD

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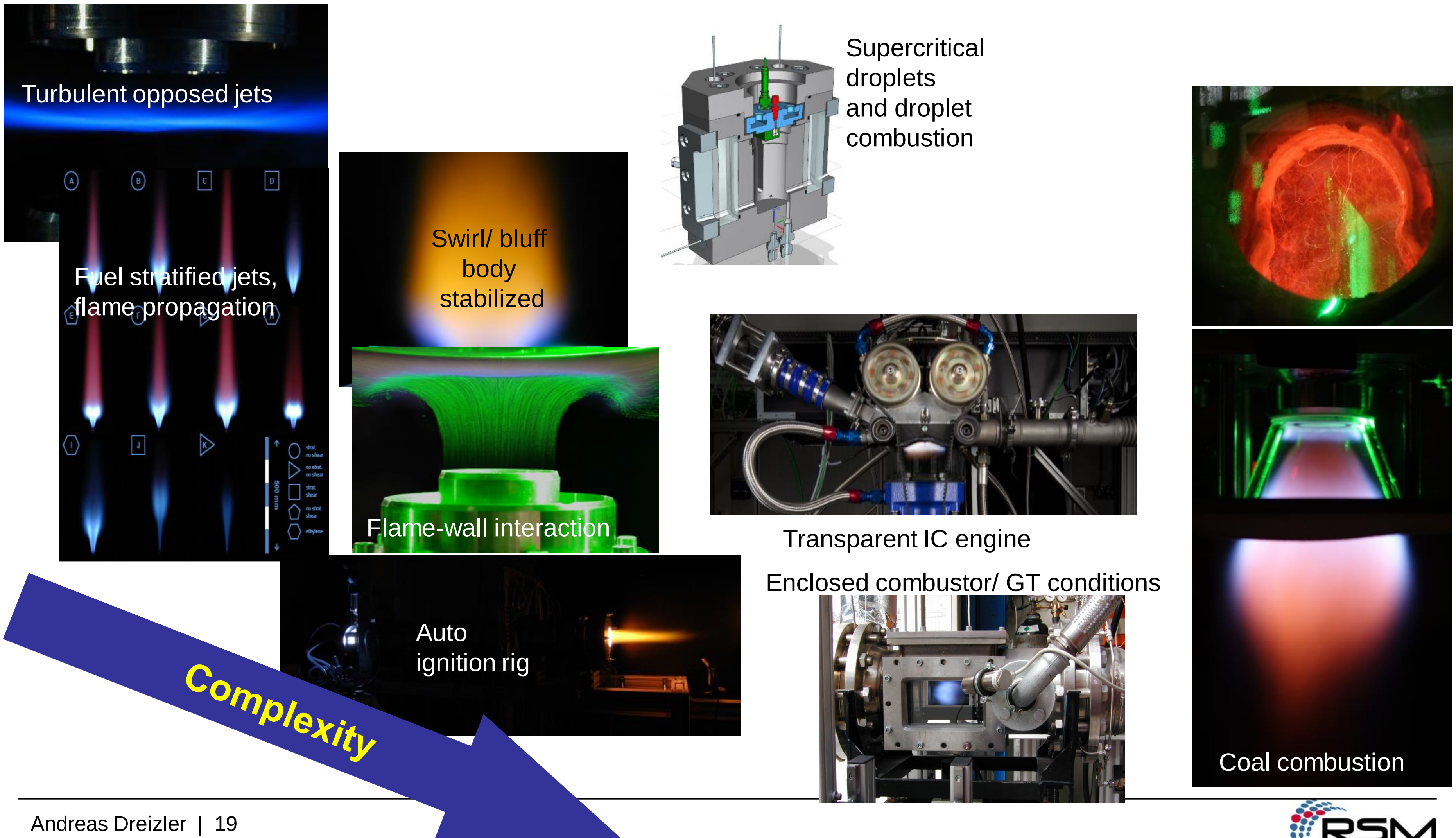

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Task 3: Support technology development

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- Development of future combustion technology requires billions of Euro (IC engine, gas turbine combustor, coal power plant, rocket motor, …)

→ Not the core-business of universities

- University task: development of methods (experimental, theoretical, numerical) supporting technology development and educate well-trained engineers

→ In this context: Transfer of measurement methods to industry

    - By graduated students
    - Bilateral industry projects

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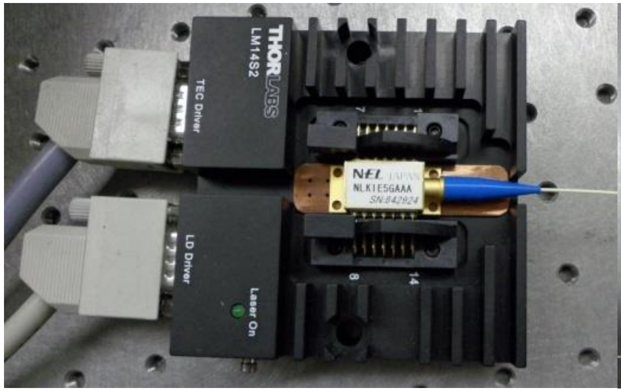
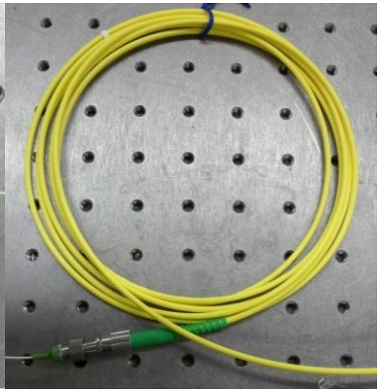
Task 4: Develop robust sensors

- Reliable components and easy operation without special training
- Applicable to real-world combustion systems

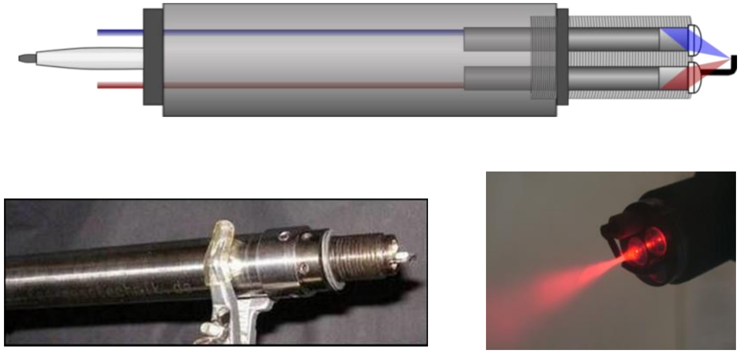
→ Fiber-based optical sensors in combination with (direct) absorption spectroscopy



DFB-diode laser, mounted



Glass fiber SMF-28



Fiber-coupled spark plug sensor