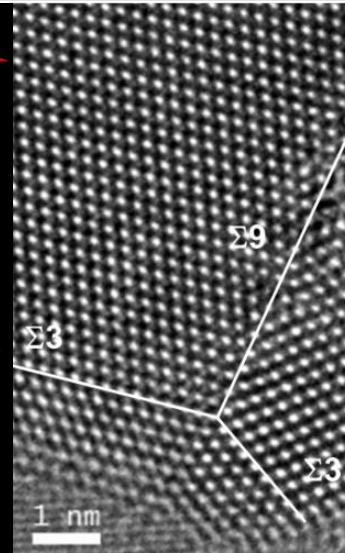
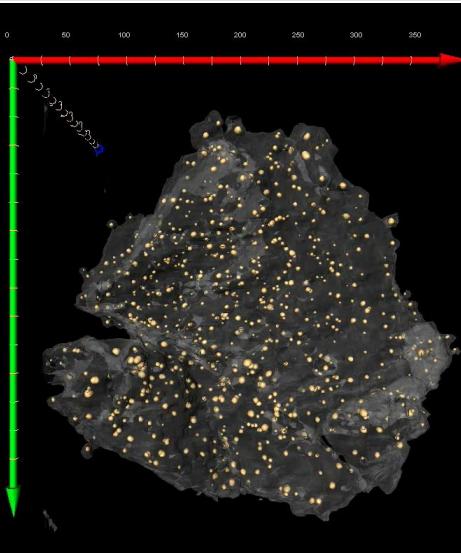
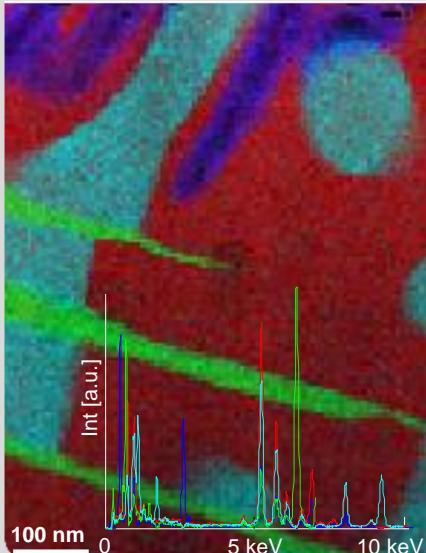


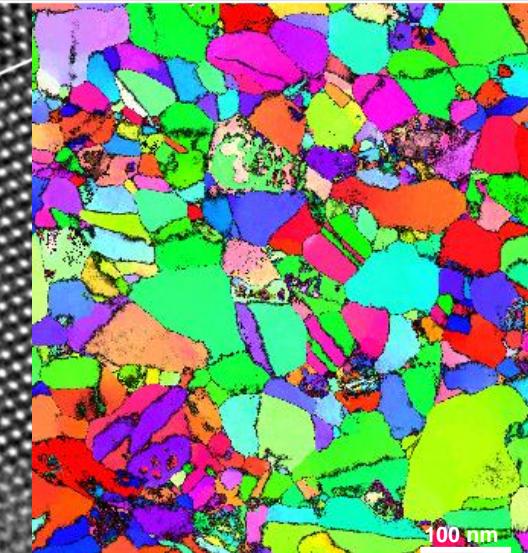
# Correlative Characterization in *ex-situ* and *in-situ* analysis

Christian Kübel, Jan Korvink, Jürgen Mohr

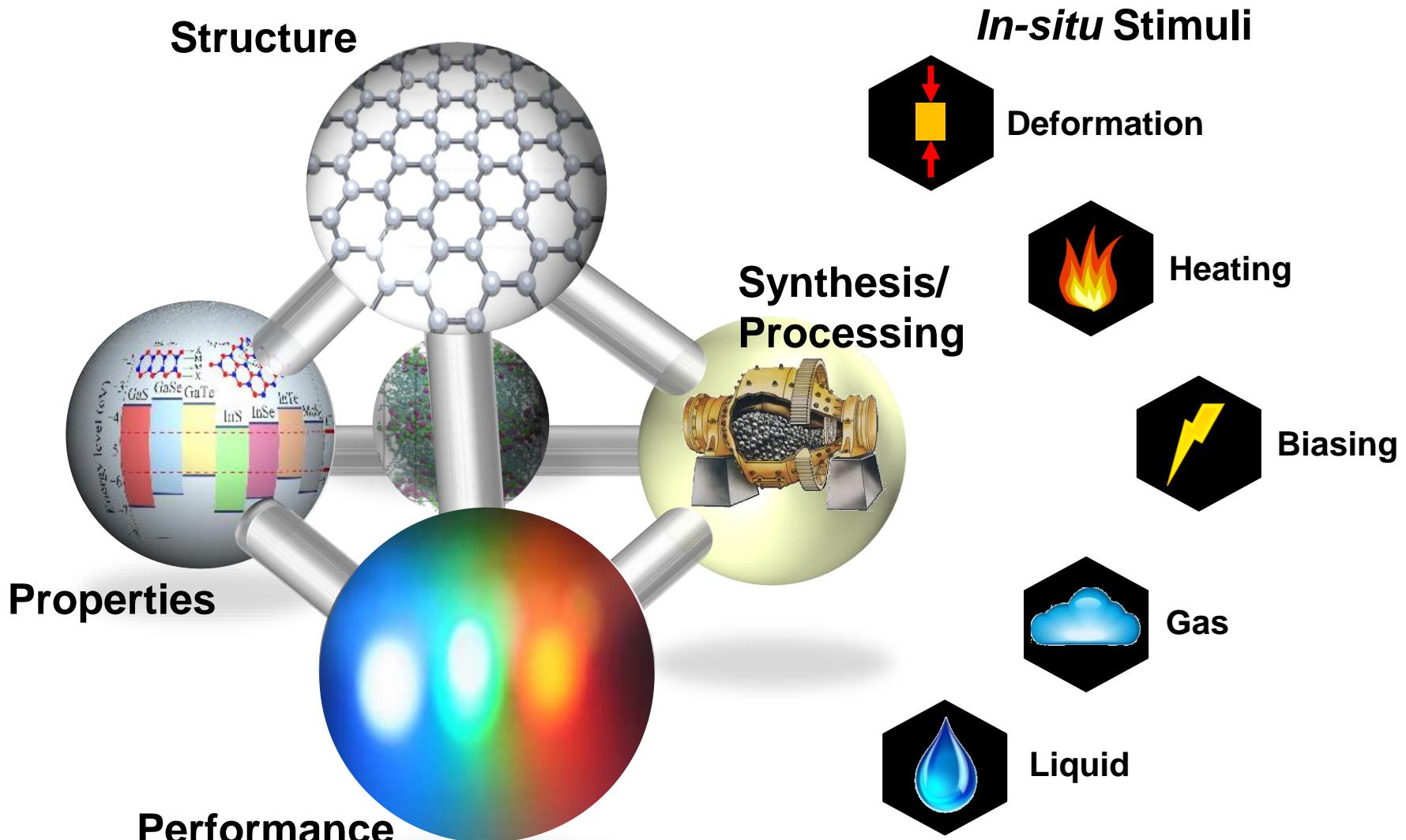
Institute of Nanotechnology



Karlsruhe Nano Micro Facility



# Motivation



## Combination of techniques to solve complex projects

HIM



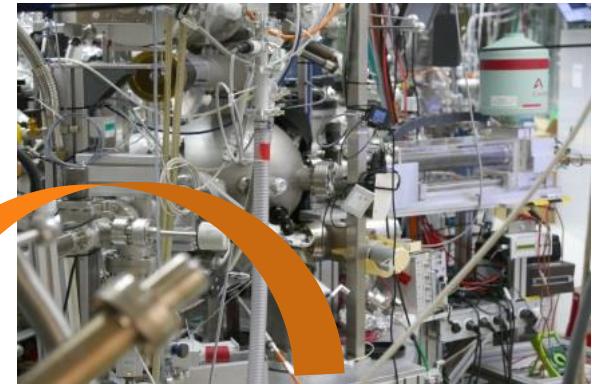
APT



AFM



WERA



XPS



ToF-SIMS



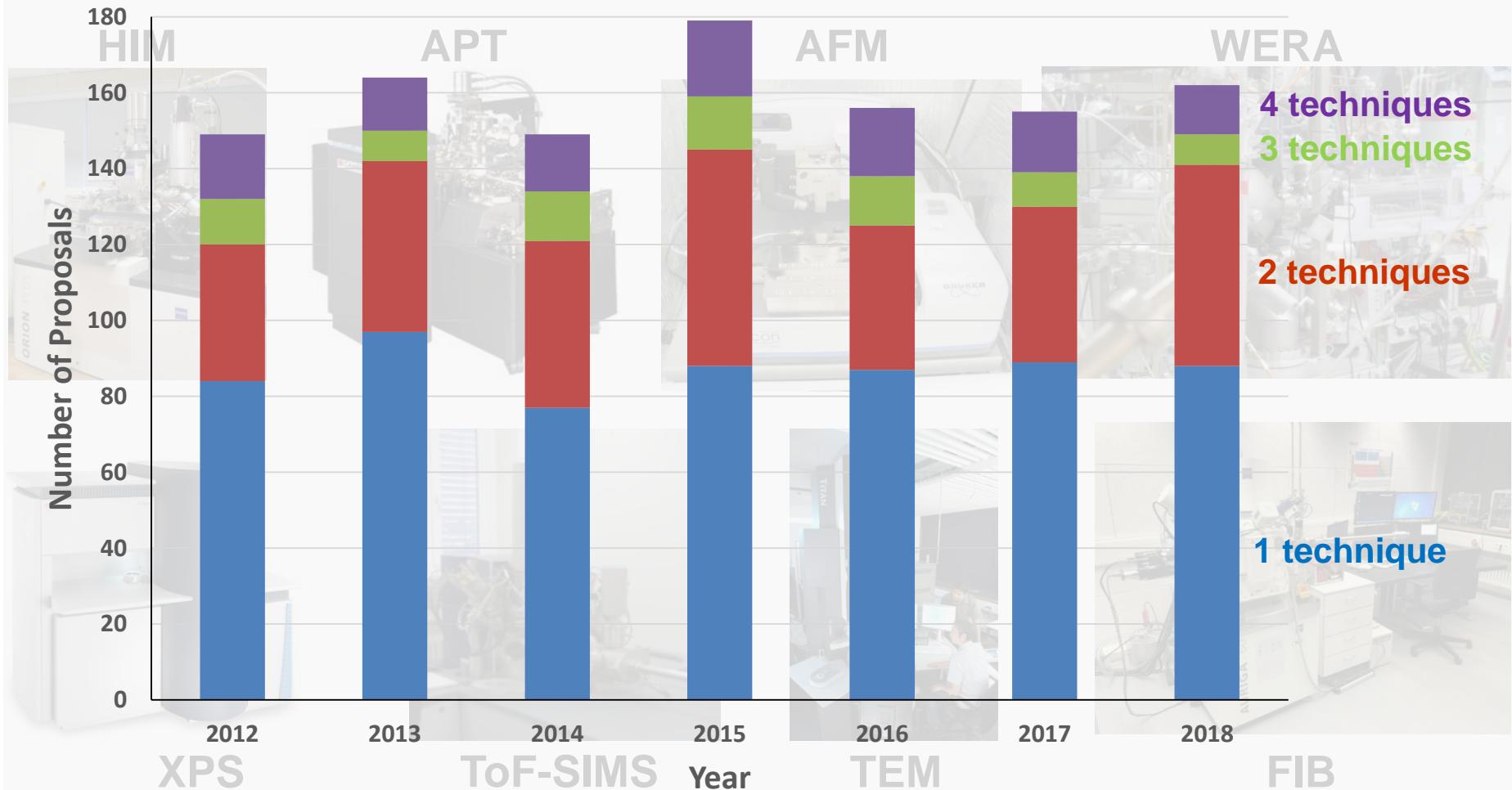
TEM



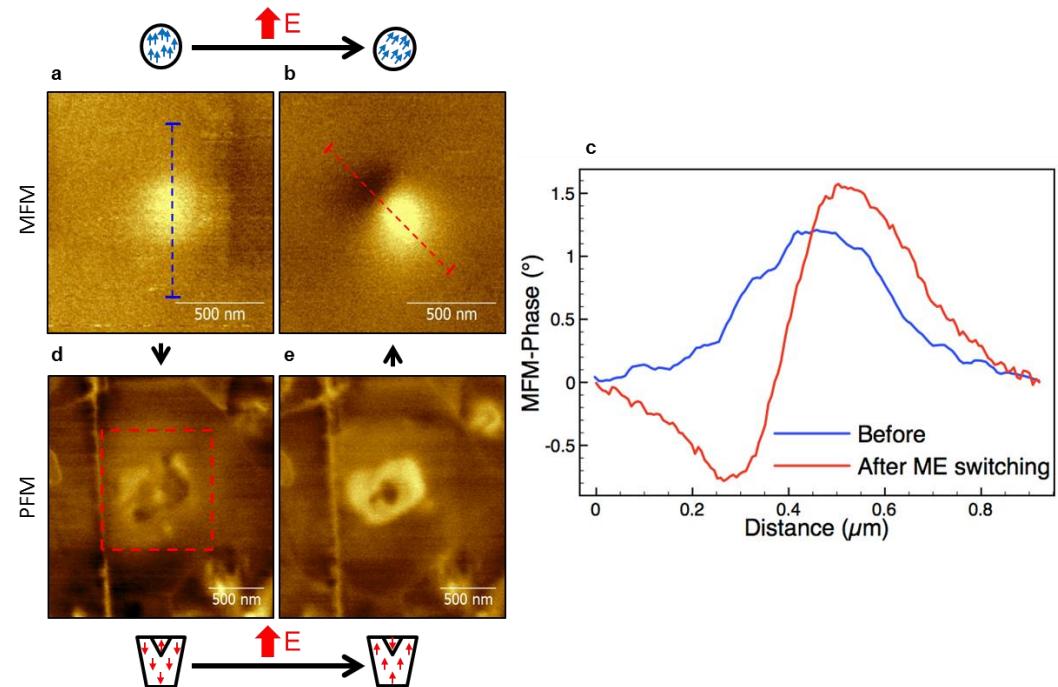
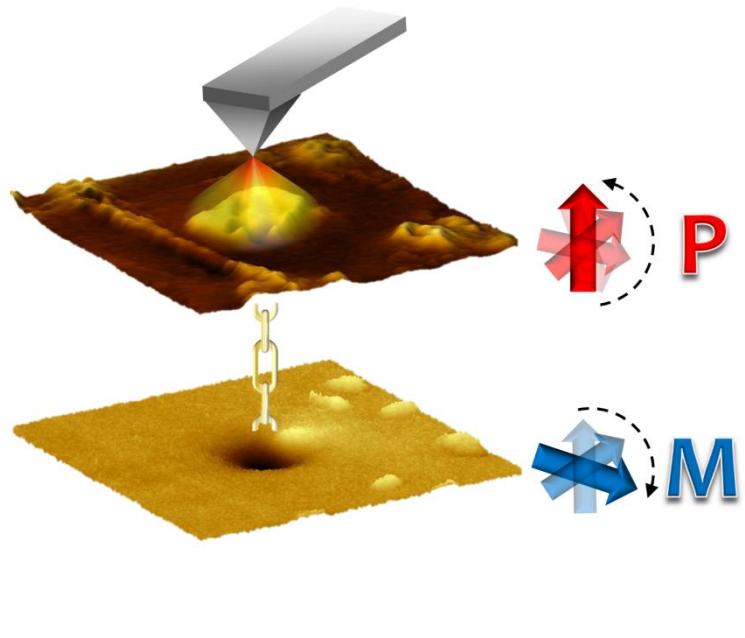
FIB



## Combination of techniques to solve complex projects



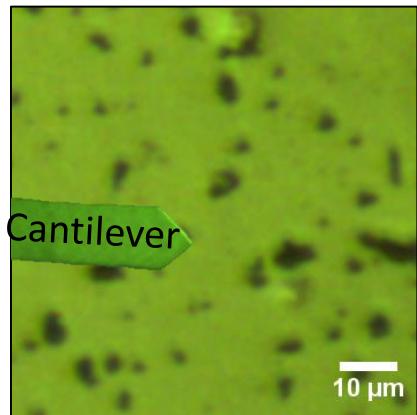
## Strong magnetoelectric coupling of ferroelectric material



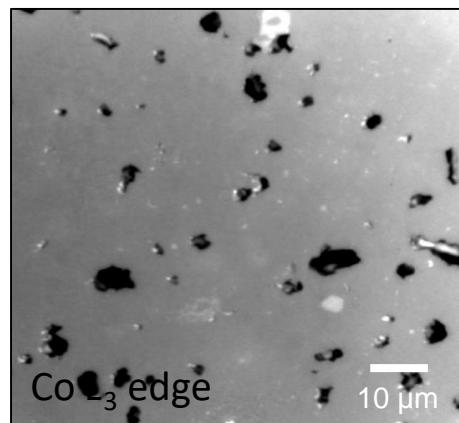
### Switching of magnetisation by electrical field

# Correlative Microscopy of Multi-ferroic Materials

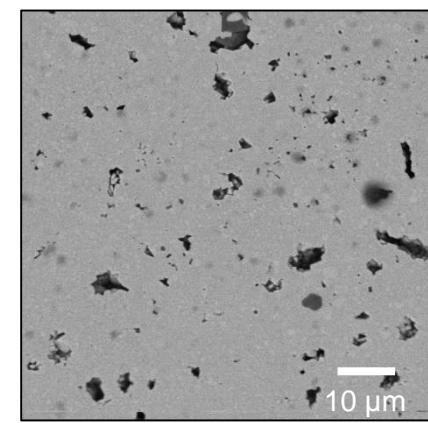
Optical Microscopy → AFM



PEEM (@ WERA)



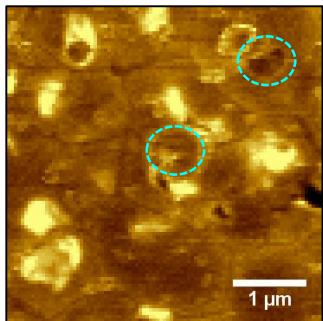
SEM



Ferroelectricity



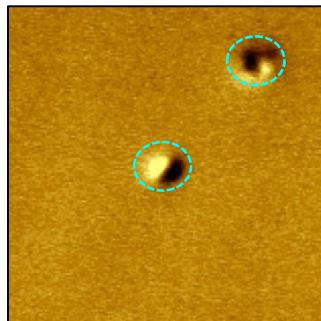
PFM



Magnetism



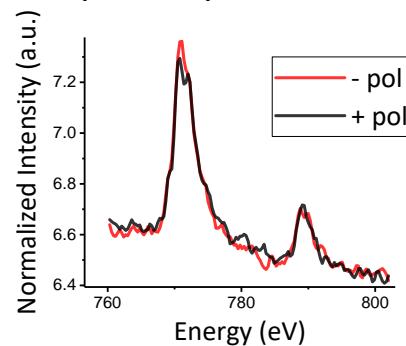
MFM



Microspectroscopy



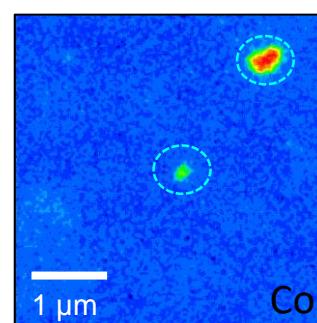
μ-XAS, μ-XMCD



Composition



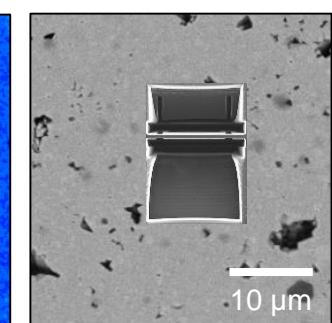
EPMA



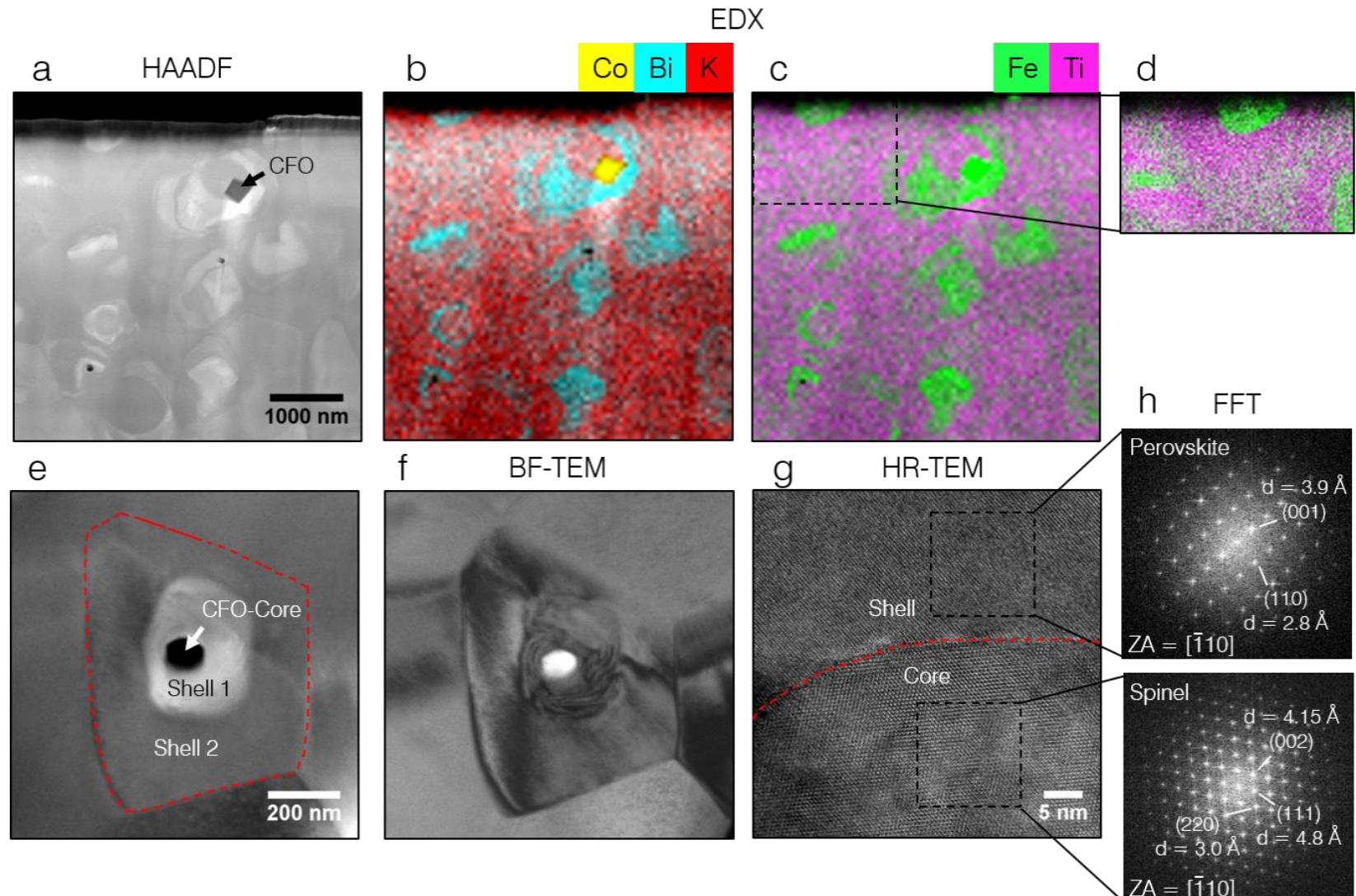
Structure



FIB



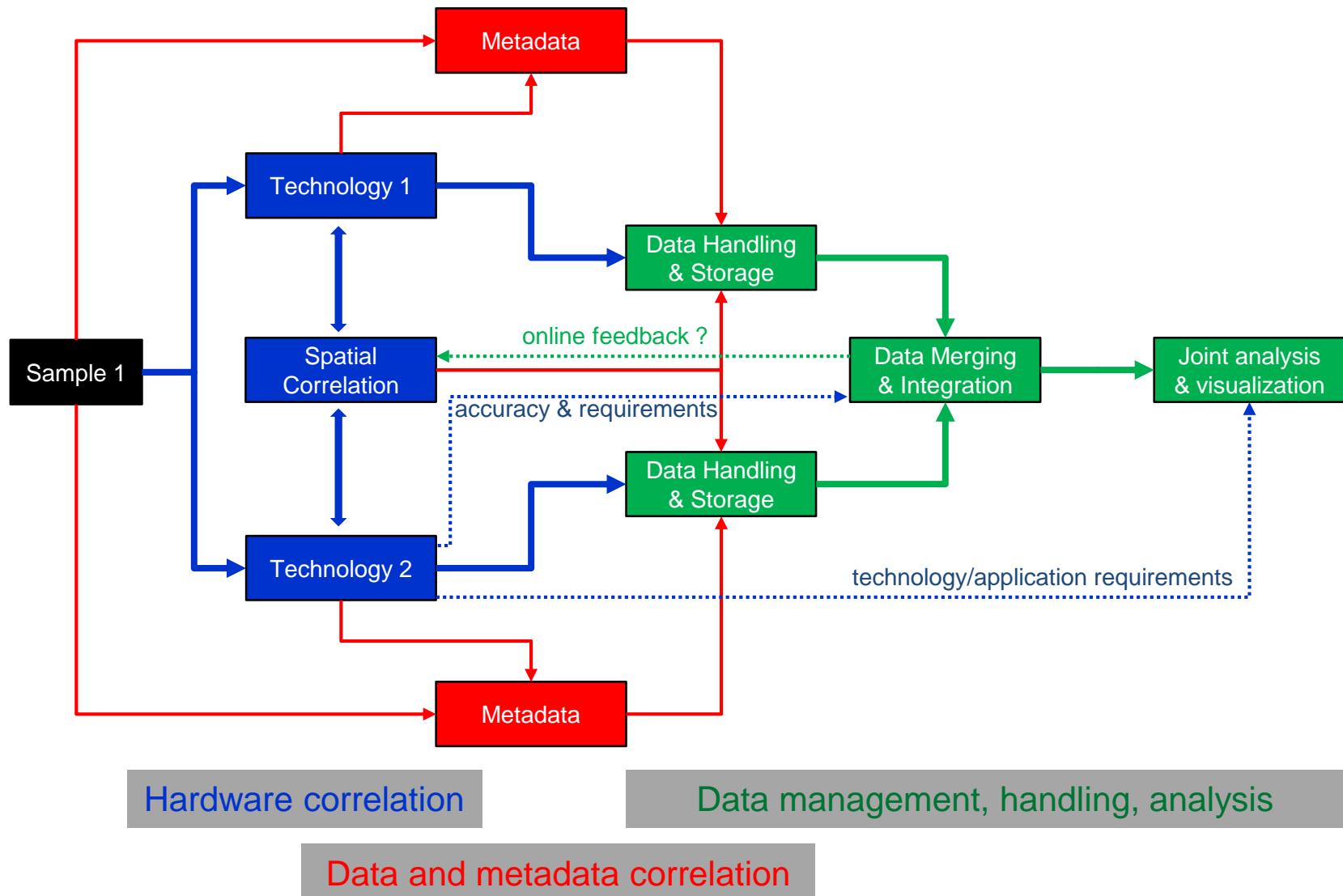
# Correlative Microscopy of Multi-ferroic Materials



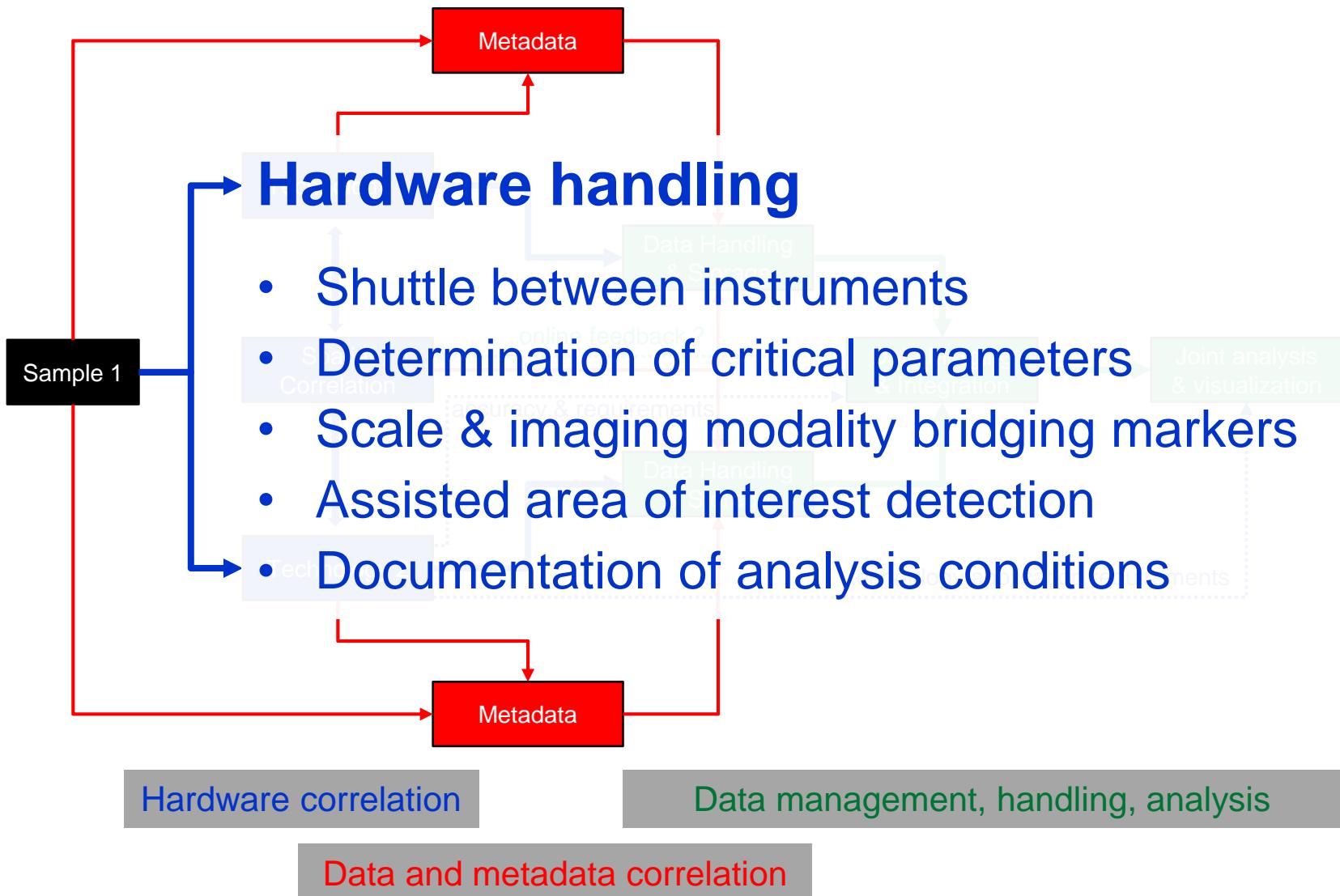
- **Sample transfer between instruments**
  - Incompatible stages
- **Switch from surface to local bulk characterization**
- **Correlation across length scales**
  - Millimeter to Ångstrom
- **Correlation across imaging modalities**
  - Images, spectroscopy, mechanical & electrical signals
  - Hyperspectral data

# Correlative Characterization

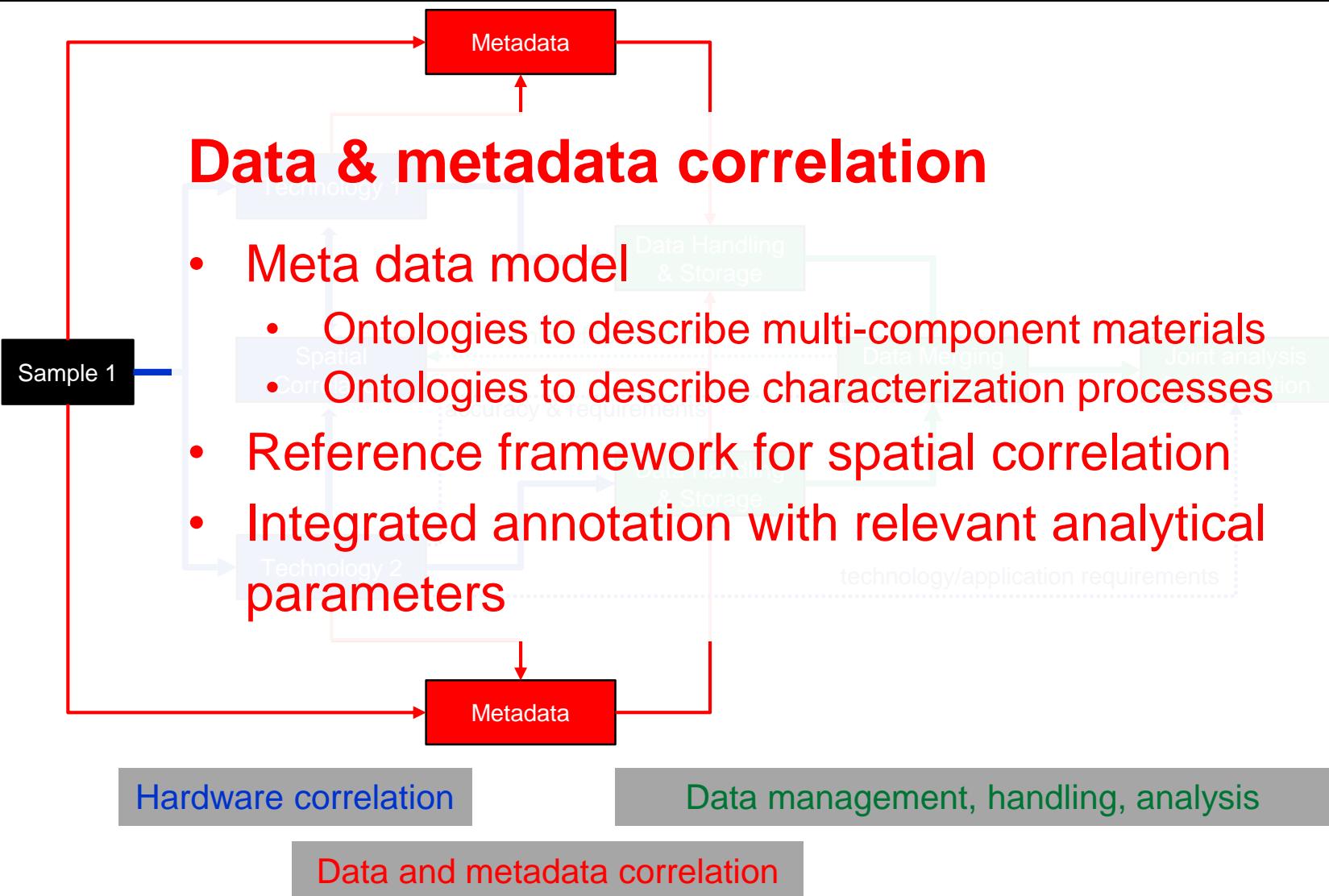
Application area 1  
Material class 1



Application area 1  
Material class 1



Application area 1  
Material class 1



## Data management, handling & analysis

- Sustainable data storage and access compatible with EOSC and enabling FAIR principles
- Handling of proprietary data formats
- Data alignment across length scales and imaging modalities
- Fusion, visualization and analysis of multi-dimensional data
- Visualization across length scales
- Analysis & processing documentation

Application area 1

Materials class

•

Technology 1

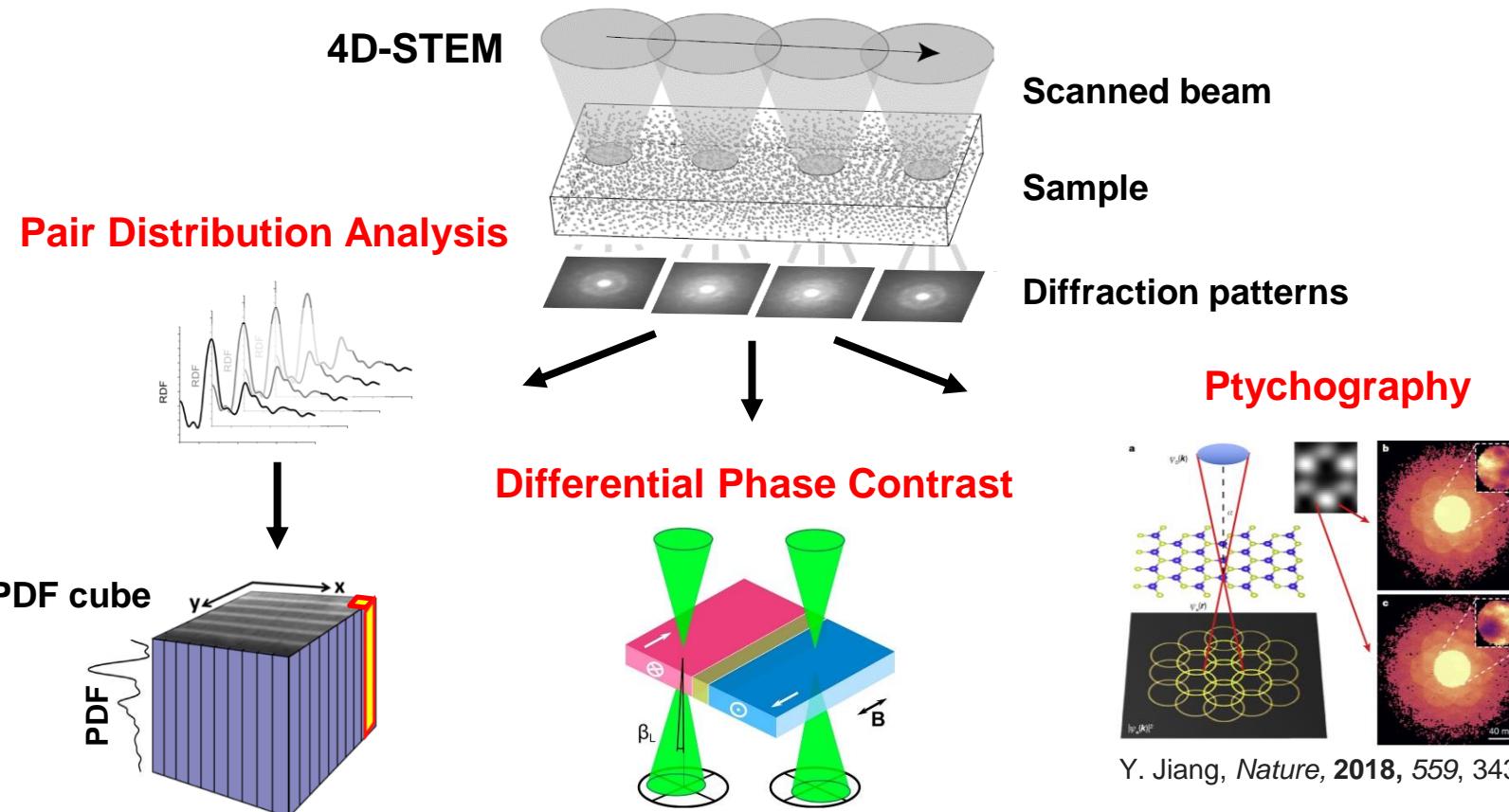
Technology 2

Hardware correlation

Data management, handling, analysis

Data and metadata correlation

## Creating additional information by implementing new types of data generation and analysis



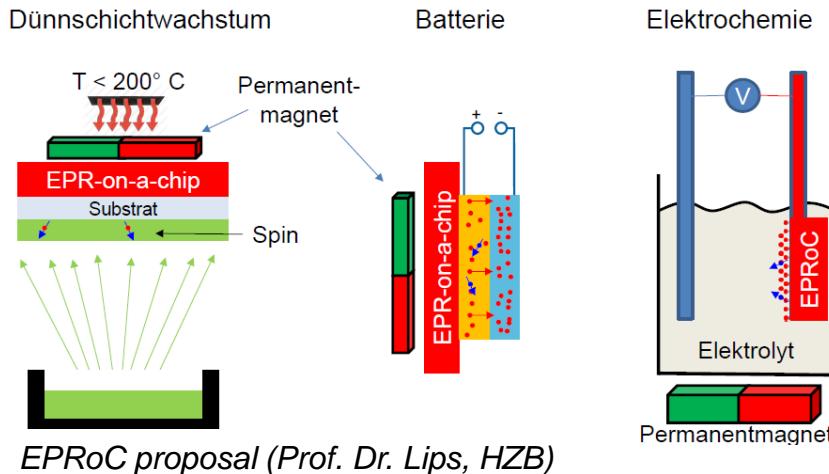
## In-system integration of different types of measurements

- miniaturized measurement setup, e.g. for NMR or EPR on chip
  - Integration into existing characterization infrastructures
- 
- Direct correlation of results
  - Feedback for measurement optimization
  - *In-situ* correlative experiments

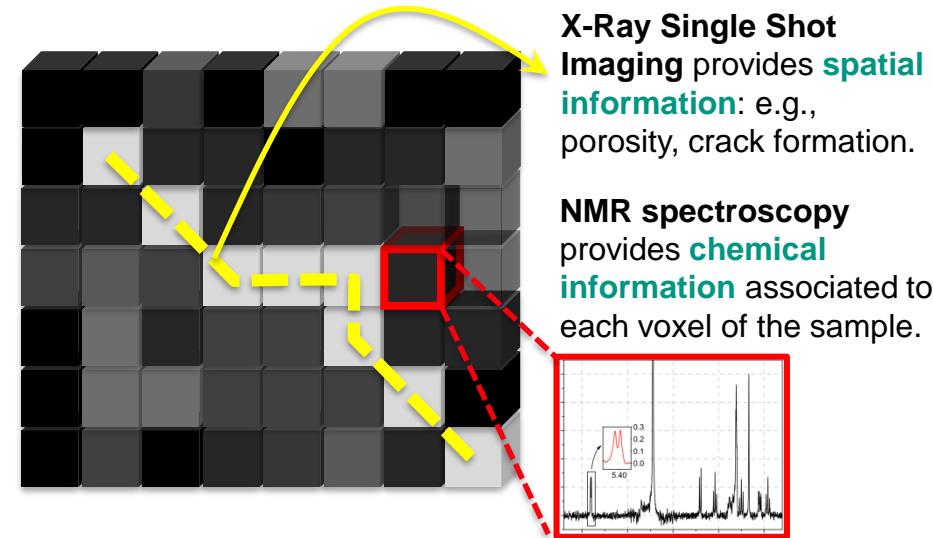
## In-system integration of different types of measurements

- Direct correlation of results
- Feedback for measurement optimization
- *In-situ* correlative experiments

### Combined EPR and XES



### Combined X-ray SSI and NMR



Parallel acquisition and correlation of complementary *in-situ* data (spatial + chemical)

- **Metadata model & ontologies**
  - Materials & samples
  - Measurement process
  - Correlation
- **Data storage & access concepts**
- **Multidimensional visualization & analysis**
- **In-system integration**
  - Miniaturized setups
  - In-situ techniques

