Plasmon Enhanced THz Electron Paramagnetic Resonance

Söllerhaus, Kleinwalsertal, Austria, 16-20 June 2019

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Institute of Physical Chemistry

University of Stuttgart

Introduction

Plasmon Enhanced THz Electron Paramagnetic Resonance

General aim

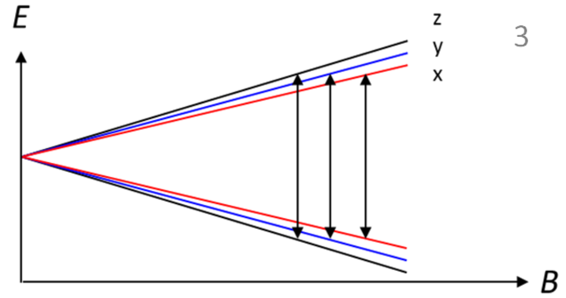
- Combine advantages of high-frequency electron paramagnetic resonance with scanning probe microscopy. Achieve a working prototype.

Novelty

- First magnetic field enhancement with plasmonic antennas (localization beyond diffraction limit)
- First scanning probe HFEPR (spatial resolution < 1 μm) .
- Closing of the THz gap (higher sensitivity)

Introduction

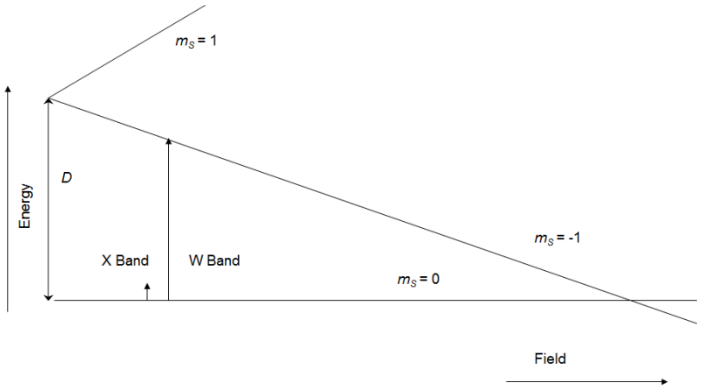
Why Plasmon Enhanced THz Electron Paramagnetic Resonance?

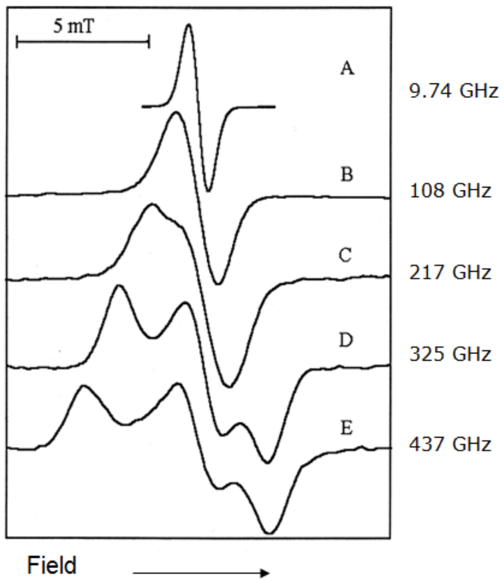


Why THz Electron Paramagnetic Resonance?

- EPR interrogates paramagnetic centers in biology, chemistry, materials science and physics.
- Reasons for going to higher frequencies in EPR:
  - Easy access to large energy splittings
  - Improve g-value resolution

$$\hat{\mathcal{H}} = D\hat{S}_z^2 + E\left(\hat{S}_x^2 - \hat{S}_y^2\right) + \mu_B \mathbf{B} \cdot \underline{\underline{g}} \cdot \hat{\mathbf{S}}$$



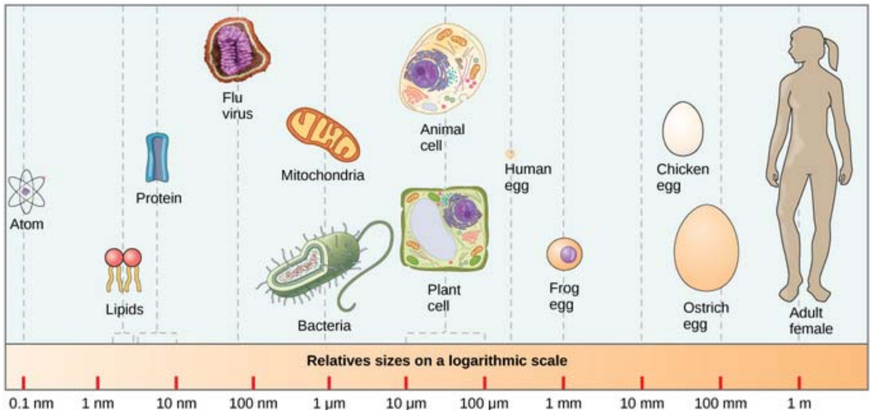


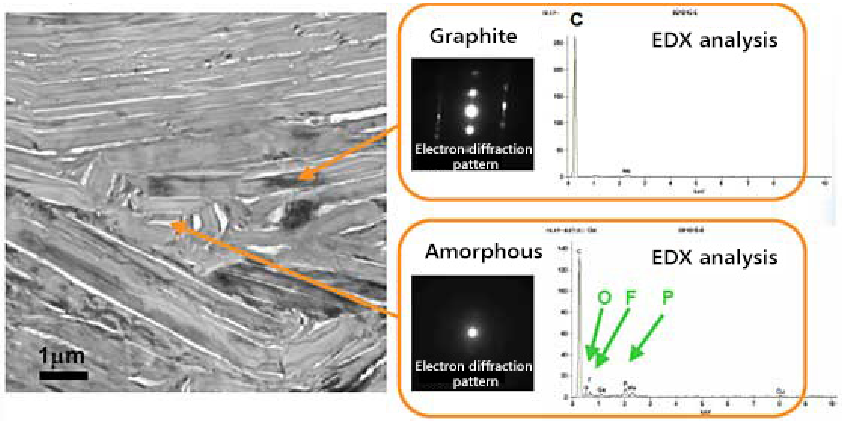
Introduction

Why Plasmon Enhanced THz Electron Paramagnetic Resonance?

Why EPR *Microscopy*?

- In systems with structure on the microscale, **spectroscopic microscopy** allows investigation of individual components.
- Wavelength is smaller at THz than in microwave regime, allowing for investigation of smaller features.





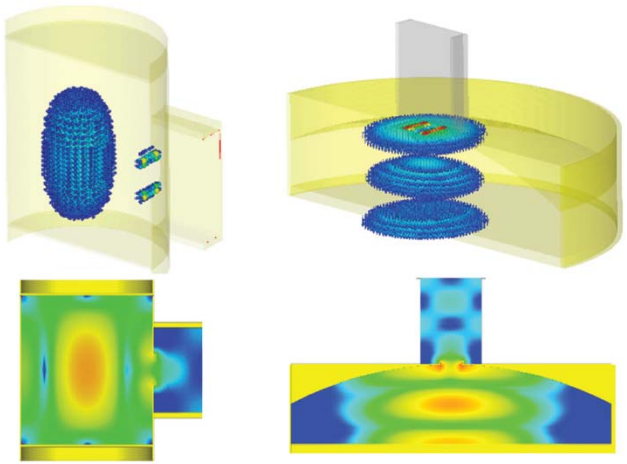
Introduction

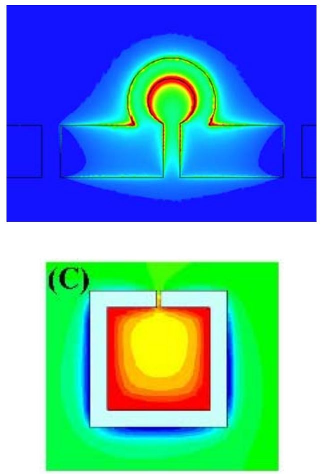
Why Plasmon Enhanced THz Electron Paramagnetic Resonance?

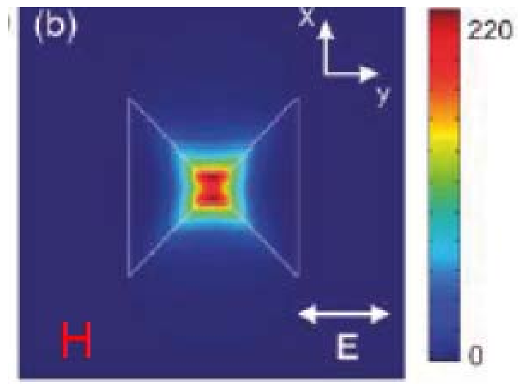
$$\hat{H}' = \mathcal{E}_0 \sum_i e^{-ikz_i}\left[q_i x_i + \frac{q_i}{2m_i c}\cdot\left(\hat{L}_{i,y} + g_i \hat{S}_{i,y}\right)\right]$$

Why Plasmon enhancement?

- Electron paramagnetic resonances are magnetic dipole transitions.
- Magnetic dipole transitions are much weaker than electric dipole transitions.
- Resonant structures are used to enhance the radiation magnetic field strength





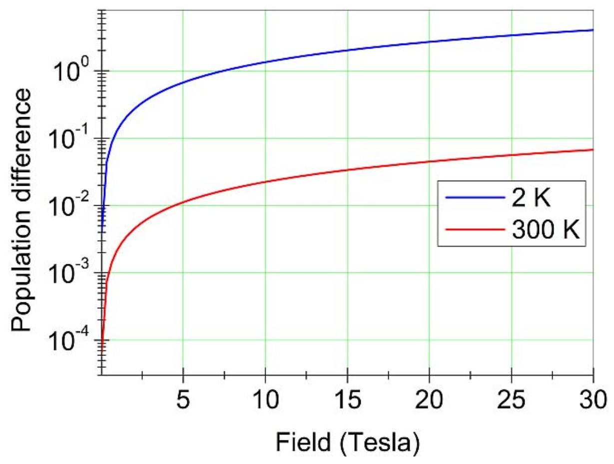


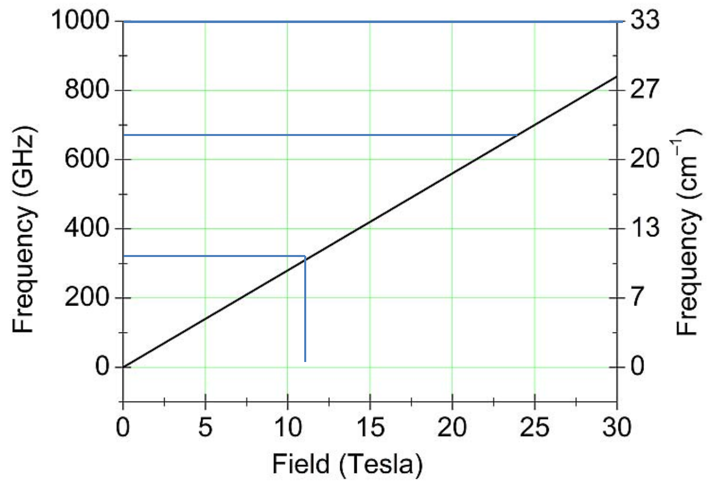
Introduction

Why Plasmon Enhanced THz Electron Paramagnetic Resonance?

Why low temperatures and high magnetic fields?

- Low temperatures increase the Boltzmann population difference.
- Magnetic field required for S=1/2 paramagnets (Zeeman splitting)



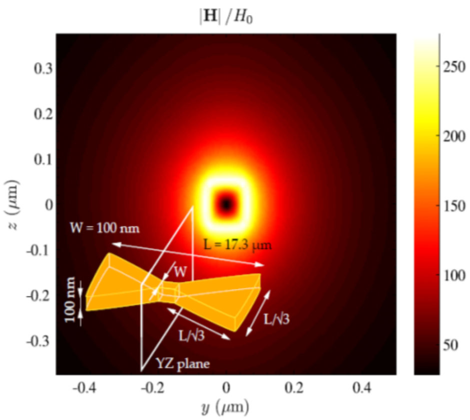


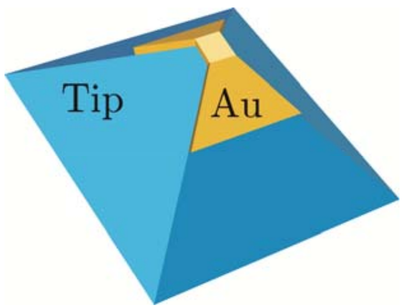
Introduction

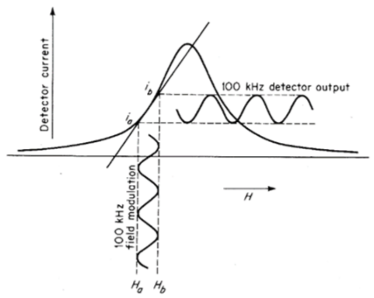
Challenges

What we need for this "future and emerging technology" to work

- Plasmonic enhancement of THz magnetic field
- Tip integration of plasmonic structure
- Scanning probe unit in low-temperature/high-field environment.
- Readout of weak signal.







The Scheme

Future and Emerging Technologies

FET OPEN

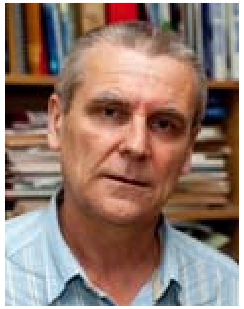
- **Radical vision**
- **Breakthrough technological target**
- **Ambitious interdisciplinary research**

Consortium

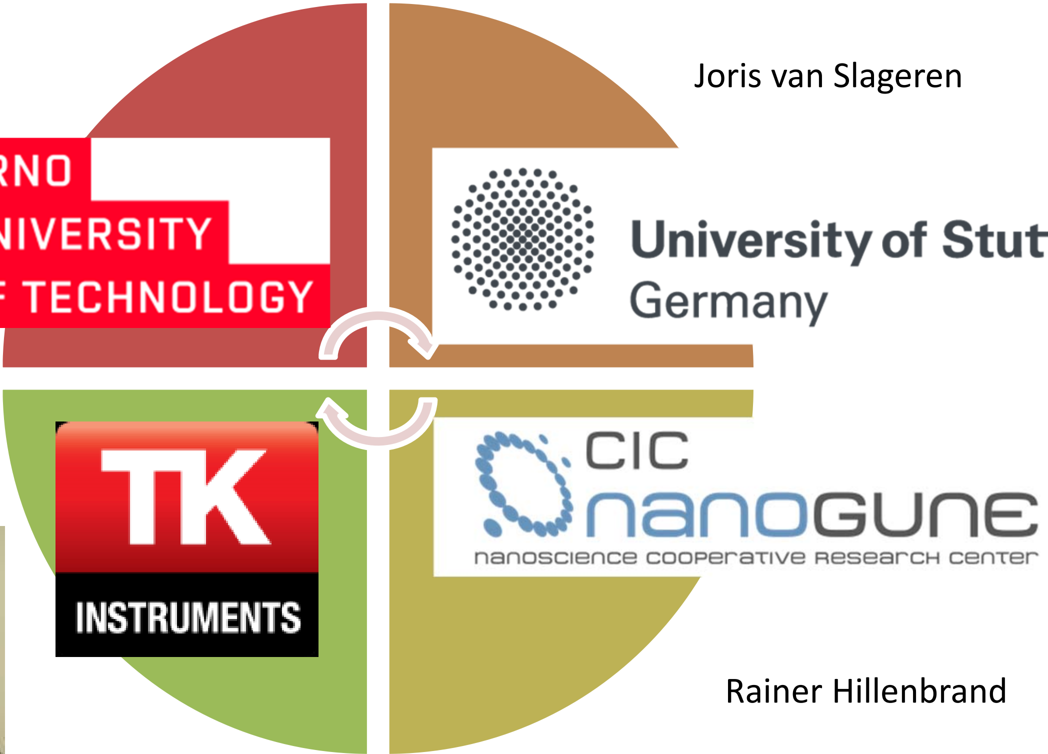
PETER

Božena Čechalová – project manager

Joris van Slageren



Tomáš Šikola – coordinator



Rainer Hillenbrand

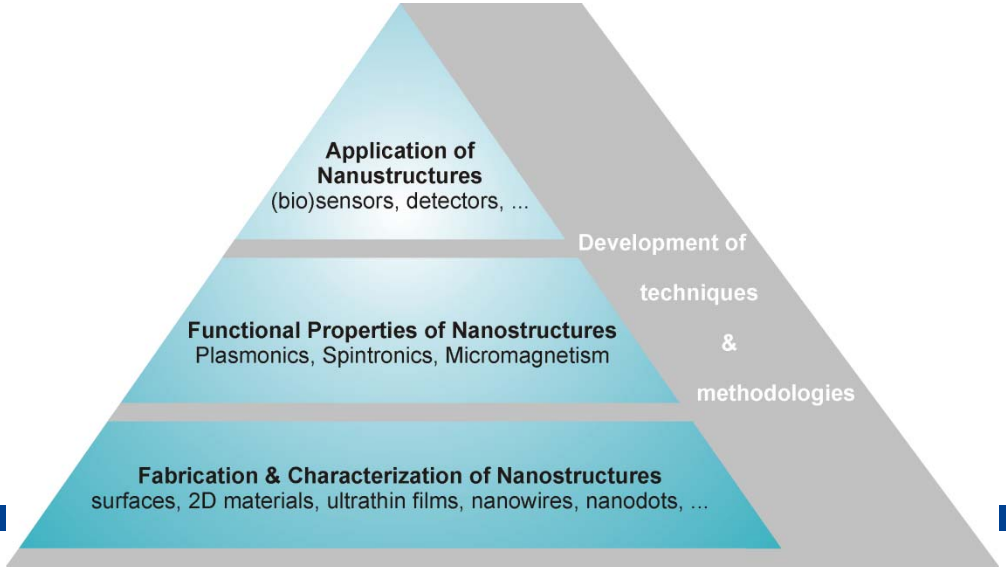
Richard Wylde

Consortium

CEITEC/BUT, group of Surfaces and Nanostructures

- Tomáš Šikola
- Vlastimil Křápek
- Jan Čechal
- Petr Neugebauer

- Martin Hrtoň
- Jan Neuman,
  Zdeněk Nováček,
  Michal Pavera (NenoVision)



Consortium

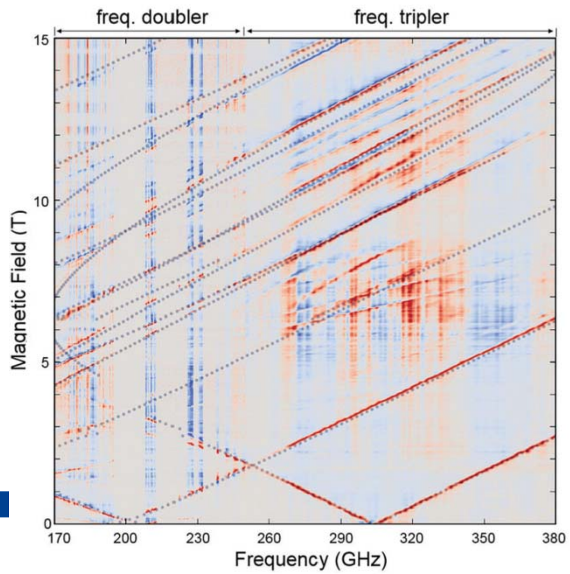
USTUTT/ AG Van Slageren

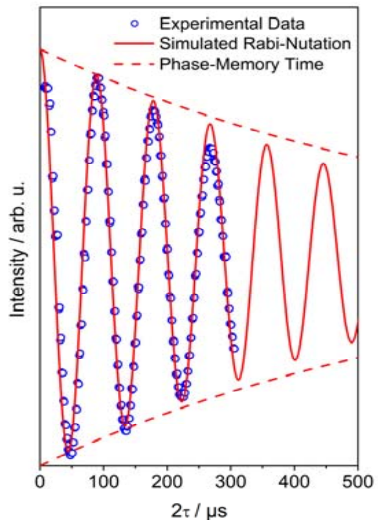
- Joris van Slageren

- Dominik Bloos
- Lorenzo Tesi



- **Magnetic anisotropy of molecular nanomagnets**
- **Quantum coherence in molecular quantum bits**
- **Molecular Spintronics**



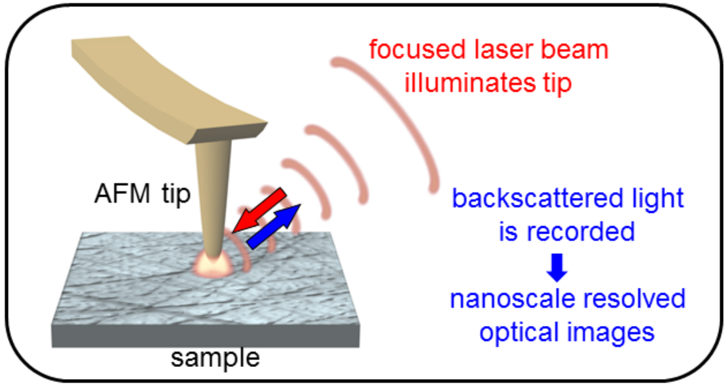


Consortium

NanoGUNE/ Nanooptics group

- Rainer Hillenbrand
- Shu Chen
- Katarína Rovenská

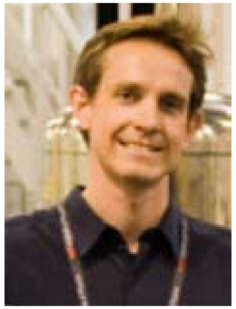
- Nanoscale optical, infrared and THz nanoscopy
- commercialized s-SNOM via Neaspec GmbH



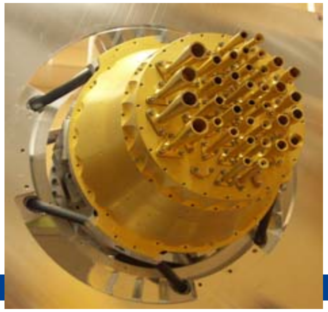
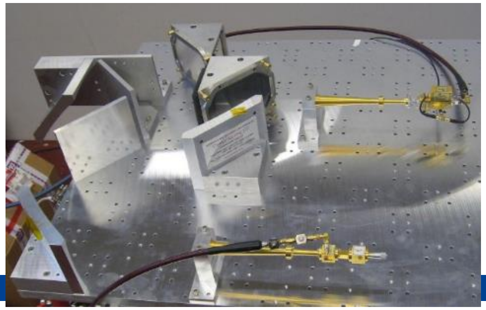
Consortium

Thomas Keating Ltd.

- Richard Wylde
- Kevin Pike
- Alisa Leavesley
- George Sebek


- Design and development of quasi-optical systems and subsystems operating in the millimetre and submillimetre regime
- Commercial enterprise dating back to 18th century

Project

Application process

- **First submission 2016: Total score 4.65**
- **Resubmission 2017/1: Total score 5.00 (first rank)**
- **2017: 760 eligible proposals, 53 funded (7%), budget 170 M€**

Proposal Evaluation Form

EUROPEAN COMMISSION

Horizon 2020 - Research and Innovation Framework Programme

Evaluation Summary Report - Research and innovation actions

Call:	H2020-FETOPEN-1-2016-2017
Funding scheme:	RIA
Proposal number:	767227
Proposal acronym:	PETER
Duration (months):	36
Proposal title:	Plasmon Enhanced Terahertz Electron Paramagnetic Resonance
Activity:	FETOPEN-RIA-2017-1

N.	Proposer name	Country	Total Cost	%	Grant Requested	%
1	VYSOKE UCENI TECHNICKE V BRNE	CZ	687,646.25	23.72%	687,646.25	23.72%
2	UNIVERSITAET STUTTGART	DE	809,980	27.94%	809,980	27.94%
3	Asociacion - Centro de Investigacion Cooperativa en Nanociencias - CIC NANOGUNE	ES	613,352.5	21.16%	613,352.5	21.16%
4	Thomask Keating Ltd	UK	787,705	27.17%	787,705	27.17%
	Total:		2,898,683.75		2,898,683.75	

Project

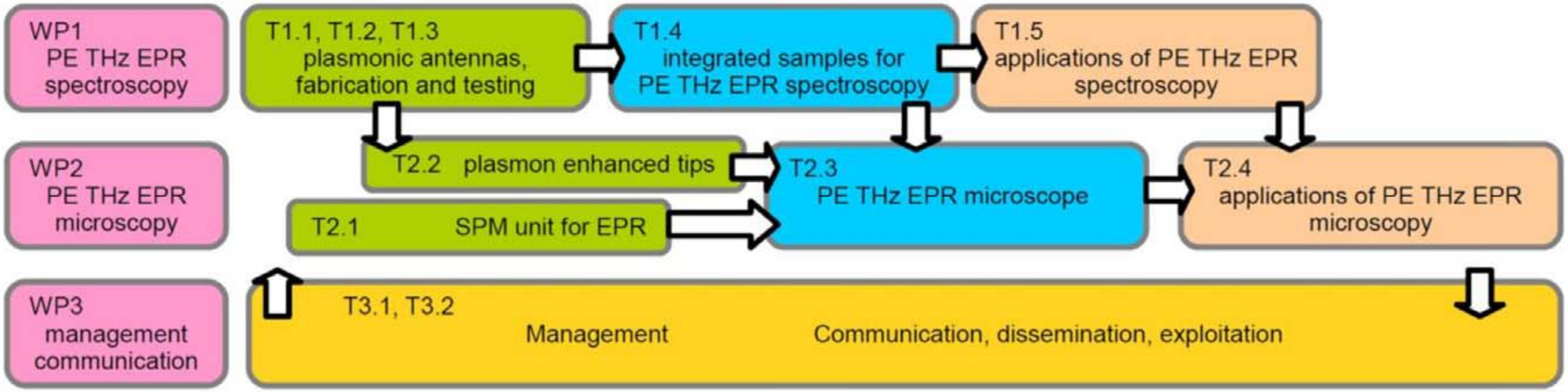
Finances

Partner	Personal Costs k€	Durable Eq.	Other Goods/ Services	Travel	Indirect costs	Total
NanoGune	340	60	60	30	123	613
USTUTT	268	300	65	15	162	810
TK	538	0	55	37	158	788
CEITEC BUT	278	115	124	33	138	688
Total						2900

Project

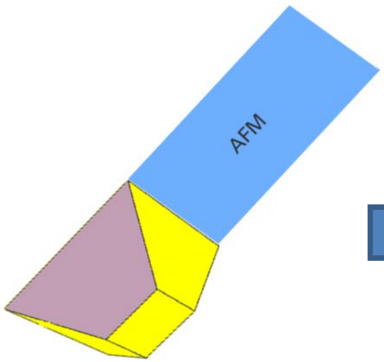
Work Plan

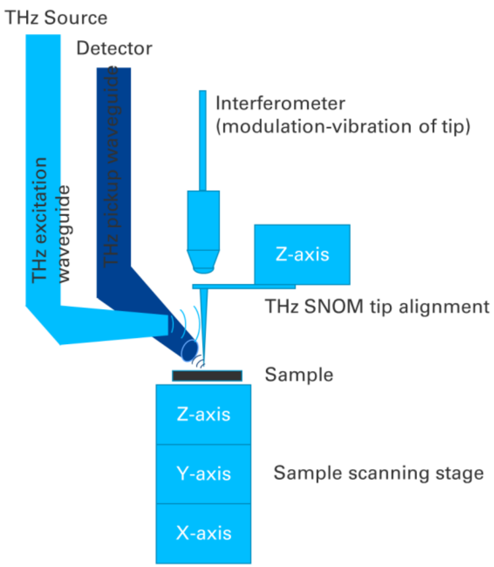
WP No	Work Package Title	Lead Participant Short Name	Person-Months	Start Month	End Month
1	PE THz EPR spectroscopy	NGU	123.5	M1	M30
2	PE THz EPR microscopy	USTUTT	130.7	M5	M36
3	Management, CDE	BUT	59.4	M1	M36

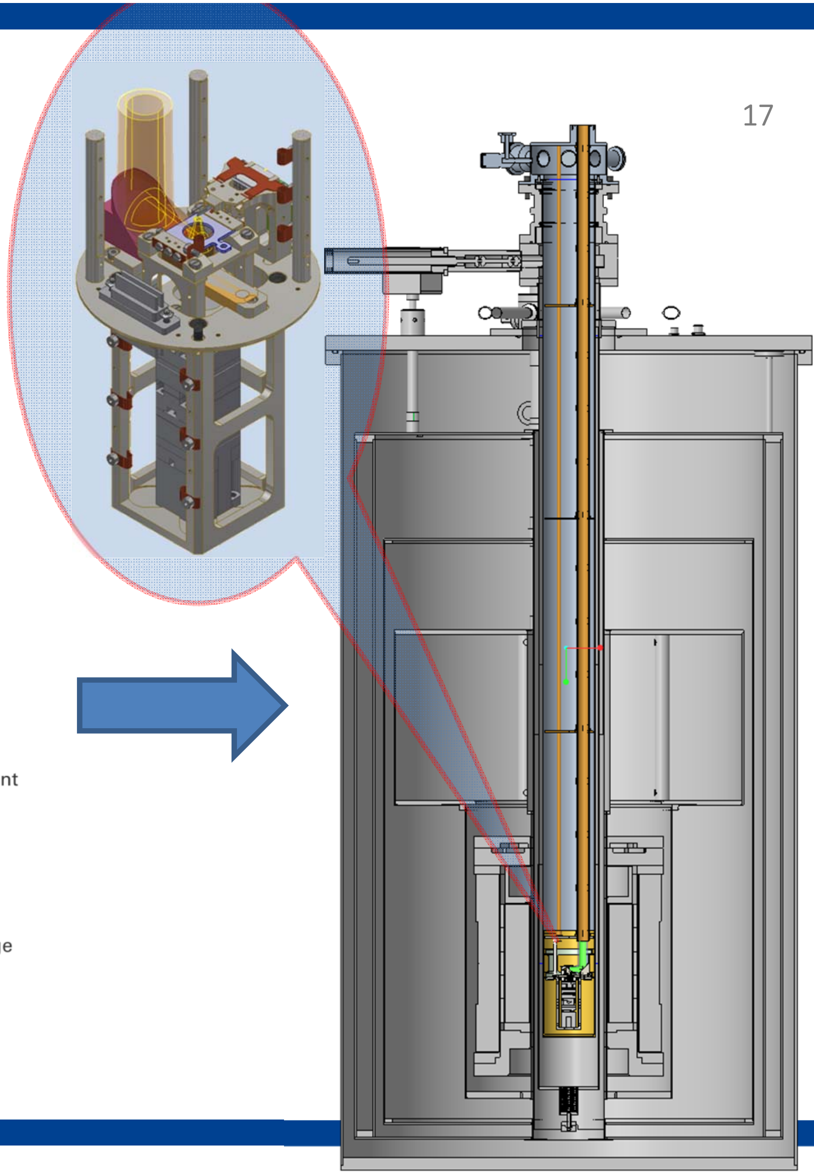


Progress so far

PETER







Workshop

Why an international workshop?

Description of work and role of partners
WP3 - Management, communication, dissemination, and exploitation [Months: 1-36] **BUT**, USTUTT, NGU, TK WP3 is led by BUT (the project coordinator - PC: Tomáš Šikola, BUT) in collaboration with the project manager (PM; BUT), WP leaders, and other key persons (see Part B, Sect. 4-5). It includes the project management and assessment, and also communication, dissemination, and exploitation (CDE) activities. The work is broken down into the following tasks: T3.1. Management (BUT, USTUTT, NGU, TK) Quality & Risk management: Defining and updating the Quality Management Plan (PC, PM) - introducing formal processes for the project life-cycle, and the evaluation and control of the deliverables and the project itself according to the quality standards and plans. Identification, evaluation and management of problems and risks to secure a timely execution of the project. Coordination and day-to-day management: PC and PM, see Sec. 3.2 for details. Meetings: Kick-off meeting (M2), mid-term meetings (M12, M24) and final meeting (M36), in urgent cases tele-conferences. Workload: M1-M36 T3.2. Communication, dissemination and exploitation (CDE) activities (BUT, TK, USTUTT, NGU) Defining, evaluating and updating the CDE plan: adoption of detailed strategy (communication messages, means, and targets), data management plan (data use, sharing, storage), open-access policy, and intellectual property rights. Evaluation and adjustment of the plan effectivity on yearly basis using quantitative indicators Providing visual identity of the project including the logo. Meeting and events: Popularization (Open days etc.): M12, M24, M36, all participants, professional: summer school (M6, BUT), workshops for scientific community (M18, M30, USTUTT and NGU) and industrial partners (M32, TK). Workload: M1–M36

Workshop

Why an international workshop?

- Dissemination to the scientific community: who we are, what we are doing.
- Learning from scientific community: THz science, materials and methods

- Support of Early Career Researchers
- Sowing PETER seeds in ECRs

PETER