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CERN related research topics at Institute of Physics in University of Tartu

Heikki Junninen - Climate research, CLOUD

Marco Kirm - Detector material development, CCC

Stefan Groote - Theoretical physics, COMPASS

Vladimir Hižnjakov

Yury Orlovskiy - Quantum technology, education

Veiko Palge

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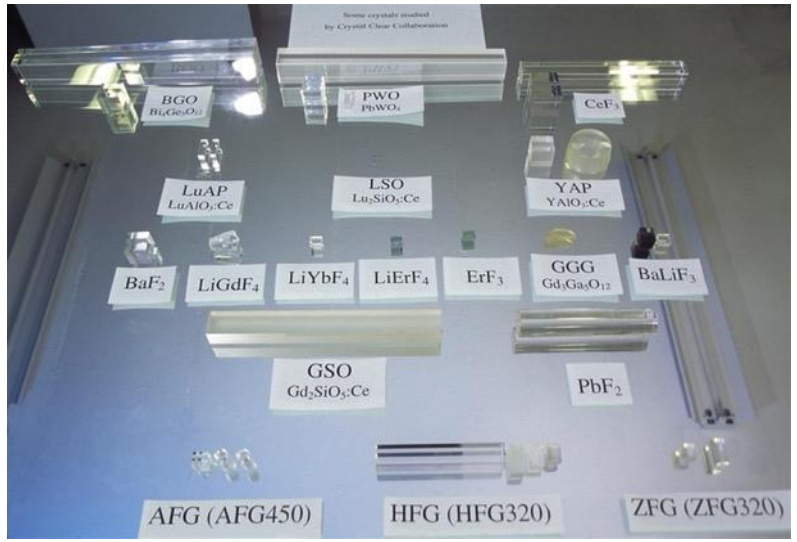
Prof. Marco Kirm
Laboratory of Physics of Ionic Crystals

CRYSTAL CLEAR COLLABORATION

The **main aim** of this project was to develop **scintillating materials**
CCC is a consortium of scientists from 17 countries world-wide (27 organisations)

University of Tartu signed MoU with CCC at CERN on July 2, 2013.



Crystal Clear achievements and current activities**:**

- **Selection of $PbWO_4$ as detector material for CMS** (76648 crystals) **and ALICE** (17920 crystals) → Higgs Boson discovery in 2012.
- **New scintillators for medical imaging:** LuAP,LuYAP, LSO,LYSO crystals
- development of PET-tomography for medical imaging.
- enhancement of LY (photonic crystals and heterostructures).
- understanding of ultrafast timing properties of scintillators.
- production of new crystal with novel techniques for particle physics

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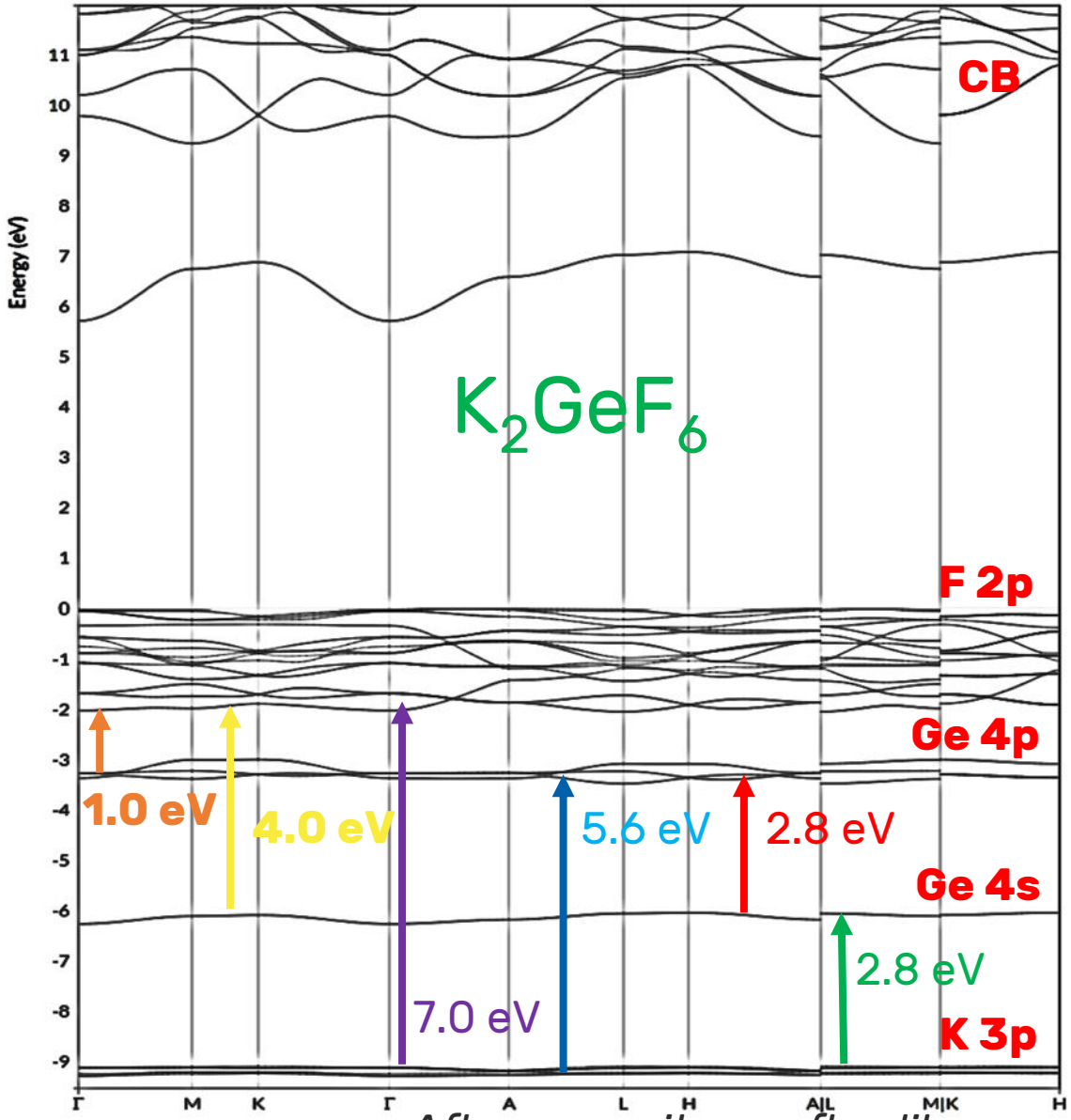
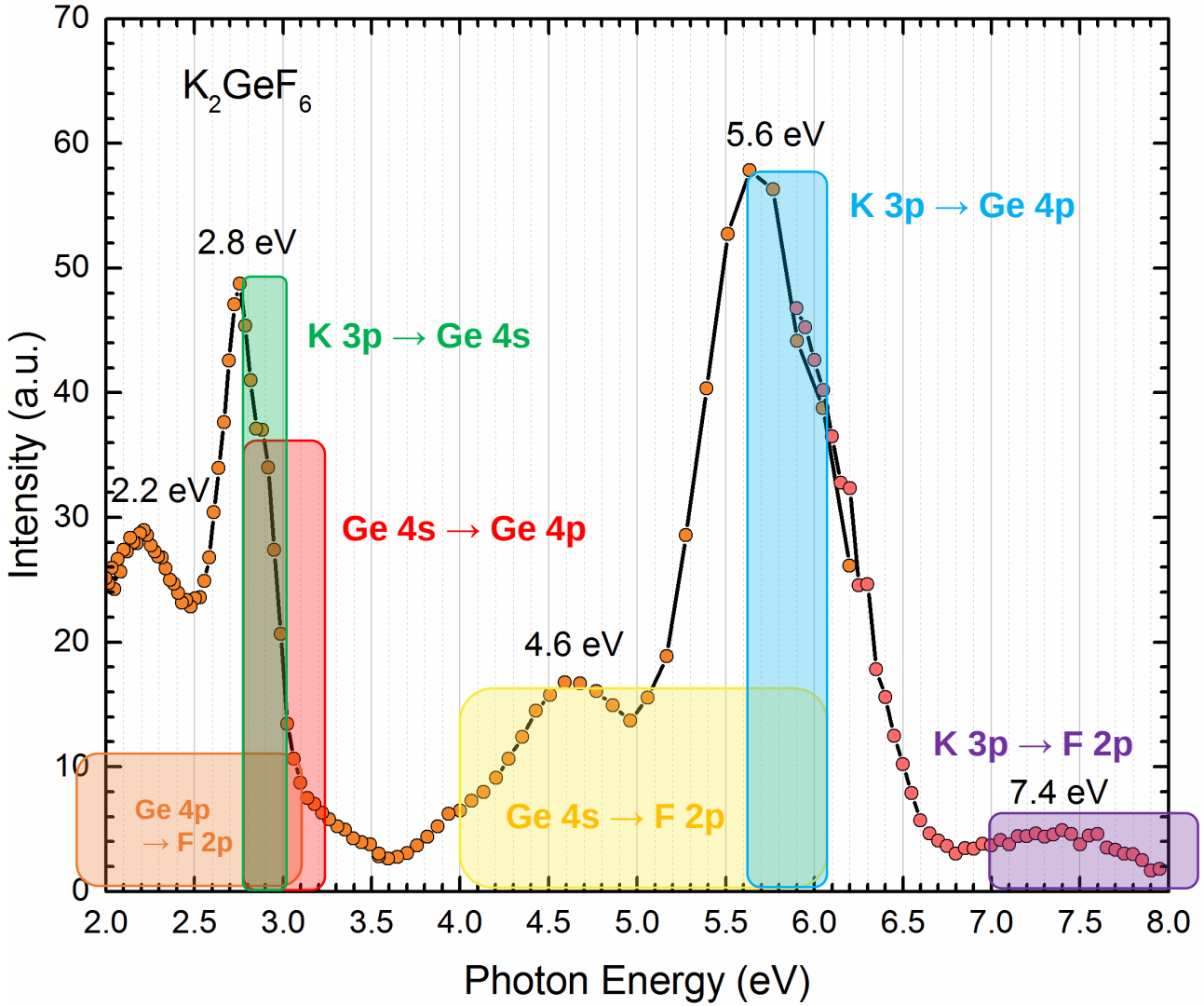
Origin of fast emissions



Aflow repository, aflowlib.org

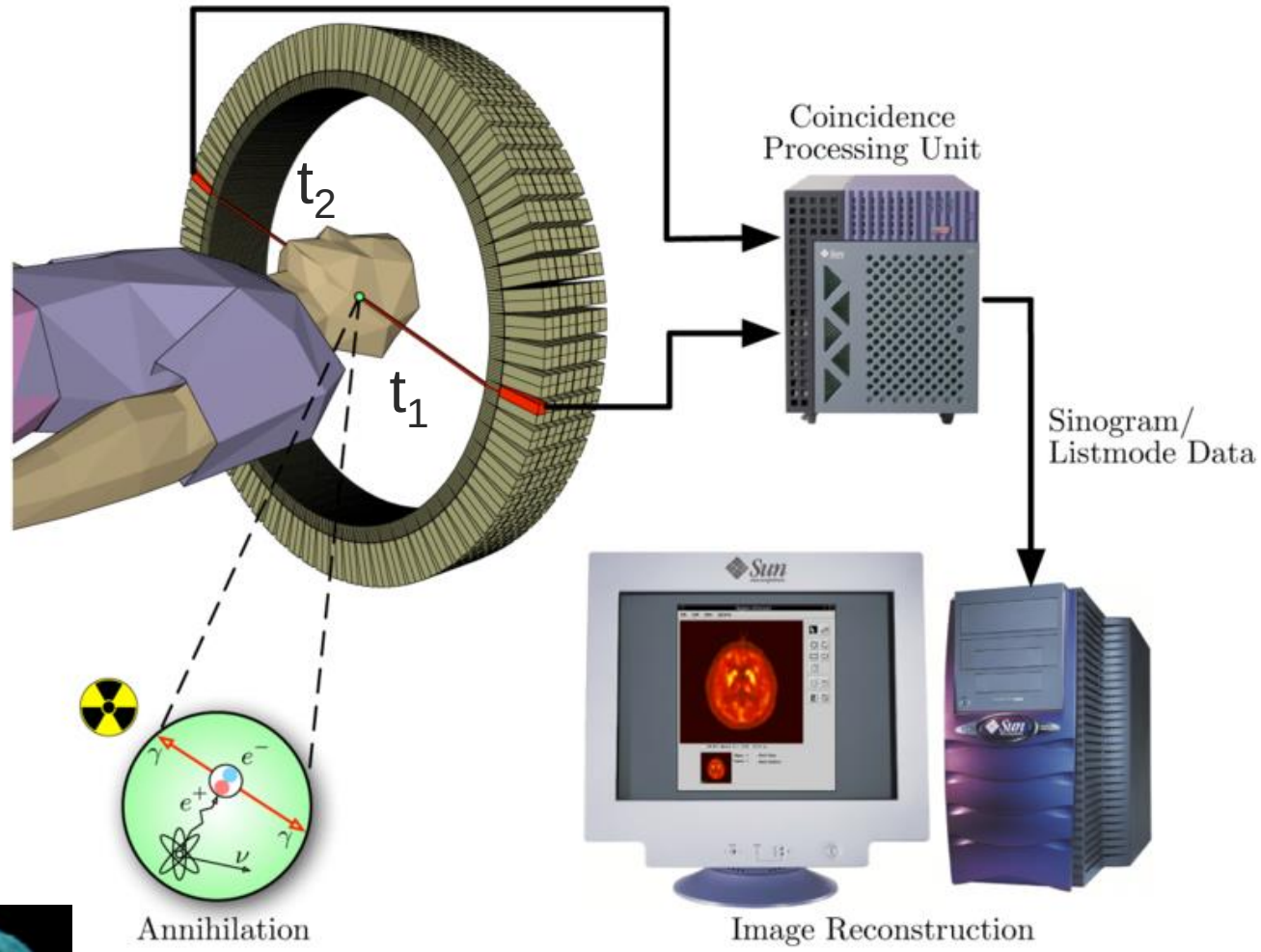
PL em. spectra in 0-3 ns TW combined with 10 kV el. exc. VUV em

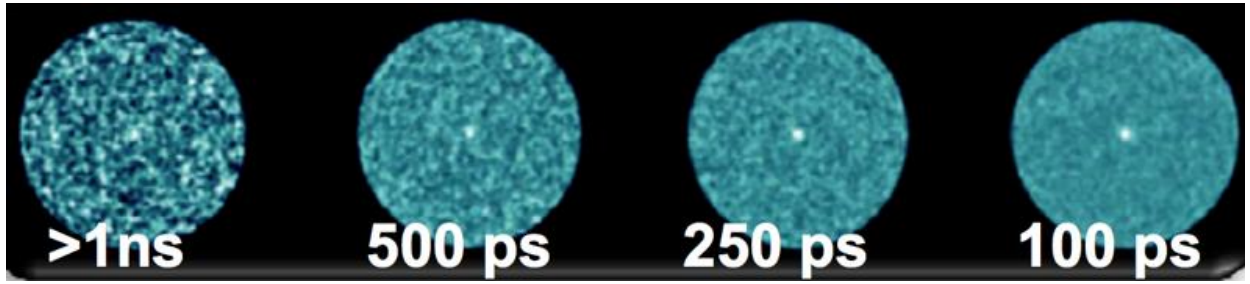


J. Saaring, *et al.*, J. Alloys Compd. **883** (2021) 160916.

TOF-PET (Time-of-Flight Positron Emission Tomography

- Ultrafast scintillators are needed in order to benefit from the precise determination of γ-quanta birthplace in the human body using time-of-flight technique (a goal in time resolution is 10 ps)
- 1 ps = 10^{-12} s

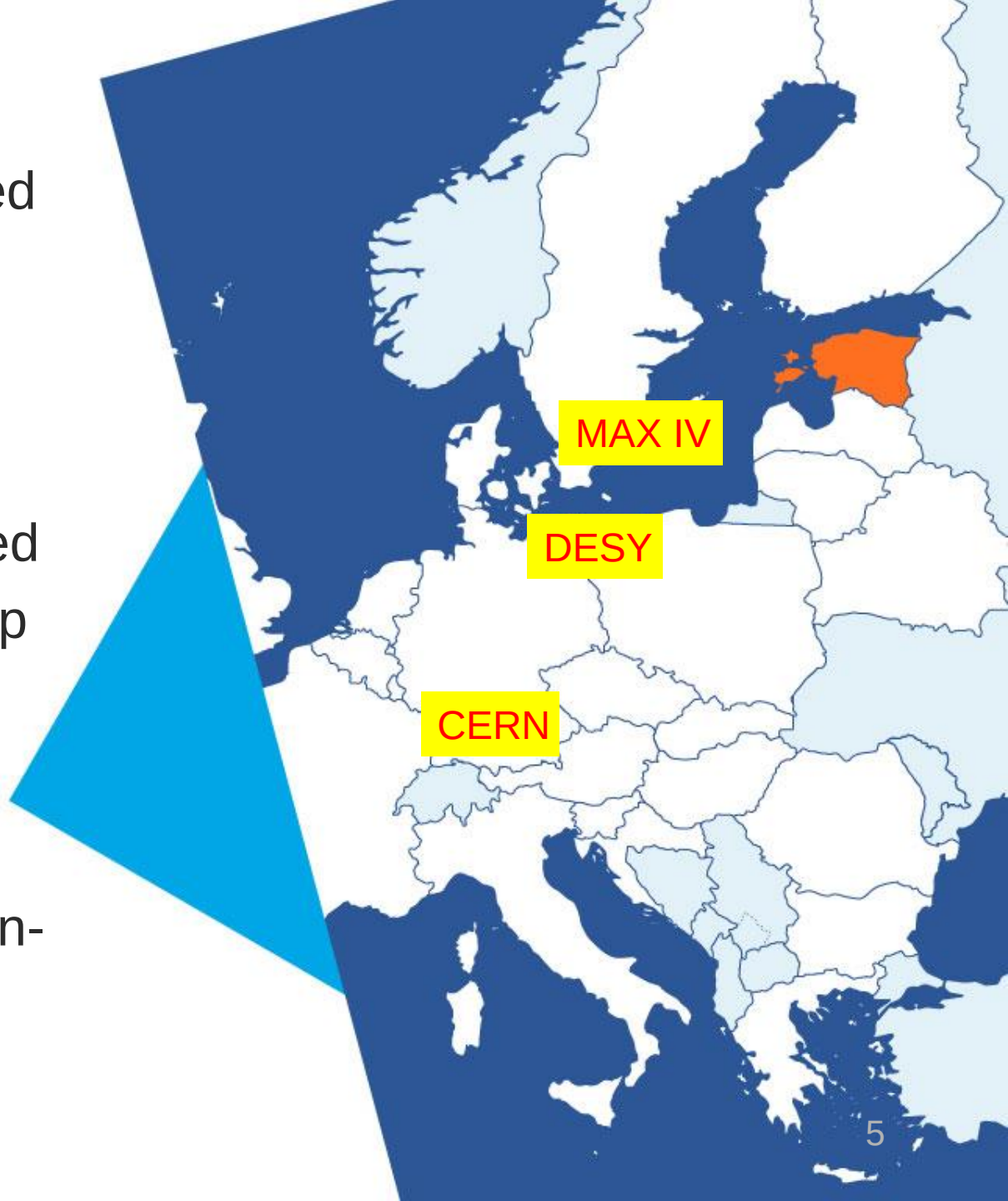




10 ps equals to 1.5 mm spatial resolu

FUTURE

- Joint research within CCC will be continued – on **ultrafast scintillators and heterostructures**
- Synthesis of **novel scintillator** materials
- **Complementary research** using advanced photon sources provided by other roadmap infrastructures like MAX IV Lab (FinEstBeAMS beamline and Short Pulse Facility - FemtoMAX) and DESY Photon Science (P23 and P66 at PETRA III) and in-house
- Theory and modelling ultrafast processes with the CCC partners



Eesti ja CERN

Production of heavy quarks via the intrinsic charm quark mechanism at the COMPASS experiment

Dr. *habil* Stefan Groote, January 21st, 2021

Institute of Physics, University of Tartu, Estonia

Work together with Dr. Sergey Koshkarev in the framework of our common associate membership to the COMPASS collaboration

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Quantum technology – building a quantum computer

Scientists at the *Institute of Physics of the University of Tartu* are working on creation of **ultrafast optical quantum computers** of a new type. The leading idea of their Estonian Science Foundation project (grant PRG347 (Profs. **Yury Orlovskiy** and **Vladimir Hizhnyakov**) is to use impurity centers in crystals with optical frequency qubits, which can work with ***ns*** and **sub-*ns* cycles**. This would allow one to overcome one the major obstacles in the creation of quantum computers: the faster the computation cycle, the less interference is caused by the surrounding environment in the work of qubits.

Profs. **Yury Orlovskiy** and **Vladimir HizhnyakoV**

Electronic states of rare earth ions doped mixed fluoride nanocrystals *as qubits for ultrafast quantum gates suitable for optical quantum computers*

Mixed fluoride crystals like **$(La,Y)F_3$ and $(Ca,Sr)F_2$** doped with **rare earth ions (REIs)** like **(Pr^{3+}, Nd^{3+}, Er^{3+}, Tm^{3+})** are found to be most promising for creation of such **optical quantum computers [1, 2].**

These **rare earth ions** have both, weakly and strongly interacting states. **Weakly interacting states** are suitable for **qubit states**, and the **strongly interacting states** are suitable for **auxiliary states** necessary for the Stark blockade to perform conditional quantum gate operations **(CNOT).** High concentration of REIs ions, very weak interaction with phonons, very small homogeneous and very large inhomogeneous broadening of spectral lines stemming from strongly inhomogeneous crystal field in the mixed crystals allowing to make quantum computers with large number of qubits, ultrafast computation speed and better reliability compared to earlier solutions.

Quantum Teaching:

"Introduction to quantum algorithms"
"Quantum computer science seminar"
"Quantum error correction and fault-tolerant quantum computing"
"More quantum algorithms"
“Fundamentals of Quantum Computing”
“Quantum Cryptography”

MSc 4; 3 graduated, 1 ongoing
PhD 2; 1 graduated, 1 ongoing

Researhers:
V Palge (FI), B Ghandchi (CS), D Unruh (CS), D. O. Theis (CS), Y. Orlovskiy (FI), V. Hizhnyakov (FI)

Laboratory of Laser Spectroscopy
Laboratory of Theoretical Physics
Laboratory of Solid State Theory

CNOT

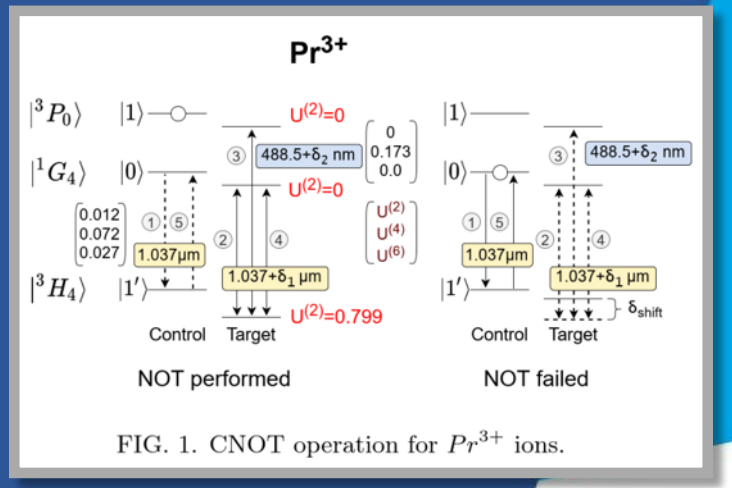

FIG. 1. CNOT operation for Pr^{3+} ions.

Notes: The scheme of the CNOT gate operation for doped crystals. The arrows indicate the excitation by π-light pulses, the numbers denote the pulse sequence. The circles indicate the initially occupied levels of the control qubits. A δ is a shift of the auxiliary level in the target qubit by changing the state of the control ones. The $U^{(k)}$ are the squares of reduced matrix elements determining the line strengths of the electronic transitions.

[1] Opt. Commun. 485, 126693 (2021) **[2]** arXiv:2103.13319v1 [quant-ph] (2021)

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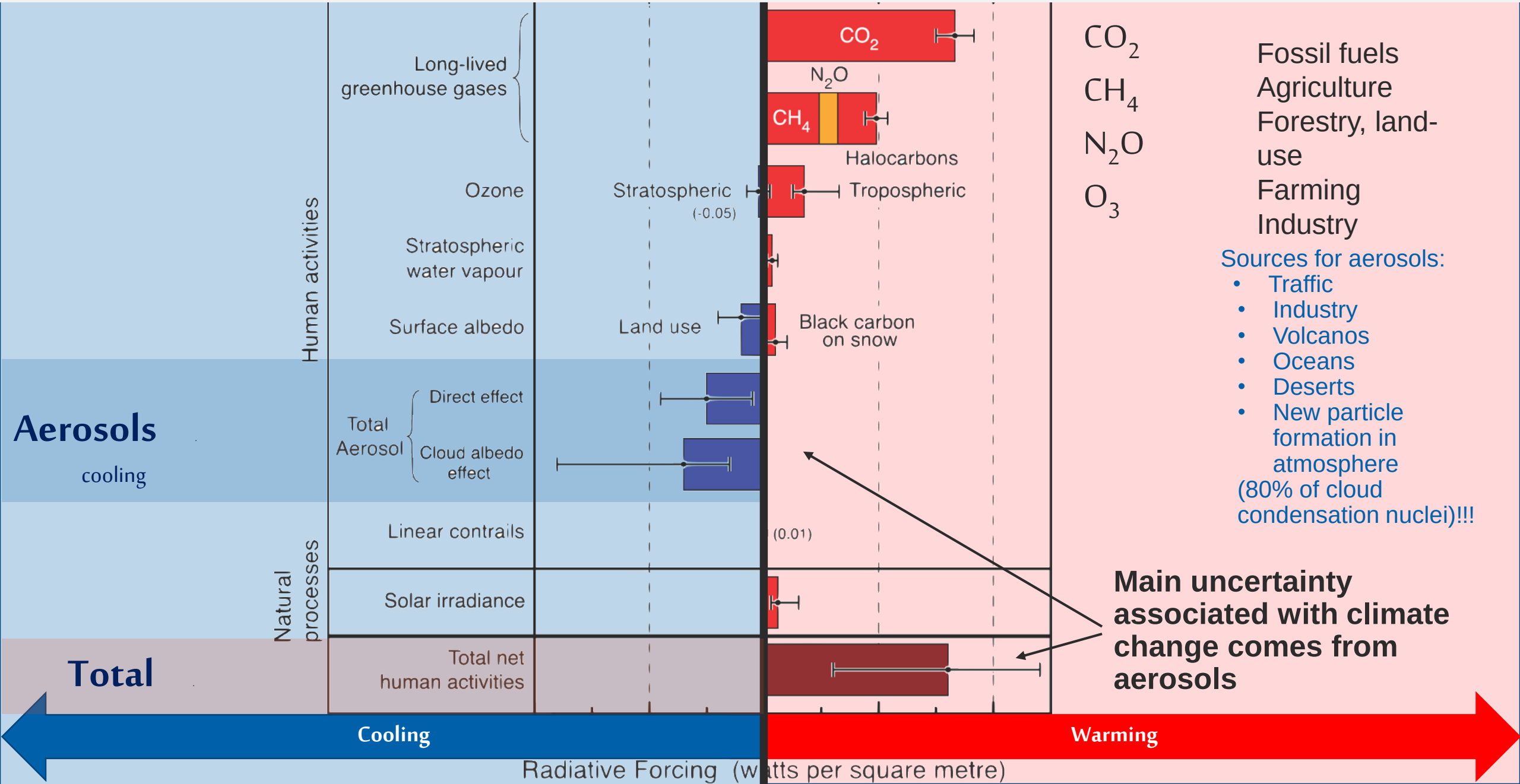
CLOUD experiment – climate research in CERN

Cosmic Leaving Outdoor Droplets

Prof. Heikki Junninen
Head of Laboratory of Environmental Physics

Aerosol physics
Atmospheric chemistry
Atmospheric long-term measurements

Anthropogenic factors in climate CHANGE



CO_2

CH_4

N_2O

O_3

Fossil fuels
Agriculture
Forestry, land-use
Farming
Industry

Sources for aerosols:

- Traffic
- Industry
- Volcanos
- Oceans
- Deserts
- New particle formation in atmosphere

(80% of cloud condensation nuclei)!!!

Main uncertainty associated with climate change comes from aerosols

What does CLOUD study?

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Kirkby, J., et al. Role of sulphuric acid, ammonia and **galactic cosmic rays** in **atmospheric aerosol nucleation**.
Nature 476, 429–433 (2011).

Almeida, J., et al. Molecular understanding of sulphuric acid-amine particle **nucleation in the atmosphere**.
Nature 502, 359–363 (2013).

Lehtipalo, K., et al. The effect of acid-base clustering and ions on the **growth of atmospheric nanoparticles**.
Nature Commun. 7, doi: 101038/ncomms11594 (2016).

Tr¨ostl, J., et al. The role of low-volatility organic compounds to initial **particle growth in the atmosphere**.
Nature 533, 527–531 (2016).

Wang., M., Kong, W., et al. Rapid growth of **new atmospheric particles** by nitric acid and ammonia condensation.
Nature 581, 184–189 (2020).

Riccobono, F., et al. Oxidation products of biogenic emissions contribute to **nucleation of atmospheric particles**.
Science 344, 717–721 (2014).

Dunne, E., et al. **Global atmospheric particle formation** from CERN CLOUD measurements.
Science 354, 1119–1124 (2016).

Lehtipalo, K., et al. Multi-component **new particle formation** from sulfuric acid, ammonia, and biogenic vapors.
Science Advances 4, 12, doi: 10.1126/sciadv.aau5363 (2018).

Yan, C., et al. Size-dependent influence of NOx on the growth rates of **organic aerosol particles**.
Science Advances 6, doi: 10.1126/sciadv.aay4945 (2020).

He, X.-C., et al. Global significance of iodic acid **new-particle formation in the atmosphere**.
Science, in press (2021).

In total 80 publications

The Nobel Prize in Physics 2021: Syukuro Manabe and Klaus Hasselmann "for the **physical modelling of Earth's climate**, quantifying variability and reliably predicting global warming"

CLOUD Experiment: the chamber

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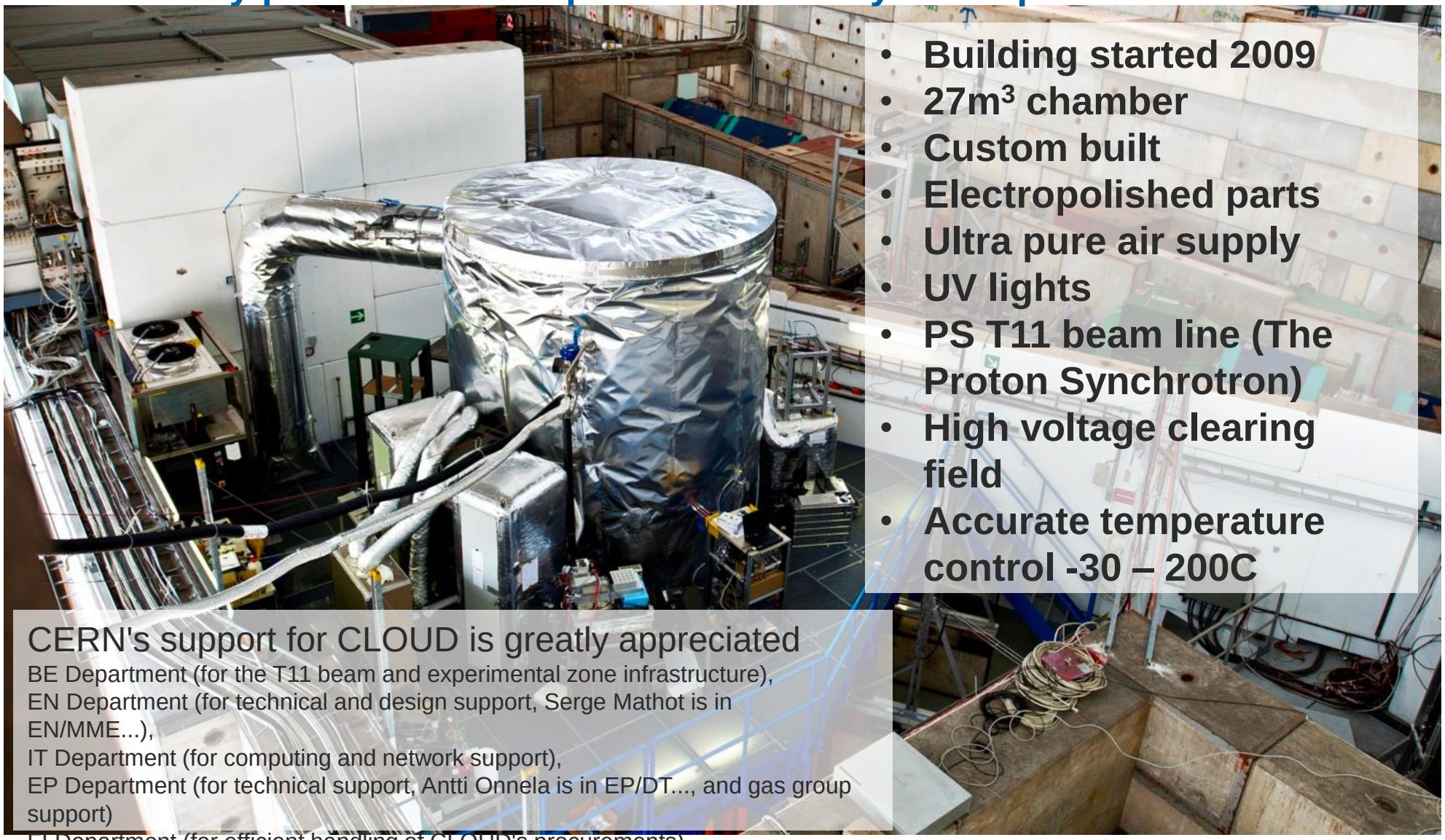
first and only particle beam experiment to study atmospheric and climate science



- Building started 2009
- 27m³ chamber
- Custom built
- Electropolished parts
- Ultra pure air supply
- UV lights
- PS T11 beam line (The Proton Synchrotron)
- High voltage clearing field
- Accurate temperature control -30 – 200C

First campaign 2010
Latest CLOUD13 2020
Next CLOUD15T 2022

Strong international collaboration:
17 institutions
9 countries from Europe and USA

MoU with UT and CERN is in signing phase

CERN's support for CLOUD is greatly appreciated
BE Department (for the T11 beam and experimental zone infrastructure),
EN Department (for technical and design support, Serge Mathot is in EN/MME...),
IT Department (for computing and network support),
EP Department (for technical support, Antti Onnela is in EP/DT..., and gas group support)
FI Department (for efficient handling of CLOUD's procurements)

CLOUD experiment hypothesis

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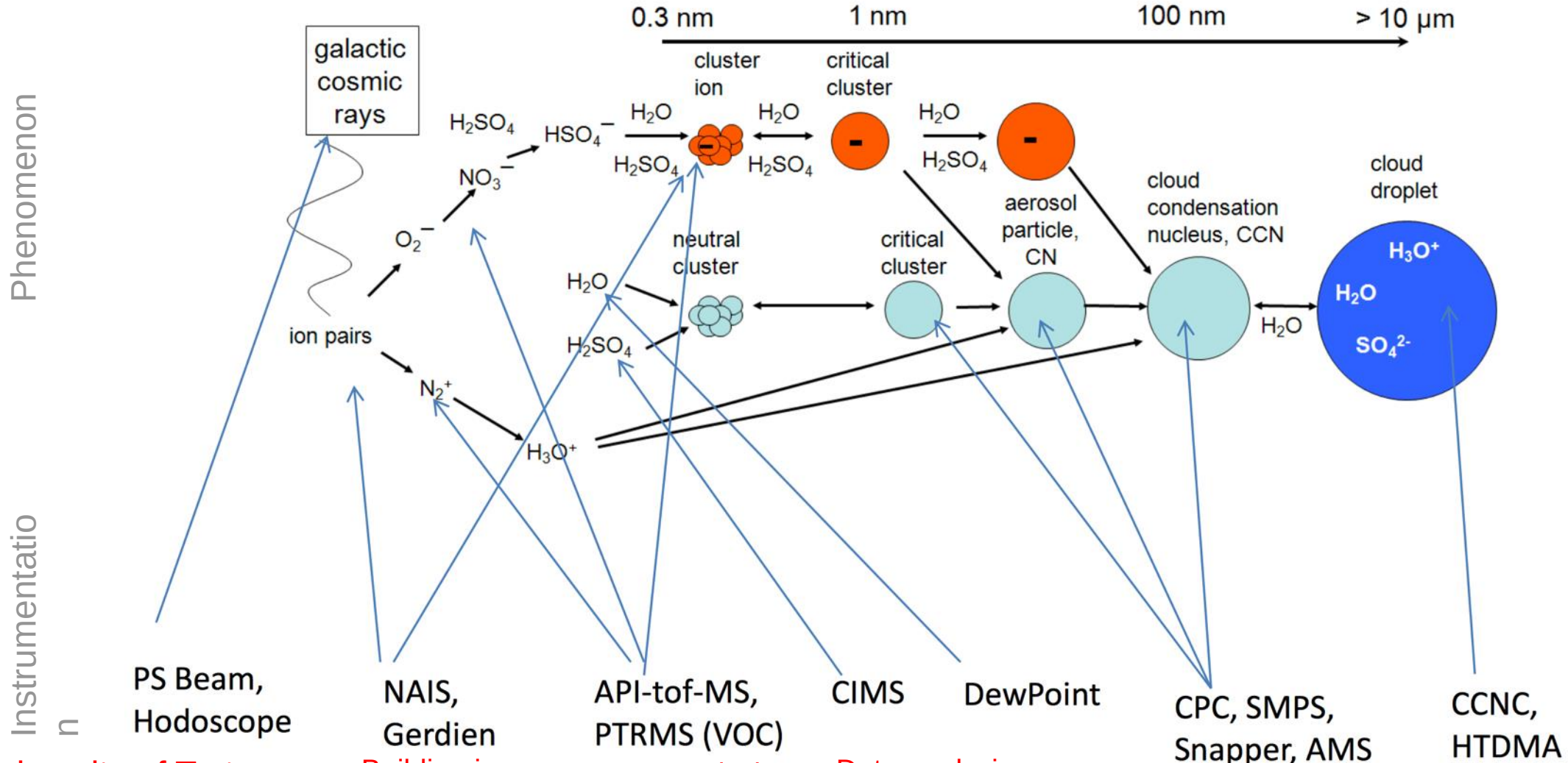


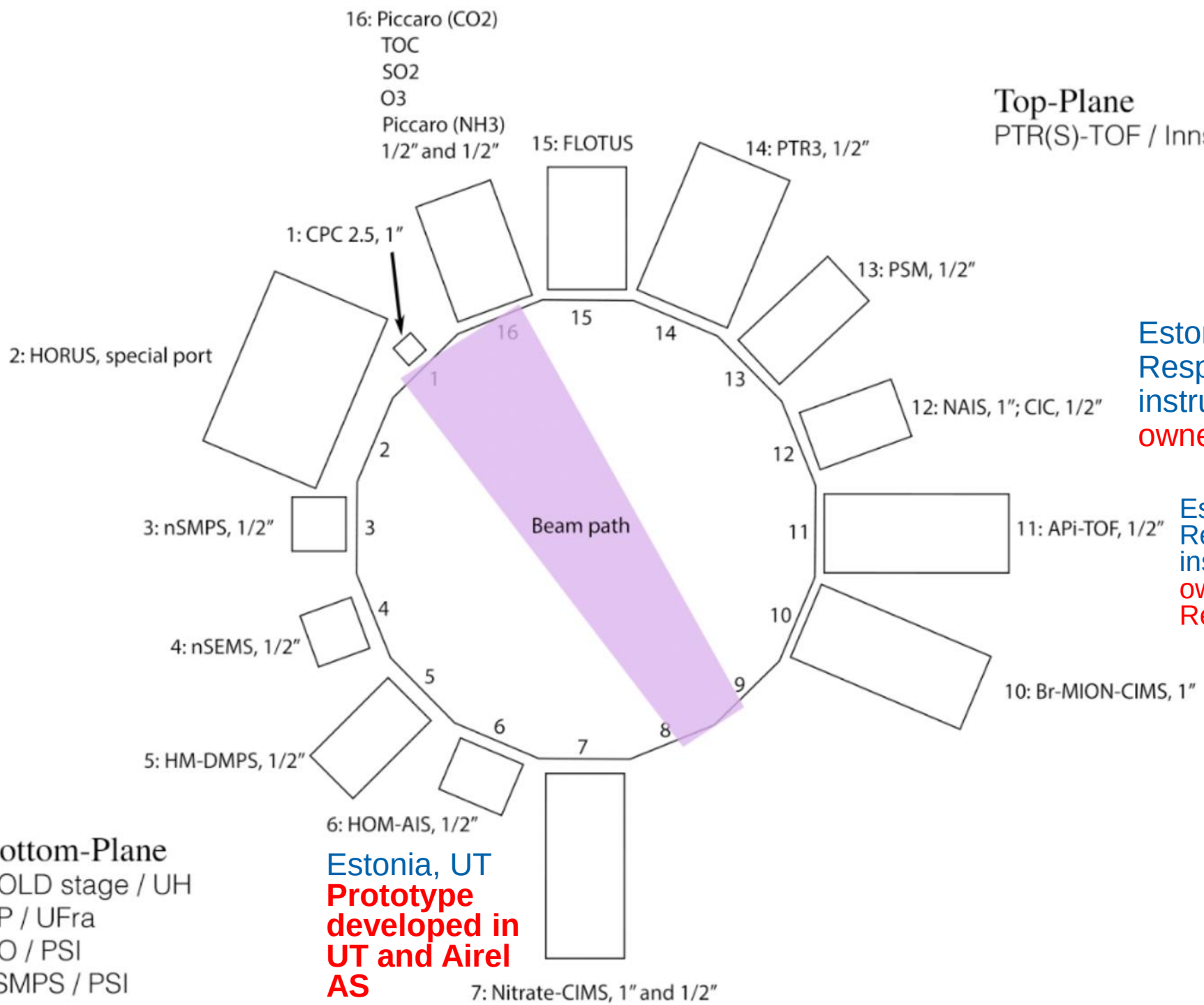
University of Tartu involvement

Building ion spectrometers, technical

Data analysis and software development

Data analysis and software development

CLOUD overview presentation by Duplissy, 2010



Top-Plane
PTR(S)-TOF / Inns

OF TARTU

Estonia, UT
Responsible for the instrument
owner by CERN

Estonia, UT
Responsible for the instrument
owner by Aerodyne Research Ltd

Bottom-Plane
COLD stage / UH
DP / UFra
CO / PSI
LSMPS / PSI

Estonia, UT
Prototype developed in UT and Airel AS

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- Scientific collaboration
- Instrument development and support
- Mass spec. data processing and analys
- Modelling of ion molecular reactions
- Student education and exchange (ITN)

Targeted national funding scheme is needed to enable productive **long-term** collaboration

Thank you for your attention!