New approach to photoacoustic imaging for medical applications

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Kungl. Fysiografiska Sällskapet i Lund

Lund Laser Centre

Outline

- Objective
- Motivation
- Optical properties of tissue
- Photo-acoustic tomography (PAT)
- Ultrasound optical tomography (UOT)
- Details UOT
- Current status and plans

General objective

- Developing a technique that can perform optical imaging with sub mm resolution down to substantial depths in the body
- Optical imaging is able to provide molecule specific information not obtainable by e.g. X-rays, ultrasound or magnetic resonance imaging

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Motivation for measuring tissue oxygen saturation

- Ischemia, i.e. the restriction of oxygenated blood in an area of tissue, is a cause of cardiovascular disease which is the most prevalent cause of death in Sweden for both men and women (Socialstyrelsen).
- The second most prevalent cause of death in Sweden is tumors which are often distinguished by having centers of dead, deoxygenated tissue.
- At Skåne University Hospital there are ~100 emergency patients per day (close to half of the total number) with symptoms related to ischemia possibly indicating stroke, heart failure or similar conditions

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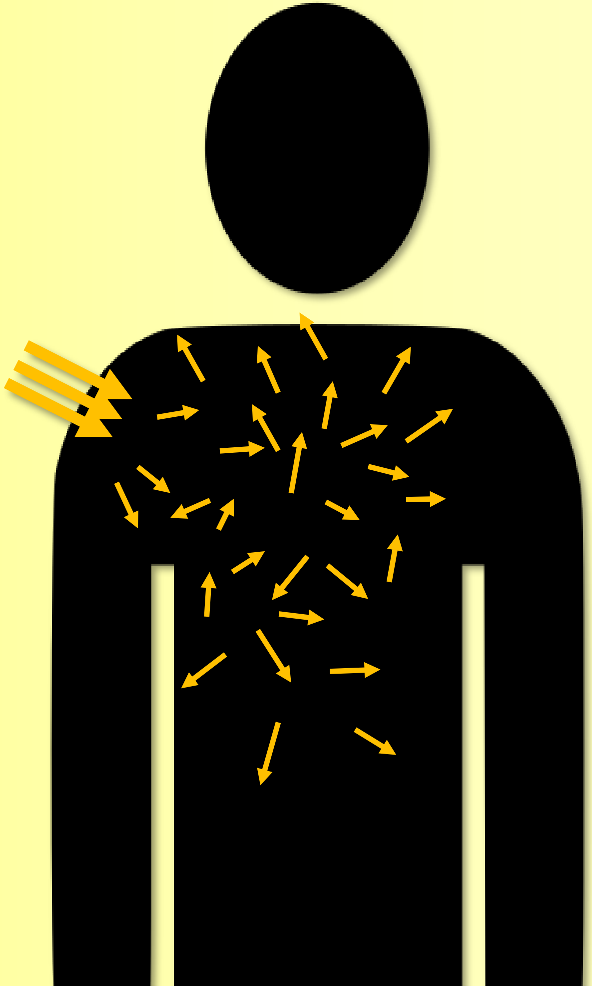
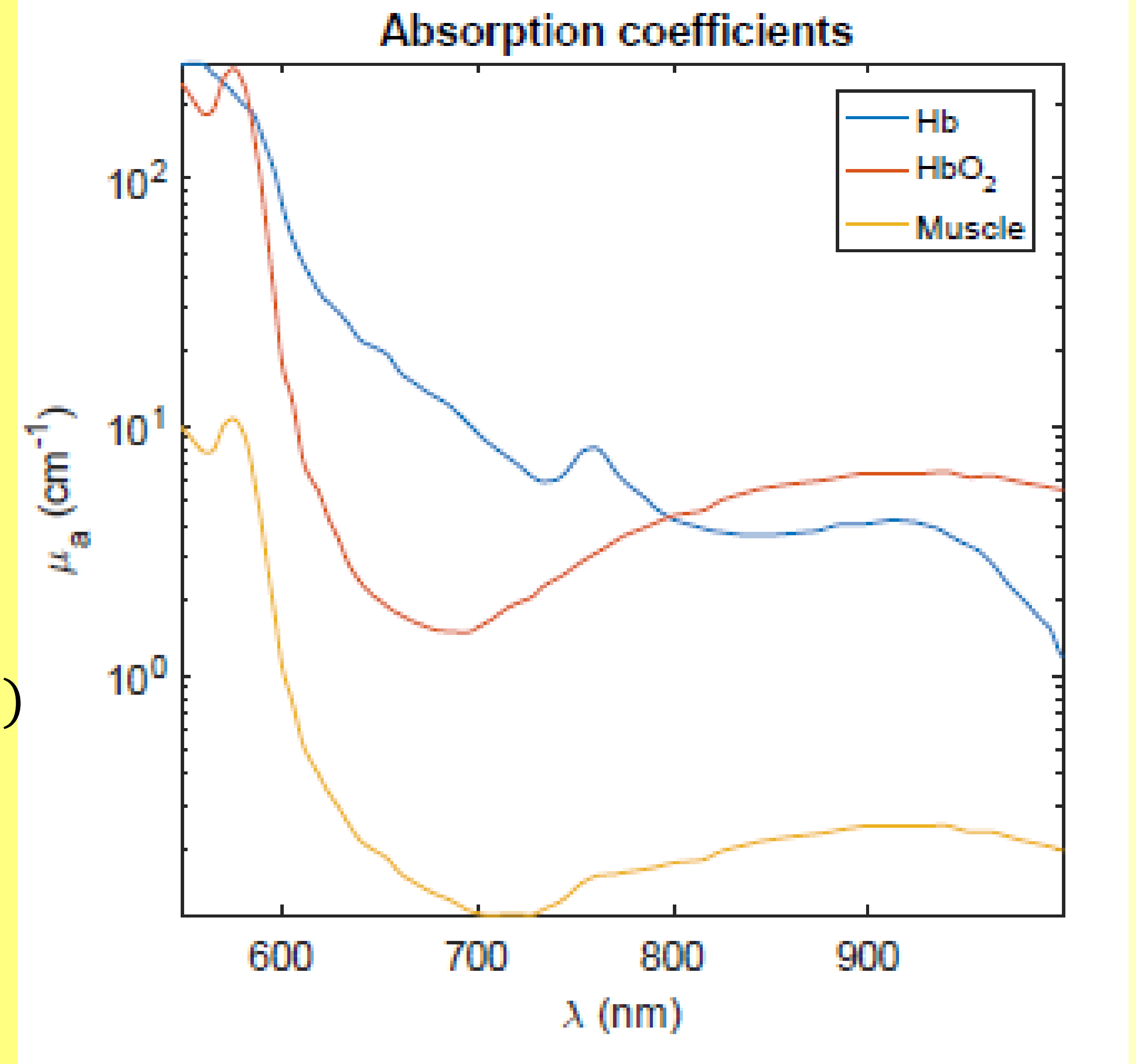
Light scattering

- Living tissue heavily scatters light
- Both scattering and absorption will limit our measurement abilities
- For example the spatial resolution in trans-illumination imaging is approximately one fifth of the depth



Courtesy: David Hill

Hemoglobin oxygenation



$$I_{trans} = I_{in} \exp(-\mu_a L)$$

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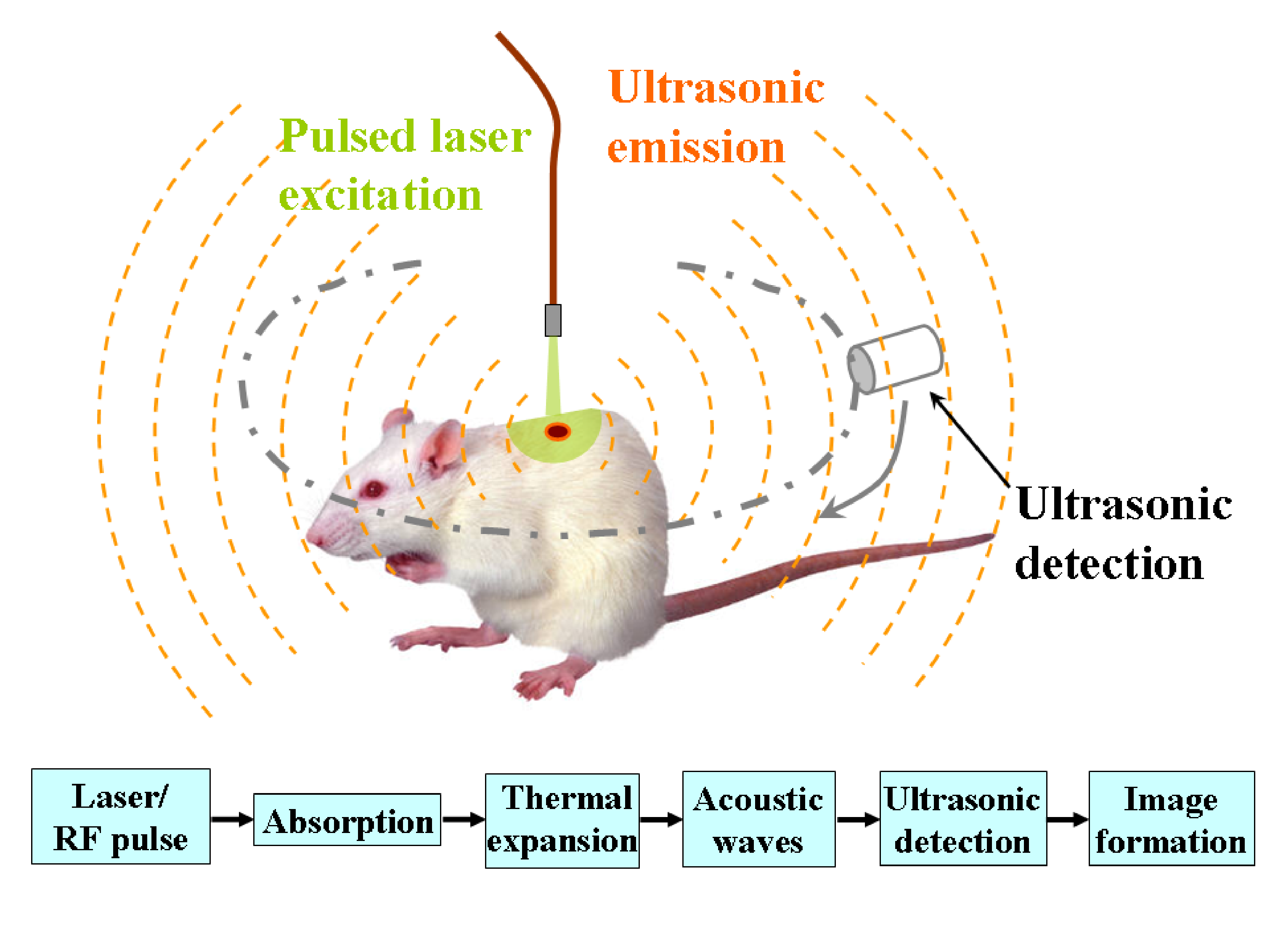
Photoacoustic tomography (PAT)

- Two PAT systems acquired by the Dept of Clinical Sciences (Bo Baldetorp)
- Used in clinical investigations of Giant cell arterisis in the temporal artery (Malin Malmsjö, Ophtalmology)

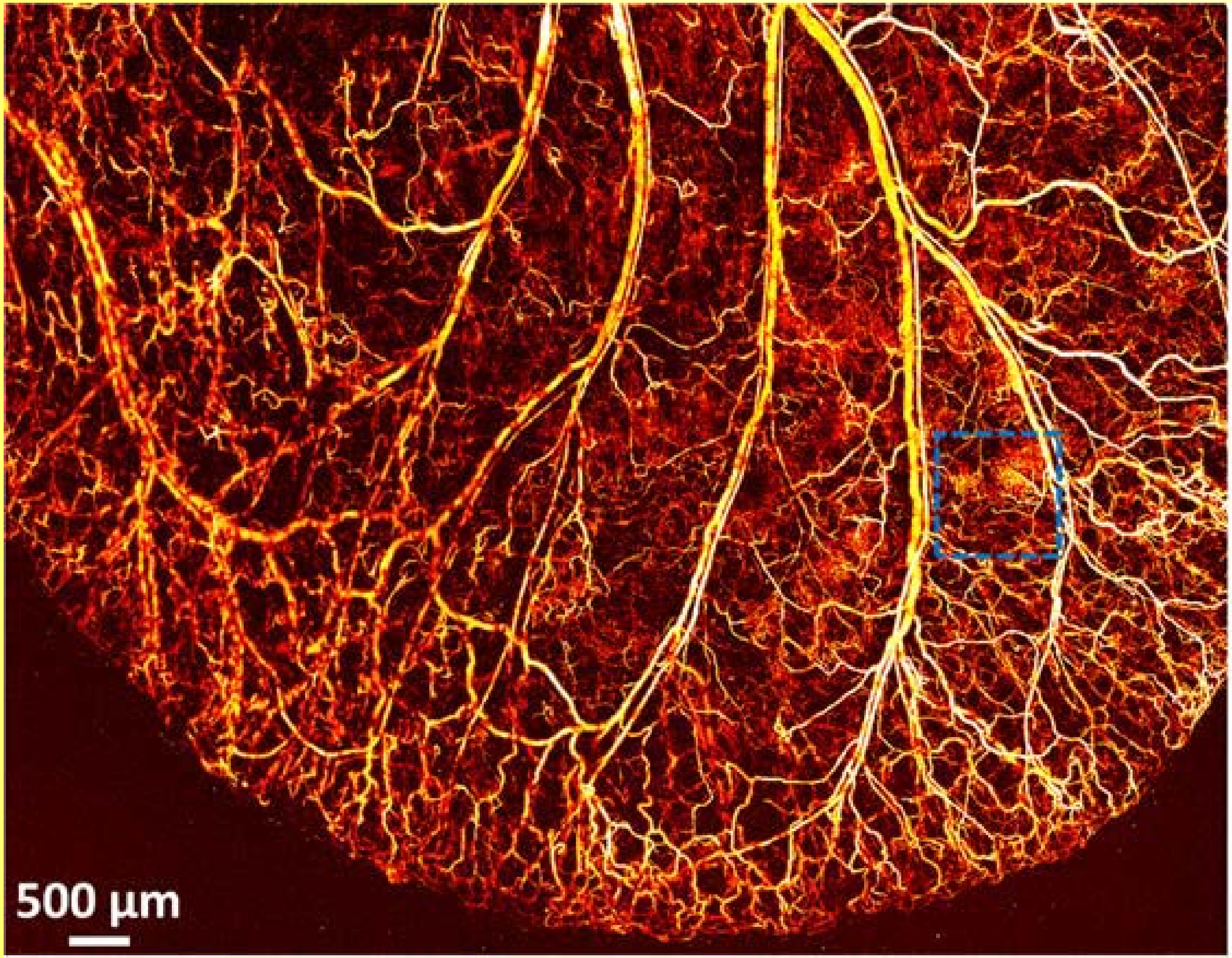
Photo-acoustic tomography



https://en.wikipedia.org/wiki/Photoacoustic_imaging

Photo-acoustic tomography (PAT)

Vasculatory anatomy in a mouse ear



70 minutes

Hu, Maslow & Wang, Opt Lett. **36**, 1134 (2011)

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What might we wish to improve?

- We would like to reach large depths and to carry out measurements within a short time

- **Ultrasound optical tomography (UOT)**

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Penetration depth & S/N for PAT & UOT

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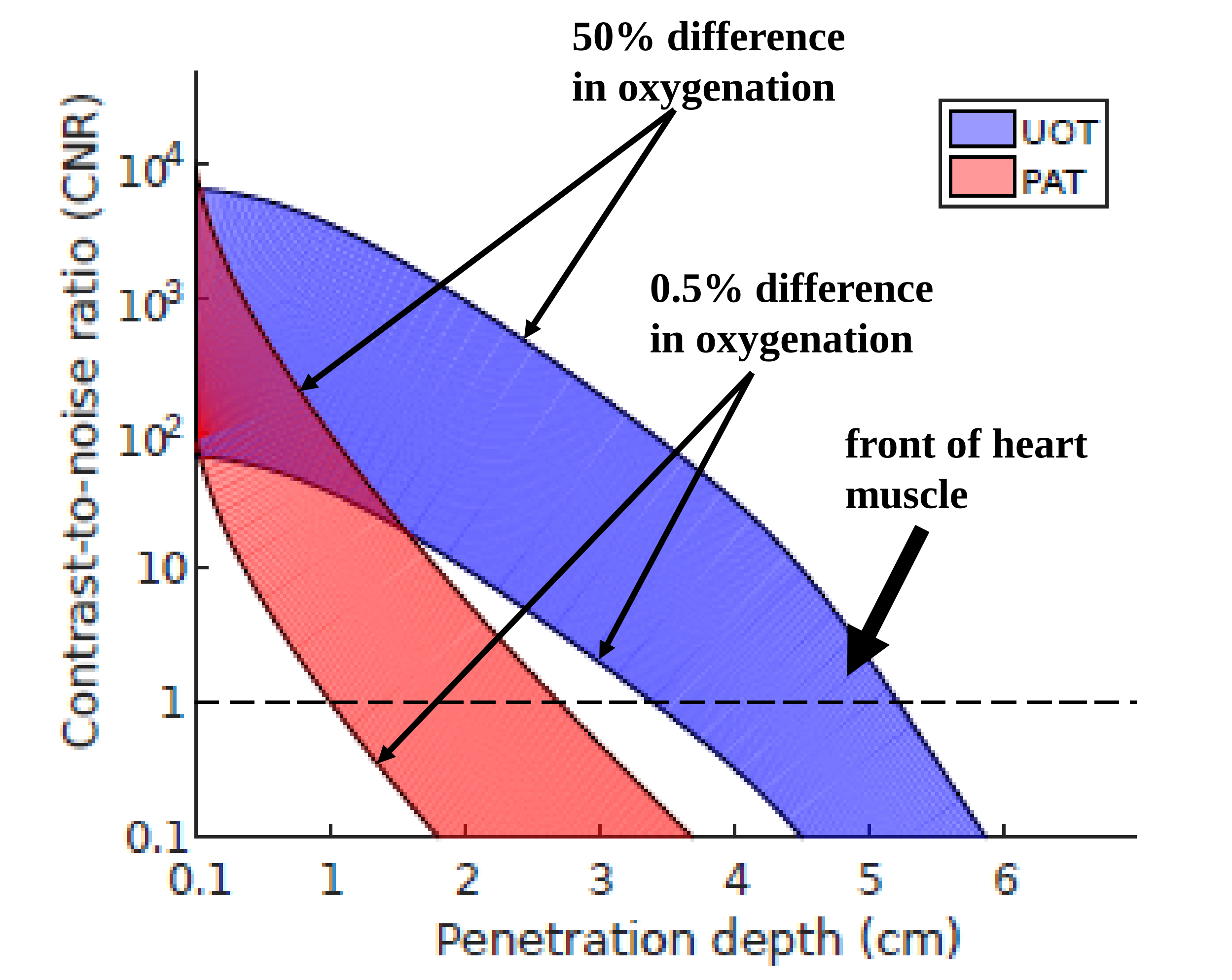
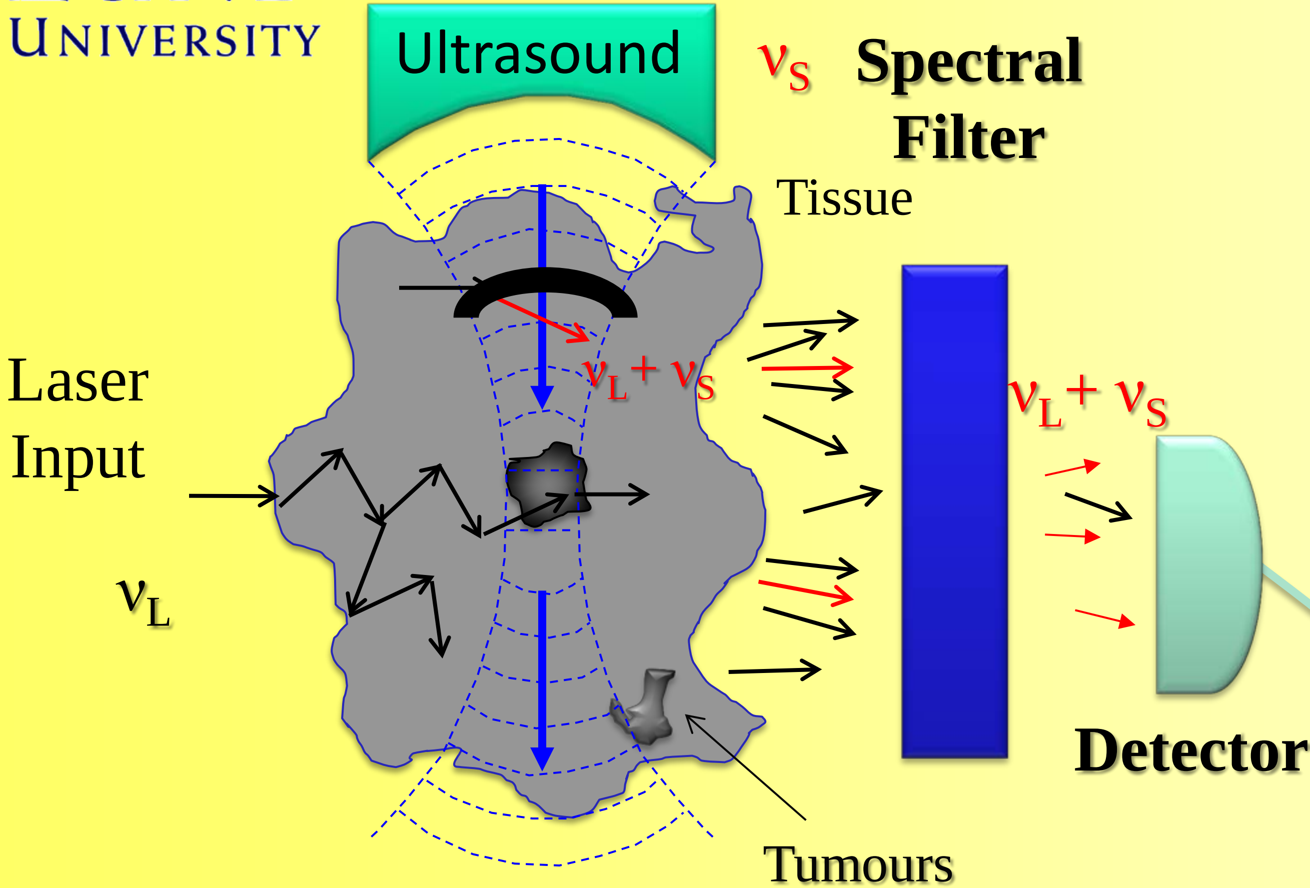
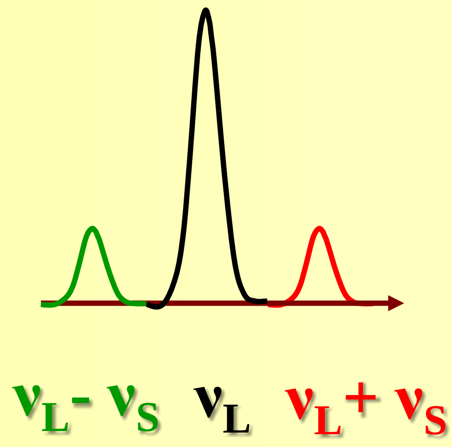
Light source inside –
Double distance

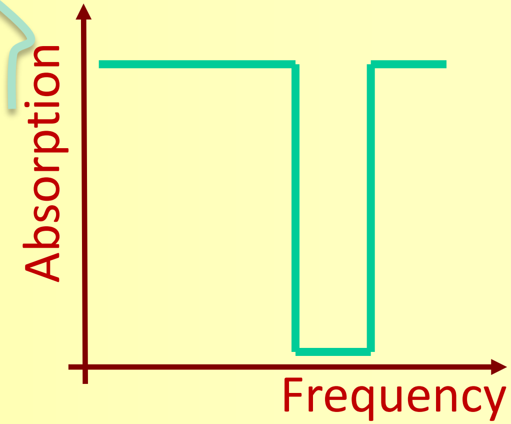


Spatial resolution: ~10 elements, ~3x3x3 mm each, measurement time, ~1s

Ultrasound optical tomography







Ultrasound attenuation coefficient in tissue 0.3 dB/(cm MHz)

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- UOT - details
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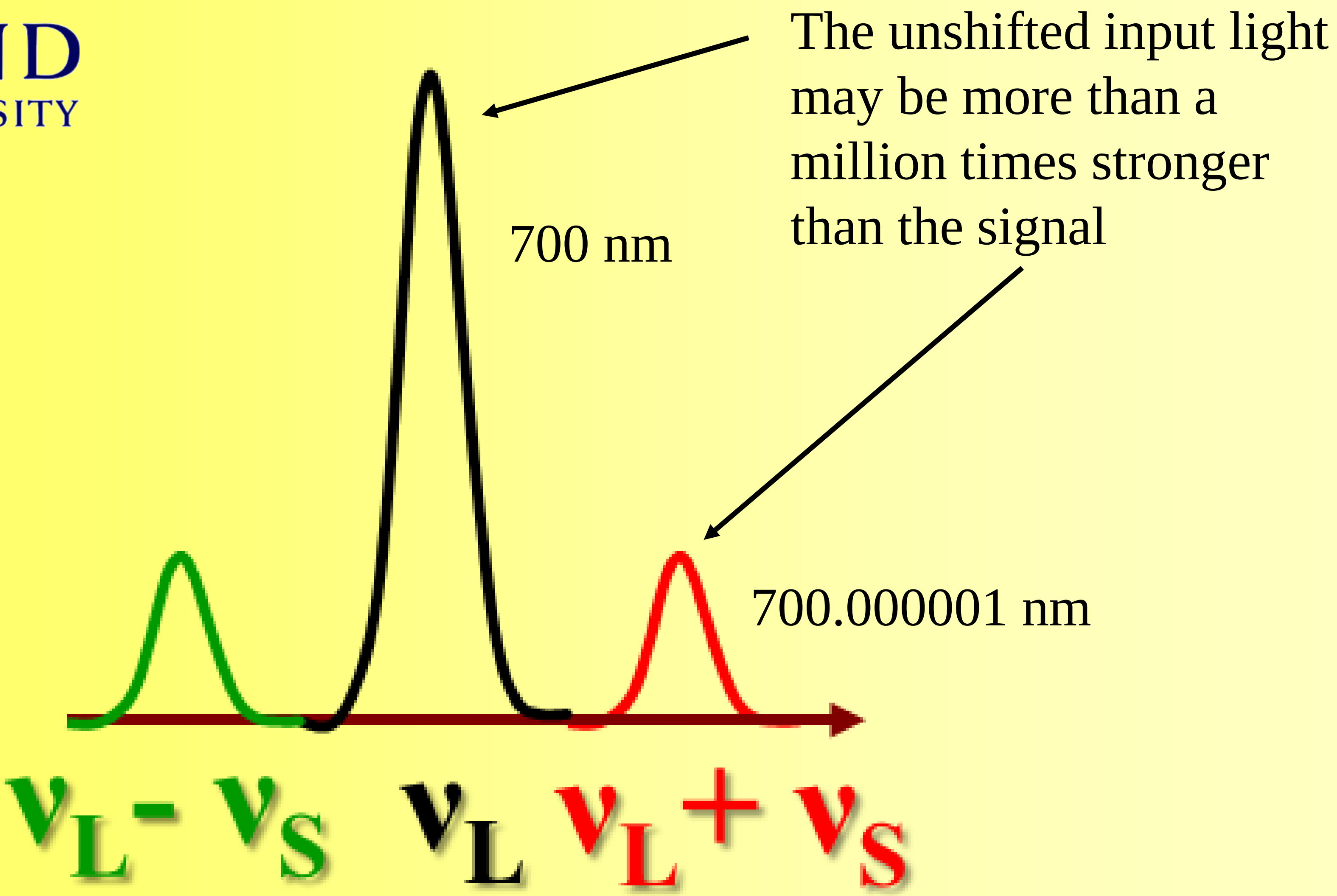
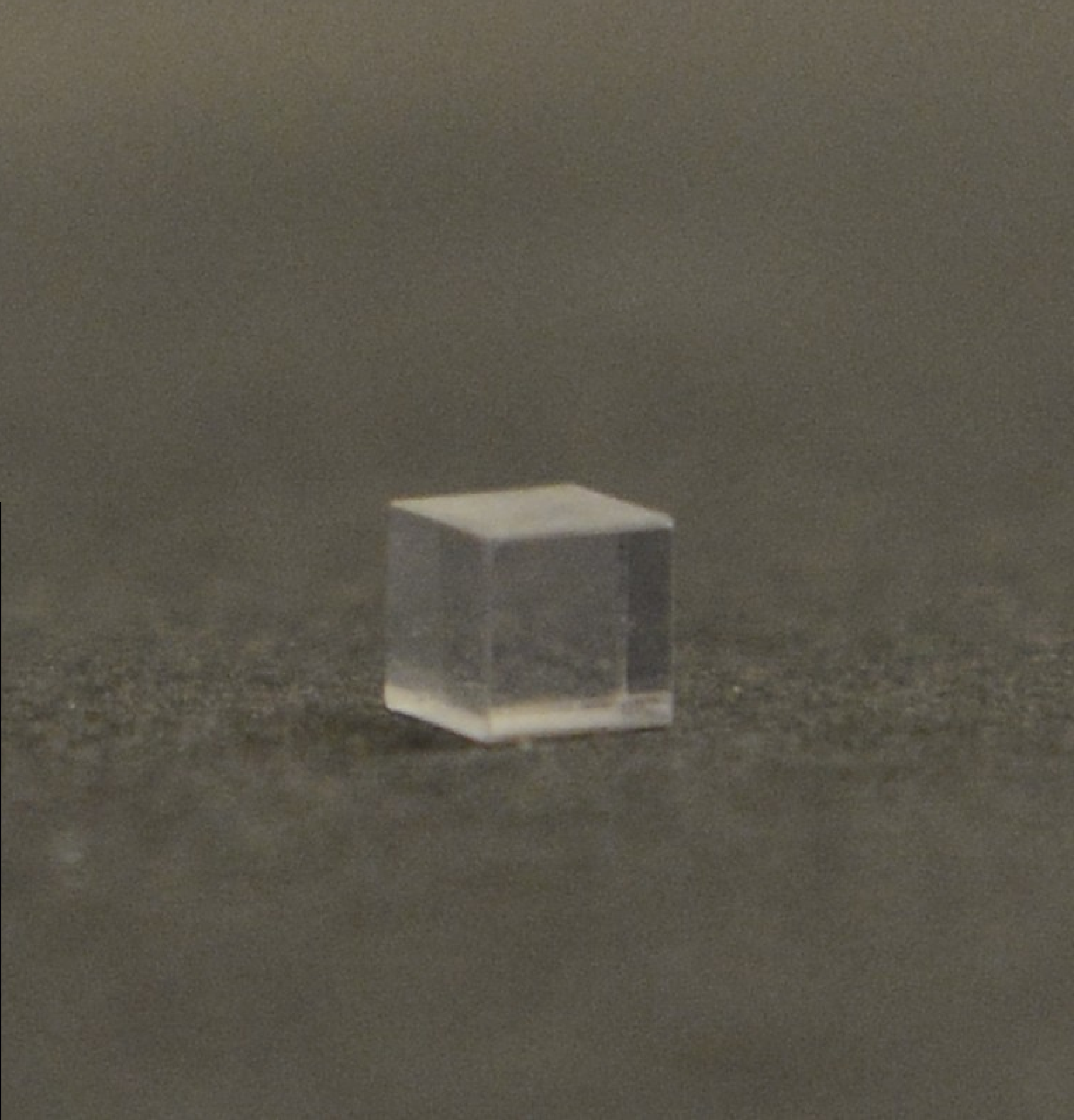
Filter requirements



Rare earth doped crystals



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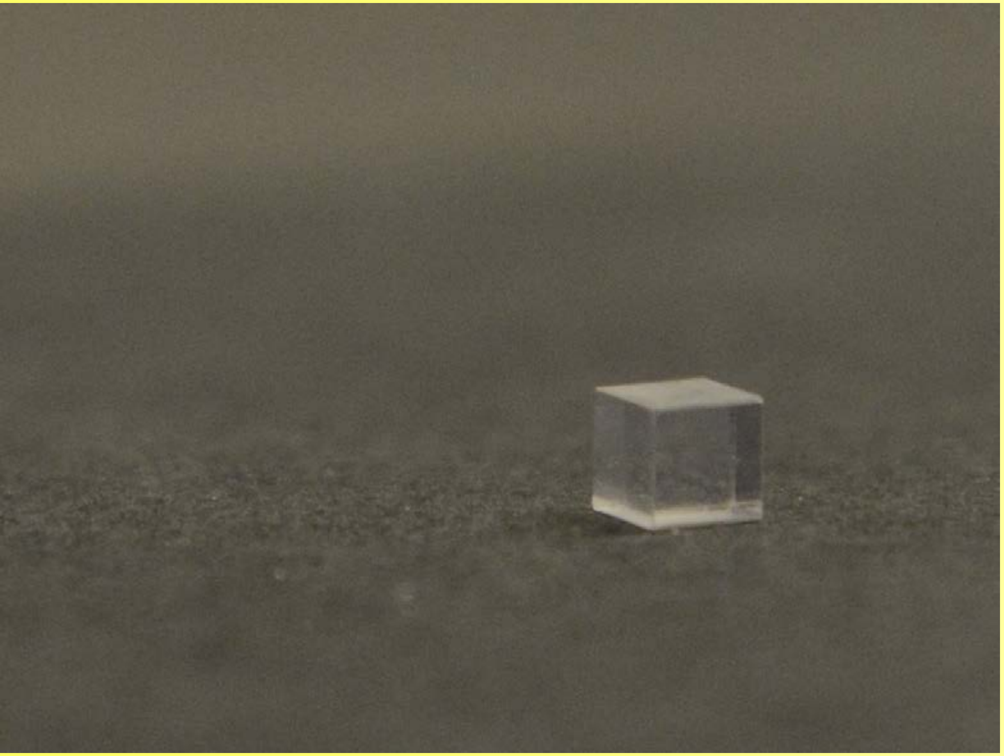
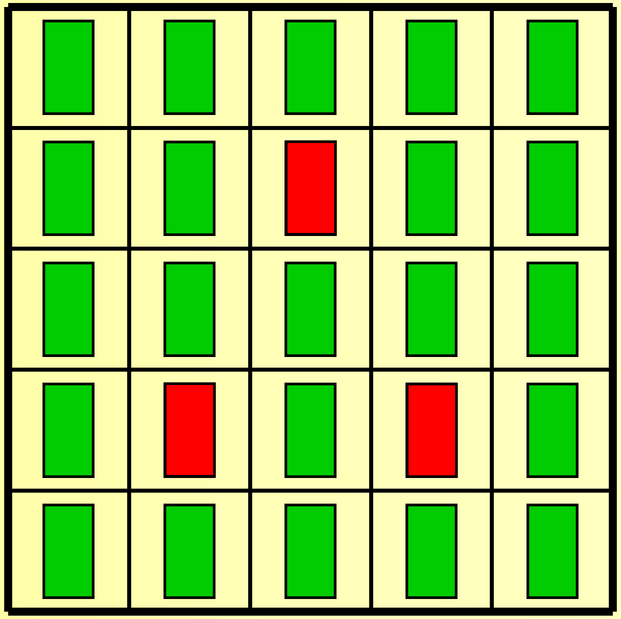
Rare earth crystals



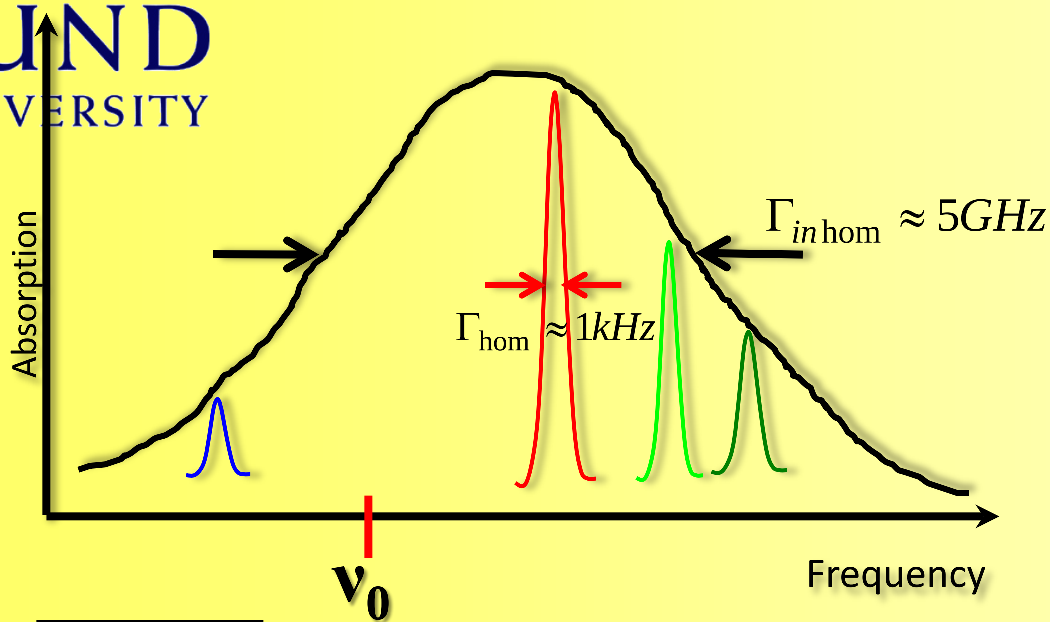
Conceptual picture of a crystal

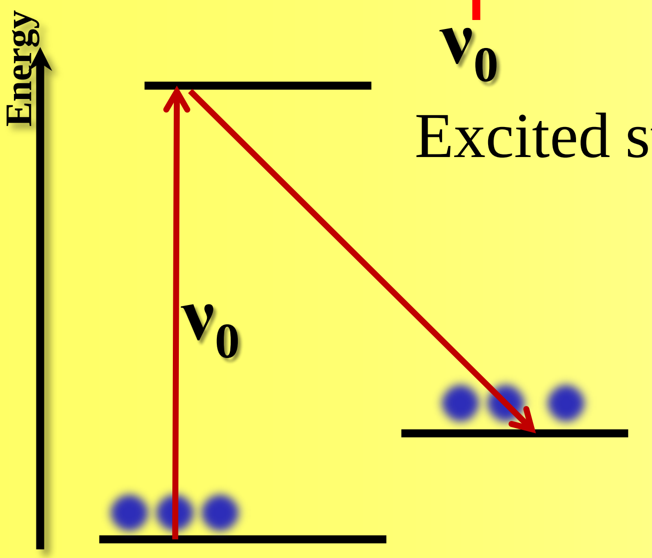


$Pr^{3+}:Y_2SiO_5$

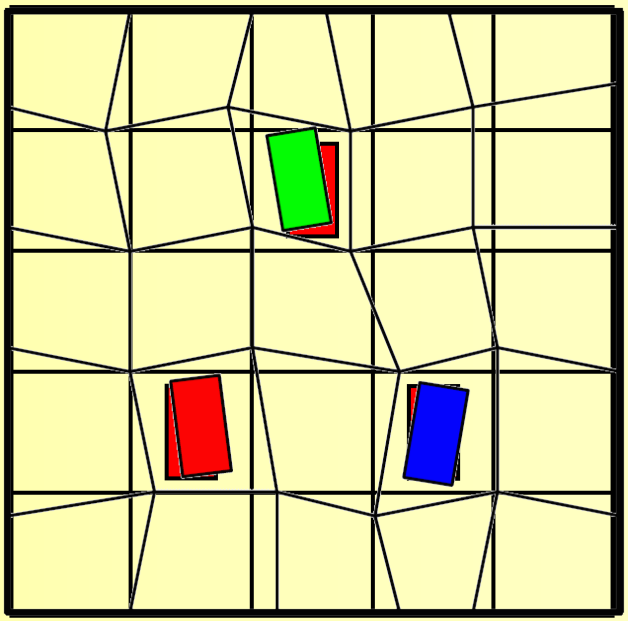
Engineering the absorption structure

700.000000000 nm
700.000001000 nm
0.000000001 nm
0.005000000 nm





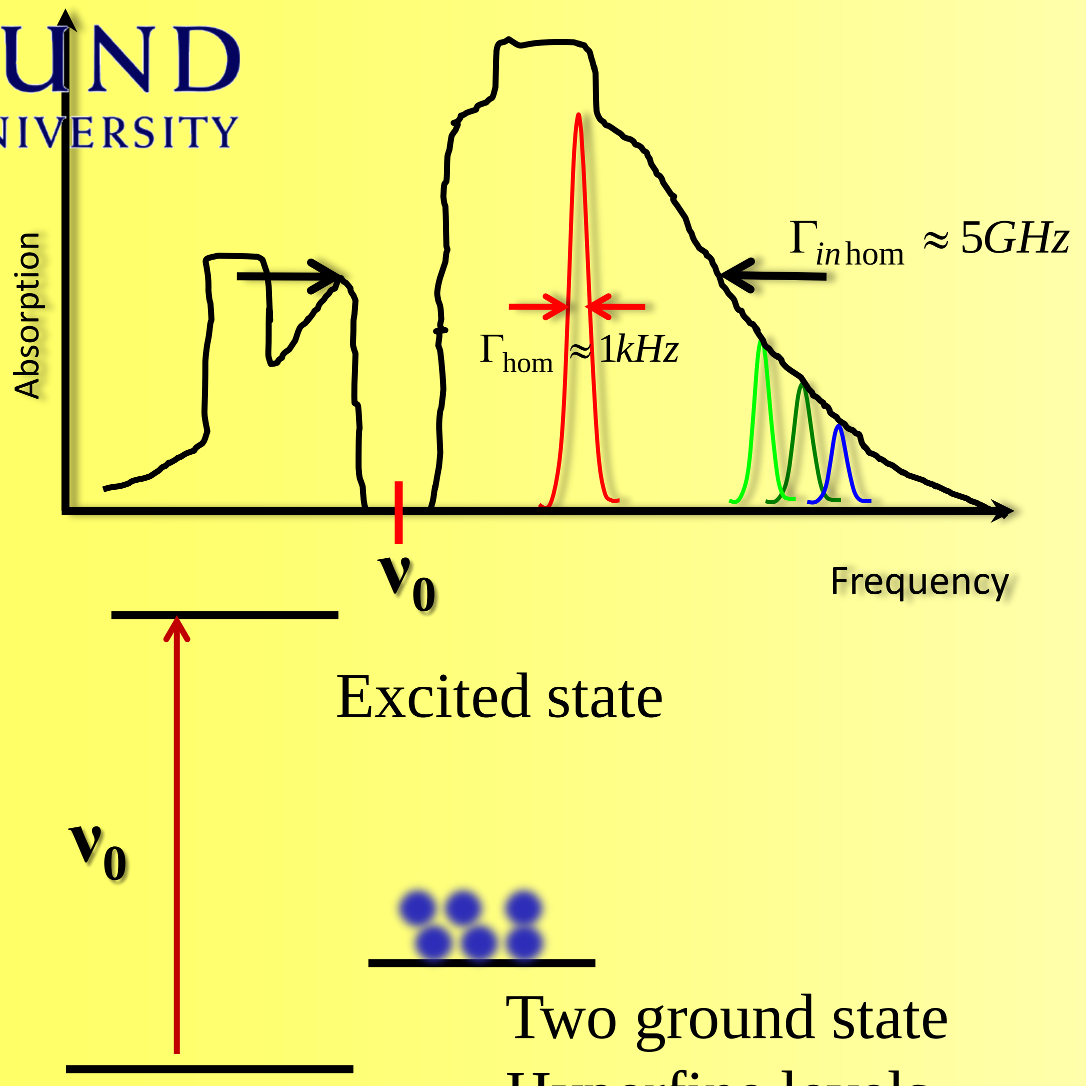
Optical pumping



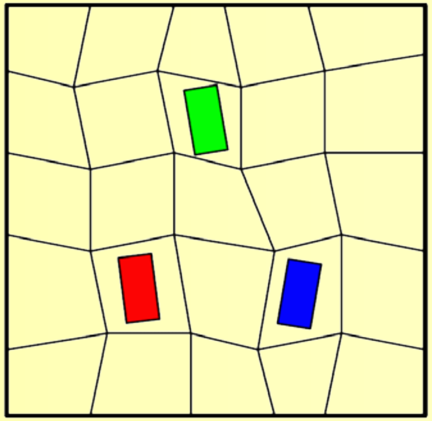
$Pr^{3+}:Y_2SiO_5$

Spectral filter engineering

Persistent Spectral Hole Burning (PSHB)



$Pr^{3+} : Y_2SiO_5$



Ultrasound optical tomography

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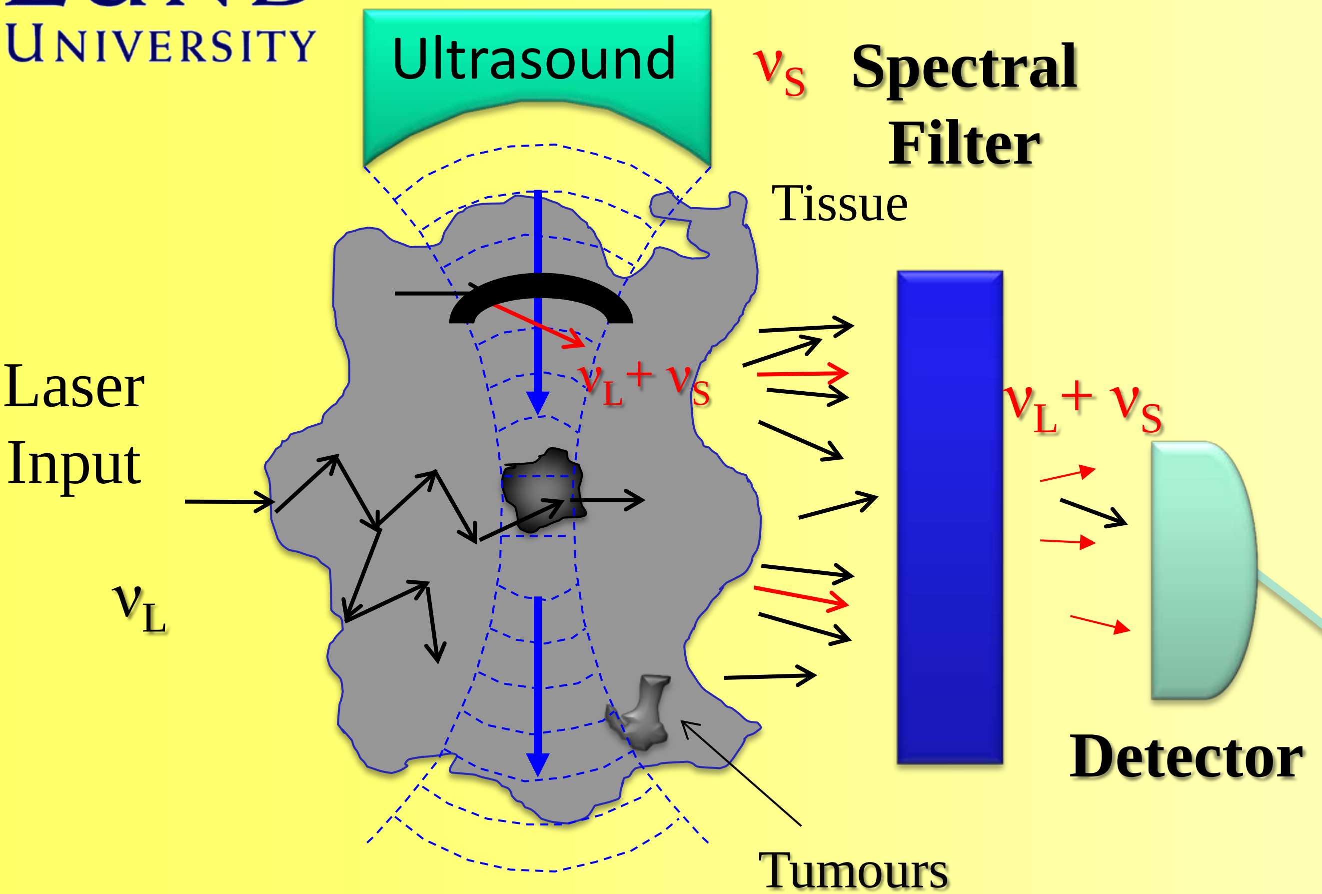
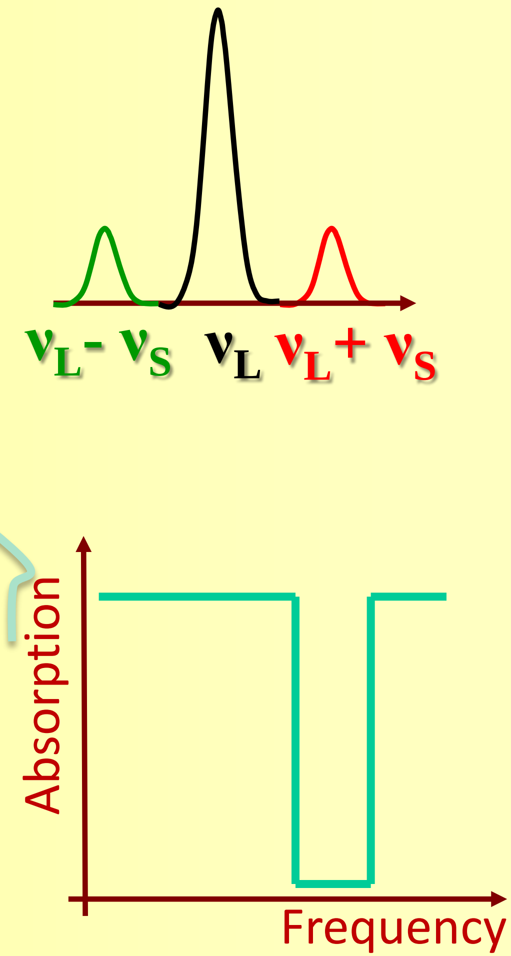
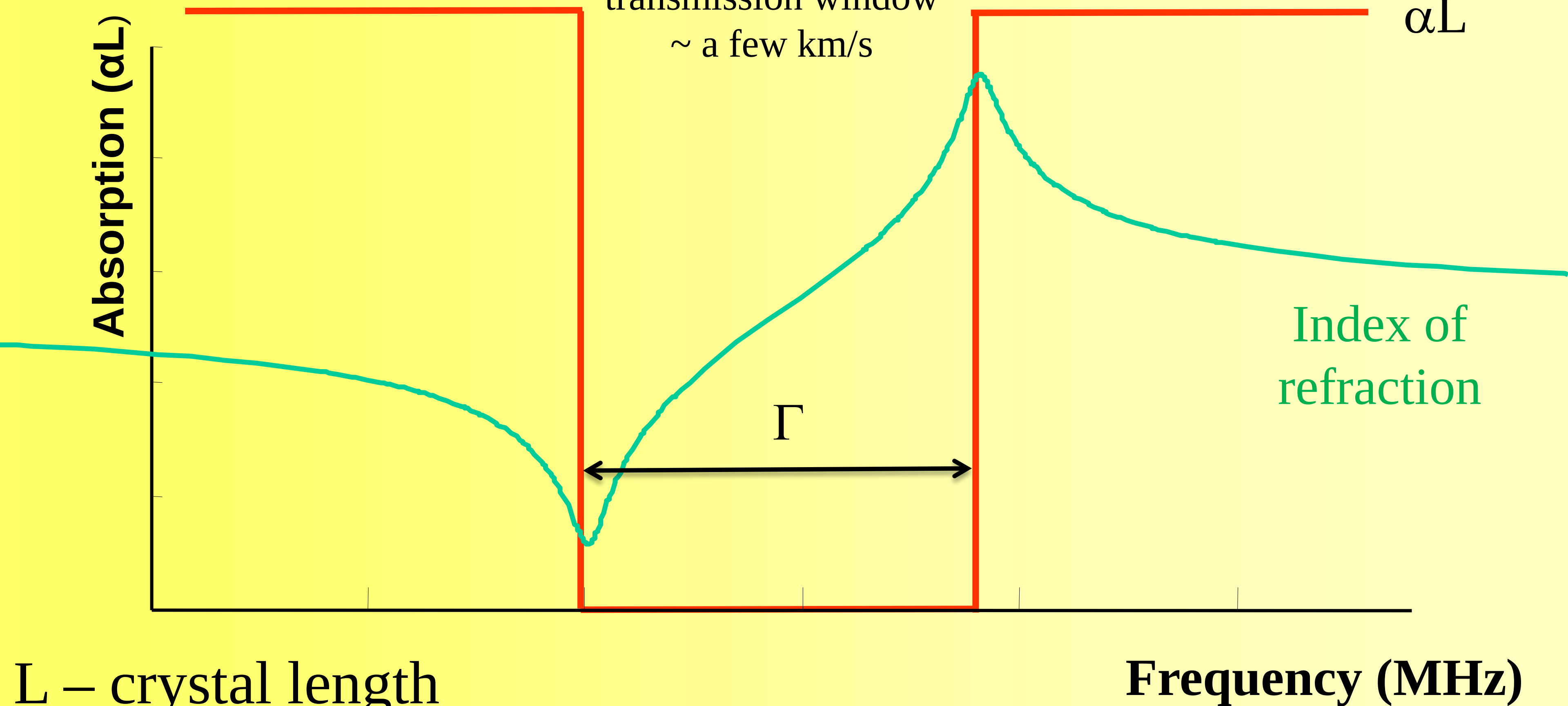




Ultrasound attenuation coefficient in tissue 0.3 dB/(cm MHz)

We use a narrow spectral transmission window within a highly absorbing frequency region



L – crystal length

α – absorption coefficient

Spectral filter delay

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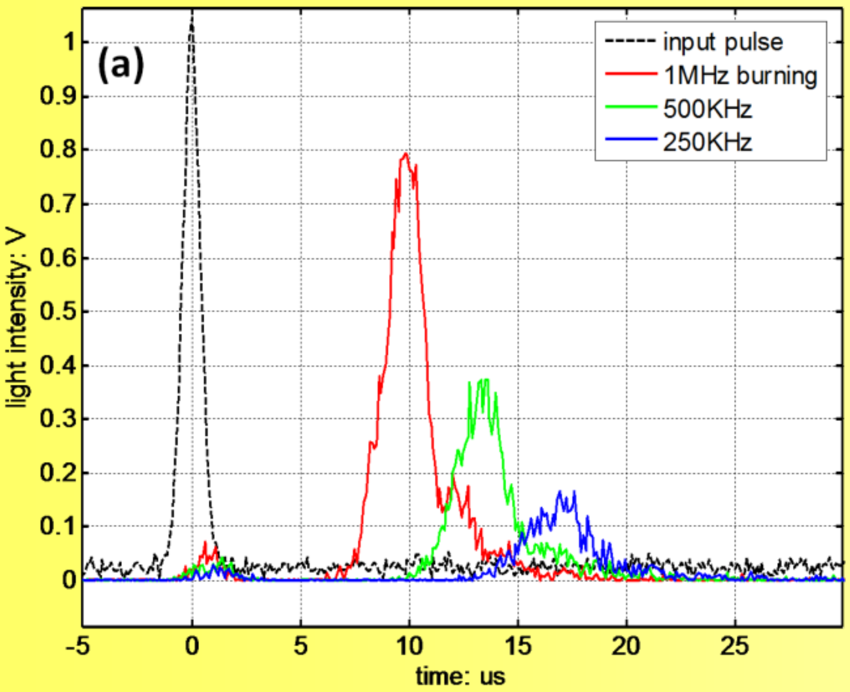
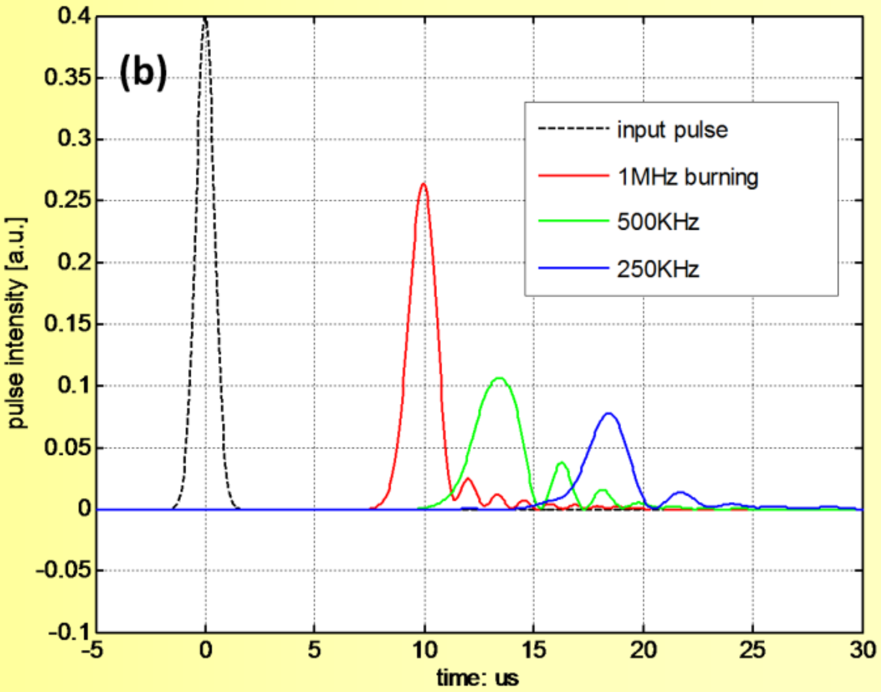
Experiment



Simulation



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Where are we?

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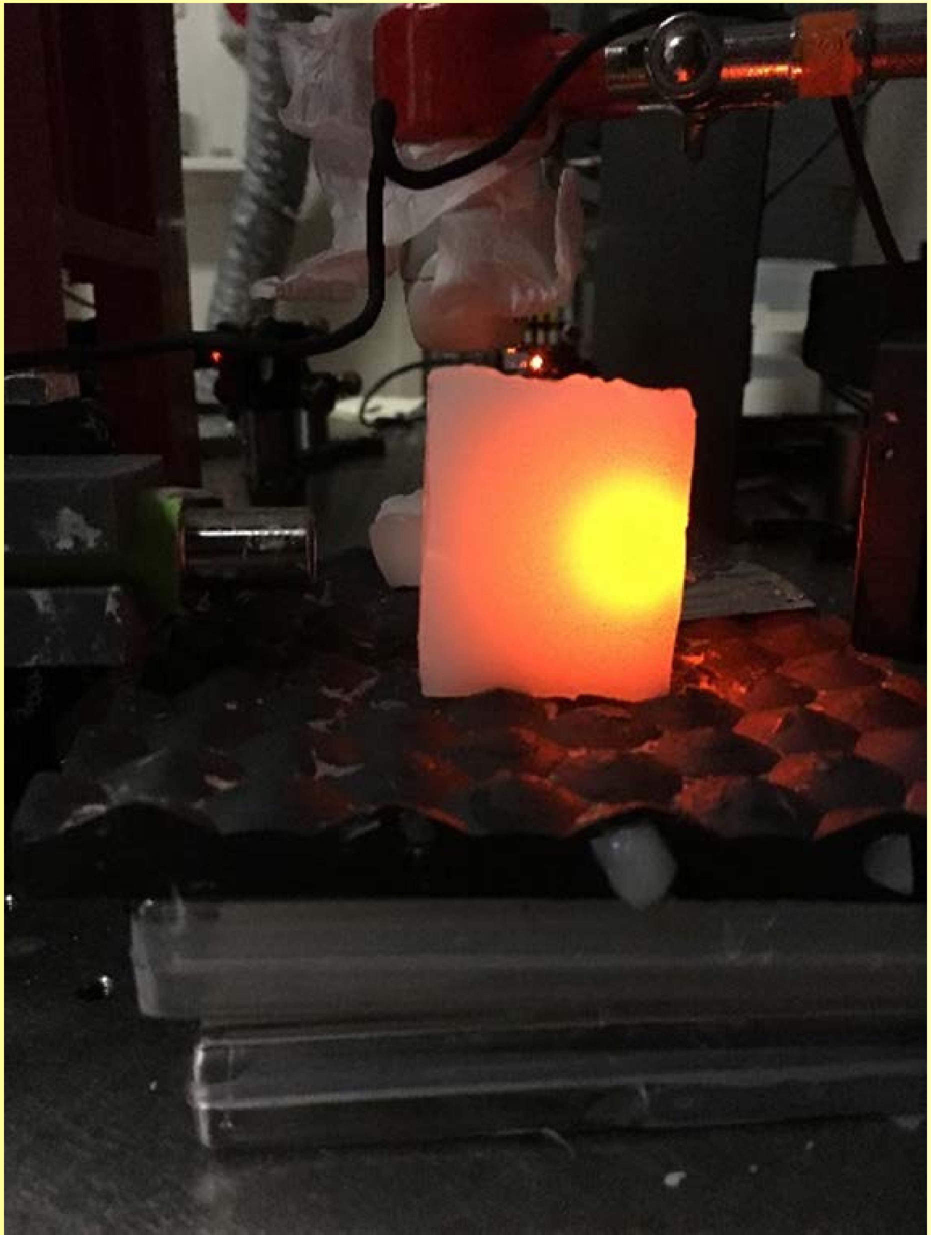
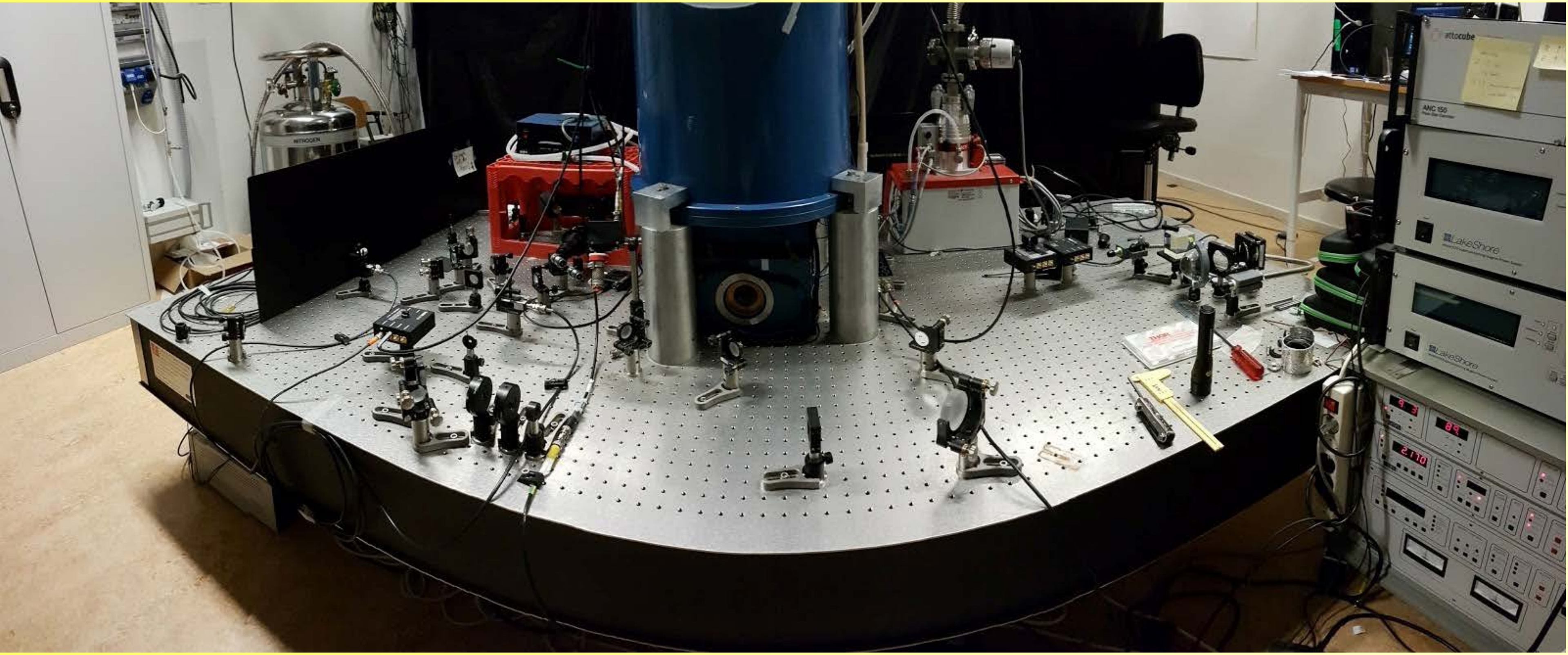
Testing and analyzing the UOT concept



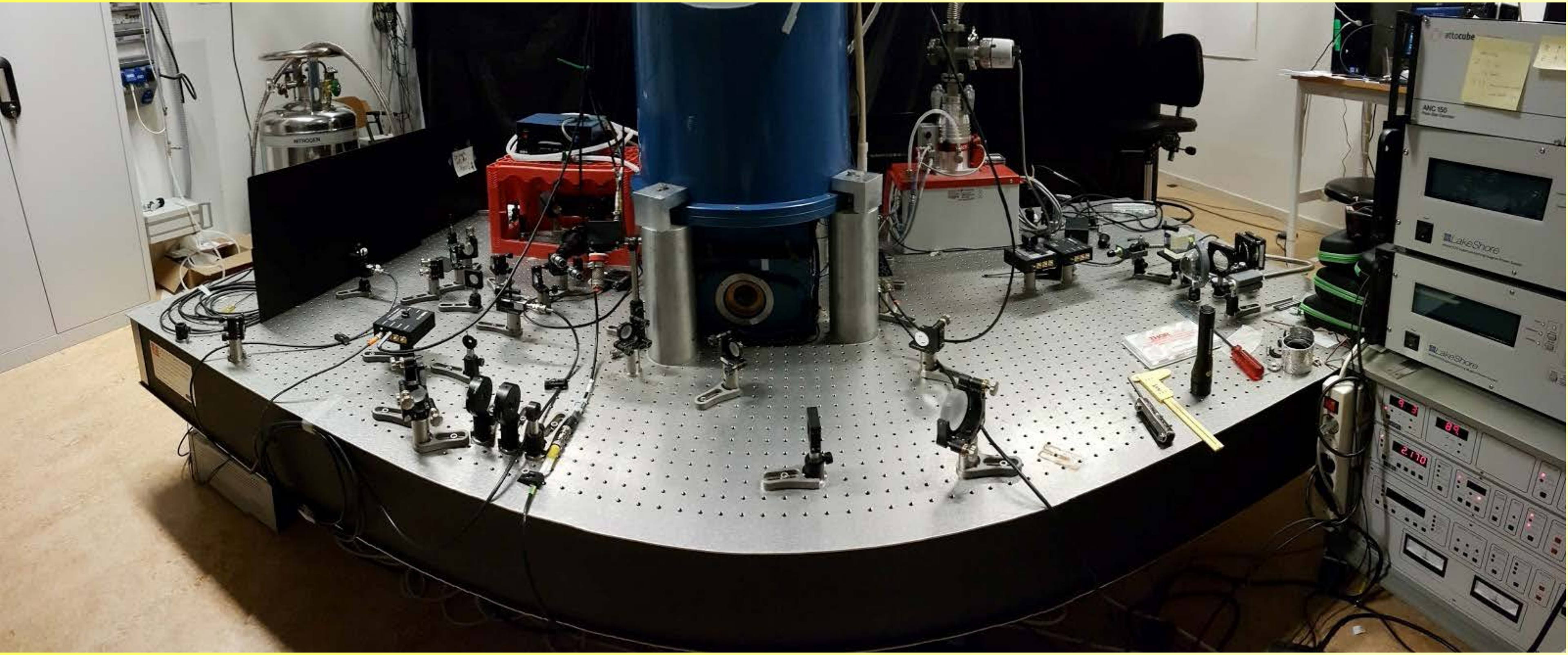
More from the experimental set-up



Project partners

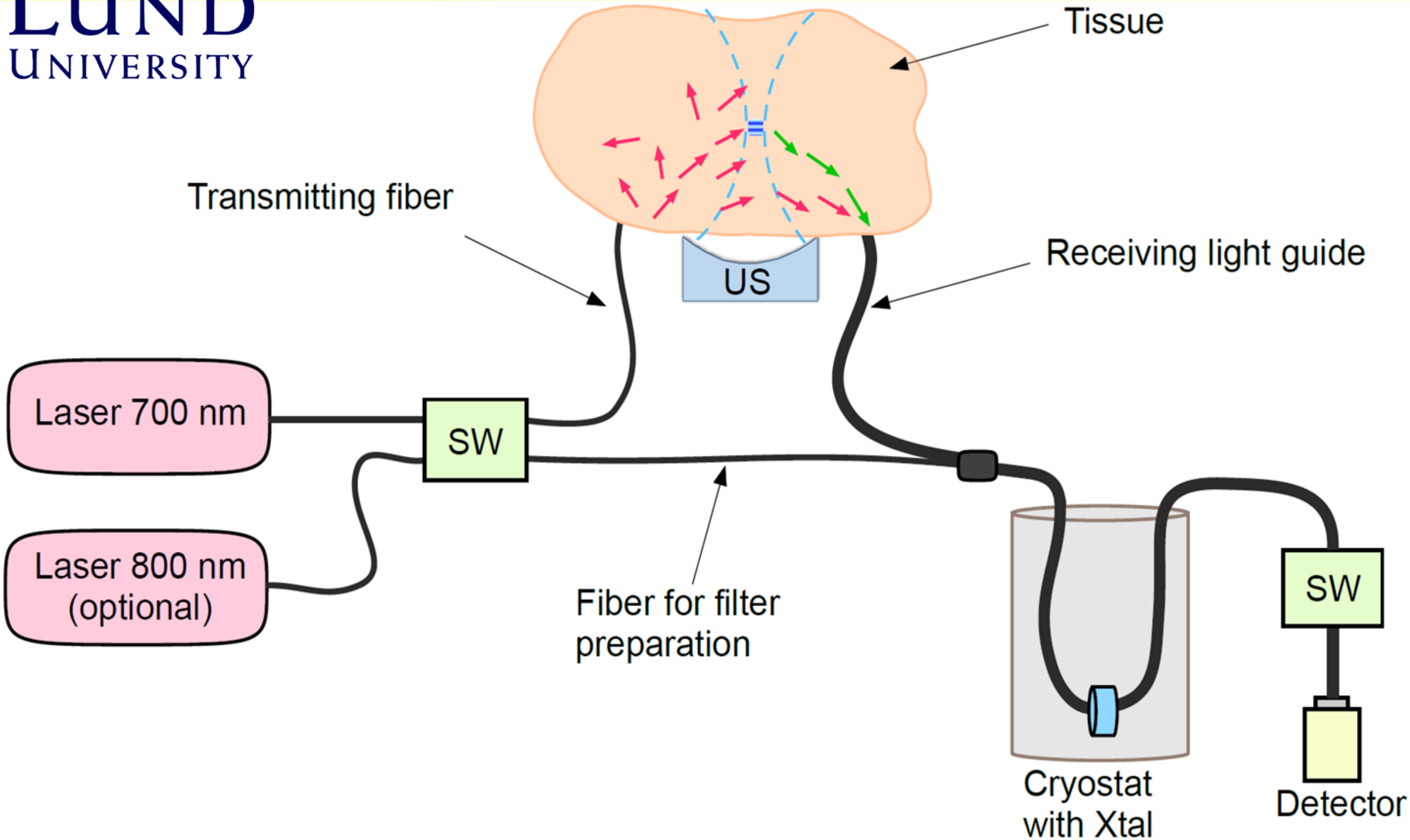
- ***Faculty of Engineering (LTH)***
- Dept of Physics: Andreas Walther, Lars Rippe, Stefan Kröll
- Dept of Biomedical Engineering: Magnus Cinthio, (Tomas Jansson)
- Dept of Electrical and Information Technology: Mats Gustafsson
- ***Faculty of Medicin, LU***
- Dept of Clinical Sciences: Lars Edvinsson (*Ischemia*, *animal models*)
- Dept of Translational Medicine: Sophia Zackrisson (*mammography*, *PAT*)
- ***Non University partners***
- SpectraCure AB
- ***International partners:***
- University College Cork: Stefan Andersson-Engels
- Lihong Wang, Caltech

More from the experimental set-up

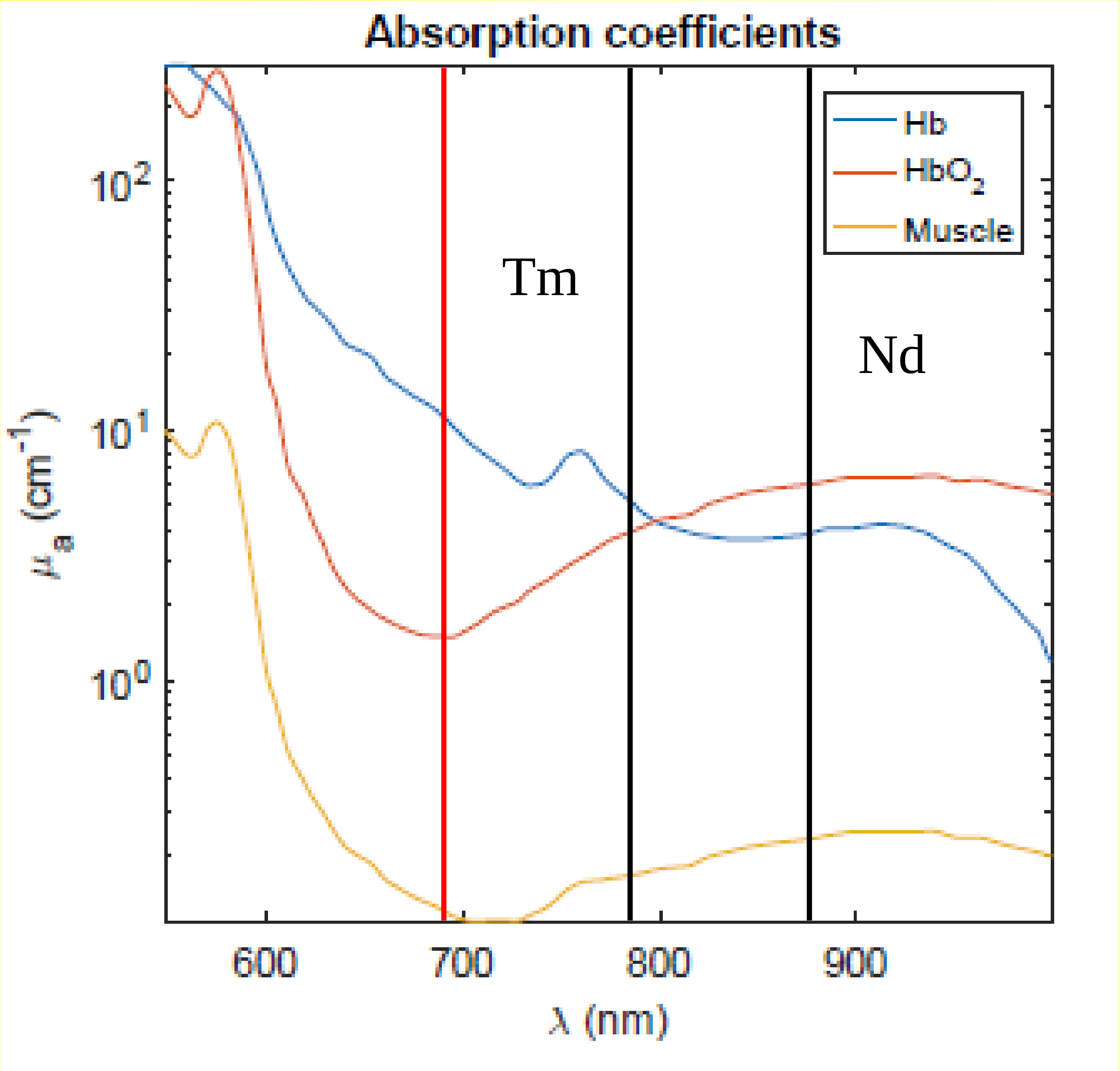


Every piece of equipment should be mountable in an 19 inch rack

Conceptual design of instrument for slow light enabled deep tissue imaging



Hemoglobin oxygenation



Plans

- Crystals Shanghai & Pisa (+Bozeman)
- Laser system procurement (dedicated setup)

Tissue properties

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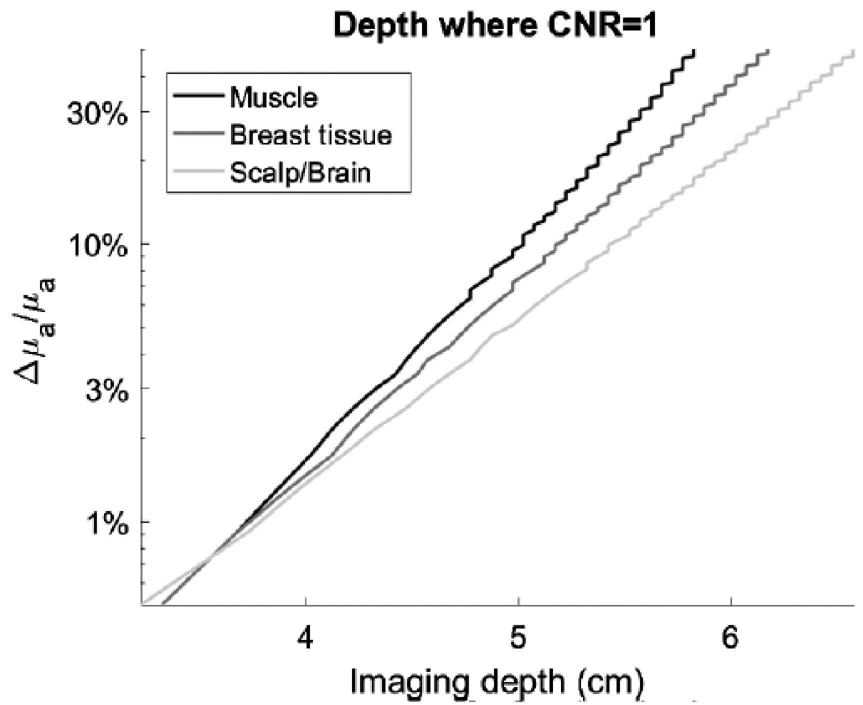
	Muscle @880 nm	Breast@880 nm	Scalp/skull	Brain
Absorption coefficient	0.2 cm^{-1}	0.08 cm^{-1}	0.095 cm^{-1}	0.14 cm^{-1}
Scattering coefficient	50 cm^{-1}	100 cm^{-1}	120 cm^{-1}	40 cm^{-1}
Transport scattering coefficient	5 cm^{-1}	10 cm^{-1}	12 cm^{-1}	4 cm^{-1}

According to simulations measurements can reach slightly larger depths in breast and brain tissue than in muscle tissue

Gunther, Walther Rippe Kröll & Andersson-Engels, J. of Biomed. Optics **23**, 071209 (2018)



Plans

- Crystals Shanghai & Pisa (+Bozeman)
- Laser system procurement (dedicated setup)
- Continued testing of performance
- 3D tissue models? (Nina Reistad, Magnus Cinthio)

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Quantum Information Group

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Thank you