EXPOSURE ASSESSMENT OF WIRELESS DEVICES FREQUENCIES ABOVE 6 GHz

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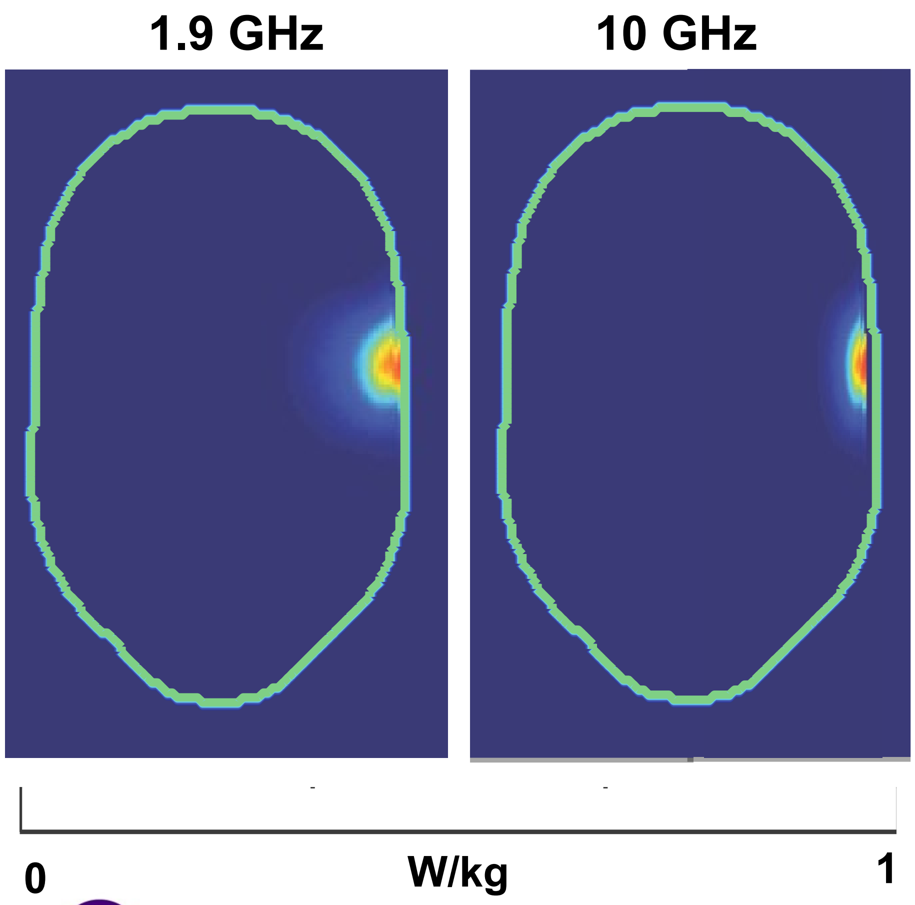
MMF Workshop, June 5th 2016

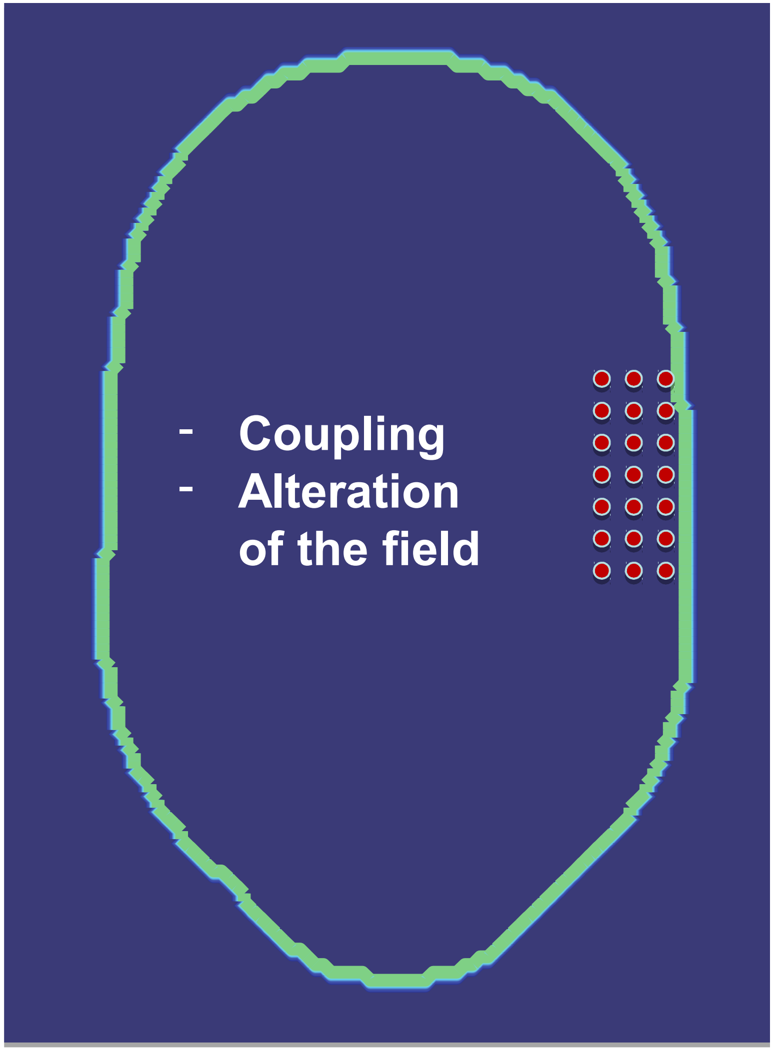
Introduction

- Millimeter-wave (mmW) frequencies between 10-300 GHz are the new frontier for wireless communications that promise orders of magnitude higher bandwidths and transfer rates.
- The short wavelength associated with high frequencies increases the number of challenges associated with dosimetric measurements.

T. Wu, T. S. Rappaport and C. M. Collins, "Safe for Generations to Come: Considerations of Safety for Millimeter Waves in Wireless Communications," in *IEEE Microwave Magazine*, vol. 16, no. 2, pp. 65-84, March 2015.

Challenge #1: Shallow Penetration Depth





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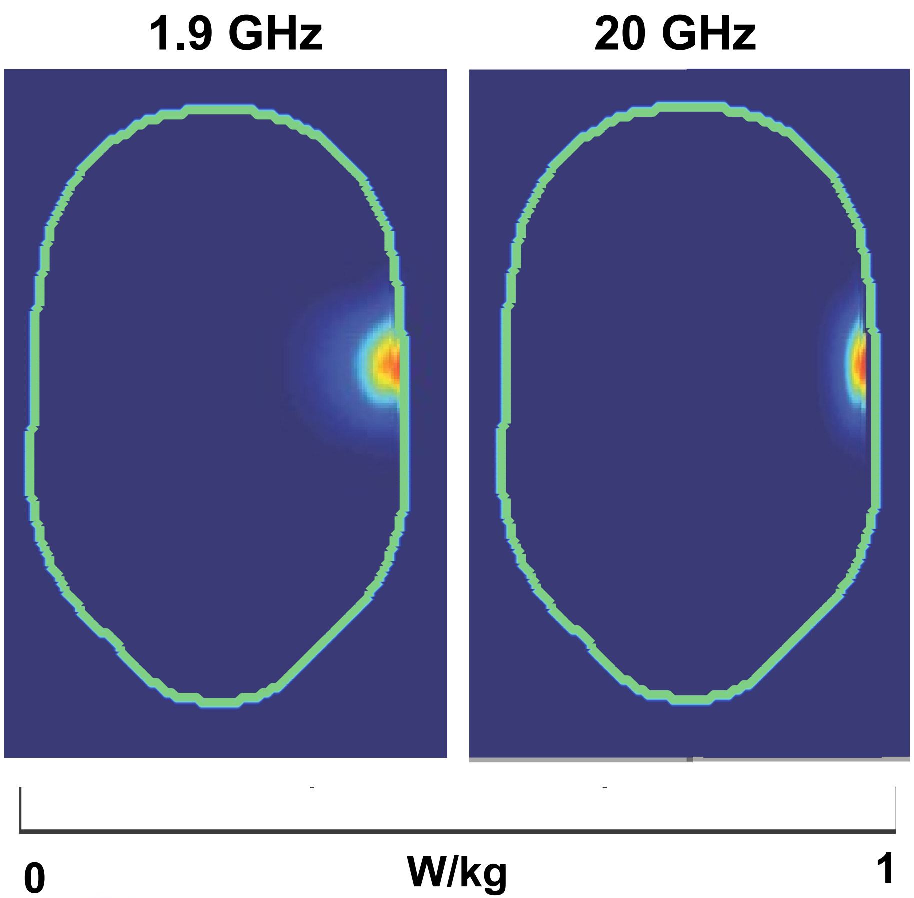

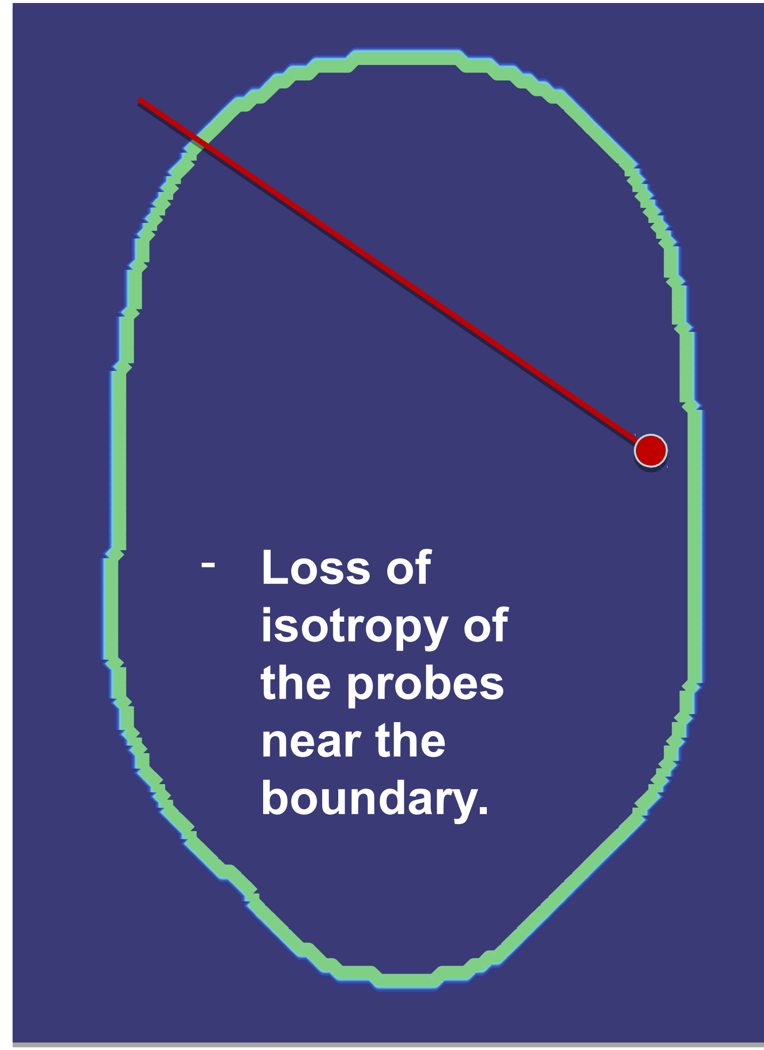

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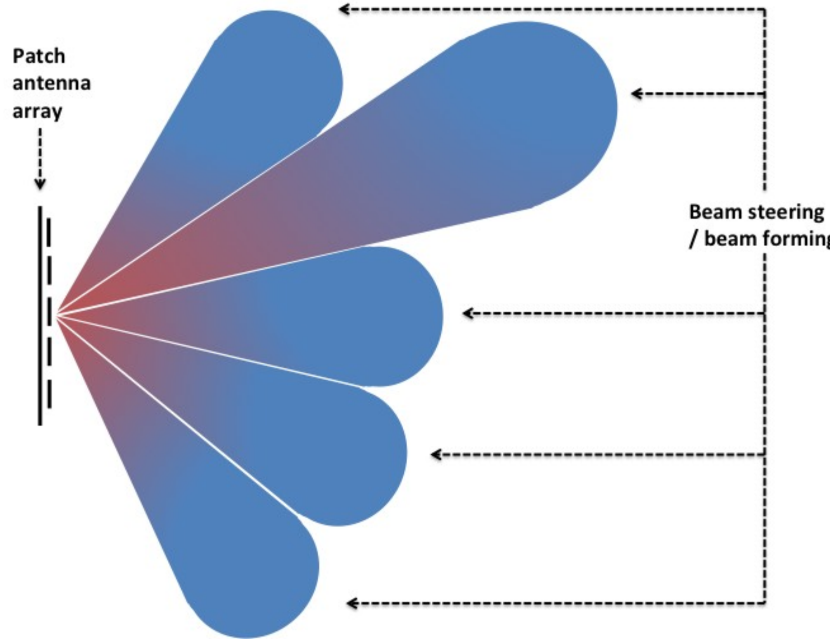
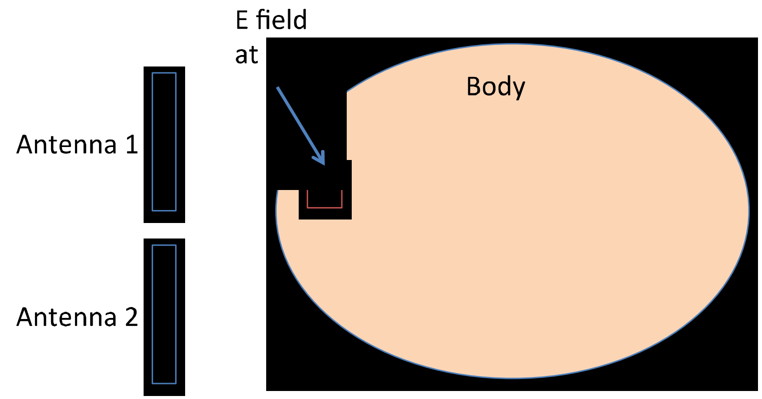
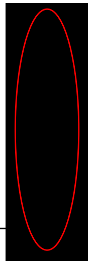
Challenge #2: The Use of Multi-Array Systems





Drive&antenna&1&		E1(r)&		Drive&antenna&2&		E2(r)&		|E|²&
Amp. (V/m)	Phase(Deg.)	Amp. (V/m)	Phase(Deg.)	Amp. (V/m)	Phase (Deg.)	Amp. (V/m)	Phase (Deg.)	
1	0	10	0	0	0	0	0	
0	0	0	0	1	0	5	90	
1	90	10	90	1	0	5	90	
1	90	10	90	1	-180	5	-90	

Alon, L., Deniz, C. M., Brown, R., Sodickson, D. K. and Zhu, Y. (2013), Method for in situ characterization of radiofrequency heating in parallel transmit MRI. Magn Reson Med, 69: 1457–1465.
doi: 10.1002/mrm.24374

Challenge #3: Discerning Spatially mmW Power Deposition

- Currently power density is used for compliance above 6 GHz.
- Power density does not provide any spatial information on the distribution of energy.

T. Wu, T. S. Rappaport and C. M. Collins, "Safe for Generations to Come: Considerations of Safety for Millimeter Waves in Wireless Communications," in *IEEE Microwave Magazine*, vol. 16, no. 2, pp. 65-84, March 2015.

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Technology Requirements to Address these Challenges

1. Spatially untangle the energy deposited inside tissue.
2. Conduct measurement in a reasonable time.
3. Be able to characterize arrays.
4. Have small uncertainty.

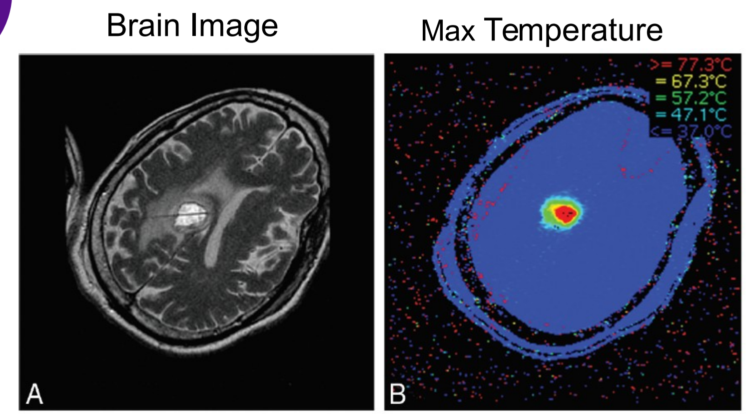
Emerging Methods for Local Exposure Assessment

- Several methods have been proposed to quantify mmW exposure distribution
  - Single point or 2D infrared (IR) temperature measurements on thin "skin" phantoms[1,2]
  - High-resolution magnetic resonance (MR) thermometry measurements on gel based water phantoms[3]
- Currently, quantifying mmWave power absorption with sufficient spatial resolution and accuracy is particularly challenging for conventional electric field probe systems[4] due to small penetration of the energy

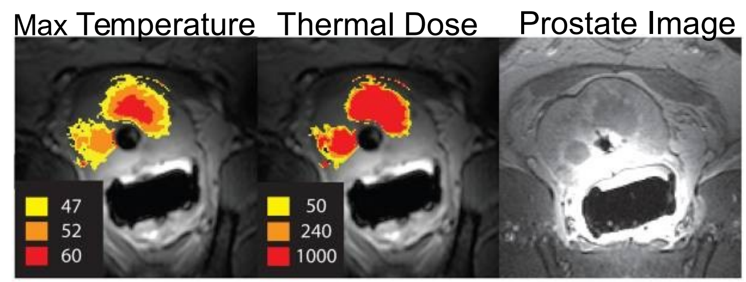
1- Alekseev S.I. et al 2009 Bioelectromagnetics
2- Alekseev S.I. et al 2011 Biofizika
3- Alon L et al. 2015 BIOEM
4- Schmid D et al 1996 IEEE Transactions on Microwave Theory and Techniques

Magnetic Resonance Thermal Imaging (MRTI)

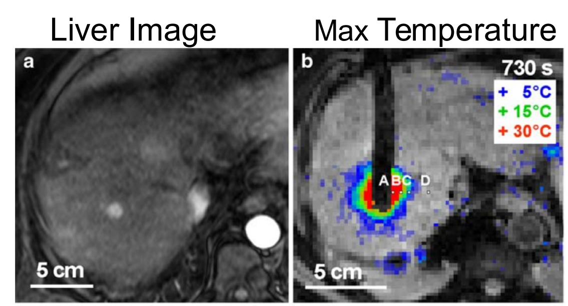
- MR thermometry has been used extensively for real-time noninvasive *in vivo* temperature monitoring
  - Laser-induced interstitial thermotherapy (LITT)
  - High-intensity focused ultrasound (HIFU)
  - RF ablation
  - Microwave heating for thermal ablation



Medvid R et al 2015 AJNR Am J Neuroradiol



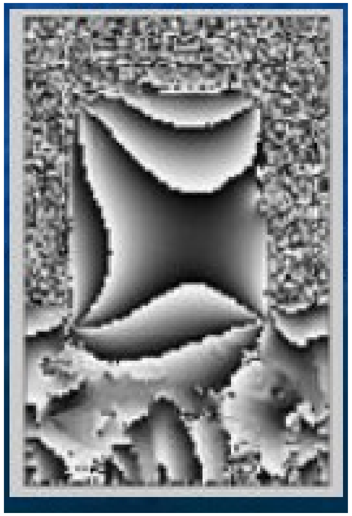
Reike V et al 2008 JMRI



Lepetit-Coiffé M et al 2009 Eur Radiology

Magnetic Resonance Thermal Imaging (MRTI)

Reference



Φ_1

$$\Delta T = \frac{\phi_2 - \phi_1}{\alpha \gamma B_0 TE}$$

Phantom relevant
(α: temperature dependency of the chemical shift)

MR spin/system relevant
(γ: gyromagnetic ratio
B_0: field strength)

Sequence relevant
(TE: Echo Time)

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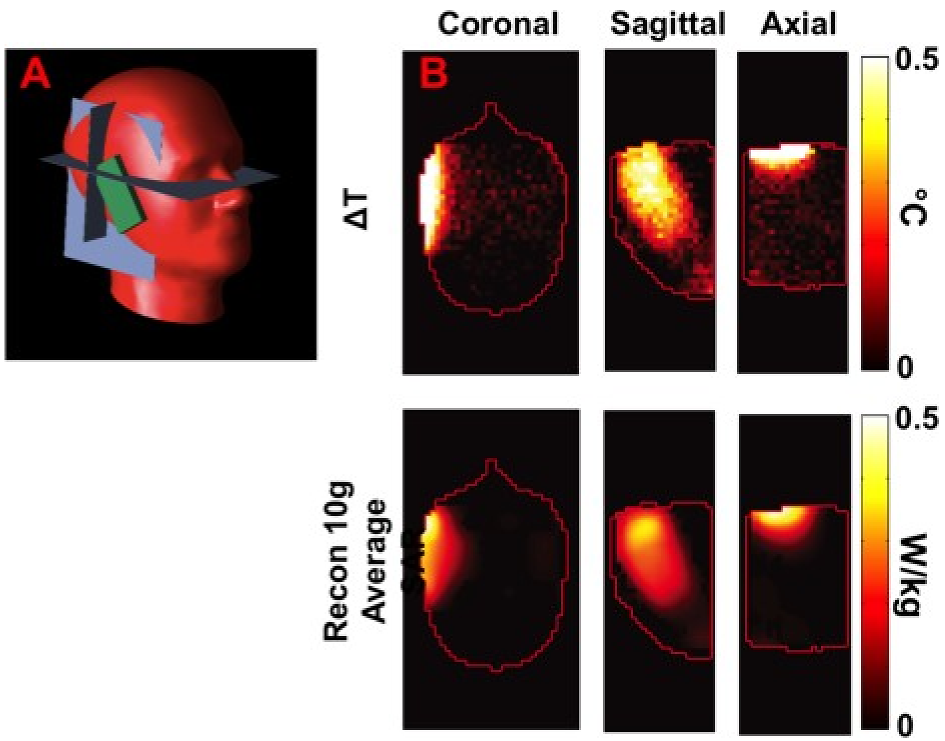
mages from Nick Todd, http://slideplayer.com/slide/3362796/

Mobile Phone Exposure Assessment with MRTI



A specific anthropomorphic mannequin (SAM) phantom was filled with dielectric water-based gel

Density = 1000 kg/m3
Heat capacity = 2940 J/kg-K
Thermal conductivity =0.347 W/m° C
α = 0.01 PPM/° C

An LG 920CU (LG Electronics, Seoul, South Korea) cell phone transmitting at maximum power at 1900 MHz GSM band

The maximum temperature change was 1.73 °C in close proximity to the cell phone antenna
The maximum 10-g average SAR was 0.54 W/kg.

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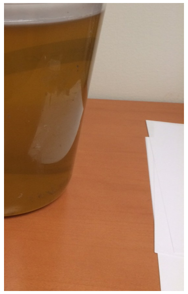
Alon L et al 2015 Magn Reson Med

Experimental Setup

- Commercial Siemens whole-body 3T Magnetom Skyra scanner
- 20-channel head array for signal reception



- Acrylic cylindrical gel phantom (gelatin, water and sugar) with a radius = 8.25 cm and height = 21.6 cm

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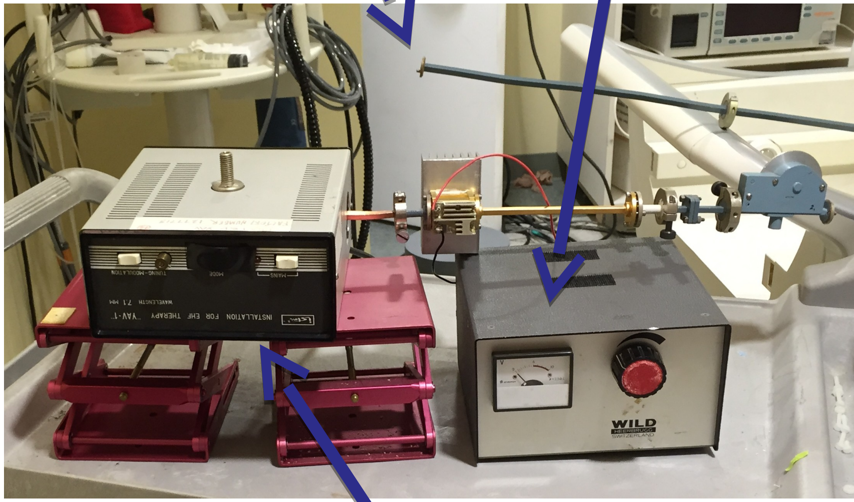
Experimental Setup

- YAV7.1 signal generator (Istok, Fryazino, Russia) operating at 42.25 GHz
- Millitech AMP-22-01120 power amplifier (Millitech, Northhampton, MA, USA)
- 3.1-meter long waveguide whose tip was placed orthogonally to the phantom

Waveguide (disconnected)

Power amplifier



Signal generator at 42.25 GHz

<u>Measured output power density = 600 W/m2 (3x ICNIRP limits)</u>

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Measurement Details

- One reference and multiple post-heating gradient echo (GRE) image were acquired with the following parameters
  - TE = 15ms
  - TR = 54ms
  - Resolution = 2 mm^3
  - Acquisition time = 7 seconds

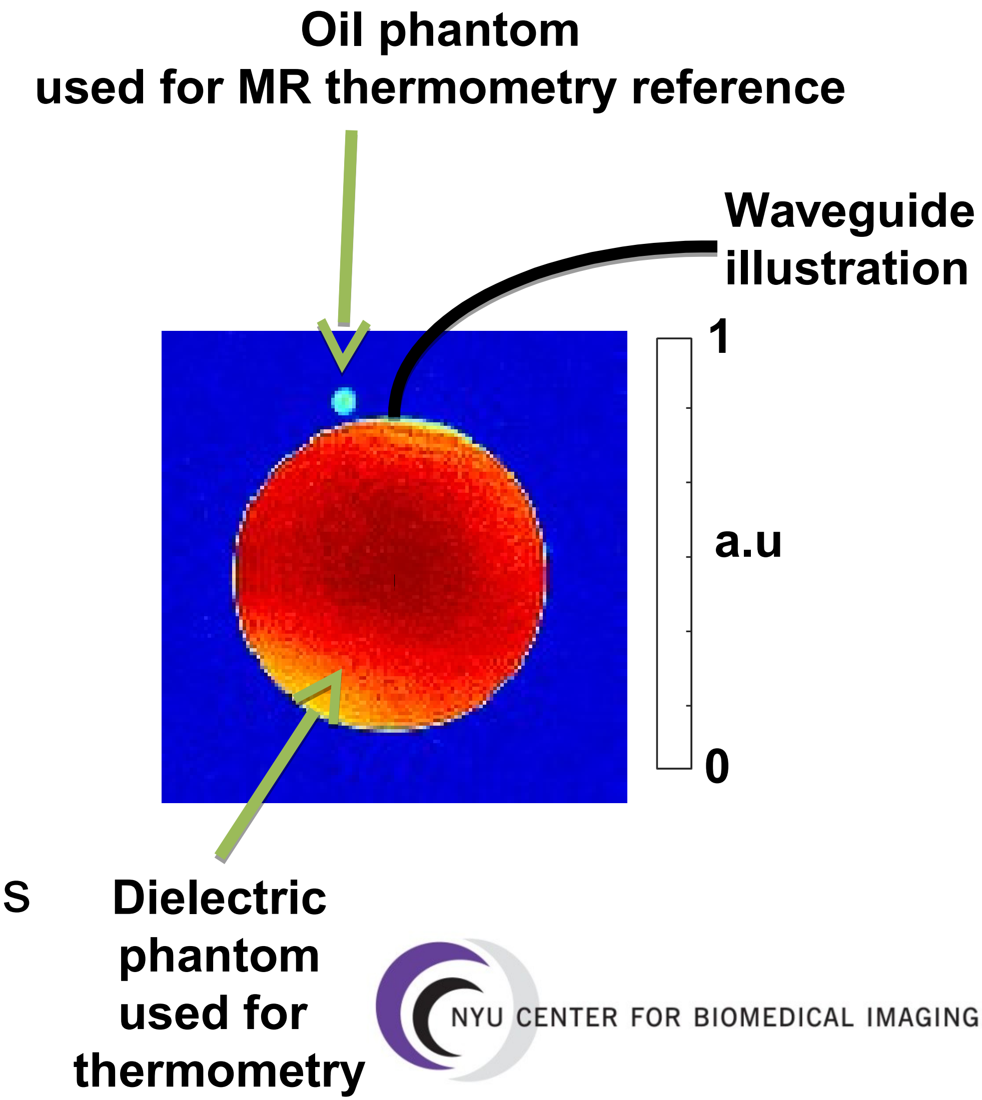

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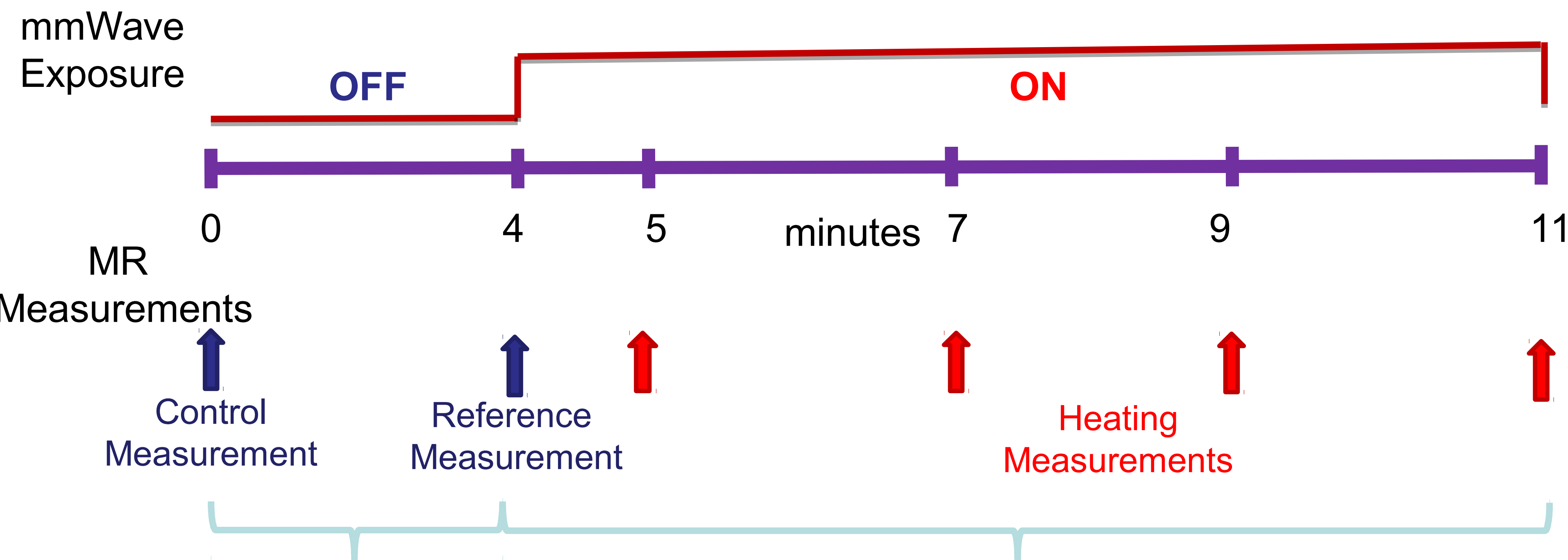
Image Acquisition Timeline



Characterize the noise behavior of the measurements

Analyze the sensitivity of the measurements

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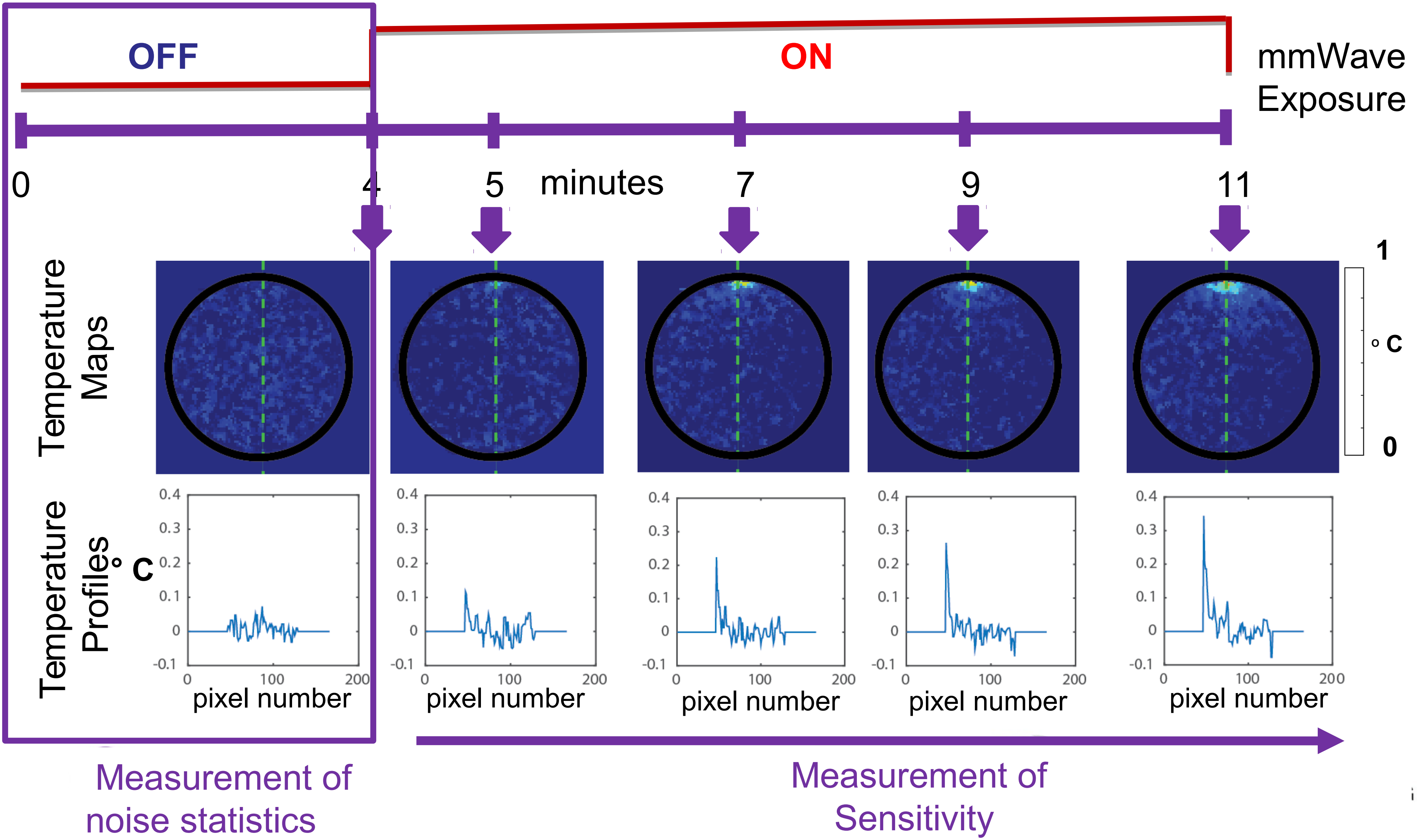
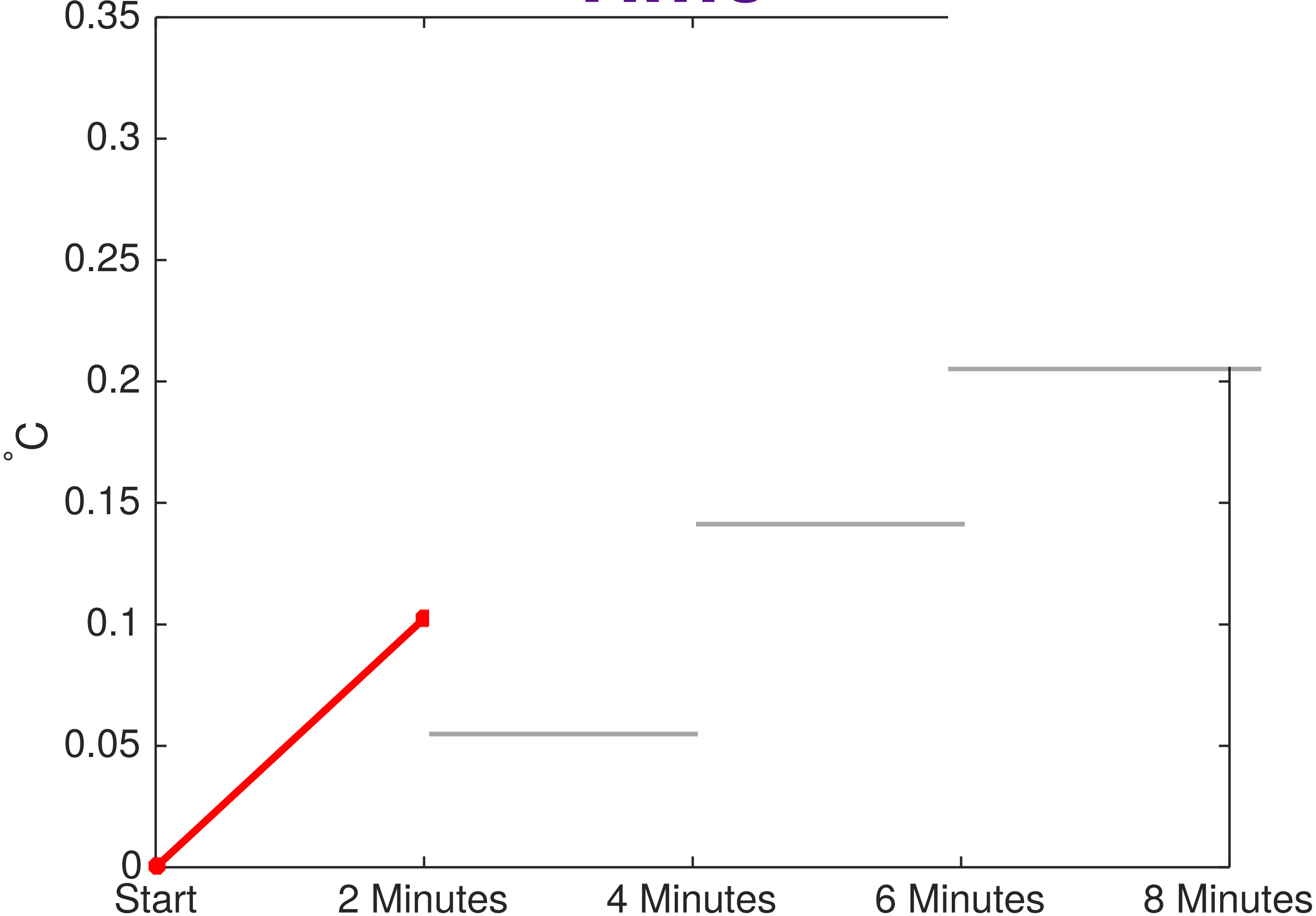
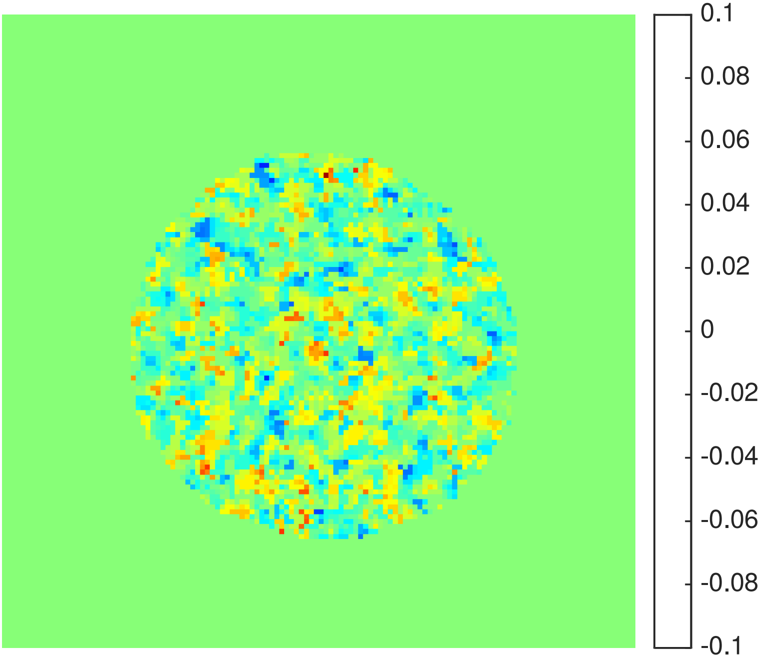
Temperature Change Results with MRTI

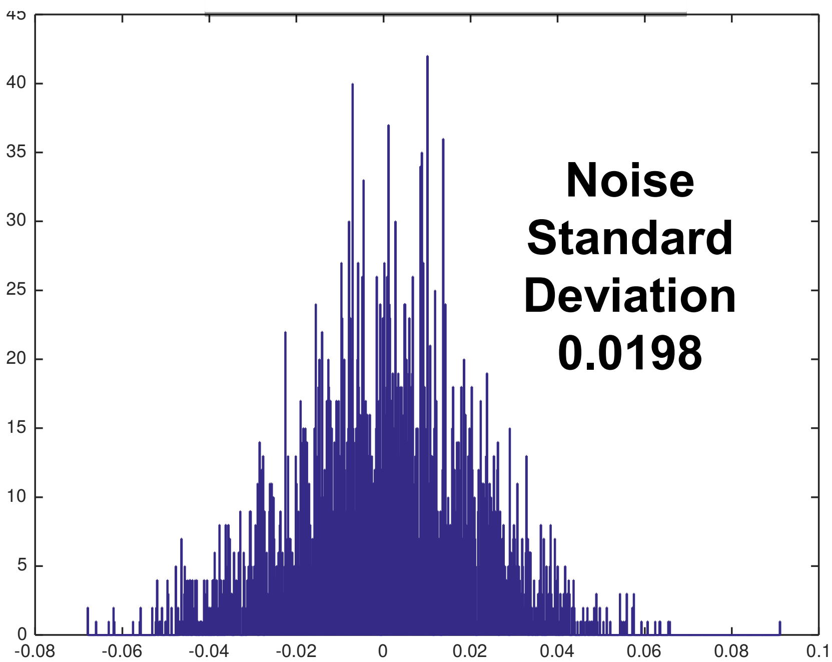


Maximum Temperature Change vs Time



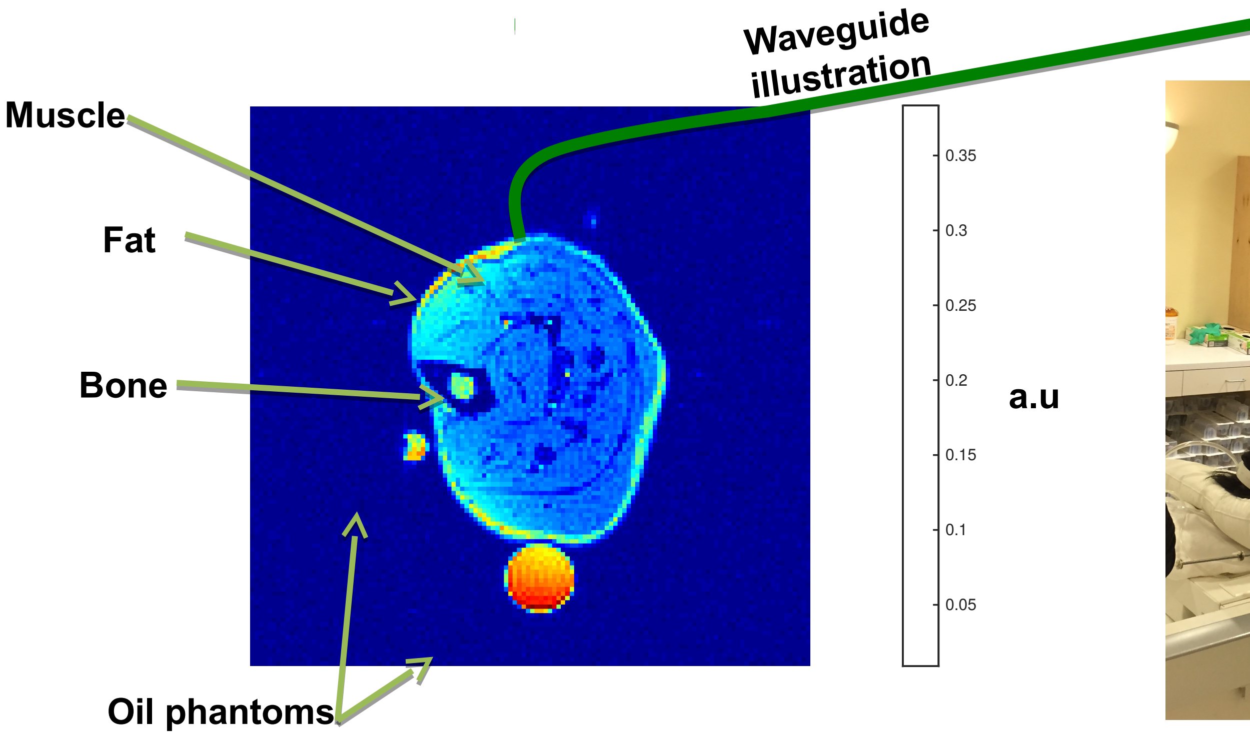
Measurement Noise Behavior

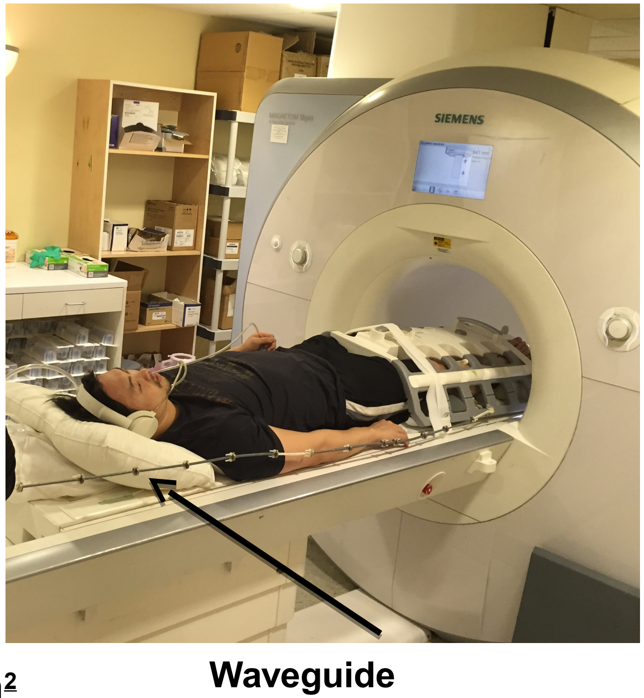




In Vivo

In vivo setup (42.25 GHz)





Output power density = 600 W/m²
(3x ICNIRP LIMIT)

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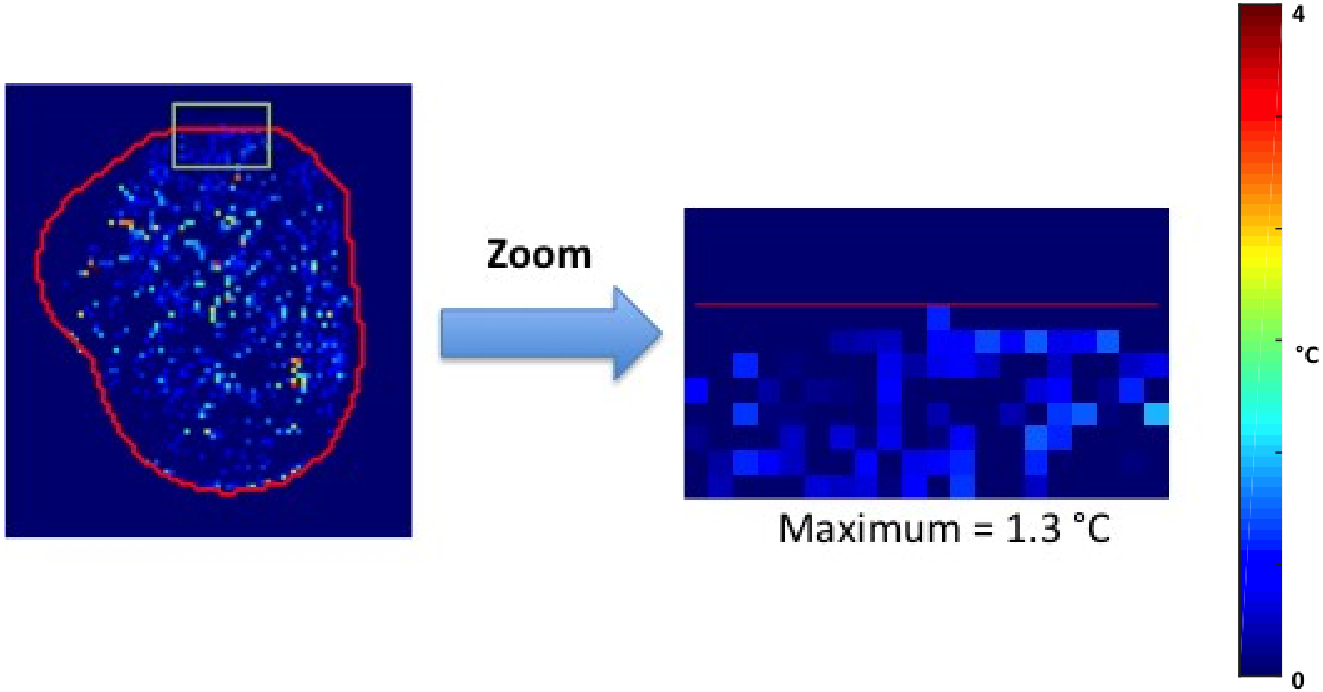
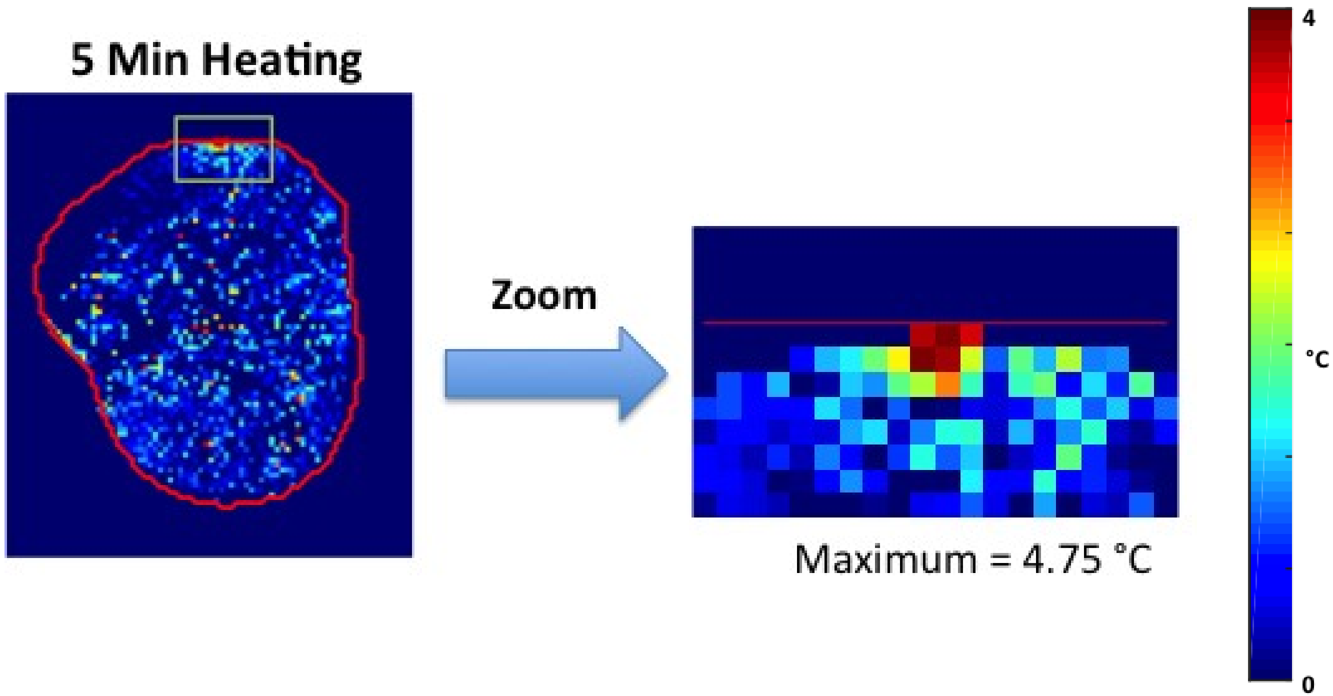
In vivo results



In vivo results – 5 minute exposure



Discussion

- We demonstrated that the heating due to mmWave exposure can be measured directly using MRTI
- MRTI provides high temporal sensitivity and high spatial resolution
  - Small increments in the maximum temperature change is traced accurately
  - 3D temperature map for local exposure assessment is measured within seconds
- MRTI provides a frequency independent exposure assessment

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Discussion

- Temperature penetration inside the phantom increases with heating time, due to heat diffusion effects.
  - This transient behavior could potentially result in precise measurements further inside the phantom shell exposure assessment for higher frequencies than presented here

Acknowledgements

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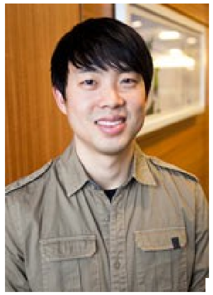

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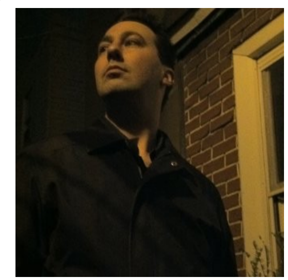

William S Slovinsky

Ted S Rappaport

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