Ocular thermal injury and ocular temperature measurements

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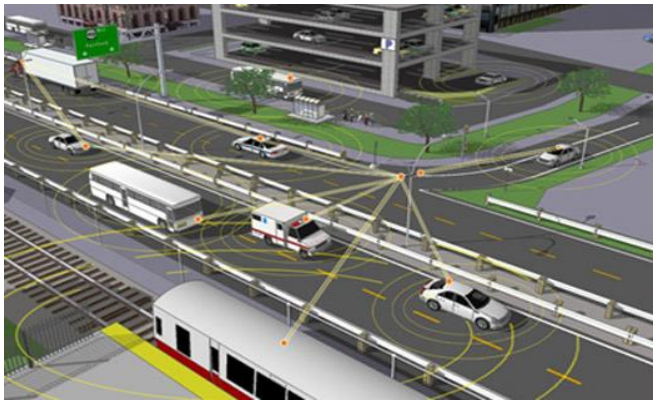
Wireless Communication Systems in Ubiquitous Society

https://www.e-globaledge.com/english/products/infrared/about/



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Intelligent transportation systems

Active millimeter wave imaging sensors

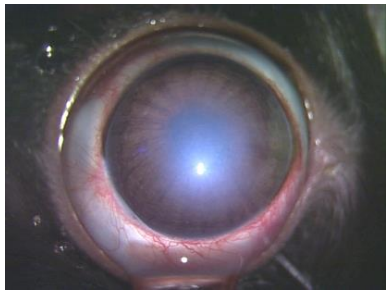
Infrared (IR) or Millimeter wave (MMW) are increasingly being used in daily life resulting in more exposure to humans.

Background

- MMWs are absorbed by surface tissue, such as skin and cornea.
- International guidelines on exposure to MMW pertain to the surface of biological tissues or organs (ICNIRP, 1998).
- Kojima et al. observed mitotic lens epithelial cells in the pupillary area after MMW exposure (Health Phys., 2009) which indicates MMW induced heat somehow transfers to the lens.

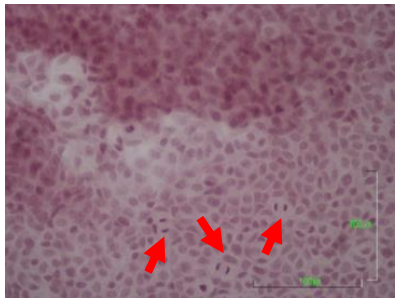
ICNIRP guidelines (1998) for 10-300 GHz

At very high frequencies (10-300 GHz), absorption of electromagnetic energy is confined largely to the epidermal layers of the skin, subcutaneous tissues, and **the outer part of the eye** (ICNIRP, 1998).

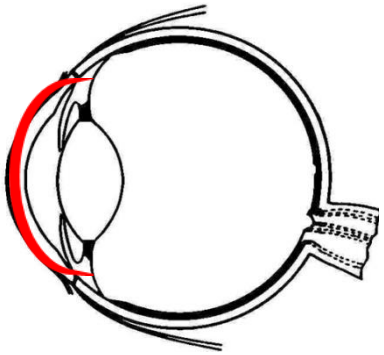


Corneal opacity

Iris vasodilation



Lens damage



60 GHz (1.9 W/cm^2, for 6 min.) exposure caused not only corneal damage, but also iris and lens damages (M. Kojima, et al., Health Phys. 2009).

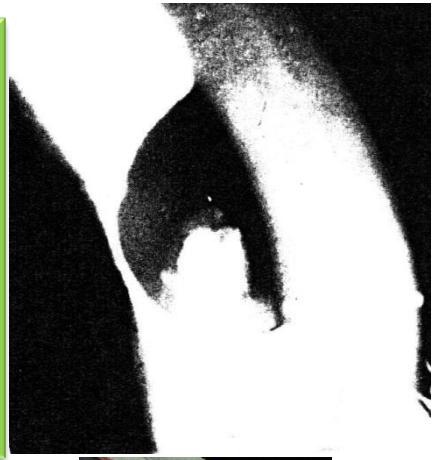
MMW induced heat somehow transfers to the iris and lens.

Here we investigated acute ocular damage threshold and ocular temperature of millimeter exposure (40 & 95 GHz), and IR (808 nm) using *in vivo* rabbit model.

Reports Concerning Heat Cataract

- Goldmann reported that IR or heat cataracts were not caused by the absorption of IR but by the resultant increased temperature in the iris (1933).

Pitts & Cullen supported the hypothesis of Goldmann that IR (715-1,400 nm) induced cataract developed at the anterior cortex and all cataractous change depended on iris involvement (Pitts & Cullen, 1981).



However, heat transport from the iris to the lens during IR exposure remains unclear.

Purpose

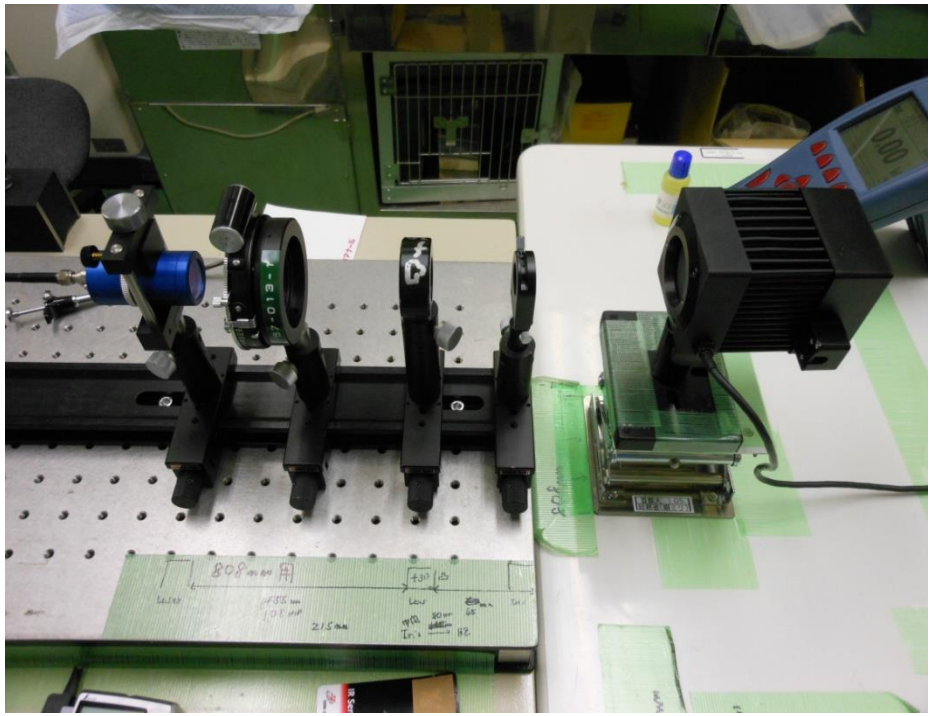
- The present study investigated 3 different ocular temperature measurement methods and evaluated the mechanism of heat induced cataract during 40 or 95 GHz MMW or IR-A (808 nm) exposure.

Materials and Methods

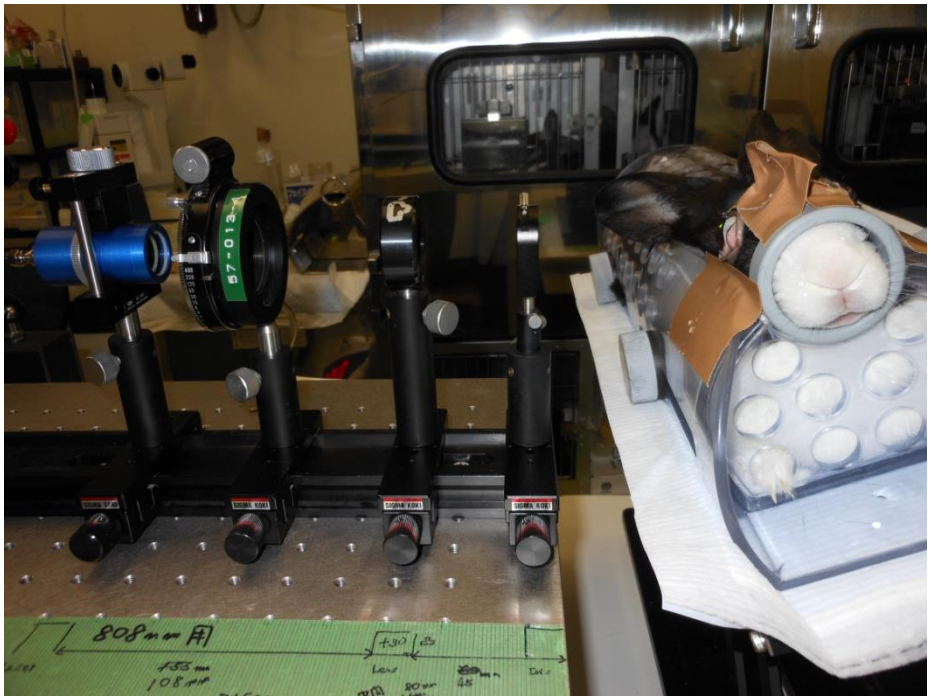
- **Experimental animal:**
  - Dutch-belted 12-15 week-old rabbits (N=30)
- **IR or MMW exposure:**
  - IR-A (808 nm: 1.0-2.0 W/cm^2)
  - MMW (40 or 95 GHz: 200-300 mW/cm^2)
- **Ocular temperature measurement:**
  - Thermography camera
  - Fluoroptic Thermometer
  - Microencapsulated Thermochromic Liquid Crystal (MTLC) injected into anterior chamber.

IR-A (808 nm) Exposure System

Exposure target: vicinity of iris and pupil boundary (Digital camera image)



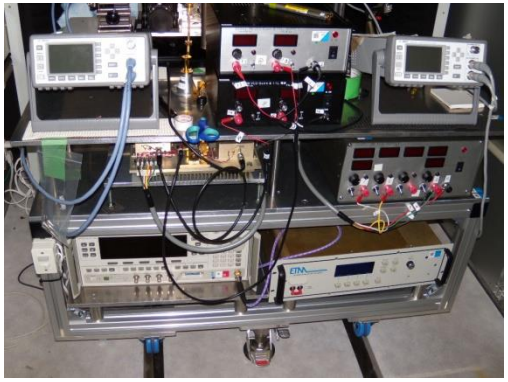
Measurement of irradiance



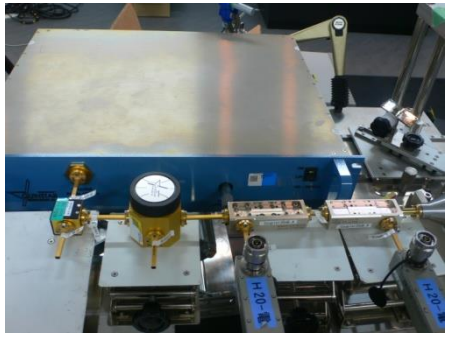
Placement of rabbit

MMW Exposure Systems

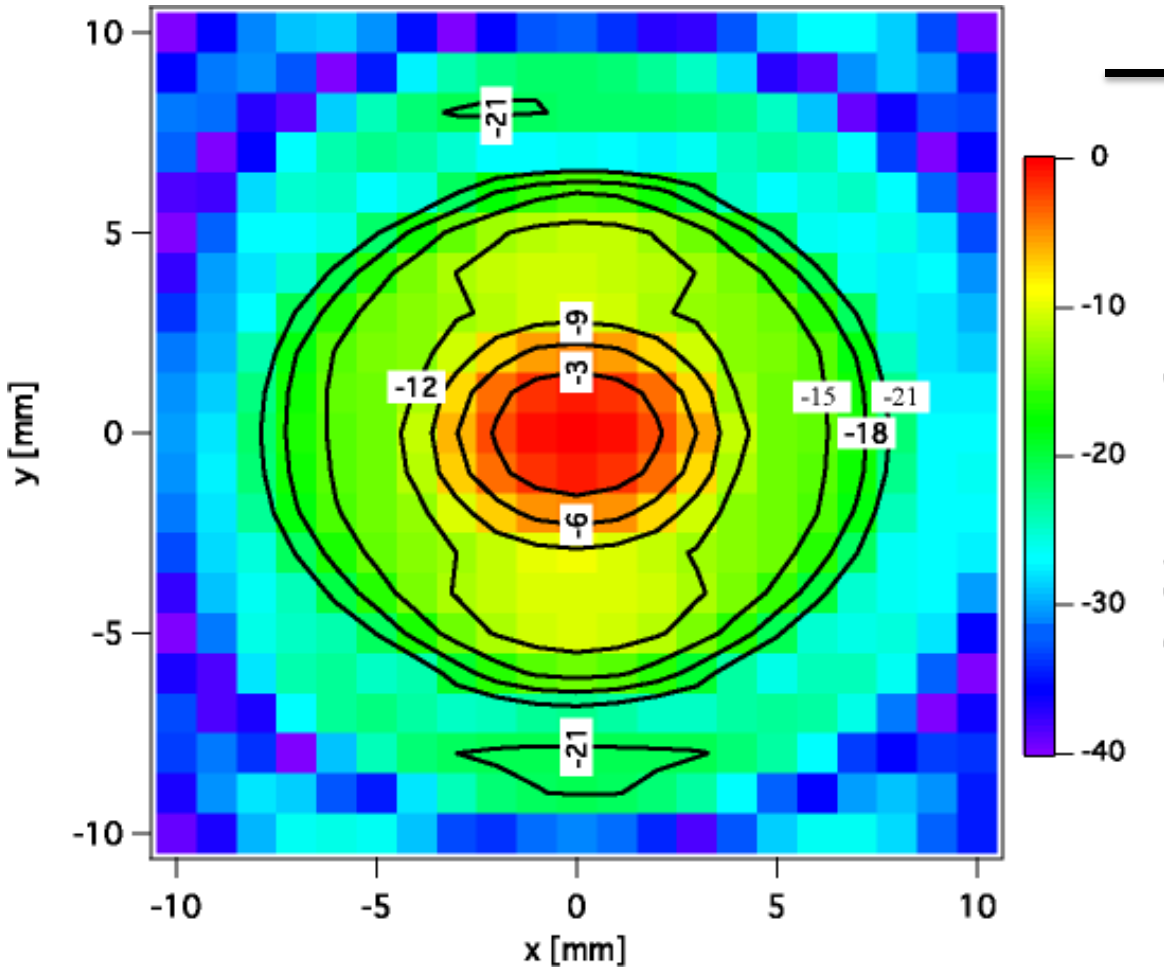
40 GHz

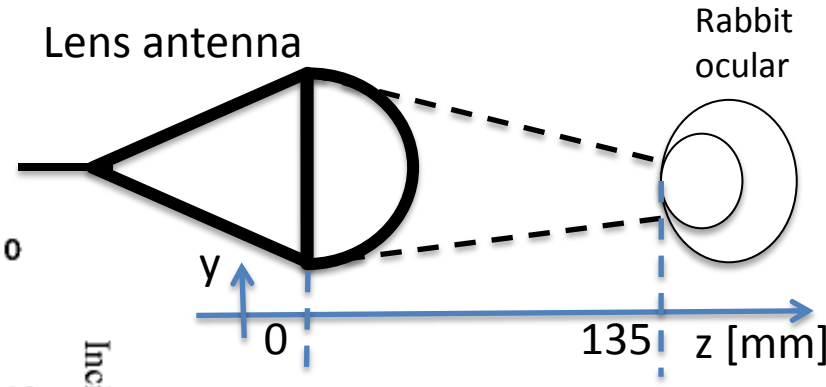


95 GHz

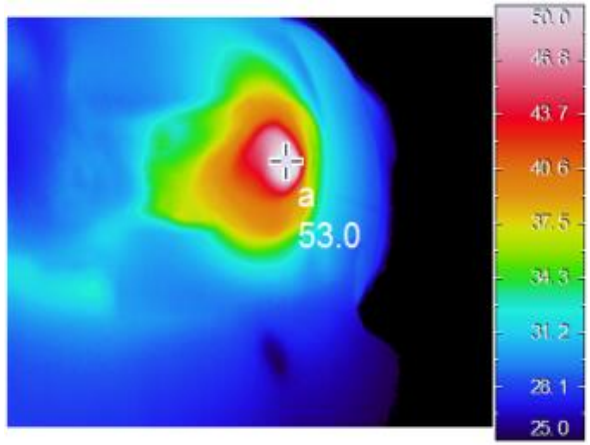


Distribution of incident power density



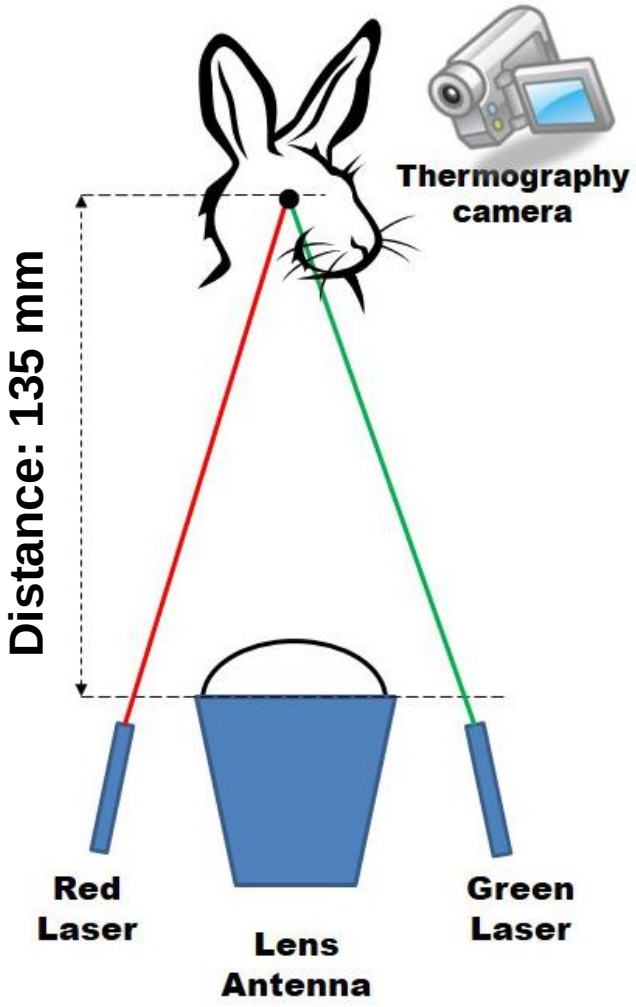


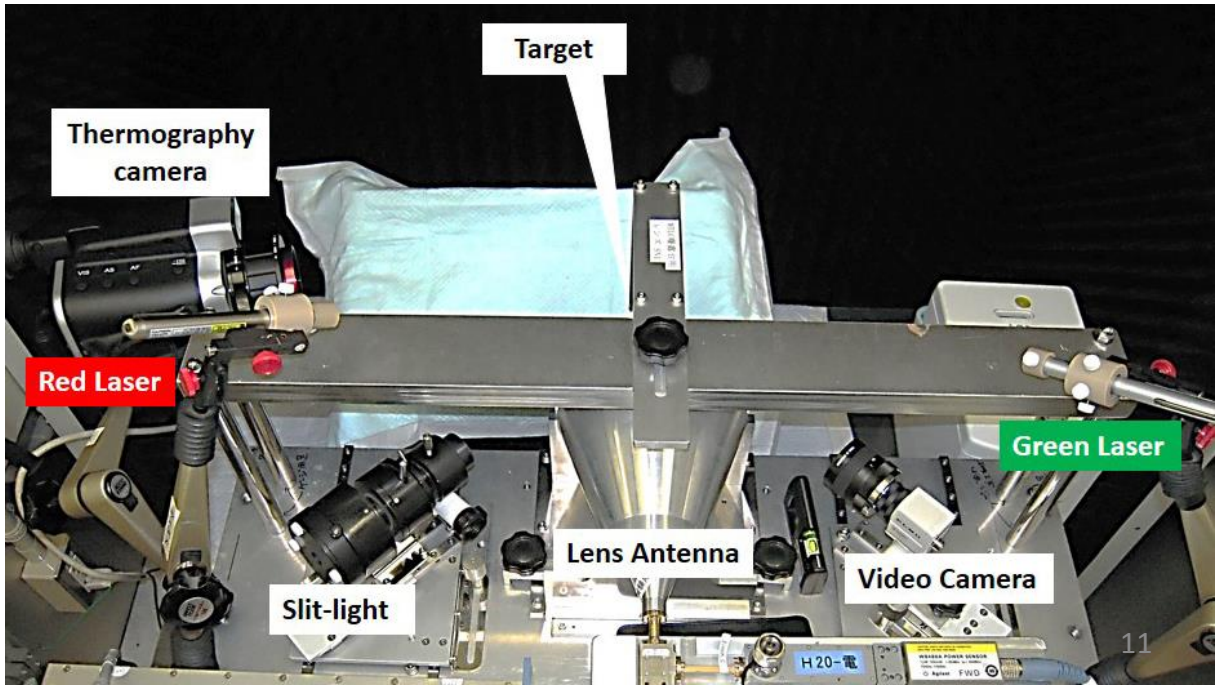
- Measured with open-ended waveguide probe (WR10)
- Interval: 1 mm



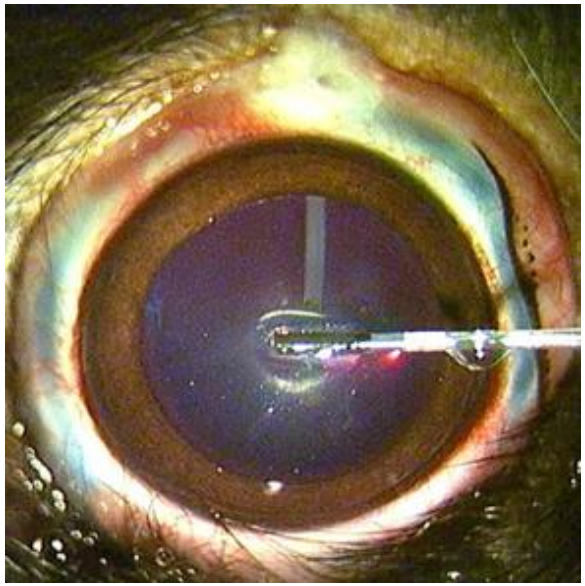
Thermography

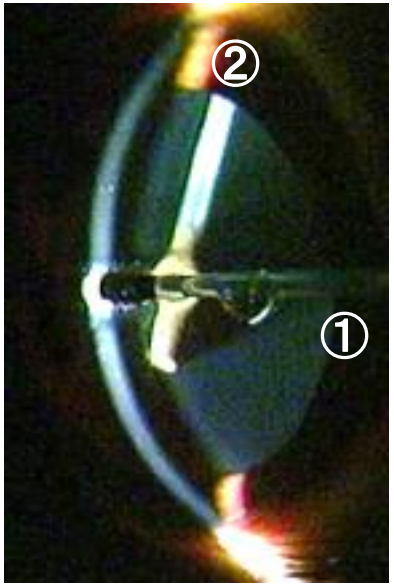
Standardized MMW Exposure System

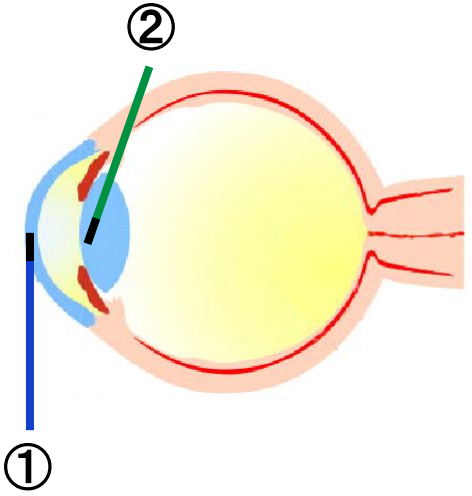




Fluoroptic Thermometer (Probe Method) Ocular Temperature Measurement

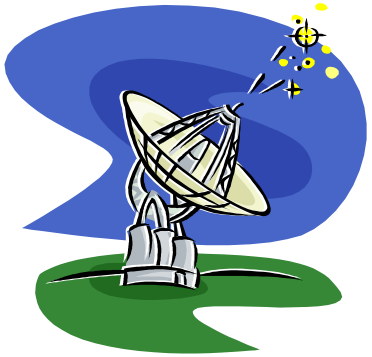






①：central cornea (stromal)
②：lens anterior cortex

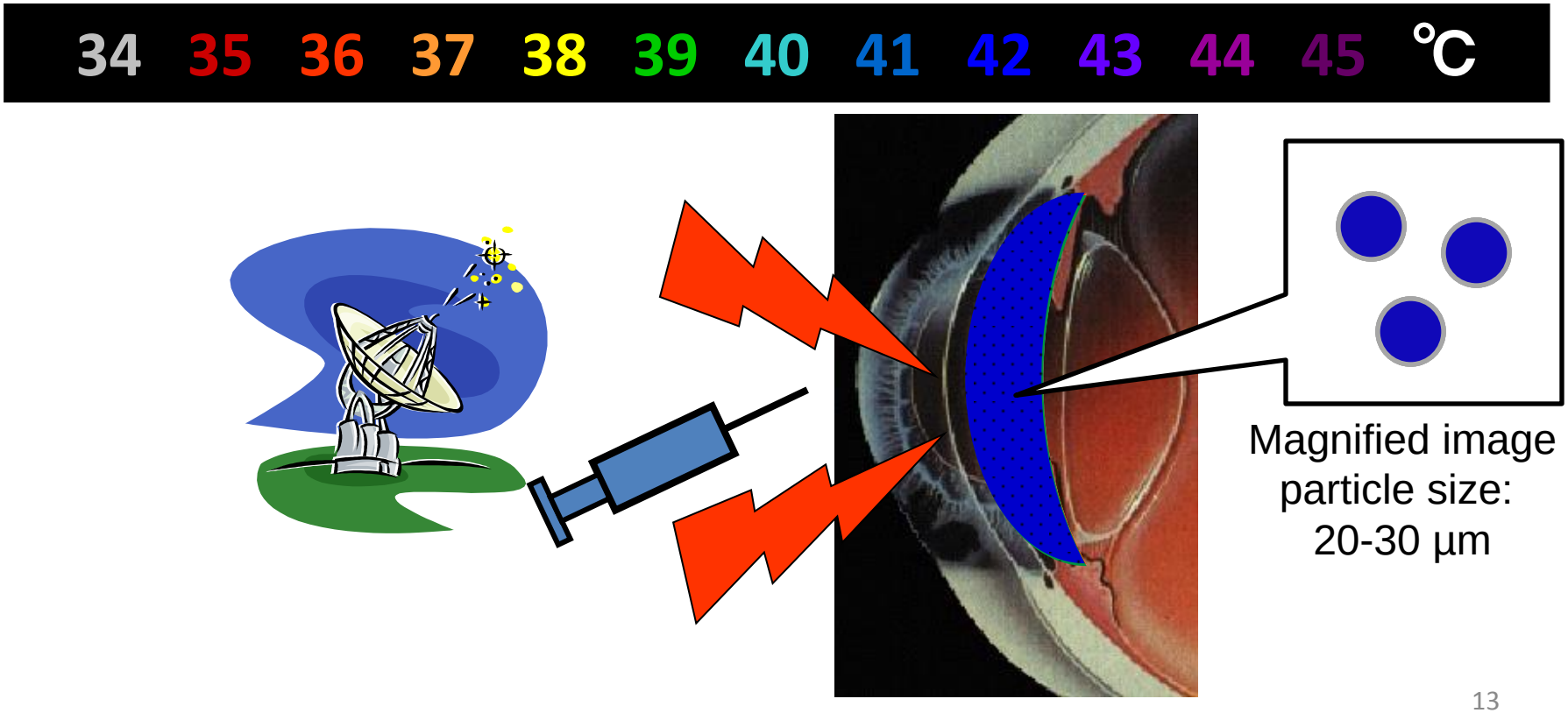
40 or 95 GHz
(200-300 mW/cm^2)



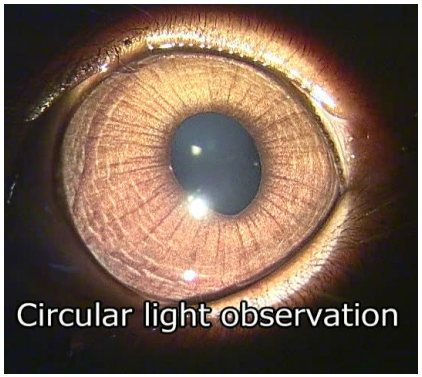
6 min. exposure

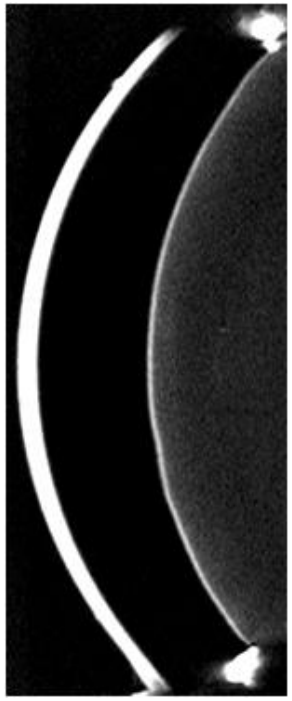
Ocular Temperature Measurement Method (MTLC Method)

- Microencapsulated thermochromic liquid crystal (MTLC) changes color depending on temperature
- MTLC injected into the anterior chamber before exposure



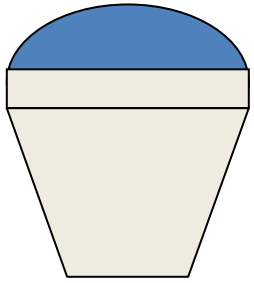
MTLC observation system



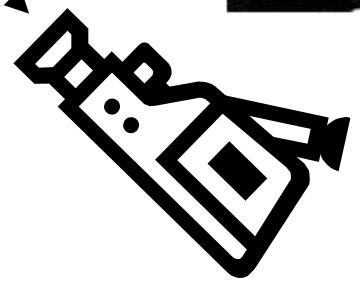


135 mm

Slit Illumination



Lens Antenna

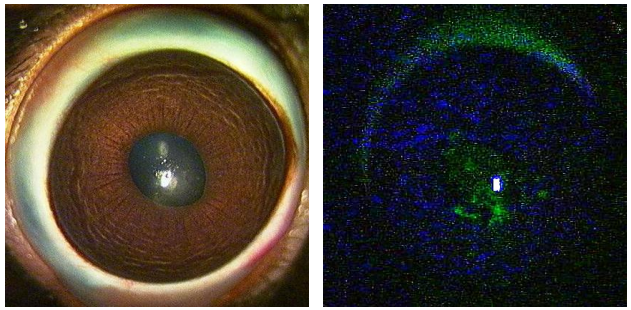


CCD Camera

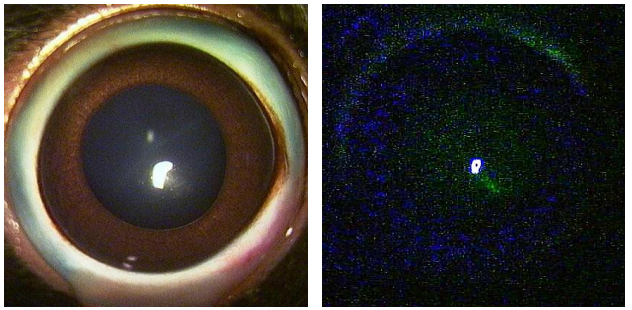
Comparison of Ocular Damage by 40 & 95 GHz 6 min exposure

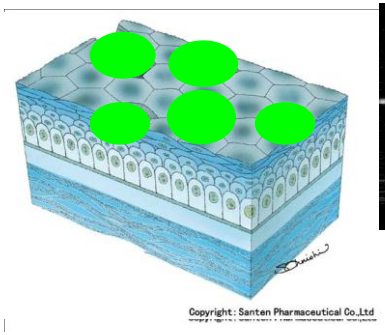
Immediately after | **1 day after**

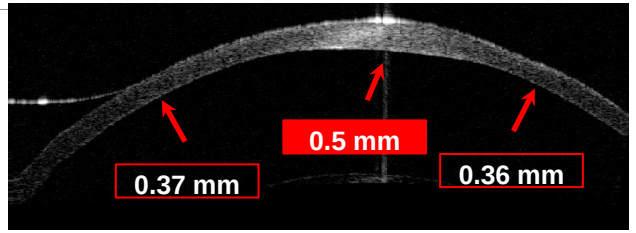
95 GHz
200 mW /cm²



Corneal Surface Temp. 43.5±1.9 ºC

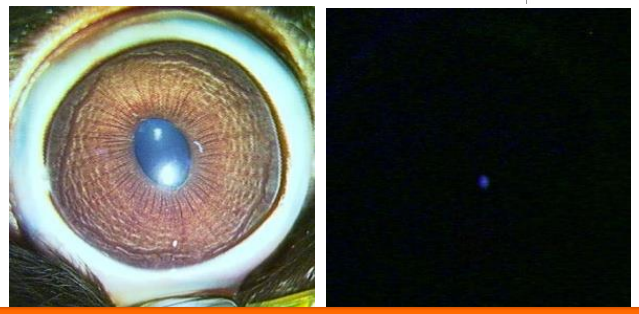




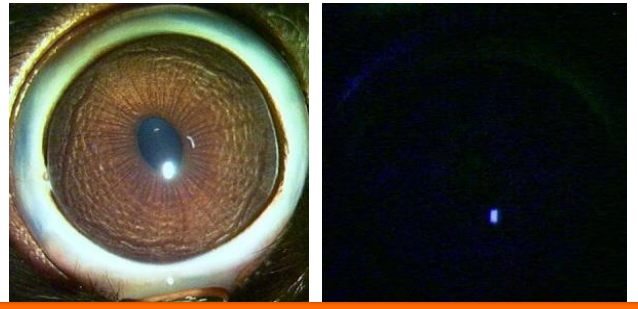


Immediately after | **1 day after**

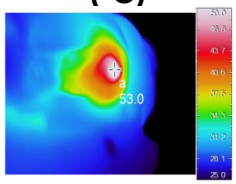
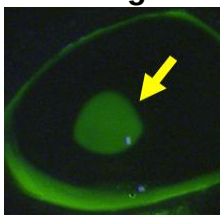
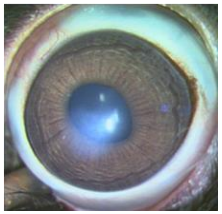
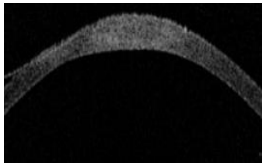
40 GHz
200 mW /cm²



Corneal Surface Temp. 41.4±1.1 ºC



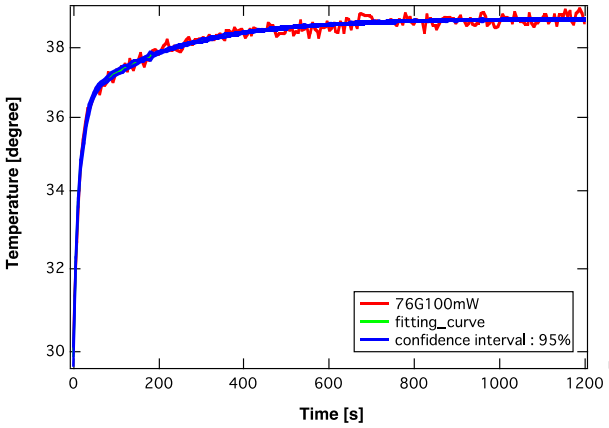
Ocular heat effects by 40 and 95 GHz MMW differed with 95 GHz being more severe.

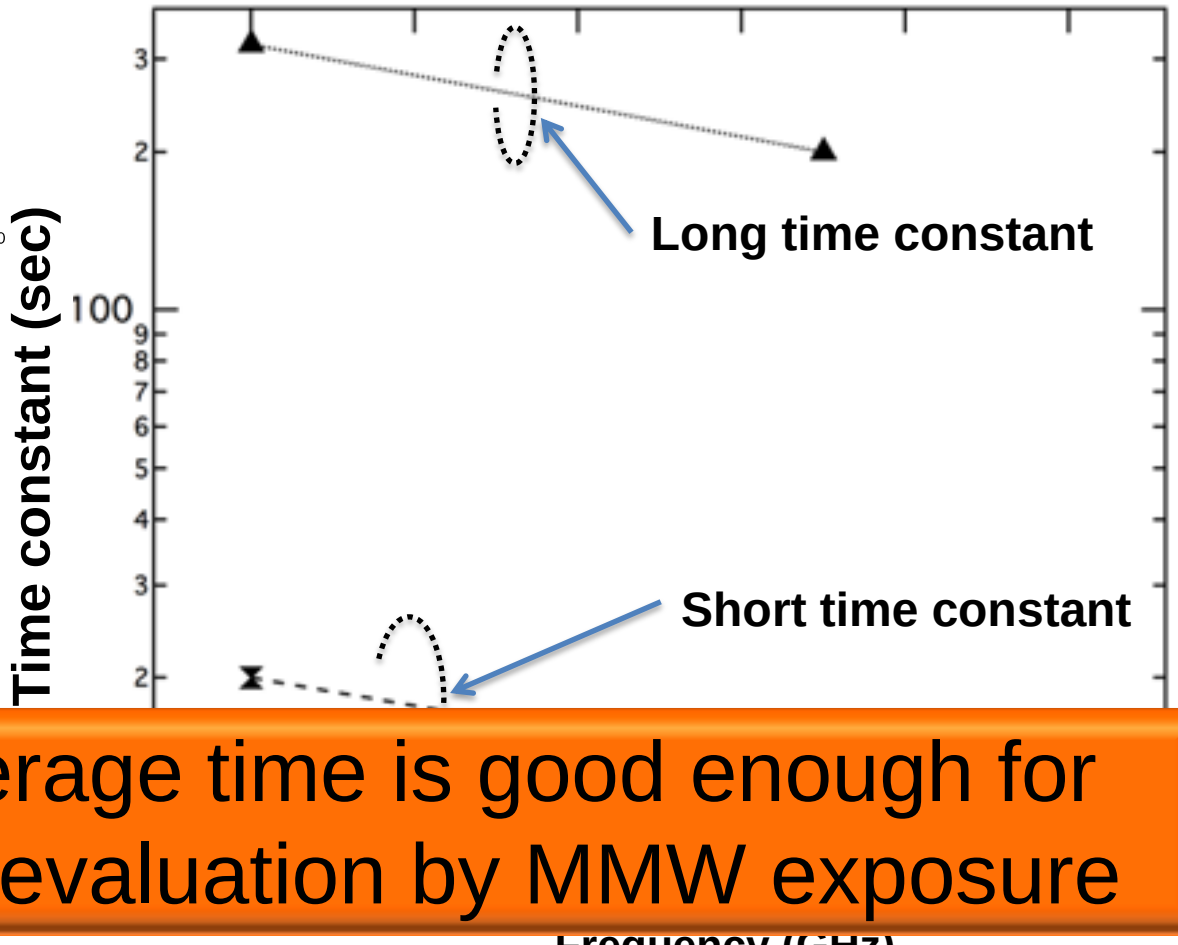
95 GHz **After 1 day exposure**	**Corneal Surface Temp. (ºC)** 	**Corneal Epithelium Damage** 	**Corneal Opaque** 	**Corneal Edema** 
300 mW/cm²_6 min	46.5±1.3	**Damage＋（2/3）**	**Damage＋（2/3）**	**Damage＋（2/3）**
200 mW/cm²_6 min	43.5±1.9	**Damage＋（13/14）**	**Damage＋（6/14）**	**Damage＋（6/14）**
100 mW/cm²_6 min	36.4±2.9	**Damage＋（1/9）**	**Damage＋（1/9）**	**Damage＋（1/9）**
50 mW/cm²_6 min	34.1±2.3	**Damage－（0/4）**	**Damage－（0/4）**	**Damage－（0/4）**
10 mW/cm²_6 min	32.5±1.5	**Damage－（0/4）**	**Damage－（0/4）**	**Damage－（0/4）**
200 mW/cm²_30 min	43.7±2.6	**Damage＋（10/10）**	**Damage＋（10/10）**	**Damage＋（10/10）**

There was no big ocular damage difference in 6 and 30 minutes exposure.

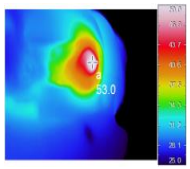
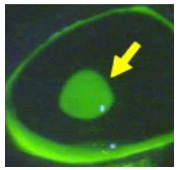
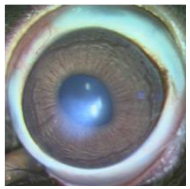
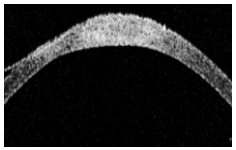
Presumption of a time constant

Corneal temperature (100 mW/cm^2)



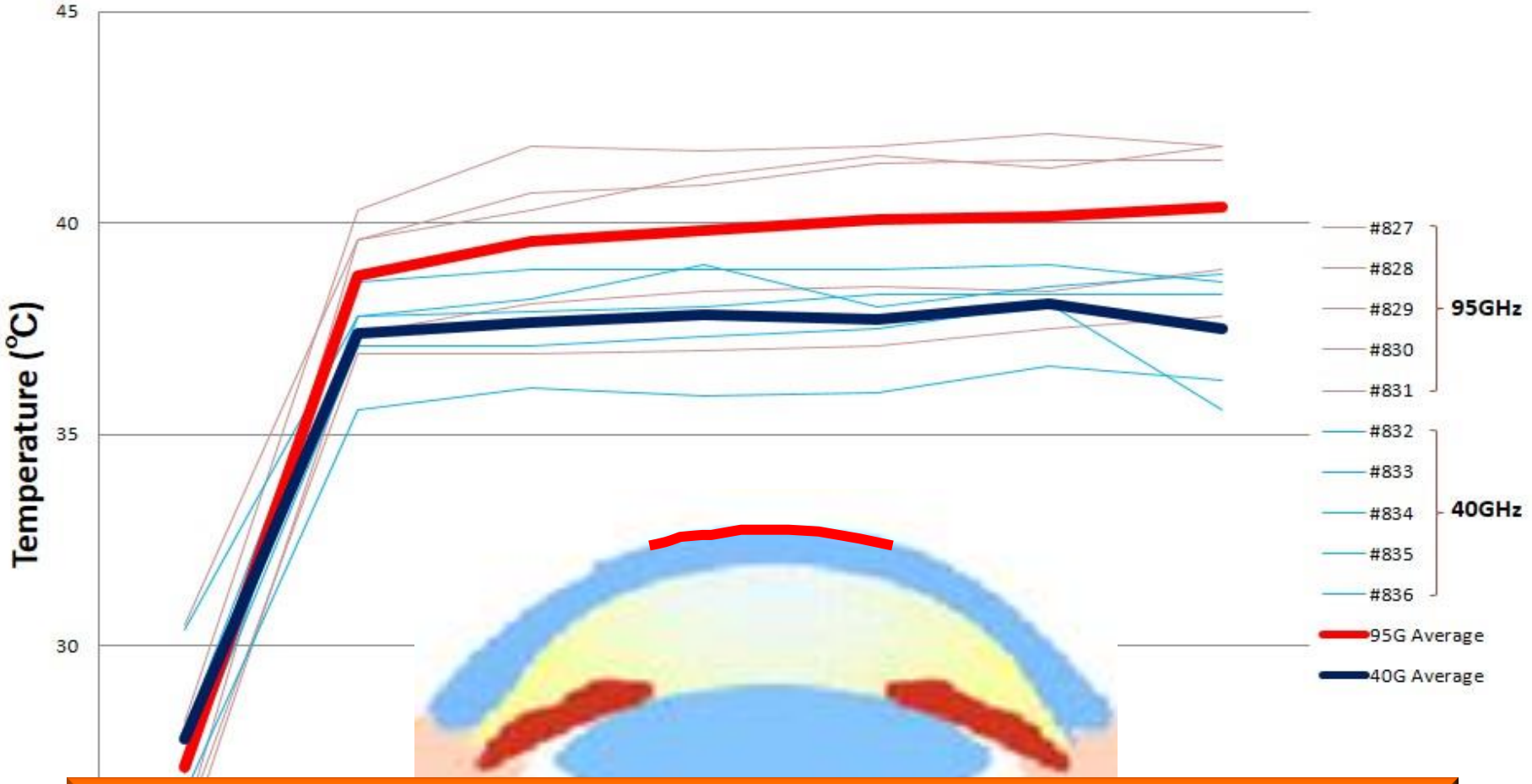


Six minutes average time is good enough for ocular damage evaluation by MMW exposure

40 GHz **After 1 day Exposure**	**Corneal Surface Temp. (ºC)** 	**Corneal Epithelium Damage** 	**Corneal Opaque** 	**Corneal Edema** 
600 mW/cm²_6 min	49.7	**Damage＋ (1/1)**	**Damage＋ (1/1)**	**Damage＋ (1/1)**
500 mW/cm²_6 min	45.0±2.4	**Damage＋ (2/2)**	**Damage＋ (2/2)**	**Damage＋ (2/2)**
400 mW/cm²_6 min	43.7±3.7	**Damage＋ (6/8)**	**Damage＋ (5/8)**	**Damage＋ (5/8)**
300 mW/cm²_6 min	41.7±1.7	**Damage＋ (6/8)**	**Damage＋ (5/8)**	**Damage＋ (5/8)**
200 mW/cm²_6 min	41.4±1.1	**Damage＋ (3/6)**	**Damage－ (0/6)**	**Damage－ (0/6)**
100 mW/cm²_6 min	37.2±2.9	**Damage＋ (2/8)**	**Damage－ (0/8)**	**Damage－ (0/8)**
50 mW/cm²_6 min	33.6±1.8	**Damage＋ (1/7)**	**Damage－ (0/7)**	**Damage－ (0/7)**
10 mW/cm²_6 min	32.9±1.3	**Damage－ (0/1)**	**Damage－ (0/1)**	**Damage－ (0/7)**

Corneal Surface Temperature

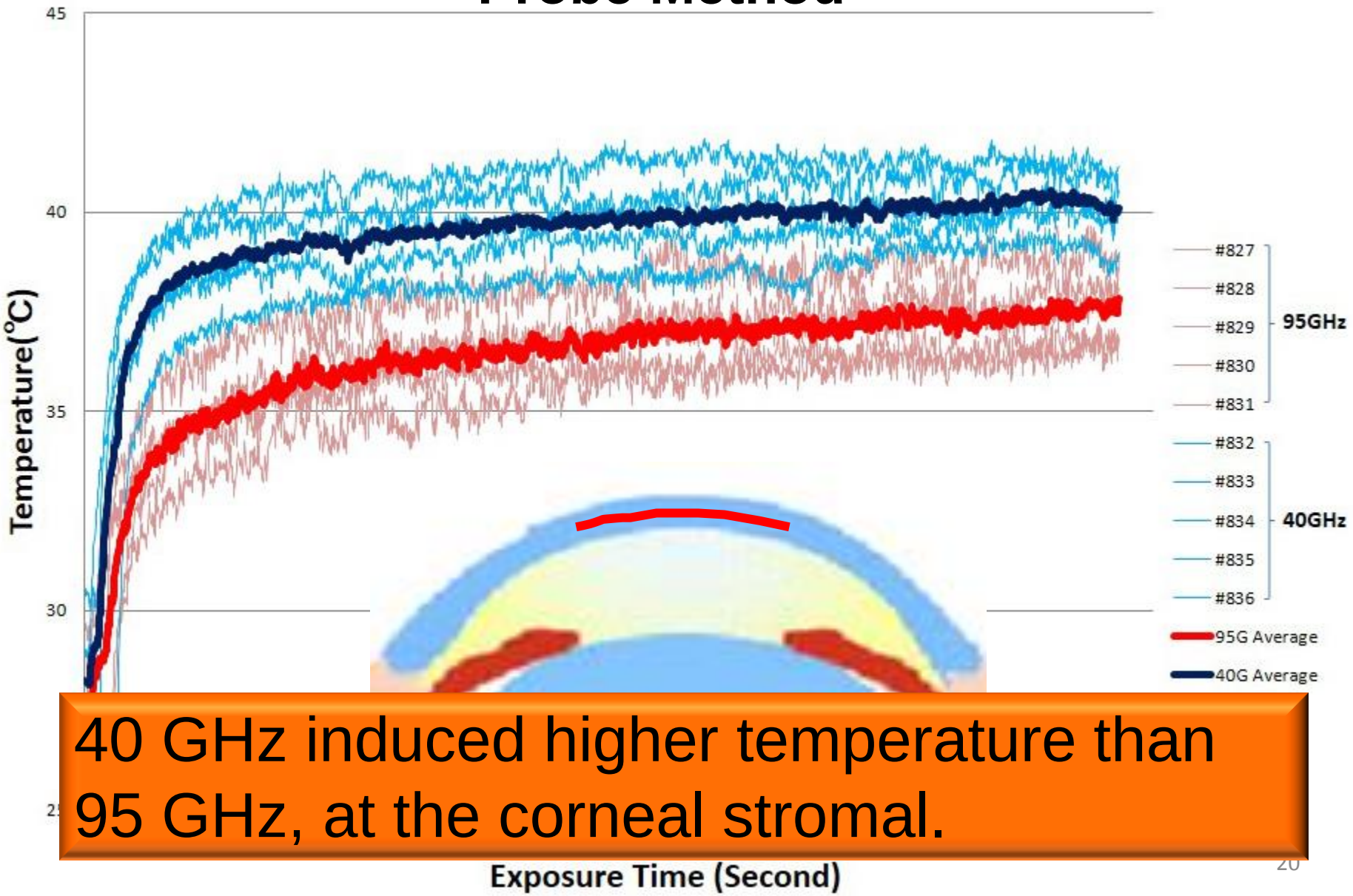
Thermography Camera Method (100 μm)



95 GHz induced higher temperature than 40 GHz, at the corneal surface (100 μm).

Corneal Stromal Temperature

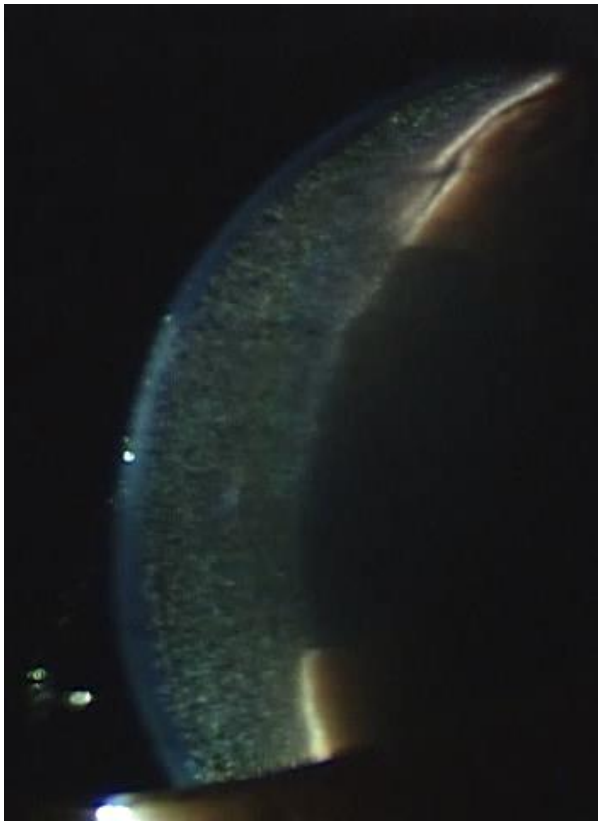
Probe Method

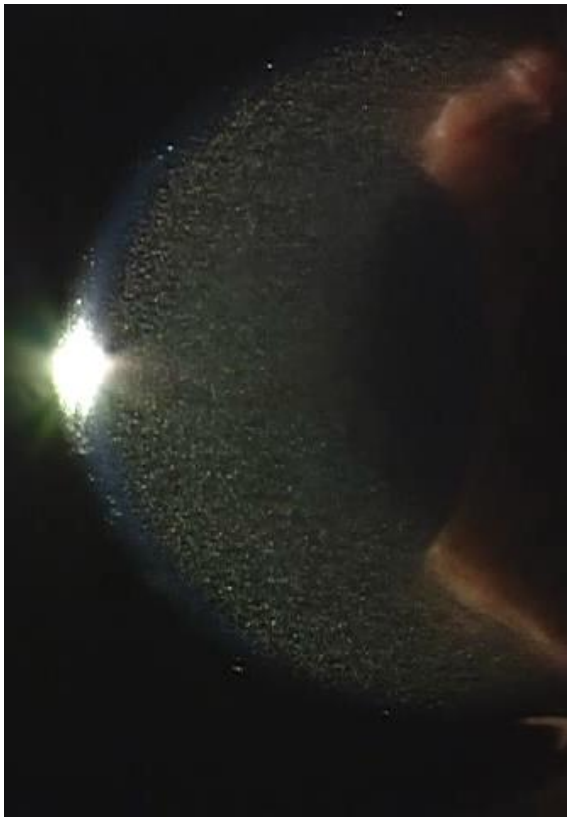


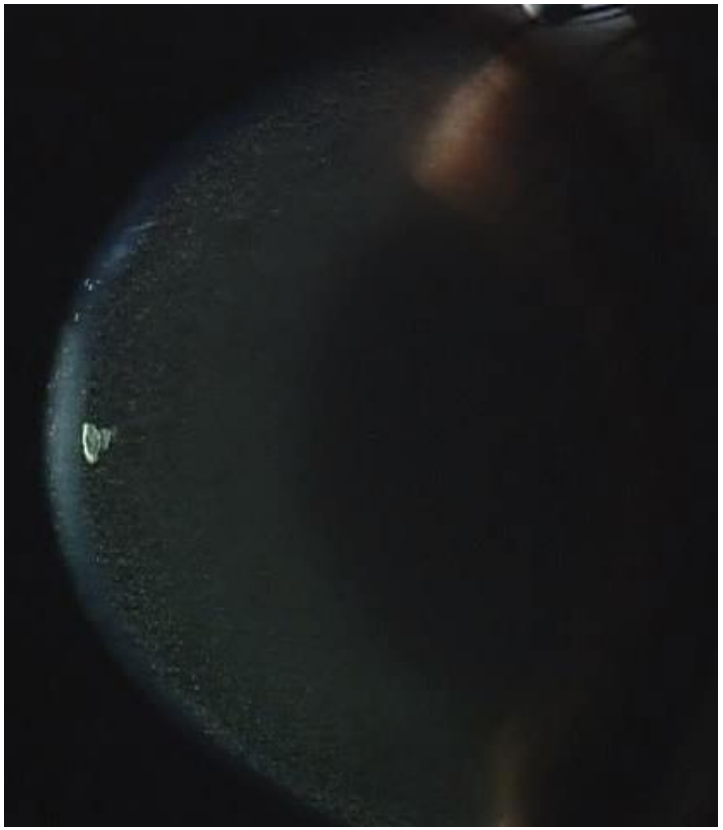
40 GHz induced higher temperature than 95 GHz, at the corneal stromal.

Visualization of Temperature Distribution During IR or MMW Exposure

34 35 36 37 38 39 40 41 42 43 44 45 ℃







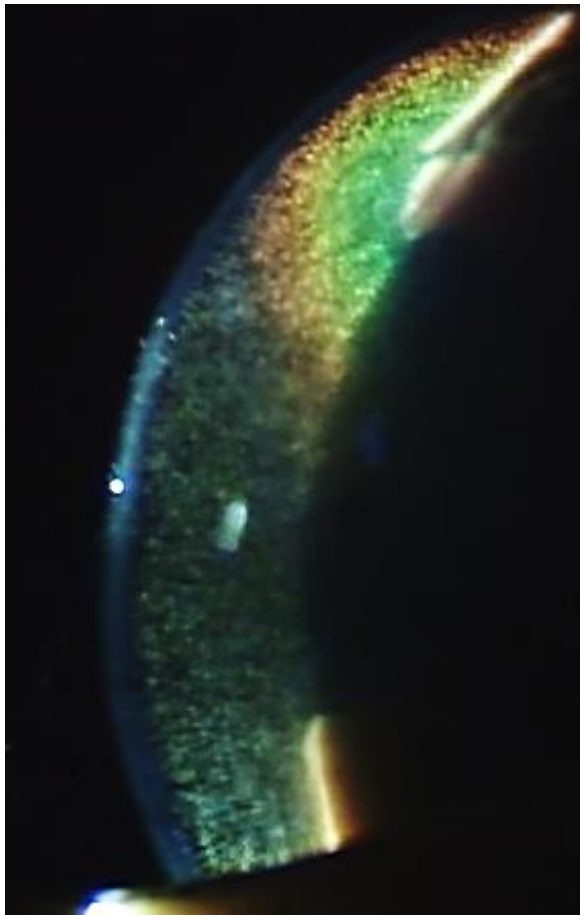
IR (808 nm)
520 mW/cm²

MMW (40 GHz)
200 mW/cm²

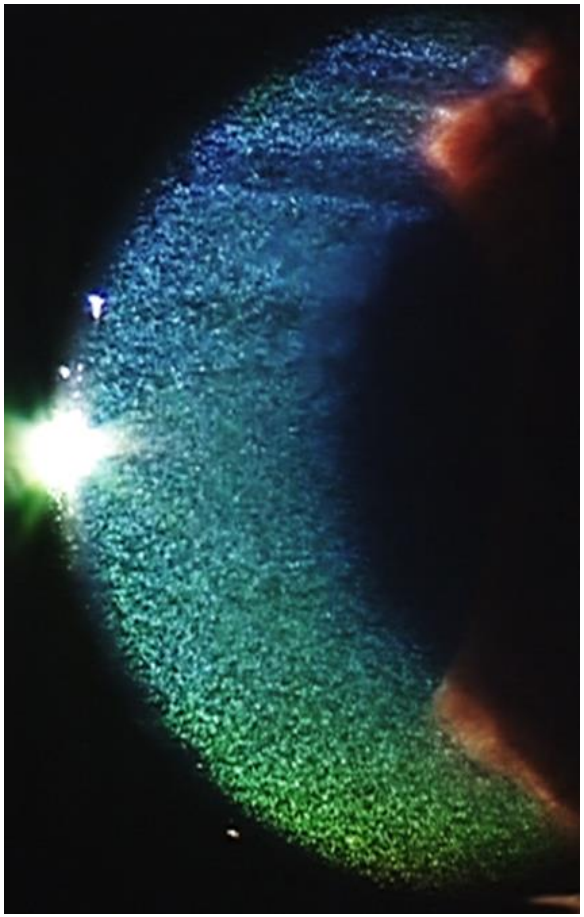
MMW (95 GHz)
200 mW/cm²

Difference of heat induction by IR and MMW

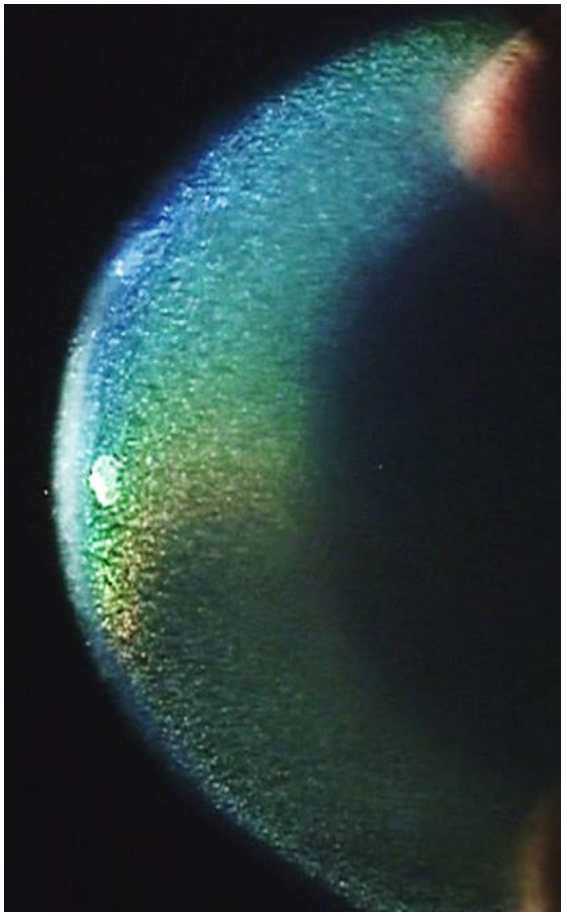
34 35 36 37 38 39 40 41 42 43 44 45 ℃



IR (808 nm)
10 s after exposure



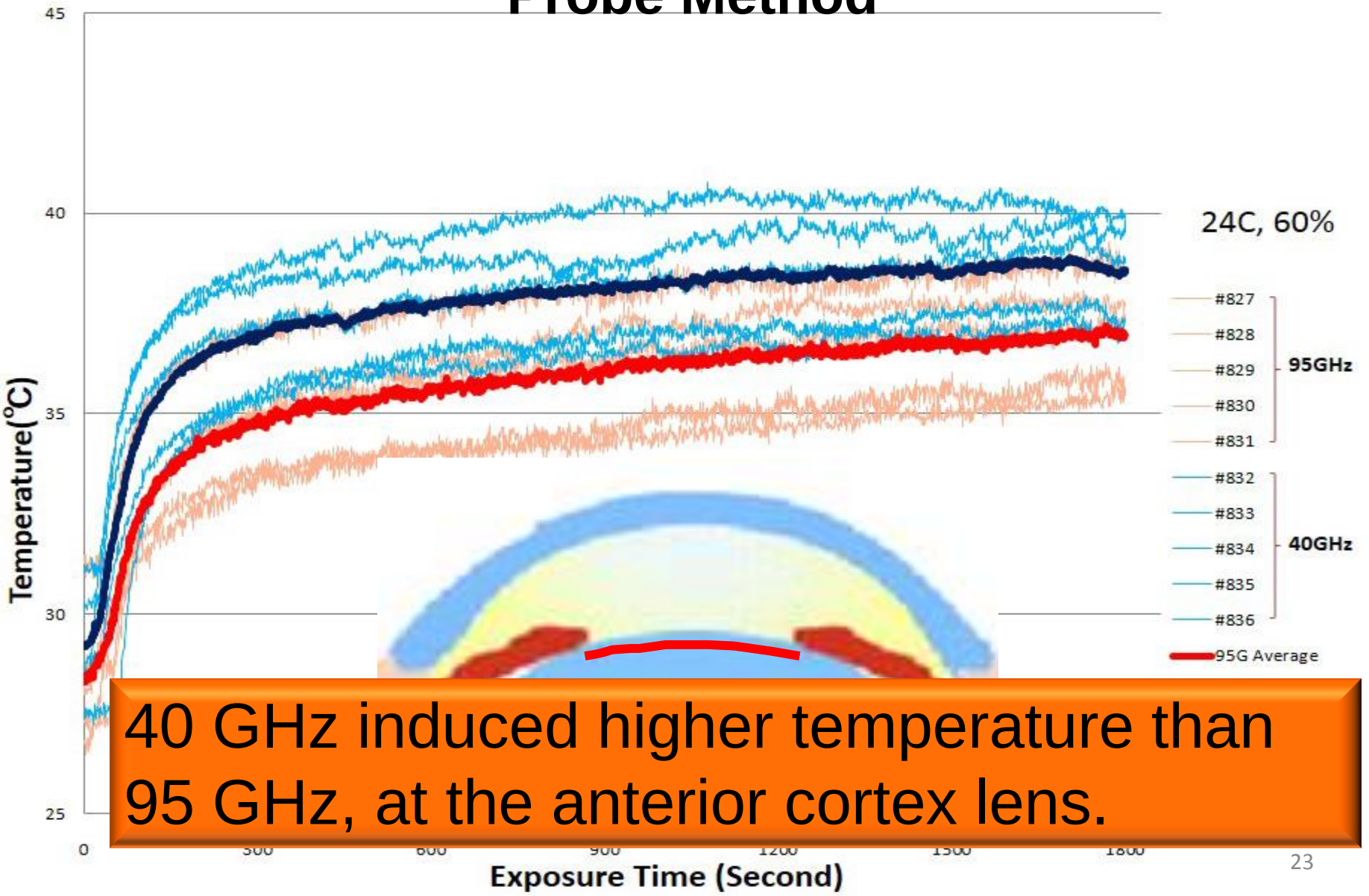
MMW (40 GHz)
30 s after exposure



MMW (95 GHz)
30 s after exposure

Anterior Cortex Lens Temperature

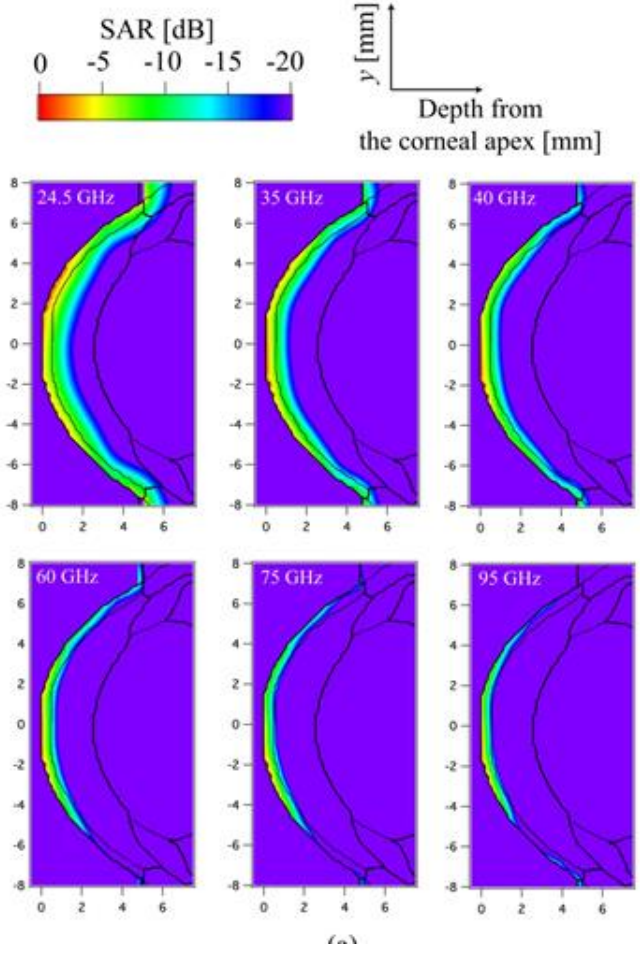
Probe Method

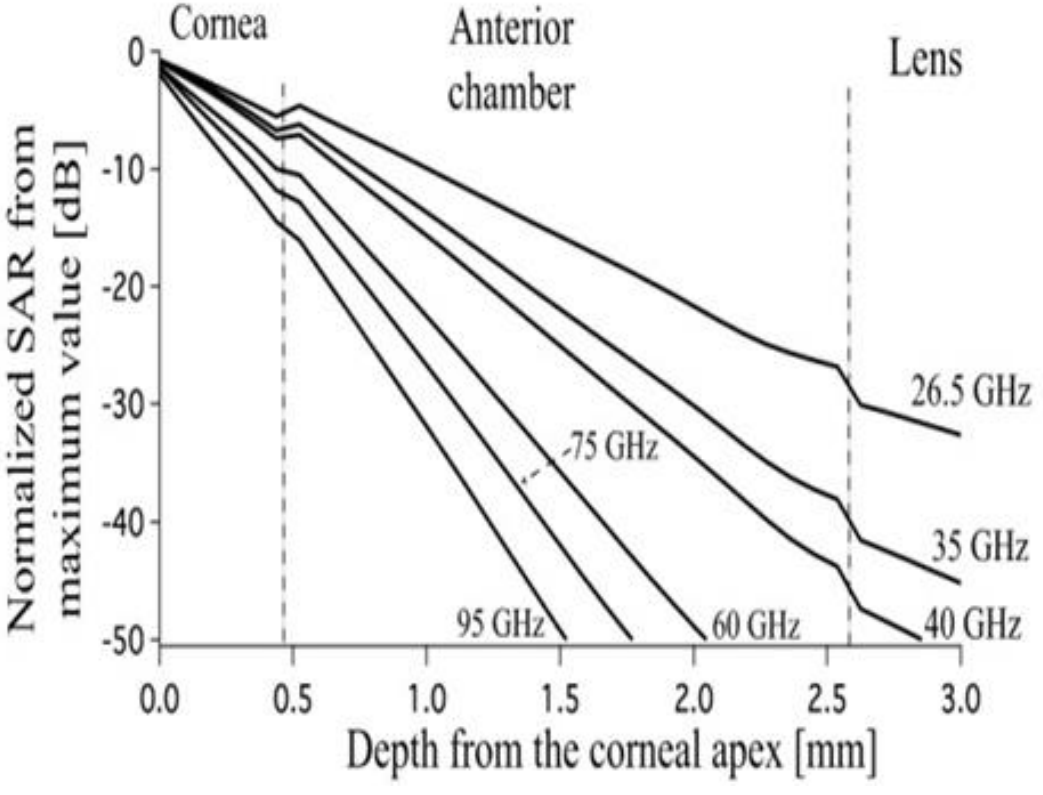


40 GHz induced higher temperature than 95 GHz, at the anterior cortex lens.

Discussion

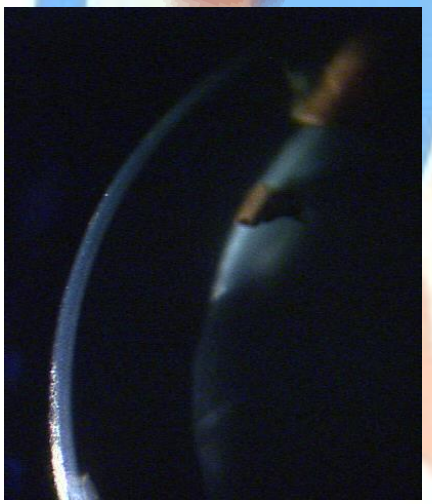
- Sasaki et al. reported specific absorption rate (SAR) among 26.5-95 GHz. Sasaki showed that as frequency increased, MMW exposure became more localized in rabbit cornea (IEEE Trans. Microwave Theory and Technique, 2014)





Discussion

Heat transfer from iris to lens is conduction dominant.



IR-A

Broad and deep temperature elevation causes wide convection

Skin depth: 0.59 mm

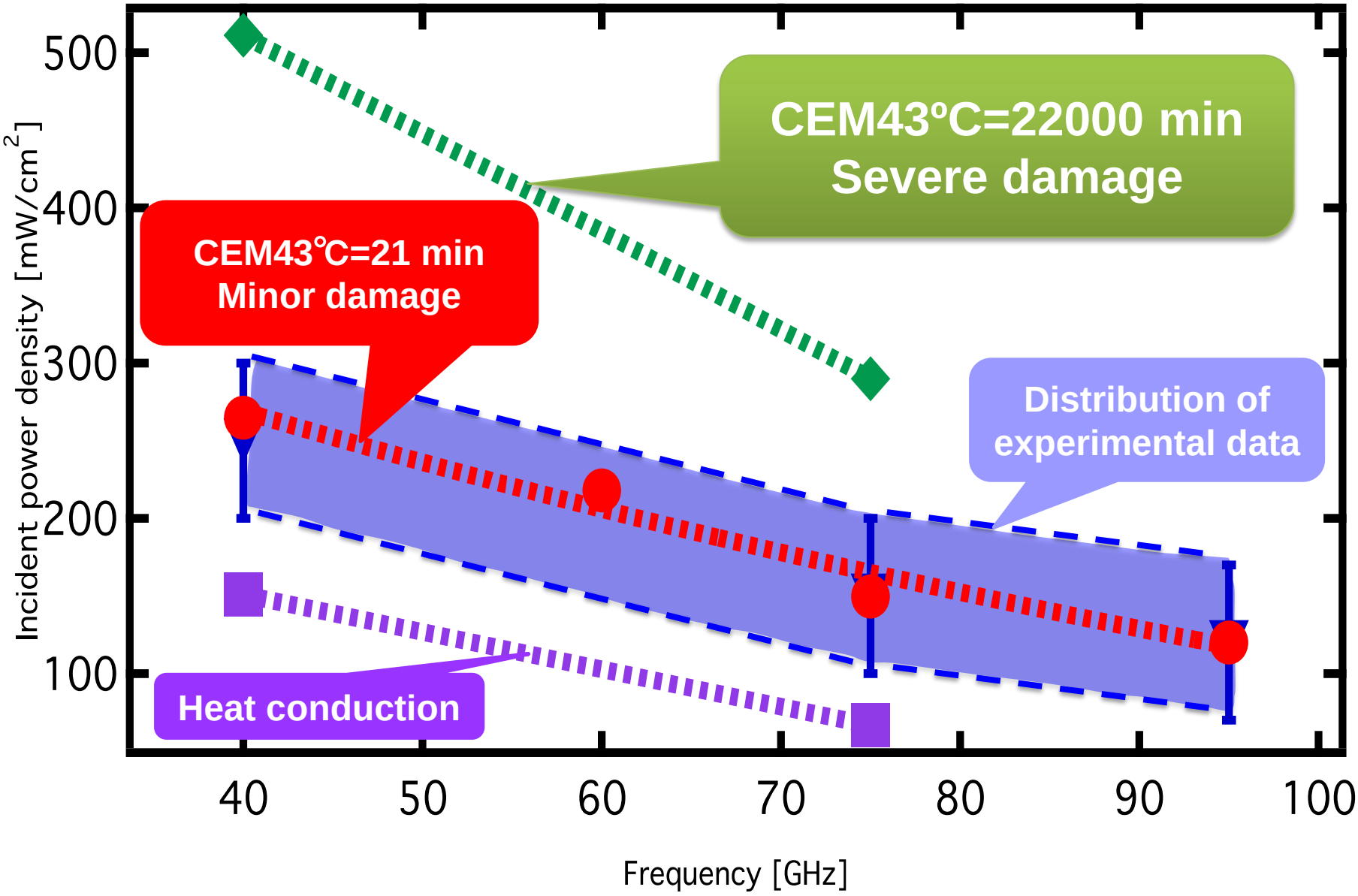
MMW (40 GHz)

Corneal surface heat generation causes an intensive convection

Skin depth: 0.31 mm

MMW (95 GHz)

Threshold of ocular damage



Conclusion

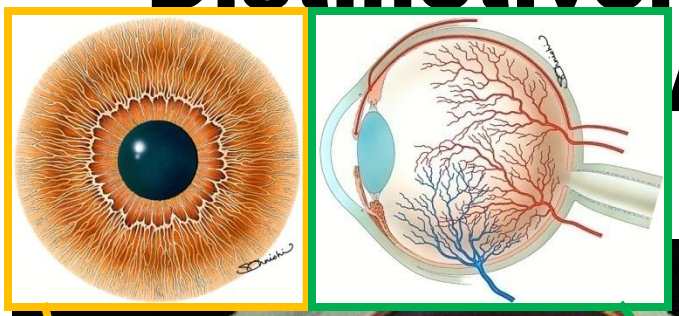
- The mechanisms of heat cataracts induced by MMW and IR are different.
- The frequency and the thermal transport absorption characteristics of the ocular tissues are important factors in ocular damage induction.
- Three methods on ocular temperature measurement did not accord with ocular damage.
- Estimated thresholds with the mathematical model based on CEM43ºC was consistent with the experiment result.

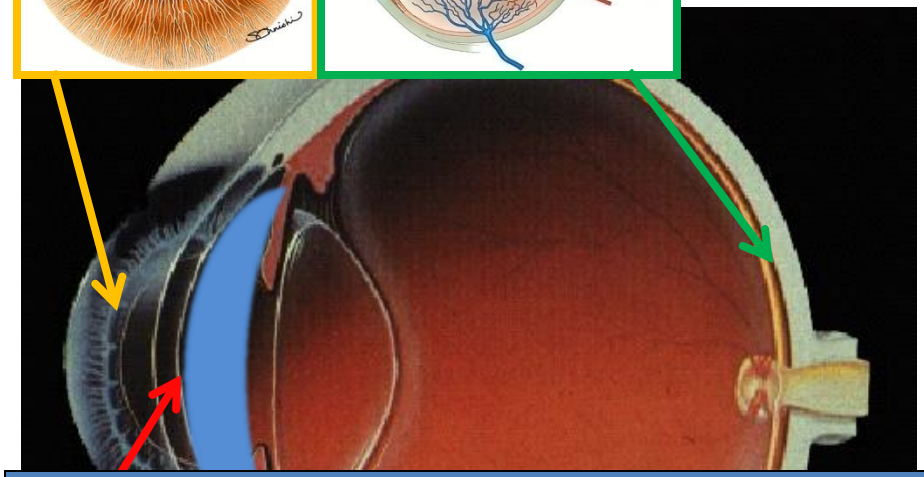
Acknowledgment

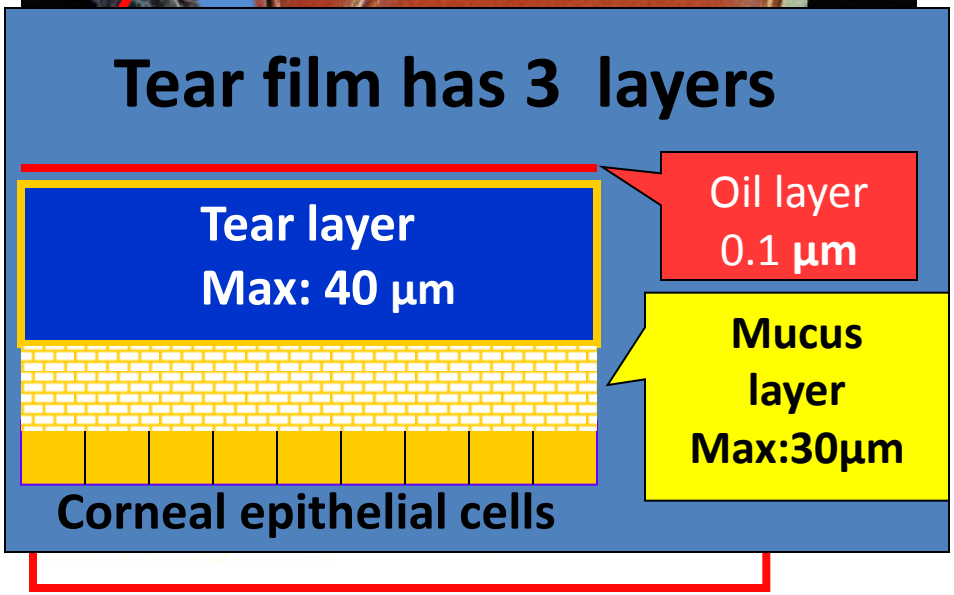
This work was supported by the Ministry of Internal Affairs and Communications, Japan.

Thank you for your attention

Distinctiveness of eyes in electric wave hazard

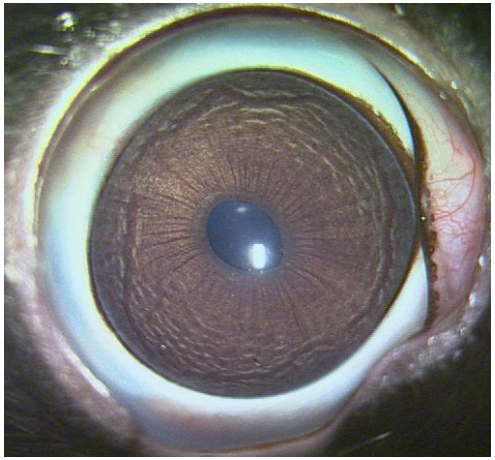




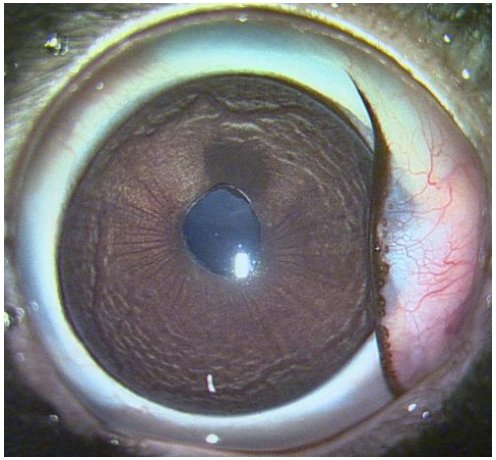


- Cornea: avascular organ, 78% water content
- The cornea is five-layer structure.
- Anterior chamber: aqueous humor (98% water content) convection
- Iris: Amount of iris blood circulation is 2.5 times higher than that of cerebral white matter.
- Lens: avascular organ, 66% water content
- Vitreous: avascular organ, 98% water content
- Choroid: Amount of Choroid blood circulation is 90 times higher than that of cerebral white matter.

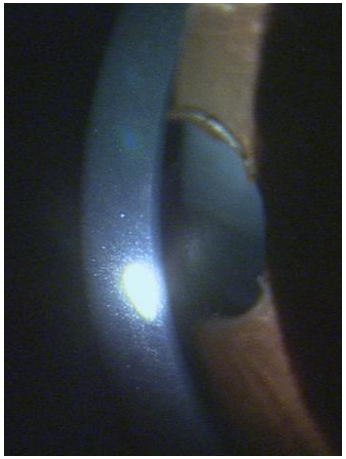
Ocular Findings after IR-A (808 nm)

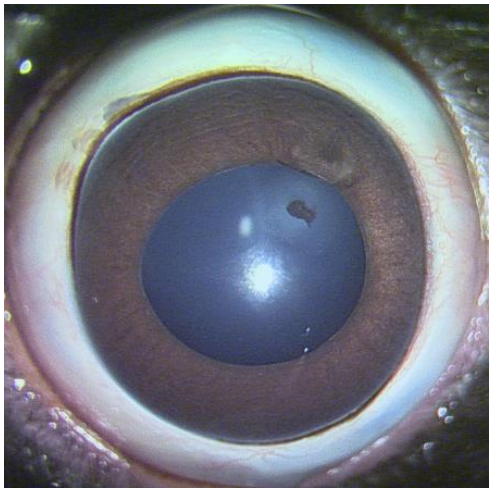


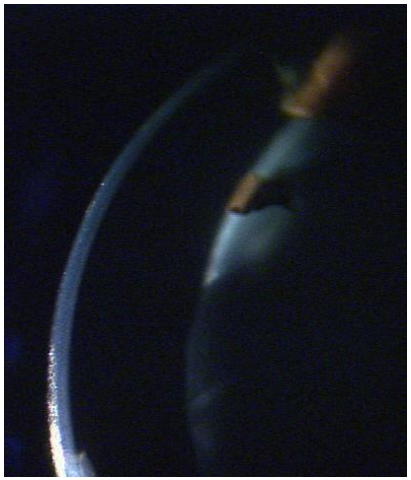
Before exposure

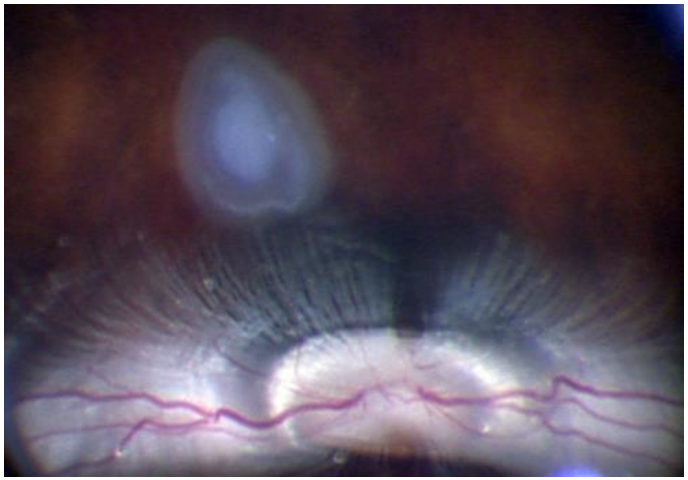


10 min after exposure





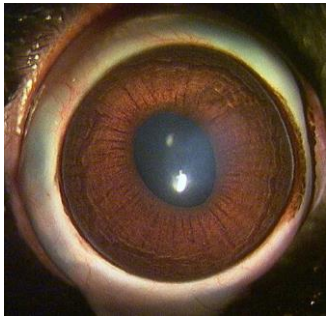
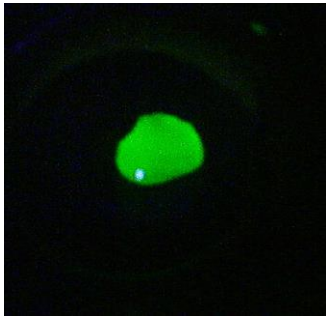
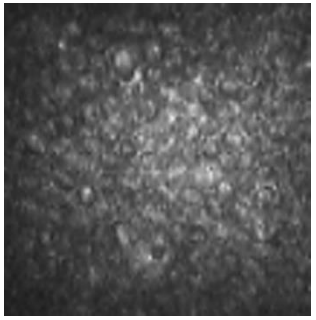




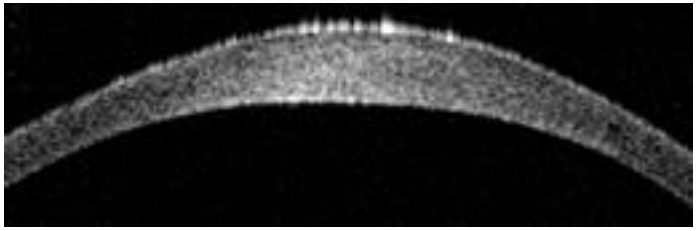
1 day after exposure

Summary of corneal endothelium observation

- **MMW (40 GHz, 600 mW/cm^2, 6 min.) did not induce prominent corneal endothelial cell damage.**

- **Epithelium and endothelium damage showed different direction of corneal swelling.**



MMW exposure:
Convex to epithelium side

Glaucoma attack:
Convex to endothelium side

- **Skip endothelium observation**

Spectrum and Uses of Electromagnetic Radiation