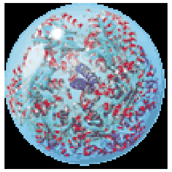
wetsus

centre of excellence for sustainable water technology

A New State of Water



Invited presentation at the
7th Annual Conference on the Physics, Chemistry and Biology of Water
Mount Snow, Vermont, USA
October 20th, 2012

Elmar C. Fuchs

combining scientific excellence with commercial relevance

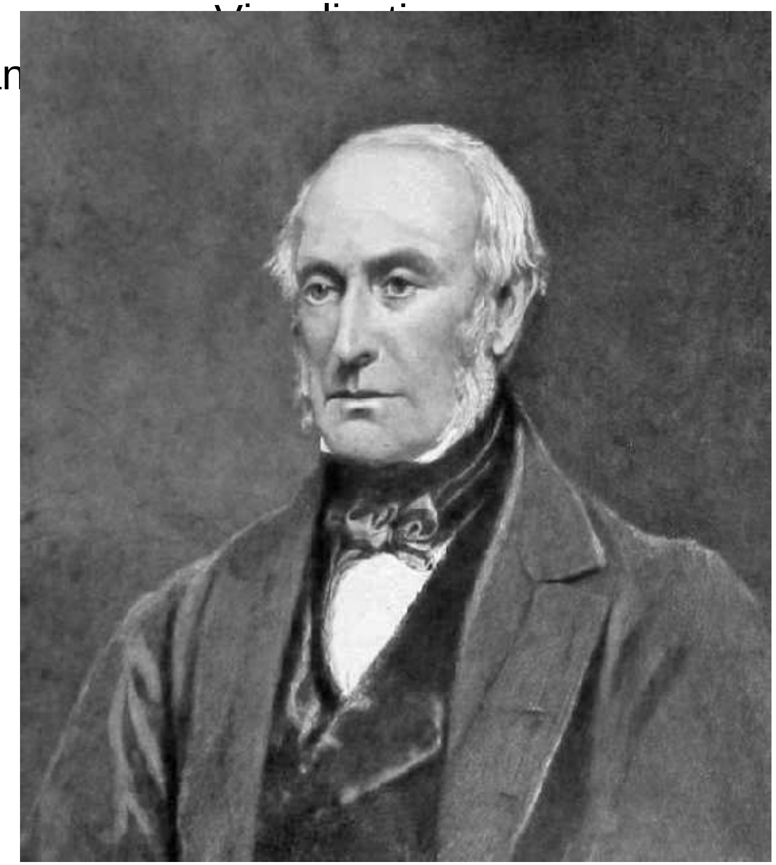
Electricity and Water

Discovery

Armstrong, William George, "Electrical Phenomena", in: THE ELECTRICAL ENGINEER, Feb 10 (1893) p154-155

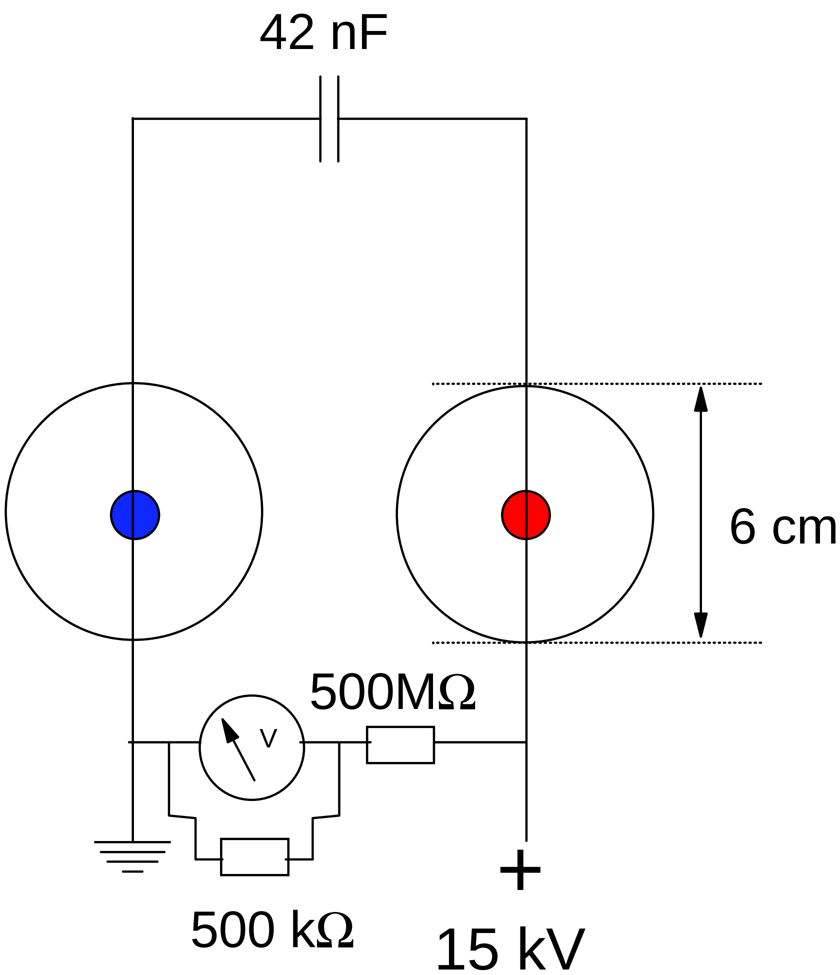
"...Amongst other experiments I hit upon a very remarkable one. Taking two wine-glasses filled to the brim with chemically pure water, I connected the two glasses by a cotton thread coiled up in one glass, and having its shorter end dipped into the other glass. On turning on the current, the coiled thread was rapidly drawn out of the glass containing it, and the whole thread deposited in the other, leaving, for a few seconds, a rope of water suspended between the lips of the two glasses. ..."

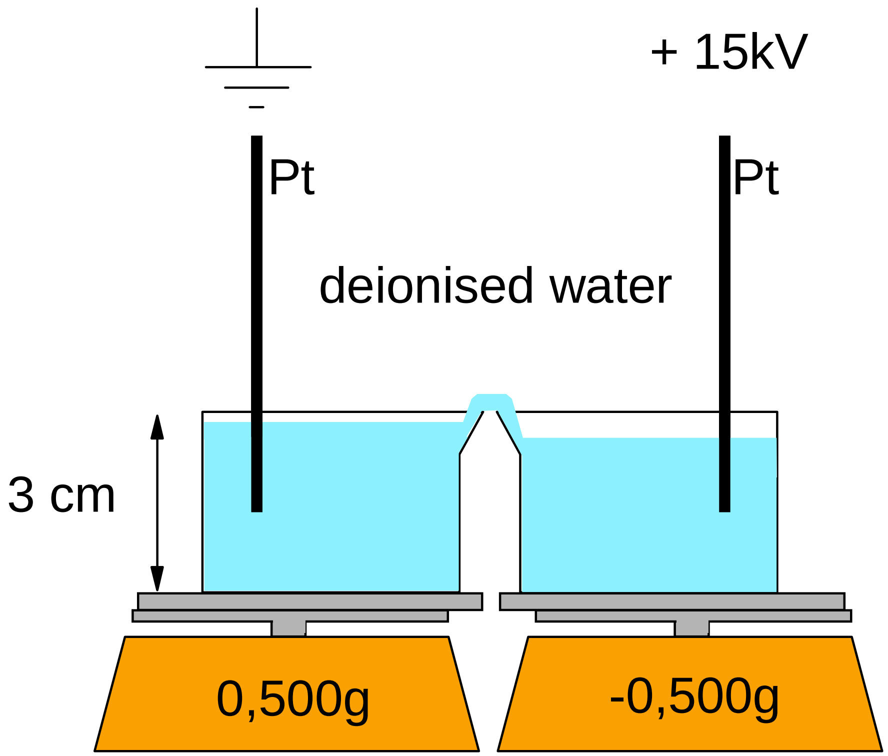
Pan



Sir William George Armstrong,
1st Baron Armstrong
* November 26, 1810
† December 27, 1900

Experimental Set-up

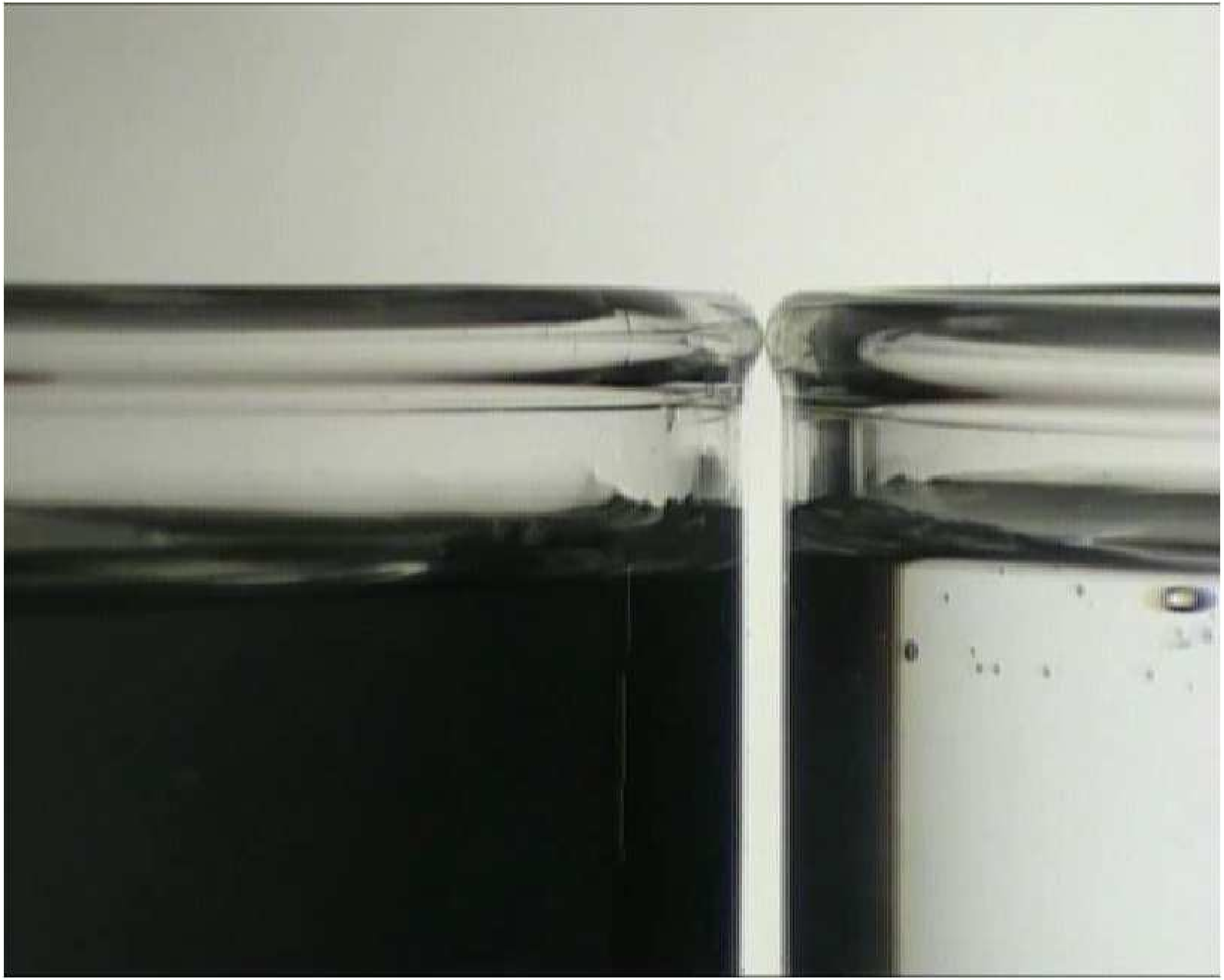




I = 0,5 mA (const.)

J. Woisetschläger, K. Gatterer, E.C. Fuchs, Experiments in a Floating Water Bridge, *Exp. Fluids* **48** (2010) 121-131

Bridge Expansion

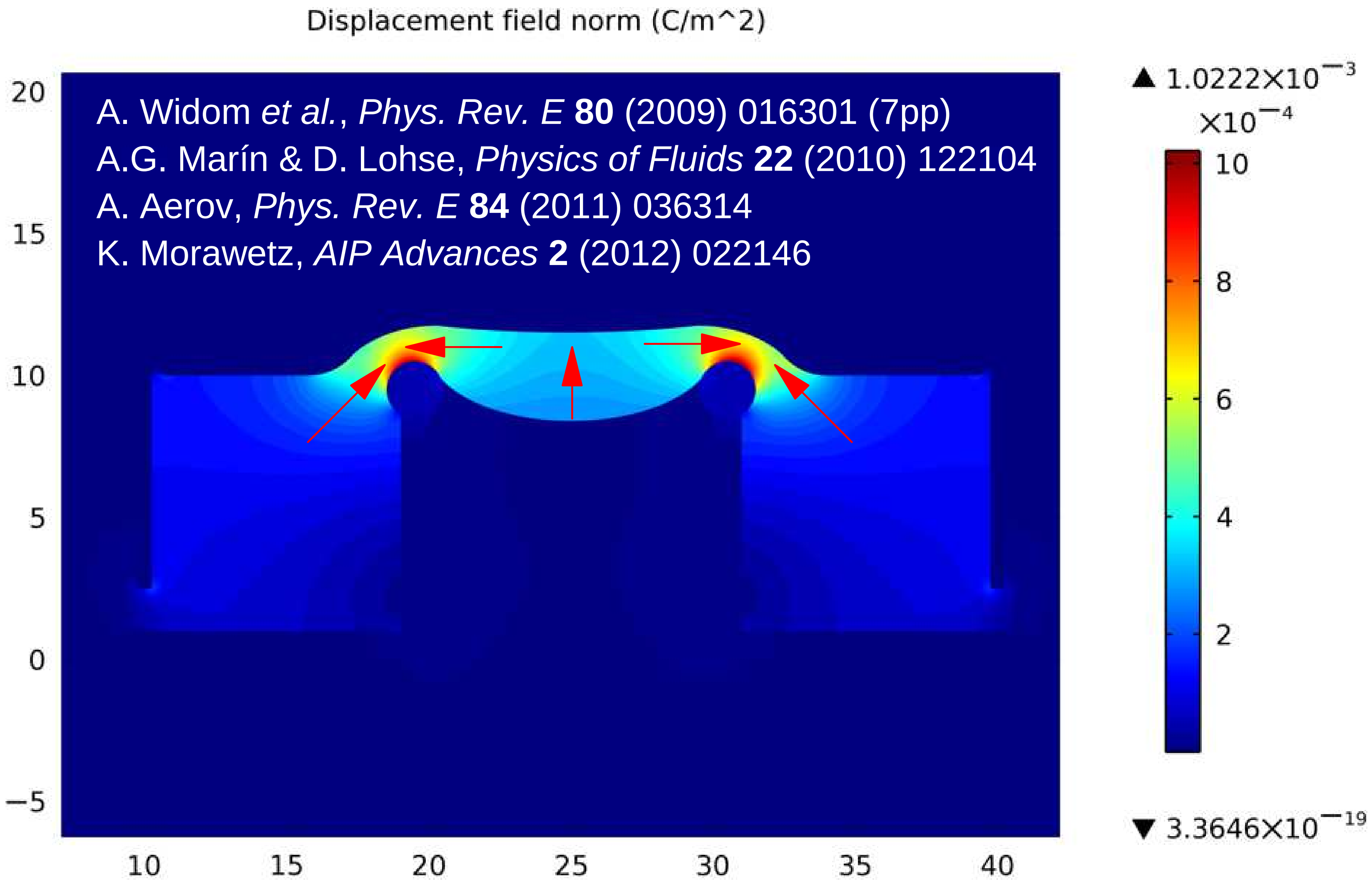


Visualisation:
Panasonic Digital
Camcorder,
real time.

J. Woisetschläger, K. Gatterer, E.C. Fuchs, Experiments in a Floating Water Bridge, *Exp. Fluids* **48** (2010) 121-131

Electric Field

- Electric displacement (calculation)



J. Woisetschläger, A. D. Wexler, G. Holler, M. Eisenhut, K. Gatterer, E. C. Fuchs, Horizontal bridges in polar dielectric liquids, *Exp. Fluids* **52** (2012) 193-205

Question

Is the bridge a

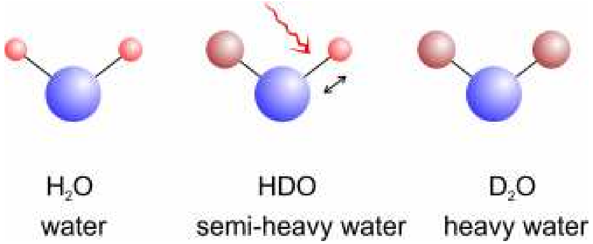
purely macroscopic phenomenon

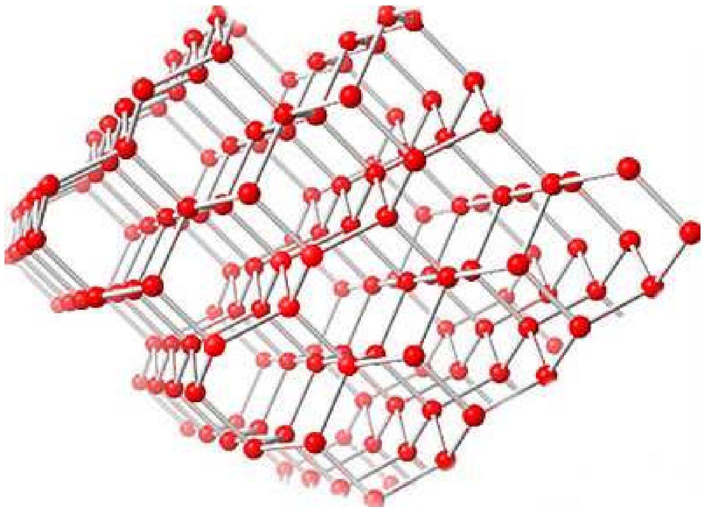
or is its water

different on a microscopic level ?

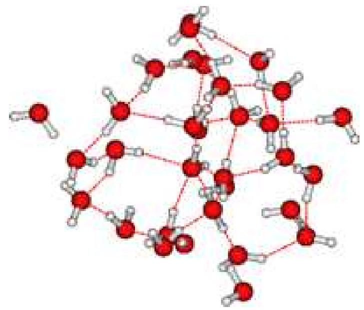
Ultrafast vibrational energy relaxation of the water bridge

- Measurement of the OH-vibration in an HDO molecule
- Duration of vibration gives information about the H-bond network

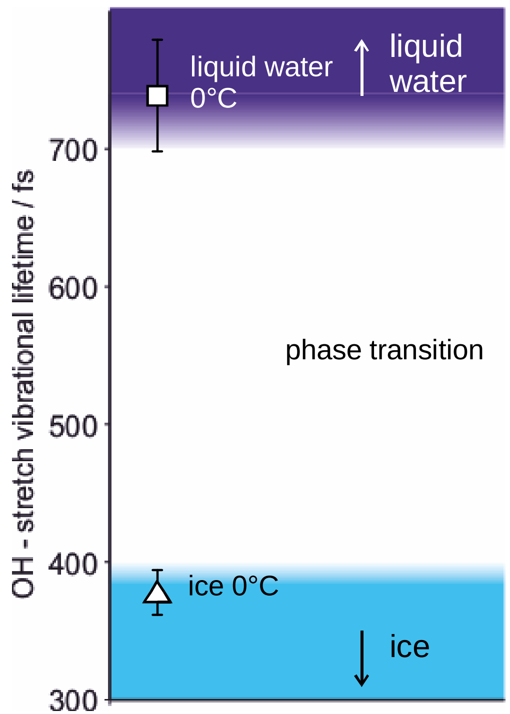




hexagonal ice



liquid water



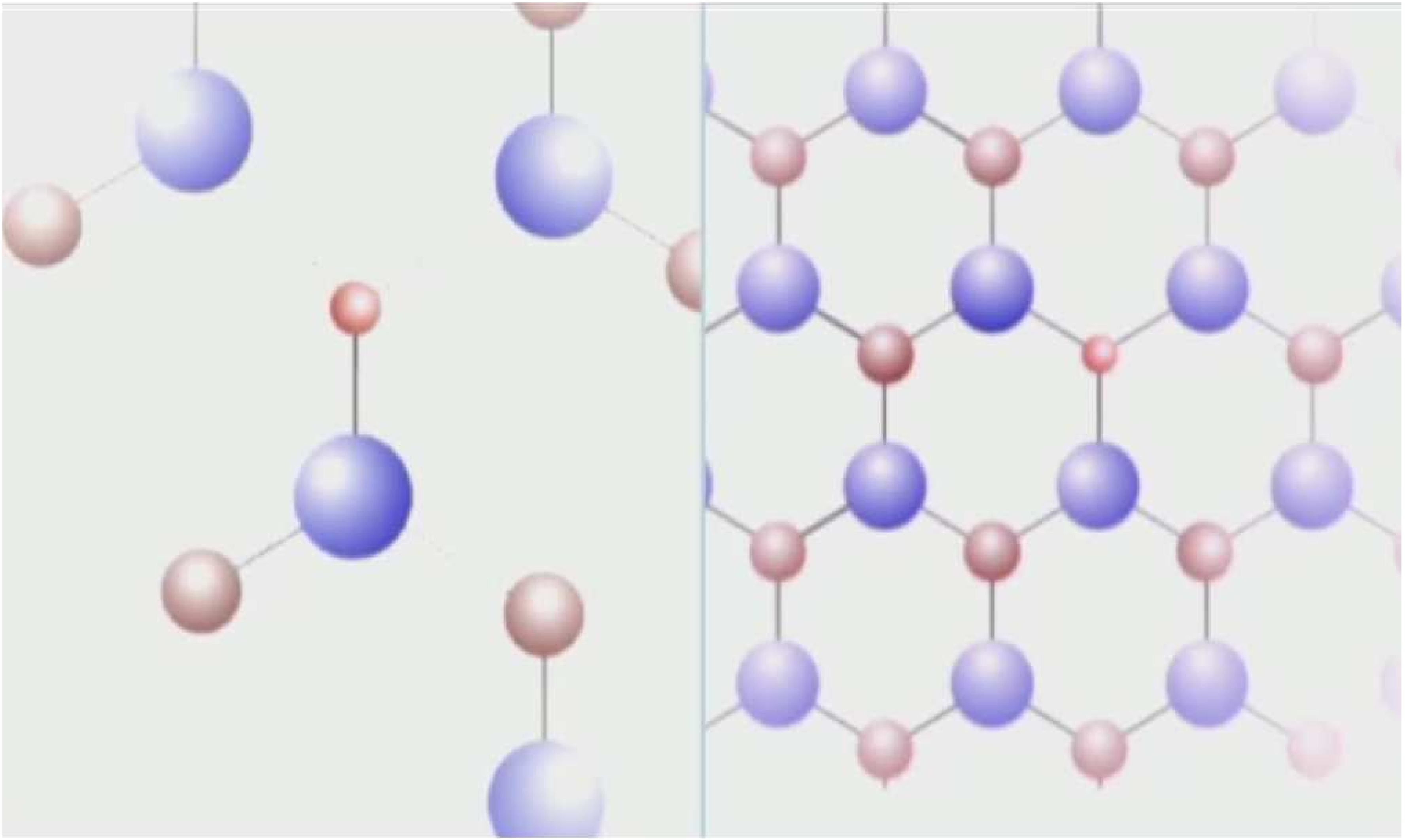
- Vibration stops faster in solid phase and last longer in liquid phase

L. Piatkowski, A.D. Wexler, E.C. Fuchs, H. Schoenmaker, H.J. Bakker, Ultrafast vibrational energy relaxation of the water bridge, *PCCP* **14** (2012) 6160-6164

Ultrafast vibrational energy relaxation of the water bridge

liquid state

solid state



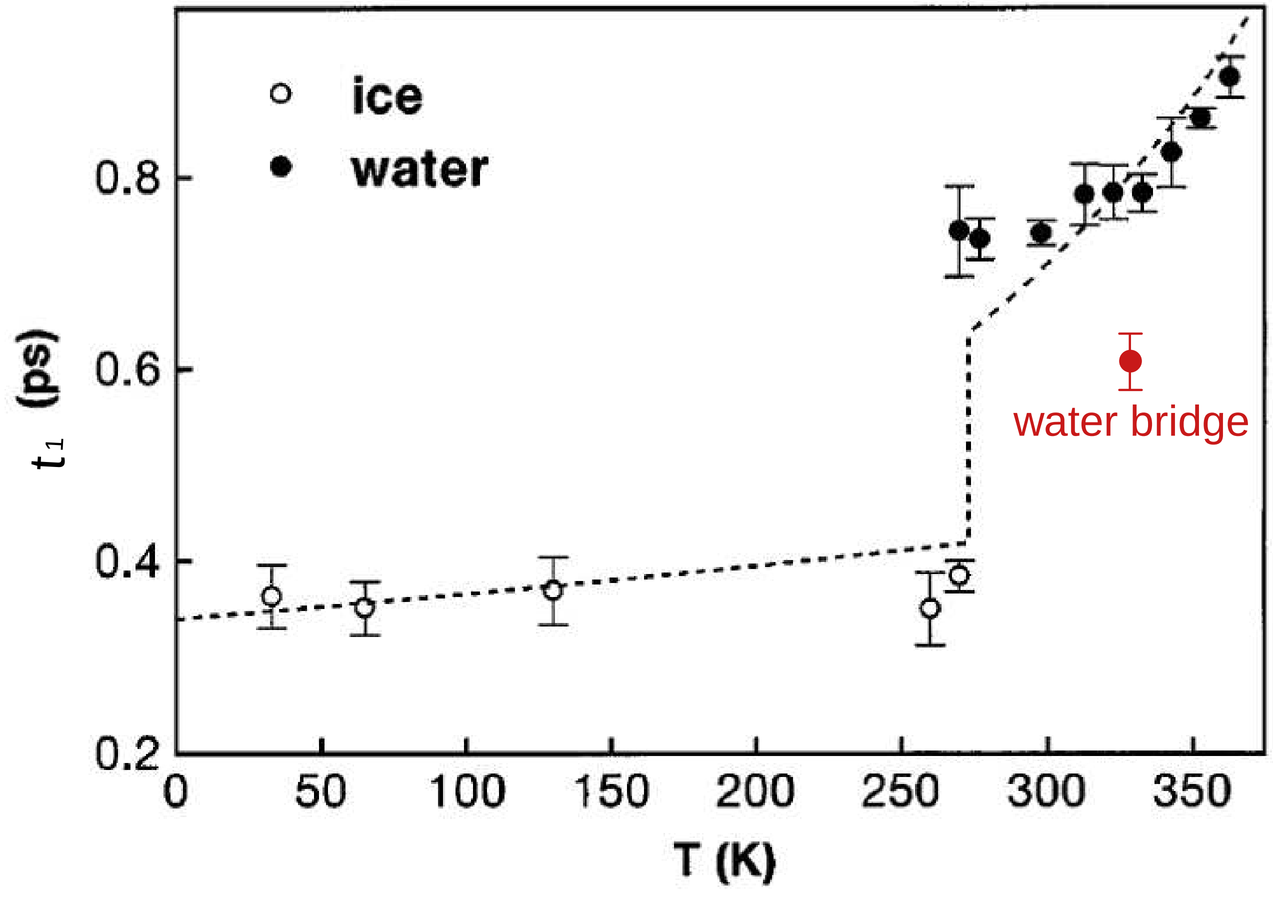
t_1 (0°C) = 740±40 fs

t_1 (0°C) = 384±16 fs

Woutersen *et al.* (1998), *Phys. Rev. Lett.* **81**, pp. 1106-1109

Ultrafast vibrational energy relaxation of the water bridge

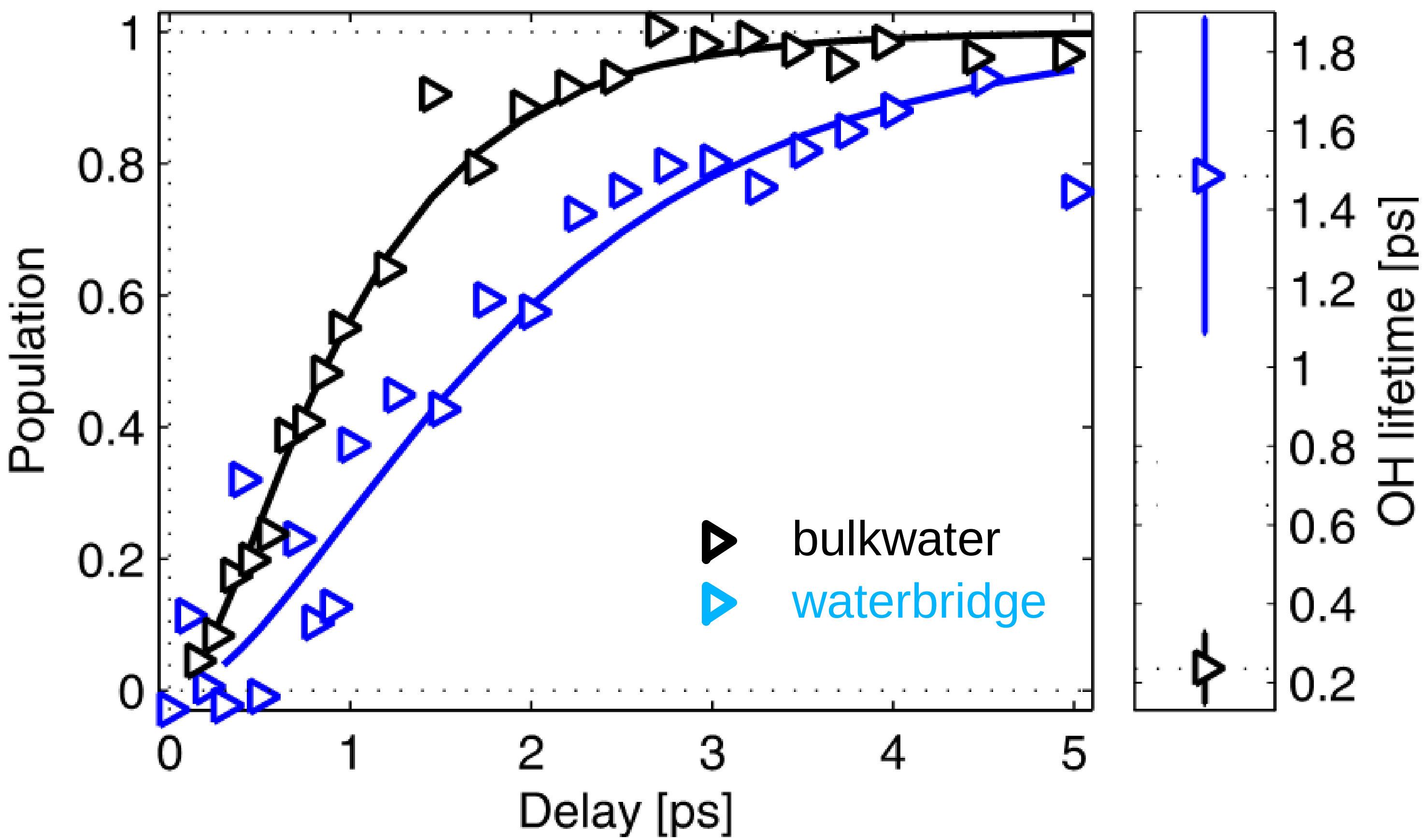
Vibrational lifetime against temperature



Woutersen *et al.* (1998), *Phys. Rev. Lett.* **81**, pp. 1106-1109

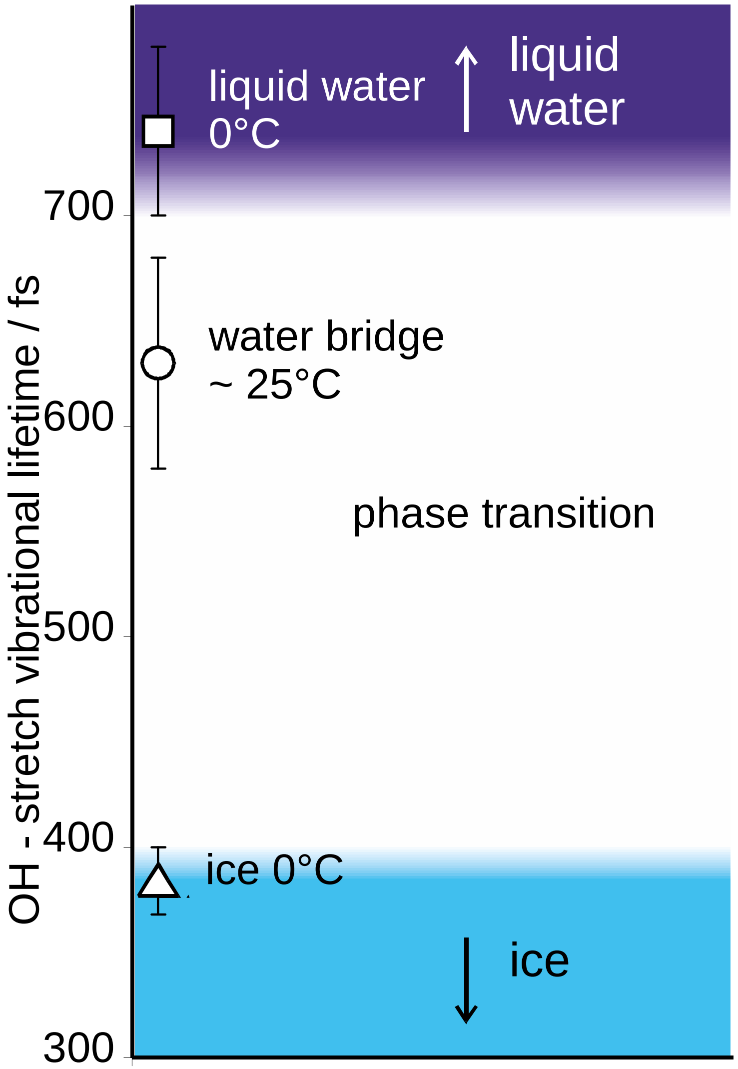
Ultrafast vibrational energy relaxation of the water bridge

Thermalization - redistribution of energy



L. Piatkowski, A.D. Wexler, E.C. Fuchs, H. Schoenmaker, H.J. Bakker, Ultrafast vibrational energy relaxation of the water bridge, *PCCP* **14** (2012) 6160-6164

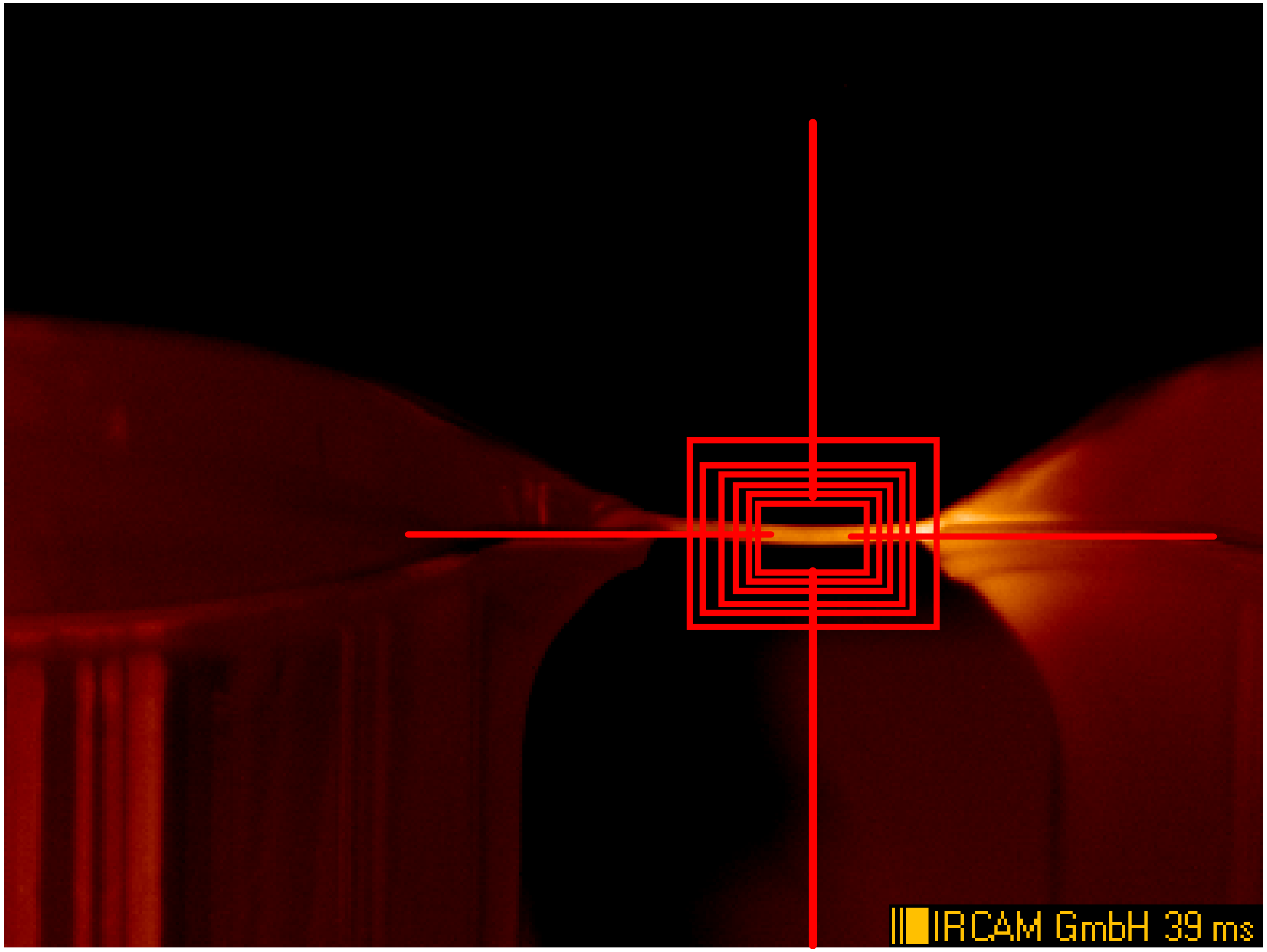
Ultrafast vibrational energy relaxation of the water bridge



- The -OH vibrational relaxation time (t_1) is faster in the floating water bridge (~630±50 fs) than in bulk water (~740±40 fs), and slower than ice (384±16 fs)
- The thermalization dynamics following the vibrational relaxation are much slower in the water bridge (~1500±400 fs) than in bulk HDO:D_2O (~250±90 fs)
- The observed relaxation time of ~630±50 fs of the water bridge is not observed *at any temperature* for bulk water
- These results clearly indicate that in the bridge *water exists in a new state.*

L. Piatkowski, A.D. Wexler, E.C. Fuchs, H. Schoenmaker, H.J. Bakker, Ultrafast vibrational energy relaxation of the water bridge, *PCCP* **14** (2012) 6160-6164

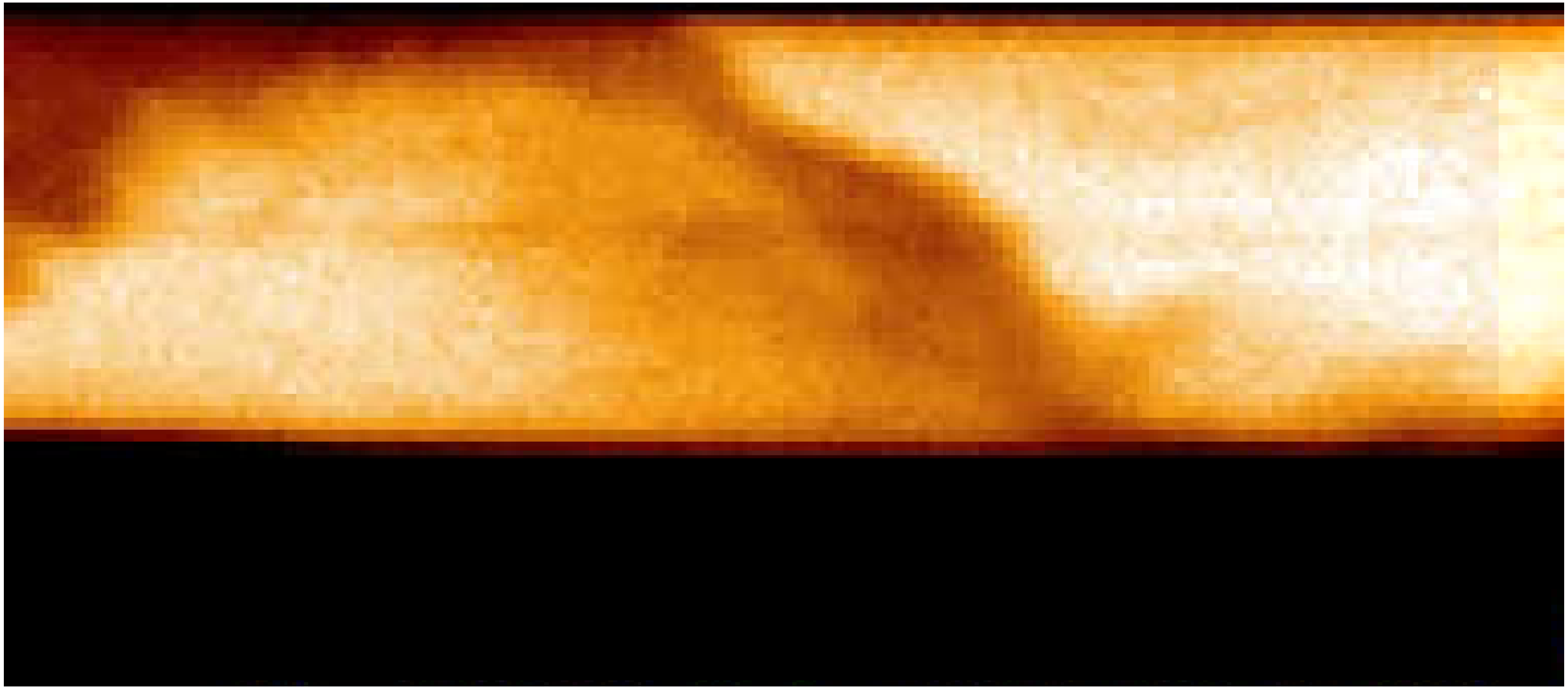
Infrared emission



Visualisation:
Equus 110L (IRCAM)
338 frames / s

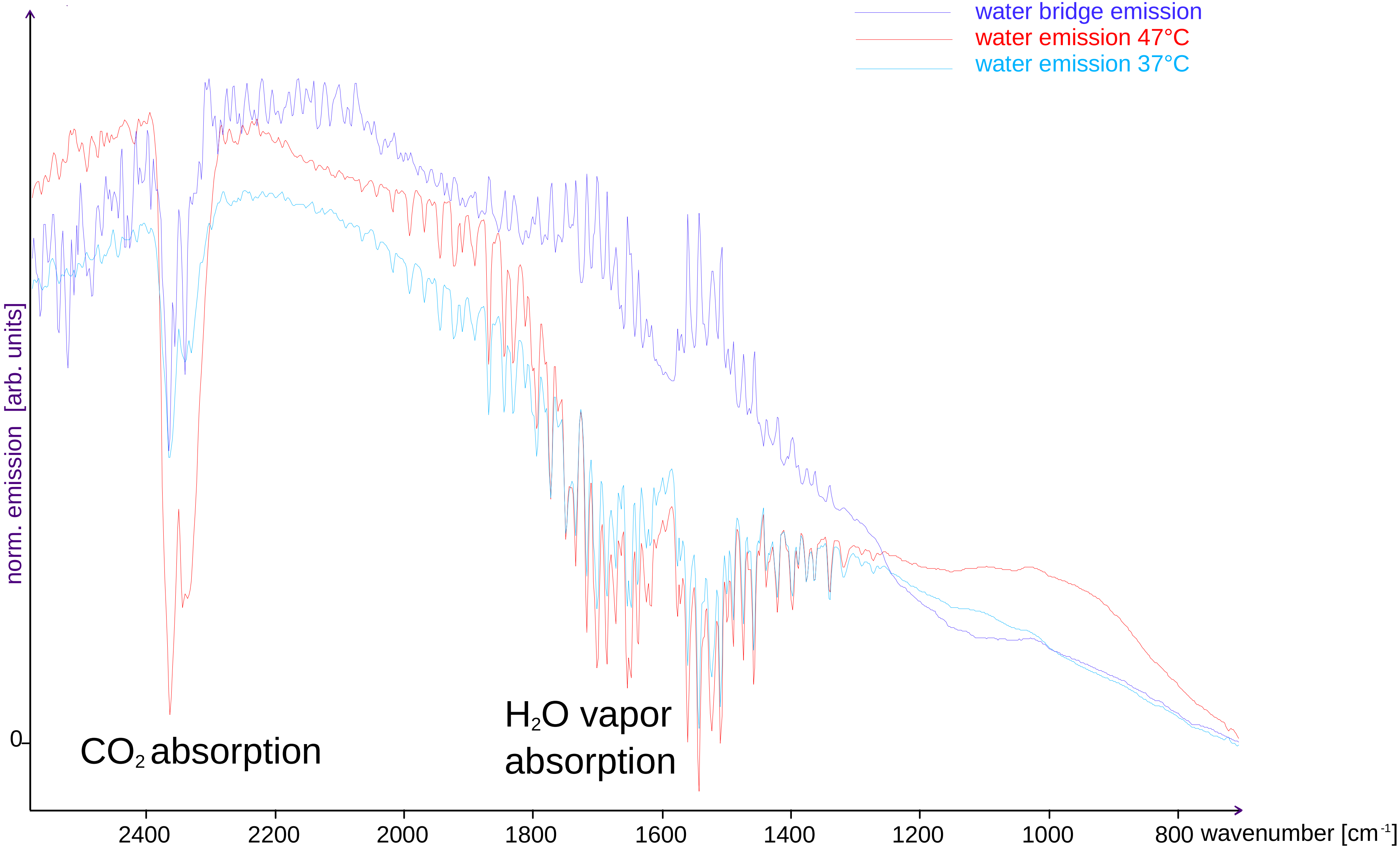
bright: ~40°C

High Speed Thermography



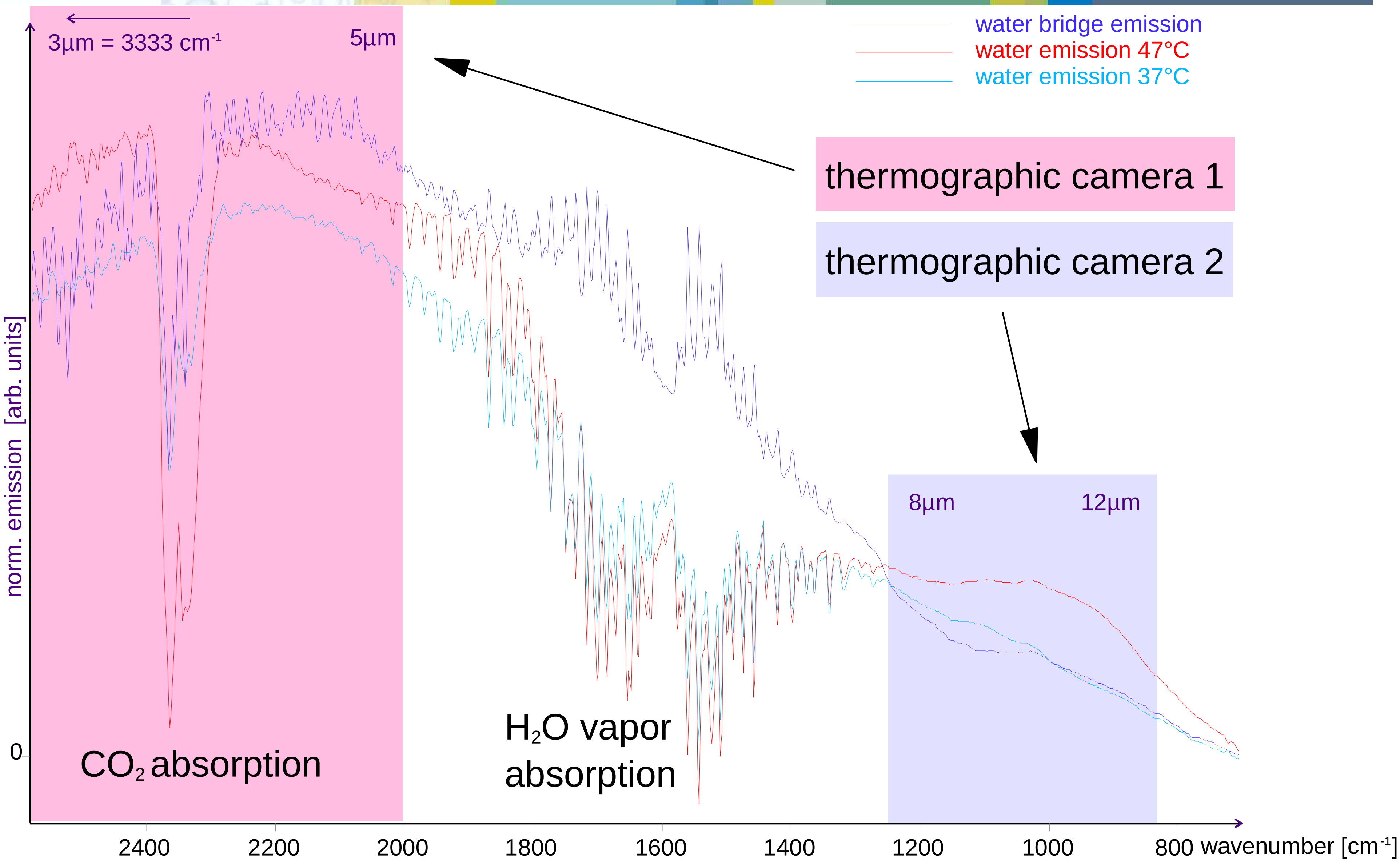
Visualisation: Equus 110L (IRCAM); bright: ~40°C

Infrared Emission



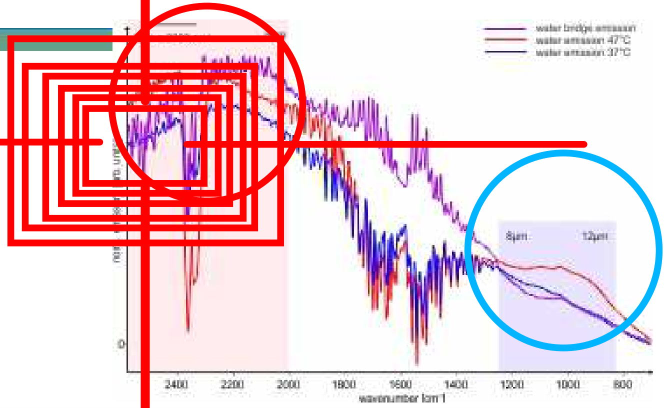
E.C. Fuchs, A. Cherukupally, A.H. Paulitsch-Fuchs, L.L.F. Agostinho, A.D. Wexler, J. Woisetschläger and F.T. Freund, Investigation of the Mid-Infrared Emission of a Floating Water Bridge, *J. Phys. D: Appl. Phys.* (2012) **i.p.**

Infrared Emission



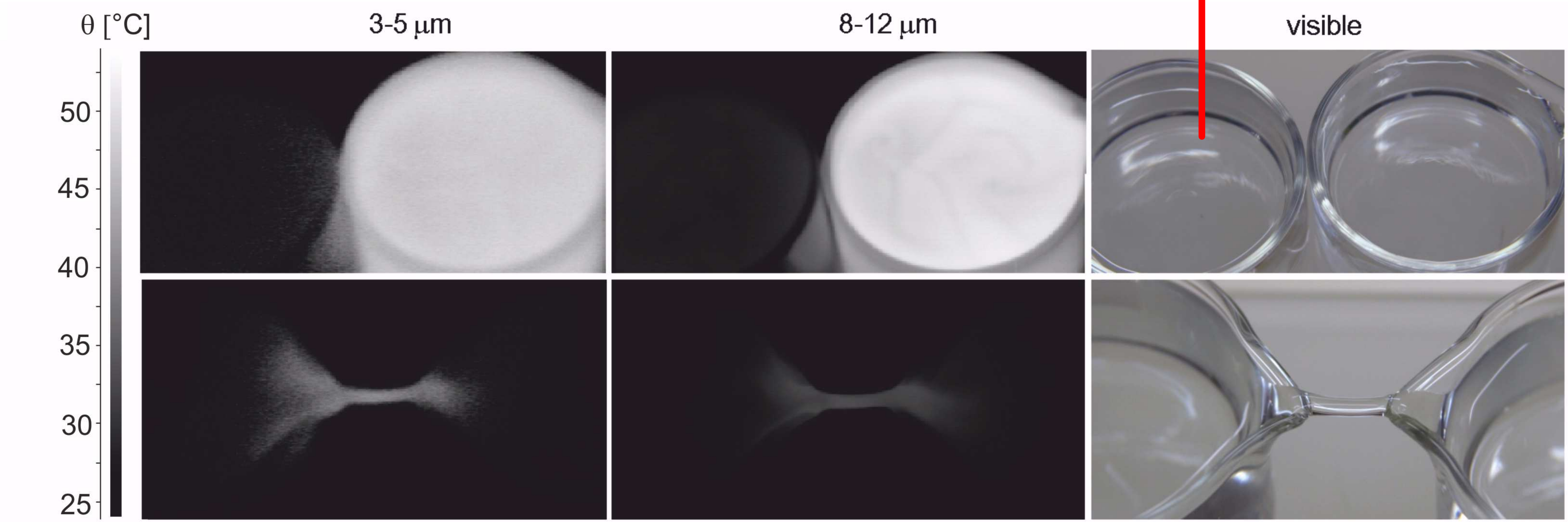
E.C. Fuchs, A. Cherukupally, A.H. Paulitsch-Fuchs, L.L.F. Agostinho, A.D. Wexler, J. Woisetschläger and F.T. Freund, Investigation of the Mid-Infrared Emission of a Floating Water Bridge, *J. Phys. D: Appl. Phys.* (2012) **i.p.**

Infrared Emission



thermographic camera 1

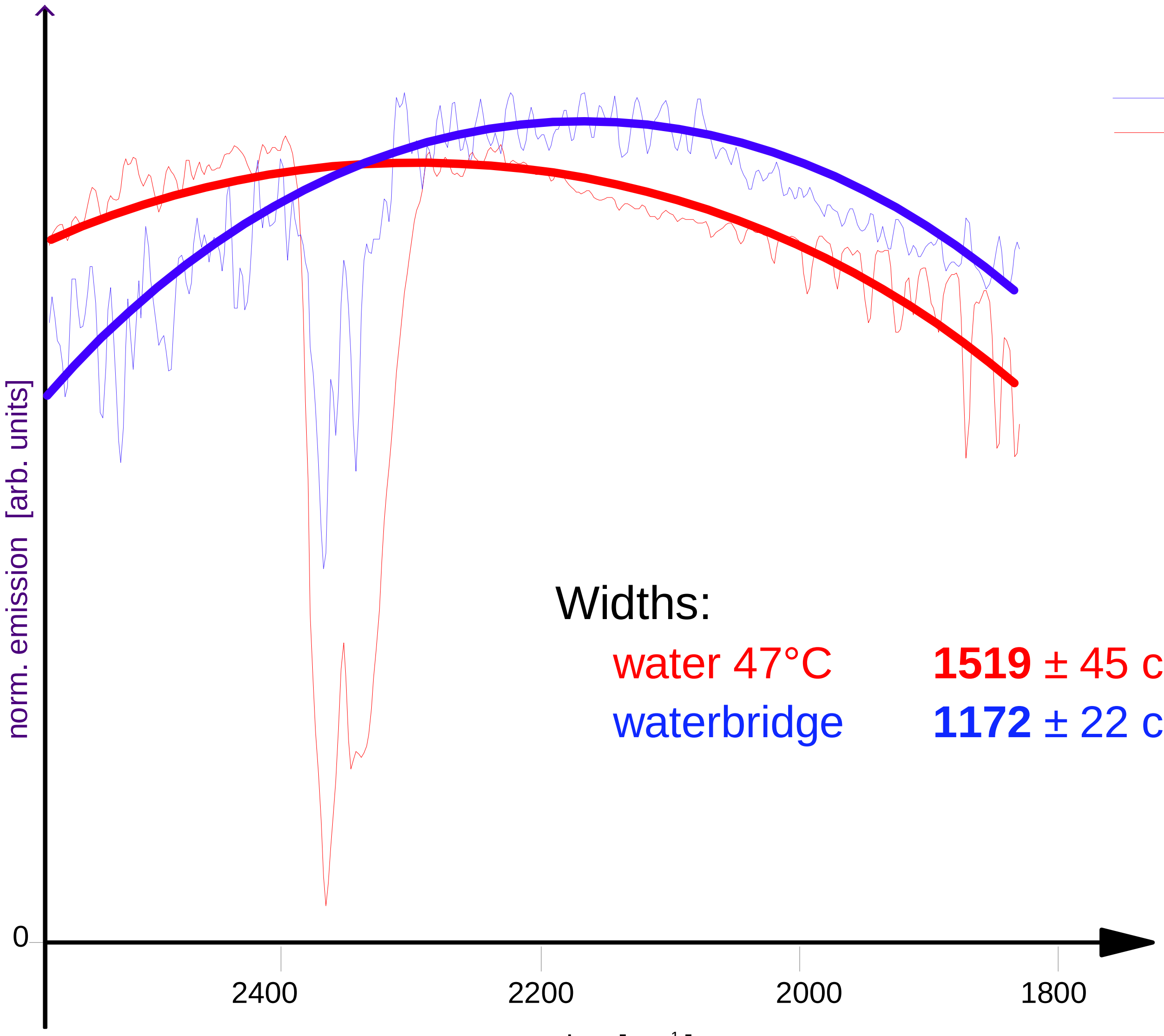
thermographic camera 2



- 3-5µm region is as bright as 47°C, 8-12µm region as bright as 37°C water
- There is an additional, non-thermic emission at shorter wavelengths

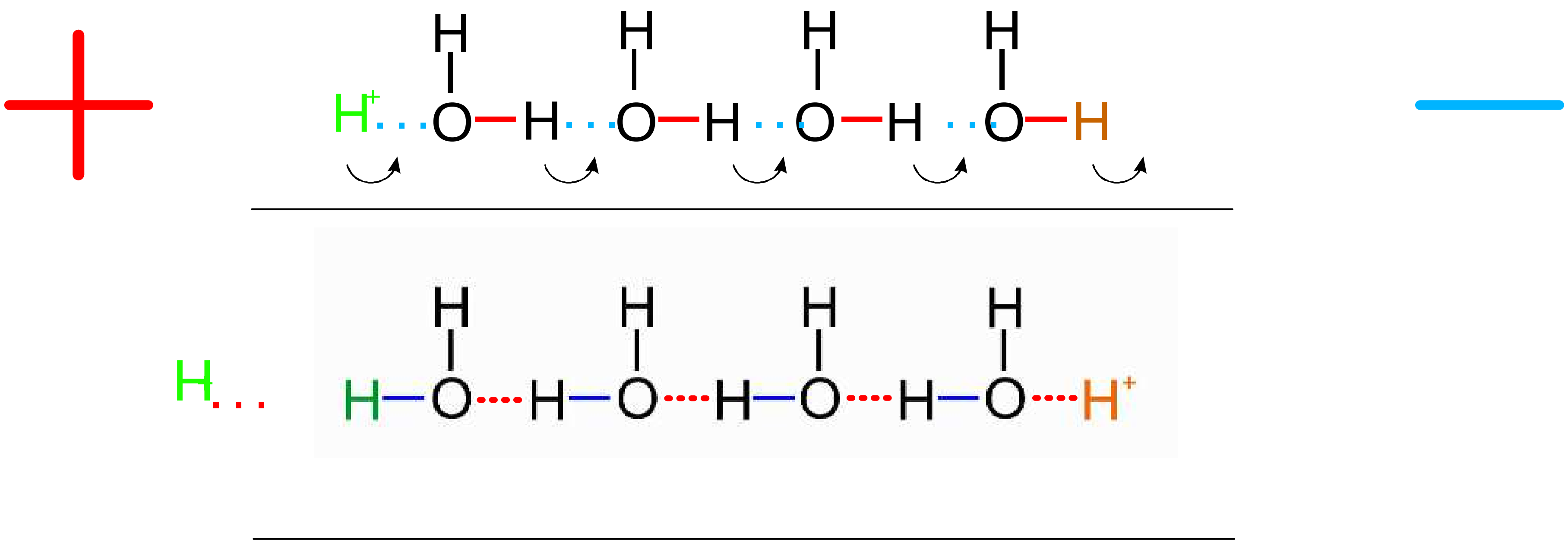
E.C. Fuchs, A. Cherukupally, A.H. Paulitsch-Fuchs, L.L.F. Agostinho, A.D. Wexler, J. Woisetschläger and F.T. Freund, Investigation of the Mid-Infrared Emission of a Floating Water Bridge, *J. Phys. D: Appl. Phys.* (2012) **i.p.**

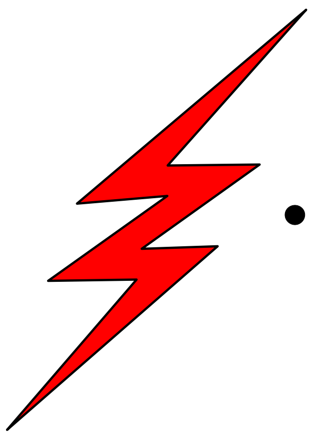
Infrared Emission



E.C. Fuchs, A. Cherukupally, A.H. Paulitsch-Fuchs, L.L.F. Agostinho, A.D. Wexler, J. Woisetschläger and F.T. Freund, Investigation of the Mid-Infrared Emission of a Floating Water Bridge, *J. Phys. D: Appl. Phys.* (2012) **i.p.**

Infrared Emission

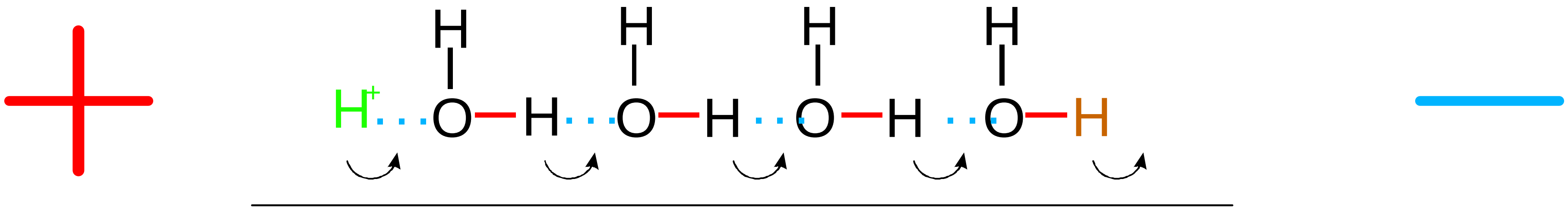


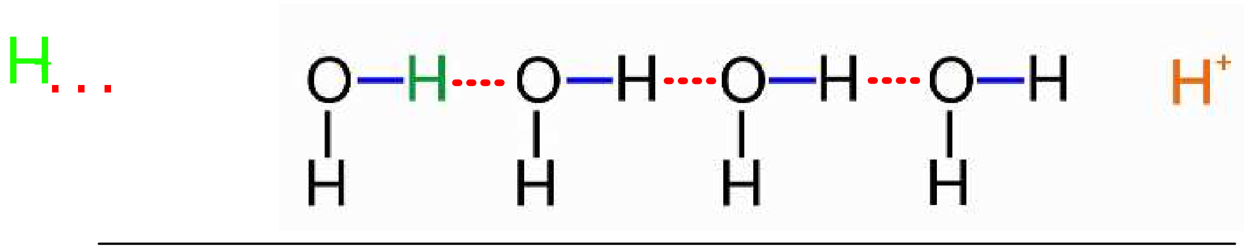


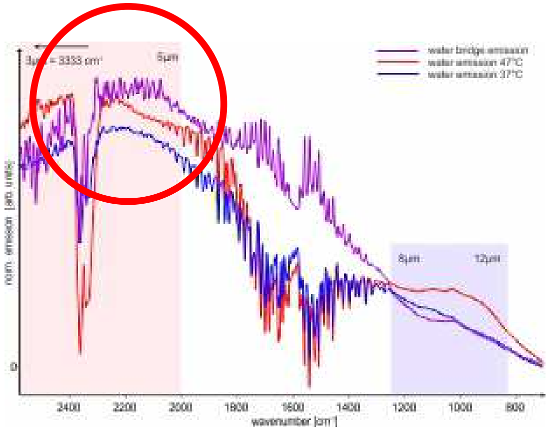
- IR emission caused by libration (hindered rotation)

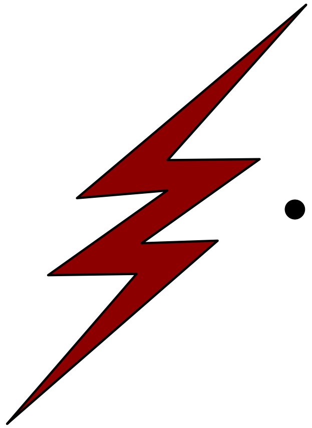
E.C. Fuchs, A. Cherukupally, A.H. Paulitsch-Fuchs, L.L.F. Agostinho, A.D. Wexler, J. Woisetschläger and F.T. Freund, Investigation of the Mid-Infrared Emission of a Floating Water Bridge, *J. Phys. D: Appl. Phys.* (2012) **i.p.**

Infrared Emission









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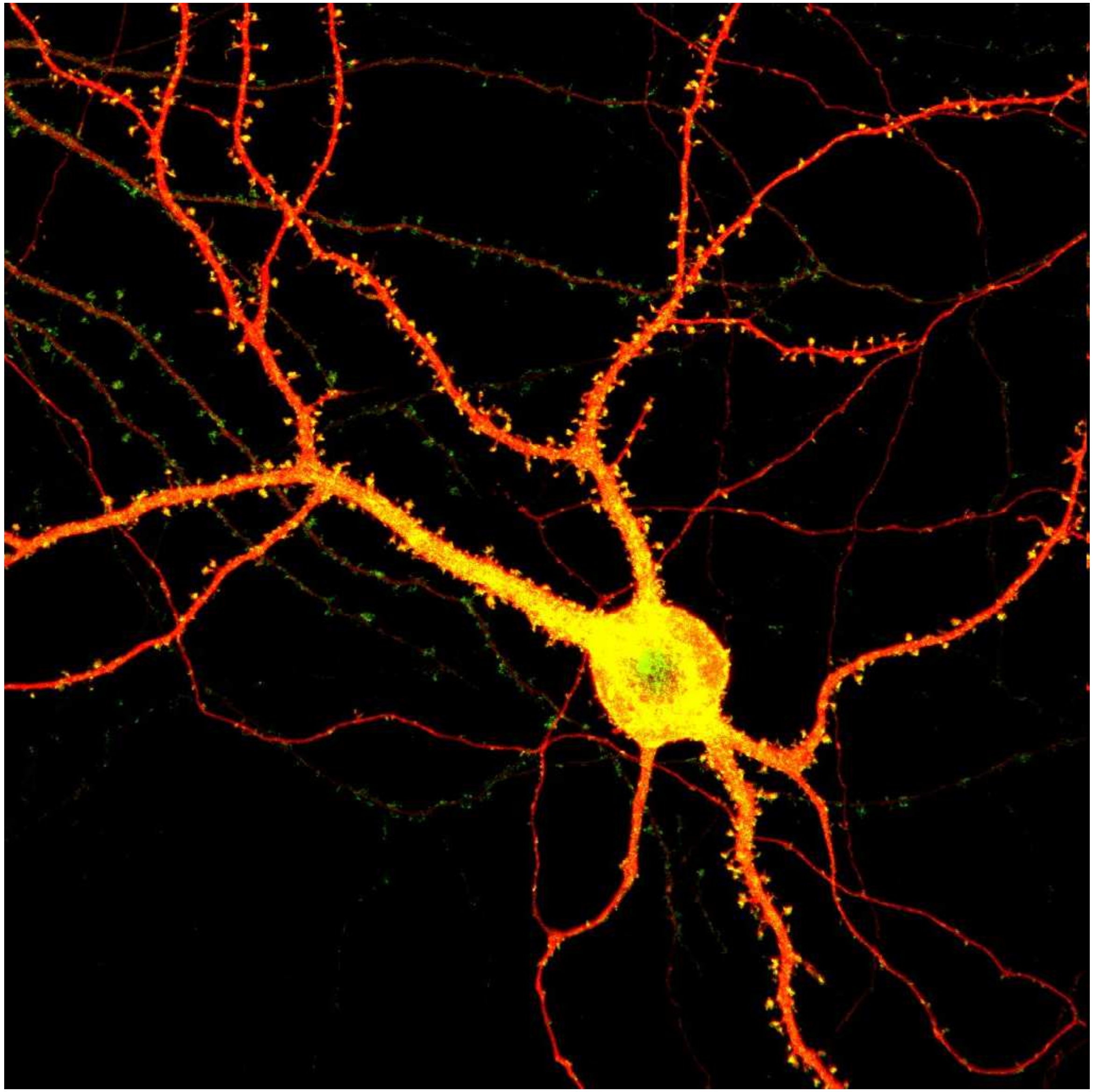
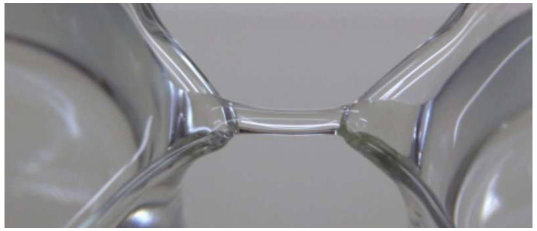
Living Systems



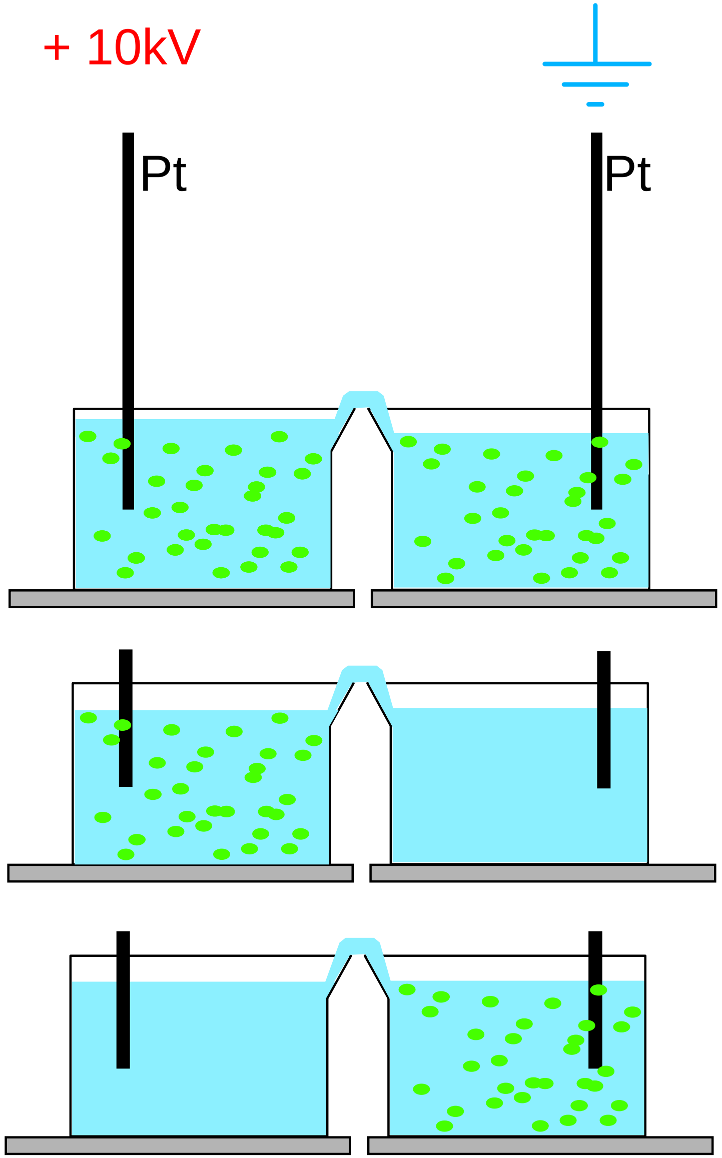


- Waterbridge
  - ~10 kV/cm
- Living cells
  - 50-300 kV/cm

Tyner *et al.*(2007), Biophysical Journal **93**, 1163–1174

Microbiological experiments

Three different experimental set-ups:



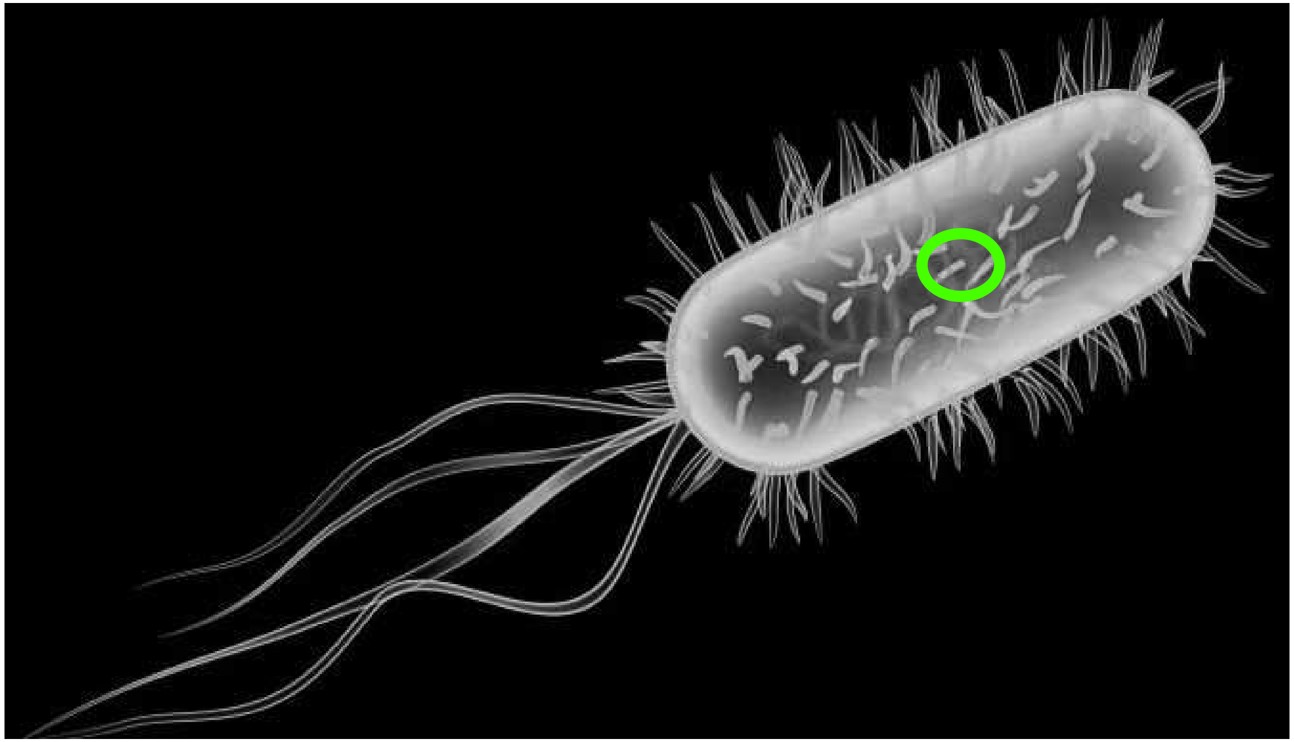
Bacteria in both beakers

Bacteria in the anode beaker only

Bacteria in the cathode beaker only

A.H. Paulitsch-Fuchs, E. C. Fuchs, A.D. Wexler, F.T. Freund, L.J. Rothschild, A. Cherukupally and G.-J. W. Euverink, Prokaryotic transport in electrohydrodynamic structures, *Phys. Biol.* **9** (2012) 026006 (11pp)

Escherichia coli lux



Enterobacteriaceae

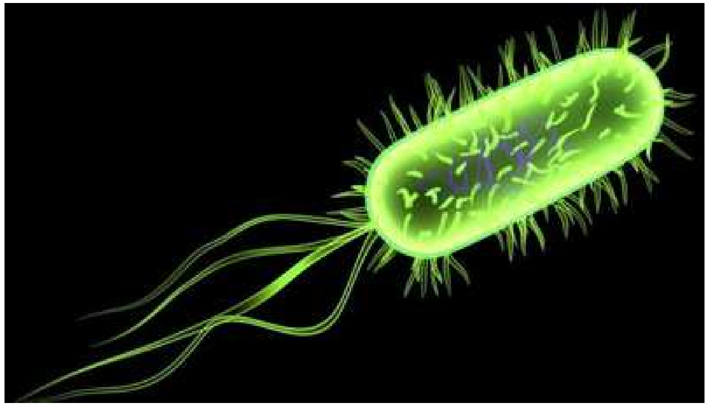
- Gram negative
- Rod
- facultative anaerob

Genes from *Vibrio fischeri*

- luxICDABEG operon
- encodes for luminescence

A.H. Paulitsch-Fuchs, E. C. Fuchs, A.D. Wexler, F.T. Freund, L.J. Rothschild, A. Cherukupally and G.-J. W. Euverink, Prokaryotic transport in electrohydrodynamic structures, *Phys. Biol.* **9** (2012) 026006 (11pp)

Escherichia coli lux



Luminescence measurements with a spectrophotometer

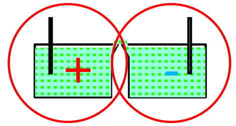
- CPS (counts per second)

Growing cultures on agar plates and count the colonies

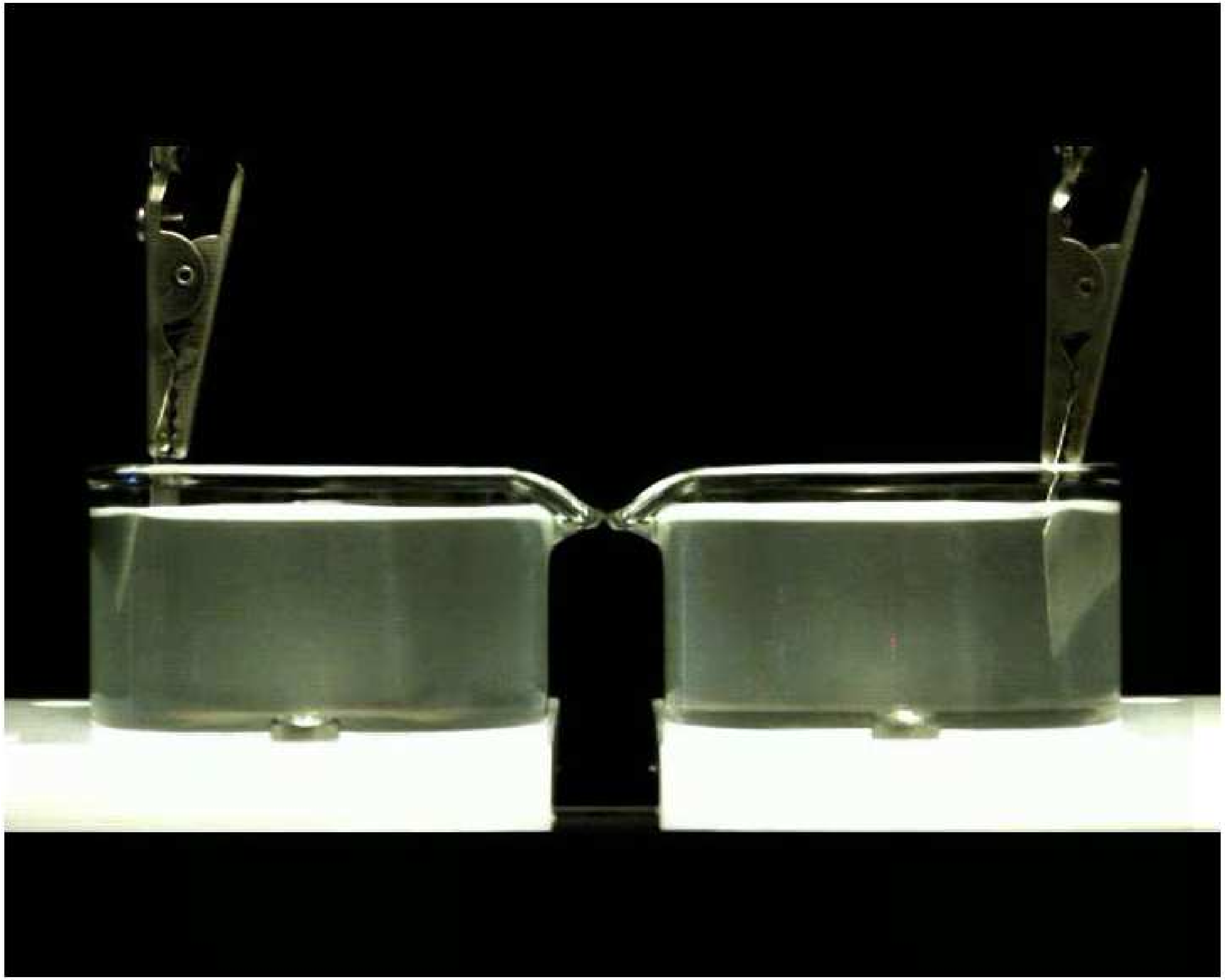
- CFU (colony forming units) / mL

A.H. Paulitsch-Fuchs, E. C. Fuchs, A.D. Wexler, F.T. Freund, L.J. Rothschild, A. Cherukupally and G.-J. W. Euverink, Prokaryotic transport in electrohydrodynamic structures, *Phys. Biol.* **9** (2012) 026006 (11pp)

Prokaryotic transport



+ 10kV

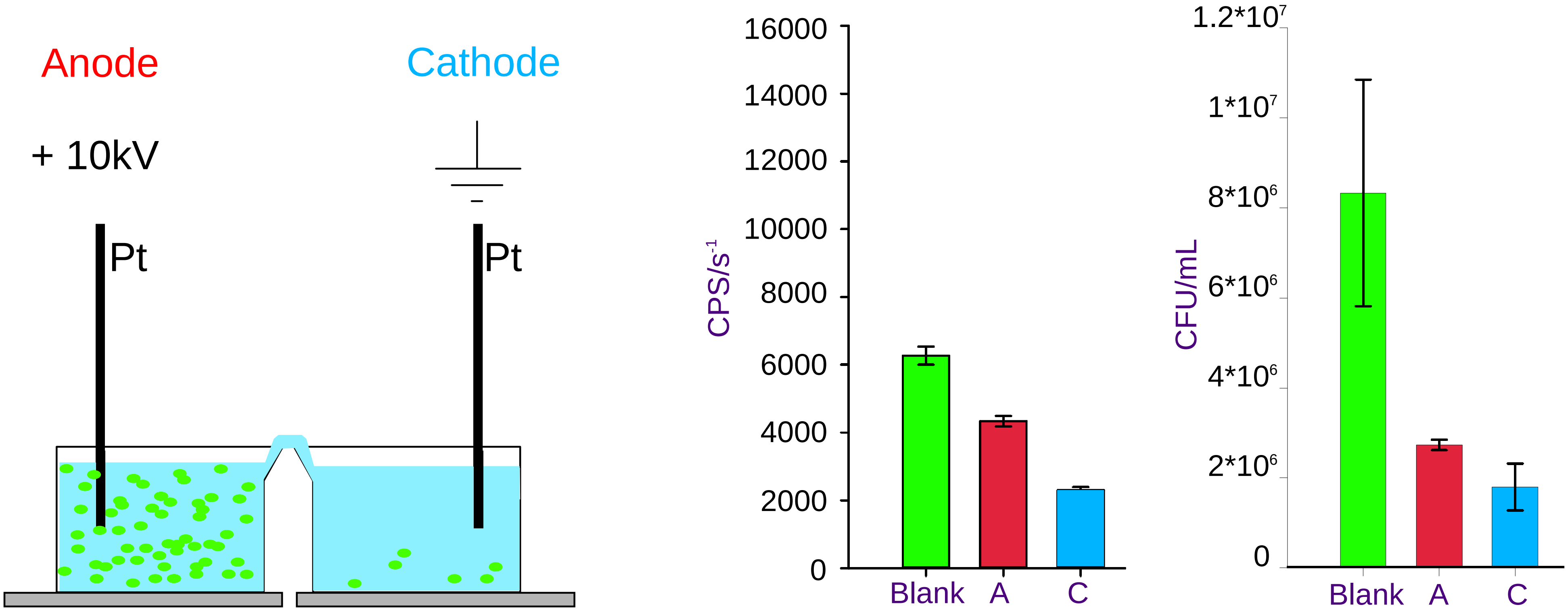


<u>Visualisation:</u>
Panasonic Video Camera; 10 x time lapse

A.H. Paulitsch-Fuchs, E. C. Fuchs, A.D. Wexler, F.T. Freund, L.J. Rothschild, A. Cherukupally and G.-J. W. Euverink, Prokaryotic transport in electrohydrodynamic structures, *Phys. Biol.* **9** (2012) 026006 (11pp)

Bacteria in both beakers

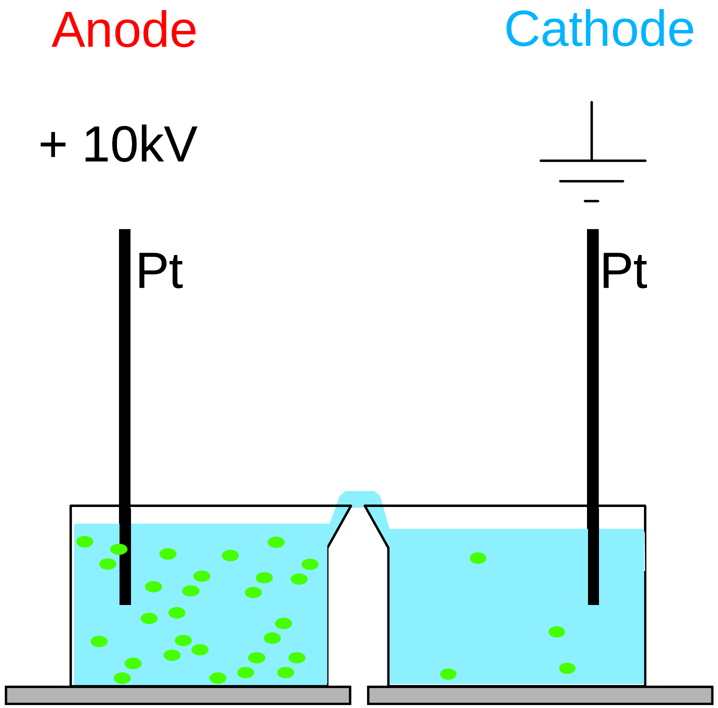
measurements directly after exposure

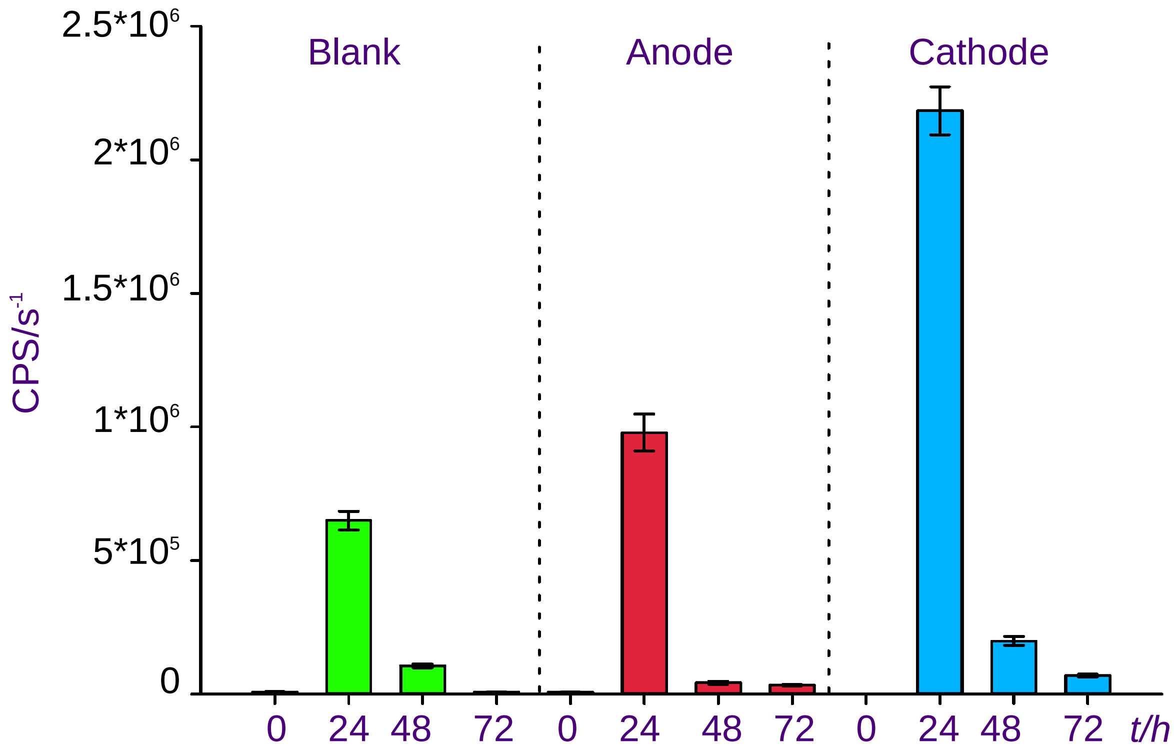


A.H. Paulitsch-Fuchs, E. C. Fuchs, A.D. Wexler, F.T. Freund, L.J. Rothschild, A. Cherukupally and G.-J. W. Euverink, Prokaryotic transport in electrohydrodynamic structures, *Phys. Biol.* **9** (2012) 026006 (11pp)

Bacteria in anode beaker only

measurements over 4 days

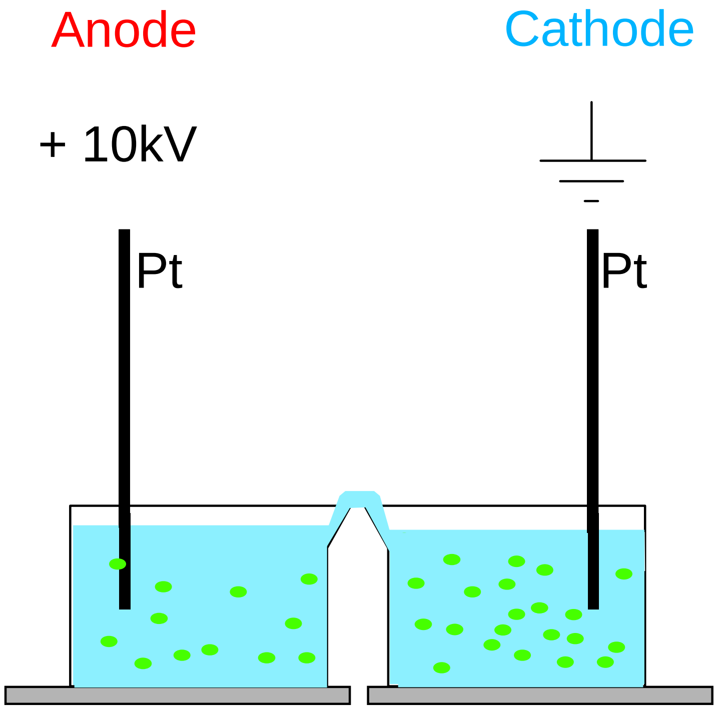


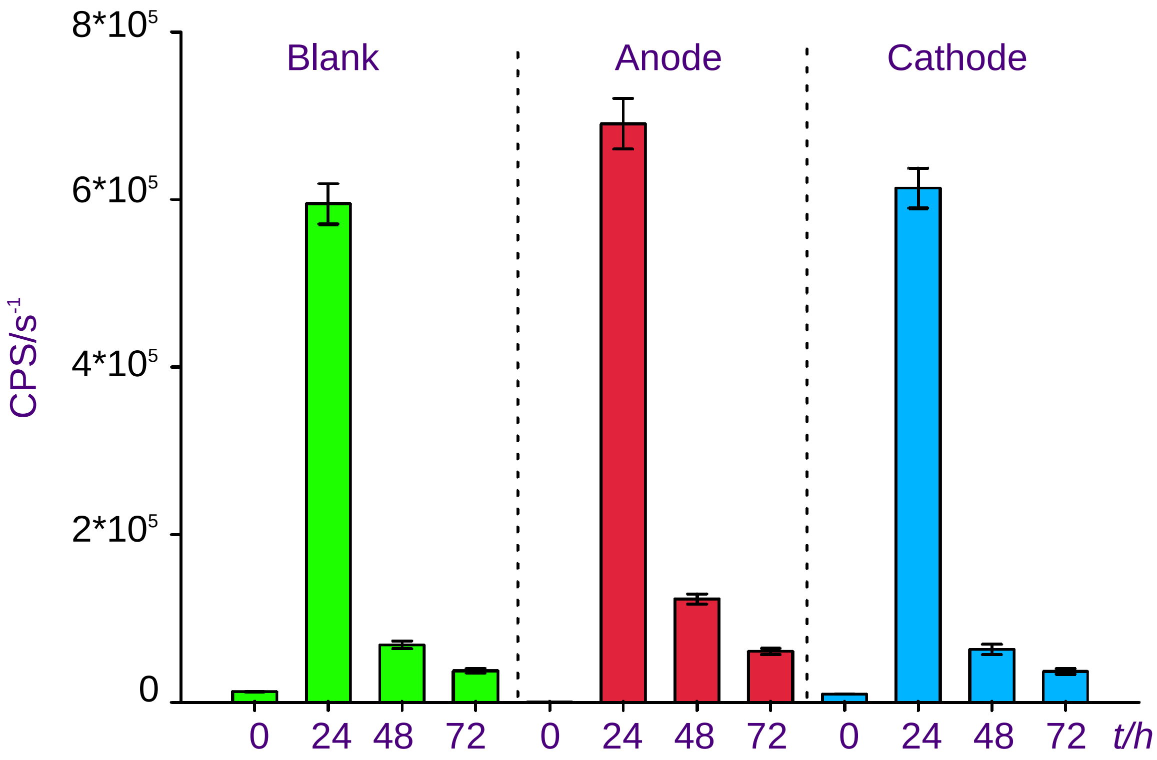


A.H. Paulitsch-Fuchs, E. C. Fuchs, A.D. Wexler, F.T. Freund, L.J. Rothschild, A. Cherukupally and G.-J. W. Euverink, Prokaryotic transport in electrohydrodynamic structures, *Phys. Biol.* **9** (2012) 026006 (11pp)

Bacteria in cathode beaker only\

measurements over 4 days

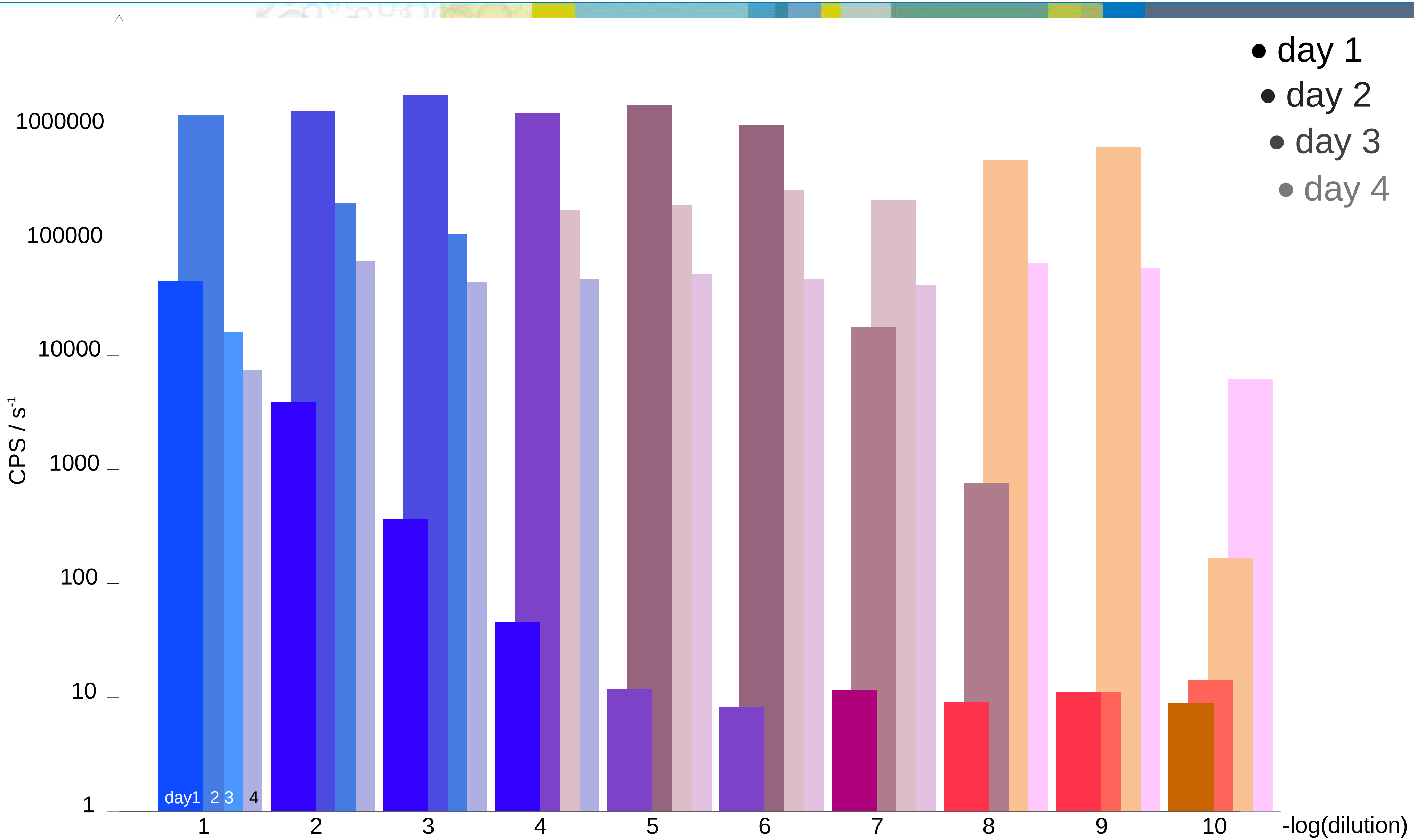




A.H. Paulitsch-Fuchs, E. C. Fuchs, A.D. Wexler, F.T. Freund, L.J. Rothschild, A. Cherukupally and G.-J. W. Euverink, Prokaryotic transport in electrohydrodynamic structures, *Phys. Biol.* **9** (2012) 026006 (11pp)

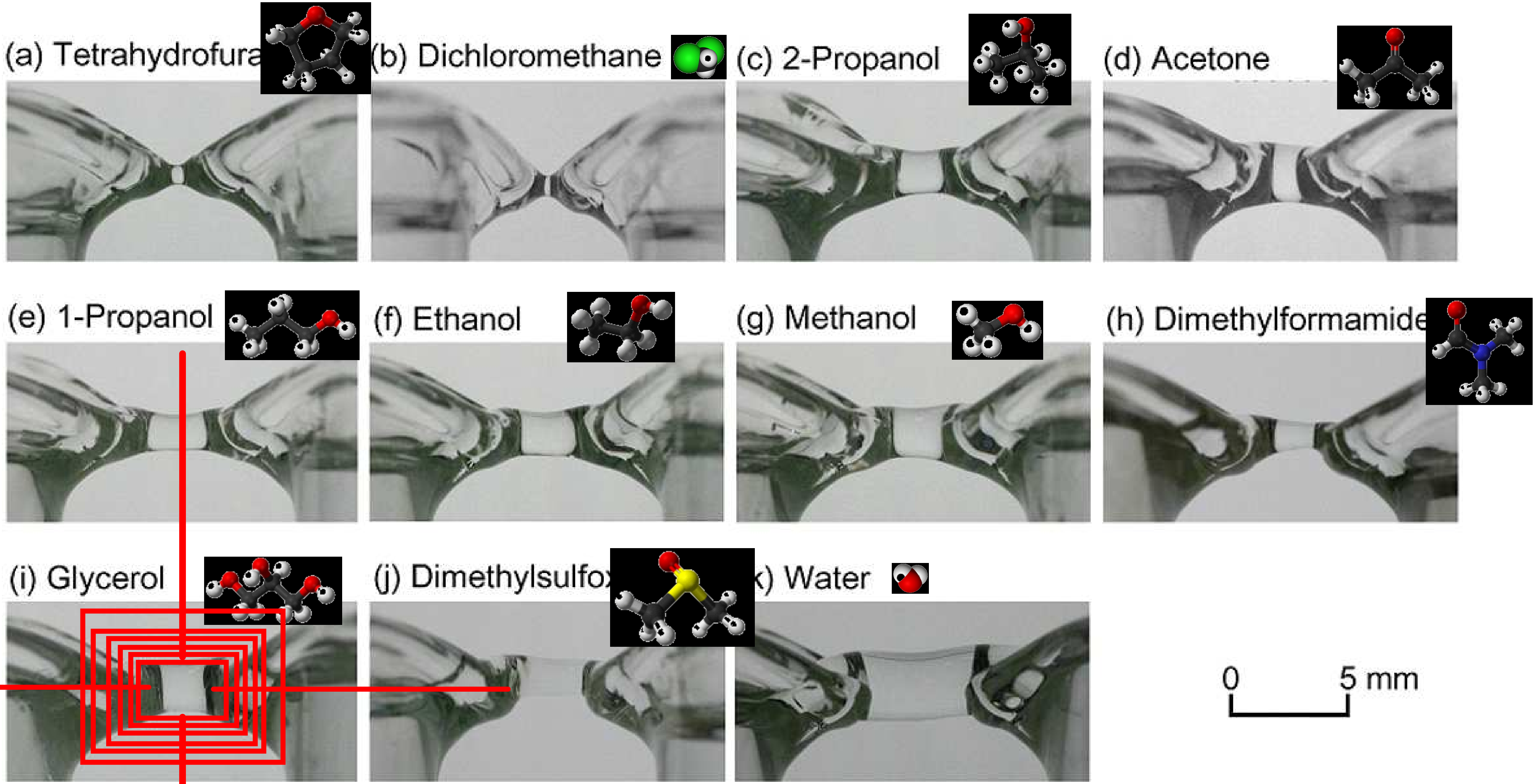
Growth experiment

different amounts of bacterial inoculate
measurements over 4 days



A.H. Paulitsch-Fuchs, E. C. Fuchs, A.D. Wexler, F.T. Freund, L.J. Rothschild, A. Cherukupally and G.-J. W. Euverink, Prokaryotic transport in electrohydrodynamic structures, *Phys. Biol.* **9** (2012) 026006 (11pp)

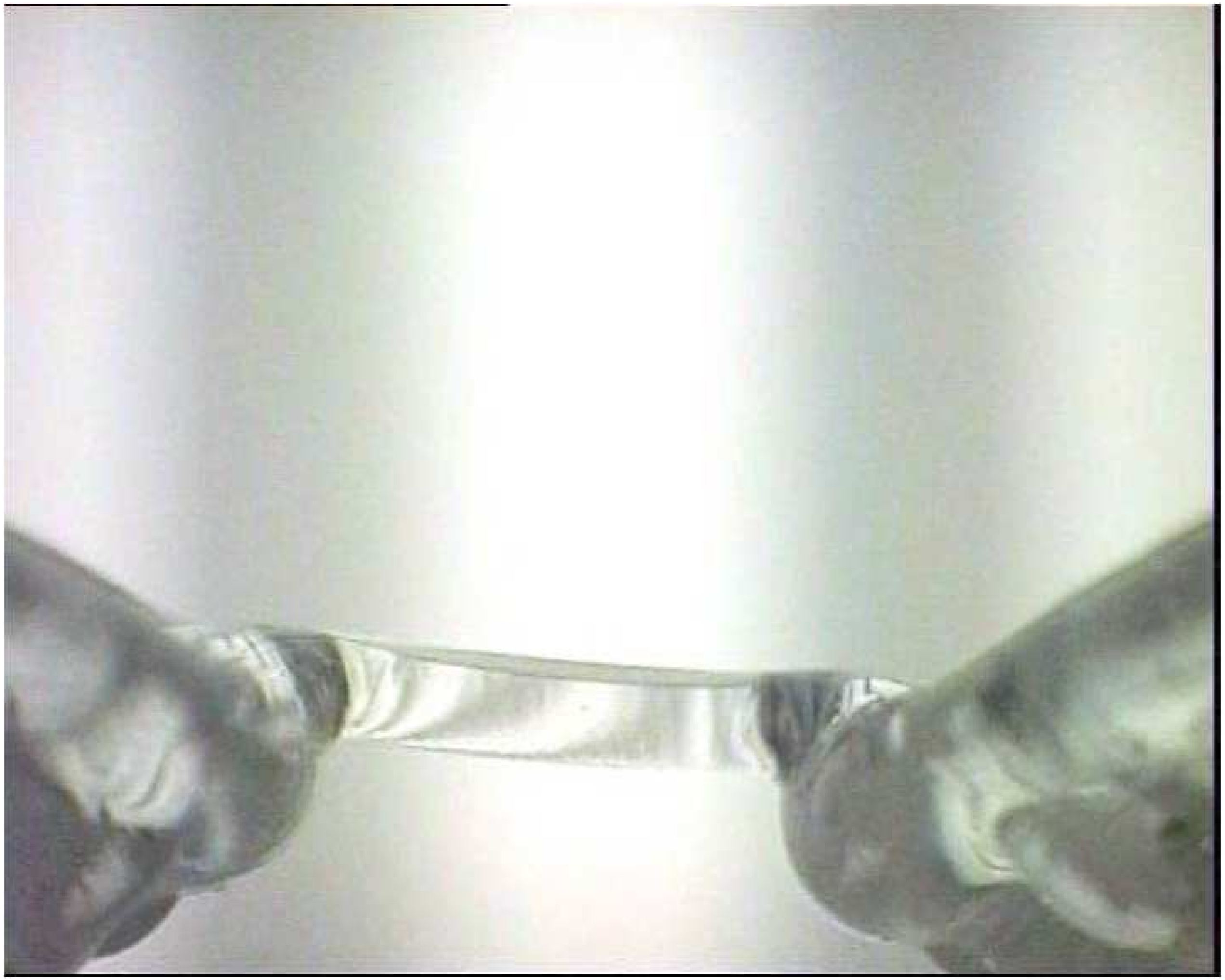
Non-Aqueous Bridges



J. Woisetschläger, A. D. Wexler, G. Holler, M. Eisenhut, K. Gatterer, E. C. Fuchs, Horizontal bridges in polar dielectric liquids, *Exp. Fluids* **52** (2012) 193-205)

Glycerol Bridge

- Classical set-up, dynamical behaviour



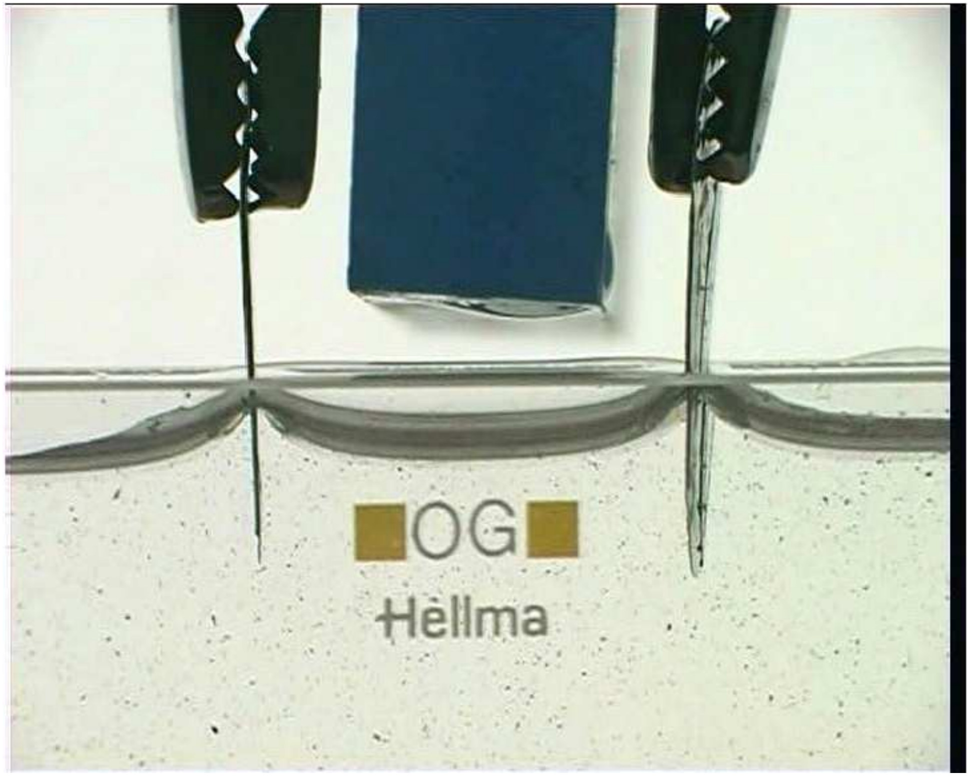
Visualisation:
Panasonic Digital Camcorder,
real time.

J. Woisetschläger, A. D. Wexler, G. Holler, M. Eisenhut, K. Gatterer, E. C. Fuchs, Horizontal bridges in polar dielectric liquids, *Exp. Fluids* **52** (2012) 193-205)

Glycerol Bridge

- Cuvette set-up with tracer particles

- Anode (+) plastic spacer - Cathode (-)



Glycerol, 5µm tracer particles

<u>Visualisation:</u>

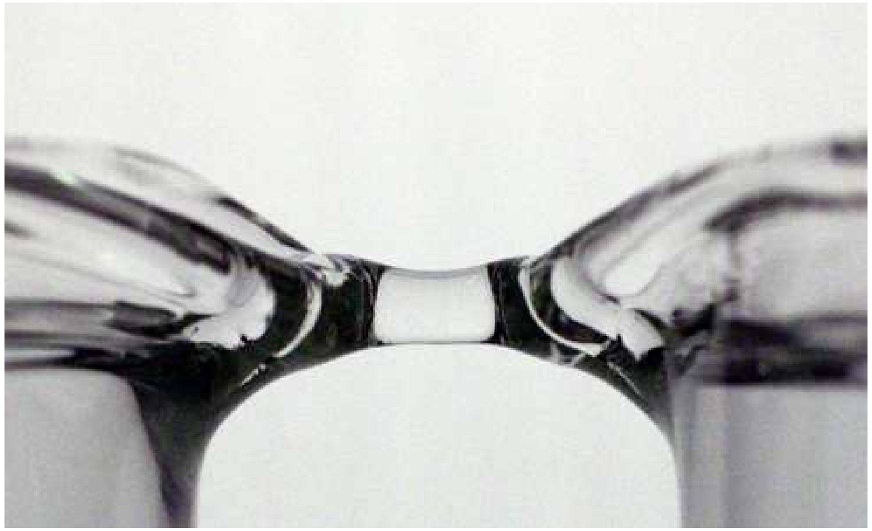
Panasonic Digital Camcorder, real time.

J. Woisetschläger, A. D. Wexler, G. Holler, M. Eisenhut, K. Gatterer, E. C. Fuchs, Horizontal bridges in polar dielectric liquids, *Exp. Fluids* **52** (2012) 193-205)

1-propanol & 2-propanol

Visual

1-propanol



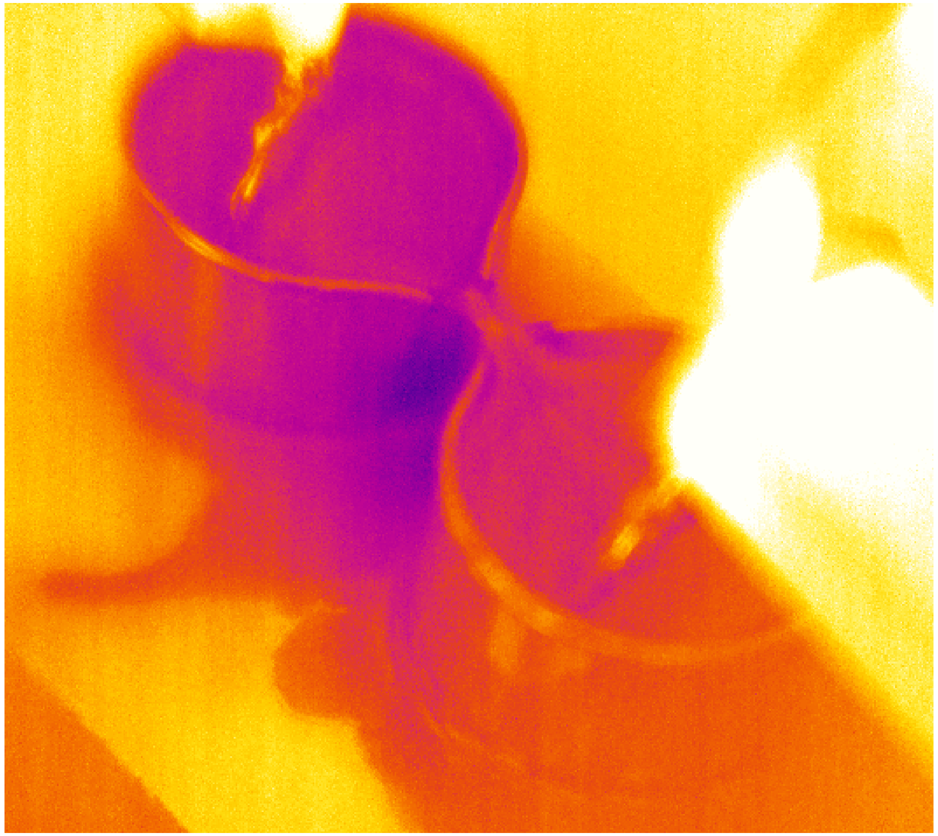
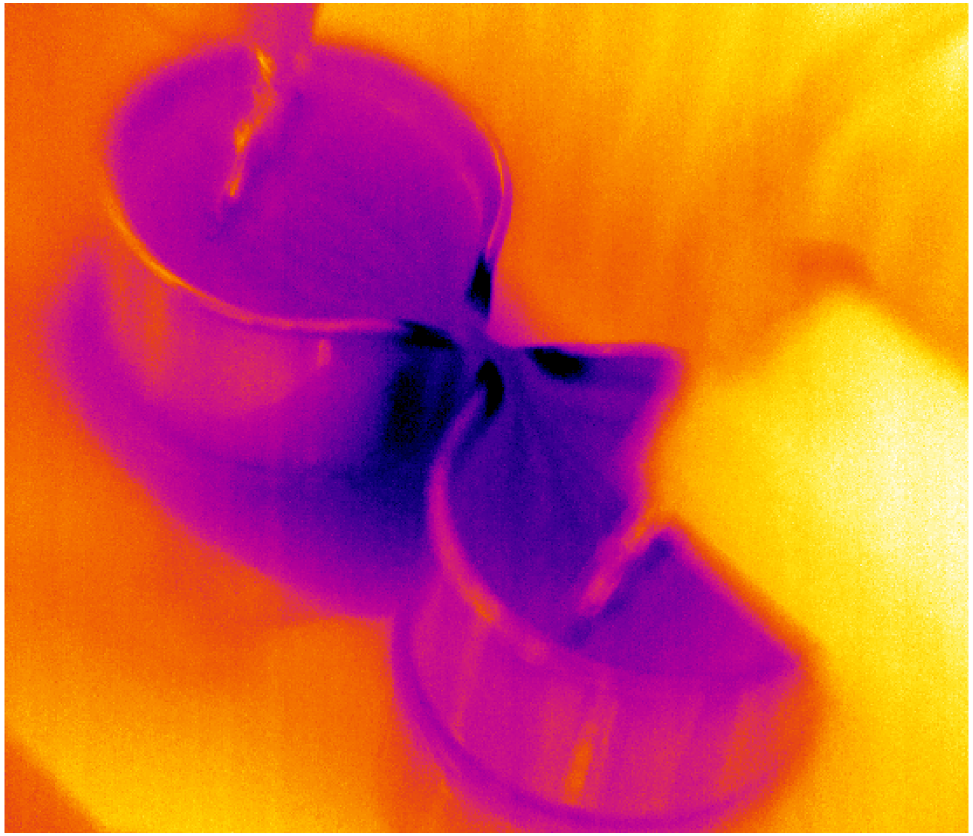
2-propanol

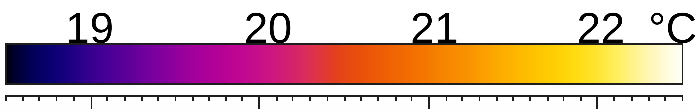
- Length ~5 mm

J. Woisetschläger, A. D. Wexler, G. Holler, M. Eisenhut, K. Gatterer, E. C. Fuchs, Horizontal bridges in polar dielectric liquids, *Exp. Fluids* **52** (2012) 193-205)

1-propanol & 2-propanol

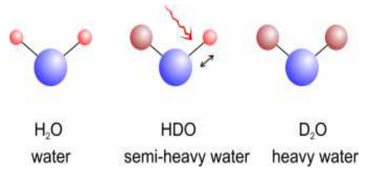
Thermography

1-propanol	2-propanol
	
warmer bridge	colder bridge

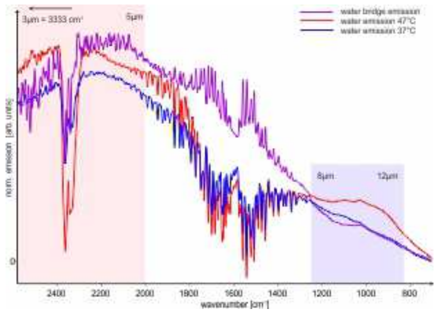


E.C. Fuchs, A.D. Wexler, L.L.F. Agostinho, M. Ramek, J. Woisetschläger, Methanol, Ethanol and Propanol in EHD liquid bridging, *J. Phys. Conf. Ser.* **329** (2011) 012003

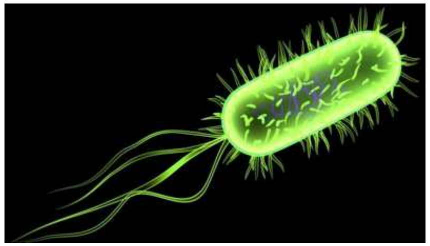
Conclusions



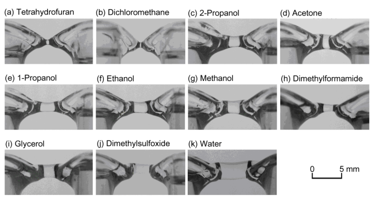
- Water bridge water represents a new state of liquid water



- The IR emission of the bridge is partly non-thermal in origin and due to librations in conjunction with proton conduction



- Luminescent *E. coli* show increased activity after being in the bridge



- Floating bridges are not water intrinsic - they can be realized with a number of polar liquids with low conductivity

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A New State of Water

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Thank you for your attention.