TERRA-MWH

Laboratory convection experiments with internal, non-contact, microwave generated heating, applied to Earth's mantle dynamics

Experimente de convecţie cu încălzire internă, non-contact, generată cu microunde, pentru studii de dinamică a mantalei Pământului

JOINT RESEARCH PROJECTS – Romania-France , no.1/2011

Project Manager's :Emanoil Surducan (RO), Angela Limare (FR)

General presentation

- **Performing laboratory convection experiments with internal, non-contact, microwave generated heating will help us to better understand Earth's convecting mantle.**

- **Although internal volumetric radioactive heating represents the major source of heat in the Earth, we still lack a quantitative understanding of its role on the thermal evolution of the Earth.**

The studies are sparse, and provide only a first order insight on the dynamics of the system, expressed typically as an average cooling rate function of the relative contribution of internal and base heating.

General presentation

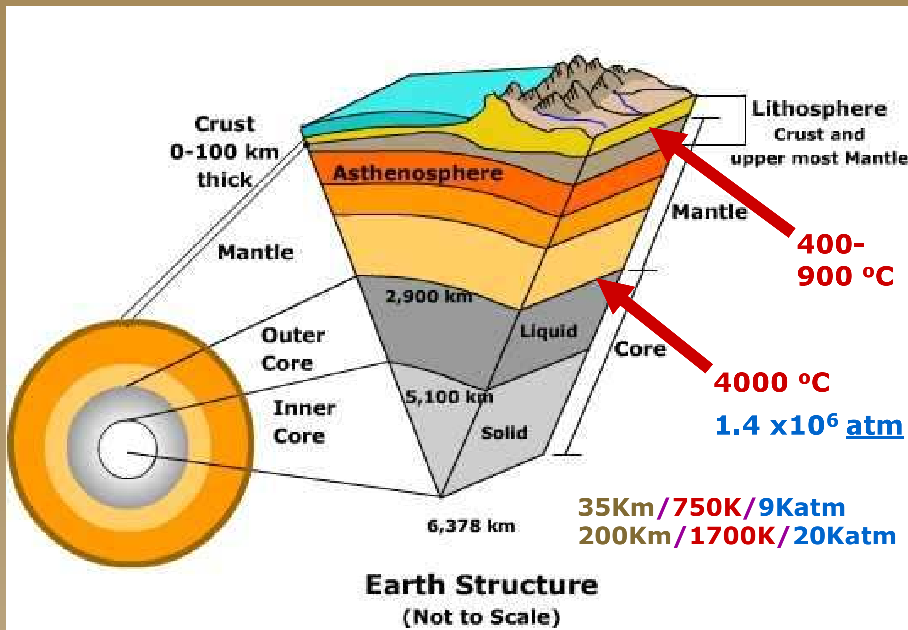
- **Thermal convection in a heterogeneous system heated from within has not been treated yet due to many technical difficulties of the problem.** Experimentally, specific techniques have to be developed to obtain heterogeneous heating in an evolving system.

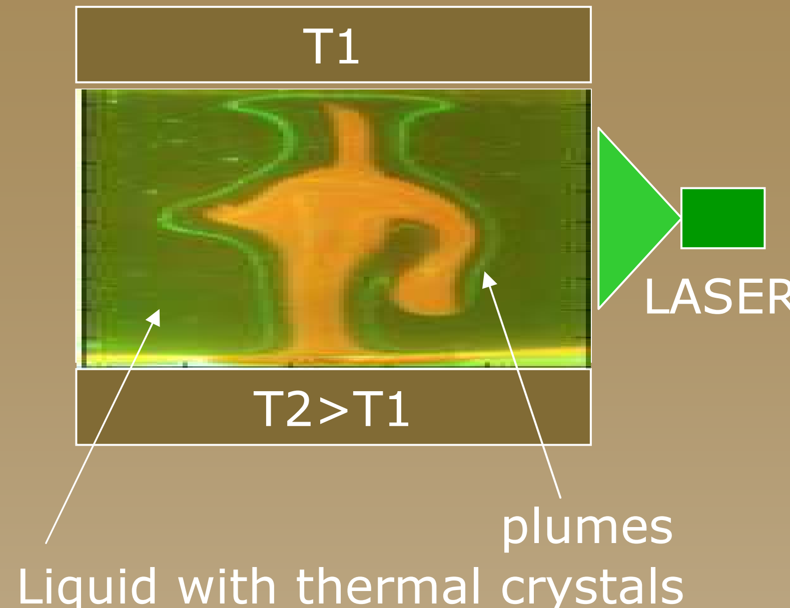
  This last point is the main objective of the present project.

- Here we propose to perform convection studies. We propose several geometries, each one meant to address particular questions relative to Earth and more general to the convection in other planets.

  The novelty of our approach relies on the fact that the internal heating is produced by microwave (MW) absorption. Microwave heating (MWH) provides an original way of producing non-contact, very localised, or yet extended heat sources by a convenient choice of microwave antenna, excitation sequence and selective absorption of fluids.

The start idea : IPGP model





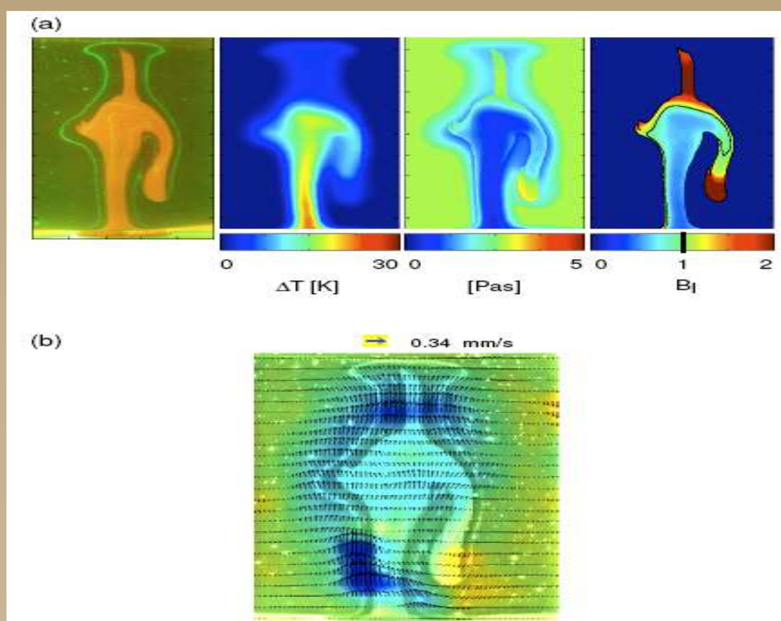
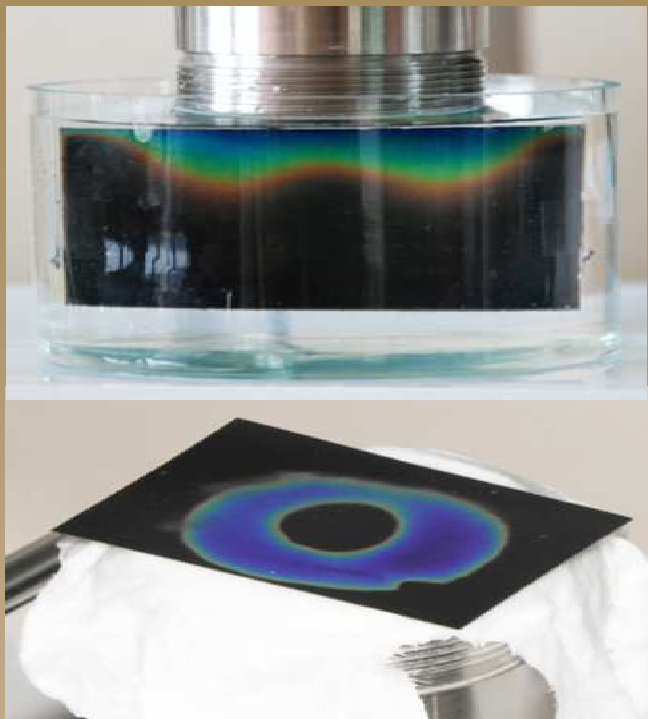
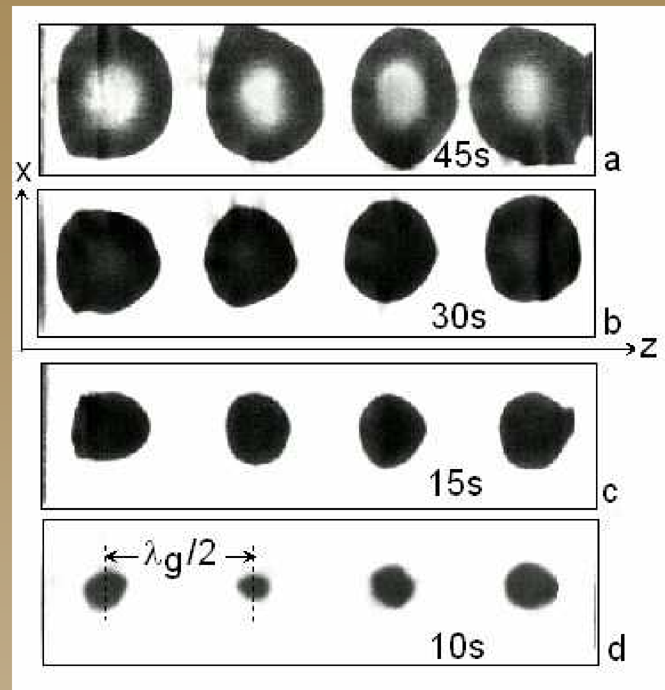


Fig. C. Simultaneous, quantitative visualization of thermochemical plumes: (a) original image, temperature anomaly, viscosity, local buoyancy. (b) Velocity field from PIV. (Kumagai, Kurita, Davaille and Limare, 2009)

The start idea : INCDTIM microwaves power distribution studies





E.Surducan, V.Surducan, C.Neamtu, C.D.Tudoran, Near-field Effect of the Microwaves Power Applicators Investigated for Liquid Processing Applications, Proceedings of IEEE International Conference on Automation, Quality and testing, Robotics - AQTR-2010, pp360-364, ISBN 978-1-4244-6722-B

Experimental distribution of MW power field in TM104 waveguide (closed resonator) at different exposure time, using a proprietary temperature sensor (<u>E.Surducan,</u> V.Surducan, *The thermographic transducer for high power microwave radiation,* Romanian Patent, RO 00116506)

Objective and stages

(I) The first objective of this project is to develop a novel, specific MW experimental setup to use it for mixed convection experiments.

- To develop a MW generator, firmware controlled from an embedded system adapted to the experiments purpose;
- To develop specific applicators (antennas and microwave cavities) correlated with the heating desired process;
- To test in microwaves the liquids proposed for convection experiments;
- To adapt de microwaves power setup to the needs of the in-situ temperature measurement and the biological protection rules.

This is the main Romanian team objective

Objective and stages

(II) The second objective is related to the convection experiments.

- Several tank geometries, the MW generator and the applicators prototyped at the Romanian institute are going to be tested in the French lab for a large set of input parameters and fluids characteristics.
- The experimental results will be used to derive scaling laws that will allow their application to mantle convection.
- This is the strong complementary French-Romanian objective.

The first two objectives are interrelated, and we expect that even if the Romanian team is in charge with the first one and the French team with the second one, the success of both relies on teams complementarities, on the quality of the exchange and competence transfer.

Objective and stages

(III) **The third objective is to apply the experimental results to geophysical modelling.**

- Different possible scenarios of mantle convection will to be tested to address several features of Earth's mantle convection that have not yet been explained satisfactorily: the thermal structure of the convecting layer and the heat flux at the top boundary.
- Experiment of localised intense thermal heating to mimic partial melting in upwelling convective current, by setting the liquid close to its boiling point.

This is the main French team objective

Project Team

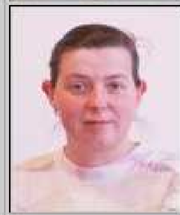
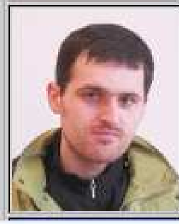
- The teams form IPGP France and INCDTIM Romania have distinct and well defined research areas: the physics of Earth and the physics of microwaves (fundamental and applied research). However, the particular purpose of this project is extremely interesting for both teams. Exchanging know-how and cooperation on non-contact MW heating techniques and thermal evolution of convecting systems will bring benefits for both groups.

- The MW research group belongs to the Molecular and Biomolecular Physics Department, Photothermal and microwaves applied research team, and is involved in MW fundamental and applied research.The contribution of the MW research group to the project is related to research, design and prototype of a microwave-heating device (MWH) for convection studies on immiscible liquids.

- L'Institut de Physique du Globe de Paris (IPGP) is a research institution associated to CNRS and member of the PRES Sorbonne Paris Cité. Its mission is to achieve research and provide education in the fields of geosciences and monitoring the natural phenomena. The team involved in the present project belong to the Geological Fluids Dynamics Laboratory. The group main interests are: convection phenomena in the mantle, cooling dynamics of the Earth and physical volcanology.

Project Team

	Team IPGP
	Limare Angela, Senior engineer, Project Manager *Laboratory experiments, prototyping, project management* http://www.ipgp.fr/~limare/
	Jaupart Claude, Professor *Laboratory experiments, numerical modelling* http://volcanomodels.sr.unh.edu/people/list/jaupart.htm
	Kaminski Edouard, Professor *Laboratory experiments, numerical modelling* http://www.ipgp.fr/~kaminski/
	Farnetani Cinzia, MC *Numerical modelling* http://www.ipgp.fr/~cinzia/

	Team INCDTIM
	Surducan Emanoil, Senior researcher, Project Manager Microwave circuitry modelling, design and implementation, project management
	Surducan Vasile, Senior engineer *Engineering, Electronic and embedded design, prototyping and testing*
	Neamtu Camelia, Senior researcher *Physicist, laboratory experiments, heat transfer studies*
	Lung Ildiko, Researcher *Organic chemistry, laboratory experiments*
	Tudoran Cristian Daniel, Researcher *Physicist, laboratory experiments*

THE EXPERIMENT

Physics of the experiment

The Earth mantle “nuclear rector” is modeled by microwaves absorption.

Tasks for the microwaves experimental setup:

-microwaves power control;

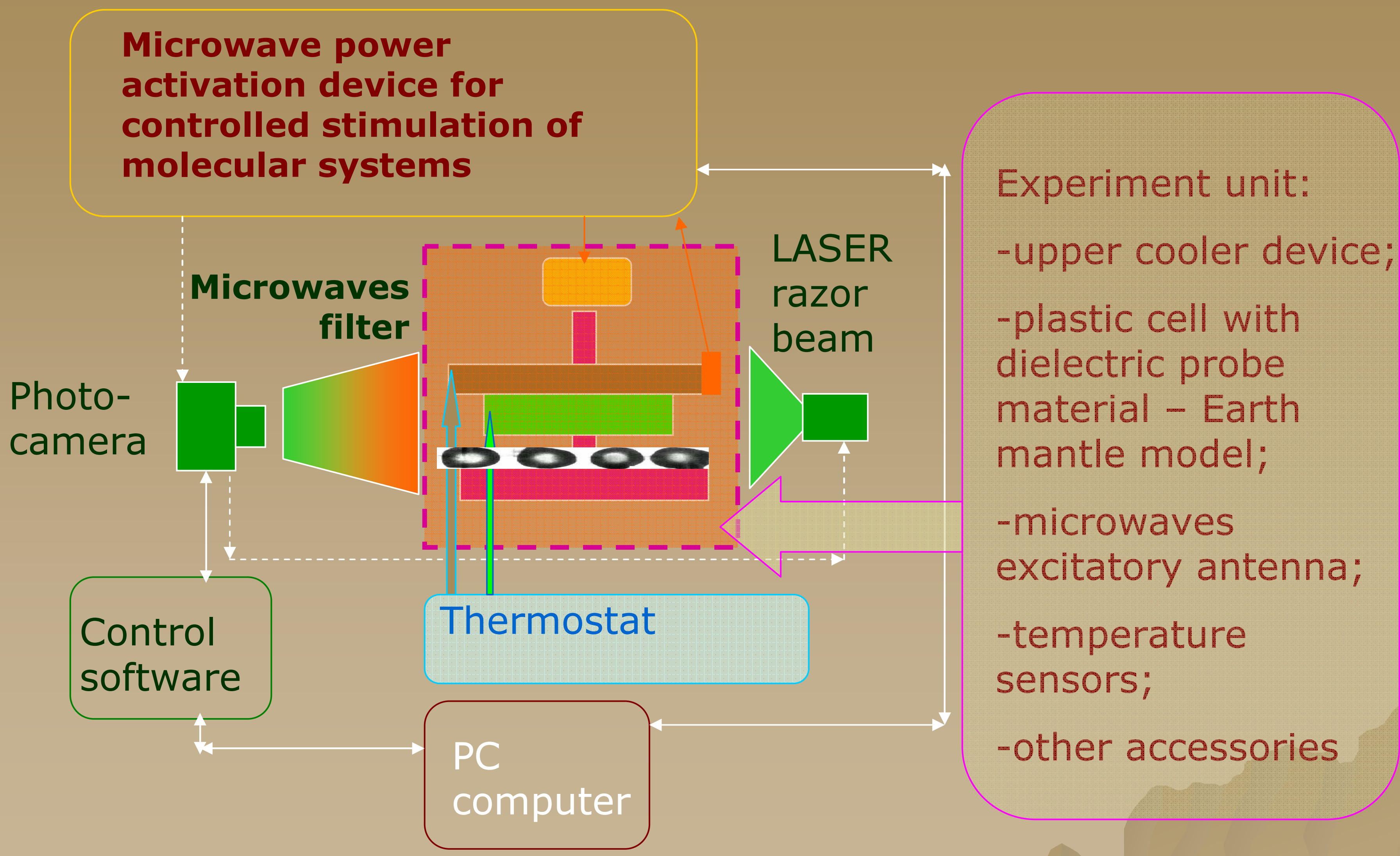
-microwaves distribution control (uniform microwaves distribution)

-to prepare a liquid material with dielectric properties (e’+je”) constants in the desired temperature interval ΔT;

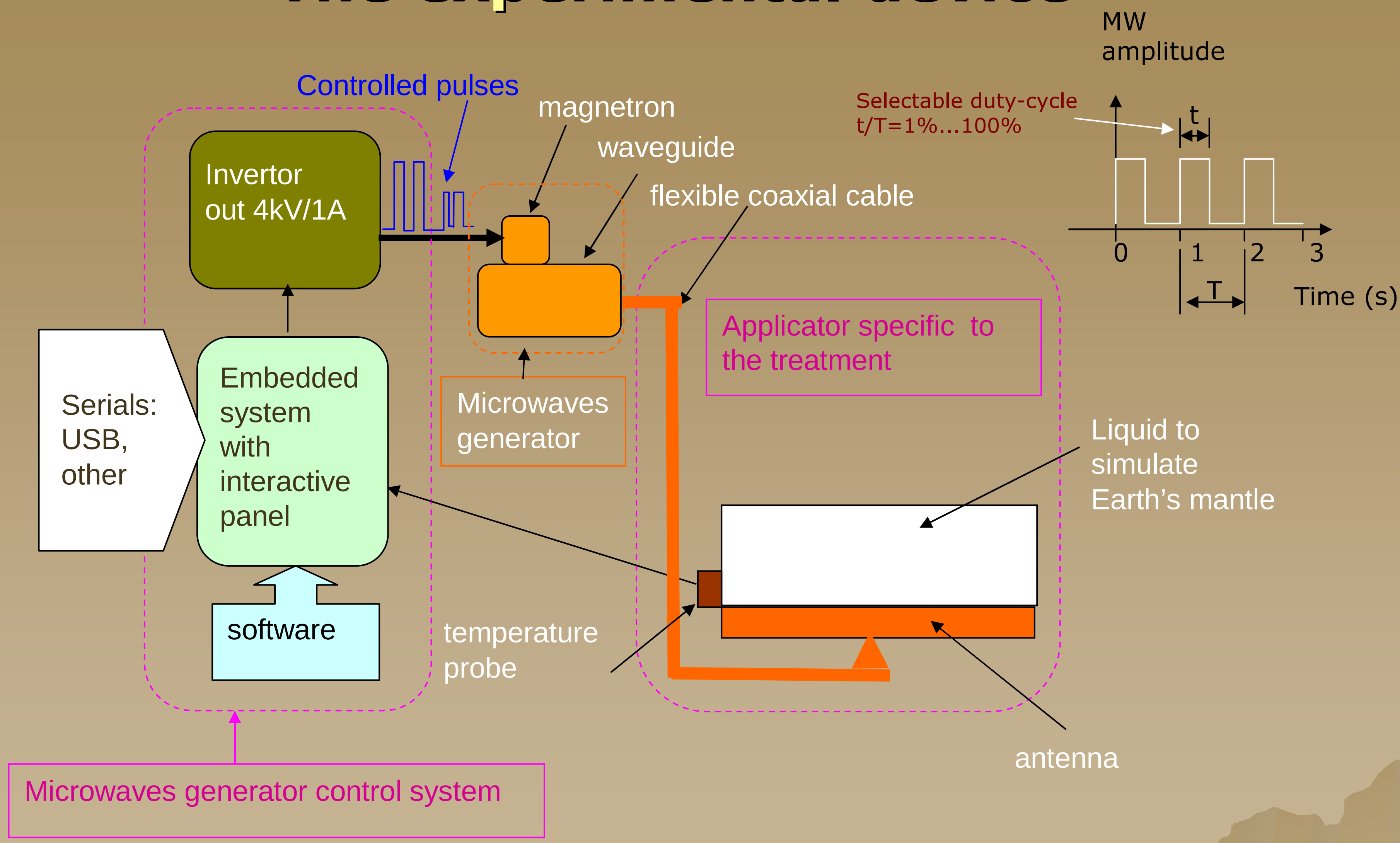
-to measure temperature inside the probe by non-contact optical method (real time image of a specific section of the probe);

- biological protection for the users of the experimental device

Experiment setup



The experimental device



Microwave power activation device for controlled stimulation of molecular systems

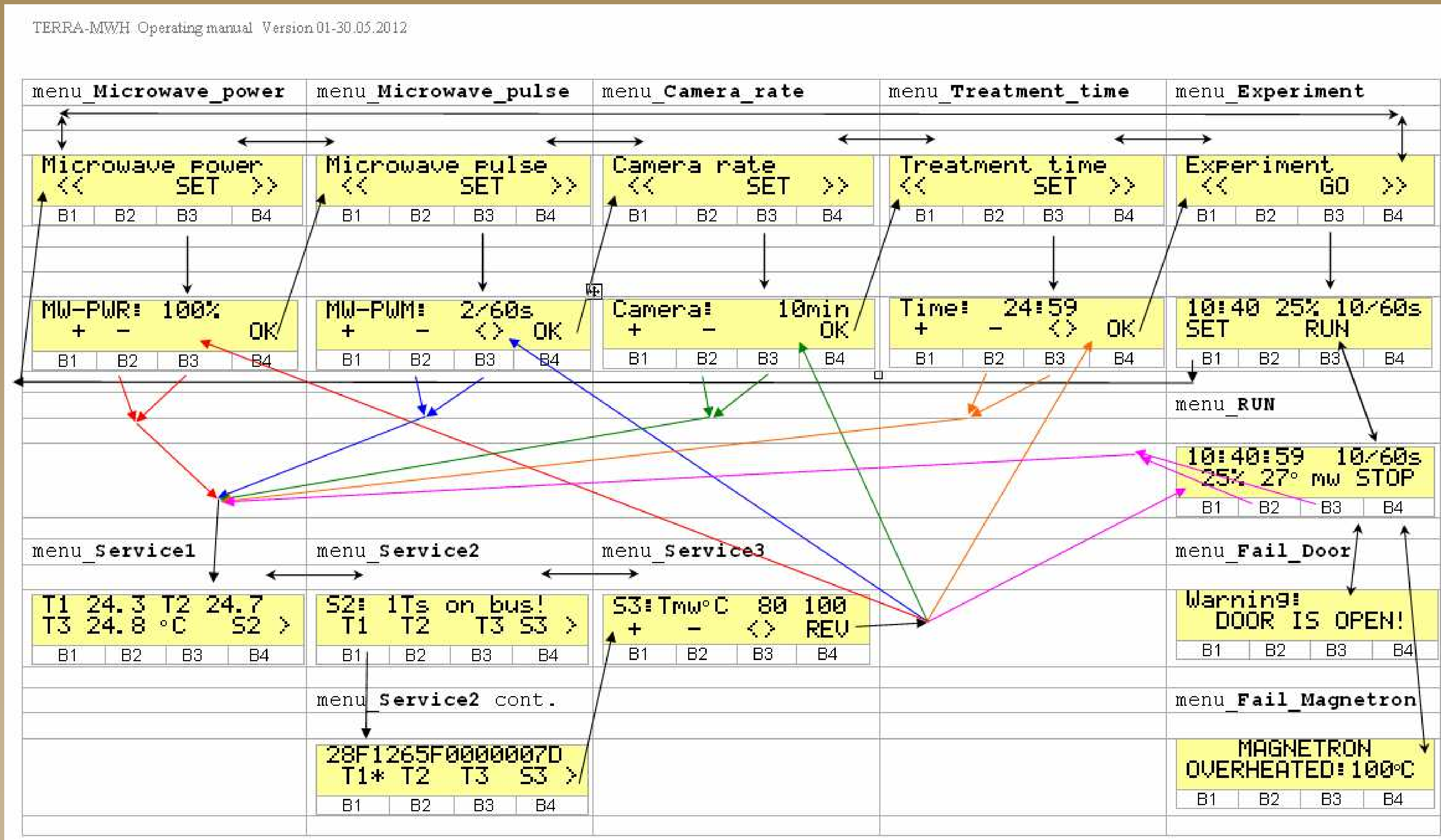
V.Surducan, E.Surducan, Camelia Neamtu, "Embedded module for driving microwave generators in medical and laboratory applications" patent pending RO – A00113/11.02.**2010**

The embedded system

- MW power control: 25%, 50%, 75%, 100% or 750W MW power;
- Driving capabilities: MW inverter, MW transformer;
- Large combinations of MW duty cycle (1s to 60s MW pulse programming, during 1s to 60s period, any combination);
- 1s to 24h MW treatment time, using real time clock;
- Photo-camera syhnchro rate: 1min to 10min;
- Three temperature sensors 0-125ºC, 0.1ºC resolution, 0.5ºC error;
- Magnetron overheating programable protection 75ºC-110ºC;
- Door open sensing&protection;
- USB communication

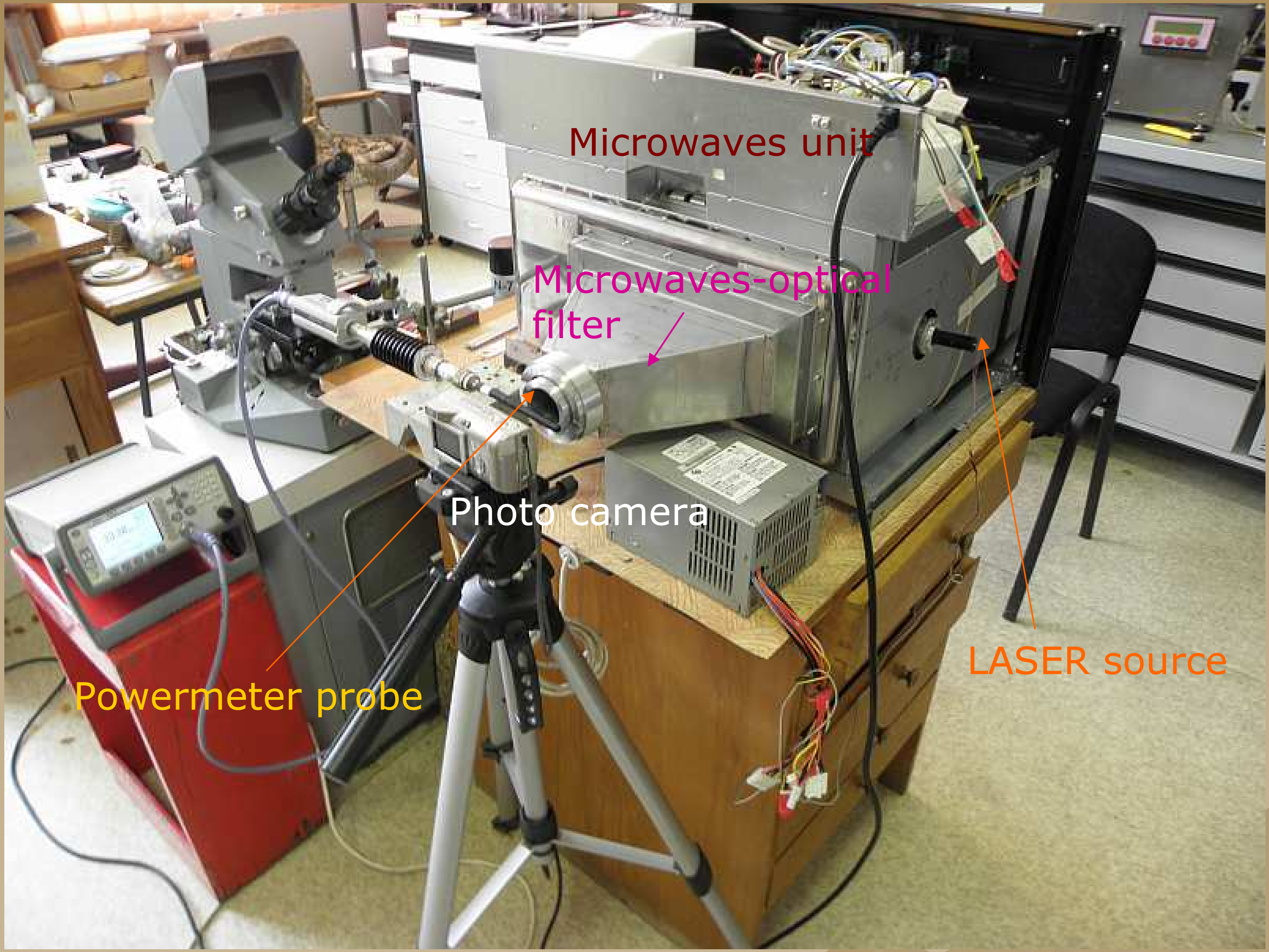
Designed and manufactured 100% in INCDTIM

The embedded system



The chain of the programming, display and service menus (from operating manual)

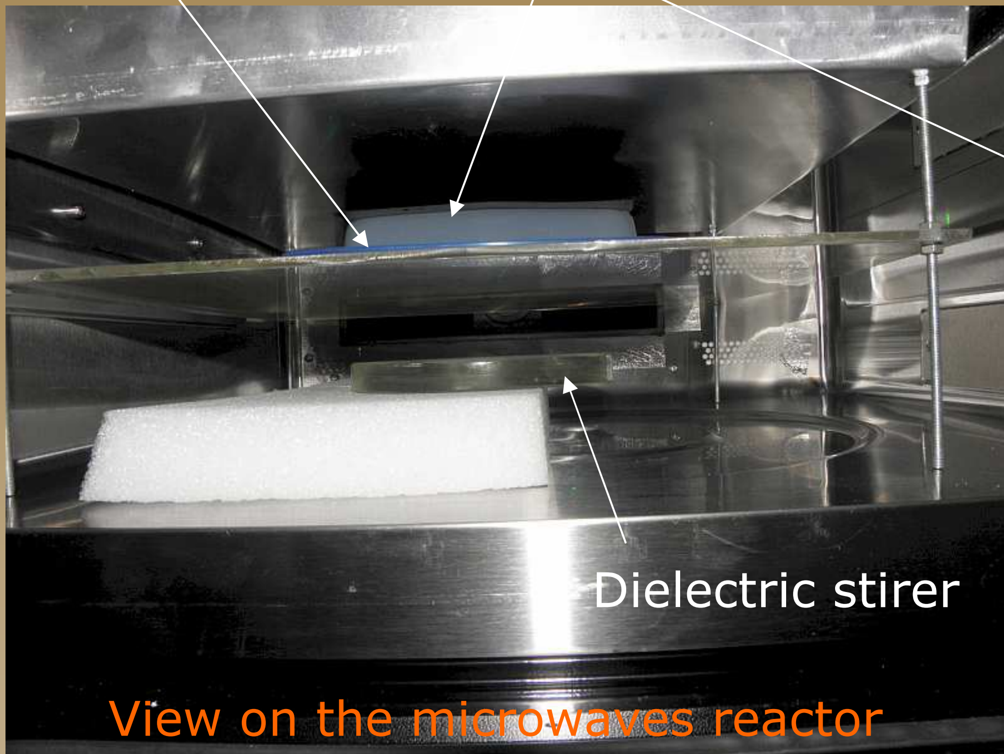
The experimental setup



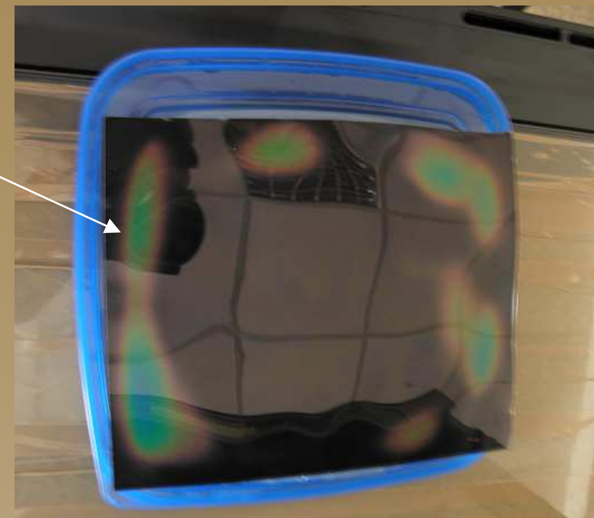
Experimental microwaves unit (setup for biological protection tests)

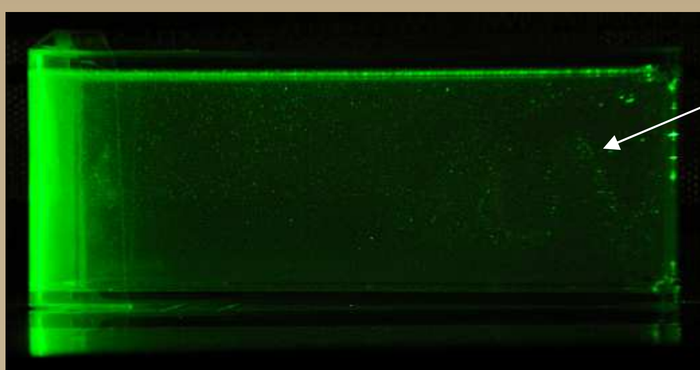
Gel probe

liquid crystal transducer
(25°C-30°C range)



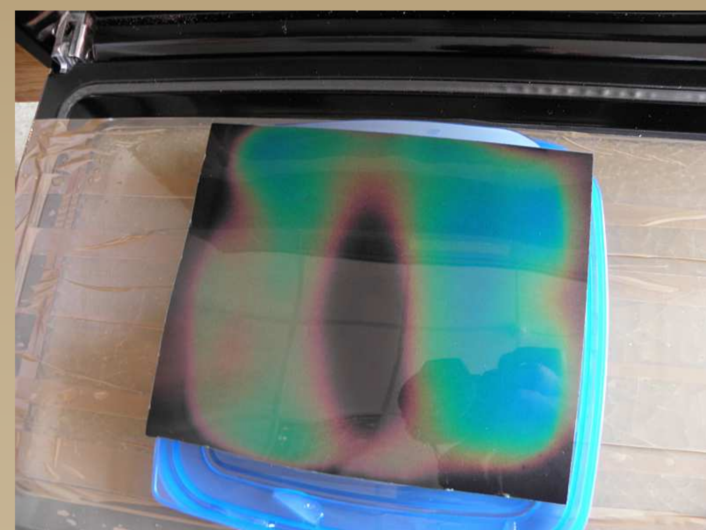
Stationary inhomogenous
heating





Convection
plumes

View on a liquid-section illuminated by
Razor-LASER



Heating with microwaves stirrer

RESULTS – April 2012

2-6 April 2012, First bilateral meeting (RO-FR) at INCDTIM- CJ RO

Objective: first tests of the microwaves unit in the experimental configuration.

Results:

- The microwaves-optical filter designed for microwave blocking was tested by microwave field radiation measurements. Photos were taken in safe conditions for the camera and the operator.

- The microwave resonator configuration for the uniform heating purpose was defined and tested;

- The microwaves distribution method on two types of material withdifferent viscosities was tested (1) low viscosity - allowing the convection and (2) gel-type to test the internal heating source distribution

- Two temperature monitoring methods were defined based on two types of liquid crystals and light sources;

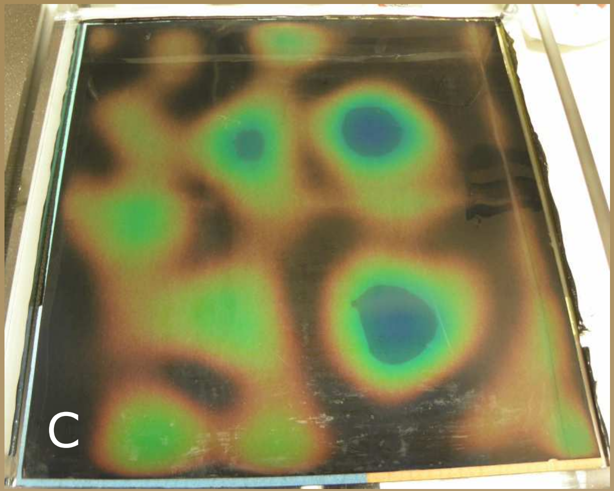
- Based on these results, we designed the resonator configuration for the first convection experiment with microwaves uniform heating case and constant temperature cooling at the top surface.

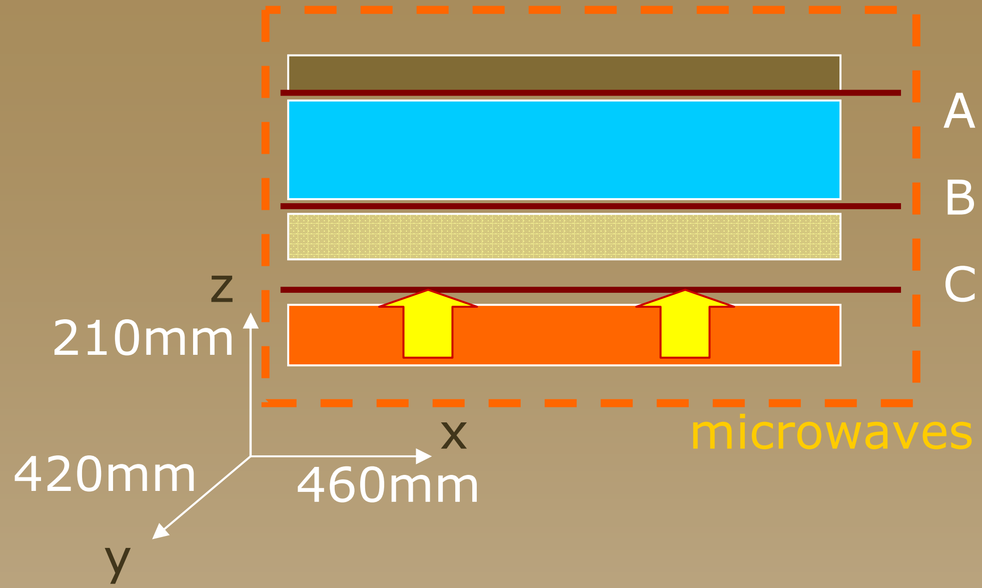
“Near” the final experimental setup ☺

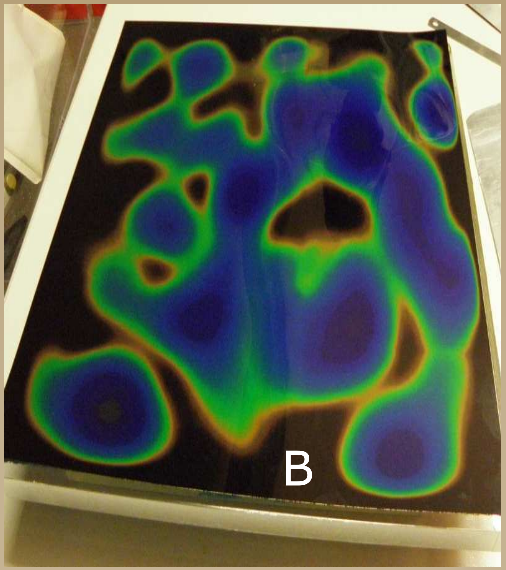
IPGP Paris

INCDTIM Cluj Napoca

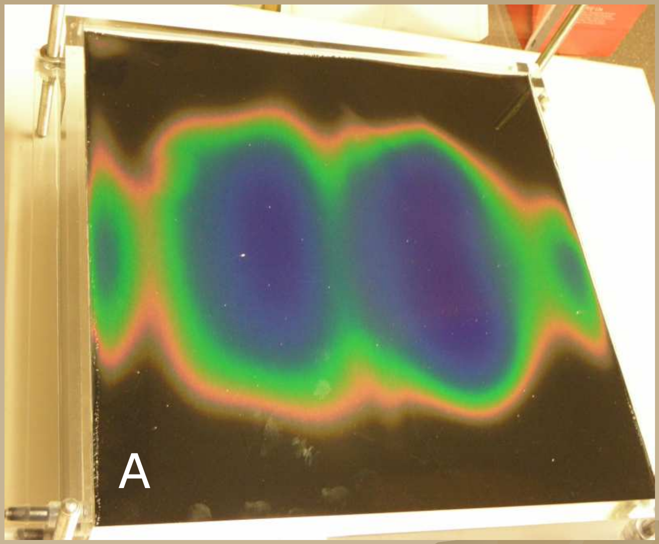
Microwaves power densities distributions

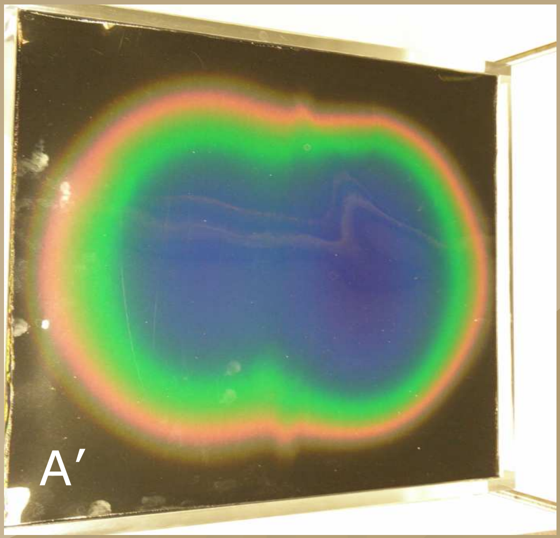






340x340 mm^2





RESULTS – June 2012

3-8 June 2012, Second bilateral meeting (RO-FR) at IPGP Paris, FR

Objective: Prepare the microwaves unit for the French team; preliminary tests for the first experimental configuration (volume internal heating and top cooling).

Results:

- Installation of microwaves control unit;
- Tests of the microwaves power distribution;
- Assemble the tank with the cooling device at the top surface and the fittings for probe filling and heat exchanger liquid circulation;
- Test of the temperature distribution at the top and the bottom of the Agar probe for the first experimental configuration: uniform internal heating and top cooling;
- Based on these results, we designed a microwaves homogenizer to improve the uniformity of internal heating for this experimental configuration.