Institute of Experimental Physics
Slovak Academy of Sciences, Kosice

Experimental Study of the Single Bubble Sonoluminescence

Doctoral Seminar IEP SAS 2009

Ivan Hamráček

June 24. 2009

Zadanie doktorandskej záverečnej práce

fakulta: Prírodovedecká fakulta UPJŠ
stredisko: Ústav fyzikálnych vied
študijný odbor: Fyzika kondenzovaných látok a akustika
školiace stredisko: Ústav experimentálnej fyziky, SAV
názov práce: Štúdium sonoluminescencie

cieľ: 1. rok (2008-2009)

- vybudovanie aparatúry pre štúdium sonoluminiscencie (SL), jej optimalizácia a automatizácia
- príprava spektrometrických meraní
- meranie spektier sonoluminiscencie pri rôznych podmienkach a kvapalinách
- reprodukovateľnost výsledkov s rôznymi rezonátormi
- porovnanie výsledkov s existujúcimi dátami
- testovanie silikónového detektora a jeho časových charakteristík

2. rok (2009-2010)

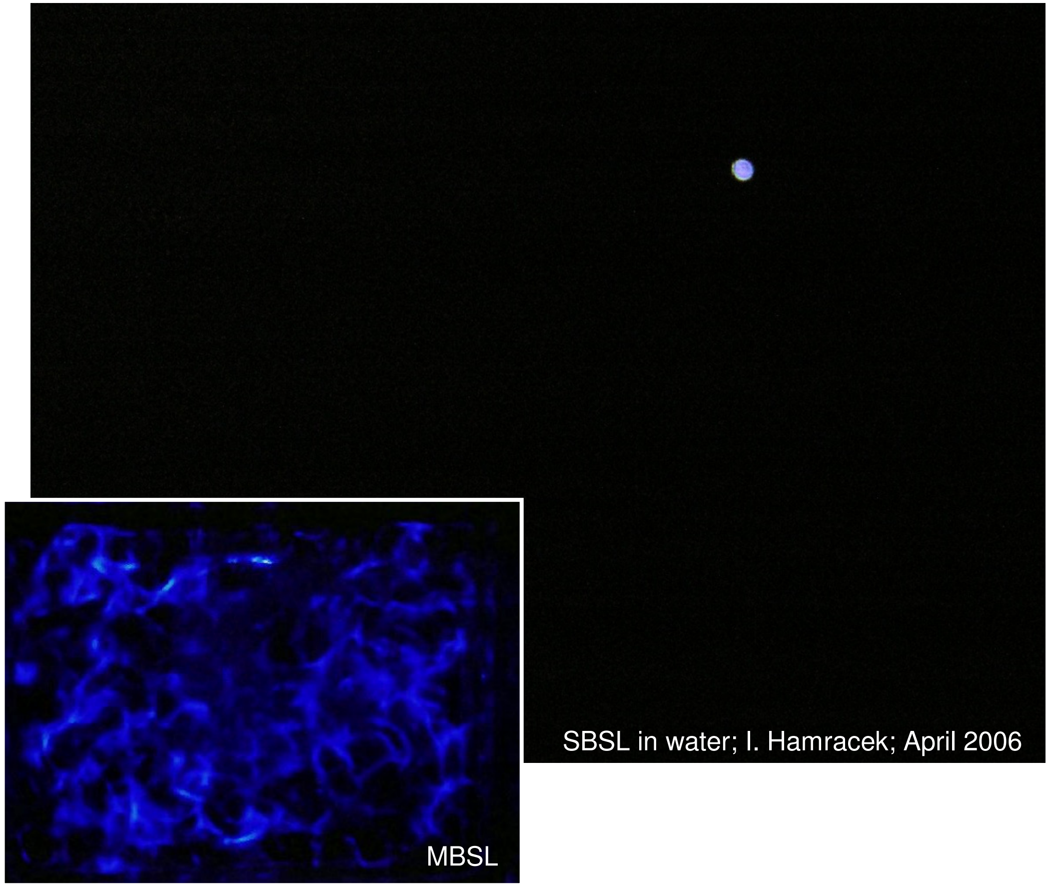
- vybudovanie a testovanie aparatúry pre meranie časových charakteristík SL
- Mie rozptyl na bubline

3.-4. rok (2010-2012)

- publikačná činnosť

školiteľ: RNDr. Jaroslav Antoš, CSc.
dátum zadania: 01.10.2008
dátum odovzdania: 30.09.2012

Sonoluminescence (SL)

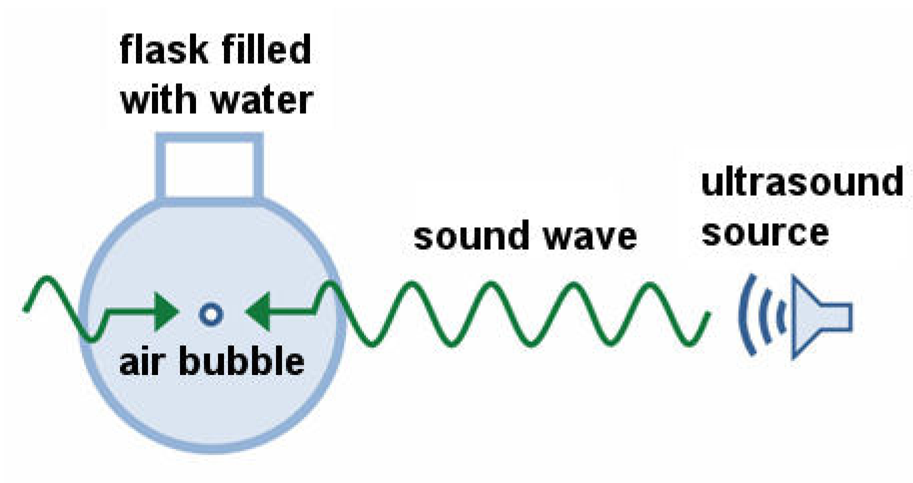


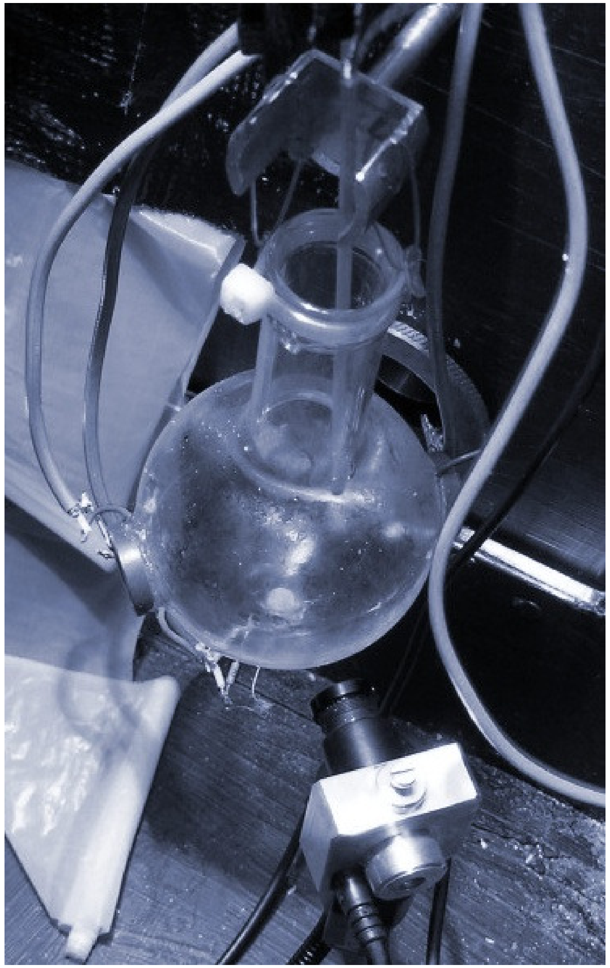
light emitting from the gaseous bubbles in the liquid excited by the acoustic pressure field

temperature in bubble
(~ 10.000 K)

light flash duration
(~100 ps)

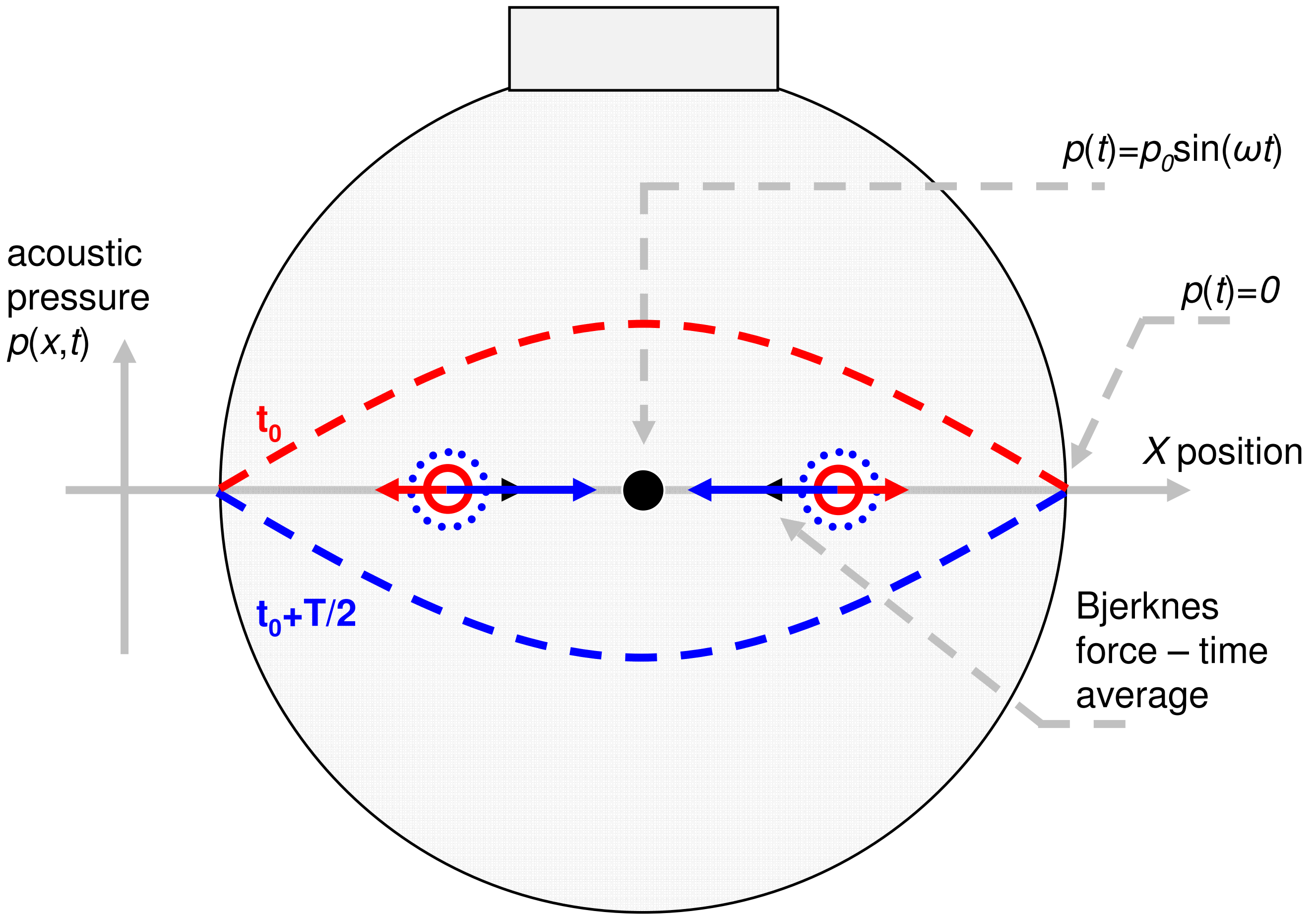
Single Bubble Sonoluminescence (SBSL)





one gaseous bubble trapped in the center of the flask exposed to ultrasound

Bubble Levitation in Liquid

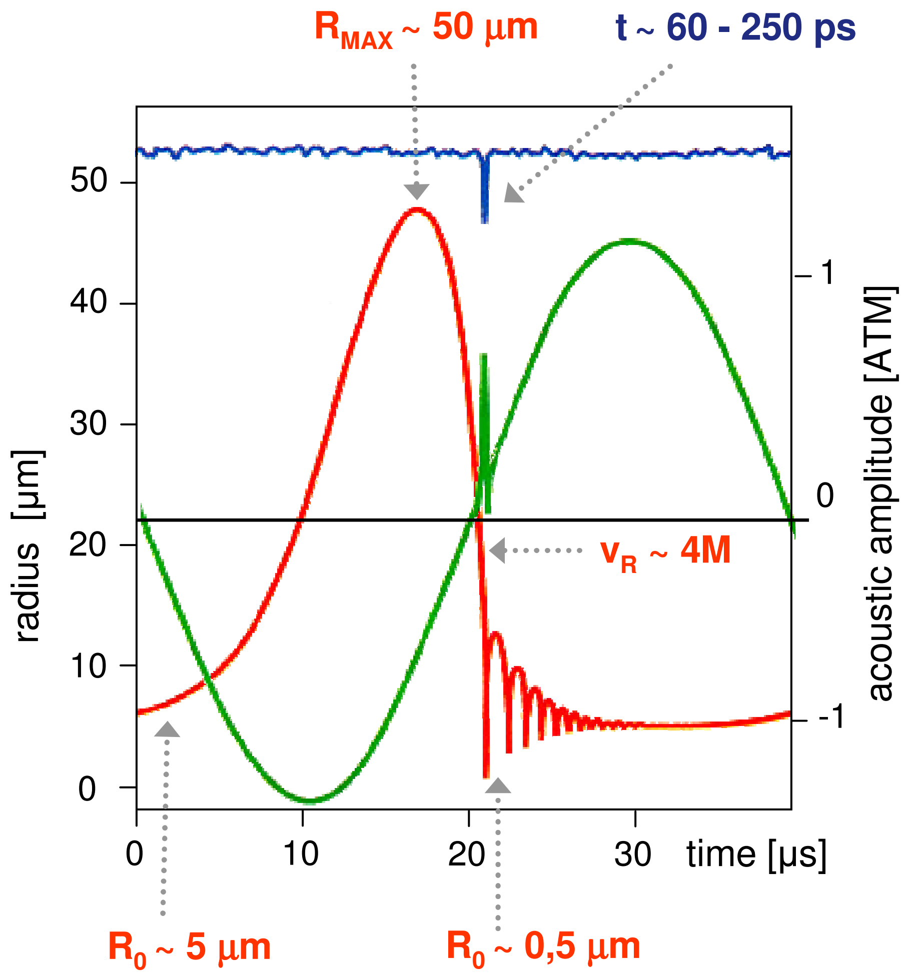


History of Sonoluminescence

- **1917, Rayleigh:** dynamics of air bubbles
- **1934, Frenzel, Schultes:** first MBSL observation
- **1960, Jarman, Megishi:** periodicity in light emission observated
- **1970, Sakensa, Nyborg:** equality of field frequency and light emission frequency confirmed
- **1988, Gaitan:** single bubble captured
- **1991 - 1993, Barber, Putterman, Hiller, Löftstedt:** temperature estimated
- **1994, Moss:** Hot Spot model

SBSL Cycle

- **bubble expansion and implosion**
  - volume shift by factor 10^6
  - slow isothermal expansion
  - fast adiabatic colaps
- **shock wave**
  - high pressure and temperature
- **flash**
  - periodic intervals
  - 10^6 photons

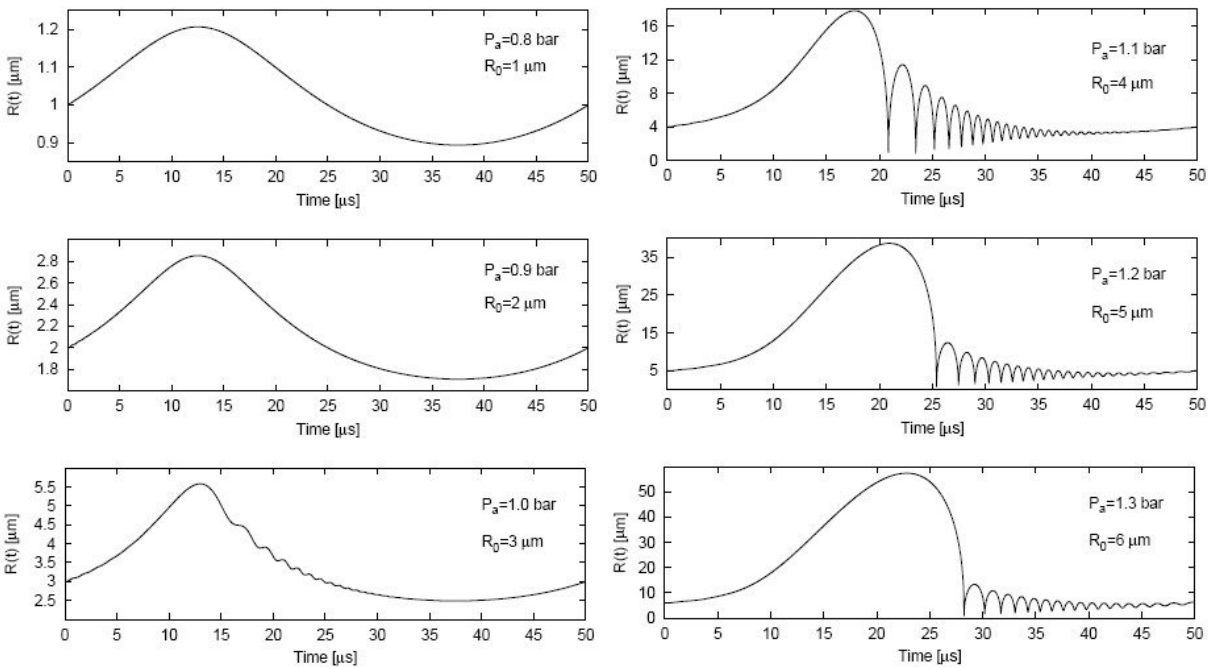


T ~ 10^4 - 10^8 K !

Rayleigh – Plesset Equation

qualitative bubble dynamics description

$$R\ddot{R}+\frac{3}{2}\dot{R}^2=\frac{1}{\rho}\left[\left(p_H+\frac{2\sigma}{R_0}\right)\left(\frac{R_0}{R}\right)^{3b}-\frac{2\sigma}{R}-\frac{4\mu\dot{R}}{R}-p_H+p_A\sin\varpi t\right]$$



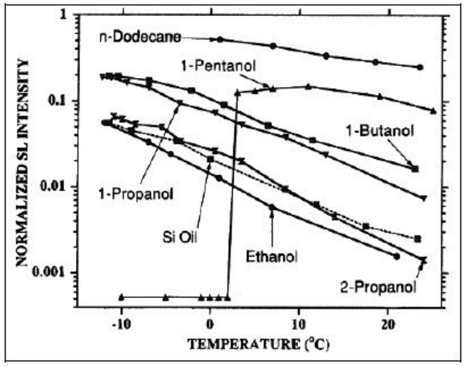
R – bubble radius
p_H – hydrostatic pressure
p_A – acoustic amplitude
σ – surface tension
μ – liquid viscosity

- **Assumptions**

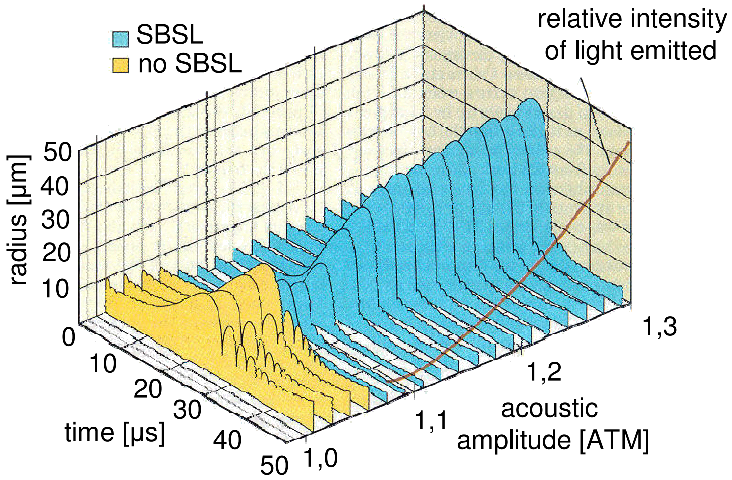
  - liquid incompressibility

  - slow radius shift

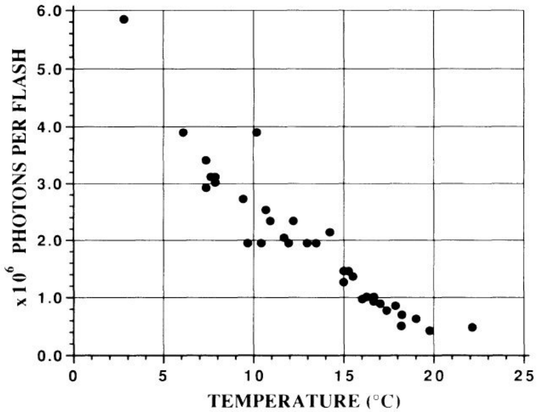
Parameters affecting on SBSL



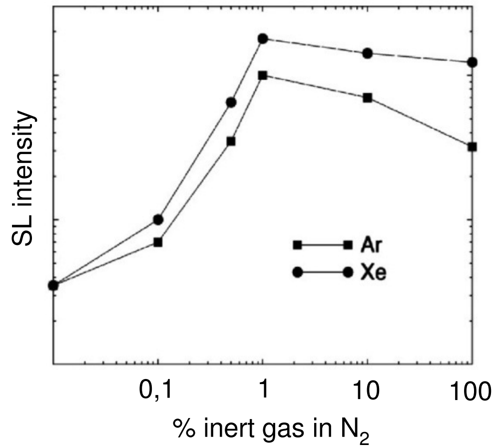
Weninger et al.; May 1995



S. Putterman; February 1995



Hiller et al.; 1992



M.P. Brenner; April 2002

- liquid used
- bubble gas used
- acoustic amplitude
- ambient temperature
- others?

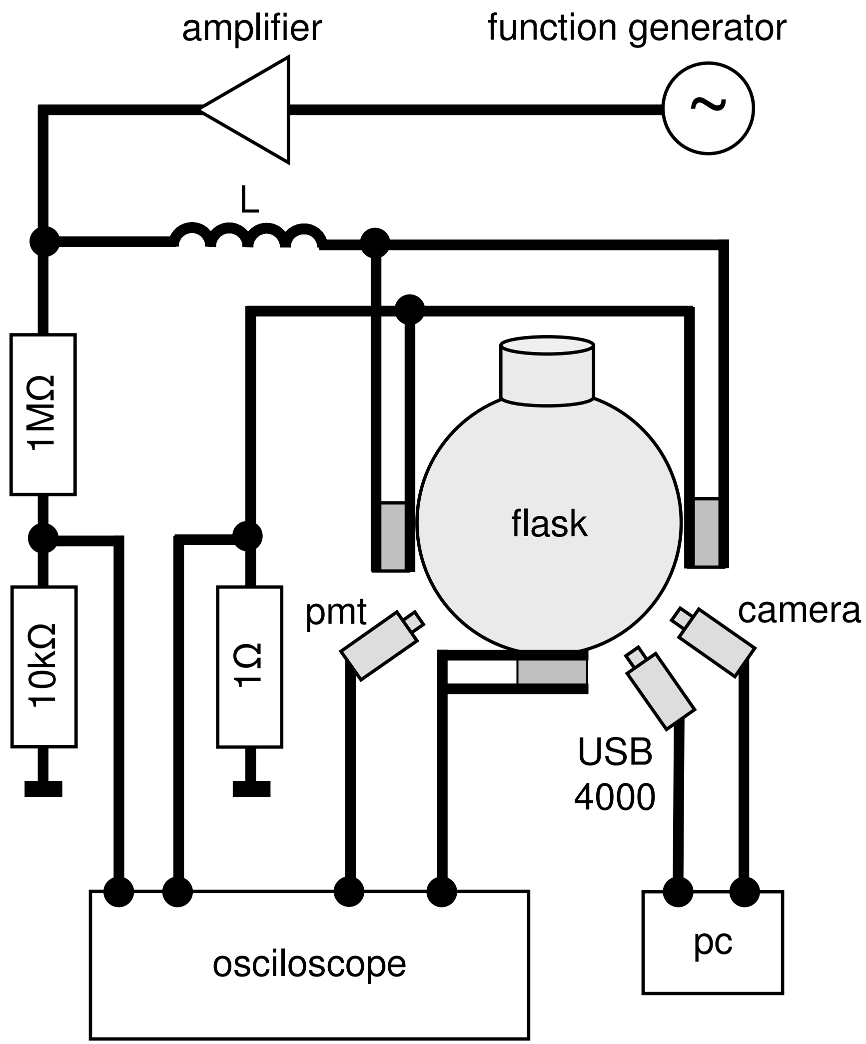
Aims and Motivation

- **motivation**
  - SBSL light production mechanism still unknown
  - bubble temperatures 10^4K (10^8K ?)
    (possible exploitation of SBSL for initiation of nuclear fusion)
  - simple apparatus required (for SBSL initiation)

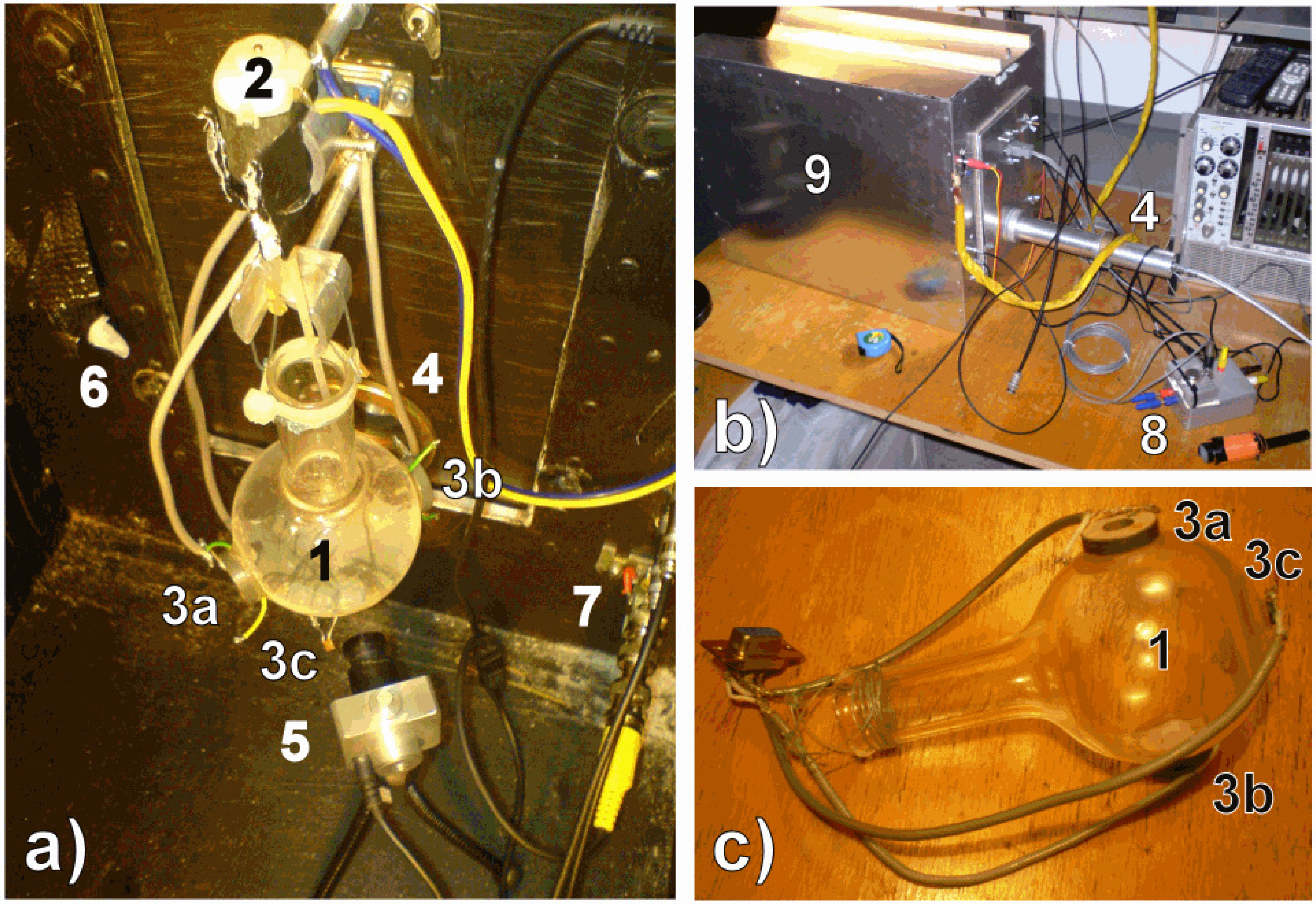
- **aims**
  - stable condition preparation for SBSL observation
  - estimate temperature inside bubble by means of spectrum of SBSL light emitted at different experiment conditions
  - estimation of flash duration (~100ps)
  - scaling of bubble temperature

SBSL Apparatus

- **requirements**
  - signal generated and amplified with frequency of ~ 27 kHz
  - transformed by piezoceramic transducers to US standing wave
- **parameters monitored**
  - function generator output voltage
  - LC circuit current
  - sound captured with microphone at the bottom of the flask
  - flash captured with photomultiplier
  - apparatus scene captured with camera
  - spectrum scanned USB 4000

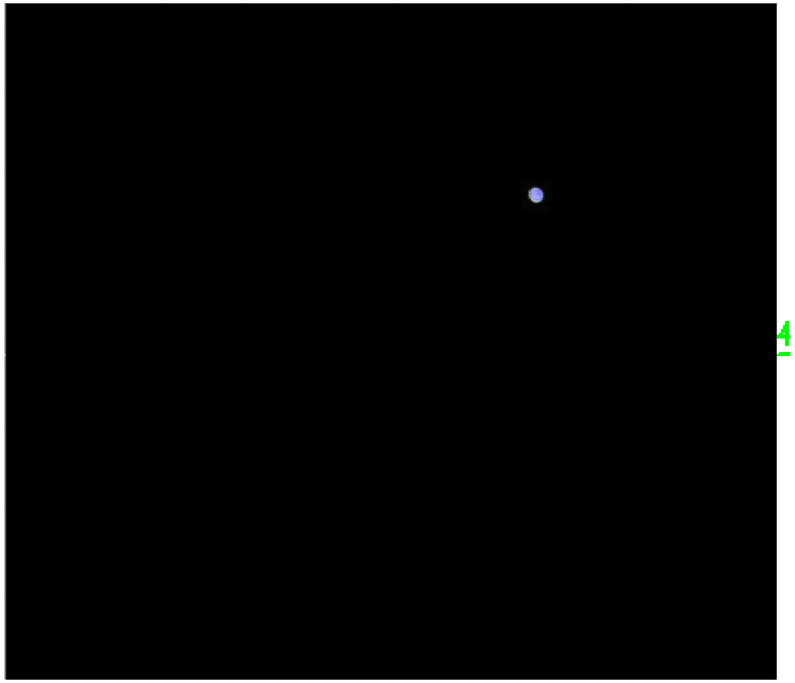


SBSL Apparatus



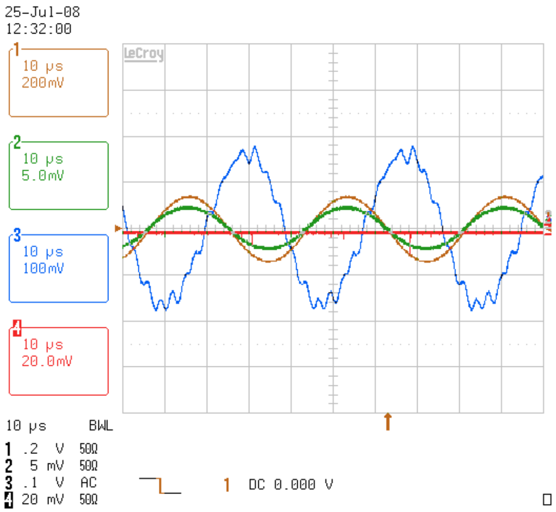
SBSL Creation and Observation

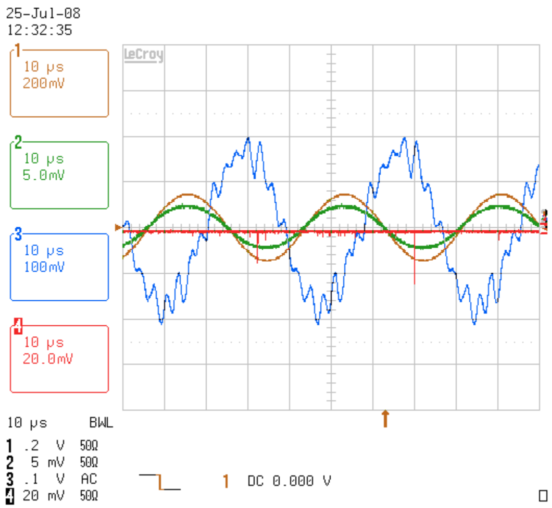
- **liquid preparation**
  - 5-10 fold cut-down of gas content in destilated water
  - 115 ml, liquid surface in flask neck for spherical liquid shape
- **signal generated**
  - 26,69 kHz, 3-5 Vpp
- **bubble creation**
  - liquid surface undulation (miniature bubble creation)
- **sonoluminescence observation**
  - microphone output signal folds
  - light pulses captured with PMT
  - in dark room we observe bluish-white shiny spot in the middle of flask

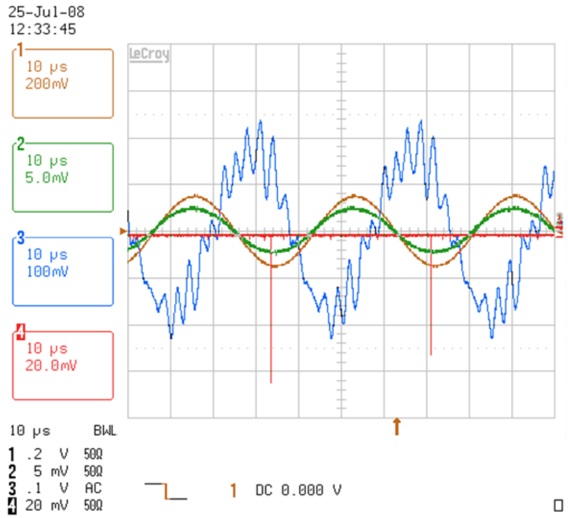


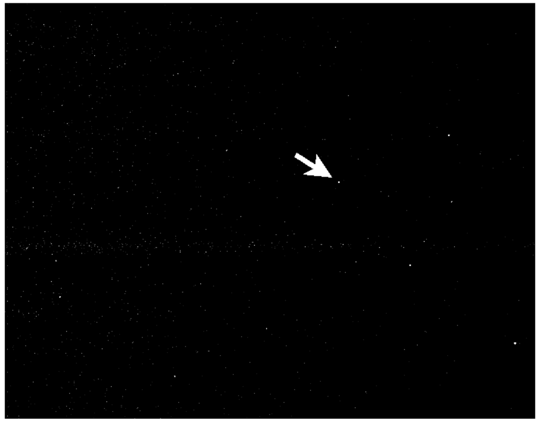
SBSL in water on osciloscope LeCroy; I. Hamráček; April 2006

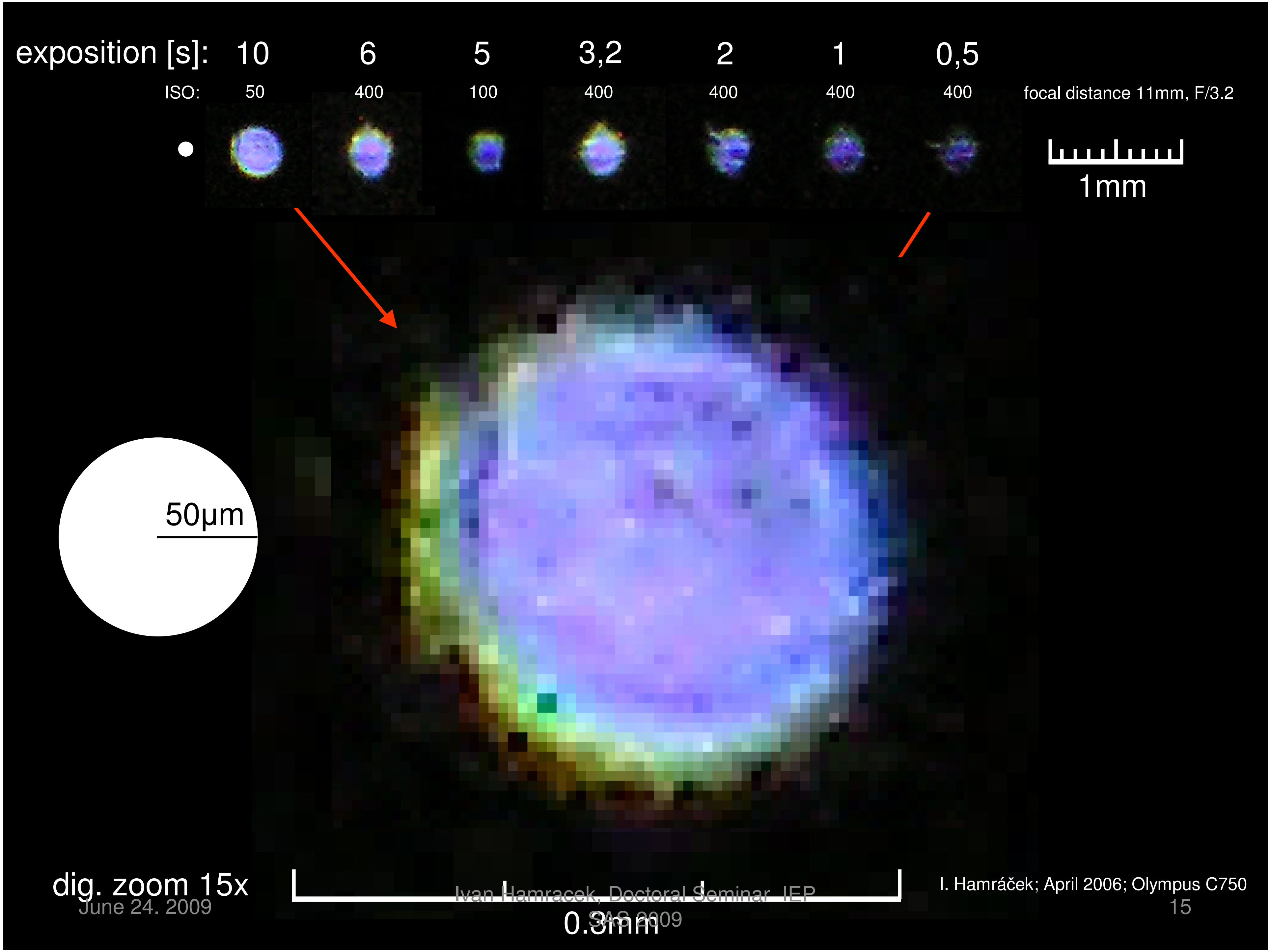
SBSL Observation





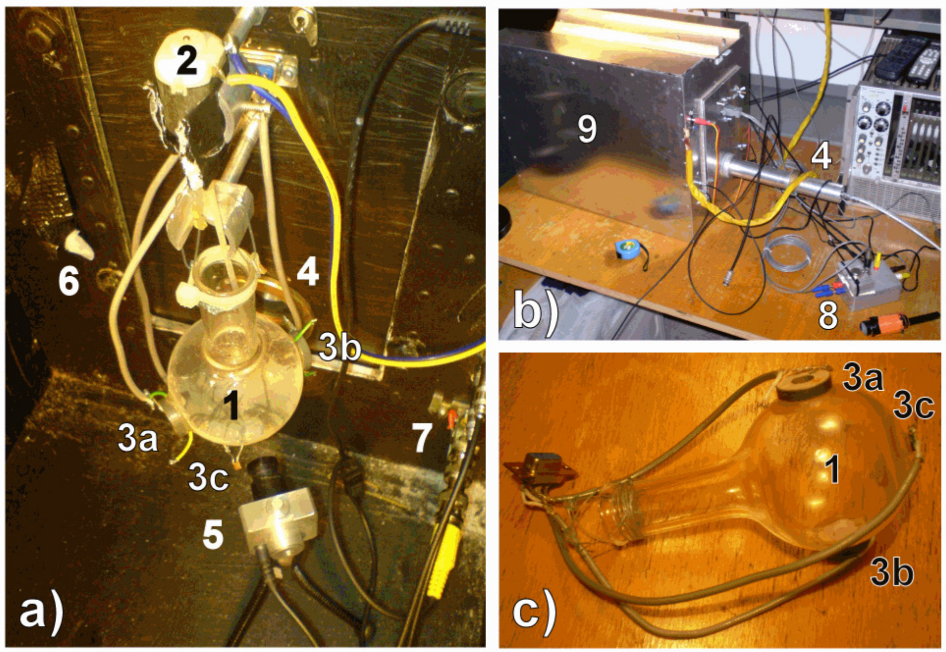


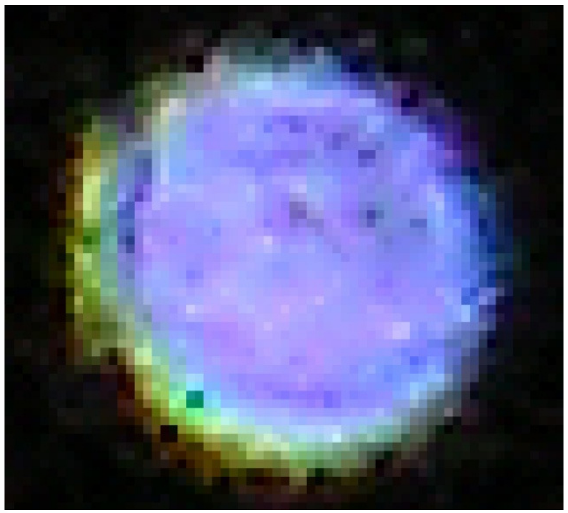



exposition [s]: 10 6 5 3,2 2 1 0,5
ISO: 50 400 100 400 400 400 400
focal distance 11mm, F/3.2
1mm
50µm
dig. zoom 15x
0.3mm
I. Hamráček; April 2006; Olympus C750

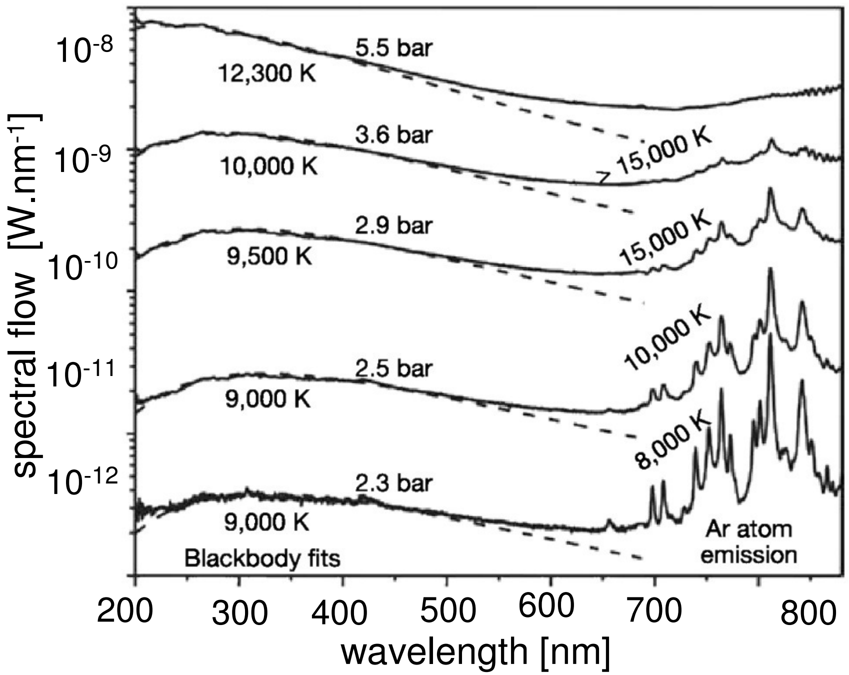
Stable condition preparation

- experimental apparatus for SBSL creation ✔
- technology of proper conditions for stable SBSL ✔
- cylindrical resonator ✔
- automation of SBSL creation ✔





Temperature estimation: SBSL Spectrum



SBSL in 85% H_2SO_4; D.J. Flannigan, K.S. Suslick; March 2005

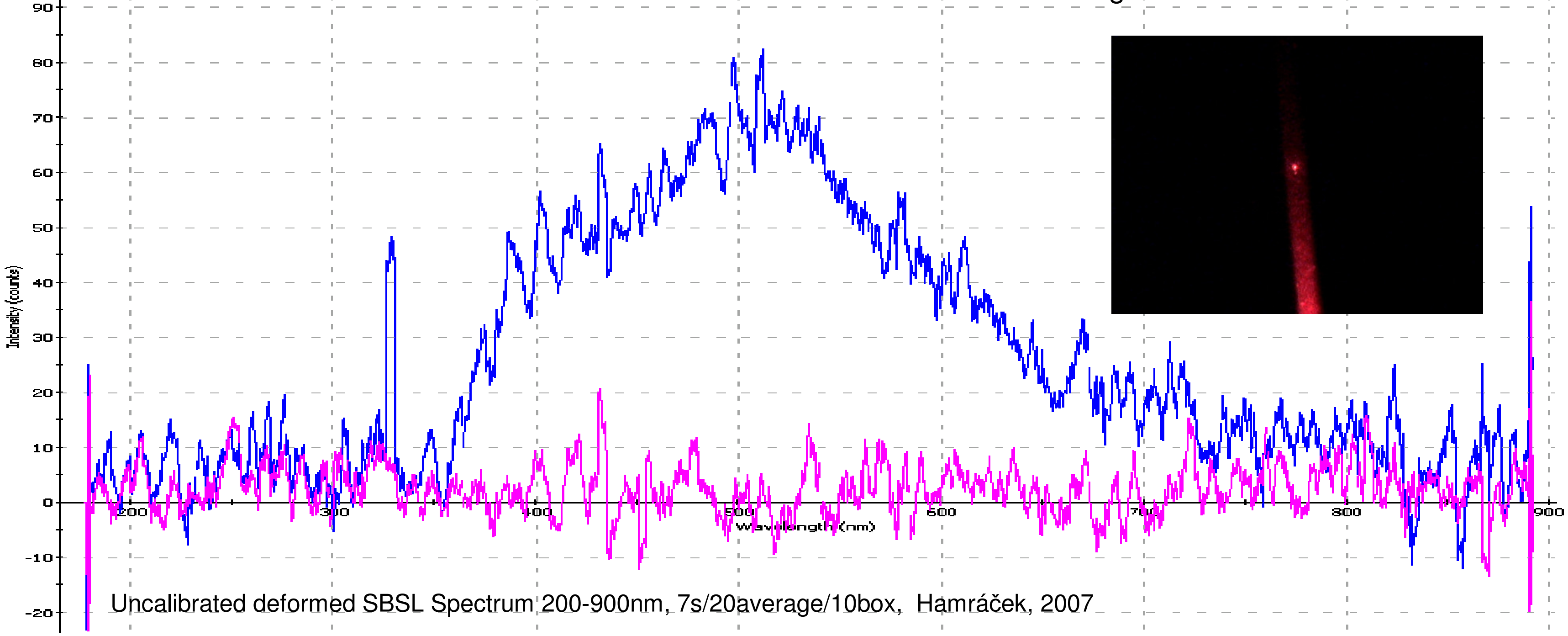
- continuous in 190nm – 700nm region
- UV sector absorbed by water
- light production mechanism still unknown

- Planck distribution fit
- peak location
- total energy

Temperature estimation: SBSL Spectrum

- wavelength calibration ✓
- absolute spectral response calibration ✓
- calibration verification ✓
- medium absorbance analysis ✓
- suitable optical apparatus ✓

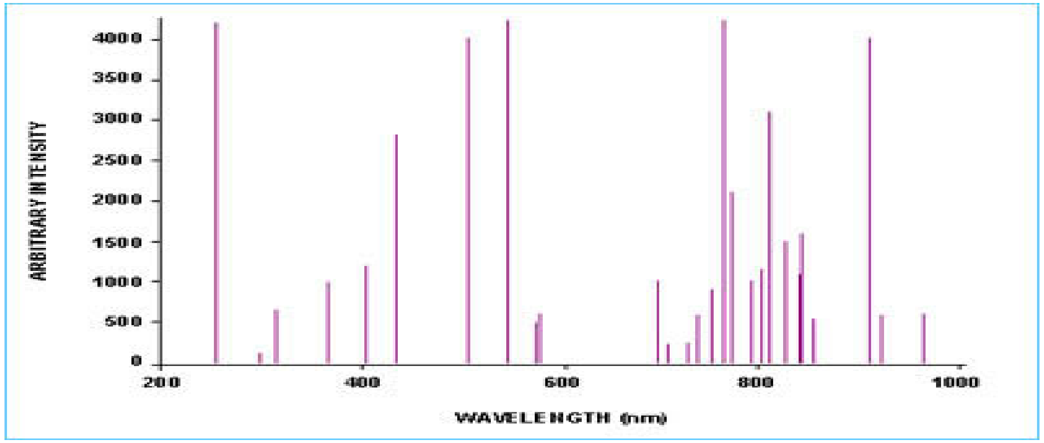
- OceanOptics USB4000 Spectrometer
  - detector range 200 – 900 nm (3648 pixels)
  - integration time 3.8 ms – 10 s



Uncalibrated deformed SBSL Spectrum 200-900nm, 7s/20average/10box, Hamráček, 2007

SBSL Spectrum
Wavelength Calibration

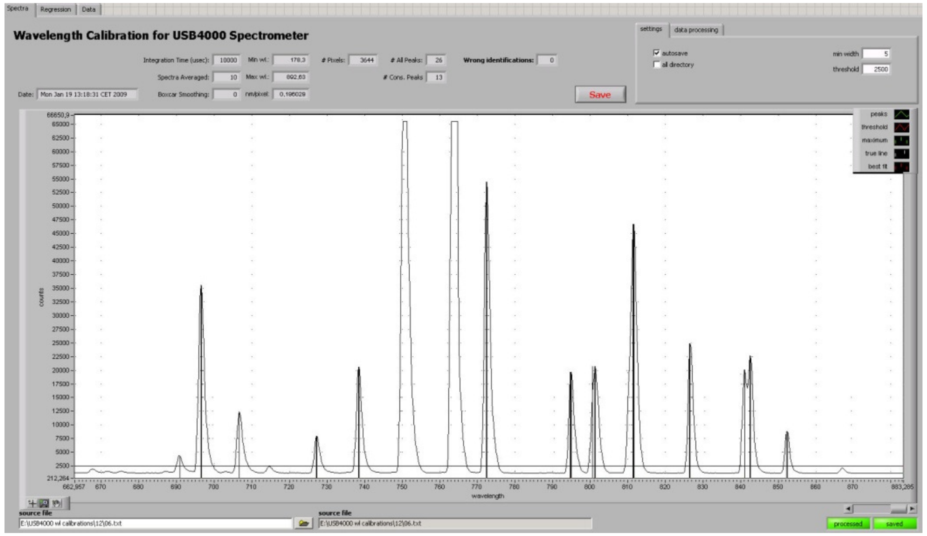
- wavelength drift slightly (time and environmental conditions)
- OceanOptics HG-1 Mercury Argon Calibration Source
  - low-pressure gas discharge lines of mercury and argon
  - 253-922 nm
  - 25 lines
- spectrum calibration included with every measurement
- automatization needed
- study of external effects on w.c. (spec. board temperature, integration time, averaging, source runtime)

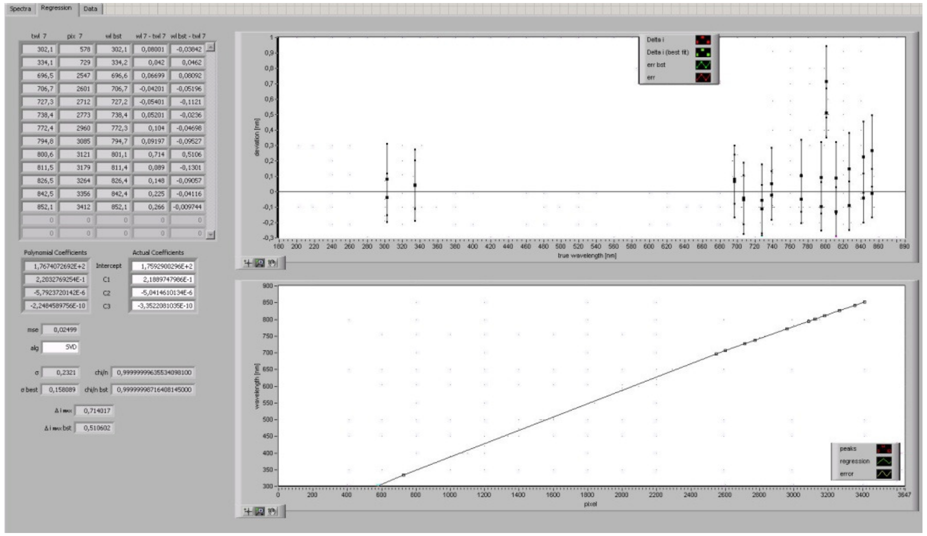


SBSL Spectrum

Wavelength Calibration

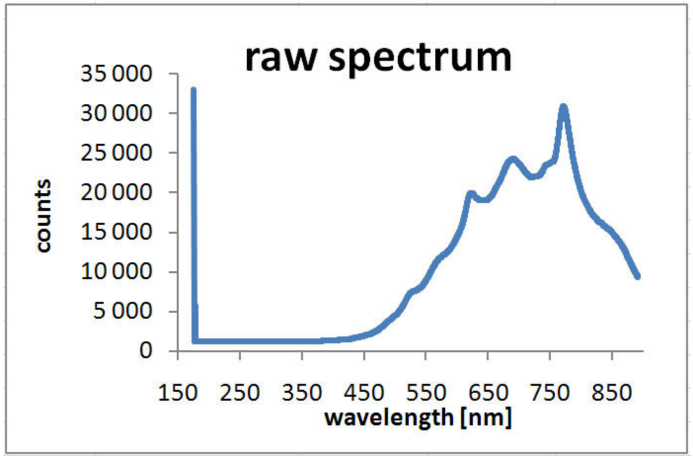
- automatized calibration in LabView environment
- HG-1 spectrum and spectrum parameters loaded
- saturated and wrong lines recognition and exclusion
- true tabulated lines identificated
- $\lambda_P = \lambda_0 + C_1P + C_2P^2 + C_3P^3$ (λ as polynomial function of pixel)
- automated decision of calibration necessity (σ and Δ_{MAX} limits)
- data saved into text file for calibration history





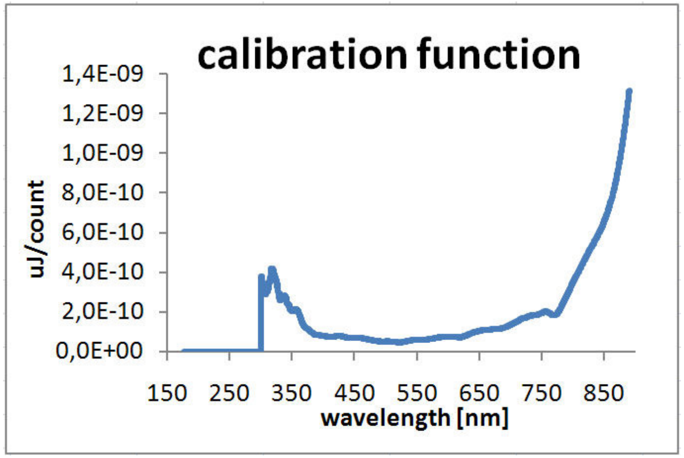
SBSL Spectrum

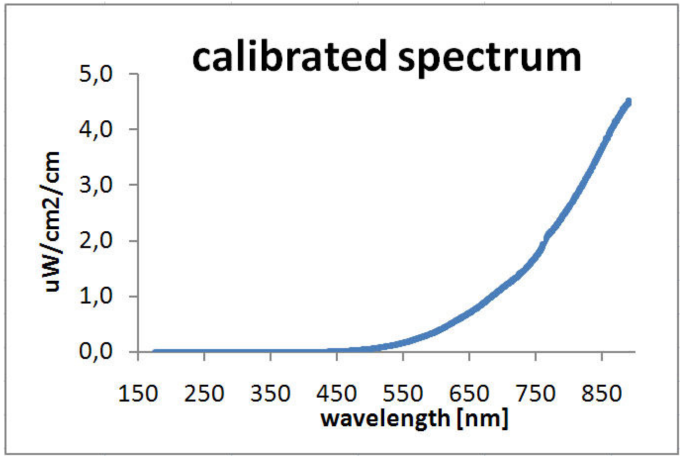
Absolute Spectral Response Calibration



LS-1-CAL Calibration Light Source
spectral range: 300 – 1050 nm
lamp file

DT-MINI-2-GS Deuterium
Tungsten Halogen Light Source
200-410nm D, 360-2000nm TH





SBSL Spectrum
Calibration Verification

- **spectrum of well-known thermal sources**
  - Tungsten filament, Sun, Mon, candle ...

- **Tungsten filament temperature estimation**
  - **Stefan – Boltzman law**

$$T = \sqrt[4]{\frac{P}{A\varepsilon\sigma} + T_0^4}$$

- A – radiation emitting area
  - filament diameter estimation
- P – radiation power (P=U.I)
- ε – emittance (gray body, ε(λ,T)), σ – Stefan Boltzmann constant

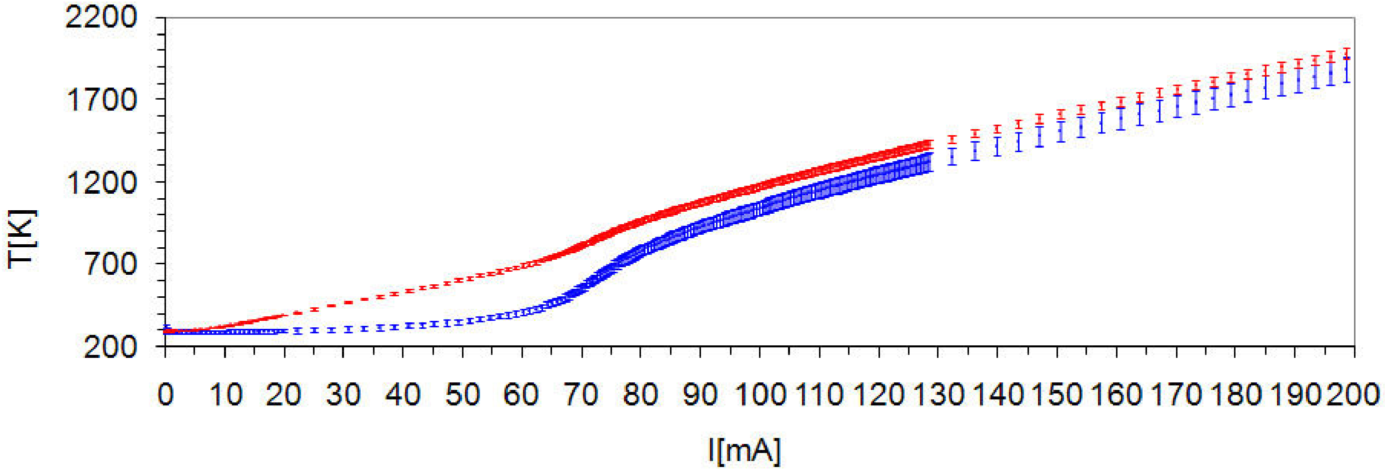
SBSL Spectrum
Calibration Verification

- **tabulated resistance-temperature fit**

  $T = T_0 \left(\frac{R}{R_0} \right)^{\gamma}$ $\gamma = 0{,}82373 \pm 0{,}00003$

- **infrared thermometer**

- **automated Tungsten filament temperature estimator (LabView)**
  - (current & voltage controling and recording, power, temperatures & uncertainities calculating, data saving)



SBSL Spectrum
Calibration Verification

- **absolute temperature**
  - Planck distribution fit (shape)

$$I(\lambda,T)=\frac{2\pi hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}}-1}$$

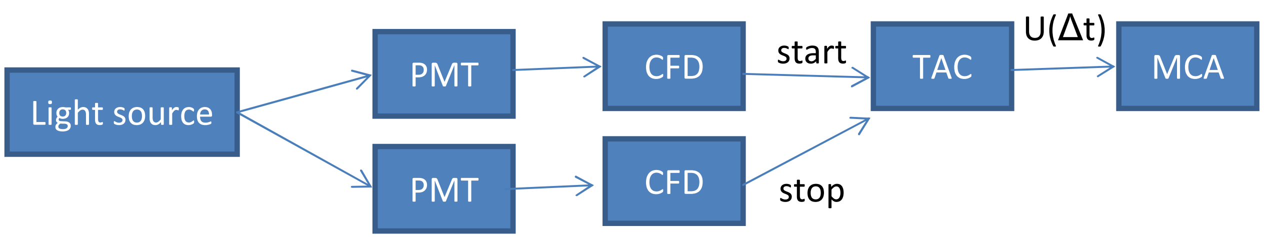
  - peak location (sufficient range)
  - total energy (sufficient range)

- **relative temperature**

$$f(\lambda)=\frac{e^{\frac{hc}{\lambda kT}}-1}{e^{\frac{hc}{\lambda kT_R}}-1}$$

Light Flash Duration
Photon Counting

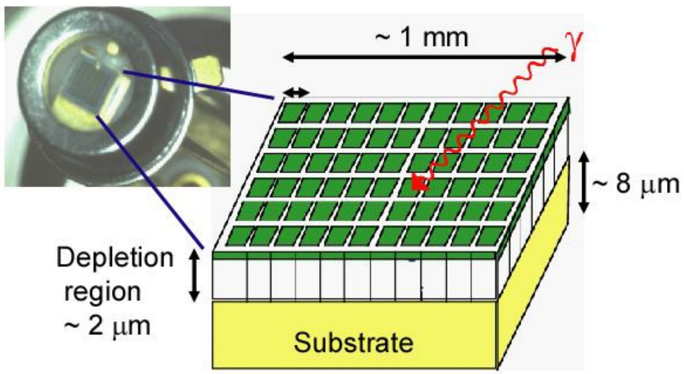
- **Photon Counting**
  - low-light-level measurements (luminescence, fluorescence)
    - incident photons are detected as separate pulses
    - average time intervals between signal pulses are wider than the time resolution of PMT
  - signal stability, detection effeciency, signal-to-noise ratio
  - <100 ps time resolution
  - 2 fast detectors - time difference of signal registration distribution



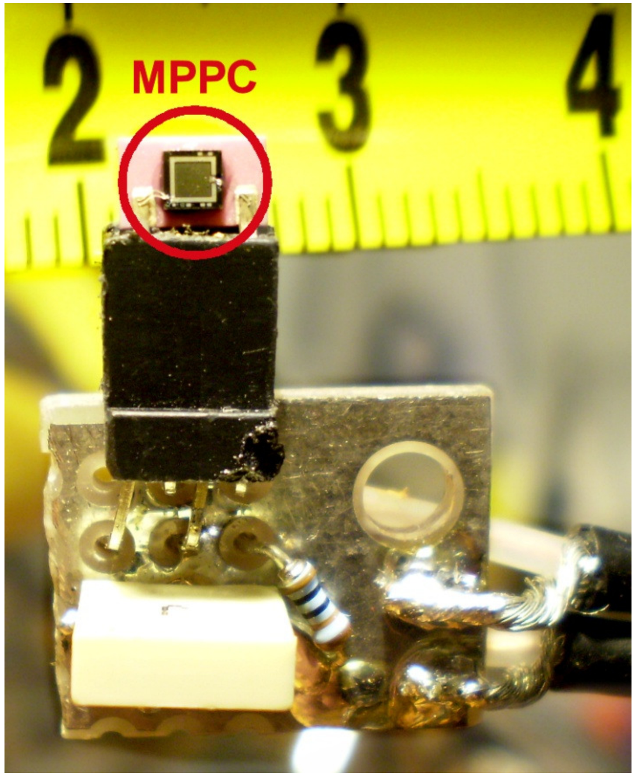
PMT – MPPC, CFD – constant fraction discriminator , TAC – time to amplitude converter, MCA – multichannel analyzer

Light Flash Duration
Silicon Photomultiplier (SiPM)

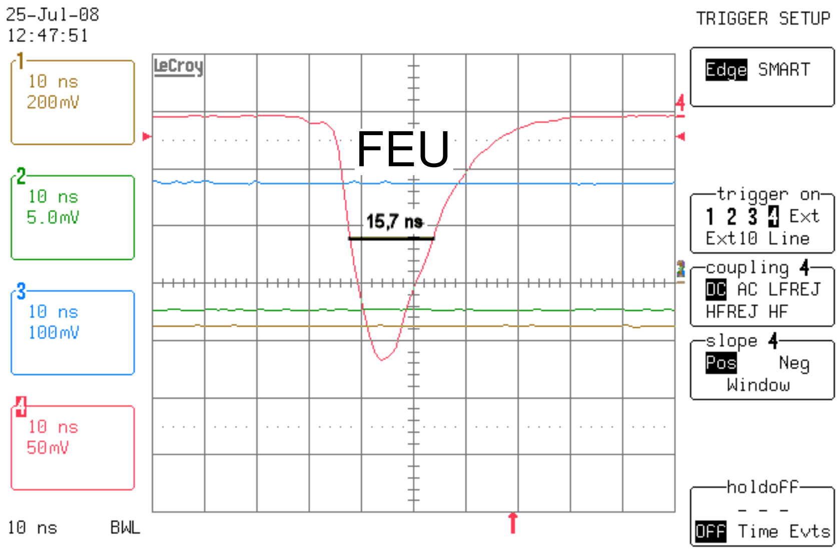
- novel type semiconducting photon senzor
- built from an avalanche photodiode (APD) array on common Si substrate
- sensitive size 1x1 mm^2
- great photon dtection ability
- excellent cost performance
- very compact size

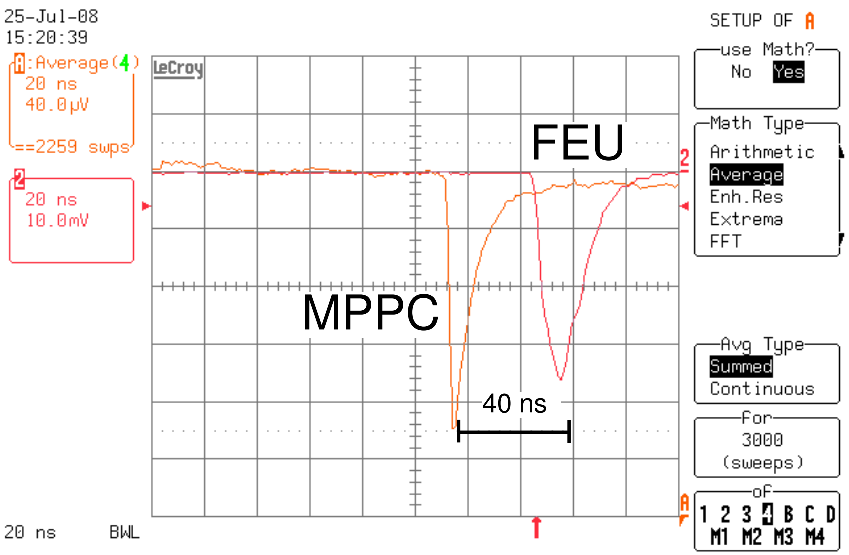


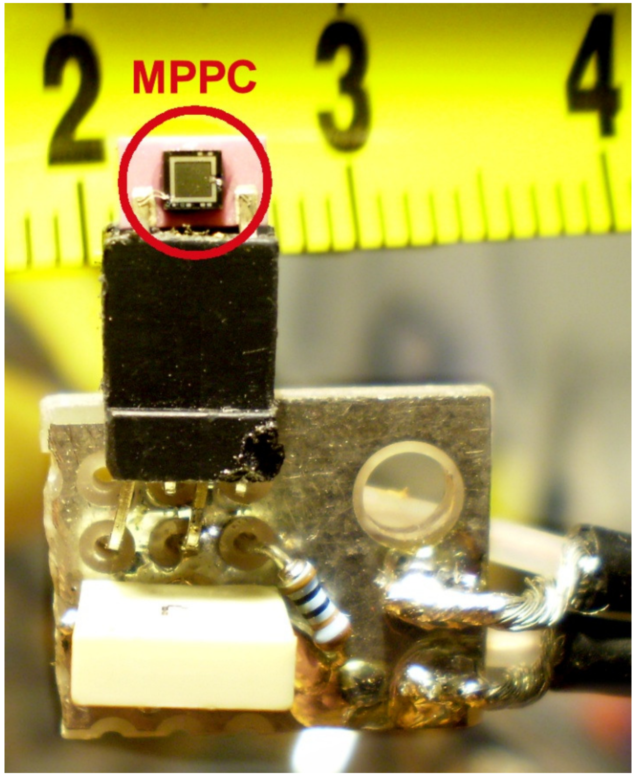
SPMMini PMT



Light Flash Duration

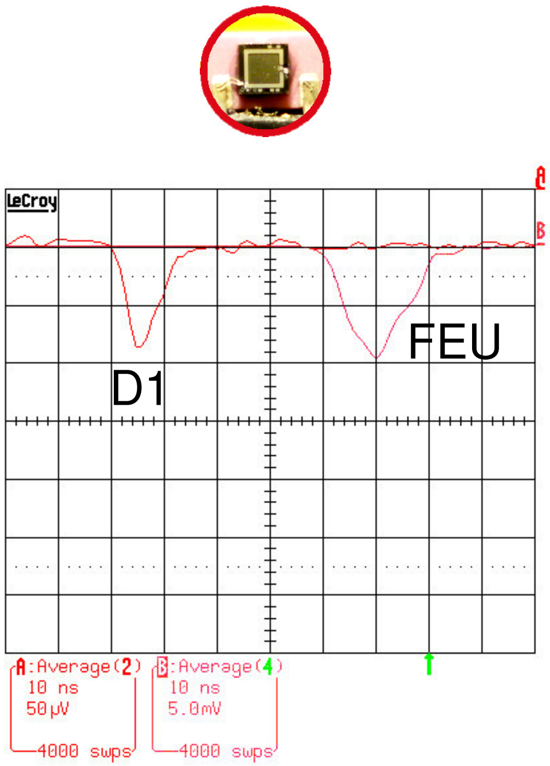


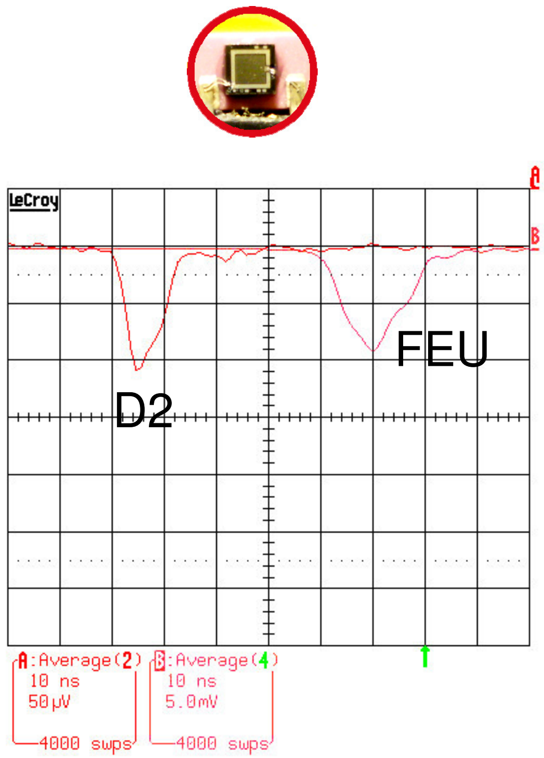


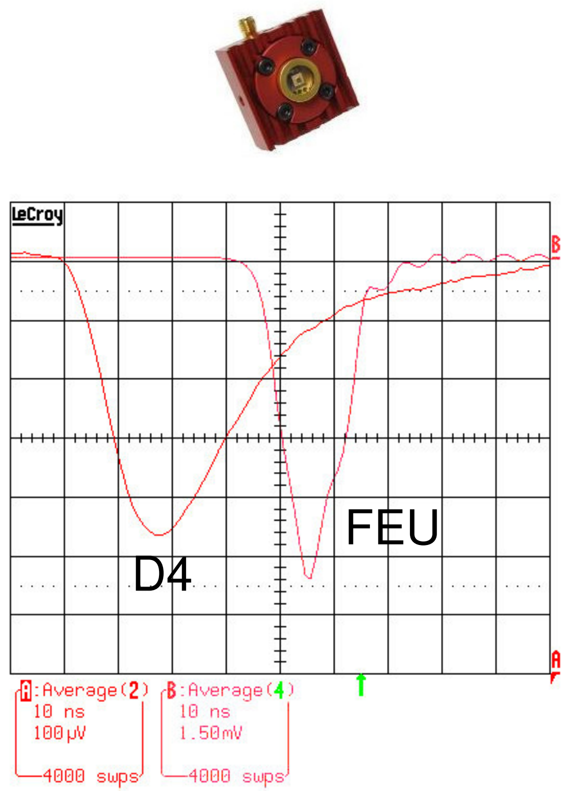


Light Flash Duration

Averaged signal

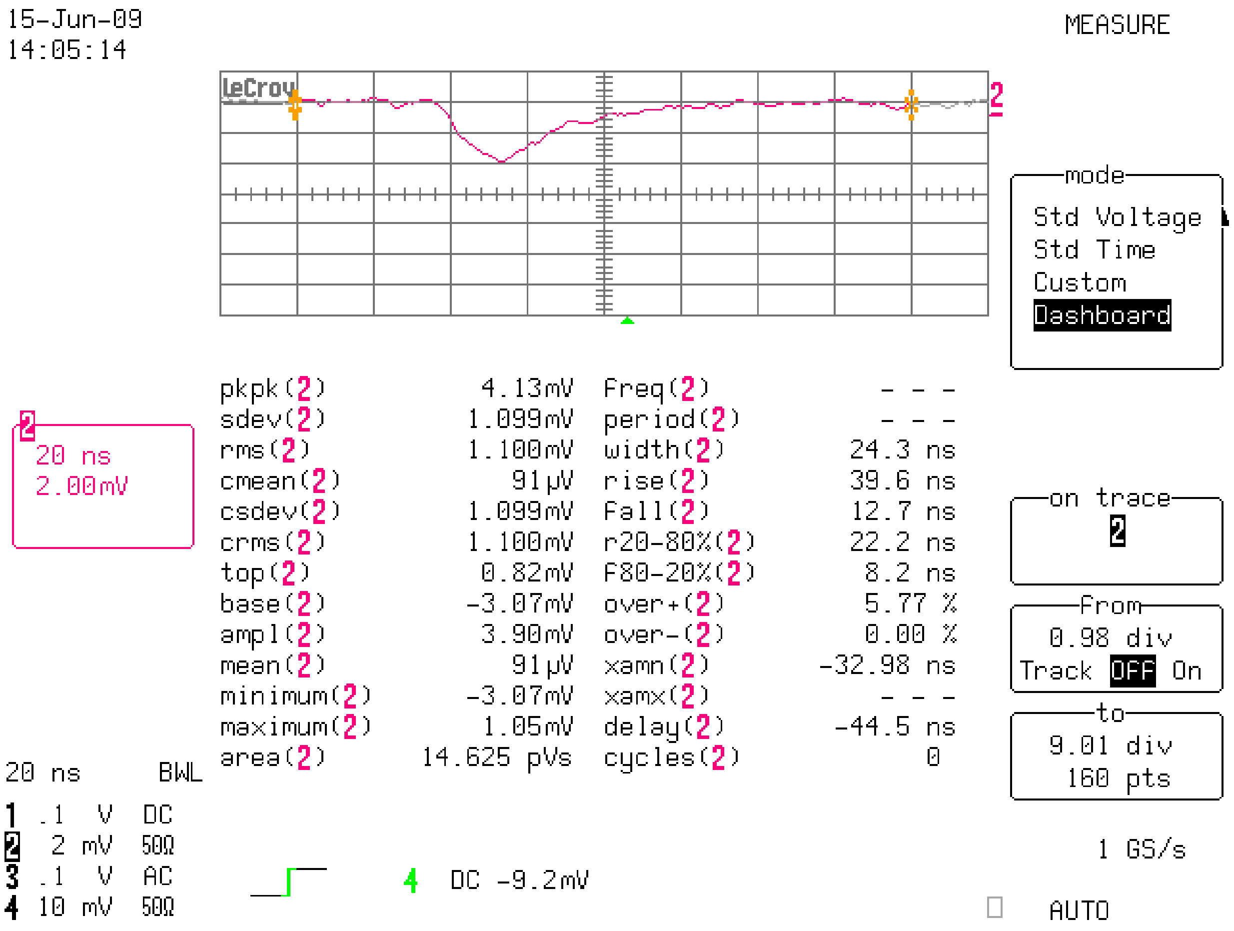




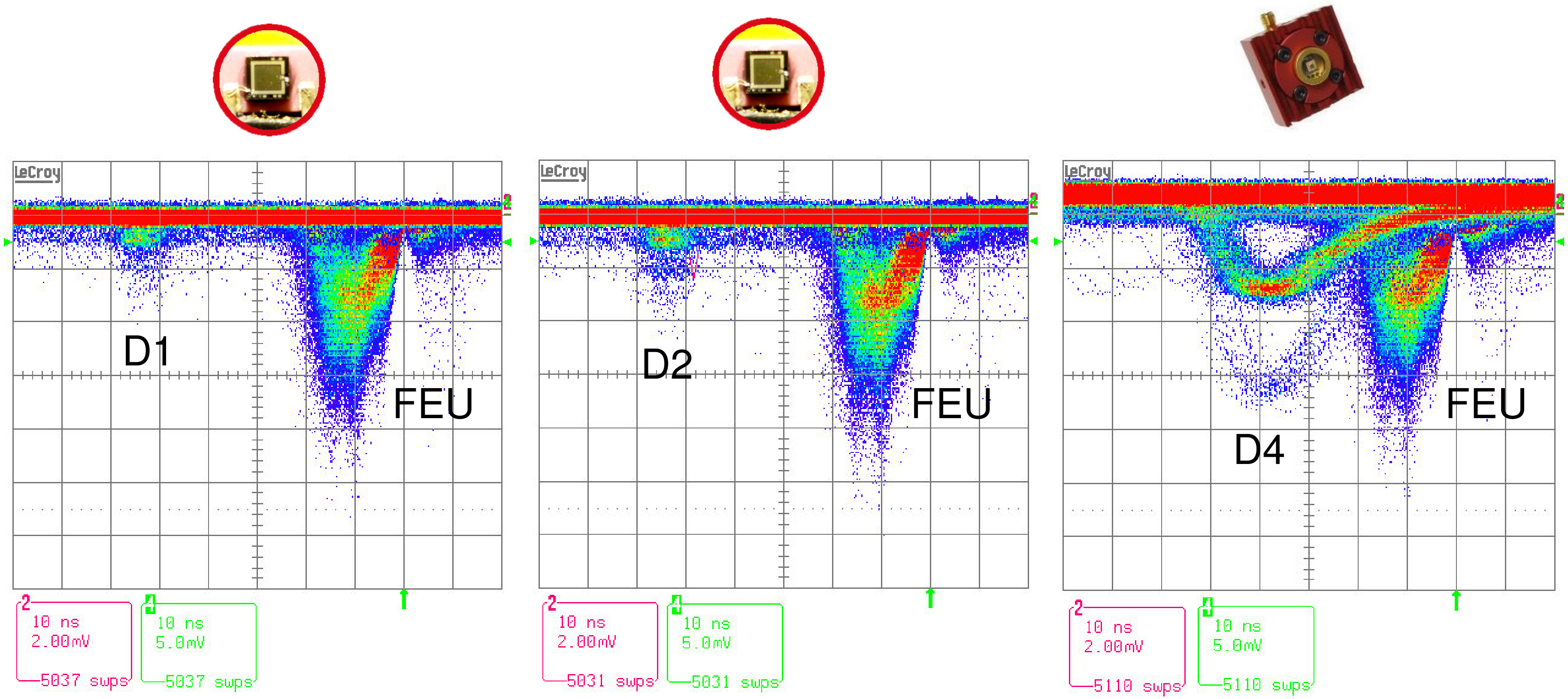


Light Flash Duration

Signal statistic



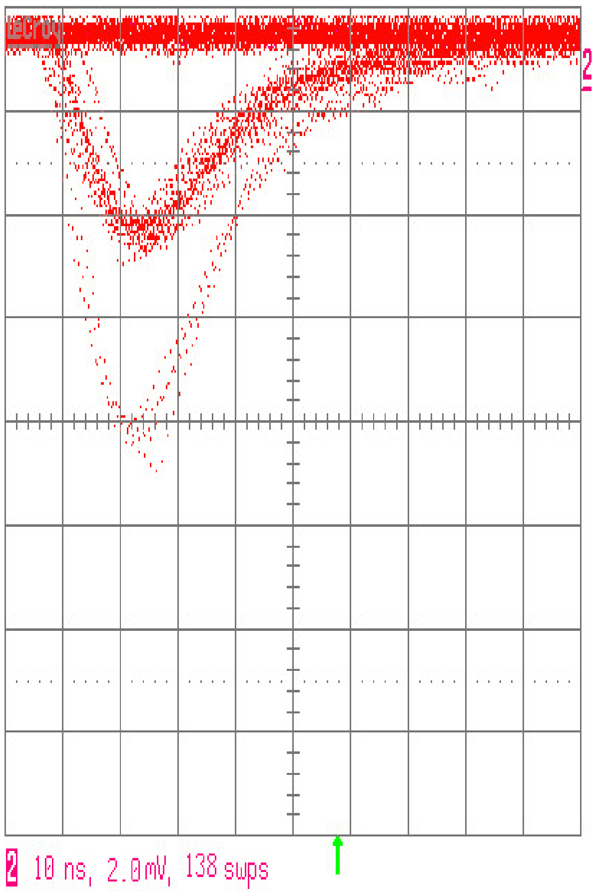
Light Flash Duration
Signal persistence

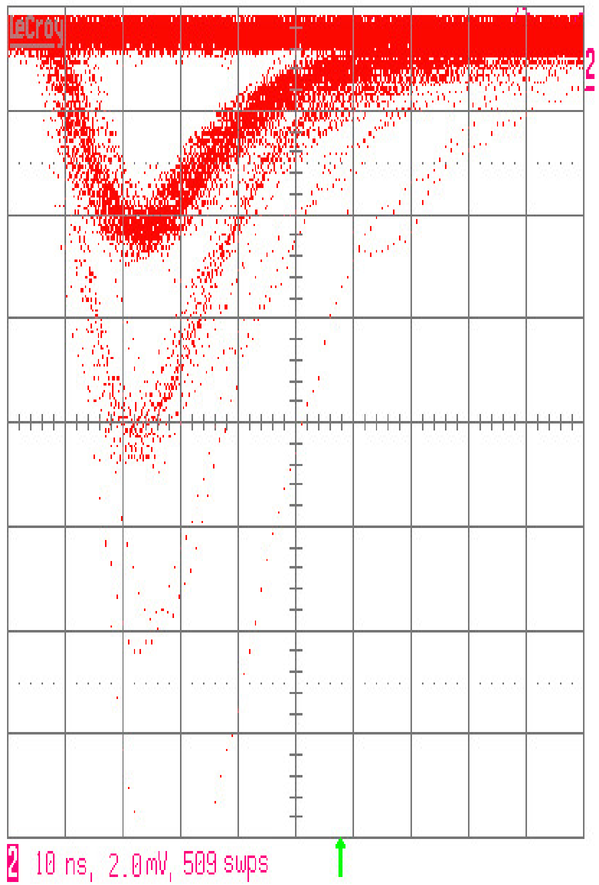


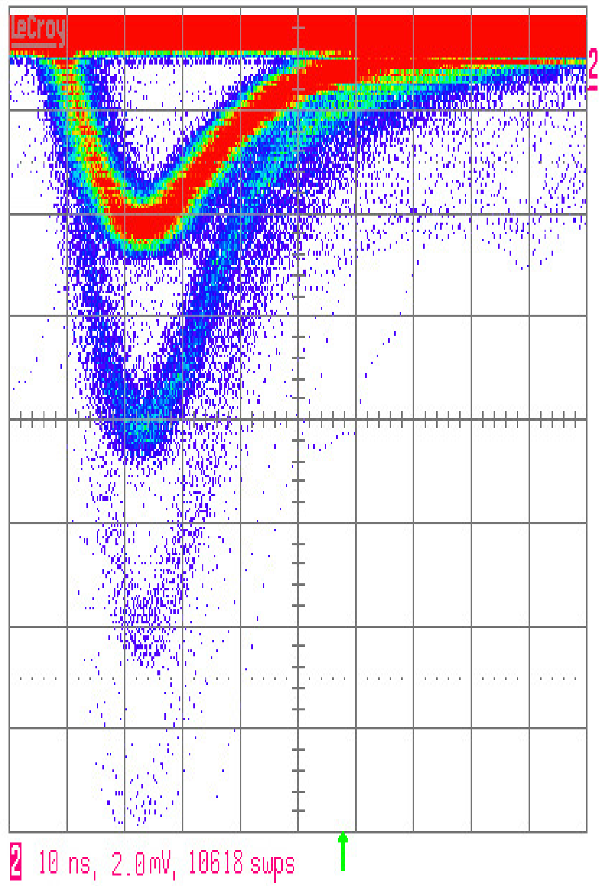
Light Flash Duration

Photon resolution

D4



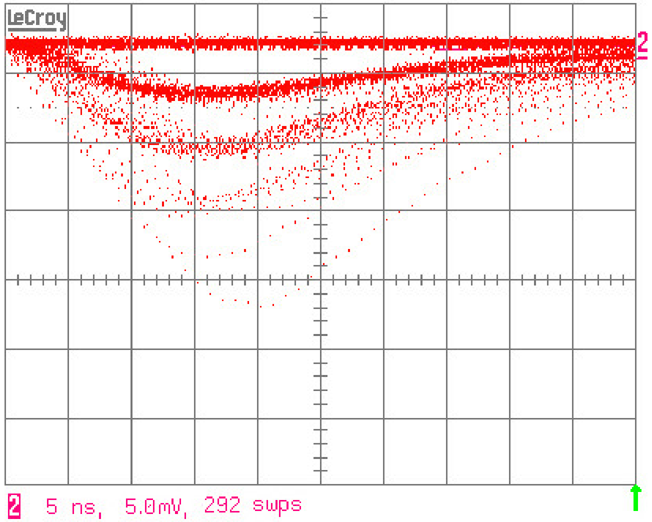


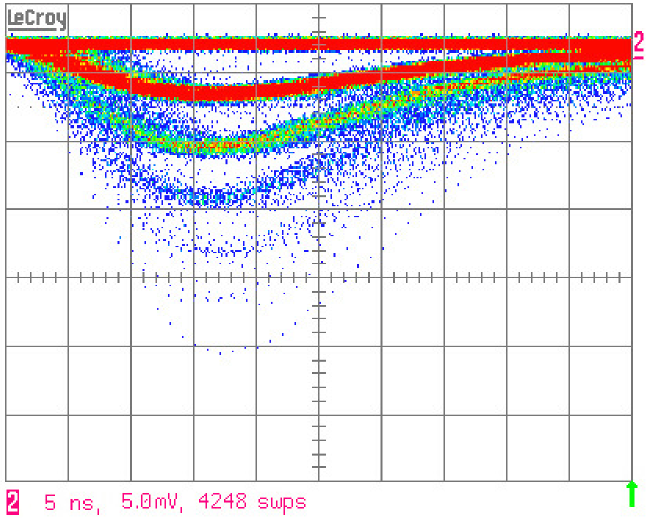


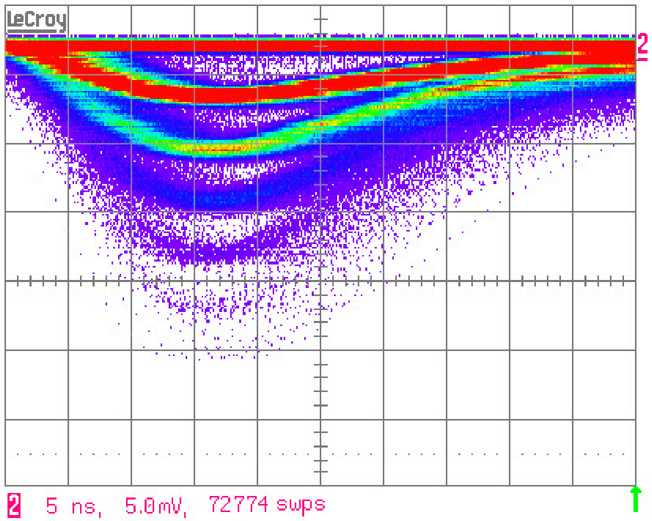
Light Flash Duration

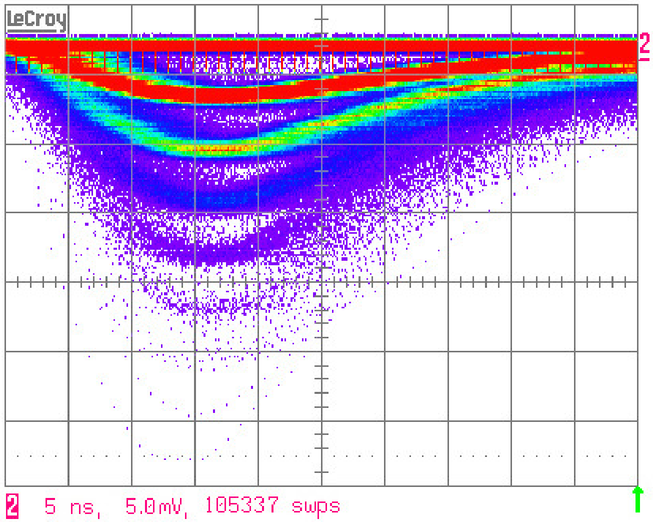
Photon resolution

D4









Conclusion

- **conditions for stable SBSLobservations**
  - experimental apparatus for SBSL creation – done
  - technology of proper conditions for stable SBSL (even hours) - done
  - cylindrical resonator

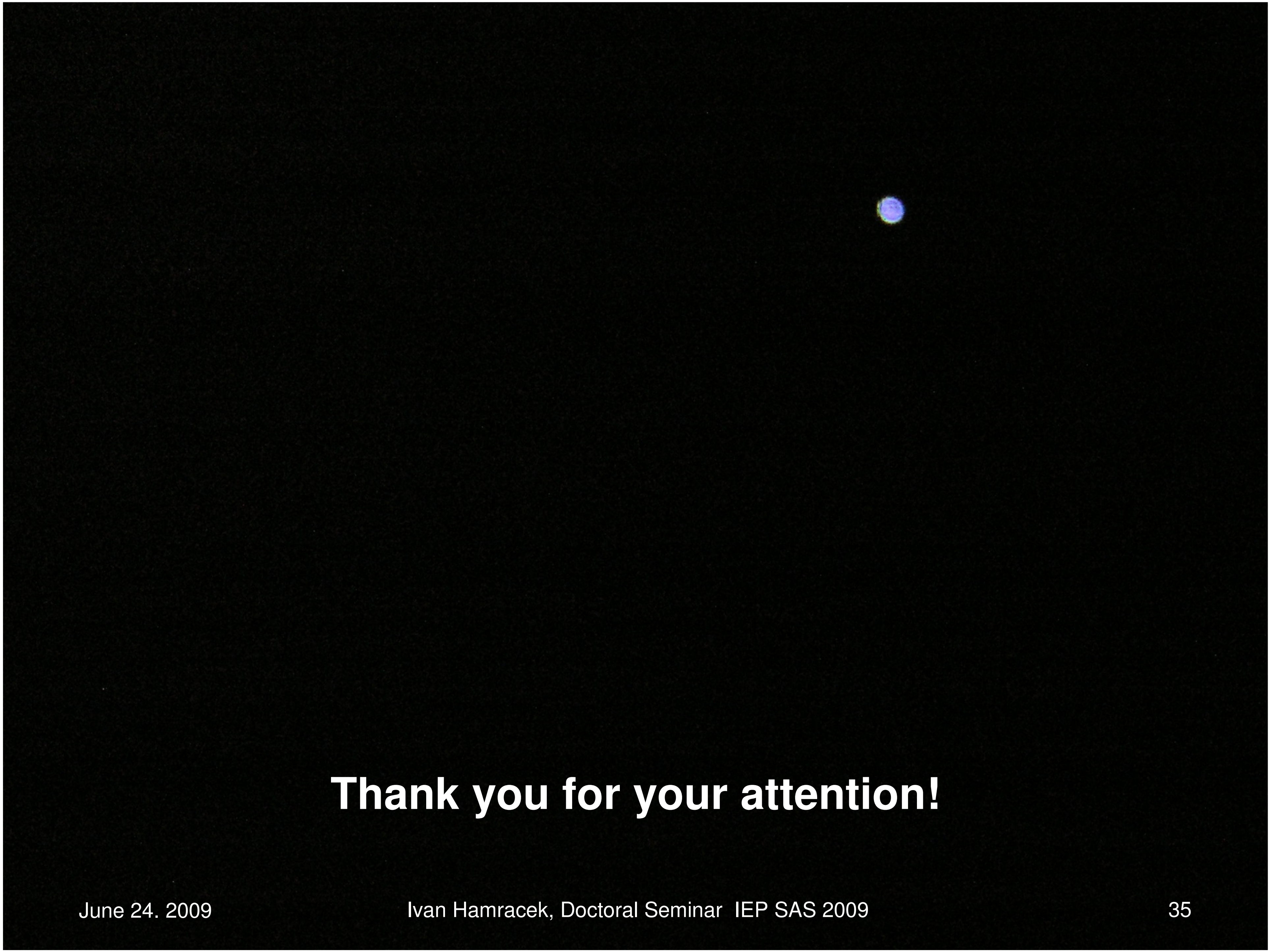
- **SBSL temperature estimation**
  - raw SL spectra - done
  - automated wavelength calibration - done
  - absolute spectral response calibration – done
    - automated tungsten filament temperature estimation – almost done
    - sun, moon temperature
  - medium absorbance analysis
  - suitable optical apparatus construction
  - uncertainities estimation
  - possibility of temperature regulations

Conclusion

- **estimation of flash duration**
  - confirmation of one light flash per one acoustic cycle – done
  - confirmation of flash duration being of couple orders lower than acoustic cycle (PMT) – done
  - flash registration with MPPC (3 bare detectors from Dolgoshein, one comercial with preamplifier and Peltier cooling) – in progress
  - uncertainities estimation

- **diameter measurements**

- **corelations between parameters** (pressure amplitude, temperature, intensity, flash duration)


Thank you for your attention!