Ultra-fast multi-wavelength pyrometer for high temperature measurements at FAIR

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Introduction

Multi-wavelength pyrometry is practically the only way for temperature measurements for Warm Dense Matter.
Ultra-fast multi-wavelength pyrometry allows to measure
- high temperatures up to few kK
- with a temporal resolution up to few ns

in a wide range of applications, from WDM studies at FAIR to the aerodynamic levitation and self-propagating high temperature synthesis experiments.

Methodes

Planck's law

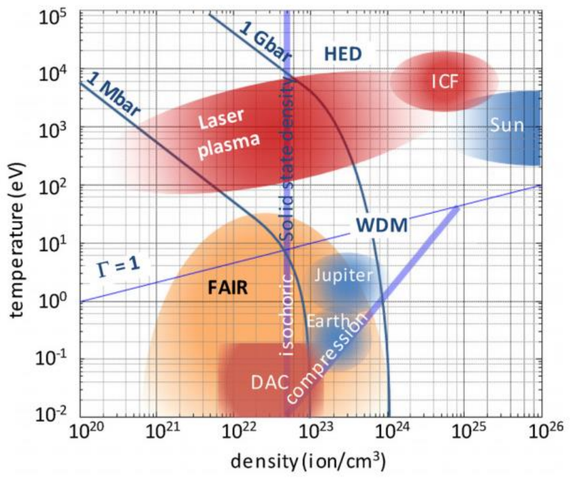
$$I = \varepsilon_{\lambda,T}\frac{C_1\lambda^{-5}}{\exp\left(\frac{C_2}{\lambda T}\right)-1}$$

For $C_2/\lambda T \gg 1$

$$\ln(\lambda^5 I) - \ln(\varepsilon_{\lambda,T}C_1) = -C_2/(\lambda T)$$

In the case of a "grey" body this formula describes a straight line in the coordinates $x = C_2/\lambda$ and $y = \ln(\lambda^5 I)$
The temperature determines the slope of this line.

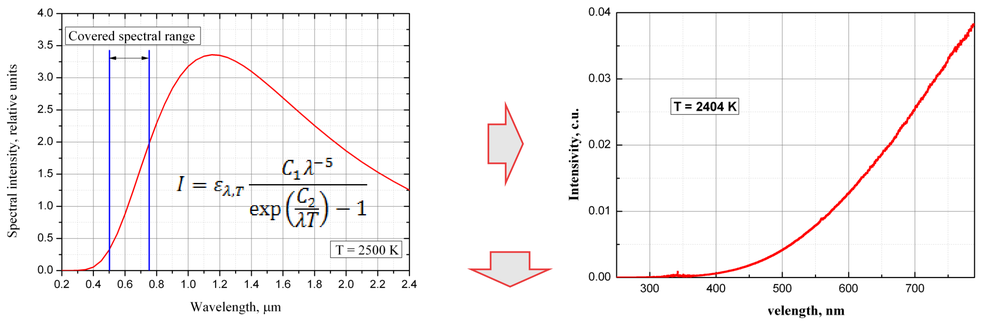
*Magunov A.N. Spectral pyrometry (Review). Instruments and Experimental Techniques, 2009, **52**(4), 451-472



*K. Schoenberg et al., Phys. Plasmas **27**, 043103 (2020)

Main principles of the multi-wavelength pyrometry

Planck's spectrum of a blackbody



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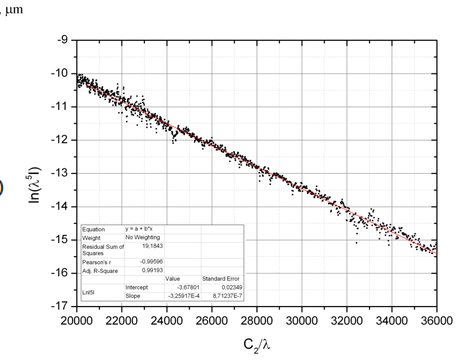
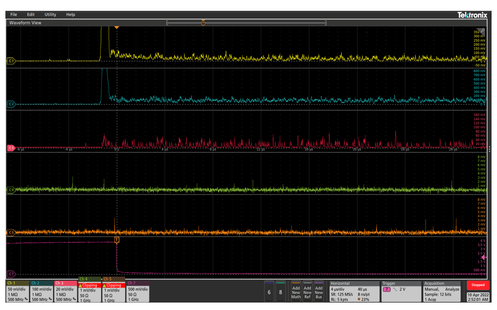
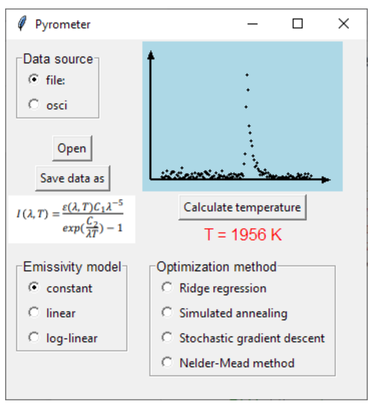


What is the spectral emissivity of WDM at high temperatures?

Experimental results

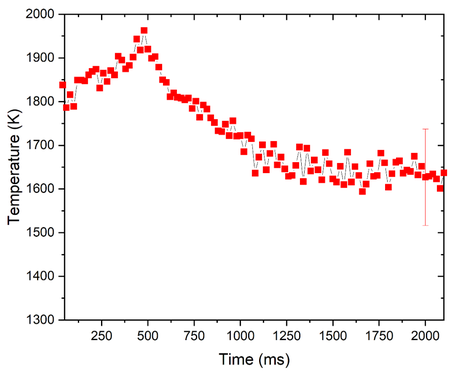
Example of the experimental data for heavy-ion heating of iron foil at GSI

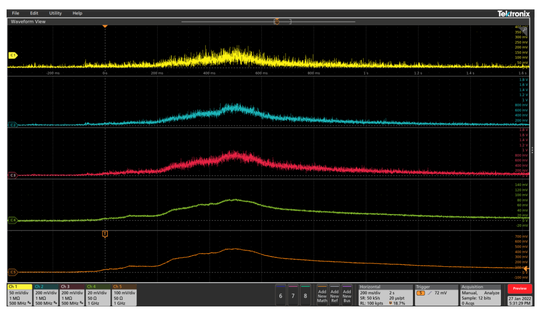




Program for data processing for multi-wavelength pyrometer. Different types of algorithms are possible.

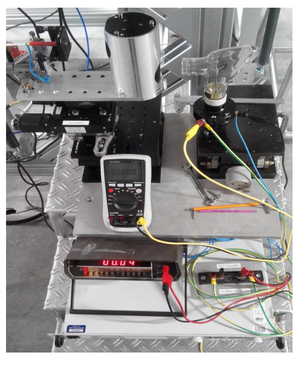
Temperature measurements for the christmas sparkler



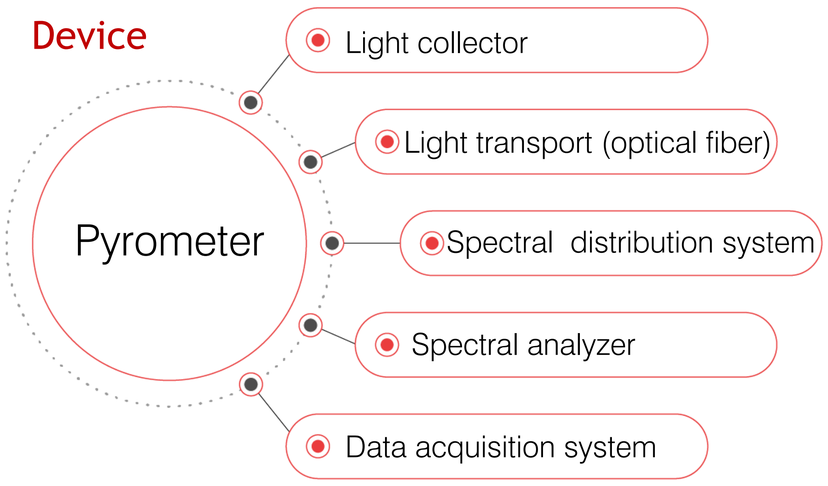


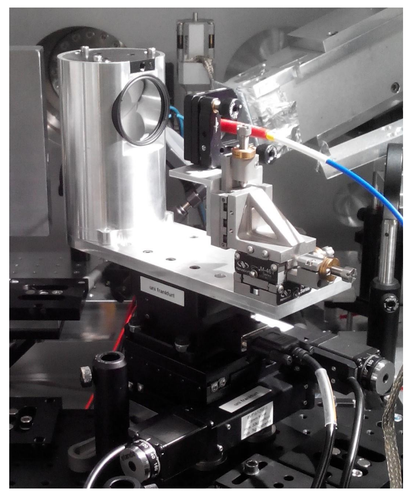
Calibration procedure

1. Calibration of pyrometer via tungsten filament pyrometrical lamp at one wavelength (650 nm).
2. Calibration of pyrometer over all spectral range via blackbody model.
3. Total calibration of spectral pyrometer using data for pyrometrical lamp and blackbody model with high accuracy



Device



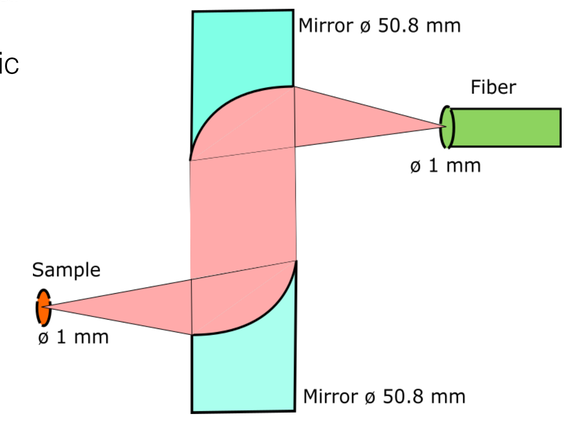


Scheme and main parts of the device

Photo of the light collecting system inside the experimental chamber at HHT area of GSI

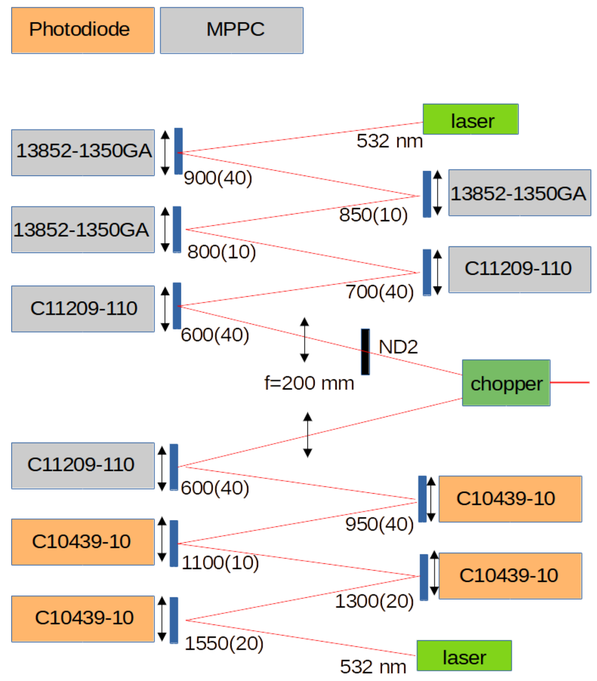
Light collector → Reflecting → Spherical / Parabolic; Refracting

Optical fibers → Low OH VIS-NIR
Ø 100 μm, 200 μm, 400 μm, 600 μm



Off-axis parabolic mirror optical focusing system

Spectral discrimination → Diffraction grating / Prism / Diffraction filters



Detectors:
— 3 MPPC C13852-1350GA ('fast' leg)
— 3 MPPC C11209-110 ('fast' and 'slow' legs)
— 4 Diodes C104209 ('slow' leg)

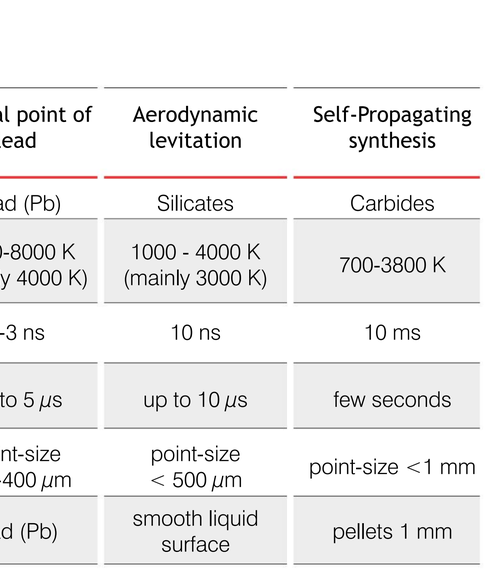


Photo of the spectral analyzation and distribution system

For data acquisition Oscilloscope Tektronix MSO-85 is used. It has 8-channels, 1 GHz bandwidth, 6.25 GS/s sample rate, 62.5 Mpoints record length and 12-bit resolution.

List of experiments

Experiment	Phase transitions in iron	X-ray absorption spectroscopy on aluminum above melting	Critical point of lead	Aerodynamic levitation	Self-Propagating synthesis
Sample material	Iron (Fe)	Aluminum (Al)	Lead (Pb)	Silicates	Carbides
Temperature range	1000-1500 K	800-1200 K	1500-8000 K (mainly 4000 K)	1000 - 4000 K (mainly 3000 K)	700-3800 K
Temporal resolution	10-20 ns	few μs	2-3 ns	10 ns	10 ms
Total duration of temporal record	heavy-ion heating ~ 500 ns duration	few ms	up to 5 μs	up to 10 μs	few seconds
Measurement spot size	200 μm spot	point-size < 100 μm	point-size 200-400 μm	point-size < 500 μm	point-size <1 mm
Surface properties	flat foil made of iron (Fe)	flat foil made of aluminum (Al)	lead (Pb)	smooth liquid surface	pellets 1 mm

Conclusions

For temperature measurements during fast processes a universal multi-wavelength pyrometer is being build.
This new pyrometer uses simultaneously 5 wavelengths from 600 to 1550 nm and different types of detectors, such as photodiodes and two different types of Multi Pixel Photon Counters (MPPC).
This allows one to measure the temperature in a broad temperature range up to a few thousand Kelvins with high temporal resolution up to nanoseconds.

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