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Near infrared hyperspectral imaging – background and application for wood characterization

A. Zitek[1], K. Böhm[1], F. Firtha[2], V. Parrag[2], B. Hinterstoisser[1]

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2nd Workshop on application of NIR spectroscopy for wood science and technology research

NIR & WOOD – SOUNDS GOOD! #2

April 19-21, 2016
CNR-IVALSA, Via Biasi 75, 38010 San Michele all' Adige, Italy

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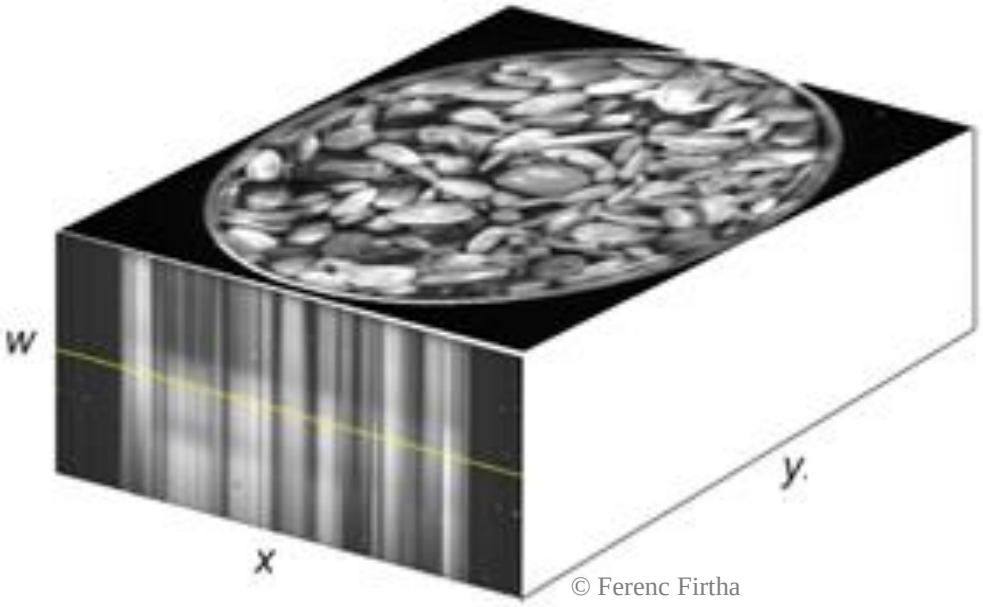
Content

- My personal contact history with HSI
- General background
- Technical information
- First results
- General workflow
- Analytical challenges



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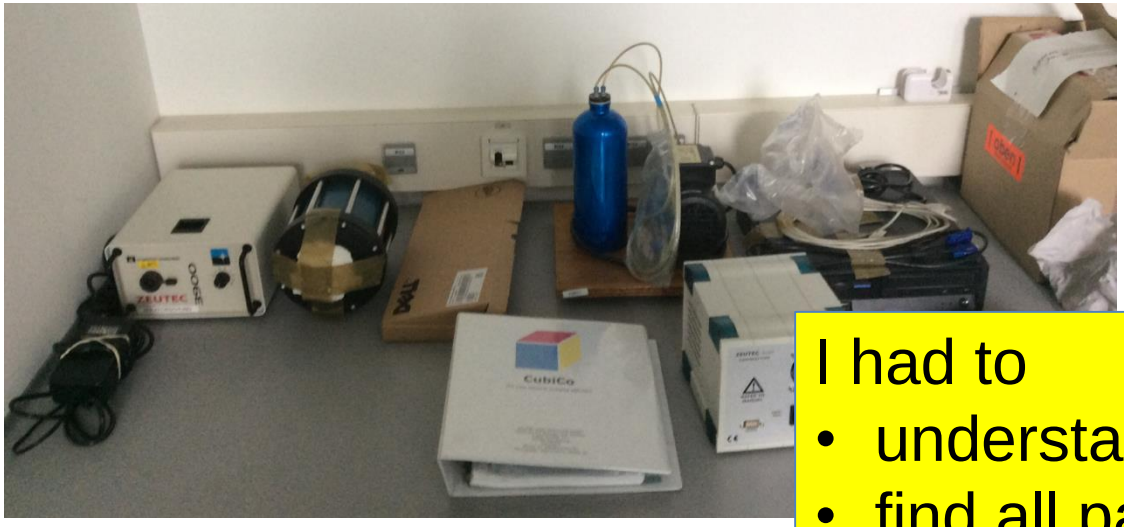
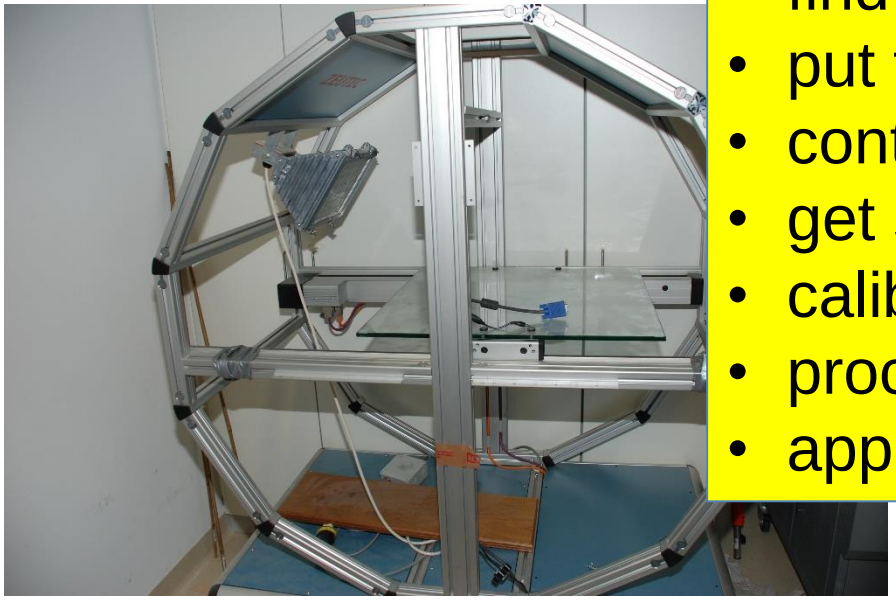
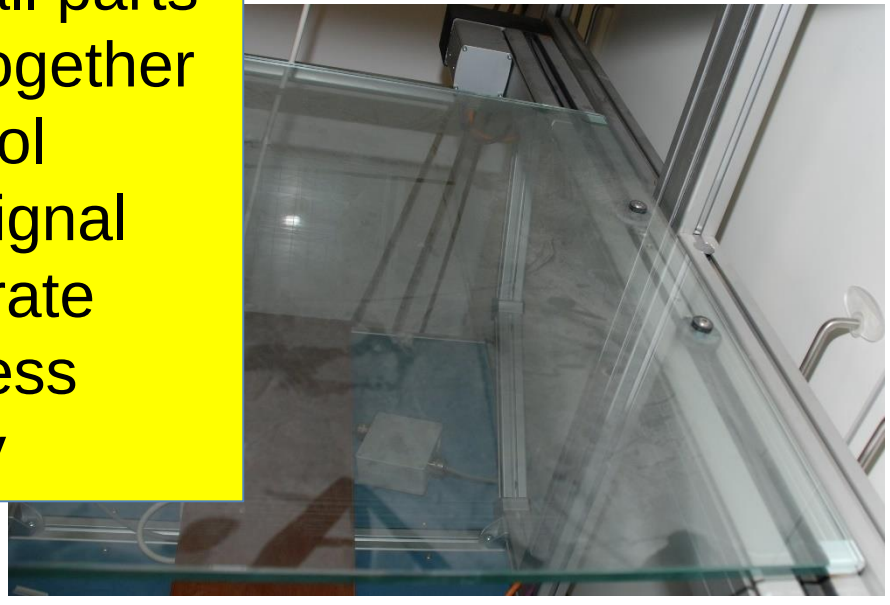
My first contact…



I had to

- understand
- find all parts
- put together
- control
- get signal
- calibrate
- process
- apply





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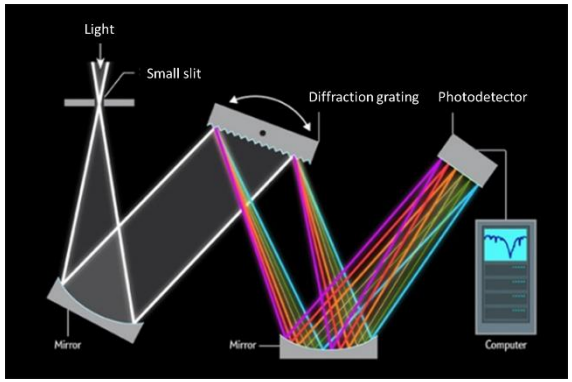
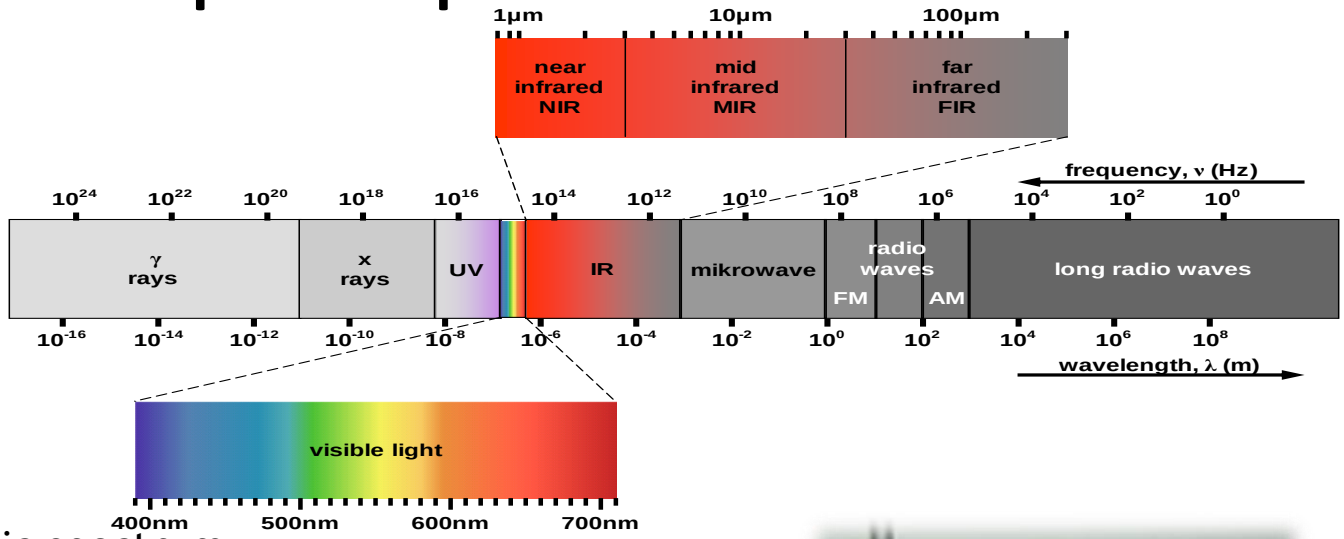
Spectral sensing – principles

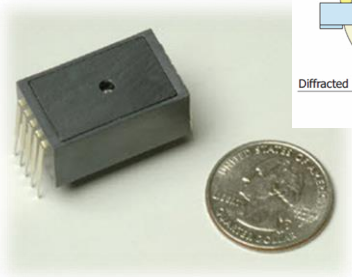


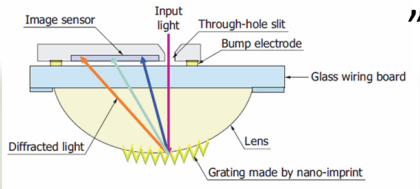


- Part of the electromagnetic spectrum
- Visible light~ 390-700 nm
- Near infrared~ 780 nm and 3 µm

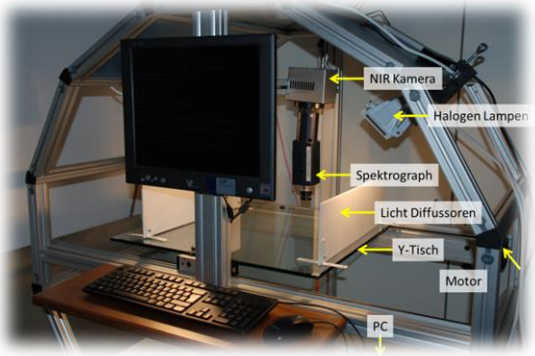
„Classical“ FT-NIR with fibre probe

Mini Sensors





„Hyperspectral“ Imaging



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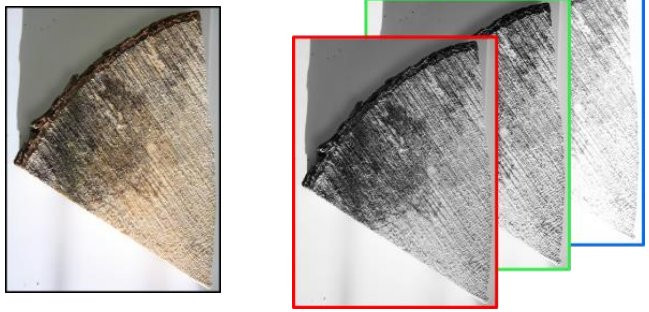
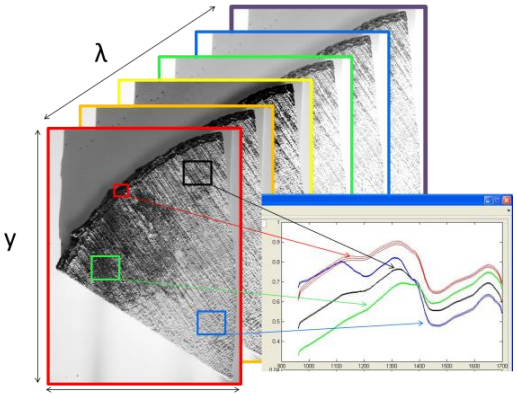
Difference RGB, multi- und hyperspectral

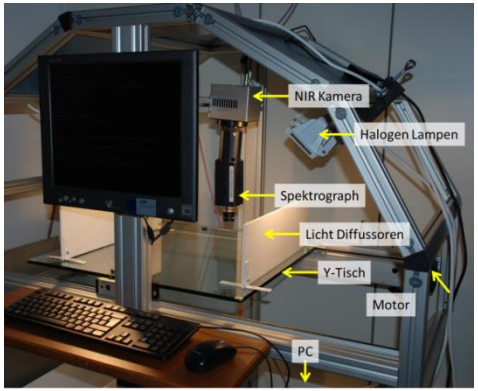


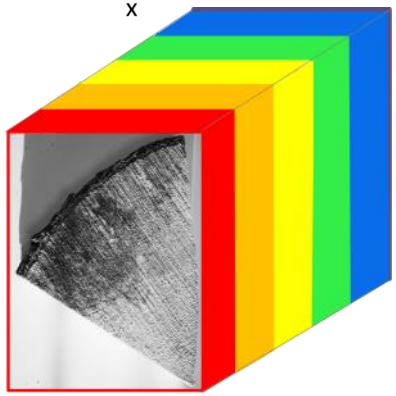
RGB: 3 wavelengths

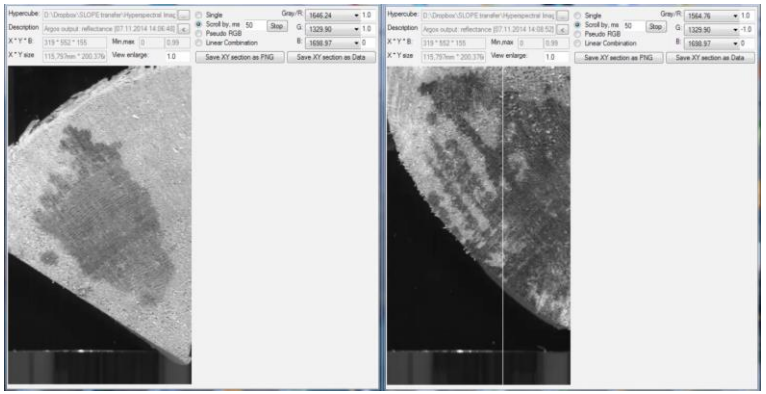


Multi: 4-10 wavelengths

Hyper: 100 wavelengths
quasi continous (in nm steps)

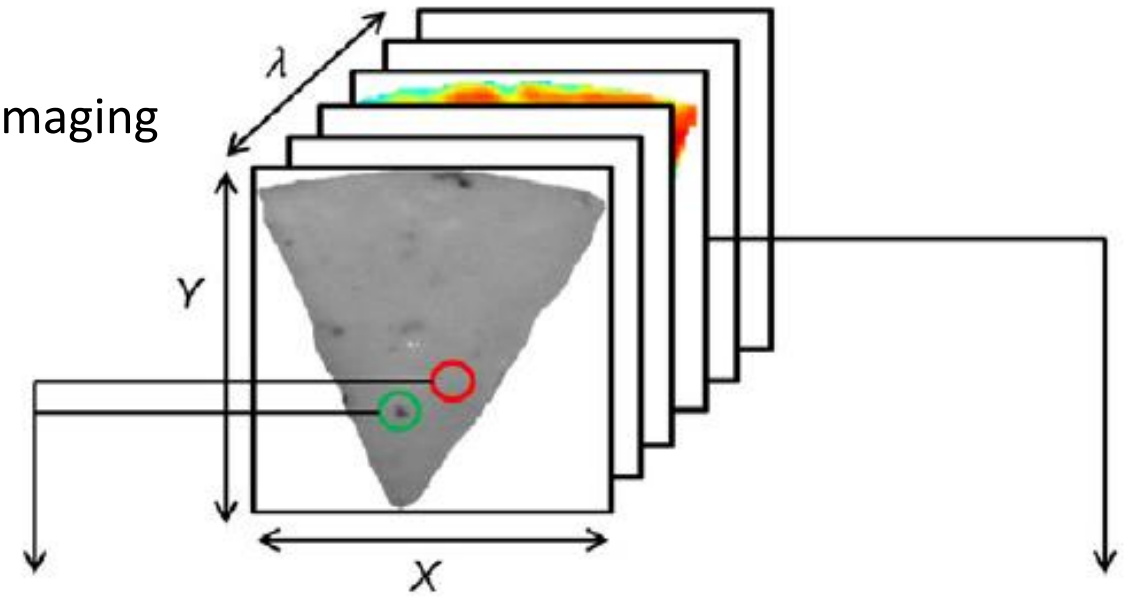






Hyperspectral Imaging

Combination of spectroscopy with Imaging



Pixel spectra

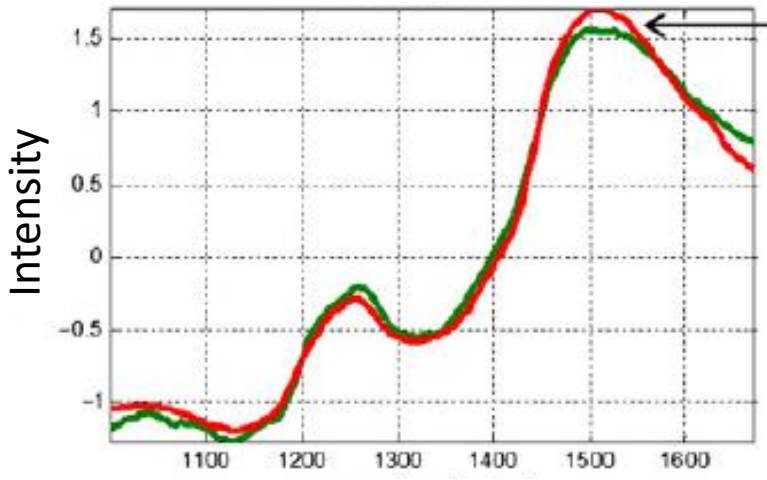
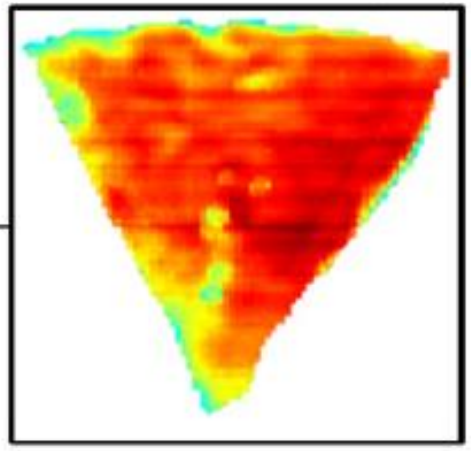
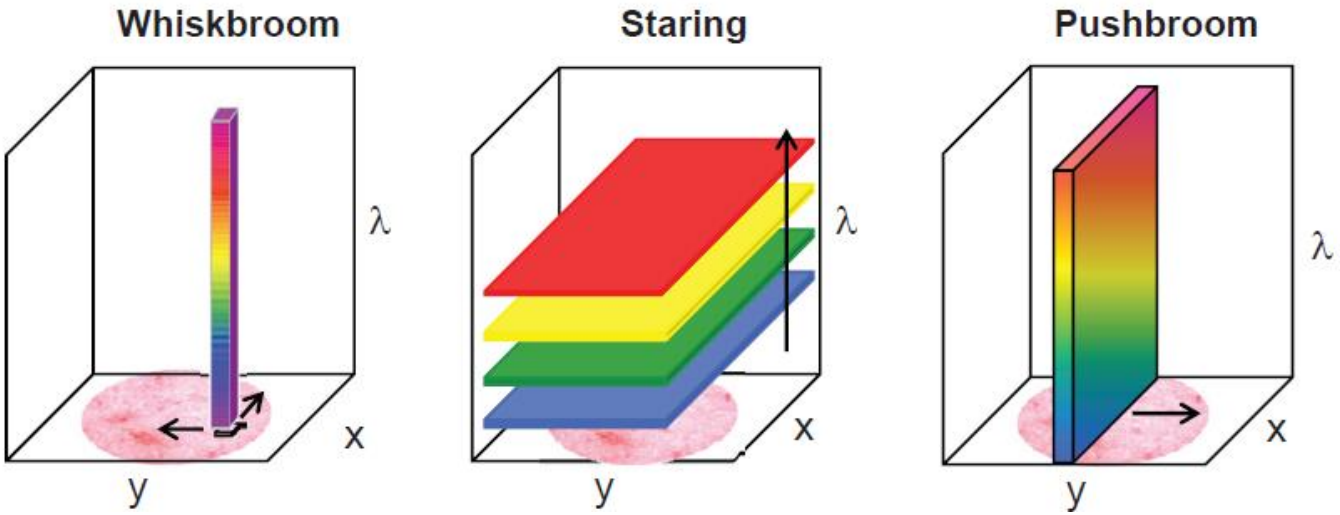


Image at wavelength λ



Duchesne *et al.* 2012

HSI – general setups



From: BOLDRINI, B., KESSLER, W., REBNER, K. & KESSLER, R. W., 2012. Hyperspectral imaging: a review of best practice, performance and pitfalls for inline and online applications. Journal of Near Infrared Spectroscopy, 20 (5): 438-508.

- **Whiskbroom imaging** : During whiskbroom imaging the sample is scanned pixel per pixel in the x-y-spatial direction in a sequential manner.
- **Staring (staredown) imaging:** Staring imaging is done by a two-dimensional camera capturing the spectral information in each pixel x-, y-plane at once.
- **Pushbroom imaging:** Pushbroom imaging as a line scanning system acquires the information for each pixel in the line at once.

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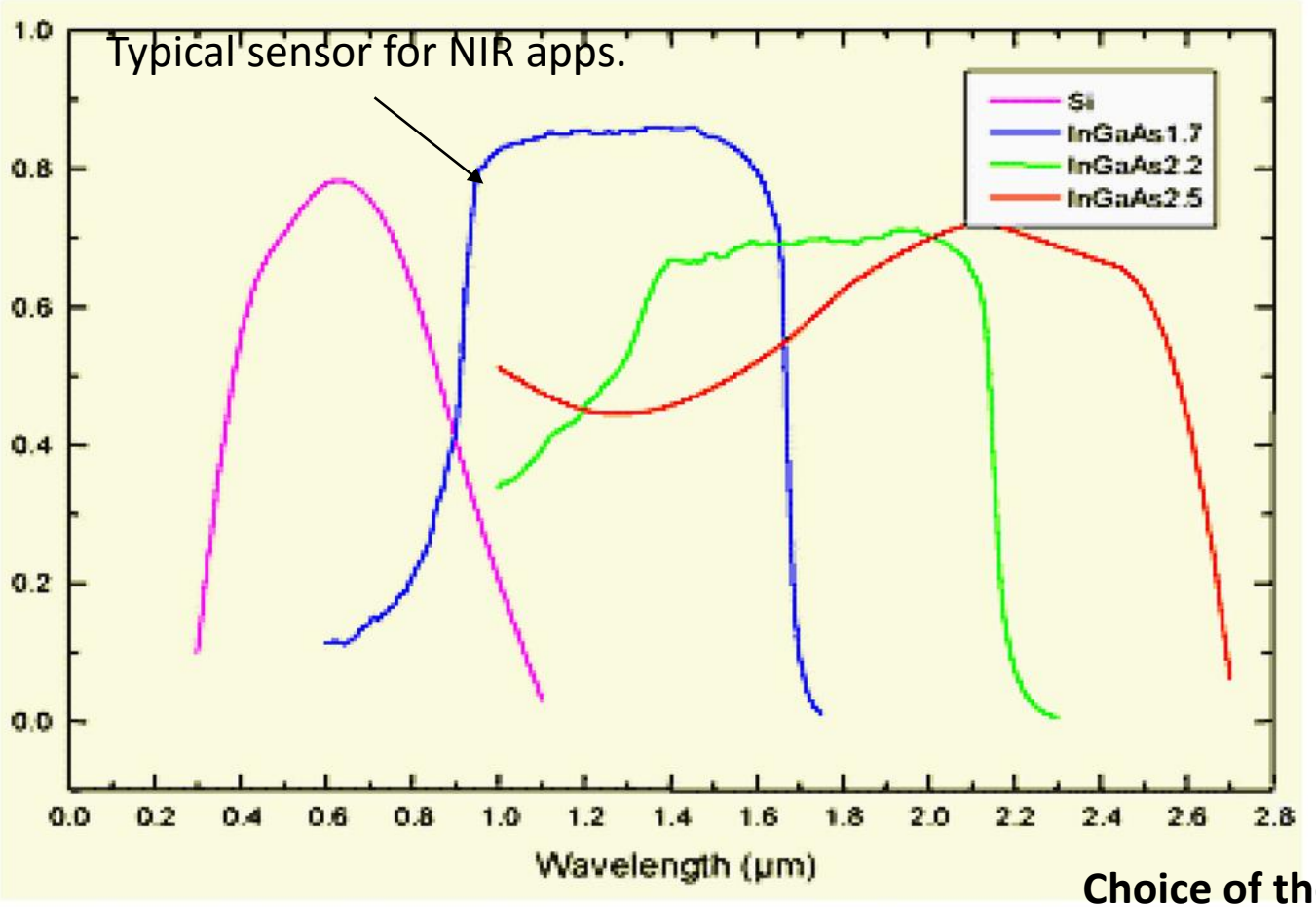
Sensor types

– and their sensitivities in different wavelenght ranges



Sensor types

- silicon (Si)-based charge-coupled device (CCD)
- complementary metal oxide semiconductor (CMOS) cameras,
- **indium gallium arsenide (InGaAs)-based array detectors,**
- mercury cadmium telluride (HgCdTe)-based array detectors.

Choice of the sensor depends on:

- the required wavelength,
- the quantum efficiency = sensitivity,
- and the cost.

Hui Huang, Li Liu and Michael O. Ngadi (2014) Recent Developments in Hyperspectral Imaging for Assessment of Food Quality and Safety, Sensors 14, 7248-7276

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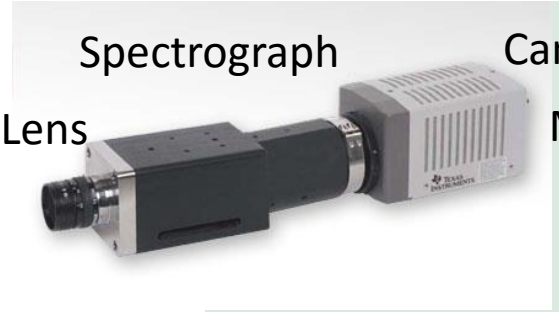
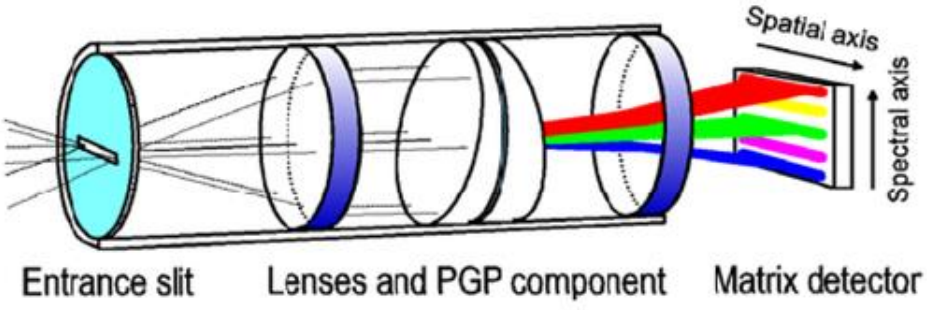
Pushbroom spectrograph and camera





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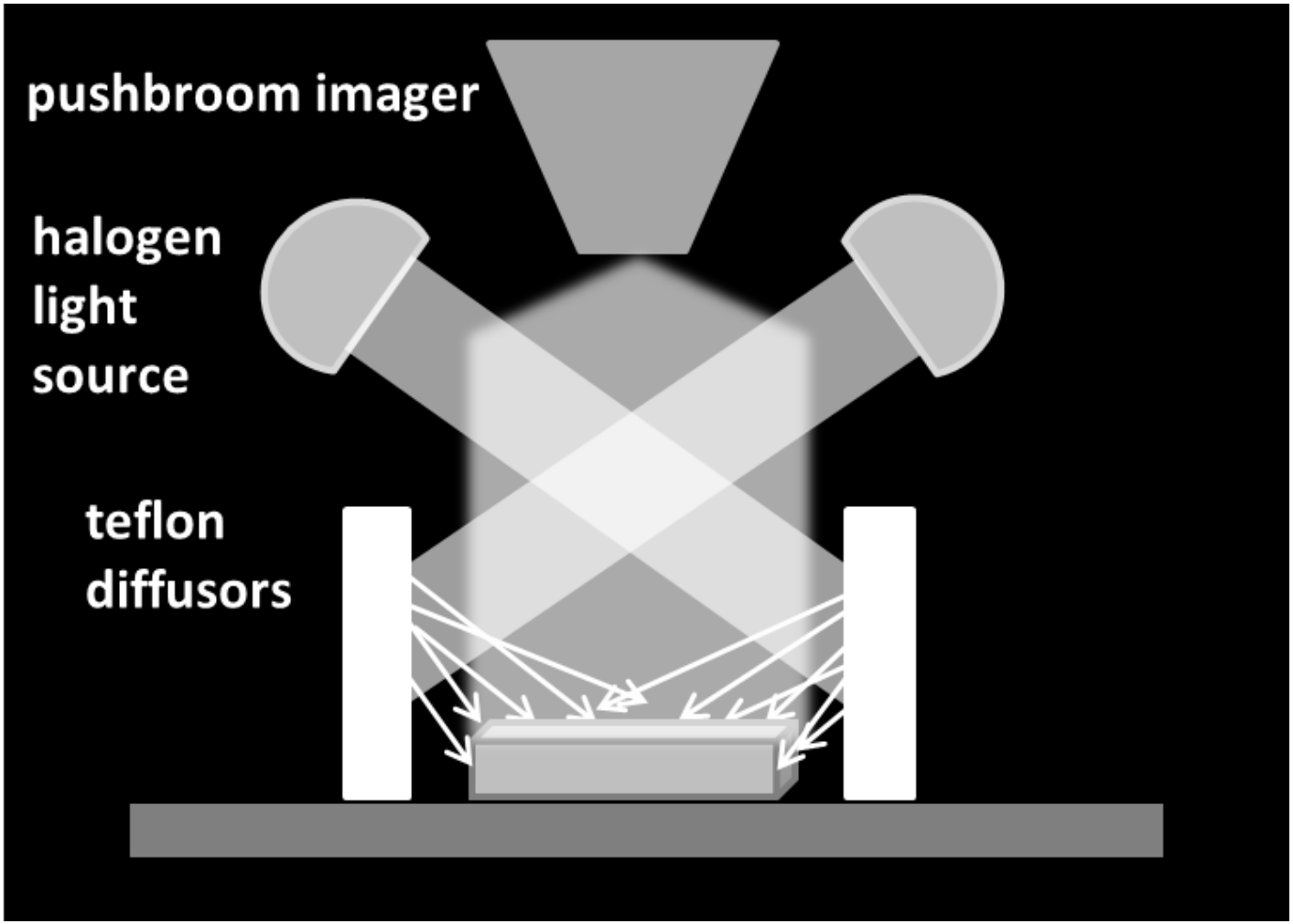
Lighting („spectral input“) for NIR imaging



(after Boldrini *et al.* 2012).

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Software for imaging and analysis

ARGUS data aquisition software

F. Firtha, Argus hyperspectral acquisition software, ftp://fizika2.kee.hu/ffirtha/Argus-CuBrowser.pdf, (2010)

Cubrowser data browsing and pre-processing software

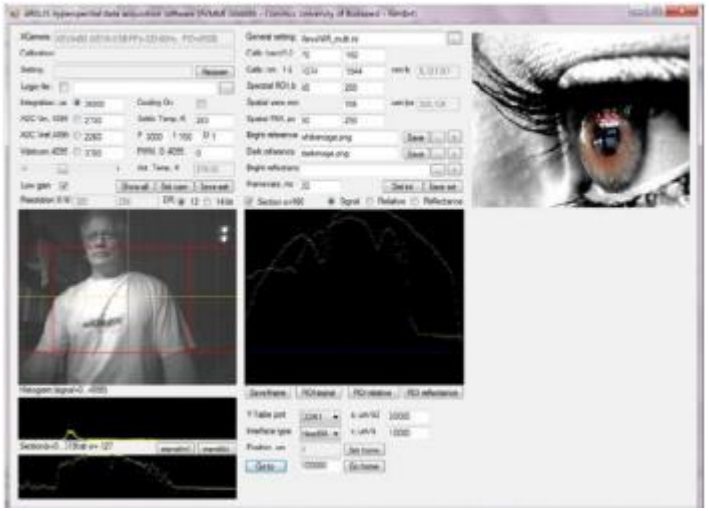
F. Firtha, CuBrowser hyperspectral data processing algorithm ftp://fizika2.kee.hu/ffirtha/Argus-CuBrowser.pdf, (2012).

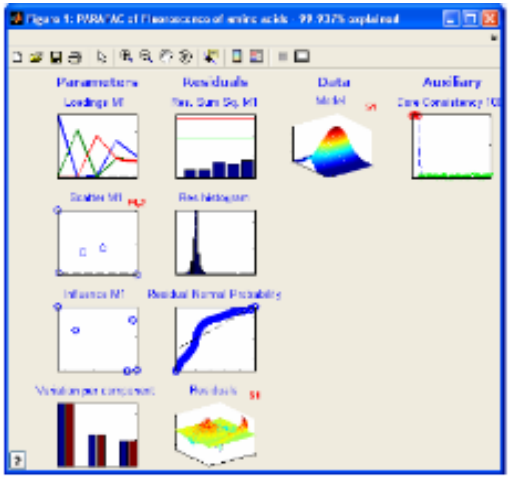
Eigenvector: PLS_toolbox, MIA, Model_exporter

Evince Software (Prediktera)

BRUKER: OPUS

CAMO: Unscrambler





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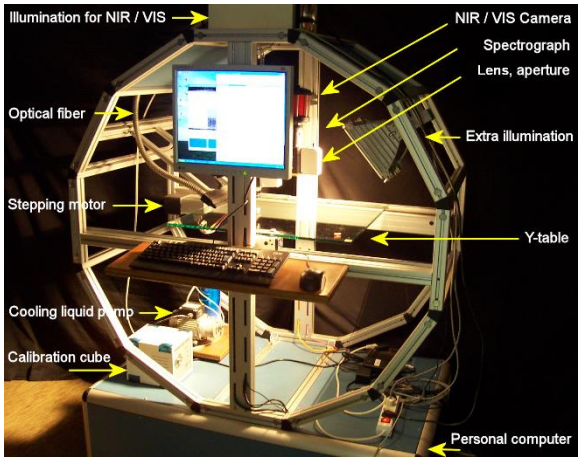
First „trials with old system“

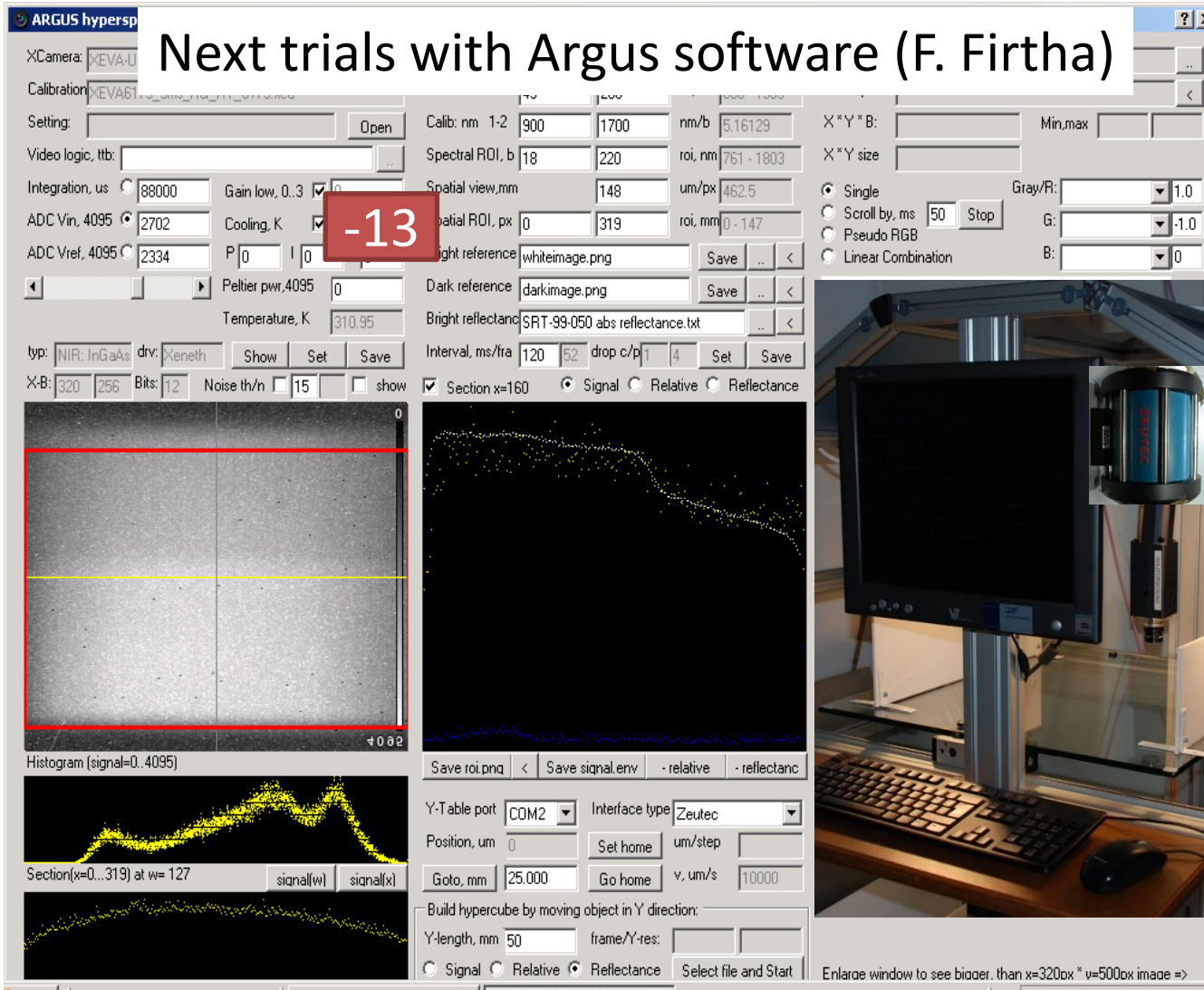
Original „ ZEUTEC“ Cubico Software – not working

„Sister system“
in Hungary,
Corvinus University



Firtha, F., Fekete, A., Kaszab, T., Gillay, B., Nogula-Nagy, M., Kovács, Z. & Kantor, D.B. (2008) Methods for improving image quality and reducing data load of NIR hyperspectral images. *Sensors*, **8,** 3287-3298.

Next trials with Argus software (F. Firtha)



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Exchange of camera and transfer of sensor

Xenics NIR camera Xeva-USB-FPA-1.7-320-TE1-100Hz camera with an InGaAs focal plane array sensor with 2% pixel noise –
XEVA 6179; 0.9 µm to 1.7 µm; 320*256 pixel matrix; 12 bit.
Cooling of the XEVA camera down to -4 to -13 ° C (269-260° K), which is needed to reduce the noise in the images, is achieved by forced **convection (TE-1) cooling.**

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Software update (Ferenc Firtha)

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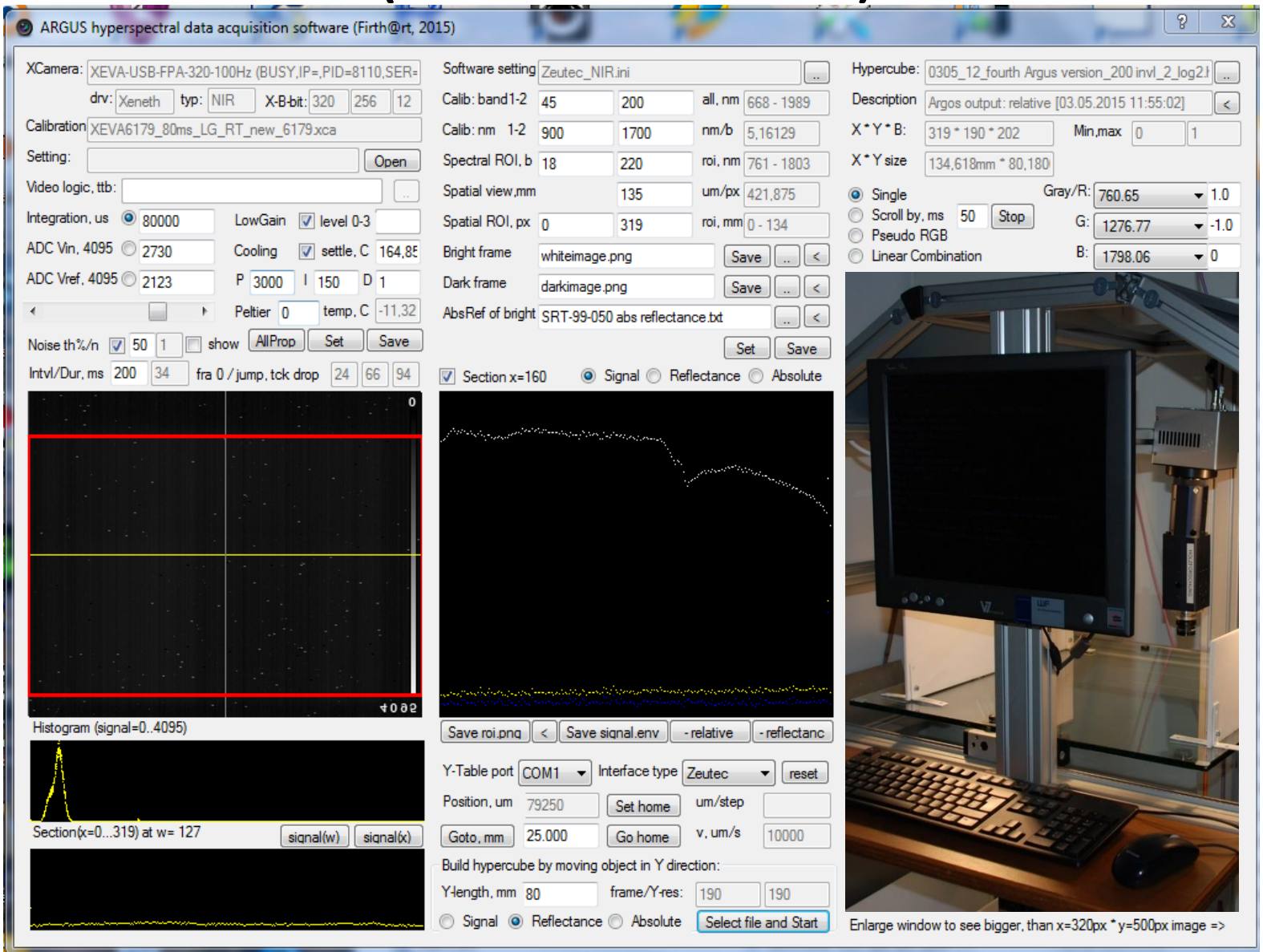

Software update Argus (Ferenc Firtha)

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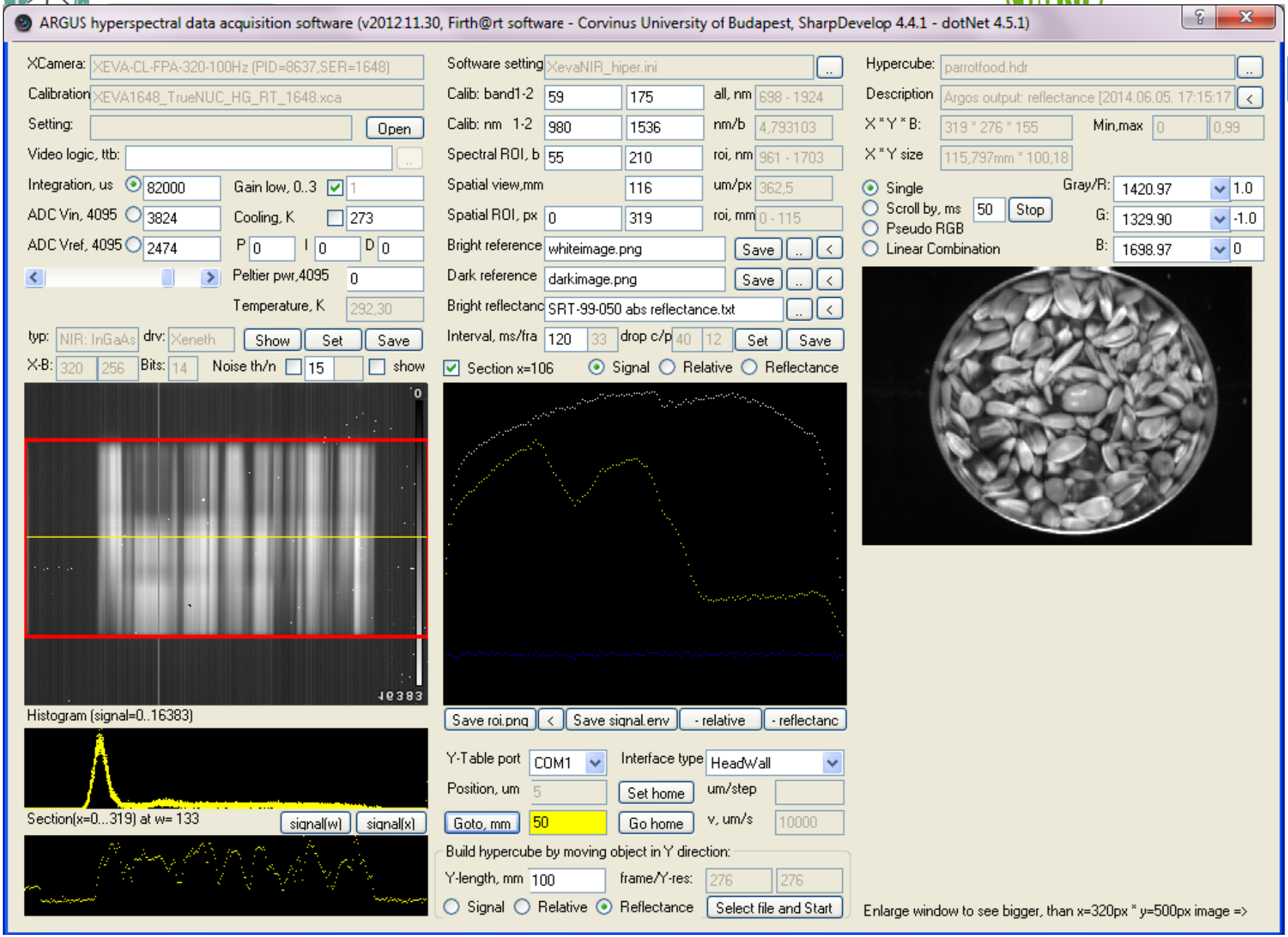
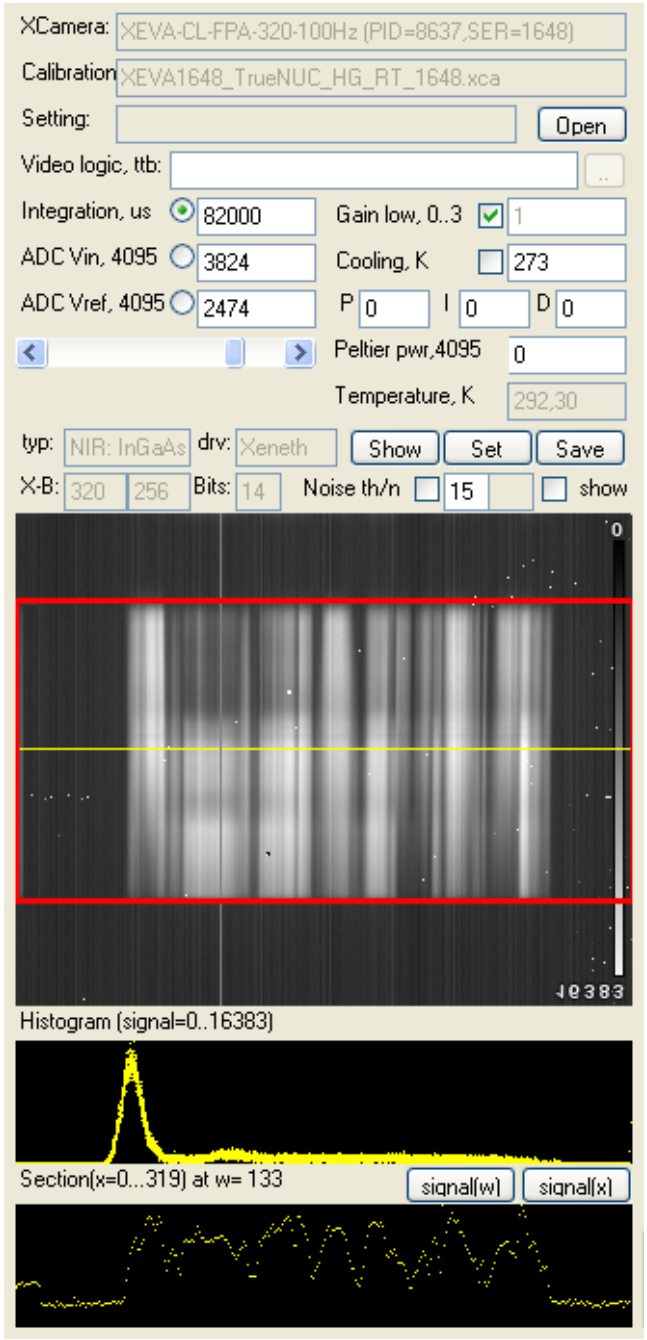


Opening, AD parameters, tuning focus: ARGUS **left** panel



open NIR sensor
and calibration file containing basic parameters

1

integration time and gain to get optimal signal level

2

sensor cooling

3

actual $R(x,b)$ frame as a grayscale image

- spectral and spatial region of interest (ROI)
  is shown by red rectangle

- spectral (gray) and spatial (yellow) cross sections
  at selected point

histogram of signal

spatial cross section of frame
to check homogenity of illumination
to tune focus plane of lens by contrast

Calibration, data acquisition: ARGUS **middle** panel

2-point spectral calibration

spectral and spatial ROI
spatial calib → px size

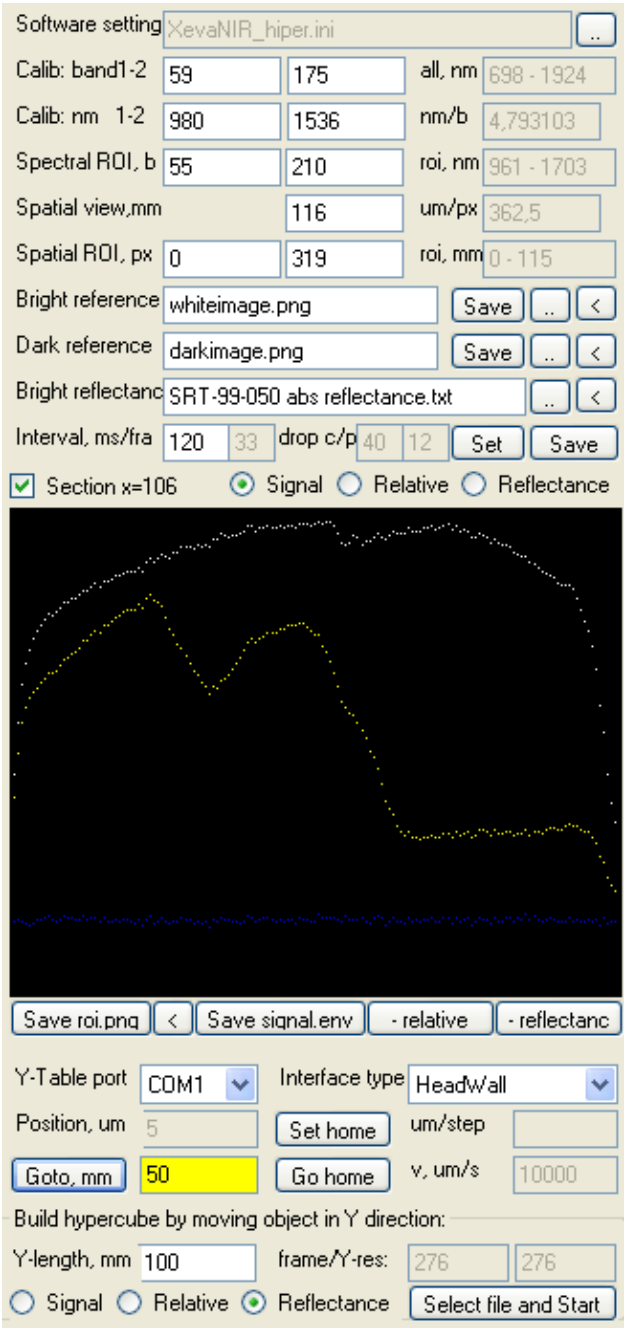
saving bright/low surfaces
→ reflectance factor
→ absolute reflectance

spectral crosssection of frame:

reflectance spectum (yellow)
between bright and dark signal

controlling Y-table
go to anywhere and back

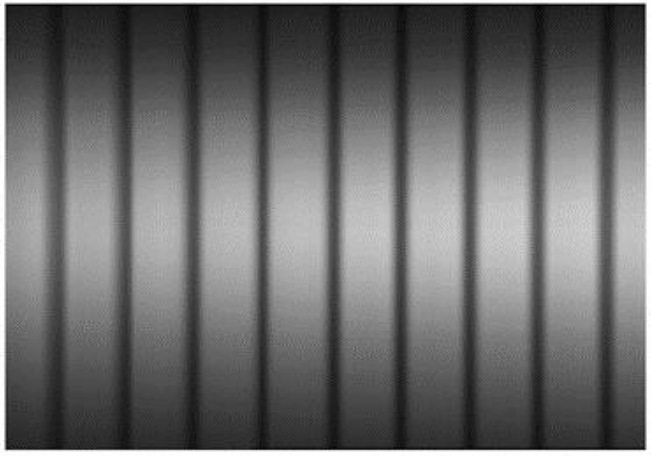
set Y length
and start measurement



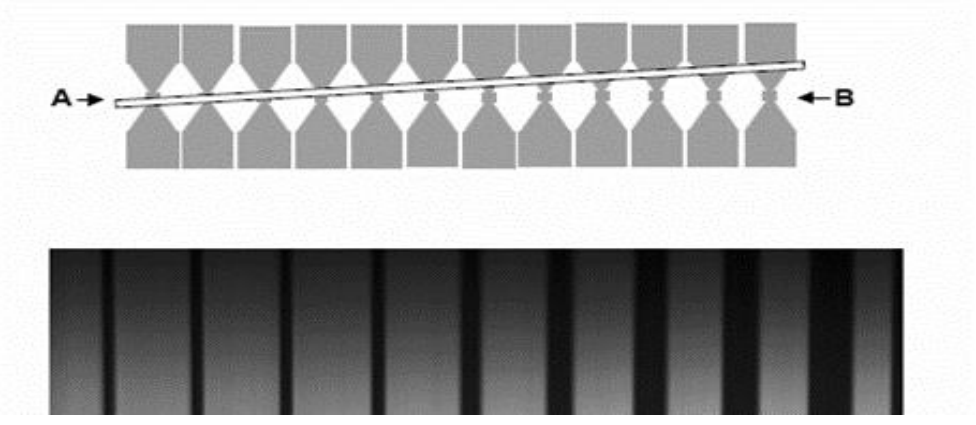
2 bands can be identified
by their wavelengthes

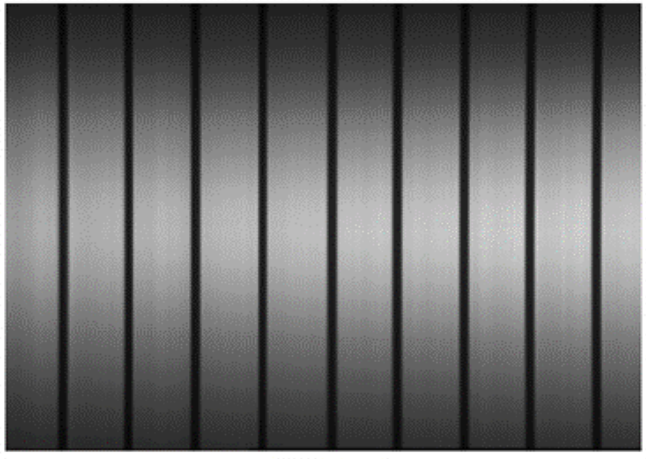
Lack of sharpness of image

First the image was sharpened by using printed black lines and focusing the optics. Spatial alignment was checked.



Out of focus.





Focus OK.

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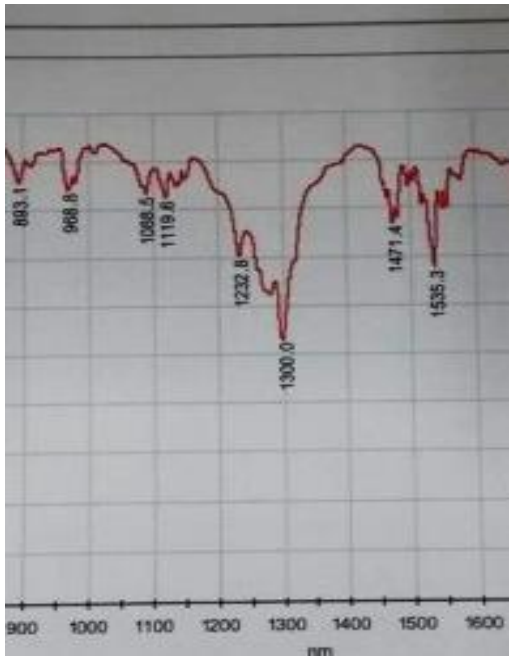
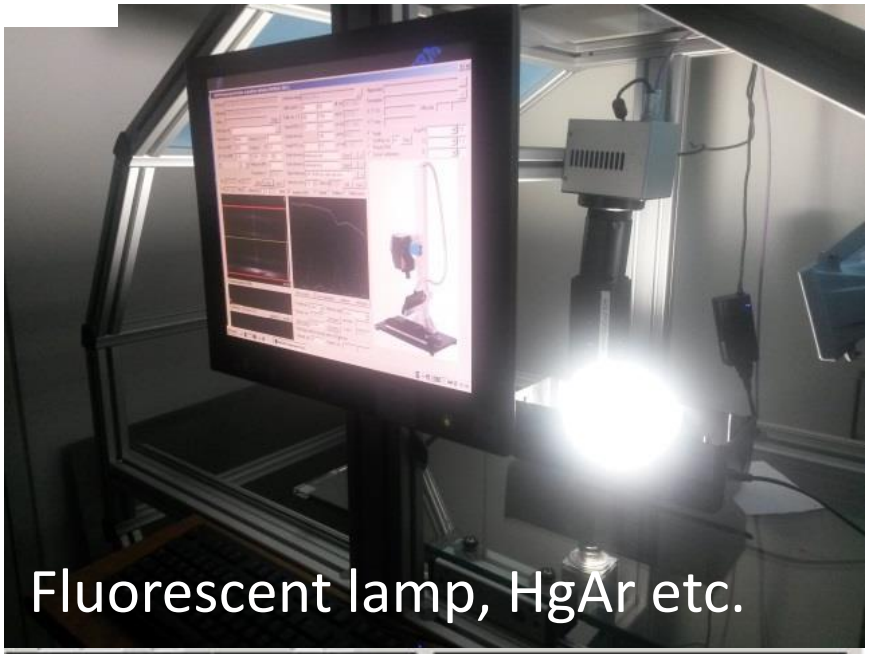
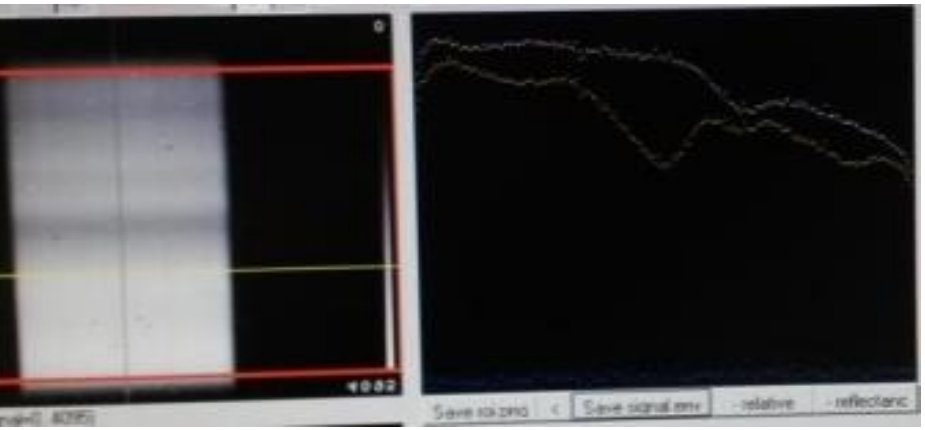
Spectral focusing

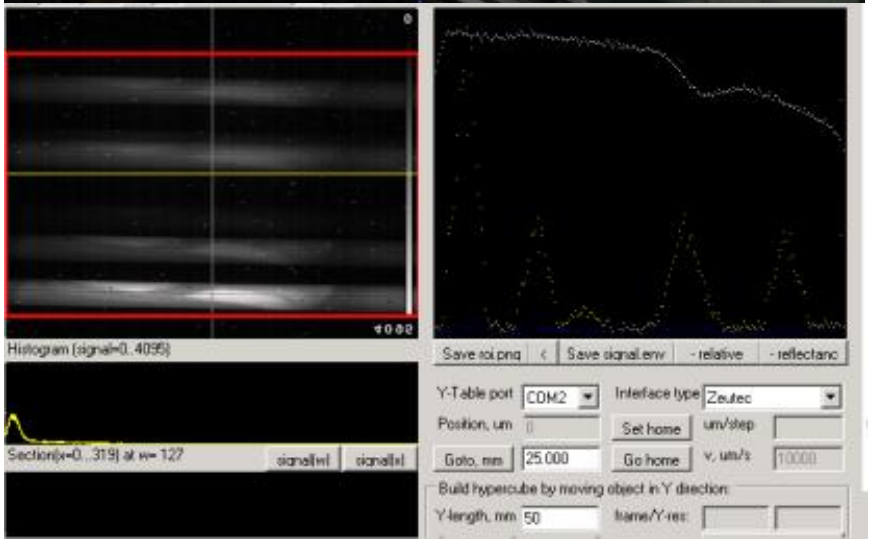
Zenith Polymer® Diffuse Reflectance Standards

Sphereoptics









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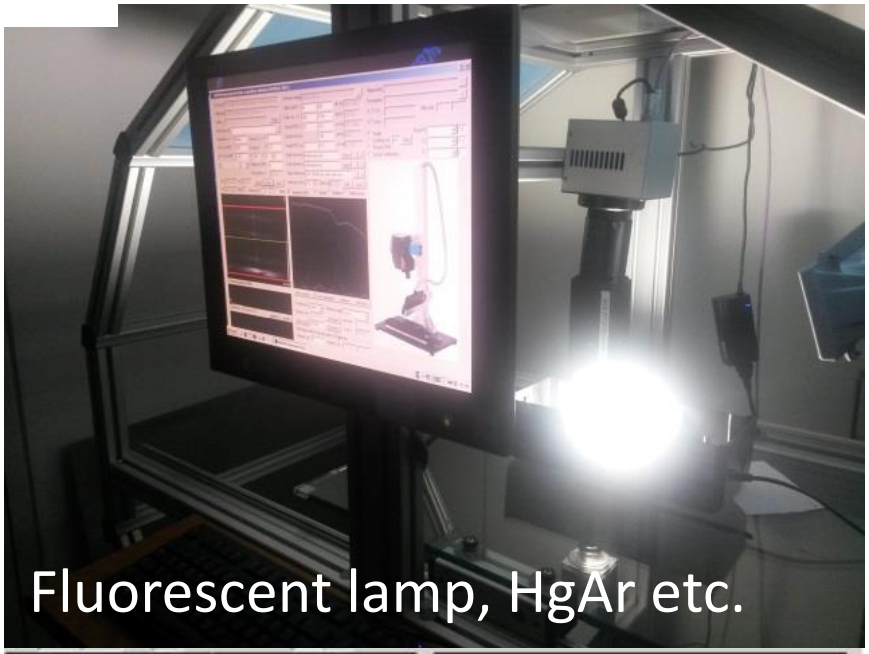
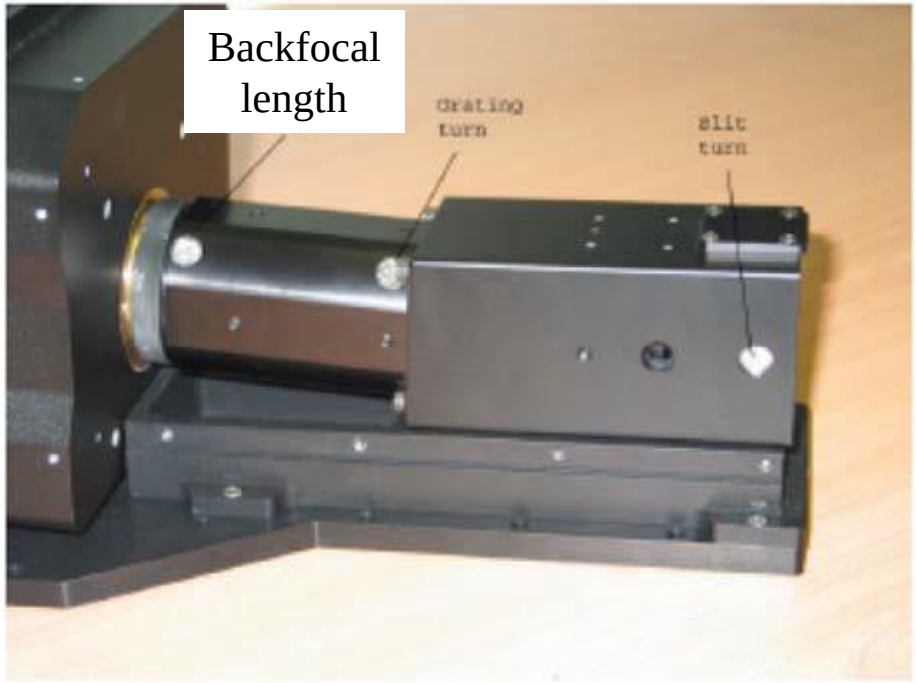
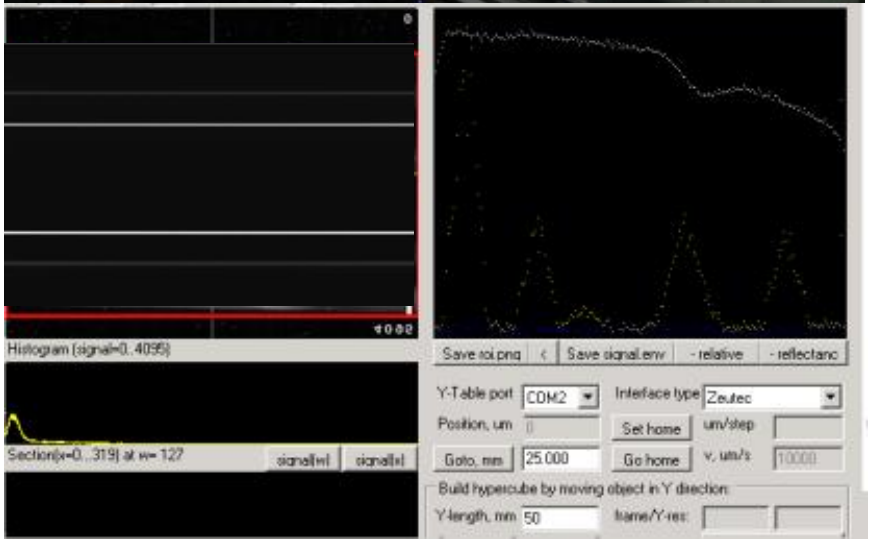
Spectral focusing

Zenith Polymer® Diffuse Reflectance Standards

- Spectral focusing was accomplished by adjusting the backfocal length
- Horizontal adjustment was done by moving the imspector respective to the camera







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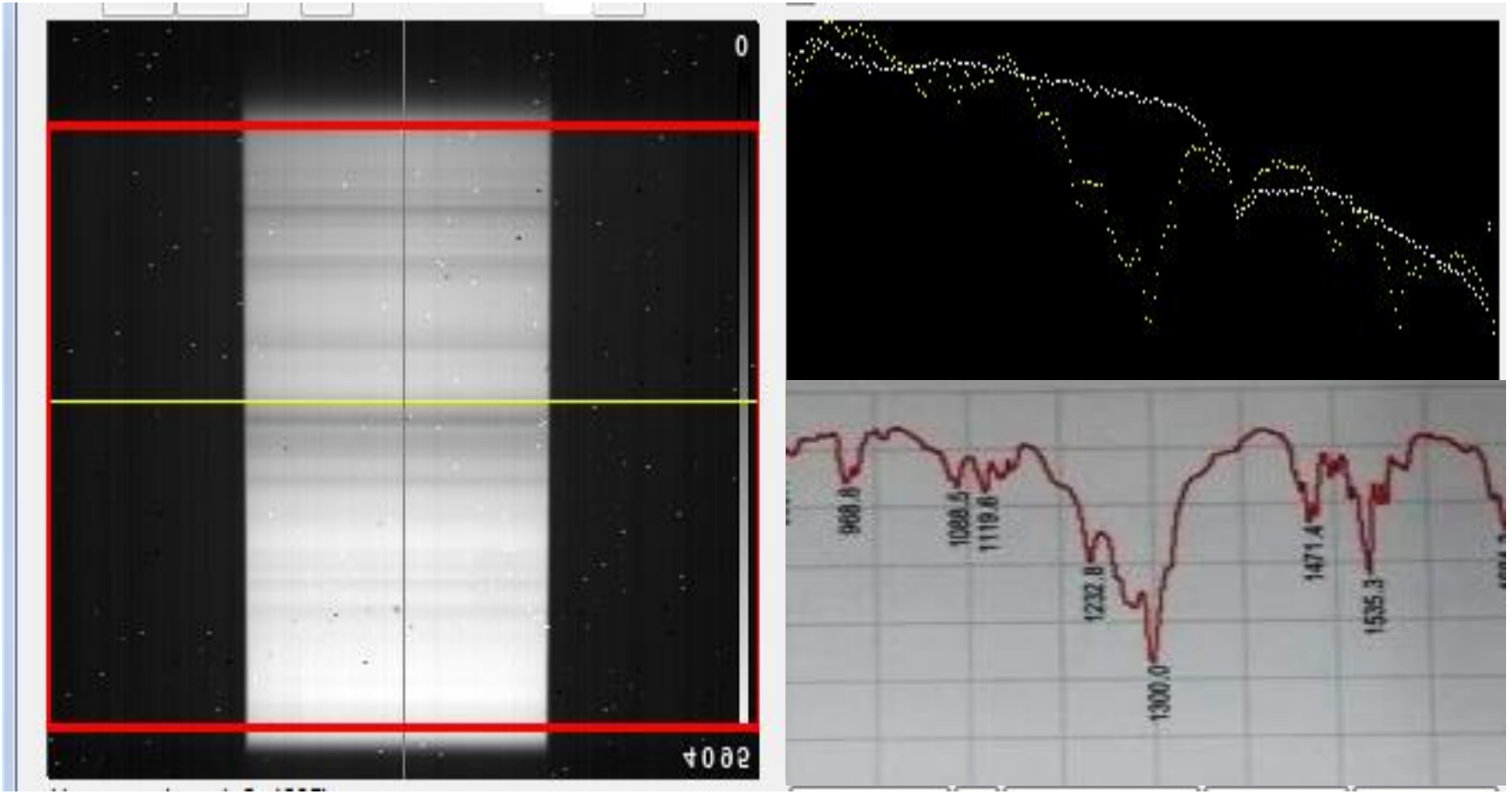
Spectral focusing

- Spectral features of Rare Earth element standard became visible, and spectral calibration could be performed.



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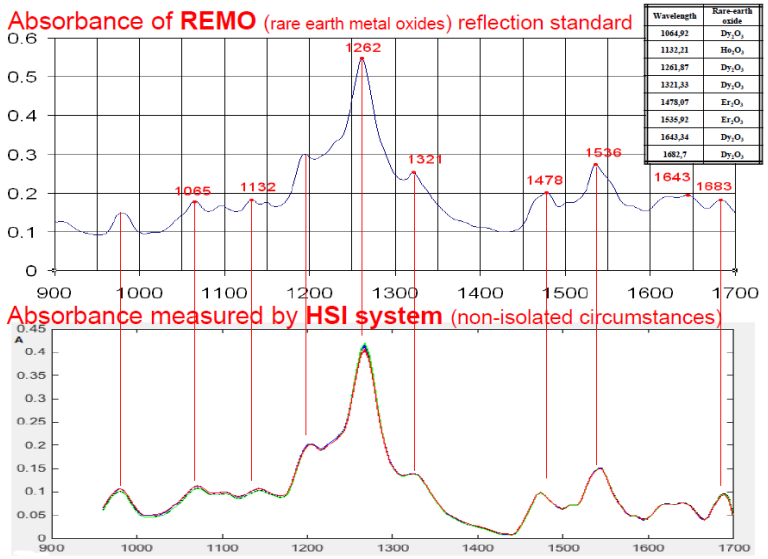
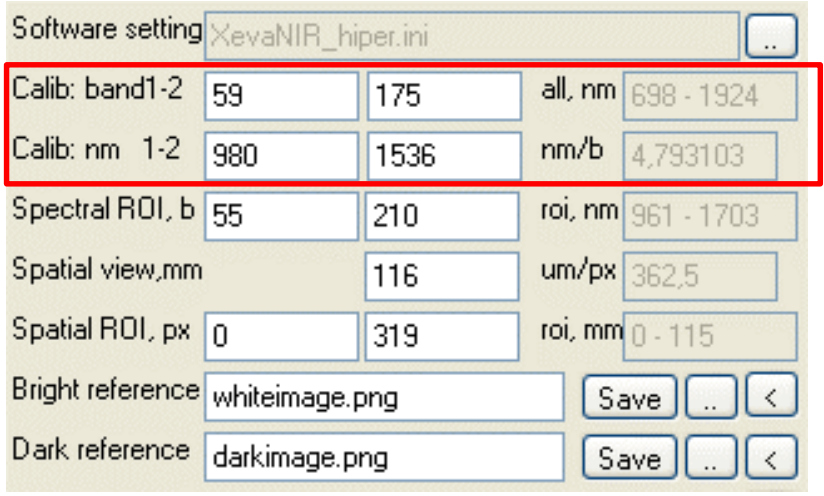
Spectral calibration

- Alignment of matrix detector bands to known spectral bands
- Done in Argus software
  - Export of hyperspectral data of REE standard
  - Import in Excel
  - Looking for absorbance peaks (minimum reflection values at given matrix detector band)
  - Assignment of known spectral bands (nm) to detector bands (done in Argus)
    - Lower and upper end of spectrum – two-point calibration





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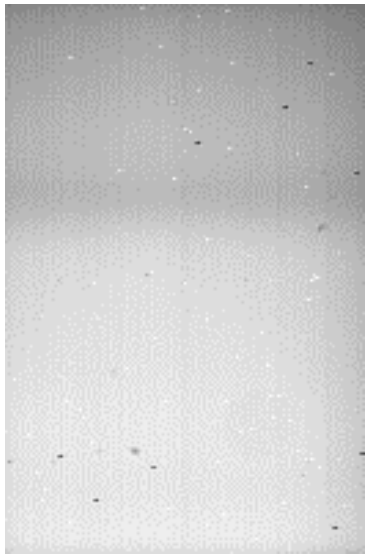
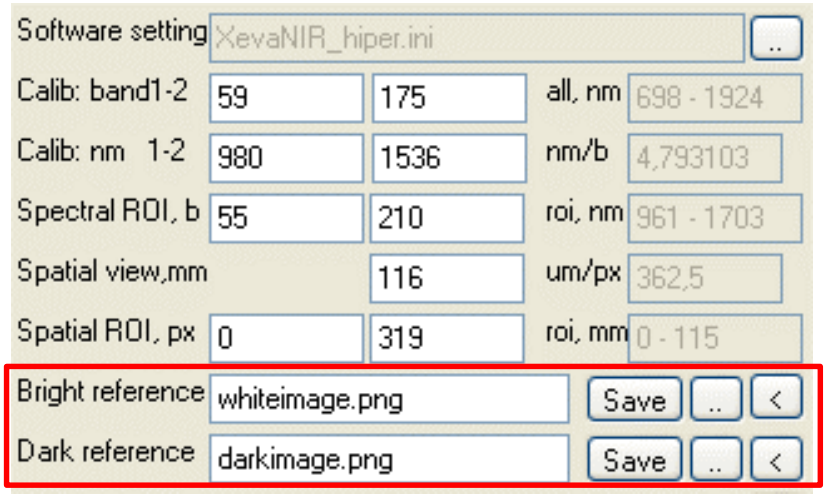
White and black reference

- White image is captured by using a Zenith polymer standard with 99 % reflection. The black image is captured by covering the lens of the optics by hand. Both images are saved by the Argus software as reference.





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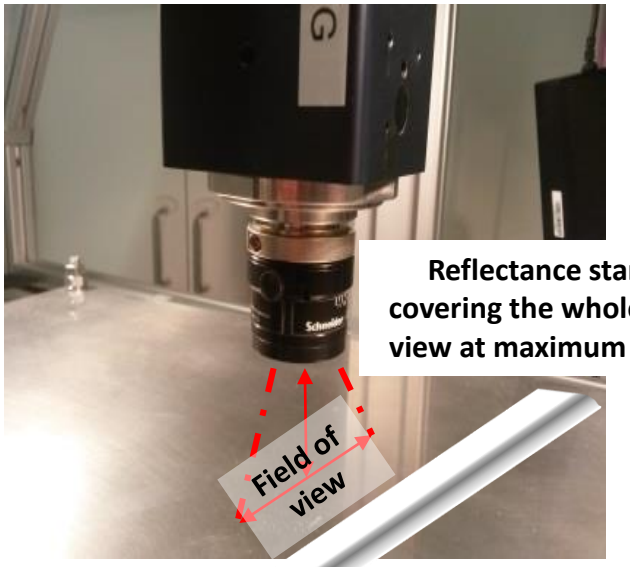
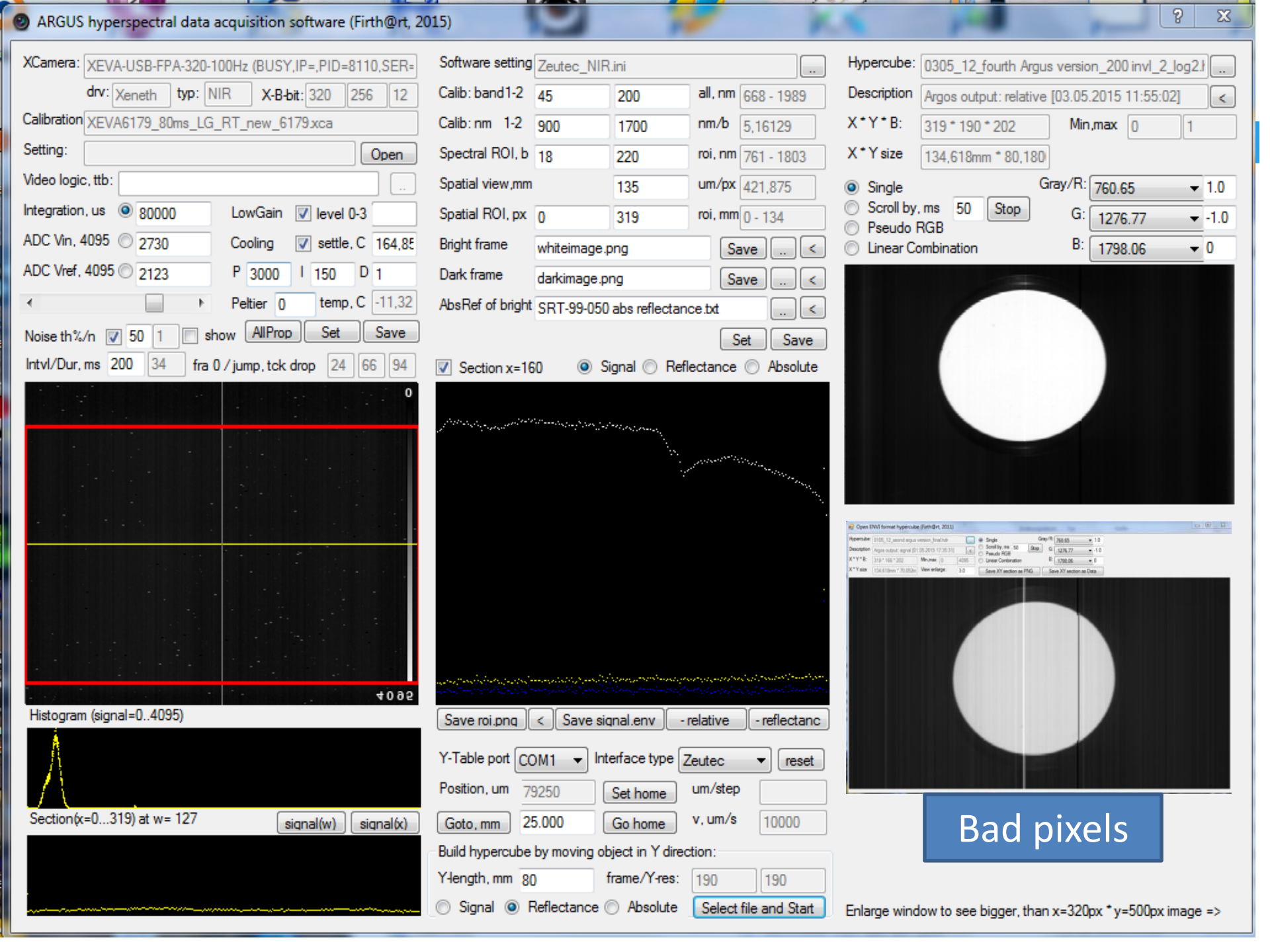
Achievable spatial resolution

- Spatial resolution is a function of working distance
- It is determined by the field of view
- The field of view divided by the number of pixels (320) yields the spatial resolution



Reflectance standard covering the whole field of view at maximum distance

Software setting		_hiper.ini		..
Calib: band1-2	59	175	all, nm	698 - 1924
Calib: nm 1-2	980	1536	nm/b	4,793103
Spectral ROI, b	55	210	roi, nm	961 - 1703
Spatial view,mm		116	um/px	362,5
Spatial ROI, px	0	319	roi, mm	0 - 115
Bright reference	whiteimage.png		Save	.. <
Dark reference	darkimage.png		Save	.. <


ARGUS hyperspectral data acquisition software (Firth@rt, 2015)
XCamera: XEVA-USB-FPA-320-100Hz (BUSY,IP=,PID=8110,SER=
drv: Xeneth typ: NIR X-B-bit: 320 256 12
Calibration XEVA6179_80ms_LG_RT_new_6179.xca
Setting: Open
Video logic, ttb:
Integration, us 80000 LowGain level 0-3
ADC Vin, 4095 2730 Cooling settle, C 164,85
ADC Vref, 4095 2123 P 3000 I 150 D 1
Peltier 0 temp, C -11,32
Noise th%/n 50 1 show AllProp Set Save
Intvl/Dur, ms 200 34 fra 0 / jump, tck drop 24 66 94
Histogram (signal=0..4095)
Section(x=0...319) at w= 127 signal(w) signal(x)
Software setting Zeutec_NIR.ini
Calib: band1-2 45 200 all, nm 668 - 1989
Calib: nm 1-2 900 1700 nm/b 5,16129
Spectral ROI, b 18 220 roi, nm 761 - 1803
Spatial view,mm 135 um/px 421,875
Spatial ROI, px 0 319 roi, mm 0 - 134
Bright frame whiteimage.png Save
Dark frame darkimage.png Save
AbsRef of bright SRT-99-050 abs reflectance.txt
Set Save
Section x=160 Signal Reflectance Absolute
Save roi.png Save signal.env - relative - reflectanc
Y-Table port COM1 Interface type Zeutec reset
Position, um 79250 Set home um/step
Goto, mm 25.000 Go home v, um/s 10000
Build hypercube by moving object in Y direction:
Y-length, mm 80 frame/Y-res: 190 190
Signal Reflectance Absolute Select file and Start
Hypercube: 0305_12_fourth Argus version_200 invl_2_log2.l
Description Argos output: relative [03.05.2015 11:55:02]
X * Y * B: 319 * 190 * 202 Min,max 0 1
X * Y size 134,618mm * 80,180
Single Gray/R: 760.65 1.0
Scroll by, ms 50 Stop G: 1276.77 -1.0
Pseudo RGB
Linear Combination B: 1798.06 0
Bad pixels
Enlarge window to see bigger, than x=320px * y=500px image =>

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Working HSI system on BOKU

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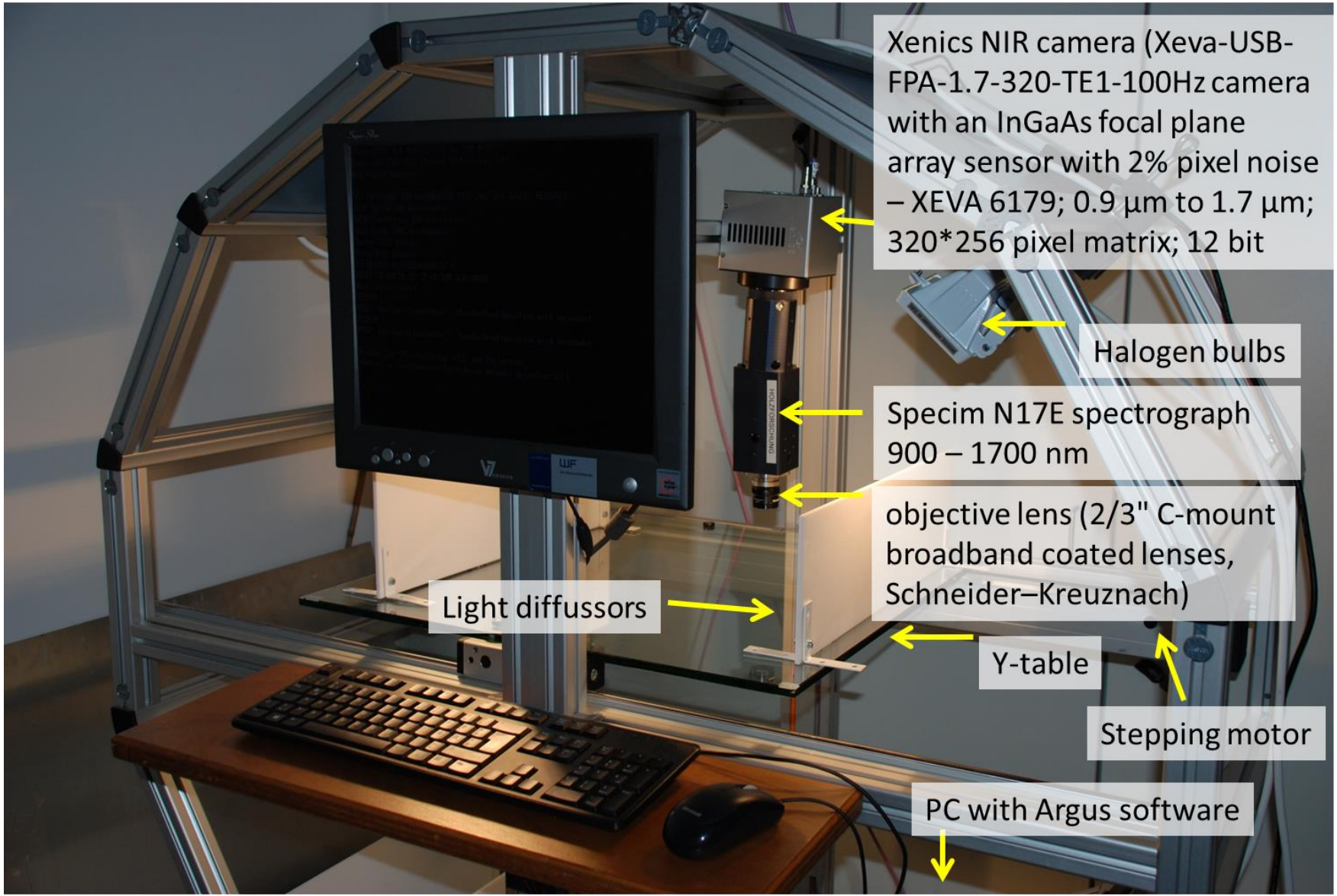
Department of Material Sciences and Process Engineering



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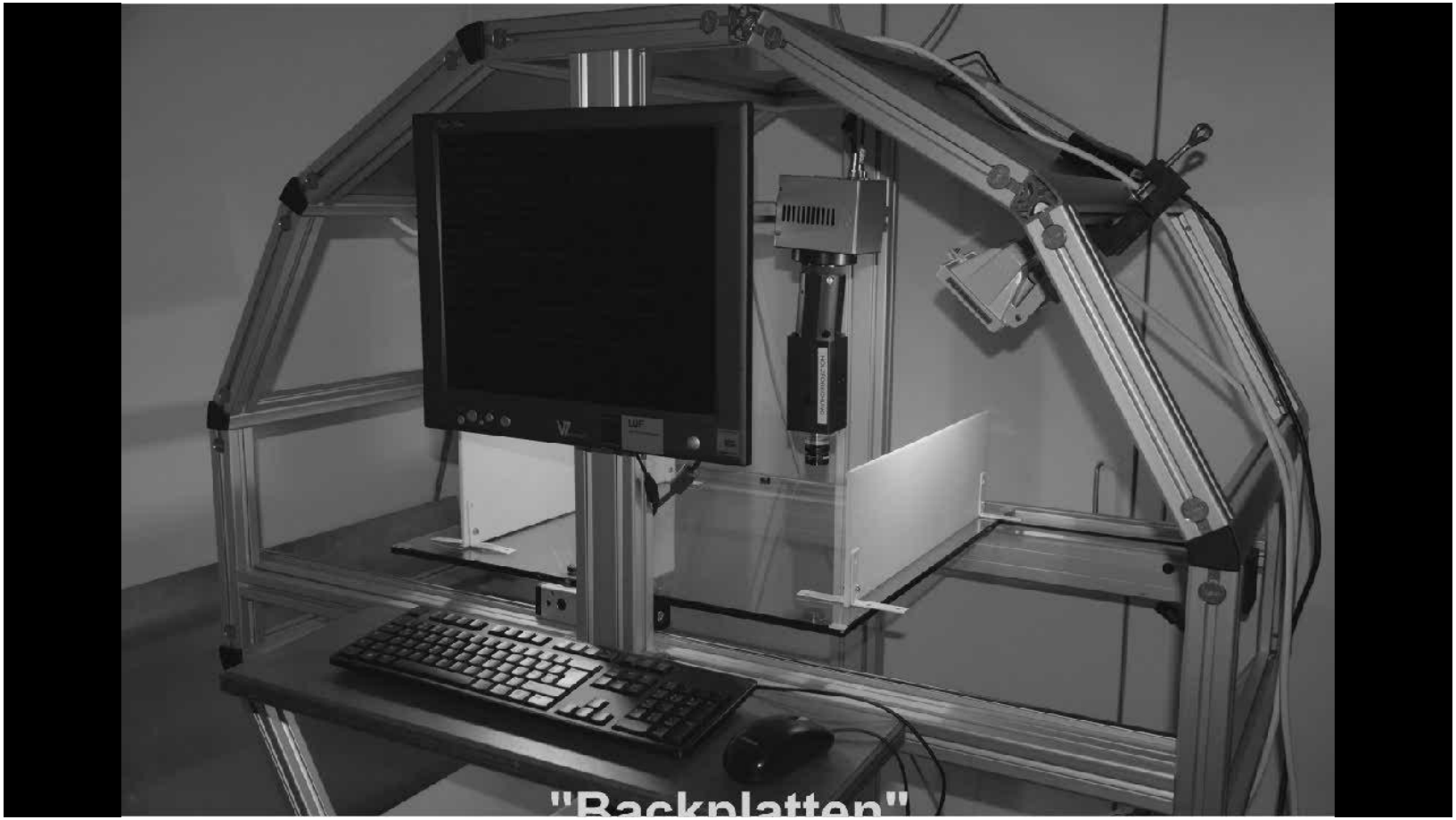
See how it works…



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CORVINUS

CNR-IVALSA

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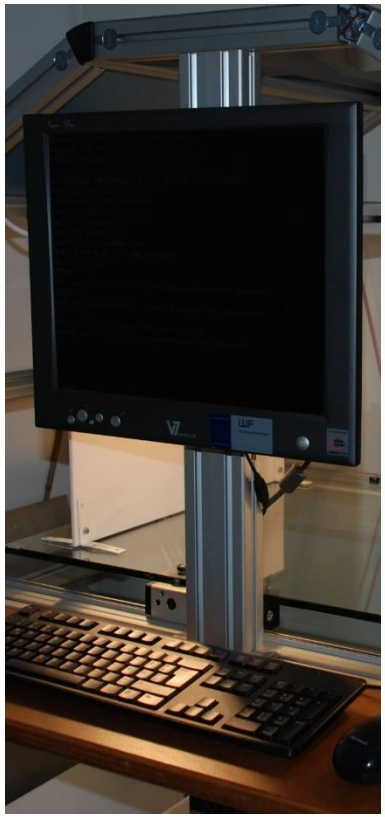
Department of Material Sciences and Process Engineering

First res
wood,



Inspection of Log Quality by Hyperspectral Imaging

A. Zitek[1], F. Firtha[2], K. Böhm[1], V. Parrag[2], J. Sandak[3], B. Hinterstoisser[1]

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[2] Physics-Control Department, Faculty of Food Science, Corvinus University of Budapest, Budapest Somlói út 14-16, H-1118, Hungary
[3] Trees and Timber Institute/National Research Council, IVALSA/CNR, Via Biasi 75, San Michele All'Adige, Italy

Motivation

- Determination of wood quality for an efficient utilization of harvested logs.
- Detection of wood deficiencies in an early stage of the production chain.
- Using Hyperspectral Imaging to assess wood quality parameters in the field.

Fig. 1: HeadWall Photonics push-broom Hyperspectral imaging system.

Hyperspectral Imaging

by HeadWall Photonics push-broom hyperspectral system (Fig.1 - Xenics NIR camera: 320*256 matrix, 14 bit A/D, 5 nm resolution, 250 mm Y-table gear, stable diffuse 45/0 illumination).

Results highlighting the possibilities of the application of this technique even on freshly cut logs (Fig. 2a):

- areas affected by fungi could be clearly identified, even in an early stage of attack - not visible to naked eye (Fig. 2c)
- areas with structural abnormalities could be clearly identified
- dry and humid wood could be measured
- measurements could be performed on a rough surface

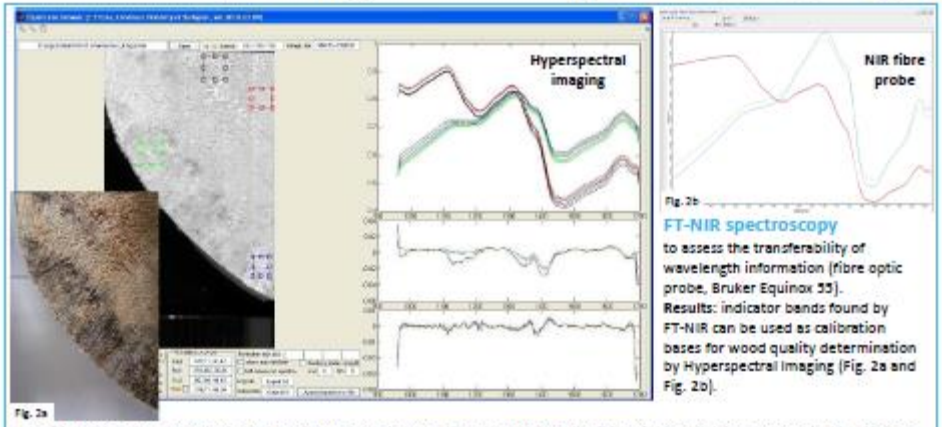


Fig. 2a

Fig. 2: (a) Hyperspectral imaging results of a wood disc of an approximately 80 year old Norway spruce (Picea abies (L.) Karst) with rough surface structure and partly visible fungi affection, (b) FT-NIR reflection spectra collected with the fibre probe, (c) pseudo RGB image of the Hyperspectral imaging scan.

Fig. 2b

FT-NIR spectroscopy

to assess the transferability of wavelength information (fibre optic probe, Bruker Equinox 55).
Results: indicator bands found by FT-NIR can be used as calibration bases for wood quality determination by Hyperspectral Imaging (Fig. 2a and Fig. 2b).

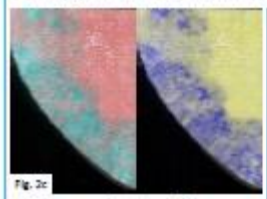


Fig. 2c

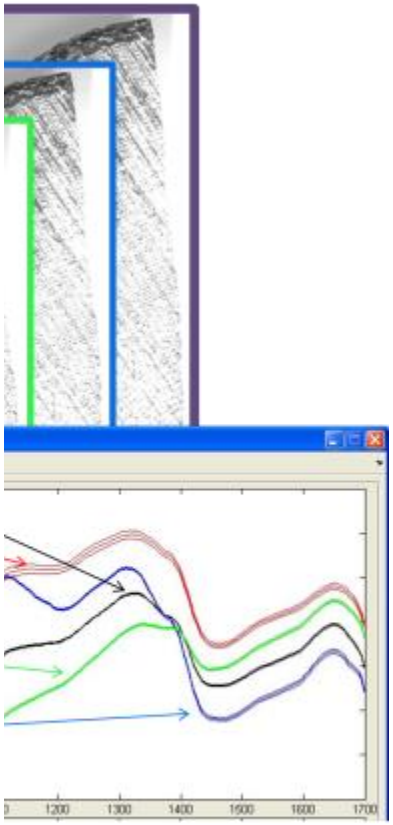
Result: a gradient not visible to the naked eye could be visualized by

Outlook

Hyperspectral Imaging is a promising technique to improve fast on-site judgment of log quality.
Issues due to influences of

- uneven distribution of wetness in the log,
- rough surfaces on the measurements,
- cracks and other inhomogeneities on the measurements,
- contaminations with soil or machine oil etc.

have to answered in further research within the SLOPE-project.



Fifth IASIM conference in spectral Imaging, IASIM-14, Rome, DEC 3-5, 2014.

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Water band and fungus

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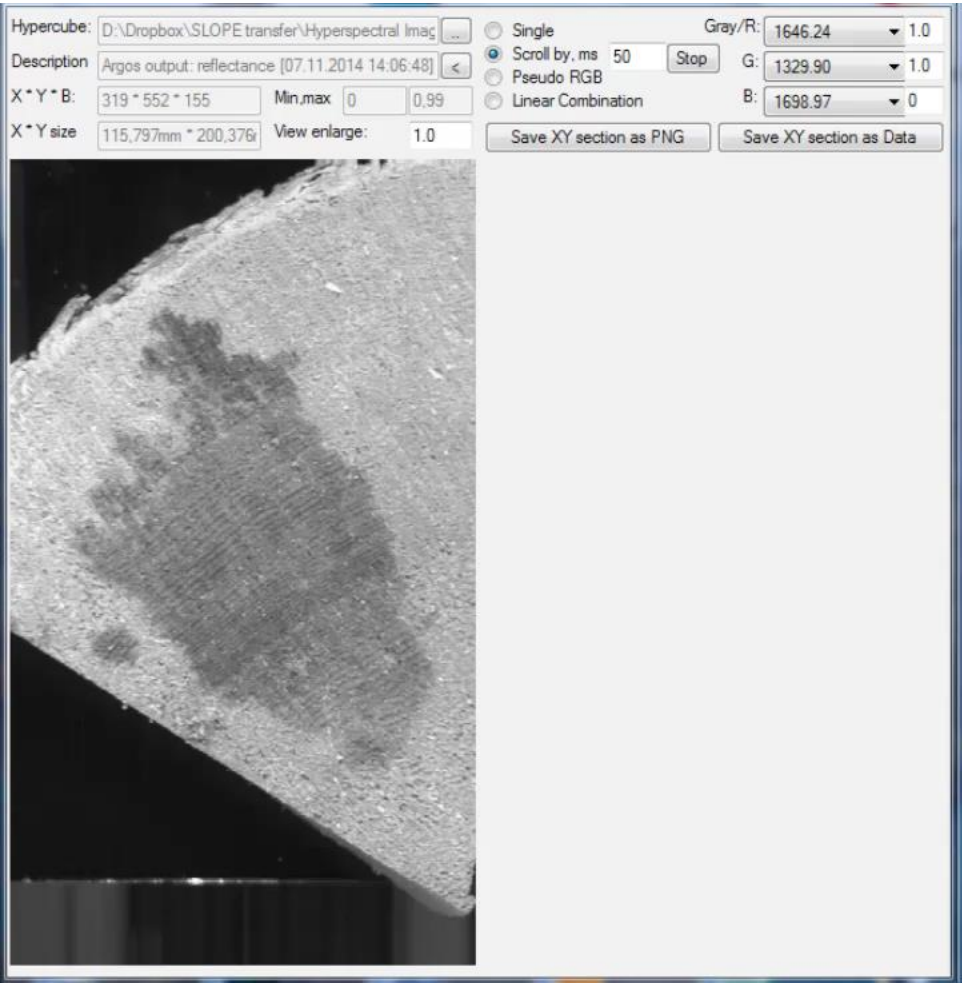
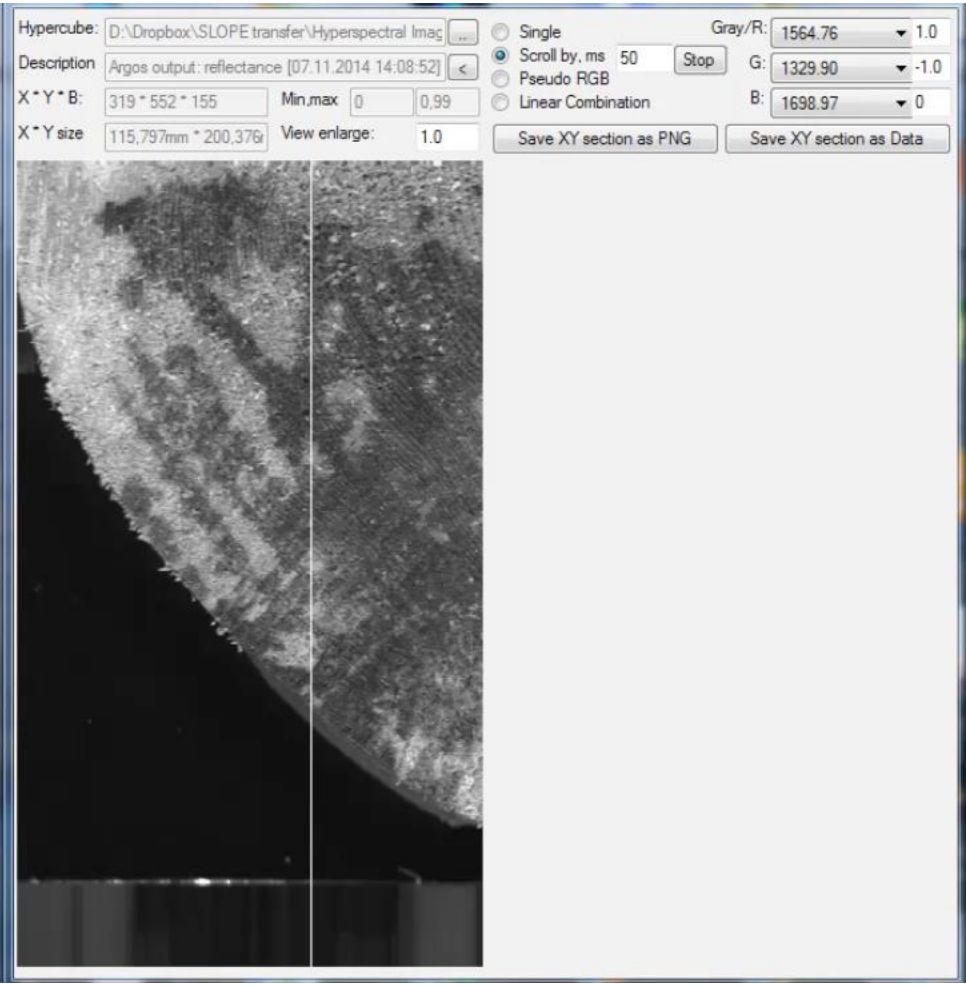




SLOPE project - Hyperspectral imaging (HI) for the determination of log/biomass "HI quality index"

25 samples of spruce (*Picea abies*) with different defects (ø 15 - 45 cm), March 2015

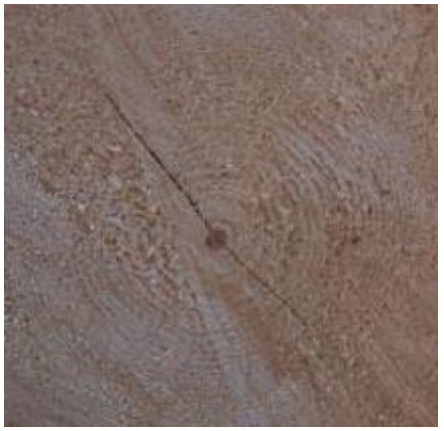
BOKU education forest at Forchtenstein (Rosalia), Burgenland

SLOPE project - Hyperspectral imaging (HI) for the determination of log/biomass “HI quality index”

resin pockets

knots

shakes, checks, splits

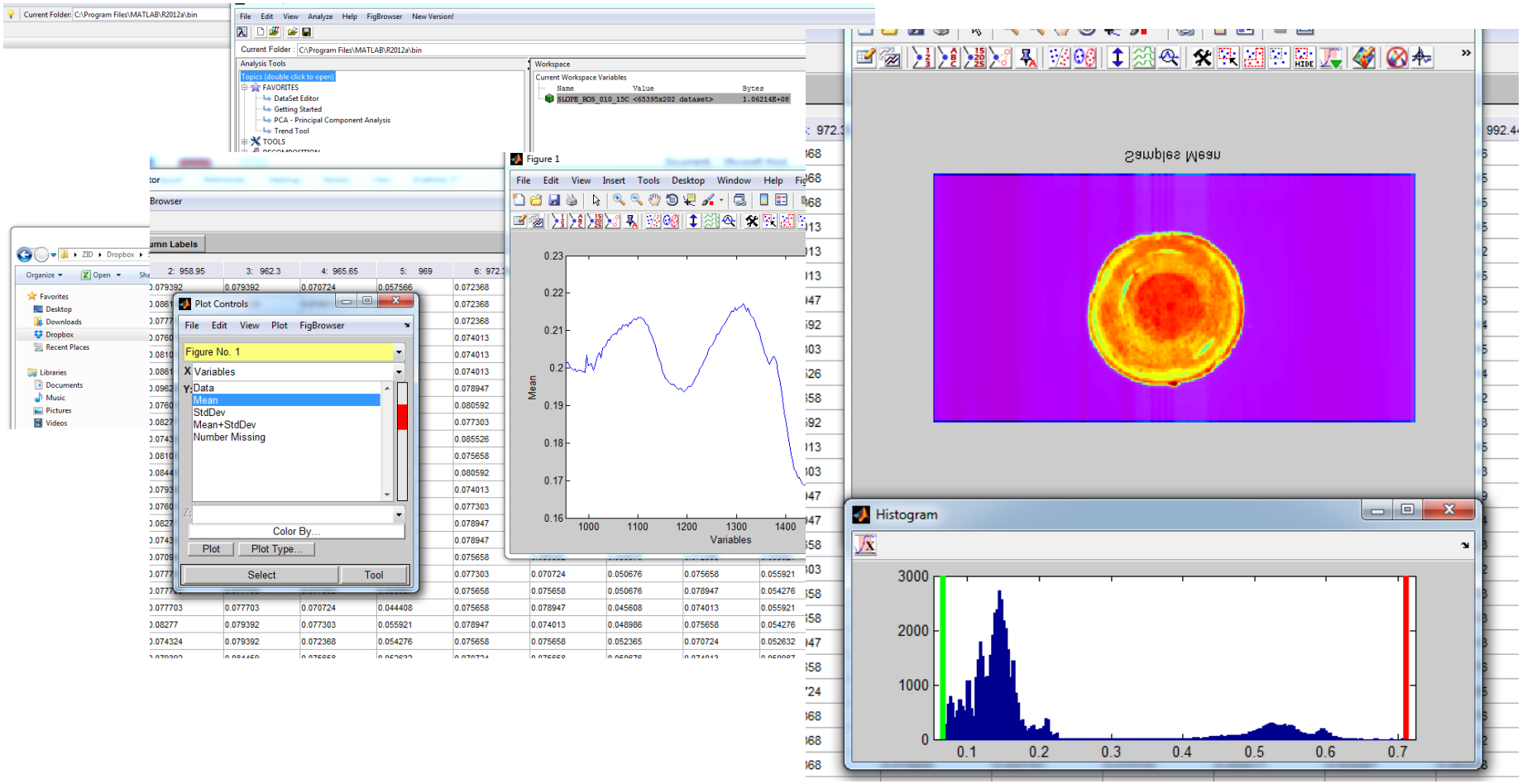


eccentric pith + compression wood + rot

Measured with FT-NIR and hyperspectral imaging at BOKU, and MicroNIR and Hamamatsu at CNR

eccentric pith + rot + knot

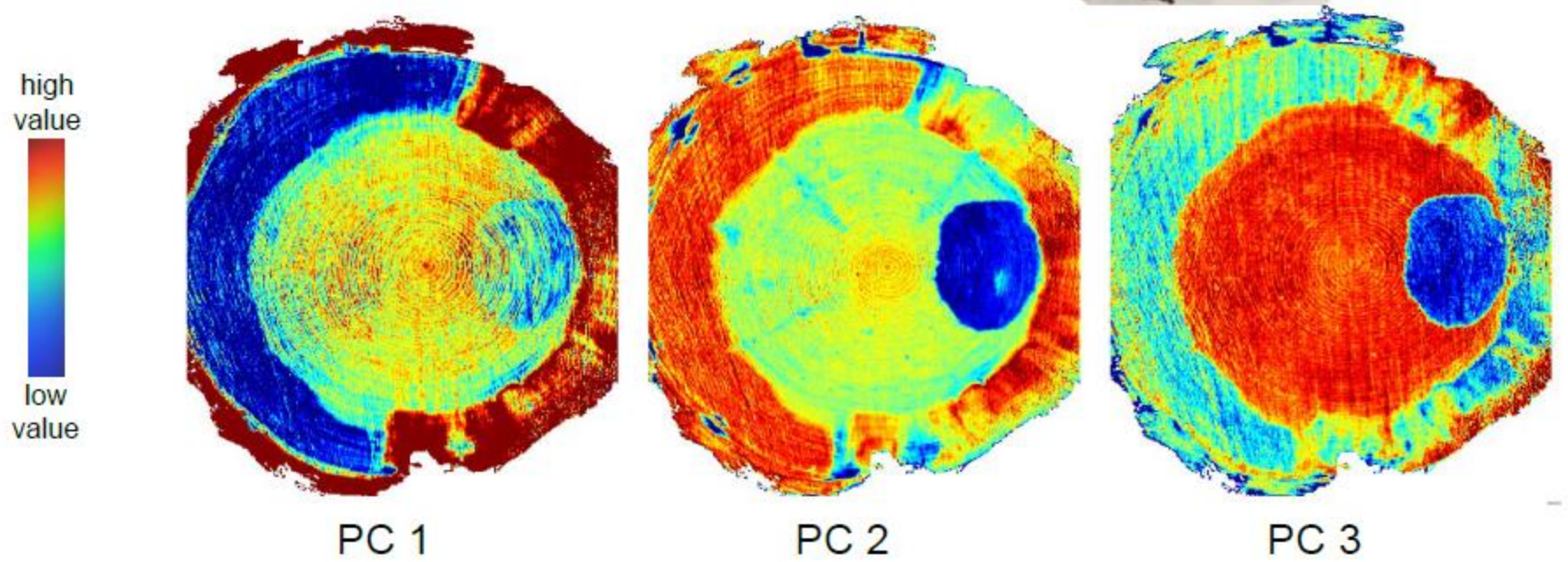
SLOPE: data analysis with PLS toolbox (Eigenvector software)



Images of

In our case: 1.4 x 1.4 mm

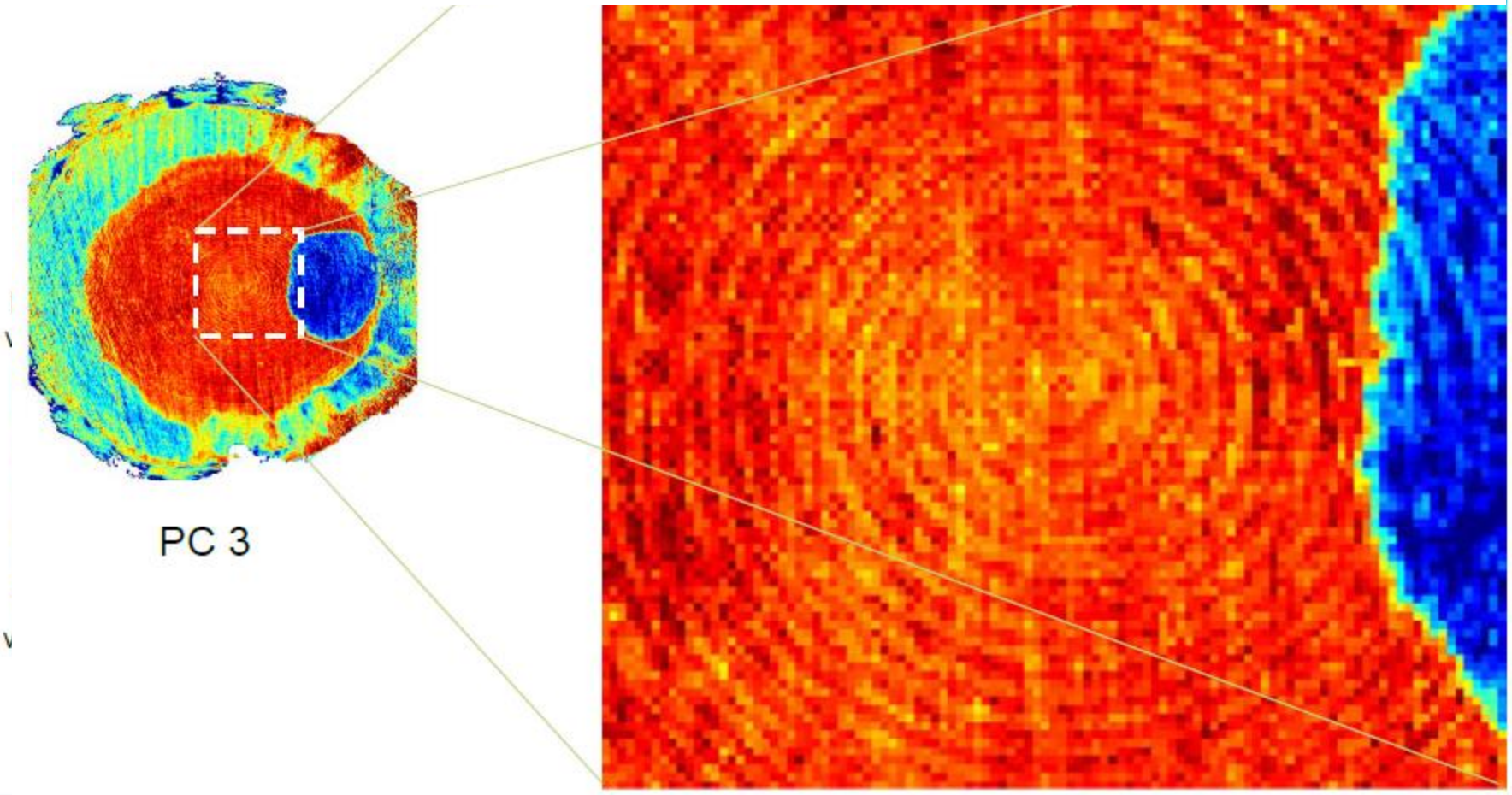
(450 mm spatial view / 320 Pixels = 1.406 mm)



Spatial resolution / pixel size: 1 mm x 1 mm

In our case: 1.4 x 1.4 mm

(450 mm spatial view / 320 Pixels = 1.406 mm)



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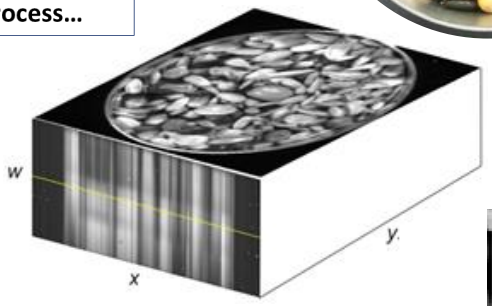
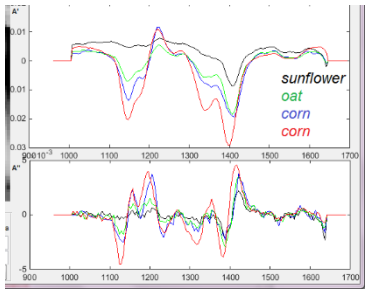
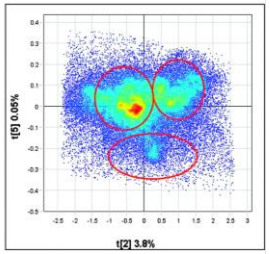
Finally:

Ability to apply workflow of HSI

- Sample
- Reflectance calibration
- Data aquisition — Spatial, spectral, time, process…
- Spectral hypercube
- Dead pixels
- Spikes
- Background/region of interest (ROI)
- Spectral pre-processing — SNV, MSC, EMSC, Norm., AsLS,WLS
- Compression, spectral processing, feature reduction/analysis, training — Chemometrics (PCA, PLS, PLS-DA,..)
- Feature extraction, image and post processing — Chemometrics (MIA, MRA, MR-MIA,. ..)
- Result
- Prediction, monitoring, control

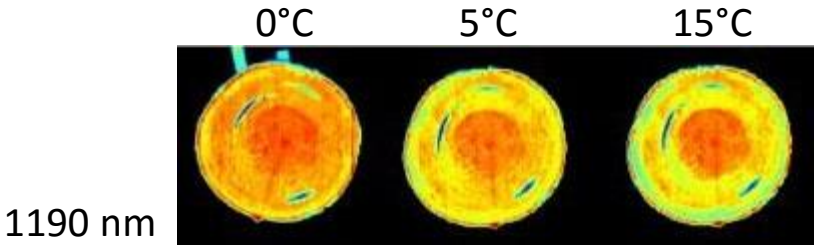




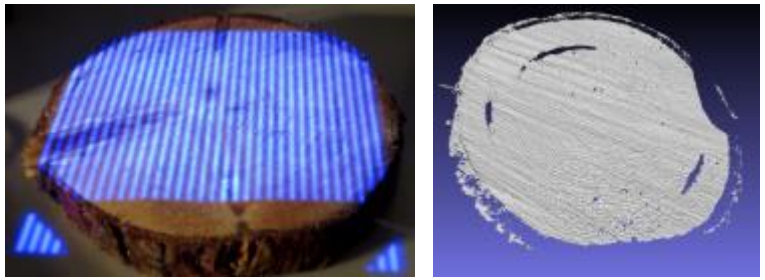


SLOPE project – analytical challenges

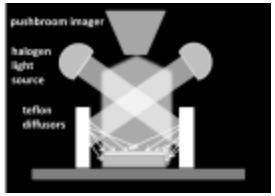
- Temperature
- Roughness
- Lightning & referencing
- Water & Ice
- Other contam.



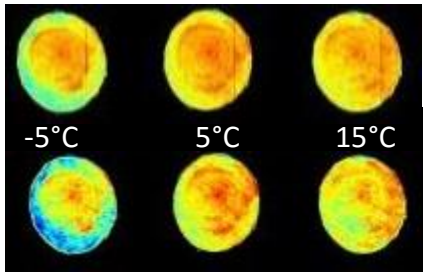
Measurements at different temperatures yield temperature effect



Roughness can be calculated by z-values of 3D scan

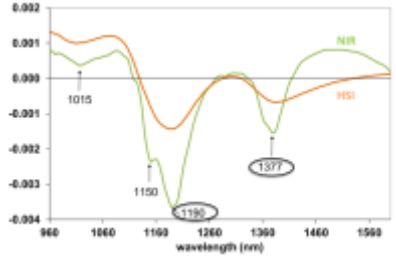


Diffuse lightning reduces morphological effects, needs to be carefully considered



1190 nm

1377 nm



Ice and water have specific bands, wavelength selection important

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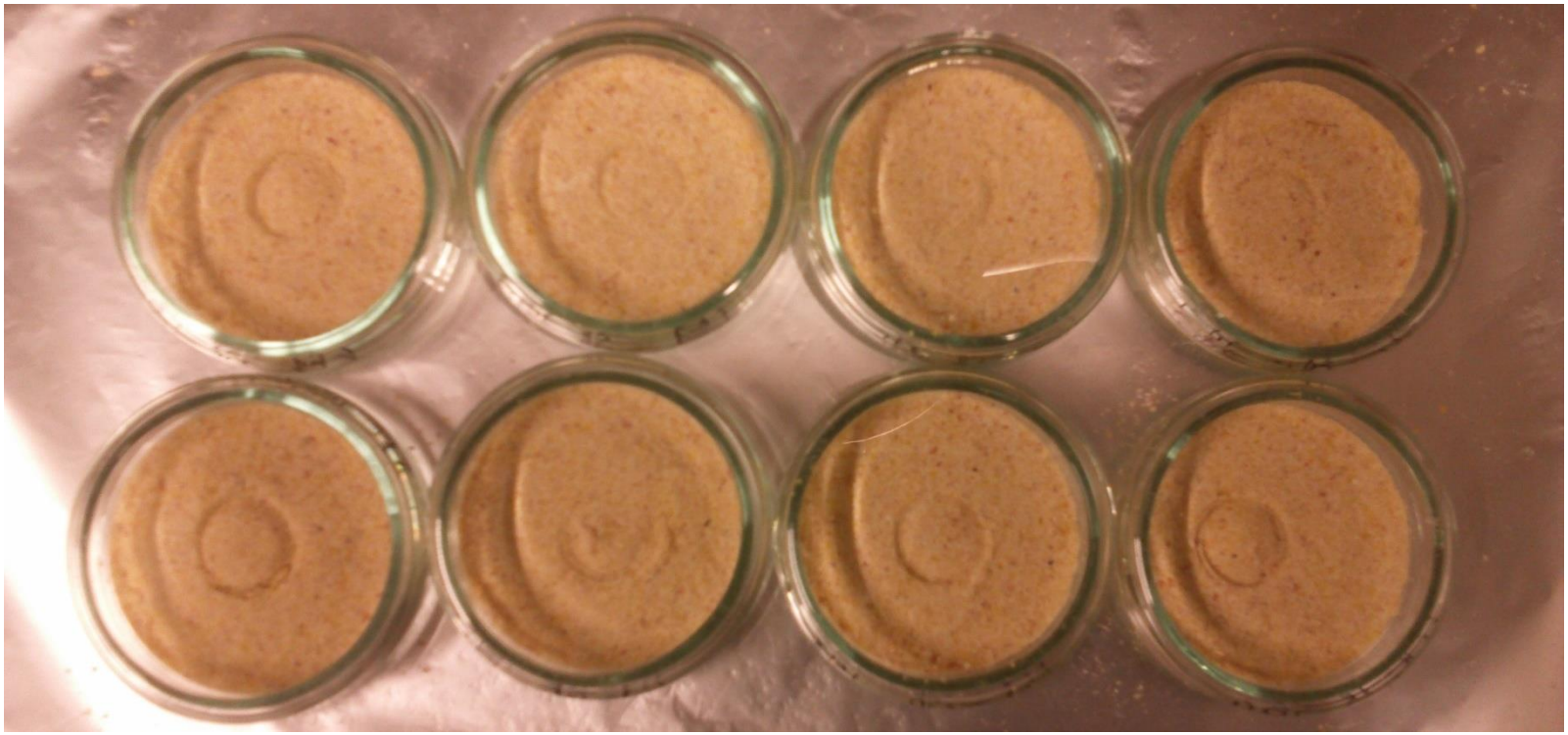
Interdisziplinäre AG Holzchemie

Department of Material Sciences and Process Engineering

HSI of mycotoxins

secondary metabolites of *Fusarium* in maize



Parrag, Sulyok, Firtha, Felföldi, Zitek, Krska, Hinterstoisser (in prepr): Application of HSI to detect toxigenic *Fusarium* infection in maize.

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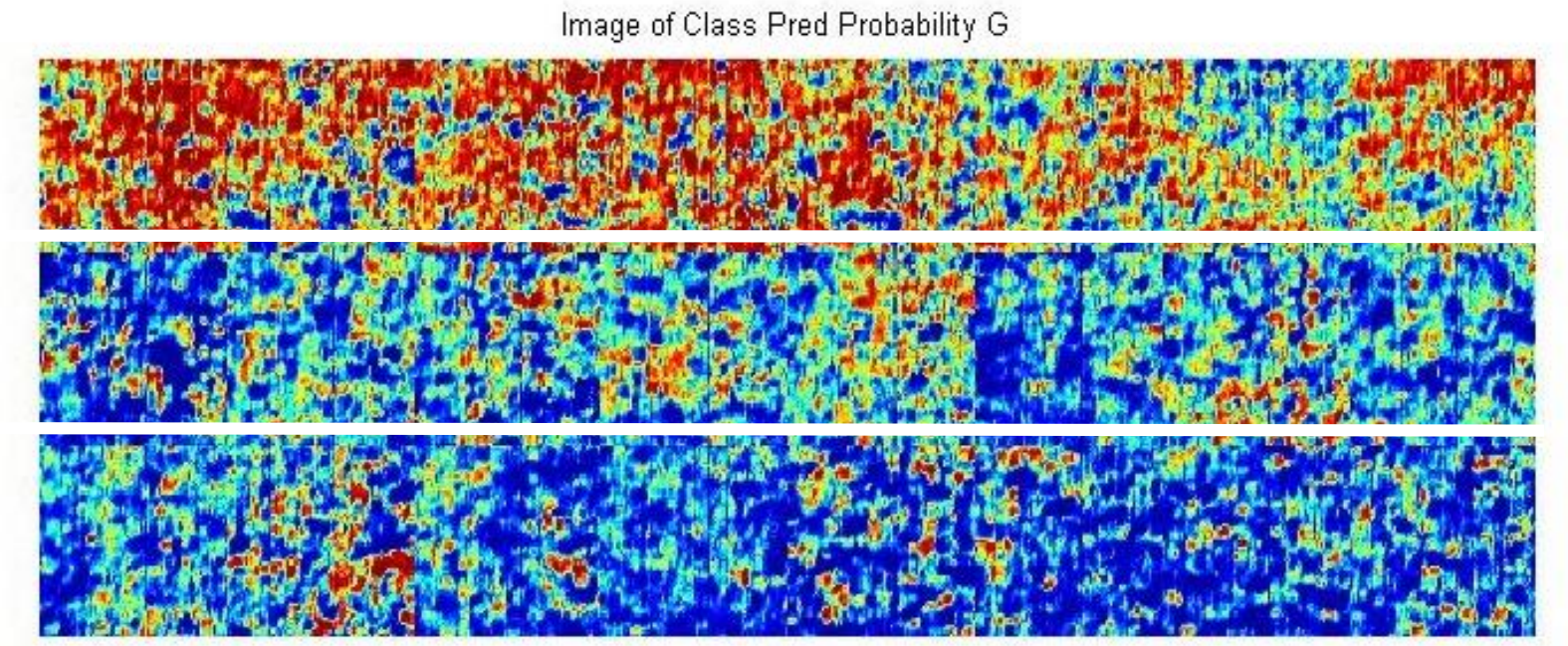

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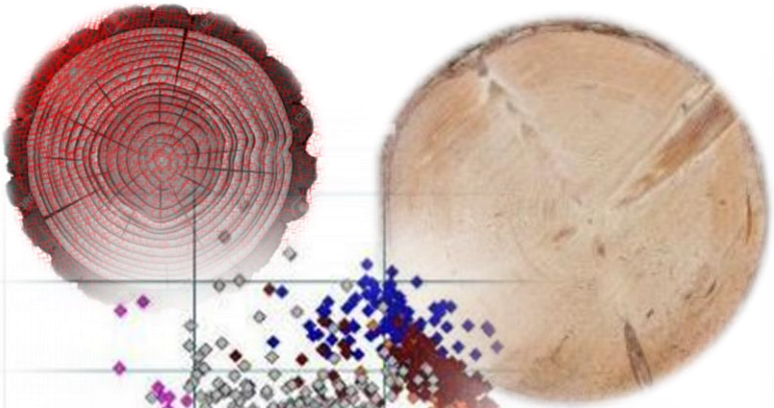

Thank you for your interest!

andreas.zitek@boku.ac.at

https://viris.boku.ac.at/wshyperspectral2015/wshyperspectral2015/PROGRAMME.html

SLOPE and BiRT WORKSHOP
HYPERSPECTRAL IMAGING
RENEWABLE RESOURCES, BIOMATERIALS AND FOOD
UFT TULLN - 2015-03-20