Calibration and Performance Verification of Hyperspectral Systems

H. Schwarzer, A. Eckardt, D. Krutz, **R. Reulke**, H. Venus
German Aerospace Center (DLR), Institute of Optical Sensorsystems
Rutherfordstr. 2, D-12489 Berlin

20. Workshop Farbbildverarbeitung - Wuppertal 25./26.09. 2014

DLR

AGENDA

Introduction

Instrument Description

Calibration and Performance Verification

Results

Summary and Conclusion

Motivation for High Spatial & Spectral Resolution Systems

Identified Very high resolution optical satellite USER APPLICATIONS:

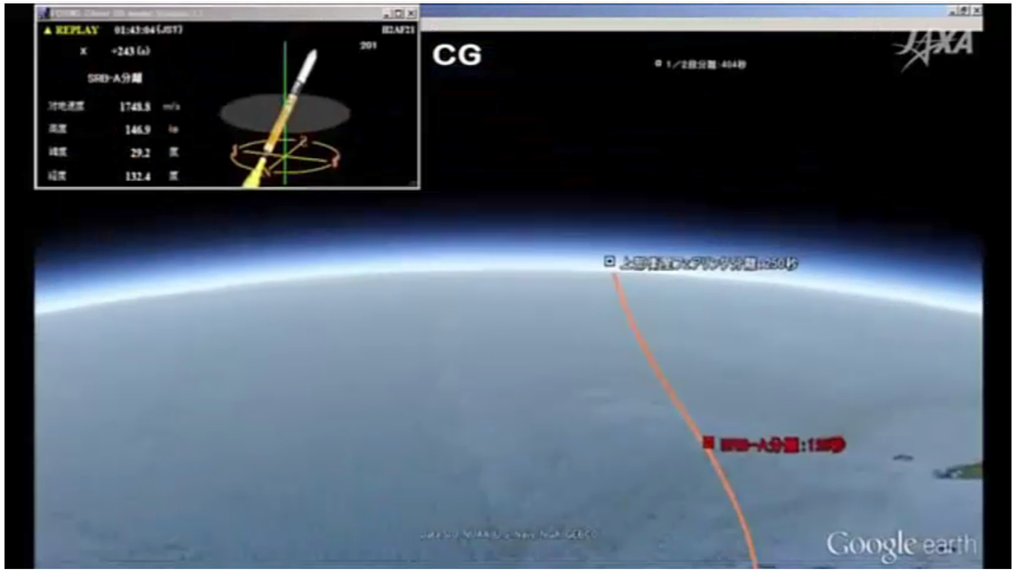
1. **Urban Mapping**

2. ***<u>On Demand</u>*** **and** ***<u>Fast Response</u>*** **for World Wide Complex Emergencies (Natural & Man Made Crisis/Disasters)**

3. **Defense & Intelligence applications: Surveillance, Reconnaissance Damage Assessment & Targeting**

DLR

German Heritage based on KompSat3



Instrument

Telescope Design	Astrium
Telescope Structure	Astrium
Focus Mechanism	DLR
Mirrors	SESO (Fr)
FPA	DLR
Real time correction	DLR
Image data Handling	Astrium
Formatter	Astrium
X-Band Modulator	USA
X-Band Antenna	Astrium

Next Modifications

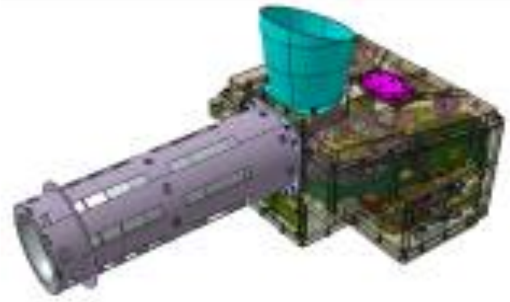
Mirror	Zeiss
X-Band Modulator	TeSat

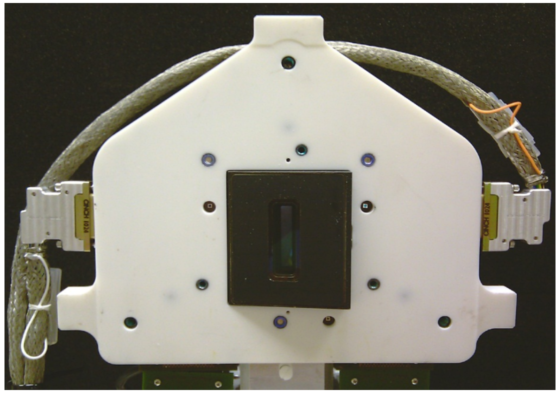
San Francisco, California, May 12, 2012

DLR

Recent Projects @DLR-OS

- MERTIS (MErcury Radiometer and Thermal Infrared Spectrometer)
- EnMAP
- Sentinal 4
- (OPSIS)
- FireBird
- DESIS on MUSES





Introduction

- DLR is involved in several hyperspectral missions for Earth remote sensing but also for deep space missions (e.g. the Mercury mission Bepi Colombo)
- Hyperspectral instruments are designed for detection of changes on planetary surfaces, oceans and the **atmosphere**
- They work in the UV, visible (VIS), near infrared (NIR), short wave infrared (SWIR) up to thermal infrared (TIR) spectral range
- Spectral sampling distance in the VIS/SWIR below 10nm
- In the spatial domain the instruments have 500 up to 1000 pixels with a Ground Sampling Distance (GSD) of about 30m up to 100m
- Calibration and performance verification procedures will be described as an example for the DLR Earth Sensing Imaging Spectrometer (DESIS) which will be installed on the Multi-User-System for Earth Sensing (MUSES) of the US Company Teledyne Brown Engineering Inc. (TBE) on the International Space Station (ISS)

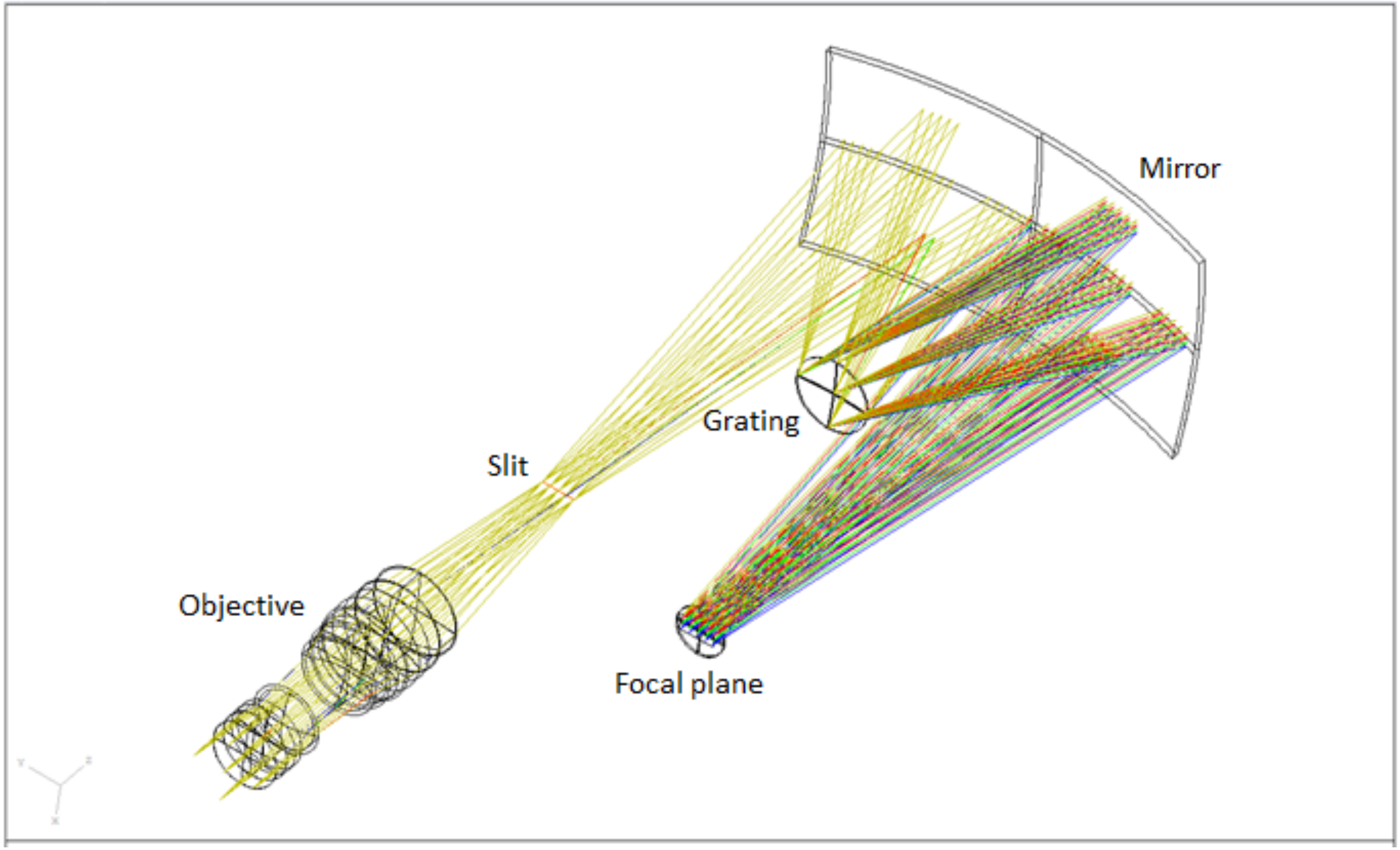
MUSES platform on ISS

Instrument Description

- Offner spectrometer, compact structure with a minimal number of optical components (lens, slit, primary mirror, convex grating and CCD array detector)
- corrected, telecentric lens objective (robust, easy adjustment, low mass) with flat field and minimal aberrations, no complicated multi-mirror system
- spherical primary mirror, which combines collimating and imaging optics
- **convex grating** as dispersion element, the appropriate optimization of the spectrometer at high spatial and spectral resolution up to a **flat focal plane** (a prerequisite for using plane CCD detectors)
- a specially designed groove profile of the grating leads to:
  - almost complete **suppression of the second order spectrum**
  - almost complete polarization insensitivity of the spectrometer over the entire spectral range
- In-orbit calibration with internal lamps besides the spectrometer slit and with a LED screen
- Pointing mirror unit

DLR

Optical scheme of DESIS



Optical performance data of DESIS for MUSES on the ISS (@330km/435km min/max)

Objective	4/100, telecentric
FOV	7.6° = 0.13rad = 44km/57km = 550pixel
IFOV (one pixel)	0.0074° = 0.13mrad = 79m/104m
Spectrometer type	Offner
Spectral range	450-950nm
Spectral channels	240
Spectral sampling	2.32nm
Polarization sensitivity	≤ 2%
Second order spectrum	≤ 0.3%
In-orbit calibration	2 internal lamps, LED screen
Pointing (along-track)	± 15°

Calibration and Performance Verification

1 Radiometric Calibration

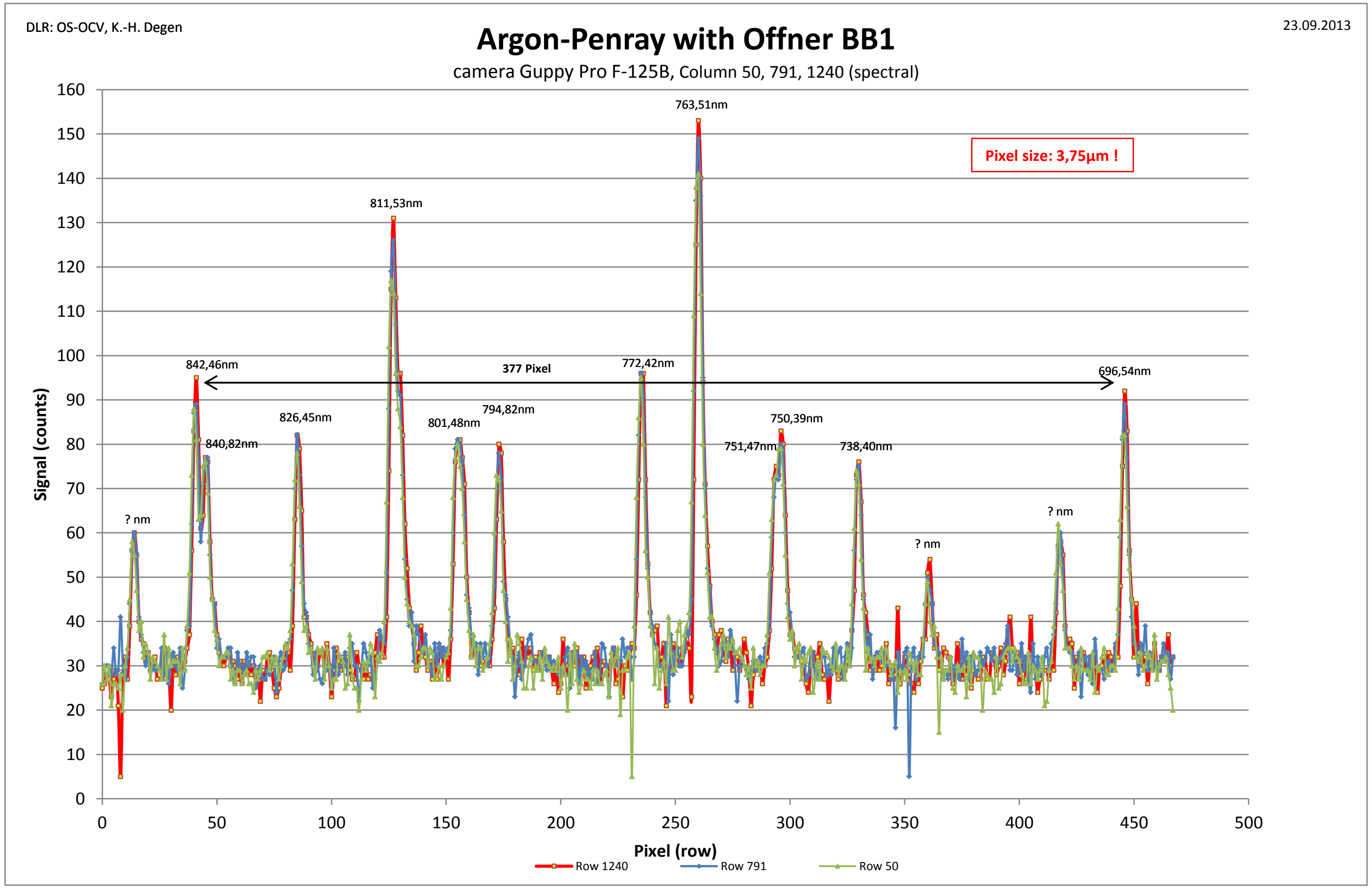
Following radiometric performance parameter are measured and derived for system verification:

- **Dark Current** (DC) and read noise measurements (including temperature dependence and dark signal non-uniformity DSNU)
- **Linearity**, saturation and non-linearity correction parameter as well as photo response non-uniformity (PRNU)
- Absolute radiometric calibration with **quantum efficiency** (QE) determination,
- **Photon transfer curve** (PTC) for system gain determination (necessary for QE and DC determination)
- Signal to Noise Ratio (SNR)

The measurements will be performed using a calibrated integrating sphere (irradiation level can be varied over a large range by shutters in front of the four QTH lamps, essential for linearity measurements).

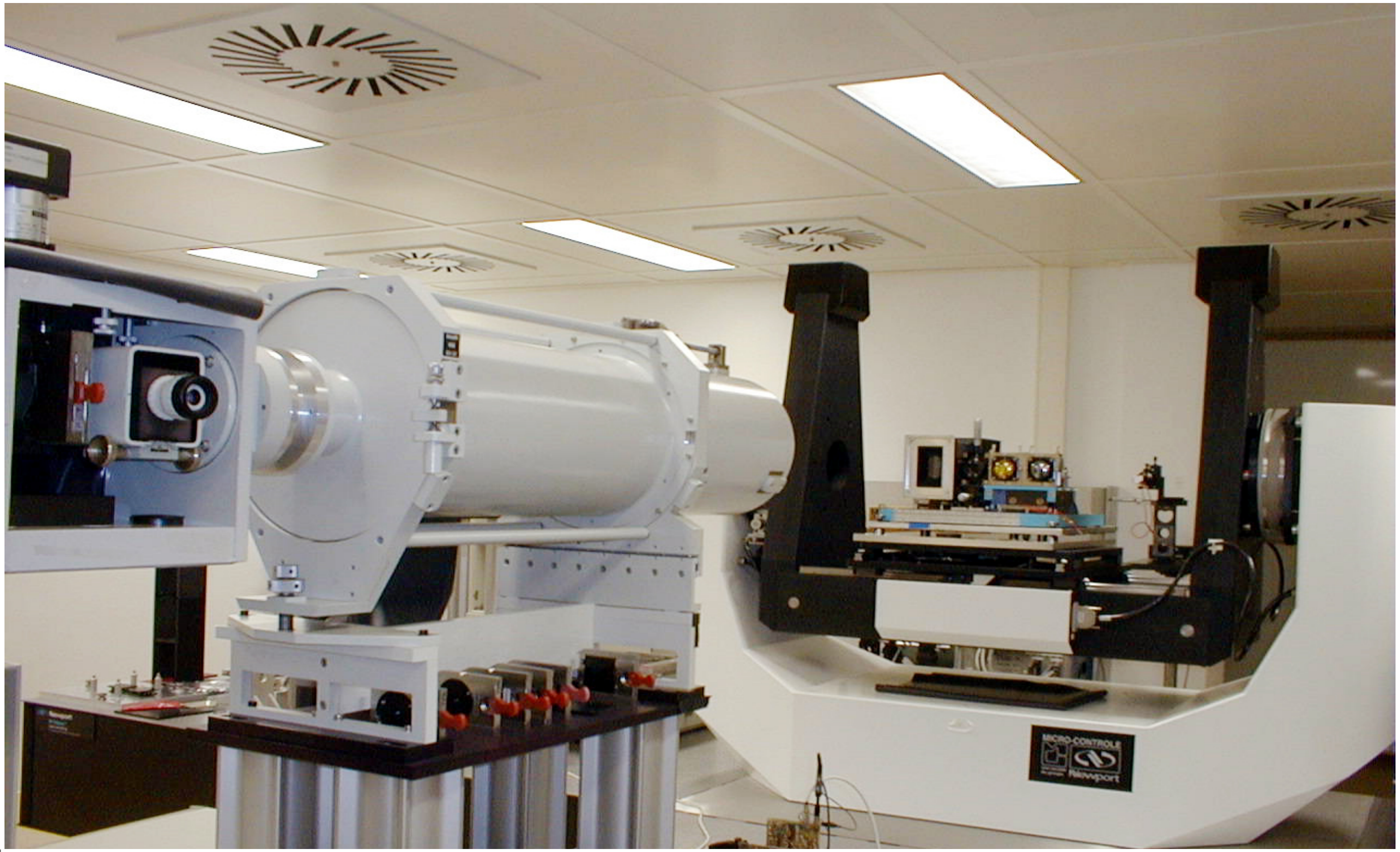
3.2 Spectral Calibration

Spectral measurements were performed using Penray lamps. Hg, Ar, Ne and Kr lamps were used for the spectral range from 450nm to 950nm.



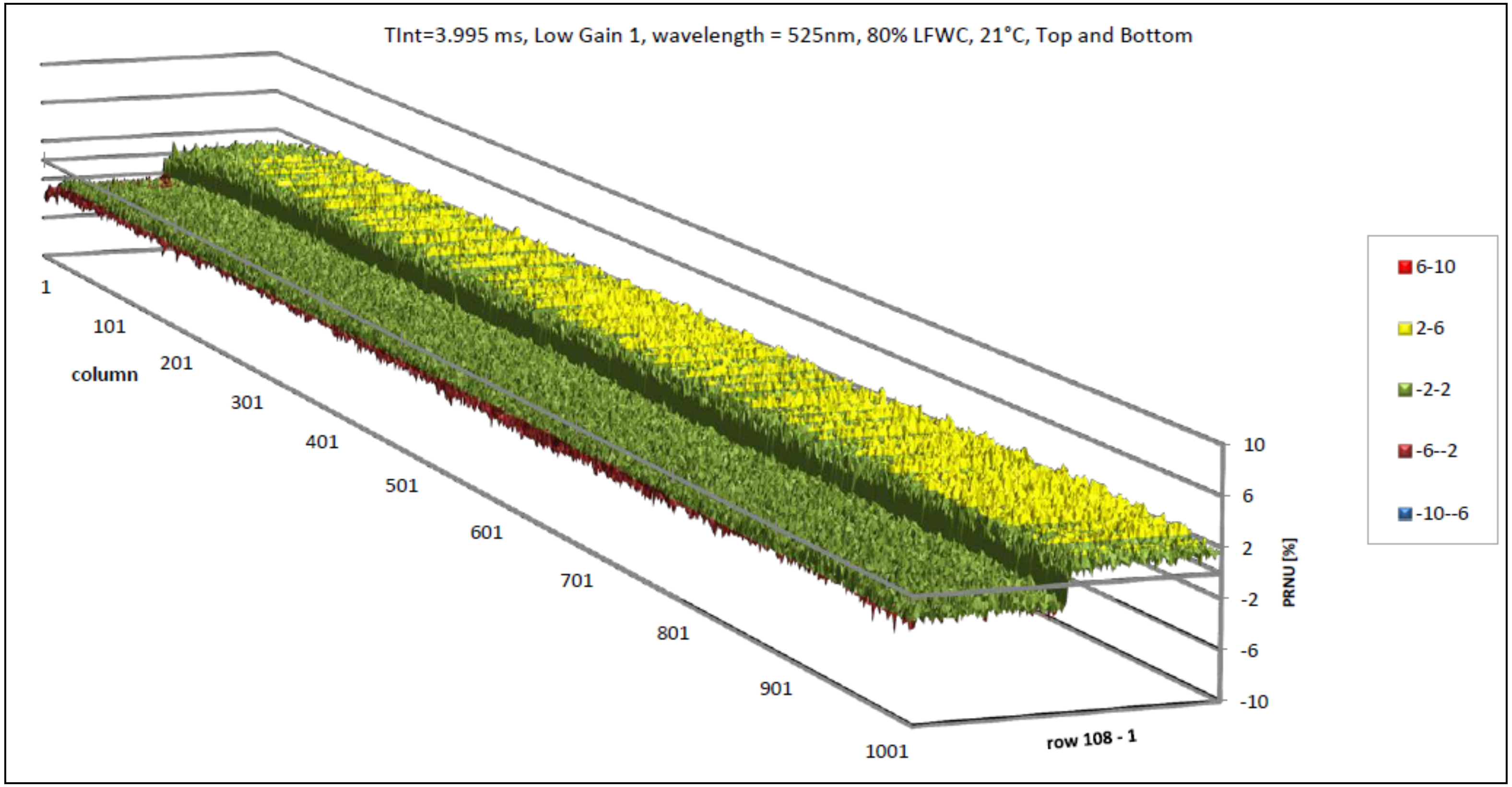
3 Spatial Calibration

The geometrical imaging performance will be determined by measuring the Line Spread Function (LSF) in spatial direction and subsequent determination of the **Modulation Transfer Function** (MTF) by Fourier transformation of the LSF.



4. First Results
4.1 Radiometric Investigations
4.1.1 PRNU

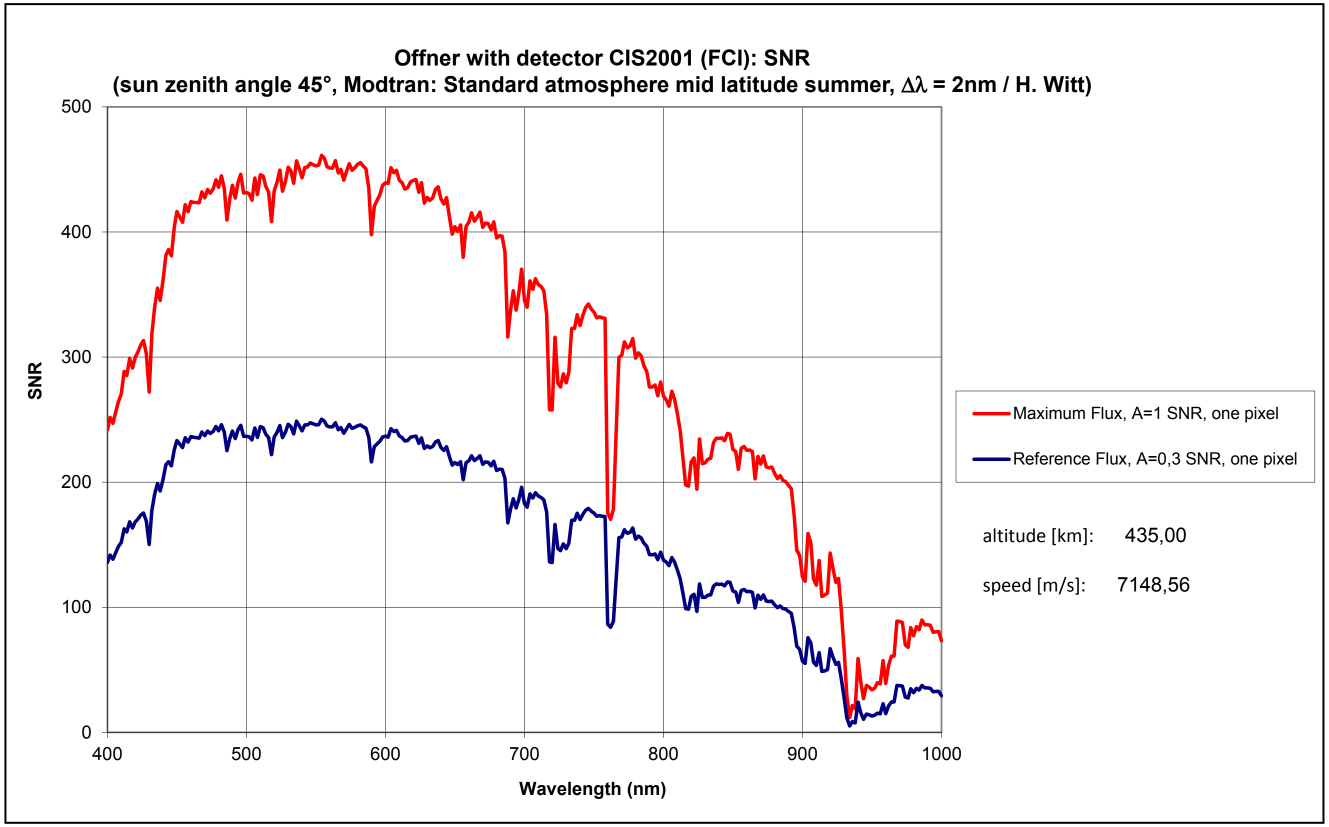
PRNU of CMOS detector



PRNU variation: about ± 3%

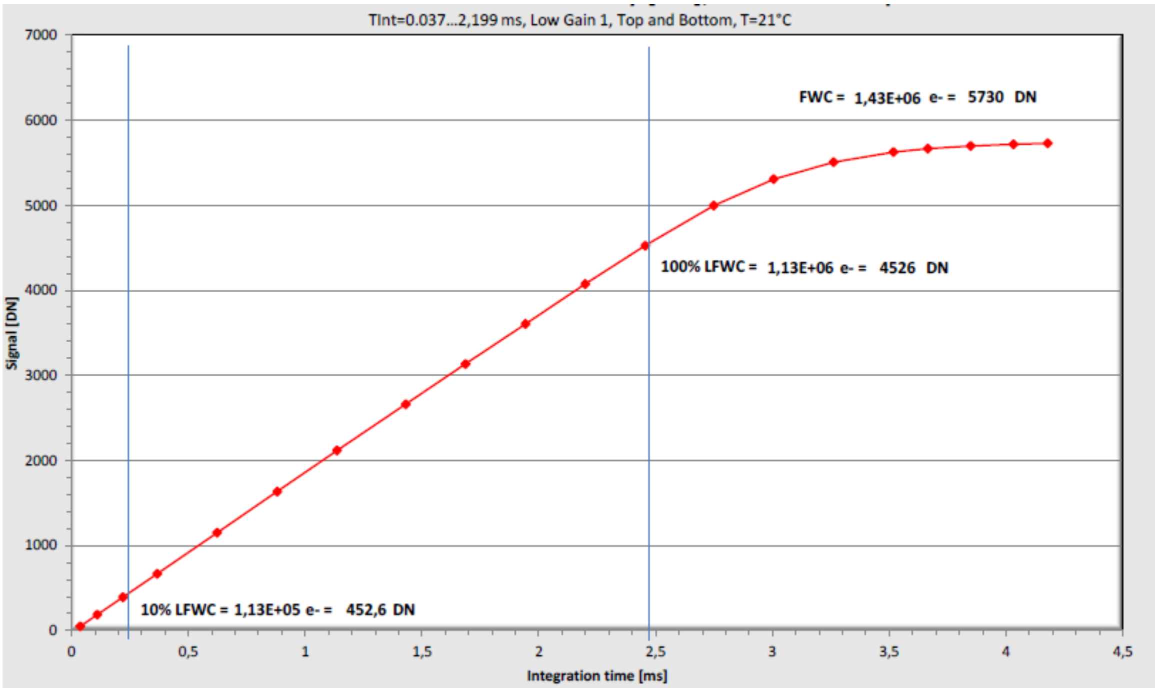
Signal to Noise Ratio (SNR)

- SNR was calculated with MODTRAN.
- Input parameters: altitude 435*km*, standard mid latitude summer atmosphere, albedo 0.3 (blue curve) and 1.0 (red curve)
- The required SNR=200 @ 550*nm* will be met



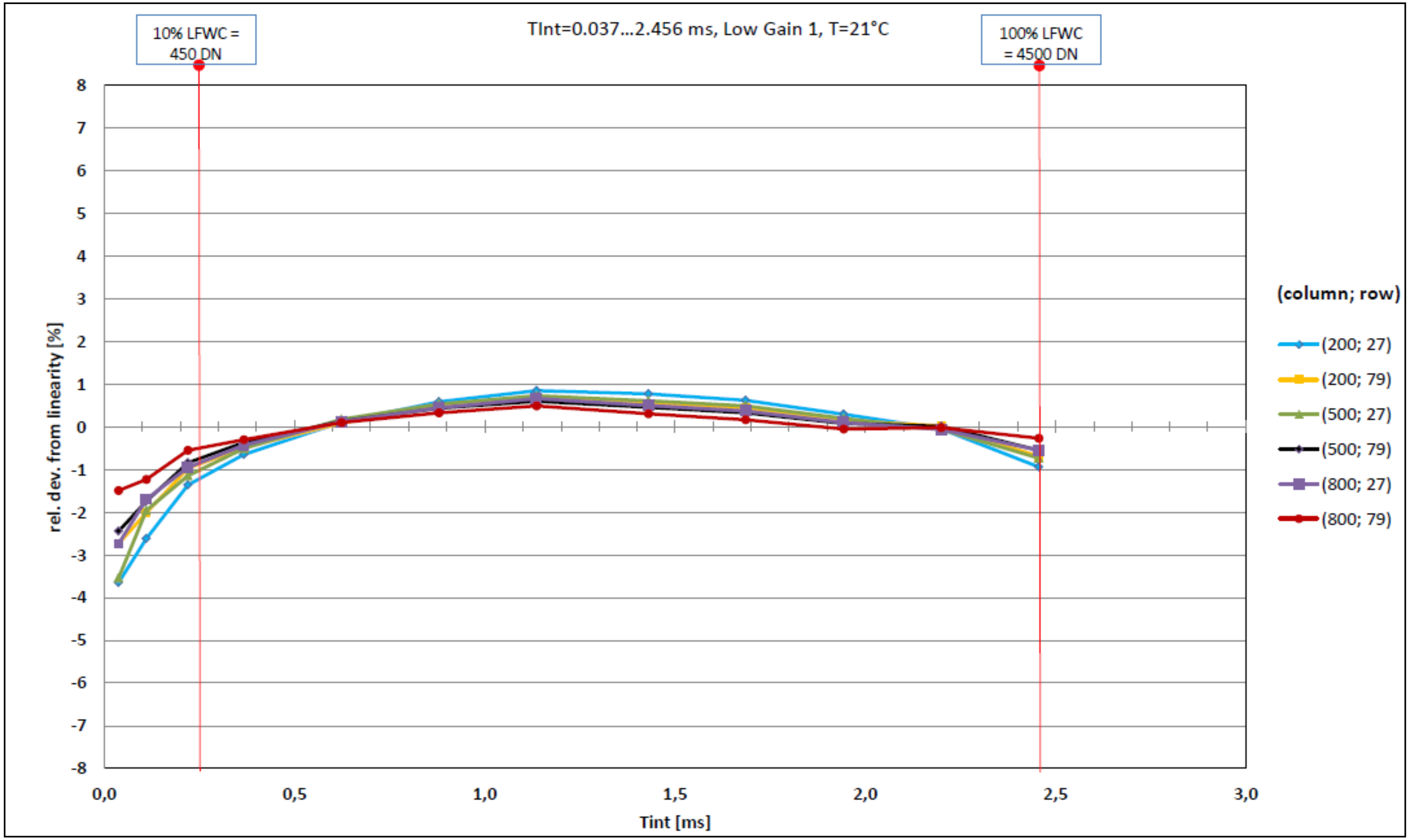
4.1.3 Linearity

- Linearity was measured by variation of the integration time at constant illumination level
- Deviations from linearity: between 10% and 100% LFWC in the order of ±1%.
- Nonlinearity can be corrected by polynomial function
- Residual deviations can be reduced up to 0.02%.



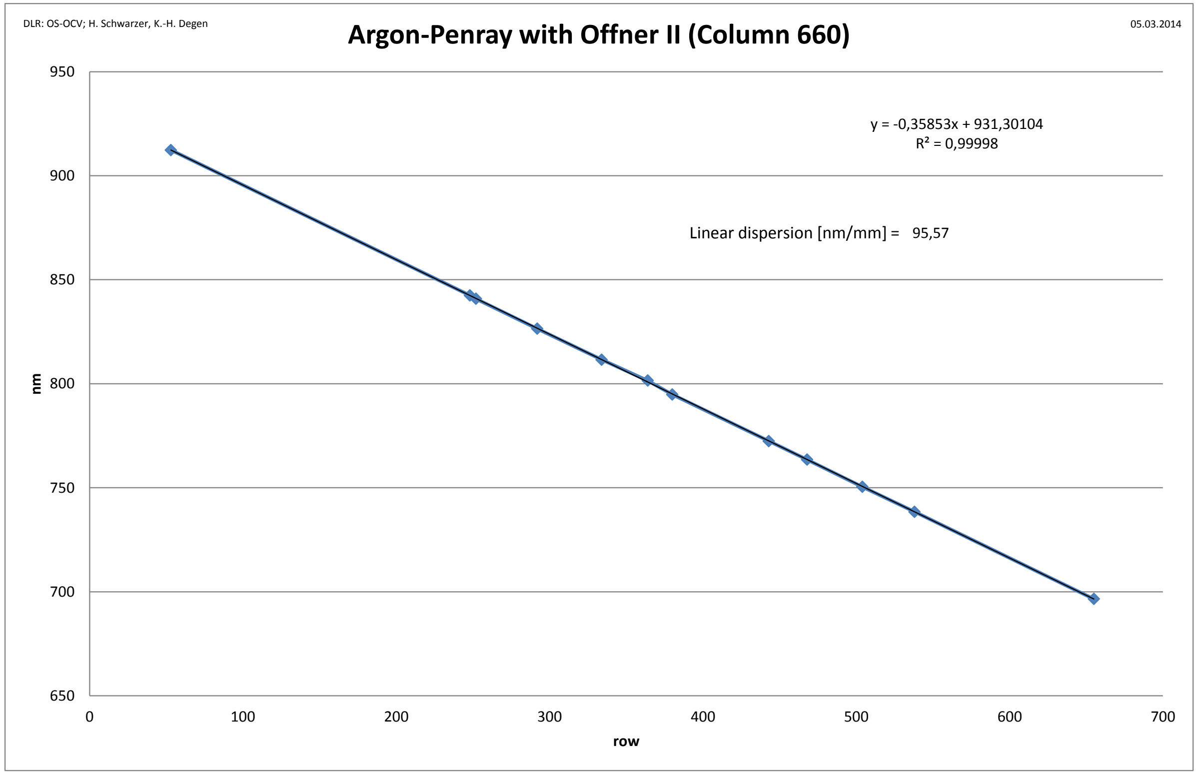
DLR

Non linearity of CMOS-detector

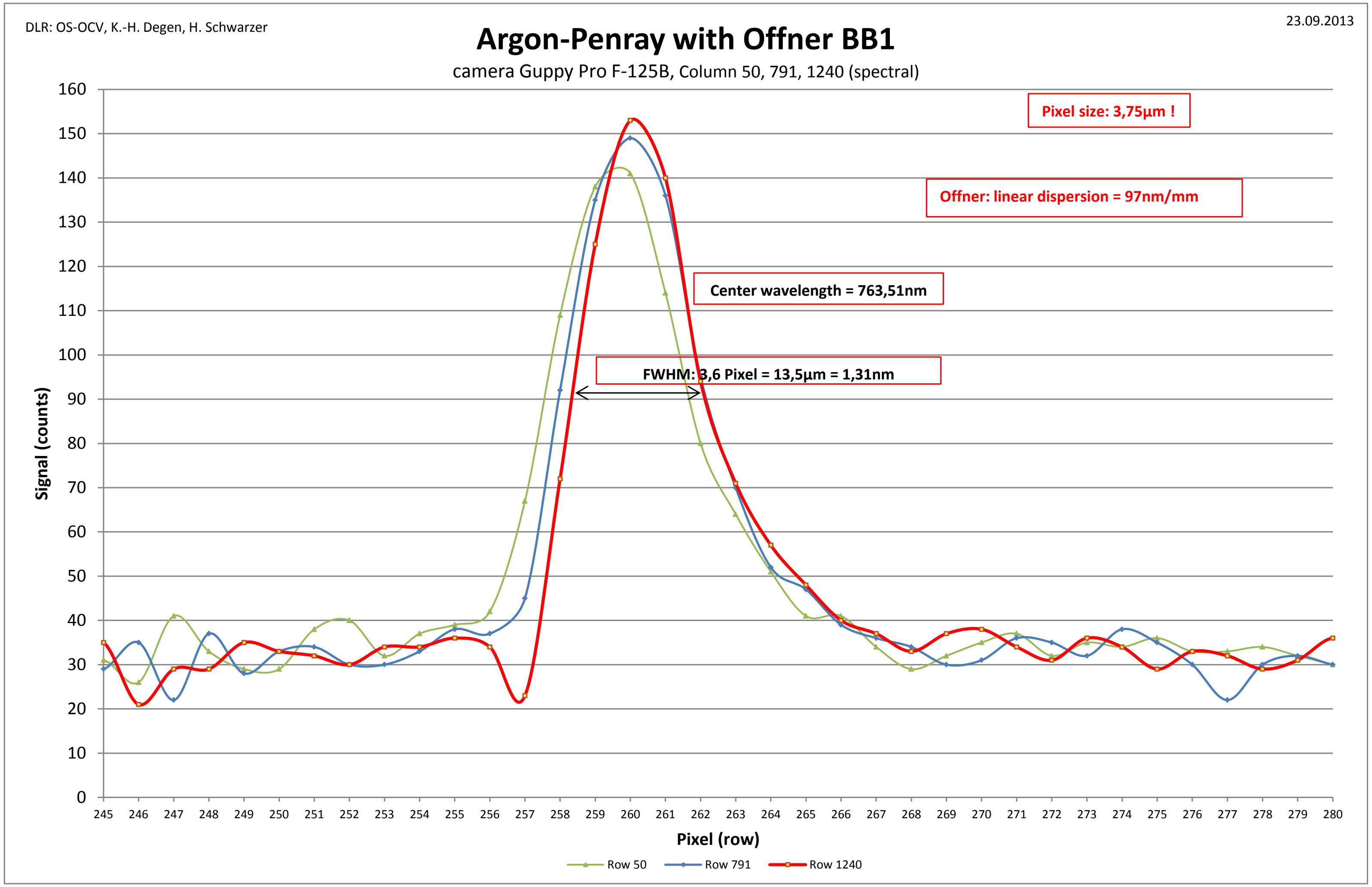


4.2 Spectral Behavior

- Linear dispersion and the equidistance of the position of the spectral channels was checked
- Linear dispersion of 95.56nm/mm confirms the simulated data
- Dispersion curve is highly linear -> strongly equidistant spectral channels
- Spectral sampling distance is 2.32nm



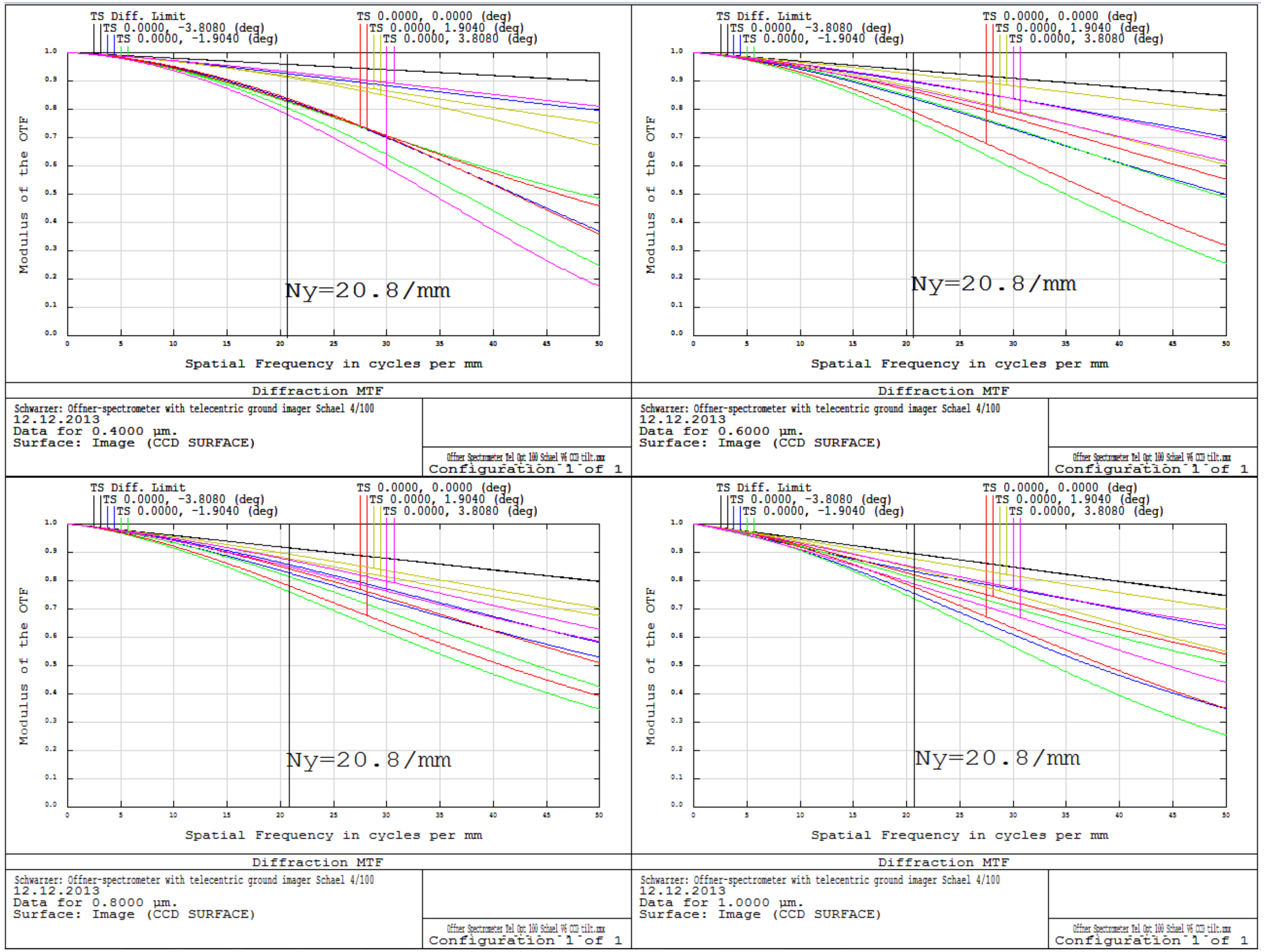
Spectral resolution in terms of FWHM of the 763.5nm Ar line



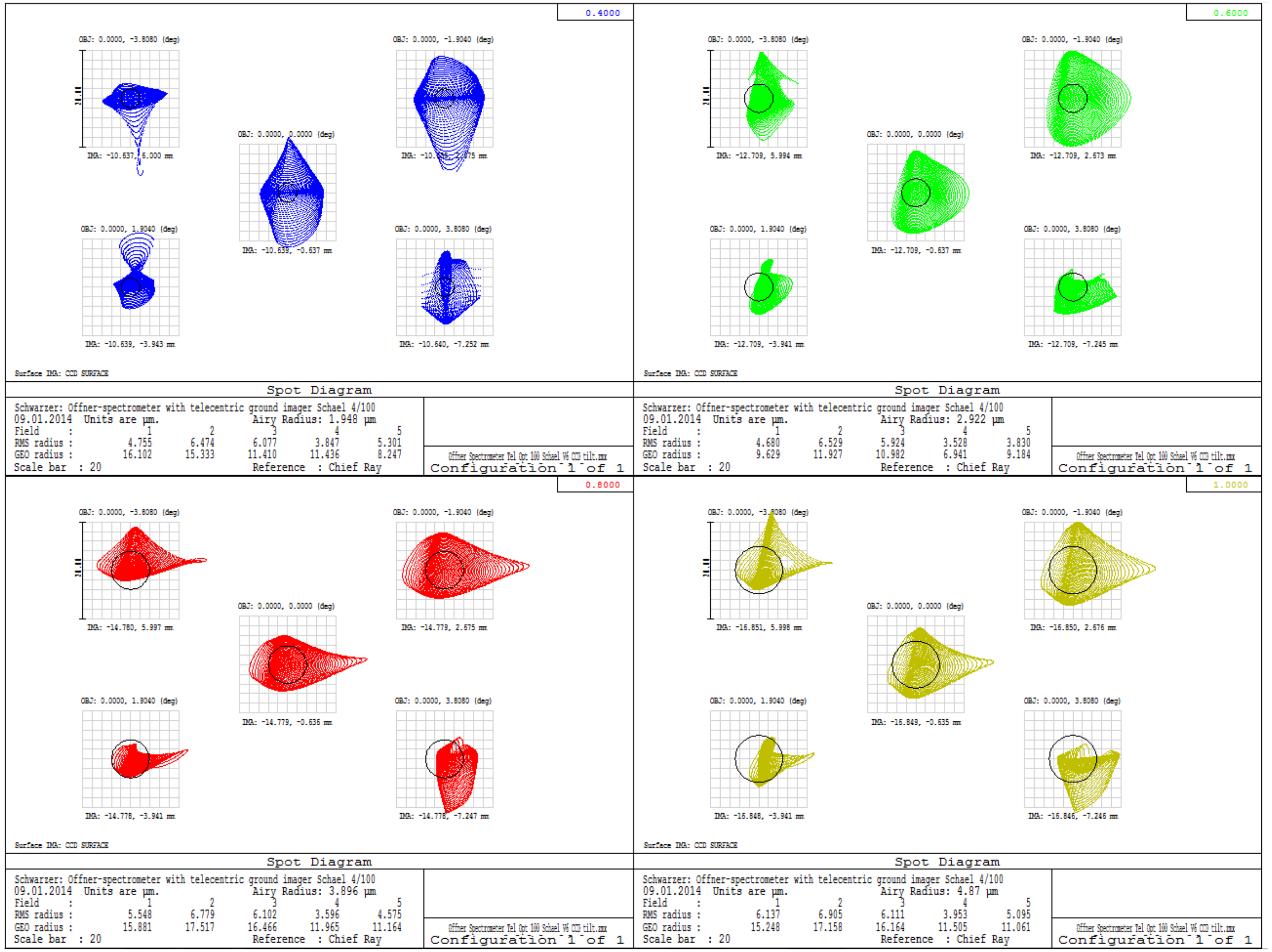
Spatial Resolution

- The optical performance was simulated and optimized using Zemax
- MTF simulation for different wavelength (400, 600, 800 and 1000nm) and for different field angles (0.0°, ±3.5° and ±7.0°)
- Nyquist frequency Ny corresponding to the pixel size of 24*µm* is 20.8lp/mm in each figure. The scaling of the squares is 20µm
- Spot diagrams are nearly completely inside the pixel area of $24 \cdot 24 \mu m^2$ (Airy radius is marked by black circles)
- Distortion (smile and frown) is very small
  - in spatial direction ±6*µm*
  - in spectral direction ±3*µm*

MTF of DESIS


TS Diff. Limit
TS 0.0000, -3.8080 (deg)
TS 0.0000, -1.9040 (deg)
TS 0.0000, 0.0000 (deg)
TS 0.0000, 1.9040 (deg)
TS 0.0000, 3.8080 (deg)
Modulus of the OTF
Spatial Frequency in cycles per mm
Ny=20.8/mm
Diffraction MTF
Schwarzer: Offner-spectrometer with telecentric ground imager Schael 4/100
12.12.2013
Data for 0.4000 µm.
Surface: Image (CCD SURFACE)
Configuration 1 of 1
Data for 0.6000 µm.
Data for 0.8000 µm.
Data for 1.0000 µm.

Spot diagrams in DESIS focal plane



5. Summary and Conclusion

- The engineering model of the DESIS instrument was tested, calibrations were carried out and performance data were verified
- The results show the compliance with the requirements and with the simulated parameters
- In the next step the flight model with the original detector will be accomplished, adjusted, calibrated and verificated.

Acknowledgements

The authors would like to thank all the colleagues who have supported this work, especially Karl-Heinz Degen for performing the measurements.

References

[1] Andreas Eckardt, Ralf Reulke, Horst Schwarzer, Holger Venus, and Christian Neumann. sCMOS detector for imaging VNIR spectrometry, 2013.

[2] Herbert Jahn and Ralf Reulke. *Systemtheoretische Grundlagen optoelektronischer Sensoren*. WILEY-VCH Verlag GmbH and Co. KGaA, 2009.

LowCost3D

- Sensors, Algorithms, Applications
- 2. and 3. December 2014 (Zusammen mit 3DNO)
- Technische Universität Berlin
- Straße des 17. Juni
  10623 Berlin - Germany
  The Workshop is part of the 3D Event Cluster Berlin "berlin3d.net"

Call for Papers, Presentations, Demonstrations

- Deadlines:

- Abstract submission (paper / presentation) until 01.11.2014