Calibration of Ocean Colour Sensors

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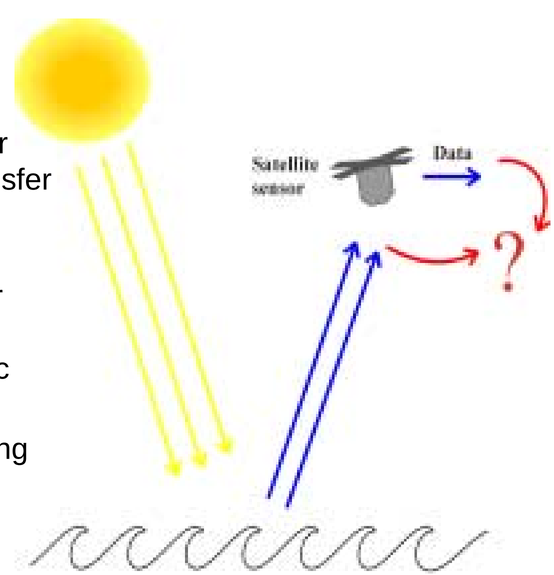
- What is Calibration, why do we need it?
- Sensor Components
- Definition of Terms
- Calibration Standards
- Pre-launch Calibration
- In-orbit Calibration
- Intercalibration between Sensors
- NASA‘s SIMBIOS Programme

Introduction - What is Calibration?

- Calibration: establish the link between sensor output signal (voltage, digital numbers) and absolute physical values at sensor input, i.e. describe the overall transfer function of the sensor
- calibration is a part of sensor characterisation, here in particular with respect to spectral and radiometric parameters (geometric calibration here not considered)
- parameters to be determined during calibration process depend on:
  - sensor principle
  - detector type
  - application



Why do we need calibration?

- In „Ocean Colour" we are talking mainly about quantitative remote sensing, i.e. the retrieval of parameters in terms of absolute values (concentrations of water constituents, aerosol content in the atmosphere etc.)
- The retrieval algorithms use values of spectral radiances (respectively derived reflectances) for the inversion procedure, the accuracy of the retrieval strongly depends on the accuracy of the radiance measurement.
- The validation of measurements as well as of used models and algorithms need a link between data acquired in-orbit and ground-based or airborne measurements

Sensor Components

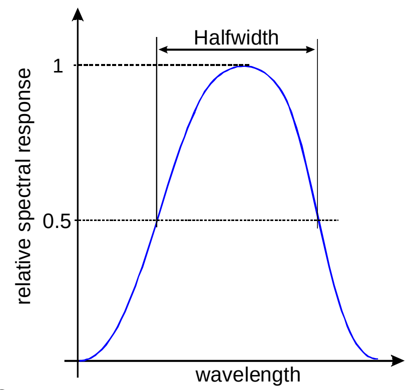
Imager/ Optics	Spectral selection unit	Focal Plane/ Detector
• Mechanical scanner • Pushbroom camera • Imaging spectrometer	• Filter • Grating • Prism	• single detector • linear array • 2D-array

Calibration characterizes the overall performance of the sensor with respect to spectrometry and radiometry , absolute and relative.

Remark: since we focus on Ocean Colour, the following implicitely refers to the VIS/NIR spectral range (~400 ... 1000 nm)

Definition of Terms (I)

- **spectral irradiance** E(λ): light flux per unit area ($Wm^{-2}nm^{-1}$)
- **spectral radiance** L(λ): light flux per unit area and solid angle ($Wm^{-2}sr^{-1}nm^{-1}$)
- **reflectance** R(λ): normalisation of upwelling and downwelling fluxes
  $R(\lambda) = E_u(\lambda)/E_d(\lambda)$
  the reflectance is directly related to target properties
- **spectral response function**: relative response of a spectral channel in an instrument as a function of wavelength
- **spectral halfwidth**: width of the spectral response function at 50% of maximum value



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Definition of Terms (II)

- **dark signal**: signal measured at instrument output with zero light at the entrance, caused mainly by thermal fluctuations in detector and electr.
- **dark signal non-uniformity (DSNU):** differences in dark signals of single pixels of a linear or 2D detector
- **sensitivity:**
  a) slope of the relationship between input and output signals
  b) minimum signal that can be measured by a sensor
- **dynamic range:** ratio of maximum and minimum measurable signal
- **noise-equivalent radiance NEΔL**: minimum resolvable change in input signal, which can be detected (related to **radiometric resolution**)
- **signal-to-noise ratio (SNR):** ratio of usable signal to non-interpretable portion of the signal (i.e. noise) at a given input signal level
- **non-linearity**: deviation from the ideal, linear relationship between input and output signals of an instrument

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Definition of Terms (III)

- **pixel-related non-uniformity (PRNU):** normalised relative slope of the response of different pixels in a linear or 2D detector
- **flat-field response:** relative response of the sensor over the total field of view when looking on a homogenous target (includes optical effects and PRNU)
- **polarisation sensitivity:** sensitivity of the sensor to polarized light at the input

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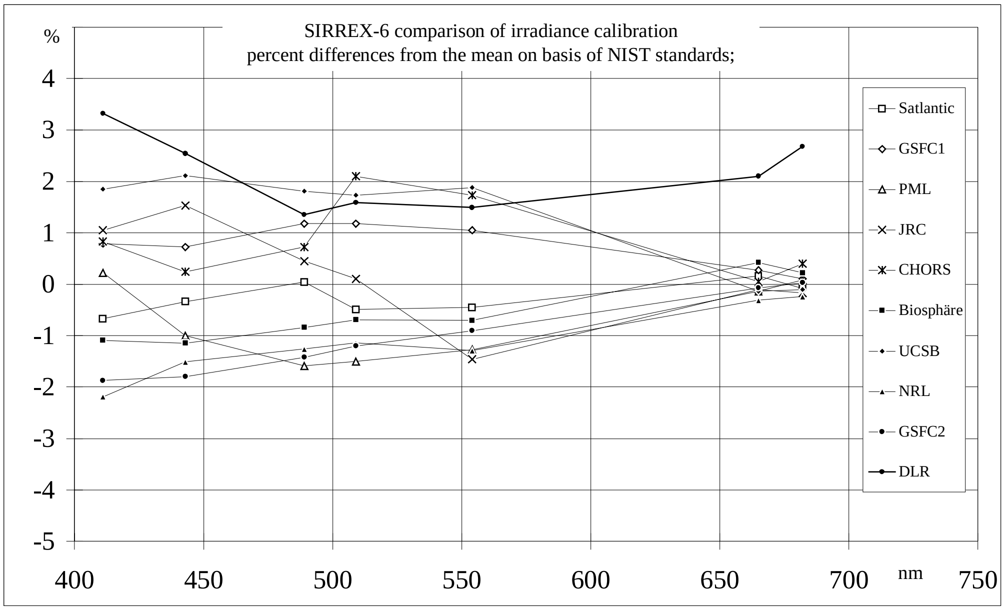
Calibration Standards

- Calibration standards are usually defined by corresponding national authorities, which are linked to international standards. They provide reference light sources with known spectral distribution as well as measurement setups to transfer this primary standard to other light sources, usually by means of transfer radiometers.
- Specific protocols are recommended by international organisations (in our case Committee of Earth Observation Satellites CEOS)
- Irradiance sources (standards) are usually lamps with a known spectral distribution, based on the link to the national standard laboratory
- Radiance sources (standards) are either calibrated radiometric spheres or a setup of a lamp and a diffuser disk with known properties

Intercomparision of Laboratory Standards



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Pre-launch Calibration

- Covers all measurements by laboratory means before instrument delivery for launch to describe spectral and radiometric sensor performance
- Goal: initial set of parameters which serves as reference for monitoring in-orbit performance and/or in-orbit calibration as well as initial functions to be used for data processing to basic physical values
- needs extensive laboratory setups, careful and time-consuming measurements
- general problem: due to lower temperature laboratory sources do not correspond to the spectrum of the Sun - signals are too low in the blue, too high in the red

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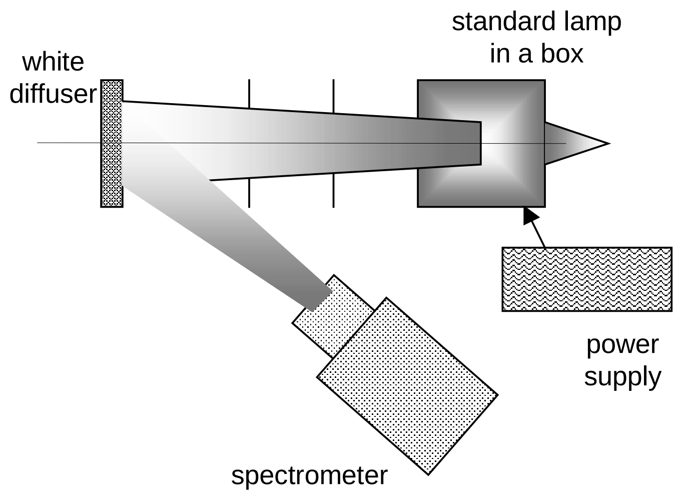
Radiance Calibration (I)

- Using lamps + diffusor



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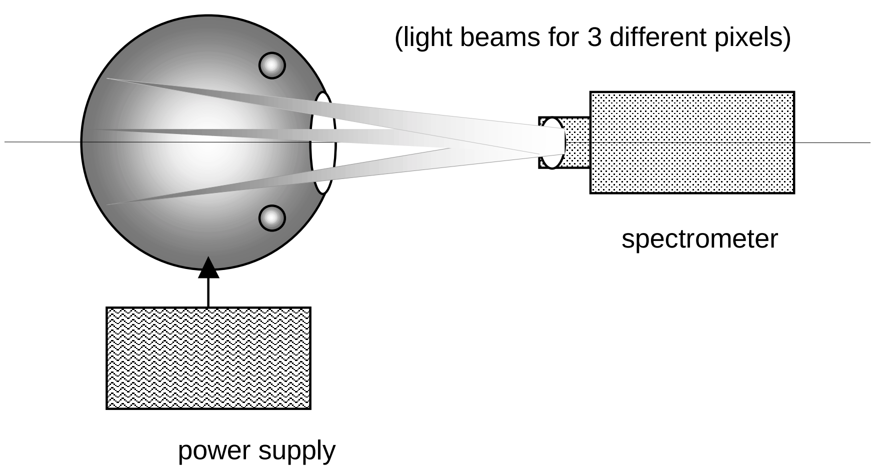
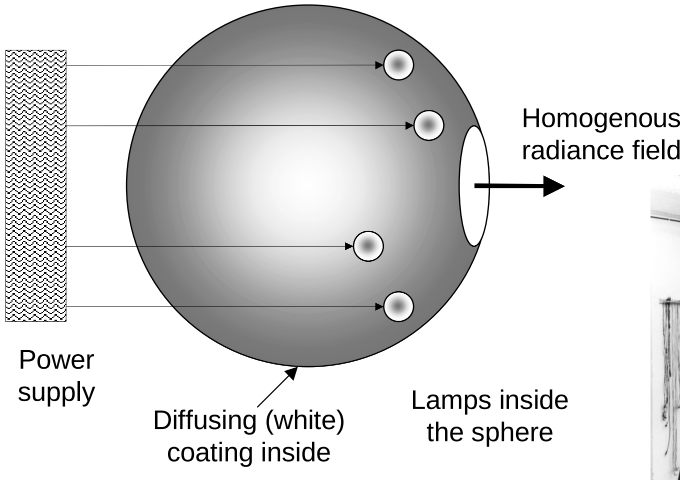
Radiance Calibration (II)

- Using radiometric sphere (Ulbricht-Sphere)



Radiometric Sphere



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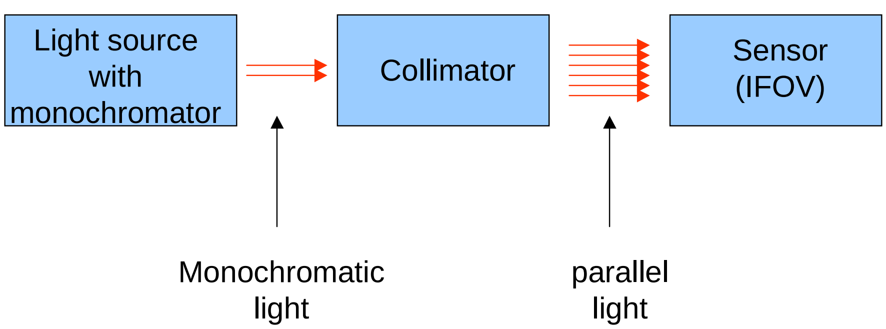
Spectral Calibration



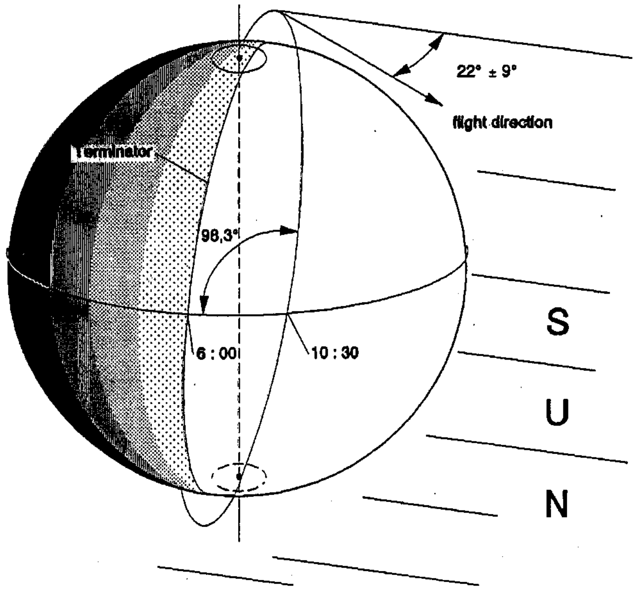
In-orbit Calibration

- Covers all measurements made in orbit to either re-calibrate the sensor or to monitor and quantify changes in instrument parameters
- Why? All instrument parameters are changing with time due to different degradations caused by:
  - „normal" aging processes
  - contamination of optical parts in orbit
  - exposure of optical parts to Sun light and radiation (UV, particles)
  - exposure of detectors and electronics to radiation (particles)
- In-orbit calibration is essential to ensure valuable data during the lifetime of the instrument through monitoring of sensor stability
- gives the basis to account for possible sensor changes in the data processing

Absolute Calibration in Orbit

- In principle two ways are possible:
  - availability of an absolute calibration source on the satellite
  - measurement of the extraterrestrial Sun irradiance
- Sun Calibration is the usual way implemented in several ocean colour instruments (e.g. MOS, SeaWiFS, MERIS)
- advantages:
  - the Sun is the most stable light source
  - includes the complete sensor performance from entrance optics up to the detector
  - allows to refer nadir measurement to the natural illumination source (top-of-atmosphere reflectance)
- problem: degradation of the diffuser
- Realisation of Sun calibration requires for:
  - a diffuser on board to convert the Sun's irradiance into radiance
  - moving parts to put the diffuser in front of the entrance optics

Principle of the Sun Calibration in Orbit



During terminator crossing over the North pole (MOS-IRS)

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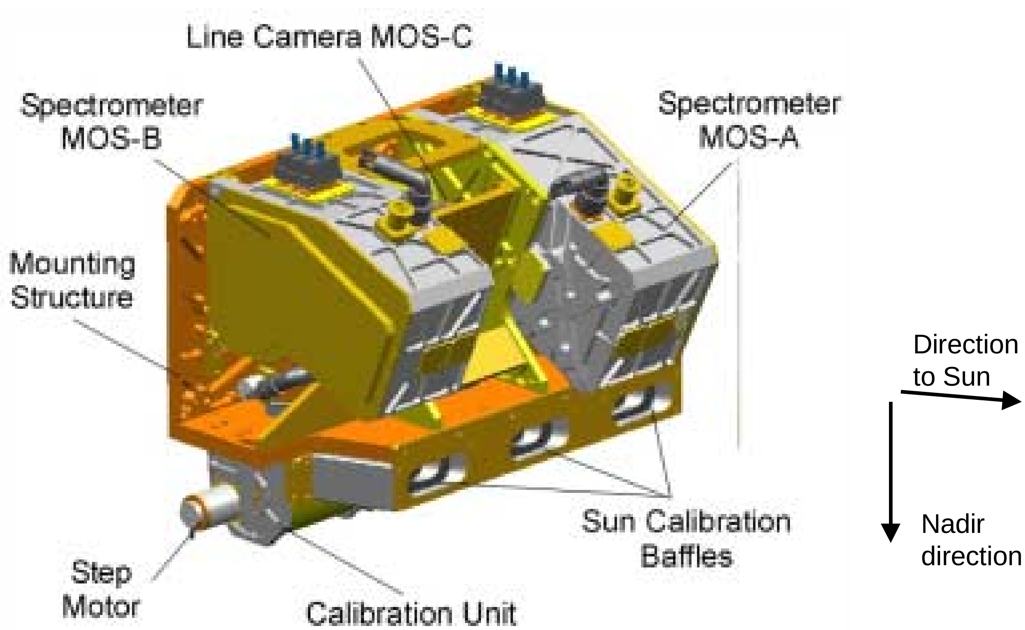
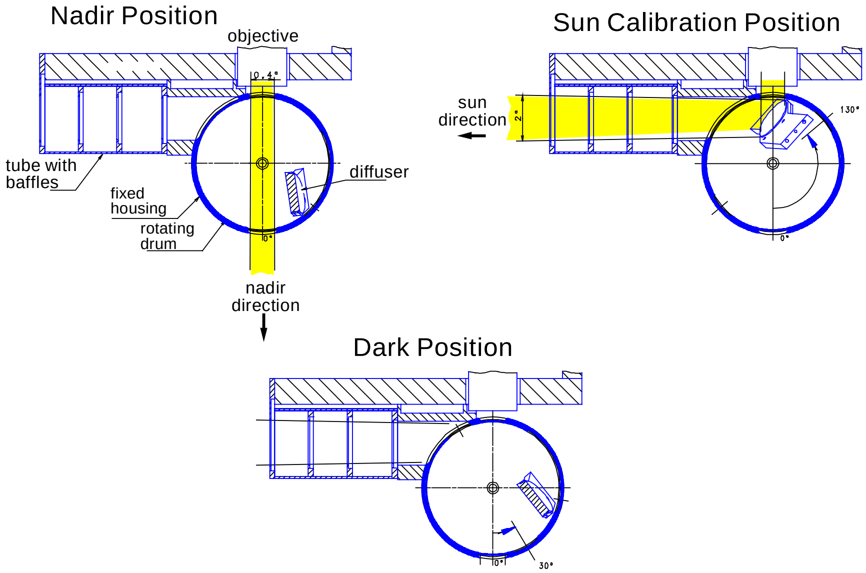
MOS-IRS Sun Calibration (I)



MOS-IRS Sun Calibration (II)



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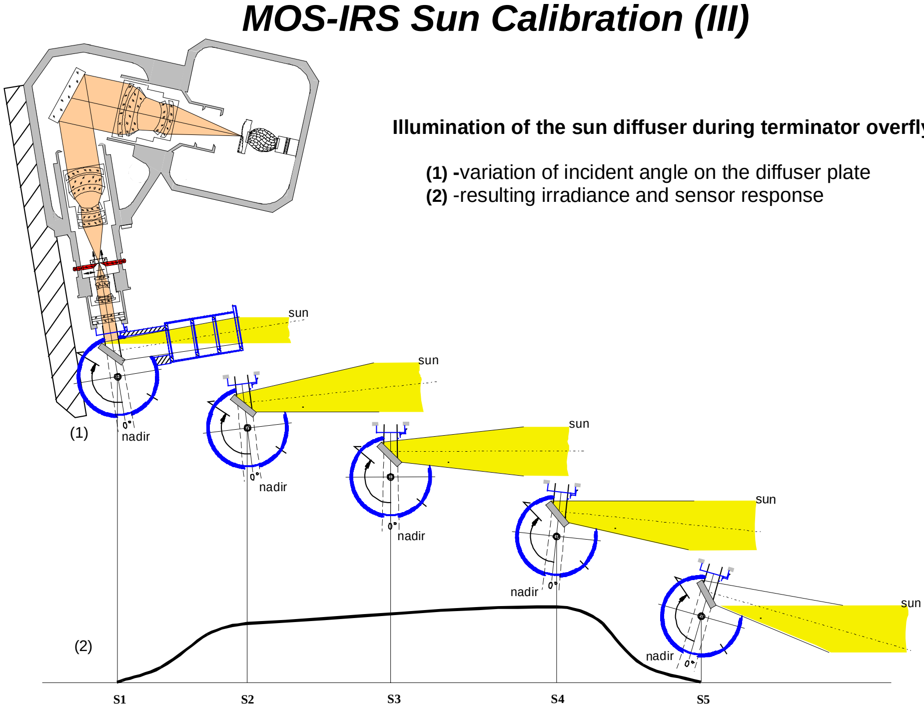
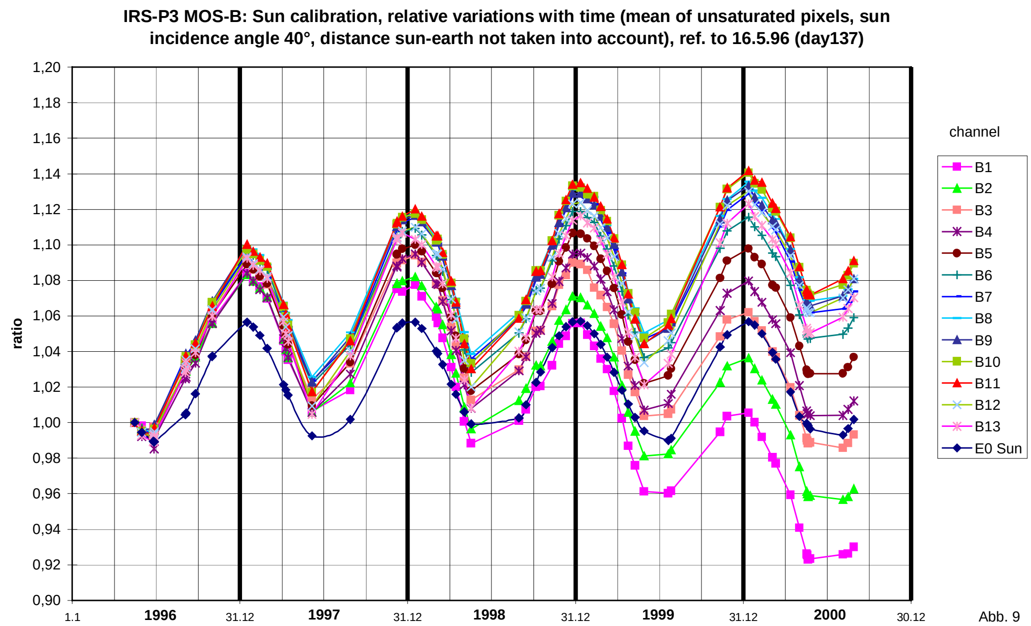
MOS-IRS Sun Calibration (III)

Illumination of the sun diffuser during terminator overfly

(1) -variation of incident angle on the diffuser plate
(2) -resulting irradiance and sensor response



MOS-IRS Sun Calibration (IV)



Relative Calibration in Orbit

- Monitoring and quantification of sensor parameters with respect to a reference status (e.g. pre-launch calibration or initial post-launch status) using non-calibrated in-orbit means:
  - built-in light sources like lamps or LEDs
  - extra-terrestial sources, e.g. the Moon
- Lamps:
  - do not necessarily cover the entire optical path, depending on construction
  - allow special features, e.g. linearity check, spectral properties, ...
  - problem: long term stability, spectral irradiance ditribution
- Moon:
  - covers entire path from entrance optics to detector
  - does not fill the total FOV for pushbroom instruments
  - may cause problems due to inhomogeneity

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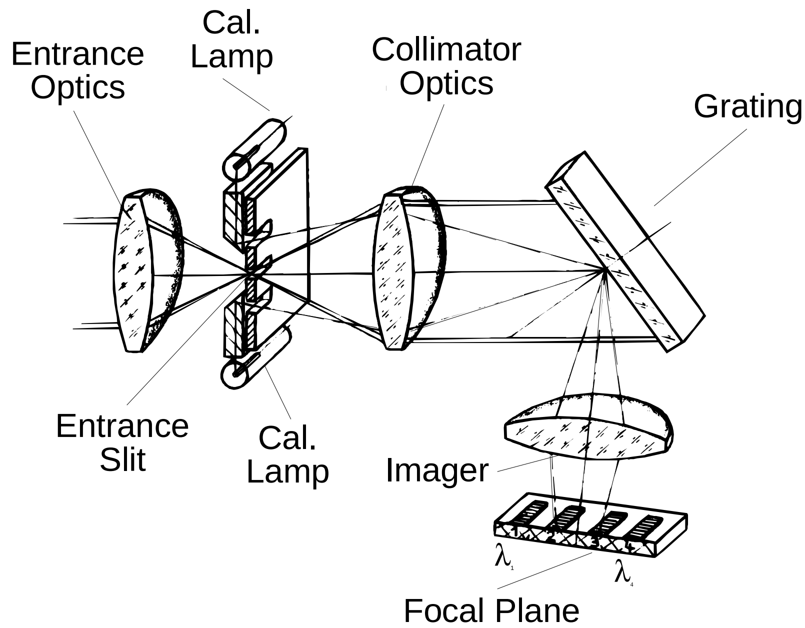
MOS-IRS Internal Calibration (I)



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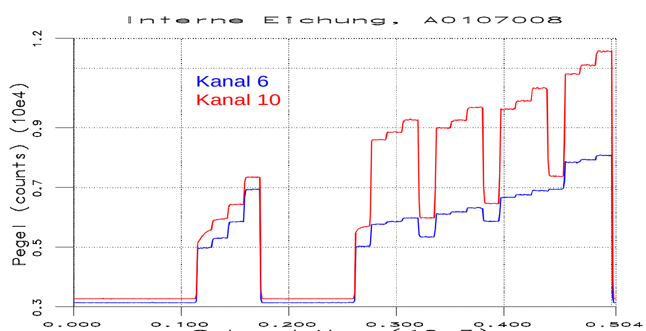
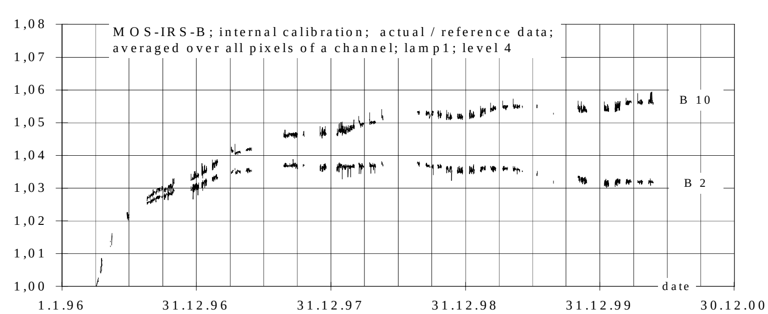
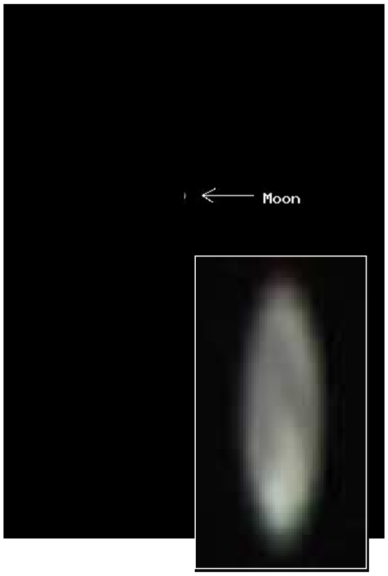


MOS-IRS Internal Calibration (II)

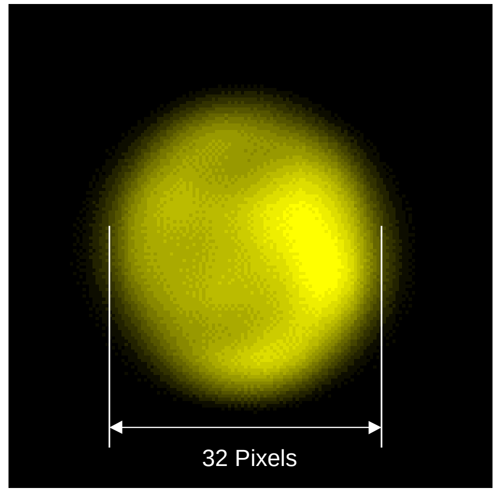


Moon Calibration

SeaWiFS



MOS



Images: NASA SeaWiFS Project

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Intercalibration between Sensors - Why?

- After ocean colour satellites matured from experimental to operational systems there are several satellites orbiting carrying different sensors, corresponding to different scientific mission goals
- The sensors acquire data of the same phenomena at different overflight time and with their specifics, e.g. with respect to viewing geometry, spectral or spatial resolution
- These measurements may complement each other and give new insight through synergetic investigations
- Therefore a unified scale for different instruments is necessary

- ideal goal would be to have a common absolute scale for all sensors

Intercalibration between Sensors - How?

- Since all sensors are calibrated pre-launch to a laboratory standard, this calibration can be linked together using transfer radiometers (see above for the problems)
- once in-orbit, the situation is more complicated: intercalibration can be achieved by common measurements of dedicated targets or sources like the Sun, the Moon or selected nadir test sites
- Another problem is the intercomparision (or intercalibration) of derived products (e.g. Chlorophyll concentrations) - this involves the entire discussion about different retrieval algorithms, bio-optical models etc.

Problems of Sensor Intercalibration

- The Sun shall be used as a common source, but still differences while looking at other targets may occure. However, the Sun forms a common normalisation standard.
- inhomogenity and small size make Moon measurements less favourable for ocean colour sensors, but as a “grey” reflector the Moon is a very stable medium level reference
- different overpassing time and different viewing geometries affect the direct comparability of TOA data. However, since TOA radiance is the primary measured parameter, it should be the value to be compared.
- computation of BOA values involves different atmospheric correction procedures and models and does not answer the question what is the “truth” on ground. The way out is the “normalisation” to an agreed reference measurement (for SIMBIOS: MOBY)

NASA's SIMBIOS Programme

(cp. http://simbios.gsfc.nasa.gov/)

- Consists of the SIMBIOS Science Team and the SIMBIOS Project Office
- The SIMBIOS program is substantially augmented by the participation of the NASA-supported MODIS Oceans Team and SeaWiFS Calibration and Validation program
- SIMBIOS supports four primary activities:
  - data product validation
  - sensor calibration
  - data merger algorithm evaluation
  - satellite data processing.
- The data processing facility is operational and is scaled for limited data storage (in situ and satellite), product generation, and analyses support as required for SIMBIOS specific investigations.