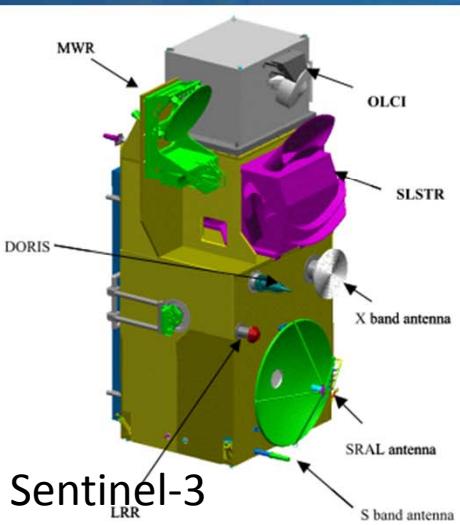


MERIS & OLCI calibration

Lessons learnt from MERIS



Ludovic Bourg, Steven Delwart

EO Level 1 Lessons Learned , ESRIN, June 2013

OVERVIEW

A. MERIS

1. Instrument & processing overview
2. Radiometric calibration method & results
 - Instrument degradation
 - Diffuser ageing
3. Spectral Calibration method & results
 - Spectral Features of Erbium doped diffuser
 - Solar Fraunhofer Lines on white diffuser
 - O2-A earth view Spectral Campaigns
 - Instrument spectral model
 - Spectral Stability
4. Conclusion

OVERVIEW

B. OLCI

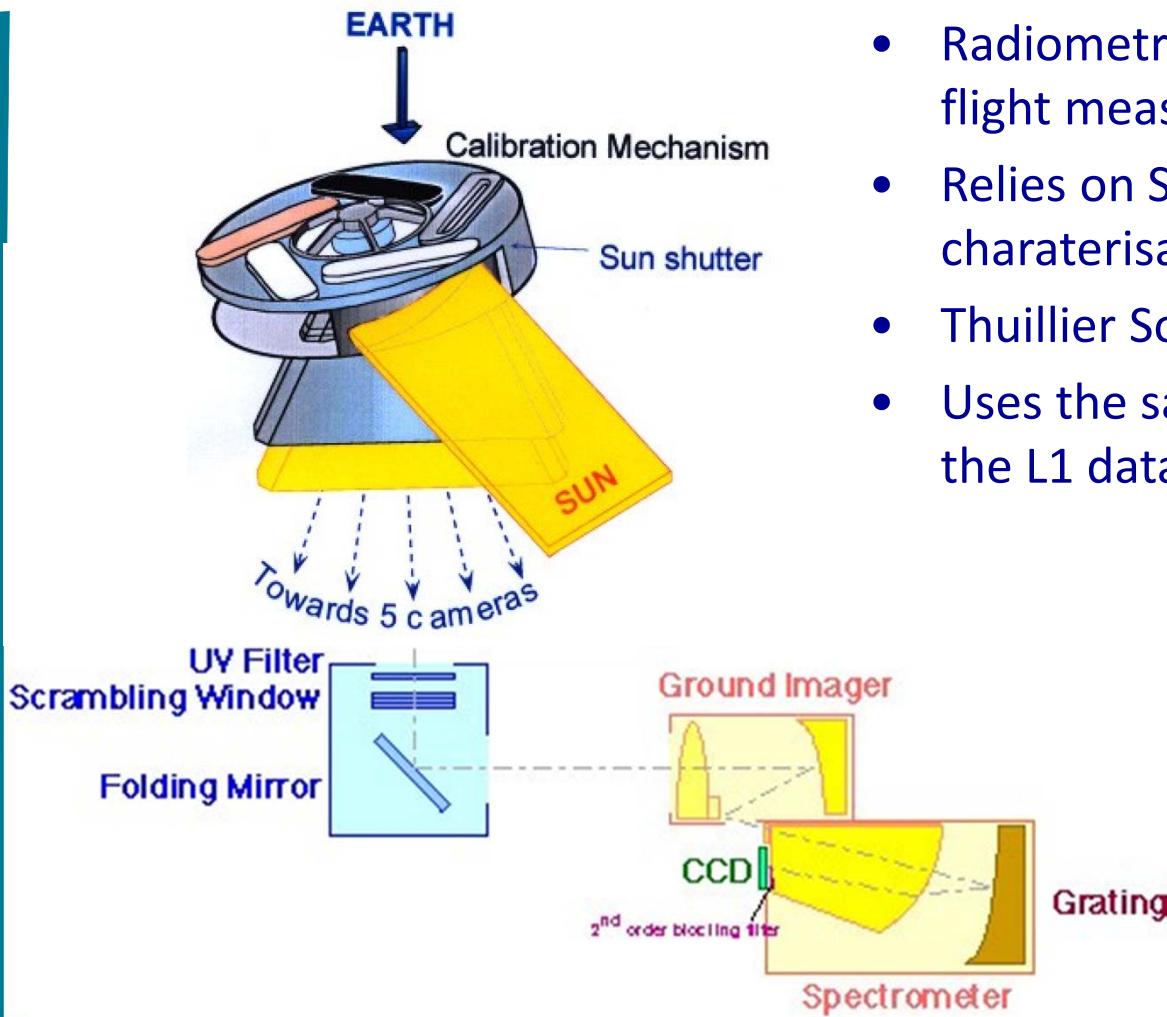
1. OLCI, successor to MERIS
2. Overall calibration strategy
 - Radiometric model
 - Calibration processing chain
 - In-flight measurements
 - On-ground characterisation
 - Analysis and modelling
3. Lessons learnt from MERIS
 - Calibration sequences
 - Calibration data & processing
 - On-ground Characterisation
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Instrument Overview



- Radiometric Calibration based on in-flight measurements
- Relies on Spectralon diffuser characterisation (pre-launch)
- Thuillier Solar Spectrum
- Uses the same radiometric model as in the L1 data processing

Calibration frequency

Diffuser-1: 15 days

Diffuser-2: 3 months

Diffuser-Er: 3 months peak 3

Diffuser-Er: 6 months peak 1

Radiometric Equation

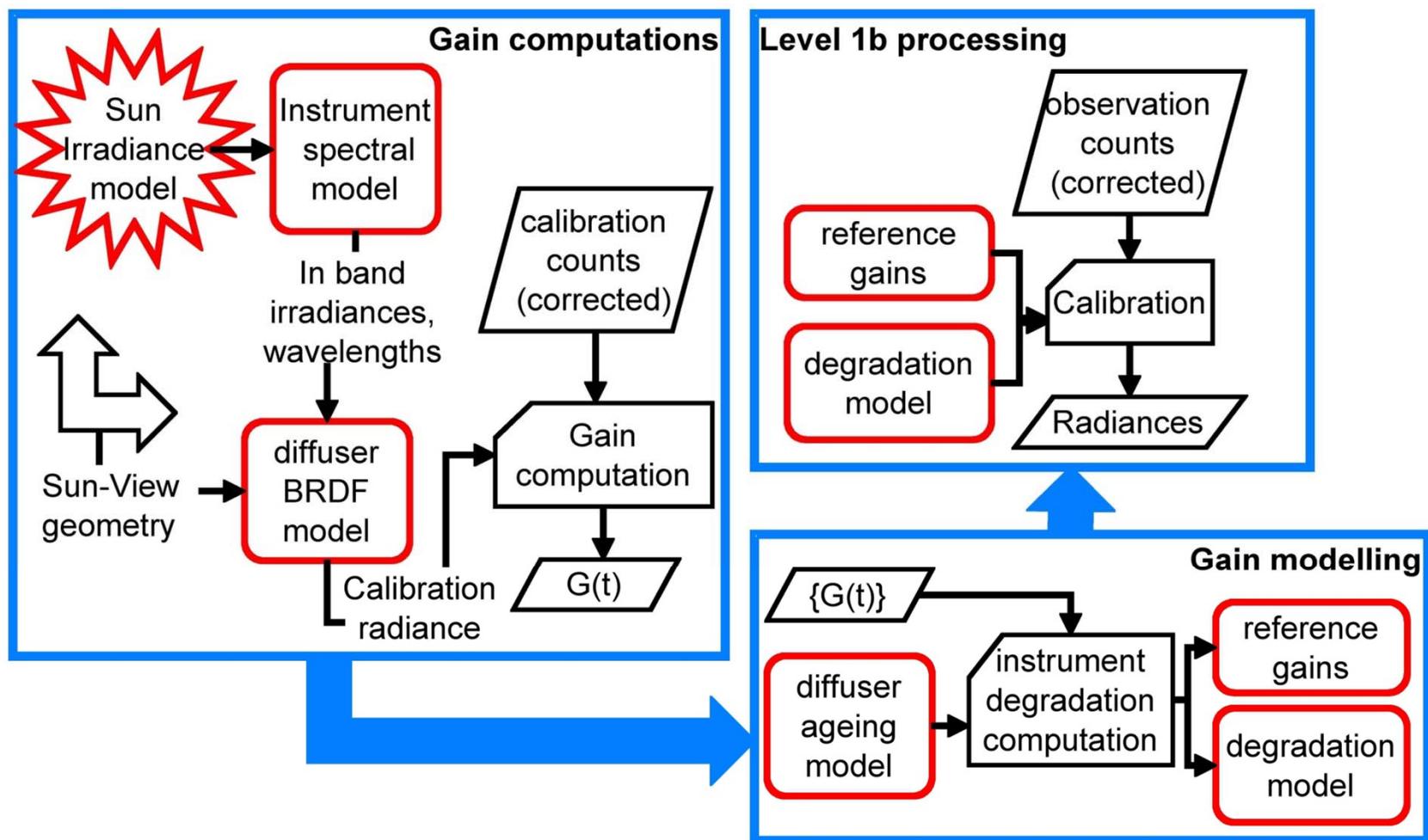
$$X_{b,k,m,f} = \text{NonLin}_{b,m} \left[g(T_f^{\text{VEU}}) \cdot \left[A_{b,k,m} \cdot (L_{b,k,m,f} + G_{b,k,m}(L_{*,*,*,f})) + S_{m,b,k,m,f}(L_{b,k,m,*}) \right] + g_c(T_f^{\text{CCD}}) \cdot C_{b,k,m}^0 \right].$$

- $X_{b,k,m,f}$ is the MERIS raw sample;
- $\text{NonLin}_{b,m}$ is a non-linear function
- T_f^{VEU} is the temperature of the MERIS amplifiers (VEUs);
- T_f^{CCD} is the temperature of the MERIS detectors (CCDs)
- $g(T)$ and $g_c(T)$ are (dimensionless) temperature correction functions;
- $A L_{b,k,m}$ the "absolute radiometric gain"
- $L_{b,k,m,f}$ the spectral radiance distribution in front of MERIS;
- $S_{m,b,k,m,f}$ the smear signal, due to continuous sensing of light by MERIS;
- $C_{b,k,m,f}^0$ the calibrated dark signal (possibly including an on-board compensation), dependent on band and gain settings;
- $G_{b,k,m,f}$ a linear operator representing the stray light contribution to the signal

Radiometric Approach

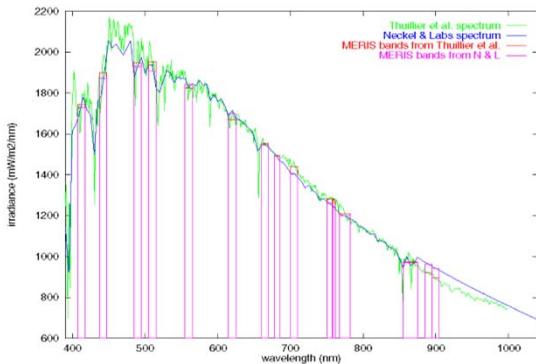
- Calibration modes provides instrument numerical counts $X_{\text{cal}}(\lambda, k)$
- Instrumental corrections (non-linearity, dark offset, smear) yields $X'_{\text{cal}}(\lambda, k)$
- Instrument Gain from $X'_{\text{cal}}(\lambda, k) = G(\lambda, k) \cdot L_{\text{cal}}(\lambda, k)$
- L_{cal} computed from $E_0(\lambda)$, geometry and diffuser BRDF
 - Diffuser BRDF characterised on-ground
 - $E_0(\lambda)$, from a model + seasonal variation
 - Geometry from orbit and instrument pointing characterisation
- Space environment implies ageing of Diffuser and Optics
 - 2nd diffuser to monitor diffuser-1 BRDF ageing
=> Diffuser Ageing model
 - frequent calibration to monitor Instrument degradation
=> instrument degradation model

Radiometric Processing

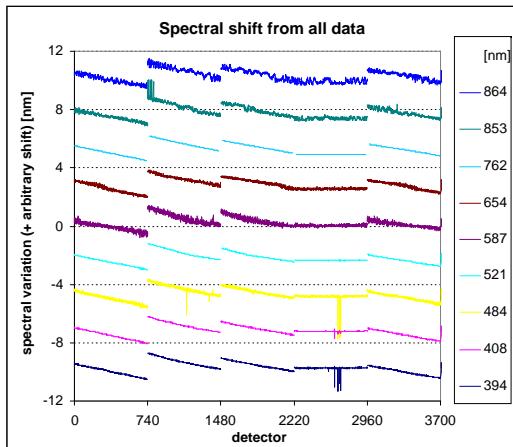
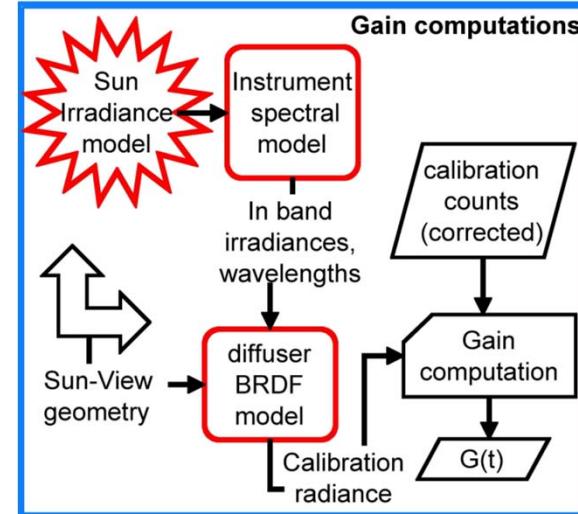


Radiometric Calibration

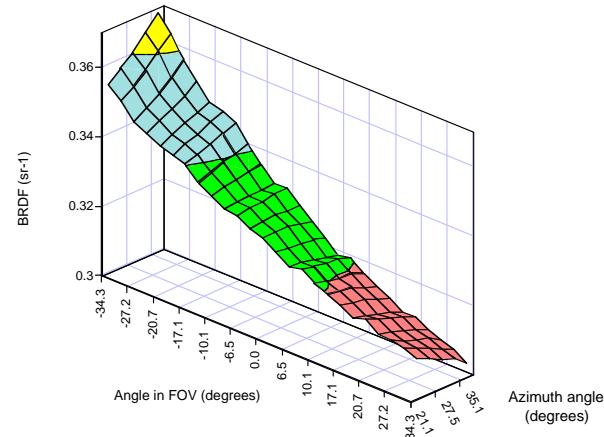
Key Inputs



Extra terrestrial solar (Thuillier et al.)
In-band irradiance computed per pixel with
on-board derived instrument Spectral Model



On-Orbit Spectral characterisation measurements
(Erbium Doped diffuser, Fraunhofer lines, O2-A)



On-ground characterisation of
diffuser-1 @ 410nm

OVERVIEW

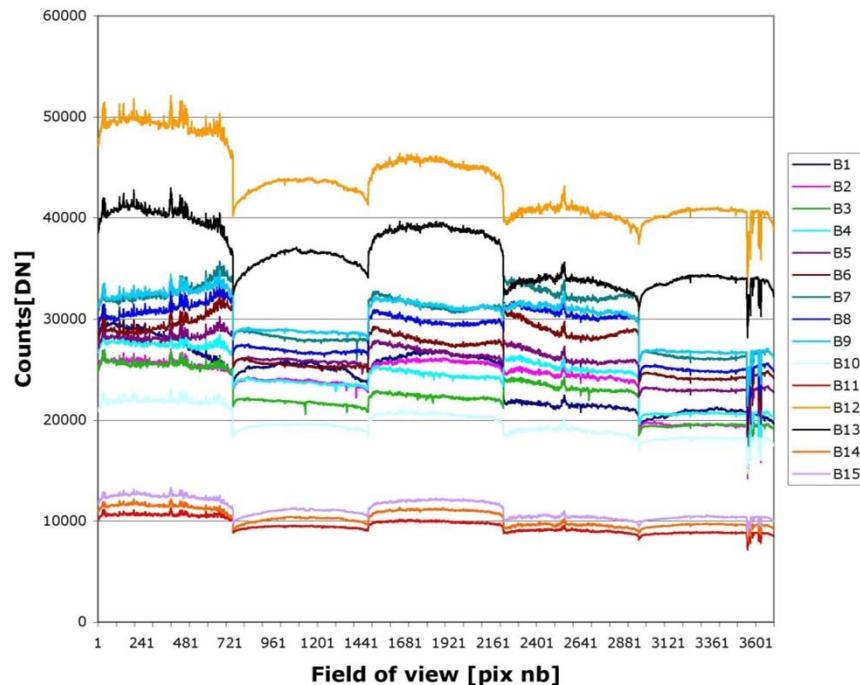
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Radiometric Calibration

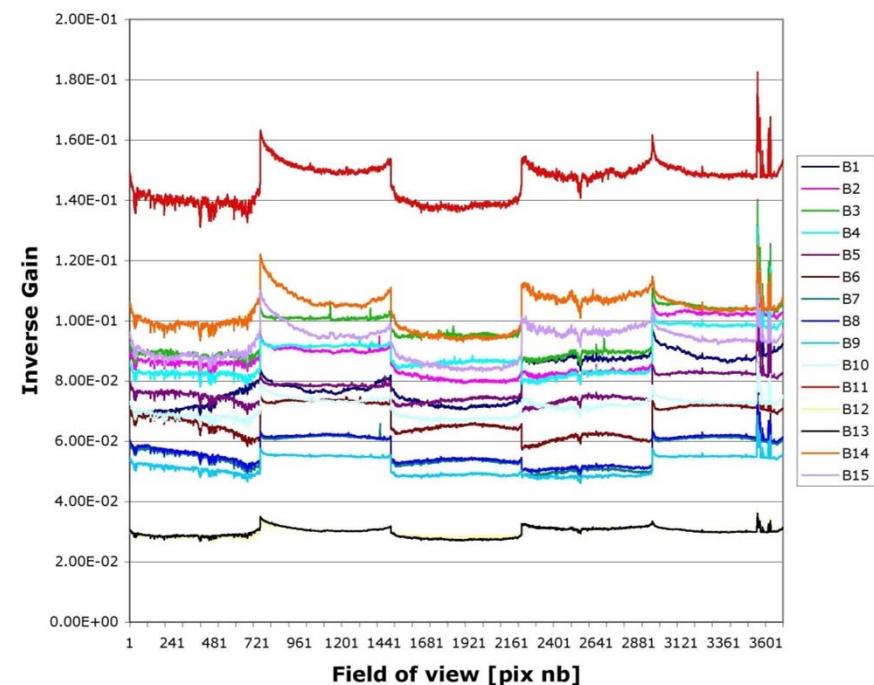
Results

Calibration Signal



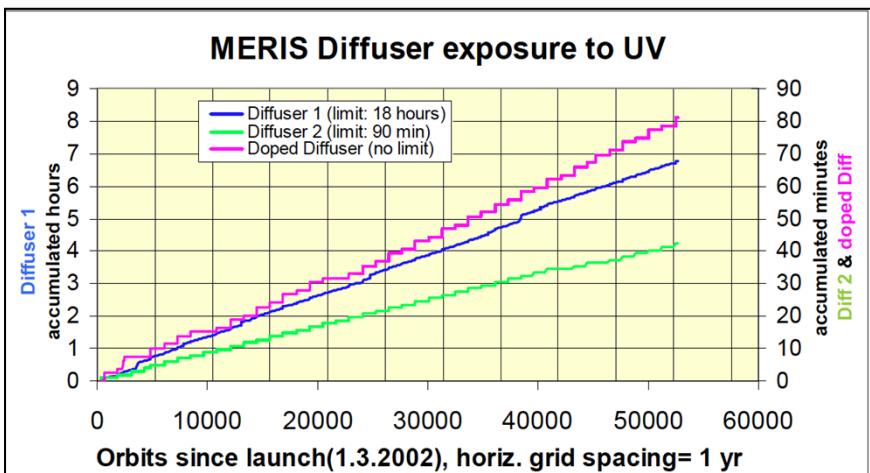
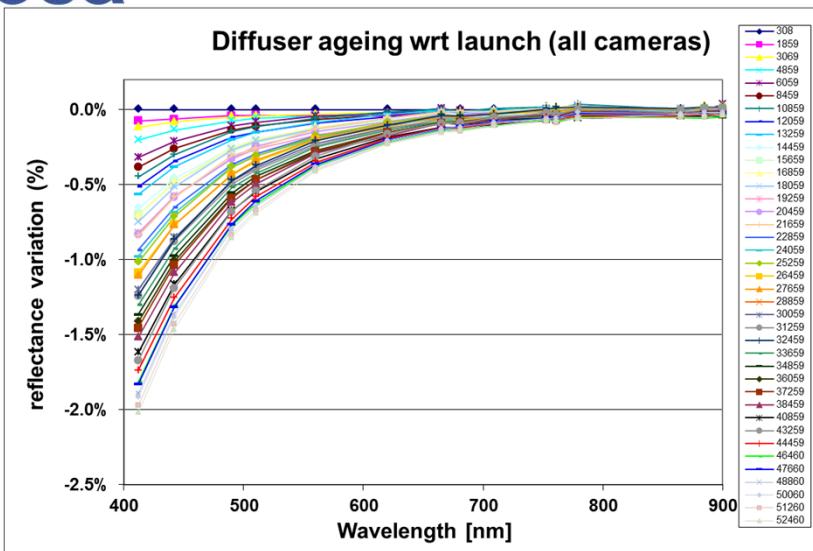
Radiometric Calibration raw digital counts

Inverse Gain



Corresponding Radiometric “Gain” Coefficients

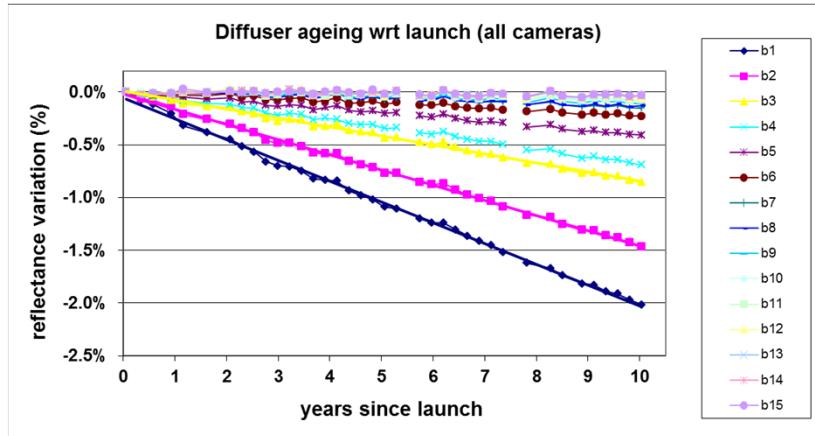
Diffuser Ageing



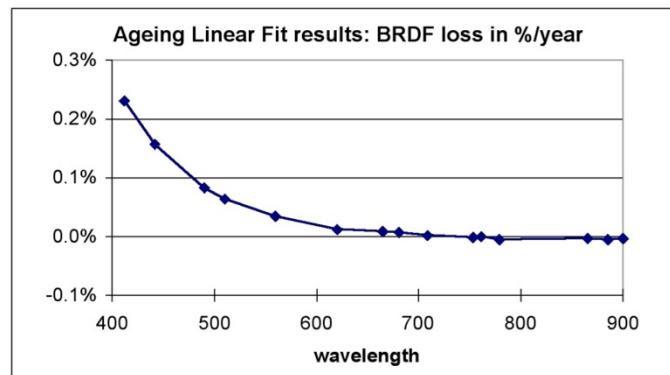
Diffuser's UV exposure
(Dif-1 [hrs], Dif-2 & doped[min])

Degradation of Diffuser-1 vs Diffuser-2

Diffuser ageing is <2 % after than 10 years in space

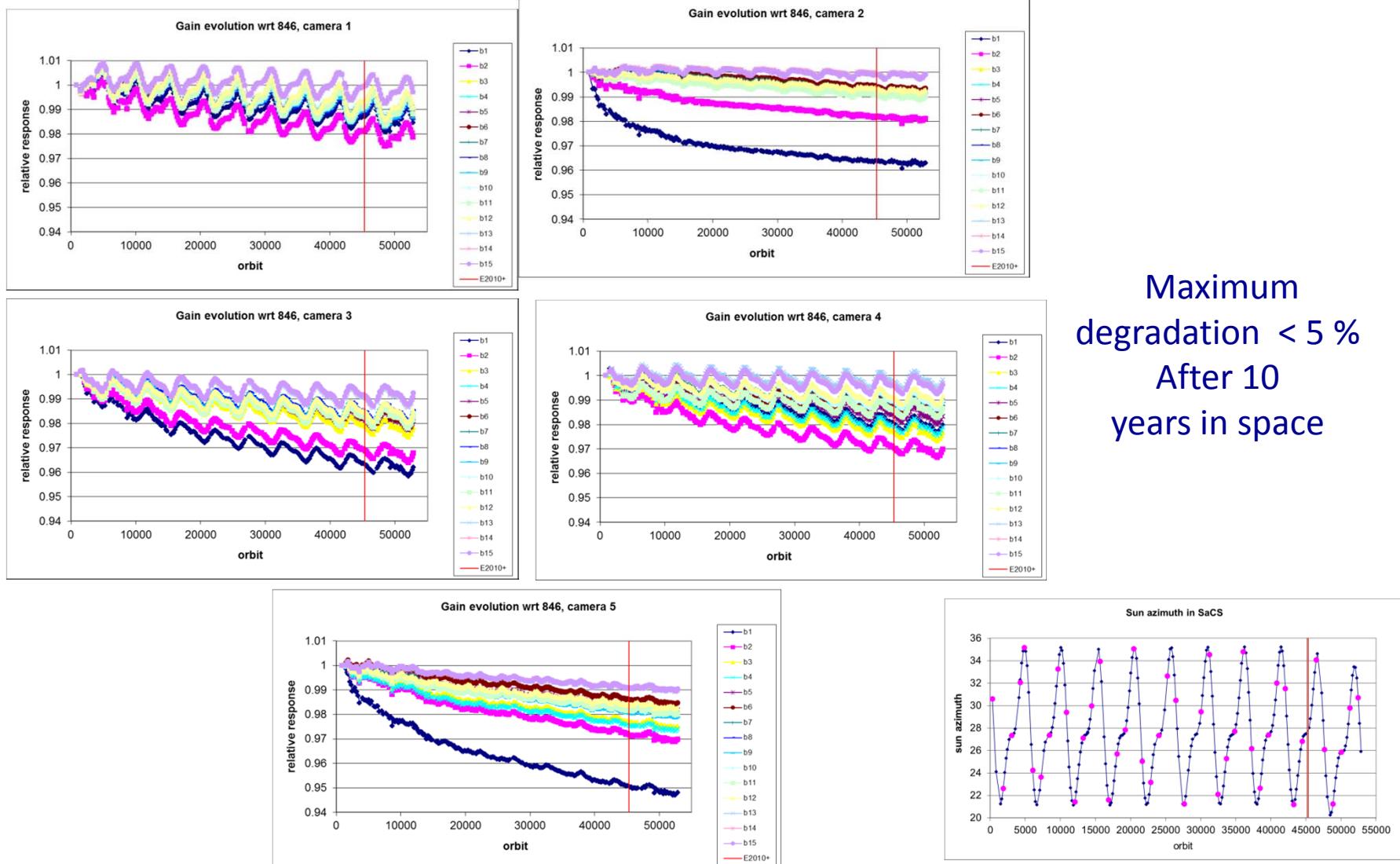


Diffuser Degradation process is linear



Diffuser Degradation rate per year
(65deg illumination)

Instrument Degradation



Maximum
degradation < 5 %
After 10
years in space

Diffuser illumination

OVERVIEW

A. MERIS

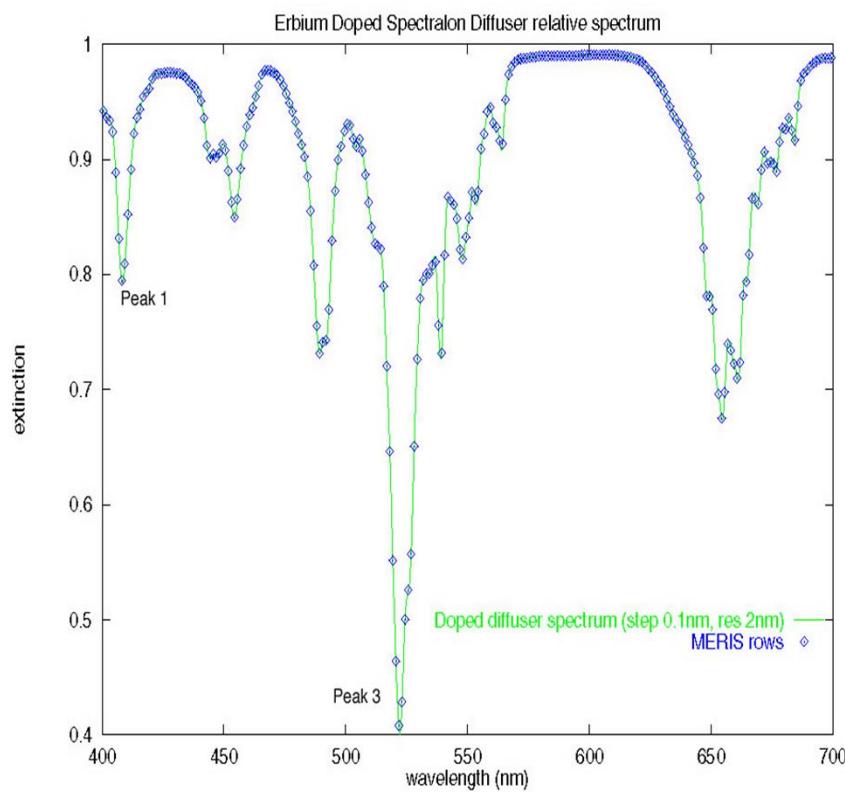
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Erbium Doped Diffuser

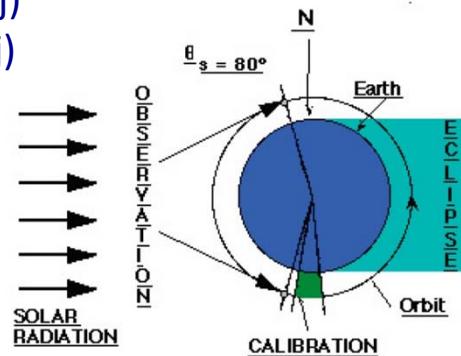
Acquisitions scenario:

Orbit n = Diffuser-1 Cal (Band setting j)

Orbit n+1 = Diffuser-Er (Band setting j)



Erbium absorption spectrum

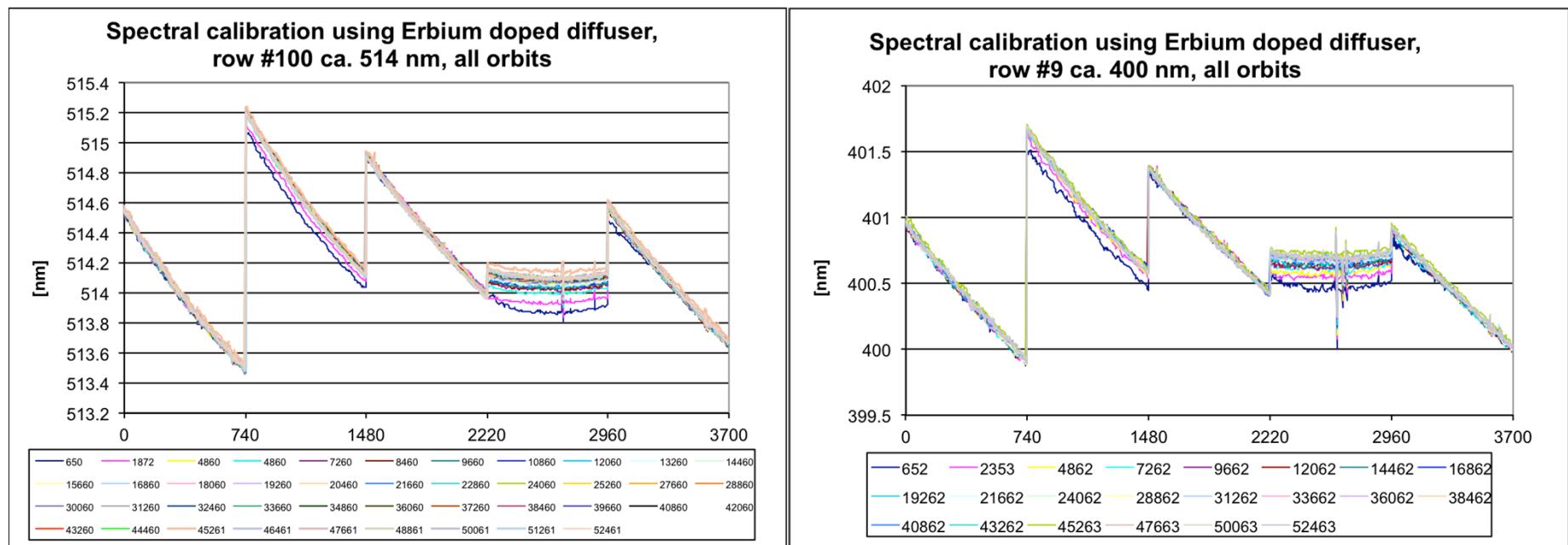


"Pink" Diffuser Measurements

centre	width (nm)	centre	width (nm)
400.625	1.25	514.375	1.25
401.875	1.25	515.625	1.25
403.125	1.25	516.875	1.25
404.375	1.25	518.125	1.25
405.625	1.25	519.375	1.25
406.875	1.25	520.625	1.25
408.125	1.25	521.875	1.25
409.375	1.25	523.125	1.25
410.625	1.25	524.375	1.25
411.875	1.25	525.625	1.25
413.125	1.25	526.875	1.25
414.375	1.25	528.125	1.25
415.625	1.25	529.375	1.25
416.875	1.25	530.625	1.25
418.125	1.25	531.875	1.25

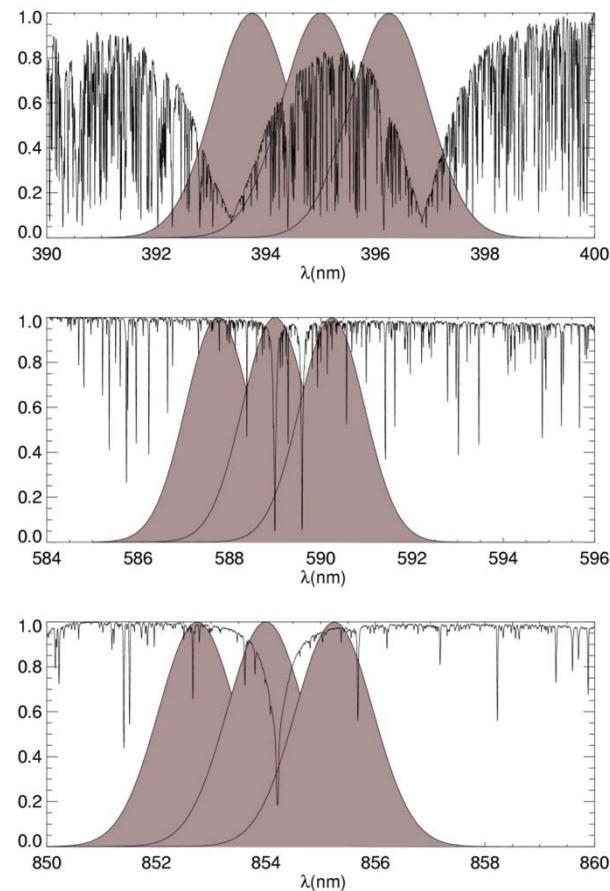
Band settings j

Erbium Results

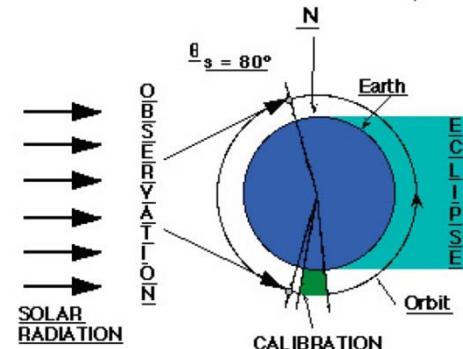


Method: Determine the position of the absorption peak in pixel number, with correction for Air-Vacuum changes (Edlen)

Fraunhofer Lines



Examples of Fraunhofer absorption spectrum
With MERIS spectral response overlay



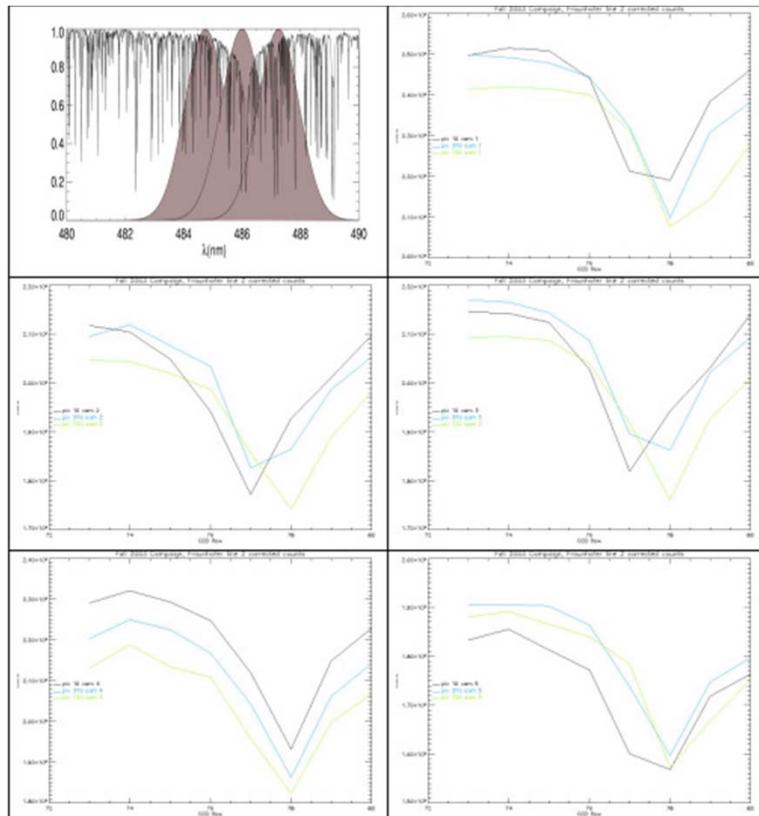
White diffuser-1 measurement

line 1 (393nm)	line 2 (485nm)	line 3 (588nm)	line 4 (655nm)	line 5 (855nm)	line 6 (867nm)
393.125	480.625	584.375	653.125	850.625	863.125
394.375	481.875	585.625	654.375	851.875	864.375
395.625	483.125	586.875	655.625	853.125	865.625
396.875	484.375	588.125	656.875	854.375	866.875
398.125	485.625	589.375	658.125	855.625	868.125
399.375	486.875	590.625	659.375	856.875	869.375
400.625	488.125	591.875	660.625	858.125	870.625
	489.375	593.125			

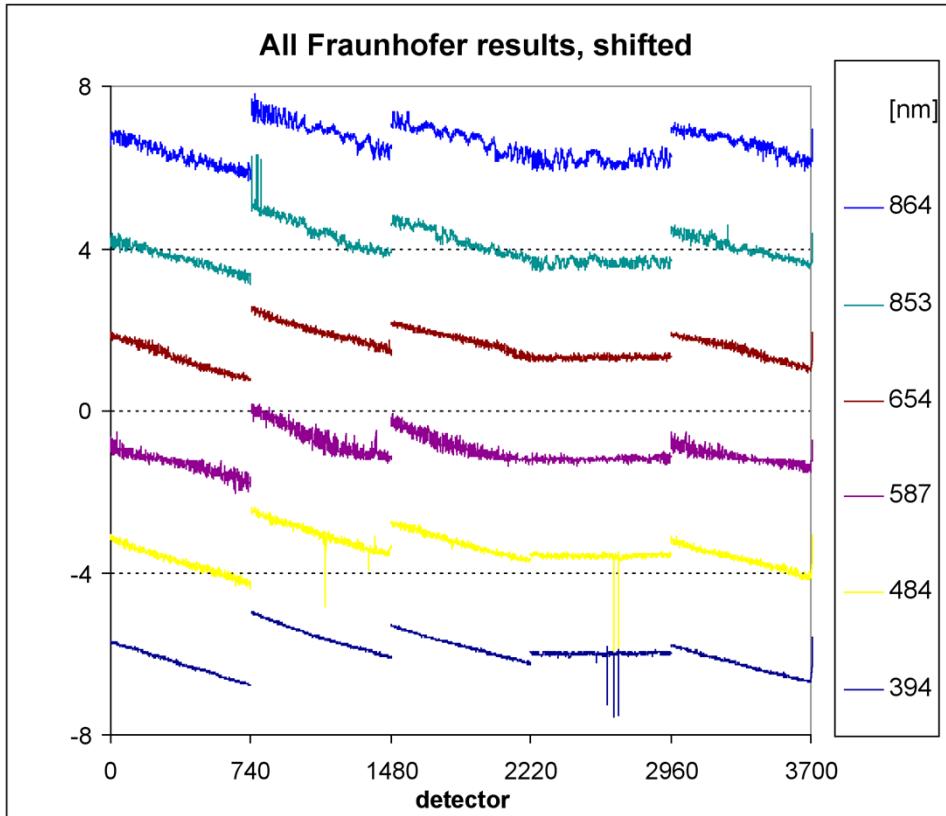
Band settings (3 configurations)

Fraunhofer Results

Line 2 Raw data: 5-cameras, 3 Fov



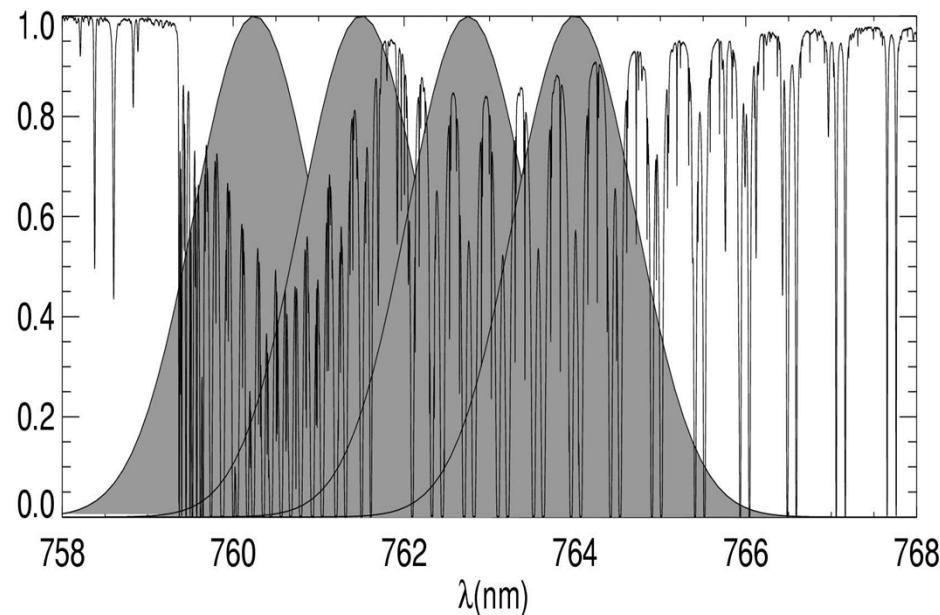
Results all Fraunhofer lines



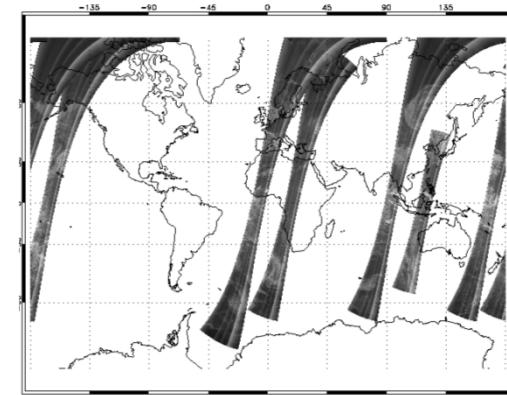
Method: Spectrum-matching, with correction for Air-Vacuum (Edlen)

Oxygen O2A

For three orbits every six months, MERIS is configured to observe in detail the O2A absorption features



Oxygen O2A absorption spectrum
MERIS spectral response overlay

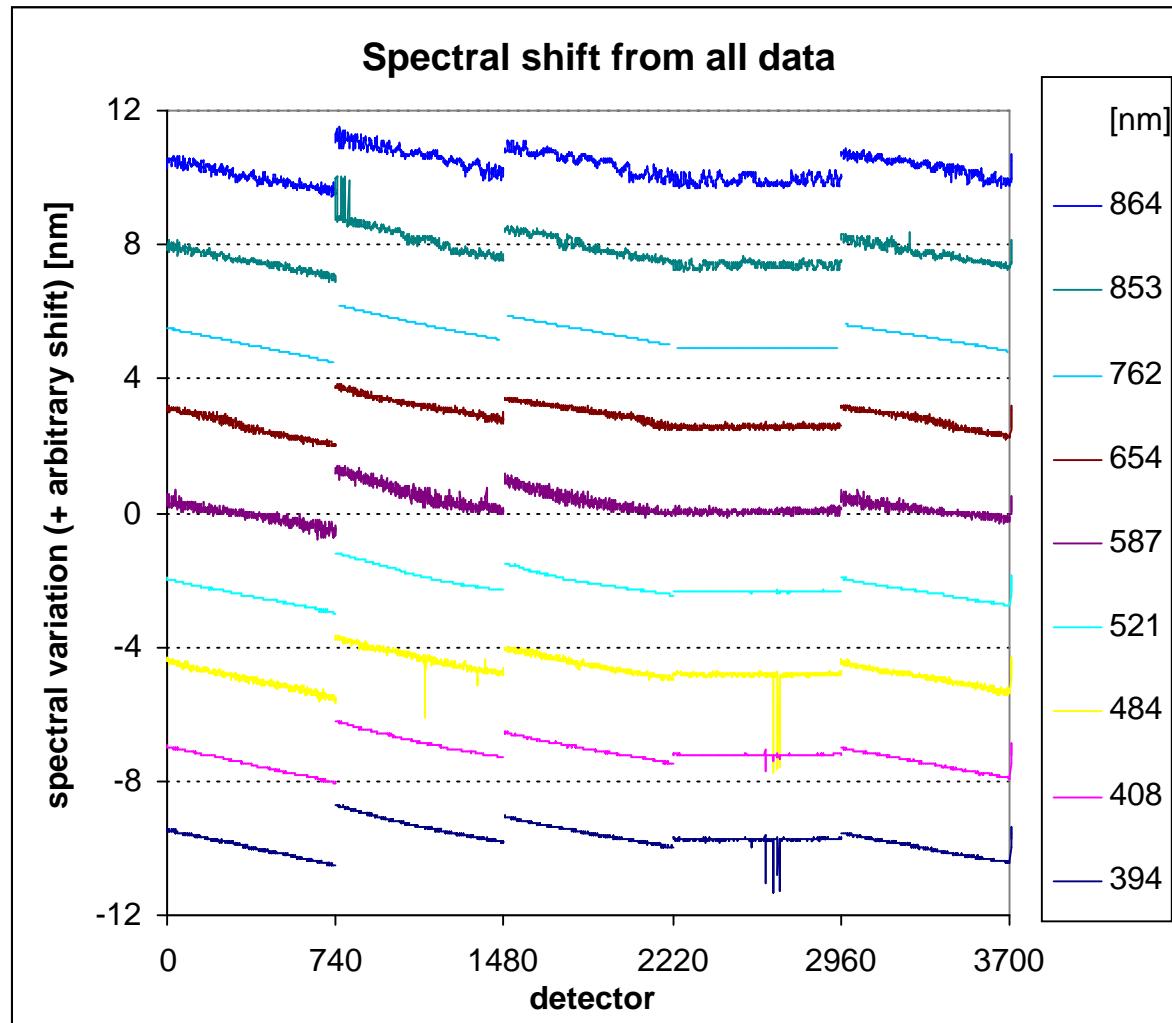


Measurements over Natural target

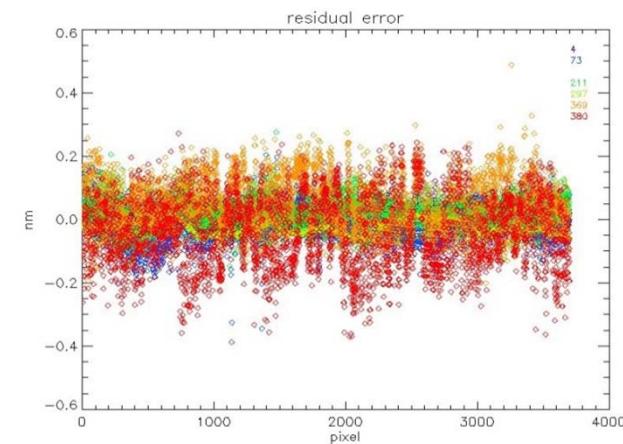
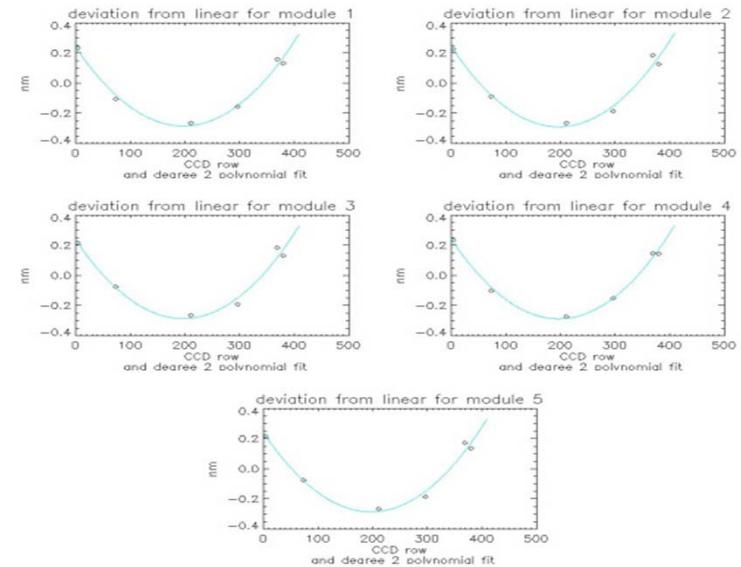
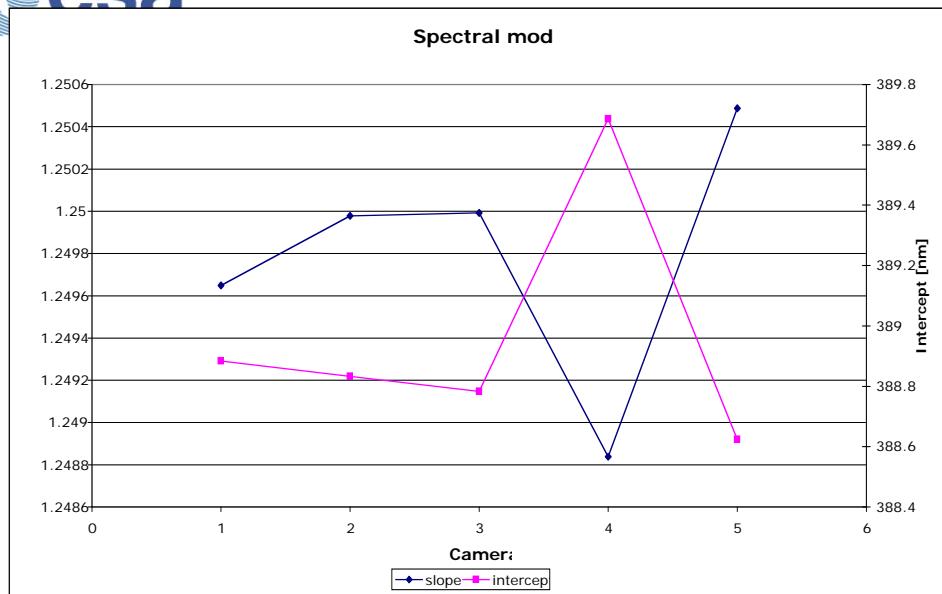
name	centre	width (nm)
blue-2	442.5	10
red-1	665	10
ref-1	753.125	6.25
O2-0	758.125	1.25
O2-1	759.375	1.25
O2-2	760.625	1.25
O2-3	761.875	1.25
O2-4	763.125	1.25
O2-5	764.375	1.25
O2-6	765.625	1.25
O2-7	766.875	1.25
O2-8	768.125	1.25
O2-9	769.375	1.25
ref-2	778.75	7.5
IR-1	865	10

O2A Campaign Band setting

Results All Methods



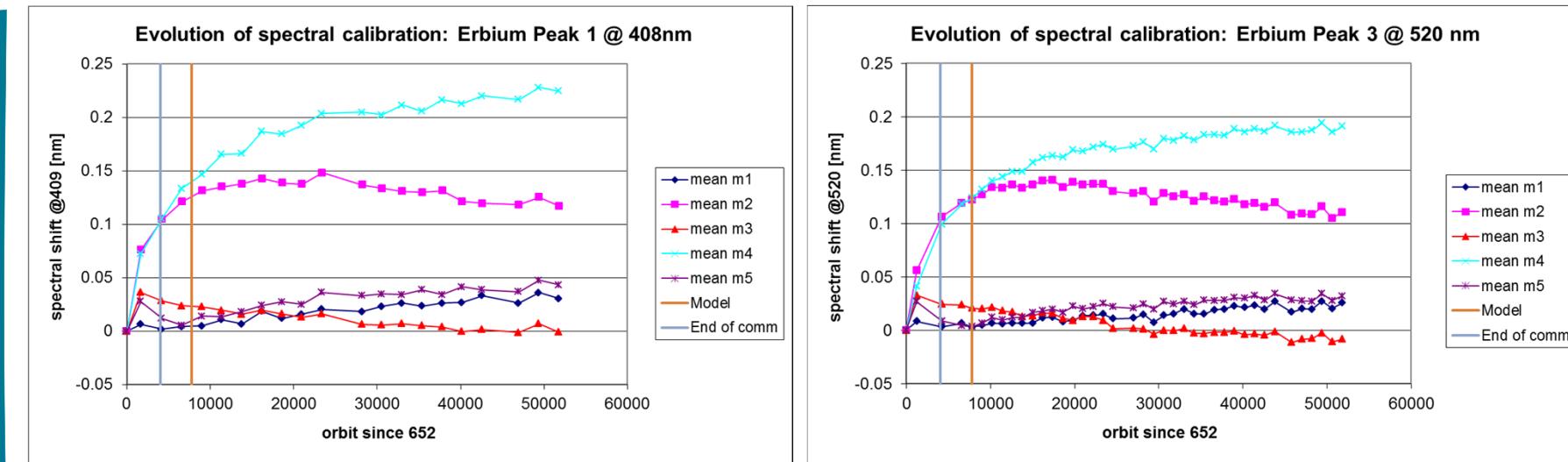
Instrument Model



Simple instrument model where k and l stand for the spatial and spectral co-ordinates of a given detector respectively , the mean dispersion law –mainly linear– is a polynomial of order 3 (best fit), and, the across-track variation term, is a linear fit of the data at 395, 656 and 671nm expressed relative to its mean value

Spectral Stability

Erbium doped diffuser measurements



Spectral stability since end of commissioning is:

- Camera 4 has drifted by less than 0.12 nm
- Camera 2 has drifted by less than 0.08 nm
- Camera 1, 3 & 5 have drifted by less than 0.05 nm

No spectral drift correction is included in the processing as the spectral model, based on Fall 2003 data (orbit ~ 7800), is representative of the complete mission.

MERIS Calibration Summary

1. In-flight spectral measurements → instrument spectral model

$$\lambda(k,l) = \bar{\lambda}(l) + \Delta\lambda(k)$$

2. In-band spectral irradiance per pixel by integration of Thuillier et al Solar Irradiance
3. Diffuser BRDF model (Rahman) fitted on characterisation data, interpolated spectrally from char. Wavelengths to MERIS bands
4. Compute instantaneous ‘gain’ factors for each calibration acquisition (every two weeks)
5. Correct for diffuser ageing
6. Model time evolution as per Barnes et al:

$G(t_0)$: gain at orbit 297, b : amplitude, d^{-1} : time constant, g : ⇔ time offset at orbit 297

$$G(t) = G(t_0) \cdot (1 - \beta \cdot (1 - \gamma \cdot e^{-\delta t}))$$

Conclusions

The Radiometric calibration of MERIS is obtained from a well protected on-board diffuser plate, used as a **secondary standard**

The stability (ageing) of the diffuser plate is monitored by the second diffuser plate deployed 10 time less frequently. Results show Diff-1 to have aged <2% => an ageing of <0.2% for Diff-2.

The precise knowledge of the instrument spectral characteristics is obtained from regular spectral calibration campaigns and a simple instrument spectral model with an accuracy of <0.2nm, and have shown the instrument to be stable to better than 0.1 nm over 10 years.

The instrument degradation (trending) has been monitored and showed that Meris has degraded by < 5% in the blue and < 1 % in the NIR.

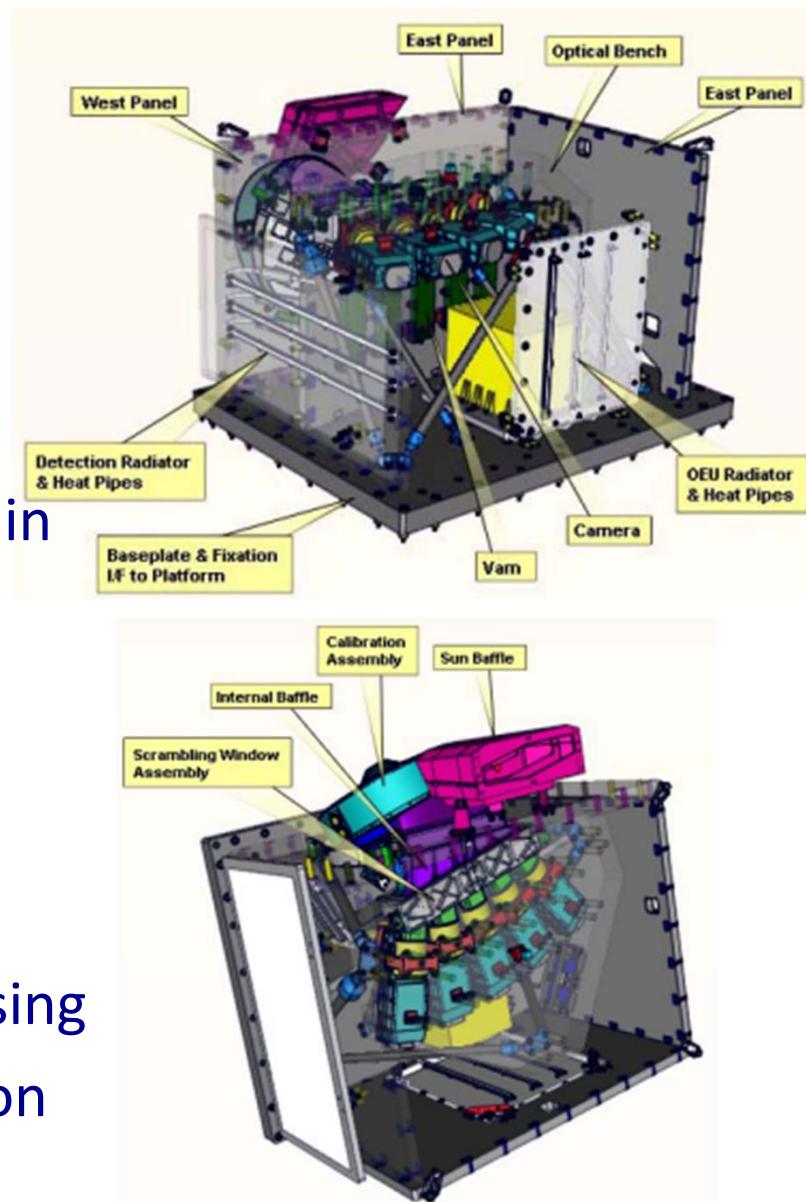
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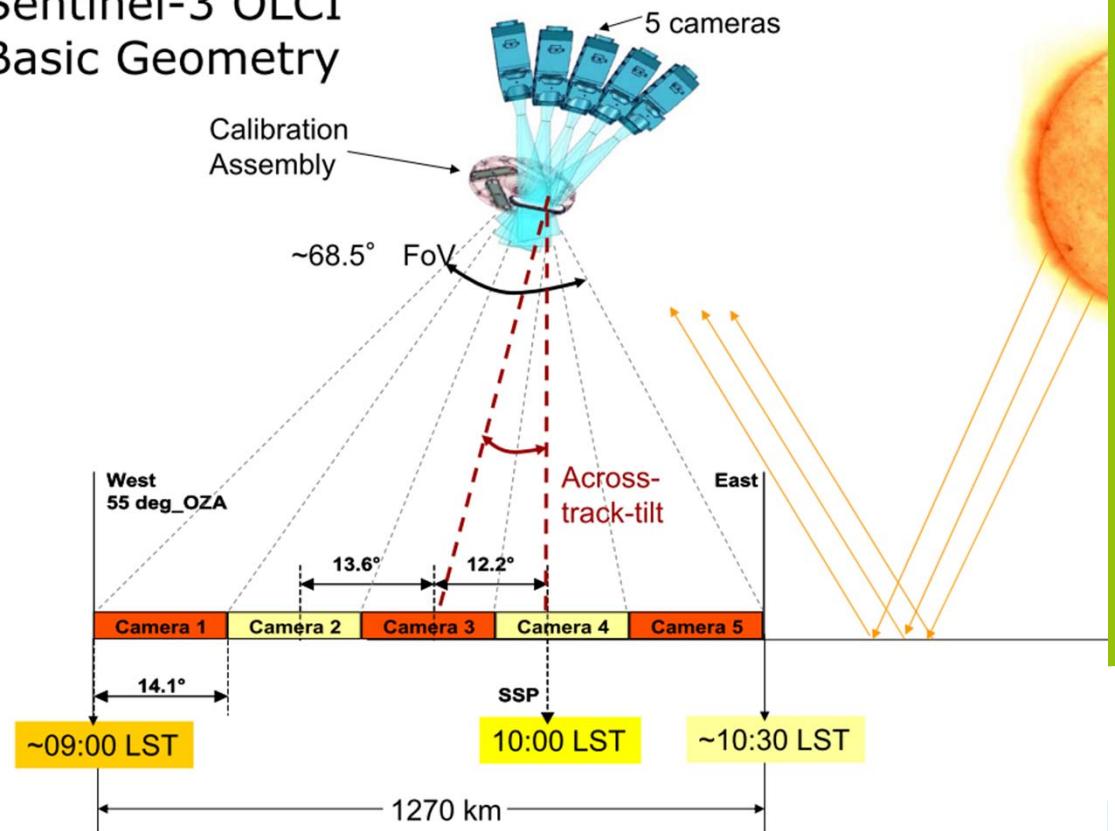
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OLCI, successor to MERIS

- ❖ Push-broom imaging spectrometer, 5 fan-arranged cameras
- ❖ Radiometric calibration based on on-board diffuser(s)
- ❖ Spectral calibration using dedicated on-board diffuser

- + **12 degrees westward tilt to avoid Sun glint and increase swath to 1250km**
- + **number of bands increased to 21**
- + **technological improvements...**

Sentinel-3 OLCI
Basic Geometry



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Overall Calibration Strategy

On-ground characterisation

+

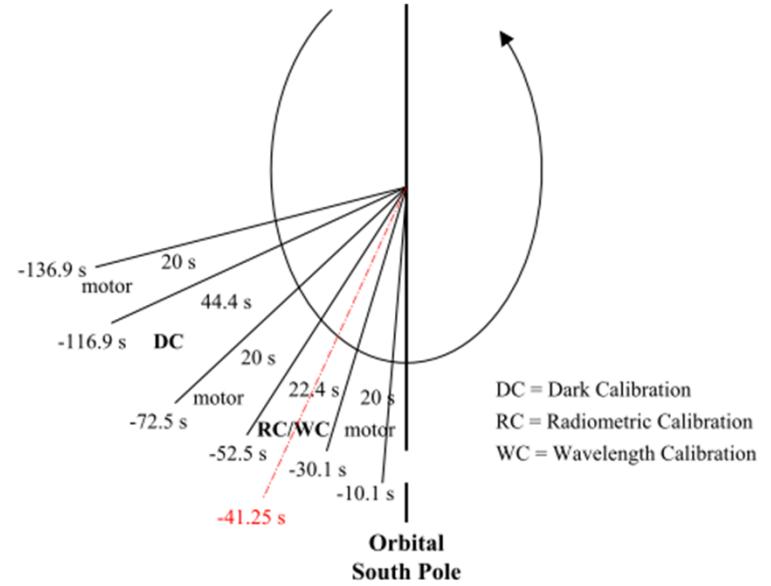
In-flight calibration measurements

+

Processing, analysis and modelling

=

Self standing absolute calibration for the EO processing chain



Radiometric model

$$X_{b,k,m,t} = NL_{b,m} \left[A_{b,k,m}^0 \cdot (L_{b,k,m,t} + SL_{b,k,m,t}(L_{*,*,*,*})) + \right. \\ \left. Sm_{b,k,m,t}(L_{*,k,m,*} + SL_{*,k,m,*}(L_{*,*,*,*})) + g_C(T_t^{CCD}) \cdot C_{b,k,m}^0 \right] + \varepsilon$$

Where:

- b = band, k / m = pixel / camera, t = time, (* = whole/partial domain)
- $X_{b,k,m,t}$ is the OLCI raw sample
- $NL_{b,m}$ is a non-linear function
- $T^{CCD}(t)$ is the temperature of the CCDs
- $g_C(T^{CCD})$ is a dimensionless temperature correction function
- $A_{b,k,m}^0$ the "absolute radiometric gain" in counts/radiance unit
- $L_{b,k,m,t}$ the spectral radiance distribution in front of OLCI
- $Sm_{b,k,m,t}$ the smear signal, due to continuous sensing of light by OLCI
- $C_{b,k,m}^0$ the calibrated dark signal (possibly including an on-board compensation)
- $SL_{b,k,m,t}$ a linear operator representing the stray light contribution to the signal
- ε is a random process representative of the noise and measurement errors.

Radiometric model applies to Calibration measurements

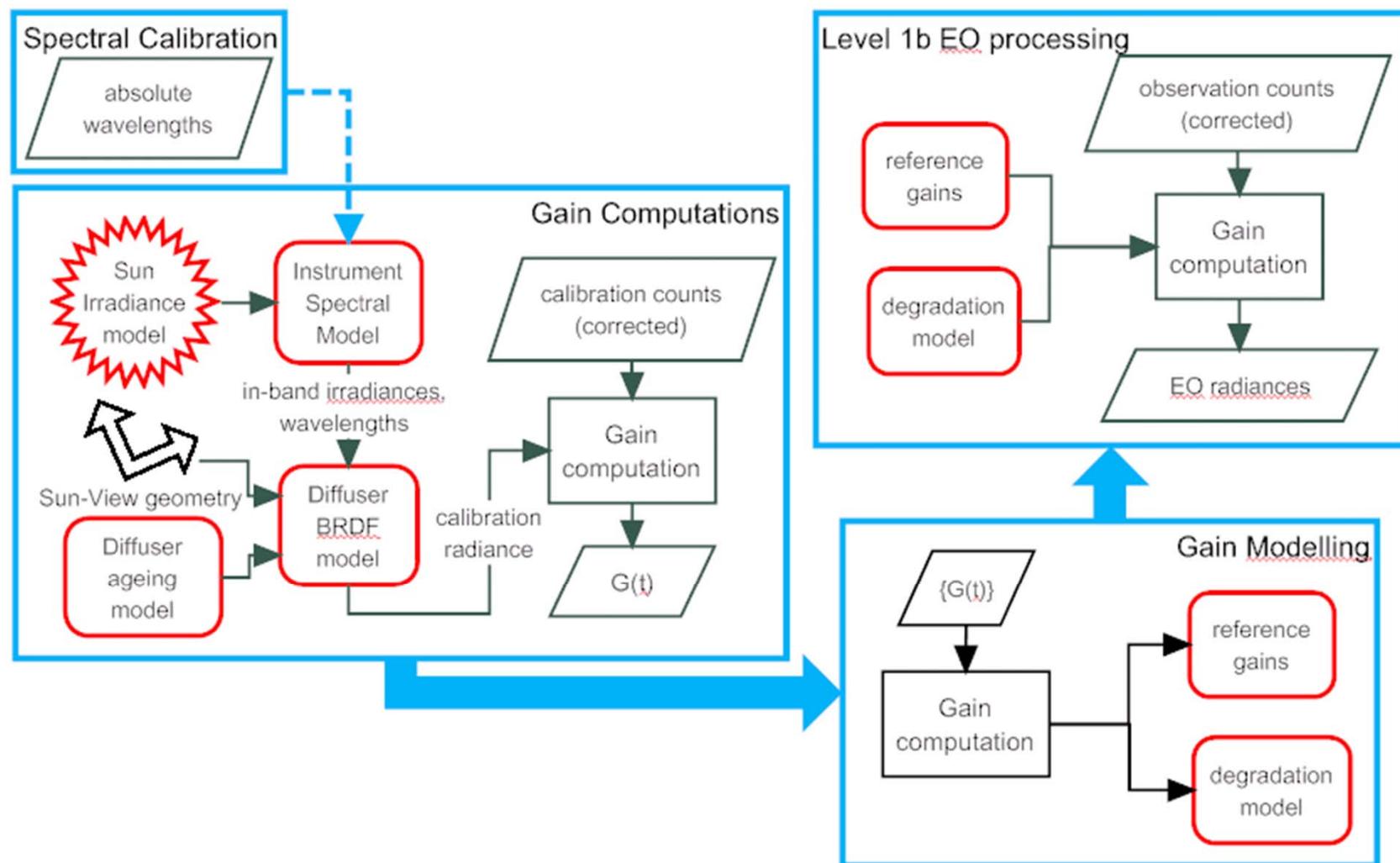
$$X_{b,k,m,t}^{\text{Cal}} = NL_{b,m} \left[A_{b,k,m}^0 \cdot \left(L_{b,k,m,t}^{\text{Cal}} + SL_{b,k,m,t}(L_{*,*,*,*}^{\text{Cal}}) \right) + \right. \\ \left. Sm_{b,k,m,t}(L_{*,k,m,*}^{\text{Cal}} + SL_{*,k,m,*}(L_{*,*,*,*}^{\text{Cal}})) + g_C(T_t^{\text{CCD}}) \cdot C_{b,k,m}^0 \right] + \varepsilon$$

$$A_{b,k,m}^0 = \left\langle \frac{NL_{b,m}^{-1}(X_{b,k,m,t}^{\text{Cal}}) - Sm_{b,k,m,t}(L_{*,k,m,*}^{\text{Cal}} + SL_{b,k,m,t}^{\text{Cal}}) - g_C(T_t^{\text{CCD}}) \cdot C_{b,k,m}^0}{(L_{b,k,m,t}^{\text{Cal}} + SL_{b,k,m,t}^{\text{Cal}})} \right\rangle_{t \in \{\text{cal}\}}$$

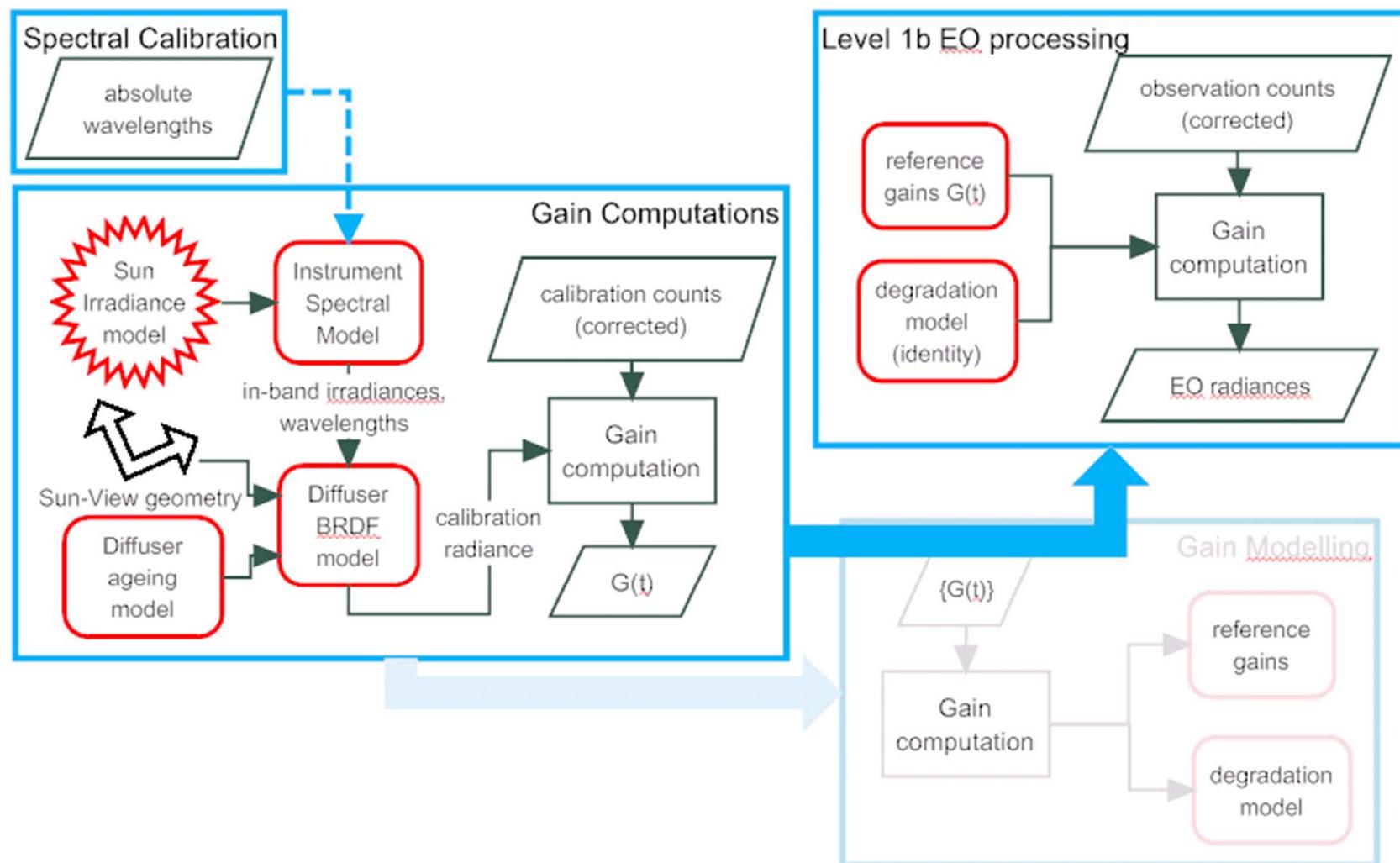
With:

- X^{Cal} from **Sun diffuser measurements**
- C^0 from **dedicated measurements** (with shutter)
- Sm from **dedicated band** (virtual, lit only during CCD frame transfer)
- L from characterised diffuser BRDF + in-flight geometry + E_0 at OLCI bands
- SL from L + characterised/modelled convolution kernels
- gC from characterisation
- NL^{-1} from characterisation

Calibration chain summary

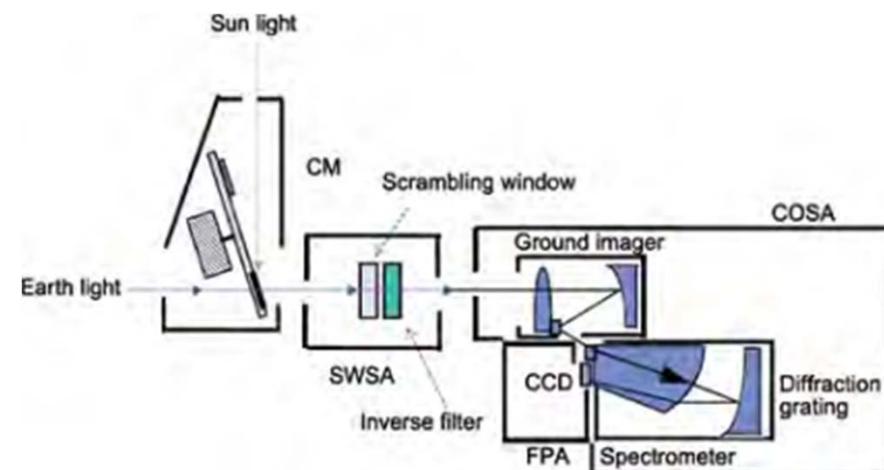


Calibration chain summary (short term)



In-flight measurements

- ❖ **Shutter: dark offset (calibration zero),**
before every diffuser acquisition (systematic) or along-orbit (infrequent)
- ❖ **Radiometric diffuser: calibration gains**
- ❖ **Reference radiometric diffuser: ageing of nominal diffuser**
- ❖ **Spectral diffuser: spectral calibration at 3 wavelengths**
- ❖ **Specific observations in support to spectral calibration**
(Fraunhofer lines on diffuser, O₂ absorption over Earth) → additional wavelengths



On-ground characterisation: Key Inputs

Main inputs for radiometric calibration:

- ❖ Spectral data: central wavelengths, spectral response curves
→ in-band equivalent irradiance
 - ❖ Diffusers characterisation: BRDF and orientation
 - ❖ Integral non-linearity
 - ❖ Instrument pointing vectors
 - ❖ Stray light operators
-
- Compute radiance at instrument entrance during radiometric calibration from in-flight geometry

Processing, analysis and modelling

- ❖ From spectral calibrations: correction of spectral model, impact on central wavelengths and in-band irradiances, if required
- ❖ From radiometric diffuser: calibration gains
- ❖ From reference diffuser comparison with nominal (ageing sequences): modelling of diffusers ageing (browning)
- ❖ Analysis of calibration gains time series (mid and long term): derivation of instrument degradation model, smoothing transitions
- Back to Calibration of EO data through auxiliary files

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Lessons learnt from MERIS 1/3

1) Calibration sequences

In addition to “classical” sequences (radiometric, ageing and spectral diffuser), the following have been included:

- ❖ Orbital stability (along-orbit dark level stability)
 - ❖ Fraunhofer lines observations on radiometric diffuser (no spectral relaxation: 1 orbit allows observing 6 lines, while 3 orbits were necessary with MERIS)
 - ❖ Earth observations of O₂ atmospheric absorption using dedicated band setting (+ corresponding radiometric calibration)
- All the MERIS spectral campaigns are pre-defined on-board OLCI

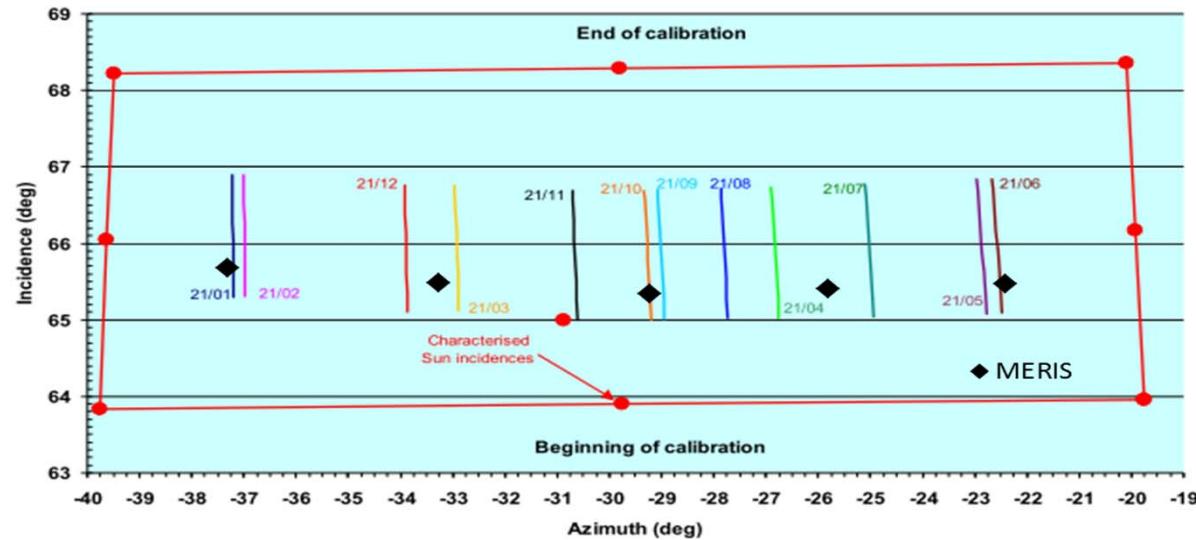
Lessons learnt from MERIS 2/3

2) Calibration acquisitions and processing

- ❖ All calibration measurements are sent to ground and processed on a frame by frame basis (i.e. without the temporal averaging of MERIS)
 - inputs to uncertainties, SNR evaluations, BRDF model assessment, diffuser speckle, sensitivity to geometry ...
- ❖ All calibration acquisitions are packed without spectral relaxation (i.e. in micro-bands, or sub-bands)
 - better processing, finer analysis
- ❖ Much more detailed stray-light modelling for both Radiometric Calibration and Earth Observation: full spatial 2D for Ground Imager and full across-track/spectral 2D for the spectrometer.
- ❖ accurate navigation/attitude from on-board system

3) On-ground Characterisation

- ❖ Improved spectral characterisation → spectral model
- ❖ Improved diffuser BRDF characterisation domain



- ❖ Much more detailed stray-light modelling for both Radiometric Calibration and Earth Observation: full spatial 2D for Ground Imager and full across-track/spectral 2D for the spectrometer.

Conclusion

Thanks to commonality between the two instruments:

- ❖ a successful calibration strategy is re-used,
- ❖ refined according to lessons learnt,
- ❖ embedded in an operational environment
should guarantee success

Surprising instrumental behaviours cannot be excluded

- Validation from vicarious is mandatory
(and adjustment if required)
- calibration team must be prepared to revise everything

Thank you for your attention