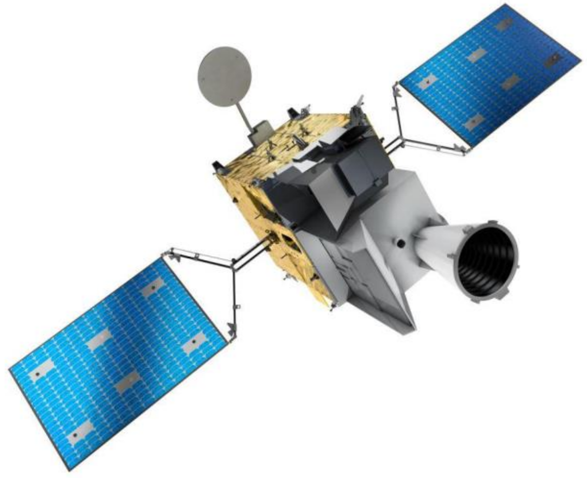
MAG – IRS Monitoring

Interferometer Alignment Monitoring

Pierre Dussarrat

IRS Alignment Monitoring

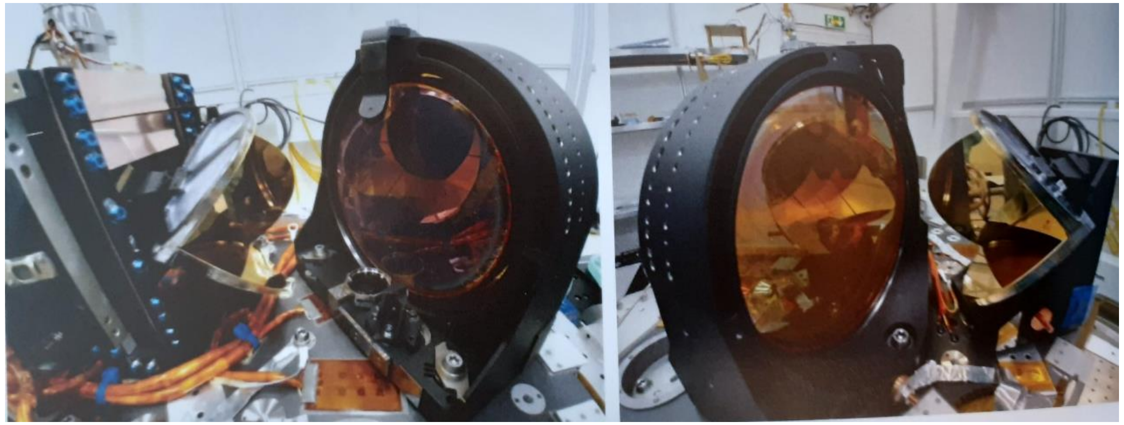


- Introduction
- Misalignment Monitoring
  - Scene generation
  - Misalignment effect on interferogram
  - Interferometer Angular Alignment Monitoring
  - Fixed Corner Cubes shifts Monitoring
- Conclusion

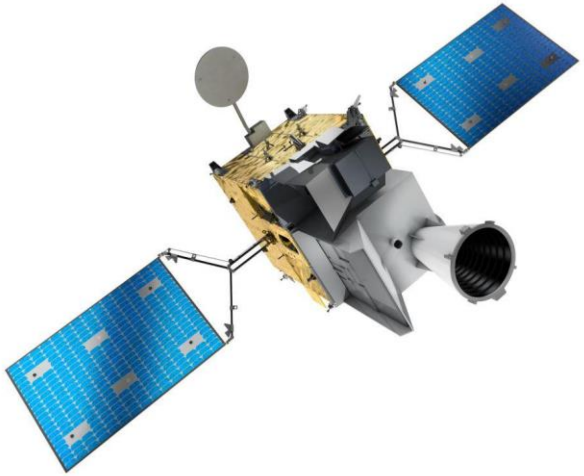
Introduction

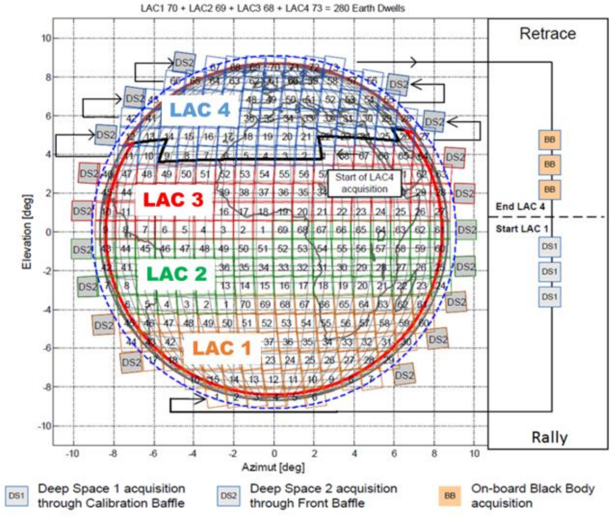
IRS = Fourier Transform Interferometer

Light enters an interferometer :



Interferometer Assembly, Beam splitter, Mobile and Fixed Corner Cubes





Geo-localised spectra are recovered from the interferogram by Fourier Transform:

$$S(\nu) = \int_{-OPD_m}^{OPD_m} Interf(x)\, e^{2i\pi\nu x}\, dx$$

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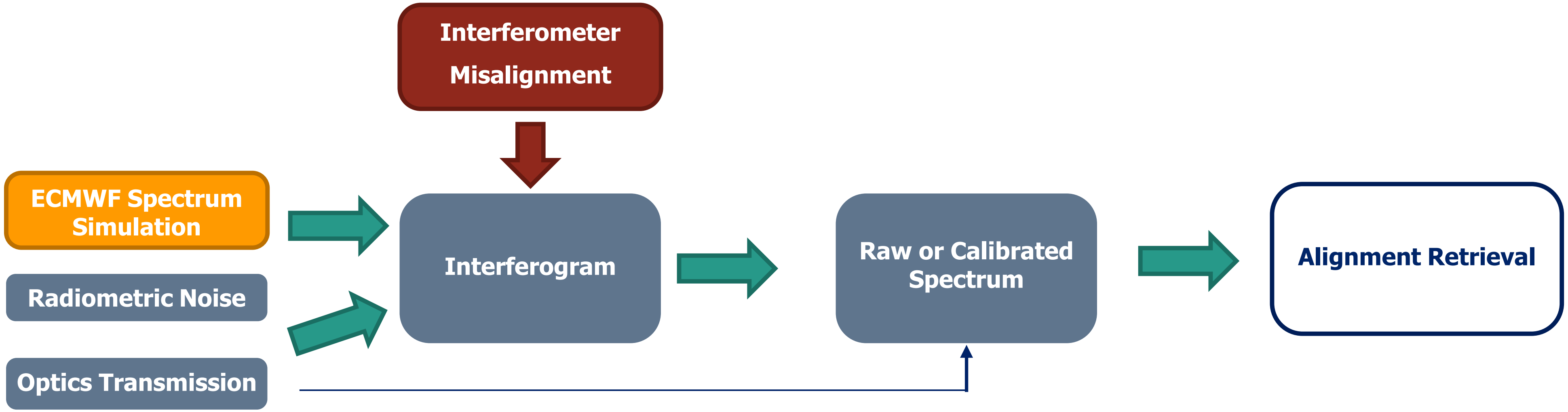
Spectrum Generation

- From ECMWF simulation over North Atlantic (clear sky) to a calibrated spectrum



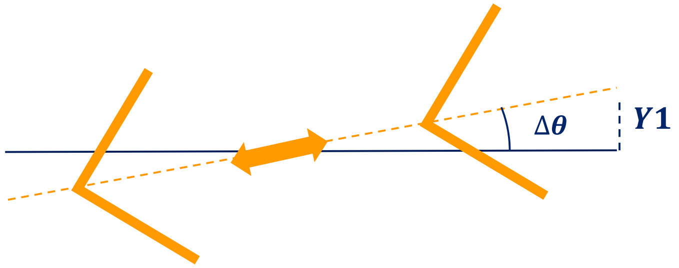
- Simplified processing for the study,
- Using representative parameters in line with the last updates by the industry (transmission, noise)

Spectrum Generation/ Misalignment

Perfect Alignment (Simulation with laser @ 4.5µm):

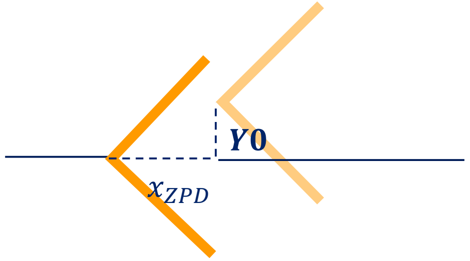
$$I(x) = 1 - cos[2\pi\nu\ \cos(\theta)\, x\,]$$

Angular MCC misalignments (or back optics optical axis drift) :

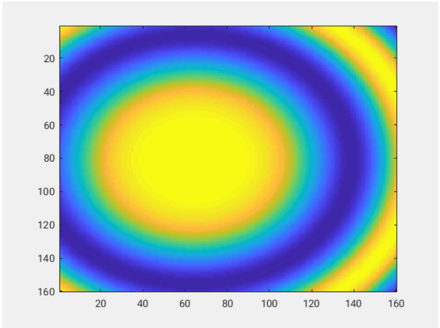


$$I(x) = 1 - cos[2\pi\nu\ \cos(\theta - \Delta\theta)\, x\,]$$

On-axis and off-axis FCC translation:



$$\begin{cases} I(x) = 1 - cos[2\pi\nu\, \{x - x_{ZPD} - x_{YZ0}(\theta)\}\,] \\ x_{YZ0} = \ Y0\sin(\theta_y) + \ Z0\sin(\theta_z) \end{cases}$$



Ex: $Y0 = \mathbf{60\mu m}$

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Spectra Scale Factors

I) Angular Misalignment

Spectral calibration specification : ~1ppm !

- The cosine factor rescales the spectrum in the field:

$$I(x) = 1 - cos[2\pi \nu \ \cos(\theta) x\,] \ \rightarrow \ TF[I(x)] = S(\nu,\theta) = S[\nu \times cos(\theta)]$$

- The IRS uses a **3-laser metrology** system that corrects the rescaling at the interferogram level

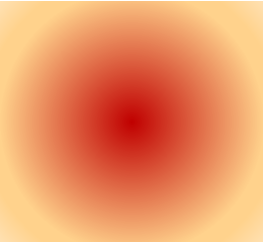
- However, **misalignment in the back telescope and cold optics** could still occur after the launch:

$$S_{metro}(\nu,\theta) = S\left[\nu \times \frac{\cos(\theta \ - \Delta\theta)}{\cos(\theta)}\right] \cong \ S[\nu\ (1 \ - \vec{\theta}.\overrightarrow{\Delta\theta})]$$

SFs

Specification gives : $\boxed{\Delta\theta < \frac{10^{-6}}{\theta} = 28\mu\text{rad}}$

- And, **focal plane defocus**: $S_{metro}(\nu,\theta) = S\left[\nu \times \frac{\cos(\theta')}{\cos(\theta)}\right] \cong \ S[\nu \times (1 \ - \theta^2 \ \frac{\delta f'}{f'})]$



SFs

Specification gives : $\boxed{\delta f'/f' < \frac{10^{-6}}{\theta^2} = 0.08\% \text{ !}}$

So the angular alignment and focal plane defocus have to be monitored and the spectra rescaled !

Scale Factor Fitting

- **In-line processing :**
  - Scale factor determination for all pixels **independently** using spectral features positions for spectra over North Atlantic (every 20min)
  - Scale factor prediction using the last few measurements
  - Spectra correction : Precision = 1ppm

- **Off-line monitoring:**
  - Scale factor fitting over the full detector to extract the physical misalignment.

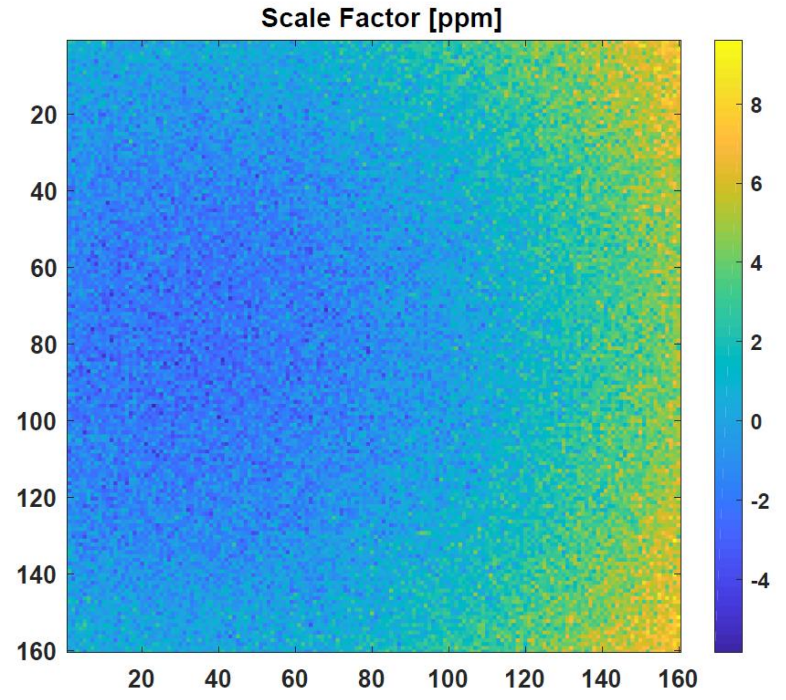
  → Circular effect : focal plane defocus

  → Slope : angular misalignment

  - Incredibly accurate parameters retrieval :

$\sigma\Delta\theta$ = 0.4μrad

$\sigma(\delta f'/f')$ = 2.2 10^{-5}



Ex: $\Delta\theta_y$= 90μrad, $\delta f'/f'$= 0.2%, with IRS Representative noise, LWIR MICOS

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FCC shifts Product quality impact

II) Fixed Corner Cube Shifts

- FCC displacements shift the interferogram: $I(x) = 1 - cos[2\pi\nu\,\{x - x_{ZPD} - x_{YZ0}(\theta)\}]$

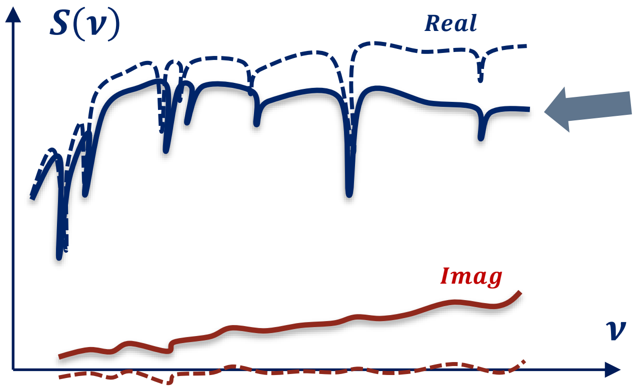
  and produce a phase proportional to the wave number:

$$\tilde{S}(\nu) = \int_{-OPD_m}^{OPD_m} I(x - \delta x)\, e^{2i\pi\nu x}\, dx \cong \int_{-OPD_m}^{OPD_m} I(x)\, e^{2i\pi\nu(x+\delta x)}\, dx$$

$$= S(\nu)\ e^{2i\pi\nu\delta x}$$

With, $\boxed{\delta x = x_{ZPD} + Y0\sin(\theta_y) + Z0\sin(\theta_z)}$

On-axis Off-axis



Noisy and Biased product !

- If the FCC shift is constant, then this effect is cancelled with the complex radiometric calibration realized with the black body and deep space views on-board.

- Moreover, the metrology system cancel most of it calculating the difference of positions between MCC and FCC at any time.

- However, if the ZPD is fluctuating between two radiometric calibrations, and the metrology fail to correct every movement, then the real part product can be **noisy and biased** !

FCC shifts Product quality impact

- The real product amplitude is related to the FCC shifts:

$$Real\left(\tilde{S}(\nu)\right) \cong S(\nu)\, cos(2\pi\nu\delta x) \cong S(\nu)\left[1 - \frac{(2\pi\nu\delta x)^2}{2}\right]$$

- The vibration can first bias the product :

$$\boxed{\text{Bias} = 0.1\% \text{ for } \sigma_{\delta x} \cong 32\text{(MWIR), 100(LWIR)nm}}$$

- The vibrations will also produce a noise, it would be equal to the expected radiometric noise for:

$$\boxed{\text{SNR}_{\text{rad}} = \text{SNR}_{\text{vib}} \rightarrow \sigma_{\delta x} \cong 100\text{[MWIR], 200[LWIR]nm}}$$

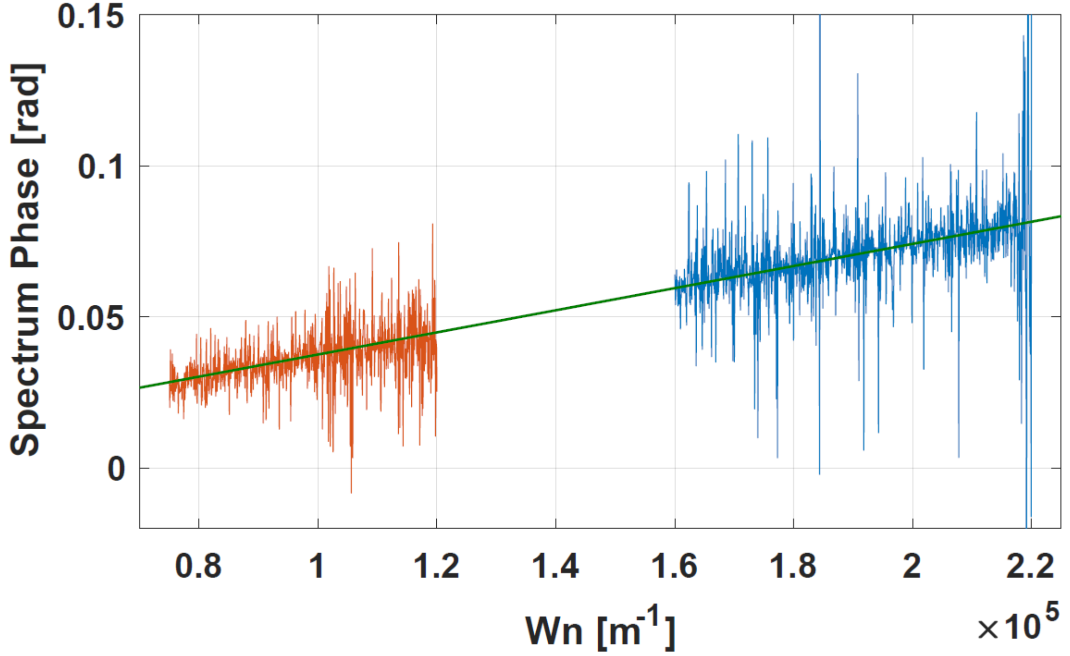
- Both longitudinal and transversal vibrations are accounted : $\delta x = x_{ZPD} + Y0 \sin\left(\theta_y\right) + Z0 \sin(\theta_z)$,
  But transversal shifts contribute only in the field and since : $\sin(\theta_{max} = 2^o) = 0.035$ the interferometer is at least 25 times less sensible to transverse vibrations.

Goal : Monitor at the nm level the Corner Cube alignment !

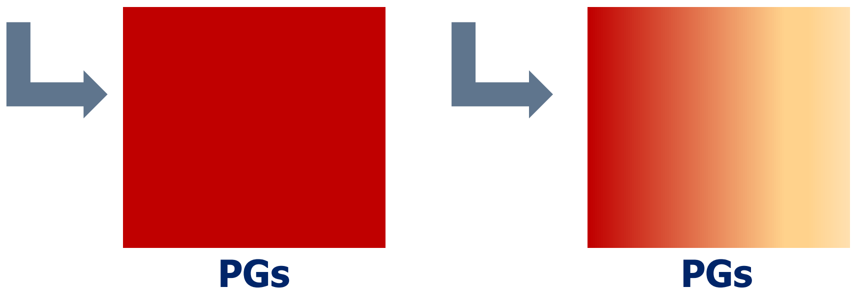
Spectrum Phase Monitoring

- Product $\tilde{S}(\nu) = S(\nu)\, e^{2i\pi\nu\delta x}$ phase gradient study:
  - Compute the spectrum phase:
    $\varphi(\nu) = \mathrm{atan}\left[Im\{\tilde{S}(\nu)\}/Re\{\tilde{S}(\nu)\}\right]$
  - Phase linear fitting (weighted with spectrum amplitude):
    $2\pi \times (A0 + A1 \times \nu) = \mathrm{LeastSquareFit}\left[\delta\varphi(\nu), Re\{\tilde{S}(\nu)\}\right]$
  - Spectrum dephasing correction (if necessary, not in the baseline):
    $S(\nu) = \tilde{S}(\nu) \times \exp(-2i\pi\,[A0 + A1 \times \nu])$

IRS representative example of phase fitting for a 50nm ZPD shift



- With : $\boxed{A1 = x_{ZPD} + Y0\sin(\theta_y) + Z0\sin(\theta_z)}$



NB : With IRS expected radiometric noise, $A1$ is retrieved at 2nm (MWIR) and 3.3nm (LWIR).

Spectrum Phase Monitoring

In-line processing :

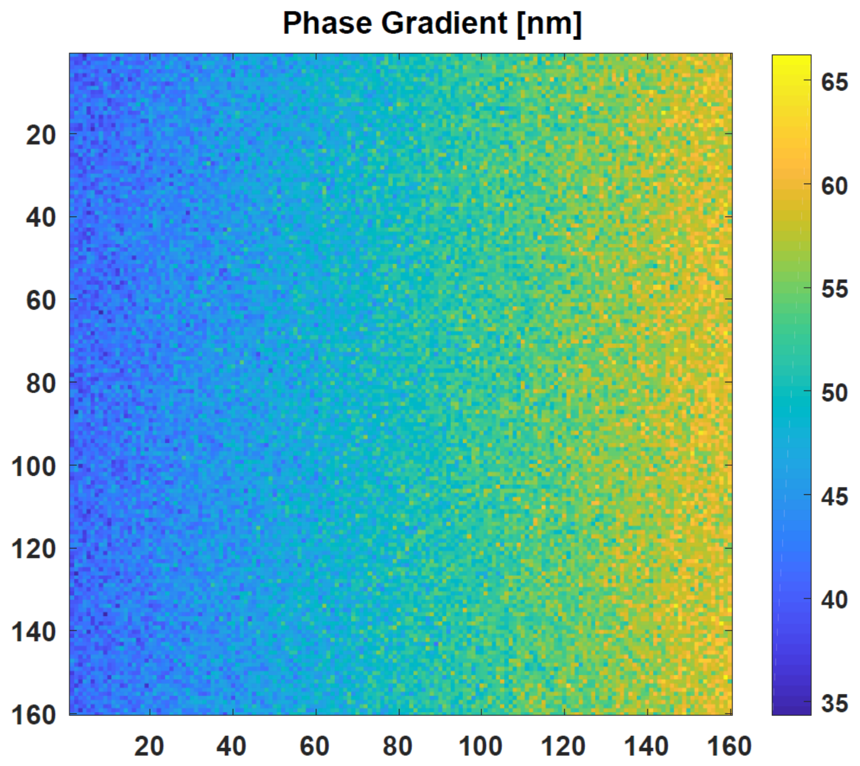
- Flag dwells with high phase gradients

Off-line processing :

- Looking at the measured phase gradients for all pixels
  - Constant component = FCC longitudinal shifts
  - Slope component = FCC transverse shifts

- Fitting over all detector give the FCC shifts monitoring at sub-nanometer level:
  - σx_{ZPD} = 14pm (MWIR), 28pm (LWIR)
  - $\sigma YZ0$ = 0.8nm (MWIR), 1.5nm (LWIR)

- Chromatism effect as a ZPD(ν, θ) ? (Waiting for first instrument data)
  - Could be taken into account adding orders in the phase fittings and/or phase gradient fit (decreasing a bit the accuracy)
  - And chromatism could then be also monitored



Ex: x_{ZPD} = 50nm, $Y0$ = 250nm, with IRS Representative noise

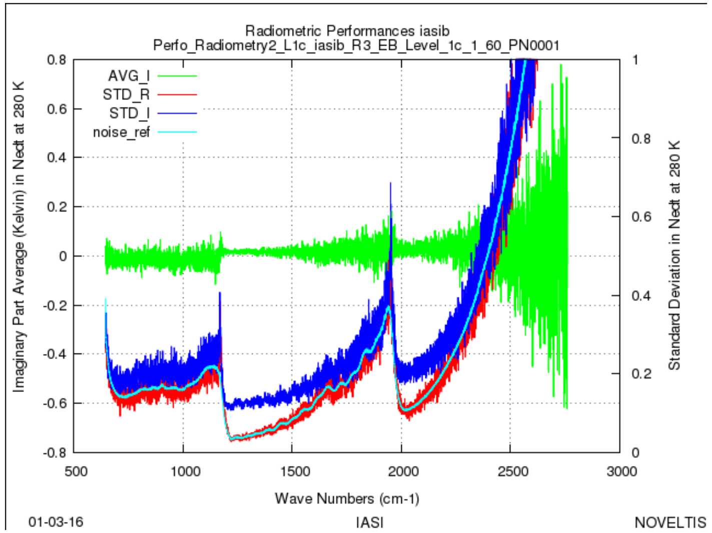
FCC vibrations on IASI ?

- Study with IASI-b black body measurements show greater noise for the imaginary component than for the real as expected since the imaginary part is more sensitive to small shifts:

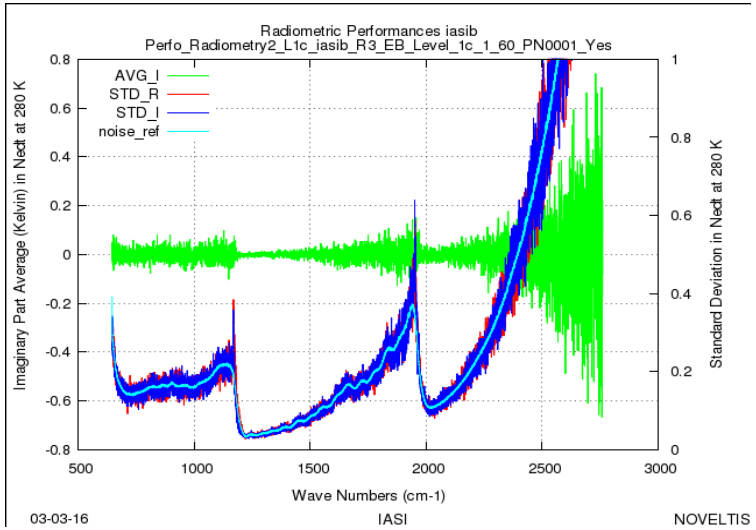
$$\rightarrow Real\left(\tilde{S}(\nu)\right) \cong S(\nu)\,cos(2\pi\nu\delta x) \cong S(\nu)\,[1-\frac{(2\pi\nu\delta x)^2}{2}]$$ (Second order perturbation)

$$\rightarrow Imag\left(\tilde{S}(\nu)\right) \cong S(\nu)\,sin(2\pi\nu\delta x) \cong S(\nu)\times(2\pi\nu\delta x)$$ (First order perturbation) **← More Sensitive !**

- Applying the residual phase correction, it equalize the real and imaginary noise to the radiometric noise.
  - Red curve (right vertical axis) the standard deviation of the real part.
  - Blue curves (right vertical axis) the standard deviation of the imaginary part.
  - Green curve (left vertical axis) the average of the imaginary part
  - Cyan curves (right vertical axis) the reference IASI noise from level 1c Black body spectra.



Residual phase correction



Credit : Bernard Tournier

- We can evaluate the ZPD drift RMS for IASI-b : $\boxed{\sigma_{\delta x} IASI \cong 3.5\text{nm},}$

-> 12.7nm expected on IRS (IA Optical Analysis Report, MTG-TAS-F-IR-TN-1489)

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Conclusion

Performances:

- Using fit over IRS full detectors lead to incredibly accurate alignment monitoring:

Method	Parameter	Accuracy
Scale Factor :	$\Delta\theta$	0.4μrad
	$\delta f'/f'$	$2.2\ 10^{-5}$
Phase gradient :	x_{ZPD}	14-28pm
	YZ0	0.8-1.5nm

- Great interest for long-term stability studies, warning of dangerous drifts (both for EUM and industry)

Open questions:

- Polynomial phase fitting could be implemented to track fluctuating chromatism ?
- Spectra are dynamically rescaled but their residual phase is not corrected yet.

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Conclusion

MAG - Conclusion :

- Development of two off-line modules for the angular misalignment and FCC drifts monitoring and physical parameters retrieval,

- Further study on this topic could only be conducted with instrument data (chromatism, vibration ?)

- EUM team pursues the study of every defects that could deteriorate the data quality.