Possibilities for handling SRF variation in the MTG-IRS detector array

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ECMWF / EUMETSAT / NWP-SAF
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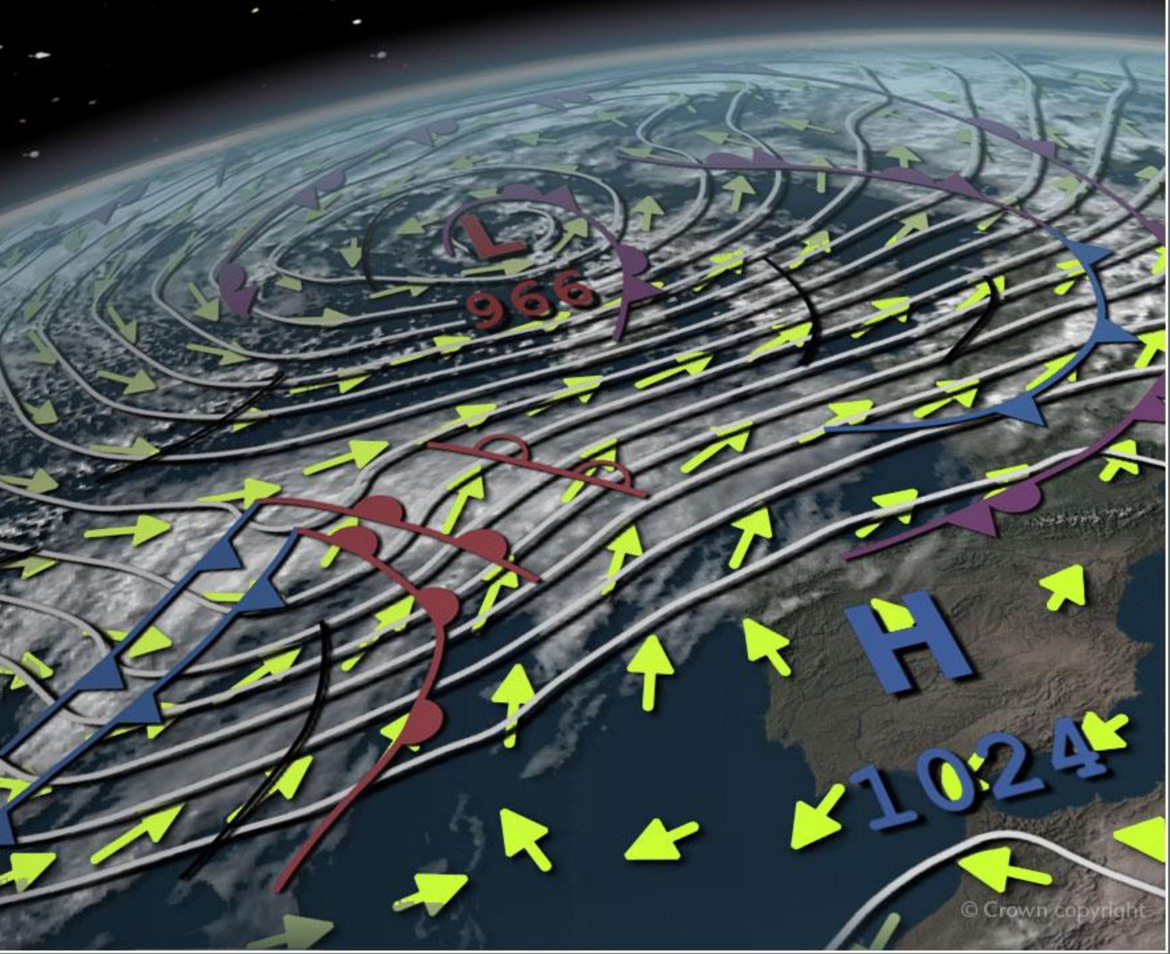
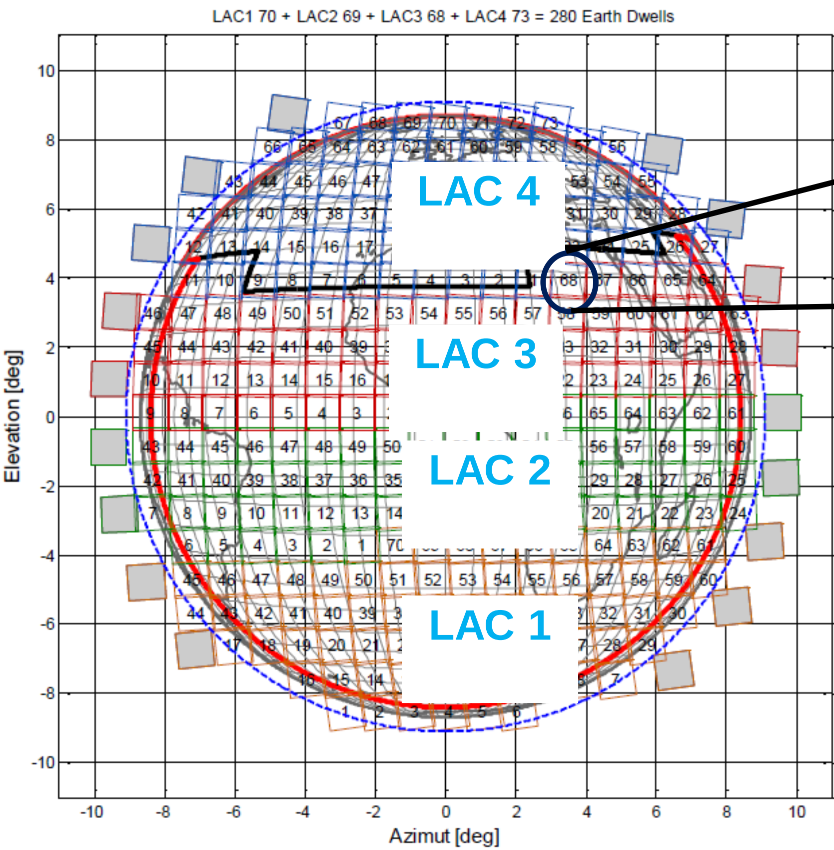
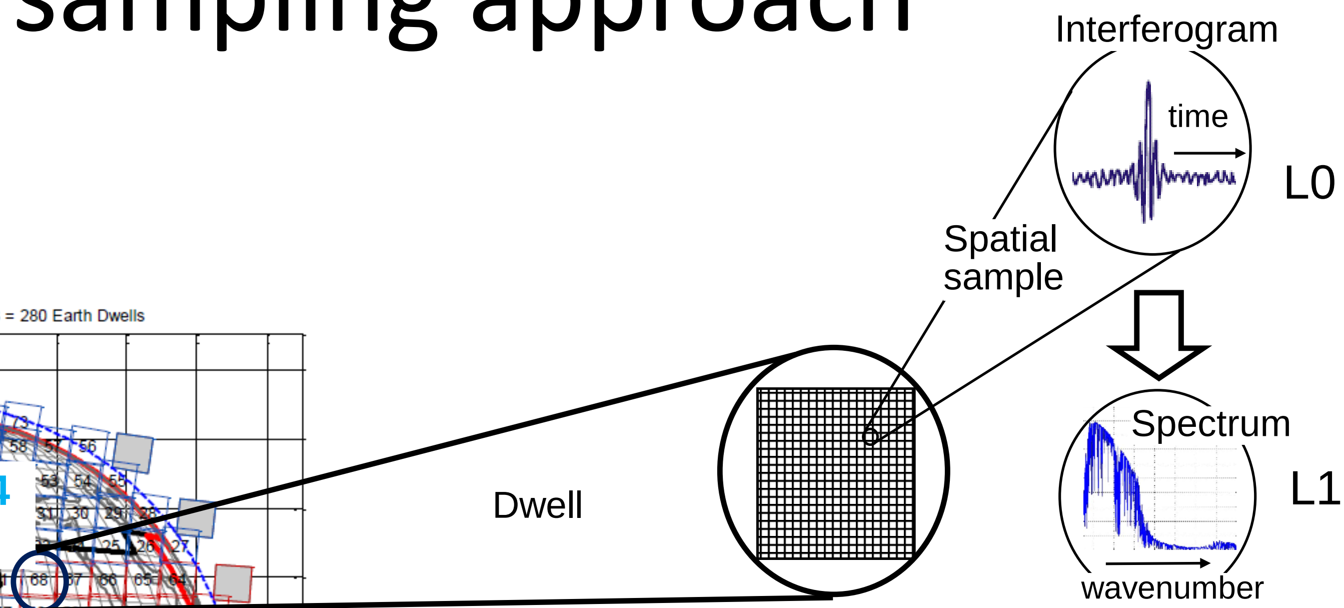


Introduction

- MTG IRS level 1 processing is complicated!
- This presentation looks at 2 effects, and how to deal with them in processing:
  – Self apodisation function (SAF) – easy
  – Detector responsivity – hard
- Looking at the physics – ignoring detail

IRS sampling approach

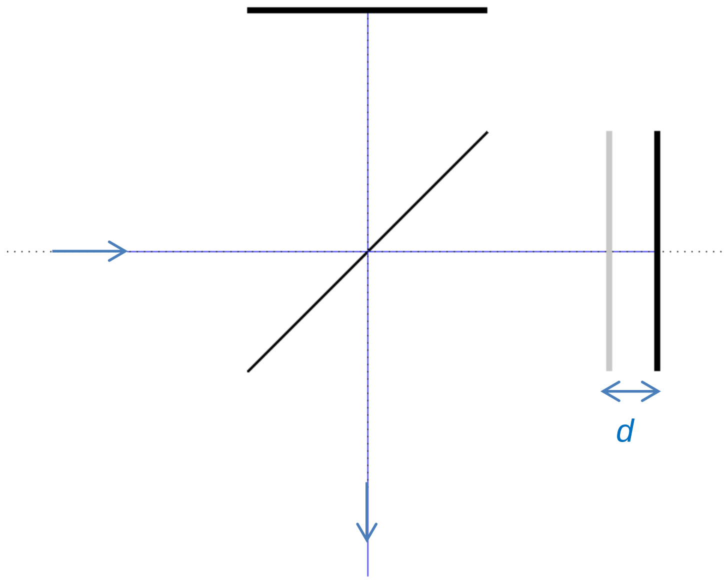




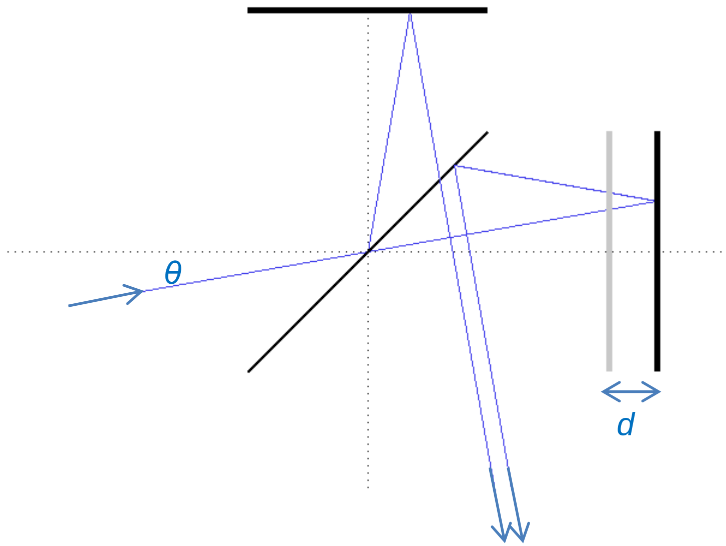
- The IRS detector is an array of 160×160 pixels – total 25600 elements per band (2 bands)
- Viewed simultaneously in a “dwell”
- Issue: the elements may have slightly different characteristics
- NWP users do not want to have to handle 2×25600 different line shapes!

Picture courtesy of EUMETSAT

Self apodisation



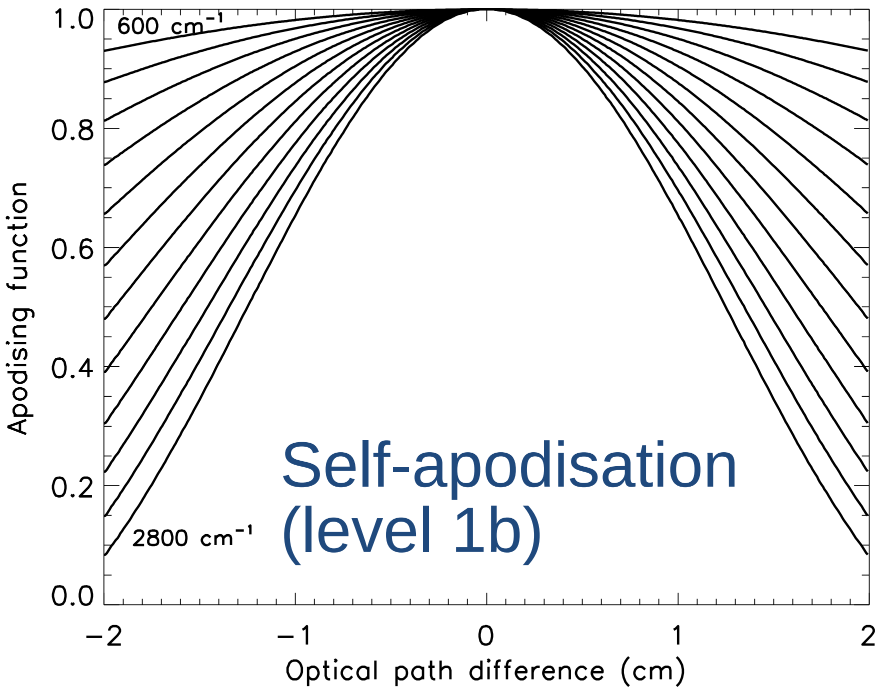
OPD = 2*d*

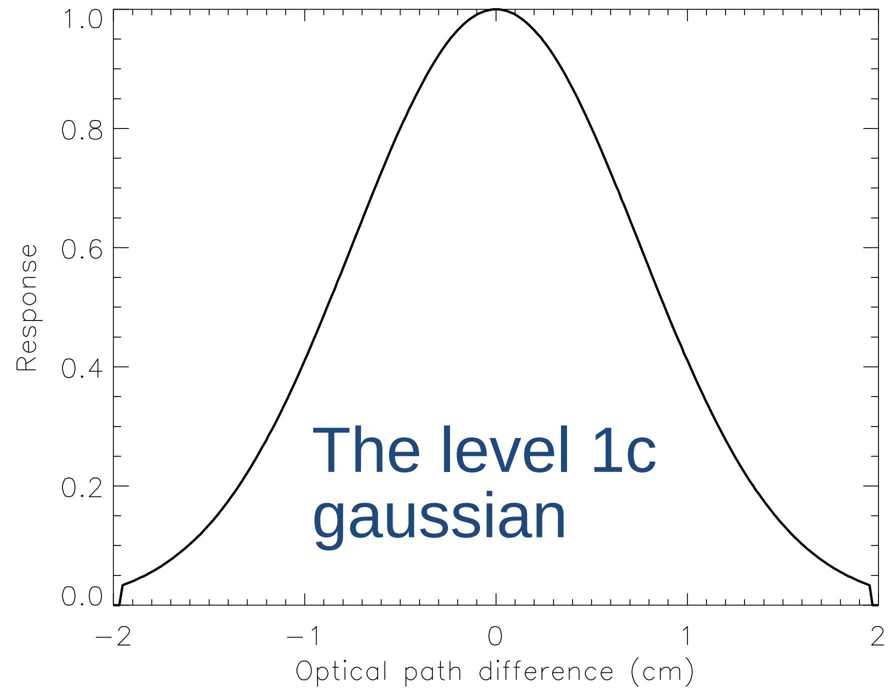


OPD = 2*d* cos(*θ*)

- Off-axis → spectral shift if uncorrected
- Finite solid angle attenuates the interferogram

Self apodisation for IASI





- Transform from level 1b to 1c:
  - split spectrum into several overlapping regions
  - FFT to interferogram domain
  - Modify and inverse FFT
  - Splice together the regions

Note: Most of the signal at high OPD is discarded!

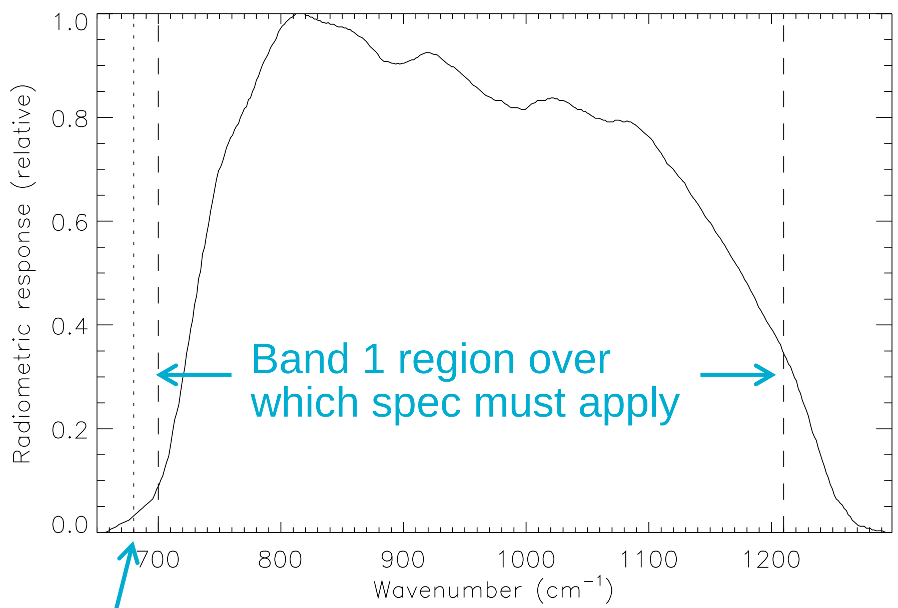
IASI and IRS compared

	IASI	IRS
Detector elements	4	25600
Footprint diameter	12 km	4 km
Satellite altitude	830 km	36000 km
Angle subtended by 1 footprint	0.8°	0.006°

- So self apodisation in IRS would be expected to be a factor >100 smaller than IASI (other things being equal)
- Maximum impact is ~0.04K in band 2 (D Coppens). Can be corrected.
- There will be spectral shifts, largest in the corners of the detector array, but these are easily allowed for.

Detector responsivity

Typical detector response for band 1



Lower boundary
680 cm^{-1}

Responsivity variations could be:

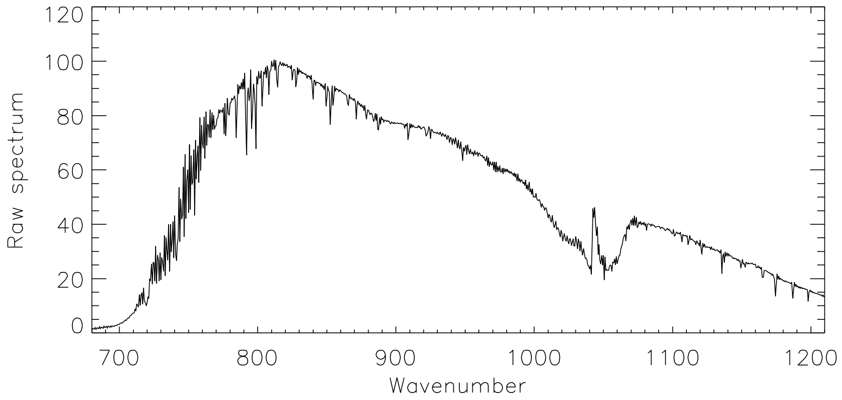
- Random
- Systematic across the detector

Magnitude is not yet known

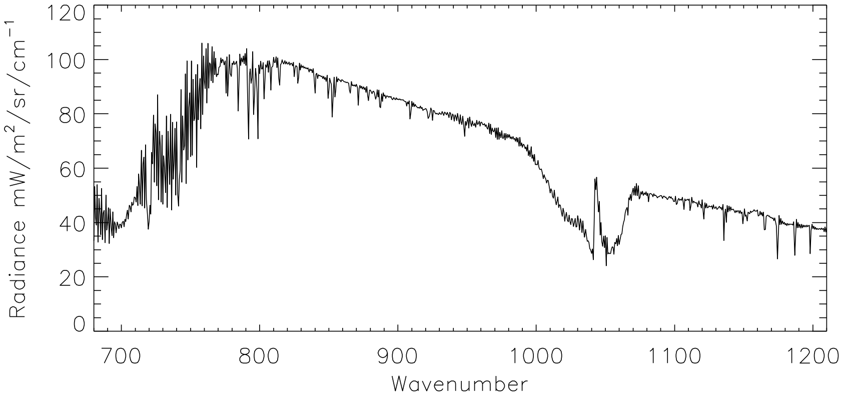
To first order, the effect of detector responsivity is removed by the radiometric calibration

In effect, divide raw spectrum by detector response

Raw spectrum



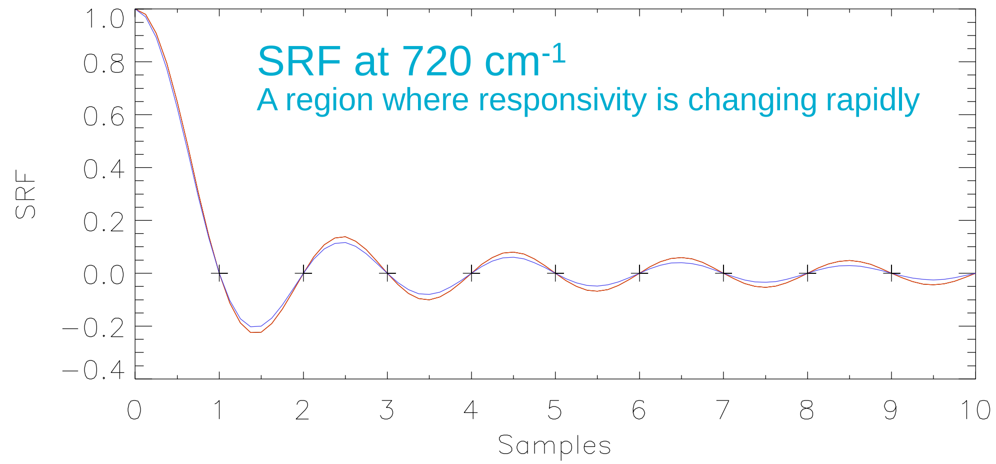
Calibrated

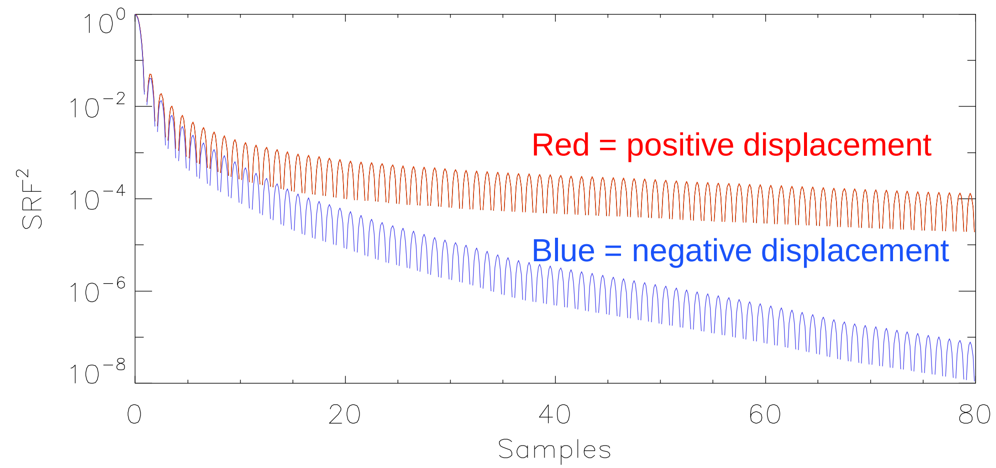


But how does this affect SRF?

SRF modified by responsivity

- For unapodised spectra, SRF is nominally a sinc function (FFT of a boxcar)
- It is modified by the responsivity – becomes asymmetric
- A sinc function has nulls at the sample positions



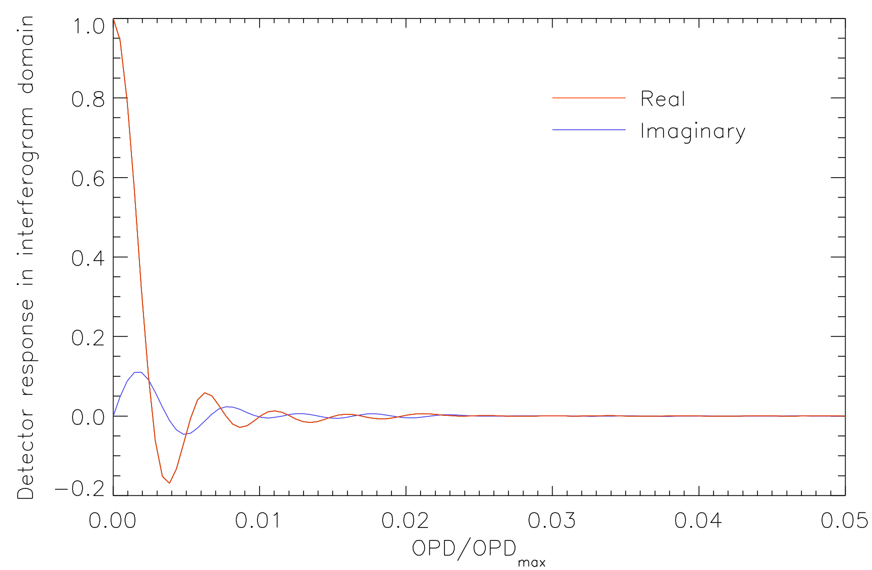


Correcting the spectra?

- An approach might be:
  - Take the ideal (symmetric) SRF and actual (asymmetric) SRF
  - transform to interferogram domain
  - Truncate both at OPD_{max}
  - The ratio is used to multiply the interferogram
- This will not work!
  - *The sample points are at nulls in the SRF* (as shown on previous slide) – for both the ideal and actual SRF
  - We have no information about the interferogram region > OPD_{max}
  - There is no way to capture information that takes place between the spectral samples
- Unapodised spectra cannot be corrected

Another way of looking at it…

- Multiplication in the frequency domain = convolution in the interferogram domin
- The response function of the “observed” interferogram is the response of the “ideal” interferogram (uniform) convolved with the FFT of the detector response, and *then* truncated at OPDmax
  - *It is still uniform!*
  - *Spreading of interferogram components across OPD_{max} (aliasing) makes full correction impossible*

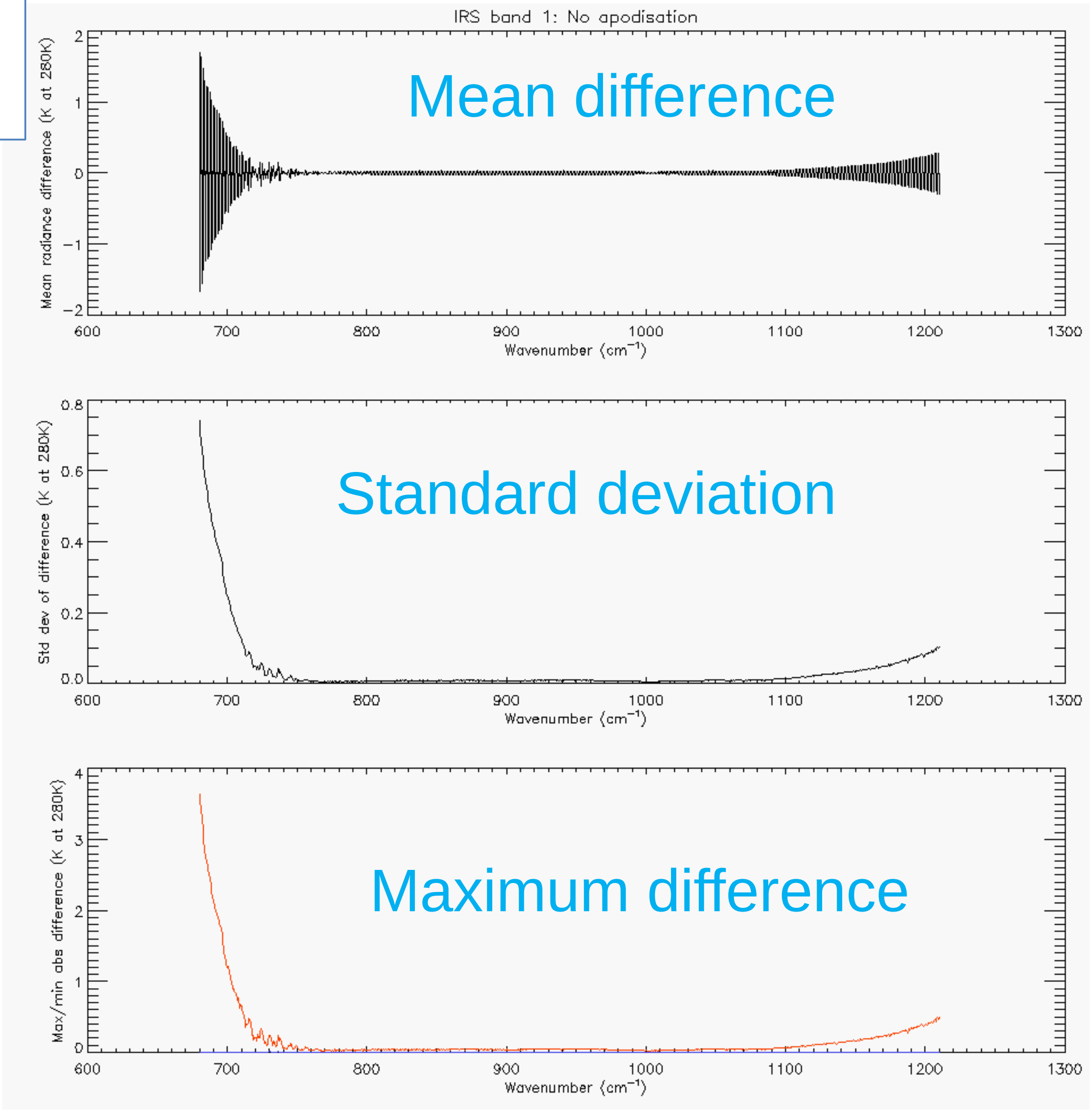


How big is the error?

1. Take raw simulated interferogram
2. FFT to spectral domain
3. Calibrate
4. Compare with ideal spectra

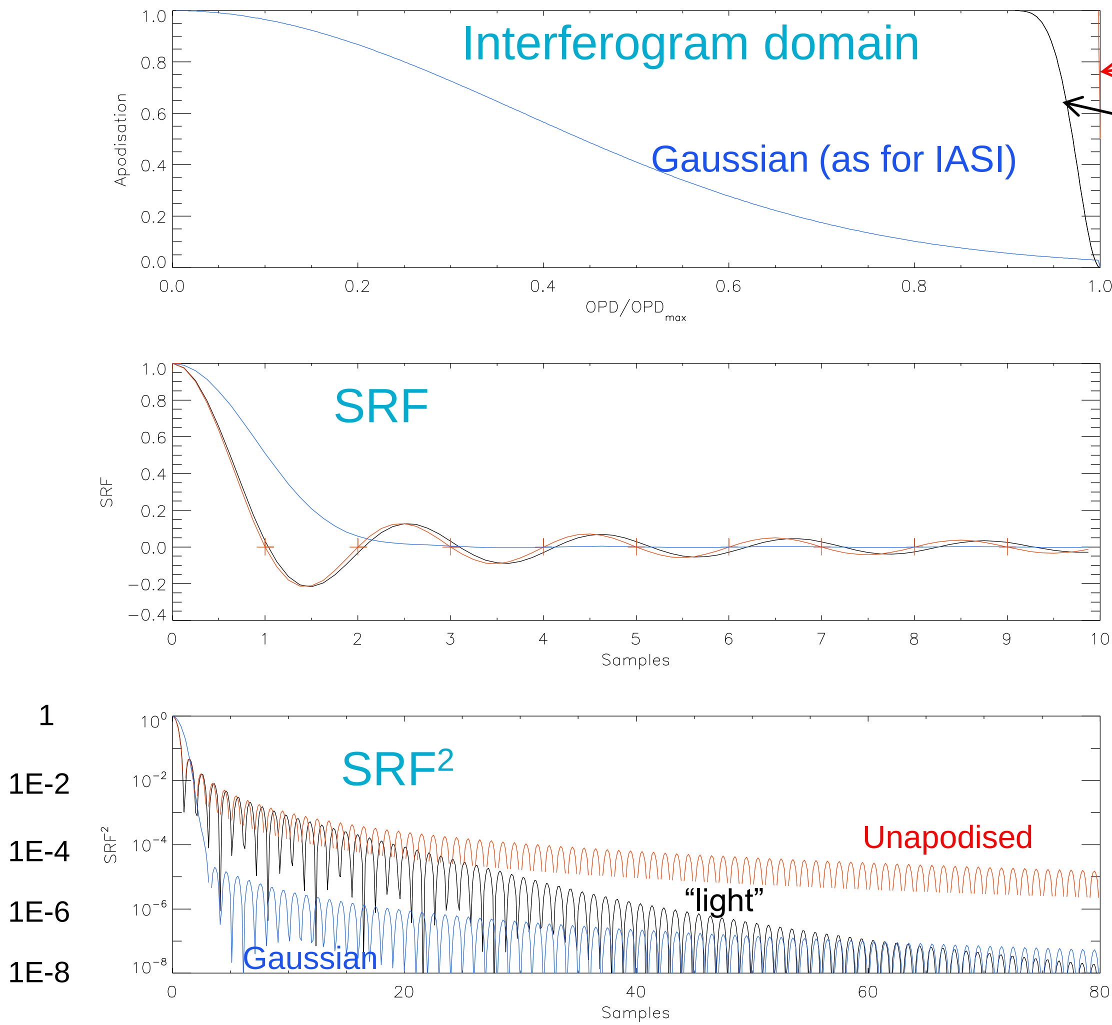
- Using 8160 IASI spectra to simulate IRS
- Sampling at 0.625 cm^{-1}
- The plot looks at the difference between "ideal" spectra and the "measured" spectra
- There are significant errors, especially at the lower edge of band 1

An issue for users of CrIS unapodised spectra?



Alleviate using *apodisation*

Apodisation reduces ringing of the SRF



Unapodised

IRS "light"

$$A = 0.5\left(1+\cos\left[\pi\left(\frac{\left(|x|-dM\right)>0}{\left(1-d\right)M}\right)^{2}\right]\right)$$

d = 0.9
x is OPD
M is max OPD

The "light apodisation" has little effect on the main-lobe, but significantly attenuates the far side-lobes

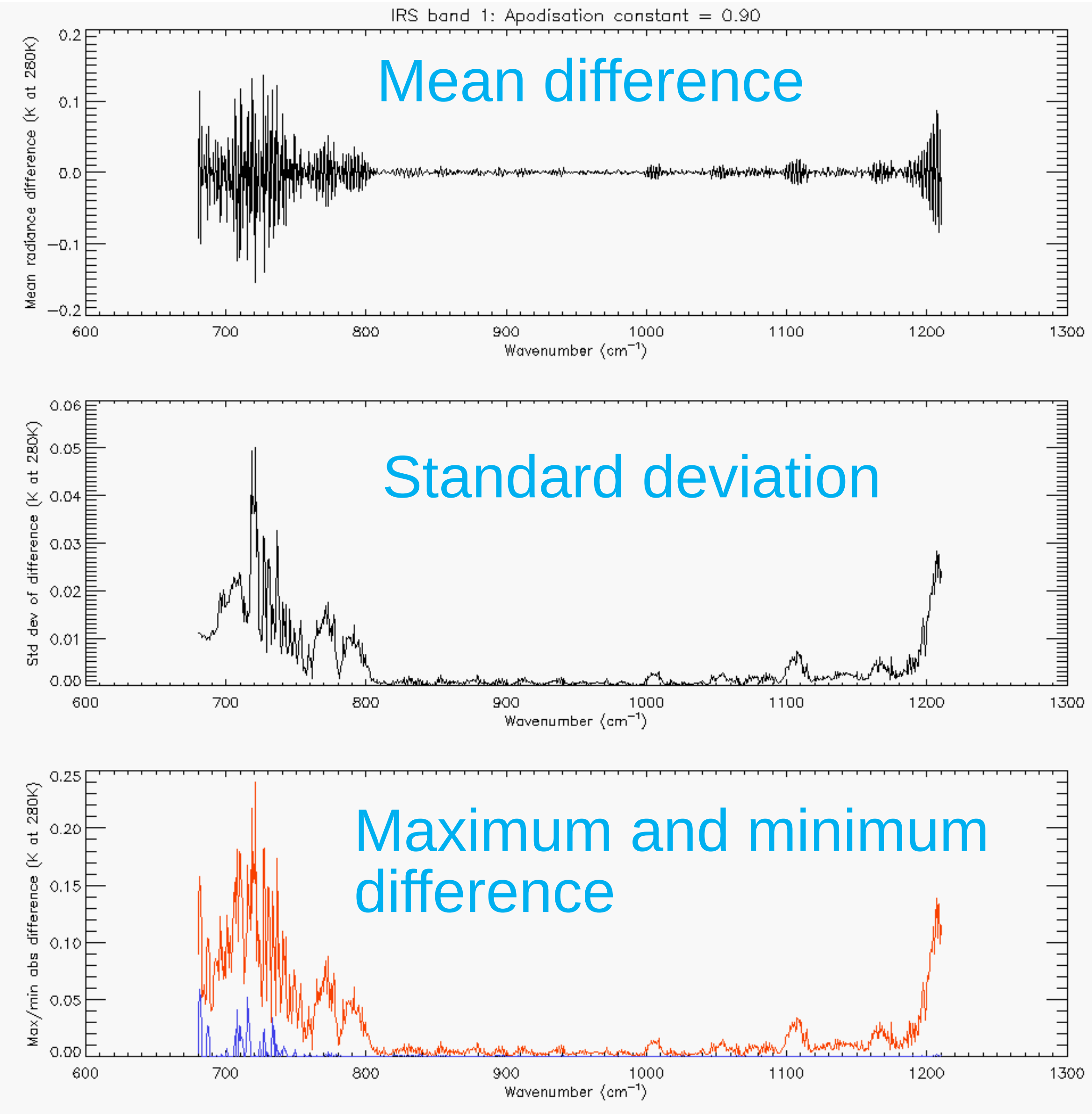
The Gaussian is not an option for IRS users because important CO_2 line structure would be heavily attenuated

Apodisation is also important for other aspects of L1 processing

Responsivity errors with “light apodisation”

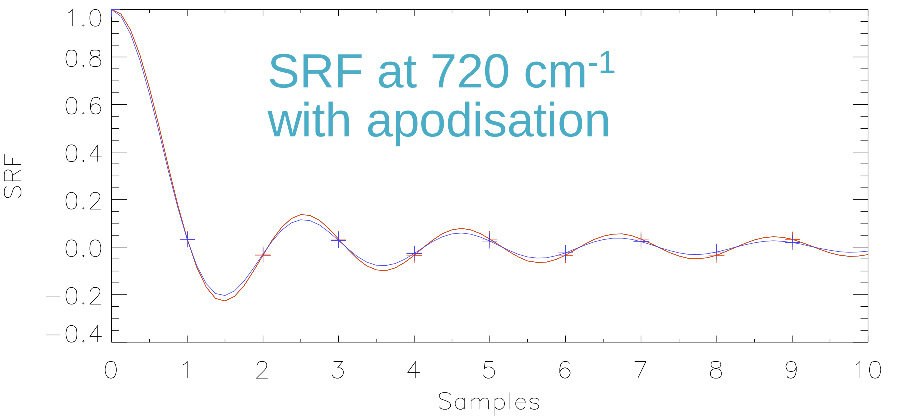
1. Apodise the interferogram
2. FFT to spectral domain
3. Calibrate
4. Compare with ideal apodised spectra

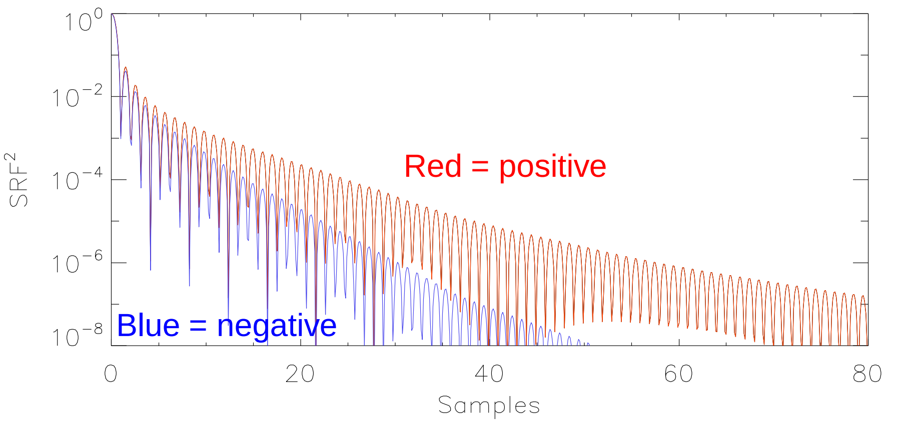
- Order of magnitude reduction in error
- As before, looking at the difference between “ideal” spectra and the “measured” spectra
- 0.1K is still just significant
- Could be larger if detector cutoff is sharper



Is any of this error correctable?

- We no longer have nulls at the sample positions
- May be able to improve it …





The key is applying the apodisation function accurately to the correct spectrum …

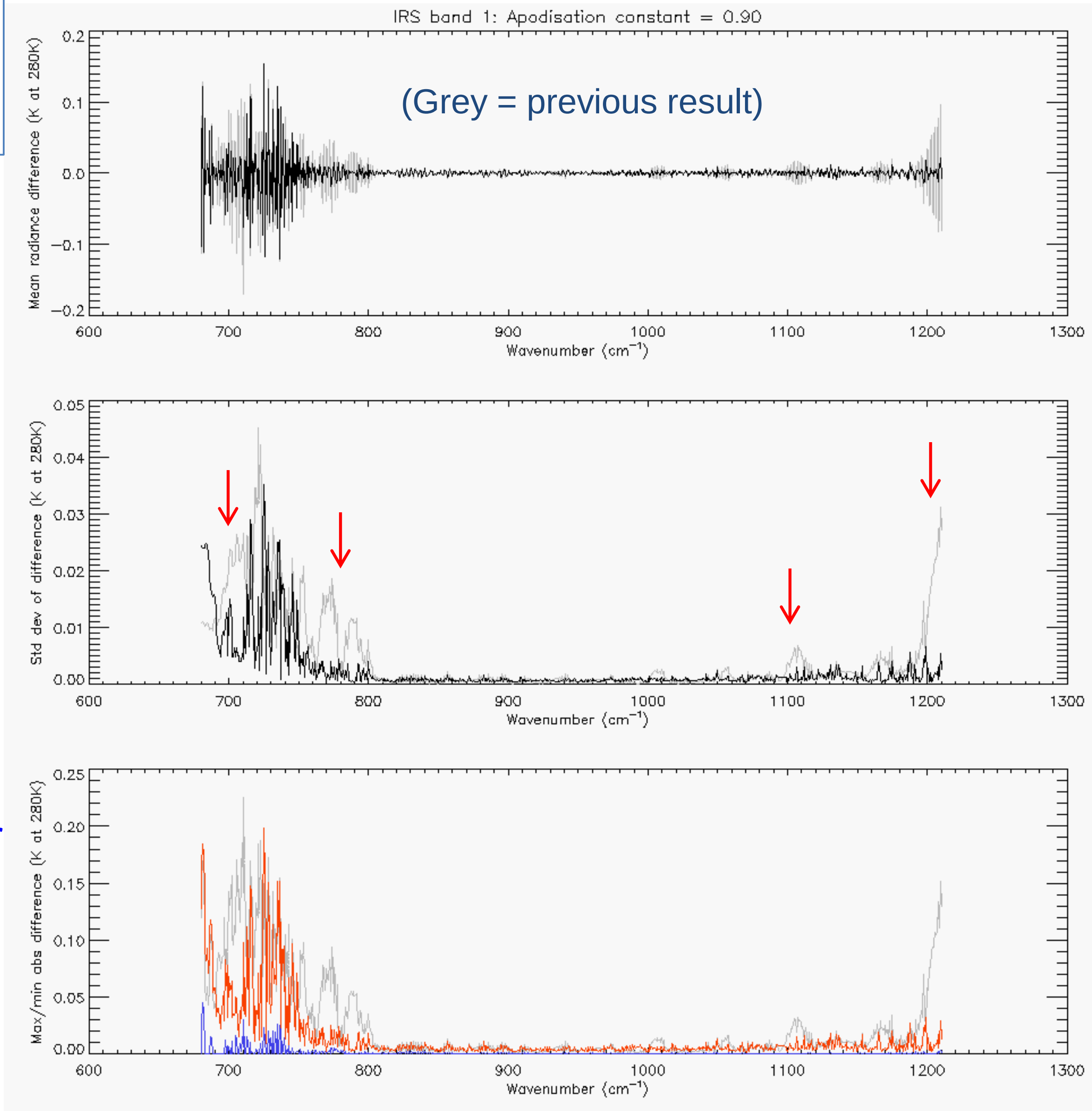
Apodising the “raw” spectrum is not the same as apodising the “calibrated” spectrum

When to apodise?

1. Take raw or very lightly apodised interferogram
2. FFT to spectral domain
3. Calibrate
4. FFT^{-1} to interferogram domain
5. Apodise
6. FFT to spectral domain
7. Compare with ideal spectra

- Improvement if the final apodisation is done on the *calibrated spectrum* rather than the raw spectrum
- Can use an initial “very light” apodisation before calibration, just to reduce long-range interactions
- Assumes L1 processing has access to spectral regions beyond the official band edges

- *This scheme may not fit in other aspects of the L1 processing*



Spectral domain approach

- Following a suggestion from John Eyre
- Assume locally linear:

$$\Delta R_i = \left(\alpha_i - \alpha_i^0\right)\mathbf{R.F}$$

Radiance correction

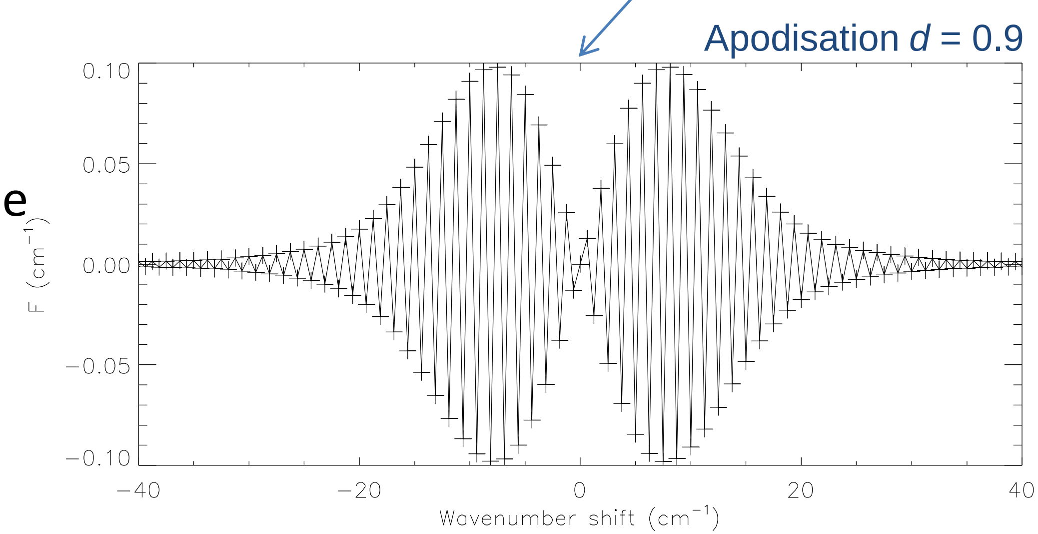
Slope of detector responsivity

Reference slope

Measured radiance spectrum

Defines spectral interactions (depends on apodisation)

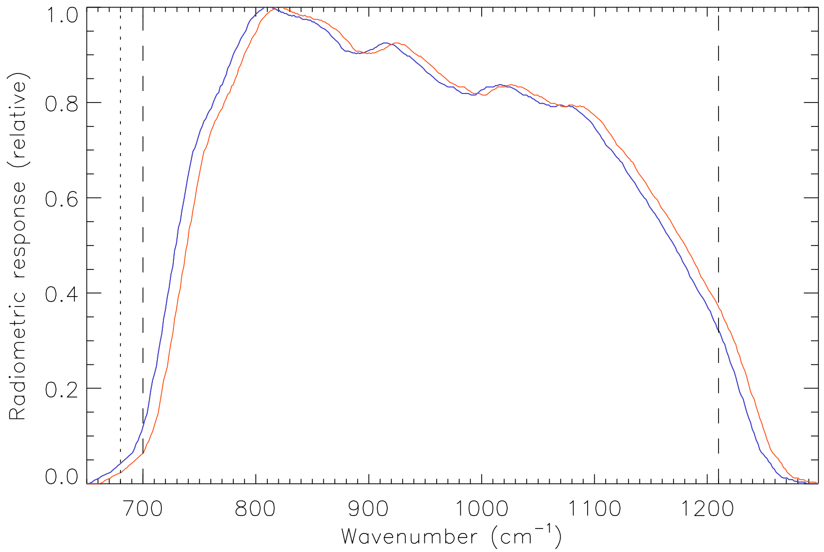
- *Unfortunately I could not get it to work*
- Perhaps the linear approximation is too crude
- Note **F** peaks at ~10cm^{-1} displacement



Correcting to something other than the ideal SRF

- So far we have assumed that the RTM simulates an *ideal* SRF
- We could get the RTM to simulate a *reference* SRF – and just consider differences across the detector array
- The reference SRF would vary with wavenumber, but would be fixed in other respects. This may be possible in RT models (though perhaps not what the users would like)

- *How big are the differences between detector elements?*
- Needs information from industry
- Guess for now …

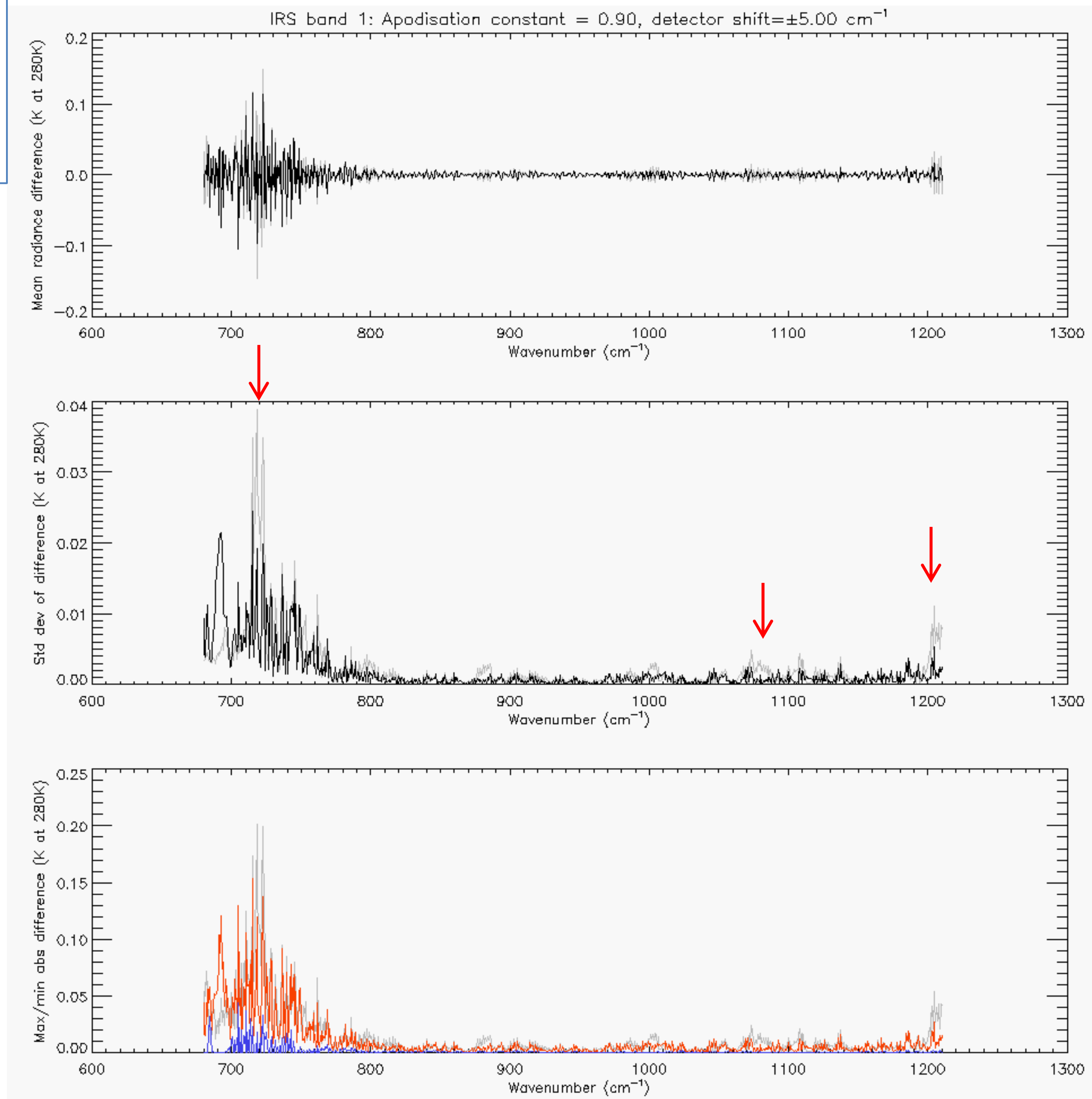


Response shifted by ± 5 cm^{-1}

Correcting to a reference detector

1. Take raw or very lightly apodised interferogram
2. FFT to spectral domain
3. Scale to reference detector
4. FFT^{-1} to interferogram domain
5. Apodise
6. FFT to spectral domain
7. Calibrate
8. Compare with ideal spectra

- The “raw” spectrum is scaled to a *reference detector* profile *before apodisation*
- Radiometric calibration is done on this modified spectrum
- Look at the differences between the 2 modified detectors
- There are some improvements, though rather small



Conclusions

- NWP users would like a constant SRF, same for all detectors and wavenumbers *– if possible*
- Self-apodisation (due to solid angle) is a much smaller effect for IRS than it is for IASI. Correctable.
- Detector responsivity causes significant errors for *unapodised* spectra (~1K) – and cannot be corrected
- “Light apodisation” greatly improves the situation (the precise formulation does not seem to matter too much)
- There are small residual errors (~0.2K max)
- Some mitigation of the residual errors is possible, by apodising *after* radiometric calibration (though this is not EUMETSAT’s current baseline)
- Some harmonisation to a reference detector profile, instead of the “ideal”, is possible (before apodisation), but forward model would need a wavenumber-dependent SRF. Again, there are residual errors.
- Beware of band-edges – changing the apodisation requires extra spectral coverage
- EUMETSAT may have other methods, not considered in this study
- RT models need to be able to handle negative sidelobes in the SRF
- Information needed from industry to refine the models

Thank you!

Questions?