Mid-Infrared Imaging and Spectroscopy Calibration

An illustration using
the example of VISIR VLT instrument

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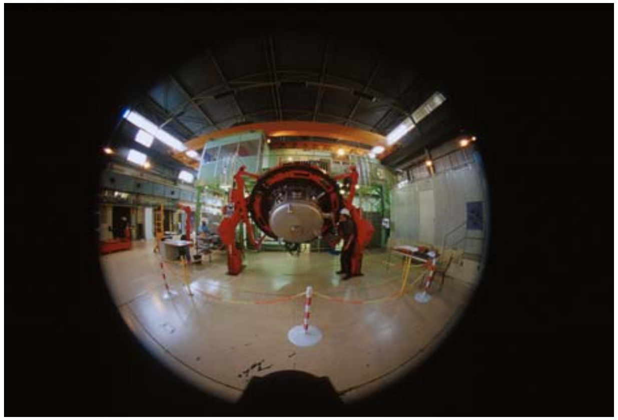
ESO/Paranal



VISIR@Melipal.Paranal

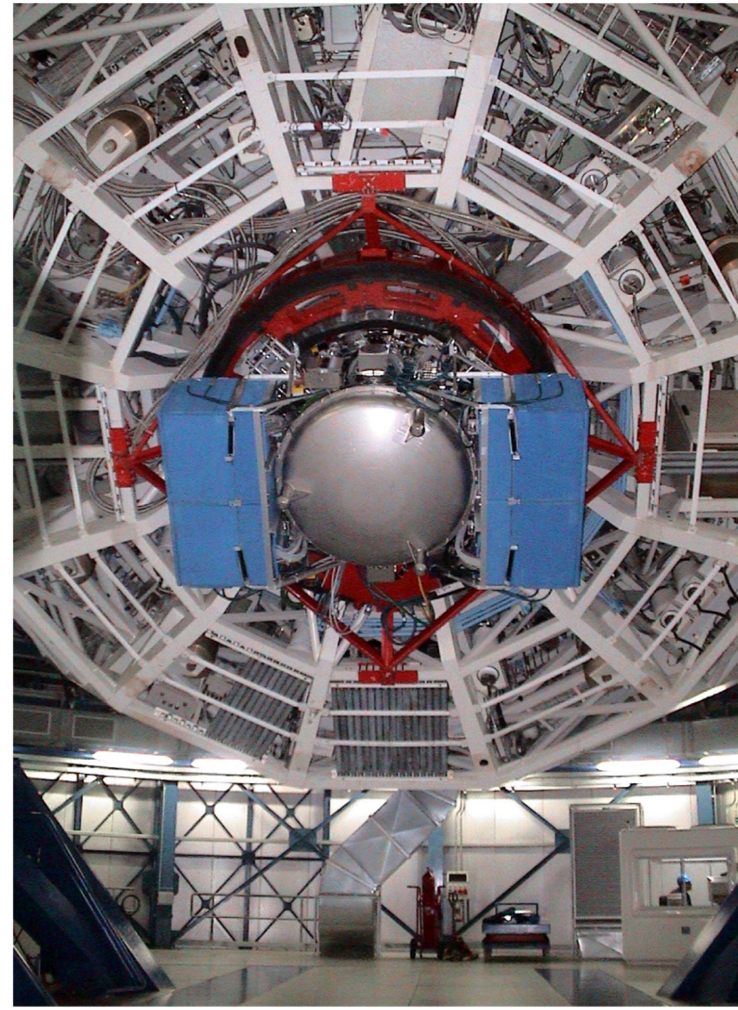
VLT Imager and Spectrometer for the InfraRed

Installed and commisionned in 2004 on Melipal

Multi-modes instrument :

Imaging in N(8-13 μm) and Q(16-24 μm) bands, R=20 to 100 filters, 2 magnifications (0.075 and 0.127 "/pixel)

Spectroscopy LR (300), MR (3000) and HR (15000-30000) in N and Q bands



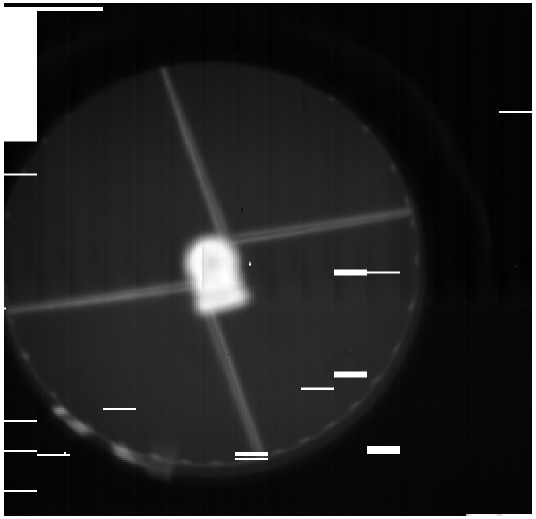
VISIR Mounted behind the 8.2-m Mirror of Melipal

ESO PR Photo 16b/04 (12 May 2004)

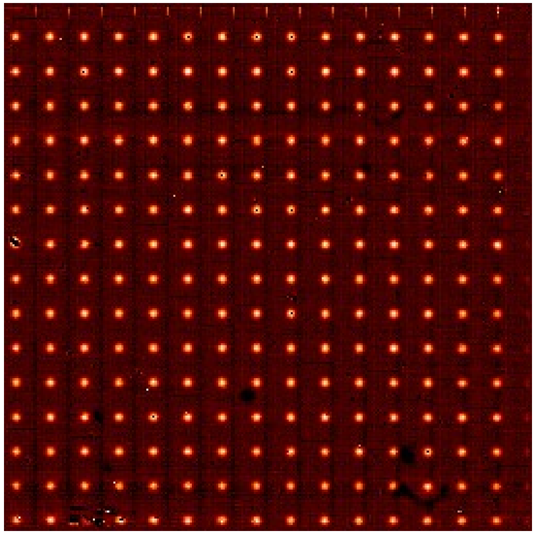
2 Boeing Si:As BIB detectors

Internal calibration devices of the Imager

Pupil Imaging
(alignment)

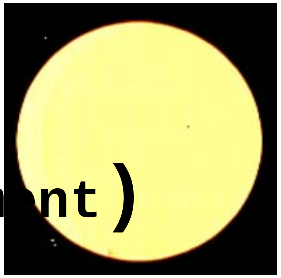


Distorsion grid
(optical field and PSF distorsions, illumination



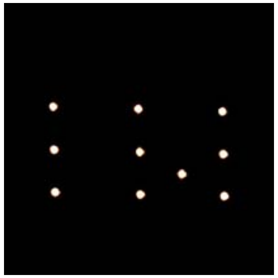
Internal calibration devices of the Spectrometer

Pupil imaging (alignment)



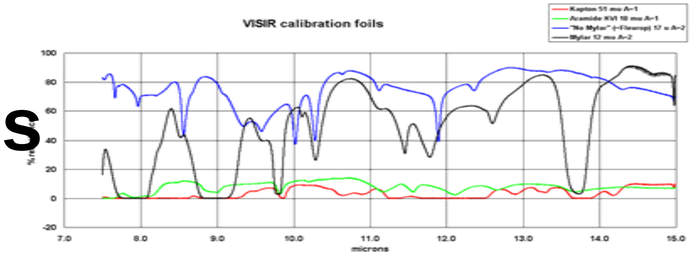
Pinholes grid

(distorsion, scale, image quality)



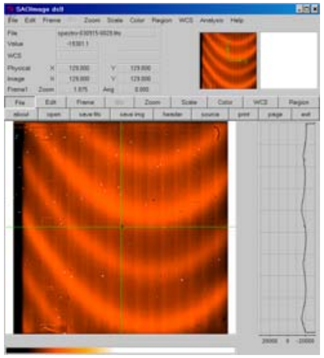
Plastic foild absorbers

(wavelength and dispersion calibration, LR)



FP plates

(wavelength calibration (HR))



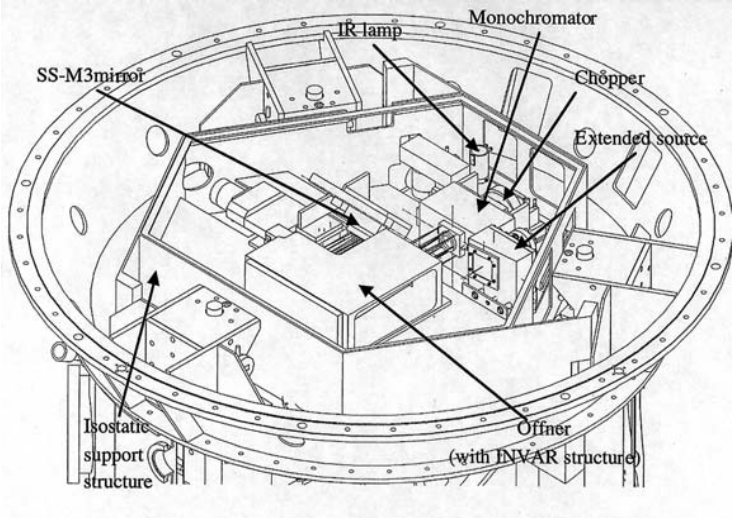
WCU

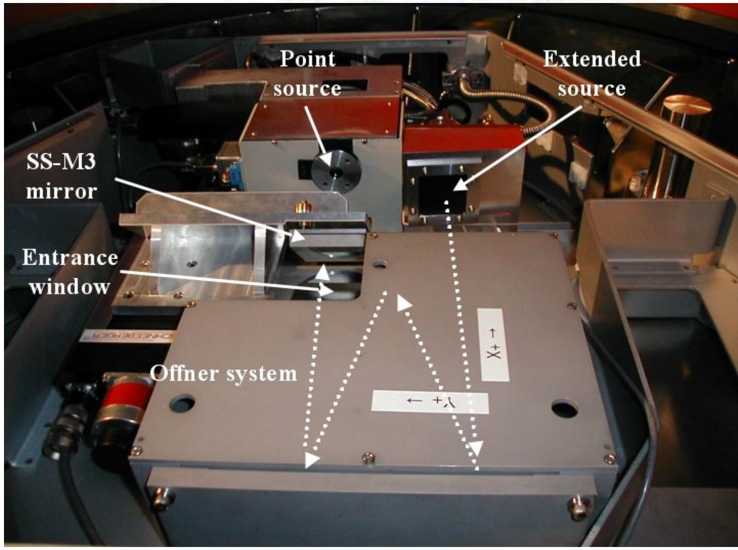
Warm Calibration Unit :

Sources :

- Point source
- Extended source (Peltier plate, temperature ➔flux)

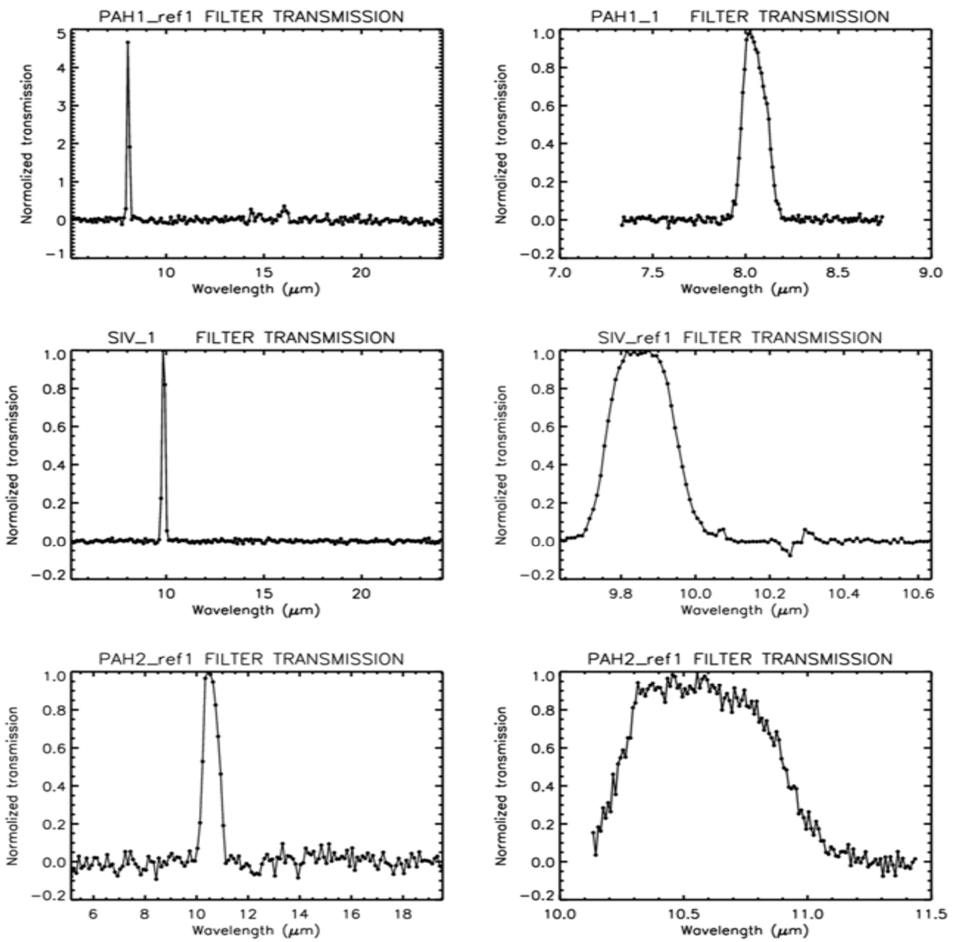
Offner telescope simulator





Filters

Calibrated twice (in Europe, then at Paranal using the WCU star simulator (monochromator)



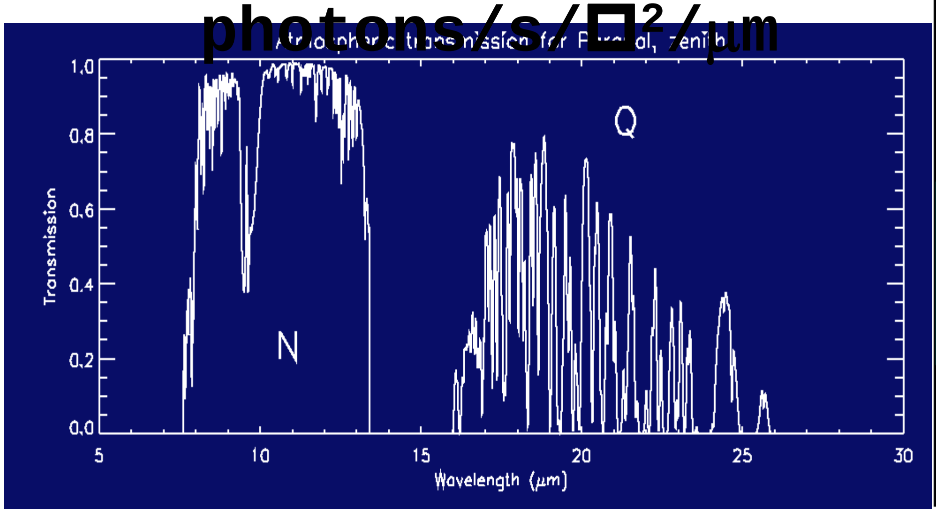
MIR observation

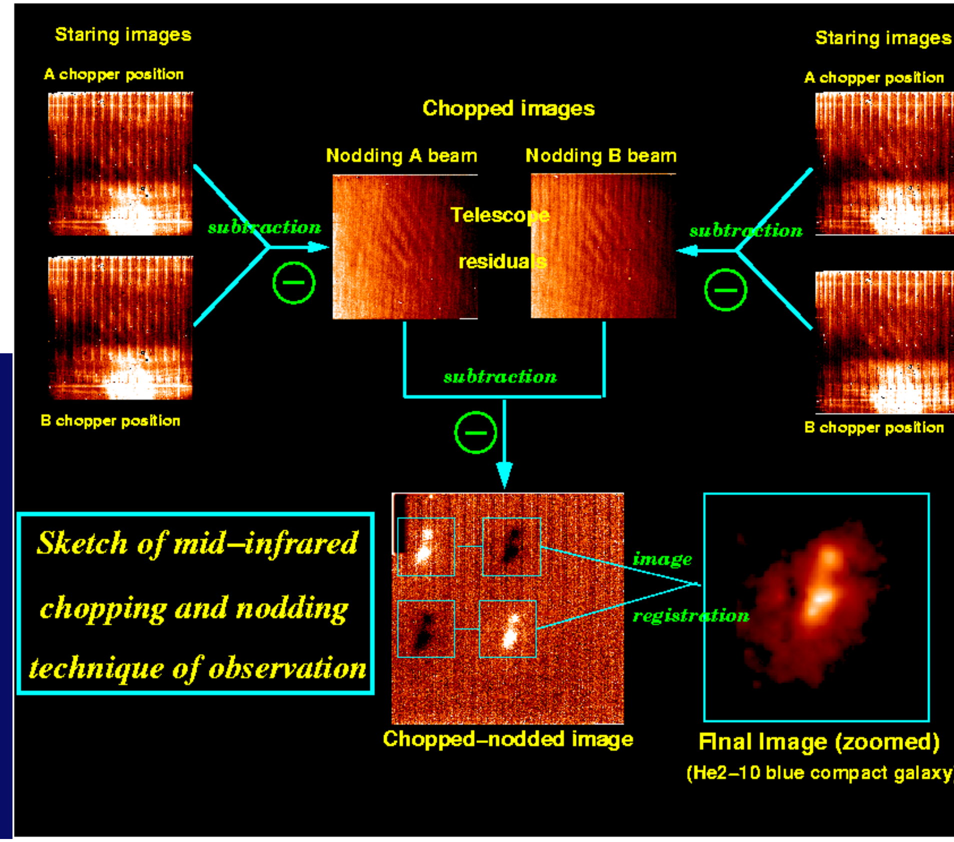
A huge background to overcome:

Atmosphere (BB, 0.1, 250 K)

+ telescope (BB, 0.2, 300 K)

↓ $1.2\ 10^{10}$ photons/s/□²/µm





« Observing in the mid-IR from the ground is like trying to observe a candle behind a lighthouse » (*P.Lena*)

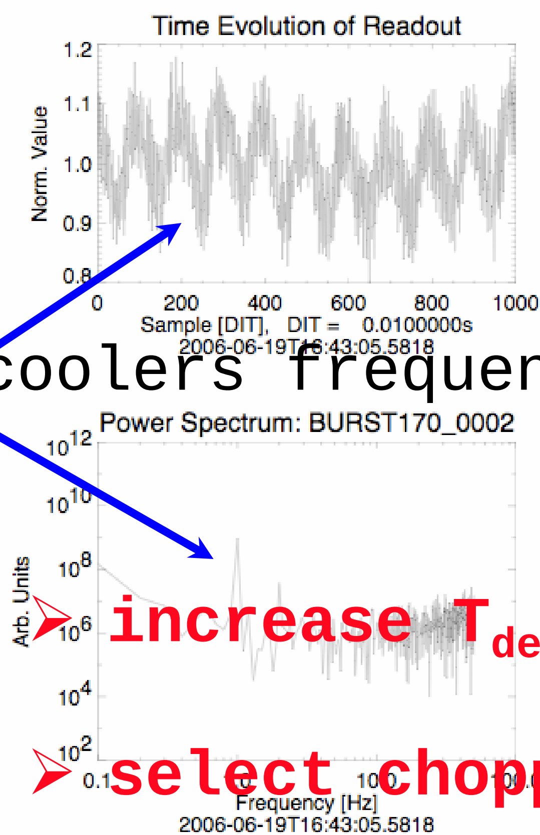
Detector and data storage

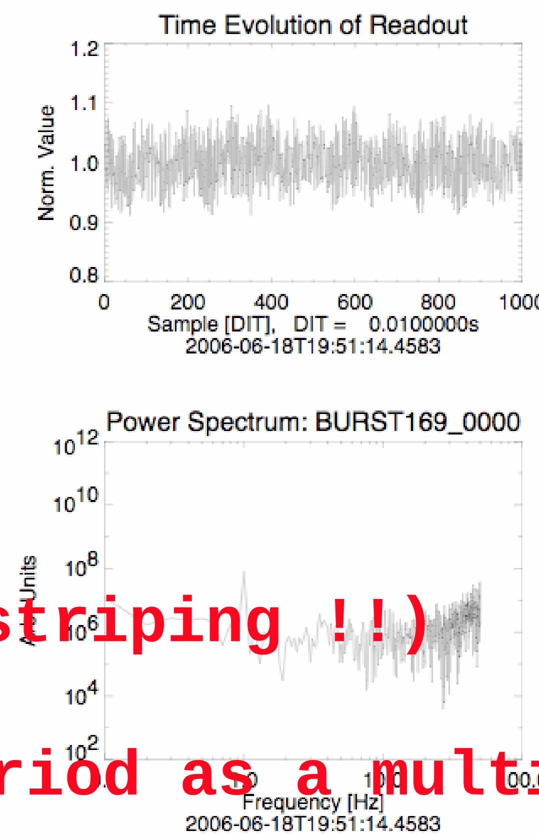
- Capacity of detectors ≈ 2.10^7 e^- ➔ 1 readout every ~ 10 ms :

- Front-end number cruncher needed (IRACE) ➔ 1 image written on disk every 2s, ~ 1Go for a standard night (10 times more if Saclay GTO observations burst mode)

- Chopping correction (1st order bgnd removal) done at IRACE level, cumulative sum of chopped images saved. Background images (staring frames) saved also.

Detectors noise





Cryo-coolers frequency !

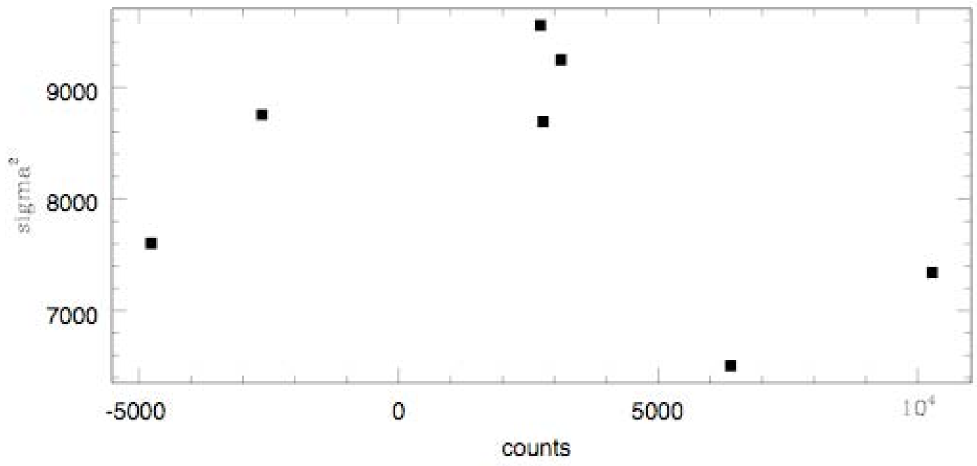
- increase T_{det} (but striping !!)
- select chopping period as a multiple of

Tdet=6.5 K

Tdet=8.0 K

Detectors noise

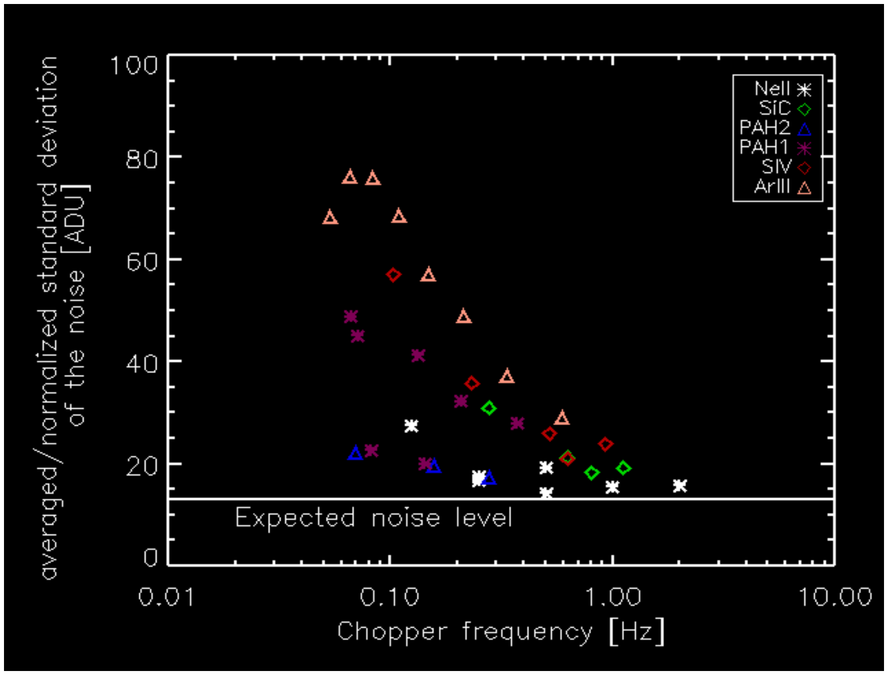
6.5 K

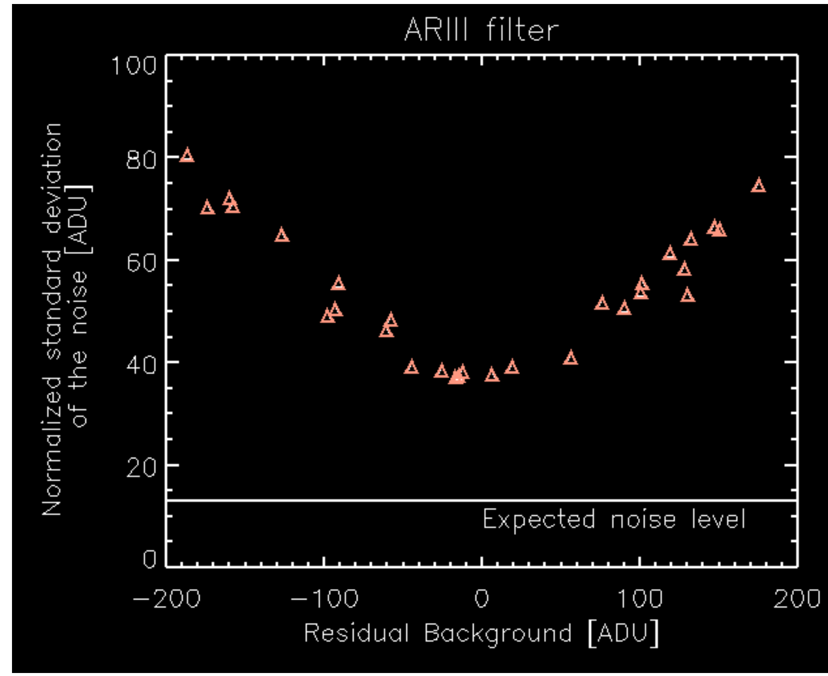


8.0 K

QuickTime™ et un
décompresseur TIFF (non compressé)
sont requis pour visionner cette image.

Sky noise

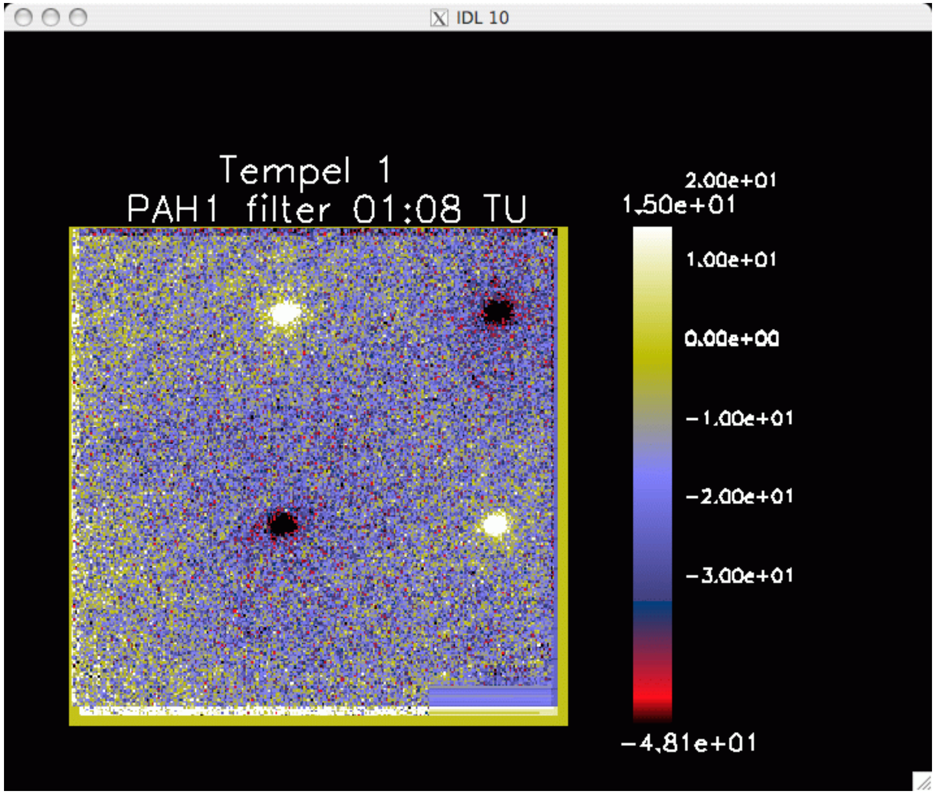


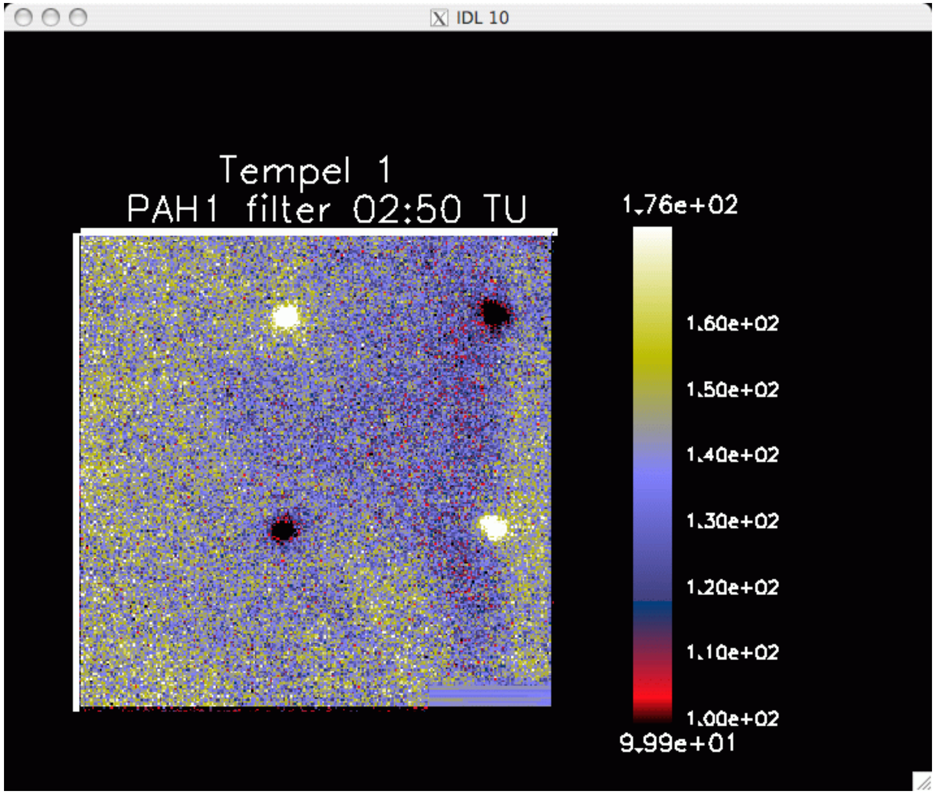


Cryo-Coolers 1Hz noise + increase of sky noise

Background errors

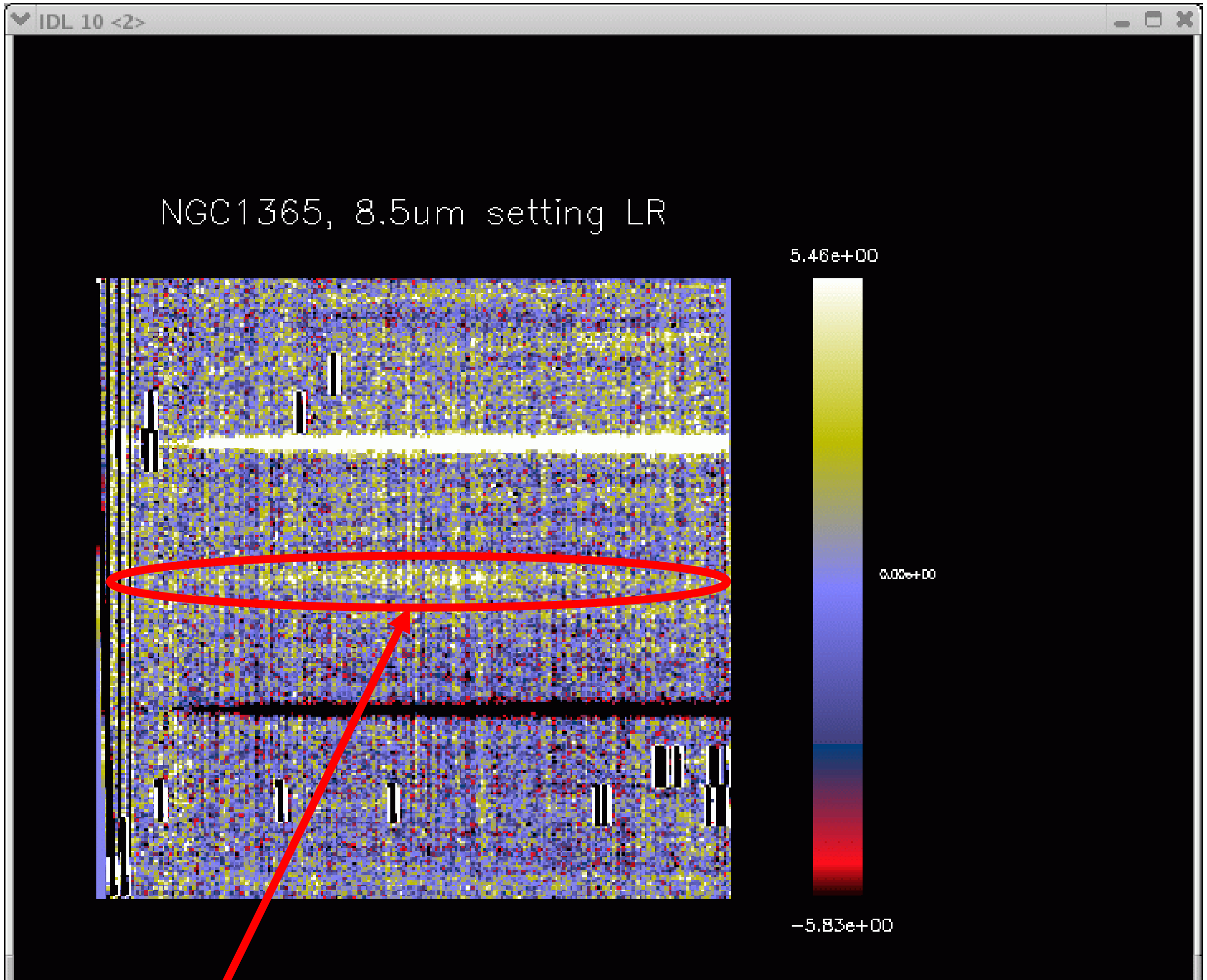
Imager





? Spatial support of the object ?

Background errors

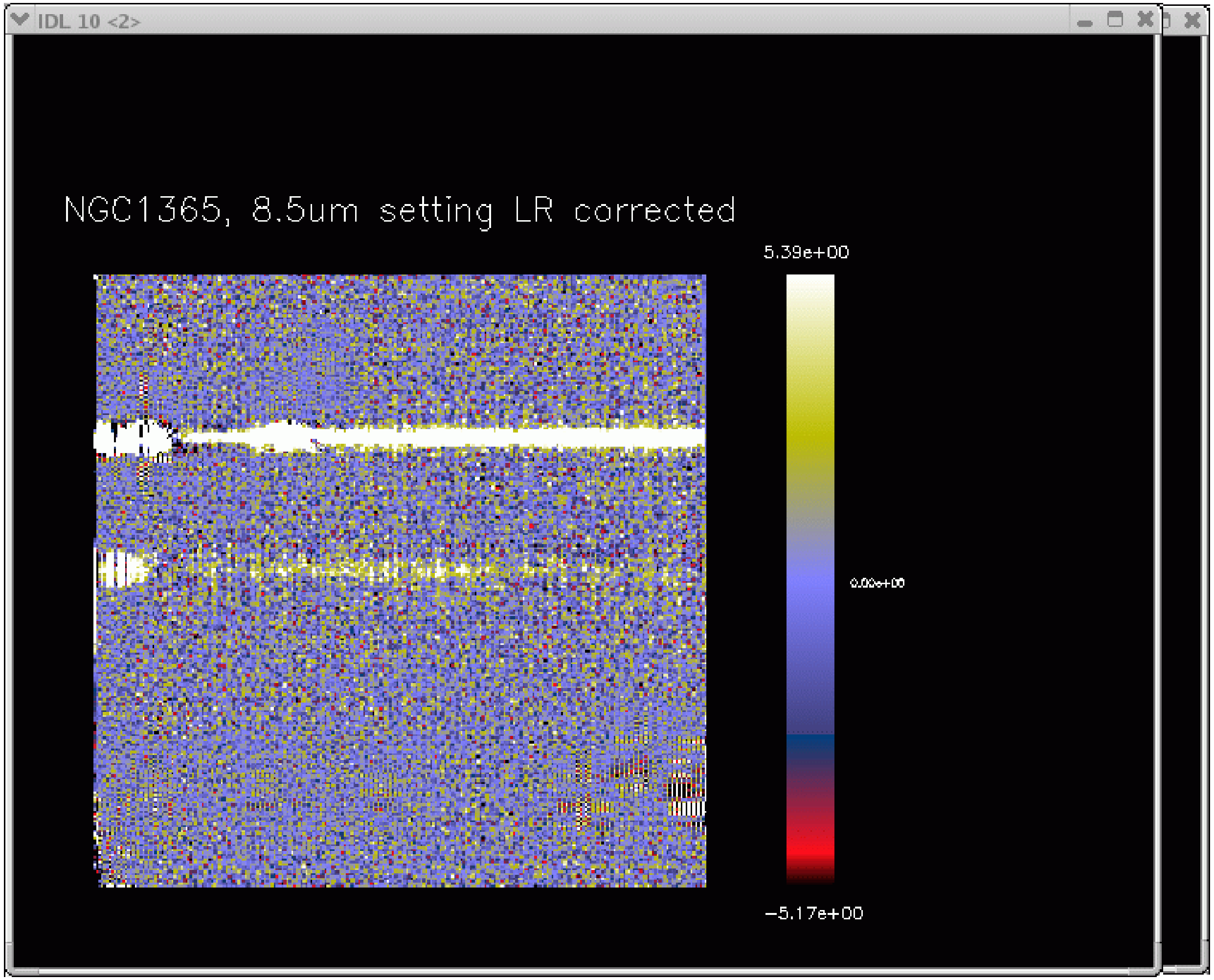


Object of interest

Spectral extraction very compl

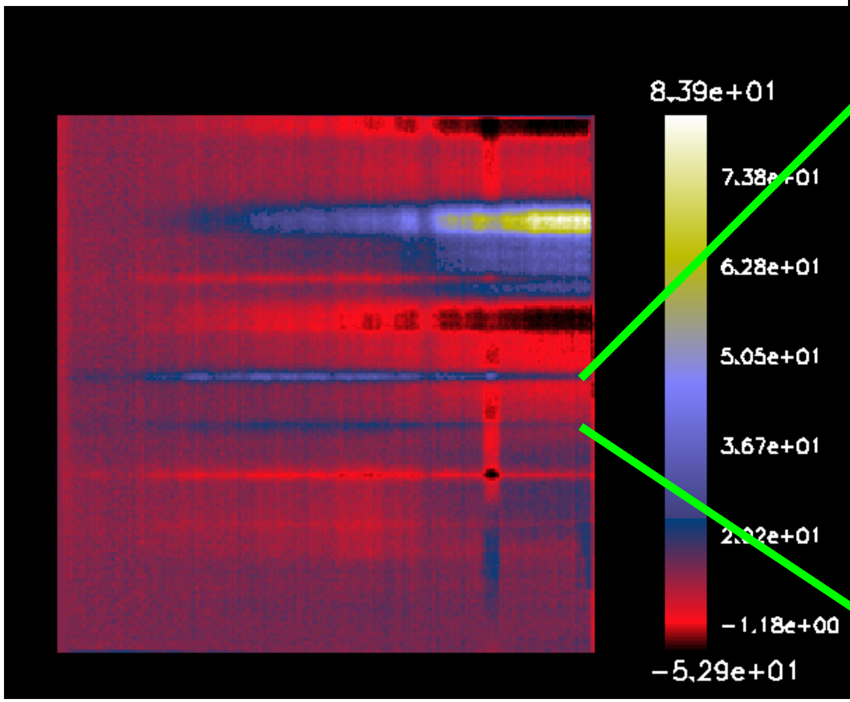
Background errors

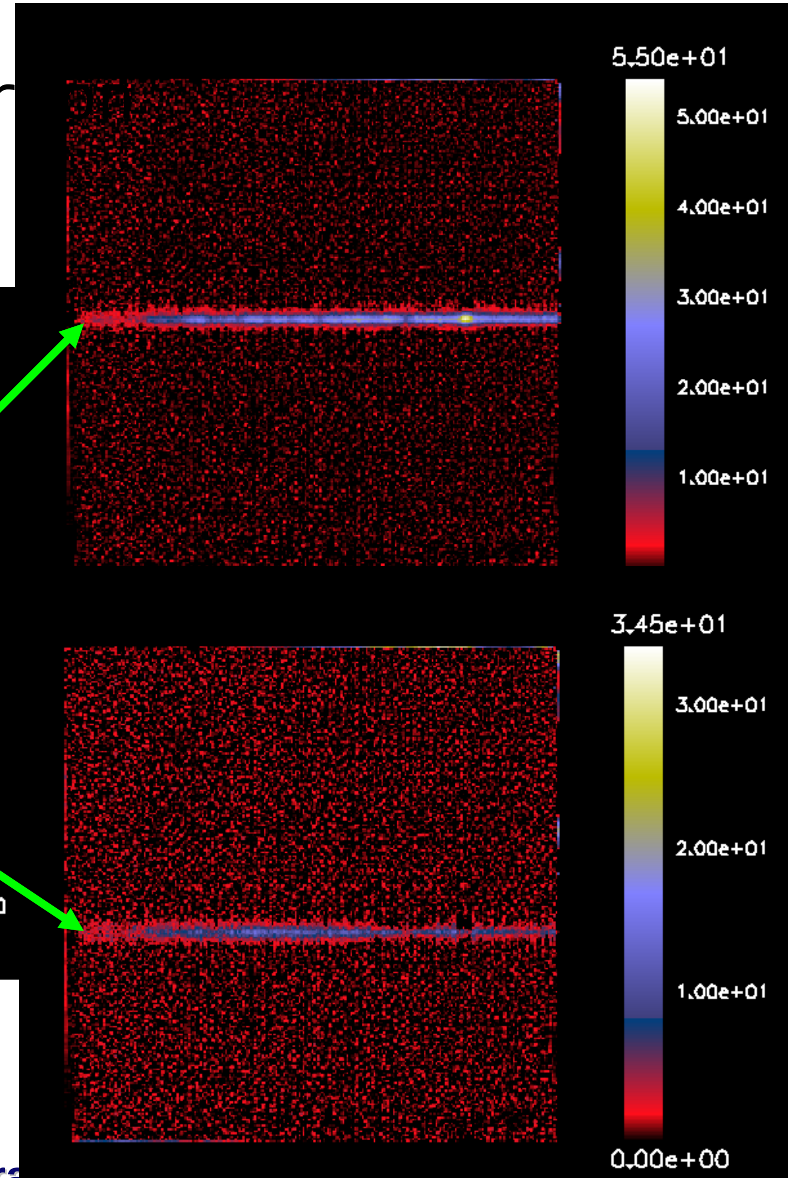
Background reconstruction in wavelets+ridgelets



Spectral extraction in presence of high extended background

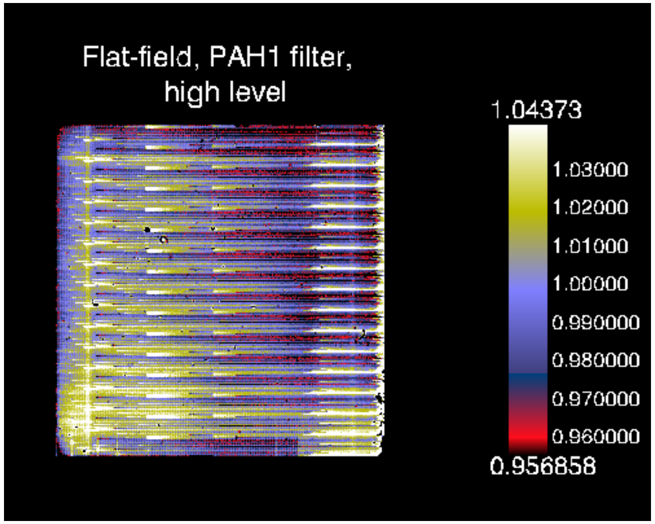
Spectra of proplyds in Or



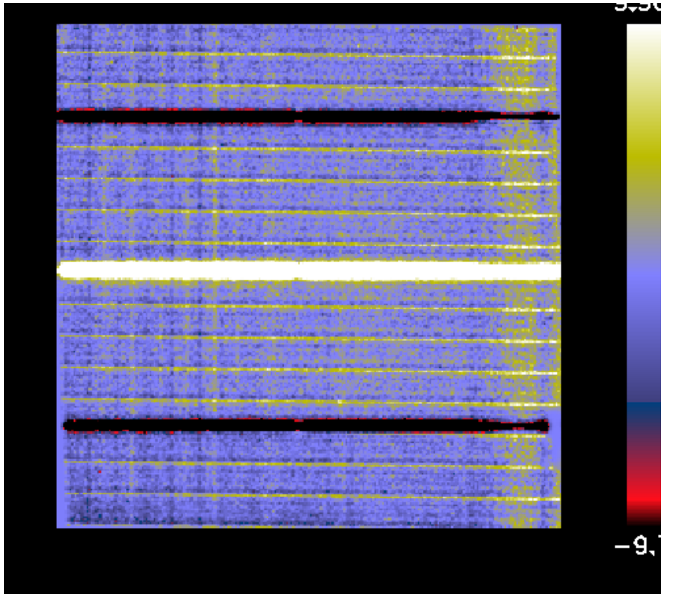


Other sources of noise :

« Background striping »



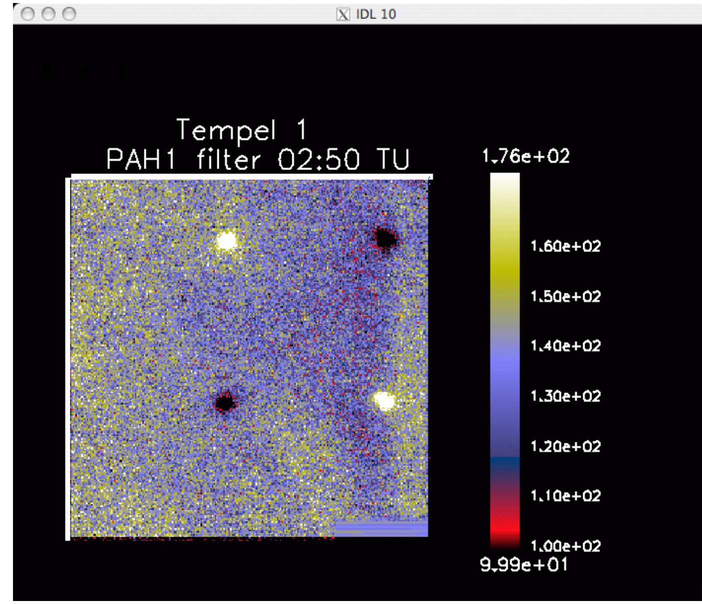
- triggered by « hot » (abnormal high gain) pixels saturating
- decrease T_{det}, work @ lower level (but sensivity ↘, sensitivity to 1Hz CC noise ↗)
- influence of weather conditions (fluctuating bgnd).
- avoid strong source hitting them !!
- additive (~constant) and periodic



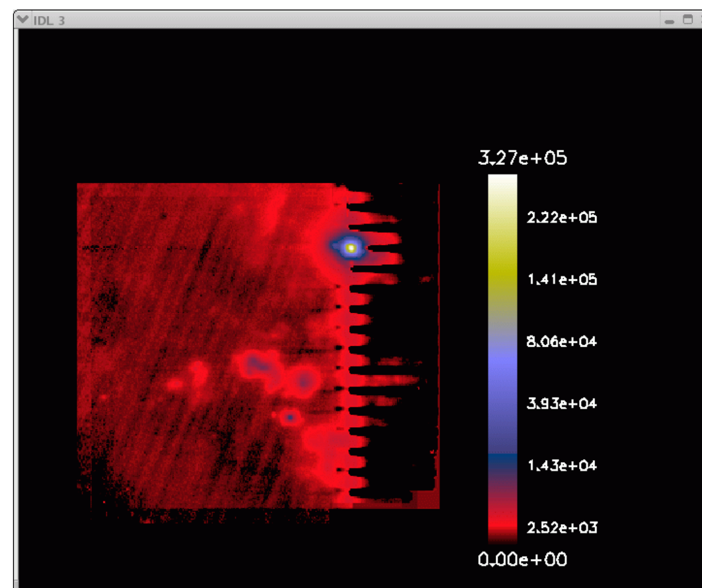
- problematic for spectroscopy

Other sources of noise :

A bunch of fun stuffs . . .



Background leftover gradients

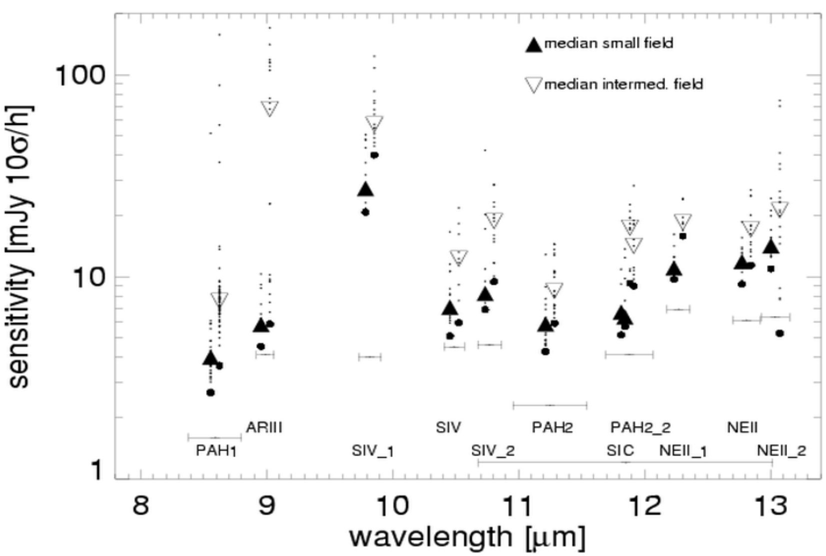


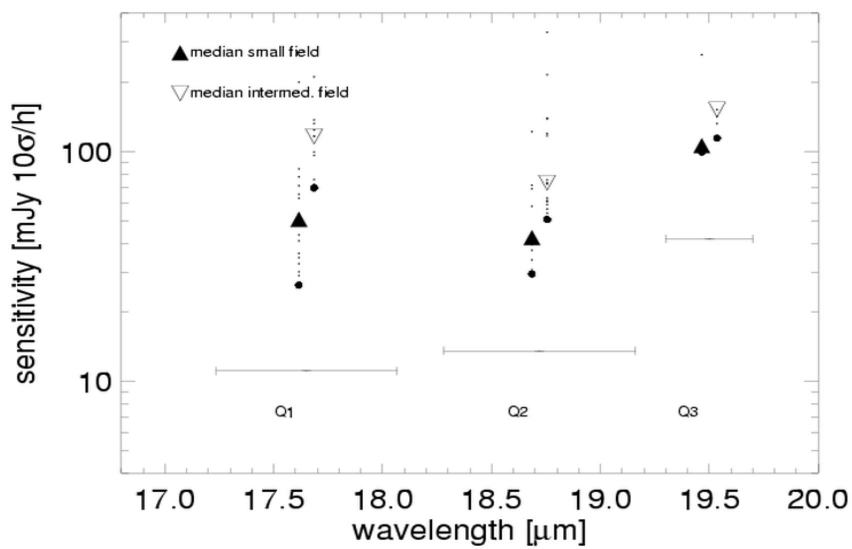
Background patterns (?? extended objects only ??)

Sensitivity

Imager

- Beginning of night, background and sensitivity monitoring on a particular standard star (1/month).
- Best sensitivities achieved : a factor of ≈ 2-3 from theoretical expectations
- Q-band sensitivity depends **dramatically** on weather conditions (e.g. H_2O content) and airmass.

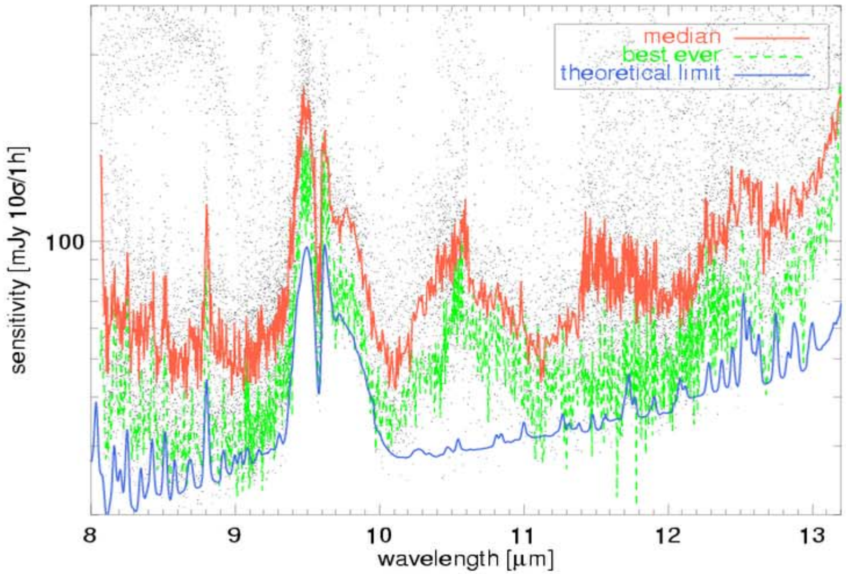


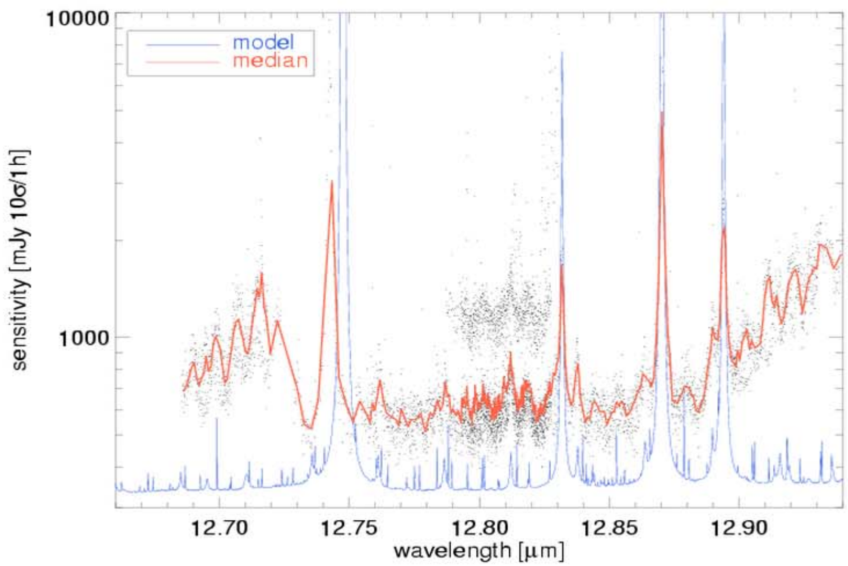


Sensitivity

Spectrometer

Similar conclusions as the imager.
Striping has a more important impact



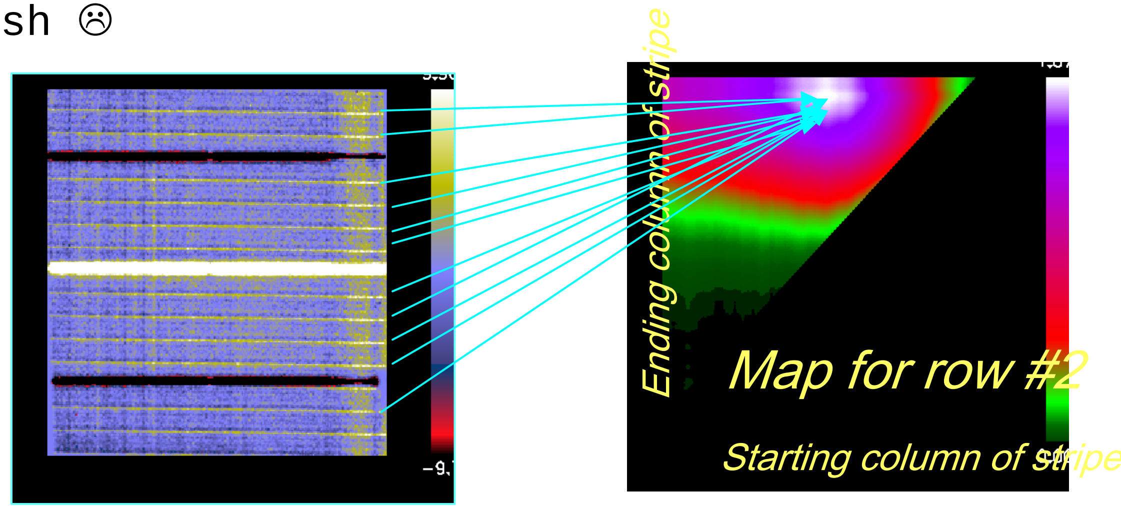


Imaging reduction/calibration

CHOP/NOD correction : easy

Low background stripes correction :

iterative stripes research in adequate space (where energetically concentrated). Automatic ☺ but slowish ☹



Beams combining : easy if efficient source detection ☺

Error/limiting sensitivity estimation : feasible on the fly ☺

FF correction : differential PP variations = 2-3 %, not applied yet, applicability must be assessed first, stability ?

Imaging reduction/calibration

Imager conversion factors

Selection within Cohen's radiometric database of standard stars (81/425)
+
Selection of A0 stars (44)

Filter	Central wavelength (μm)	Mean conversion factor (ADU/Jy)	Dispersion 1 σ (%)
PAH1	8.6	257000	3.0
ArIII	9.0	83300	4.7
SIV	10.4	94200	2.0
PAH2	11.2	32000	3.0
NeII	12.8	79400	4.5
Q1	17.6	11000	10.9
Q2	18.7	9600	9.9
Q3	19.5	19200	3.5

Very stable in N band !!

But careful : different "weather flags" (G/F/B/GTB) (adjustment of DITs) ➔ probably different conversion factors and sensitivities! (TBC)

Spectrometer data reduction/calibration

Imaging basic reduction + optical distorsion correction : theoretical, fast, easy ☺, stability : rock solid

Spectral extraction : not an easy task !!

1) Remove left-over sky-lines (pattern subtraction)

2) Make sure no residual background left-over !!

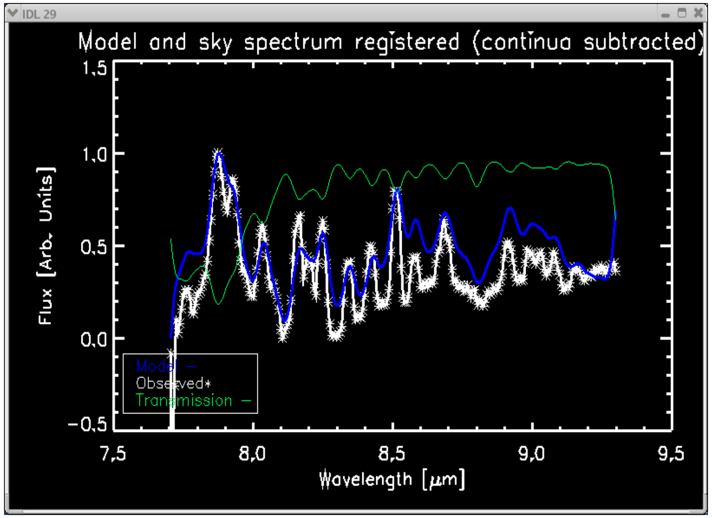
3) Optimal extraction (max. SNR with linear combining, *Horne 86, Robertson 86*): $S_j=\Sigma_i w_i I_{ij}$
   - Wi must be a « noise-free » representation of the local spatial profile. Visible range : polynomia/gaussian fitting. MIR : lot of efforts to measure the « true » profile.
   - Any left-over stripe hurts a lot … ☹

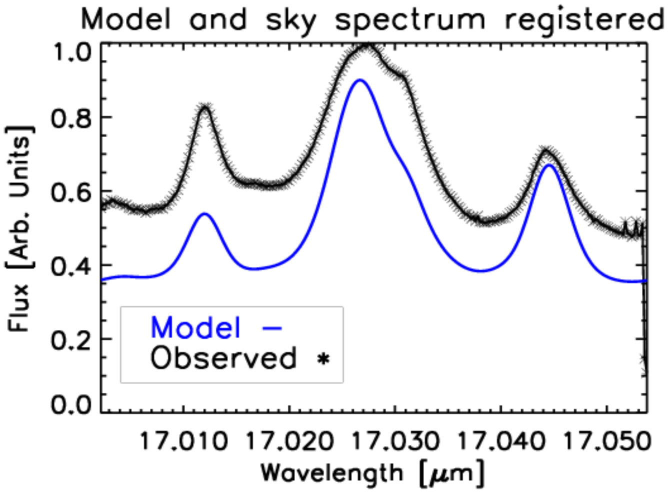
Spectrometer data reduction/calibration

Wavelength calibration :

HITRAN DB+ATRAN model of Paranal site vs sky spectrum (« staring » sky frames) by correlation method.

- On the fly !!! ☺ ☺ ☺ ☺
- LR, MR ☺
- HR : works fine also some clean ranges in N band may be problematic (larger detector) 😐. FP plates not used so far.





Spectrometer data reduction/calibration

Conversion into physical unis

LR, MR

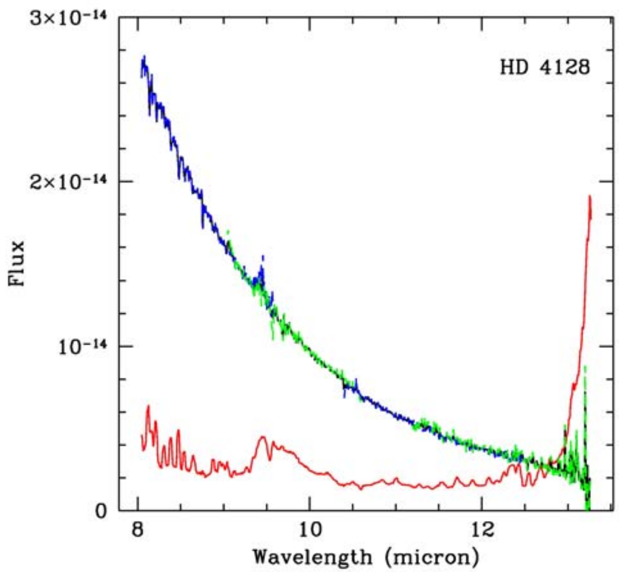
- The spectra are extracted (or not in the case of extended objects), then recalibrated using the standard star spectrum (same as imager)
- Photometric accuracy 5-10 % in N band, limited by accuracy on standard star libra

HR

- Cohen/A0 stars can be used, but asteroids give a much better accuracy (Ceres : 200 Jy !):

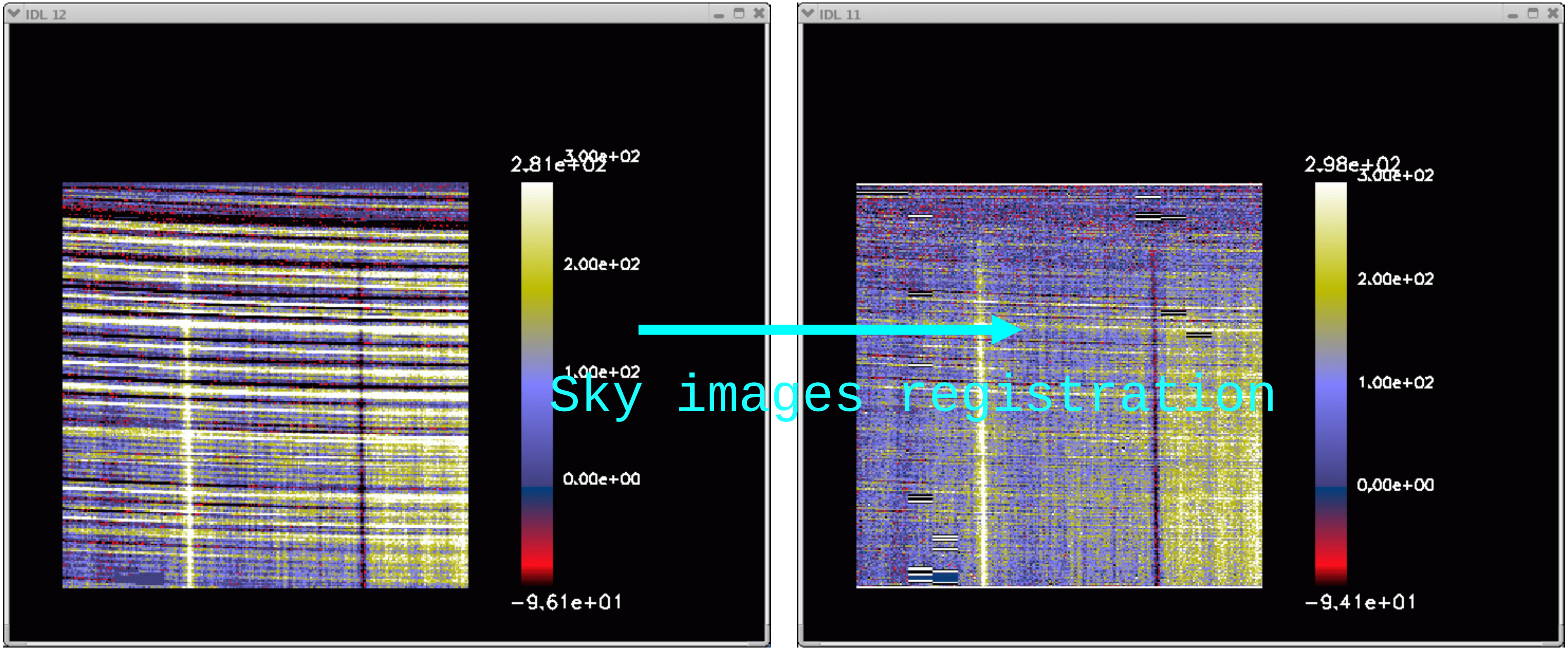
☺ bright and featureless spectra

😐 need of a physical model of mid-IR emission for absolute calibration



Spectrometer jitter

Low resolution spectroscopy

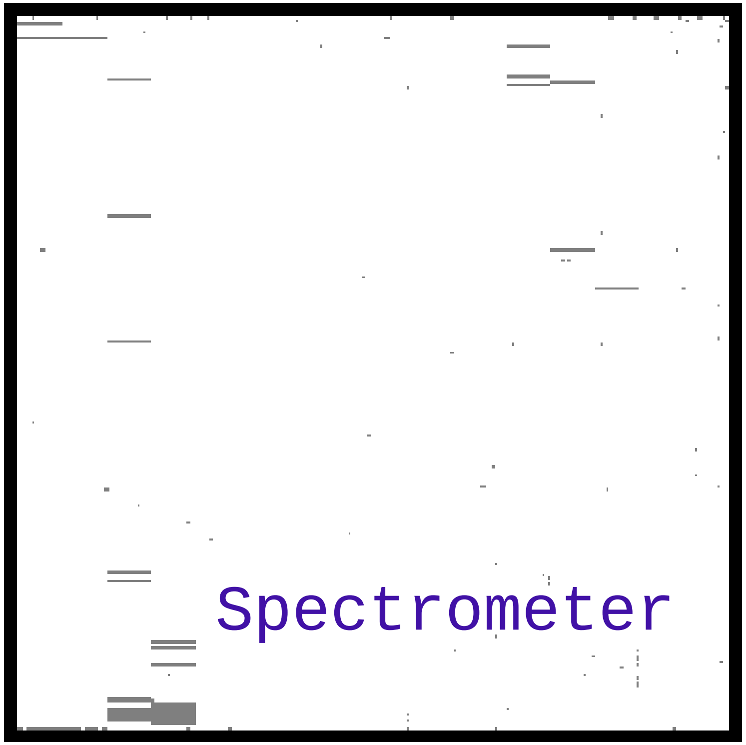


Detectors gain and flat-fielding

(ongoing work)

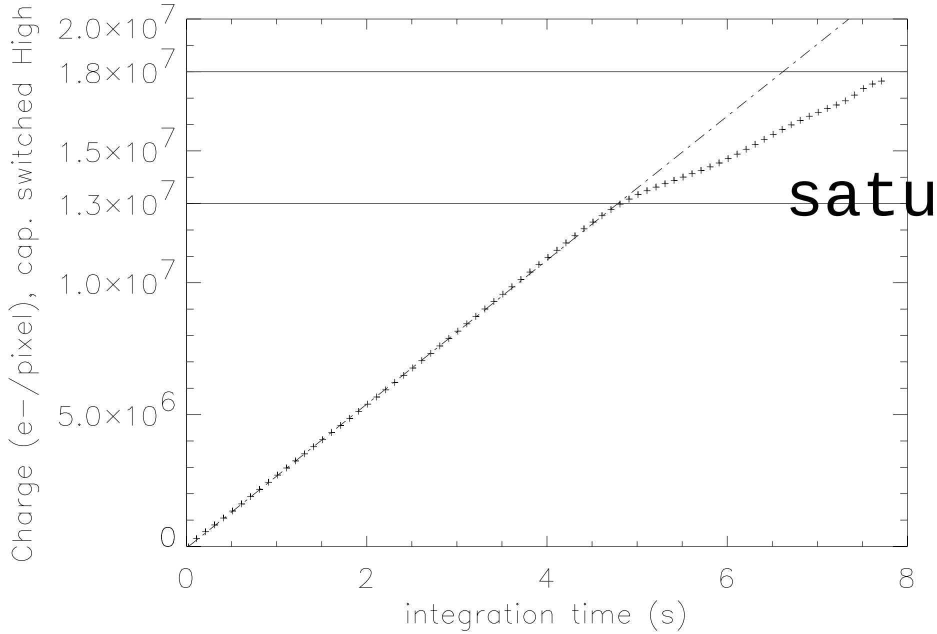
Detectors cosmetics

Originally : <1% of bad pixels. Masking to avoid striping ➔ some unusable areas :



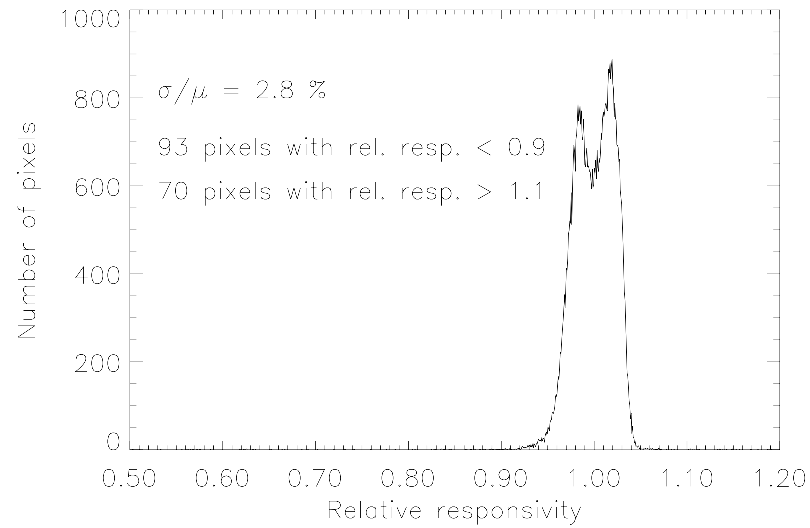
Defined by bulk and sequencer ➔ Stable on timescales of months

Detectors gain (lab)



saturation @ 7600 ADU

Gain dispersion measured in the lab



Flat-fielding

Timmi2 webpage :

"For all ground-based mid-IR instruments no possibility of a reliable flatfield correction exists up to now"

Okamoto et al. (COMICs) :

"If one takes flat frames at different elevation angles and PAIRs from those of object frames, flat-fielding cannot be done accurately. To avoid this problem, one should take flat frames for the object frames at the same elevation angle and PAIRs as the object frames. The same method should be taken for the calibration star frames and their flat frames"

Watson et al., 2006, REv Mex As:

"We did not apply a flatfield correction; a grid of standard stars showed that the variation across the field was only about 2.5%RMS, and this is negligible in comparison to other sources of error."

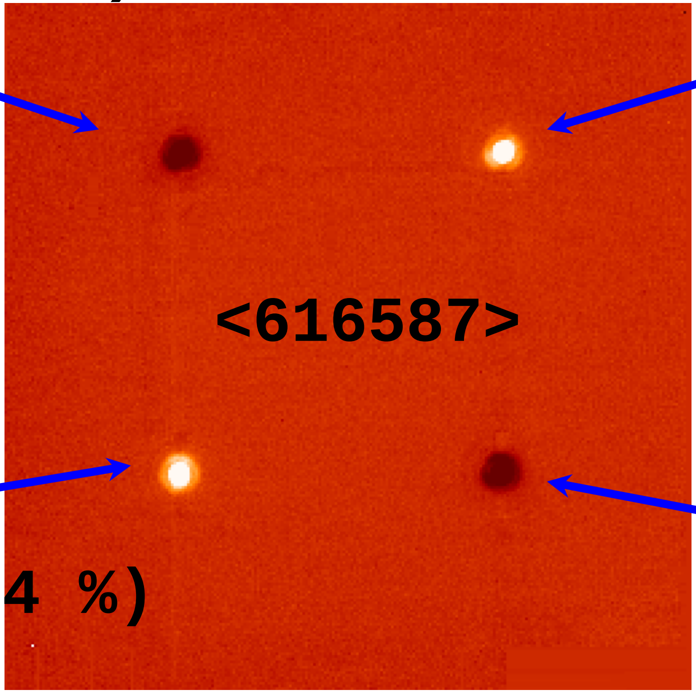
No real consensus !!

Flat-fielding

Imager

616696 (+0.01 %)

605336 (1.80 %)



630458 (+2.24 %)

613858 (-0.44 %)

4 beams ➔ Average of spatial variations

Flat-fielding

Imager other experiment :put a star@various positions, and try flat-field correction (WCU extended source)

pos.	X, Y	not flat-fielded	flat-fielded
1	64, 192	1064984	1062446
2	128,192	1062225	1055189
3	192, 192	1063278	1070739
4	192, 128	1043385	1063152
5	128, 128	1067682	1060228
6	64, 128	1071651	1063375
7	64, 64	1063241	1045931
8	128, 64	1047735	1039944
9	192, 64	1045511	1053869

Table 1: Results of the photometry without and with flat fielding.

The dispersion reduces only from 1 to 0.9

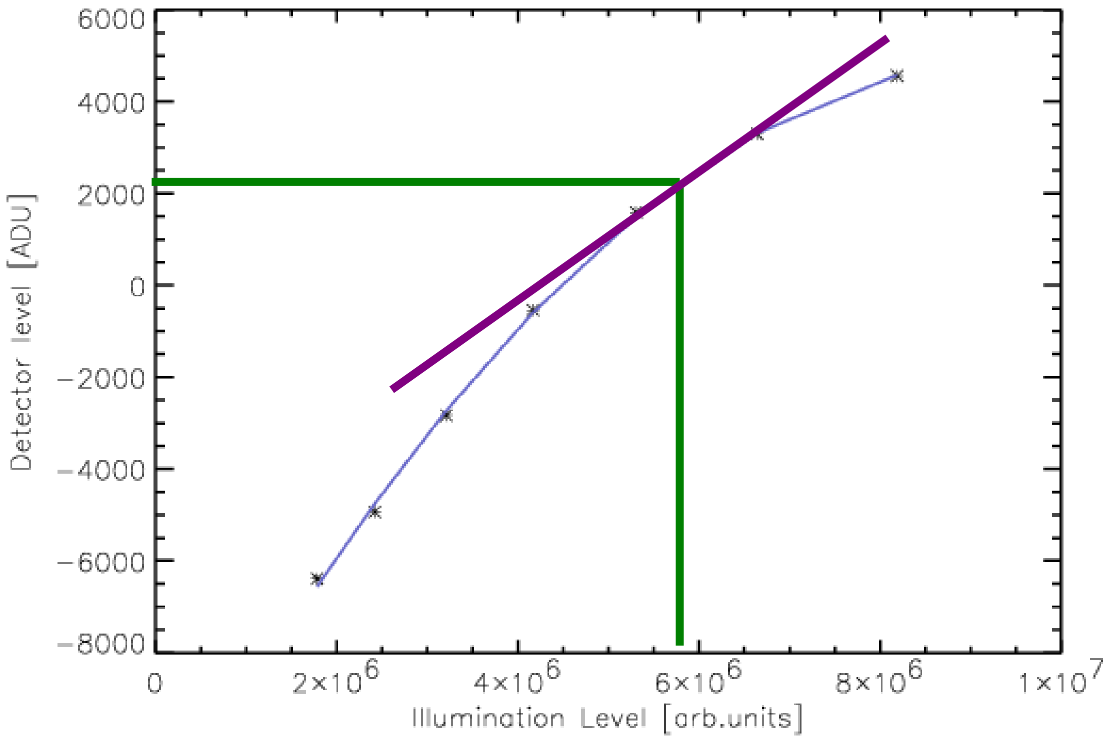
Flat-fielding

Spectrometer : how to estimate the GM ?

1) Measure pixels levels for various illuminations

2) For each pixel, determine best fit by 2nd order polynomium

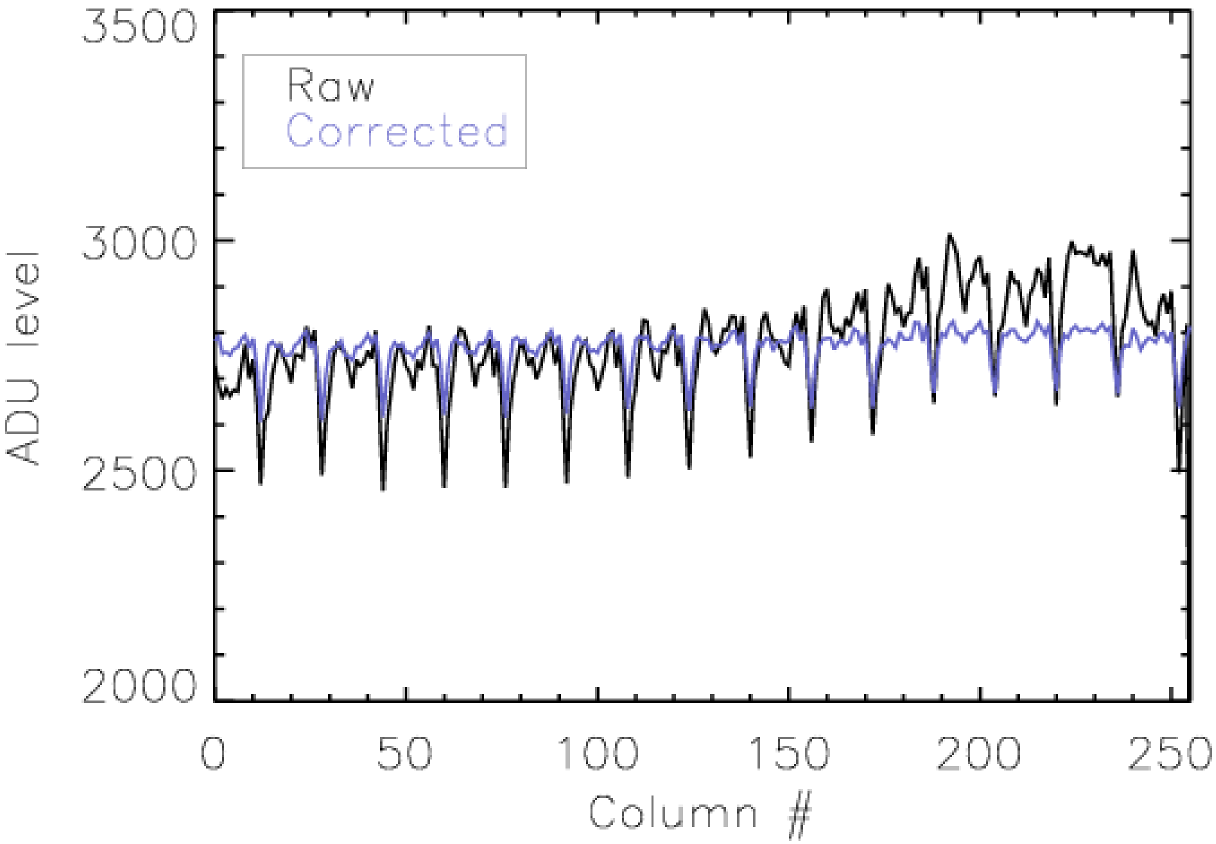
3) For any data level and pixel, estimate the local derivative slope
Normalization ➔gain map



nb : frames are corrected from optical distorsion prior to any operation

Flat-fielding

Spectrometer



Flat-fielding

Spectrometer : stability in time

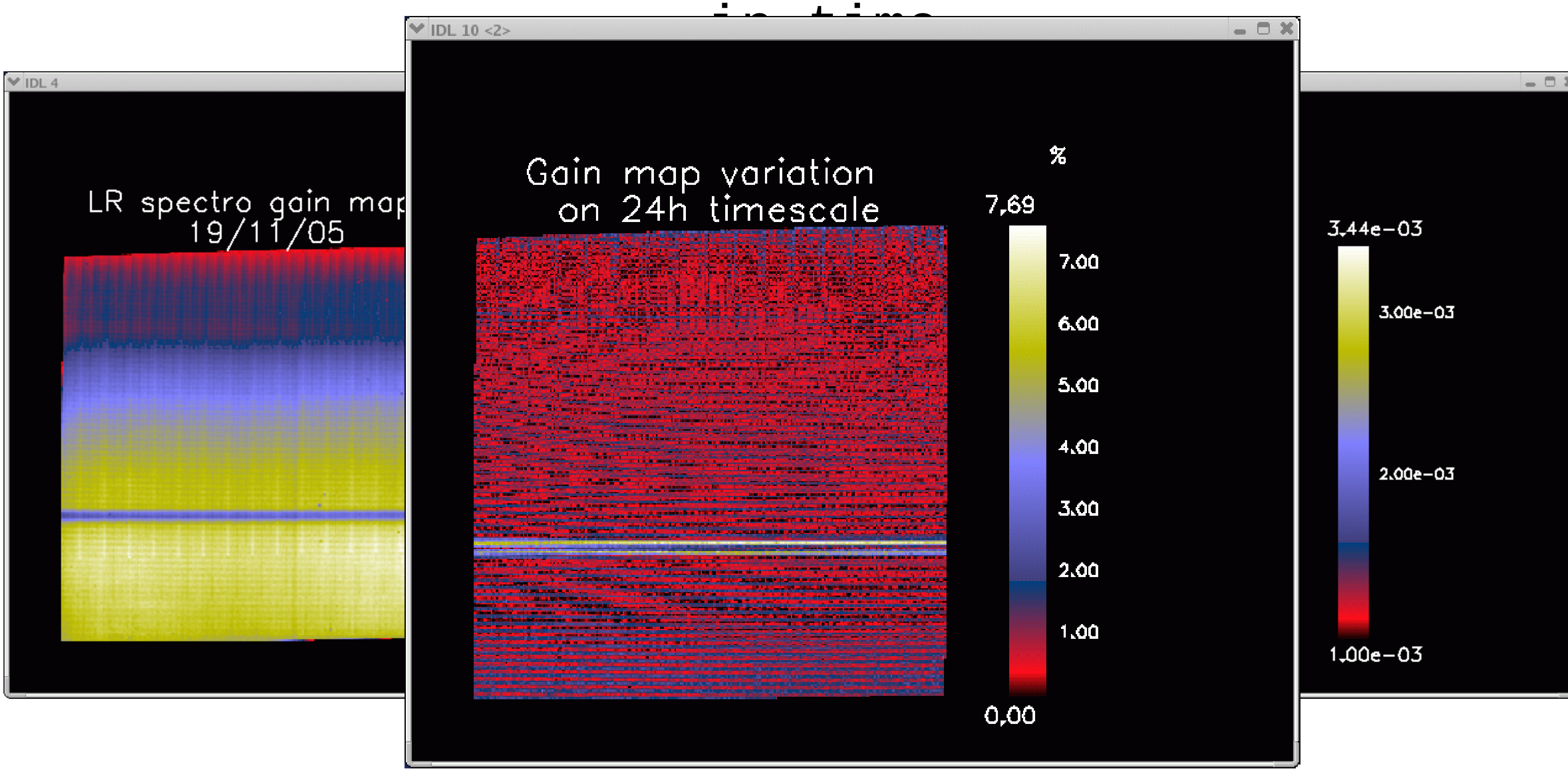
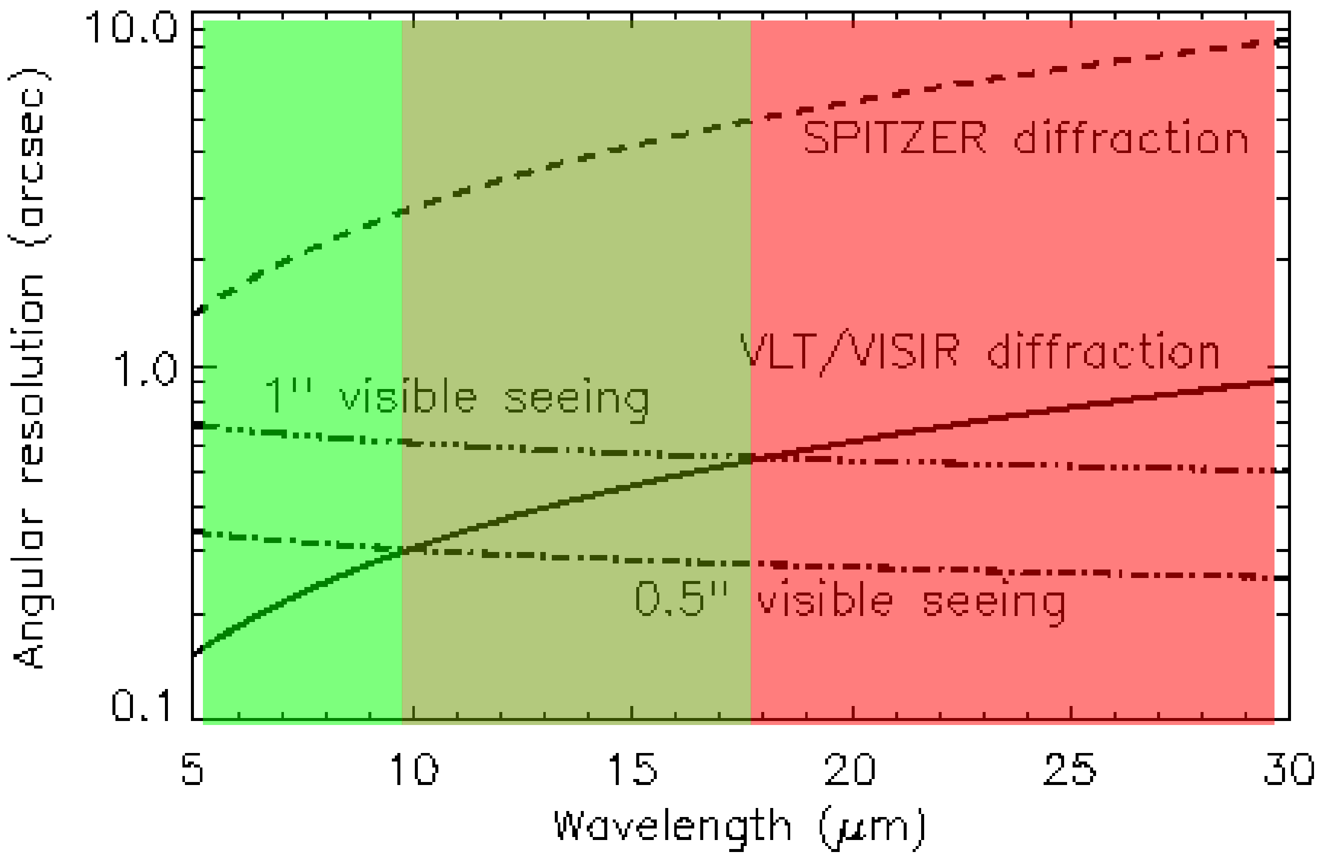


Image quality

Point Spread Function

1.0" seeing in visible

0.5" seeing in visible

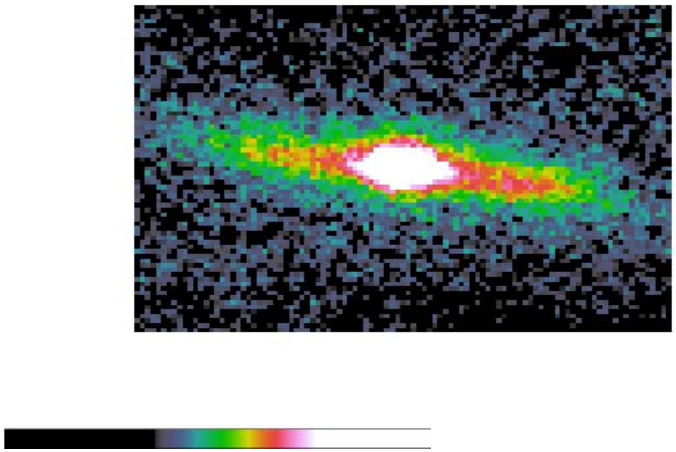


N and Q bands diffraction-limited spatial resolution

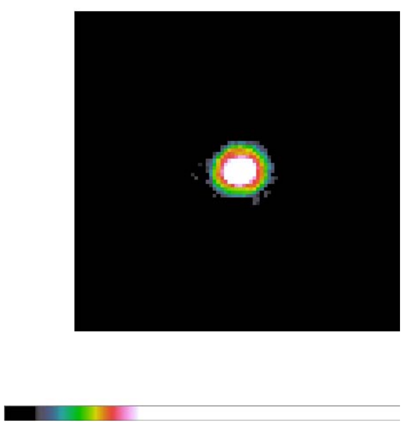
Q band only diffraction-limited spatial resolution

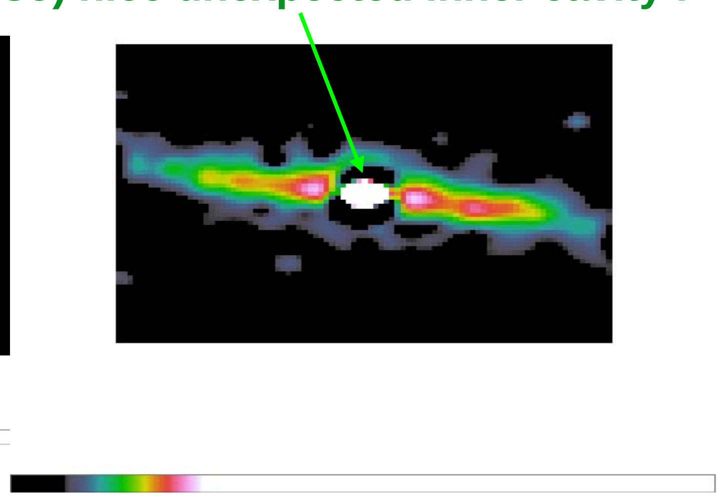
Impact on data of PSF inaccuracy

Image deconvolution : β Pic dust disk



(Not so) nice unexpected inner cavity !



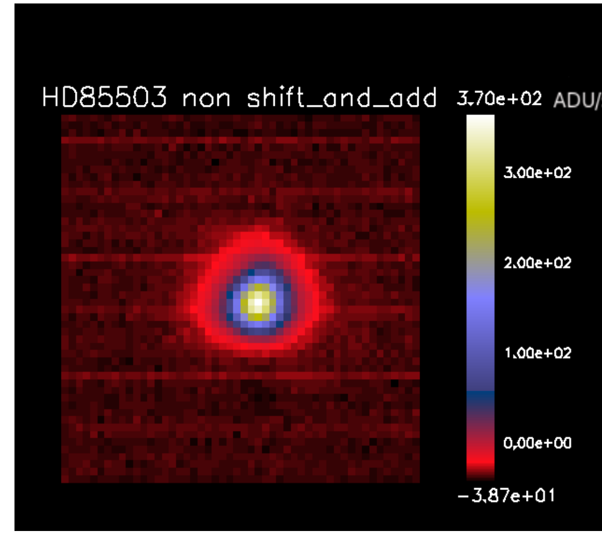


Early calibration plan : all scientific targets observations shall be interlaced with PSF measurements (std stars) : does not work in practice.

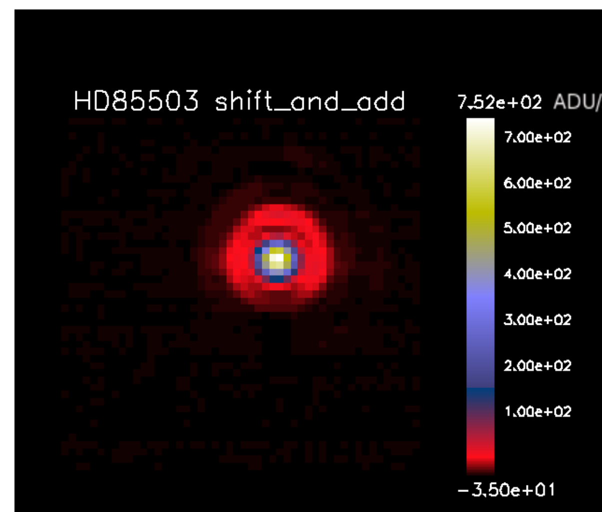
Need to go for myopic or blind deconvolution methods !! ☹ ☹ ☹

How to recover the best spatial resolution : the « burst mode »

1 image ~10 ms : if source detected in individual frames ↓ shift&add possible ↓ correction of any type of tip-tilt degradation (seeing, ...). In case of degraded conditions, image selection possible (reject > 1 speckle images)



- ☺ Sensitivity 2x better !
- ☺ If visible range seeing < 1.2'' ↓ diffraction-limited resolution can be recovered !
- ☺ PSF much stabler !!



- ☹ (a bit) time-consuming reduction. Source detection <u>must be</u> efficient.
- ☹ observing efficiency reduced by a factor ~3
- ☹ bright sources only ... (> 2-3 Jy)
- ☹ Disk space (and DH nerves !) consuming (□~100 Go/night !!). Need to offer an

Conclusions/perpectives

- Conversion in physical units is relatively easy (ISO,SPITZER databases); « Poor-men » calibration is possible concerning the Imager.
- Poor weather ➔ residual backgrounds left-over (gradients !) ☹ Good background estimation ➔ larger detectors (larger field, oversampling ➔ better noise statistics, deconvolution ☺ ☺ ☺)
- A good source detection is the « pierre de Rosette » to correct for a large number of intrumental artifacts/signatures
- On the fly calibration as much as possible, **based on data themselves**
- Flat-field correction not proven yet to be really useful/accurate
- PSF variations is a key issue : stabilize the PSF !! (simple adaptive optics)

End