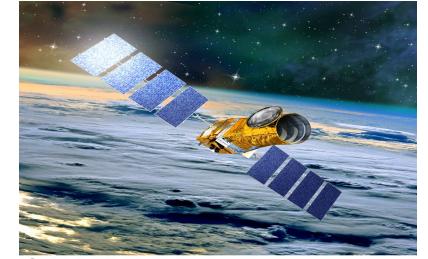


The N0-N1 pipeline

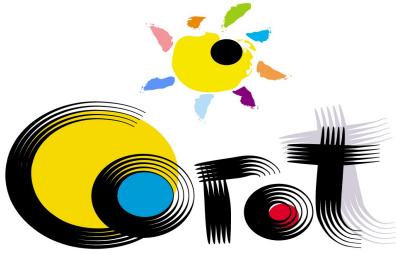


Objectifs : to correct the raw data (N0) from instrumental and environmental perturbations, well known and modelled so far.

Supplier for :

- The alarm mode (for exo-planets search)
- Evaluation of the performances (M. Auvergne)
- the N1-N2 pipeline
- Target follow-up (exo-planet channel)

People involved : M. Auvergne, F. Baudin, S. Chaintreuil, R. Drummond, F. Fialho, E. Grolleau, G. Jeanville, L. Jorda, P. Journoud, V. Lapeyrere, L. Pinheiro, D. Naudet, R. Romagnan, R. Samadi



The N0-N1 Pipeline extracting the star flux



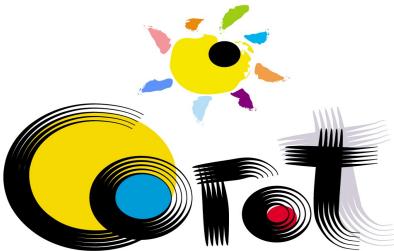
A simple algebra....

$$F_e = JCF * TCF * (gain * (F_{ADU} - offset) - BG_e)$$

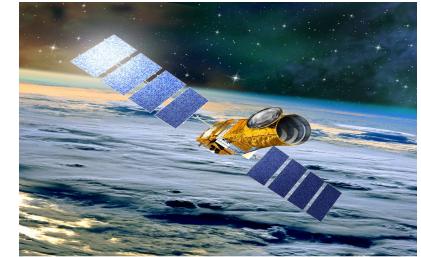
$$BG_e = gain * (BG_{ADU} - offset)$$

... but some important issues:

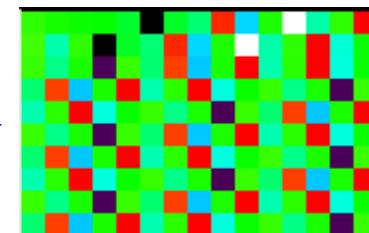
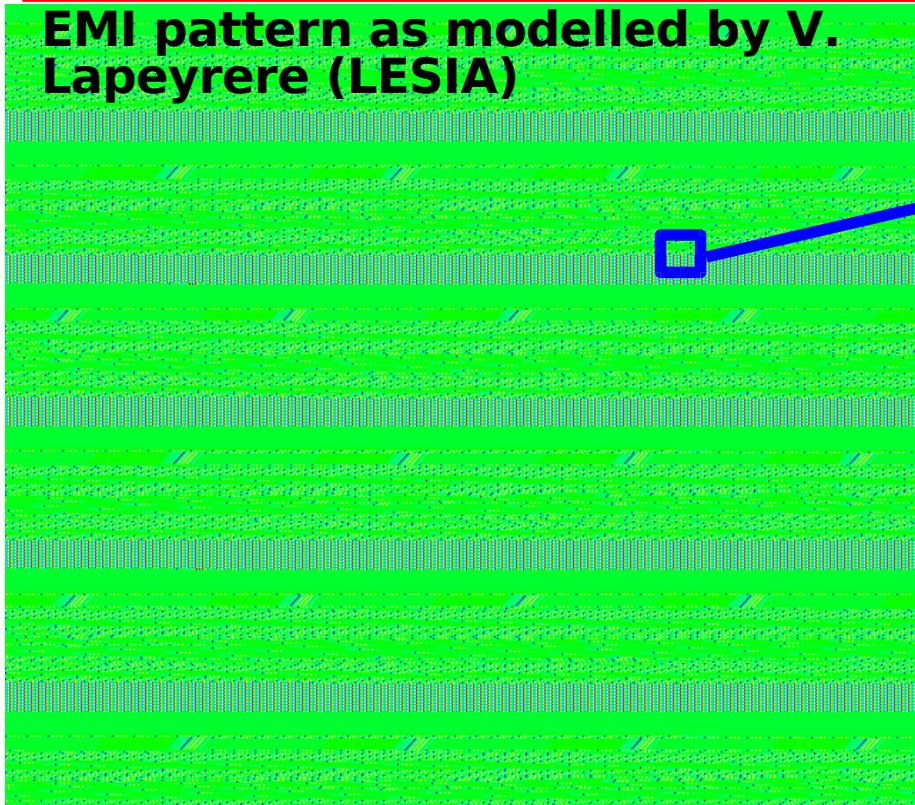
- ◆ Electro-Magnetic Interferences (EMI)
- ◆ Background to use ?
- ◆ Integration time variations
- ◆ Jitter noise
- ◆ Correction of the outliers
- ◆ Hot pixels
- ◆ Long term variations



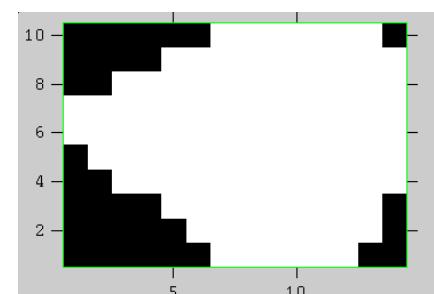
The Electromagnetic interferences (EMI)



EMI pattern as modelled by V. Lapeyrere (LESIA)



*

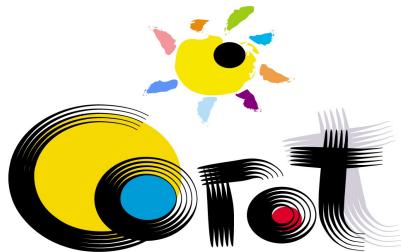


template

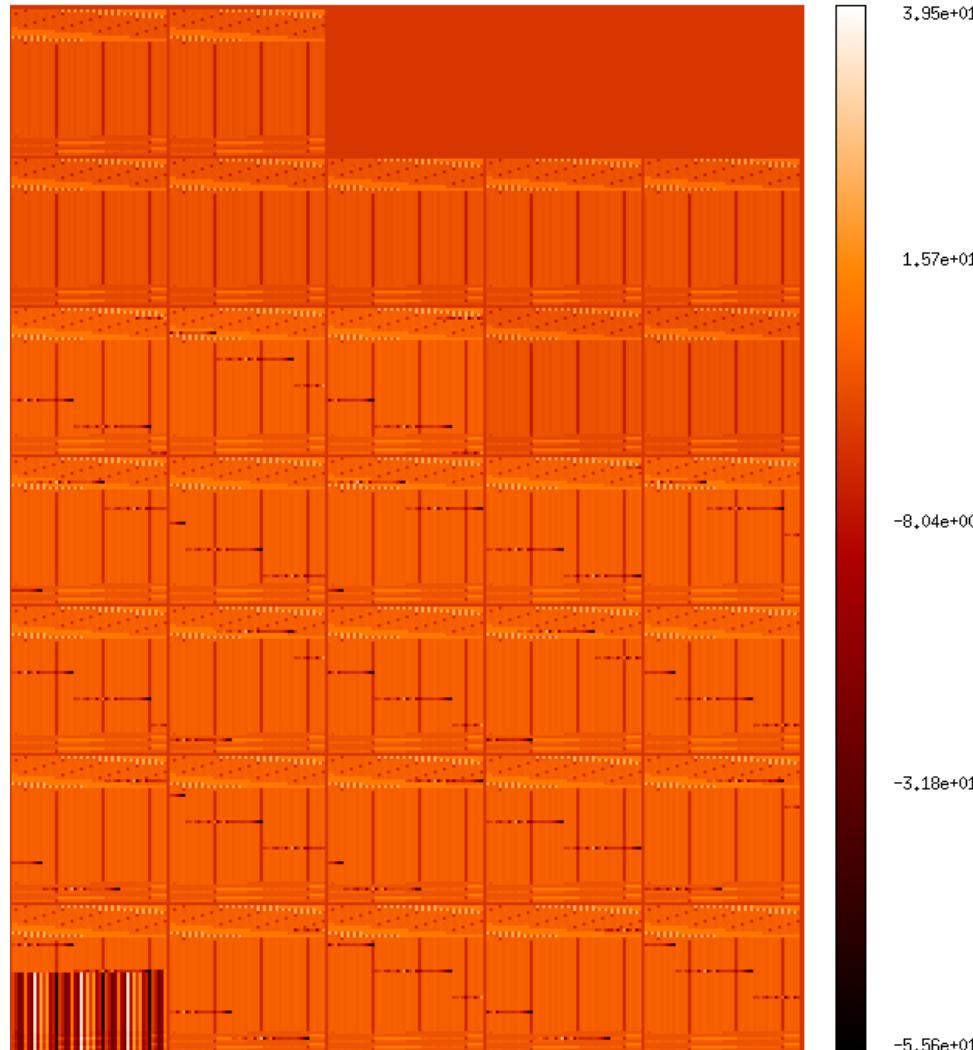
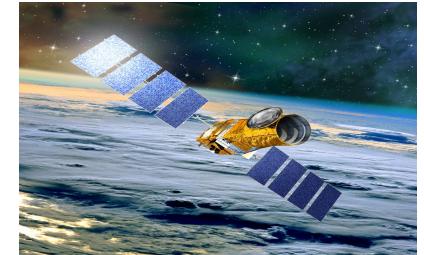
Integration over the template:
offset applied on the LC

For monochromatic LC : 1 offset value

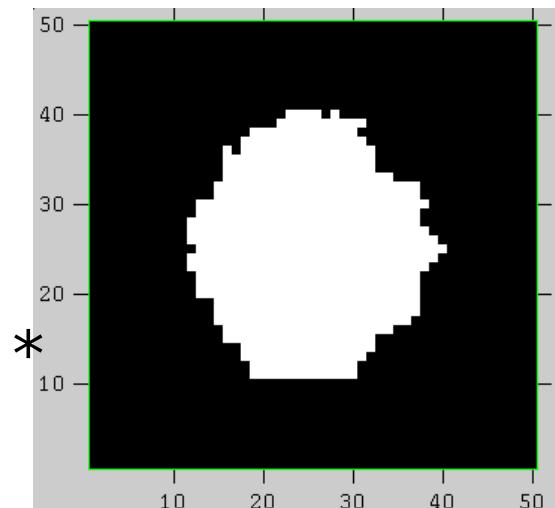
For chromatic LC : 3 offset values : Red Green Blue



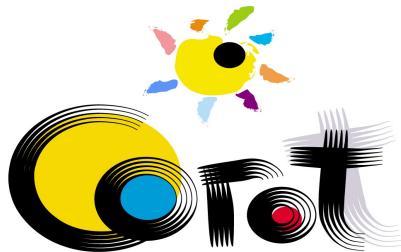
The Electromagnetic interferences (EMI)



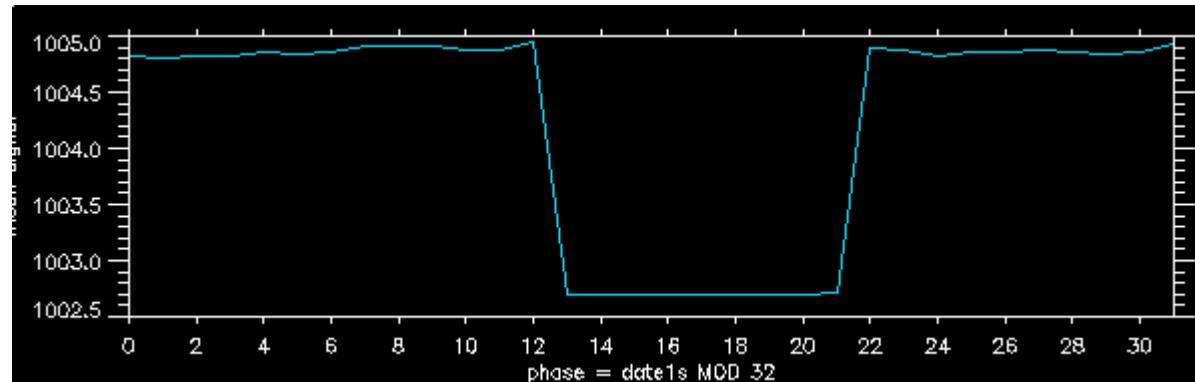
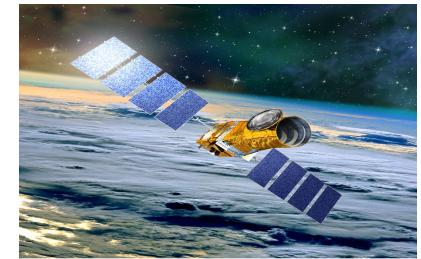
32 EMI patterns (V. Lapeyrere)



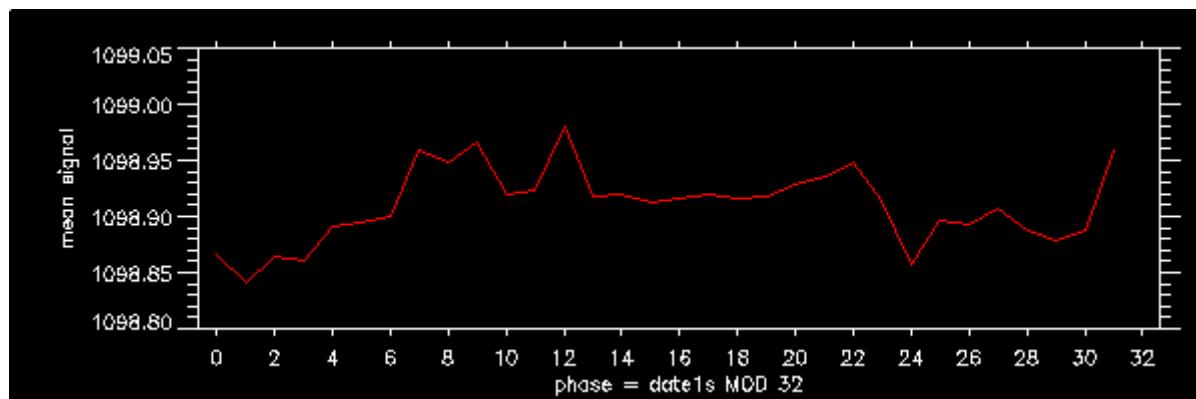
Integration over the mask:
offset applied on the LC,
we then derive 32 offset values



EMI corr. : Offset of the electronic (astro channel)



2.5 ADU

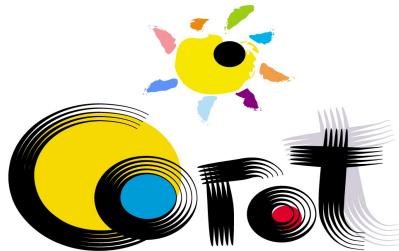


residual: < 0.1 ADU

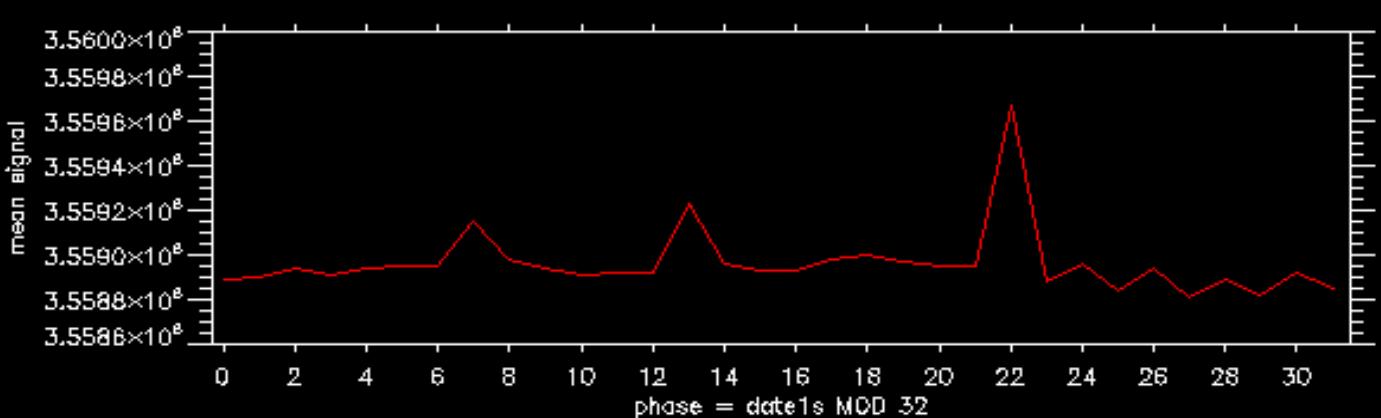
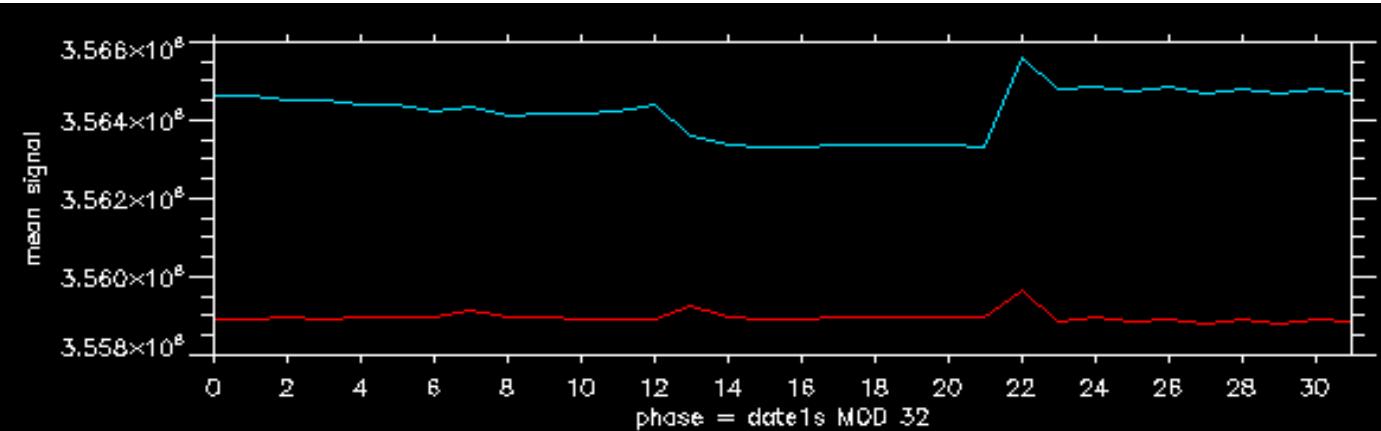
averaged value changed
by ~ 5 ADU

long term variations of
the residual : ~ 0.1
ADU

variations with time of the
EMI are NOT taken into
account

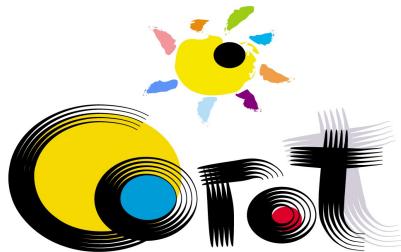


EMI correction : on a star LC (astro channel)

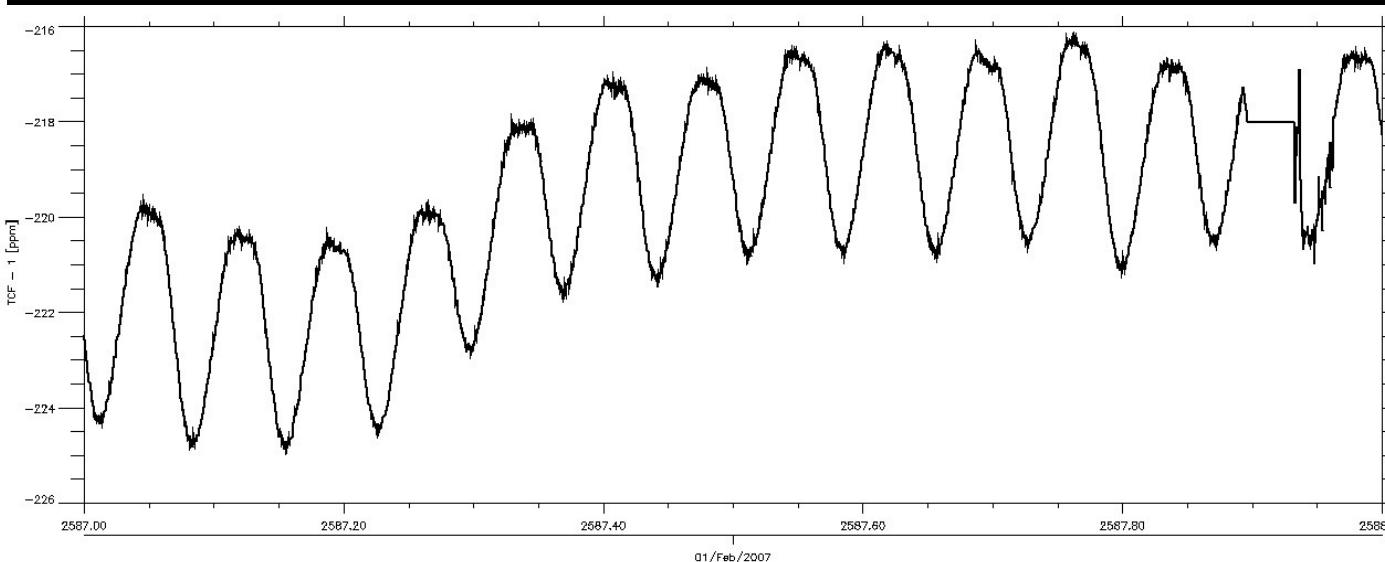
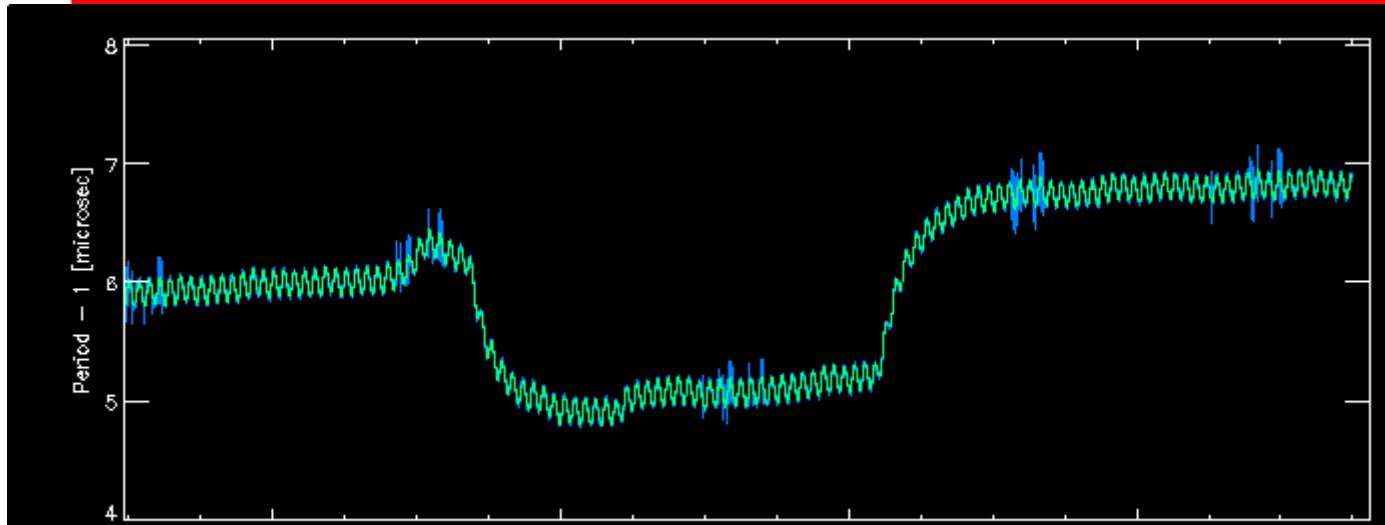


↔
~ 800 ADU
~ 10 ADU/pix
due to the onboard clock

(ColD=20 , mv=5.77, Tobs =9 days)



Variations of the on-board clock (On-board Time : OBT)



Using the GPS tops and the on-board counter we compute the variations of the OBT (method by J. Mesnager, CNES)

A tool to follow the variations of the OBT

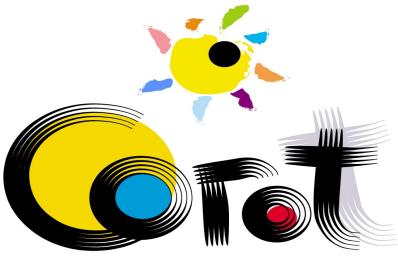
Some times the GPS tops are delayed or unavailable : we discard those measurements

Low temperature coefficient ($\sim 0.5 \text{ ppm/K}$).

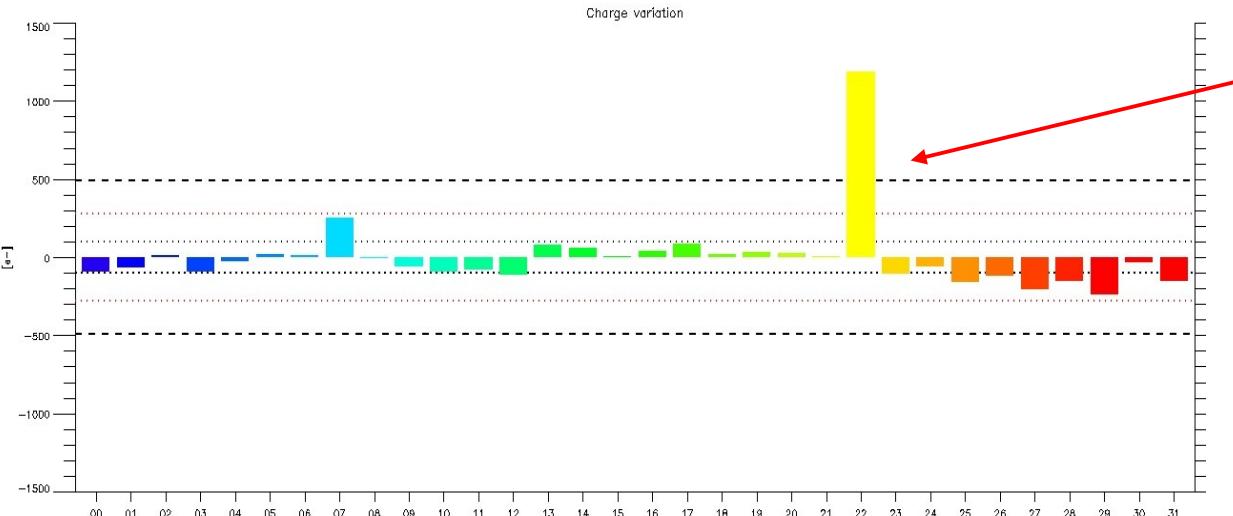
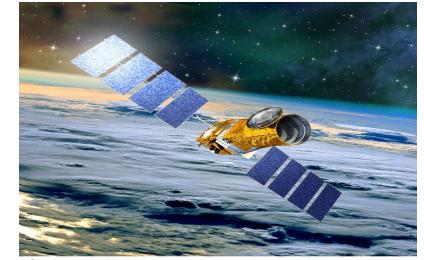
Orbital variations: $0.2 \mu\text{s}$

Systematic diff. : $5 - 7 \mu\text{s}$

High freq. noise: $\sim 20 \text{ ns}$ (rms)



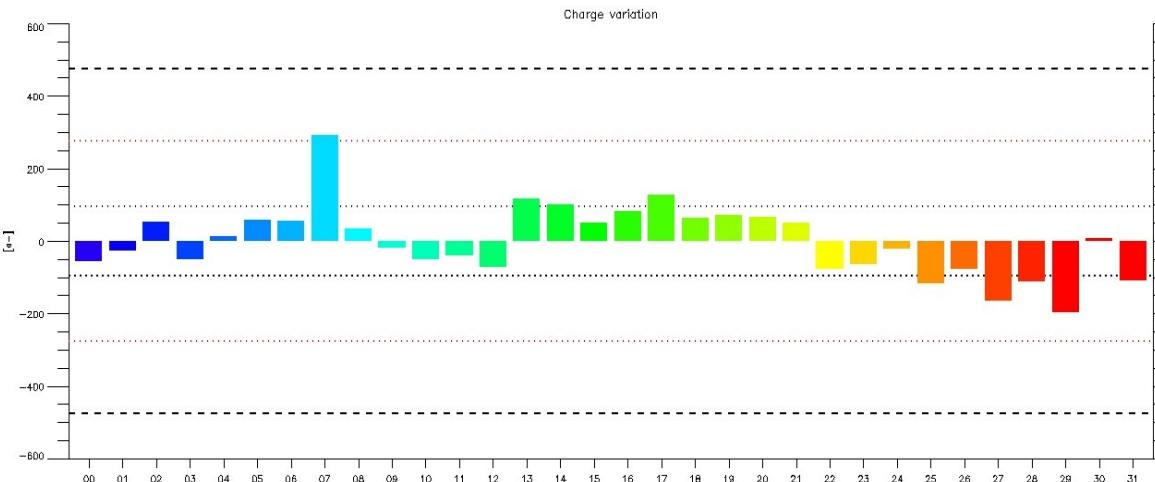
Correction of the integration time variations



Exposure controlled by the OBT variations of ~ 220 ppm ($200 \mu\text{s}$)

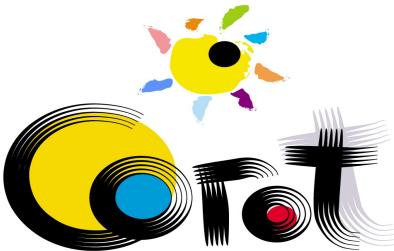
Time Correction Factor:

$$TCF = \frac{\text{nominal integration time}}{\text{effective integration time}}$$

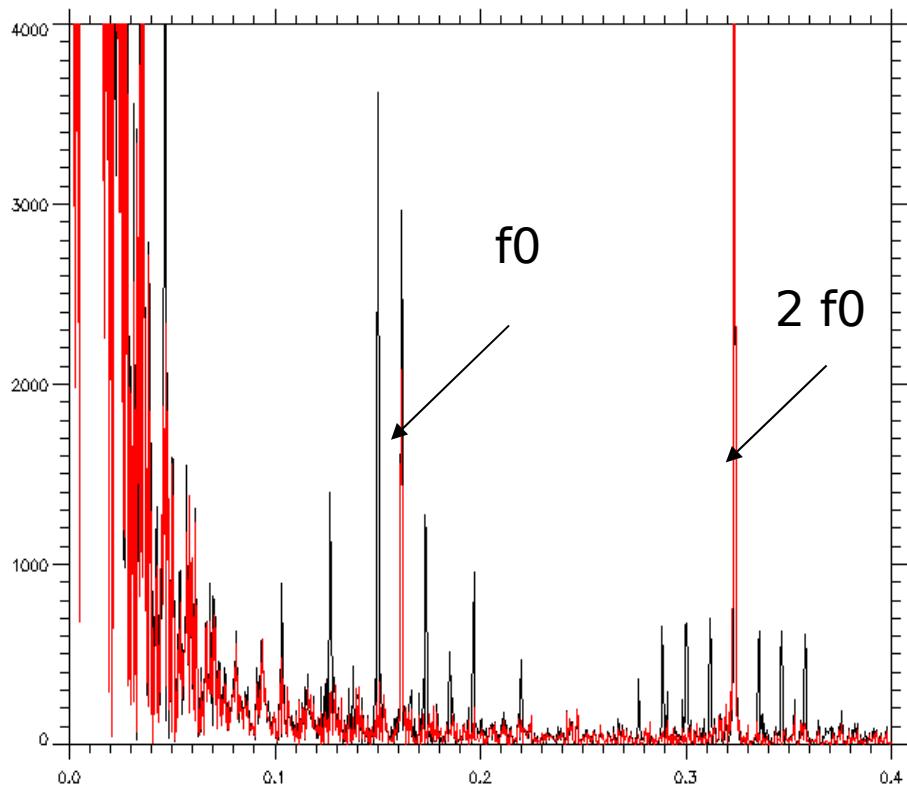


Hyp.: the 31 other exposures are supposed constant

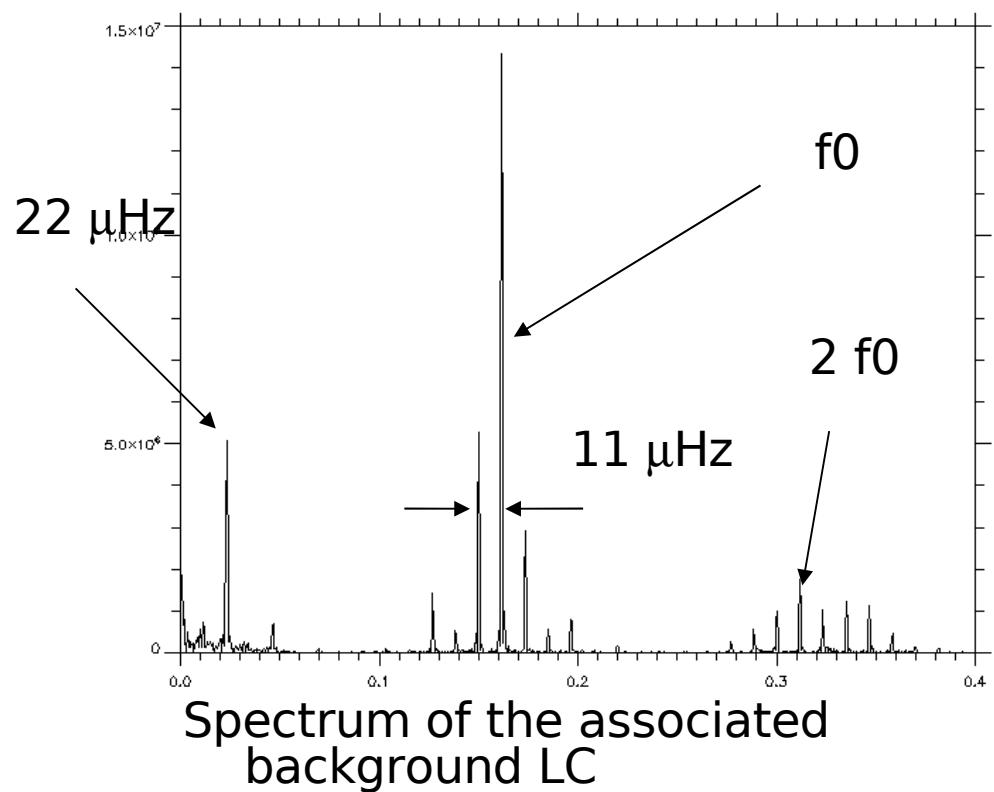
Jitter of $10 \mu\text{s}$ between the OBT and the instrument clock : cyclic error of up to 5 % introduced in the correction



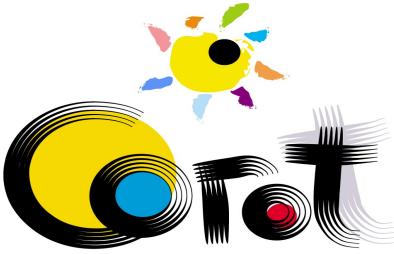
Background correction (BG) Astero Channel



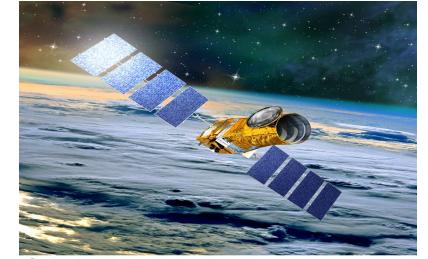
Star (CoID 83, $mv=9.4$), Fourier Spectrum : before (black) and after (red) the background corr.



the BG perturbations are removed , but some small residuals may remain : take care!

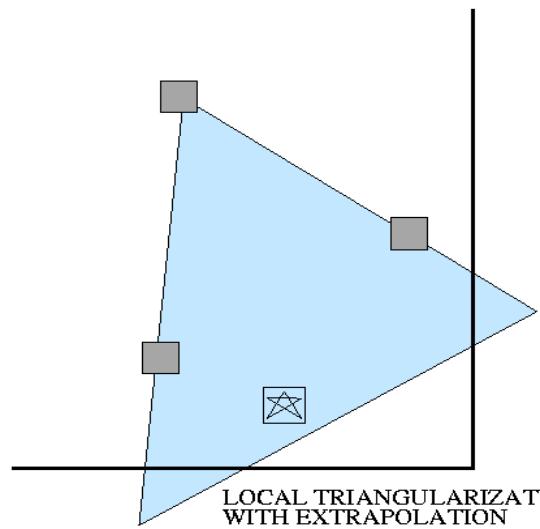


Background correction (exo channel)



Three methods :

- ◆ The closest background light-curve
- ◆ Triangularization
- ◆ Sky background model (under development and test)



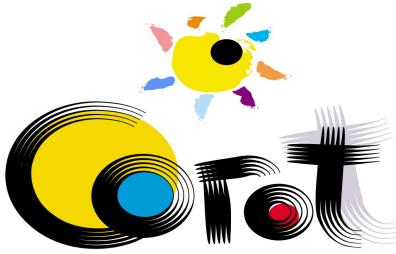
Problem addressed by
Rachel Drummond
(Leuven)

Gradient:

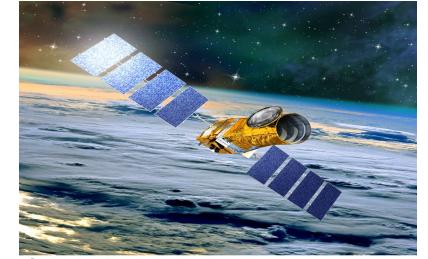
along X : 4 e- / 1000 pix (half CCD)

along y : 1.3 e- / 1000 pix (half CCD)

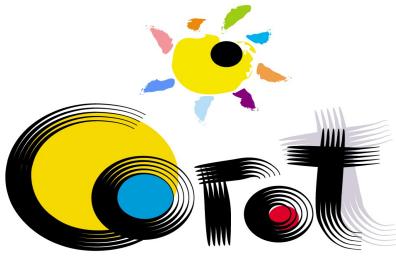
Range : 360 e- to 390 e-



Background correction conclusions (exo channel)



- Closest window : the simplest correction, can have a bad result when a hot pixel occurs in the BG LC – care should be taken!
- Triangularisation doesn't improve the quality : the probability to have one hot pixel in one of the 3 BG windows is 3 times higher.
- A polynomial fit is of comparable quality when all windows are used (512 s fit). It is beneficial in cases of bright pixels in the nearest background window
- The initial run window placement was not homogeneous



Correction of the jitter noise



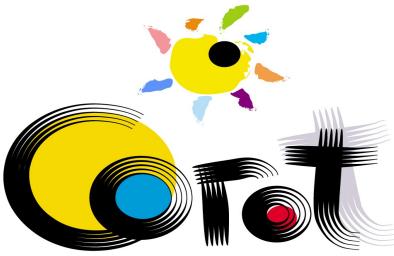
Two steps :

- ◆ Calculation of the star displacements
- ◆ Correction of the jitter noise

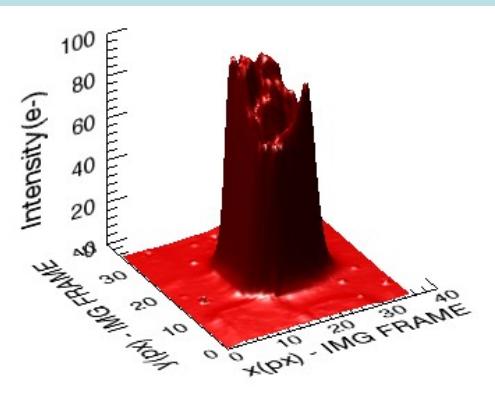
methods used :

- ◆ Correction based on the star PSF (astero channel)
- Correction based on the star spectrum (exo channel) : correction of the jitter noise *induced by the color frontiers (method proposed by M. Ollivier)*

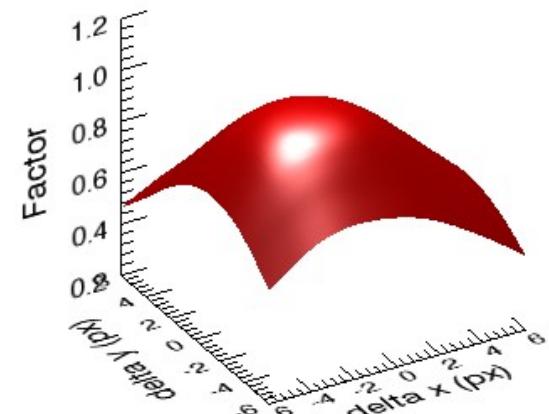
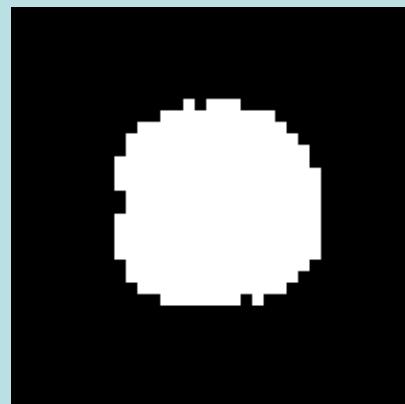
Conception, development and validation by Fabio Fialho (LESIA)



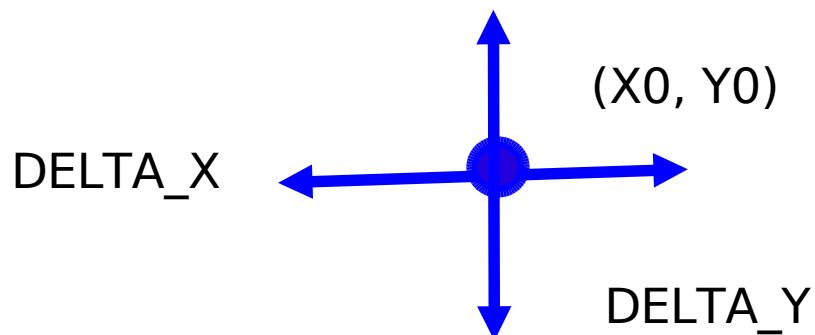
Correction of the jitter noise (astro channel)

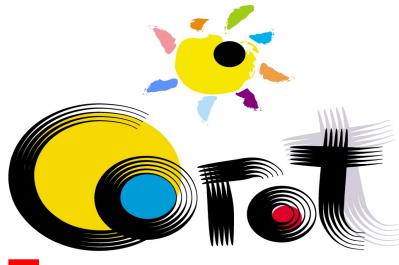


PSF with a sub-pixel resolution (1/4 px)
(method by Leonardo Pinheiro)

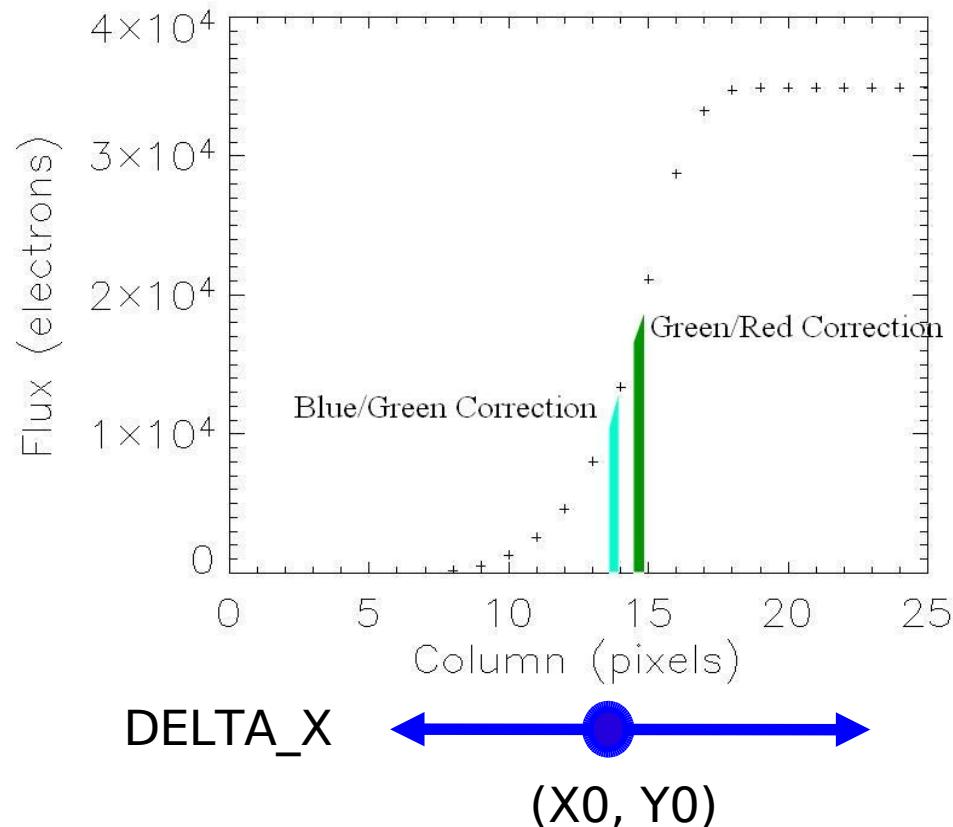
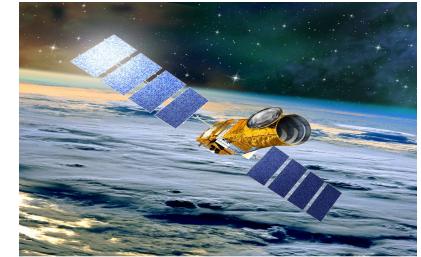


Surface for the jitter correction
(method by F. Fialho)





Jitter correction corr. based on the star spectrum (exo channel)

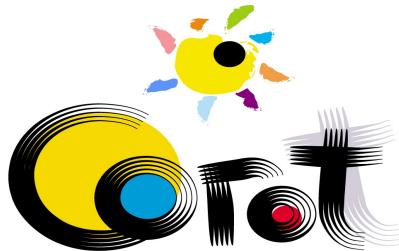


JCFR, JCFG, JCFB : jitter correction factors

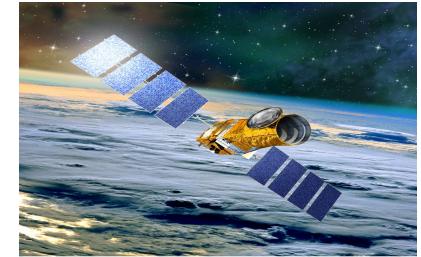
Hyp. : the star flux is constant during the exposure (32s) and during the accumulation time (512s)

$$F'_R = JCFR \cdot F_R$$

$$JCFR + JCFG + JCFB = 1$$



Jitter correction : calculation of the star displacements



Star Right Ascension (RA) and declination (DEC) + Field of View Model (FoVM, modelled by L. Jordà, OAMP) \Rightarrow X0 and Y0 the star set point position

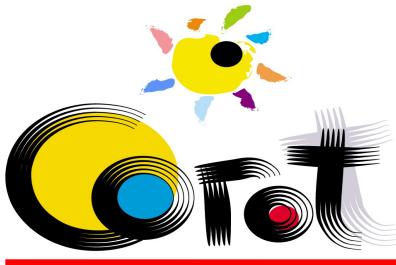
Using the 10 targets + FoVM \Rightarrow variation of the satellite Line of Sight (3 angles Theta, Psi, Phi)

Linearisation of the FoVM at X0, Y0 + variation of the satellite Line of Sight

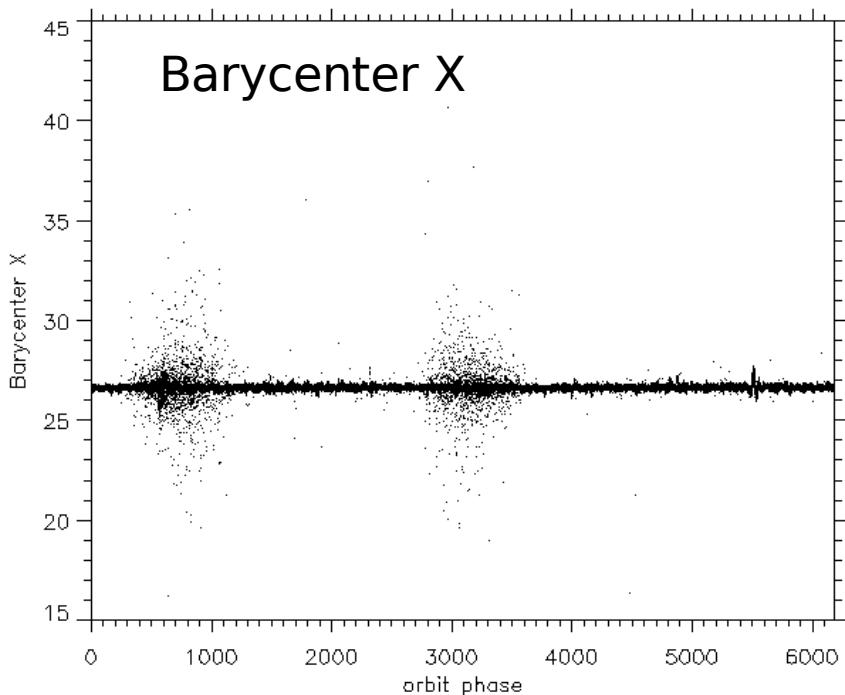
\Rightarrow DELTA_X and DELTA_Y , the star displacements with respect to the set point position and time

Calculation validated using either:

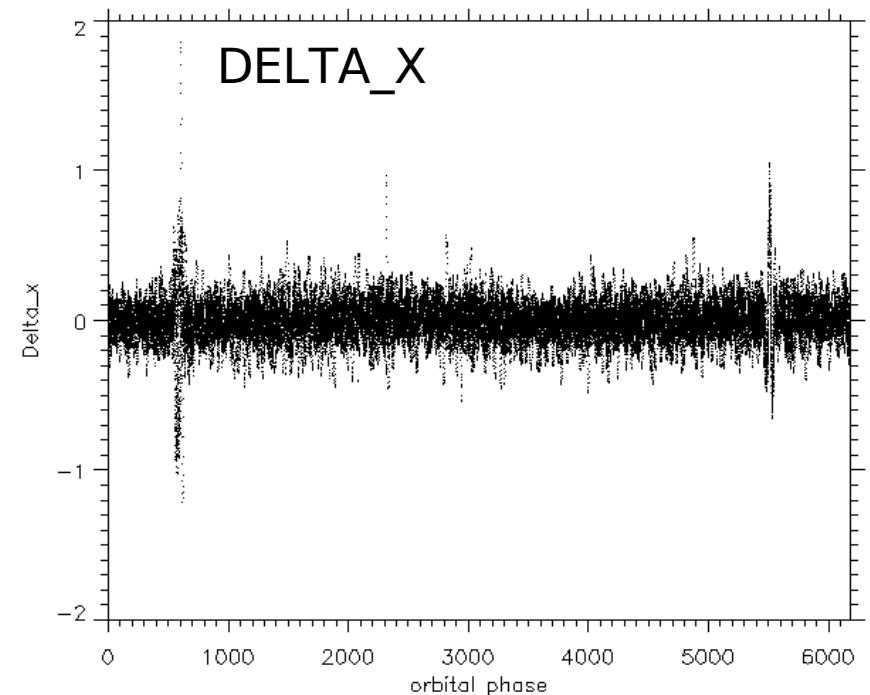
- the star barycenter measured on-board (astero channel)
- The imagettes (astero and exo channels)
- the satellite Line of Sight derived on-board from the two guide stars.

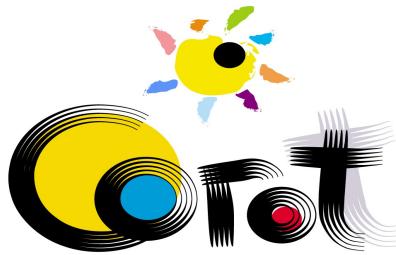


The star displacements (astero channel)

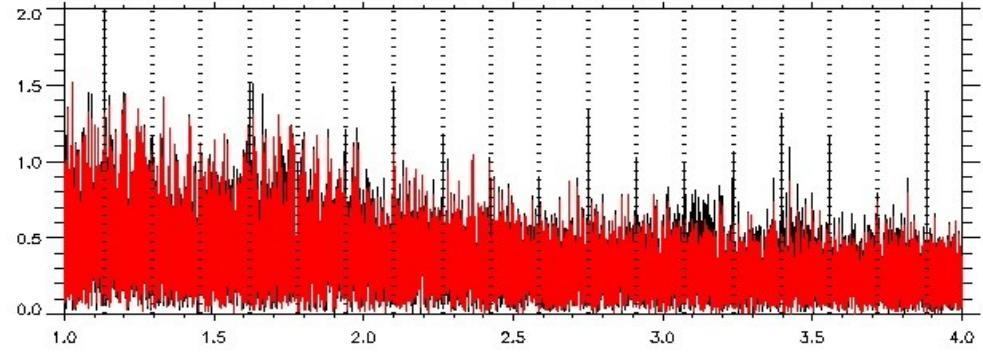
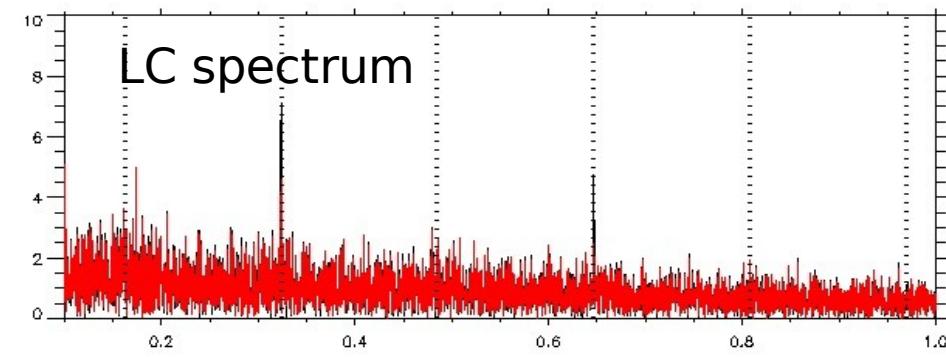
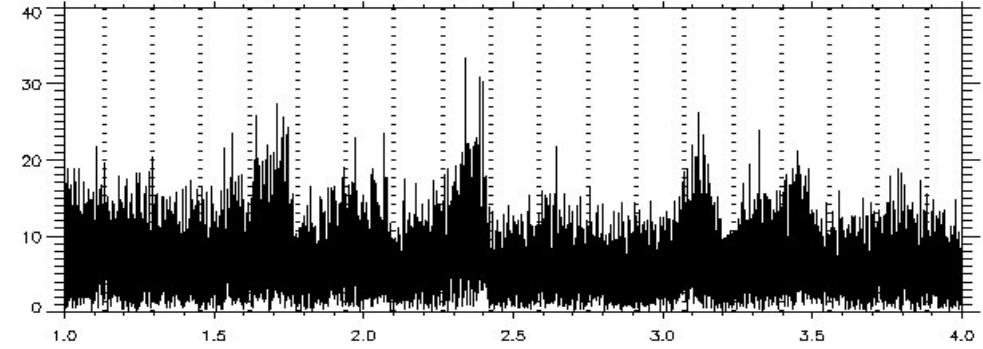
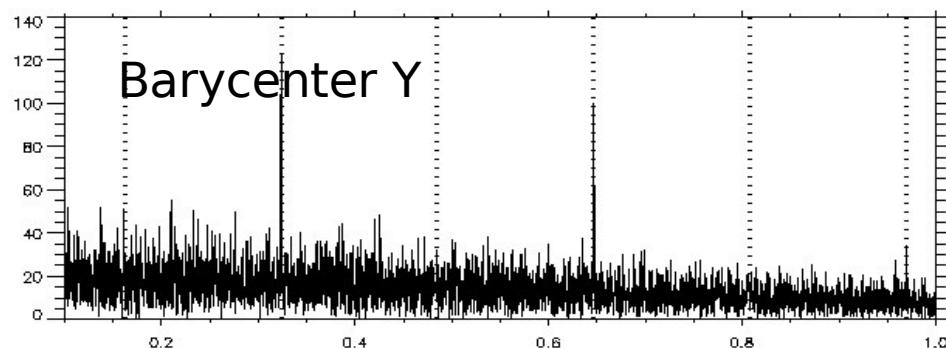
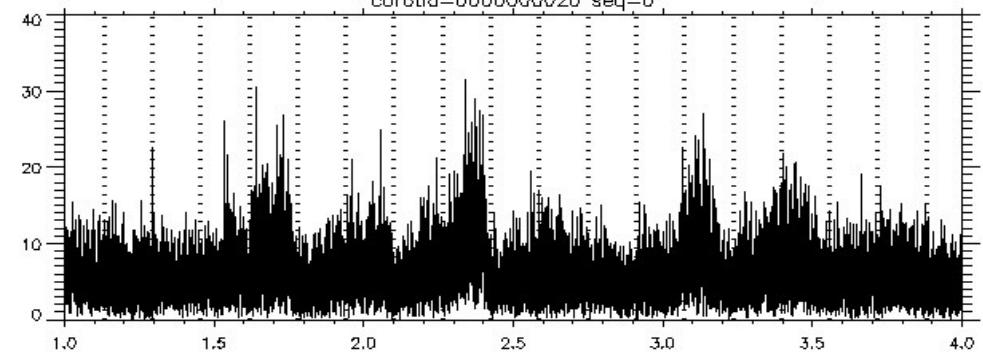
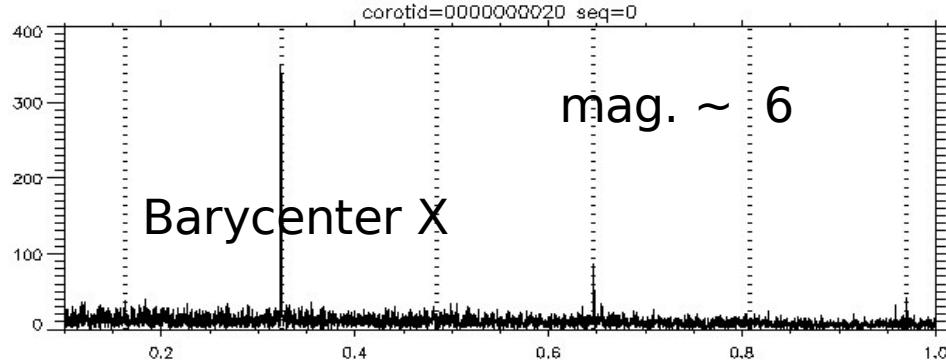


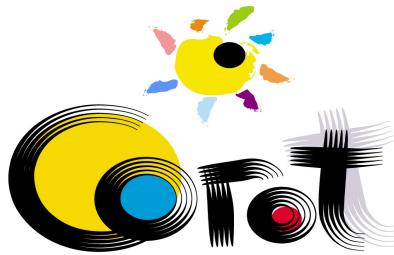
Reconstructed
displacements:



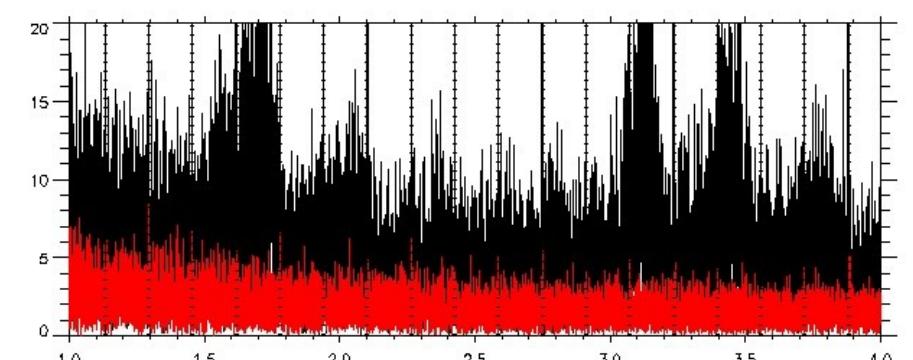
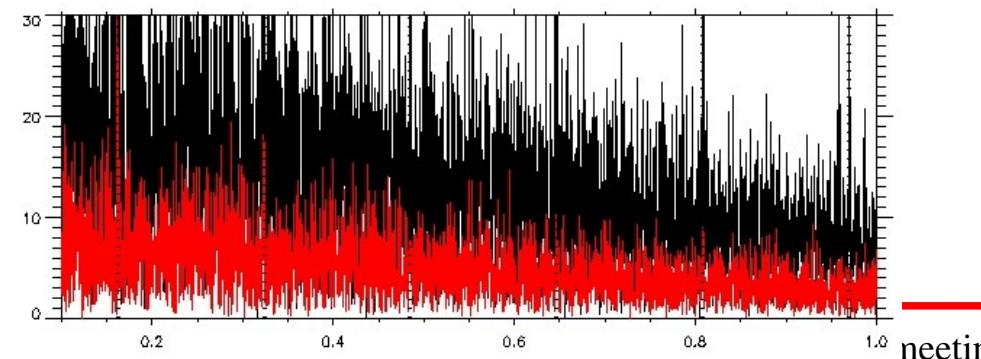
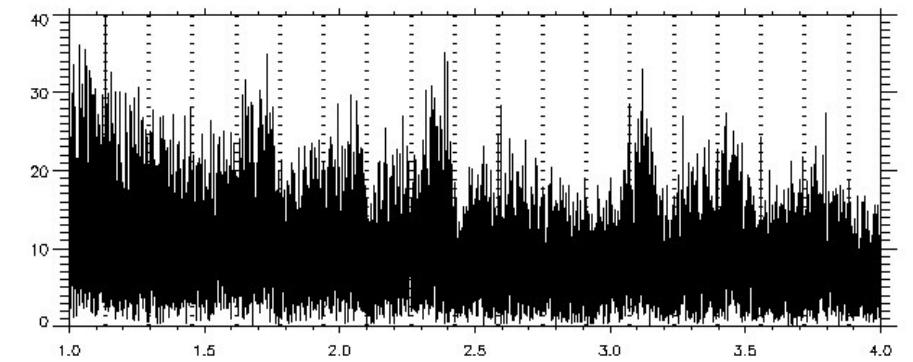
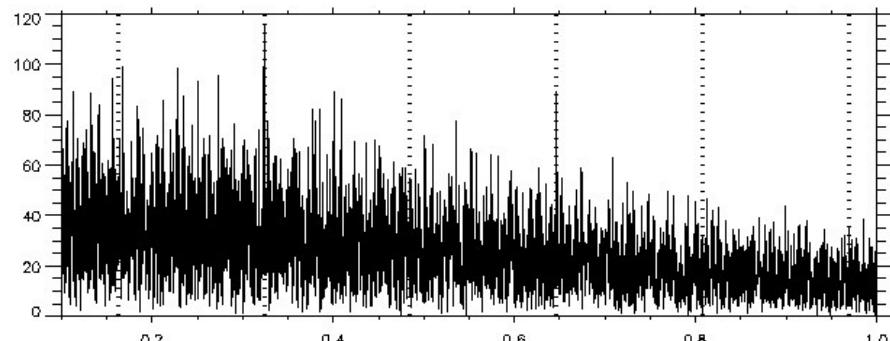
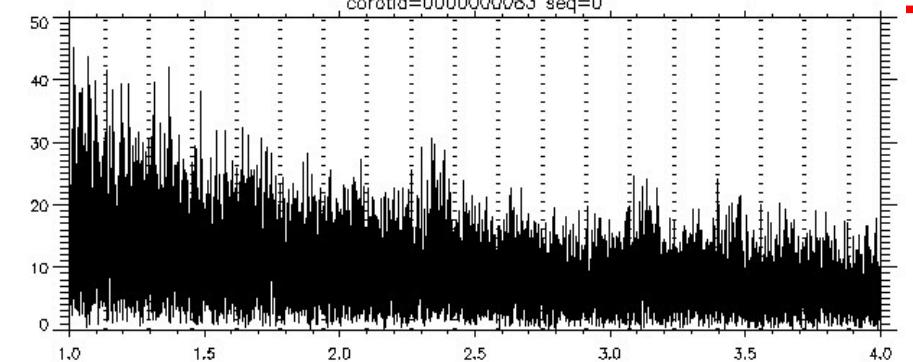
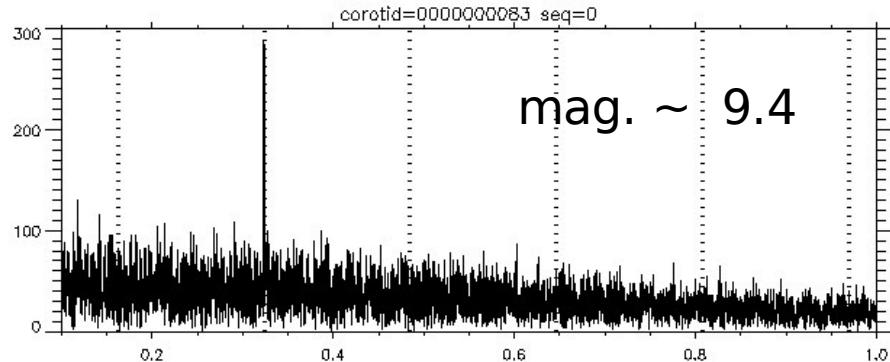
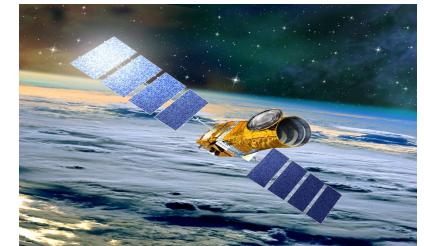


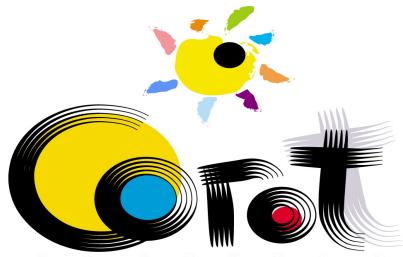
Correction of the jitter noise: results for a *bright* star and a *rough* mask



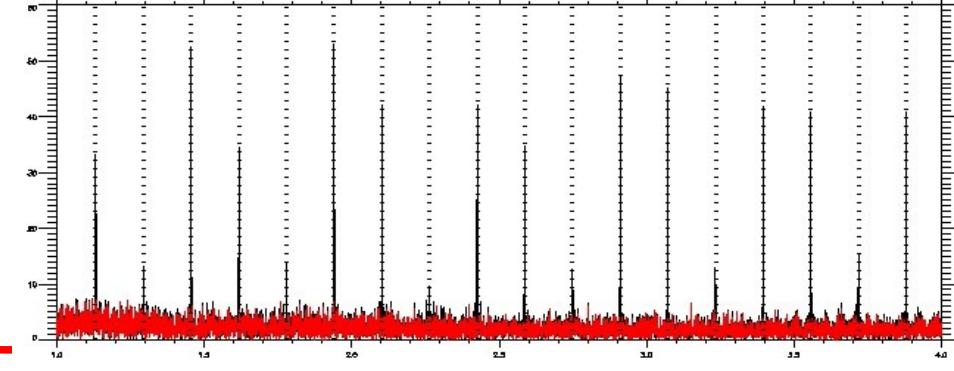
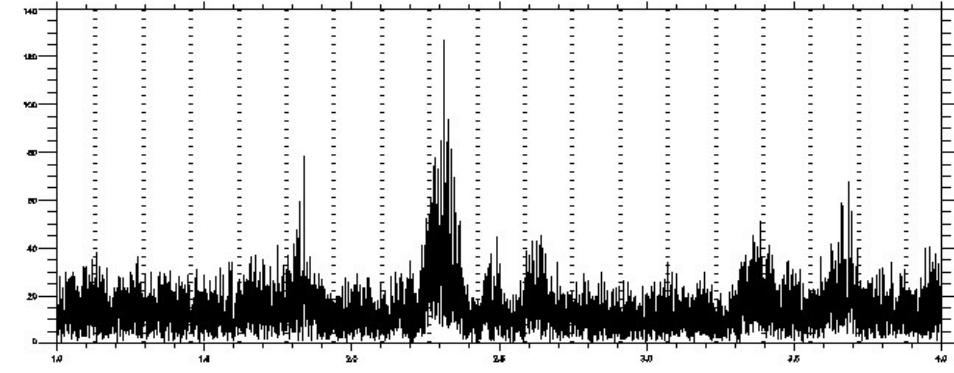
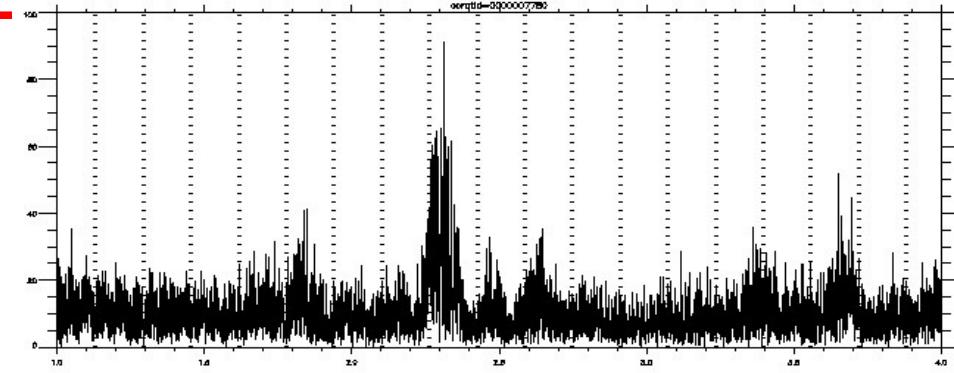
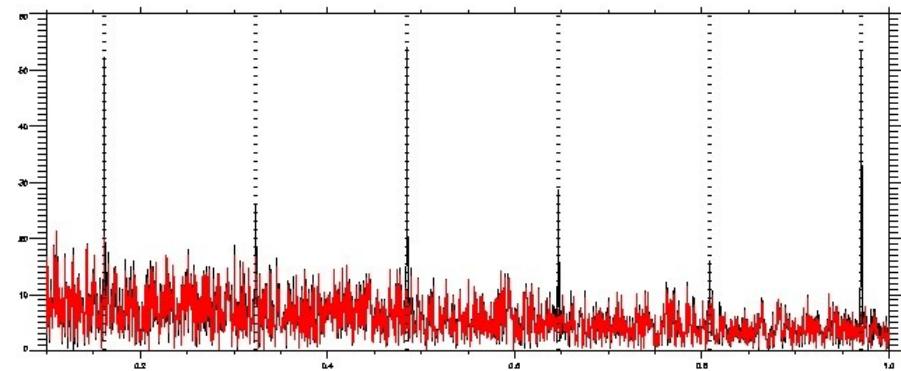
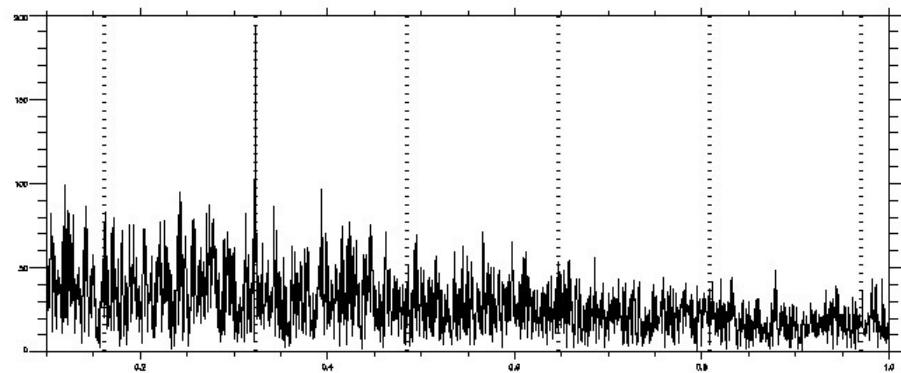
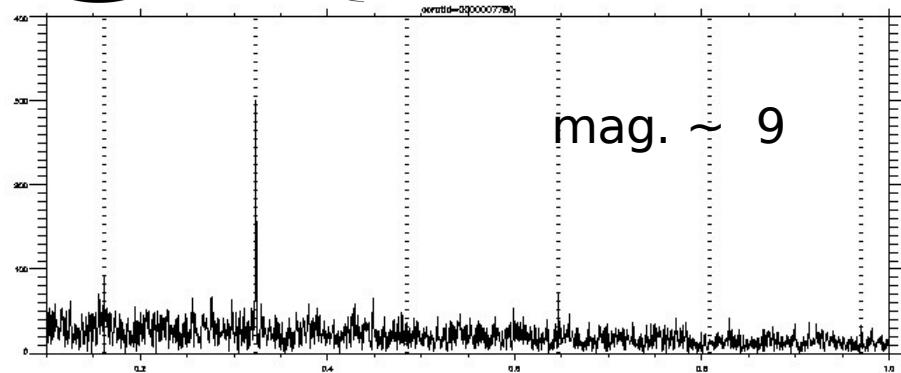


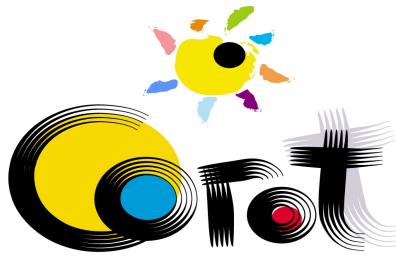
Correction of the jitter noise: results for a *faint* star and a *rough* mask



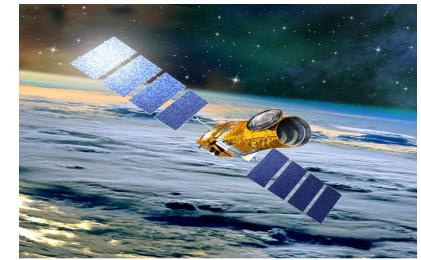


Correction of the jitter noise: results for a *faint* star and a *fine (optimal)* mask





Jitter correction, 32s LC (exo channel)



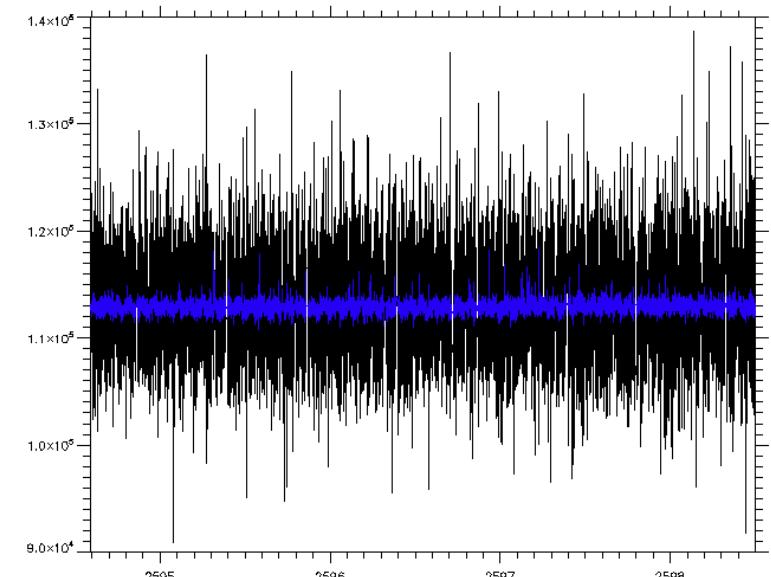
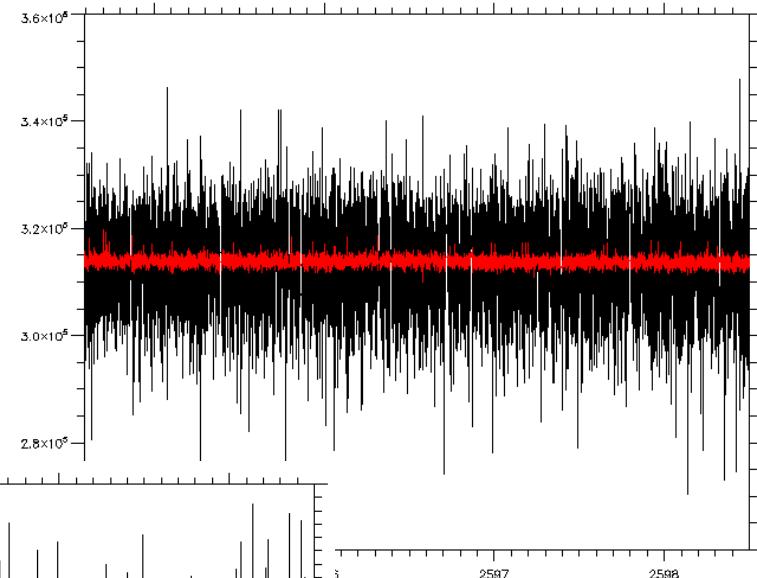
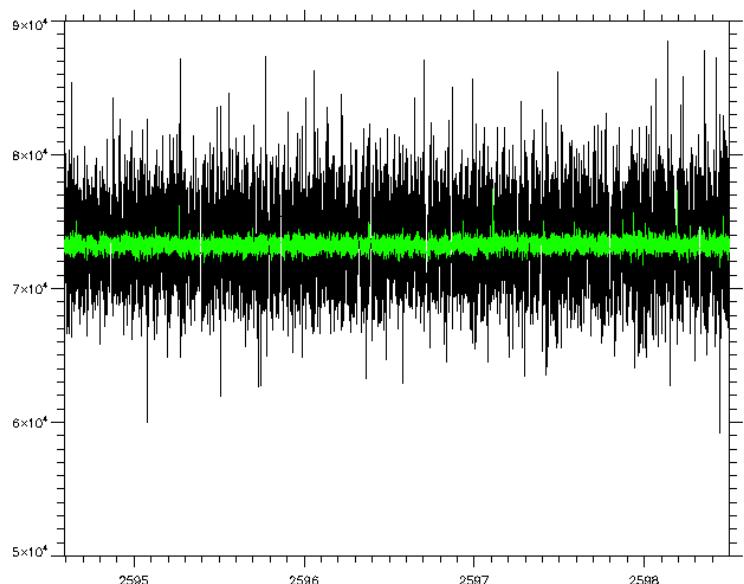
$mv = 12.5$

$n = 4.9 \times 10^5 \text{ e-} / 32\text{s}$

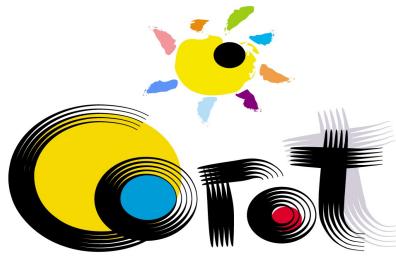
$nR = 3.1 \times 10^5$

$nG = 0.7 \times 10^5$

$nB = 1.1 \times 10^5$



S/N	Red	Green	Blue	White
Before	40	25	24	503
After	417	194	208	503
Gain	10,4	7,8	8,7	1
Theor.	561	271	336	707



Jitter correction, 512s LC



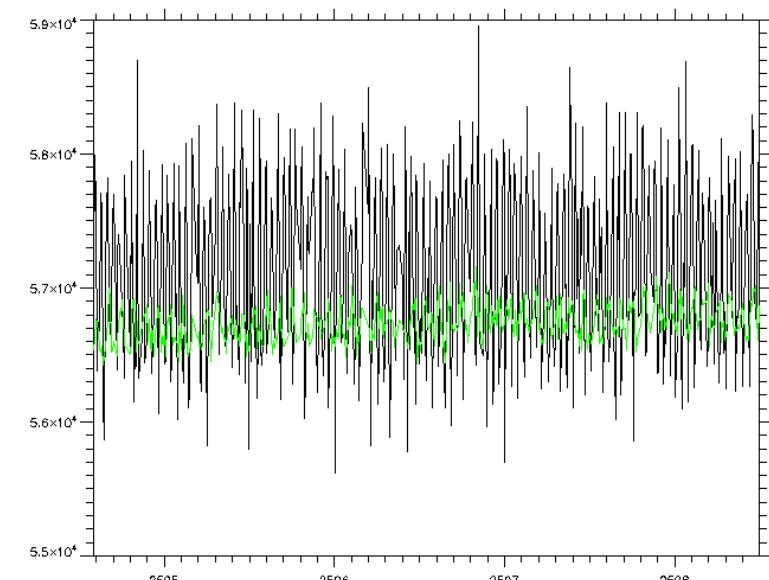
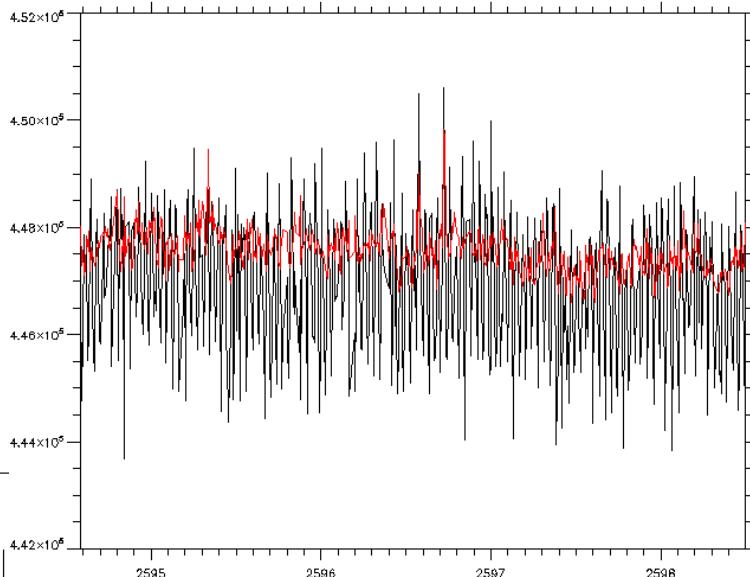
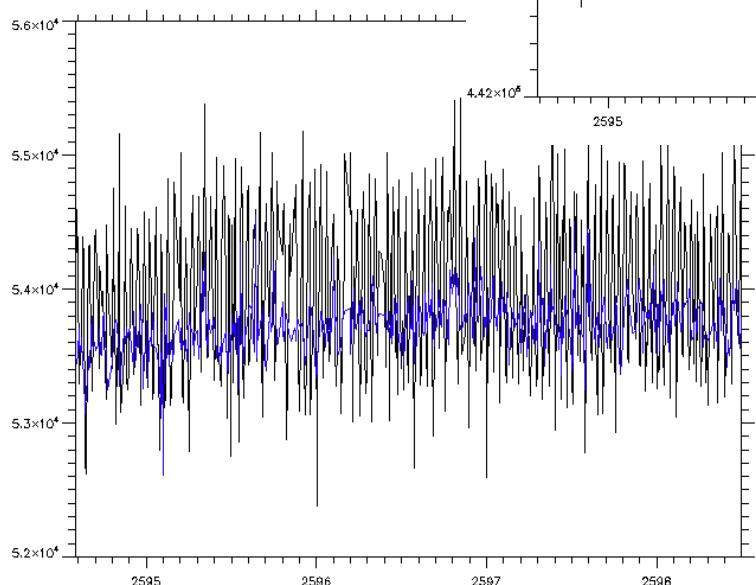
$mv = 12.4$

$n = 5.6 \times 10^5 \text{ e- } /32\text{s}$

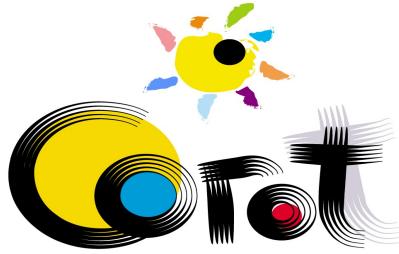
$nR = 4.5 \times 10^5$

$nG = 0.6 \times 10^5$

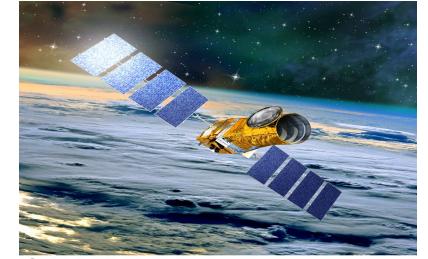
$nB = 0.5 \times 10^5$



S/N	Red	Green	Blue	White
Before	360	90	90	1243
After	1110	430	270	1243
Gain	3,1	4,8	3	1
Theor.	2680	950	930	2990



Jitter correction – white noise Summary



Exo channel

Gain in term of S/N
(4 days data set)

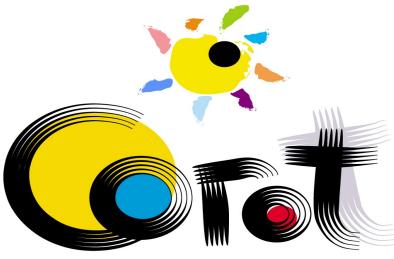
	Red	Green	Blue	Sampling	Mag.	#stars
Gain	7,1	7	6,8	32	12-12.5	86
Gain	2,3	2,7	2,2	512	12-12.5	92
Gain	2,4	2,5	2,5	32->512	12-12.5	86
Gain	1,6	1,7	1,4	512	14.5-15	624

Important residual at 2 f0: probably due to the linearisation of the FoVM

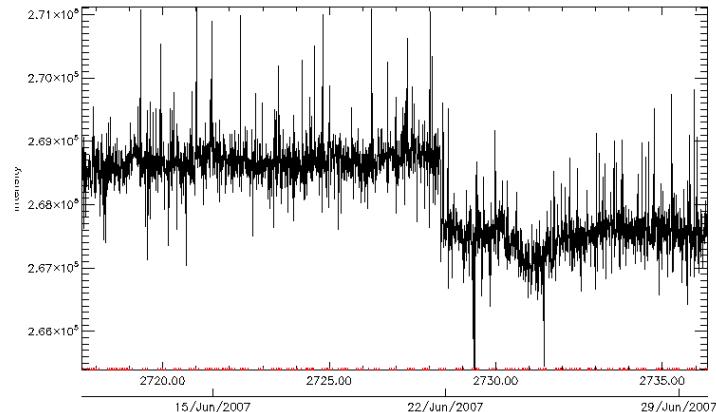
Astero channel

White noise above 5 mHz compared to the photon noise limit, before and after jitter correction

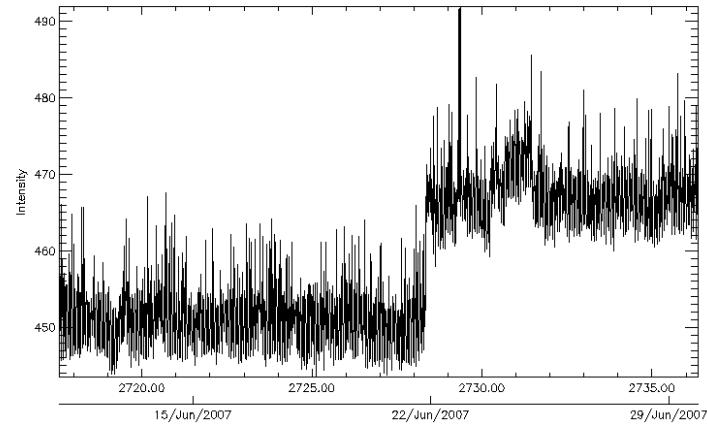
	ID	mv	With noise w.r.t. photon noise limit		
			Mask	Before	After
	7780	9	Rough	200,00%	14,00%
			Fine	19,00%	14,00%
	7636	5,6	Rough	11,00%	8,00%



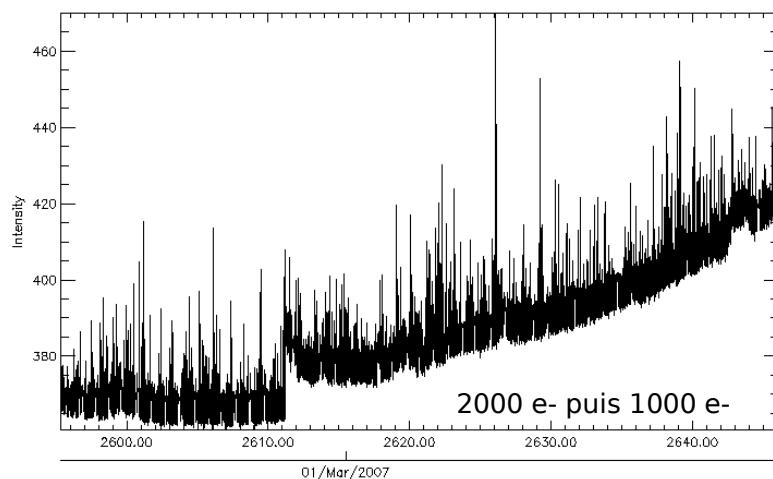
Hot pixels ... and their consequences



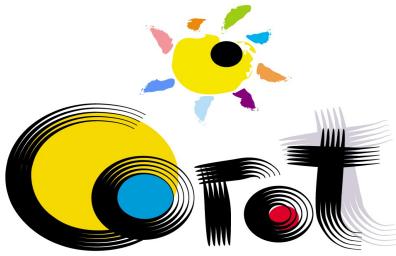
A star LC corrected from the BackGround (BG) using the closest BG window



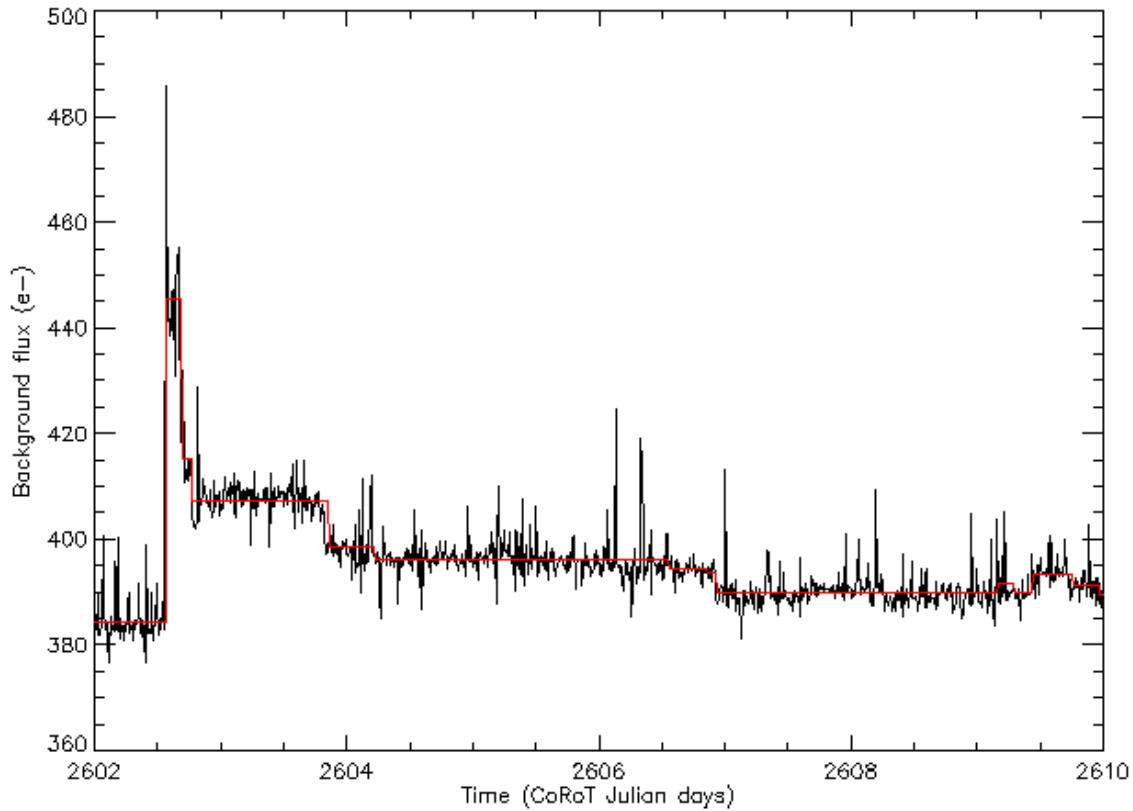
The BG LC used



Credit V. Lapeyrere



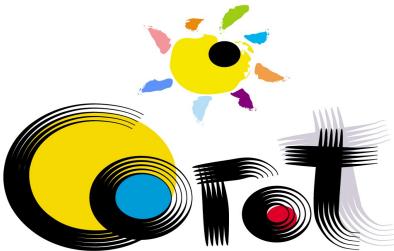
Hot pixels



- Problem addressed by V. Lapeyrere
- Hot pixel relaxation : modelled and corrected using Scargle (1998)'s method (NOT yet implemented in the pipeline)

Exo Background window during 10 days

Credit V. Lapeyrere



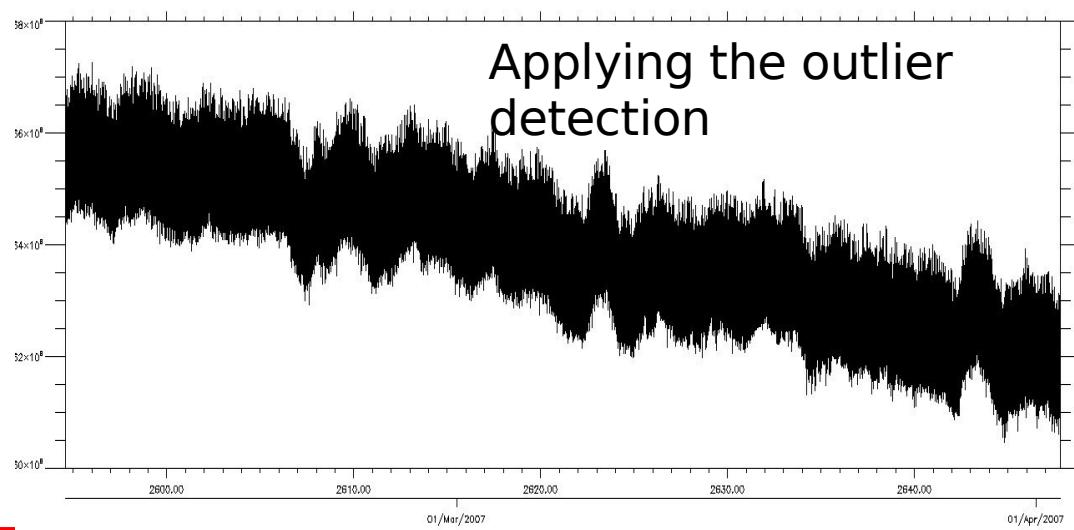
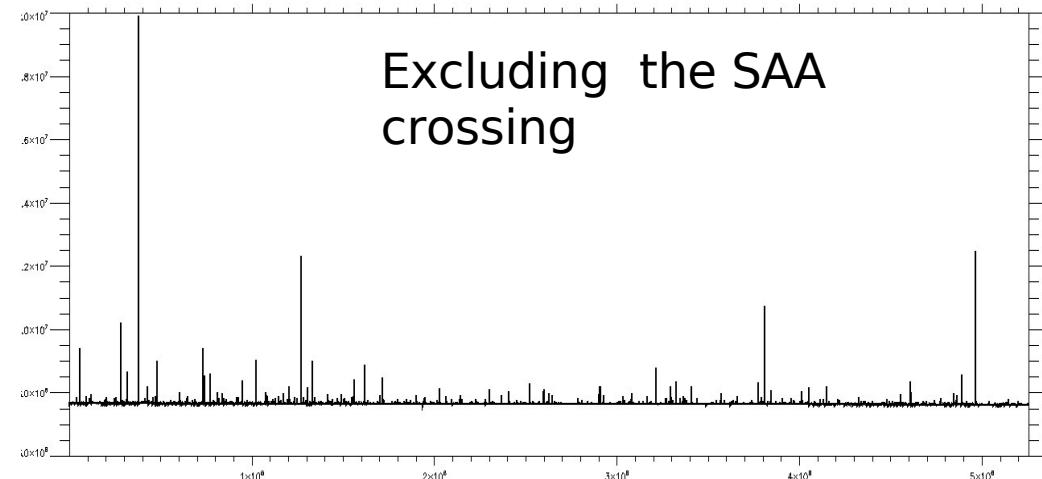
Detection of the outliers

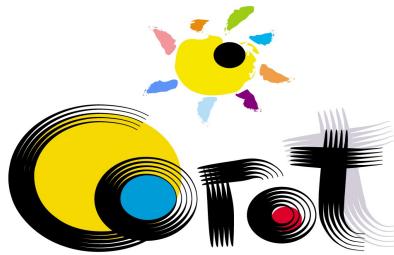


- Several methods implemented
- The SAA crossings are flagged

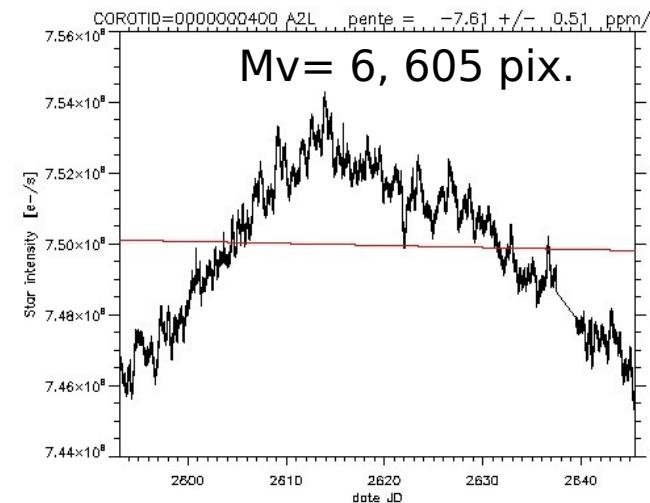
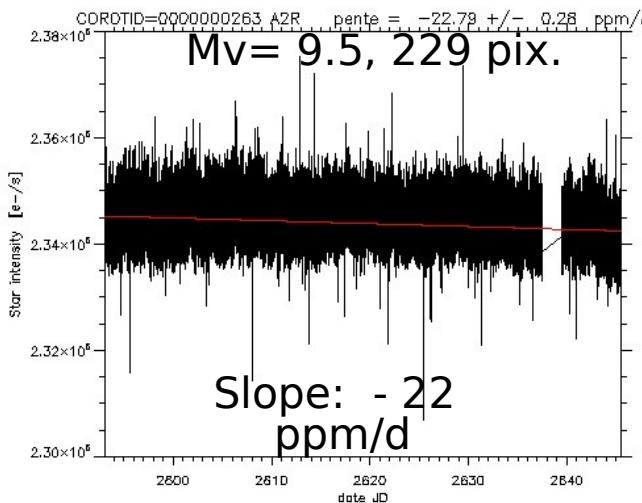
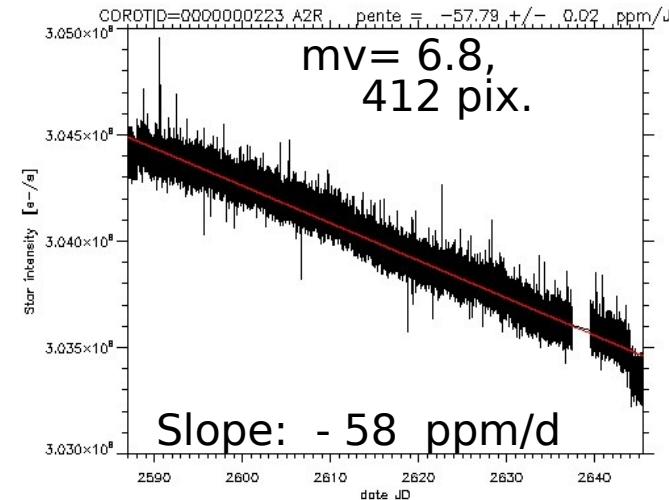
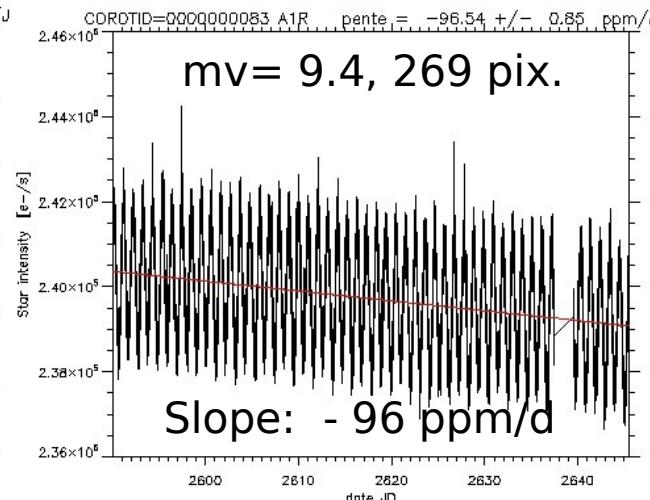
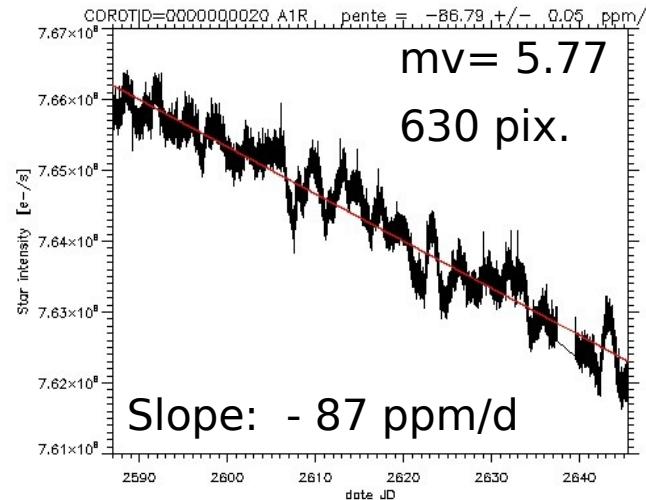
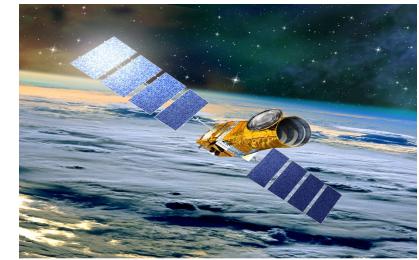
Duty-cycle (for the IR/astero) :

- ~ 92 % if we apply the outlier detection
- ~ 90 % if we exclude in addition the SAA crossings





Long terms variations : Astero Star LC

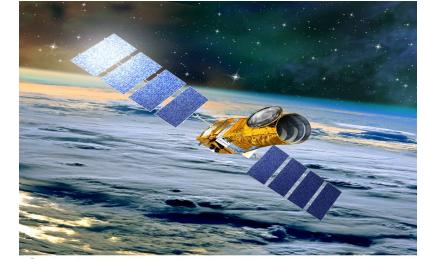


Different slopes : ~ - 20 to ~ -100 ppm/days

Most of the stars (IR and LR) have a slope of ~ 100 ppm/days



Perspectives (astro channel)

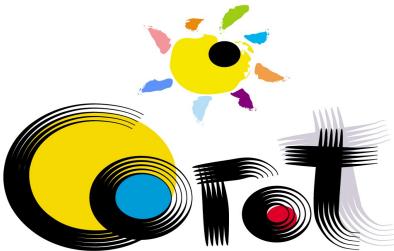


Current status:

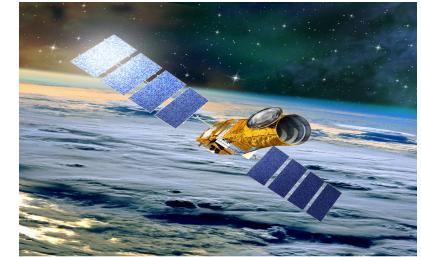
- The astro pipeline (V 1.0) has been validated by the *Groupe Traitement Segment Sol* (GT2S) on beginning of June.
- V 1.1 released middle of September

Perspectives:

- Improving the speed performances
- **Decreasing the orbital residuals, probably possible**
- Decreasing the EMI residuals, if possible
- Detection of the hot pixels and suppression
- Correction of the long term variations
- Improving the automation of the pipeline



Perspectives (exo channel)



Current status:

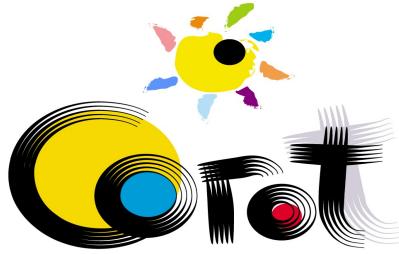
- The current exo pipeline (V 0.2) is being improved ;

Short term perspectives (for the first validated release)

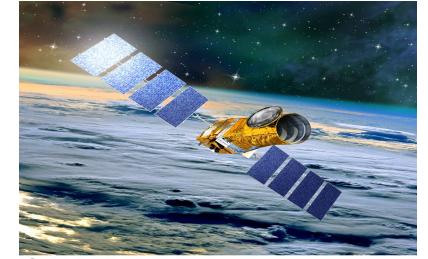
- **Detection and suppression of the hot pixels occurring in the Background LC**

Long term perspectives:

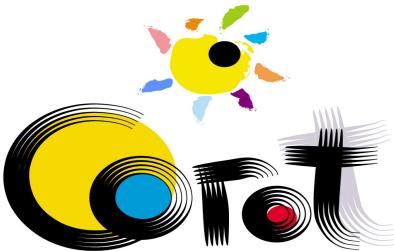
- **Improving the speed performances**
- **Decreasing the orbital residuals due to the jitter**
- **Detection of the hot pixels in the star LC and suppression (?)**
- Correction of the long term variations
- Improving the automation of the pipeline



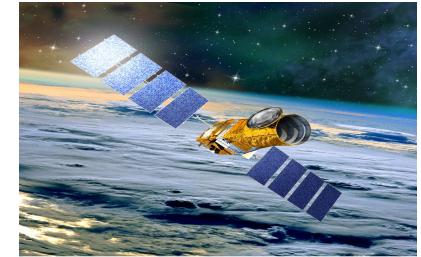
Documentation (N0-N1)



- “Description of the N1 products generated at the CMC during the observation session” (COR.LESIA.06.008; version 1.1; in English). V 1.2 coming soon...
- Contribution to the CoRoT Book : “Chap V.5/ Extraction of the photometric information”, Samadi et al 2007, astro-ph/0703354
- “Description du contenu des corrections N0 à N1 en mode observation” (COR.LESIA.06.026; version 0.4; in french)
- “Contenu et fonctionnalités de la Boite à Outil (BaO) du segment sol” (COR.LESIA.06.025, version 0.5, in French)



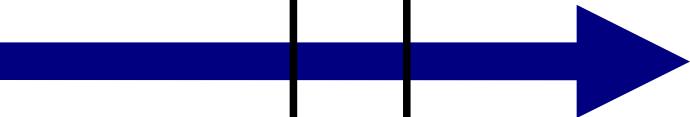
The N0-N1 Pipeline



Auxiliary data

- Housekeeping (temperature, voltage)
- Offset
- Background Light-Curves
- GPS tops

N0 data



N1 data

Auxiliary data

- House Keeping
- Offset
- Background Light Curves
- Sky Background Model
- Line of Sight
- Clock variations

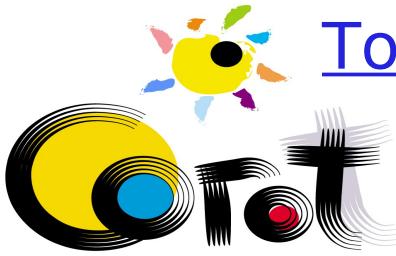
Science data:

- Stellar Light Curves
- “Imagettes”

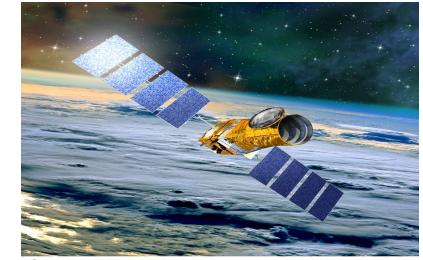


Science data:

- Stellar Light-Curves
- “Imagettes”



Tool Box for the Ground Segment ("Boite À Outils", BaO)

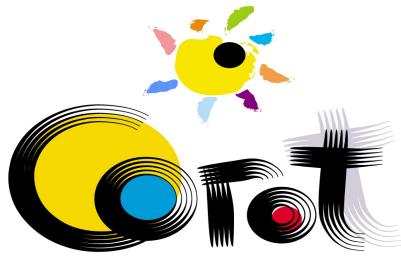


Goal: to have available a set of tools for:

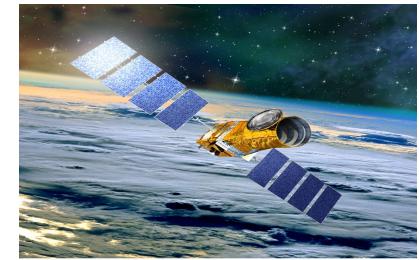
- **Visualization** (1D and 2D)
- **Diagnostics** and **characterization** of the N0, N1, and N2 data
- **Evaluation** of the correction performance
- Help for the **development** of new correction strategies

Current contents and functionalities :

- Outlier removal (2 methods)
- Fast Fourier Transform, amplitude, and power spectra
- Fit of analytical functions (Gaussian, sine, sinc, polynomials)
- Correlation products between two signals with different sampling
- Detection and correction of discontinuities in a time series
- Statistical test (Kolmogorov-Smirnov)
- Detection and fit of several sinusoids (**NEW**)
- Filtering in the Fourier domain (**NEW**)
- Visualization of several 1D data : CoRoTgraph (**NEW**)



Jitter correction, 512s LC Magnitude ~ 15



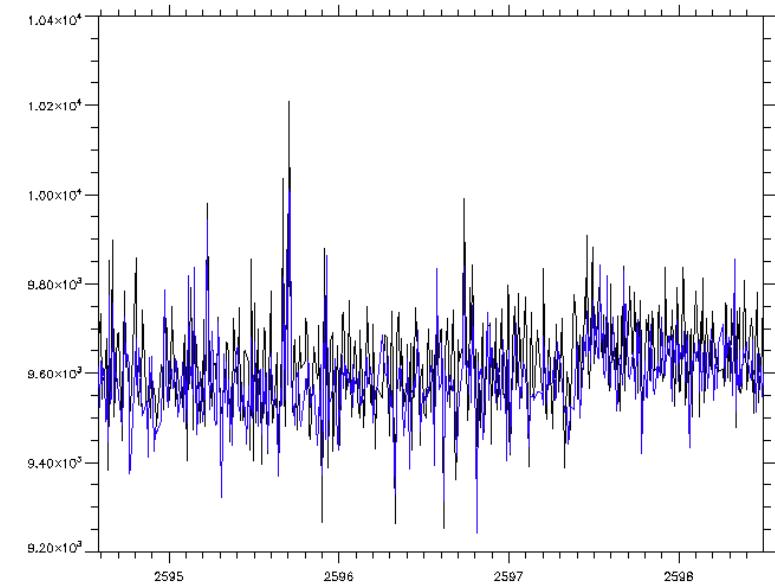
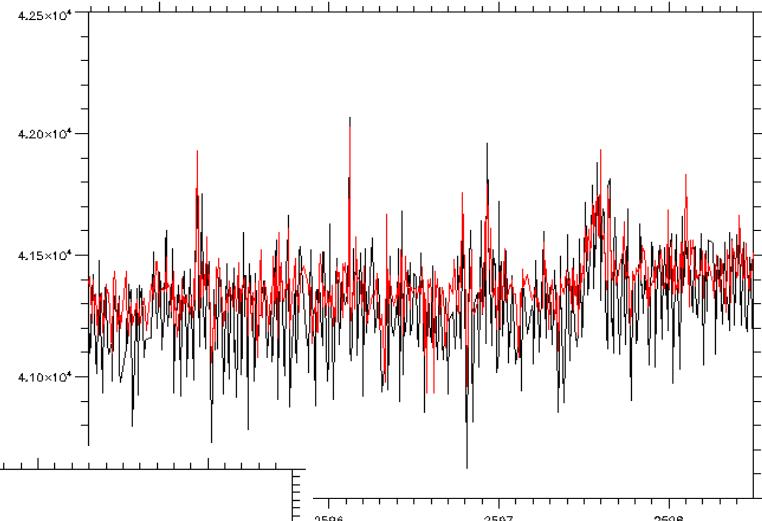
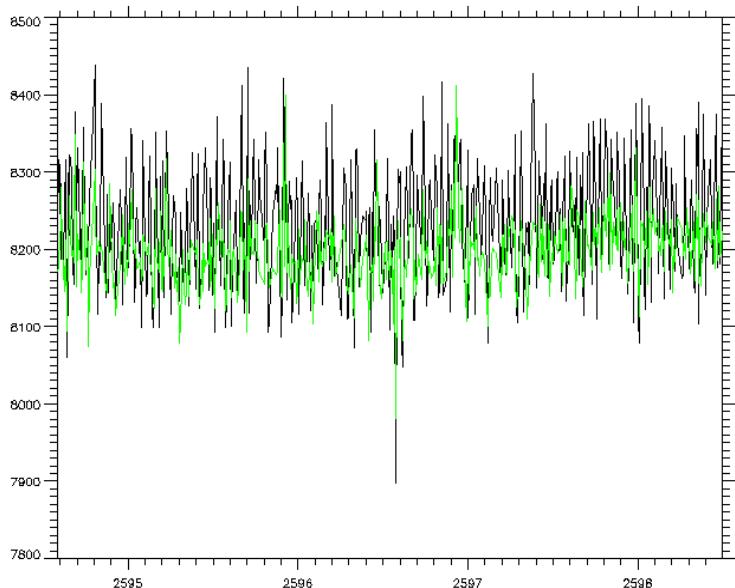
$mv = 14.7$

$n = 5.8e4 \text{ e-/32s}$

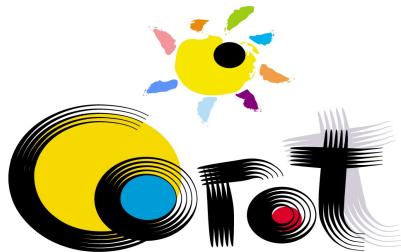
$nR = 4.1e4$

$nG = 0.8e4$

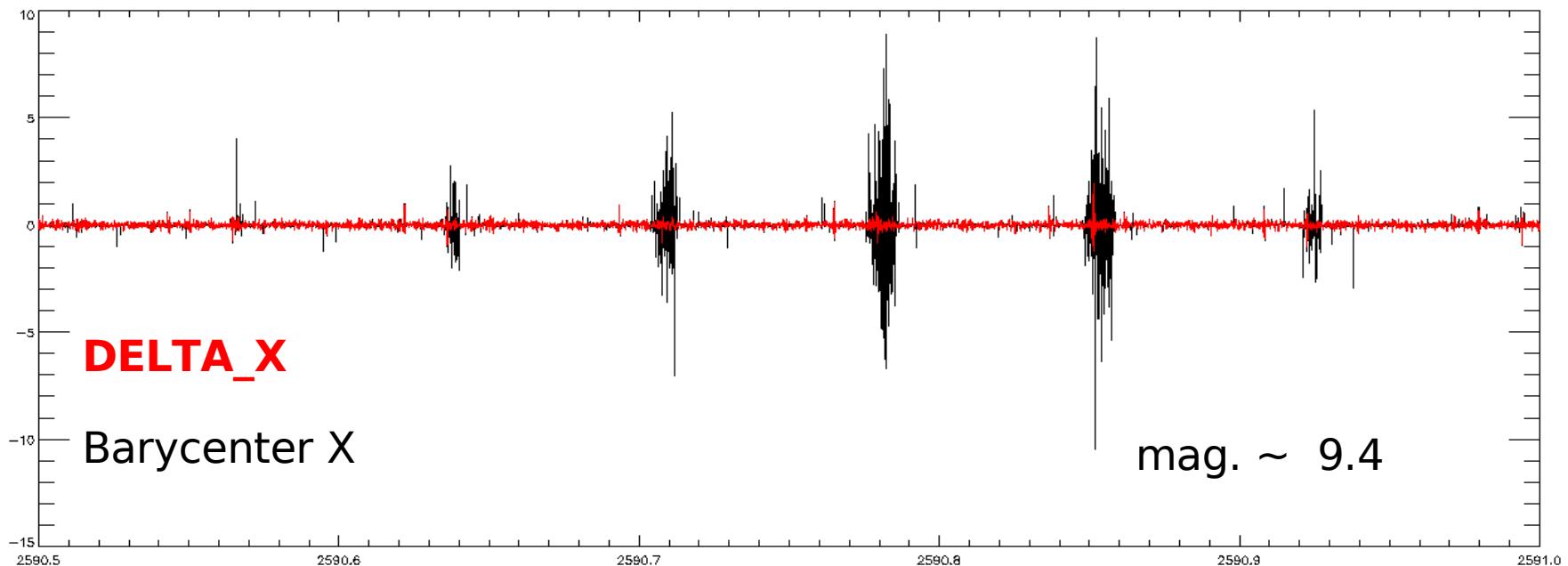
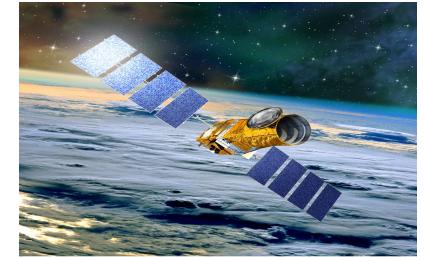
$nB = 0.9e4$



S/N	Red	Green	Blue	White
Before	212	106	88	293
After	325	188	100	293
Gain	1,54	1,77	1,25	1
Theor.	814	363	392	970

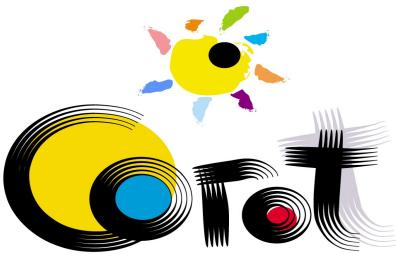


Jitter correction : calculation of the star displacements

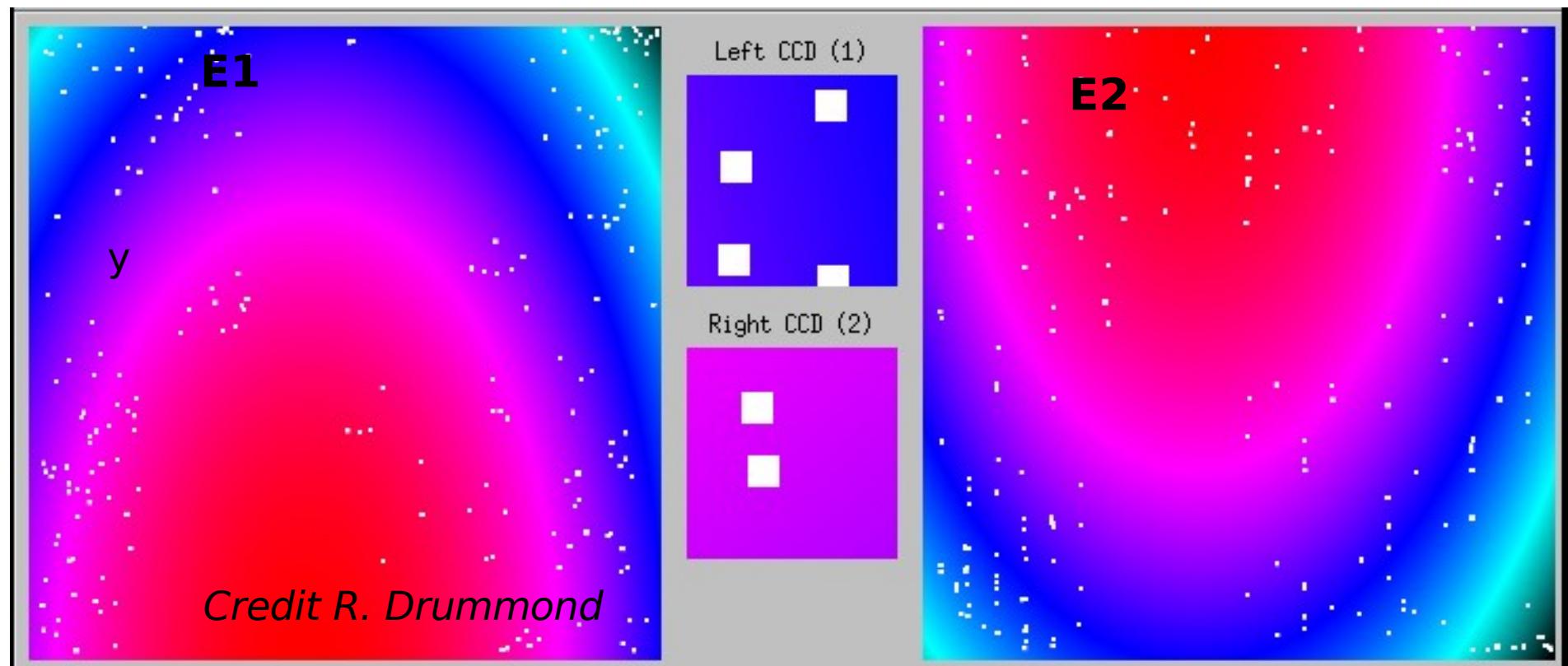
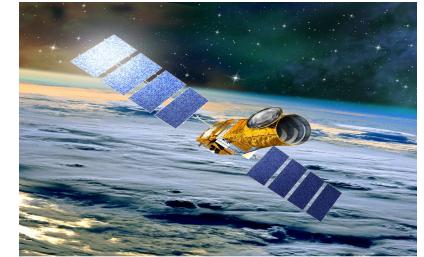


$\text{DELTA}_X - \text{Barycenter}X \sim 0.28 \text{ pix (rms)}$ (1 pix = 2.3 arcsec)

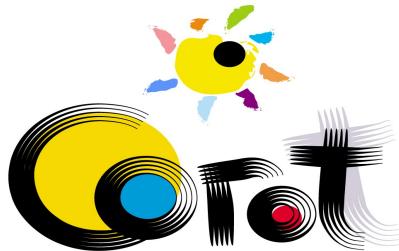
$\text{DELTA}_Y - \text{Barycenter}Y \sim 0.29 \text{ pix (rms)}$



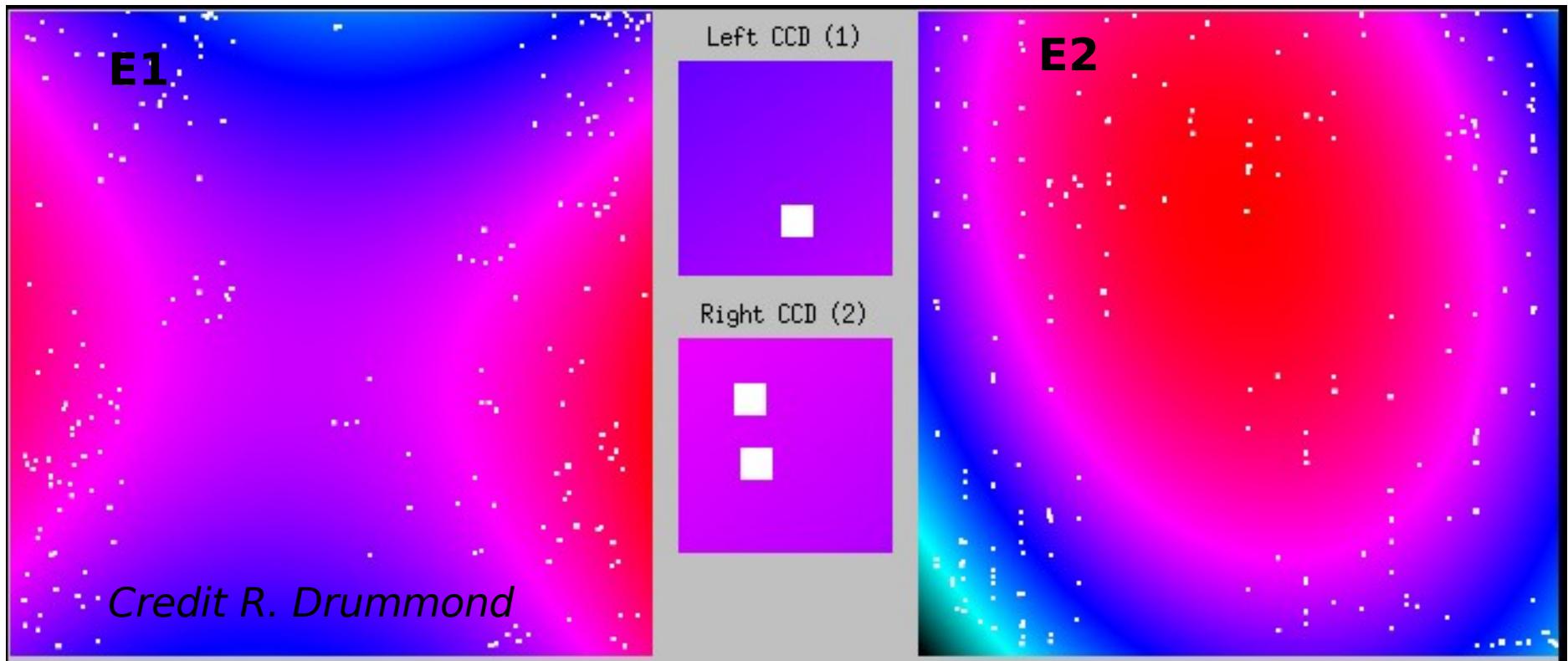
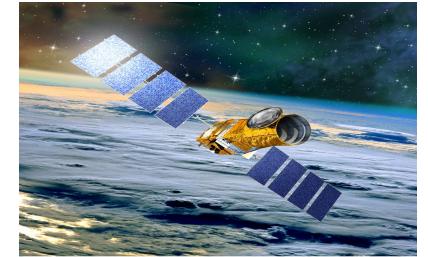
Background correction polynomial fit



The two CCDs are fitted *together* for each time step

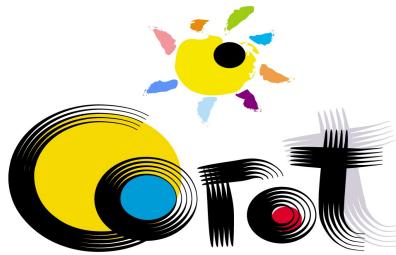


Background correction polynomial fit

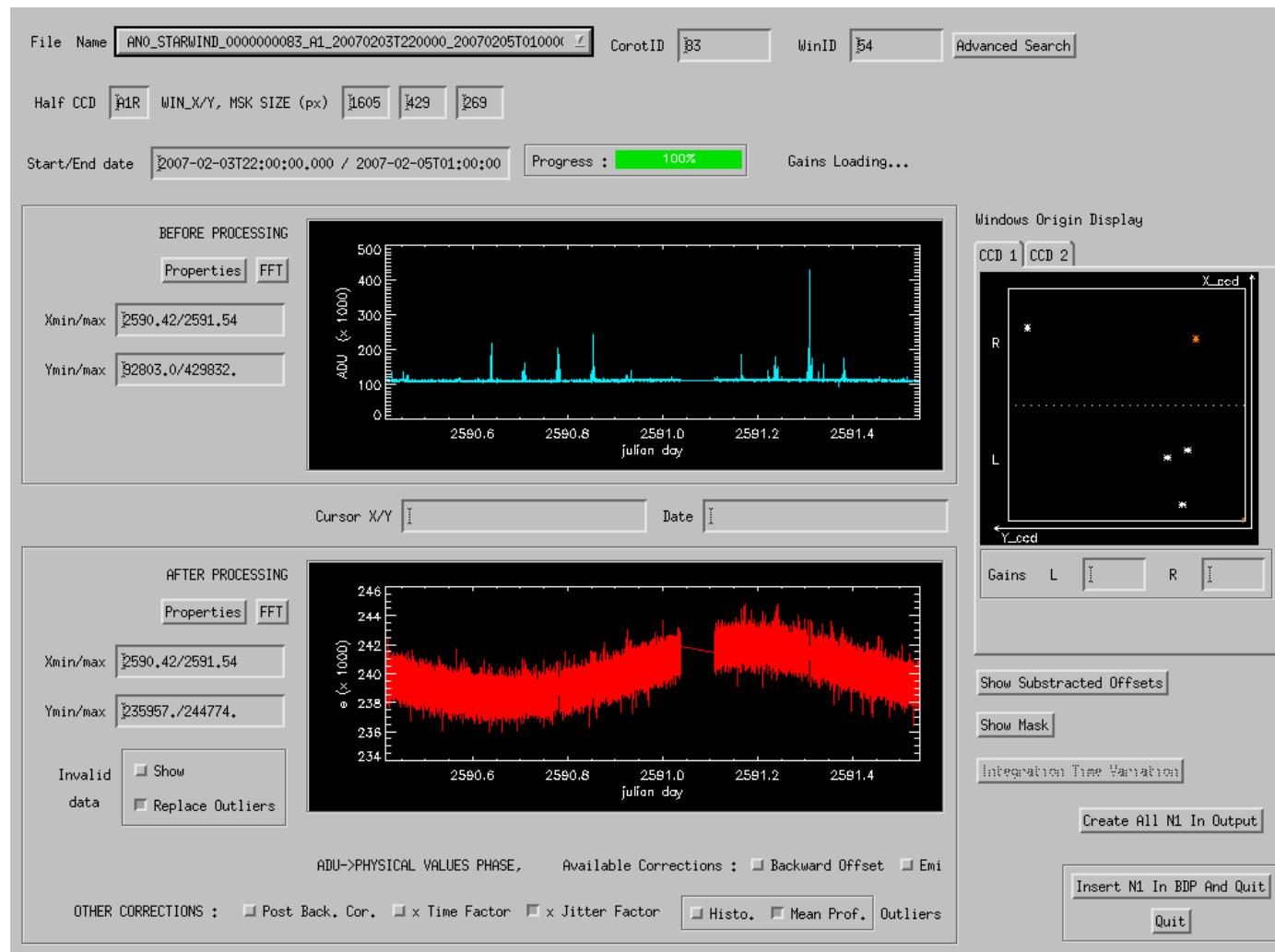
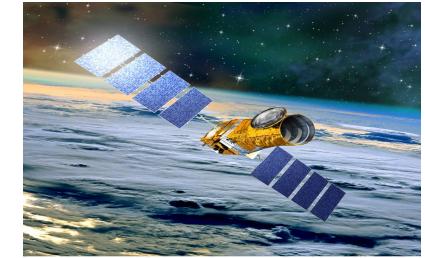


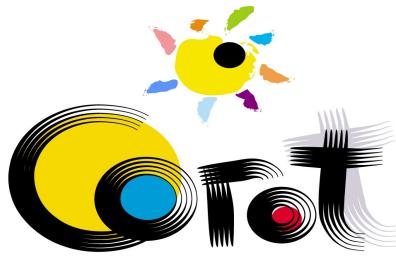
The two CCDs are fitted *separately* for each time step

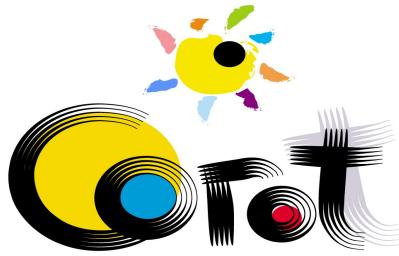
- No matching between the two fits !



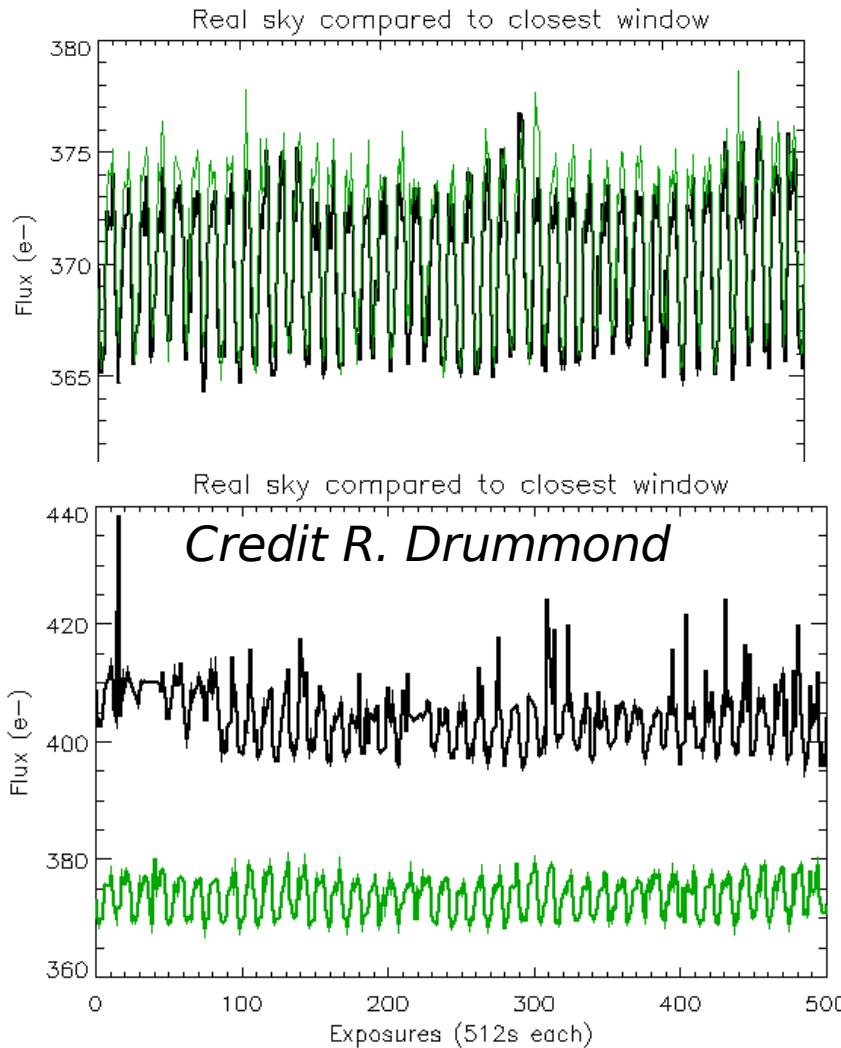
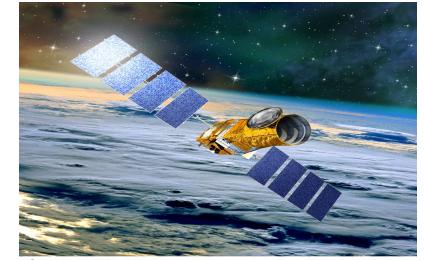
Astro-channel LC process 'asprocess'







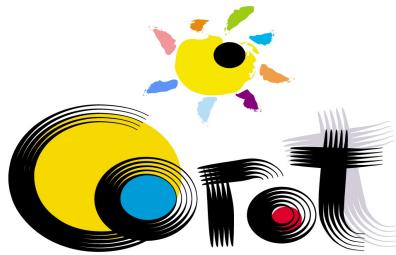
Background correction closest window



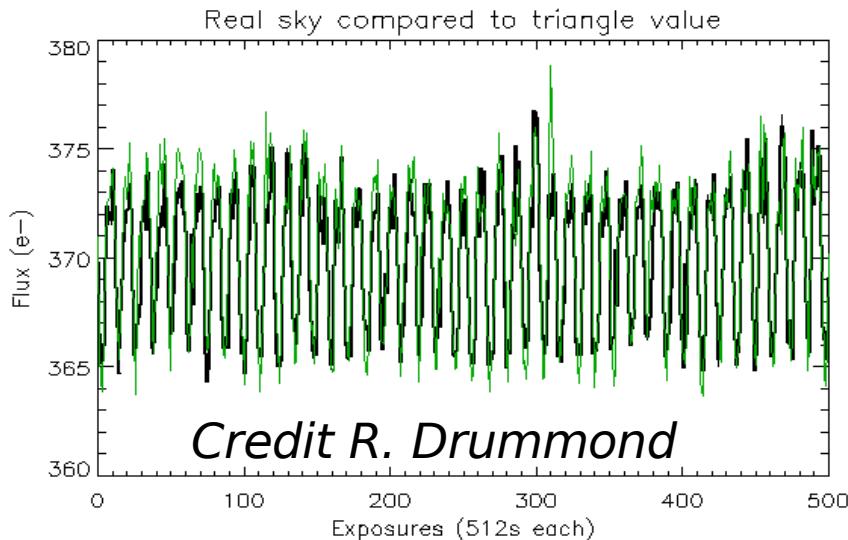
Standard deviation = 1.02
Square difference = 1121

Standard deviation = 9.82
Square difference = 41960

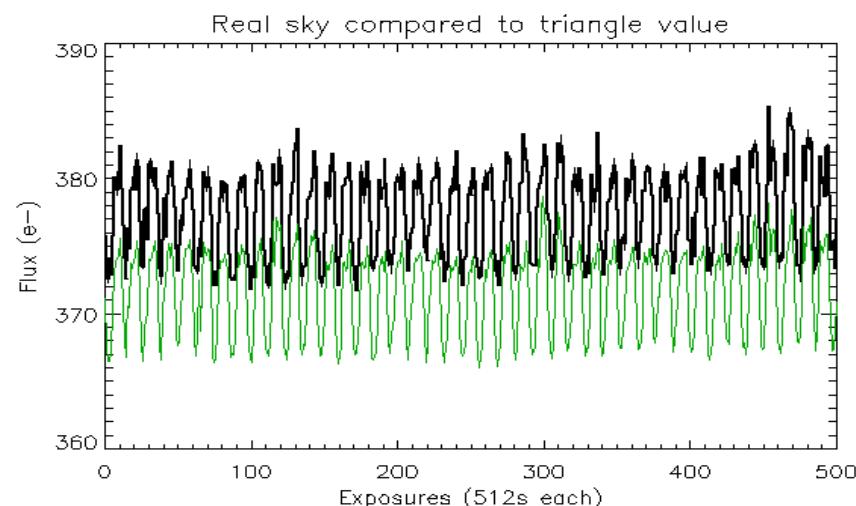
Values given outside SAA



Background correction 'triangularisation'

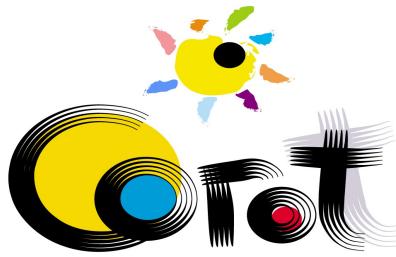


Standard deviation = 1.15
Square difference = 788

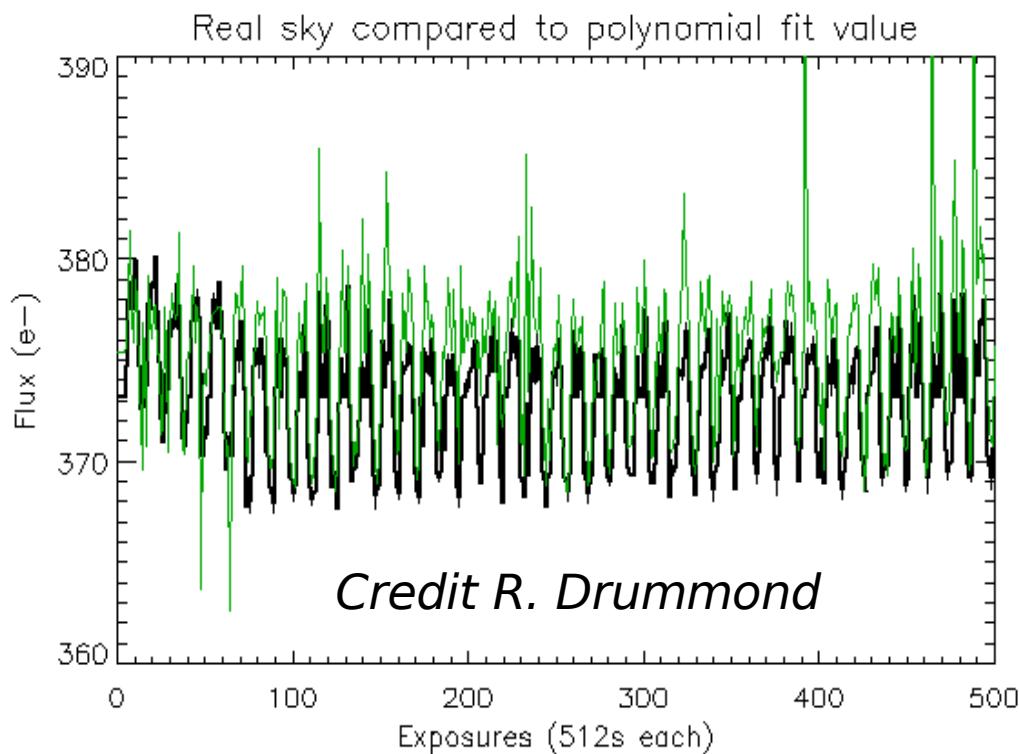


Standard deviation = 1.97
Square difference = 16134

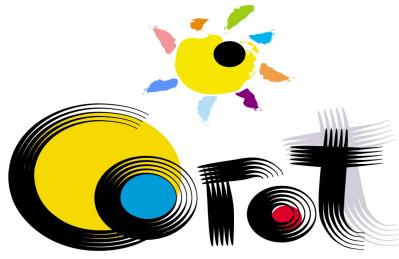
Values given outside SAA



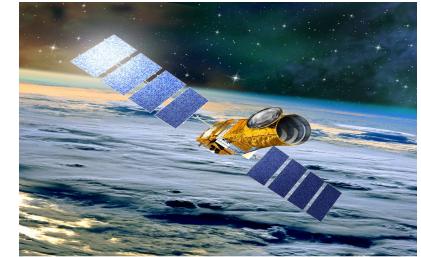
Background correction polynomial fit



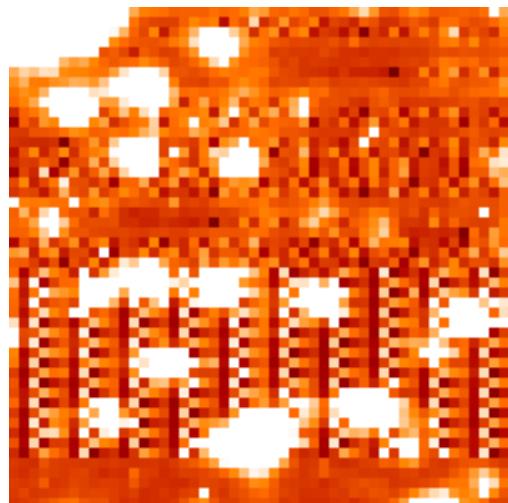
Standard deviation = 5.78



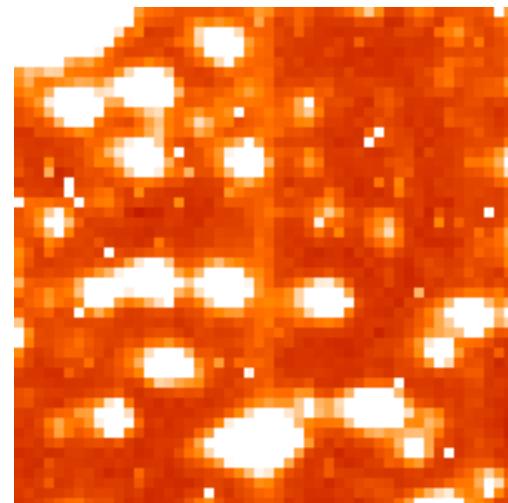
The Electromagnetic interferences (EMI)



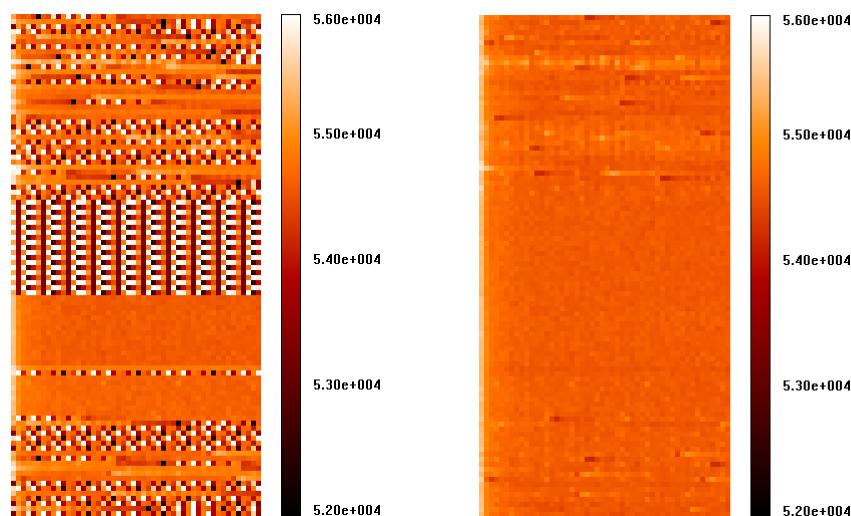
Before correction

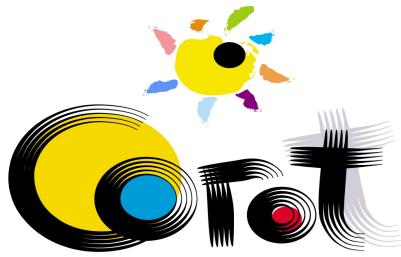


After correction

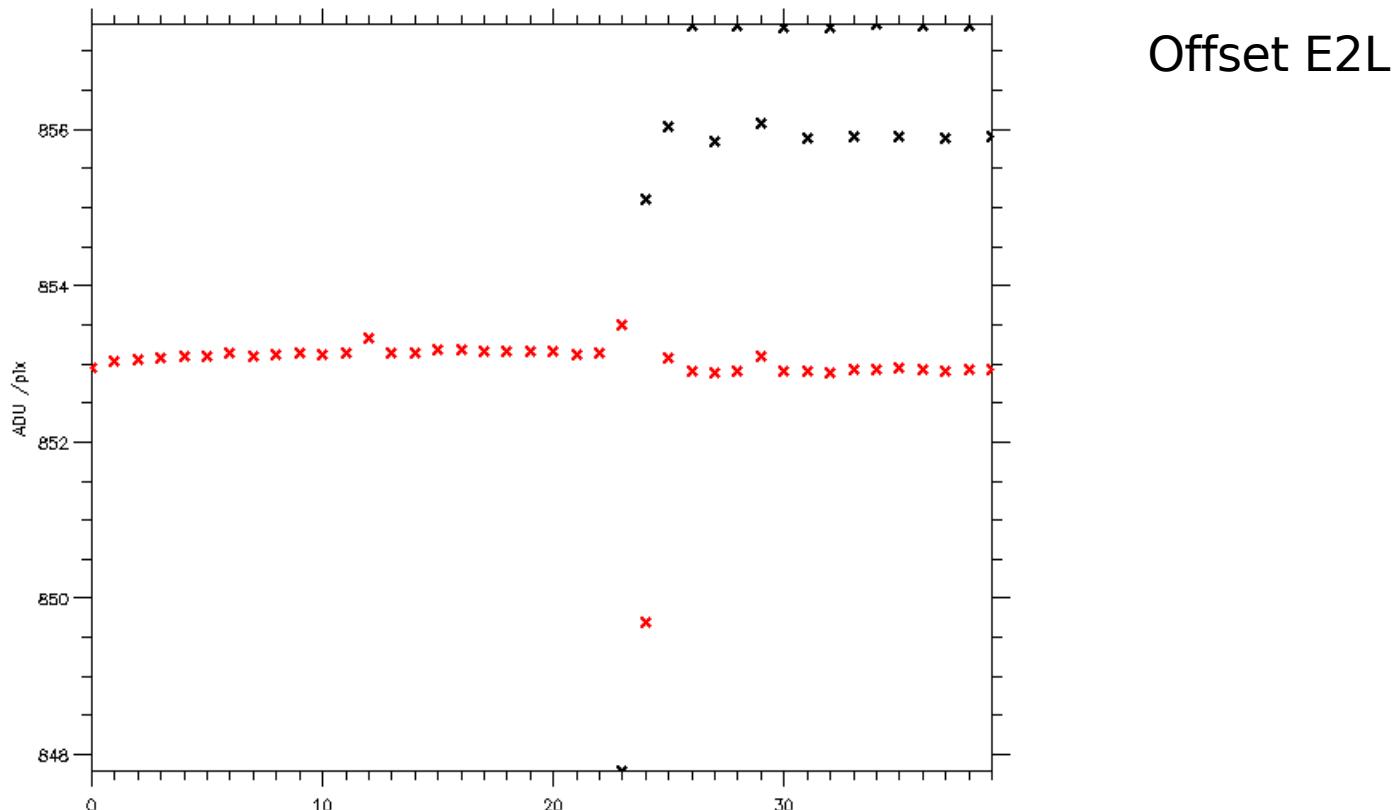


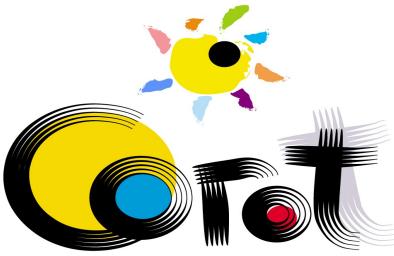
Residual (as seen on the prescan line) : more important on E2 (~10 adu)



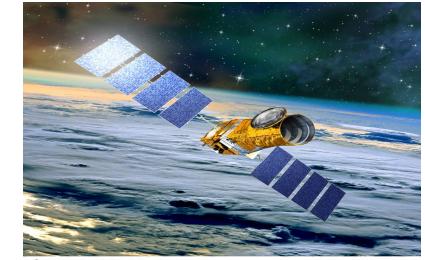


The Electromagnetic interferences (EMI)



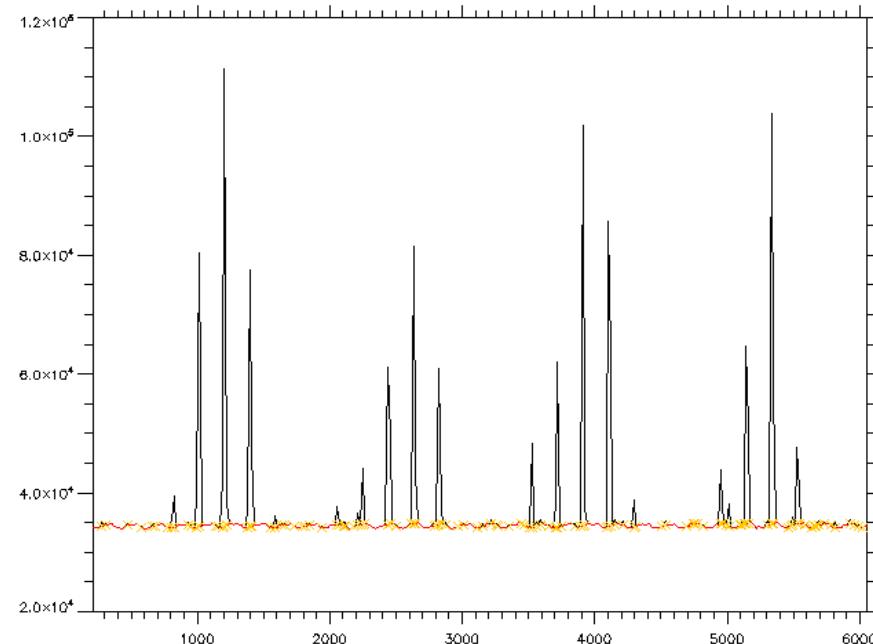
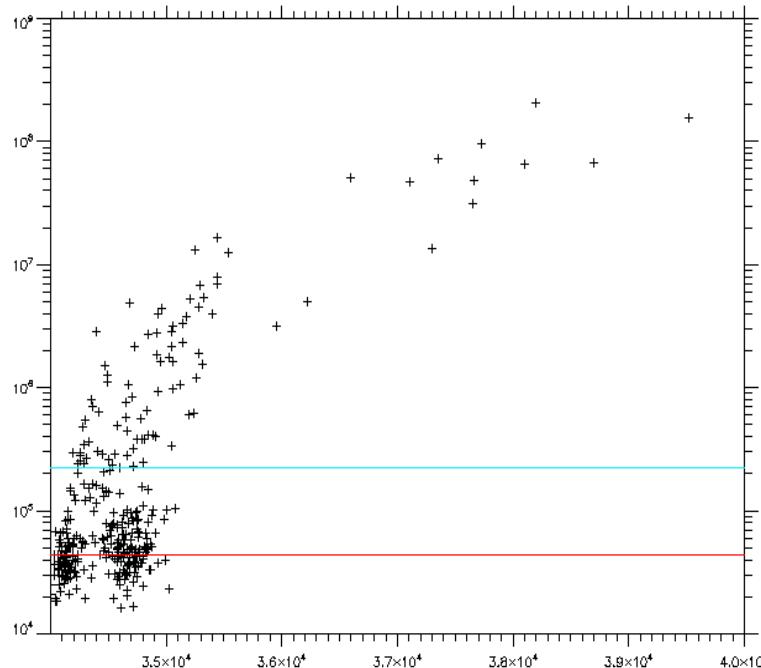


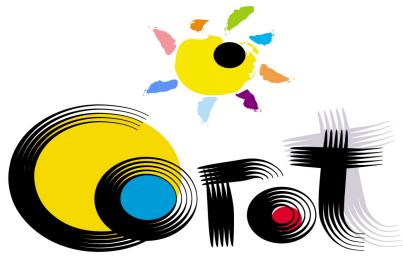
Correction of the outlier



Three methods :

- Correction based on the signal histogram
- Correction based on a running box
- Correction using the variance computed on board (for averaged light-curve : 512s sampling) : to be implemented in the pipelines





Correction of the integration time variations

