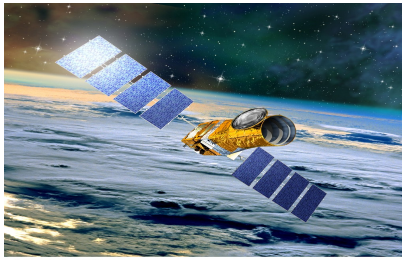
The N0-N1 pipeline



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

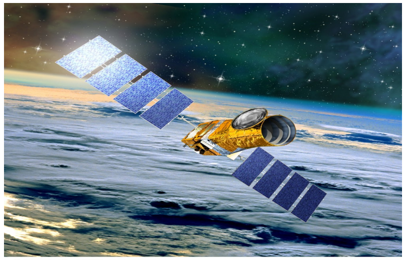
(“N1” =”Niveau 1” = Level 1)

Supplier for :

- The alarm mode (for exo-planets search)
- Evaluation of the performances (M. Auvergne)
- The N1-N2 pipeline (see Baudin's talk)
- 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....

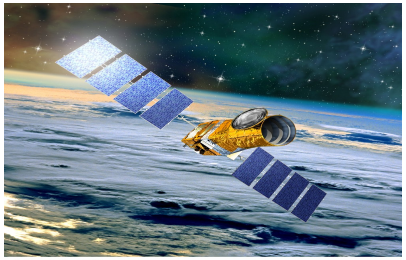
$$F_e = JCF \ x \ TCF \ x \left(gain \ x \left(F_{ADU} - offset \right) - BG_e \right)$$

$$BG_e = gain \ x \left(BG_{ADU} - offset \right)$$

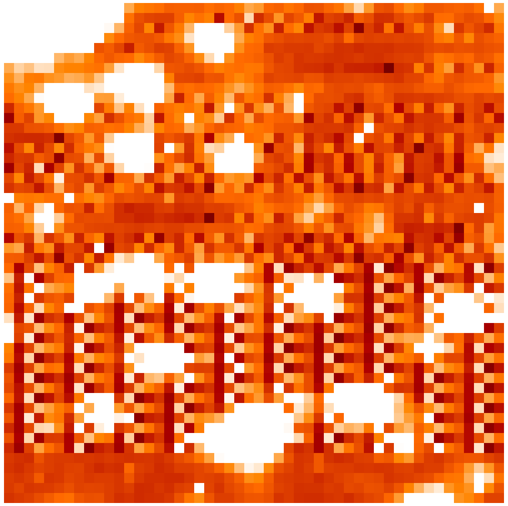
... but some important issues:

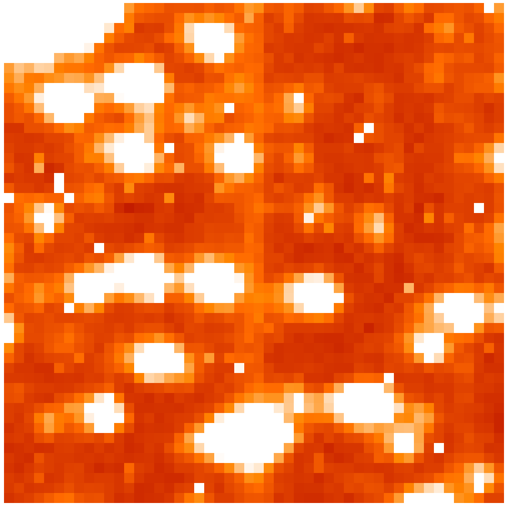
- Electro-Magnetic Interferences (EMI)
- Background to use ?
- Integration time variations
- Jitter noise
- Correction of the outliers (eg. cosmics rays)
- *Hot pixels*
- Long term variations

The Electromagnetic interferences (EMI)



Before correction

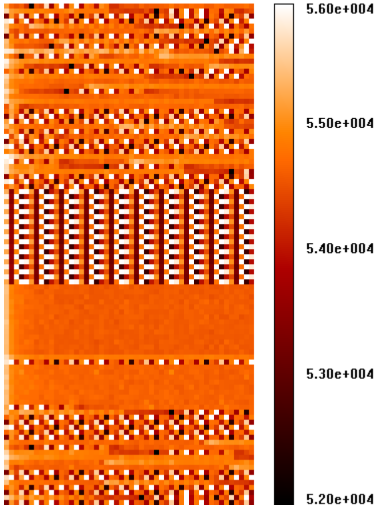


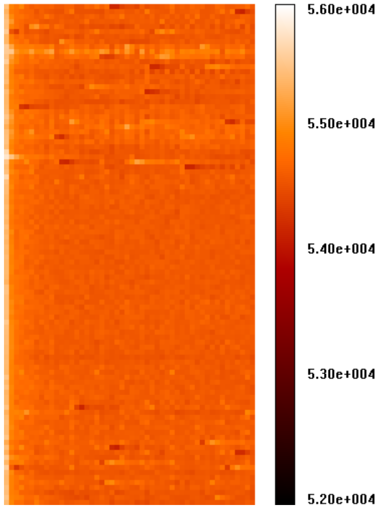


After correction

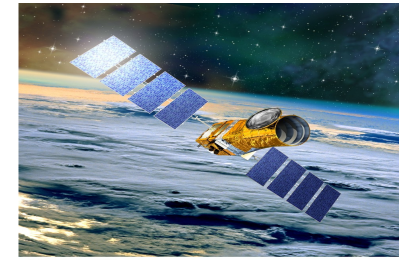
EMI pattern modelled by V. Lapeyrere (LESIA)

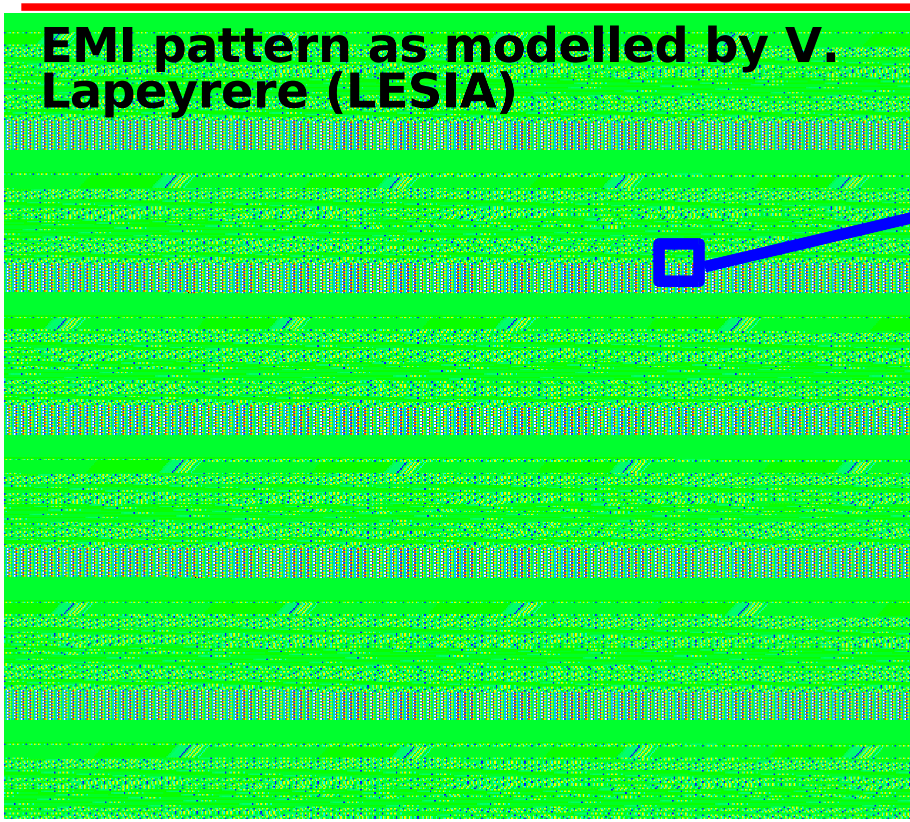
Residual (as seen on the prescan line) : more important on E2 (~10 adu)

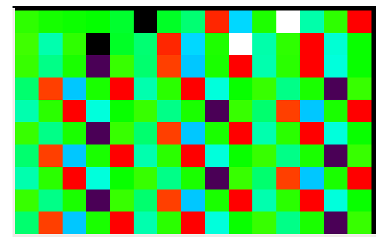




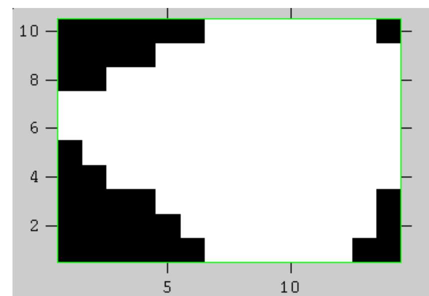
The Electromagnetic interferences (EMI)







*



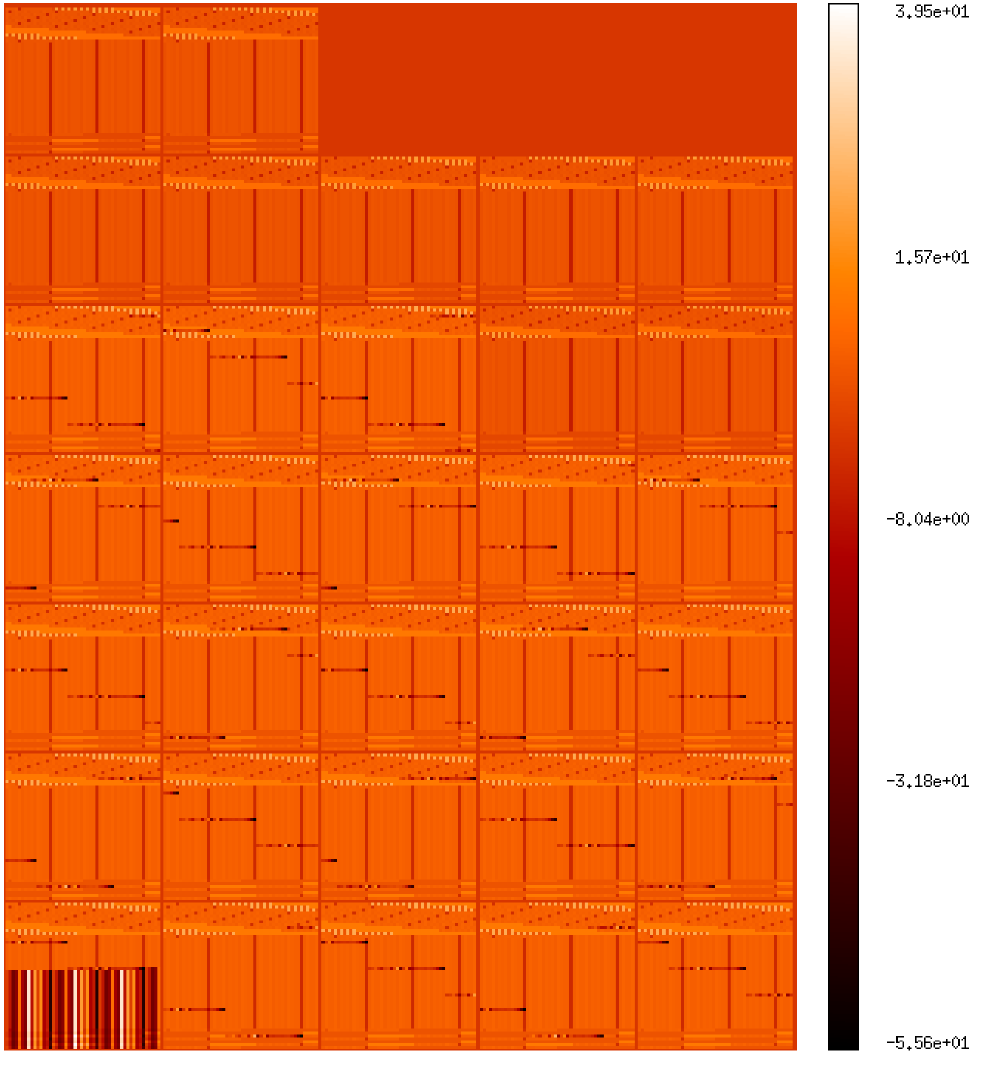
template

Integration over the template: offset applied on the LC

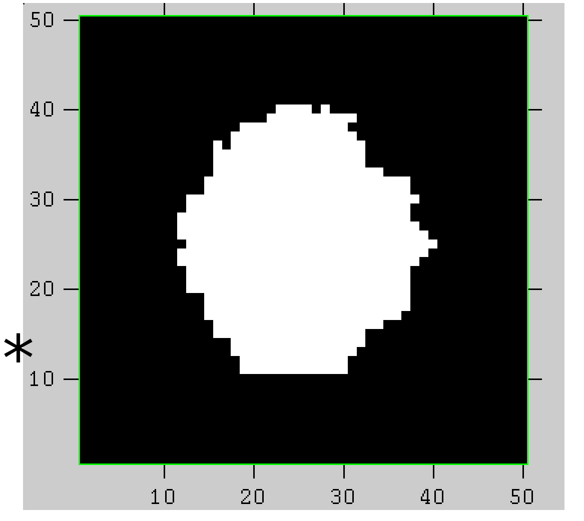
For monochromatic LC : 1 offset value

For chromatic LC : 3 offset values : Red Green Blue

The Electromagnetic interferences (EMI)



32 EMI patterns (V. Lapeyrere)

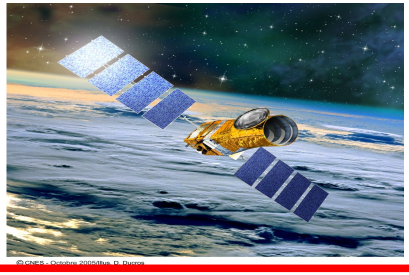


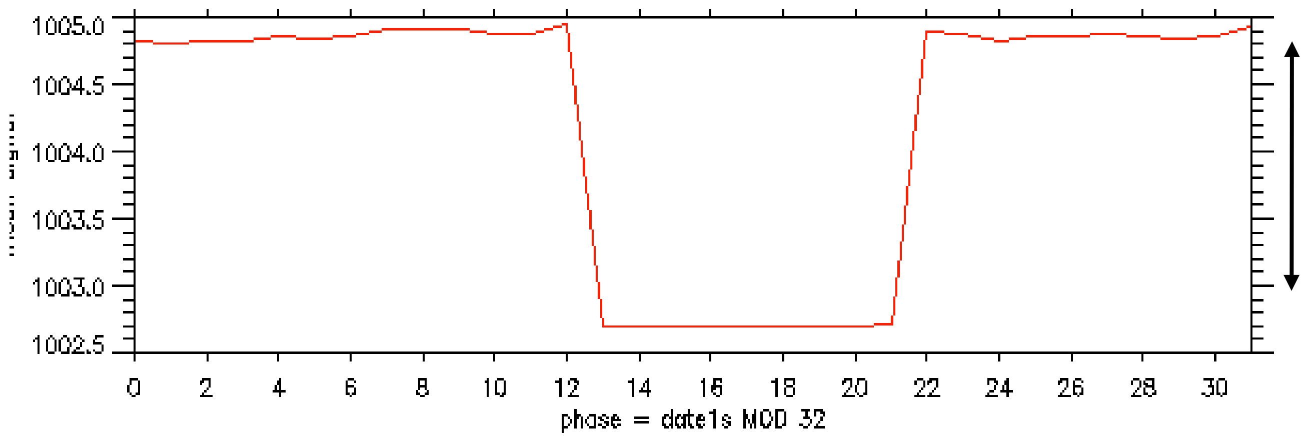
Integration over the mask:

offset applied on the LC,

we then derive 32 offset values

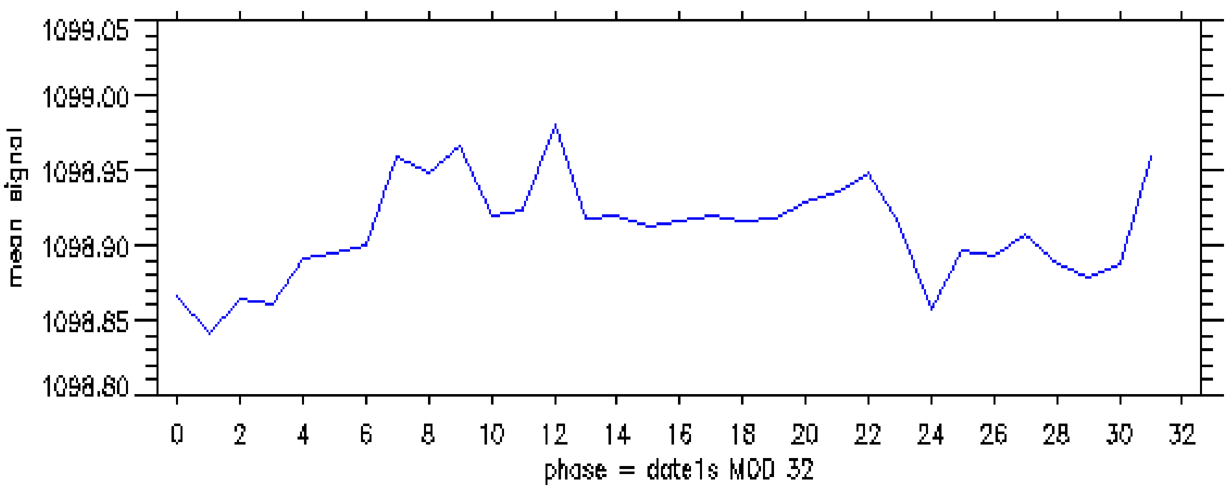
EMI corr. : Offset of the electronic (astero channel)





2.5 ADU

(1 ADU = 2 electrons)



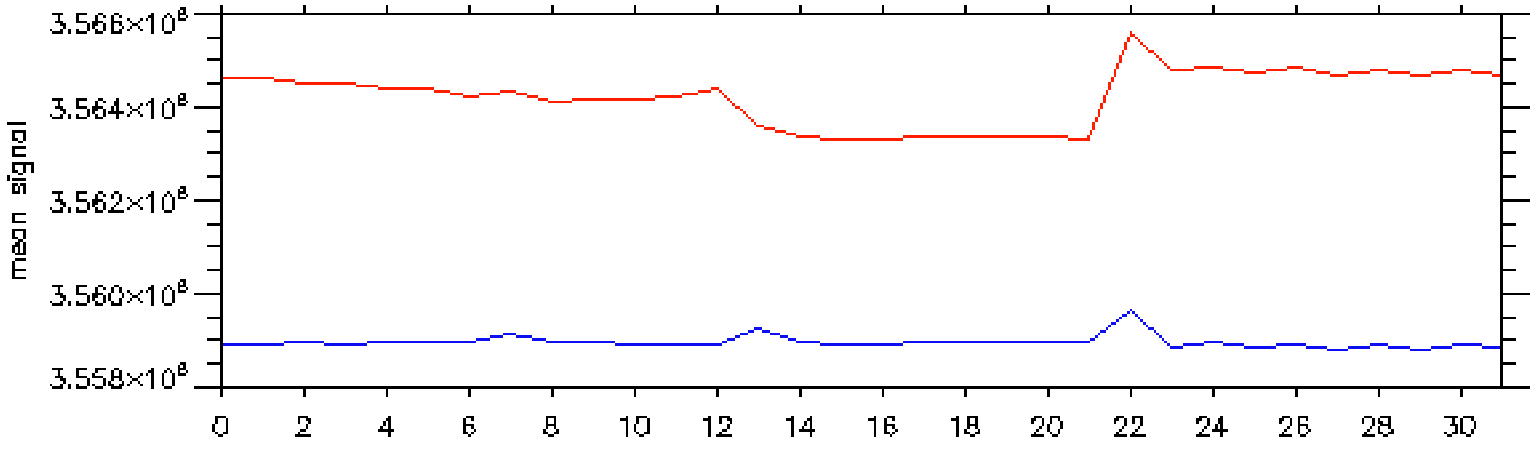
residual: < 0.1 ADU

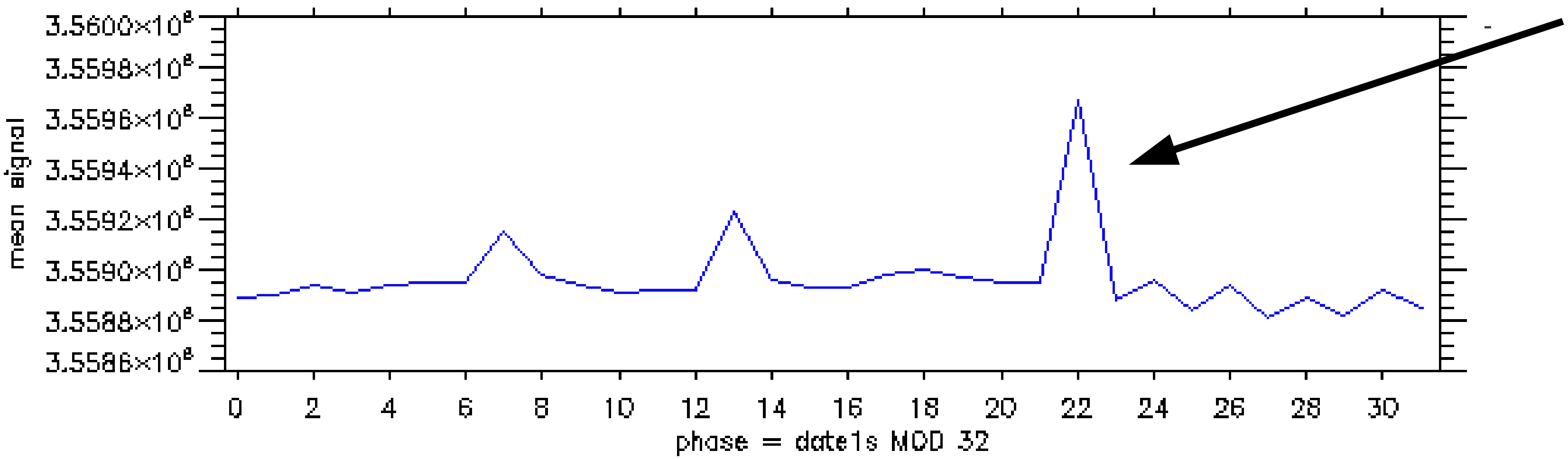
averaged value changed by ~ 5 ADU

long term variations of the residual : ~ 0.01 ADU

variations with time of the EMI are NOT taken into account

EMI correction : on a star LC (astero channel)





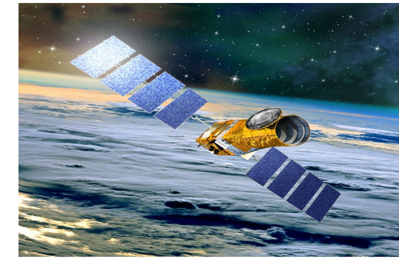
~ 800 ADU

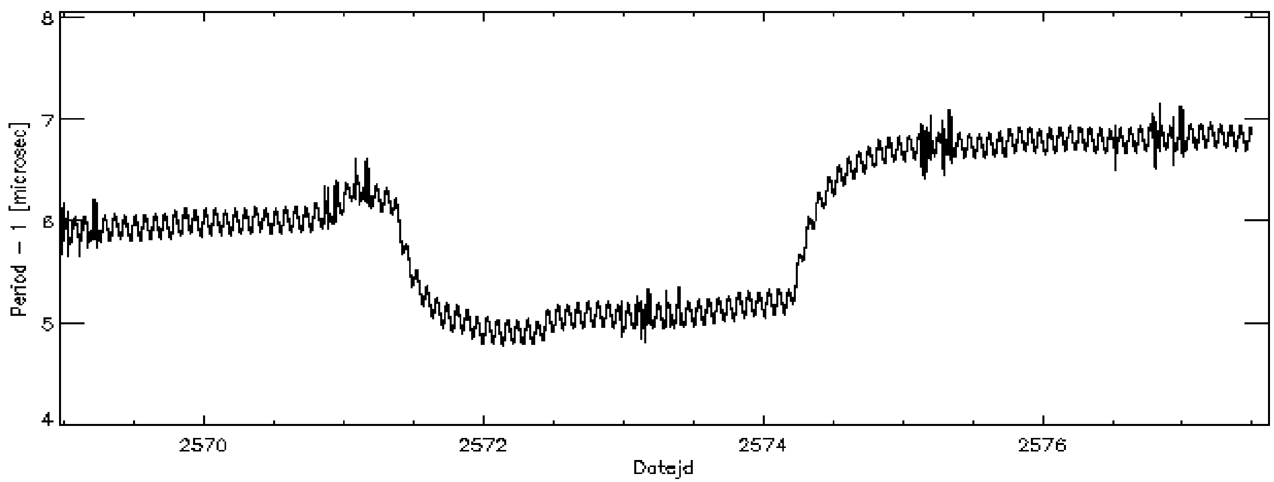
~ 10 ADU/pix

due to the onboard clock

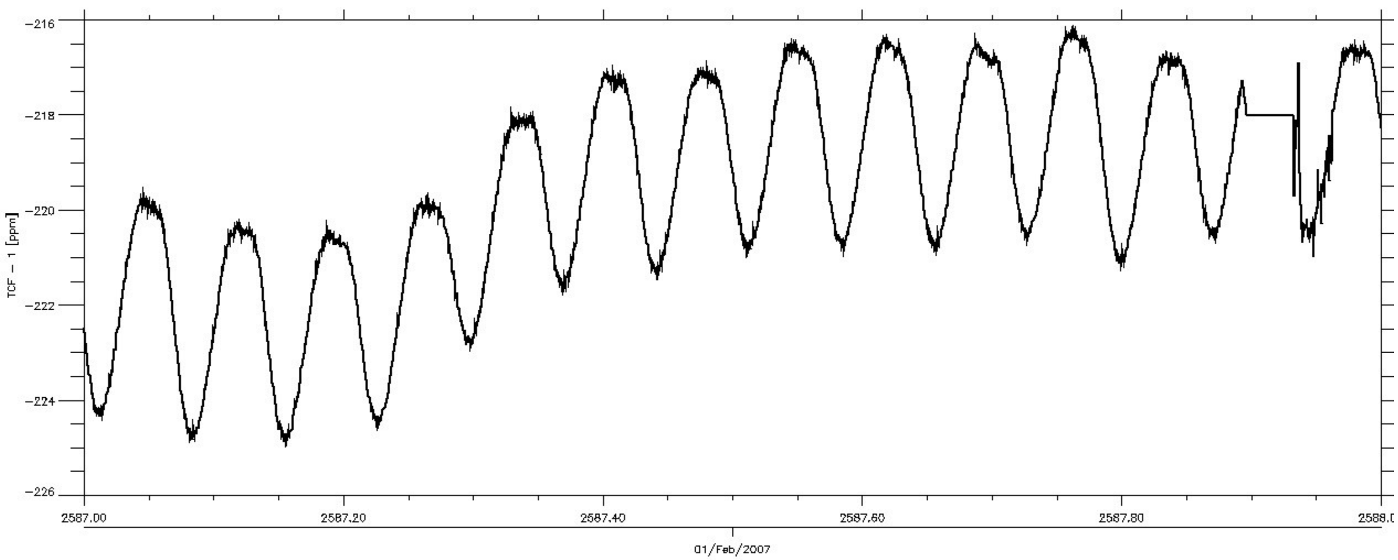
(CoID=20 , mv=5.77, Tobs =9 days)

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)



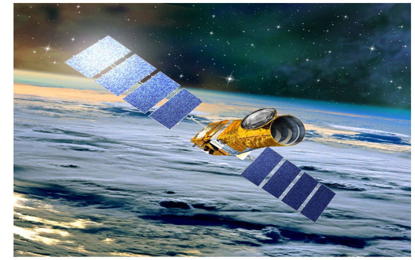
Low temperature coefficient (~0.5 ppm/K).

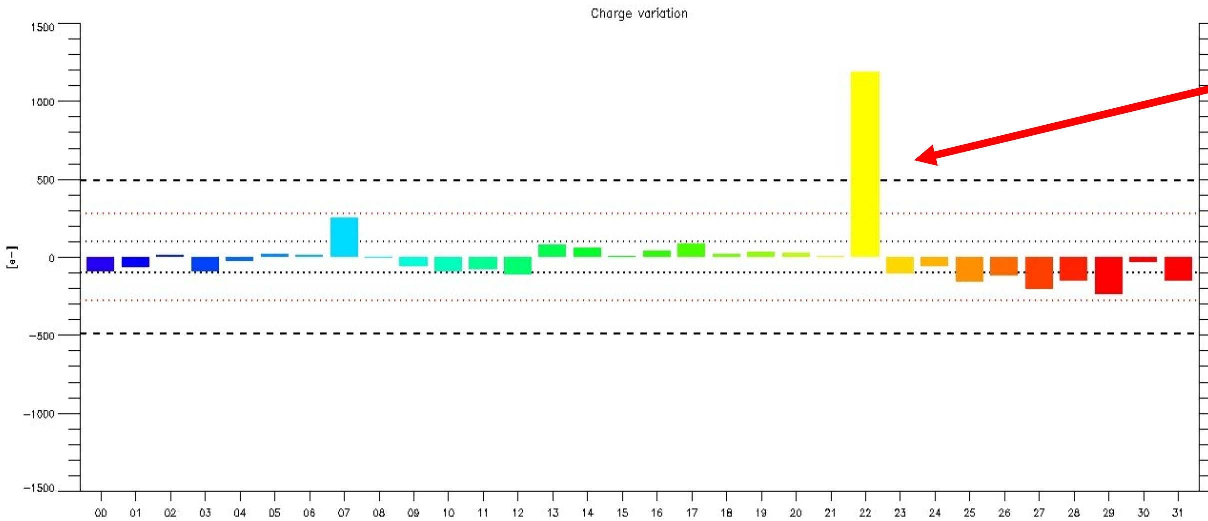
Orbital variations: 0.2 μs

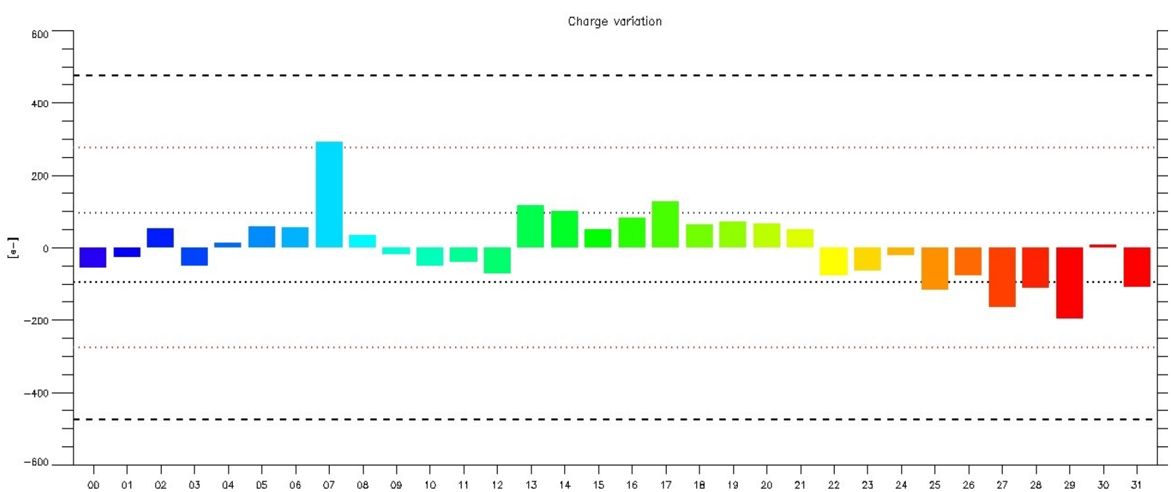
Systematic diff. : 5 – 7 μs

High freq. noise: ~ 20 ns (rms)

Correction of the integration time variations





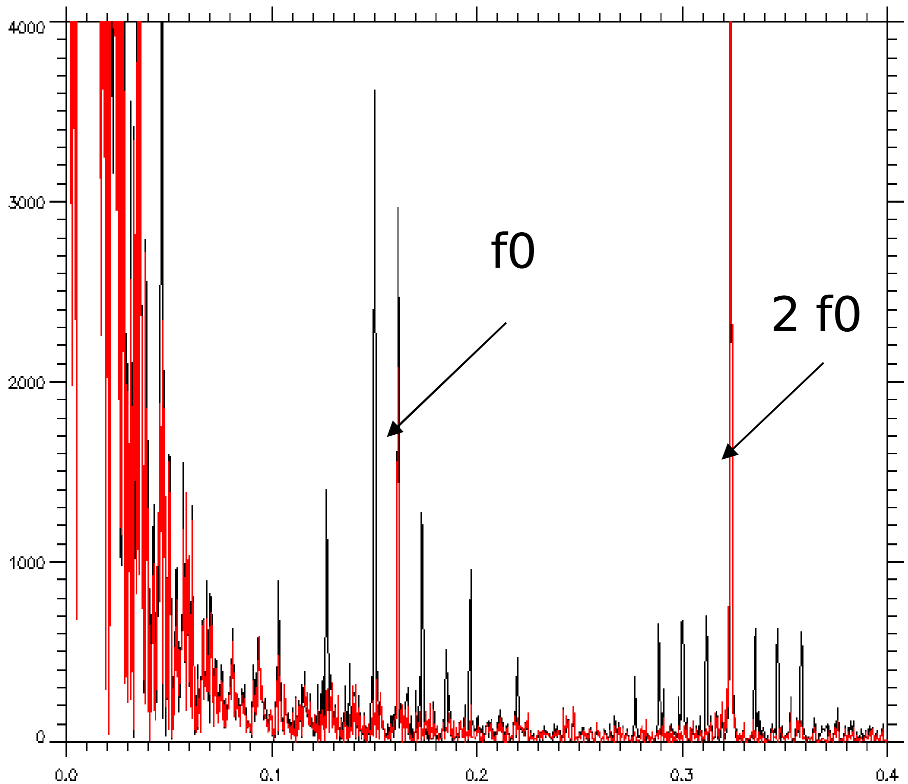


Exposure controlled by the OBT
variations of ~ 220 ppm (200 μs)

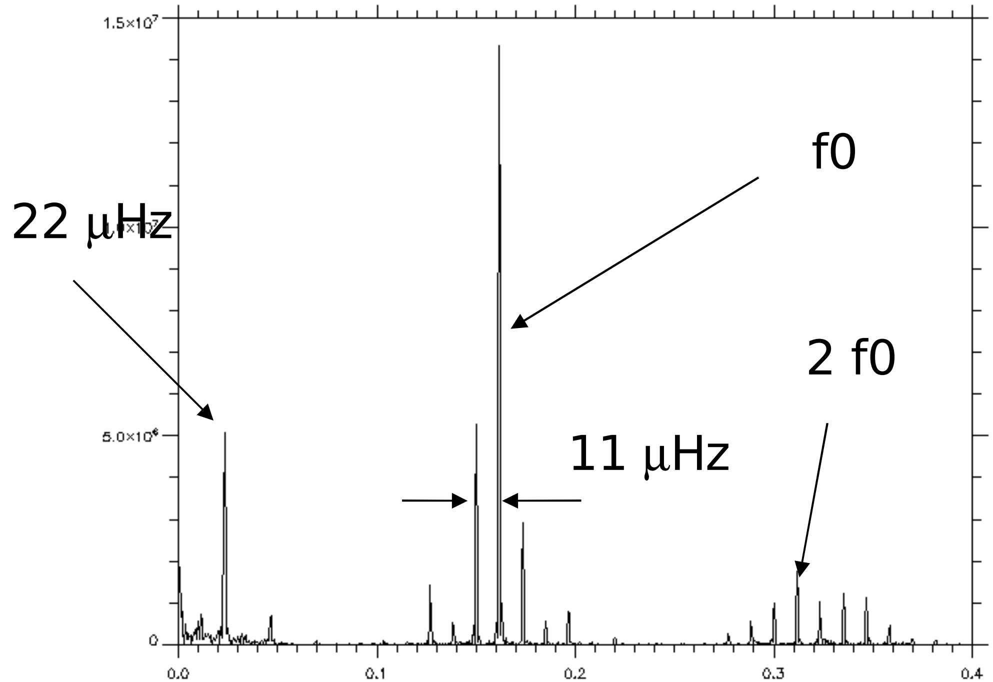
Time Correction Factor:

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

Background correction (BG)
Astero Channel

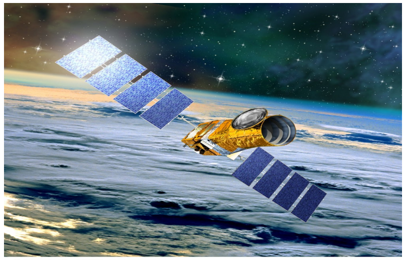


Star (CoID 83, mv=9.4), Fourier Spectrum : before (black) and after (red) the background corr.



Spectrum of the associated background LC

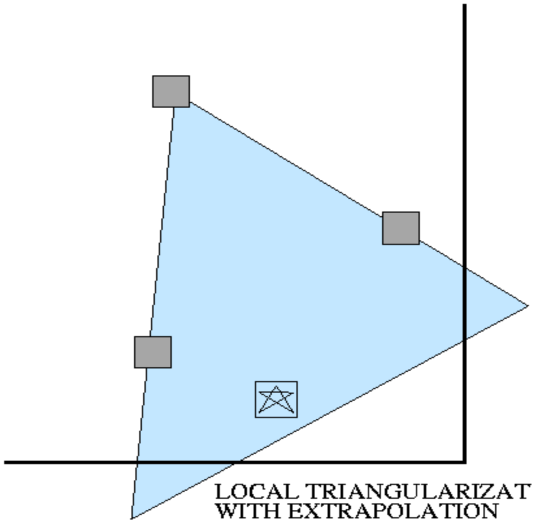
the BG perturbations are removed , but some small residuals may remain : take care!



Background correction (exo channel)

Three methods :

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



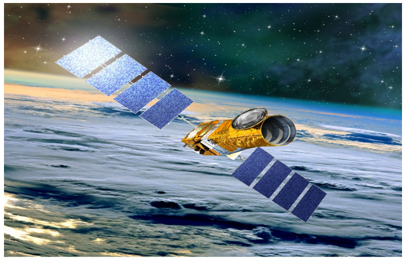
Problem addressed by Rachel Drummond (Leuven)

Gradient:

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

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

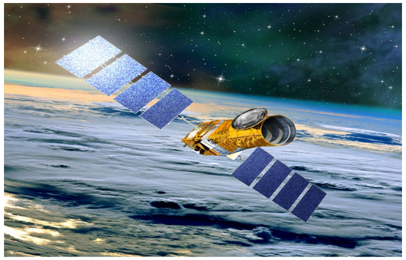
Range : 360 e- to 390 e-



Background correction conclusions (exo channel)

- Closest window : the simplest correction, can have a bad result when a hot pixel occurs in the BackGround (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

Correction of the jitter noise



Two steps :

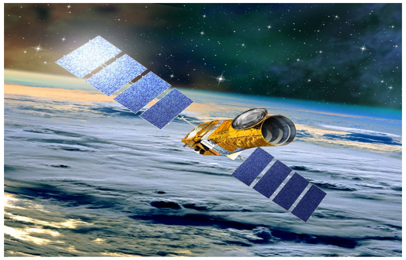
- Calculation of the star displacements
- Correction of the jitter noise

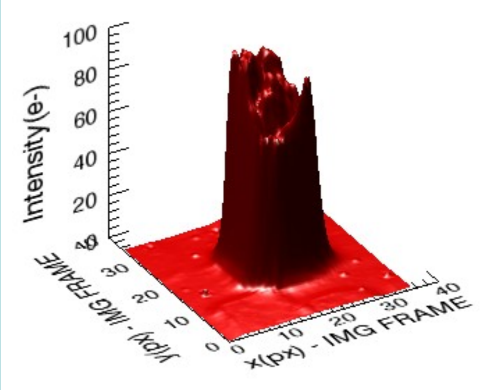
methods used :

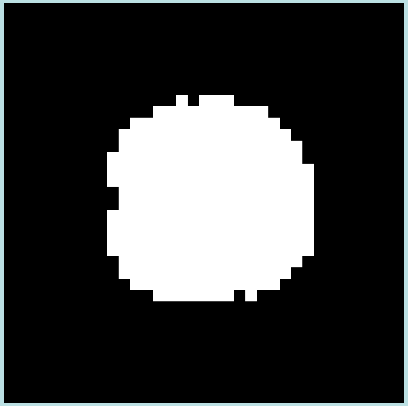
- Correction based on the star PSF (astero channel)
- Correction based on the star spectrum (exo channel) : correction of the jitter *noise induced by the color frontiers (method proposed by M. Ollivier)*

Conception, development and validation by Fabio Fialho (LESIA)

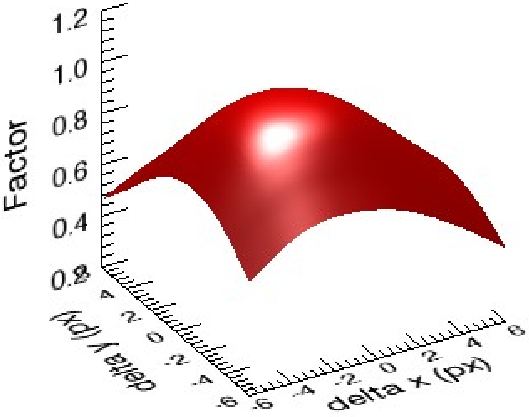
Correction of the jitter noise (astero channel)



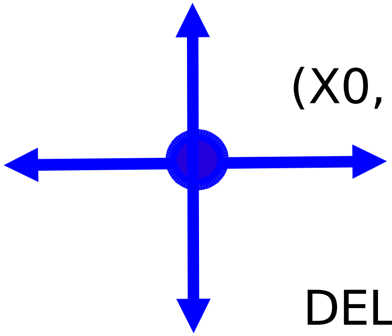




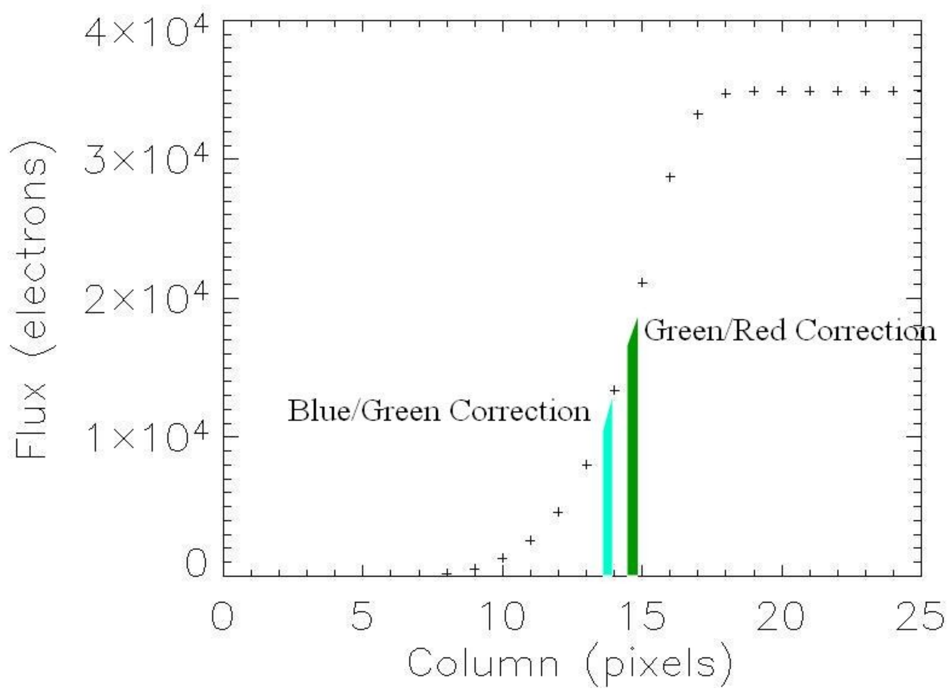
PSF with a sub-pixel resolution (1/4 px)
(method by Leonardo Pinheiro)



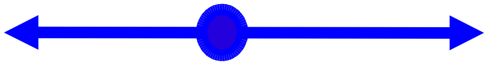
Surface for the jitter correction
(method by F. Fialho)



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



DELTA_X



(X0, Y0)

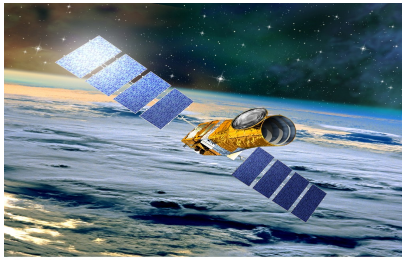
JCFR, JCFG, JCFB : jitter correction factors

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. Jorda, OAMP) ⇒ X0 and Y0 the star set point position

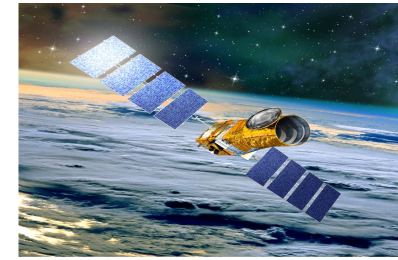
- Using the 10 targets + FoVM ⇒ variation of the satellite Line of Sight with respect to time ⇒ 3 angles: ΔTheta(t) , ΔPsi (t) , ΔPhi (t)

- Linearisation of the FoVM at X0, Y0 + variation of the satellite Line of Sight (ΔTheta(t) , ΔPsi (t) , ΔPhi (t)) :

⇒ DELTA_X (t) and DELTA_Y (t) , the star displacements with respect to the star *set point position* and *time*

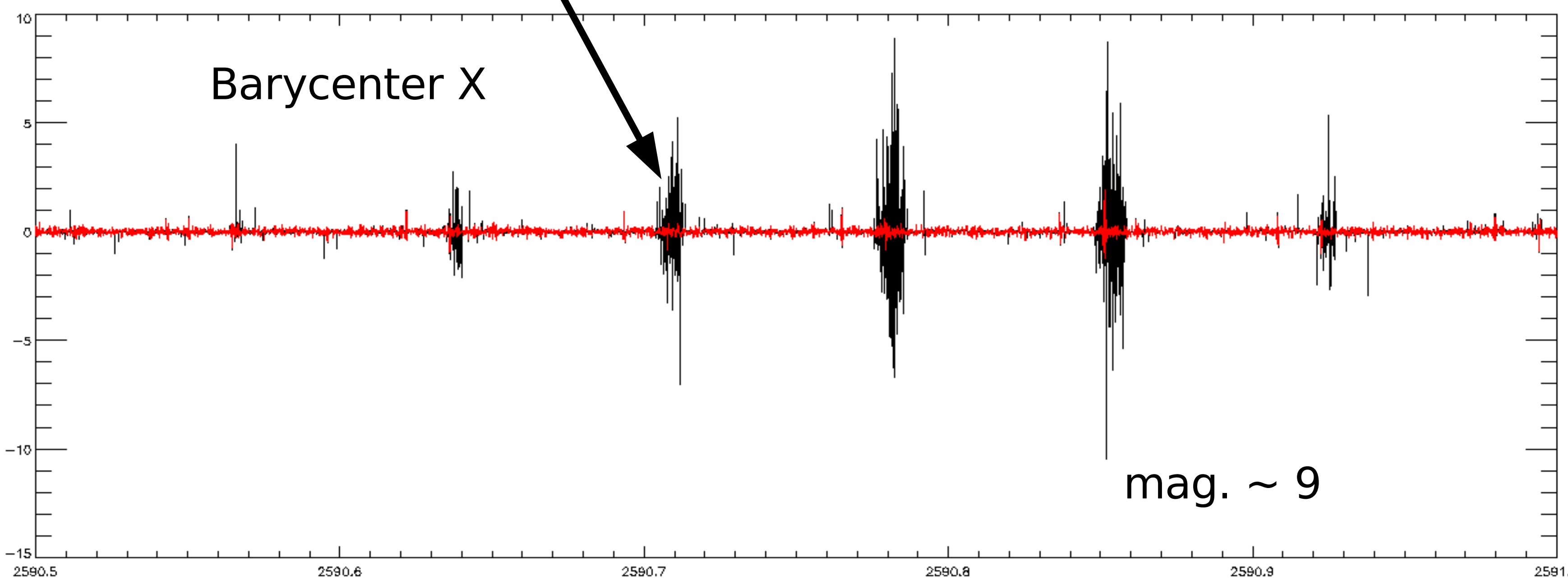
The star displacements

(astero channel)



On-board barycenter :
polluted by the SAA crossing
and by photon noise

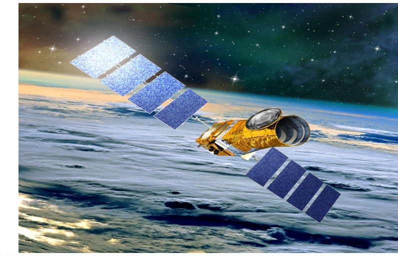
Reconstructed displacements: **DELTA_X**

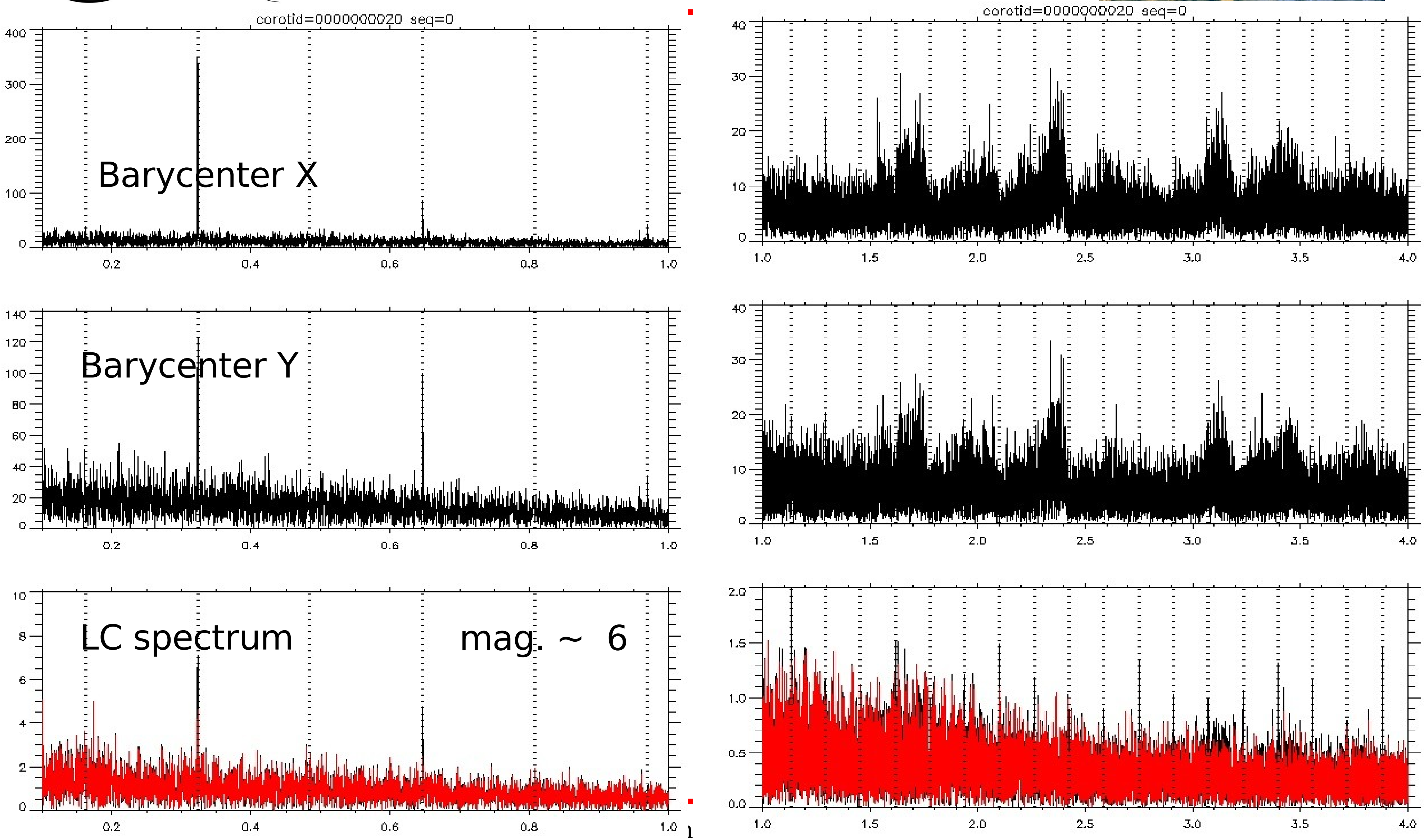


DELTA_X – BarycenterX ~ 0.28 pix (rms)   (1 pix = 2.3 arcsec)

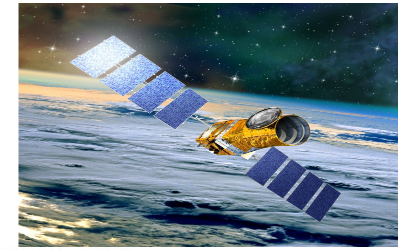
DELTA_Y – BarycenterY ~ 0.29 pix (rms)

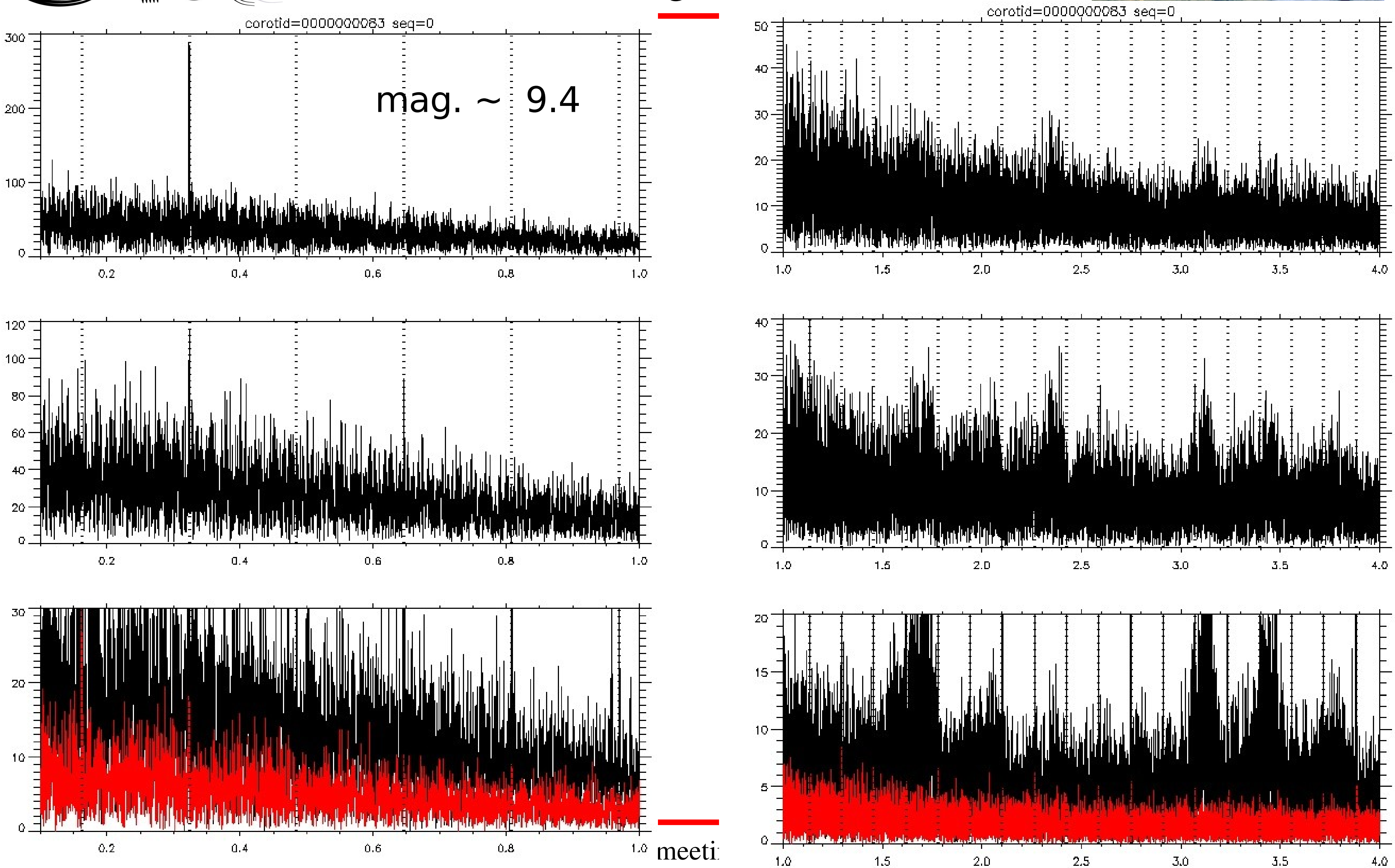
Correction of the jitter noise: results for a *bright* star and a *rough* mask





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

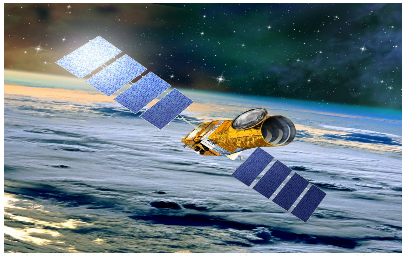


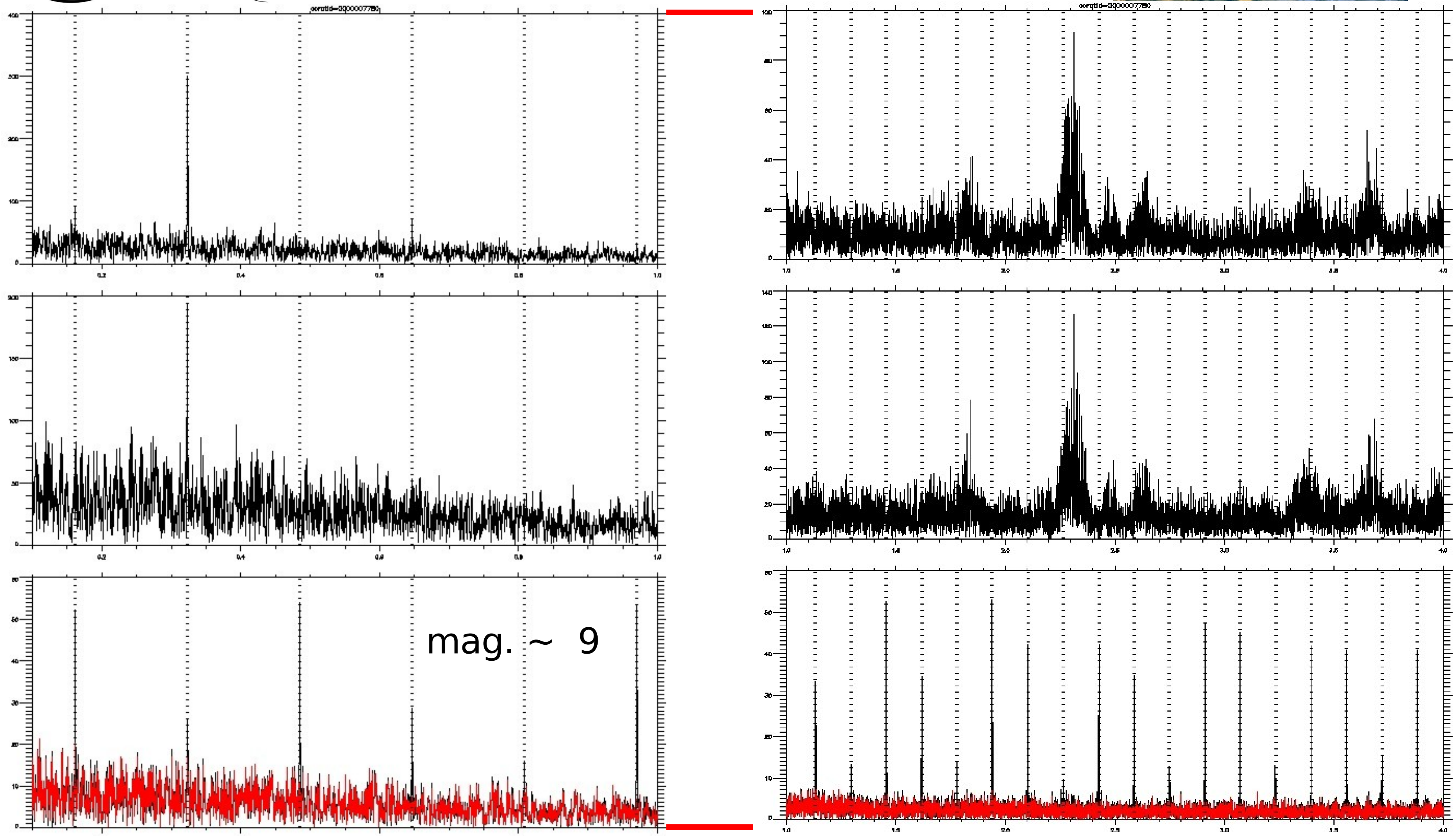


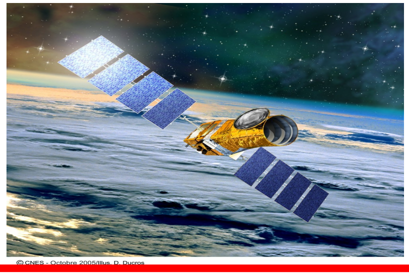
Correction of the jitter noise:

results for a *faint* star

and a *fine (optimal)* mask







Jitter correction, 32s LC (exo channel)

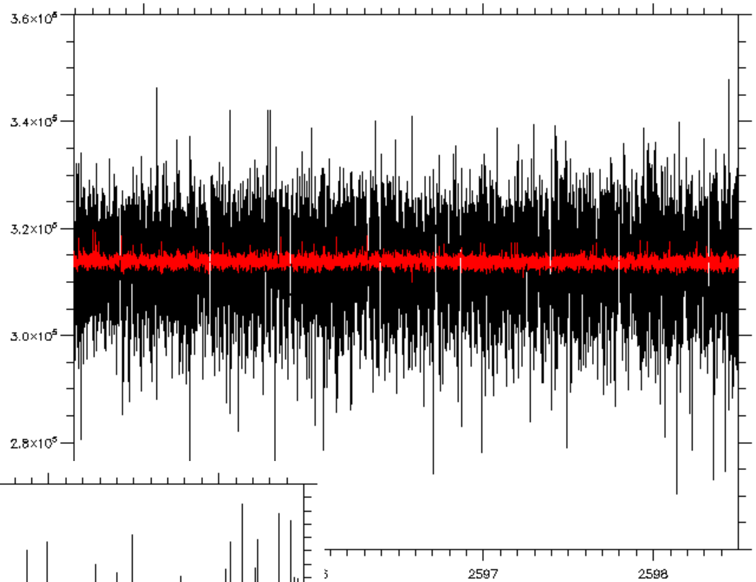
mv= 12.5

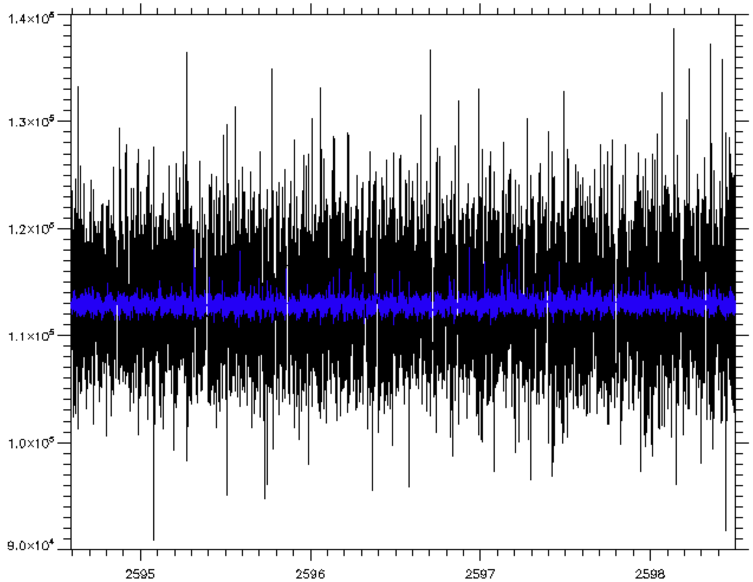
n = 4.9e5 e- /32s

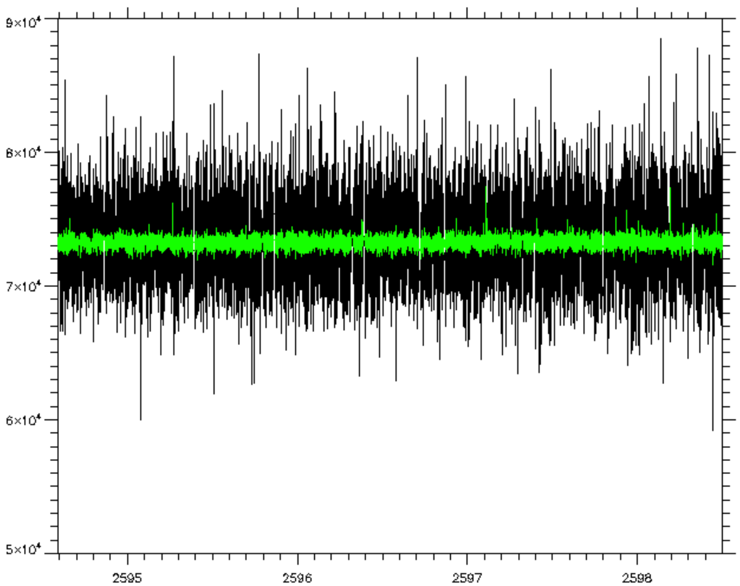
nR = 3.1e5

nG = 0.7e5

nB = 1.1e5







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

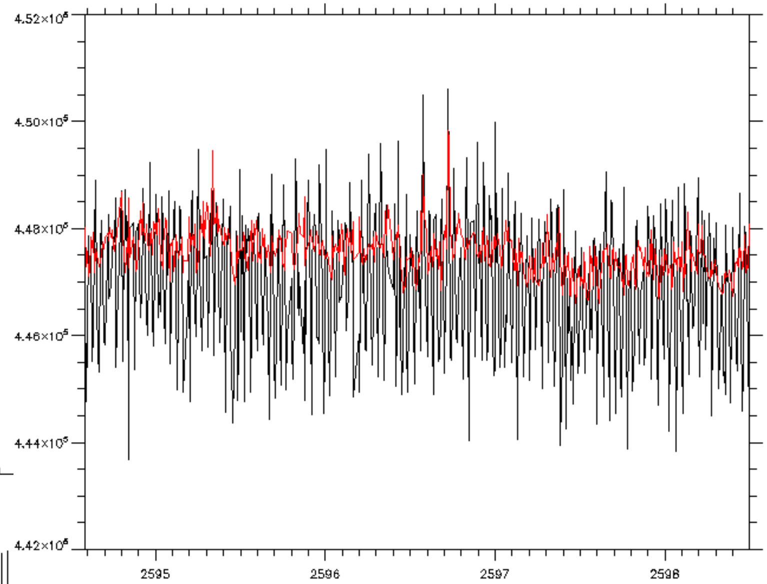
mv= 12.4

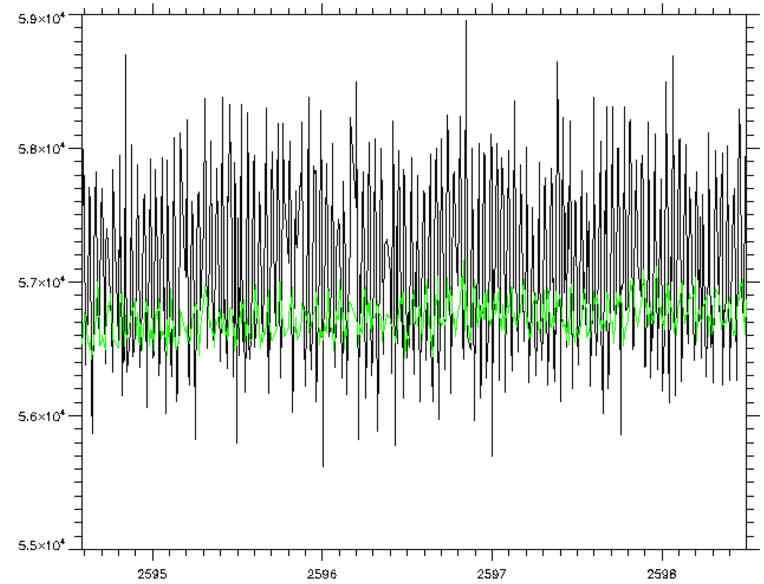
n = 5.6e5 e- /32s

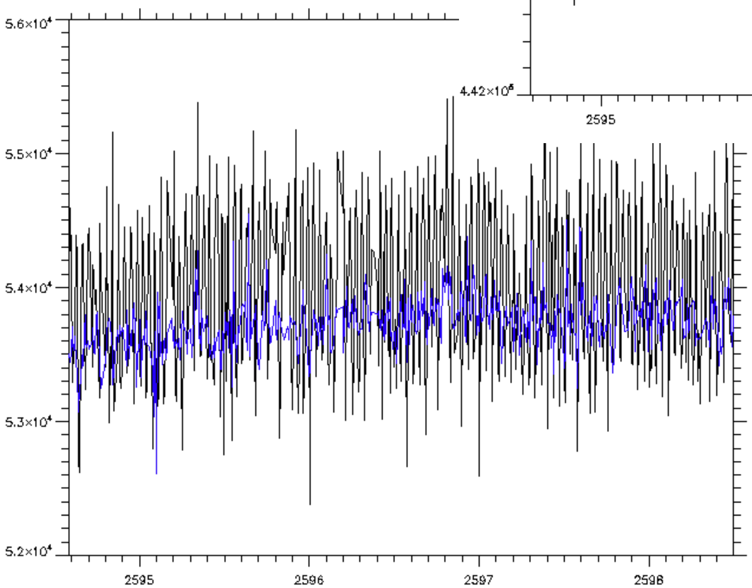
nR = 4.5e5

nG = 0.6e5

nB = 0.5e5



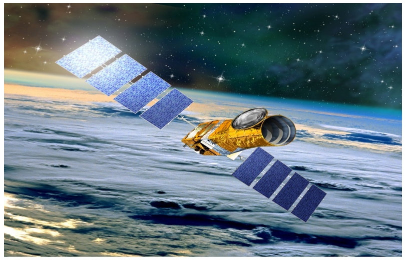




S/N	Red	Green	Blue	White
Before	360	90	90	1243
After	1110	430	270	1243
Gain	3,1	4,8	3	1
Theor.	2680	950	930	2990

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

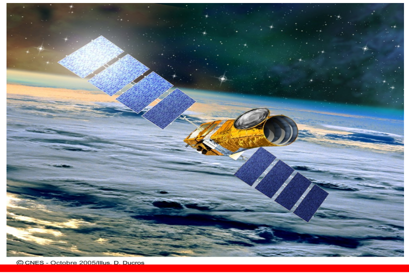
Important residual at 2 f0: probably due to the linearisation of the FoVM

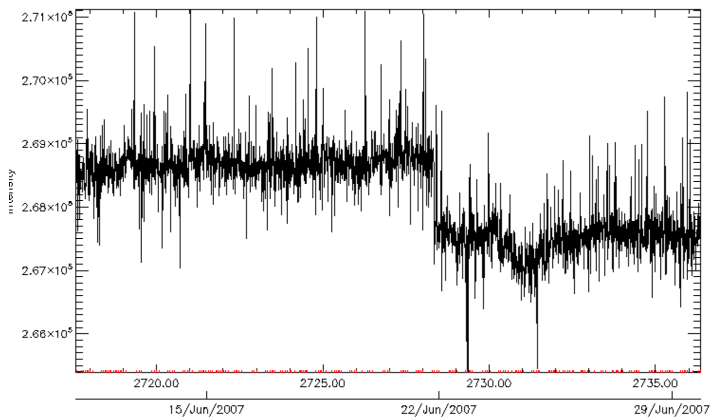
Astero channel

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

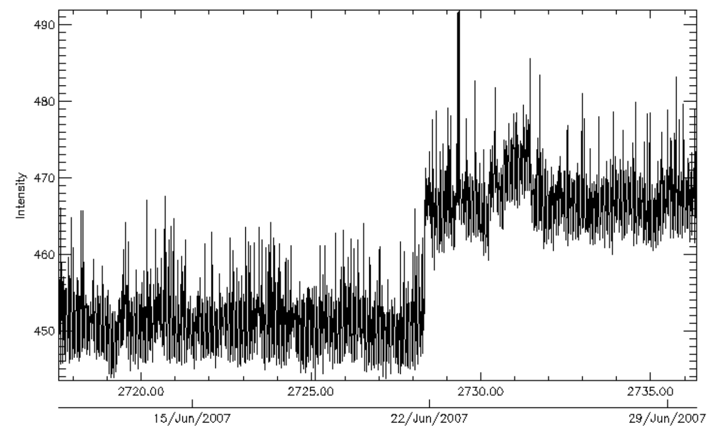
		Withe noise w.r.t. photon noise limit		
ID	mv	Mask	Before	After
7780	9	Rough	200,00%	14,00%
		Fine	19,00%	14,00%
7636	5,6	Rough	11,00%	8,00%

Hot pixels
... and their consequences

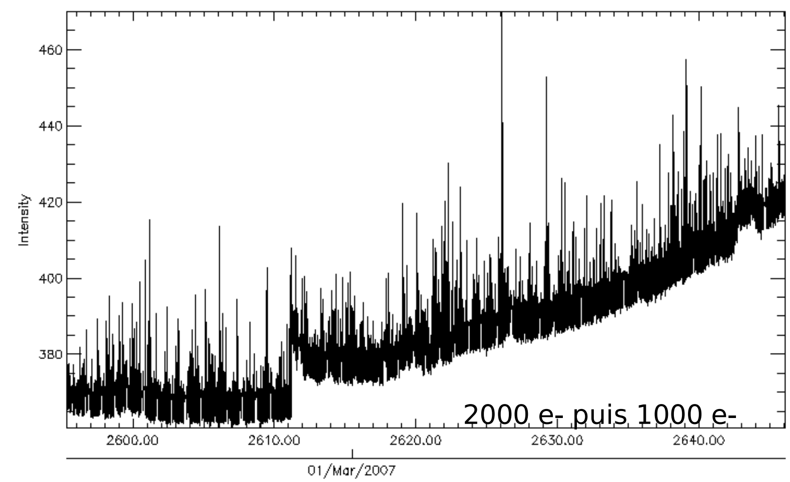




A star LC corrected from the BackGround (BG) using the closest BG window

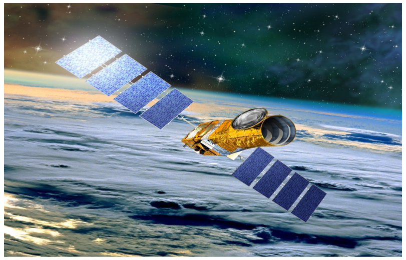


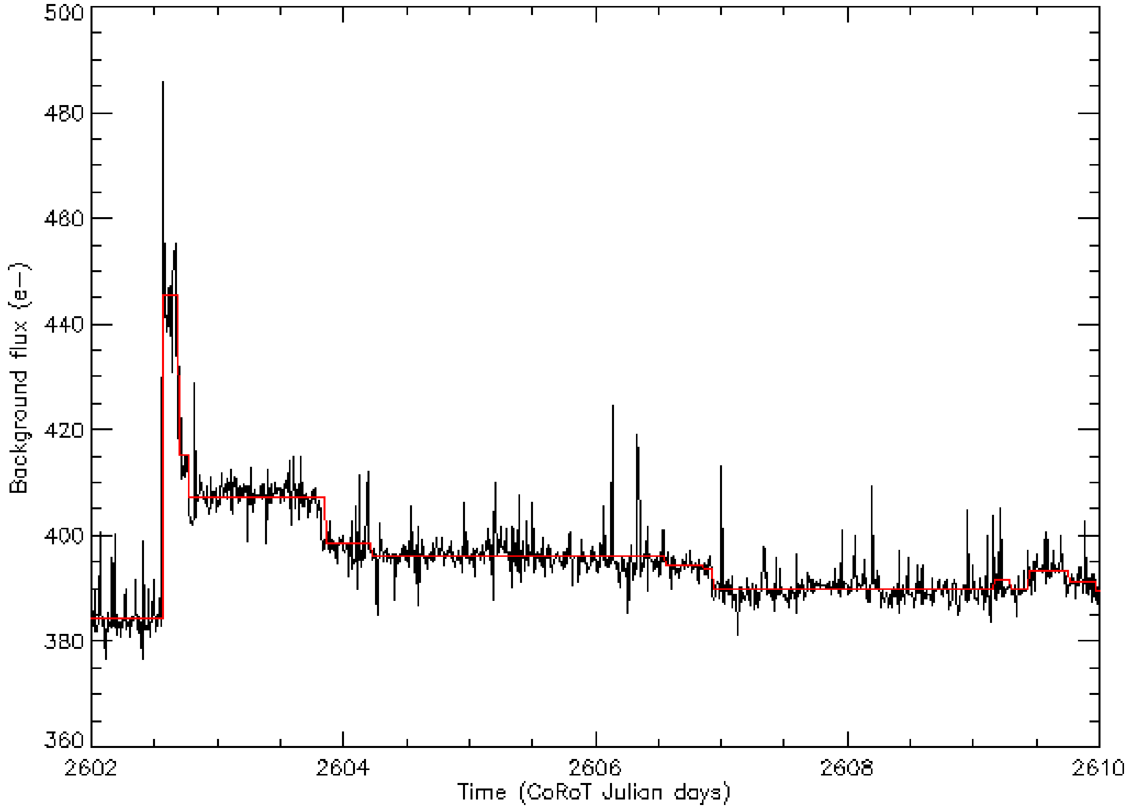
The BG LC used



Credit V. Lapeyrere

Hot pixels



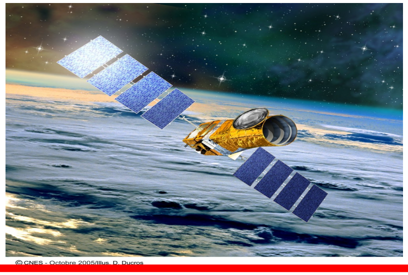


- Problem addressed by V. Lapeyrere
- Hot pixel relaxation : modelled and corrected using Scargle (1998)'s method (to be implemented in the pipeline)

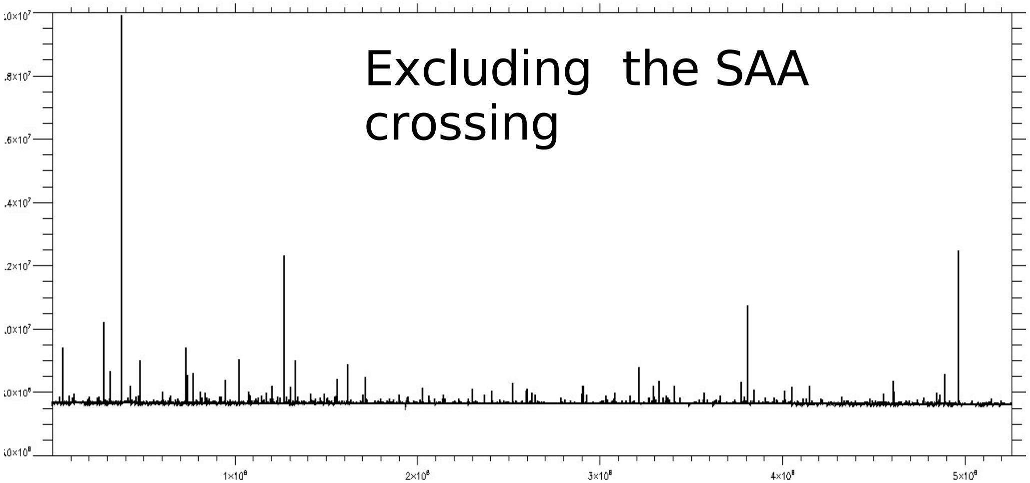
Exo Background window during 10 days

Credit V. Lapeyrere

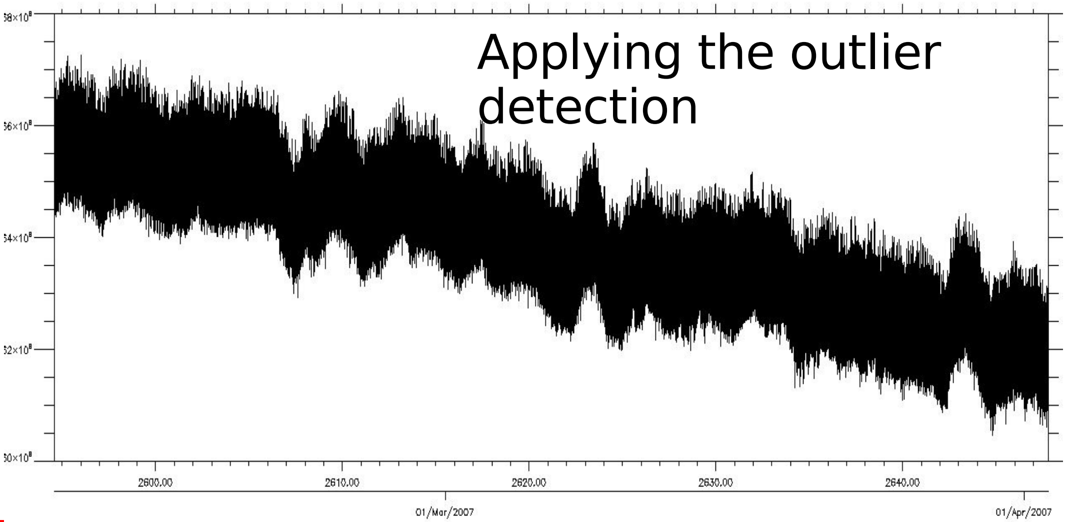
Detection of the outliers



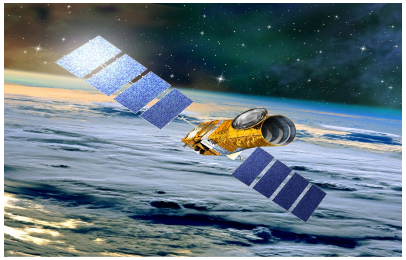
- Several methods implemented
- The SAA crossings are flagged

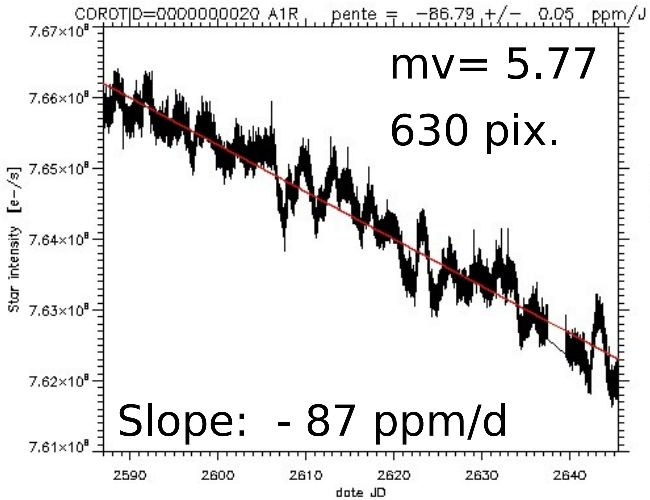


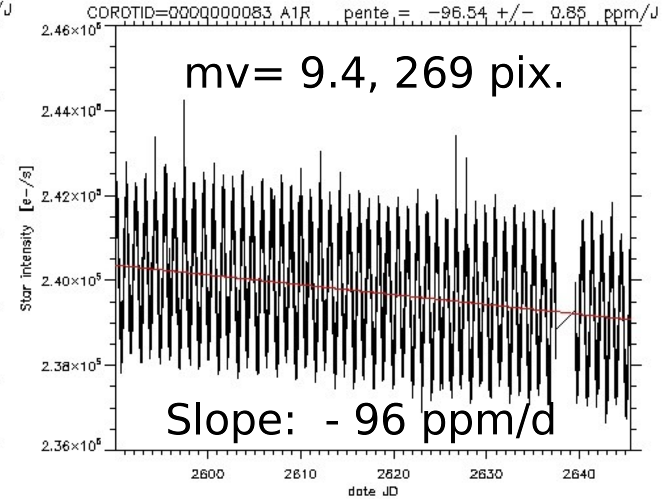
Duty-cycle (for the IR/astero) :
• ~ 90 % if we apply the outlier detection
• ~ 88 % if we exclude in addition the SAA crossings

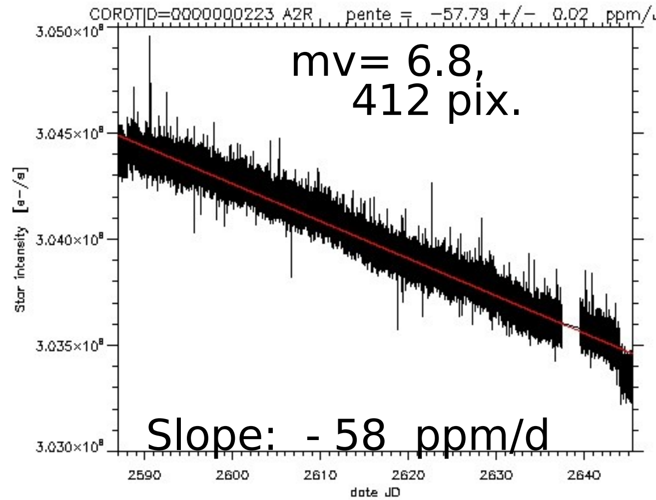


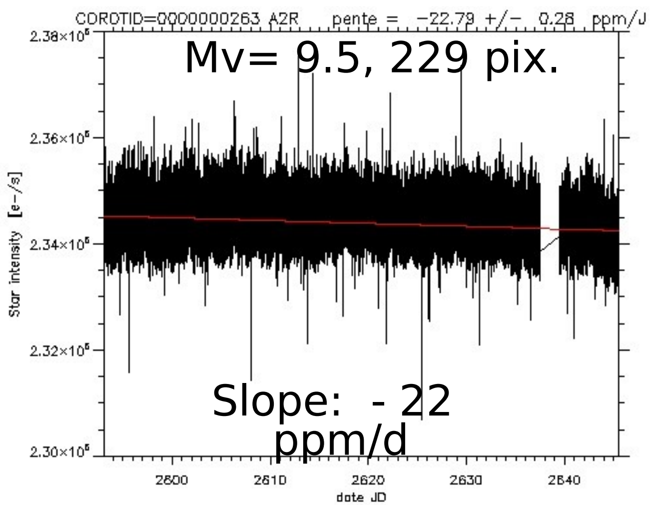
Long terms variations : Astero Star LC

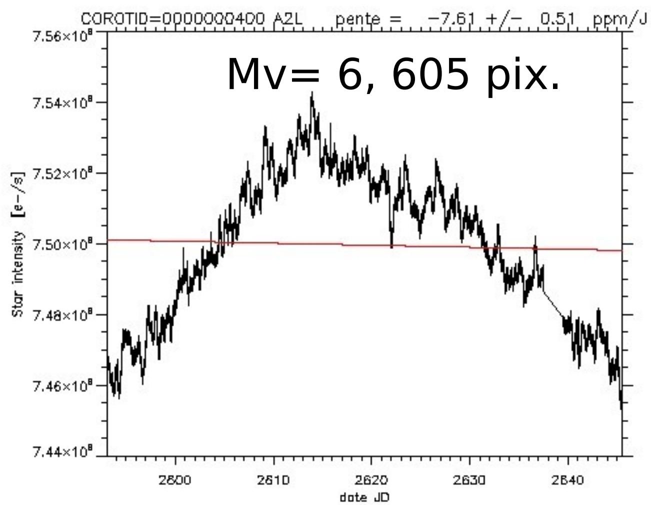








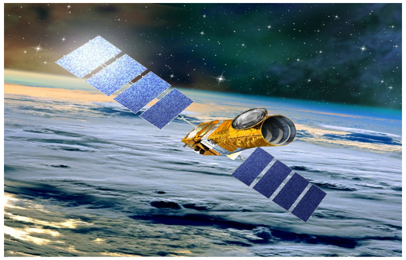




Different slopes : ~ -20 to ~ -100 ppm/days

Most of the stars (IR and LR) have a slope of ~ 50-100 ppm/days

Perspectives
(astero channel)



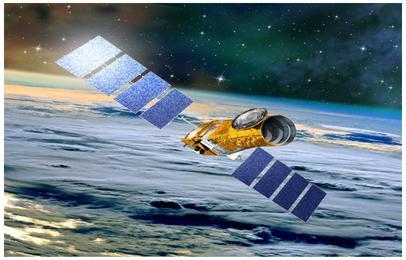
Current status:

- The astero 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:

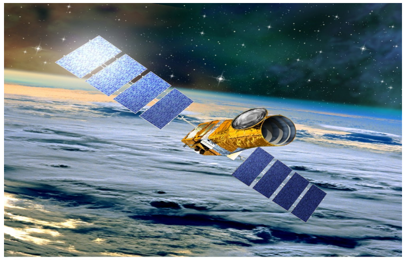
- The current exo pipeline (V 0.2) is being improved ;

Short term perspectives (for the first validated release)

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

Long term perspectives:

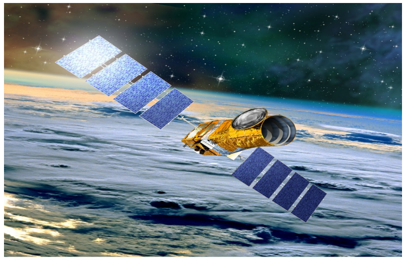
- **Improving the speed performance**s
- **Decreasing the orbital residuals due to the jitter**
- **Detection of the hot pixels in the star LC and suppression (?)**
- Correction of the long term variations
- Improving the automation of the pipeline



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



N0 data | Pipeline | N1 data

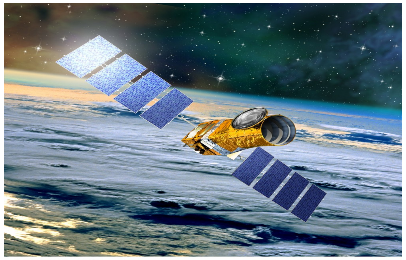
Auxiliary data (N0)
- Housekeeping (temperature, voltage)
- Offset
- Background Light-Curves
- GPS tops

Auxiliary data (N1)
- House Keeping
- Offset
- Background Light Curves
- Sky Background Model
- Line of Sight
- Clock variations

Science data (N0):
- Stellar Light Curves
- “Imagettes”

Science data (N1):
- Stellar Light-Curves
- “Imagettes”

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



Goal: to have available a set of tools for:

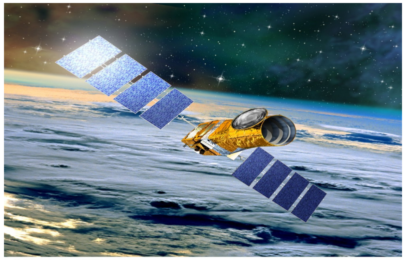
- **Visualization** (1D and 2D)
- **Diagnostics** and **characterization** of the N0, N1, and N2 data
- **Evaluation** of the correction performance
- **Help** for the **development** of new correction strategies

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

Magniture ~ 15



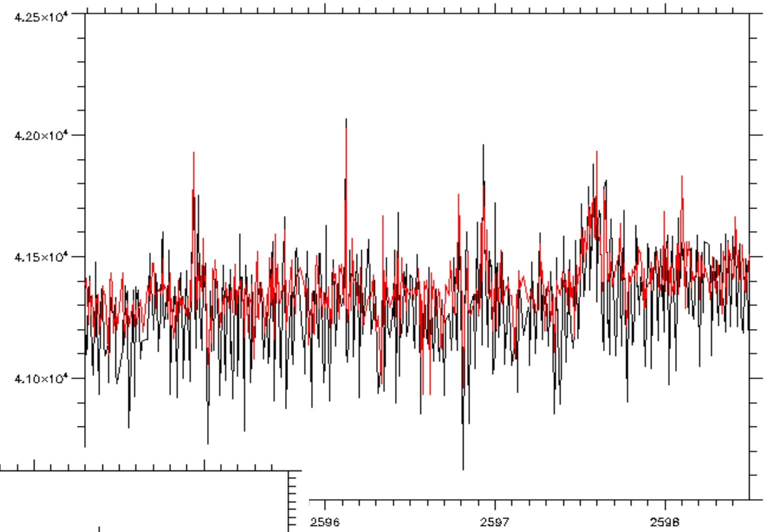
mv= 14.7

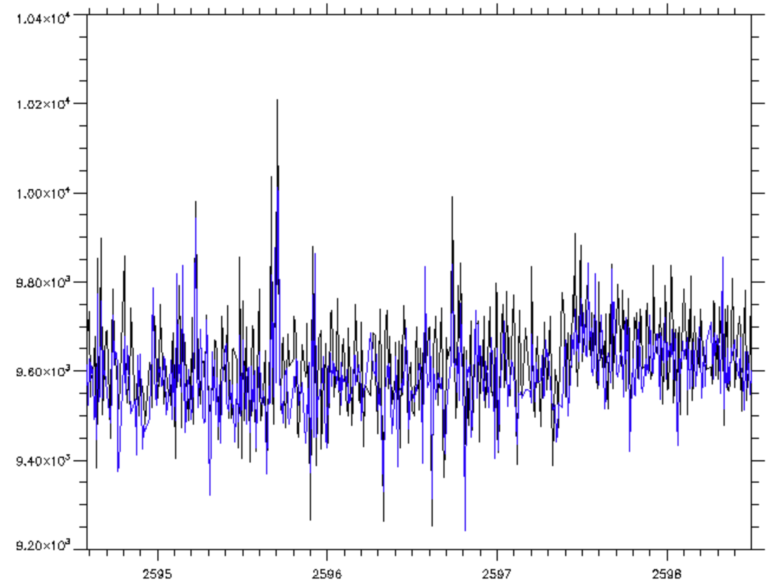
n= 5.8e4 e-/32s

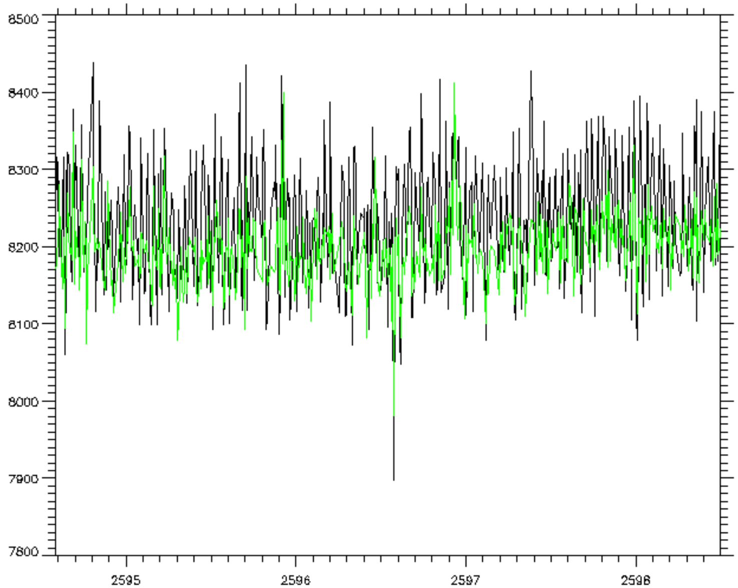
nR = 4.1e4

nG = 0.8e4

nB = 0.9e4



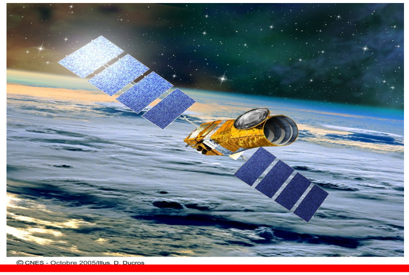




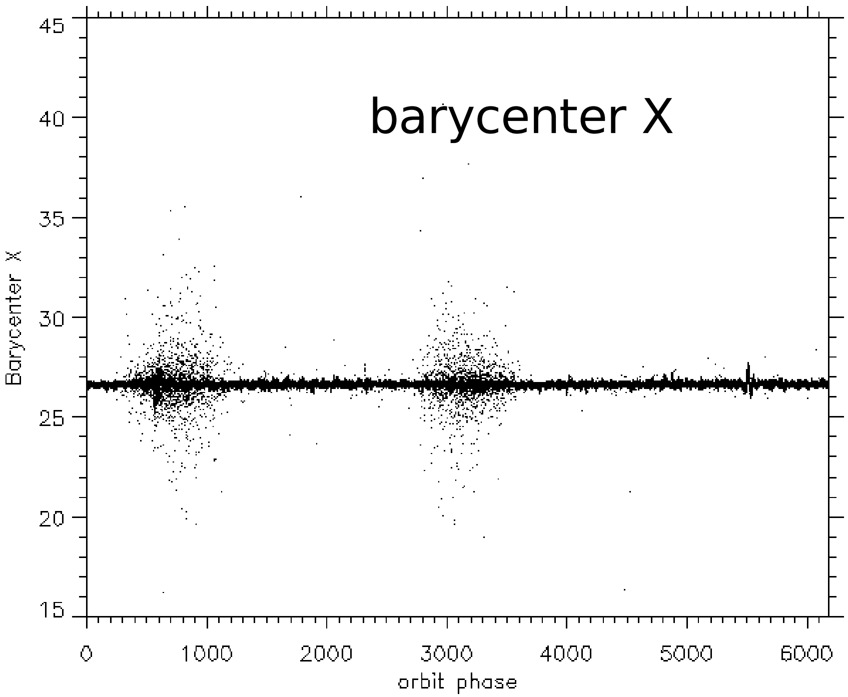
S/N	Red	Green	Blue	White
Before	212	106	88	293
After	325	188	100	293
Gain	1,54	1,77	1,25	1
Theor.	814	363	392	970

The star displacements

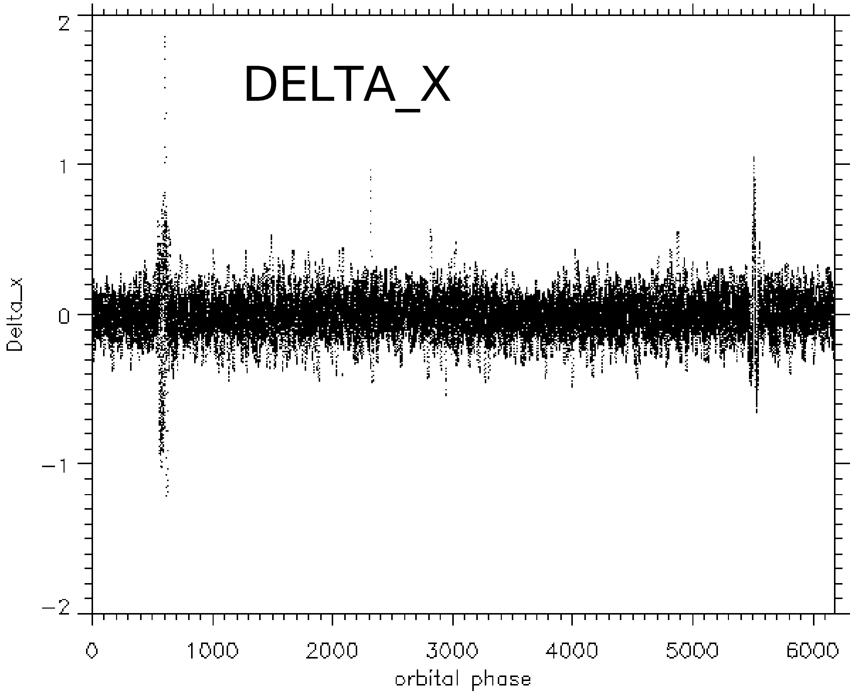
(astero channel)



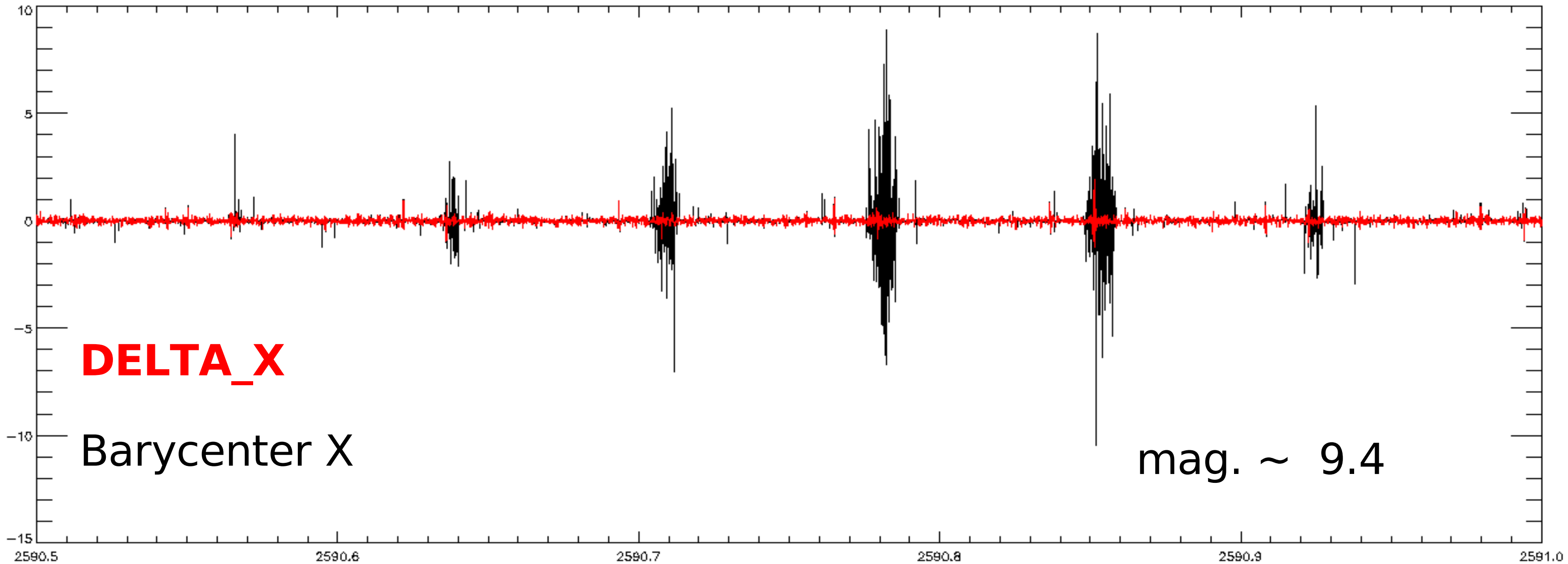
On-board barycenter :
polluted by the SAA crossing
and by photon noise



Reconstructed
displacements:



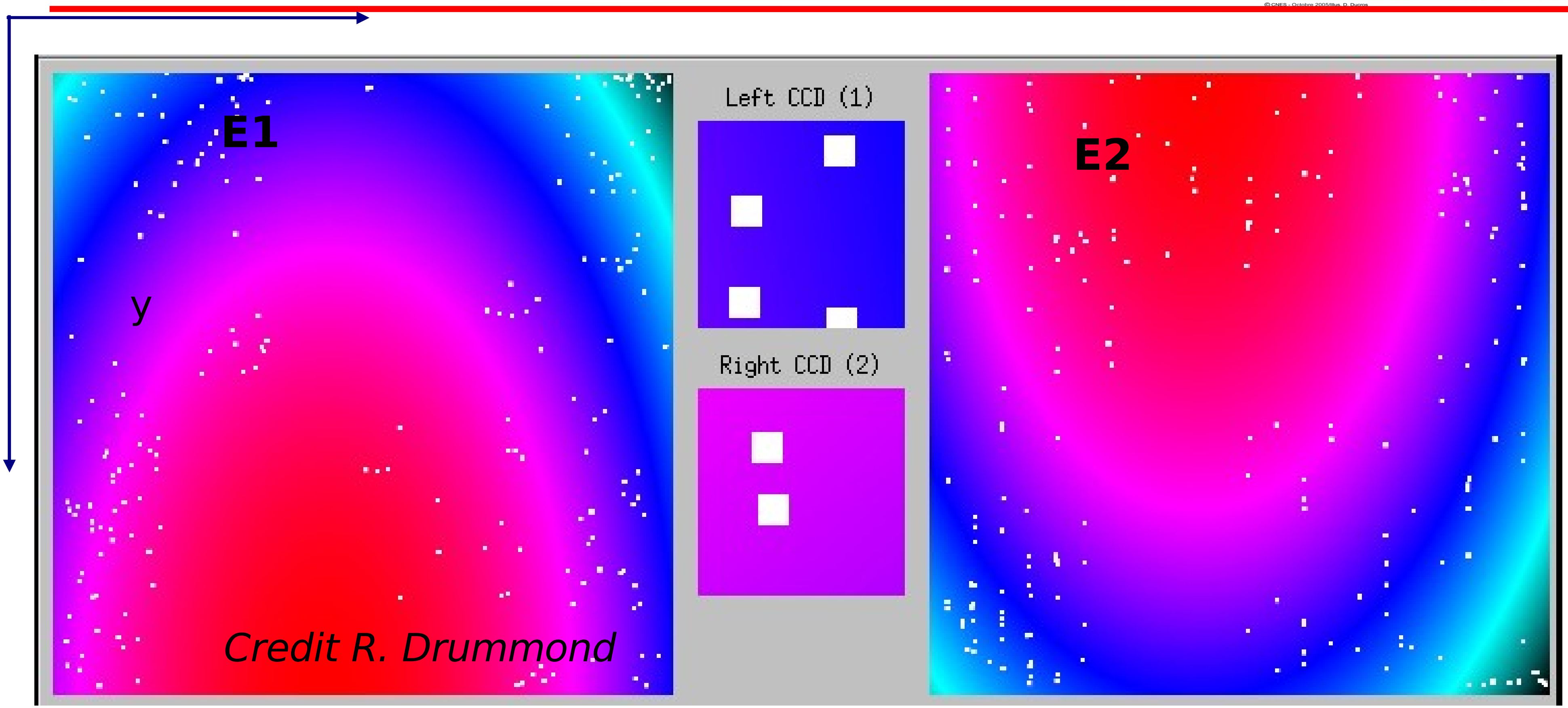
Jitter correction : calculation of the star displacements



DELTA_X – BarycenterX ~ 0.28 pix (rms)   (1 pix = 2.3 arcsec)

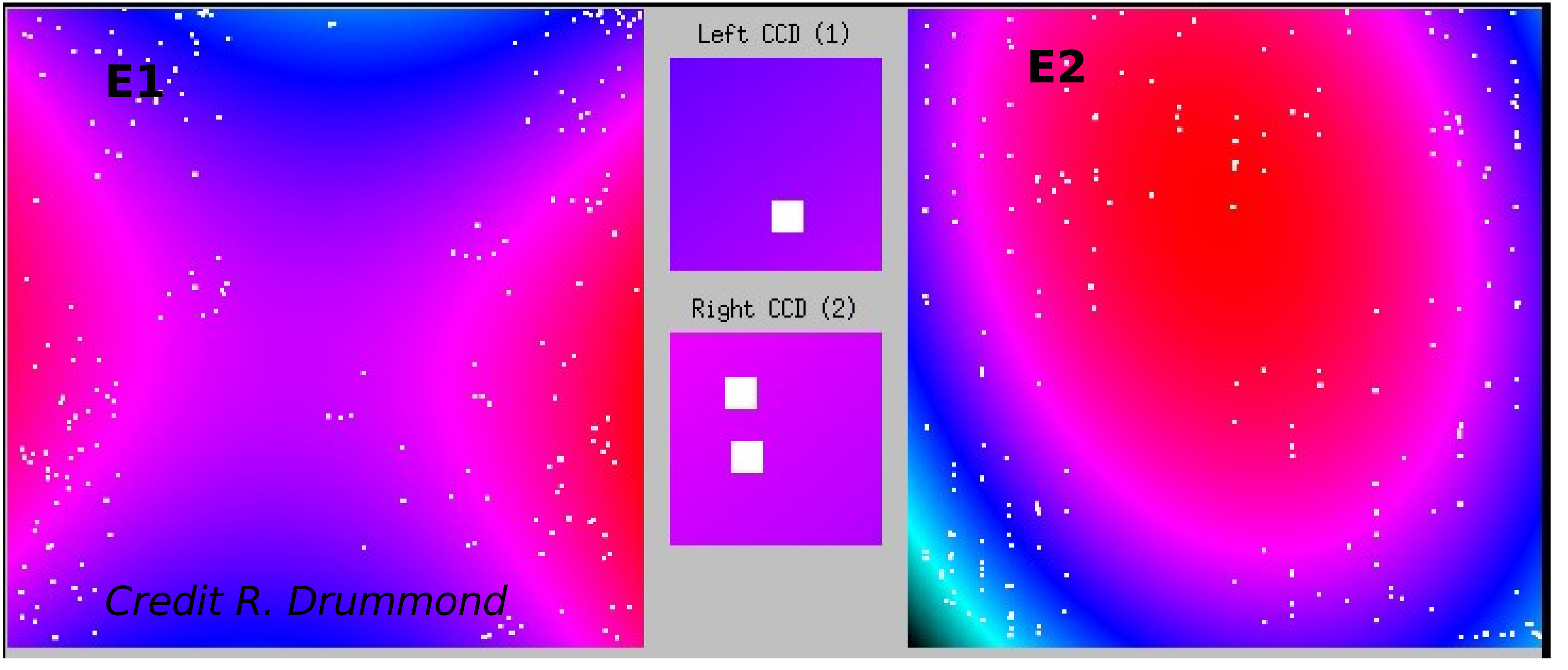
DELTA_Y – BarycenterY ~ 0.29 pix (rms)

Background correction polynomial fit



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

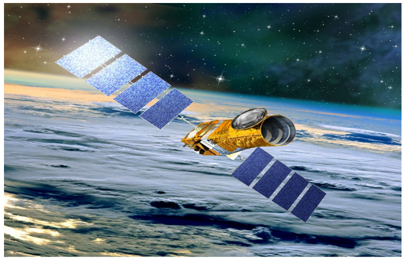
Background correction polynomial fit

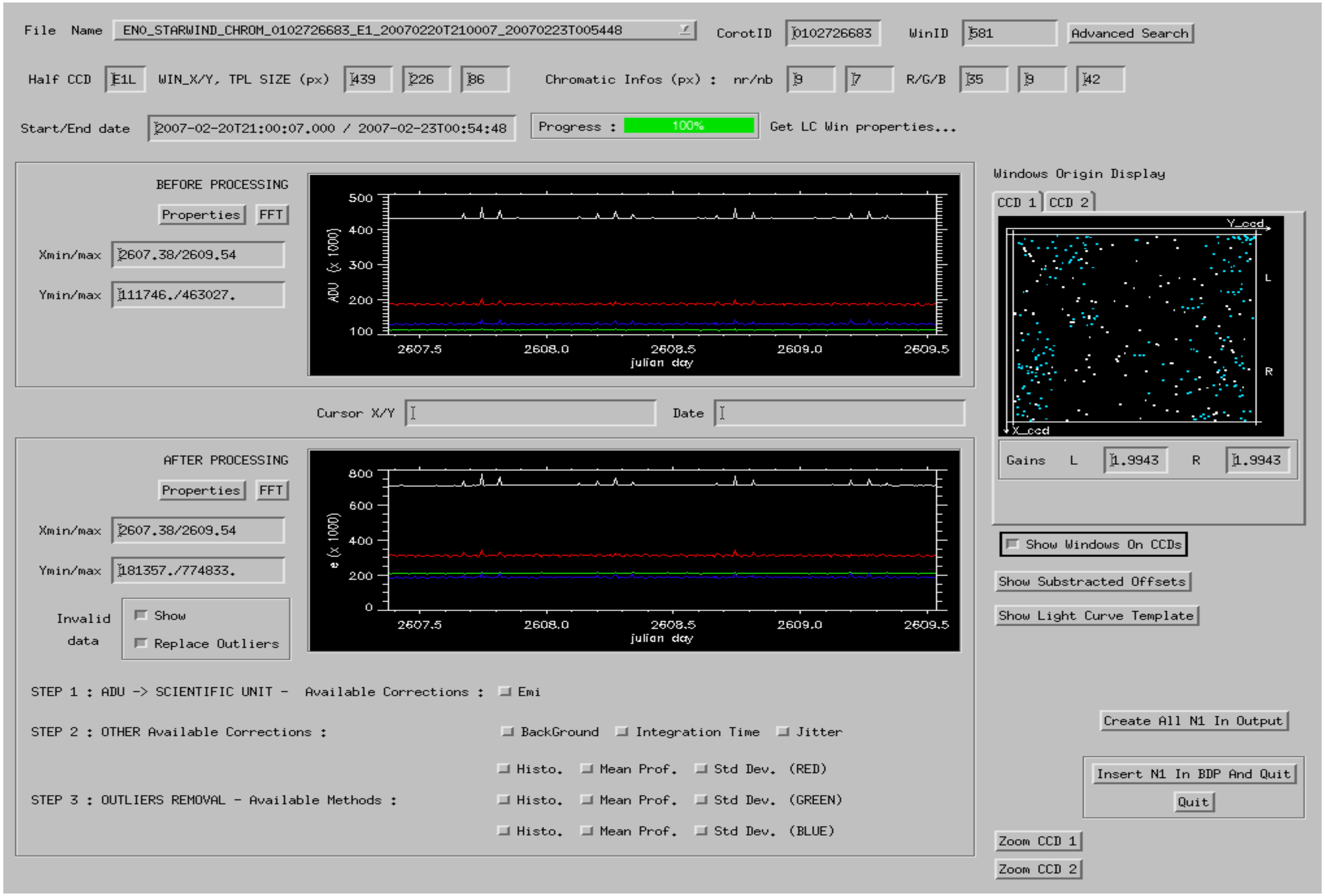


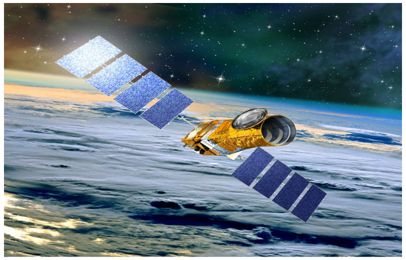
The two CCDs are fitted *separately* for each time step

- No matching between the two fits !

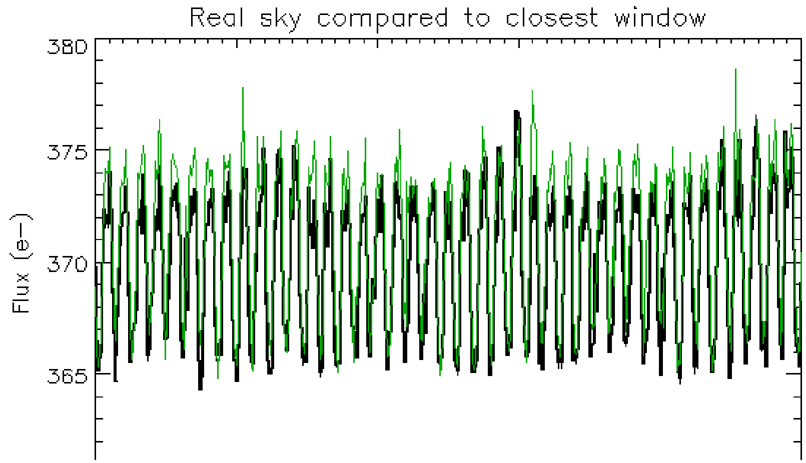
Astero-channel LC process 'asprocess'



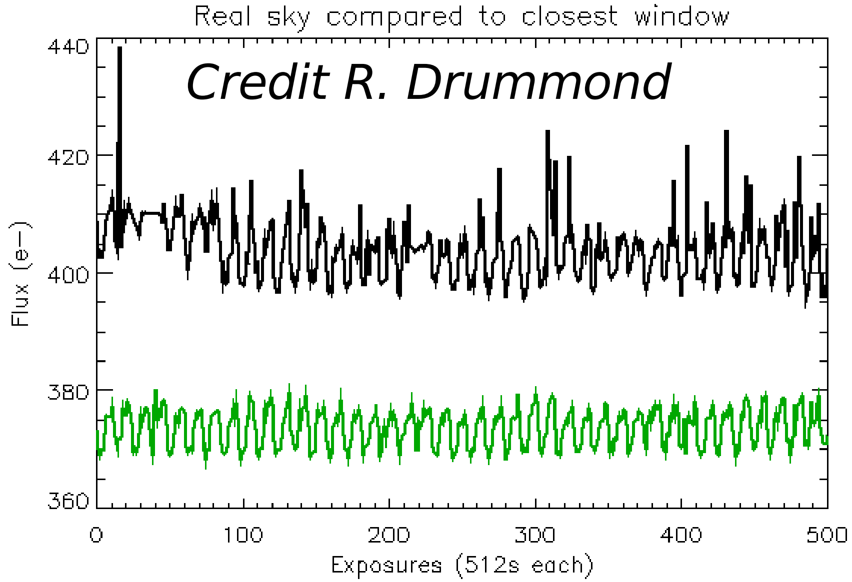

File Name
ENO_STARWIND_CHROM_0102726683_E1_20070220T210007_20070223T005448
CorotID
0102726683
WinID
581
Advanced Search
Half CCD
E1L
WIN_X/Y, TPL SIZE (px)
439
226
86
Chromatic Infos (px) : nr/nb
9
7
R/G/B
35
9
42
Start/End date
2007-02-20T21:00:07.000 / 2007-02-23T00:54:48
Progress :
100%
Get LC Win properties...
BEFORE PROCESSING
Properties
FFT
Xmin/max
2607.38/2609.54
Ymin/max
111746./463027.
ADU (x 1000)
julian day
Windows Origin Display
CCD 1
CCD 2
Y_ccd
X_ccd
L
R
Gains L
1.9943
R
1.9943
Cursor X/Y
Date
AFTER PROCESSING
Properties
FFT
Xmin/max
2607.38/2609.54
Ymin/max
181357./774833.
e (x 1000)
julian day
Invalid data
Show
Replace Outliers
Show Windows On CCDs
Show Substracted Offsets
Show Light Curve Template
STEP 1 : ADU -> SCIENTIFIC UNIT - Available Corrections : Emi
STEP 2 : OTHER Available Corrections :
BackGround
Integration Time
Jitter
Histo.
Mean Prof.
Std Dev. (RED)
STEP 3 : OUTLIERS REMOVAL - Available Methods :
Histo.
Mean Prof.
Std Dev. (GREEN)
Histo.
Mean Prof.
Std Dev. (BLUE)
Create All N1 In Output
Insert N1 In BDP And Quit
Quit
Zoom CCD 1
Zoom CCD 2



Background correction closest window



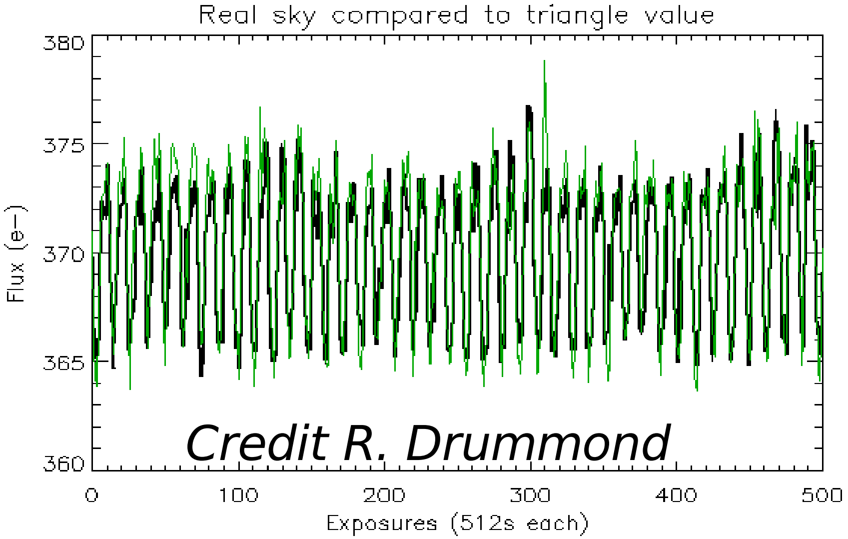
Standard deviation = 1.02
Square difference = 1121



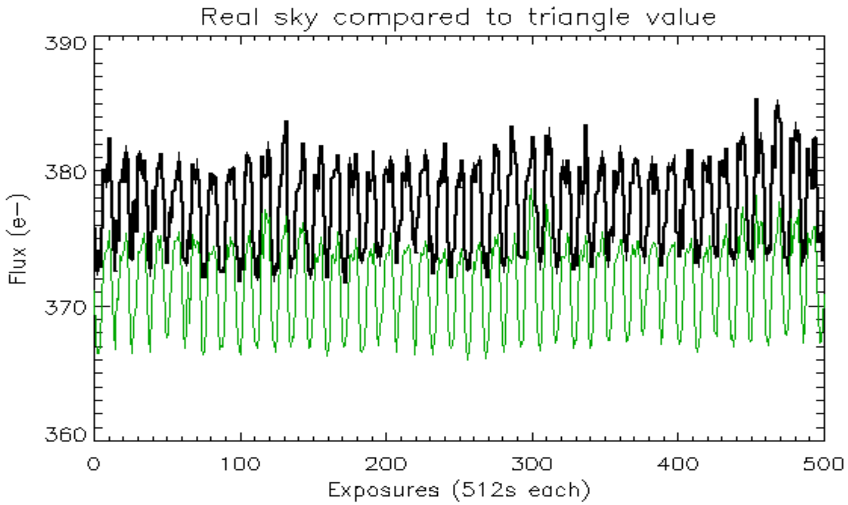
Standard deviation =9.82
Square difference = 41960

Values given outside SAA

Background correction 'triangularisation'

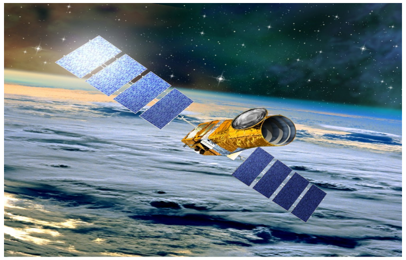


Standard deviation = 1.15
Square difference = 788

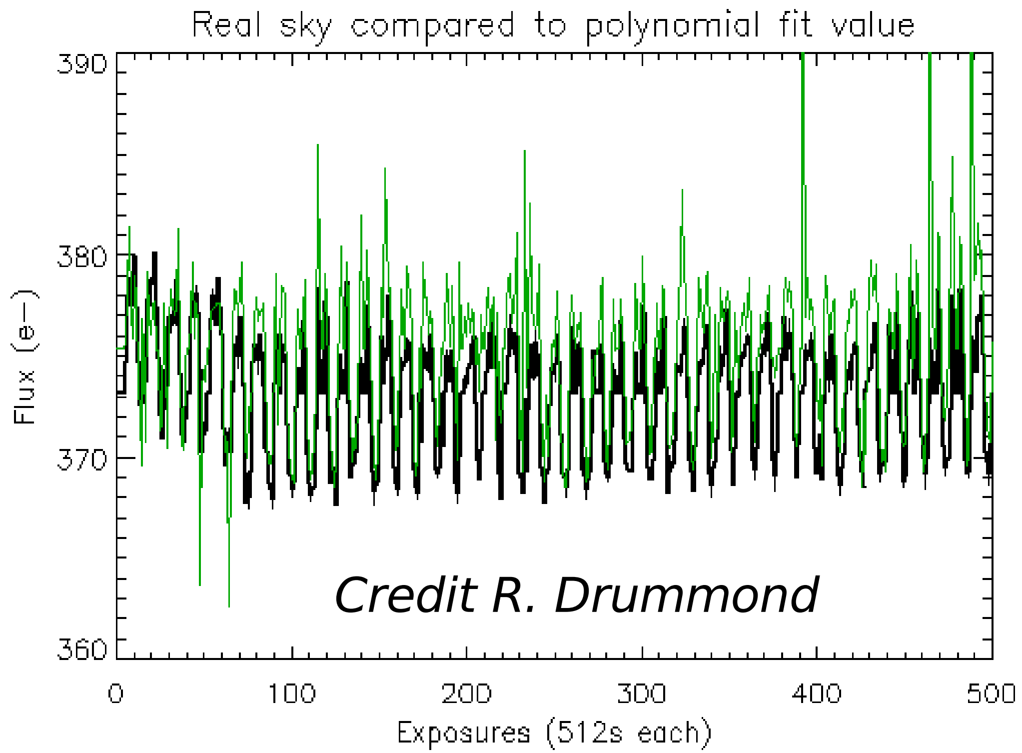


Standard deviation = 1.97
Square difference = 16134

Values given outside SAA

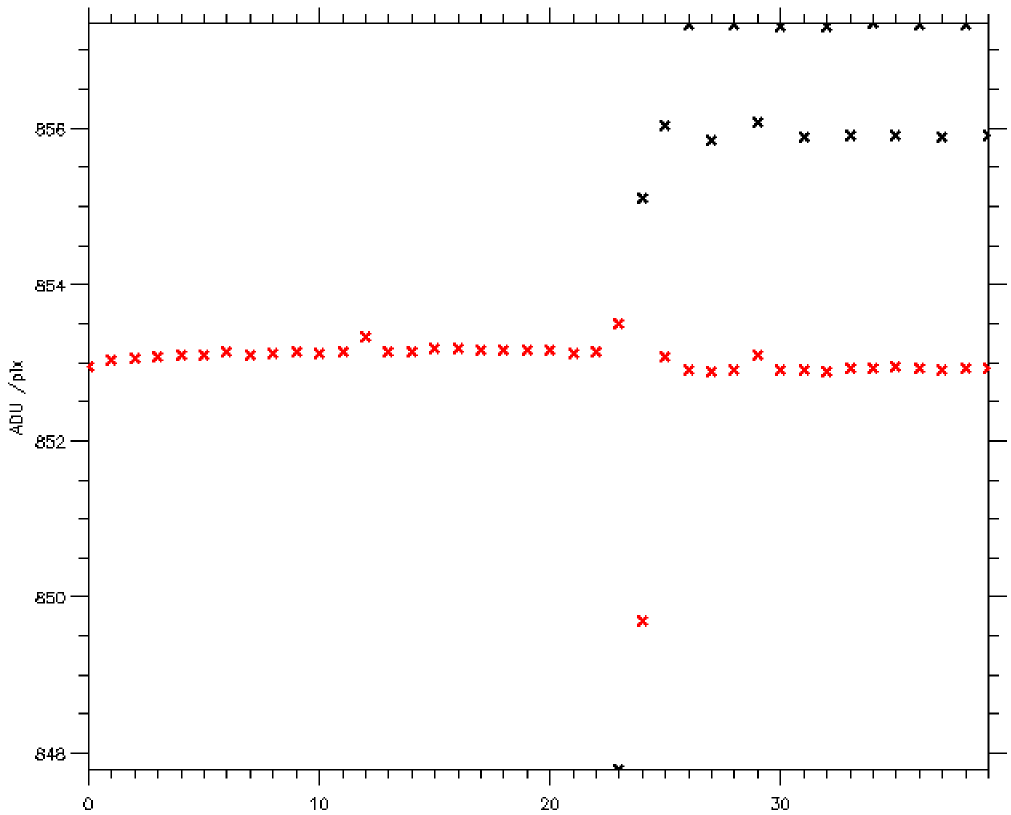


Background correction
polynomial fit

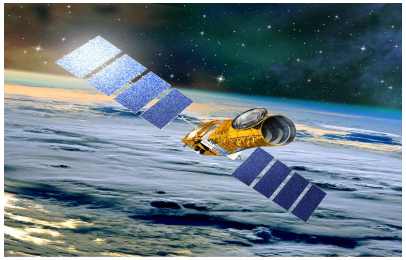


Standard deviation = 5.78

The Electromagnetic interferences (EMI)



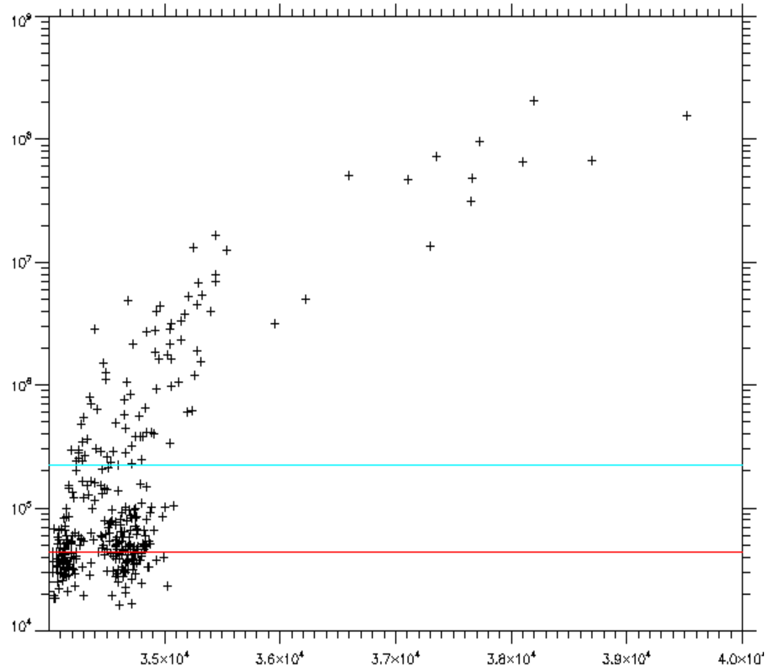
Offset E2L

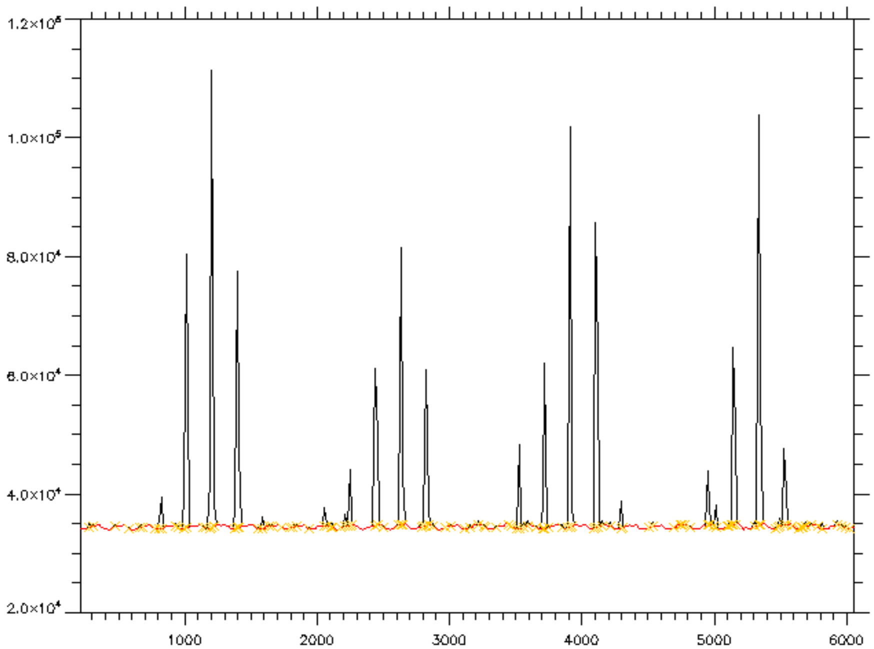


Correction of the outlier

Three methods :

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





Correction of the integration time variations