Lessons from CoRoT

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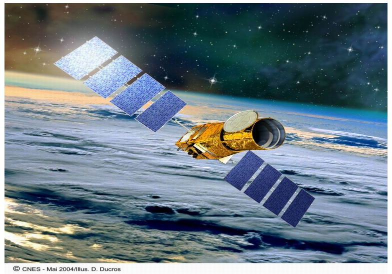
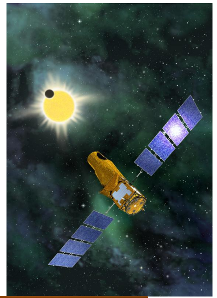
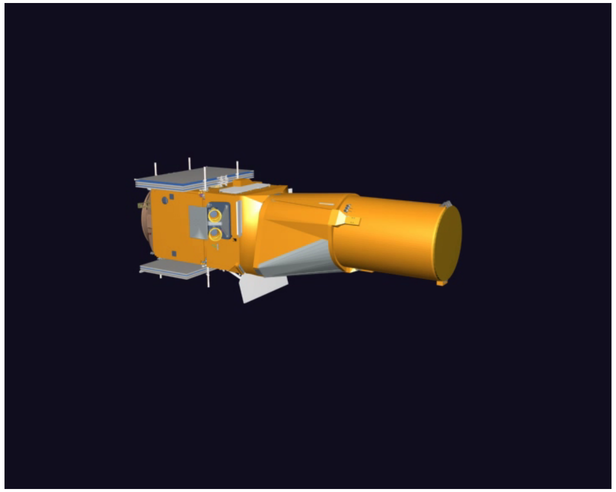


CoRoT in Brief

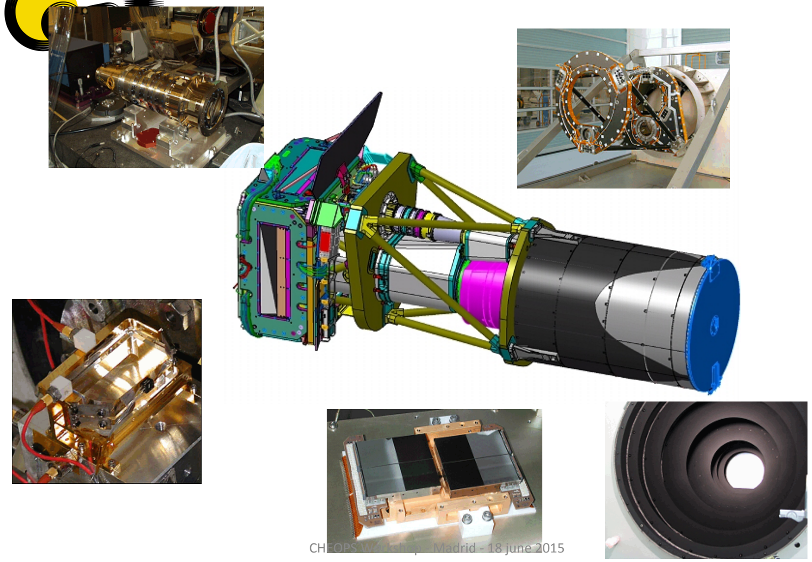
- « Small » CNES Mission + Belgium + Germany + Austria + Spain + Brasil+ ESA
- 3rd PROTEUS mission (minisat)
- Double program : asteroseismology and search for planetary transits
- Launch : 27 Dec 2006 : Soyouz Starsem 2b from Baïkonour
- Circular polar orbit at 896 km
- Loss of detection chain 2 in March 2009
- Loss of detection chain 1 in Nov 2012
- End of the mission june 2013
- End of operations june 2014



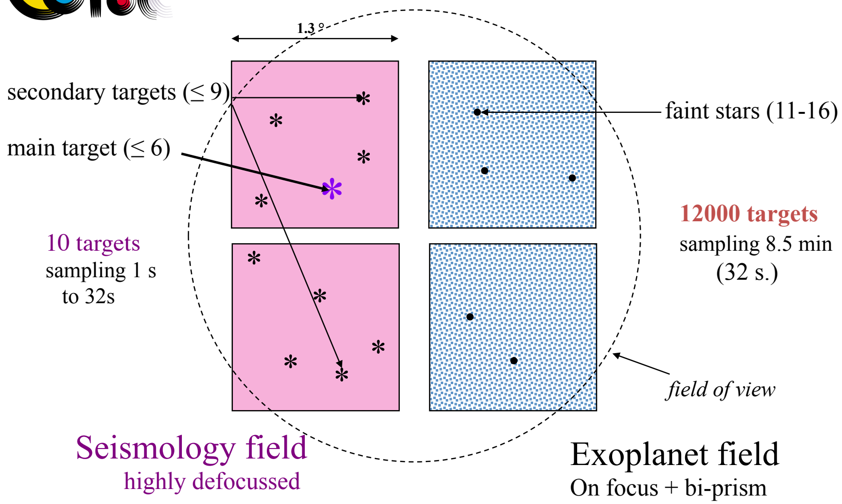
The CoRoT observatory



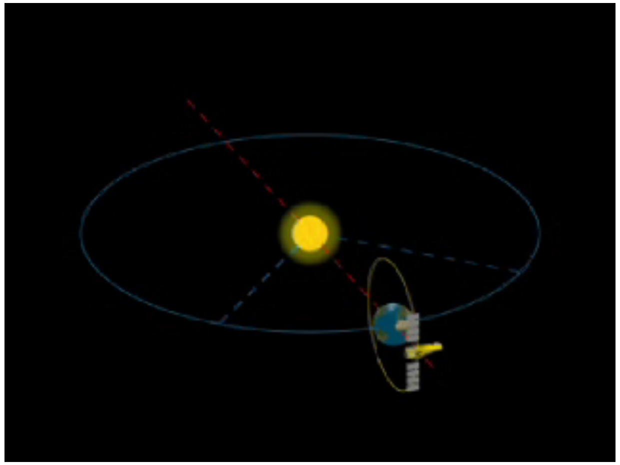
The CoRoT satellite



The focal plane

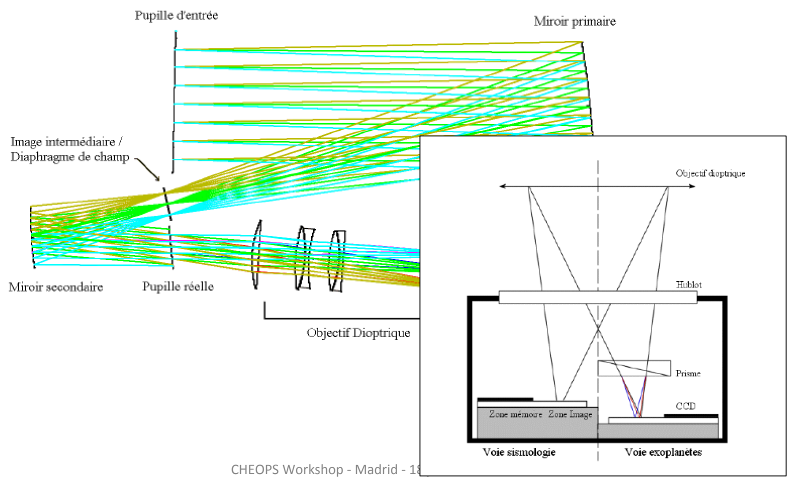


CoRoT : Observation and orbital constraints

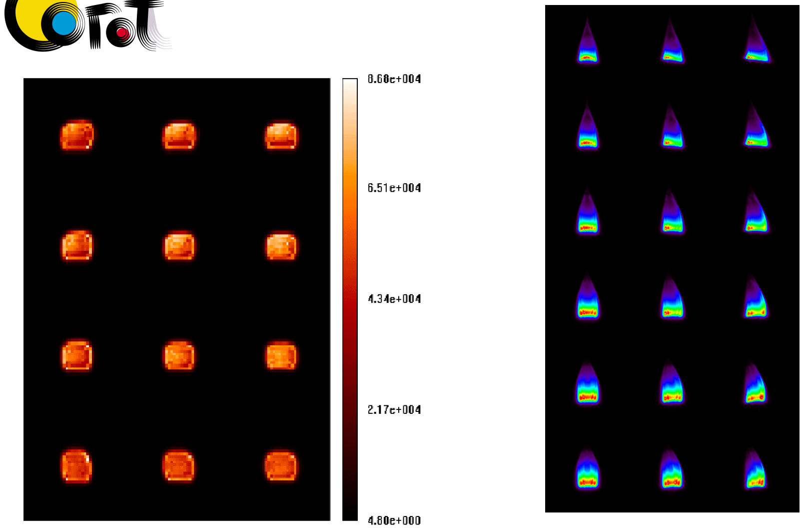


1st lesson : it is necessary to understand as much as possible how the instrument works and responds

Modeling of optical chain



Modeling of optical chain



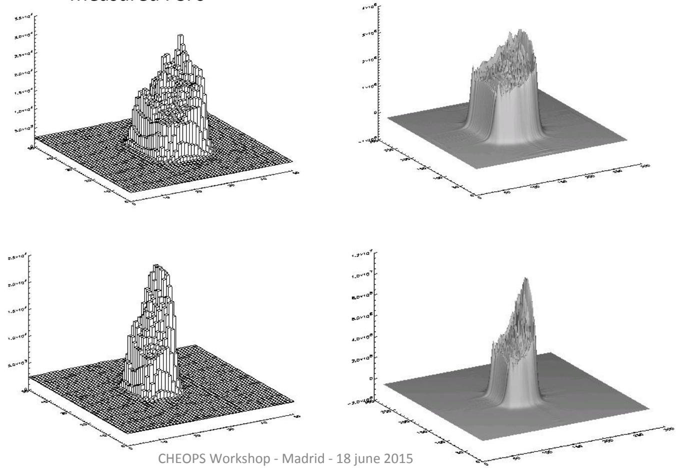
PSFs Huygens at INFA2 point

Measured PSFs

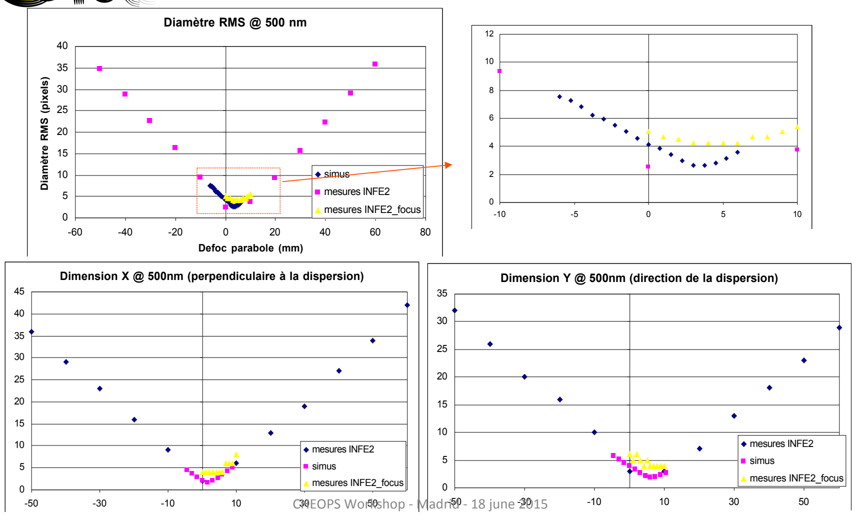
Computed PSFs

Defoc parabole = 0mm

Defoc parabole = +10mm



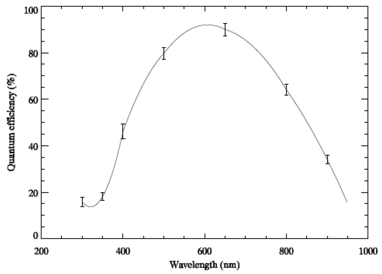
Comparing simulation and measurements



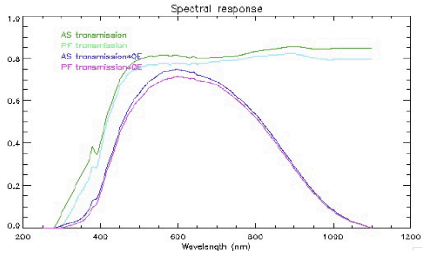
Defining the detection chain

Paramètre			*Min*	*Typ*	*Max*
Transfert ligne image => mémoire		[µs]		80	100
Transfert d'un pixel dans le registre sans numérisation		[µs]		0,5	1
Transfert d'un pixel dans le registre avec numérisation		[µs]		10	
Gain de l'amplificateur de sortie CCD		[µV/e⁻]	3,8	4,5	6
Bruit de l'amplificateur de sortie à 100 KHz		[e⁻ rms]			5
Courant d'obscurité moyen à -40°C		[$e^-.pix^{-1}.s^{-1}$]			0,5
QE moyen :	300 nm	[%]	7		
	350 nm		15		
	400 nm		50		
	500 nm		88		
	650 nm		86		
	800 nm		65		
	900 nm		33		
PRNU local :	350 nm	[% c-c]			9
	450 nm				7
	550 nm				7
	650 nm				7
	750 nm				8
	850 nm				10
Cosmétiques : obscurité > 100 $e^-.s^{-1}$ ou réponse < 50 %		[nb pixels]			750
		[nb colonnes]			6
Capacité des pixels		[10^3e-]	80	100	
Capacité du registre		[10^3e-]	400	450	
Capacité du *summing well*		[10^3e-]	800	1000	

And checking the specifications

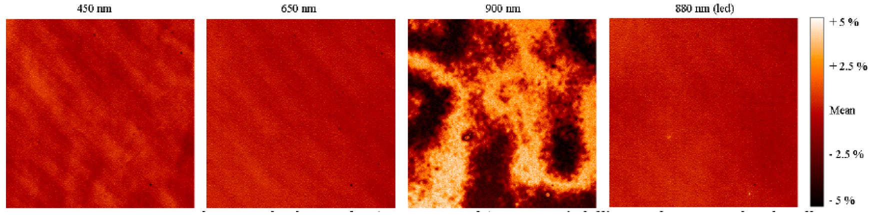


Data given by E2V

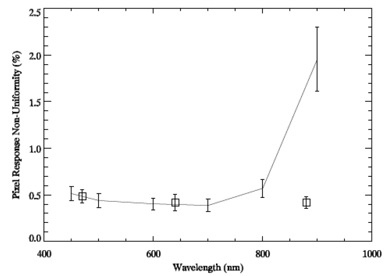


Auvergne et al (2009)

Calibrating the detection chain PRNU

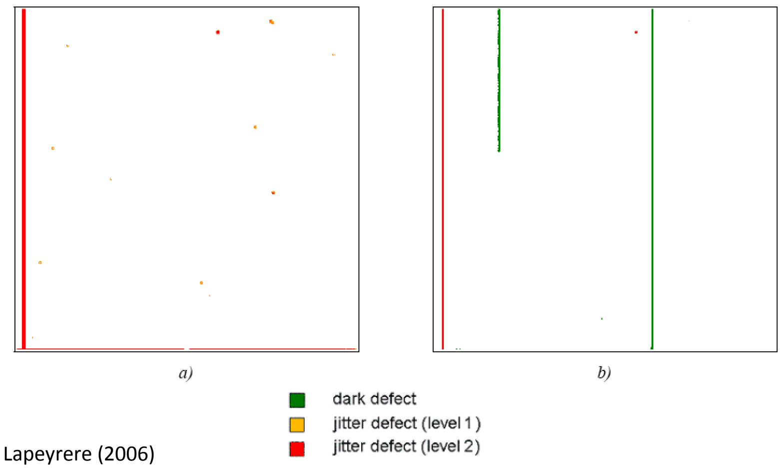


PRNU @ 450, 650, 900 nm (δλ=10nm) and 880 nm (δλ=80nm)



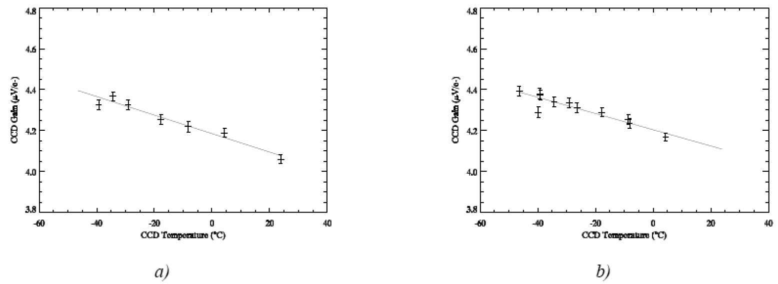
Lapeyrere (2006)

Calibrating the detection chain Bright star channel



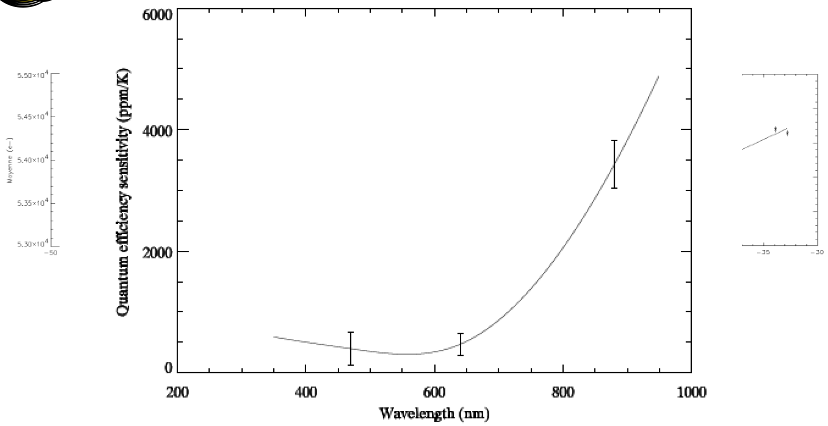
Lapeyrere (2006)

CCD gain variation with T



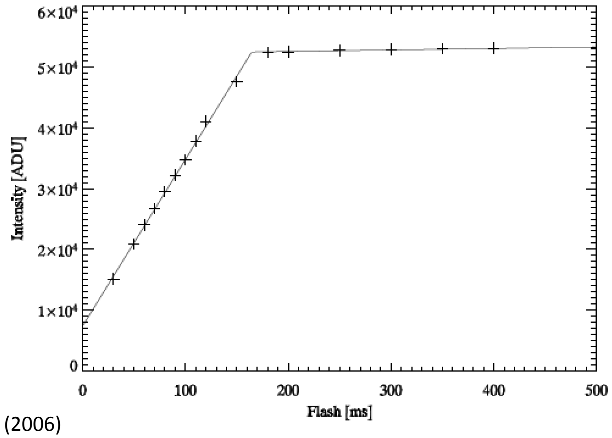
Lapeyrere (2006)

CCD QE variations with T



Lapeyrere (2006)

Well capacity and saturation



Lapeyrere (2006)

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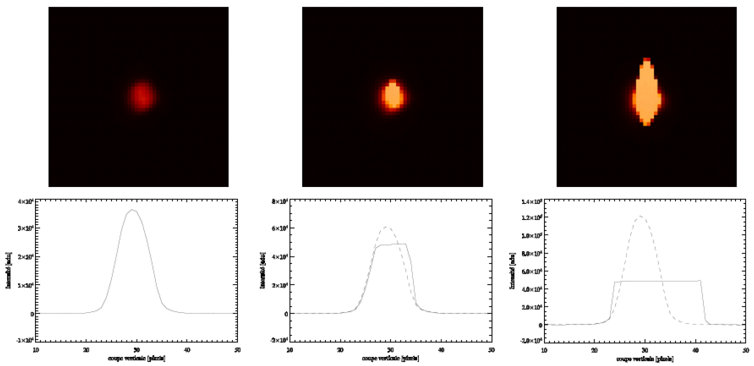
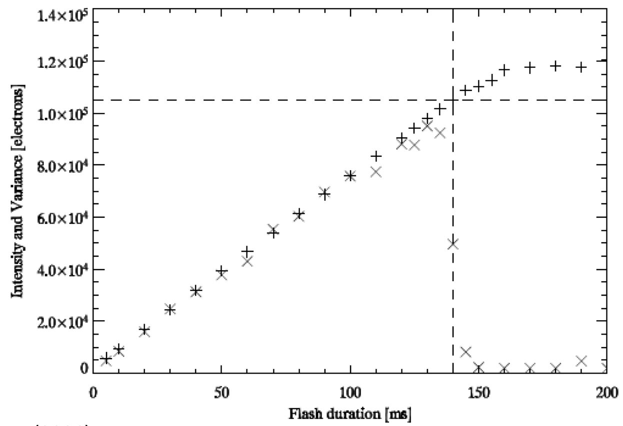


a) b) c)

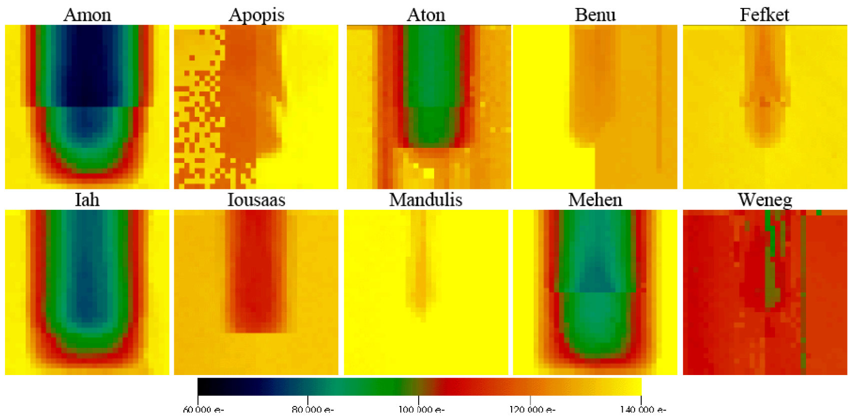
Lapeyrere (2006)

Well capacity and saturation



Lapeyrere (2006)

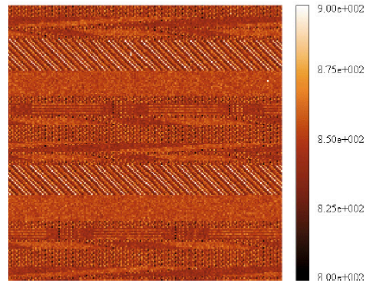
Well capacity and saturation

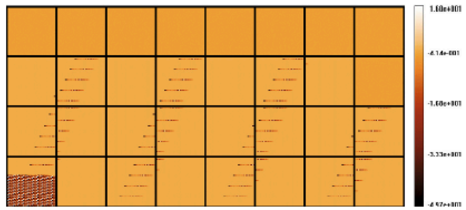


Lapeyrere (2006)

Cross talks

Faint stars channel (32s)



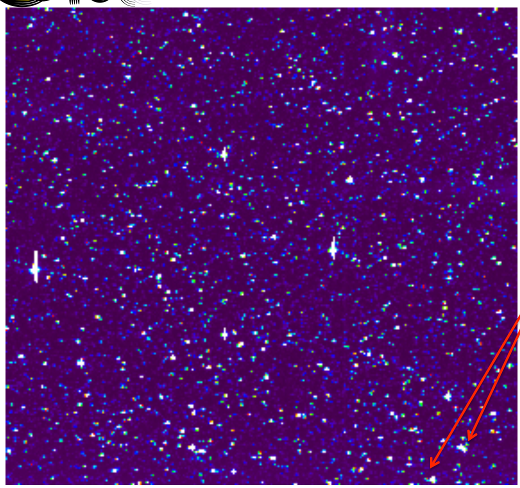


Bright stars channel (1s)

Auvergne et al (2009)

Lesson 2 : it is necessary, but not always sufficient

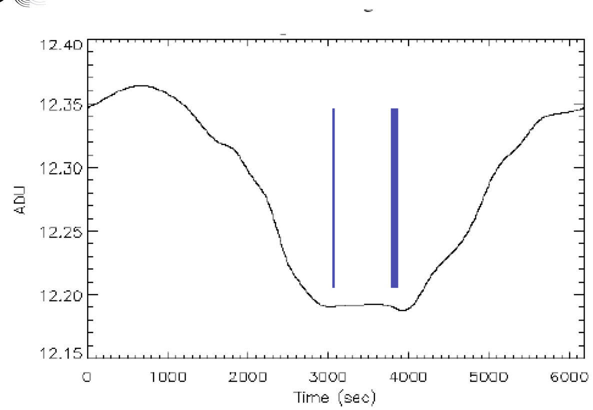
CCD saturation



Some stars saturate the DAC before the CCD (i.e : FWC much larger than measured

Lesson 3 : the worst is not necessary mandatory

The baffle efficiency



Rejection ~10^{13} : difficult to model, impossible to measure in the lab

Auvergne et al (2009)

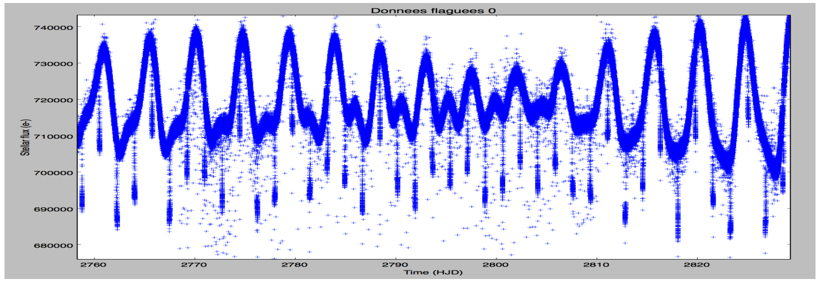
Lesson 4 : you should be prepared to work on your data

Preparing the exploitation phase

- Data reduction pipelines should be ready before the launch
- They should have been tested on « real-like » data (format, dynamics range…)
- You should know what you expect…
  - Biases
  - Noise
- You should be prepared to correct what you expect
- You should be prepared to correct what you don't expect
- You should expect what you don't know how to correct

Preparing the exploitation phase

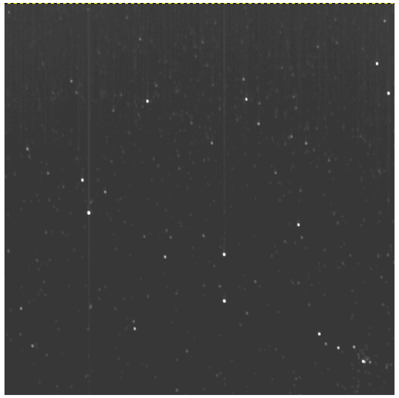
- Simulated data are always simulated data
- Don't be too proud of you if you manage to extract signal from simulated data : real biases and noises should have been forgotten or under-estimated... (I'am joking, blind tests are useful !!!)

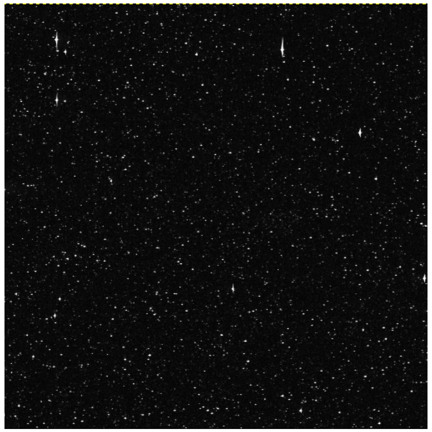


Lesson 5 : even if your pipelines are (finally!) ready, you will need to improve them continuously

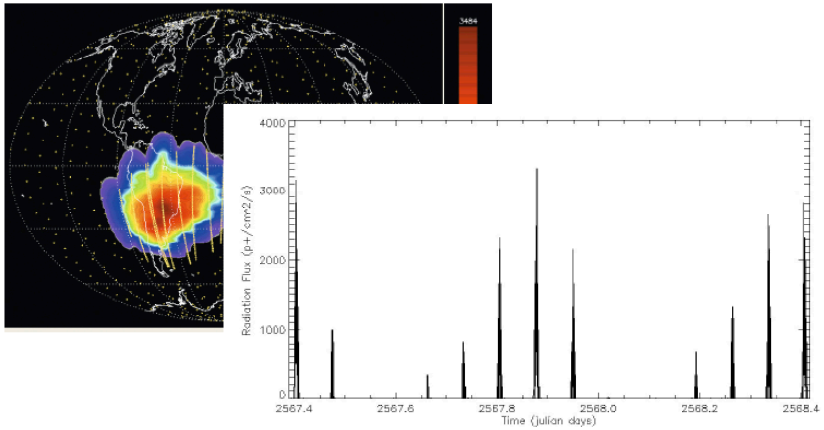
(because time is a perpetual instrument killer...)

Investigation tools

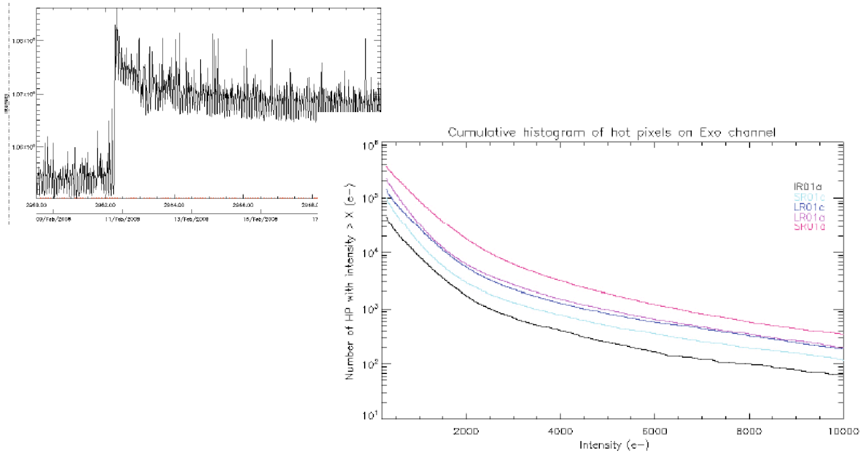




Protons impacts

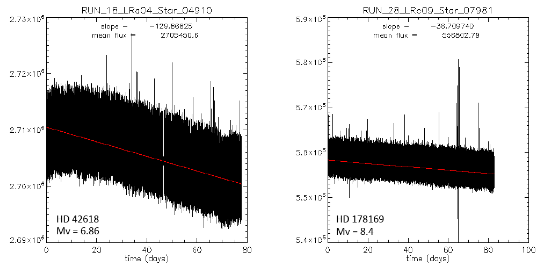


Protons impacts



Effects of the radiations

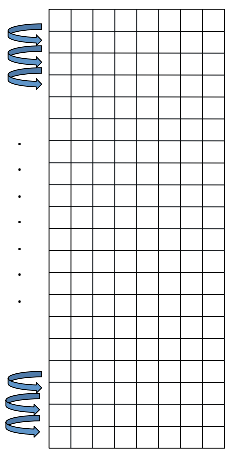
- Drop of the overall transmission of the dioptric chain (objective (6 lenses), window, prisms)
- Drop of the quantum efficiency
  - Estimated over 1 run duration (5 months) and several years when a star is re-observed



Photometric loss of about 10% in 6 years

Charge transfer inefficiency

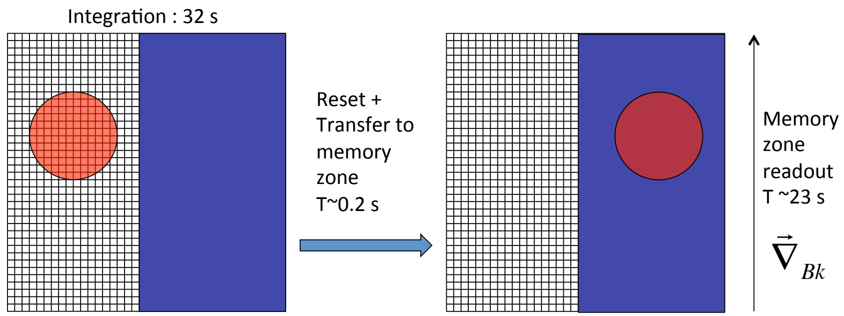
- CTI = 1-CTE
- CTI= 10^{-4} for STIS (HST) after 7 years at alt = 500 km
- Loss of about 10% max of the e- during the readout process, i.e 0.11 mag for a 1K CCD
- Strongly depends on the detector type and the instrument altitude
- Cannot be seen on the CoRoT star windows
- Cannot be seen on the CoRoT background windows



Dark current

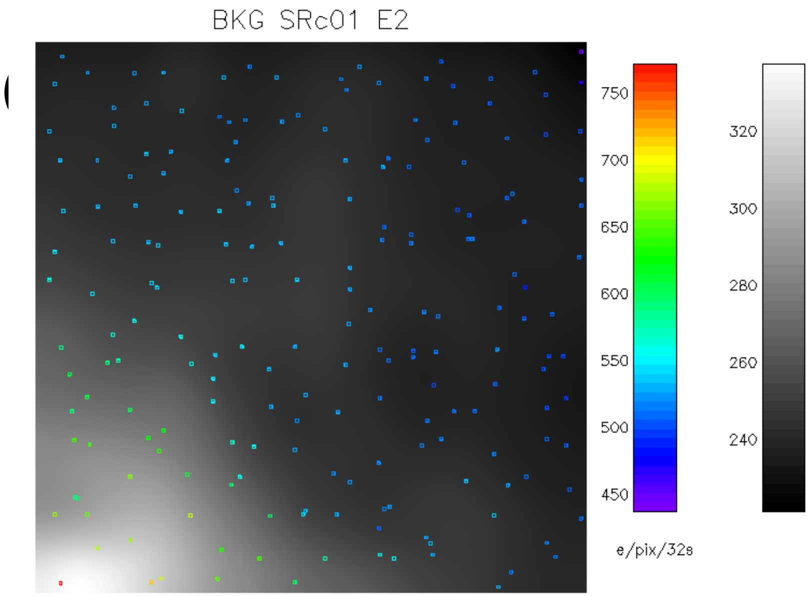
- Negligible at CoRoT's launch
- Increase with time (and radiation exposition)

A slope appears on the background due to the readout time



reminders

- 196 sky background windows on the CCD : 147 windows @ 512s, 49 windows @ 32s
- The CCD is split in 14*14 square zones, 1 window per zone; ~ 3/4 sampled @512s and 1/4 sampled @ 32s (starting at SRc01)
- Several methods proposed for the background correction:
  - Subtraction of the nearest background window value
  - Subtraction of the combination of the 3 nearest background windows value
  - Subtraction of a sky background model
- The first two methods are very sensitive to hot pixels => subtraction of the median value of all the background windows
  - Small sensitivity to hot pixels
  - Same correction for the whole CCD
    - OK at the beginning (no dark current, uniform background)
    - Not OK with ageing (cf. dark current and readout process)



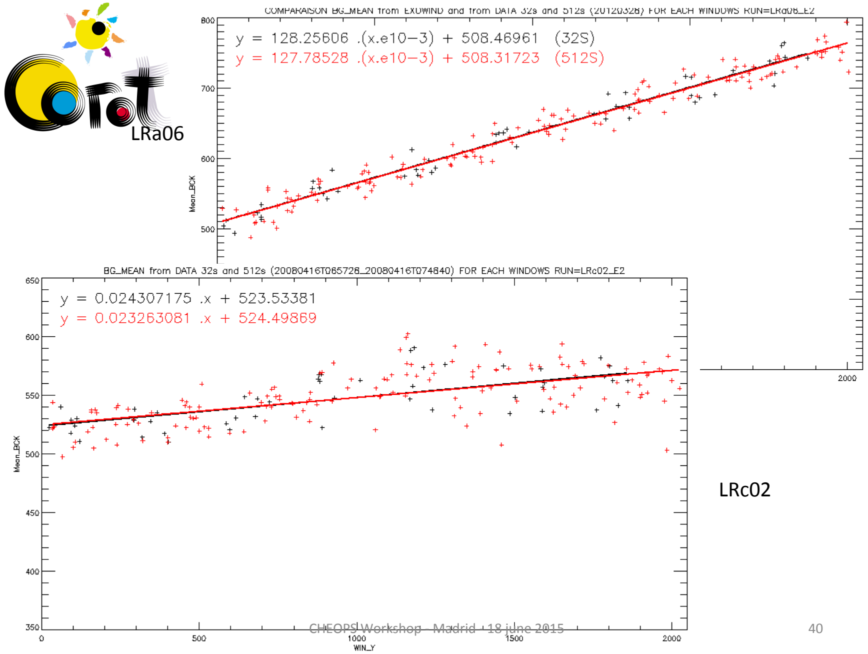
The windows colors correspond to the mean of each BG window over the day 20070414.
196 windows (32s and 512s)

Sky backgrouds components

- The effective sky background
- The satellite environment : uniform effect, well corrected by the median value
- The dark current
  - A uniform value (integration phase) corrected by the median value
  - Depends on the position of the window (Y-axis) during the readout phase
    - Small effect at the beginning of the mission
    - The gradient increases with time
  - Depends on the CCD temperature

- Need to correct the lightcurves from the dark current

LRa06

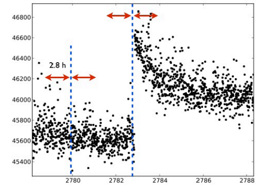


LRc02

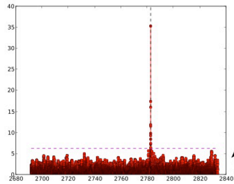
Adopted correction
(A. Deru)

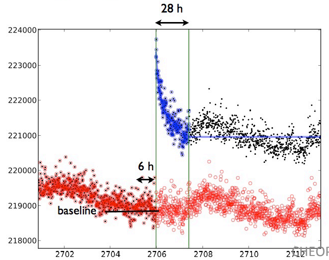
- Subtraction of a median sky background depending on time (unchanged) : correction of the real sky background + dark current during integration
- Subtraction of a component depending on theY position of the window : correction of the dark current during readout
- Dark(y) = α * y + Cte
  - α : mean of the slopes at the beginning and end of the run
  - Cte = Dark(0) – Median_bk (0)
  - Ex : for Corot_ID=223942686
    - SRa01 : y = 409 ; Cte = -13,17 e-/pix/32s ; -1 172,21 e-/32s
    - SRa05 : y = 196 ; Cte = -122,62 e-/pix/32s ; -9 442,02 e-/32s
    - To be compared with the minimal values 660 000 et 690 000 e-/32s

Jump corrections
(effects of impacts)
(J-M Almenara)



$$S = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{\sigma_1^2+\sigma_2^2}{N}}}$$



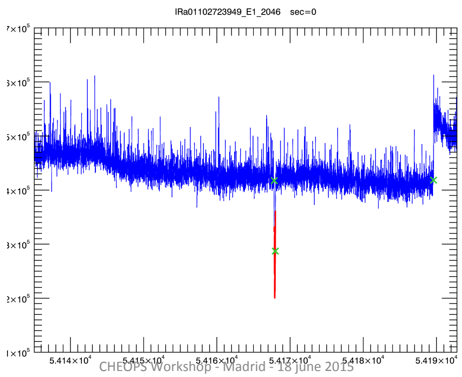


$$F' = \frac{F}{c_0 + c_1\, t + e^{c_2(t-c_3)}} \quad baseline$$

$$F' = \frac{F}{b + e^{c(t-d)}} \quad with \;\; c \leq 0$$

Jump corrections

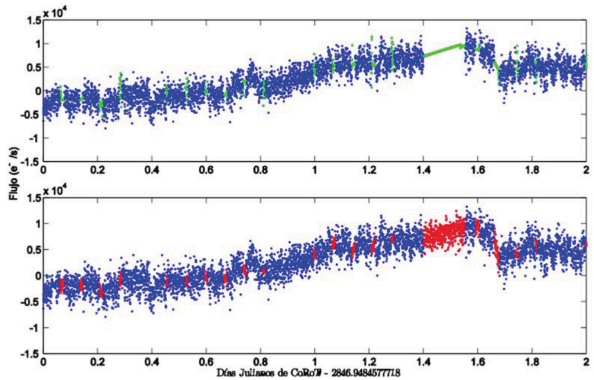
Jump detection coupled with ephemerises of known phenomena (planetary transits, binary systems…) for negative jumps



Gap filling

MIND THE GAP

Filling the gap without changing the Fourier spectrum



Gap filling

MIND THE GAP

2 methods tested :

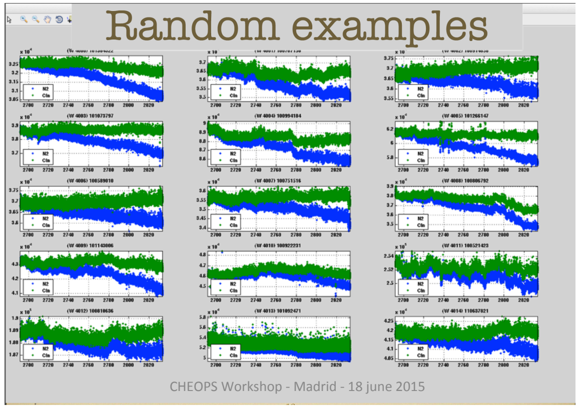
- ARMA : J-P Granado : sliding average and self regressive algorithm.
- Inpainting : CEA Algorithm (R. Garcia, S. Pires)

Inpainting method implemented

- 2 correction steps to correct mainly SAA crossing and longer gaps.

Systematics correction

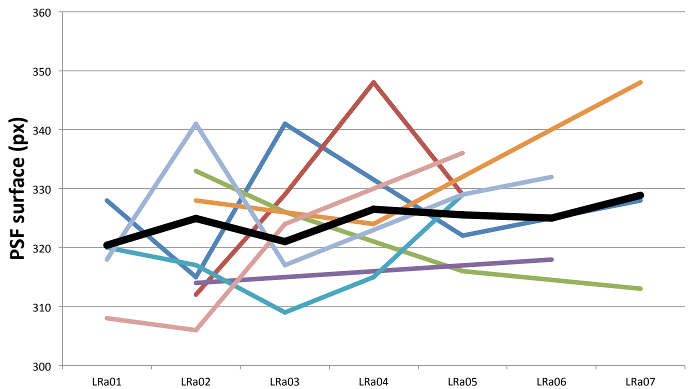
- Estimation of localised biais on the detector with time.



Systematics correction

- Computation for each run of correction coefficients for each point of the LC
- Need the gap filled and jump corrected data to reduce the biases

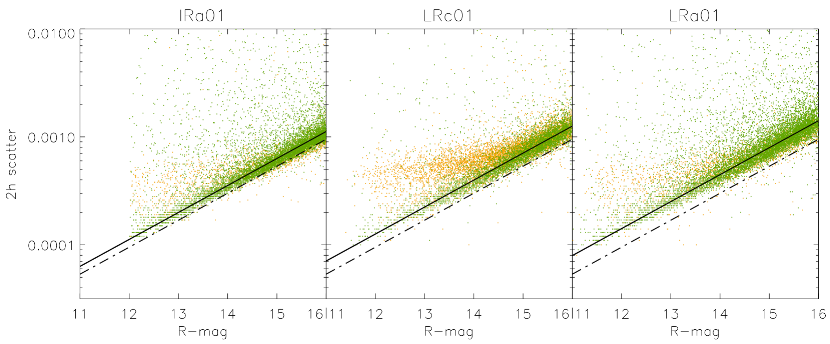
Evolution of the PSF size (focus variations ?)



Colors = positions on the A1 CCD

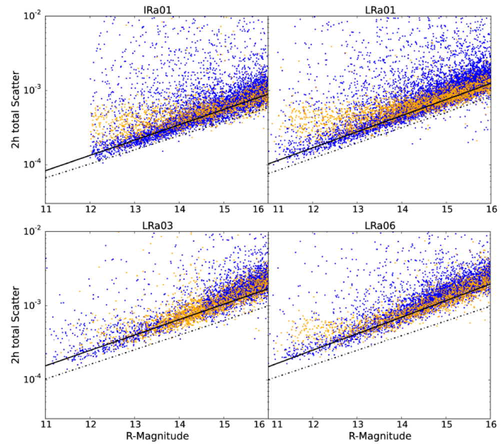
Overall increase of the noise with time (Aigrain et al. 2009)

- Estimation of the variation of the 2h data scatter using the Median Absolute Deviation method



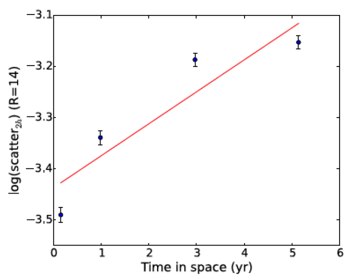
Overall increase of the noise with time (R.Asensio : Master Thesis)

- Estimation of the variation of the 2h data (with the method used by Aigrain et al. 2009) over 6 years



Overall increase of the noise with time (R.Asensio : Master Thesis)

- Estimation of the variation of the 2h data scatter for R=14 with time using the Median Absolute Deviation method (used by Aigrain in 2009) using several CoRoT runs over 6 years



- However : no observation of transmission or QE loss…

Conclusions

- High accuracy photometry is difficult, but not impossible
- Initial and inflight calibrations / monitoring are mandatory. Investigation tools should be foreseen.
- The data reduction pipelines role is crucial. The time required to make them work should not be under-estimated
- Ageing is real, but does not prevent from good observations and science if ageing can be monitored.

Lesson 6 : the force of a project is the force its team

CW 11 @ IAC

Corolar lesson : Don’t be attracted by the dark side of the force….(hum… sorry, it is another story)…

Last lesson : life continues after ~~CoRoT~~ CHEOPS