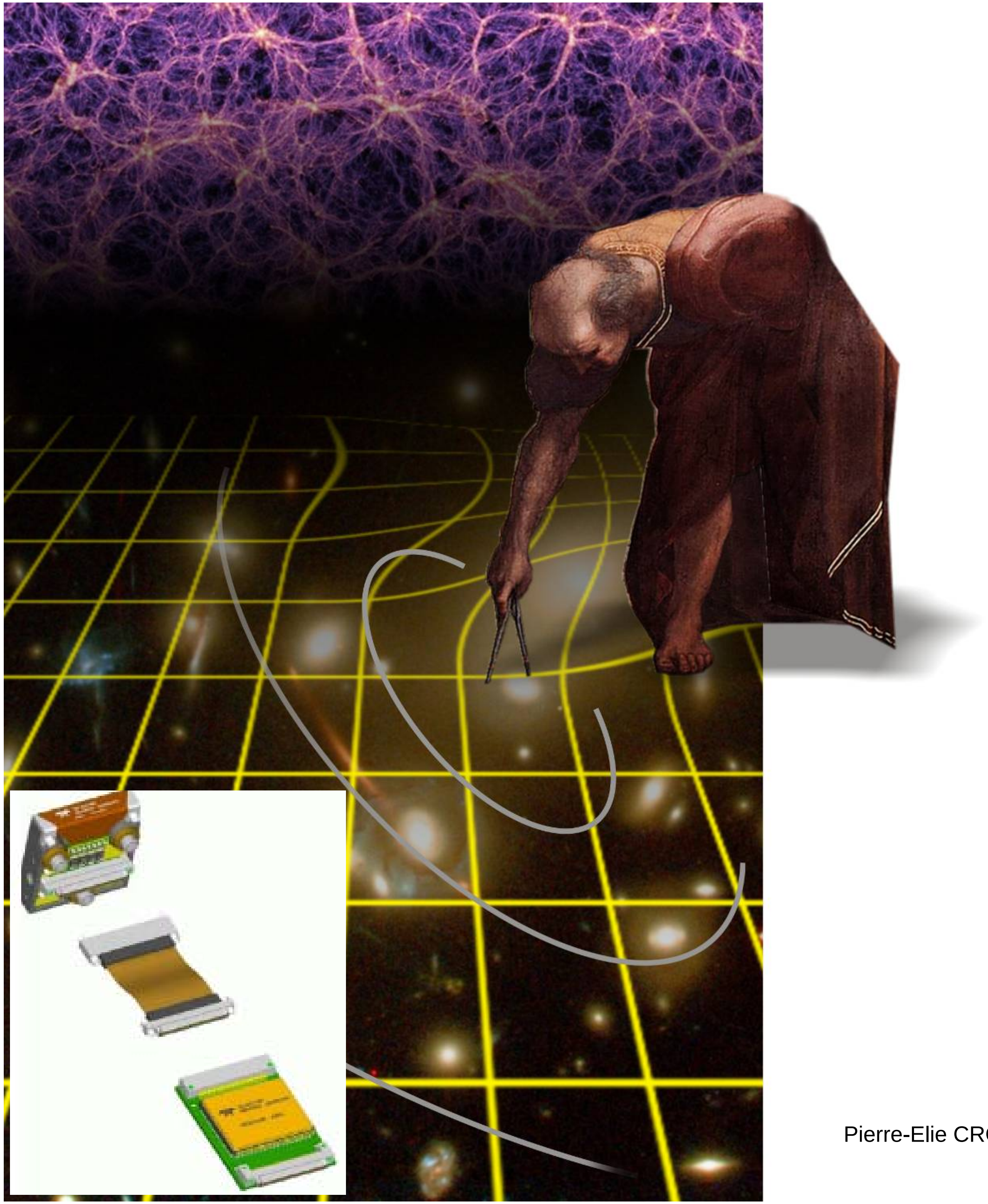

On-board processing for the Euclid mission

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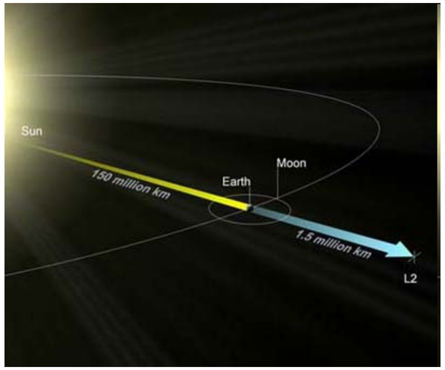
Outline

- Euclid mission case study
- The H2RG infrared detector
  - Readout chain
  - Specifications
  - Way of sampling
  - Requirement
- Data processing
  - Data processing steps
  - Results with a LEON2 board
  - Consequences
- Conclusion

Euclid case study

- Nature of dark matter and dark energy
- Euclid will perform a sky survey and is optimized to measure simultaneously two principal dark energy probes:
  - Weak lensing measurement down to in band 550 to 920 nm
  - Baryon Acoustic Oscillations (galaxy distribution power spectrum)

- Main parameters:
  - Launch 2018 (Soyouz)
  - **L2 orbit (1.5 10^6 km away from Earth)**
  - 7 years mission nominal
  - 1.2 meter telescope
  - 2 instruments:
    - VIS channel: 36 CCDs 4k x4k, 550-920 nm imager
      - 0.1 arcsec/pixel, FoV 0.5 deg^2
      - 150 K operational temperature.
      - magAB=24.5, Y,J,H
    - NISP channel: **16 H2-RG (large focal plane),** 2k x2k, 1.0-2.0 um photo-spectrometer
      - 0.3 arcsec/pixel, FoV~0.5 deg^2
      - 90-100 K for the FPA
      - magnAB=24 Y,J,H



Infrared detectors: H2RG

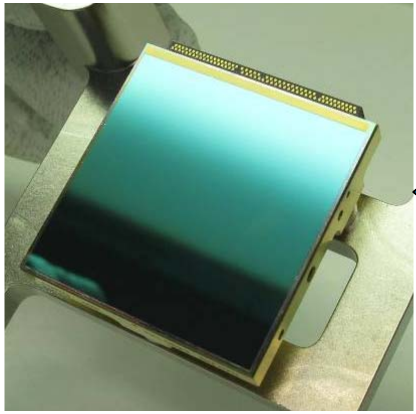
- State of the art detector already used for
  - Hubble Space Telescope, Wild Field Camera 3
  - NIFS Gemini north (Mauna Kea, Hawaii)
  - JWST Near Infrared Spectrograph
  - ESO, X-shooter (spectrograph), Paranal

Usually data processing done on ground but not for Euclid :

- L2 satellite
- Efficiency of observation (downlink during 4 hours/day)



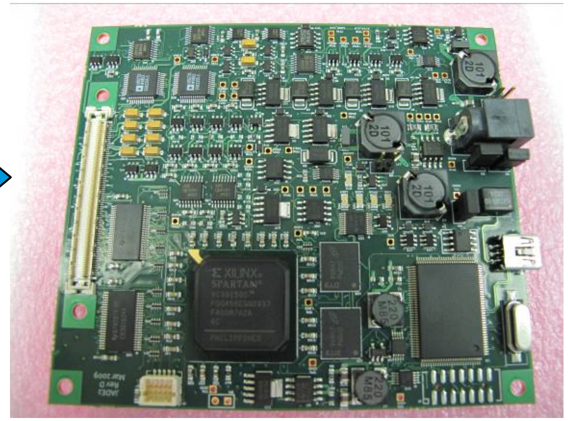
Readout chain



H2RG detector

SIDECAR ASIC

Clock generation
Bias generation
Digital interface to instrument electronics
Low power operation
- Less than 150 mW at 100 kHz, 32 channel, 16 bit ADC

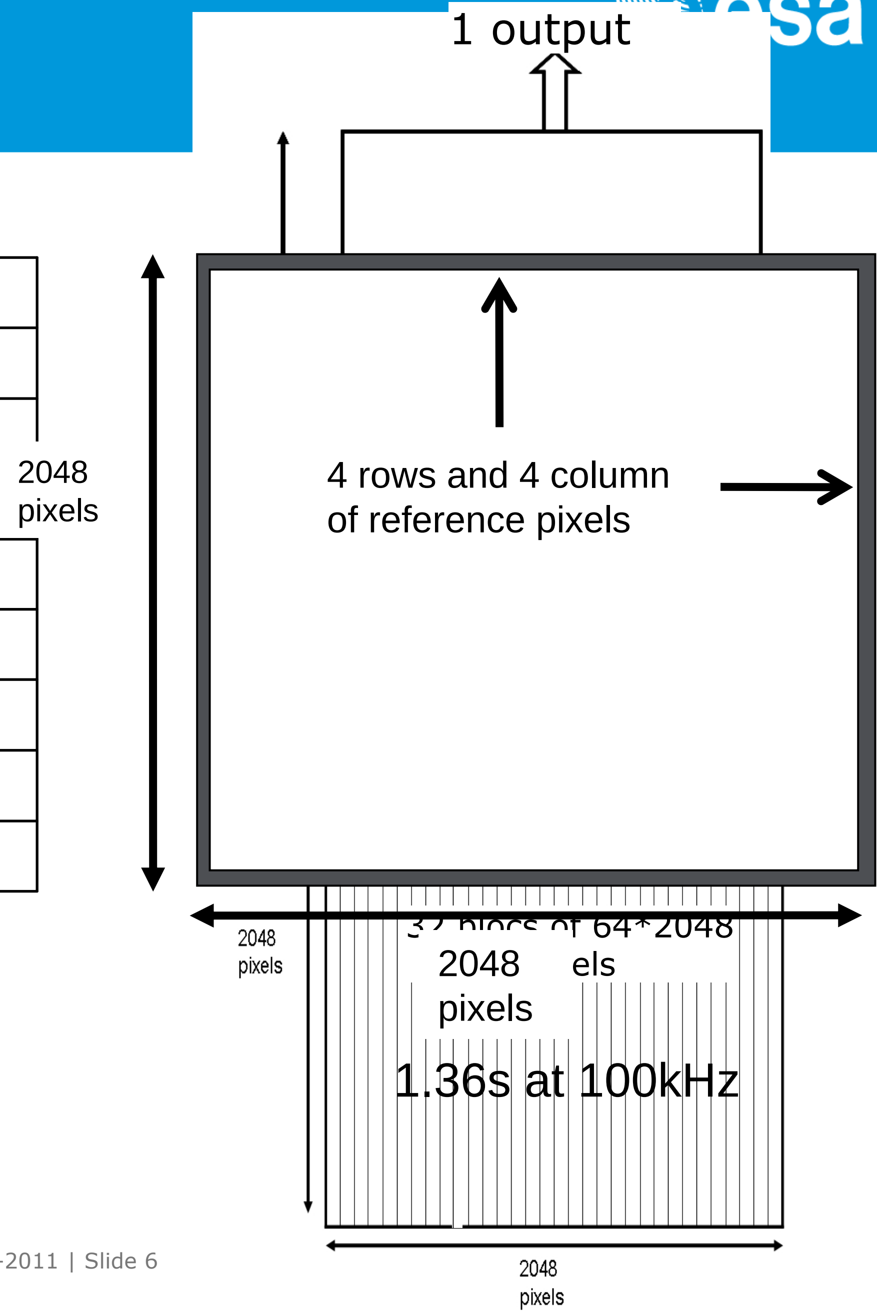


JADE2 card

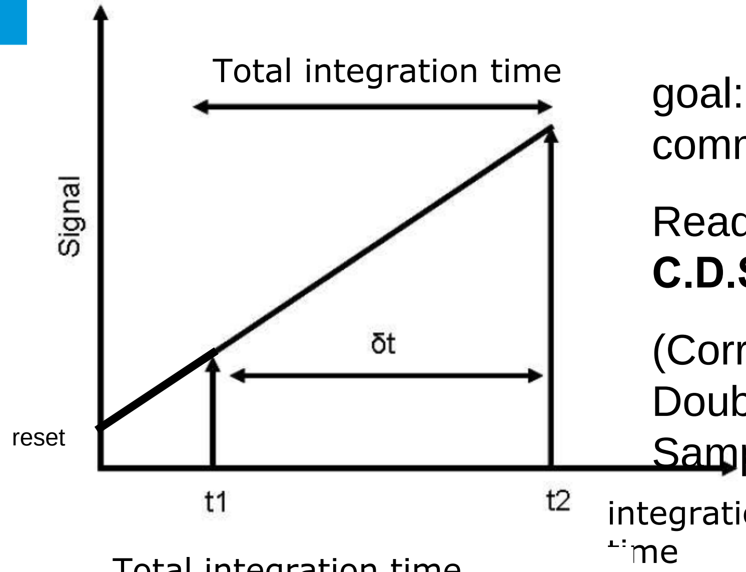
JADE: JWST ASIC Drive Electronics

Specifications

Company	Teledyne
Detector name	HAWAII-2RG
Pixel size	18 µm
Number of pixels	2048 x 2048
Readout frequency	100kHz or 5Mhz
Number of outputs	1,4 or 32
Frame size	Full frame, window mode
Reference	Pixels or one channel
Reset scheme	By pixel, by line or globally



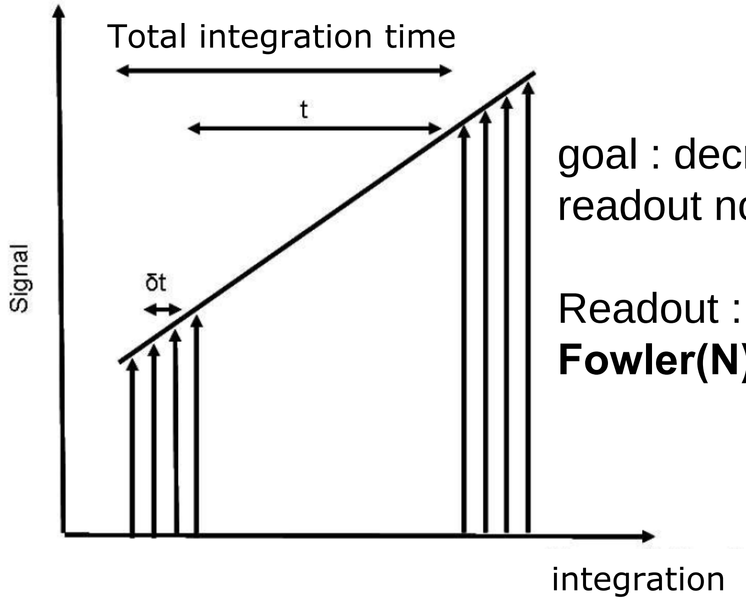
Way of sampling



goal: remove common noise

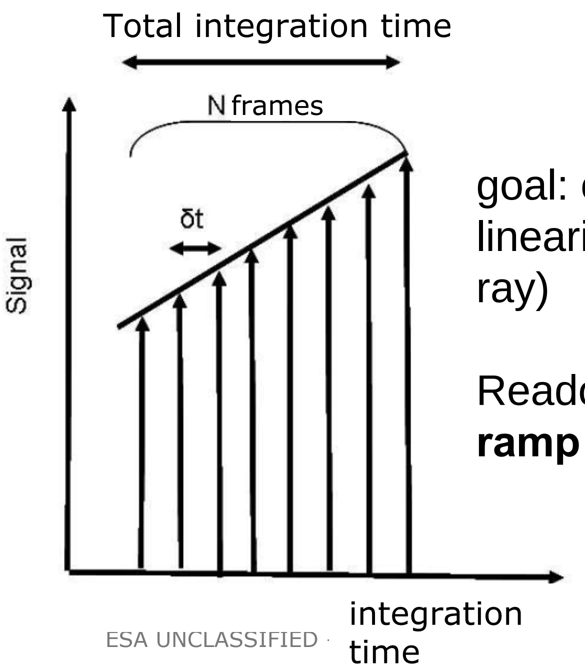
Readout : **C.D.S**

(Correlated Double Sampling)



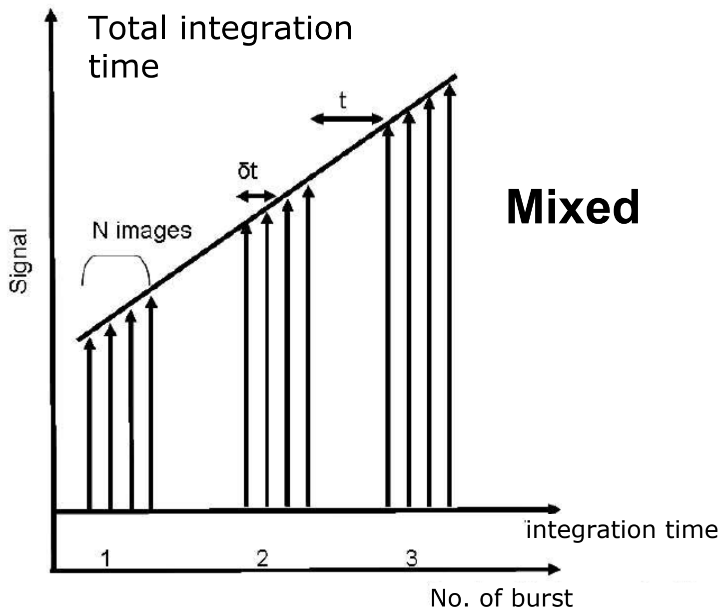
goal : decrease readout noise

Readout : **Fowler(N)**



goal: check linearity (cosmic ray)

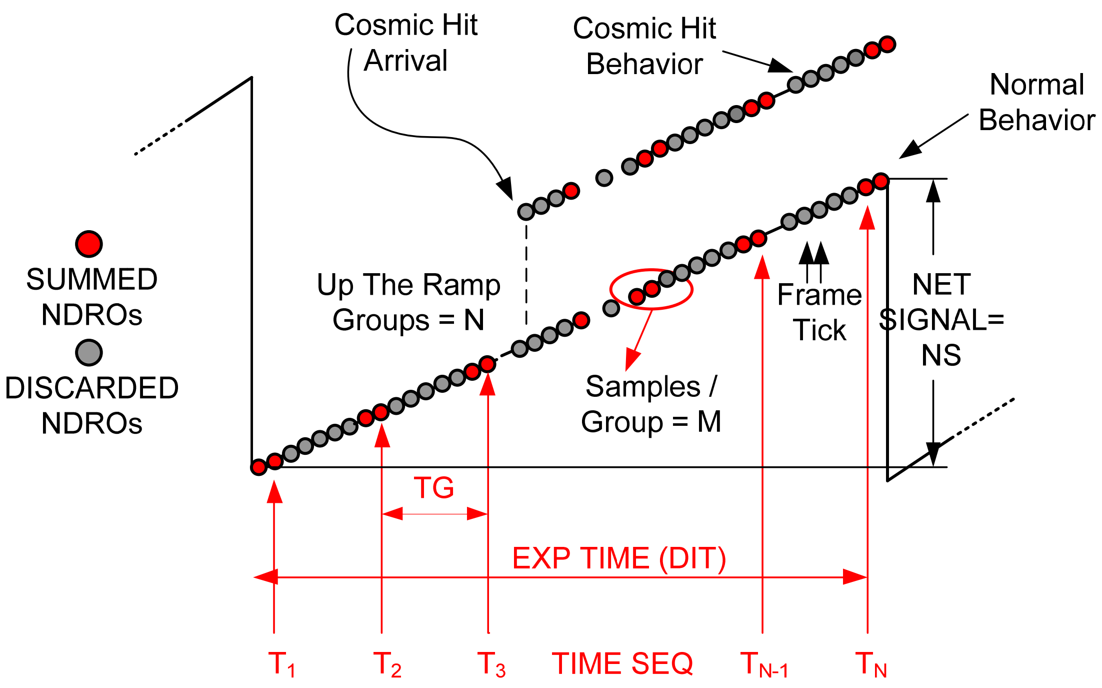
Readout : **up the ramp**



Mixed

Way of sampling

- Example of one acquisition:
  - Non destructive readout (not like a CCD)
  - Evolution of the signal for one pixel



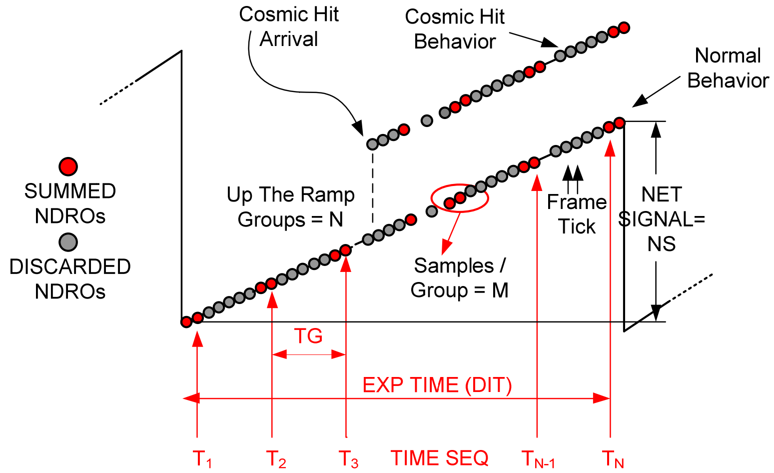
Data processing is needed to compute final signal and its uncertainty

Euclid NISP channel requirements

Requirement:

- Real time processing of 2048*2048 pixels (16 bit per pixel)
- 560s of exposure time

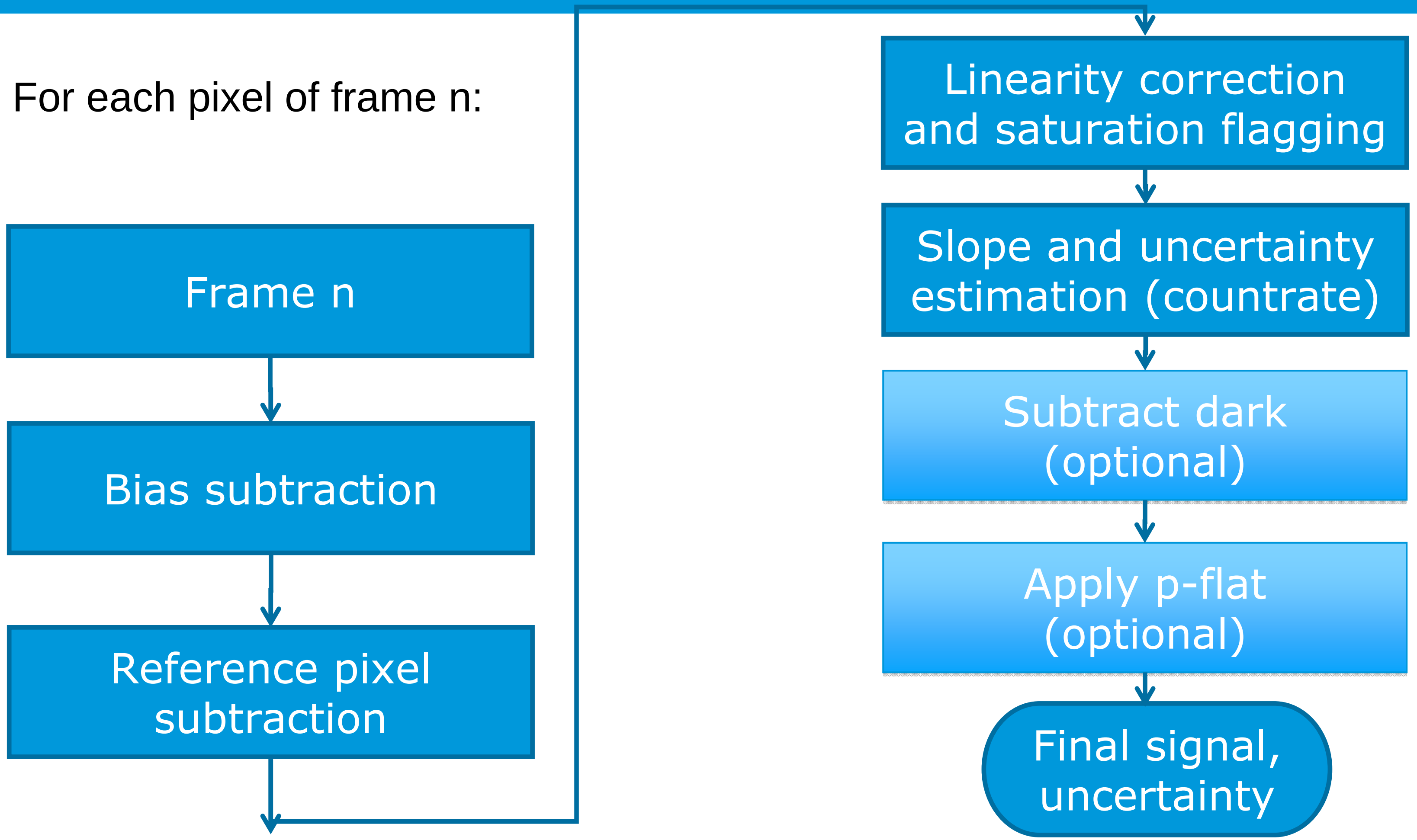
  → baseline : 30 groups of 8 samples and 5 discarded



Between 15s to 32s (time between groups) to process each frames (2048*2048 pixels)

Overview of pre-processing steps

For each pixel of frame n:



Bias

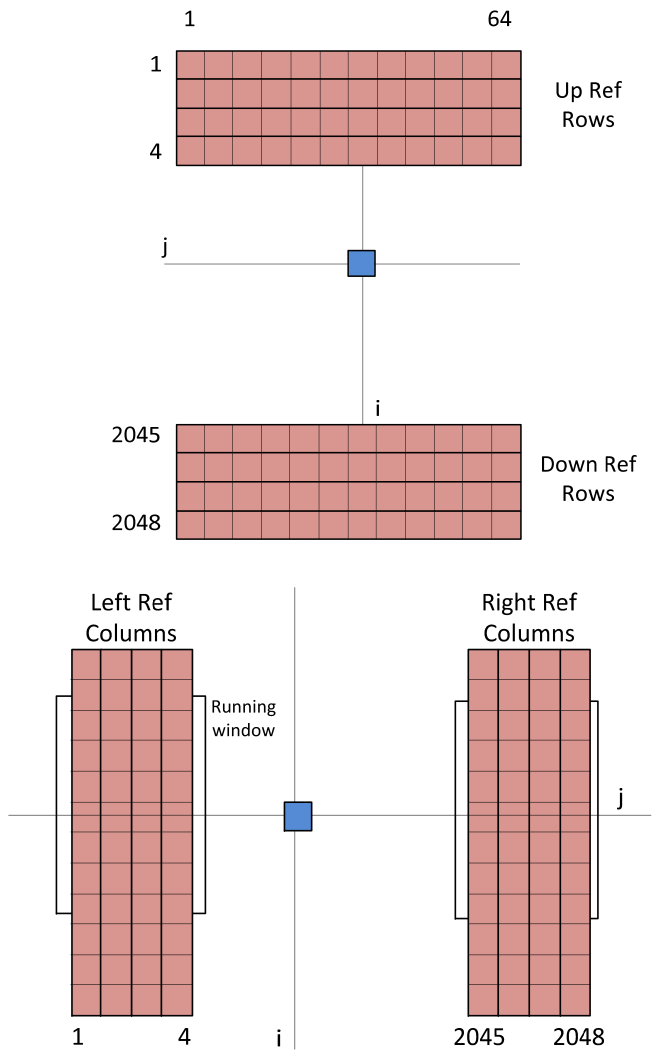
- Goal: remove pixel-to-pixel variation in offset
- Subtract a map of bias frames to all frames in science exposure
  - Need to access to a bias frame (2048*2048 pixels)
  - One subtraction for each pixel (2048*2048 pixels)
  - Quicker if it is done in parallel for each pixels

Function	Operations per Pixel	
	Integer	**Floating point**
Subtract Bias	6.0	1.0

Results obtained thanks to Andreas Jung (TEC-SWE)

Reference pixel correction

- Goal: remove common noise
- For each 32 outputs :
  - calculates the mean of the odd and even pixel of the first 4 and last 4 rows and removes it from the odd and even pixel of the image.
  - Running average of the lateral pixel



Function	Operations per Pixel	
	Integer	Floating point
Reference Pixel Correction	10.5	2.1

Operations can be done in parallel for each outputs, odd and even pixels

Results obtained thanks to Andreas Jung (TEC-SWE)

Linearity correction

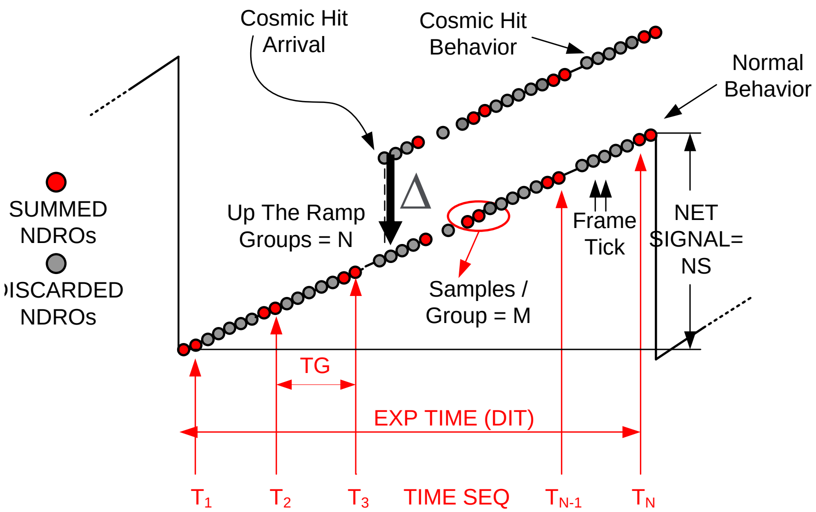
- Goal: correct from non-linearity in the detector
- 4th order polynomial correction with a single set of coefficients for all pixels or, in the worst case an independent set for each pixel
    - Need to access to 4 frames of coefficients

Function	Operations per Pixel	
	Integer	Floating point
Linearity Correction And Saturation Detection	15.0	12.0

Results obtained thanks to Andreas Jung (TEC-SWE)

Slope and uncertainty calculation

- Real time processing and cosmic detection
- for each pixel:
  - Estimation slope and intercept (linear least square method)
  - Extrapolation next point
  - Add noise to interpolated point
  - Flag if next point is not in the threshold
  - Subtracting running mean of all the following differences found (Δ)
  - Continue estimate slope and intercept



CPU results without cosmic

Environment:

LEON2 @ 80MHz with 3 memory wait states and caches enabled and execution only in SDRAM

Euclid pre-processing algorithms profiling program - Version 20110601_1415
Image size: 1024x1024
Timer CLOCKS_PER_SEC: 1e+06
Main: start...

- **Subtract Bias**: start... end.
  --> Execution time: 447.591ms
- **linearity Correction And Saturation Detection**: start... end.
  --> Execution time: 2177.544ms
- **subtract Reference Pixel**: start... end.
  --> Execution time: 744.822ms
- **detect Cosmic Ray**: start... end.
  --> Execution time: 6479.772ms

For each frame (1024*1024)

$t_{process}$= 9.8s

→ 40s for 2048*2048 pixels!

- **calculate Final Signal Frame**: start... end.
  --> Execution time: 2041.450ms
- **subtract Dark Current Pedestal**: start... end.
  --> Execution time: 447.591ms
- **apply Flat Field Correction**: start... end.
  --> Execution time: 447.592ms

Adding 2.9s at the end

Main: ...end reached.

Improvement can be done (only integer is on going) but multi-core architecture is beneficial

Results obtained thanks to Andreas Jung (TEC-SWE)

Consequences

- Memory consumption for 4 MPixel →228MB is expected (can be decreased to 148MB if we assume same coefficient for non-linearity correction)
- Only 6 frames can be processes (instead of ≈240) in 400s

→ Can be improved with 3, 4… Leon2 per detector

  → Power consumption increase

  → Need more space in the payload

Multi-core processor is an ideal candidate!!

Conclusion

- Data processing for Euclid
  - 16 detectors, 2048*2048 pixels per detector
  - For each detector and each frame : multi parallel operations (bias, reference pixels correction)
  - Non optimized results with LEON2 show to much time needed

→ For the incoming mission at L2 with large focal plane multi-core processing is welcome!

Telemetry

– For K-band communications, the maximum daily downlink telemetry rate is 0.85 Tbits/day for a daily telemetry communication period of 4 hours.