Observation of asteroids on the GAIA astrometric focal plane

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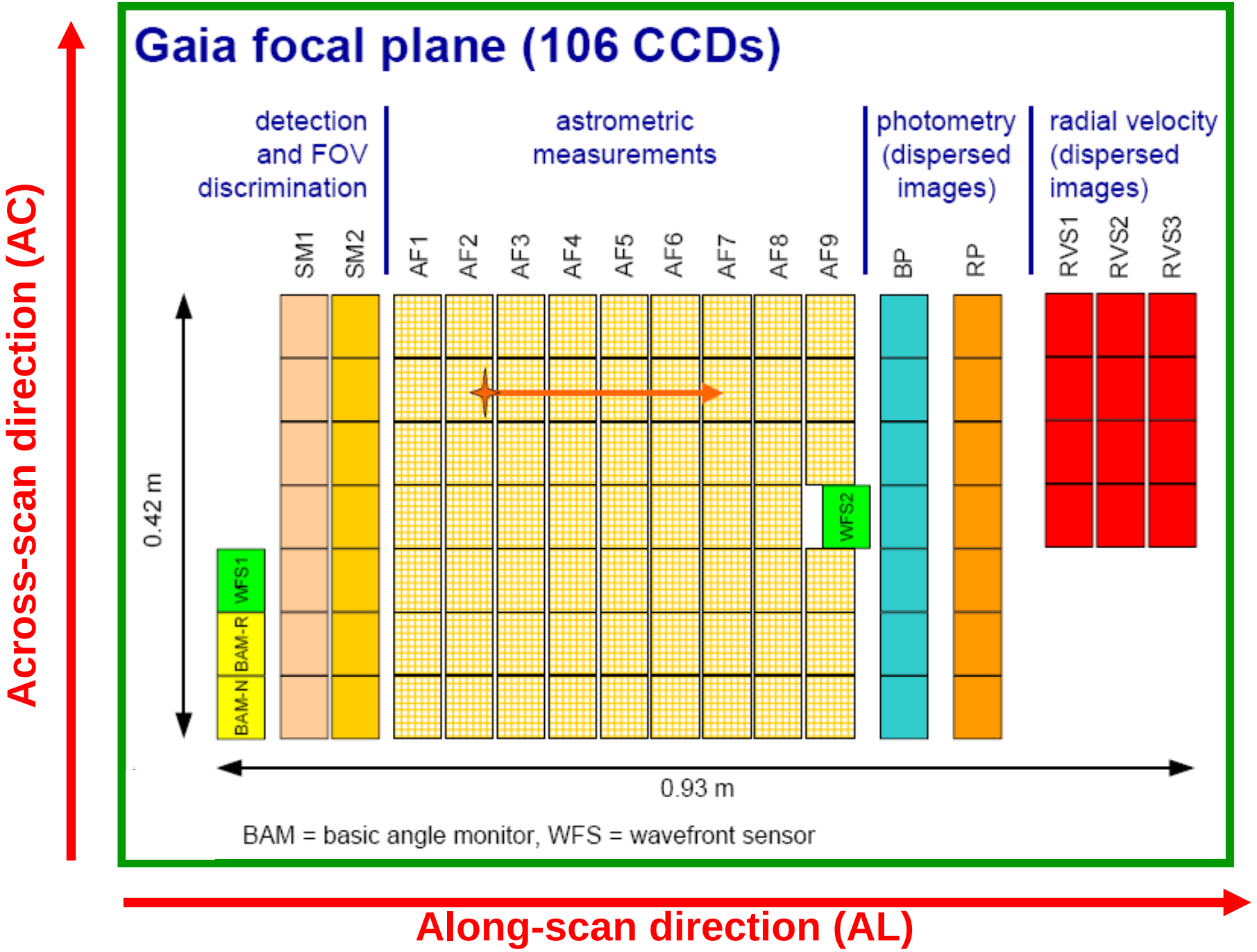
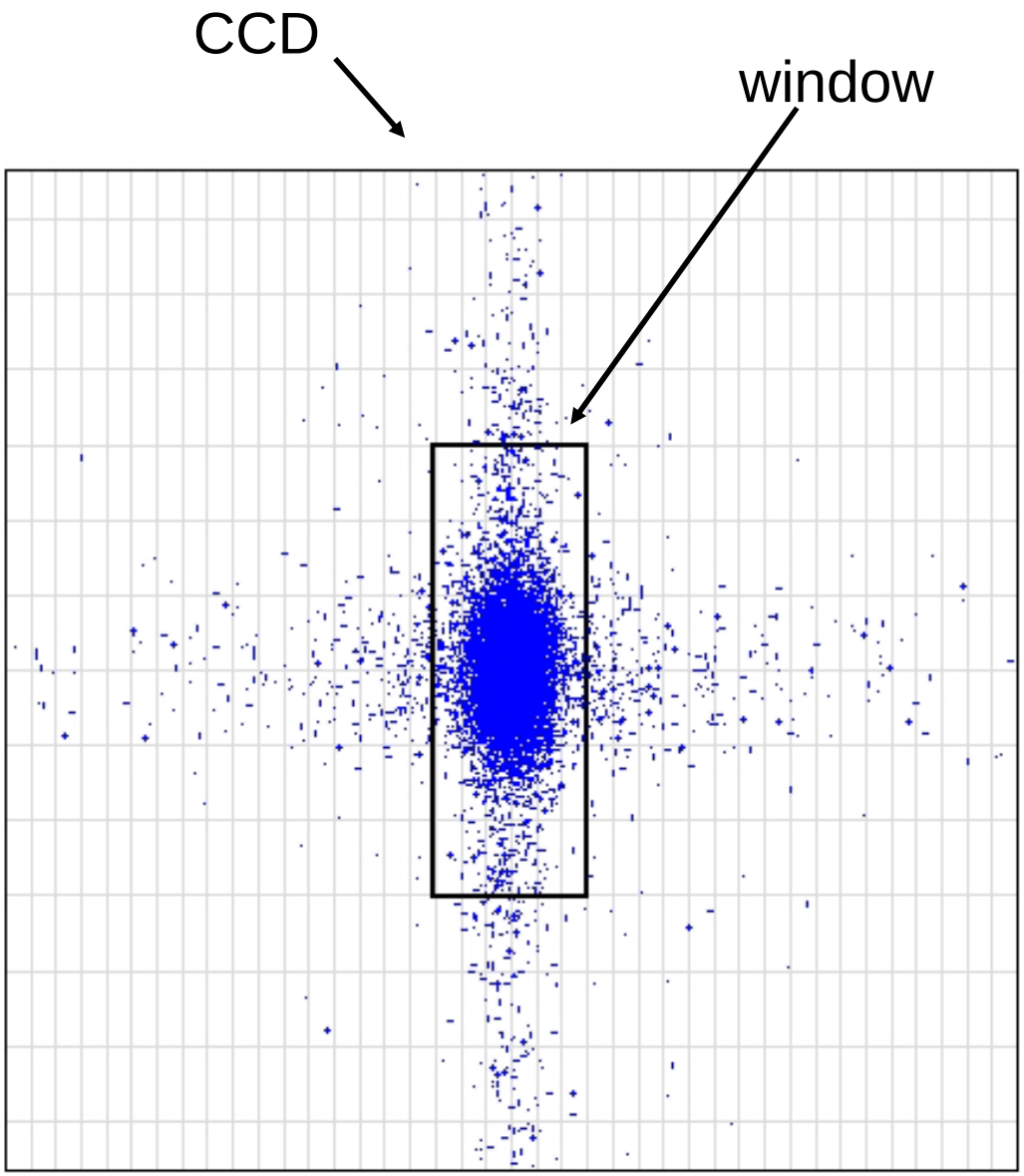
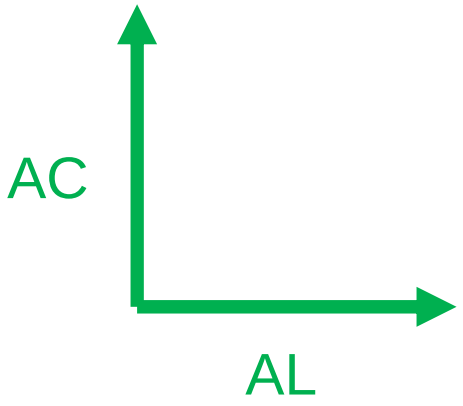
INAF – Osservatorio Astronomico di Torino

"Solar System science before and after Gaia"
Pisa
May 4-6, 2011


Gaia focal plane (106 CCDs)
detection and FOV discrimination
astrometric measurements
photometry (dispersed images)
radial velocity (dispersed images)
SM1
SM2
AF1
AF2
AF3
AF4
AF5
AF6
AF7
AF8
AF9
BP
RP
RVS1
RVS2
RVS3
WFS1
BAM-R
BAM-N
WFS2
0.42 m
0.93 m
BAM = basic angle monitor, WFS = wavefront sensor
Across-scan direction (AC)
Along-scan direction (AL)

How does the instrument work?





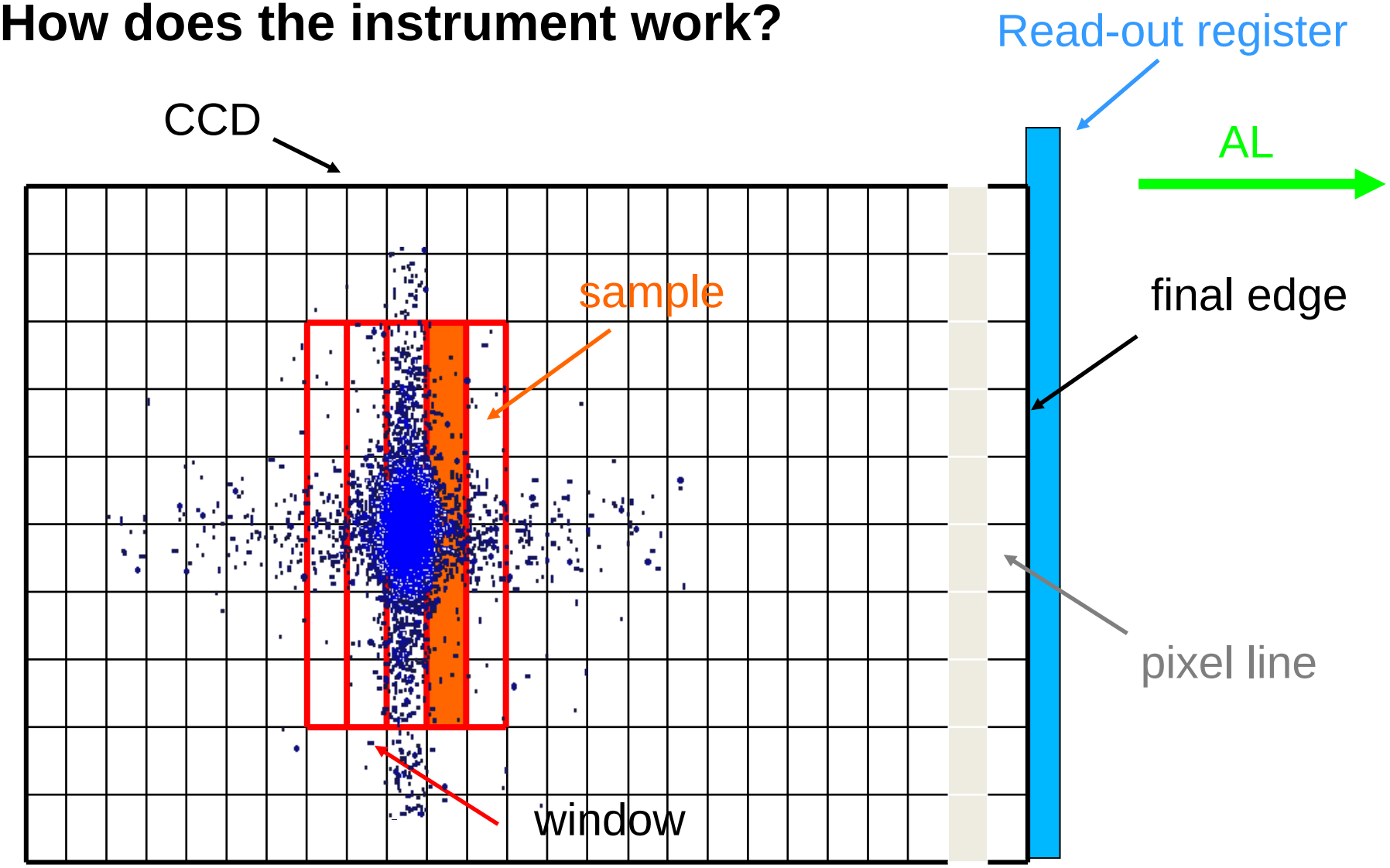
CCD matrix is 4500 pixels AL and 1966 pixels AC.

Only a small window of pixels around each source is read-out and transmitted.

The size of the window depends on the magnitude of the source.

Generally the window is 6 or 12 pixels wide in the AL scan direction.

How does the instrument work?



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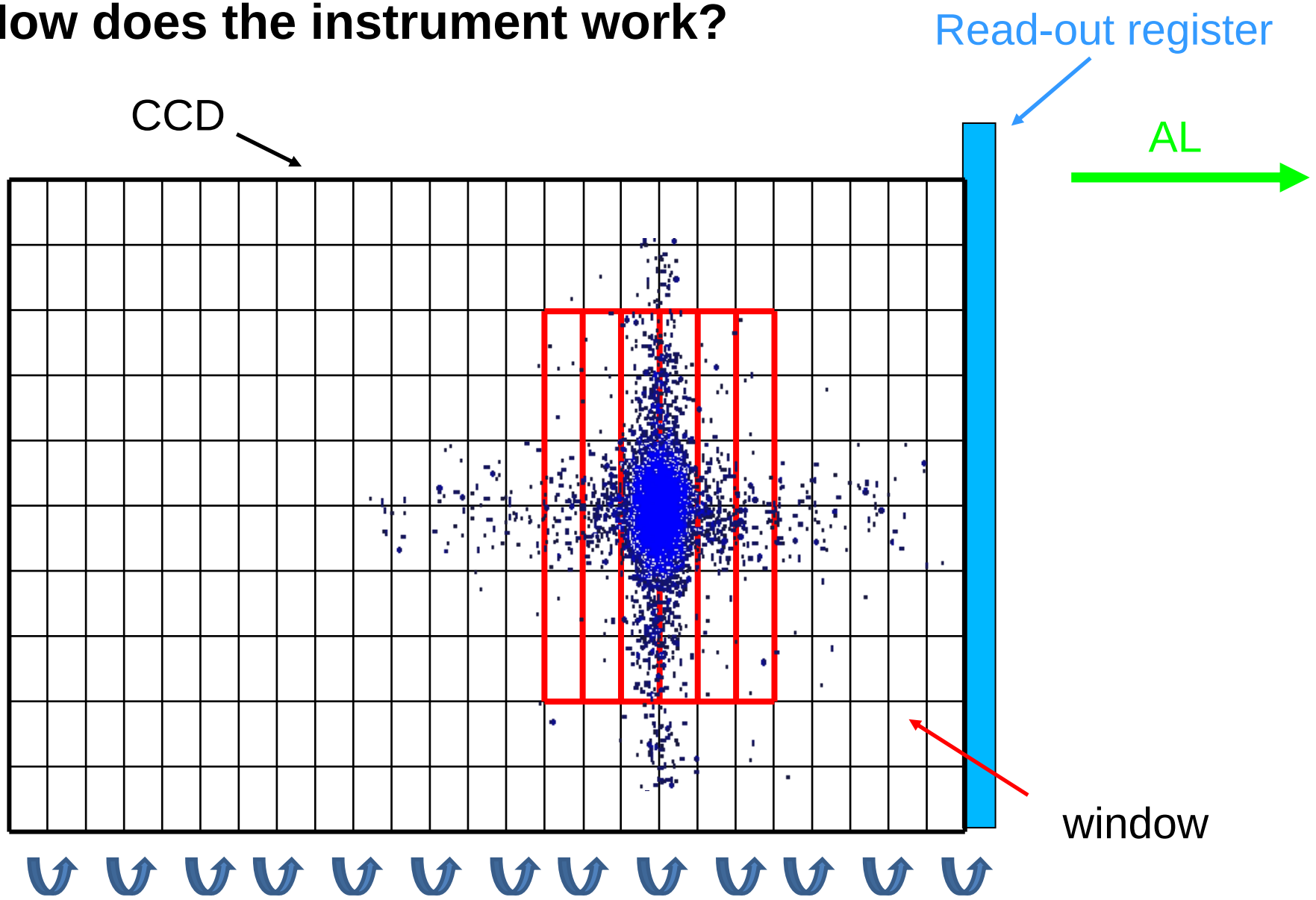
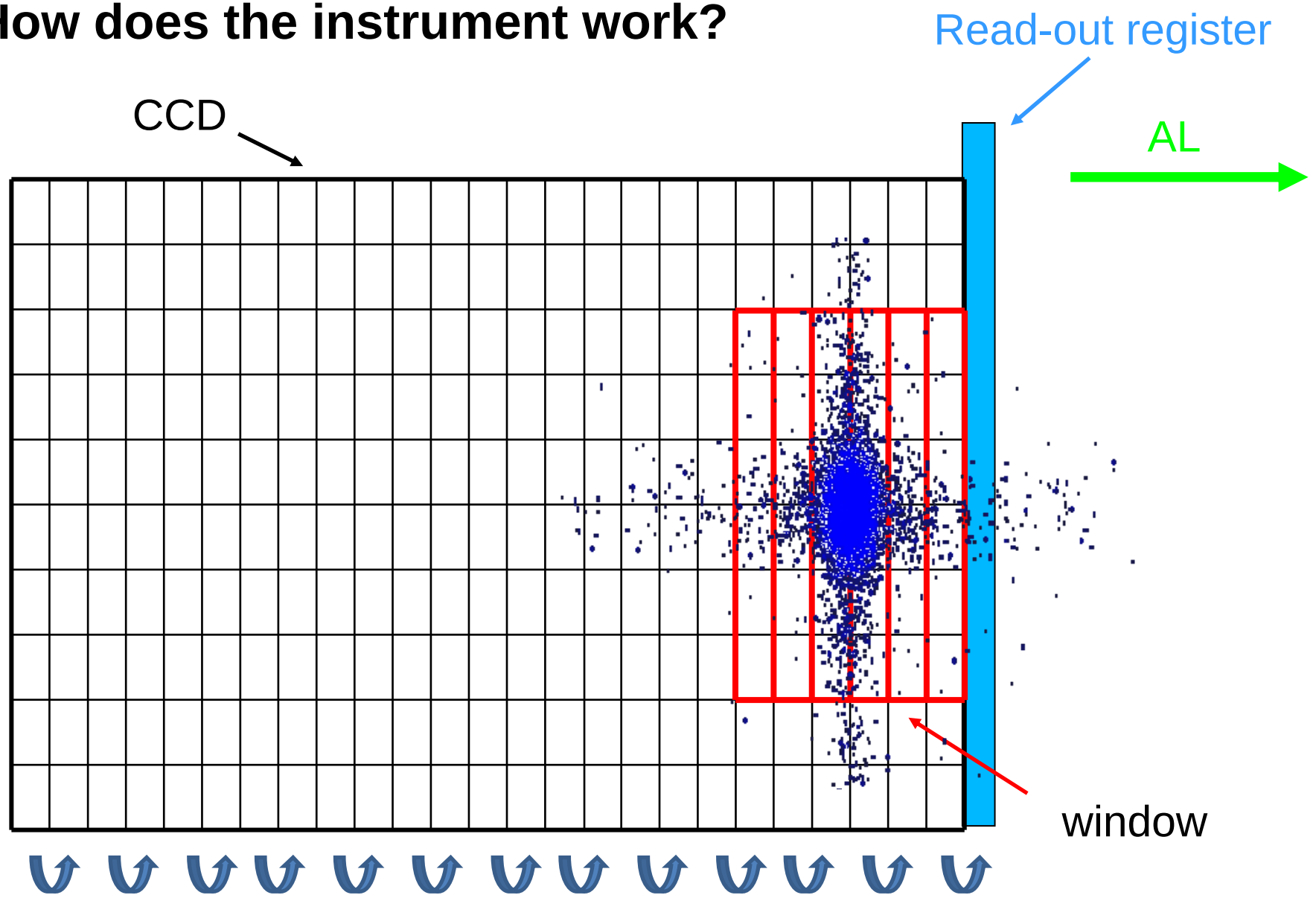


Time Delay Integration (TDI) mode: charge transfer pixel to pixel following the AL motion of the signal (for <u>fixed stars</u>)

How does the instrument work?



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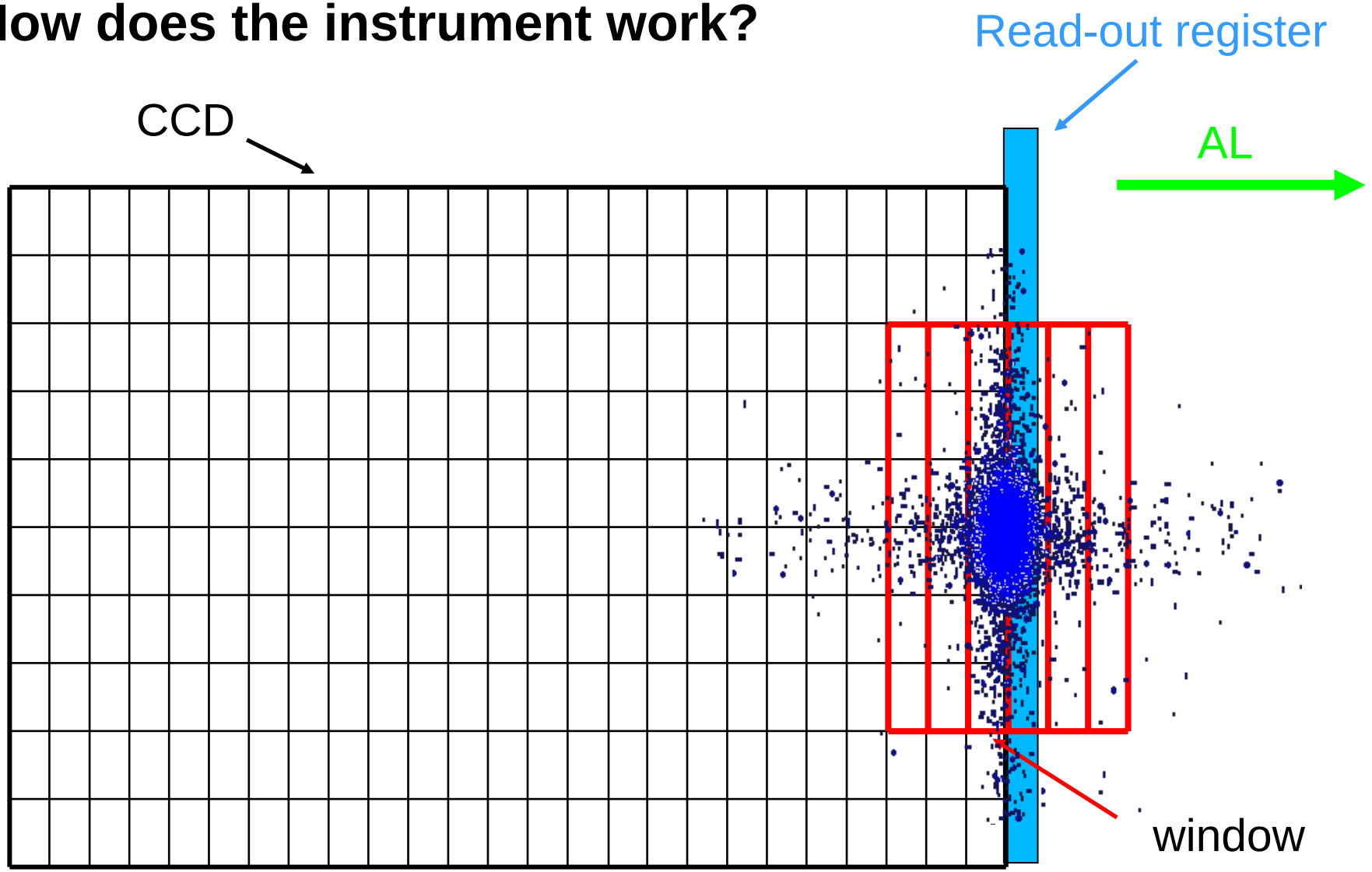
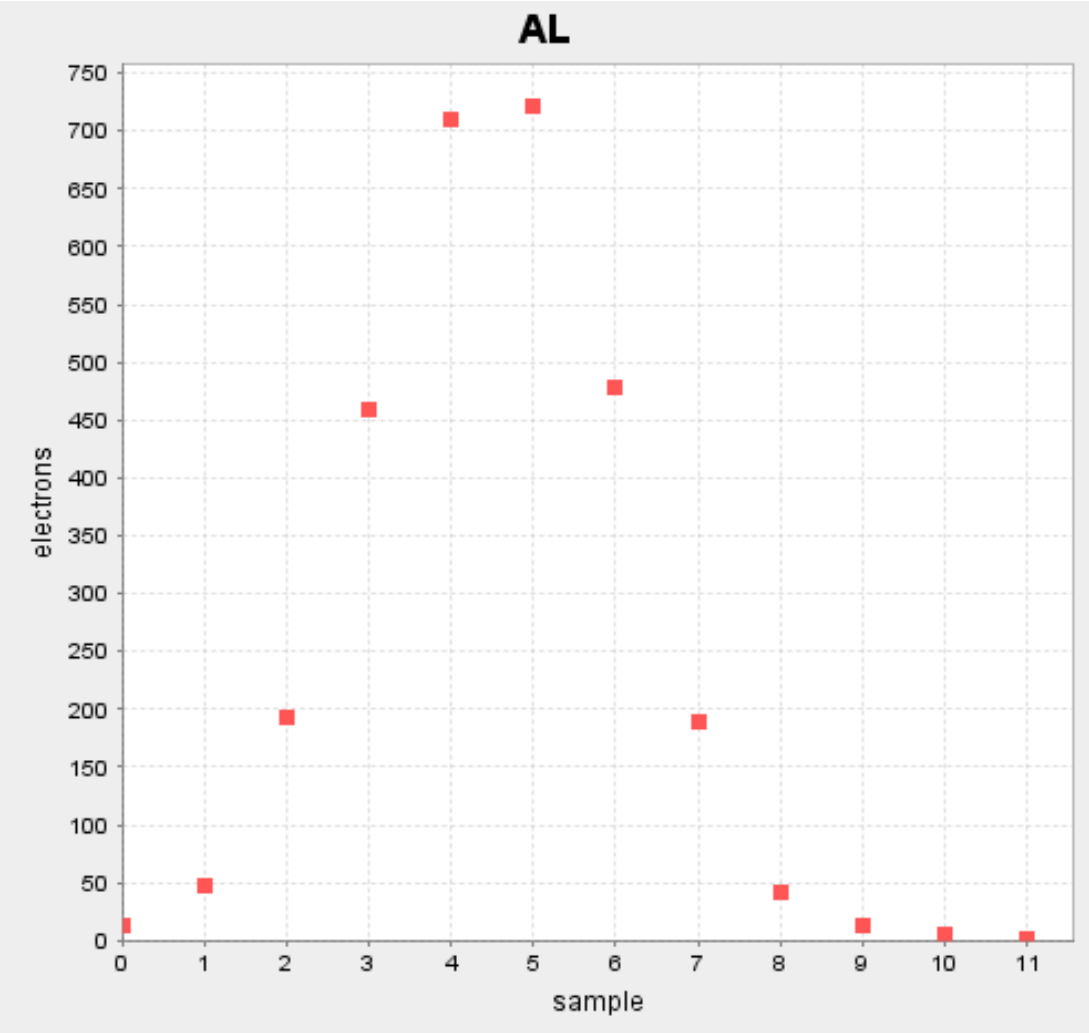


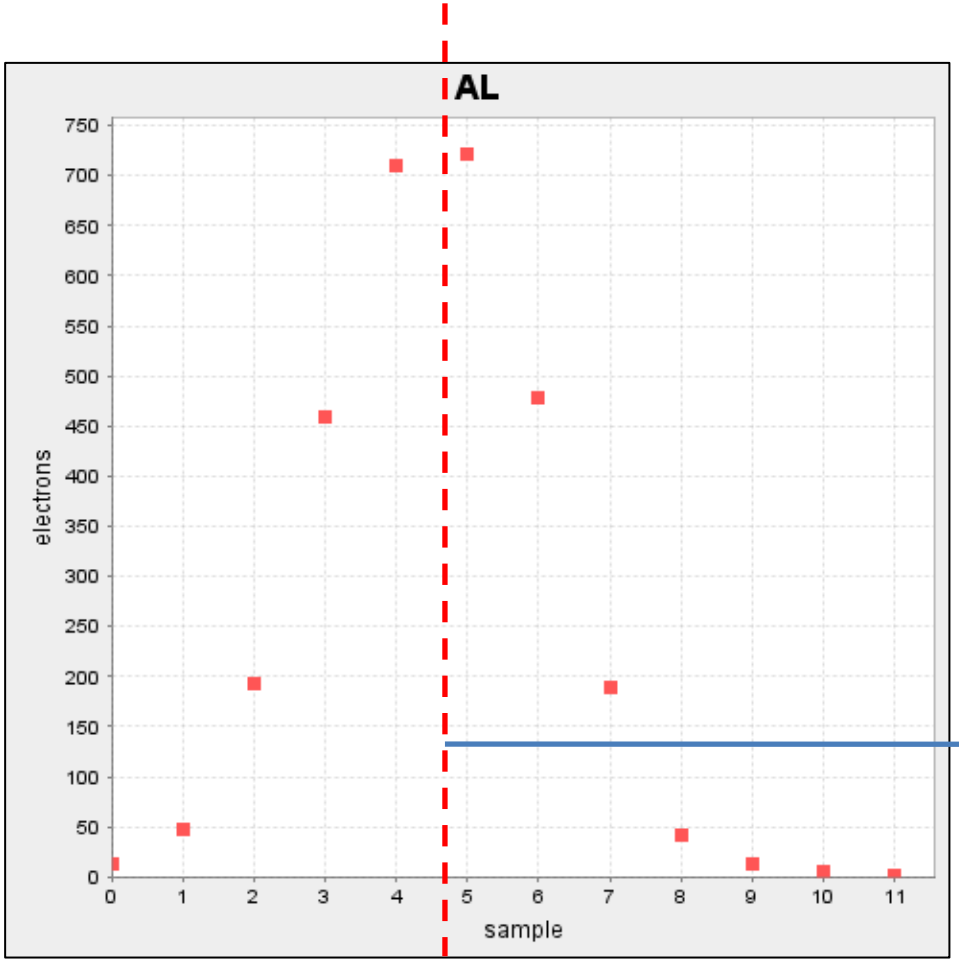
Number of collected photo-electrons in each window sample (ADUs)

Final transmitted signal

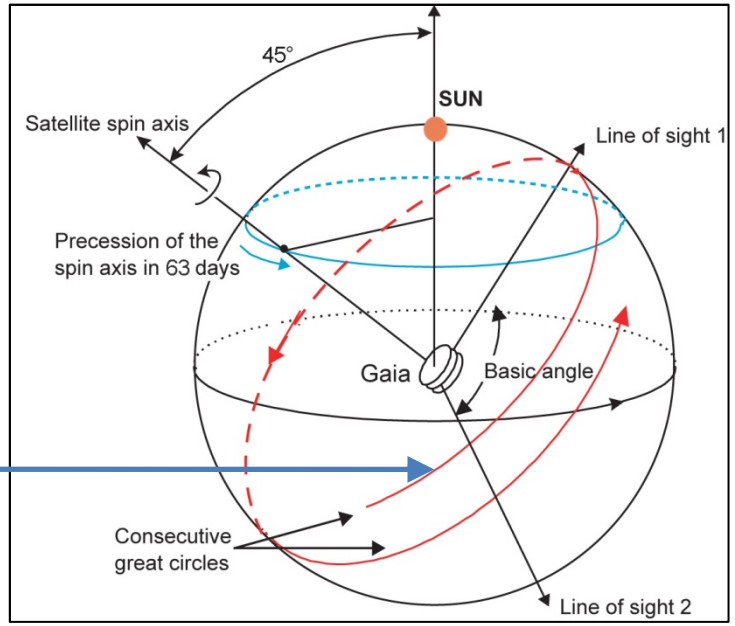


AL direction

Final transmitted signal: astrometry



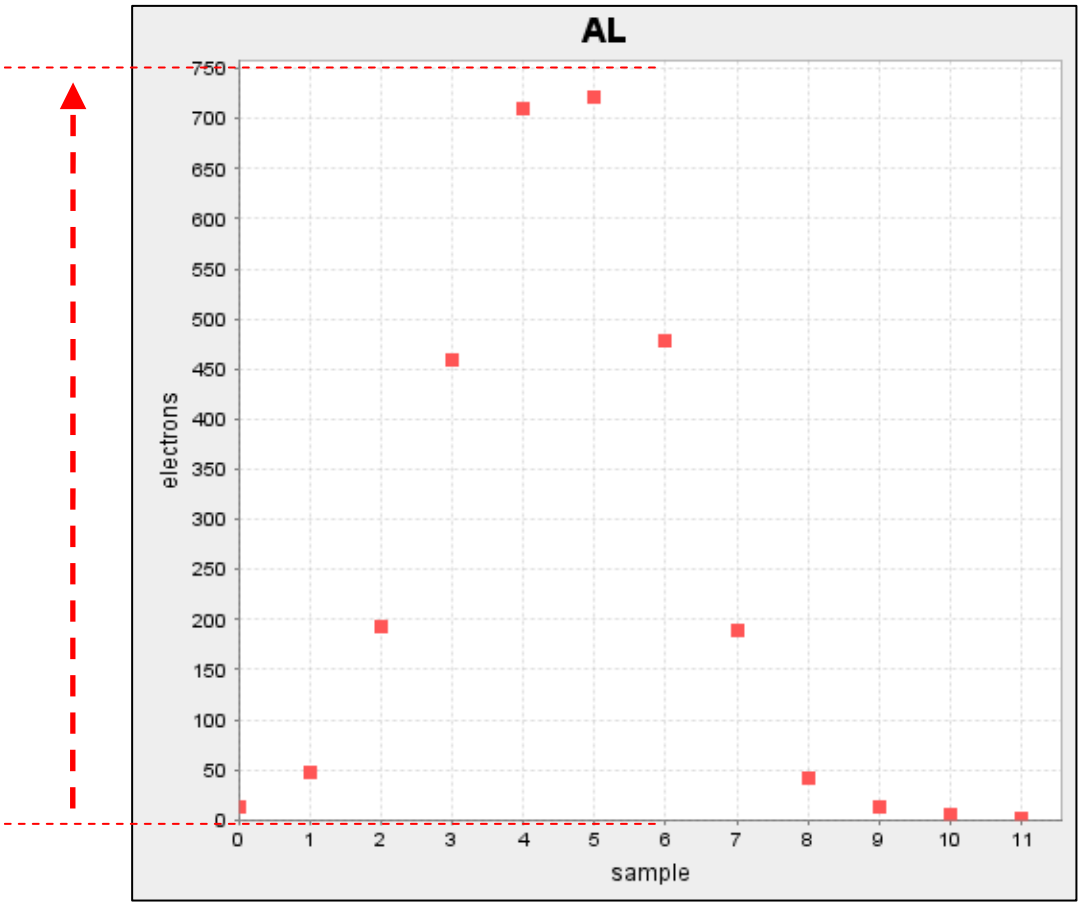
orbit determination



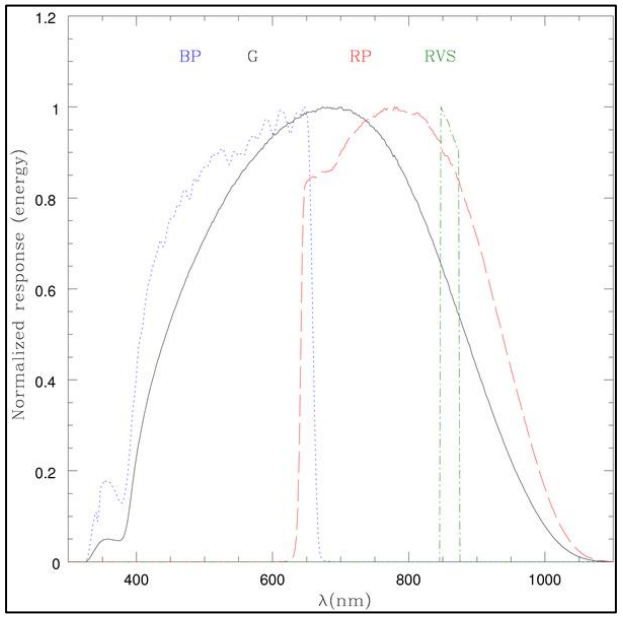
centroid determination

Astrometric reduction (α, δ)

Final transmitted signal: photometry



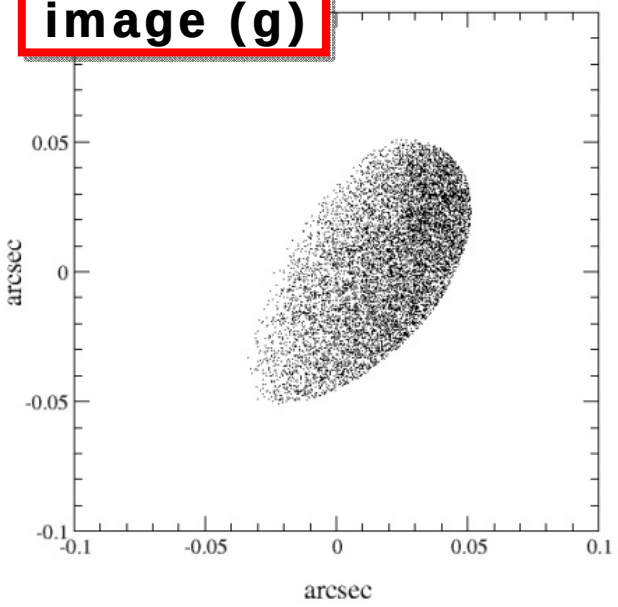
photometric Inversion: shapes and spins



flux determination

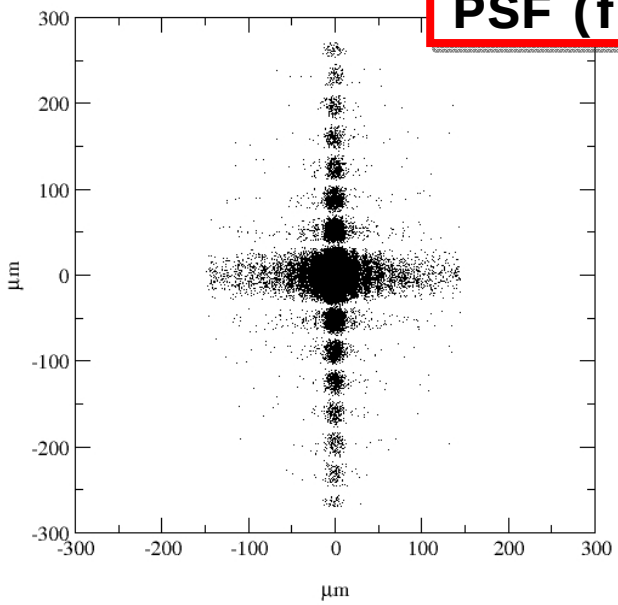
G-band magnitude

image (g)



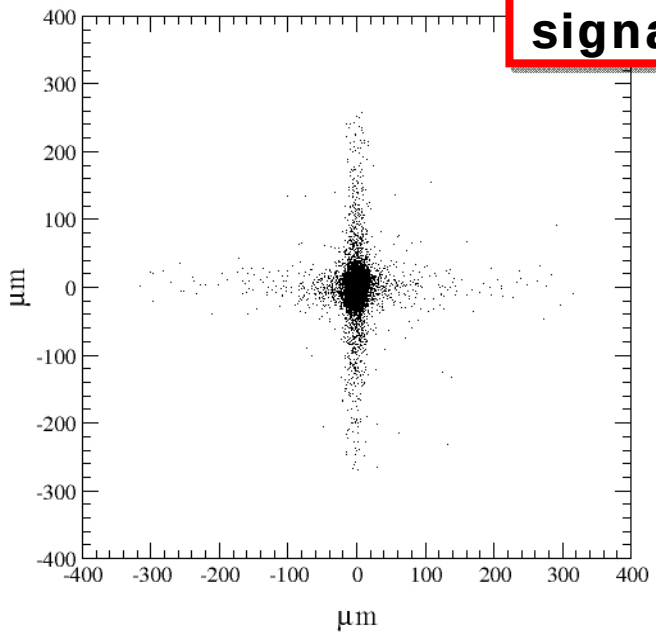
*

PSF (f)



convolution

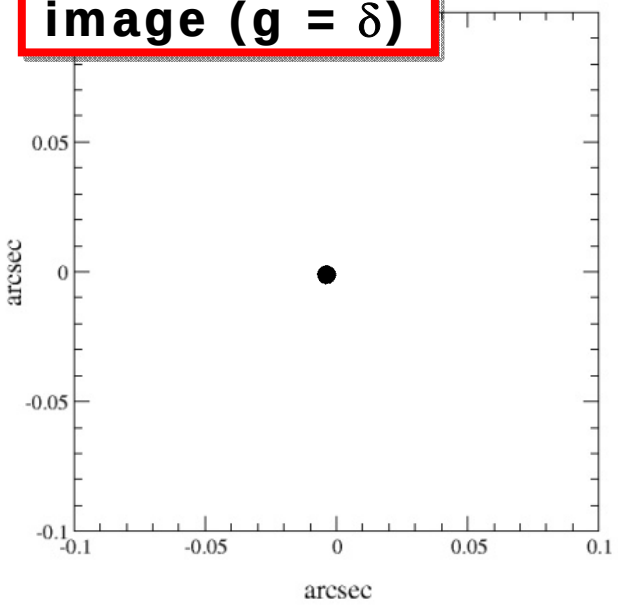
signal (g*f)



signal formation for <u>extended</u> sources (asteroids)

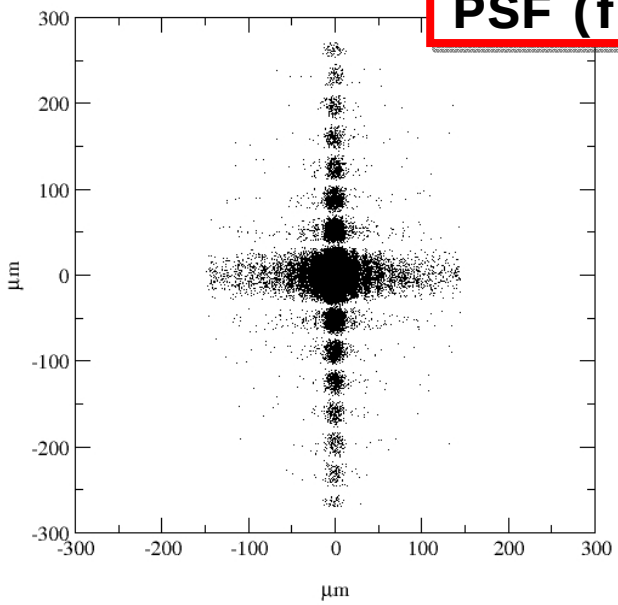
$$(f * g)(t) = \int f(\tau) g(t - \tau)\, d\tau$$

image (g = δ)



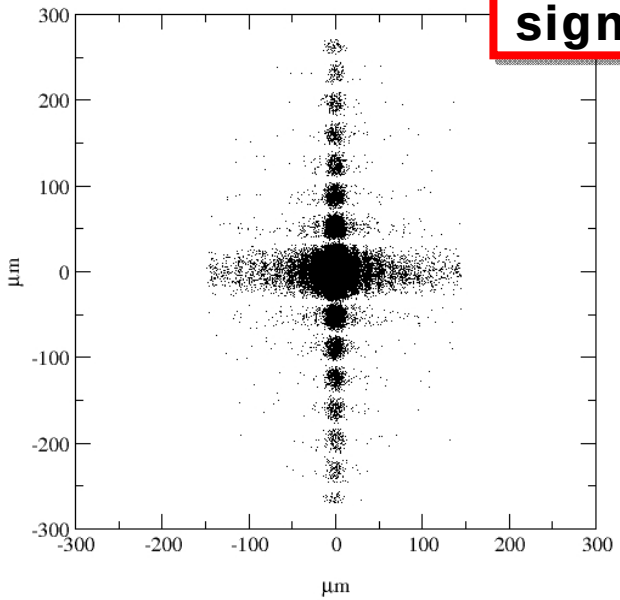
*

PSF (f)



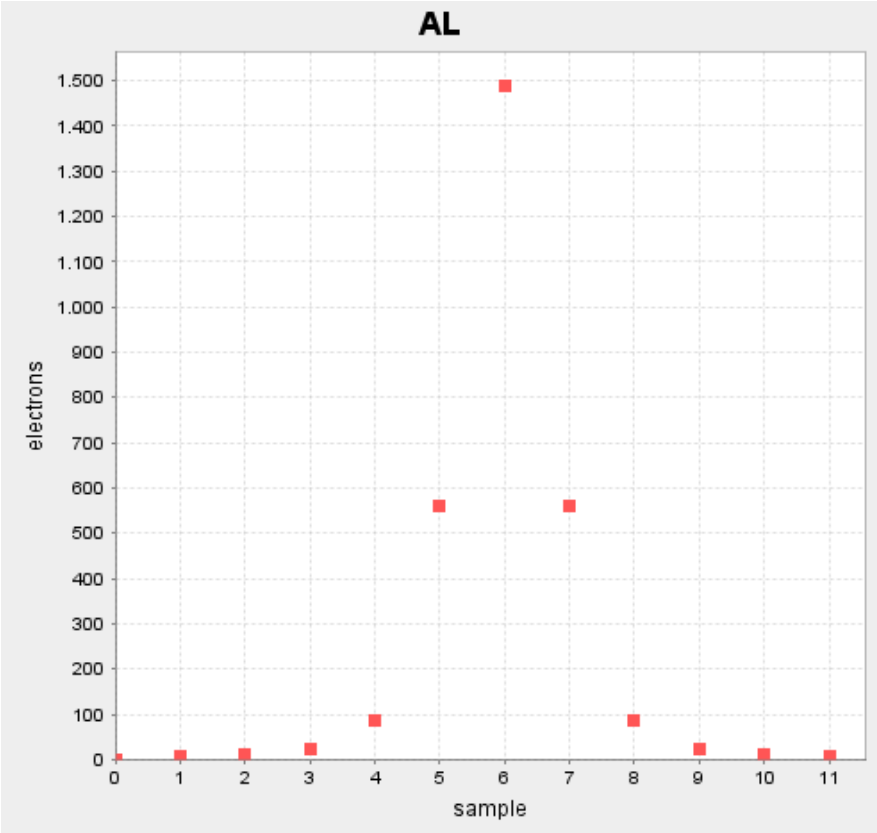
convolution

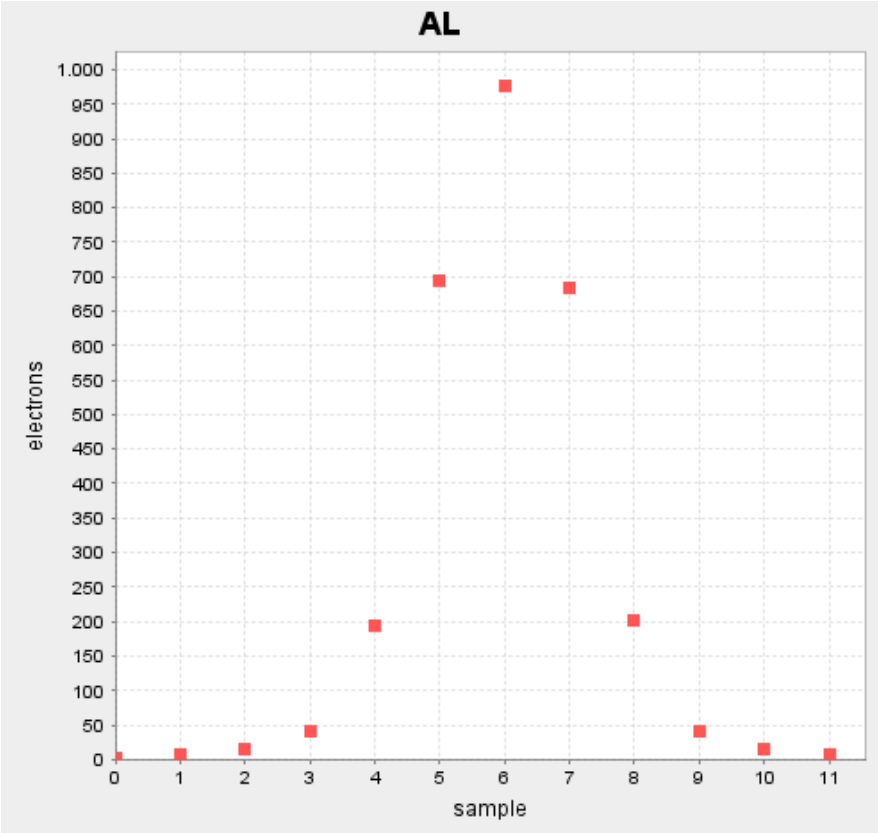
signal (g*f) = f



signal formation for <u>point-like</u> sources (stars)

$$(f * g)(t) = \int f(\tau) g(t - \tau)\, d\tau$$

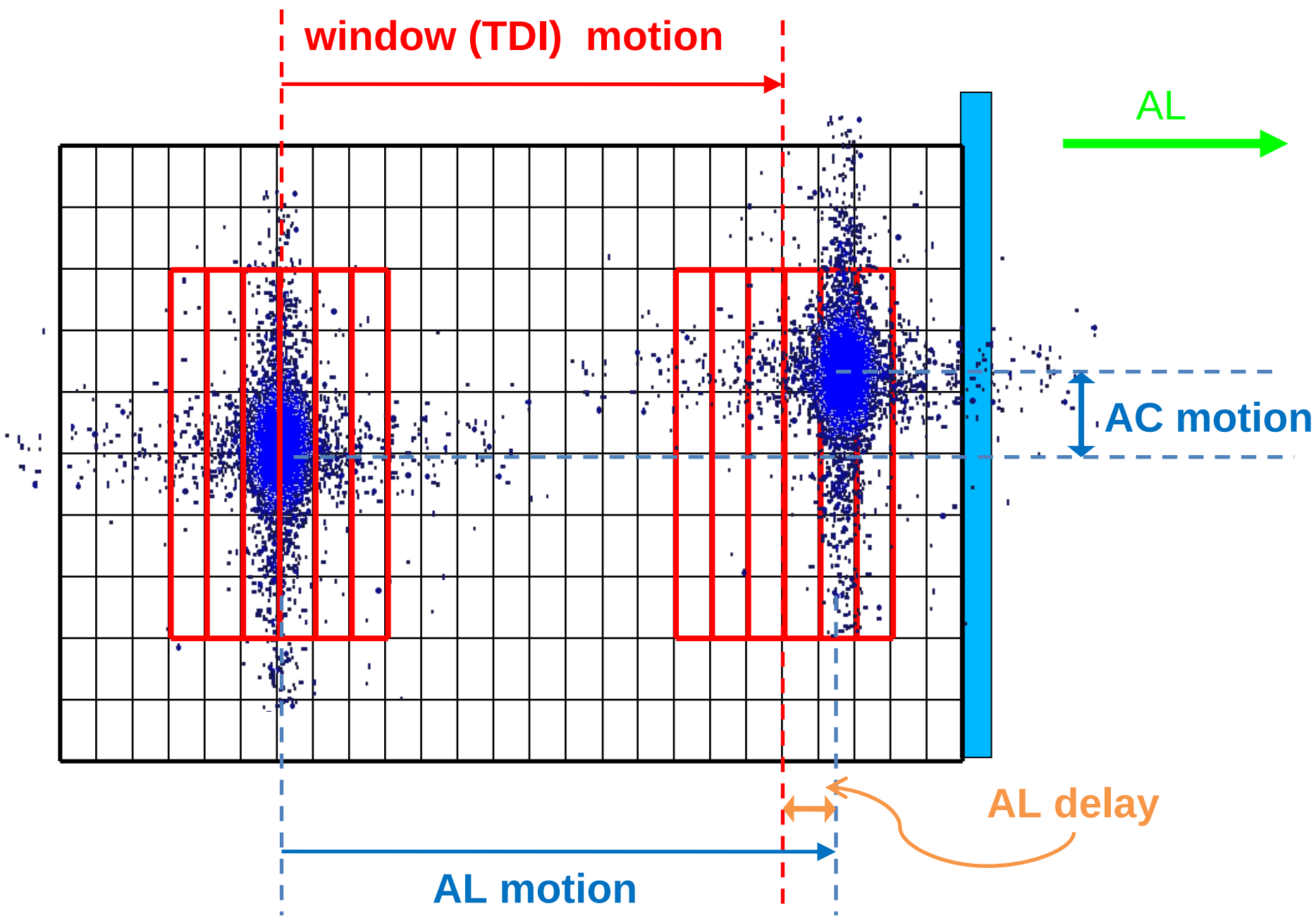


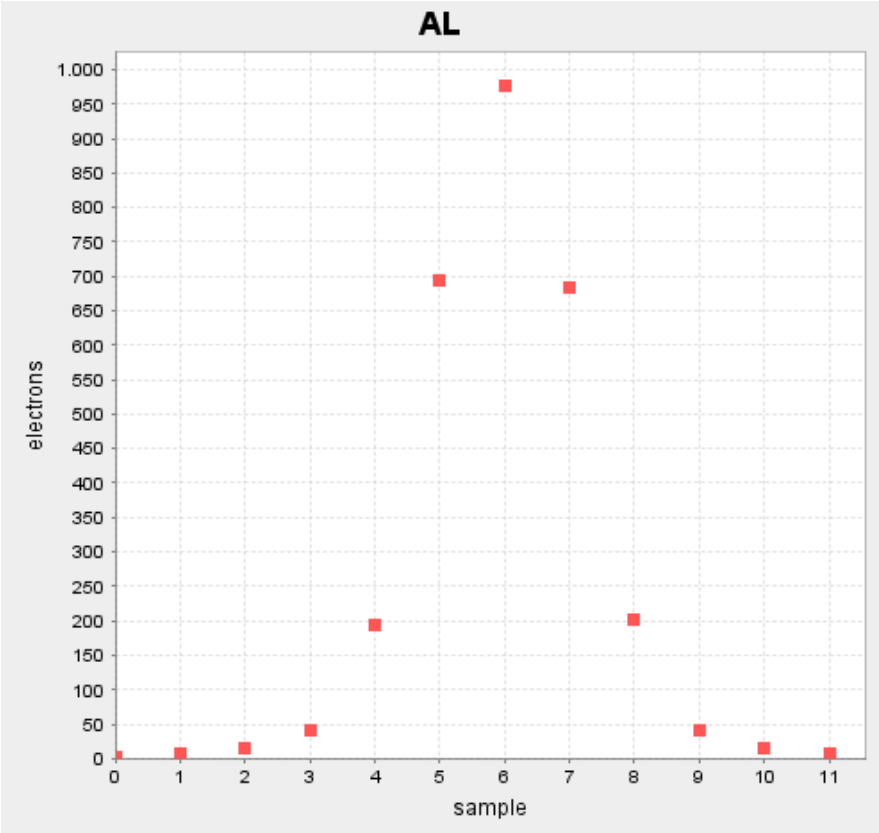


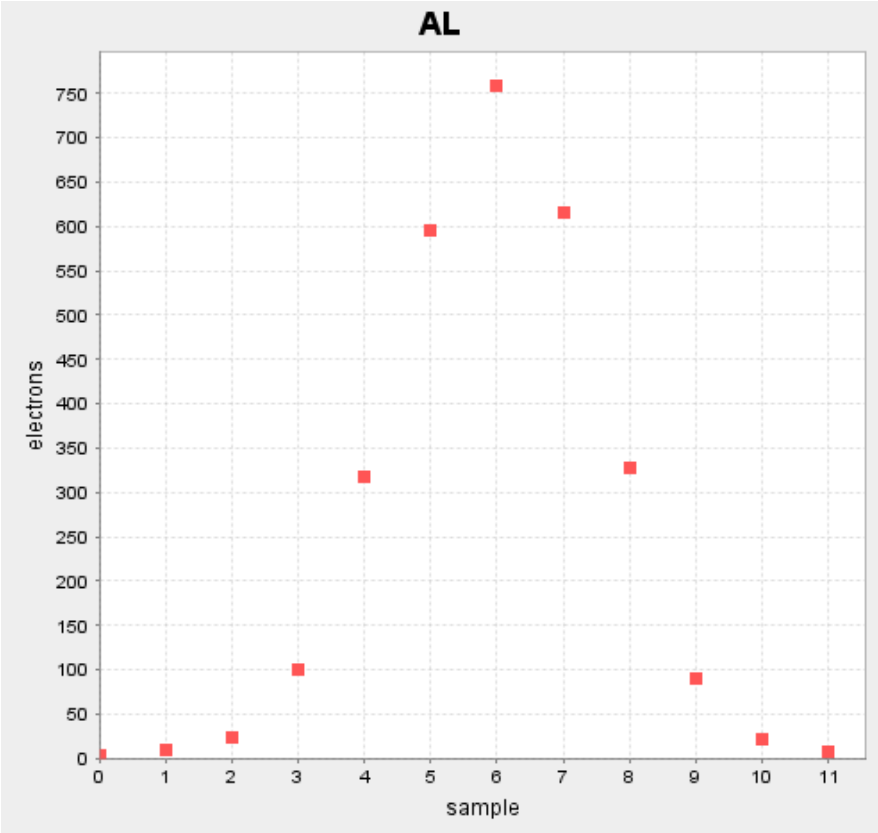
point-like source

extended source (∅ = 3 pixels):

- **How much is it different from a PSF signal?**
- **Can the angular size be measured?**


window (TDI) motion
AL
AC motion
AL delay
AL motion

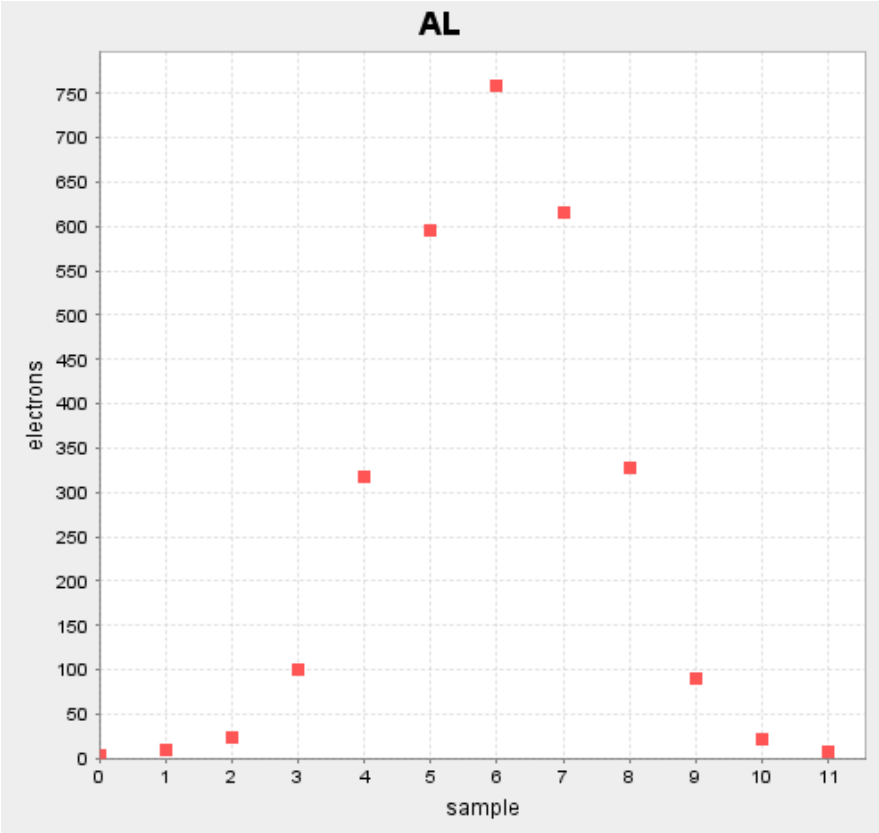




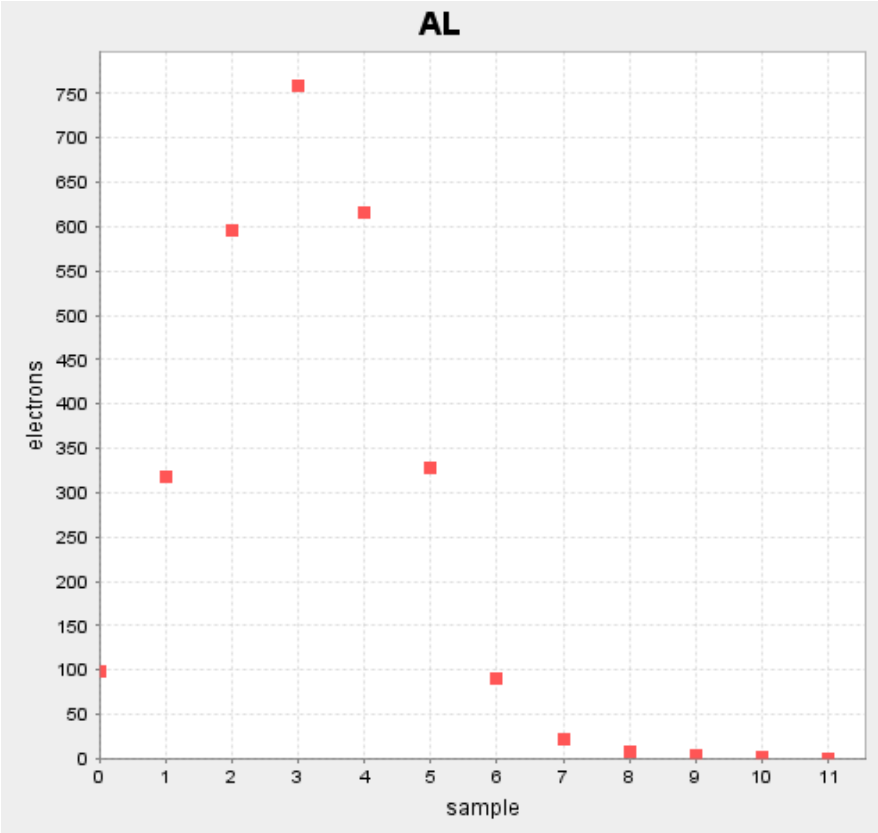
extended
source
(∅ = 3 pixels)

extended & moving
source
(~ 100 mas/sec):

Additional signal spread:
“extra-size” in apparent
angular extension



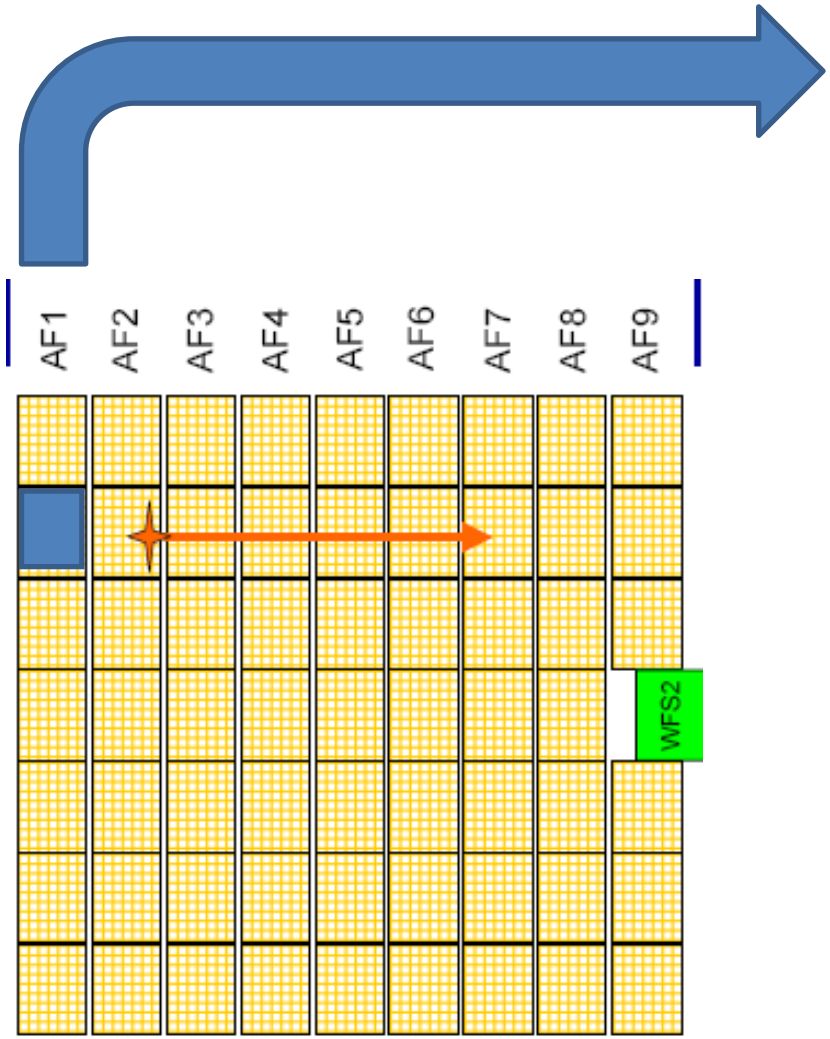
extended source (∅ = 3 pixels)

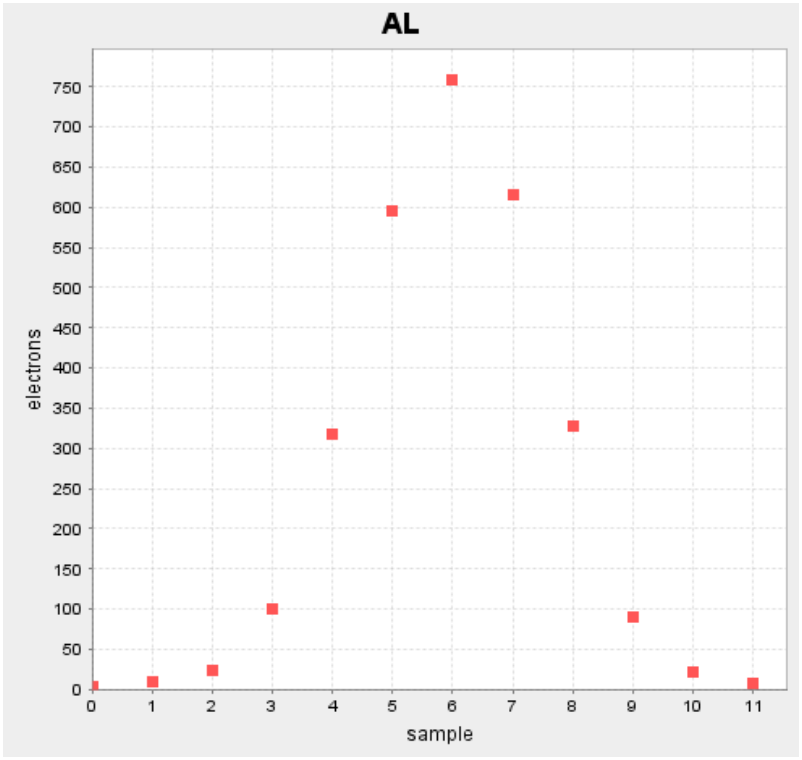


extended & moving source (delay of 3 pixels):

Not TDI-synchronized motion: shift of the centroid position

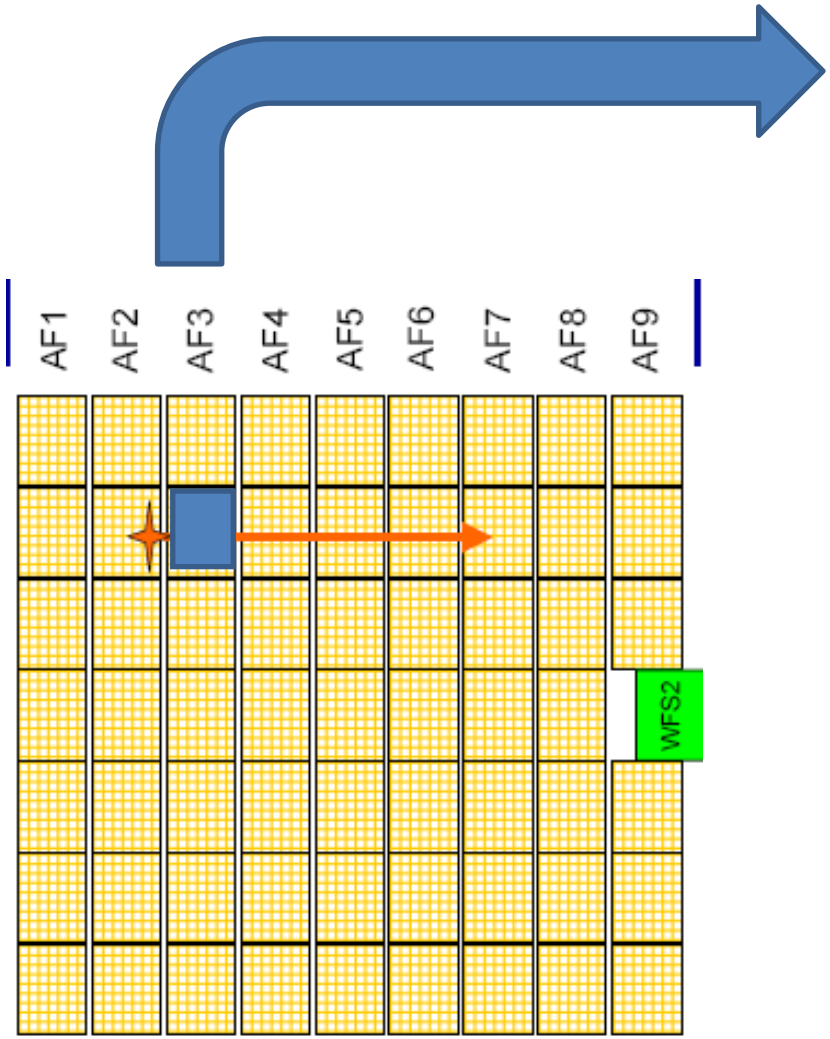
Centroids' delays and motion determination

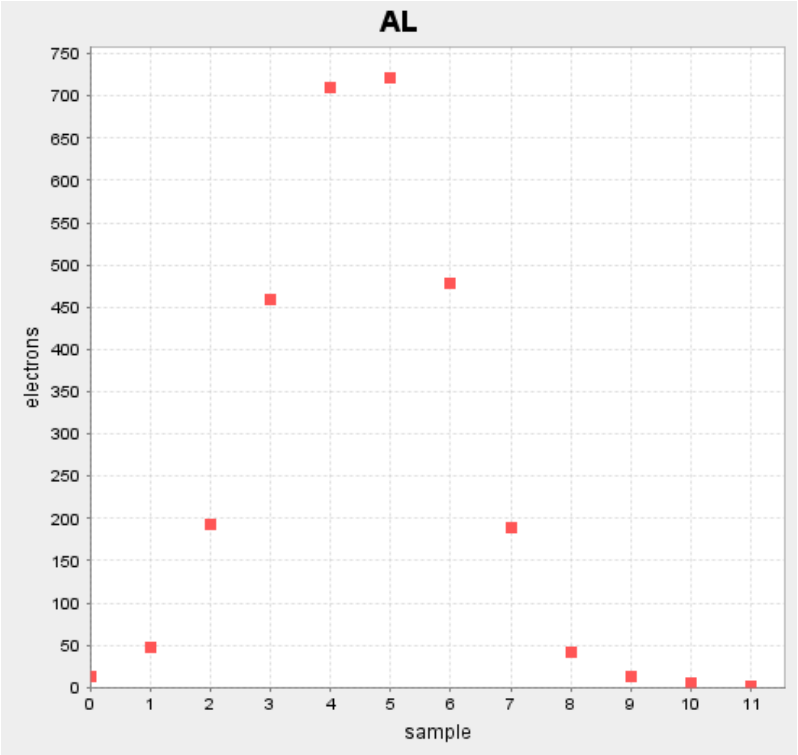




AF1 centroid

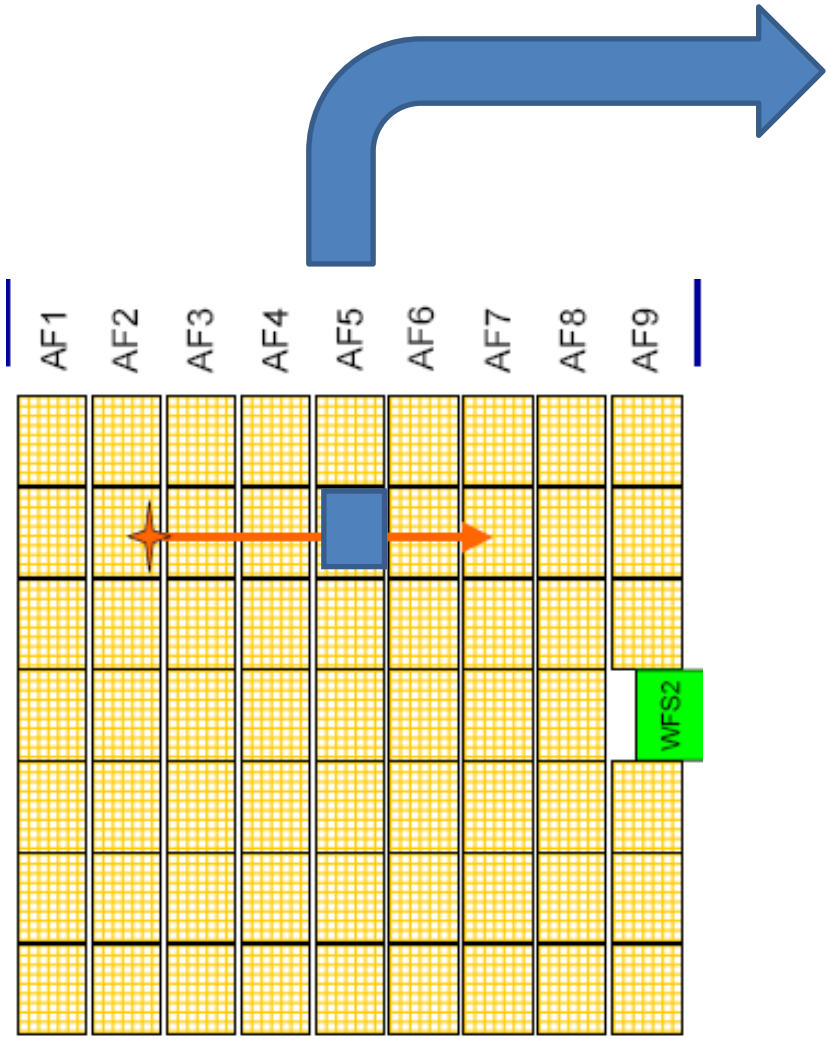
Centroids' delays and motion determination

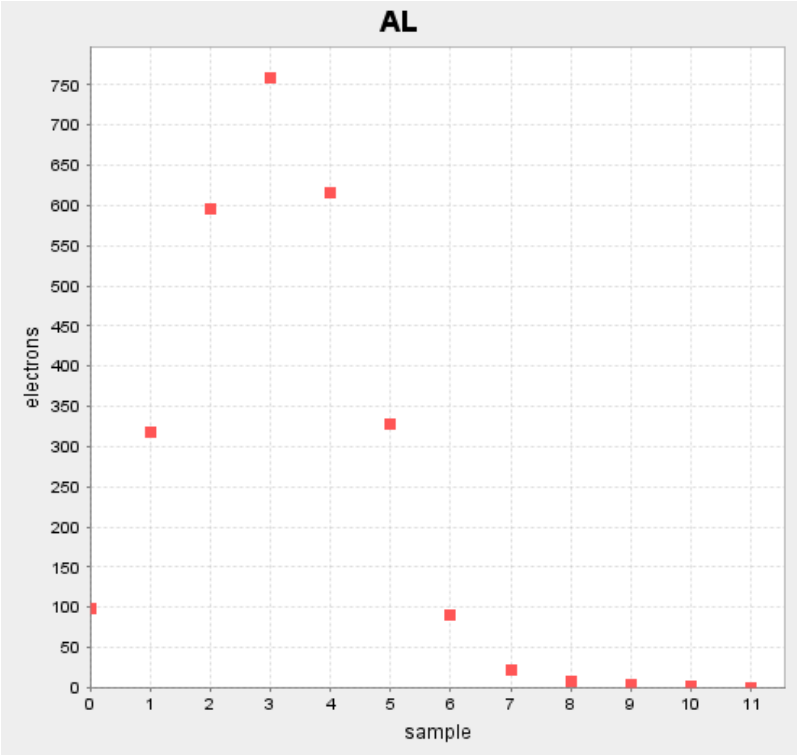




AF1 centroid
AF3 centroid

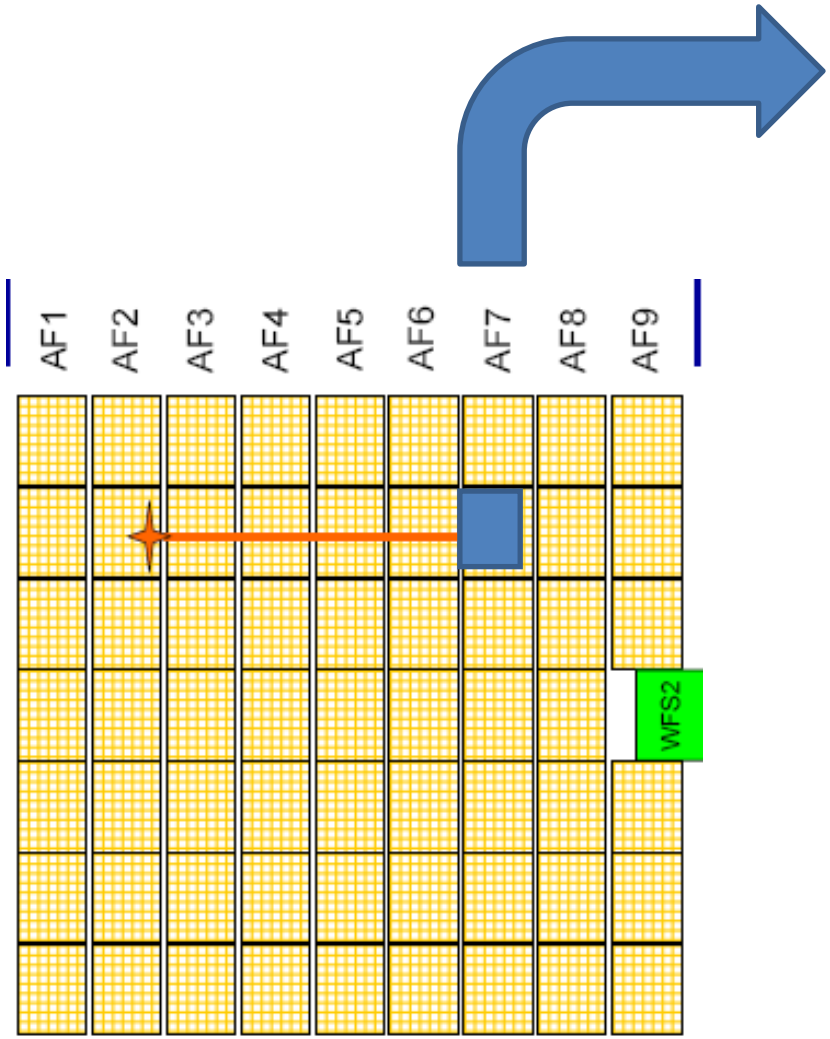
Centroids' delays and motion determination

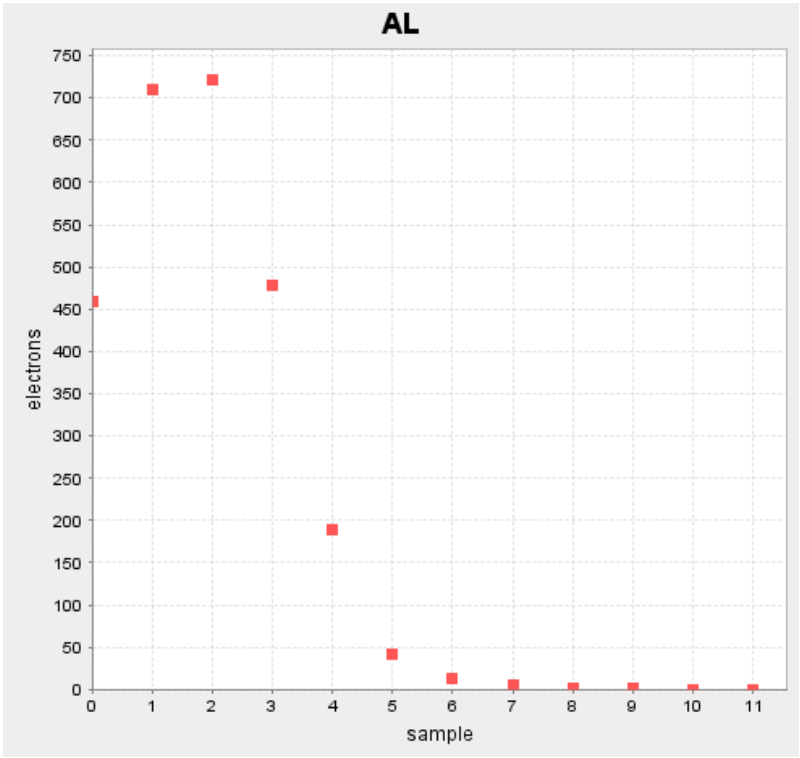




AF1 centroid
AF3 centroid
AF5 centroid

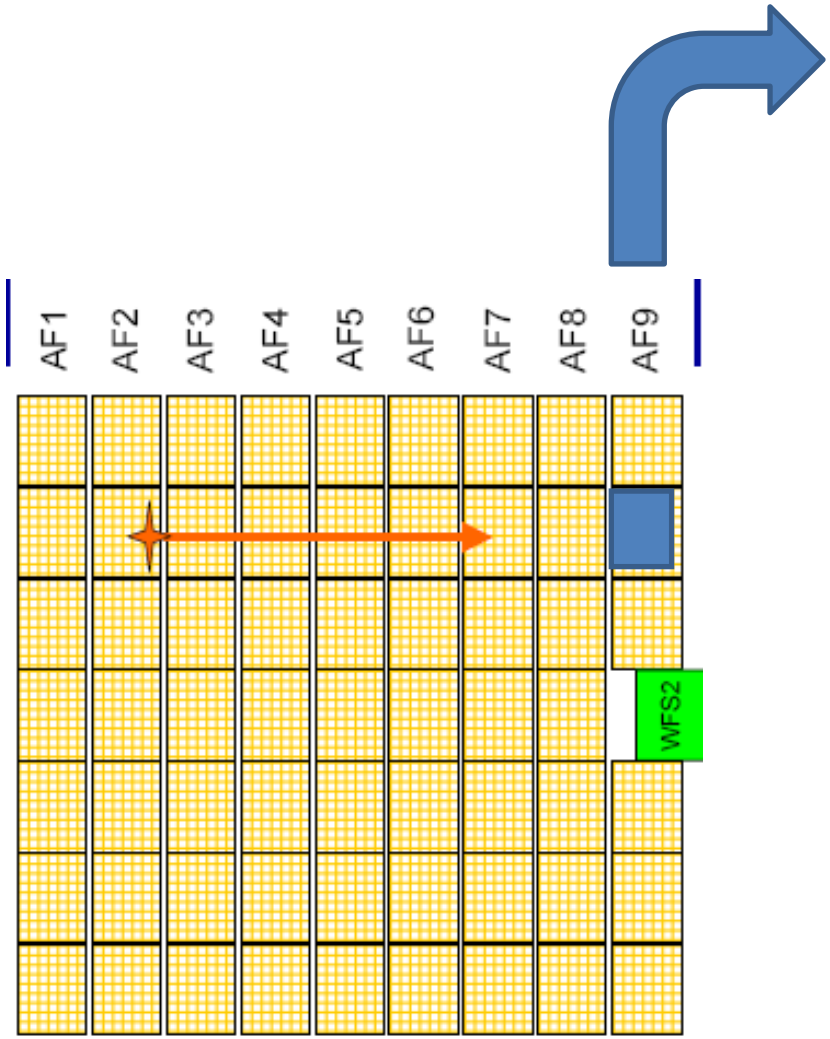
Centroids' delays and motion determination

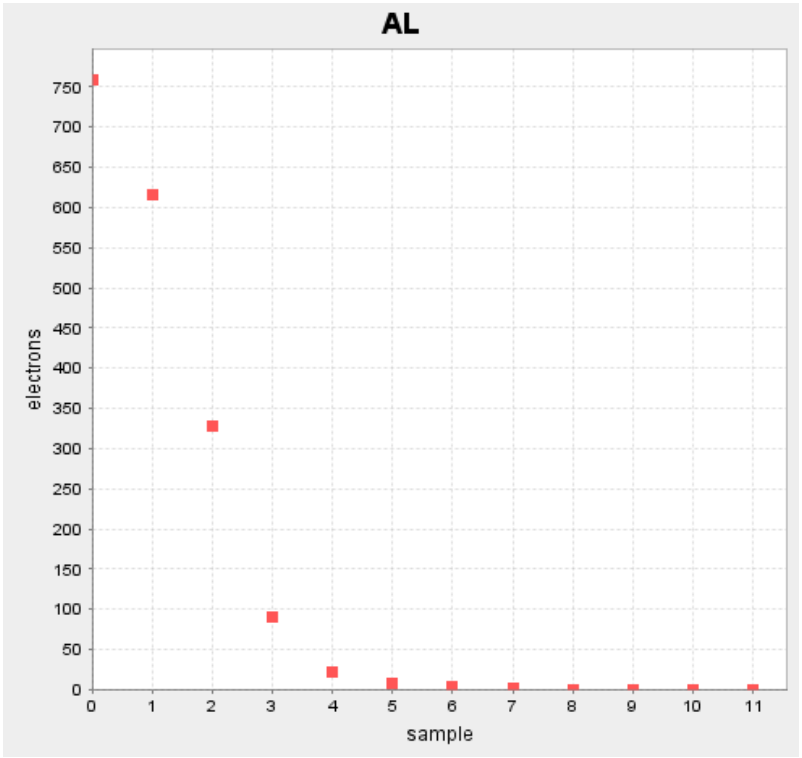




AF1 centroid
AF3 centroid
AF5 centroid
AF7 centroid

Centroids' delays and motion determination



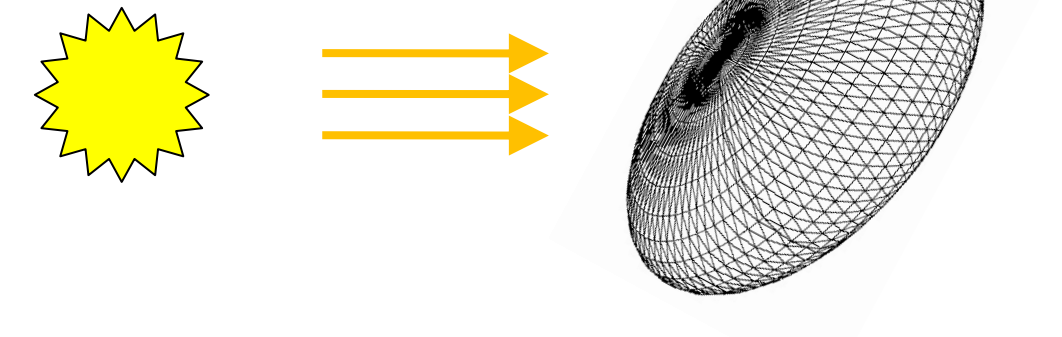


AF1 centroid
AF3 centroid
AF5 centroid
AF7 centroid
AF9 centroid

AL motion determination

Correction of the extra-size due to motion

Optical image formation



illumination conditions

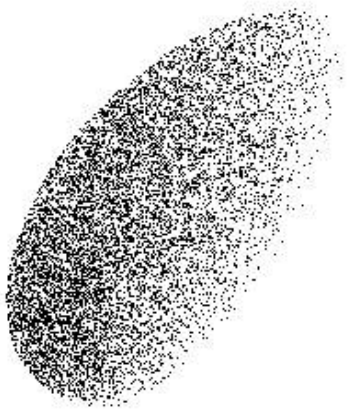
+

shape, size, orientation

+

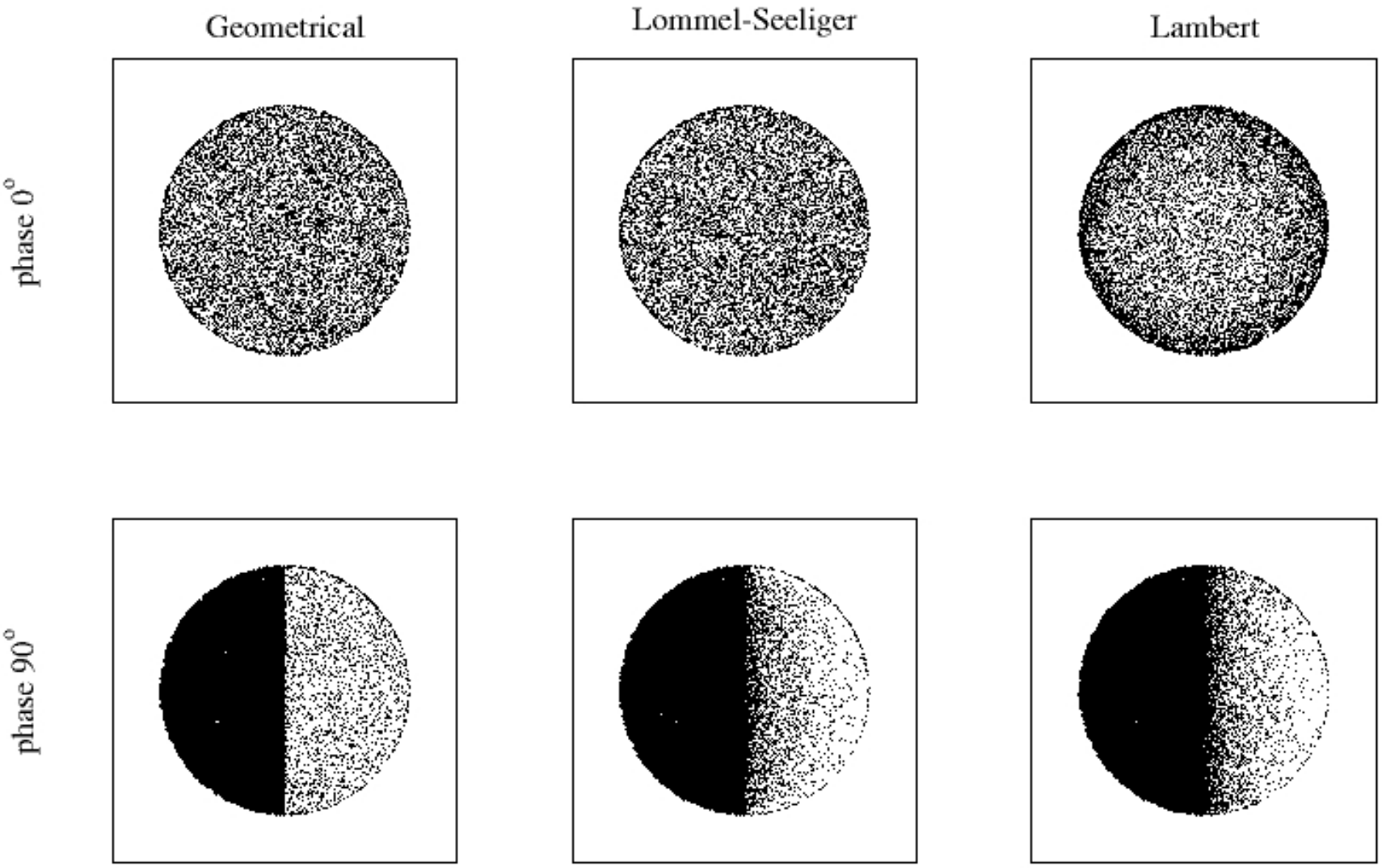
Scattering Law
(Reflection Coefficient, or *Bidirectional Reflectance Distribution Function)*

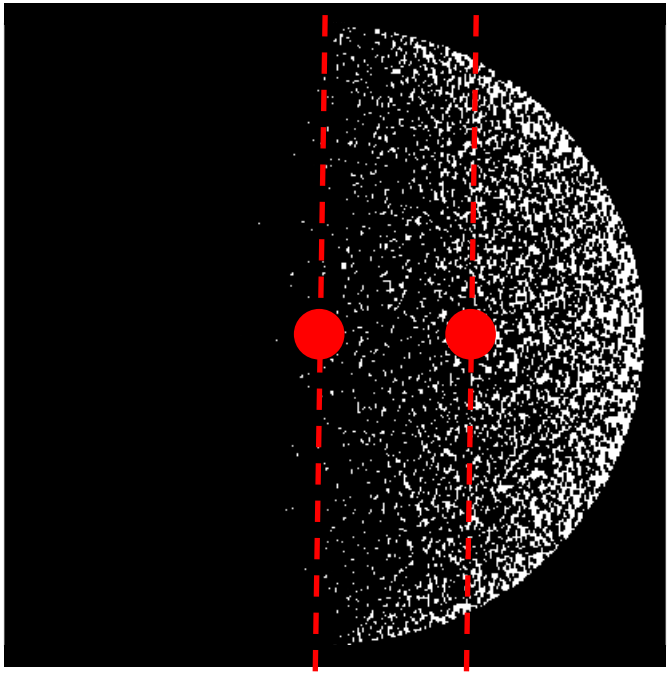
=

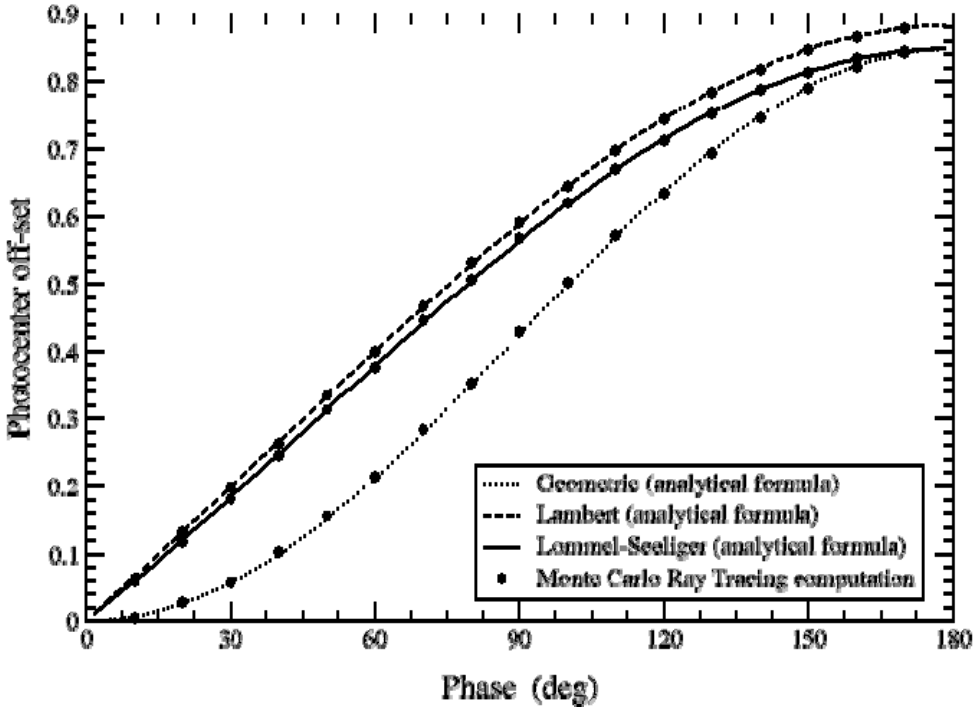


←

apparent source photometric distribution (***L***)


Geometrical
Lommel-Seeliger
Lambert
phase 0°
phase 90°





bary-center

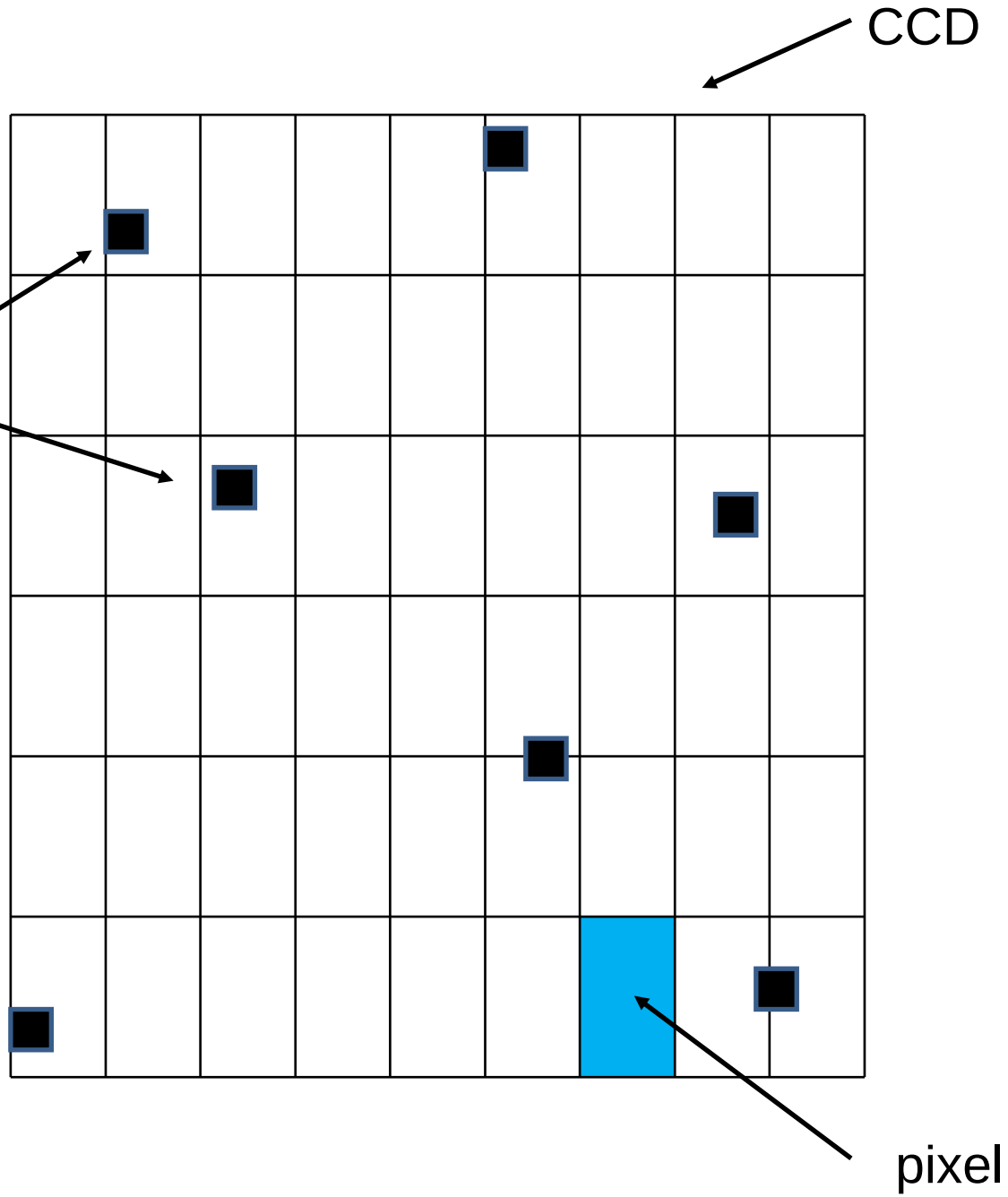
photo-center

centroid

photo-center shift

correction

Radiation damage

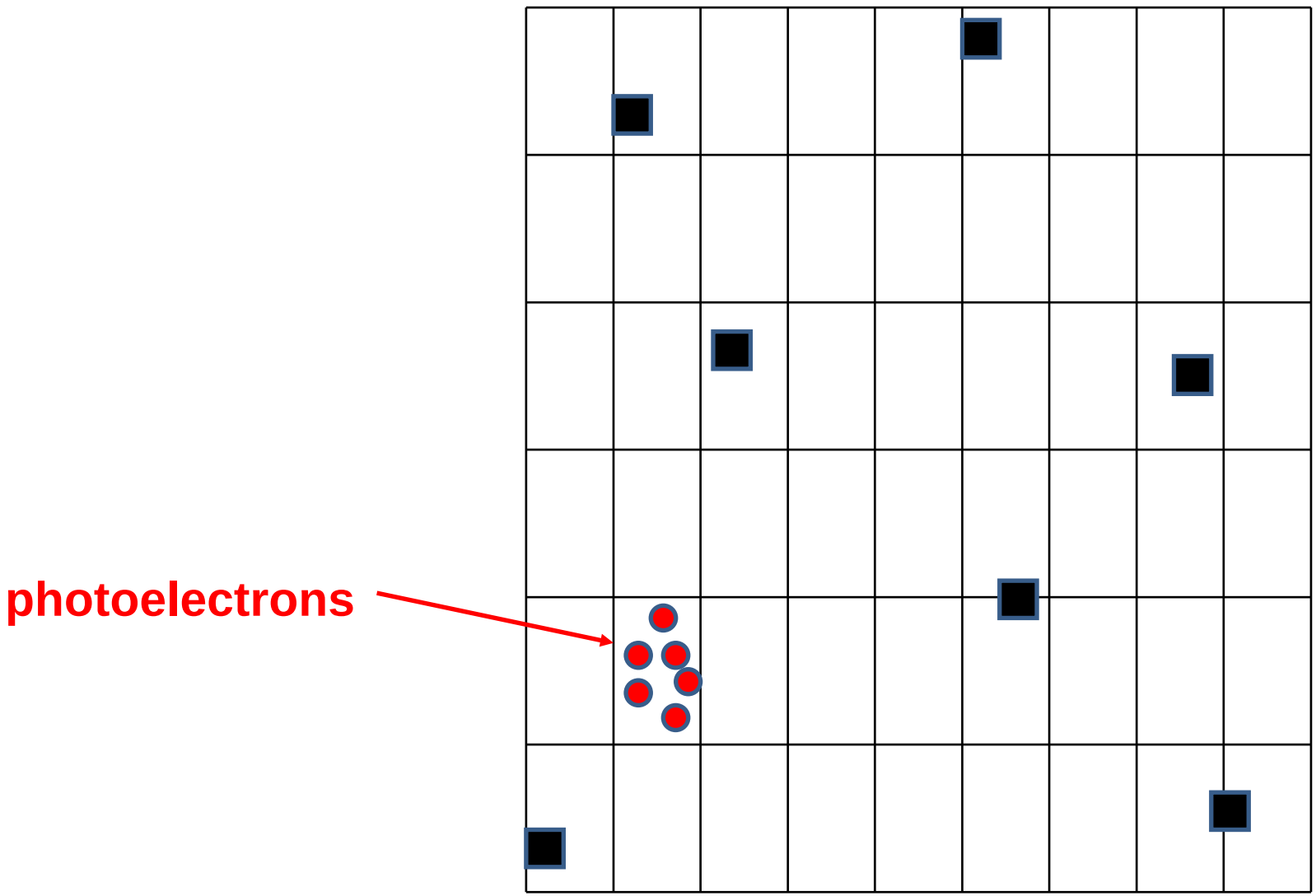


electronic traps

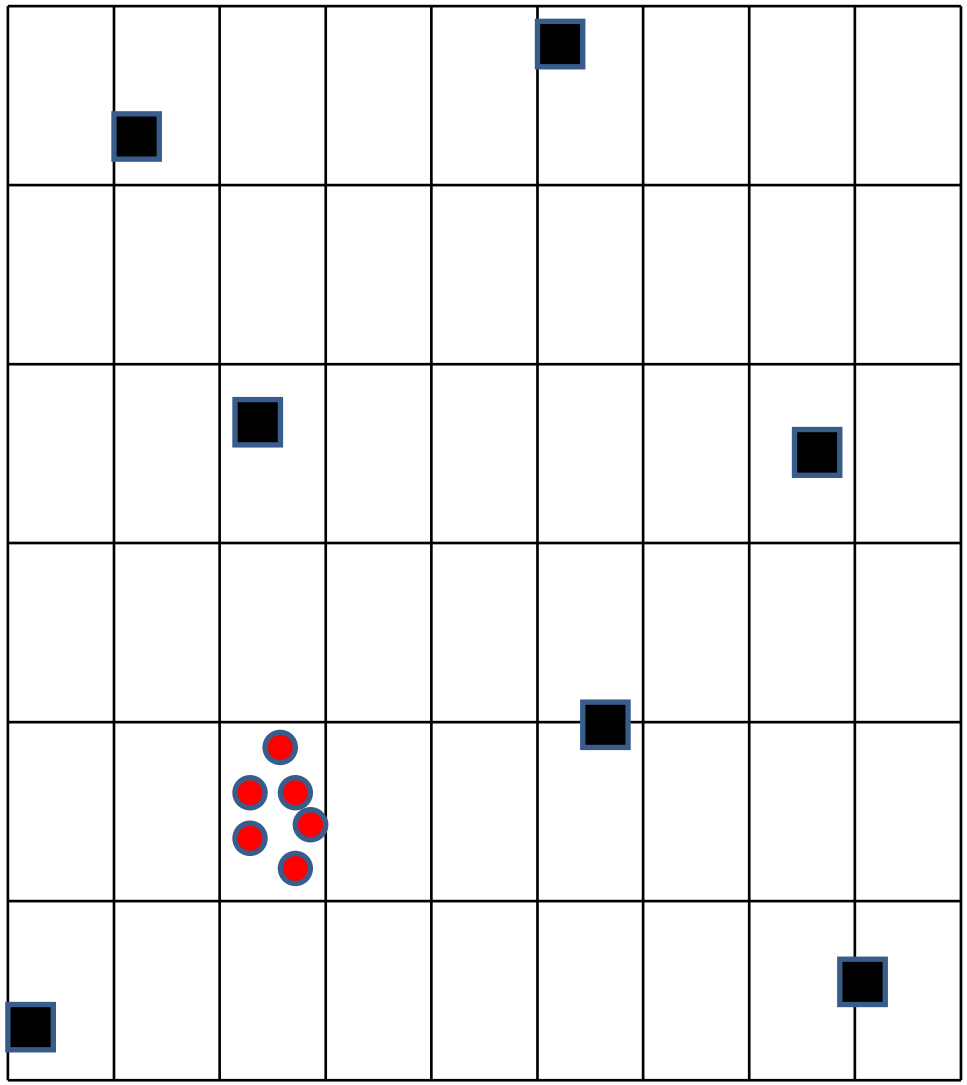
Interplanetary radiation environment includes high-energy extra-solar cosmic rays, but the particle fluence is dominated by lower energy solar protons from solar flares (Gaia's launch is planned around the next solar maximum).

Energetic particles can cause an electronic damage of the CCDs, producing the formation of "traps" for the photoelectrons.

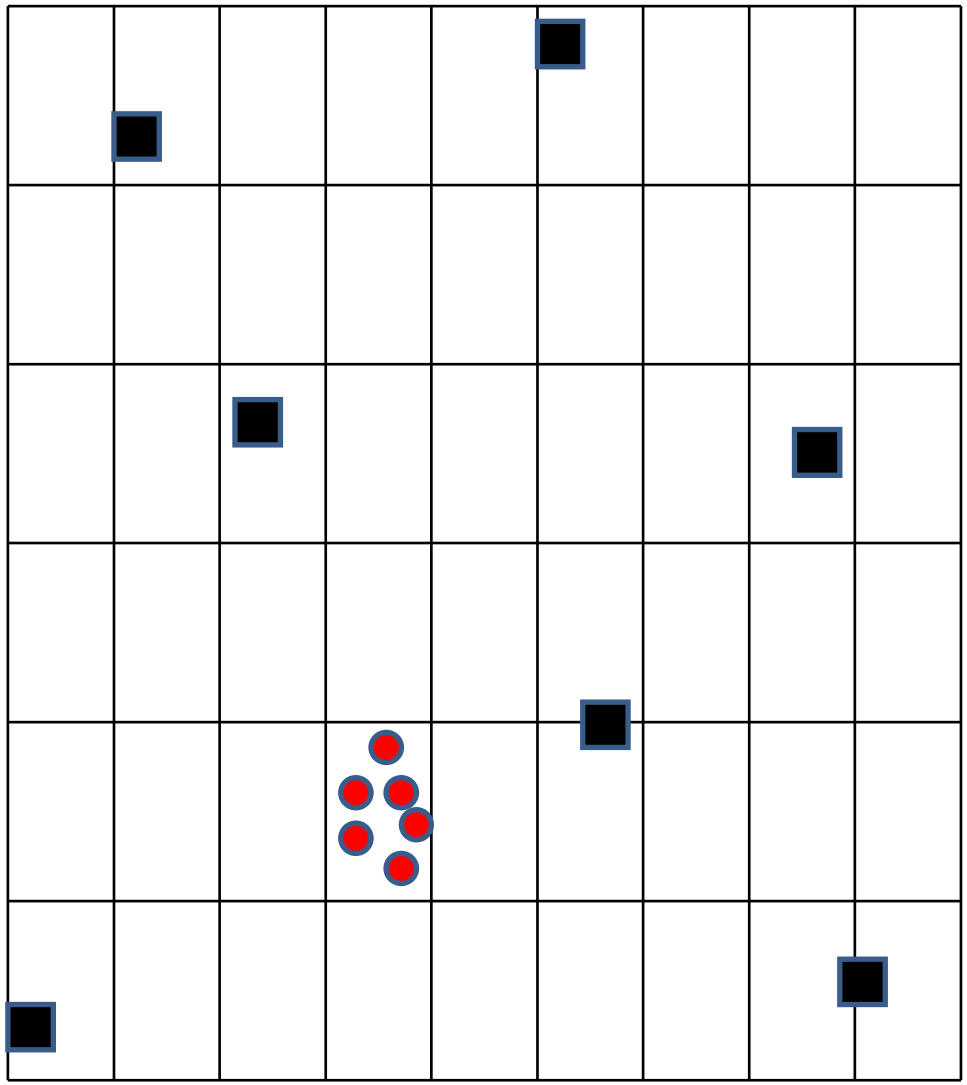
Regular charge transfer



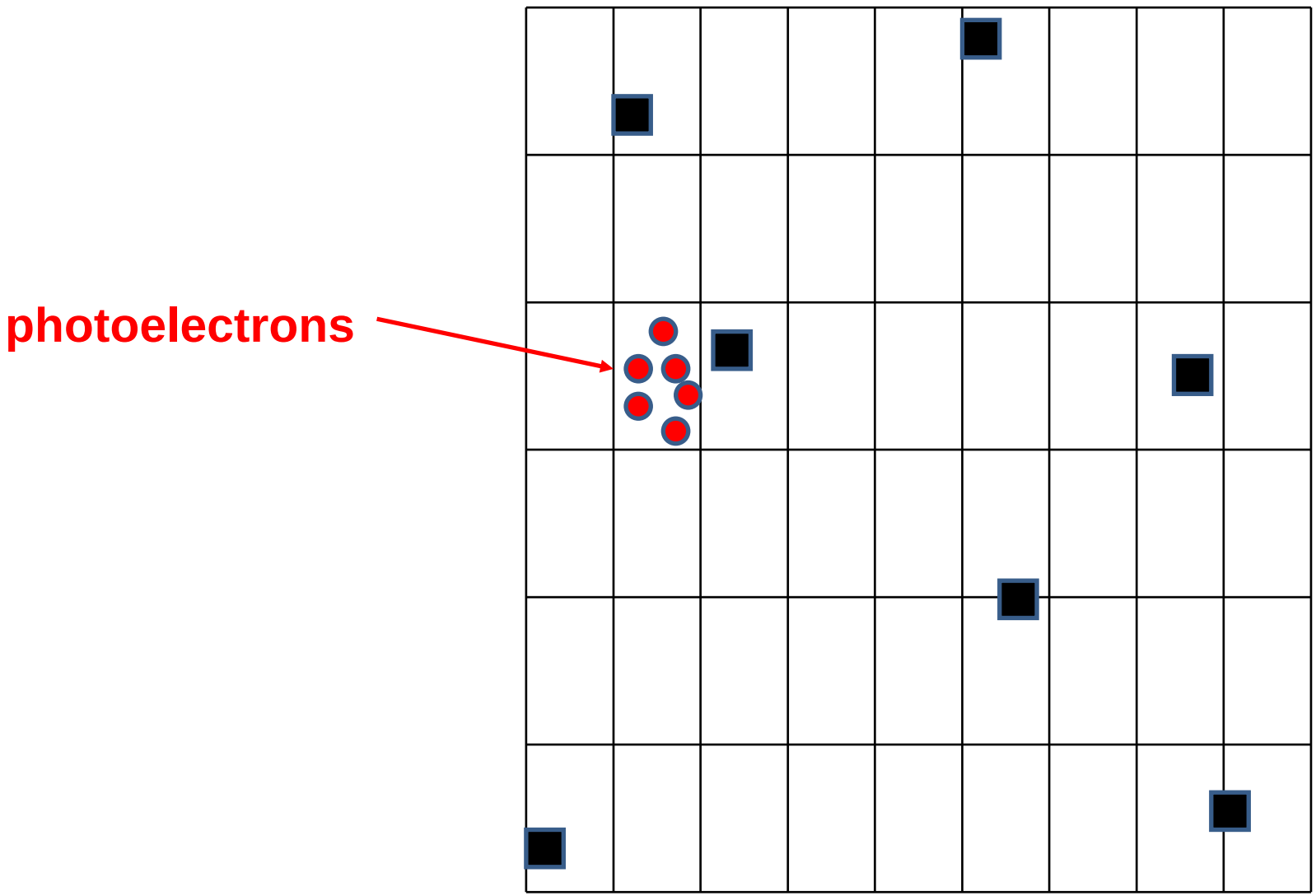
Regular charge transfer



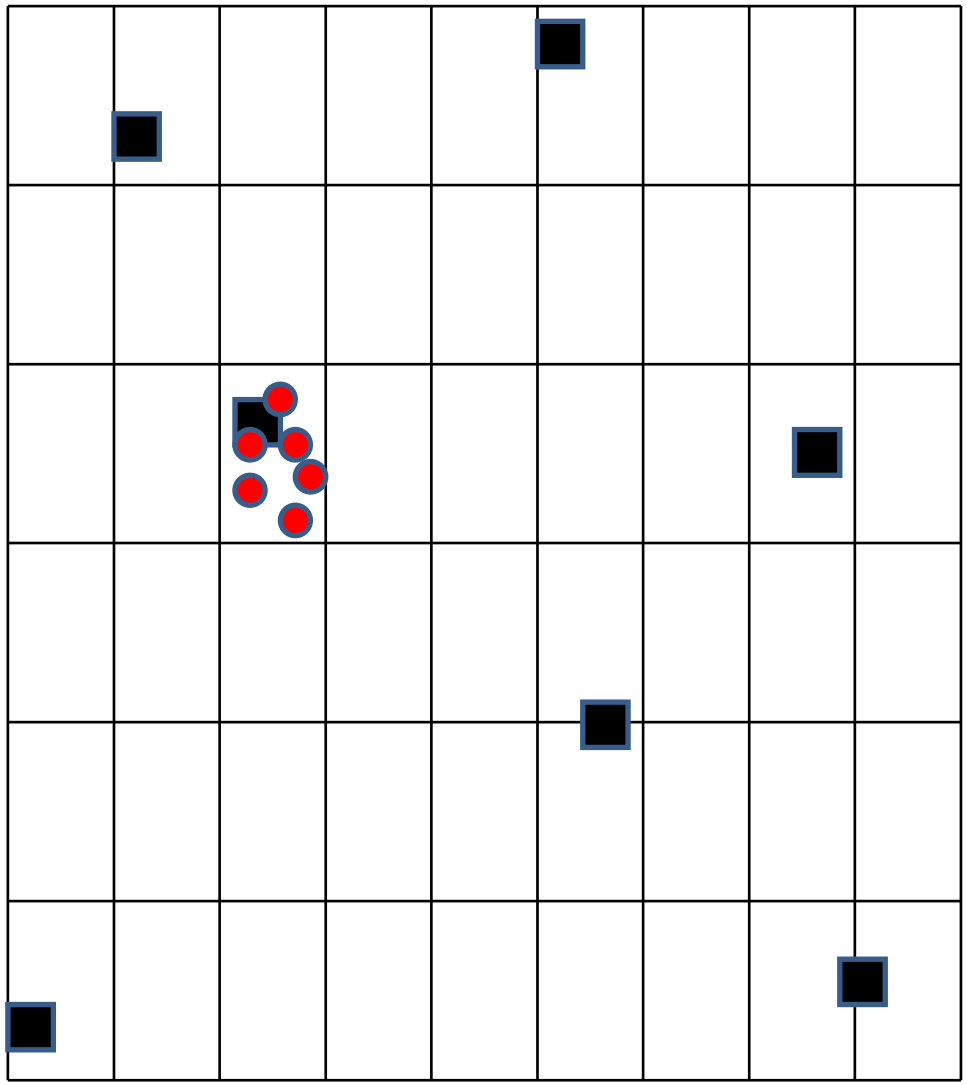
Regular charge transfer



Charge transfer inefficiency (CTI)

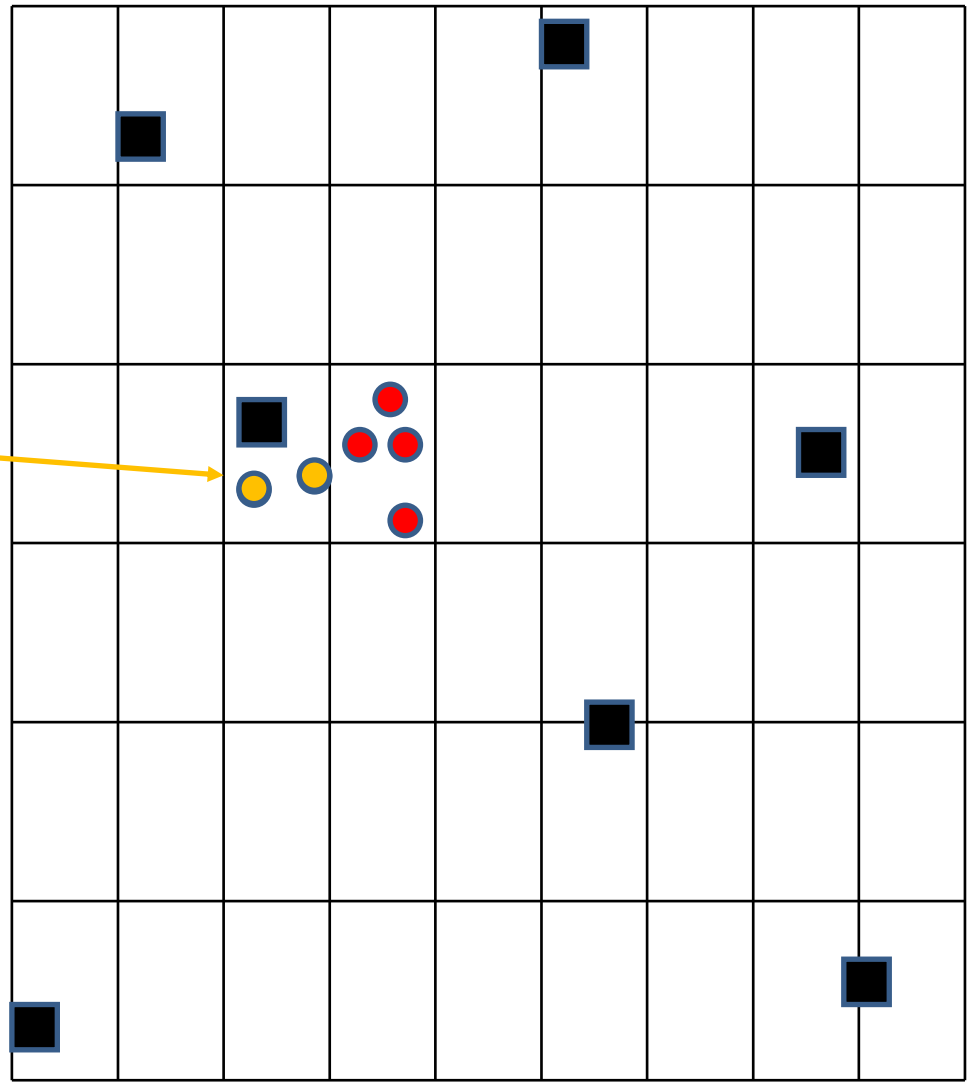


Charge transfer inefficiency (CTI)

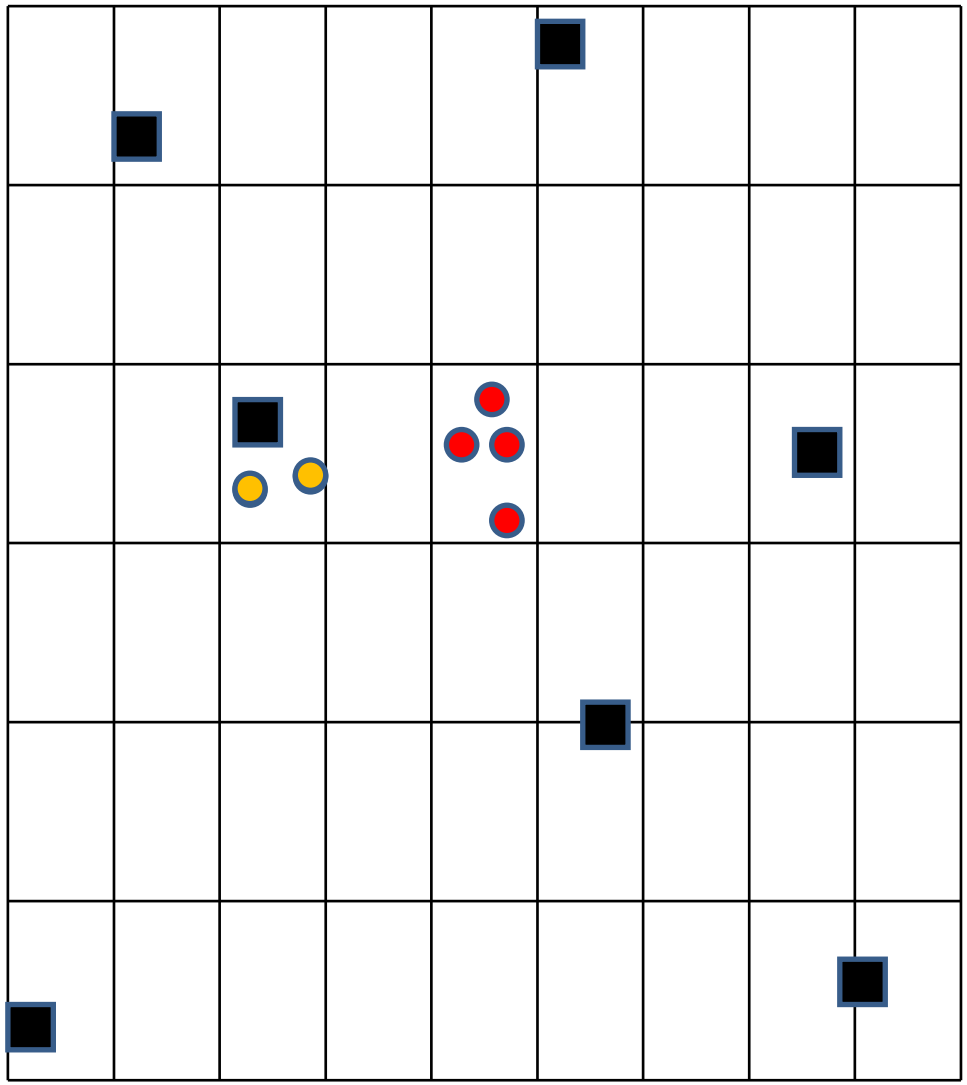


Charge transfer inefficiency (CTI)

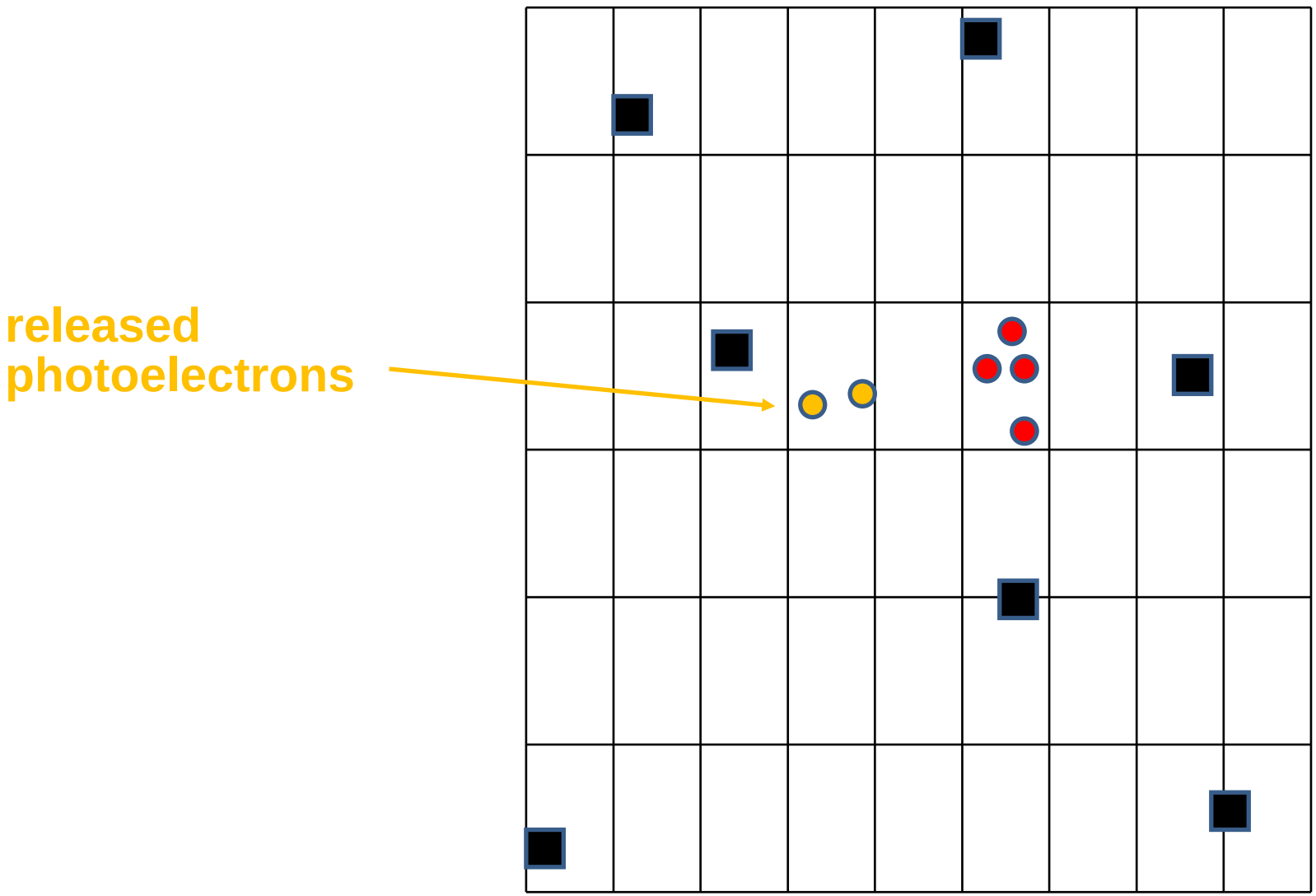
captured
photoelectrons



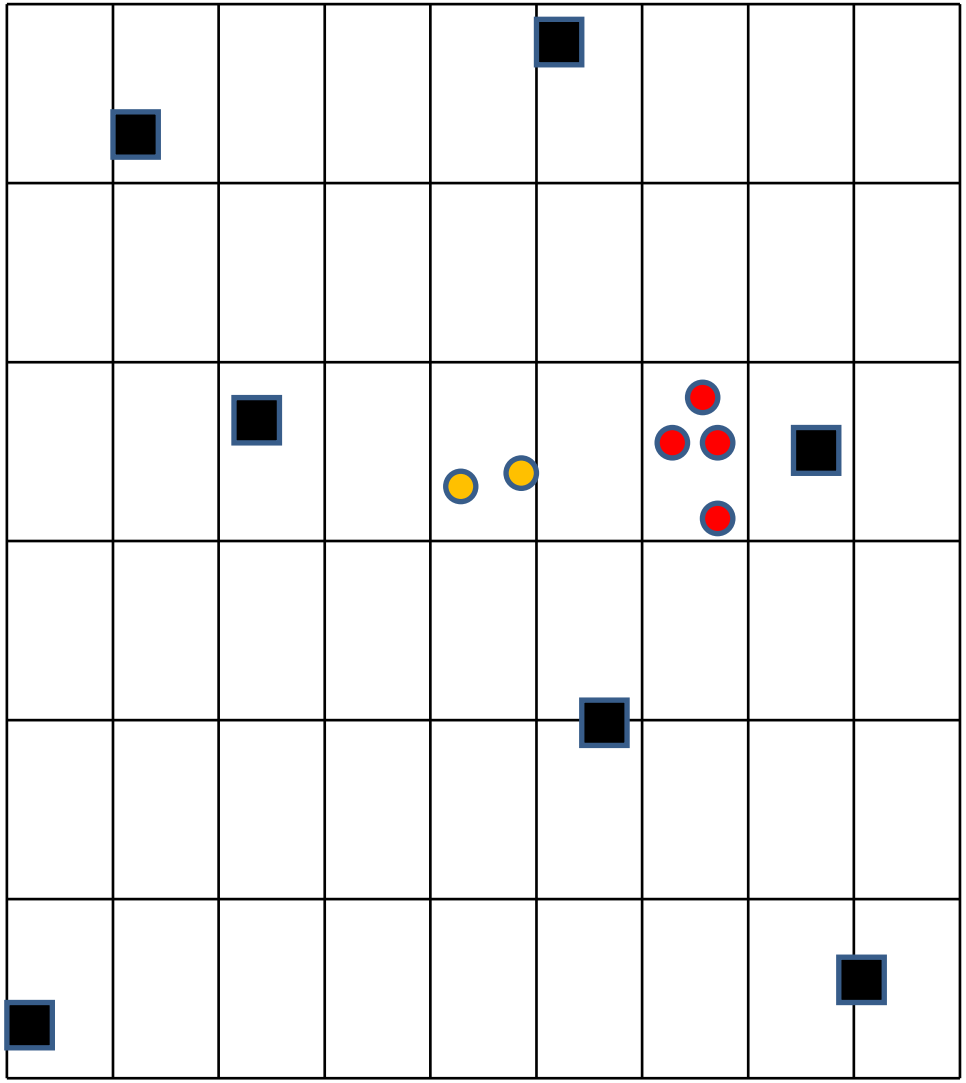
Charge transfer inefficiency (CTI)



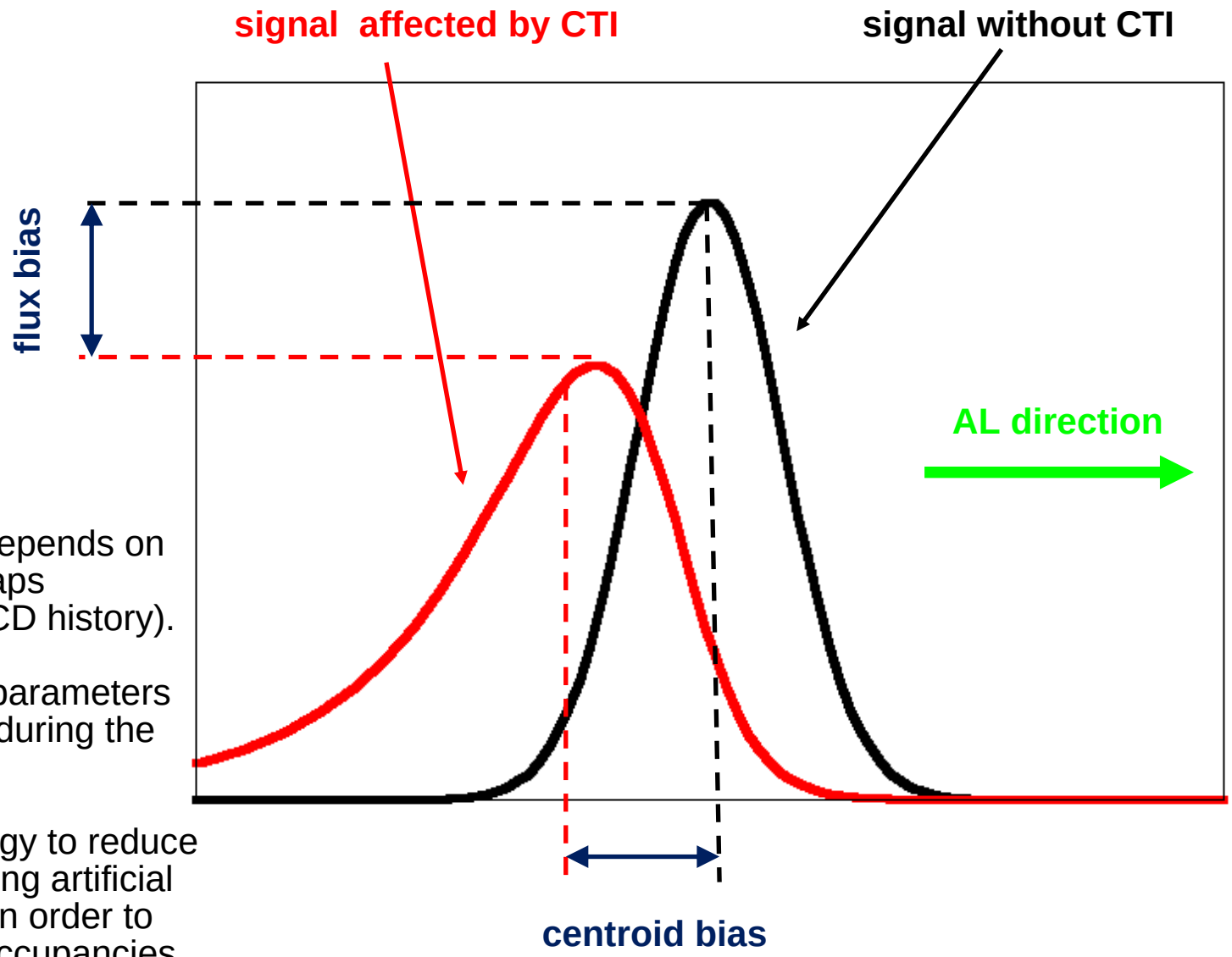
Charge transfer inefficiency (CTI)



Charge transfer inefficiency (CTI)



CTI: effect on centroid and magnitude



Signal distortion depends on source flux and traps population (the CCD history).

Traps population parameters can be calibrated during the mission.

A mitigation strategy to reduce CTI is adopted using artificial charge injections in order to “reset” the traps occupancies.

Conclusions

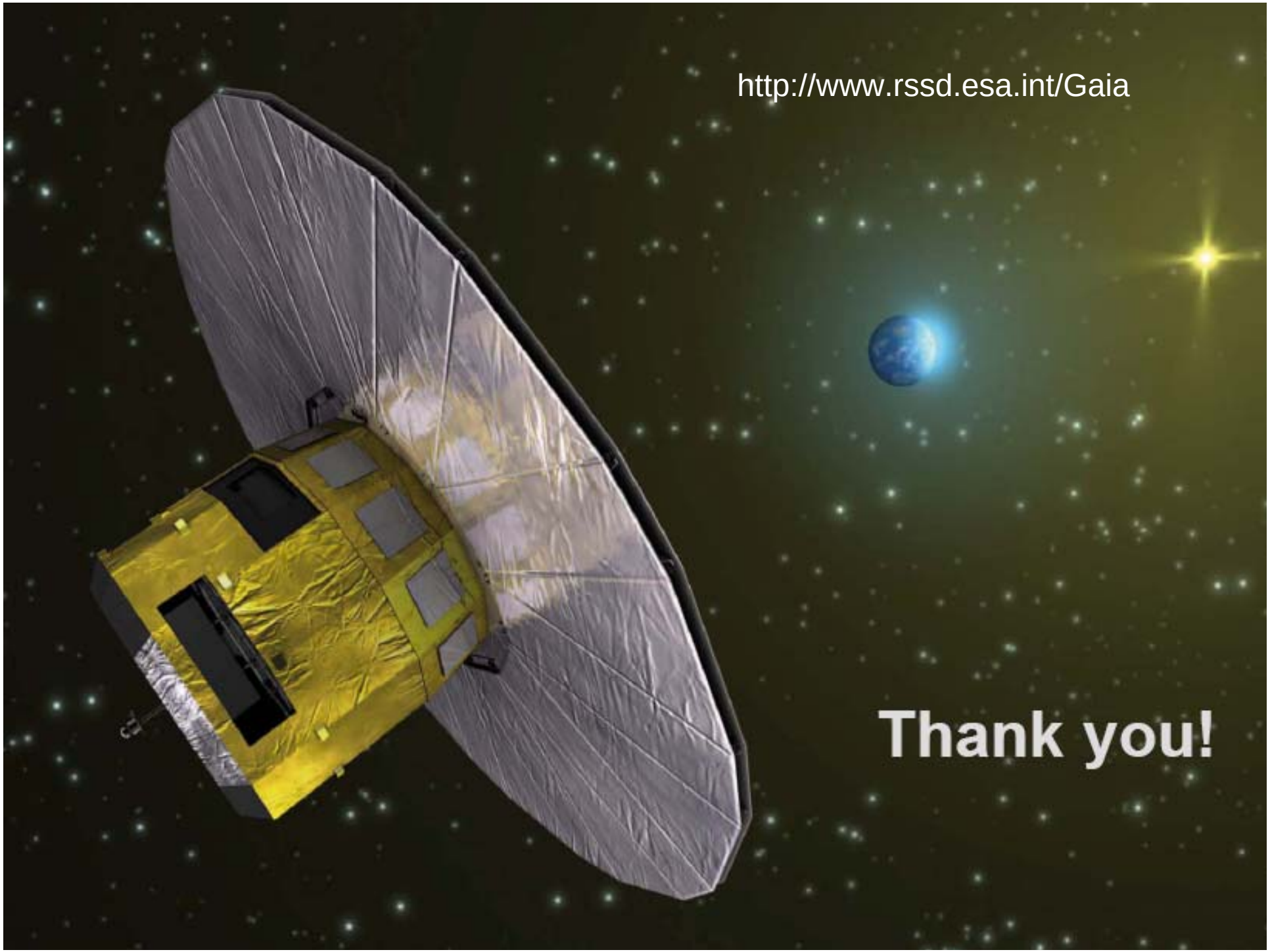
GAIA will provide an important opportunity to obtain a **large** amount of **homogeneous** astrometric and photometric data about asteroids.

The prospect of the final data is excellent: **mass** measurement for ~100 asteroids, **size** for ~1000 objects, and **shape & rotational** properties for tens of thousands asteroids.

Nevertheless, extraction of information about positions, fluxes and angular size of those sources requires a careful analysis of the signal from the astrometric CCDs.

Unlike fixed stars, for which the instrument is conceived specifically, asteroids require a procedure of analysis apart on account of their **motion** and apparent angular **extension**.

Potential critical problems can rise from the lack of information for each detected asteroid about the **reflectance properties** of the surface (impacting on size determination and photo-center shift correction), and from the disturb introduced by the CCD **charge transfer inefficiency** that can be particularly tricky to treat for extended moving sources.


http://www.rssd.esa.int/Gaia
Thank you!