D.B.SEATON ON BEHALF OF THE SWAP TEAM
EUI CONSORTIUM MEETING
ROYAL LIBRARY OF BELGIUM ☀ 11 DECEMBER 2014

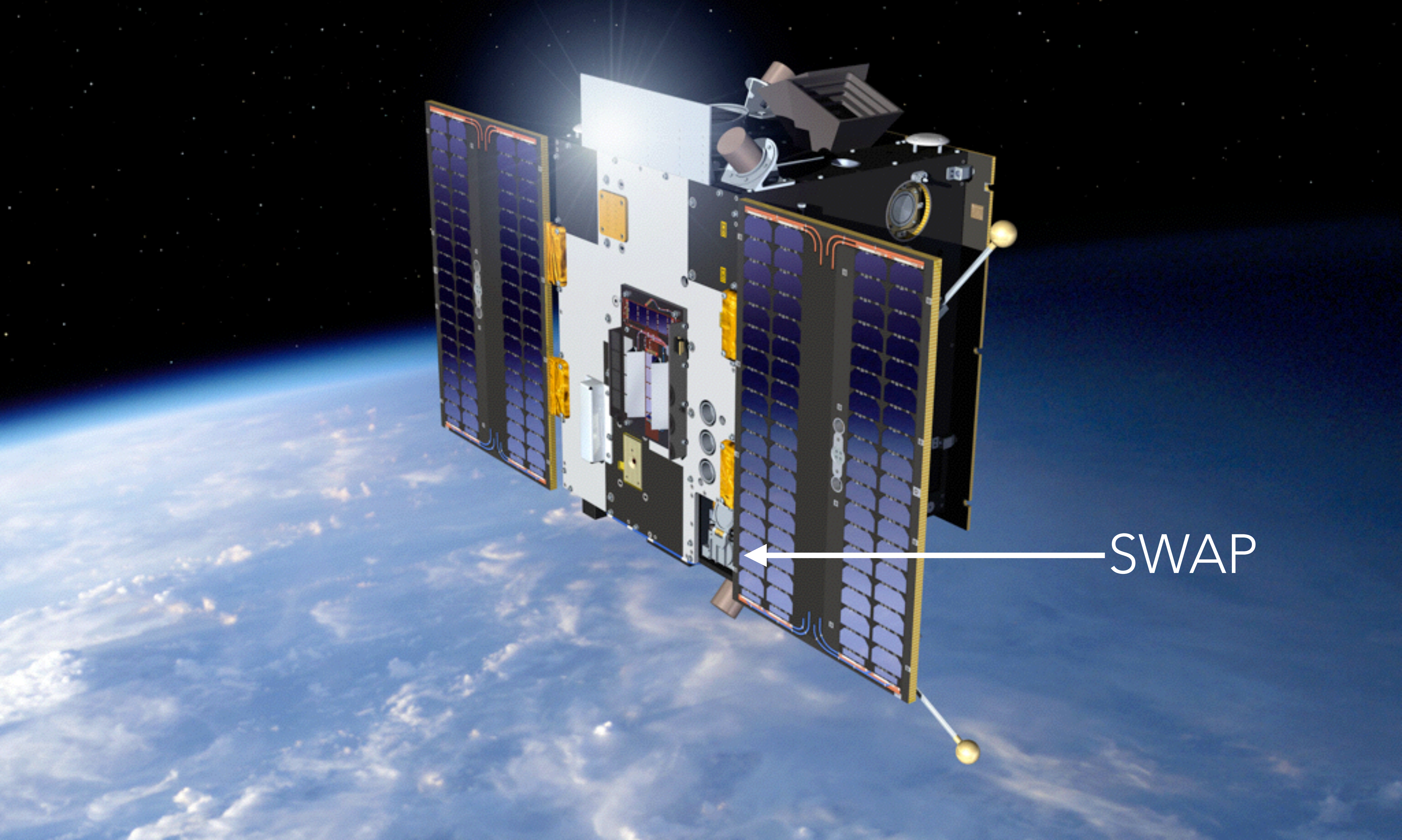
THE SWAP CMOS-APS: LESSONS LEARNED

PROBA2/SWAP

A BRIEF INTRODUCTION

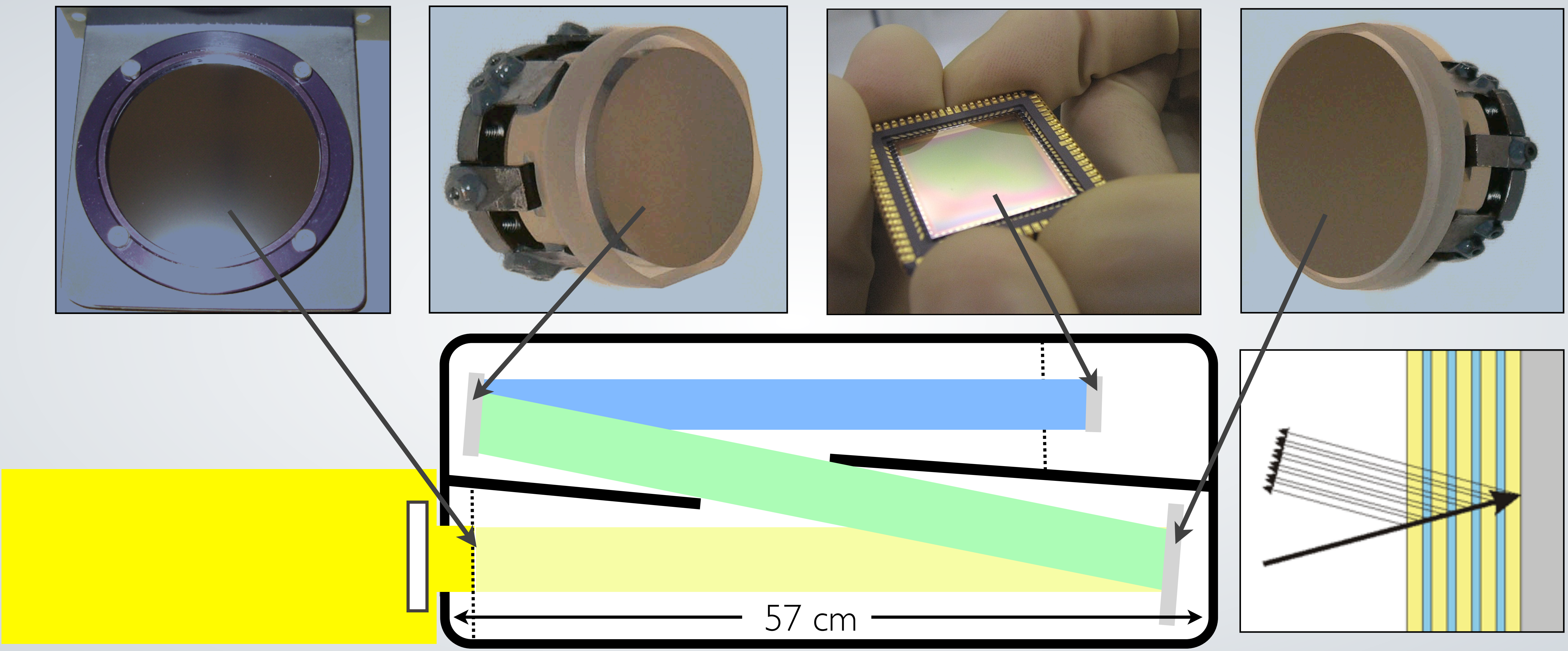
SUN WATCHER WITH ACTIVE PIXELS AND IMAGE PROCESSING

ABOUT SWAP



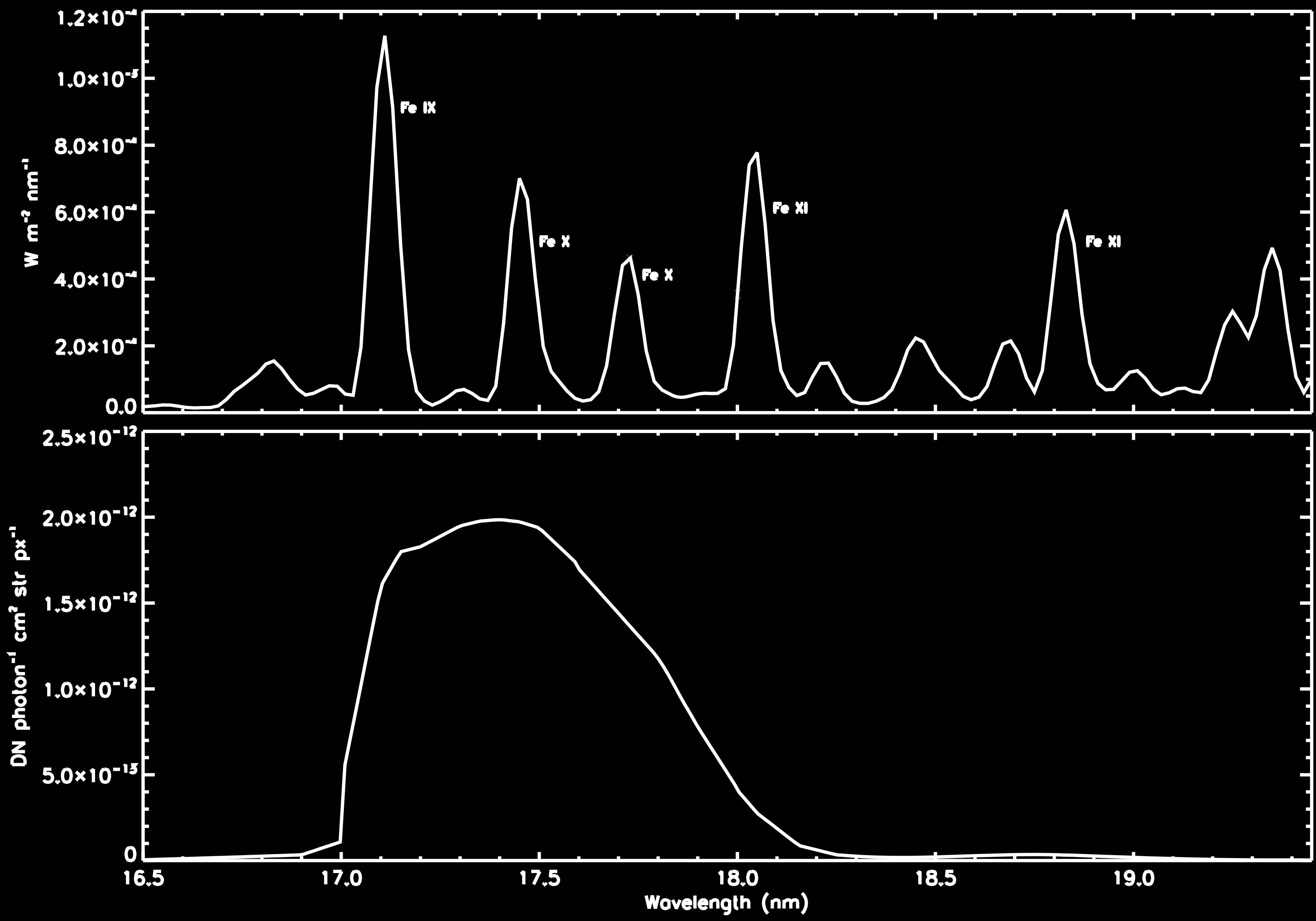
OFF-AXIS RITCHEY-CHRÉTIEN SCHEME

SWAP DESIGN



BANDPASS PEAK AT 17.4 NM

RESPONSE FUNCTION



SWAP'S APS DETECTOR

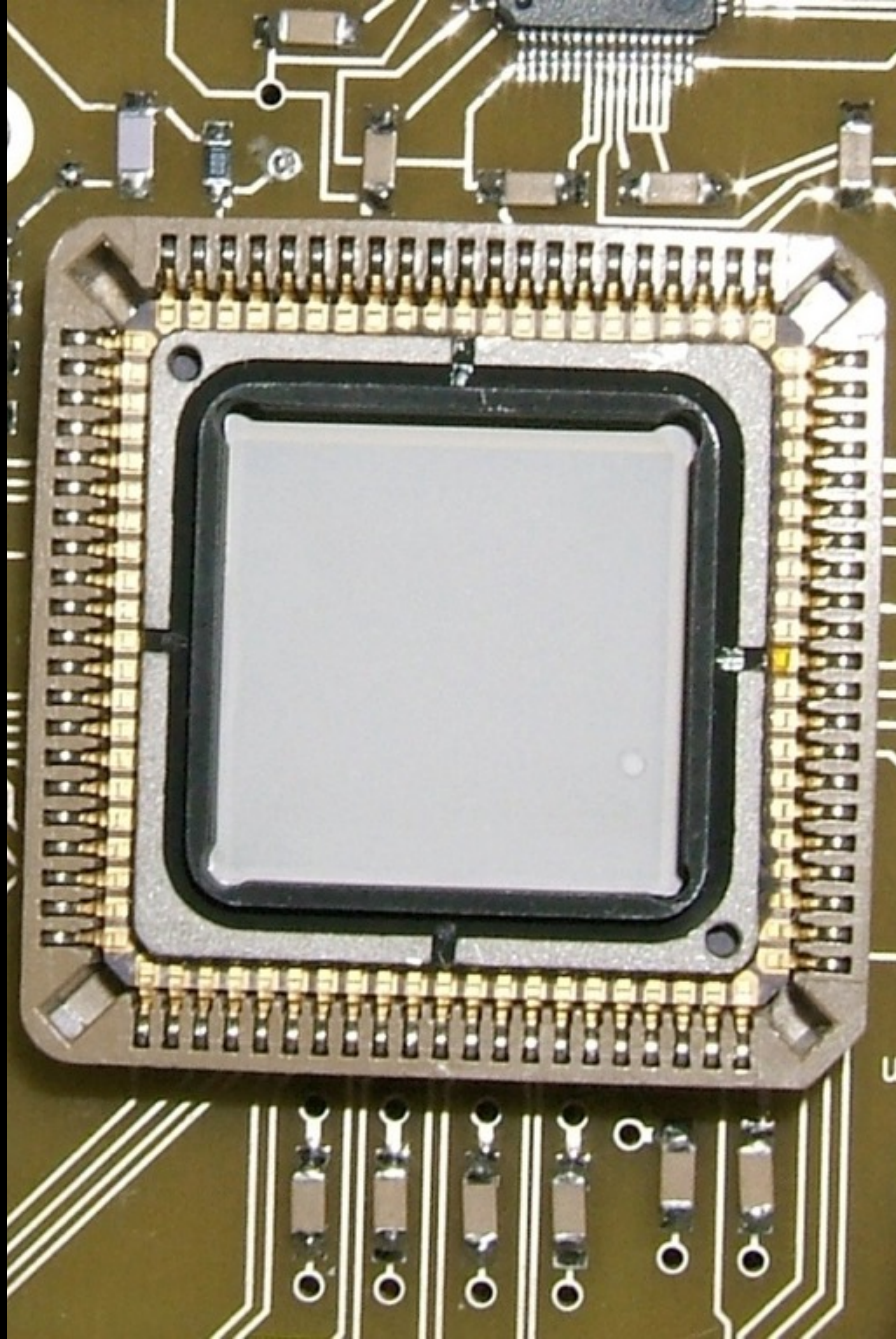
HAS Sensor
by Fillfactory (now Cypress)

1024 × 1024 Pixels

Visible light sensor—EUV imaging via scintillator coating

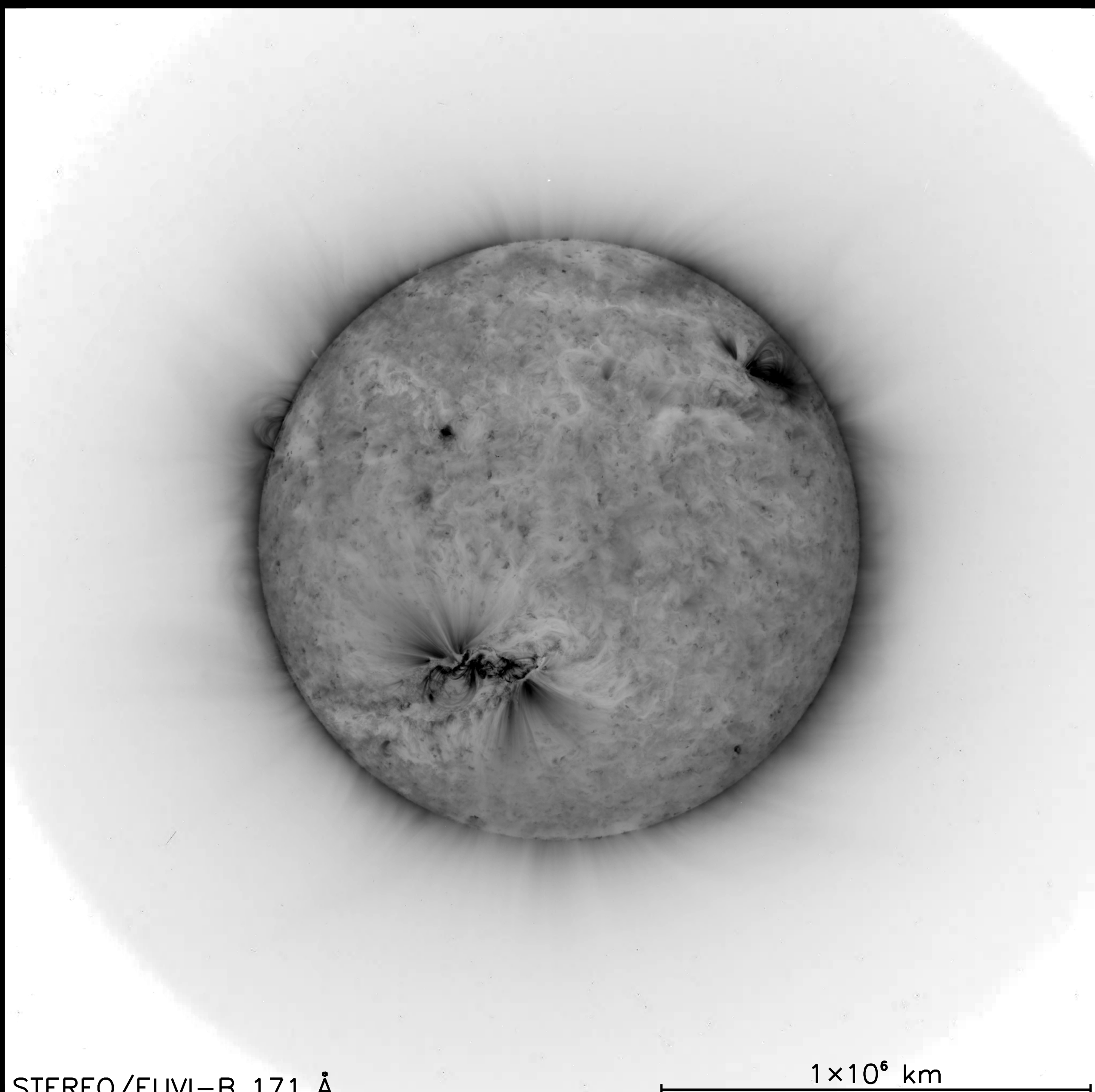
Extremely low power consumption

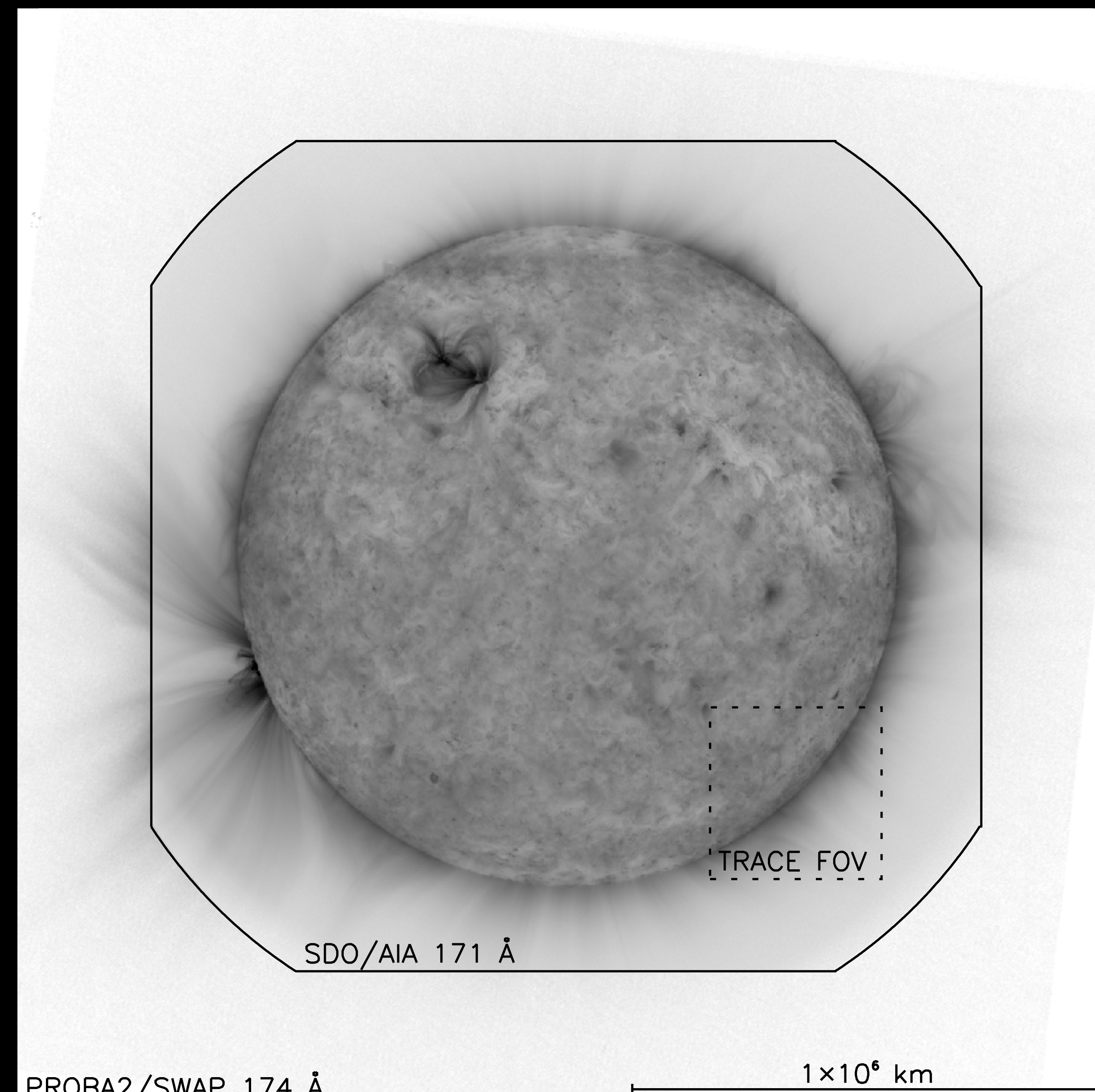
No shutter needed



COMPARISON WITH STEREO/SECCHI, SDO/AIA, & TRACE

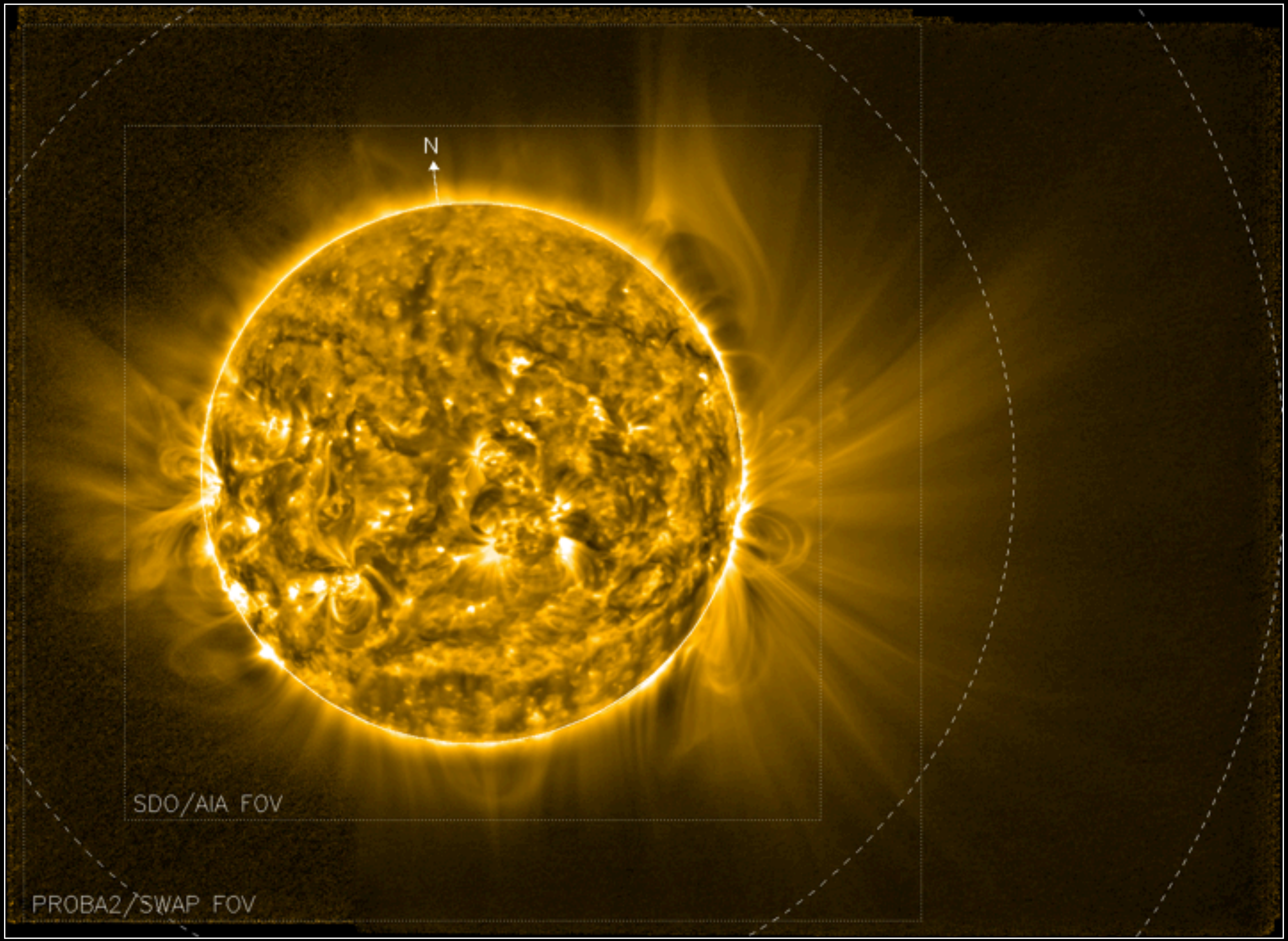
SWAP'S VIEW OF THE SUN

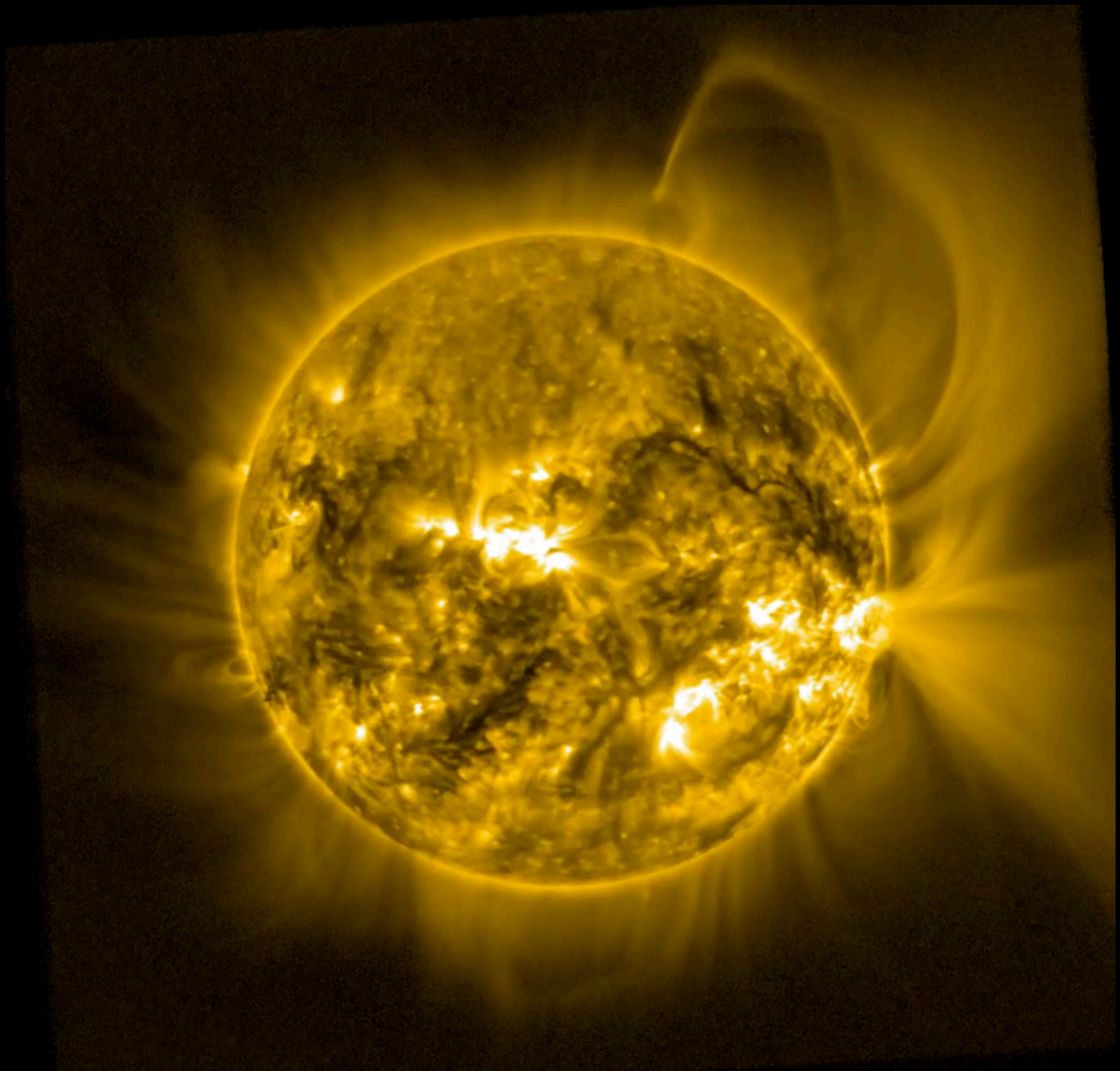




MOSAIC IMAGES

SWAP'S VIEW OF THE SUN





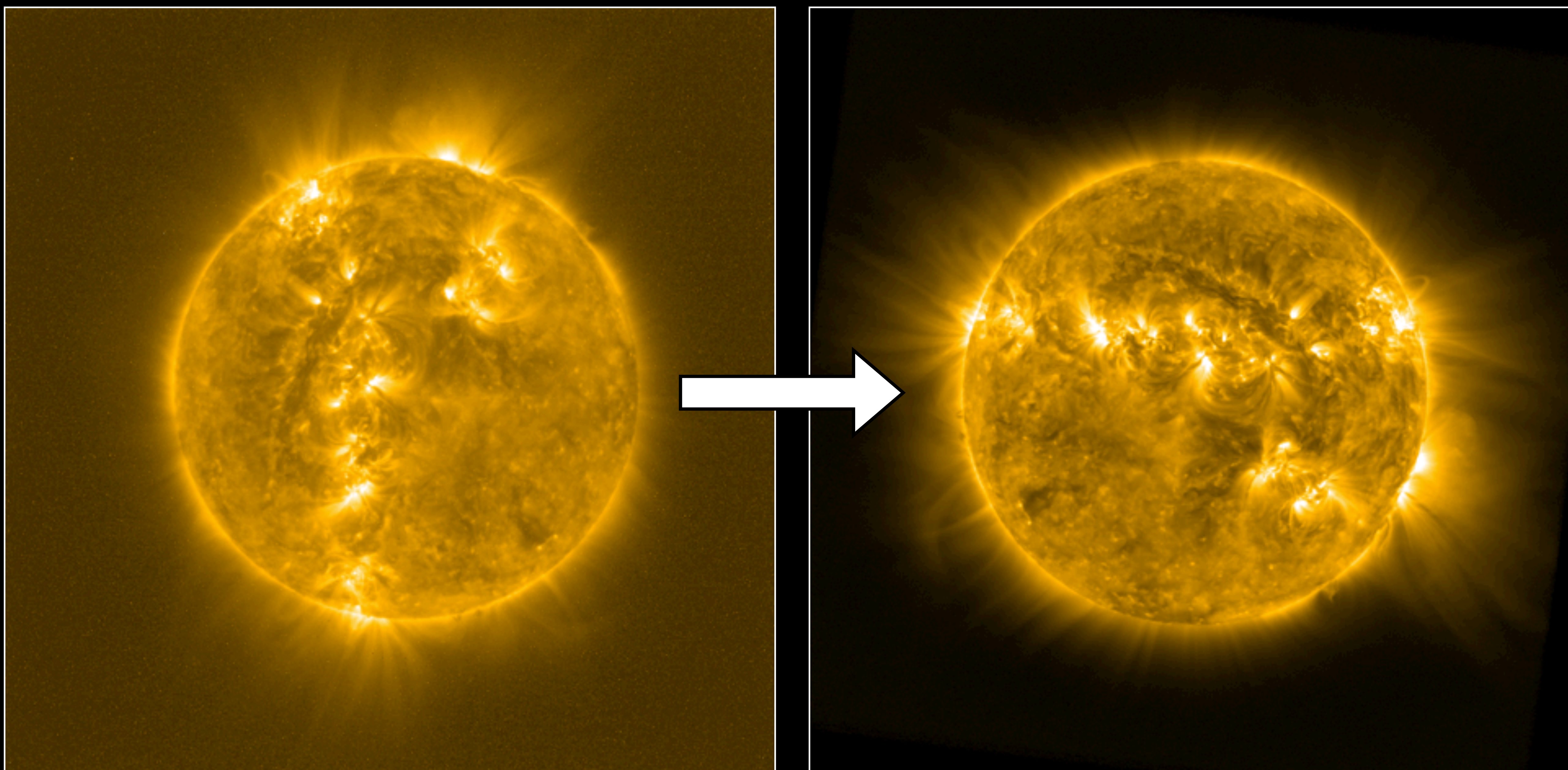
PROBA2/SWAP 17.4nm   2014-08-07 15:31:32

PROBA2/SWAP CMOS-APS

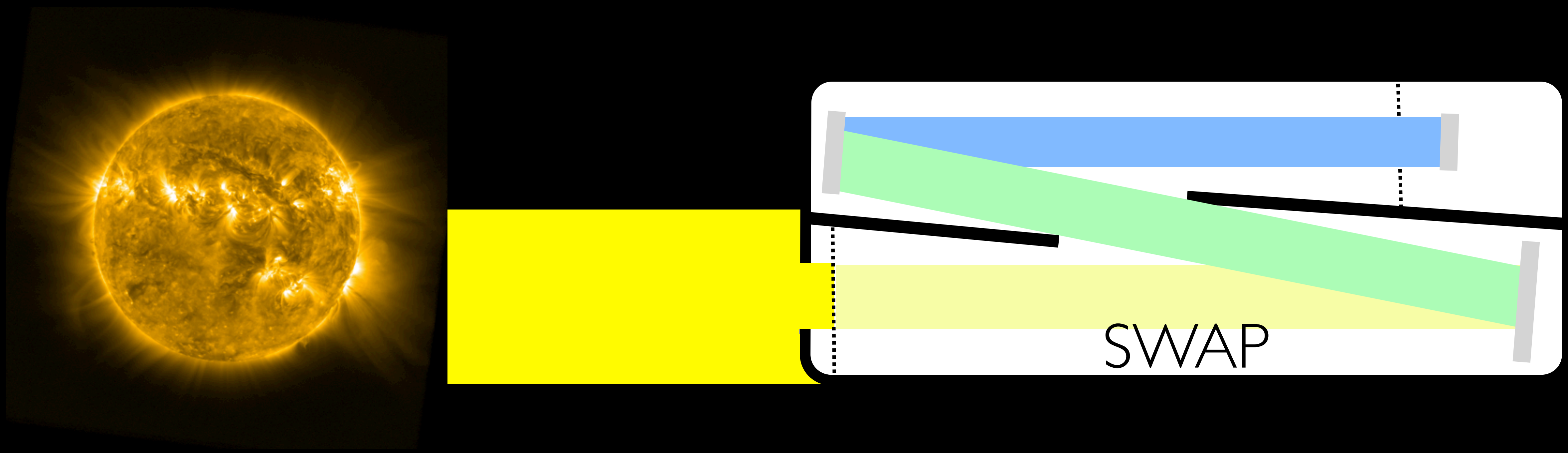
AN INTRODUCTION TO CALIBRATION

PROBA2/SWAP CALIBRATION

CALIBRATING IMAGES



FROM SUN TO SOLAR IMAGES



Platform Effects:

Pointing

Roll

Optical Effects:

Distortion

Attenuation

Dispersion

Detector Effects:

Noise

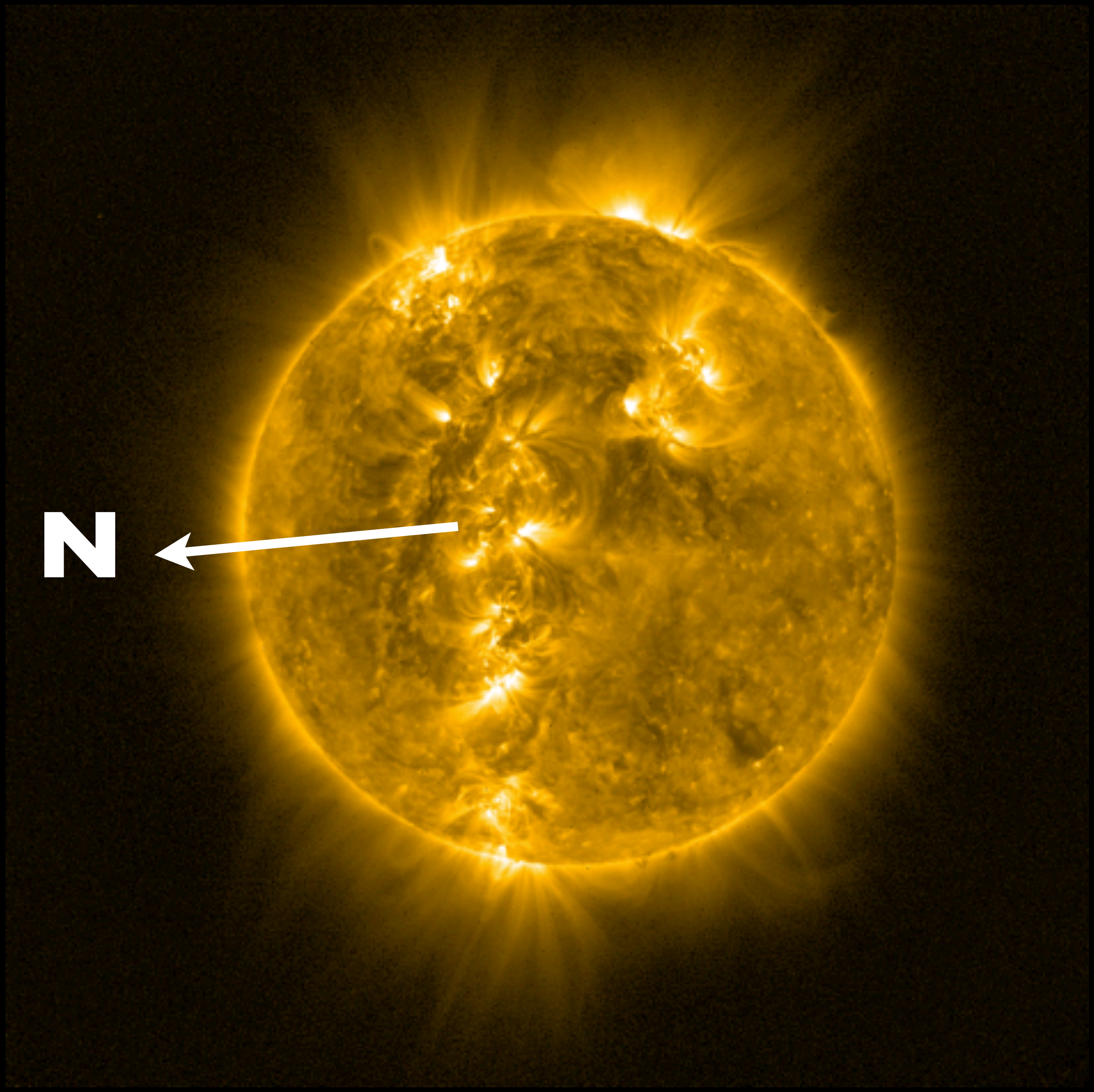
Defects

Digitization

PLATFORM EFFECTS

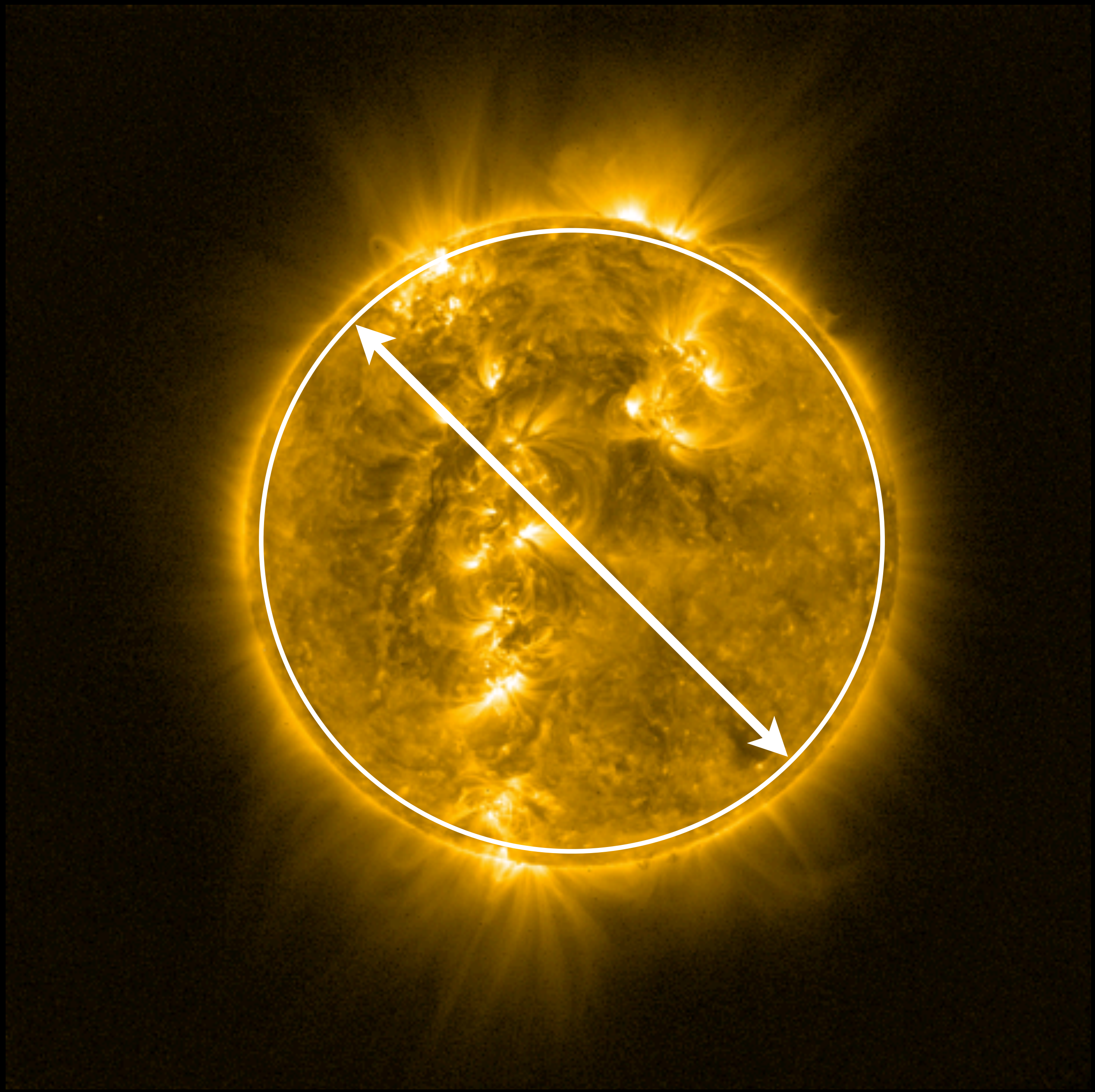
Inaccurate pointing

Spacecraft roll angle



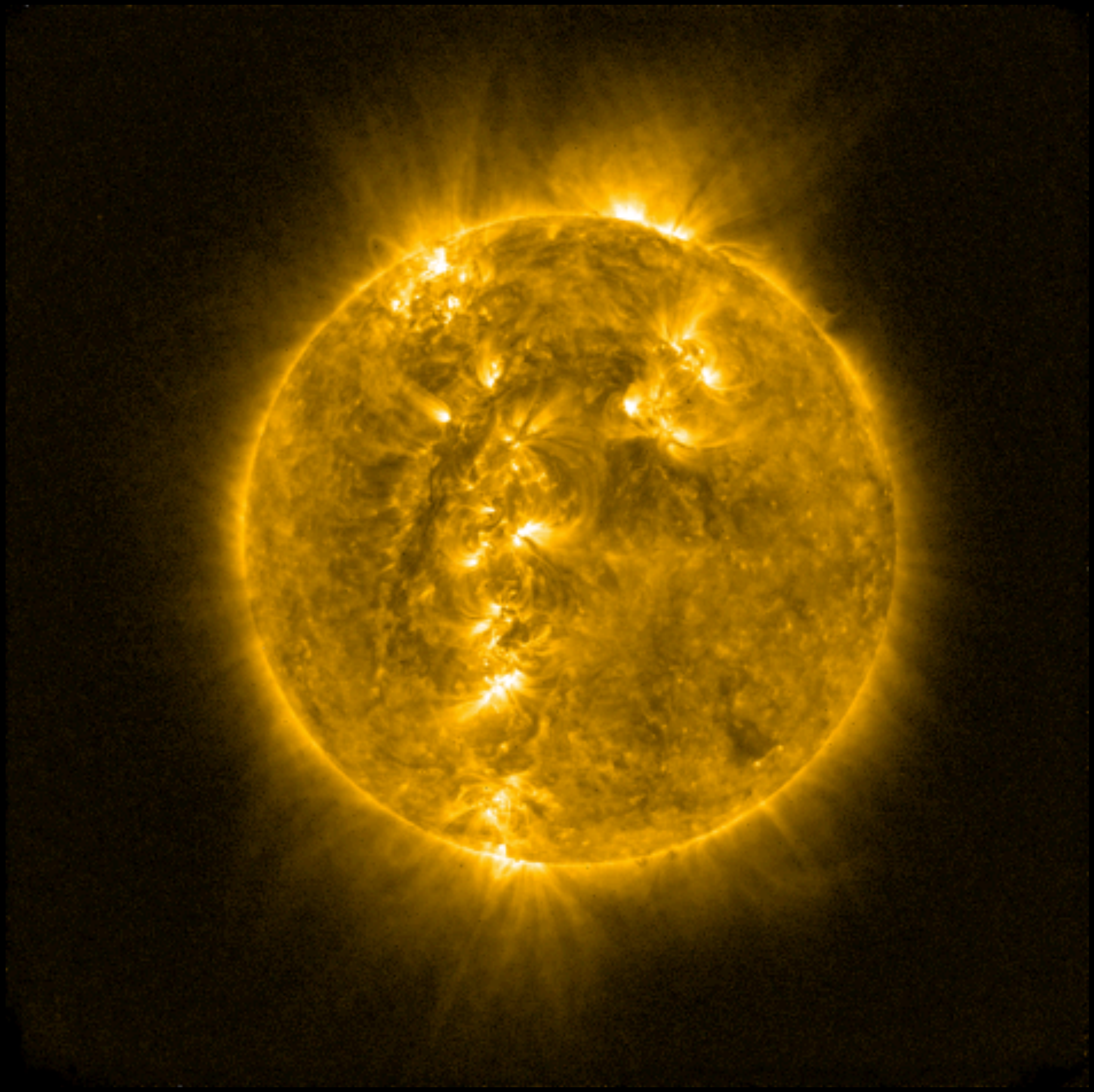
OPTICAL EFFECTS

Image distortion

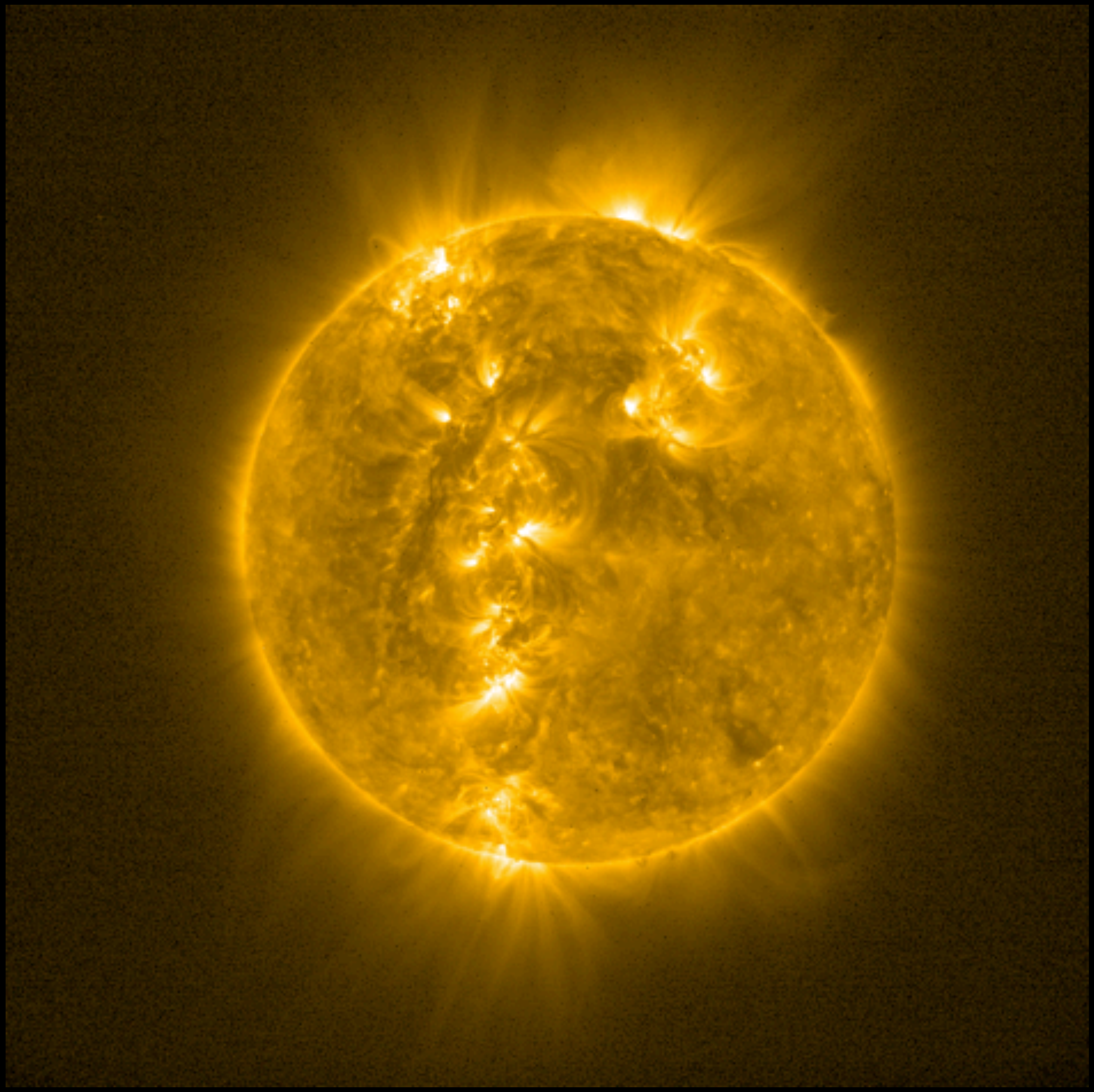


OPTICAL EFFECTS

Attenuation & flat-field (exaggerated here)



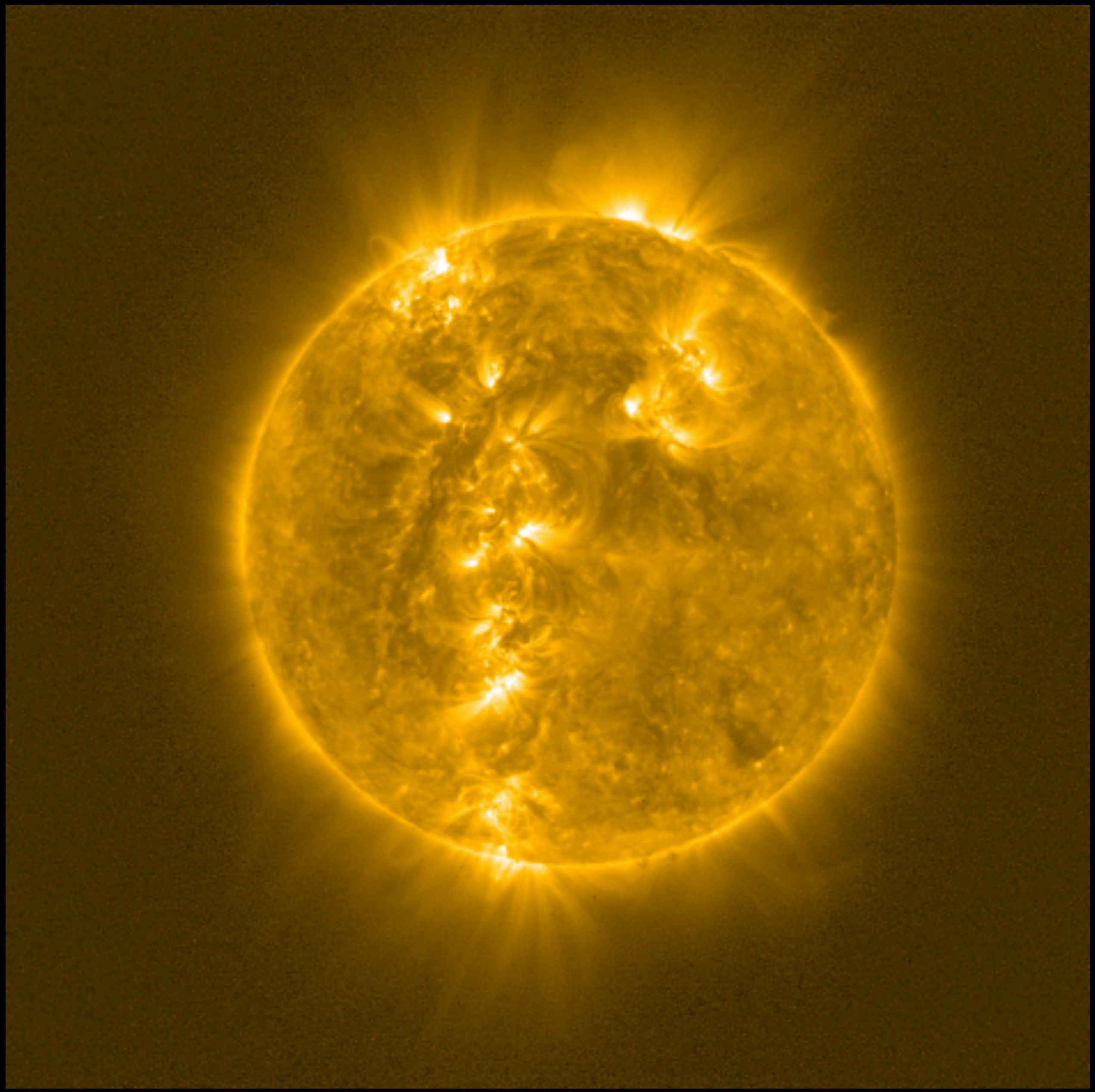
OPTICAL EFFECTS



Dispersion & stray light
(point-spread function)

DETECTOR EFFECTS

Dark current

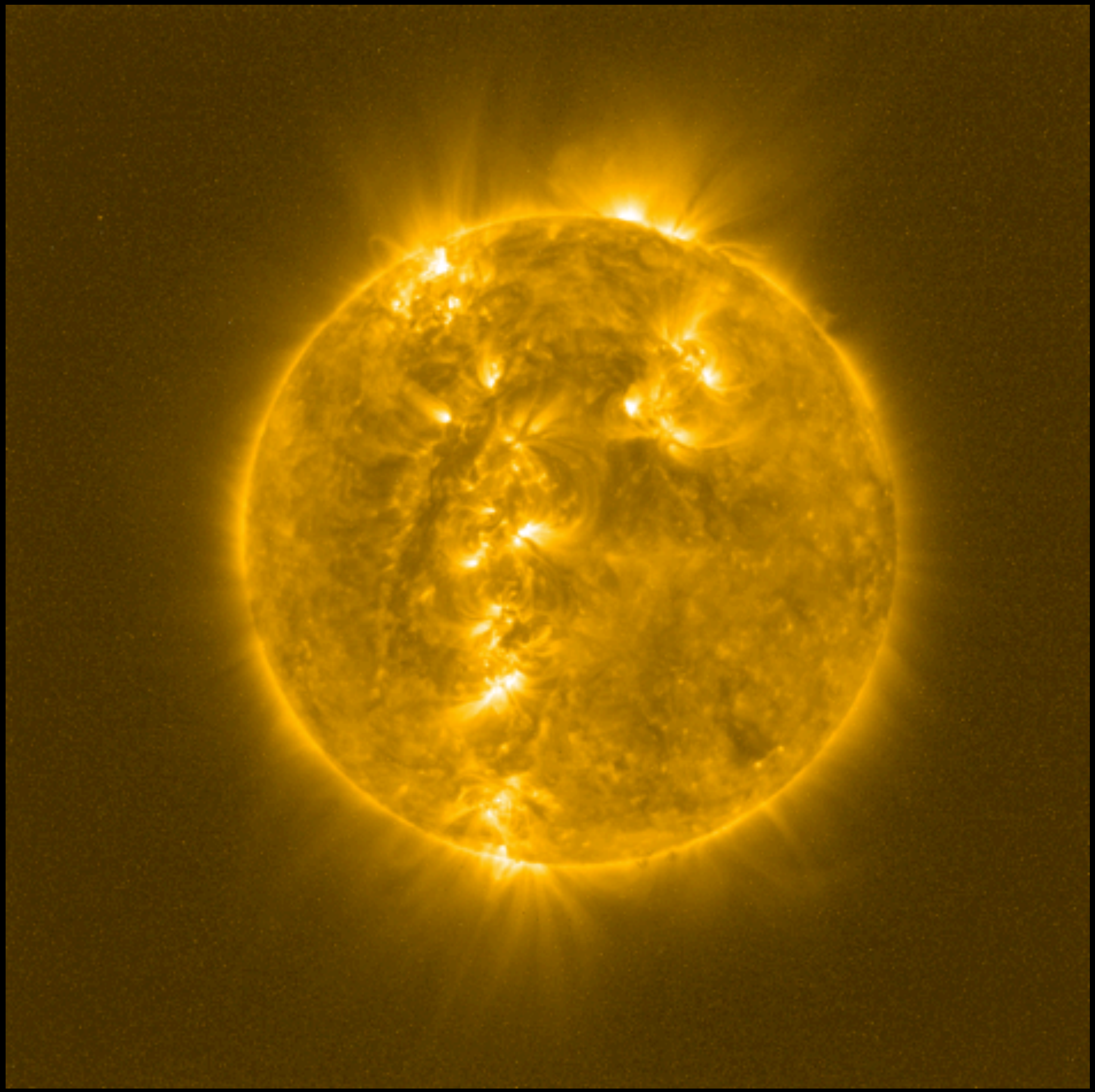


DETECTOR EFFECTS

Defective pixels

Radiation effects

Other noise



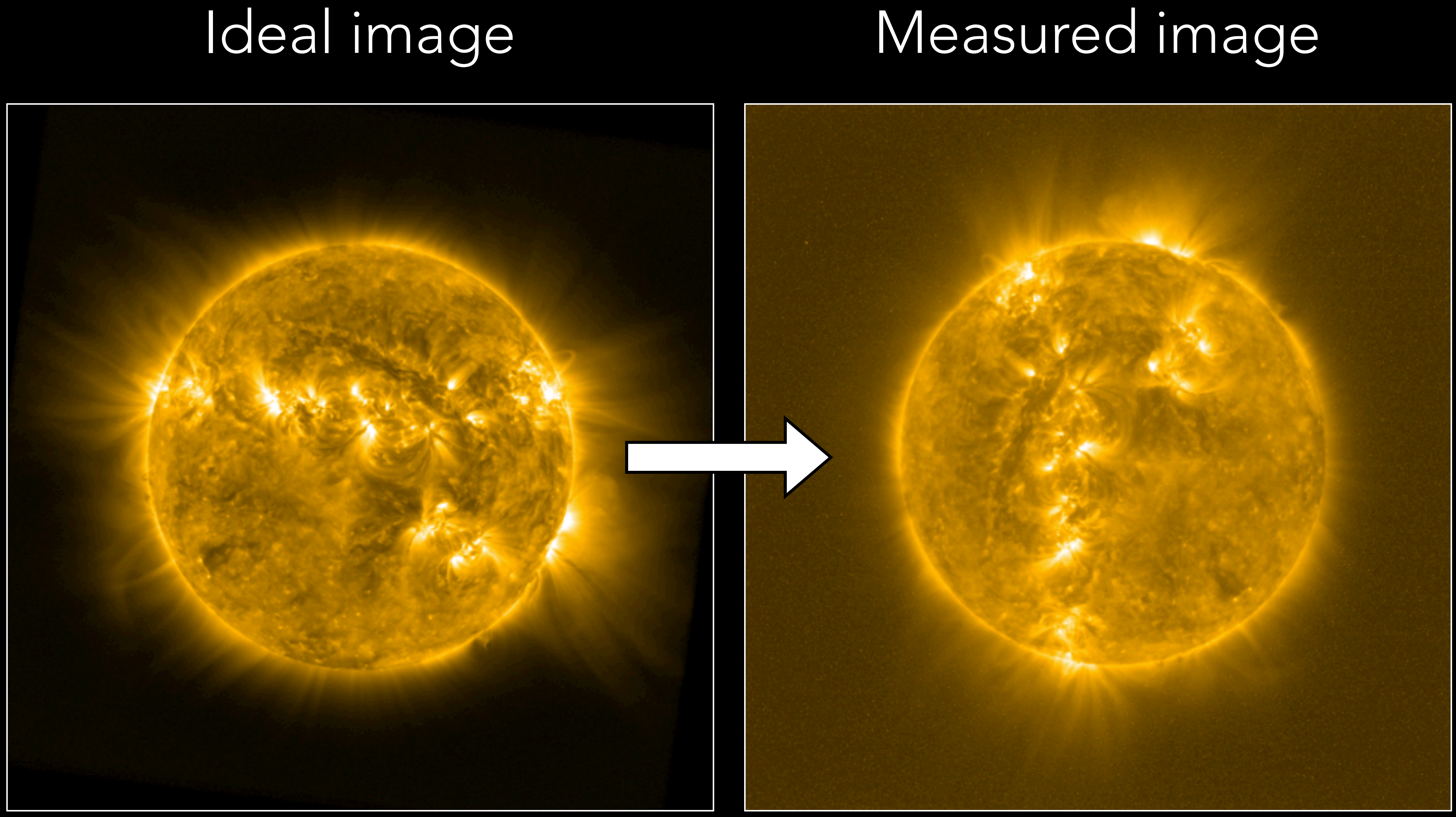
OTHER EFFECTS & CONCERNS

Instrument degradation: performance changes, evolution over time

Integration time: controls signal/noise

Uncorrectable noise: photon shot noise, read noise, etc.

Digitization: physical units ⟶ “data numbers”


Ideal image
Measured image

SWAP CALIBRATION

IMAGE RECORDING “EQUATION”

Transformations → $\mathbf{T}_{\text{Tel}}\,\mathbf{T}_{\text{Opt}}$

PSF → $P(x,y)$

Bias → B_0

$$\mathbf{I} = \{[\mathbf{S}\Delta t\ \mathbf{T}_{\text{Tel}}\,\mathbf{T}_{\text{Opt}}\,G(x,y)] * P(x,y)\} + d(x,y,T)\Delta t + B_0 + \text{Error}$$

Gain/ flat-field → $G(x,y)$

Dark → $d(x,y,T)$

CALIBRATION REVERSES THESE OPERATIONS

$$\mathbf{S} = \frac{[\mathbf{I} - B_0 - d_{\text{Estimated}}(x, y, T)\Delta t] * P^{-1}_{\text{Estimated}}(x, y)}{G(x, y)\,\Delta t}\,\mathbf{T}^{\mathbf{-1}}_{\text{Tel}}\,\mathbf{T}^{\mathbf{-1}}_{\text{Opt}}$$

Measured image

Work outwards →

PROBA2/SWAP CMOS-APS

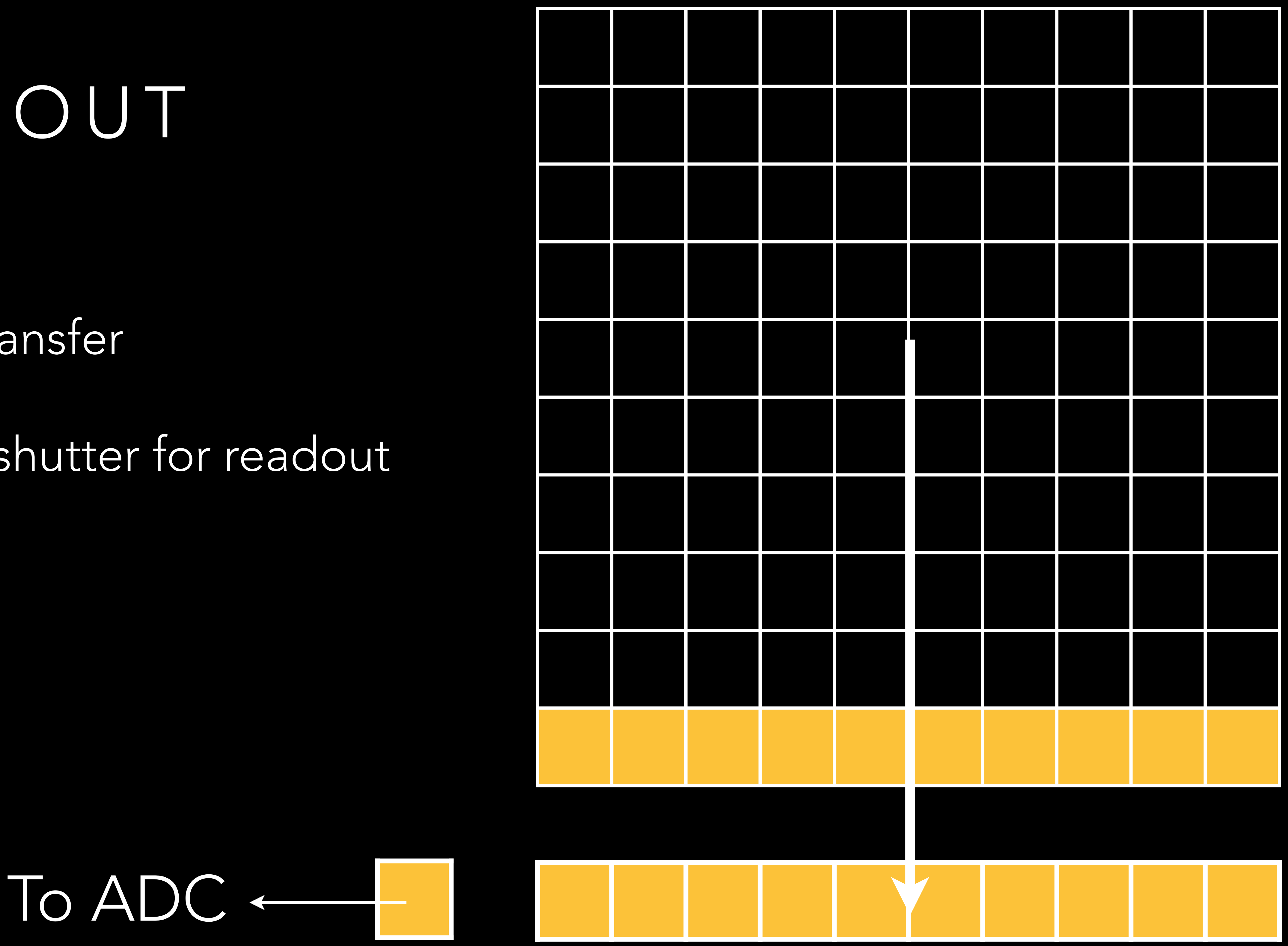
OBSERVING WITH SWAP'S APS DETECTOR

What is novel about APS detectors?

CCD READOUT

Charge transfer

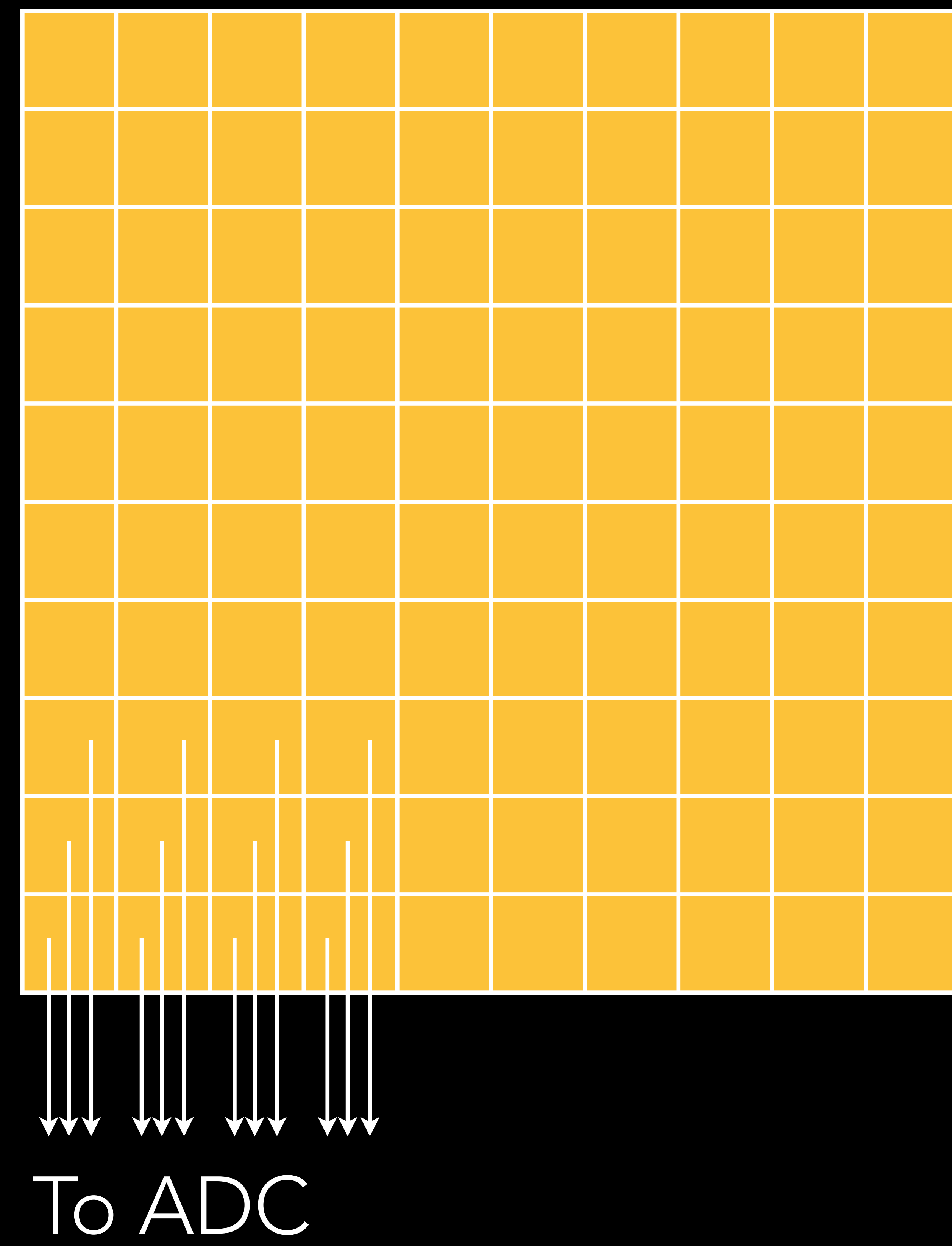
Requires shutter for readout



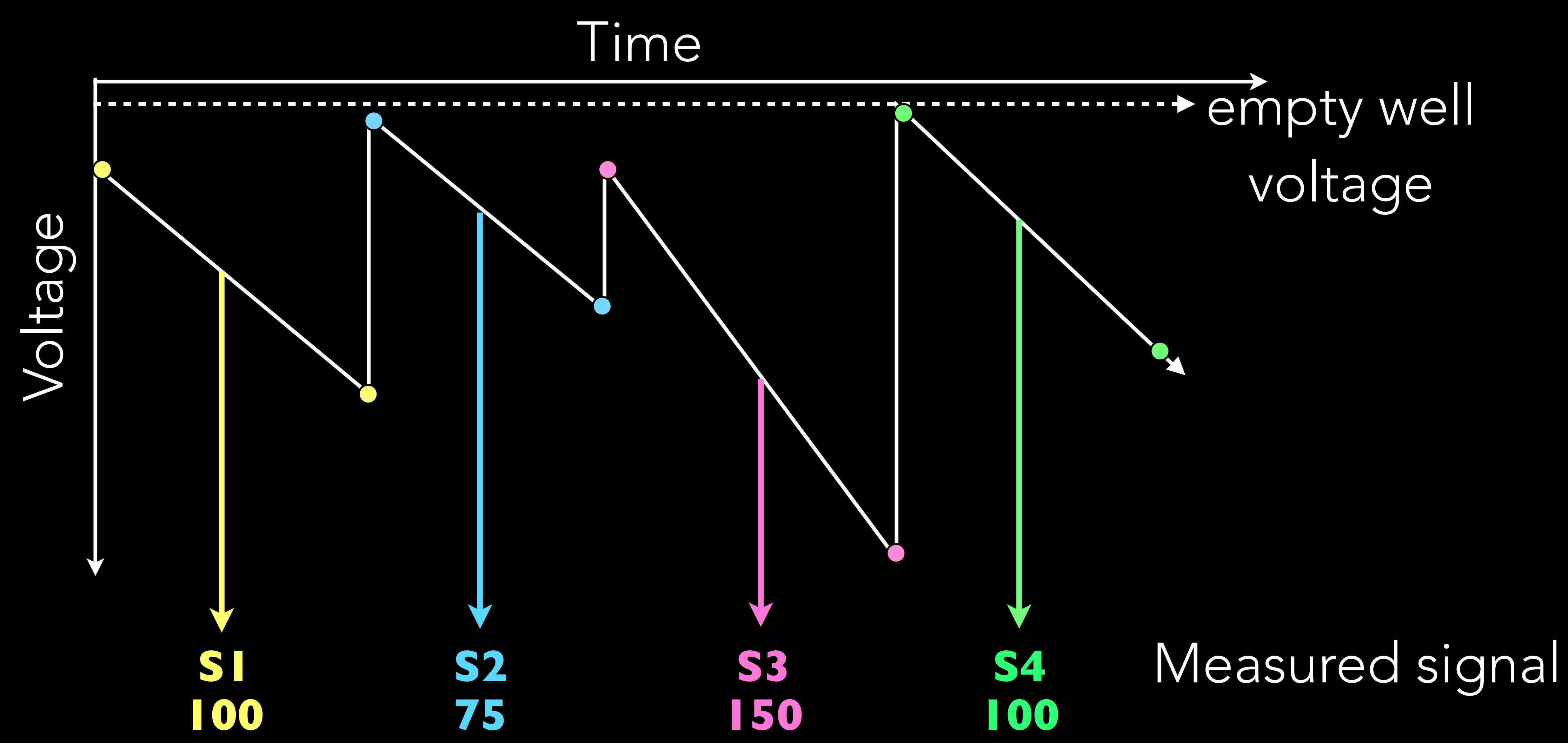
CMOS-APS READOUT

No charge transfer

No shutter for readout
Detector can be read non-destructively

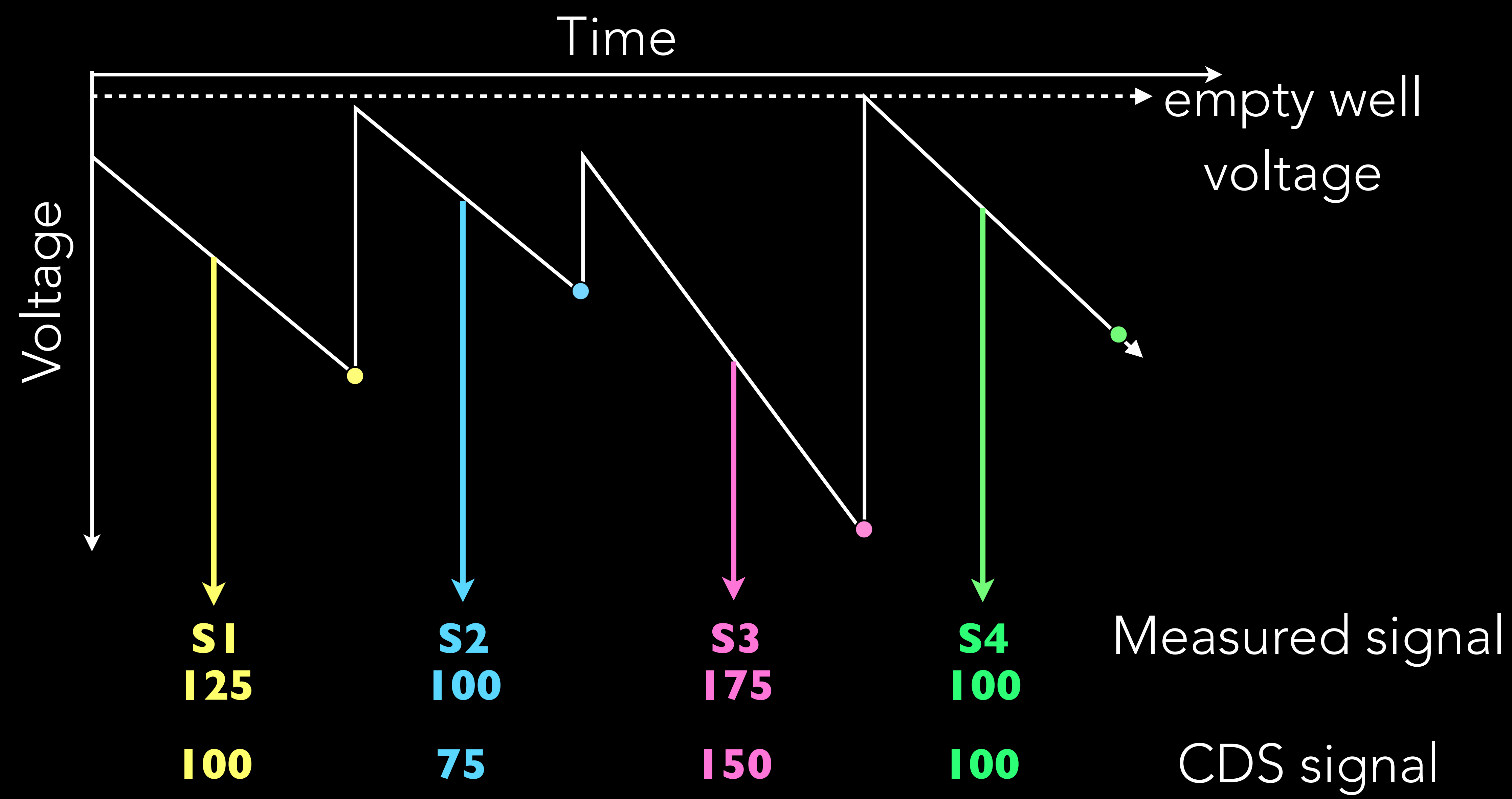


CMOS-APS READOUT MODES



Correlated double sampling (CDS)

CMOS-APS READOUT MODES

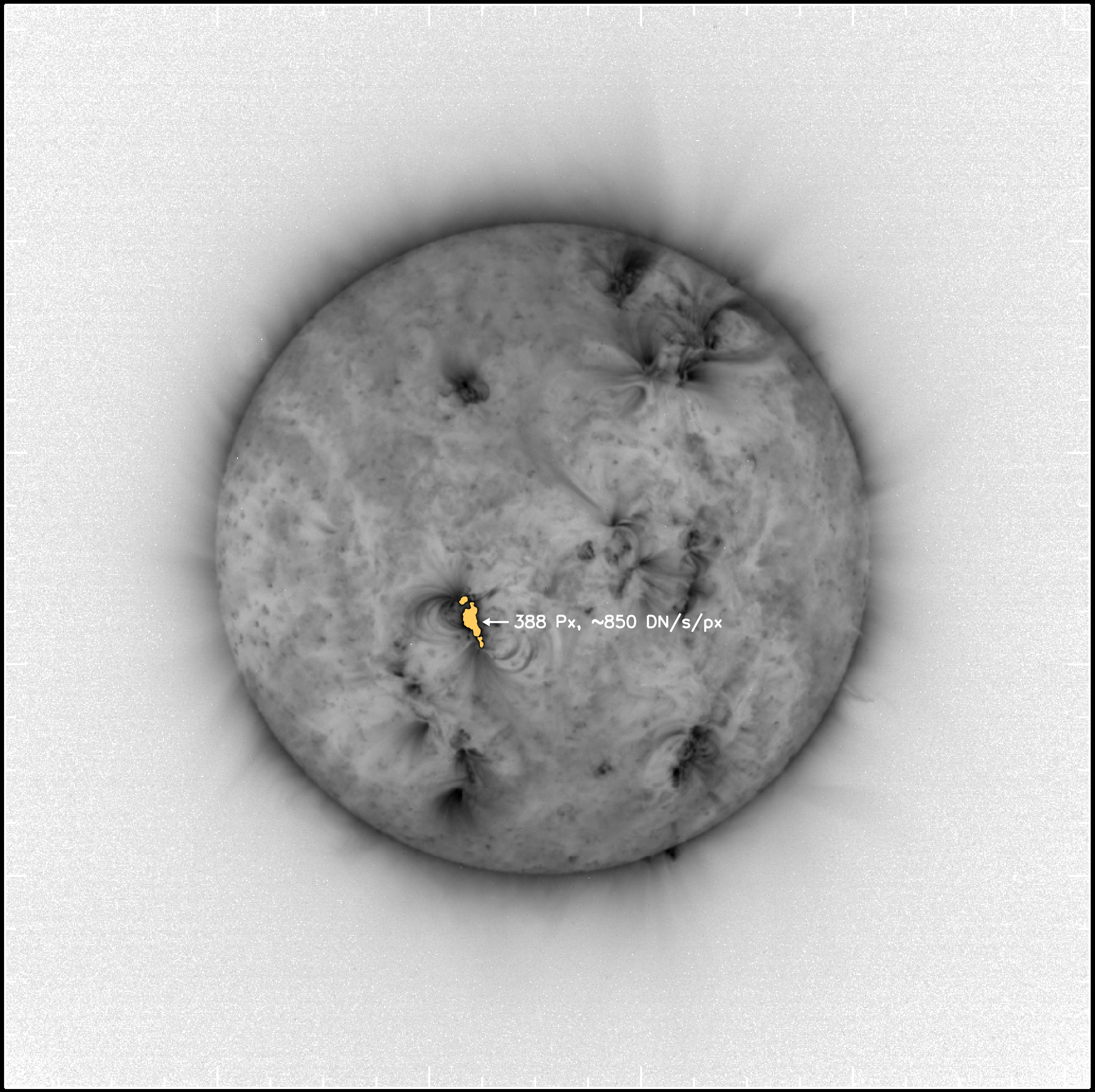


Double sampling (DS)

What are the consequences?

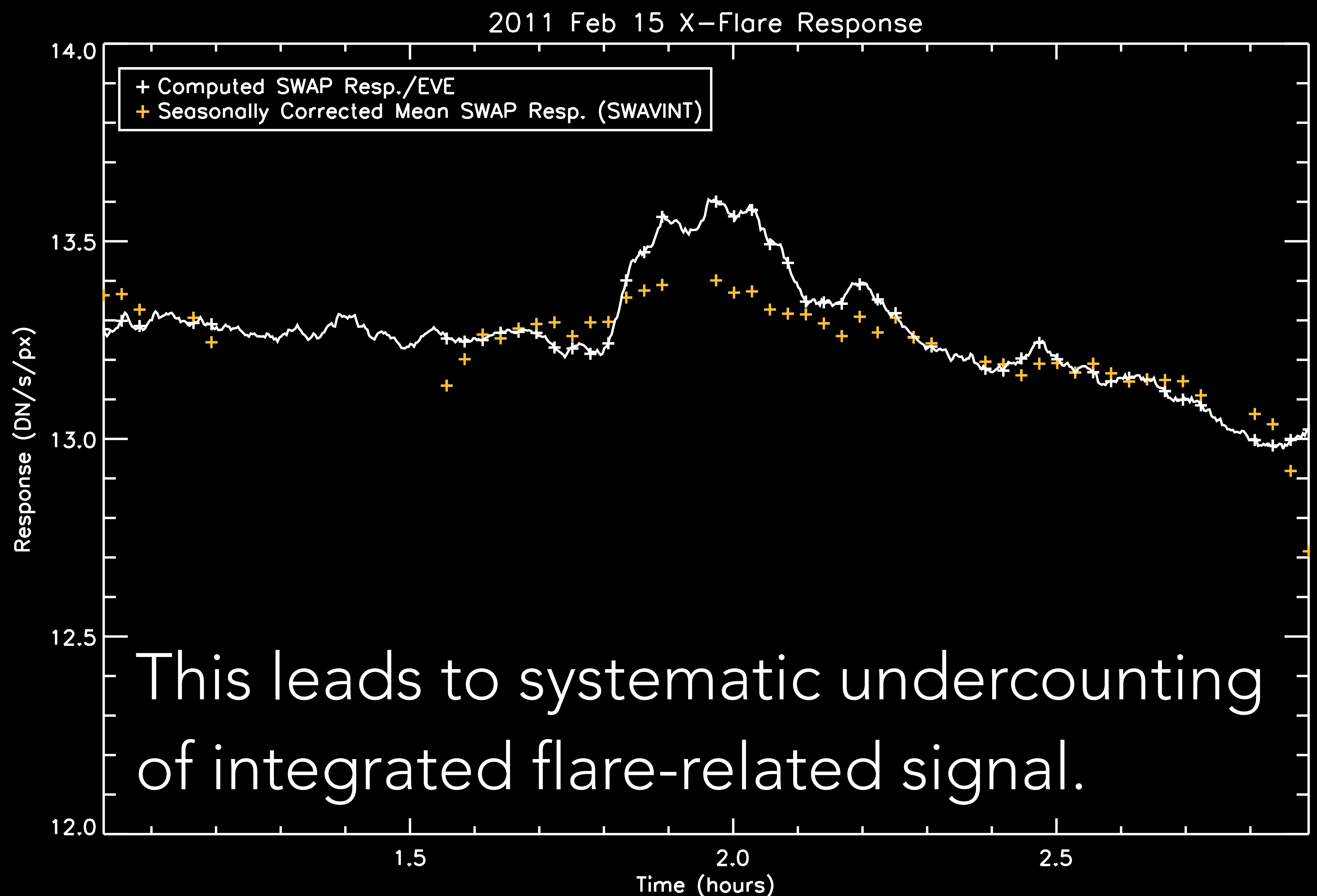
BLOOMING

Highly saturated regions in flares remain self-limited, signal is clipped.



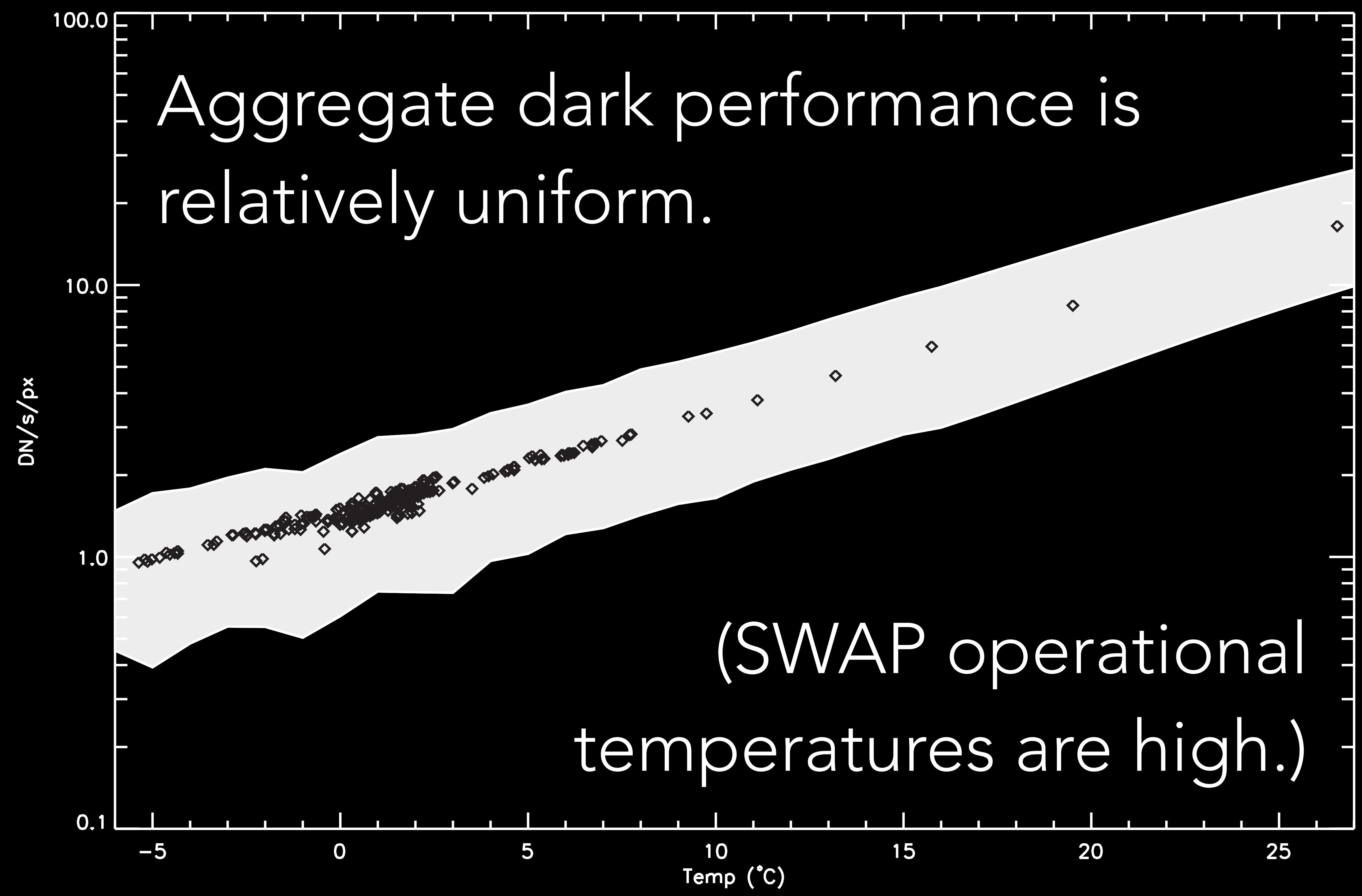
CMOS-APS BEHAVIORS

BLOOMING

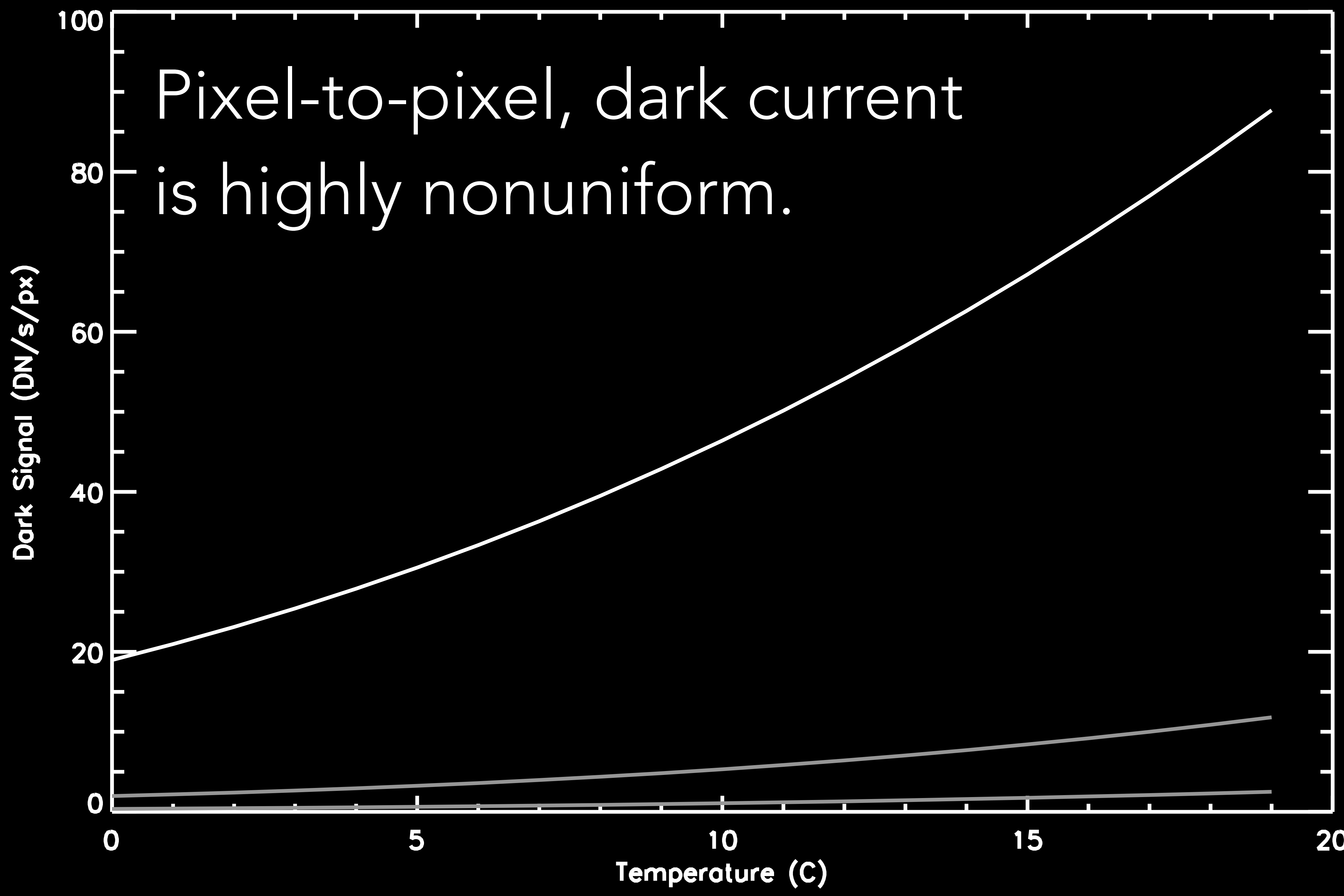


This leads to systematic undercounting of integrated flare-related signal.

DARK CURRENT

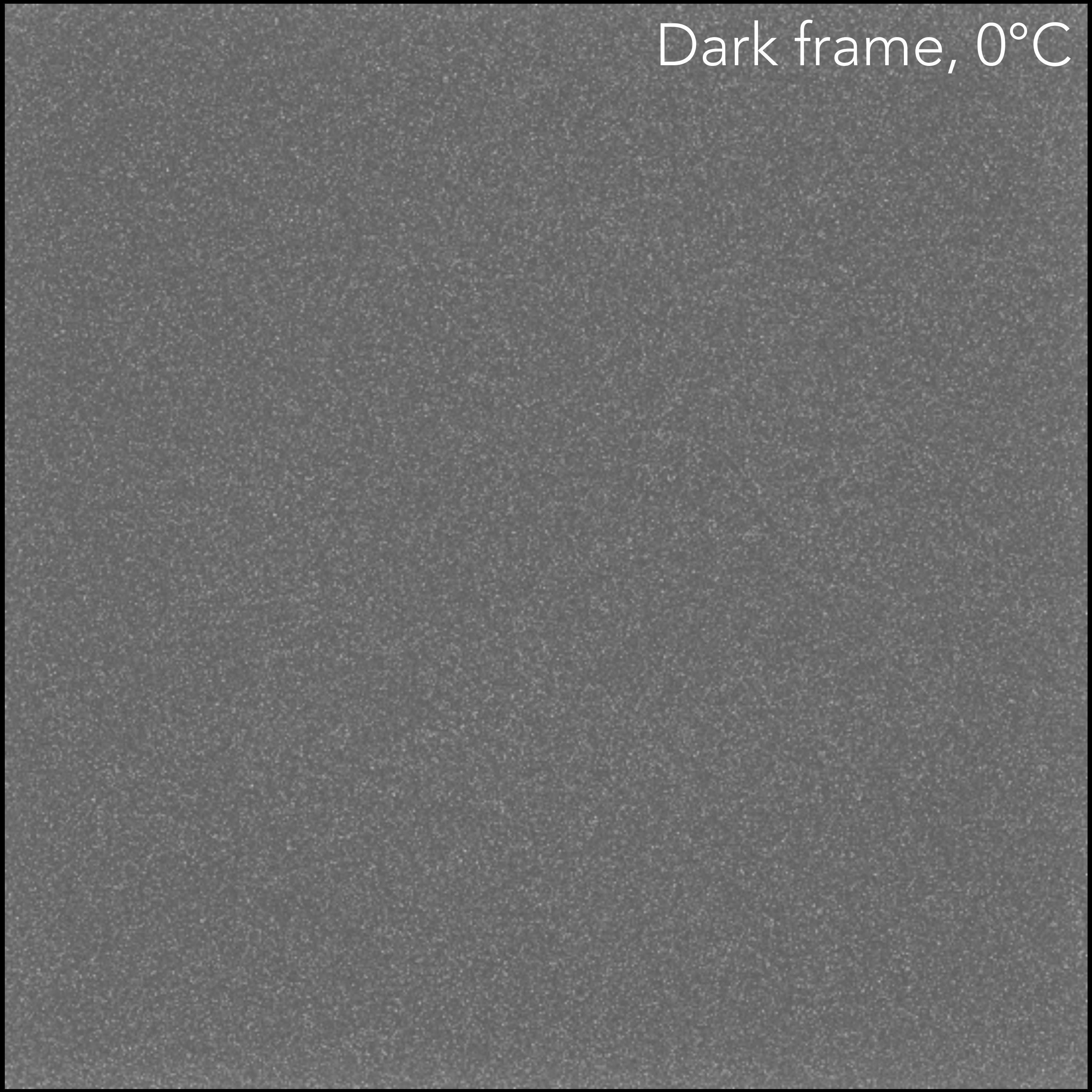


DARK CURRENT



CMOS-APS BEHAVIORS

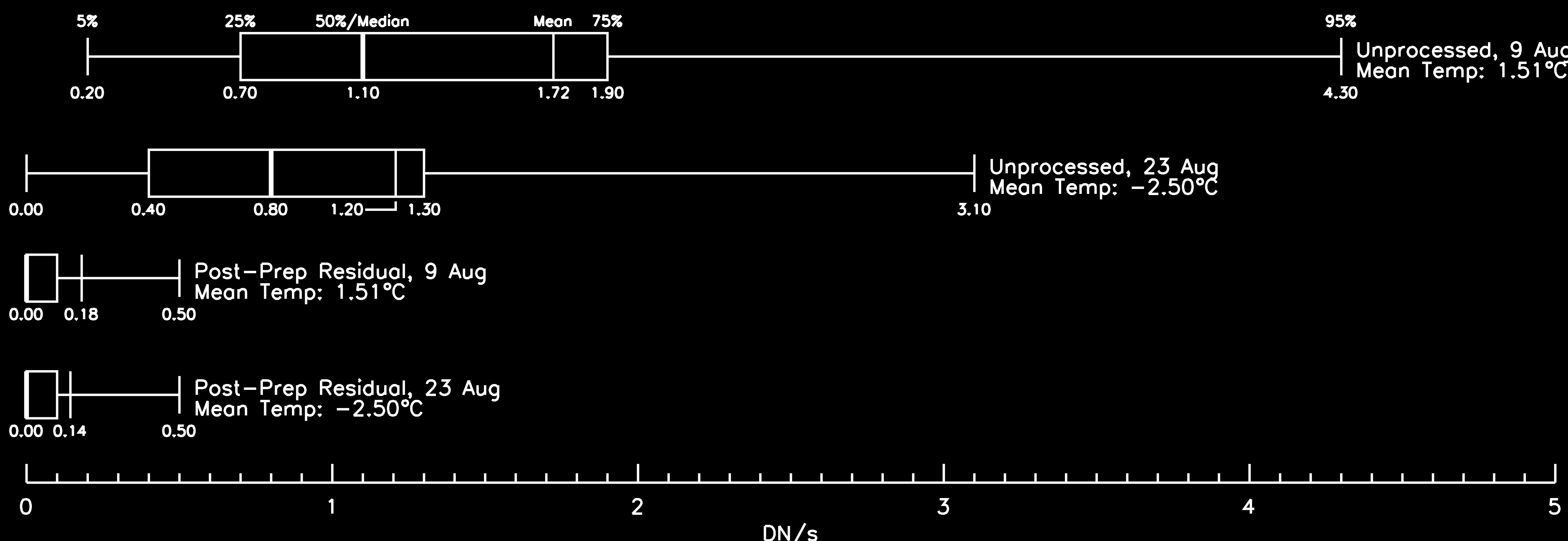
DARK CURRENT



CMOS-APS BEHAVIORS

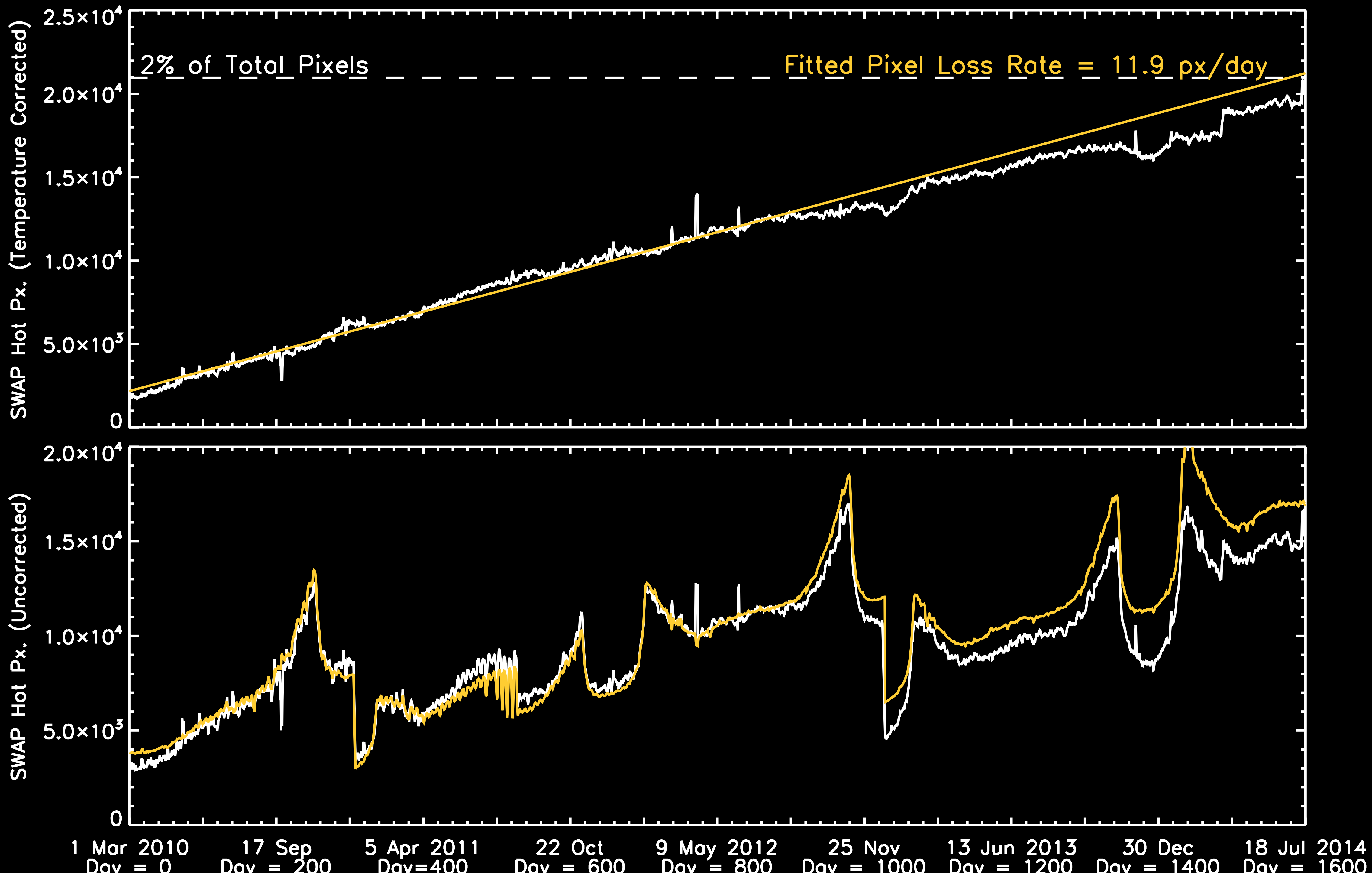
DARK CURRENT

Dark current can be corrected — to an extent.



CMOS-APS BEHAVIORS

HOT PIXELS



ROLLING SHUTTER

RECIPROCITY & LINEARITY

If the **law of reciprocity** holds for a detector:

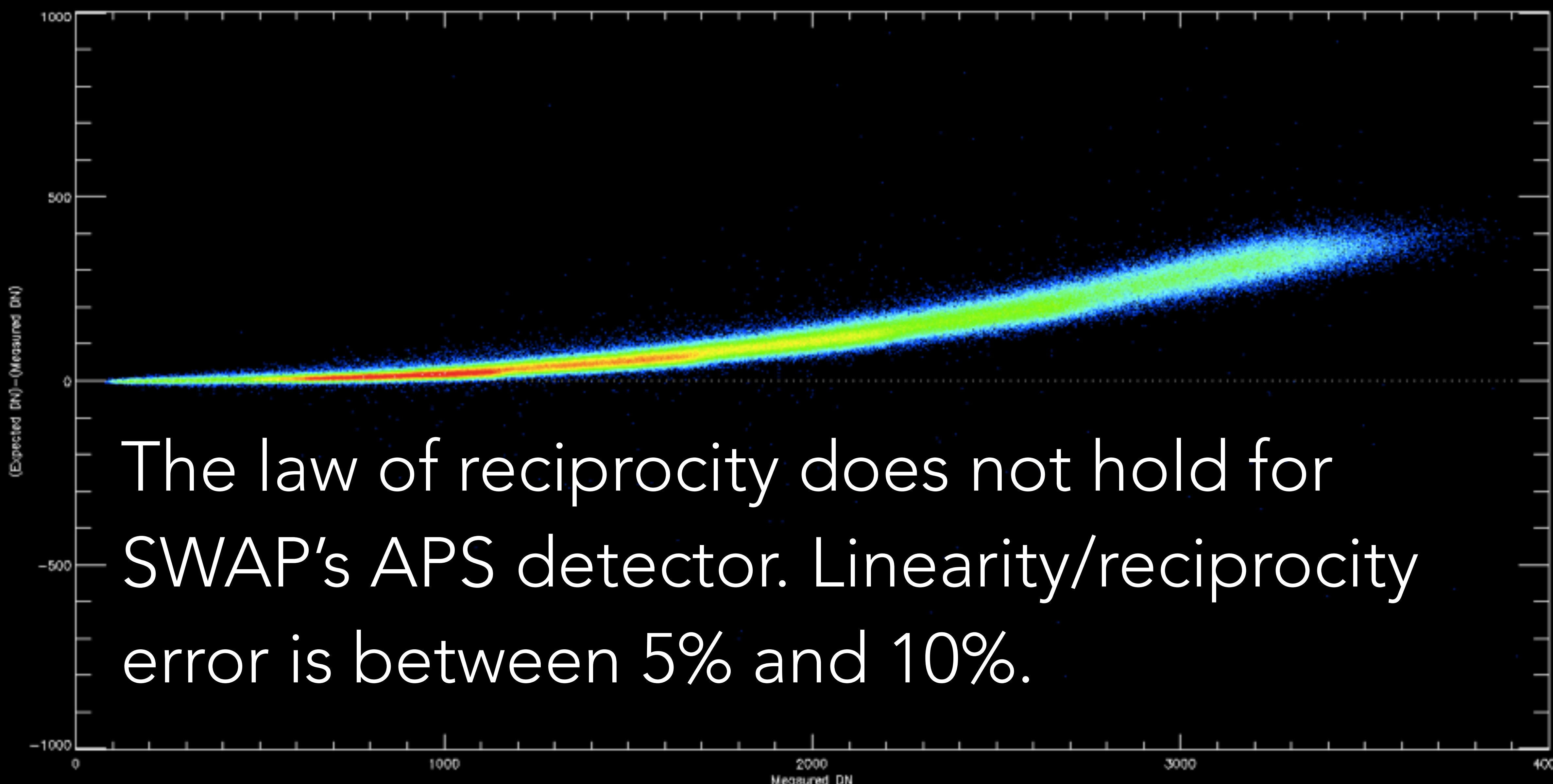
$$\text{response} = \text{intensity} \times \text{time}$$

RECIPROCITY & LINEARITY

SIGNAL		INT. TIME		MEASURED SIGNAL
1 BRIGHTNESS UNIT	+	20 SECONDS	→	20 MEASURED UNITS
2 BRIGHTNESS UNITS	+	10 SECONDS	→	20 MEASURED UNITS
2 BRIGHTNESS UNITS	+	20 SECONDS	→	40 MEASURED UNITS

CMOS-APS BEHAVIORS

RECIPROCITY & LINEARITY



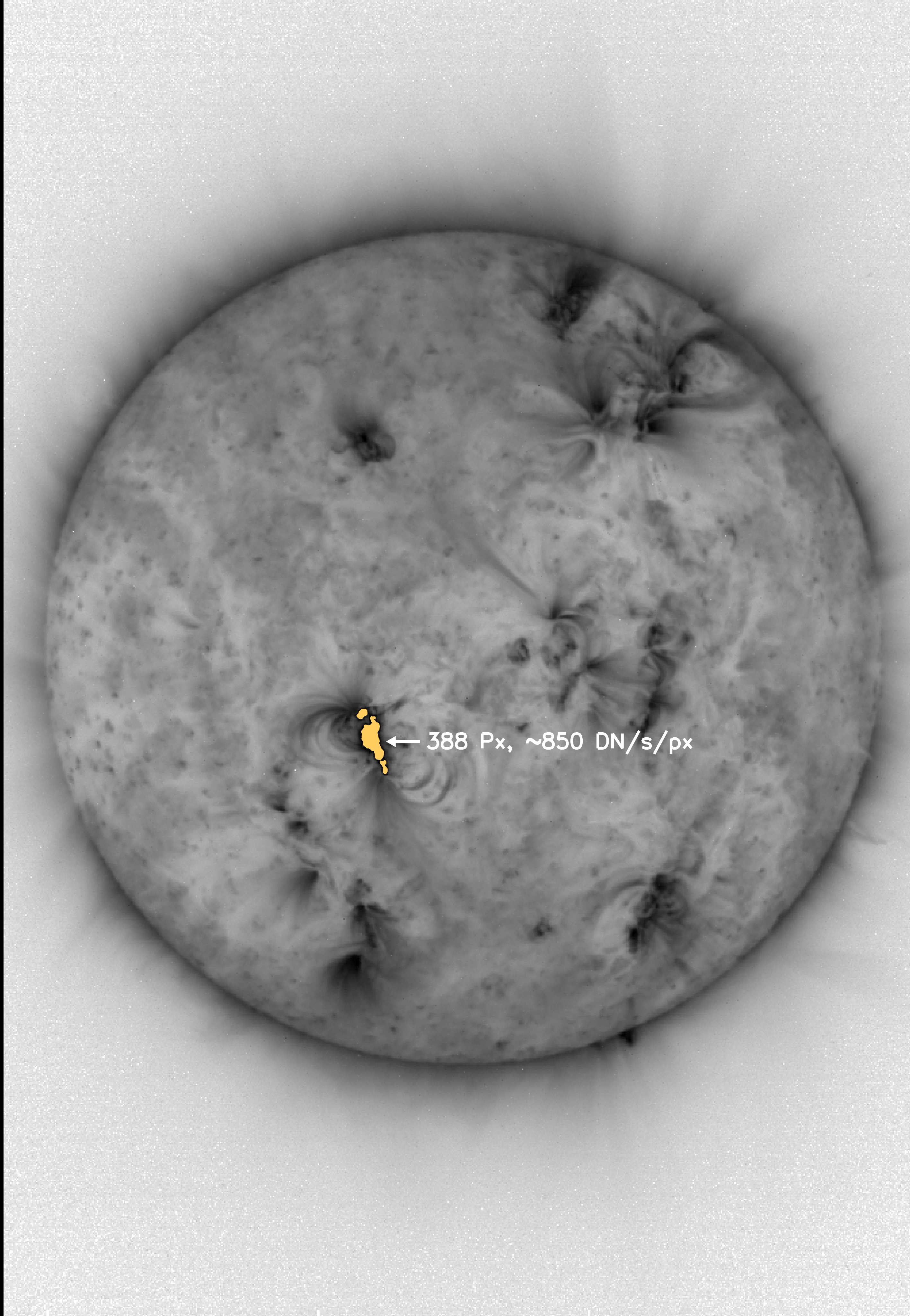
The law of reciprocity does not hold for SWAP's APS detector. Linearity/reciprocity error is between 5% and 10%.

What are the impacts and risks?
How can they be mitigated?

BLOOMING

In general, this behavior is **beneficial** to overall image quality.

However, this behavior **can interfere** with automated event detection.

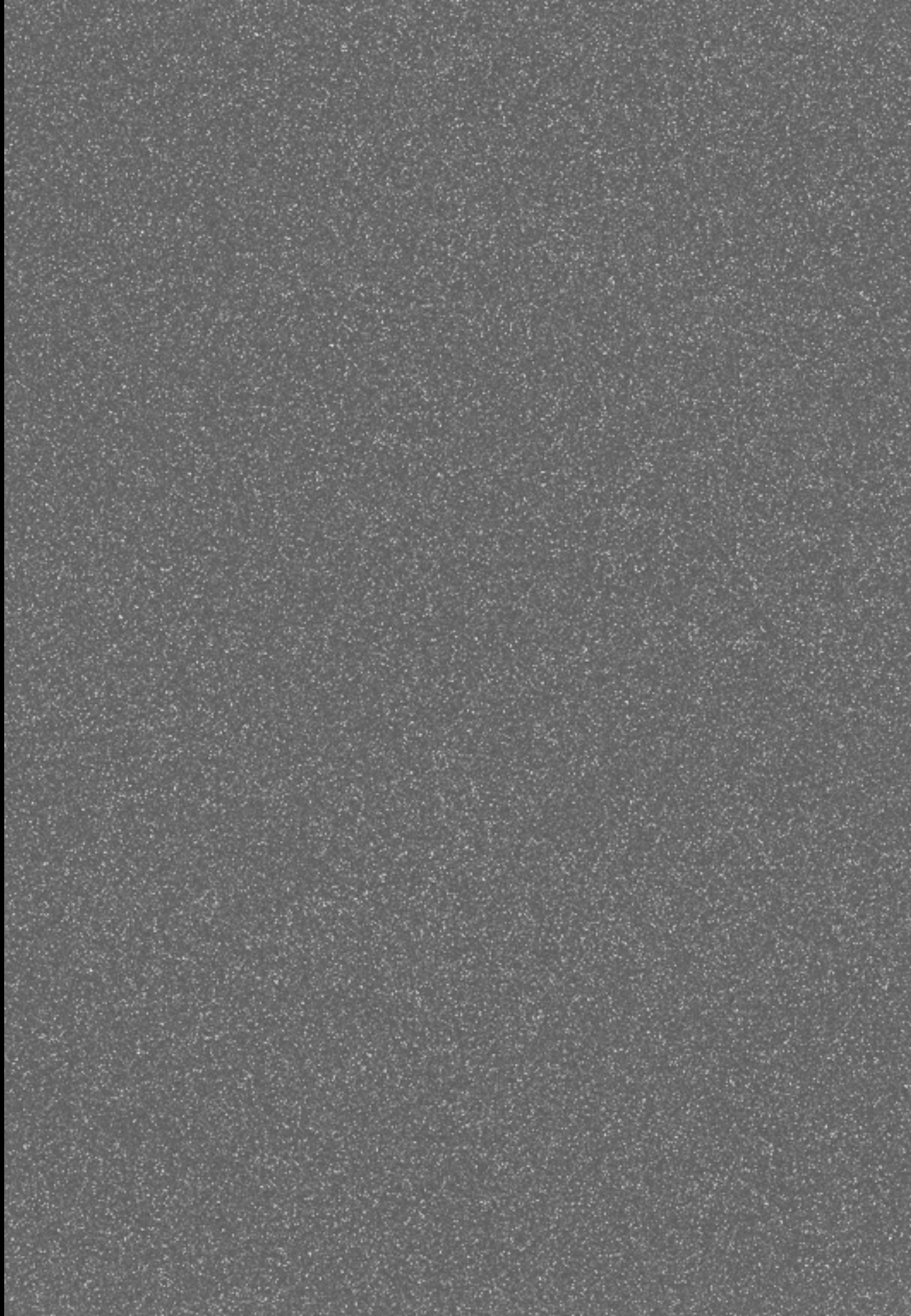


DARK CURRENT

All detectors have dark current.

Efficient cooling and **careful dark calibration** can limit impacts.

Residual signal remains at the lowest levels due to uncorrectable noise.

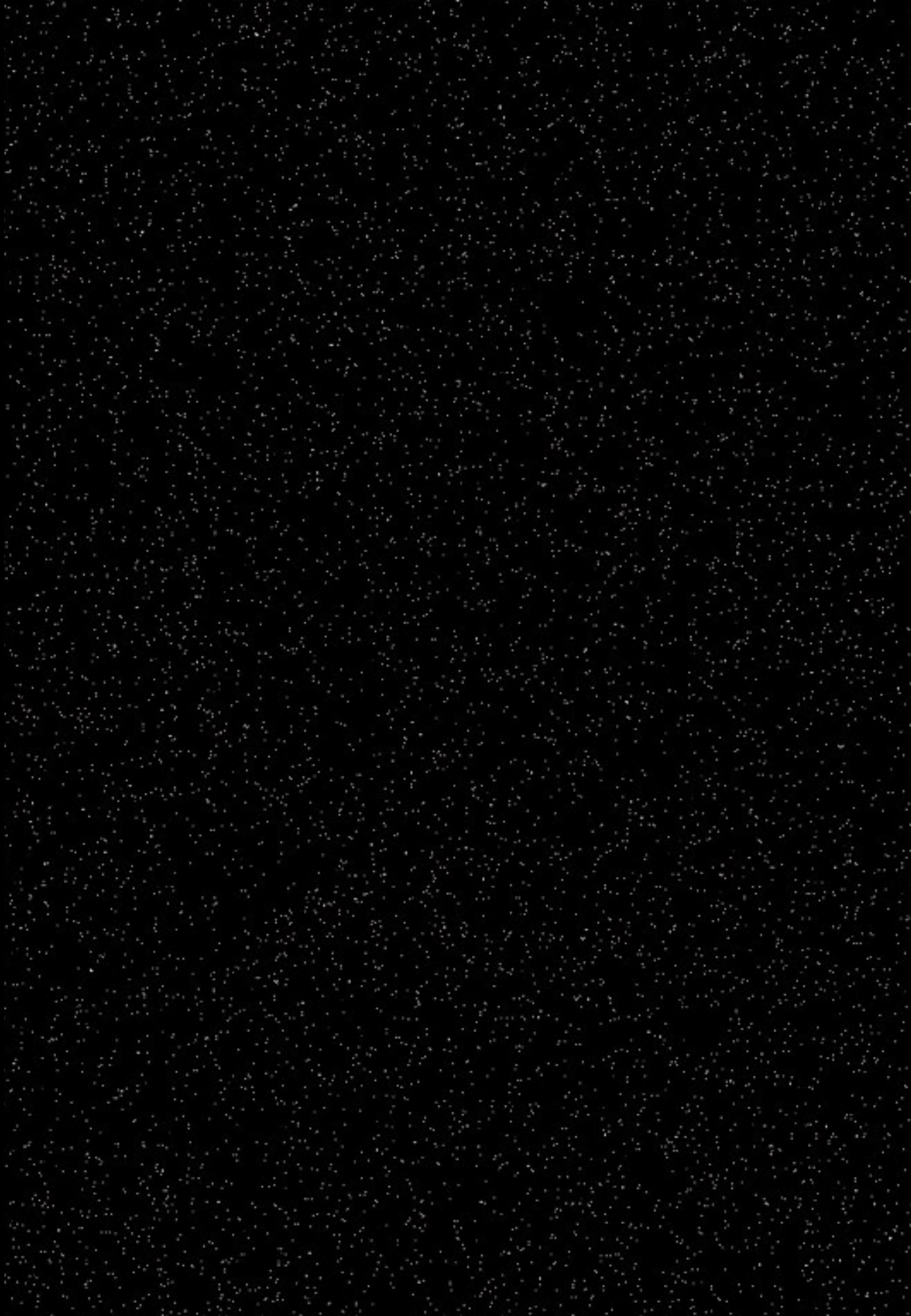


HOT PIXELS & EVOLUTION

Hot pixels are **detrimental to image compression**.

Hot pixels are (generally) **not random**, but the pattern may **evolve**.

Various, highly effective strategies to **remove** them exist.



ROLLING SHUTTER

Rolling shutter introduces **distortion** into APS images.

Even **slowest** readout times are **much faster** than global solar timescales.

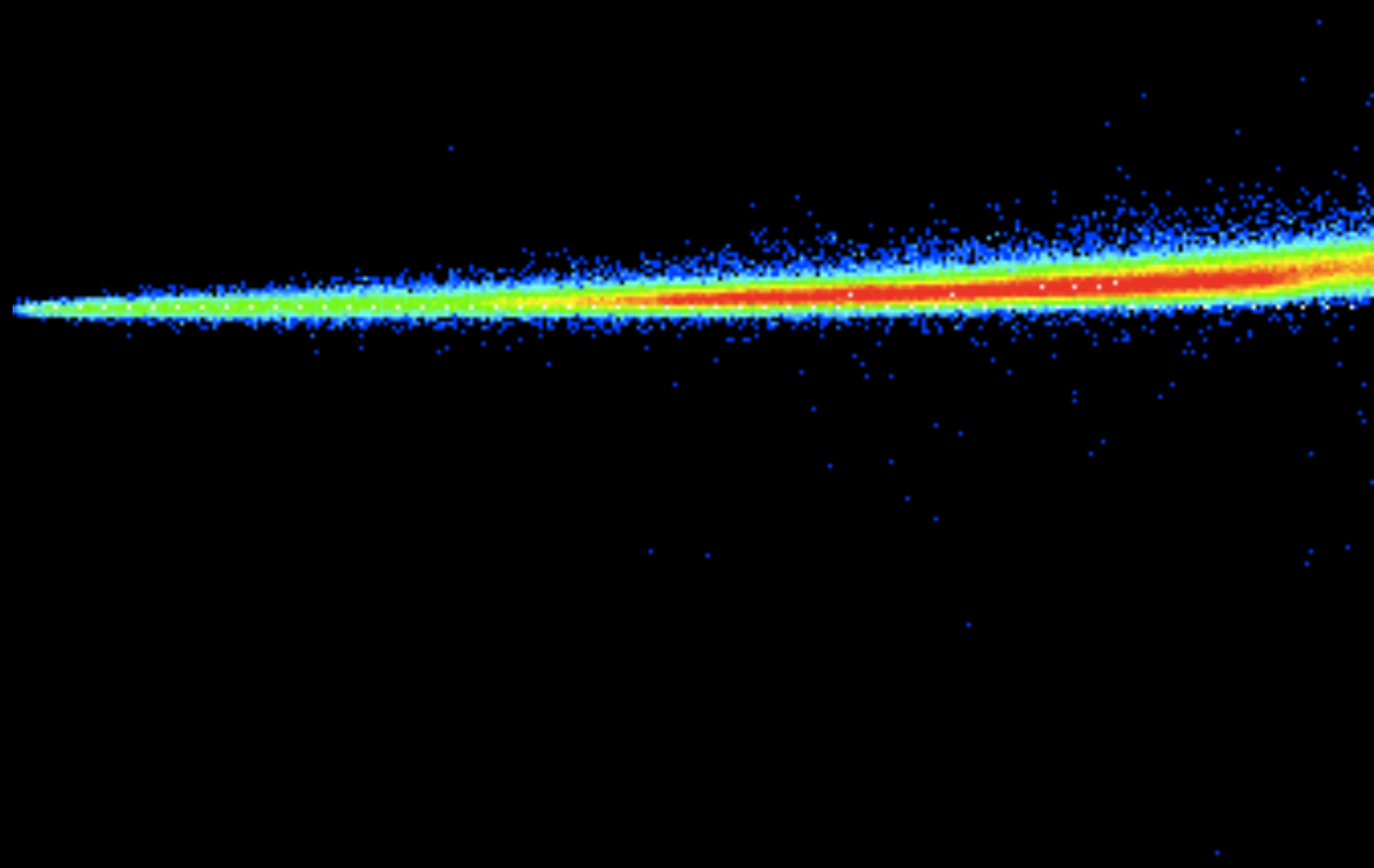
Rolling shutter could be problematic for **high-speed, small-scale** observations.

RECIPROCITY & LINEARITY

Reciprocity & linearity are **essential for photometry**.

Nonlinearity in a reciprocal detector can be **corrected**.

Nonreciprocity is **difficult to correct** without complex operational strategies.



PROBA2/SWAP CMOS-APS

LESSONS LEARNED

PROBA2/SWAP CMOS-APS

LESSONS LEARNED

Instrument calibration **success depends on camera calibration** success.

APS detectors have **different behaviors than CCDs**, which may affect images and image processing.

Most tricky **problems can be mitigated** — with **careful** on-ground preparation & in-flight calibration programs.