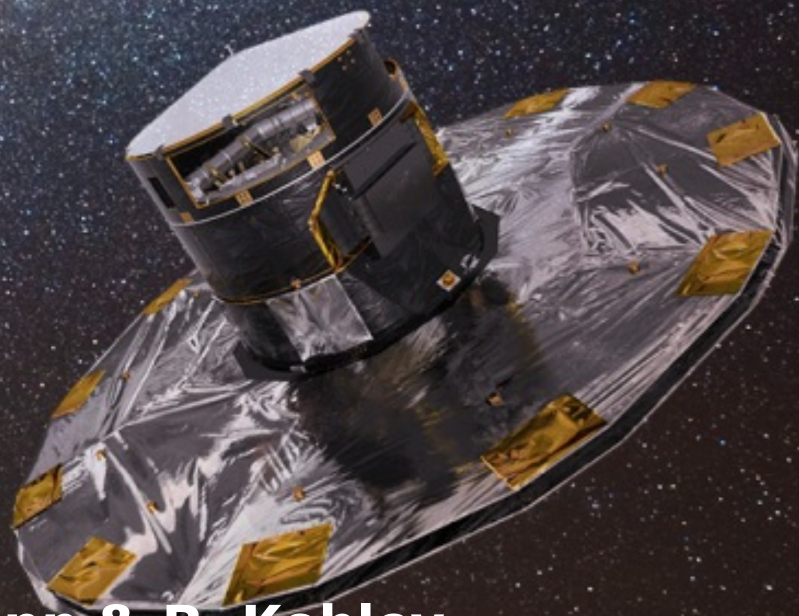
Observing Very Bright Stars with Gaia



J. Martin-Fleitas, A. Mora, J. Sahlmann & R. Kohley.

6th- Inter-Departmental Science Workshop

Aranjuez, 2013/11/19-21

Photo: ESA

SUMMARY

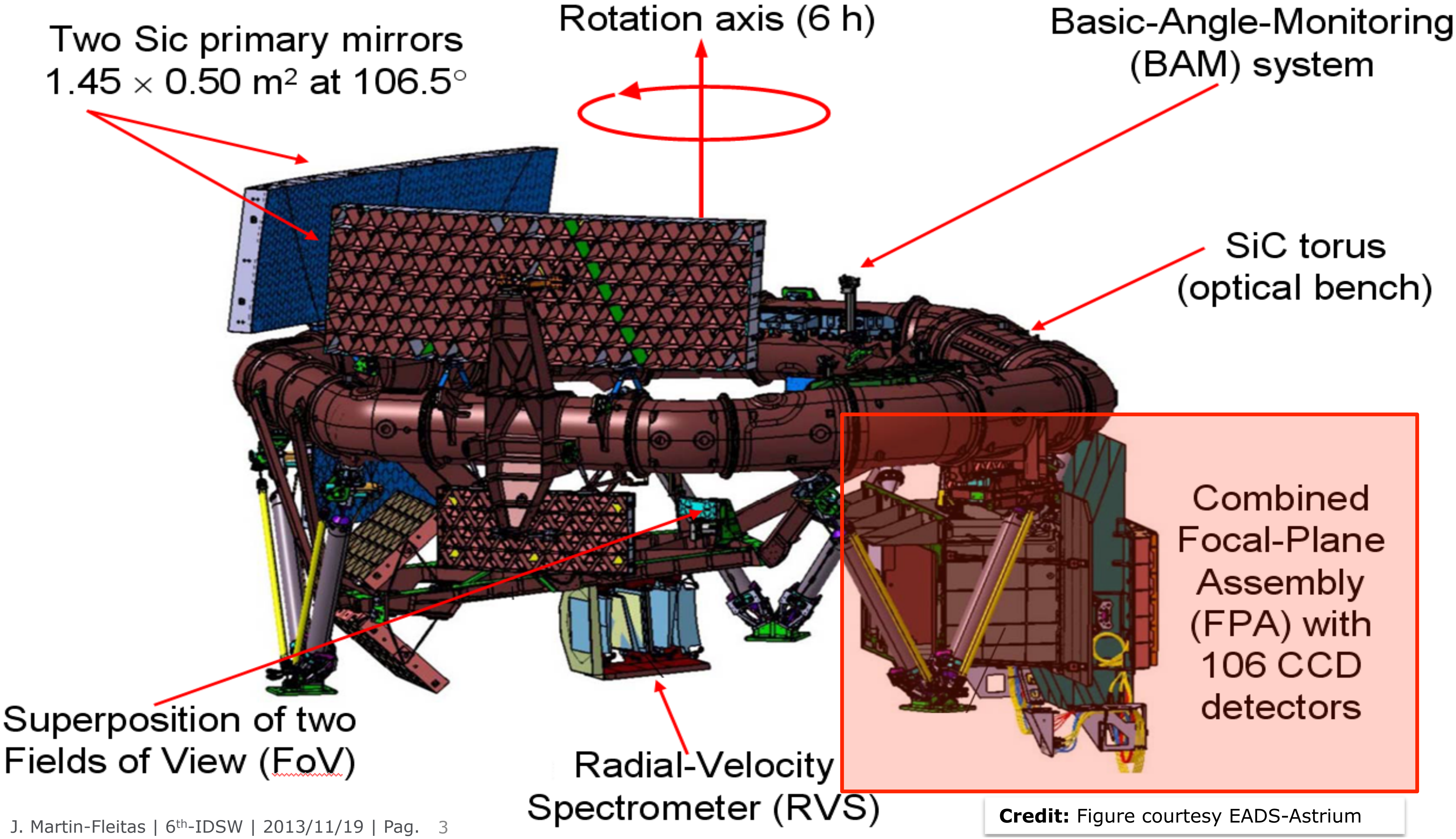
- **Gaia Detection/Observation System**
- **Observing Very Bright Stars with Gaia**

Gaia Presentation (T. Prusti)

- 6^{th} IDSW Session 3, 20^{th} Nov, 9:30 am

Photo: ESA

Gaia Observation System



Credit: Figure courtesy EADS-Astrium

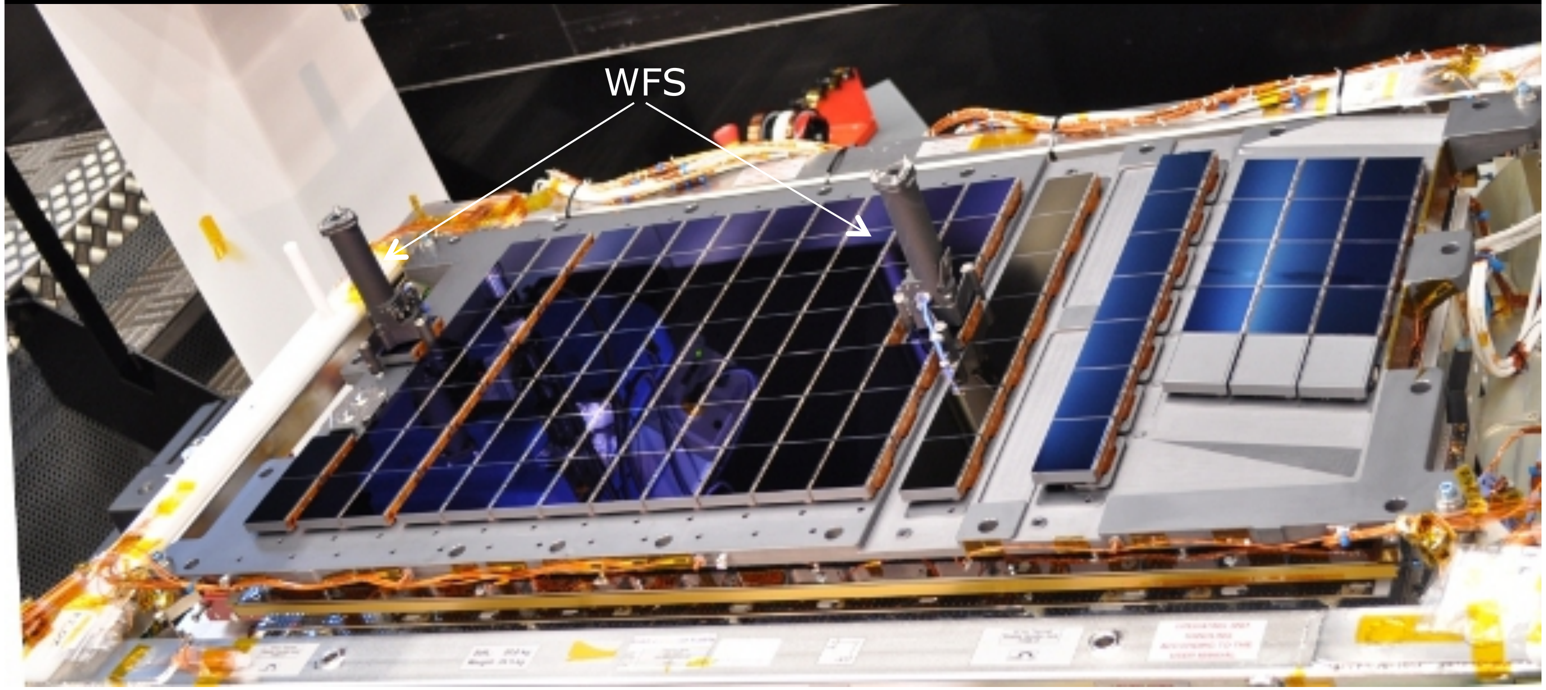
Observing Very Bright Stars with Gaia

Gaia Observation System

CCDs integrated on common support structure (CSS):

- 1 x 0.5 m in size
- 20 kg, all Silicon Carbite (SiC)
- Excellent thermal and mechanical stability
- 106 CCDs mounted on CSS aligned in 7 rows and 17 functional strips.
- 0.28 m^2 of Silicon
- WFS opto-mechanical assemblies directly mounted on the CSS in front of WFS CCDs.

- **1 billon pixels => Huge amount of TM.**
- **on-board selection of objects.**
- **Spinning mission => CCDs in TDI mode.**



Credit: Figure courtesy EADS-Astrium

gaia

Detection & FOV Disc Confirmation (AF1)

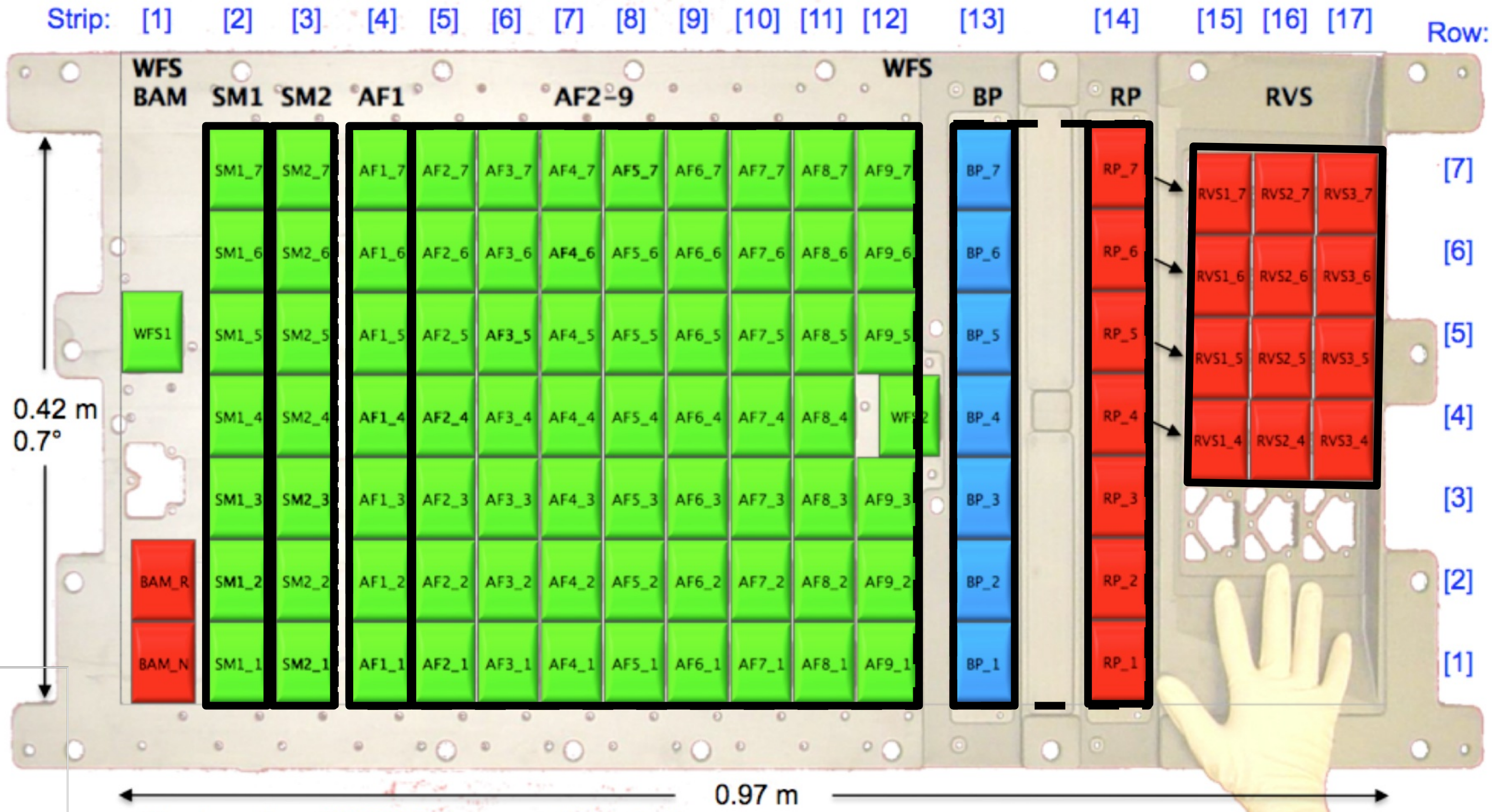
Astrometric Measurements (AF)

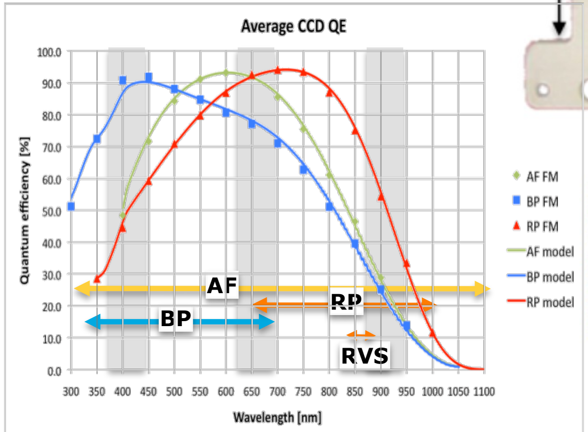
Photom (Disper Image (BP/RP)

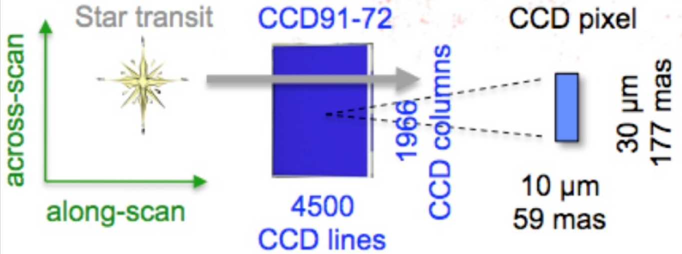
Spectrometry Radial Velocities (Dispersed Images) (RVS)

Radial Velocity Spectrograph:

- High resolution integral field spectrograph (R ~ 11,500)
- 847 – 874 nm
- Objects down to 17 mag
- Radial velocities from Calcium triplet



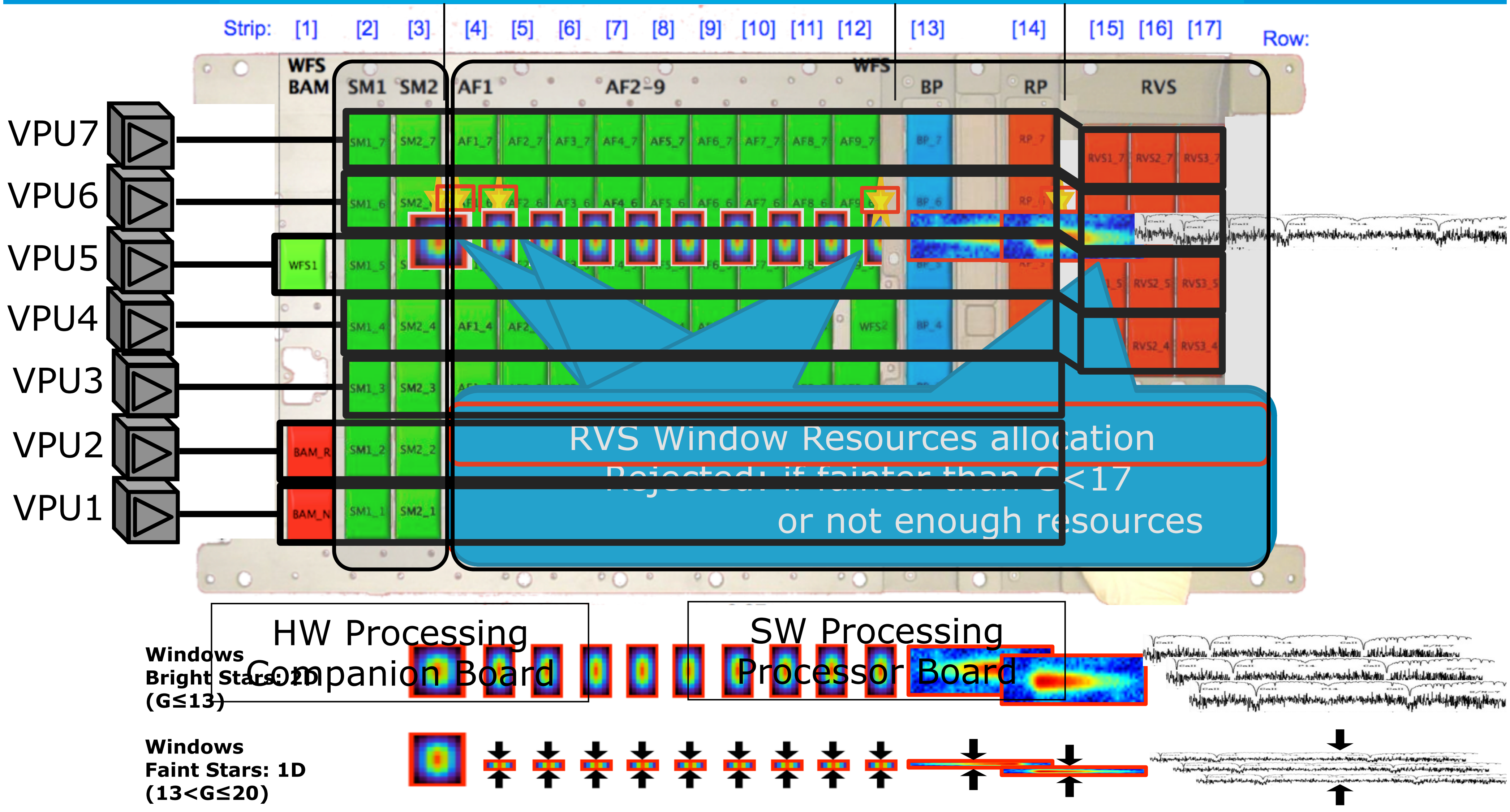




CCD model courtesy Maximilian Fabricius

Credit: Figure courtesy EADS-Astrium

Detection & Observation



Credit: Figure courtesy EADS-Astrium & B. Holl. **Animation idea:** B. Holl

Observing Very Bright Stars with Gaia

Detection & Observation

Catalogue

Astrometry
Positions (α, δ)
Parallaxes (ϖ)
Proper motions ($\mu_{\alpha^*}, \mu_\delta$)

Astrophysical parameters
(Teff, log g, [M/H], Av…)
Chromatic corrections

Radial Velocities

Time Stamping + Centroids + ~70 observations/obj

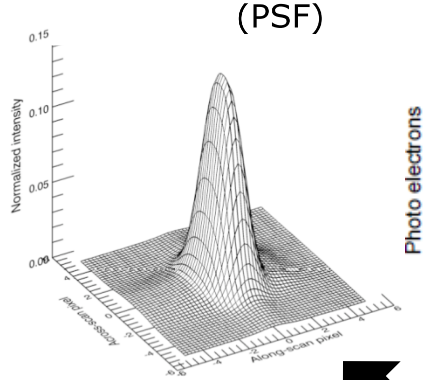
Low Resolution Blue spectrum

Low Resolution Red spectrum

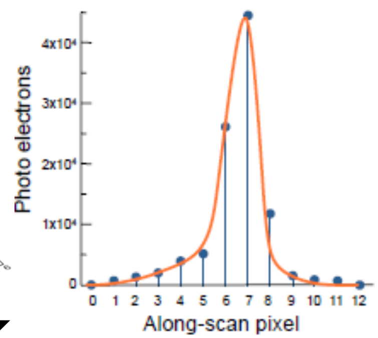
High Resolution spectra

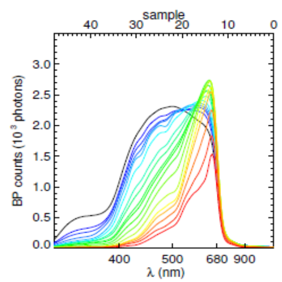
On-Ground Processing DPAC

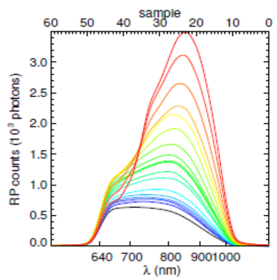
Point Spread Function (PSF)

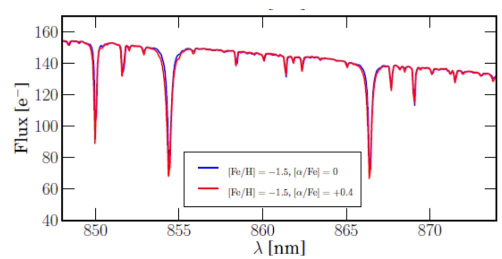


Line Spread Function (LSF)









TM

Accurate Time Stamping

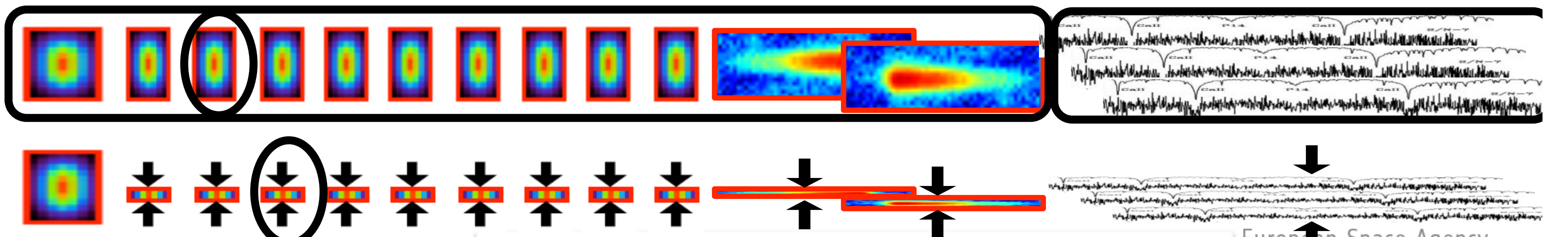
Star Packet (SP1)

Star Packet (SP2)

On-board

Windows Bright Stars: 2D (G≤13)

Windows Faint Stars: 1D (13<G≤20)



Credit: Figures Berry Holl, A. Brown and P.Sartoretti

"Very" Bright Stars

- Gaia Magnitude Range ⇒ $5.7 \leq G \leq 20.$
- Bright Stars ⇒ $5.7 \leq G \leq 13.$
- "Very" Bright Stars ⇒ $G \leq 5.7$ NOT OBSERVED by Gaia!!

- Gaia will observe billions of stars but not the ones visible with naked eye.

- The SOC studied the issue:
  - What is the science case for observing very bright stars?
  - What is actually the limitation?
    - No scientific requirement exists.
    - Development-phase design led to this limitation.

(G−V relation in Jordi et al., 2010, A&A, 523, A48)

Observing Very Bright Stars with Gaia

Science opportunity

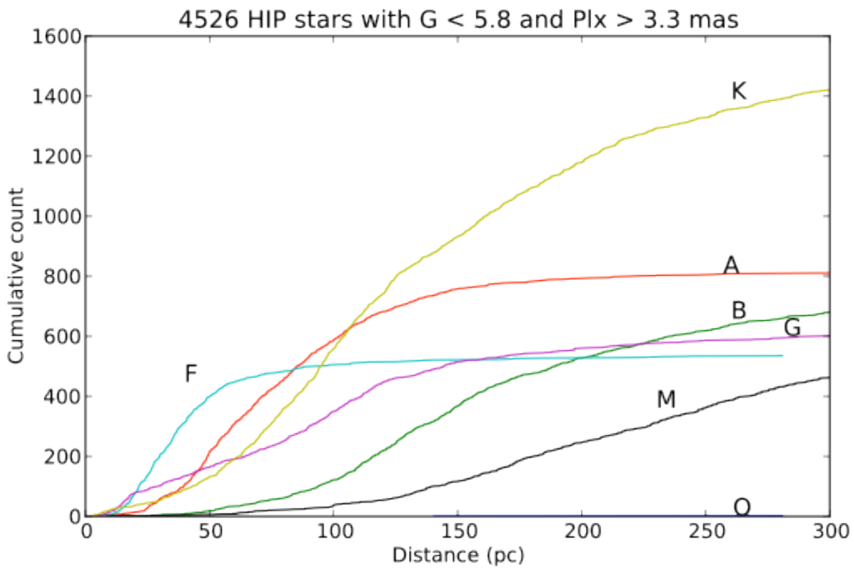
5300 Hipparcos stars have $G < 5.7$

1. Accurate masses of known exoplanets ⇒ 20 – 60 planet masses

2. New exoplanets around very bright stars
⇒ dozens of new giant planets (e.g. around A/F type stars)

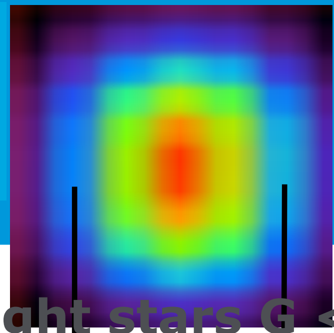
3. Parallaxes and proper motions of the 5300 brightest stars
gain >one order of magnitude in precision (unique Gaia legacy)

4. Very bright binary stars
25 % of very bright stars are astrometric non-standard in HIP2



Detection & FOV Discrimination

"Very" Bright Stars

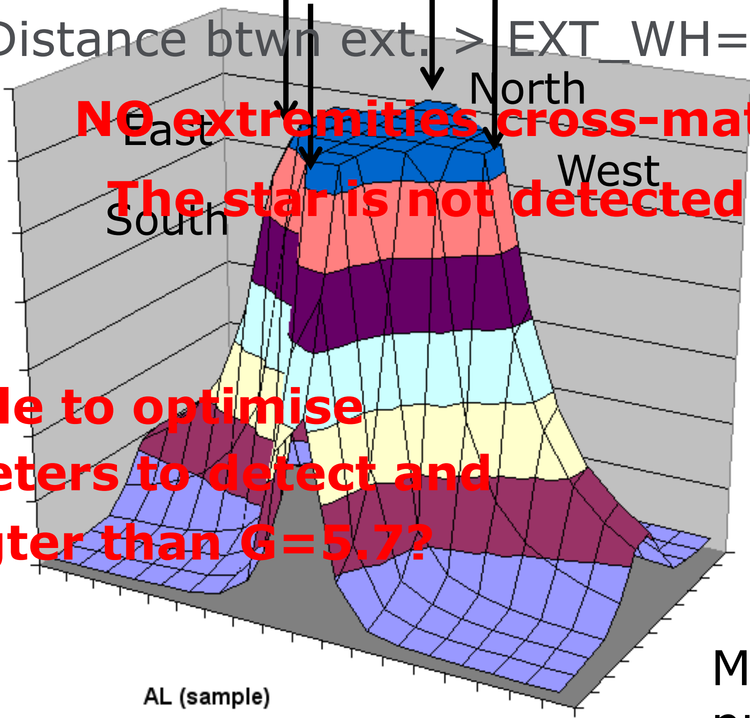


Successful match if the extremities:

- Distance btwn ext. < EXT_WH
- Difference in mag. < DELTA_MAG

"Very" bright stars G < 5.7:

- Distance btwn ext. > EXT_WH=25

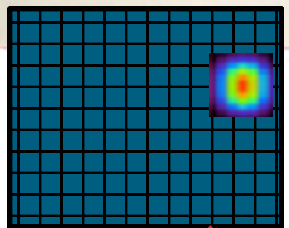


NO extremities cross-match!!

The star is not detected !!

Could it be possible to optimise these VPU parameters to detect and observe stars brigter than G=5.7?

SM2 Raw Data buffer (rolling buffer) SM FVP



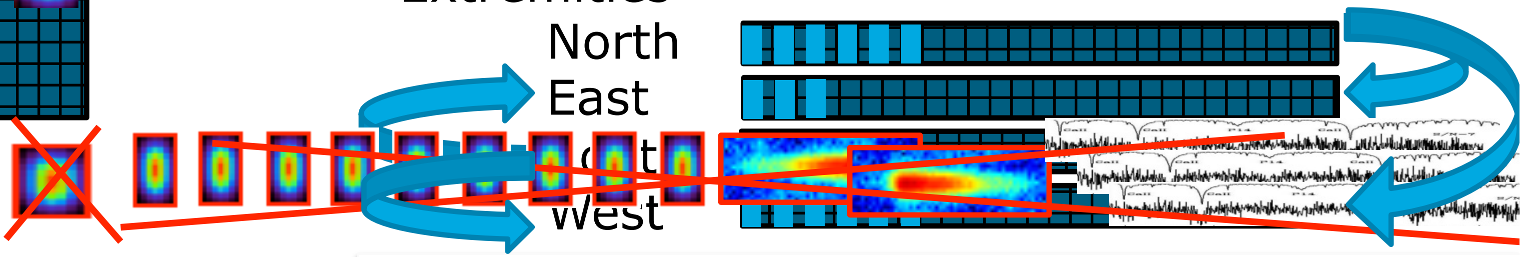
Windows Bright Stars: 2D (G≤13)

Extremities

North

East

West



Matching process

Credit: Figure courtesy EADS-Astrium. **Animation:** Berry Holl & Juanma Fleitas

“Very” Bright Stars

VPU parameters Optimisation

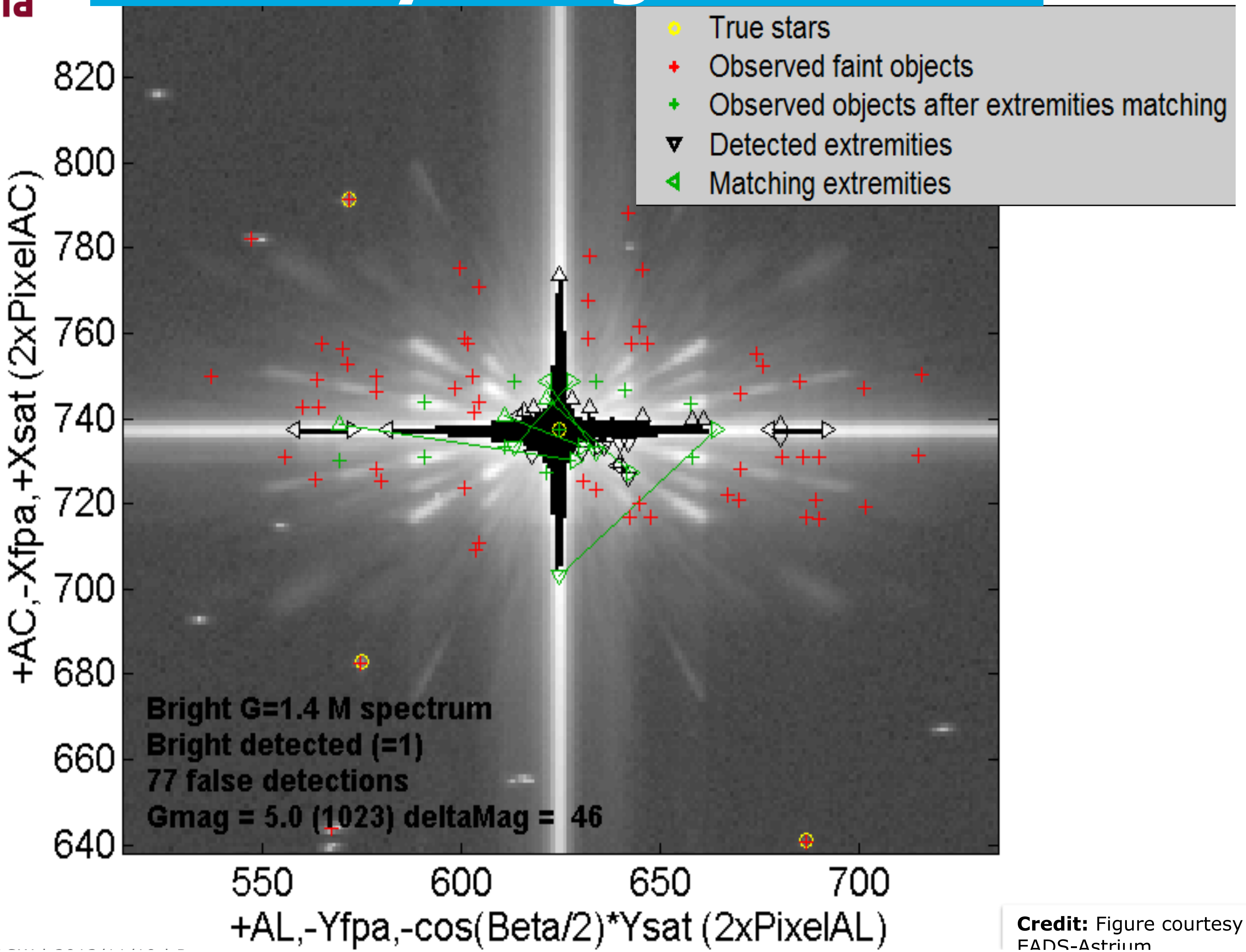
- SOC Simulator
  - VPU Prototype (from Astrium)
  - Image generator:
    - Gaussian PSF
    - Photon Shot noise
    - Telescope & CCDs QE
  - Output: tool to show the results

5 VPU Parameters:

- EXT_WH: max. distance btwn extremities
- DELTA_MAG: max. difference in mag.
- EXT_IN_BUFFER: max. nb of extremities.
- MAG_AL_LUT: extremity AL magnitude.
- MAG_AC_LUT: extremity AC magnitude.

	SOC	**ASTRIUM**
Ref. doc.	(JMF-005)	(PLM-00884)
VPU SW	version 2.5	version 2.6
Simulations	Gausian PSF Photon Shot noise Telescope&QE	AC smearing, subpixel location PSF quilting effect,
Spectral types	G2V	B1V, G2V, M6V
Mag. range	$0.0 \le G \le 8$	$0.0 \le G \le 11$
Magnitude step	$\Delta G=0.5$	$\Delta G=0.1$
Regression test	2 stars (G=6, G=8)	6 stars (G=6, G=11)
Coverage(FOVs)	Telescope 1	Telescope 1
Coverage(Row)	Row4	Row1 & Row4
Outcome (set of optimum parameters)	EXT_WH = 128 EXT_IN_BUFFER=6 DELTA_MAG = 32	EXT_WH = 127 EXT_IN_BUFFER = 6 DELTA_MAG = 90 MAG_AL_LUT=[file] MAG_AC_LUT=[file]
Side effects	Completeness	Multiple detections

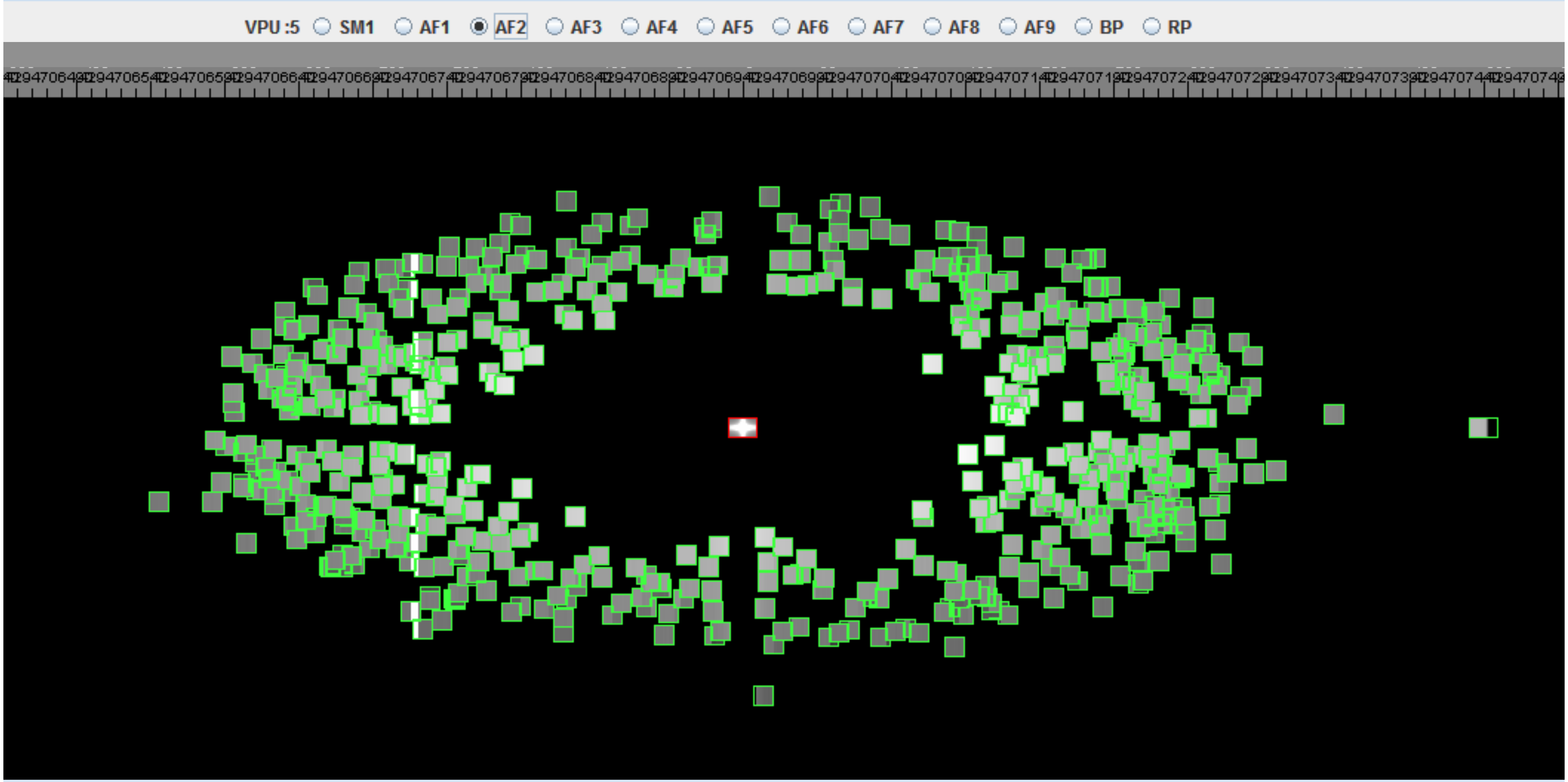
“Very” Bright Star



Credit: Figure courtesy EADS-Astrium

Observing Very Bright Stars with Gaia

"Very" Bright Stars



Gaia Magnitude bright end G=2 !!

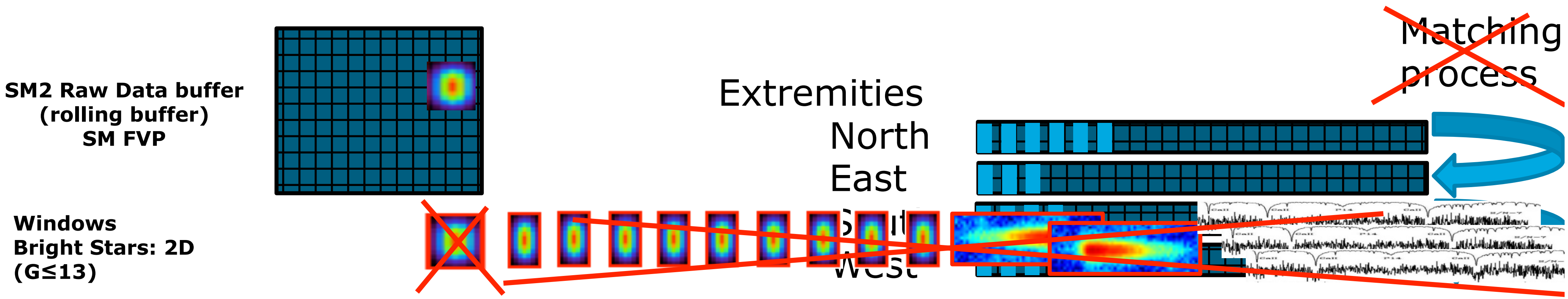
Detection & FOV Discrimination

"Ultra"-Bright (G<2)

- 62 stars are brighter than G=2
- Distance among extremities > EXT_WH maximum

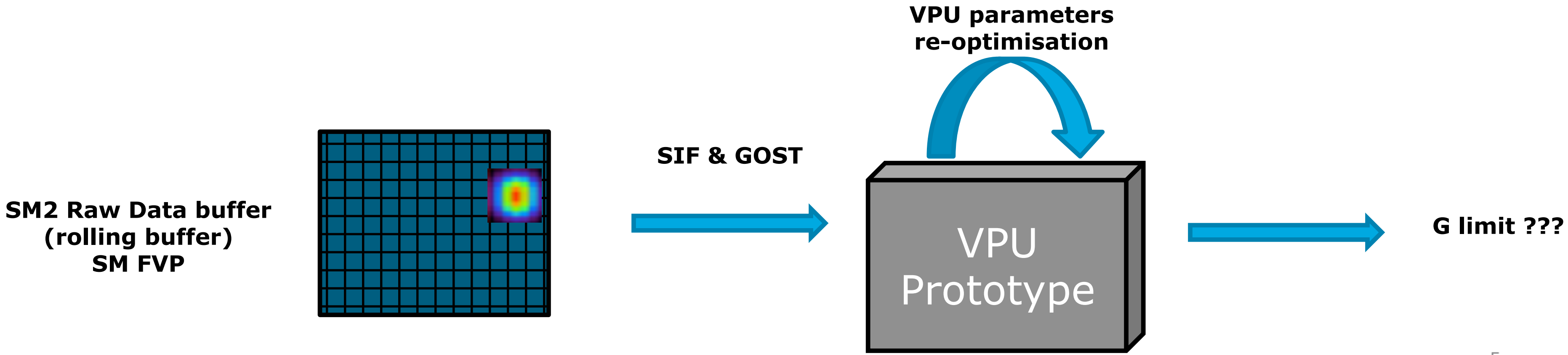
NO extremities cross-match!!

The star is not detected !!



Commissioning Real G limit

- SMx Raw Data Buffers stores the FVPs.
- SIF (Service I/F):
  - Read an copy an area in the memory of the VPU, i.e. the SM2 Raw Data Buffer.
  - VPU generates a SIF packet and stores it to be downlinked.
  - Ad-Hoc tools must be developed, i.e. data not treated by the Gaia pipeline.
- SIF command:
  - 4 memory areas can be sampled simultaneously.
  - 8MB per sample could be downloaded
- GOST (Gaia Observation Schedule Tool)
  - The transit time and position must be predicted => GOST presently under development in SOC



Conclusions

- Gaia nominal magnitude range: $5.7 \leq G \leq 20$
- SOC investigation showed that **observing** very bright stars ($2.0 \leq G \leq 5.7$, N=5336) is possible ⟹ VPU optimum parametrization
- Achievable performance to be verified during commissioning
  - Data treatment by the nominal Gaia pipeline? ⟹ To be tested

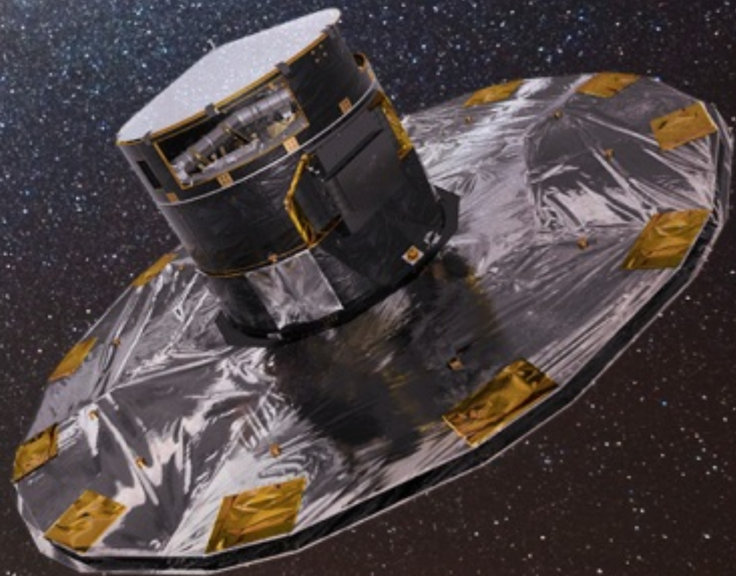
- Gaia Science Gain:
  - Parallaxes and proper motions of the brightest stars.
  - Accurate masses of known exoplanets.
  - New exoplanet detections
  - Very bright binary stars.

- “Ultra” Bright Stars ($G < 2$, N=62): we are working on it …

Observing
"Very" Bright Stars with Gaia

Launch: 20th Dec 2013, 09:08:14 UTC
(10:08:14 MAD)

Questions ?



J. Martin-Fleitas
A. Mora
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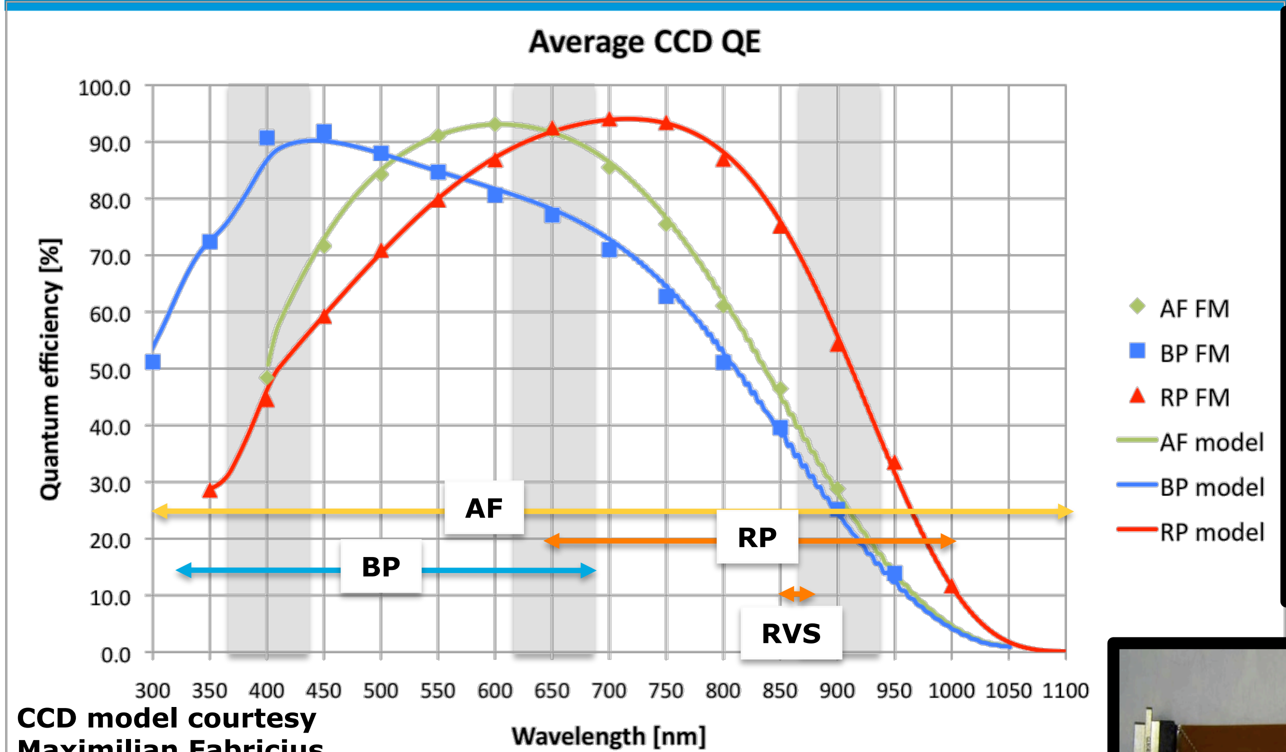
R. Kohley

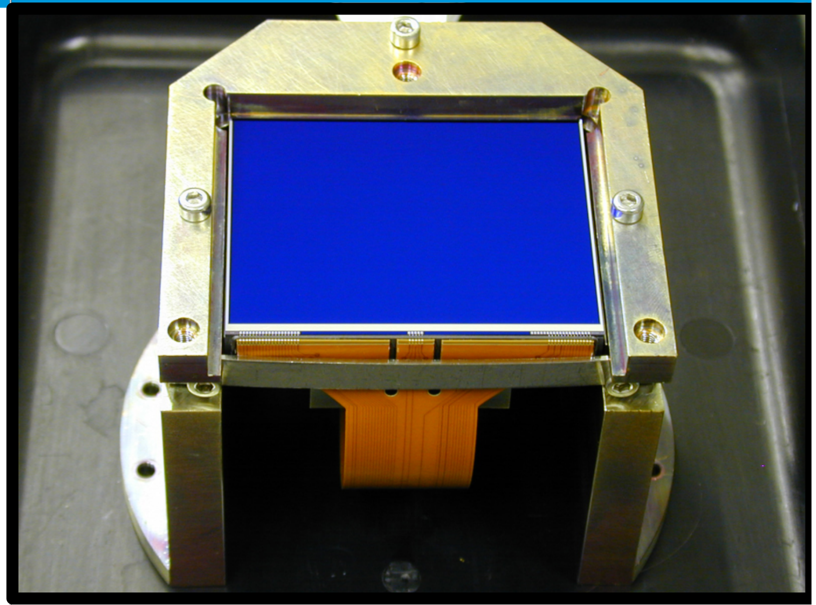
Photo: ESA

Observing Very Bright Stars with Gaia

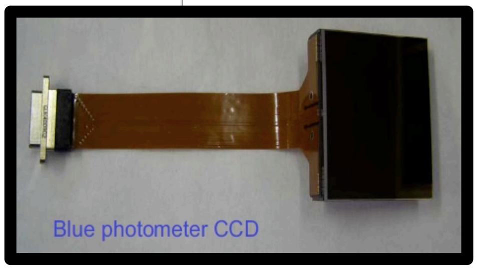
CCDs

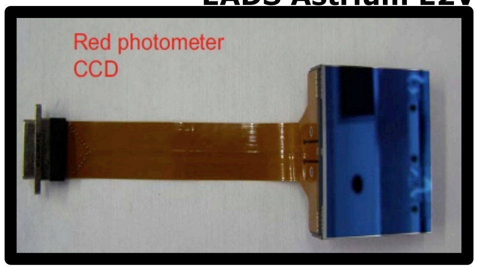


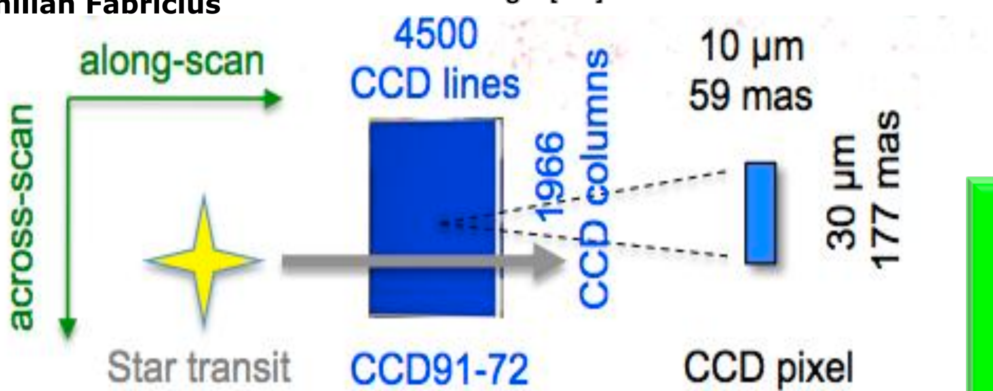
CCD model courtesy Maximilian Fabricius



EADS Astrium E2V





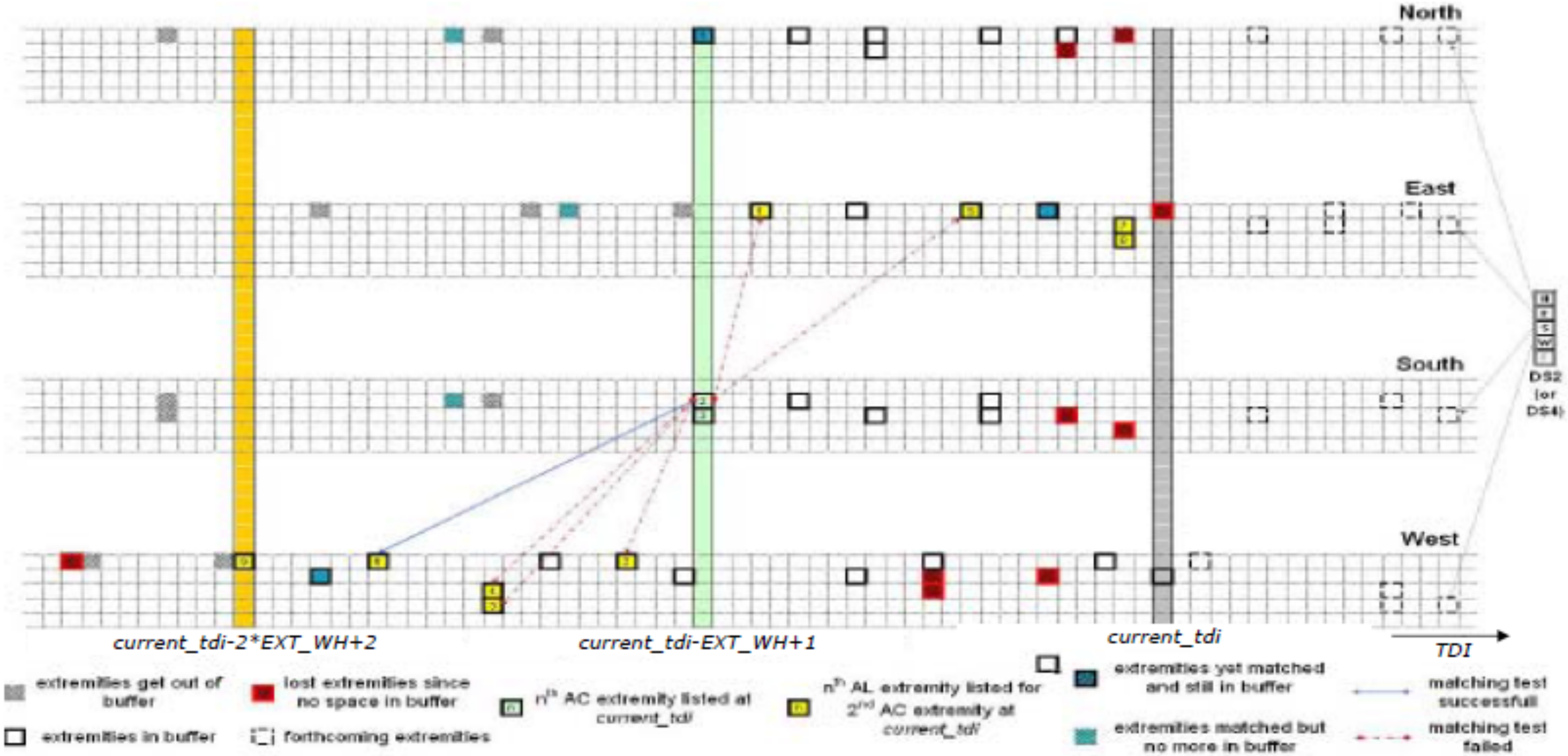


78 AF-type

7 BP-type

21 RP-type

Bright Stars



EXT_IN_BUFFER = 6

(max num of extremities per buffer)

EXT_WH = 25

(Length of research horizon)

Credit: Figure courtesy EADS-Astrium

Bright Stars

- Extremity: N & S => AC_ext

  W & E => AL_ext
- Extremity on-board magnitude:

$$AC\_ext.mag = MAG\_LOG \times \ln(flux_{sm}) + MAG\_ZERO$$
$$AL\_ext.mag = MAG\_LOG \times \ln(flux_{sm}) + MAG\_ZERO$$

- Extremity on-board magnitude corrected by pre-computed LUT:

$$mag\_AC = AC\_ext.mag + SW\_MAG\_AC\_LUT_{[fov][lut\_index\_ac]}$$
$$mag\_AL = AL\_ext.mag + SW\_MAG\_AL\_LUT_{[fov][lut\_index\_al]}$$

- Extremity on-board magnitude corrected by modeled PSF:

$$abs(mag\_AC - mag\_AL) \leq DELTA\_MAG$$

- Bright Star magnitude:

$$gmag = {(mag\_AC + mag\_AL)}/{2}$$

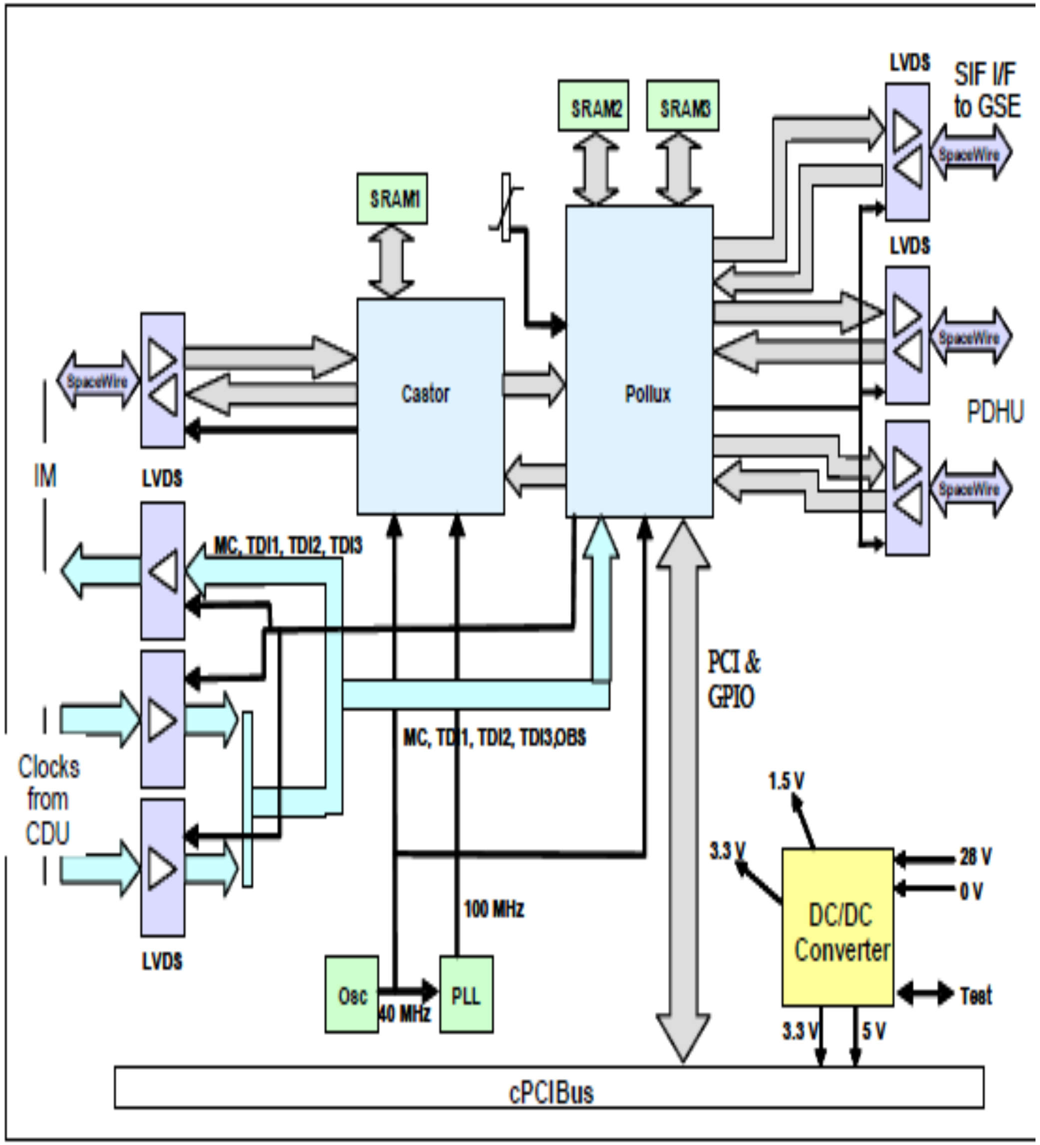
Credit: Figure courtesy EADS-Astrium

VPU: on-board processing

- Gaia can not downlink the whole sky
  - But the stars do not fill the whole sky.
- Objects selection on-board
  - Detection & selection on-board.
  - Small windows around the stars G < 20 observed.
- Video Processing Unit (VPU)
  - 7 units, one per CCD row.
  - Highly parametrized.
  - Radiation hard components and operation.
- Processor Board:
  - Maxwell Technologies “SCS750”.
  - 3 PowerPC. TMR (Triple Majority Redundancy).
  - Software algorithms.
- Companion Board:
  - 2 Actel FPGAs. Not patchable.
  - Repetitive & high-BW processing

VPU: on-board processing
Companion Board: HW processing

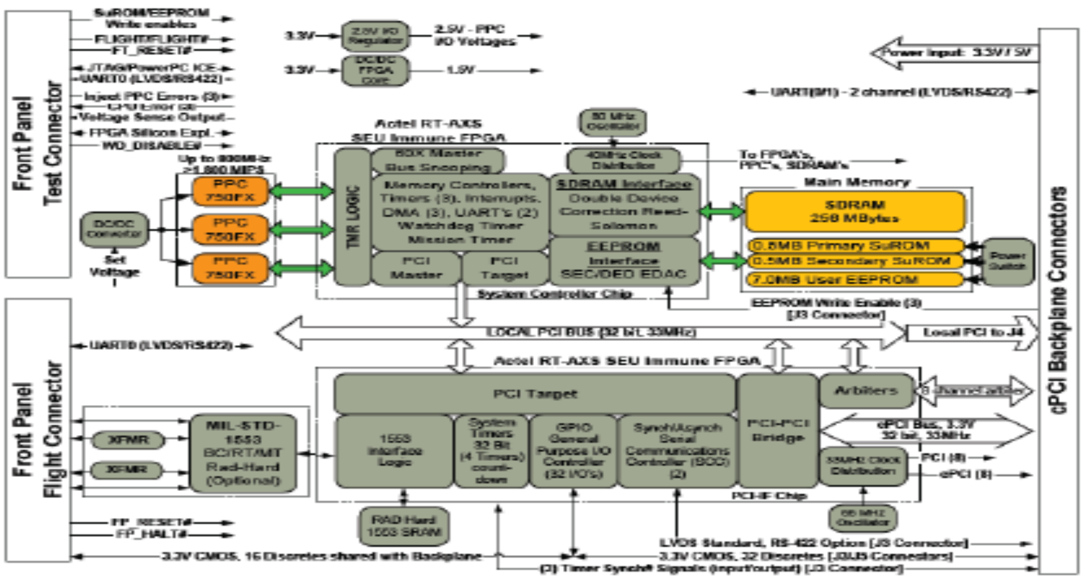
- 2 Actel FPGAs (“Castor” & “Pollux”)
- Repetitive & high-BW processing tasks.
- Highly parameterized. Not patchable.
- 3 SRAMs:
  - SRAM1: store coefficients, intermediate data processing results,
  - SRAM2: store data prior to transmission to the Processor board.
  - SRAM3: store incoming and outgoing data packets for the PDHU.



EADS Astrium

VPU: on-board processing
Processor Board: SW processing

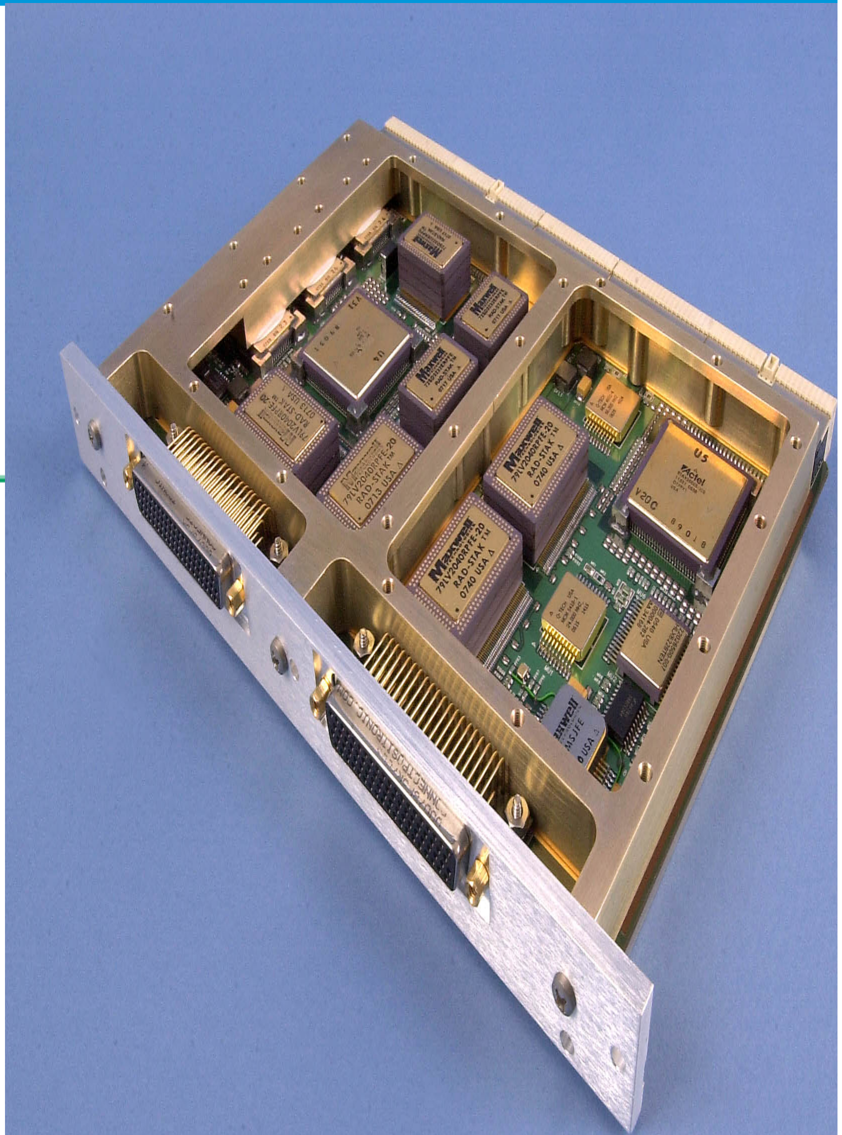
- Maxwell Technologies "SCS750"
- Single computer board designed for space.
- 3 TMR-protected PowerPC 750 FX processors,
  - error detection, resynchronisation & processor scrubbing
- Processing speed between 400 MHz - 800 MHz
- 256 Mbyte SRAM, 8 Mbyte EEPROM



Auto Controller/Peripheral Configuration
Cold Sparing Capable

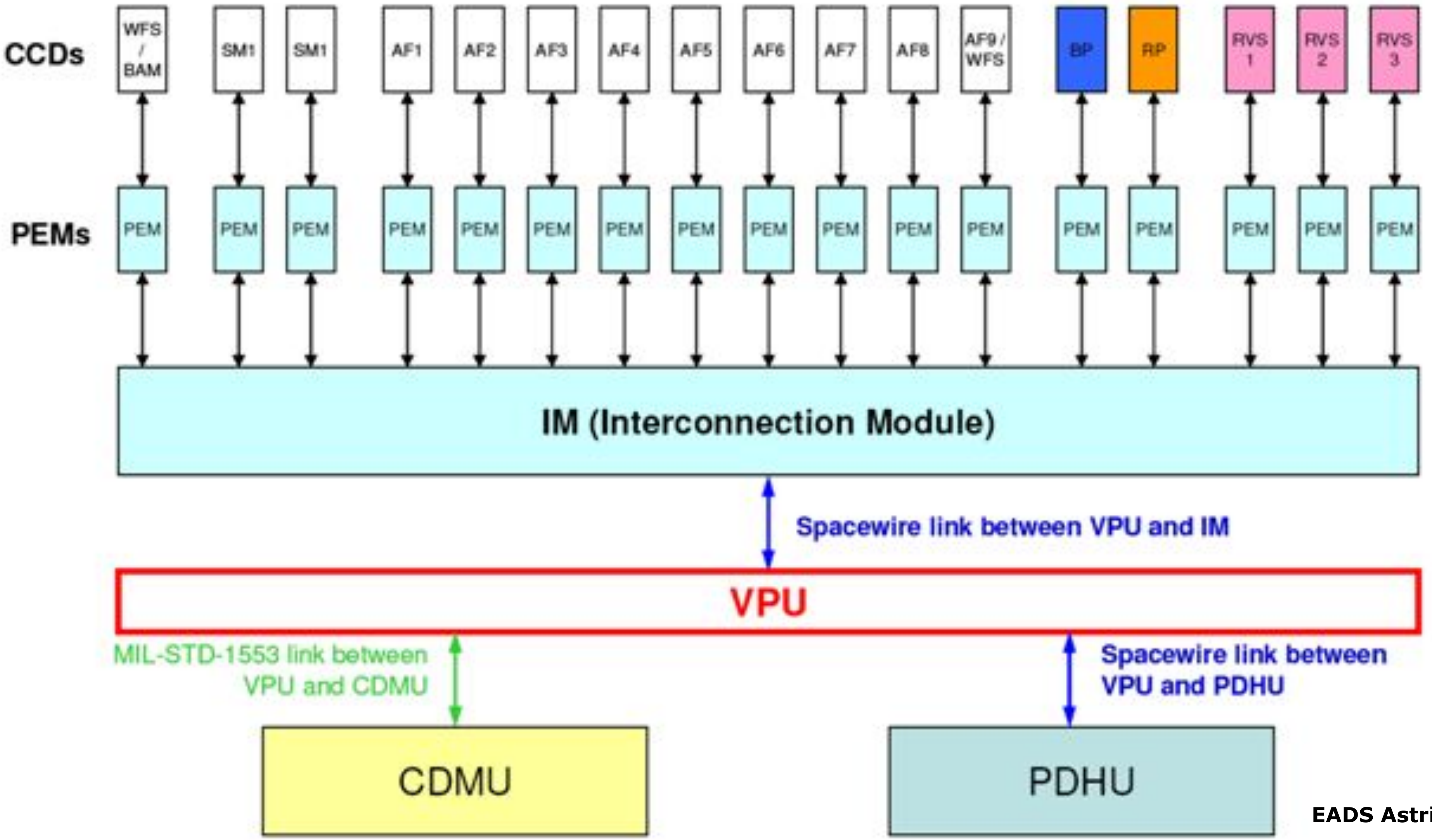
EADS Astrium

Processor & SDRAM Error Logging
Front Panel Test Connector
Front Panel Flight Connector



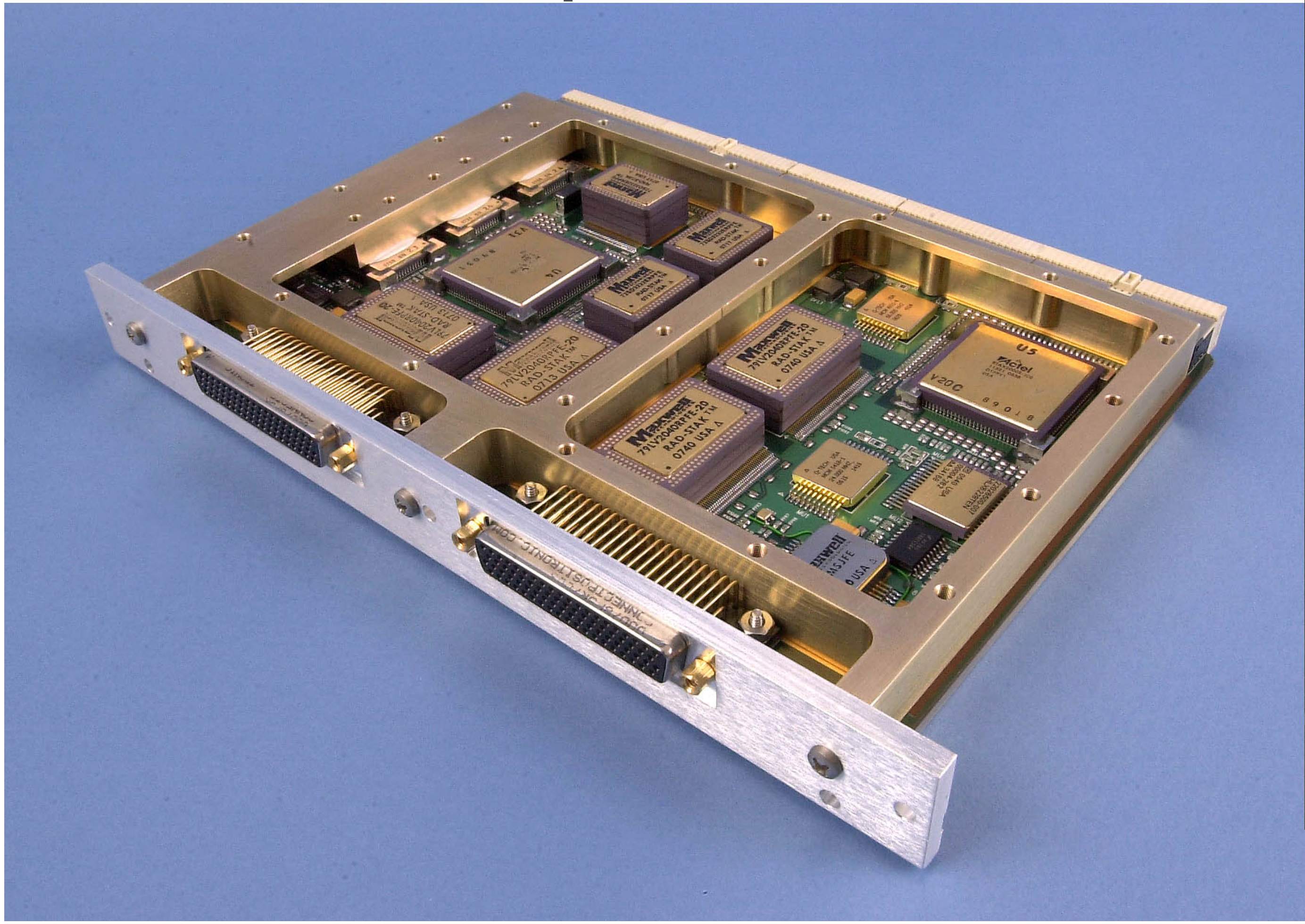
Maxwell Technologies, Inc., San Diego, USA

VPU: on-board processing Row, CDMU & PDHU I/F



VPU: on-board processing

Radiation hard components



Maxwell Technologies, Inc., San Diego, USA

EADS Astrium

Gaia Detection System

Gaia observation particularities

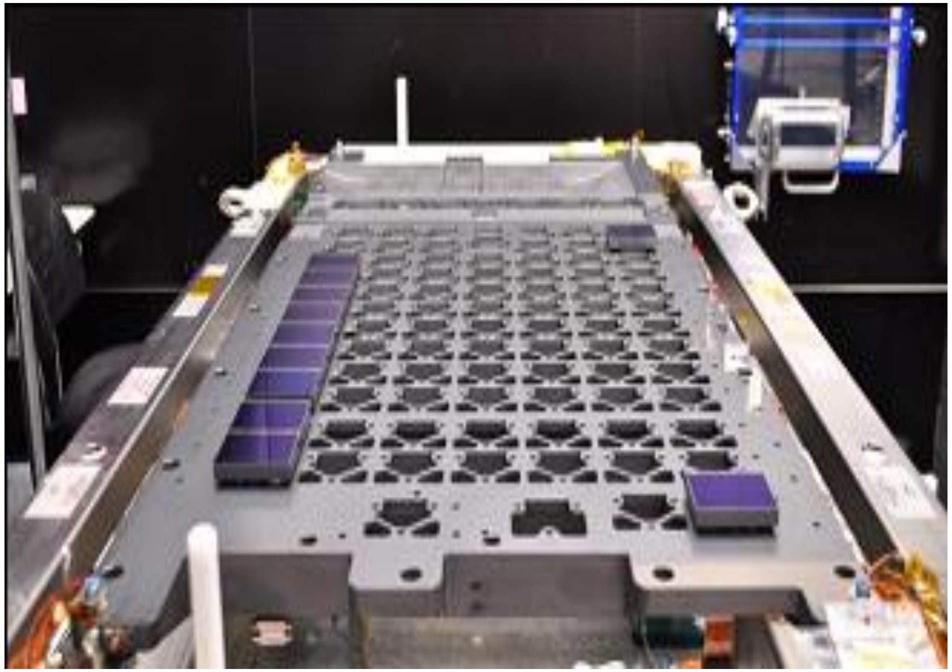
- Biggest FPA ever flown => 106 CCDs => Huge amount of TM
- Two telescopes => two FOVs => on-board classification of objects from each FOV.
- Spinning mission => TDI mode operation

SUMMARY

- FPA: detection/observation
- VPU: Observer
- PDHU: TM storage and limitations

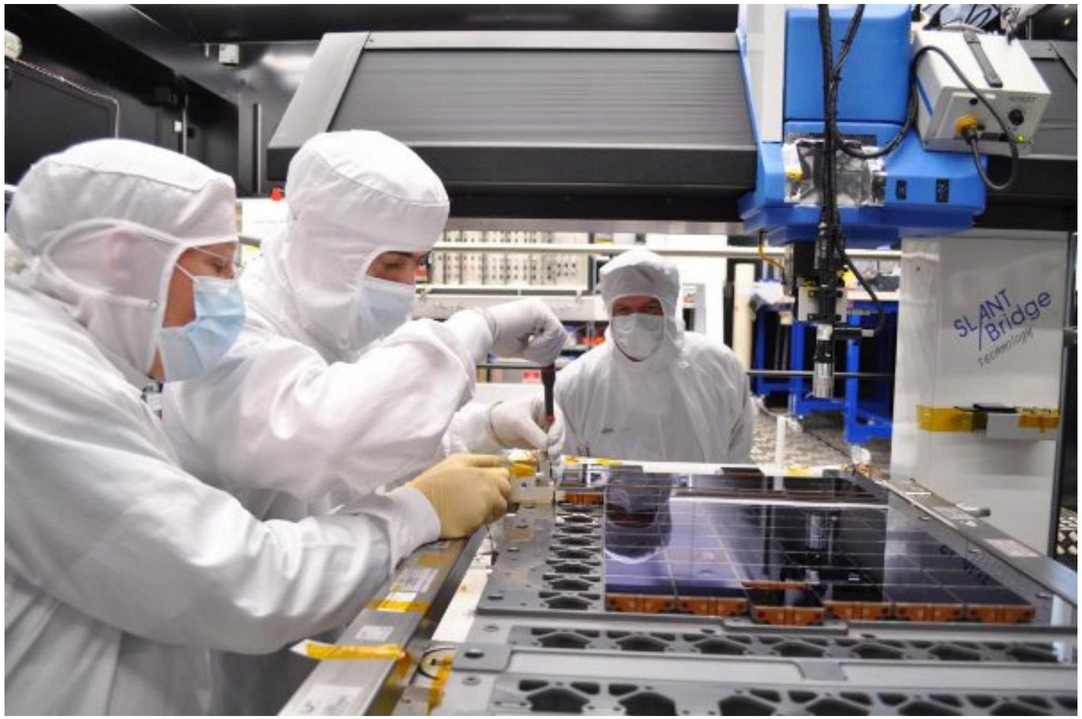
Plano focal: integración

Credit: Images courtesy of ESA and EADS-Astrium

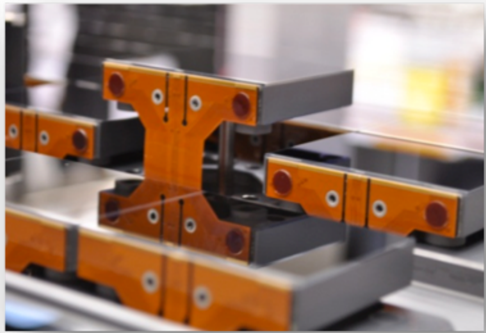


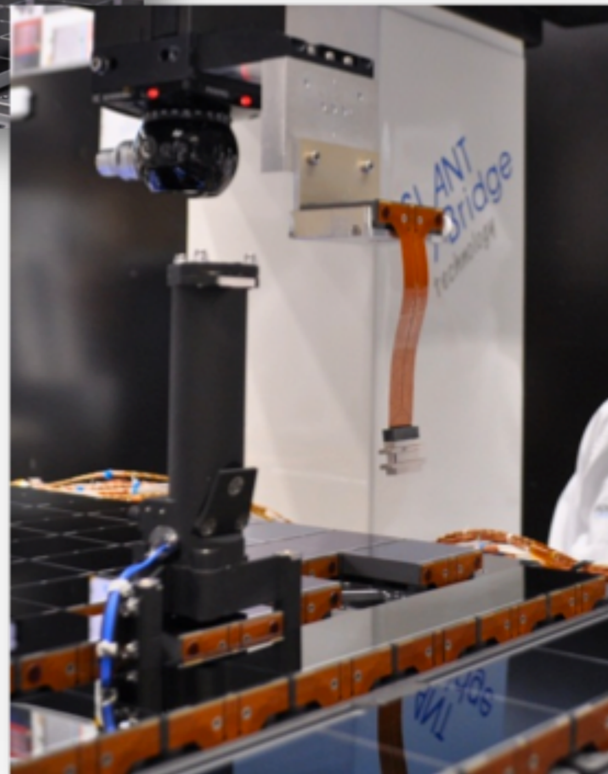
CCDs integration:

- Highly modular arrangement
- Precision alignment optically controlled
- Mounting of SiC CCD package to SiC CSS without shims.
- Astrometric field CCDs mounted to ± 50µm flatness.



Plano focal: integración





Credit: Images courtesy of EADS-Astrium

Gaia Focal Plane Array

- Largest FPA ever developed for space applications => 1 Giga pixels.
- The FPA is common to both Gaia telescopes and is composed of five distinct areas:
  - Metrology & Alignment (WFS & BAM)
    - Wave-Front Sensor (2 CCDs) => measure the optical quality of each telescope.
    - Basic Angle Monitor (2 CCDs) => monitor fluctuations in the basic angle.
  - Star Detection (SM1 & SM2)
    - Sky Mappers (2x7 CCDs) => The SMs identify which telescope is viewing the object.
  - Astromery (AF)
    - Astrometric Field (62 CCDs) => Astrometric measurements.
  - Photometry (BP & RP)
    - Blue Photometer (7 CCDs) => low res. spectrophotometric measurements λrange = 330-680nm
    - Red Photometers (7 CCDs) => low res. spectrophotometric measurements λ_{range} = 650-1050nm
  - Spectrometry (RVS)
    - Radial Velocity Spectroscopy (3x4 CCDs) => spectra, R = $\lambda/\Delta\lambda$ = 11,500, V<17, λ_{range} = 847-874nm.

- All CCDs are read out in time-delayed integration mode (TDI) synchronised to the satellite scanning motion

http://sci.esa.int/gaia/

Gaia Focal Plane Array

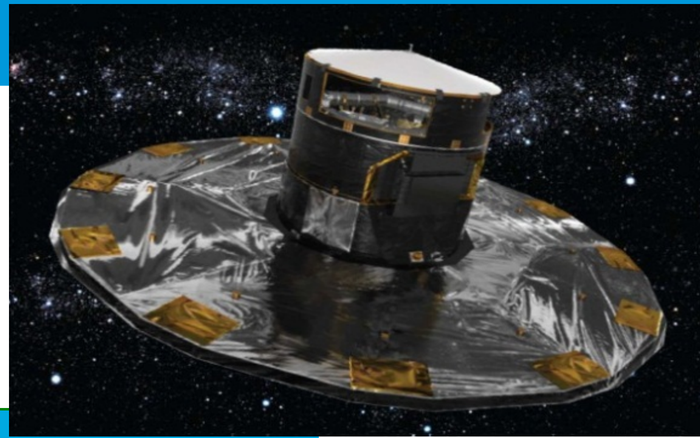
- Largest FPA ever developed for space applications => Almost 1 billion pixels.
- The focal plane is common to both Gaia telescopes and is composed of five distinct areas:

Function	CCDs	Details
Metrology and Alignment	4	2 wave front sensors (WFS), 2 basic angle monitoring (BAM) CCDs
Star detection	14	2 × 7 sky mapper (SM) CCDs, 7 per telescope
Astrometry (AF)	62	8 × 7, 1 × 6
Photometry (BP, RP)	14	7 blue and 7 red
Spectrometry (RVS)	12	3 × 4

From Hipparcos to Gaia

gaia

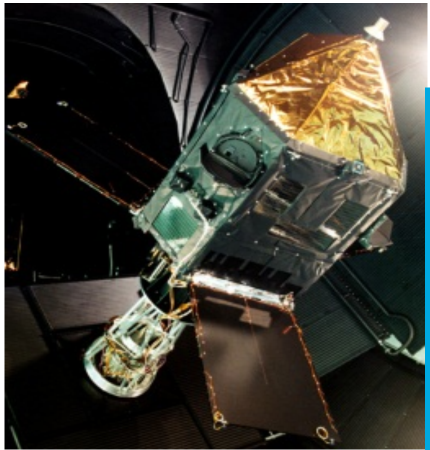
esa



2013

24 years of technological evolution

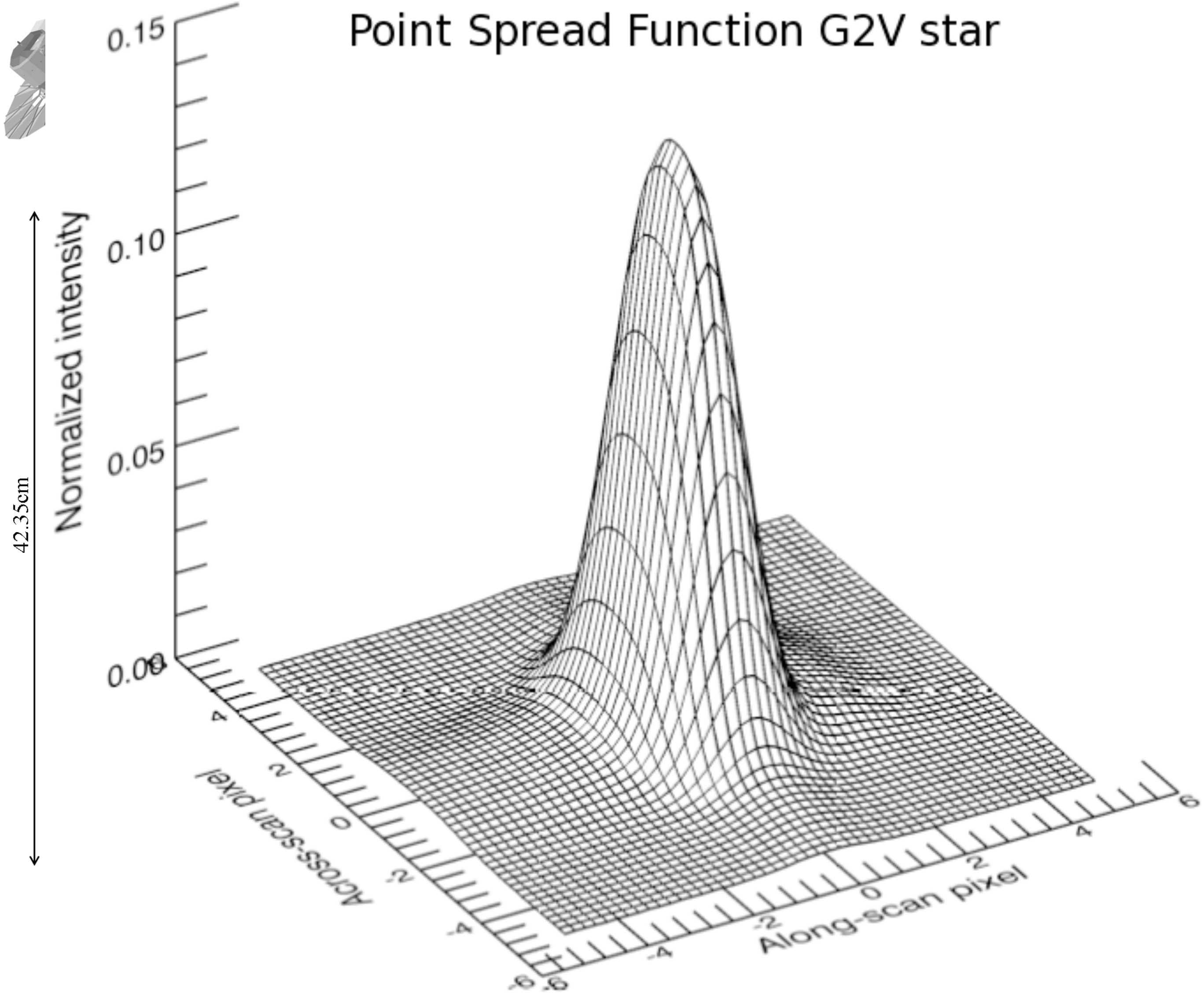
1989



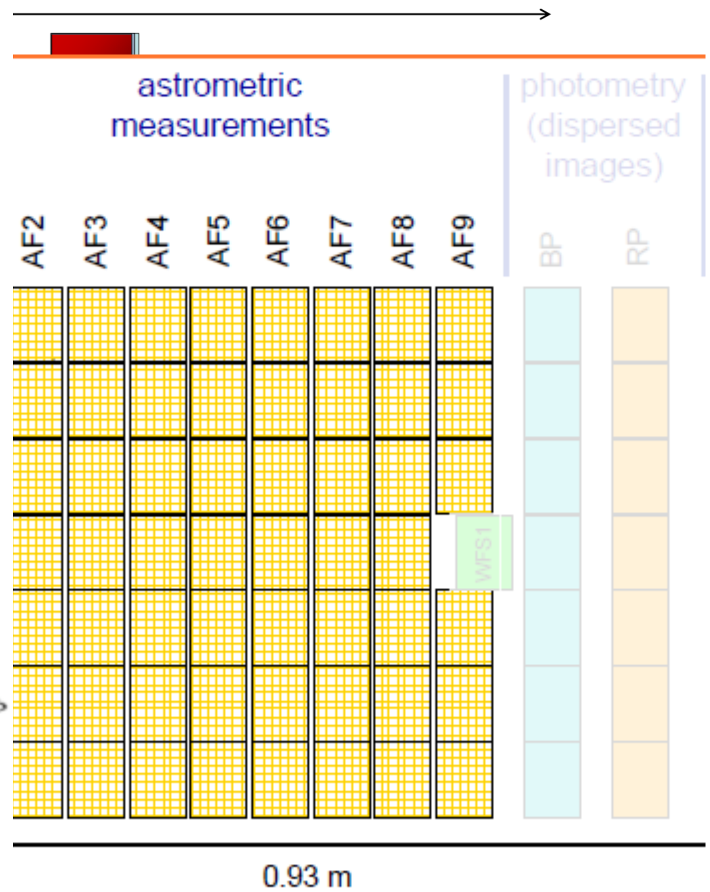
	Hipparcos	Gaia
Magnitude limit	12 mag	20 mag
Completeness	7.3 – 9.0 mag	20 mag
Bright limit	0 mag	6 mag
Number of objects	120,000	26 million to V = 15 250 million to V = 18 1000 million to V = 20
Effective distance	1 kpc	50 kpc
Quasars	1 (3C 273)	500,000
Galaxies	None	1,000,000
Accuracy	1 milliarcsec	7 μarcsec at V = 10 10 – 25 μarcsec at V = 15 300 μarcsec at V = 20
Photometry	2-colour (B and V)	Low-res. spectra to V = 20
Radial velocity	None	15 km s^{-1} to V = 17
Observing	Pre-selected	Complete and unbiased

Large Focal Plane

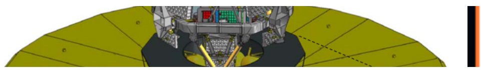
Extremely stable optical bench



Point Spread Function G2V star
Normalized intensity
0.15
0.10
0.05
0.00
42.35cm
Across-scan pixel
4
2
0
-2
-4
-6
Along-scan pixel
-6
-4
-2
0
2
4
6



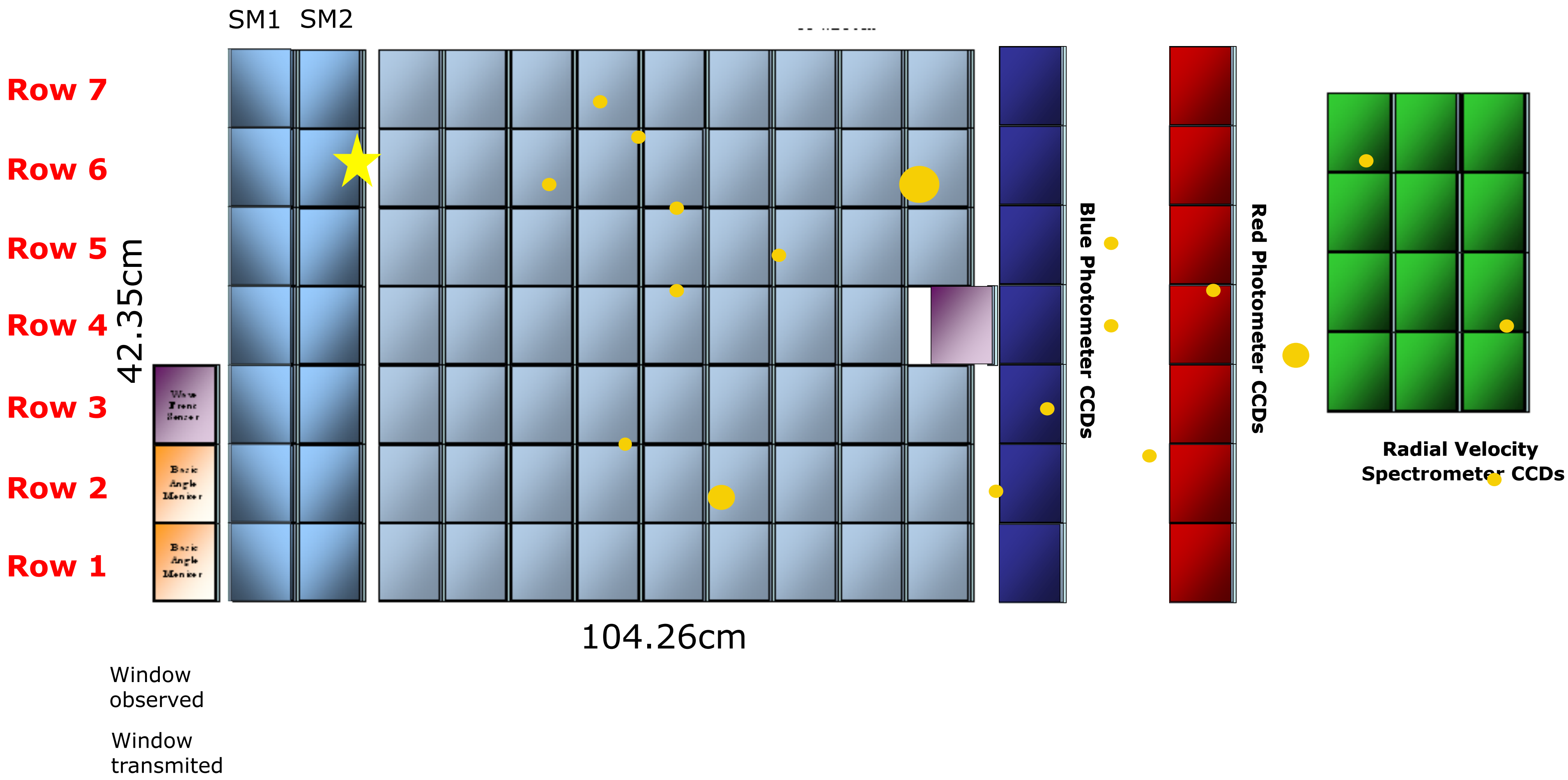
astrometric measurements
photometry (dispersed images)
AF2
AF3
AF4
AF5
AF6
AF7
AF8
AF9
BP
RP
WFS1
0.93 m



Observing Very Bright Stars with Gaia

Focal Plane Array

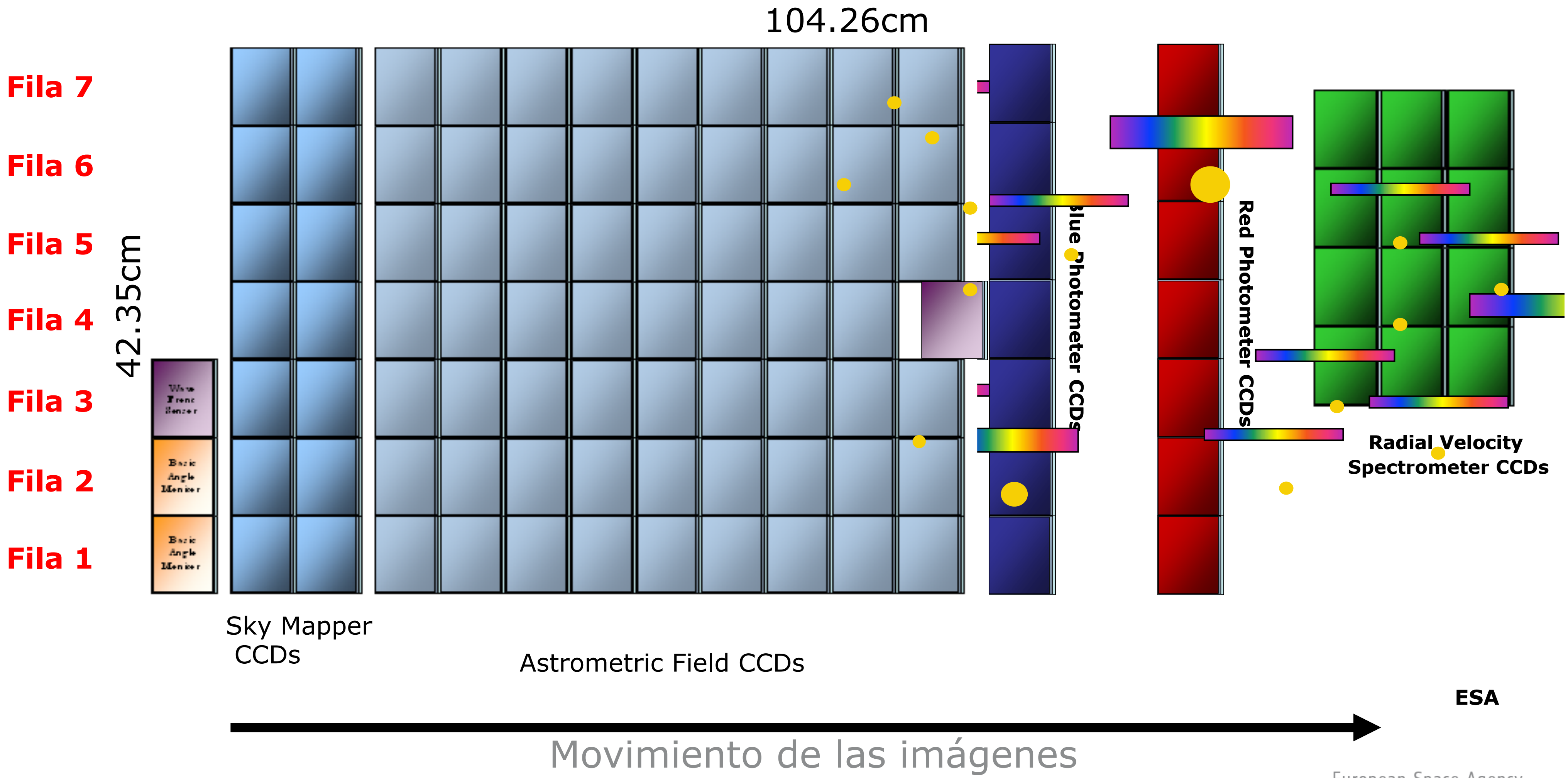
106 CCDs , 938 million pixels, 2800 cm^2



Credit: picture courtesy from ESA.
Animation from B. Holl & J.Fleitas

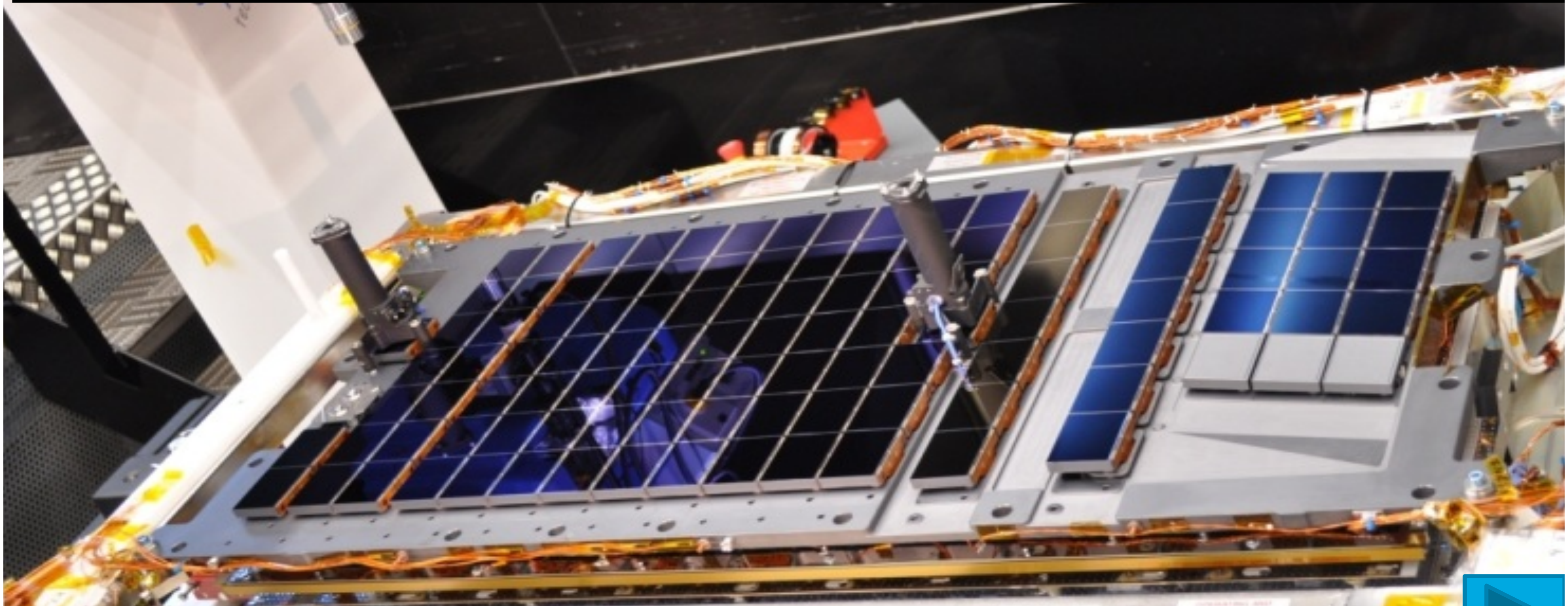
Procesado a bordo: Una VPU por fila

106 CCDs , 938 million pixels, 2800 cm^2



Gaia Observation System

- Biggest FPA ever flown => 106 CCDs => Huge amount of TM.
- 2 telescopes combined => on-board classification of objects.
- Spinning mission => CCDs in TDI mode operation.



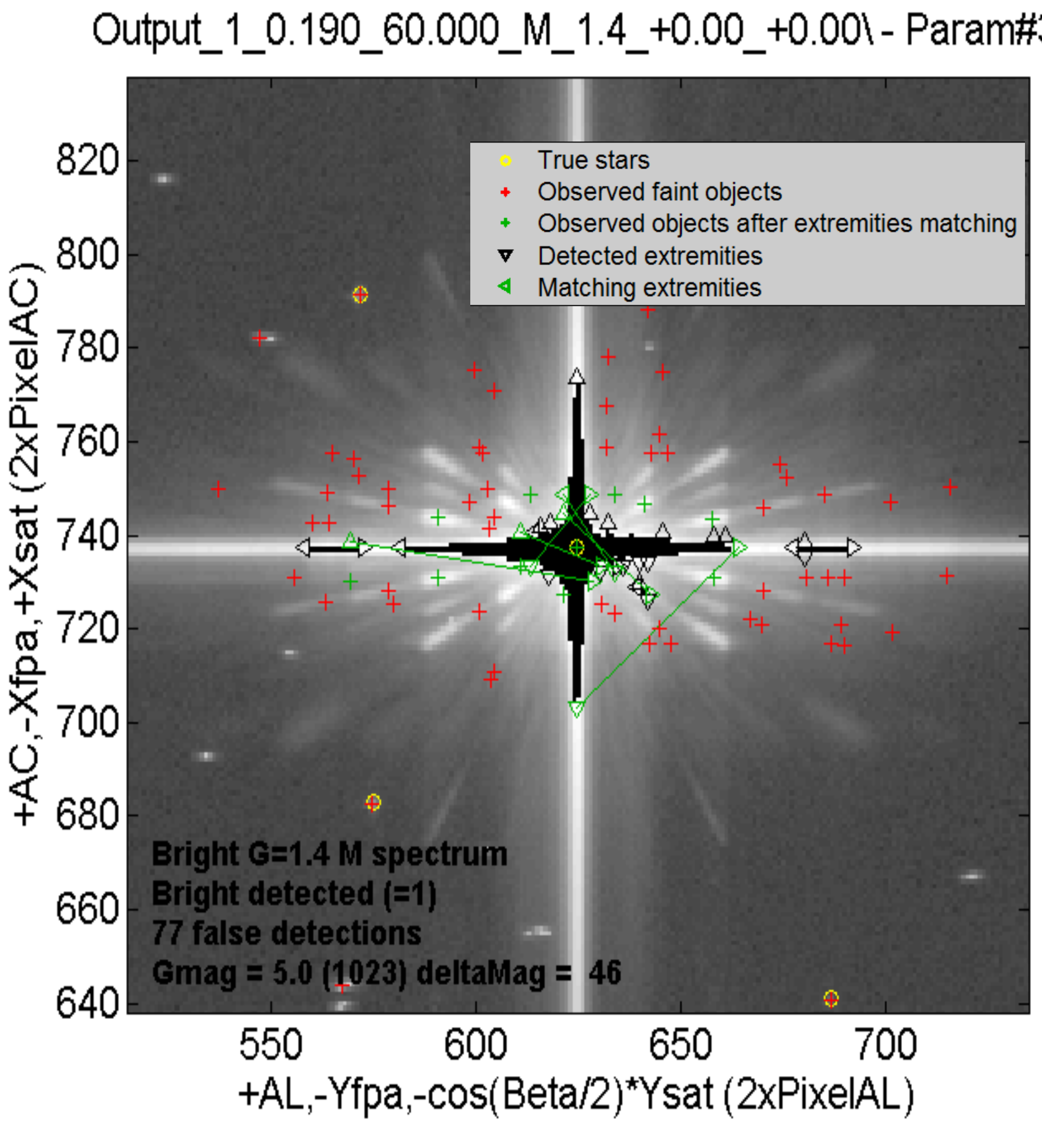
Credit: Figure courtesy EADS-Astrium

Bright Stars Detection
VPU parameters Configuration

- New VPU default configuration

EXT_WH = 127,
EXT_IN_BUFFER = 6,
DELTA_MAG = 90,
MAG_AL_LUT = [file],
MAG_AC_LUT = [file].

G_{min}	Row 1			Row 4		
	B	G	M	B	G	M
Nominal AC/AL speed	2.0	1.8	1.6	2.2	1.8	2.0
Maximal AC speed	2.0	1.7	1.4	2.0	1.6	1.9
Maximal AL speed	2.0	1.8	1.6	2.2	1.8	2.0



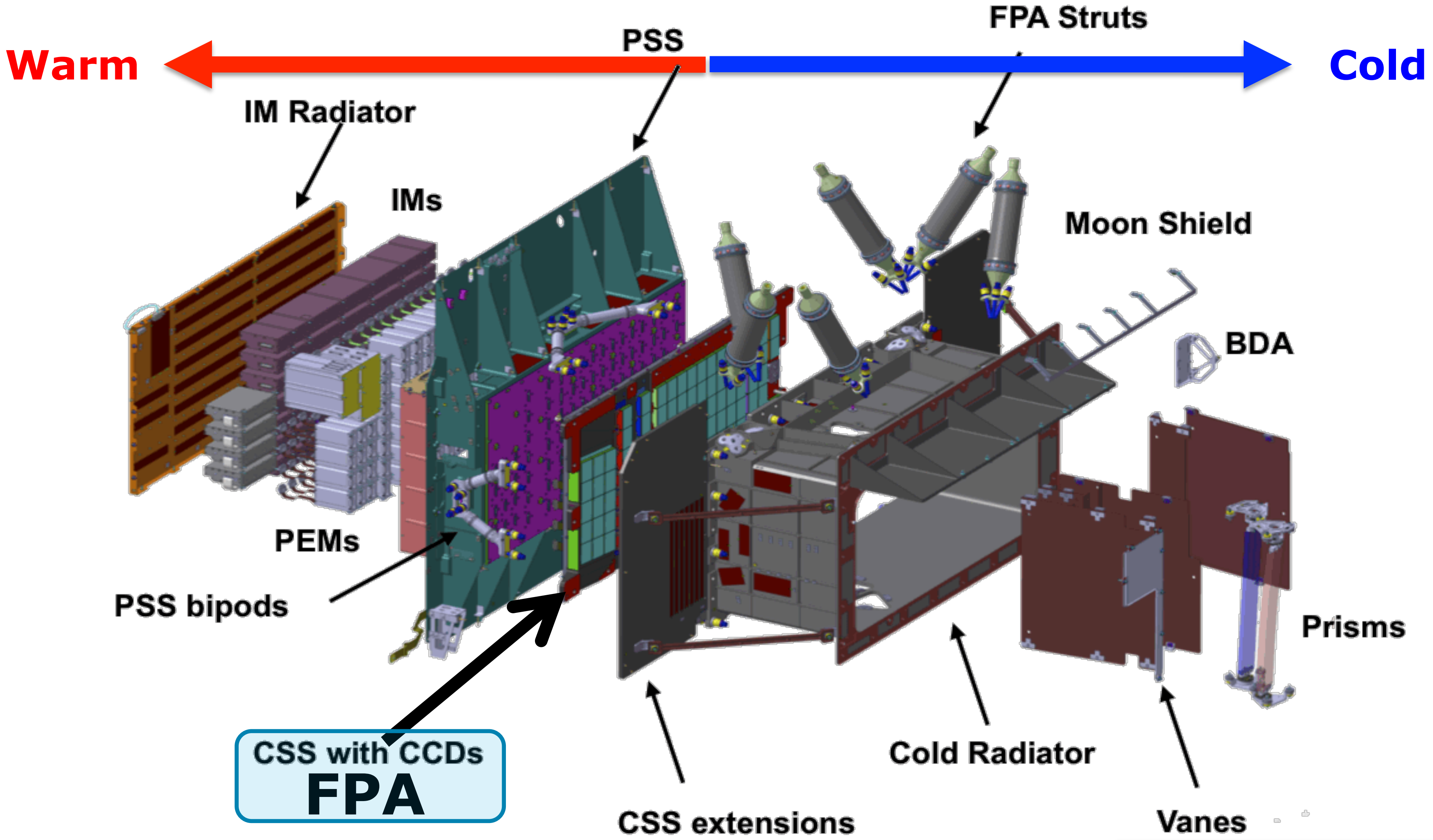
Bright Stars Detection
VPU parameters Configuration

- Lisajous orbit
- http://sci2.esa.int/interactive/media/flashes/5_5_1.htm

G_{min}	Row 1			Row 4		
	B	G	M	B	G	M
Nominal AC/AL speed	2.0	1.8	1.6	2.2	1.8	2.0
Maximal AC speed	2.0	1.7	1.4	2.0	1.6	1.9
Maximal AL speed	2.0	1.8	1.6	2.2	1.8	2.0

Observing Very Bright Stars with Gaia

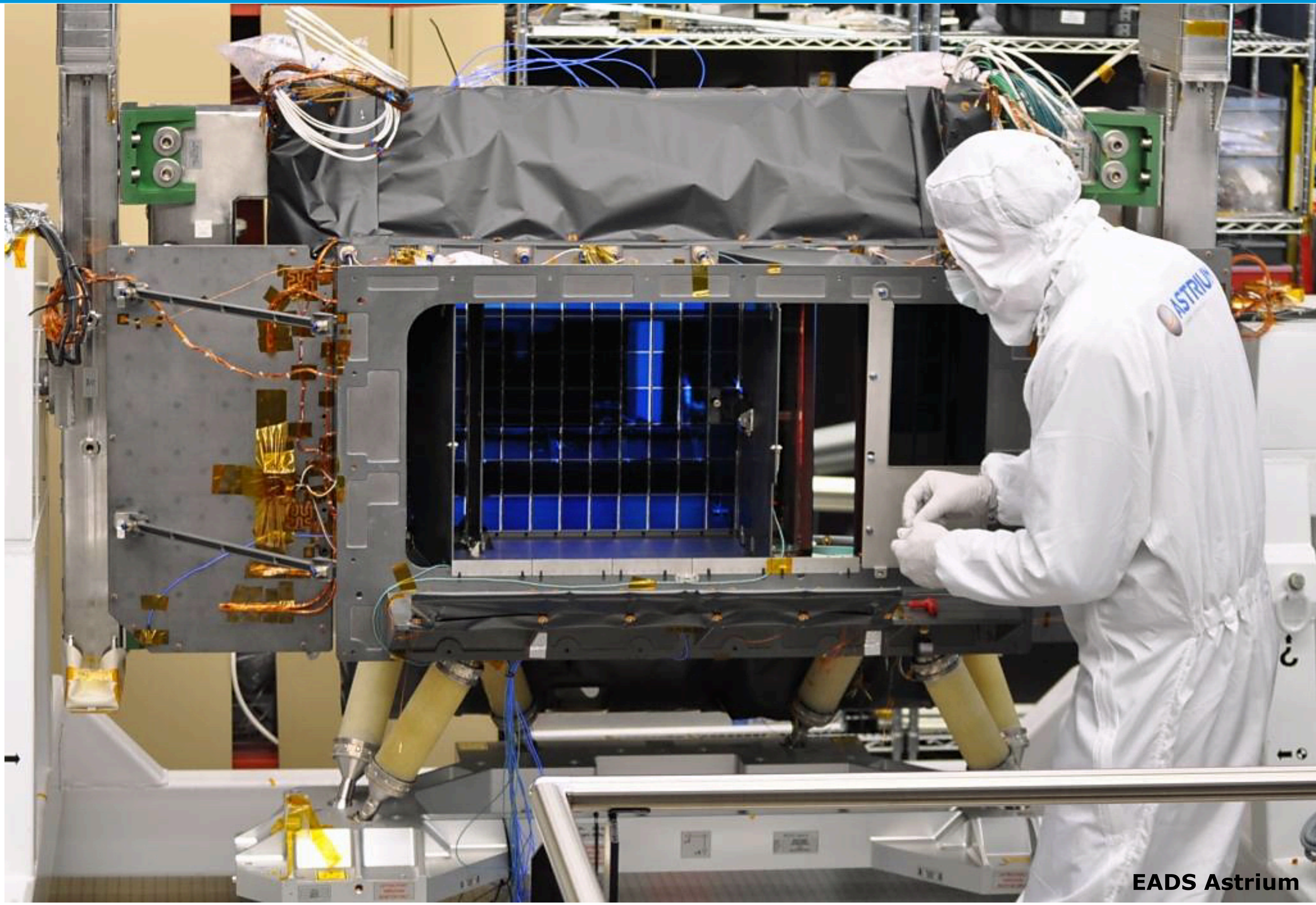
Gaia Observation System



Credit: Figure courtesy EADS-Astrium

Observing Very Bright Stars with Gaia

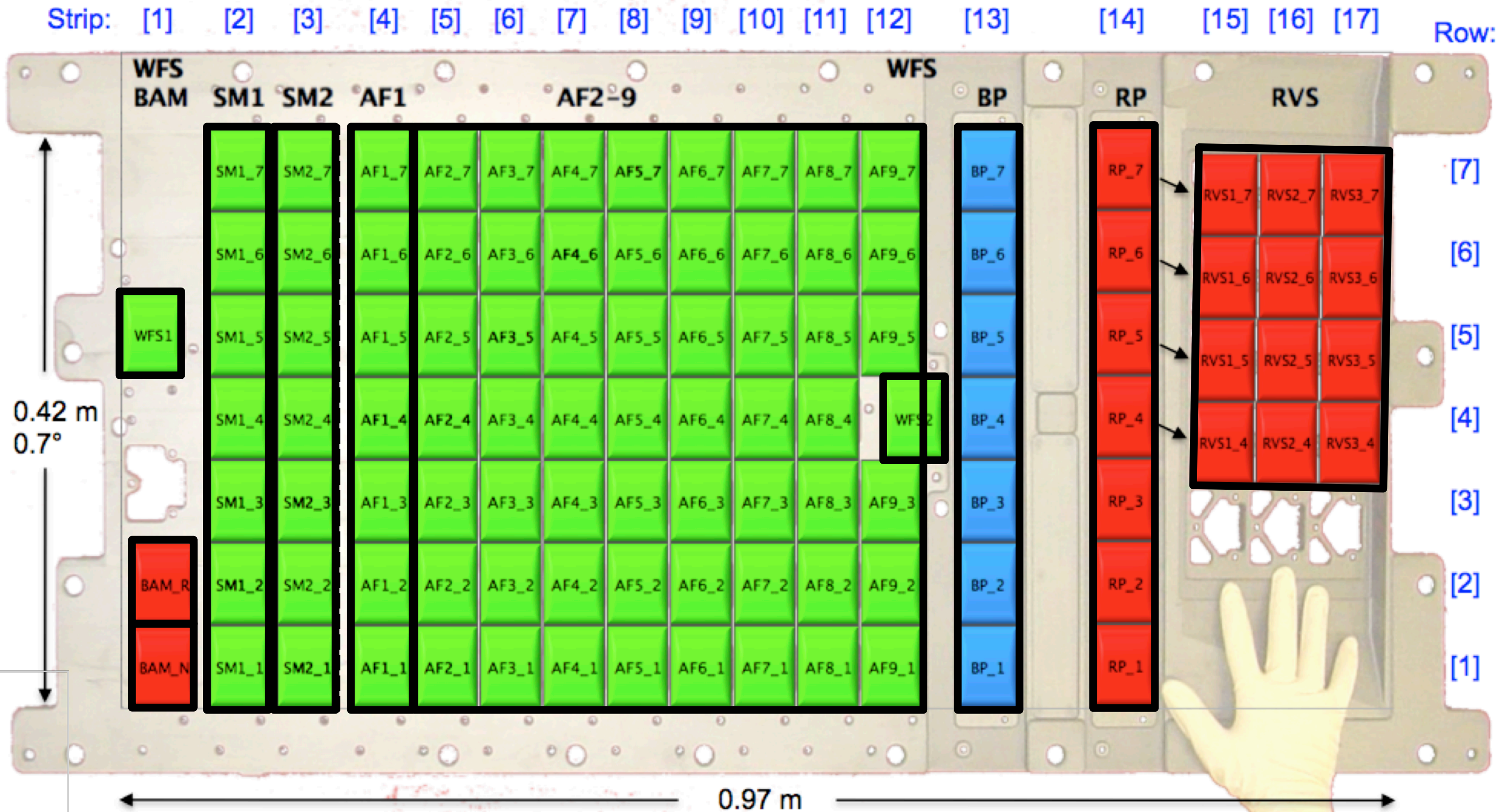
Focal Plane Array

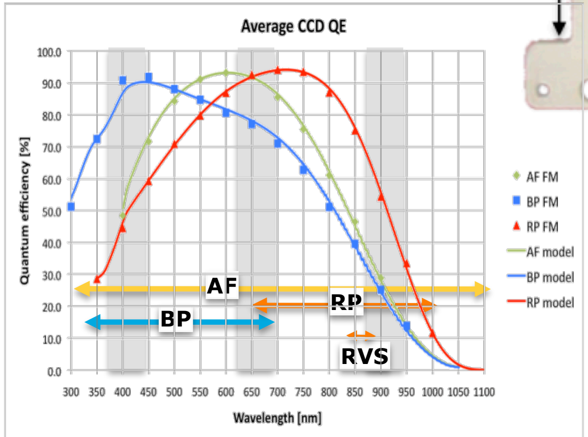


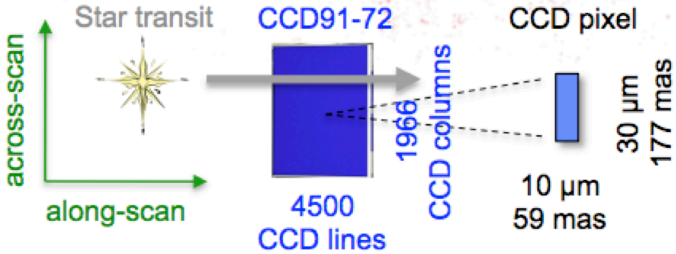
Alignment & Focusing (WFS)	Detection Confirmation Discrimination (SM)	Astrometric Measurements (AF)	Photometry (Dispersed Images) (BP/RP)	Spectrometry Radial Velocities (Dispersed Images) (RVS)

Radial Velocity Spectrograph:

- High resolution integral field spectrograph (R ~ 11,500)
- 847 – 874 nm
- Objects down to 17 mag
- Radial velocities from Calcium triplet







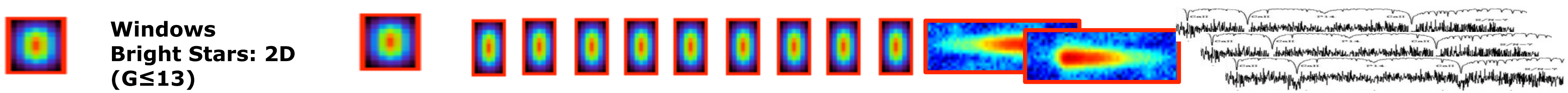
55 AF-type **7** BP-type **12** RP-type

CCD model courtesy Maximilian Fabricius

Credit: Figure courtesy EADS-Astrium

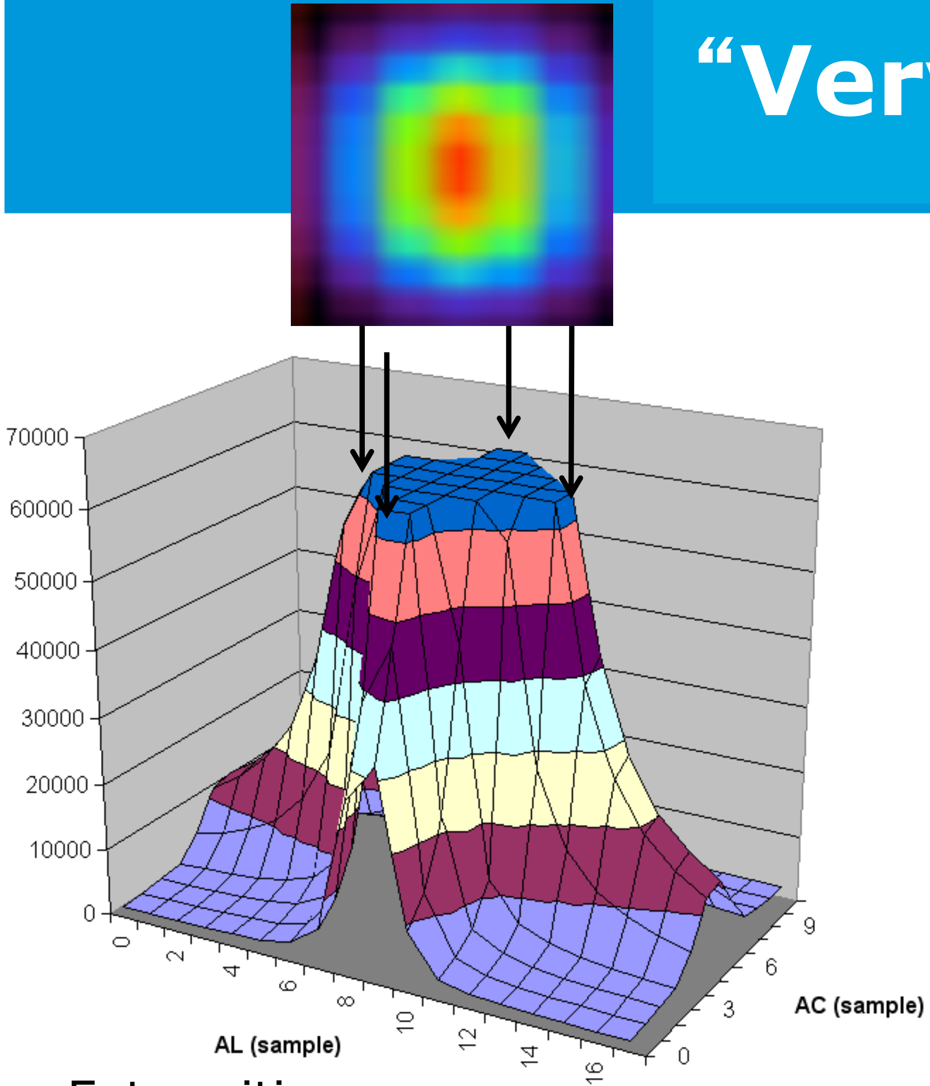
Detection & FOV Discrimination

"Very" Bright Stars



Credit: Figure courtesy EADS-Astrium. **Animation:** Berry Holl & Juanma Fleitas

“Very” Bright Stars



arameters to be optimized:

- N_BUFFER: max. nb of extremities on buffer.
- VH: Working Horizon.
- _MAG: max. difference in magnitude.
- AL_LUT: AL magnitude correction.
- AC_LUT: AC magnitude correction.

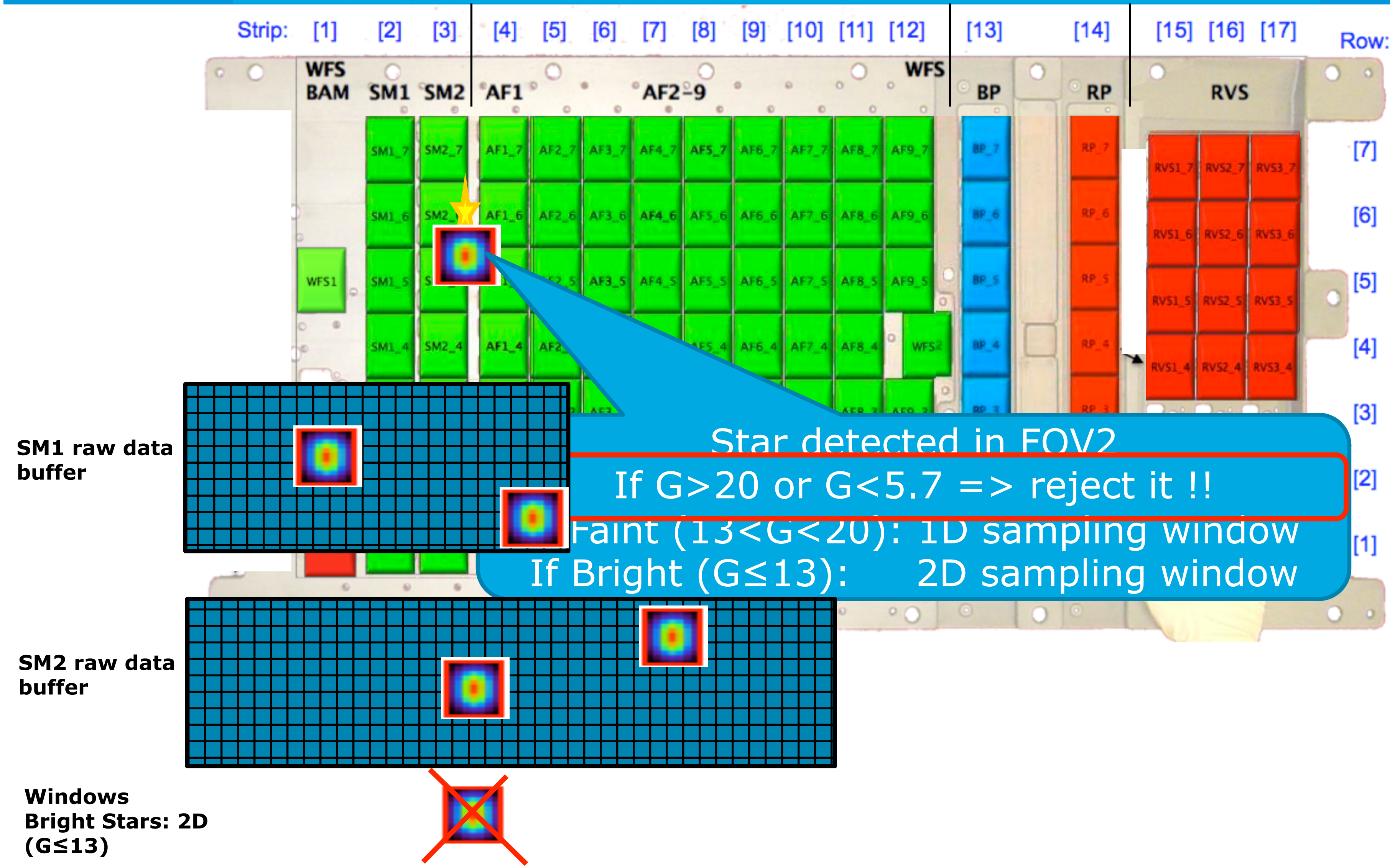
Extremities

- North
- East
- South
- West

Credit: Figure courtesy EADS-Astrium

Observing Very Bright Stars with Gaia

G >2

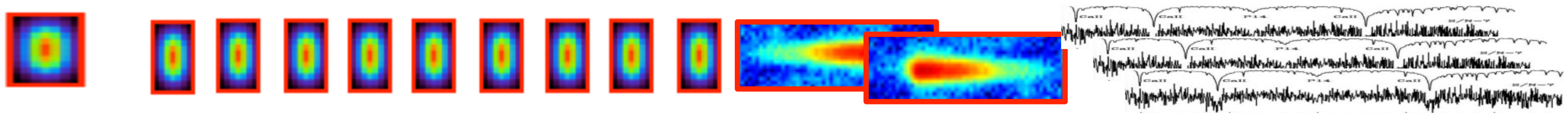


Credit: Figure courtesy EADS-Astrium. **Animation:** Berry Holl & Juanma Fleitas

"Very" Bright Stars

Detection
& FOV
Discrimination

Windows
Bright Stars: 2D
(G≤13)



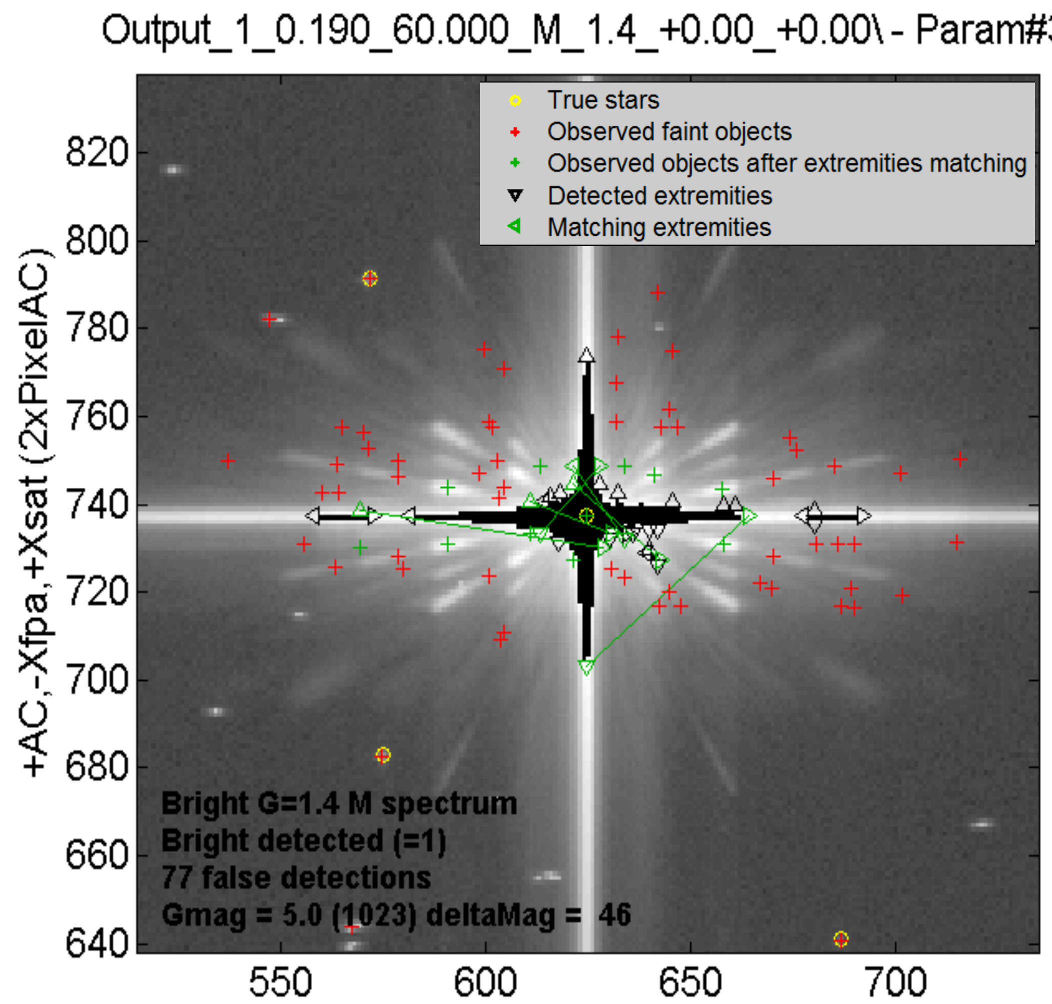
Credit: Figure courtesy EADS-Astrium. **Animation:** Berry Holl & Juanma Fleitas

"Very" Bright Stars

VPU parameters Optimisation

	SOC	ASTRIUM
Ref. doc.	(JMF-005)	(PLM-00884)
VPU SW	version 2.5	version 2.6
Simulations	Gausian PSF Photon Shot noise Telescope&QE	AC smearing, subpixel location PSF quilting effect,
Spectral types	G2V	B1V, G2V, M6V
Mag. range	$0.0 \leq G \leq 8$	$0.0 \leq G \leq 11$
Magnitude step	$\Delta G=0.5$	$\Delta G=0.1$
Regression test	2 stars (G=6, G=8)	6 stars (G=6, G=11)
Coverage(FOVs)	Telescope 1	Telescope 1
Coverage(Row)	Row4	Row1 & Row4
Outcome (set of optimum parameters)	EXT_WH = 128 EXT_IN_BUFFER=6 DELTA_MAG = 32	EXT_WH = 127 EXT_IN_BUFFER = 6 DELTA_MAG = 90 MAG_AL_LUT=[file] MAG_AC_LUT=[file]

G_{min}	Row 1			Row 4		
	B	G	M	B	G	M
Nominal AC/AL speed	2.0	1.8	1.6	2.2	1.8	2.0
Maximal AC speed	2.0	1.7	1.4	2.0	1.6	1.9
Maximal AL speed	2.0	1.8	1.6	2.2	1.8	2.0



Gaia Magnitude bright end G=2 !!