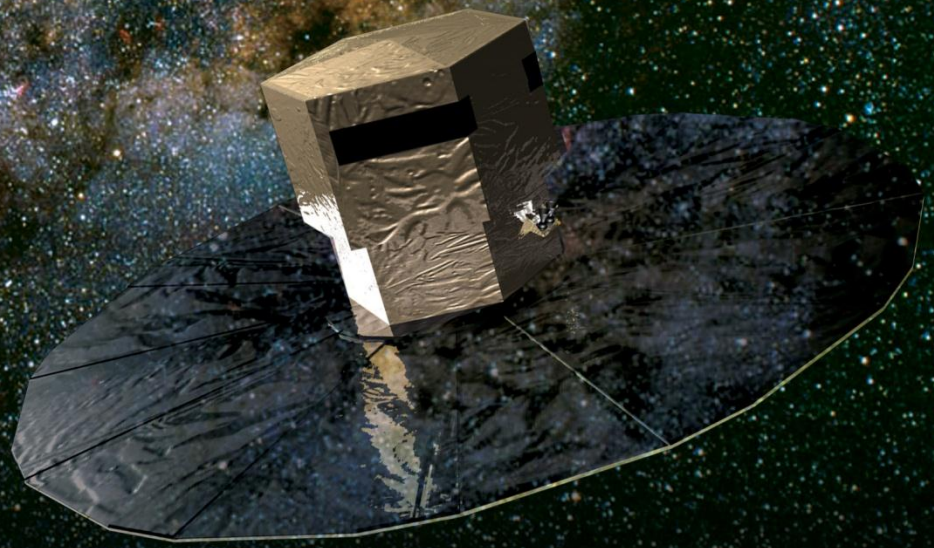
Gaia: la galaxia en un Petabyte

Jordi Torra y el Grupo Gaia

Universidad de Barcelona

ICC/IEEC



VII Jornada Usuarios RES, 13 de septiembre de 2013

Gaia Calendar

- Gaia is the*Cornerstone Mission 6* in "Horizon 2000+" (ESA)

- Approved in 2001
- **2001-2003:** Phase A (feasibility studies)
- **2005-2006:** Phase B (detailed design)
- **2006-2013:** Phase C/D (construction)
- **Nov-2013: Launch**
- **2013-2018:** nominal operations (+1yr extension)
- **2013-2021:** data reduction

1. Gaia
   - Objetivos científicos
   - La misión

2. El instrumento

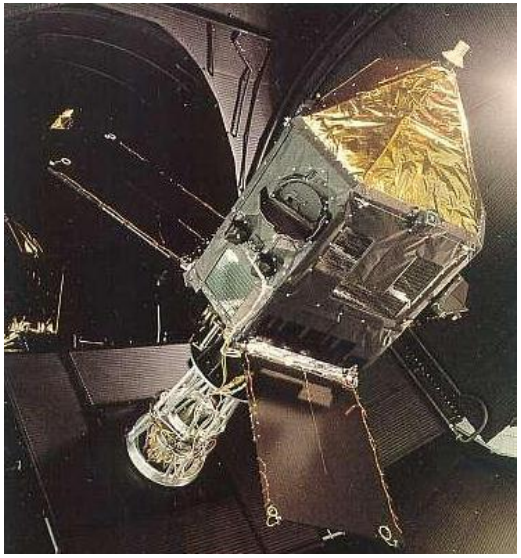
3. El tratamiento de datos (BSC)

Gaia: global astrometry mission

Gaia's main science goal is to unravel the dynamical and chemical evolution of the Galaxy – back in time to its formation – and to study its kinematics, dynamics, and structure

A large 3D survey of the Milky Way (and beyond)

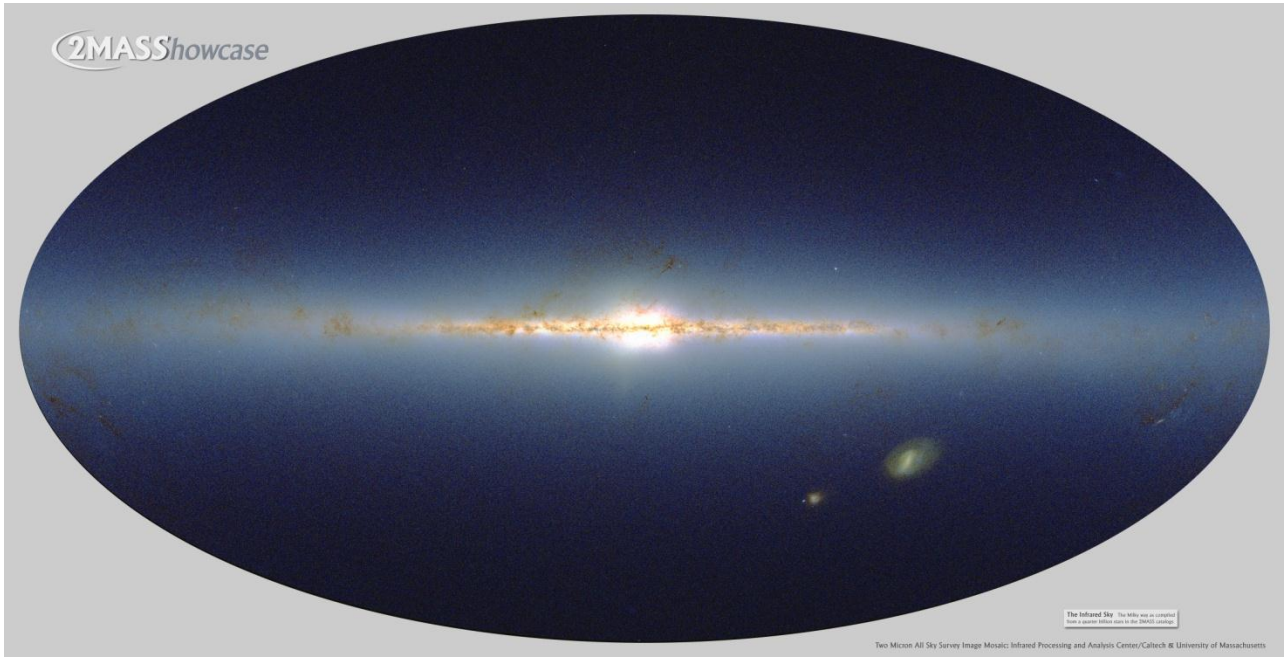
Based on Hipparcos principles (large angle, global astrometry) and success



Hipparcos: launched Aug. 1989
Operations: 1988 -1993
Data reduction: 1988 -1997
European leadership

La Via Láctea : una galáxia de tipo Sbc

- Galaxia espiral
- Masa aproximada de $2*10^{14}$ masas solares
- Contiene unos 200-400 mil millones de estrellas
- Diámetro aproximado de 100000 años luz



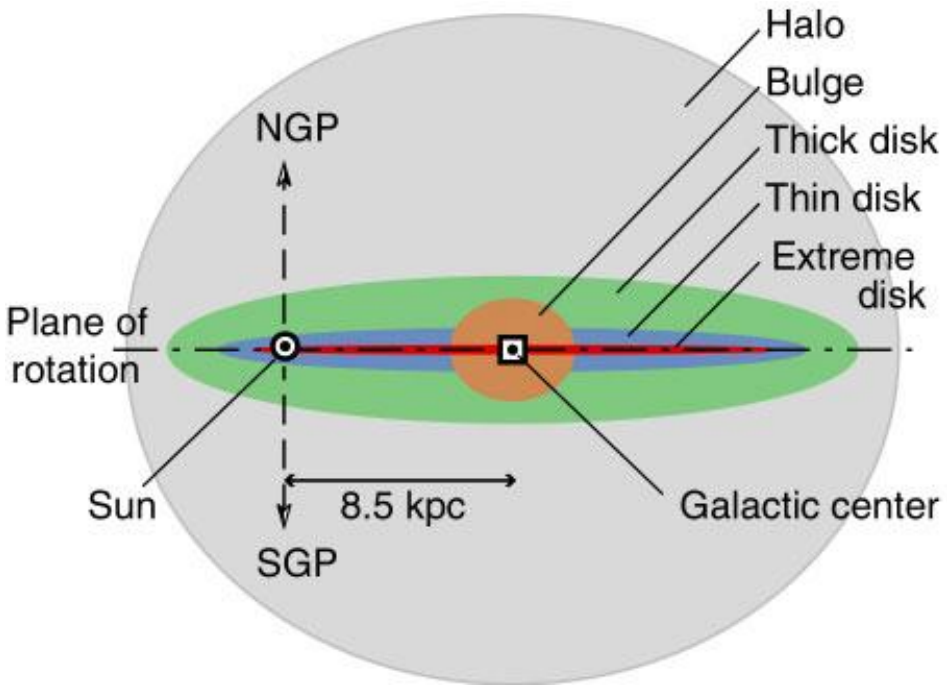
Estructura, componentes, formación y evolución de la Galáxia

Posiciones

Distancias

Movimientos

Propiedades físicas:
Composición, edad



Gaia capabilities

- >10^9 objects (~1% Milky Way)
- Complete up to magnitude 20
- Positions, proper motions, parallaxes
  - Nominal precision (15^{th} mag):
    ~20μas (10^{-10} rad), 20μas y^{-1}
    ~300 μas at mag 20
- G band

- Spectrophotometry
  (400-1000 nm, R=10-50)

- Spectroscopy and radial velocities (G<16)
  - IR Ca II triplet, R=11000

- No input catalogue → unbiased survey

Gaia capabilities

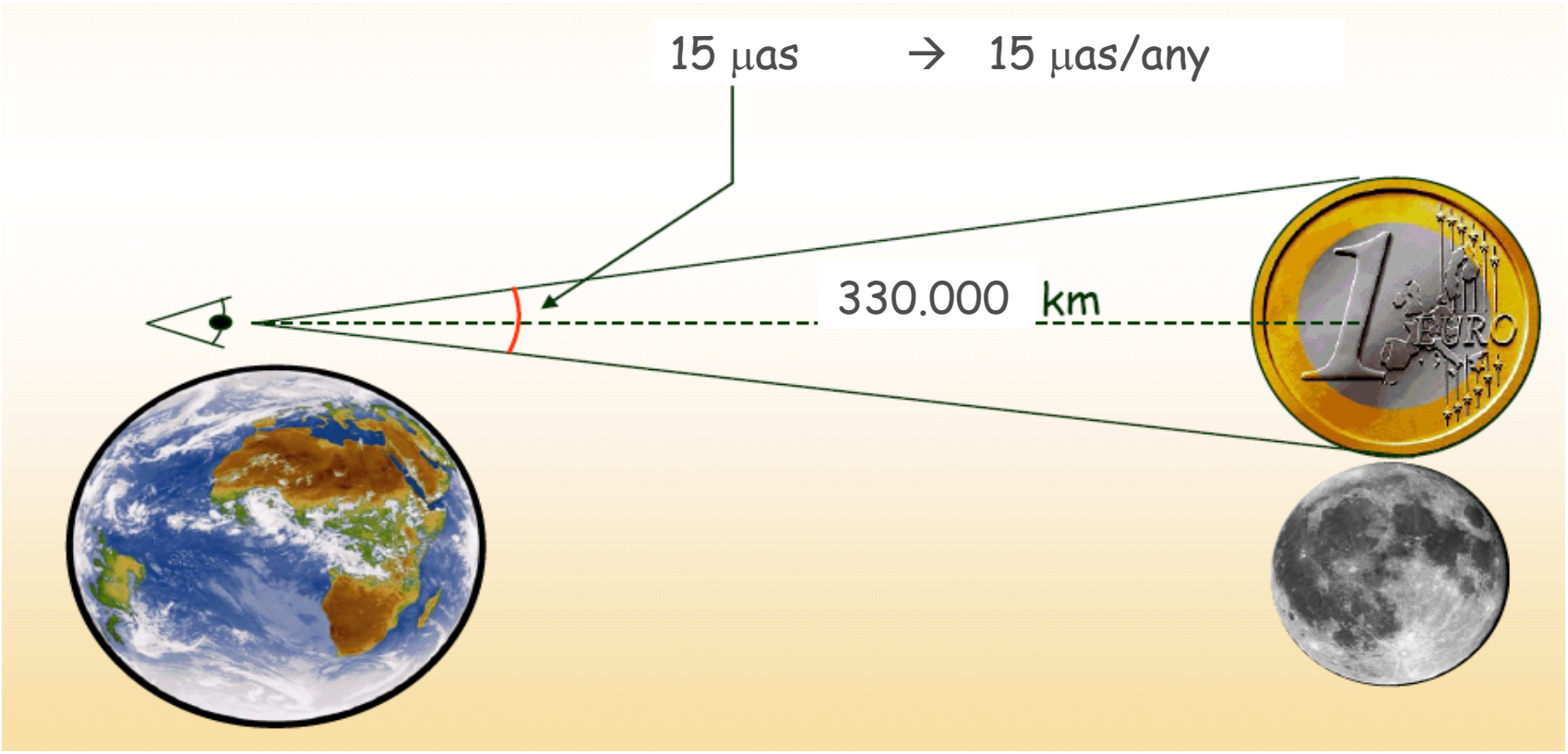
- Positions, proper motions and parallaxes for 1 billion stars (G < 20)

- Low resolution spectrophotometry for 1 billion stars, allowing estimations of Teff, logg, Av and [Fe/H]

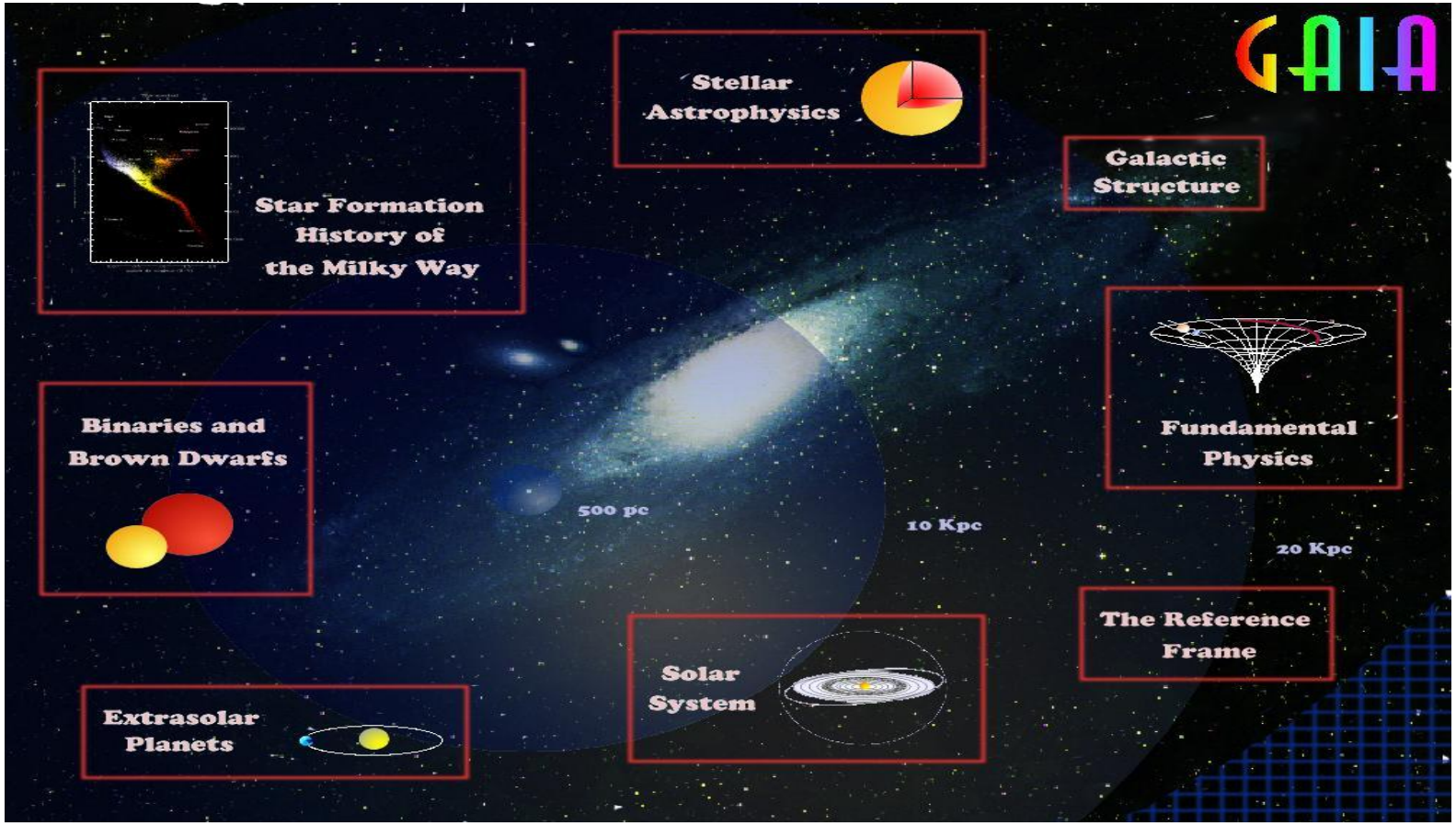
- Radial velocities for 150 million stars (G < 16)

- Atmospheric parameters, reddening and rotational velocities for 5 million stars (G < 12)

- Detailed chemical abundances for 2 million stars (G < 11)


15 μas → 15 μas/any
330.000 km
1 EURO

Scientific Goals

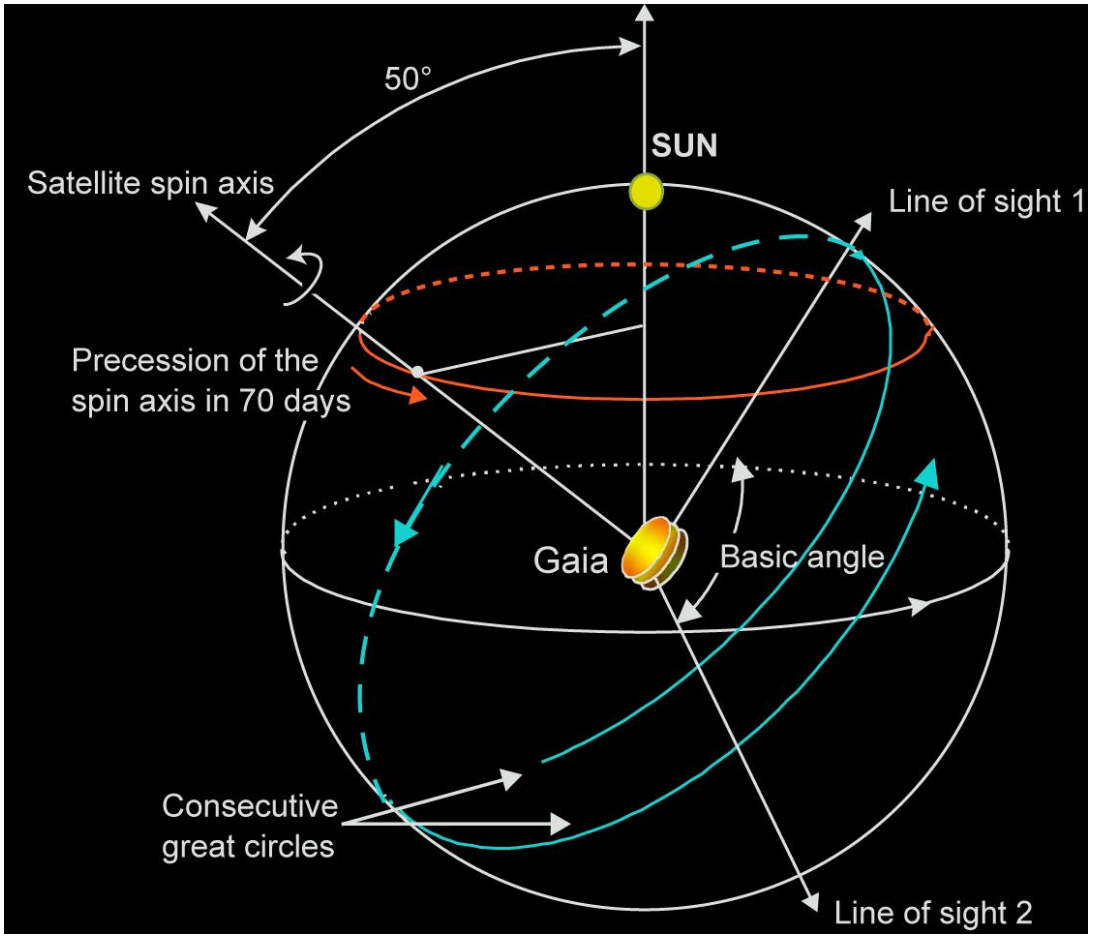


Two Challenges:

- To build the satellite:
  - Thermal and mechanical stability
    =>CCDs operate at ~ -110^{o}C
    =><1mK at focal plane
    =>~μK in the torus
  - High precision
  - The largest focal plane + TDI sinchronized with rotation

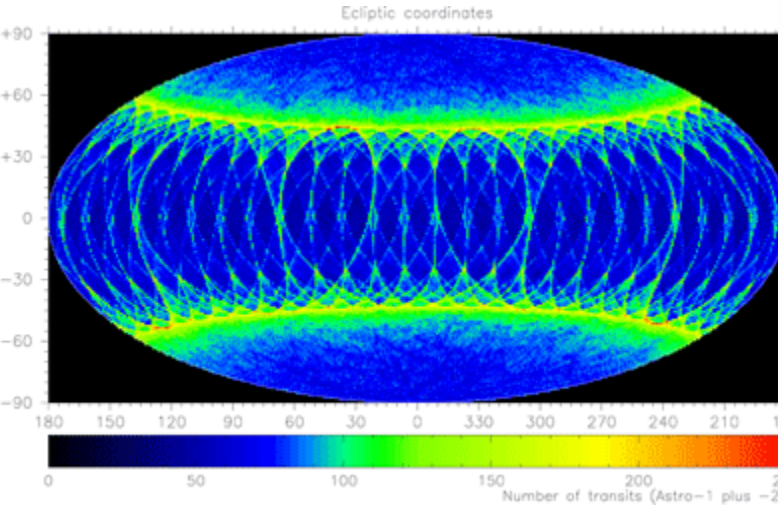
- Data processing:
  - Complex relationship as astrometry, photometry and spectroscopy
  - ~1 PetaByte of data, 10^{20-21} flop
  - μas accuracy, 0.1 μas = 10^{-13} rad
  - Hipparcos approach (flat files, sequential process) not possible

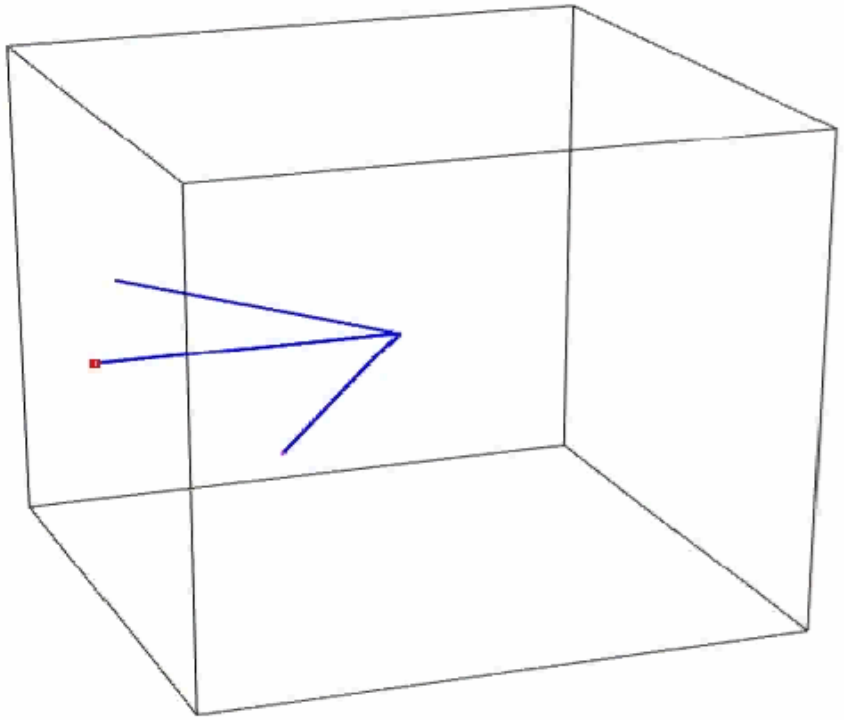
Scan law


50°
SUN
Satellite spin axis
Line of sight 1
Precession of the
spin axis in 70 days
Gaia
Basic angle
Consecutive
great circles
Line of sight 2

Ley de barrido

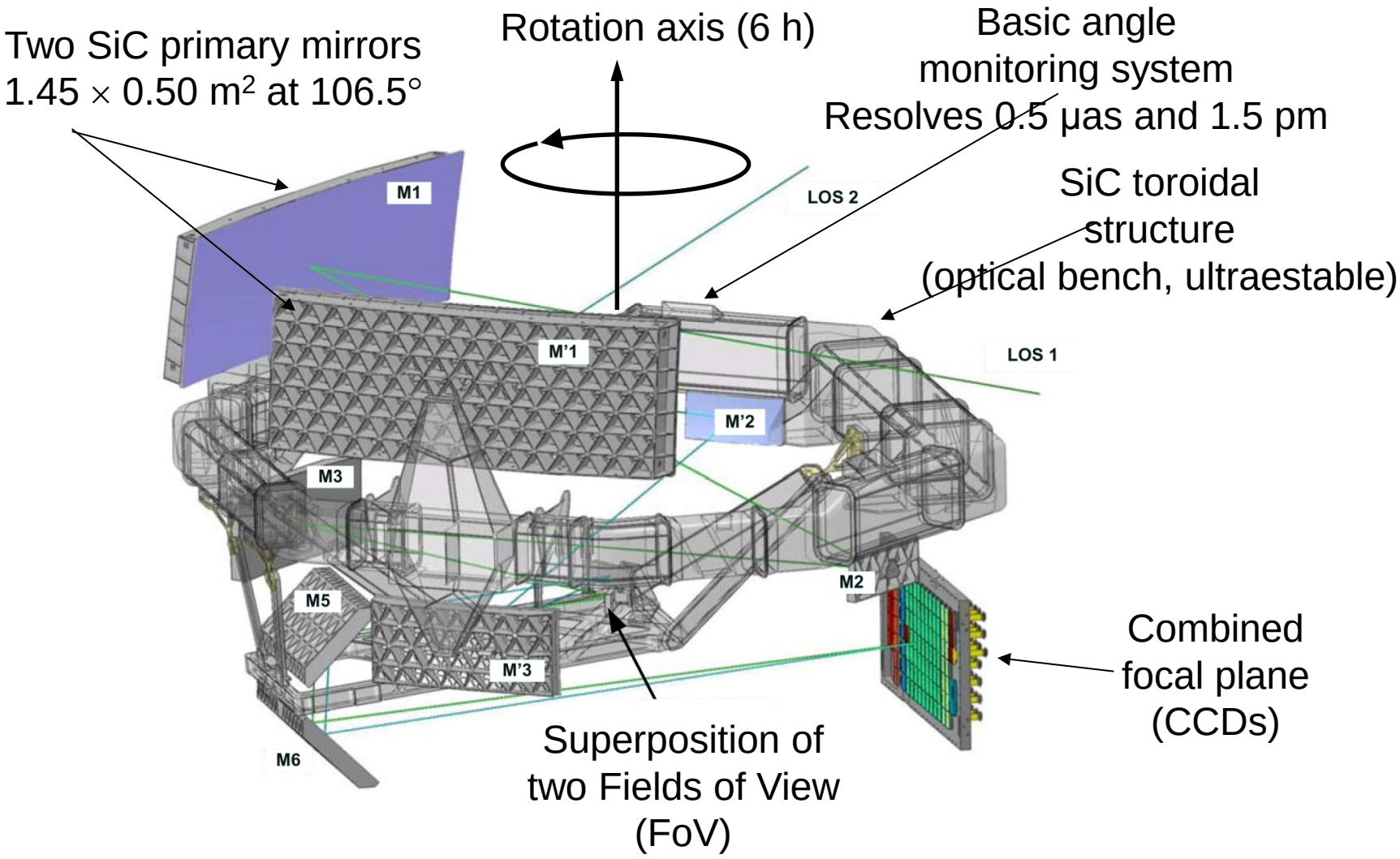
Precesión:70 días
Rotación: 6 horas





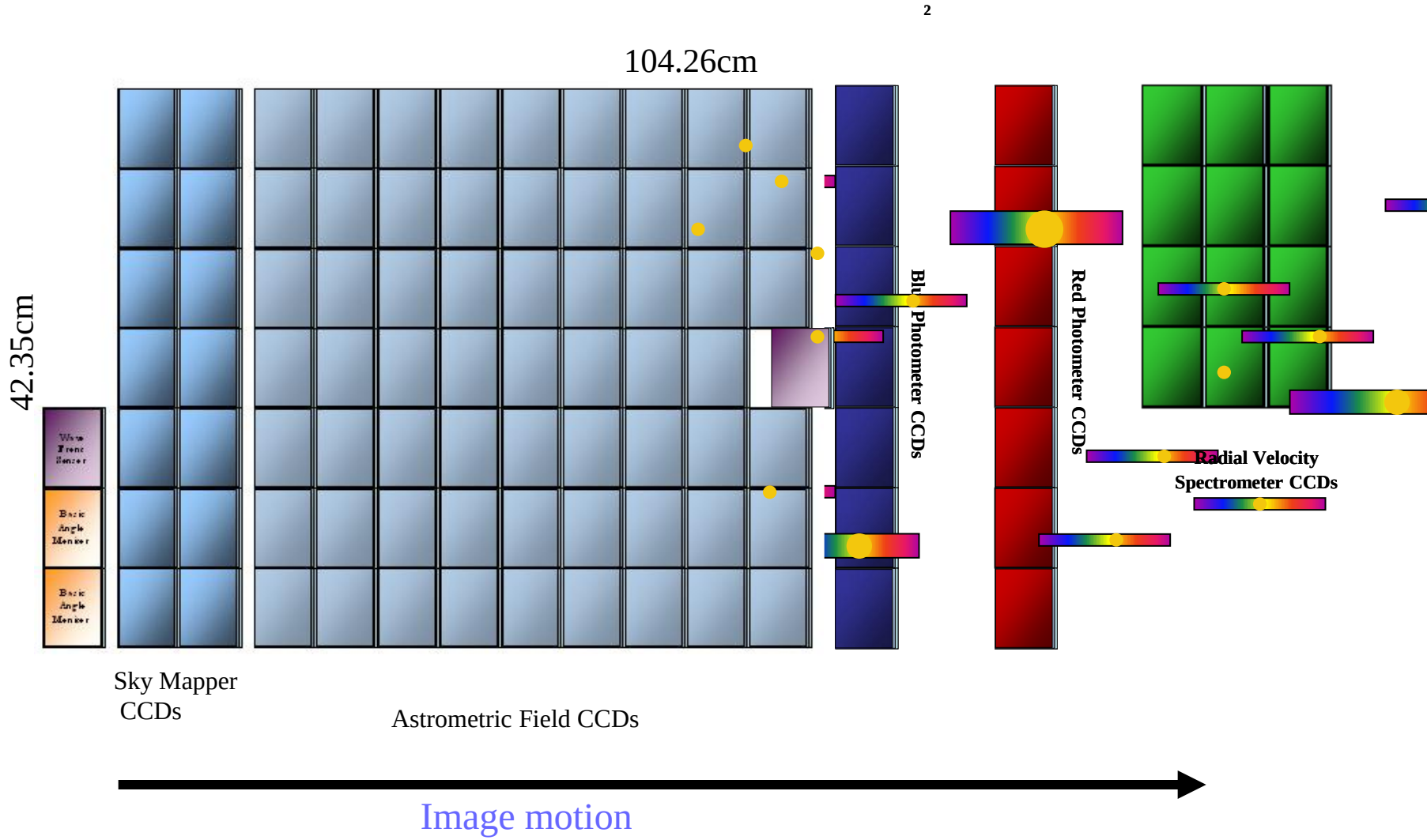
Images courtesy EADS-Astrium

Telescopes, focal plane

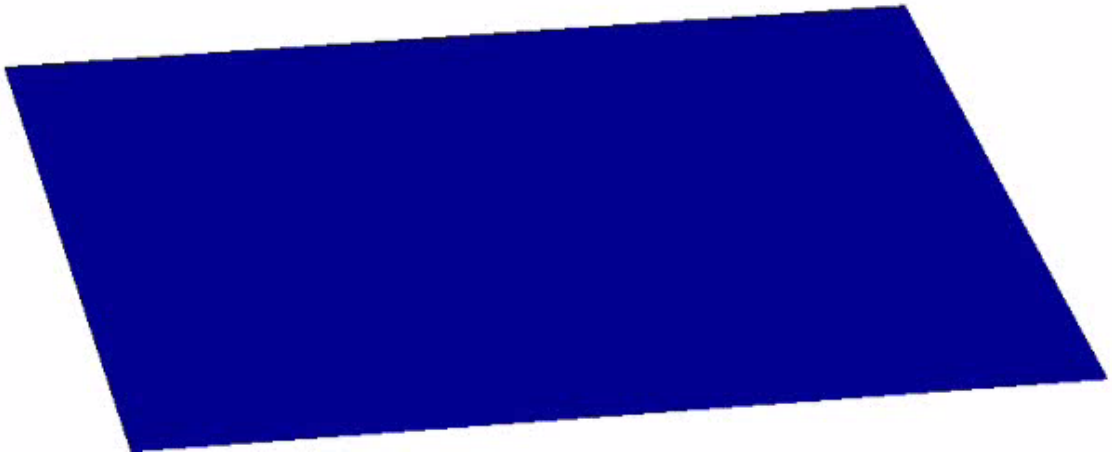


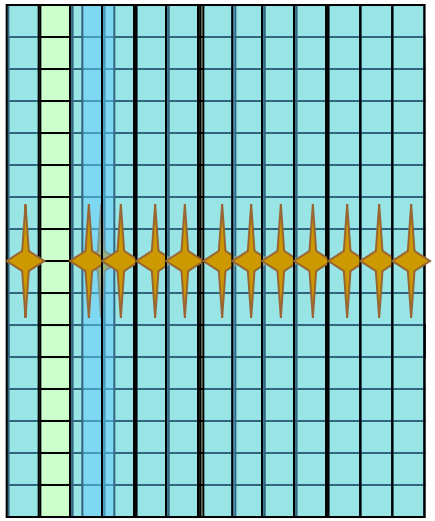
Telescopes, focal plane

106 CCDs , 938 million pixels, 2800 cm^2, 0.75 sqdeg
CCDs: 4500x1966 pix, operated in TDI mode

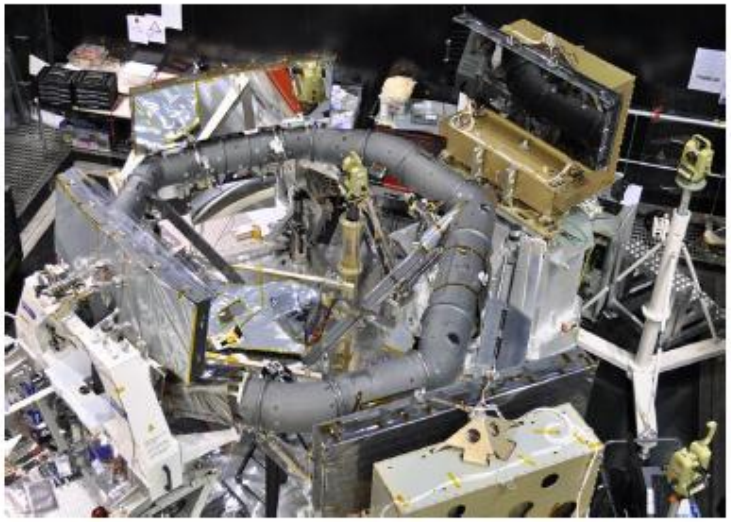


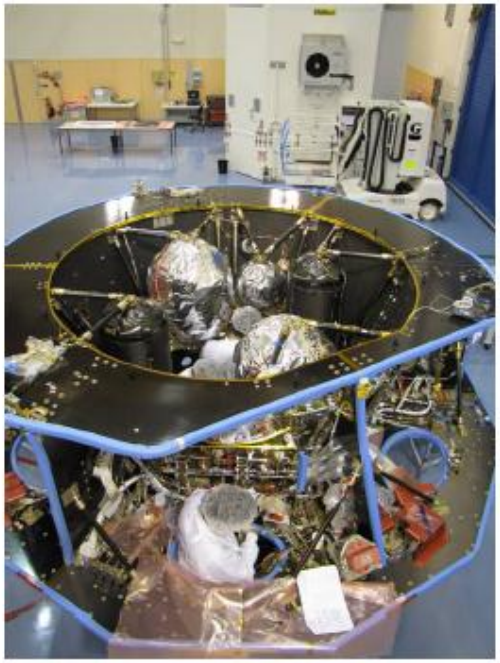
Time-delayed integration (TDI)

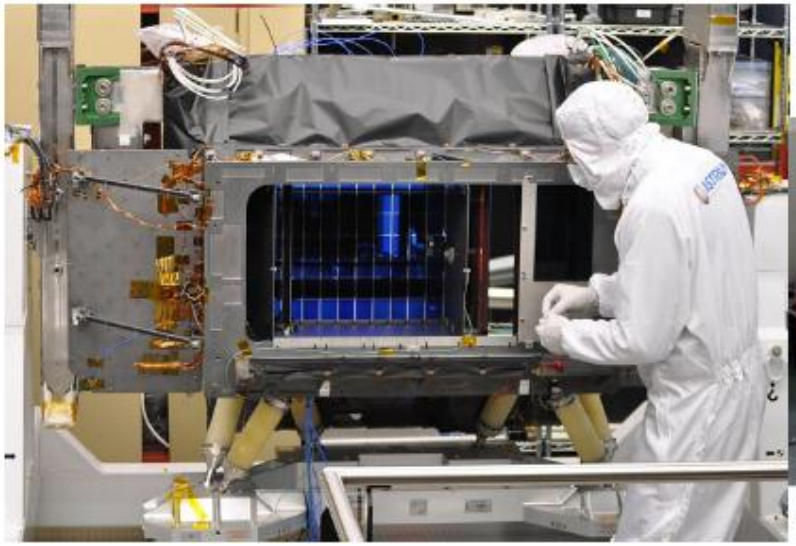


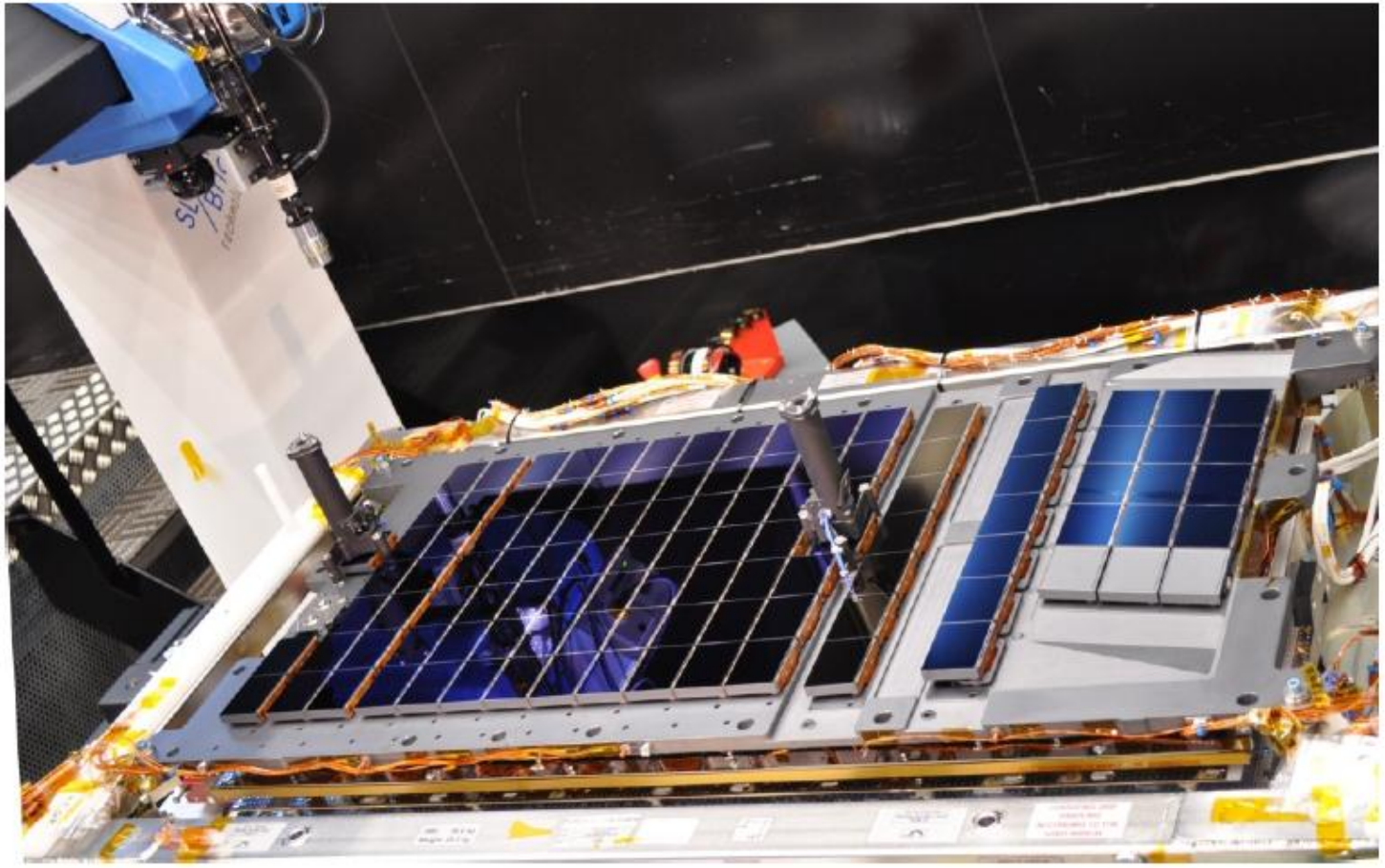


4.4 s/CCD







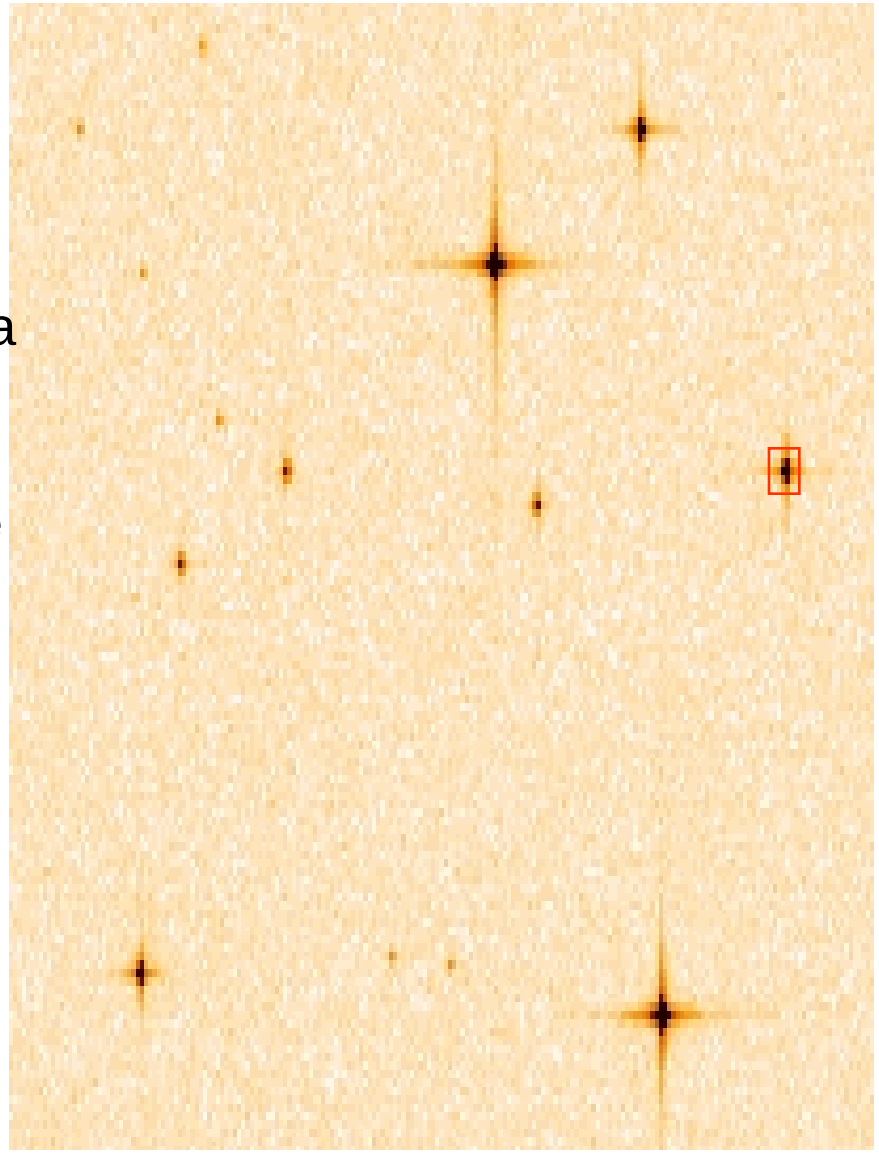


Images courtesy EADS-Astrium

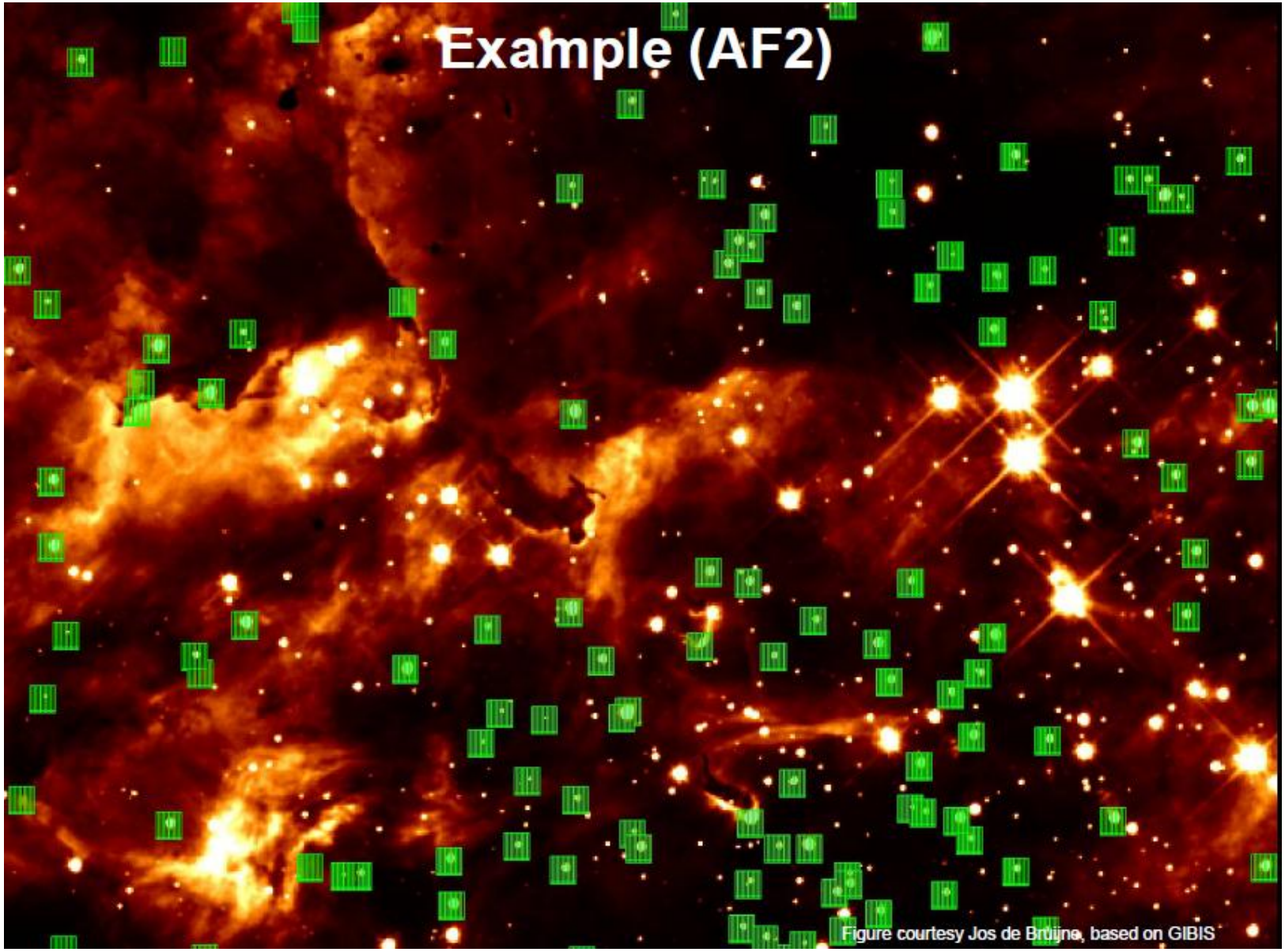
Windowing

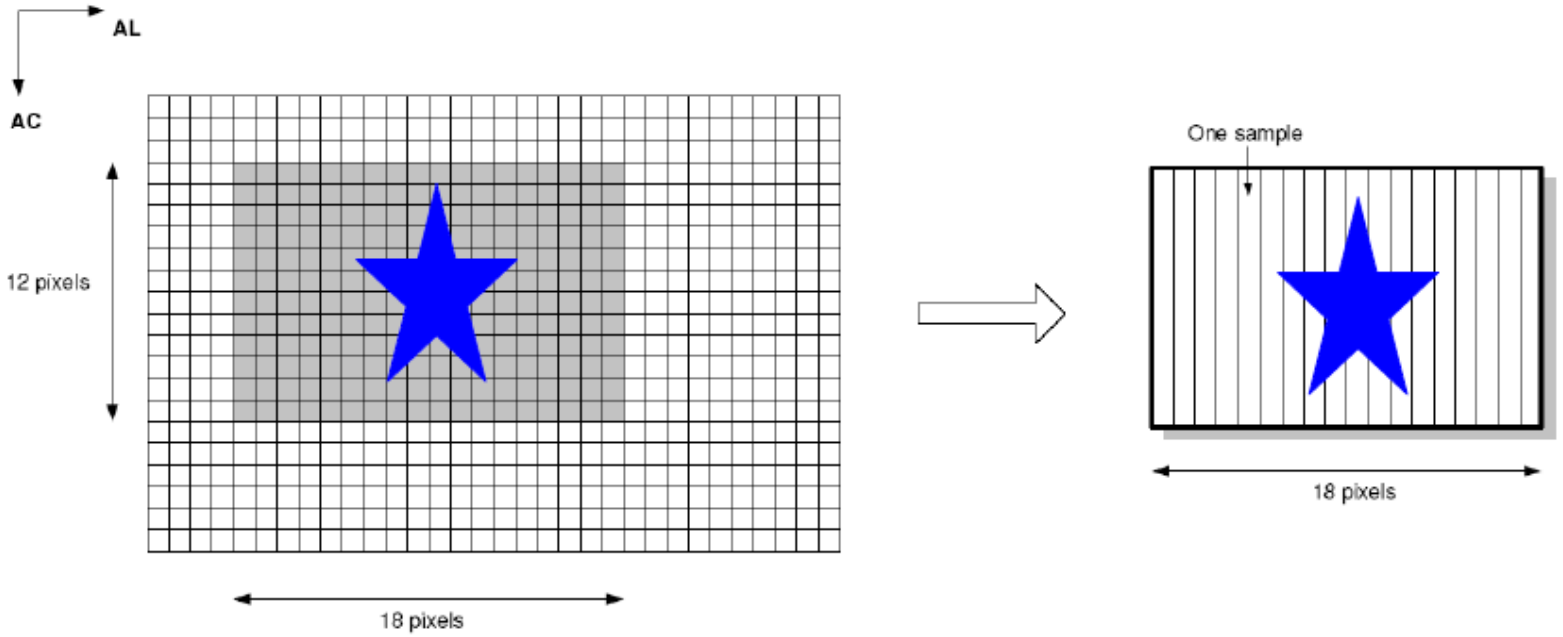
N = 45 10^6 obs/día

Not all the pixels are readed



Window (in red): to be downloaded for each object detected and confirmed

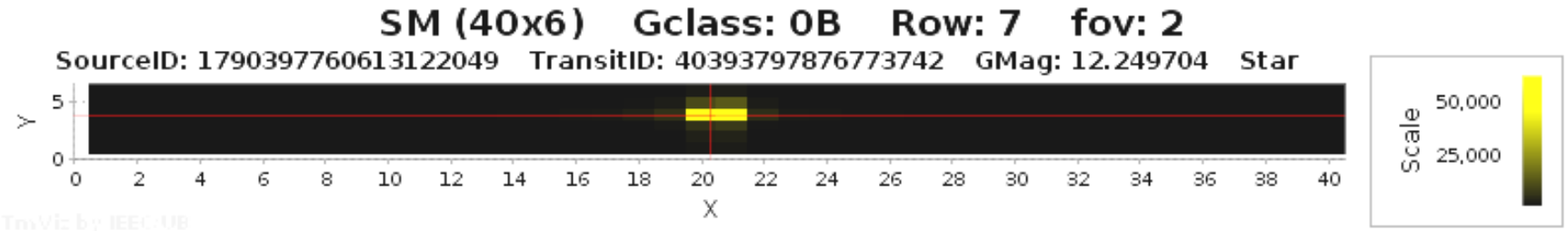

Example (AF2)
Figure courtesy Jos de Bruijne, based on GIBIS

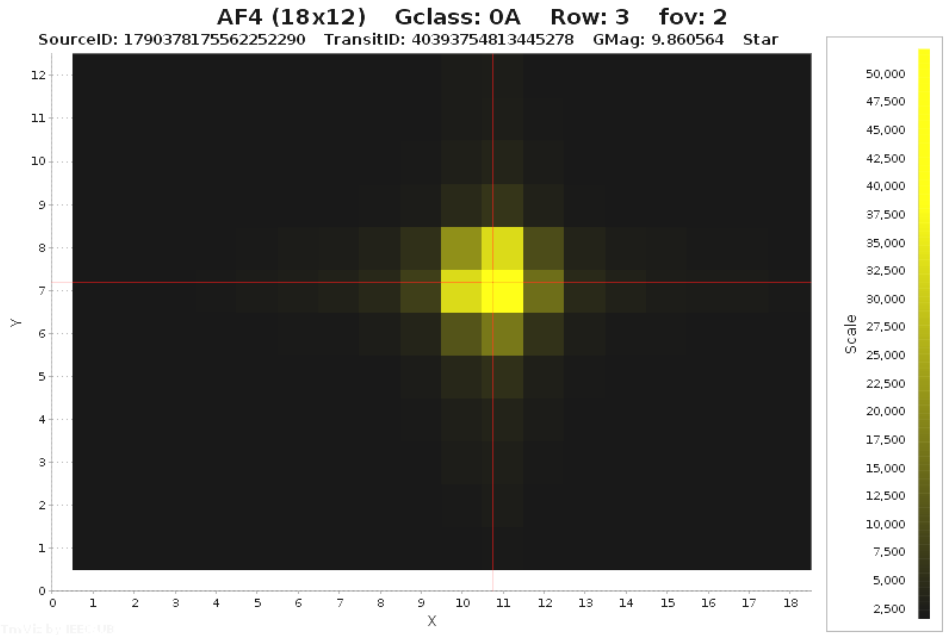


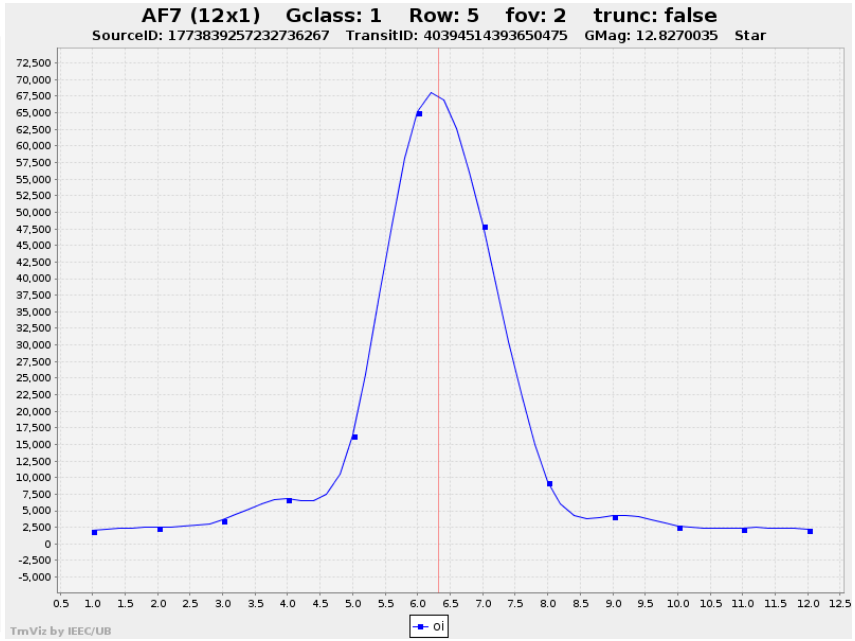
Example:

- The required window around the star covers 18×12 CCD pixels
- The read window is composed of 18 along-scan samples of 1×12 pixels
- Only the 18 electron-count sample values are sent to the ground

Posiciones, G magnitud

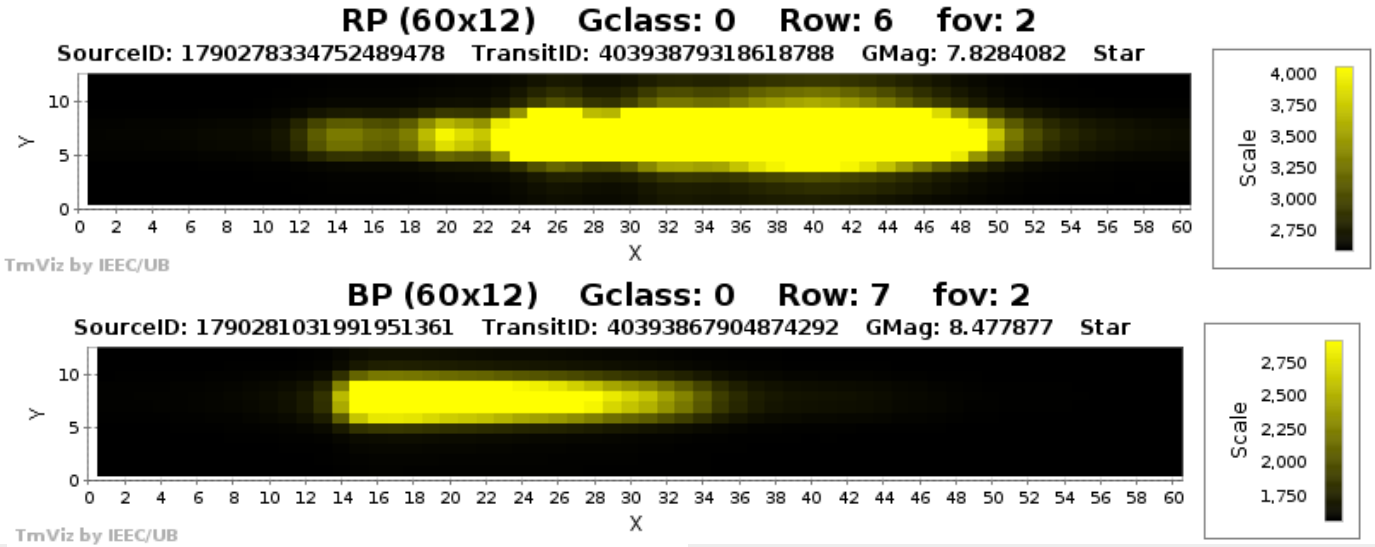


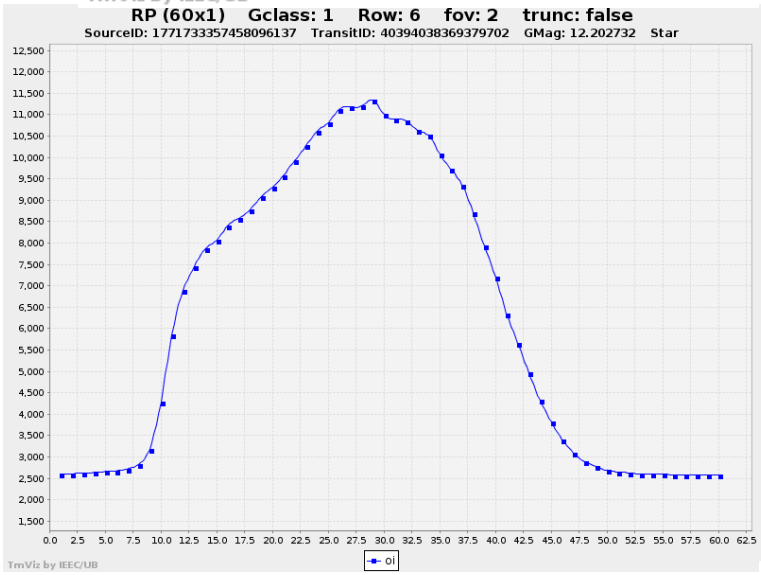


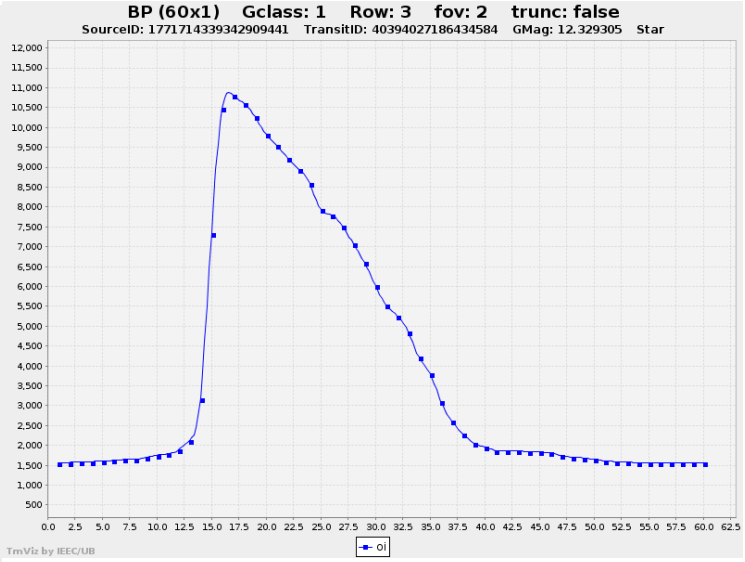


(9 medidas en cada observación)

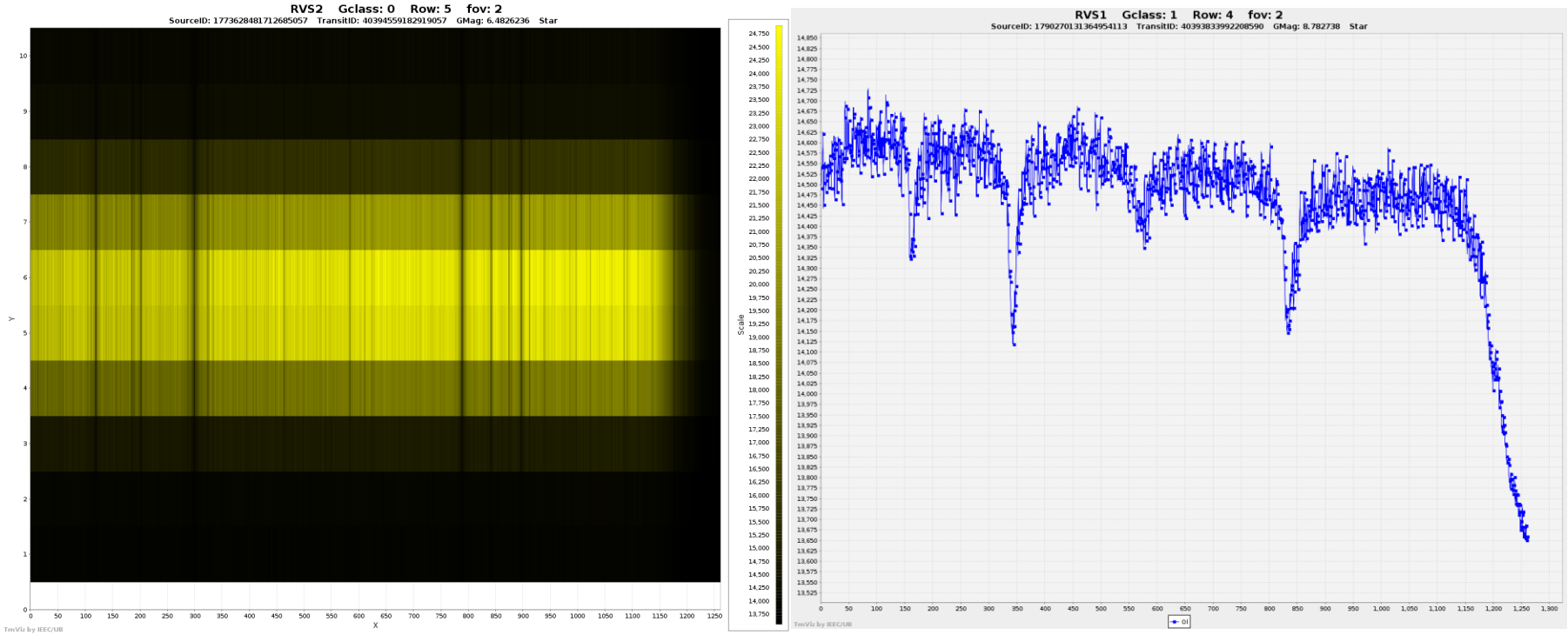
Colores


RP (60x12) Gclass: 0 Row: 6 fov: 2
SourceID: 1790278334752489478 TransitID: 40393879318618788 GMag: 7.8284082 Star
Y
X
Scale
4,000
3,750
3,500
3,250
3,000
2,750
TmViz by IEEC/UB
BP (60x12) Gclass: 0 Row: 7 fov: 2
SourceID: 1790281031991951361 TransitID: 40393867904874292 GMag: 8.477877 Star
Y
X
Scale
2,750
2,500
2,250
2,000
1,750
TmViz by IEEC/UB


RP (60x1) Gclass: 1 Row: 6 fov: 2 trunc: false
SourceID: 1771733357458096137 TransitID: 40394038369379702 GMag: 12.202732 Star
oi
TmViz by IEEC/UB


BP (60x1) Gclass: 1 Row: 3 fov: 2 trunc: false
SourceID: 1771714339342909441 TransitID: 40394027186434584 GMag: 12.329305 Star
oi
TmViz by IEEC/UB

Espectros, velocidades radiales



Data reduction

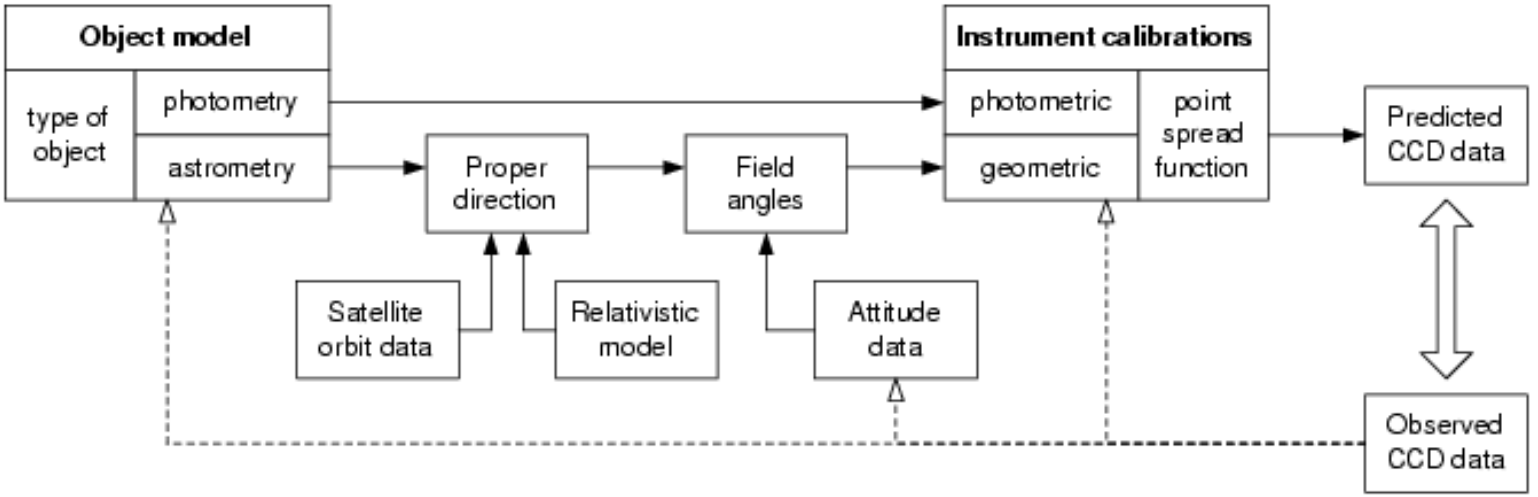
- 10^{12} Individual measurements
- 10^{10} Unknowns
- All of them are related ➔ simultaneous determination

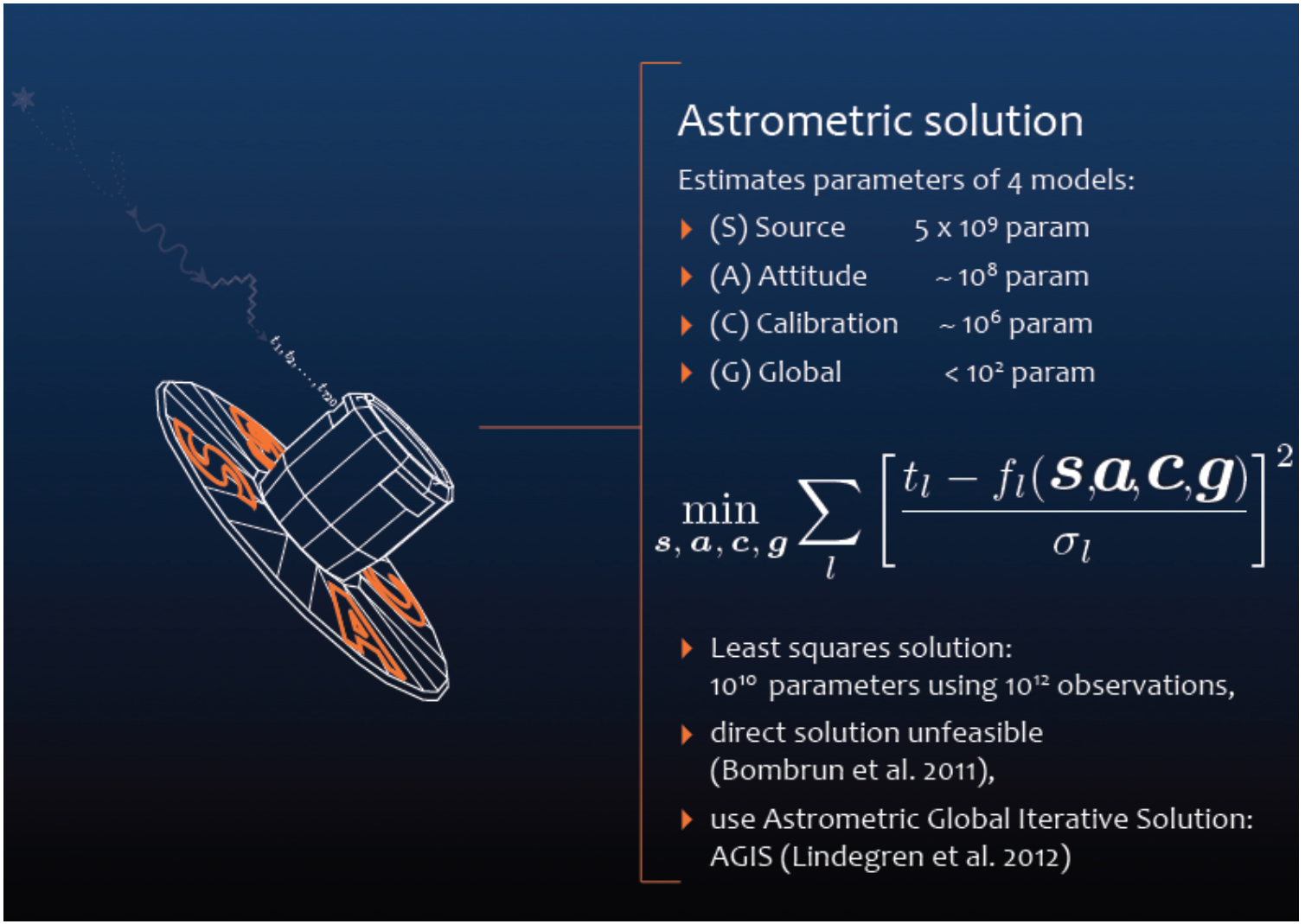
- 5000 10^6 unknowns (pos, pm., par.,) stars
- 150 10^6 unknowns in attitude
- 10 - 50 10^6 unknowns in calibration
- Some tens of “global” parameters

Mil millones de estrellas
a un segundo por estrella

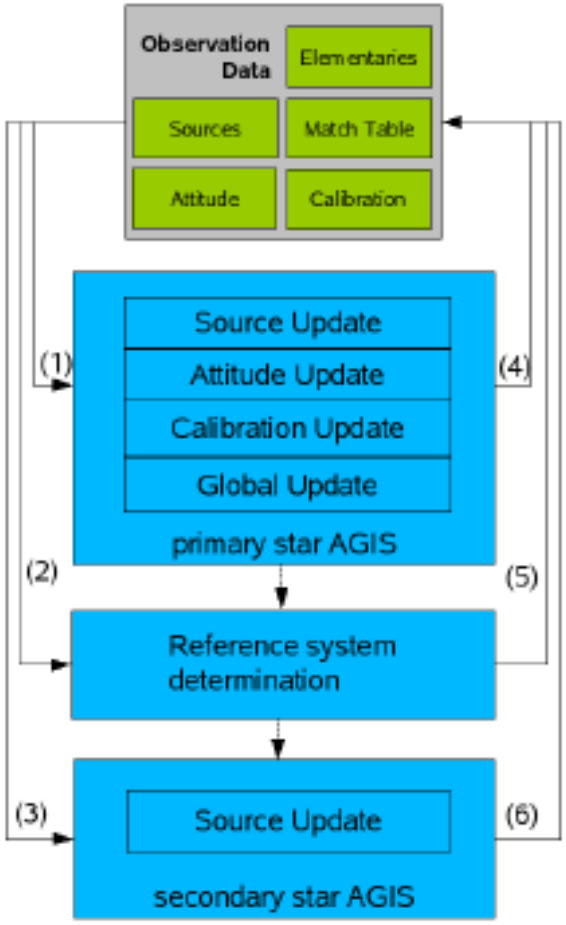
= …. años

Data Analysis: Concept and Requirements




Astrometric solution
Estimates parameters of 4 models:
(S) Source 5 x 10^9 param
(A) Attitude ~ 10^8 param
(C) Calibration ~ 10^6 param
(G) Global < 10^2 param
$\min_{s,a,c,g} \sum_l \left[\frac{t_l - f_l(s,a,c,g)}{\sigma_l}\right]^2$
Least squares solution:
10^10 parameters using 10^12 observations,
direct solution unfeasible
(Bombrun et al. 2011),
use Astrometric Global Iterative Solution:
AGIS (Lindegren et al. 2012)

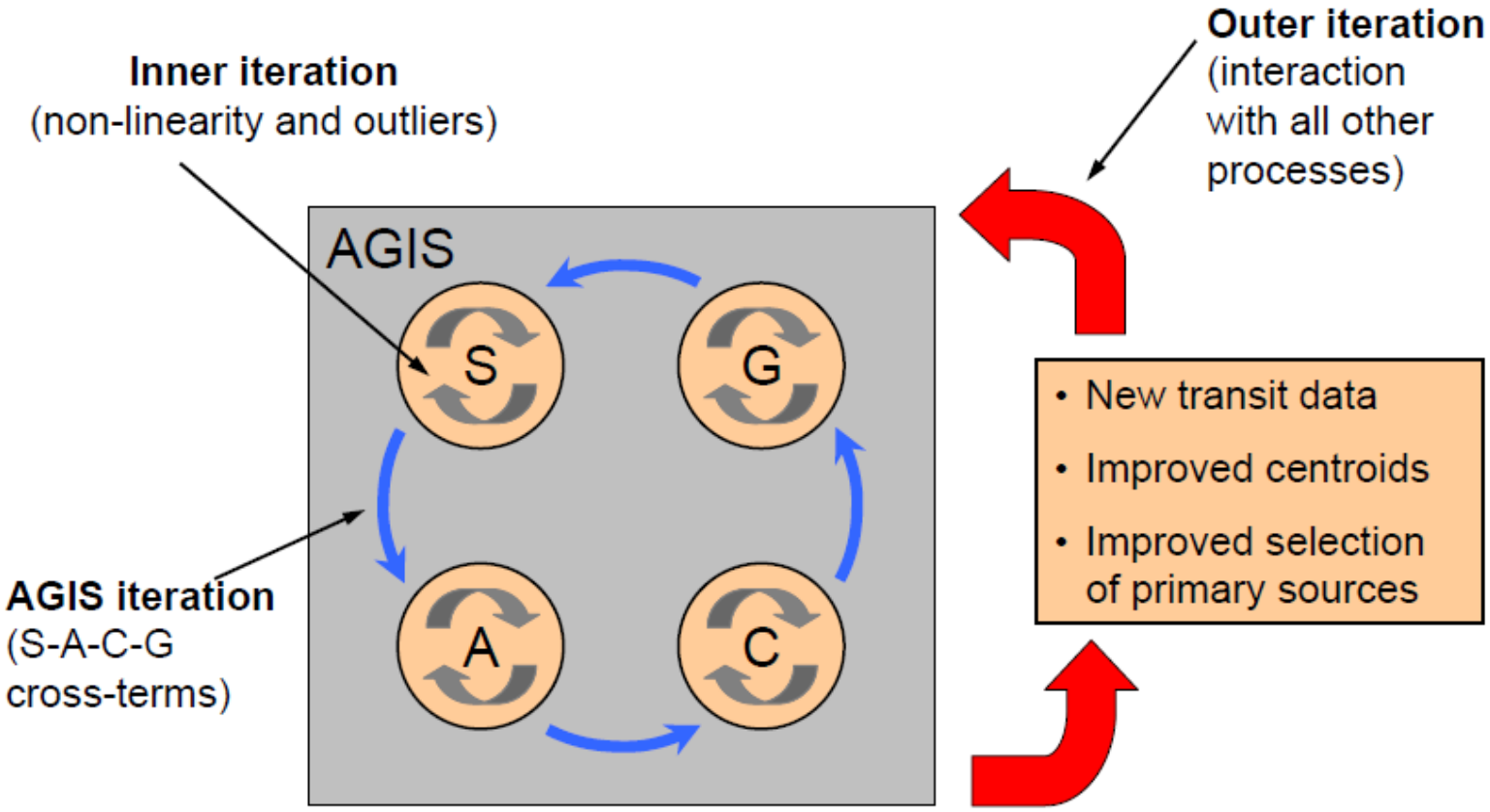
Astrometric Global Iterative Solution



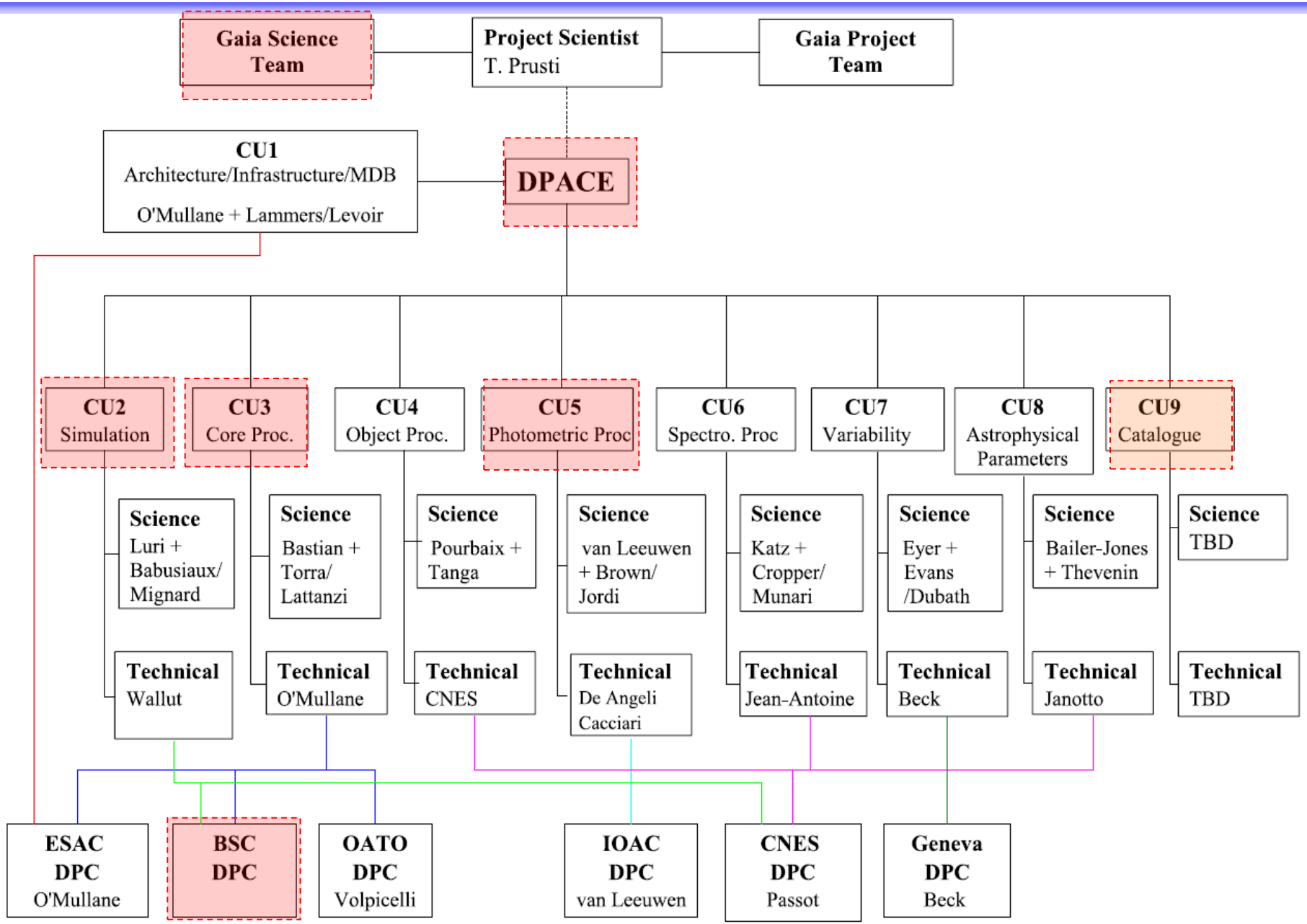
- 100 milion stars
- Model for secondary stars
- Not fitting to the model: CUx
- Improved after new data are available => Data Updating

FIGURE 1: Functional overview of AGIS processes and top-level data flow

Intermediate Data Update



Data Processing and Analysis Consortium (DPAC)

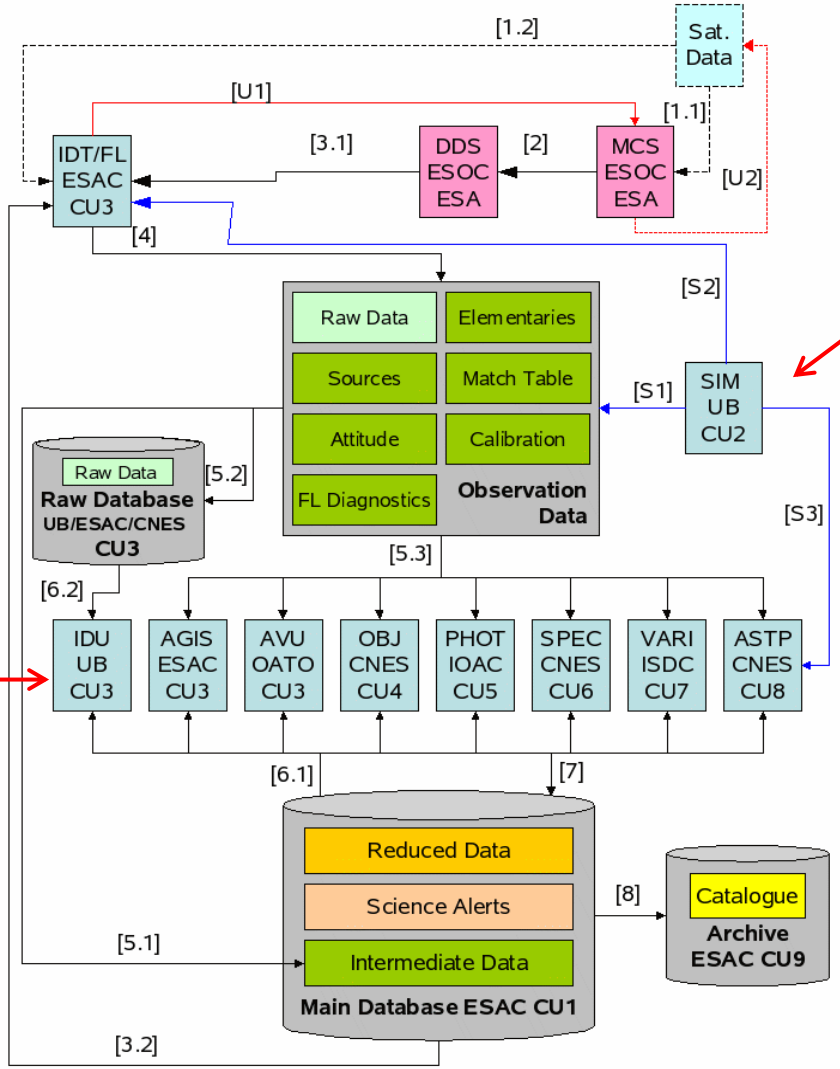


Data Processing & Analysis Consortium

- Consorcio para el Procesado y Análisis de Datos
- 6 Centros de Procesado de Datos:
  - ESAC (Madrid), *BD Principal*
  - **BSC (Barcelona)**
  - CNES (Toulouse)
  - ISDC (Geneva)
  - IoA (Cambridge)
  - OATo (Torino)
- 450 especialistas: astrónomos, programadores, ingenieros, etc.

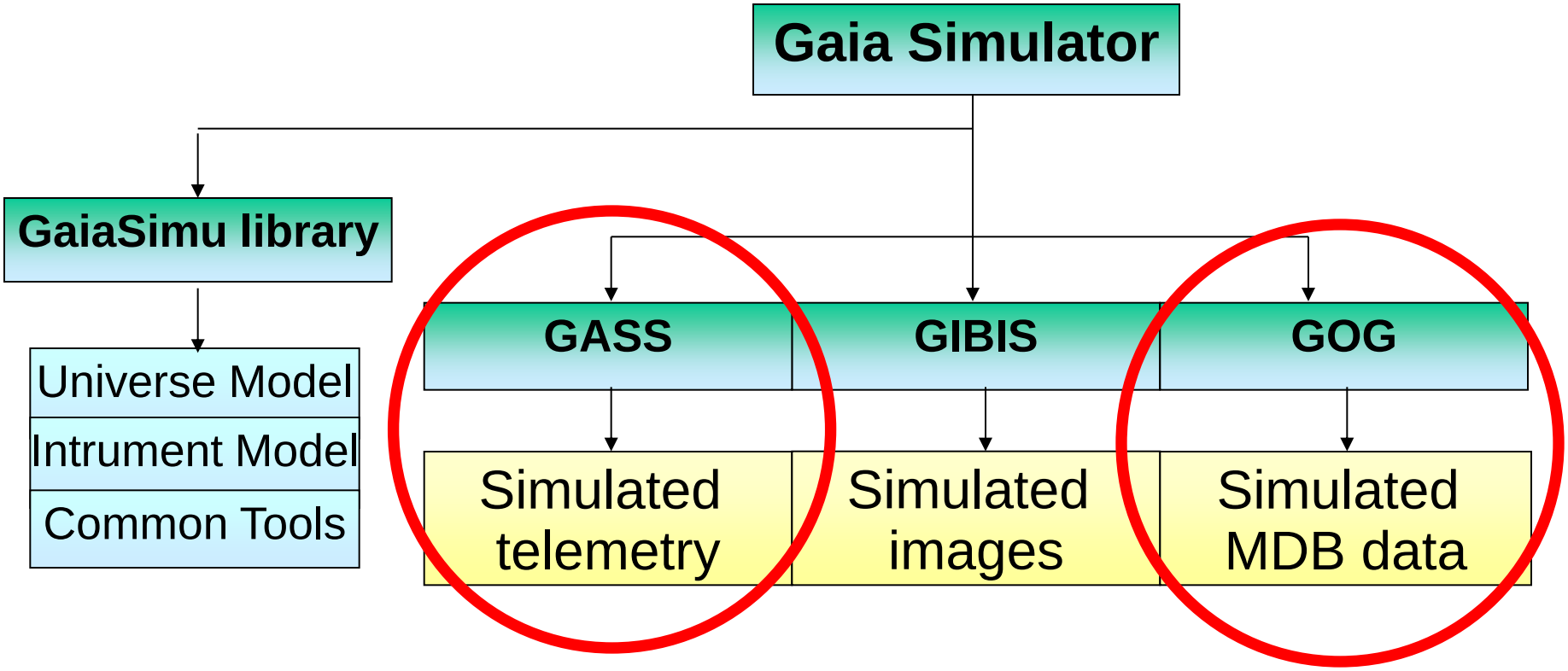
Simulación

Intermediate Data Updating

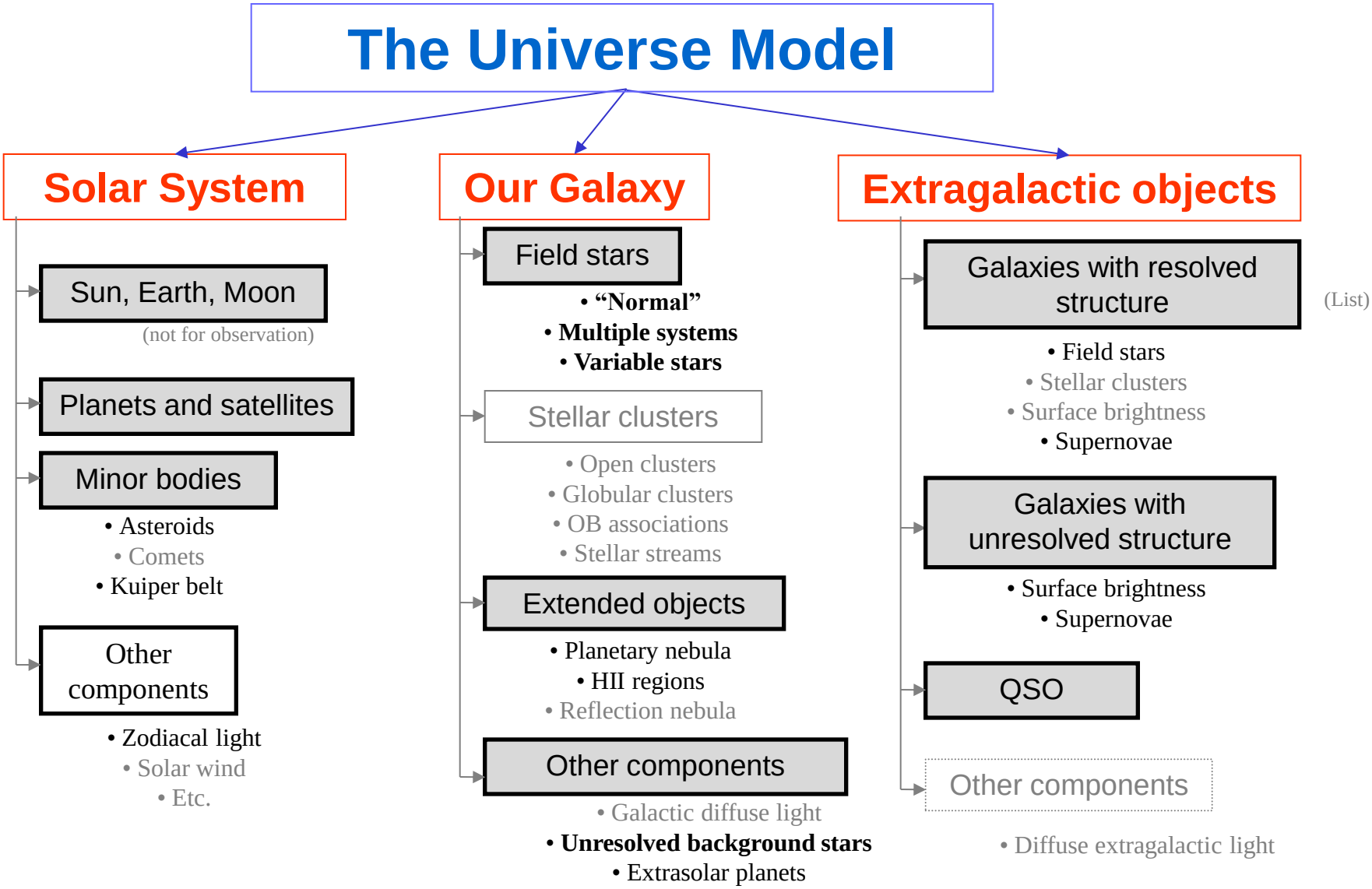


Simulators

Gaia DPAC (Data Processing and Analysis Consortium) has developed 3 data generators to simulate the data provided by the mission:



The Universe Model

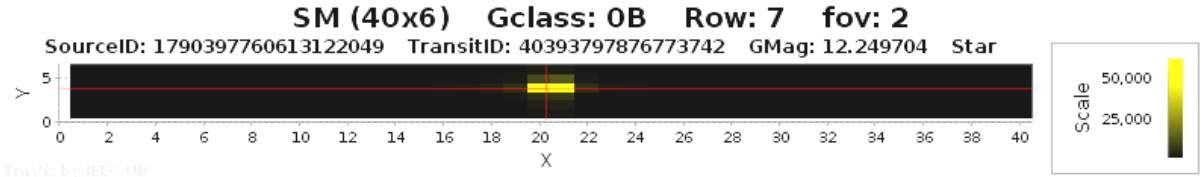


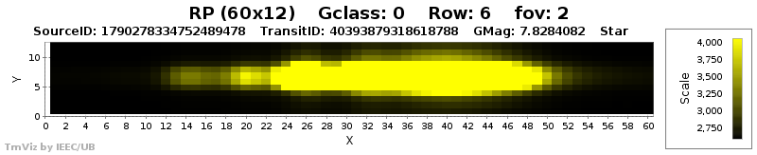
Tareas en BSC (I)

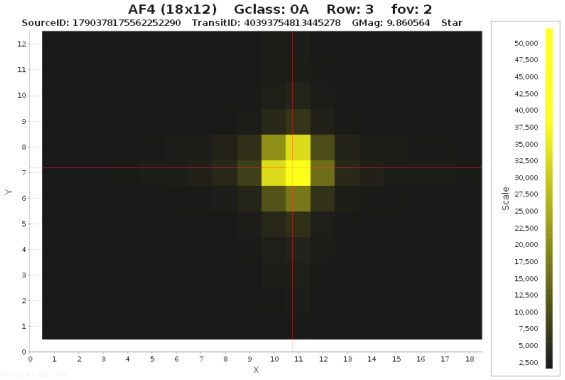
- Simulations for testing the whole Gaia-DPAC processing chain:
  - High-realism simulation of the Gaia instrument - GASS
  - High-realism simulation of the Gaia catalogue - GOG

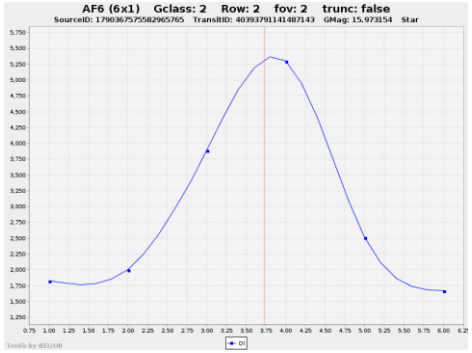
- Provision of:
  - Full-scale sky simulations for Operations Rehearsals – testing of the main Scientific Critical software involved in the daily processing of Gaia Telemetry stream.
  - Reduced density simulations covering long term periods for the testing of the whole Gaia data processing chain

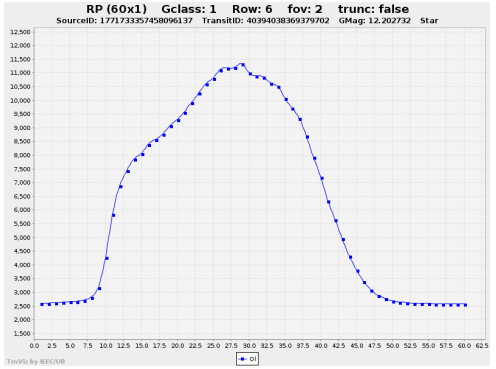
Observaciones simuladas

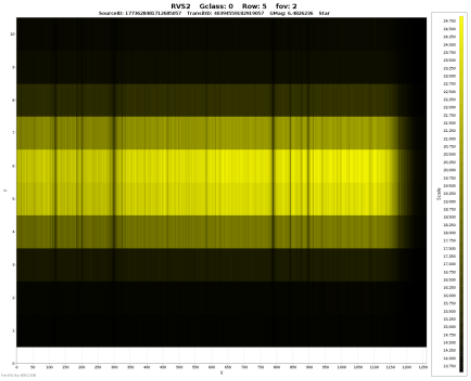


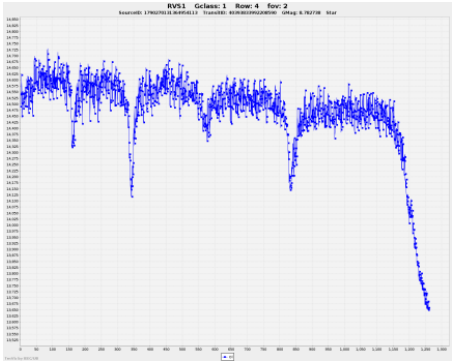






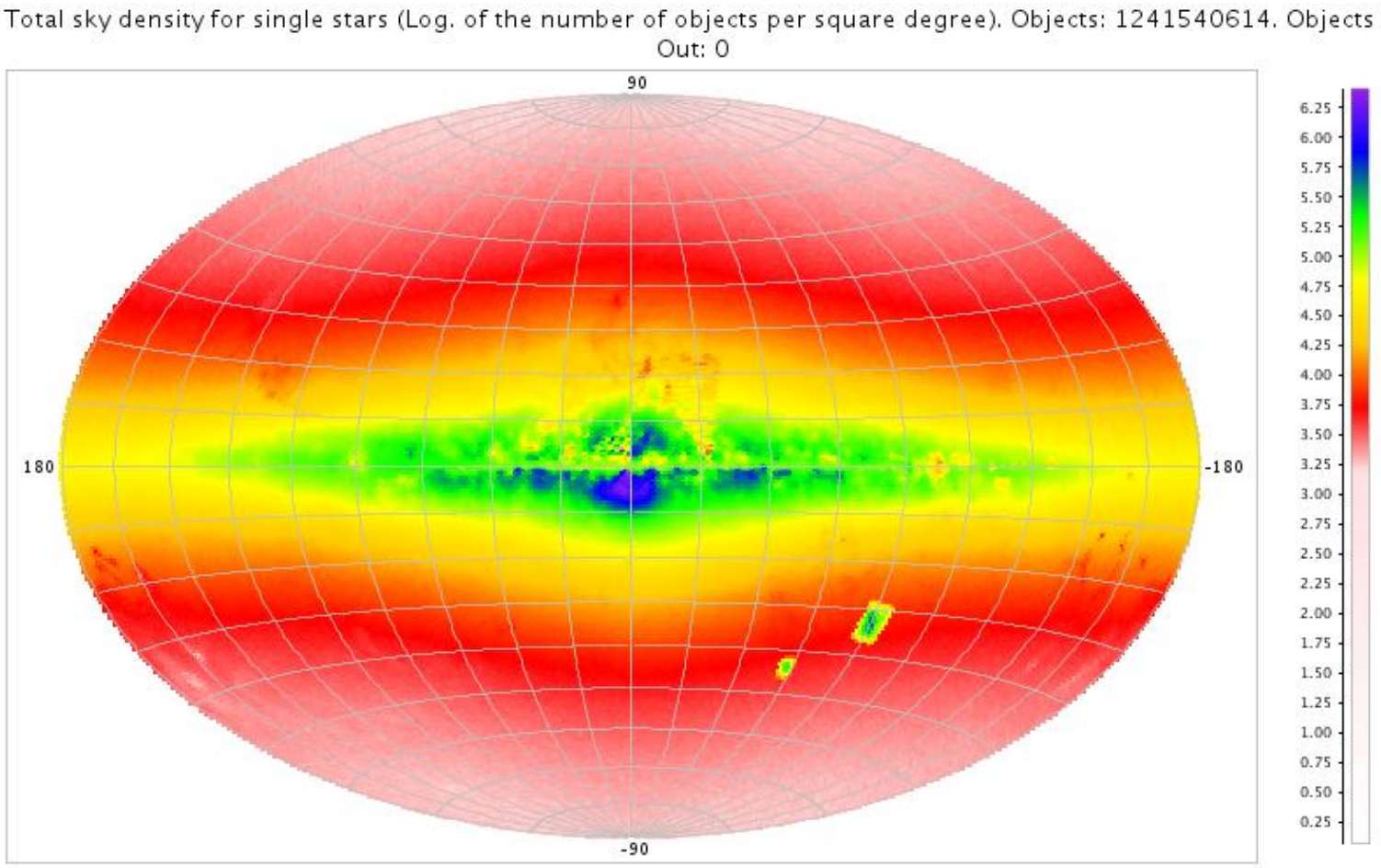




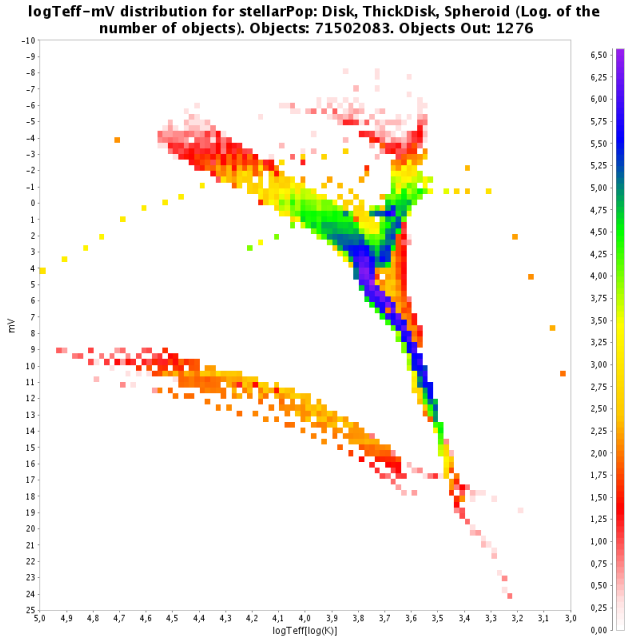


The Universe Model

Sky density distribution: Milky Way stars + LMC + SMC (G<20)

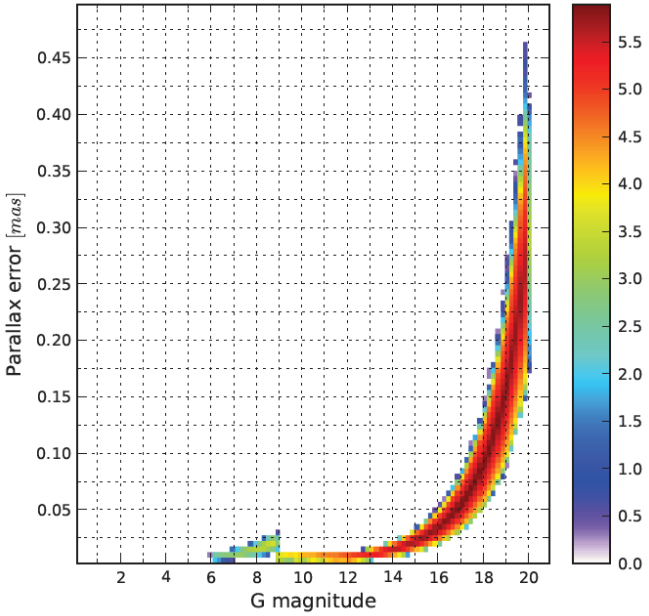


Data products



Gaia Simulations

HR diagram of the Operations Rehearsal 2 dataset

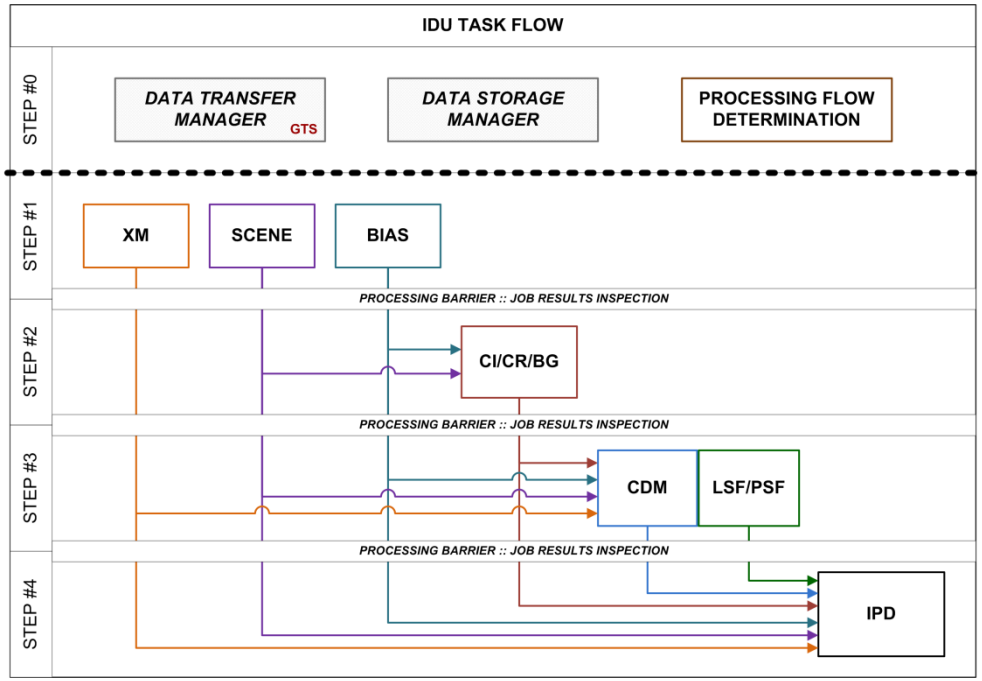


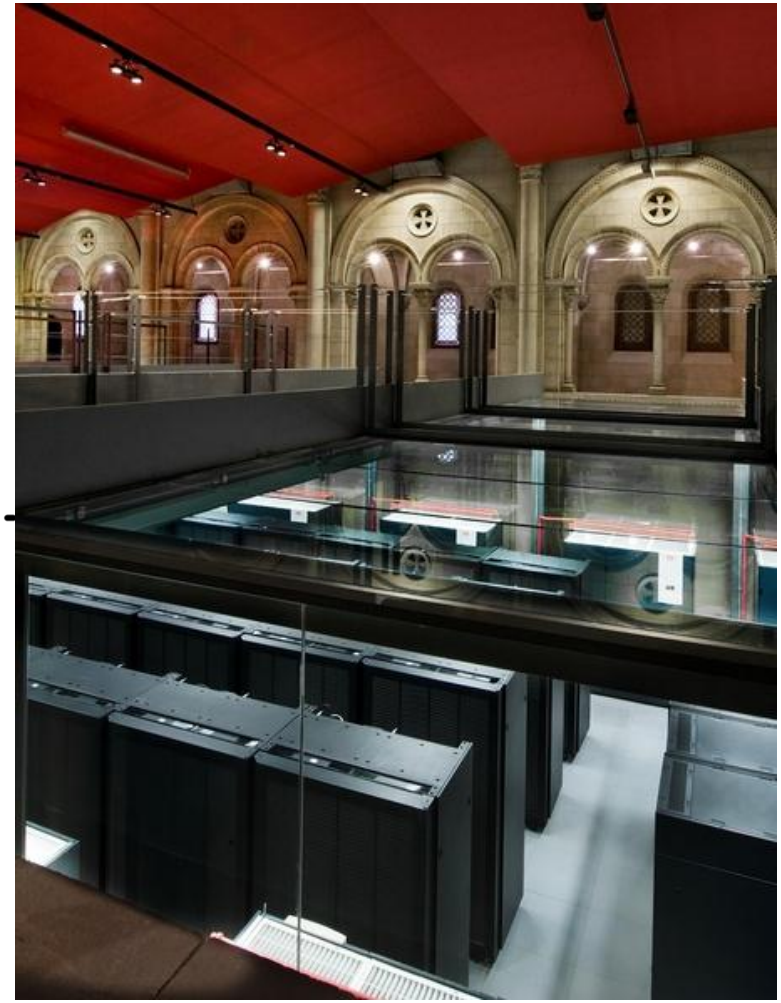
Parallax error

Distribution of the errors in parallax in a simulated Gaia catalogue

IDU: Intermediate Data Updating

- IDU: mejora de Datos Intermedios
  - Re-procesar todos los datos brutos con nuevas calibraciones
  - **MareNostrum**
    - **Hasta ~50TB**

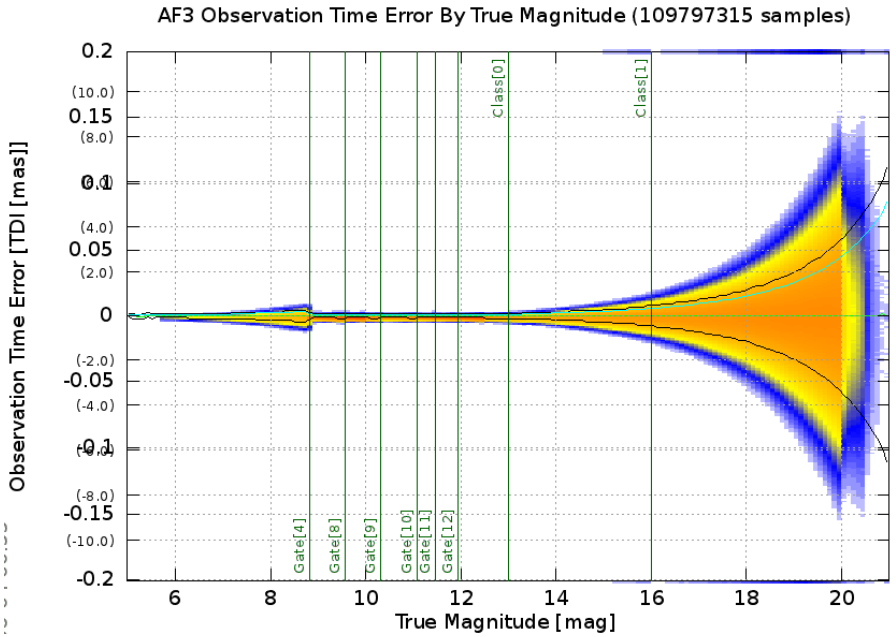




Tareas en BSC (II)

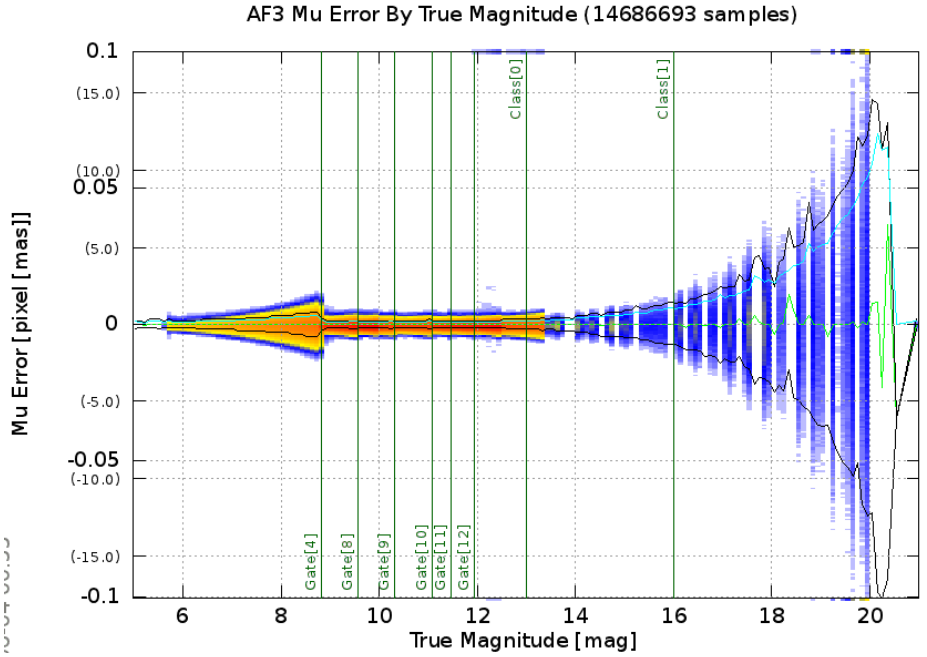
- Raw data re-processing and calibration system – Intermediate Data Updating (IDU)
- Detailed design and first implementation
- Assessing feasibility of concept and correct integration in the whole Gaia processing chain
- Test on 1.5 years of downsized data (700M observations, equiv. 8 days mission) in just 5 days using up to 84 MareNostrum II nodes

Data products



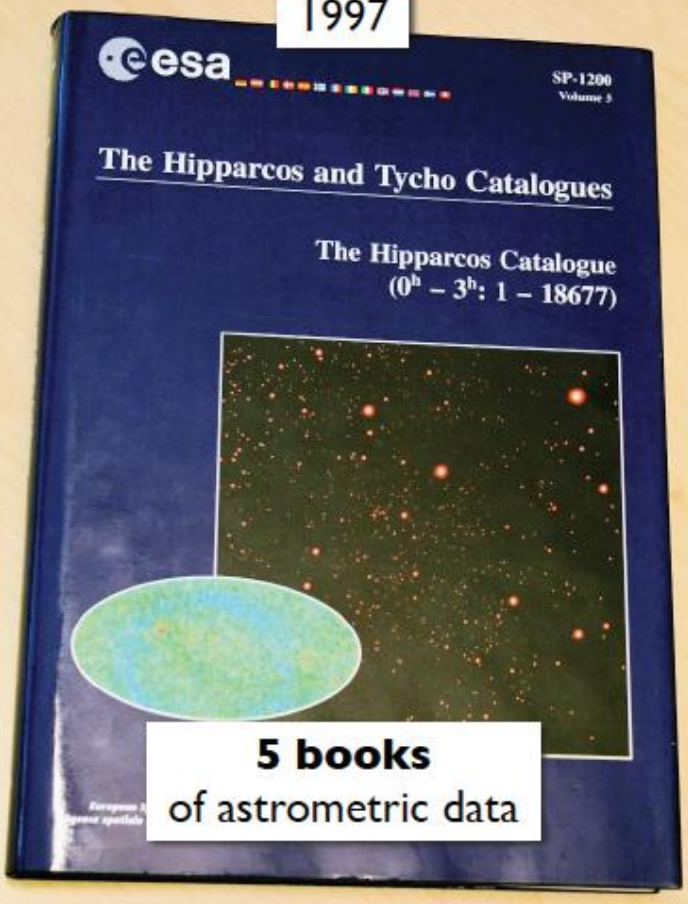
Gaia raw data re-processing system (IDU)

Determination of the along-scan and across-scan positions of the observations



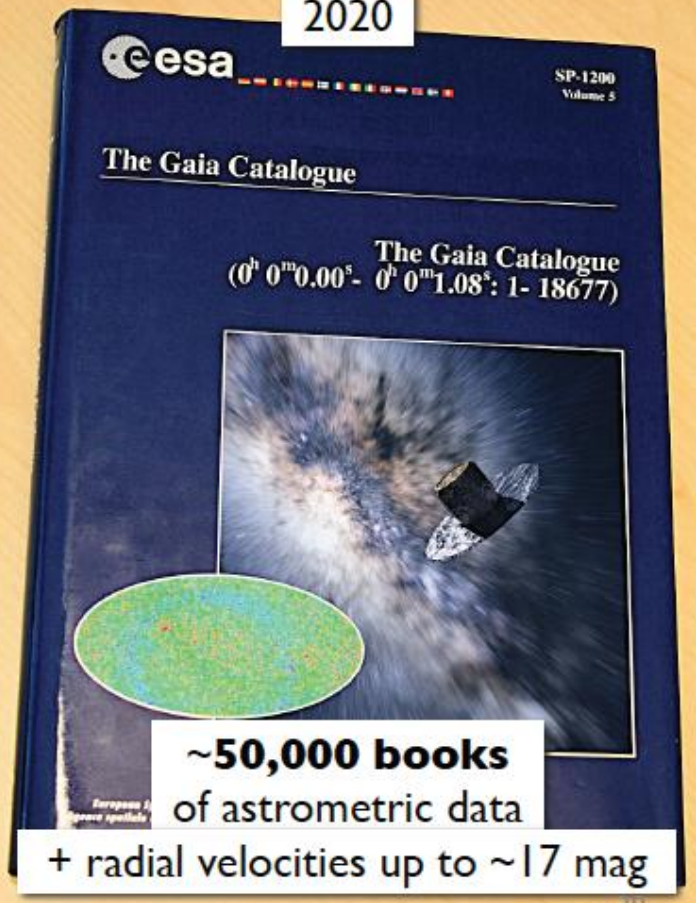
Hipparcos vs Gaia catalogue

1997



5 books
of astrometric data

2020



~50,000 books
of astrometric data
+ radial velocities up to ~17 mag

Resumen

- Gaia, misión astrométrica de ESA.
  - Astrometría, espectrofotometría, espectroscopia
  - Mil millones de estrellas: mapa 6D de nuestra galaxia
  - Objetivos científicos:
    - Historia de la galaxia,
    - Datos fundamentales en todas las ramas de la astrofísica
- Lanzamiento: Nov 2013, 5 años de operaciones
- Gestión y reducción de datos muy compleja. Datos finales 2021-22
- La RES en Gaia: Un papel fundamental
- Antes del lanzamiento:
  - Simuladores GASS y GOG
  - Implementación y test de IDU
- Fase de operaciones:
  - GOG (validación científica)
  - IDU en producción

Gracias