Gaia satellite status, data access and the VO

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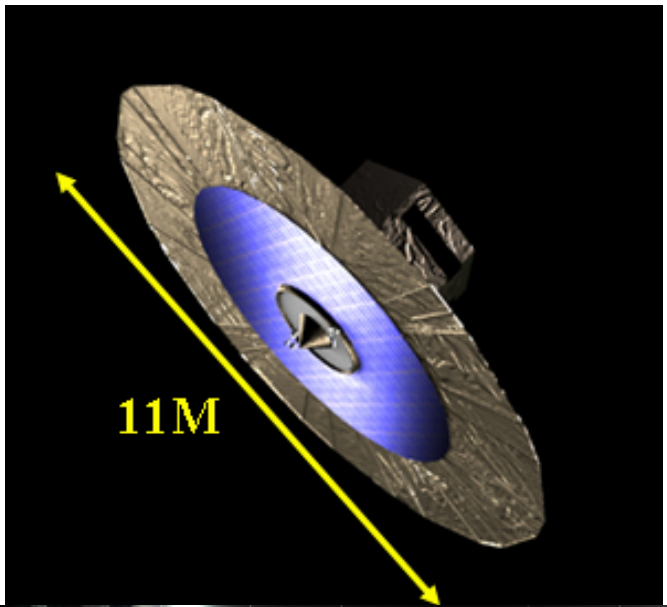
special thanks to Anthony Brown for many of these slides

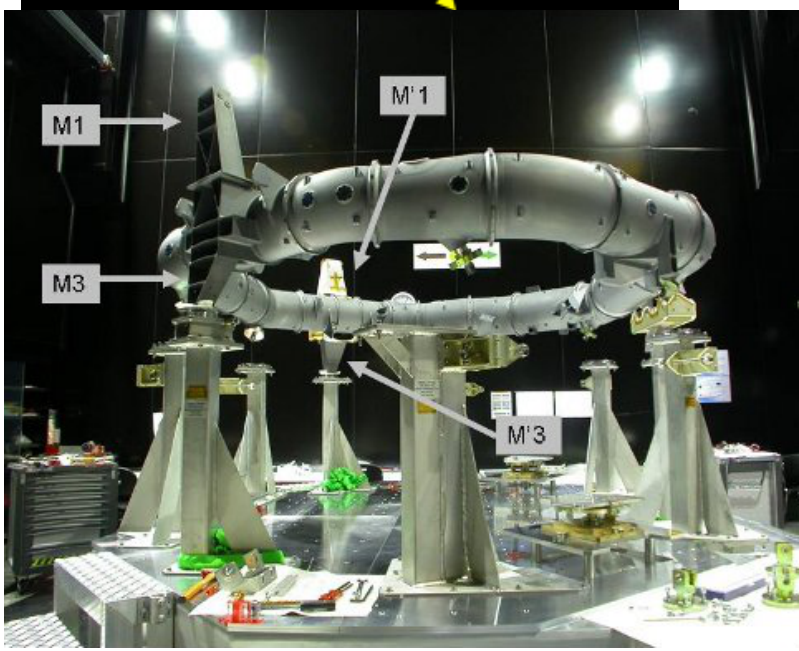
A little background and context ..

- Space astrometry with Hipparcos 1989 to 1993 (Perryman, 2009, 2010)
- Thoughts on Hipparcos II 1991
- Gaia proposed to ESA October 1993 (Lindegren & et al, 1993)
- Concept and technology study approved 1996
- Science Programme Committee (SPC) Oct 2000 selected Gaia as Corner Stone 6 (BepiC as 5)
- **Gaia presented at virtual observatories of the future 2000** (O'Mullane & Luri, 2001)
- April 2005 Data Analysis Consortium Committee (DACC) for set up
- August 2005 Science Operations Centre (SOC)
- Phase B2 (development) Feb 2006
- May 2007 SPC accept Data Processing & Analysis Consortium
- Launch 19 December 2013 - nominal ops 25 July 2014.

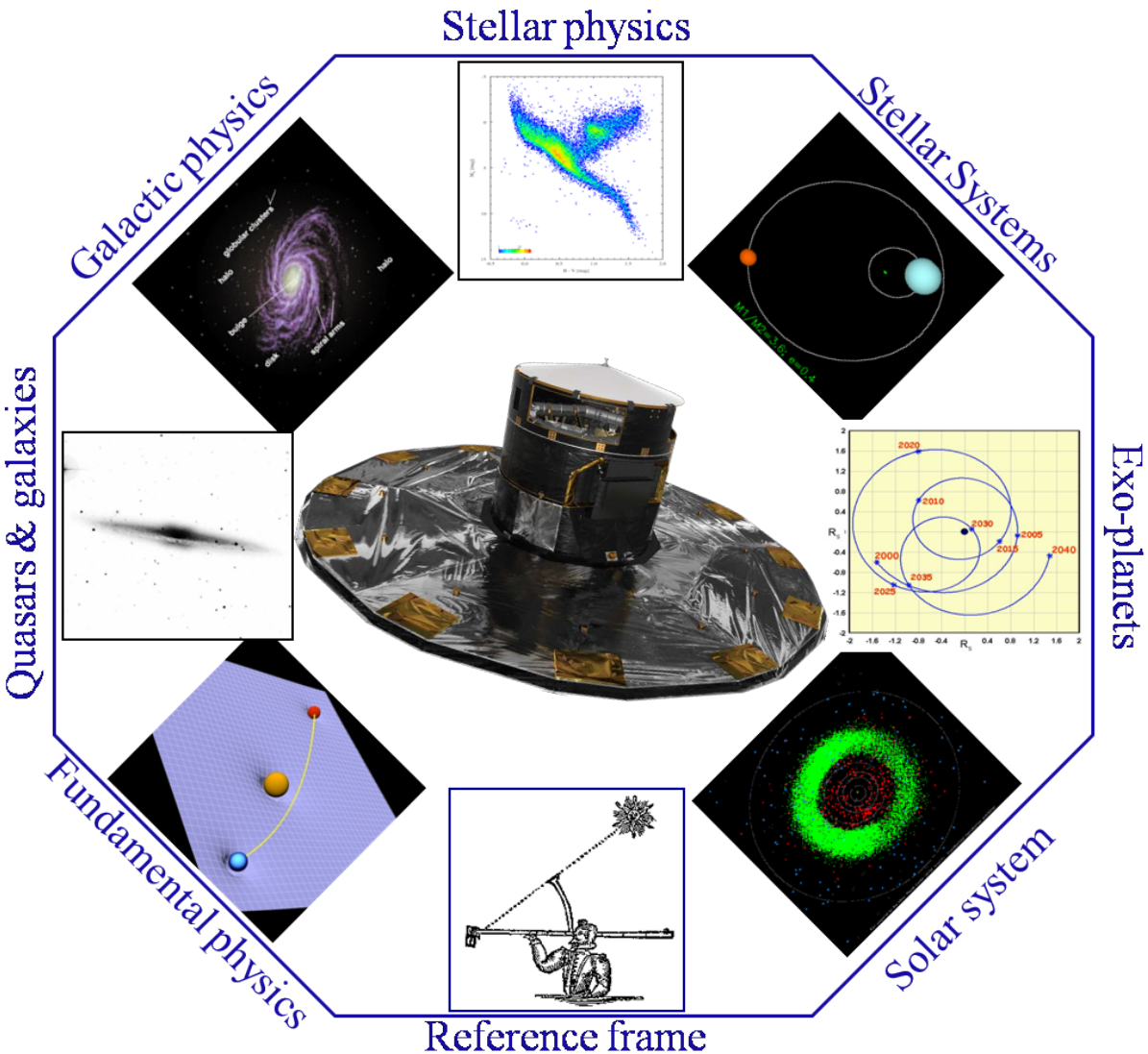
Satellite overview

- Mission:
  - ESA Corner Stone 6
    - ESA provided the hardware and launch
      Mass: 2120 kg (payload 743 kg)
      Power: 1631 W (payload 815 W)
  - Launched December 19 2013.
  - Stereoscopic Census of Galaxy over 5 years
    - Possible extension of 1 year - have fuel for at least that
  - Astrometry $G < 20$ (10^9 sources)
    25 μarcsec at V=15
  - Radial Velocities $G < 16$
  - Spectro Photometry $G < 20$ (millimag)
- Final catalogue ≈ 2022

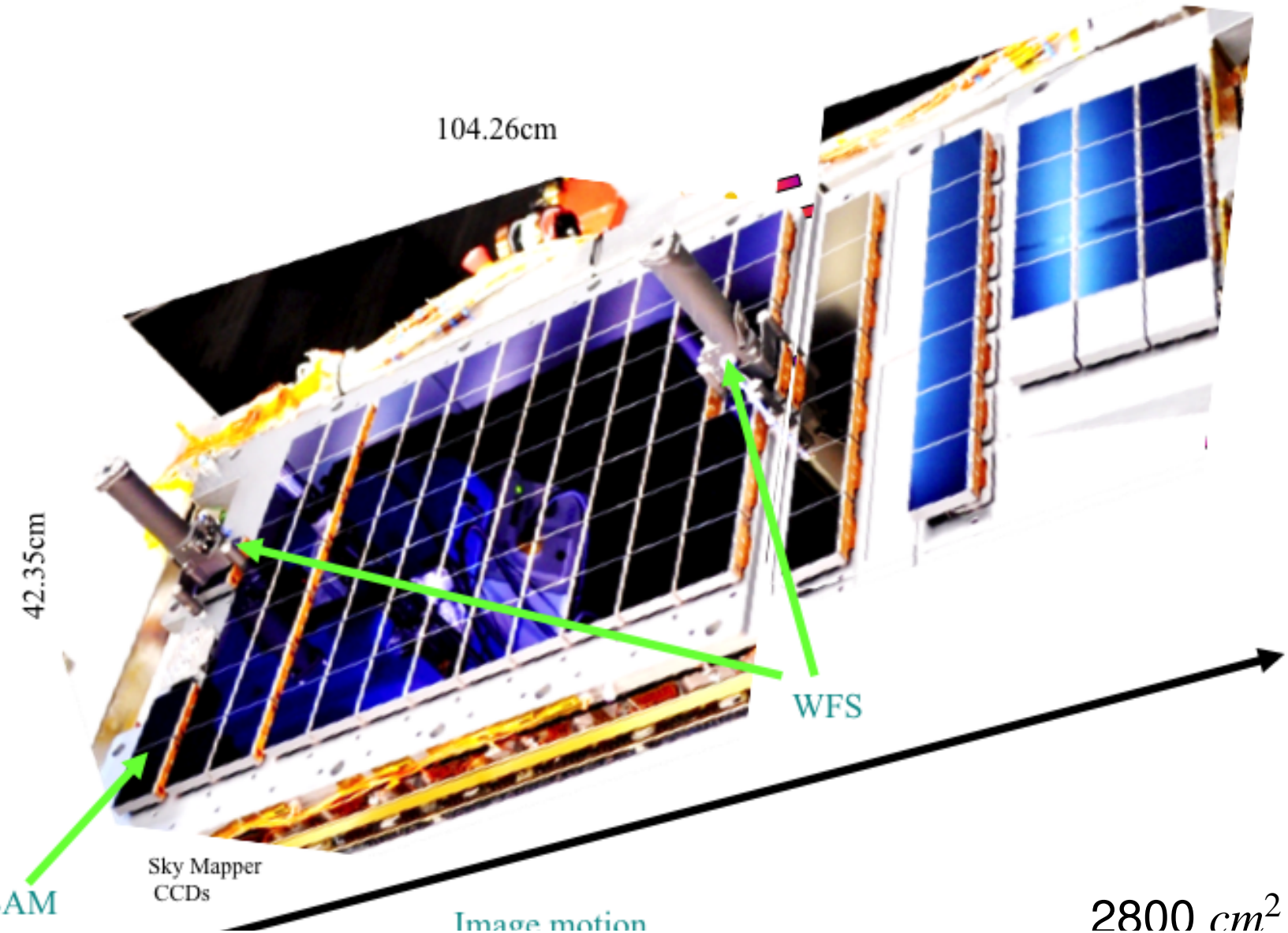




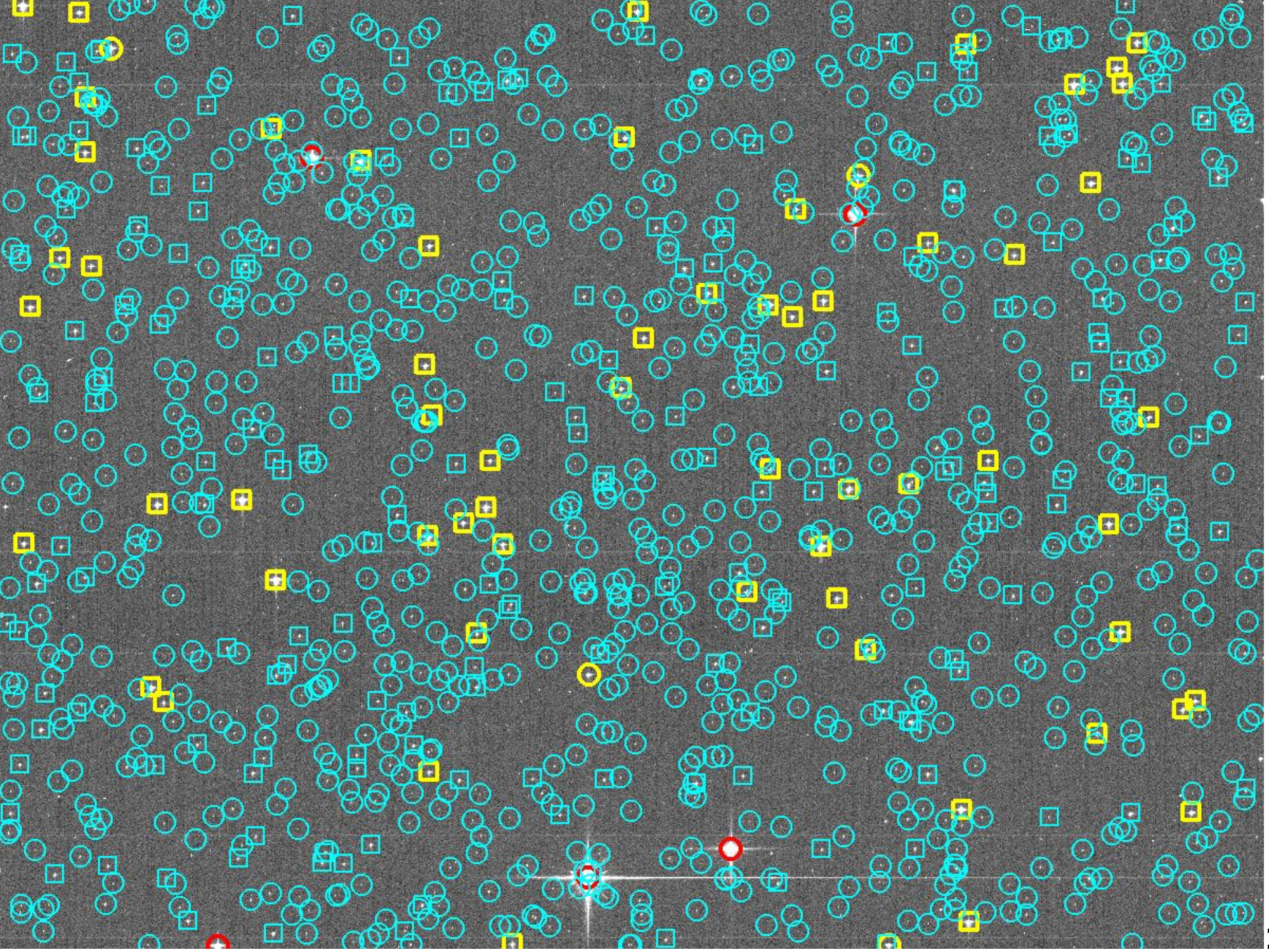
Science topics



106 CCDs, 938 million pixels



$2800\ cm^2$



Data processing - challenging

- Astrometric centroid of the CCD image to be determined to an accuracy of 1% of the pixel size!
  - There will be 10^{12} images ≈ 100TB downlink need to handle ≈ 1PB
  - At 1 millisecond each that is ≈ 30years
  - Processing estimate remains $\approx 10^{20}$ FLOP
- Reconstructed attitude is required to order 20 μarcsec
  - Path of light through instrument needed to nanometre level
  - System must be extremely stable
  - Must consider relativistic light bending from solar system objects.
- Attitude and Geometric calibration can only by done using Gaia's own observational data. (AGIS)
- Testing and verification is very difficult - still running Operational Rehearsals

Data collection stats

Statistics up to June 5

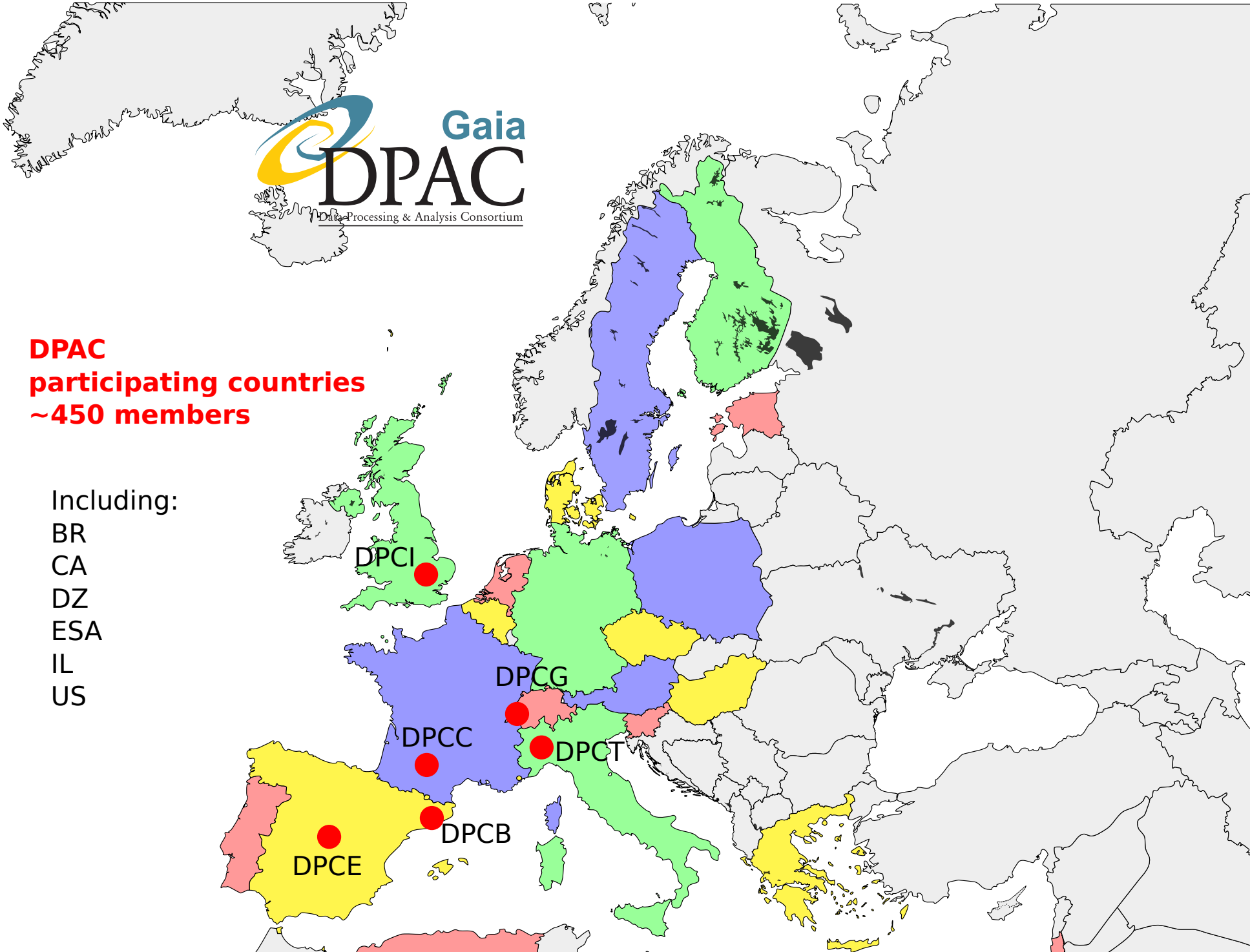
Nominal Mission Data

Type of Data	Amount	
Science telemetry	17 TB	
Astrometry transits	22.5×10^9	225×10^9 images
Photometry transits	22.5×10^9	45×10^9 images
Spectroscopy transits	1.5×10^9	4.5×10^9 spectra
Main Database	44TB	

- $\approx 30GB/day- > \approx 100TB$ total
- with products can be 1PB total data by mission end

Data Processing and Analysis Consortium

- Formed to answer the Announcement of Opportunity (AO) for Gaia data processing (2006)
- Involves large number of European institutes and observatories (> 400 people,> 20 institutes)
- The national agencies must fund the majority of the Gaia processing
- Lead by Executive (leaders of Coordination Units) and Project office for management and planning.
- A steering committee formed of funding agency representatives (and ESA) sits on top - this governs the multi lateral agreement on funding.


Gaia
DPAC
Data Processing & Analysis Consortium
DPAC
participating countries
~450 members
Including:
BR
CA
DZ
ESA
IL
US
DPCI
DPCG
DPCC
DPCT
DPCB
DPCE

Coordination Units & DPCs

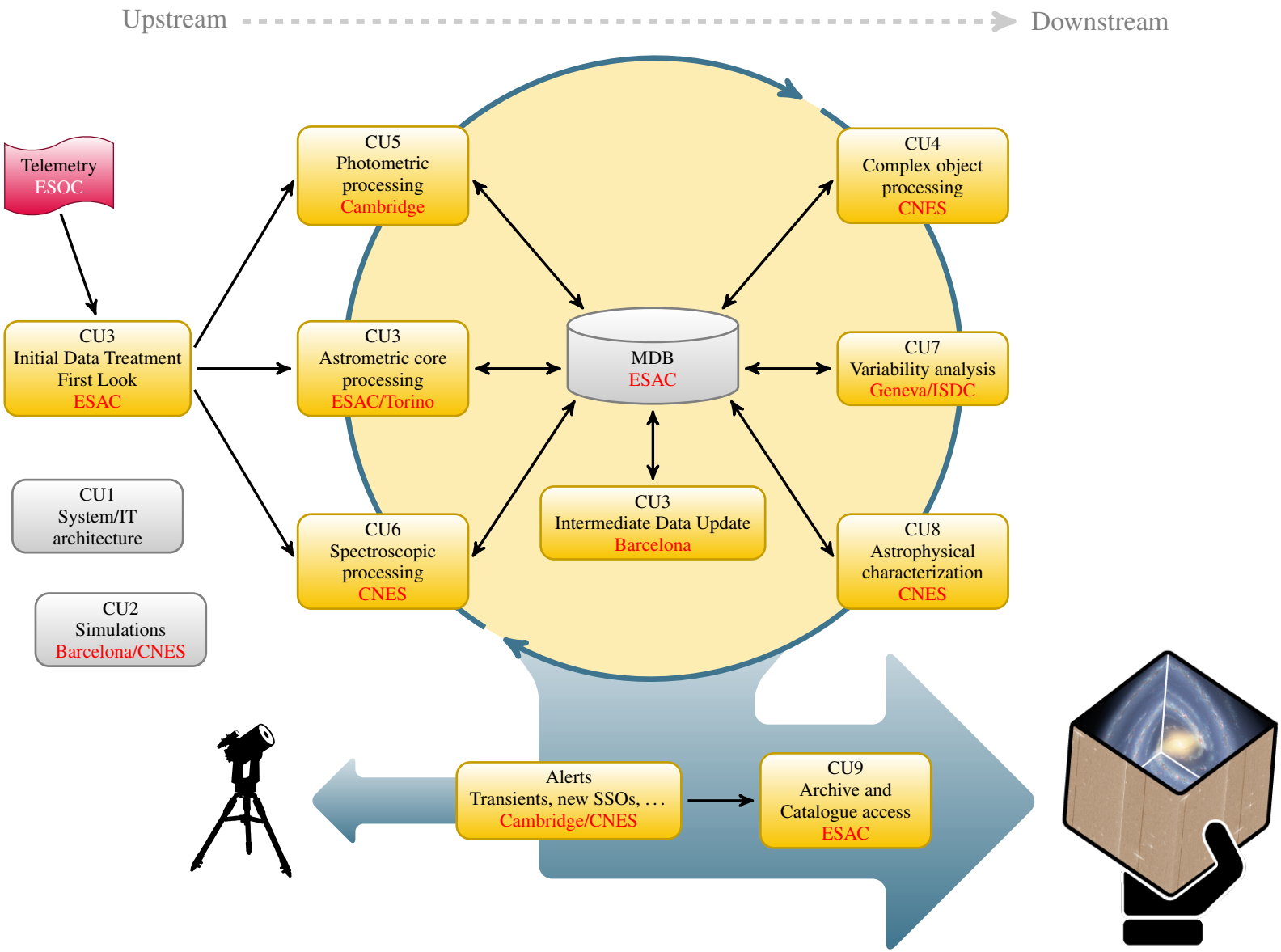
- CU1: System Architecture
- CU2: Data Simulations
- CU3: Core Processing
- CU4: Object Processing
- CU5: Photometric Processing
- CU6: Spectroscopic Processing
- CU7: Variability Processing
- CU8: Astrophysical Parameters
- CU9: Catalogue Access

ESA Contribution

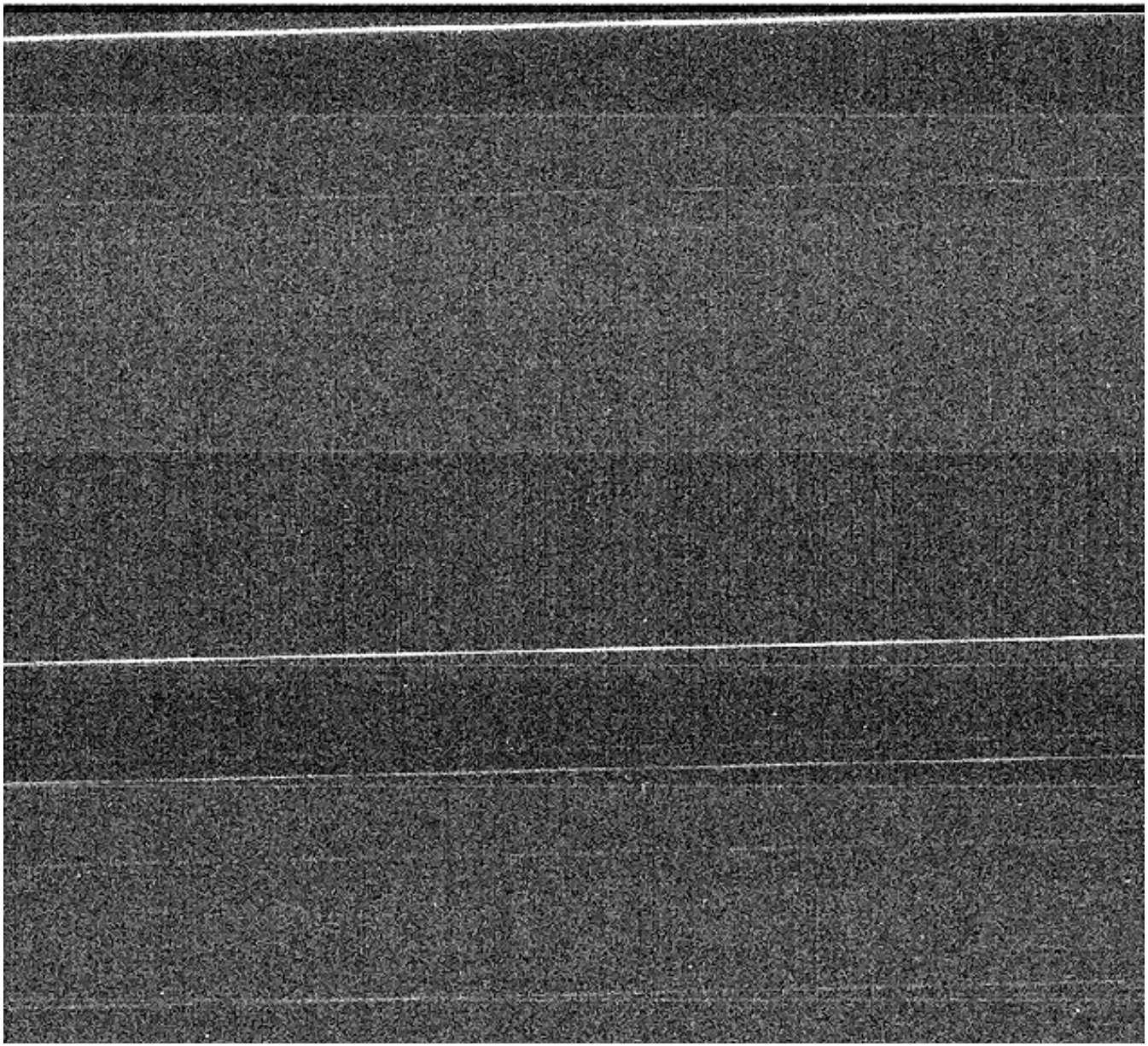
Data Processing Centres underpin and support CUs. They integrate and operate the processing system(s).

- ESAC (CU1,3) Madrid
- BPC (CU2,3) Barcelona
- CNES (CU4,6,8) Toulouse
- ISDC (CU7) Geneva
- IoA (CU5) Cambridge
- OATO (CU3) Torino

Simplified processing overview



First image NO SPIN, NOT FOCUSED



Searching for Focus

Focus and spinrate are intertwined. So it was an iterative process for some weeks.

left spinrate close to TDI read out rate - right image blurry while spinrate incorrect.

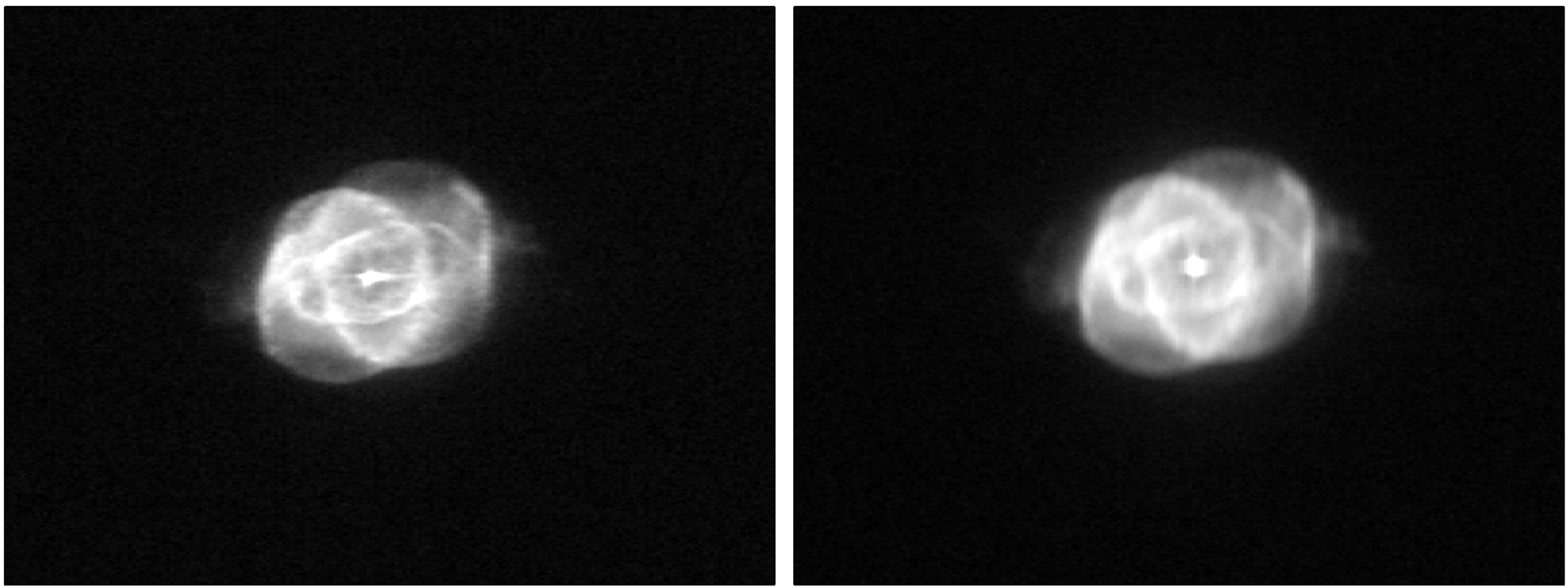
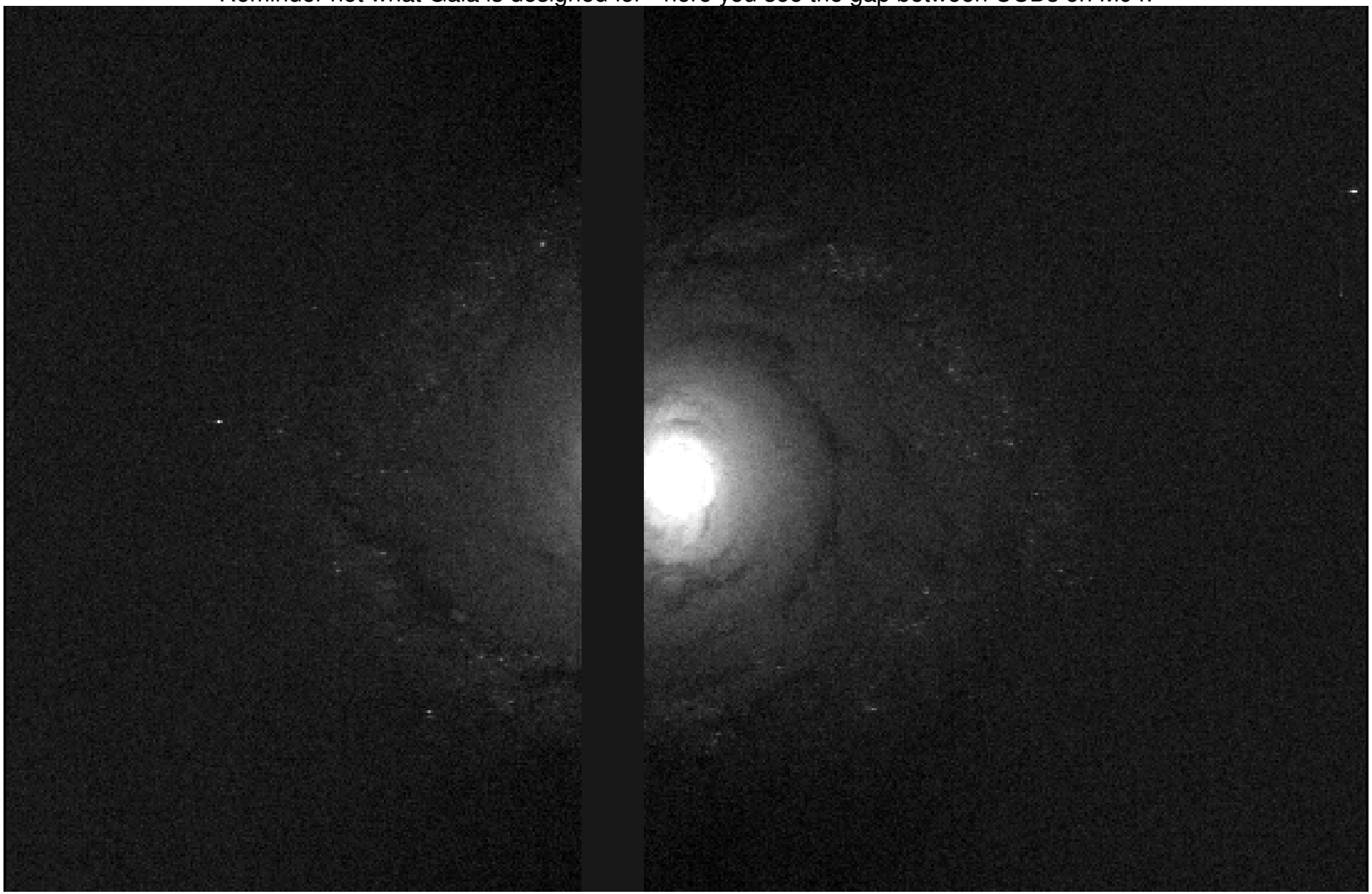


Image Gaia SOC

Don’t mind the gap !

Reminder not what Gaia is designed for - here you see the gap between CCDs on M94.



Unpleasant surprises

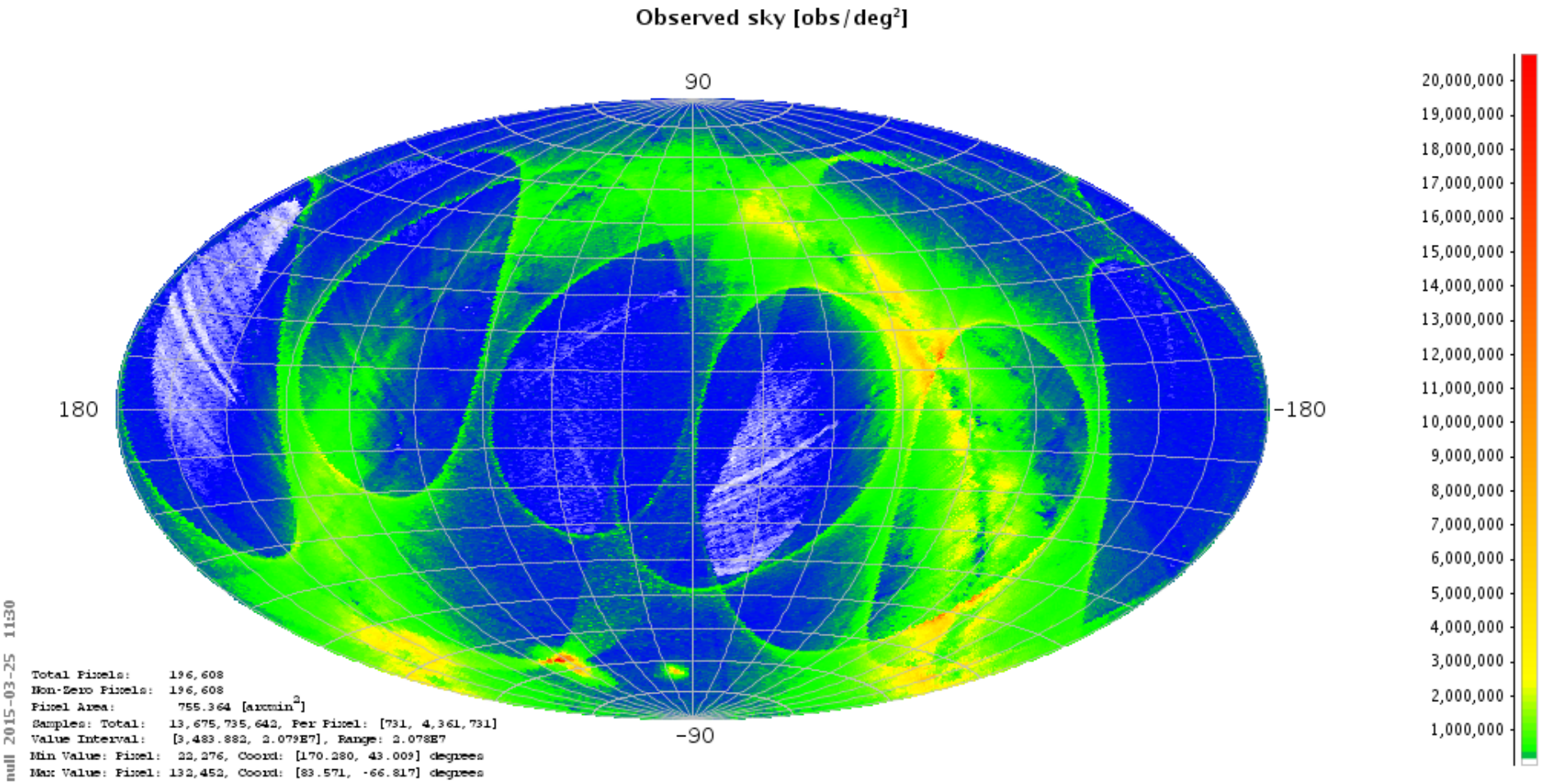
- Stray light both from astronomical sources and the Sun
  - Sun stray light due to scattering of fibres at the edge of the Sun shield
  - Impacts faint sources especially in spectroscopy
- Transmission loss due to continuing contamination of mirrors by water
  - Water source not yet exhausted although contamination rate much less than during commissioning
- Basic Angle variation larger than expected
  - Variation measured by on-board metrology device and verified at milliarsec level by astronomical sources

Status - next steps

- Stray light
  - We have to live with it
  - On-board s/w modification under optimisation for spectroscopy
- Contamination
  - Successful decontamination procedure executed 22-23 September 2014 =¿ full transmission recovery and re-focus 24 October 2014
  - Next decontamination currently underway
- Larger than expected Basic Angle variation
  - Full thermomechanical modelling on-going at prime industrial partner to chase the root cause
  - Extensive tests being executed around the decontamination campaign

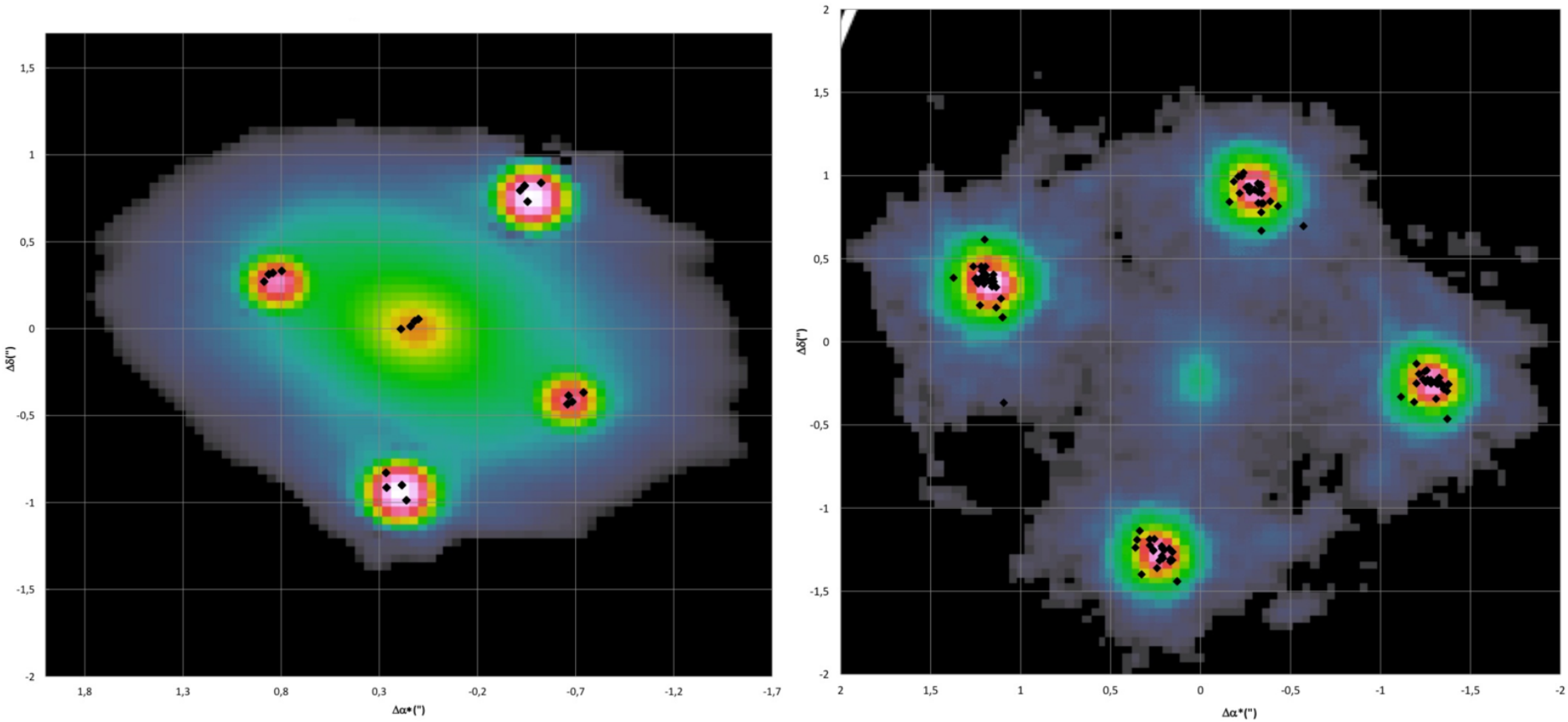
Sun straylight due to detached fibres in the sun shield

Nominal mission: actual sky coverage



Need at least two full scans to get Gaia astrometry.

International year of light

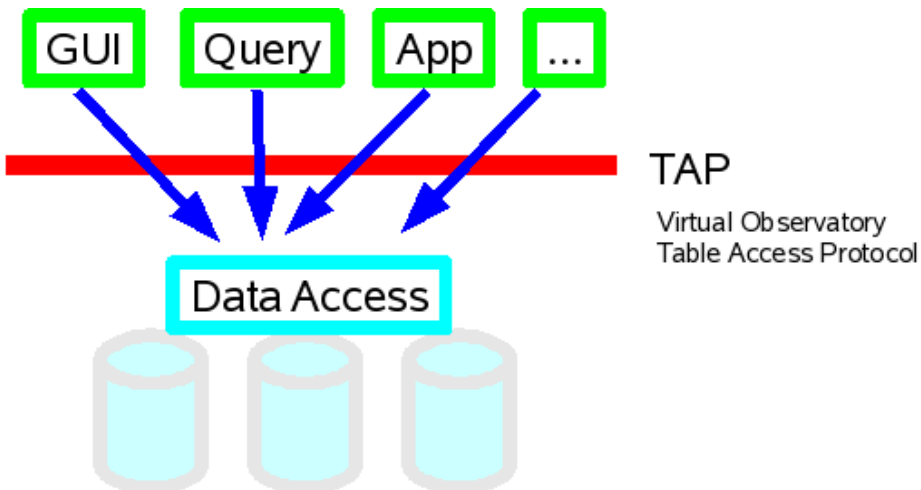


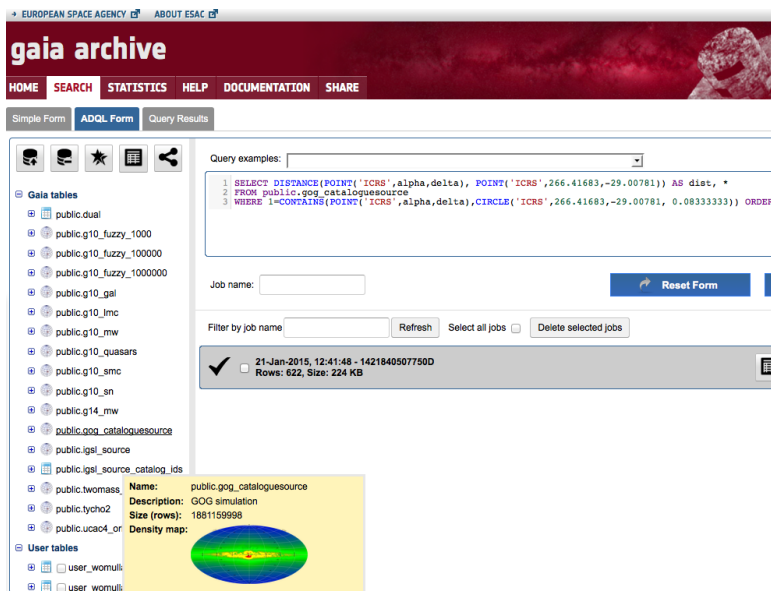
http://www.cosmos.esa.int/web/gaia/iow_20150409

Einstein Cross (left) and HE0435-1223 (right)
Gaia astrometric positions placed over HST images.
Gaia onboard detection works well
4 images detected in both cases within the $\approx 2''^2$ area.

Gaia archive - VO compatible for now

- Will have $\approx 10^9$ sources with average 80 observations and $\approx$ spectral sources with average 40 observations each.
- collecting use cases since 2011 here http://great.ast.cam.ac.uk/Greatwiki/GaiaDataAccess
- Basic CasJobs type system backed by TAP + UWS + VOSpa already implemented at ESAC (JSB-004 ok for 2016 data rel
- VOEvent being used for alerts (Wyrzykowski et al., 2012)



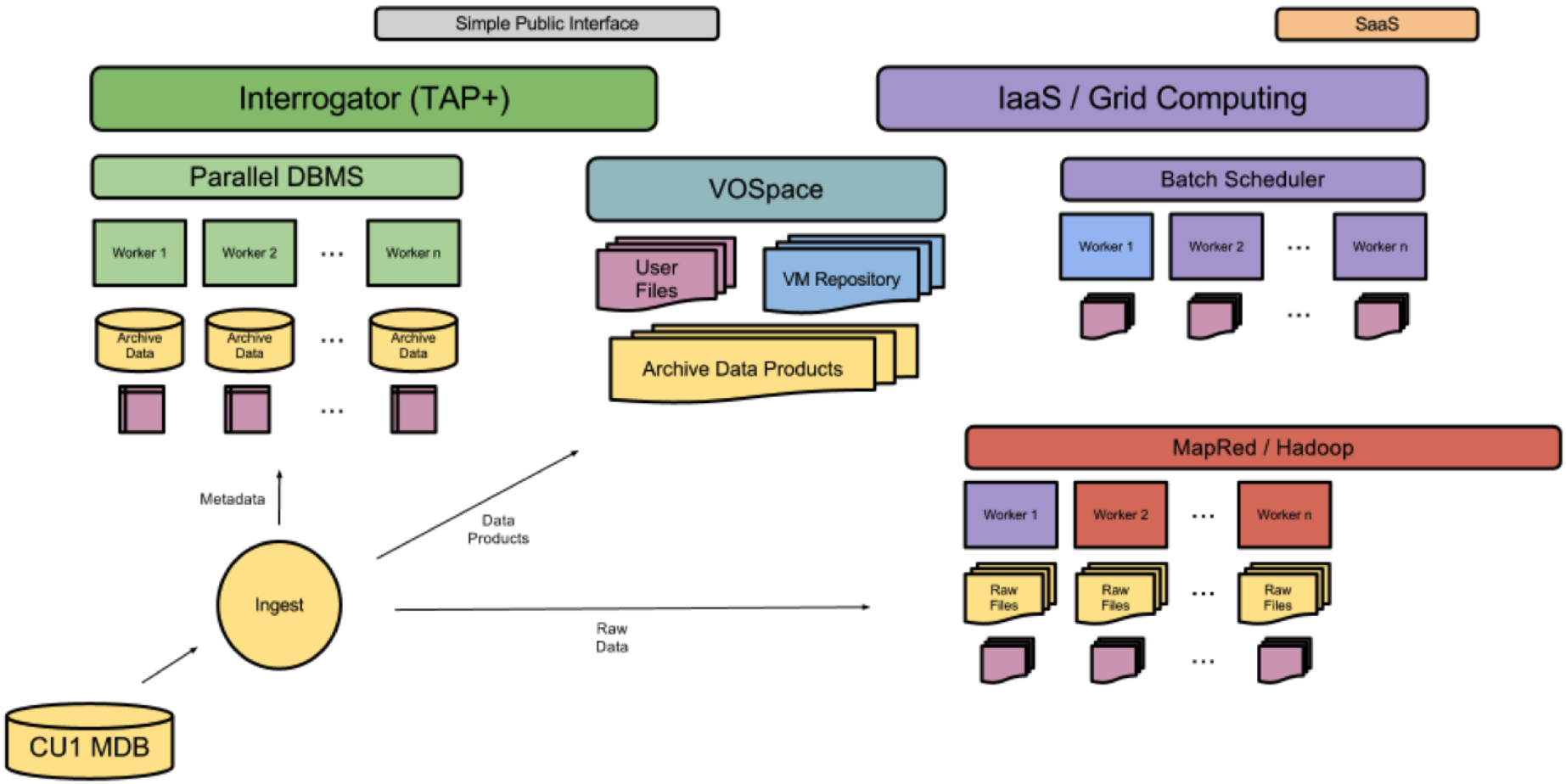


Basic to advanced system

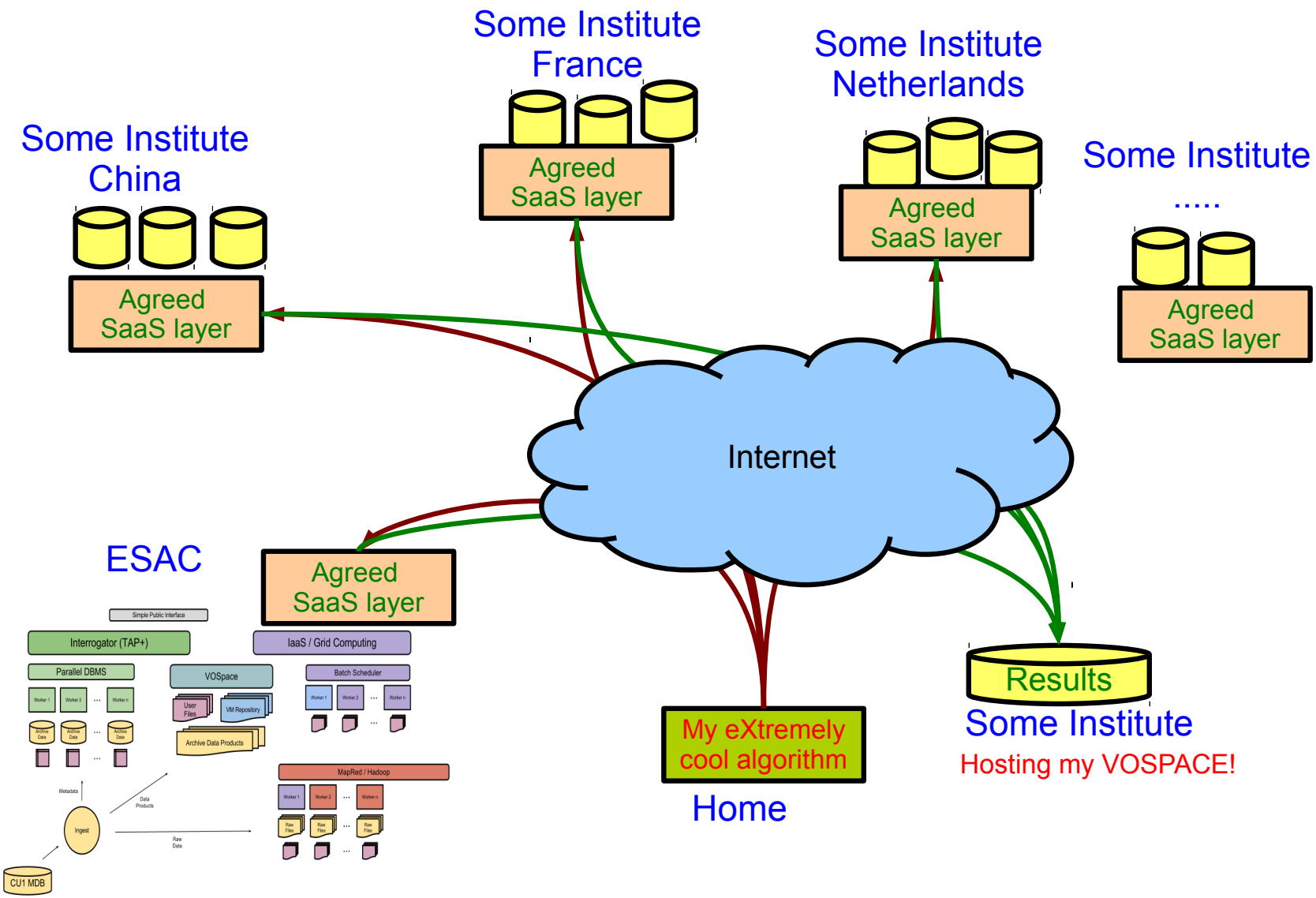
- Science team favour of general distribution of Source Catalogue ($\approx 1TB$)
  - The catalogue covers probably 80-90% of user needs
  - can get it to them through established channels (several European centres in CU9 for this XL-034)
  - it is specifically requested in use case GDAS-OA-10
  - how do we do footprints ... ESAC already working with HiPS
- But still need an archive of all data (epoch, transit , TM) and software.
  - One size (or one DB) probably does not fit all
  - so queries and some processing framework like HADOOP and possibly more - demonstrated in (Tapiador et al., 2014)
  - VO protocol for delivering code ?
  - a sort of *Cloudy* architecture - turn VO into *Virtualized Observatory* - yea a little like CANFAR.

ESAC Architecture

User requirements WOM-033 - use cases AB-026 - System requirements (Jesus - GGA-031)



Sofware As A Service multisite dream



Gaia Value Added Interface Portal - not VO

- currently under development by Geo Return Contract.
- Provide a container (Docker) with Python installed (Anaconda) and access to archive
- Has front end and back end part i.e. part can be exposed to user
- Container deployed in the Archive (bring the program to the Data)
- Portal to allow users select Apps.
- Could be used to host Apps developed by anyone
  - Specialised visualisation (light curve folding , 3D ..)
  - variable analysis
  - transient analysis
  - simulator execution
  - . . .

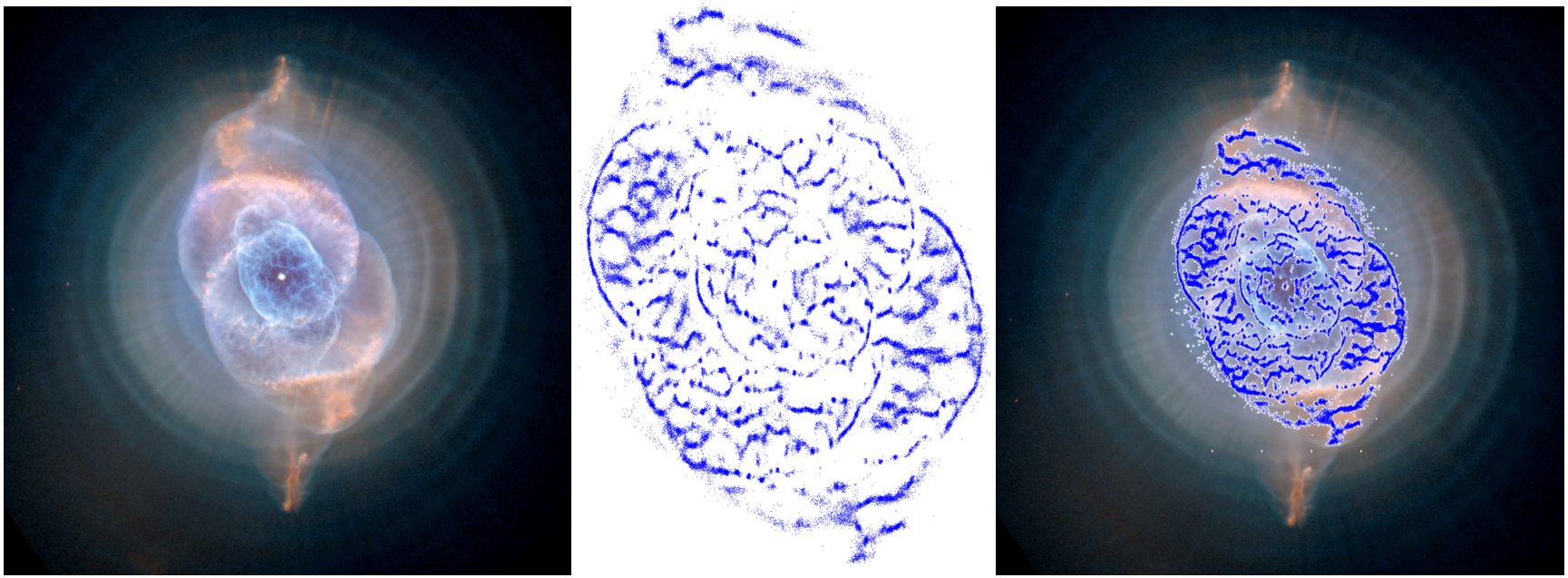
Food for thought - not VO?

- None of the use cases yet require general querying/working with epoch/transit data ! Probably need HADOOP type access
- WOM-057 proposed many fancy features for the archive including Wolfram Alpha
- Living archive (Anthony Brown)
  - Can we/should we allow additions to the Archive? e.g. improved solutions for binaries using follow observations
- Archive as a model (James Binney)
  - How can we compare models of the Galaxy to Gaia Data ? - Probably need Gaia simulator
- David Hogg goes further - encode archive in model Hogg & Lang (2011)

Conclusion and Issues

- Gaia hardware is commissioned and the mission is on !
- There are a few problems being *lived* with
- Gaia flying well and commanding from MOC is very good.
- DPAC has processed all the data so far coping with the actua satellite and its issues very well.
- Like all science missions Gaia is a mixture of innovative hard scientific algorithms, software and people.
- We are working hard to get the first catalogue out in 2016.
- We are looking to VO where appropriate
- We may push VO a little in some areas

The END



Gaia observations of Catseye Nebula over HST image.

Questions ??

- The Gaia ESA home page `http://www.cosmos.esa.int/web/gaia`
- You may send any question to `mailto:gaia-helpdesk@cosmos.esa.int`

Acronyms I

The following table has been generated from the on-line Gaia acronym list:

Acronym	Description
AGIS	Astrometric Global Iterative Solution
AO	Announcement of Opportunity
BAM	Basic-Angle Monitoring (Device)
BPC	Barcelona Processing Centre
CCD	Charge-Coupled Device
CNES	Centre National d'Etudes Spatiales (France)
DACC	Data Analysis Coordination Committee (obsolete)
DB	DataBase
DPAC	Data Processing and Analysis Consortium
DPC	Data Processing Centre
ESA	European Space Agency
ESAC	European Space Astronomy Centre (VilSpa)
FLOP	FLoating-point OPeration
GB	GigaByte
HST	Hipparcos Science Team
ISDC	INTEGRAL Science Data Centre
IoA	Institute of Astronomy (Cambridge; also denoted IOA)
MOC	Mission Operations Centre
OATO	Osservatorio Astronomico di Torino
OBMT	On-Board Mission Timeline
SOC	System On a Chip

Acronyms II

SPC	Science Programme Committee (ESA)
TAP	Table Access Protocol
TB	TeraByte
TDI	Time-Delayed Integration (CCD)
TM	Telemetry (Packet)
TOC	Table of Contents
VO	Virtual Observatory
VPU	Video Processing Unit

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