# Gaia:
# an overview on a cornerstone mission

**Giorgia Busso**
**(IoA, Cambridge)**

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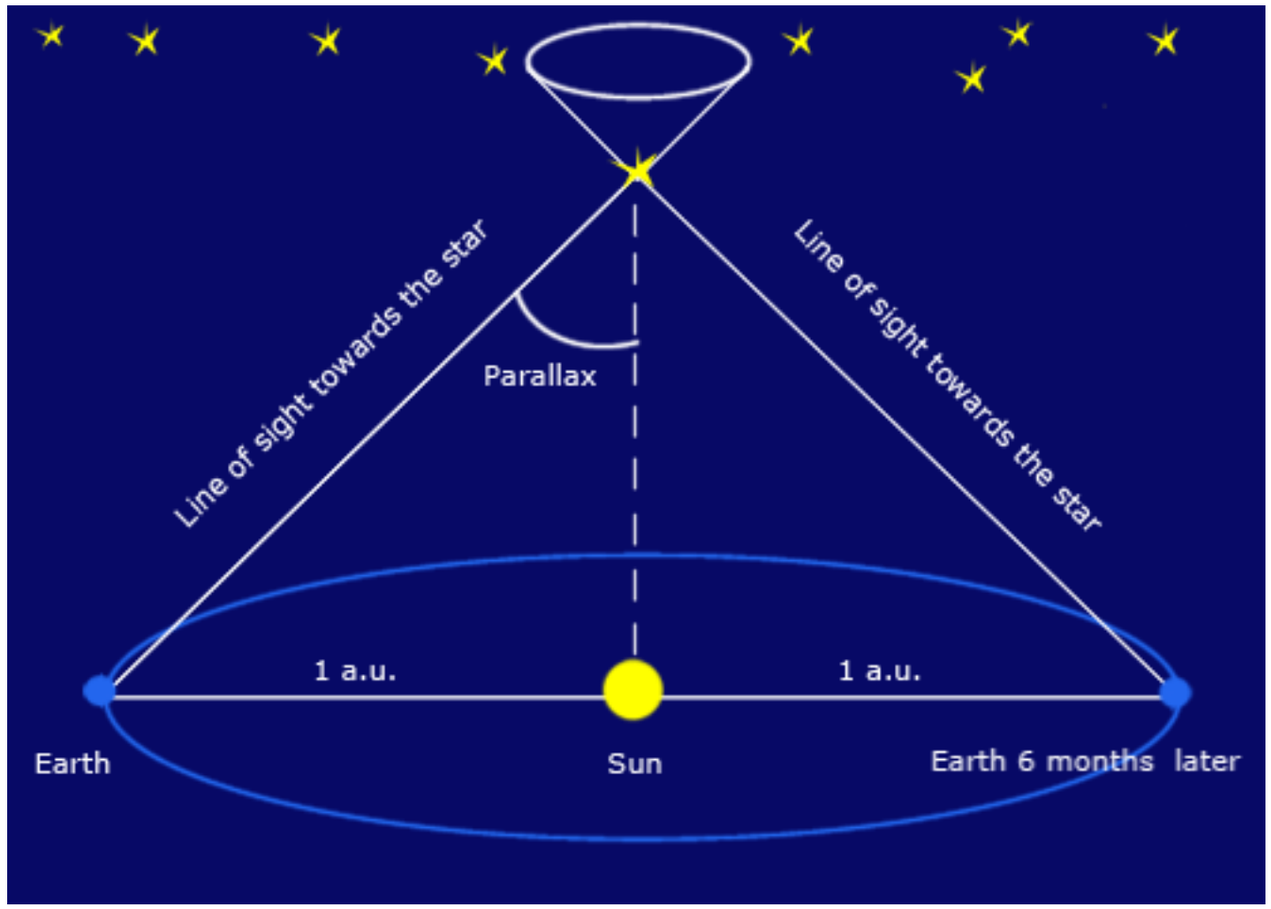
# Outline

- Gaia Mission and Status
- Gaia in UK: Photometric Processing
- Gaia in UK: Science Alerts
- Gaia Data Release 1
- Gaia Archive

# Astrometric Mission: positions and proper motions



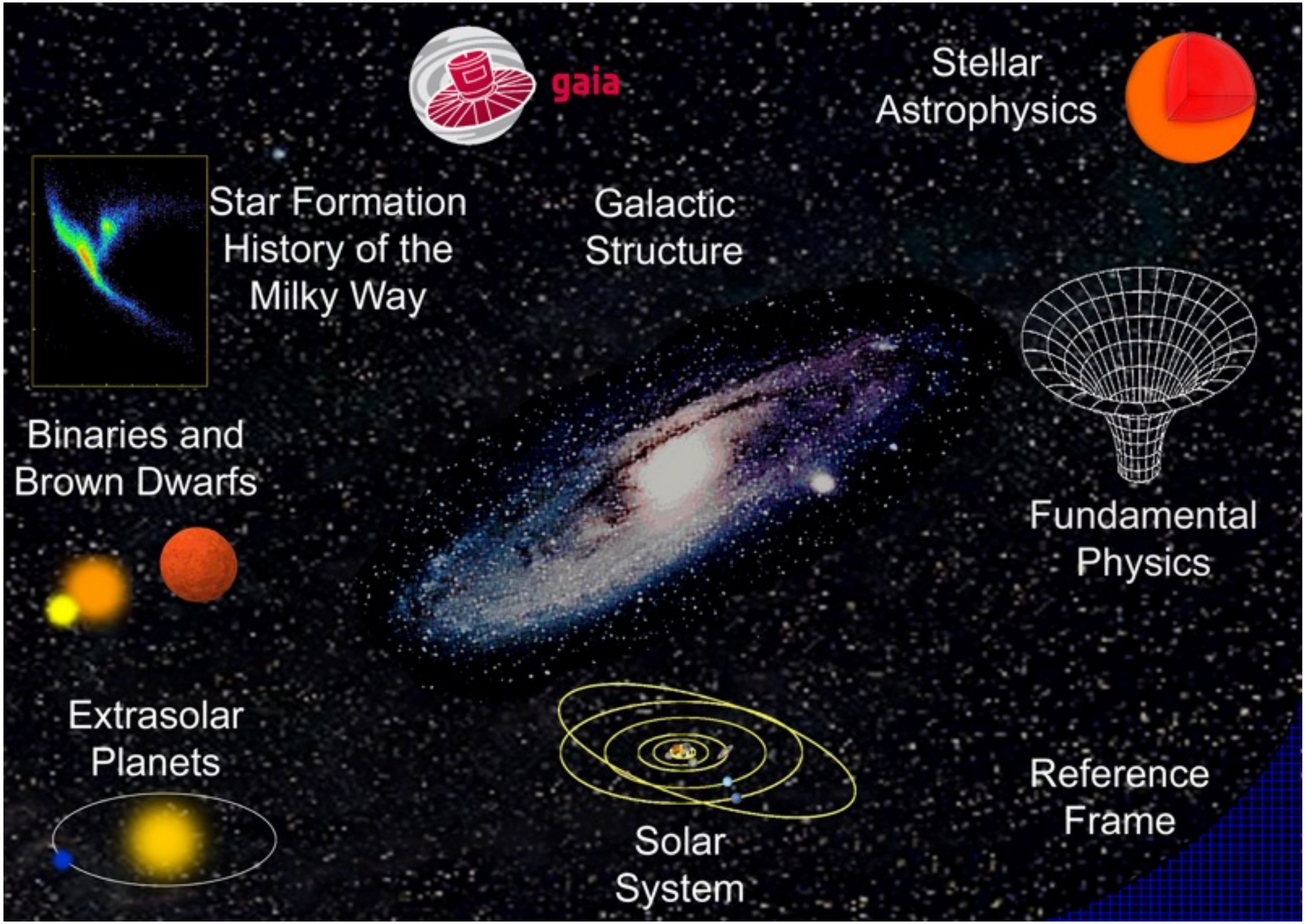

**3D map of the Milky Way**

photomers -> colors
spectrograph -> radial velocities

# Gaia: Complete, Faint, Accurate

| | Hipparcos | Gaia |
|---|---|---|
| Magnitude limit | 12 mag | 20 mag |
| Completeness | 7.3 – 9.0 mag | 20 mag |
| Bright limit | 0 mag | 3 mag |
| Number of objects | 120,000 | 47 million to G = 15 mag<br>360 million to G = 18 mag<br>1192 million to G = 20 mag |
| Effective distance limit | 1 kpc | 50 kpc |
| Quasars | 1 (3C 273) | 500,000 |
| Galaxies | None | 1,000,000 |
| Accuracy | 1 milliarcsec | 7 μarcsec at G = 10 mag<br>26 μarcsec at G = 15 mag<br>600 μarcsec at G = 20 mag |
| Photometry | 2-colour (B and V) | Low-res. spectra to G = 20 mag |
| Radial velocity | None | 15 km $s^{-1}$ to $G_{RVS}$ = 16 mag |
| Observing | Pre-selected | Complete and unbiased |

# Gaia Mission

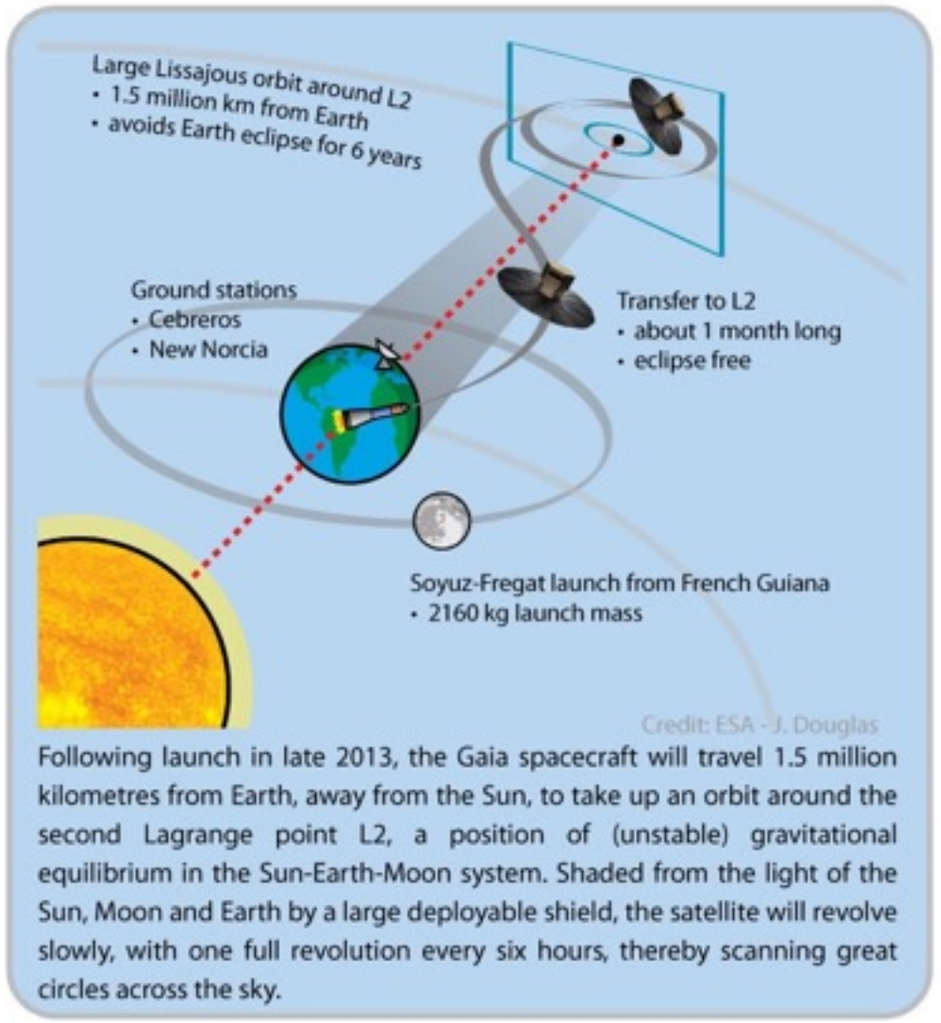


# Gaia Mission

- Comprehensive luminosity calibration, for example:
  - distances to 1% for ~11 million stars to 2.5 kpc
  - distances to 10% for ~150 million stars to 25 kpc
  - rare stellar types and rapid evolutionary phases in large numbers
  - parallax calibration of all distance indicators (e.g., Cepheids and RR Lyrae to LMC/SMC)

- Physical properties, for example:
  - clean Hertzsprung–Russell diagrams throughout the Galaxy
  - Solar-neighbourhood mass and luminosity function, e.g., white dwarfs (~400,000) and brown dwarfs (~500)
  - initial mass and luminosity functions in star-forming regions
  - luminosity function for pre-main-sequence stars
  - detection and dating of all spectral types and Galactic populations
  - detection and characterisation of variability for all spectral types

# Gaia Mission




Following launch in late 2013, the Gaia spacecraft will travel 1.5 million kilometres from Earth, away from the Sun, to take up an orbit around the second Lagrange point L2, a position of (unstable) gravitational equilibrium in the Sun-Earth-Moon system. Shaded from the light of the Sun, Moon and Earth by a large deployable shield, the satellite will revolve slowly, with one full revolution every six hours, thereby scanning great circles across the sky.

- ESA-only mission
- Launch: 19 December 2013
- Launcher: Soyuz–Fregat from French Guiana
- Orbit: L2 Lissajous orbit
- Ground stations: Cebreros, New Norcia + Malargüe
- Lifetime: 5 years (1 year potential extension)

# Gaia: the instrument

# Payload and Telescope

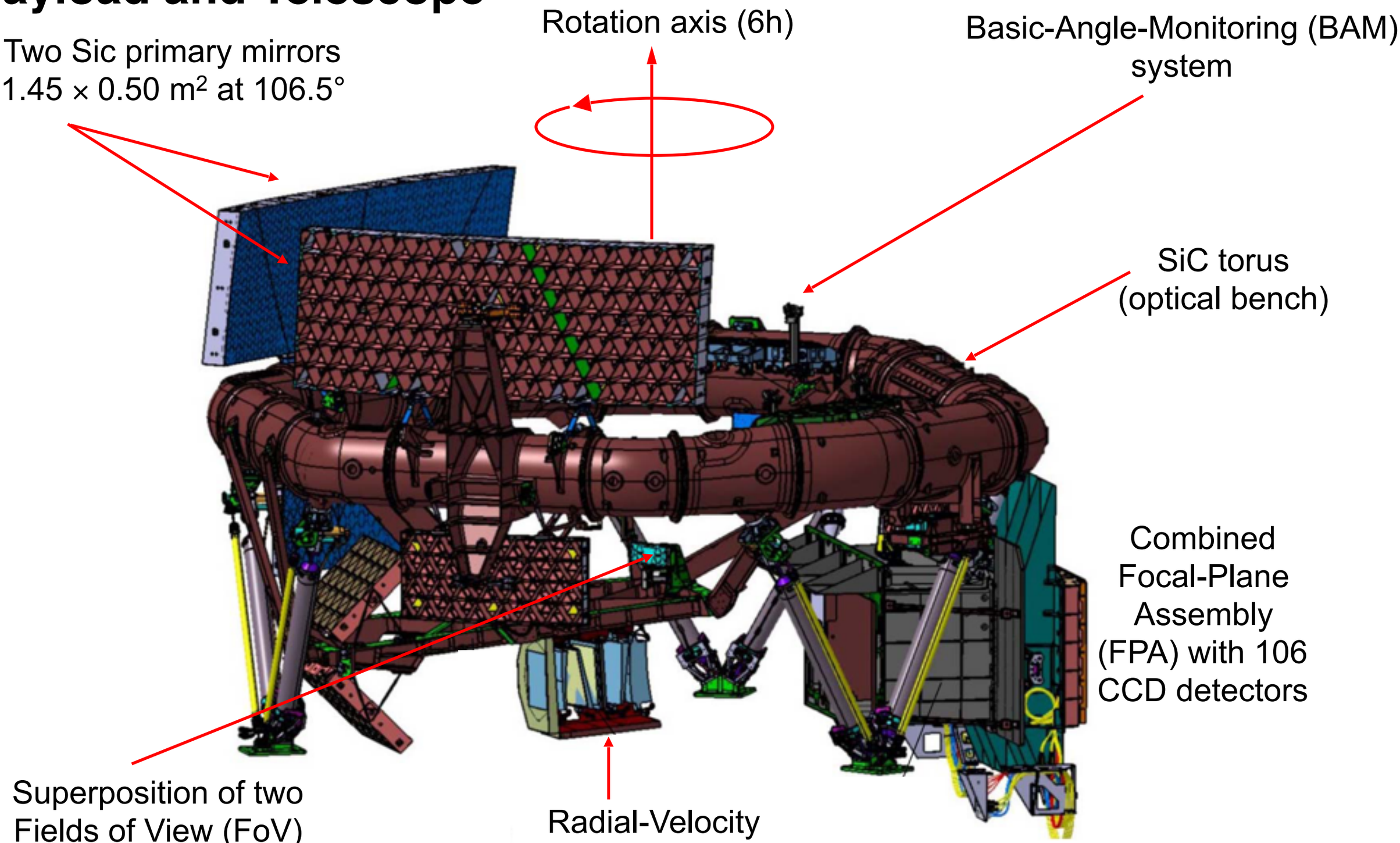
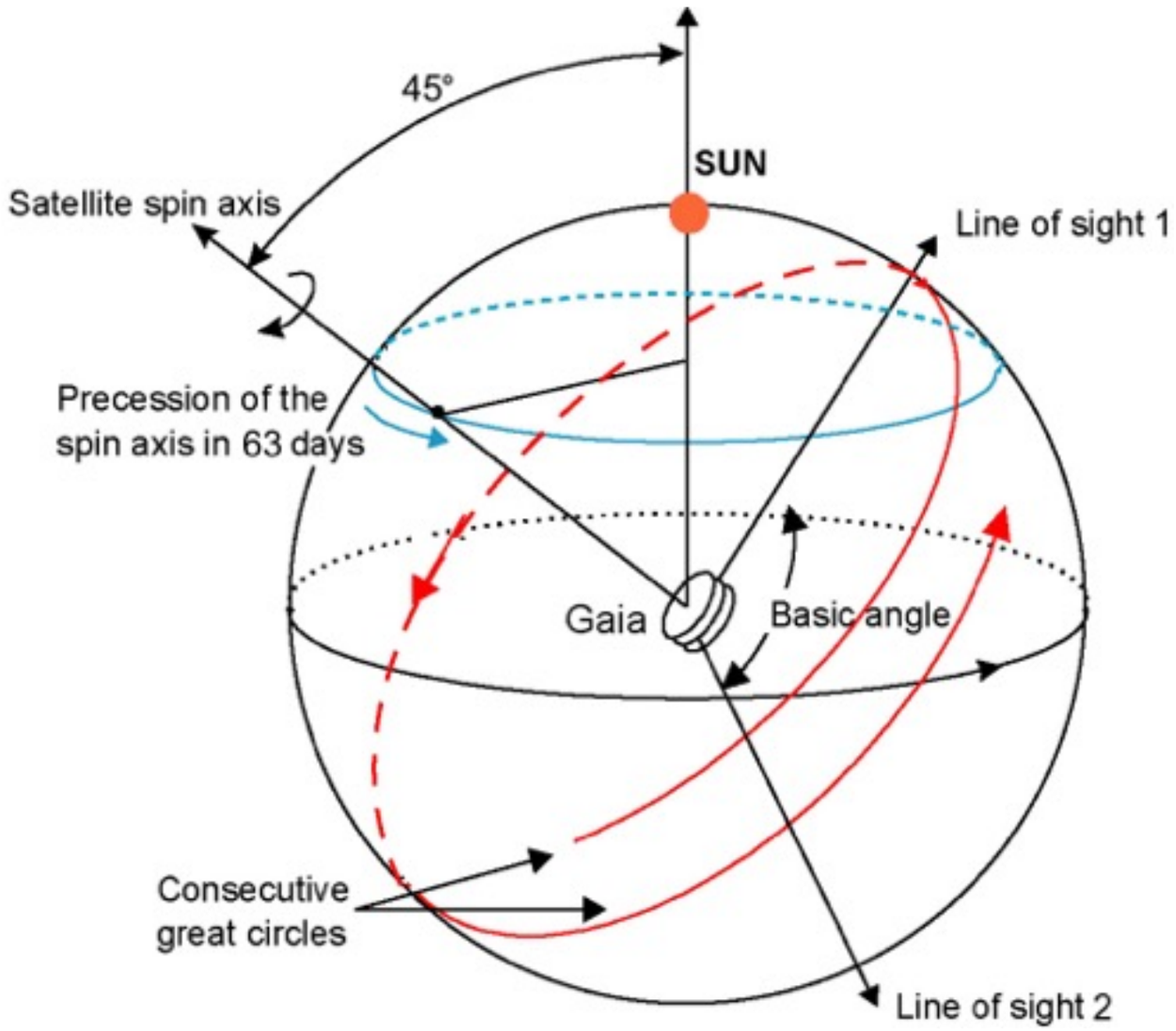



Figure courtesy EADS-Astrium

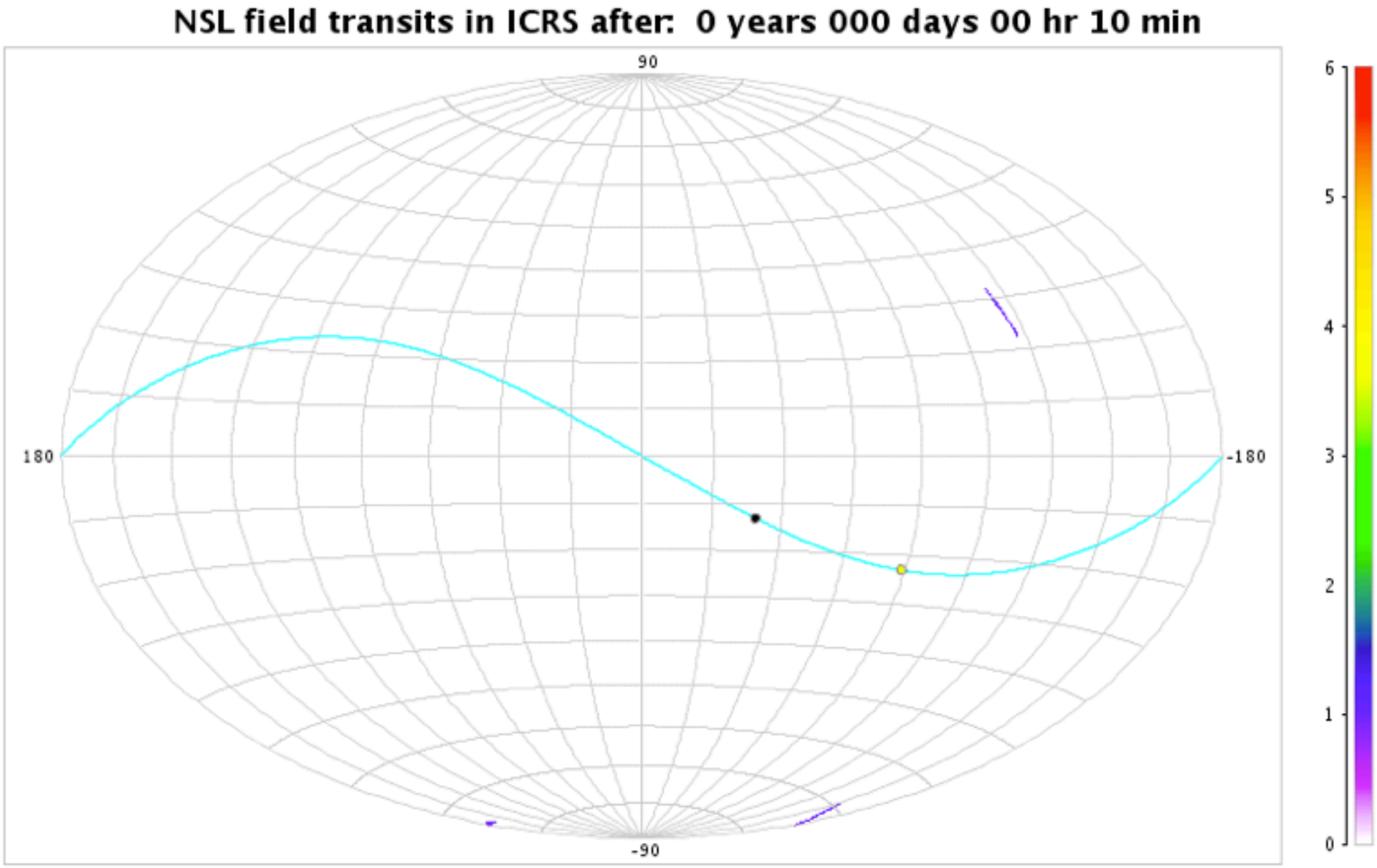
# Scanning Law




Spin axis 45° to Sun
Scan rate: 60 arcsec $s^{-1}$
Spin period: 6 hours

In average every source is observed ~80 times

# Scanning Law




**http://www.cosmos.esa.int/documents/29201/304590/Gaia_scanLaw_movie.mov/024d4a49-e0d5-4d47-8f80-c1a32ead6a46**

## Data-Reduction Principles

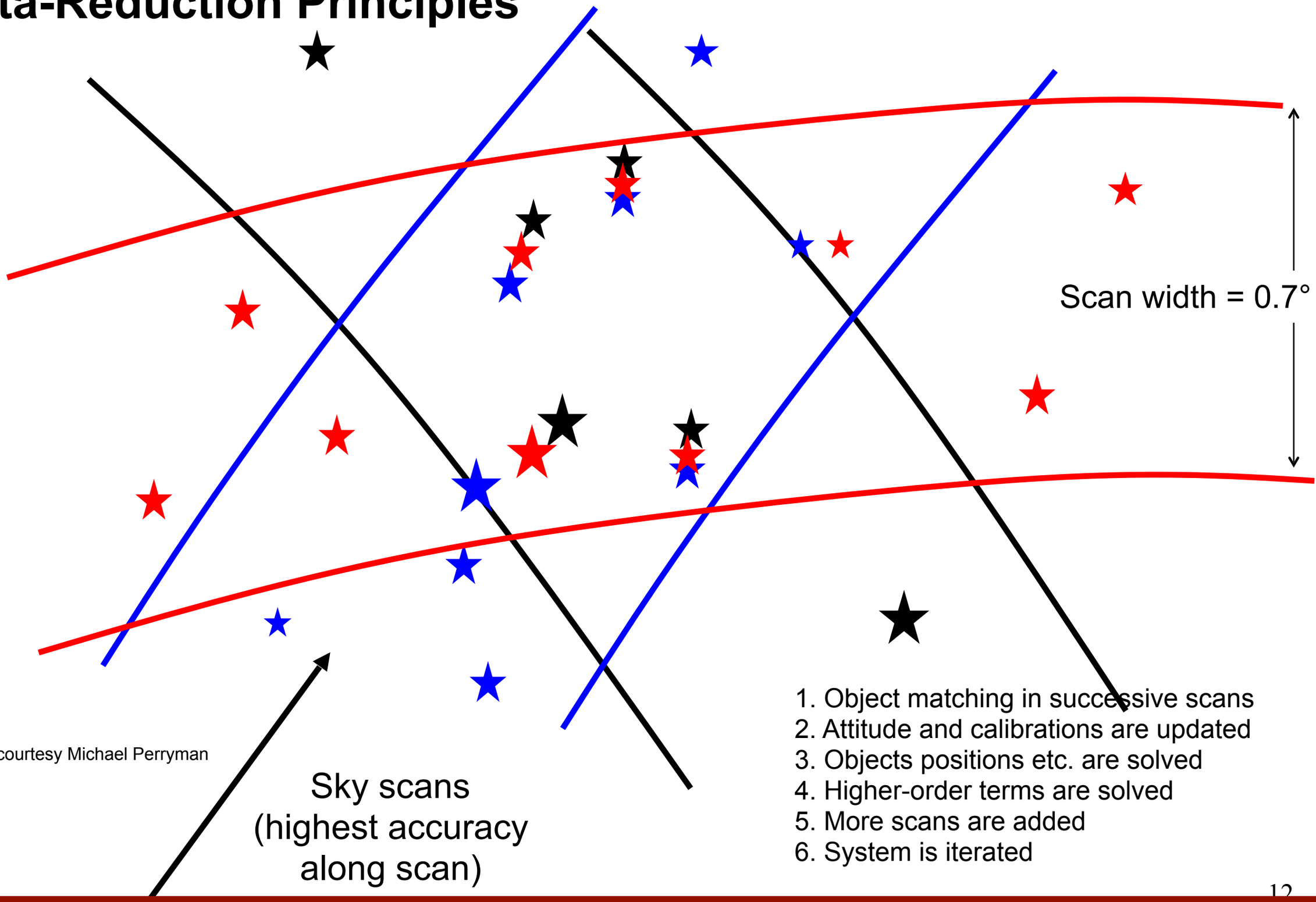
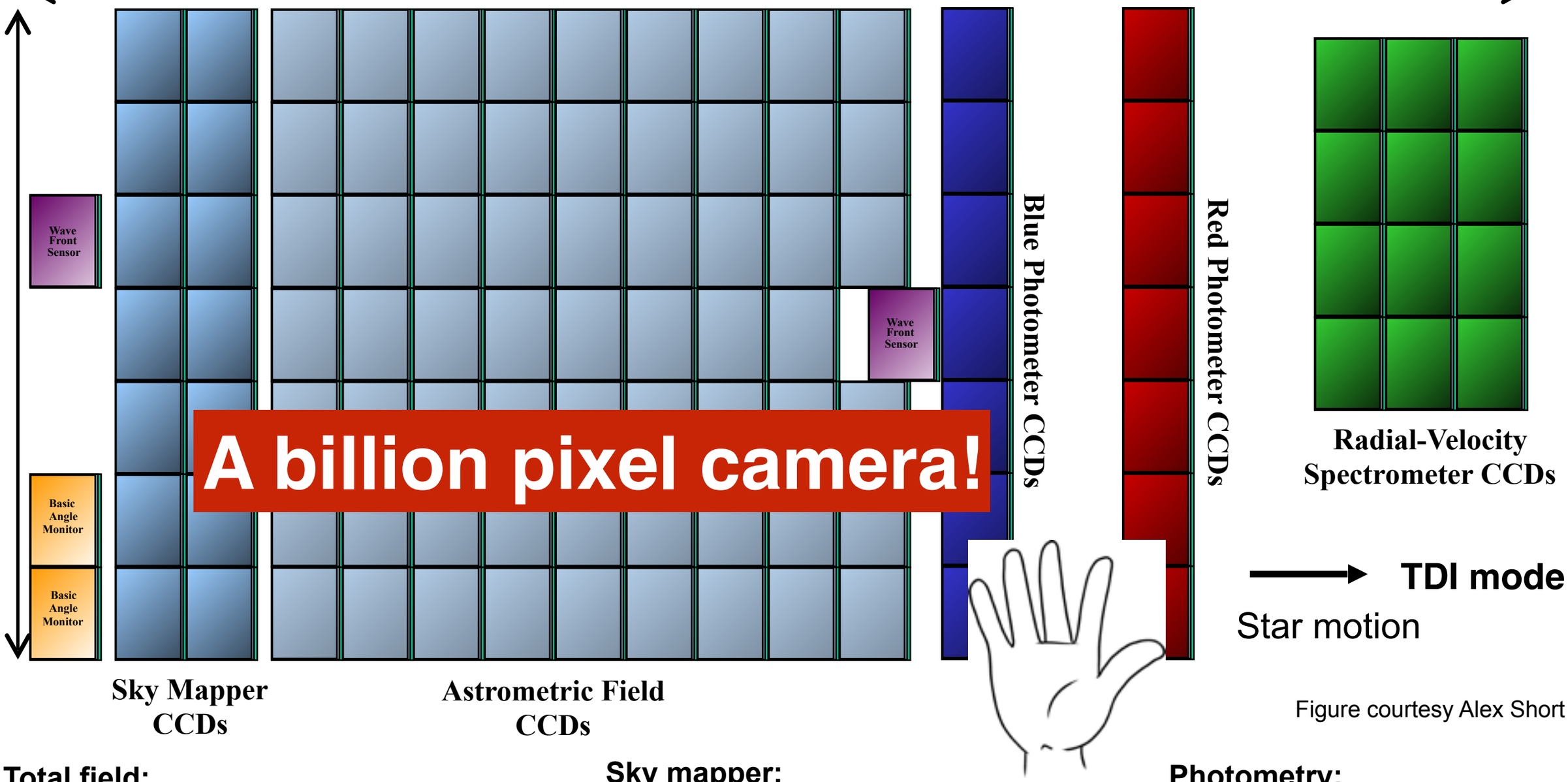



Figure courtesy Michael Perryman

1. Object matching in successive scans
2. Attitude and calibrations are updated
3. Objects positions etc. are solved
4. Higher-order terms are solved
5. More scans are added
6. System is iterated

## Focal Plane




**A billion pixel camera!**

Figure courtesy Alex Short

**Total field:**

- active area: 0.75 deg$^2$
- CCDs: 14 + 62 + 14 + 12 (+ 4)
- 4500 x 1966 pixels (TDI)
- pixel size = 10 μm x 30 μm
  = 59 mas x 177 mas

**Sky mapper:**

- detects all objects to G=20 mag
- rejects cosmic-ray events
- field-of-view discrimination

**Astrometry:**

- total detection noise ~ 4 e$^-$

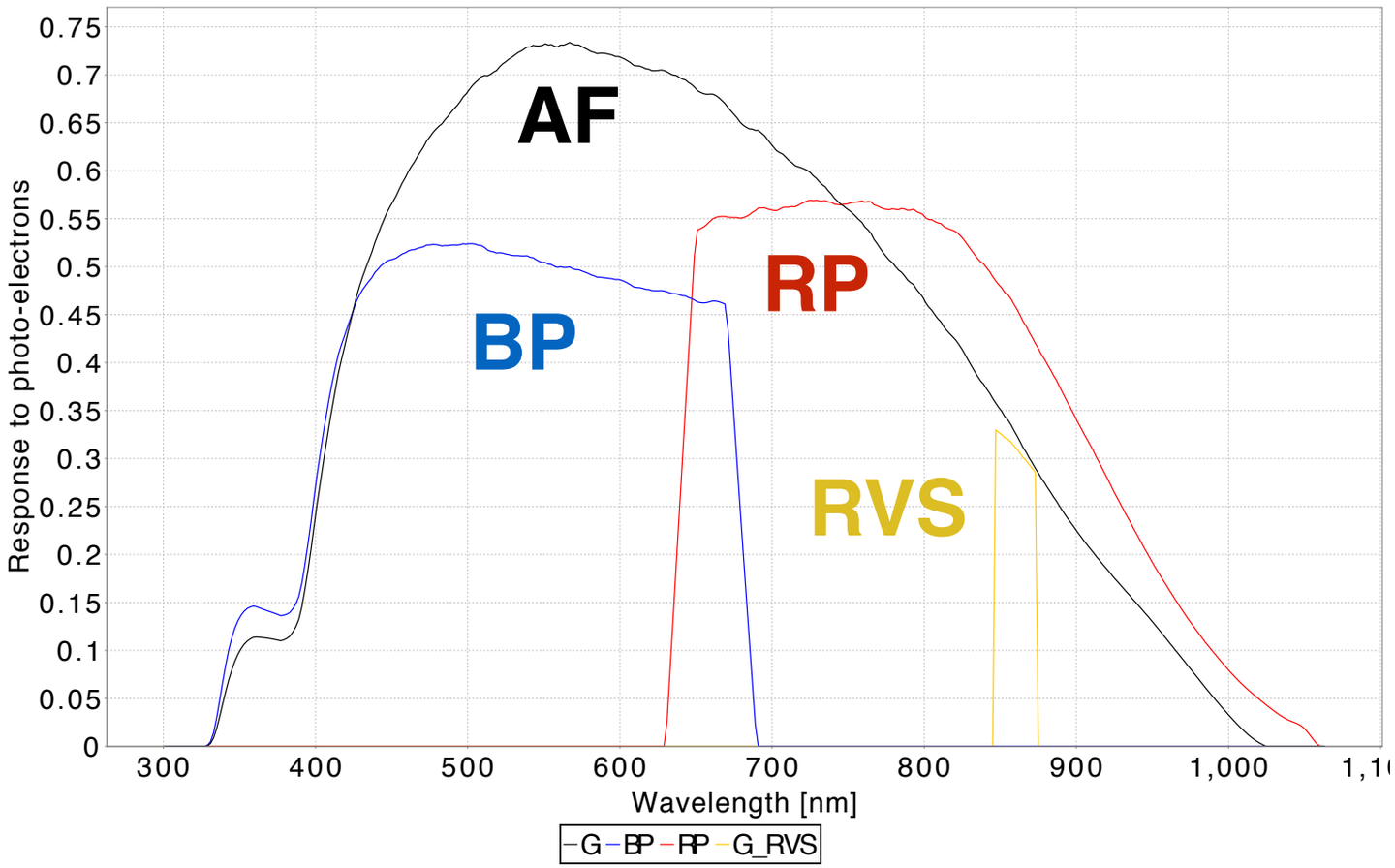
**Photometry:**

- spectro-photometer
- blue and red CCDs

**Spectroscopy:**

- high-resolution spectra
- red CCDs

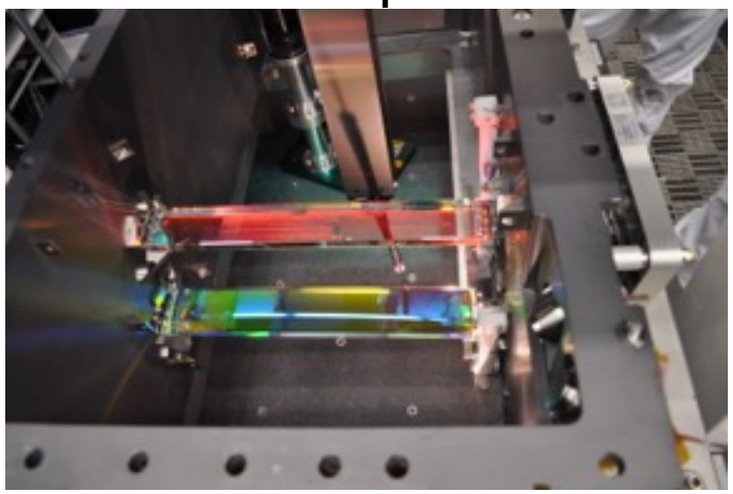
# Passbands



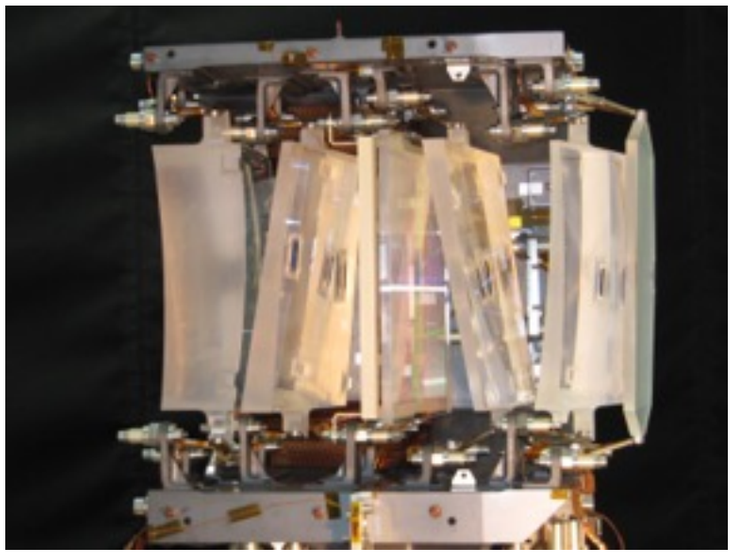

Blue photometer:
330 - 680 nm

Red photometer:
640 - 1050 nm

## BP-RP prisms

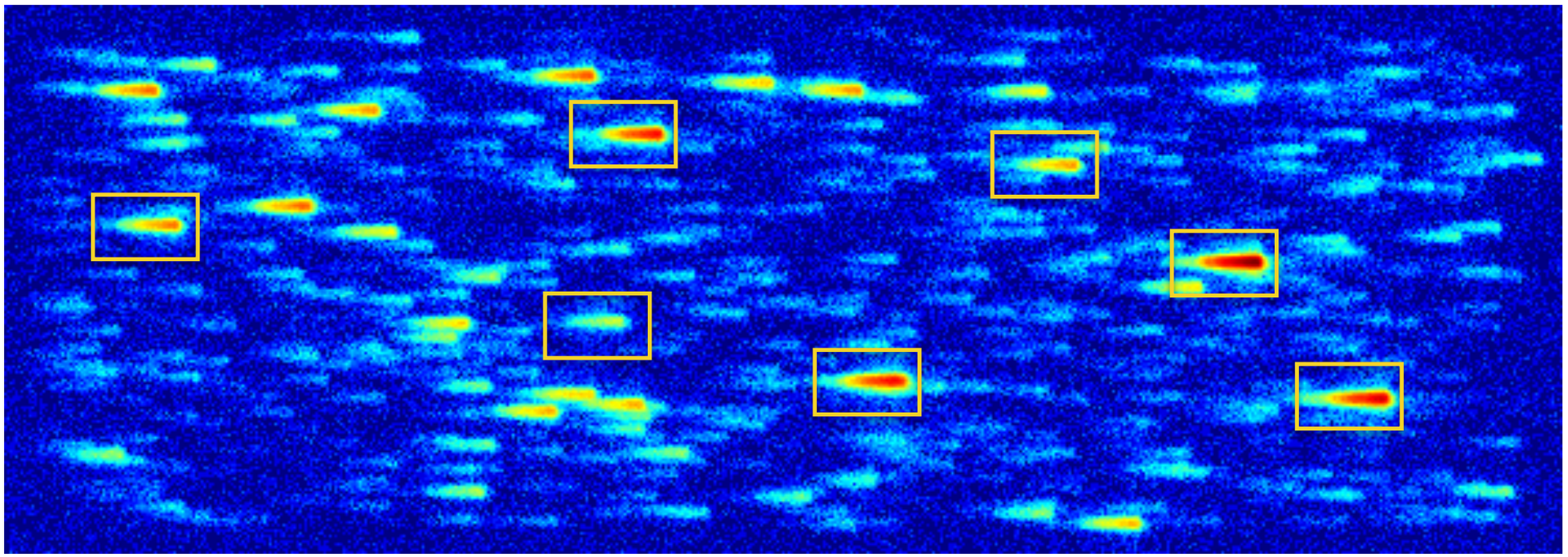


low resolution



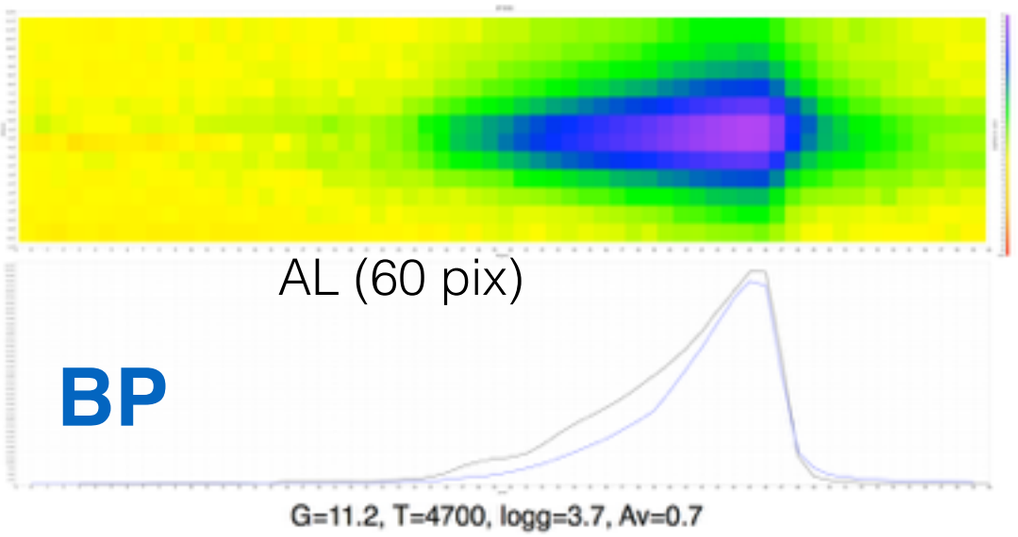
λ/Δλ ~ 11500

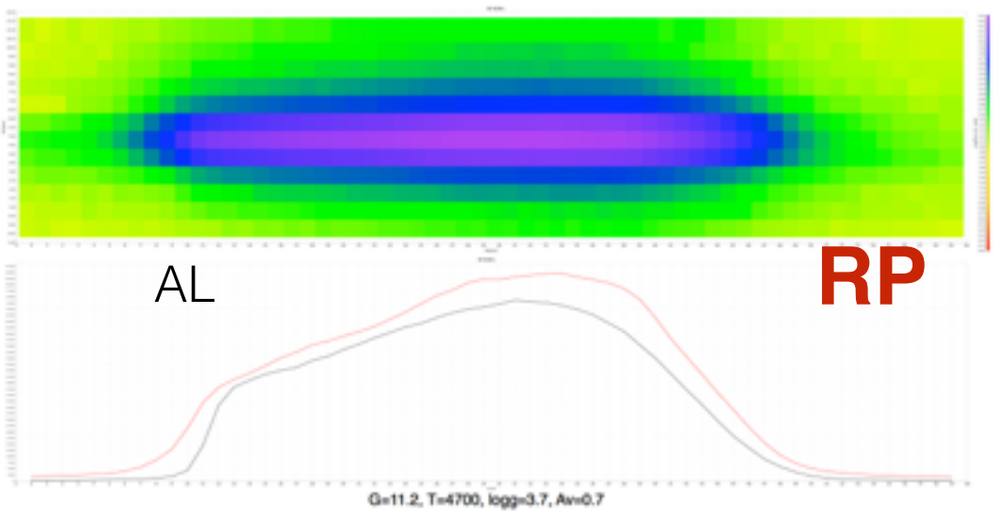
# Window strategy



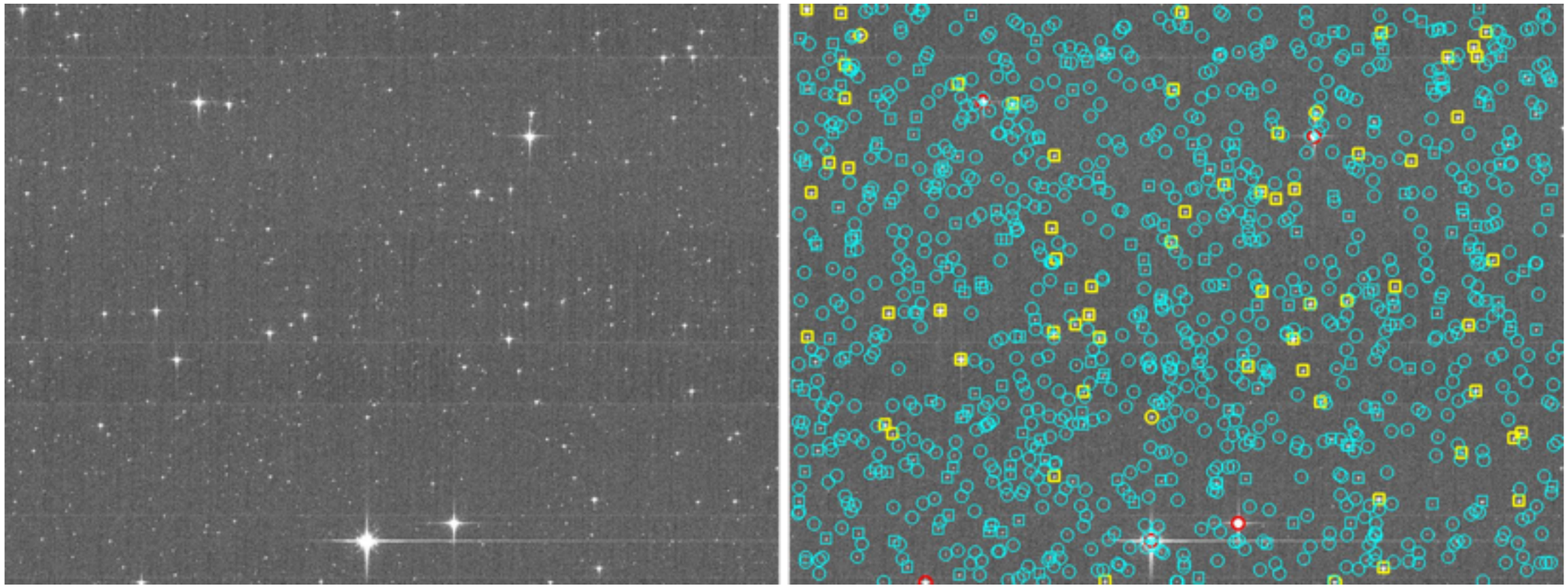
Across scan

Along scan



# Source detection



G<13 ;2D window

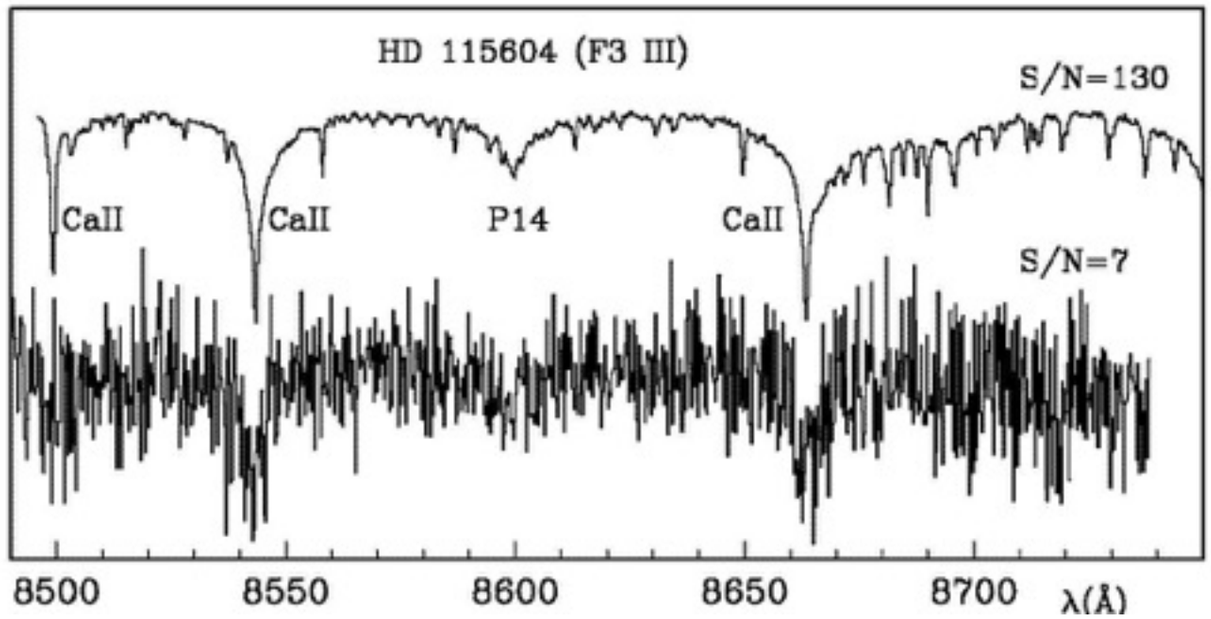
13<G<16 ;1D window

16<G<20 ;1D window

## Radial Velocity Spectrograph

847-874 nm

λ/Δλ ~ 11500



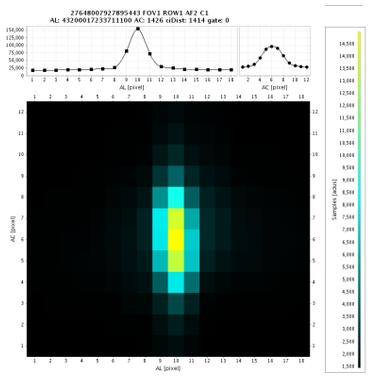

Figures courtesy David Katz

RVS spectra of F3 giant (V = 16 mag)
S/N = 7 (single measurement)
S/N = 130 (summed over mission)

# Gaia: the photometric processing

## Data Processing Center IoA

**Astrometric Field**

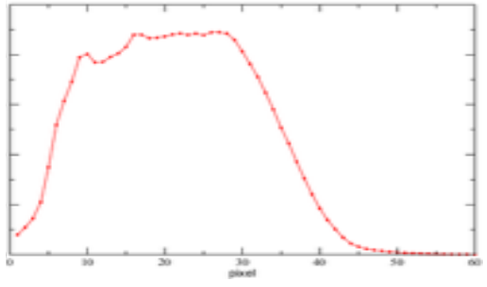


**Initial Data Treatment / Intermediate Data Update Image Parameter Determination**

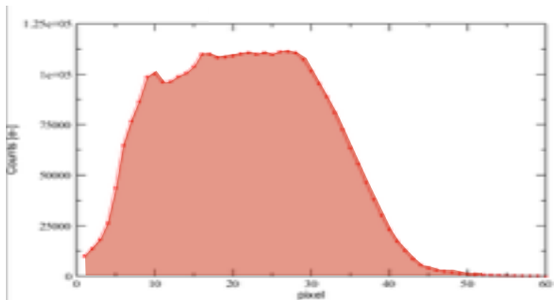
**bias and background correction**
**LSF/PSF fit**

**centroid & G-band flux per CCD transit**

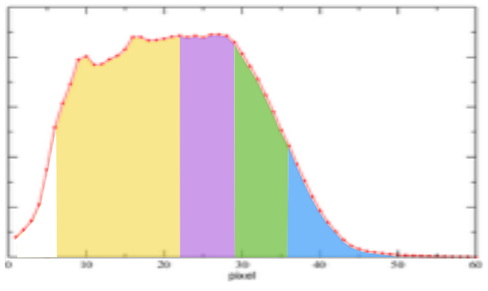
**BP and RP low-resolution spectra**

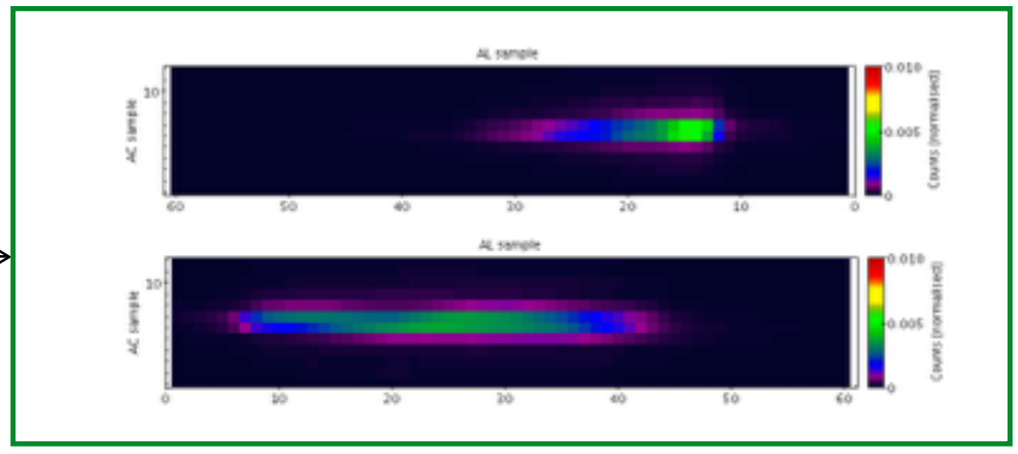


**integrated BP and RP flux**



**spectral shape coefficients (SSCs)**






**PhotPipe**

**bias and background correction**
**dispersion function**

# Gaia: the photometric processing

## Internal Calibration

large number of sources
no external reference data

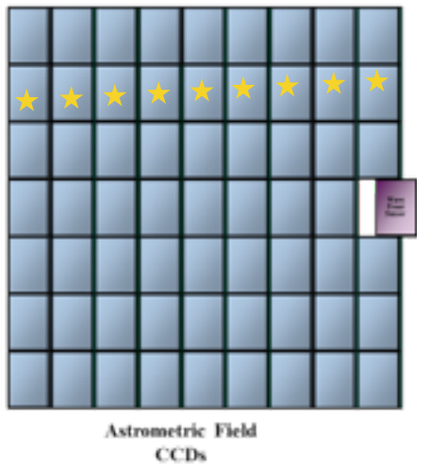
## External Calibration

smaller number of sources
(~200 SPSS)
calibrate the average instrument to the external reference system

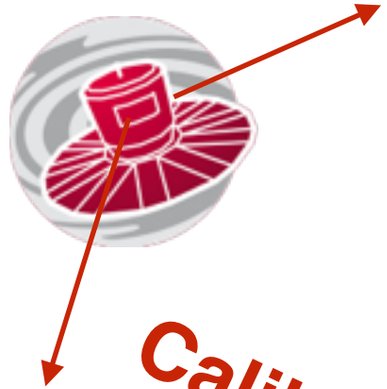
# The calibration principles

## Internal Calibration → bring all observations to the same average instrument

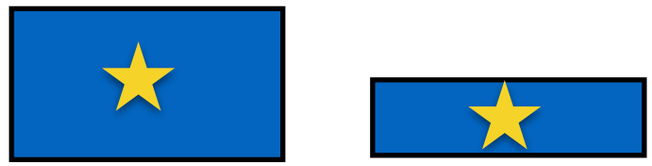
### different CCDs



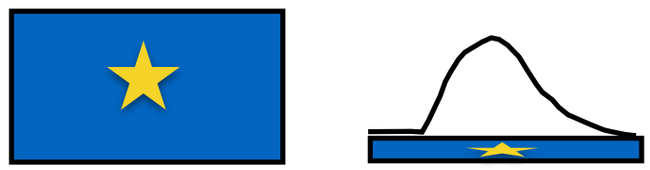

### different FoVs



### different observations



window size



2D 1D


different exposure time (gates)

**Calibration Unit**

**Link Calibration**

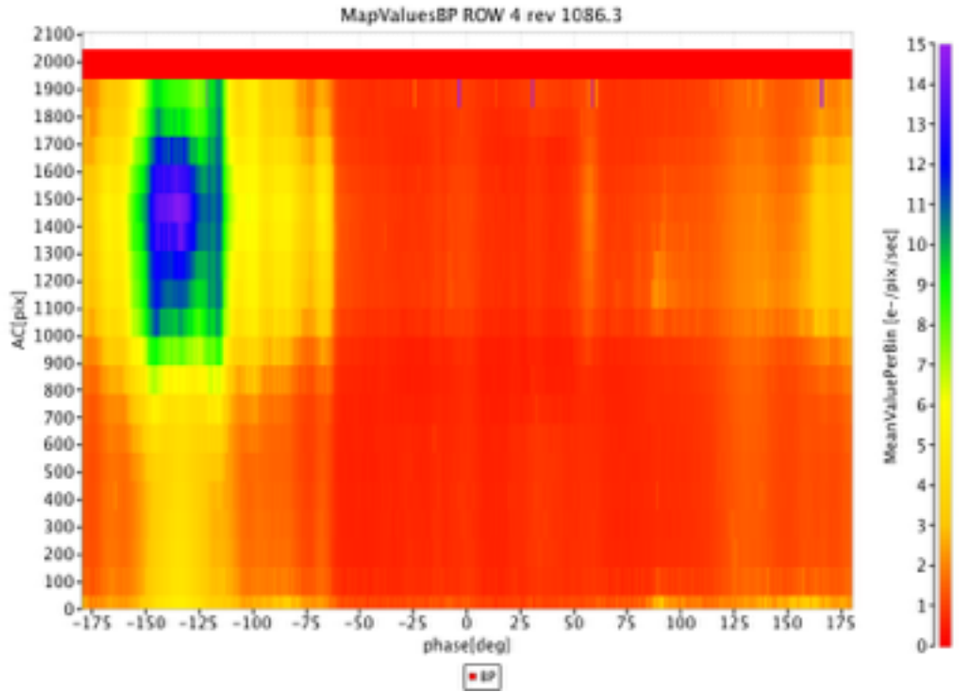
**Large-Scale**
CCD, FoV, Gate, WinClass
Short time scale (1d)

**Small-Scale**
group of 4 pixel columns, Gate, WinClass
Long time scale (months)

# Gaia: the photometric processing

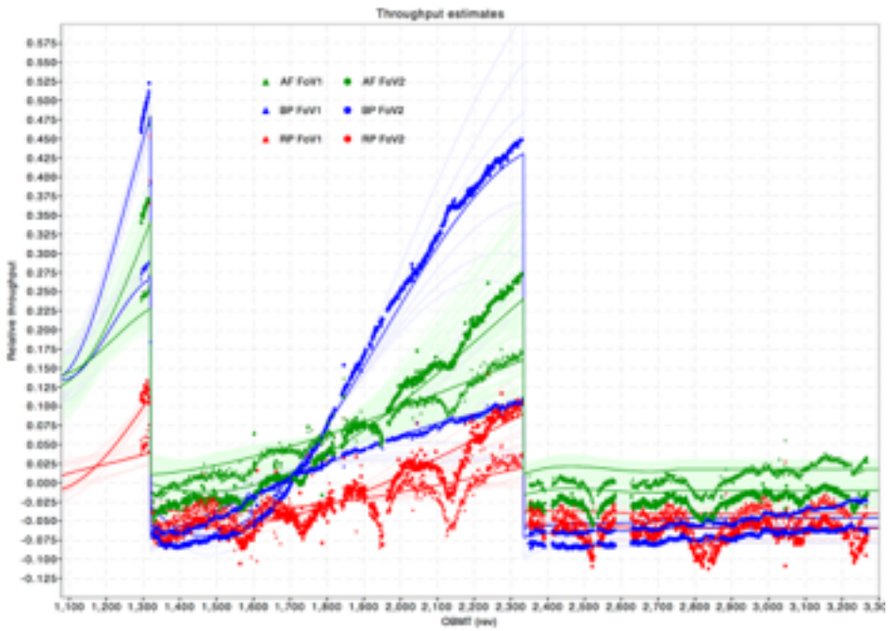
## The problems

### Stray light




**solved adapting the software**

### Contamination



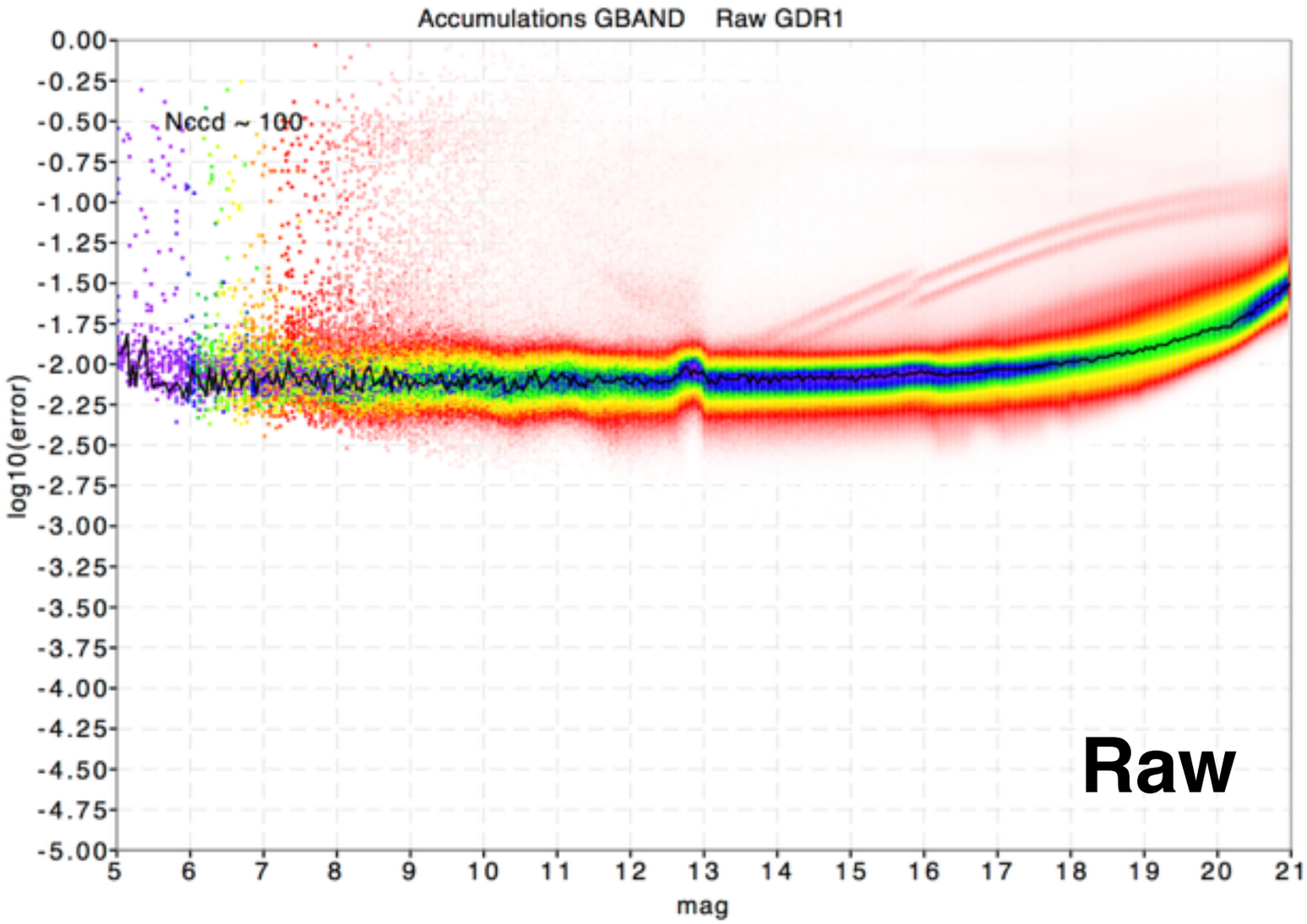

**solved with decontamination campaigns**

**and adapting the software**

(Time-Link Calibration)

# The results

## Errors during different steps



# The results

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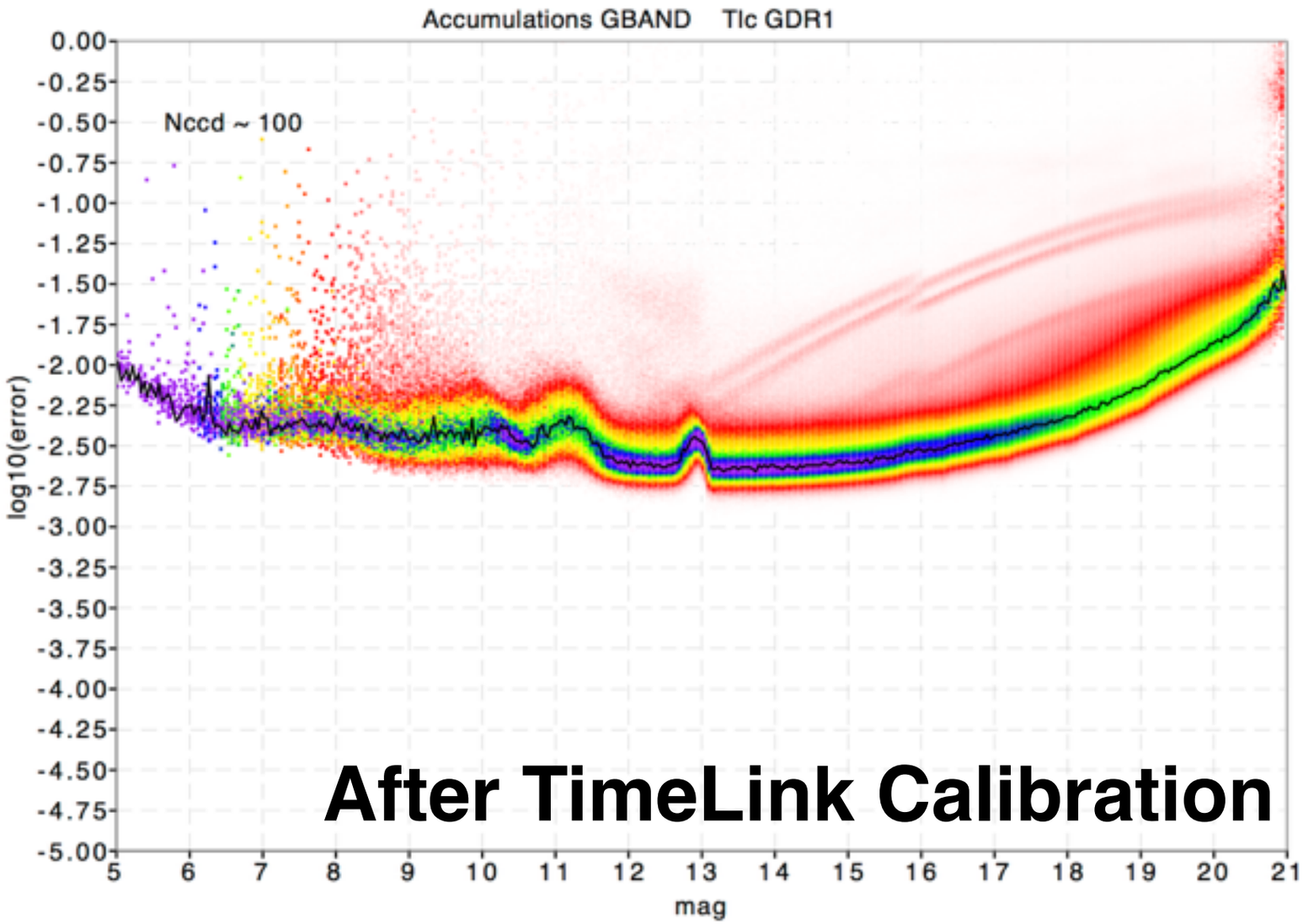

# The results

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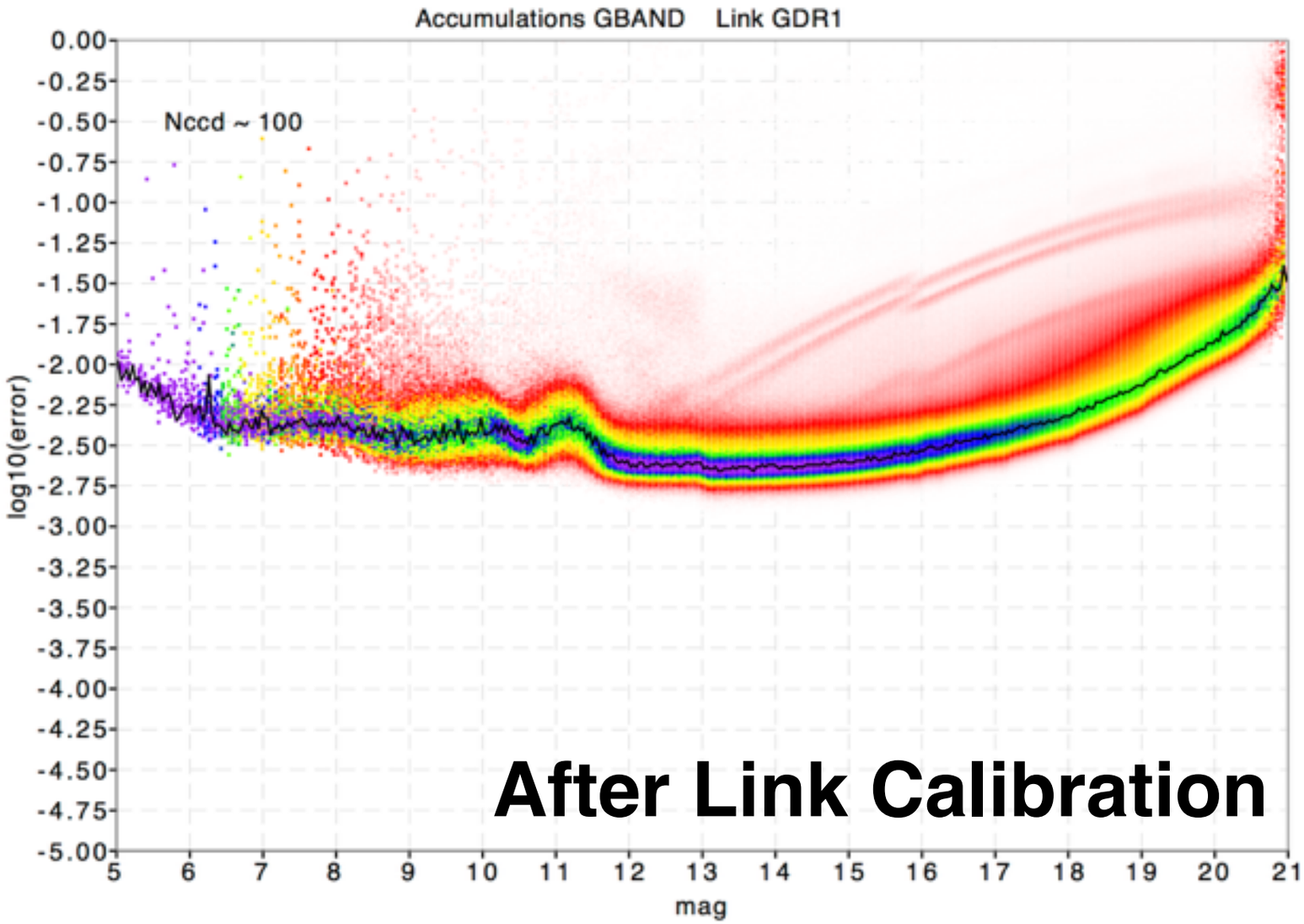

# The results

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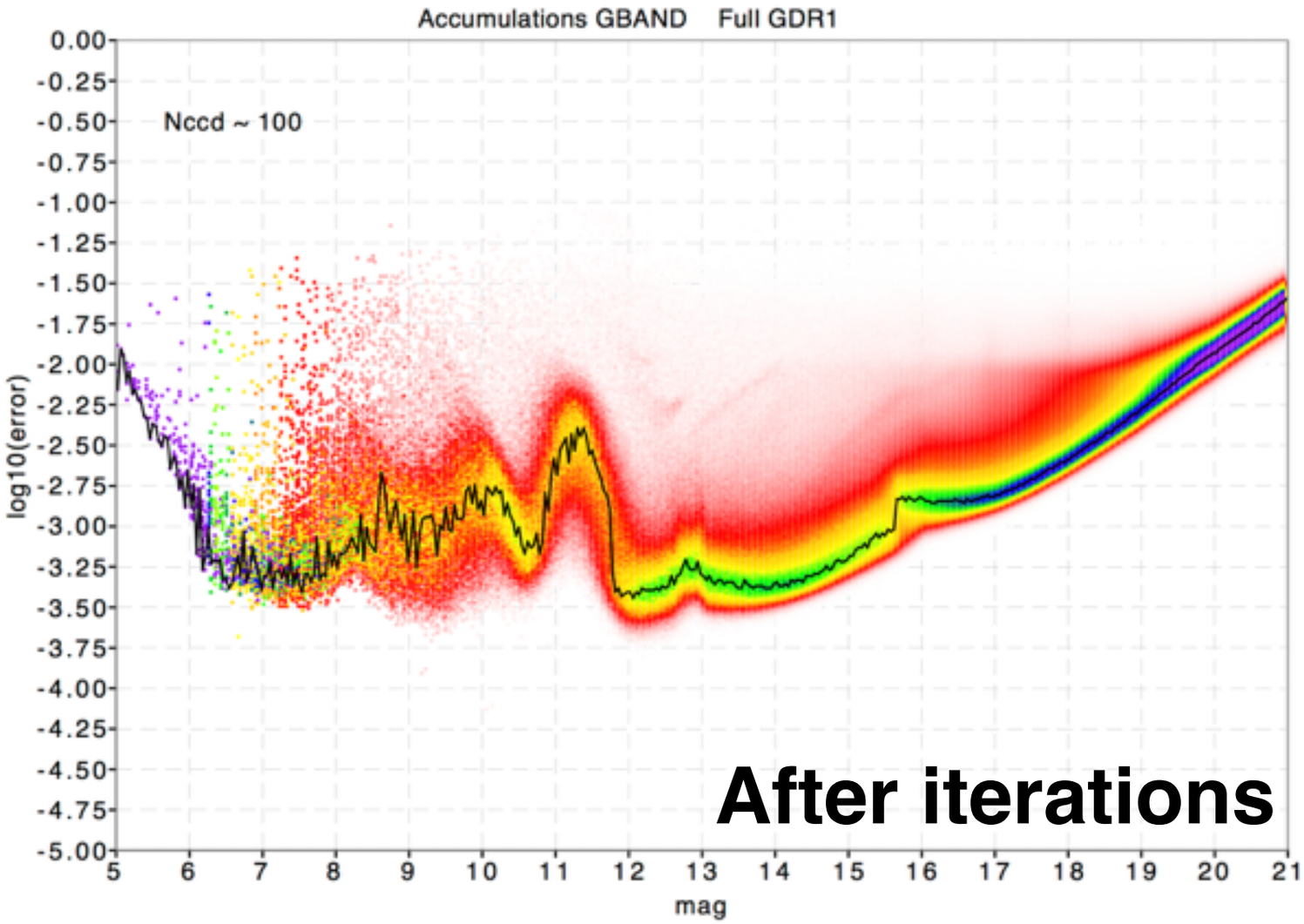
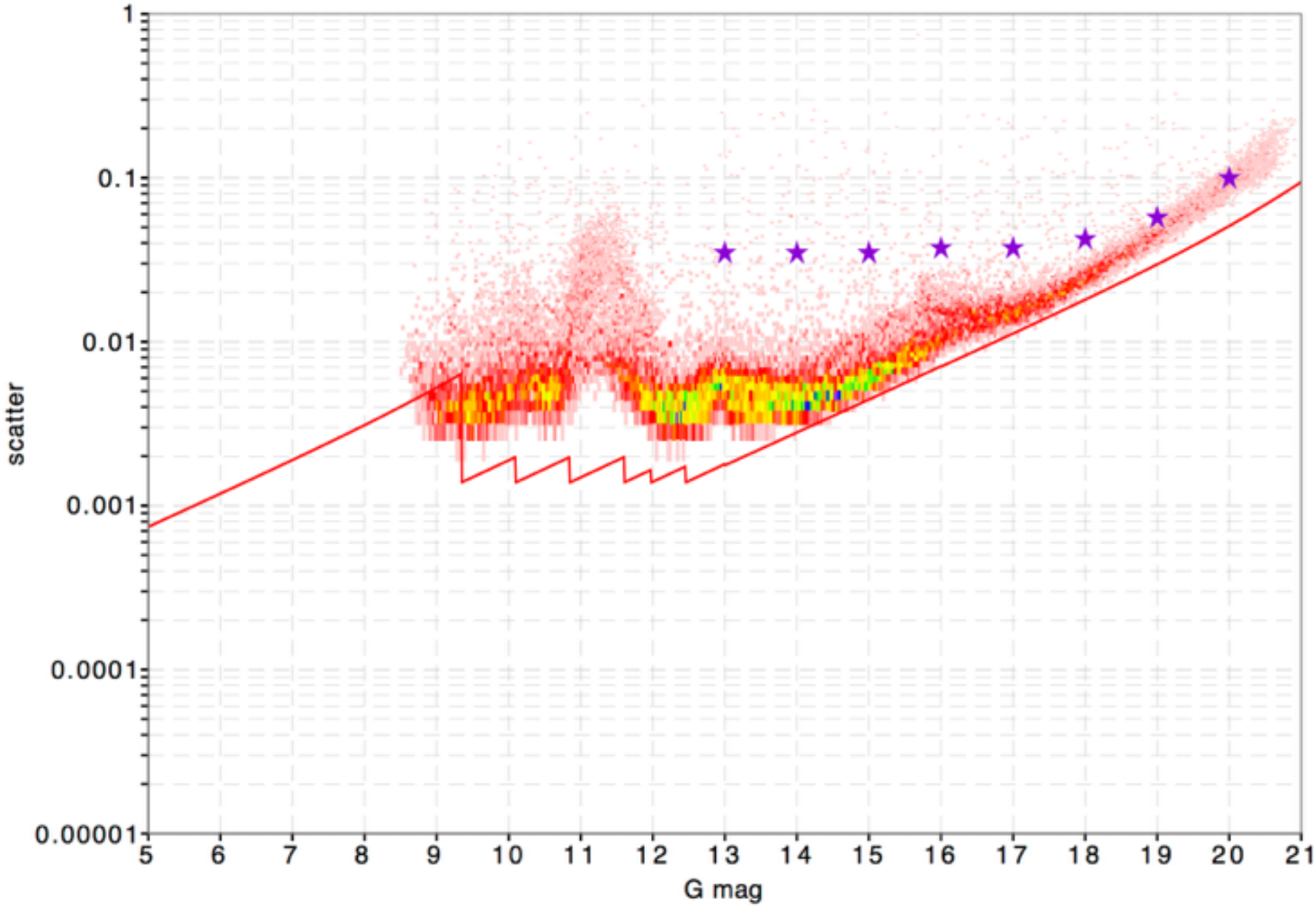
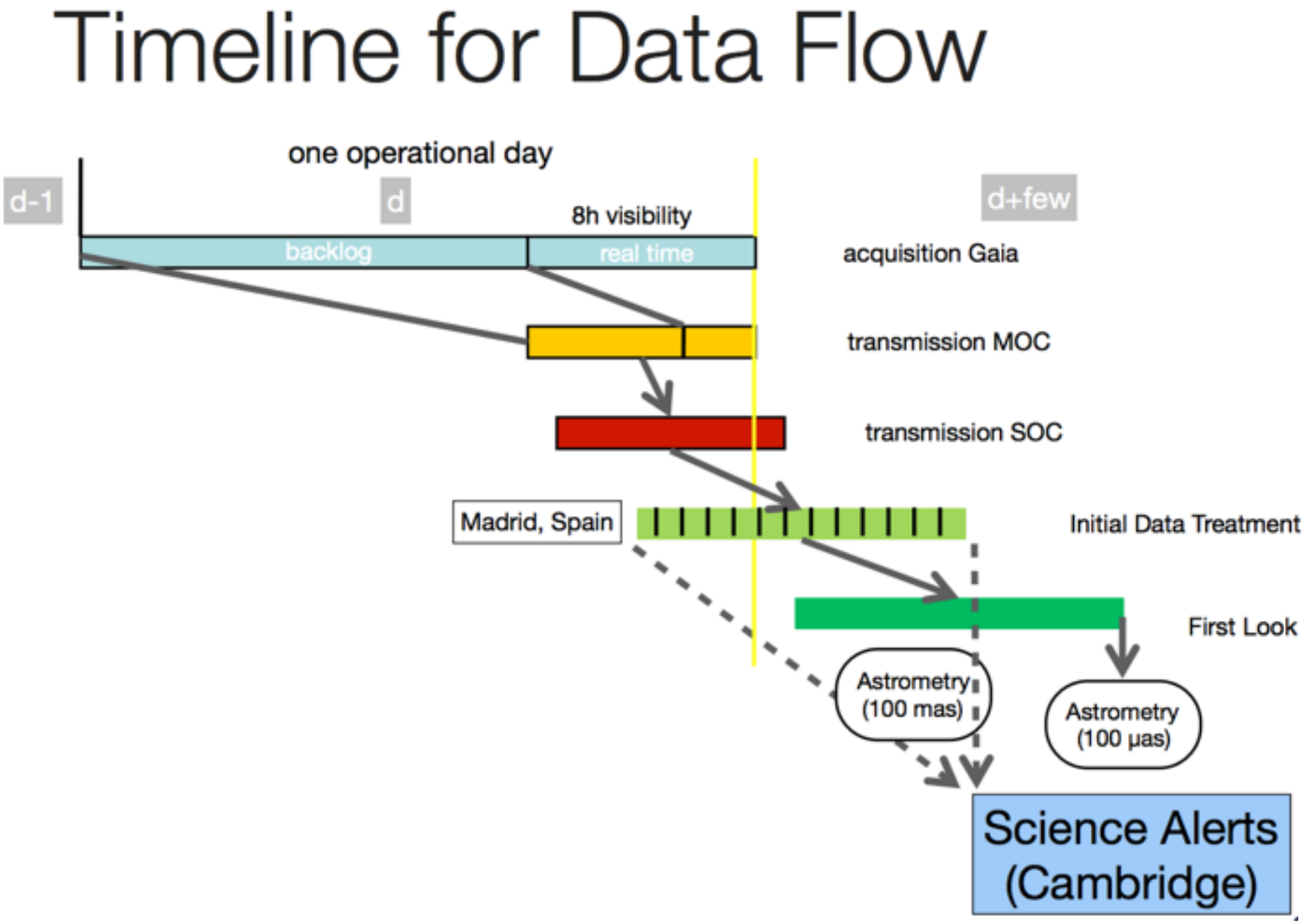


# The results

## Observed scatter



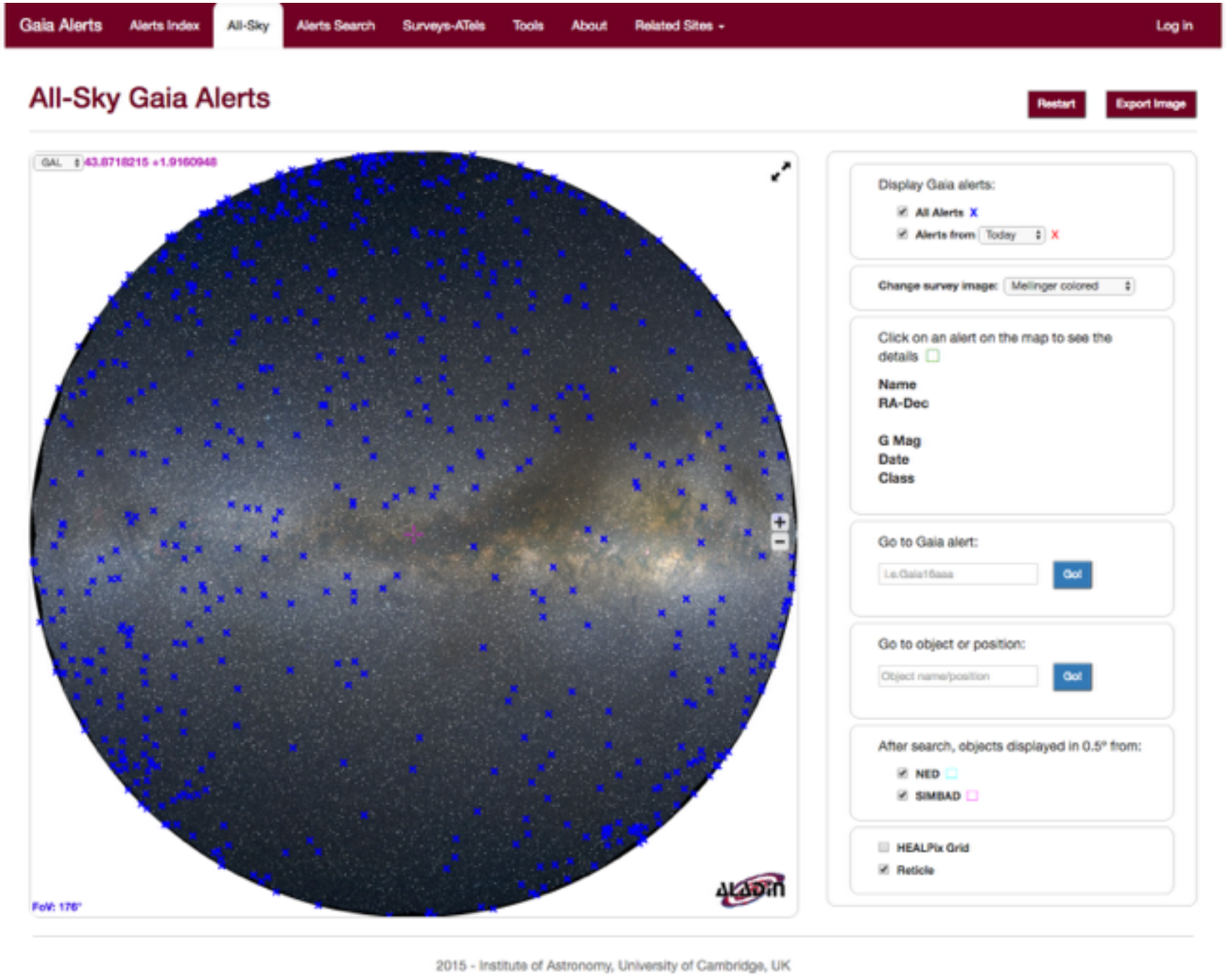
# Science Alerts



# Gaia: the results (before GDR1)

## Science Alerts

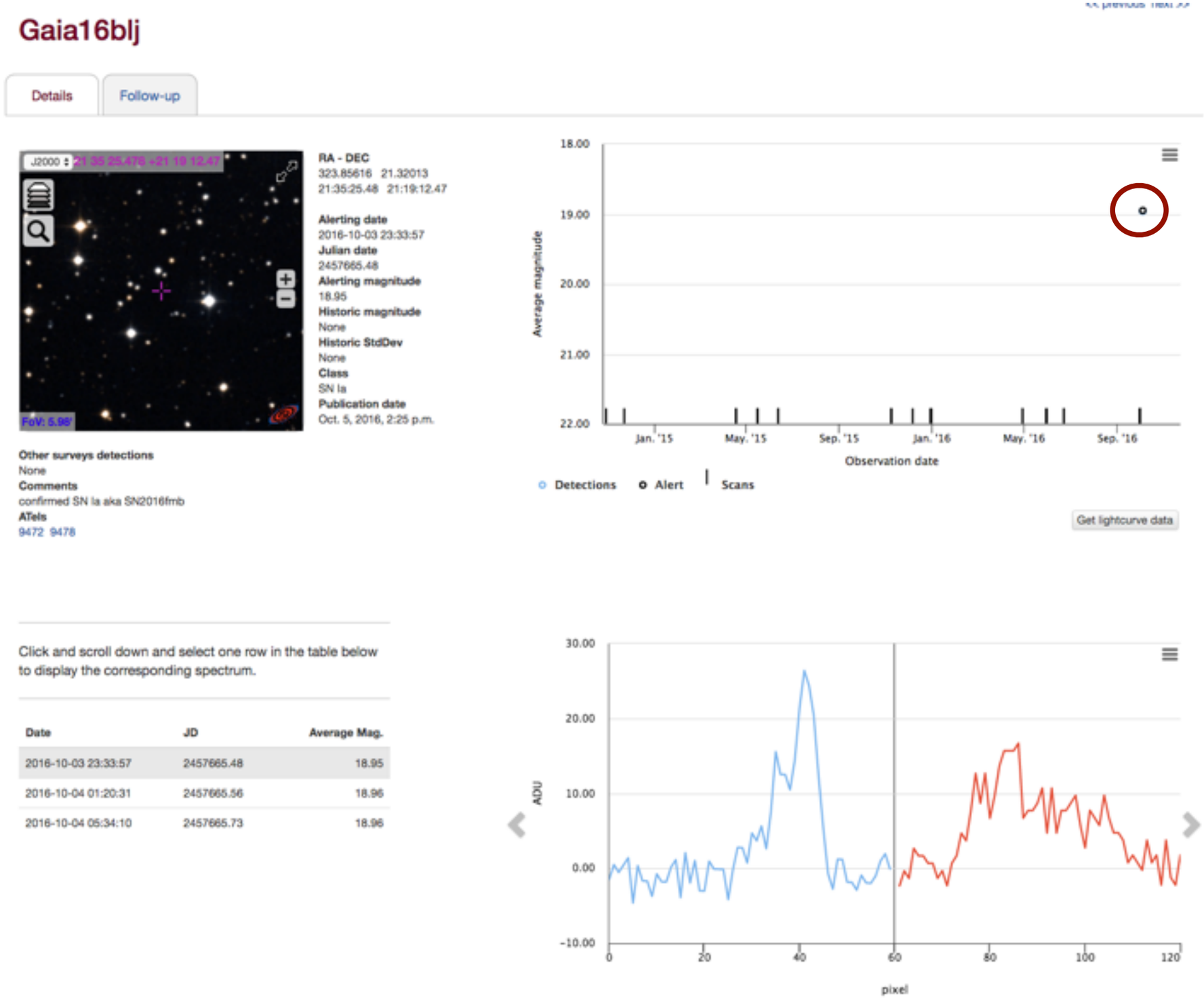
http://gsaweb.ast.cam.ac.uk/alerts/home



# Gaia: the results (before GDR1)

## Science Alerts

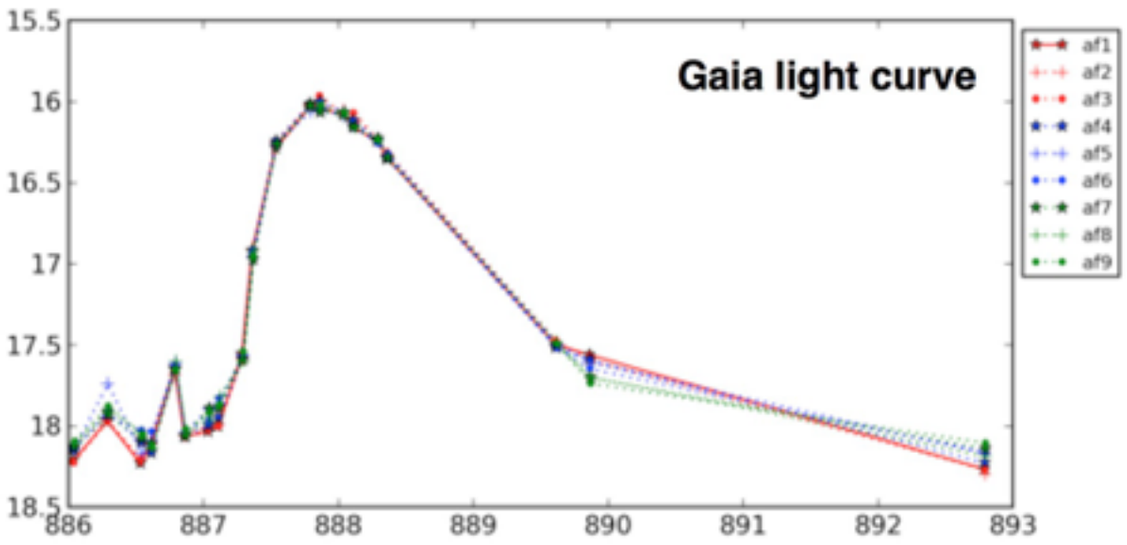
http://gsaweb.ast.cam.ac.uk/alerts/home



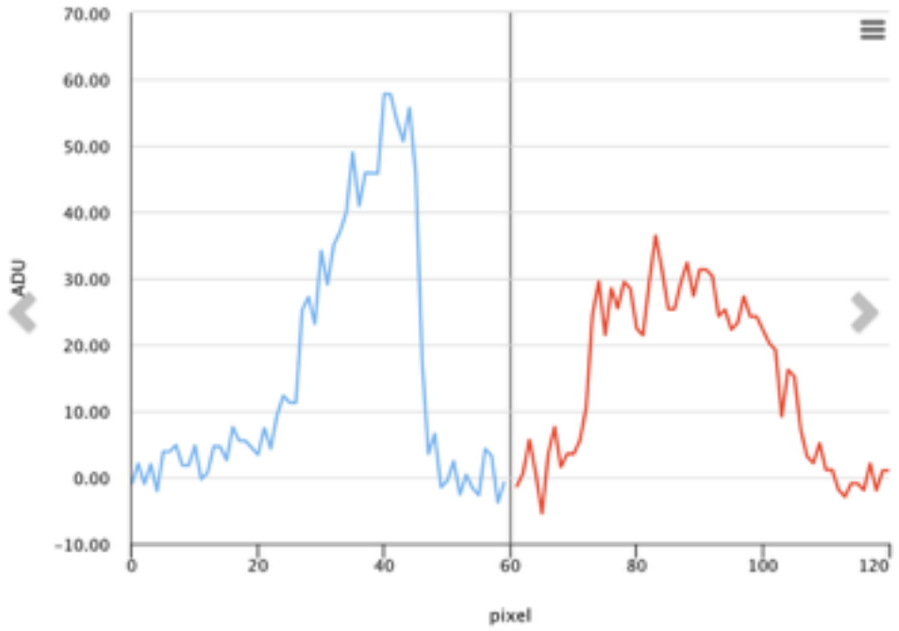
# Gaia: the results (before GDR1)

**Science Alerts:** First Science Discovery Publication

Gaia14aae identified as a transient by the Gaia Science Alerts project and independently by ASAS-SN (Shappee et al.) and during two separate outbursts.




Gaia light curve

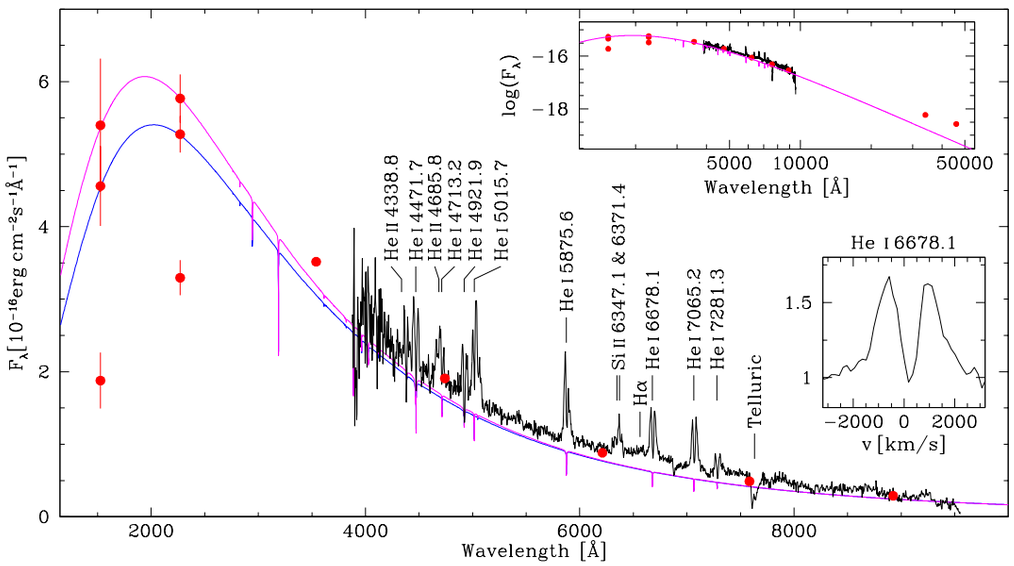



BP + RP

Images courtesy of H. Campbell

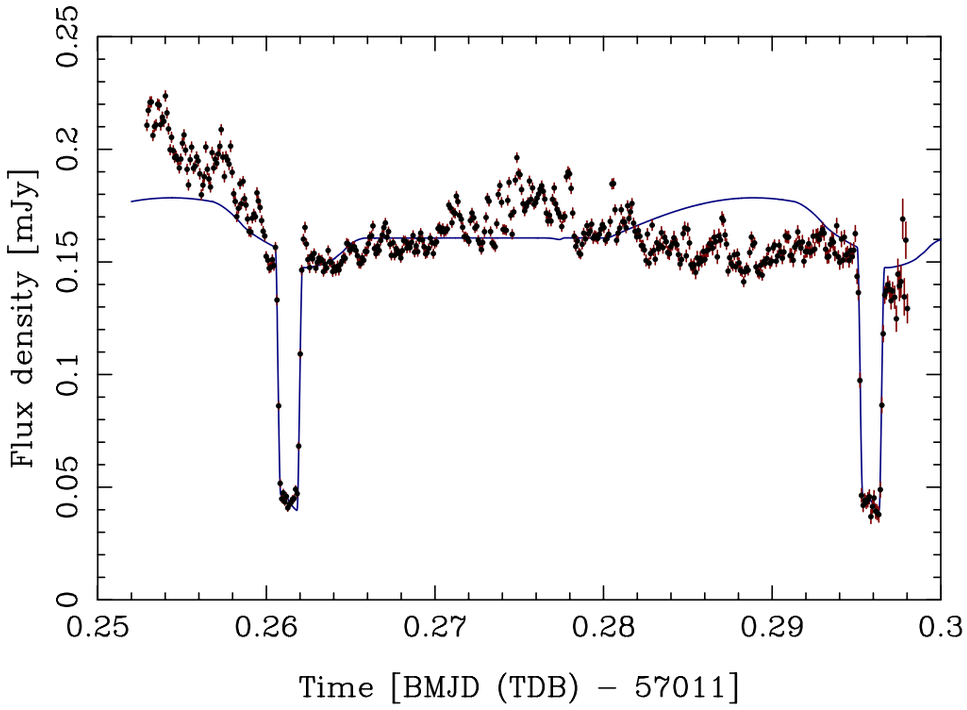
## **Science Alerts:** First Science Discovery Publication

Spectroscopic and photometric follow-up and comparison with previous survey




The historical GALEX, SDSS and WISE photometry

WHT spectrum: double-peaked He emission and an absence of H lines.



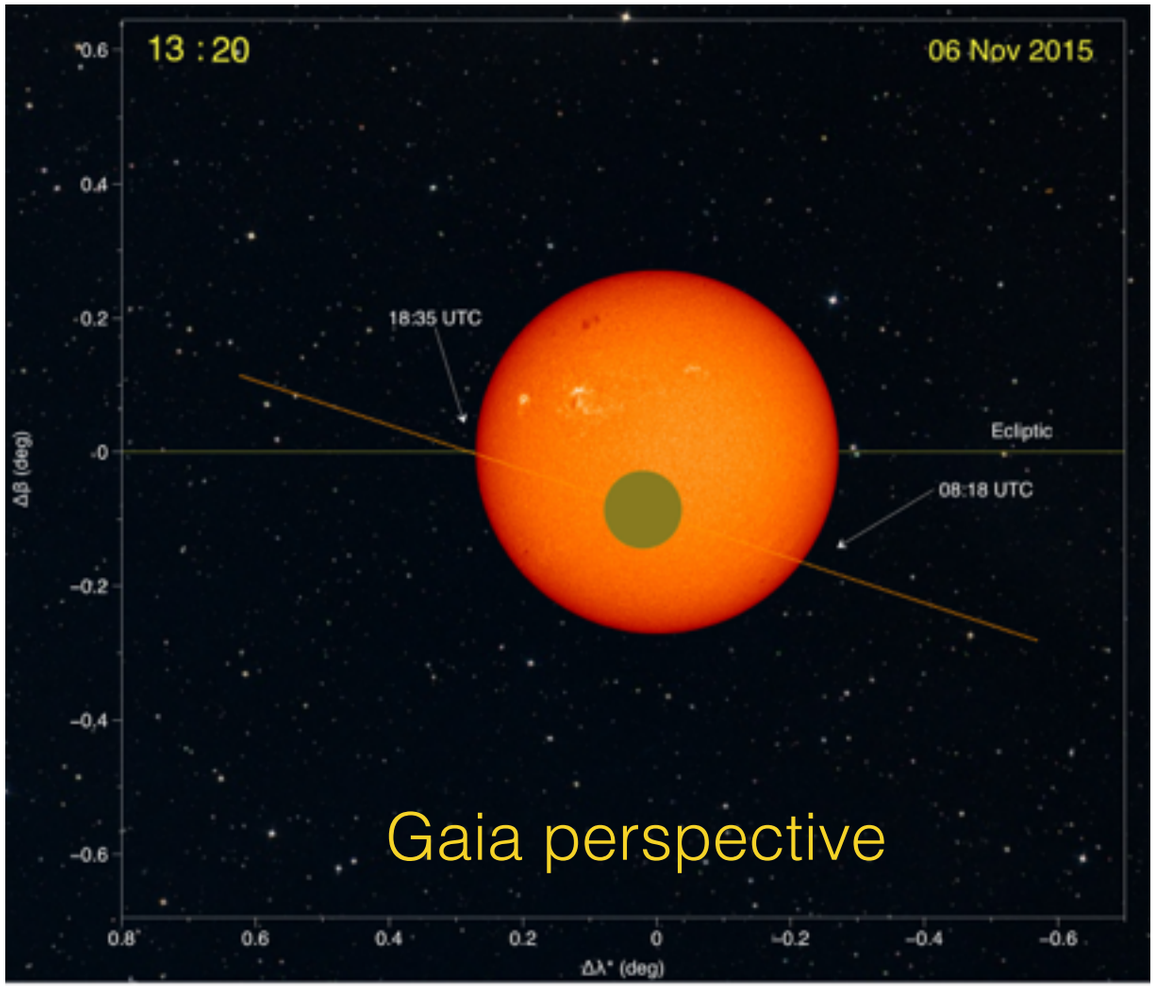

**AM CVn** WD accreting He from low mass degenerate companion

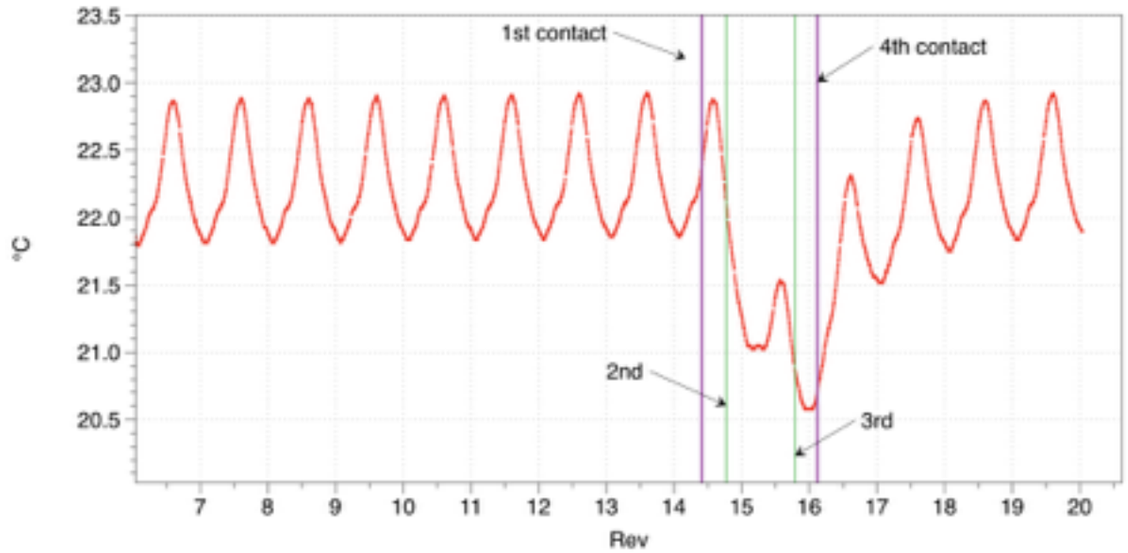
Third observed so far and first with total eclipse

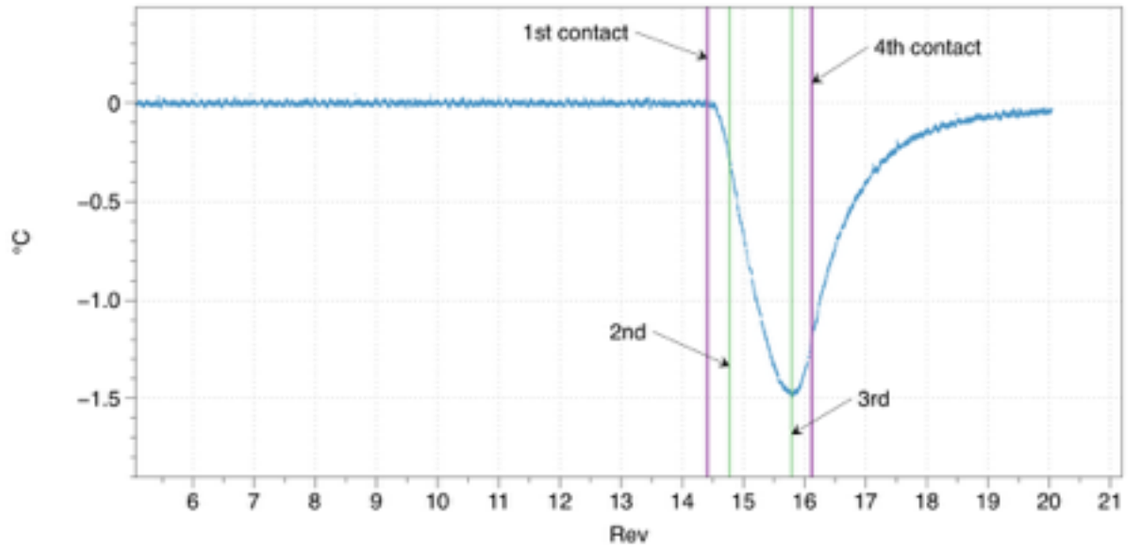
Campbell, H.C. et al. MNRAS 452, 1060

Images courtesy of H. Campbell

# Lunar Transit



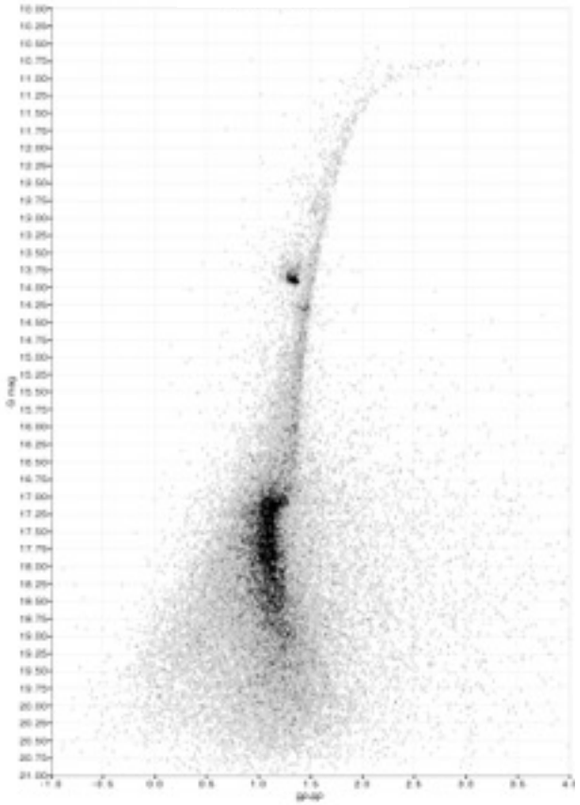




*Images Courtesy of F. Mignard and J.Hernandez*

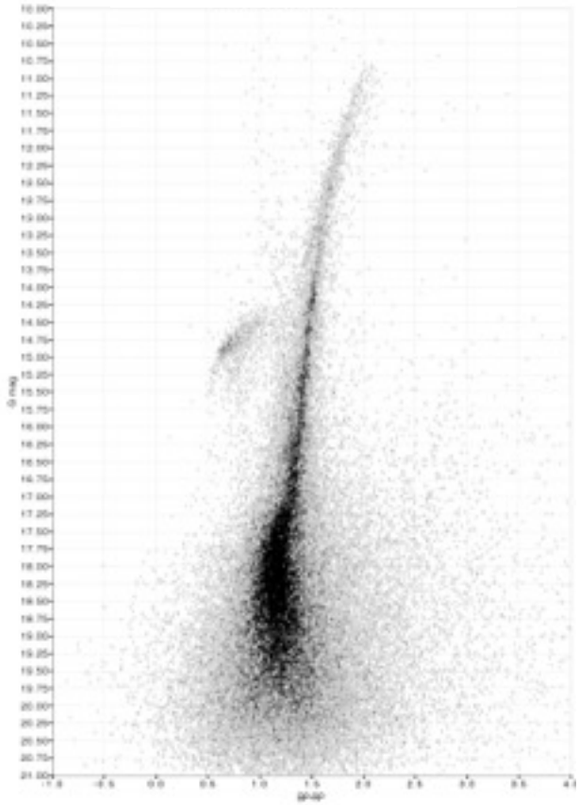
# The results

## Picture of the week

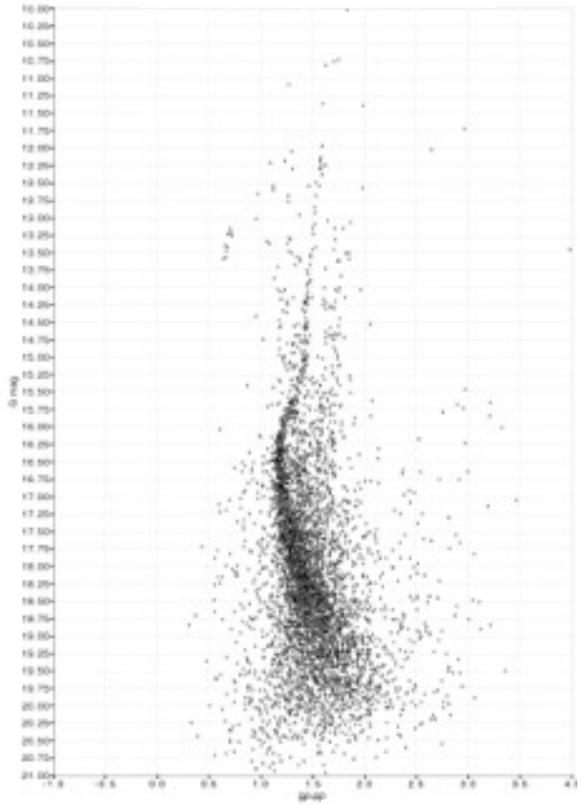
47 Tuc



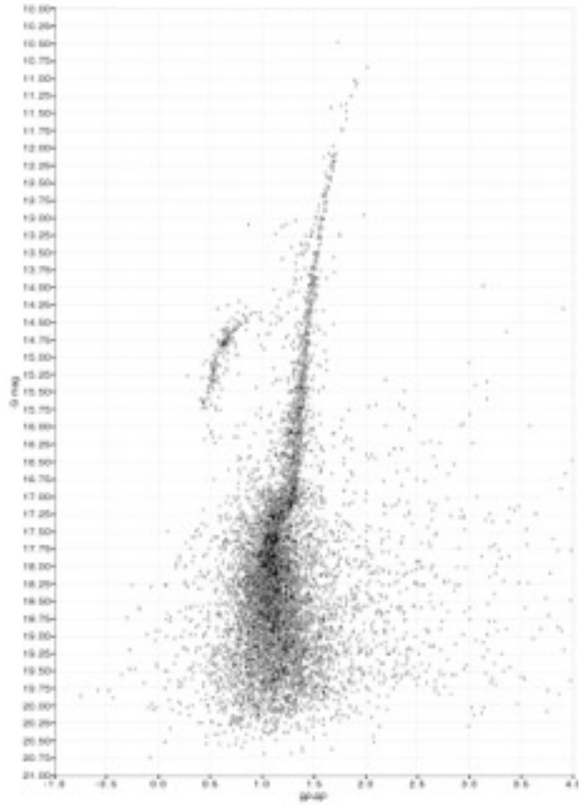
Omega Cen



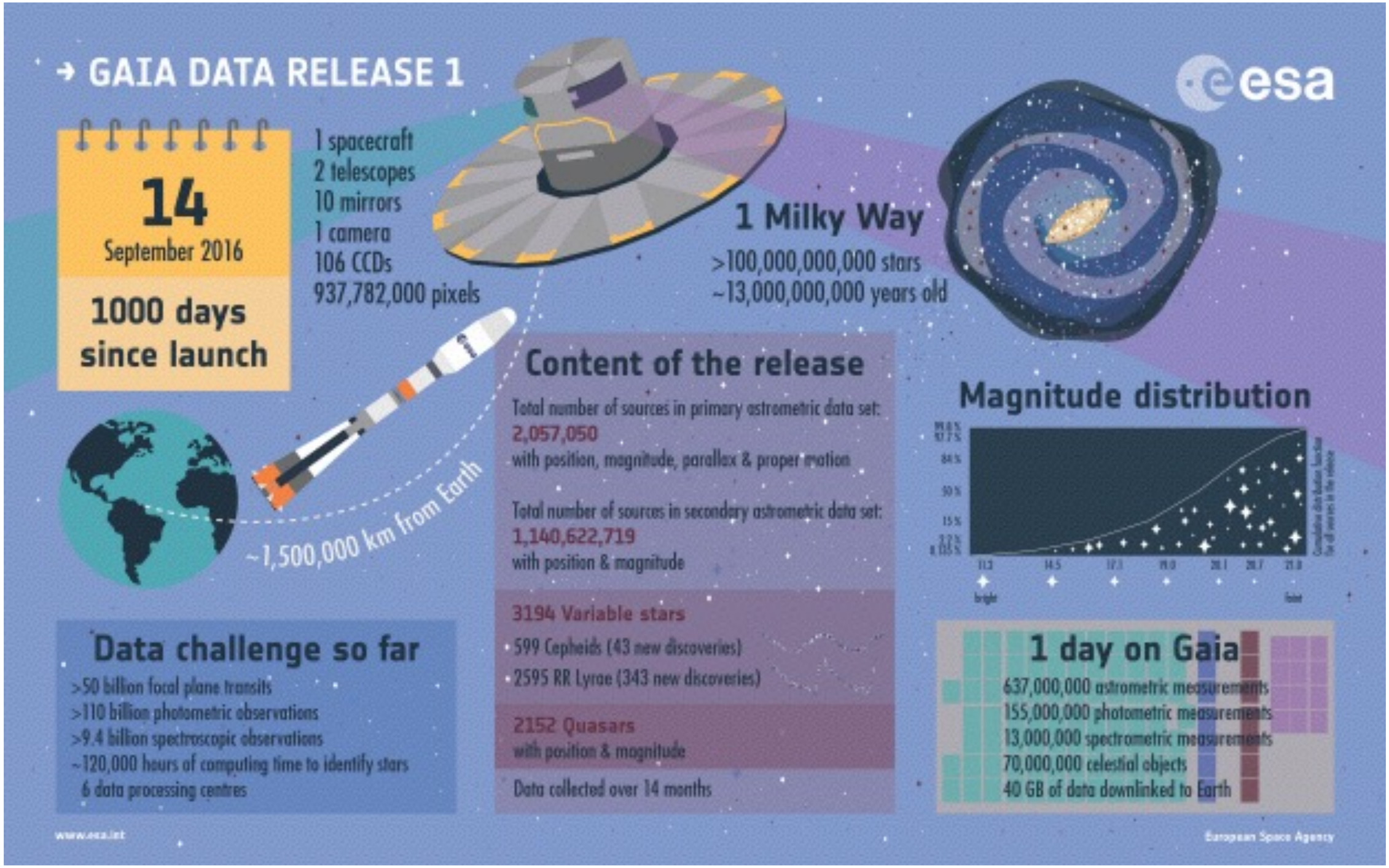
NGC 6397



NGC 6809

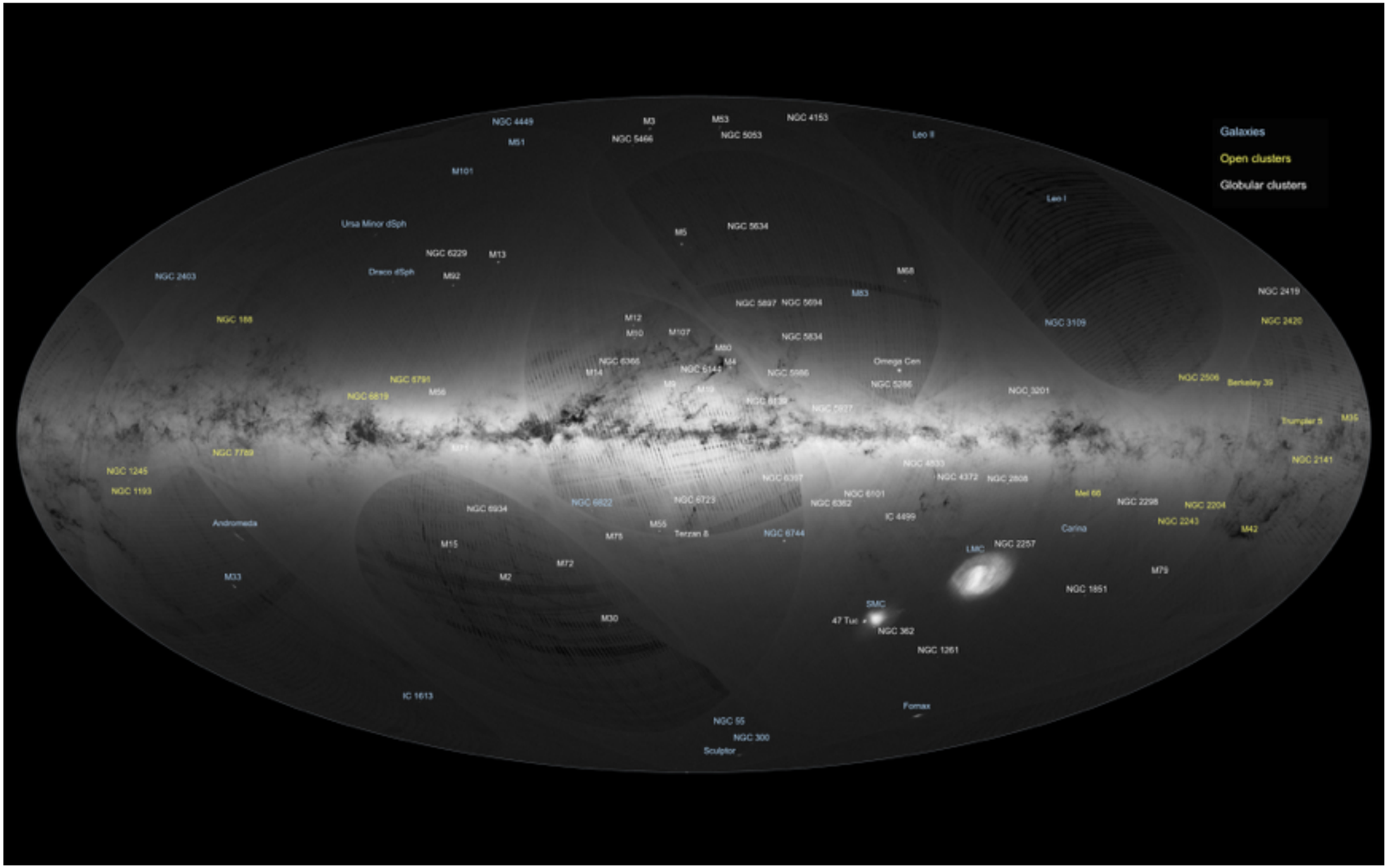


# Gaia Data Release 1



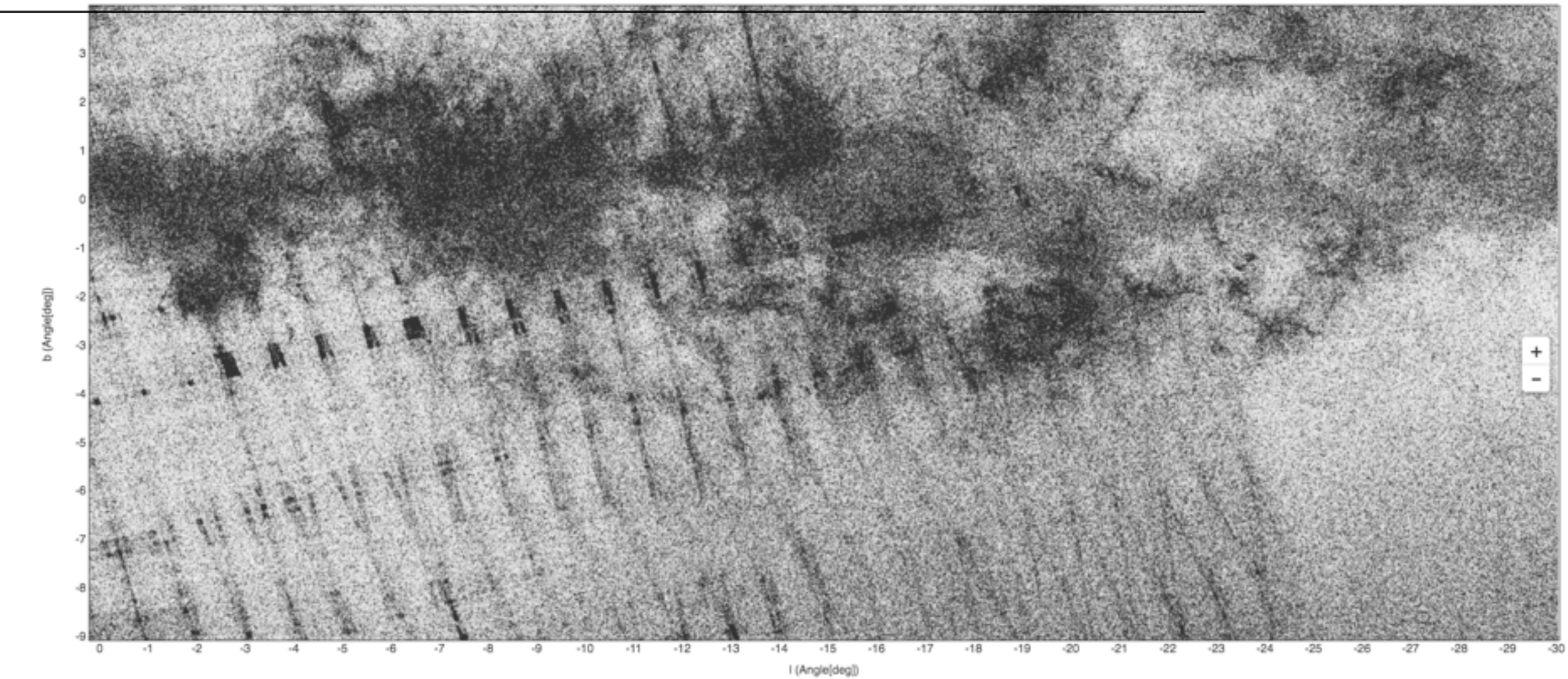

Data between 25 July 2014 and 16 September 2015.

# The Gaia Sky




http://www.esa.int/spaceinimages/Images/2016/09/Gaia_s_first_sky_map_annotated

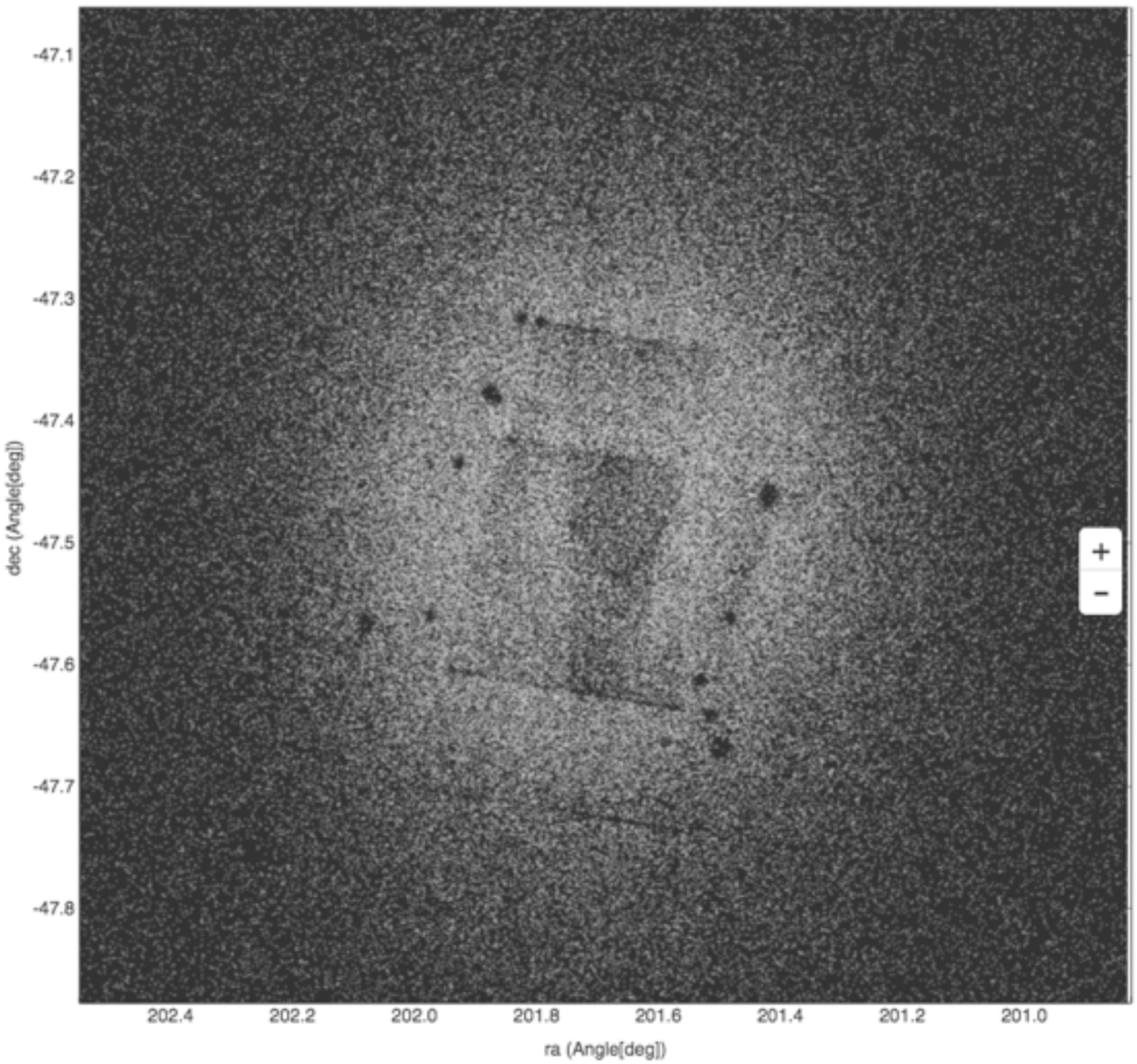
# The Gaia Sky… zooming in




Scanning pattern is visible

- dense regions
- areas with poor scanning law coverage
- filtering on number of observations

# The Gaia Sky… zooming in

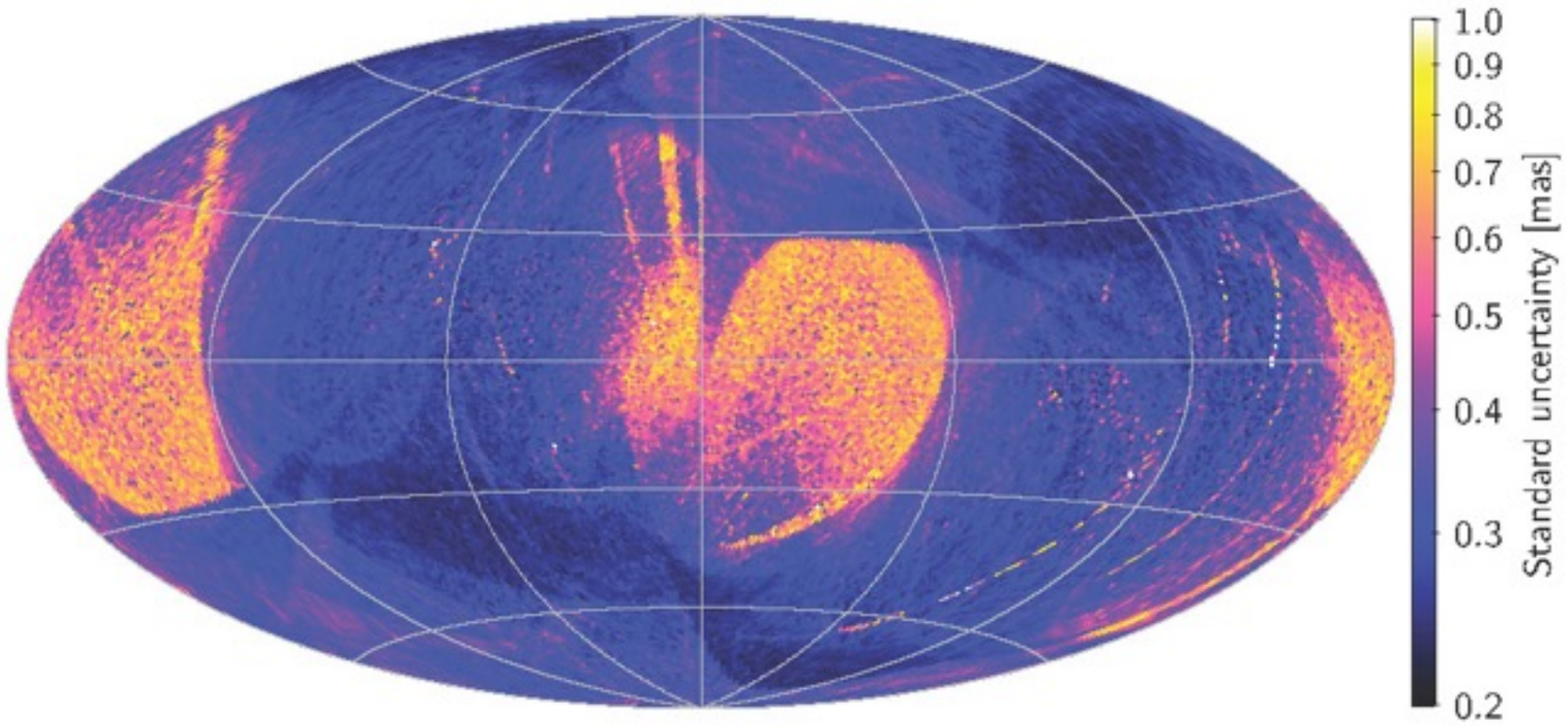



OmegaCen saturation effects in dense core

# Astrometry

**Primary** data set**: positions, parallaxes, mean proper motions**
for **~2x10e6** stars in T-GAS
σ ~ **0.3 mas** for the positions
σ ~ **1 mas yr** for the proper motions. Only Hipparcos (~9x10e5) 0.06 mas yr−1
σ ~ **0.3 mas** for the parallaxes

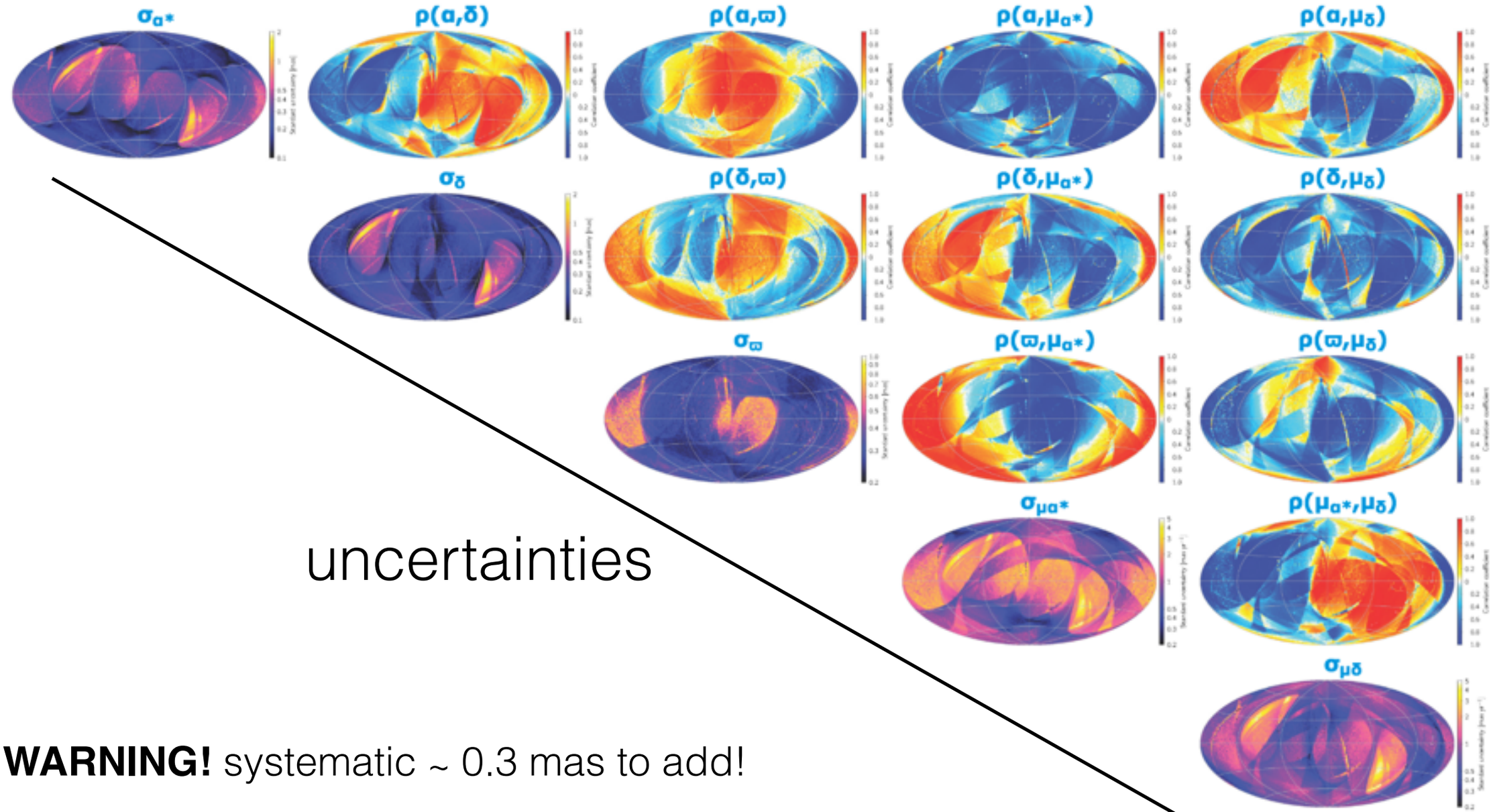
**Secondary** data set: **positions** for more than **1x10e9** sources.
σ ~ **10 mas**




parallax uncertainty

**Astrometry:** more statistics

correlations



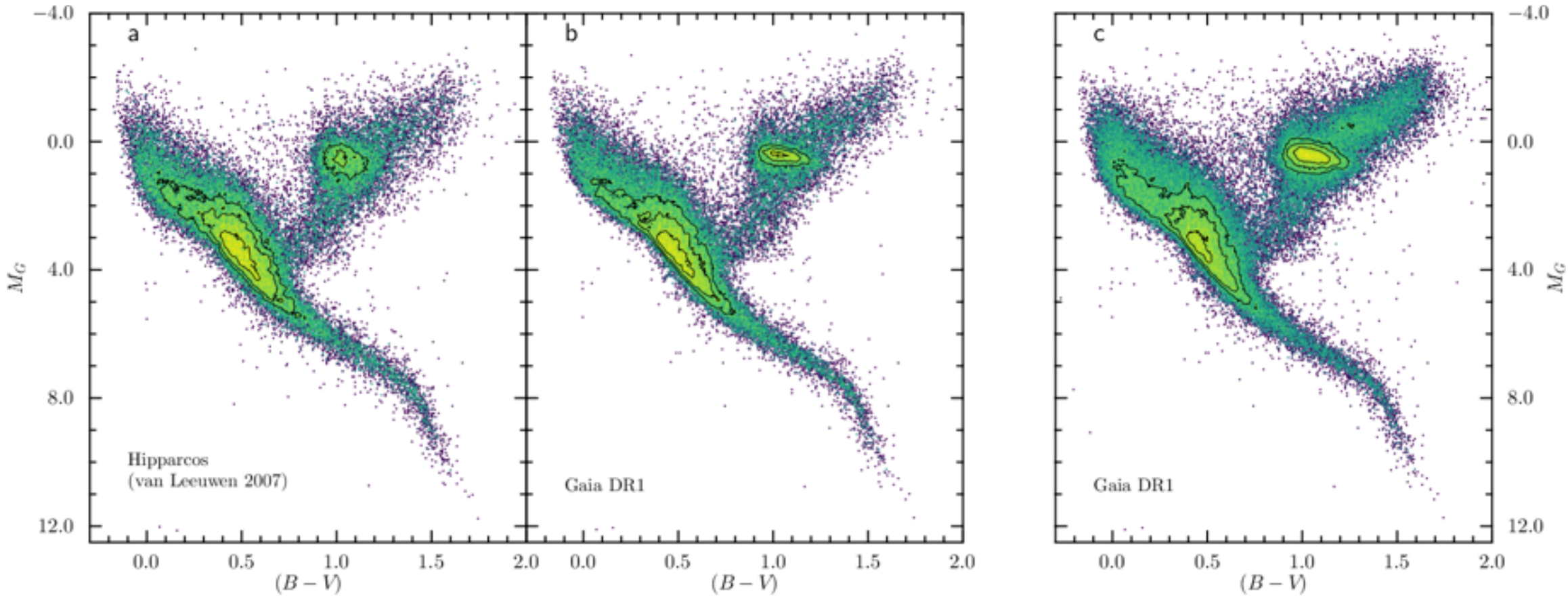

uncertainties

**WARNING!** systematic ~ 0.3 mas to add!

# Astrometry

## Comparison with Hipparcos

B-V from Hipparcos
G from Gaia




Selected on parallaxes and magnitude on both catalogues

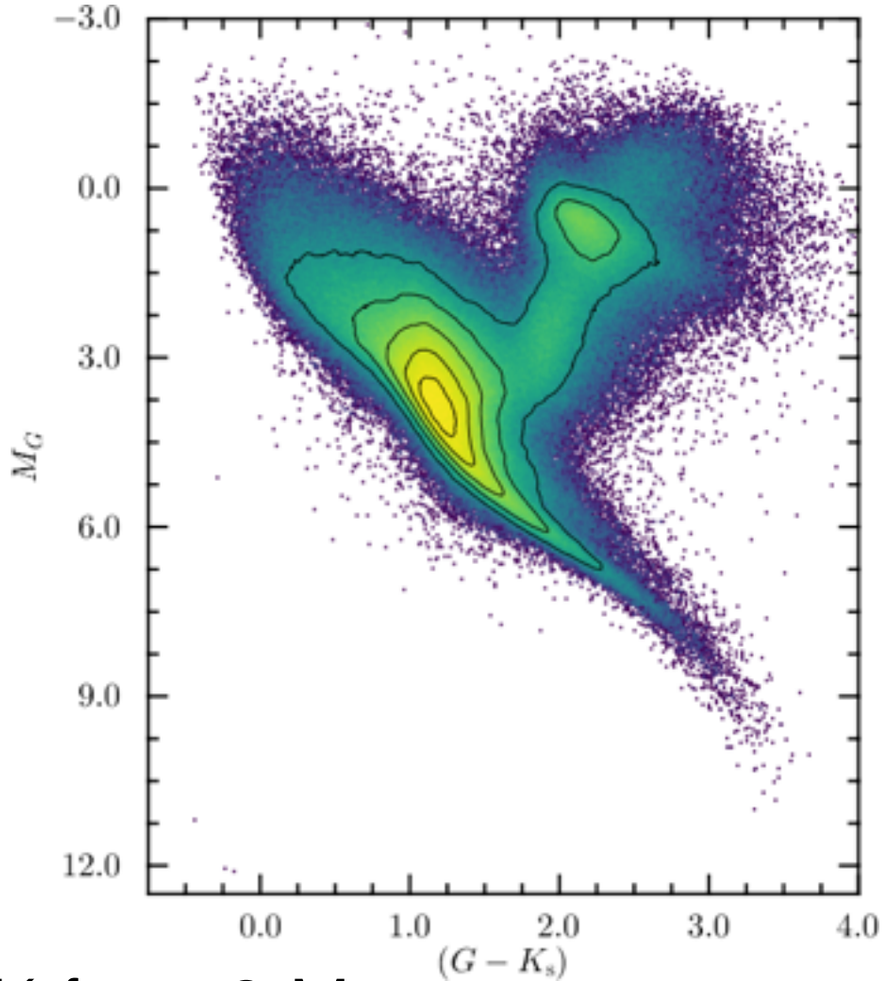
$(\omega/\sigma)_{Gaia} \geq 5$ $\quad \sigma_G < 0.05$

$(\omega/\sigma)_{Hipparcos} \geq 5$ $\quad \sigma_{B-V} < 0.05$

Same selection in magnitude, but only selected in Gaia parallaxes

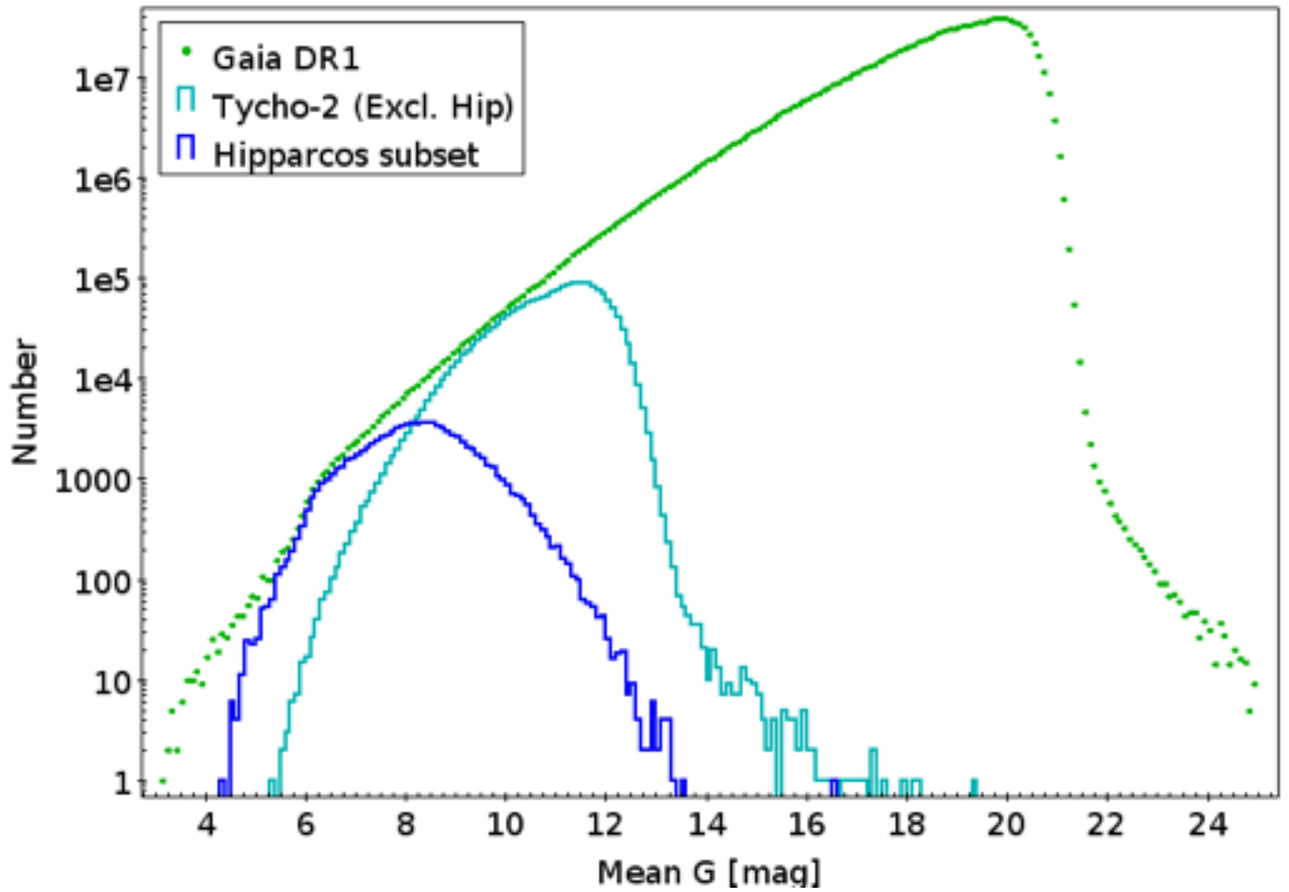
# Photometry

## All GDR1



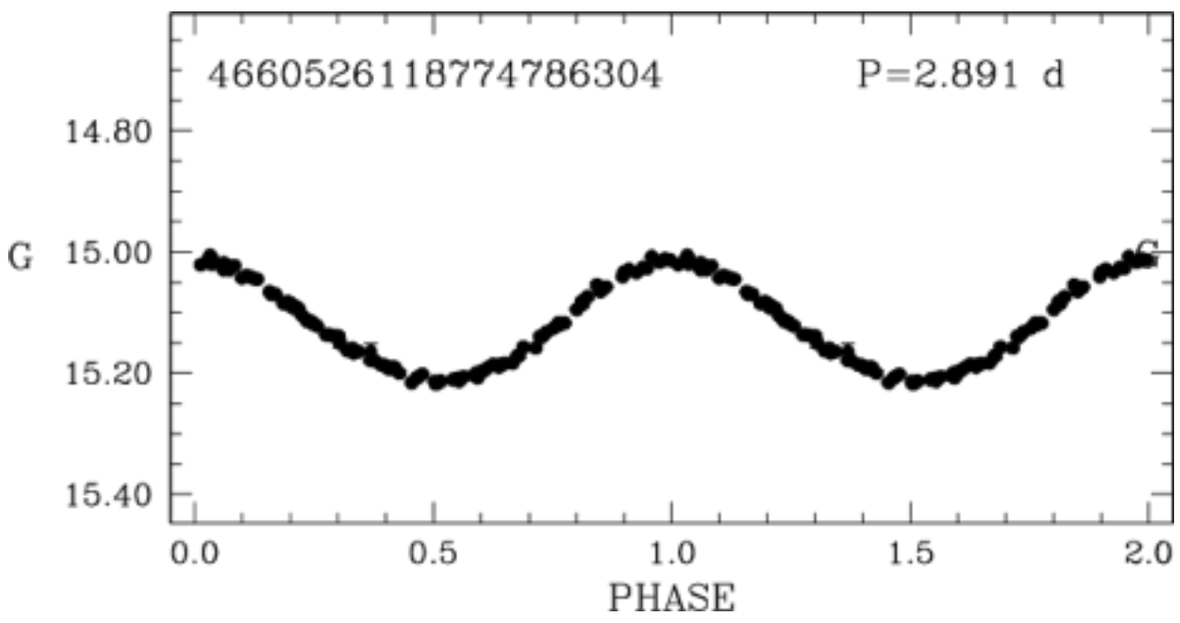

K from 2-Mass
G from Gaia
10%, 30%, 50%, 70%, and 90%

**mean Gaia G-band magnitudes**
for **all** the sources contained in Gaia DR1.
G max = 3.2,
99.7% with 11.2 ≤ G ≤ 21.
σ ~ **0.1** for **G>13**
σ ~ **0.03** at **G ~21**

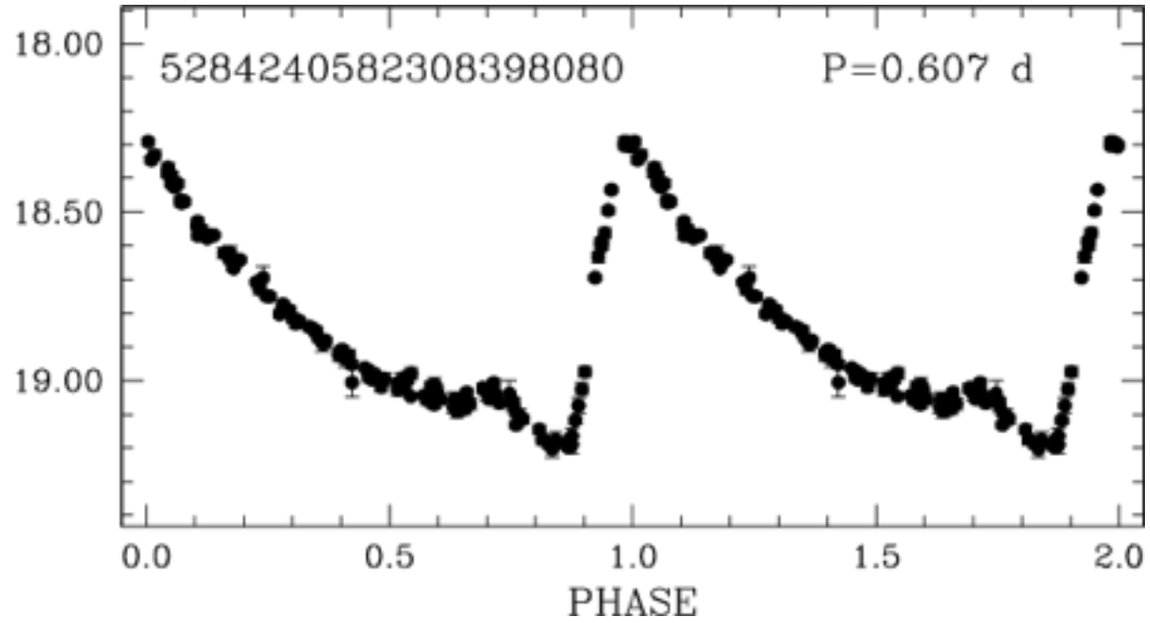


# Variables

**G-band light curves** and characteristics
for 599 Cepheid (43 new) and 2595 RR-Lyrae (343 new)
observed during the EPSL




Cepheid

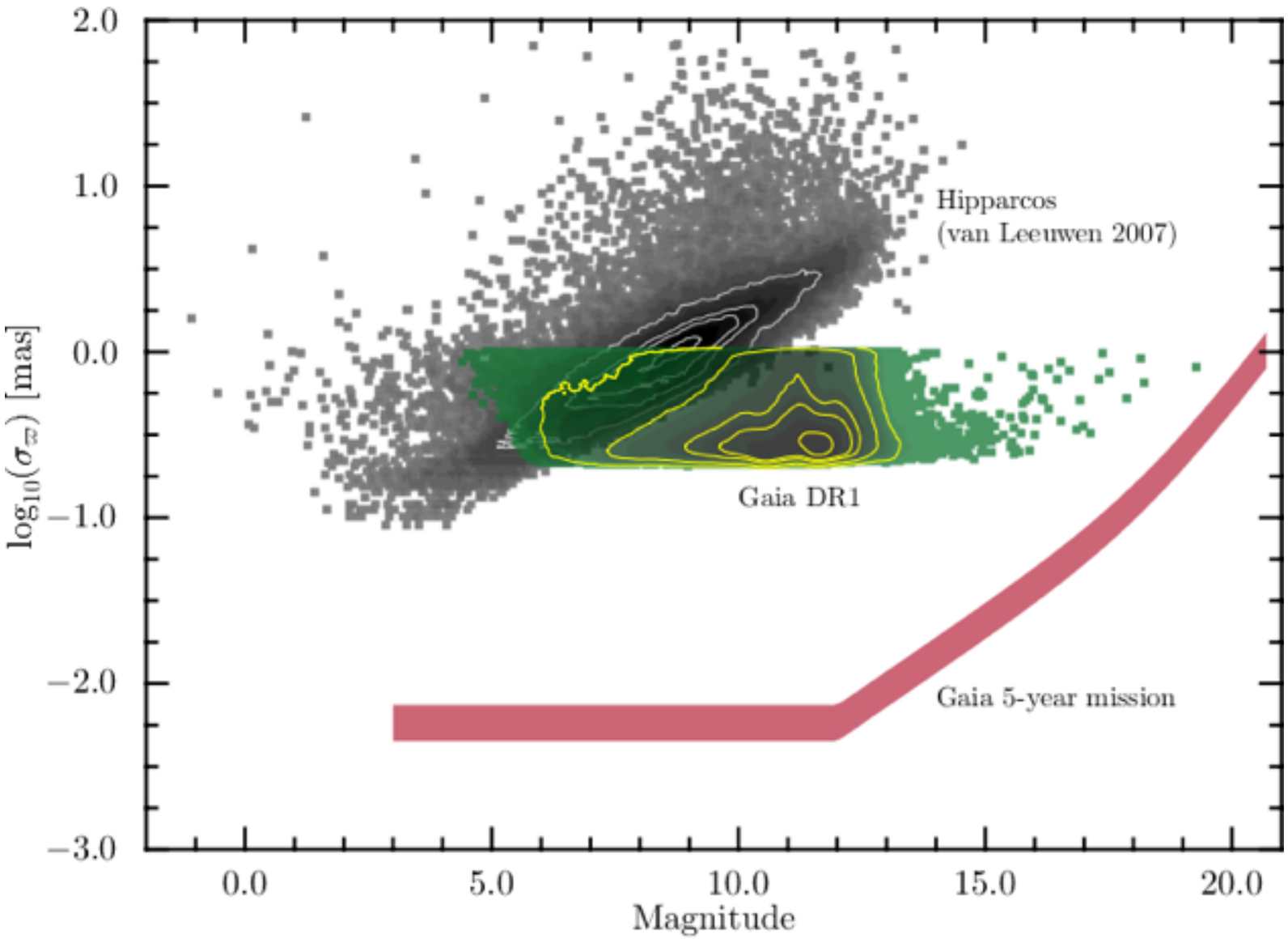



RRab

## Known problems :(

- **Accurate PSF modeling**
- **Photometric Calibration not yet accurated**
- **Source modelling**: All sources were treated as single stars without taking their radial velocity into account (binaries?)
- **Basic Angle Periodic Variation**: ~ 1 μas, ok for GDR1 accuracy, will be better calibrated in future releases in the astrometric solution
- **Correlated astrometric parameters:** especially in certain region of the sky, will improve in future releases
- **Colour dependent** and **Spatially correlated systematics:** caused by incomplete model of the attitude -> 0.3 mas in the parallaxes

# Astrometry: comparison with Hipparcos



# The gory details

The Gaia mission,  Gaia Collaboration, Prusti, T., de Bruijne, J.H.J., et al., 2016a (arXiv 1609.04153)

Gaia Data Release 1: Summary of the astrometric, photometric, and survey properties,Gaia Collaboration, Brown, A.G.A., Vallenari, A., et al., 2016b (arXiv 1609.04153),

Gaia Data Release 1: Astrometry: one billion positions, two million proper motions and parallaxes, Lindegren et al. (arXiv 1609.04303)

Gaia Data Release 1: The photometric data, van Leeuwen et al,

Gaia Data Release 1: Data validation: procedures, statistics and conclusions, Arenou et al.

Gaia Data Release 1: The variability processing & analysis and its application to the south ecliptic pole region,  Eyer et al.

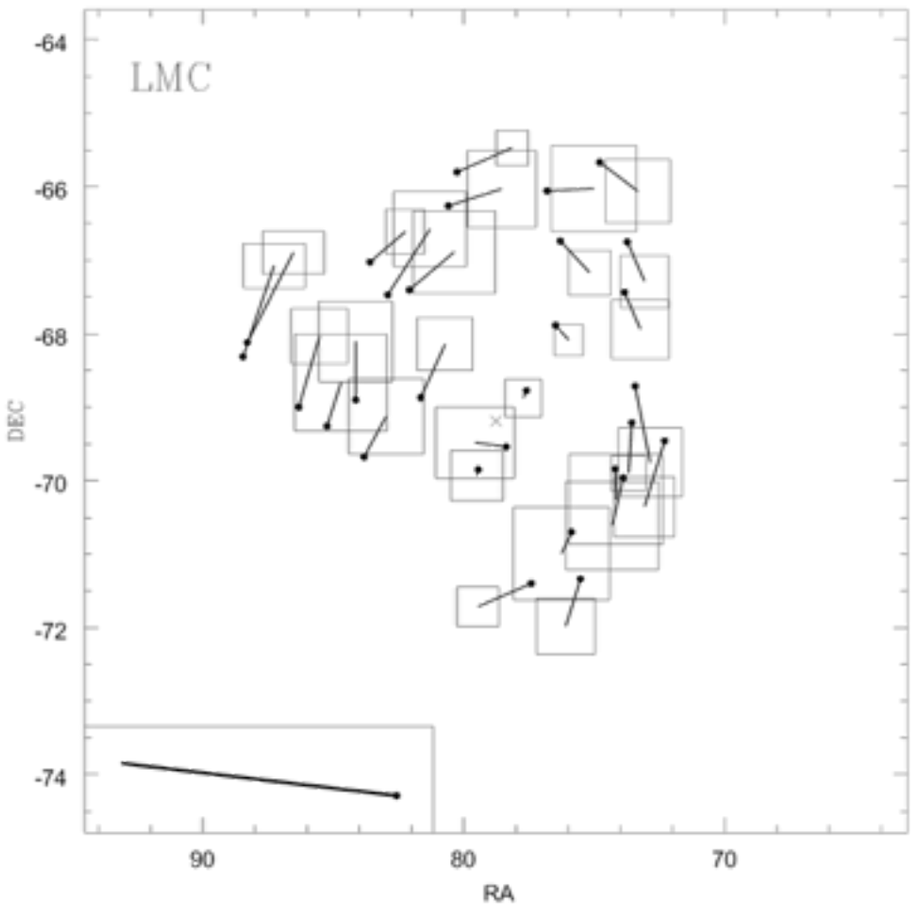
Gaia Data Release 1: The Cepheid & RR Lyrae star pipeline and its application to the south ecliptic pole region, Clementini et al. (arXiv 1609.04269)

Gaia Data Release 1: Open cluster distances, Gaia Collaboration et al.

and more…

# The fastest paper!

First Gaia Local Group Dynamics: Magellanic Clouds Proper Motion and Rotation, **arXiv 1609.04395**, Roeland P. van der Marel, Johannes Sahlmann




Gaia proper motions have similar accuracy agree to within the uncertainties with existing HST measurements.

The TGAS LMC proper-motion field clearly shows the clockwise rotation of the disk.

# Gaia: future releases

## Gaia-DR2 : Q4 2017

- full astrometric solution (positions, parallaxes, and proper motions ) for 90% of the sky (single sources)
- integrated BP/RP photometry, with appropriate standard errors, for sources with verified astrophysical parameter
- mean radial velocities for objects showing no radial-velocity variation and for which an adequate synthetic template could be selected

**under the assumption that this can be done for 90% of the bright stars on the sky!**

## Data Releases Scenario

### Gaia-DR3 : 2018 (TBD) :

- Orbital solutions + radial velocity and five-parameter astrometric solutions for binaries with P>2months
- Object classification and astrophysical parameters + BP/RP spectra and/or RVS spectra they are based on, for well-behaved objects (non variable)
- Mean Radial velocity for non variable objects

### Gaia-DR4 : Summer 2019 (TBD):

- variable epoch spectra
- Solar System Objects
- Non single stars

### Gaia-DR final : Summer 2022 (TBD): everything!

# Gaia Archive

Where are the data:

http://gea.esac.esa.int/archive

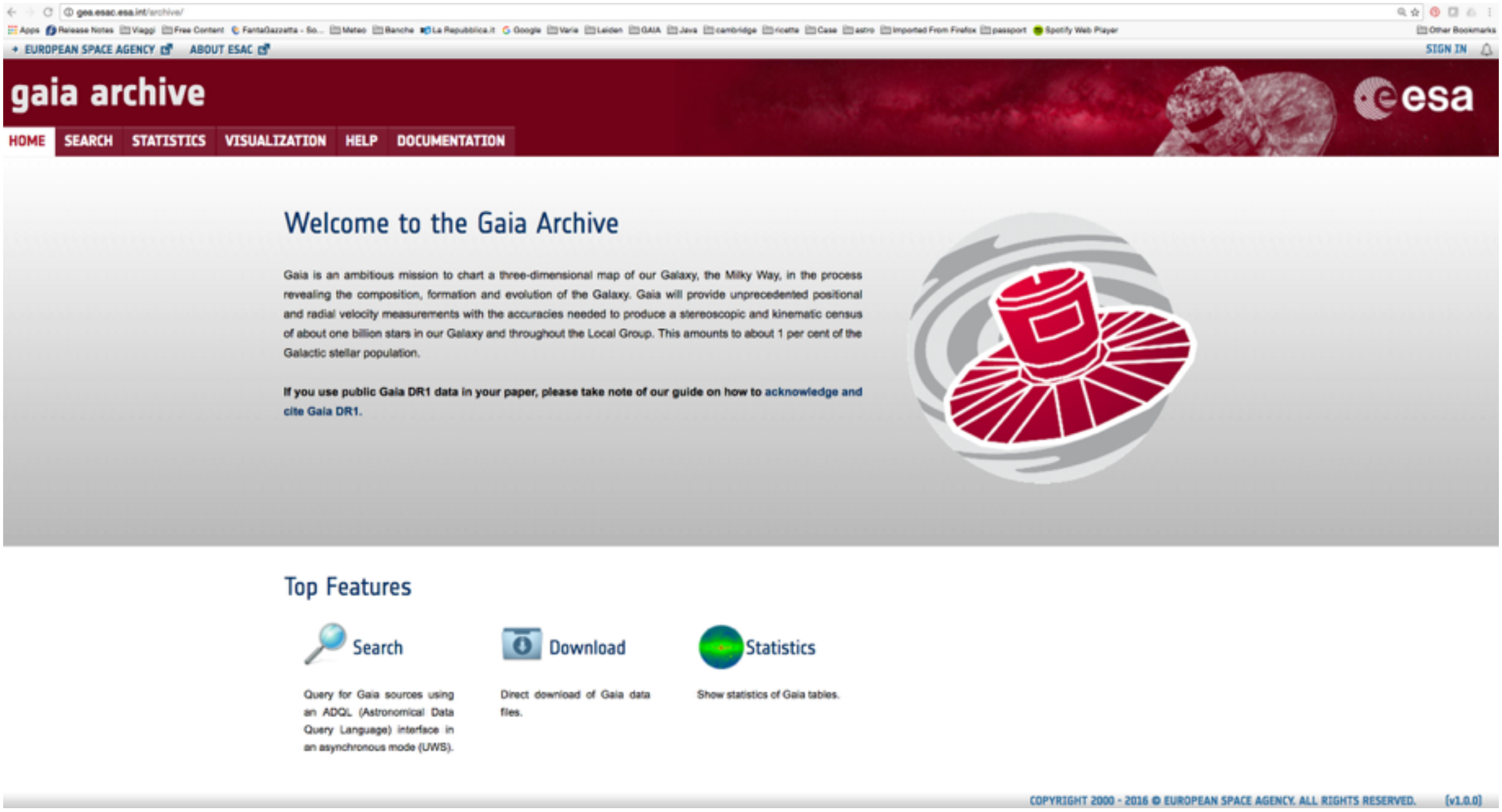
http://gaia.ari.uni-heidelberg.de/

http://cdsxmatch.u-strasbg.fr/xmatch

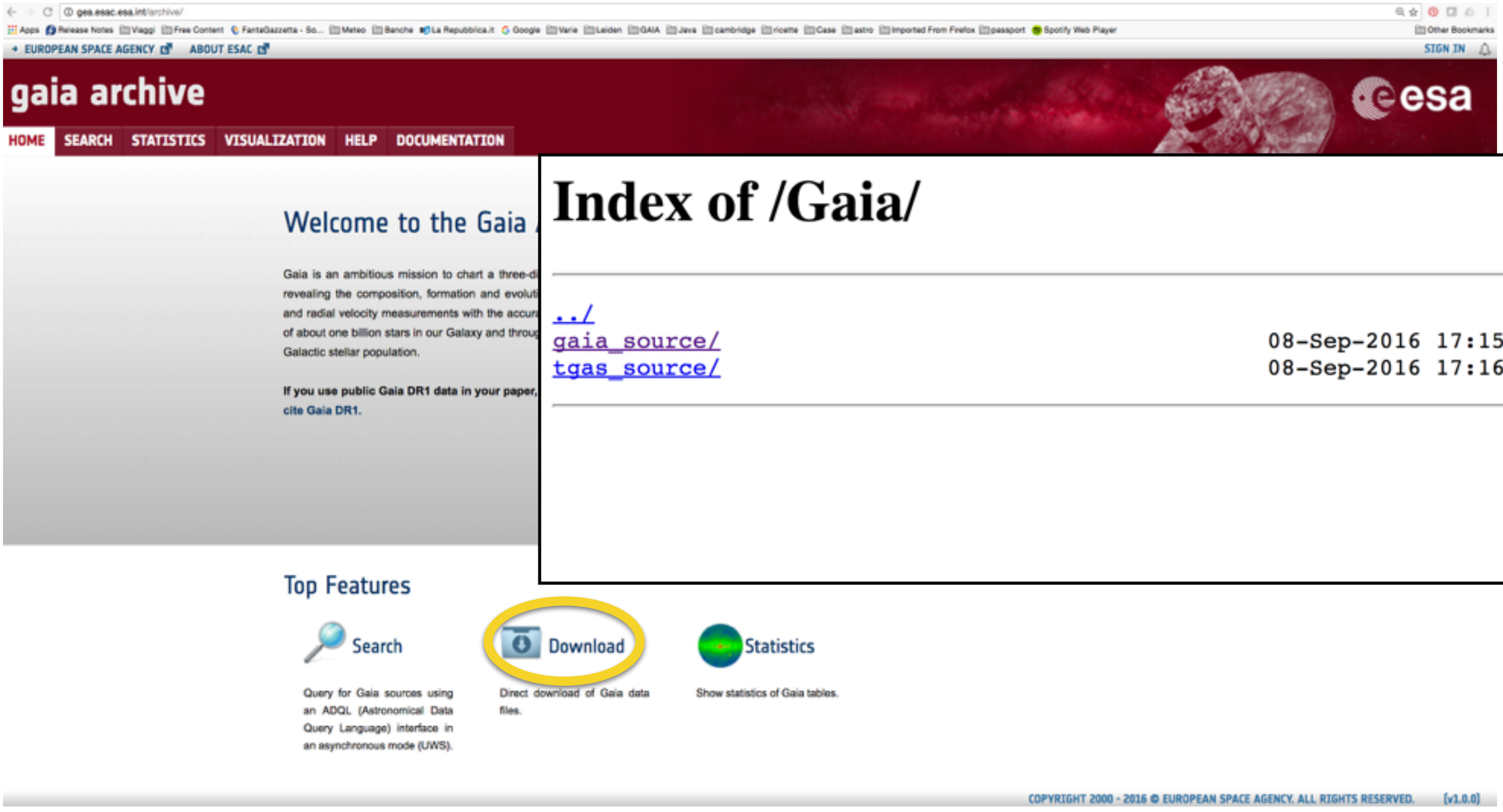

https://gaia.aip.de/


http://gaiaportal.asdc.asi.it/

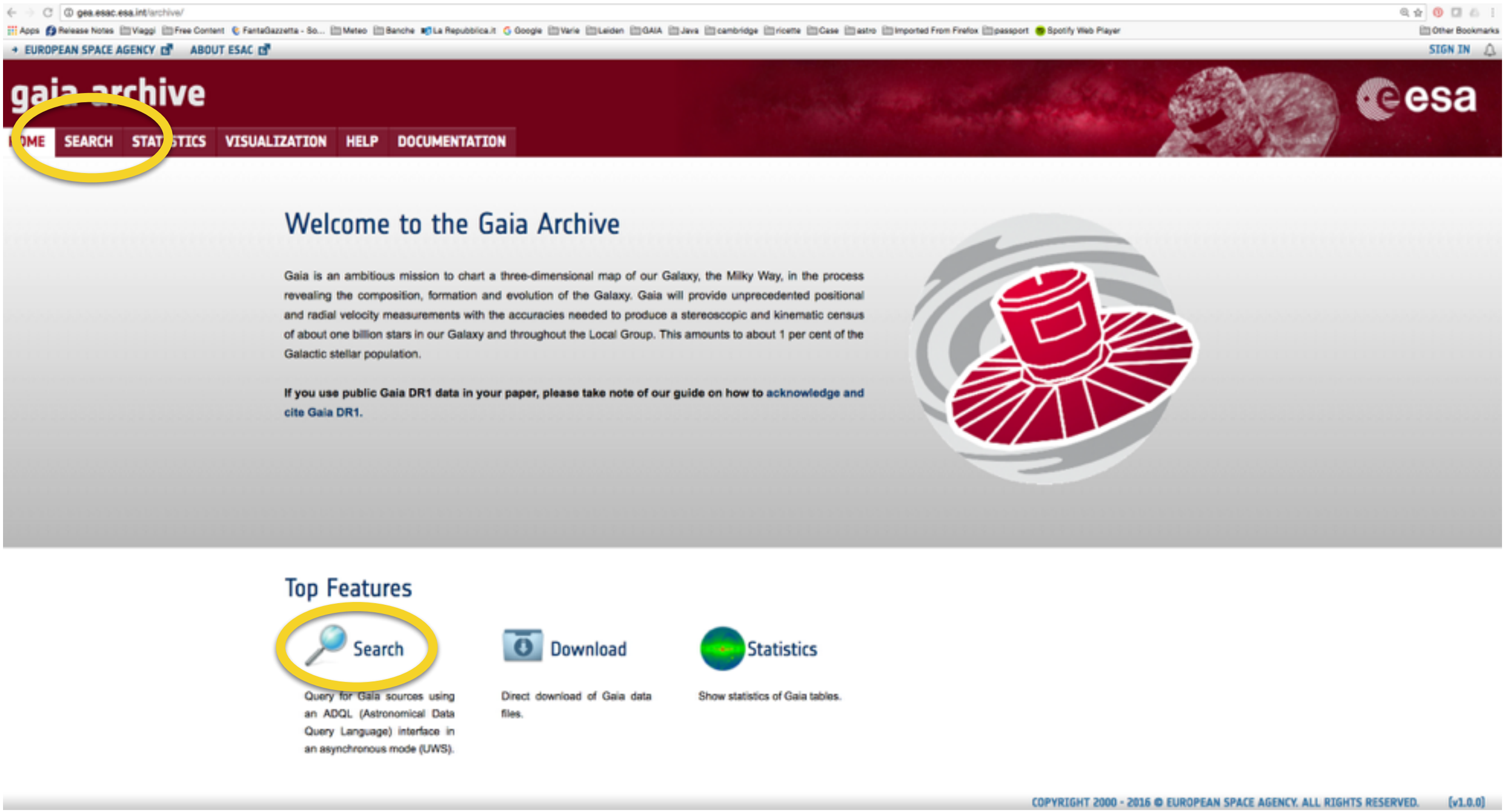
# Gaia Archive



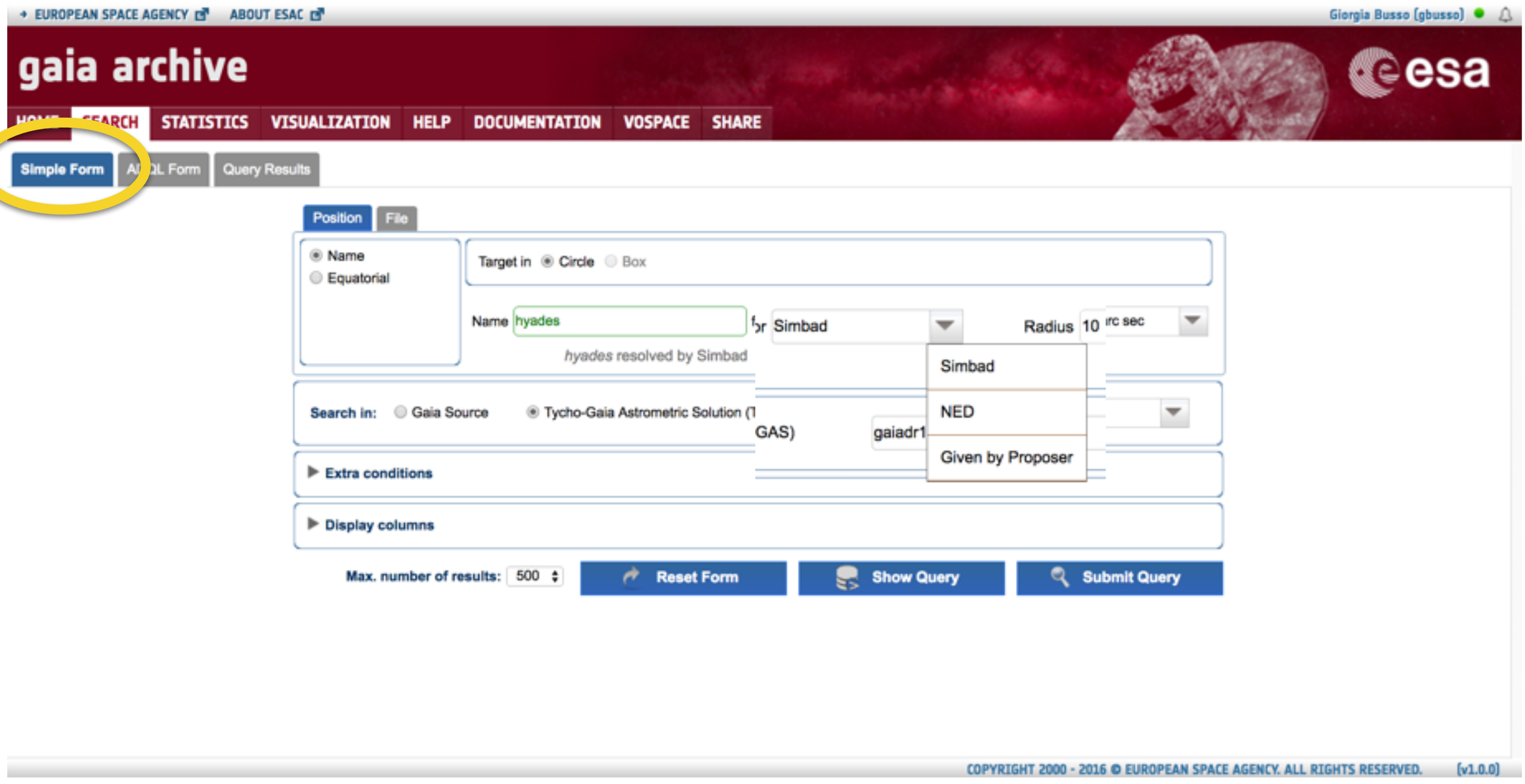
# Download everything!



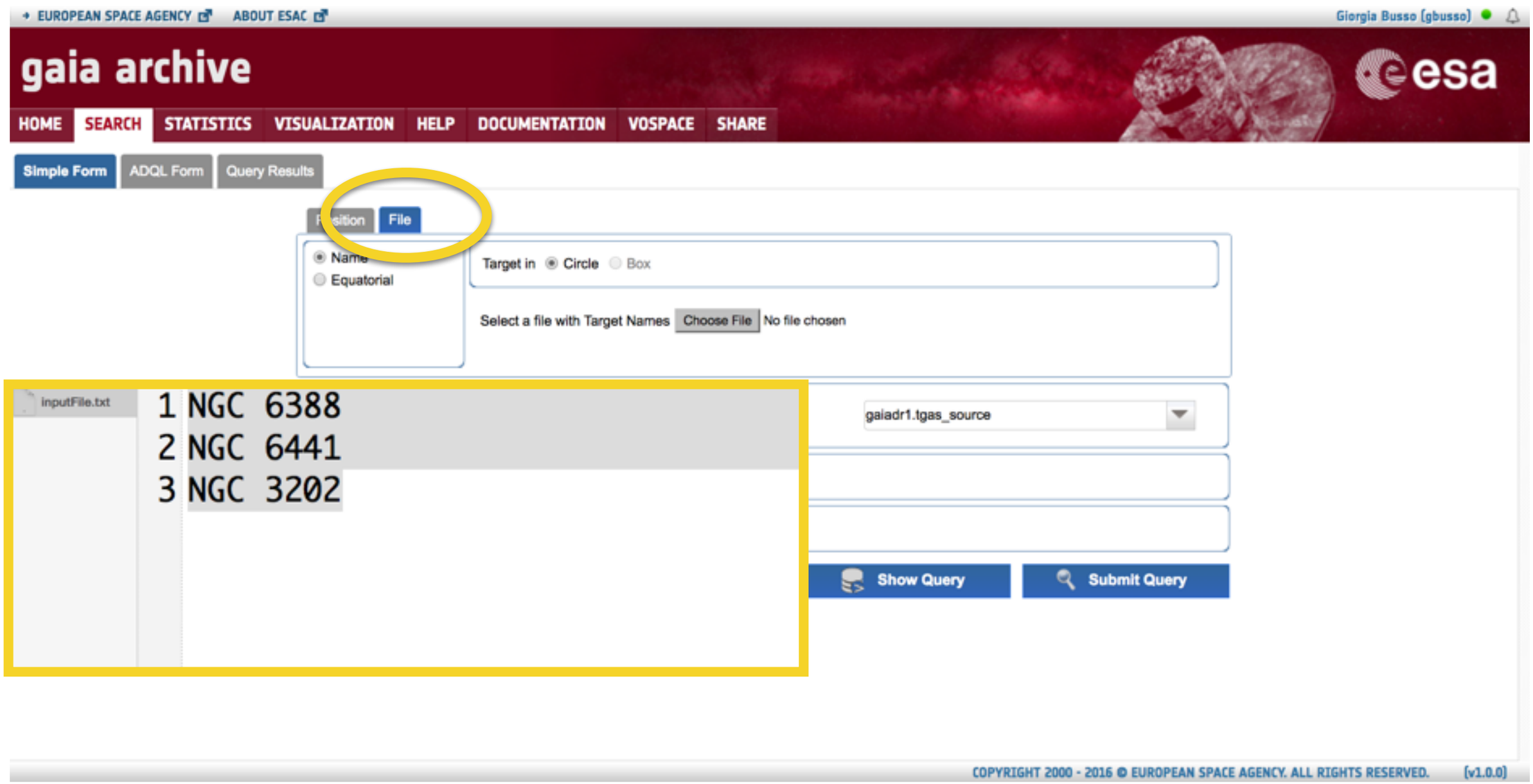
# Gaia Archive



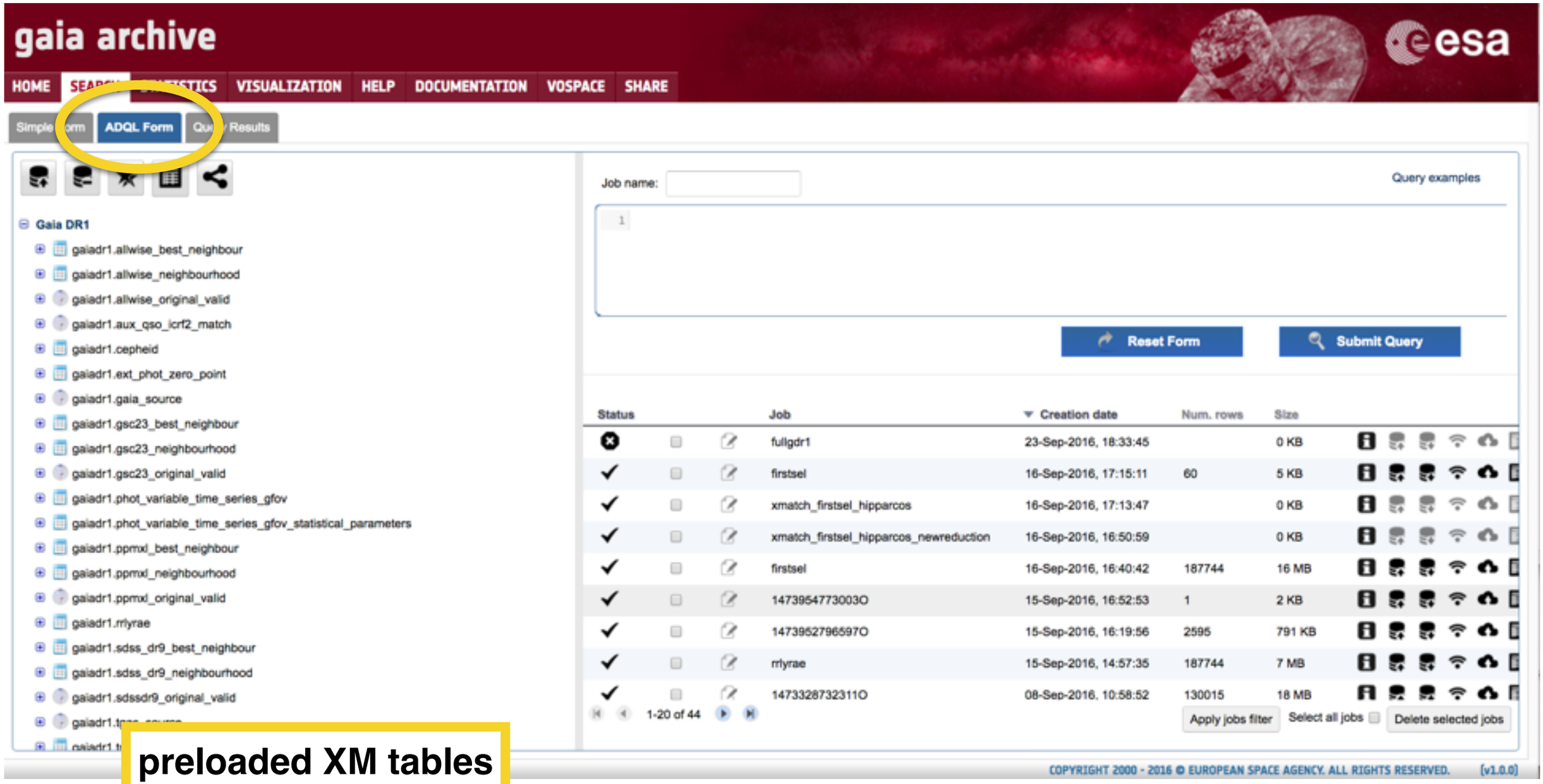
# Simple Search



# Simple Search: input file



# ADQL


gaia archive
esa
HOME
SEARCH
STATISTICS
VISUALIZATION
HELP
DOCUMENTATION
VOSPACE
SHARE
Simple Form
ADQL Form
Query Results
Job name:
Query examples
1
Reset Form
Submit Query
Gaia DR1
gaiadr1.allwise_best_neighbour
gaiadr1.allwise_neighbourhood
gaiadr1.allwise_original_valid
gaiadr1.aux_qso_icrf2_match
gaiadr1.cepheid
gaiadr1.ext_phot_zero_point
gaiadr1.gaia_source
gaiadr1.gsc23_best_neighbour
gaiadr1.gsc23_neighbourhood
gaiadr1.gsc23_original_valid
gaiadr1.phot_variable_time_series_gfov
gaiadr1.phot_variable_time_series_gfov_statistical_parameters
gaiadr1.ppmxl_best_neighbour
gaiadr1.ppmxl_neighbourhood
gaiadr1.ppmxl_original_valid
gaiadr1.rrlyrae
gaiadr1.sdss_dr9_best_neighbour
gaiadr1.sdss_dr9_neighbourhood
gaiadr1.sdssdr9_original_valid
Status
Job
Creation date
Num. rows
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firstsel 16-Sep-2016, 17:15:11 60 5 KB
xmatch_firstsel_hipparcos 16-Sep-2016, 17:13:47 0 KB
xmatch_firstsel_hipparcos_newreduction 16-Sep-2016, 16:50:59 0 KB
firstsel 16-Sep-2016, 16:40:42 187744 16 MB
1473954773003O 15-Sep-2016, 16:52:53 1 2 KB
1473952796597O 15-Sep-2016, 16:19:56 2595 791 KB
rrlyrae 15-Sep-2016, 14:57:35 187744 7 MB
1473328732311O 08-Sep-2016, 10:58:52 130015 18 MB
1-20 of 44
Apply jobs filter
Select all jobs
Delete selected jobs
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(v1.0.0)
preloaded XM tables

## ADQL

https://gaia.ac.uk/science/gaia-data-release-1/adql-cookbook

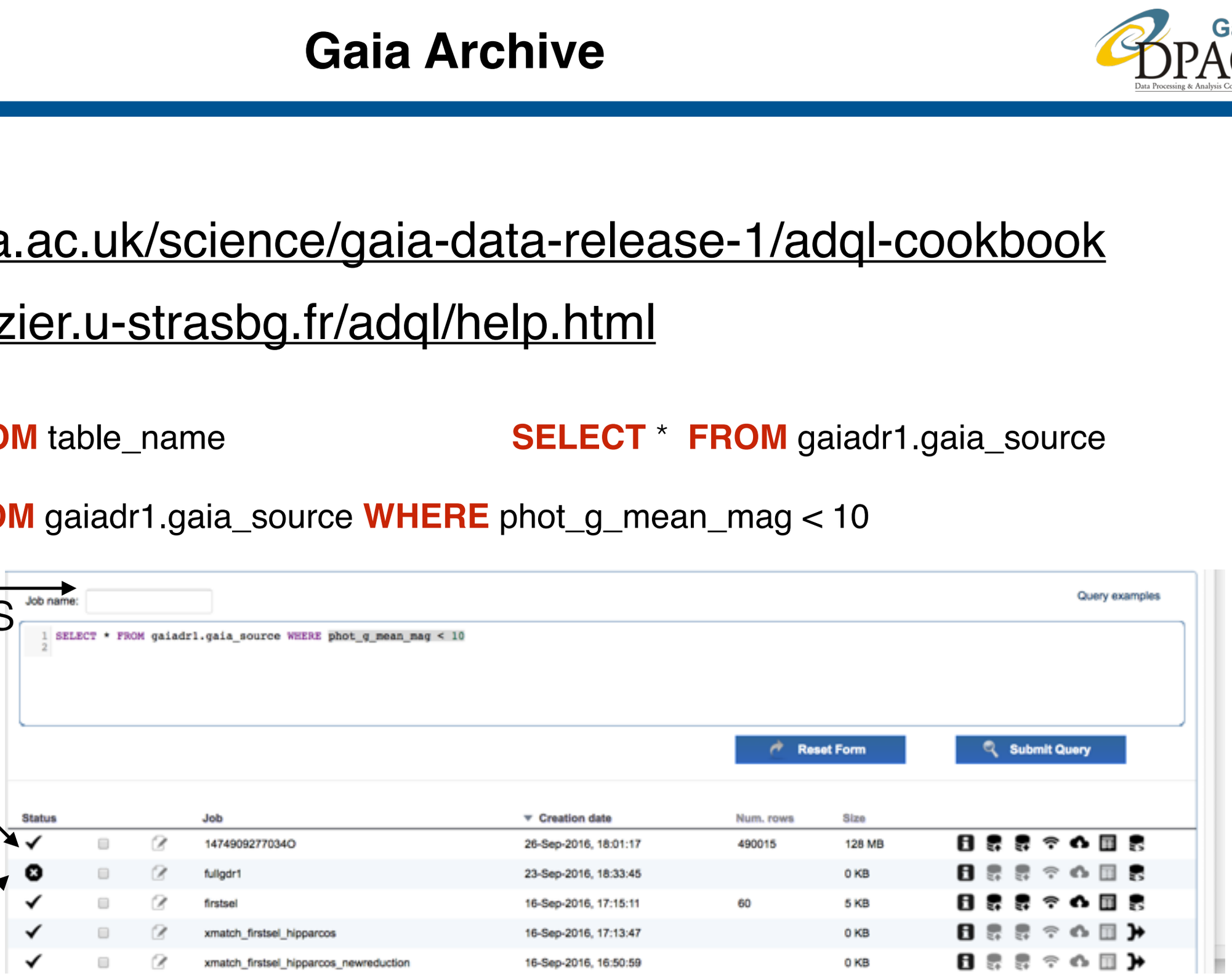
http://tapvizier.u-strasbg.fr/adql/help.html

**SELECT** * **FROM** table_name

**SELECT** * **FROM** gaiadr1.gaia_source

**SELECT** * **FROM** gaiadr1.gaia_source **WHERE** phot_g_mean_mag < 10

brightstars




good

bad

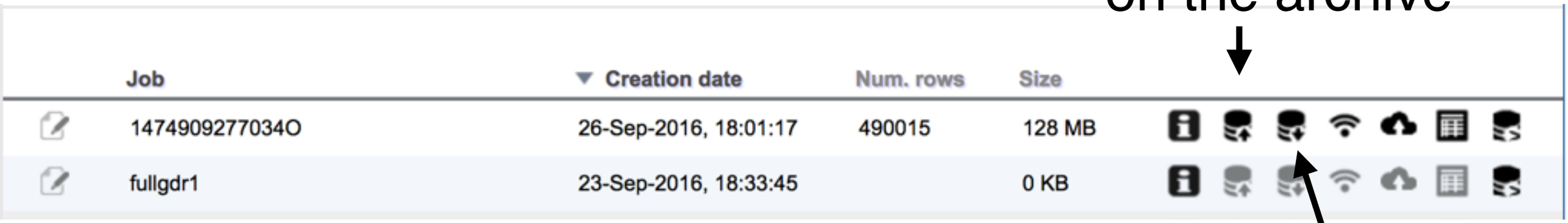
# ADQL : query results

info

| Job | Creation date | Num. rows | Size |
|---|---|---|---|
| 14749092770340 | 26-Sep-2016, 18:01:17 | 490015 | 128 MB |
| fullgdr1 | 23-Sep-2016, 18:33:45 | | 0 KB |

# ADQL : query results

upload the table
on the archive

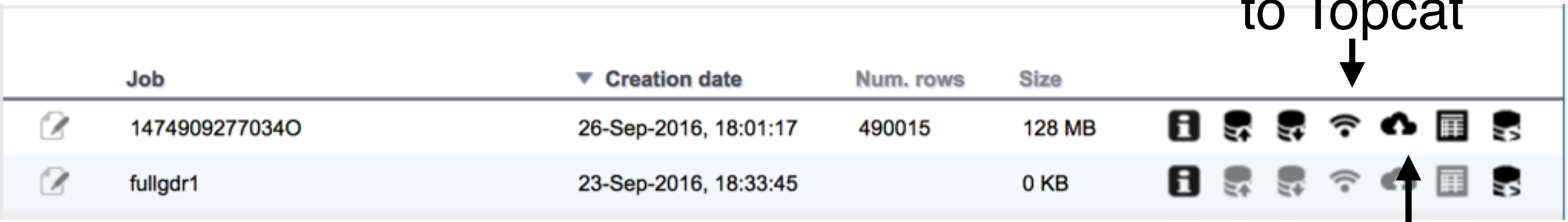


| Job | Creation date | Num. rows | Size |
|---|---|---|---|
| 14749092770340 | 26-Sep-2016, 18:01:17 | 490015 | 128 MB |
| fullgdr1 | 23-Sep-2016, 18:33:45 | | 0 KB |

download the table

# ADQL : query results

send it
to Topcat



| Job | Creation date | Num. rows | Size |
|---|---|---|---|
| 14749092770340 | 26-Sep-2016, 18:01:17 | 490015 | 128 MB |
| fullgdr1 | 23-Sep-2016, 18:33:45 | | 0 KB |

send it
to VOspace

# ADQL : query results

gaia archive

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Simple Form | ADQL Form | Query Results

1474909277034O

| solution_id | source_id | random_index | ref_epoch | ra | ra_error | dec | dec_error |
|---|---|---|---|---|---|---|---|
| 1635378410781933568 | 3704342291310623488 | 534069337 | 2015 | 193.8989092776972 | 1.1907661927999527 | 3.3972436062113993 | 1.13898744007903 |
| 1635378410781933568 | 5589311353427428096 | 341482726 | 2015 | 109.28560014186127 | 2.596384220886428 | -37.09745047651609 | 3.443323785170246 |
| 1635378410781933568 | 329384512263823360 | 1104751764 | 2015 | 32.386693753639456 | 9.342913407306291 | 34.987129159781965 | 3.62454217932869 |
| 1635378410781933568 | 4629125166197136256 | 1020977432 | 2015 | 56.810529640189145 | 1.0646690352129475 | -74.23848479469156 | 0.94785853538478 |
| 1635378410781933568 | 2968097043220615808 | 999688351 | 2015 | 82.06132082333338 | 0.7455106999497315 | -20.759791133467935 | 0.91951071304680 |
| 1635378410781933568 | 2202629997292988928 | 224833179 | 2015 | 325.87694117487257 | 0.8501974726850964 | 58.78002891128556 | 0.86075771876503 |
| 1635378410781933568 | 2962546601148655488 | 793401152 | 2015 | 76.36537706401334 | 0.8598492653194981 | -22.371346268225047 | 0.92735119769610 |
| 1635378410781933568 | 5786929086547274112 | 36495278 | 2015 | 211.33122211767343 | 1.600122906095055 | -76.7968966538706 | 1.22020955416304 |
| 1635378410781933568 | 426558456578909056 | 749378401 | 2015 | 14.177423983107415 | 5.44391553002595 | 60.716724357505605 | 4.08715846223543 |
| 1635378410781933568 | 4473334470304897024 | 828121356 | 2015 | 265.8679594521625 | 2.075681012358508 | 4.567967792113831 | 2.07059623652664 |
| 1635378410781933568 | 2199493434211840512 | 439710857 | 2015 | 332.713762075799 | 1.355170104322635 | 58.20128624278751 | 1.39835043622160 |

1-20 of 2,000

Show query in ADQL form



see the result

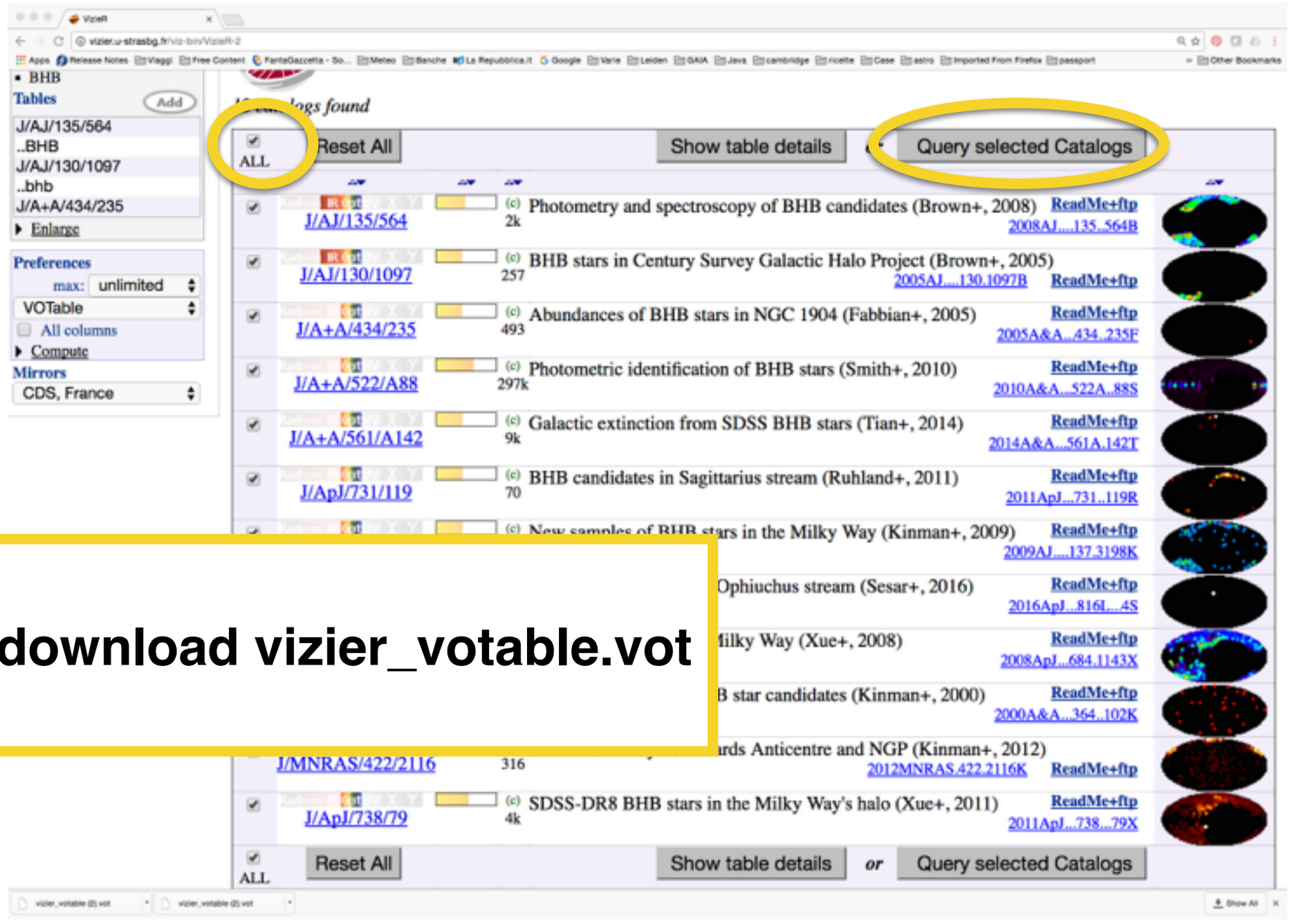
see the query

# ADQL Search: input file

example: BHB stars

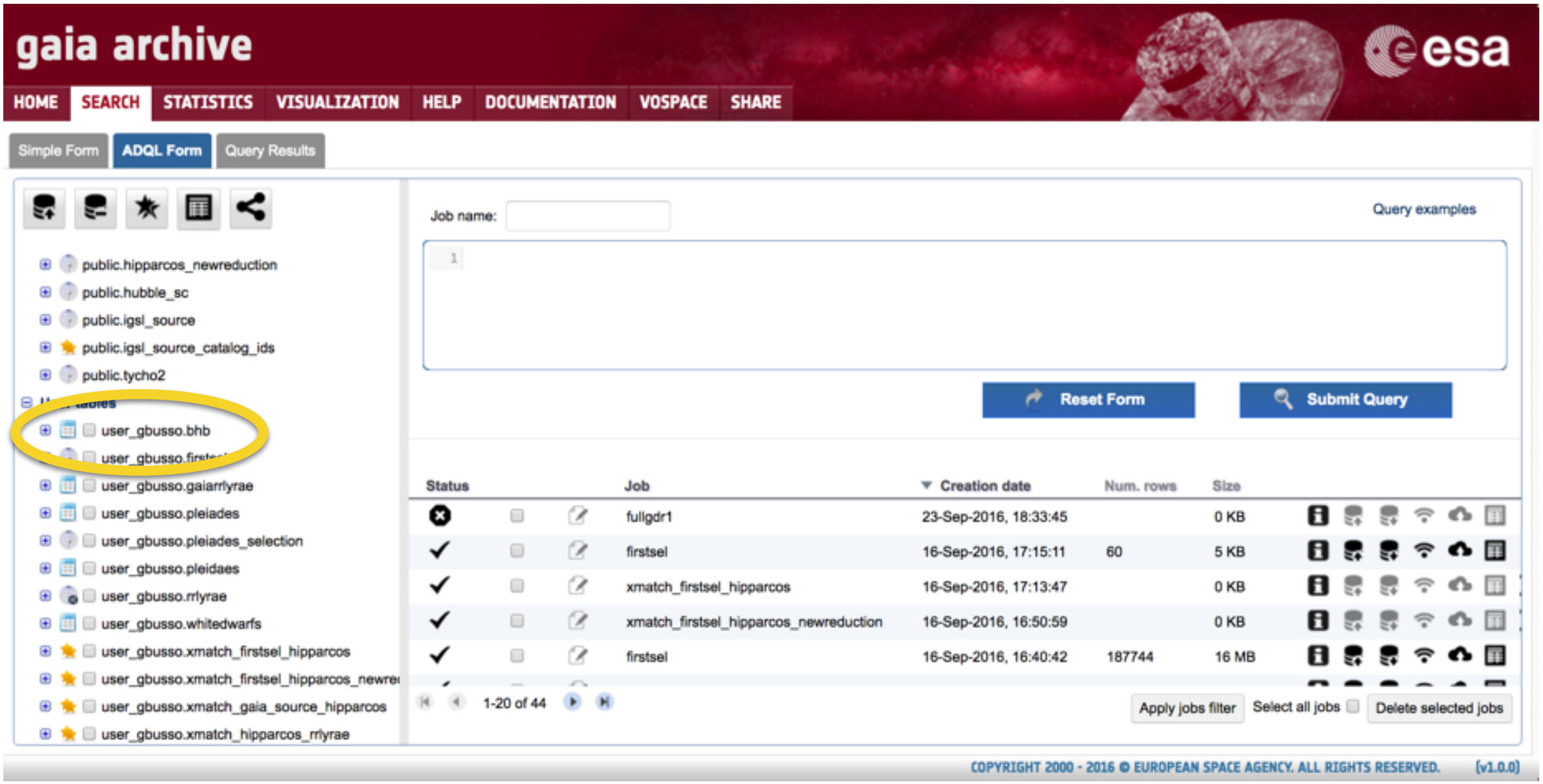
# ADQL Search: input file

# example: BHB stars




**download vizier_votable.vot**

# ADQL Search: input file



## Cross Match example

BHB in Gaia DR1..

## Cro

BH

2 st

GAIA Cross-Match

Table A: gaiadr1.gaia_source

Table B: user_gbusso.bhb

Output table name: xmatch_gaia_source_bhb

Job name:

Query examples

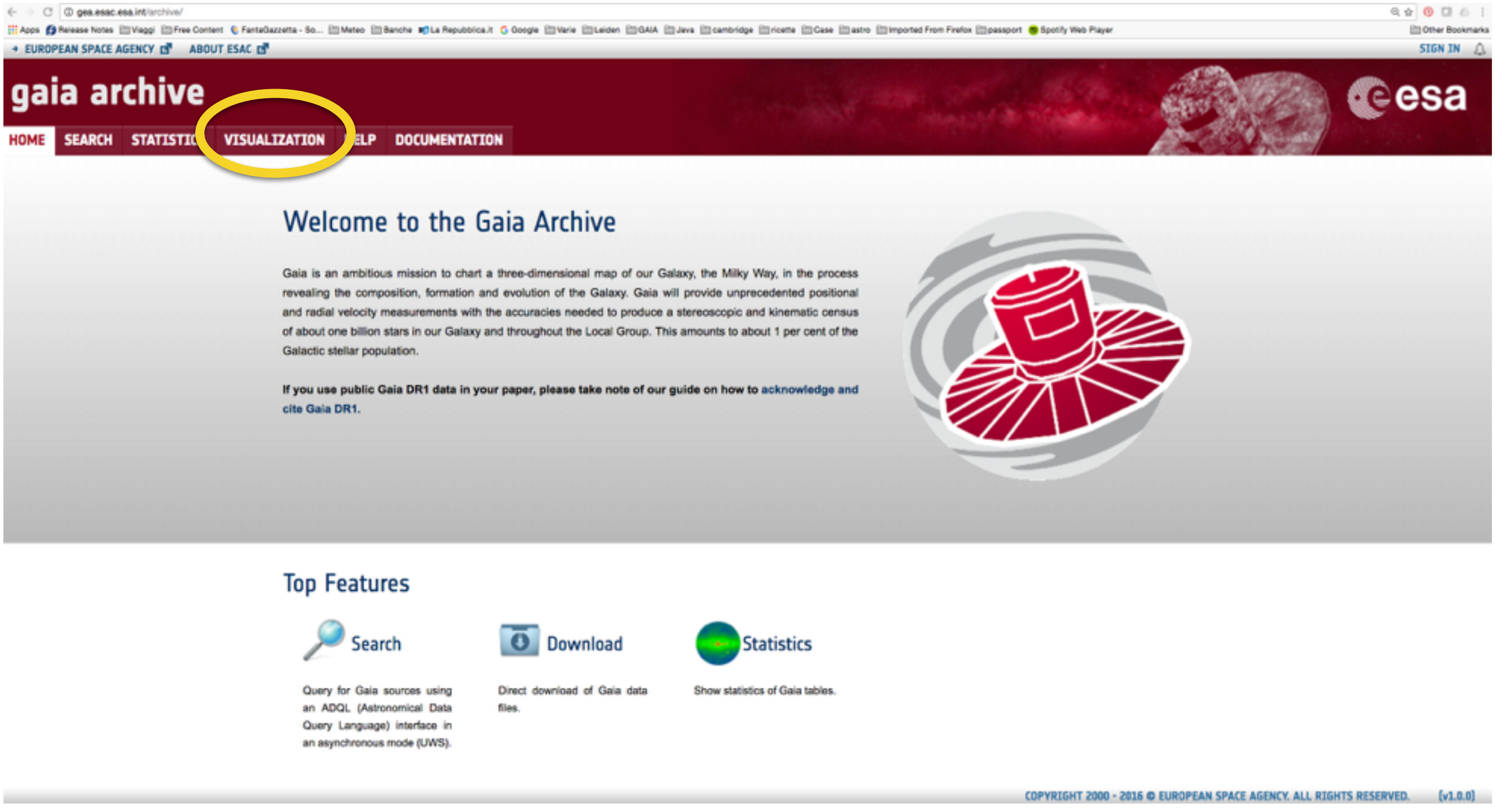
```
SELECT c."dist", a."solution_id", a."source_id", a."random_index", a."ref_epoch", a."ra", a."ra_error", a."dec", a."dec_error",
a."parallax", a."parallax_error", a."pmra", a."pmra_error", a."pmdec", a."pmdec_error", a."ra_dec_corr", a."ra_parallax_corr",
a."ra_pmra_corr", a."ra_pmdec_corr", a."dec_parallax_corr", a."dec_pmra_corr", a."dec_pmdec_corr", a."parallax_pmra_corr",
a."parallax_pmdec_corr", a."pmra_pmdec_corr", a."astrometric_n_obs_al", a."astrometric_n_obs_ac", a."astrometric_n_good_obs_al",
a."astrometric_n_good_obs_ac", a."astrometric_n_bad_obs_al", a."astrometric_n_bad_obs_ac", a."astrometric_delta_q",
a."astrometric_excess_noise", a."astrometric_excess_noise_sig", a."astrometric_primary_flag", a."astrometric_relegation_factor",
a."astrometric_weight_al", a."astrometric_weight_ac", a."astrometric_priors_used", a."matched_observations",
a."duplicated_source", a."scan_direction_strength_k1", a."scan_direction_strength_k2", a."scan_direction_strength_k3",
```

Reset Form | Submit Query

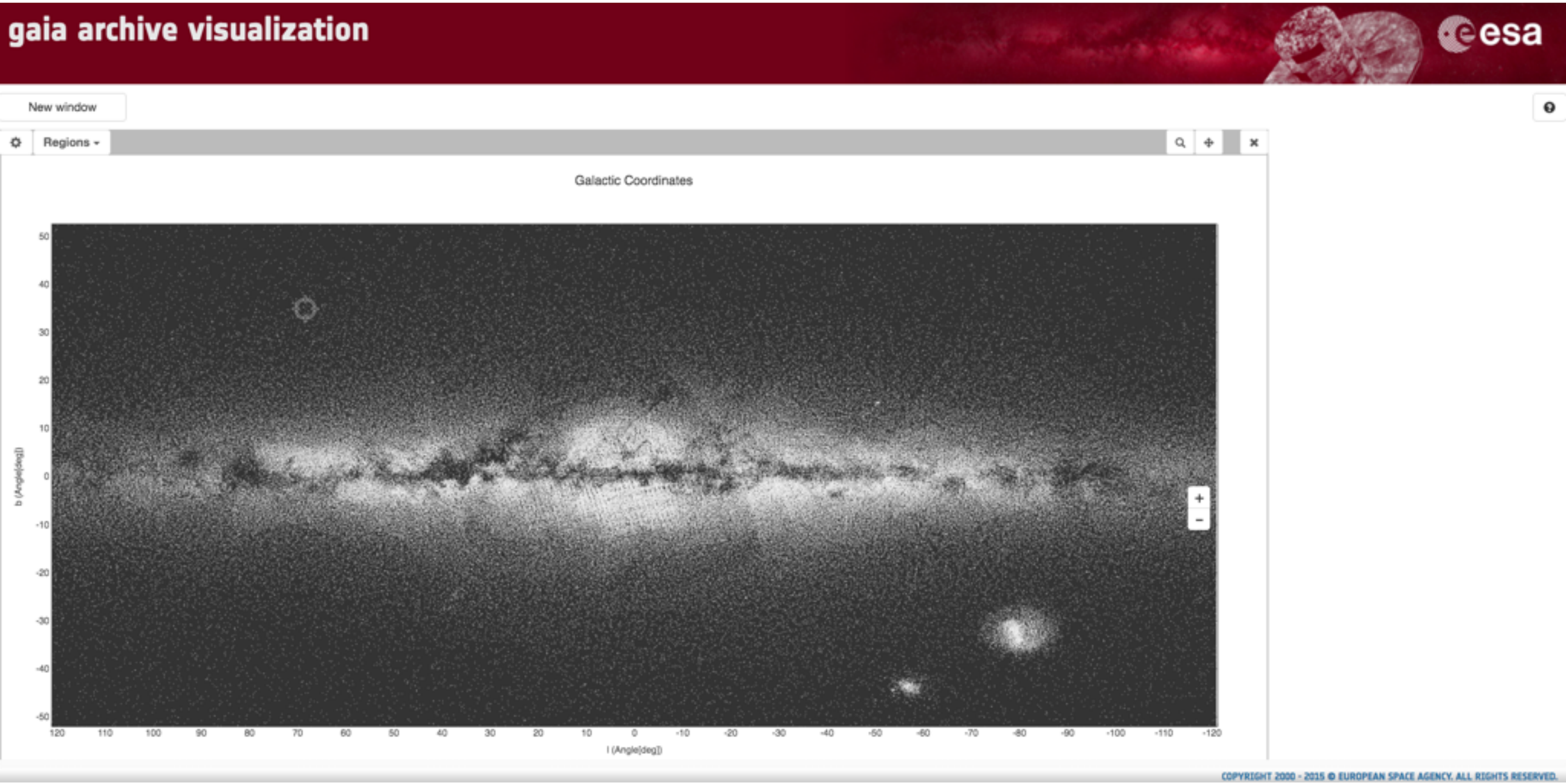
| | | | | | |
|---|---|---|---|---|---|
| gaia_bhb | 26-Sep-2016, 23:08:18 | 2168 | 605 KB | | |
| xmatch_gaia_source_bhb | 26-Sep-2016, 22:47:15 | | 0 KB | | |

Cancel | Execute

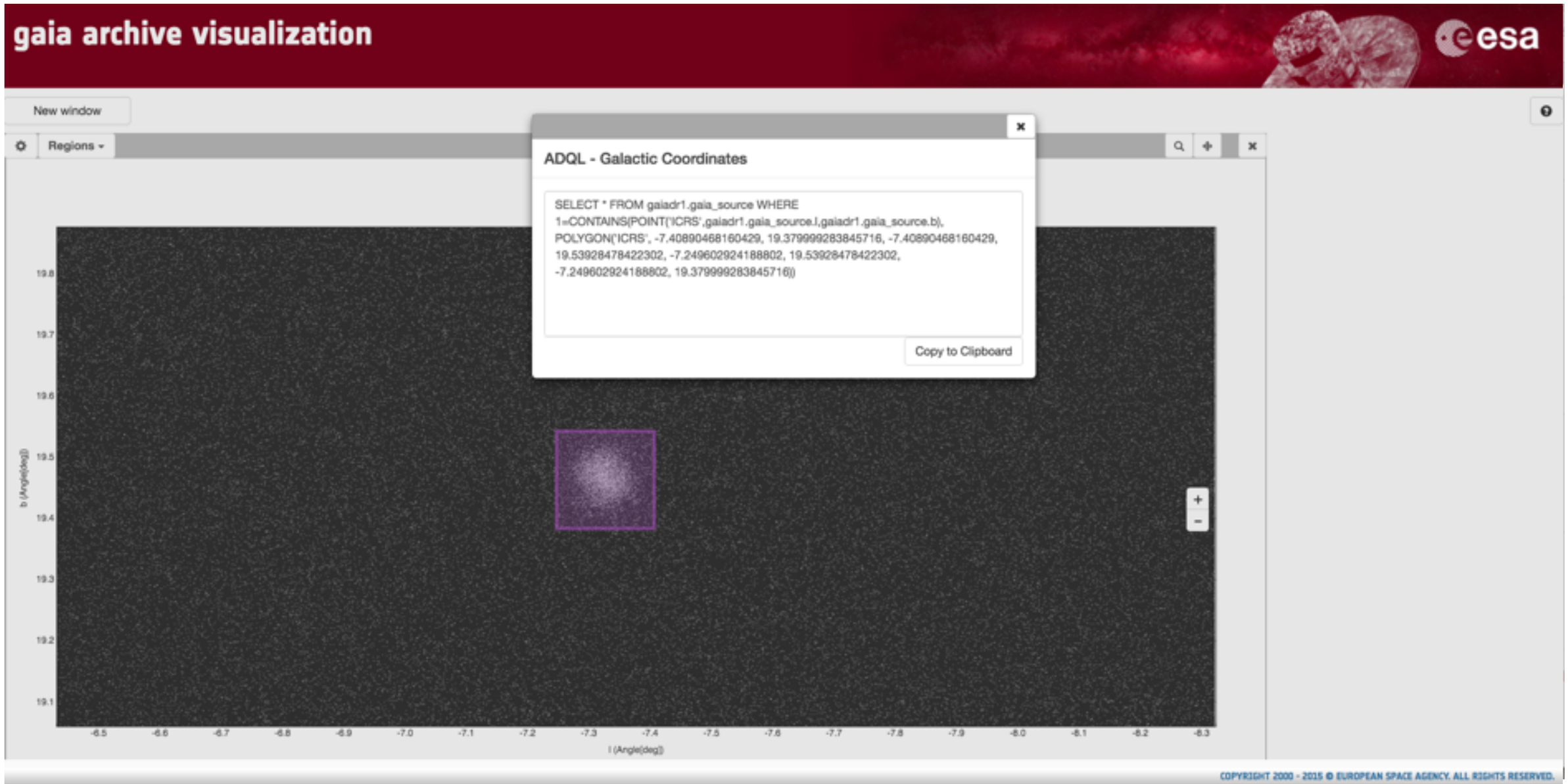
# Visualisation



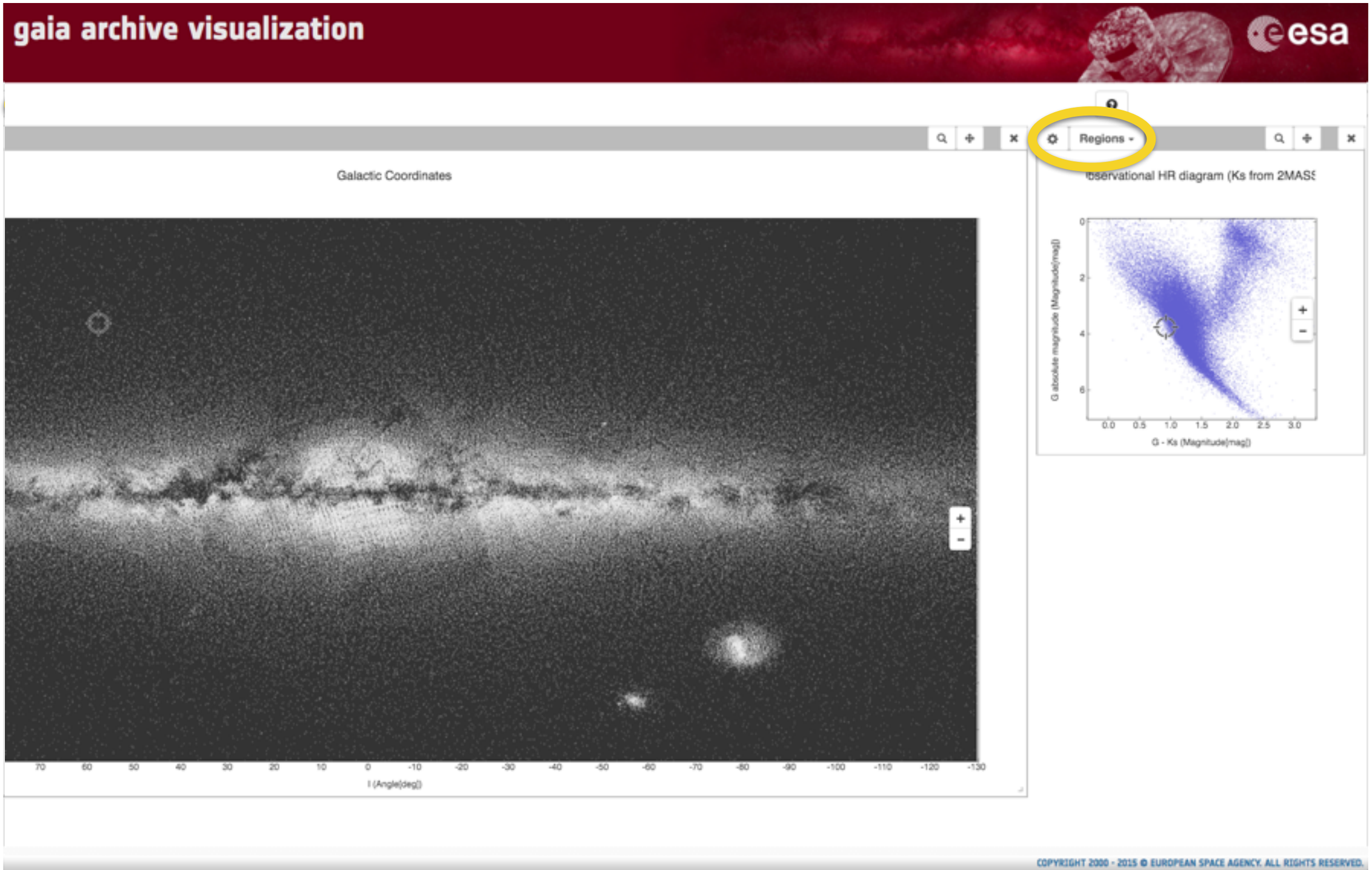
# Visualisation



# Visualisation: selecting regions



# Visualisation: 2D plots



# Visualisation: 2D plots —> select subsets

gaia archive visualization

esa

New window

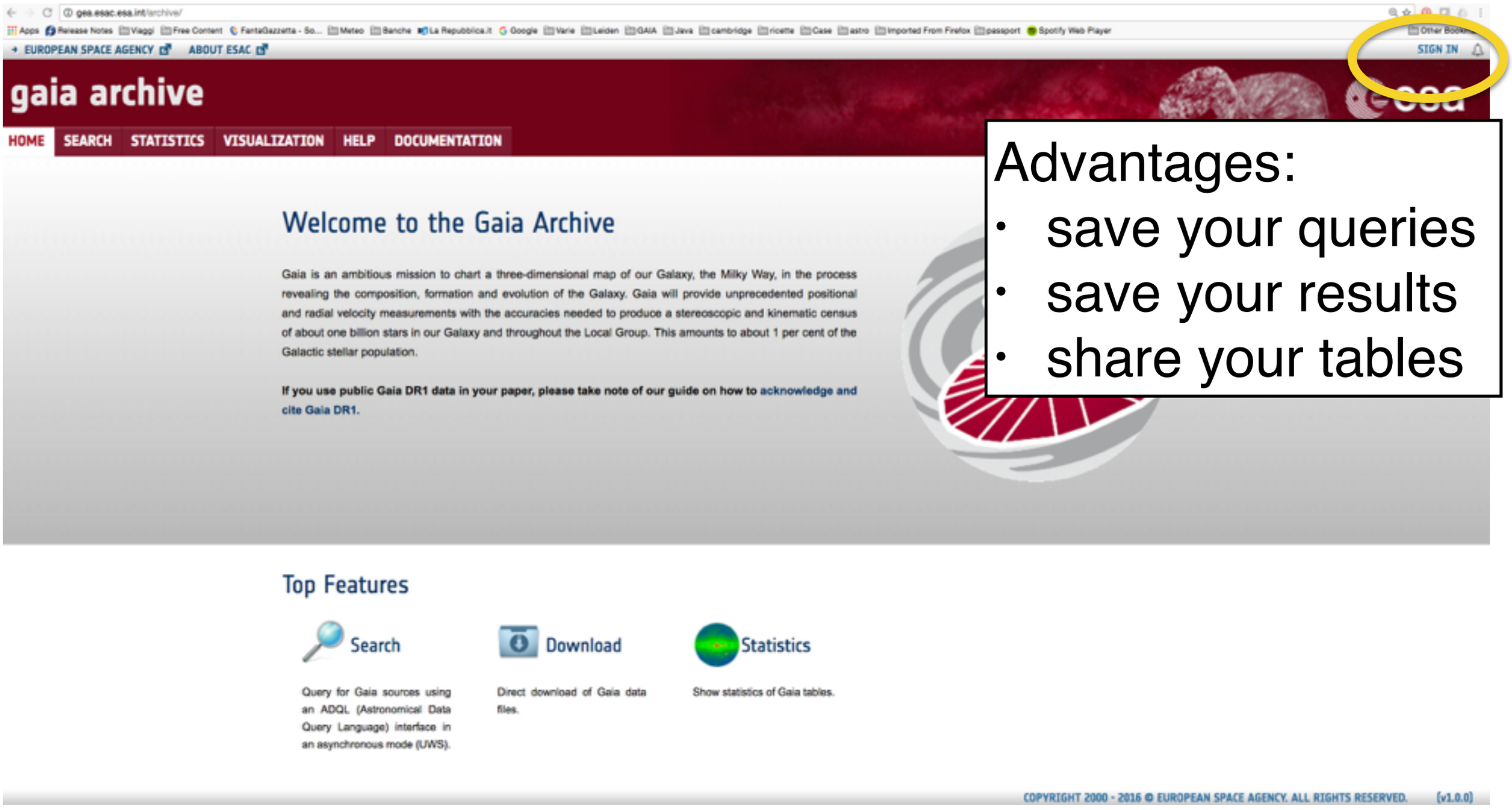
Regions

Observational HR diagram (Ks from 2MASS)

```
global coordsys
polygon(1.8112974482131687, 0.1346259586602661, 1.9706074439093906, -0.01217316813122854, 2.2162103539410656,
0.031866569906219853, 2.35560660017526, 0.29610499813091024, 2.5215545123588243, 0.6337429897513479,
2.5481061783081946, 0.9567010686926362, 2.3954340990993153, 1.2943390603130738, 2.209572437453723, 1.1915796715590274,
2.0369866087828163, 1.1035001954841308, 1.8710386965992518, 0.8686215926177393, 1.7581941163144281, 0.4722639502807038,
1.8112974482131687, 0.1346259586602661) # color=#d93e5b
```

**save region**

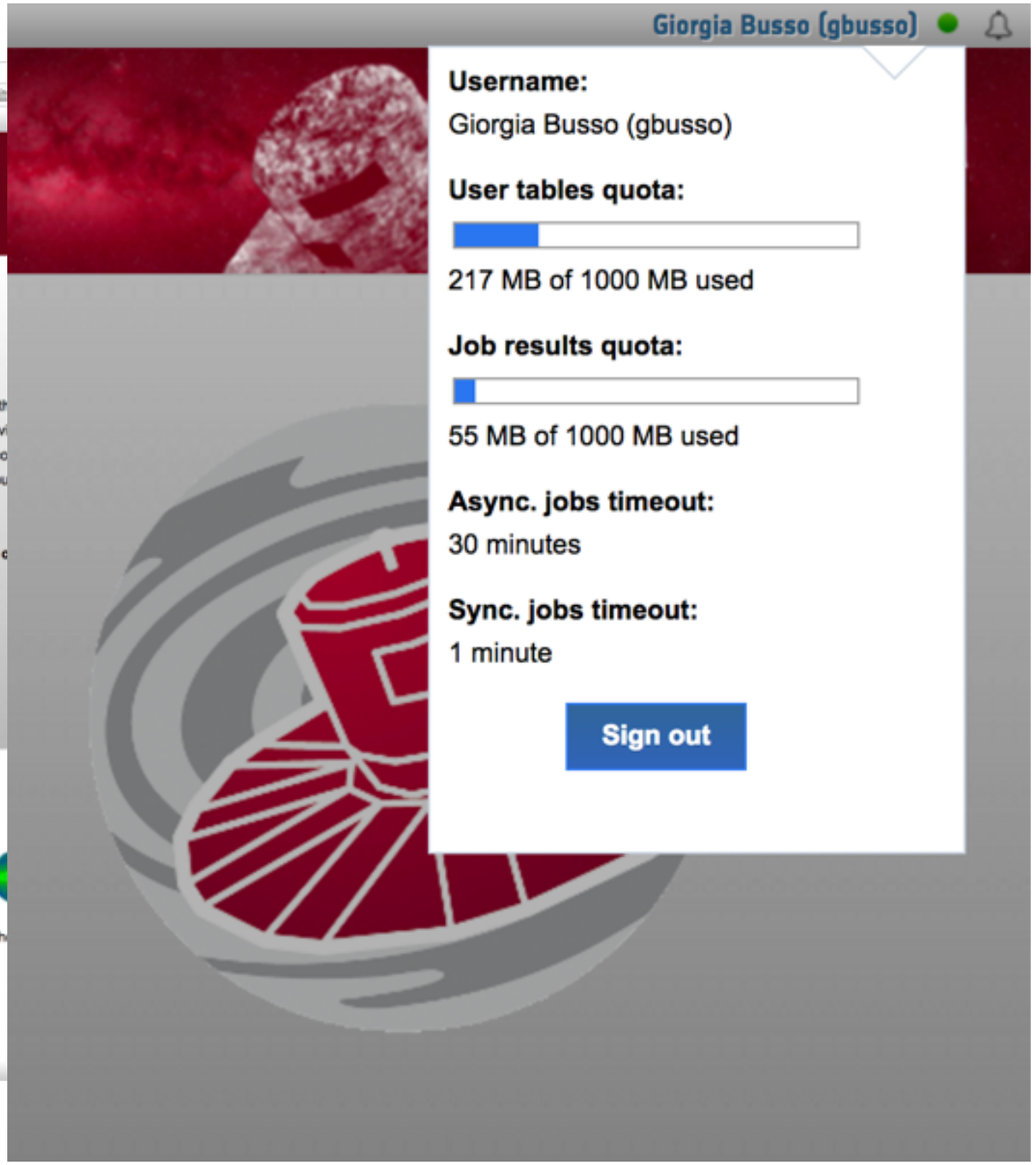
# Sign In or not Sign In



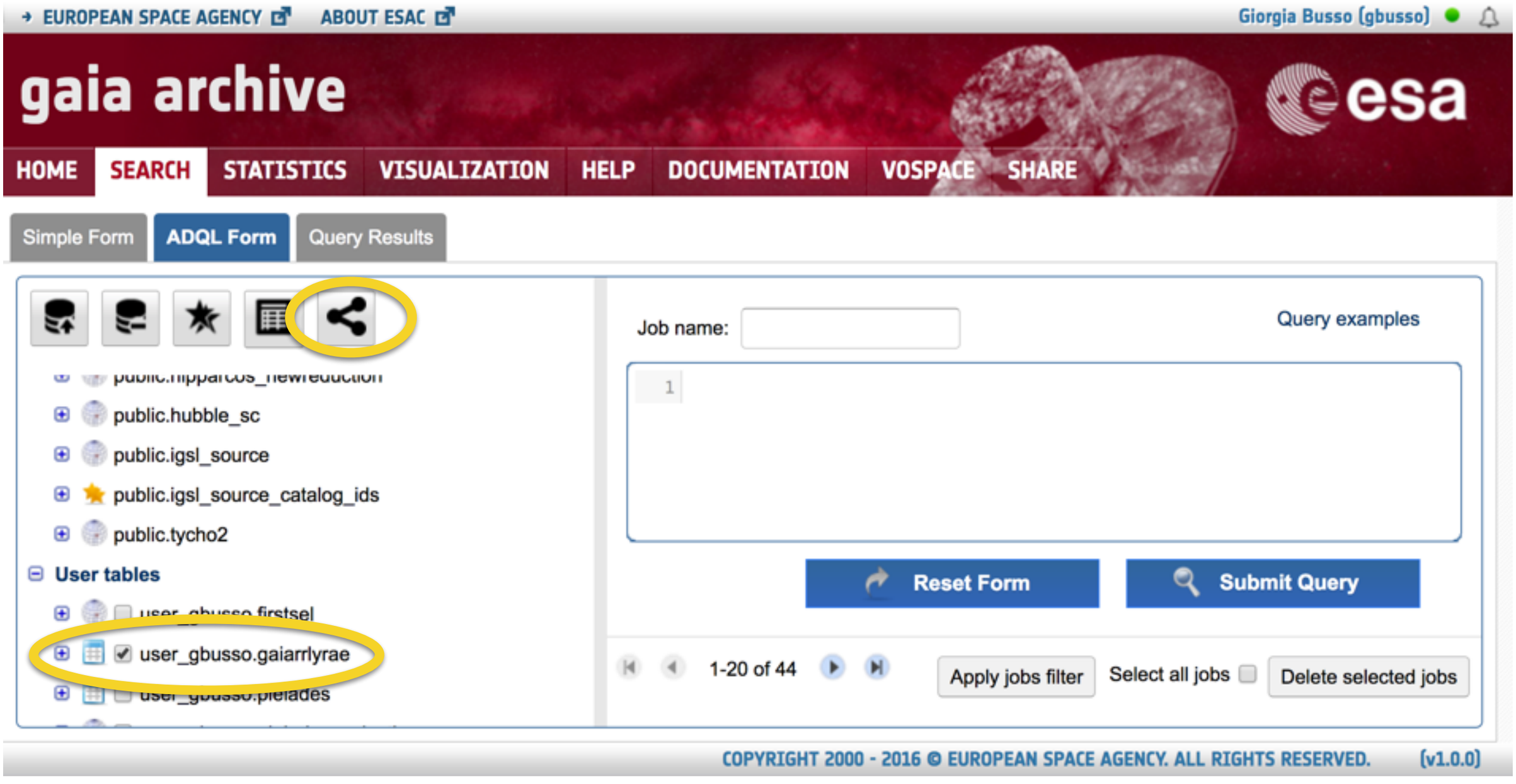

Advantages:

- save your queries
- save your results
- share your tables

# Sign In or not Sign In

# Share your results




**go and get them!**