The Gaia Archive

A. Mora, J. Gonzalez-Núñez, J. Salgado,
R. Gutiérrez-Sánchez, J.C. Segovia, J. Duran
ESA-ESAC Gaia SOC and ESDC

IAU Symposium 330. Nice, France

Outline

1. Introduction
2. The Gaia Archive
3. Tables: catalogue, cross-match and light curves
4. Archive demo
5. How to select a stellar cluster (basic query)
6. How to create an HR diagram (2MASS cross-match)
7. How to reconstruct an RR Lyrae light curve
8. Additional resources
9. Conclusions

1. Introduction

ESA Gaia Archive: key points

Code to the data (workflows)

Gaia Archive contents. Provided by DPAC

- Catalogues (tables)
- Pre-computed cross-match (pivot tables)
- Light curves (one entry per point)

Gaia Archive functionality

- ADQL: SQL dialect for queries ➔ reproducibility ➔ papers
- TAP+ VO standard: web data query, user tables, sharing, …
- SAMP VO standard: interoperability ➔ 3rd party software
- DR2+ evolution: ~PB size, parameters, spectra, epoch data, …

Learning curve: reproducing DR1 Brown+ 2016 plots

Code to the data (workflows)

There is no correct workflow! if it works, it is good

Traditional (bring the data to the code)

Download tgas_source (~1GB), gaia_source (~1TB) and external catalogues

Ingest in local supercomputer. Do cross-match

Do science!

Gaia archive (towards bringing the code to the data)

Selection (ADQL query) at Gaia Archive ➔ Reproducibility!

Refinement (in Archive): Xmatch, computations, external catalogues, share

Download and do science! ➔ Data (size) reduction

2. The Gaia Archive

Gaia Archive contents: DR1

Where?

Main Gaia archive: ESAC

Partner data centres: AIP, ARI, ASI, BCN, CDS

Affiliated and other data centres, enthusiasts: tens

What?

tgas_source (~2M 5 parameter astrometry): all

gala_source (~1.1G positions): most

Variability (599 cepheids, 2595 RR Lyrae), QSOs (2191): ESAC+

Xmatch (2MASS, PPMXL, SDSS9 , UCAC4, URAT1, WISE): ESAC

External catalogues (for Xmatch): ESAC+

What else @ESAC?: TAP+ (data base, user space, share), cross-match

Gaia Archive contents: DR1

Total DR1: 1.6 TB

Gaia

•Gaia DR1 catalogue	1.1	billion rows
•TGAS	0.002	billion rows

External Catalogues

•Hipparcos & Hipparcos new red.	0.0012	billion rows
•IGSL (Initial Gaia Source List)	1.2	billion rows
•2MASS	0.47	billion rows
•Tycho2	0.0025	billion rows
•UCAC4	0.11	billion rows
•Hubble Source Catalogue v1.0	0.029	billion rows

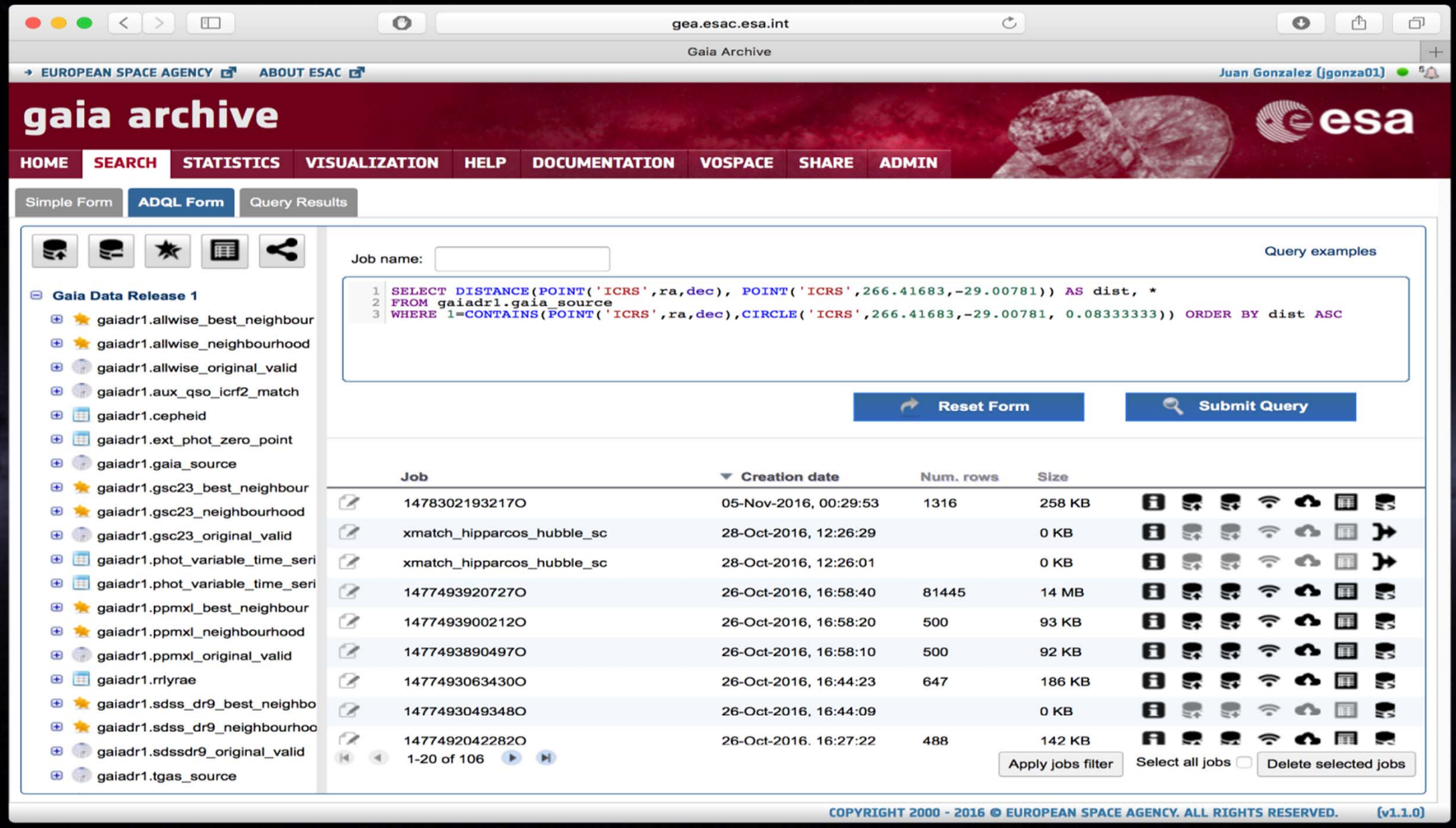
Crossmatches

•Crossmatch tables between Hipparcos, 2MASS, Tycho2… and Gaia expressed as neighbourhood and best neighbour, e.g:

•AllWise-Gaia neighbourhood	0.31	billion rows

11.59 billion rows

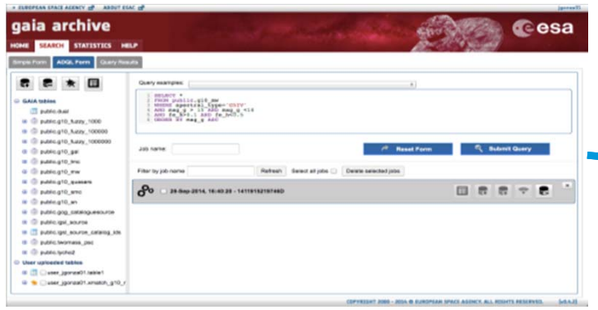
The User Interface



http://archives.esac.esa.int/gaia

TAP+

Open APIs



TAP+ I/F

Command line tools

External Apps

Data Validation

Public area

- Publicly released catalogues

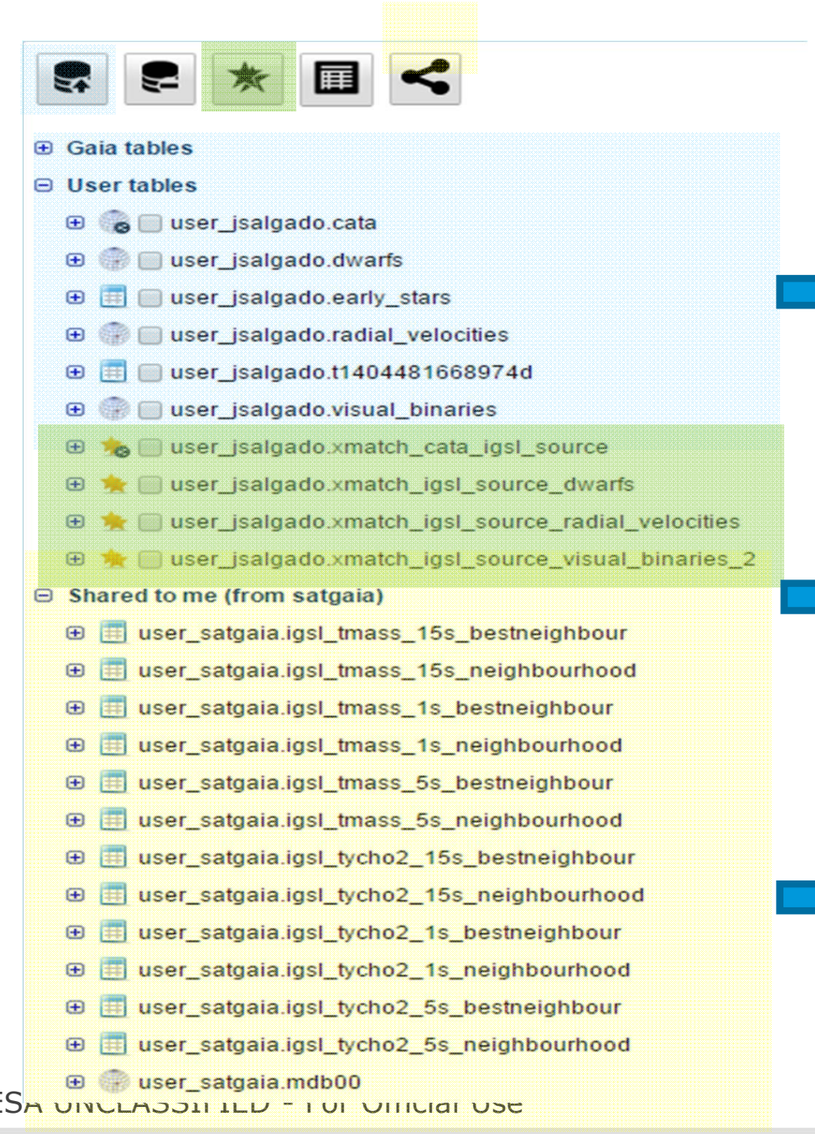
Restricted area

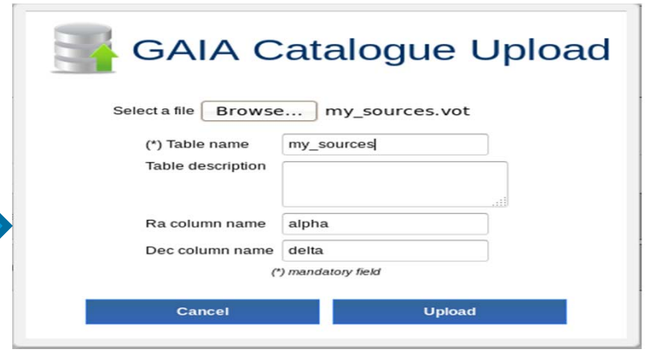
- Catalogues during validation or proprietary exploitation

User Space

- User-uploaded data

Gaia Archive: TAP+ Schema



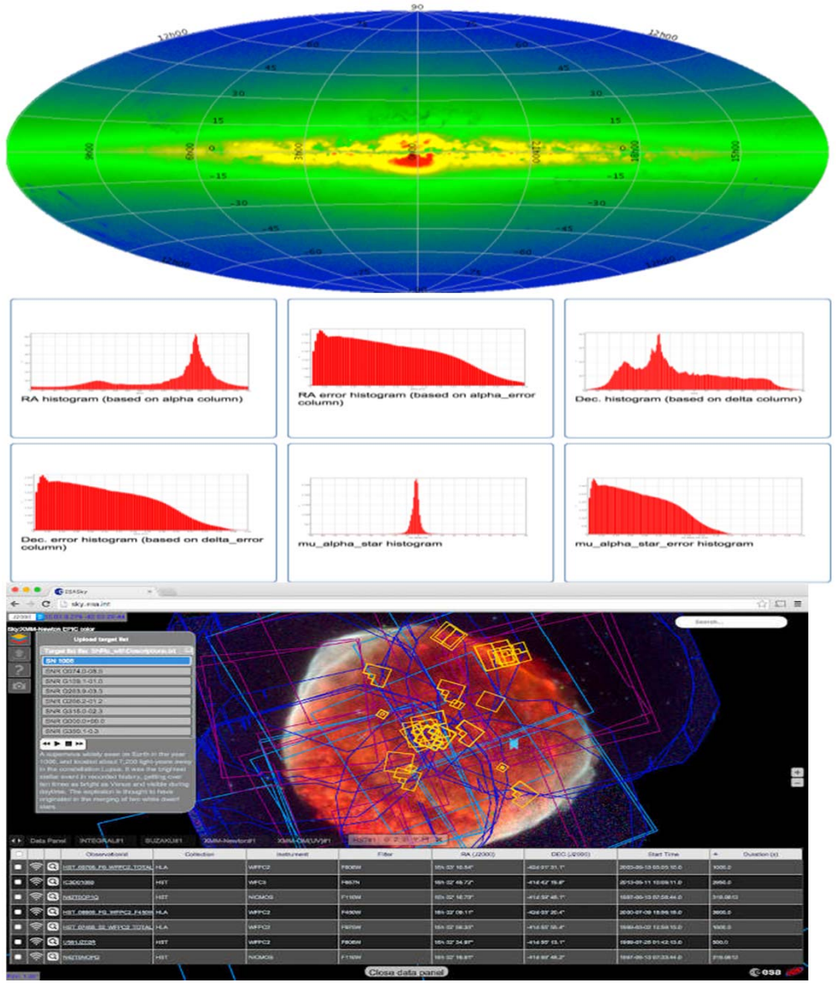


Persistent Upload

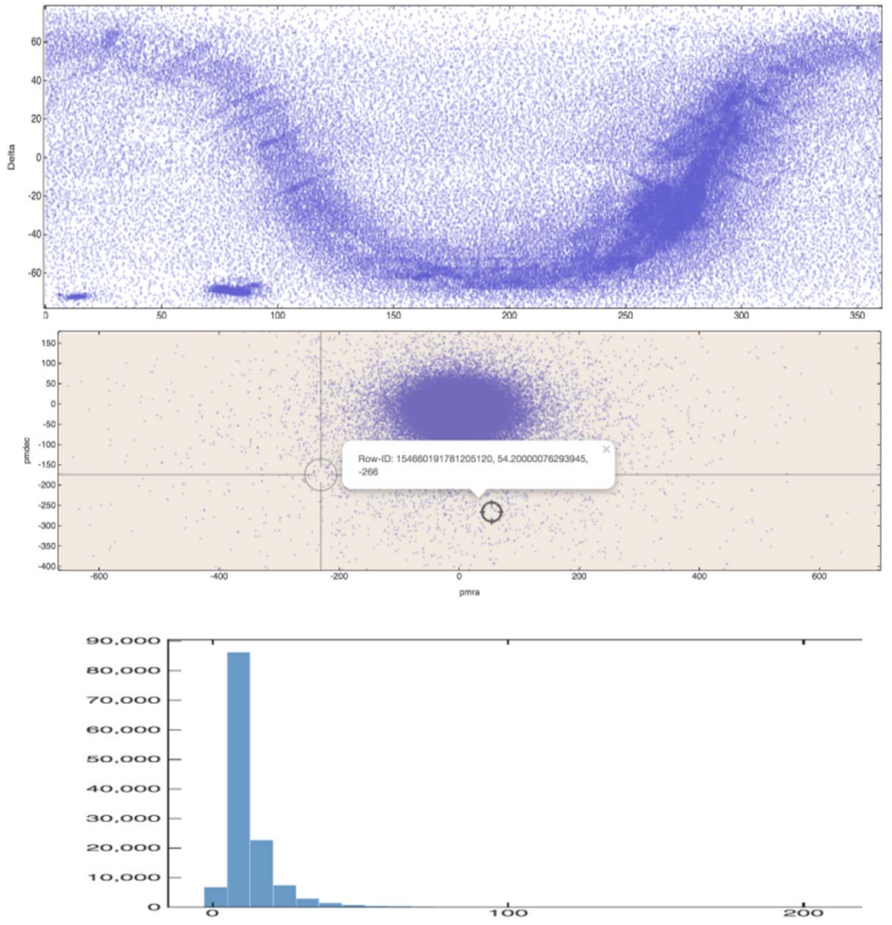
Server Crossmatch

Table sharing

Visualization

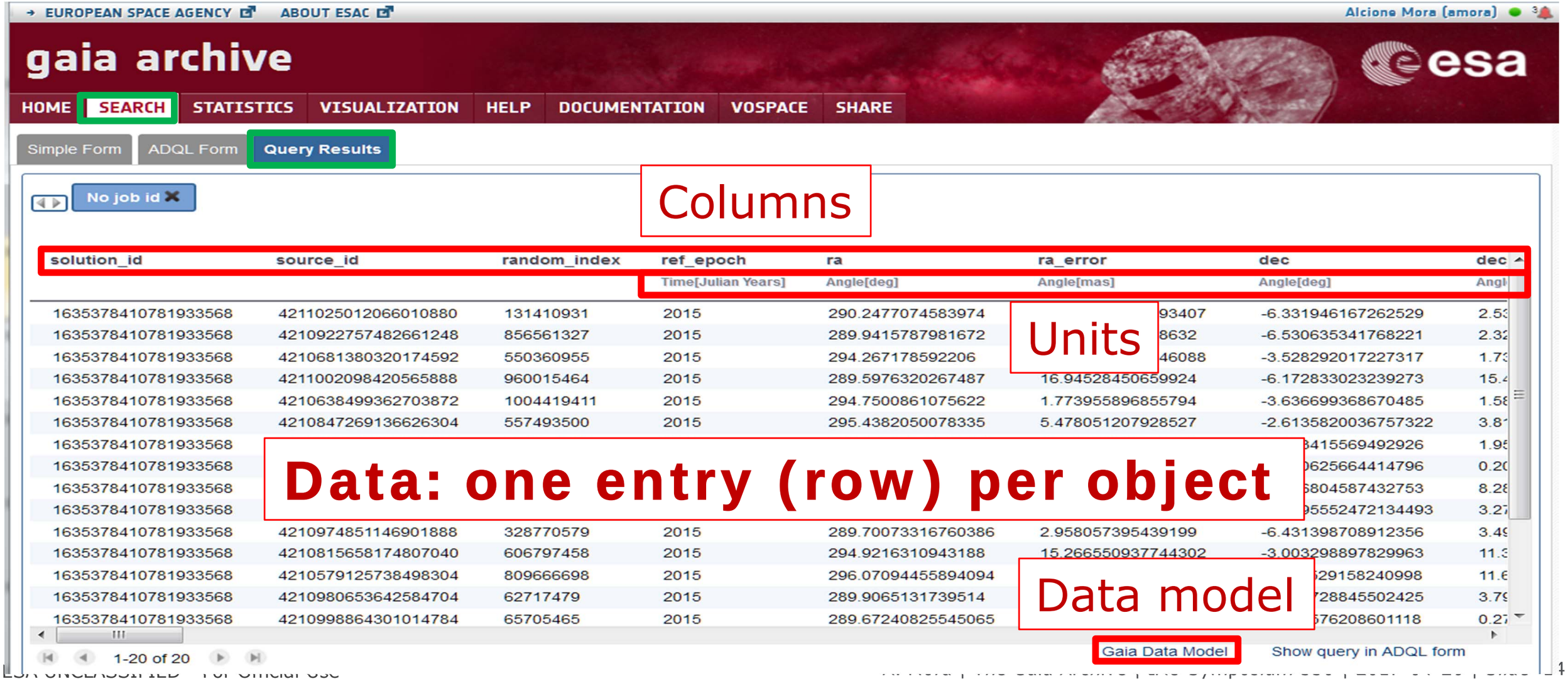


- Visualization is a need
- Statistics provide holistic views. Big data techniques
- Validated static stats
- On-the-fly visualization (Lisbon University)
- ESASky integration
- Virtual Reality prototype



3. Tables: catalogue, cross-match and light curves

Gaia source: main table



solution_id	source_id	random_index	ref_epoch	ra	ra_error	dec	dec
			Time[Julian Years]	Angle[deg]	Angle[mas]	Angle[deg]	Angl
1635378410781933568	4211025012066010880	131410931	2015	290.2477074583974	93407	-6.331946167262529	2.53
1635378410781933568	4210922757482661248	856561327	2015	289.9415787981672	8632	-6.530635341768221	2.32
1635378410781933568	4210681380320174592	550360955	2015	294.267178592206	46088	-3.528292017227317	1.73
1635378410781933568	4211002098420565888	960015464	2015	289.5976320267487	16.94528450659924	-6.172833023239273	15.4
1635378410781933568	4210638499362703872	1004419411	2015	294.7500861075622	1.773955896855794	-3.636699368670485	1.58
1635378410781933568	4210847269136626304	557493500	2015	295.4382050078335	5.478051207928527	-2.6135820036757322	3.81
1635378410781933568						8415569492926	1.95
1635378410781933568						0625664414796	0.20
1635378410781933568						6804587432753	8.28
1635378410781933568						95552472134493	3.27
1635378410781933568	4210974851146901888	328770579	2015	289.70073316760386	2.958057395439199	-6.431398708912356	3.49
1635378410781933568	4210815658174807040	606797458	2015	294.9216310943188	15.266550937744302	-3.003298897829963	11.3
1635378410781933568	4210579125738498304	809666698	2015	296.07094455894094		529158240998	11.6
1635378410781933568	4210980653642584704	62717479	2015	289.9065131739514		728845502425	3.79
1635378410781933568	4210998864301014784	65705465	2015	289.67240825545065		576208601118	0.27

Variables: light curve

One entry per object and epoch: 3194 stars, 233,181 rows
~Trillion size by DR5!

observation_time Time[Barycentric JD in TCB - 2455197.5 (day)]	g_flux Flux[e-/s]	g_flux_error Flux[e-/s]	g_magnitude Magnitude[mag]
1666.4708409132627	323.3406240378528	6.139588887158467	19.25061938345054
1666.646999930693	286.7358824320857	56.91077458377935	19.381064952793295
1666.7210076079693	255.0714586668238	4.621548747960895	19.508115399450226
1666.8971667883682	473.9340937184366	3.863806252197325 5	18.835475183940574
1666.9711745074405	368.06374709170376	4.482043542948077	19.1099624559301
1667.147333701442	270.0869075966821	2.90891365826153	19.446011232919545
1667.2213414646678	262.13781543831874	3.894873668425852	19.478445874202386

Table: phot_variable_time_series_gfov

Pre-computed cross-matches

DR1 one data set. Other catalogues: astrometry, velocities, photometry, parameters

Ambiguity: resolution, wavelength, epoch, proper motion, …

Many to many relationship ➔ pivot tables needed ➔ **traceability!**

Gaia Archive: catalogue copies and pre-computed cross-matches

Speed: indices. Efficiency: avoids ~100 M rows traffic

2MASS PSC: Skrutskie et al. 2006. 470,992,970 entries

AllWISE: Cutri et al. 2013, 747,634,026 entries

GSC2.3: Lasker et al. 2008. 945,592,683 entries

PPMXL: Roeser et al. 2010. 910,468,688 entries

SDSS DR9: Ahn et al. 2012. 469,029,929 entries

UCAC4: Zacharias et al. 2013. 113,728,883 entries

URAT-1: Zacharias et al. 2015. 228,276,482 entries

Xmatch: neighbourhood

gsc23_oid	source_id	original_ext_source_id
185522891	6083712739771159808	S99R046506
185522891	6083712735454214528	S99R046506
185522891	6083712739771159424	S99R046506
185522891	6083712739771173760	S99R046506
186638244	6083712739771163360	S99R121241
186638244	6083717786336870400	S99R121241
186638244	6083717790654613888	S99R121241
186638244	6083717790654613760	S99R121241

~Many to many relationship ➔ double entry ➔ one row per pair

ω Cen core

Xmatch: neighbourhood

gsc23_oid	source_id	original_ext_source_id
186167520	6083518091833868416	S99R056045
186168205	6083518091833868416	S99R055731
186172303	6083518091833868416	S99R120298
186176636	6083518091833868416	S99R056043
[illegible]	6083714492121489280	S99R055944
186208246	6083714492121489280	S99R055942
186211491	6083714492121489280	S99R139072
186211811	6083714492121489280	S99R139057

~Many to many relationship ➔ double entry ➔ one row per pair

ω Cen core

Xmatch: best neighbour

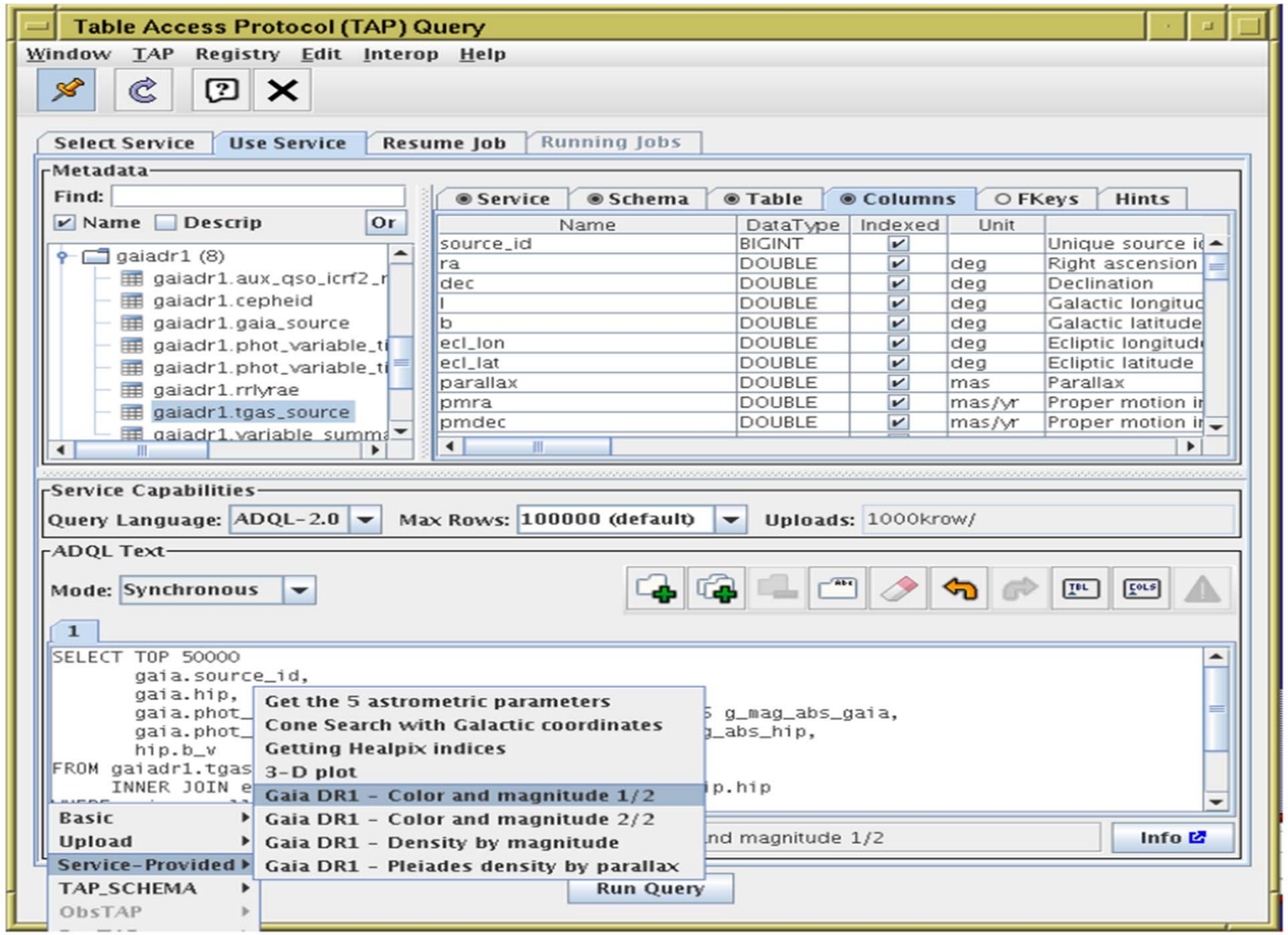
>0 ➔ other Gaia sources share best neighbour

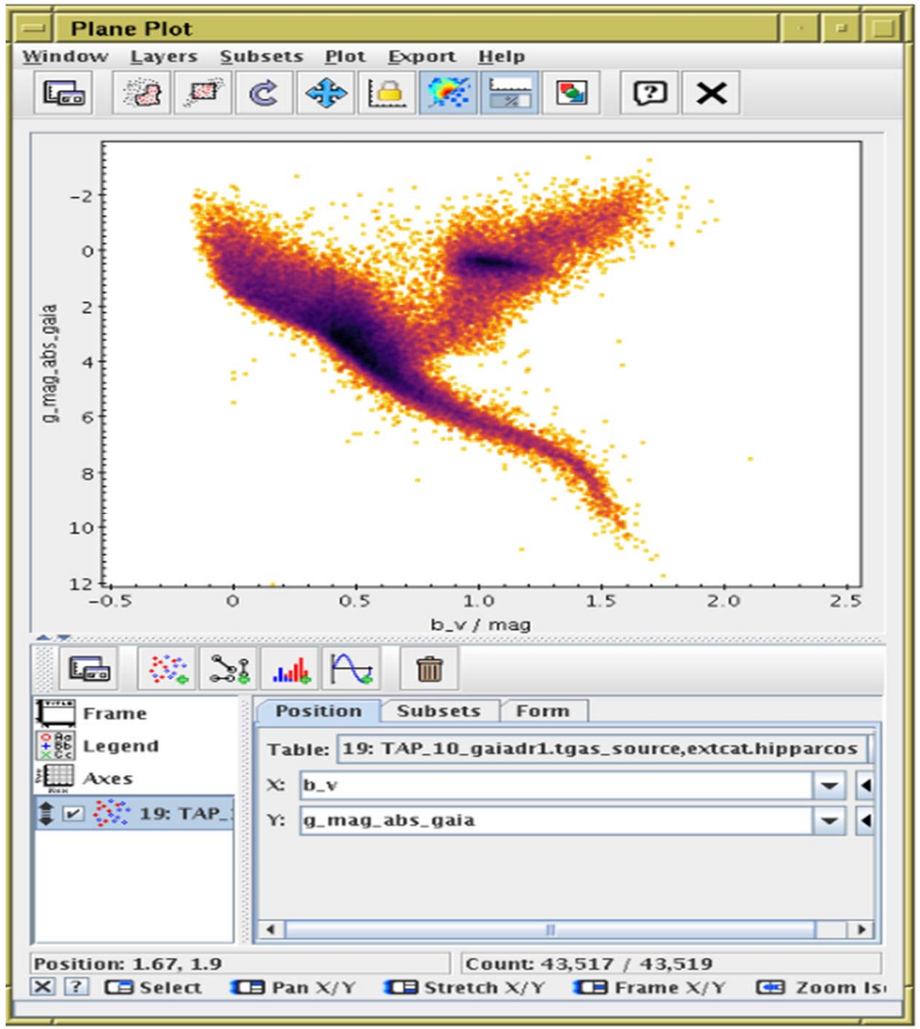
number_of_neighbours	number_of_mates	best_neighbour_multiplicity
8	1	1
8	0	1
8	0	1
8	2	1
8	0	1
7	0	1
7	0	1

ω Cen core

VO standards ➔ 3rd party

Topcat (M. Taylor): Data query (TAP), reception (SAMP) & plotting



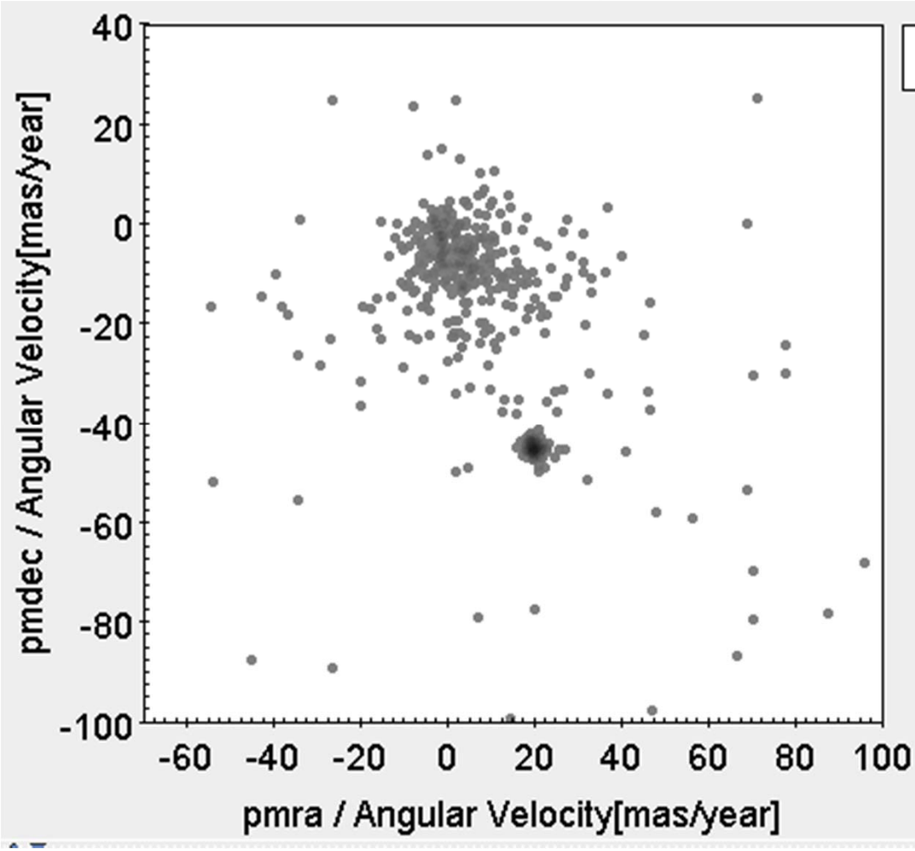


4. Archive demo

5. How to select a stellar cluster (basic query)

Tutorial: Pleiades gross selection

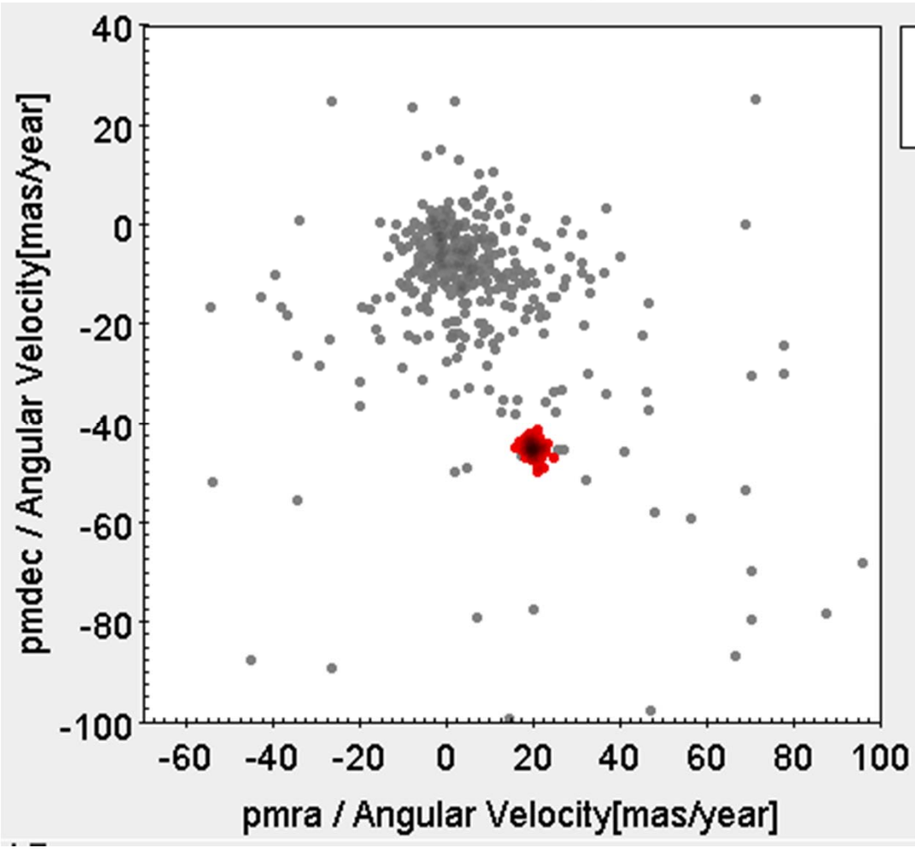
```
SELECT *
FROM gaiadr1.tgas_source
WHERE CONTAINS(
        POINT('ICRS', ra, dec),
        CIRCLE('ICRS', 56.75, 24.1167, 2)
        )=1
```



Cone search: 2º radius ➔ Apparent in proper motion

Tutorial: Pleiades gross selection

```
SELECT *
FROM gaiadr1.tgas_source
WHERE CONTAINS(
        POINT('ICRS', ra, dec),
        CIRCLE('ICRS', 56.75, 24.1167, 2)
        )=1
AND pmra IS NOT NULL AND pmra != 0
AND pmdec IS NOT NULL AND pmdec != 0
AND abs(pmra_error/pmra) < 0.10 AND abs(pmdec_error/pmdec) < 0.10
AND pmra BETWEEN 15 AND 25 AND pmdec BETWEEN -55 AND -40
```



PM filter

6. How to create an HR diagram (2MASS cross-match)

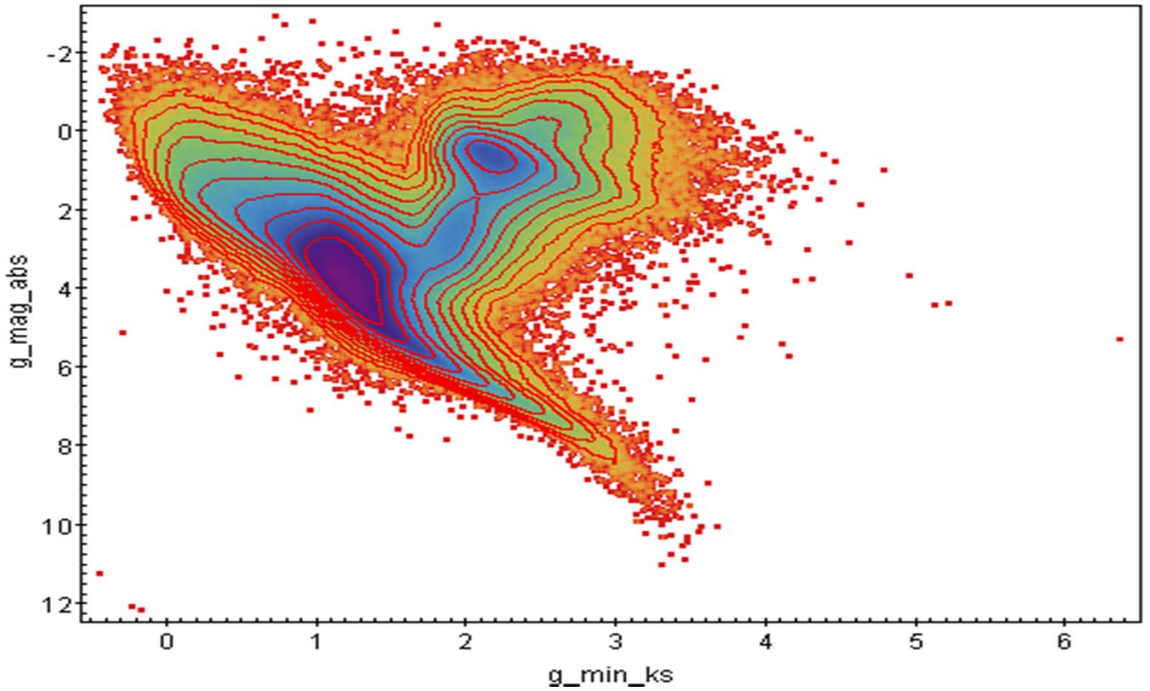
Brown+ 2016: HR diagram

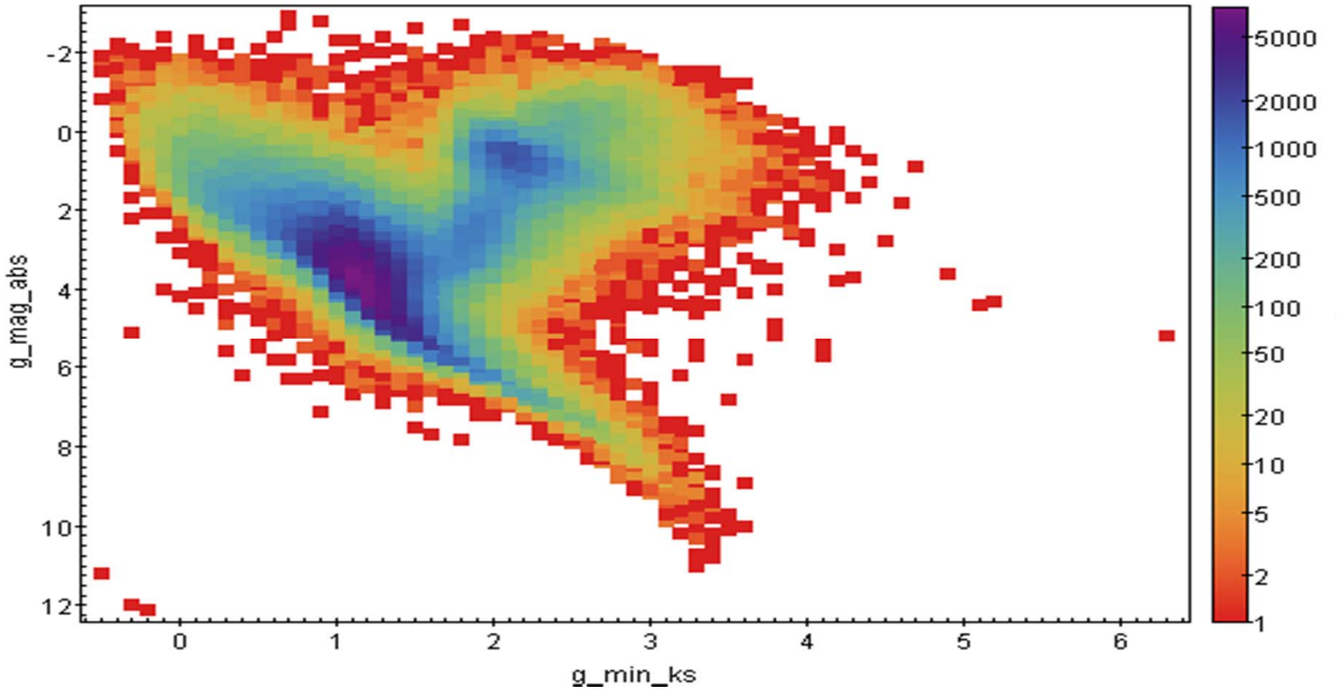
Plots are reproducible! ADQL queries in the paper

Uses Gaia parallaxes and fluxes ➔ absolute magnitudes

Uses pre-computed cross-match and external catalogue: 2MASS

Histograms can be generated in the archive ➔ Code to the data ➔ DR2+





Brown+ 2016: HR diagram

```
select gaia.source_id,
          gaia.phot_g_mean_mag + 5 * log10(gaia.parallax)- 10 as g_mag_abs,
          gaia.phot_g_mean_mag-tmass.ks_m as g_min_ks
from gaiadr1.tgas_source as gaia
inner join gaiadr1.tmass_best_neighbour as xmatch
          on gaia.source_id = xmatch.source_id
inner join gaiadr1.tmass_original_valid as tmass
          on tmass.tmass_oid = xmatch.tmass_oid
where gaia.parallax/gaia.parallax_error >= 5 and
          ph_qual = 'AAA' and
          sqrt(power(2.5/log(10)*gaia.phot_g_mean_flux_error
                    /gaia.phot_g_mean_flux,2) ) <= 0.05 and
          sqrt(power(2.5/log(10)*gaia.phot_g_mean_flux_error
                    /gaia.phot_g_mean_flux,2)
                    + power(tmass.ks_msigcom,2)) <= 0.05
```

ADQL: Learning curve

Brown+ 2016: HR diagram

```
select gaia.source_id,
       gaia.phot_g_mean_mag + 5 * log10(gaia.parallax)- 10 as g_mag_abs,
       gaia.phot_g_mean_mag - tmass.ks_m as g_min_ks
from gaiadr1.tgas_source as gaia
inner join gaiadr1.tmass_best_neighbour as xmatch
       on gaia.source_id = xmatch.source_id
inner join gaiadr1.tmass_original_valid as tmass
       on tmass.tmass_oid = xmatch.tmass_oid
where gaia.parallax/gaia.parallax_error >= 5 and
       ph_qual = 'AAA' and
       sqrt(power(2.5/log(10)*gaia.phot_g_mean_flux_error
                  /gaia.phot_g_mean_flux,2) ) <= 0.05 and
       sqrt(power(2.5/log(10)*gaia.phot_g_mean_flux_error
                  /gaia.phot_g_mean_flux,2)
                  + power(tmass.ks_msigcom,2)) <= 0.05
```

ADQL: on the fly computation

Gaia + 2MASS:
Pre-computed Xmatch

ADQL: filters

Brown+ 2016: HR diagram

```
select
            g_min_ks_index / 10 as g_min_ks,
            g_mag_abs_index / 10 as g_mag_abs,
            count(*) as n
from (
            select gaia.source_id,
                        floor((gaia.phot_g_mean_mag+5*log10(gaia.parallax)-10) * 10) as g_mag_abs_index,
                        floor((gaia.phot_g_mean_mag-tmass.ks_m) * 10) as g_min_ks_index
            from gaiadr1.tgas_source as gaia
            inner join gaiadr1.tmass_best_neighbour as xmatch
                        on gaia.source_id = xmatch.source_id
            inner join gaiadr1.tmass_original_valid as tmass
                        on tmass.tmass_oid = xmatch.tmass_oid
            where gaia.parallax/gaia.parallax_error >= 5 and
                        ph_qual = 'AAA' and
                        sqrt(power(2.5/log(10)*gaia.phot_g_mean_flux_error/gaia.phot_g_mean_flux,2)) <= 0.05 and
                        sqrt(power(2.5/log(10)*gaia.phot_g_mean_flux_error/gaia.phot_g_mean_flux,2)
                                    + power(tmass.ks_msigcom,2)) <= 0.05
            )as subquery
group by g_min_ks_index, g_mag_abs_index
```

2D histogram in the archive:
no billion object download ➔ DR2

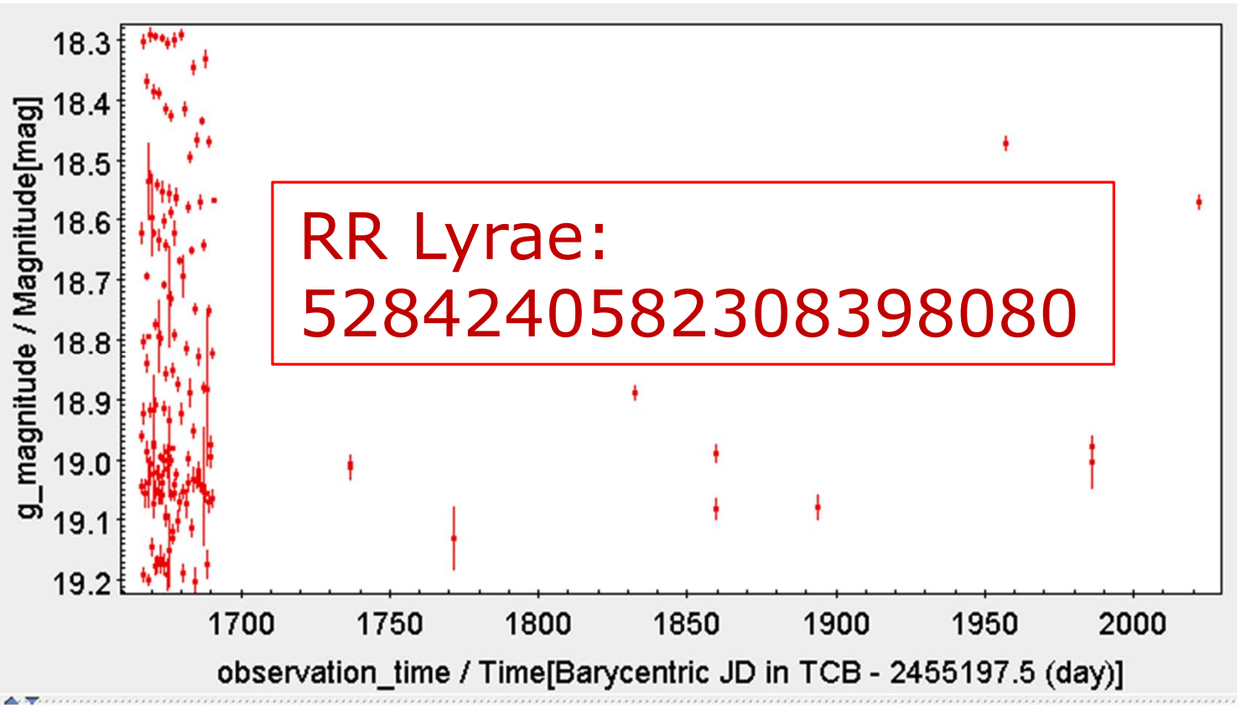
7. How to reconstruct an RR Lyrae light curve

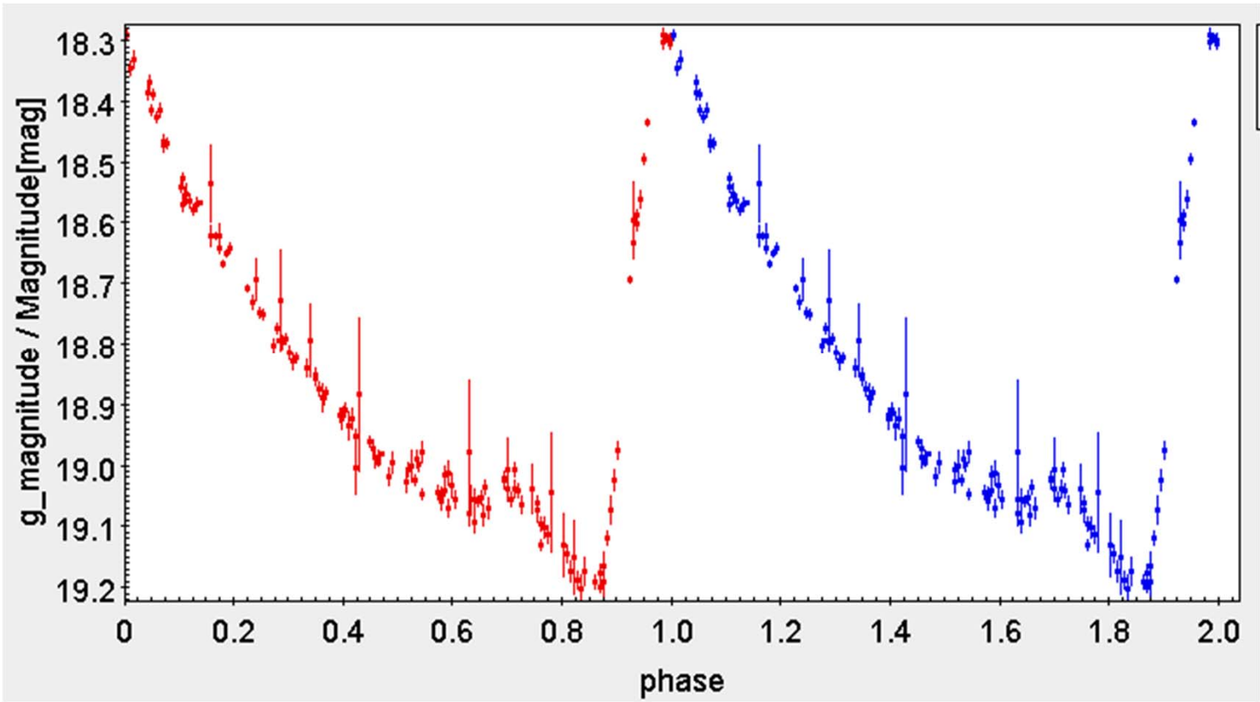
Brown+ 2016: light curves

Plots are reproducible! ADQL queries in the paper

Uses Gaia epoch photometry and best fit period

Light curves in a relational data base! Best strategy? ➔ DR2+





Brown+ 2016: light curves

```
select
        curves.observation_time,
        mod(curves.observation_time - rrlyrae.epoch_g, rrlyrae.p1)
                / rrlyrae.p1 as phase,
        curves.g_magnitude,
        2.5/log(10)* curves.g_flux_error/ curves.g_flux
                as g_magnitude_error
from gaiadr1.phot_variable_time_series_gfov as curves
inner join gaiadr1.rrlyrae as rrlyrae
         on rrlyrae.source_id = curves.source_id
where rrlyrae.source_id = 5284240582308398080
```

Brown+ 2016: light curves

```
select
        curves.observation_time,
        mod(curves.observation_time - rrlyrae.epoch_g, rrlyrae.p1)
                / rrlyrae.p1 as phase,
        curves.g_magnitude,
        2.5/log(10)* curves.g_flux_error/ curves.g_flux
                as g_magnitude_error
from gaiadr1.phot_variable_time_series_gfov as curves
inner join gaiadr1.rrlyrae as rrlyrae
        on rrlyrae.source_id = curves.source_id
where rrlyrae.source_id = 5284240582308398080
```

Light curve reconstruction

Source selection

8. Additional resources

Partner data centres

Alternative and complementary access at data release time

Selected data. Custom interface. Additional functionality

AIP (Leibniz-Institut für Astrophysik Potsdam, Germany)

https://gaia.aip.de/

ARI (Astronomisches Rechen-Institut, Heidelberg, Germany)

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

ASDC (ASI Science Data Center, Rome, Italy)

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

CDS (Centre de Données astronomiques de Strasbourg, France)

http://cdsweb.u-strasbg.fr/gaia

Affiliated Data Centres. Receive full release after a small delay ➔ efficient mirroring

Documentation and resources

Gaia Archive. Includes help and tutorials

https://archives.esac.esa.int/gaia

Gaia DR1 papers http://www.cosmos.esa.int/web/gaia/dr1#A&A

Online documentation (361 pages)

http://gaia.esac.esa.int/documentation/GDR1/index.html

Data model documentation

https://gaia.esac.esa.int/documentation/GDR1/datamodel/

ADQL: GAVO short course, UK ROE cookbook

http://docs.g-vo.org/adql-gaia/html/index.html

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

Gaia Helpdesk. https://support.cosmos.esa.int/gaia/

9. Conclusions

Conclusions

Archive: https://archives.esac.esa.int/gaia

Helpdesk: https://support.cosmos.esa.int/gaia/

Functionality: TAP+ (data base, user space, sharing), cross-match

Data: main tables, TGAS, variables, QSO, Xmatch, external catalogues

Bring code to the data: select, refine (ADQL, user tables) and download

Prepare for DR2 (~10^9 sources). Archive might be the only way forward

Add ADQL queries to your papers (Brown+ 2016, Clementini+ 2016) ➔ Reproducibility

Use it. User demand is a key driver for future developments

Ask us. Via Helpdesk for additional support. **Please provide feedback**

Want to support Gaia? ➔ keep writing papers (and acknowledging)