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ARC Journal Club
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Gaia DR3
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Outline *These Notes contain some example ADQL queries for querying Gaia catalogs. This presentation is very closely based off of a presentation called Gaia DR3 Highlights given by Laurent Eyer and Joris De Ridder at the TASC6/KASC13 Workshop in Leuven, Belgium in July, 2022.*

Contents

1 Gaia ADQL Queries

Gaia queries can be submitted to *https://gea.esac.esa.int/archive/*, or using packages such as `asteroquery.gaia`.

ADQL scripts are of the form `select–from–where`, indicating the desired columns, catalog, and conditions you wish to apply.

1.1 Default 5 deg cone search around NGC 6397

This is the default ADQL query generated by the Gaia Archive using their GUI, for a cone search of 5 deg around NGC 6397.

```
SELECT TOP 2000 gaia_source.source_id,gaia_source.ra,gaia_source.dec,gaia_source.parallax
    ,gaia_source.pmra,gaia_source.pmdec,gaia_source.ruwe,gaia_source.phot_g_mean_mag,
    gaia_source.bp_rp,gaia_source.radial_velocity,gaia_source.phot_variable_flag,
    gaia_source.non_single_star,gaia_source.has_xp_continuous,gaia_source.has_xp_sampled,
    gaia_source.has_rvs,gaia_source.has_epoch_photometry,gaia_source.has_epoch_rv,
    gaia_source.has_mcmc_gspphot,gaia_source.has_mcmc_msc,gaia_source.teff_gspphot,
    gaia_source.logg_gspphot,gaia_source.mh_gspphot,gaia_source.distance_gspphot,
    gaia_source.azero_gspphot,gaia_source.ag_gspphot,gaia_source.ebpminrp_gspphot
FROM gaiadr3.gaia_source
WHERE
CONTAINS(
       POINT('ICRS',gaiadr3.gaia_source.ra,gaiadr3.gaia_source.dec),
       CIRCLE(
              'ICRS',
              COORD1(EPOCH_PROP_POS
                  (265.175375,-53.674333,.4160,3.3000,-17.6000,18.3900,2000,2016.0)),
              COORD2(EPOCH_PROP_POS
                  (265.175375,-53.674333,.4160,3.3000,-17.6000,18.3900,2000,2016.0)),
              2)
)=1
```

The GUI will only produce scripts which limit the output to 2000 stars. You can easily modify the query to remove `TOP 2000` to lift this cap. If you want to do more than 3 million, you must also register an account on the website.

1.2 Bare-bones 2 deg cone searches around NGC 6397

The following query returns 1889811 stars, and took me 75 seconds. The downloadable `.fits` file is 77 MB.

```
select
   source_id, ra, dec, parallax, pmra, pmdec
from
   gaiadr3.gaia_source
where
   1 = contains(point('ICRS', ra, dec), circle('ICRS', 265.175375, -53.67433333, 2))
```

Usually, though, you would like to impose extra conditions to exclude stars you do not actually care about (e.g., stars with bad/missing proper motions, field stars, etc.). This next query makes a rough rectangular cut on proper motions, and returns a 2 MB file of 37410 stars in a few seconds.

```
select
    source_id, ra, dec, parallax, pmra, pmdec
from
    gaiadr3.gaia_source
where
    1 = contains(point('ICRS', ra, dec), circle('ICRS', 265.175375,-53.67433333, 2))
    and pmra between 1.5 and 5
    and pmdec between -20 and -15
```

1.3 Inner join example

Below, we make the same query but inner join the Gaia DR3 catalog (`gaiadr3.gaia_source`) table to the astrophysical parameters (`gaiadr3.astrophysical_parameters`) table, abbreviating it as `ap` and pulling some columns from it. Inner joining means that we require that all items returned be in both tables which are joined. The query below returns 33546 entries.

```
select
    source_id, ra, dec, parallax, pmra, pmdec, ap.teff_gspphot, ap.logg_gspphot
from
    gaiadr3.gaia_source
    inner join
    gaiadr3.astrophysical_parameters as ap using (source_id)
where
    1 = contains(point('ICRS', ra, dec), circle('ICRS', 265.175375,-53.67433333, 2))
    and pmra between 1.5 and 5
    and pmdec between -20 and -15
```

1.4 Custom columns

The following query will return a catalog of the magnitude values of the proper motion.

```
select
    source_id, SQRT(POWER(pmra,2)+POWER(pmdec,2)) as pmmag
from
    gaiadr3.gaia_source
where
    1 = contains(point('ICRS', ra, dec), circle('ICRS', 265.175375,-53.67433333, 2))
    and pmra between 1.5 and 5
    and pmdec between -20 and -15
```

1.5 Avoiding computations on columns

The following query is a naïve attempt to find the bluest stars in Gaia DR3. It will be unreasonably computationally intensive because it asks Gaia's servers to perform a (simple) computation on more than a billion rows. The query is shown in red to indicate that you should not try to run this.

```
select
    source_id, ra, dec, parallax, pmra, pmdec
from
    gaiadr3.gaia_source
where
    phot_bp_mean_mag - phot_rp_mean_mag < -2
```

Instead, you should use the pre-computed column for color:

```
select
   source_id, ra, dec, parallax, pmra, pmdec
from
   gaiadr3.gaia_source
where
   bp_rp < -2
```

The above query only takes 11 s, and returns 180382 stars.

Similarly, on the left panel of the Gaia Archive, you will notice that certain columns are **bolded**. This indicates that they have fast look-up tables associated (they are "indexed"), which means that they can be looked up especially quickly.

1.6 Example query for absolute G magnitudes, with quality cuts

We can consider the following query over the entire NGC 6397 field, with a custom column for the absolute magnitude. This returns 104297 stars.

```
select
   phot_g_mean_mag - 5*log10(distance_gspphot) + 5 as abs_g_mag, bp_rp
from
   gaiadr3.gaia_source
where
   1 = contains(point('ICRS', ra, dec), circle('ICRS', 265.175375,-53.67433333, 2))
```

We can make quality cuts on the astrometric solution:

```
select
   phot_g_mean_mag - 5*log10(distance_gspphot) + 5 as abs_g_mag, bp_rp
from
   gaiadr3.gaia_source
where
   1 = contains(point('ICRS', ra, dec), circle('ICRS', 265.175375,-53.67433333, 2))
   and ruwe < 1.4
   and parallax_over_error > 10
```

This returns 104297 stars.

1.7 Random indexing

There is also a pre-computed column called `random_index`, which is a random number which you can cut on if you want a statistically significant but not necessarily complete sample satisfying some conditions. The following query only returns 104297 items.

```
select
    phot_g_mean_mag - 5*log10(distance_gspphot) + 5 as abs_g_mag, bp_rp
from
    gaiadr3.gaia_source
where
    1 = contains(point('ICRS', ra, dec), circle('ICRS', 265.175375,-53.67433333, 2))
    and random_index < 1e6
```

1.8 Example DR3 query from [1]

The following query appears in [1], and is one example of how Gaia DR3 can be used for science purposes. It is a cut for "single-lined" spectroscopic binaries, which are candidates for stellar binaries containing black holes (although it is found that this is not the case).

```
select * from gaiadr3.binary_masses as bm,
gaiadr3.nss_two_body_orbit as nss
where bm.m2_lower > bm.m1_upper
and bm.m2_lower > 3
and bm.source_id = nss.source_id
and nss.nss_solution_type = 'SB1'
and nss.significance > 20
```

References

[1] Kareem El-Badry and Hans-Walter Rix. What are the spectroscopic binaries with high-mass functions near the gaia dr3 main sequence? *Monthly Notices of the Royal Astronomical Society*, 515(1):1266–1275, 2022.