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Gaia use case in Spoke 3

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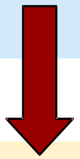
Scientific Rationale beyond the Spoke 3 goals

- Generation of a deep and complete sky, on 4π sterrad, as a reference tool and therefore interoperable for the integration of multiband data (from radio to high energies) and multi messenger data (e.g. sources of gravitational waves, neutrinos, ...) for efficient data mining aimed at fast multidimensional scientific data exploitation;
- Capacity for ad hoc recalibrations of astrometric and photometric data for the reclassification and redetermination of the fundamental properties (motions and magnitudes) of classes of objects of particular astrophysical interest;
- Interoperability and integration of metadata from non-astronomical databases, i.e. engineering and orbital data, data from service modules or payloads, or data coming, e.g., from Space Weather and/or surveillance of space debris (space debris surveillance);
- Operations of telescopes from Earth and space and support for studying new missions/projects.

Technical Objectives

Final Spoke 3 goal: study and implement a **prototype open-source platform** tailored for supporting and allowing scientific analysis on subsets of extracted Gaia data and metadata, alongside the Gaia database and data lake at DPCT, e.g. Gaia GW use case on a different platform (see Busonero talk's 1° Tech Meeting 10/10/23).

Beyond the Spoke 3 goal: an infrastructure for archiving, management, processing, visualization, reprocessing, and analysis of Gaia data from raw data to processed data, not only for astrophysical exploitation but also for space science technological exploitation to enable large-scale reprocessing.



To create a database and filesystem platform capable of extracting all sources within different specific areas of the sky simultaneously and associating with each source the information regarding its transits and its calibration data.

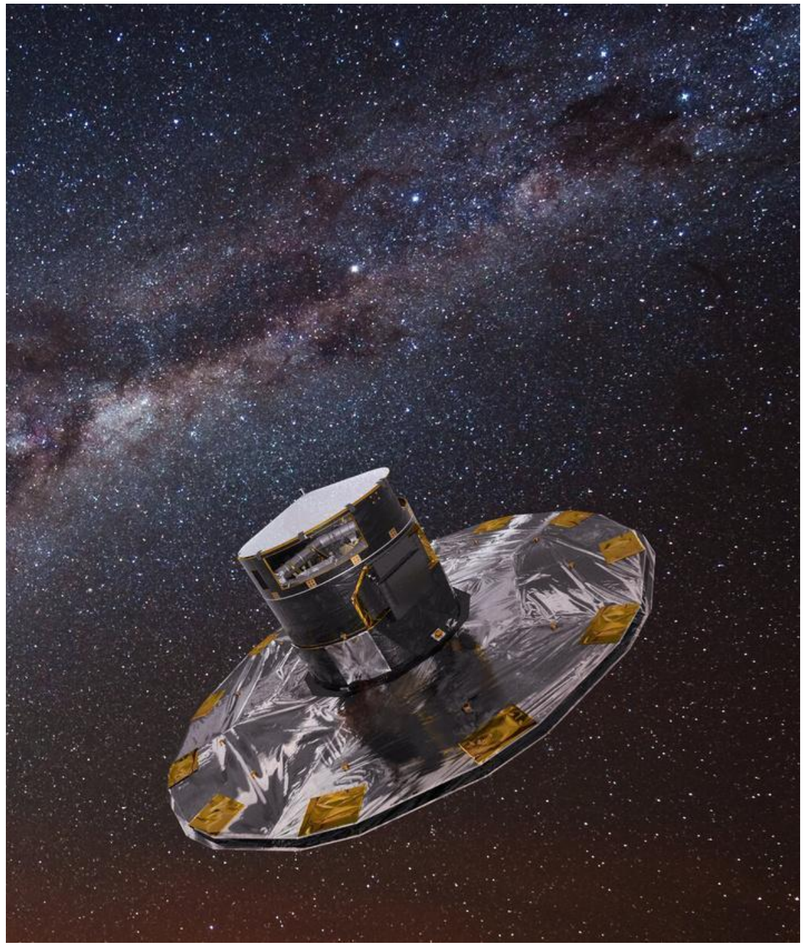
Technical Objectives

We need fast queries and analysis of data from different perspectives:

- *Run queries at billions of rows (sources) per second*
- *Switching between a source-oriented search by row (space) to a columnar search by transit (time) leveraging both indexing methods without the need to duplicate the DB volume;*

We also need to pre-aggregate and pre-calculate the information in the database before delivering it to the users.

The GAIA operations DM is not suitable for technical/scientific exploitation.



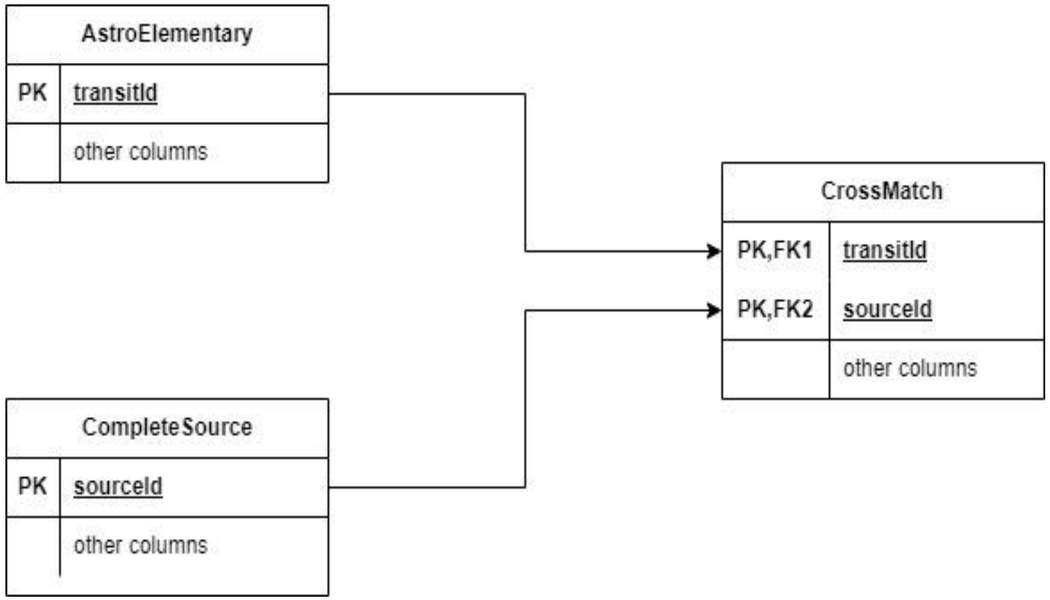
Credits: ESA/DPAC

Data overview

- **CompleteSource**:
  source information (180 attributes), ~ 4.8 TB with 2.793×10^9 elements.

- **AstroElementary**:
  transit information (33 attributes), ~ 70 TB with 99.9×10^9 elements.

- **CrossMatch**:
  association of sources and transits (8 attributes), ~ 1.4 TB with 88.997×10^9 elements.



Challenges

- DM and metadata definition to be queried in an efficient way;
- Blob attributes as links to other tables;

- The data are covered by an NDA - NO PUBLIC DATA;

- We experience some delay retrieving data from DPCT because of the HW infrastructure update.

Each of the billion astronomical objects is observed on average 200 times over the 10 years of the mission's duration!

GBIN

- Requires specialized tools for interpretation
- Converted gbin to another format for easier usage
- GBIN files can contain multiple CS/XM/AE entries


```
'sourceId': 3376960784291370112,
'alpha': 1.6257970447712626,
'alphaStarError': 415.1820205532908,
'delta': 0.389743536501208,
'deltaError': 304.3747106045399,
'linDecompNormalsParamSolved': 31,
'muAlphaStar': None,
'muAlphaStarError': None,
'muDelta': None,
'muDeltaError': None,
'radialVelocity': None,
'radialVelocityError': None,
'varpi': None,
'varpiError': None,
'linDecompNormals': [0.17978651002121898,
0.21658186521428793, 0.021359902368825224,
0.15672888162006487, -0.007329793929945749,
0.1774723087349154, -0.12139129917298573,
0.09194578488838766, -5.103146522638524e-05,
0.01918613887682385, -0.1353116037702648,
0.09556740757878916, -5.341107177382422e-05,
0.0028955756289015286, 0.019095000561812434,
4.645244283992821e-18, -3.3773274466869448e-18,
1.875151880209317e-21, -1.0141508864111856e-19,
-9.097583078950226e-20, 0.0010000000474974513],
'refEpoch': '<javaobj:gaia.cu1.tools.time.GaiaTime>'
'colConstLevel': None,
'f2': 1.2288812398910522,
'noiseFlag': 8,
'solutionId': 1636042515805110273,
'bpMean': None,
'fieldOriginators': '<javaobj:java.util.EnumMap>',
'gMean':
'<javaobj:gaia.cu1.mdb.cu5.photpipe.phot.dmimpl.MeanPhotImpl>'
'rpMean': None,
'Gof': 0.0,
'assumedModelOrigin': 0,
'assumedPhysicalMultiple': False,
'assumedVariableCombSpec': False,
'astrometricDuplicateSourceId': 0,
'astrometricPseudoColor': None,
'astrometricPseudoColorError': None,
'astrometryFromEarlierCycle': False,
'bpIntegratedSpectrum': None,
'converged': True,
'deltaQ': None,
'emissionLinesCombined': False,
'epoch': None,
'excessNoise': 9.363175726773374,
'excessNoiseSig': 16.60973007898822,
'expectedSigToNoise': None,
'gRvs': None,
'gRvsConstancyProbability': None,
'gRvsError': None,
'hasRadVelSpeBarSys': False,
'inPencilBeam': False,
'inverseConditionNumber': 2.485626464476809e-05,
'ipdFracHighGof': 11,
'ipdFracMultiPeak': 0,
'ipdFracOddWin': 0,
'ipdGofHarmonicAmplitude': 194292.4375,
'ipdGofHarmonicPhase': 39.968650817871094,
'isGrvsValid': False,
'isPhotometricOutlier': False,
'isRadVelVariable': False,
'isSB2': False,
'isWeakClassification': False,
'matchedObservations': 2,
'matchedObservationsUsedByAgis': 2,
'meanFluxExcess': None,
'meanOnBoardGMag': 20.7109375,
'meanVarpiFactorAc': 0.7114633321762085,
'meanVarpiFactorAl': -0.5583772659301758,
```


Disclaimer: example with fake data

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'radialVelocityError': None,
'varpi': None,
'varpiError': None,
```

Disclaimer: example with fake data

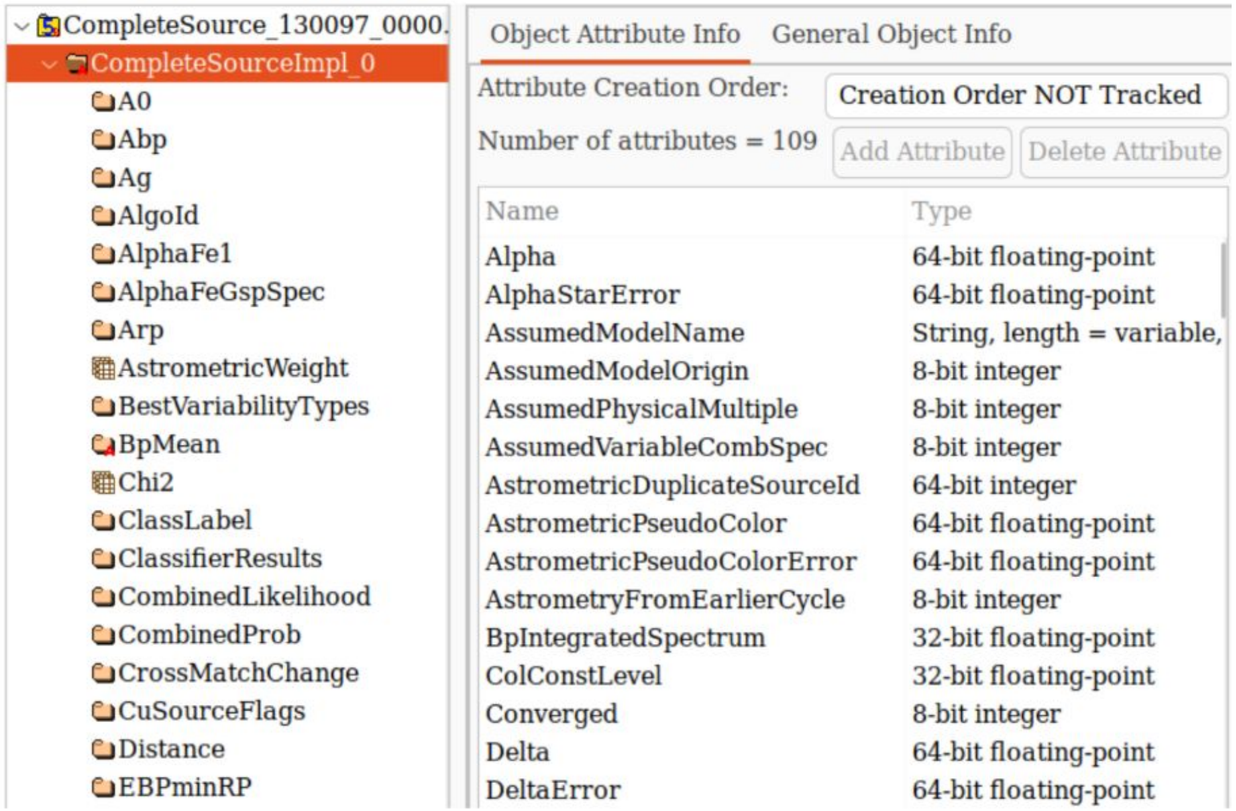
FITS

- Initially considered FITS format but faced challenges
- Created FITS files for each gbin, defining expected structures.
- Challenges with FITS rigid structure for dynamic needs.

HDF5

- Considered HDF5 for a more flexible structure
- Intuitive search
- Better blob integration

Java Objects ➡ HDF5 Groups
Java arrays ➡ HDF5 Datasets
Java primitives ➡ HDF5 Attributes



Possible queries

EASY

- Given a specific source;
- Find all the transit information associated with this source.

INTERMEDIATE

- Given an area of the sky;
- Find all the source within this area;
- Associate all the transit information to each source.

COMPLEX

- Given a direction, a cone radius and the half amplitude of meridian band;
- Find all the source in the band perpendicular to the direction and within the cone;
- Associate all the transit information to each source.

Possible queries

EASY

```
SELECT * FROM completesource
JOIN crossmatch ON completesource.sourceId = crossmatch.sourceId
JOIN astroelementary ON astroelementary.transitId = crossmatch.transitId
WHERE sourceId = 3425096028968232832;
```

INTERMEDIATE

```
SELECT * FROM completesource
JOIN crossmatch ON completesource.sourceId = crossmatch.sourceId
JOIN astroelementary ON astroelementary.transitId = crossmatch.transitId
WHERE alpha < 1.61835 AND alpha > 1.61815
AND delta < 0.40205 AND delta > 0.40185;
```

Possible queries

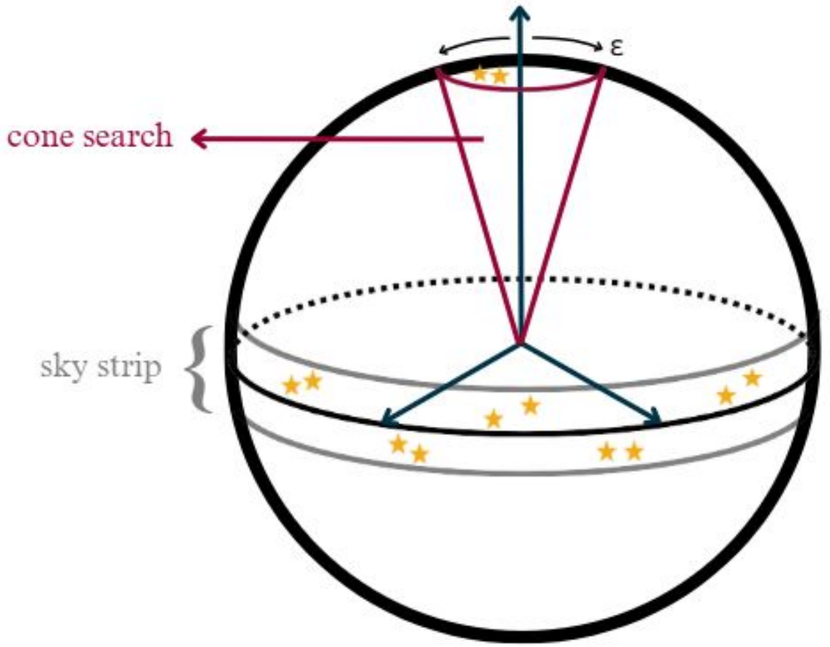
COMPLEX

$\alpha = 0$ [rad]
$\delta = \pi/4$ [rad] = 45 [deg]

cone radius: $\varepsilon = 0{,}0017453$ [rad] = 1/10 [deg]

$\alpha = 0$ [rad] $\pm \varepsilon$
$\delta = \pi/4$ [rad] $\pm \varepsilon$

half amplitude meridian band: $2{,}91\ 10^{-4}$ [rad] = 1/60 [deg]



A generic source of coordinates (α', δ') is inside the cone search if:

$$\cos(\theta) \geq \cos(\varepsilon) \quad \text{where:}$$

$$\cos(\theta) = [\ \cos(\delta)\cos(\delta')\cos(\alpha' - \alpha) + \sin(\delta)\sin(\delta')\ ]$$

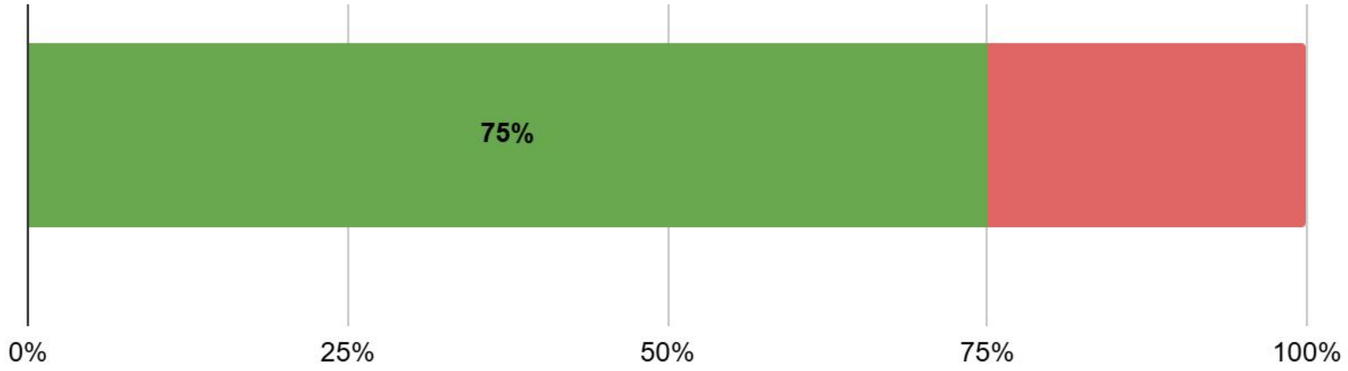
While it fall within the plane of half amplitude ε and perpendicular to the direction (α,δ) if:

$$-\ \sin(\varepsilon) \leq \cos(\theta) \leq \sin(\varepsilon)$$

Timescale, Milestones and KPIs

MILESTONE	KPI	TARGET	
M10 - August 2025	proceeding	proceeding @ PDP 2025	DONE
M10 - August 2025	conversion	final conversion in hdf5 of the data	DONE
M10 - August 2025	queries definition	final assessment of the queries for the final dataset	DONE
M10 - August 2025	dataset delivery	delivery of the final dataset	ON GOING

Percentage: 75 %



Final steps

- Delivery the final dataset;

- Verify that the output results are consistent with the DPCT Oracle system to ensure data integrity;

- Perform validation and performance tests on OPS4 platform (Oracle + ZFS + customized data lake) and Spoke 3 platform across all query types, with particular focus on the most complex query.

Thanks for your attention!