Italian Gaia Data management, processing infrastructure and Legacy

A joint collaboration between INAF and ALTEC

Enrico Licata
on behalf of INAF & ALTEC teams

INAF USC-C - General Assembly
March 09 – 13, 2026
Savoia Excelsior Palace - Riva del Mandracchio, 4, 34124 Trieste TS

The Team

ALTEC

Lorenzo Bramante
Ruben De March
Daniele Gontero
Rosario Messineo
Luigi Squillante
Leonardo Tolomei

Former Members
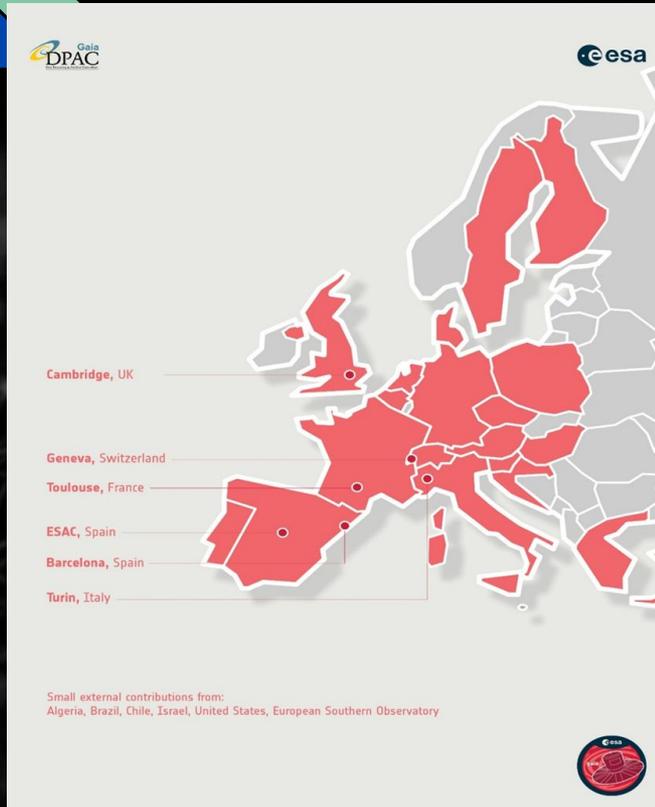Fabio Filippi
Andrea Fonti
Enrico Pigozzi
Marco Vaschetto

INAF
ISTITUTO NAZIONALE DI ASTROFISICA

Ummi Abbas
Beatrice Bucciarelli
Deborah Busonero
Raffaella Buzzi
Mario G. Lattanzi
Enrico Licata
Roberto Morbidelli
Alberto Vecchiato

Former Members
Luca Bianchi
Marco Pecoraro

The DPAC

DPAC (Data Processing and Analysis Consortium) is responsible for the processing of Gaia's data with the final objective of producing the Gaia Catalogue

The responsibilities of DPAC:

- **preparation of the data analysis algorithms** to reduce the astrometric, photometric, and spectroscopic data within a coherent and integrated processing framework,

- **generation and supply of simulated data** to support the design, development and testing

- **design, development, procurement and operation** of all aspects of the hardware and software processing environment

- design, development and operation of the Gaia database and archive

Cambridge, UK

Geneva, Switzerland
Toulouse, France
Barcelona, Spain
ESAC, Spain

Turin, Italy

○ Data Processing Centres

Small external contributions from: Algeria, Brazil, Chile, China, Israel, United States, European Southern Observatory

DPCT & The DPCs

Each DPC has its own infrastructure and it's responsible for the execution of specific software components, covering all or part of the need of a single or multiple Coordination Unit (CU). These are:

- DPCB (Barcelona)
- DPCC (CNES)
- DPCE (ESAC)
- DPCG (Obs. Geneva / ISDC)
- DPCI (IoA, Cambridge)
- DPCT (Turin)

DPCT: one of the 6 data processing centers (DPCs) of the Gaia SGS, hosted in ALTEC in Turin. Under dedicated ASI industrial and scientific contracts, its construction and operation is the result of the work of an integrated INAF-OATo / ALTEC team.

The DPCT provides the infrastructure and operations support to the Astrometric Verification Unit (AVU) activities for CU3

CU3 and the CUs

DPCT provides the infrastructure support (in terms of HW, DB and software framework) to run the CU3 sw systems that are part of the AVU (Astrometric Verification Unit): AIM, BAM and GSR

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

AVU is the unit responsible for the development and maintenance of the following three CU3 software systems:

AIM - Astrometric Instrument Model Data Analysis Software System, in charge of processing the Astro data telemetry in order to monitor and analyse the Astro instrument response over the mission lifetime.

BAM/AVU - Basic Angle Monitoring software system, in charge of processing the BAM telemetry in order to monitor and analyse the BAM behaviour over time.

GSR - Global Sphere Reconstruction, the mathematical and numerical framework that shall be used to verify the astrometric mission products produced by AGIS

Language, Versioning, Repository

To create a uniform environment and improve the software integration between partners JAVA was chosen as the standard language for the project across all DPCs and CUs to leverage its portability due to the JVM

The chosen versioning system is SVN, using the standard structure of Trunk, Branch and Tags to manage versioning and releases of sow across all CUs

All libraries required by the software developed in the scope of the project is maintained on a Nexus repository hosted by ESA. Only the libraries available on the repository can be used in the released code

Data Model & Dictionary Tool

MDB DM which is used by all DPCs
different DMs for each of the DPCs, giving flexibility to
each operational center.

The DM itself is a versioned SW, with trunk, branches
and tags

The dictionary Tool:
- allows the creation and editing of DM objects
- is shared by all DPCs and allows consultation
  of all the DMs of all the DPCs
- Each entry/table contains: fields, descriptions,
  types, multiplicity, units
- Each table has a table level description and a
  table level history
- All these informations can be edited and
  committed to a remote server

Data Format - GBIN

GBIN is a specialized, Java-serialized file format used by the Gaia Data Processing and Analysis Consortium (DPAC) to store astrometry data. It requires specific Gaia data model classes on the classpath at runtime for decoding. It is not a standard, general-purpose file format, but rather a niche, data-driven structure.

- Developed for handling data from the Gaia astrometry satellite during operations
- Compressed serialized java objects
- Requires a specific java sw (Gaia Tools) with the correct Data Model classes to be able to access the data.
- Can also be accessed via reflection in tools like TOPCAT
- Lightweight and suitable for operations

- Not suitable for scientific exploitation and dissemination

Serialization　　　　　　**Deserialization**

Object → Stream of Bytes → File / Data Base / Memory → Stream of Bytes → Object
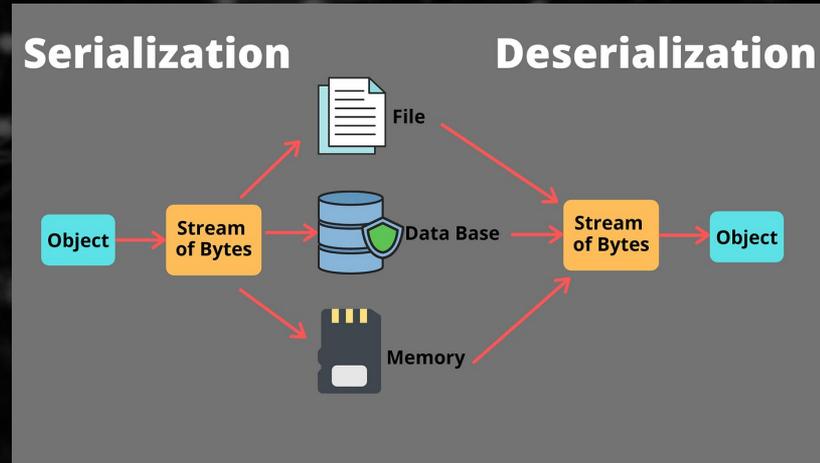
ECSS standard

European Cooperation for Space Standardization: is a collaboration between the European Space Agency (ESA), the European space industry represented by Eurospace, and several space agencies, to develop and maintain a coherent, single set of user-friendly standards for use in all European space activities

It is a comprehensive system of standardization that includes a tailoring process to help in elaborating the ECSS Applicability Requirements Matrix

For example with respect to the software production, GAIA project adopted the following documents:

Defined at the planning stage:
- Software Design Document (SDD)
- Software Requirements Specifications (SRS)
- Software Test Specifications (STS)

Updated with each sw release:
- Software Release Notes (SRN)
- Software Test Report (STR)
- Software User Manual (SUM)

AIM 22.0 Software Release Note

22.0.6 patch release

prepared by: E. Licata, D. Busonero
approved by: DPCT CCB
authorized by: M. G. Lattanzi
reference: GAIA-C3-SP-INAF-ELC-005-03
issue: 03
revision: 5
date: 2020-10-20
status: Issue

More than 10 years of continous science Operations !!

SKY-SCANNING COMPLETE FOR ESA'S MILKY WAY MAPPER GAIA

From 24 July 2014 to 15 January 2025, Gaia made more than three trillion observations of two billion stars and other objects, which revolutionised the view of our home galaxy and cosmic neighbourhood.

3 TRILLION
Observations

2 BILLION
Stars & other objects observed

938 MILLION
Camera pixels on board

15 300
Spacecraft 'pirouettes'

55 KG
Cold nitrogen gas consumed

3827
Days in science operations

50 000 HOURS
Ground station time used

580 MILLION
Accesses of Gaia catalogue so far

13 000
Refereed scientific publications so far

2.8 MILLION
Commands sent to spacecraft

142 TB
Downlinked data (compressed)

500 TB
Volume of data release 4
(5.5 years of observations)

esa
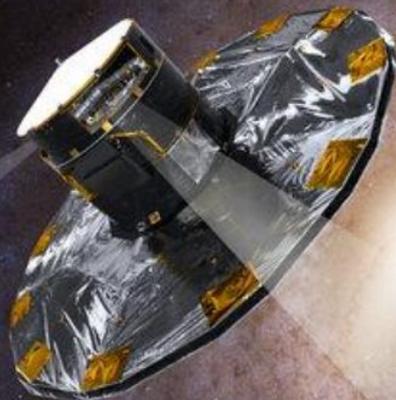
gaia

A few info on Gaia and its Data

- Launched on 19/12/2013
- Expected duration ~5 years
- Actual duration 10+ years
- End of Gaia scientific data collection: March 2025
- Observed and measured 2+ billion sources
- Each source has been observed on average ~200 times
- Each source transit is comprised by
  - telemetry data
  - actual raw data (6.5k ~ 35k windows, 18x12 px, every 4.41s for every one of the 62 AF CCDs)
  - data and metadata generated by multiple processing pipelines across europe (9 CUs)
  - and much more...
- Estimated size of the full dataset @DPCT (including outputs) ~ 3PB
- Estimated size of the full dataset at the end of data reduction in 2030 ~ tenth of PB
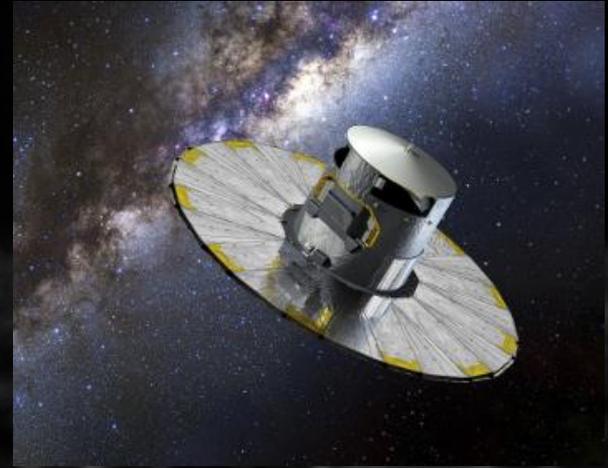
Raw data are NOT images

Processing Requirements @ DPCT
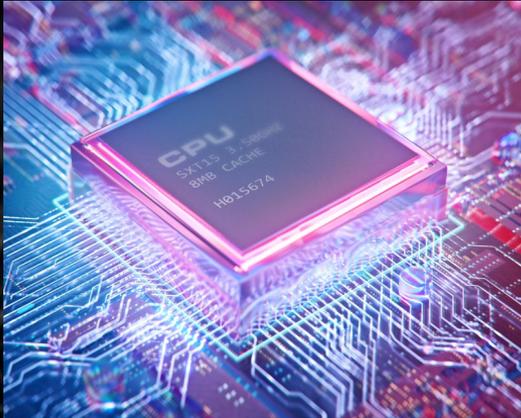
1. Handle a massive dataset: $10^6 \sim 10^7$ transits / day
2. Pipeline integrated DBMS capable of supporting OLTP (online transactional processing) and OLAP (online analytical processing) operations
3. Max processing time for Daily pipeline < 24h
4. Heterogeneous workloads
   - Computation
   - Monitoring
   - Visualization
5. Store all mission data and all produced outputs of both daily and cyclic processing
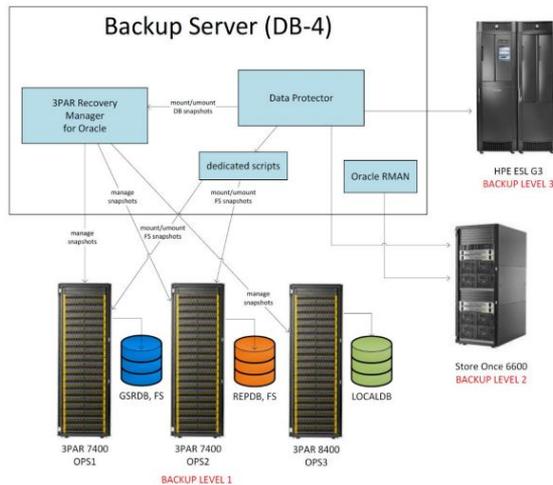
HW infrastructure 1/2

DPCT Overall HW infrastructure
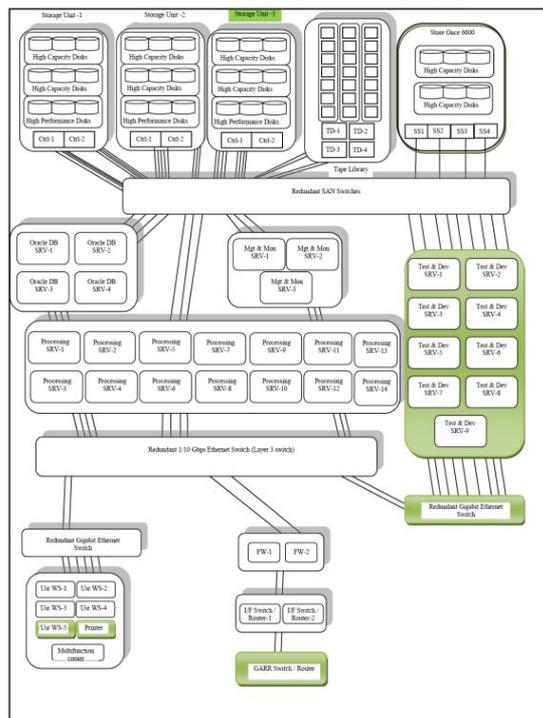
Backup Server (DB-4)

Credits: ALTEC

INTERNET LINK: 10Gbps (300 Mbps guaranteed) via GARR

STORAGE CAPACITY: about 2.6 PB overall rawdisk space distributed among 2 HP P7400 and 1 HPE P8400, HPE Nimble HF40, Oracle ZFS and Oracle ODA

COMPUTING: 14 servers HP DL580 G7/G9 with a total of about 600 CPU cores and 4.5TB RAM.

DEV & TEST: 7 servers HP

DB SERVERS: 3 HP DL580 G10 dedicated to the database cluster based on Oracle RAC technology

NETWORK CONNECTION: LAN network up to 10 Gbps. SAN network redundant at 8/16 Gbps.

SECURITY SERVICE: redundant firewall on 2 HPE DL380 G10 servers for replacement. based on pfSense, enabling secure remote access via VPN.

INFRA MONITORING AND MANAGEMENT: services based on VMWare virtual environment configured with 2 HP DL580 G7 servers clustered and managed by vCenter Server.

BACKUP SERVERS: HP DL580 G7 dedicated to database and file system backups from data volume snaphotsand HPE DL580 G10 servers for replacement.

3 LEVELS BACKUP: L1 on primary storage array, L2 on disks (StoreOnce 6600) and L3 on tape libraries (HP ESL G3).

HPC INTERCONNECTION: access to HPC supercomputer at CINECA for dedicated processing
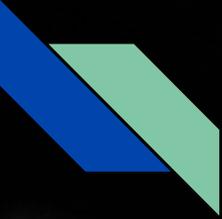
HW infrastructure 2/2

The DPCT hardware infrastructure is based on a distributed environment, including a computational grid, a database grid and a storage area network.

The DBMS choice is Oracle that provides advanced availability and scalability features. Oracle allows multiple computers to run the Oracle DBMS software simultaneously while accessing a single database, thus providing a clustered database.

The database grid will use the following Oracle products:

- Oracle Server
- Oracle RAC
- Oracle Partitioning
- Oracle ASM to manage storage used by database
- Oracle Spatial

Simplified Functional Schema

For the execution of each production run:
- Data is retrieved from Mission DB and sent to the DataServer (DS)

- The DS performs checks, selects data, creates data packages to be sent to the processing nodes

- Each node runs the scientific SW.
  - Statistical data collection is performed at this level

- Outputs produced by the nodes is used to populate the Web Interface, and to perform Monitoring and Diagnostic Operations, while being stored back to the Mission DB
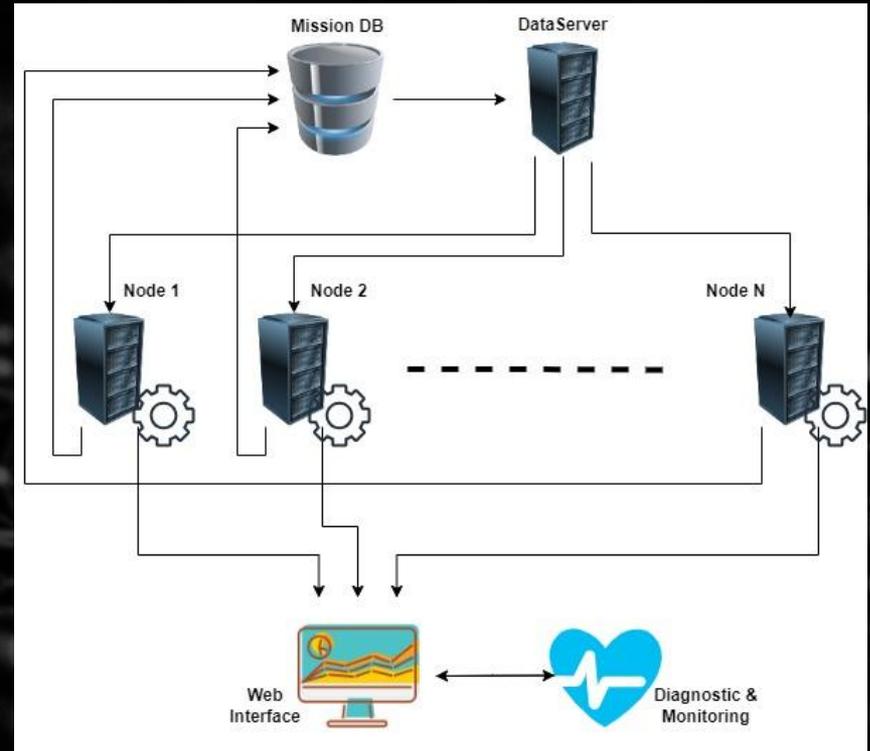
Production & Test Environments

To be able to develop your project you also need an appropriate dev and testing environment, together with a solid SW life-cycle

Development Environment	Testing Environment	Production Environment
Develop	Identify	Deploy
Coding	Fix issue	Available to users

Phases of the Software Development Lifecycle

- Maintain
- Plan
- Deploy
- Design
- Test
- Implement

PROD ENV: 14 servers with a total of about 600 CPU cores and 4.5TB RAM.

DEV & TEST: half as much (is it enough?)

- Ensure consistency with sw baseline and configuration
- Unit Tests → Use Cases → System Test → Integration Test → Prod
- SRN → STR → Release
- ALL documentation adhere to ECSS standards (European cooperation for space standardization)
- Test automation via Jenkins + Ant Tasks
- 3 SW systems competing for HW resources

Considerations

- Is it reasonable / necessary to have a full scale test env?
- Plan for a procedure to keep Prod and Test envs configuration aligned
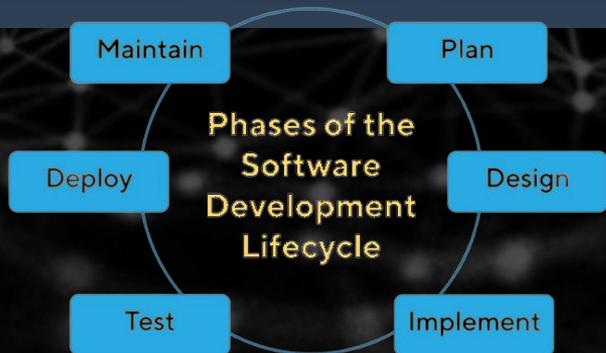
Workflow - CD/CI - Issue Tracking

- Centralized management utility VMware vCenter: deployment of VMs across the servers

- Ingestion, Archive, and daily Workflow, are automated using custom GAIA SW system developed in Java

- A monitoring web interface updated in real time (in house sw)

- All main project's branches on SVN (both for infrastructure and scientific SW) are monitored by a Jenkins instance that manages

    ○ svn checkouts

    ○ compilation

    ○ tests with apache ant tasks

- Daily pipelines programmatically generate a report each day

- Issue tracking is managed with JIRA
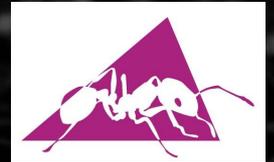
GAIA TOOLS

Agile Project Management

A project management approach that involves breaking the project into phases and emphasizes continuous collaboration and improvement.

- Periodic "STAFF Meetings" with whole team: 1/month to keep everyone engaged and discuss procurement and contractualization between all parties involved
- Operations briefing: checking the status of operations, bi-weekly
- Scrum / Dev meetings: among INAF and ALTEC developers to tackle specific technical issues

The frequency of each of these meetings has been adjusted during the project's life-cycle (Planning /Commissioning / Early Operations / Operations) with the intent of maintaining minimal overhead
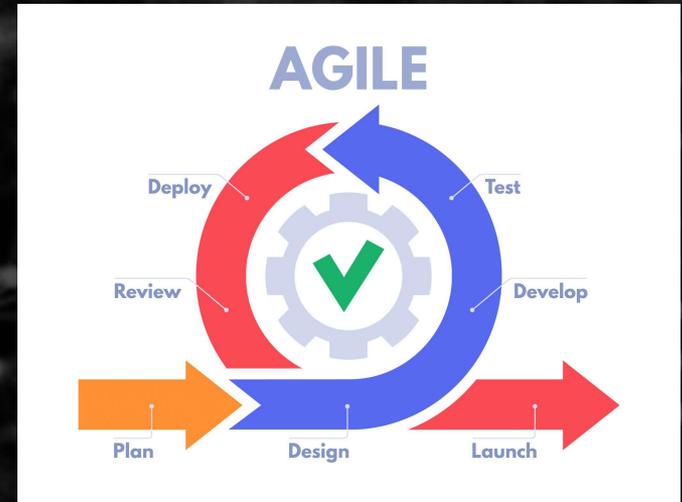
Infrastructure Software

- DPCT_SoftwareSystem
  - manages workflow
  - node deployment
  - db interaction
- DPCT_SoftwareConfiguration
  - manages the conf of daily and DRC workflows
  - separate conf for all project modules
  - plot descriptors
- DPCT_ConnectorLibrary
  - Integration between the Infra SWs and the scientific SWs

The integration between Infra and Scientific code managed by the ConnectorLibrary required:

- A Shared effort between INAF and ALTEC on specific parts of the source code
- Required tight cooperation and coordination between research institution and industry for the development and maintenance

Scientific Code - Overview

- 5 pipelines:
  - **AIM** - Astrometric Instrument Modeling - daily/cyclic
  - **BAM** - Basic Angle Monitoring - daily/cyclic
  - **GSR** - Global Sphere Reconstruction - cyclic
- Parallelization is managed by the infrastructure
  - but many parts have been parallelized to allow testing of large batches of data
- Source code is under version control using SVN (chosen by ESA and imposed to the Consortium)
- Implements established design patterns such as: Chain of Responsibility / Singletons / Abstract Factory
- The data packages send to the processing nodes are not stored "as is": they are runtime items, built from an underlying db and following a specific DM
- the whole AIM and BAM pipelines are performed locally on the DPCT infrastructure
- Computational requirements for GSR exceeds the capability of the DPCT
  - the SOLVER is executed on LEONARDO

HIGH LEVEL ACTIVITY DIAGRAM of AIM PIPELINE:
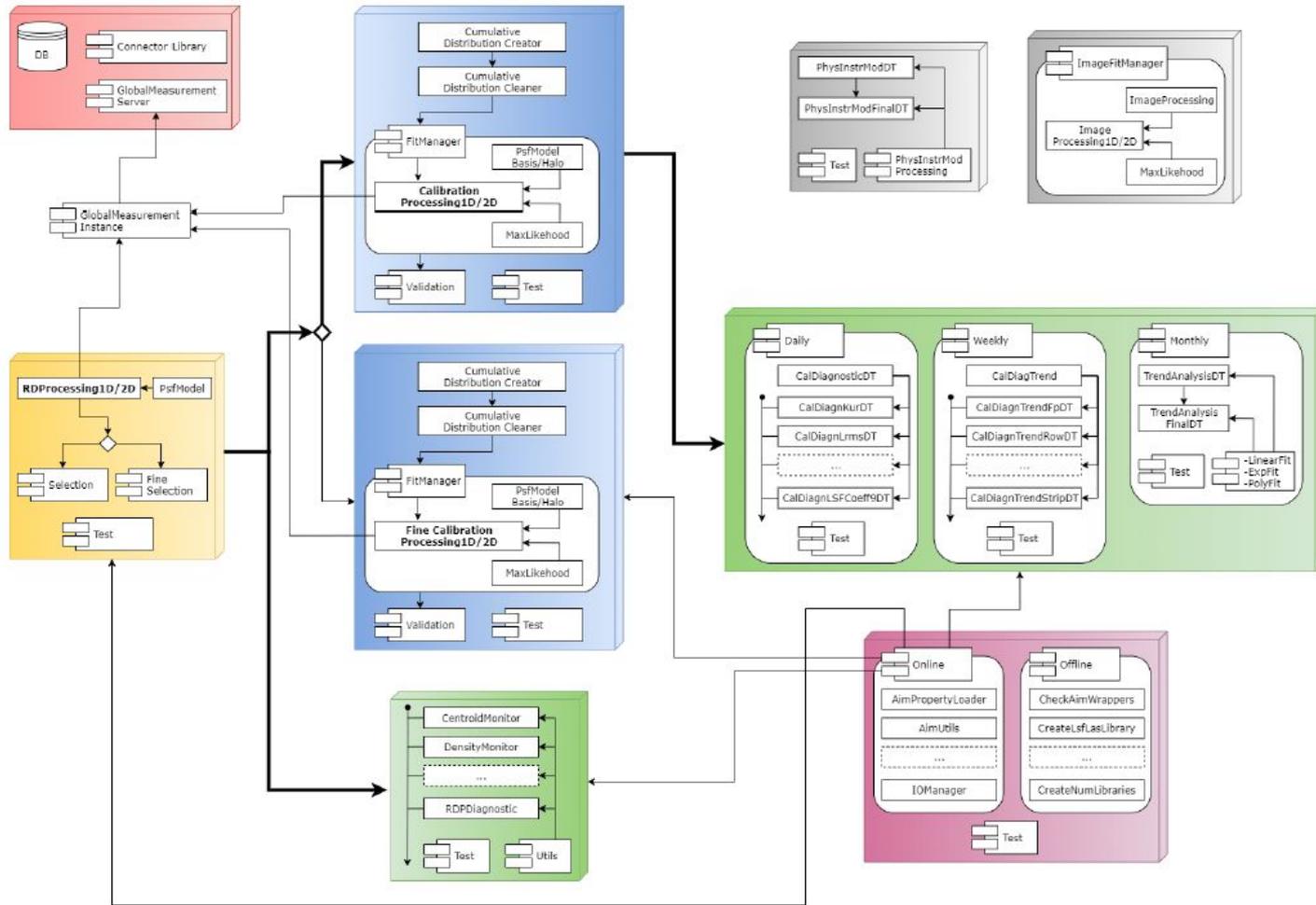
AIM - Astrometric Instrument Modeling

AIM daily pipeline: Raw data processing, image parameter determination, LSF/PSF modelization and calibration, astrometric instrument monitoring and diagnostics throughout the mission lifetime

- Daily sw version 100.000+ lines of code
- Cyclic sw version about 100.000+ lines of code
- 24 hours of raw data each run : from $2x10^6$ to $15x10^6$ ~~raw images~~ transits
- Complex structure of the pipeline: 10 sw modules managed by an unsupervised coordinator, the output of one run become the input of the next one
- ~6 hours of time execution on the DPCT Operation platform for each run

Cyclic version of AIM the software aims to reprocess images for calibration improvement and refined image parameters calculation
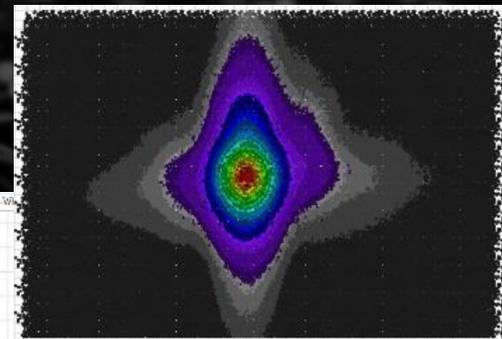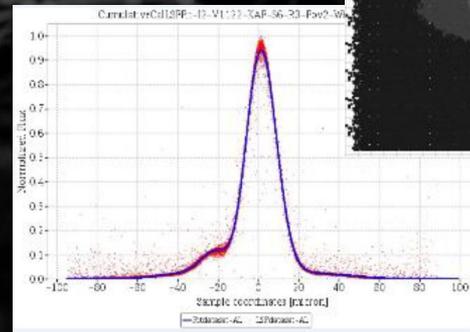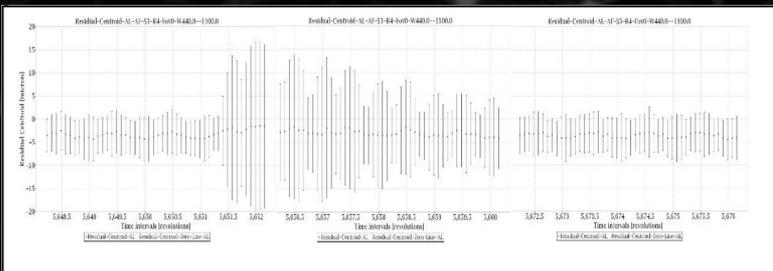
HIGH LEVEL ACTIVITY DIAGRAM of BAM PIPELINE:

BAM - Basic Angle Monitoring

AVU/BAM daily pipeline: raw data coming from the Basic Angle Monitoring (BAM) instrument , i.e. fringes , for monitoring and analyzing the instrument behaviour throughout the mission and performing the BAV calibration

- Daily sw version 100.000+ lines of code
- Cyclic sw version circa 50.000+ lines of code
- 24 hours of raw data each run : almost 8×10^4 images (1 pair every ~23s)
- ~2 hours for each run:
- proved fundamental to correct basic angle variation that were way over spec
- The pipeline output is sent to DPCE and ingested into the MDB

Cyclic version of the AVU/BAM software aims to reprocess fringes for calibration improvement

HIGH LEVEL DIAGRAM OF GSR PIPELINE
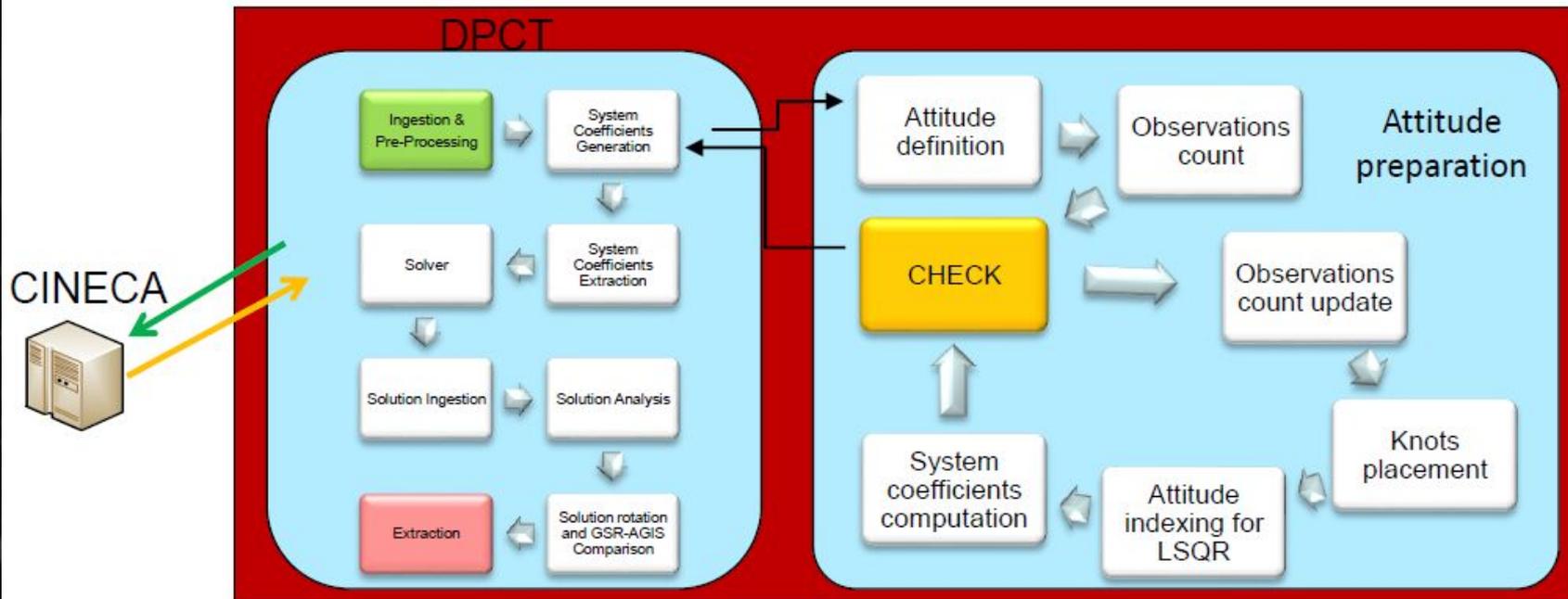
GSR - Global Sphere Reconstruction

The Global Sphere Reconstruction (GSR) solves a linearized system of equations whose result gives the global astrometric reference system (position, parallax, proper motions).

- Starting from 10^7 to 10^8 objects for each run
- Very complex pipeline structure
- 130.000+ lines of code in Java for data preparation, selection and analysis, and...
- The Solver running at CINECA
  - See any of Valentina Cesare's presentations on the GPU implementation of the solver
- Final GSR output sent to DPCE in the MDB
- The Solver module run at CINECA which is managed as one processing node of the DPCT
- The whole process could be iterated for Non-Linearity
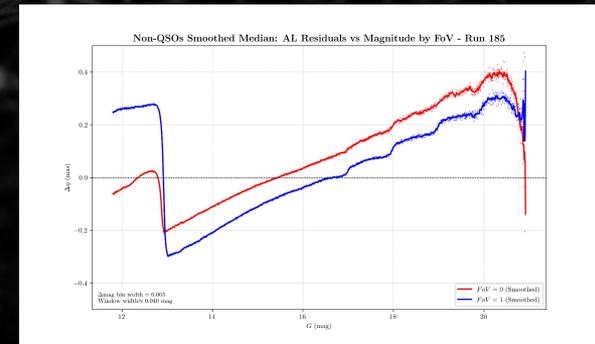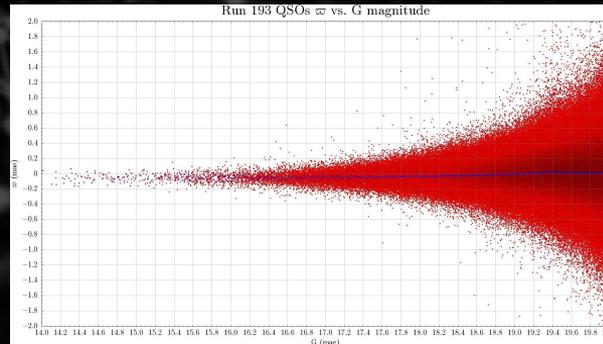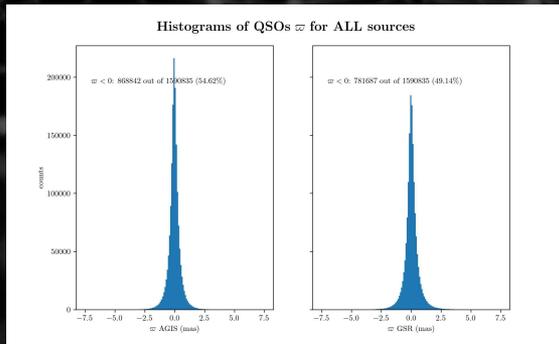
Transitioning towards a new DMS 1/3

Why

1. Mission extended far beyond the expected timeframe
2. Massive databases/tablespaces (~TB) with detrimental effect on DMBS performance and maintenance
3. Daily / Cyclic operations require different DBMS paradigms
4. Heterogeneous requirements for the data model and its indexing/partitioning:
   - Hybrid DM: Relational with serialized objects (BLOB)

How

1. New Data Management System : Hybrid FS (ZFS) and DB solution
   - data lake with all mission data as GBINS
   - 2 different databases for medata and mission metadata
   - ODA dedicated to the scientific exploitation of the data
2. New data model:
   - Vertical cut of the original tables
   - removed / exploded every BLOB

Transitioning towards a new DMS 2/3
HW & Logical Design
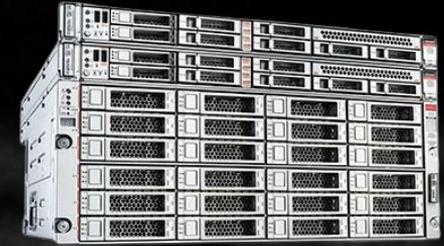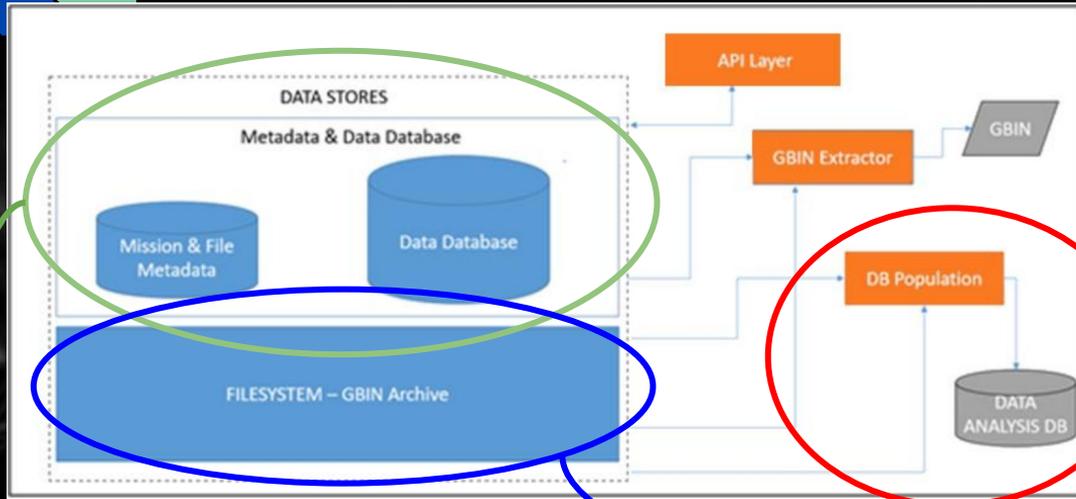
Oracle Database Appliance X8-2-HA, TAA

Oracle ZFS Storage Appliance Racked System ZS9-2

HPE Nimble HF40

Transitioning towards a new DMS 3/3

Original GAIA DM and Data format

GAIA DM it's an hybrid between relational and document based:

- Every object is represented as a table but some fields are objects as well
- Impossible to query on some of its data/metadata
- Access to the data requires specific sw tools

GAIA Data Format

- Gbin data format is a zipped serialized java object
- very limited interoperability
- very lightweight (structure not included)

New DM and Data Format

OPS4 DM is fully relational

- all fields are query-able with standard SQL
- data can be accessed directly on the DB (vertical cut) or retrieved fully from the archive

Data Format:

- Experimenting with HDF5
- greatly improved interoperability
- increased storage requirements (by a factor of 2)

Spoke 3 - WP4 IDL and IGUC
Interoperability Data Lake for the Gaia Use Case

The purpose of Spoke 3 is the development of innovative applications and software capable of fully exploiting cutting-edge HPC technologies and big data storage solutions, to achieve excellence in the areas of astronomy, high-energy astrophysics, astroparticle physics, and cosmology.

WP4

WP4 builds upon best practices and already implemented frameworks for managing data and software with FAIR and Open Science principles, to develop innovative frameworks capable of addressing the Big Data Challenge

IGUC

The IGUC innovation grant originates within the National Center for HPC, Big Data and Quantum Computing and is developed through a joint collaboration between INAF and Leonardo S.p.A. to study various technological solutions, such as DMS and the use of alternative DBMS, to manage, store, and access big data for the GAIA use case.

The Team in IGUC

INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

Deborah Busonero
Giacomo Coran
Massimo Costantini
Sara Gelsumini
Cristina Knapic
Mario G. Lattanzi
Enrico Licata

Filippo Balla
Gennaro Chiorazzo
Fabrizio Lupi
Daniel Procopio
Sonia Regis

CHERRY
DATA

Chiara Francalanci
Paolo Giacomazzi

LEONARDO

Carolina Berucci

IGUC Objectives

Technological testing of various DBMS and Data Management Systems, starting from the GAIA use case, with the objective of estimating and comparing the performance of the different systems, in a way that is as hardware and scale invariant as possible

OPS4@DPCT
- Oracle DBMS
- ZFS Filesystem
- HDF5 File format
- Oracle ODAx8

Spoke 3 - WP4 IDL
- Postgres DBMS,
- Rucio DMS,
- HDF5 File format,
- INFN Data Lake machines

IGUC - Leonardo/Cherrydata
- AyraDB,
- ext4 Filesystem,
- HDF5 File format,
- INAF infrastructure (bare metal and virtualized)

GAIA Test Case: Dataset 1 - Cone search + Meridian

Given a direction defined by (α,δ) and a radius ε, we have that a generic source of coordinates (α',δ') is inside the cone search if:
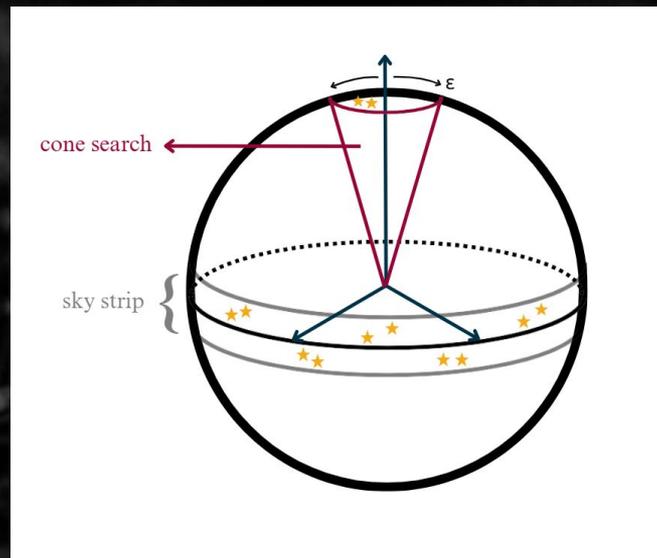
$$cos(\theta) \geq cos(\epsilon)$$

where

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

While it falls within the plane of semi-width ε and perpendicular to the direction (α,δ) if:

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

GAIA Test Case: Dataset 1 - Cone search + Meridian

Select all sources and related transits for the specified regions of space and the specified timeframe

Search details:

- Cone search direction:
  - α = 0 [rad],
  - δ = PI/4 [rad] = 45 (deg)
- Cone radius & semi-width of meridian band:
  - ε = 0,002182 [rad] = 1/8 (deg)
- Time range: 1 month of data
- Identified ~ $4.5 * 10^6$ Sources

Data Volume:

- Gbin Format (serialized compressed java objects):
  - CS ~ 91 GB, AE ~ 1.1 TB, XM ~ 76 GB
- HDF5 Format
  - CS ~ 9.6 TB, AE ~ 34.7 TB, XM ~ 22.6 TB
- HDF5 compressed (7z, LZMA2):
  - CS ~ 425.6 GB, AE ~ 2.3 TB, XM ~ 721.9 GB

Cardinality of the dataset:

- CompleteSources (CS) : 148.958.258
- AstroElementaries (AE) : 2.391.111.378
- CrossMatch (XM): 5.467.623.512
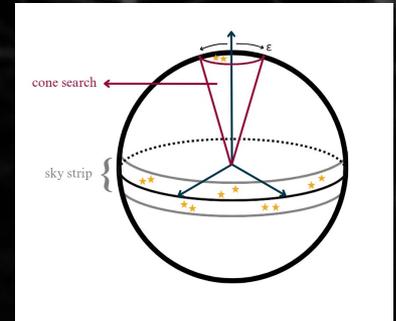
GAIA Test Case: Dataset 2 - 20k Cone searches

Select all sources and related transits for the specified regions of space over the entire mission

Search details:

- Cone search direction:
  - α_k, δ_k = 1 of 20.000 directions equally spaced along an homogeneous spiral from celestial north pole
- Cone radius
  - $\varepsilon = 4{,}71 \cdot 10^{-4}$ [rad] ~ 96,7 arcsec
- TransitID range:
  - all available mission data

Expected search results:
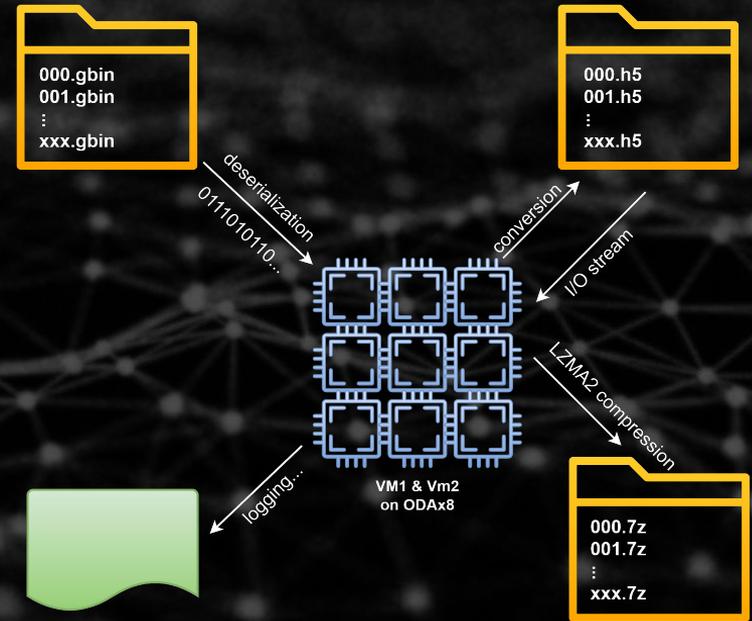
- Identified ~ $2.0 \cdot 10^{6}$ Sources

The extraction of this dataset required the development of a specific sw solution based on Apache NiFi.

Without it the number of gbins selected by this dataset and their total volume, covered almost the entire GAIA datalake at DPCT

HDF5 Converter

The software heavily leverages reflection and recursion to explore each input objects, regardless of its type, structure or complexity, and creates a corresponding HDF5 file mapping: Java objects, arrays and primitives are mapped respectively to HDF5 Groups, Datasets, and Attributes.

- Gbin files are read from a folder and all its subfolders
- Using MDBDM (Gaia Datamodel) and HDFQL (library) an .h5 version of each gbin is created and stored in a temp folder
- Each h5 is then read through a bufferedStream, compressed using LZMA2 compression algorithm and stored into an output folder
- The hierarchical structure of the original gbin is conserved into the final HDF5

000.gbin
001.gbin
⋮
xxx.gbin

000.h5
001.h5
⋮
xxx.h5

deserialization
011101010...

conversion

I/O stream

LZMA2 compression

logging...

VM1 & Vm2
on ODAx8

000.7z
001.7z
⋮
xxx.7z

OPS4 @ DPCT - Oracle + ZFS

The legacy project transitions from operational real-time data processing (OLTP) to a hybrid data management approach (OLAP + FS)

New DMS based on the interaction between Data Lake (GBIN format) managed by ZFS and two different DBs hosting metadata and mission metadata implementing a FAIR paradigm.

The submission of query/Data request is managed via an API layer, and outputs are delivered as files (GBINS / FITS / HDF5) or are used to populate a specific Data Analysis DB hosted on the ODA

HW & Logical Design

Oracle Database Appliance X8-2-HA, TAA

Oracle ZFS Storage Appliance Racked System ZS9-2

HPE Nimble HF40
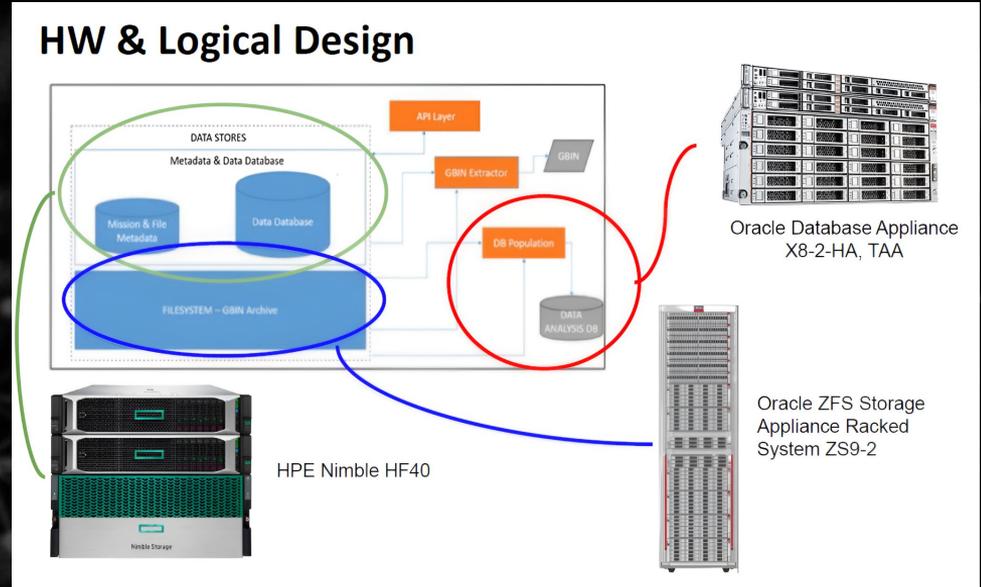
Spoke 3 WP4 IDL

- DBMS: postgreSQL
  - Datamodel an indexing based on the metadata (ATTRIBUTES) of the provided HDF5 Data-Lake
- DMS: Rucio instance hosting the Data-Lake
- Cut and Merge custom SW:
  - Able to retrieve specific parts of the original HDF5 file and provide only the required GROUPS / DATASETS / ATTRIBUTES to the user
- Web interface to allow the submission of queries from the users

Jportal Retrieval System

- Query on objectName, sourceId, or other metadata
- Results pair metadata retrieved from PostgreSQL to the corresponding files from Rucio Data Lake
- Data downloadable thanks to MinIO

Tap Endpoints following IVOA standards

- enables the execution of queries from other clients such as TOPCAT

IGUC - Leonardo & Cherrydata

- DBMS: AyraDB
  - database developed by Cherrydata,
  - Key-Value core
  - SQL operations
- Custom SW for data extraction from the HDF5 files
- Data-Lake: HDF5 files
- Deployment of a test AyraDB cluster on INAF infrastructure@OATs

Ayra DB

SQL Query

Sources & Transits

Client / User

SourceID, alpha, delta

Pairs (SourceID, SourceID)

Processing server
INAF idlserv3
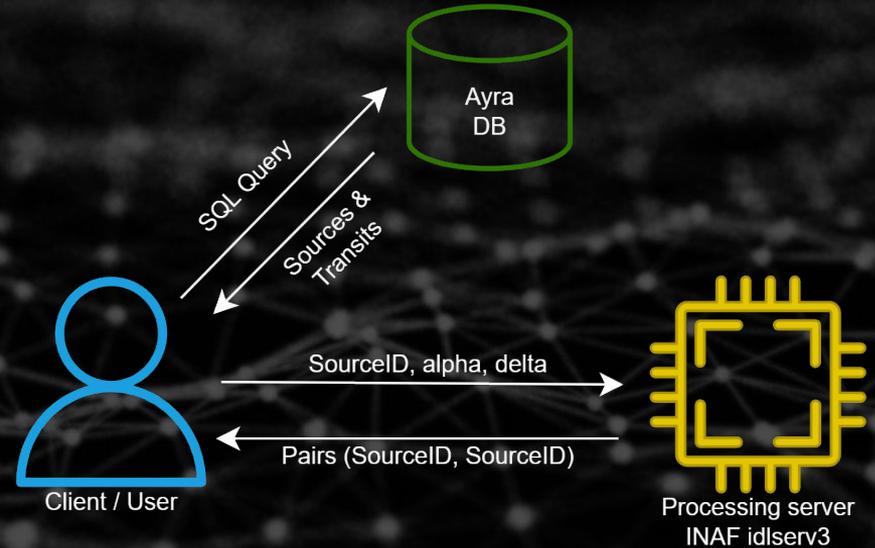
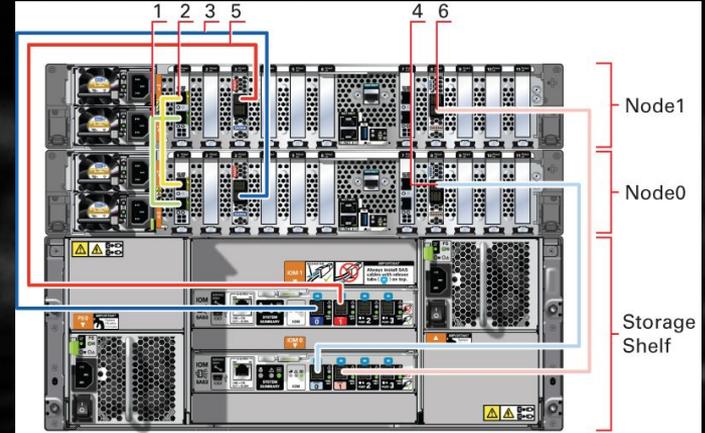# Results on Oracle DBMS + Oracle Spatial + ZFS

ODAx8 integrated system:
- **2 processing servers** with a total of **64 Intel® Xeon® Gold 5218**, and **384 GB of memory** per server.
- Storage shelf with 6 x 7.68TB SSDs and **18 x 14TB HDDs**
- connected via **dual 12Gb/s SAS interface**
- DBMS Oracle **19c** + Oracle **Spatial** and Oracle **BI**
- Storage **ZFS**

Data are ingested directly into the DB tables **using TLS Integrator: a parallel software developed inside the project**, that reads from gbin and populates the database. Sample ingestion times (subset):

|				
1 Reader Thread	CS entries: 3.105.011,	time: 101s,	~32 µs per entry,	30 krecord/s
10 Writer Threads	AE entries: 128.407.793,	time: 1696s,	~13 µs per entry,	75 krecord/s
RAM used: ~12GB	XM entries: 129.062.767,	time: 206s,	~1.6 µs per entry,	626 krecord/s

Results on AyraDB + KNN + ext4 fs

gaiaserv1:
CPU: 16
RAM: 64 GB
Disk: 110 TB, virtual disk

calcolo2:
CPU: 128 Intel Xeon gold 6548Y+
RAM: 206 GB
Disk: 4 TB, local SSD
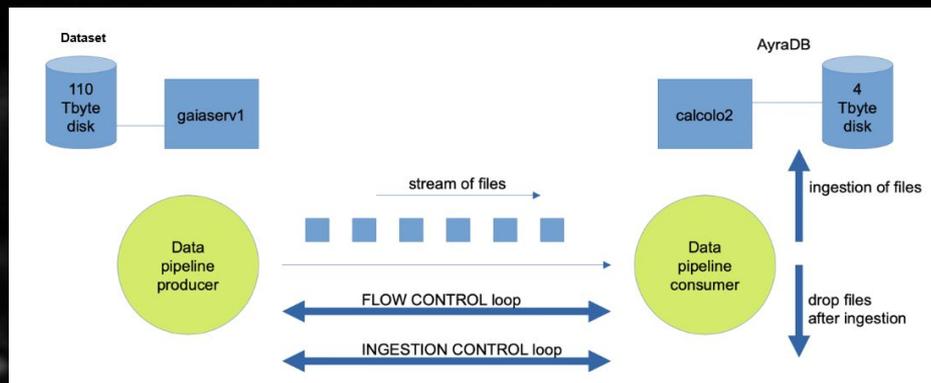
The dataset is on ingested on calcolo2, streaming from gaiaserv1.
Calcolo2 then manages the DBMS and client queries.
KNN computation if offloaded to INAF idlserv3
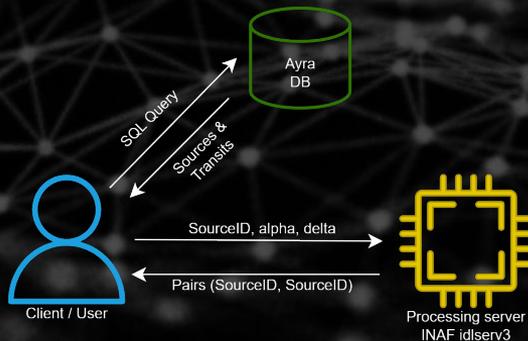
Dataset	N. files	Gross size	N. records	Ingestion time	Throughput
AstroElementary	199648	5.4 Tbyte	2,434,219,917	16 hours	42 krecord/s
CompleteSource	15949	432 Gbyte	159,440,000	2 hours	22 krecord/s
CrossMatch	60710	1.1Tbyte	6,068,000,000	6 hours	280 krecord/s

Results on PostgreSQL + RUCIO

- DBMS: postgreSQL
  - Datamodel an indexing based on the metadata (ATTRIBUTES) of the provided HDF5 Data-Lake
  - "standard" environment and "sharding" environment based on HEALPIX lvl6 (64 shards) to speed up source identification and healpix lvl12 to build spatial index in each shard
- DMS: Rucio instance hosting the Data-Lake
- Cut and Merge custom SW:
  - Able to retrieve specific parts of the original HDF5 file and provide only the required GROUPS / DATASETS / ATTRIBUTES to the user

Jportal Retrieval System

- Web interface to allow the submission of queries from the users
- Query on objectName, sourceId, or other metadata
- Results pair metadata retrieved from PostgreSQL to the corresponding files from Rucio Data Lake
- Data downloadable thanks to MinIO

Tap Endpoints following IVOA standards

- enables the execution of queries from other clients such as TOPCAT

IGUC results Summary

- Testing on the Oracle solution showed great results (constant time) when leveraging the Spatial index, but we found a clear degradation of the performance when the change in geometry lead to the full table scans

- Testing of the AyraDB solution, showed good results on cone searches and surprising results on meridian searches. However meridian searches showed a clear dependency on the dataset size, and which suggest possible scalability issues

- For the GAIA test case, both solutions proved to be appropriate

- Having completed these assessments in the scope of IGUC will surely allow us to make informed choices about the technologies we will use in future projects

- The goals of the IGUC project can be considered achieved

Lesson Learned & Friendly advices

- Plan for the future:
  - space missions can outlive the planned lifetime and you and your infrastructure need to be ready for it
- Do not skimp on the test environments!
  - Make sure to scale them properly and plan procedures (automated if possible) to keep the envs consistent
- A broad amount of different expertise is required for the success of such projects:
  - leverage the expertise and tools of your colleagues (MIRTA :D)
- Share information and foster communication:
  - this keeps people involved and motivated, since these projects are a loooong commitment
- Be ready for the turnover:
  - Having good documentation and even better procedures to bring the new members up to speed is paramount!

The 20 years GAIA SGS experience, similarly to other mission like Euclid, Planck etc formed a community of experts, that is now an asset for INAF in perspective of future large missions and projects

Lesson Learned... continued

- **HDF5: great for accessibility**, maybe not optimal for the Gaia dataset
  - Rich hierarchical format
  - great potential for chunking and lookup
  - a lot more volume overhead than expected (probably due to the data model)

- **Do not underestimate the importance of the correct data format for your project**
  - Starting from gbins and the development and optimization of the HDF5 Converter resulted a task way more complex and time consuming than expected

- **Always have contingency plans for unexpected setbacks**
  - The intermittent availability of the DPCT, especially during the first part of the project, due to GAIA Mission constraints, and infrastructure maintenance, posed a few challenges

- We would like to continue experimenting on this ideas, testing other technologies and data formats like Parquet and and DBMS like DuckDB

- Use the knowledge acquired through IGUC, to improve our infrastructure to support the italian scientific community

Bibliography

partial... there are too many contributions to cite them all

1. Italian Gaia data management and processings infrastructure for the AVU systems at DPCT, Enrico Licata, Deborah Busonero, Sara Gelsumini - USCVIII General Assembly 14-18 Ott 24

2. Gaia use case in Spoke 3, Sara Gelsumini, Enrico Licata, Deborah Busonero - Spoke 3 Final Workshop, Sexten, 14-19 Dec 2025

3. Spoke 3 Archive Infrastructure - Giacomo Coran, Massimo Costantini – INAF OATs - Spoke 3 Final Workshop, Sexten, 14-19 Dec 2025

4. INAF - Relazione Attività delivery 02 - Filippo Balla - 29 Luglio 2025

5. INAF - Relazione Attività delivery 03 - Filippo Balla, Valentina Nalessio - 7 Novembre 2025

6. CherryData - Relazione finale Attività Gaia - Chiara Francalanci, Paolo Giacomazzi - Settembre 2025

7. TN-IGUC-INAF-EL-001, TN-IGUC-INAF-EL-002, TN-IGUC-INAF-EL-003 TN-IGUC-INAF-EL-004

   Enrico Licata, Deborah Busonero, Mario Lattanzi - Settembre 2024 - Settembre 2025