JAXA's science ground segments for data processing and archives

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About myself…

- Professor at the Department of Space Astronomy and Astrophysics @ISAS/JAXA
- Member of the Center of Science-satellite Operation and Data Archive (C-SODA) @ISAS/JAXA
- Mainly studying X-ray astronomy, AGNs, black holes, neutron stars, Galactic X-ray emission etc.
- Have been working on the ground segments of high energy astrophysical missions at JAXA, NASA and ESA for ~30 years.
- Member of the LiteBIRD pre-project team @ISAS/JAXA since 2023 April
- Chair of the LiteBIRD Science Ground Segment (SGS) task force since 2022

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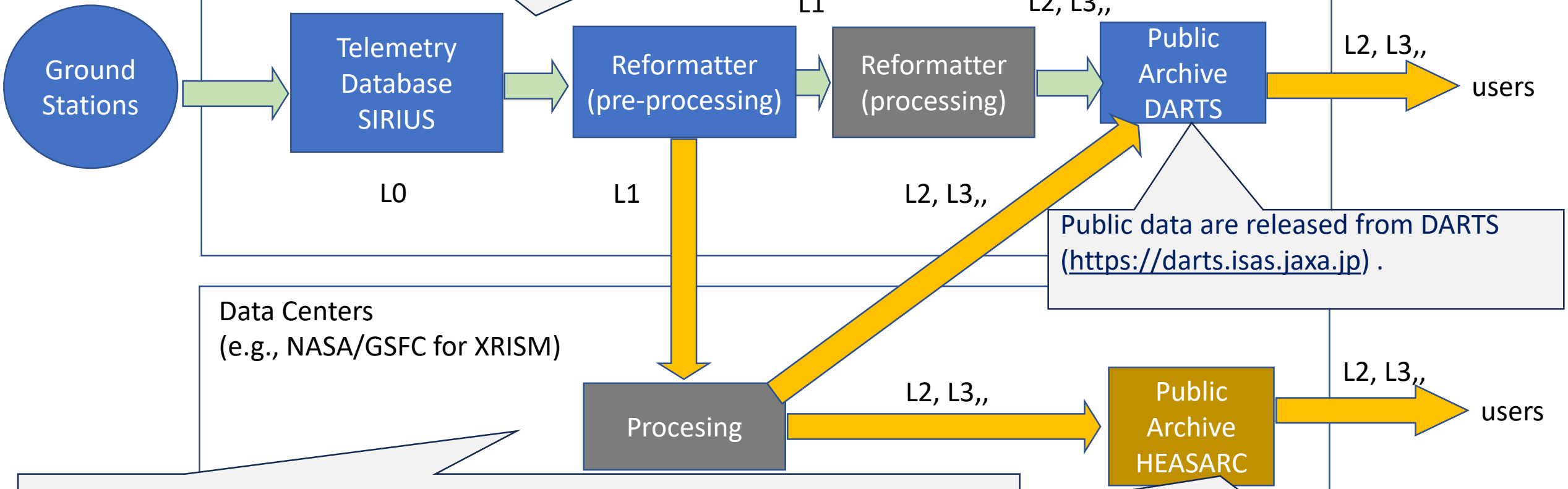
- Telemetry data (L0) taken at the ground stations are sent to the telemetry database named SIRIUS.
- L0 data are pre-processed by REFORMATTER to L1, where only de-packeting, formatting, and minimum corrections are made (e.g. time assignment).



- Processing, including instrumental calibration (L1 →L2, L3) may be carried out on the REFORMATTER or outside of JAXA.
- In the case of XRISM (JAXA's X-ray mission launched recently), the processing is carried out at NASA/GSFC.

Public data may be archived also outside of JAXA, e.g., HEASARC (https://heasarc.gsfc.nasa.gov).

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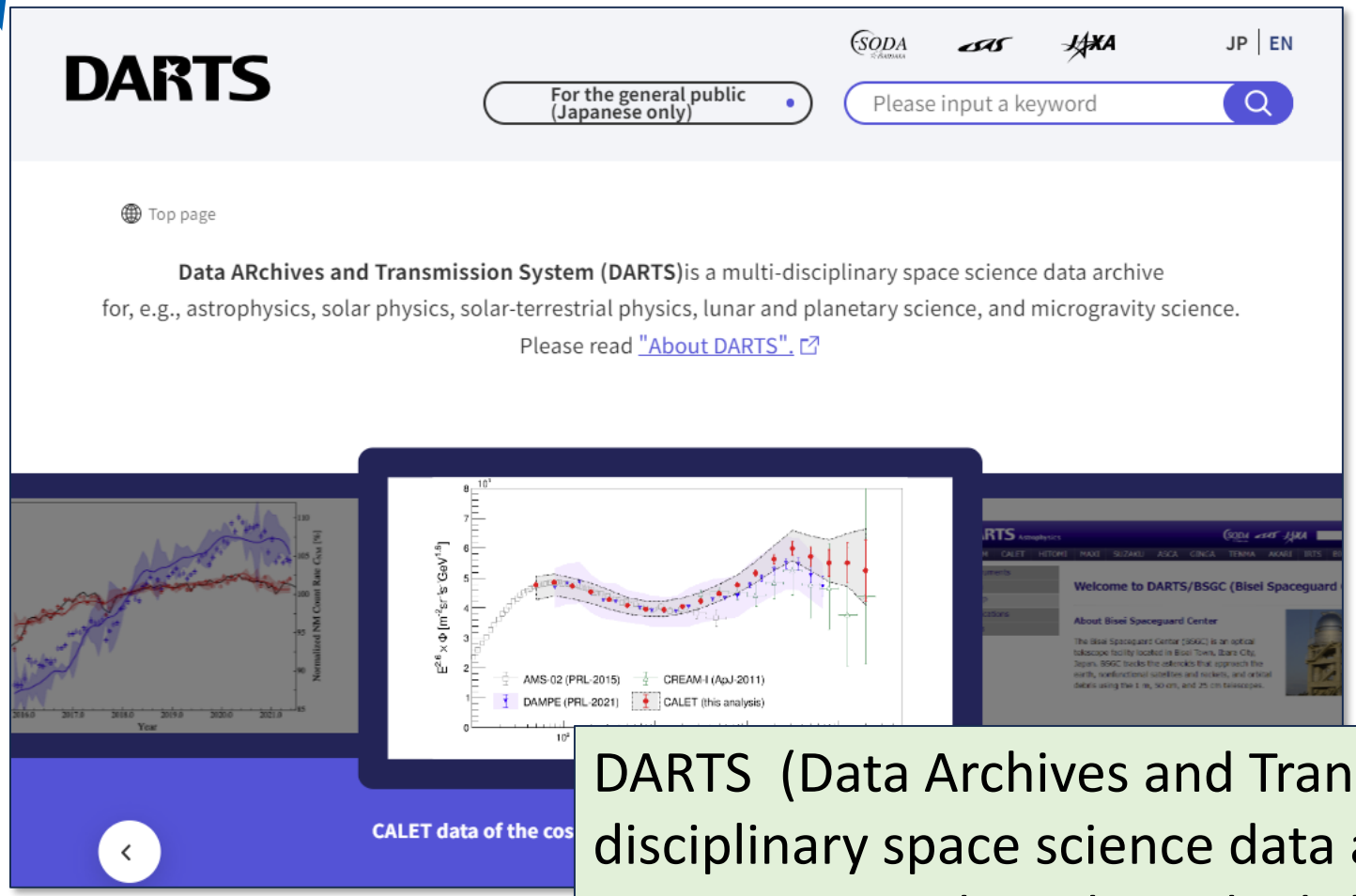
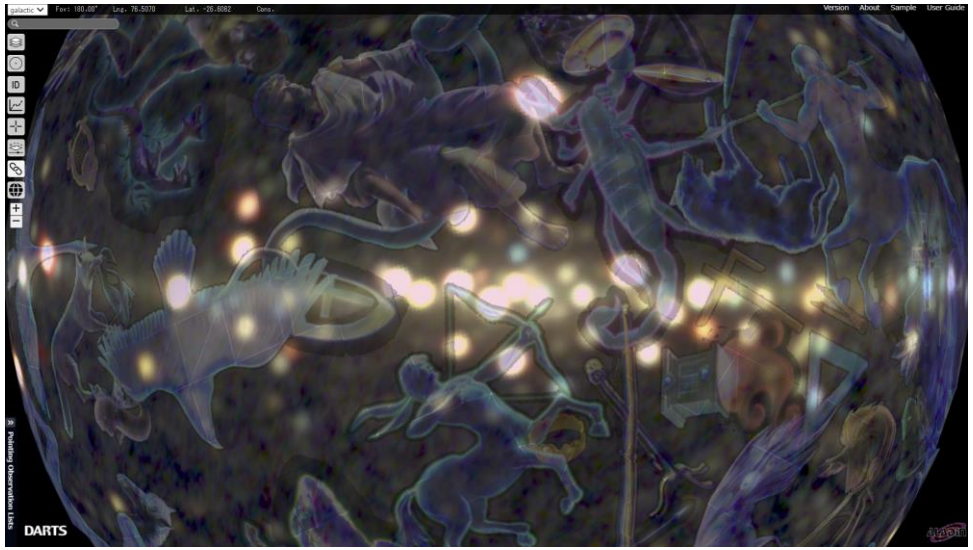
https://darts.isas.jaxa.jp

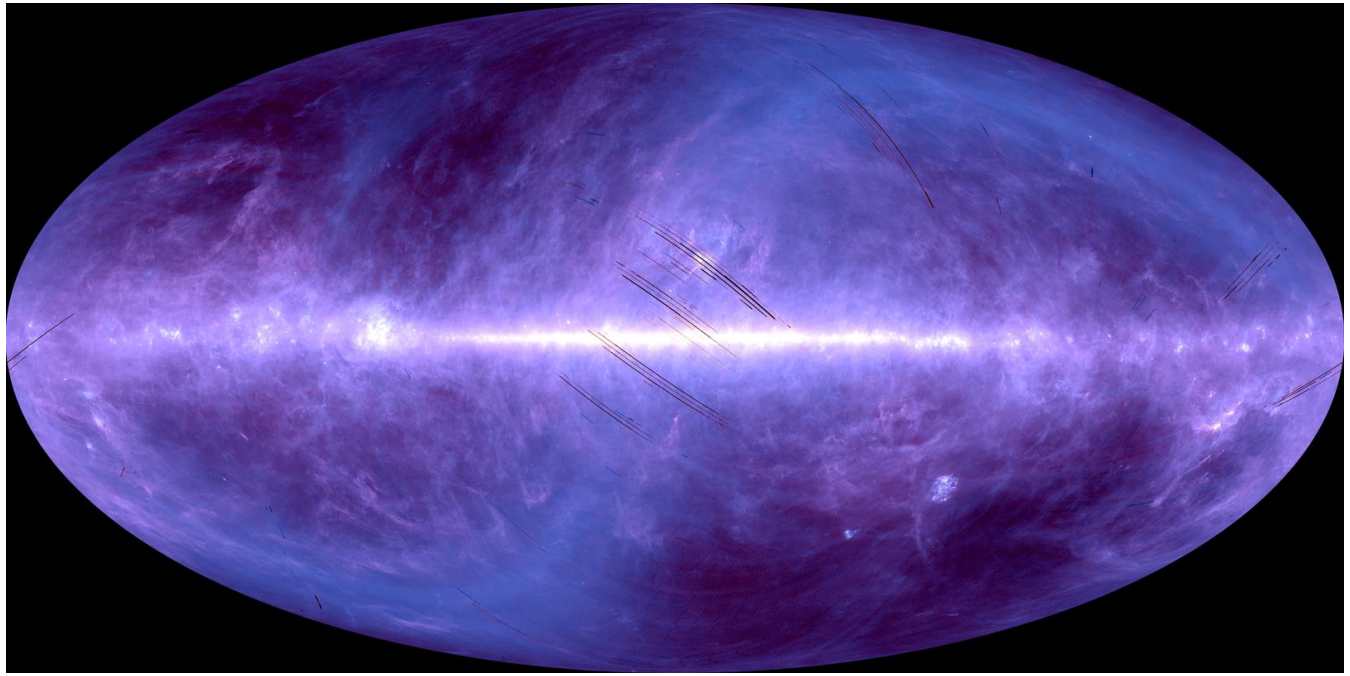




MAXI X-ray image and constellation displayed with JUDO2

DARTS (Data Archives and Transmission System) is a multi-disciplinary space science data archive.
DARTS primarily archives high-level data products obtained by JAXA's space science missions in astrophysics (X-rays, radio, infrared), solar physics, solar-terrestrial, and lunar and planetary science, as well as microgravity science data obtained by the International Space Station.

Akari archives



https://darts.isas.jaxa.jp/astro/akari/data/AKARI-FIS_Image_AllSky_Map_2.1.html

Akari FIS All-Sky image maps made in four bands, at around 65, 90, 140, and 160 microns. Akari FIS bands cover the thermal dust peak, and it has a much better spatial resolution than Planck.

Akari was operational from 2006 to 2011. Akri carried two instruments, FIS (Far-Infrared Surveyor) and IRC (Infrared Camera).

A new project has started with the Akari team to combine Akari TOD and Planck TOD to develop the best thermal dust model!

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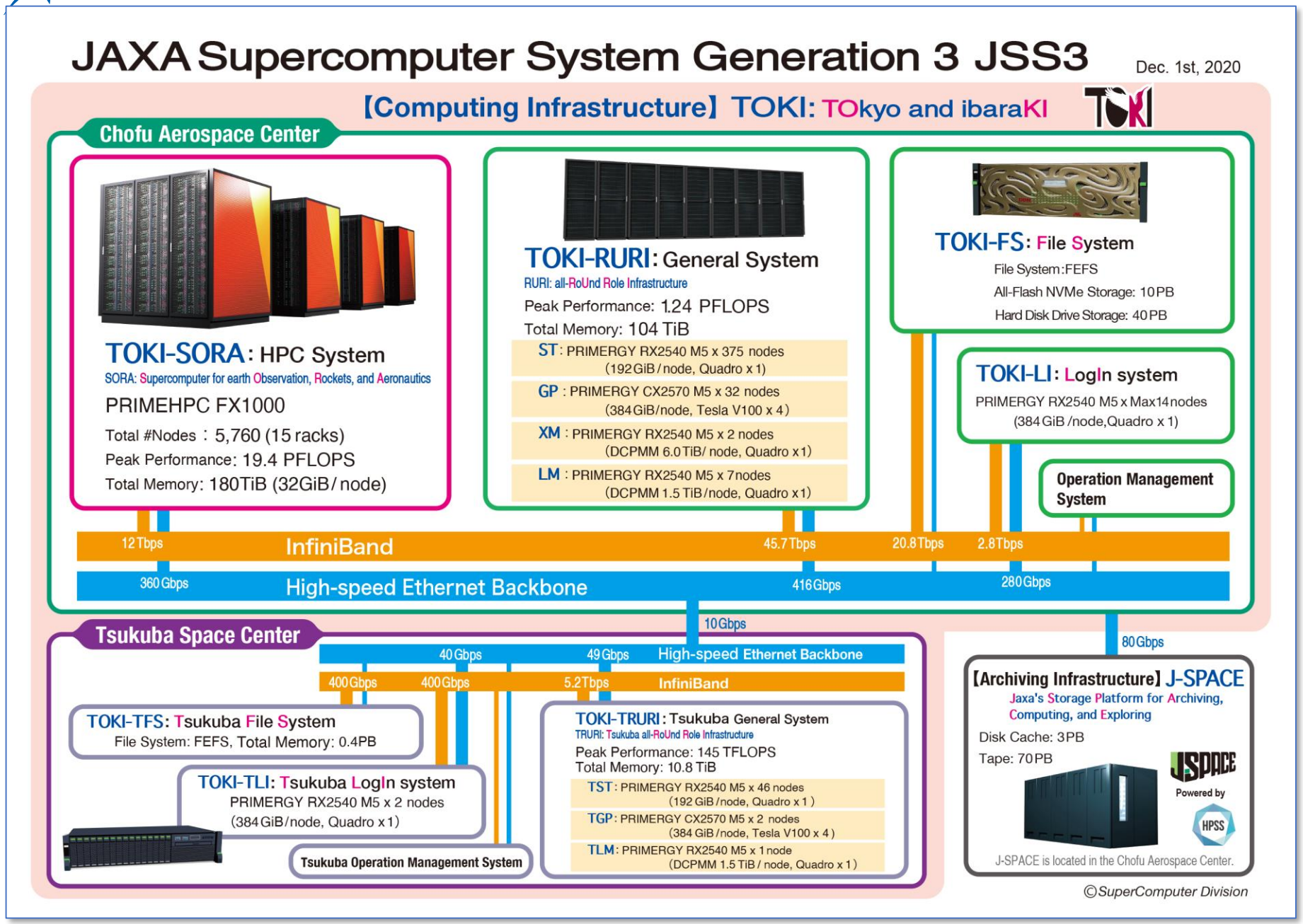

A collaborative research using JSS3 titled "Detailed *observational simulation* of cosmic microwave background radiation for precise determination of the cosmological parameters" was formally approved by ISAS/JAXA, involving the Universities of Ferrara, Milan and Catania.

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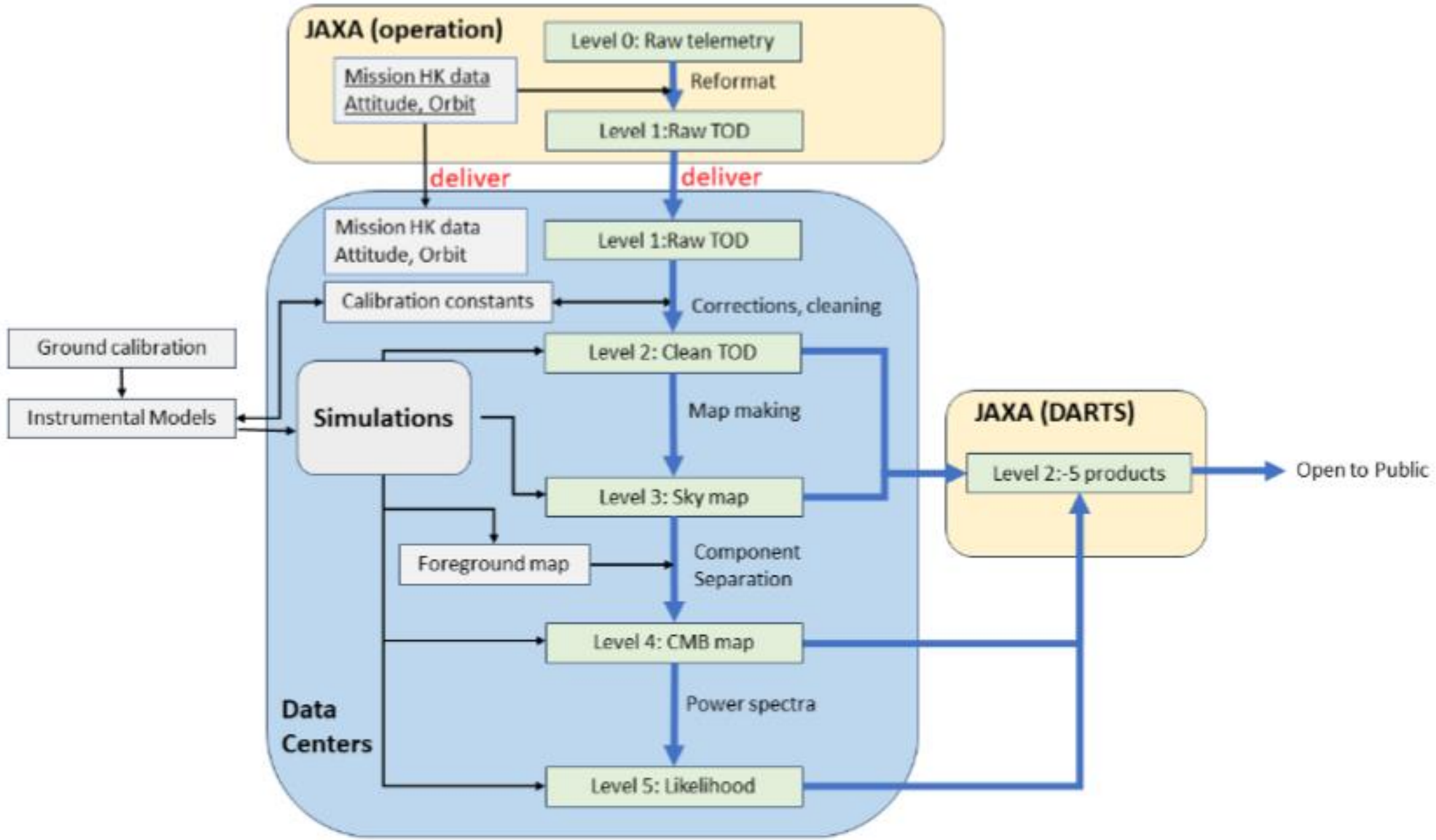
Requirements for the LiteBIRD SGS

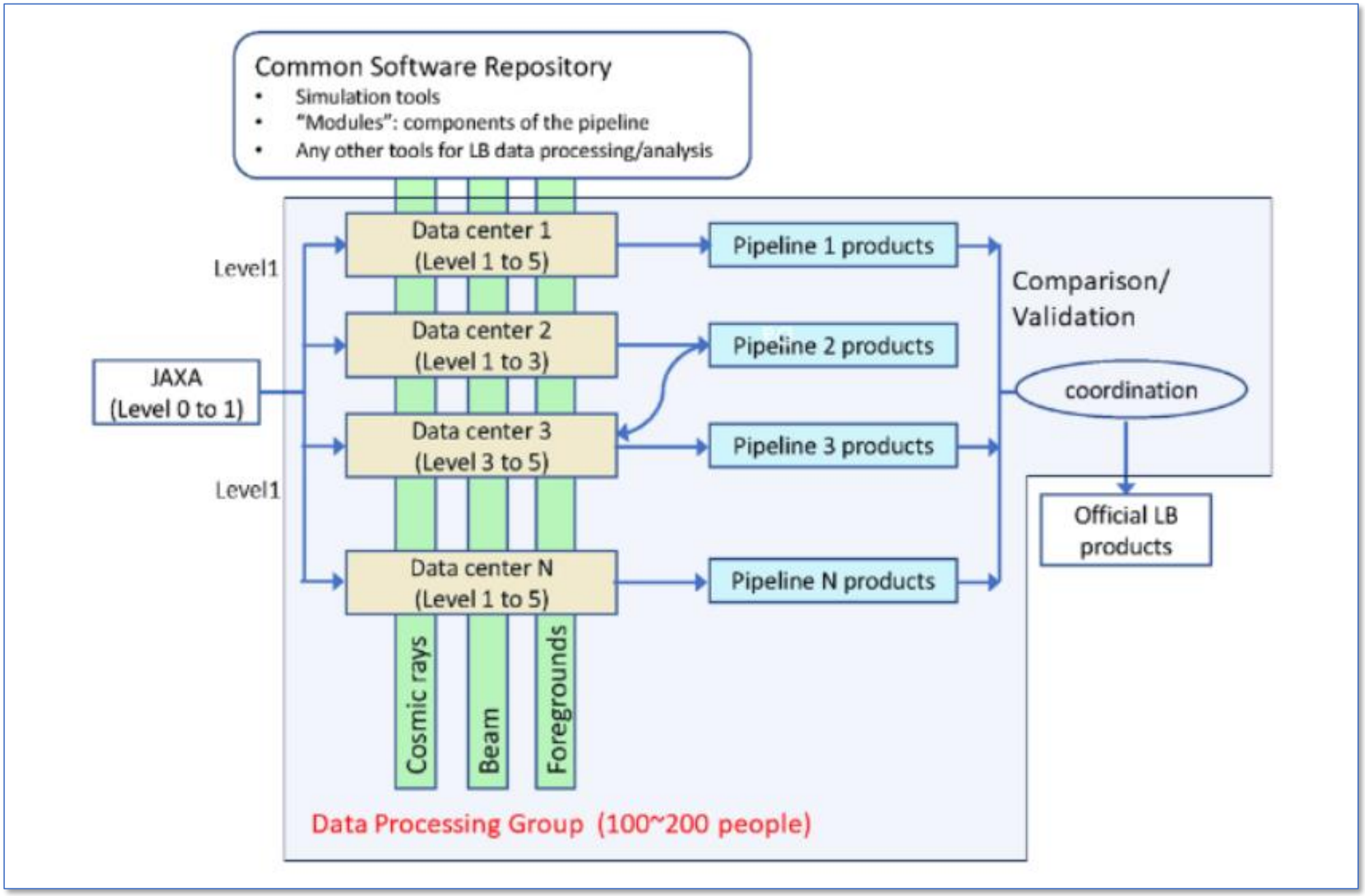
- Based on the lessons learned from previous CMB missions/experiments, the SGS TF identified requirements on the LiteBIRD SGS:

1. JAXA should carry out the minimum data processing. Further instrumental calibration should be carried out outside of JAXA.
2. There can be several data centers world-wide, which should have equal status.
3. Level 5 (likelihood) should be a part of the pipeline.
4. Software and tools, as well as data products, should be shared among the data centers.
5. All the LiteBIRD team members are allowed to participate in any parts of the data processing/analysis.


JAXA (operation)
Level 0: Raw telemetry
Mission HK data
Attitude, Orbit
Reformat
Level 1:Raw TOD
deliver
deliver
Mission HK data
Attitude, Orbit
Level 1:Raw TOD
Calibration constants
Corrections, cleaning
Ground calibration
Level 2: Clean TOD
Instrumental Models
Simulations
Map making
JAXA (DARTS)
Level 2:-5 products
Open to Public
Level 3: Sky map
Foreground map
Component
Separation
Level 4: CMB map
Power spectra
Data
Centers
Level 5: Likelihood

A desirable scheme of the LiteBIRD SGS

1. JAXA delivers the identical L1 data package to each data center.
2. There should be a Common Software Repository accessible by all the LiteBIRD team members
3. Data centers are independent so that they can build their own pipelines
4. Simulations will be run at each data center.
5. There will be task-oriented working teams to facilitate communications among data centers.
6. Data Processing Group (DPG) may be defined to have 100~200 LiteBIRD team members to participate in the data processing/analysis activities.
7. There should be an organization that will coordinate the DPG.
8. Different pipelines and data products should pass the predefined tests
9. After the coordination among data centers, official results/data products are published.


Common Software Repository
• Simulation tools
• "Modules": components of the pipeline
• Any other tools for LB data processing/analysis
Level1
Level1
JAXA
(Level 0 to 1)
Data center 1
(Level 1 to 5)
Data center 2
(Level 1 to 3)
Data center 3
(Level 3 to 5)
Data center N
(Level 1 to 5)
Pipeline 1 products
Pipeline 2 products
Pipeline 3 products
Pipeline N products
Comparison/
Validation
coordination
Official LB
products
Cosmic rays
Beam
Foregrounds
Data Processing Group (100~200 people)

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Mission goal of LiteBIRD

- Currently, LiteBIRD Mission Definition Review (MDR) is ongoing at JAXA.
- The mission goal of LiteBIRD is to achieve $\delta r<0.001$ for the three-year observation and the three-year data analysis period.
- LiteBIRD is different from other JAXA missions in that the results of the ground data analysis are within the mission goal.
  - For most satellites, the missions produce “data”, and “observers/users” produce scientific outputs using these data.
  - Producing the good enough data is a mission goal for most satellite missions.
  - LiteBIRD is different.

Data analysis plan

- For Planck and many ground-based experiments, the length of the initial observation period and the subsequent analysis period are almost identical.
- We require a three-year observation period to achieve the mission goal ($\delta r<0.001$) from a statistical point of view.
- We estimate a three-year concentrated analysis period is required.

- Once we *fully* understand the performance of the instruments, deriving the value of r with an accuracy of $\delta r < 10^{-3}$, is not very difficult.
- The time-consuming part of the data analysis is to
  - run a large number of simulations and compare them to the observational data
  - understand the performance of the instruments as completely as possible.

This loop has to be repeated ~10 times. In total 10^6 simulations will be needed.

1. A Monte Carlo simulation (MC) is performed to simulate the three year LiteBIRD observation data. Since there are statistical fluctuations in the universe realized from the same cosmological parameters, about 1,000 MC runs are needed to simulate a single observation.
2. Analyze the simulated and observed data in exactly the same manner, and the “Null tests” are performed. We may carry out ~100 patterns.
3. In the Null tests, we will find differences between the observation data and simulation data. Adjust instrument parameters and run the MC again (go to 1)

- About 100 to 200 LiteBIRD team members will share the workload and participate in collaborative data processing, simulation, and data analysis.
- It is estimated that each iteration will take 3 to 4 months. To repeat this process about 10 times, the data is about 3 years.
- “Coordination” of the data analysis is essential.

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Summary

- I have explained JAXA's science ground segments for data processing and archives.
- Current preprocessing, super-computing, data archiving facilities are readily usable for LiteBIRD.
- LiteBIRD is different from JAXA's other science missions in **that achieving the data analysis goal ($\delta r < 0.001$) is in the project scope.**
- Data processing/analysis will be made under the SGS, which is mostly outside of JAXA.
- The conceptual design of the LiteBIRD SGS is in good shape.
- The implementation of the SGS will be considered during Phase A after MDR.