DSA-2000 Document No. 00013

Public Archive Requirements and Design

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IPAC

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Abstract

This document describes the design for the DSA-2000 public archive implemented by IPAC. This archive will include calibrated images from the Cadenced All-Sky Survey, as well as a derived source catalog.

# Introduction

The IPAC design for the DSA-2000 public archive and Science Platform architecture provides access to public data products, as well as access to computing resources co-located with the data, to support end-user data analysis. This system architecture is closely based on existing projects in which IPAC is either the lead institution or a major partner. The architecture also provides for the creation of the source detection and measurement pipeline, which will produce a billion-object-scale all-sky catalog from the single-band all-sky images. The design covers both the creation of the pipeline itself, and the provision of a reusable infrastructure for pipeline creation which can be used by other teams within the project to produce other internal data products.

The DSA-2000 data will be housed and served through the NASA/IPAC Infrared Archive (IRSA). IRSA is one of the NASA Astrophysics Archives and is chartered to curate the science products of NASA's infrared and submillimeter missions, including many large-area and all-sky surveys. Community access to the public data products will be available through IRSA's data access Web applications and International Virtual Observatory Alliance (IVOA) service infrastructure. Co-location of the public data products at IRSA will make the image and catalog datasets from DSA-2000 available alongside the near- and mid-IR all-sky photometric datasets already located there, including 2MASS and WISE/NEOWISE, the Euclid survey data that will start to become available in 2024, and the SPHEREx all-sky data that will start to be released in 2025. In addition, IRSA hosts or provides access to many additional datasets on the Galactic and extragalactic sky, from the Spitzer mission to Herschel and Planck, notably including extensive collections of data on the community's well-known deep fields, highly valuable for calibration and in-depth understanding of the properties of larger, all-sky surveys.

# Architecture Overview

The archive user interfaces are based on the "Science Platform" concept currently influencing the design of multiple projects' and centers' archive interfaces and analysis environments, in astronomy and beyond. Data will be accessible through standards-based Web APIs (Application Program Interface), through a graphical "portal" user interface layered on these services, and through an interactive programming environment based on JupyterLab (Figure 1). Authorized users will have access to storage and computing to use for their own data analysis, at the sites where such resources are provided, in addition to the available data products. The design of the DSA-2000 Science Platform combines ideas and existing code from the Rubin Science Platform and multi-archive science platform initiatives within NASA. The data and analysis services available at the partner sites will be customizable, via a flexible configuration-management system, to reflect the unique data holdings and missions of each site.

The data service architecture is based on IVOA standards for metadata and service definitions. Existing standards already cover much of the space required to provide a high-quality service for the planned public data products. At IPAC, we are already implementing the pipelines and archive for the NASA SPHEREx mission, which will release public data products strikingly similar to the planned public data products for DSA-2000, and we will work with the IVOA to cover any gaps that are found.

A diagram of a computer system

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Figure 1: High-level architecture for IRSA data, services, and user interfaces.

Data services for authorized users at the other DSA-2000 sites will be based on the same concepts, but customized as needed for the specific data products at each site. The multi-site architecture will be supported by data discovery services, based on the IVOA's Registry concept. Site-independent names for datasets will be defined, so that, for datasets replicated at multiple sites, the same user queries and analysis codes can be executed at whichever site is most appropriate.

The architecture uses contemporary software deployment approaches, including containerization and configuration-as-code techniques, to lower the complexity and maintenance requirements of service deployment, and speed up the time from conception of a service to its deployment. It leverages proven technologies from industry and the open-source community to this end, including Kubernetes, as well as techniques for their application already deployed in production in other archives, notably by the NSF/DOE Vera C. Rubin Observatory.

The deployment architecture supports both on-premises and cloud-based deployments of the same components. Both are already in use today in the Rubin Observatory's Science Platform deployments at the Observatory summit, at the US Data Facility at the SLAC National Accelerator Laboratory, and in the Google cloud. We will perform a cost and technical performance trade study on cloud usage before the Final Decision Review. This will include the evaluation of the cloud for data storage, photometry pipeline operations and user compute resources.

A common authentication and authorization system, based on contemporary Web standards and security practices, will be shared by all sites, providing for identity management and grouping that supports access to proprietary data, collaborative work on science analyses, and the management of limited resources.

The implementation of the source catalog generation will draw on a long baseline of experience at IPAC. This experience includes current projects to develop the image analysis pipelines for SPHEREx and NEO Surveyor, and the currently active ZTF and NEOWISE pipelines.

## Commissioning Data Access

IPAC will implement project access to data during commissioning with the following restrictions:

* Release dates set in advance on large groups of data.
* Data and people belong to groups, where each group can have access levels which differ by data set.
* All data access requests are routed through control software.

This feature will also use the IRSA services for the team to validate data during commissioning and before release to the community.

# Public Data Archive and User Interface

The public data product interface, to be provided in association with IRSA, will initially be aimed at the Cadenced All-Sky Survey imaging dataset and its derived billion-row source catalog. Basic read-only data query services will be available to anonymous users, as they currently are for IRSA, but capabilities requiring server-side storage, such as the user workspace for files IRSA currently provides, or substantial computation, will be available only to authenticated users. In particular, the JupyterLab interactive computing service can only be made available to authenticated users.

As mentioned above, the data services will be based on the use of contemporary IVOA standards for both service protocols and data model metadata. This will facilitate access to the archive not only through the IPAC-provided User Interface (UI) but also through common community tools such as TOPCAT and Aladin, as well as programmatic access via community software such as PyVO.

## Image Service

Service of the 10-band, 16-epoch Cadenced All-Sky Survey public image dataset will be based on existing and future IVOA-standard image metadata services at IRSA, likely exposed via both the SIAv2 and ObsTAP protocols. These services are based on the standardized ObsCore data model, which provides for spatial, temporal, wavelength, and polarization metadata usable in queries via both SIAv2 and ObsTAP.

In addition to ObsCore, IRSA uses the de-facto community standard CAOM2 for a richer image metadata model (from which ObsCore may be derived). We will create CAOM2 metadata for the images to allow for a more uniform service at IRSA and facilitate more complex queries. CAOM2 allows for the provision of, among other things, additional flexible observational metadata, such as descriptions of observing conditions.

The services for the images themselves, given a metadata entry, use a service architecture from the IVOA DataLink and ObsCore standards used at several other archives including the Rubin Observatory, which facilitates the discovery and retrieval of related data products such as image previews, tables of sources discovered on the image, and image provenance data.  This capability will be used to offer users access to all available images for the selected field. The DataLink architecture can also link to calculational services that operate on the image. Essential to the envisioned archive is the image cutout service, which would be accessed via the same DataLink interface.

The final design will specify serving the image data as 10-layer spectral cubes, one per epoch, versus as 16-layer temporal cubes, one per sub-band, or as individual images. The architecture can support any of these options or even allow for multiple copies of the data organized on different axes, if that were found to facilitate downstream use. The 10-band wide-area imaging data will be made available as a "HiPS cube", an IVOA standard for the rapid visualization of wide-area datasets, including pre-computed hierarchical tiles at lower resolutions. A wide range of community tools can display these, and they are also used in the existing IRSA UI tools.

Existing IRSA image visualization capabilities will be used for the visualization of 2D and 3D (cube) FITS images. These already include support for spectral cubes. These tools already support the generation of color images based on the combination of data from multiple user-selected bands, but these features would be enhanced to ease the selection of desired inputs from the image collection.

## Source Catalog Service

The public source catalog derived by IPAC from the Cadenced All-Sky Survey image data will be served from a large relational database at IRSA. Initial estimates put the catalog size at roughly 1 billion rows. Existing all-sky catalog holdings at IRSA are already at and well beyond this scale. The relational database will be made available for query through an IVOA-standard TAP service based on the ADQL query language. This service already exists at IRSA. Query results will be annotated with community-standard metadata defining units and other aspects of the catalog data model, enabling richer displays and programmatic use of the data, especially in combination with other datasets.

In particular, we plan to add annotations for the IVOA PhotDM data model, or a successor, to the data to enable completely data-driven display of not only the per-band fluxes but also the band centers, ultimately enabling the automatic display of SEDs for individual sources based on the combination of data across all the passbands available in IRSA data - or from external archives supporting this standard.

The TAP service will be extended with IVOA DataLink metadata that allows navigating from catalog entries to related data. This is an existing capability of the IRSA TAP service, but will be populated with links specific to DSA-2000, including links to the source images on which the catalog entries were observed. The planned user interface will provide seamless access to these related items. Moreover, these links can be traversed by any IVOA-compatible tool that supports DataLink, such as TOPCAT, as well as by compatible Python interfaces such as PyVO.

Using the underlying service, the planned graphical user interface, based directly on the existing TAP query capabilities in IRSA and the Rubin Science Platform, will allow for form-driven queries based on spatial coordinates as well as other attributes of the catalog entries. It also assists users in constructing and executing free-form queries in the ADQL language.

Query results will be displayed as tabular data, as well as in overlays on user-selectable image data, either from DSA-2000 itself, or other missions. Once a tabular result is displayed, the IRSA interface provides for seamless search of the other major available all-sky source catalogs on the archive, including WISE/CatWISE, 2MASS, and SPHEREx, around selected sources in the query result.

IRSA will also make the Source Catalog available for bulk data access and analysis in the form of a spatially sharded set of tiles. IRSA is currently evaluating using the Parquet data format in this role for existing data holdings because of its efficient compression and columnar data-access properties. The Rubin Observatory is also planning to release its main object catalog in this form. These ongoing projects are aimed at enabling bulk access for many purposes, including two reference use cases: large-scale statistical and machine-learning analyses, and cross-matching with other catalogs. To support the latter use case, we are currently engaged in collaborative efforts with other archives and the IVOA to define a common spatial sharding procedure and data format that will facilitate writing interoperable cross-matching software.

## Visualization and User Interface

The data portal graphical user interface for the DSA-2000 archive will be based on IPAC’s open-source “Firefly” user interface toolkit used in IRSA, NED, the Exoplanet Archive, and the Rubin Science Platform. The user interface will provide both query and visualization capabilities based on the Firefly toolkit, covering both images and catalogs. Image queries by location, wavelength, time, and image collection (e.g., data product type) are supported and the resulting image metadata tables are displayed along with context imagery as well as the selected images themselves.

For the specific data products, existing Firefly image visualization capabilities will be used for the visualization of 2D and 3D (cube) FITS images, including spectral cubes. These tools also already support the generation of color images based on the combination of data from multiple user-selected bands.

The image visualization tool supports a wide range of features for image viewing and analysis, including panning and zooming, stretching and colorizing image data, inspection of the data from individual pixels, image statistics, overplotting of coordinate systems, overplotting of catalogs, blinking of images, calculation of profiles across the image (e.g., enabling the visualization of the effective PSF, or a transect through an extended source), and extraction of reprojected spectral data from a point or region in a spectral cube.

For catalog queries, the user interface will support spatial searches by coordinates or by object names from well-known databases. Both cone and polygon searches are supported, as well as multi-object searches. For catalog query results, the existing toolkit supports scientific visualizations and exploratory data analysis, including 1D and 2D histograms and scatter plots, with “brushing and linking" features such as filtering on numeric and category columns and selecting regions on plots. Catalog results can be overplotted on large-area context imagery or on specific image data products.

## Python Notebook Interactive Service

The Science Platform component of the archive, as adopted from the Rubin Observatory, incorporates not only data services and a Web-based portal user interface, but also an interactive computing capability based on JupyterLab. This allows users to write their own code to work directly with the data, running on servers co-located with the data. Python is the natural language to use in such an environment, as it is the implementation language of JupyterLab, but other interactively-oriented languages such as R and Julia can also be supported in JupyterLab.

We will provide such a service in the public archive which is restricted to registered users because of the implications for resource utilization. The baseline design includes a basic level of service, based on initial Rubin experience for a typical load of 100 active users, but this should be revisited during the final design phase.

## Cross-matching Service

The TAP protocol for catalog queries already provides a mechanism for performing queries against archive catalogs based on a list of targets from a user-provided table. Queries of this nature will be possible using the data services and graphical front-end planned to be used for the public archive. This sort of query, when submitted through TAP, is implemented as temporary-table uploads to the back-end relational database, followed by spatial join operations. This approach is functional and widely available in the community, including in existing IRSA interfaces, but does not scale adequately to very large target lists.

The rapid growth of interest in the statistical exploitation of large-scale, all-sky or near-all-sky catalog datasets is outgrowing the capabilities of traditional database-based solutions for cross-match queries. Motivated by the size of the expected Rubin object catalog (tens of billions of rows) and others expected to be available in this decade, a number of groups are researching more parallel cross-matching technologies for application to all-sky datasets. A key requirement for the widespread acceptance of a solution would be the definition of a standard data format, suitable for datasets from many projects and missions, and scalable to datasets of many sizes and sky coverage fractions.

IPAC is currently involved in a multi-project effort to develop one of these solutions, led by the LINCC project and based on spatial sharding of a dataset into tiles in the HEALPix system, using Parquet for the file format, and enabling parallel computation for efficiency and low latency for cross-match queries. Rubin Observatory requirements for a solution in this space in the next 2-3 years make it very likely that a community-accepted data format and associated open-source software will be available in time for DSA-2000.

The baseline design includes provision of a copy of the catalog data in Parquet to facilitate this use case. This dataset could be analyzed locally in the public archive or downloaded by users and analyzed on their own computing resources. We will provide a software toolkit to support such analyses and will include it in the software pre-installed in the JupyterLab environment.

# Source Catalog Generation

IPAC will develop and operate a pipeline to generate a source catalog from the Cadenced All-Sky Survey, along with photometry for each epoch. As the radio camera produces calibrated images rather than calibrated visibilities, this pipeline will not utilize standard interferometry techniques. The catalog pipeline will draw on a long baseline of experience at IPAC, including current projects to develop the image analysis pipelines for SPHEREx and NEO Surveyor, and the currently active ZTF and NEOWISE pipelines. The catalog pipeline will include data quality metrics, multi-wavelength bandmerging, and flags for extended sources (Figure 2). As part of the final design phase, we will evaluate different detection algorithms against simulated data to determine the detection threshold and false positive rates. Methods to be evaluated including those used for the VLA Sky Survey and using the calculated beam as input for PSF-driven fitting. The expected high dynamic range will mitigate the impact of sidelobes in the images, but given the high sensitivity of the survey, very bright sources can still generate false positive detections, and this will be included as part of the algorithm evaluation and in the catalog data quality assessments. We will also utilize ongoing work at IPAC to simultaneously fit sources across multiple frequencies. We will work with the DSA-2000 team to select the final source detection algorithm and detection thresholds. The initial derivation of the catalog will be with the first data delivery to IPAC, with reprocessing updates at 2.5 and 5 years after the survey stars. Each catalog version will be available at IRSA for users to access. IPAC will make the catalog pipeline code public including documentation on how it is run at IPAC. Support for operation in other environments will be very limited.

A diagram of a process

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Figure 2: Catalog generation pipeline flow.

Each version of the catalog will contain data quality assessment (QA) metrics. These metrics will include flags for use by archival users when utilizing these data for science investigations. Examples of these flags and metrics include:

* Flags for source photometry measured from flagged image regions, such as those with excessive noise
* Thresholds for noise per image and calibration values
* Thresholds for photometric and astrometric solution precision

# Additional Archive Elements

This section includes possible additions to the DSA-2000 Archive. These elements are not part of the current baseline budget, but will be examined further during the final design phase to establish if any of these functionalities should be added to the baseline.

## Interface to Partner Archives

In addition to the DSA-2000 data products held at IRSA, there will be additional partner archives holding other science data products. IPAC will provide and support an infrastructure to allow users to search pre-selected data products from a single interface hosted at IRSA.

This partner archive search capability would work based on the following principal elements:

* local storage;
* metadata specification following a consistent protocol and data model, based on IVOA standards, across all the archive sites and data products;
* data-naming conventions that are site-independent and allow for migration or replication of datasets between sites;
* data discovery services at each site that facilitate identification of and access to remote datasets (subject to bandwidth and authorization) when needed;
* standard data at each site for the creation of image cutouts and the selection of time series; and
* a common authorization solution.

We plan a common deployment architecture for the above services for each site, based on the use of containerized software run in a container orchestration system (such as Kubernetes) with service definition and configuration based on a Devops-style model with "configuration as code", and founded on common community open-source tool sets. The deployment architecture would include common tools for monitoring and logging, as well as for authorization/access control, across the deployed services.

The architecture will be compatible with both on-premises and cloud-based deployment, recognizing that the economics and performance considerations may differ from archive site to archive site, as well as over the lifetime of the DSA-2000 project. The data services will be designed to be compatible with both Posix-like filesystems and cloud-style object stores as storage backends.

The deployment architecture and implementation details will be specified during the final design phase. However, we note that the Rubin Science Platform (RSP), with which IPAC is closely involved, already provides a fully open-source deployment infrastructure (sometimes referred to as "phalanx" or the Rubin Science Platform) that meets nearly all these requirements today. This deployment system is already in active use across on-premises and cloud instances of the RSP, as well as having been successfully deployed by multiple institutions[[1]](#footnote-2) that are not part of the Rubin Observatory project team. This system therefore represents at least a proof of concept and one likely viable option for the DSA-2000 archive deployment software infrastructure.

As the archive subsystem partner, IPAC would provide deployable software with guidance and documentation to other partners providing the additional archive sites, including:

* interface and metadata specifications that ensure interoperability among the DSA-2000 archive sites;
* code to produce image cutouts and select time series data from data stored at the partner site;
* a specification for the common infrastructure layer to be run at each site to support containerized deployments (e.g., Kubernetes);
* software to provide an easily configured service-deployment mechanism above that layer;
* a common authentication and authorization solution; and
* a test suite for verifying basic compliance with the common metadata and service standards.

The partners operating the other archives are responsible for implementation of the above to ensure product availability through IRSA.

### Pulsar Data

One example of a partner dataset is the pulsar timing data in the NANOGrav dataset. In this case, during the final design phase, we will examine how to achieve the greatest possible convergence between their archive system design and the planned common architecture. We believe the most important points to work on would be a) encouraging their use of IVOA standards for data discovery and metadata, and b) determining the need for––and if appropriate––ensuring interoperability of the authorization mechanisms for data and resource access.

## Differential Image Products

In the baseline plan, IPAC will produce the source catalog at the first data delivery and again at 2.5 and 5 years after the start of the survey. All versions of the source catalog will be available to archive users, with the most recent version as the search default. Additional science would be enabled with more frequent comparisons of the reference sky to current images to find transient sources. During the final design phase, IPAC will develop a design and cost for this capability.

## Additional archival data products

The DSA-2000 survey data can be combined to form many additional data products beyond the 10-channel multi-epoch survey. During the final design phase, IPAC will document the additional resources needed to include other archival level data products. Possible products include:

* HI dataset: catalog of sources with image cube for each
* Polarization dataset: Catalog of source with image for each
* Additional pulsar and FRB products

# Execution Plan

This section includes the work planned from the final design phase through operations. In each of these phases, IPAC will follow its standard practices, covering processes like configuration management and software development. IPAC uses a suite of standard tools, including GitHub, jira and confluence.

## Final Design Phase

In preparation for the Final Design Review, IPAC will produce the following:

* Detailed design of the DSA-2000 archive, user interfaces, and catalog generation pipeline.
* Level 3 requirements covering the IPAC work.
* List and evaluation of implementation and operation risks.

As part of the detailed design work, specific items to be studied or prototyped include:

* Cloud vs. on-premises data storage and compute resources. This will be considered for both the pipeline processing needs and the user compute resources.
* Architecture for the partner archive interface.
* Photometry methodology and artifact identification for the catalog generation pipeline.
* The interactions between bright source handling in the real-time camera system and the statistics and flagging of data in the image catalog.
* A more frequent (~monthly) difference imaging analysis to look for transient events.
* Storage, interface and content for additional data products.

The IPAC team will also work with the other project elements to define and document interfaces.

## Archive and Pipeline Implementation

All work described here will be performed by IPAC staff. The development and operations of the archive and interface will be done by the IPAC Archive Service Center (IASC), a Caltech recharge center. The IASC, led by Steve Groom and Vandana Desai, consists of a team of scientists and engineers with specialized skill sets and provides to IRSA data archive services including: requirements definition, archive design and architectural adaptation, data ingest scripts, database administration, user-interface development and adaptation, the database query system, “backend processing” connecting the database to the user-interface and web-servers, adaptation of analysis tools to the specifics of a project’s data, system administration, archive testing and validation, and interaction with the science community about the contents of the archive, as well as the scientific, engineering, and managerial leadership to organize and accomplish the deliveries for each project.

The work will follow standard IPAC procedures for software development, including coding standards, configuration management and issue tracking.

## Operations

Processed data will be transferred to IPAC on a regular basis, but no more frequently than monthly. Upon receipt, IPAC will make image data available within two weeks. The catalog generation pipeline will be run after the first year of data collection to generate the initial catalog. The data will be reprocessed and new catalog versions produced after two and five years of survey data collection.

Support for archival users will be provided through the standard IRSA channels, including online documentation, help desk support and a searchable knowledgebase.

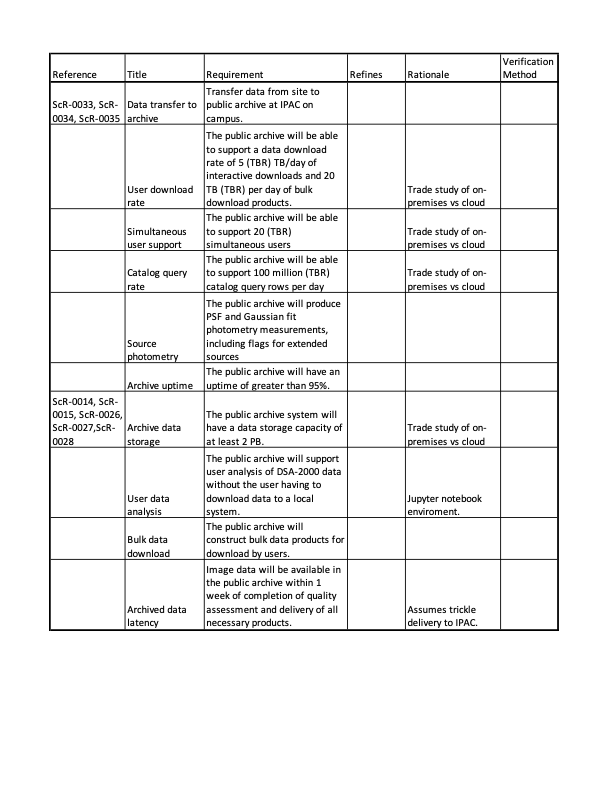
Additional operational support will be considered as part of the final design phase. This includes

1. Using the first all-sky (deep) catalog in searching for pulsars in all future epochs.

2. Using the first all-sky image as a reference image for a transient source search via difference imaging in on-site catalog processing pipeline.

# Requirements

The following table includes the Level 2 requirements for the ARC system.



# Acronyms

|  |  |
| --- | --- |
| Acronym |  |
| 2MASS | Two-Micron All Sky Survey |
| ADQL | Astronomical Query Data Language |
| API | Applications Program Interface |
| CAOM2 | Common Archive Observation Model Version 2 |
| DOE | Department of Energy |
| FITS | Flexible Image Transport System |
| IASC | IPAC Archive Service Center |
| IPAC | Historically known as the Infrared Processing and Analysis Center |
| IRSA | Infrared Science Archive |
| IVOA | International Virtual Observatory Alliance |
| LINCC | LSST Interdisciplinary Network for Collaboration and Computing |
| PhotDM | Photometry Data Model |
| NASA | National Aeronautics and Space Administration |
| NED | NASA Extragalactic Database |
| NEOWISE | Near Earth Object Wide-field Infrared Survey Explore |
| QA | Quality Assessment |
| RSP | Roman Science Platform |
| SED | Spectral Energy Distribution |
| SIAv2 | Simple Image Access Version 2 |
| SPHEREx | Spectrophotometer for the History of the Universe, Epoch of Reionization and Ices Explorer |
| TAP | Table Access Protocol |
| TOPCAT | Tool for OPerations on Catalogues And Tables |
| UI | User Interface |
| WISE | Wide-field Infrared Survey Explore |
| ZTF | Zwicky Transient Facility |

1. Including the IfA at the Royal Observatory, Edinburgh, and the national CC-IN2P3 computing center in Lyon, France. [↑](#footnote-ref-2)