The NASA/IPAC Infrared Science Archive

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ABSTRACT

The NASA/IPAC Infrared Science Archive (IRSA) is the steward of the data products, tools, and documentation from infrared and sub-millimeter missions. IRSA serves data from projects including *Spitzer*, *WISE*, NEOWISE, 2MASS, and *IRAS*, operates the US archive for *Planck*, and enables seamless access to *Herschel* data. IRSA also hosts copies of data from several complementary space missions, including *AKARI* and *Gaia*, by arrangement with the respective projects. IRSA is able to broaden the reach of *AKARI* data by placing it in the context of other infrared missions.

The guiding principle of IRSA activities is to enable cutting-edge science through strategic response to the evolving needs of the user community. We provide powerful services to researchers that combine data sets across the infrared sky. IRSA services offer interoperability with other archives through program-friendly interfaces and the use of Virtual Observatory protocols. In total, IRSA manages more than 1 PB in the data center, including databases containing more than 125 billion rows.

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1. INTRODUCTION

The NASA/IPAC Infrared Science Archive (IRSA[1]) is the steward of the data products, tools, and documentation from infrared and sub-millimeter missions. IRSA is the permanent home for data from *Spitzer*, *WISE*, *Planck*, 2MASS, and *IRAS*. In addition, IRSA provides seamless access to *Herschel* data. Soon, IRSA will also be NASA's archive for IRTF and *SOFIA*. We serve an unparalleled array of all-sky surveys covering a total of 24 bands from 1 micron to 10 millimeters. IRSA also hosts copies of data from several complementary space missions, including *AKARI* and *Gaia*, by arrangement with the respective projects. In total, IRSA manages more than 1 PB in the data center, including relational databases containing more than 125 billion rows.

The 2010 Decadal survey report stressed that NASA's long-term support for data archives is providing a "major return on the considerable investment the agency made." At IRSA, we see strong and growing community use of NASA's infrared datasets. In 2016, scientists across the nation and the world submitted over 40 million queries to IRSA. In each year since 2007, refereed journal articles using archival data from the *Spitzer Space Telescope* have outnumbered those published by General Observers using their own data (Figure 1). IRSA enables research that meets NASA's strategic astrophysics science objectives, by providing powerful services to researchers that combine data sets across the infrared sky. Of particular interest here, IRSA is able to broaden the reach of missions like *AKARI* data by placing it in the context of other infrared missions.

1.1. High Level Science Products

NASA's archives curate data at every level of data processing. Archival users sometimes require access to the raw data in order to implement novel reduction methods. Others need science-ready images or simply catalog data for their research. The availability of high level science products (HLSP) has greatly increased the usage of archival data.

HLSP are sometimes created by mission data centers, and other times they are contributed by the user community. IRSA serves HLSP of both types. For example, the *Spitzer* Science Center has created several enhanced products for use by the community, including the *Spitzer* Enhanced Imaging Products (SEIP) and the *Spitzer* IRS Enhanced Products. The *WISE* Atlas images and the *WISE* Catalog are core products from the mission. IRSA serves HLSP contributed by the teams that carried out large, coherent projects with missions such as *Herschel* and *Spitzer*. IRSA serves 34 data sets from the *Spitzer* Legacy and Exploration Science programs. In addition, IRSA serves data from 27 of the *Herschel* Key Projects (a subset of the *Herschel* data available at the ESA *Herschel* Science Archive). IRSA also serves HLSP from a variety of other projects, large and small.

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[1] http://irsa.ipac.caltech.edu

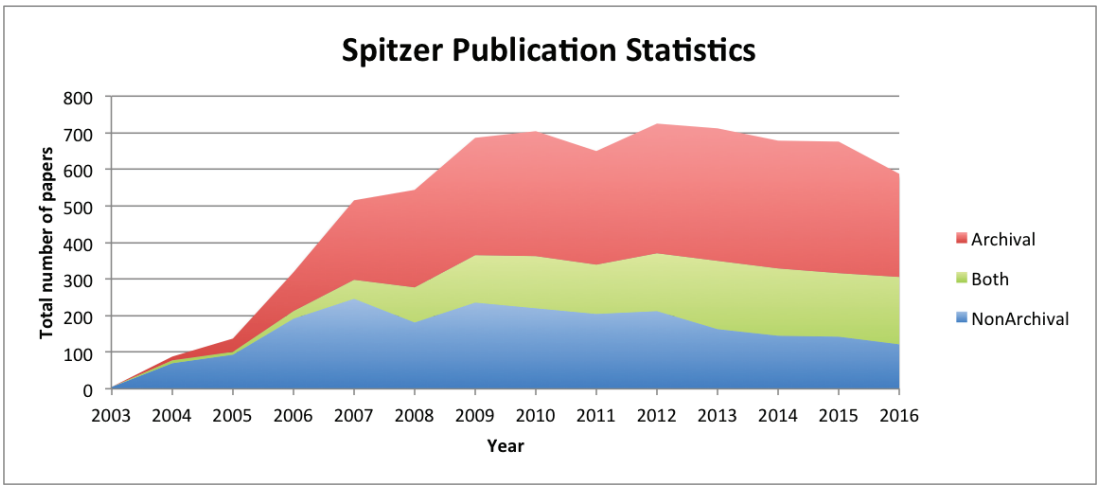

Figure 1. Publications using data from the *Spitzer Space Telescope* per year. The blue region indicates papers published by General Observers using their own data. The red region indicates papers for which the author list includes none of the original observers. The green region indicates papers with a mixed author list.

The HLSP make complex data sets accessible to a wider audience of researchers. The NASA archives in general, and IRSA in particular, find that HLSP are used as much or even many times more than typical mission products. IRSA invites additional contribution of data that will be of interest to the community. Interested researchers can contact the IRSA Helpdesk[2]

2. *AKARI* AT IRSA

IRSA hosts copies of data from several complementary space missions, including *AKARI*. This arrangement is beneficial to both the *AKARI* mission and to IRSA's research community. IRSA can broaden the reach of *AKARI* data by: (1) placing the data in the multi-wavelength context by serving it alongside other infrared data sets; (2) offering sophisticated data exploration and visualization services; and (3) enabling command-line access through the Virtual Observatory (VO).

In October 2017, IRSA began serving *AKARI* FIR All-sky Survey Maps at 65, 90, 140, and 160 microns. In addition, IRSA serves the *AKARI*/FIS Bright Source Catalog, the *AKARI*/IRC Point Source Catalog, and the *AKARI* Asteroid Catalog. In this section, we review the IRSA services available for access and exploration of *AKARI* data.

2.1. Image Exploration

AKARI FIR all-sky images are available through the IRSA Image & Spectrum Server (Figure 2). This tool offers user-friendly search features, including position-based searches for single targets or for a user-supplied table of positions. The tool also enables data browsing using a click-to-search option on an all-sky map. Results are presented in simple tabular format, with appropriate metadata displayed (RA, Dec, waveband, etc.). IRSA also offers complex exploration of returned images including:

- *Images*: IRSA offers full FITS visualization with image manipulation tools: zoom, stretch, rotate, WCS readout, and many others. Image cross-comparison is enabled by displaying additional FITS images accessed via IRSA, a user-supplied URL, or the user's local system.
- *Catalog Overlay*: Catalogs hosted at IRSA, accessible through the VO, or supplied by the user may be overlaid on FITS images or be used as the data source for X-Y plots. Instrument footprints or DS9 region files may also be overlayed.
- *Component interaction*: All components (FITS images, catalogs, X-Y plots) are connected: filtering in one is reflected in others.

IRSA's data exploration services use a common set of interface tools across many missions. These components (known as "Firefly by IPAC") ensure a common "look and feel" between IRSA's various services. This technology has enabled IPAC to quickly and affordably create mission-specific interfaces for multiple projects. Unlike many traditional web applications where most of the processing occurs on the server, Firefly uses a "heavy client." This takes advantage of client desktop processing power, and allows for interactive features. The client-side is composed of dynamic HTML, CSS, and JavaScript to create a rich, interactive application. No plugins are required to use IRSA.

[2] https://irsasupport.ipac.caltech.edu

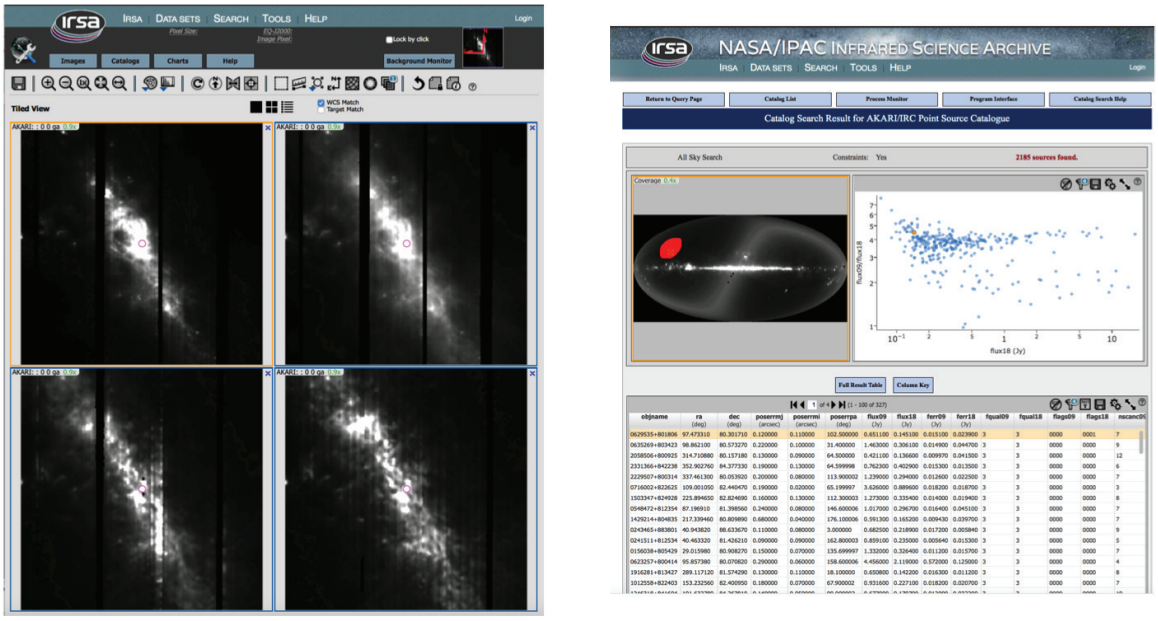

Figure 2. *(left) AKARI* images at galactic coordinates 0h 0deg in the four FIR bands (65, 90, 140, 160 microns) displayed in IRSA's Image & Spectrum Server. The target position is shown as the small red circle in the center of each image. *(right)* The results of a search of the *AKARI*/IRC Point Source Catalog via the IRSA Catalog Search Service. The table at the bottom displays the full (paginated) data returned by the query. The upper-left image panel shows the positions of returned sources overlayed on the *IRAS* all-sky map. The upper-right an x-y plot for user-selected columns in the returned table.

2.2. **Catalog Search Service**

To date, four *AKARI* catalogs are served by IRSA's Catalog Search Service (Figure 2). Catalogs can be queried by position, with selectable search region shape (cone, box, polygon), as well as with arbitrary constraints on column values. For advanced users, IRSA offers full SQL queries (against single catalogs). These features allow filtering for objects that have, for example, extreme or unusual colors. This service efficiently queries some of the largest catalogs in astronomy (billions of rows). The service can take as input tables uploaded by the user with a list of positions to query, thus enabling cross-matching of tabular data.

Catalog searches return a user-selected subset of available columns and advanced visualization. Source positions are overlaid on a selectable image of the sky, which itself is a fully interactive FITS preview. Catalog data are presented as both tables and (user-selected) x-y plots. The images, plots, and tables are interactive, sortable, and filterable. Links are provided to related services, such as NED sources in the search region.

The Catalog Service is available interactively through the IRSA website and as an Application Program Interface (API) for scripted access (see Section 2.4 for discussion of VO-compatible API options).

2.3. **Finder Chart**

One of IRSA's most popular tools is the Finder Chart image cutout generator and catalog browser (Figure 3). It provides side-by-side cutouts from *WISE*, 2MASS, *IRAS*, SDSS, and DSS around a user-specified location. In January 2018, SEIP and *AKARI* images will be added. The service will also search the most popular corresponding catalog, return the tabular data, and overlay the results on the images. It also serves 2MASS and *WISE* artifact tables. Although originally intended for generating finder charts for use at ground-based telescopes, the tool has found many other applications. For example, it has been used to verify brown dwarfs through proper motion (Kirkpatrick et al. 2014) and to verify a *K2* planet (Crossfield et al. 2015)

2.4. **Virtual Observatory**

IRSA is committed to maintaining international interoperability between astrophysics archives by enabling access through Virtual Observatory protocols. The International Virtual Observatory Alliance (IVOA) protocols are intended to standardize API access to astrophysics data. IRSA is an active part of the NASA Astrophysics Virtual Observatory (NAVO[3]), which coordinates NASA astronomy archives efforts to provide "comprehensive and consistent access" to NASA's astronomical data via the VO protocols.

IRSA offers millions of images and billions of rows of catalog data through VO-compliant program interfaces. Catalogs are available via the Simple Cone Search protocol and the Table Access Protocol (TAP). Images are available via the

[3] https://heasarc.gsfc.nasa.gov/vo/summary/

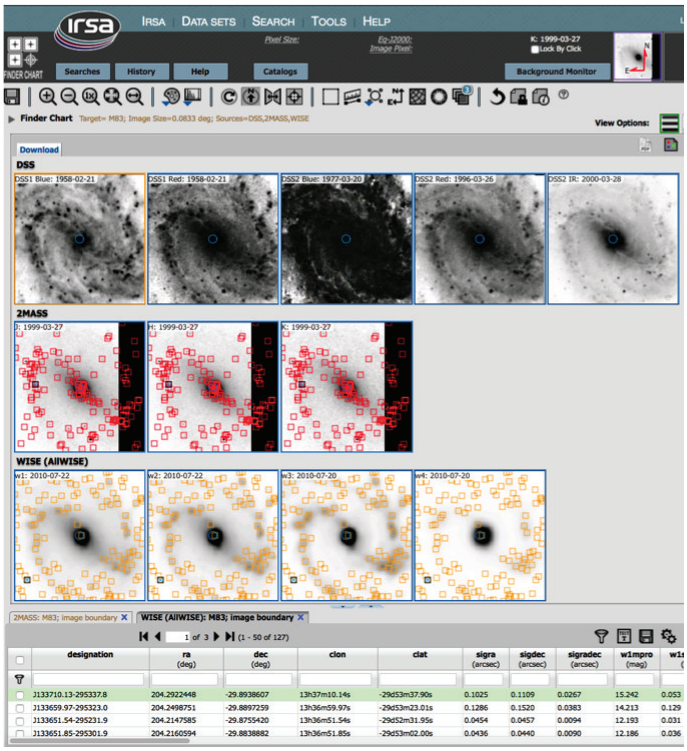

Figure 3. IRSA's Finder Chart displaying images of M83 from DSS, 2MASS and *WISE*. The positions of catalogs ources from 2MASS and *WISE* are overlayed on the corresponding images. Those tables are displayed at the bottom of the screen.

Simple Image Access (SIA) and Simple Image Access 2 (SIA2) protocols. Spectra are available via the Simple Spectral Access (SSA) protocol. IRSA resources are discoverable in VO registries, allowing tools such as TOPCAT (Taylor 2005) to access IRSA via the API.

3. SUMMARY

Long-term, stable archives greatly increase the return on observatory investment. IRSA enables cutting-edge archival research by providing critical, long-term access to infrared data from past and ongoing NASA missions. Lessons learned from IRSA include:

- Robust support for both novice and expert users pays off
- Placing data in the context of multiple missions expands usage
- Standardization of tools within and archive increases efficiency
- High level data products can expand the reach of large data sets

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