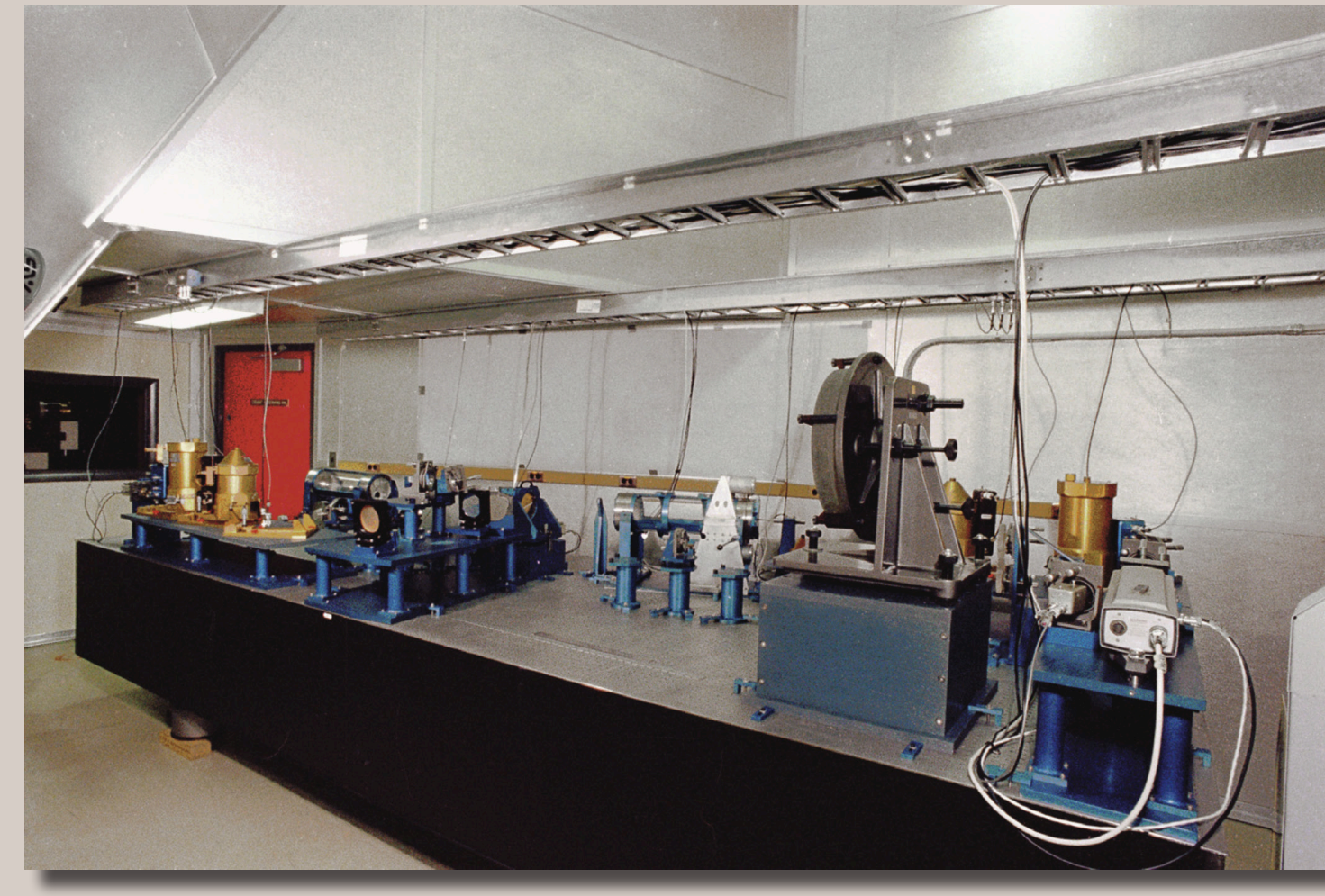


SpArc: Preservation of 20 Years of Spectrographic Data

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Mayall Fourier Transform Spectrograph (1975-1995)



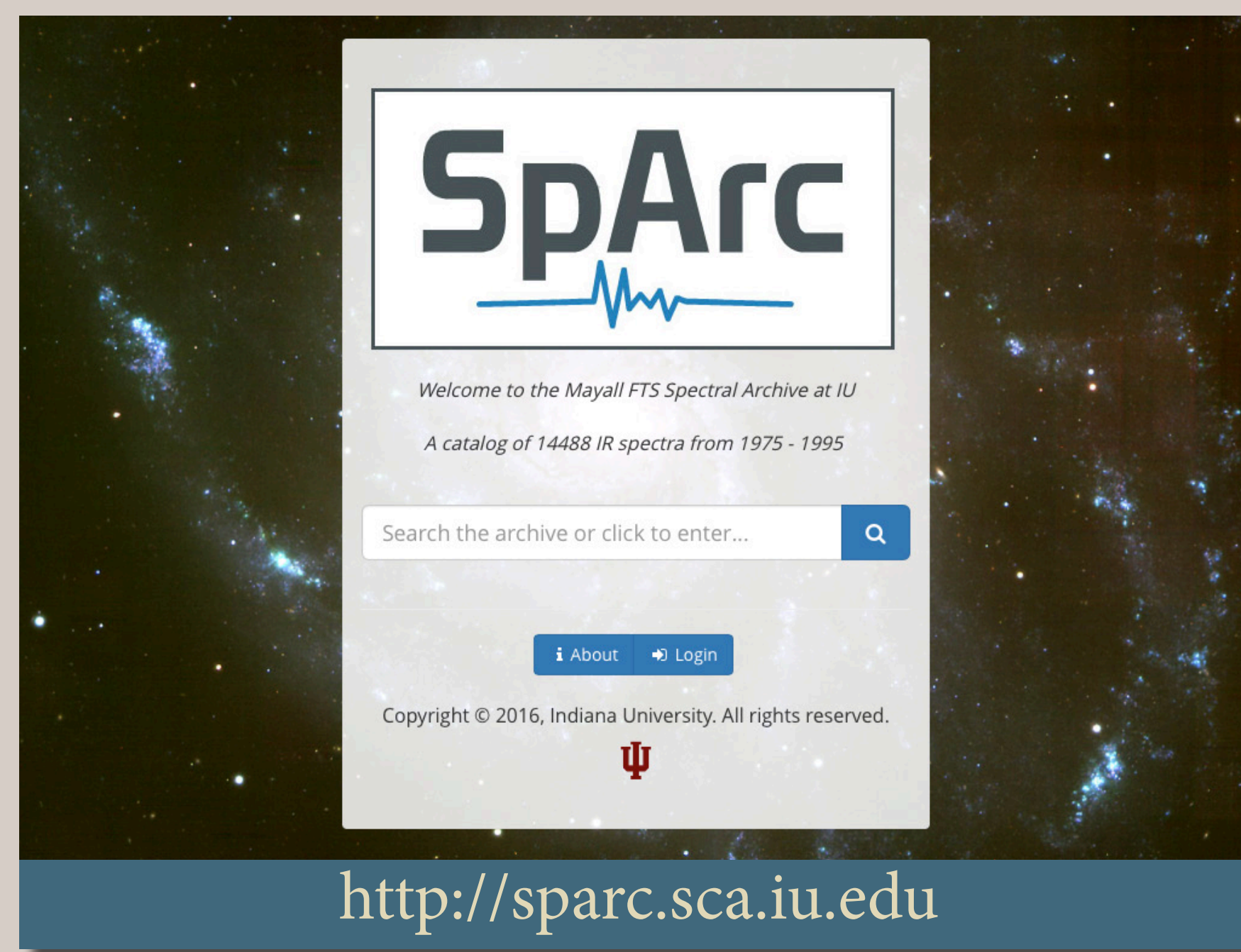
Photograph of the Mayall Fourier Transform Spectrometer in the east coudé room. The number 5 coudé mirror was through the window at the left. The number 5 coudé mirror tracked the f/160 beam onto the large mirror on the right. The reference laser can be seen to the right of large mirror.

Image Credit: NOAO/AURA/NSF

In the mid-1970s a prototype FTS with 10 cm travel and a design based on a modified commercial instrument was installed at the f/160 coudé focus of the Mayall 4 m telescope on Kitt Peak. The 4 m telescope had been dedicated in 1973 and this was the first scientific use of the coudé focus. In 1978 the prototype FTS was replaced with a facility instrument with a maximum travel of 1.4 m, significantly increasing the resolution. The spectra generally cover a relatively wide wavelength range within the J, H, K, L, or M atmospheric window, and FTS spectrometers provide the advantage of a very clean line profile compared to traditional spectrographs. Over the next 17 years ~14000 spectra were taken, resulting in nearly 120 refereed papers, including 20 since the year 2000.

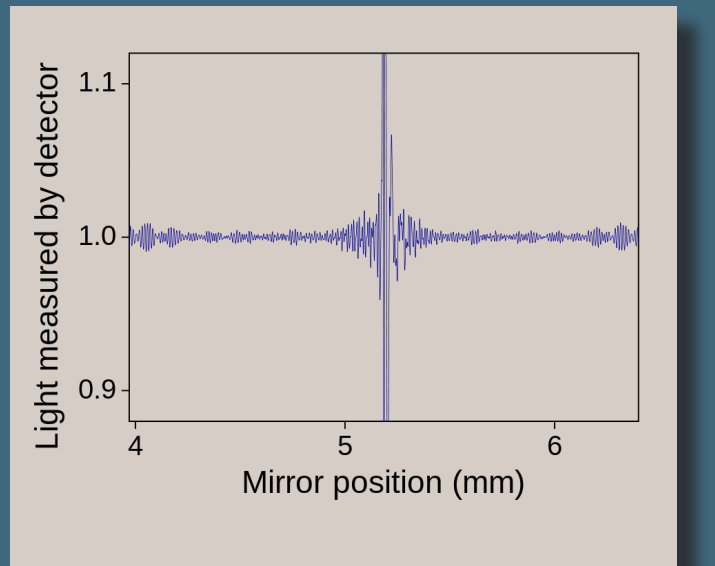
The FTS was developed and maintained at Kitt Peak by Donald Hall, Stephen Ridgway, and Kenneth Hinkle, in partnership with the solar FTS at the McMath-Pierce Solar Telescope, developed by James Brault

- Fed by f/160 coudé beam
- Rapidly reconfigure from f/8, f/16, and f/160
- Coverage from 0.3 - 30 microns with multiple beamsplitters and detectors
- Dual beam design to allow for sky cancellation
- Near and mid-infrared spectroscopy during daylight hours
- 3 arcsecond beams
- Forward and reverse scans to ensure data quality
- Moderate to high resolution (~20 cm⁻¹ to 0.005 cm⁻¹)
- Magnitude limit in the K band was about K=4 for resolving power R = ~20,000 with S/N of 100 in 4 hours of observing
- Broad band (K+H) observations at R = 70000 and S/N=100 took about 4 hours at K=+1



What is Fourier Transform Spectroscopy?

Before the development of infrared detector arrays, Fourier transform spectrometers allowed observations of infrared spectra of bright astronomical sources at relatively high spectral resolution. The light from a bright source enters a Michelson interferometer equipped with a movable mirror, and the changing path length introduces a path difference in one arm. The interference of the two beams while the moveable mirror is scanned produces an interferogram. Applying a Fourier transform to this interferogram recovers the spectrum of the original source.



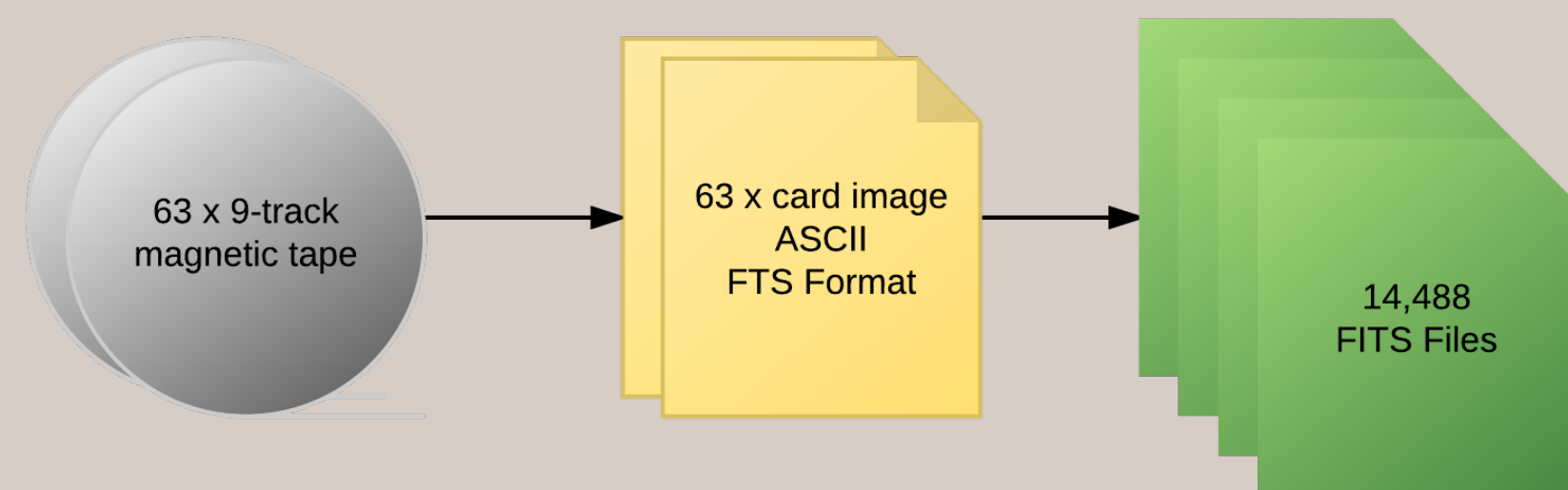
An example of an interferogram

SpArc - Spectroscopy Archive

SpArc was developed with the intention of providing long-term storage and accessibility to the collection of historical FTS observations, feeding the 'long-tail' of science. The design of the SpArc web portal follows principles laid out for other Scalable Compute Archive (SCA) systems developed through the Trident project at Indiana University. The archive employs a modern, intuitive web interface for searching, identifying, and viewing the spectra. PHP/Zend, Bootstrap, AngularJS, and the HighCharts JavaScript library are used to produce the web interface elements, and these are connected by a REST API to backend data registration and retrieval services written in Python. A key element in the design is the reuse of components common to multiple projects and only modifying or developing those elements that are unique to meet the requirements of SpArc.



Data Preservation and Conversion



The data collected by FTS was copied and combined multiple times. Fortunately from the beginning multiple copies of the archive were made and in spite of the poor quality of the recording media it was ultimately possible to recover all the spectra ever transformed. The full set of data occupied 63 9-track magnetic tapes. The FITS data storage format was a pre-FITS format invented by J. Brault. This format was readable on CDC and SUN computers but not easily decoded on other machines. To read the archived data on desktop computers, the archive was converted to ASCII using DECOMP on Sun computers in the late 1990's.

The 63 ascii "card image" files holding the full collection of FTS spectra were formatted into sequential records of information blocks and data blocks. Each of the files contained multiple observations. While the data were preserved, accessibility was limited and tedious. An effort was undertaken to convert this data to the FITS standard to enable long-term storage and accessibility to this collection of observations.



A reel of 9-track tape

Each of the observations, including low resolution images and the forward and backward FTS scans were converted to FITS format. The original metadata are preserved in the FITS headers. Where possible, actual telescope coordinates recorded at the epoch of observation have been precessed and matched to SIMBAD objects to obtain J2000 coordinates, identifications, spectral types, and photometry. In some cases, the object name recorded by the observer at the time of observation does not match the telescope coordinates. Resolving possible discrepancies is an ongoing effort, and users should be cautious in suspicious cases. Examine the header data carefully.

What's in the archive?

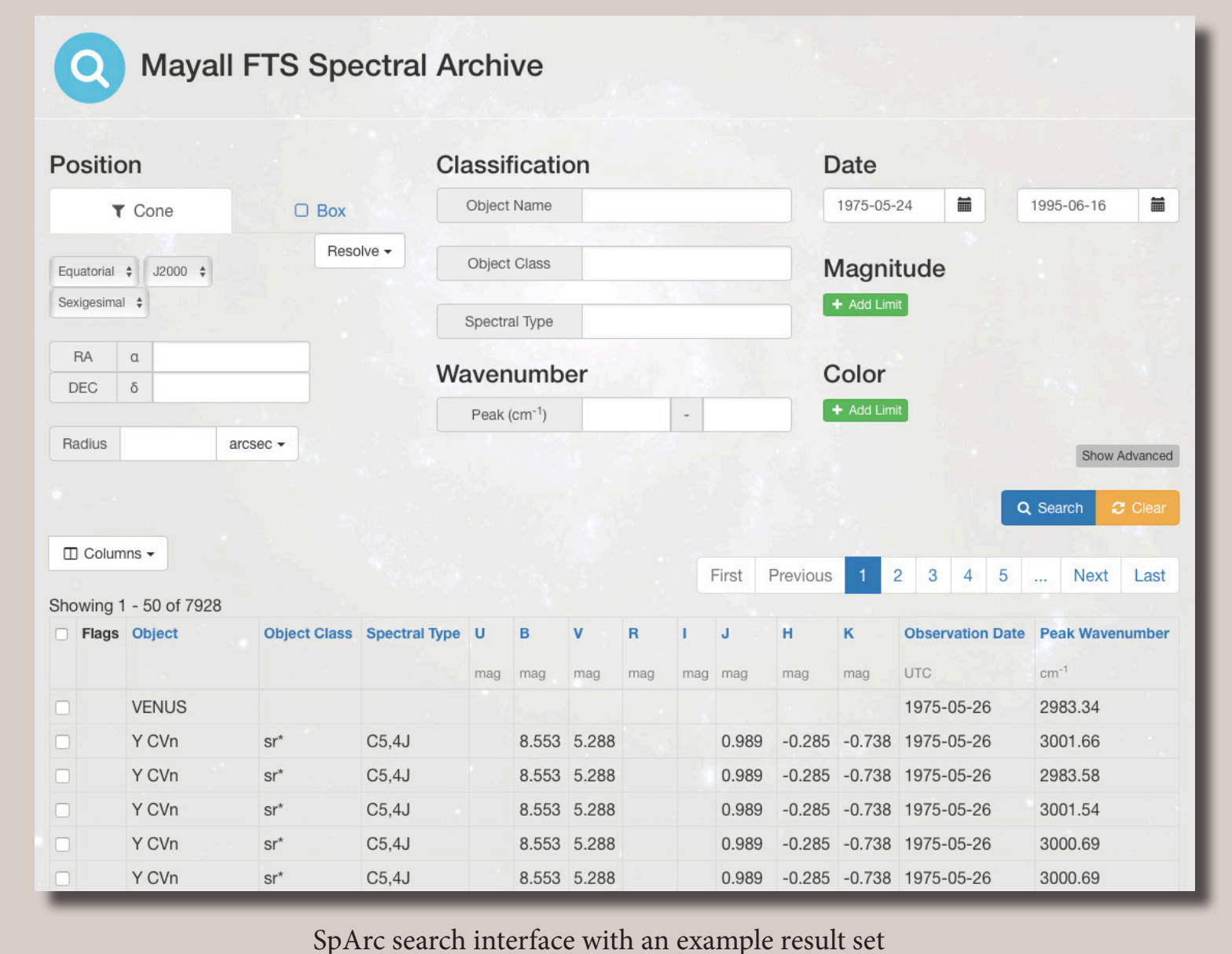
The archive includes nearly 900 individual (non-solar system) targets observed with the Kitt Peak Mayall 4-m FTS instruments from 1975-1995. The archive includes 780 individual stars, most with multiple observations. Observations of the Galactic center, variety of protostars and Galactic star-forming regions, and several galaxies are also available. In addition to these targets, the dataset includes multiple observations of Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune, Comet IRAS, Titan, Io, and the Moon.

Using the Archive

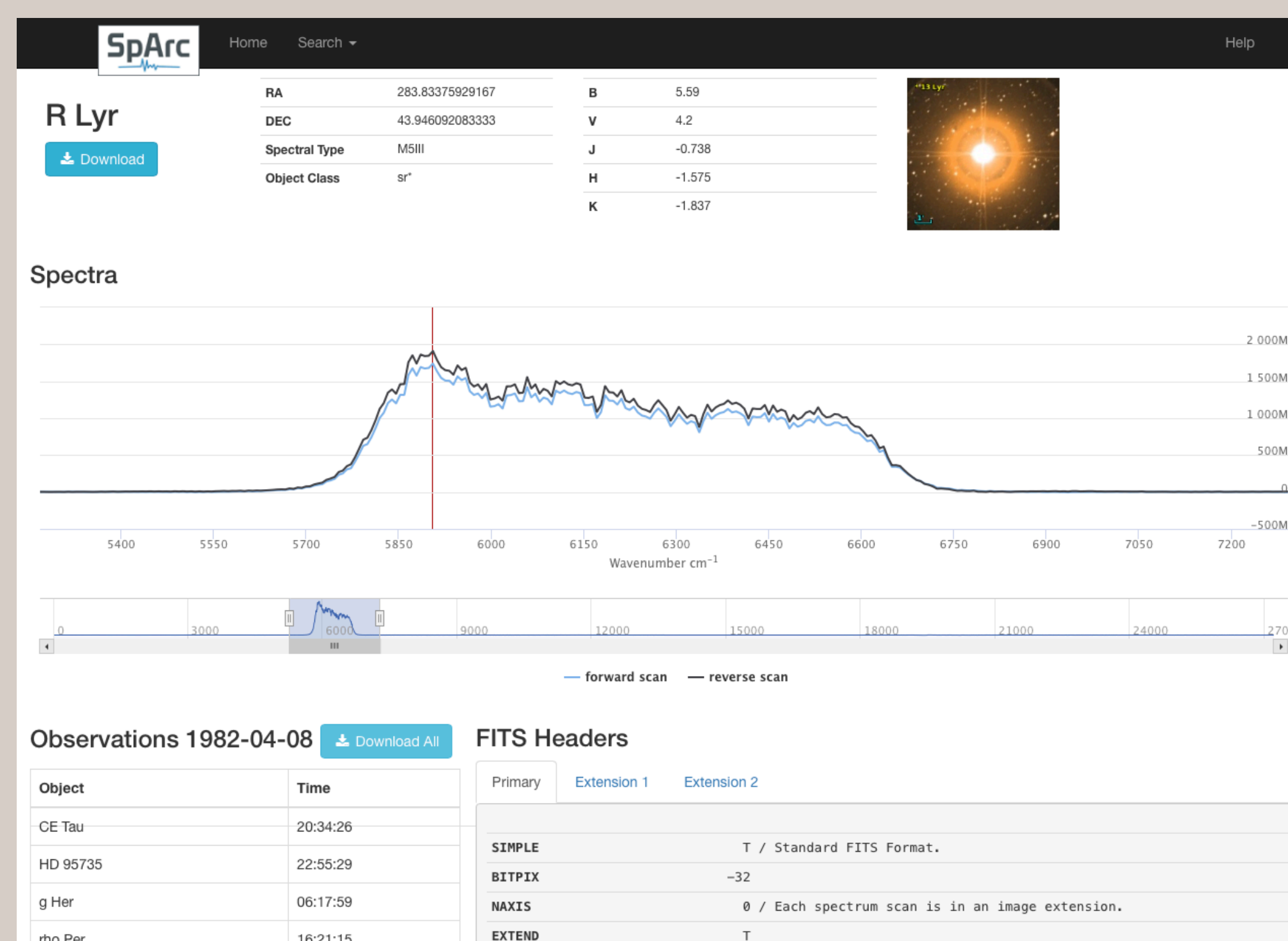
SpArc requires no registration to view and download spectra. Users are greeted by an intuitive interface which allows them to search by:

- Position (cone/box)
- Object Name/Class/Spectral Type
- Peak Wavenumber
- Date observed
- Object magnitude (UBVRIJHK)
- Object color (any combination of the above)

Users can dictate which metadata columns to display and sort on. Some objects in the database have uncertain dates or are low-resolution images, and these can be hidden or shown as desired. The default search operation utilizes a Boolean AND to return results that match all of the requested parameters. If users wish they can flip this to a Boolean OR to match any of the requested parameters. In addition to the standard search, a batch search that returns results based on a list of positions is also available.



SpArc search interface with an example result set



Detail page for an example spectra. The Highcharts-based spectral viewer allows interactive zooming down to the full resolution. Object reference images and magnitudes are retrieved via SIMBAD

Clicking on any result in the search page will bring up the details view. The details page includes:

- Spectral viewer
- Object attributes
- Object thumbnail
- Primary FITS header
- Forward and reverse scan FITS headers
- Observations taken on the same date
- Download options

The spectral viewer uses the Highcharts Javascript library, and allows the user to zoom in on the spectra down to the full resolution. The magnitudes and object thumbnail are sourced from SIMBAD based on the object name and position. The entire list of observations taken on the same date can be downloaded with a single click to streamline calibration efforts.

