The NOAO Data Lab

Current Status and Future Vision

Stéphanie Juneau (NOAO)
on behalf of the DL team

National Optical Astronomy Observatory
Cerro Tololo Inter-American Observatory
Kitt Peak National Observatory
Community Science and Data Center

Data Lab Team

Current team:

Mike Fitzpatrick, Lead Developer

Matthew Graham, Scientist/Developer

Wendy Huang, Software Engineer

Stephanie Juneau, Data Scientist

David Nidever, Data Scientist

Robert Nikutta, Data Scientist

Pat Norris, Test Engineer

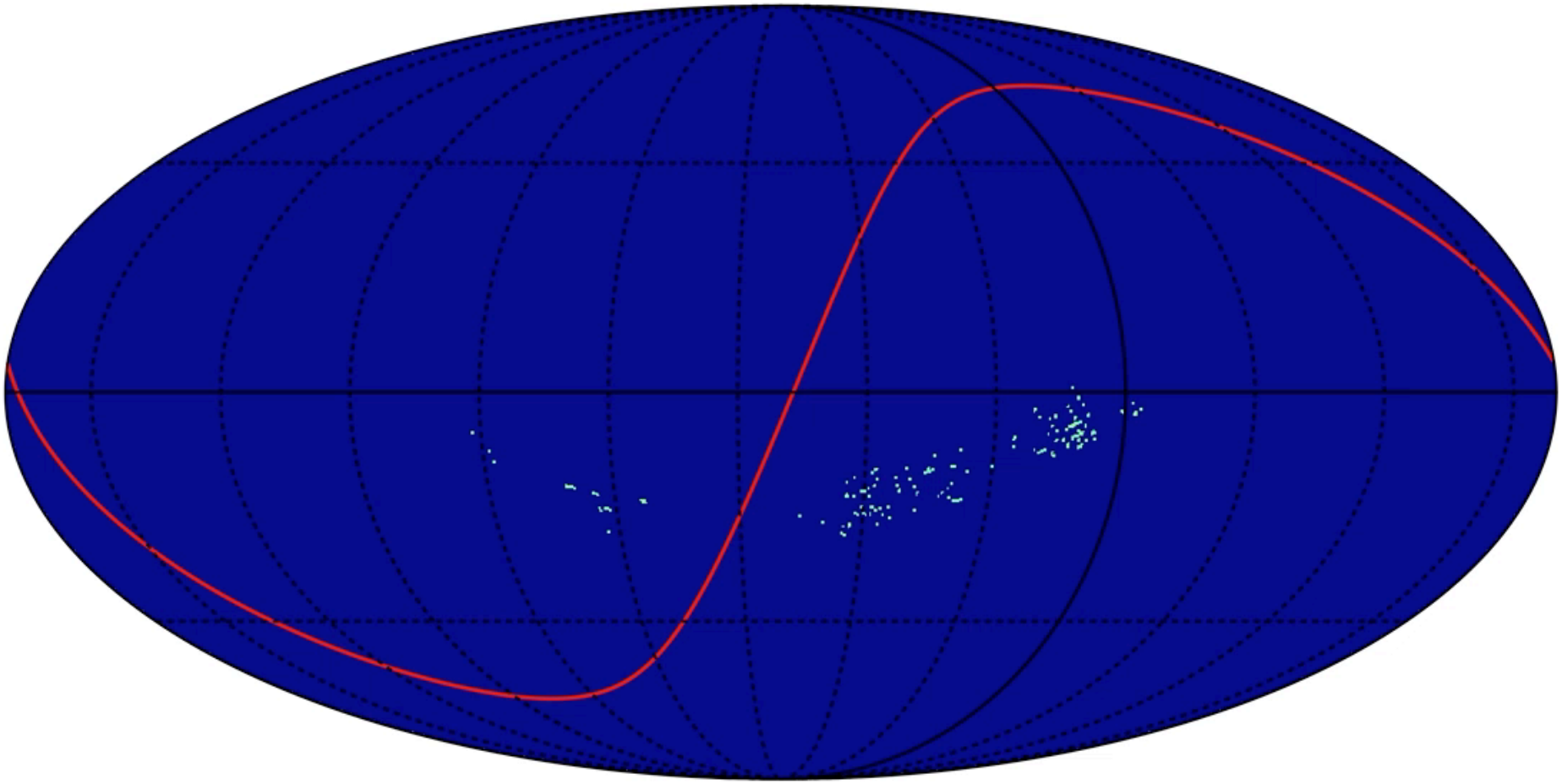
Knut Olsen, Project Scientist

Steve Ridgway, Scientist

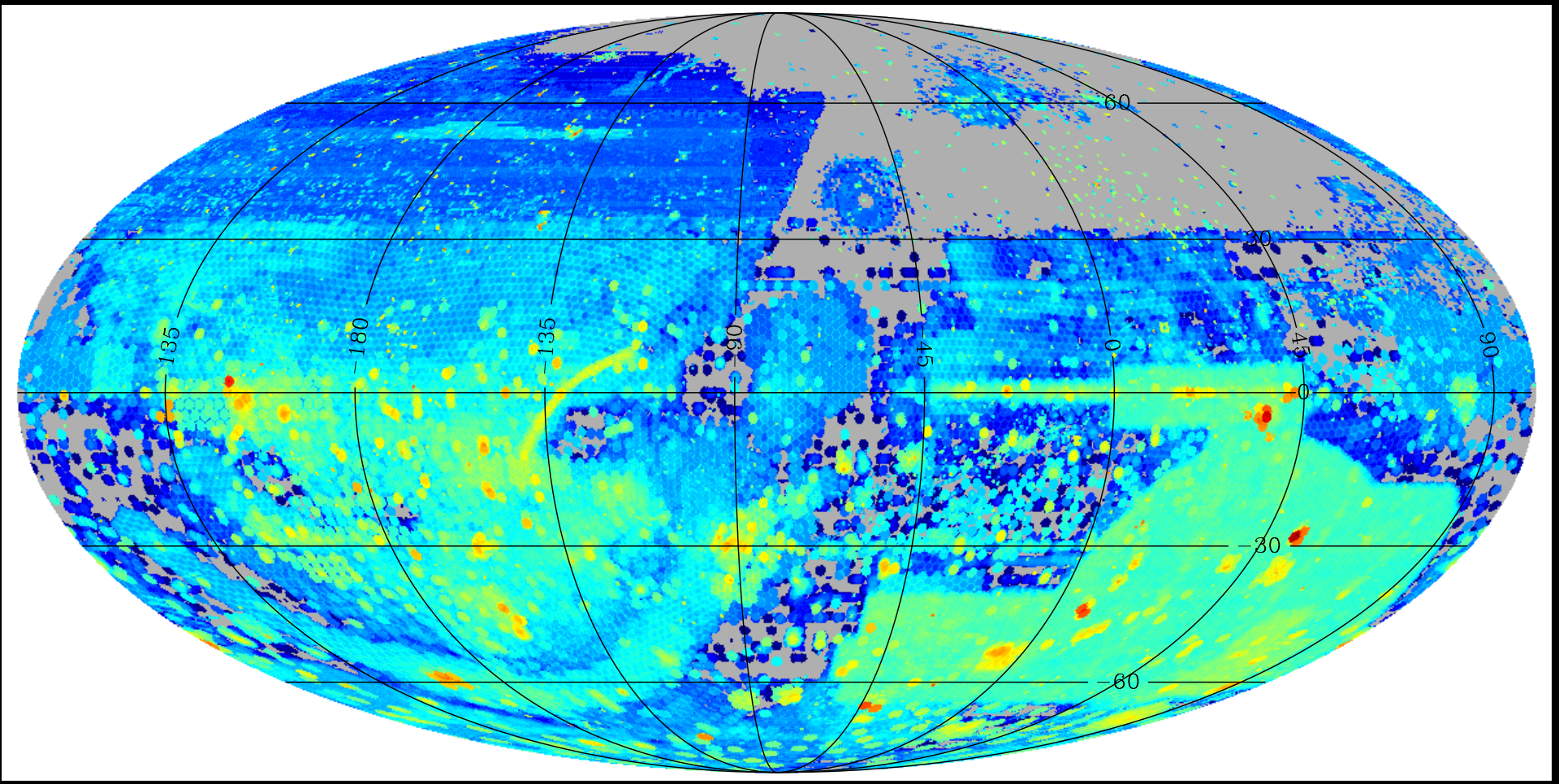
Adam Scott, Database Architect

Pete Wargo, System Administrator

August 11, 2004



DECam and Mosaic data in June 2017



NOAO Data Lab

datalab.noao.edu

Goal

Efficient exploration and analysis of large datasets with an emphasis on NOAO wide-field 4-m telescopes

Approach

→ High-value catalogs from NOAO and external sources (e.g. SDSS, GAIA) and NOAO-based images linked to catalog objects

→ Data discovery

→ Developing intuition through interaction with selected catalog and image set of known objects

→ Automation of analysis to aid discovery of unknown objects

Data Lab in a Nutshell

datalab.noao.edu

Large Catalogs – TB-scale databases

Pixel Data – images & spectra in NOAO Science Archive

Virtual Storage – 1 TB per user to minimize data transfer

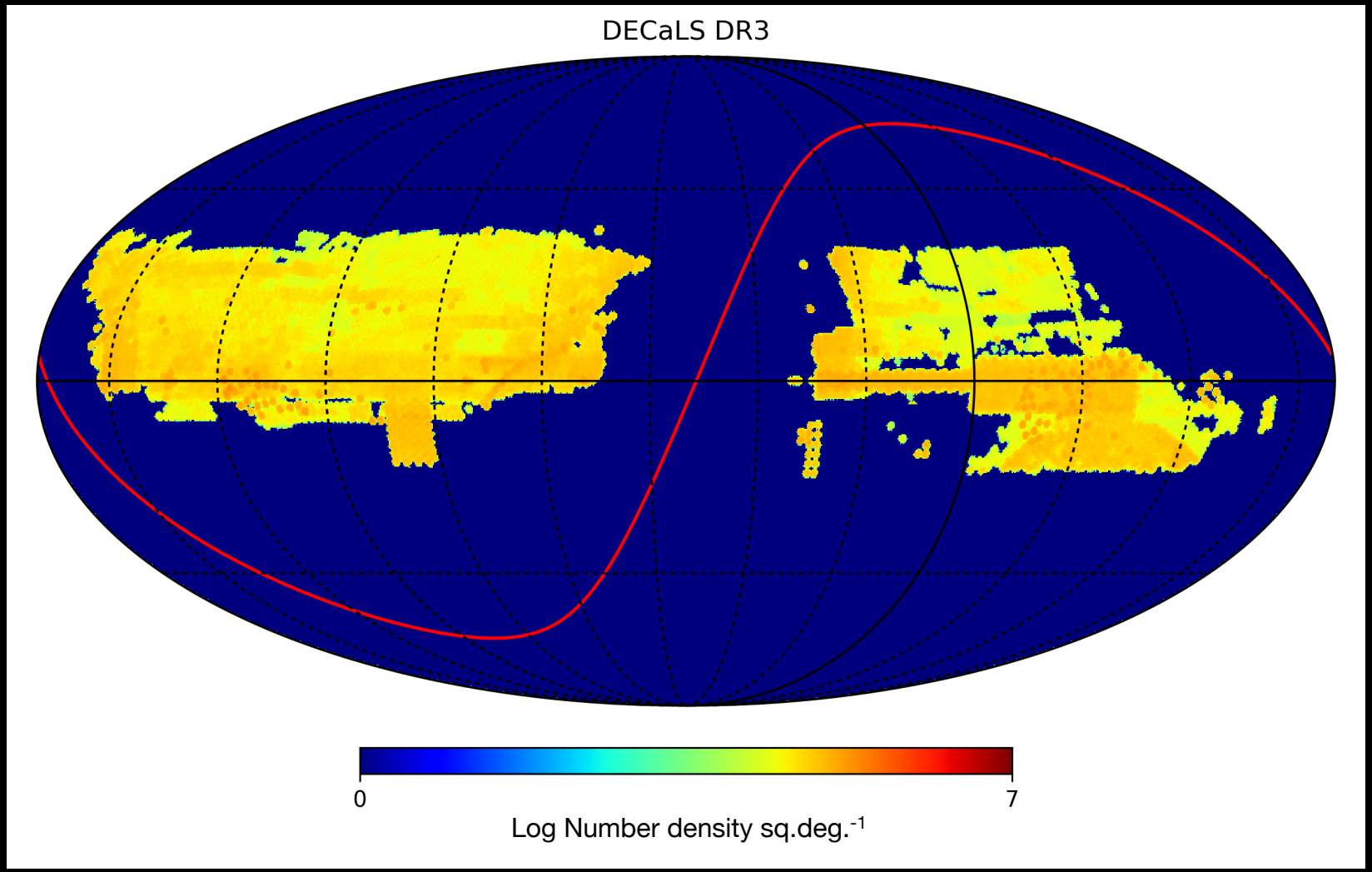
Visualization – data exploration

Compute Processing – workflows run close to the data

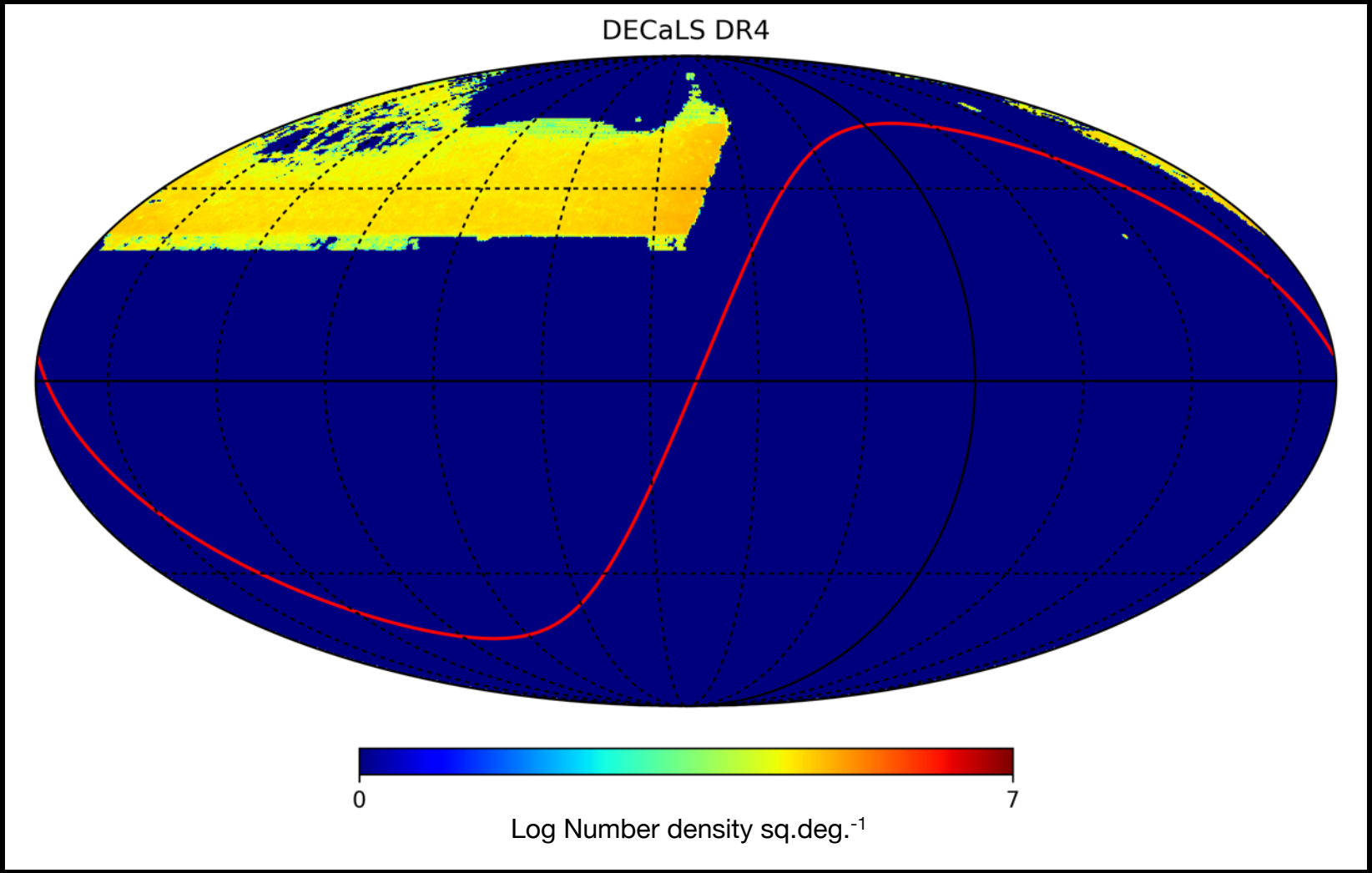
++ Access to published datasets, data publication, exportable workflows, distributable software

Data Lab 1.0 released in June 2017 (AAS)

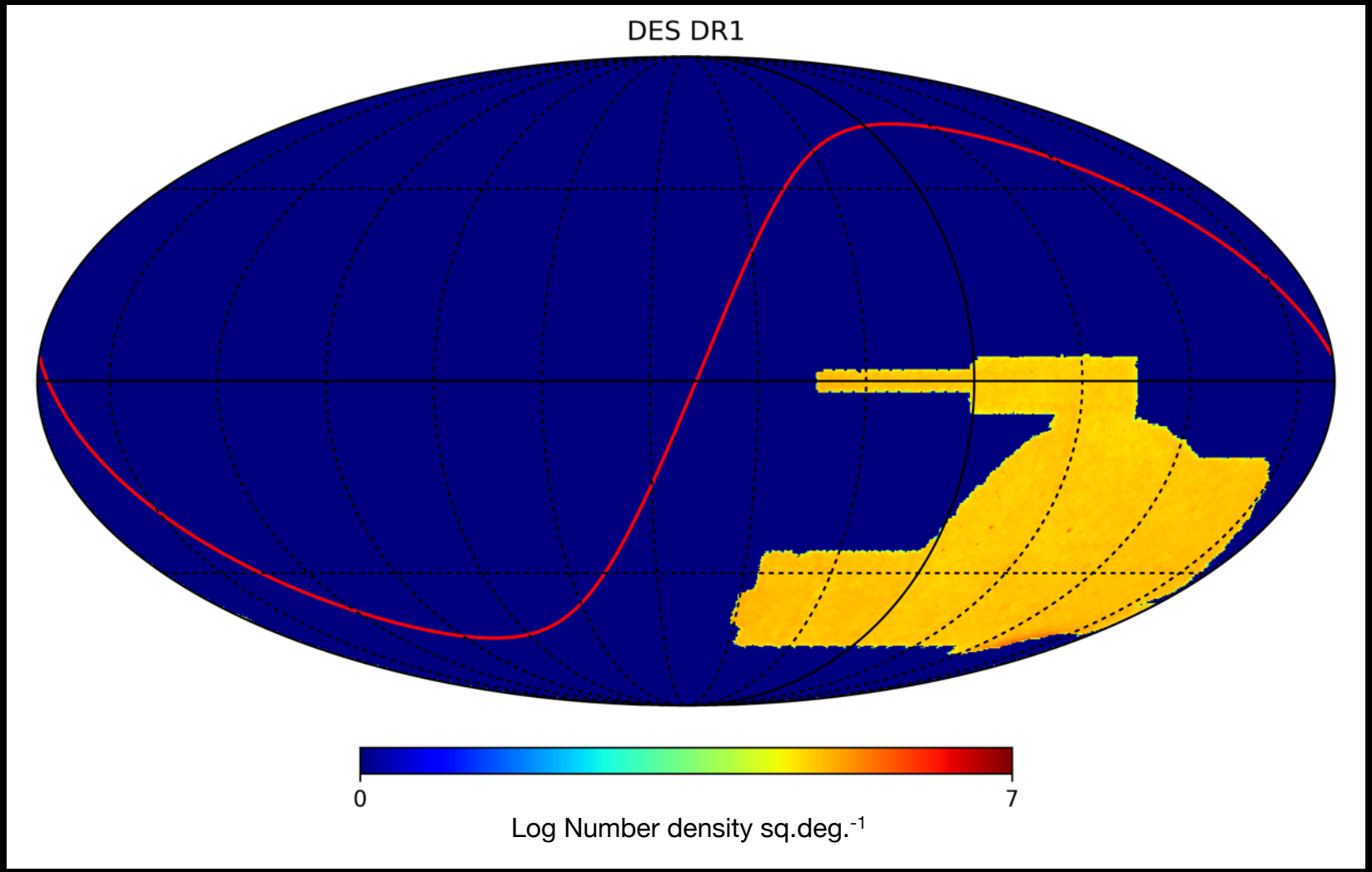
DESI imaging Legacy Survey (LS DR3)



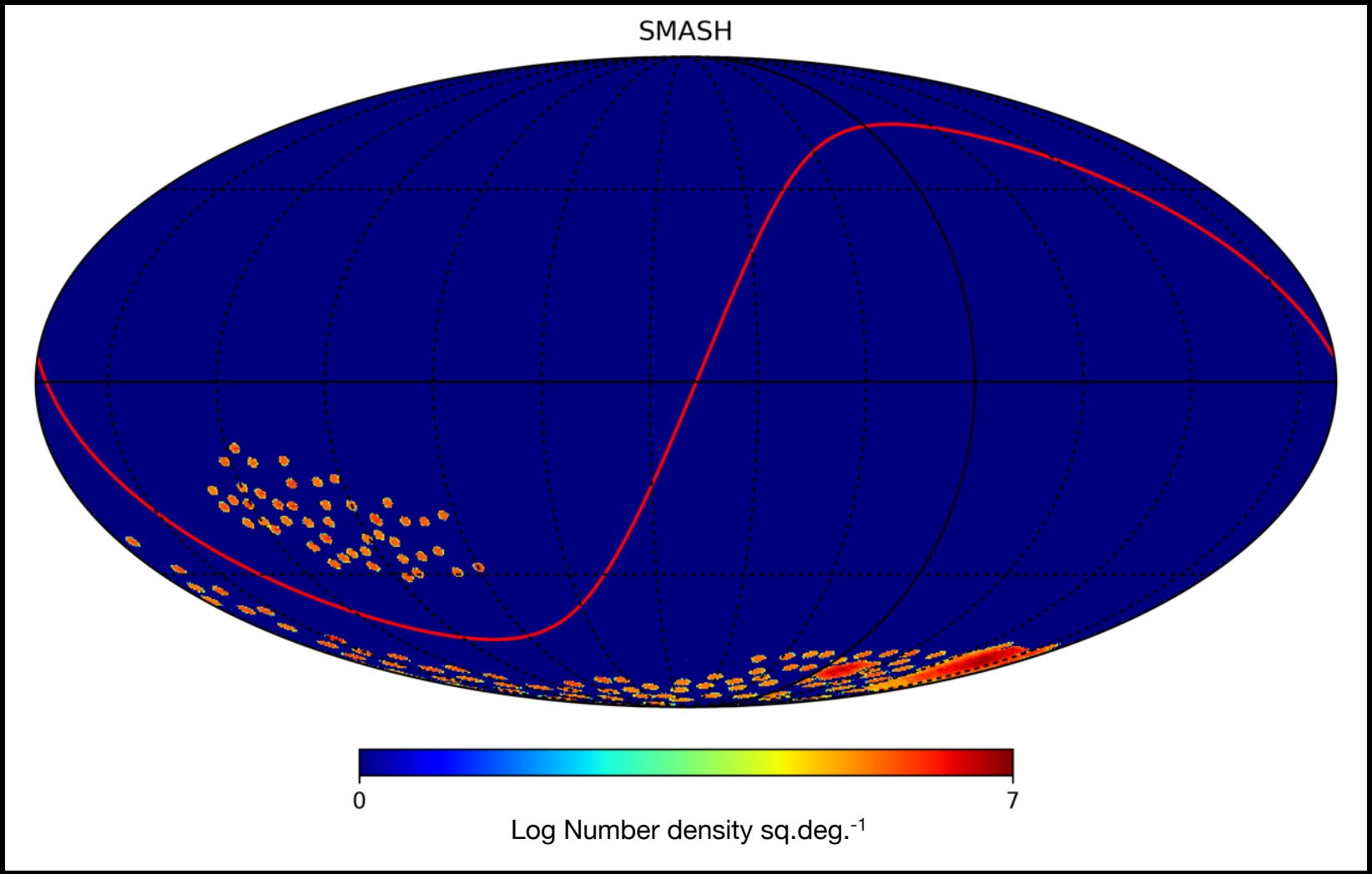
DESI imaging Legacy Survey (LS DR4)



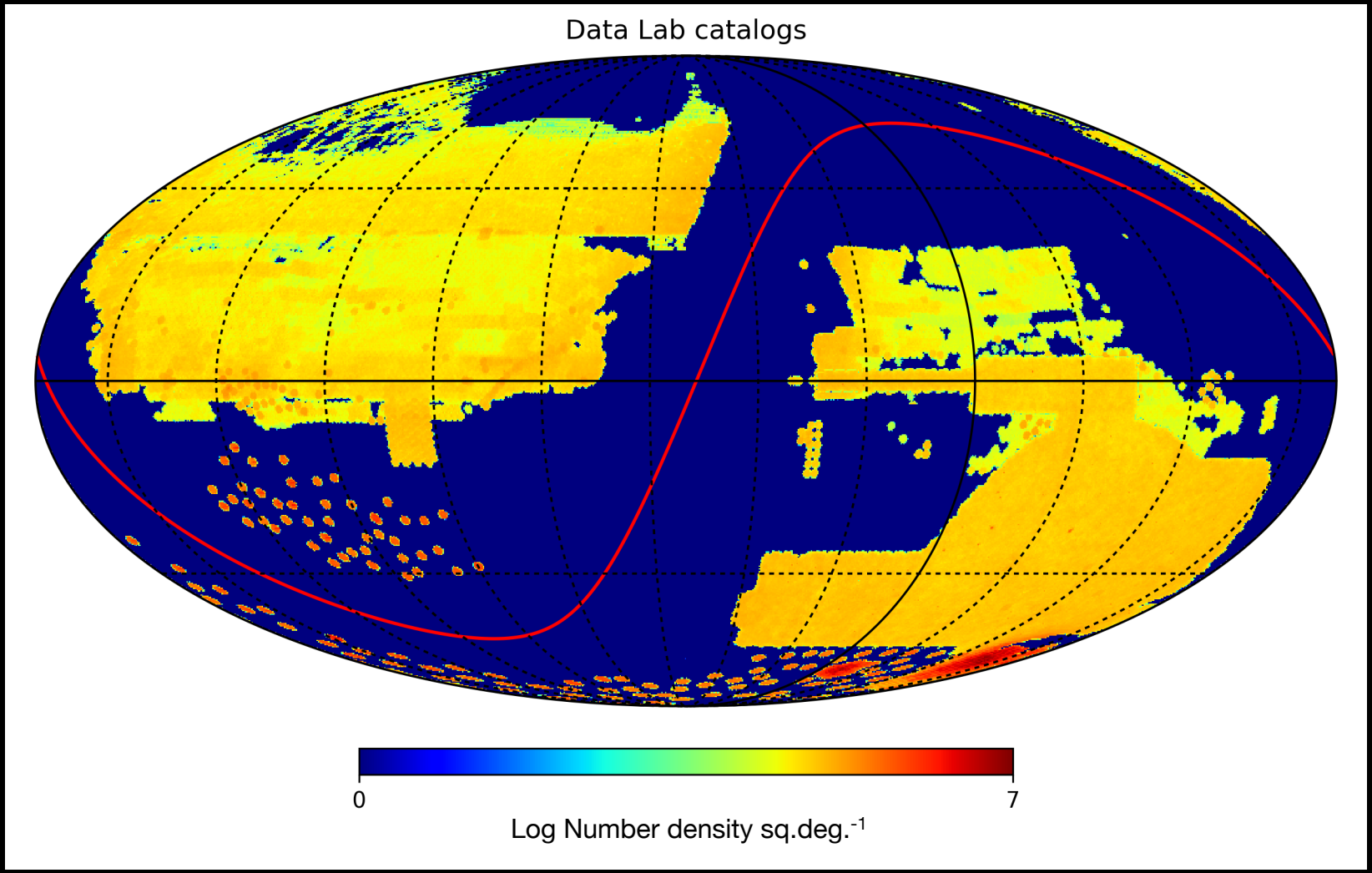
DES catalog (DR1)



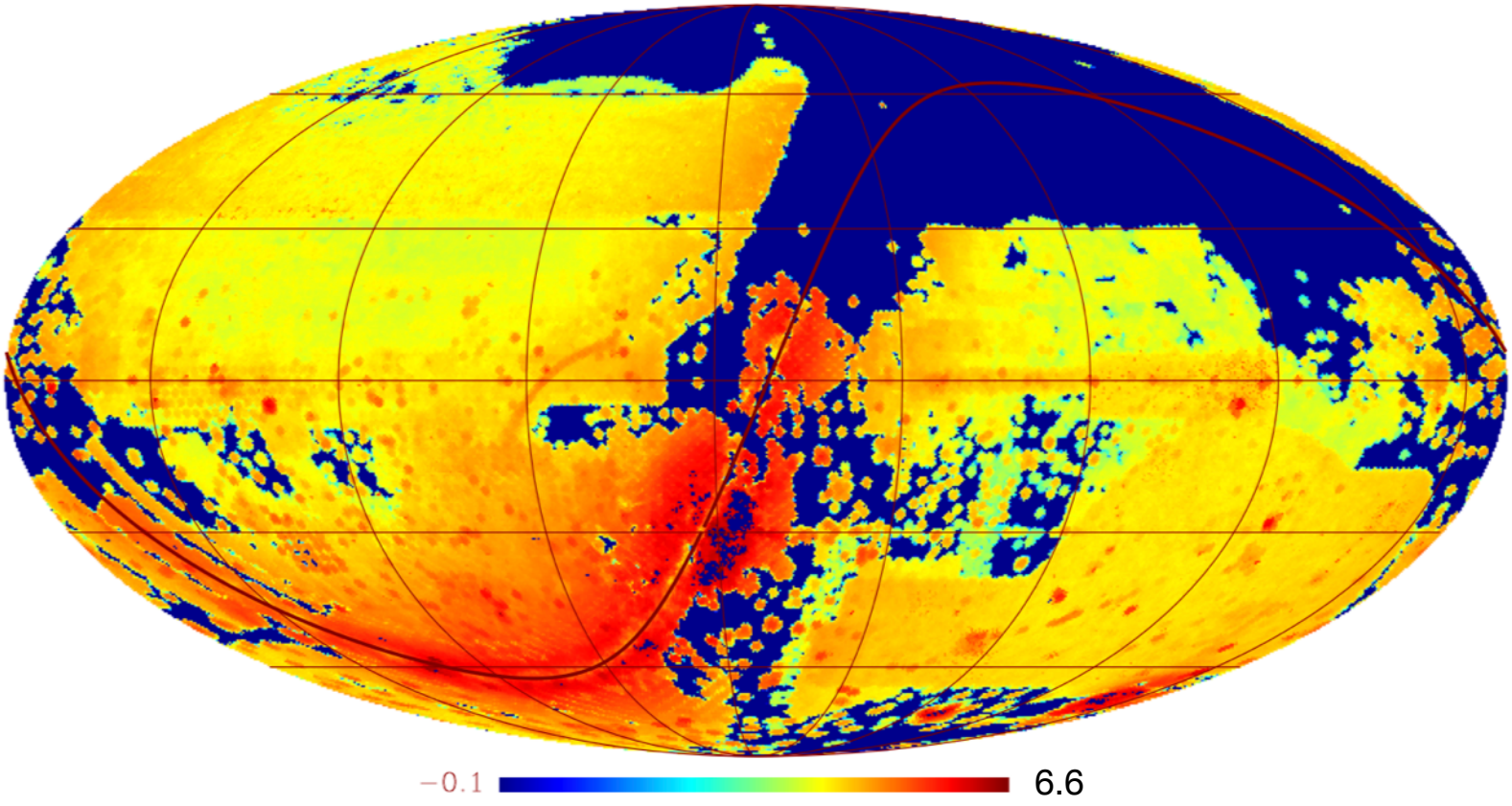
SMASH catalog (DR1)



LS + DES + SMASH



NOAO All Sky Catalog



Data Volume and Complexity

~500 TB (February 2017) of on-target imaging data (t_{exp}>30s) currently from:

- Dark Energy Survey
- Legacy Surveys for DESI Targeting
- Community DECam and Mosaic programs and surveys

Hundreds of TB more coming

Total holdings at PB scale

Large catalogs, e.g.:

- Dark Energy Survey – 7 TB
- Complete DESI Targeting Survey – ~5 TB
- Community programs and surveys – up to several TB each

Data Volume and Complexity

NOAO Facilities Featured Surveys:

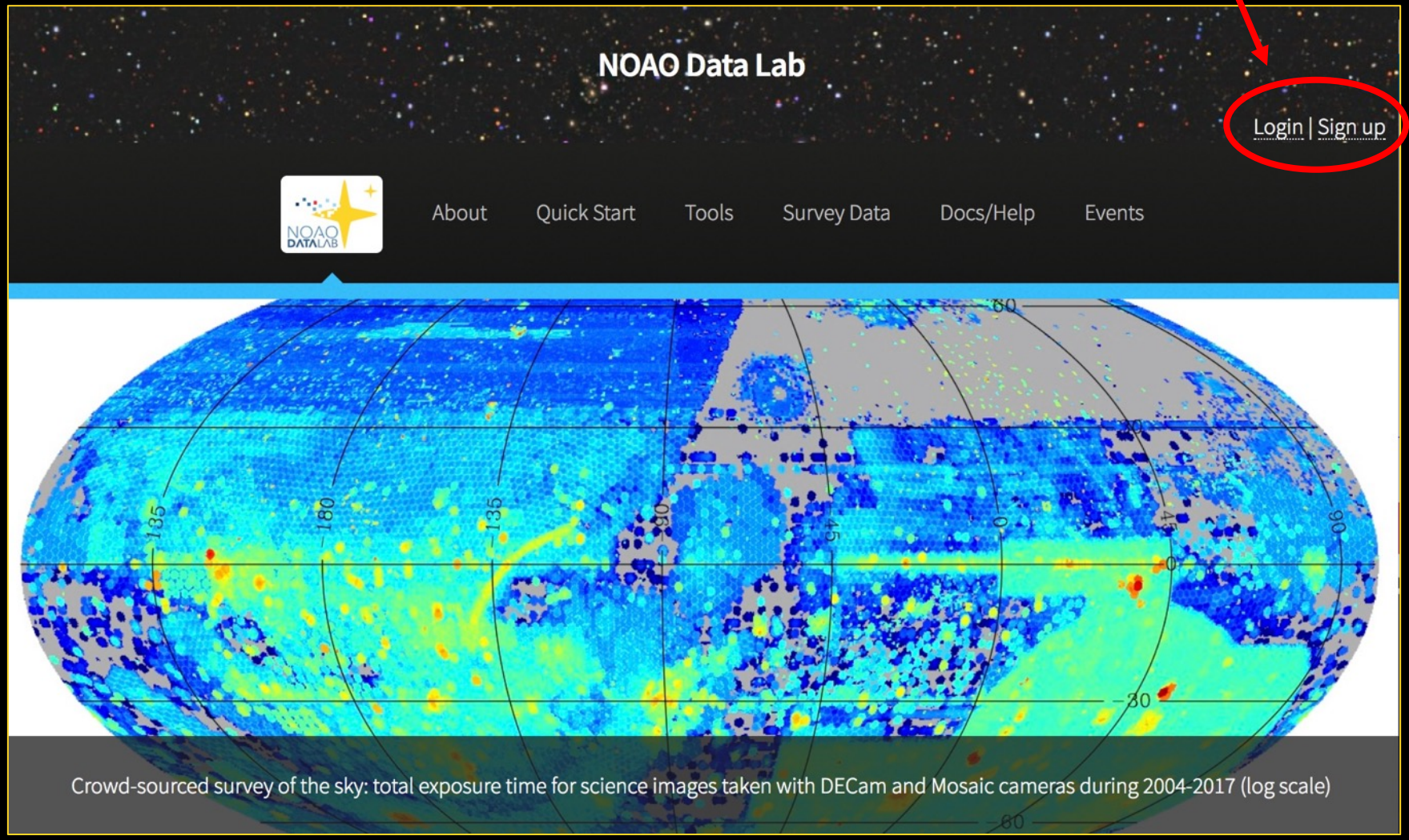
- DESI imaging Legacy Survey (LS): ~860 million objects in DR4+5 (now)
- SMASH: ~100 million objects in DR1 (now)
- DES: ~400 million objects in DR1 (AAS 01/2018)
- DECaPS: ~2 billion objects (AAS 01/2018)
- NOAO All-Sky Source Catalog (NSC): ~2.5 billion objects (AAS 01/2018)

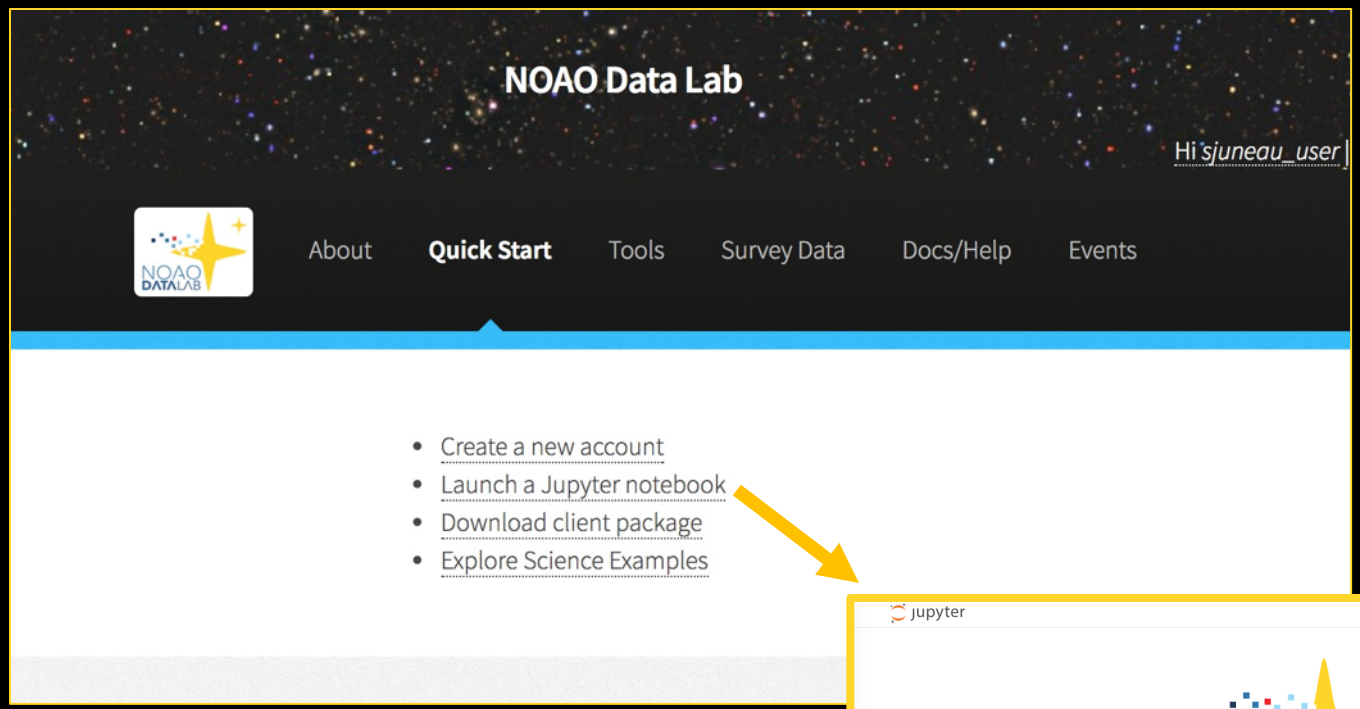
Additional Surveys:

select tables from SDSS/BOSS DR13 & DR14, GAIA DR1, DES SVA1, the Allen NEO catalog, and USNO-A2/B, *skinny* Pan-STARRS DR1, etc.

Using the NOAO Data Lab

datalab.noao.edu





1) User logs in to Data Lab

2) Launch Jupyter Notebook server

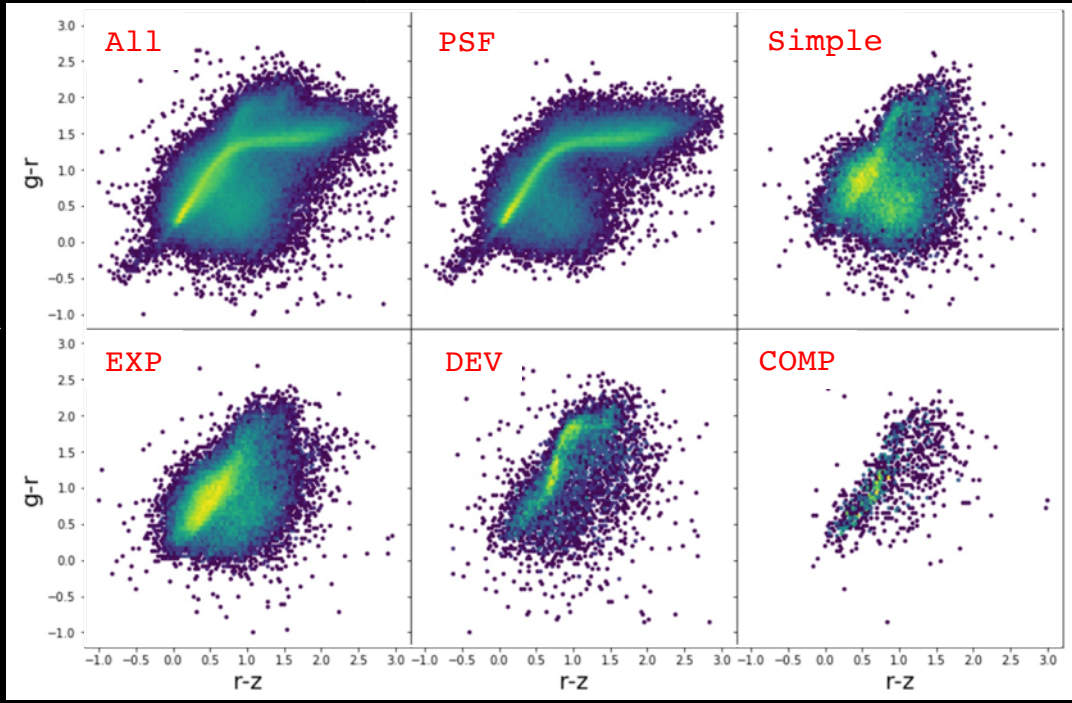
Query to database:

magnitudes and object shape (type)

```
query = """
        SELECT dered_mag_g as gmag, dered_mag_r as rmag,
               dered_mag_z as zmag,
               dered_mag_w1 as w1mag, dered_mag_w2 as w2mag, type,
               snr_g, snr_r, snr_z, ra, dec
        FROM ls_dr3.tractor_primary
        WHERE (snr_g>3 and snr_r>3 and snr_z>3)
        LIMIT 200000"""

# dered_mag_g,r,z  = AB mag in DECam g,r,z bands corrected
#                    for Galactic reddening
# dered_mag_w1,w2  = AB magnitudes in WISE bands W1 & W2
#                    corrected for Galactic reddening
# type             = object type (PSF, SIMP, EXP, DEV, COMP)
# snr_g,r,z        = signal-to-noise ratios (S/N) in g,r,z bands
# ra,dec           = celestial coordinates
#
# WHERE: requirement that S/N>3 in each DECaLS band
# LIMIT: returns 200,000 rows that satisfy the query
```

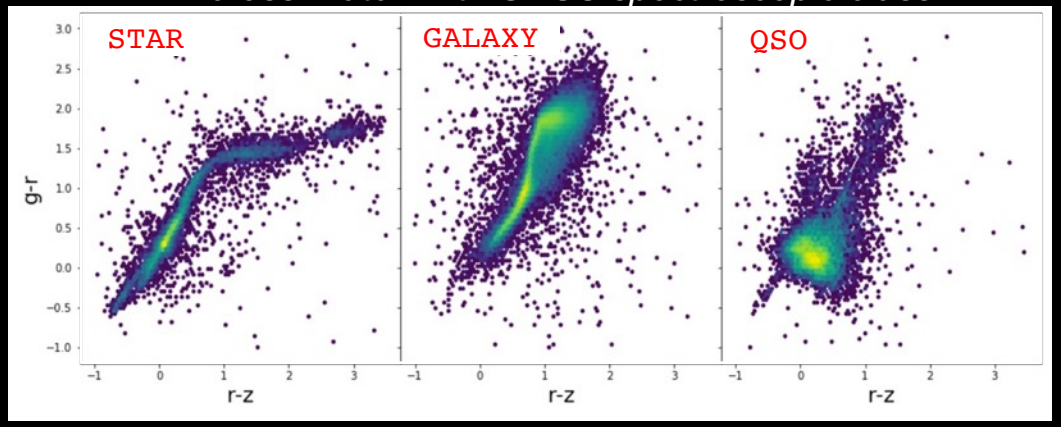
Example Workflow

Analysis: *color-color plot per type*



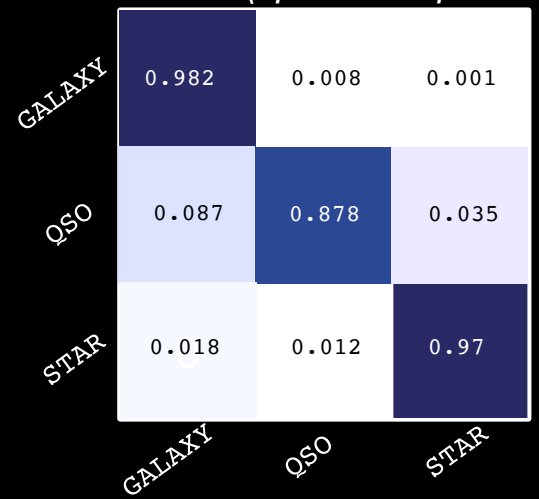
Joint query:

cross-match with SDSS spectroscopic class



Machine-Learning:

Confusion matrix (spectroscopic training set)



Roles for the Data Lab with DESI

Host DESI imaging Legacy Surveys (DECaLS, BASS/MzLS)

→ Databases (ls_dr3, ls_dr4, ls_dr5)

→ Images in NOAO Science Archive (raw + processed)

now!

Host DESI targets

→ Database for final, public set of targets

Host DESI redshifts

→ Database for public releases of redshift catalogs

→ Tools for spectra visualization/analysis

future

Create example Notebooks & workflows

Users can work with all data products

Roles for the Data Lab in the LSST Era

Doing LSST pathfinder science today, e.g.

→ Explore ways to perform star/galaxy separation, including machine learning techniques

→ Automated search for dwarf galaxies & streams in all-sky data

→ Identify variable sources in all-sky photometry, retrieving time series of variable stars, QSOs, etc.

→ Cross-match large catalogs, e.g. LSST Stack-reduced crowded field vs. DAOPHOT/DoPHOT as part of Q.A.

→ Upload table of moving objects, retrieve image cutouts from Archive, stack and analyze

Roles for the Data Lab in the LSST Era

As a complementary tool for LSST science

→ Unique datasets for comparison with LSST + users can publish datasets

→ Legacy code close to Data Lab data + users can upload personal data

→ Different technology on the backend thus a diversity of solutions

→ User friendly platform for large data analysis (similar to LSST DAC; with support for greater diversity of datasets)

→ “Skinny” version of LSST main catalog table* (subset of columns, but all rows) to perform cross-match + preliminary analysis [*needs feasibility tests]

Data Lab Future Visions

Easy access to data for entire astronomy community

→ Databases: Tables, Images, Spectra

User-friendly yet powerful analysis tools

→ Quick start analysis

→ Automated & sophisticated workflows

Data Publication Service

→ User contributed datasets

Interactive interface with advanced visualization

→ connected exploration & analysis, drag-and-drop workflow

Data Lab software package

→ widely distributed, user-contributed developments

Data Lab Future Visions (cont'd)

Machine-Learning algorithms

→ Running in background on all the datasets

Education & Public Outreach

→ Astronomy/Data Science activities for classrooms

→ Art/Science Collaborations

Citizen-science projects

Challenges

Combining increasingly larger datasets including multi-wavelength cross-analysis & combining with simulations/simulated data

Interface between different Data Centers

- → different technologies
- → different data models and/or formats
- → cannot always have co-located data (e.g., full LSST)

Balancing public (astro/cosmo community) and private (survey team) needs for data access and analysis tools

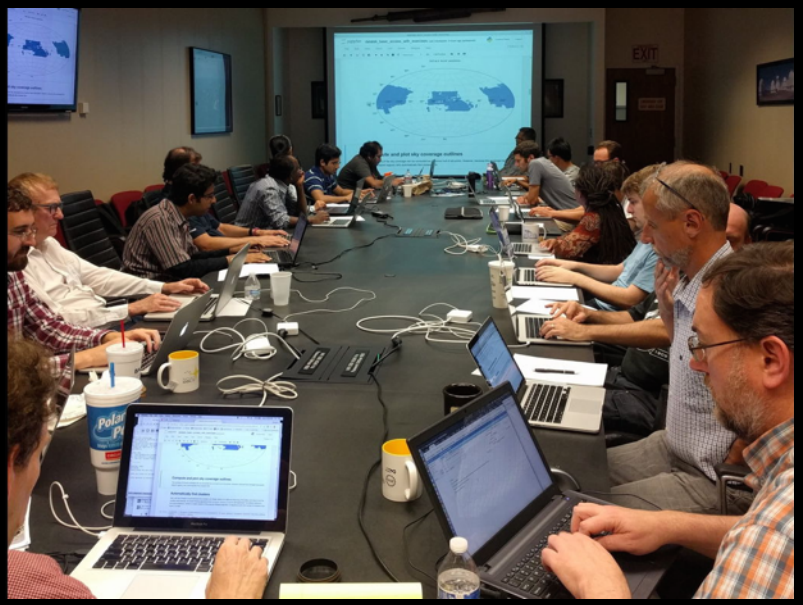
Try it out and get in touch!

Web: datalab.noao.edu

Email: datalab@noao.edu

GitHub: https://github.com/noao-datalab

Twitter: @NOAODataLab



Extra Slides: Data Lab Info & Tutorial

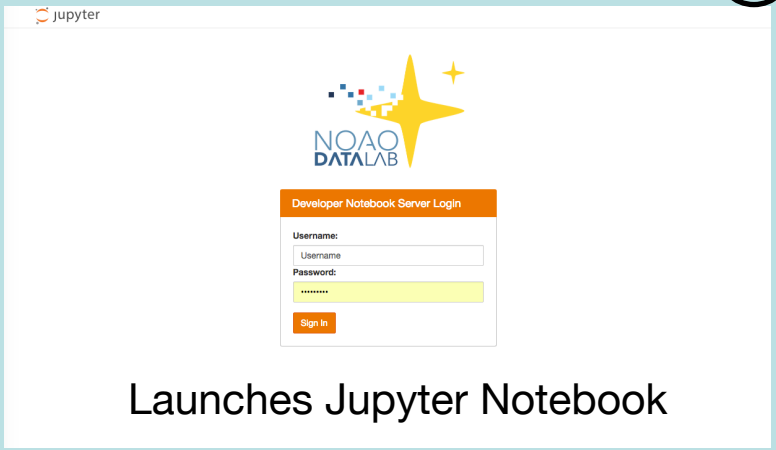
Summary of Current Functions

Function	Method
Sky exploration	Image discovery tool Catalog overlay tool Catalog visualization tool (prototype)
Authentication	Web interface datalab command Python authClient, DL interface
Catalog query	Web interface datalab command line (CLI) Python queryClient, DL interface TOPCAT
Image query	Simple Image Access (SIA) service
Query result storage	myDB Virtual storage space
File transfer	datalab command and Virtual storage space
Analysis	Jupyter notebook server

Example: Detecting a faint dwarf galaxy

User logs in to Data Lab

1



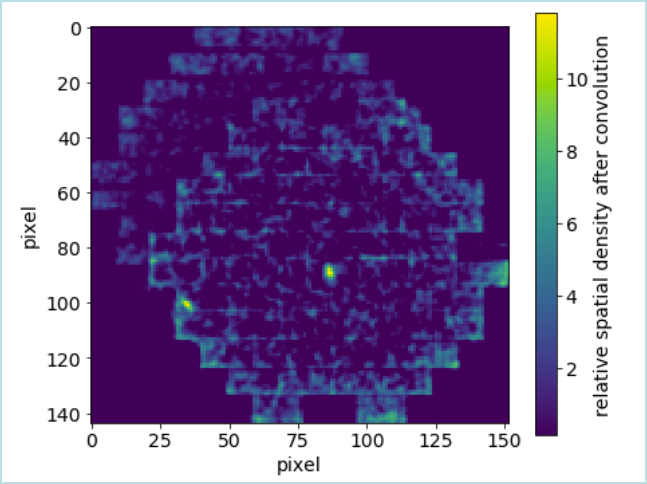
Launches Jupyter Notebook

Queries database for blue stellar objects in SMASH DR1 Field

2

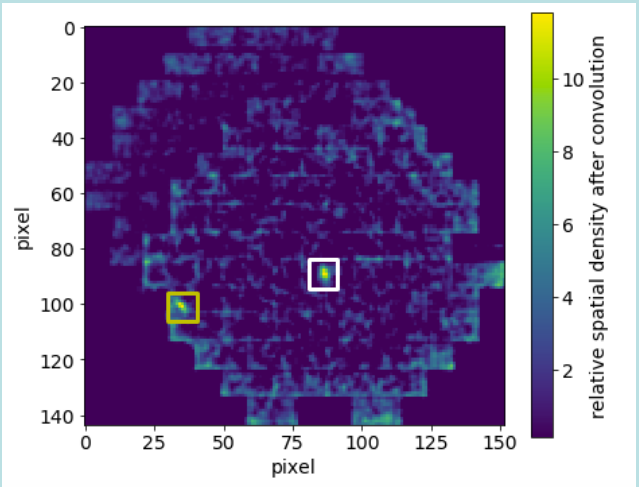
```
field = 169 # SMASH field number to query
depth = 1   # depth (=no short exposures please)

# Create the query string; SQL keyword capitalized for clarity
query_template =\
"""SELECT ra,dec,gmag,rmag,imag FROM smash_dr1.object
   WHERE fieldid = '%d' AND
         depthflag > %d AND
         abs(sharp) < 0.5 AND
         gmag BETWEEN 9 AND 25 AND
         (gmag-rmag) BETWEEN -0.4 AND 0.4"""

query = query_template % (field, depth)
```

Applies filter to spatial distribution



3

Runs automatic peak detection

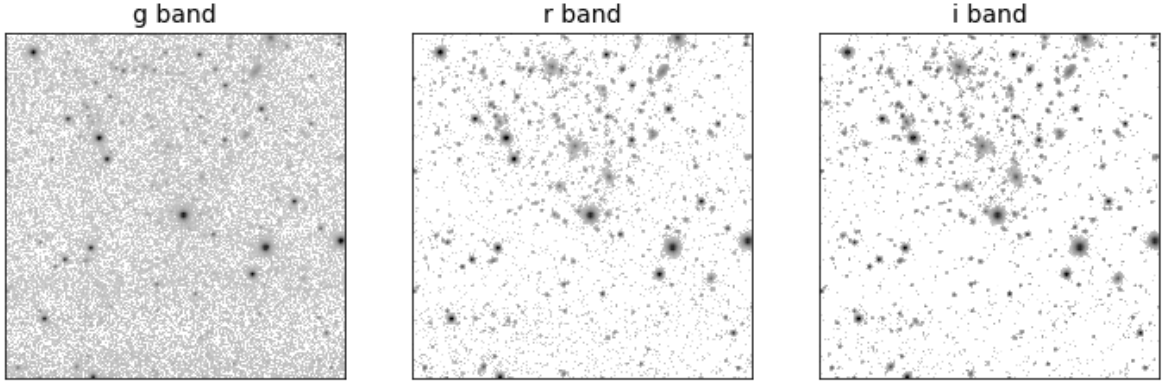


4

...

Queries peak locations for image cutouts

5

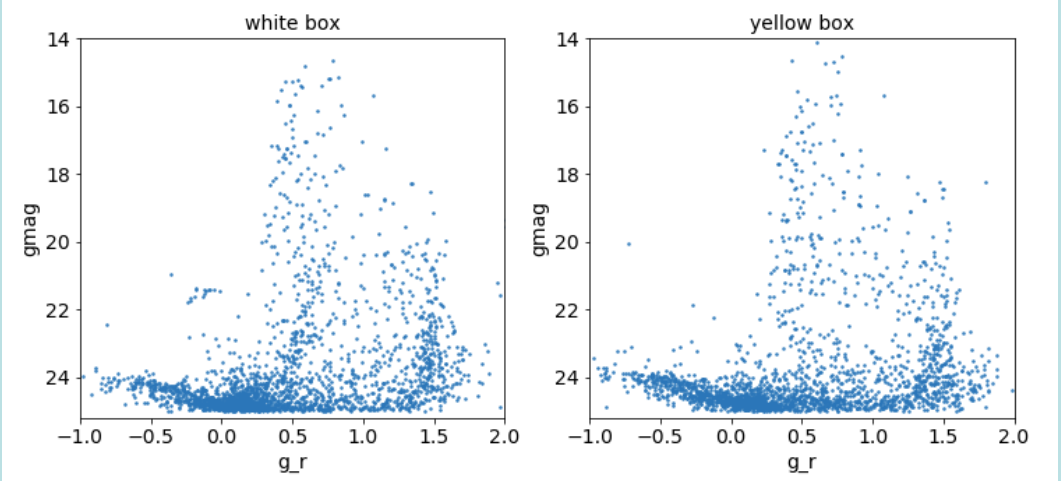


Stores all results in virtual storage…

…and repeat!

7

Queries peak locations for full photometry

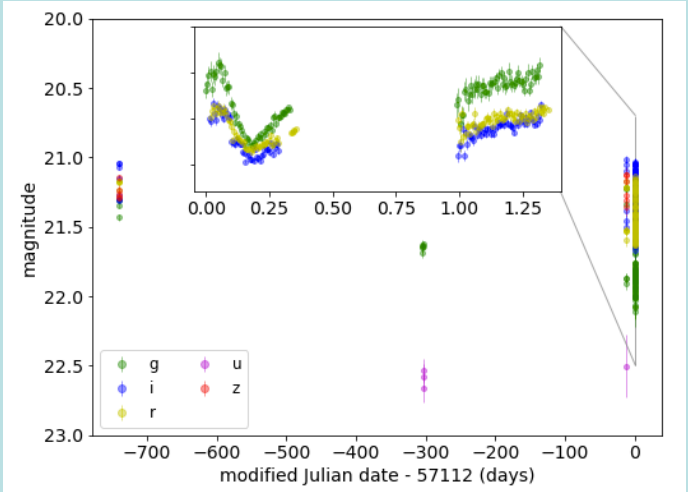


6

Example: Detecting variables

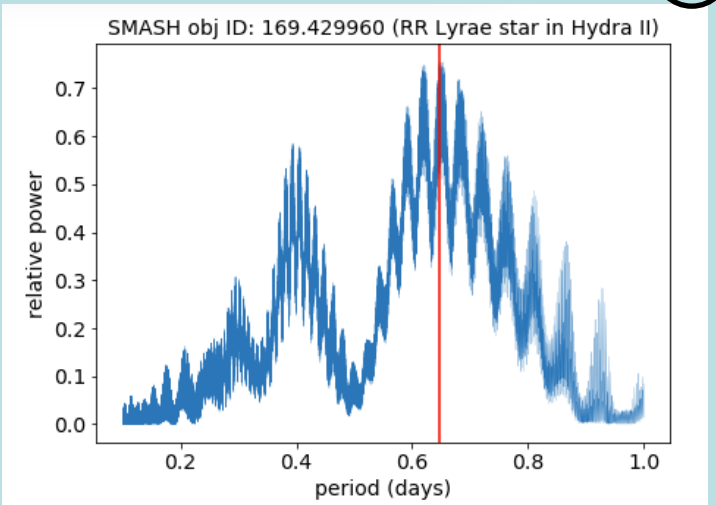
Retrieve light curve of candidate Hydra II variable

1



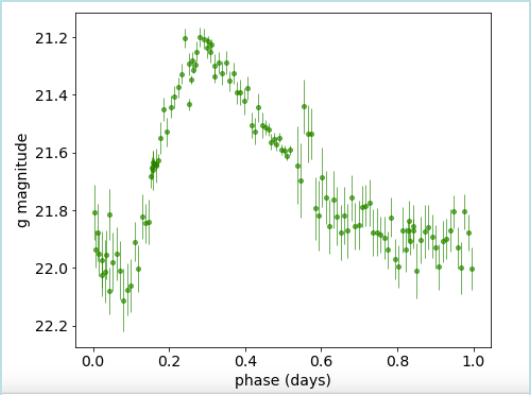
Apply Lomb-Scargle

2



Fold light curve

3

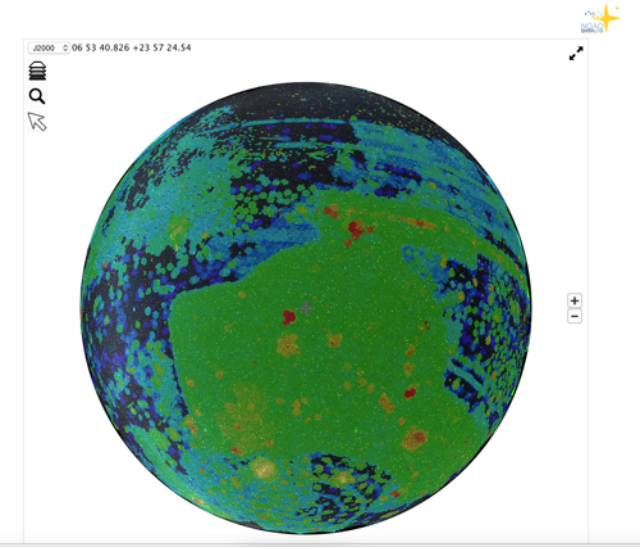


Identify more variables through statistical techniques!

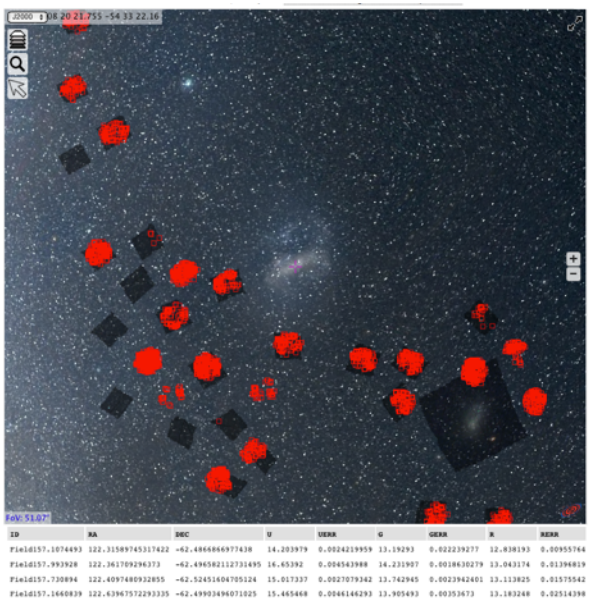
4

Exploring the sky

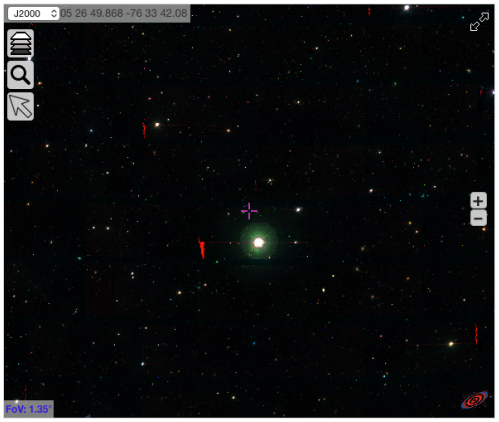
Images

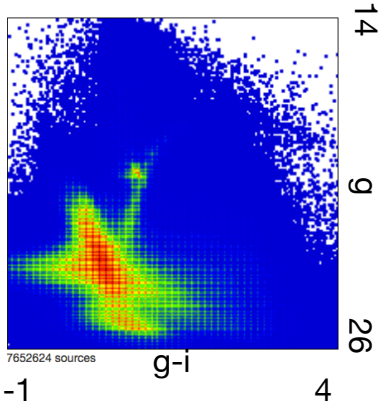


Catalogs



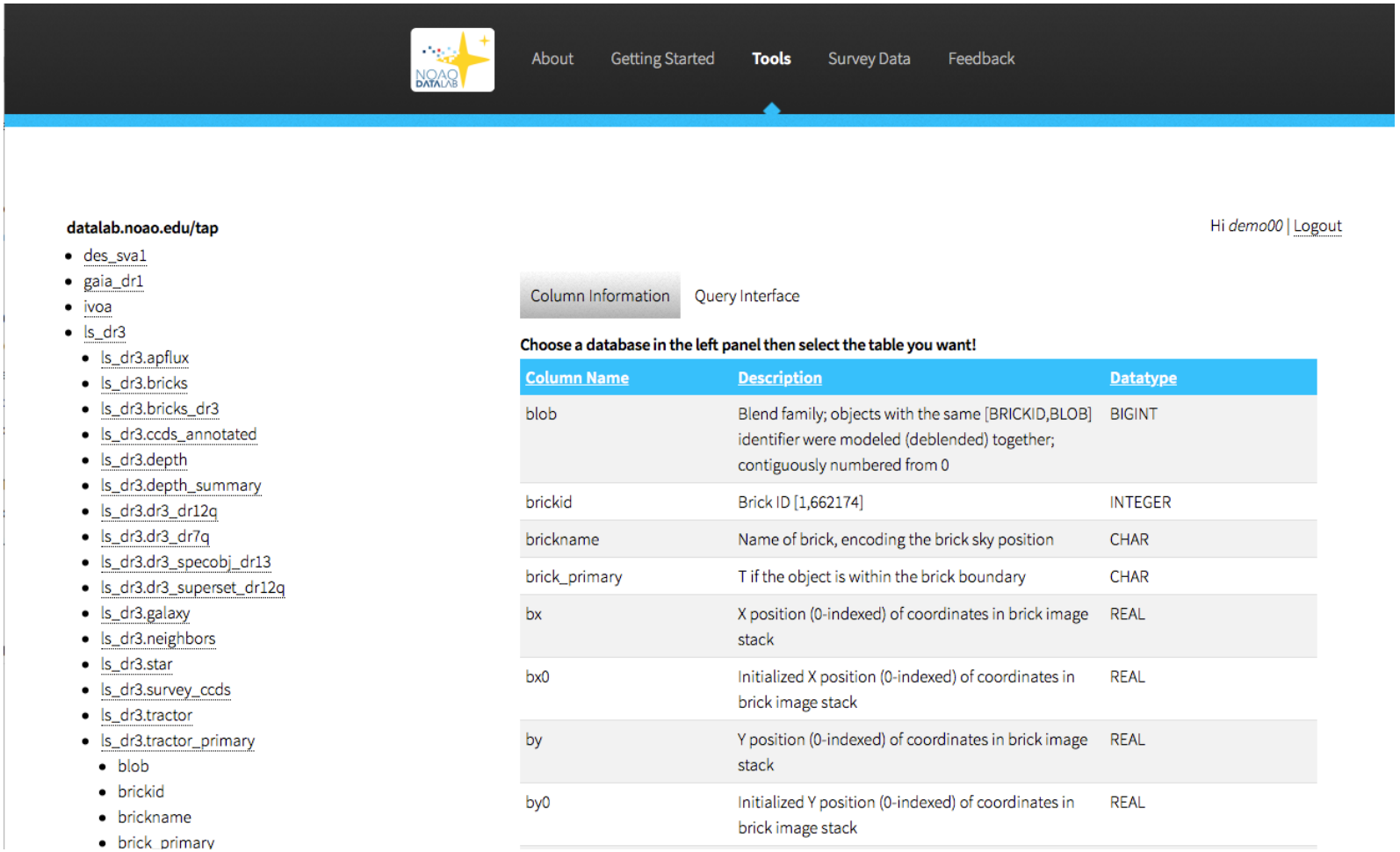
Catalog visualization (prototype)





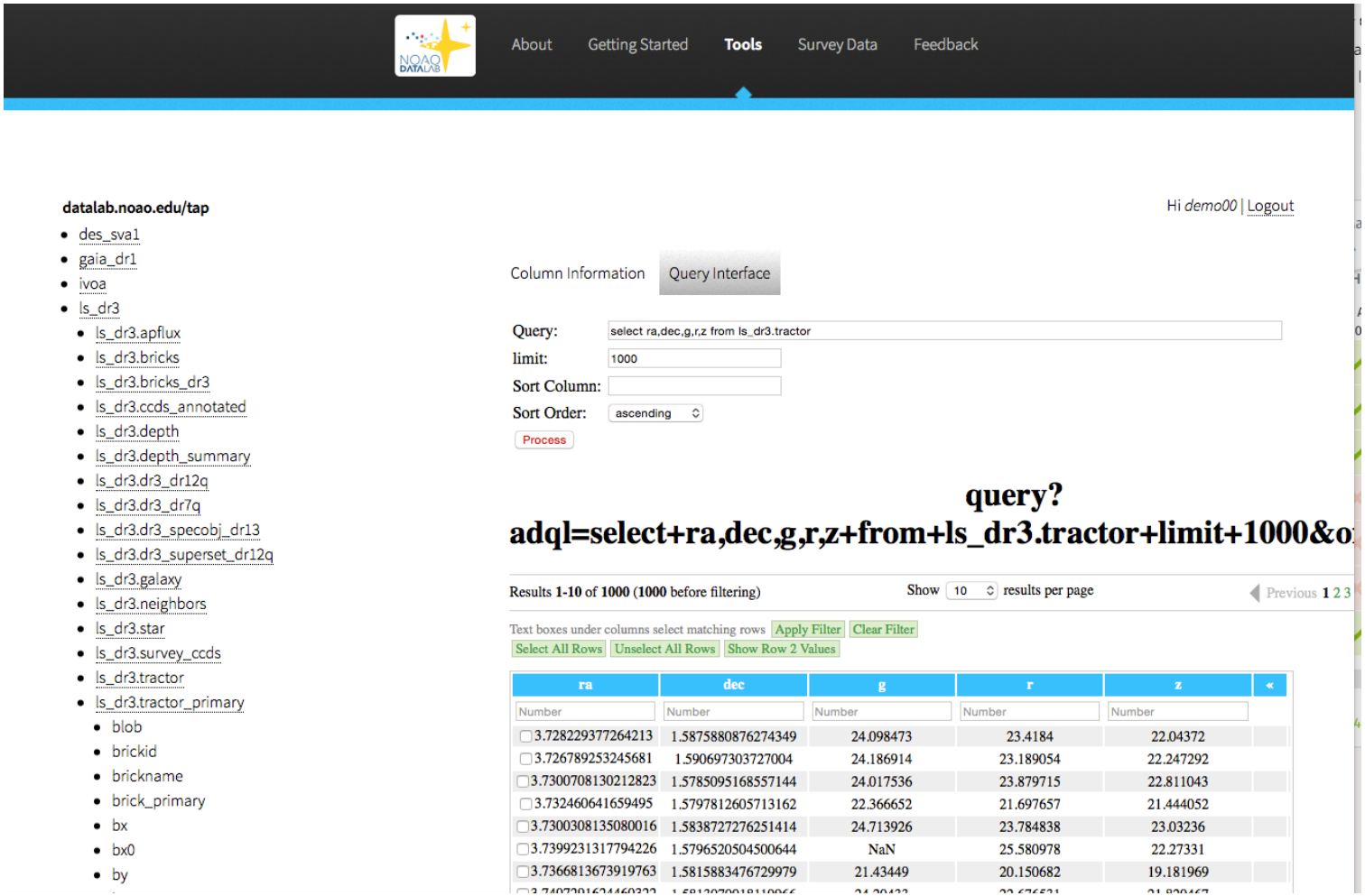
Querying the catalogs

- Through the Data Lab website:



Querying the catalogs

- Through the Data Lab website:



Querying the catalogs

- Through the datalab command:

```
[kolsen@gp02 ~]$ datalab login user=demo00 password=[redacted]
Welcome to the Data Lab, demo00
[kolsen@gp02 ~]$ datalab query sql="select * from usno.a2 limit 10"
id,raj2000_,dej2000_,actflag,mflag,bmag,rmag,epoch,raj2000,dej2000
0150-00069690,00:14:47.196,-68:49:48.92, , ,19.6,17.9,1981.81,3.696648,-68.830256
0150-00070481,00:14:54.972,-68:49:58.22, , ,19.8,18,1981.81,3.72905,-68.832839
0150-00069562,00:14:45.900,-68:49:37.66, , ,18,17.8,1981.81,3.69125,-68.827128
0150-00069750,00:14:47.844,-68:49:29.41, , ,19.4,18,1981.81,3.699348,-68.824837
0150-00070904,00:14:59.041,-68:49:25.26, , ,20.2,18,1981.81,3.746003,-68.823684
0150-00072260,00:15:12.458,-68:54:06.12, , ,18.9,17.1,1981.81,3.801909,-68.9017
0150-00072812,00:15:17.694,-68:54:09.03, , ,16.4,15.2,1981.81,3.823725,-68.902509
0150-00072863,00:15:18.280,-68:53:21.92, , ,17.7,16.5,1981.81,3.826164,-68.889423
0150-00073055,00:15:20.016,-68:53:23.36, , ,18.7,17.5,1981.81,3.8334,-68.889823
0150-00074055,00:15:29.570,-68:54:38.01, , ,19.3,18,1981.81,3.873206,-68.910559

[kolsen@gp02 ~]$ datalab query sql="select * from usno.a2 limit 10" out="mydb://usno_test2"
[kolsen@gp02 ~]$ datalab query sql="select * from usno.a2 limit 10" out="vos://foo2.csv"
[kolsen@gp02 ~]$
```

Querying the catalogs

- Through the Python queryClient module:

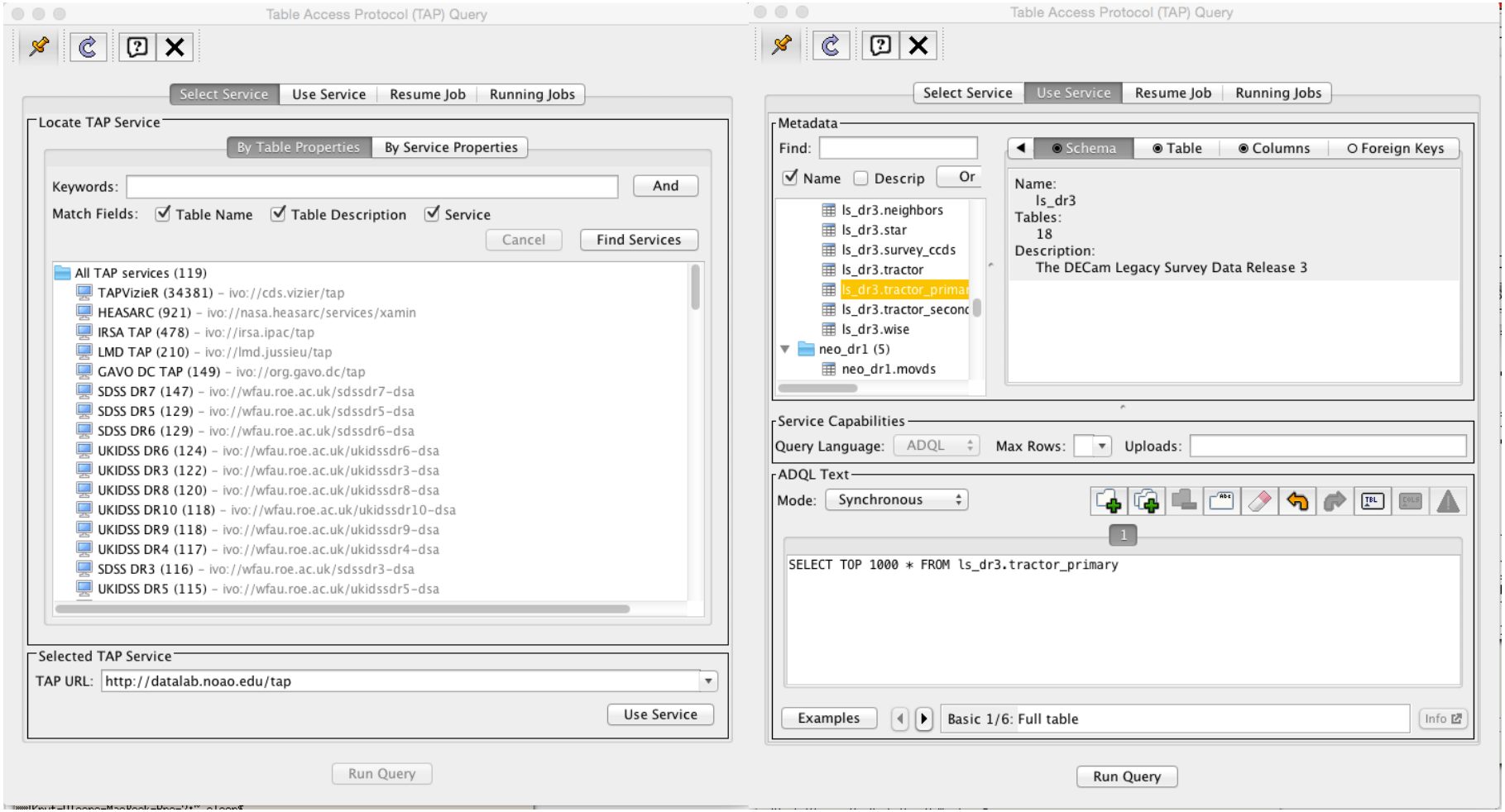
In [4]:
```
from dl import authClient, queryClient
from getpass import getpass
token = authClient.login(raw_input('Enter username: '),getpass('Enter password: '))
```

In [29]:
```
%%time
query="SELECT id,ra,dec,gmag,rmag FROM smash_dr1.object WHERE fieldid=169 LIMIT 100"
try:
  response = queryClient.query(token, sql = query, fmt = 'csv')
except Exception as e:
  print e.message
  raise
print response[:205]
```

```
id,ra,dec,gmag,rmag
169.458572,185.342365895208,-32.1201617232873,24.8856,24.6991
169.460663,185.348188180985,-32.1200524648251,24.665,24.5361
169.1065651,185.353177442806,-32.1208638198927,25.0639,24.6239
CPU times: user 7.4 ms, sys: 956 µs, total: 8.36 ms
Wall time: 53 ms
```

Querying the catalogs

- Through TOPCAT:



Querying the images

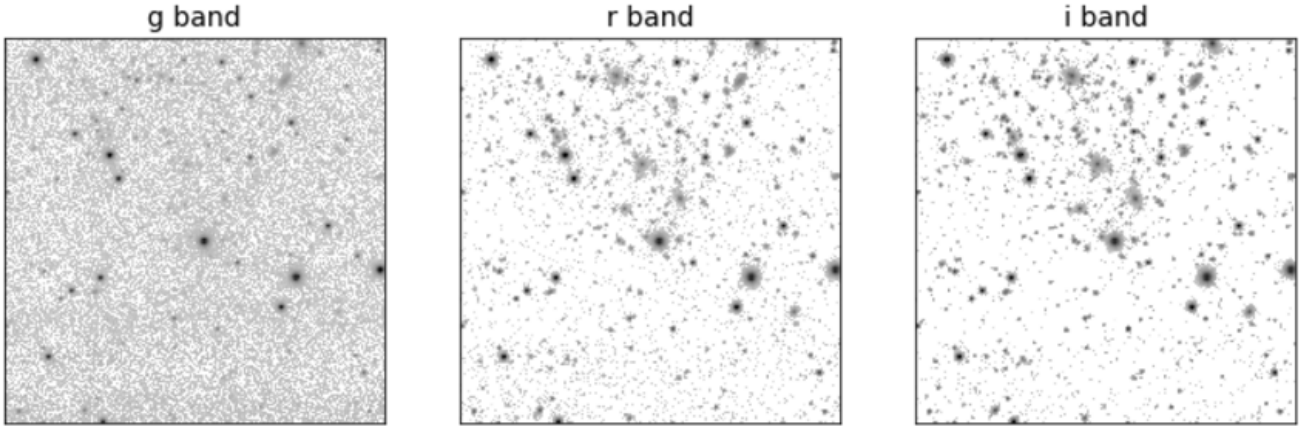
In [14]: Slide Type -

```
bands = list('gri')
images = download_deepest_images(tbl['ra'][1], tbl['dec'][1], fov=0.07, bands=bands) # FOV in de
```

```
The full image list contains 2514 entries
Band g: downloading deepest stacked image...
Band r: downloading deepest stacked image...
Band i: downloading deepest stacked image...
Downloaded 3 images.
```

In [15]: Slide Type -

```
plot_images(images,bands=bands)
```



Saving the results

- myDB:

```
In [29]: query = "select * from usno.b1 limit 1000"
         try:
             response = queryClient.query (token, adql=query, fmt='csv',
                                           out='mydb://mags3')
             #queryClient.list (token, table='mydb://mags3')
         except Exception as e:
             # Handle any errors in the query.  By running this cell multiple times with the same
             # output file, or by using a bogus SQL statement, you can view various error messages.
             print (e.message)
         else:
             if response is not None:
                 print (response)            # print the response
             else:
                 print ("OK")

         http://dlsvcs.datalab.noao.edu/query/list?table=mydb://mags3
         OK
```

```
datalab query sql="select * from usno.a2 limit 10" out="mydb://usno_test2"
```

Saving the results

- Virtual storage:

```
try:
    response = queryClient.query (token, adql=query, fmt='csv',
                                  out='vos://mags.csv')
except Exception as e:
    # Handle any errors in the query.  By running this cell multiple times with the same
    # output file, or by using a bogus SQL statement, you can view various error messages.
    print (e.message)
else:
    if response is not None:
        print (response)           # print the response
    else:
        print ("OK")

# Remove the file we just created, but list it first to show it exists
storeClient.ls (token, name='vos://mags.csv')
storeClient.rm (token, name='vos://mags.csv')
```

```
datalab query sql="select * from usno.a2 limit 10" out="vos://foo2.csv"
```

Virtual storage

- File transfer:

```
[kolsen@gp02 ~]$ datalab put fr=/etc/hosts to=vos://
(1 / 1) /etc/hosts -> vos://hosts
[kolsen@gp02 ~]$ datalab get fr=vos://hosts to=/tmp/myhosts
(1/1) [====================] [   281B] hosts
```

Try it out and get in touch!

- Web: datalab.noao.edu
- Email: datalab@noao.edu
- GitHub: https://github.com/noao-datalab
- Twitter: @NOAODataLab