HiPS and MOC - enabling publication and interoperability of large astronomy data sets

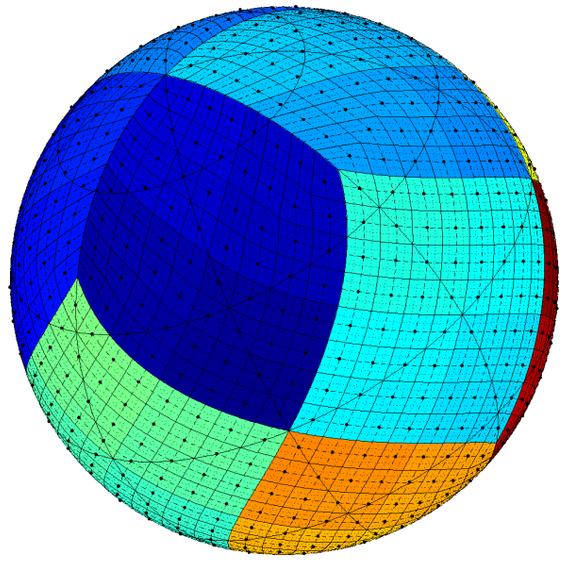
Mark Allen, Pierre Fernique, Thomas Boch, Caroline Bot, Mihaela Buga, François-Xavier Pineau + CDS team

Centre de Données Astronomiques de Strasbourg (CDS)

CENTRE DE DONNÉES
ASTRONOMIQUES DE STRASBOURG

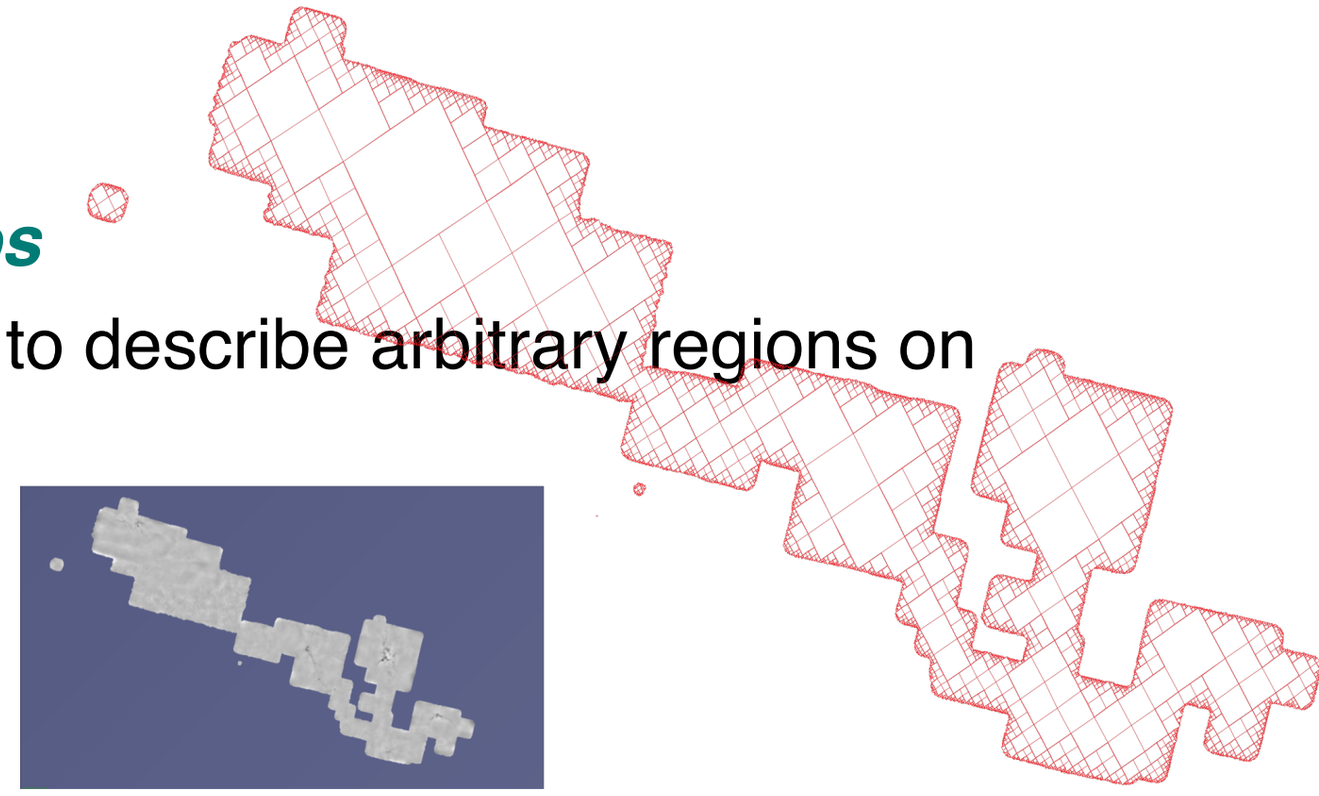
Asterics
Astronomy ESFRI & Research Infrastructure Cluster

HiPS and MOC

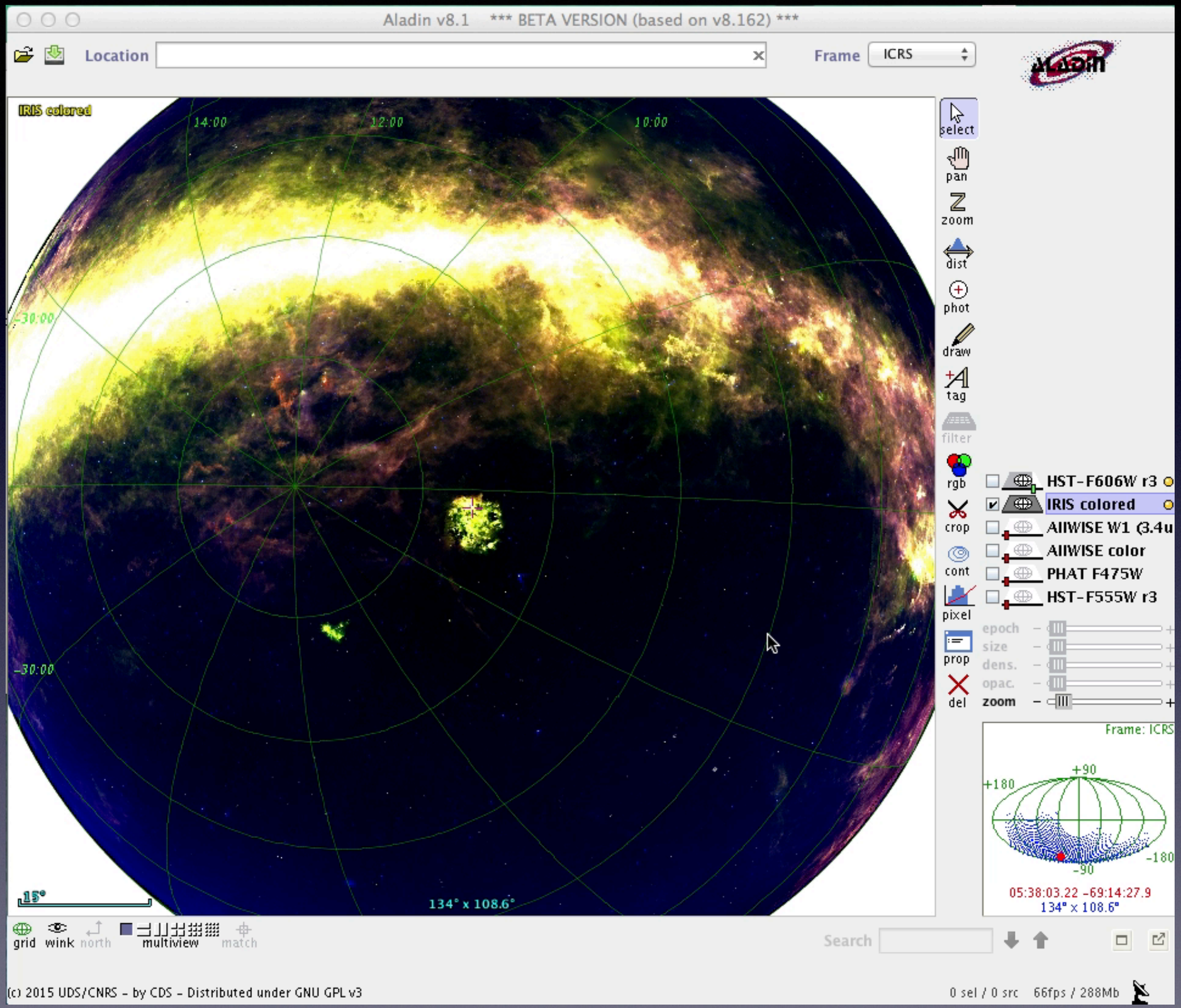


- **HiPS:** ***Hierarchical Progressive Surveys***
  - multi-resolution HEALPix* data structure for
    - images, 3-d image cubes, catalogues
  - the more you zoom, the more you see by accessing higher and higher resolution tiles

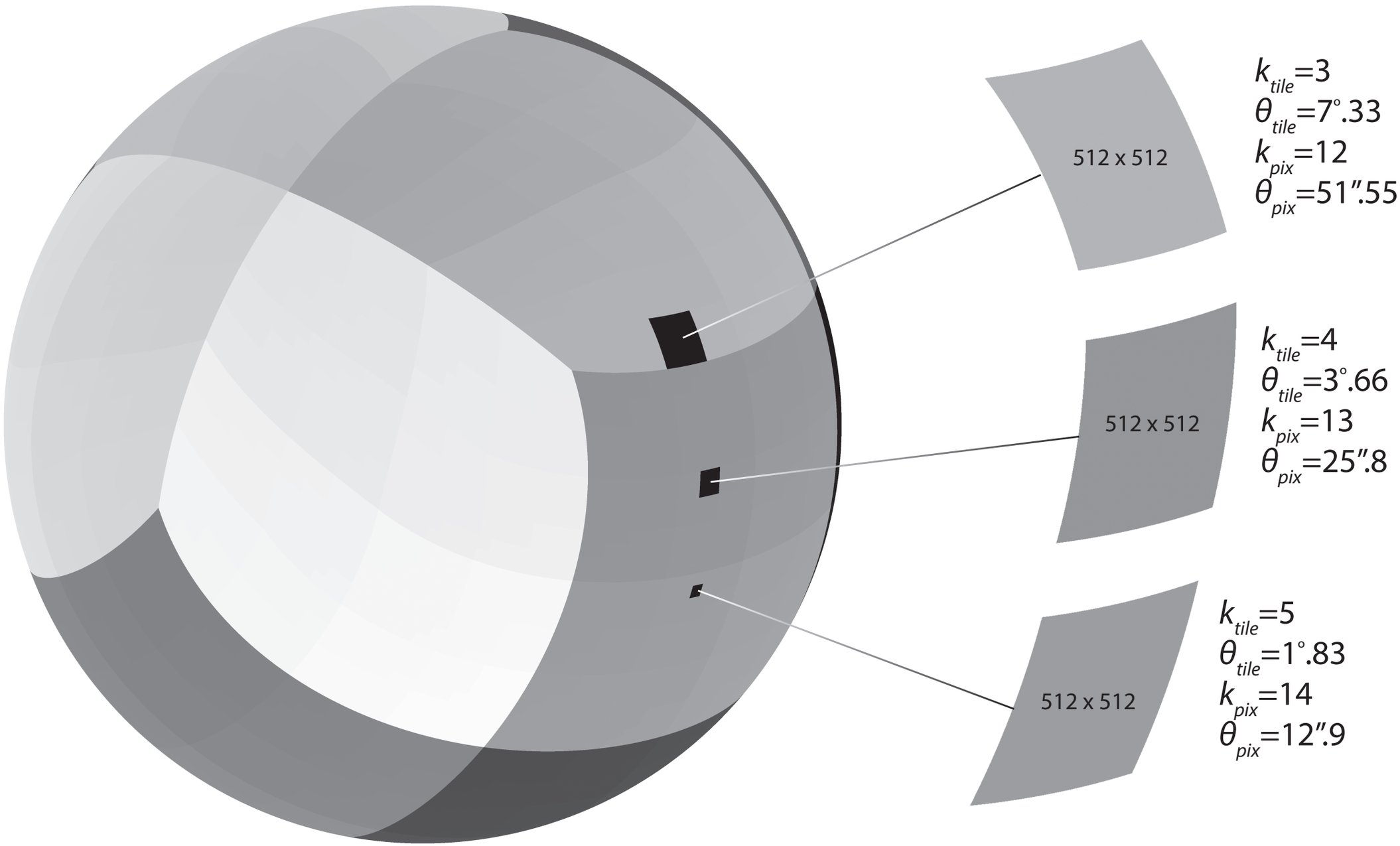
- **MOC:** ***Multi-Order Coverage maps***
  - HEALPix tiles at multiple orders to describe arbitrary regions on the sky



*Gorski et al. 2005


Aladin v8.1 *** BETA VERSION (based on v8.162) ***
Location
Frame ICRS
IRIS colored
14:00
12:00
10:00
-30:00
-30:00
15°
134° x 108.6°
select
pan
zoom
dist
phot
draw
tag
filter
rgb
crop
cont
pixel
prop
del
HST-F606W r3
IRIS colored
AllWISE W1 (3.4u
AllWISE color
PHAT F475W
HST-F555W r3
epoch
size
dens.
opac.
zoom
Frame: ICRS
+90
+180
-180
-90
05:38:03.22 -69:14:27.9
134° x 108.6°
grid
wink
north
multiview
match
Search
(c) 2015 UDS/CNRS - by CDS - Distributed under GNU GPL v3
0 sel / 0 src
66fps / 288Mb

HiPS – Tiles and Pixels

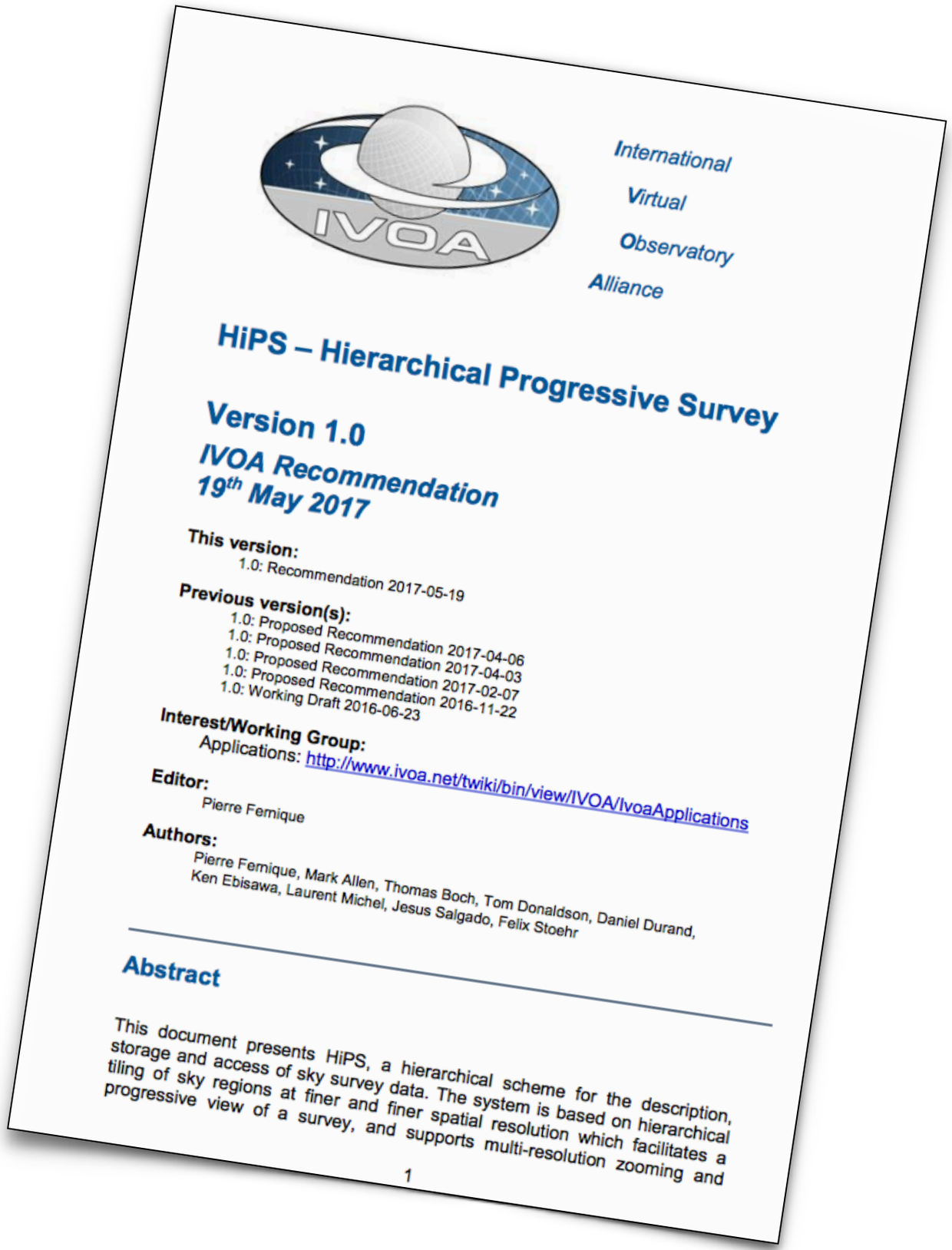


k	$N_{side} = 2^k$	N_{pix}	θ_{pix}	$k_{tile,512}$	$N_{tile,512}$	$\theta_{tile,512}$
0	1	12	58.6			
1	2	48	29.3			
2	4	192	14.7			
3	8	768	7.33			
4	16	3072	3.66			
5	32	12,288	1.83			
6	64	49,152	55.0			
7	128	196,608	27.5			
8	256	786,432	13.7			
9	512	3,145,728	6.87	0	12	58.6
10	1024	12,582,912	3.44	1	48	29.3
11	2048	50,331,648	1.72	2	192	14.7
12	4096	201,326,592	51.5	3	768	7.33
13	8192	805,306,368	25.8	4	3072	3.66
14	2^{14}	3.22×10^9	12.9	5	12288	1.83
15	2^{15}	1.29×10^{10}	6.44	6	49152	55.0
16	2^{16}	5.15×10^{10}	3.22	7	196608	27.5
17	2^{17}	2.06×10^{11}	1.61	8	786432	13.7
18	2^{18}	8.25×10^{11}	0.81	9	3,145,728	6.87
19	2^{19}	3.30×10^{12}	0.40	10	12,582,912	3.44
20	2^{20}	1.32×10^{13}	0.20	11	50,331,648	1.72
21	2^{21}	5.28×10^{13}	0.10	12	201,326,592	51.5
22	2^{22}	2.11×10^{14}	50.3 mas	13	805,306,368	25.8
23	2^{23}	8.44×10^{14}	25.1 mas	14	3.22×10^9	12.9
24	2^{24}	3.38×10^{15}	12.6 mas	15	1.29×10^{10}	6.44

-------- Tiles --------

- WMAP
- PLANCK HFI
- IRAS
- NVSS
- SCUBA
- DSS
- SDSS
- CFHTLS
- HST ACS

HiPS - standardised in IVOA



International Virtual Observatory Alliance

HiPS – Hierarchical Progressive Survey

Version 1.0

IVOA Recommendation
19th May 2017

This version:
1.0: Recommendation 2017-05-19

Previous version(s):
1.0: Proposed Recommendation 2017-04-06
1.0: Proposed Recommendation 2017-04-03
1.0: Proposed Recommendation 2017-02-07
1.0: Proposed Recommendation 2016-11-22
1.0: Working Draft 2016-06-23

Interest/Working Group:
Applications: http://www.ivoa.net/twiki/bin/view/IVOA/IvoaApplications

Editor:
Pierre Fernique

Authors:
Pierre Fernique, Mark Allen, Thomas Boch, Tom Donaldson, Daniel Durand, Ken Ebisawa, Laurent Michel, Jesus Salgado, Felix Stoehr

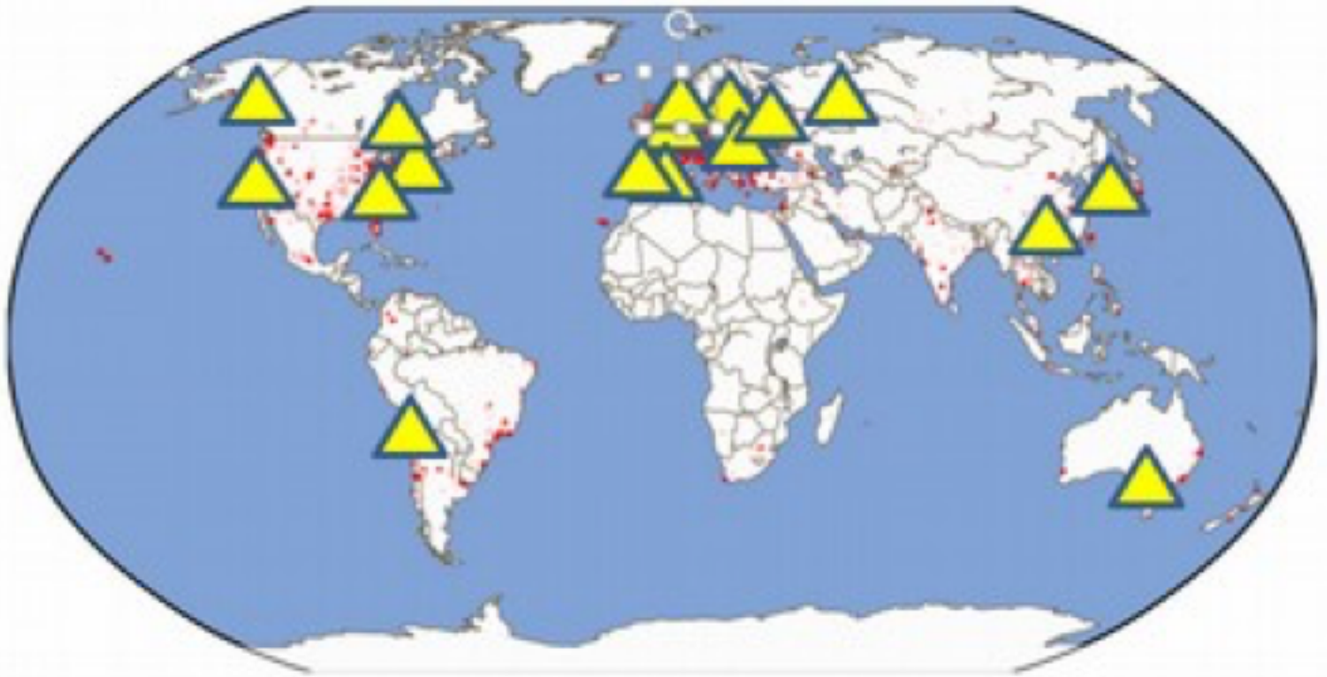
Abstract

This document presents HiPS, a hierarchical scheme for the description, storage and access of sky survey data. The system is based on hierarchical tiling of sky regions at finer and finer spatial resolution which facilitates a progressive view of a survey, and supports multi-resolution zooming and

1

HiPS Network - a life of its own!

- **20 HiPS nodes**
  - 8 new in last 6 months
- **Independent HiPS clients**
  - Aladin Desktop (JAVA)
  - Aladin Lite + derived (javascript)
  - CNES/MIZAR (javascript + WebGL)
  - Firefly/IPAC (javascript)
  - Stellarium (C), Kstars (C)
  - + 40 Aladin Lite implementations
- **Libraries:** astropy — Hipspy, MOCpy



HiPS Nodes:

Leiden, IRAP, SSC, 3xCDS, AMIGA, svo.cab, IAS, ESAC, JAXA ,IPAC, ANU, 2xCADC, HEASARC, China-VO, MPIK, PADC

Coming soon:

ESO, Stellarium AWS/S3, Chile-VO

HiPS Data in the network:

- ~500 HiPS, mirrored on average 2x in network
- 280 TB of pixels/cubes/catalogs by end of 2018

New HiPS the last months:

- PanSTARRS, SkyMAPPER, VISTA, SWIFT, DECaLS, DECaPS, DES, BASS, Gaia DR2, …

- **Usage:** about **600,000 HiPS tile queries per day** => +200,000/day in last months

Aladin Lite API example

AAS225 demonstration

SDSS DR9 band r image of APG 240 pair of galaxies, with an overlaid HST image and a WFPC2 footprint.

Javascript

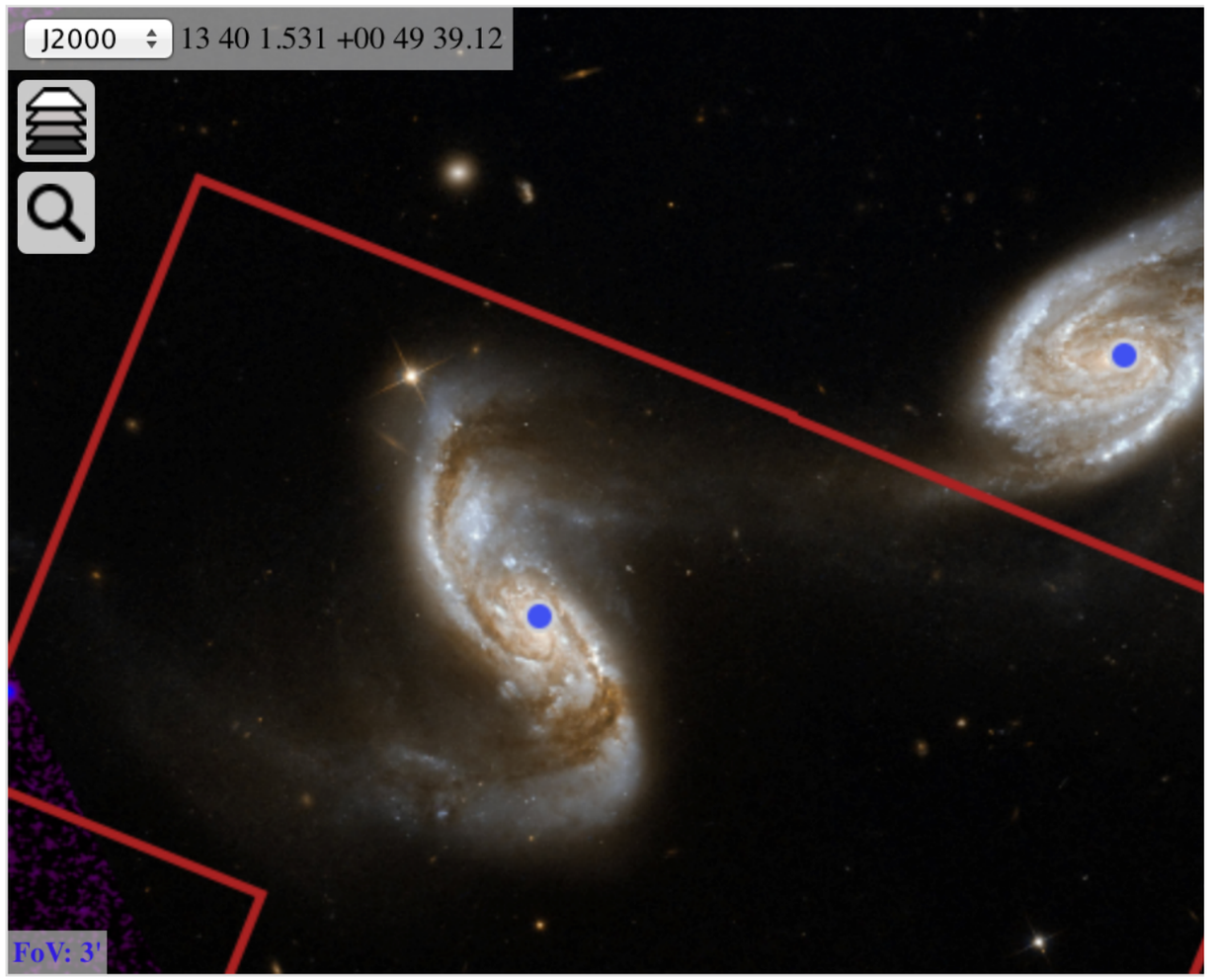
```
var aladin = A.aladin('#aladin-lite-div', {fov:0.15, tar
aladin.setBaseImageLayer(aladin.createImageSurvey('SDSS-
aladin.getBaseImageLayer().getColorMap().update('rainbow
var simbad = A.catalog({name: 'Simbad', sourceSize: 16,
aladin.addCatalog(simbad);
simbad.addSources([A.marker(204.97010833333336, 0.840016

 var overlay = A.graphicOverlay({color: '#aa2222', lineW
 aladin.addOverlay(overlay);

 overlay.addFootprints(A.polygon([[204.970214, 0.81206],

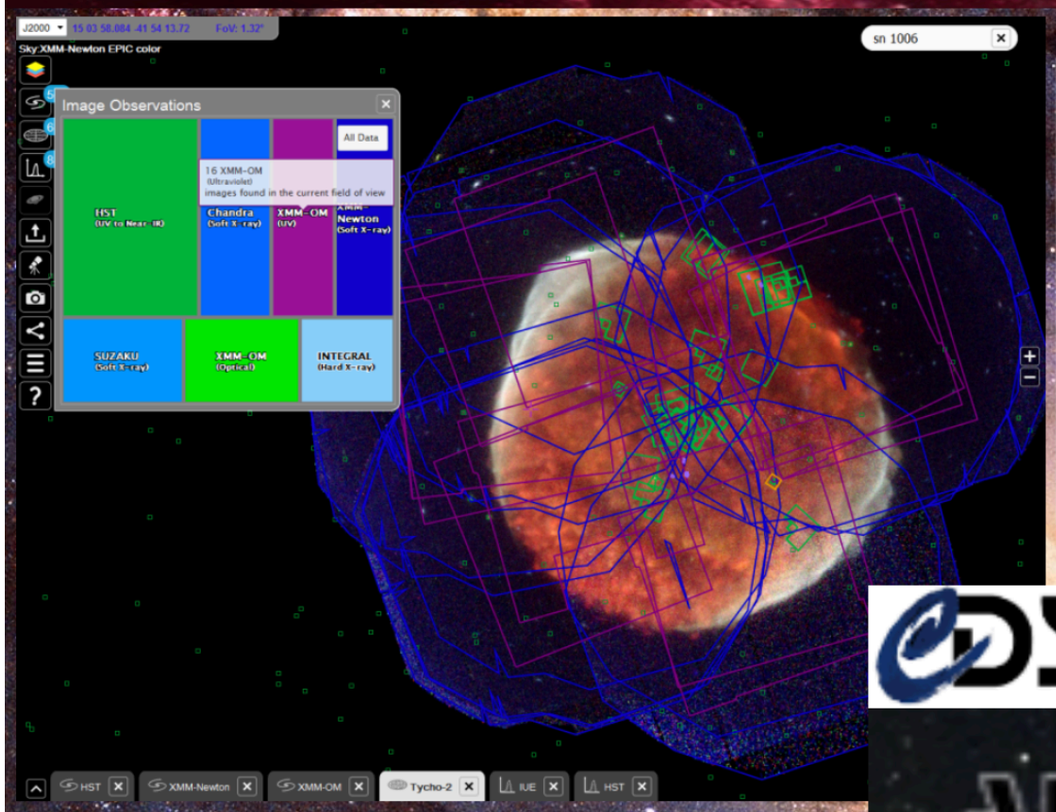
aladin.displayJPG('http://images.ipac.caltech.edu/stsci/
```

Result



Collaboration is key

http://sky.esa.int

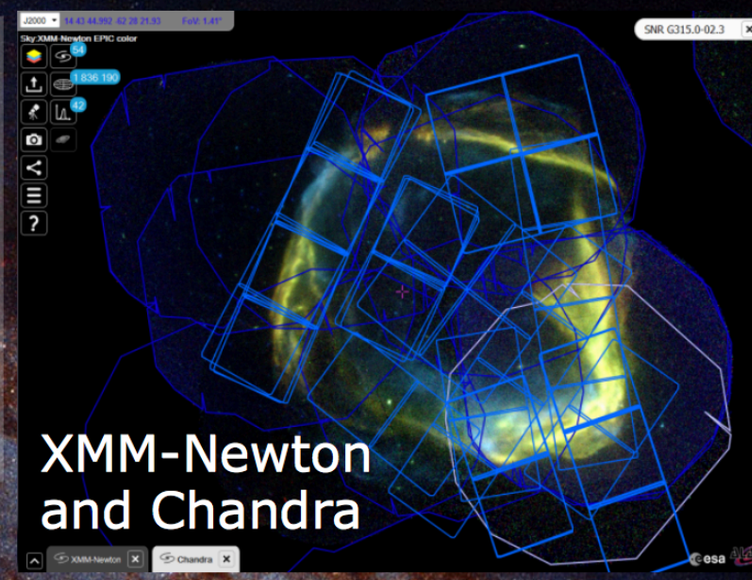


International Virtual Observatory Alliance

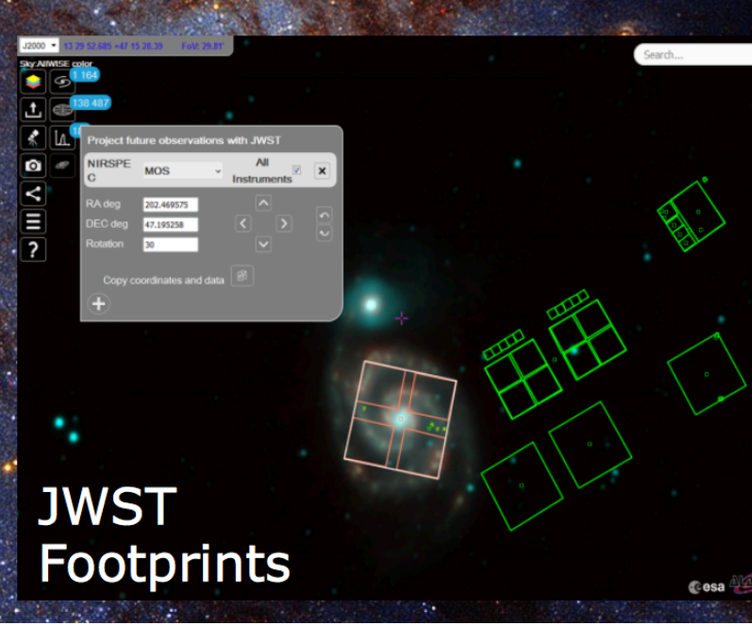
Standards: HiPS

SAMP TAP

ObsCoreDM MOC

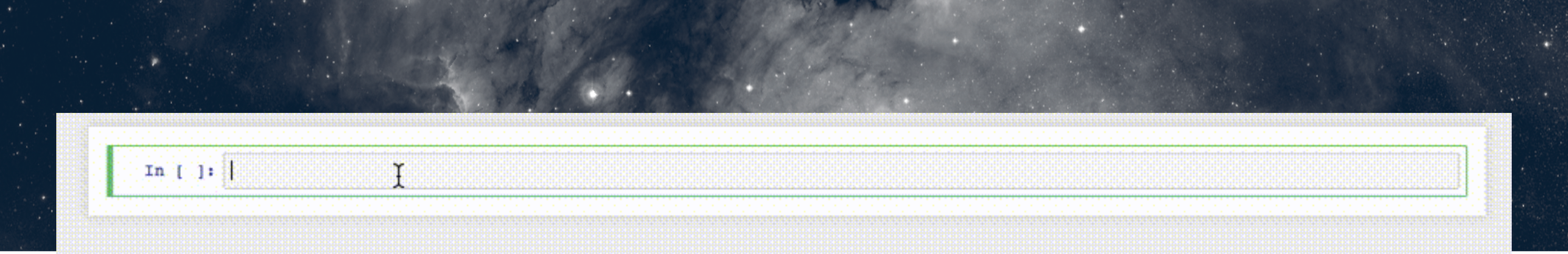


XMM-Newton and Chandra



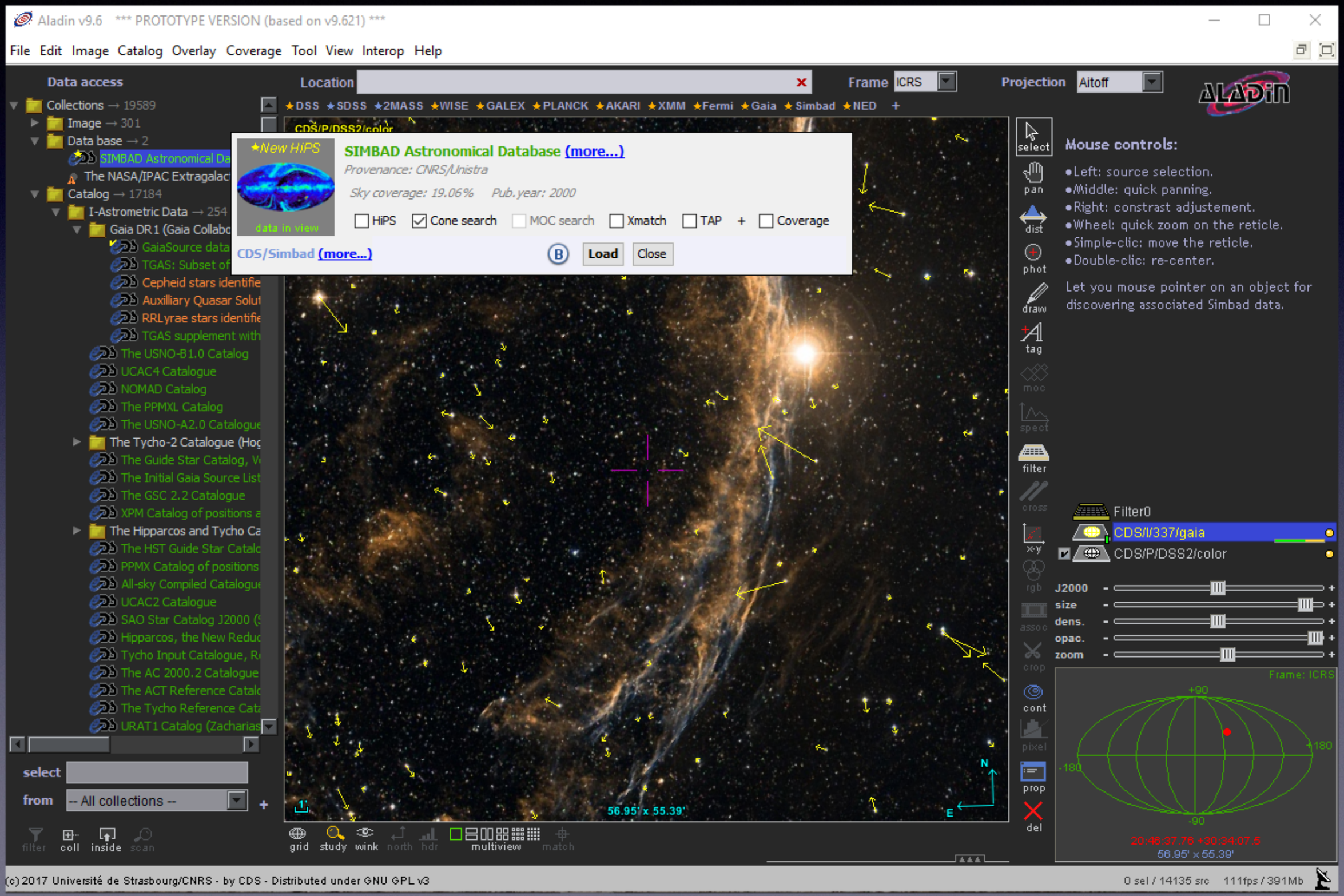
JWST Footprints

Dedicated Python module to ESASky

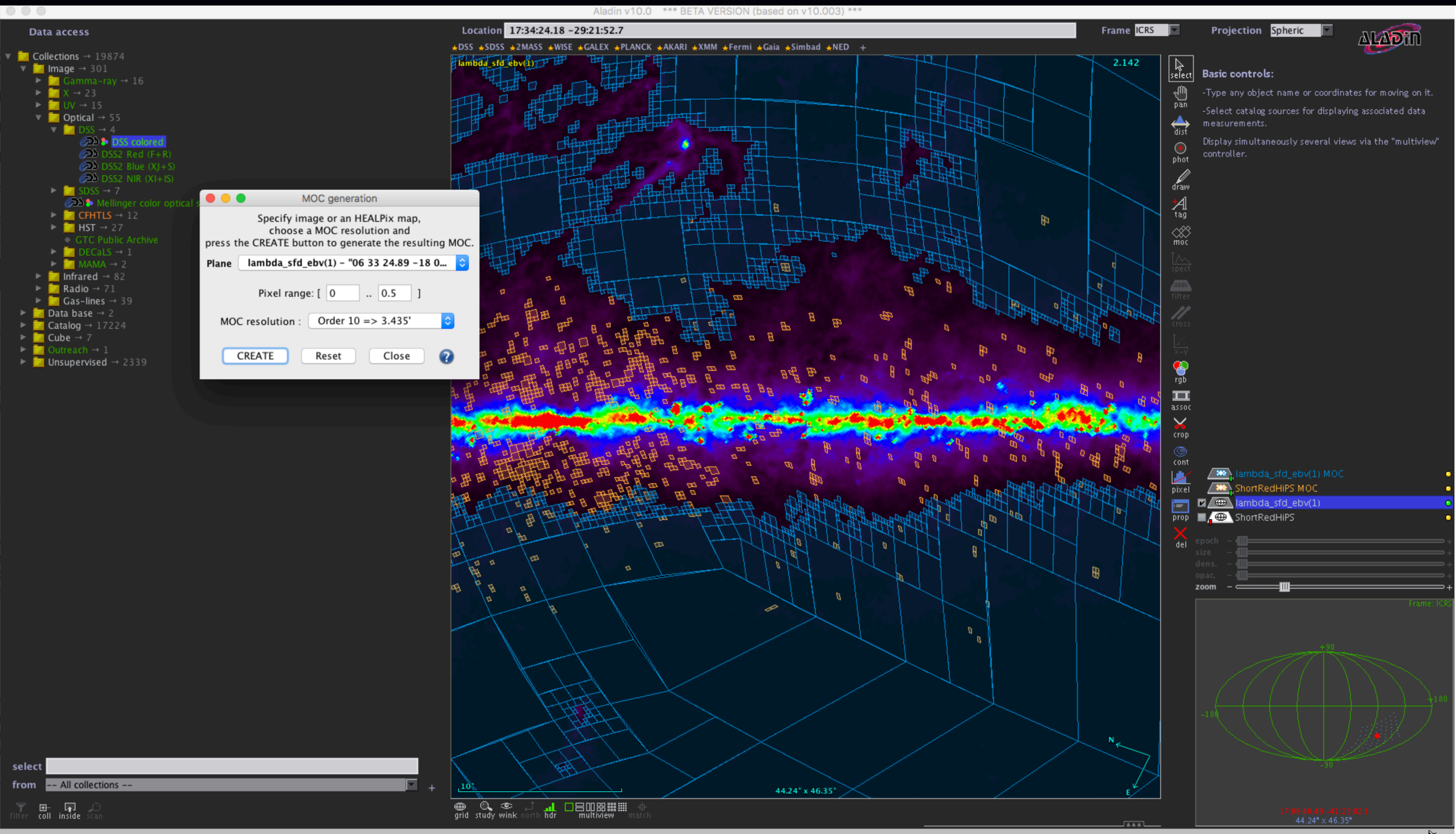


In [ ]:

Aladin Desktop

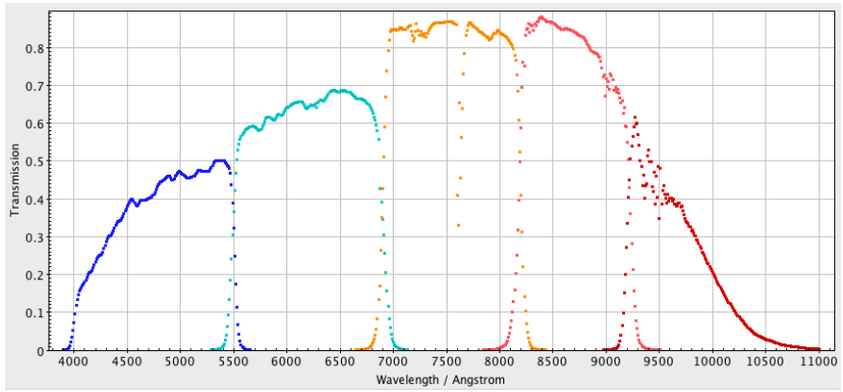


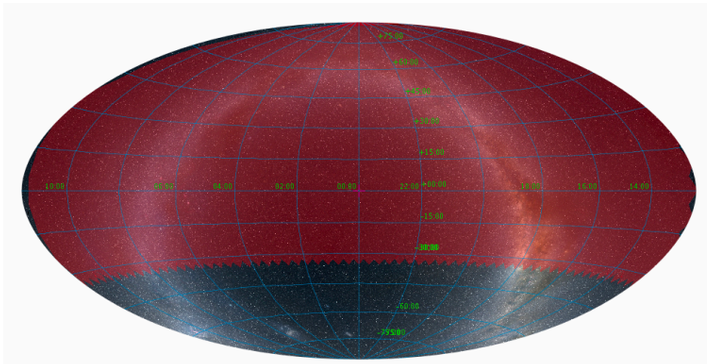
HiPS & MOC for complex catalog/image queries



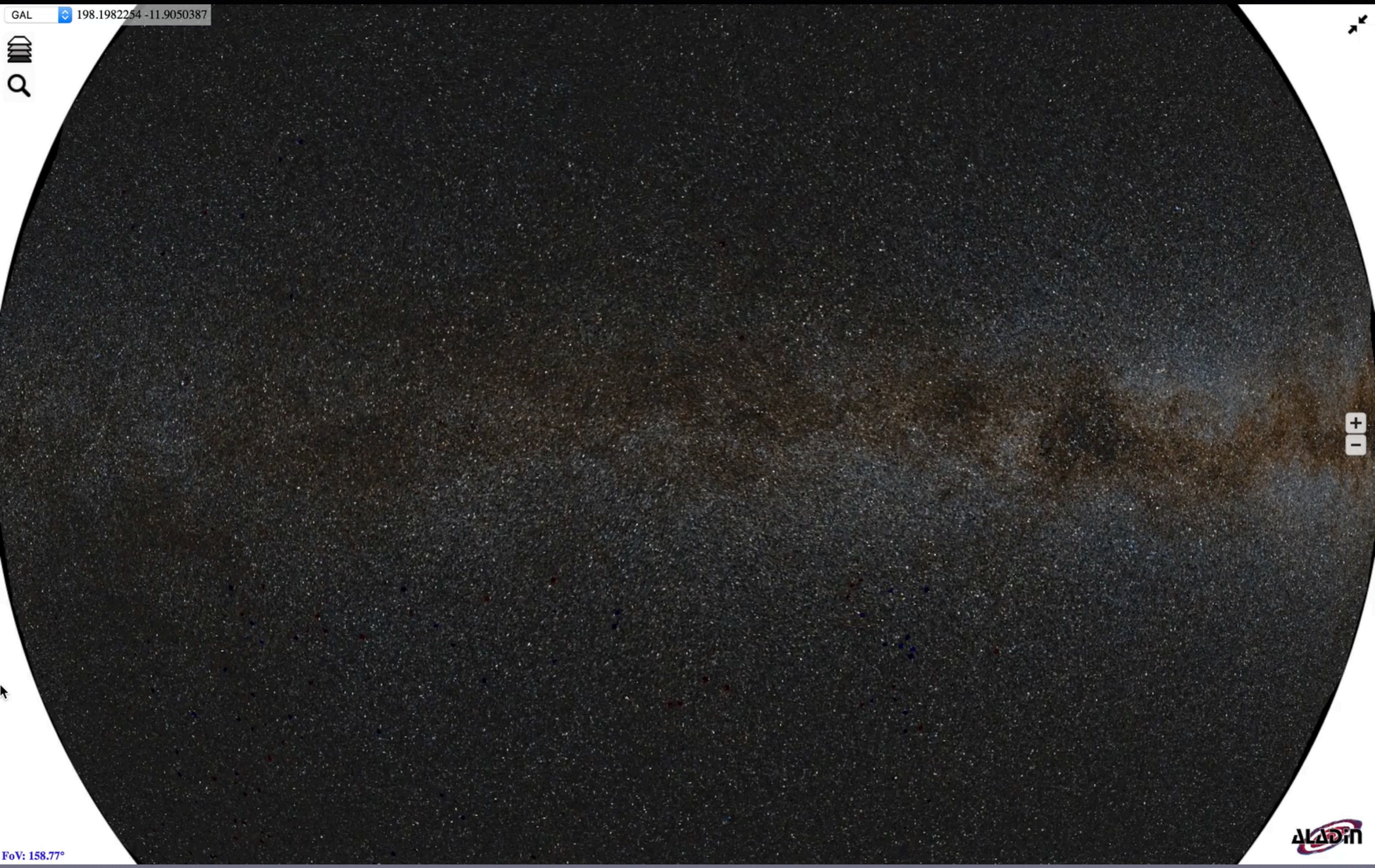
The biggest one - PanSTARRS HiPS

- Pan-STARRS PS1 images
  - 5 bands: g, r, i, z, y
  - resolution: 0.25"/pixel
  - 15 TB per band
- HiPS generation
  - resolution: 200 mas (HEALPix order 20)
  - with 512x512 tiles: 47 million tiles
  - 10 trillion pixels per band
  - FITS tiles generation (with Hipsgen) - 25 TB per band
  - JPEG tiles generation (with Hipsgen)



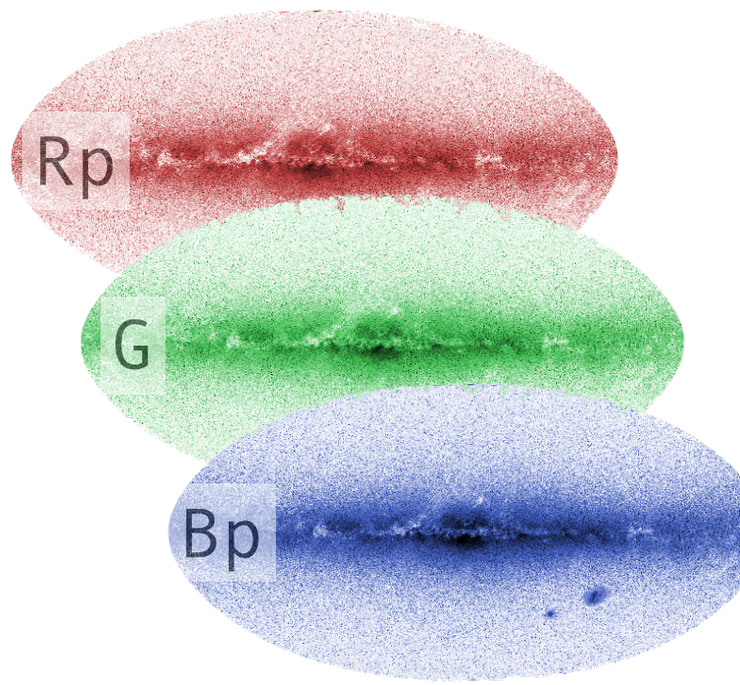


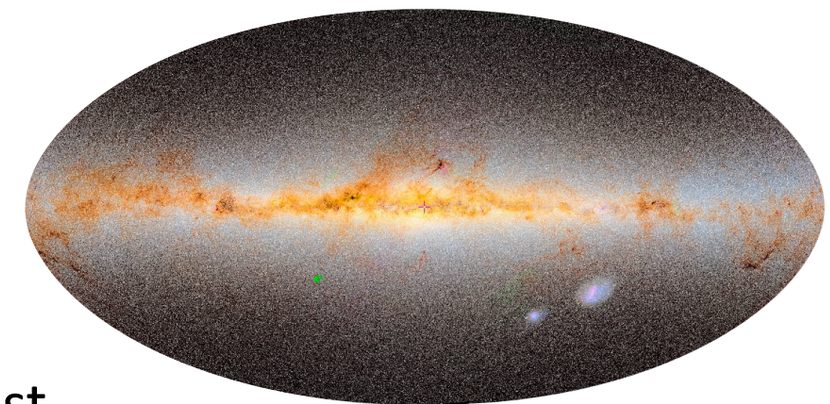
PanSTARRS - HiPS



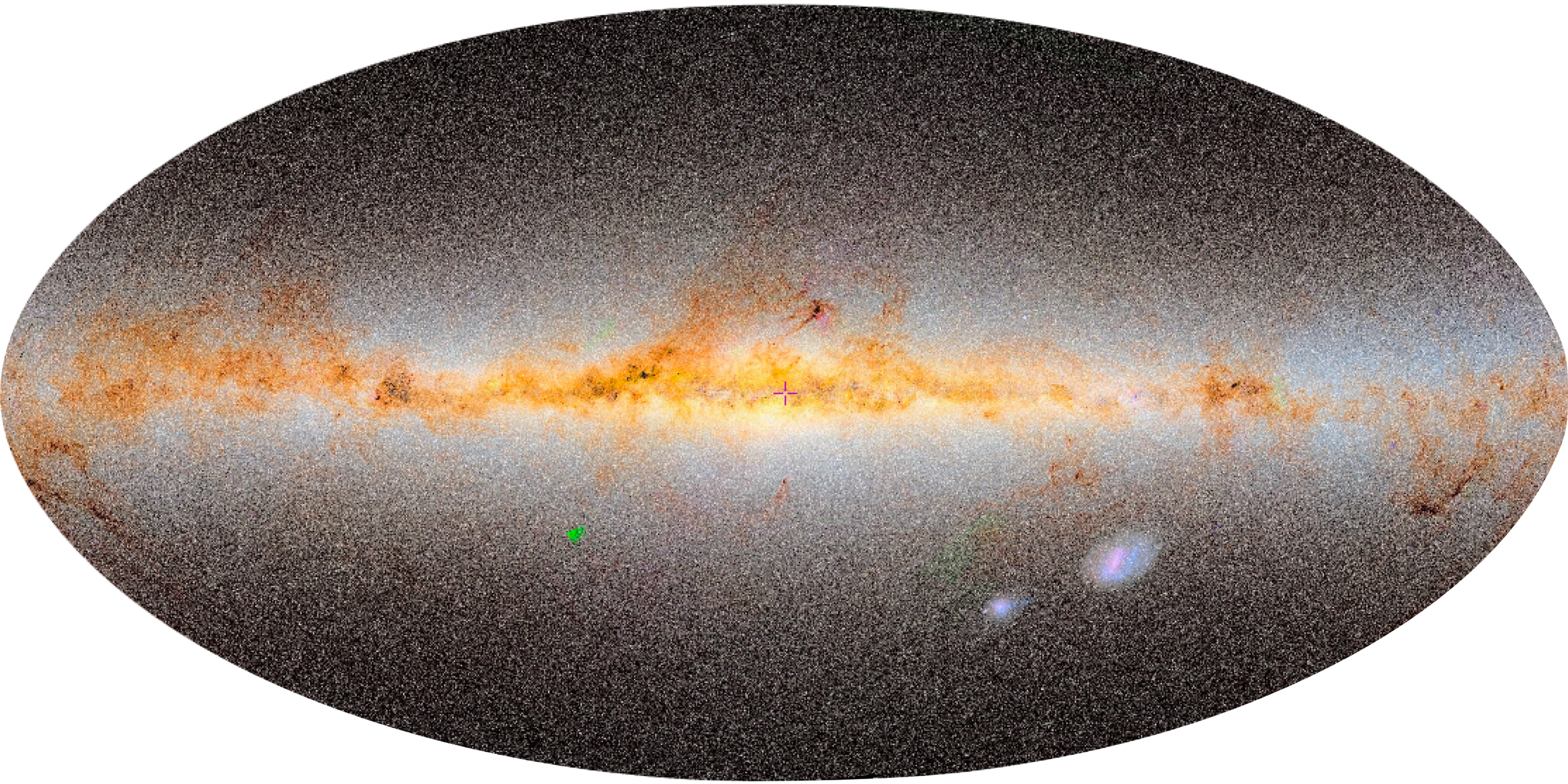
Gaia DR2 flux map

- HEALPix map for each band (integrated flux, weighted density map)
  - generated with *healpy* at `NSIDE=8192`
    - initial tests with Java unsuccessful:
      unable to create a 800 million items float array
  - map converted to HiPS with Hipsgen (order: 4)
  - alternative approach: generate individual G from TAP request
    - ```
      SELECT HEALPIX(ra, dec, 5+9) AS ipix,
      SUM(phot_g_mean_flux) as g,
      SUM(phot_bp_mean_flux) as b,
      SUM(phot_rp_mean_flux) as r
      FROM "I/345/gaia2"
      WHERE HEALPIX(ra, dec, 5)= 42
      GROUP BY ipix
      ```
  - Color tiles
    - G, Rp, Bp bands map to green, red and blue channels
    - Python script with Lupton-like stretch to maximize contrast




      ```

GAIA DR2 flux map - HiPS

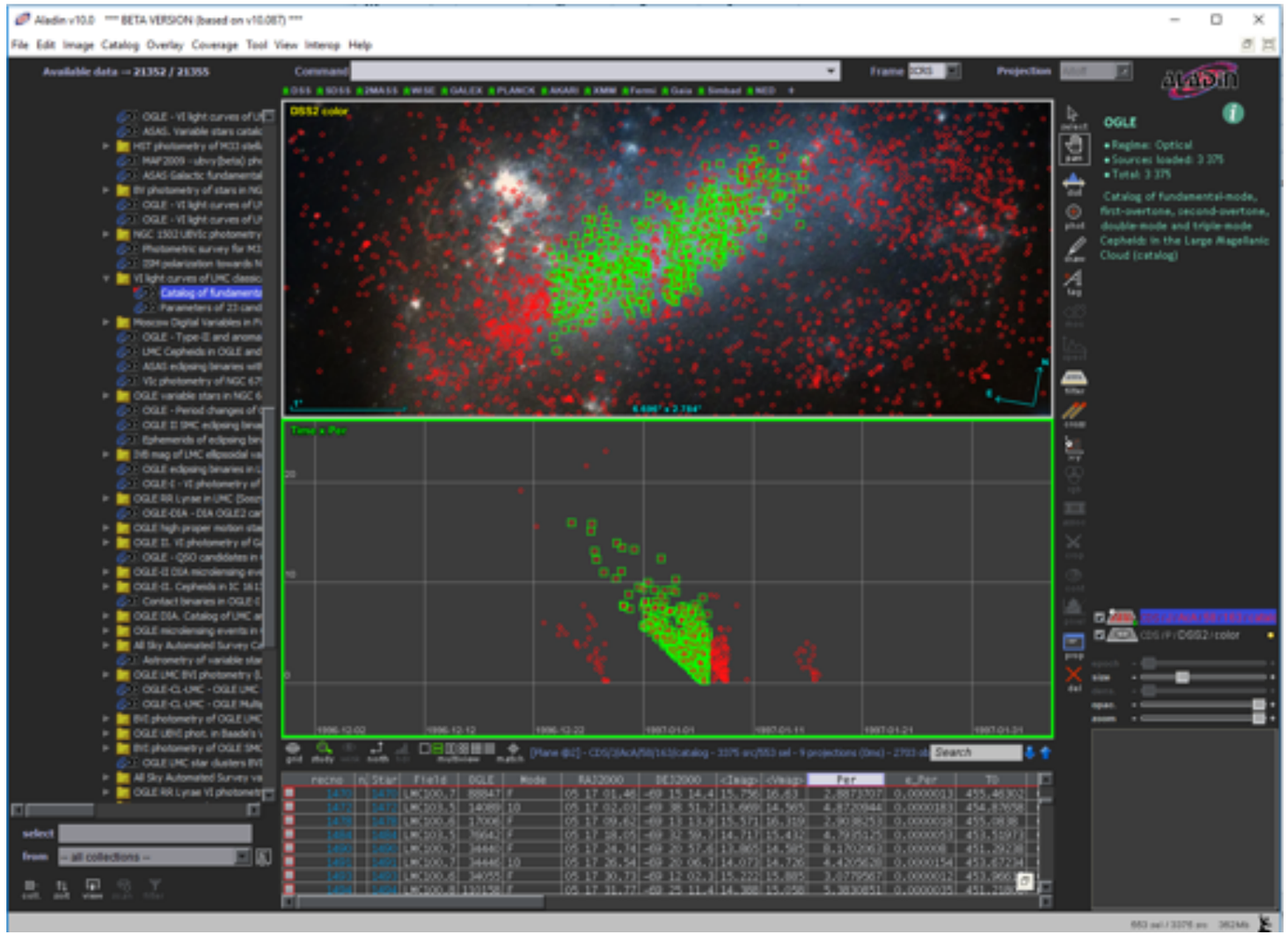


CDS Aladin - *time exercise*

- Testing use of **time metadata**
  - Query for data (across all CDS or VO resources) based on time constraints
  - Time plots - time series etc.

- Testing the potential of **temporal coverage** systems
  - For temporal coverage of observations, events, publications(?)
  - Aladin / HiPS / MOC - already very good spatial coverage
    - Tests using the same recipes for Time coverage
  - Towards a combined spatial-temporal index ??

- Detection of catalogues with time measurements
- Time view panel
- Spatial & Time view
  - plot COL vs. time
- Cross-selection of objects



- Temporal Coverage
  - T_MOC like S_MOC
  - Union / Intersection etc.
  - Works with MOC server
  - Modified MOC libraries
    - *coming to MOCpy*

Aladin v10.0 *** BETA VERSION (based on v10.087) ***

File Edit Image Catalog Overlay Coverage Tool View Interop Help

Available data → 408 / 21355

● in view ● out view

- HST → 28
  - PHAT → 6
    - HST PHAT - F275W - WFC3
    - HST PHAT - F336W - WFC3
    - HST PHAT - F475W - ACS/
    - HST PHAT - F814W - ACS/
    - HST PHAT - F110W - WFC3
    - HST PHAT - F160W - WFC3
  - GOODS → 5
    - GOODS b
    - GOODS v
    - GOODS i
    - GOODS color
    - GOODS z
  - HLA → 8
    - HLA-B : F450W, F439W, F
    - HLA-SDSSg : F475W
    - HLA-V : F555W, F547W, F
    - HLA-SDSSr : F625W and F6
    - HLA-R : F702W and F675W
    - HLA-wideV : F606W and F6
    - HLA-I : F814W, F791W, F7
    - HLA-SDSSz : F850LP
    - HST-B includes the following filt
    - HST-SDSSg incudes the followir
    - HST-V includes the following filt
    - HST-SDSSr includes the followir
    - HST-R includes the following filt
    - HST-wideV includes the followir
    - HST-I includes the following filt
    - HST-SDSSz includes the followi
    - HST-Others
- Infrared → 6 / 92
  - HST → 6
    - HLA → 3
      - HLA-J : F140W, F125W, F

select HST

from -- all collections --

coll. sort view scan filter

Command | Frame ICRS | Projection Aitoff

DSS SDSS 2MASS WISE GALEX PLANCK AKARI XMM Fermi Gaia Simbad NED +

DSS2 color

53.04' x 29.21'

N E

Time graph

10-09 1998-07-05 2001-03-31 2003-12-26 2006-09-21 2009-06-17 2012-03-13

HST-B includes the following filters: F450W, F439W, F438W,... ...

Provenance: Canadian Astronomy Data Centre

Coverage: 9.059°² 3.7µm/81THz .. 5.2µm/57.7THz 1994-01-25 .. 2017-03-05 Res: 50.29mas

Access mode & derived prod. progressive + space cov. time cov. Links to orig.img.

Image data in view

CDS/P/HST/B Load

select pan dist phot draw tag moc spect filter cross xy rgb assoc crop cont pixel prop del

TMoc_CDS/P/HST/R
TMoc_CDS/P/HST/SDSS
TMoc_CDS/P/HST/V
TMoc_CDS/P/HST/SDSS
TMoc_CDS/P/HST/B
CDS/P/HST/B
CDS/P/DSS2/color

epoch size dens. opac. zoom

M31

+90 +180 180 -90

00:42:44.33 +41:16:07.5

53.04' x 29.21'

grid study wink north hdr multiview match [Plane @4] - TMoc_CDS/P/HST/SDSSg - drawn in 0ms[CanBeTransp, Vi

0 sel / 0 src 420Mb

Summary

- HiPS network is growing fast, and is heavily used
- MOC is being deployed for many uses
- Together HiPS and MOC enable new types of queries
- Libraries and tools are available
- Scalable for large data - e.g. PanSTARRS, GAIA

Extra Slides

Links

- Hierarchical Progressive Surveys (HiPS)
- Fernique et al. 2015, A&A 578, 114
- HiPS on CDS web pages: http://aladin.u-strasbg.fr/hips
- Aladin http://aladin.u-strasbg.fr/AladinDesktop/
- Aladin Lite http://aladin.u-strasbg.fr/AladinLite/
- HiPS generation tools: http://aladin.u-strasbg.fr/hips/#tools

CDS X-Match: HSC wide vs. Gaia DR2

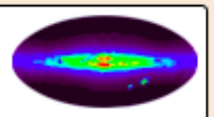
Choose tables to cross-match

HSC_PDR1_WIDE **VizieR** SIMBAD My store

HSC_PDR1_WIDE
52,658,163 rows

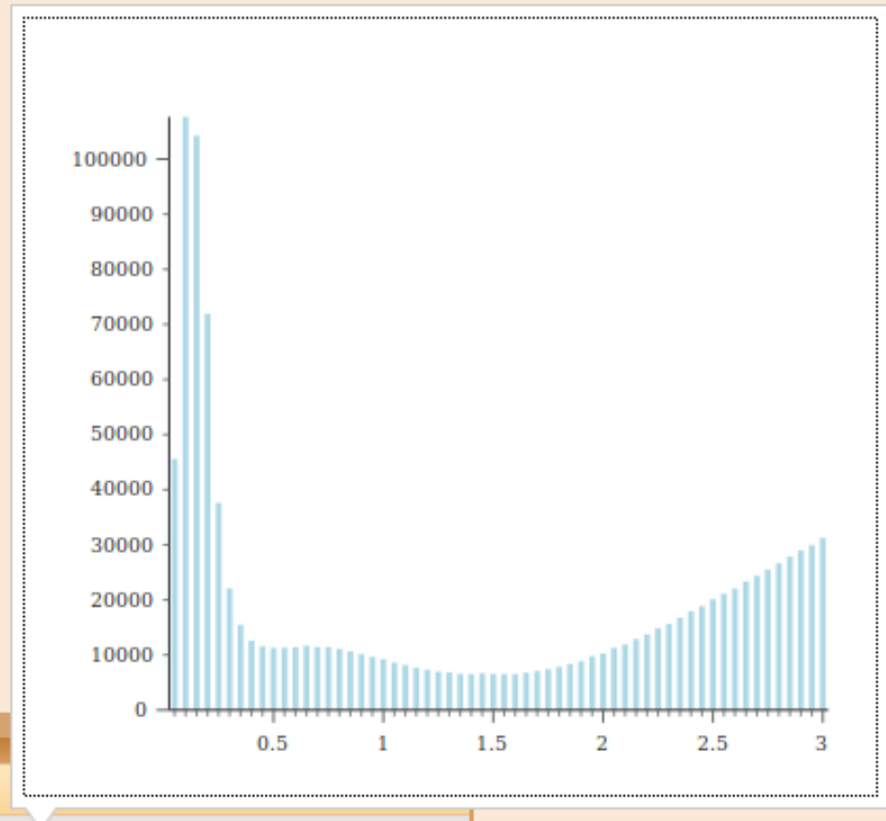
Gaia DR2 **VizieR** SIMBAD My store

Gaia DR2 (Gaia Collaboration, 2018)
1,692,919,135 rows



Show options

Begin the X-Match



Visualize and manage your cross-match jobs

List of X-match jobs

Table 1	Table 2	Options	Begin	Status
HSC_PDR1_WIDE	Gaia DR2	fixed radius	08/06/2018 at 17:09	completed
HSC_PDR1_WIDE	Gaia DR2	fixed radius	08/06/2018 at 15:26	completed
HSC_PDR1_DEEP	Gaia DR2	fixed radius	08/06/2018 at 15:26	completed
HSC_PDR1_UDEEP	Gaia DR2	fixed radius	08/06/2018 at 15:26	completed

Get result

Job executed in **30s**
20s to correlate
10s to generate file
Result: **1,097,461** rows (390MB)

For the selected job(s): Delete

MOCPy

- **Python** library to handle **spatial MOCs**
  - creation of MOCs
  - operations: intersection, union, …
  - retrieval of VizieR tables MOC
  - filter a table to keep sources inside MOC
  - query a VizieR table by MOC
  - visualisation

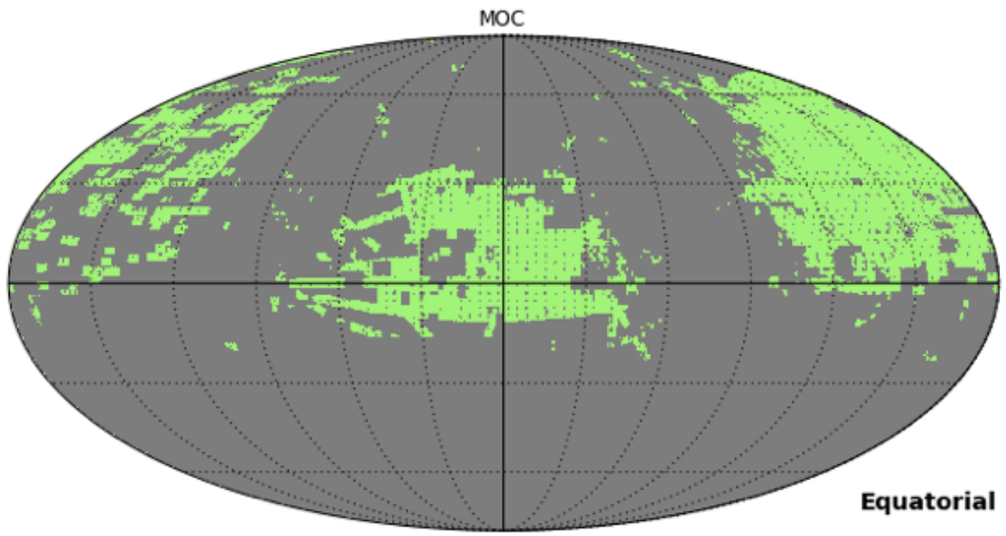
- See wiki.ivoa.net/internal/IVOA/InterOpJune2015Apps/MOCPy.pdf for details

```
In [1]: from mocpy import MOC

In [2]: m1 = MOC.from_vizier_table('II/313/table3', nside=512)

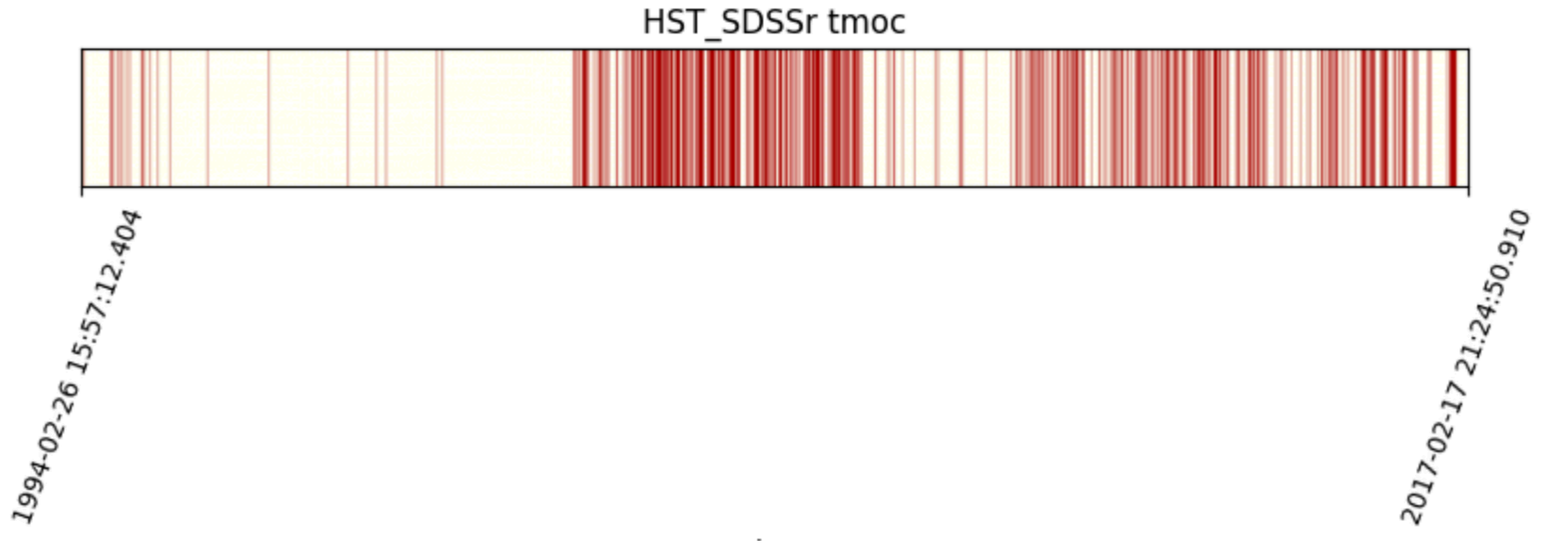
In [3]: m2 = MOC.from_vizier_table('V/139/sdss9', nside=512)

In [4]: m1.intersection(m2).plot()
0.0 180.0 -180.0 180.0
The interval between parallels is 30 deg -0.00'.
The interval between meridians is 30 deg -0.00'.
```



Demonstration

- Notebook
  - read HST band SDSSr T-MOC
  - create a T-MOC from a table with time column
  - filter table
  - intersection of TMOCs



Links

- Github project
  github.com/cds-astro/mocpy

- Notebook
  mybinder.org/v2/gh/cds-astro/mocpy/tmoc?filepath=notebooks%2Ftmoc_example.ipynb