News from MOC Lib Rust, MOCPy and other derivatives

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MOC: an IVOA standard

- MOC = Multi Order Coverage Map
- IVOA standard (see P. Fernique's talk)
- **v1.0**: **discretized sky regions** description
  - HEALPix based
- **v2.0**: add **Time** and **Space-Time**
  - time: discretized quantity (microsec since $JD = 0$)
  - **uniform precision** (int64; microsec)
- **vx.x**: add **Frequency** (and Space-Frequency, ...)
  - frequency: continuous quantity
  - **relative precision** (float64; Hz)
- Main interests:
  - fixed systems (ICRS/TCB/Hz): **easy comparison**
  - describe **any region** (possibly complex)
  - **fast** operations (union/intersection/contains/...)

MOC Lib Rust

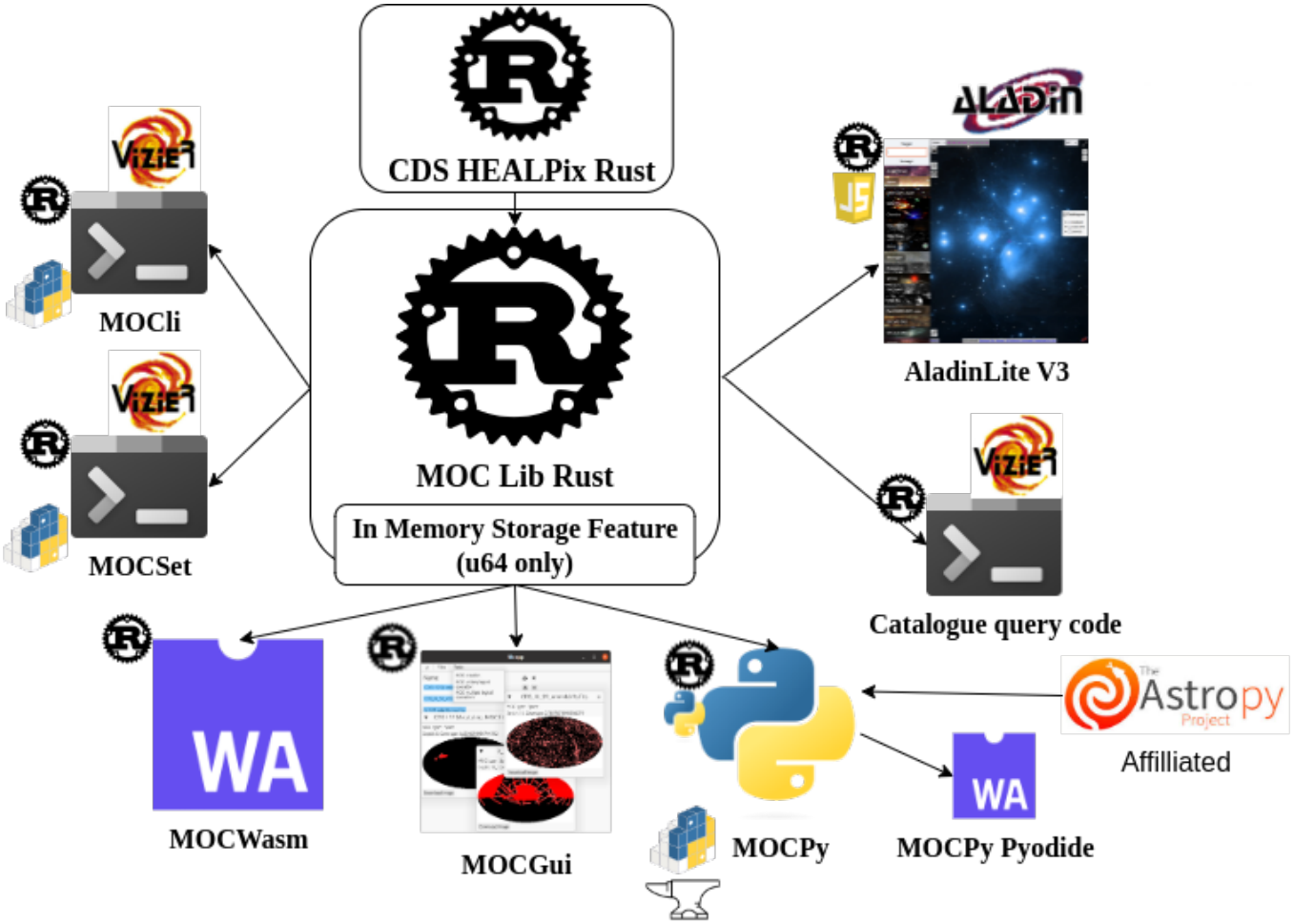


Figure 1: MOC Lib Rust ecosystem, see IVOA April 2022 slides

MOC Lib Rust functionalities

- Serialize/deserialize S/T/**F**/ST-MOCs
  - ASCII, JSON, (gzipped) FITS
- Build S-MOCs from:
  - cone, elliptical cone, box, zone, polygon, ring
  - list of positions, list of large/small cones
  - multi-order map, skymap
- Build T-MOCs, **F-MOCs**, ST-MOCs
- Logical operations (both standard and lazy):
  - complement, intersection, union, sym. diff, minus
  - multi union and intersection
  - lazy = operations on iterators => streaming mode
  - generic: same code for Space u32 or **Frequency** u64
- Other S-MOC operations
  - degrade, extend, contract, external/internal border
  - **split** into disjoint MOCs, **fill holes**, **find barycenter**, ...
- **S-MOC visualization**

New storage

- Before
  - MOCPy: **heterogeneous solutions** (historical reasons)
    - MOC, T-MOC: data (ranges) stored on Python side
    - ST-MOC: data stores on Rust side
  - MOCWasm: **MOC** data stored in WASM, **accessed by name**
  - MOCGui: **large duplication** of MOCWasm code
- Now
  - **One generic storage (u64) in MOC Lib Rust**
    - R/W protected slab
  - **Same storage used in MOCPy, MOCWasm and MOCGui**
    - MOC objects (Python or JS) only store a **slab** index
    - remove duplicate code (DRY principle)
    - smaller and more uniform Python and JS/WASM wrappers

MOCPy v0.12

- **Python library** to load, parse and manipulate MOCs
  - M. Baumann, T. Boch, F.-X. Pineau, M. Marchand
- Based on PyO3, available in both pypi and conda-forge
- Rust and Python code **completely restructured from v0.12**
  - **breaking changes** introduced (we do have users :))
    - use the MOC Lib Rust storage feature
    - fix MOC pre v2.0 / v2.0 inconsistencies
  - less Python code (`contains`, ...)

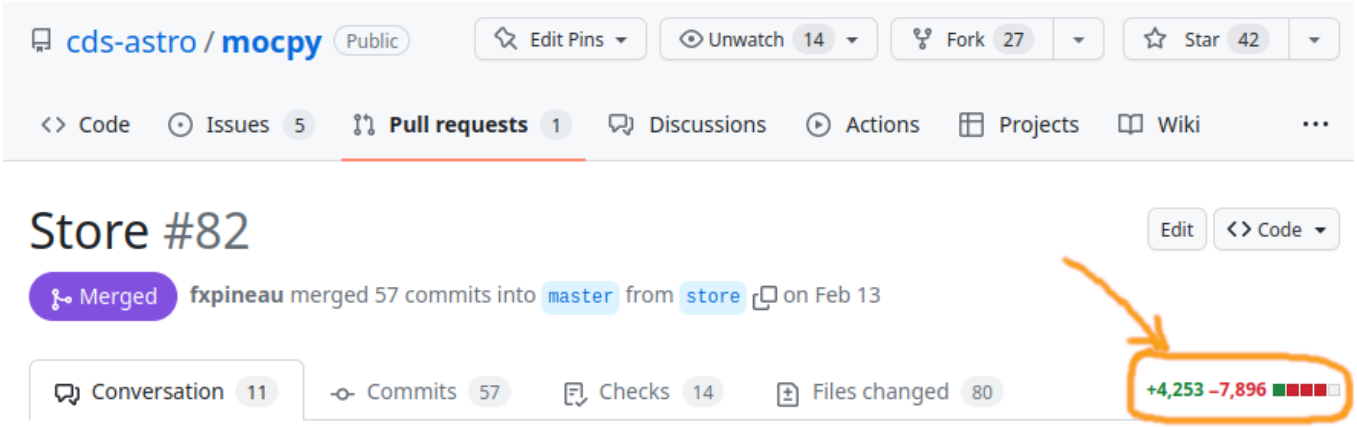
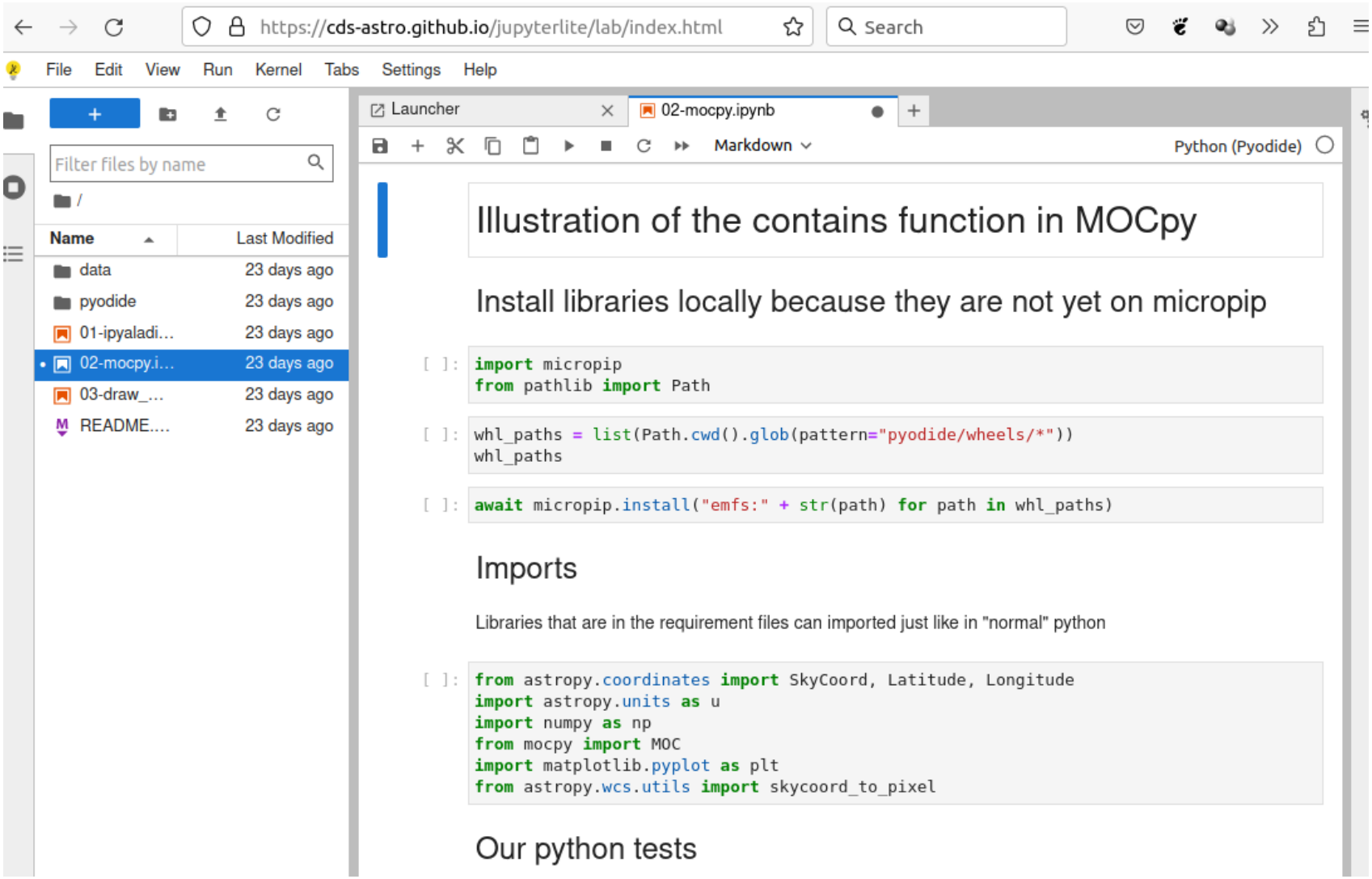


Figure 2: Large refactoring for MOCPy v0.12

MOCPy v0.12

- **Improvements: doc + quality checks (Manon Marchand)**
  - `git pre-commit`
    - Black: check code style
    - Ruff: Python linter (in Rust ;))
    - nbQA: notebook quality assurance to check notebooks
  - docsting improved following:
    - PEP 257
    - some of the numpy rules
- Experiments to run **MOCPy in web browser** (M. Marchand)
  - Jupyter Lite, REPL, Retrolab
    - plugged in Pyodide (WebAssembly port of CPython)
  - Need MOCPy Emscripten wheels to run in Pyodide
  - Try it! cds-astro.github.io/jupyterlite/lab/index.html
  - Pros
    - nothing to install locally
    - do not depends on server resources
    - multi-mode: keep client notebook, reset, live collaboration
  - Cons: not "code near data", local resources

MOCPy v0.12.3 in JupyterLite



MOCWasm v0.7

- **MOC library in JS/WebAssembly for your web apps**
  - dual-licensing **MIT**/Apache-2.0 (GPLv2-compatible)
  - **100% Rust**, uses wasm-bindgen
- Sub-project in moc-lib-rust: see `crates/wasm`
- Available in github release section
  - moc-wasm-v0.7.0.tar.gz
  - main files: `moc.js`, calling `moc_bg.wasm` (~800 KB)
- **New**: published on npm: `@fxpineau/moc-wasm`
  - WARNING: not tested (feedback welcome)!
- **Breaking changes from v0.6 to v0.7**
  - Large code refactoring
    - use MOC Lib Rust storage
  - **Now resort on** (T/F/ST)**MOC JavaScript objects**
    - v0.6: `fromCone(name, depth, lon, lat, r)`
    - v0.7: `let mymoc = MOC.fromCone(depth, lon, lat, r)`
- **Try it!** (from your Web Browser console)
  - `http://cdsxmatch.u-strasbg.fr/lab/mocwasm/`

MOCWasm v0.7

Filter Output | Errors | Warnings | Logs | Info | Debug | CSS

```
// Load 2MASS and SDSS DR12 MOCs from CDS
let moc2mass = await moc.MOC.fromFitsUrl('http://alasky.u-strasbg.fr/footprints/tables/vizier/II_246_out/MOC');
console.log("2MASS MOC depth: " + moc2mass.getDepth());
console.log("2MASS MOC coverage: " + moc2mass.coveragePercentage() + "%");
let mocsdss = await moc.MOC.fromFitsUrl('http://alasky.u-strasbg.fr/footprints/tables/vizier/V_147_sdss12/MOC');
console.log("SDSS DR12 MOC depth: " + mocsdss.getDepth());
console.log("SDSS DR12 MOC coverage: " + mocsdss.coveragePercentage() + "%");
```

```
2MASS MOC depth: 9
2MASS MOC coverage: 99.99980926513672%
SDSS DR12 MOC depth: 7
SDSS DR12 MOC coverage: 38.7420654296875%
← undefined
```

```
// Performs MOC intersection
let tmass_inter_sdss12 = moc2mass.and(mocsdss);
```

```
← undefined
```

```
// Print the ASCII and JSON serializations of '2mass_inter_sdss12_d2'
console.log(tmass_inter_sdss12.toAscii());
```

```
▶ 1/5 8 10 27 2/16-17 19 25 28 36 38 70 73-78 103 107 3/10 32 34 72-73 75 97 116 150 176-178 184 197 208 271
275-278 284 286-287 291 316-318 341 405-407 411 421 423 427 491 494-495 506 4/0 2 34 46-47 106 123 132-134 140 160
162-163 166 176 296-297 299 385 396-397 399 468-469 472 592 594-595 624 626 629 631-632 634 639 716 718 720 722 740
744 746 768-769 771-774 785 787 797 799 836-838 840-841 848 1078-1079 1083 1095 1099 1116-1118 1140 1142-1143 1159
1163 1276-1277 1369 1372-1373 1375 1397 1399 1431 1635 1637-1639 1641-1643 1689-1691 1701-1703 1705-1707 1877 1958
1961-1963 2018 2030-2031 2042 2299 2302 3063 5/5-7 12 27 30-32 69 71 76-78 85-88 97 99 104 106 131 140 142-143 149
151 154-156 158 177-181 183 205 207 227-228 230-231 233-234 249 252-253 256-258 260-262 264-265 267-268 292 295
312-313 391 396-398 417 419-420 422 428-429 440-441 444-445 488-489 504-505 508-509 540-542 568-569 574 576 599
605-607 627-629 644 661 668-669 672-673 676 708-709 712 723 726-727 768 770 776 898-899 909 9…
```

MOCWasm use case

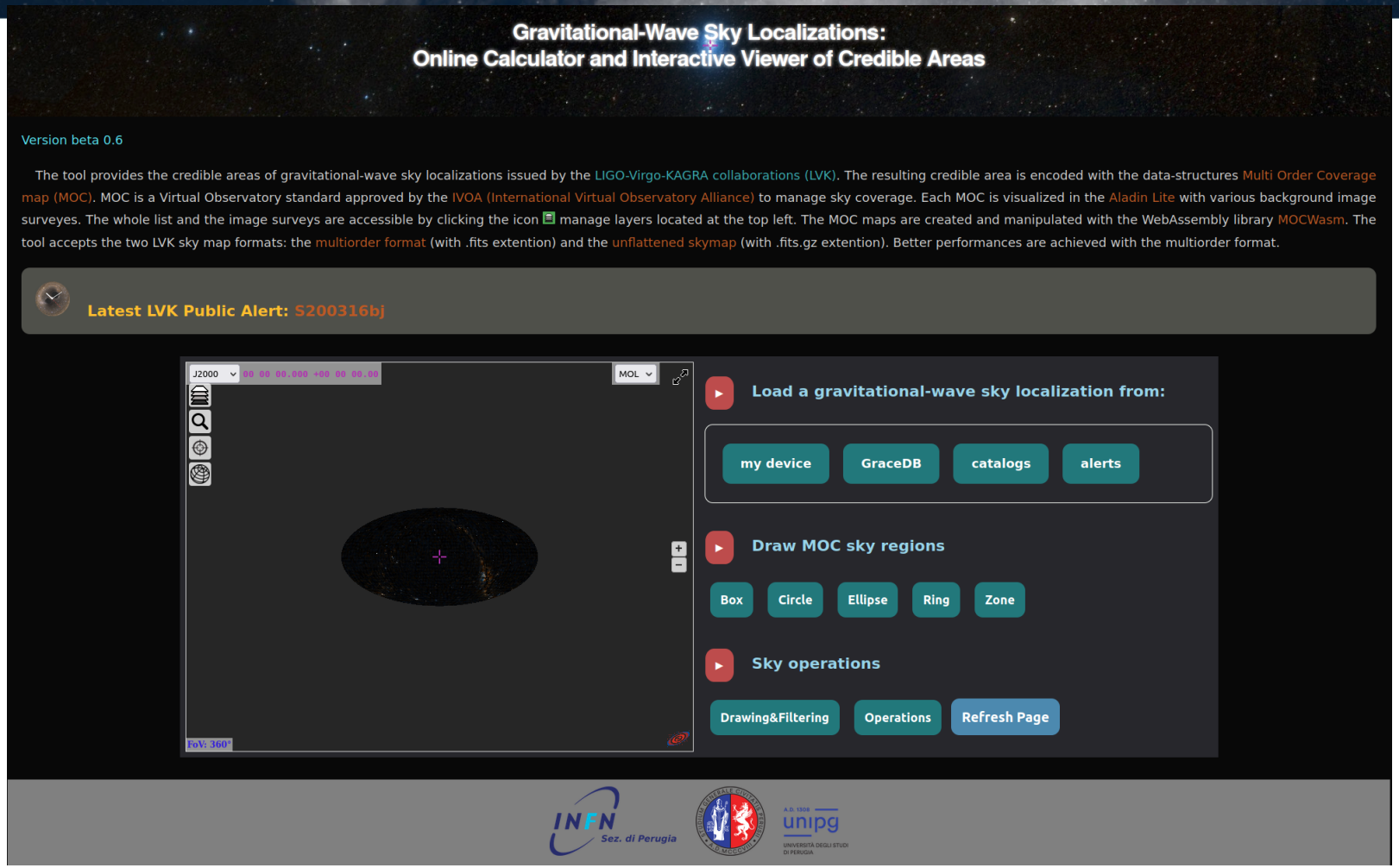


Figure 3: Web page https://virgo.pg.infn.it/maps/index.html by Giuseppe Greco; Mateusz Bawaj; Roberto De Pietri

MOCGui v0.1.0-alpha

- T. Dumortier, supervised by F.-X. Pineau and M. Baumann
- Purpose: provide a **simple GUI to manipulate MOCs**
  - **both native** (to be distributed/installed)
  - and in **web browsers** (in wasm; simple URL)
- Based on egui: simple immediate mode GUI library

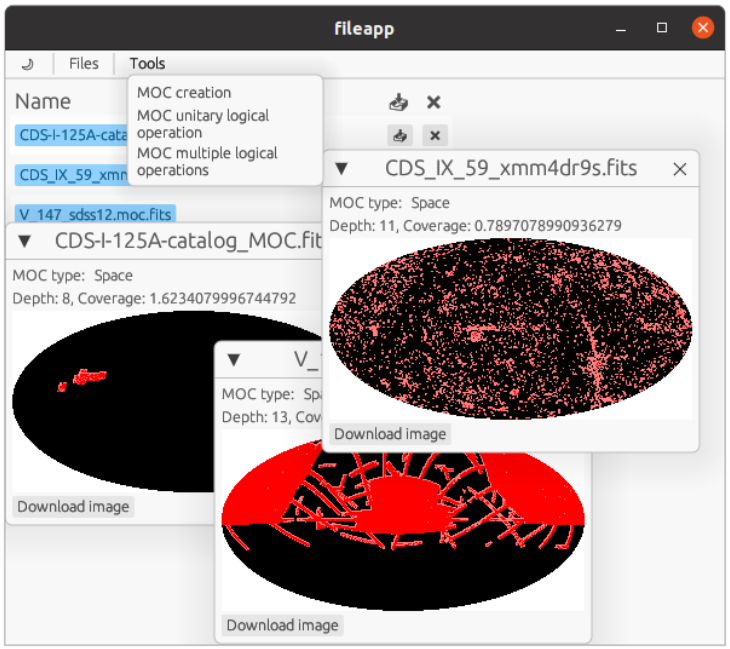


Figure 4: Native GUI on Ubuntu

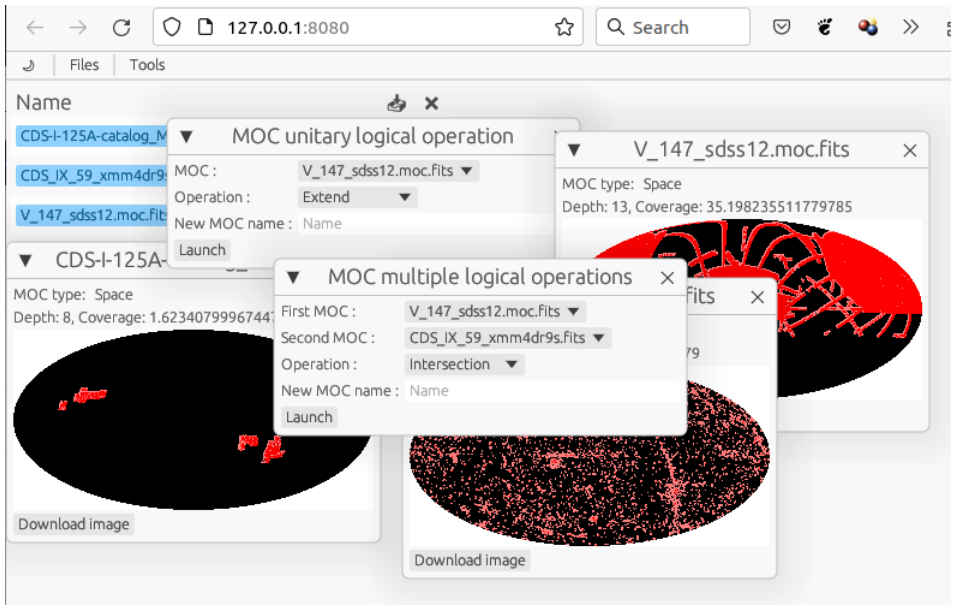


Figure 5: WASM GUI in Firefox

MOCCli and MOCSet

- 2 **command line tools** (scriptable, only 1 binary each)
  - MOCCli: manipulate MOCs
  - MOCSet: build, update and query a set of MOCs from the disk
- Distribution
  - pre-compiled binaries and .deb packages in github releases
  - **New!** available on pypi
    - `https://pypi.org/project/moc-cli/`
    - `https://pypi.org/project/moc-set/`

```
pineau@cds-dev-fxp:~$ moc
moc 0.6.0
Create, manipulate and filter files using HEALPix Multi-Order Coverage maps (MOCs).

See the man page for more information.

USAGE:
    moc <SUBCOMMAND>

FLAGS:
    -h, --help       Prints help information
    -V, --version    Prints version information

SUBCOMMANDS:
    convert    Converts an input format to the (most recent versions of) an output format
    filter     Filter file rows using a MOC
    from       Create a MOC from given parameters
    help       Prints this message or the help of the given subcommand(s)
    hprint     Print a MOC to a human readable form
    info       Prints information on the given MOC
    op         Perform operations on MOCs
    table      Prints MOC constants
    view       Save a PNG of a S-MOC and visualize it
```

```
pineau@cds-dev-fxp:~$ mocset
moc-set 0.5.0
F.-X. Pineau <francois-xavier.pineau@astro.unistra.fr>
mocset is a command-line tool to build, update and query a persistent set of
Multi-Order Coverages maps (MOCs), see https://ivoa.net/documents/MOC/.

USAGE:
    mocset <SUBCOMMAND>

OPTIONS:
    -h, --help       Print help information
    -V, --version    Print version information

SUBCOMMANDS:
    append       Append the given MOCs to an existing mocset
    chgstatus    Change the status flag of the given MOCs identifiers (valid, deprecated,
                 removed)
    extract      Extracts a MOC from the given moc-set
    help         Print this message or the help of the given subcommand(s)
    list         Provide the list of the MOCs in the mocset and the associated flags
    make         Make a new mocset
    purge        Purge the mocset removing physically the MOCs flagged as 'removed'
    query        Query the mocset
```

VizieR indexation by MOC

- MOCs of all VizieR catalogues
  - computed by MOCCli: from coos, union of tables, ...
  - put in a MOCSet
- New service (by Alicia Flint and Gilles Landais)
  - Python **CGI** on top of MOCCli and MOCSet
  - base URL: `https://cdsarc.cds.unistra.fr/viz-bin/moc`
  - get a MOC
    - **MOC of V/146**: base URL/V/146?order=9&format=ascii
  - or a **list of MOCs**
    - **more recent than** 2023-05-04: base URL?date=2022-10-0
    - **by cone**: base URL?ra=2&dec=2&sr=0.01&format=html

Catalog name	MOC file	Date modified
B/assocdata	cat_102036.moc.fits	2023-02-03
B/avo.rad	cat_102013.moc.fits	2022-09-27
B/bax	cat_102017.moc.fits	2022-09-27

VizieR indexation by MOC

New way to pre-filter VizieR global queries (26K tables).

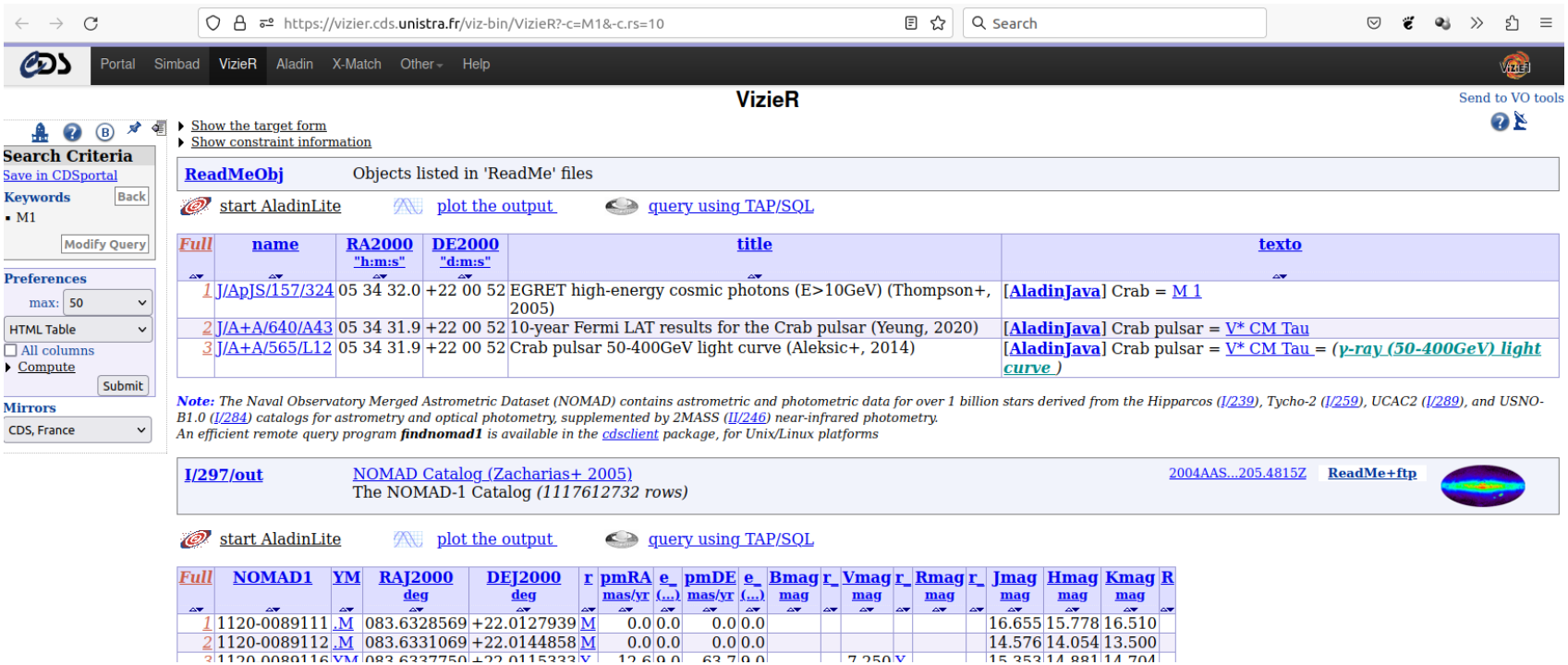


Figure 6: Look for all sources in VizieR at 10 arcsec around M1

MOCSet/Py in AMORA

AMORA: **A**synchronous **M**ulti **O**bservation **R**egion-based **A**nalysis

- Purpose: run XMM reduction tasks on regions drawn by the user on Aladin Lite
  - MOCSet use to select observations matching the region
    - 3 x 14 000 Obs
    - by cone
    - by polygon
  - (+ SQL lite to store obs. metadata)

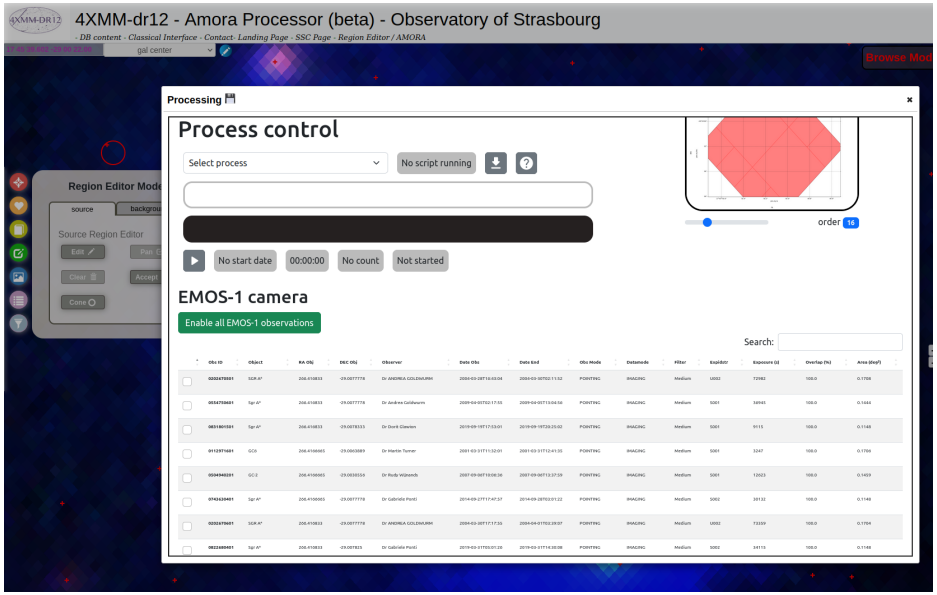
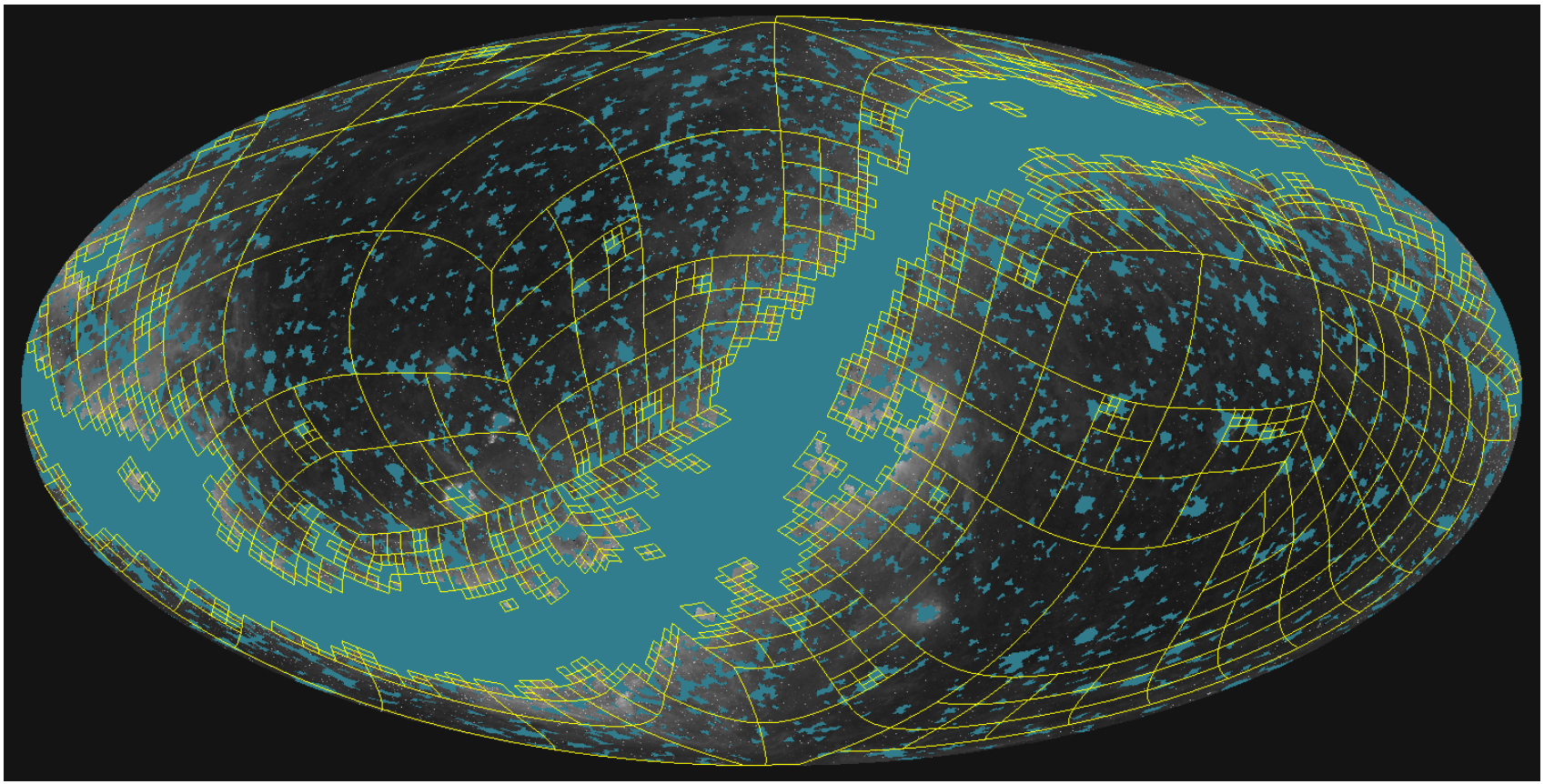


Figure 7: AMORA Web page

By XMM team in Strasbourg: ask **Laurent Michel** for more details

Aladin Lite v3

- MOC Lib Rust in Aladin Lite v3 (Matthieu Baumann)
  - load MOCs (FITS/JSON/ASCII), iterate on cells
  - MOC from polygon / cone
  - MOC intersection



MOC Lib Rust

New functionalities apart from the **storage** feature

New: F-MOCs

- S-MOC index:
  - 12 base cells (4 bits b)
  - plus 2-D z-order curve of depth 29 in each base cell $((i, j))$
  - $ipix_{29} = 00\boxed{b_3 b_2 b_1 b_0}\boxed{j_1 i_1 j_2 i_2 \ldots j_{29} i_{29}}$
- T-MOC index
  - microsec since $JD = 0$, $\in [0, 2^{62}[$ (1-D Z-order curve)
  - $ipix_{61} = 00\boxed{t_0 t_1 t_2 t_3 \ldots t_{61}}$
- **F-MOC** (see also P. Fernique talk in App 1)
  - **simply re-encode f64 Hz value**
  - regular f64: $\boxed{s}\boxed{e_{10} \ldots e_0}\boxed{f_{51} \ldots f_0}$
    - $v = (-1)^s (1.f_{51} \ldots f_0)_2 \times 2^{e-1023}$
    - 1 sign bit (not needed!)
    - 11 exponent bits (smaller range ok)
    - 52 fraction bits (keep full precision)
  - $ipix_{59} = 0000\boxed{e_7 \ldots e_0}\boxed{f_{51} \ldots f_0}$
    - **nice properties** (order, ...) $\Rightarrow$ operations on int64 representation $\Leftrightarrow$ **operations on f64 Hz ranges**

New: F-MOCs

- For F-MOC order $\in [7, 53]$:
  - relative precision in Hz: $\epsilon \in [1/2^{1+order-7}, 1/2^{order-7}]$
  - number of significant digits: $n \approx \ln_{10} \frac{1}{prec}$
  - at order 59: $\epsilon \in [1.1 \times 10^{-16}, 2.2 \times 10^{-16}]$, $n \approx 16$
- **New!** Human print option **hprint** in MOCCli

```
> echo "25/3047" | moc hprint -f ascii -t fmoc -
# Frequency ranges in Hz
from_inclusive,to_exclusive
5.114326226619749e-29,5.1143454859191 93e-29

> echo "150000000.0" |\
>   moc from freqval 59 - ascii |\
>   moc hprint -f ascii -t fmoc -
# Frequency ranges in Hz
from_inclusive,to_exclusive
1.5e8,1.5000000000000003e8
```

New: quick view (allsky)

- MOCCli: `> moc view moc.fits moc.png allsky 600`
- MOCPy: `MOC.display_preview(y_size=600)`
- MOCWasm: TBD (ask if you need it)

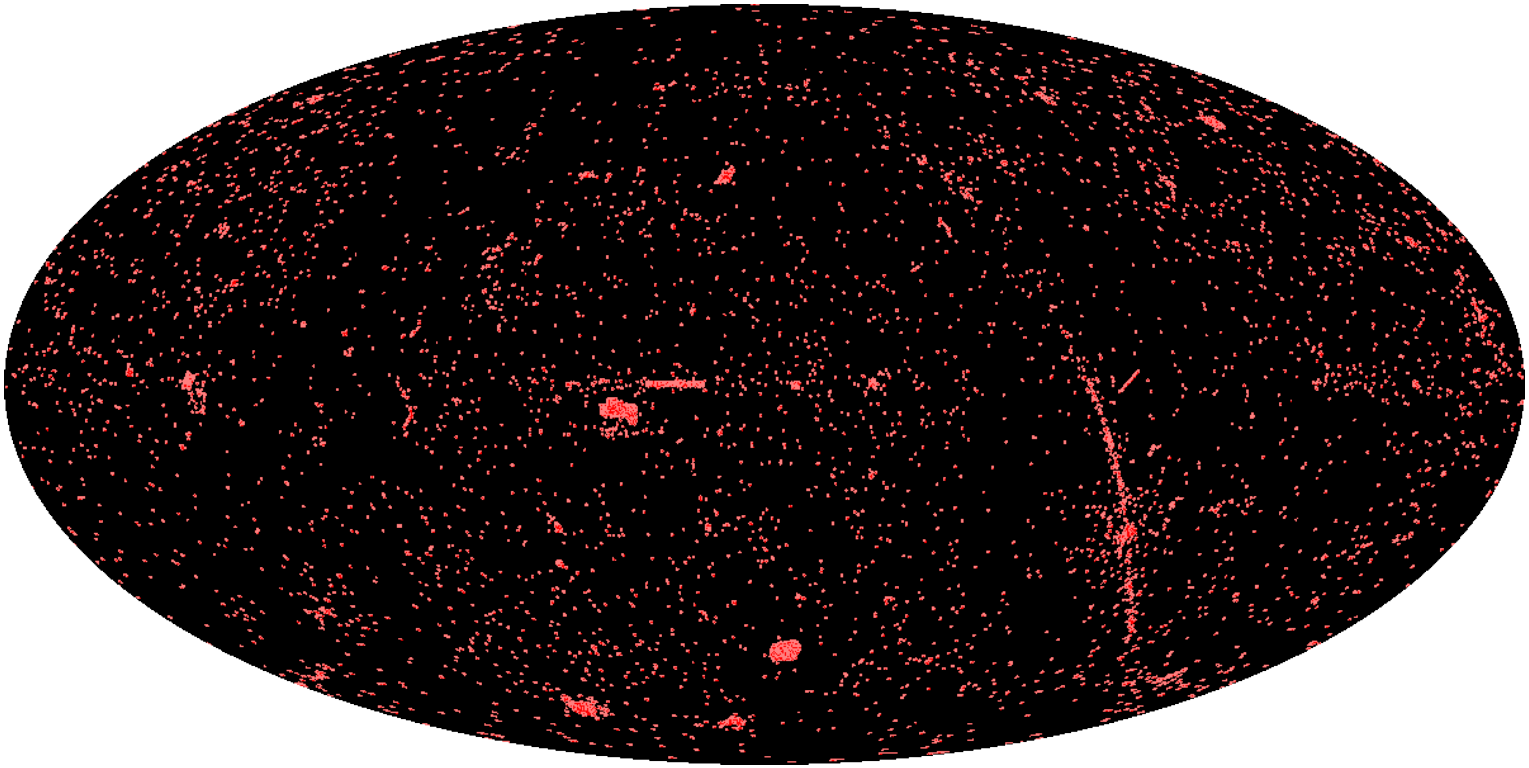


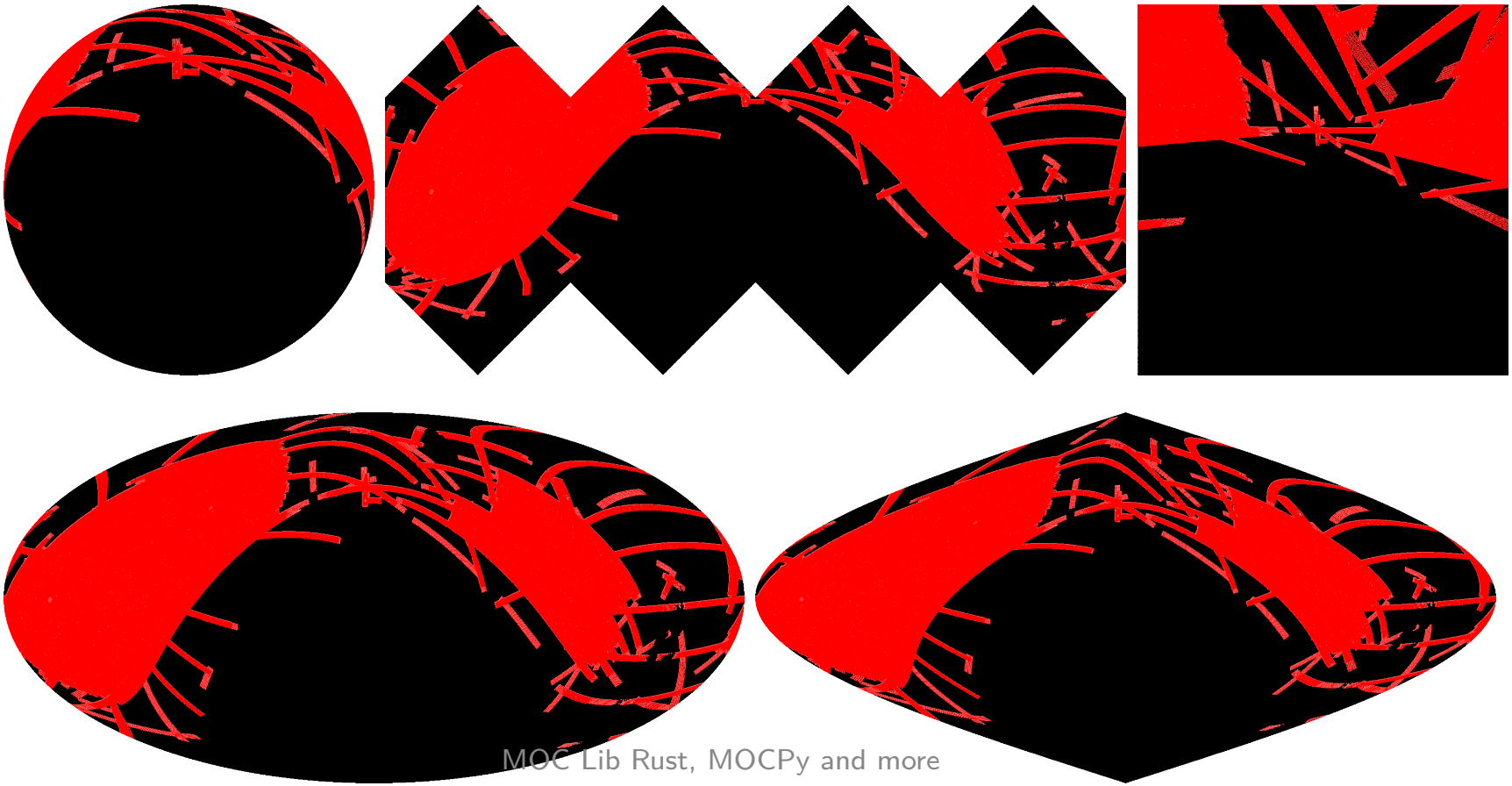
Figure 8: XMM MOC in 1200x600

New: quick view algo

- Algo different from Aladin/Aladin Lite
  - not real time $\Rightarrow$ not the same perf. needs
- Algo details:
  - for each image pixel
    - de-project to find sky coordinates
    - compute HEALPix cell
    - switch on (100% opacity) pixel if HEALPix cell is in MOC
  - for each MOC cell
    - compute the projected coordinate of the cell center
    - switch on (50% opacity) the image pixel
- Why?
  - support case of sparse MOCs made of cells smaller than image pixel
  - better visualization of MOC borders
  - performances are ok (~1s for 1600x800 image preview)

New: custom quick view

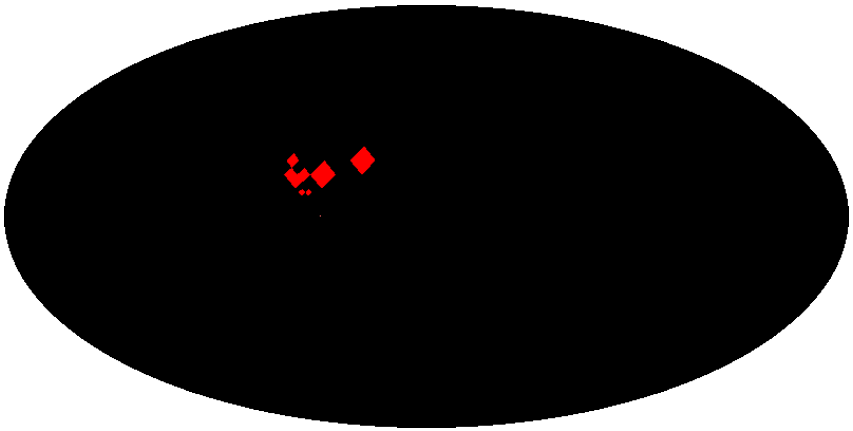
- Support various projections
  - mapproj Rust library, also used in Aladin Lite v3
- Implemented in *MOC Lib Rust* and *MOCCli*
  - `> moc view moc.fits moc.png custom -l 80.0 -b -45.0 sfl 1600 800`

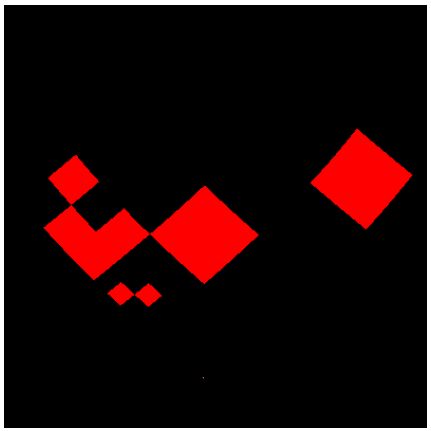


New: autodetect MOC FOV

- MOC "barycenter" and "radius" (nothing fancy)
  - barycenter: mean cell center ponderated by cell area
  - radius: distance from center to furthest vertex
  - motivation: allow viewers to center the FOV around a MOC
- MOCCli: `> moc view moc.fits moc.png auto 800`
- MOCPy (feature requested by Laurent Michel):
  - `MOC.barycenter()`
  - `MOC.largest_distance_from_coo_to_vertices(coo)`

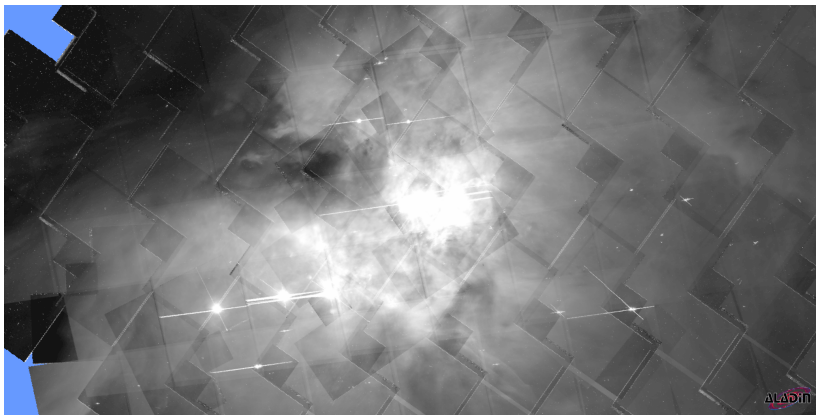
```
> moc view moc.fits moc.png allsky 400
> moc view moc.fits moc.png auto 400
```





New use case for split

- **Split** a MOC **into disjoint sub-MOCs**
  - feature request by **G. Greco** (grav. waves credible regions)
- New **use case for HiPS**, see T. Boch talk (App 1)
  - split a HiPS into independent regions
  - apply one cut by region (instead of a global cut)
  - also implemented **in HiPS gen Java now** (P. Fernique)



Summary

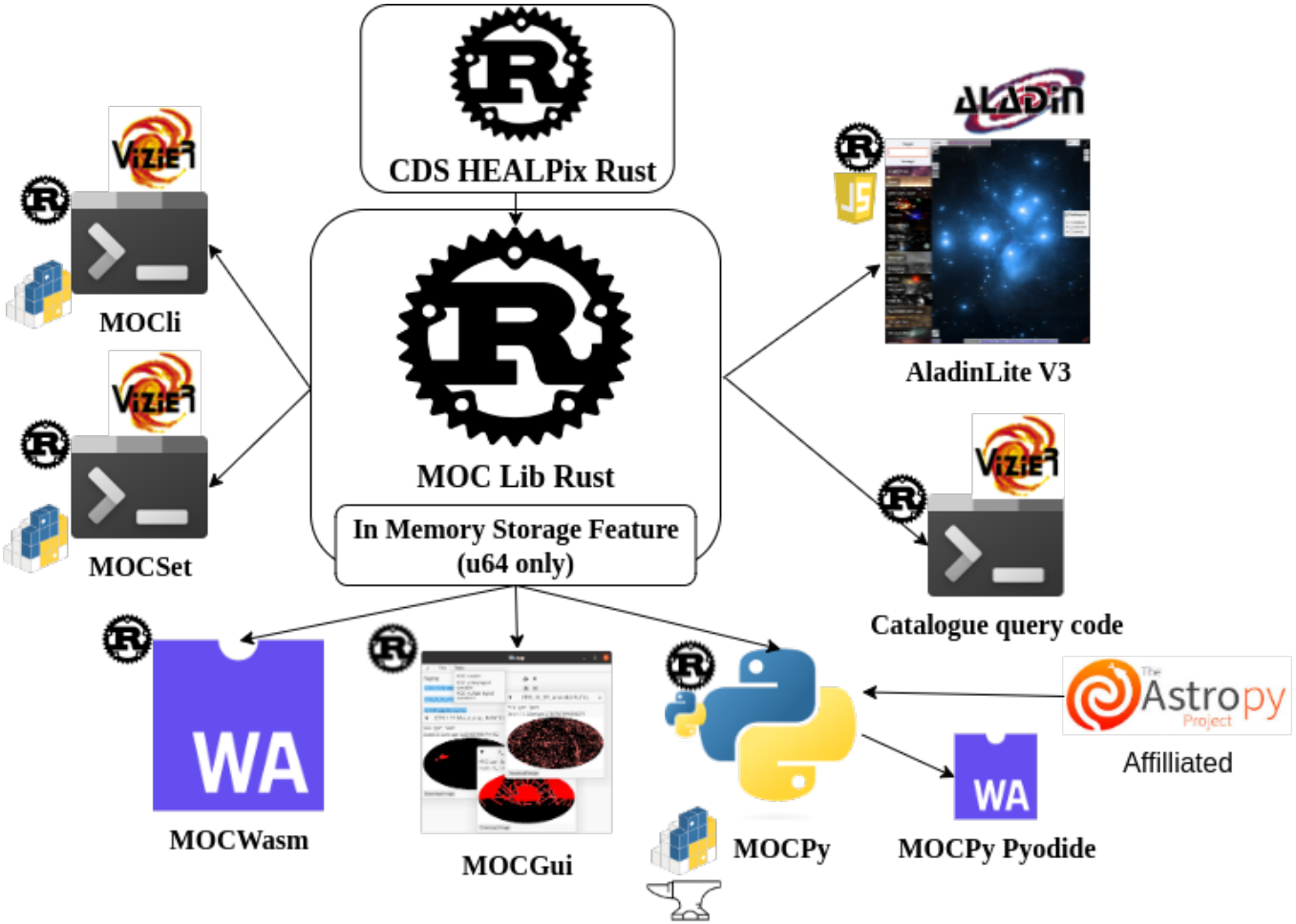


Figure 9: one Rust core lib (still evolving) + thin wrappers: many benefits (it is fast!)