Connecting **space** and **time** in a multi-messenger landscape: **STMOC** behind the scene

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IVOA

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A few Space-Time use-cases

What is the 2MASS mission coverage in space & time ?

What are the list of catalogs having data for my list of SN detections (time and position) ?

Are there coincidental observations in space and time for XMM and Chandra missions ?

Which observations are available for this Gravitational Wavelength probability area detected at this epoch ?

Time and Space in astronomy

Space and **Time** already the two **main index** of the **astronomical data** centers and archives

But:

- **Heterogeneous** space reference systems (Gal, Eq, …)
- **Heterogeneous** time reference systems (TDB, TCB, TT, ..)
- **Heterogeneous** DB systems (SQL, TAP, asu…)

=> required **conversions**
=> required multiple syntaxes and translations…

=> Merging results are **complex** and **slow**

The challenge behind these use cases

Determine **Where** & **When**

+ in **distributed** and **heterogeneous data**

+ as **fast** as possible

= **Manipulation of coverages**

We already did it for space

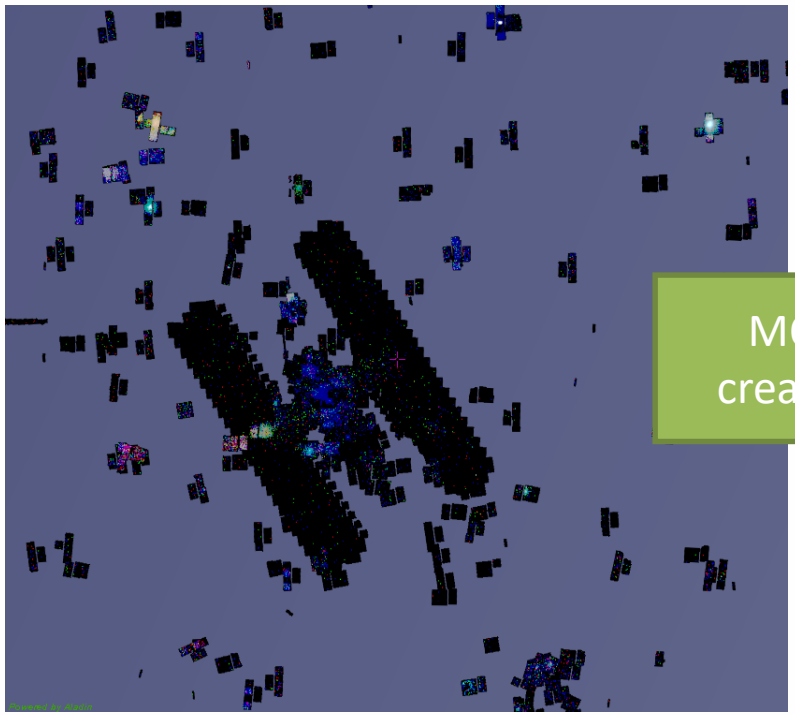
- **MOC** = Multi-Order-Coverage map
- Presented at ADASS 2012 - Urbana
- Standardized in the framework of IVOA in 2014
- Implemented in various tools (Aladin, TOPcat, ...) and already provided by various data providers (Virgo/Ligo, CDS, …)

=> That works extremelly well

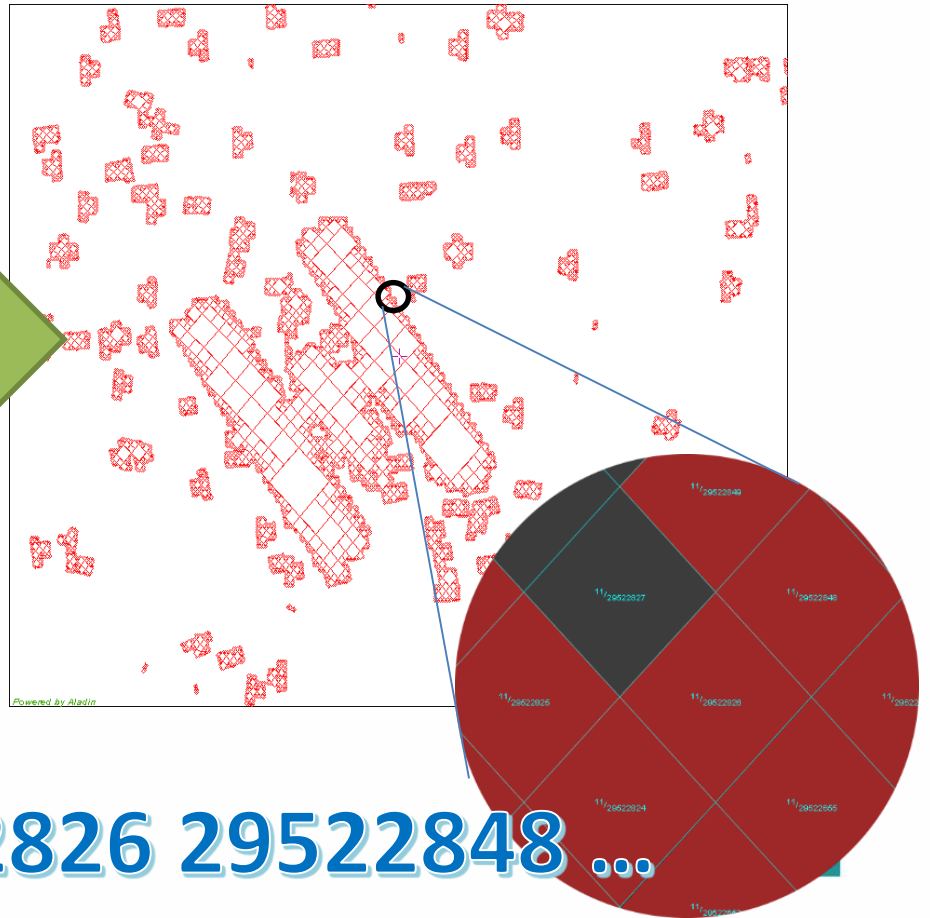
Spatial MOC overview

a **MOC** = a **list of numbers**

based on HEALPix hierarchy tessellation



MOC creation

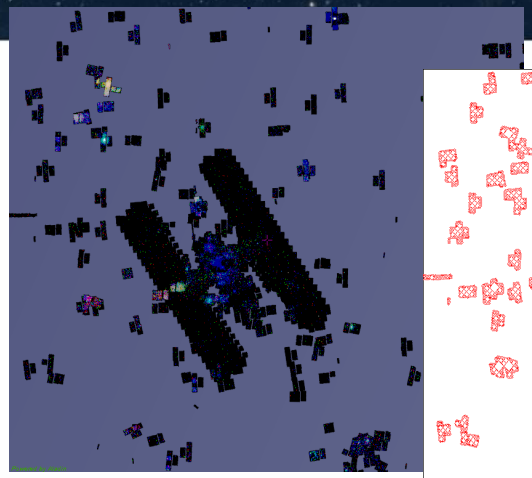


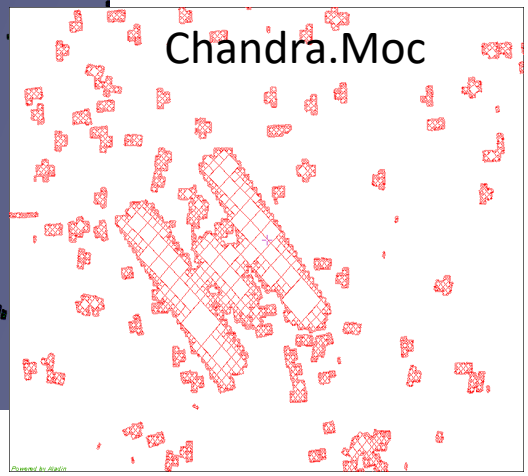
…10/34758…11/29522826 29522848 …

The success keys of MOC

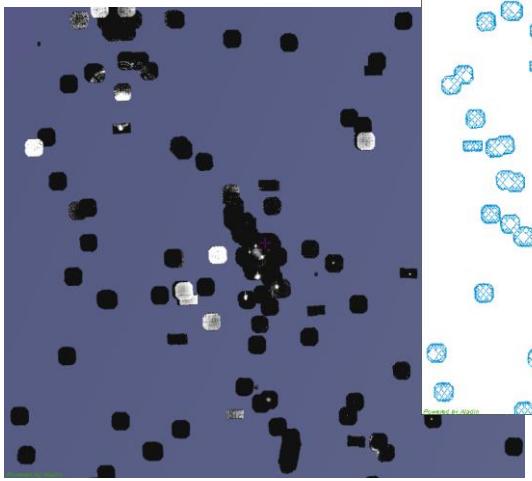
1. **Discretisation** of the space dimension
   => HEALPix
2. A **unique convention** => ICRS
3. **Multi** compatible **resolution** => hierarchical
4. **Canonical representation** => list of integers
5. Simple and **fast basic** operations (intersection, union, complement, subtraction) => a few ms
6. **Basic** syntax and **packaging** => ASCII, FITS

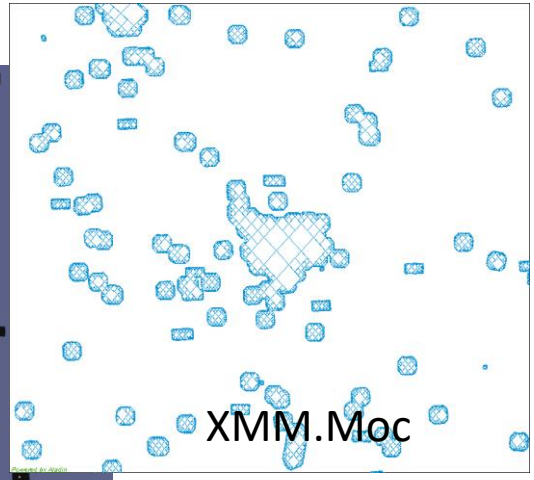
MOC in practice





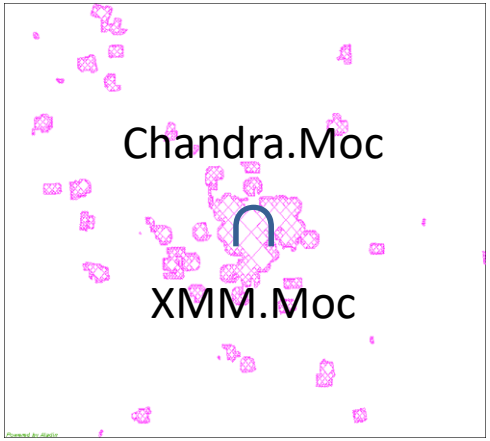
=> **Compact** (by collapsing adjacent cells)

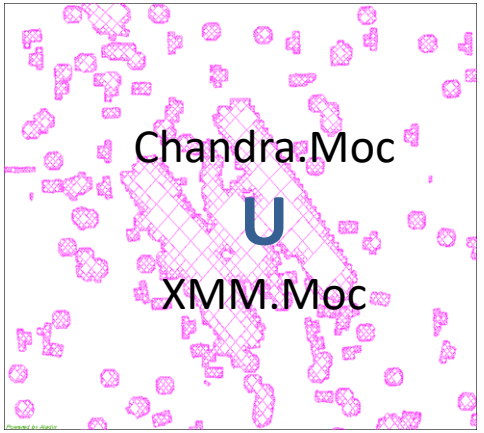




=> Operations are extremely **fast** => a few ms

(union, intersection, subtraction, compl)

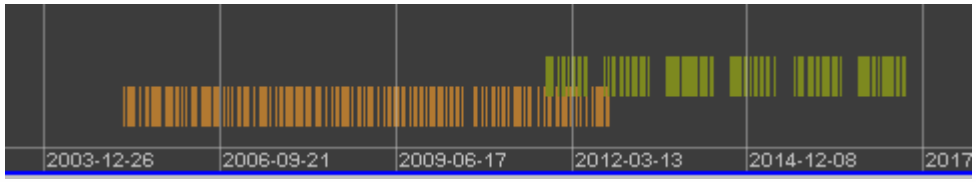




Time Coverage => the idea

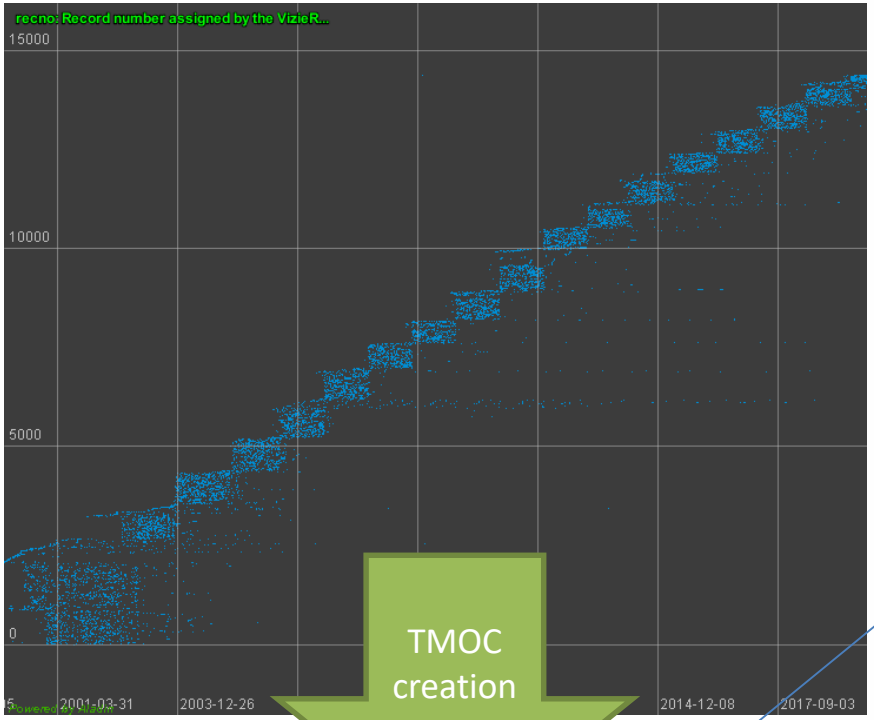
- *Why not reuse the same winning recipe*
  => **TMOC** = **Time** MultiOrder Coverage
  = A list of hierarchical time numbers

- => Just by reusing MOC lib for Time:
  1. Discretisation of the Time dimension
     => Julian Day division
  2. A unique convention **=> TDB, Barycentric, no offset**



- TMOC conventions:
  - JD(TDB,Barycentric,no offset)
  - Order 29 -> 1 µs TMOC resolution
  - Allow to describe 9133 years from JD=0

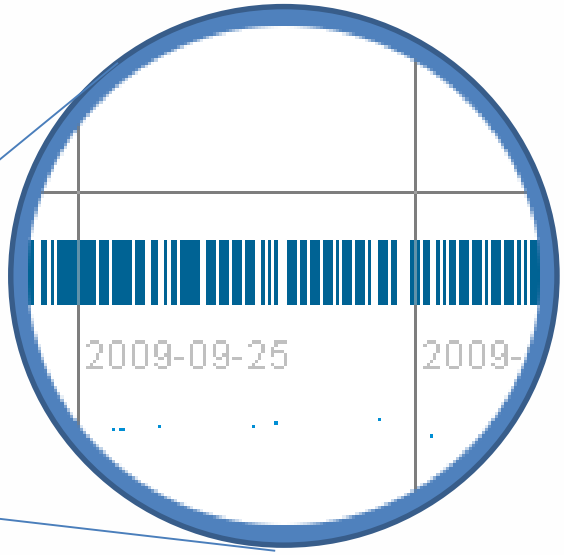
Time MOC overview



TMOC creation

a **TMOC** = a **list of numbers**

based on JD time discretisation



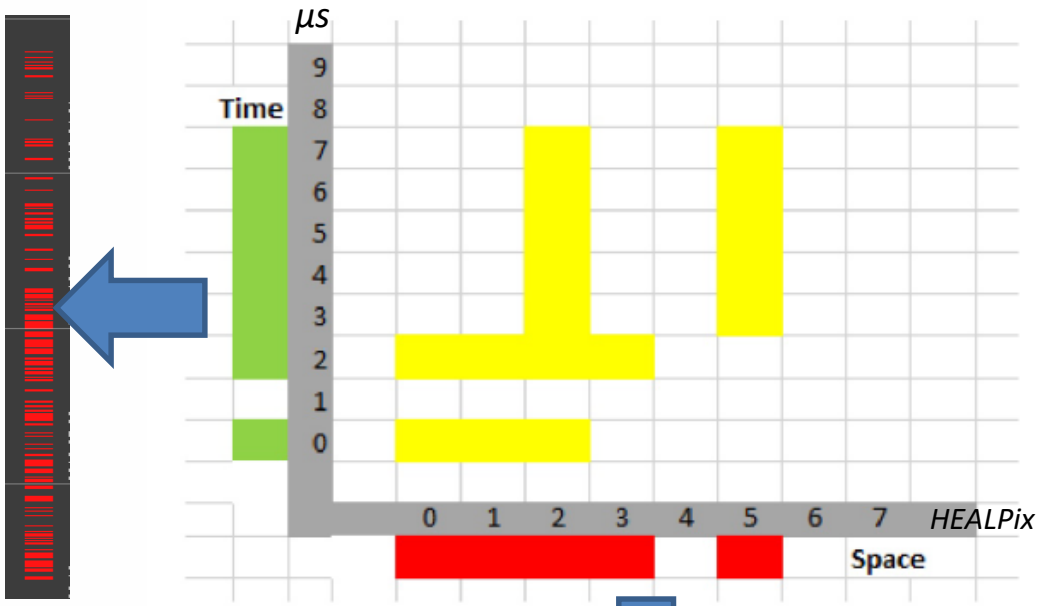
…13/34758…29/295226295248 …

When **AND** Where !

- *Where **OR** When not enough*
  *=> We need Where **AND** When*
- The **STMOC** = **Space Time MultiOrder Coverage**
- Merge together both dimensions in a unique MOC in order to have simultaneously space and time coverage

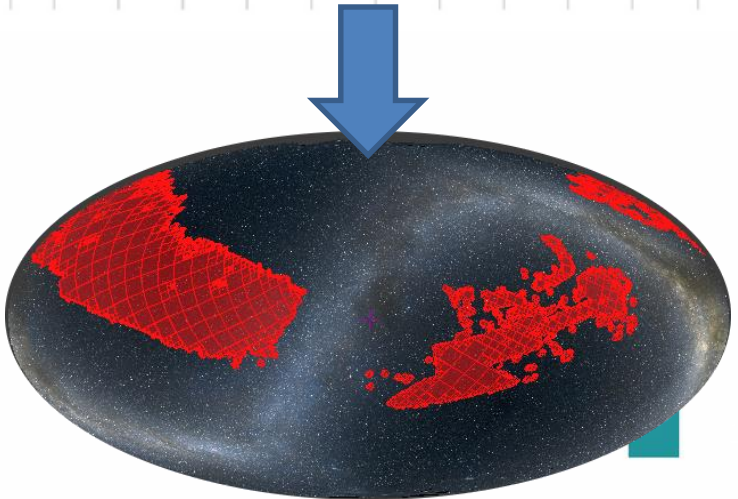
STMOC concept & challenge

- (S)MOC = a list of numbers (red)
- TMOC is also a list of numbers (green)
- **STMOC** is the 2D table of numbers (yellow)



=> The challenge:

How to describe and manipulate a 2D table efficiently



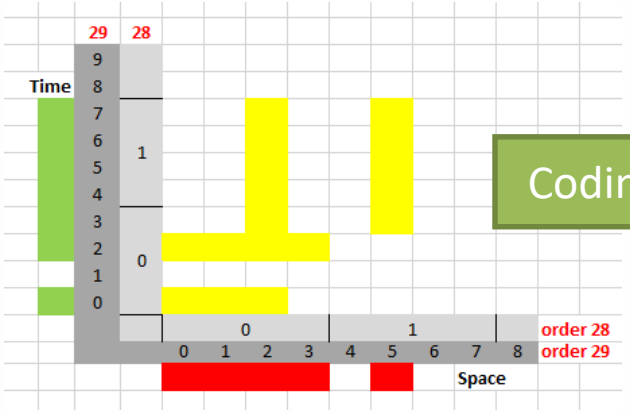
STMOC study

How to manipulate efficiently a potentially huge 2D matrix ?

1. *1st try:* Global hierachical numbering (= MOC 1D)
   => Force to use the same resolution for space and time
   => not a good idea !
2. *2nd try:* **Two independent numberings** (= MOC 2D)
   => Time and Space resolutions unattached

+ Coding a la « **Battleship** »

} It's work



Coding

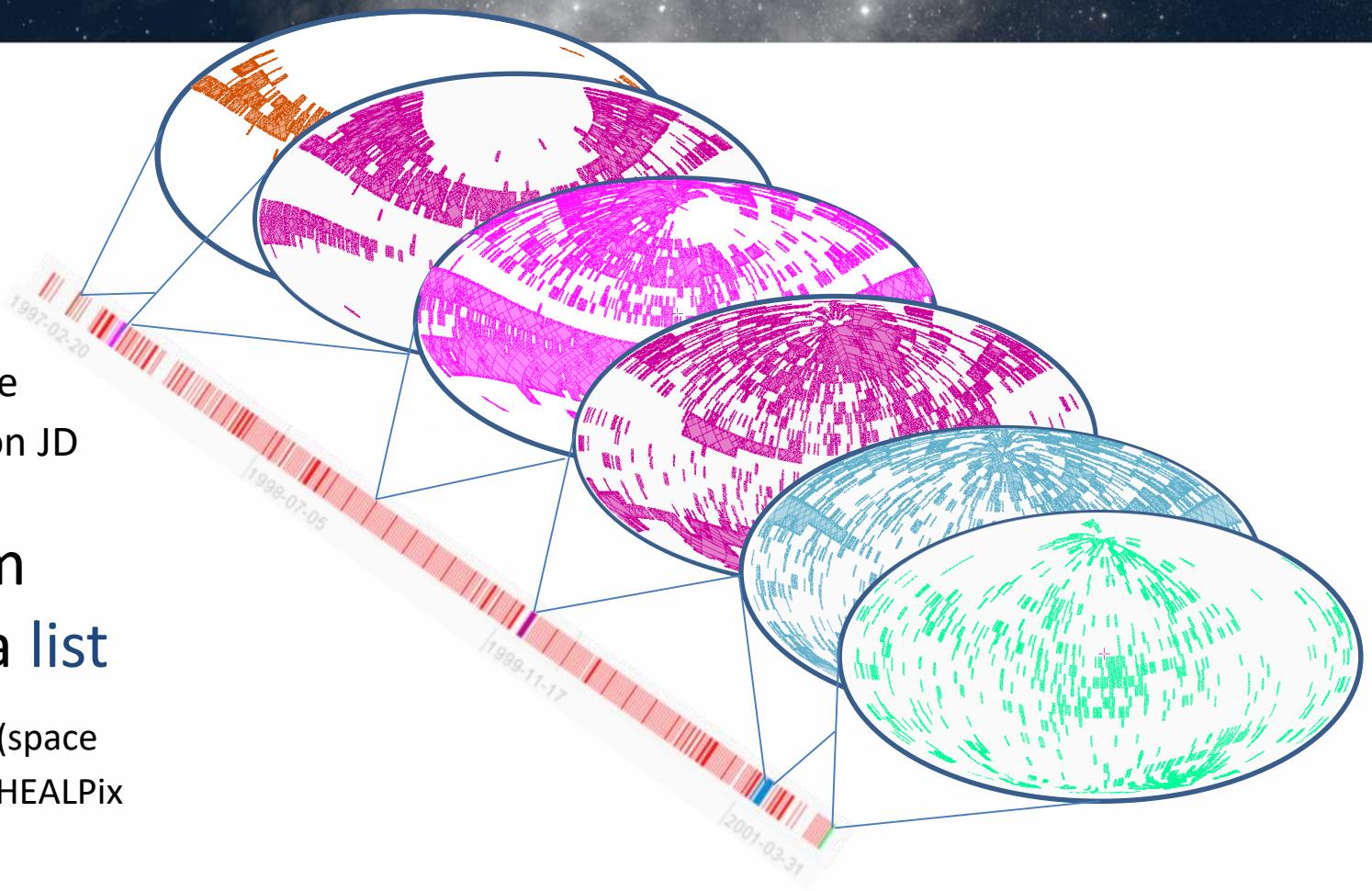
t29/0 s29/0-2
t29/2 s28/0
t28/1 29/3 s29/2,5

packaging

FITS binary table
alternating Time and Space index

Space-Time-MOC overview

a **STMOC**
= a list of numbers (time coverage – based on JD discretisation)
Each of them pointing to a list of numbers (space coverage – based on HEALPix disc.)



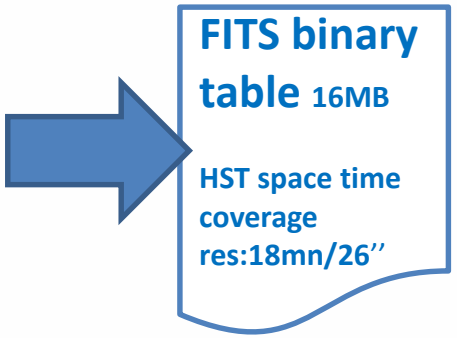
…t13/3475 s29/2952295248 …t13/6389 s28/..

Size and performance

- STMOC **generation** from a catalog of 211K sources (ACS/HST observations)

  Using RA,DE,JD
  - T-Order 10 (3d), S-Order 10 (3.4') => **0.25s**, **313KB**
  - T-Order 14 (18mn), S-Order 13 (26'') => **0.8s, 1.6MB**

  Using FoV,JD
  - T-Order 10 (3d) S-Order 10 (3.4') => **9.8s**, **654KB**
  - T-Order 14 (18mn), S-Order 13 (26'') => **59s, 15.6MB**



- STMOC **operations**
  (unions, intersect., subtrac., compl.)
  => about **2ms** to **50ms**
- **Filtering** a catalog by STMOC
  => **300ms** for 800K sources => 22K matches

In details

ACS/HST log – 211453 observations

Torder	Sorder	Time resolution	Space resolution	# time ranges	Size	Time to generate
29	29	1µs	393.2µas	126636	4.2MB	3.4s
20	14	262ms	12.9"	126636	3,9MB	3s
14	20	~18mn	201.3mas	70632	2.8MB	2.2s
14	14	~18mn	12.9"	52732	1.8MB	1.4s
14	10	~18mn	3.245'	43843	1.4MB	1.2s
10	14	~3d4h	12.9"	1856	498KB	0.3s
10	10	~3d4h	3.245'	1854	314KB	0.27s
3	3	~143y	7.329°	1	342B	0.4s

Operations on STMOCs

ACS	Saturn	Union	Inter
29/29	29/29	19ms	11ms
14/20	20/14	8ms	3ms
14/14	14/14	5ms	2ms
10/14	14/10	13ms	26ms
3/3	3/3	0ms	0ms

Saturn ephemerid – 20K positions

Torder	Sorder	Time resoluation	Space resolution	# time ranges	Size	Time to generate
29	29	1µs	393.2µas	19994	625KB	92ms
20	14	262ms	12.9"	19994	625KB	83ms
14	20	~18mn	201.3mas	19994	625KB	77ms
14	14	~18mn	12.9"	19994	625KB	51ms
14	10	~18mn	3.245'	19994	625KB	98ms
10	14	~3d4h	12.9"	3143	353KB	47ms
10	10	~3d4h	3.245'	3076	197KB	47ms
3	3	~143y	7.329°	2	532B	26ms

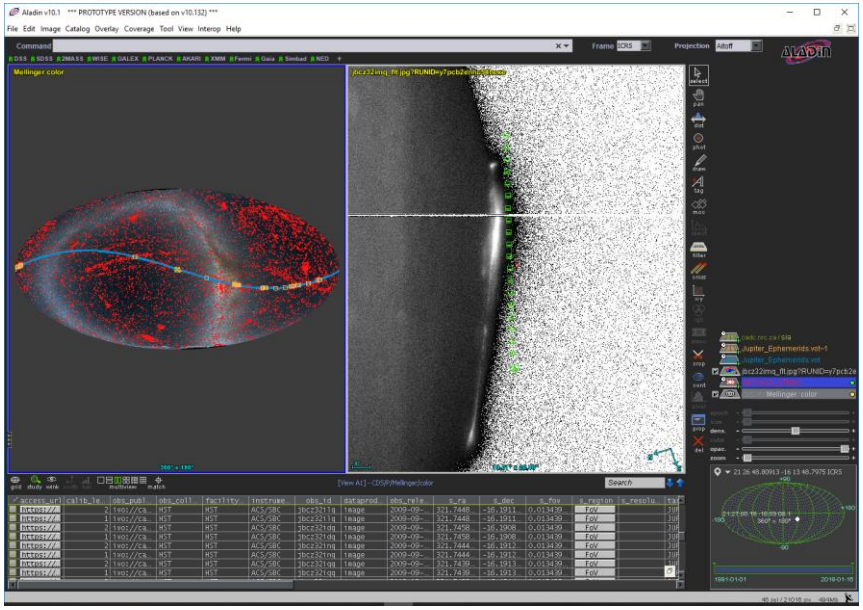
Catalog filtering by STMOC

STMOC	Catalog	Time	Matches
ACS 14/14	Saturn	30ms	4
Saturn 14/14	ACS	75ms	23

A use case in live (video)

*I want to find **HST ACS** observations matching a **Jupiter** ephemerid*

Please in a few seconds…



Creating and using STMOC ?

- **Doc**: IVOA note - May 2019 - Daniel Durand, Pierre Fernique, Ada Nebot, Thomas Boch, Francois-Xavier Pineault

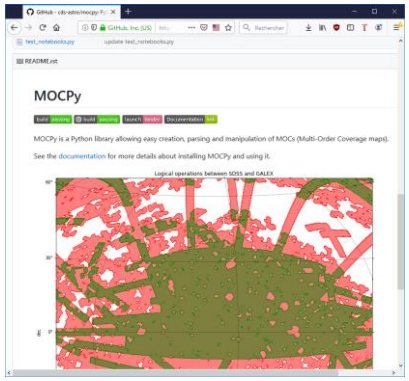
  => http://www.ivoa.net/documents/stmoc

- **Tool**: Aladin Beta

  => http://aladin.u-strasbg.fr/AladinBeta.jnlp

- **Python library**: MOCpy (M.Baumann)

  => https://github.com/cds-astro/mocpy



- **List** of **STMOCs** already generated by CDS

  => http://alasky.u-strasbg.fr/footprints/STMOC

Last but not least…

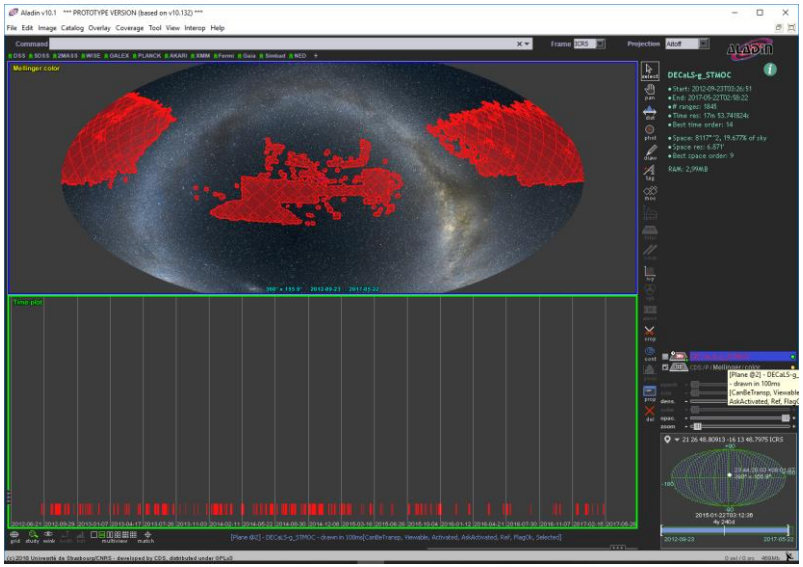
And now … we can apply the same mechanism for:

- **Alternate dimension** => ex: **Space-Redshift** MOC
- Or even to introduce a **third dimension**

  => ST**E**-MOC = Space-Time-**Energy** MOC

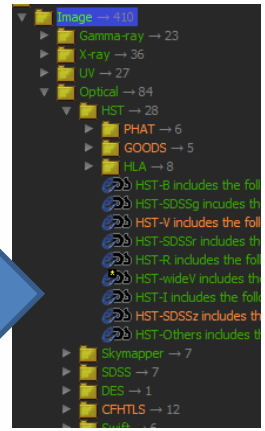
To be continued

Thanks !
Question ?



Next steps

- Generated STMOCs
  (from **VizieR catalogs,** and **HiPS)**
- Ingested in CDS **MocServer**:
  => Aladin Resource Tree by Space & Time



- Extend the IVOA MOC standard
  for supporting TMOC and STMOC
  => see IVOA meeting next days