Space Time Coverage by STMOC

ESCAPE TechForum – 4-6 February 2020

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A few Space-Time use-cases

What is the ESO-VISTA 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-wave sky localization 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

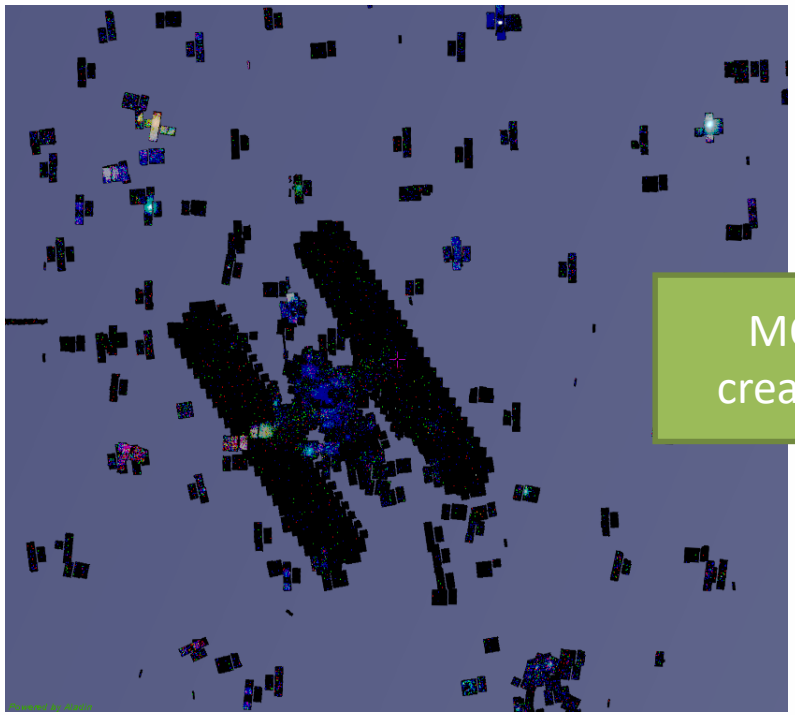
- **MOC** = Multi-Order-Coverage map
- Presented at ADASS 2012 - Urbana
- Standardized in the framework of IVOA in 2014
- Implemented in various tools (Aladin, TOPcat, ...) and already provided by various data providers (Virgo/LIGO, CDS, …)

=> That works extremelly well

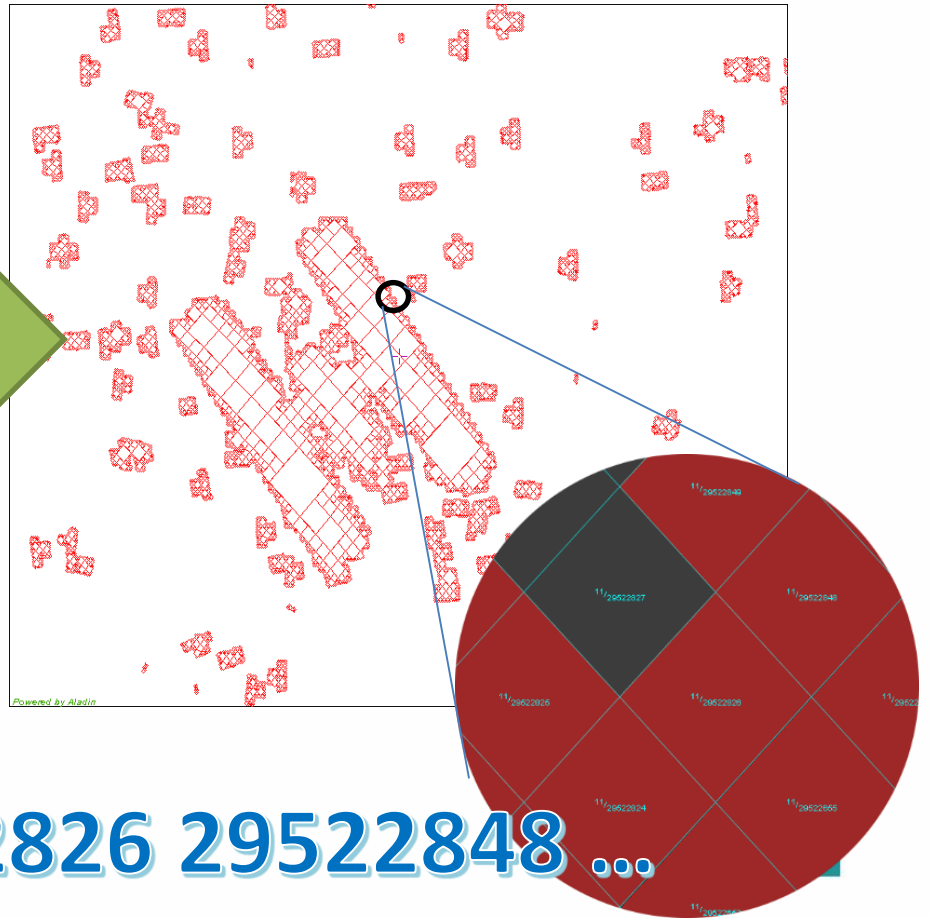
Spatial MOC overview

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

based on HEALPix hierarchy tessellation



MOC creation

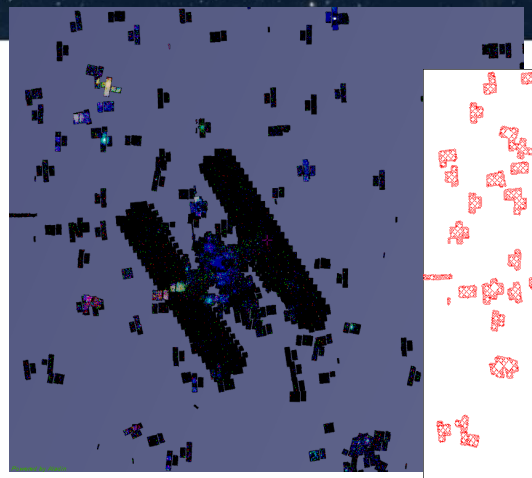


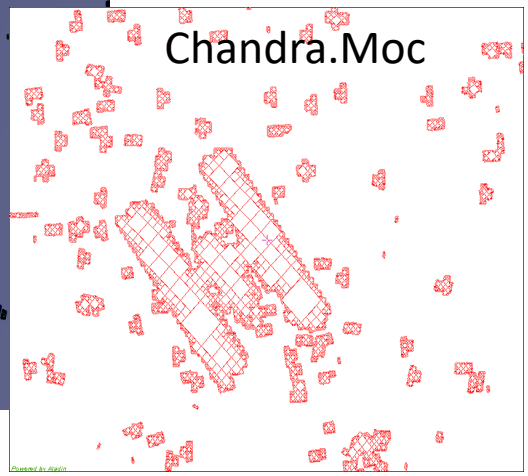
…10/34758…11/29522826 29522848 …

The success keys of MOC

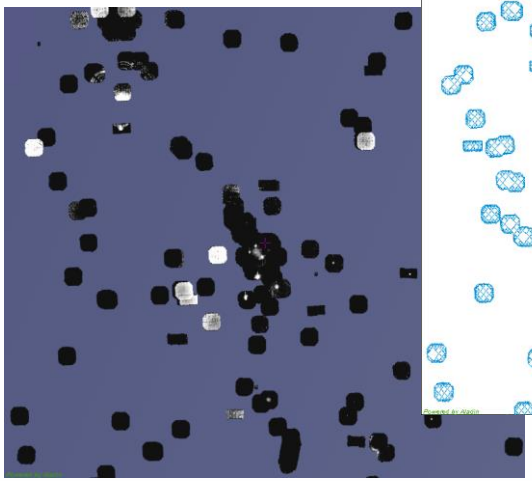
1. **Discretisation** of the space dimension
   => HEALPix
2. A **unique convention** => ICRS
3. **Multi** compatible **resolution** => hierarchical
4. **Canonical representation** => list of integers
5. Simple and **fast basic** operations (intersection, union, complement, subtraction) => a few ms
6.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

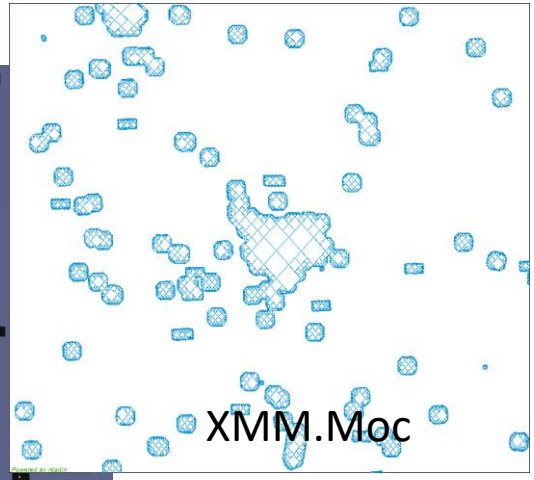
MOC in practice





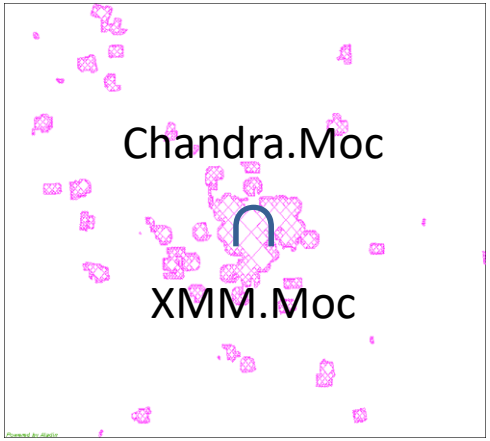
=> **Compact** (by collapsing adjacent cells)

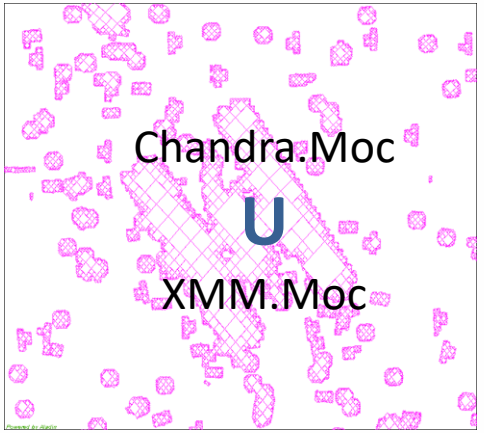




=> Operations are extremely **fast** => a few ms

(union, intersection, subtraction, compl)

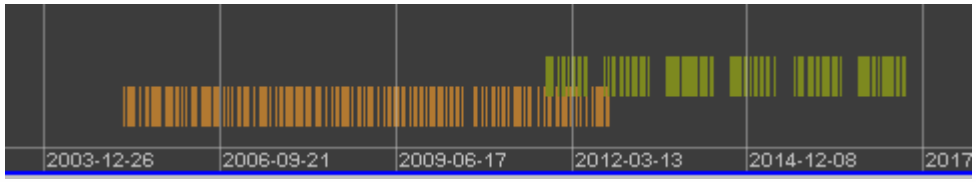




Time Coverage => the idea

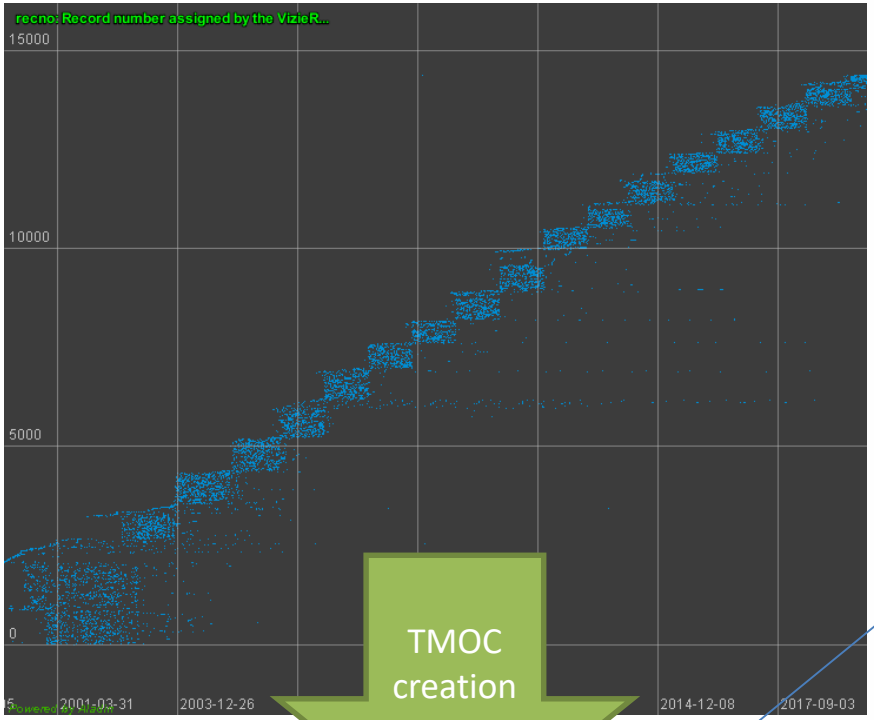
- *Why not reuse the same winning recipe*
  => **TMOC** = **Time** MultiOrder Coverage
  = A list of hierarchical time numbers

- => 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

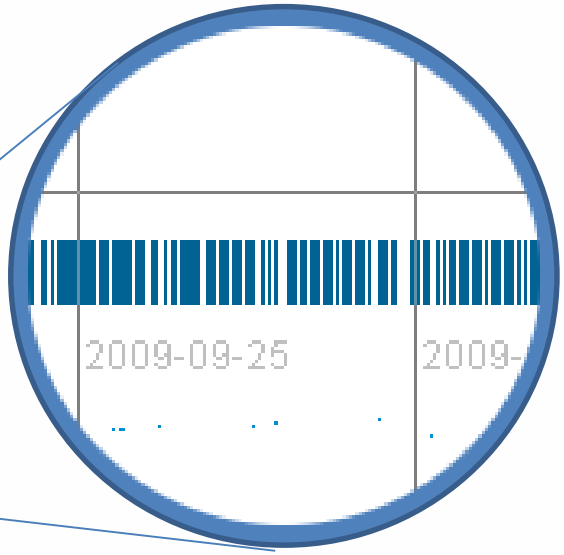
Time MOC overview



TMOC creation

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

based on JD time discretisation



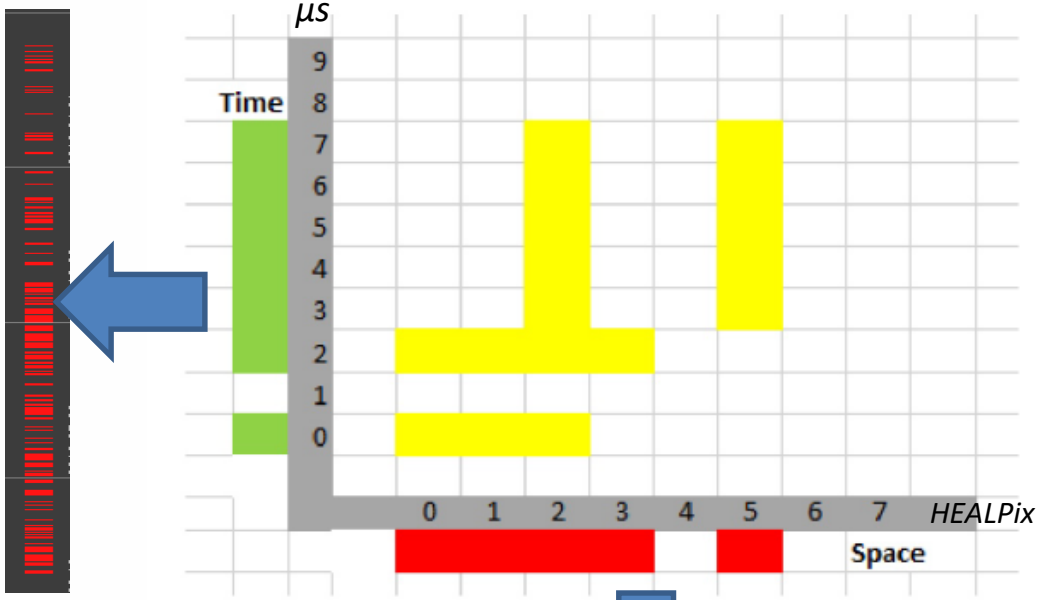
…13/34758…29/295226295248 …

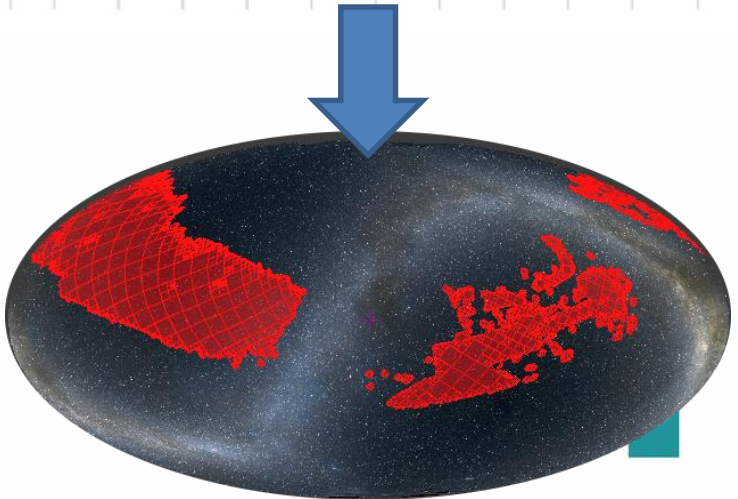
When **AND** Where !

- *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

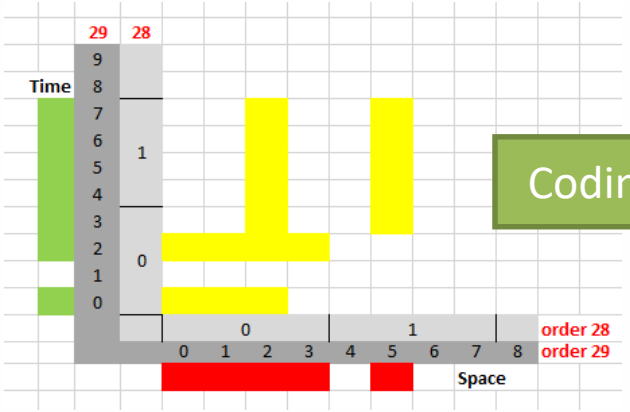
STMOC study

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

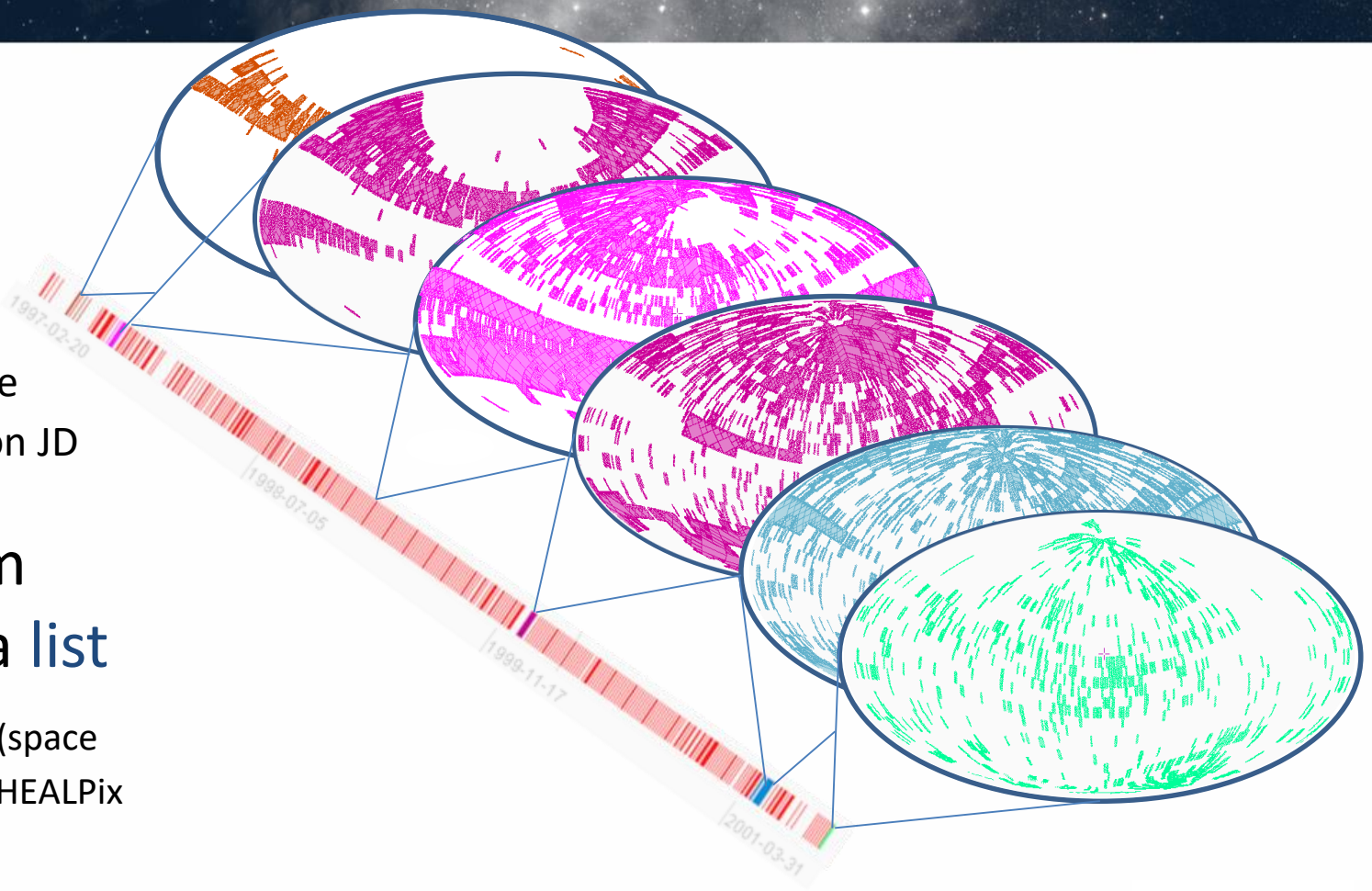
t29/0 s29/0-2
t29/2 s28/0
t28/1 29/3 s29/2 5

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.)



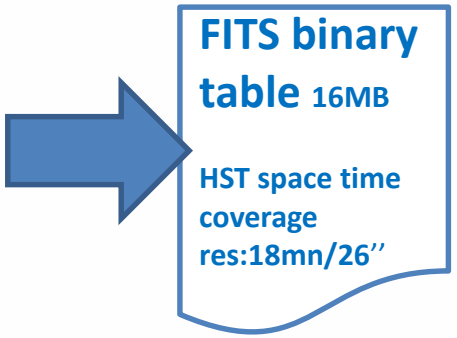
…t13/3475 s29/2952295248 …t13/6389 s28/..

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

Two use cases in live

What is the ESO-VISTA mission coverage in space & time ?

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

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

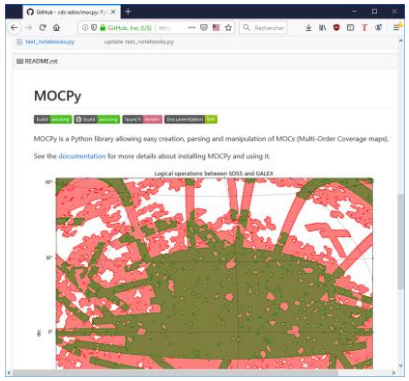
  => http://www.ivoa.net/documents/stmoc

- **Tool**: Aladin V11

  => http://aladin.u-strasbg.fr/AladinV11.jnlp

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

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

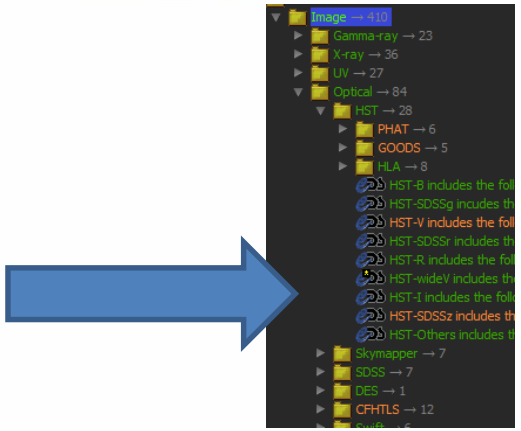


- **List** of **STMOCs** already generated by CDS

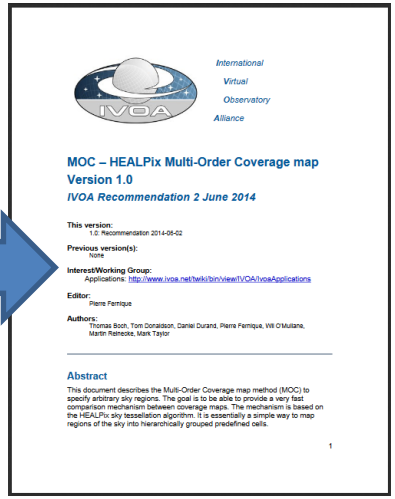
  => http://alasky.u-strasbg.fr/footprints/STMOC

Next steps

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



- Renew the IVOA MOC standard
  for supporting TMOC and STMOC
  => IVOA agreed in Nov => **MOC2.0**



Thanks !
Question ?