Let's talk coverage...
T-MOC & F-MOC for ObsCore?

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The plan

1. Why coverages?
2. Existing IVOA solutions
3. MOC & extensions, state of art
4. And ObsCore?

Goal reminder: interoperability

- **Simplify/accelerate selections:**
  => a priori knowledge of coverage avoids unnecessary queries
- What kind of coverage?
  => **Space, Time, Frequency…**
- 2 challenges:
  – **Use appropriate methods**? efficient, easy to use,…
  – **Which precision vs. Volume**? where to set the cursor?

IVOA solutions: state of art

- Level 1 : **targets, intervals** (e.g. *What, Where, When* fields in *VOEvent*; *t_min, t_max, em_min, em_max*, etc in *ObsCore*)
  - Very easy to fill in, but approximate, often lacunar, not very efficient (reference frame? resolver?...).
- Level 2 : **dedicated syntaxes** (e.g. *STC* in *s_region*)
  - Syntax to be mastered, adaptive content, but difficult to manipulate (multiple reference systems, complex coverages, etc.).
  - In practice: STC being abandoned by the IVOA, and/or simplified (J2000 only, basic shapes only (e.g. *xtype DALI*), etc.).
- Level 3 : **MOC** (e.g. *Moc.fits* in *HiPS, coverage* field in *RM registry*)
  - Requires dedicated tools/libs, adaptive content, but in a unique reference system, easy to manipulate (adaptive resolution, performance, ...)
  - In practice: integrated into many tools/libs (spatial MOCs)

For newcomers, a MOC...

Abstract

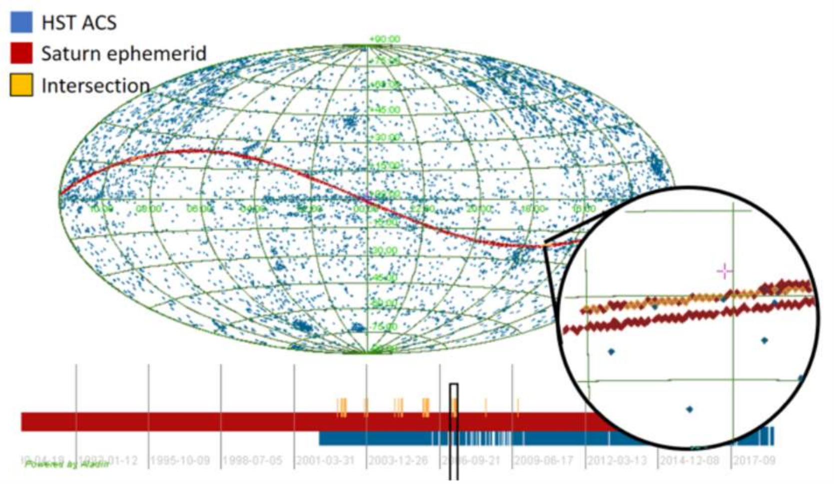
This document describes the Multi-Order Coverage map method (MOC) version 2.0 to specify arbitrary coverages for sky regions and/or time coverages and potentially other dimensions. The goal is to be able to provide a very fast comparison mechanism between coverages. The mechanism is based on a discretization of space and time dimensions. The system is based on the definition of a specific storage of the map coverage using predefined cells hierarchically grouped which makes it easy to produce and use for exploring astronomical collections. There are already a few applications and libraries which are taking advantage of this new standard.

... specifies arbitrary **coverages** for **sky regions** and/or **time coverages**...

... provides a **very fast comparison** mechanism...

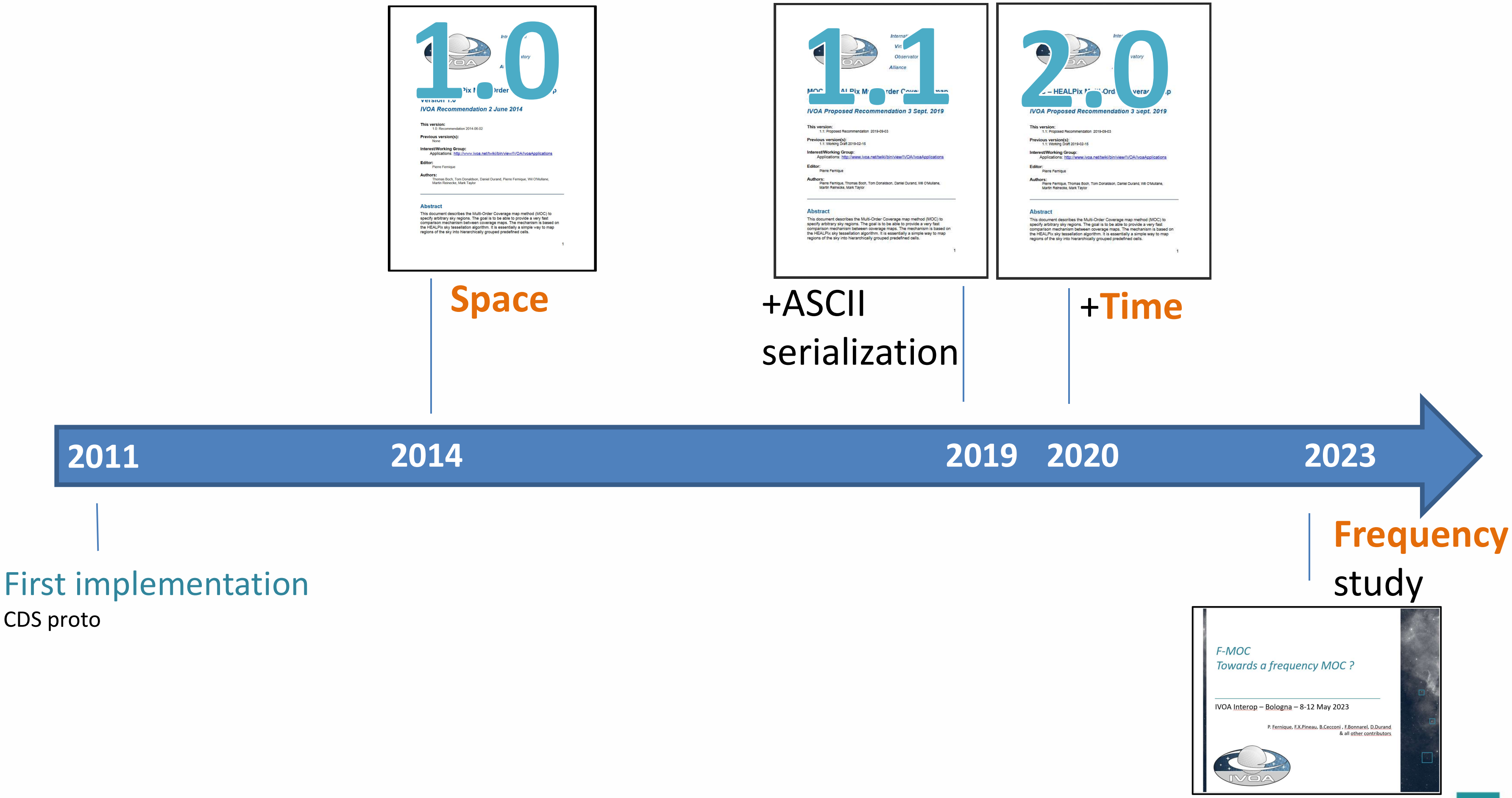
... is based on a discretization of space, resp. time, dimensions...

... is based on specific storage of the map coverage using predefined cell hierarchically...



See the IVOA MOC 2.0 document for details

MOC standard evolution



MOC principles

3 MOC principles

The MOC standard is defined using four basic building blocks: discretization, unique reference system, hierarchization and efficient encoding:

1. Determine a proper tessellation/discretization methodology for each dimension axis (space, time, ...);
2. Fix a unique referential system for each dimension (ICRS for the spatial dimension, TCB for the temporal one), to avoid reference conversions and thus allowing to easily compare different data collections;
3. Use an hierarchical procedure and a unique representation (canonical form) for compacting and quickly manipulating each axis coverage at any level of accuracy;
4. Implement at least one serialization in a binary encoding format (other serializations are possible, e.g. ASCII).

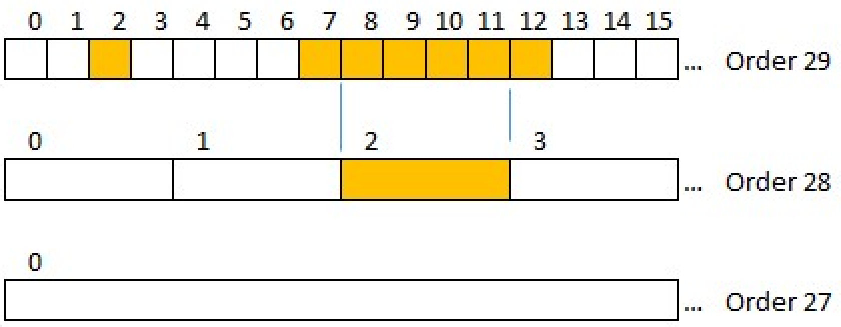
1. Discretization
2. Unique referential
3. Hierarchical and unique representation
4. Serializations

MOC principles (cont)

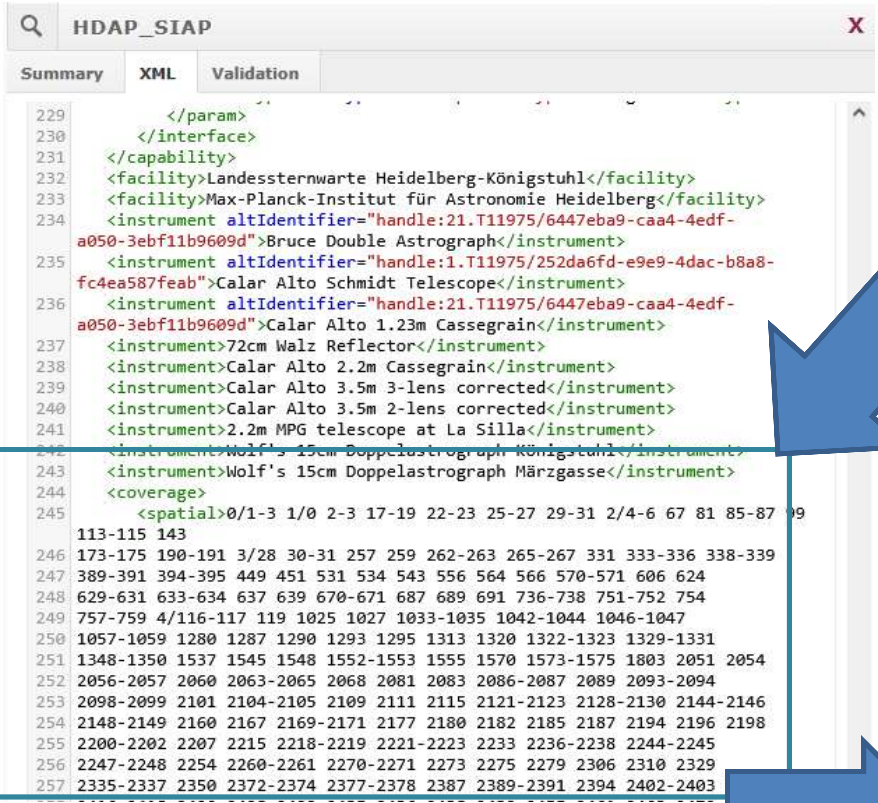
With these principles, a MOC consists of a list of numbers which represent the indices of the cells mapping the coverage of the spatial or temporal axis. As soon as the consecutive cells are used at order n, they will be hierarchically grouped in their parent cell at order n-1, and this recursively. This introduces the notion of orders and associated cell index. The cell boundary alignment implied by the hierarchical structure facilitates the combination of cells at different orders. Because of current technological possibilities, to operate efficiently, we are limiting to encode any pair (order, index) on 64 bits (a long), (in fact only 62 bits since we are using one bit for distinguishing space from time in binary encoding and one bit for future usage). The earlier MOC standard was limited to spatial coverage. We are reusing these principles to manipulate temporal coverages, as well as space-time coverages where we can manipulate the two physical dimensions simultaneously.

- List of numbers
  => 2,7,8,9,10,11,12

- As soon as the **consecutive cells** are **used at order n**, they will be **hierarchically grouped in their parent cell at order n-1**, and this recursively
  => **29**/2,7,12 **28**/2



In practice...



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113-115 143
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247 389-391 394-395 449 451 531 534 543 556 564 566 570-571 606 624
248 629-631 633-634 637 639 670-671 687 689 691 736-738 751-752 754
249 757-759 4/116-117 119 1025 1027 1033-1035 1042-1044 1046-1047
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252 2056-2057 2060 2063-2065 2068 2081 2083 2086-2087 2089 2093-2094
253 2098-2099 2101 2104-2105 2109 2111 2115 2121-2123 2128-2130 2144-2146
254 2148-2149 2160 2167 2169-2171 2177 2180 2182 2185 2187 2194 2196 2198
255 2200-2202 2207 2215 2218-2219 2221-2223 2233 2236-2238 2244-2245
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257 2335-2337 2350 2372-2374 2377-2378 2387 2389-2391 2394 2402-2403
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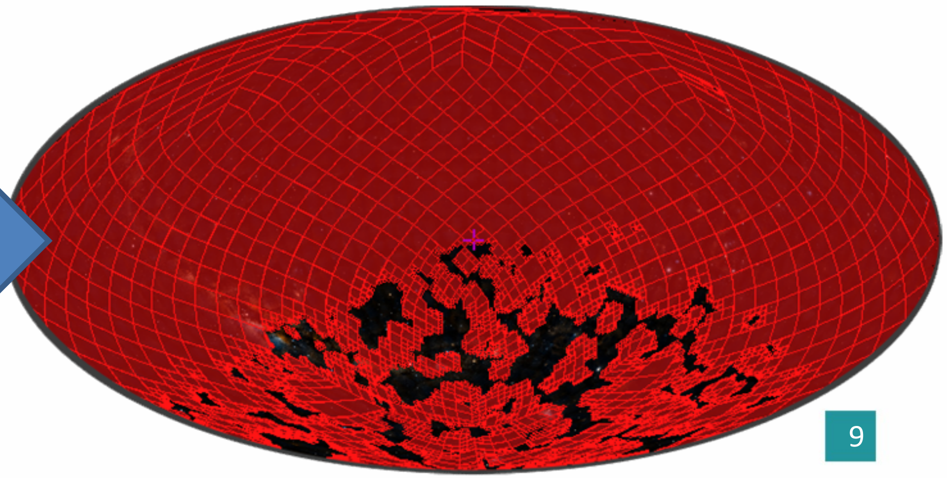
E.g. Coverage/spatial field in VO *RM registry*

~200 records
(+ all CDS records)



Time extension =TMOC

TDIG/Apps joint effort 2018 - 2021

3.2 Time MOC conventions

In order to represent time coverage, we need to select a-priori the total range of time that we will cover with the notation. Following the same SMOC principles, we need to use a discrete time axis which each unit element of this axis has a constant duration. We adopt the Julian Date convention, very common in astronomy and a nominal resolution of 1μs.

- Discretization based on JD

We opt for the TCB reference according to the IAU 2006 definition (https://www.iau.org/static/resolutions/IAU2006_Resol3.pdf). Our choice is motivated by the fact that this system is linear by construction and has been adopted by numerous missions such as Gaia.

- TCB reference

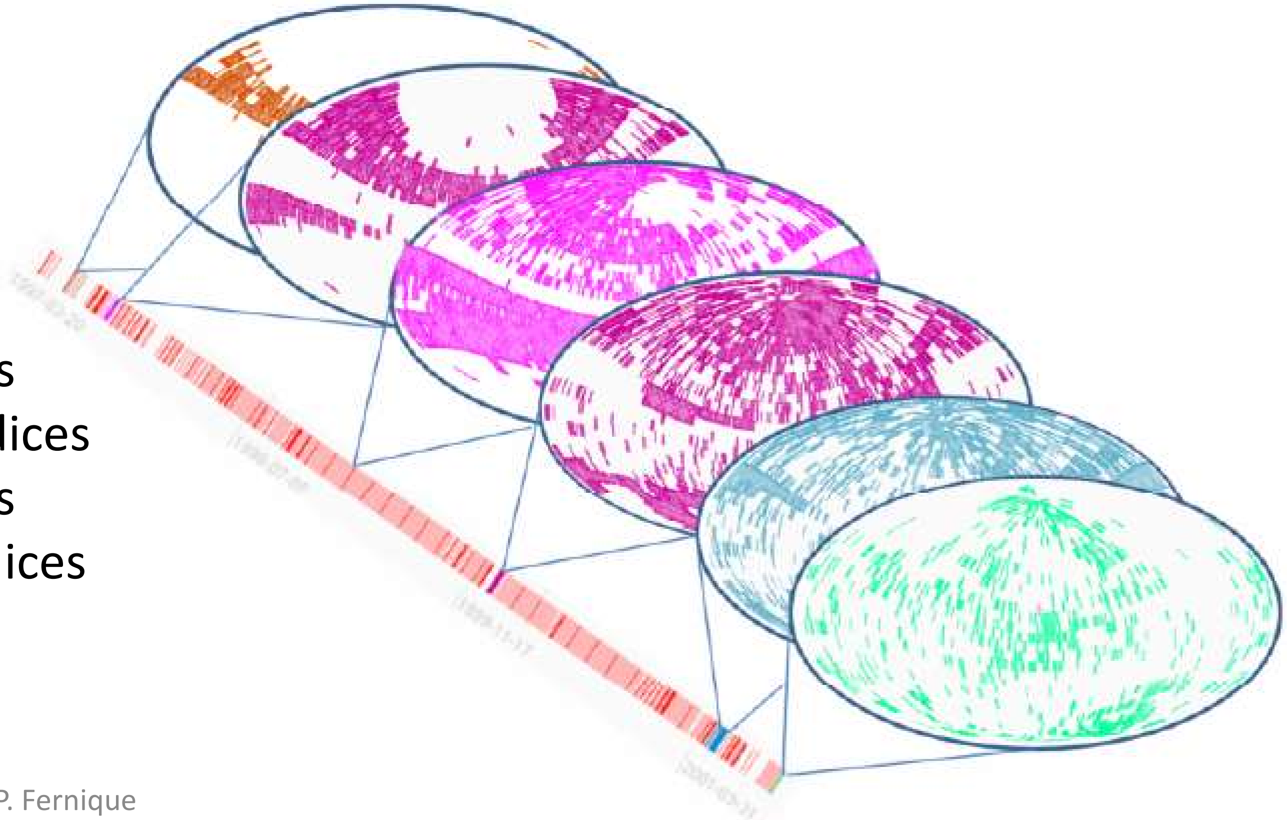
This way we can address 2^{62} cells in an unsigned 64-bit integer, i.e. a little bit more than 73000 years at 1μ resolution, enough for most astronomical time events.

- Able to address 73 000 years at 1µs resolution from JD=0

Time-Space combination

> Our approach is to combine these two dimensions - time and space - by associating to each time period (coded according to the TMOC convention), its spatial region (coded according to the SMOC convention). For that, we interleave the information of time coverage with the information of space coverage for this period.

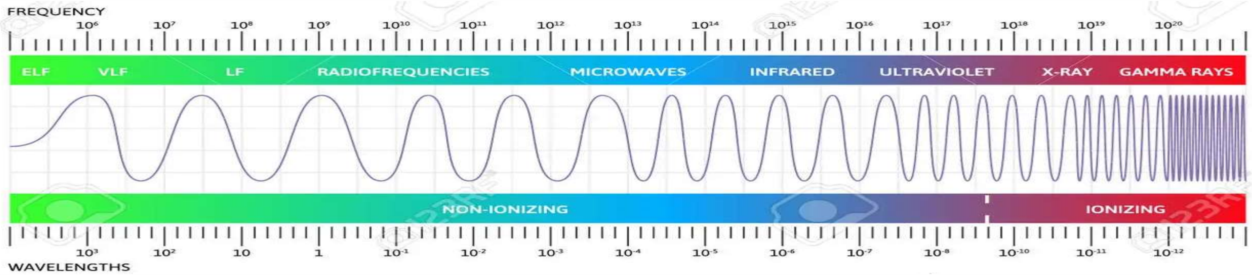
Time indices
-> **Space** indices
Time indices
-> **space** indices
…



What about Energy ? => FMOC

Proto 2021 - …

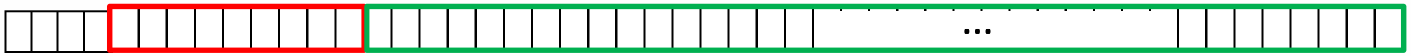
- Reuse the same MOC principles to handle **coverages** on the **electromagnetic axis**



- **Frequency** values map in FMOC coding as an **exponential** expression in 60 bits (idea F.X.Pineau & B.Cecconi)

Exponent
8 bits

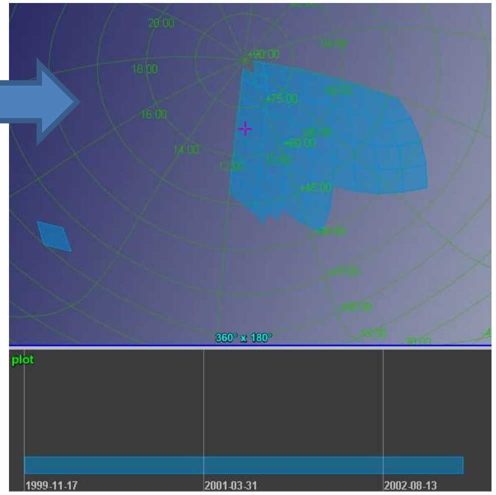
Mantissa
52 bits



☐ It all works perfectly!

Now **we have MOCs to describe coverage in space, time & energy**, as well as combinations (currently 2 to 2).

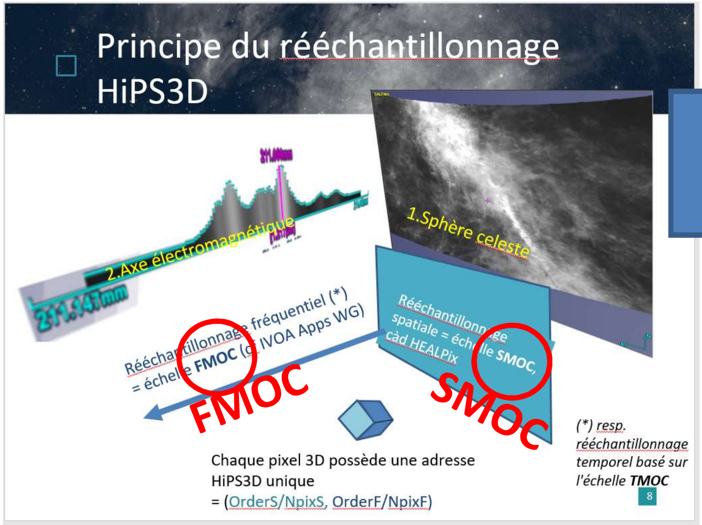
e.g. : ***t****16/6020-6022* ***s****3/128 4/345-510*

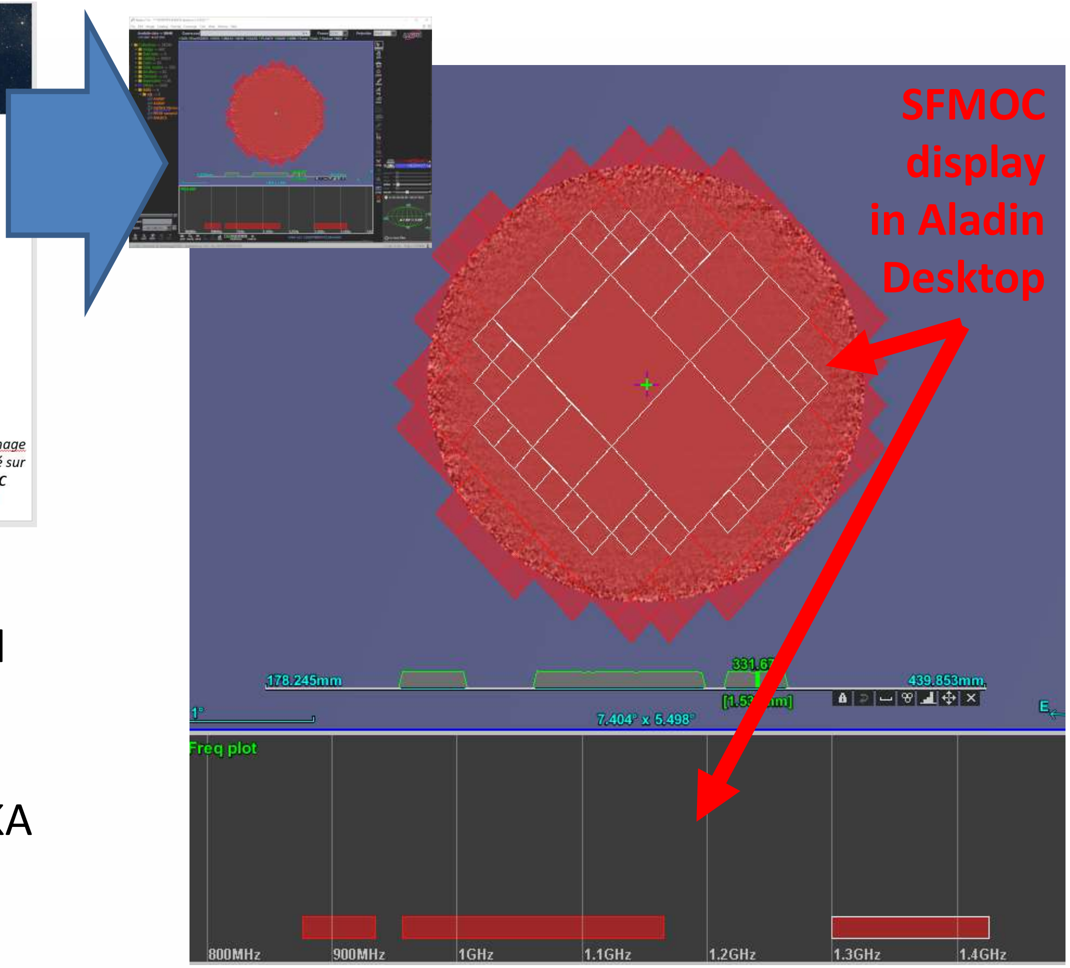


So why not extend our IVOA standards based on these generalized MOCs:

- **HiPS3D**: in progress…
- **VOEvent** 3.0 : currently under discussion
- **ObsCore :** discuss in this workshop
- **VO Registry** ?
- …

HiPS3D already fully based on **SF-MOC** principles





- Implemented in Hipsgen and AladinDesktop
- Very promising results (ADASS 2024, ASOV 2025, SKA SRC-FR…)

What about ObsCore?

- MOC **completes** and/or **duplicates** some ObsCore fields.
  - *s_ra/ s_dec / s_region / s_fov*
  - *t_min / t_max / t_exptime*
  - *em_min / em_max*
- Possible implementation:
  - Currently (proto): **MOC ASCII serialization** in **s_region**, but covering only spatial usecases
  - **Proposal**: define a **dedicated ObsCore field** whatever the MOC is [space, time, freq, or combinations)
    => "moc" ? "multid_coverage" ?

Questions ? Comments ? Suggestions ?