

Time-Frequency Catalogue Model & Format

- **Why?**

In low frequency radio astronomy, spectro-temporal features are key for science analysis.

- **Features:**

- planetary emissions (auroral, lightnings...)
- solar emissions

- **Geometries:**

- contour of feature (polygon, points...)
- crest line / shape of feature (line, points)

Jupiter DAM emissions (Nançay/NDA)

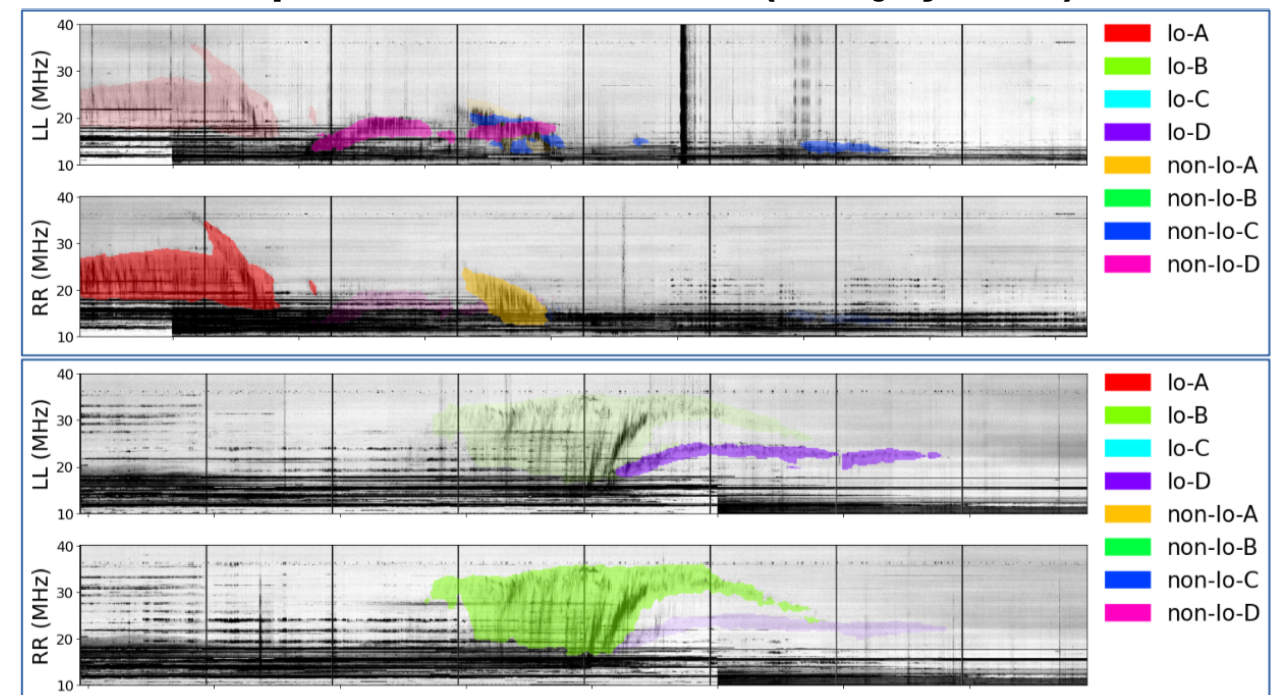
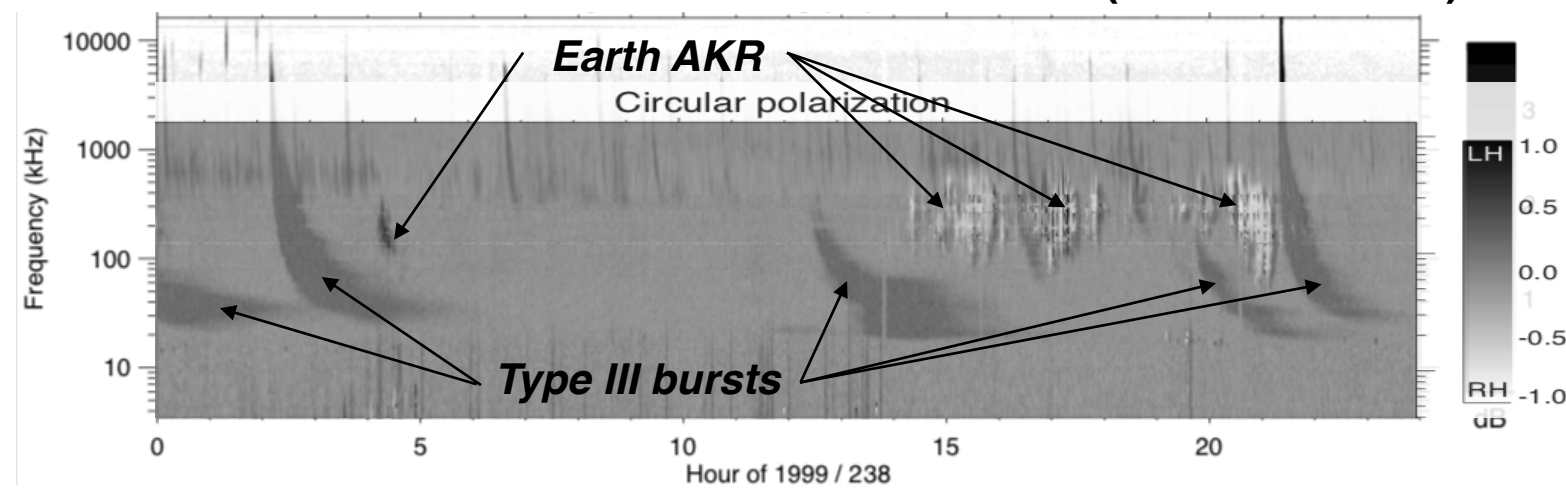


Figure 4. Spectrogrammes radio du NDA annotés, avec (en haut) le catalogue publié (Marques et al. 2017), (au milieu) les événements reconstruits pour la même observation, et (en bas), de nouveaux événements sur une observation récente (hors du catalogue d'entraînement).

Solar bursts + Earth AKR emissions (Cassini/RPWS)



Events and Catalogues

- **IVOA**

- VOTable => table (dates, spectral range...) + STC for geometry
- VOEvent => content + location (centroid)

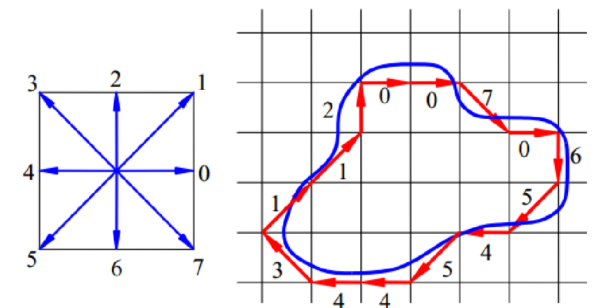
- **IHDEA**

- HPEventList => table with “main time” of event and other parameters (arbitrary, but simple tabular data)
- HPEventList serialisation = VOTable

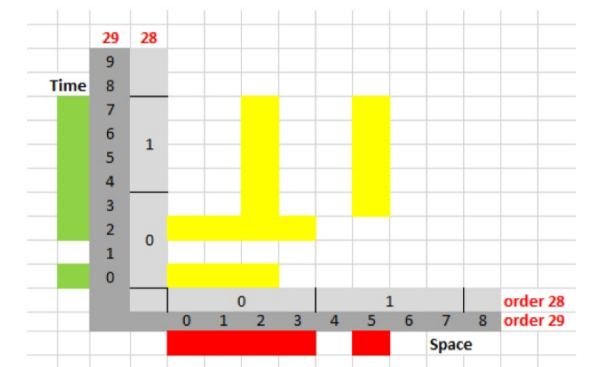
- **Geometries** (set of coordinates, with type)

- Images: *Chaincode* (starting point + step-by-steps directions in pixel coordinates)
- *VO-STC* (spatial regions, but no spectro-temporal coordinates)
- *VO-(ST)MOC* => Time-Spectral MOC ?
- *OGC-GeoJSON* => geo-referenced spatial features

Chaincode



STMOC



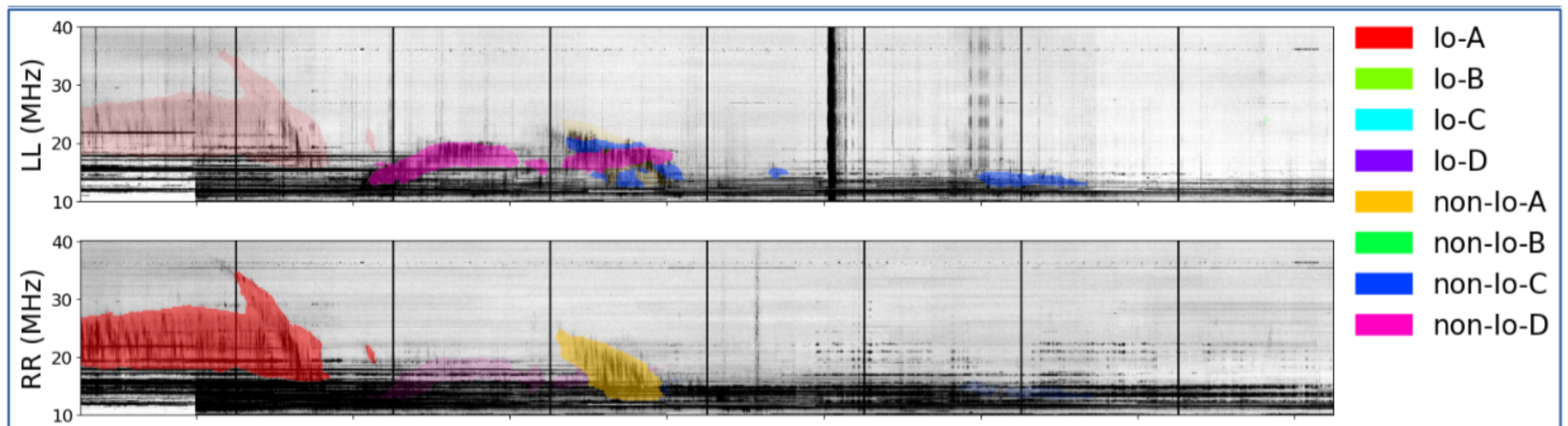
GeoJSON

```
{
  "type": "Feature",
  "geometry": {
    "type": "Point",
    "coordinates": [125.6, 10.1]
  },
  "properties": {
    "name": "Dinagat Islands"
  }
}
```

Plenty of Catalogues

Planetary radio emissions

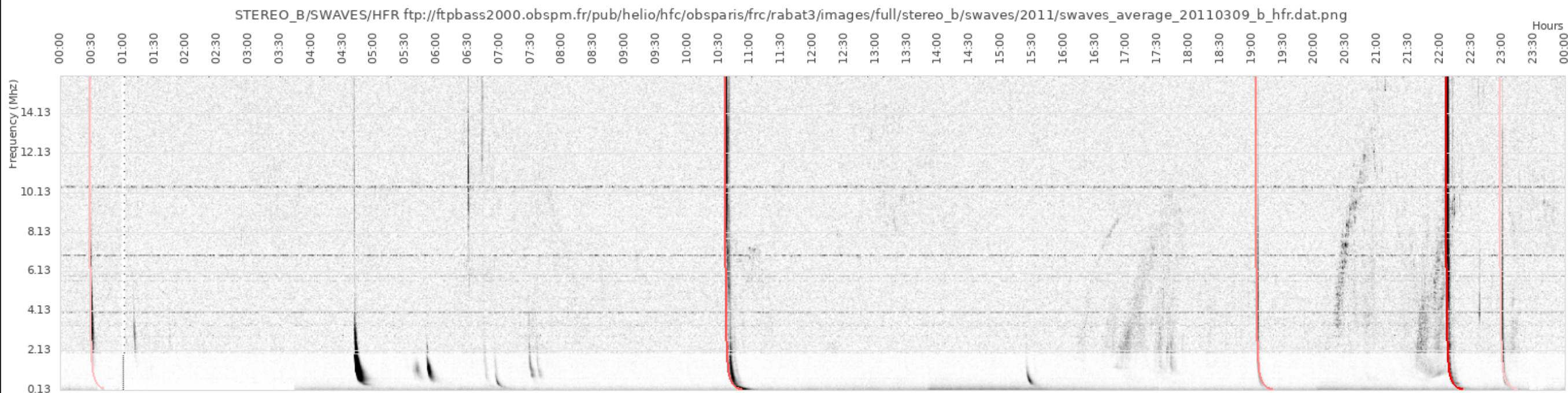
- Leblanc et al. A&A series (1981-1993): Jupiter
- Marques et al 2017 (Jupiter)
=> in Vizier, but not satisfactory format
(not really usable)
- Taubenschuss et al (2021) submitted (Saturn)
<https://doi.org/10.25935/R11G-6J63>
- many other, list being compiled
- ...



Plenty of Catalogues

Solar radio bursts

- Gopalswamy, N., Mäkelä, P., and Yashiro, S., “A Catalog of Type II radio bursts observed by Wind/WAVES and their Statistical Properties”, *Sun and Geosphere*, vol. 14, pp. 111–121, 2019. doi:10.31401/SunGeo.2019.02.03.
https://cdaw.gsfc.nasa.gov/CME_list/radio/waves_type2.html
- HELCATS FP7 Project:
https://www.helcats-fp7.eu/catalogues/wp7_cat.html
- HELIO Feature Catalogue: HFC.
<http://voparis-helio.obspm.fr/hfc-gui/>
- Kayser et al, A&A, Solar Type III bursts
<http://articles.adsabs.harvard.edu/pdf/1988A%26AS...73..243K>
- many other, list being compiled
...



TFCat Model

- A **TF-geometry** is a geometry (point, line-string, polygon, multi-points, multi-line-strings, multi-polygon), with coordinates in time and frequency (or wavelength, or wavenumber, or energy).
- The **catalogue contains a list of features**, with a TF-geometry (or a set of geometries), and parameters.
- The **catalogue contains a definition of the features additional properties**, with data type, description, unit, UCD, etc.
- The **catalogue contains a set of global properties**, at catalogue level, with data type, description, unit, UCD, etc.
- The **catalogue contains a description of the CRS** (coordinate reference system) defining the temporal and spectral axes, as well as the frame reference position.

TFCat Object Example

TFCat Object

Features

Feature #1

- Polygon([
 (t_{min},f_{min}),
 (t_{max},f_{min}),
 (t_{max},f_{max}),
 (t_{min},f_{max}),
 (t_{min},f_{min})
])
- obs_id=1
- polar="RH"

Feature #2

- Polygon([
 (t_{min},f_{min}),
 (t_{max},f_{min}),
 (t_{max},f_{max}),
 (t_{min},f_{max}),
 (t_{min},f_{min})
])
- obs_id=1
- polar="LH"

Feature #3

- Polygon([
 (t_{min},f_{min}),
 (t_{max},f_{min}),
 (t_{max},f_{max}),
 (t_{min},f_{max}),
 (t_{min},f_{min})
])
- obs_id=1
- polar="LH"

Feature #4

- Polygon([
 (t_{min},f_{min}),
 (t_{max},f_{min}),
 (t_{max},f_{max}),
 (t_{min},f_{max}),
 (t_{min},f_{min})
])
- obs_id=2
- polar="RH"

Feature #5

- Polygon([
 (t_{min},f_{min}),
 (t_{max},f_{min}),
 (t_{max},f_{max}),
 (t_{min},f_{max}),
 (t_{min},f_{min})
])
- obs_id=2
- polar="RH"

Fields

property

- name = obs_id
- info = "observation ID"
- ucd = "meta.id"
- datatype = "char"

property

- name = polar
- info = "Polarisation sense (RH or LH)"
- ucd = "meta.code;phys.polarization"
- datatype = "char"

CRS

time_coords

- ID = 'unix'
- name = 'UNIX Timestamp'
- scale = TT
- unit = s
- origin = 1970-01-01

spectral_coords

- name = "Frequency"
- unit = Hz

ref_position

- ID = Cassini

Properties

property

- name = instrument_host_name
- value = "Cassini/RPWS"

property

- name = instrument_name
- value = "RPWS"

property

- name = title
- value = "Faraday Rot. Patches"

property

- name = "bibref"
- value = "2004JGR20...40P"

property

- name = "authors"
- value = [...]

property

- name = "publisher"
- info = "PADC/MASER"

TFCat current implementation

- **Based on GeoJSON**, a catalogue model & format for geo-referenced shapes (on Earth, with lat-long coordinates).
- Using JSON for transport
- Implementation in Python reusing GeoJSON python library
- **With astronomy standards** when applicable:
 - Using IVOA vocabularies (UCD, VOUnits...) as much as possible
 - *STC1*: no support for *complex spectro-temporal geometries** / *STC2*: the same
 - *VOTable*: no support for *complex spectro-temporal geometries**
 - Use of TAP for distributing and searching?
 - Geometry in TAP and ADQL?
 - *Datalink* to link catalogue of feature to catalogue of observation?
 - Export to *Astropy* table: ok, possible for complex geometries (as objects)
- NB: *complex spectro-temporal geometries = something else than a point or a bounding box*

TFCat <=> VOTable

TFCat CRS model

TFCat/properties

TFCat/fields

TFCat/features

TFCat/CRS/properties/time_coords/scale

TFCat/CRS/properties/time_coords/origin (ISO)

TFCat/CRS/properties/time_coords/unit

TFCat/CRS/properties/spectral_coords/unit

TFCat/CRS/properties/ref_position/ID

IVOA VOTable model

VOTable/Resource/Params

VOTable/Resource/Fields

VOTable/Resource/Table

VOTable/Resource/TIMESYS/timescale

VOTable/Resource/TIMESYS/timeorigin (JD)

VOTable/Resource/FIELD/unit

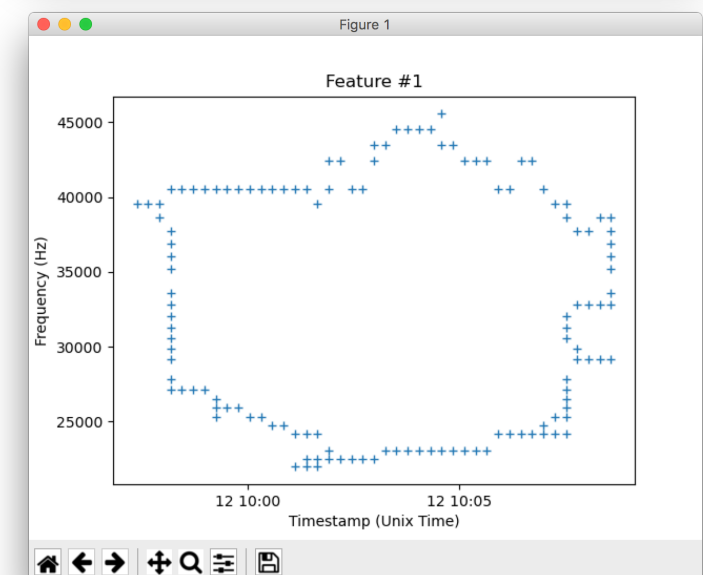
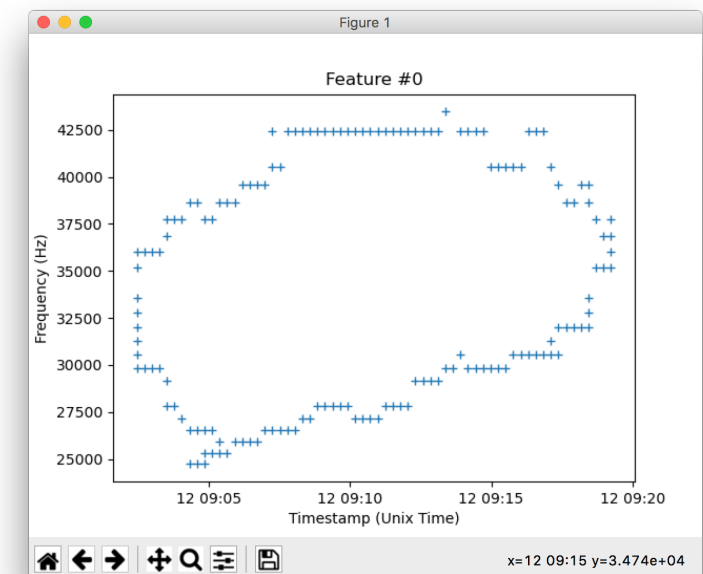
VOTable/Resource/FIELD/unit

VOTable/Resource/TIMESYS/refposition

TFCat material

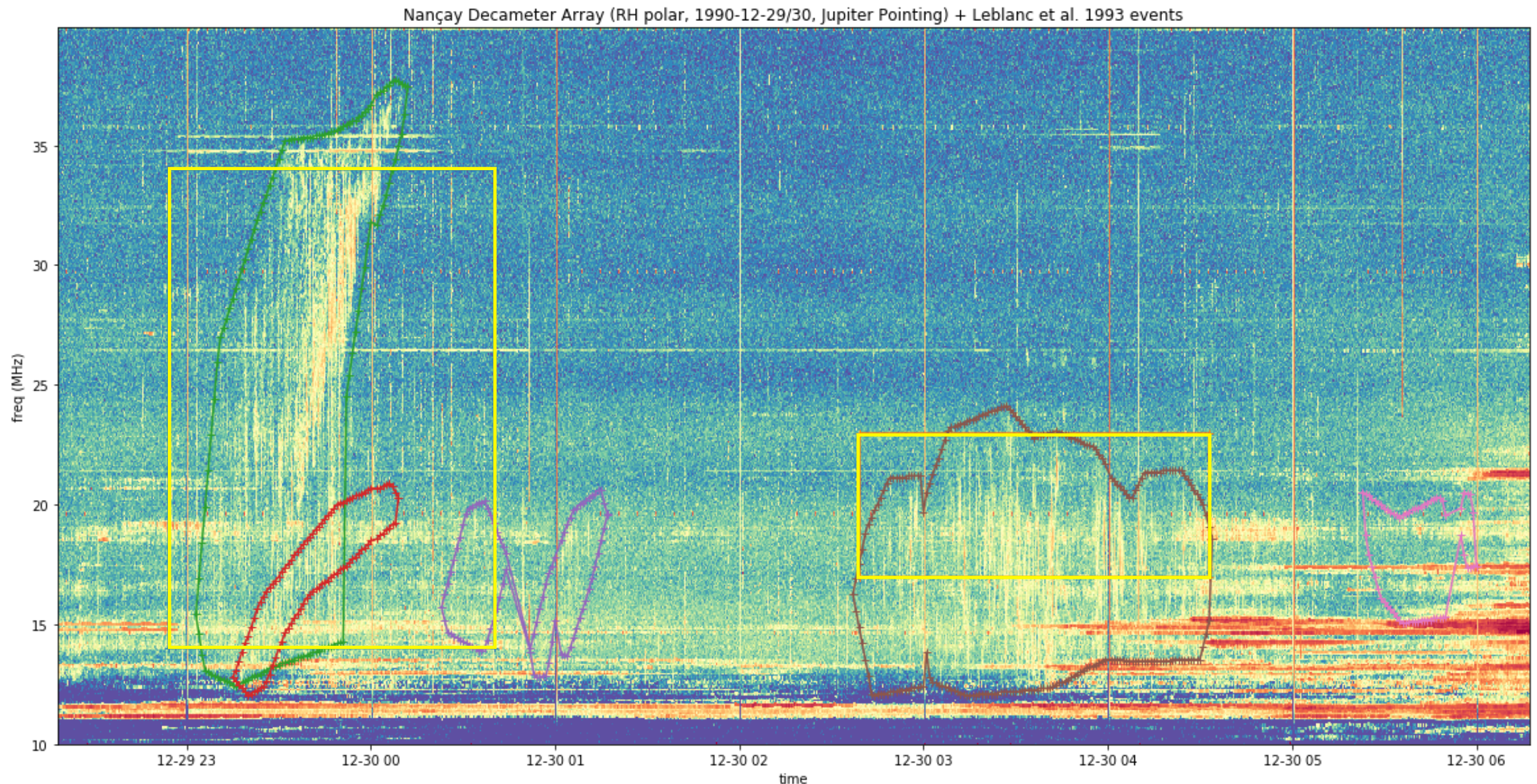
- TFCat catalogue specification:
<https://gitlab.obspm.fr/maser/catalogues/catalogue-format>
- TFCat python library (version 0.0.7):
<https://gitlab.obspm.fr/maser/catalogues/tfcats>

```
(tfcats) macbookbc:taubenschuss_2021 baptiste$ python
Python 3.7.10 | packaged by conda-forge | (default, Feb 19 2021, 15:59:12)
[Clang 11.0.1 ] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> from tfcats import TFCat
>>> tf_file = 'cassini_faraday_patches_2006.json'
>>> cat = TFCat.from_file(tf_file)
>>> cat.crs
{"name": "Time-Frequency", "properties": {"ref_position": {"id":
"Cassini"}, "spectral_coords": {"name": "Frequency", "unit": "Hz"},
"time_coords": {"id": "unix", "name": "Timestamp (Unix Time)",
"time_origin": "1970-01-01T00:00:00.000Z", "time_scale": "TT", "unit":
"s"}}}
>>> cat.plot_feature(0)
>>> cat.plot_feature(1)
>>> cat.crs.time_converter(cat.feature(0).tmin).isot
'2006-09-12T09:02:26.750'
>>> cat.crs.spectral_converter(cat.feature(0).fmax)
<Quantity 43469. Hz>
```



Example: TFCat + Das2

- Data loaded from Nançay Das2 server (daspy), catalogue from 2 catalogues (Leblanc 1993 & Marques 2017)



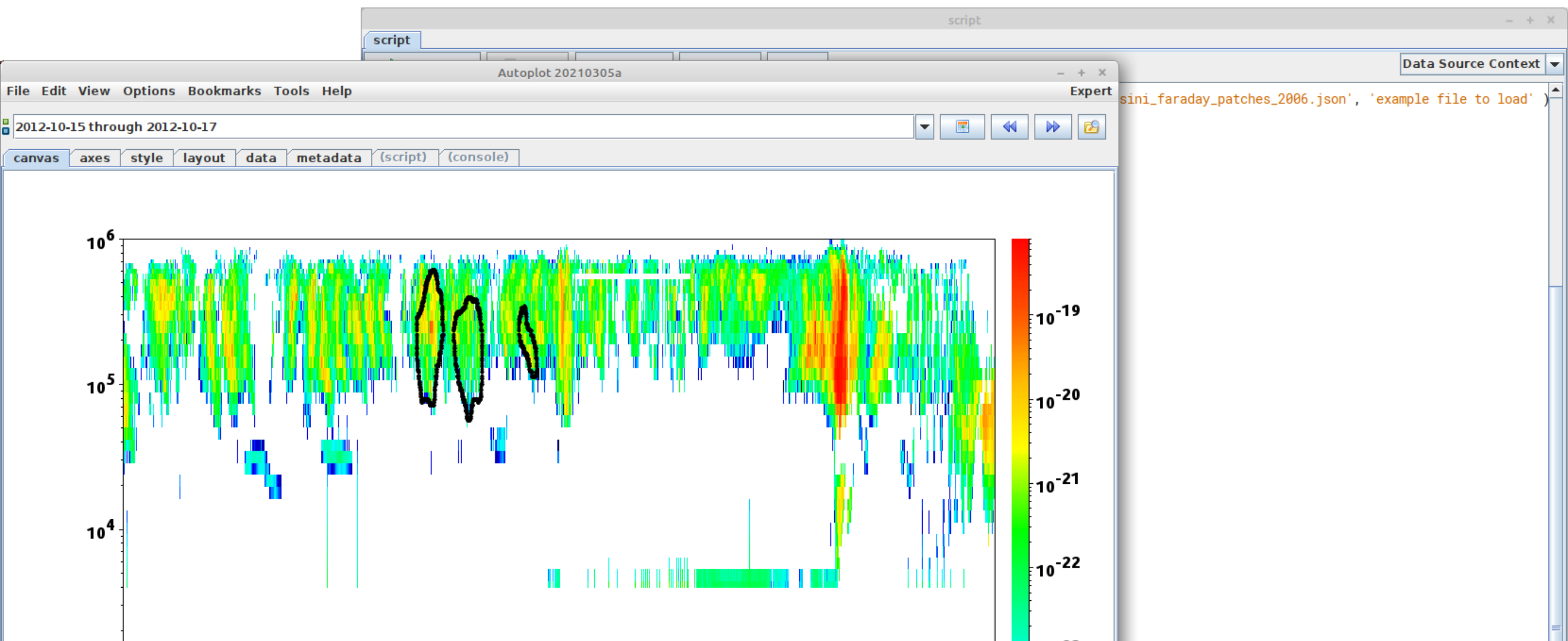
TFCat + TAP exploration

- 1 Feature per row, Geometry as JSON string, Feature mapped properties into columns
- JSON-string allows to keep all information (geometry type, CRS, coordinates) of Feature for future use.

Id	Time_start	Time_end	Freq_min [Hz]	Freq_max [Hz]	Geometry_type	Geometry	Quality	Area [s.Hz]	Nop
cassini_faraday_patches_2006-emi-0	2006-09-12T09:02:26.750000	2006-09-12T09:19:14.740000	24730.0	43469.0	MultiPoint	<pre>{ "type": "Feature", "crs": { "name": "Time-Frequency", "properties": { "time_coords": { "id": "unix", "name": "Timestamp (Unix Time)", "unit": "s", "time_origin": "1970-01-01T00:00:00.000Z", "time_scale": "TT", "spectral_coords": { "name": "Frequency", "unit": "Hz", "ref_position": { "id": "Cassini" } } } } }, "geometry": { "type": "MultiPoint", "coordinates": [[1158051858.75, 24730.0], [1158051874.75, 24730.0], [1158051890.75, 24730.0], [1158051890.75, 25318.0], [1158051938.75, 25318.0], [1158051970.75, 25920.0], [1158051970.75, 25920.0], [1158051858.75, 26536.0], [1158051906.75, 26536.0], [1158052050.75, 26536.0], [1158051842.75, 27167.0], [1158052210.75, 27167.0], [1158052258.75, 27167.0], [1158052130.75, 27813.0], [1158052178.75, 27813.0], [1158052290.74, 27813.0], [1158051810.75, 29152.0], [1158052370.74, 29152.0], [1158051762.75, 29845.0], [1158052402.74, 29845.0], [1158052466.74, 29845.0], [1158052514.74, 29845.0], [1158052530.74, 29845.0], [1158051746.75, 30555.0], [1158052434.74, 30555.0], [1158052546.74, 30555.0], [1158052562.74, 30555.0], [1158052578.74, 30555.0], [1158052594.74, 30555.0], [1158052610.74, 30555.0], [1158052626.74, 30555.0], [1158052642.74, 30555.0], [1158051746.75, 31282.0], [1158052626.74, 31282.0], [1158051746.75, 32025.0], [1158052642.74, 32025.0], [1158052658.74, 32025.0], [1158052674.74, 32025.0], [1158052690.74, 32025.0], [1158052706.74, 32025.0], [1158051746.75, 32787.0], [1158052706.74, 32787.0], [1158051746.75, 33567.0], [1158052706.74, 33567.0], [1158051746.75, 35182.0], [1158052722.74, 35182.0], [1158052738.74, 35182.0], [1158052754.74, 35182.0], [1158051746.75, 36019.0], [1158051762.75, 36019.0], [1158051778.75, 36019.0], [1158051794.75, 36019.0], [1158052754.74, 36019.0], [1158051810.75, 36875.0], [1158052738.74, 36875.0], [1158052754.74, 36875.0], [1158051810.75, 37752.0], [1158051826.75, 37752.0], [1158051842.75, 37752.0], [1158051890.75, 37752.0], [1158051906.75, 37752.0], [1158052722.74, 37752.0], [1158052754.74, 37752.0], [1158051858.75, 38650.0]] } }</pre>	2	12025431.0	880

TFCat + Autoplot

- Autoplot = “heliophysics” tool for timeseries and spectrograms
Cassini/RPWS data (das2) + a TFCat catalogue:



Other use cases ?

- Astronomy transients: Pulsars, FRB, GW, CTA... for Machine Learning training sets?

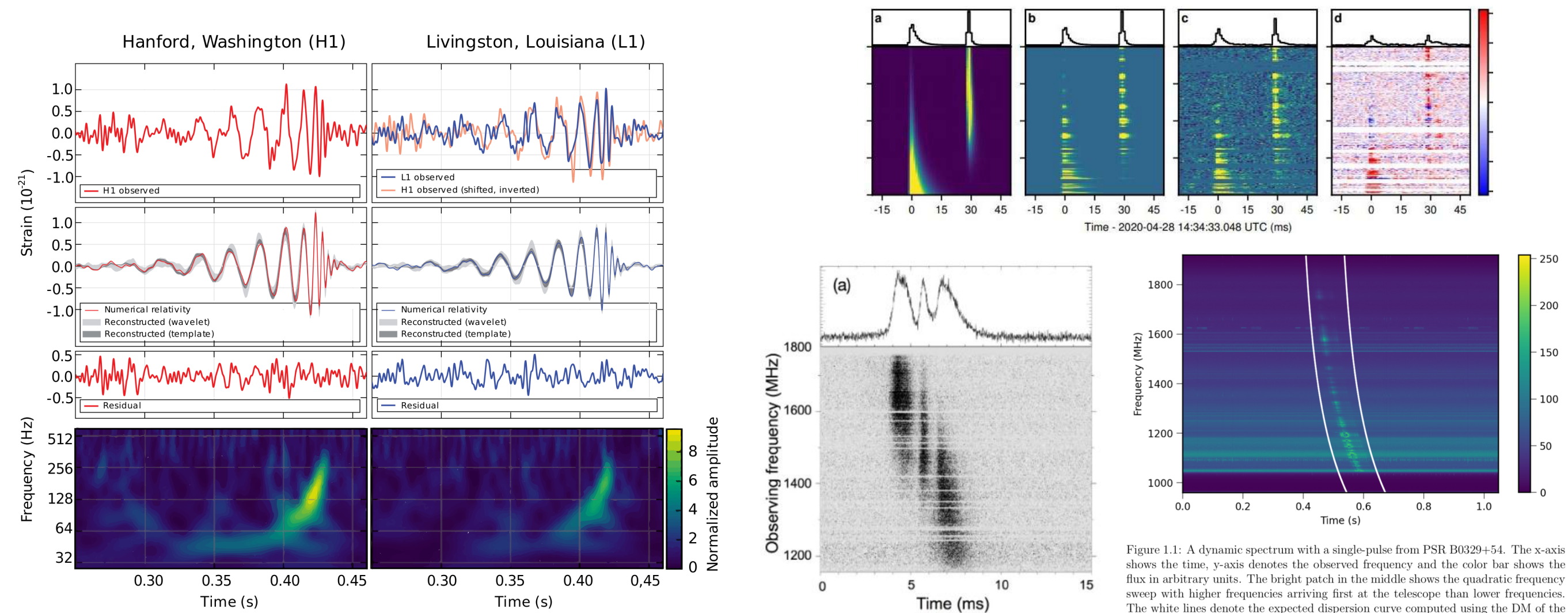


Figure 1.1: A dynamic spectrum with a single-pulse from PSR B0329+54. The x-axis shows the time, y-axis denotes the observed frequency and the color bar shows the flux in arbitrary units. The bright patch in the middle shows the quadratic frequency sweep with higher frequencies arriving first at the telescope than lower frequencies. The white lines denote the expected dispersion curve computed using the DM of the pulsar.