Enhancing Radio Data Access and Usage with the Virtual Observatory

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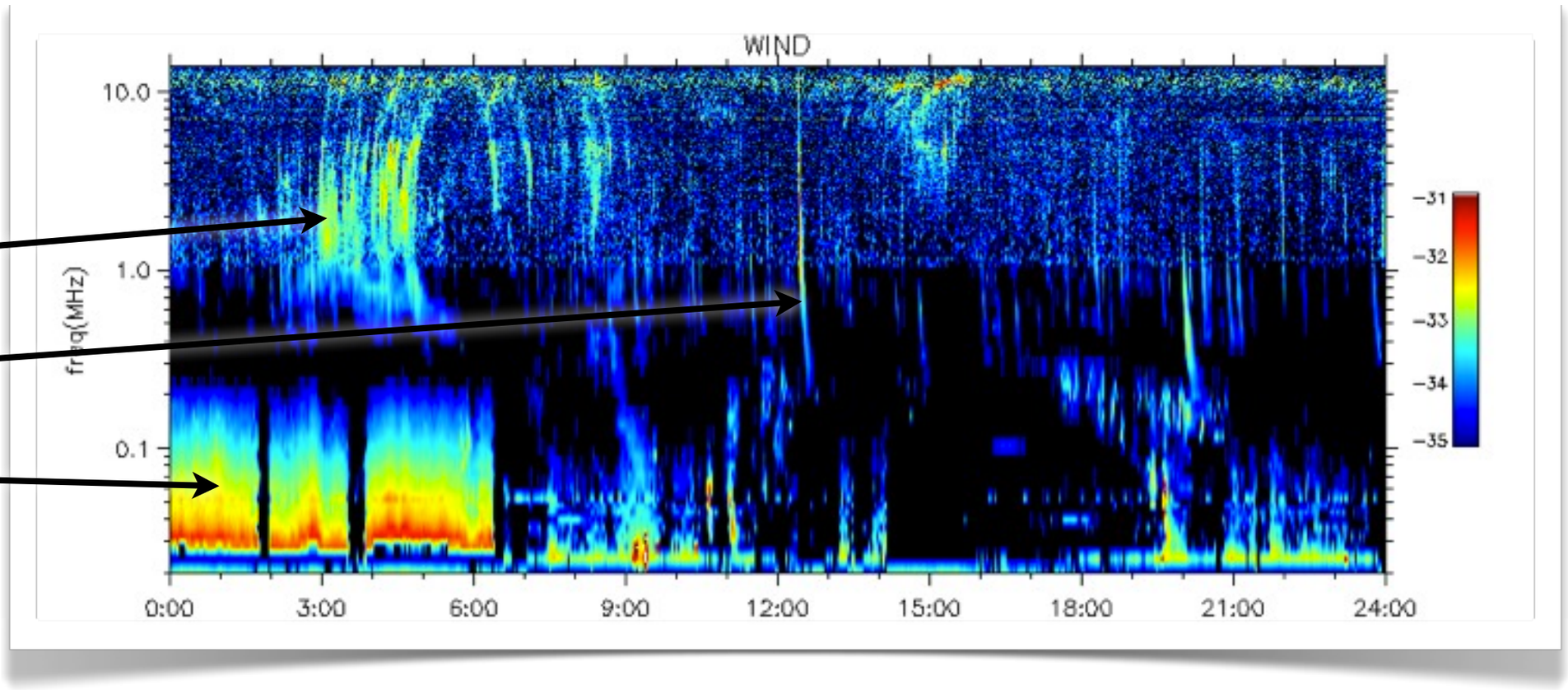
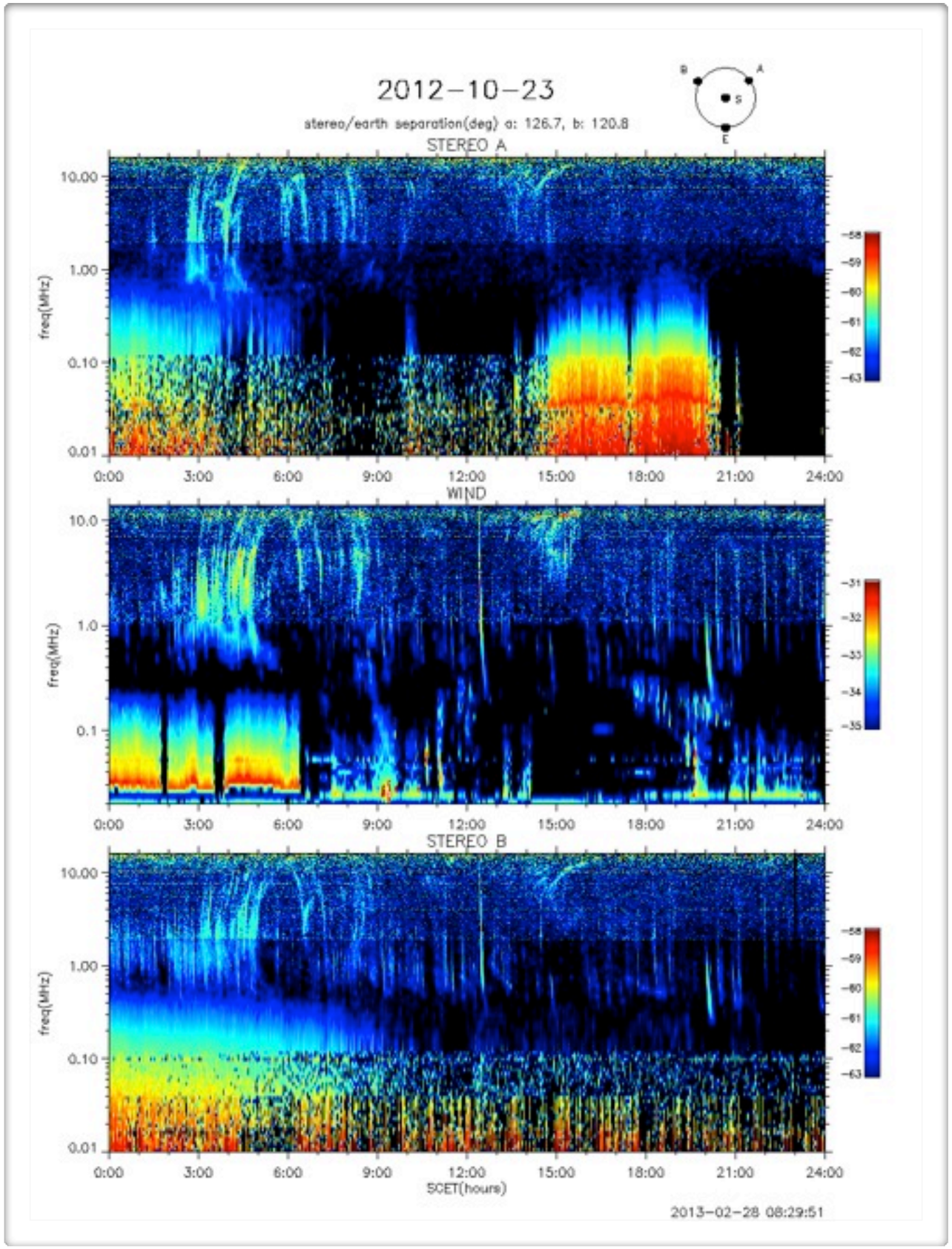
Low Frequency radio data

- Frequency band:
  - a few kHz to ~50 MHz
- Solar system sources:
  - magnetized planets (auroral emissions)
  - the Sun
- Data:
  - type: dynamic spectra
  - main physical parameters: spectral flux density, polarization degree



Low Frequency radio data

- Radio emissions are: sporadic and temporally variable
- Radio emissions are not isotropic !
  Observer/Source geometry must be taken into account
- Time-Frequency shape is a characteristic of the radio emission physics
  (no fixed frequency lines!)



Existing databases

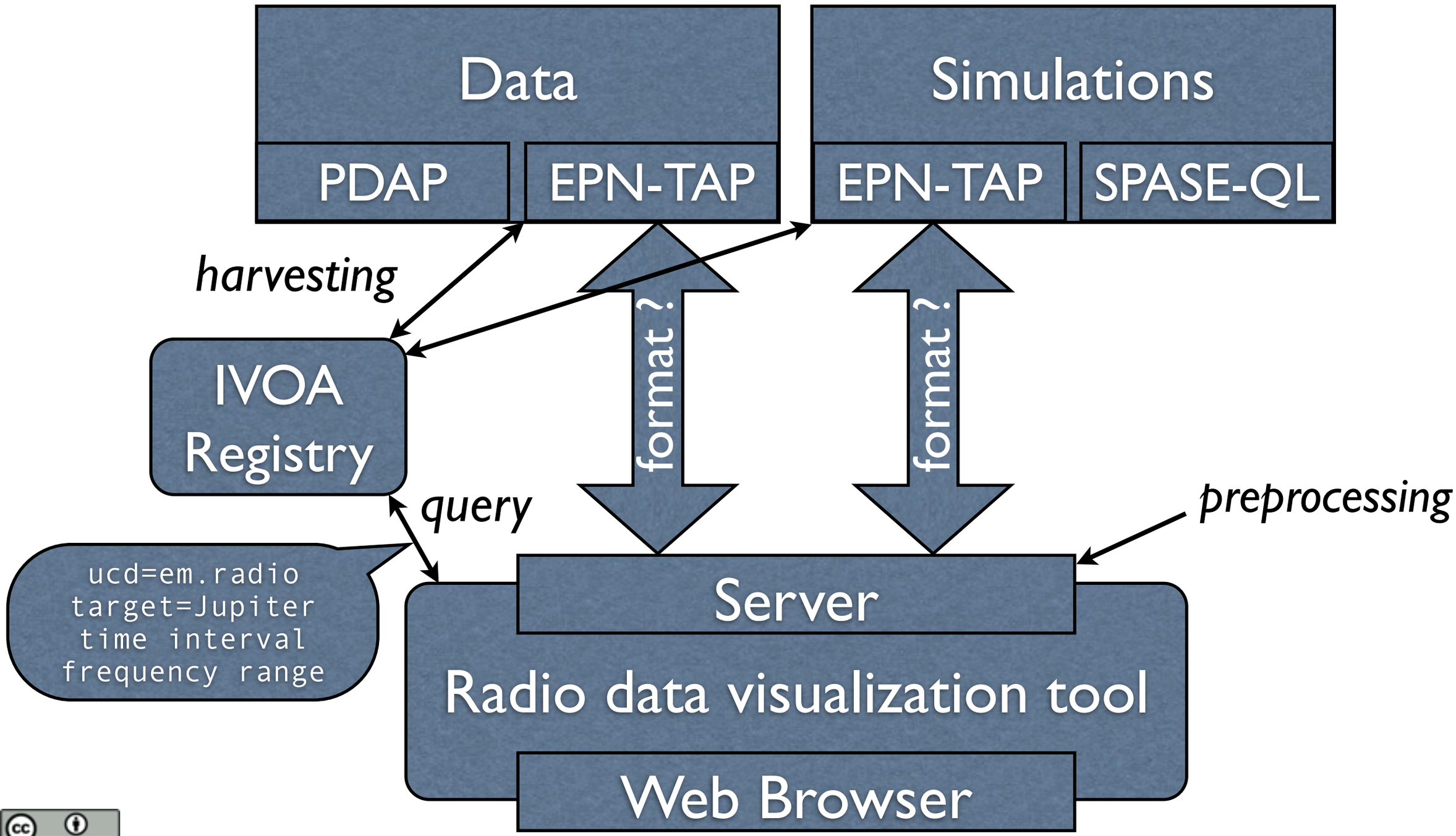
Agency	Science Objective	Archive (format)	Missions / Observatory	Access
NASA	Planetary	PDS (PDS, *CDF*)	Voyager, Galileo, Cassini, JUNO	HTTP, FTP
NASA	Sun-Earth	CDAweb (CDF)	WIND, STEREO	HTTP, WSDL
ESA	Planetary	PSA (PDS, *CDF*)	Bepi-Colombo/MPO, JUICE	HTTP, FTP, PDAP
JAXA	Earth, Planets	DARTS (CDF, PDS)	Geotail, Bepi-Colombo/MMO	HTTP, PDAP
CNES	All	CDPP (CDF, native)	Interball, Cluster, Viking (Swedish), Cassini, STEREO	HTTP, WSDL, EPN-TAP
Obs. Paris	Jupiter, Sun	RDN (Native, FITS, VOTable)	Nançay Decameter Array	HTTP, EPN-TAP
Tohoku Univ.	Jupiter, Sun	Iitate (FITS)	Iitate Observatory	HTTP
ETH Zurich	Sun	e-Callisto (FITS)	Plenty of stations all over the world.	HTTP
LOFAR	All	(HDF5)	LOFAR proposals	Not defined yet

Tab. 1. List (non exhaustive) of existing databases providing low frequency radio data. Data formats in italics are for not yet approved formats in the corresponding database.

- Standard metadata format: (PDS3), PDS4, SPASE, IVOA, CDPP...
  Standard data format: Text, Binary, CDF, NetCDF, VOtable, HDF5, FITS...

- Simulation database:
  - ExPRES (Exoplanetary and Planetary Radio Emission Simulator)

Architecture (projet)



Formats & Protocoles

- **Data formats currently under study:** VOTable, CDF, FITS
- **Future study**: *NetCDF, HDF5*
- **EPN-TAP as query protocol:**
  - developed in the frame of the Europlanet(EPN)/IDIS project.
  - based of IVOA TAP (Table Access Protocol) + keywords for solar system science.
  - implemented for:
    - Nançay (Decameter Array Routine Observations)
    - CDPP/AMDA (e.g., Galileo/PWS data)
  - planned:
    - Cassini/LESIA (Cassini/RPWS data)
    - ExPRES/LESIA-LATMOS (simulation database)
- **Implementation of EPN-TAP:**
  - using DaCHS framework developed and maintained by Markus Demleitner (from GAVO)
  - very easy process: full tutorial available at VOParis
  - VOParis team willing to help data providers to set up their services

Distributing data with VOTable

- Using Spectrum DM from IVOA and UCDs (including those proposed in: http://www.ivoa.net/Documents/Notes/Polarization/20100203/NOTE-Polarization-1.0-20100203.pdf)

- Tests with Nançay and Cassini data:

- Nançay (format 1):

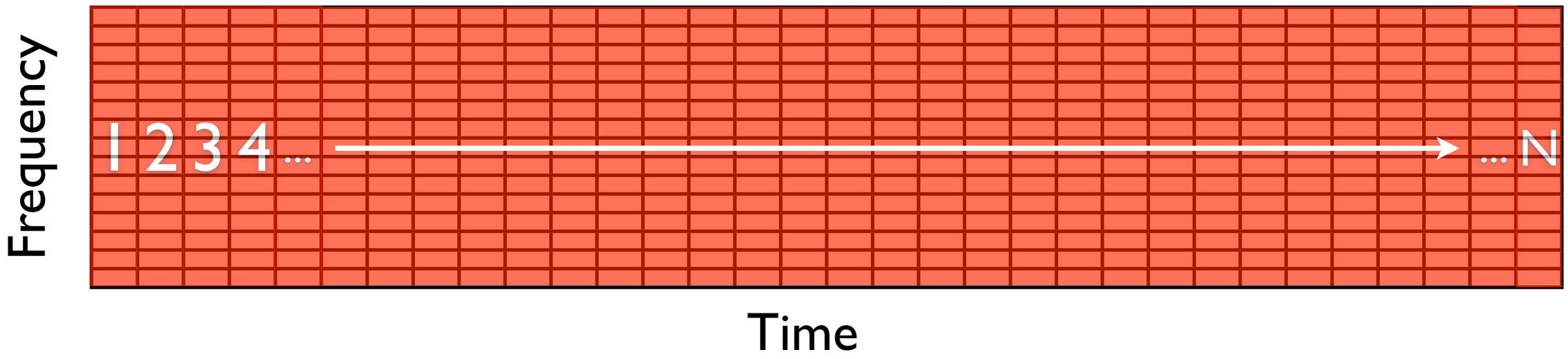
Spectrum: 400 frequencies (10-40 MHz)
Cadence: 1 spectrum per second, left and right hand polarization.
VOTable: 1 column contains 400 values.
Spectral axis (values, resolution...) is defined separately in the metadata of the VOtable

- Cassini (format 2):

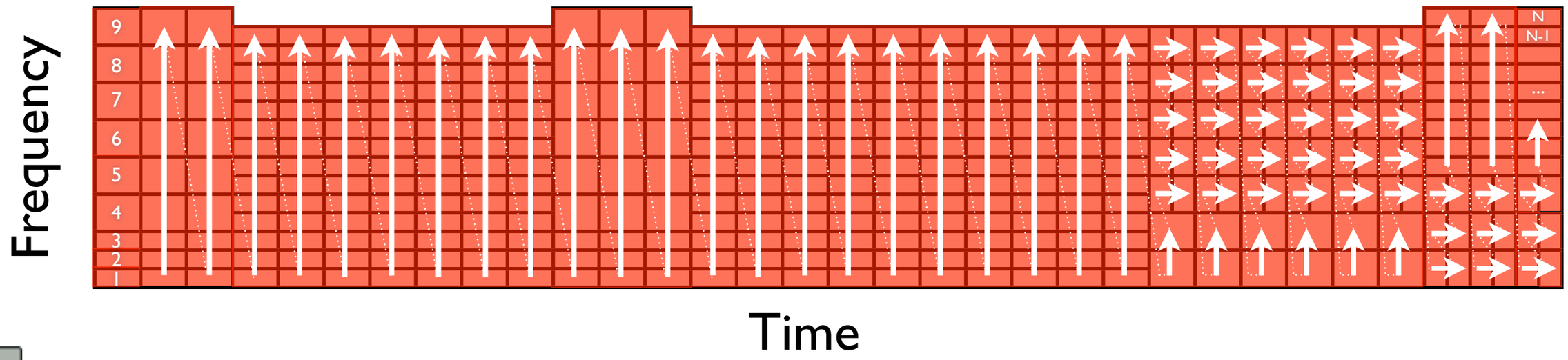
Spectrum: 150 to 300 frequencies [variable!] (3 kHz-16 MHz)
Cadence: 1 spectrum every 20 to 60 seconds (depending on the spectral and temporal resolution)
VOTable: 1 line = 1 «time-frequency» record

Distributing data with VOTable

- Format 1: *single spectral sampling*



- Format 2 : *variable spectral (and temporal) sampling*



VOTable (format 1)
(fixed number of frequencies)

```
<?xml version="1.0" encoding="UTF-8"?>
<VOTABLE version="1.2" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xmlns:spec="http://www.ivoa.net/xml/Spectrum/Spectrum-1.01.xsd"
    xmlns="http://www.ivoa.net/xml/VOTable/v1.2"
    xsi:schemaLocation="http://www.ivoa.net/xml/Spectrum/Spectrum-1.01.xsd http://www.ivoa.net/xml/Spectrum/Spectrum-1.01.xsd
    http://www.ivoa.net/xml/VOTable/v1.2 http://www.ivoa.net/xml/VOTable/v1.2">

    <RESOURCE name="Nancay DAM Jupiter data (2012-10-31)">
        <DESCRIPTION>
            <![CDATA[
        Jovian radio emissions routine observations from Nançay Decameter Array, Nançay, France.
        Website: http://www.obs-nancay.fr
        EPN-TAP server: http://vogate.obs-nancay.fr/__system__/tap/run/tap
        EPN-TAP Database Name: dam.epn_core

        This dataset contains two series of dynamic spectra recorded on each of the Nançay decameter
        sub-arrays (i.e. on Left Hand and Right Hand Polarization). The receiver is sampling from 10
        MHz to 40 MHz with 75 kHz steps on the spectral axis. It records one spectrum every second on
        each polarization. The list of observation frequencies is provided.
        ]]>
        </DESCRIPTION>
        <GROUP ID="freq_table" utype="spec:Char.SpectralAxis">
            <PARAM value="Frequency" datatype="char" arraysize="*" name="Spectral Axis Name"
                utype="spec:Char.SpectralAxis.Name"/>
            <PARAM datatype="int" name="Number of Frequencies" ucd="meta.number" value="400"
                utype="spec:Length"/>
            <PARAM value="10.0000" datatype="float" name="Minimum Frequency" unit="MHz"
                ucd="em.freq" utype="spec:Char.SpectralAxis.Coverage.Bounds.Range.Min"/>
            <PARAM value="40.0000" datatype="float" name="Maximum Frequency" unit="MHz"
                ucd="em.freq" utype="spec:Char.SpectralAxis.Coverage.Bounds.Range.Max"/>
            <PARAM datatype="float" name="Frequency" unit="MHz" ucd="em.freq" arraysize="400"
                utype="spec:Char.SpectralAxis.Coverage.Location.Value"
                value="10.0000 10.0750 10.1500 10.2250 10.3000 10.3750 10.4500 10.5250
                10.6000 10.6750 10.7500 10.8250 10.9000 10.9750 11.0500 11.1250 11.2000
                11.2750 11.3500 11.4250 11.5000 11.5750 11.6500 11.7250 11.8000 11.8750
                11.9500 12.0250 12.1000 12.1750 12.2500 12.3250 12.4000 12.4750 12.5500
                12.6250 12.7000 12.7750 12.8500 12.9250 13.0000 13.0750 13.1500 13.2250
                13.3000 13.3750 13.4500 13.5250 13.6000 13.6750 13.7500 13.8250 13.9000
                13.9750 14.0500 14.1250 14.2000 14.2750 14.3500 14.4250 14.5000 14.5750
```

ID=«freq_table»

spectrum DM

frequency list

VOTable (format 1)
(fixed number of frequencies)

```
<TABLE name="Left Hand Polarization Data Table">
    <FIELD datatype="double" name="Time (Julian Day)" ucd="time.epoch" xtype="julianDay"
        unit="d"/>
    <FIELD datatype="char" arraysize="24" name="Time (ISO)" ucd="time.epoch"
        xtype="dateTime"/>
    <FIELD datatype="float" arraysize="400" name="Spectral Power Density" ref="freq_table"
        unit="dB(V2/Hz)" ucd="phot.flux.density;phys.polarization.circular.LL;em.radio"/>
    <FIELD datatype="unsignedByte" arraysize="1" ucd="meta.code" name="code"/>
    <DATA>
        <BINARY>
            <STREAM/>
        </BINARY>
    </DATA>
</TABLE>
<TABLE name="Right Hand Polarization Data Table">
    <FIELD datatype="double" name="Time (Julian Day)" ucd="time.epoch" xtype="julianDay"
        unit="d"/>
    <FIELD datatype="char" arraysize="24" name="Time (ISO)" ucd="time.epoch"
        xtype="dateTime"/>
    <FIELD datatype="float" arraysize="400" name="Spectral Power Density" ref="freq_table"
        unit="dB(V2/Hz)" ucd="phot.flux.density;phys.polarization.circular.RR;em.radio"/>
    <FIELD datatype="unsignedByte" arraysize="1" ucd="meta.code" name="code"/>
    <DATA>
        <BINARY>
            <STREAM/>
        </BINARY>
    </DATA>
</TABLE>
```

ref=«freq_table»

UCDs

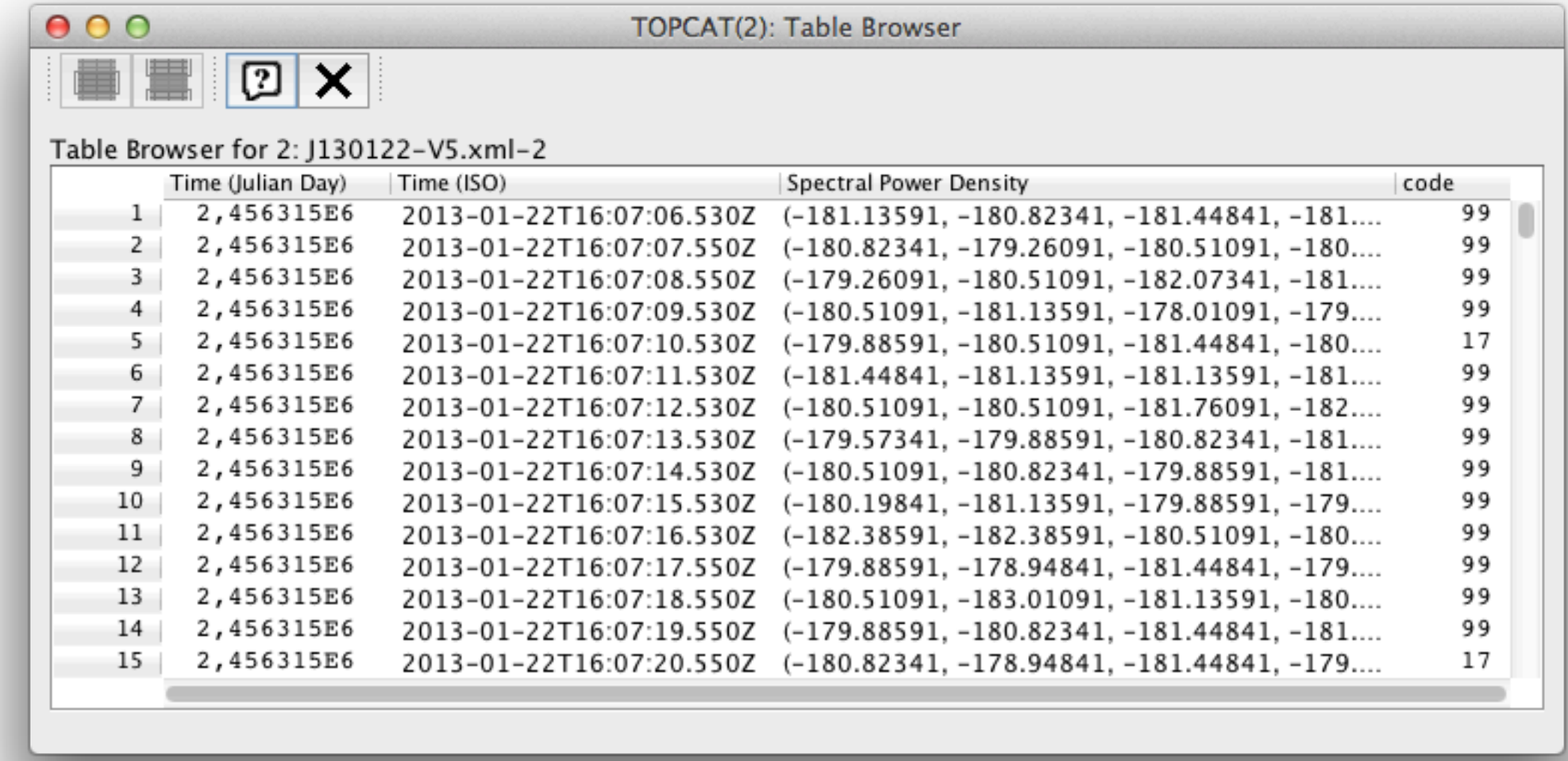
VOTable (format 1)
(fixed number of frequencies)

- **Specification:**
  - a group must be declared as `<GROUP ID=«freq_table»>`.
  It must contain the spectral axis information (min, max, values, resolution...) linking to the Spectrum DM using utypes.
  - each line of the table corresponds to an observation date
  - each column (defined with a `FIELD` element) containing a spectrum must have a reference to the spectral axis group (`ref=«freq_table»`).
  It is possible to have as many spectral columns as available observables.
  - Several frequency table groups may be defined if necessary.
  - Base64 encoding is recommended but not mandatory.

- **Advantages:**
  - the spectral structure of the data is preserved.

- **Drawback:**
  - TOPCAT can not plot data from multi-valued columns.

VOTable (format 1)
(fixed number of frequencies)



	Time (Julian Day)	Time (ISO)	Spectral Power Density	code
1	2,456315E6	2013-01-22T16:07:06.530Z	(-181.13591, -180.82341, -181.44841, -181....	99
2	2,456315E6	2013-01-22T16:07:07.550Z	(-180.82341, -179.26091, -180.51091, -180....	99
3	2,456315E6	2013-01-22T16:07:08.550Z	(-179.26091, -180.51091, -182.07341, -181....	99
4	2,456315E6	2013-01-22T16:07:09.530Z	(-180.51091, -181.13591, -178.01091, -179....	99
5	2,456315E6	2013-01-22T16:07:10.530Z	(-179.88591, -180.51091, -181.44841, -180....	17
6	2,456315E6	2013-01-22T16:07:11.530Z	(-181.44841, -181.13591, -181.13591, -181....	99
7	2,456315E6	2013-01-22T16:07:12.530Z	(-180.51091, -180.51091, -181.76091, -182....	99
8	2,456315E6	2013-01-22T16:07:13.530Z	(-179.57341, -179.88591, -180.82341, -181....	99
9	2,456315E6	2013-01-22T16:07:14.530Z	(-180.51091, -180.82341, -179.88591, -181....	99
10	2,456315E6	2013-01-22T16:07:15.530Z	(-180.19841, -181.13591, -179.88591, -179....	99
11	2,456315E6	2013-01-22T16:07:16.530Z	(-182.38591, -182.38591, -180.51091, -180....	99
12	2,456315E6	2013-01-22T16:07:17.550Z	(-179.88591, -178.94841, -181.44841, -179....	99
13	2,456315E6	2013-01-22T16:07:18.550Z	(-180.51091, -183.01091, -181.13591, -180....	99
14	2,456315E6	2013-01-22T16:07:19.550Z	(-179.88591, -180.82341, -181.44841, -181....	99
15	2,456315E6	2013-01-22T16:07:20.550Z	(-180.82341, -178.94841, -181.44841, -179....	17

VOTable (format 2)
(variable number of frequencies)

```
<?xml version="1.0" encoding="UTF-8" standalone="no" ?>
<VOTABLE xmlns="http://www.ivoa.net/xml/VOTable/v1.2"
    xmlns:spase="http://www.spase-group.org/data/schema"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://www.spase-group.org/data/schema http://www.spase-group.org/data/schema/spase-2_2_1.xsd
http://www.ivoa.net/xml/VOTable/v1.2 http://www.ivoa.net/xml/VOTable/v1.2">
    <RESOURCE name="loc_3A_SPV_2008268.18">
        <TABLE>
            <DESCRIPTION><![CDATA[SKR Location data file from Cassini/RPWS/HFR 3 Antenna GP data. SPV Magnetic Field
model. Source files: P2008268.18[N2], N3b_dsq2008268.18[N3b], loc_3A_SPV_2008268.18[loc]. The data set contains 17 fields:
time (ISO-8601), frequency (kHz), Antenna configuration code, SNR on Channel 1 (dB), SNR on Channel 2 (dB), Stokes S
(power density in V^2/Hz), Stokes Q (linear polarization degree, in percent), Stokes U (linear polarization degree, in
percent), Stokes V (circular polarization degree, in percent), Cartesian coordinates of source in Saturn Solar Equatorial
frame (in Saturn Radii, Rs), Spherical coordinates of source magnetic footprint (radial distance in Rs, latitude and
(sub-solar) longitude in degrees), source beaming angle (in degrees), quality parameter distance (best data are for
distance = 0).]]></DESCRIPTION>
            <GROUP name="Time Range" utype="spase:Catalog/TimeSpan">
                <PARAM arraysize="*" datatype="char" name="Catalog Start Time" ucd="time.start"
                    utype="spase:Catalog/TimeSpan/StartDate" value="2008-09-24T18:00:00.000Z"
                    xtype="dateTime"/>
                <PARAM arraysize="*" datatype="char" name="Catalog Stop Time" ucd="time.stop"
                    utype="spase:Catalog/TimeSpan/StopDate" value="2008-09-24T18:59:99.999Z"
                    xtype="dateTime"/>
            </GROUP>
            <GROUP name="Contact" ucd="meta.id">
                <PARAM arraysize="*" datatype="char" name="Name" utype="spase:Person/PersonName"
                    value="Baptiste Cecconi"/>
                <PARAM arraysize="*" datatype="char" name="SPASE Person ID"
                    utype="spase:Person/ResourceID" value="spase://SMWG/Person/Baptiste.Cecconi"/>
            </GROUP>
            <PARAM arraysize="*" datatype="char" name="CreateDate" ucd="time.creation"
                value="2011-02-29T15:44:00.000Z" xtype="dateTime"/>
            <PARAM arraysize="*" datatype="char" name="ModifyDate" value="2011-02-29T18:40:00.000Z"
                xtype="dateTime"/>
            <FIELD arraysize="*" datatype="char" name="time" ucd="time.epoch" xtype="dateTime">
                <DESCRIPTION>Cassini SCET</DESCRIPTION>
                <VALUES null="0000-00-00T00:00:00.000Z"/>
            </FIELD>
            <FIELD datatype="float" name="frequency" ucd="em.freq" unit="kHz" utype="">
                <DESCRIPTION>Frequency of Observation</DESCRIPTION>
                <VALUES null="0.0"/>
            </FIELD>
            <FIELD datatype="int" name="antenna_code" ucd="meta.id" unit="none" utype="">
                <DESCRIPTION>Antenna combination code</DESCRIPTION>
                <VALUES null="-1"/>
            </FIELD>
            <FIELD datatype="float" name="snr_channel_1" ucd="stat.snr" unit="dB" utype="">
                <DESCRIPTION>SNR on Channel 1</DESCRIPTION>
                <VALUES null="NaN"/>
            </FIELD>
            <FIELD datatype="float" name="snr_channel_2" ucd="stat.snr" unit="dB" utype="">
                <DESCRIPTION>SNR on channel 2</DESCRIPTION>
```

SPASE descriptors

time field

frequency field

other parameters

VOTable (format 2)
(variable number of frequencies)

```
<FIELD datatype="float" name="r_foot" ucd="pos.bodyrc.alt" unit="km" utype="">
    <DESCRIPTION>Magnetic footprint location of radiosource in Saturn Solar Equatorial
        coordinate (SSQ) (radial component)</DESCRIPTION>
    <VALUES null="NaN"/>
</FIELD>
<FIELD datatype="float" name="lat_foot" ucd="pos.bodyrc.lat" unit="deg" utype="">
    <DESCRIPTION>Magnetic footprint location of radiosource in Saturn Solar Equatorial
        coordinate (SSQ) (latitudinal component)</DESCRIPTION>
    <VALUES null="NaN"/>
</FIELD>
<FIELD datatype="float" name="long_foot" ucd="pos.bodyrc.long" unit="deg" utype="">
    <DESCRIPTION>Magnetic footprint location of radiosource in Saturn Solar Equatorial
        coordinate (SSQ) (longitudinal component)</DESCRIPTION>
    <VALUES null="NaN"/>
</FIELD>
<FIELD datatype="float" name="beam_opening" ucd="pos.posAng" unit="deg" utype="">
    <DESCRIPTION>Measured opening angle of the radio source beaming
        pattern</DESCRIPTION>
    <VALUES null="NaN"/>
</FIELD>
<FIELD datatype="float" name="dist" ucd="pos.distance" unit="km" utype="">
    <DESCRIPTION>Straight light propagation distance to iso-Fc surface. Iso-Fc surface
        is the set of locations where the local Cyclotron frequency (Fc) is equals to
        the observation frequency. Zero value means that ray intersects iso-Fc
        surface.</DESCRIPTION>
    <VALUES null="NaN"/>
</FIELD>
<DATA>
    <TABLEDATA>
        <TR>
ISO Date ..... <TD>2008-09-24T18:00:11.140Z</TD>
frequency (kHz) ..... <TD>3.68560</TD>
instrument mode ..... <TD>11</TD>
SNR channel 1 ..... <TD>19.4803</TD>
SNR channel 2 ..... <TD>21.6288</TD>
Stokes Params: S ..... <TD>2.32804e-14</TD>
S in V²/Hz  Q ..... <TD>-20.8362</TD>
Q,U,V in %  U ..... <TD>12.5162</TD>
            V ..... <TD>32.7757</TD>
Source location X ..... <TD>-0.690487</TD>
SSQ coords  Y ..... <TD>2.03219</TD>
(Saturn Radii) Z ..... <TD>5.94452</TD>
Source Mag. Field Line Footprint  R ..... <TD>0.902957</TD>
                                  Lat ..... <TD>83.8810</TD>
                                  Long ..... <TD>108.766</TD>
Source beam opening ..... <TD>33.6697</TD>
distance to iso-fc ..... <TD>0.00000</TD>
        </TR>
```

data

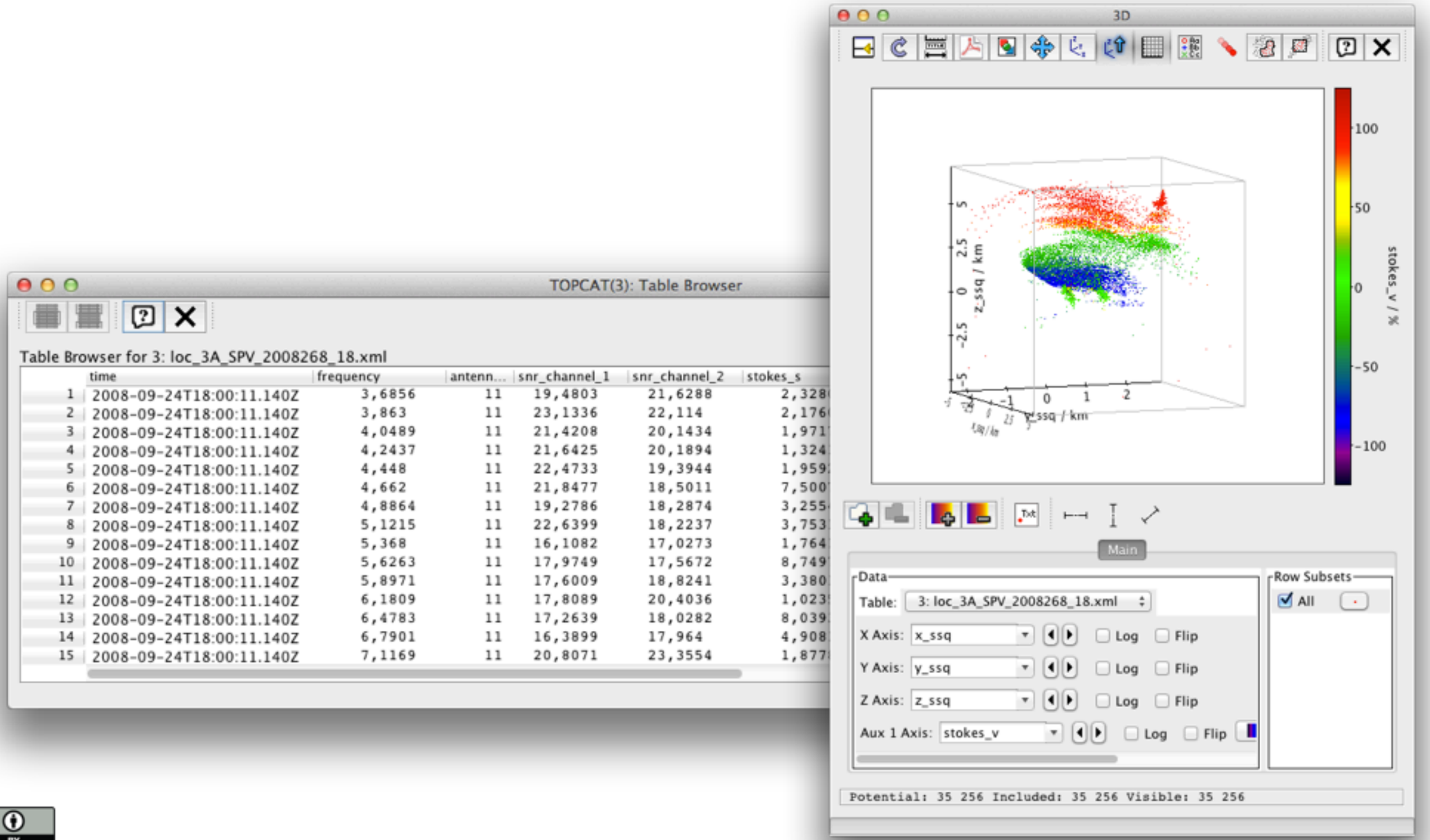
VOTable (format 2)
(variable number of frequencies)

- **Specification:**
  - each line is a single time-frequency record
  - there must be time column and a frequency column

- **Advantages:**
  - very simple description
  - TOPCAT naturally accepts this type of data.

- **Drawback:**
  - the spectral structure of the data is partially lost.

VOTable (format 2)
(variable number of frequencies)



CDF file format

Still under study !

CDF = «Common Data Format»
Space Physics oriented format.
- Used a lot in Space Physics (standard format in SPDF/CDAWeb NASA archive).

Data description is done with a «skeleton file» that contains the structure of the file:
- data = variables;
- metadata = global/variable attributes

TOPCAT can read CDF files

NB:
- NetCDF was branched from CDF (but now not compatible one to the other...)
- Recently adopted as an acceptable NASA-PDS archive format
- ongoing tests with STEREO/Waves and Nançay DAM Jovian Routine data

```
! Skeleton table for the "1395249321251" CDF.
! Generated: Wednesday, 19-Mar-2014 18:15:38
! CDF created/modified by CDF V3.5.0
! Skeleton table created by CDF V3.5.0_1

#header

                        CDF NAME: 1395249321251
                   DATA ENCODING: PPC
                        MAJORITY: COLUMN
                          FORMAT: SINGLE

! Variables  G.Attributes  V.Attributes  Records  Dims  Sizes
! ---------  ------------  ------------  -------  ----  -----
    0/7          64            37         0/z      1    400
! CDF_COMPRESSION: None
! (Valid compression: None, GZIP.1-9, RLE.0, HUFF.0, AHUFF.0)
! CDF_CHECKSUM: MD5
! (Valid checksum: None, MD5)


#GLOBALattributes

! Attribute         Entry       Data
! Name              Number      Type       Value
! ---------         ------      ----       -----

! ISTP Specific Global Attributes
! -------------------------------

  "Project"             1:    CDF_CHAR     { "ObsNancay>Observatory of Nancay" }
                        2:    CDF_CHAR     { "VOPDC>VO Paris Data Center " } .

  "Discipline"          1:    CDF_CHAR     { "Planetary Physics" -
                                             ">Waves" } .

  "Data_type"           1:    CDF_CHAR     { "EDR" } .

  "Descriptor"          1:    CDF_CHAR     { "RJUP" } .

  "Data_version"        1:    CDF_CHAR     { "0.1" } .

  "Instrument_type"     1:    CDF_CHAR     { "Radio Telescope" } .

  "Logical_file_id"     1:    CDF_CHAR     { "dam_rjup_edr_000000000000_000000000000_V1.cdf" } .

  "Logical_source"      1:    CDF_CHAR     { "JupDAM_Nancay" } .

  "Logical_source_description"
                        1:    CDF_CHAR     { "Jupiter Routine Observations " -
                                             "from the Nancay Decameter Array" } .
```

CDF file format

```
! PDS Specific Global Attributes
! ------------------------------
  "Observation_start_time"
                       1:    CDF_CHAR     { "0000-01-01T00:00:00.000Z" } .

  "Observation_stop_time"
                       1:    CDF_CHAR     { "0000-01-01T00:00:00.000Z" } .

  "Observation_target"
                       1:    CDF_CHAR     { "Jupiter" } .

  "Observation_type"
                       1:    CDF_CHAR     { "Radio" } .

! CDPP Specific Global Attributes
! ------------------------------


! VESPA Specific Global Attributes
! ------------------------------

  "dataproduct_type"
                       1:    CDF_CHAR     { "DS>Dynamic Spectra" } .

  "target_class"
                       1:    CDF_CHAR     { "planet" } .

  "time_min"
                       1:    CDF_REAL8    { 0.0 } .

  "time_max"
                       1:    CDF_REAL8    { 0.0 } .

  "time_sampling_min"
                       1:    CDF_REAL4    { 0.0 } .

  "time_sampling_max"
                       1:    CDF_REAL4    { 0.0 } .


  "instrument_host_name"
                       1:    CDF_CHAR     { "DAM>Nancay Decameter Array" } .

  "instrument_name"
                       1:    CDF_CHAR     { "Routine" } .

  "measurement_type"
                       1:    CDF_CHAR     { "phys.flux.density;em.radio" } .

  "access_format"
                       1:    CDF_CHAR     { "cdf" } .
```

```
! Variable          Data      Number                 Record   Dimension
! Name              Type     Elements  Dims  Sizes  Variance  Variances
! --------          ----     --------  ----  -----  --------  ---------

  "RH_FLUX"       CDF_REAL4      1       1     400         T     T

  ! VAR_COMPRESSION: None
  ! (Valid compression: None, GZIP.1-9, RLE.0, HUFF.0, AHUFF.0)
  ! VAR_SPARSERECORDS: None
  ! (Valid sparserecords: None, sRecords.PAD, sRecords.PREV)
  ! VAR_PADVALUE: -1.0e+30

  ! Attribute       Data
  ! Name            Type       Value
  ! --------        ----       -----

    "CATDESC"     CDF_CHAR     { "RH polar flux density" }
    "DEPEND_0"    CDF_CHAR     { "Epoch" }
    "DEPEND_1"    CDF_CHAR     { "Frequency" }
    "LABL_PTR_1"  CDF_CHAR     { "Frequency" }
    "DICT_KEY"    CDF_CHAR     { "RH_FLUX" }
    "DISPLAY_TYPE"
                  CDF_CHAR     { "time_series" }
    "FIELDNAM"    CDF_CHAR     { "RH_FLUX" }
    "FILLVAL"     CDF_REAL4    { -1.0e+31 }
    "FORMAT"      CDF_CHAR     { "E12.2" }
    "LABLAXIS"    CDF_CHAR     { "RH polar flux density" }
    "UNITS"       CDF_CHAR     { "W/m^2/Hz" }
    "VALIDMIN"    CDF_REAL4    { 0.0 }
    "VALIDMAX"    CDF_REAL4    { 1.0e+06 }
    "VAR_TYPE"    CDF_CHAR     { "data" }
    "SCALETYP"    CDF_CHAR     { "log" }
    "SCALEMIN"    CDF_REAL4    { 0.0 }
    "SCALEMAX"    CDF_REAL4    { 20.0 }
    "UCD"         CDF_CHAR     { "phys.flux.density;em.radio" } .

  ! RV values were not requested.
```

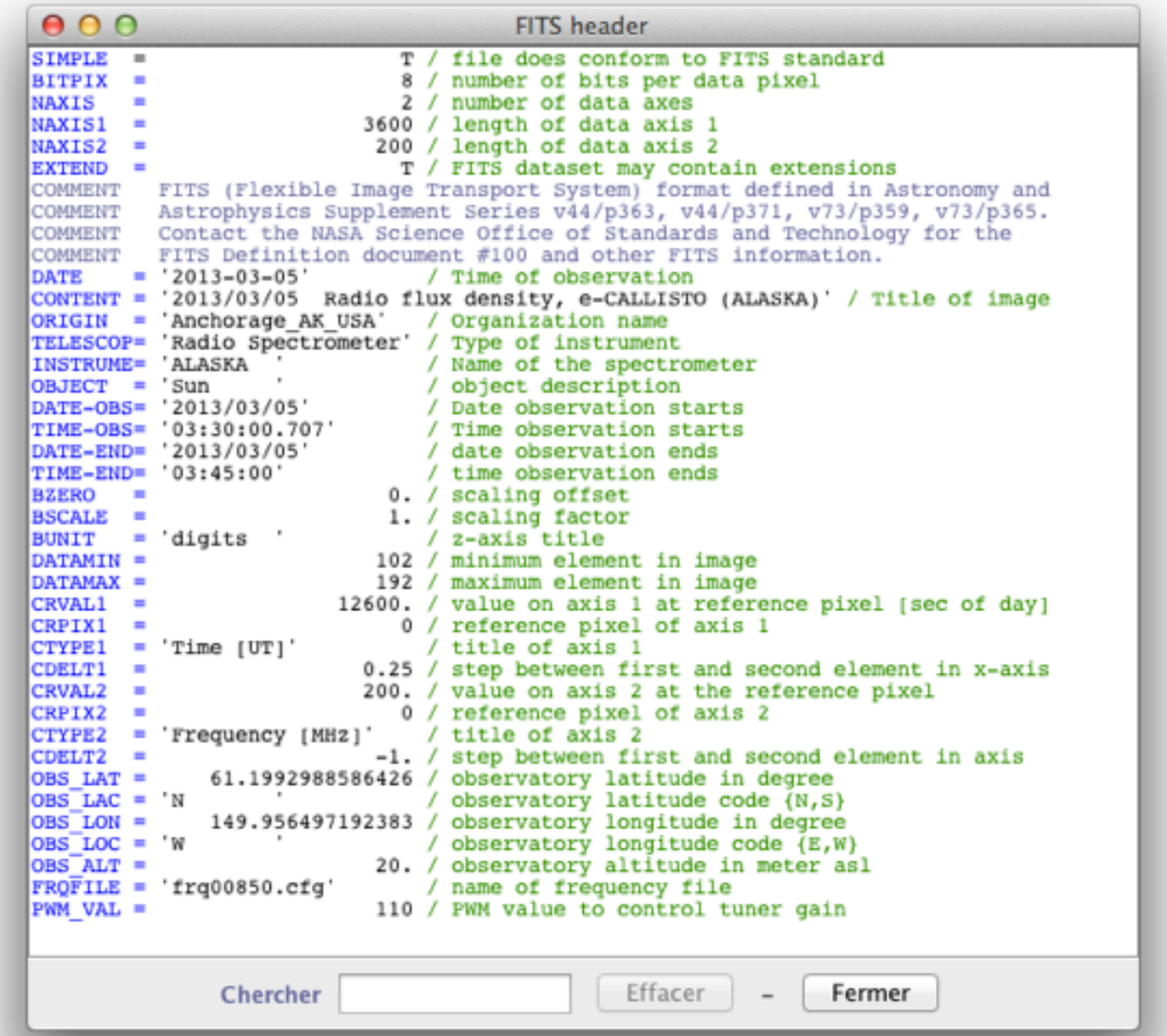
FITS file format

Still under study !

FITS = «Flexible Image Transport System»
Image oriented format
- A dynamic spectrum is like a time-frequency image, but the temporal and spectral grids are not regularly sampled in general.
- Used a lot in astrophysics.

Frequency table (and also often the date table) must be declared as an extension of the FITS file

Example of e-Callisto data files:



NetCDF / HFD5

- NetCDF and HDF5:
  - Tests to come with NetCDF and HDF5 (used by LOFAR) formats
  - Some work on the definition/specification of metadata in NetCDF and HDF5 required

IVOA Data Model Serialization

- Usage of IVOA standards is proposed
- IVOA data models are in a phase of rewriting after the adoption of the VODML (Virtual Observatory Data Model Language)
- Serialization of Data Models (SpectrumDM, etc) in the selected data formats will be proposed:
  - VOTable and FITS have partial serialization to be checked
  - CDF, NetCDF and HDF5 have no such serialization.

Linking IVOA, PDS and SPASE Resources

- Radio datasets are currently described in several repositories using description from IVOA, NASA/PDS or SPASE data model (or keyword dictionaries)
- We have to provide a mechanism to cross the resource descriptors and be able to access to the metadata from each of the 3 virtual worlds.
- Ongoing work with the IGPP/UCLA technical team (involved in NASA/PDS and SPASE)

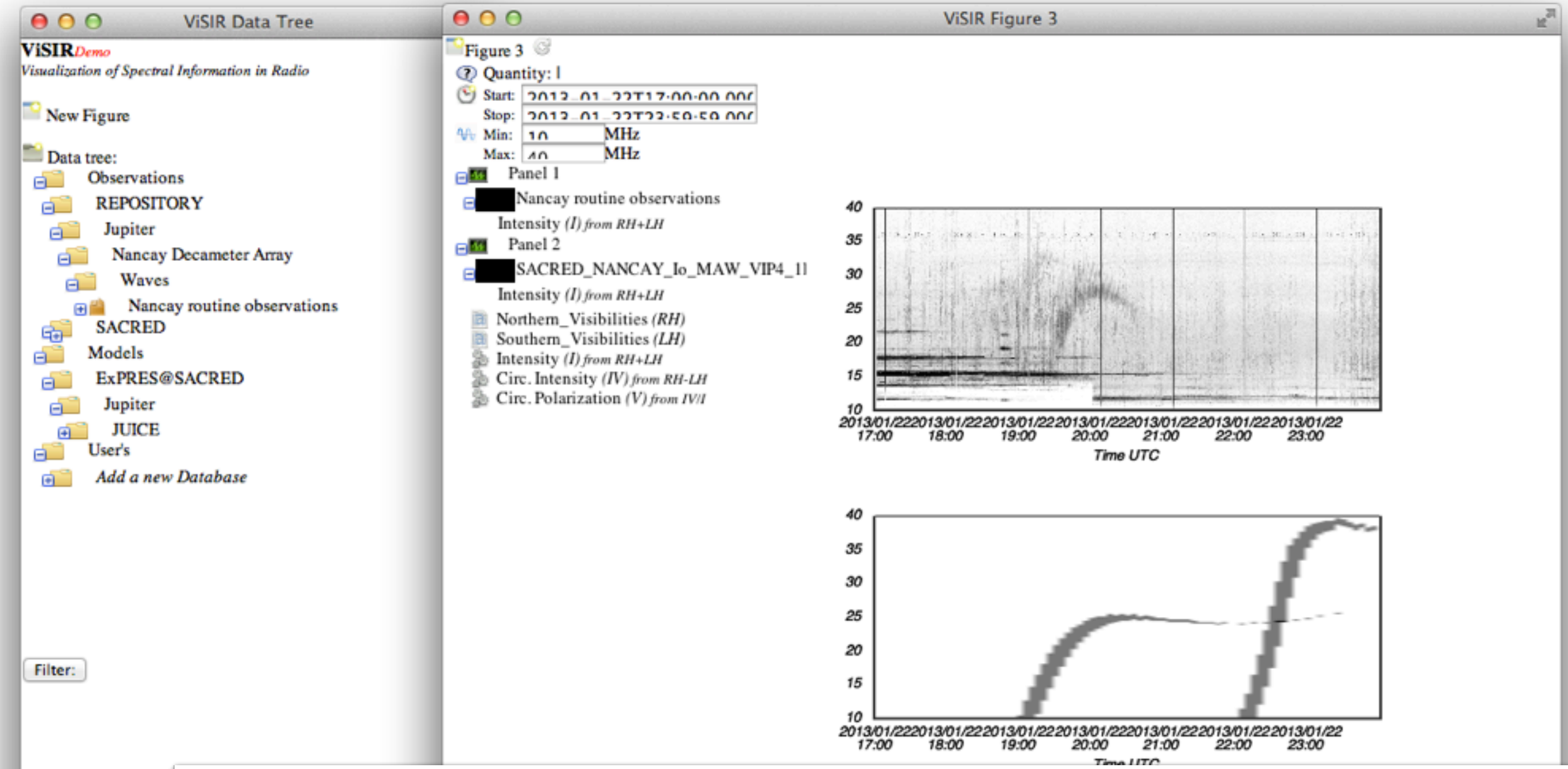
Projects and Prototype(s)

- Context: *The CDPP (french data centre for plasma physics) wants to propose tools to exploit radio datasets (especially those archived at CDPP). A «radio» tool, comparable to the AMDA/ CDPP tool, is planned: ongoing definition phase, possible funding available within 2-3 years. This tool should:*
  - be interoperable, multi-instrument, multi-point,
  - contain selection tools adapted to the various radio observables (flux, polarization, location...)
  - allow light travel time correction

- First prototypes:
  - SACRED database (*Simulated Auroral Cyclotron Radio Emission Database*).
  Use case: Comparison of simulations and observations, preparation of future missions…
  - SILFE tools (*Spectral Information of Low Frequency Emissions*):
    - at the moment access to local data only
    - observation and simulation data stored on server with VOTable format #1 (degraded resolution for faster display on client)
    - future: remote access (with EPN-TAP) + SAMP
    - formats: VOTable (soon FITS, CDF and NetCDF)

- Prototype demo:
  http://typhon.obspm.fr/maser/SILFE

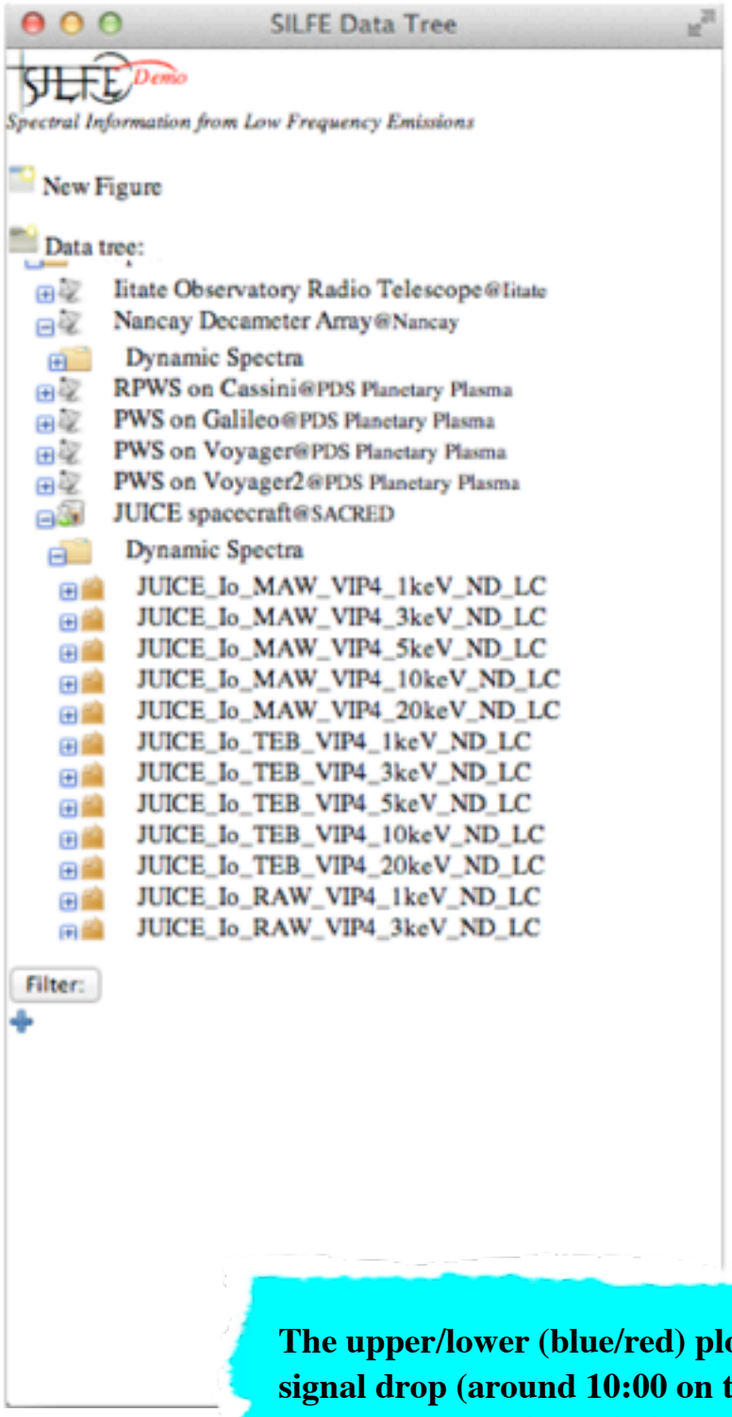
Comparison Simulation/Observations

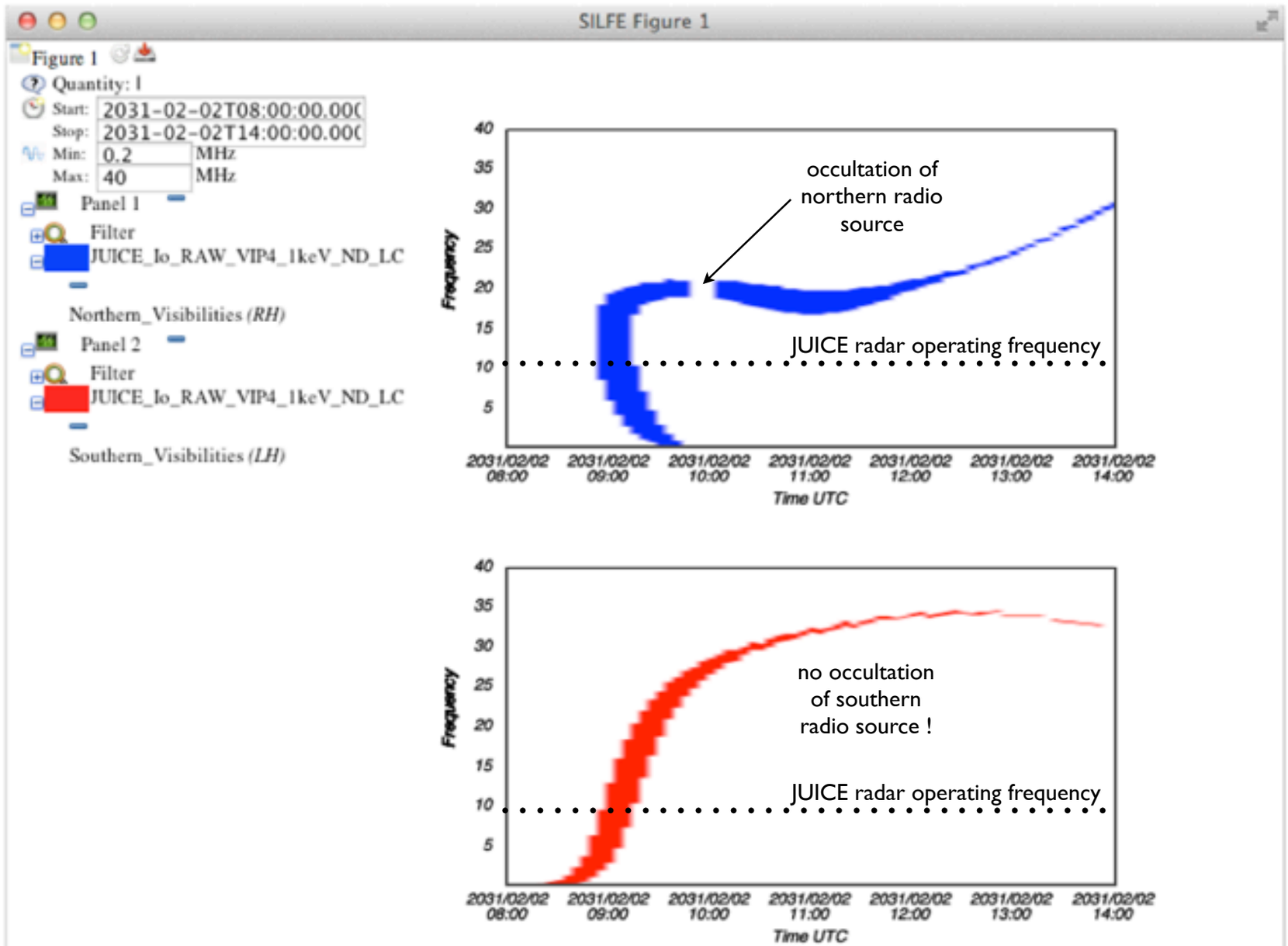


Databases recently added:

- NASA/PDS (Galileo/PWS, Voyager/PWS, Cassini/RPWS...)
- Iitate Observatory Radio Telescope (Japan)

Space Mission Planning





The upper/lower (blue/red) plots are the Io-controlled DAM emissions emanating from the Northern/Southern polar regions of Jupiter. The signal drop (around 10:00 on the northern curve) is the geometrical occultation of the northern source by Callisto. The Southern source is not occulted during this flyby. This information is crucial for the observation planning of the subsurface radar of the JUICE mission, as they are operating at 10 MHz and the natural Jovian radio emissions are orders of magnitude stronger than there expected echoes.