

MASER

A Science Ready Open Toolbox for Low Frequency Radio Astronomy

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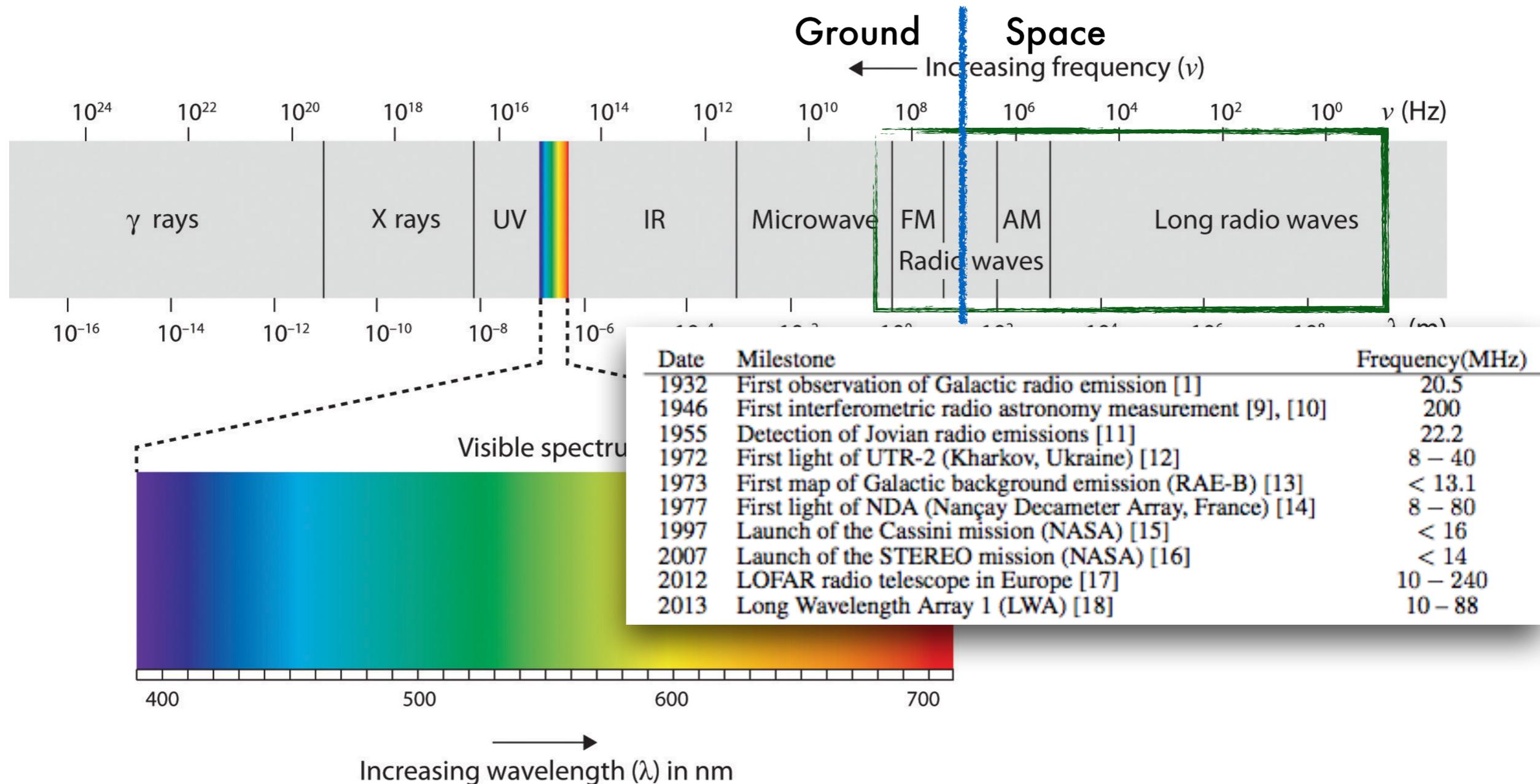
MASER – *Measure, Analyze,
Simulate Emissions in Radio range*

Outline

- **Low Frequency Radio Astronomy**
- **Data product types**
- **Software Library**
- **Data on demand and visualization**
- **Simulation tools**
- **Applications**

Radio astronomy is a young science

- Radioastronomy = radio sky observation



“Classic” radioastronomy: Large ground observatories

very large instruments



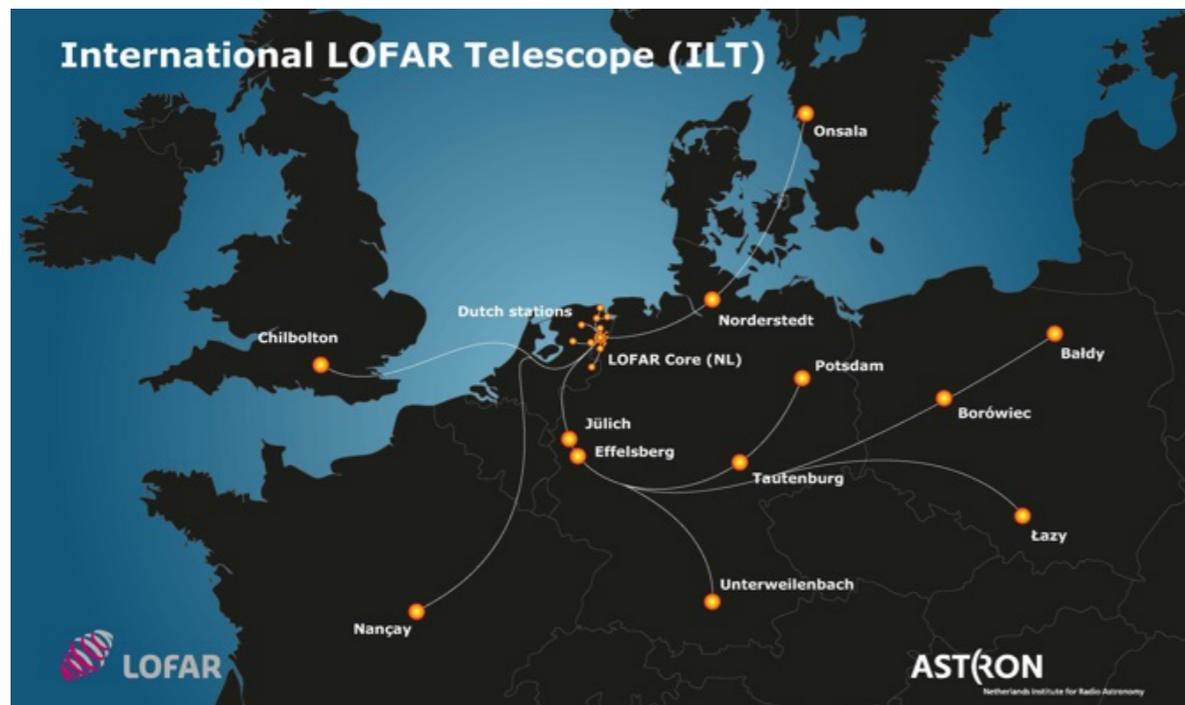
Greenbank, USA: 100 m diametre



Nançay, France: tilted mirror = 200 m x 40 m
fix spherical mirror = 300 = x 35 m

“Modern” radioastronomy: Large ground interferometers

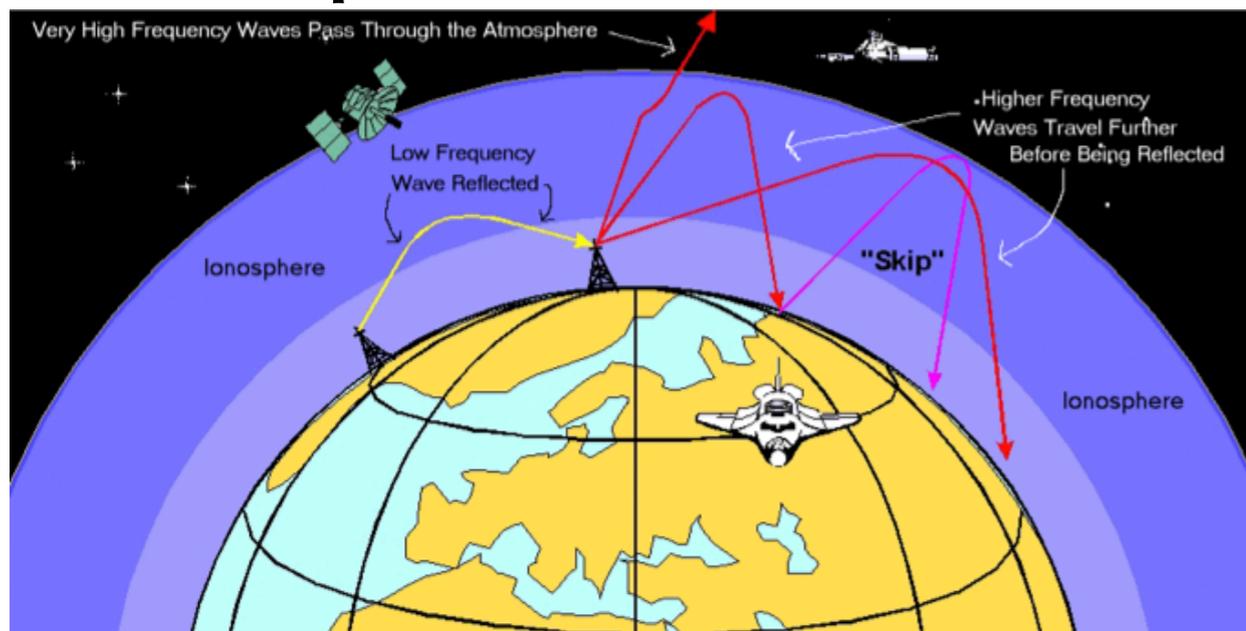
- Ground low frequencies = interferometers.
- Example: LOFAR (Low Frequency Array)



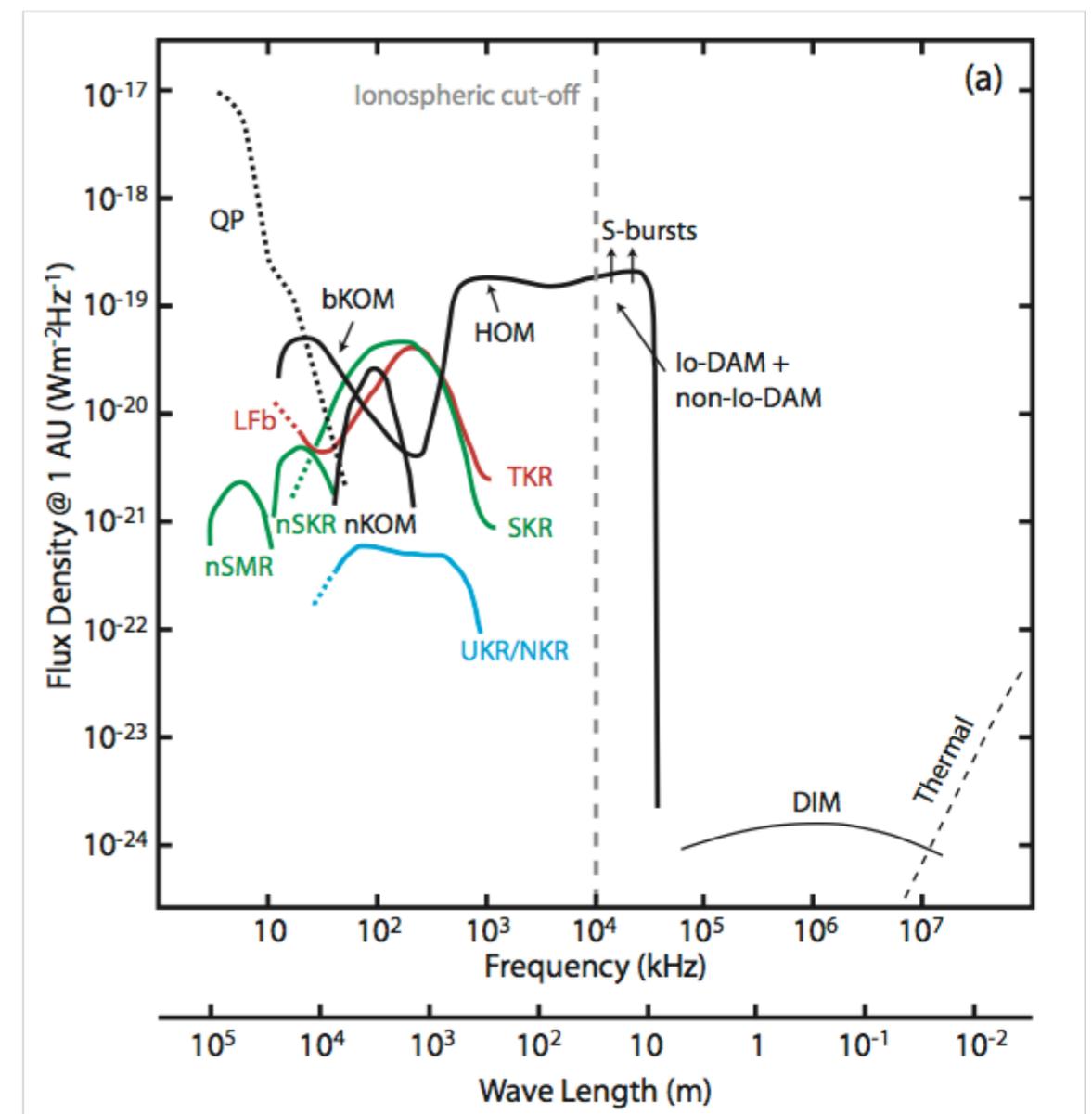
Radioastronomy from space

- Earth's ionosphere reflects radio waves below 10 MHz
- Except with Jupiter, planetary radio sources are observed below 1 MHz
- Radio frequency interferences: (human activity): we have to get away from Earth

Ionospheric cut off at 10 MHz

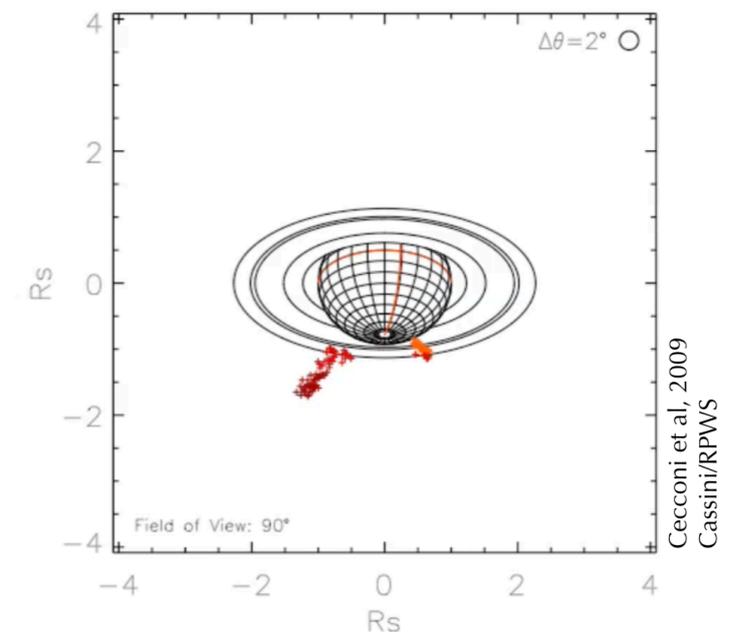
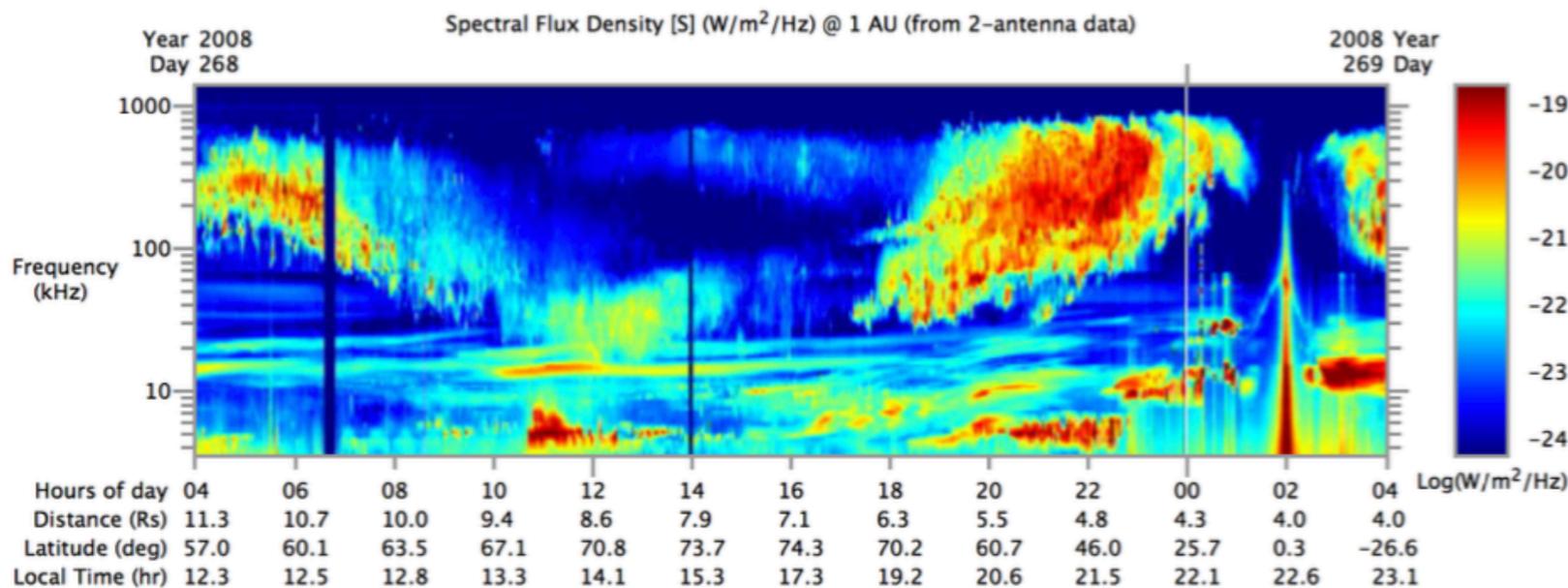
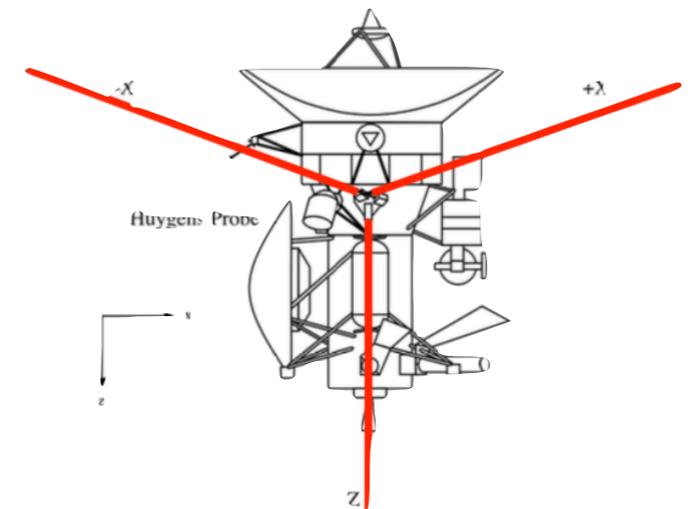


Planetary Radio Emissions



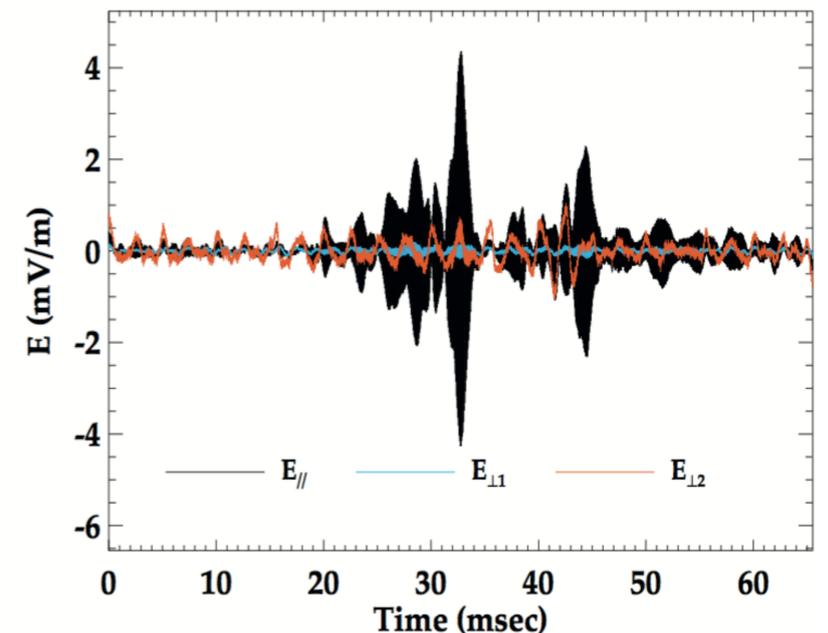
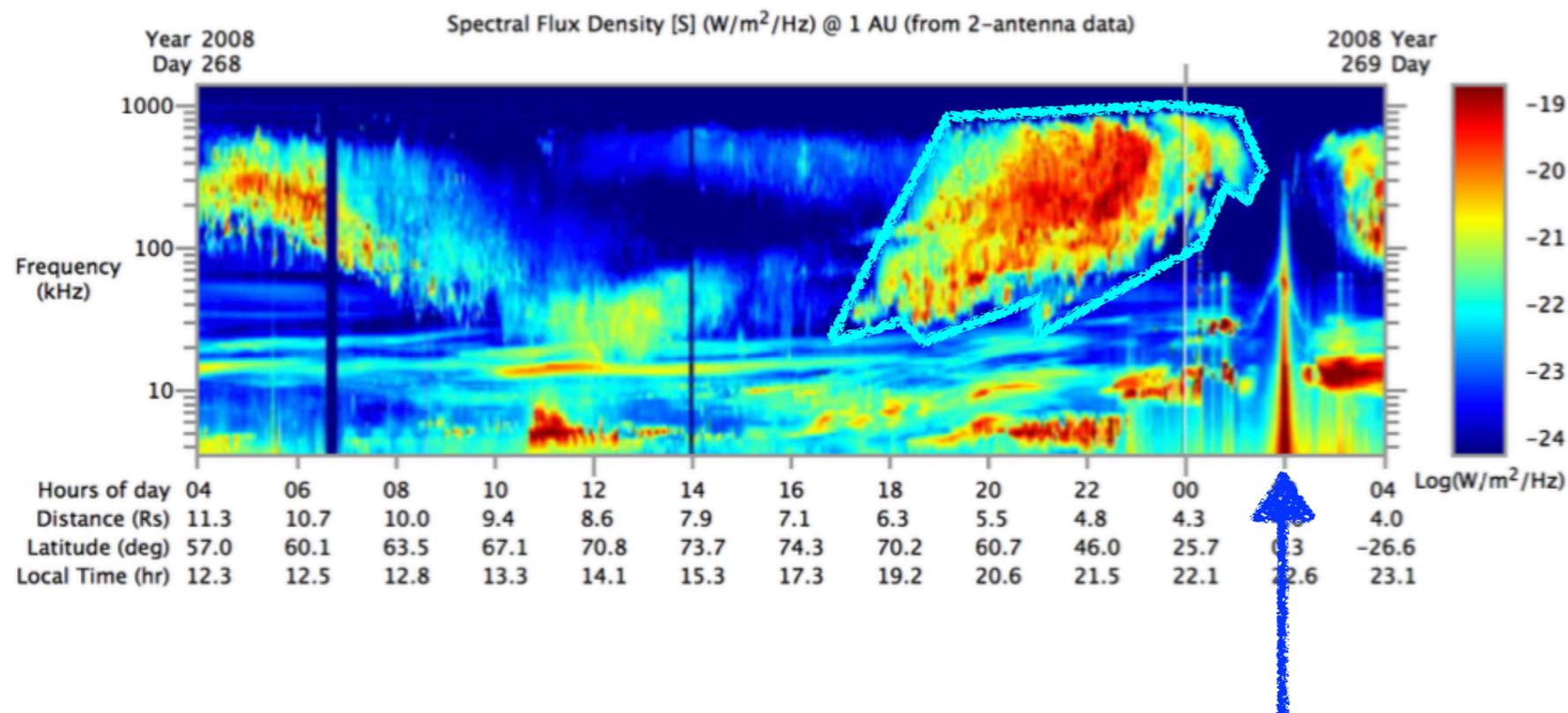
Radioastronomy from space

- Sensors: linear antenna (same as on kitchen radio sets, but often longer)
- Measurements: spectrograms of intensity, polarization direction of arrival.
- Example: Cassini Mission at Saturne



Data product types

- Mostly **spectrograms**. Measured parameter (flux, polarization...) depending on time and frequency.
- Sometime: “**waveform**” (direct sampling of electric signal temporal fluctuations). Much higher data rate needed.
- also, **events**. timestamp + label + parameters (coverage) + data ? waveform snapshot can be considered as an event.



Data Collections

- **Large archives for space missions**
 - NASA/HPDE (NASA - heliophysics)
 - NASA/PDS (NASA - planetary sciences)
 - CDPP (CNES - space plasma physics)
 - DARTS (JAXA - all sciences)
- **Ground based data collections:**
 - Nançay Decameter Array (Nançay, France)
 - URAN-UTR-2 (Kharkov, Ukraine)
 - Iitate Radio observatory (Iitate, Japan)
- Plenty of other observatory/laboratory/team data collections, not comprehensively distributed yet.
- **Catalogue of events**, from published papers (from the 70's to last year): solar and jovian events.

Data format and metadata

- NASA Heliophysics, archive format = **CDF** (common data format), with ISTP standard.
Recommended by CDPP and JAXA too.
NASA/PDS now accepts CDF as archive format.
- Other standard formats in use:
 - Solar community: **FITS**
 - Modern ground interferometers (LOFAR, LWA): **HDF5**
- Other (again): **raw binary** streams, with custom descriptions (most of the data collections...)

Data volumes

- **Space data:**

about 1 spectrum (~ 250 steps * 8 Bytes) / minute

=> ~ 35 B/sec, or ~ 3 MB/day

(space constraints: power, telemetry rate...)

Several decades of continuous coverage (Cassini, STEREO, Wind) are “easy” to store and share (~ 20 GB for 20 years)

- **Ground data:**

about 100 spectra (15000 steps * 16 Bytes) / second

=> ~ 30 MB/sec, or ~ 2 TB/day

Specific solutions needed for remote access of data.

- Very different needs for architecture, infrastructure, archive and distribution systems.

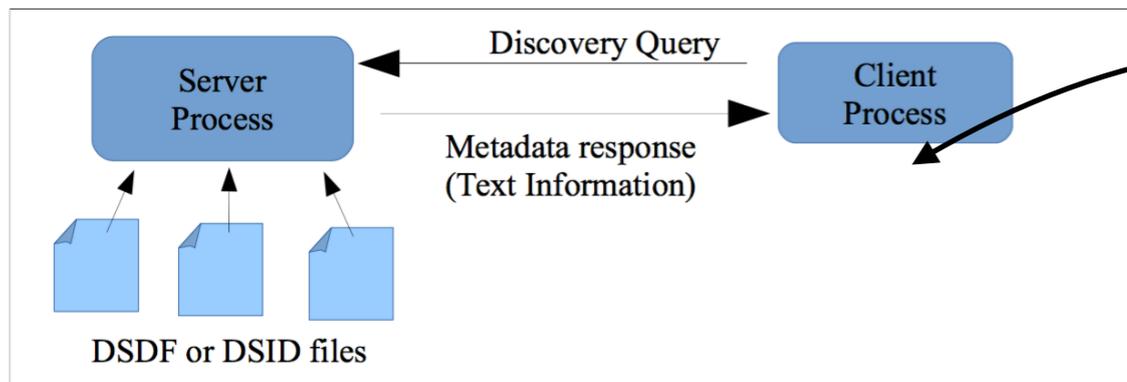
Software library: MASER

- **MASER** (Measure, Analyse, Simulate Emissions in the Radio range): github.com/maserlib
- Maser4py: Python 3.5+ modules
 - current developments: reading data collections in various data formats (specifically raw binary formats), using homogeneous classes (same interface)
- Currently implemented data collections:
 - from LESIA: Cassini/RPWS, Voyager/PRA, SolarOrbiter/RPW;
 - from CDPP: Demeter, Interball, Viking (Swedish auroral mission), ISEE3, Wind
 - from NASA/PDS: Cassini/RPWS, Voyager/PRA
 - from Nançay: Nançay Decameter Array, NenuFAR
 - from Radio amateurs: RadioJOVE
- Open source development, GPLv3

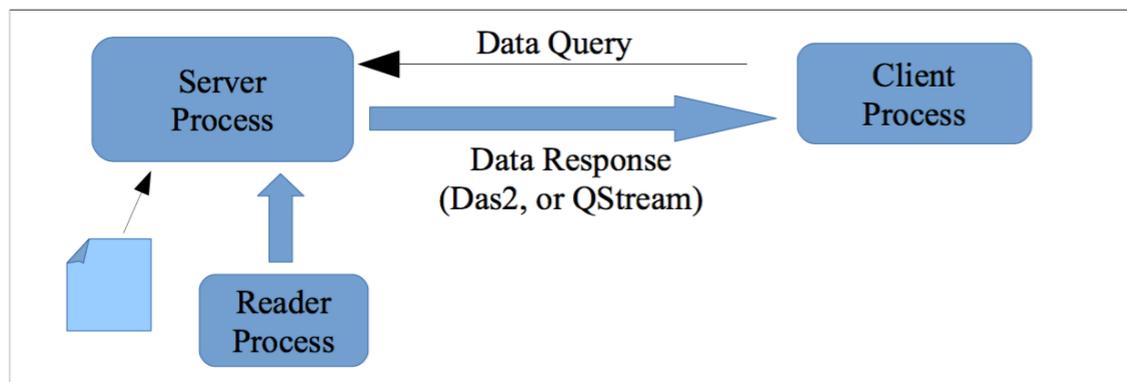
Data on demand

- **Large data rate or long times intervals**
=> need for optimized client/server distribution system.
- Existing solution developed by University of Iowa (USA):
server=**Das2** (<http://das2.org>) and client=**Autoplot** (<http://autoplot.org>)
- **Built for space data** (low data rate), but capable of serving long **resampled** times series.
Tested with success on ground Nançay datasets: adapted also for ground based high data rate collections.
- Very simple configuration:
data collection description files + data reader that produces “das2stream” formatted data.
- Implemented on LESIA, CDPP, and Nançay data collections (using the Maser4py modules):
 - LESIA: <http://voparis-maser-das.obspm.fr/das2/server>
 - Nançay: <https://das2server.obs-nancay.fr/das2/server>

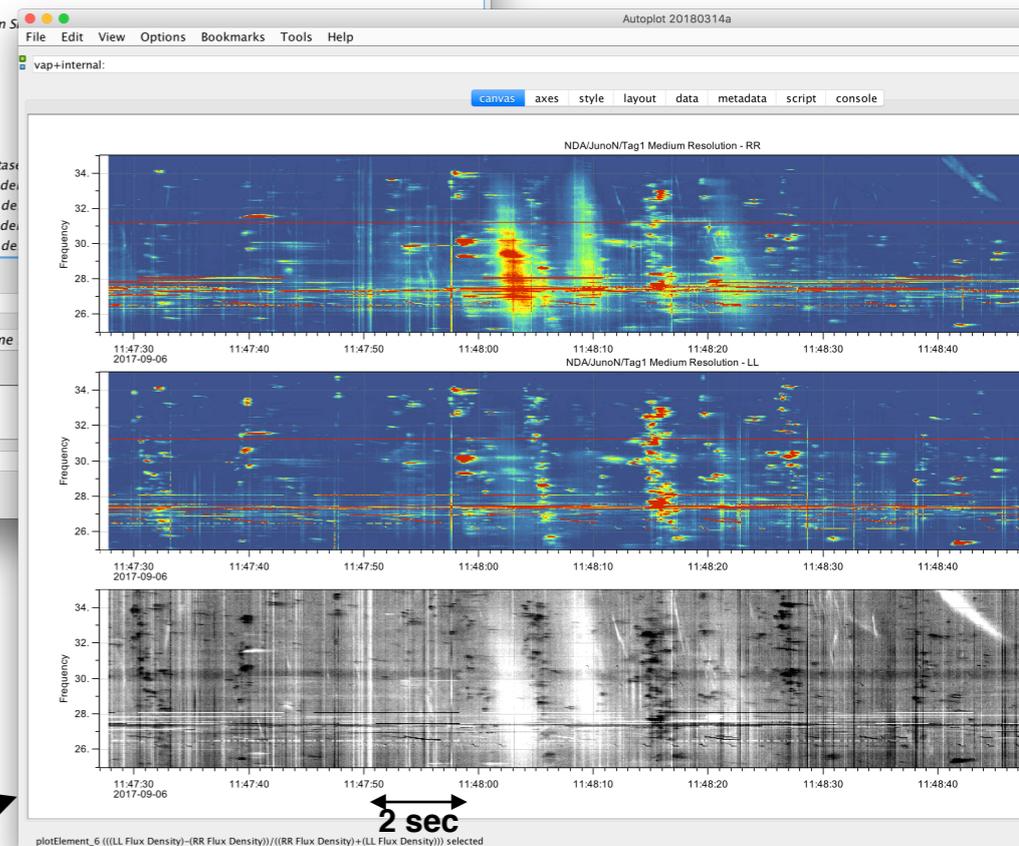
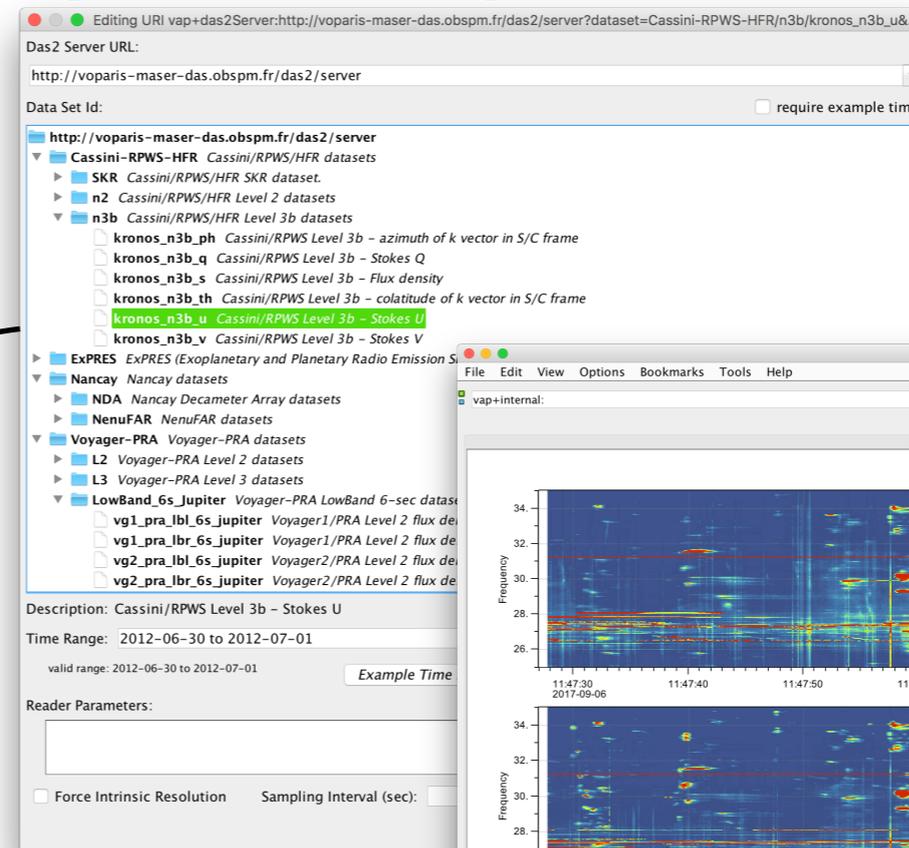
Das2 / Autoplot process



Discovery Query Information Flow



Data Query Information Flow



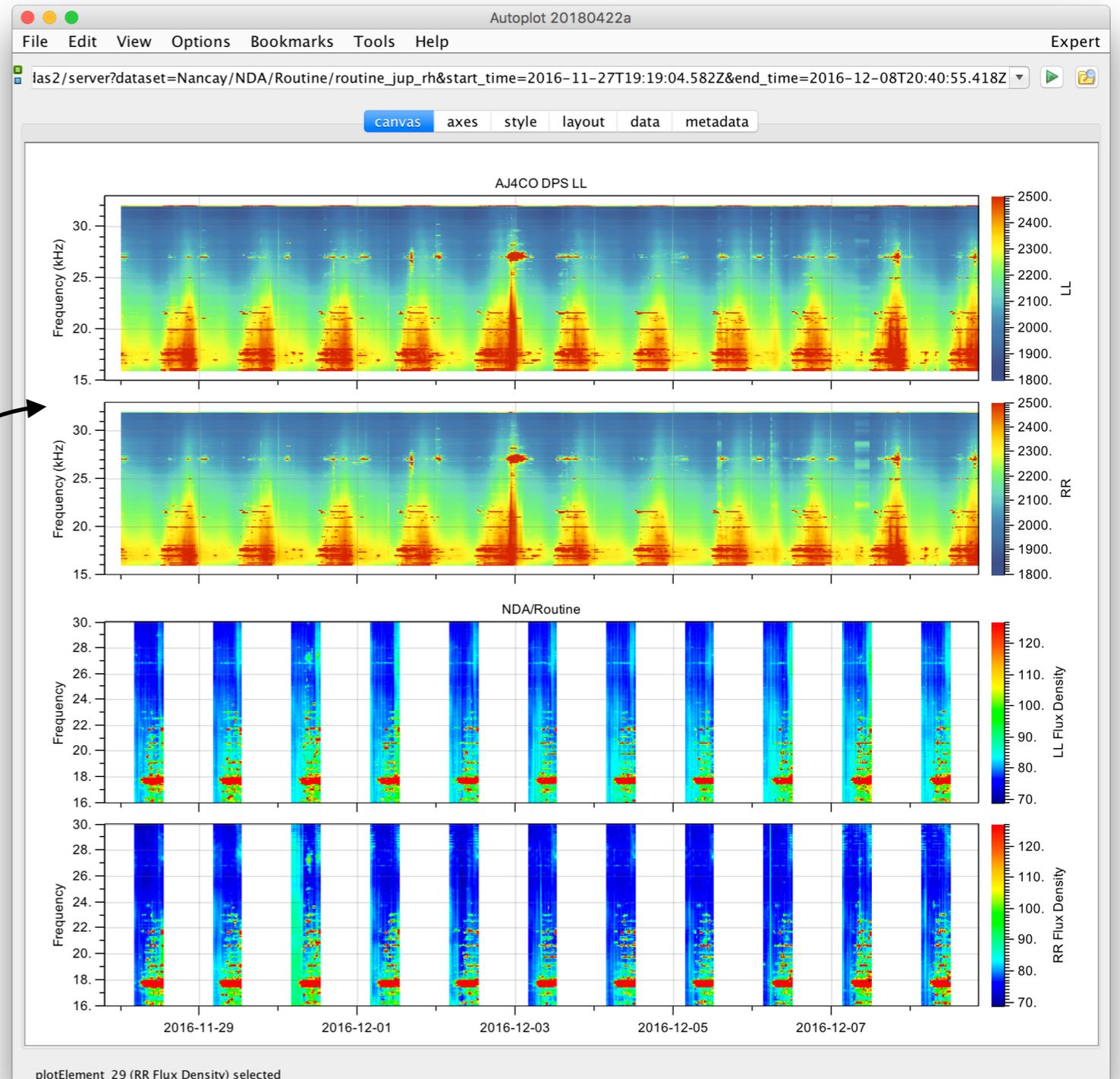
NDA/JunoN dataset (3TB/day)

- Das2 = **data distribution** system for time series + **on demand resampling** (averaging on the fly).
HTTP REST Query: data collection + time interval + temporal resolution

Examples

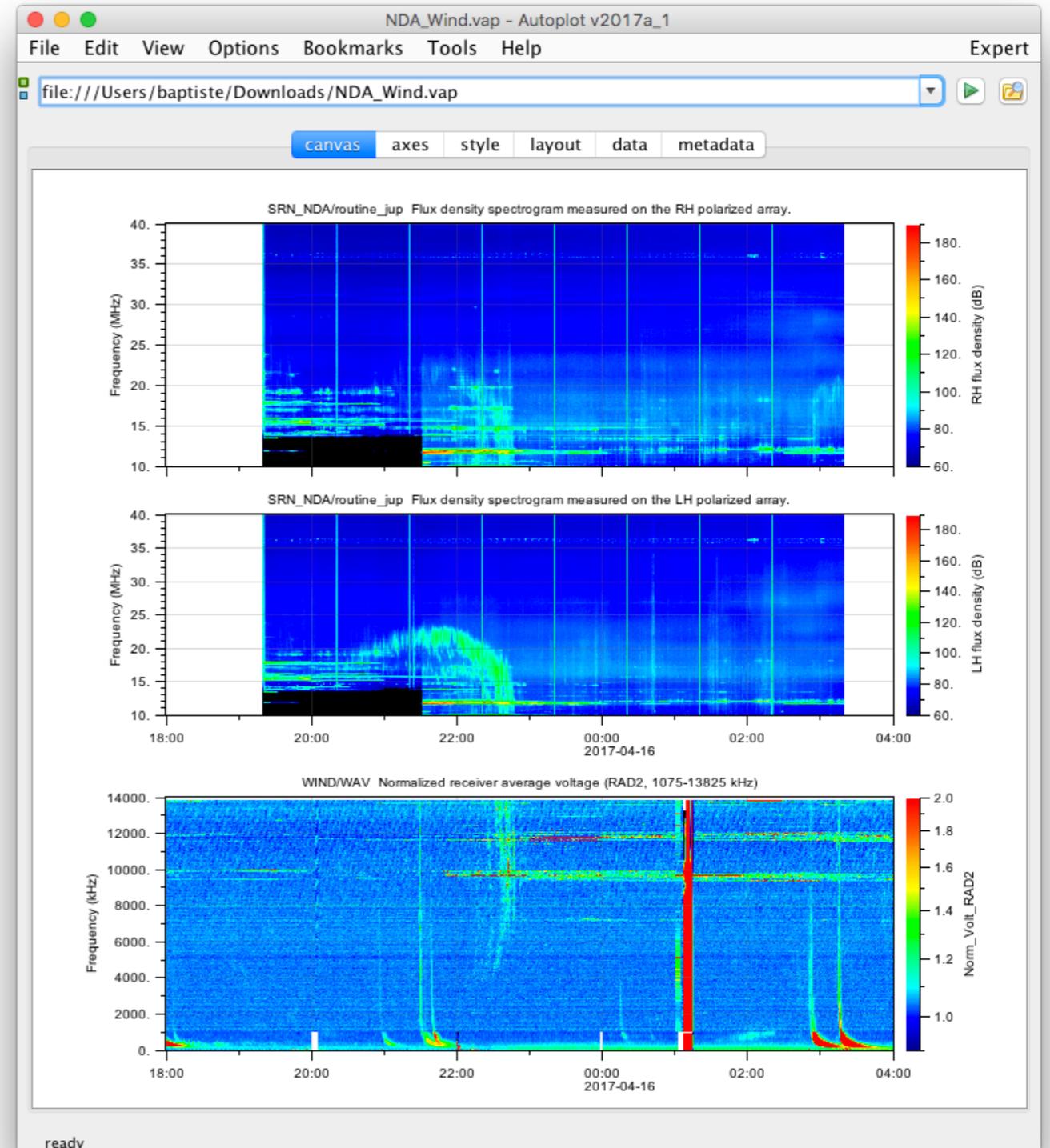
- Pro + Amateurs
- Ground + Space
- Old missions

2 top rows : ~7 GB raw data,
only 760kB downloaded for display



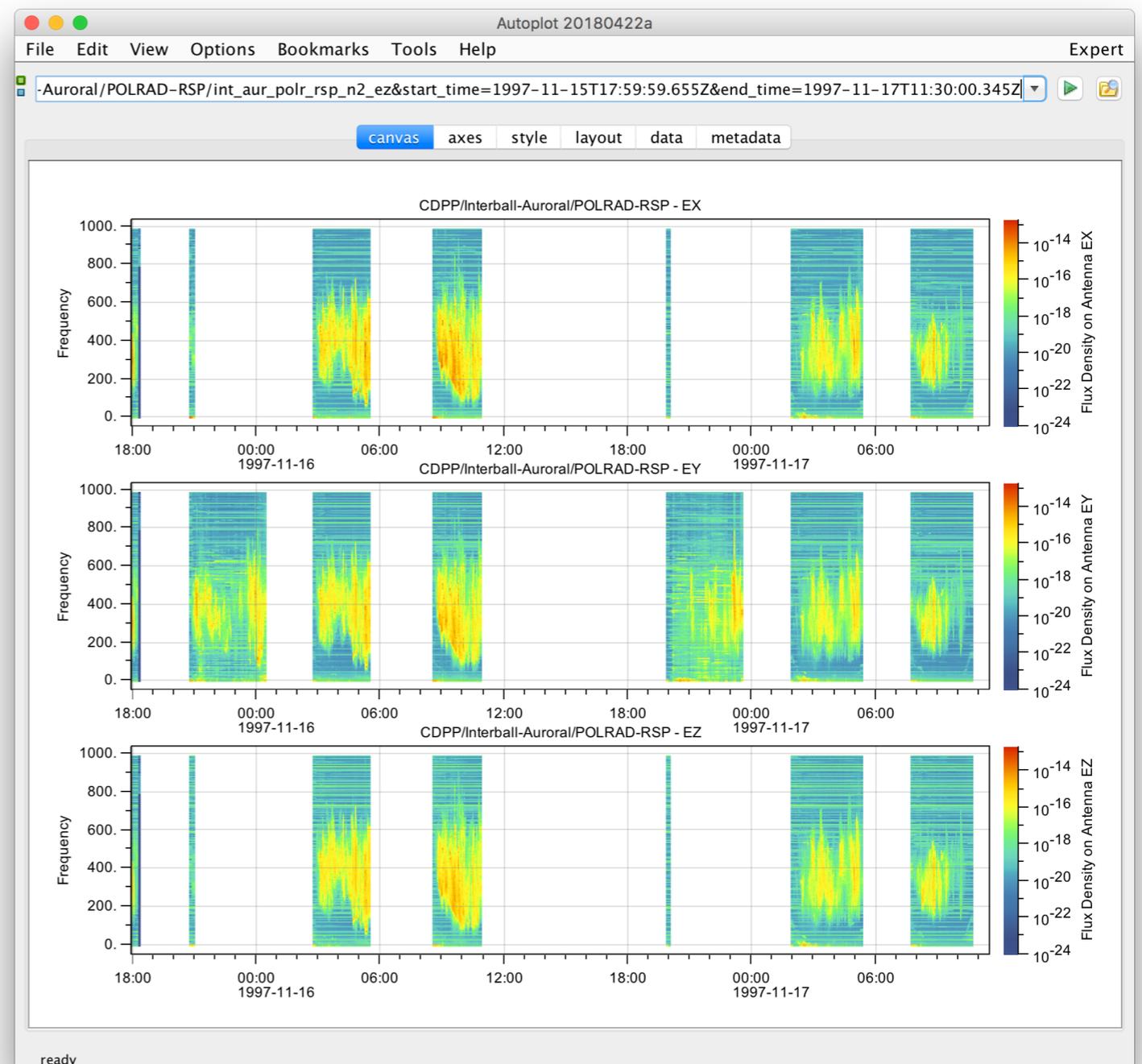
Examples

- Pro + Amateurs
- Ground + Space
- Old missions



Examples

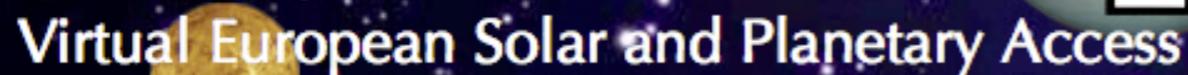
- Pro + Amateurs
- Ground + Space
- Old missions



Interball/POLRAD

Data discovery

- Data collection catalogue with standard metadata forged for solar system sciences (EPNcore)
Same protocol for all catalogues (TAP, from IVOA)
=> VESPA (see Erard et al., talk)
- Discovery of data products with content metadata (coverage, observation...)

The logo for VESPA, consisting of the letters 'VESPA' in a bold, white, sans-serif font.The full name of the project, 'Virtual European Solar and Planetary Access', written in a smaller white font below the logo.

- Solar System Virtual Observatory (<http://vespa.obspm.fr/>)



Results in service NDA Obs. Database

Show 10 entries

Column visibility Show all Hide all
 Select All in current page Reset Selection

granule_uid	dataproduct_type	target_name	time_min (d)	time_max (d)	access_url
J991231_rt1	dynamic_spectrum	Jupiter	1999-12-31T14:48:00.219	1999-12-31T22:47:59.280	http://realtime.obs-...
J991231_pdf	dynamic_spectrum	Jupiter	1999-12-31T14:48:00.219	1999-12-31T22:47:59.280	http://realtime.obs-...
J991231_cdf	dynamic_spectrum	Jupiter	1999-12-31T14:48:00.219	1999-12-31T22:47:59.280	http://realtime.obs-...
J991230_rt1	dynamic_spectrum	Jupiter	1999-12-30T14:51:00.199	1999-12-30T22:50:59.260	http://realtime.obs-...
J991230_pdf	dynamic_spectrum	Jupiter	1999-12-30T14:51:00.199	1999-12-30T22:50:59.260	http://realtime.obs-...
J991230_cdf	dynamic_spectrum	Jupiter	1999-12-30T14:51:00.199	1999-12-30T22:50:59.260	http://realtime.obs-...
J991229_rt1	dynamic_spectrum	Jupiter	1999-12-29T14:55:00.090	1999-12-29T22:54:59.140	http://realtime.obs-...
J991229_pdf	dynamic_spectrum	Jupiter	1999-12-29T14:55:00.090	1999-12-29T22:54:59.140	http://realtime.obs-...
J991229_cdf	dynamic_spectrum	Jupiter	1999-12-29T14:55:00.090	1999-12-29T22:54:59.140	http://realtime.obs-...
J991228_rt1	dynamic_spectrum	Jupiter			

Showing 1 to 10 of 26,046 entries 1 row selected

Data Selection Metadata Selection All Data All Meta

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 Contact : support.epnta

Sharing data products:

- data files
- quicklook images
- data access webservice

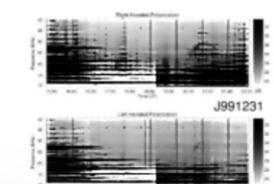
Plotting tools

- TOPCAT
- Aladin
- SPLAT
- CASSIS
- 3DView

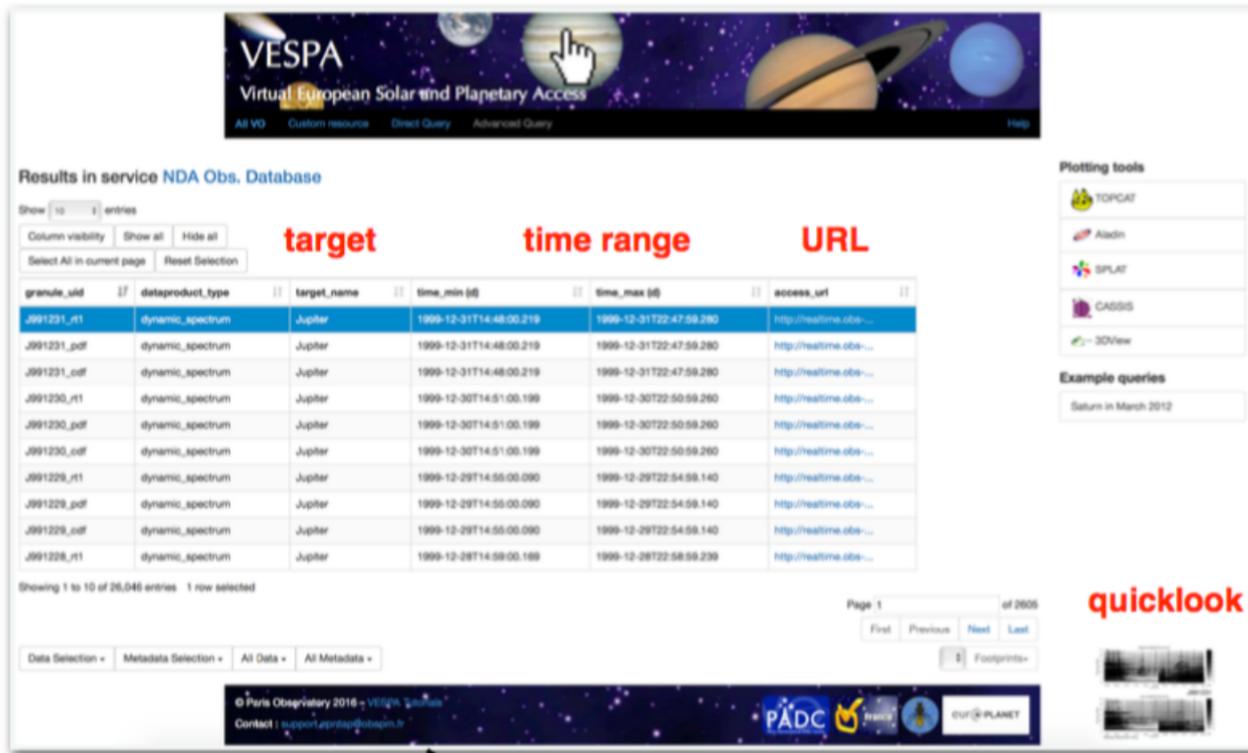
Example queries

Saturn in March 2012

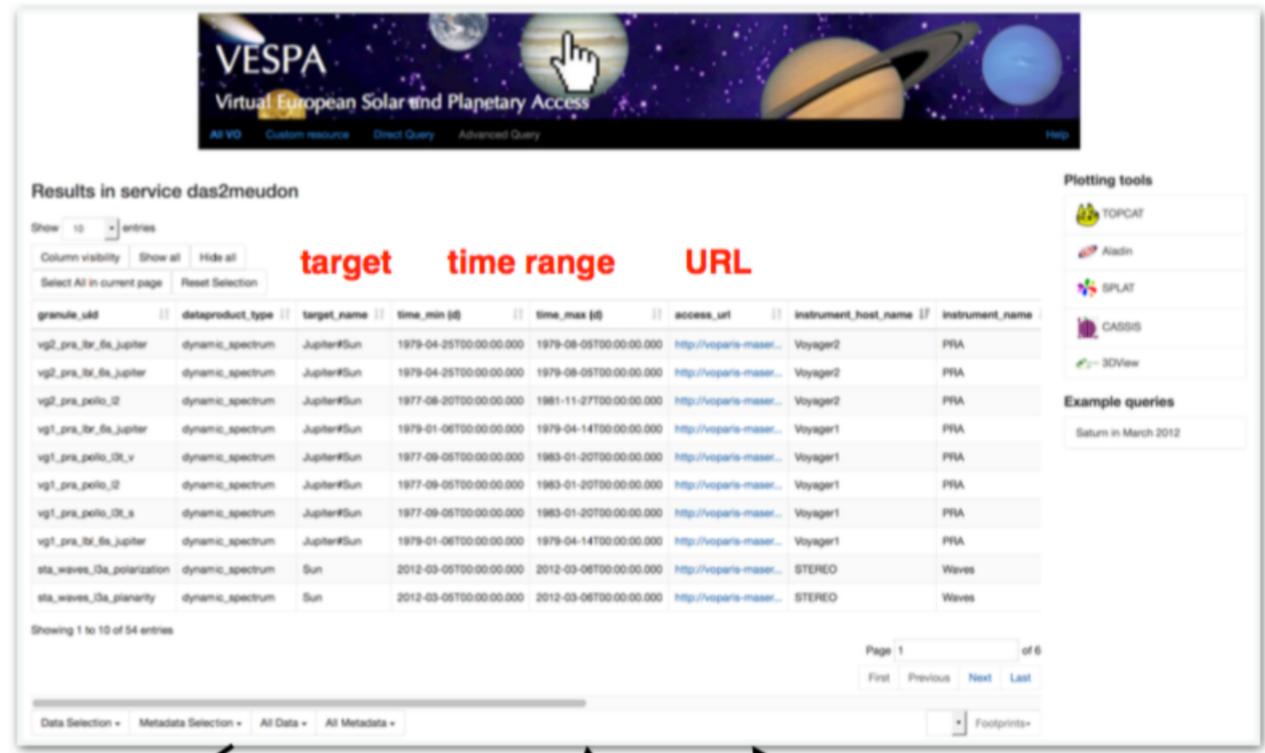
of 2605
 Previous Next Last
 Footprints
 eur@PLANET



VESPA result page in Nançay/NDA EPN-TAP service



VESPA result page for all das2server dataset in Meudon



mtype=load.table.cdf

mtype=load.table.das2

next: distribute .vap files

SAMP hub

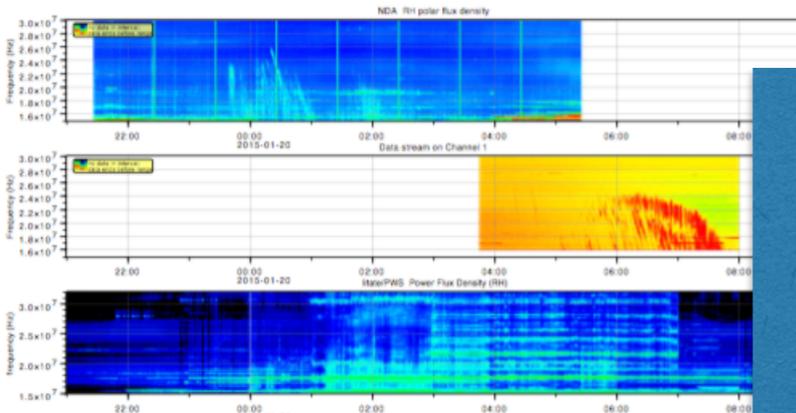
das2 dataset discovery feature

das2 dataset publication through VESPA

Das2 server catalog in Autoplot

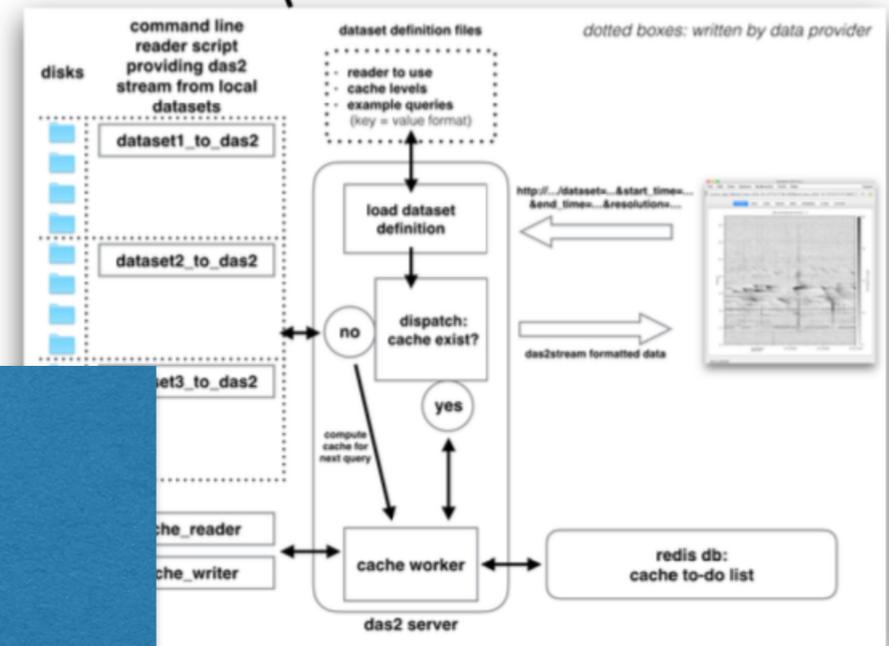
Data Selector

Plot



Sharing data products:

- data files
- quicklook images
- data access webservice



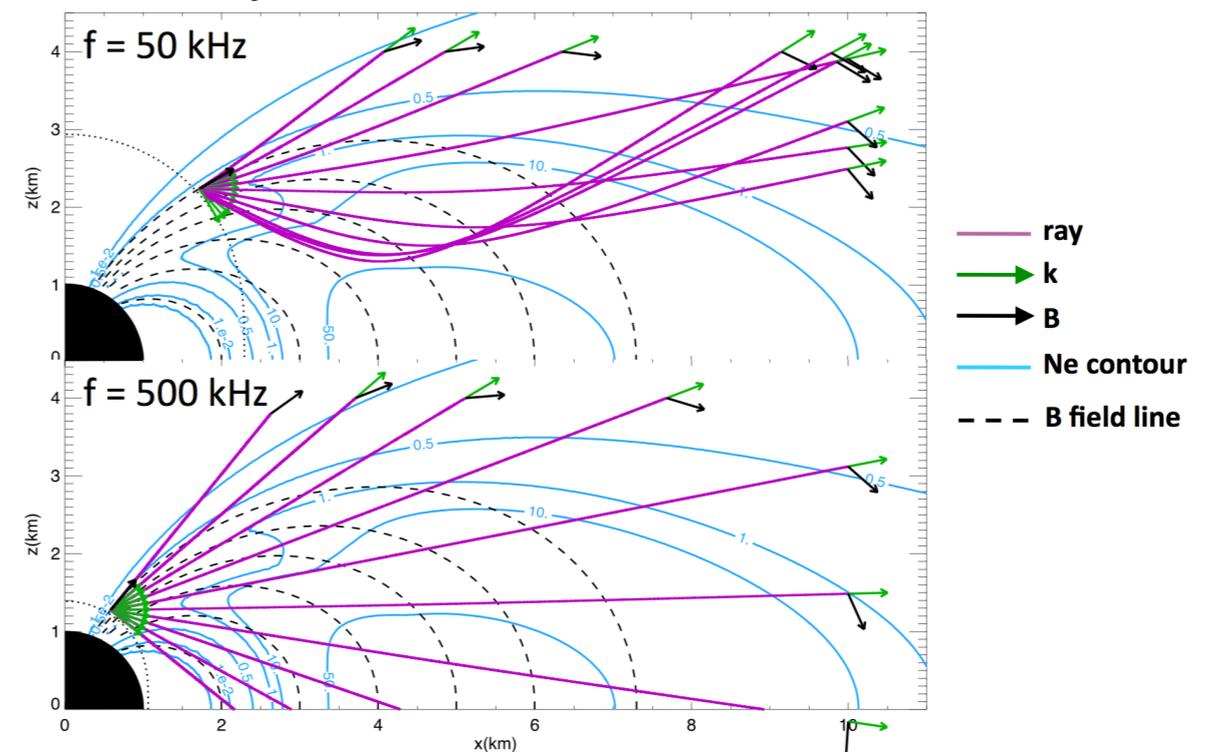
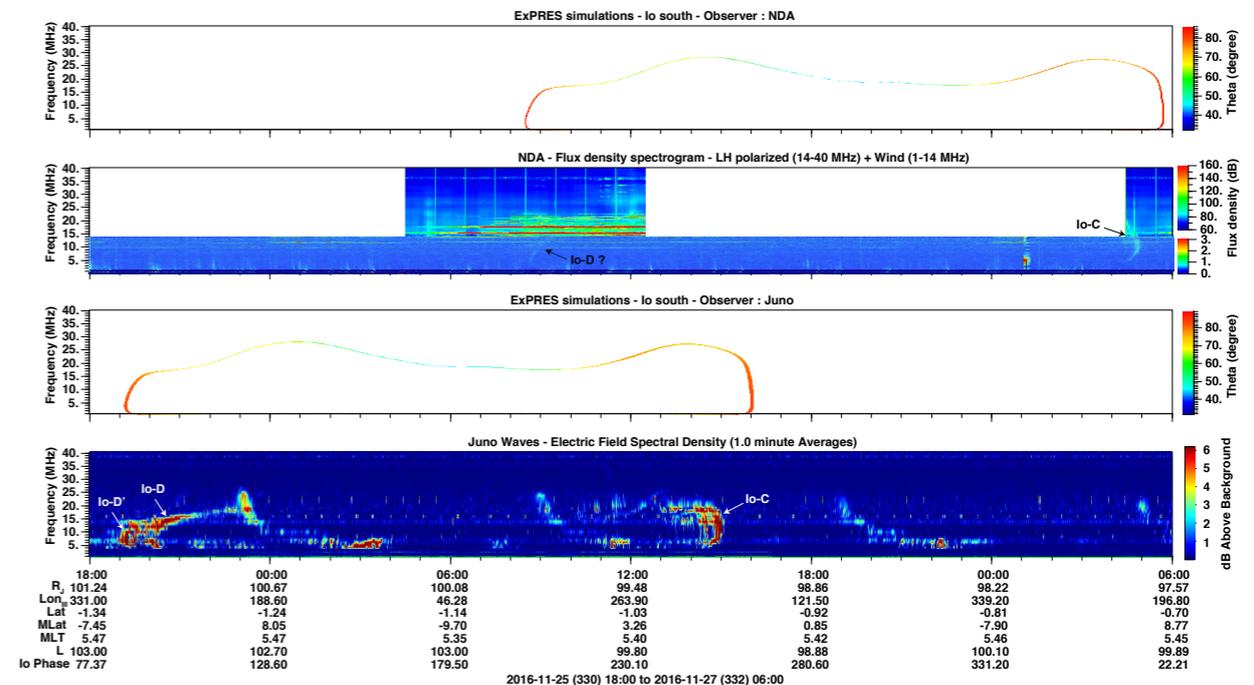
Das2 server block diagram

Simulation and modeling

- Modeling of planetary radio emissions spectrograms
ExPRES (Exoplanetary and Planetary Radio Emission Simulator)

- Modeling low frequency radio wave propagation with ray tracing

ARTEMIS-P (Anisotropic Ray Tracing code for Electromagnetic waves in Magnetospheres, Ionospheres and Solar wind, including Polarization)



Event Catalogues

- Digitized Jovian radio emission catalogues from NDA at Voyager era (published in A&A)
- HELIO Feature Catalogue (HFC)

Catalogue Collections

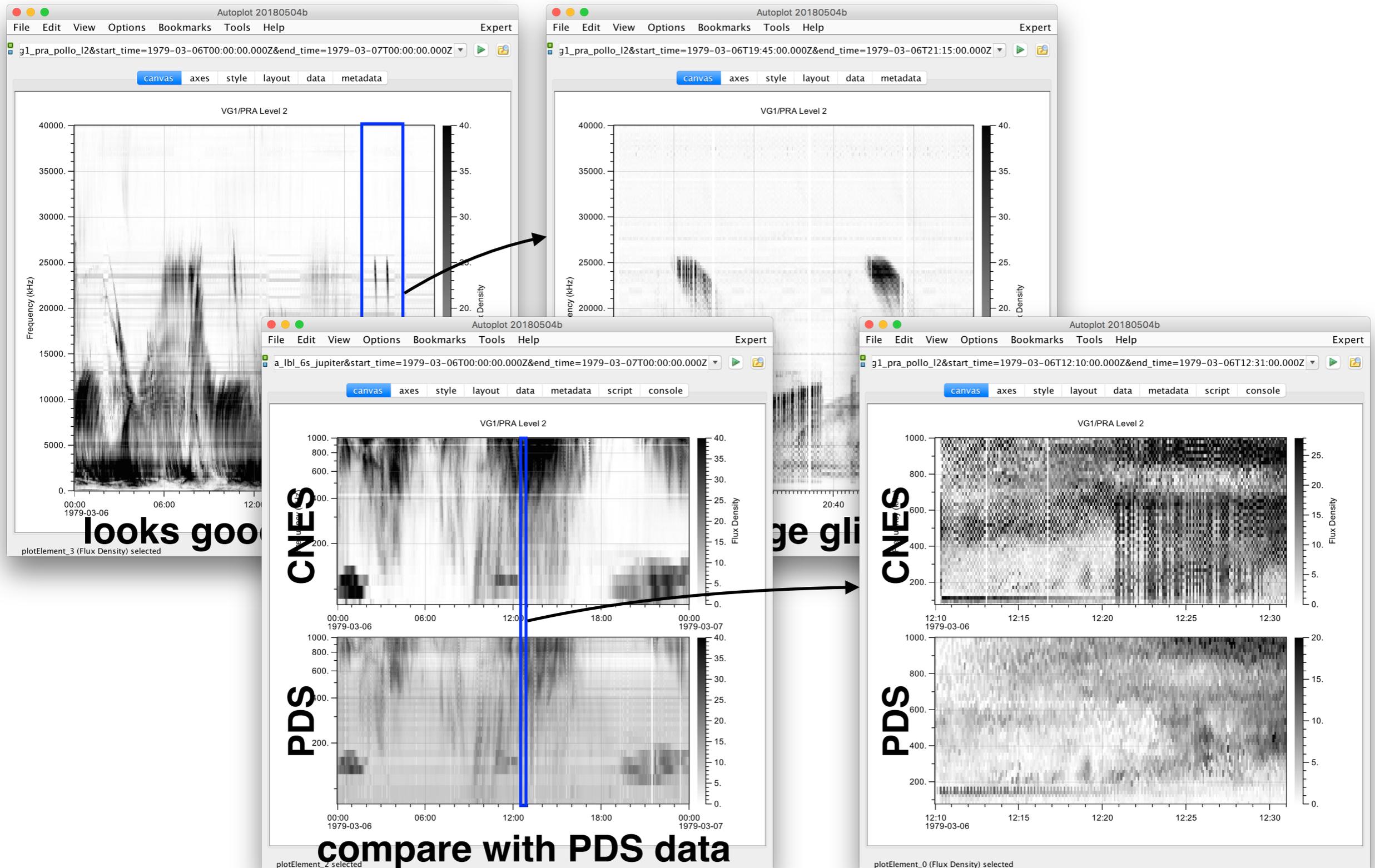
- Leblanc, Y., et al. **2020** *A catalogue of Jovian decametric radio observations from January 1978 to December 1979* (Digitised version) [Data set]. PADC. <https://doi.org/10.25935/GXZF-ZT33>
- Leblanc, Y., et al. **2020** *A catalogue of Jovian radio observations from January 1980 to December 1981* (Digitised version) [Data set]. PADC. <https://doi.org/10.25935/RAS0-ER93>
- Leblanc, Y., et al. **2020** *A catalogue of Jovian decametric radio observations from January 1982 to December 1984* (Digitised version) [Data set]. PADC. <https://doi.org/10.25935/403B-VA51>
- Leblanc, Y., et al. **2020** *A catalogue of Jovian decametric radio observations from January 1985 to December 1987* (Digitised version) [Data set]. PADC. <https://doi.org/10.25935/GH59-PY87>
- Leblanc, Y., et al. **2020** *A catalogue of Jovian decametric radio observations from January 1988 to December 1990* (Digitised version) [Data set]. PADC. <https://doi.org/10.25935/CMQB-JJ10>

Applications

- Old data recovery: Voyager/PRA
- Juno-Ground-Radio support group
- NenuFAR (SKA precursor) commissioning phase

Validation of CNES Voyager-PRA data

Using *Das2/Autoplot* + *Maser4py* reader modules for *CNES* and *PDS* datasets



Juno-Ground-Radio observation support group

France (Nançay) + USA (RadioJOVE, LWA), Ukraine (Kharkov), Japan (Iitate)...
 Using: VESPA+CDF (now); das2+autoplot (soon)

Data providers

Users

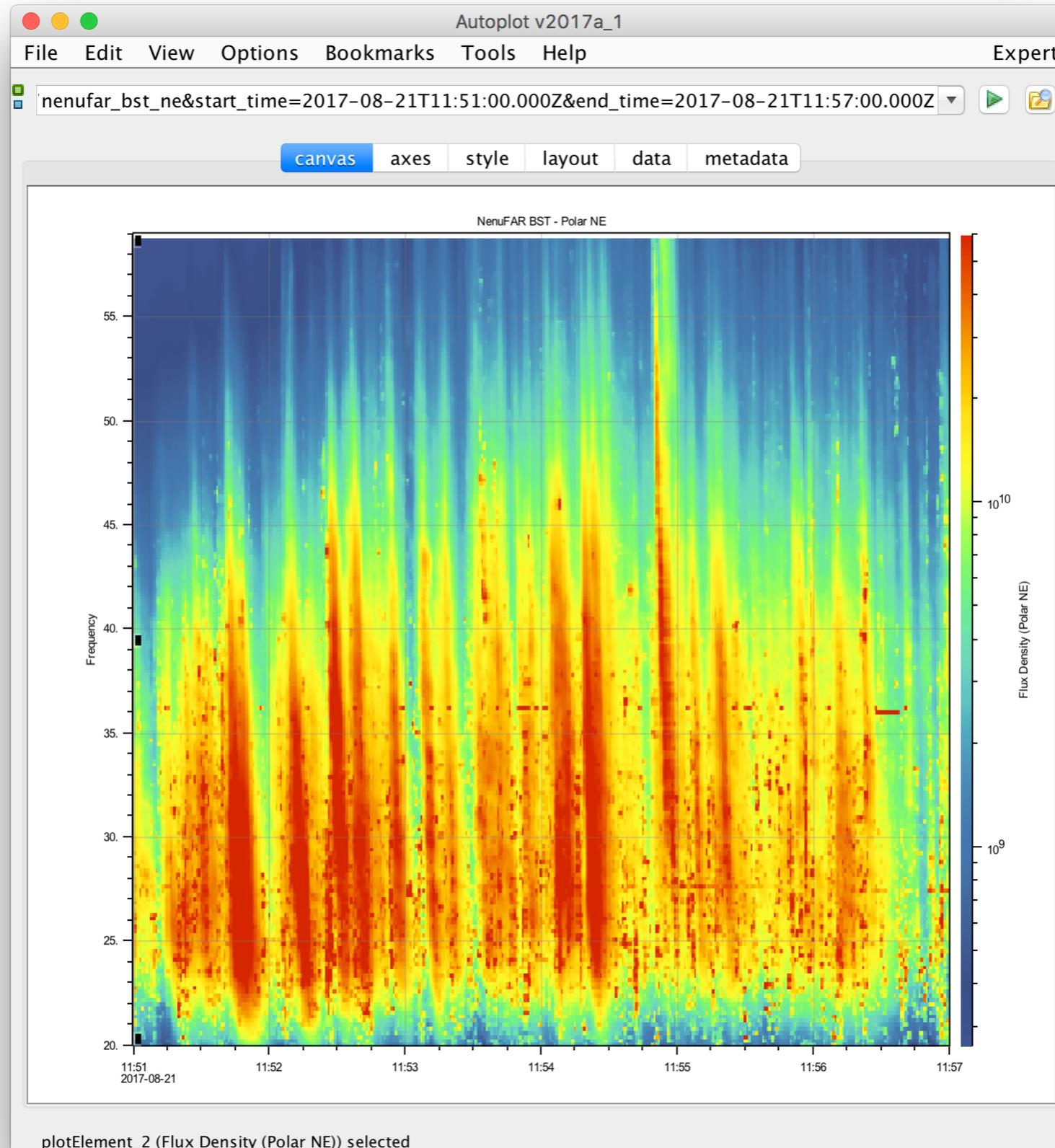
The diagram illustrates the data flow from providers to users. On the left, three data providers are shown in purple boxes: SRN-NDA France, Tohoku-Iitate Japan, and RadioJOVE. Each provider is connected to a central purple diamond labeled 'TAP'. Arrows labeled 'list of p...' point from these diamonds to a central screenshot of the MASER website. The website screenshot shows a navigation menu on the left with items like 'Accueil', 'Data Access', and 'JUNO Ground Radio'. The main content area features a news article titled 'JUNO-Ground-Radio / Planning Tool' dated Thursday 30 June 2016. Below the article is a 'TimeLine of planned Juno Ground Radio Observations' table. The table lists observation periods for various stations from 2016 to 2018. A vertical red line indicates the current date is in 2018.

Station	2016	2017	2018
litate HF radio monitor	Continuous	Continuous	Continuous
LWA1	Intermittent	None	None
Nançay Decameter Array	Continuous	Continuous	Continuous
URAN-2	Intermittent	None	None
UTR-2	None	Intermittent	None

NB: the time line take a few tens of seconds to load.

NenuFAR (a SKA precursor) commissioning phase

Using: FITS, *das2+autoplot (now)*, *EPN-TAP+ObsTAP (soon)*;



Future (sooner to later)

- More data modules and features to **maser4py**, cleaner interfaces, coordination with PyHC / HelioPy
- Distribution of **event catalogues** (published Solar radio bursts, Jovian radio bursts catalogues...)
- Launch **machine learning** activities/studies for radio spectrograms feature recognition
- **Citation** of data collections/products/events
- ESA Solar Orbiter / NASA Parker Solar Probe **ground support** (as currently done for Juno and JUICE)
- Better integration of **modelling tools** with visualisation
- Extension to **astronomical observations** (pulsars...)
- Connection with **SPASE** (NASA Space Physics registry)
- Improve Das2 interface for adaptive **spectral resampling**