A distributed data-mining software platform for extreme data across the compute continuum

Real-time detection of Solar and Jovian radio bursts with NenuFAR: a part of the EXTRACT project.

An overview of TASKA – A use cases

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The EXTRACT project

EXTreme data Across the Compute conTinuum

- Develop novel data-driven orchestration mechanisms to efficiently deploy and execute data mining workflows.

- Personal Evacuation Route (PER) :

Transient Astrophysics with a Square Kilometer Array (TASKA)

- Radio observations with higher resolution and sensitivity → next generation radio telescopes like NenuFAR or SKA produce massive data volumes
- ⟹ Need for efficient tools to manage, analyse and store data.

- **TASKA** uses **EXTRACT** technologies to handle these massive data fluxes (~100GB/hr in beamformed for NenuFAR)
- Several projects:
  - **A1-A2** : dedicated to real-time detection of solar spikes and jovian millisecond bursts (C.Viou, E.Mauduit, L.Bondonneau),
  - **C** : creating an interactive workflow that connects multiple platforms
  - **D** : developing an imager with deep learning to reconstruct transient radio sources

NenuFAR radiotelescope

- $\sim$ 2000 antennas (96 MR of 19 antennas + 6 distant MR
- Beamforming mode: 4.3 TB/hr (~ 35 PB/yr)
- Imaging mode : 8.6 TB/hr (~ 74 PB/yr)

➢ Local storage: 3.5 PB

➢ Data reduction by scientists → diminution of data volume by a factor 100

➢ Reduced data are transferred towards data centres (3 PB in Meudon and 5 PB in Orléans)

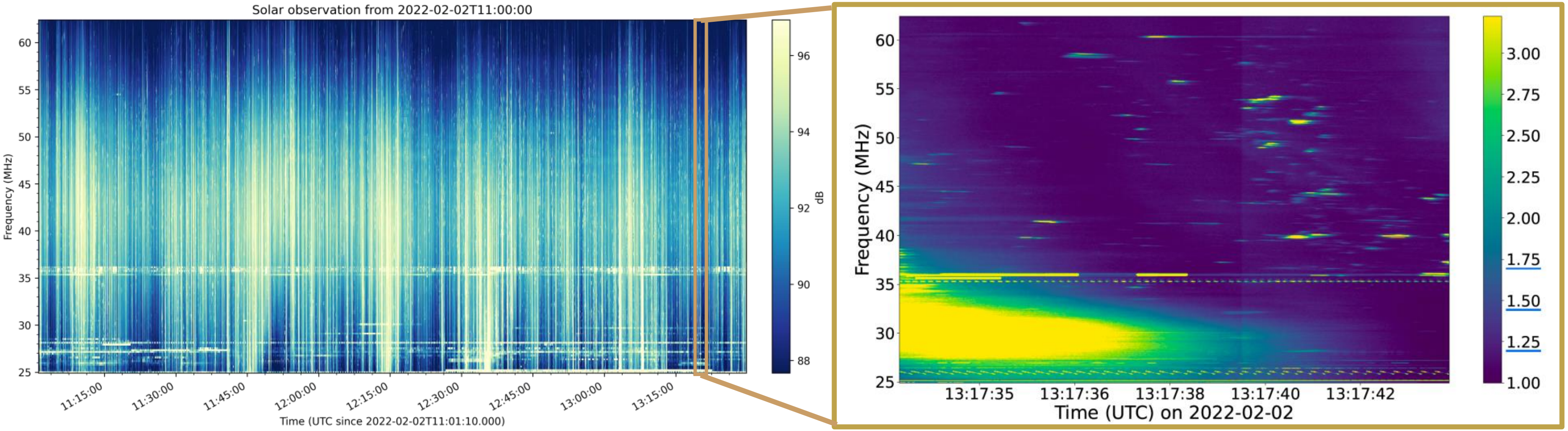
⟹ Data must be processed where it is stored !

- Range 10-80 MHz
- resolution :
  - dt = 0.3-84 ms
  - df = 0.1-12 kHz

TASKA – A1 : Solar spikes

Solar radio spikes

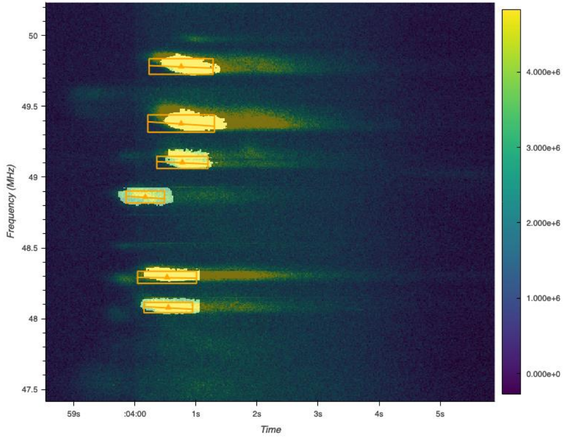
- Dedicated to automatically detect solar radio spikes using SpikeNet

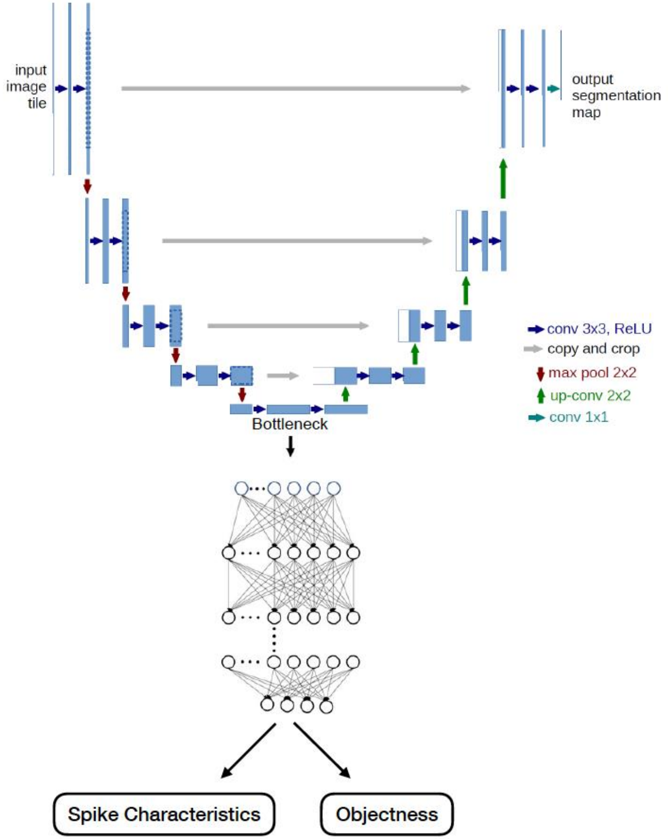


[Murphy et al, OJA, 2024]

Detection method : SpikeNet

- ML model trained on ~100 000 samples of solar spikes (64 by 64 pixels)
- Produced segmentation masks for radio spikes in the validation set and predicted the spike characteristics, i.e. location in time and frequency, duration, spectral width and drift rate
- Bursts that are not fully in one tile can not be detected



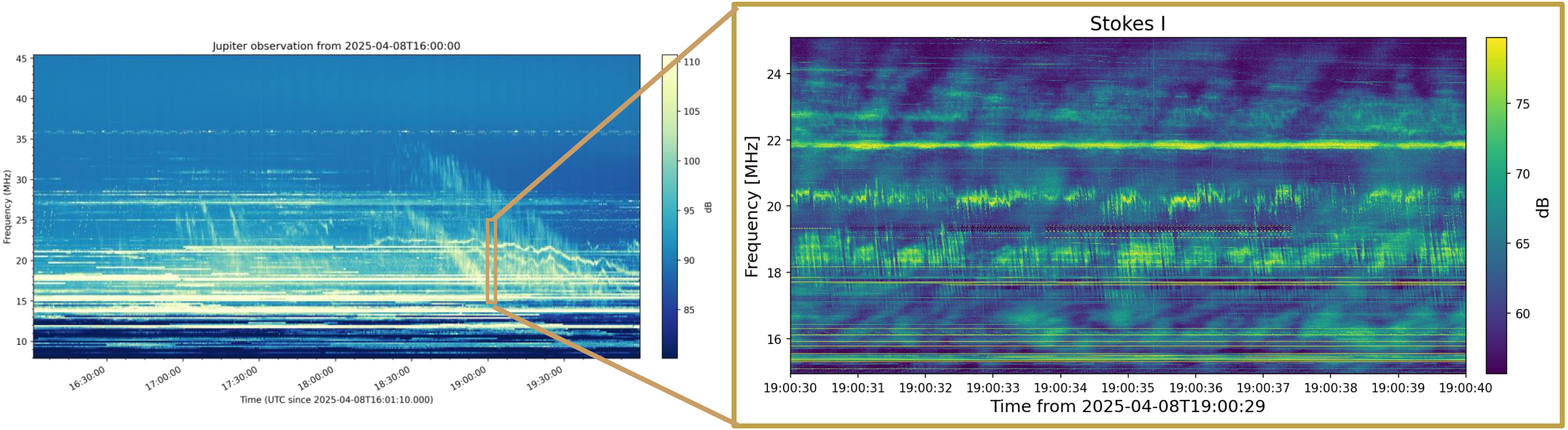


[Murphy et al, OJA, 2024]

TASKA – A2 : Jovian S-bursts

Jovian S-bursts

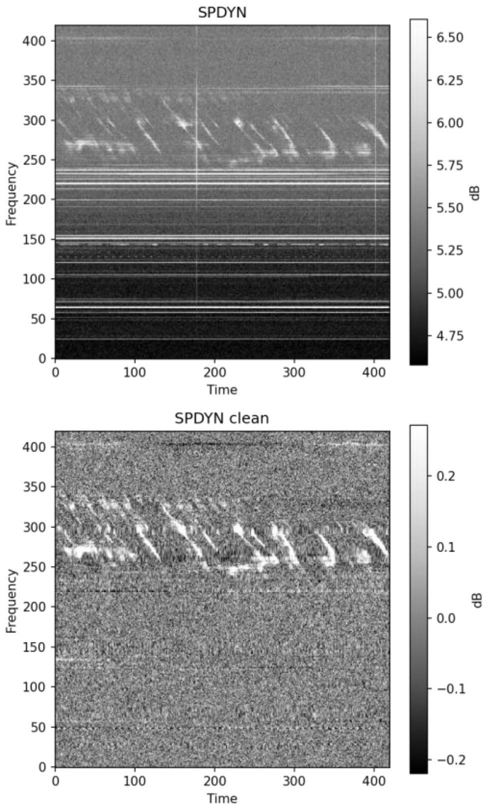
- Developing an algorithm for real-time detection of fine drifting structures during radio observations with NenuFAR
- Use a method originally developed for Jupiter observations with NDA-JunoN data *[Mauduit et al, 2023, Nat Coms]*



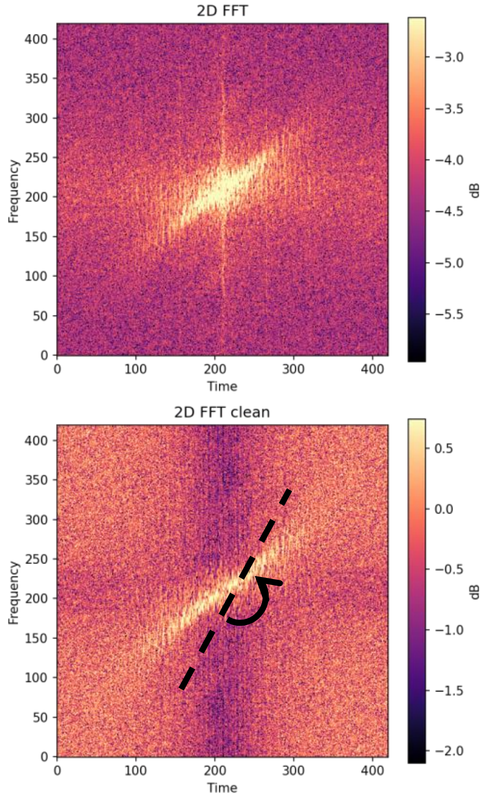
Detection algorithm : spyburst

spyburst

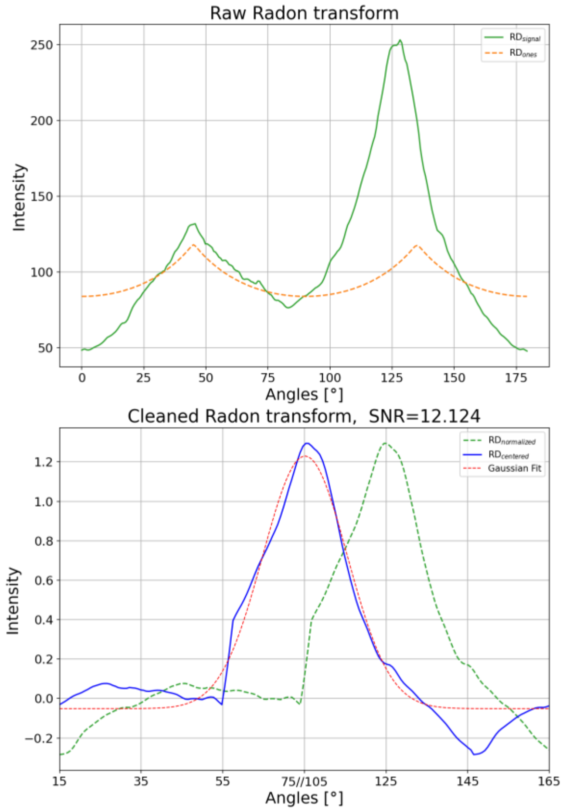
1 - RFI mitigation

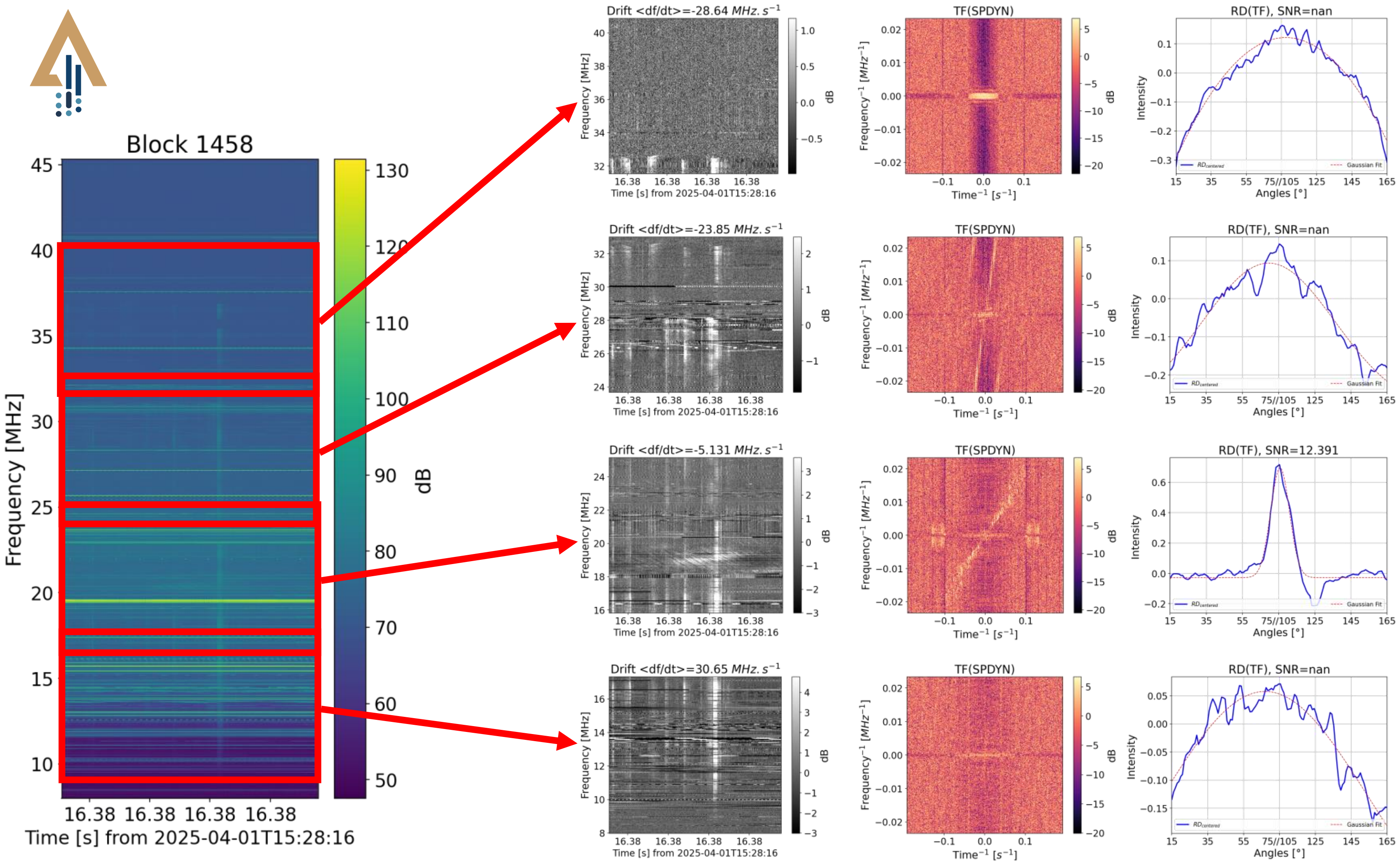


2 – FFT2D



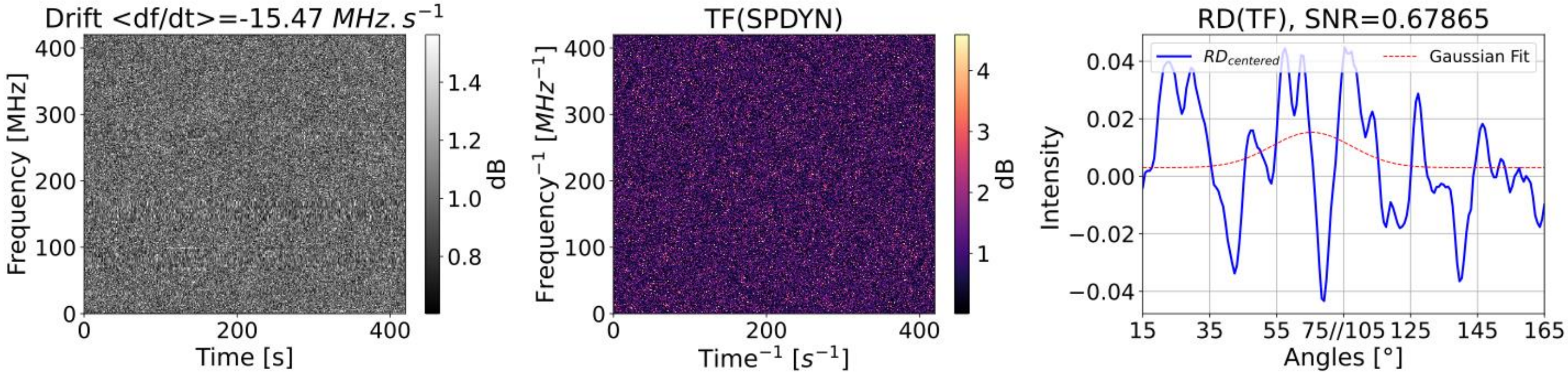
3 - Radon transform



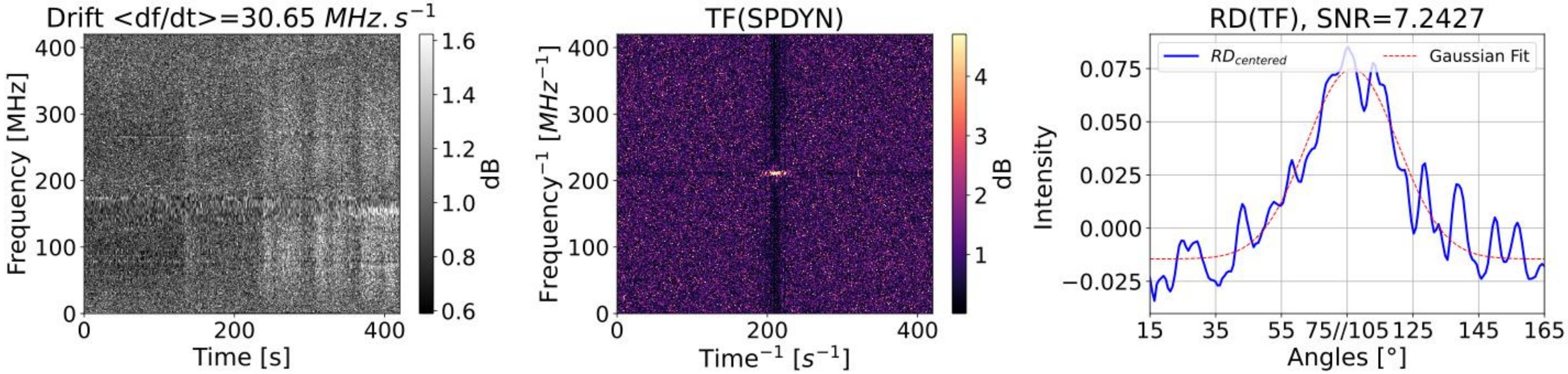

Block 1458
Frequency [MHz]
Time [s] from 2025-04-01T15:28:16
dB
Drift <df/dt>=-28.64 MHz. s⁻¹
TF(SPDYN)
RD(TF), SNR=nan
Drift <df/dt>=-23.85 MHz. s⁻¹
TF(SPDYN)
RD(TF), SNR=nan
Drift <df/dt>=-5.131 MHz. s⁻¹
TF(SPDYN)
RD(TF), SNR=12.391
Drift <df/dt>=30.65 MHz. s⁻¹
TF(SPDYN)
RD(TF), SNR=nan
Frequency⁻¹ [MHz⁻¹]
Time⁻¹ [s⁻¹]
Intensity
Angles [°]
RD_centered
Gaussian Fit

Exemples de non-détection

Pas de détection



Pente positive



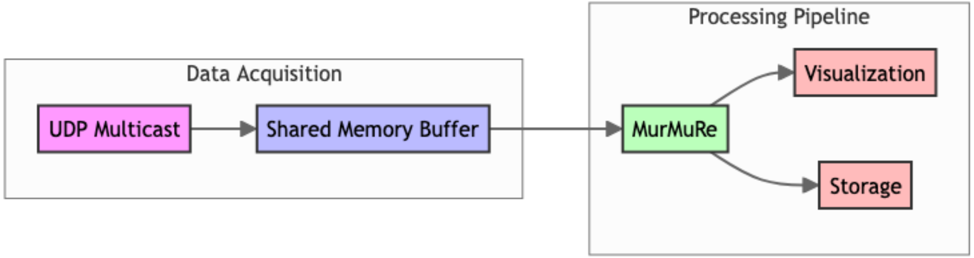
MurMuRe pipeline and EXTRACT interfaces

Modular Multicast Receiver

MurMuRe

L.Bondonneau (ORN)

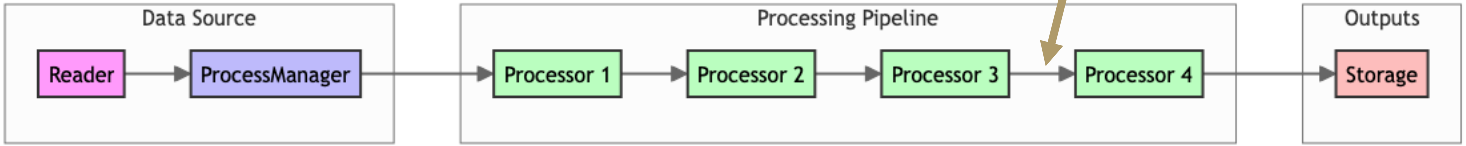
Pipeline Architecture



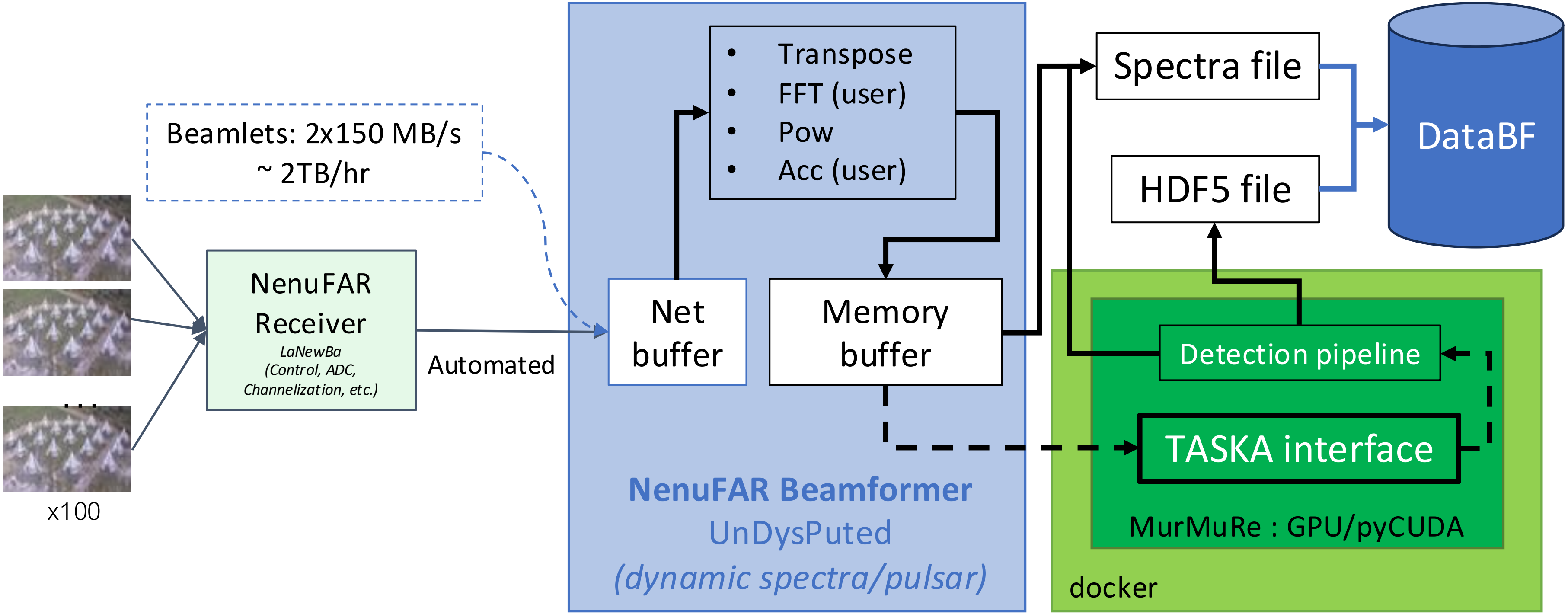
A1 or A2 processors

- MurMuRe :

Simple Example

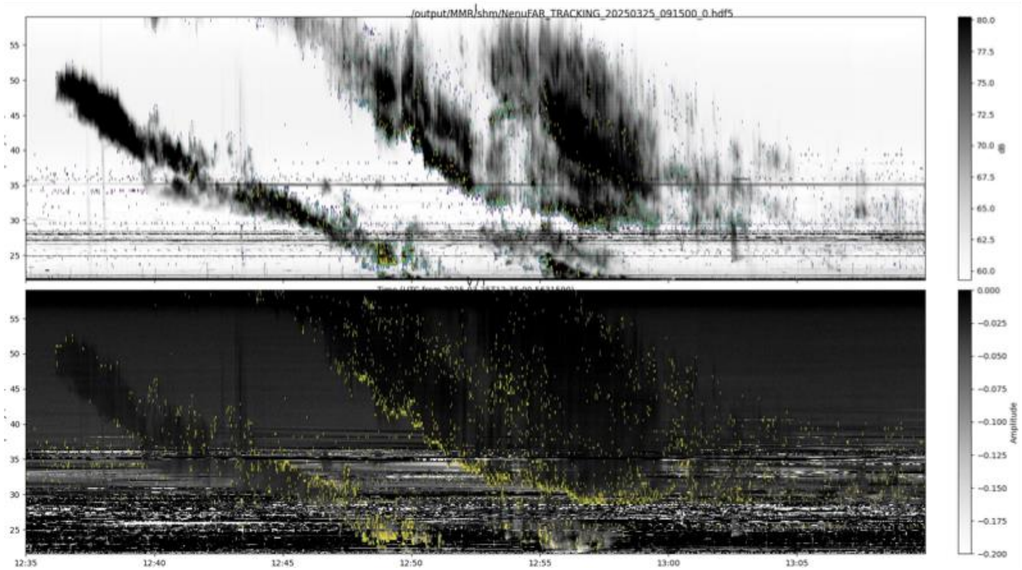


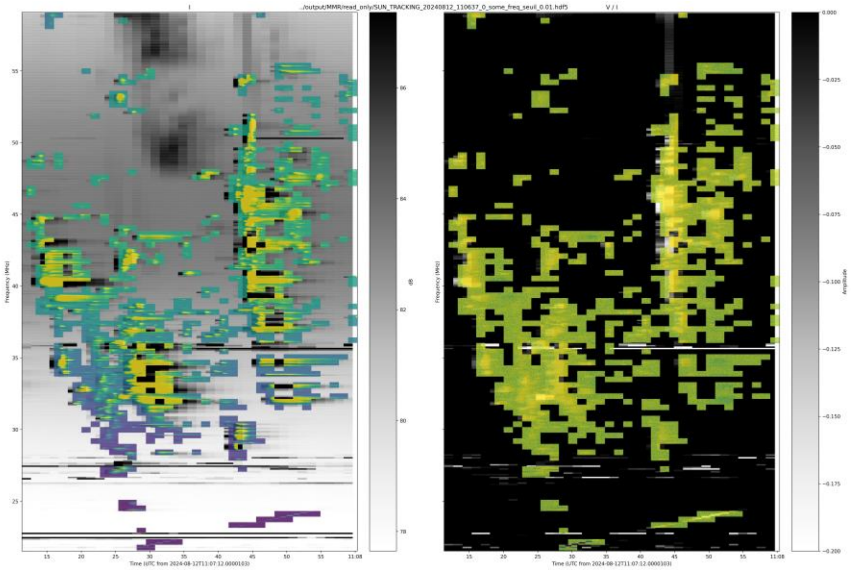
Undysputed-tf with MurMuRe and EXTRACT



Real-time detection with NenuFAR

SpikeNet successfully applied to real-time observations





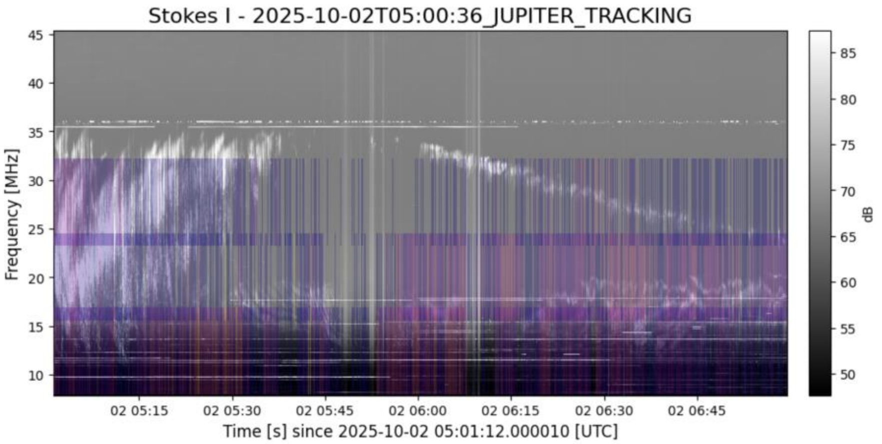
Observation campaign : from 22 to 29/03/2025, 09h15-14h50, 21-84 MHz

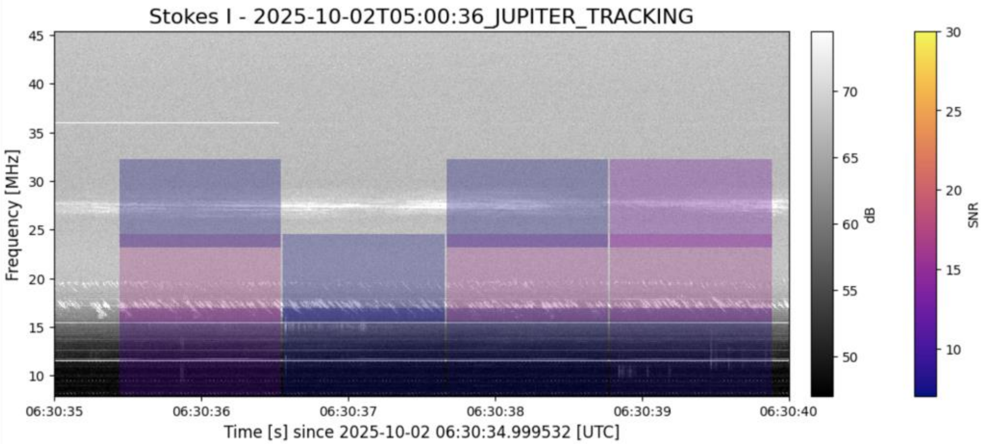
→ 10x data volume reduction !

GitLab repository

	Original pipeline	TASKA-A2 pipeline	
df, dt	6.1 kHz, 21 ms	98 kHz, 1.34 s	6.1 kHz, 21 ms
.spectra file size	27 Gb/hr	0.037 Gb/hr	-
.hdf5 file size	-	-	2.5 Gb/hr

Spyburst successfully applied to real-time observations





→ Réduction du volume de données d'un facteur 10 environ !

[GitLab repository]

	Original pipeline	TASKA-A2 pipeline	
df, dt	3.05 kHz, 2.5 ms	24 kHz, 1.06 s	3.05 kHz, 2.5 ms
.spectra file size	250 Gb/hr	0.082 Gb/hr	-
.hdf5 file size	-	-	40 Gb/hr

Conclusions

Conclusions

- Important step toward smart data filtering for next generation radiotelescopes such as NenuFAR or SKA.
- It also paves the way for “analog to information” processing, which would drastically reduce the storage needs.
- The type of emissions studied in this work require a high time-frequency resolution, but they are embedded within larger slowly-varying emissions that can be studied at a lower resolution.
- This approach helps optimizing data storage while maintaining its value for scientific analysis, thus preparing for scalable solutions in the SKA era.
- Code available on GitLab, easy to clone and use with documentation and notebook tutorials provided.

[https://gitlab.obspm.fr/extract]

Next steps and perspectives

- Develop a CNN for S-bursts based on anomaly detection.
- Optimize existing algorithms to have better detections → see V. Harff poster
- spyburst is being used with data from other instruments (LWA, Juno, ..)
- Find an even more efficient way to store the outputs.
- Include multi-scale processing

SpikeNet

MurMuRe

spyburst

Thank you !

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Follow us on social media:

www.extract-project.eu

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