EXTRACT

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

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Real-time detection of Solar and Jovian radio bursts with NenuFAR: advancing astrophysical data mining with the EXTRACT project.

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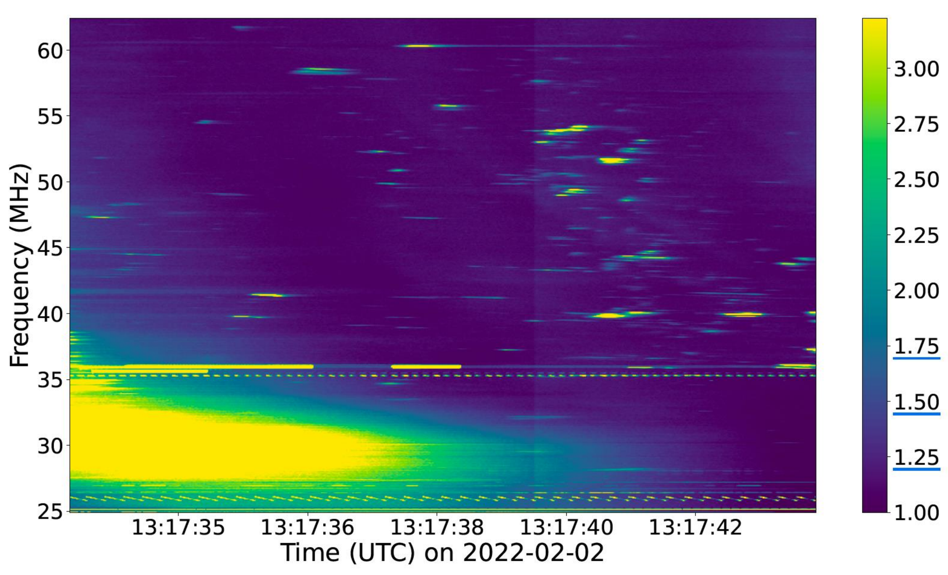
Context and motivations

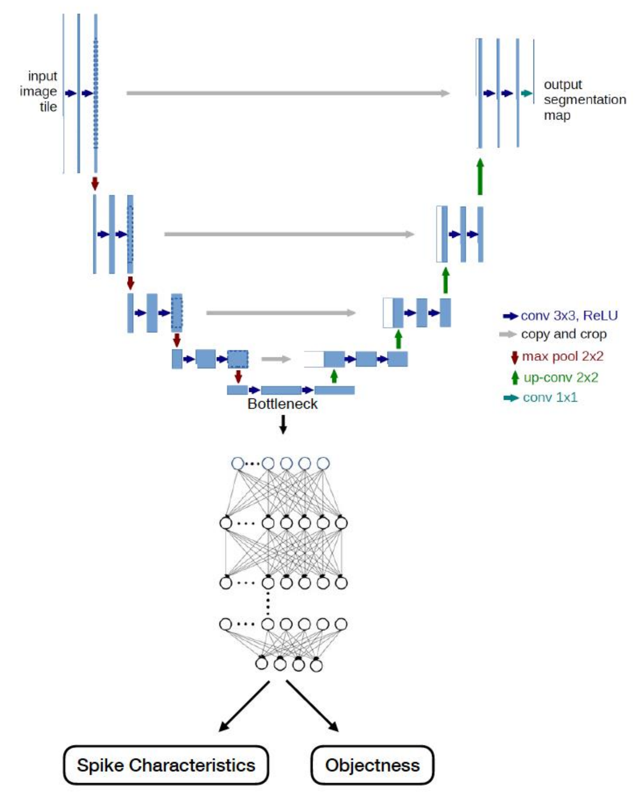
- There is an increasing need for ultra-high-resolution radio observations with enhanced sensitivity and this has led to a surge in data volumes from next-generation radiotelescopes such as NenuFAR or SKA, [1,2].
- To help scientific analysis, the development of efficient tools for data management, processing, and storage optimization is important.
- The Transient Astrophysics with a Square Kilometer Array (**TASKA**) use case, takes advantage of the technologies developed by the **EXTRACT** [3] project to handle massive data streams (~100GB/hr in beamformed mode) produced by NenuFAR, one of SKA pathfinders.
- In this work we present two projects focusing on real-time detection of radio emissions :
  - **A1** : dedicated to Solar radio spikes, it uses the deep-learning based SpikeNet convolutional neural network, [4].
  - **A2** : dedicated to Jovian millisecond bursts (S-bursts), it takes advantage of a detection method based on Fast Fourier and Radon transforms, [5].

A1 - Solar bursts with SpikeNet [6]

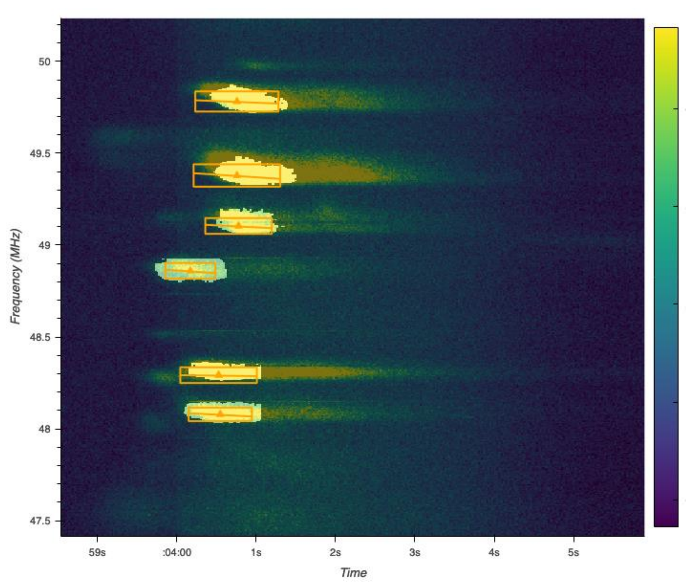
Example of an observation with spikes :



SpikeNet structure:



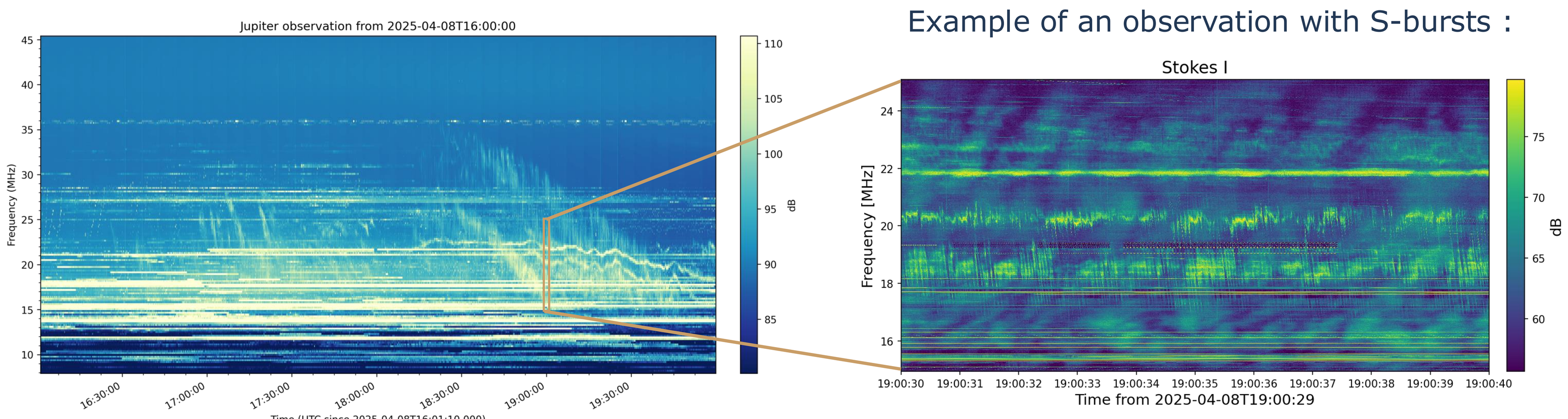
Detection example:



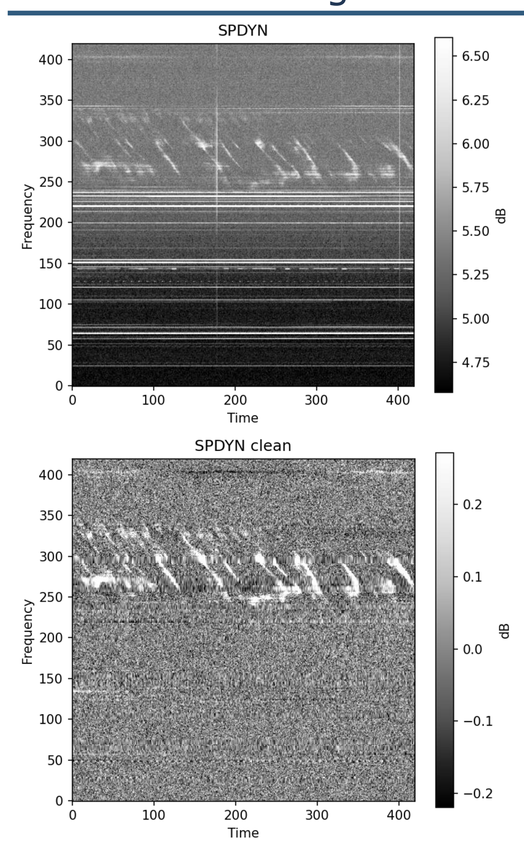
- ML model trained on ~100 000 samples of solar spikes (64 by 64 pixels)
- Produced segmentation masks for radio spikes in the validation set and predicted the spike characteristics, i.e. location in time and frequency, duration, spectral width and drift rate
- Bursts that are not fully in one tile can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

A2 – Jovian S-bursts detection method [6]

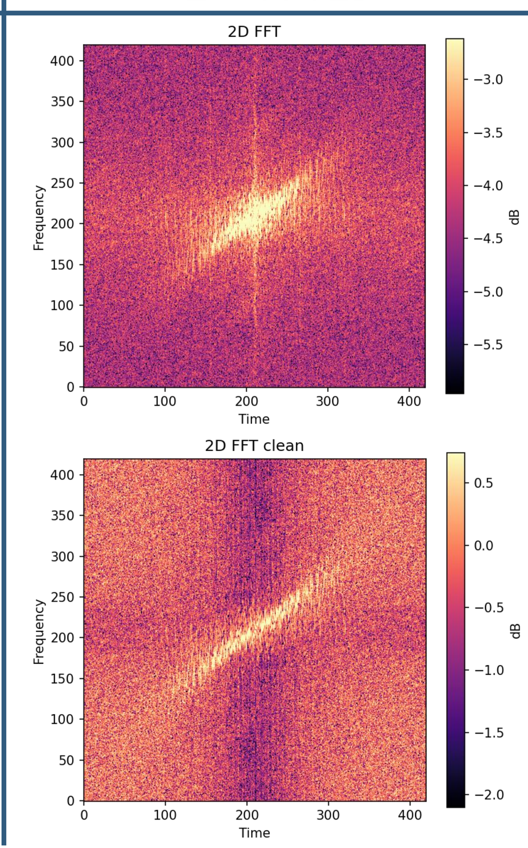
Example of an observation with S-bursts :



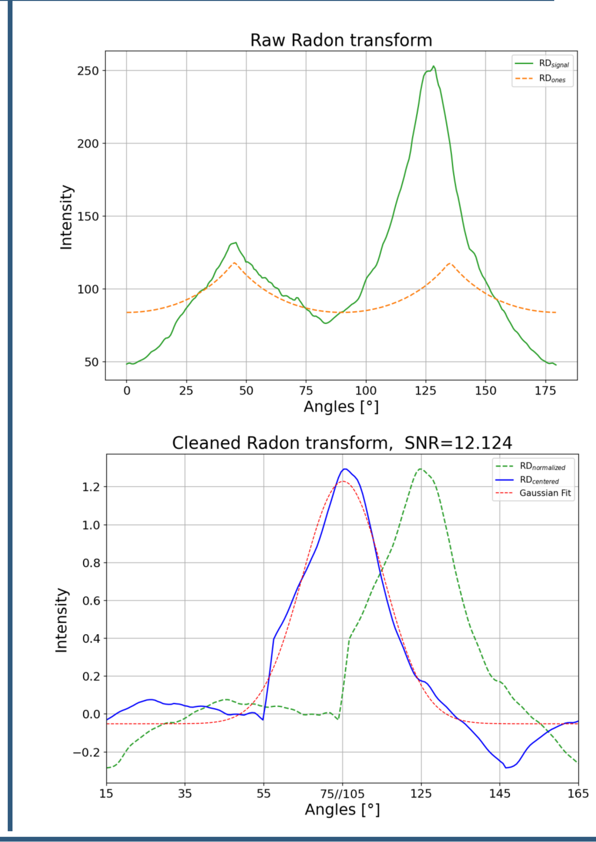
1 - RFI mitigation



2 – FFT2D

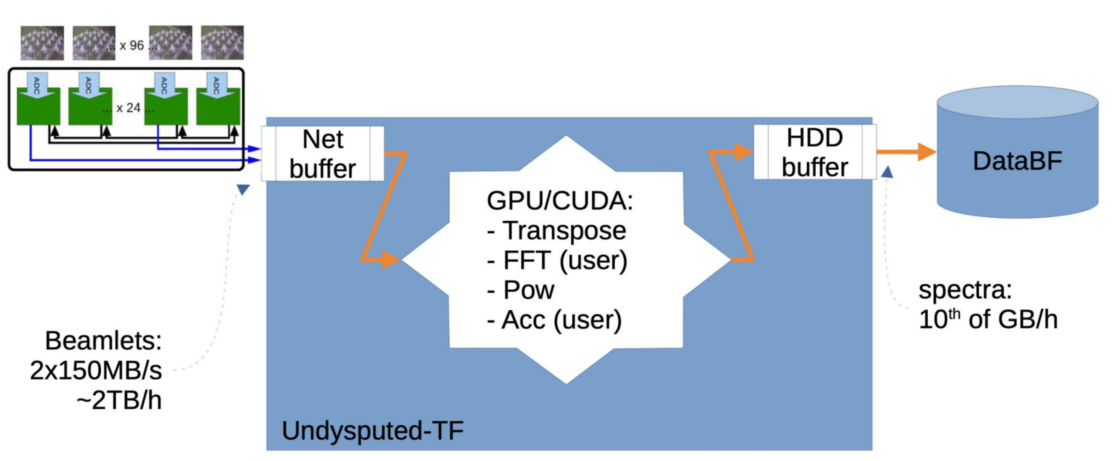


3 - Radon transform

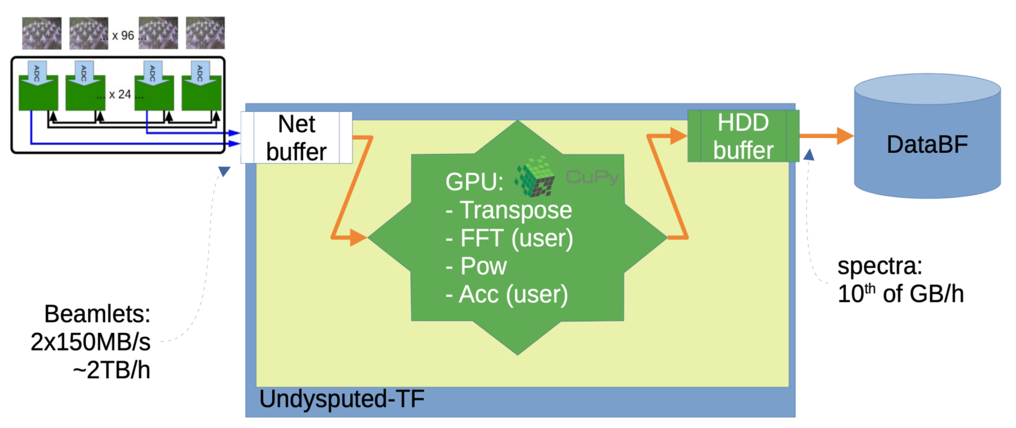


MurMuRe [7] and EXTRACT interfaces

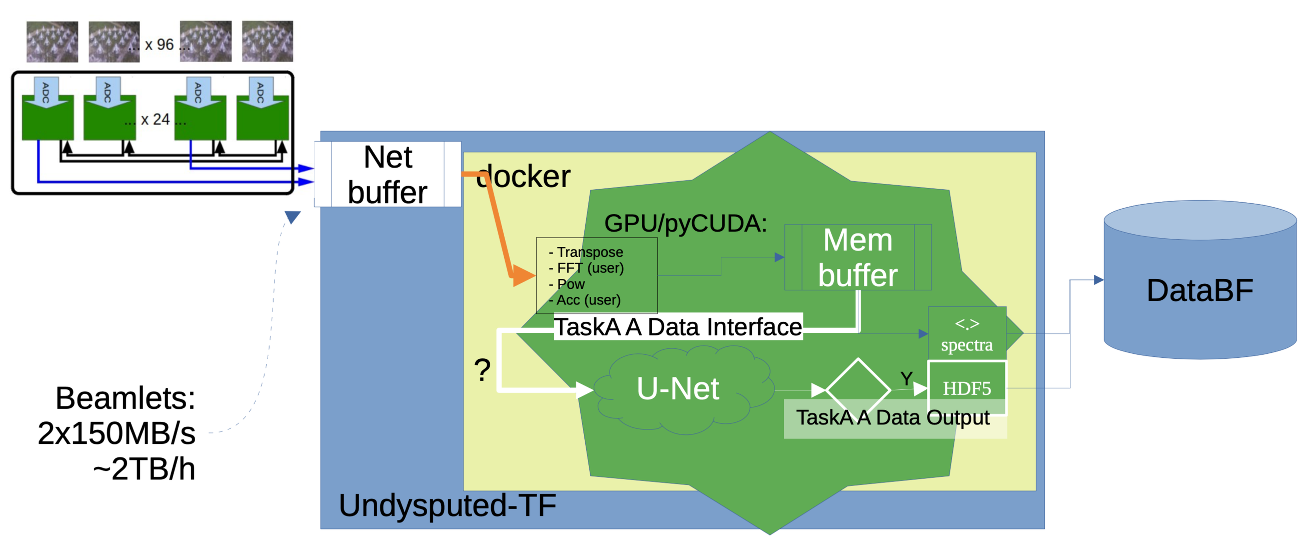
Original Undysputed-TF interface :



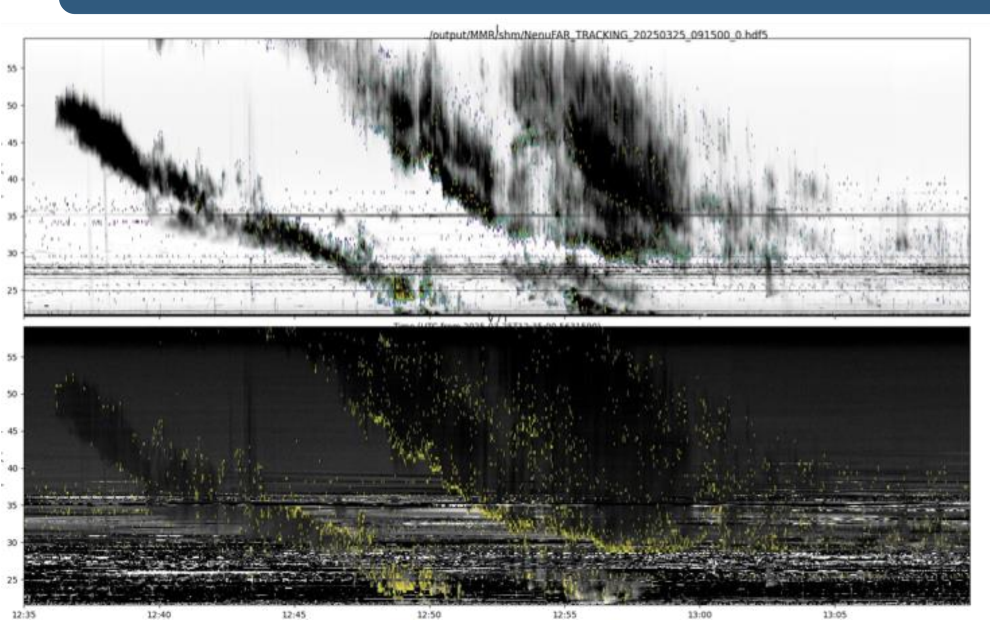
Undysputed-TF interface with MurMuRe :

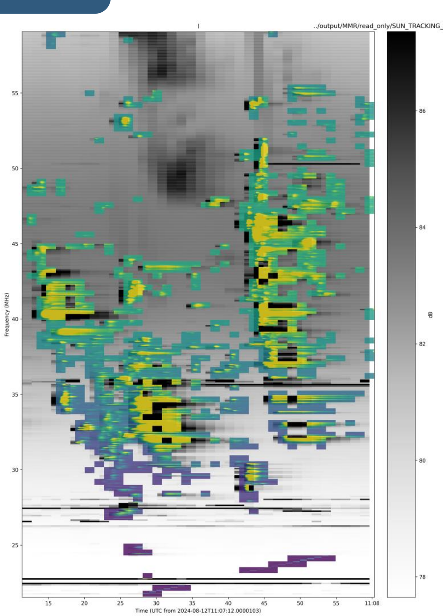


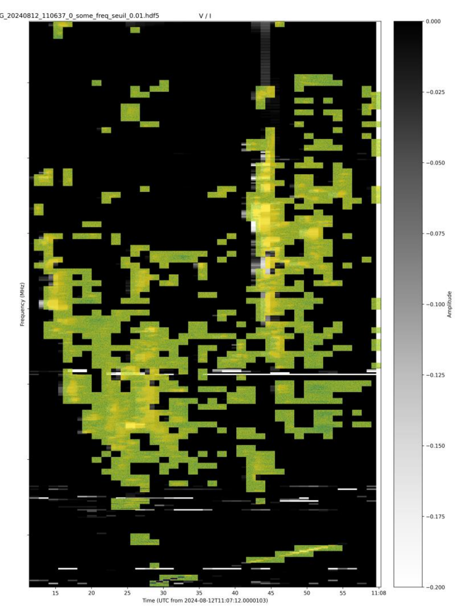
Undysputed-TF interface with MurMuRe and EXTRACT :



A1 – Real-time detection with NenuFAR







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

	Original pipeline	TASKA-A1 pipeline
(df,dt)	(6.1 kHz, 21 ms)	(98 kHz, 1.34 s)
Spectra	27 GB/hr	0.037 GB/hr
HDF5	--	2.5 GB/hr

- SpikeNet was successfully applied to real-time observations with NenuFAR !
- 10x data volume reduction

→ Next steps for A1 are to find the best parameters to limit false alarms and optimize what is stored in the HDF5 files.
→ Next steps (ongoing) for A2 are to be able to the same with the current algorithm and to develop a CNN based on anomaly detection to enhance the detection performances.

Conclusions and perspectives

- These advancements provide an important step toward smart data filtering for next generation radiotelescopes such as NenuFAR or SKA.
- It enables real-time decision-making which allows astronomers to dynamically store high-resolution data for only the most scientifically valuable events while preserving lower-resolution data for broader analysis.
- 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 these very short emission are often 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.

References

[1] – Zarka et al. “The Low-Frequency Radiotelescope NenuFAR”, 2nd URSI Atlantic Radio Science Meeting (AT-RASC), 2018
[2] – Dewdney et al, “The Square Kilometre Array”, IEEE Proceedings 97.8, 2009, p. 1482-1496
[3] - https://extract-project.eu/
[4] - Murphy et al, “Semantic segmentation of solar radio spikes at low frequencies”, The Open Journal of Astrophysics, 2024, 10.33232/001c.120317
[5] - Mauduit et al, “Drifting discrete Jovian radio bursts reveal acceleration processes related to Ganymede and the main aurora”, Nature Communications, 2023, 10.1038/s41467-023-41617-8
[6] - https://gitlab.obspm.fr/extract
[7] - https://gitlab.bsc.es/extract/extract-use-cases/taska/use-case-a/modular_multicast_receiver

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This project has received funding from the European Union’s Horizon Europe programme under grant agreement number 101093110.

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