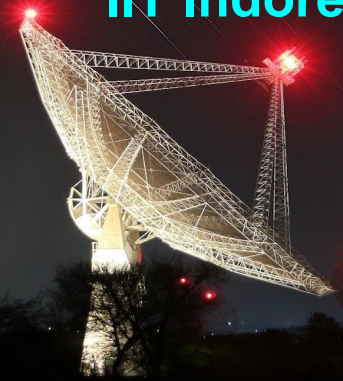
GARUDA with TraP:

Hunting for LPTs in the GMRT Archive

Abhinav Narayan

IIT Indore



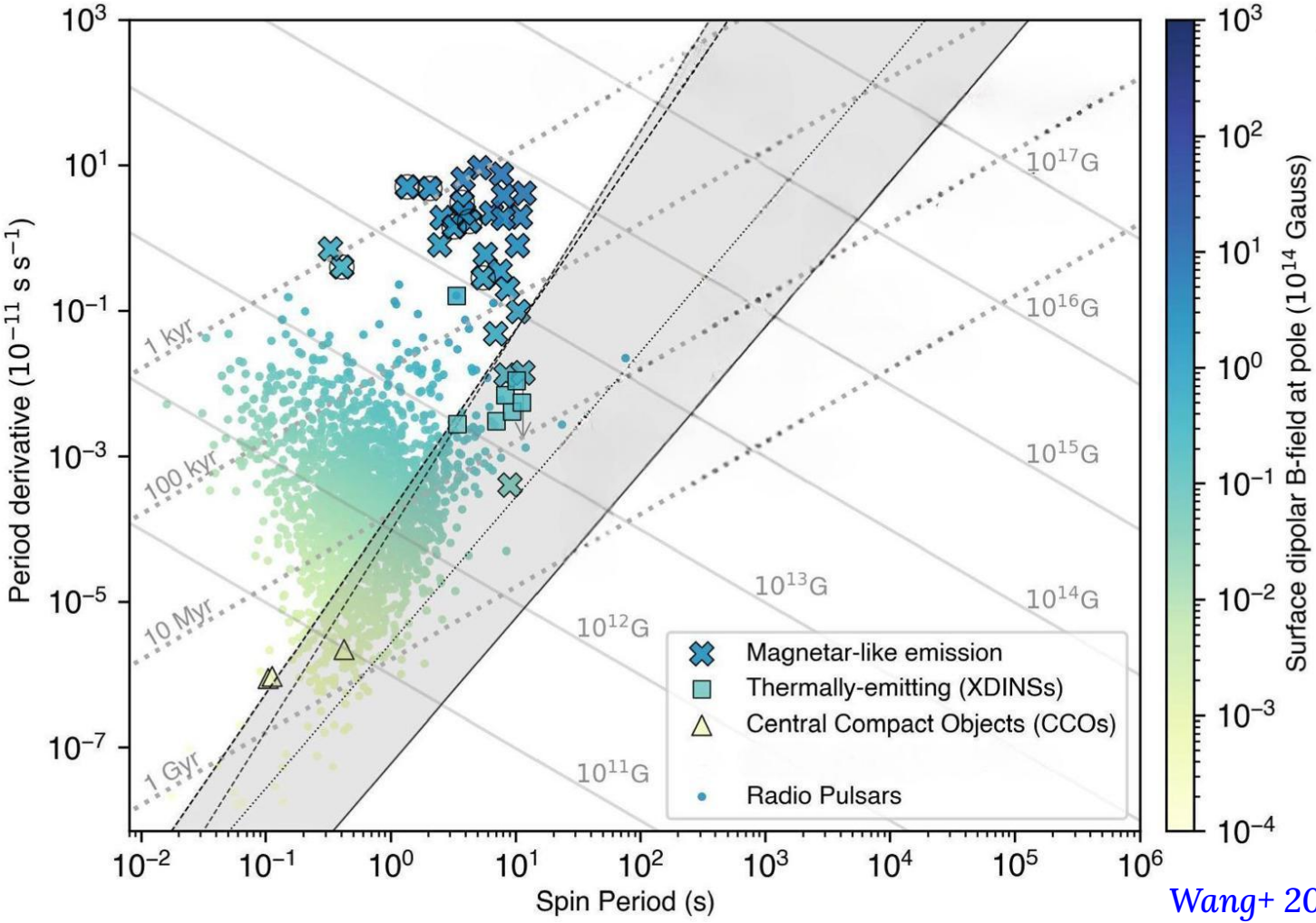
Collaborators:
Chahat Dudeja, Sridhar Gajendran, Kshitij Bane, Narendra Nath Patra, Jayanta Roy, Siddhartha Bhattacharya

FTSky 2025, ICTS

Picture courtesy: Chitrana Vishram & Divya Oberoi

Class	Period Range	Main Emission	Example(s)	Reference(s)
Normal Pulsars	0.1–23.5 s	Radio, some X-ray/γ	PSR B0329+54	*Hewish+ 1968*
Millisecond Pulsars (MSPs)	1–10 ms	Radio, X-ray/γ	PSR J0437–4715	*Backer+ 1982*
Magnetars	2–12 s	X-ray, γ-ray, some radio	SGR 1806–20	*Kaspi & Beloborodov 2017*
Rotating Radio Transients (RRATs)	sec–min	Sporadic radio	PSR J1819–1458	*McLaughlin+ 2006*
Central Compact Objects (CCOs)	~0.1–0.4 s	Soft X-ray	Cas A CCO	*Pavlov+ 2000*
Isolated Thermal NS ("Magnificent Seven")	~3–10 s	Soft X-ray	RX J1856.5–3754	*Haberl 2007*
X-ray Binaries (LMXB/HMXB)	ms–s	X-ray	Her X-1, Sco X-1	*Giacconi+ 1971; Lewin+ 1995*
Transitional MSPs (tMSPs)	ms	Radio ↔ X-ray switching	PSR J1023+0038	*Archibald+ 2009*
Long Period Transients (LPTs)	minutes–hours	Radio bursts, some multi-λ	GLEAM-X J1627–52	*Hurley-Walker+ 2022*

Neutron Star Zoo



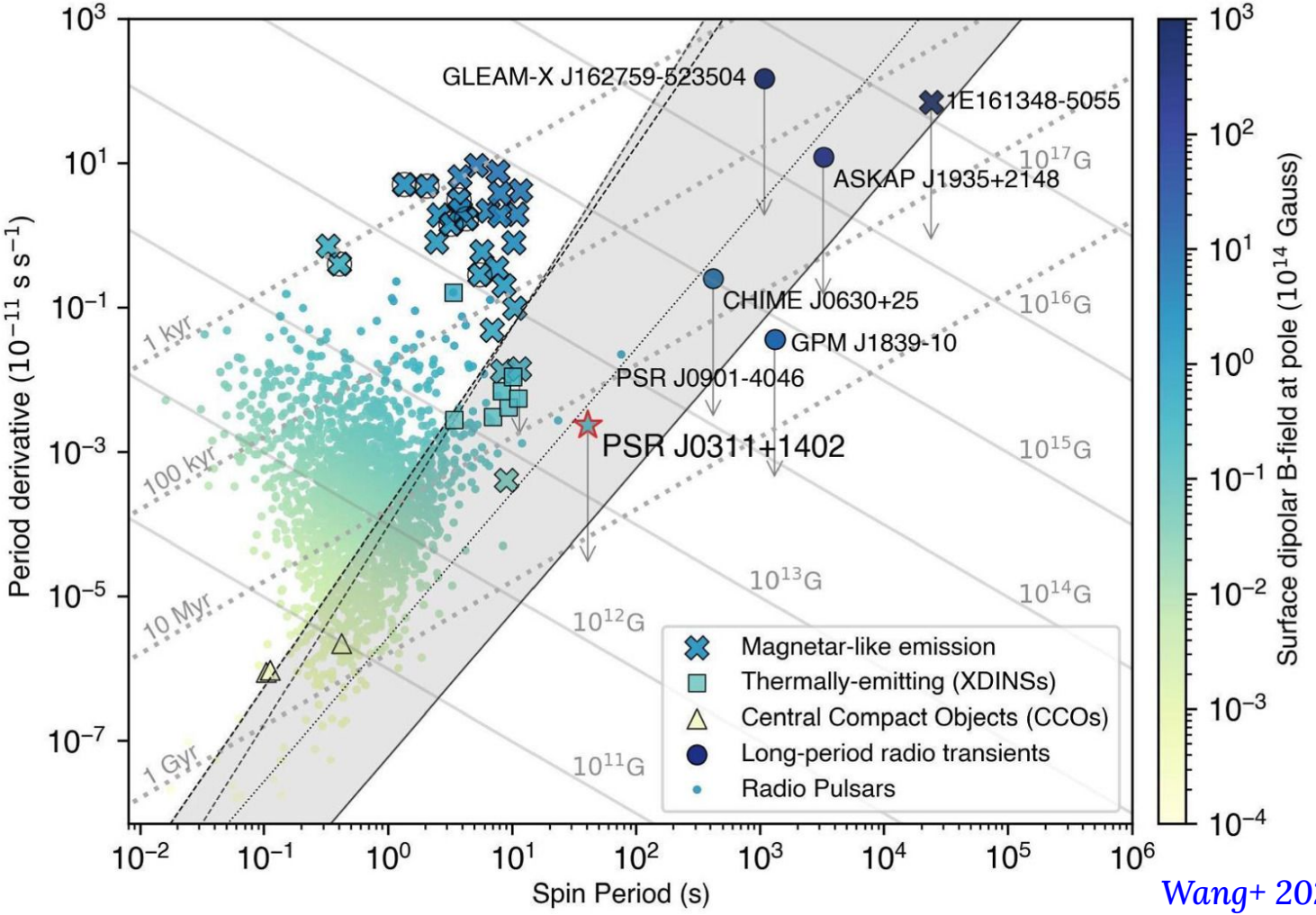
Caption: *Spin period (**P**) vs. period derivative (**Ṗ**) for NS.*

Symbols: ATNF isolated radio pulsars (dots), magnetar-like X-ray emitters (stars), XDINSs (squares), and CCOs (triangles).

Color bar: surface dipolar magnetic field

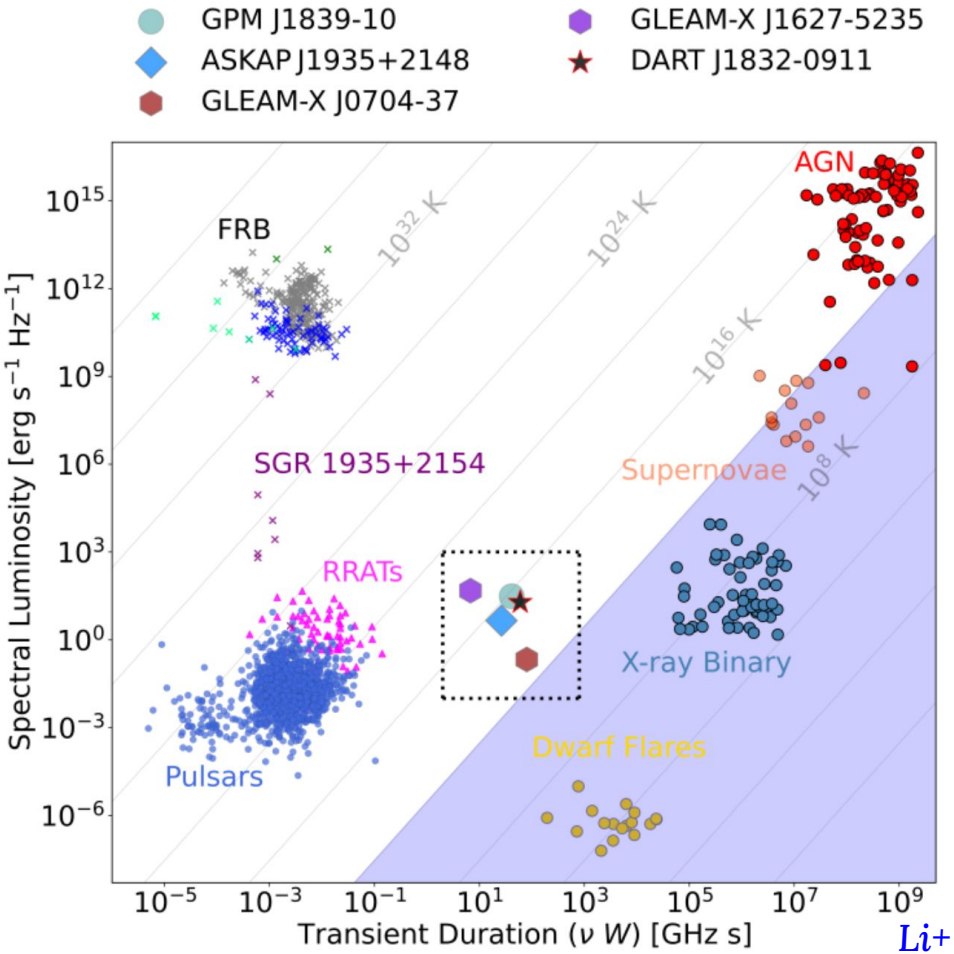
Lines: dashed (pure dipole death-lines), dotted (twisted dipole), solid (twisted multipole). Shaded region: "death valley" for neutron stars.

Wang+ 2025



LPTs

Wang+ 2025



- Transient Landscape Diagram showing coherent and incoherent emitters
- LPTs bridge the gap between these two populations

Li+ 2024

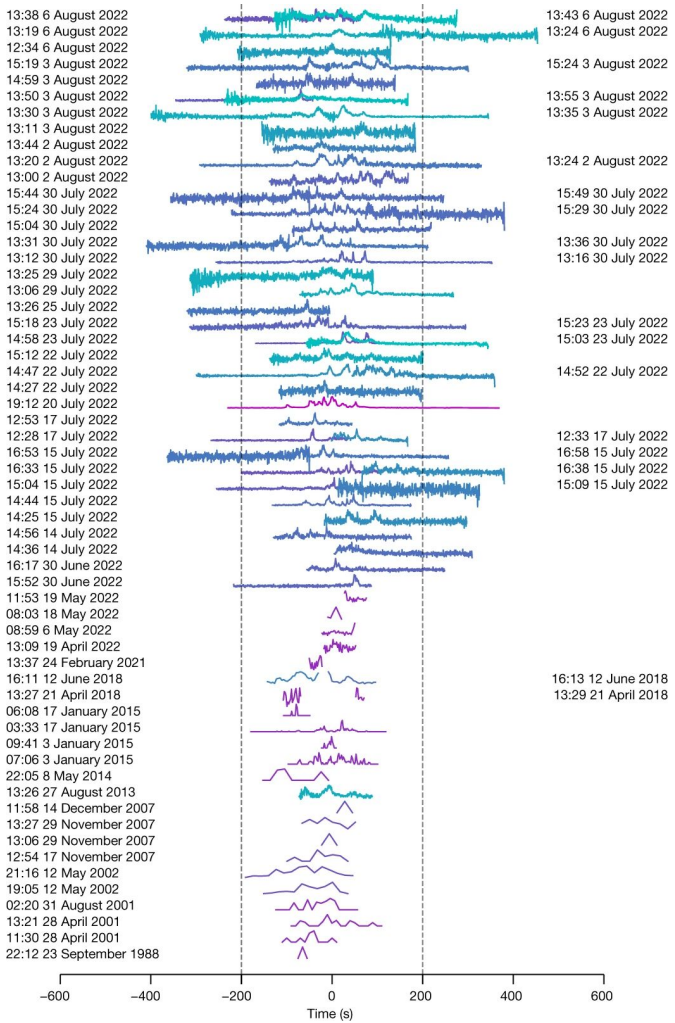
What Are Long-Period Transients (LPTs)?

- Exhibit periods of several minutes to hours
- Pulse durations range from seconds to minutes
- Show highly polarised, coherent radio emission
- Unknown Galactic origin
- Physical nature remains uncertain
  - Proposed models: long-period magnetars, white dwarfs, binary systems
- Some are strictly periodic, others show variable behavior
- Some have X-ray/optical counterparts

[*Hurley-Walker+ 2022, 2023; Caleb+ 2024; Li+2024; Rea+2024 and all others*]

Why Traditional Searches Miss LPTs

1. **Search algorithms assumed periodicity**
    - Fourier-domain searches optimized for periodicity up to seconds.
2. **Boxcar matched filtering for short widths**
    - Templates span microseconds to seconds.
    - Several second to minute-long pulses fall outside range → low S/N never peaks in the matched filter.
3. **Observation time limits**
    - Short observations (few minutes) miss pulse having minutes-long periodicity
    - Single detected pulse often discarded as RFI.
4. **RFI excision biases**
    - Bright, isolated events flagged as interference.
    - Red-noise limits the search period range



- **GLEAM-X J1627-5235** discovered with MWA archival data
- ~18 min period
- Active only for 2 months in eight years of observations
- Progenitor could be ULP magnetar
- **GPM J1839-10** discovered by MWA.
- Period: ~ 21 min
- Pulse duration: 30–300 s
- **Active since: ≥ 1988** (found in radio archives)
- Progenitor: Unknown
- Implication: Decades-long persistence suggests more such long-lived sources may exist, **awaiting discovery in archival data.**

Hurley-Walker+ 2022, 2023

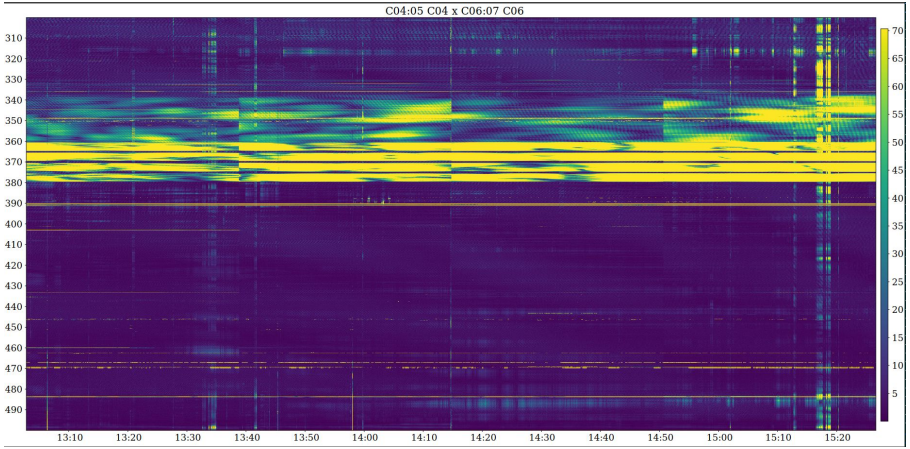
GARUDA

1. Leveraging the huge GMRT archive. > 20 yrs of data.
2. Data reduction pipeline designed for GMRT
3. Written in Python. Highly modular.
4. Uses CASA modules for calibration. SubMS structuring allows scalable parallel processing.
5. Need for an automated flagger robust to a wide range of observations
6. Flagging using a DL based flagging module - GNET

GNET - Deep Learning based RFI detection

1. **UNET based segmentation model. Trained on generated data.**
2. **Ease of use:**
    a. **Statistical methods (eg. Sumthreshold) have too many tunable parameters**
    b. **GNET has 2 parameters**
3. **Accuracy:**
    a. **Statistical methods are unreliable with data > 50% corruption**
    b. **GNET has been trained and tested reliably on data with >80% corruption. (GMRT Band 2)**
4. **Speed:**
    a. **AOFlagger is an order of magnitude faster. However.....**
    b. **With GPU acceleration, GNET can perform near real time flagging (100Gb/hr)**

BAND-3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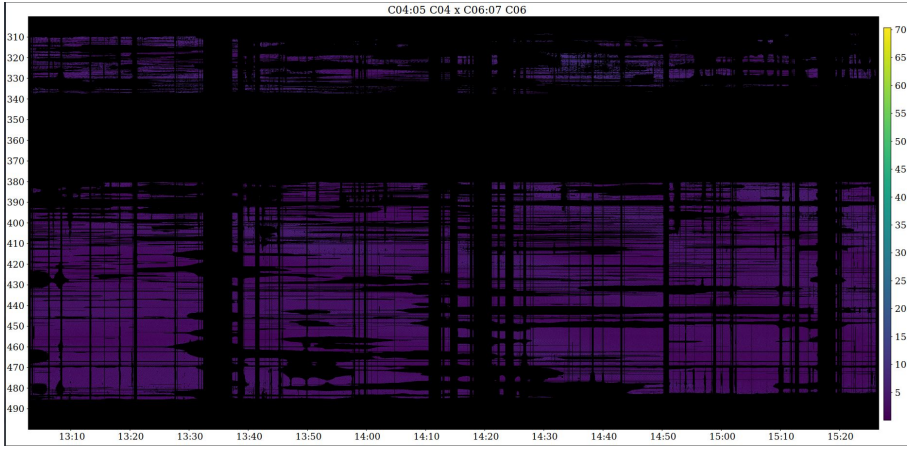
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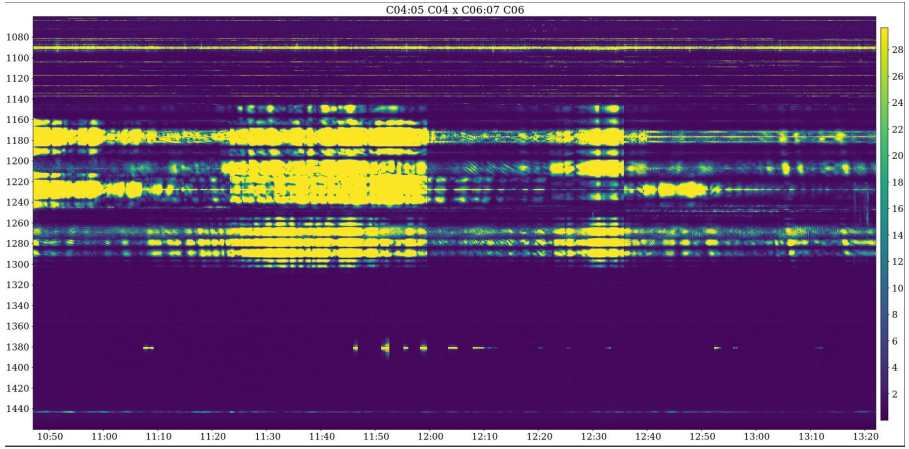
BAND-5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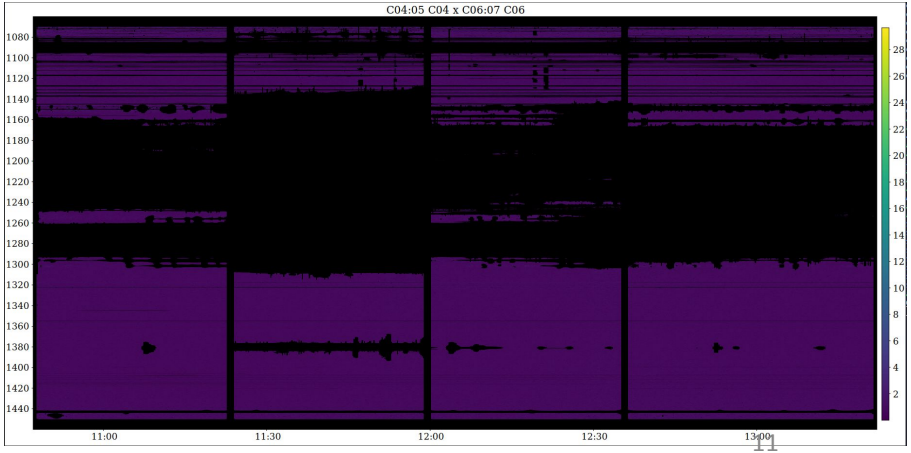
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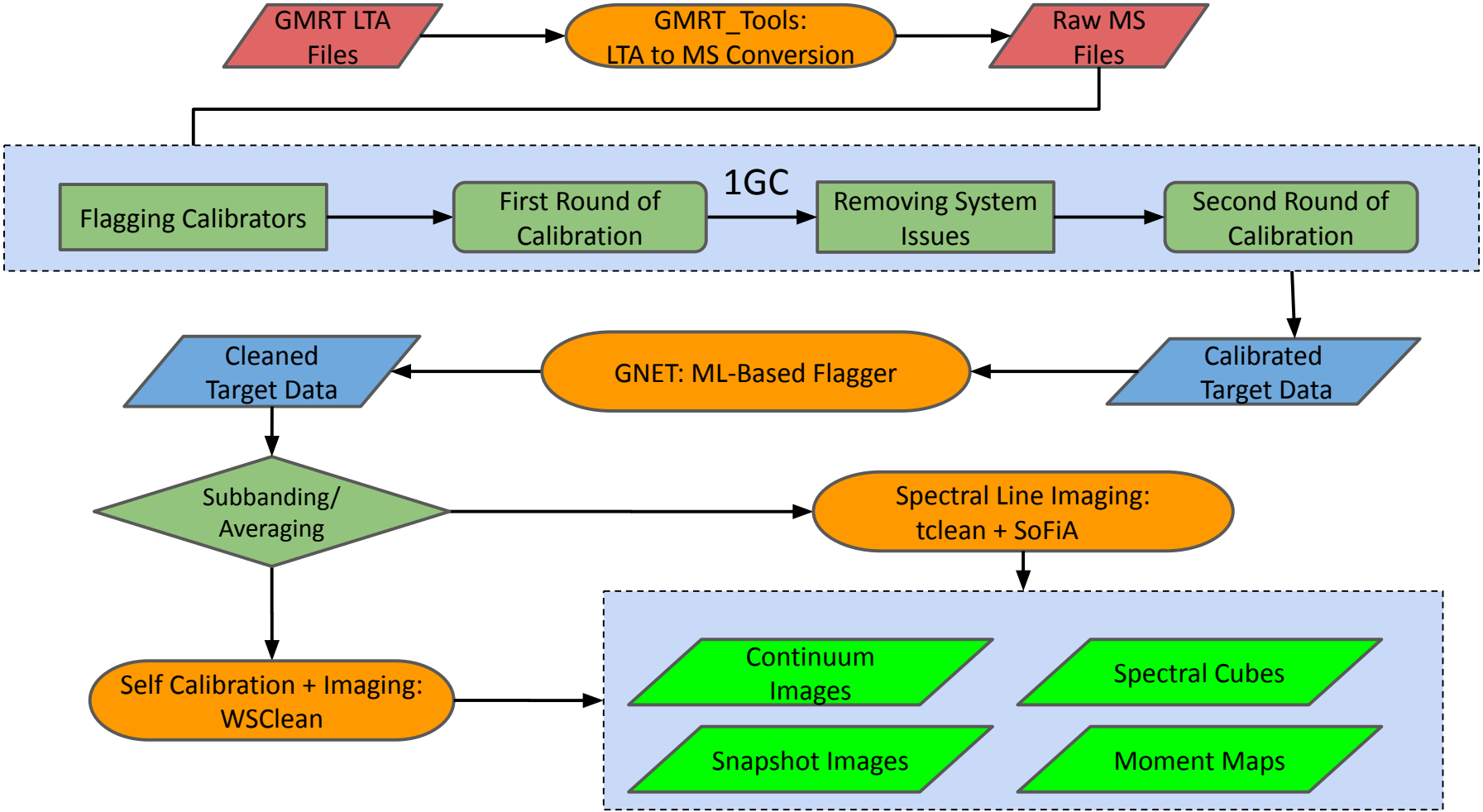

GMRT LTA Files
GMRT_Tools: LTA to MS Conversion
Raw MS Files
1GC
Flagging Calibrators
First Round of Calibration
Removing System Issues
Second Round of Calibration
Calibrated Target Data
GNET: ML-Based Flagger
Cleaned Target Data
Subbanding/ Averaging
Spectral Line Imaging: tclean + SoFiA
Self Calibration + Imaging: WSClean
Continuum Images
Spectral Cubes
Snapshot Images
Moment Maps

LOFAR's Transients Pipeline (TraP) (Swinbank et al 2015)

1. Image Domain searches in Snapshot images
2. Detects transients and stores in a database

TRACK (Kshitij Bane and Abhinav Narayan)

1. Post processing TraP output
2. Filtering false positives:
    a. Clustering
    b. MAD filter
    c. Rolling median
3. Cropping cubes and generating lightcurves
4. Dynamic spectra

LIGHT: Long-period transIents in GMRT arcHival daTa

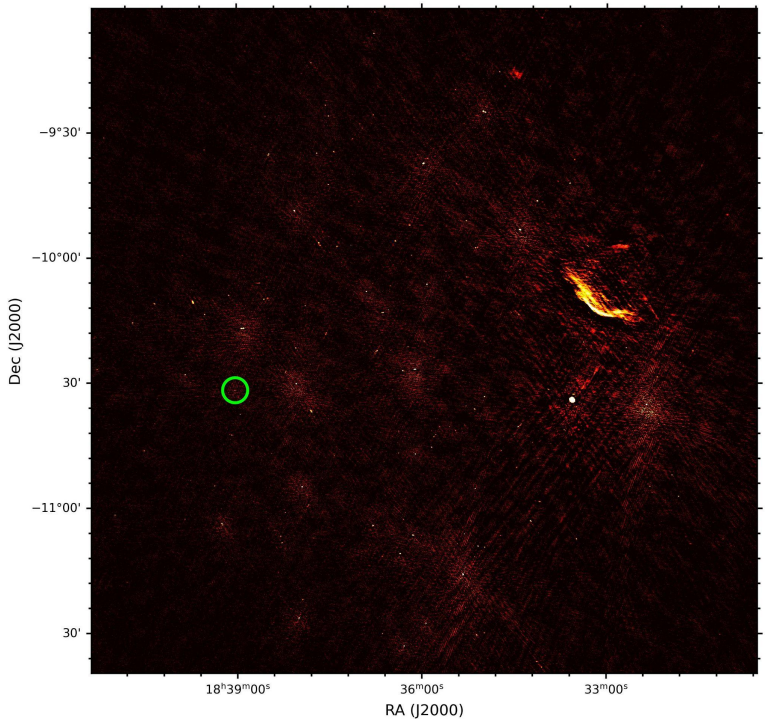
GTAC Code: 27_031 (GSB)

GARUDA

GMRT data reduction, ML-based RFI excision, Imaging

TraP

Transient Identification in snapshot images



Riptide

Periodicity Search (if any)

Track

Cropping/dynamic spectra after further filtering

GARUDA: *Narayan et al. (In Prep)*, TraP: *Swinbank et al. (2015)*, Riptide: *Morello et al. (2020)*

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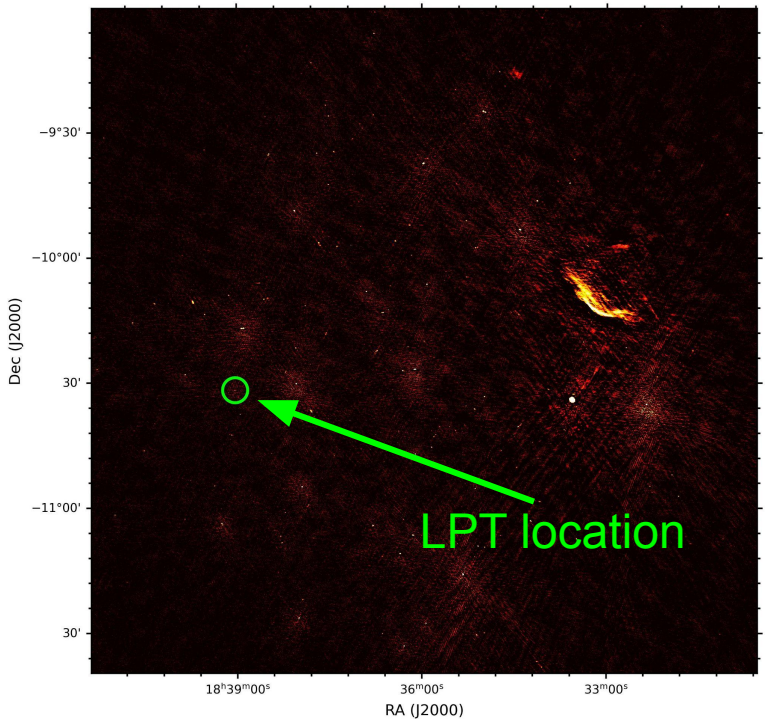

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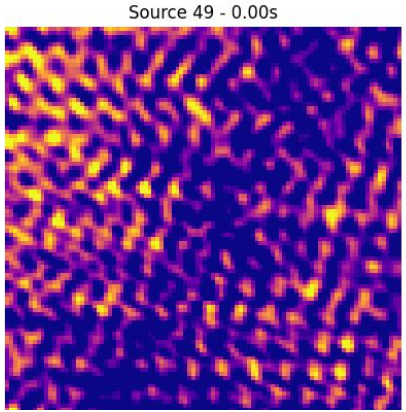

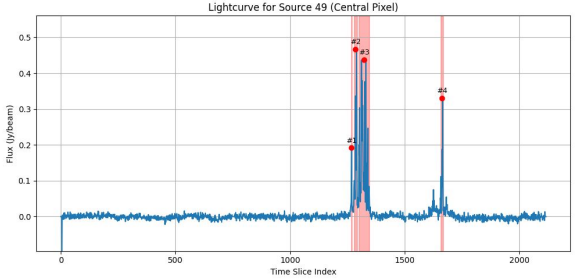

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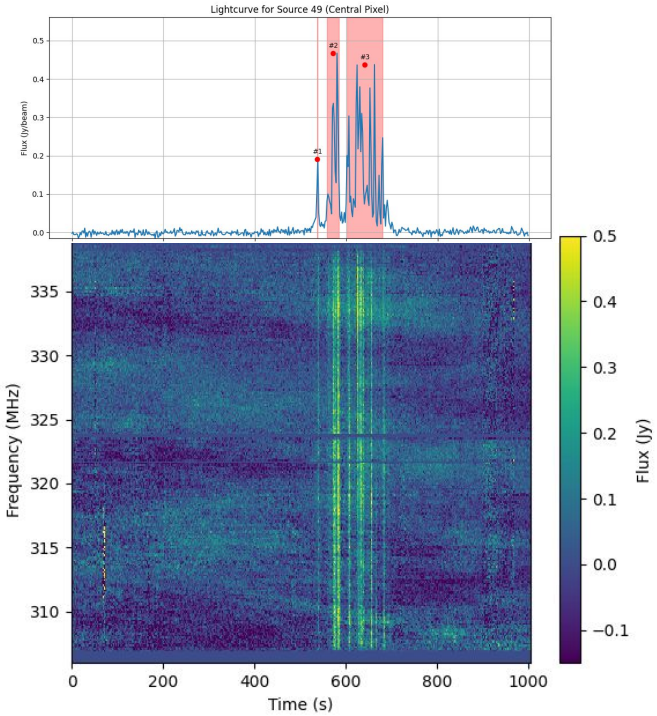

Riptide

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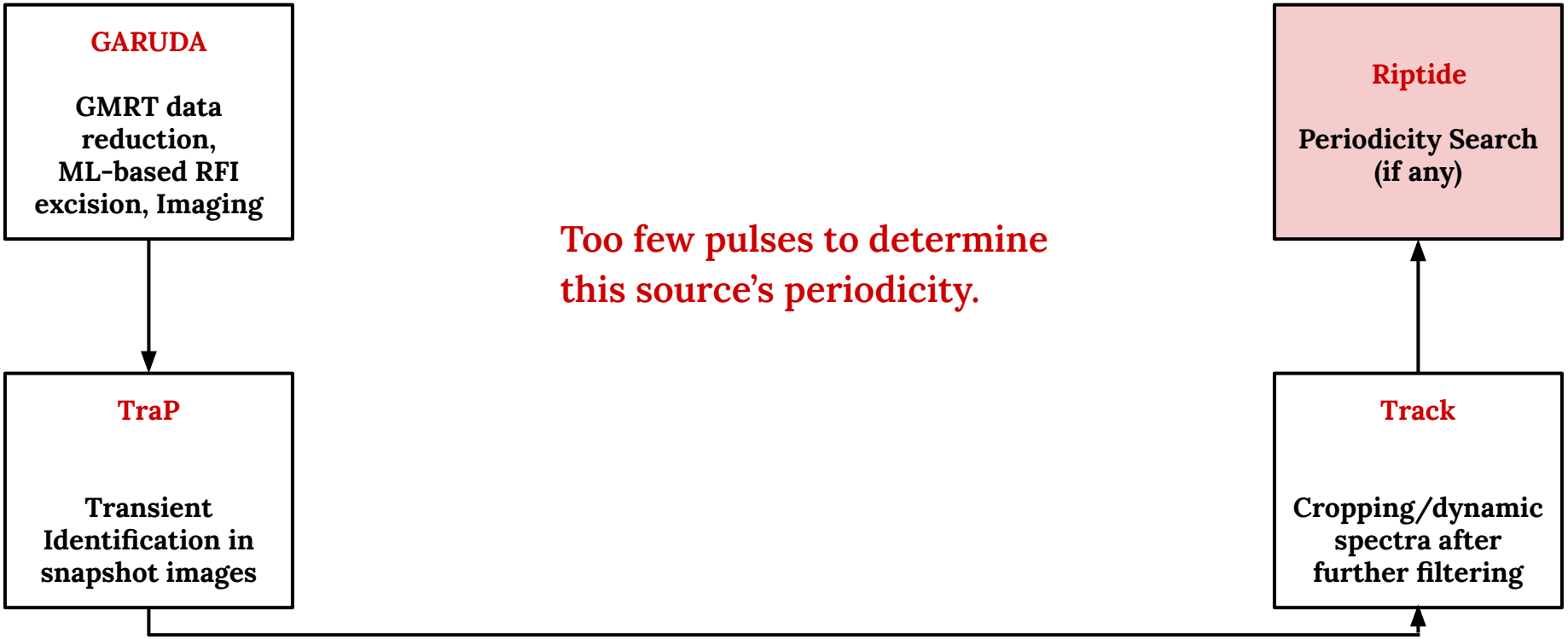
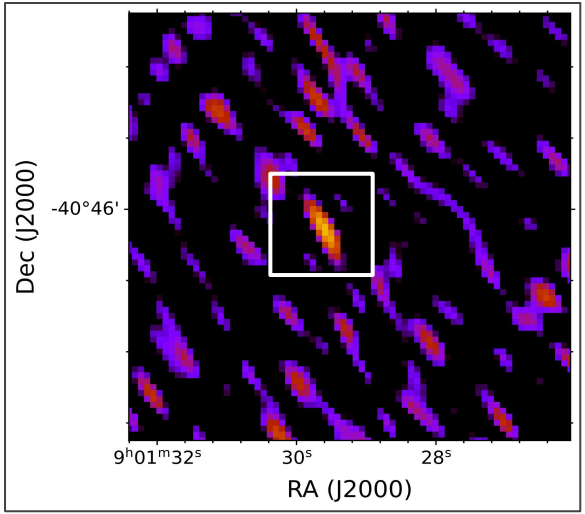
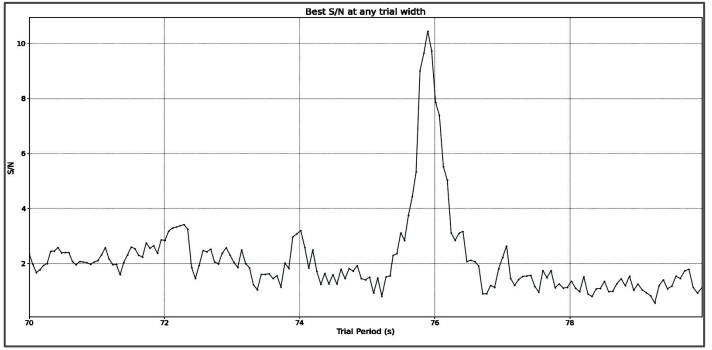


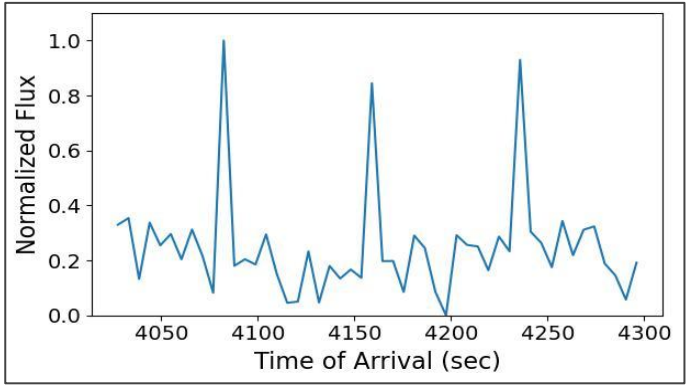
GARUDA: *Narayan et al. (In Prep)*, TraP: *Swinbank et al. (2015)*, Riptide: *Morello et al. (2020)*

LIGHT: Long-period transIents in GMRT arcHival daTa

Band-4 PSR J0901-4046 (76s)
GTAC Code: 41_055 (GWB)



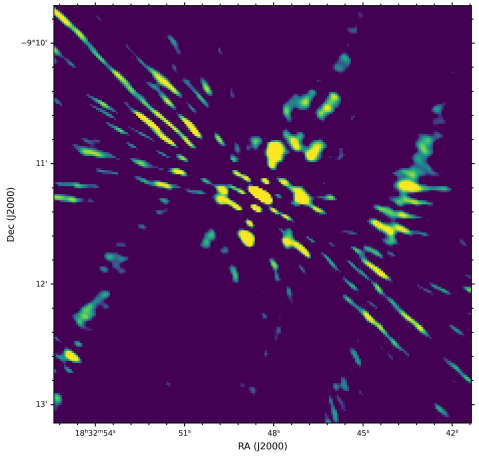


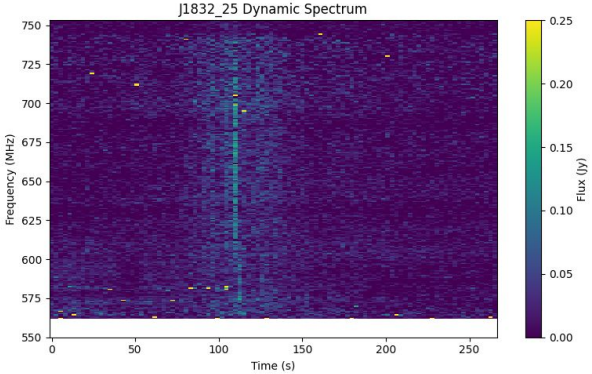


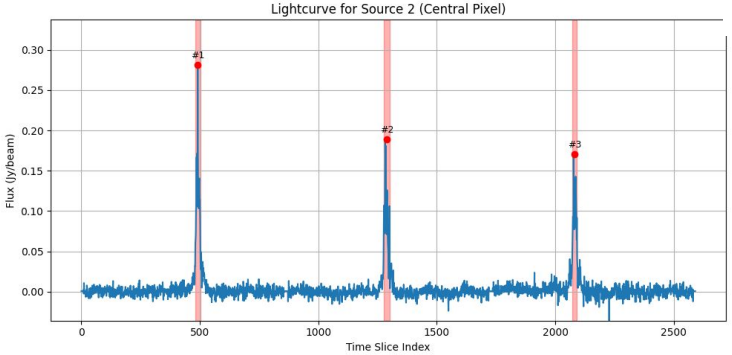
Caleb+ 2022

LIGHT: Long-period transIents in GMRT arcHival daTa

Band-4 ASKAP J1832-091 (44 mins)
GTAC Code: ddtC341 (GWB)







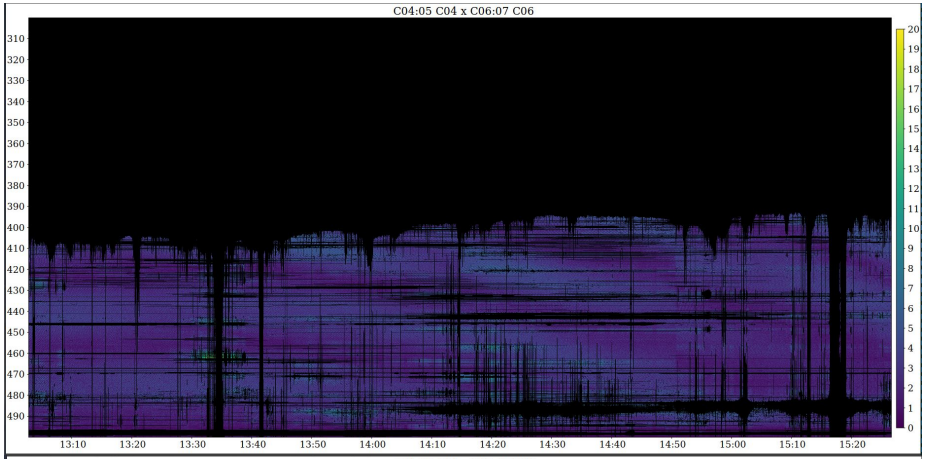
Wang+ 2025

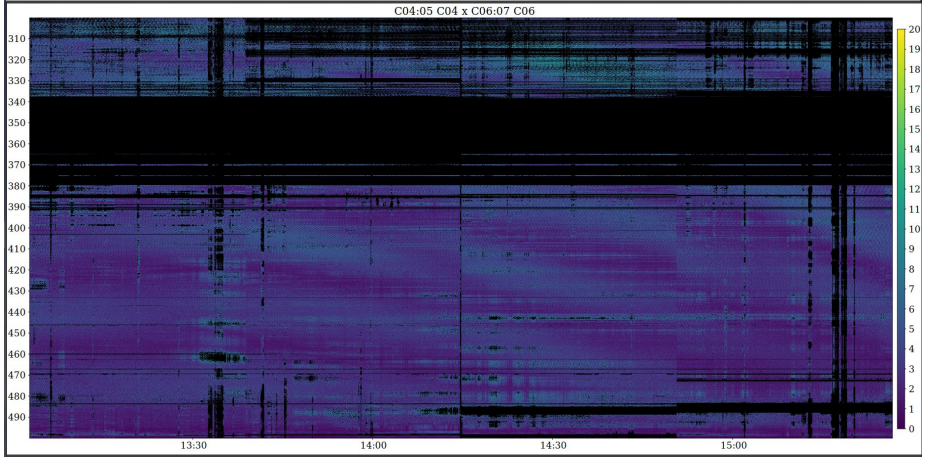
Summary and Future Work

- LPTs challenge current models of neutron star emission and evolution.
- Observational biases make them difficult to find.
- The LIGHT pipeline for GMRT archival data offers strong potential to uncover new LPTs.
- Tested on known LPTs.
- Processing ongoing for GMRT galactic plane observations.
- Stay tuned for updates!

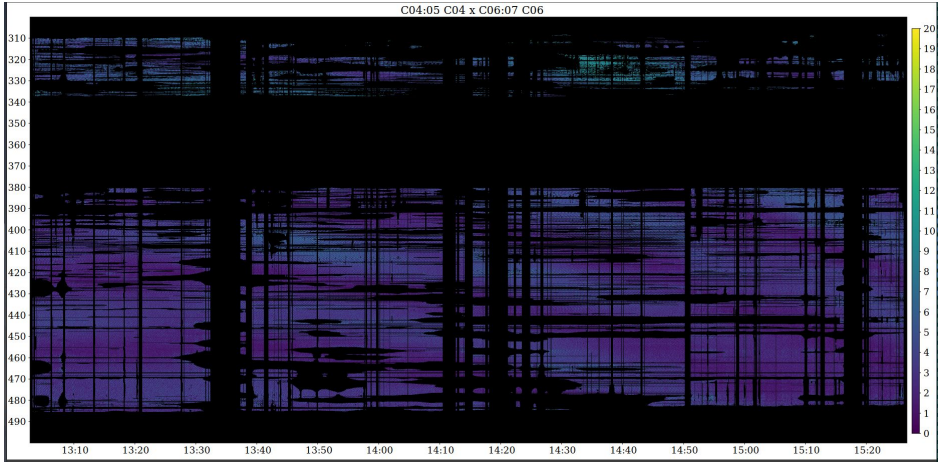
Thank You!

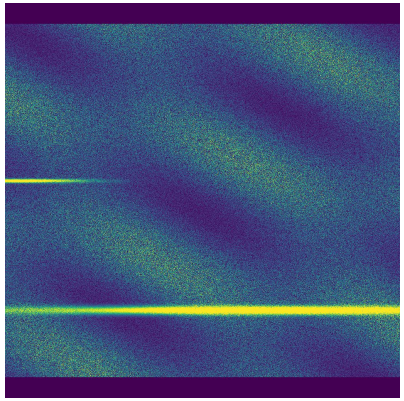
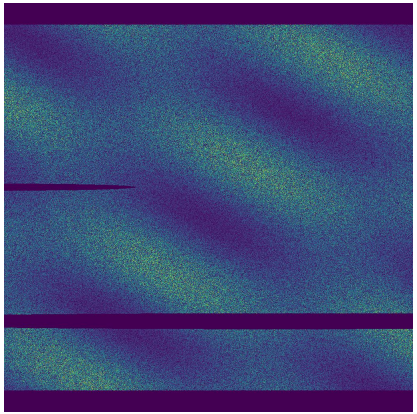
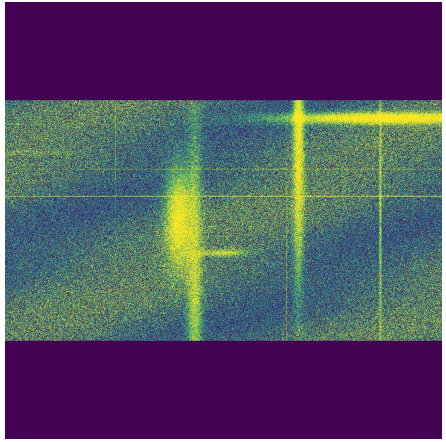
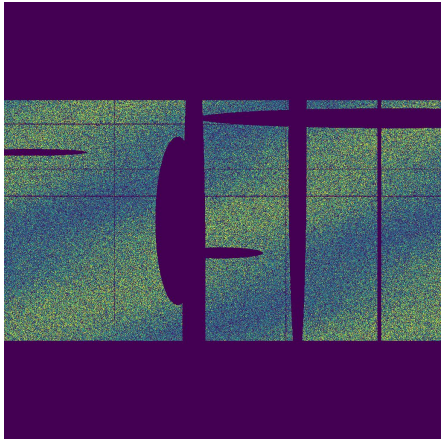
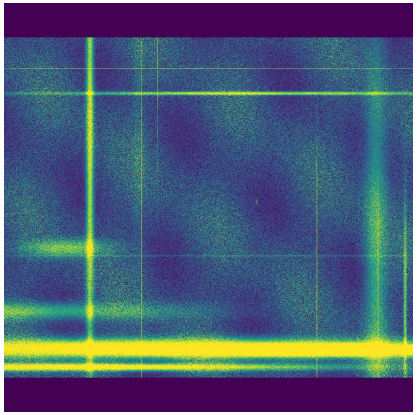
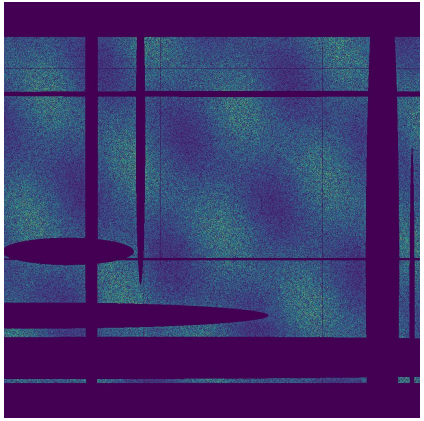
Extra slides

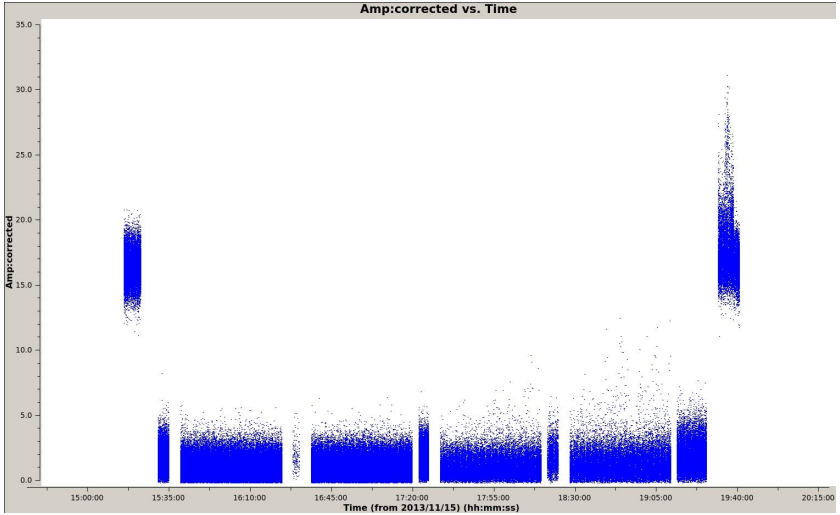




GNET

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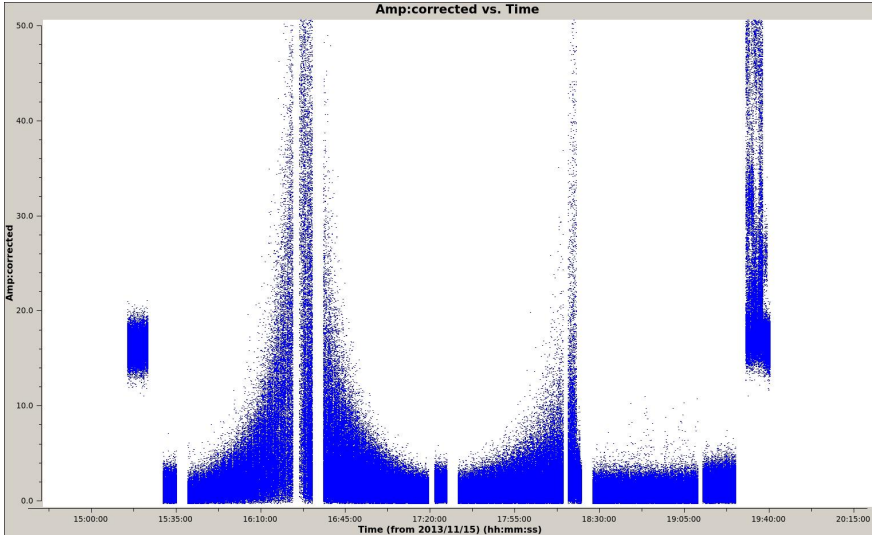
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Time (from 2013/11/15) (hh:mm:ss)