NenuFAR pulsar KP (ES03)

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Outline

• KP team
• NenuFAR pulsar hardware + software
• Scientific context
• Observations & first results
KP Team

• Jean-Mathias Grießmeier, Gilles Theureau (PIs)
• Anna Bilous, Louis Bondonneau, Mark Brionne, Ismaël Cognard, Gemma Janssen, Julian Donner, Lucas Guillemot, Krishnakumar M.A., James McKee, David McKenna, Michael Kramer, Vlad Kondratiev, Robert Main, Aris Noutsos, Jérôme Petri, Maura Pilia, Andrea Possenti, Macej Serylak, Golam Shaifullah, Caterina Tiburzi, Oleg Ulyanov, Joris Verbiest, Ziwei Wu, Olaf Wucknitz, Serge Yerin, Vyacheslav Zakharenko

• open for new team members!
Pulsars

- Rotating neutron star
  - Mass of $\sim 1.4$ M$\odot$
  - Diameter of $\sim 14$ km
  - Period of rotation $\sim 1$ s
  - Curvature radiation from magnetic poles $\rightarrow$ radio beam
  - Emission is always « on »; visible 1/rotation « lighthouse effect »
  - Average pulse $\neq$ individual pulse

22 s time series
NenuFAR as stand-alone phased array

targets: compact sources

data products: → light-curves
              → dynamic spectra
              → pulsar data

| NenuFAR ES1: Cosmic Dawn                  |
| NenuFAR ES2: Exoplanets & Stars          |
| NenuFAR ES3: Pulsars                     |
| NenuFAR ES4: Transients                  |
| NenuFAR ES5: Fast Radio Bursts           |
| NenuFAR ES6: Planetary Lightning         |
| NenuFAR ES7: Jupiter joint studies       |
| NenuFAR ES8: Cluster of galaxies & AGNs  |
| NenuFAR ES9: Cluster Filament & Cosmic Magnetism |
| NenuFAR ES10: Radio recombination lines  |
| NenuFAR ES11: Sun                        |
| NenuFAR ES12: Radio Gamma                |
| NenuFAR ES13: SETI                        |
| NenuFAR ES14: Cas A                      |
| NenuFAR ES15: Large Scale Background Survey |
| NenuFAR ES16: Formation of students      |
| NenuFAR ES17: Radio-Amateurs             |
NenuFAR pulsar hardware

**real-time pulsar backend**

"LUPPI" (10-85 MHz)

- folding
- coherent de-dispersion
- coherent correction of Faraday rotation

(Unique to NenuFAR!)

[See presentation by Louis Bonduanneau]!

[Bondonneau et al. 2021]

[Bondonneau et al. 2021; Bondonneau et al. in prep.]
NenuFAR pulsar software

- NenuFAR (UnDypPuTeD backend)
  - tf
  - dynamic spectra data (*.spectra)
  - waveform TF (*.raw)
- waveform (filesize compressed to ~60%) for O. Wucknitz (*.zst)
- LUPPI
  - coherent dedispersion
- singlepulse/search data (32 bit *.fits)
- folded data (psrfits, *.fits, default: 10.737s)
- presto filterbank data (*.fbk)
  - conversion volume/16
  - data
  - testlook

See presentation by Louis Bondonneau!
Pulsars at low frequencies

- turnover at 100-140 MHz for many pulsars
- high sky temperature (galactic background)
- strong dispersion, scattering, scintillation, ...

→ difficult to observe
→ high precision on DM, scattering, ...
→ RFM model: study high altitudes & large volume in magnetosphere
→ test emission models, ...

Radio-spectrum of PSR B1508+55 (added with LOFAR FR606 measurements)
# NenuFAR pulsars projects

- regular NenuFAR observations since 07/2019
- some observations during commissioning
- >3000 observations (~1000h)
- 15 projects
- NenuFAR alone
- with other radio-telescopes

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<th>project</th>
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<td>DEC &gt; 39°</td>
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<td>62 targets; 14 targets observed simultaneously with NRT; energy distribution, mode changes; drifting Subpulses; comparison to theory (J. Petry)</td>
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<td>phase 1: 28 sources (CHIME, GHT and Pushchino sources), 60-90 minutes each. Aim: detection. Can be extended to the study of spectral energy distribution of single pulses</td>
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Pulsar census

- observation of 711 pulsars known at higher radio frequencies
- DEC > -20°, DM < 100 pc/cm³
- 184 pulsar detected (~100 for the first time <100 MHz)

[Bondonneau et al. in prep.]
Pulsar census & MSPs

- Observation of 711 pulsars known at higher radio frequencies
- DEC > -20°, DM < 100 pc/cm³
- 184 pulsar detected (~100 for the first time <100 MHz)
- 11 MSPs detected (7 for the first time <100 MHz)
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• [Bondonneau et al. in prep.]
• study of pulsar spectra, turnover, ... (e.g. [Agar et al. 2021])
Pulsar blind survey

- survey of north polar cap (DEC > 39°)
- 7691 pointings
- observations since August 2020 (1st pass complete)
- search space: DM < 100 pc/cm³ & P > 80 ms
- expect slow pulsars [Tan et al. 2018]
- [Brionne et al. in prep.]
Single pulses & giant pulses

Single pulses

B1237+25

Study of giant pulses

B0950+08

[Kondratiev et al. in prep.]

[Bilous et al. in press]

Frequency evolution of single pulses at low frequency: Radius-to-frequency mapping

Characterisation of single pulses from B0950+08.
Ionized interstellar medium

- high sensitivity & low frequencies
- → precision of $10^{-4}$ or even $10^{-5}$ pc/cm$^3$ on DM
- [Bondonneau et al. 2021]
- → DM monitoring, statistics of DM events
- → improve timing (e.g. for pulsar timing arrays)
- long-term project!
Heliosphere

- DM contribution of solar wind
- observation near solar conjunction
- wider signal path at low frequencies [Cordes et al. 2016]
- → expect frequency-dependent DM
- different DM observed LOFAR-HBA ↔ NenuFAR
  → more observations taken 2021/08-2021/09, under analysis
- [Tiburzi et al. submitted; Shaifullah et al. in prep.]
• high sensitivity, **coherent Faraday correction**, low frequencies
• $\rightarrow$ precision of $10^{-5}$ to $10^{-4}$ rad/m$^2$ on RM
• 100 times more accurate than existing ionospheric models
• $\rightarrow$ can be used to compare ionospheric models
• [Bondonneau et al. in prep.]
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[Agar et al. 2021]
[Tiburzi et al. submitted; Shaifullah et al. in prep.]
... and more in preparation!

- Monitoring campaign
  - Spectra
  - DM monitoring

- Scintillation studies
  - Monitoring
  - Test of scintillation laws

- Globular clusters
  - Population

- Single pulses
  - Nulling
  - Mode switching
  - Drifting subpulses

- VLBI
  - Scintillation/pulse echoes

- Polarisation
  - Polarisation fraction
  - Profiles