Low frequency pulsar observations with NenuFAR

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Introduction: LOFAR (FR606 + NenuFAR) Nançay

NenuFAR 10-85 MHz

LOFAR FR606 in Nancay (2015)

LOFAR HBA 110-240 MHz

NenuFAR (New Extension in Nançay Upgrading loFAR)
« under construction »

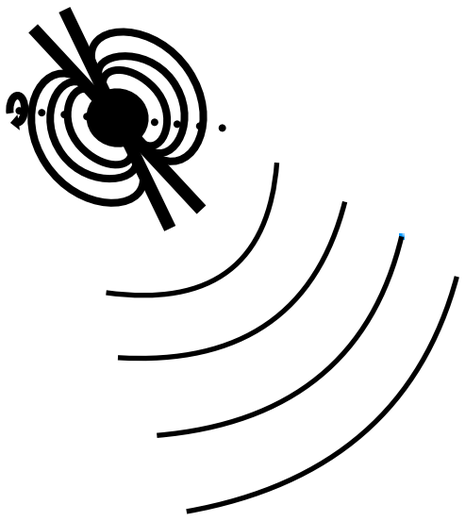
- 96 groups of 19 antennas

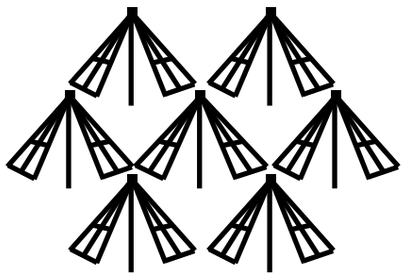
LOFAR (FR606)

- 96 HBA and 96 LBA antennas

LOFAR LBA 10-90 MHz
in practice 30-80 MHz

Introduction: NenuFAR (New Extension in Nançay Upgrading loFAR)





NenuFAR = 4 instruments!

NenuFAR = Imager

extended radio sources, HI power spectrum @ Cosmic Dawn
→ radio images (1°...10')

NenuFAR = LOFAR superstation

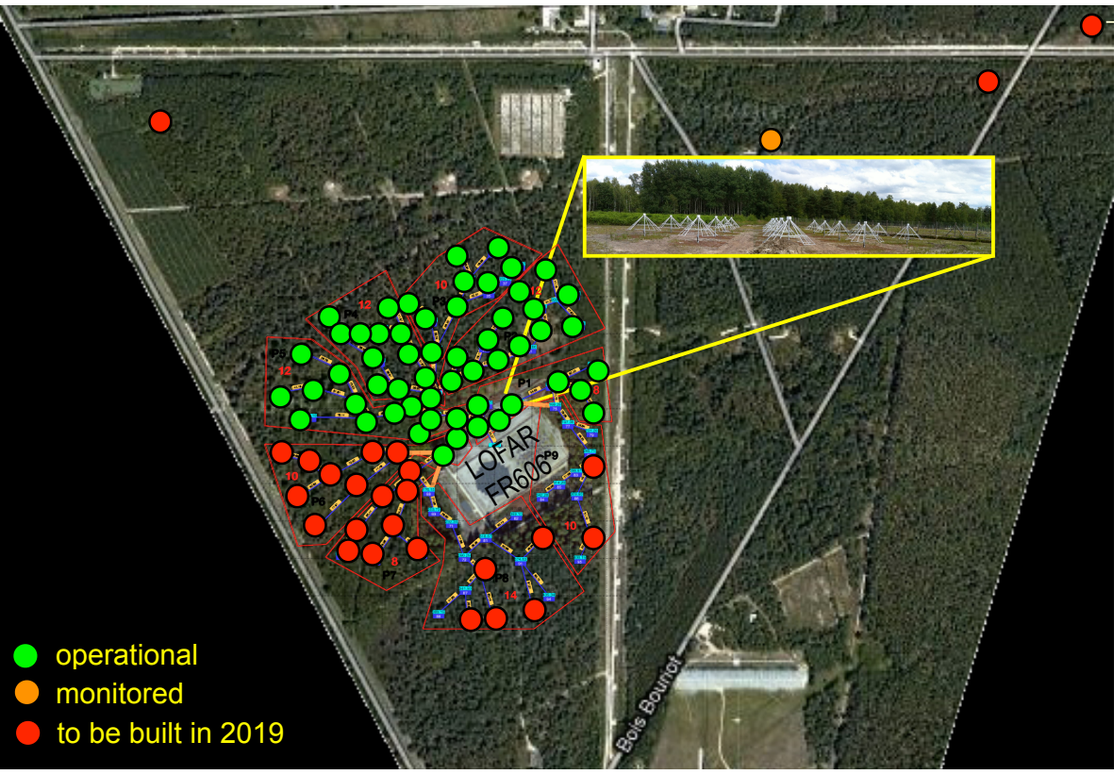
small spatial scales!
→ high resolution images (<1")

NenuFAR = TBB machine

→ transients

NenuFAR = Beamformer

compact sources
→ light-curves, dynamic spectra & pulsars



Nançay mini-array status

NenuFAR numbers

- LOFAR-compatible phased array (& interferometer)
- target: 1824 antennas (96 mini-arrays x 19 antennas)

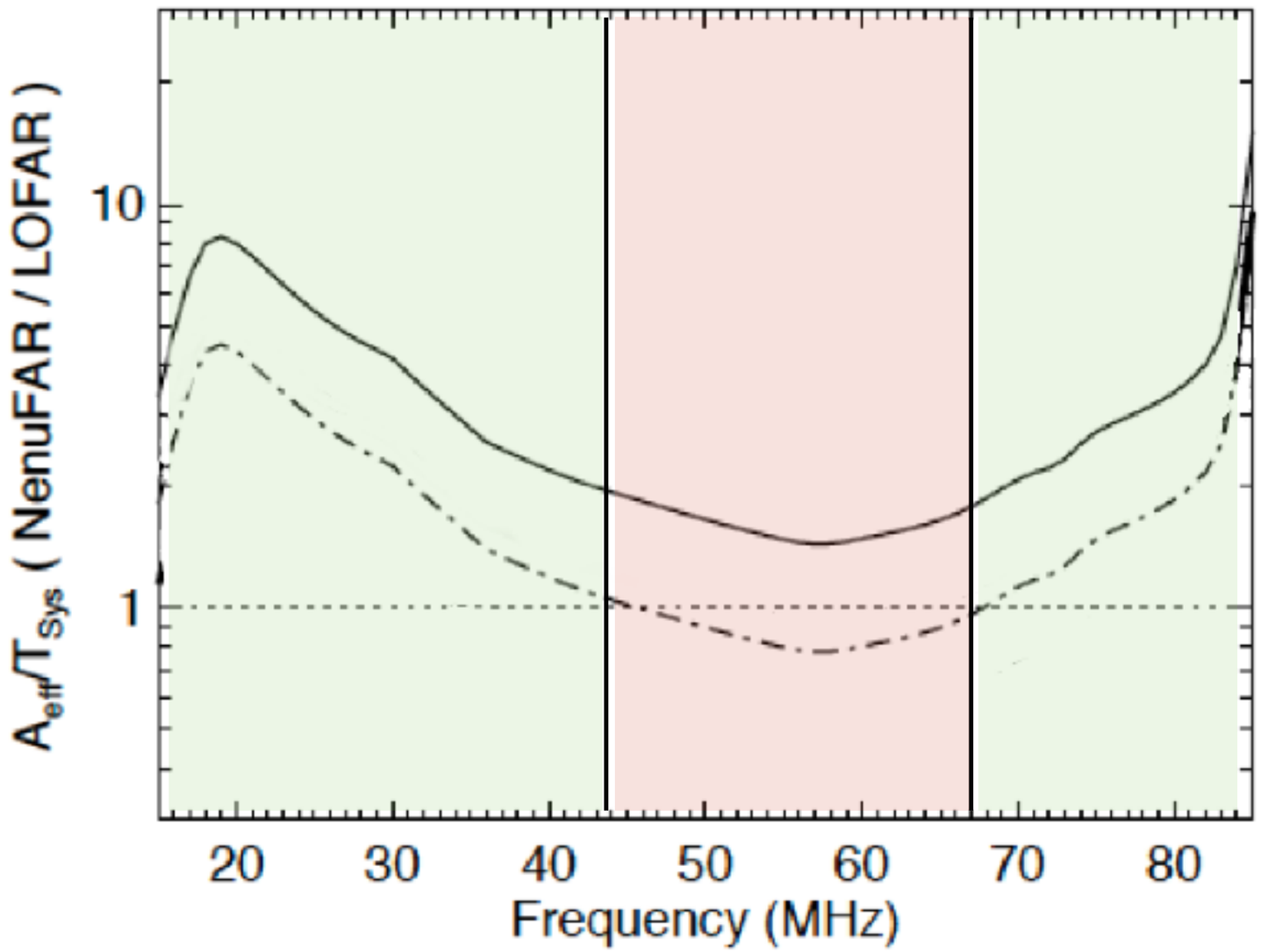
  + 6 distant MR
- funded: 1368 antennas (72 mini-arrays)

  + 4 distant MR
- built: 1064 antennas (56 min-arrays)
- Diameter: ~400 m
- Broad FoV: (8°-60°)
- Angular resolution 0.5-4° (standalone)
- Collecting area ~ 62 000 m^2 @ 30 MHz ($\propto\lambda^2$)
- Frequency range = 10-85 MHz (optimized: 20-60 MHz)
- observable sky: DEC > -23°
- sampling frequency 200 MHz → 5.12 µs
- Full polarization (4 Stokes)
- current sensitivity: S_{mean}^{min}=3 mJy, SNR=5 in 1h

Introduction: NenuFAR low frequency wide band

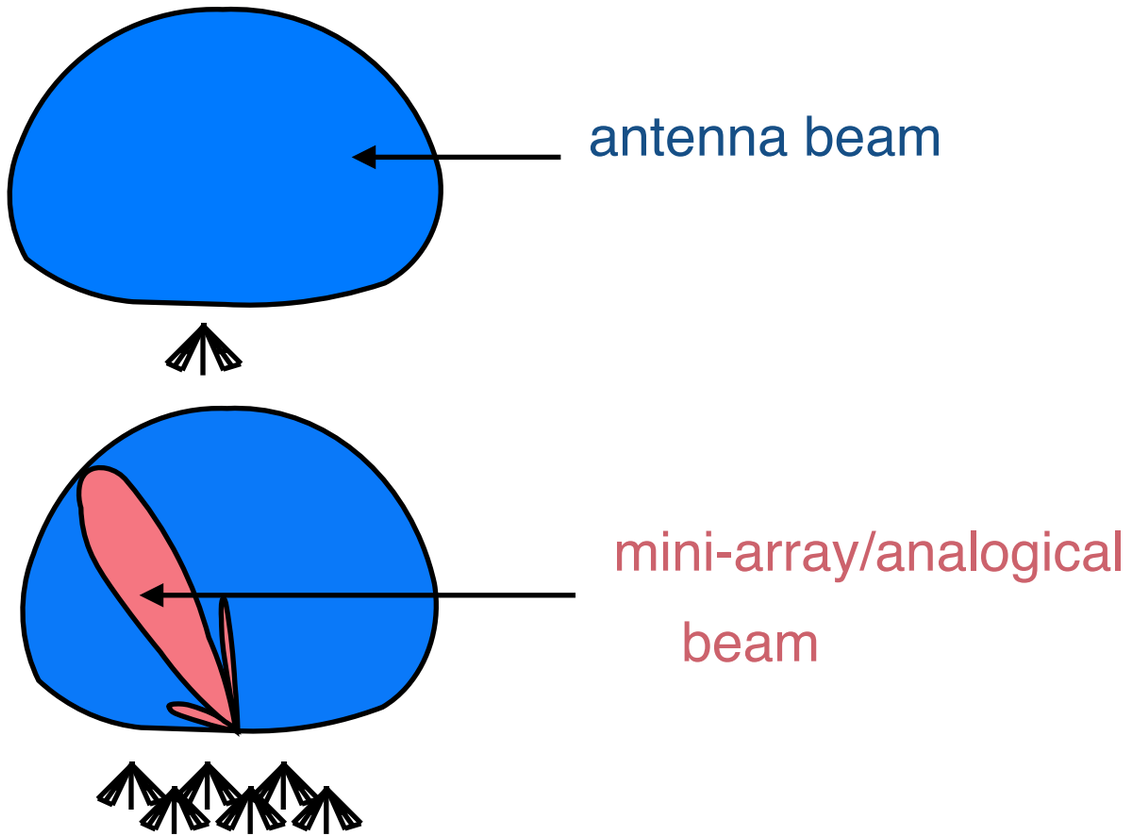
NenuFAR-2 / core (96 mini-arrays)

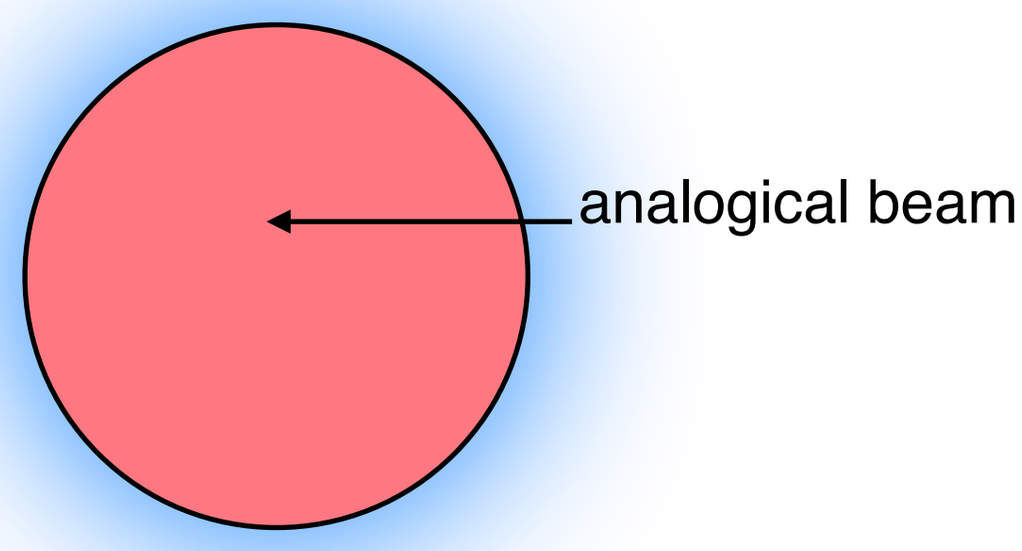
NenuFAR-1 / core (52 mini-arrays) yesterday



Introduction: NenuFAR beam

1. one analogical beam

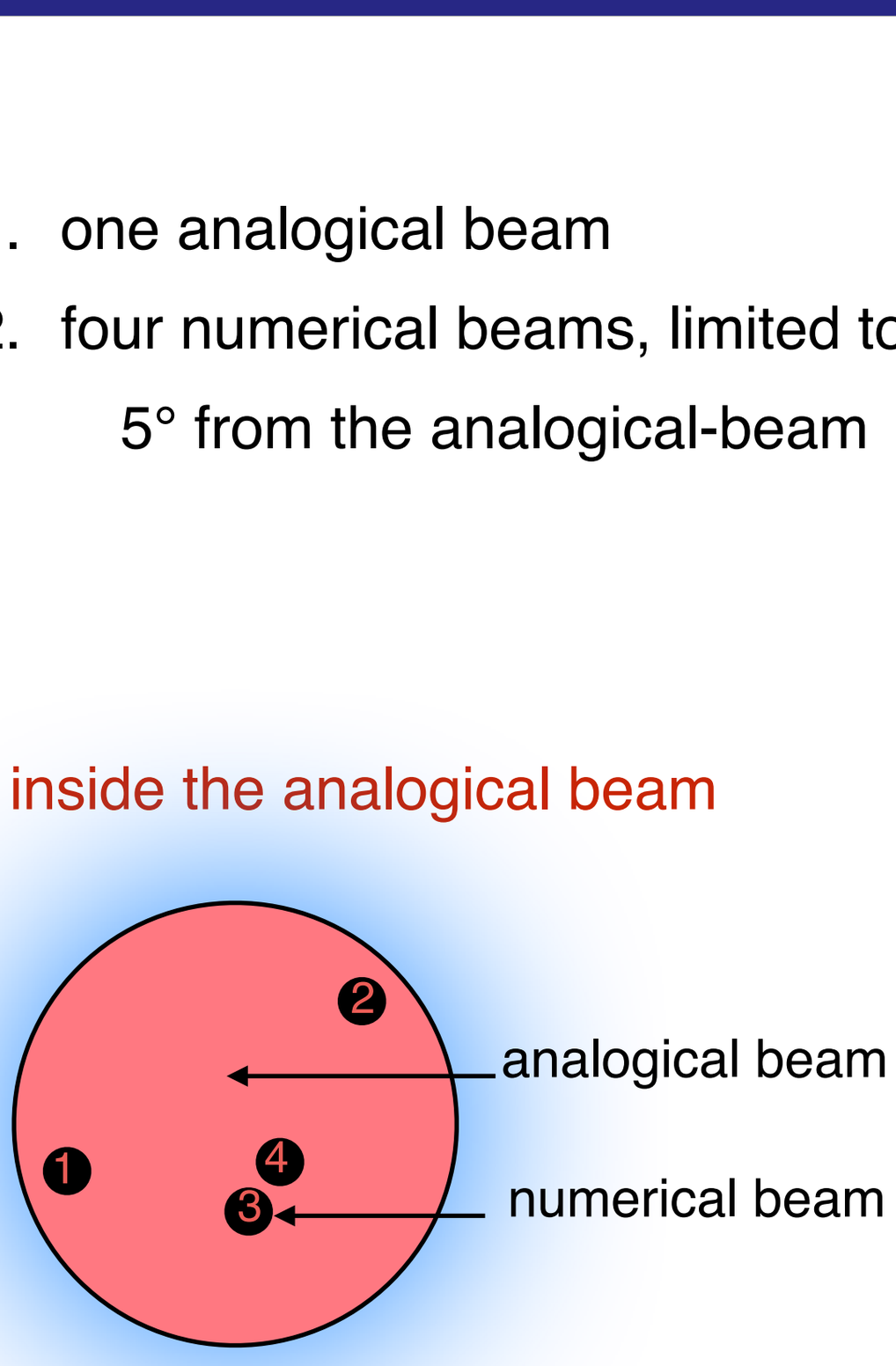


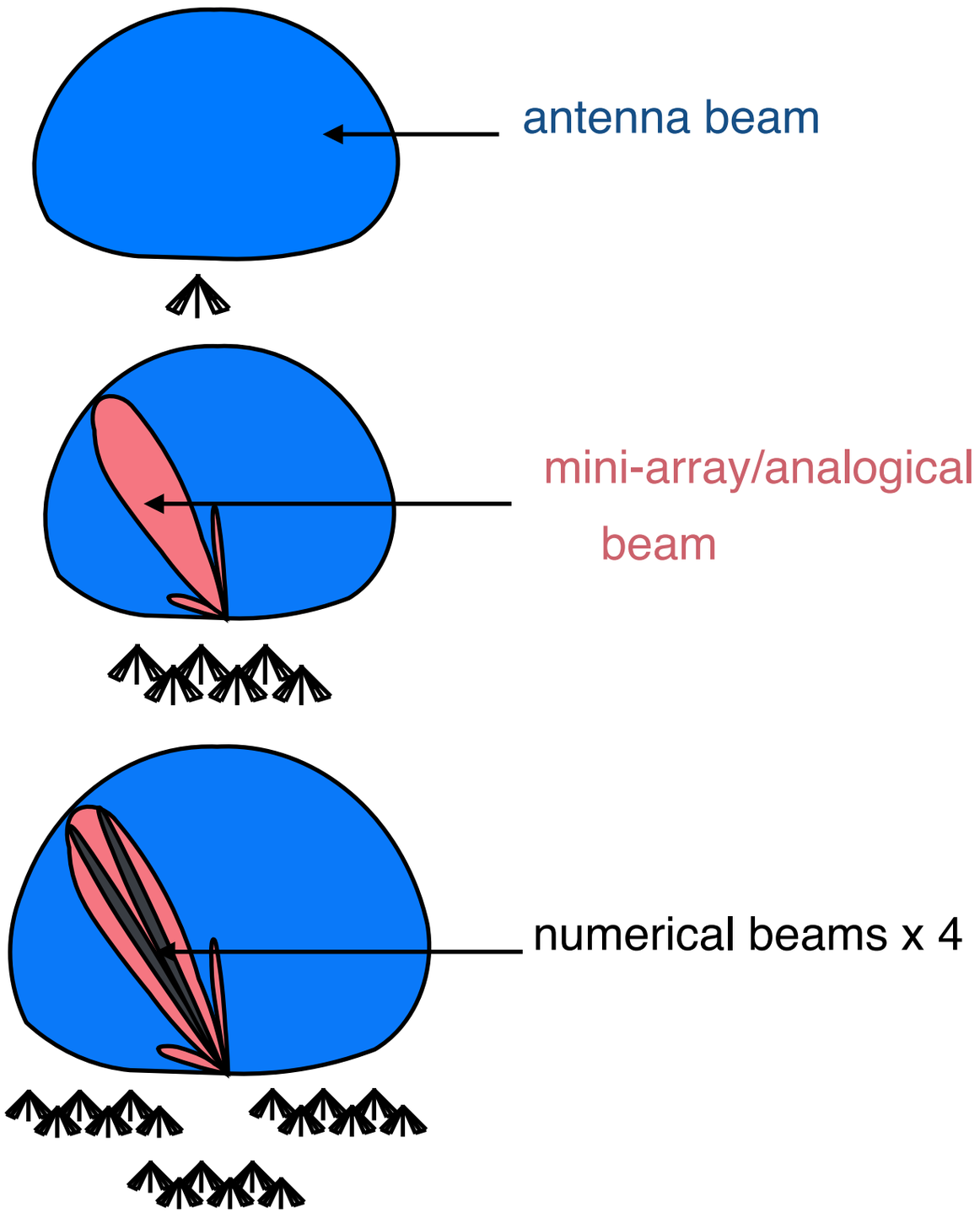


Introduction: NenuFAR beam

1. one analogical beam
2. four numerical beams, limited to 5° from the analogical-beam

inside the analogical beam





The first observation of pulsar

Jocelyn Bell, 1968

The IPS array (Interplanetary Scintillation Array) near Cambridge

Pulsars and radio

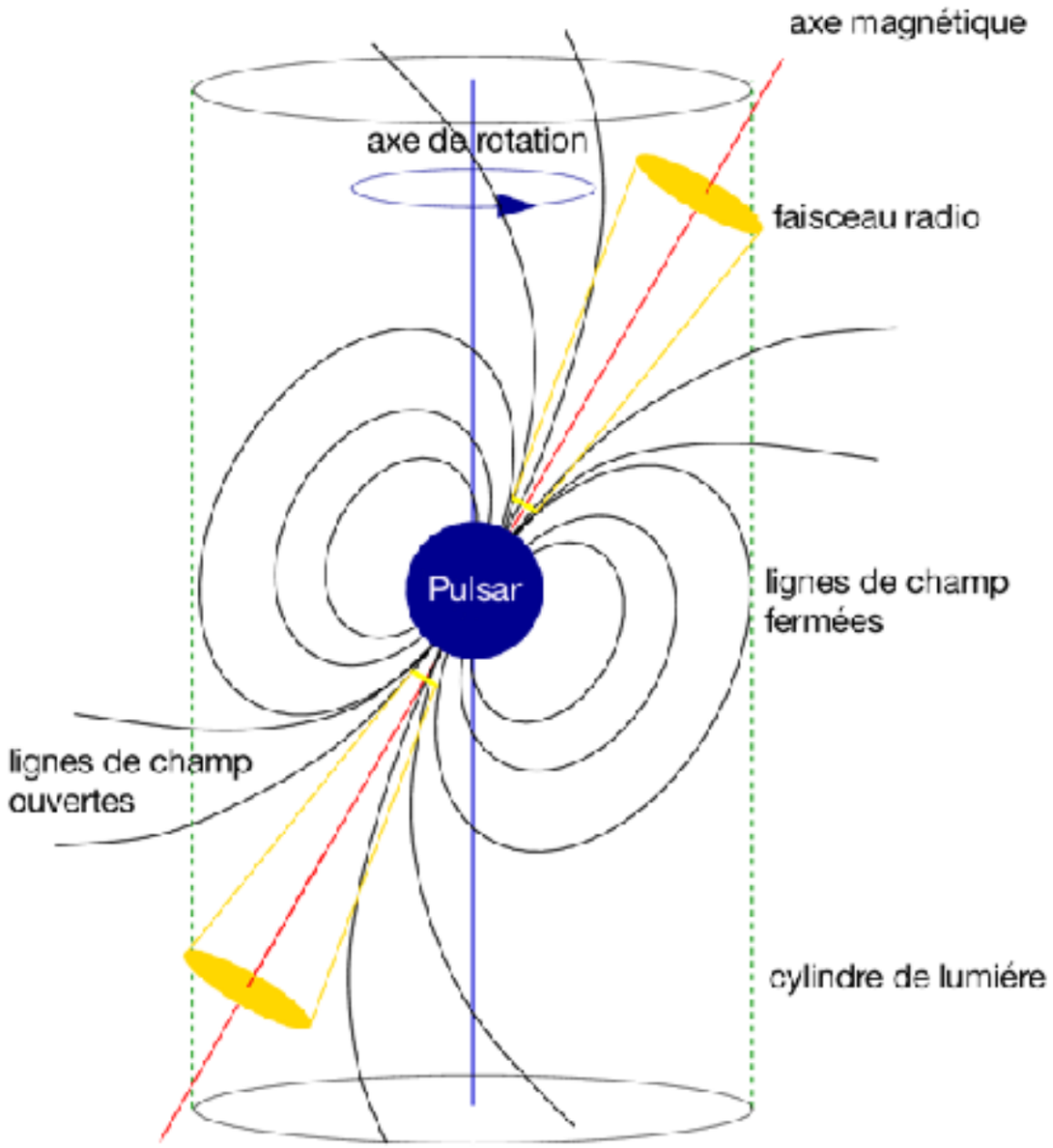
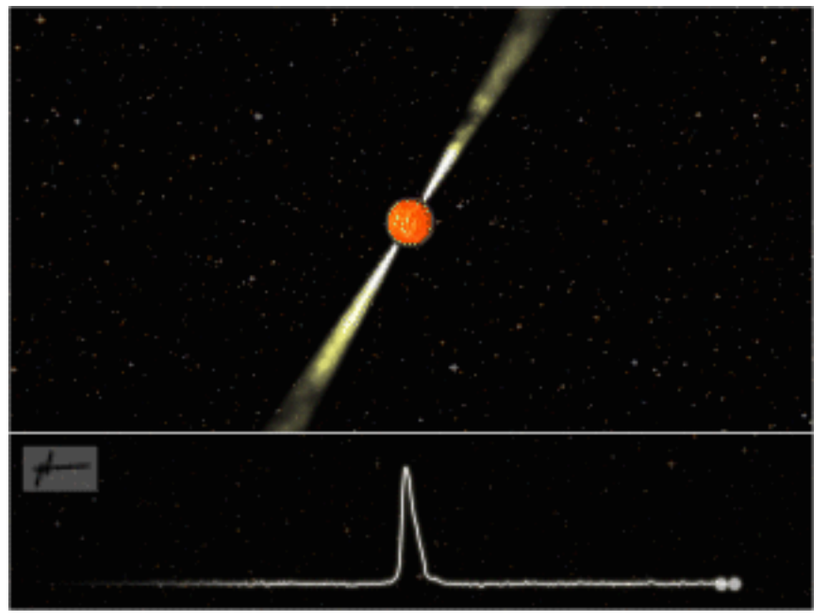
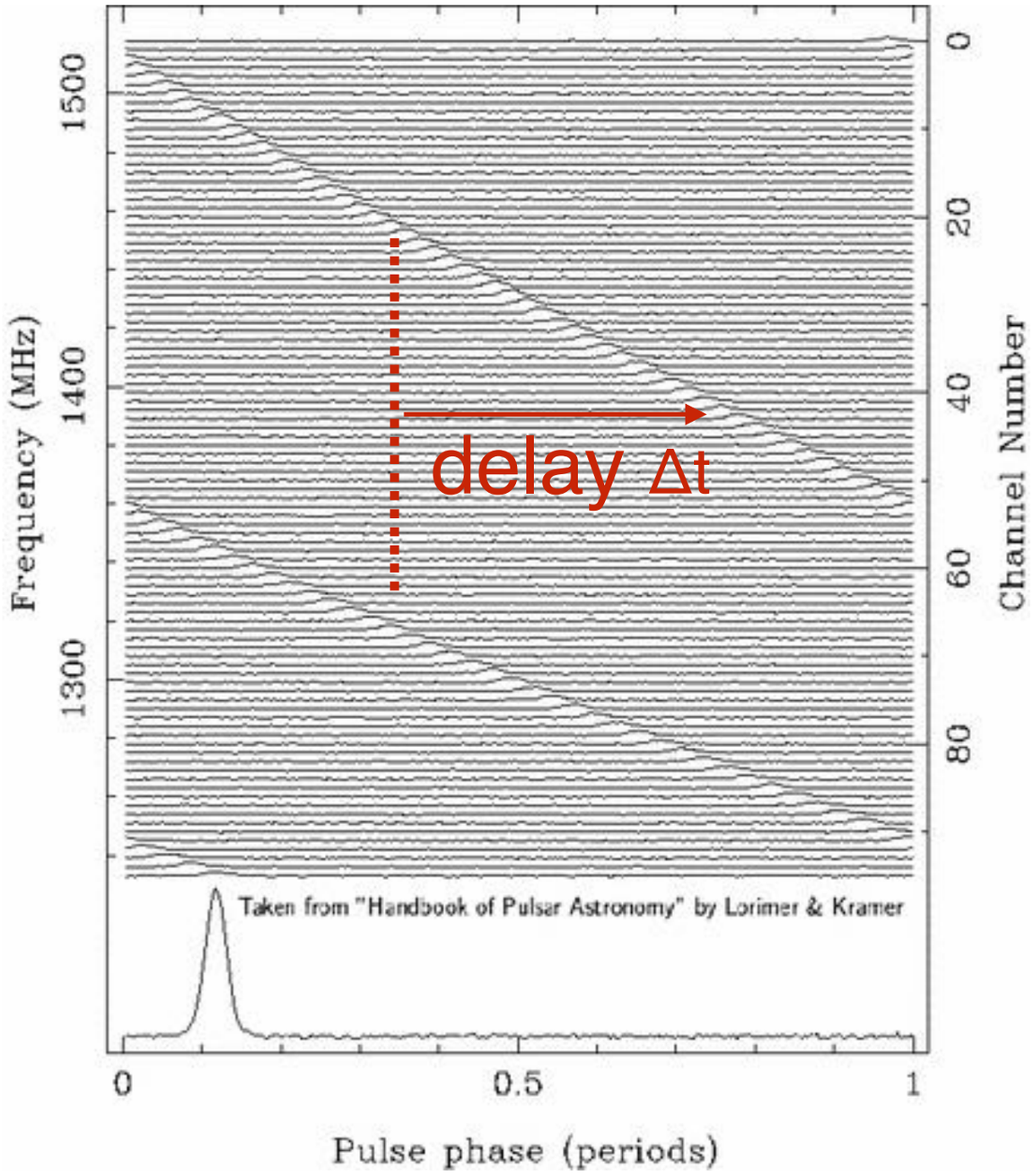


Diagram of a pulsar Handbook of Pulsar Astronomy D.Lorimer & M.Kramer.

- Rapidly rotating neutron star of ~1.4 M⊙ for a diameter of 14 km.
- Synchrotron Radiation from the magnetic poles.
  - generating a radio beam



The dispersion



Pulsar Astronomy A. Lyne & F. Graham-Smith

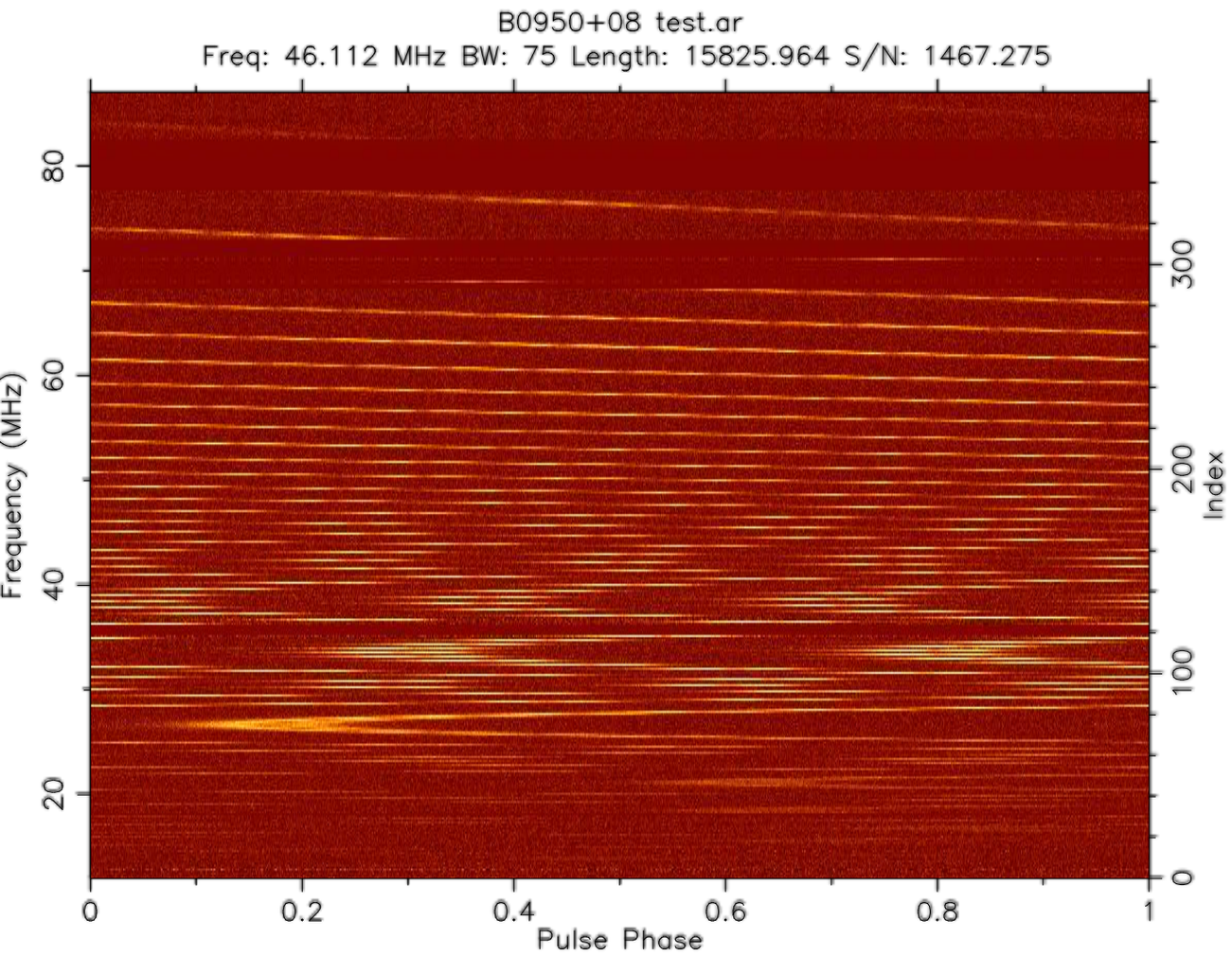
- Delay due to the frequency-dependance of group velocity.

$$\Delta t \; \alpha \; f^{-2}$$

The Dispersion

Low frequency

Dispersed



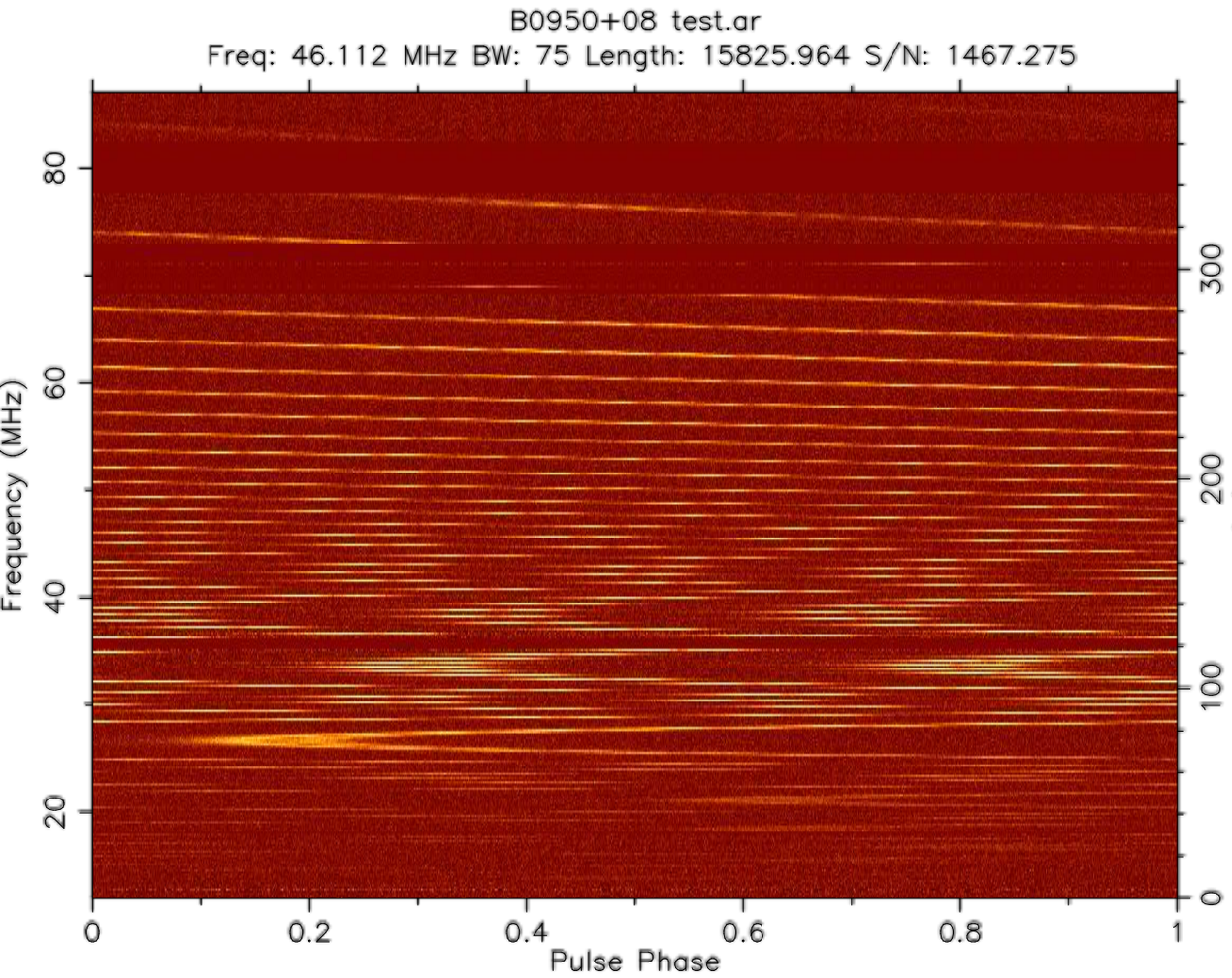
The Dispersion

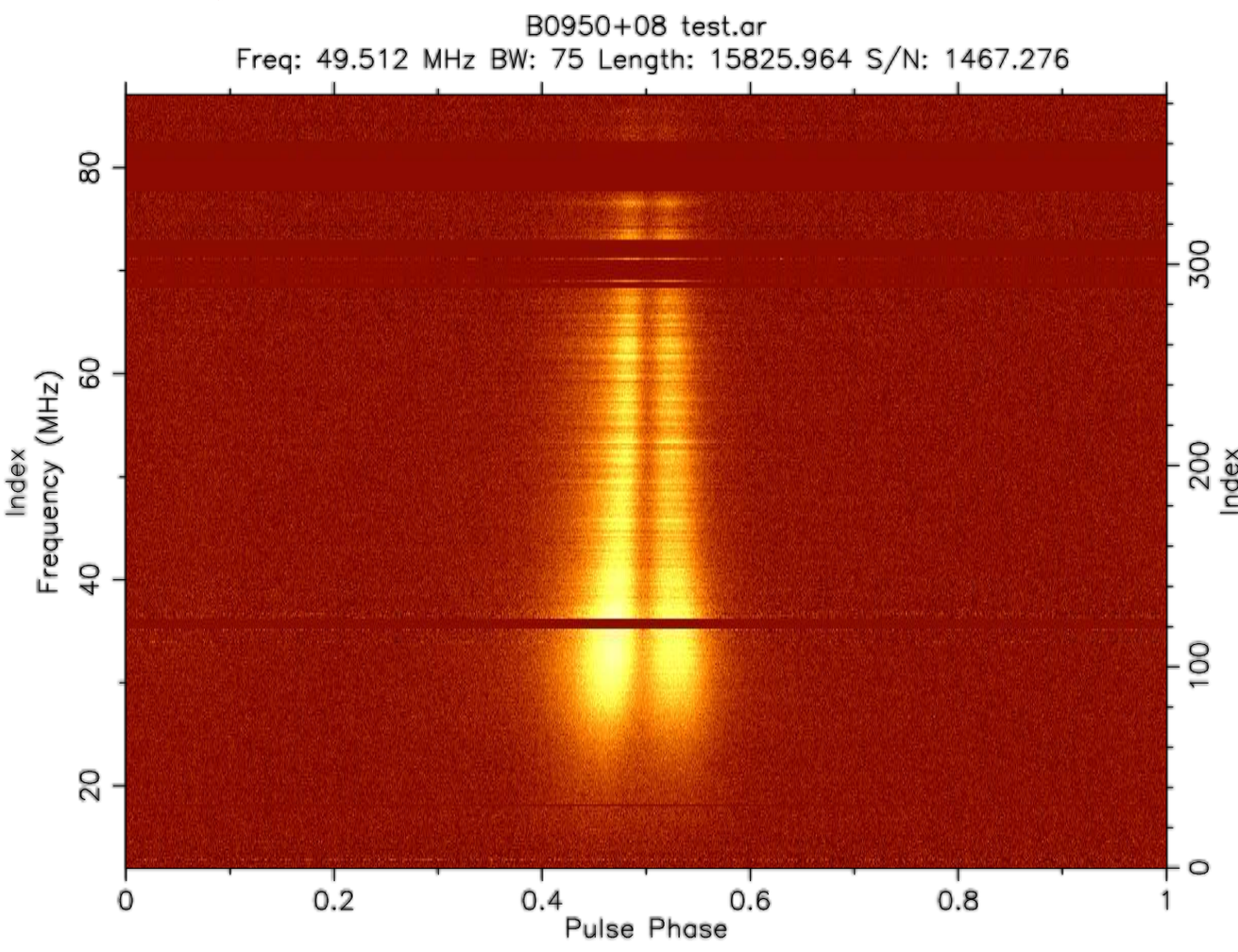
Low frequency dedispersion

Dispersed

Pulsar backend

Dedispersed





The Dispersion

Low frequency dedispersion

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Pulsar backend

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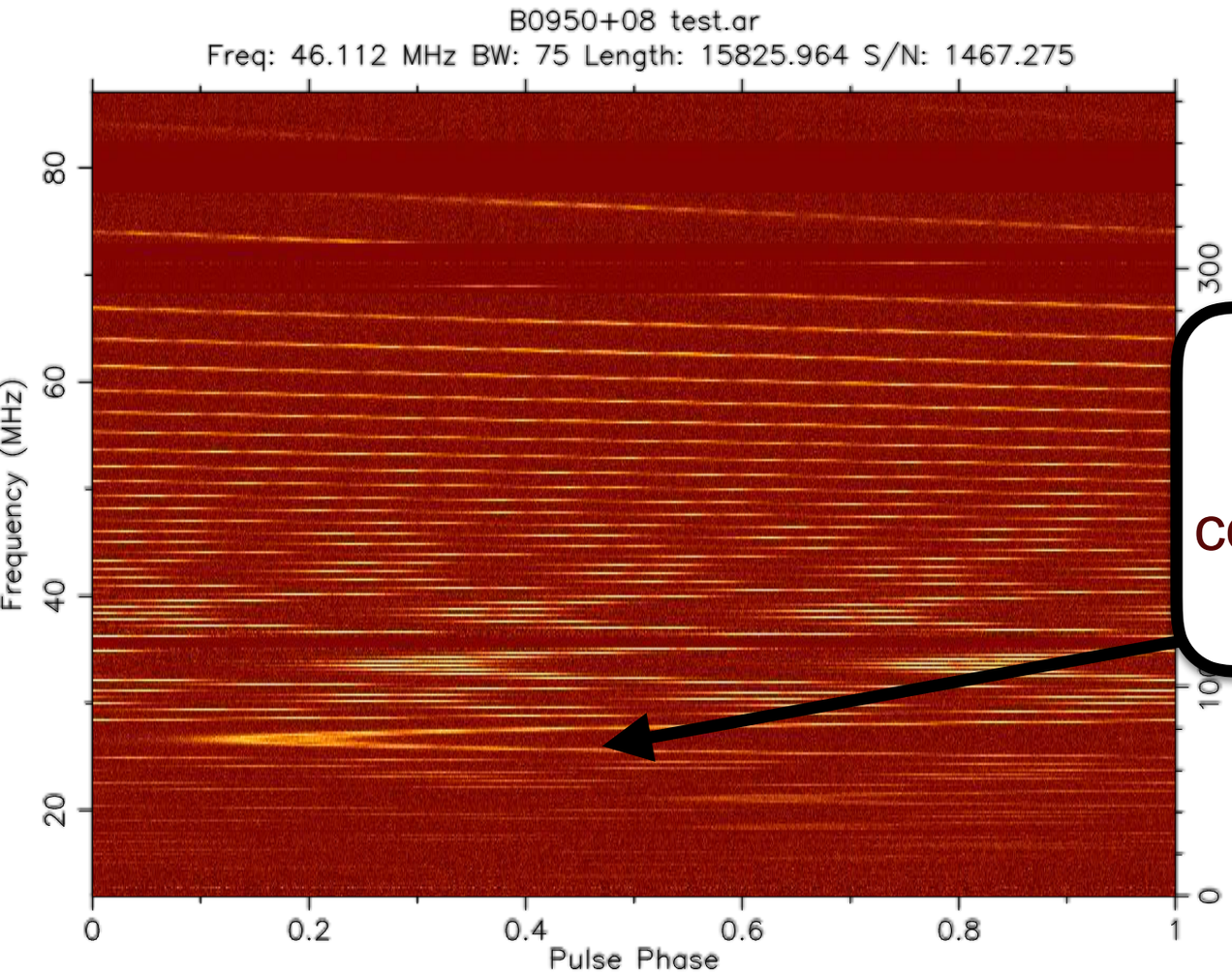
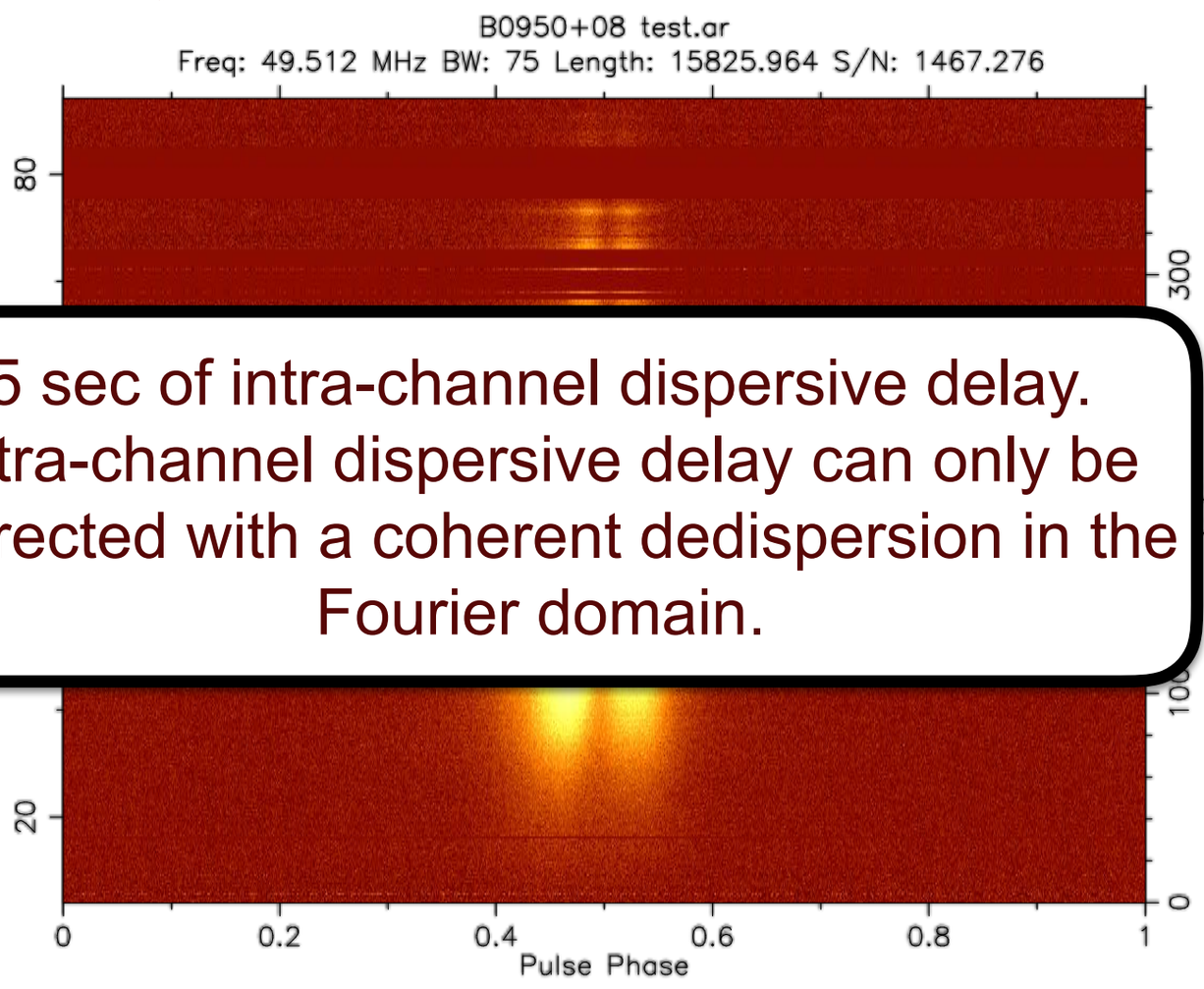


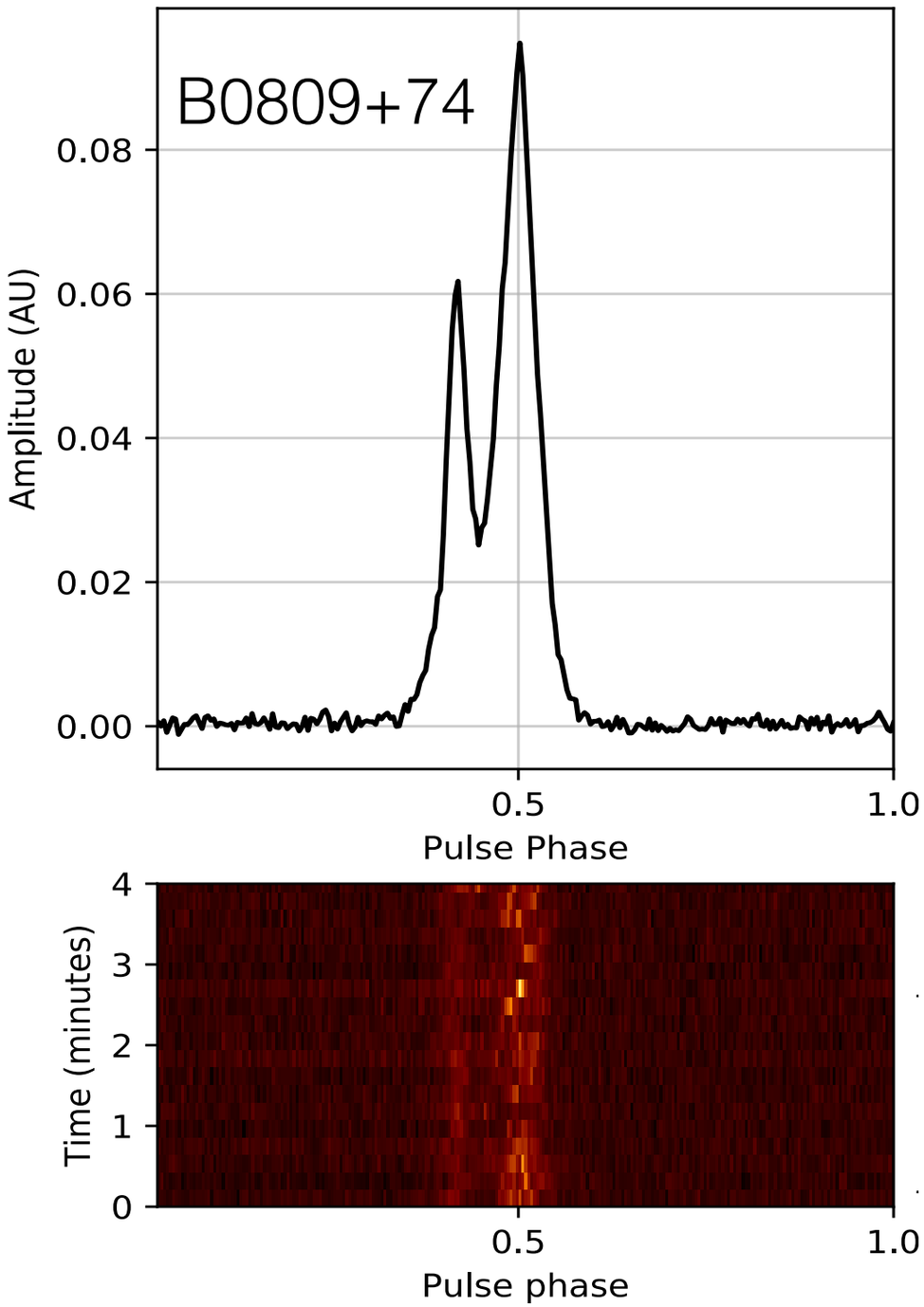


5 sec of intra-channel dispersive delay.
Intra-channel dispersive delay can only be corrected with a coherent dedispersion in the Fourier domain.

NenuFAR: Observation modes

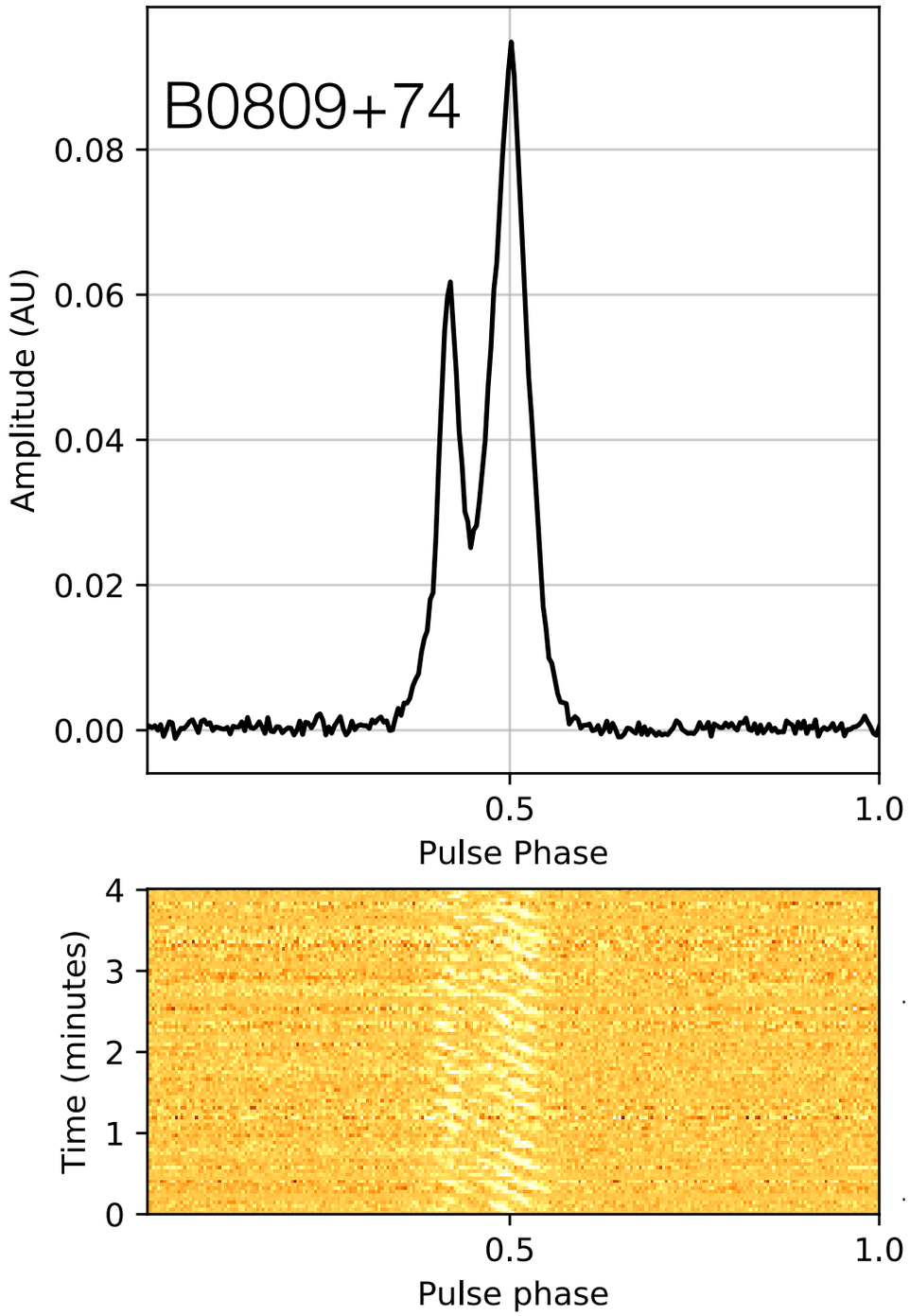
Folding

10 sec subintegrations



Single pulse

All rotations



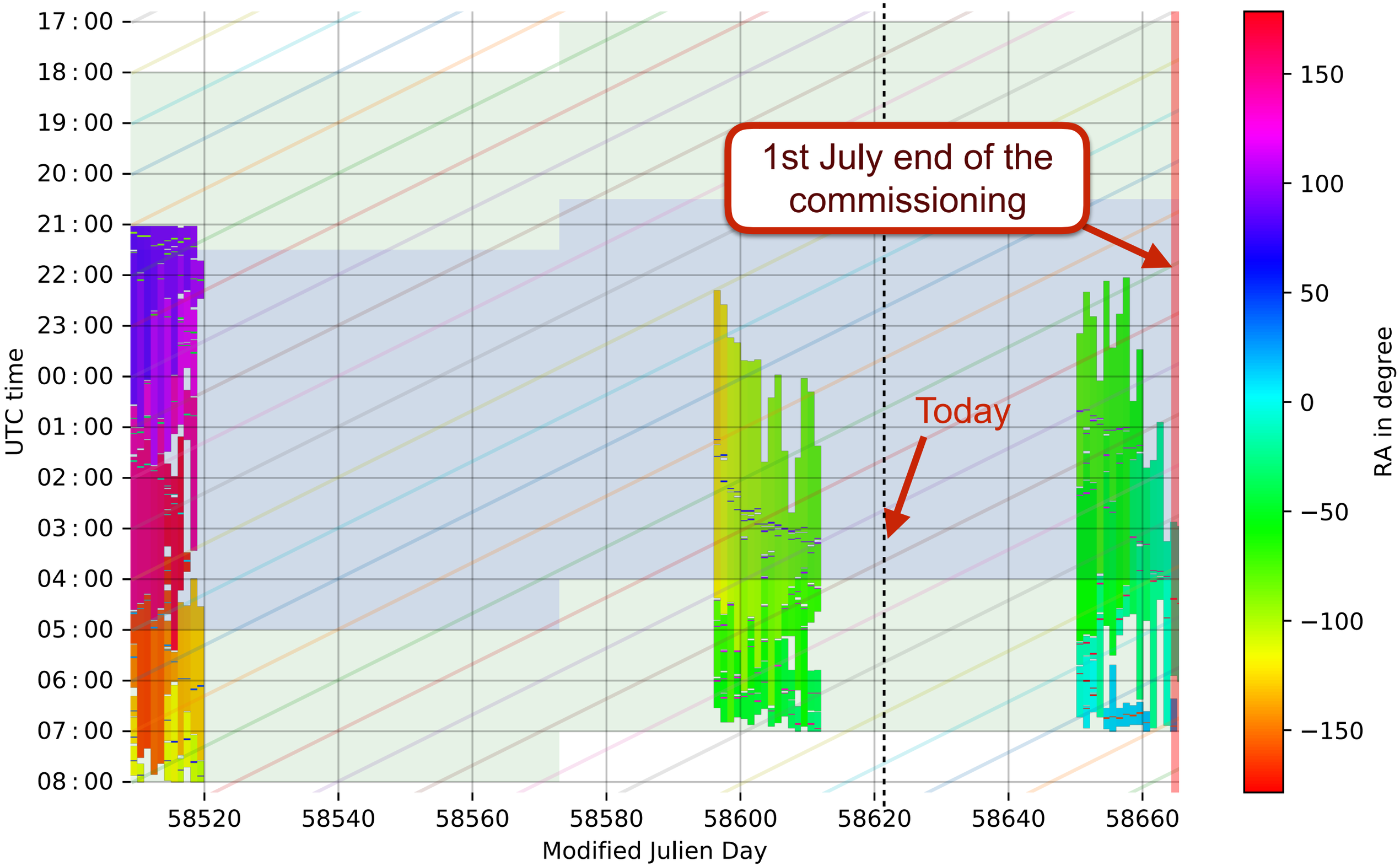
NenuFAR: Pulsar commissioning project

Studying pulsars during the commissioning phase:

A census of 513 pulsars with low DM is started. (340 hours)

- DM < 100 and declination > -10°
- 1h per observation at 60° (length α $\sin(\text{elev})^2$)
- Using up to 4 simultaneous beams
- 6 month project
- Mainly in night time

NenuFAR: Pulsar commissioning project



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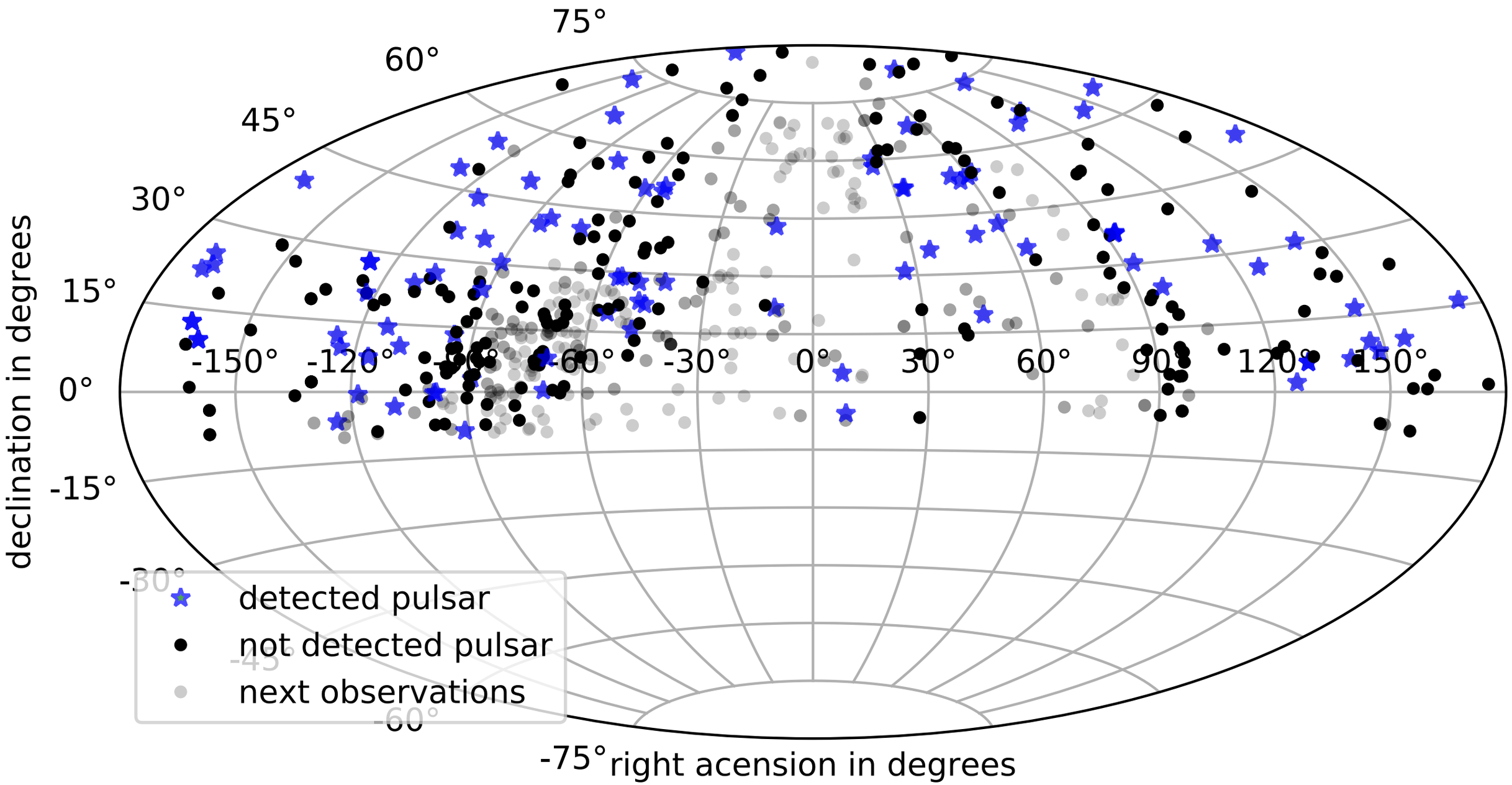

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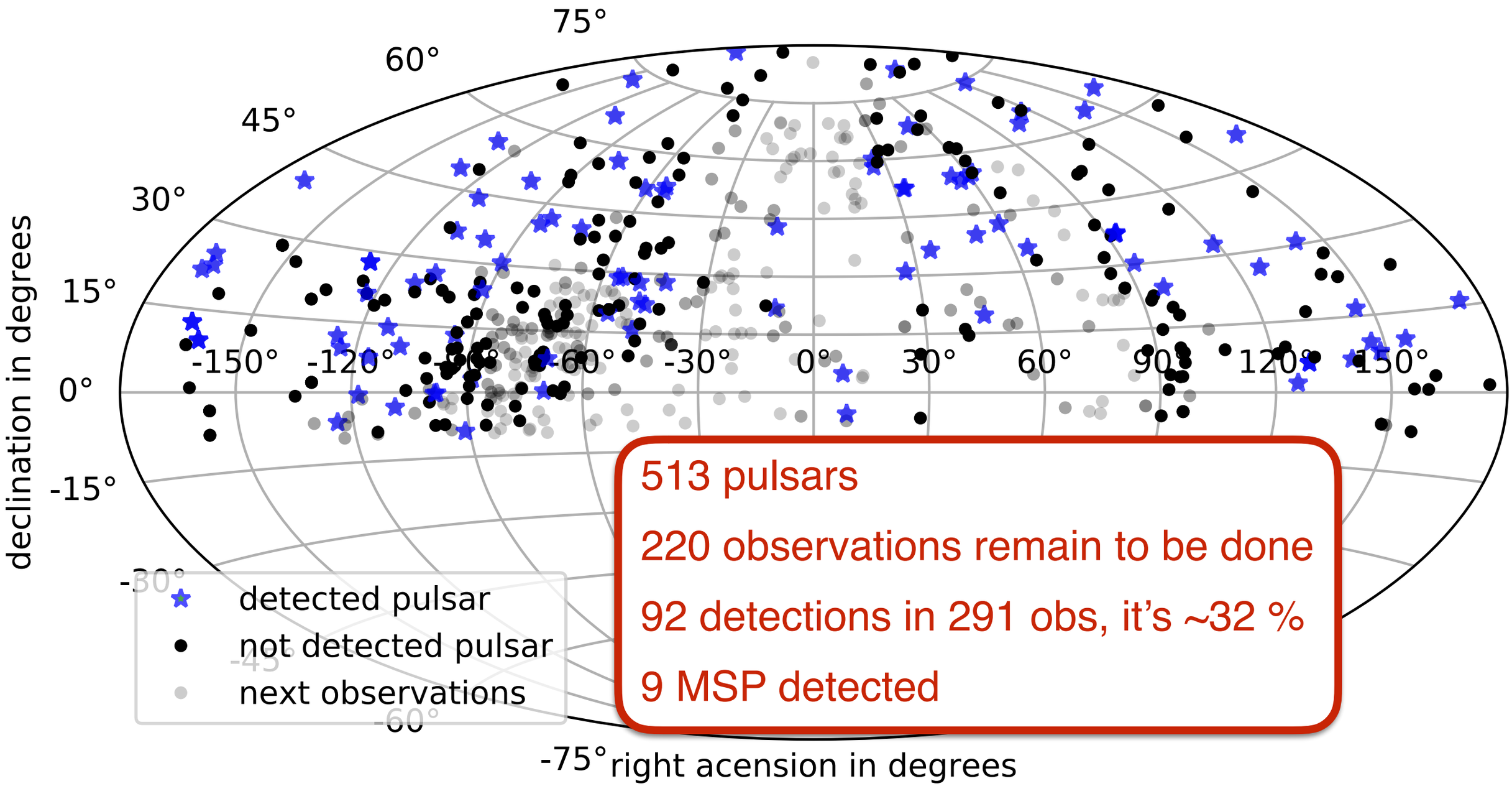

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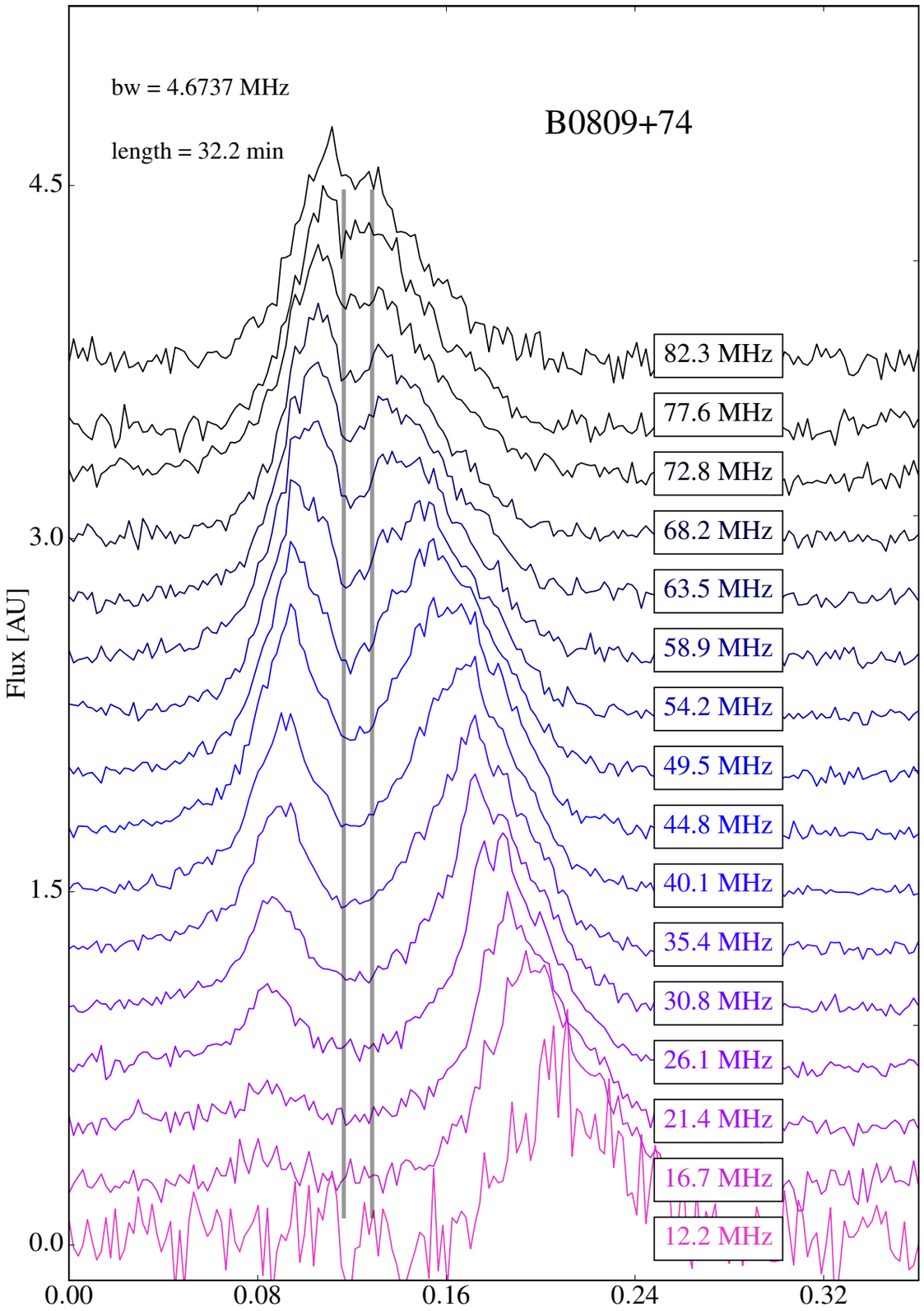

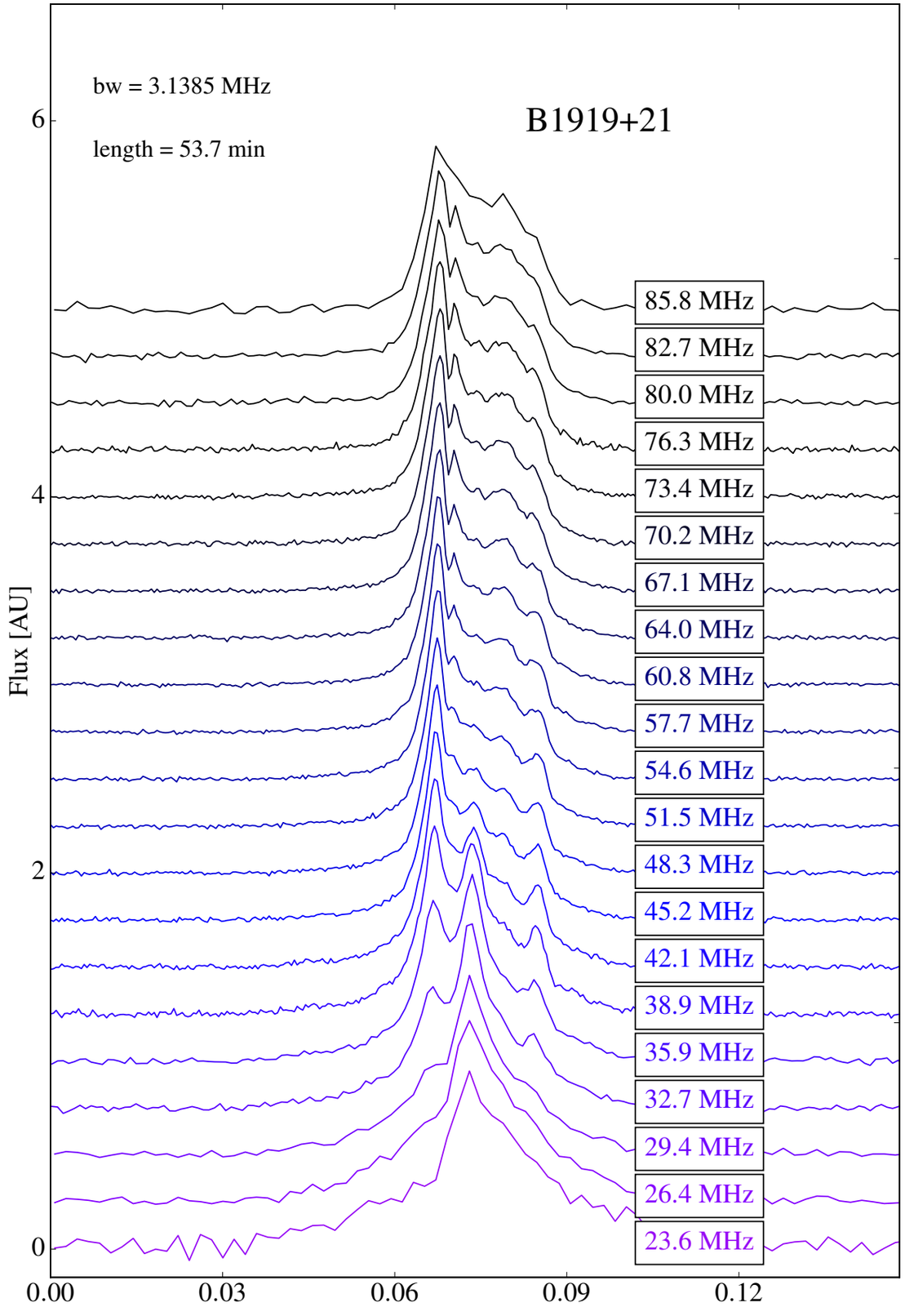

NenuFAR: Polarisation with NenuFAR

One enemy -> the Faraday rotation.

-> impossible to use the linear polarisation with the standard (195 kHz) channels.

The RM (Rotation Measure) is limited to 1 rad.cm^{-3}.

One solution:

Increase the number of channels using sub-channels.

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One solution:

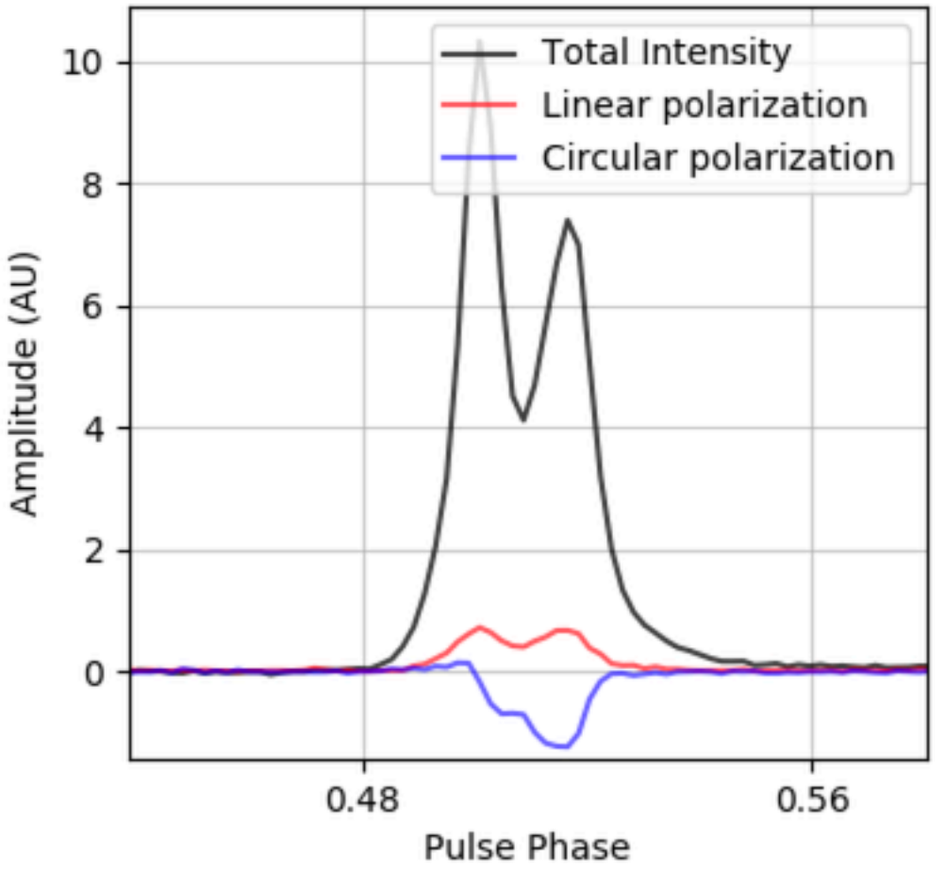
Increase the number of channels using sub-channels.

But like the dispersion the Faraday rotation is a coherent process.

-> can be corrected coherently in Fourier domain!!

NenuFAR: Polarisation with NenuFAR

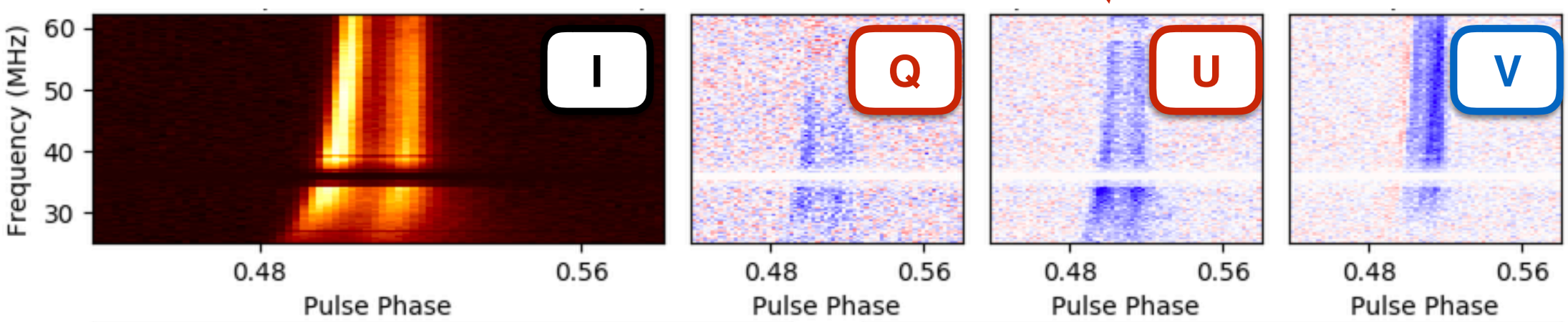
Without any special treatment: (192 channels in 37.5 MHz BW)



name	Source name	J0837+0610
nbin	Number of pulse phase bins	512
nchan	Number of frequency channels	192
npol	Number of polarizations	4
nsubint	Number of sub-integrations	70
length	Observation duration (s)	3537.16371456
dm	Dispersion measure (pc/cm^3)	12.8640003204

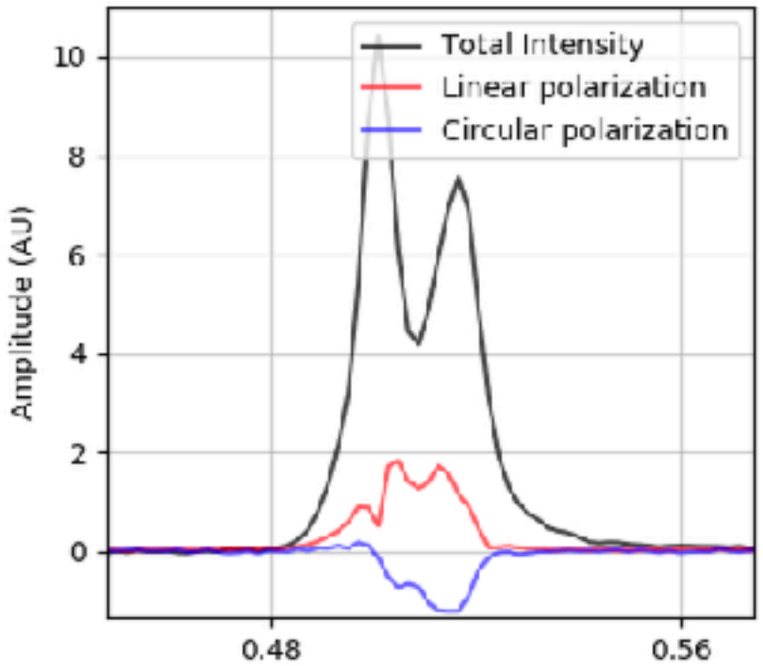
RM = 26.05 rad.cm^{-3}

Strong Faraday rotation so the linear polarisation is mixed!



NenuFAR: Polarisation with NenuFAR

With coherent defaraday: (192 channels in 37.5 MHz BW)



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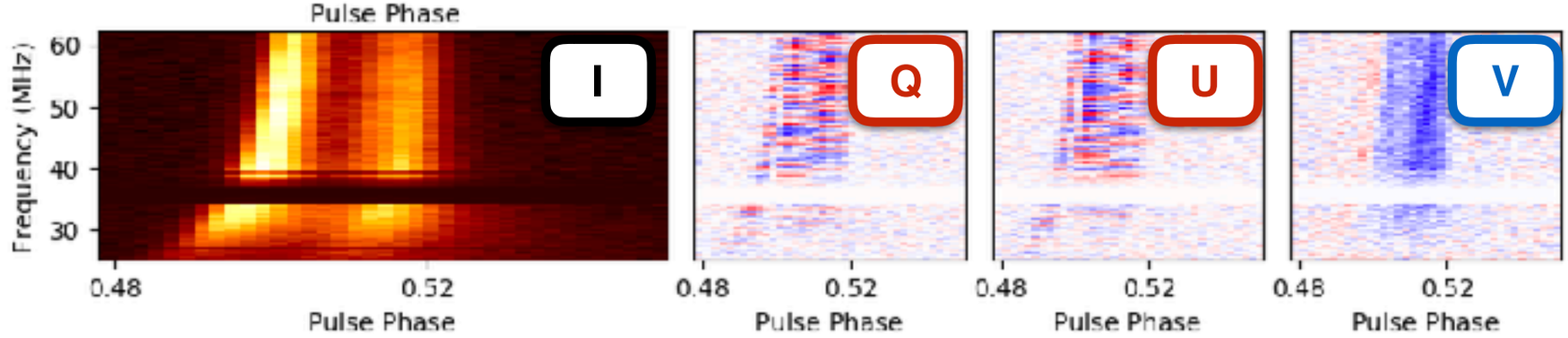
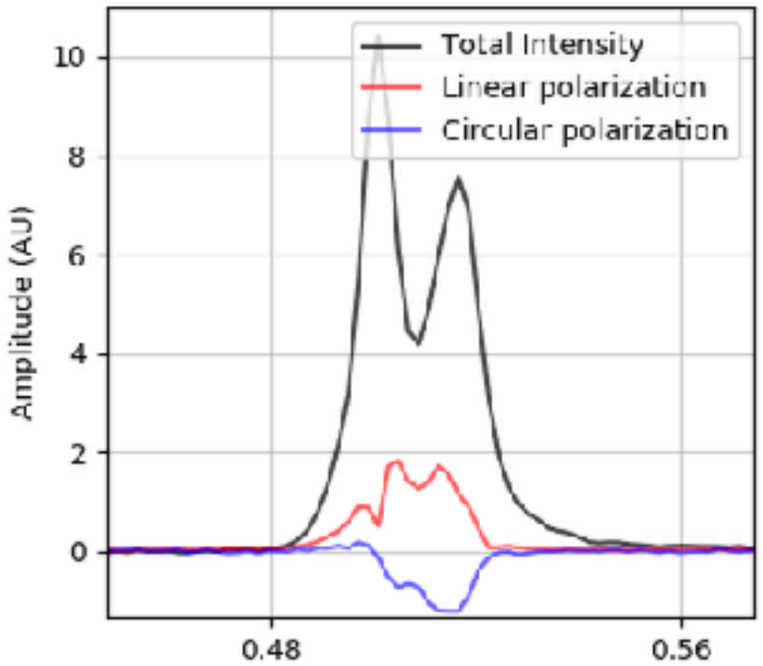


Coherently defaraday to the center frequency for each channel.

NenuFAR: Polarisation with NenuFAR

With coherent defaraday: (192 channels in 37.5 MHz BW)



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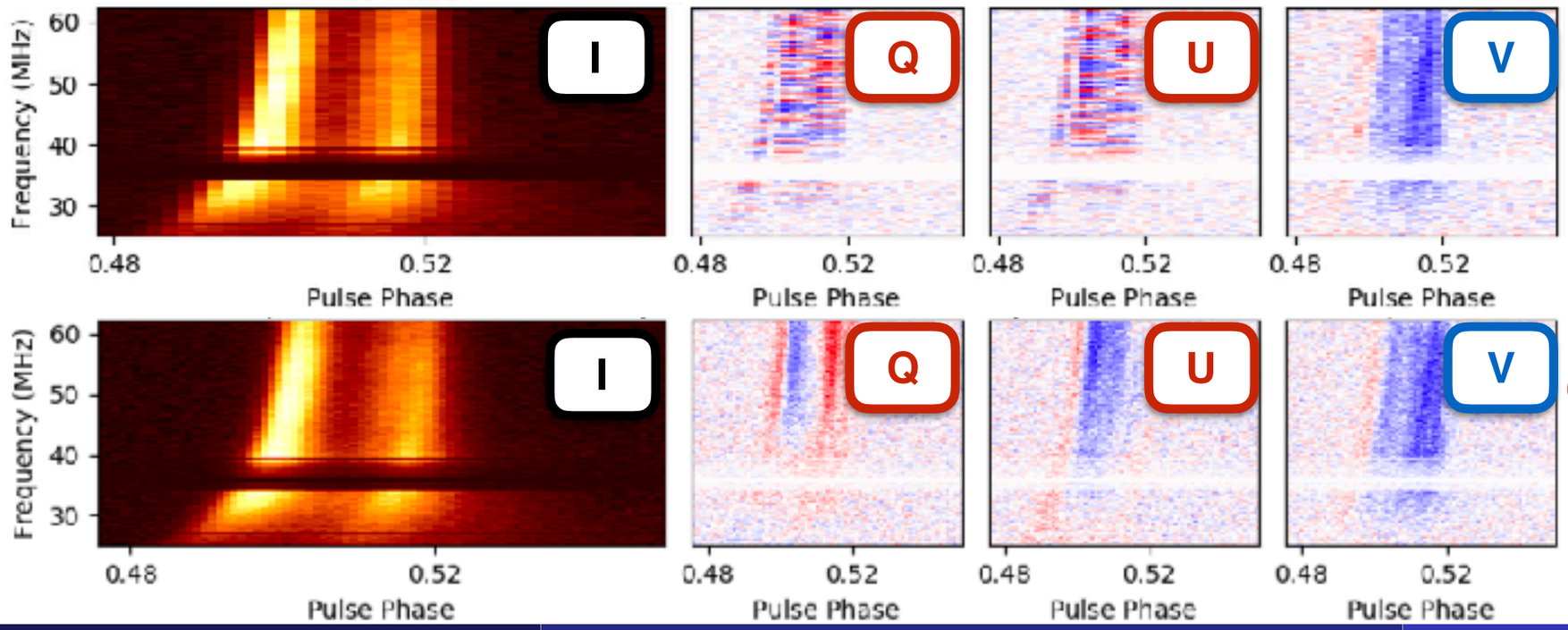
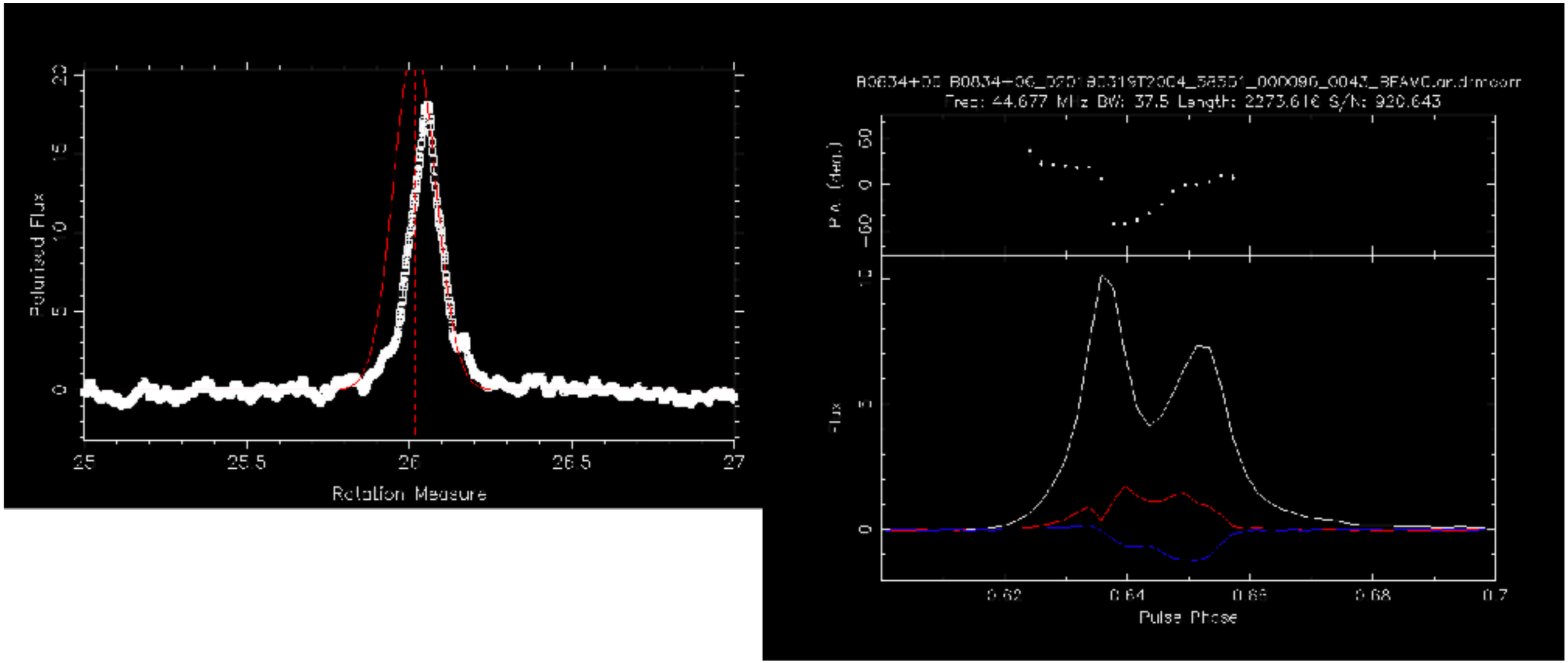


Coherently defaraday to the center frequency for each channels.

Coherently defaraday to an infinite frequency

NenuFAR: Polarisation with NenuFAR

With coherent defaraday: (192 channels in 37.5 MHz BW)



Measurements of the Rotation Mesure (RM) and Polarisation Angle (PA) are now possible for high RM.

NenuFAR: Pulsars Key Projet

Sub-program	Telescope time (hour)	Studies
Census 100-200 pc.cm^{-3}	90	Extension of the census
Blind survey	960	Full sky survey for slow pulsars
Monitoring 41 PSR	720	1 observation per month per pulsar
Eclipsing binaries	41	DM/scatt variations in binaries
Spectral Index/ turnover	Monitoring time	Emission mechanism
Polarised emission	30	
Single pulse	44	
Drifting sub-pulse	20	
ISM/GP	78	
VLBI observations	23	VLBI with LOFAR

NenuFAR: Conclusion

Conclusion

- NenuFAR works now with more than 1064 antennae (1501 soon).
- Scientific key projects starts in July.
- The low frequency coherent dedispersion and defaraday backend in real time is operational.
- Ready to observe up to 4 PSRs simultaneously.
- A census of 513 pulsars with low DM is in progress. (340 hours)
- Highly sensitive low frequency observation is now a reality,

stay tuned: lots of science will come in the coming months !

Low frequency pulsar observations with NenuFAR

Thank you