Low frequency pulsar observations with LOFAR and NenuFAR

Louis Bondonneau

Phd supervisor : Gilles Theureau

Co-supervisor : Jean-Mathias Griessmeier

Low frequency: First observation and historical evolution

First pulsar discovered at 81.5 MHz (Hewish et al. 1968),

observations progressively moved to higher frequency for 3 reasons:

- Dispersion of the interstellar medium (ISM)
- Scattering (multi path propagation effect in the ISM)
- Low telescope sensitivity at this wavelength (astrophysical background and instrumental effects)

Introduction: LOFAR

LOFAR « Low-Frequency Array »

- Array of omnidirectional antennas
- 24 core stations (near Exloo)
- 14 remote stations in the Netherlands
- 13 international stations

Total: 51 stations

Introduction: LOFAR (FR606)

NenuFAR 10-85 MHz

LOFAR FR606 in Nancay (jun 2015)

LOFAR HBA 110-240 MHz

NenuFAR (New Extension in Nançay Upgrading loFAR)

« In construction »

- 96 groups of 19 antennas
  72 already funded

LOFAR (FR606)

- 96 HBA and 96 LBA antennas

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

Introduction: Pulsars

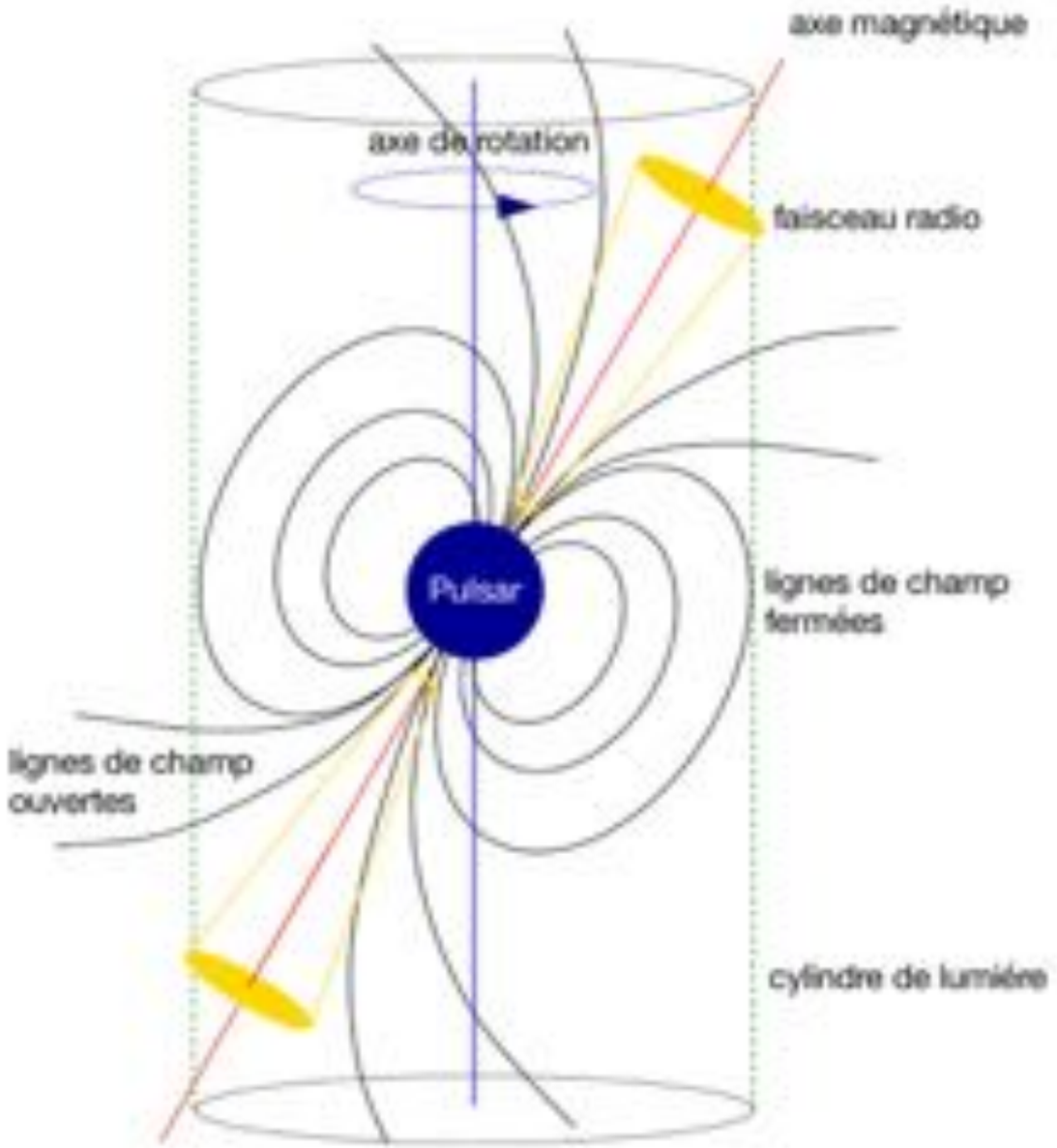
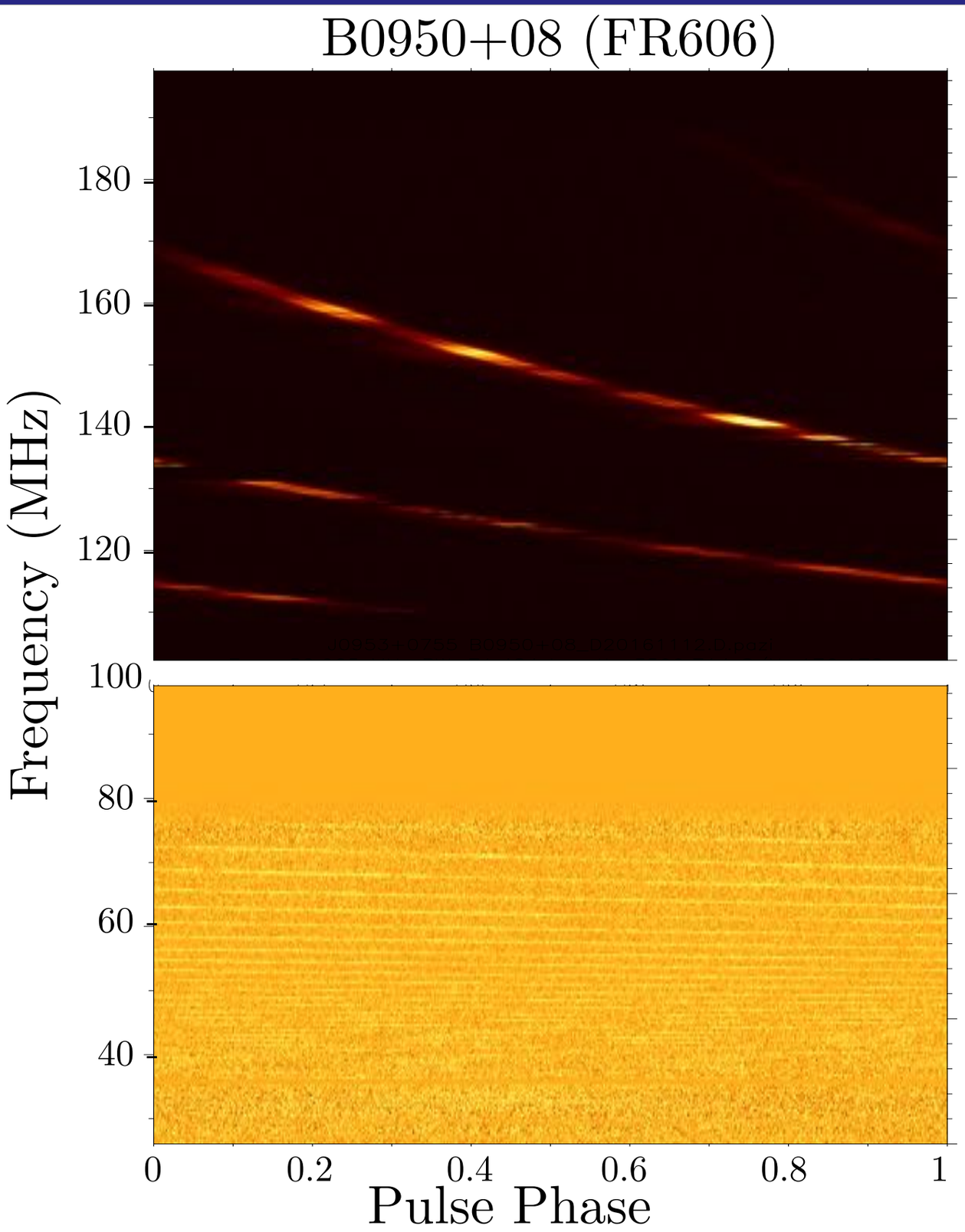


Diagram of a pulsar *Handbook of Pulsar Astronomy* D.Lorimer & M.Kramer.

- Rapidly rotating neutron star of ~1.4 M⊙ for a diameter of 20 km.
- Synchrotron Radiation from the magnetic poles.
  - generating a radio beam

Introduction: ISM dispersion

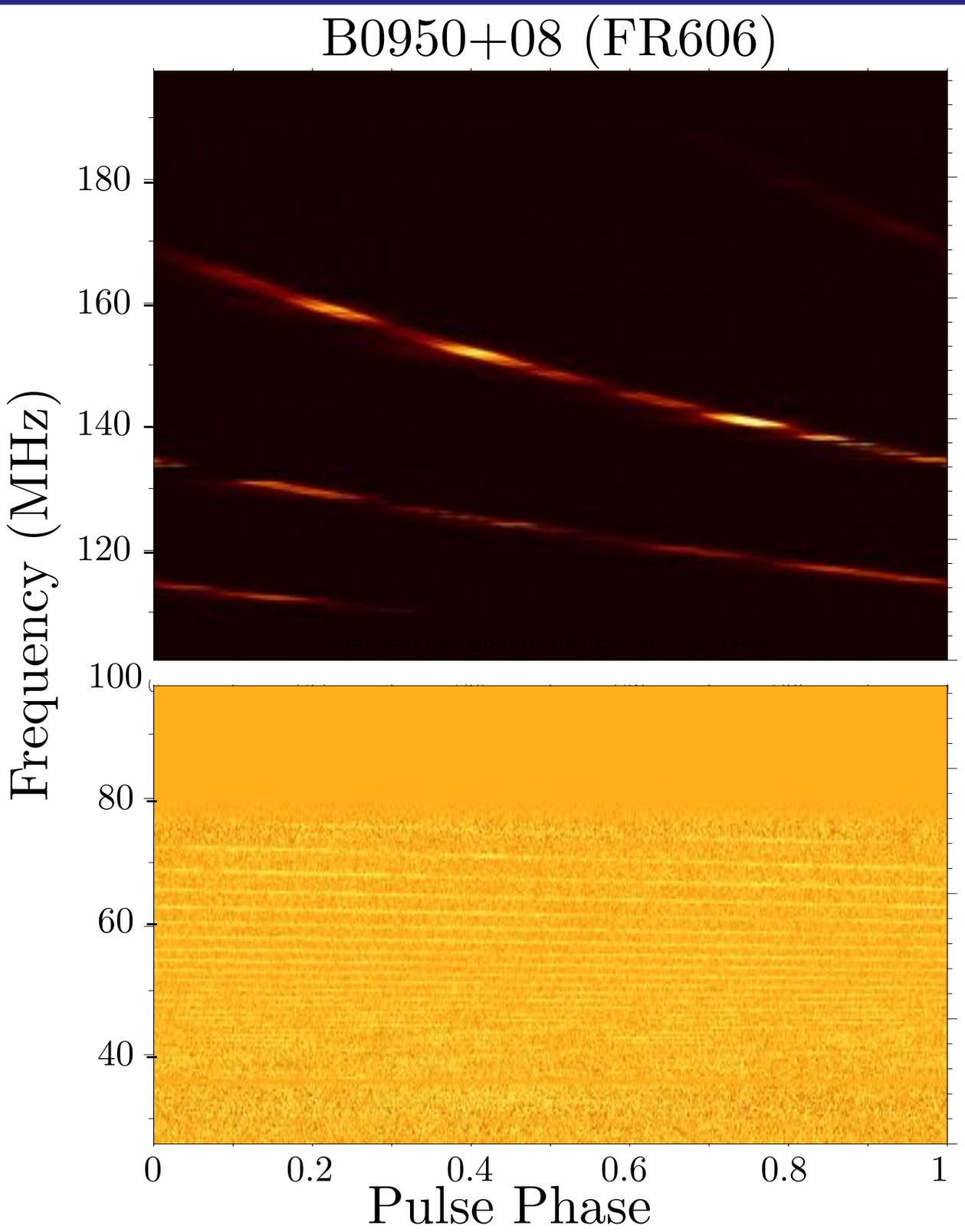


- Delay due to the frequency-dependance of group velocity.

$\Delta t \propto f^{-2}$

=> coherente dedipersion

Introduction: ISM dispersion



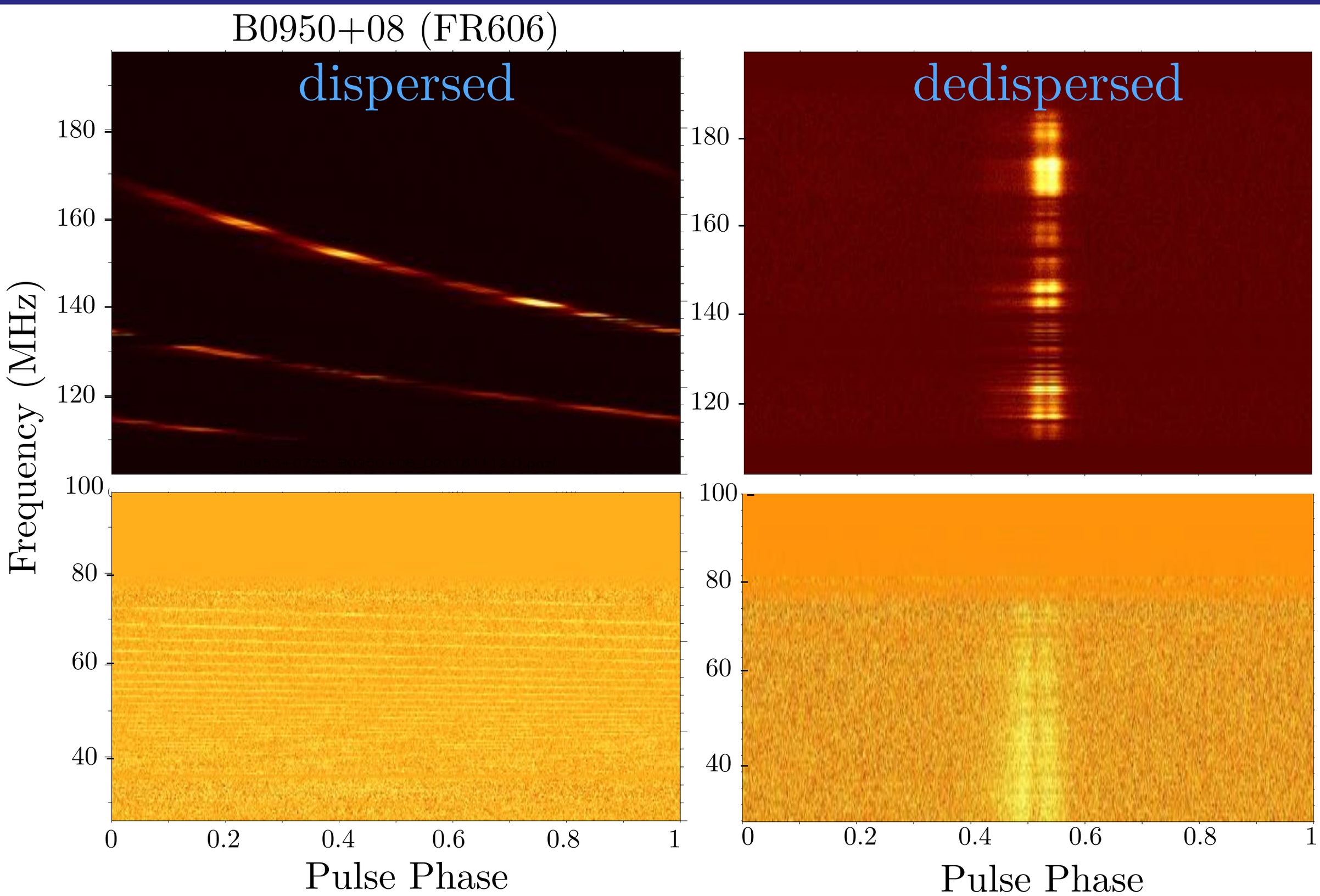
- Delay due to the frequency-dependance of group velocity.

$\Delta t \propto f^{-2}$

=> coherente dedipersion

<= Pulsar weakly dispersed

Introduction: ISM dispersion



Low frequency: First observation and historical evolution

Why it is interesting today ? (for pulsars science)

- More sensitivity (NenuFAR, LOFAR), both polarisation, coherent dedispersion (growing computational resources)

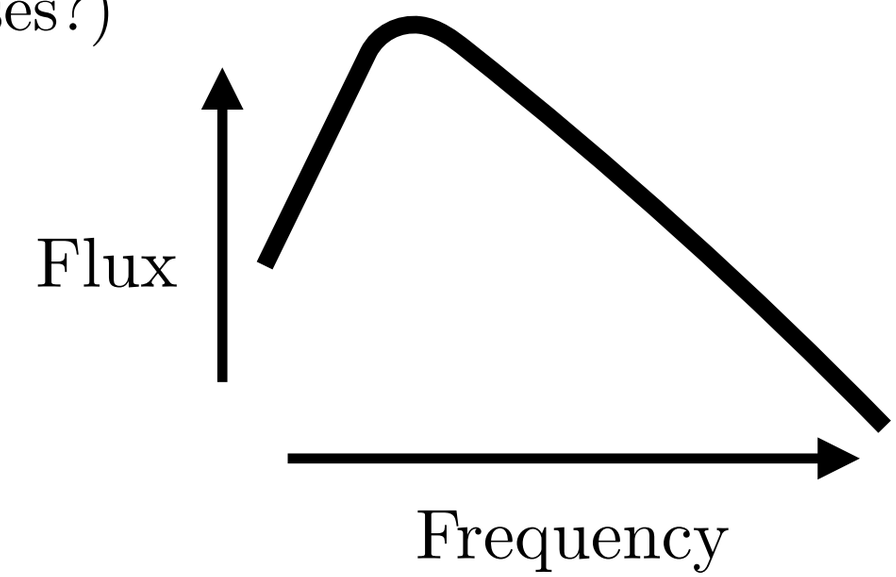
  -Population studies at low frequencies:local pulsars census, explore faint end of the luminosity function

- Multi-telescope/multi-wavelength (e.g. in Nançay : 10MHz-3.5 GHz):

  -variation in frequency of the profile (substructures, duty cycle)

  -spectral turnover at low frequencies (subclasses?)

  -constrain mecanisms of emission and models of the magnetospheric structure



Low frequency: First observation and historical evolution

Observational program:

FR606 pilot projects:

- Pulsars census (77 sources)
- Spectrum long term monitoring (16 sources)

NenuFAR early science:

- Pulsars census (~500 sources)
- Spectrum long term monitoring (~50 sources)
- Single pulse (multi wave-length)

FR606: The LBA census

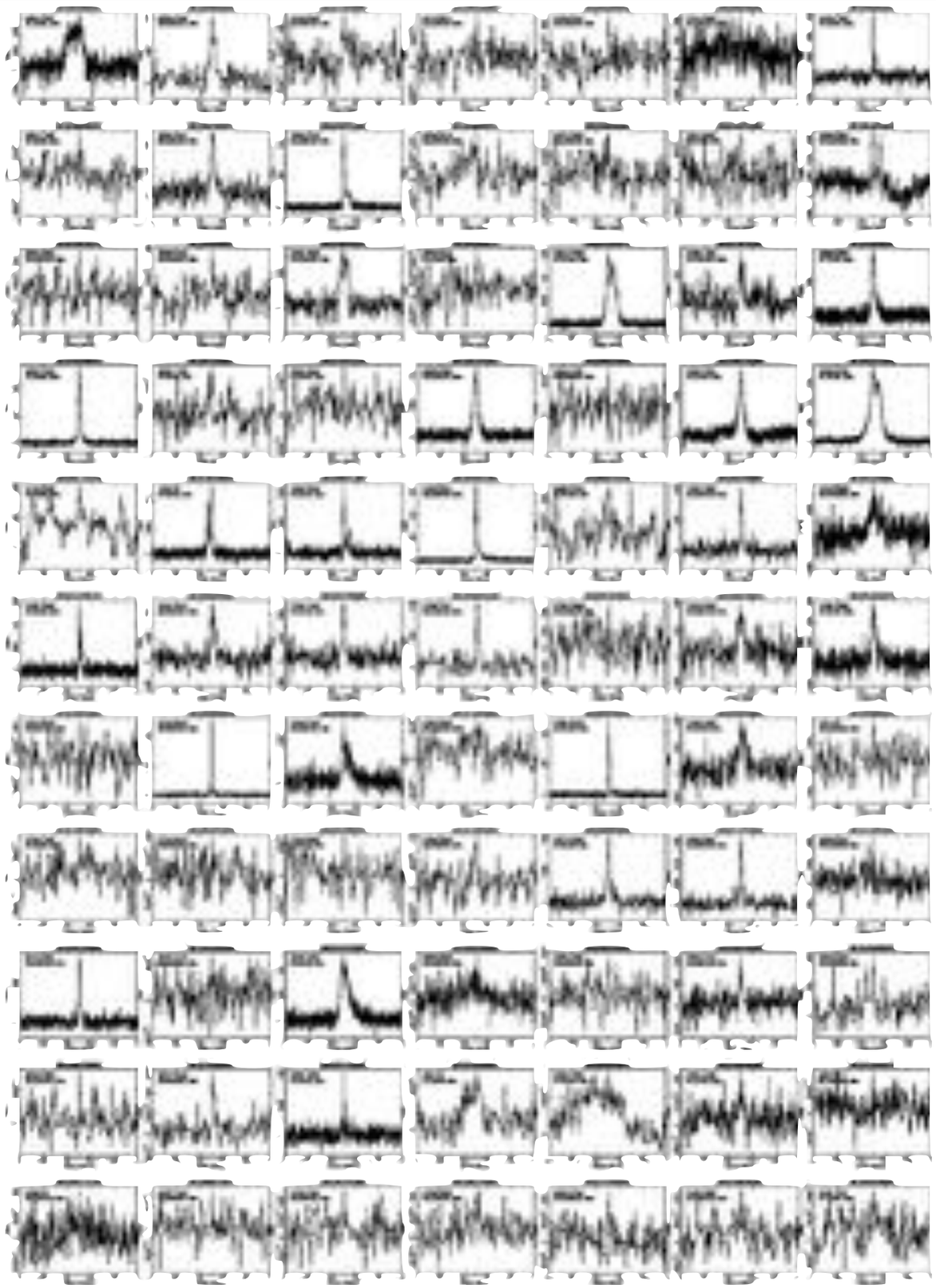
FR606 LBA census

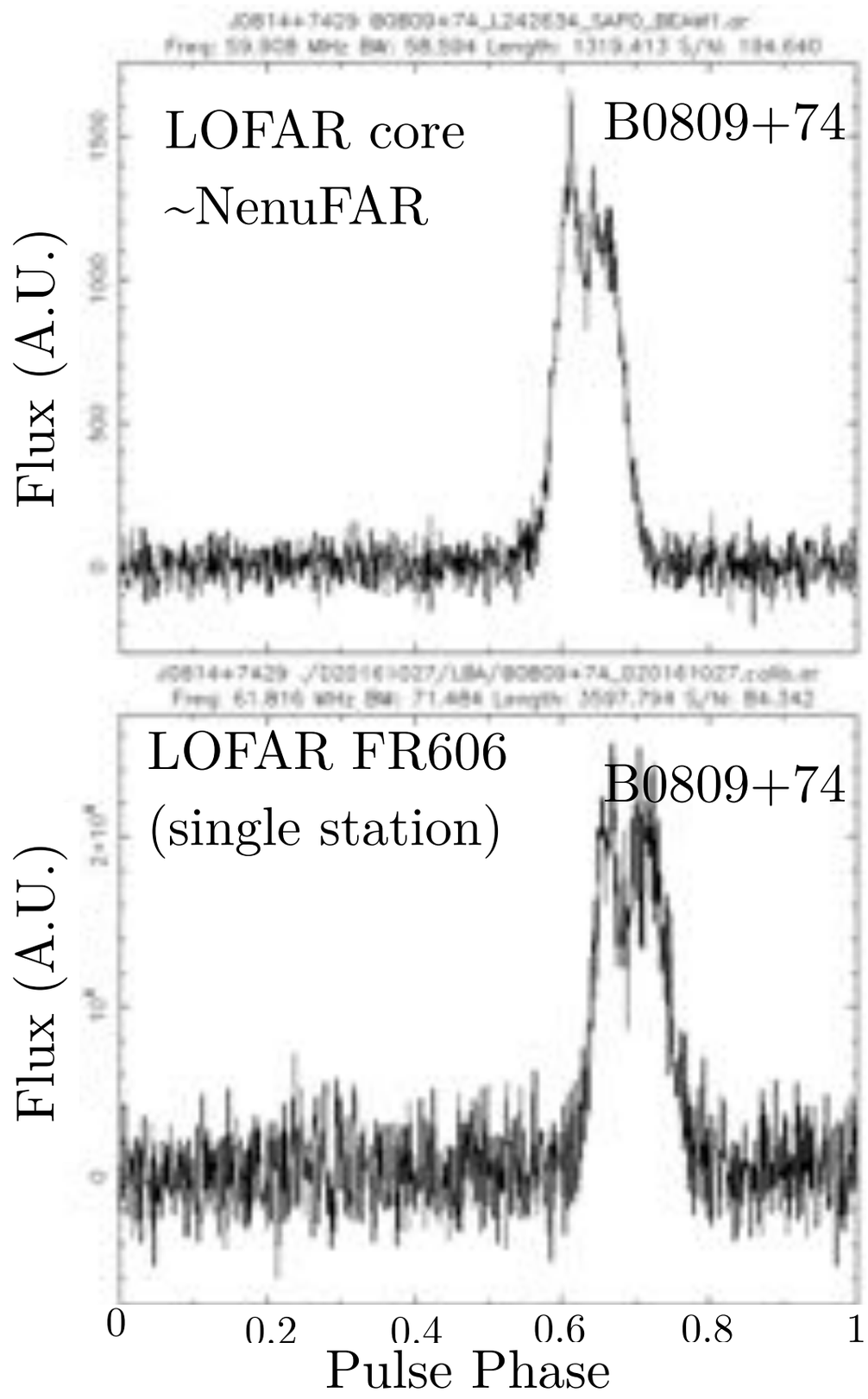
- single beam (but 10 times larger than the core)
- for ≥1 hour per pulsar
- more schedule flexibility

motivations:

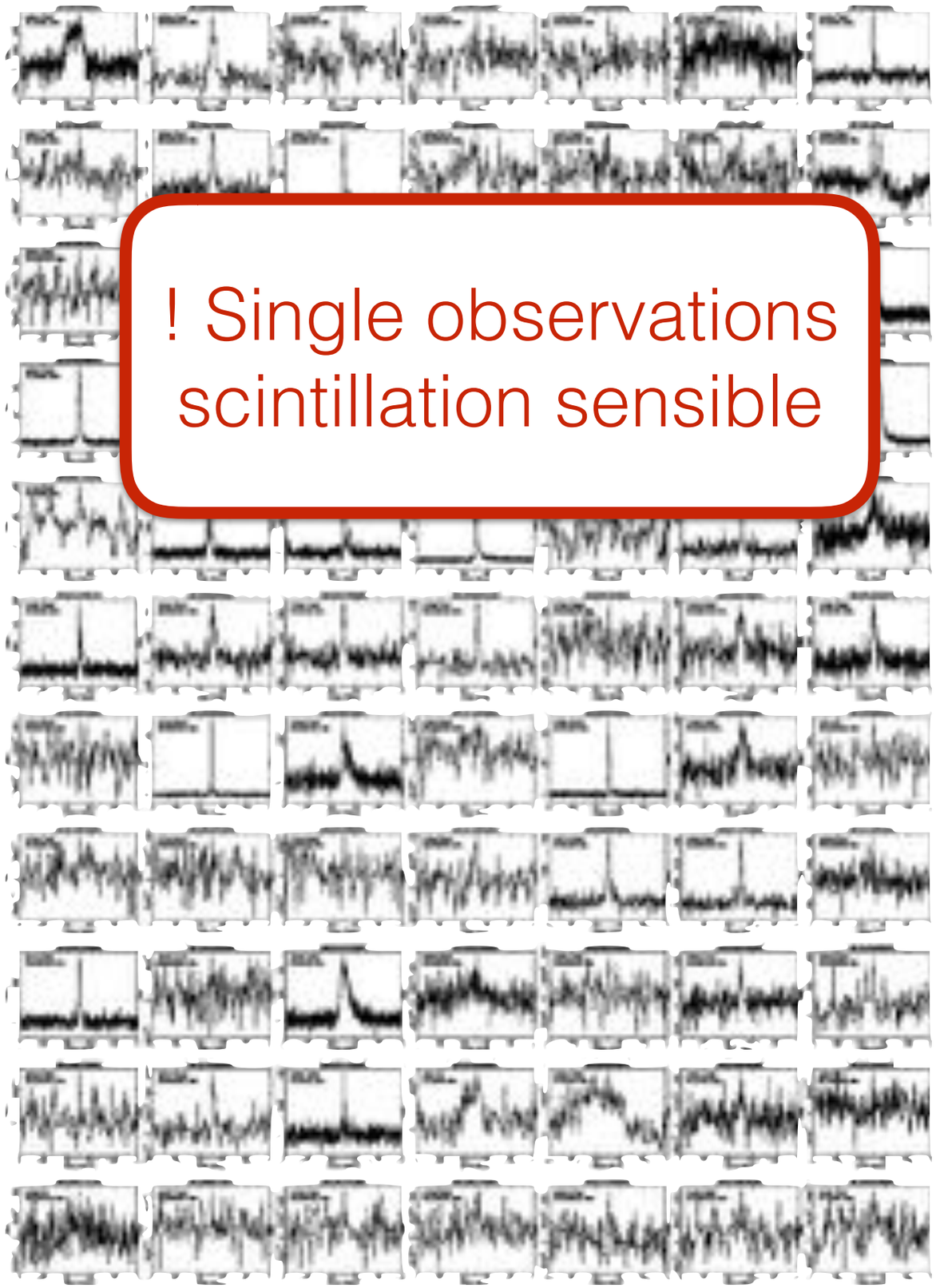
1. representative population (with strong pulsars)
2. select objects for the monitoring
   - take only strong pulsars

FR606: The LBA census 50 integrated profiles and flux

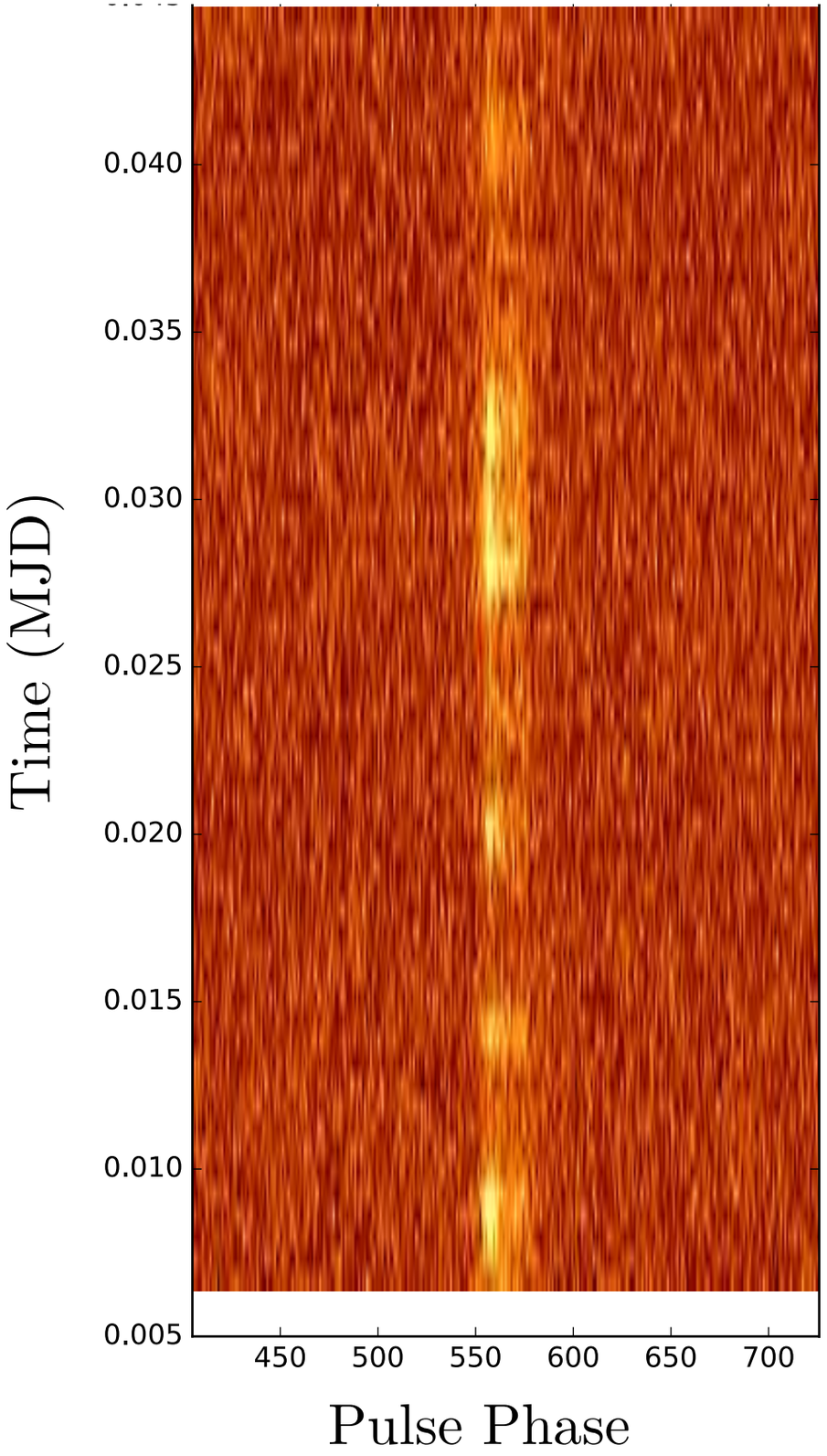




FR606: The LBA census 50 integrated profiles and flux



! Single observations scintillation sensible



LOFAR FR606 spectrum monitoring

FR606 LBA + HBA monitoring

- long term monitoring to absorb time variations
- single beam (but 10 time larger than the core)
- ~1 hour per pulsar

LOFAR FR606 spectrum monitoring

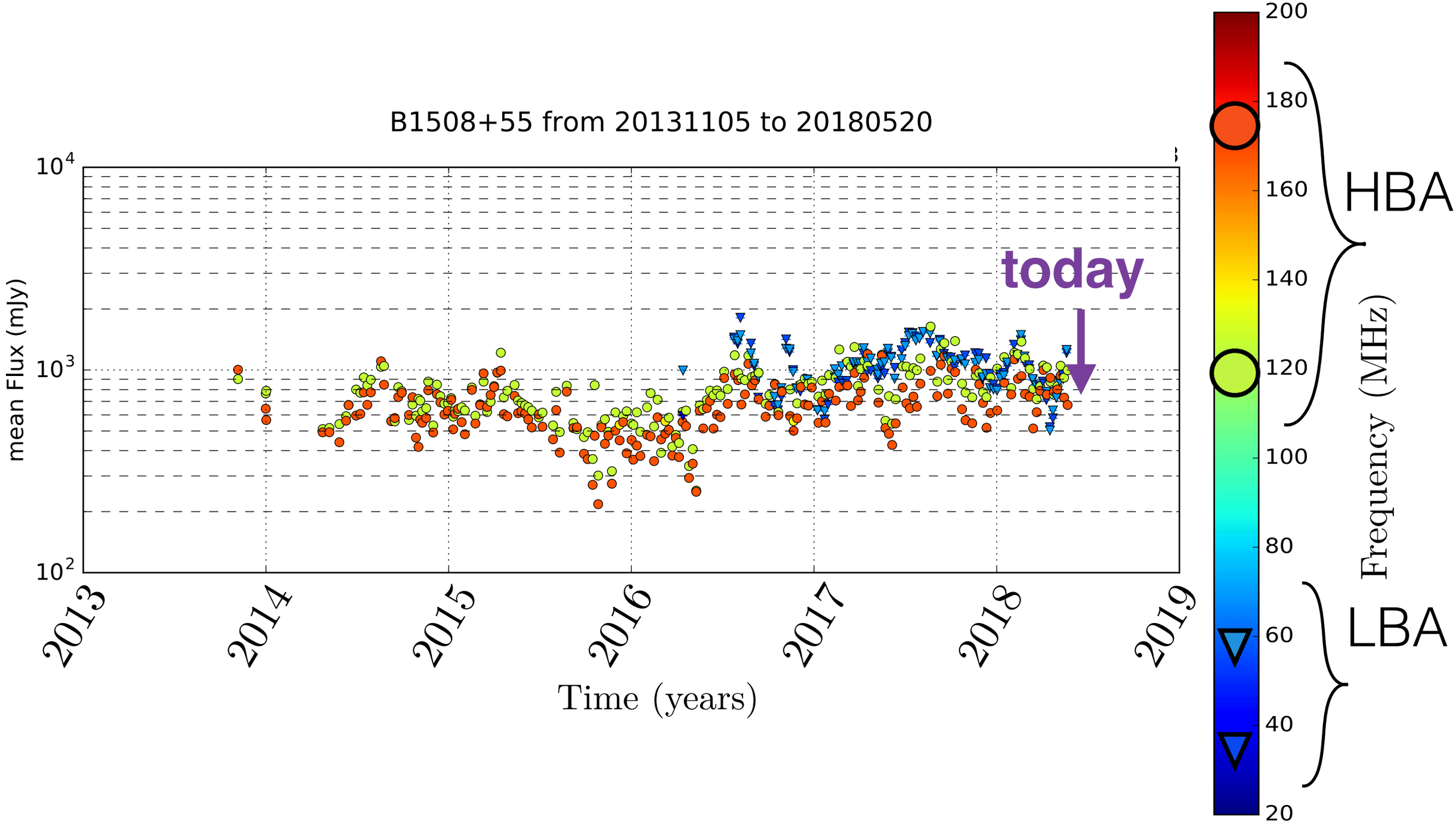
FR606 LBA + HBA monitoring

- long term monitoring to absorb time variations
- single beam (but 10 time larger than the core)
- ~1 hour per pulsar

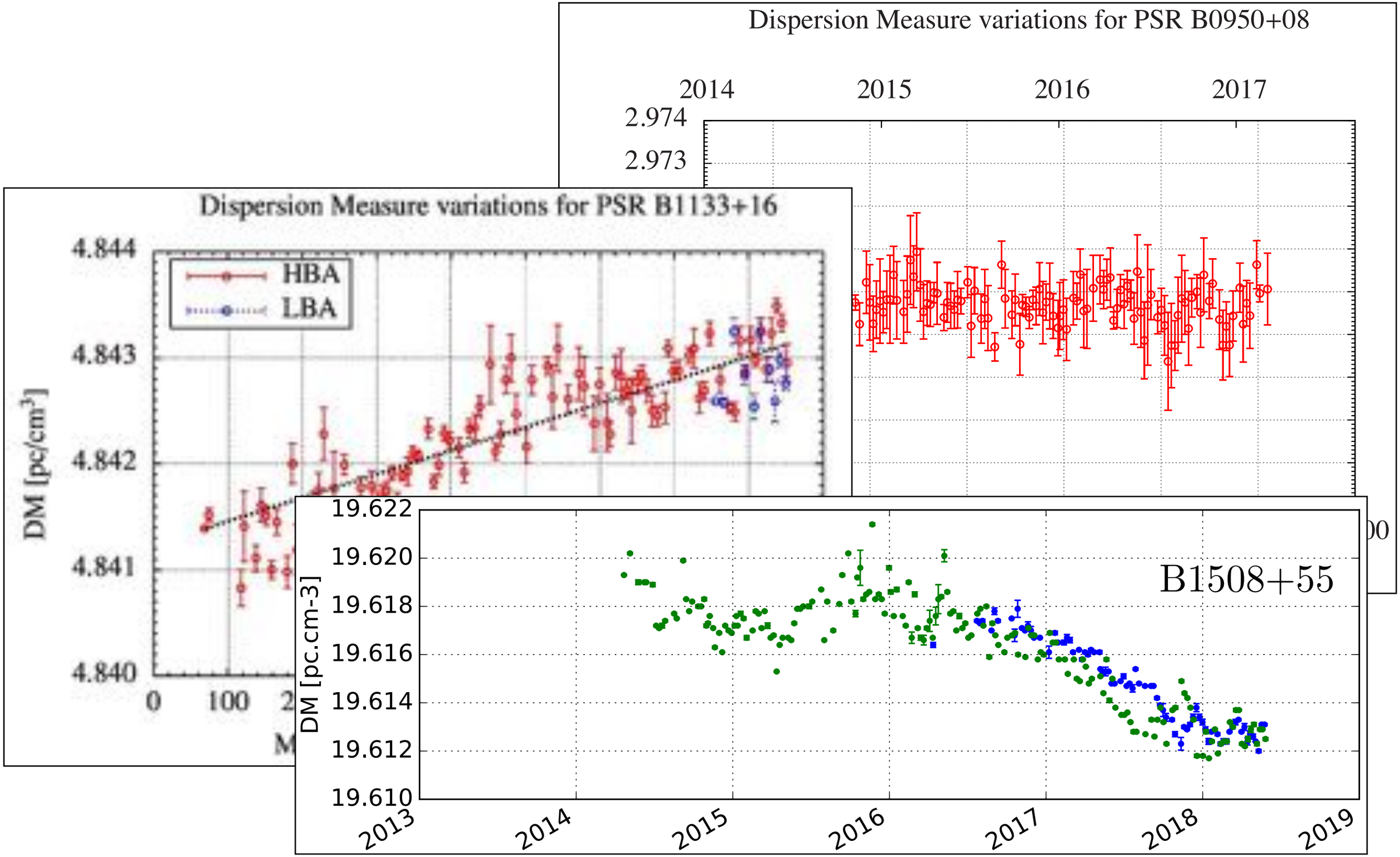
motivations:

1. observe DM variations (timescale: month)
   - characterisation of the Interstellar Medium (ISM)
2. absorb scintillation (timescale: hour)
   - build spectrum for “turnover” studies

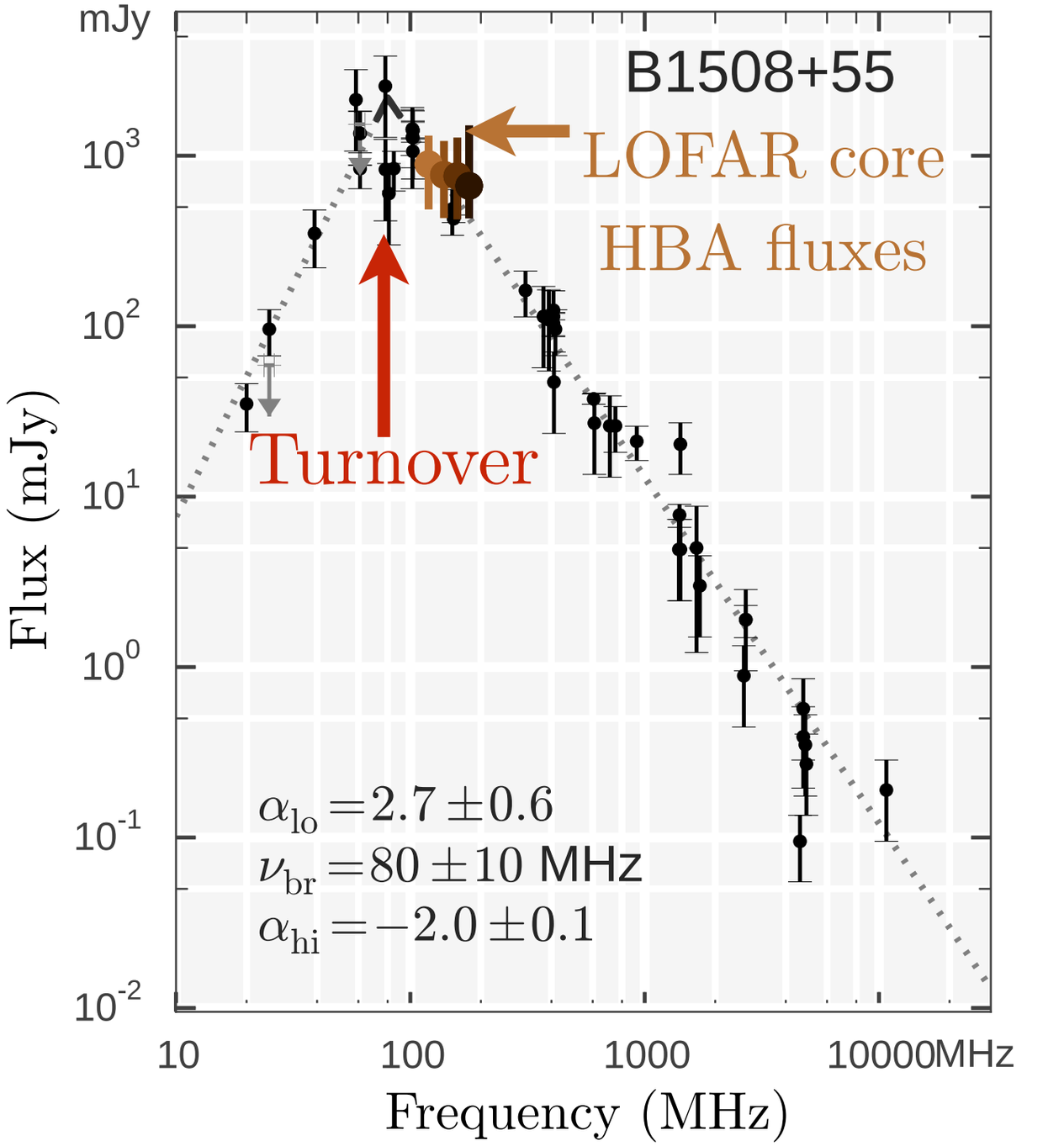
LOFAR FR606 spectrum monitoring



LOFAR FR606 spectrum monitoring



LOFAR FR606 spectrum monitoring

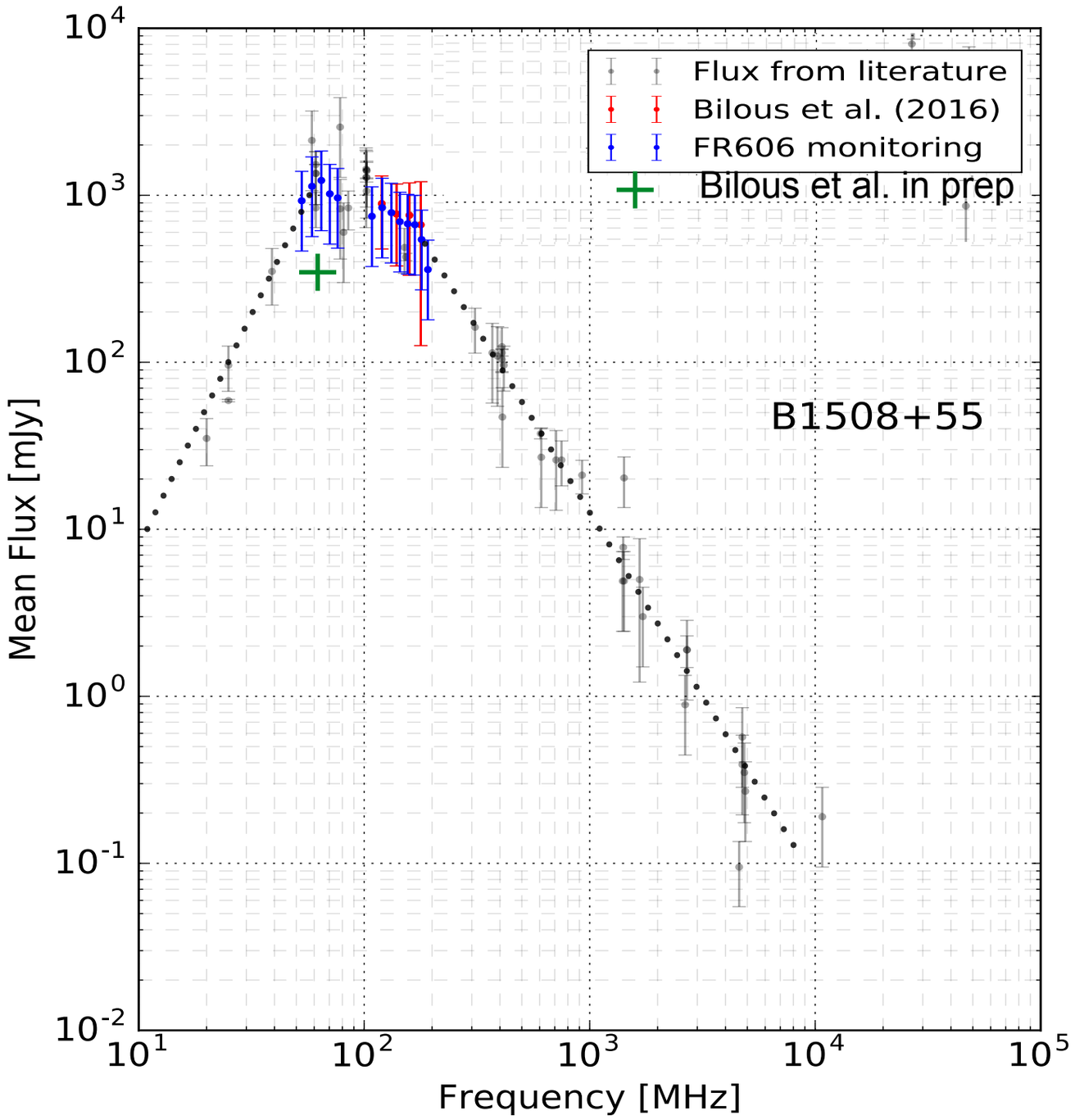


Bilous et al. (2016)

Possible reasons of this turnover?

- A loss of efficiency in the emission mechanism
- An absorption

LOFAR FR606 spectrum monitoring



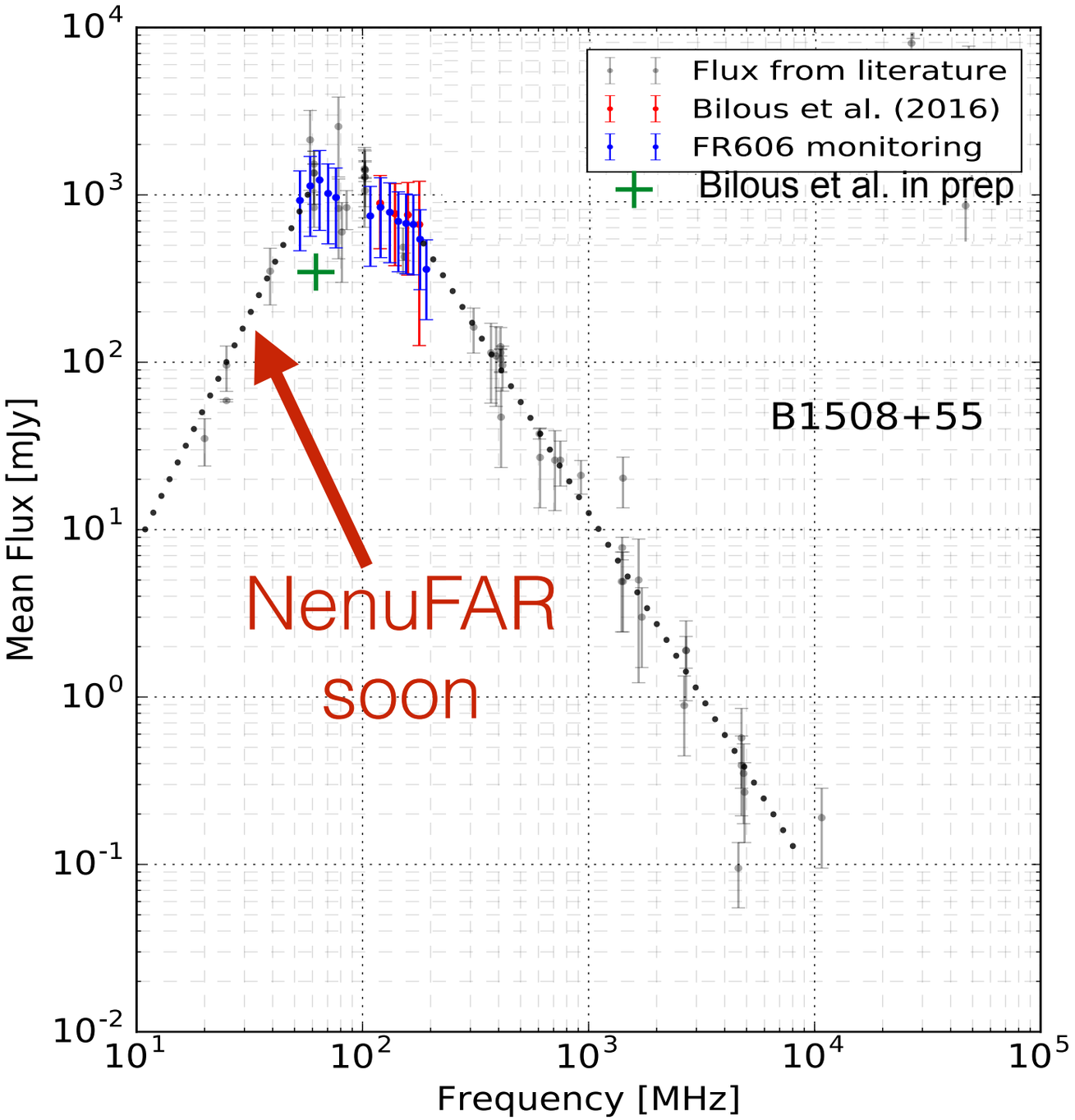
FR606 monitoring:

- Flux from the core census is lower due to flux variations

=> 16 LBA-HBA spectrum

and DM monitoring

LOFAR FR606 spectrum monitoring



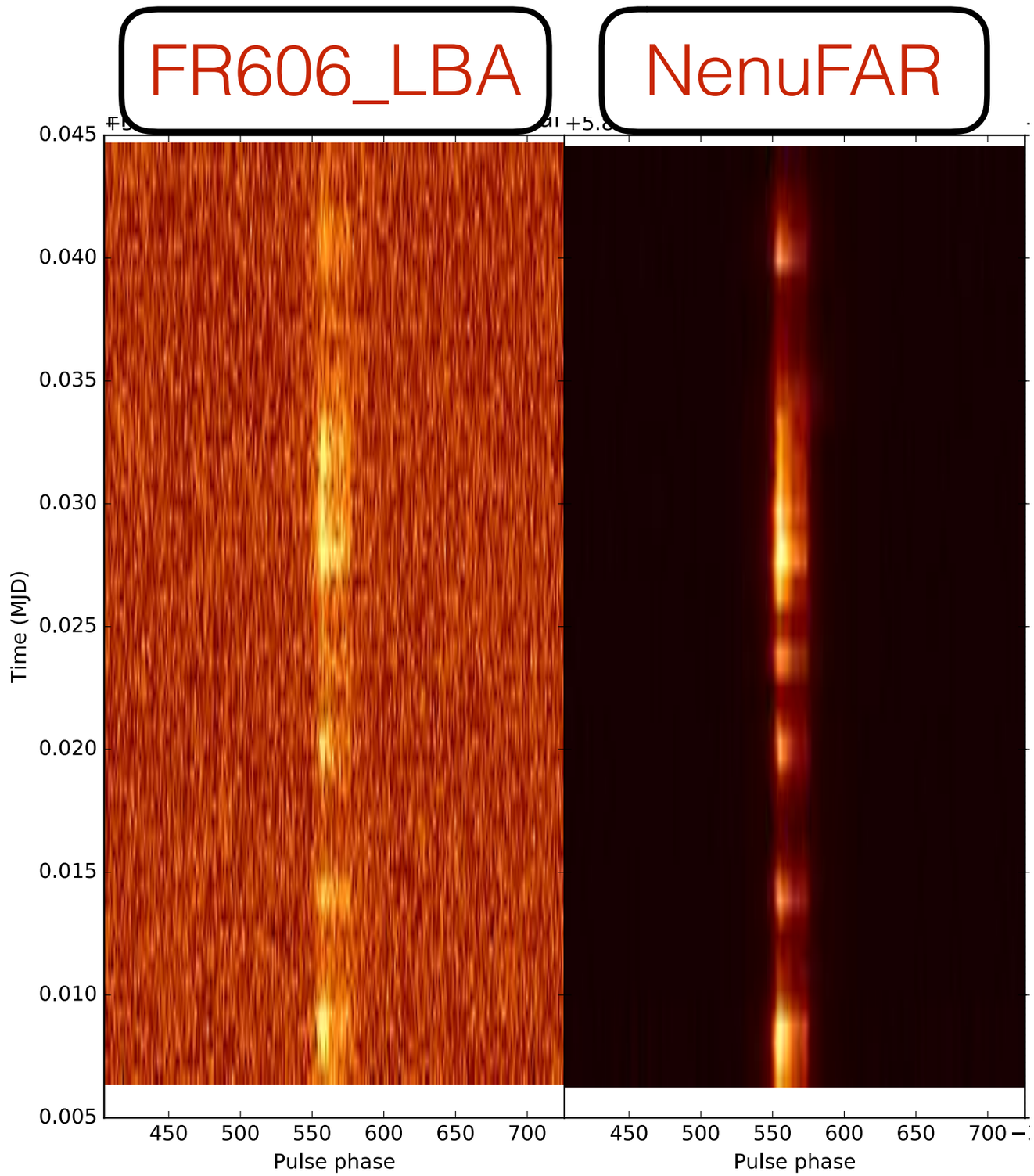
FR606 monitoring:

- Flux from the core census is lower due to flux variations

=> 16 LBA-HBA spectrum

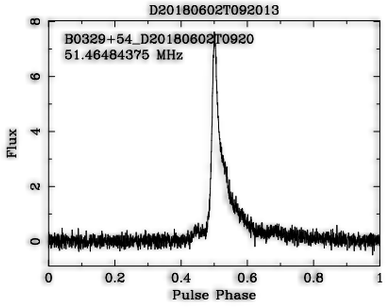
and DM monitoring

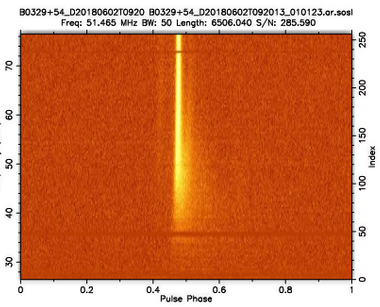
Commissioning: simultaneous observation FR606 vs NenuFAR

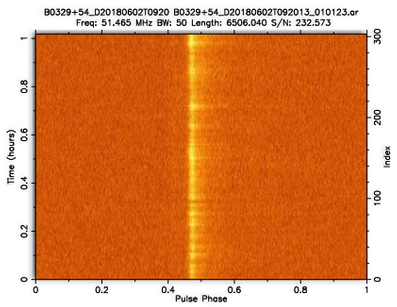


Commissioning: NenuFAR PSR observations

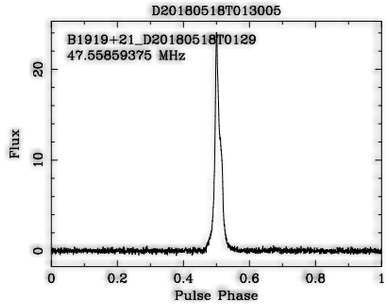
observatory	nenufar
obs.id	B0329+54_D20180602T092013_010123
PSRNAME	B0329+54
JNAME	J0332+5434 cp68
P0	0.714515741197457
DM	26.7641
length	6506.03969999999
nsubint	303
center freq.	51.46484375
BW	50
S/N	510.11
%RFI	12.01
quicklook created	June 3, 2018
by	quicklook.sh (version 1.11.00, 08.11.2017)

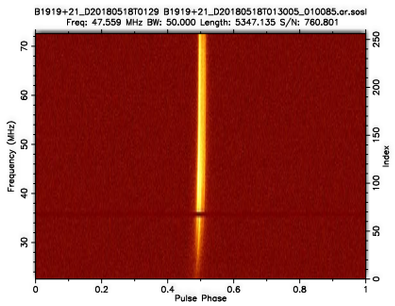


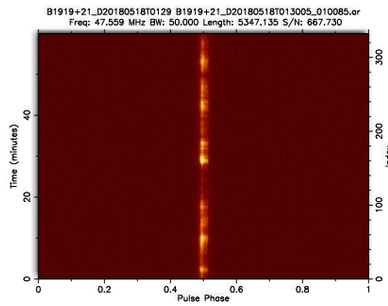




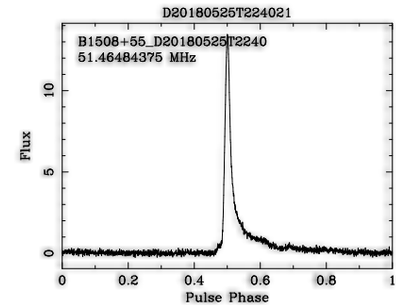
observatory	nenufar
obs.id	B1919+21_D20180518T013005_010085
PSRNAME	B1919+21
JNAME	J1921+2153 hbp+68
P0	1.3372186226874
DM	12.4439894211604
length	5347.13549999999
nsubint	332
center freq.	47.55859375
BW	50
S/N	998.36
%RFI	2.60
quicklook created	May 18, 2018
by	quicklook.sh (version 1.11.00, 08.11.2017)

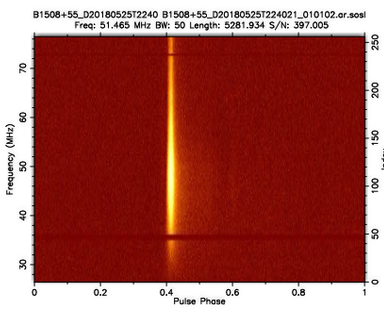


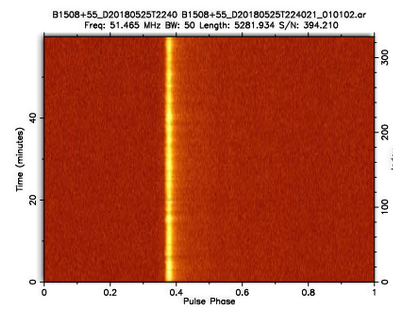




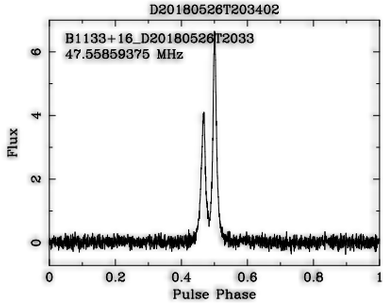
observatory	nenufar
obs.id	B1508+55_D20180525T224021_010102
PSRNAME	B1508+55
JNAME	J1509+5531 htg+68
P0	0.73970876928001
DM	19.6121
length	5281.93439999999
nsubint	328
center freq.	51.46484375
BW	50
S/N	1111.72
%RFI	4.27
quicklook created	May 26, 2018
by	quicklook.sh (version 1.11.00, 08.11.2017)

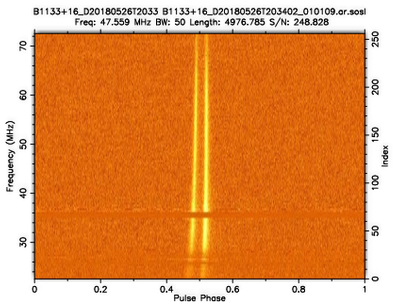


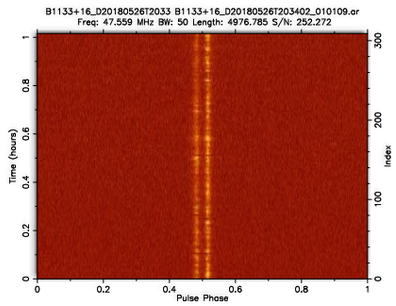




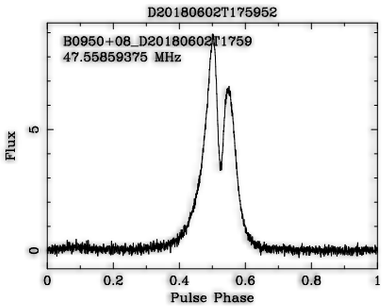
observatory	nenufar
obs.id	B1133+16_D20180526T203402_010109
PSRNAME	B1133+16
JNAME	J1136+1551 phbc68
P0	1.18802799119182
DM	4.848
length	4976.78489999999
nsubint	309
center freq.	47.55859375
BW	50
S/N	417.28
%RFI	11.31
quicklook created	May 27, 2018
by	quicklook.sh (version 1.11.00, 08.11.2017)

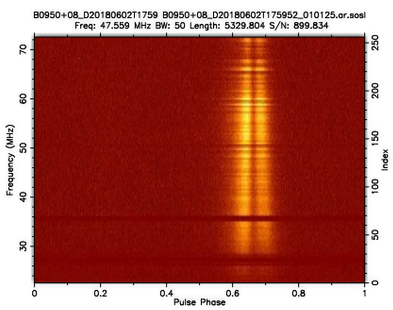


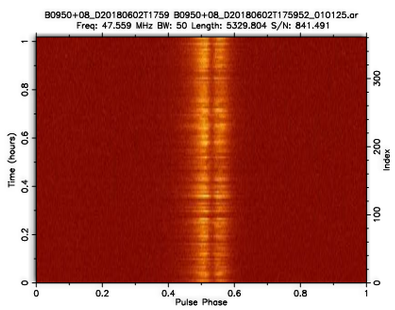




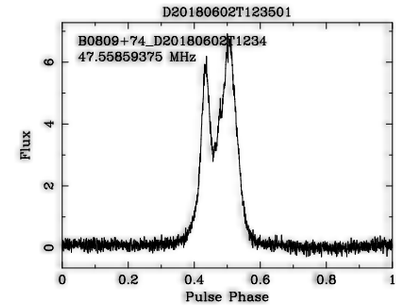
observatory	nenufar
obs.id	B0950+08_D20180602T175952_010125
PSRNAME	B0950+08
JNAME	J0953+0755 phbc68
P0	0.253089458632261
DM	2.9704
length	5329.80400000002
nsubint	361
center freq.	47.55859375
BW	50
S/N	1141.62
%RFI	14.56
quicklook created	June 3, 2018
by	quicklook.sh (version 1.11.00, 08.11.2017)

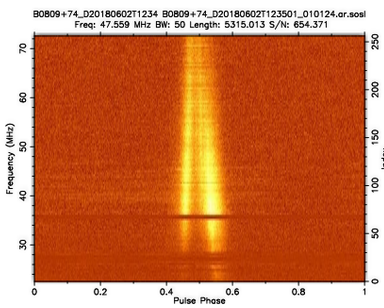


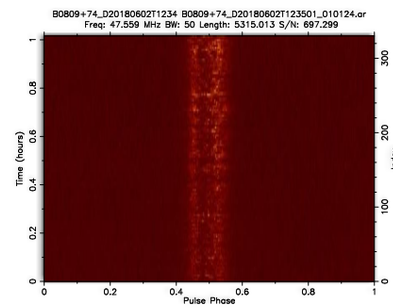




observatory	nenufar
obs.id	B0809+74_D20180602T123501_010124
PSRNAME	B0809+74
JNAME	J0814+7429 cp68
P0	1.2922830973301
DM	5.75066
length	5315.01299999999
nsubint	330
center freq.	47.55859375
BW	50
S/N	853.75
%RFI	22.30
quicklook created	June 3, 2018
by	quicklook.sh (version 1.11.00, 08.11.2017)

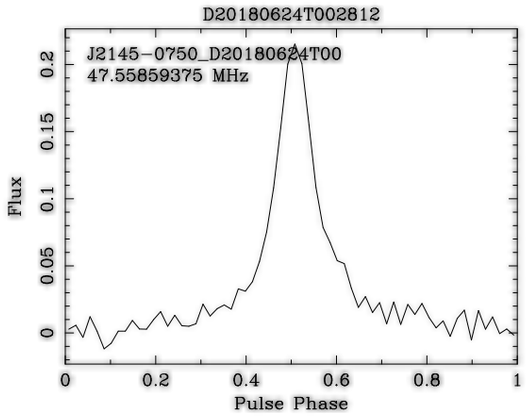


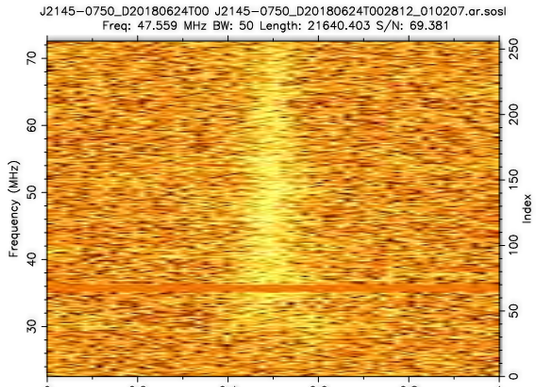


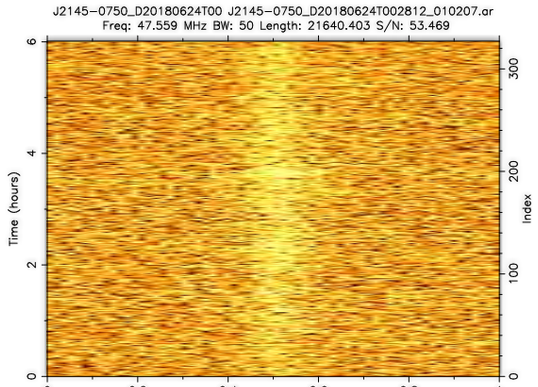


Commissioning: NenuFAR millisecond PSR

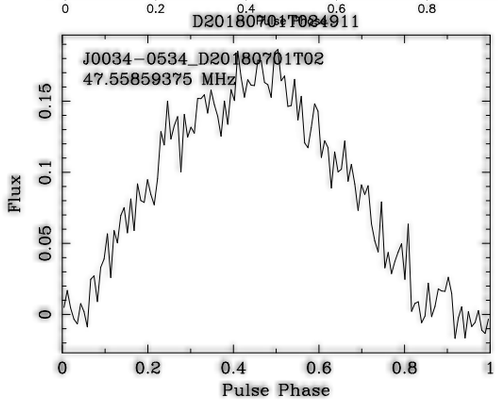
observatory	nenufar
obs.id	J2145-0750_D20180624T002812_010207
PSRNAME	J2145-0750
JNAME	J2145-0750 bhl+94
P0	0.0160505001715402
DM	9.0059
length	21640.4034
nsubint	327
center freq.	47.55859375
BW	50
S/N	65.10
%RFI	4.24
quicklook created	June 25, 2018
by	quicklook.sh (version 1.11.00, 08.11.2017)

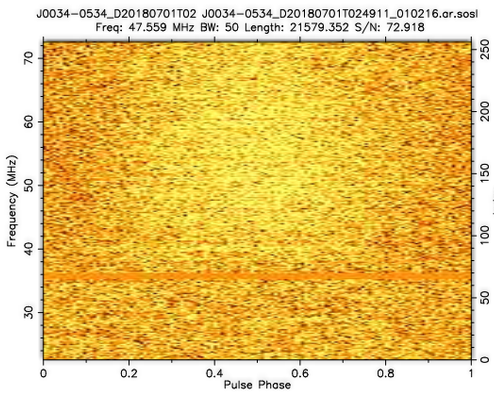


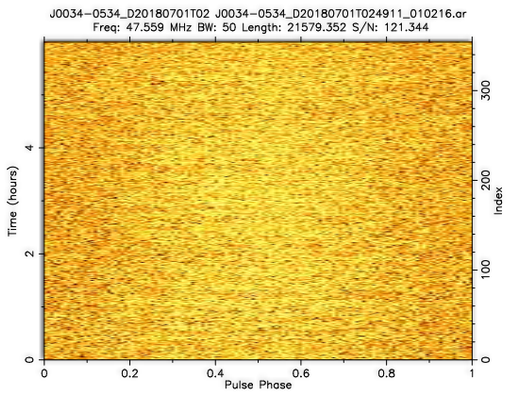




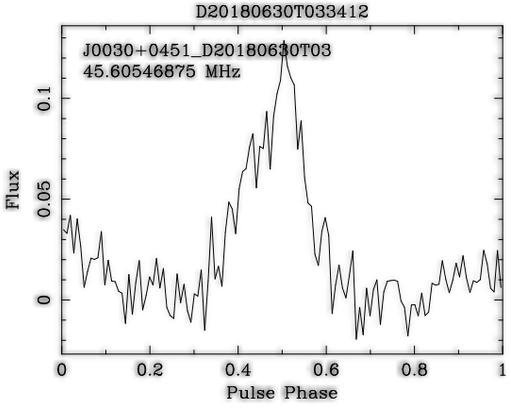
observatory	nenufar
obs.id	J0034-0534_D20180701T024911_010216
PSRNAME	J0034-0534
JNAME	J0034-0534 bhl+94
P0	0.00187698965153315
DM	13.7665
length	21579.3517499999
nsubint	354
center freq.	47.55859375
BW	50
S/N	42.27
%RFI	3.78
quicklook created	July 1, 2018
by	quicklook.sh (version 1.11.00, 08.11.2017)

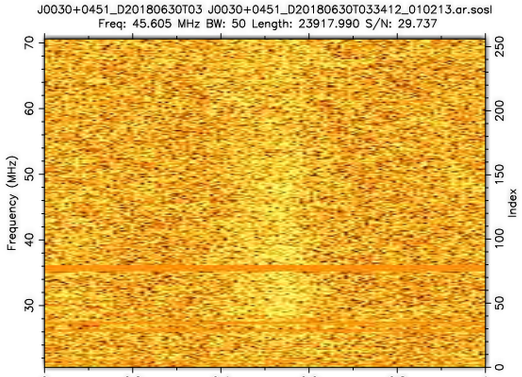


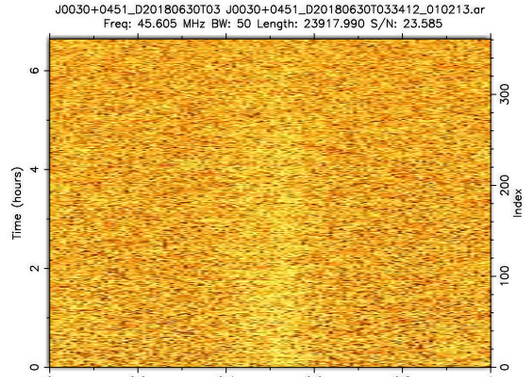




observatory	nenufar
obs.id	J0030+0451_D20180630T033412_010213
PSRNAME	J0030+0451
JNAME	J0030+0451 lzb+00
P0	0.0048649755744798
DM	4.3333
length	23917.9898000001
nsubint	361
center freq.	45.60546875
BW	50
S/N	39.16
%RFI	5.69
quicklook created	June 30, 2018
by	quicklook.sh (version 1.11.00, 08.11.2017)







- 6 hours observations on millisecond pulsars

NenuFAR: prospect

- NenuFAR will unveil 10x more sources than current population known @ 30 MHz:
- Study the ISM
  - NenuFAR could be coupled with data from LOFAR HBA and the Nancay Radio Telescope (NRT)
    - High precision DM due to high sensibility on the low band
- NenuFAR will help to understand the pulsar magnetospheric structure
  - Single pulses multi-telescope observations 15 Mhz - 1.8 GHz
  - Characterize the spectral energy distribution (turnover)

END