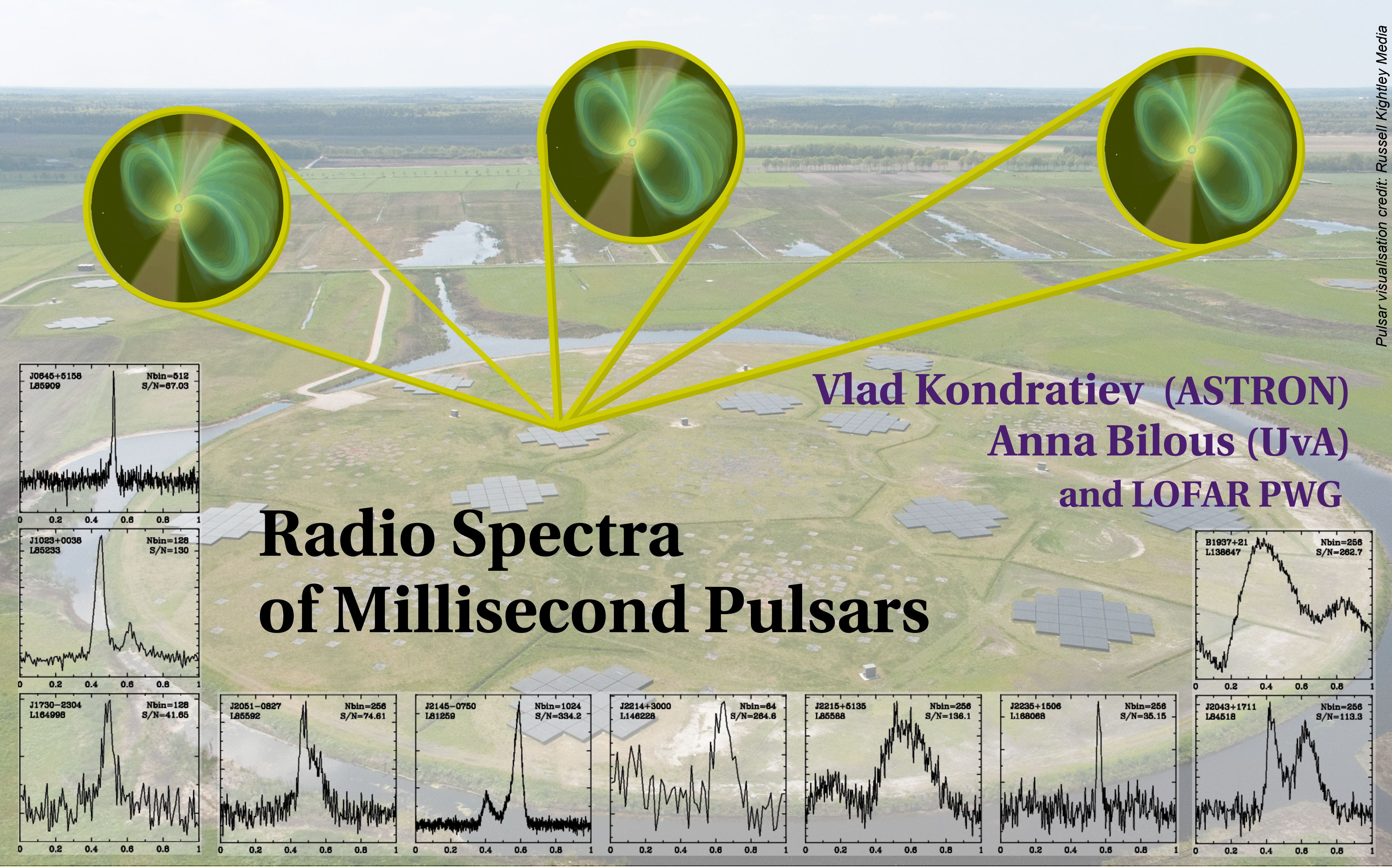


Radio Spectra of Millisecond Pulsars

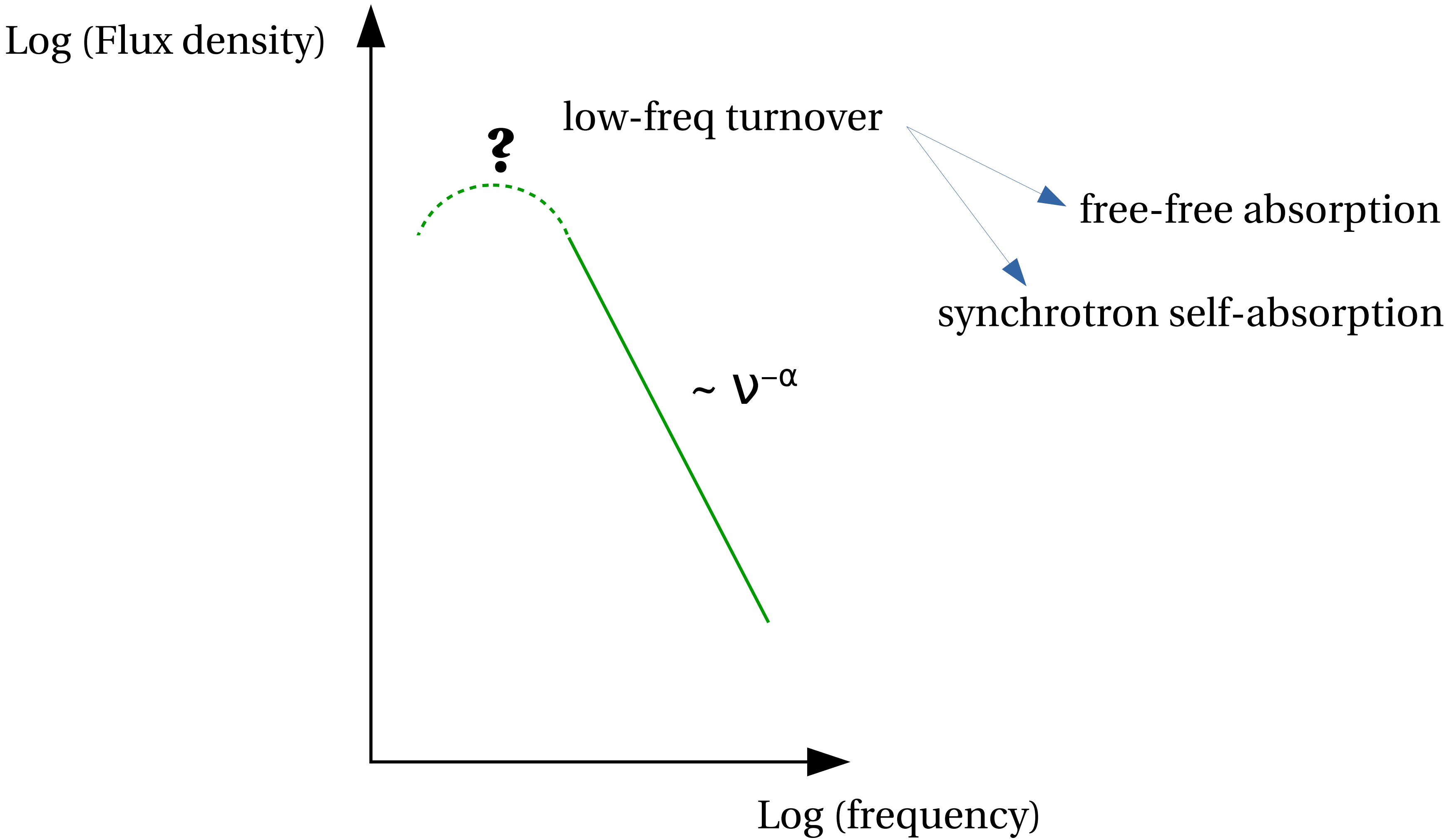
Vlad Kondratiev (ASTRON)
Anna Bilous (UvA)
and LOFAR PWG

LOFAR

LOFAR Science 2016, Zandvoort aan Zee — Apr 5, 2016

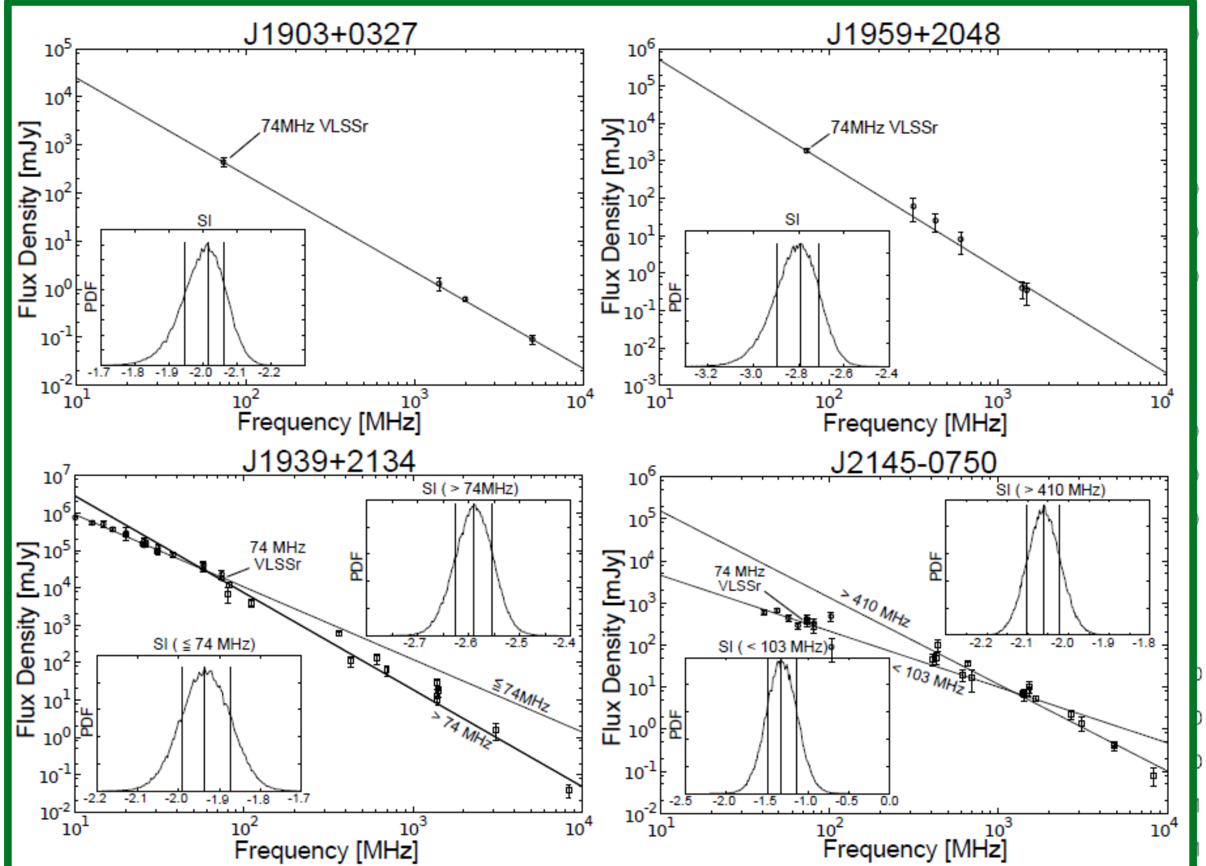
ASTRON

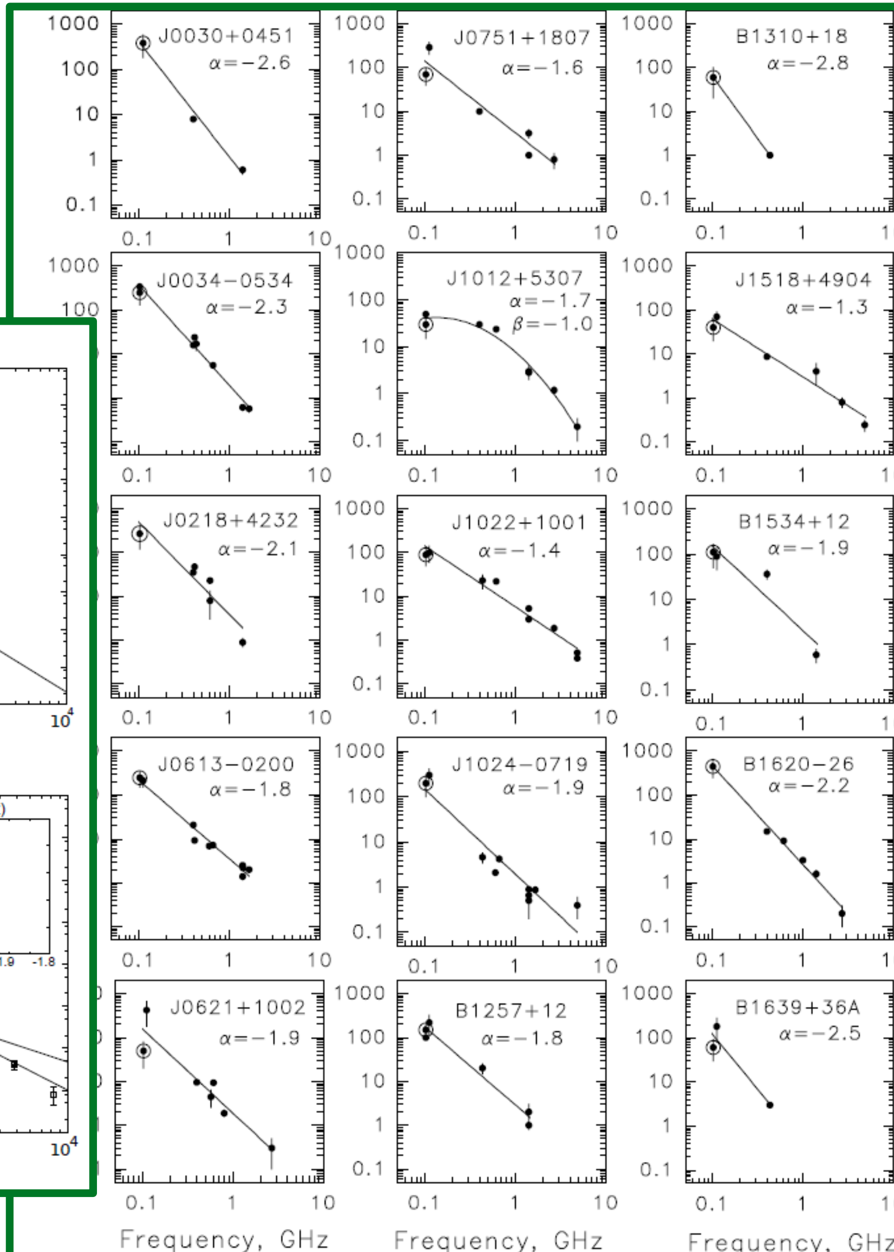
Spectra


Log (Flux density)
?
low-freq turnover
free-free absorption
synchrotron self-absorption
~ ν^−α
Log (frequency)

Previous studies

Kuniyoshi et al. (2015)

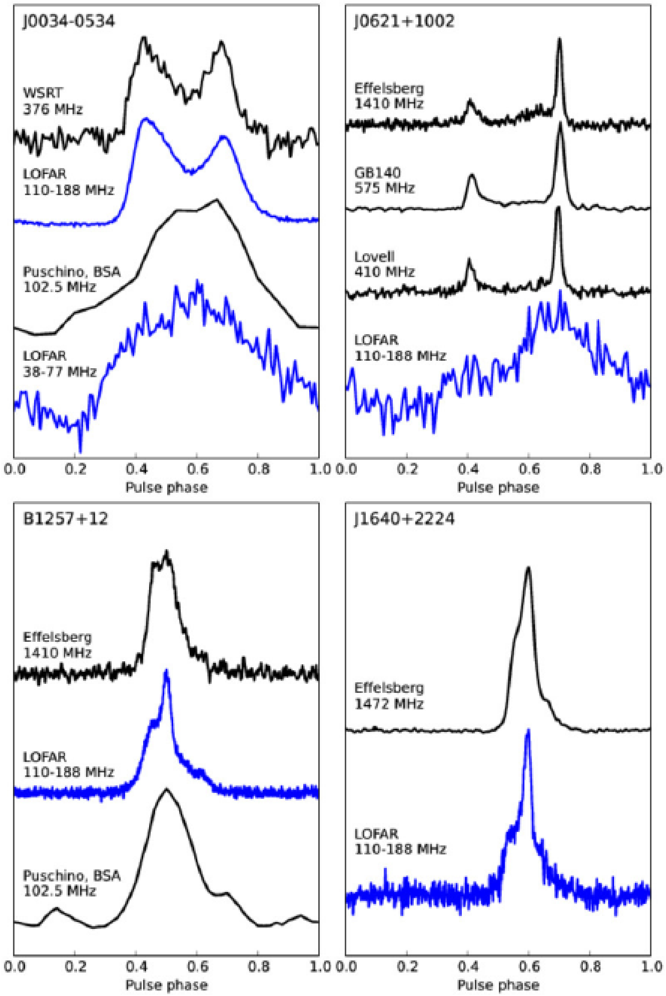




Kuzmin & Losovskii (2001)

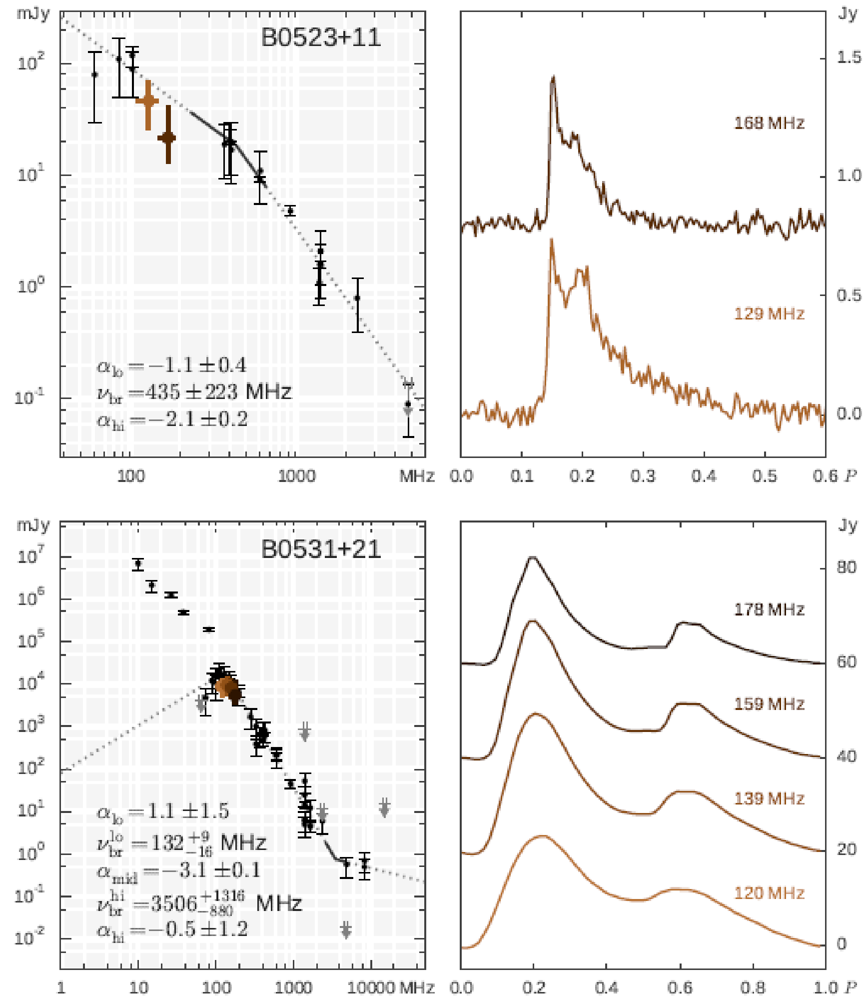
Recent LOFAR studies

LOFAR MSP Census



Kondratiev et al. 2016, A&A, 585, 128

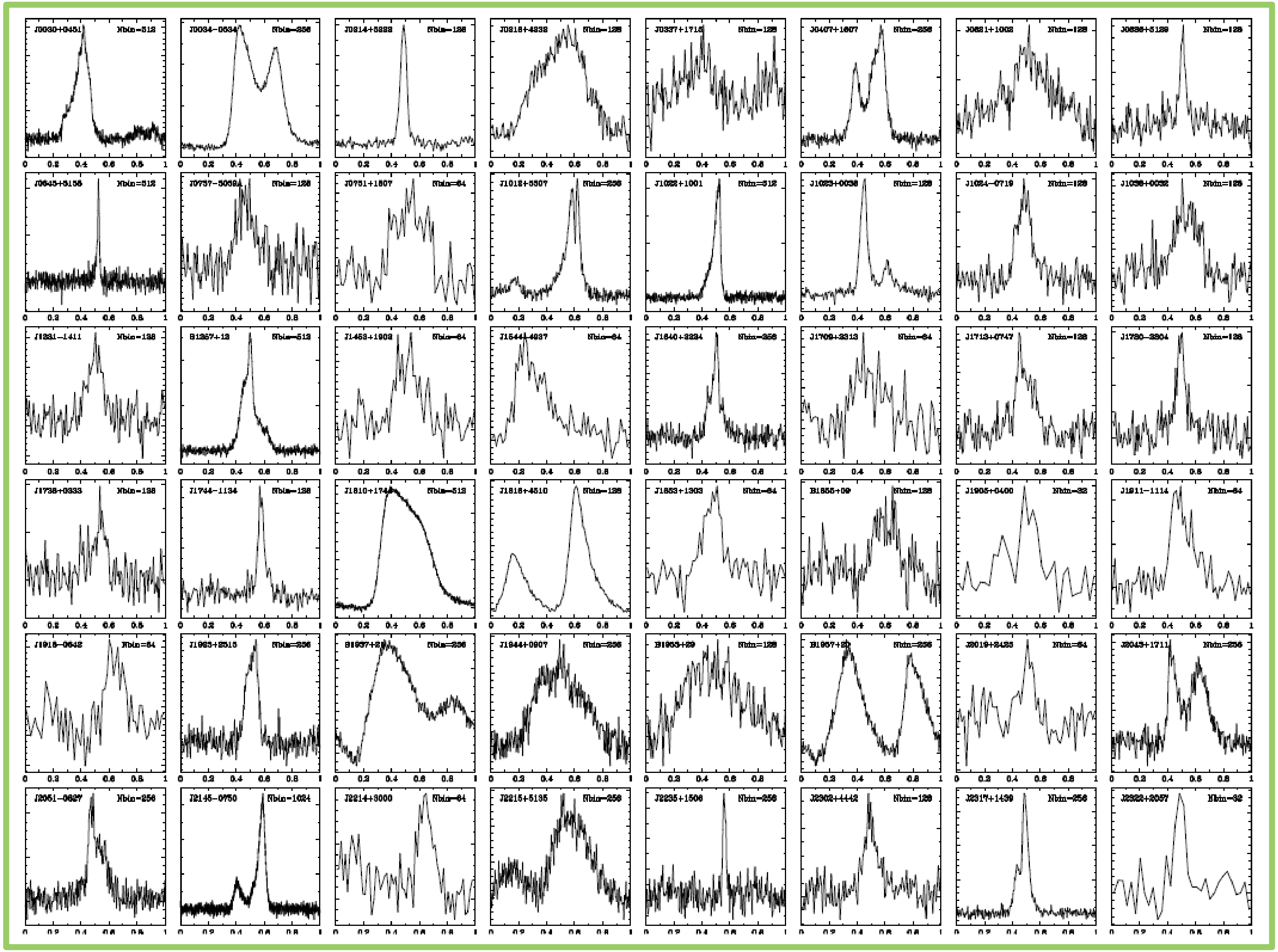
HBA Census of slow pulsars



Bilous et al. 2016, A&A, accepted; arXiv:1511.01767

Detected MSPs

VK+ 2016, A&A



75 MSPs observed

9
4~~8~~ detected (65%)

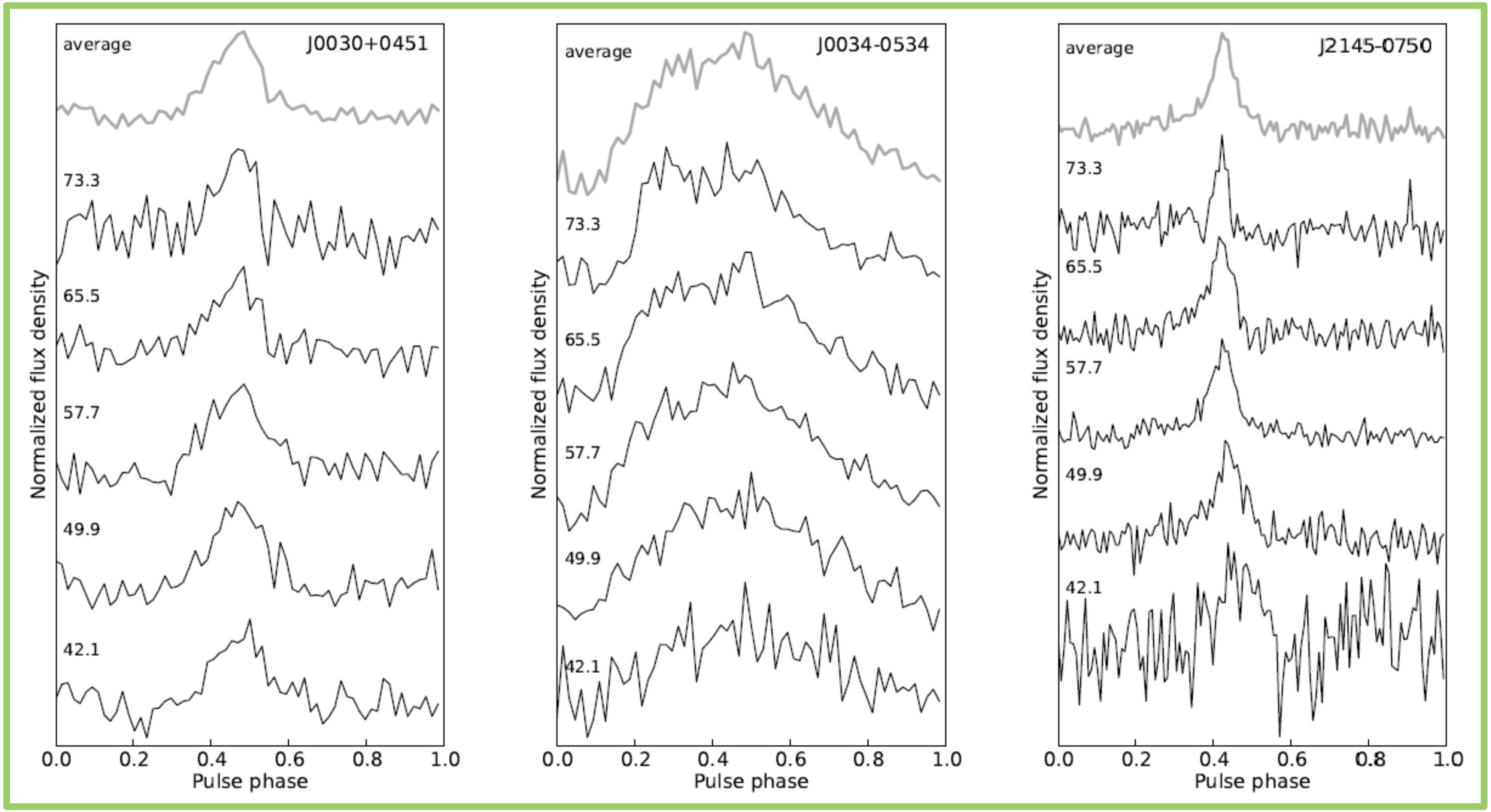
+
J1400–1438

Best 20-min profiles (for most)

LBA detections

38–77 MHz

J0030+0451 **J0034–0534** **J2145–0750**



LBA non-detections: J0621+1002, J1012+5307, J1022+1001, J1024-0719, B1257+12, J1810+1744, J2317+1439, J1744–1134, and J1231–1411

More data

- From 1 to **MANY** flux measurements → proper mean flux density, refractive scintillations (RISS) can be accounted for; spectra (together with other freqs)
- RISS study (?), still there will be systematic error/offset due to other factors...

Data (total number of HBA obs = 1311, LBA obs = 17):

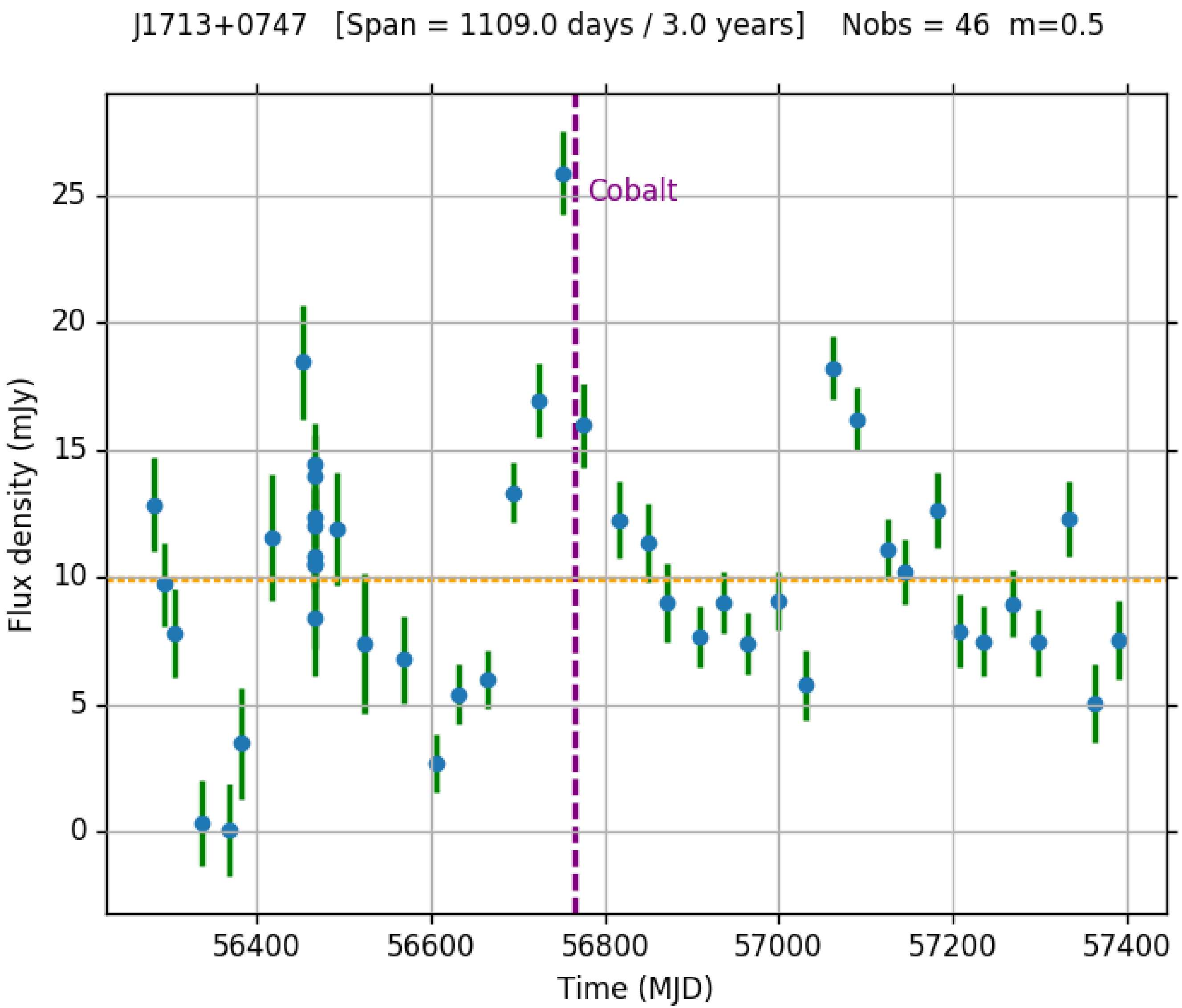
- Cycles 0-5, mainly timing data, but also LC2_026 (MSP cyclic spectroscopy), LC0_008 («known psrs» proposal), LC0_022, LC1_035, LC2_007 (timing of GBNCC pulsars), DDT_004 (J1713 24-h global campaign)
- For some msps 2.5 — 3 years of data (35+ observations), few with a span of 1-2 years, few msps with a single observation
- Setup: HBA, Full core, CV, 400 subs, 100-188 MHz, 5.12 mcs — for most observations. Few Stokes I, 16ch/sub data (GBNCC timing)

Processing:

- LTA download → Apply same ephemerides, psr names, coordinates, etc. to archive file → RFI zapping (most with clean.py, some with paz -r + manual, LBA data all manually zapped) → dedisperse + pscrunch → pdmp (when necessary for weaker pulsars, wrong DM, etc.) → preparing data for flux calibration (e.g. choosing off-pulse window or with polynom…) → lofar_fluxcal.py

Flux vs. Time

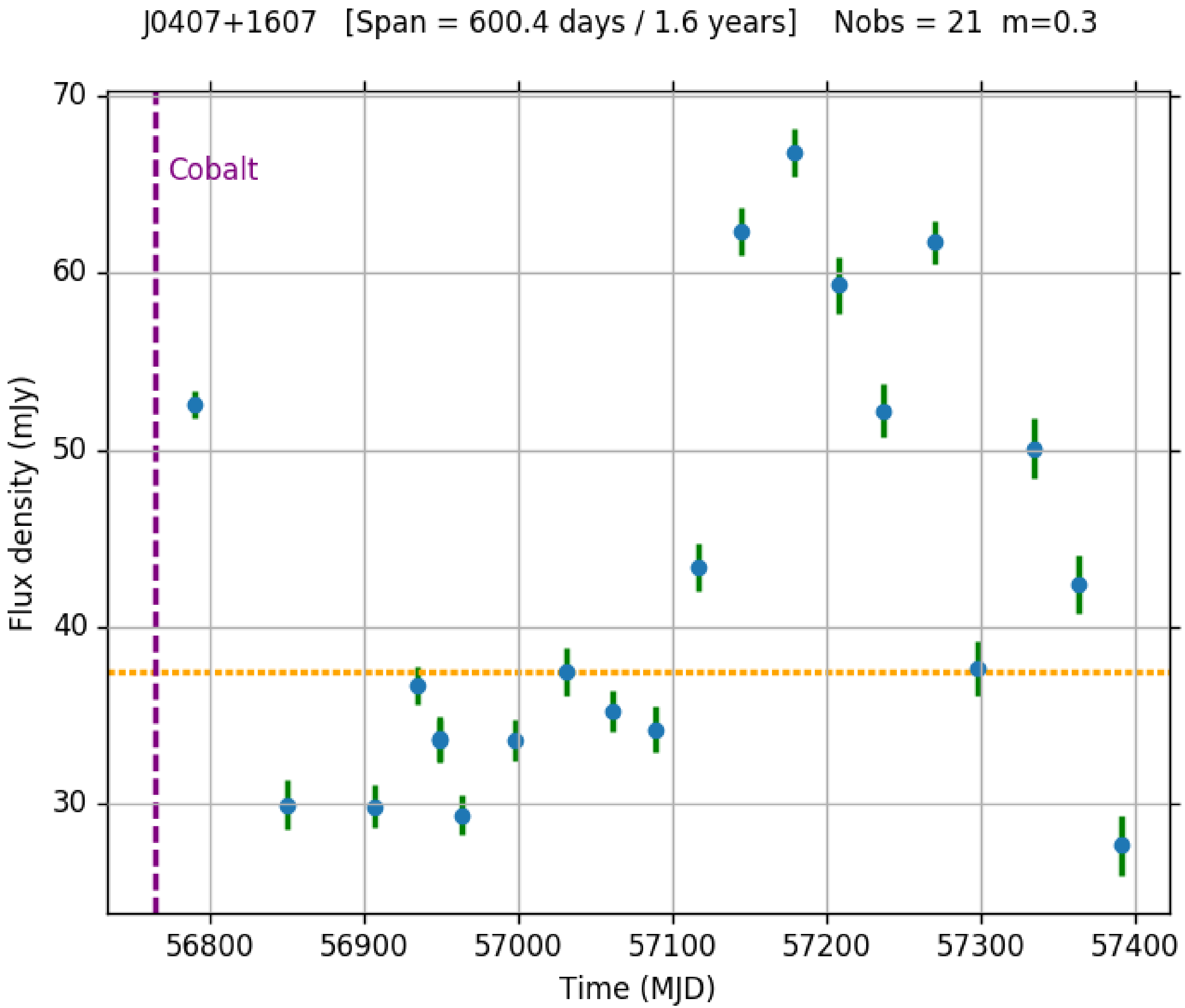
Preliminary



Some periodic flux variation?

Flux vs. Time (2)

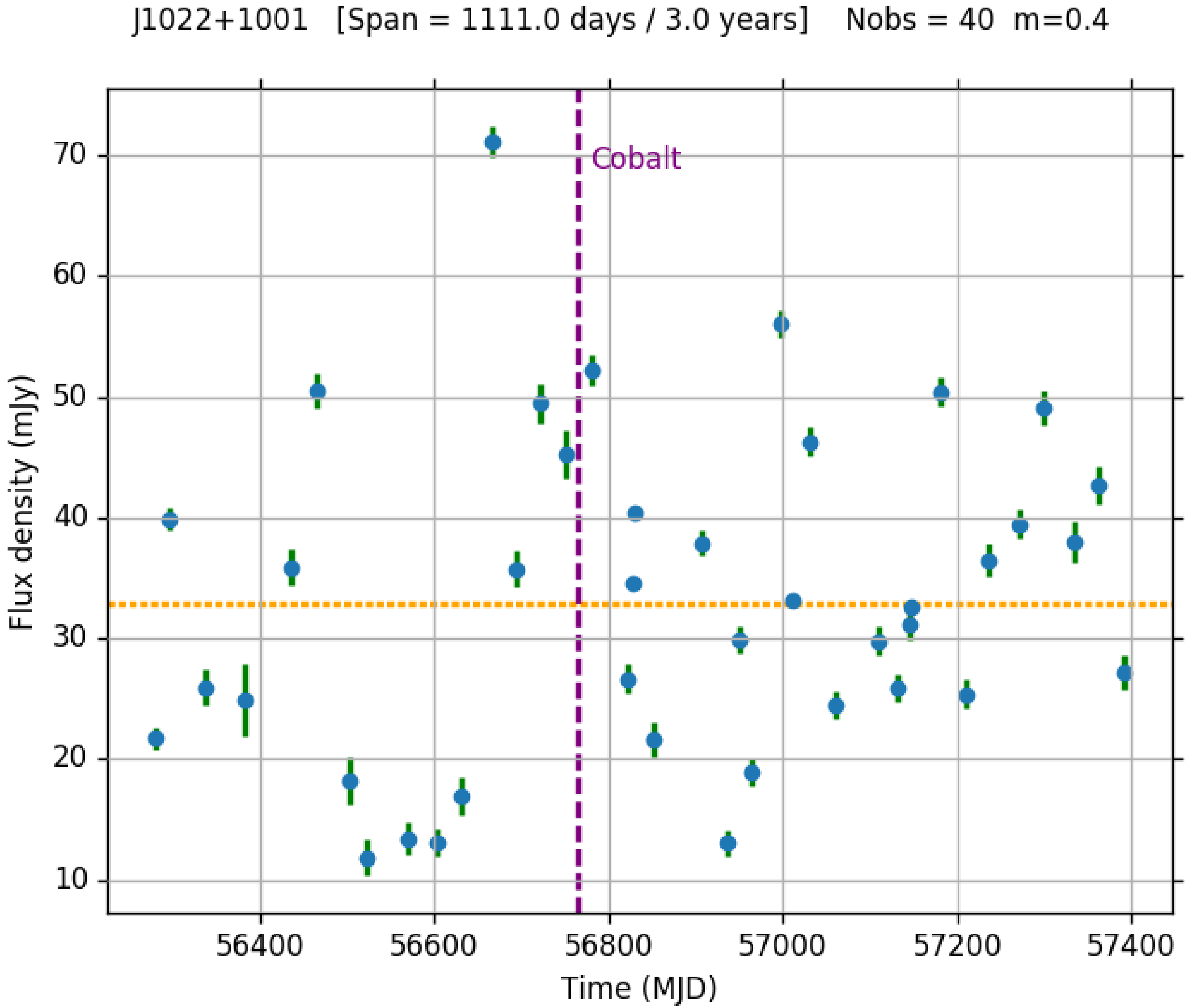
Preliminary



Some regular flux variation?

Flux vs. Time (3)

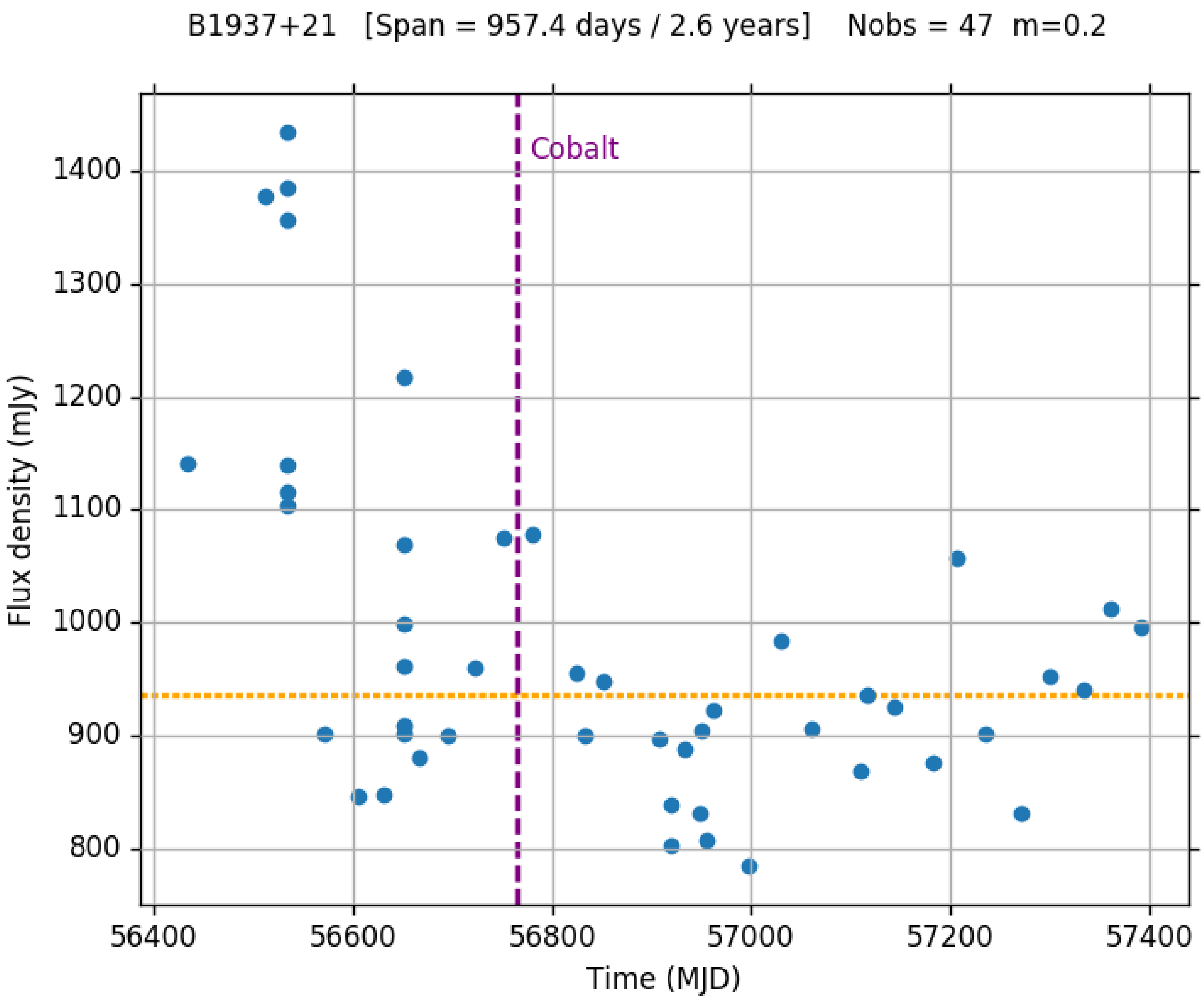
Preliminary



No similar regular structure, somewhat chaotic

Flux vs. Time (4)

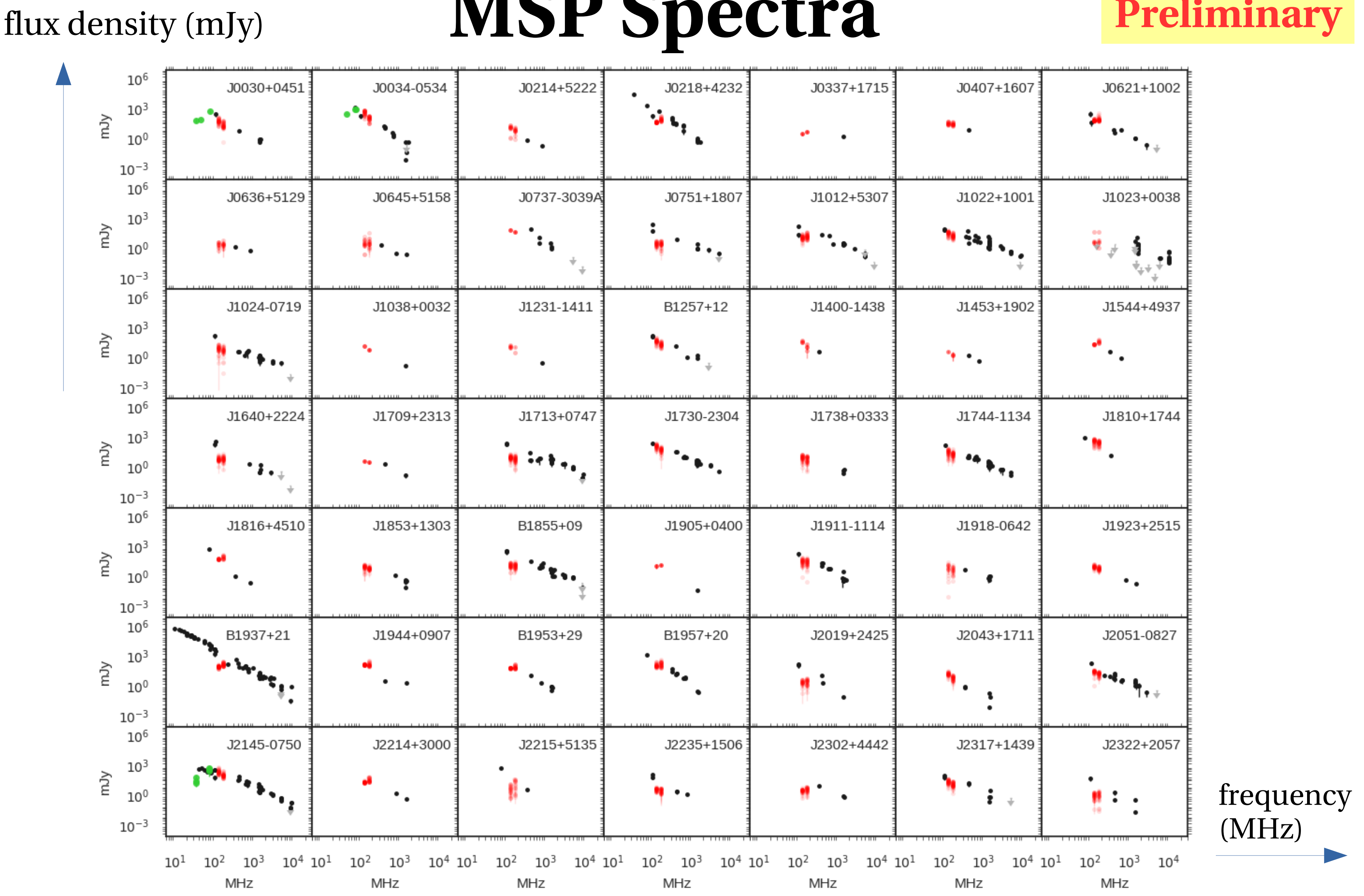
Preliminary



Slow flux decline (seen for several pulsars)

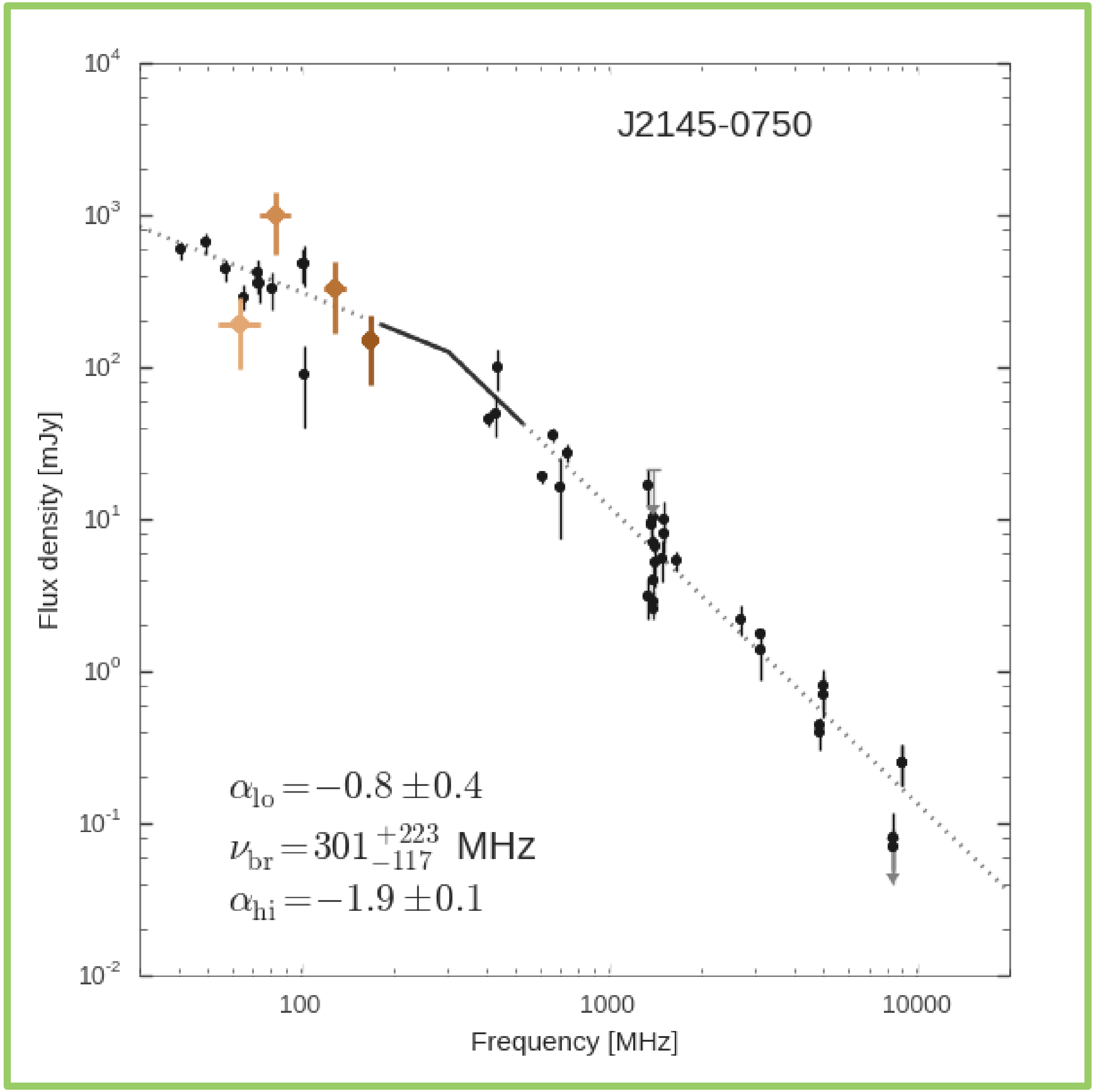
MSP Spectra

Preliminary



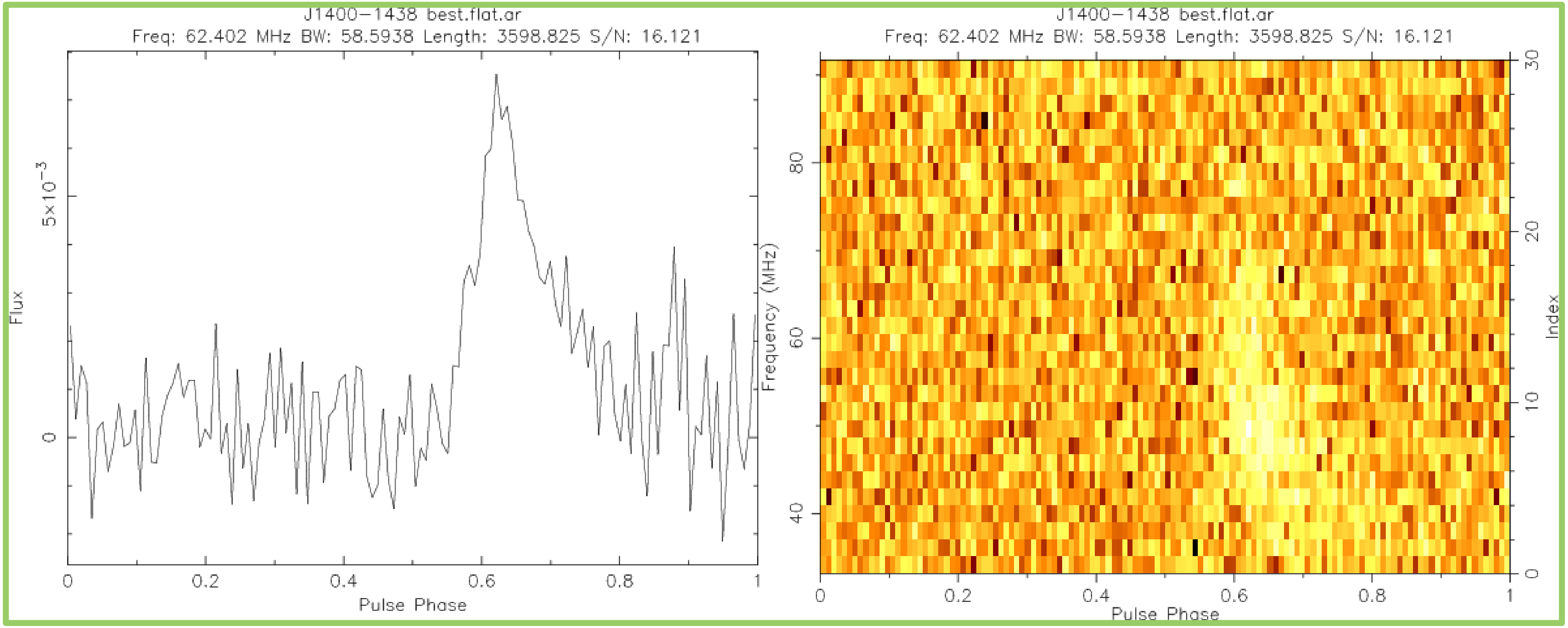
MSP Spectra (2)

Preliminary



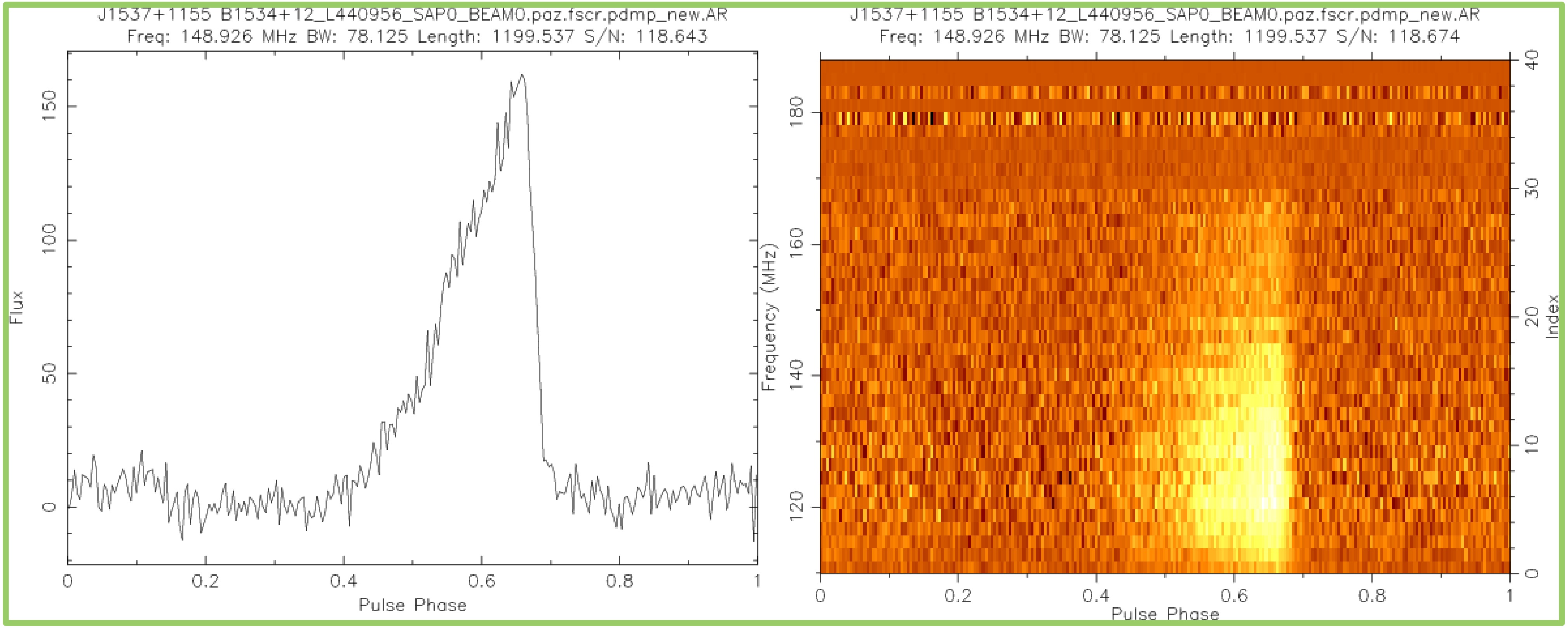
LBA detections (2)

J1400–1438

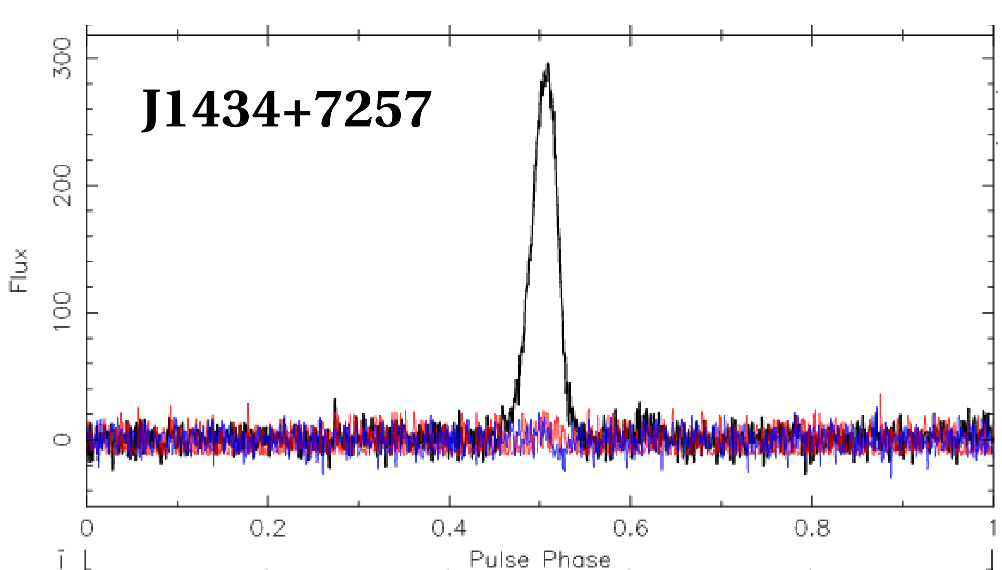


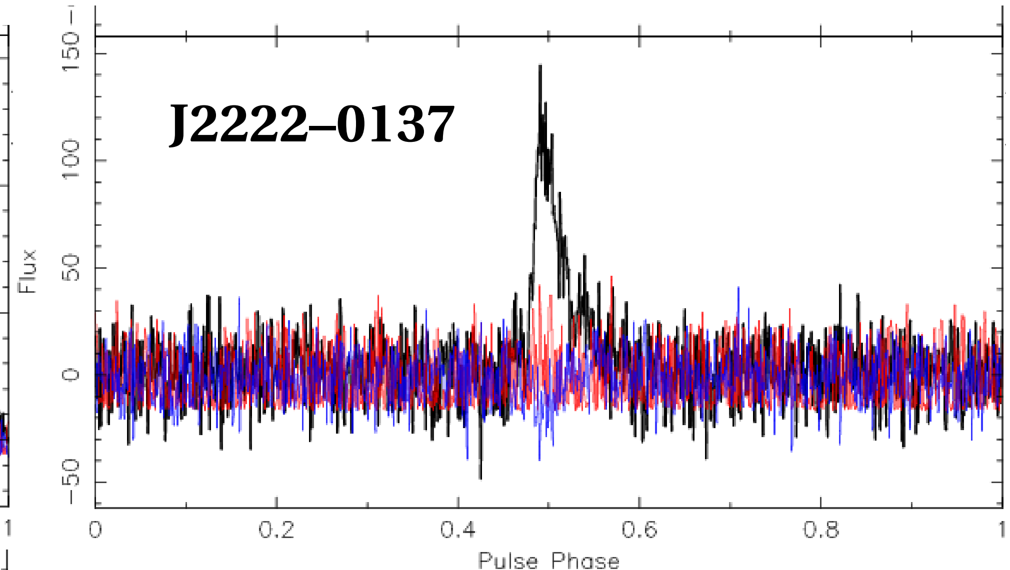
New HBA detections

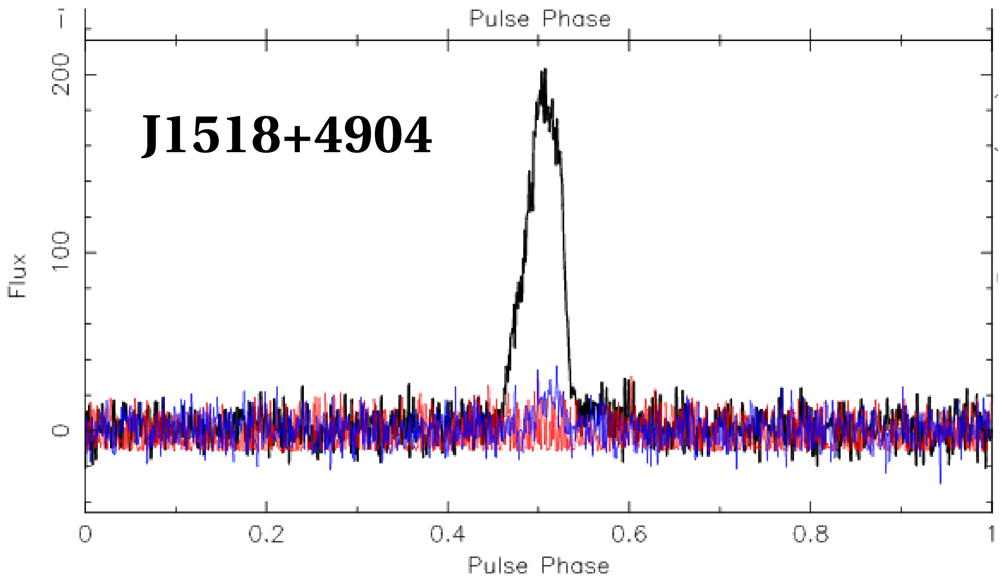
B1534+12



New HBA detections (2)







Currently:
LOFAR MSP census = 53 MSPs
+ 4 MSPs in LBA

Summary:

- Flux density variation with time shows a variety of different patterns, such as periodic, regular, chaotic, and so on. Investigating now if there is a correlation with AZ/EL, known system problems, etc. Could be due to truly refractive scintillations but also other factors, e.g. beam wander by ionosphere.

- MSP spectra seem to be no different from those of slow pulsars: some show turn-over, others do not. Fluxes below 100 MHz are needed in most of the cases to probe spectral shape → hard (if not possible at all) due to scattering with beamformed observations → imaging.

- Continuing exploratory observations of other MSPs with LOFAR. Current status of LOFAR MSP census is at 53 MSPs detected in HBA frequency range, and 4 MSPs detected in LBA frequency range.

Thank you!

Flux calibration

In general (see e.g. Lorimer & Kramer 2005):

C = SEFD

$$\Delta S_{\rm sys} = \frac{T_{\rm sys}}{G\sqrt{n_{\rm p} t_{\rm obs} \Delta f}} = C\sigma_{\rm p},$$

$$\mathrm{SEFD} = \frac{2\beta k[T_{\rm inst}(f) + T_{\rm sky}(f, \mathrm{GL}, \mathrm{GB})]}{N_{\rm s}^{\gamma} A_{\rm eff}(f, \mathrm{EL})[1-\xi]\sqrt{n_{\rm p}[1-\zeta(f)](\frac{\mathrm{T_{obs}}}{\mathrm{nbins}})\Delta f}}$$

β — digitization factor = 1
GL, GB — Galactic longitude and latitude
γ — coherence factor ≈ 0.85
N_s — number of stations used
n_p — number of polarizations (2)
A_{eff} — effective area of a 48-tile station

ξ — average fraction of bad/flagged dipoles/tiles
ζ — RFI fraction
nbins — number of bins in the profile
T_{obs} — observation length (s)
Δf — frequency channel width (Hz)

Beam models

1) **"arts"**, improved Hamaker model, provides full EM simulations of a 24-tile HBA sub-station, including edge effects and grating lobes (Hamaker's model is based on an infinite array of elements).

In practice →

Table of 91 ELs * 361 AZs * 29 frequencies

- AZ, 0 — 360 deg, 1-deg step
- EL, 0 — 90 deg, 1-deg step
- Frequency, 110 — 250 MHz, 5-MHz step

Note! When calibrating, for a given EL Aeff is averaged over all azimuths, as the stations are randomly rotated.

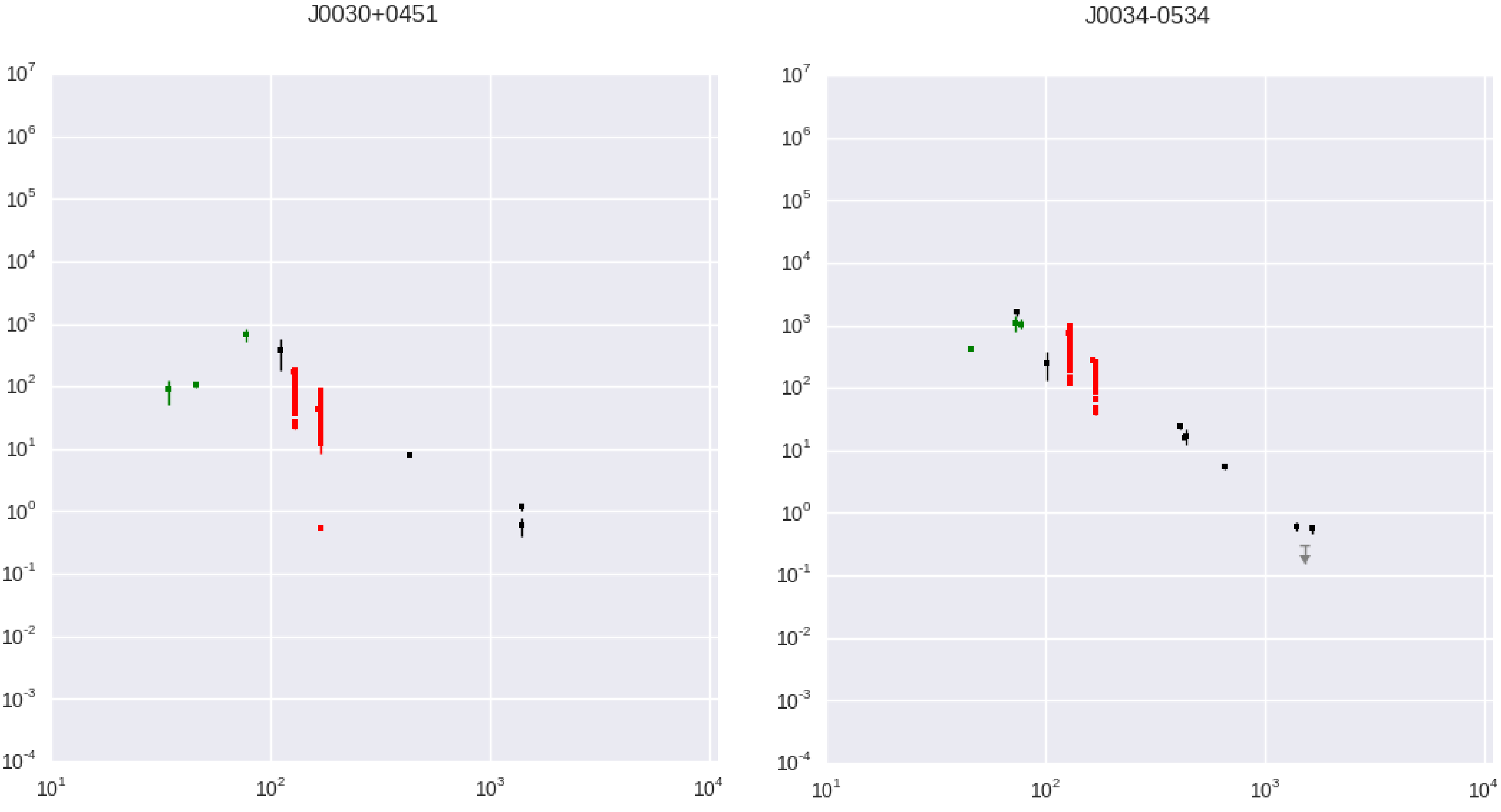
2) **"arisN"**, maximum theoretical value of A_{eff} (A_{max}) is scaled as ~sin(EL)^1.39 as in Noutsos et al. (2015). For HBA, $A_{max} = 48 * 16 * \min\{\lambda^2/3, 1.5625\}$.

3) **"hamaker_carozzi"**, maximim theoretical value of A_{eff} (A_{max}) is corrected by a corresponding factor calculated from the Carozzi's implementation of the Hamaker model. In practice, we use functions from the "mscorpol" package (on Github) written by Tobia Carozzi that calculate Jones matrices for a given HBA station, date/time and frequency (there is also a standalone script antennaJones.py to do that). Unlike "arts" model, this model is based on a real station (it uses coordinates, cable delays and time deltas). We used CS001, the difference for other stations is much smaller than the nominal flux error.

Aeff is scaled by B(PSR)/B(CasA), where $B= 0.5 * | J_{xx} \times J_{xx}^* + J_{xy} \times J_{xy}^* + J_{yx} \times J_{yx}^* + J_{yy} \times J_{yy}^* |$, The value of B(PSR) is normalized by reference value of the CasA observation B(CasA) used in Wijnholds & van Cappelen for A/T measurements. Although, for all freqs the value for CasA is almost 1.0 (changing in 2-3 digits after decimal point).

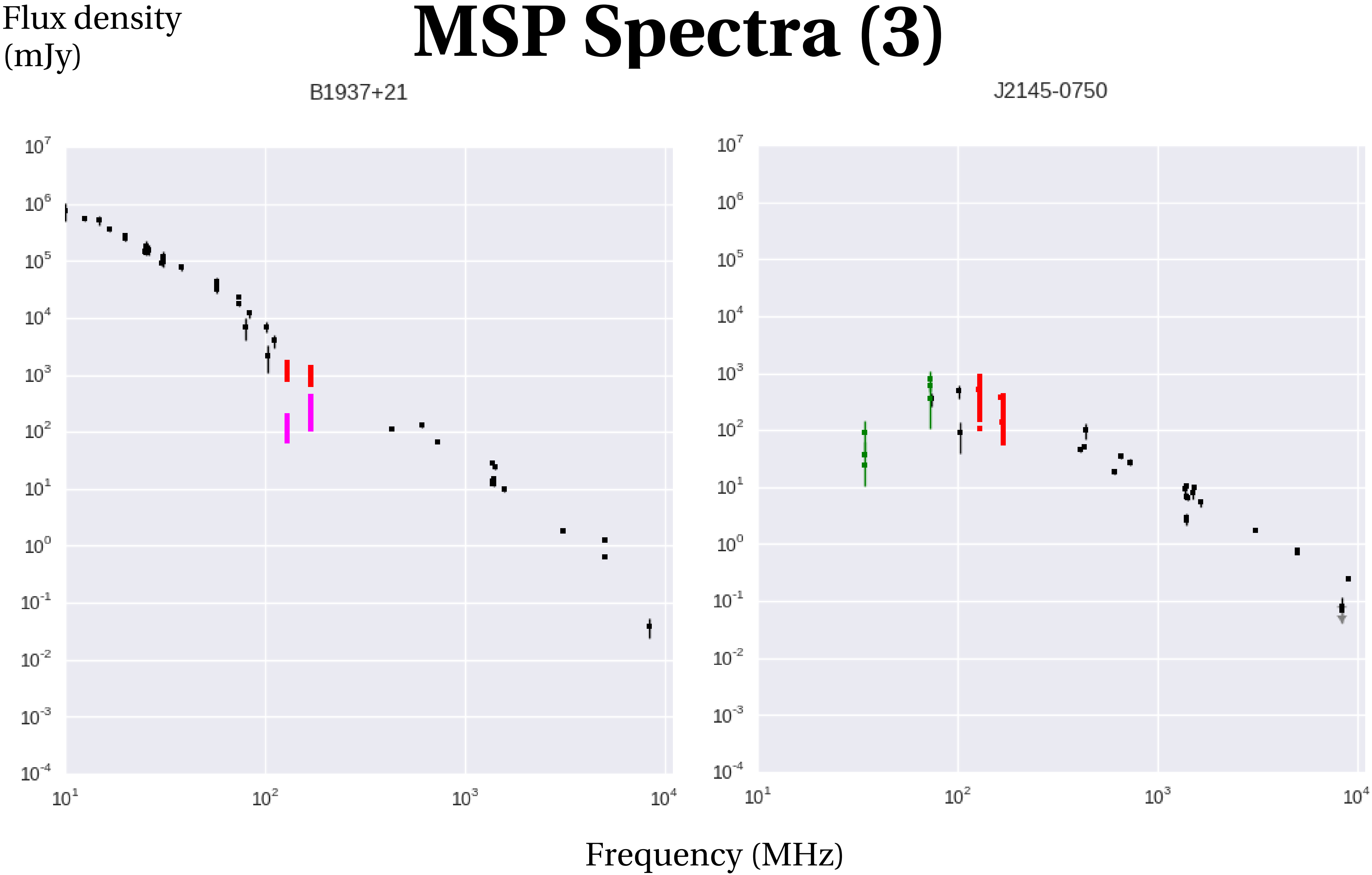
MSP Spectra (2)

Flux density (mJy)



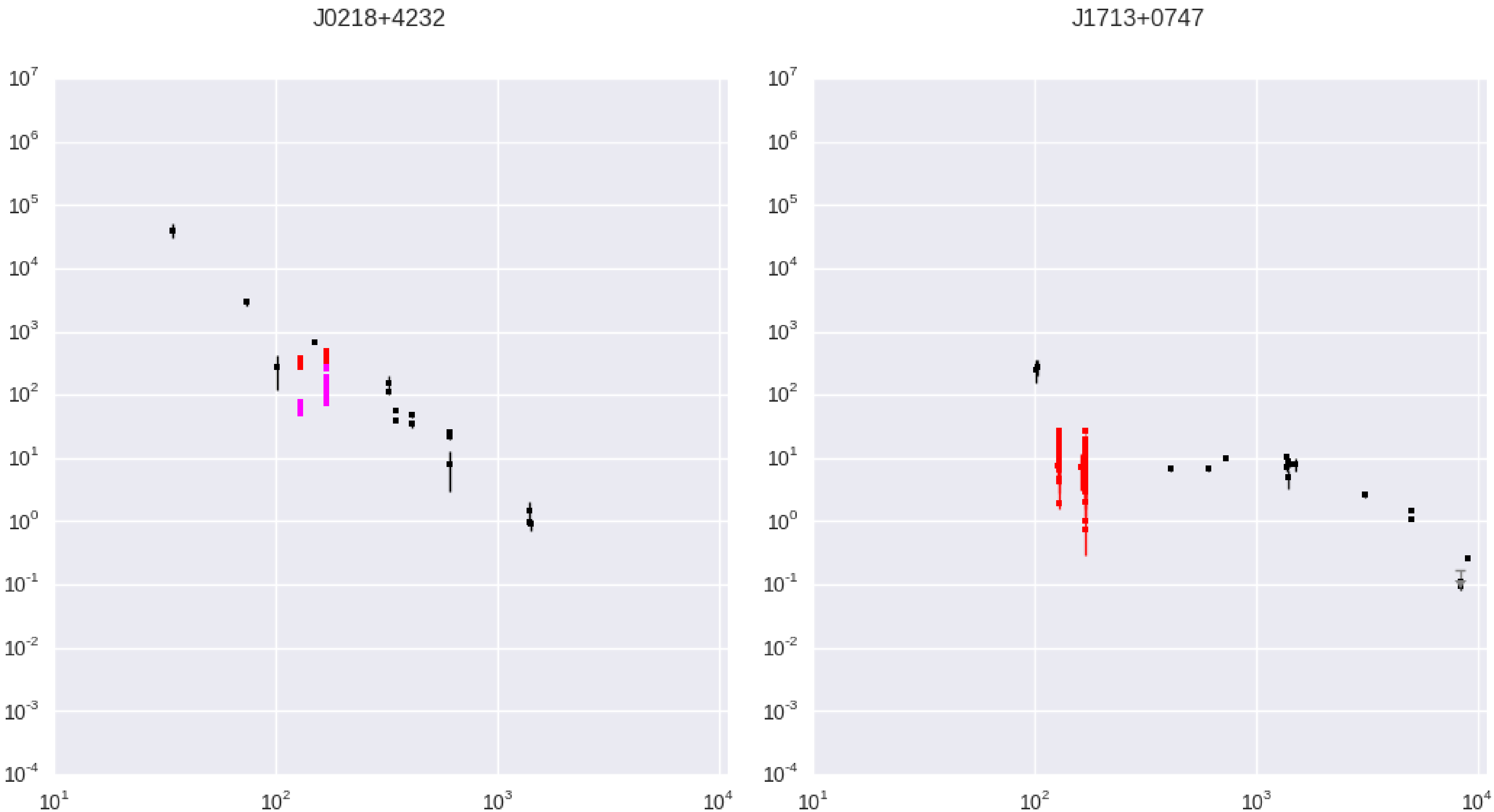
Frequency (MHz)

MSP Spectra (3)



MSP Spectra (4)

Flux density (mJy)



Frequency (MHz)