Finding millisecond pulsars with LOFAR

Cees Bassa

Ziggy Pleunis, Jason Hessels, Vlad Kondratiev,
Sotiris Sanidas, Elizabeth Ferrara

ASTRON

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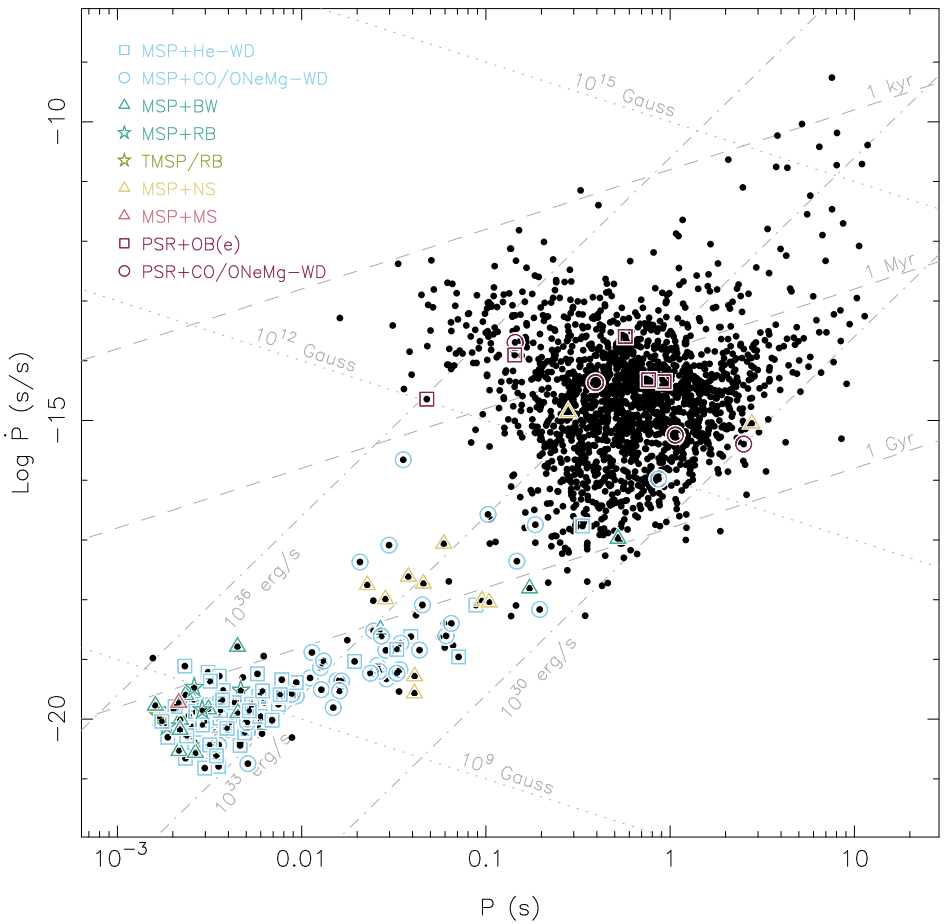
LOFAR

Why search for millisecond pulsars?



MSPs are flywheels in space

Extremely stable rotation rivals terrestial atomic clocks; provides km scale measurements of distance changes on distances of kpc

MSPs can be used to understand:

- the neutron star equation-of-state
- tests of General Relativity
- binary evolution
- the physics of accretion
- the emission mechanism

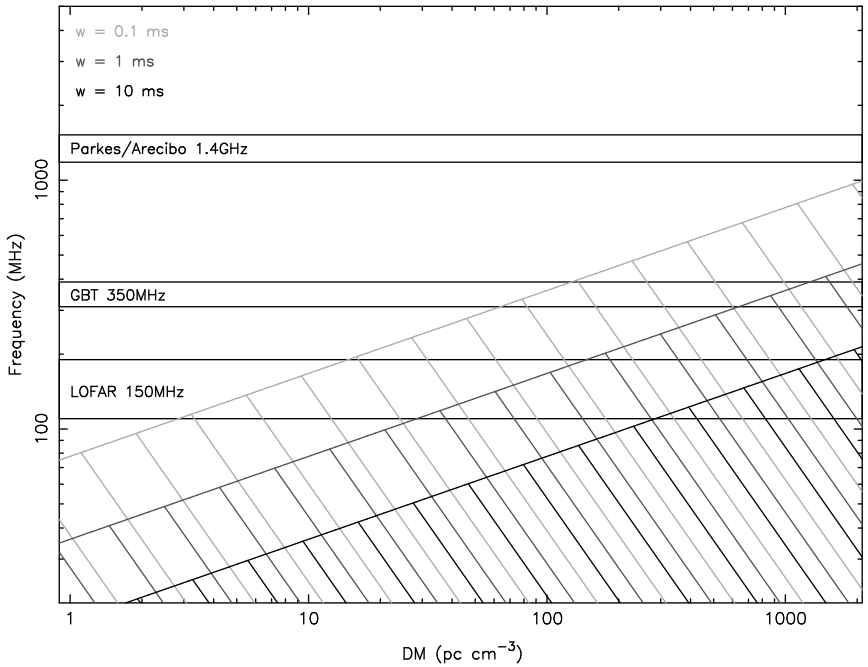
Searching for MSPs with LOFAR

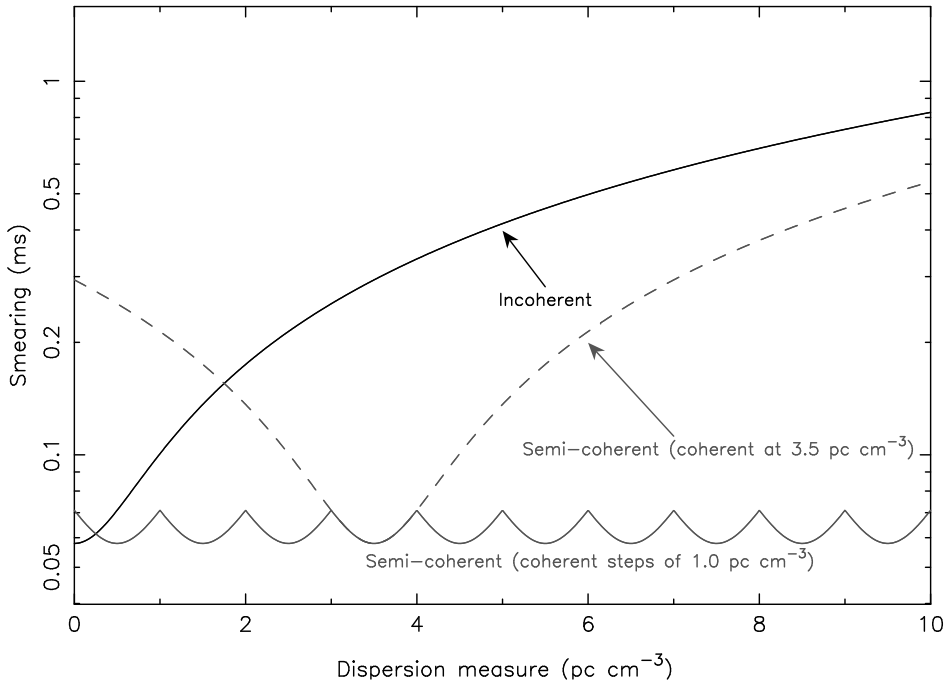
Advantages:

- Steep radio spectra → bright at low frequencies
- Unexplored parameter space

Disadvantages:

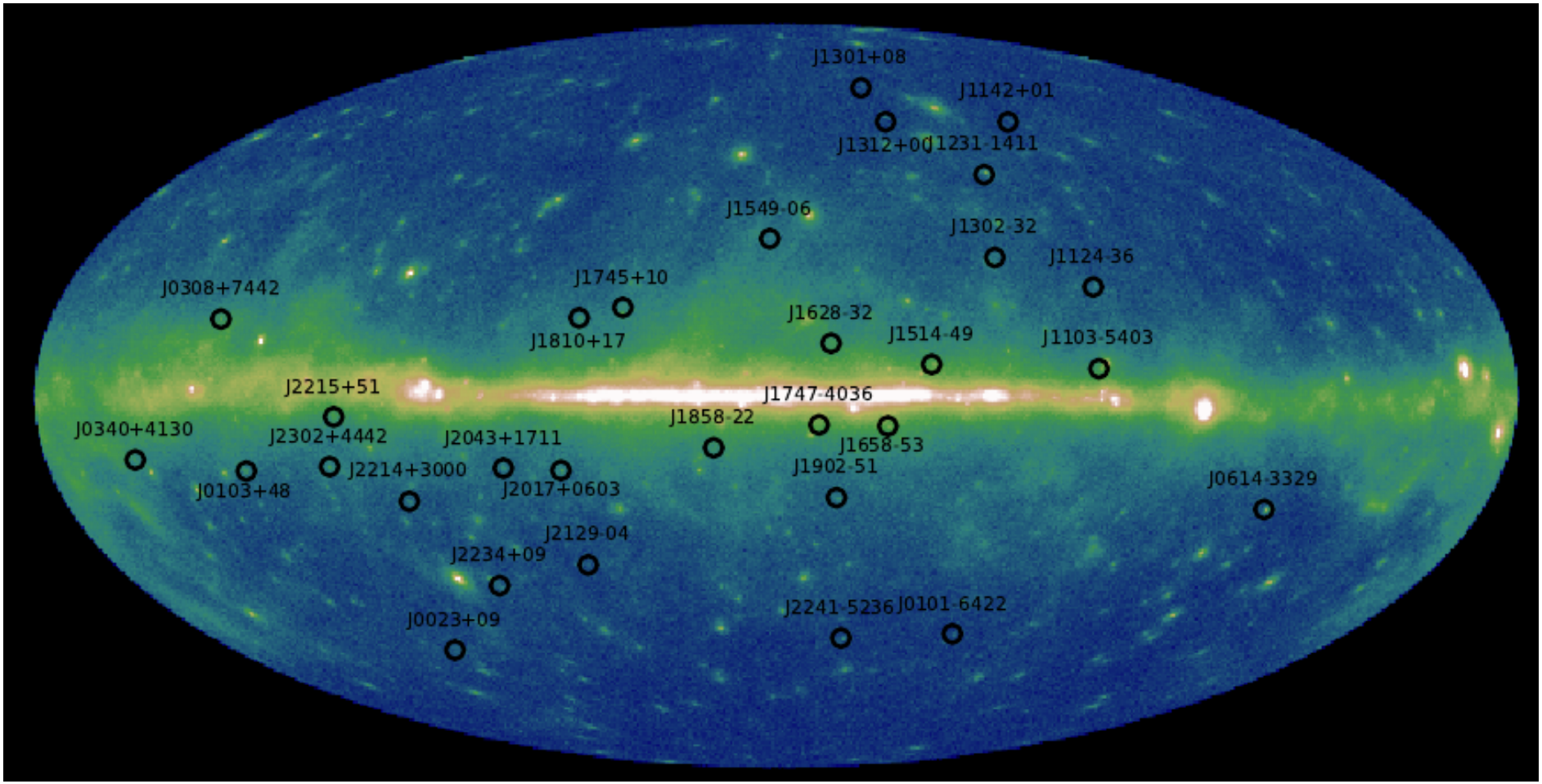
- Interstellar medium (dispersion & scattering)
- High time resolution/data rates, limited field-of-view





Semi-coherent dedispersion (Bassa et al. 2017)

Targeted surveys of *Fermi* γ-ray sources



(Scott Ransom)

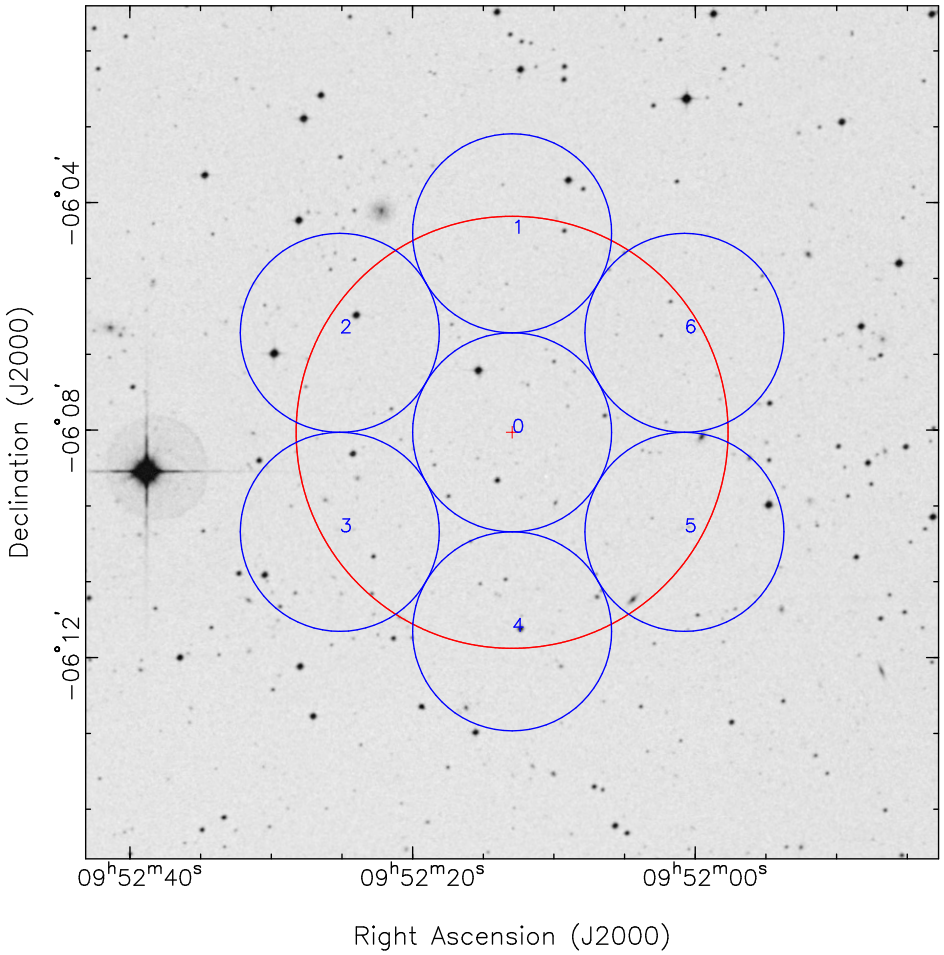
LOFAR MSP survey of *Fermi* γ-ray sources

Observational setup:

- complex voltage data
- 7 tied-array beams
- 21 HBA core stations
- 115 to 155 MHz (200 subbands)
- target MSP-like γ-ray sources
- 2×20 min per target

Processing:

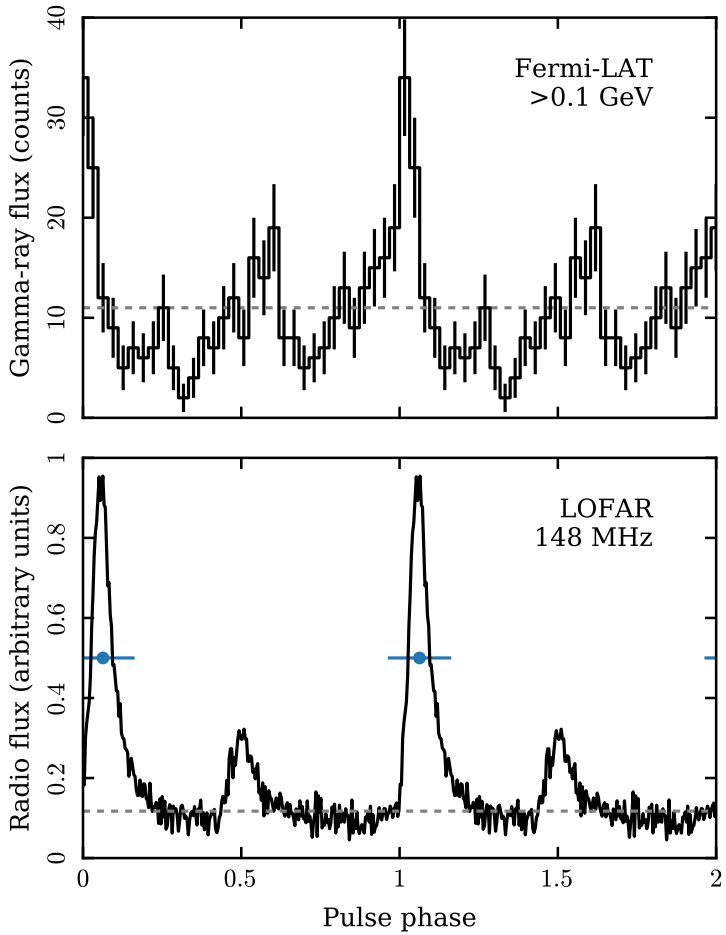
- 80 coherent DM trials up to 80 pc/cc
- 40k incoherent DM trials
- frequency-domain acceleration searches with PRESTO
- processing on DRAGNET GPU cluster (8 h per 20 min observation)



1st Discovery: PSR J1552+5437

Properties:

- Discovered in LOFAR pilot survey (52 3FGL sources targeted)
- $P = 2.43$ ms (412 Hz), $\mathrm{DM} = 22.90$ pc/cc
- Isolated pulsar
- Steep radio spectrum ($S_\nu \propto \nu^\alpha$ with $\alpha < -2.8$)
- Radio and γ-ray profiles are aligned

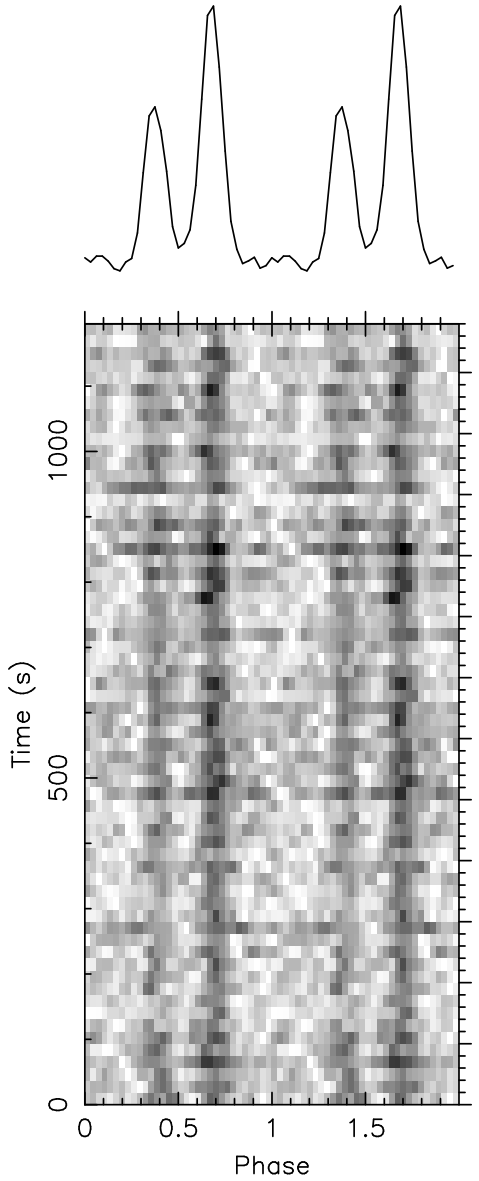


(Pleunis et al., submitted)

2nd Discovery: PSR J0952−0607

Properties:

- Discovered in follow-up survey (targeting unpublished *Fermi* sources)
- $P = 1.41$ ms (707 Hz), $\mathrm{DM} = 22.41$ pc/cc
- Fastest MSP in the Galactic field!
- Bright! (S/N $\sim$ 50 in 20 mins)
- Binary system: $P_\mathrm{b} = 6.42$ hr, very low-mass companion ($M_\mathrm{c} \gtrsim 0.02\,\mathrm{M}_\odot$; black widow type)
- Highly variable optical companion
- Steep radio spectrum ($S_\nu \propto \nu^\alpha$ with $\alpha \sim -3.3$)
- γ-ray analysis ongoing...
- Proximity makes it an excellent target for follow-up (measure masses through optical spectroscopy/light curve modelling).

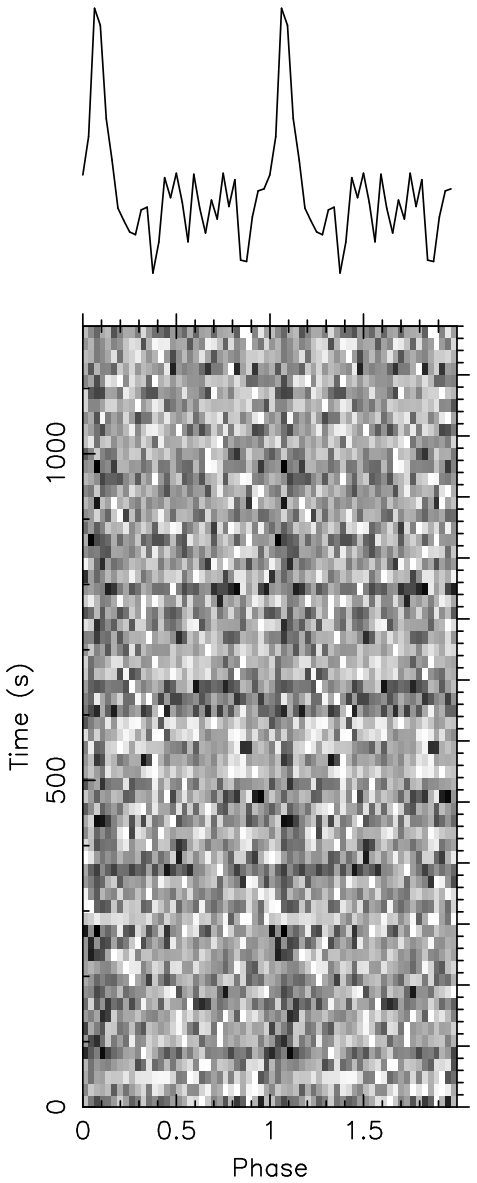


(Bassa et al., submitted)

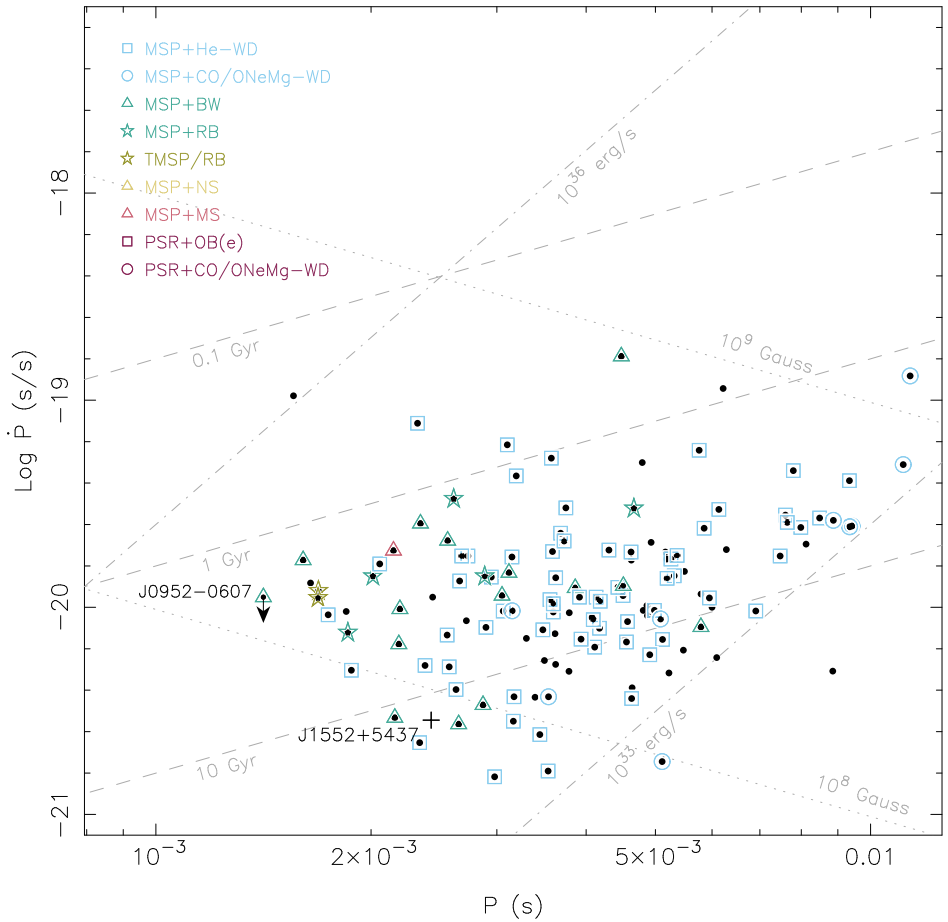
3rd Discovery: PSR J0652+47

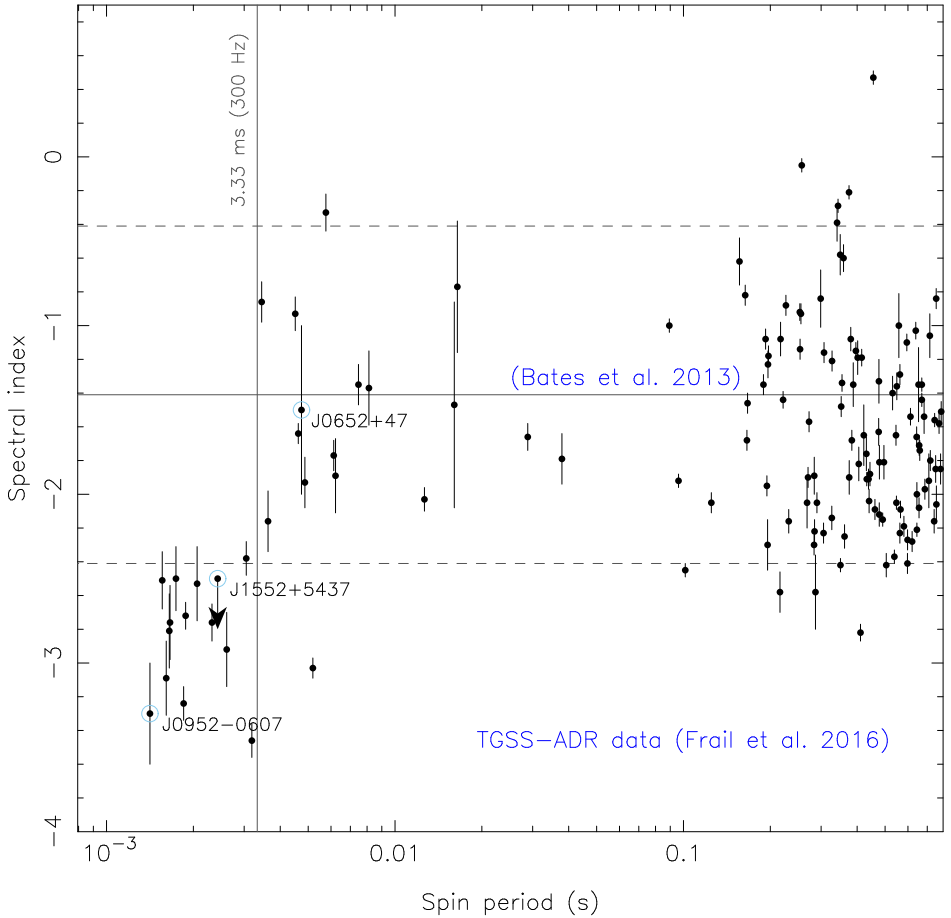
Properties:

- Discovered in follow-up survey (targeting unpublished *Fermi* sources)
- $P = 4.75$ ms (211 Hz), $\mathrm{DM} = 25.54$ pc/cc
- Binary system: $P_\mathrm{b} = 5.84$ d, probable white dwarf companion ($M_\mathrm{c} \sim 0.2\,\mathrm{M}_\odot$)
- Brighter at 350 MHz, also seen at 1.4 GHz ($\alpha = -1$ to -2)
- Sky location interesting for pulsar timing arrays



MSP properties





- Do the fastest spinning MSPs have the steepest spectra?
- Related to small light cylinder, low magnetic fields?

Conclusions

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- Discovery of 3 MSPs with LOFAR
- Tendency for steep radio spectra; hard to discover at higher frequencies
- 707 Hz MSP is fastest in Galactic field
- Insight into emission mechanism from γ-ray/radio profile alignment
- Coherent dedispersion is a must for finding MSPs at these low frequencies
- LOFAR/SKA1-low are ideally suited to find these steep spectrum MSPs
- Are all steep spectrum MSPs fast? If so, they provide constraints neutron star Equation-of-State...

Thank you!

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Thank you!