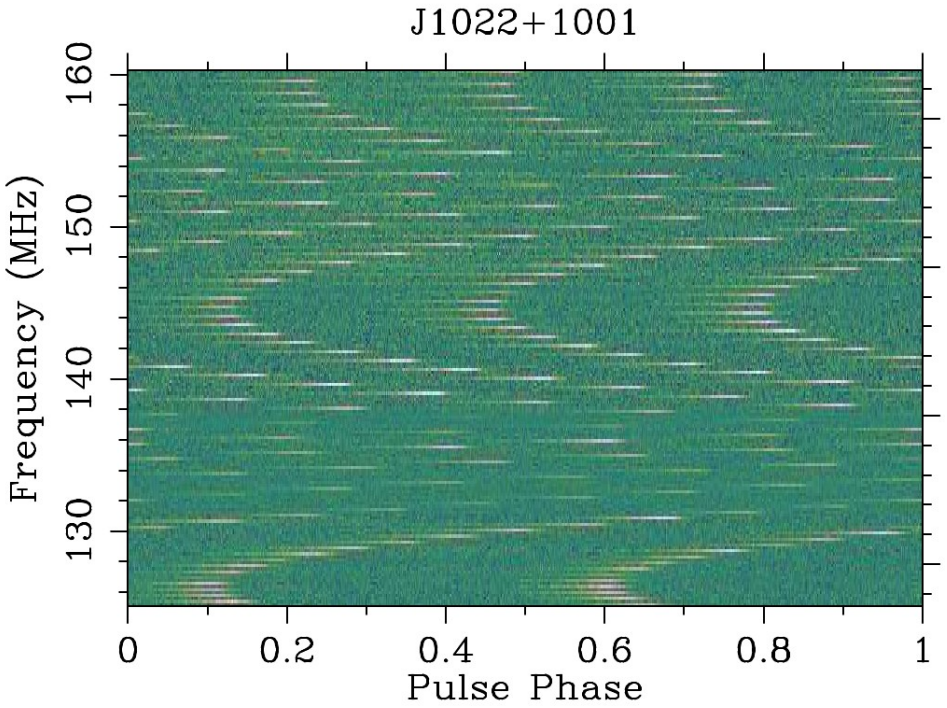
Pulsar timing at low frequencies



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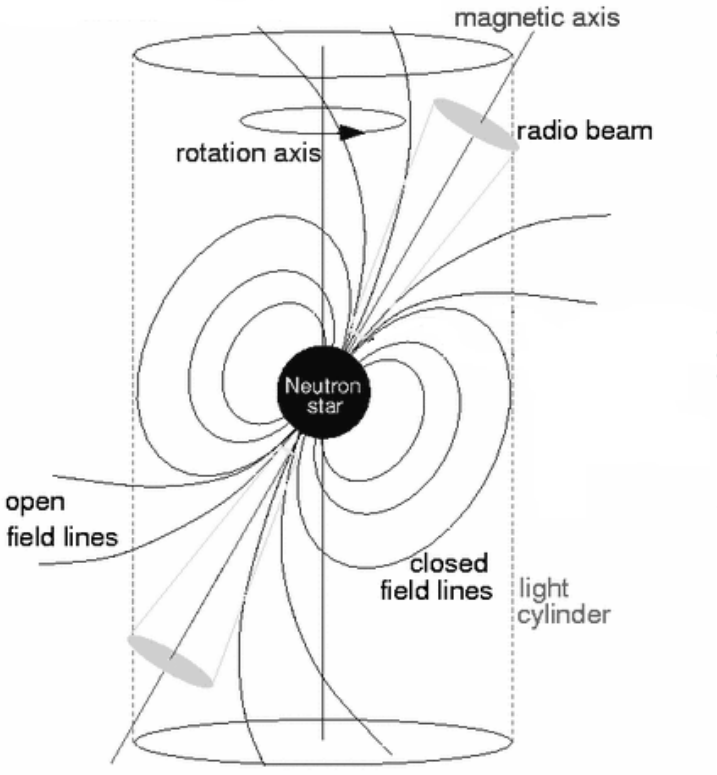
Contents

- Pulsar timing
- Challenges of pulsar timing at low frequencies
- Why is it important?
- Highlights
- Conclusions and outlook

Pulsars

Pulsars are stable "cosmic clocks" – once known the pulsar's ephemeris, it is possible to predict the radiation's arrival time on the Earth with very high precision



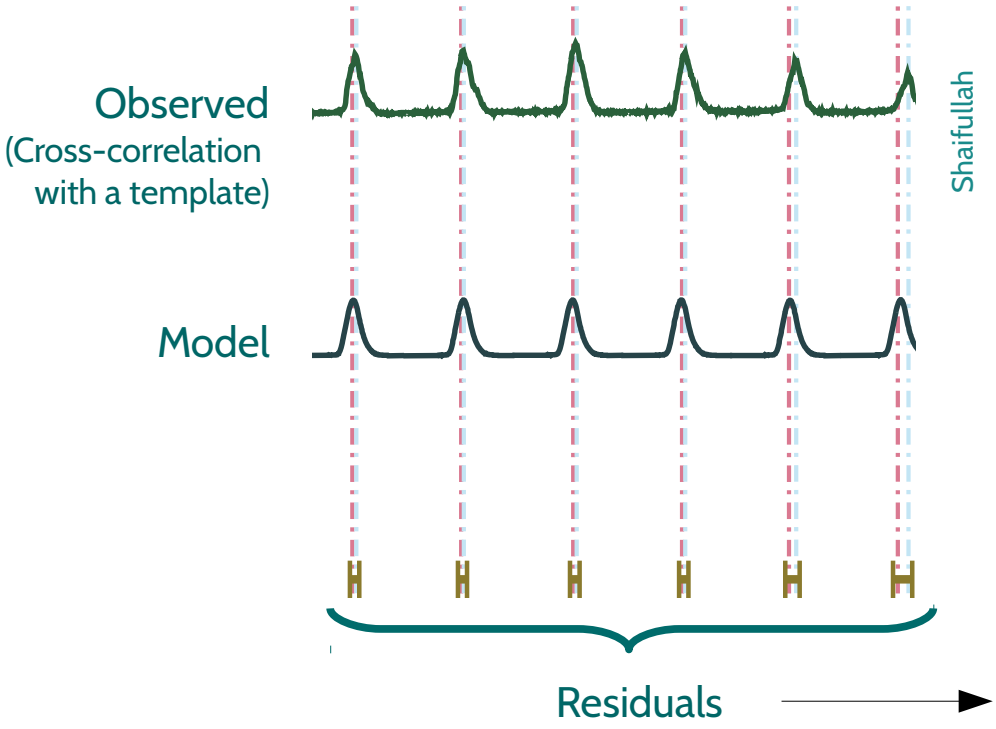
Lorimer & Kramer 2005

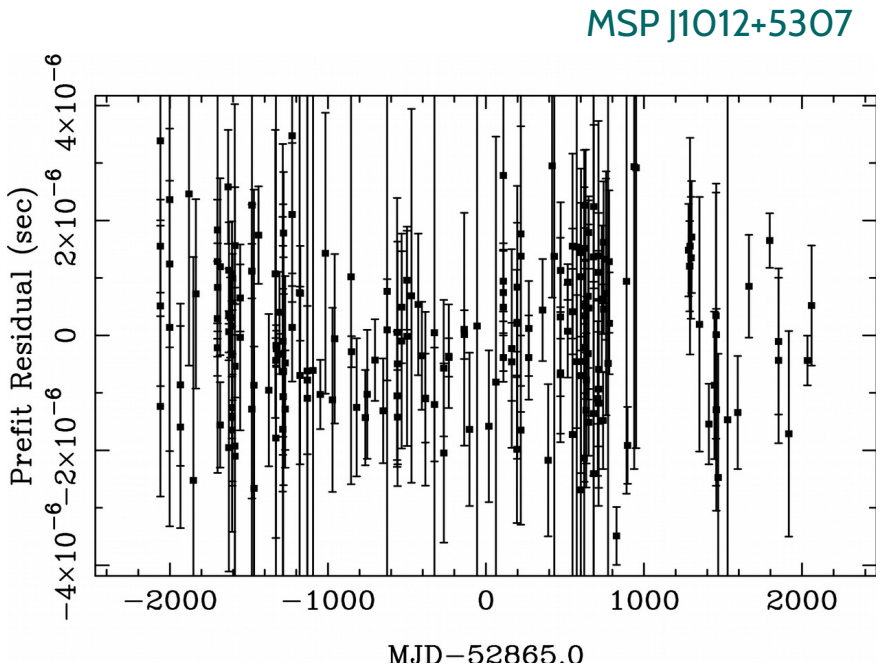
PSRJ	J1012+5307
RAJ	10:12:33.437521
DECJ	+53:07:02.29999
DM	9.02314
PEPOCH	55000
F0	190.2678376220576
F1	-6.20063E-16
PMRA	2.609
PMDEC	-25.482
POSEPOCH	55000
BINARY	ELL1
PB	0.604672722901
A1	0.58181703
T0	50700.229
TASC	50700.08174604
EPS1	1.30E-6
EPS2	5E-8
PBDOT	6.1E-14
RM	2.98
PX	0.71
A1DOT	2.0E-15
M2	0.16
UNITS	TCB

Pulsar ephemeris, our **model**

- Spin parameters
- Astrometric parameters
- Interstellar medium parameters
- Terrestrial time standard
- Planetary ephemeris
- ...

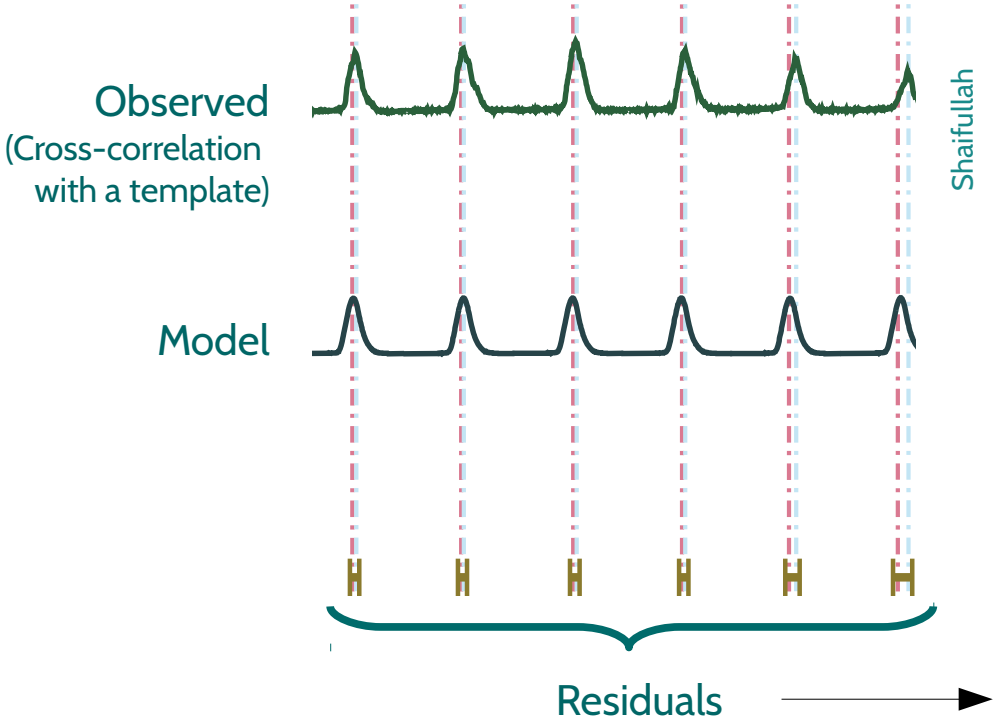
Pulsar timing



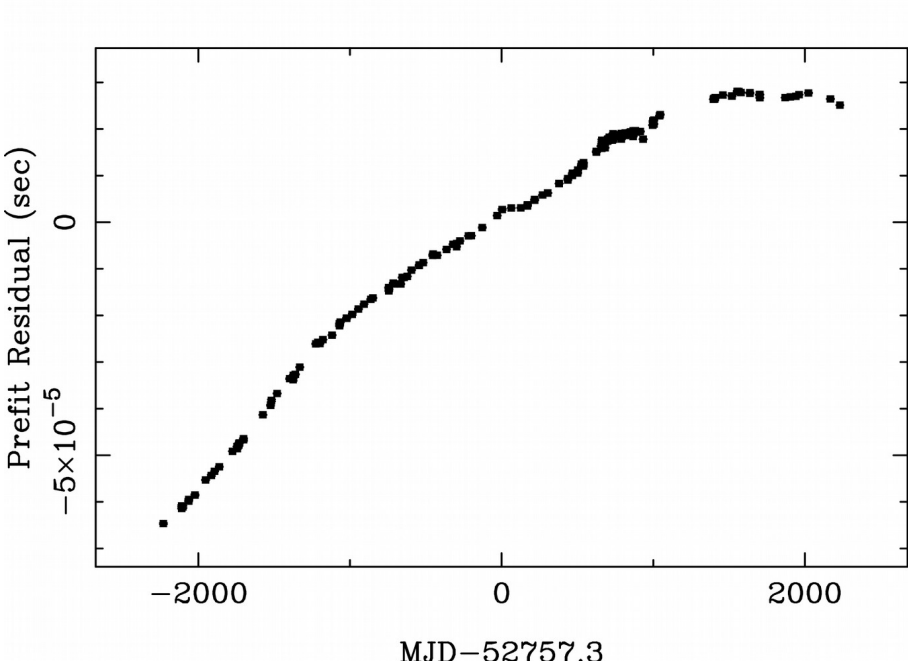


Iteratively, the parameters in the timing models are updated and refined, yielding more and more accurate ToA modeling

Pulsar timing



MSP J1939+2134



Iteratively, the parameters in the timing models are updated and refined, yielding more and more accurate ToA modeling

Why is it difficult?

Observing pulsars at low frequencies is difficult, especially because of the effects of the ionized interstellar medium (IISM):

- ✗ Dispersion → f^{-2}
- ✗ Scattering/scintillation → $f^{-4.4}$
- ✗ Faraday rotation → f^{-2}

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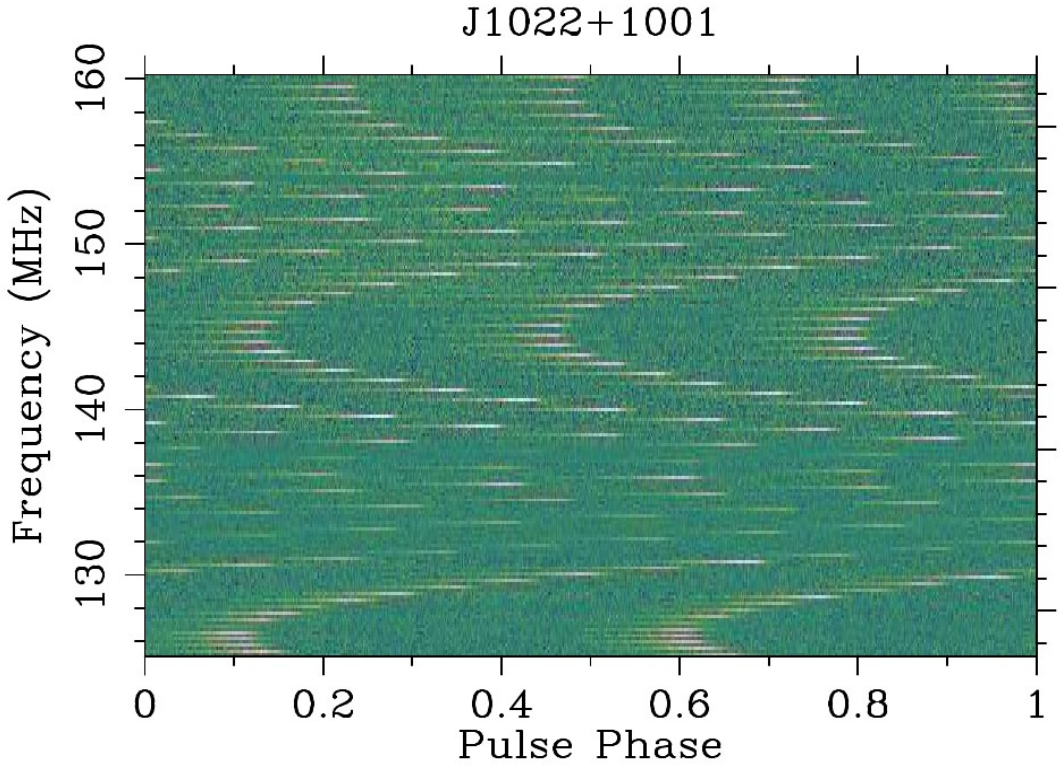

Why is it difficult?

- ✗ Frequency evolution of the pulsar profile;
- ✗ Dispersion measure (DM)/scattering variability;
- ✗ Chromaticity of the IISM dispersive effects;
- ✗ Syncrotron emission from the Galactic background

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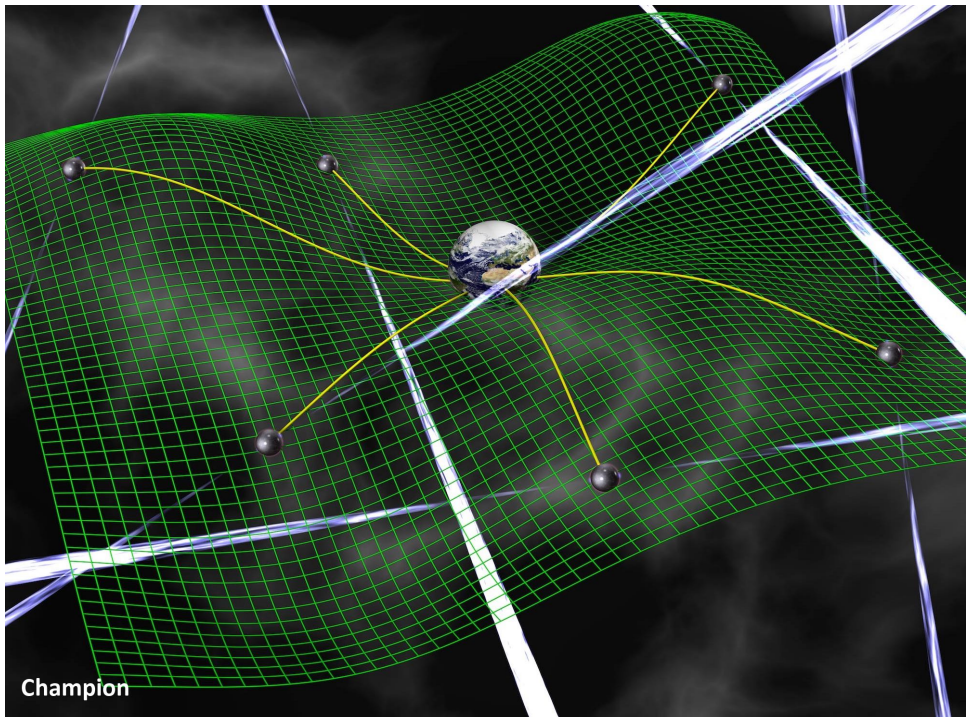
... PAUCITY OF PULSAR TIMING STUDIES AT LOW FREQUENCIES TO DATE!

A mine of information about the IISM

Experiments like Pulsar Timing Arrays mainly rely on observations around 1400 MHz. The increasing timing precision at these frequencies implies that IISM effects become more and more evident and more important to understand.



A mine of information about the IISM

Pulsar timing at low frequencies will NEVER be as precise, but it provides a **mine of information about the IISM!**

- The inverse dependency with powers of the observing frequency allows to measure the IISM phenomena with much higher precision;
- Potential of 'back-correcting' the effects of the IISM from low to high frequencies;
- Possibility of an amazing characterization of the large and small scale structures of the IISM via studies of dispersion variation, scintillation, scattering

Pulsar timing at low frequencies, why now?

Hardware improvements and **increase in computational power** brought to a revival of pulsar studies at low frequencies, allowing **real time dedispersion** and **bandwidth increment**

LWA, New Mexico

www.nasa.gov

LOFAR, the Netherlands ++

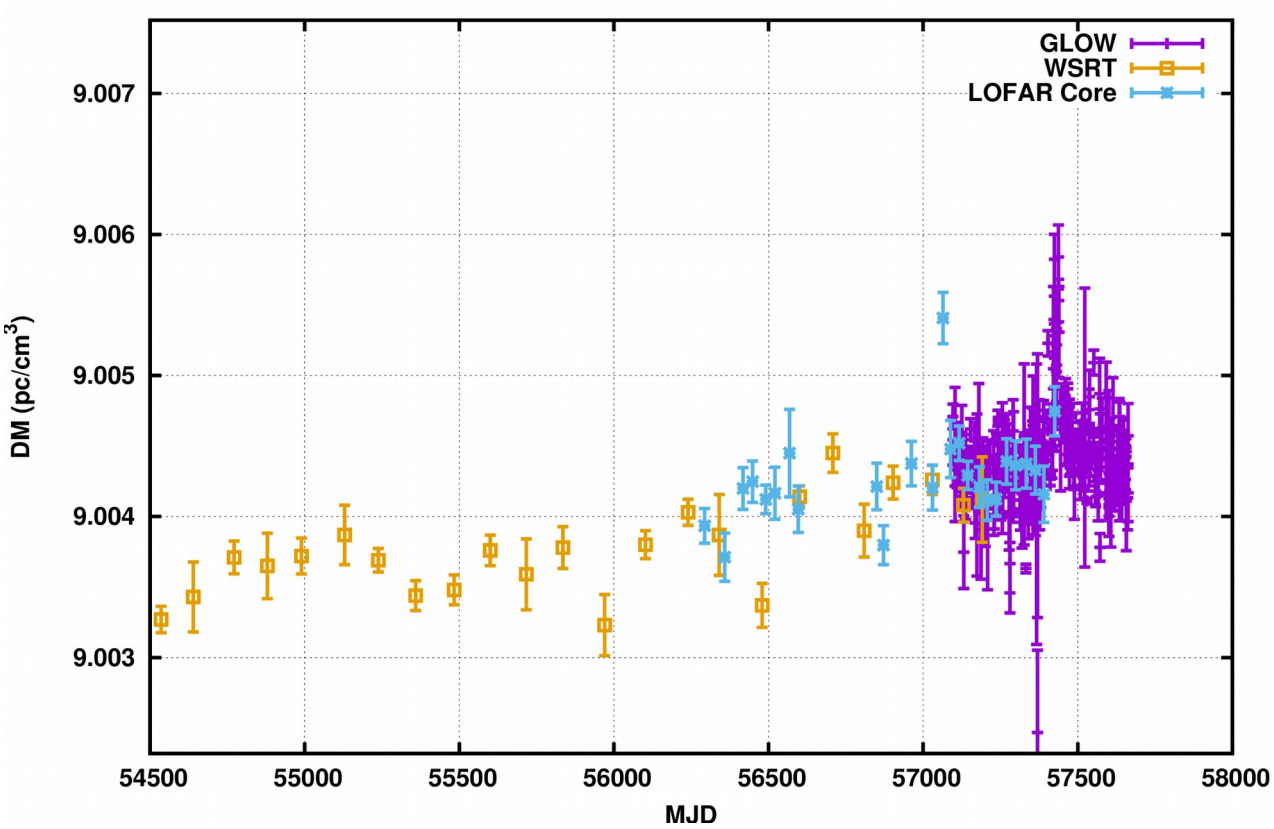
www.astron.nl

MWA, Western Australia

Natasha Hurley-Walker

Variations in dispersion measure

MSP J2145-0750

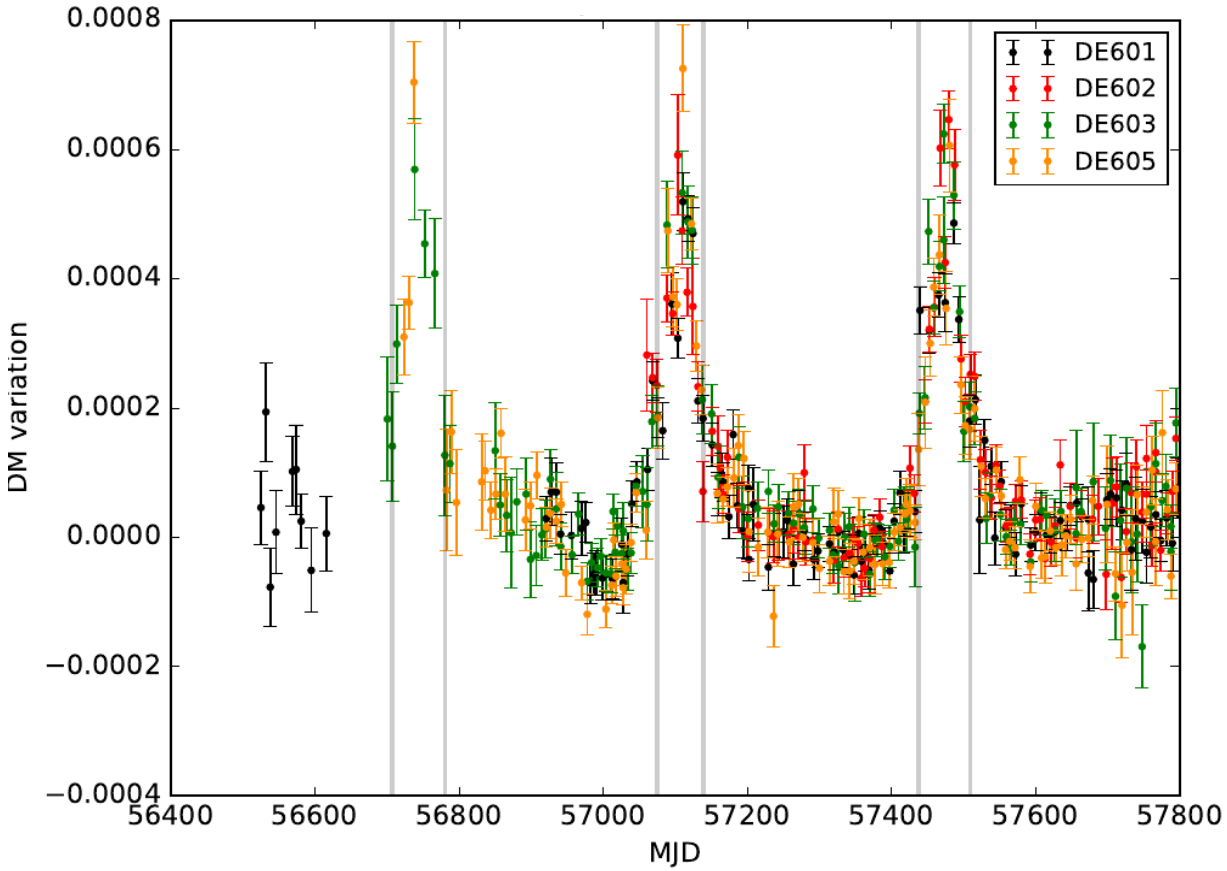


- WSRT + LOFAR core + GLOW
- High precision DM tracking
- Highly cadenced measurements

J. Verbiest, Bielefeld University

Solar wind

MSP J0034-0534

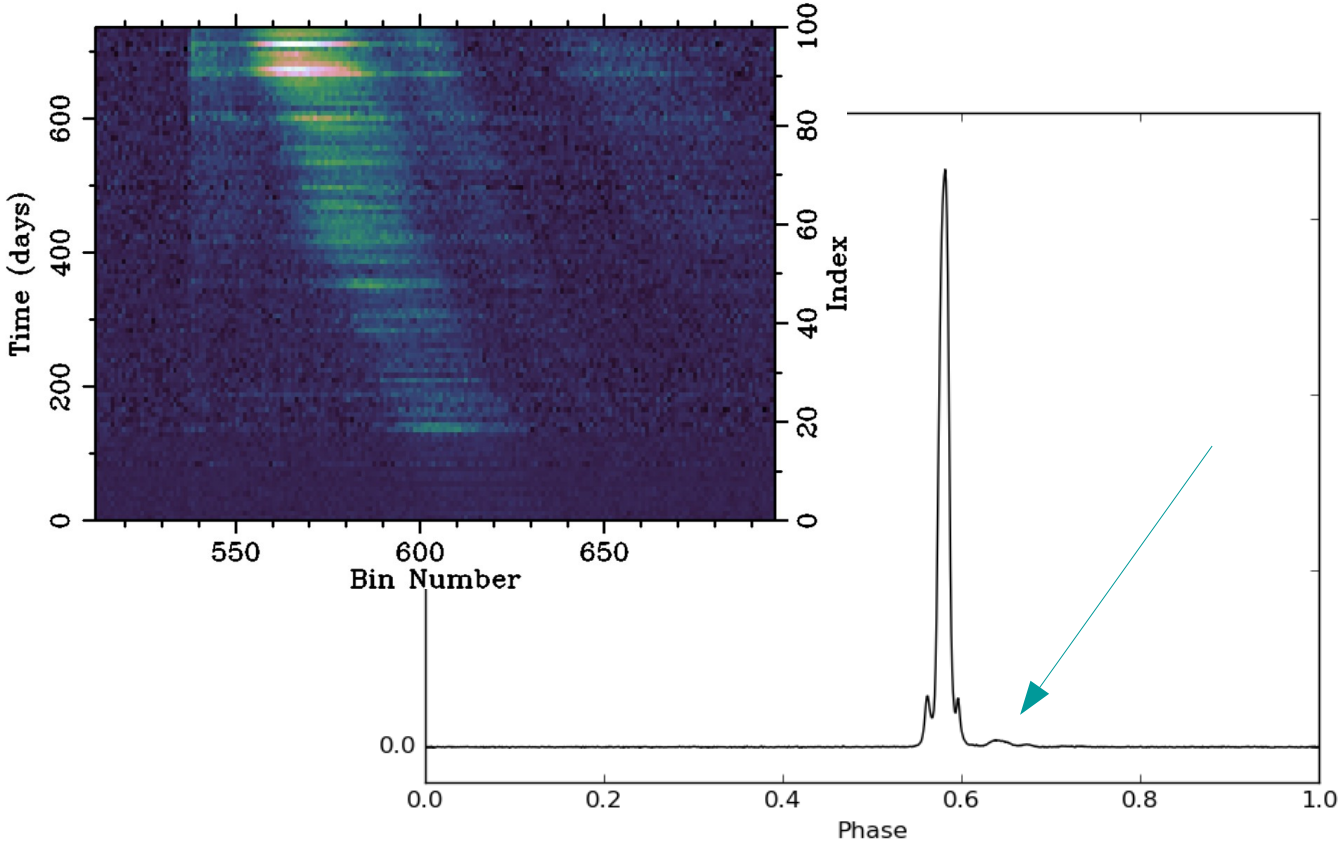


- GLOW stations
- Precise Solar wind monitoring
- Unprecedented cadence

C. Tiburzi, MPIFR/Bielefeld University

Extreme scattering events

PSR J1509+5531



- GLOW stations and Swedish station
- Probing IISM's structures

S. Osłowski, Swinburne University of technology

Conclusions and outlook

- IISM effects and Galactic background give hard times to pulsar timing at low frequencies;
- BUT… now we have new fantastic facilities with great hardware and computing power!
- High frequencies, high-precision timing needs us!
- Amazing precision can be achieved for IISM studies!

Thank you for your attention

... Wait!

LOFAR census

Non-recycled pulsars (Bilous et al., 2016)

- HBAs;
- |Gb|>3° – Dec>8°;
- 158 detections over 194;
- Dispersion measures more precisely measured than at high frequencies

Recycled pulsars (Kondratiev et al., 2016)

- HBAs;
- 48 detections over 75;
- Dispersion measures more precisely measured than at high frequencies