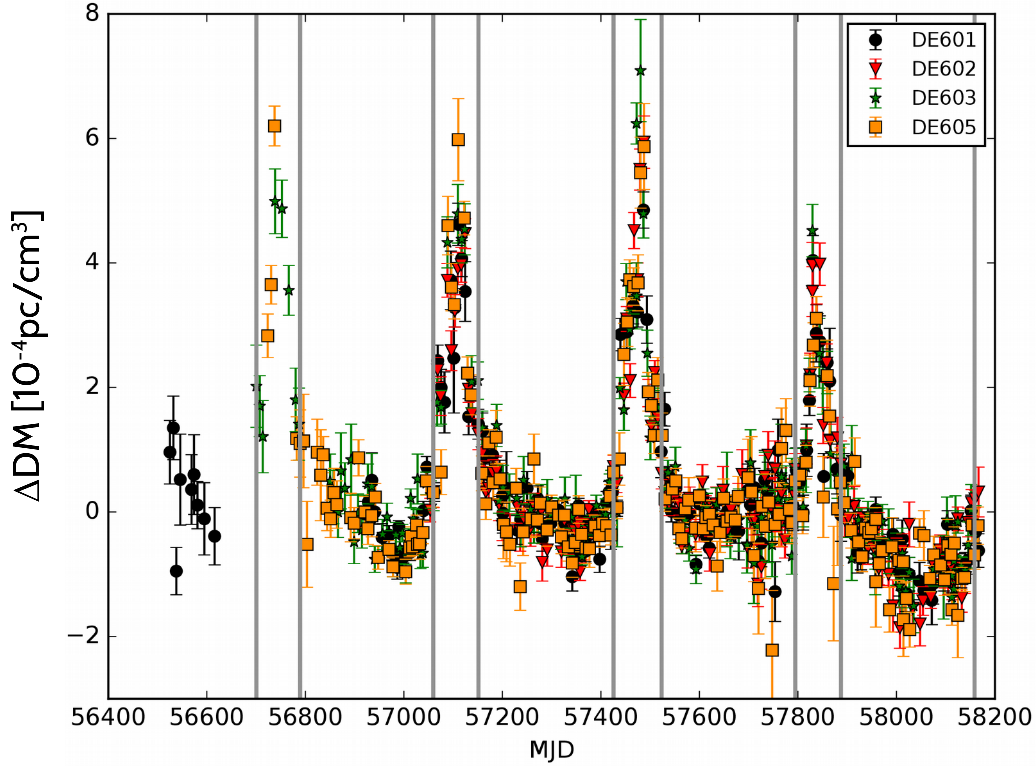
MWSKY II – 19th of March 2019

Solar wind models in pulsar timing



C. Tiburzi,

J. Verbiest, G. Shaifullah, W. Coles,
the GLOW consortium

Universität Bielefeld

ASTRON

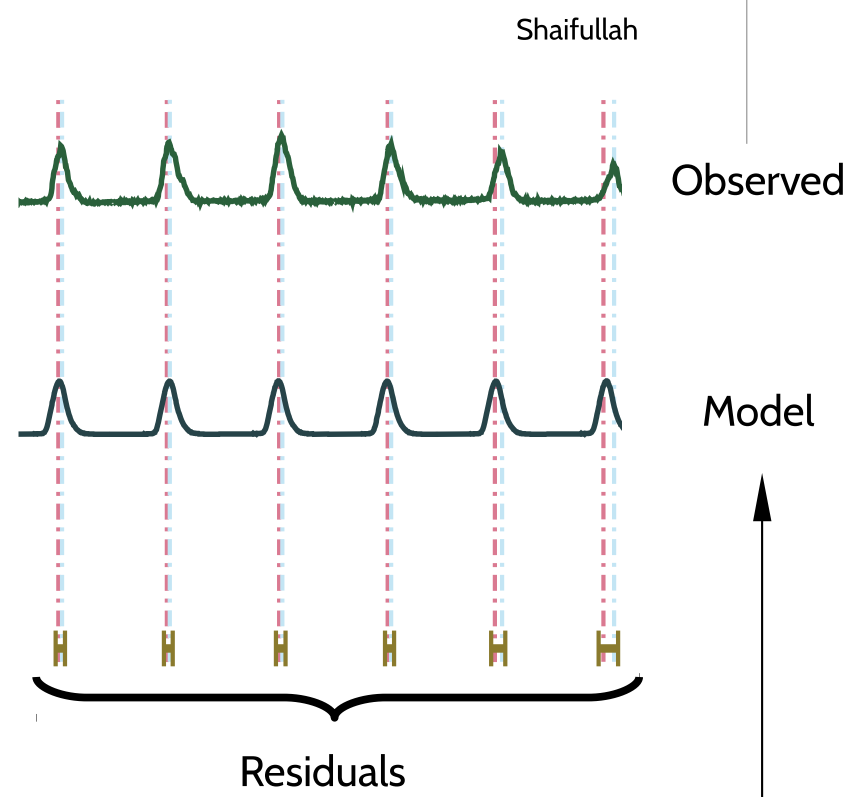
Outline

- Pulsar timing and SW models
- Dataset
- Application of the SW models and results
- Takeaway lessons
- A glance at the future

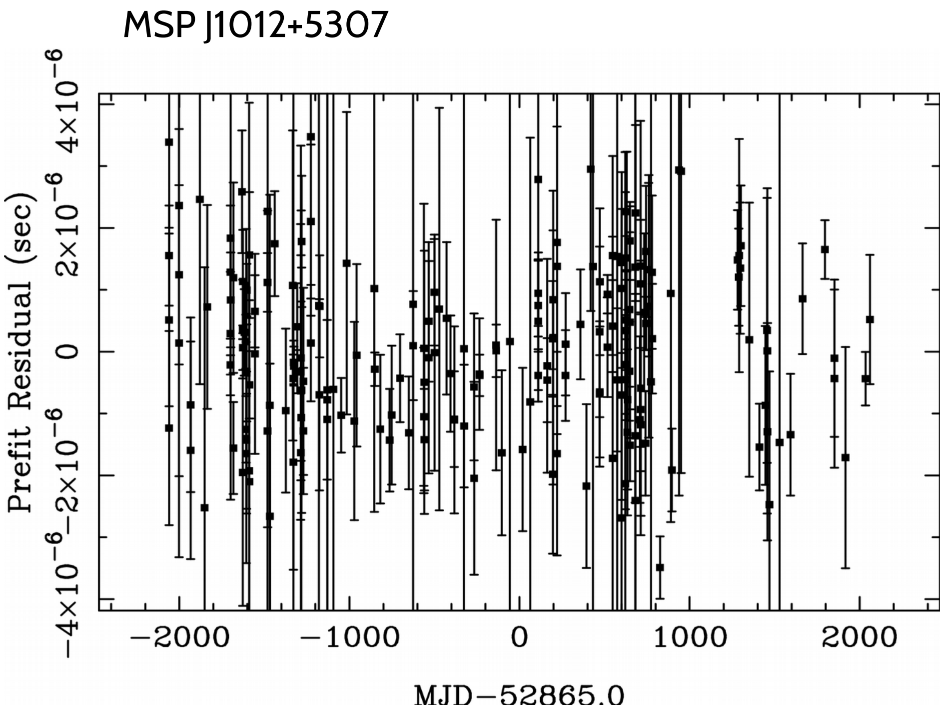
Pulsar timing

PSRJ	J1012+5307
RAJ	10:12:33.437521
DECJ	+53:07:02.29999
DM	9.02314
F0	190.2678376220576
F1	-6.20063E-16
PMRA	2.609
PMDEC	-25.482
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
NE_SW	4

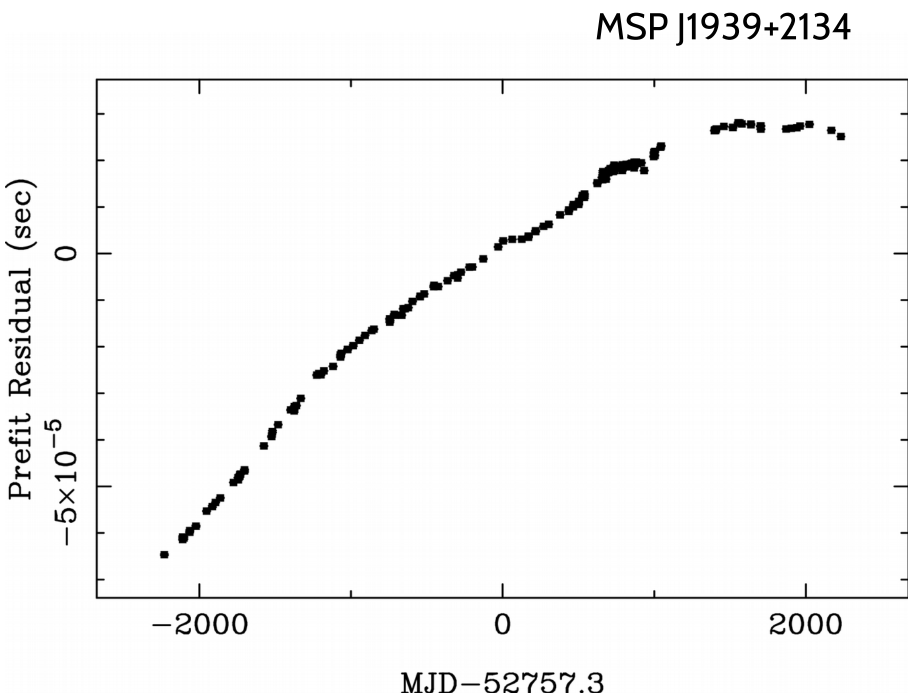
Pulsar Ephemeris



Pulsar timing



GOOD EPHEMERIS



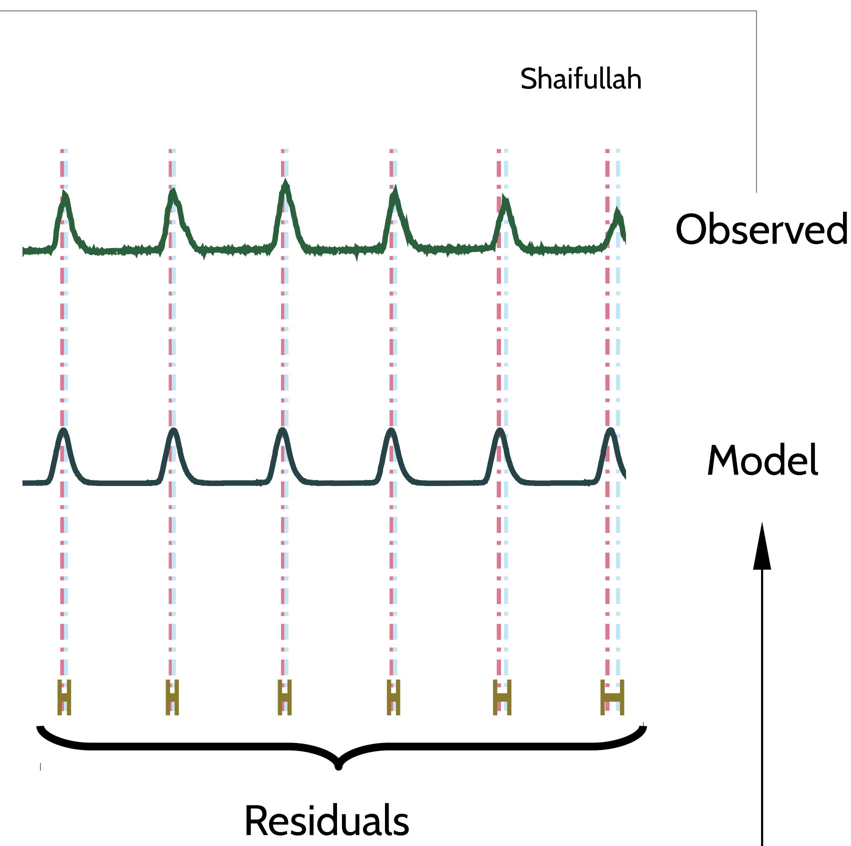
BAD EPHEMERIS

Pulsar timing, dispersive effects of ionised media

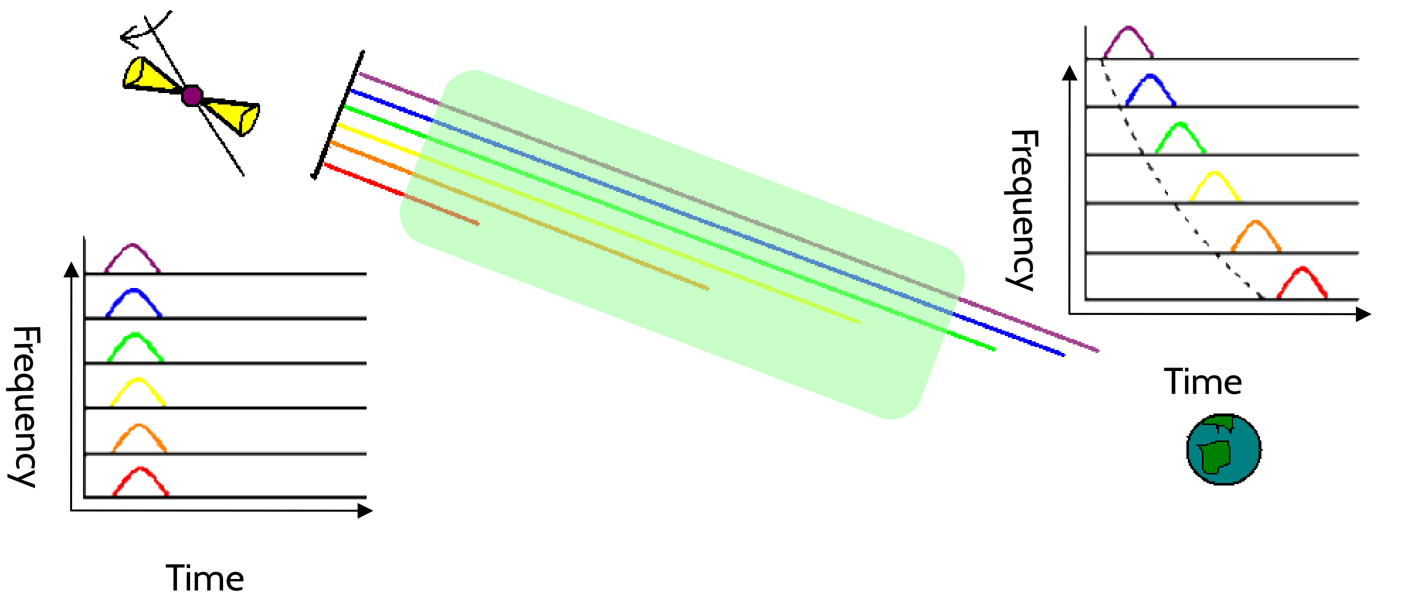
Ionised interstellar medium effects

PSRJ	J1012+5307
RAJ	10:12:33.437521
DECJ	+53:07:02.29999
DM	9.02314
F0	190.2678376220576
F1	-6.20063E-16
PMRA	2.609
PMDEC	-25.482
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
NE_SW	4

Solar wind effects



Pulsar timing, dispersive effects of ionised media



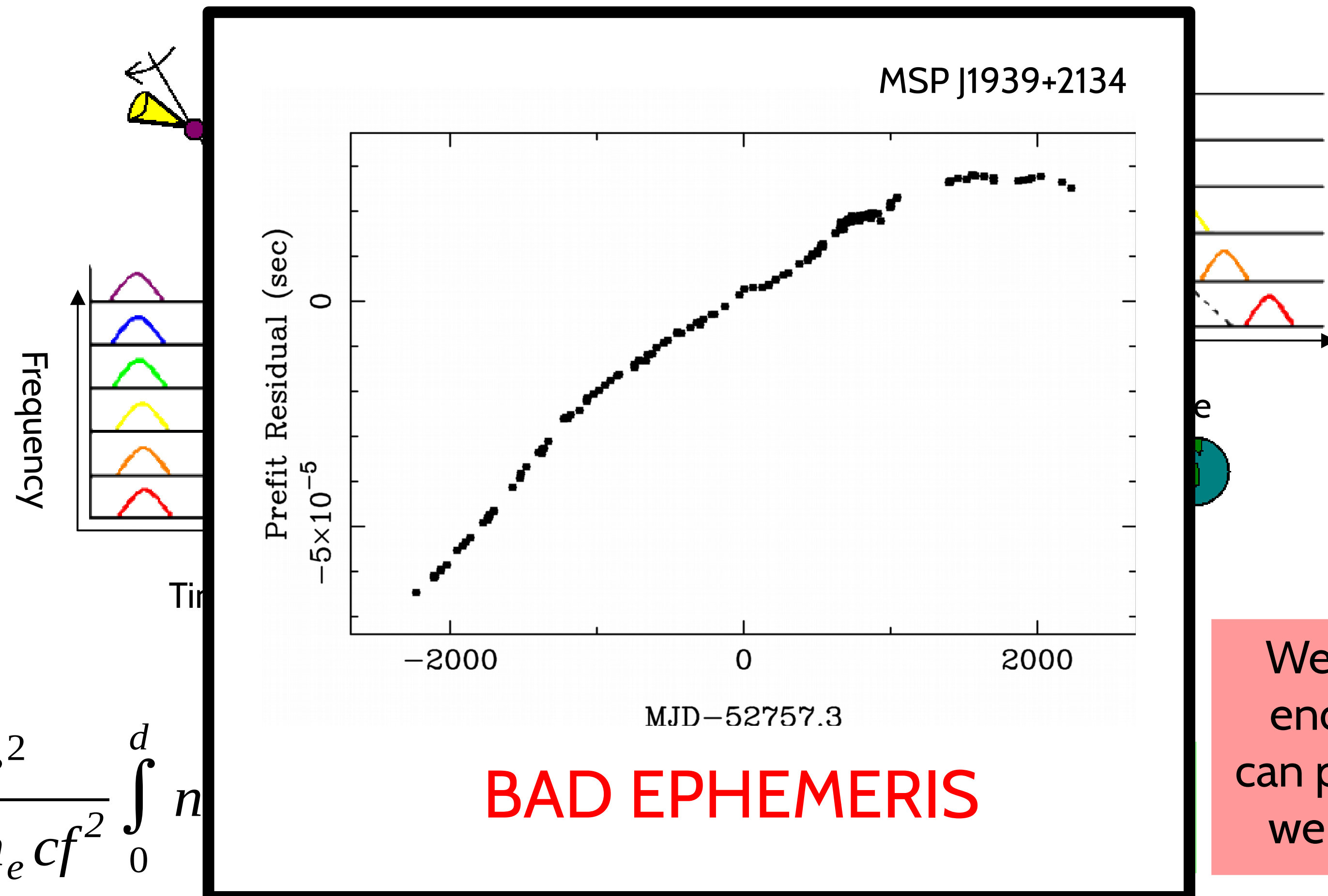
$$\Delta t = \frac{e^2}{2\pi m_e c f^2} \int_0^d n_e \, dl \propto \frac{DM}{f^2}$$

We cannot predict it

We know it well enough and we can predict it (or so we like to think)

$$DM = \int_0^d n_e \, dl \longrightarrow DM_{tot}(t) = DM_{IISM}(t) + DM_{SW}(t) + \ldots$$

Pulsar timing, dispersive effects of ionised media

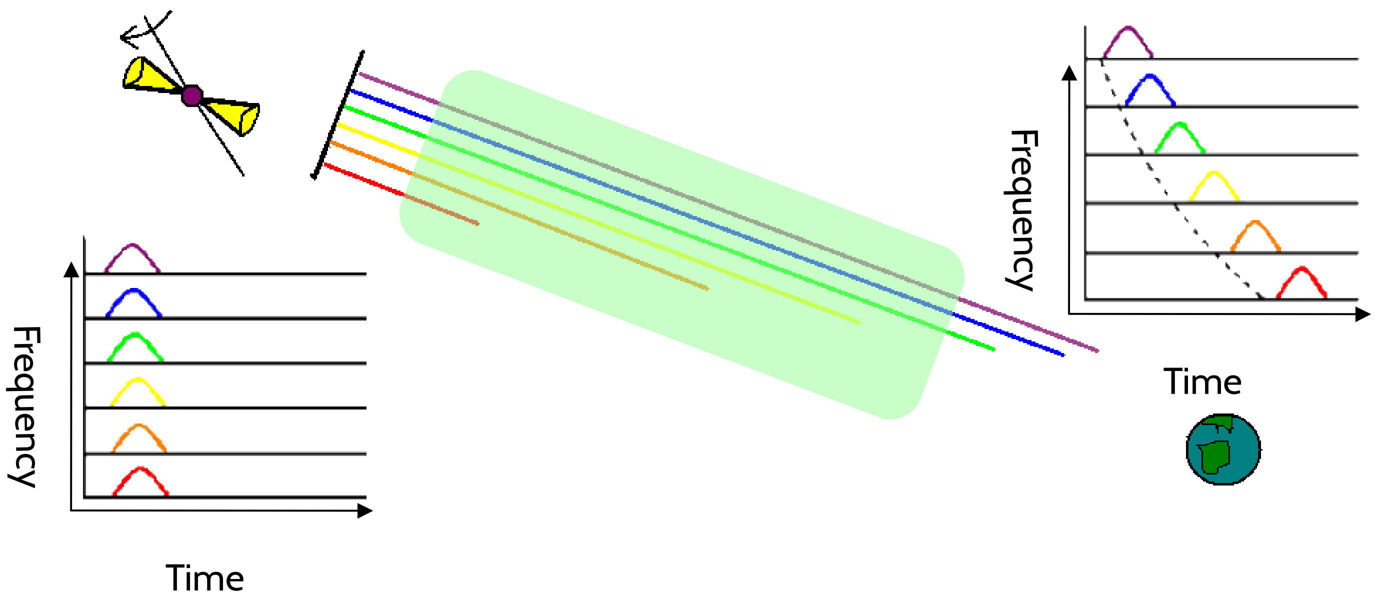


We know it well enough and we can predict it (or so we like to think)

$$\Delta t = \frac{e^2}{2\pi m_e c f^2} \int_0^d n$$

$$DM = \int_0^d n_e \, dl \longrightarrow DM_{tot}(t) = DM_{IISM}(t) + DM_{SW}(t) + \ldots$$

Pulsar timing, dispersive effects of ionised media



$$\Delta t = \frac{e^2}{2\pi m_e c f^2} \int_0^d n_e \, dl \propto \frac{DM}{f^2}$$

We cannot predict it

We know it well enough and we can predict it (or so we like to think)

$$DM = \int_0^d n_e \, dl \longrightarrow DM_{tot}(t) = DM_{IISM}(t) + DM_{SW}(t) + \ldots$$

SW electron distribution models in pulsar timing

One-phase, spherical model

- $n_e(R) = n_0/R^2$
- Non-physical
- Well known, implemented in standard pulsar timing software
- Notoriously, it does not perform well at close angular distances from the Sun

Two-phase, radial model (You+2007)

- Distinct n_e laws for the two SW phases
- More physical, based on magnetograms from the WSO
- Not widely used, bugs in the implementation, need to download magnetic field maps...
- Was proven to perform better than the spherical model in 2007 (L-Band data)

Dataset

The German Long Wavelength Consortium
GLOW

PSR J0034 – 0534
GLOW DATASET

Period: ~1.88 ms

Dispersion Measure: ~13.76 pc/cm^3

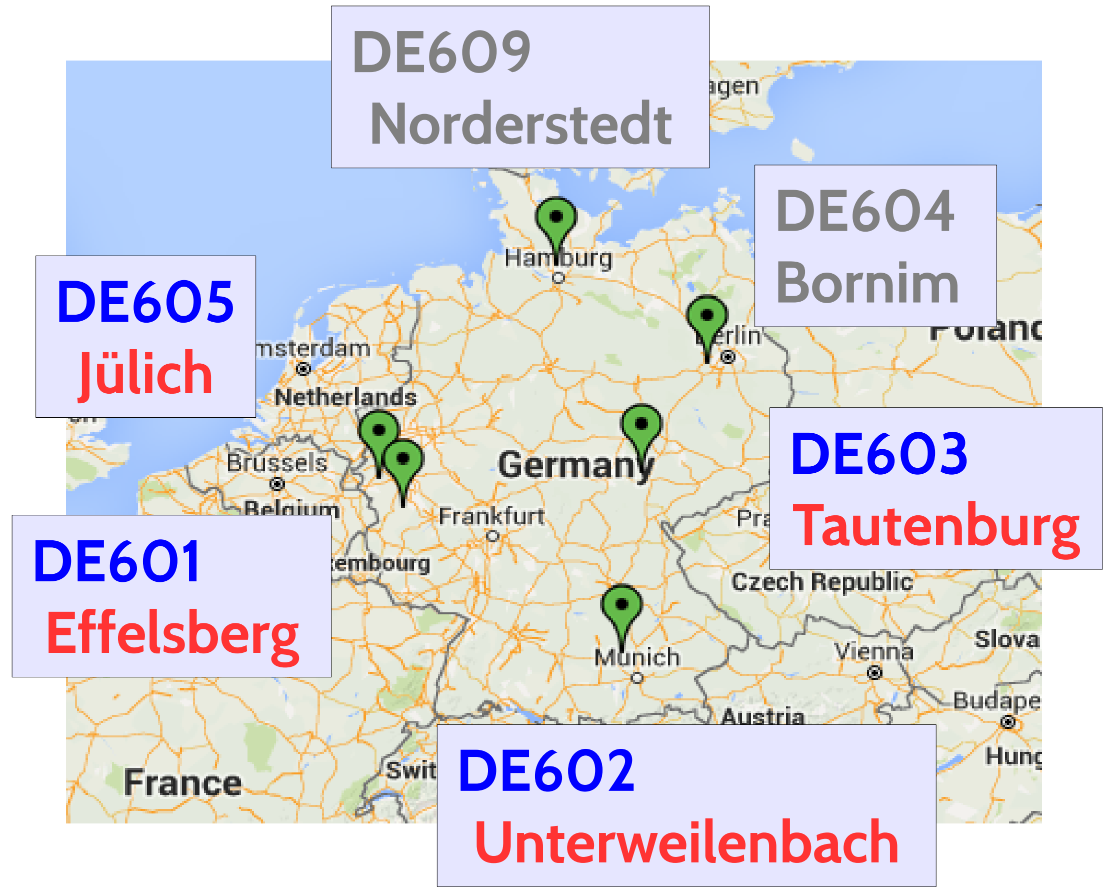
Ecliptic latitude: -8.53°

Central frequency: 150 MHz

Bandwidth: ~70 MHz

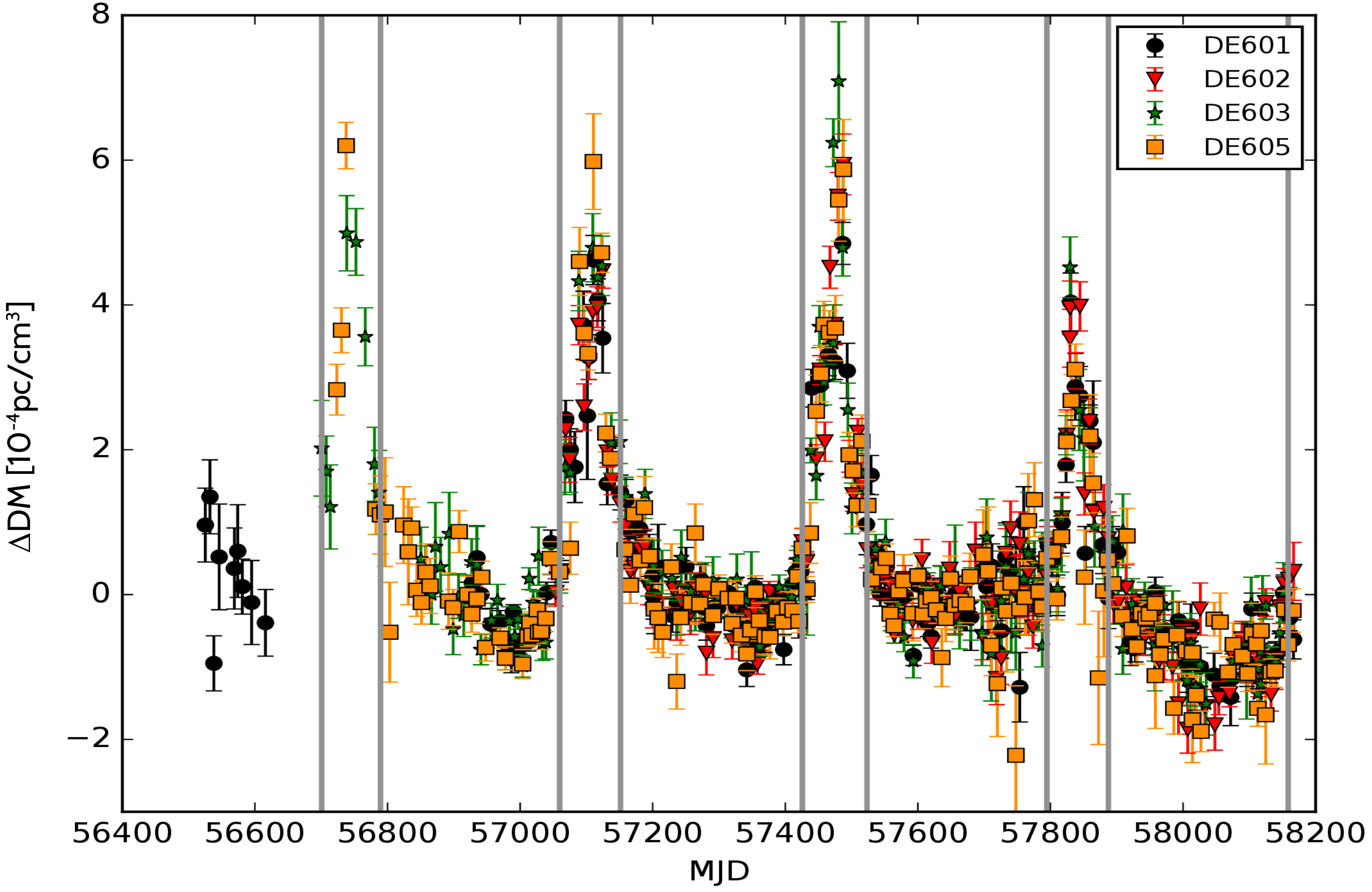
Timespan: ~4.5 yrs

Number of independent "telescopes": 4



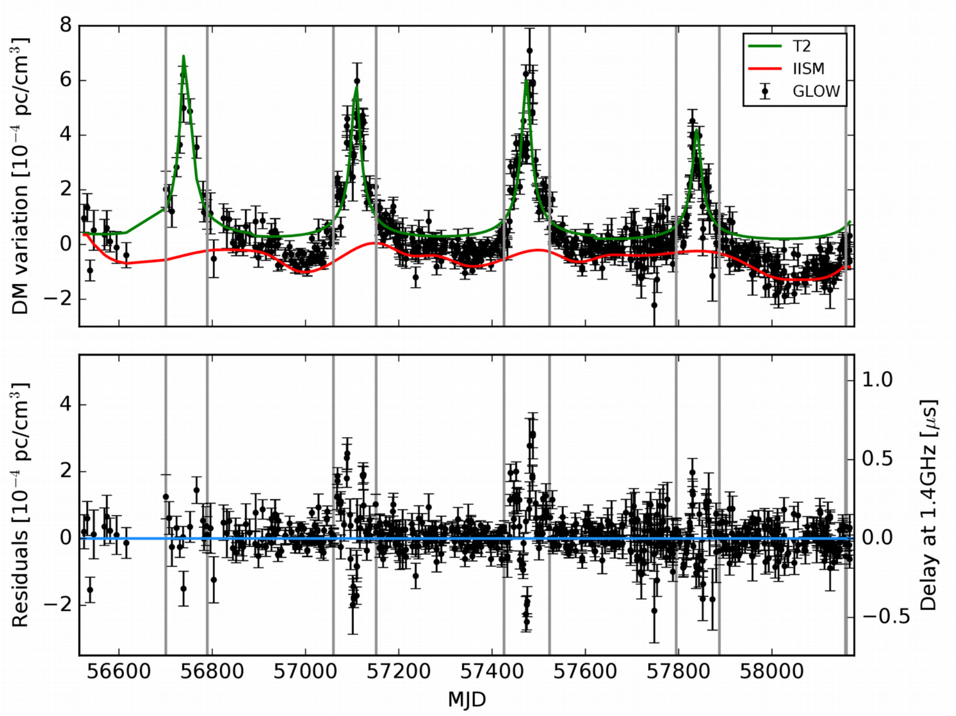
See Krishnakumar's poster!

DM variations

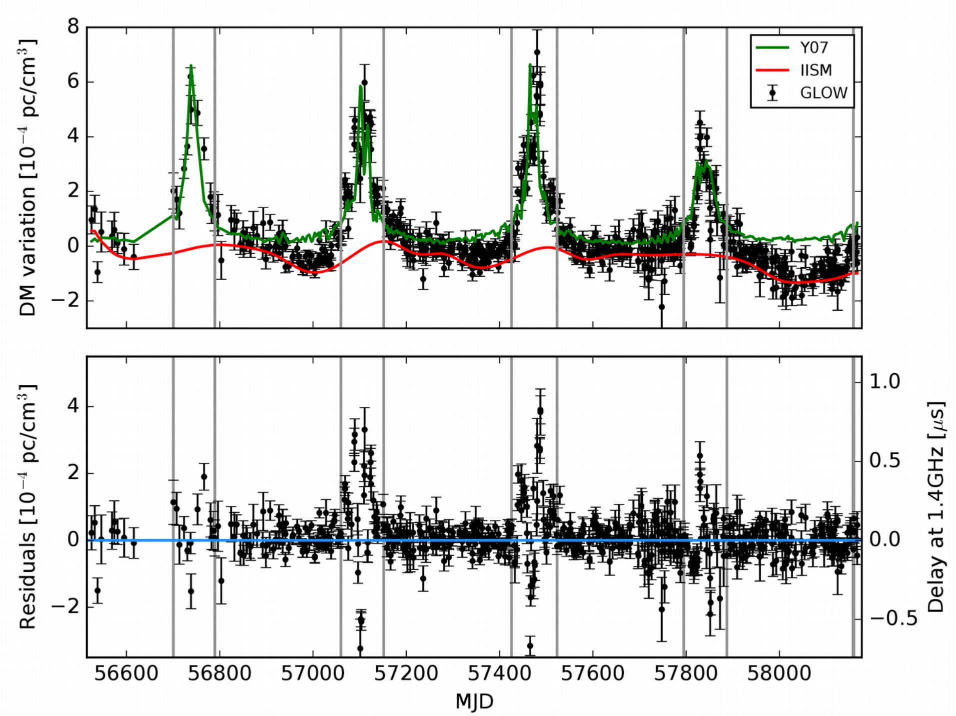


Application of the SW models

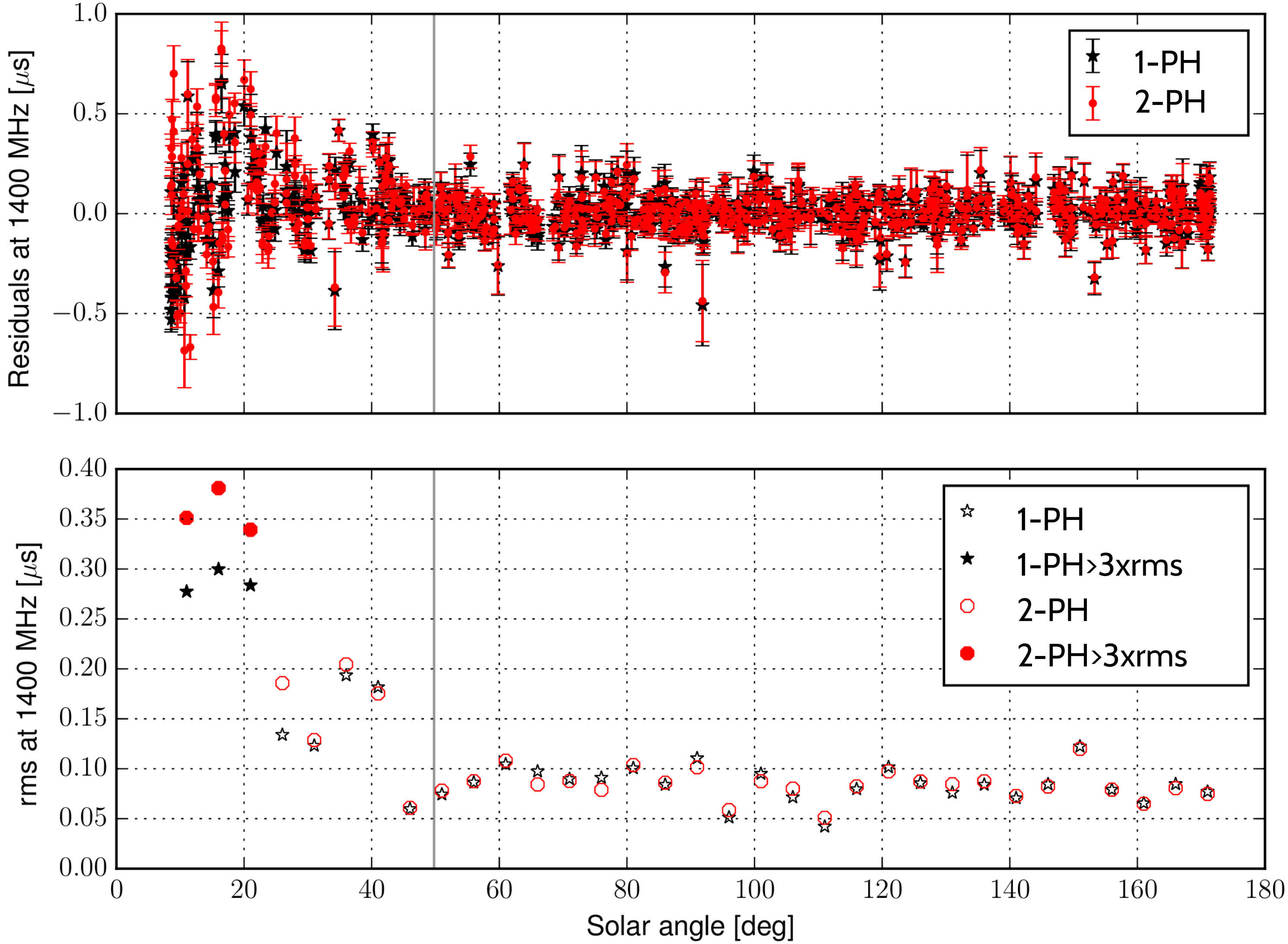
One-phase, spherical model



Two-phase, radial model

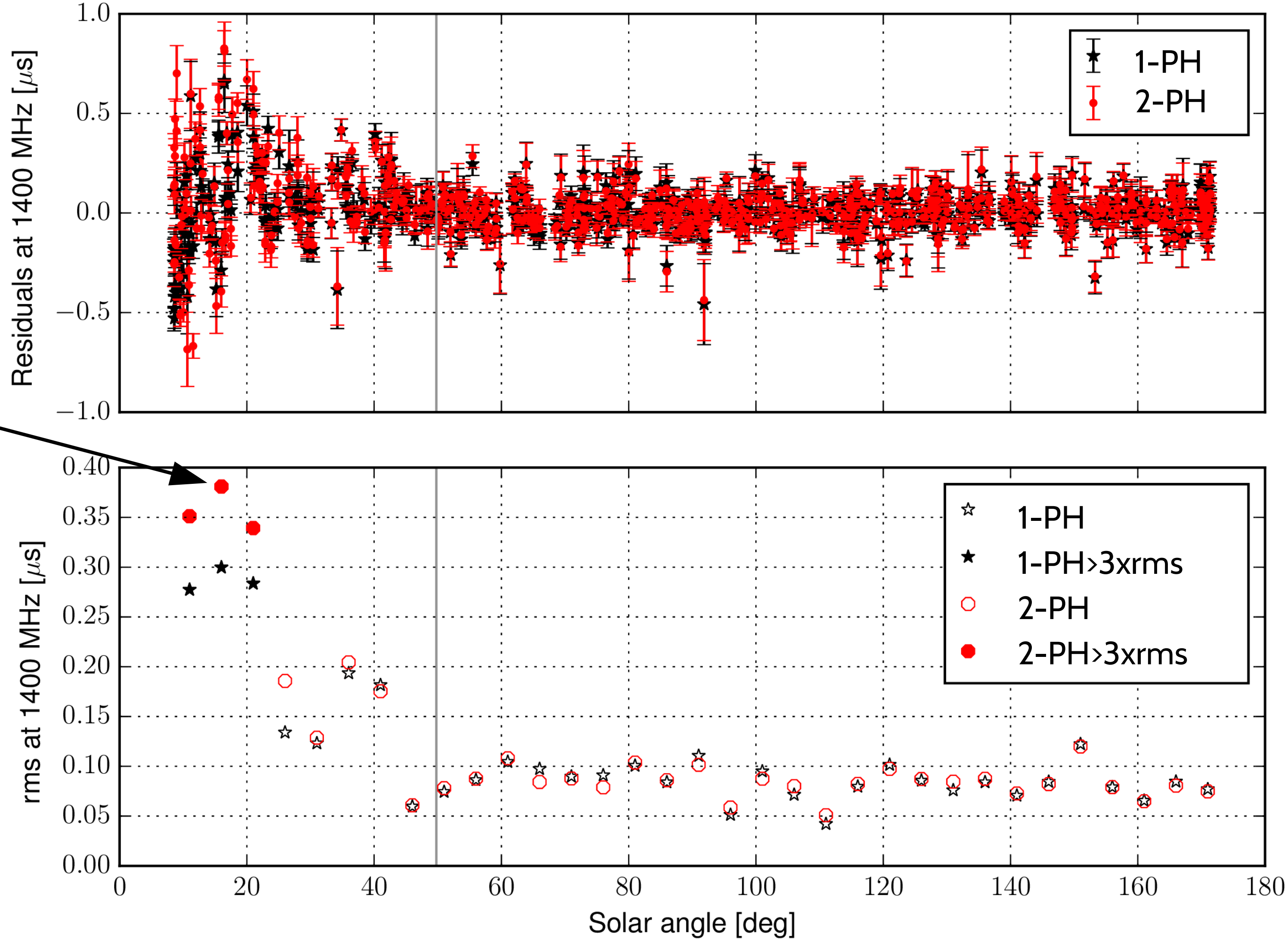


Results


Residuals at 1400 MHz [μs]
1.0
0.5
0.0
−0.5
−1.0
1-PH
2-PH
rms at 1400 MHz [μs]
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1-PH
1-PH>3xrms
2-PH
2-PH>3xrms
0
20
40
60
80
100
120
140
160
180
Solar angle [deg]

Results

28%!


1.0
0.5
0.0
−0.5
−1.0
Residuals at 1400 MHz [μs]
1-PH
2-PH
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
rms at 1400 MHz [μs]
1-PH
1-PH>3xrms
2-PH
2-PH>3xrms
0
20
40
60
80
100
120
140
160
180
Solar angle [deg]

Takeaway lessons

- Both of the SW models in pulsar timing are really bad, but one is worse than the other

  - And it's not the one that you expect (with caveats)

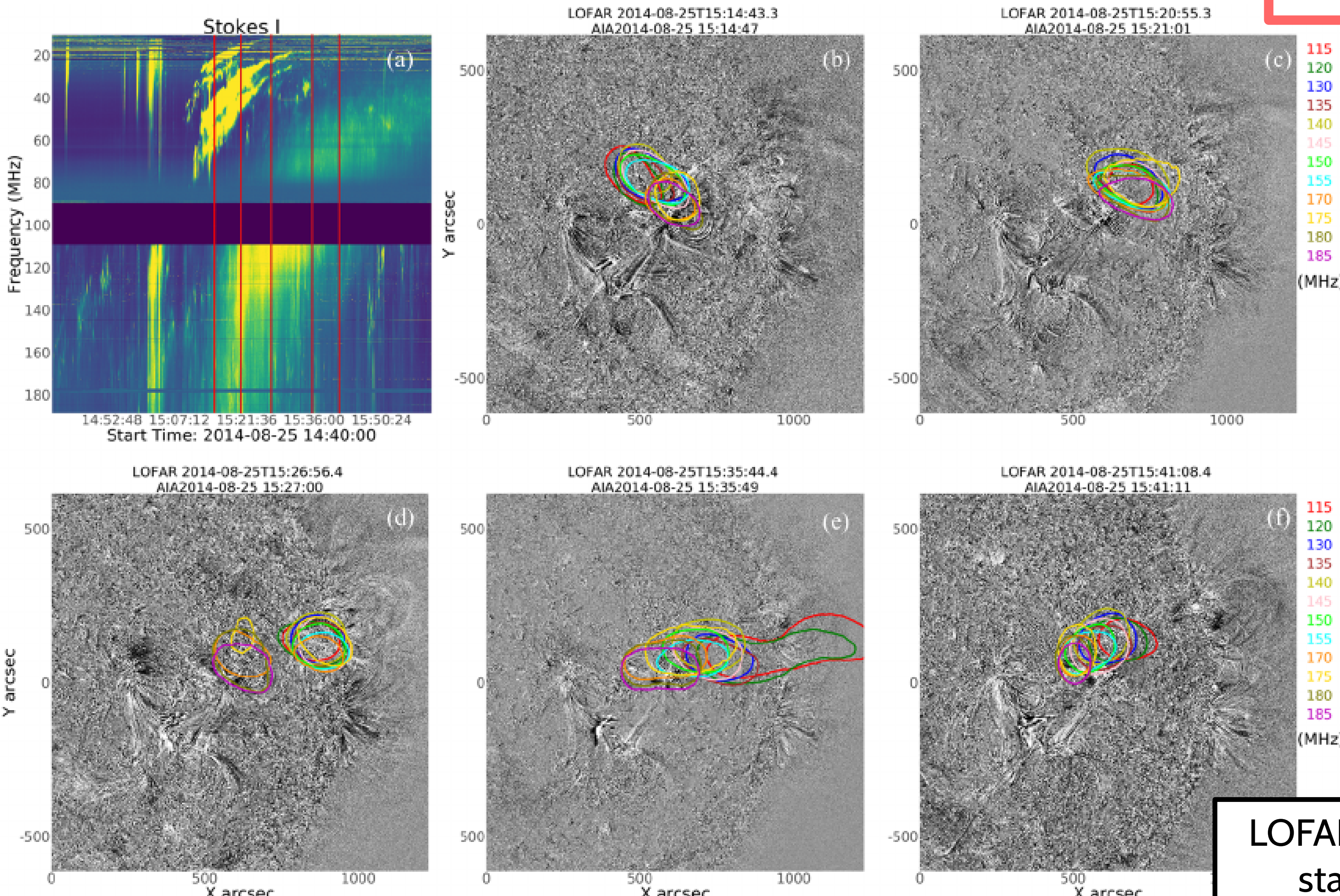
- Excluding observations within 5 degrees away from the Sun is far from being optimal with highly sensitive instruments

- Possible options:

1) Use low-frequency observations to correct at high-frequencies
2) Develop new SW models
3) Go to high frequencies

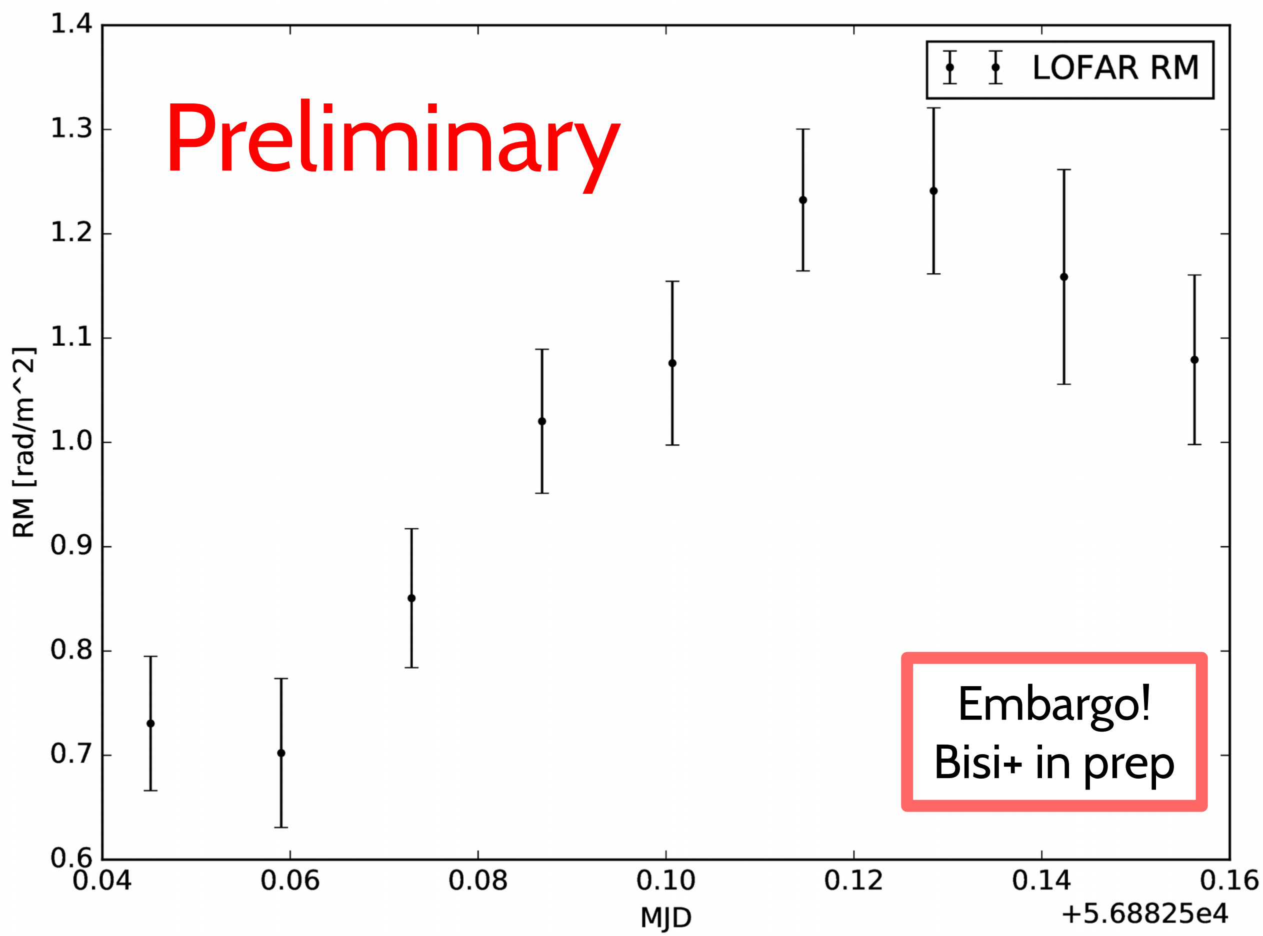
Solar imaging and dynamic spectra

Courtesy of P. Zucca, ASTRON



LOFAR, Dutch stations (~150 MHz)

CME's Faraday rotation



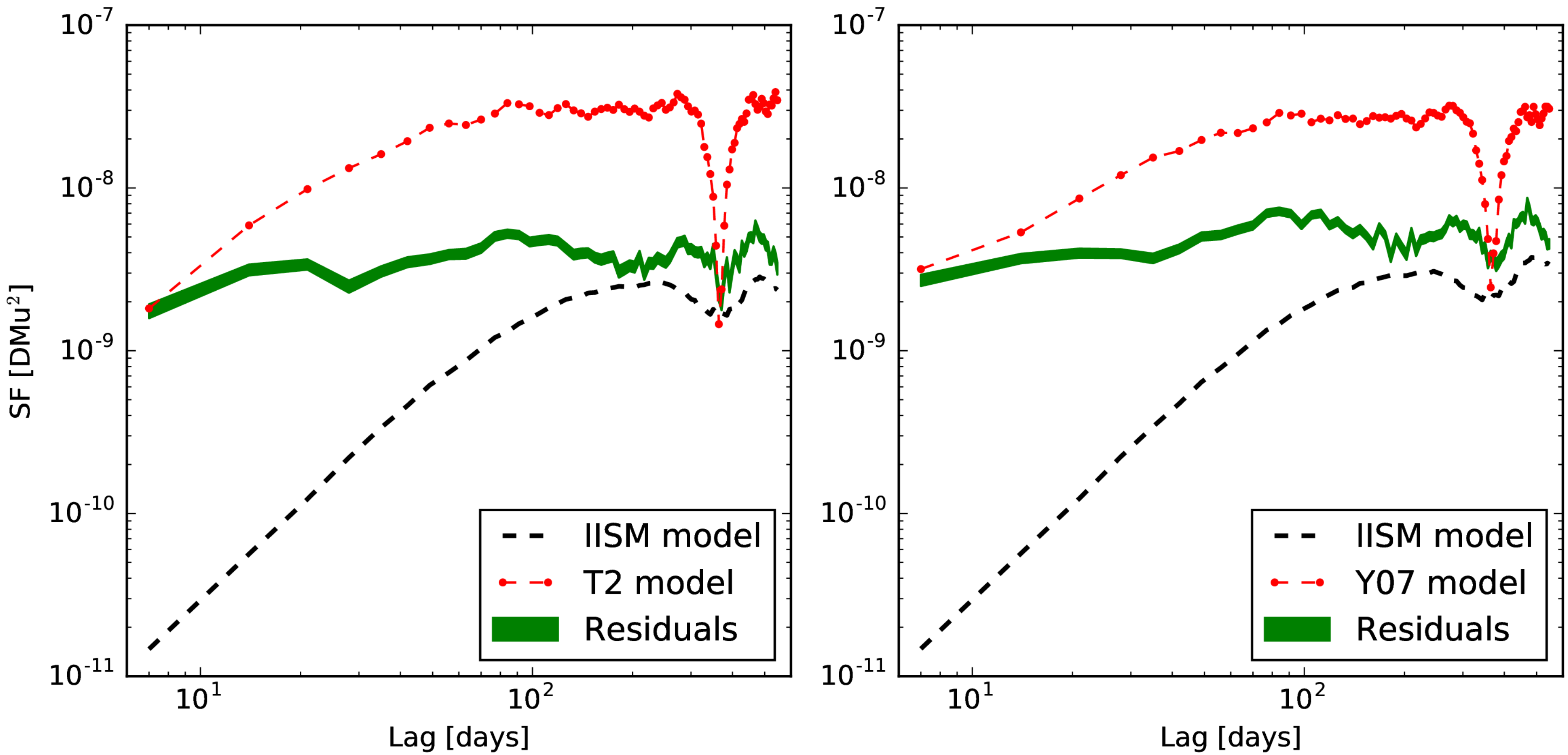
- With Golam Shaifullah and Nataliya Porayko
- Coronal Mass Ejection in August 2014
- Transit in front of PSR 1022+1001 (Elat ~ 0.2 deg)
- Clear detection of the magnetic field signature of the CME

See the LOFAR4SW poster!

Thank you for your attention!

Comparison of structure functions

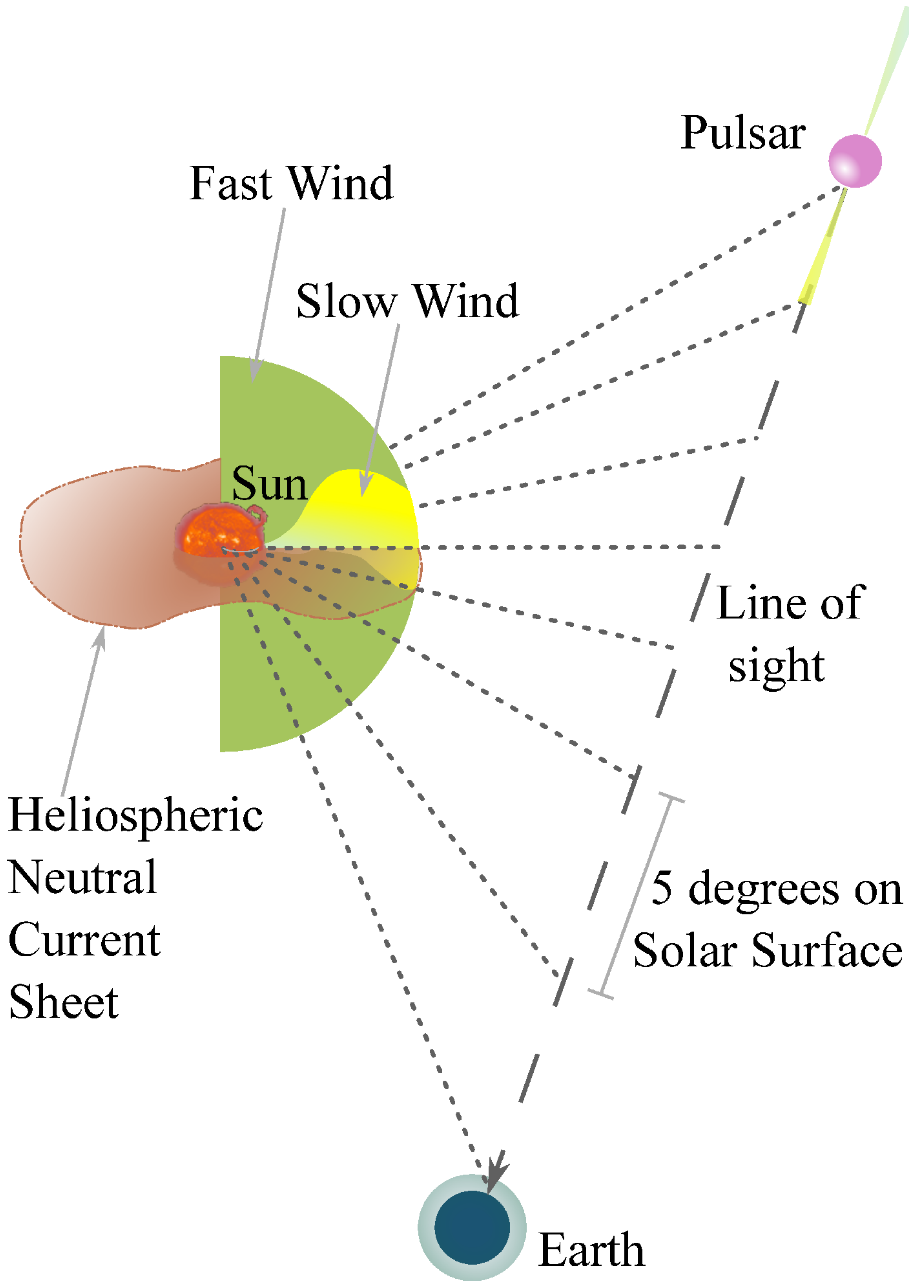
$$DM_{tot}(t) = DM_{IISM}(t) + DM_{SW}(t) + res(t)$$



$$SF_{DM}(\tau) = \left\langle \left(DM(t) - DM(t+\tau) \right)^2 \right\rangle$$

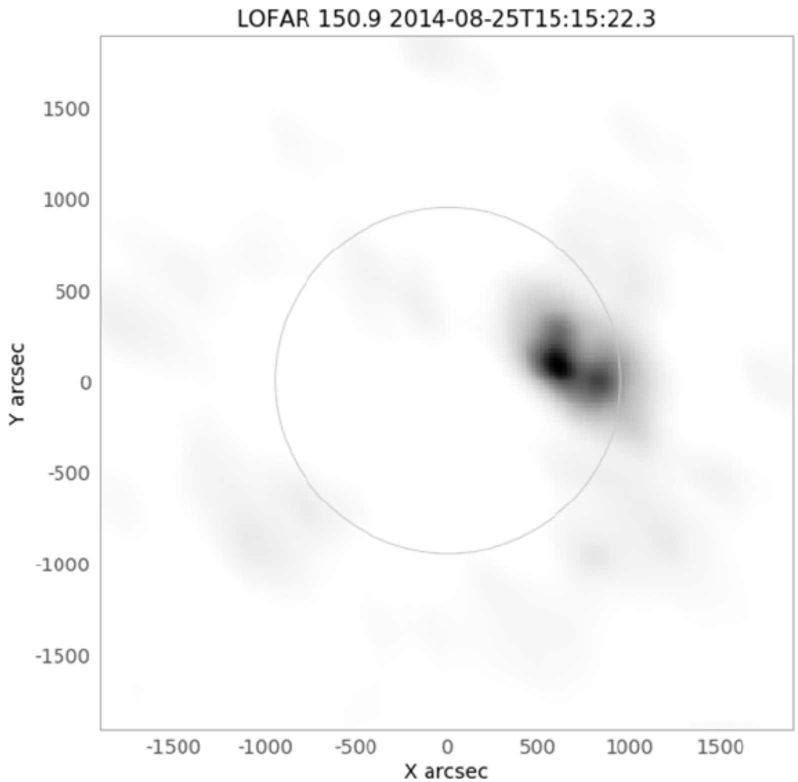
You+07 model

Shaifullah

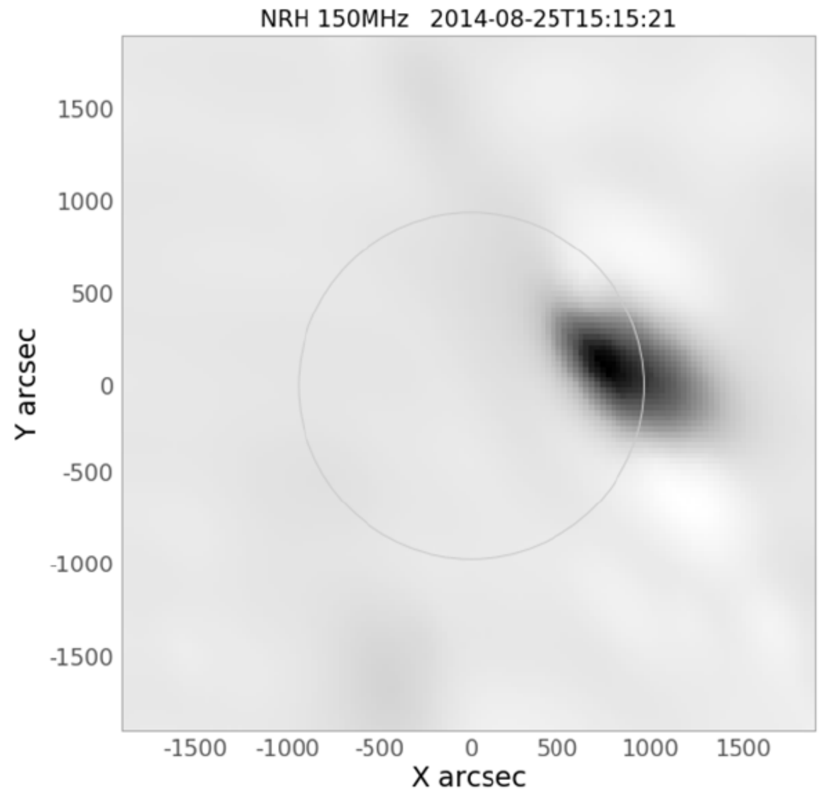


Solar imaging and dynamic spectra

Courtesy of
P. Zucca,
ASTRON



LOFAR core
(~150 MHz)



Nançay Radio Heliograph
(~150 MHz)