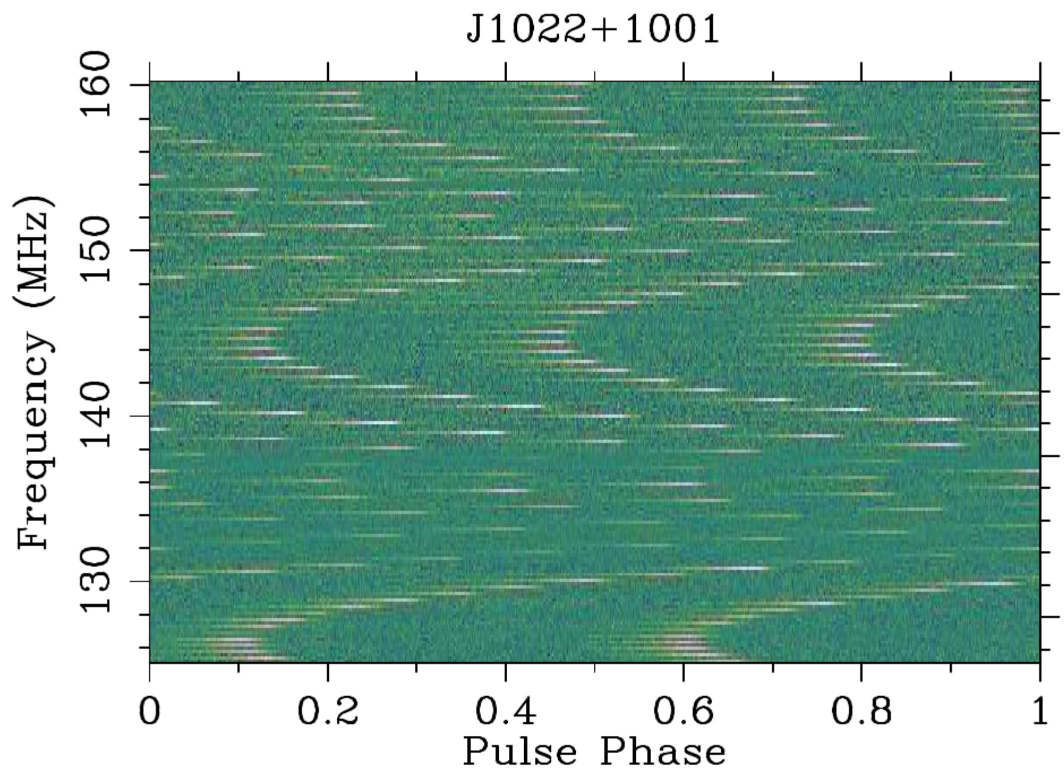
Neutron Star Workshop – 11th of December 2017

Probing the magnetoionic media with millisecond pulsars



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Universität Bielefeld

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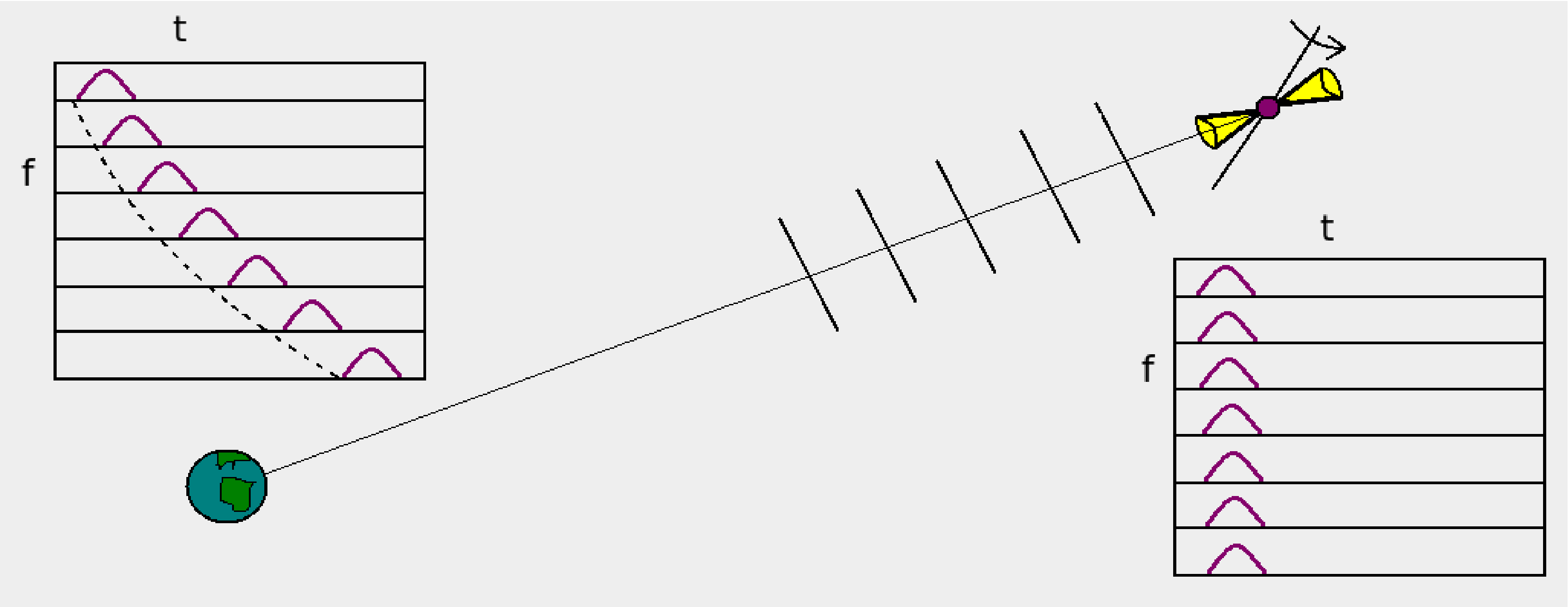
Contents

Dispersion

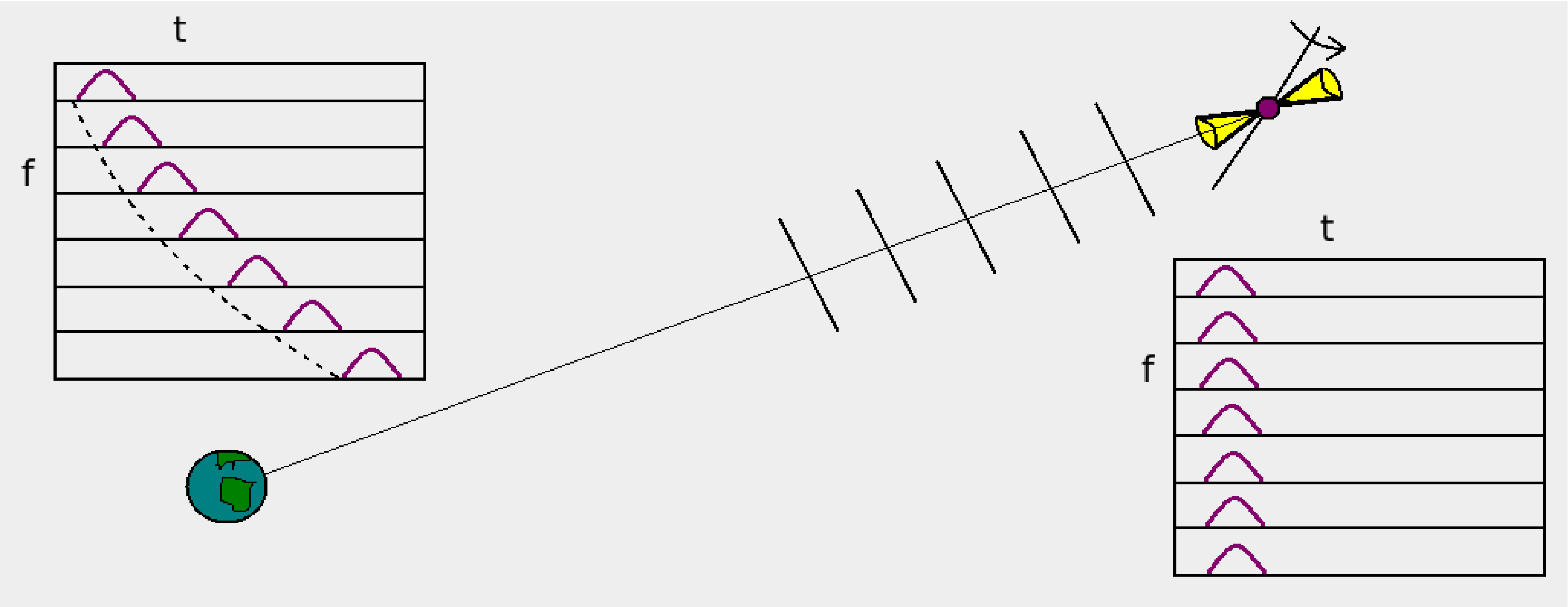


$$\Delta t = \frac{e^2}{2\pi m_e c} \frac{\int_0^d n_e \, dl}{f^2} \propto \frac{DM}{f^2}$$

(And your friend is...

$$DM = \int_0^d n_e \, dl$$

Dispersion



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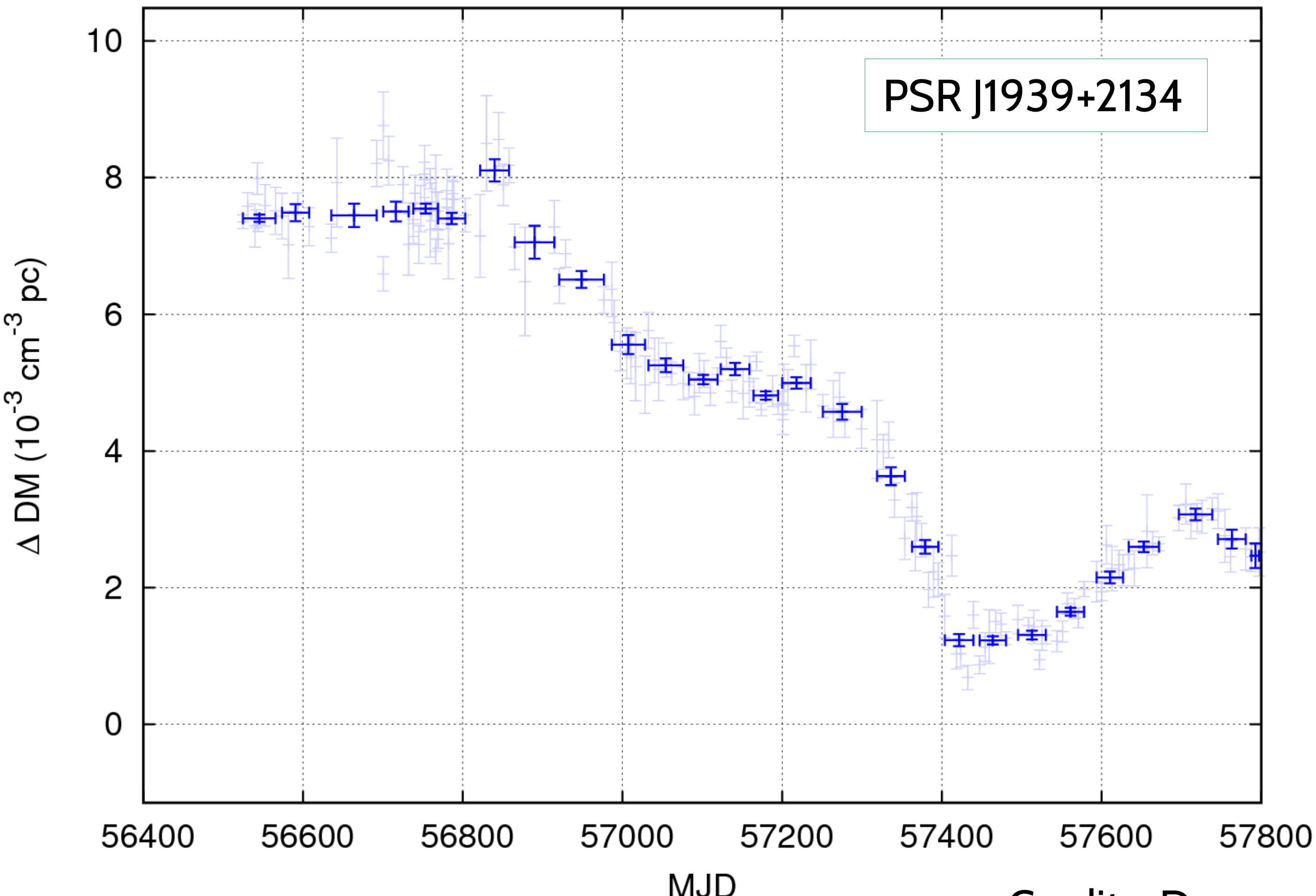
$$DM = \int_0^d n_e \, dl$$

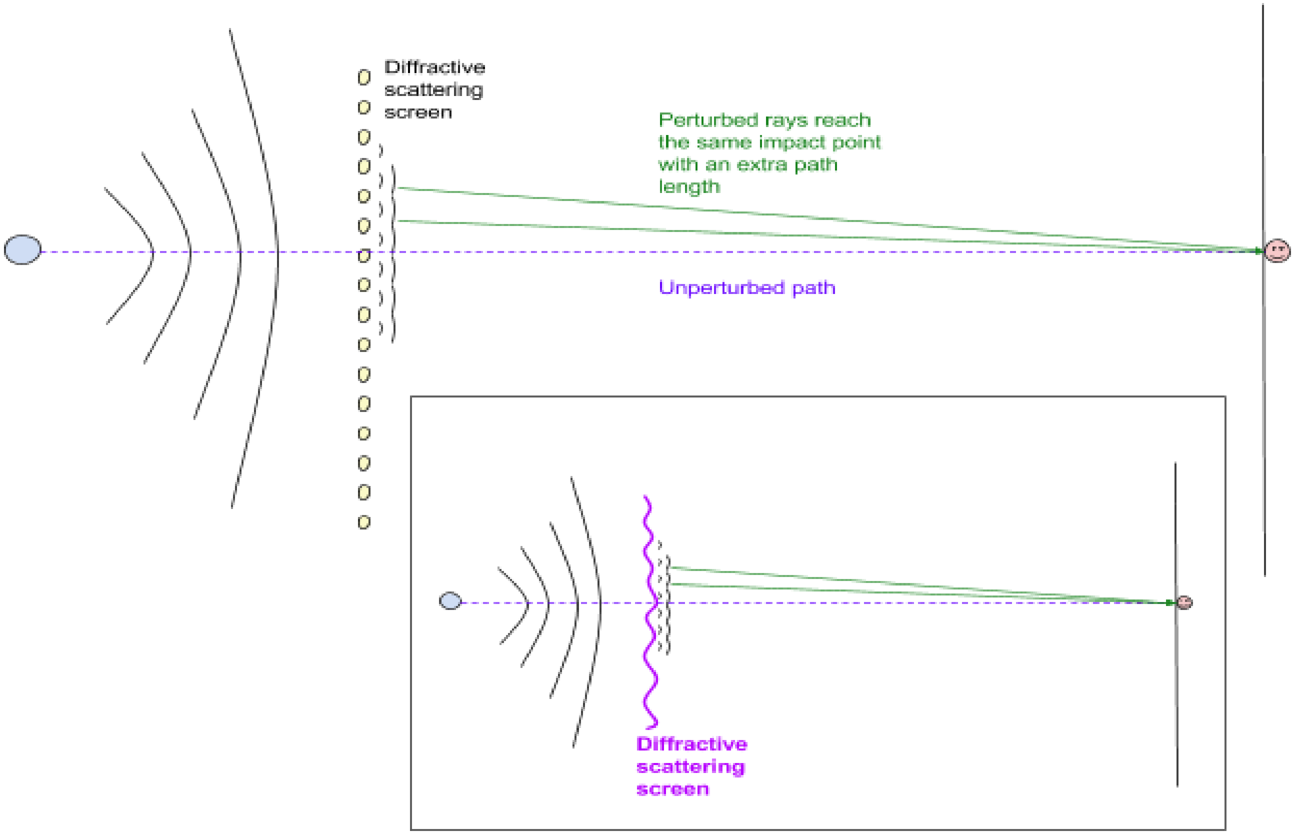
(And your friend is... *PULSAR TIMING*)

Dispersion



Credits: Donner

Scattering



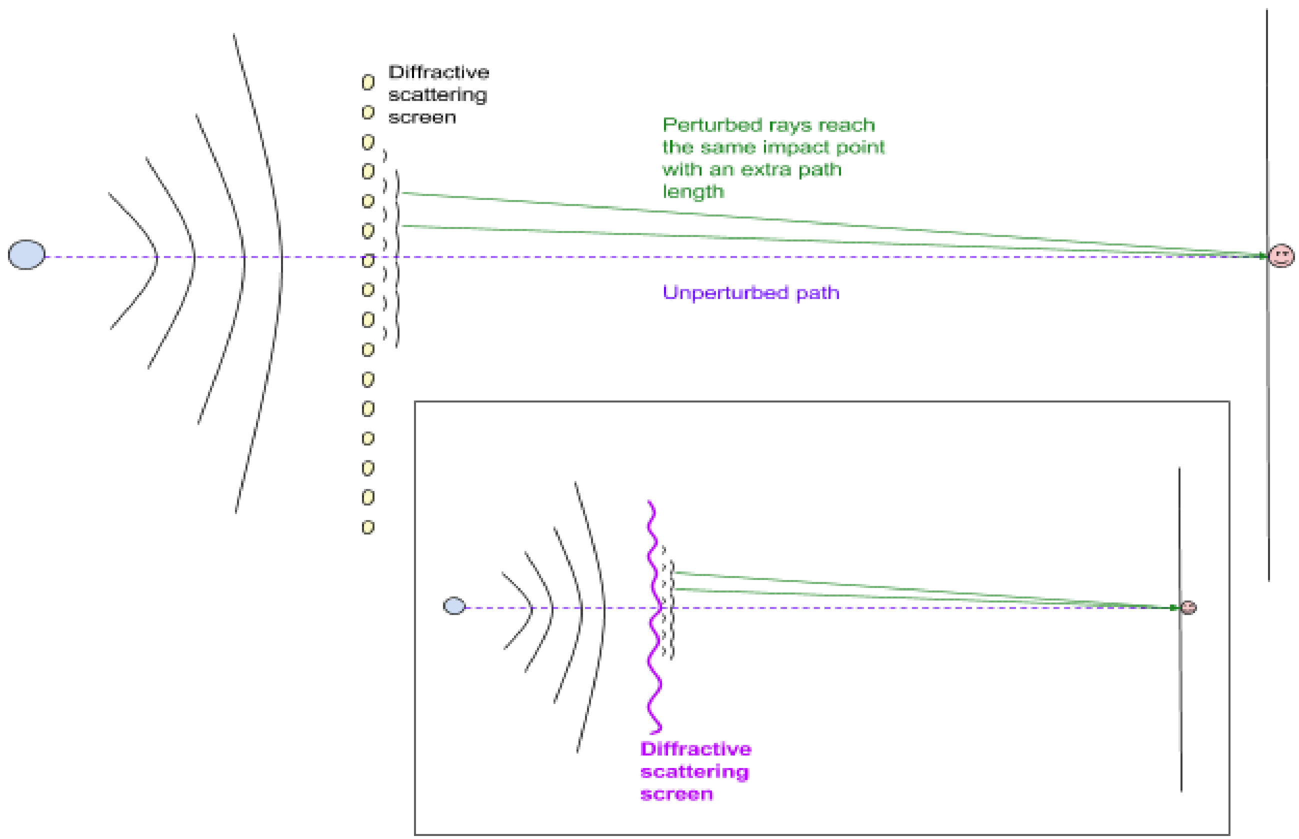
$$I(t)=I_0\exp(t/\tau_s)$$

$$\tau_s=\frac{e^4}{4\pi^2 m_e^2}\frac{\Delta n_e^2}{a}D^2 f^{-4}$$

(Kolmogorov spectrum, thin screen approximation and same-sized inhomogeneities)

(And your friend is...

Scattering



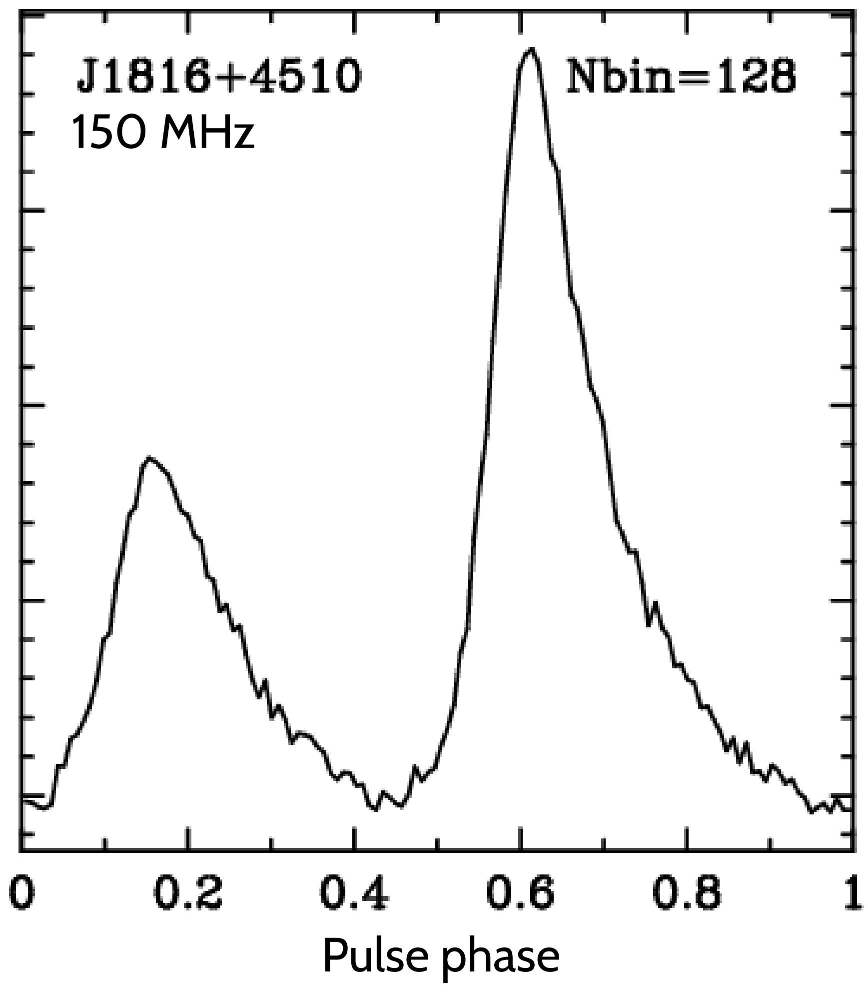
$$I(t) = I_0 \exp(t/\tau_s)$$

$$\tau_s = \frac{e^4}{4\pi^2 m_e^2} \frac{\Delta n_e^2}{a} D^2 f^{-4}$$

(Kolmogorov spectrum, thin screen approximation and same-sized inhomogeneities)

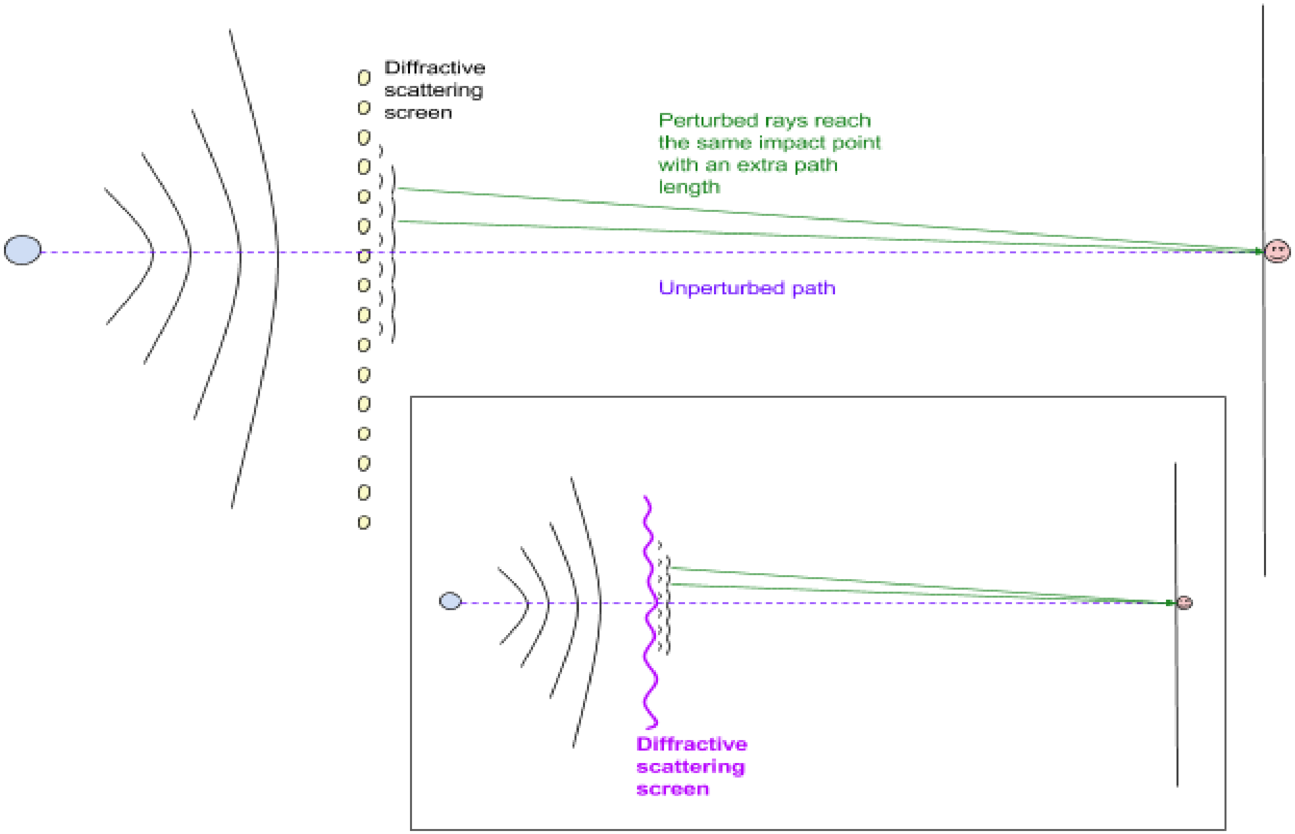
(And your friend is…
a deconvolution algorithm)

Scattering



Credits: Kondratiev et al. 2016

Scintillation



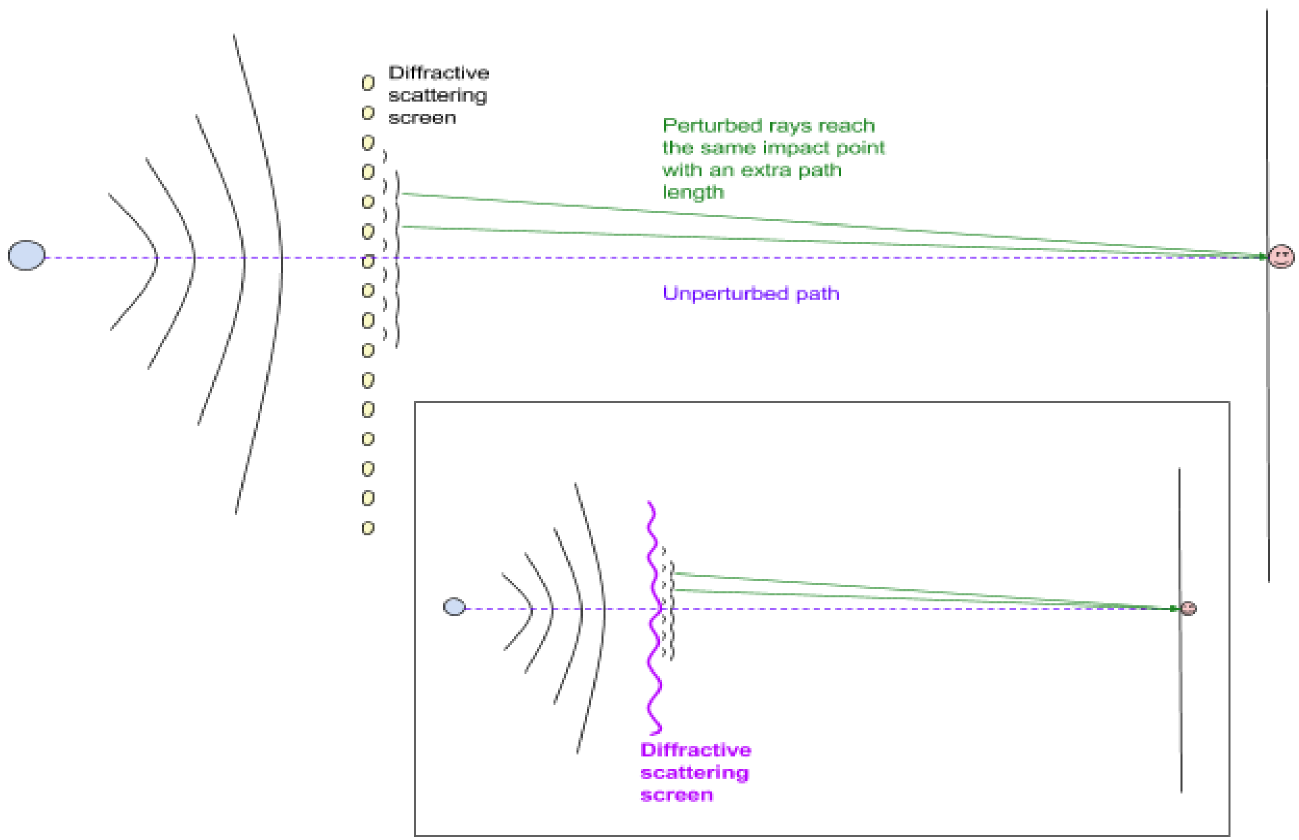
$$\delta\phi \propto 2\pi\Delta f\,\tau_s \sim 1$$

$$\Delta f \propto \frac{1}{\tau_s} \propto f^4$$

(Kolmogorov spectrum, thin screen approximation and same-sized inhomogeneities)

(And your friend is...

Scintillation



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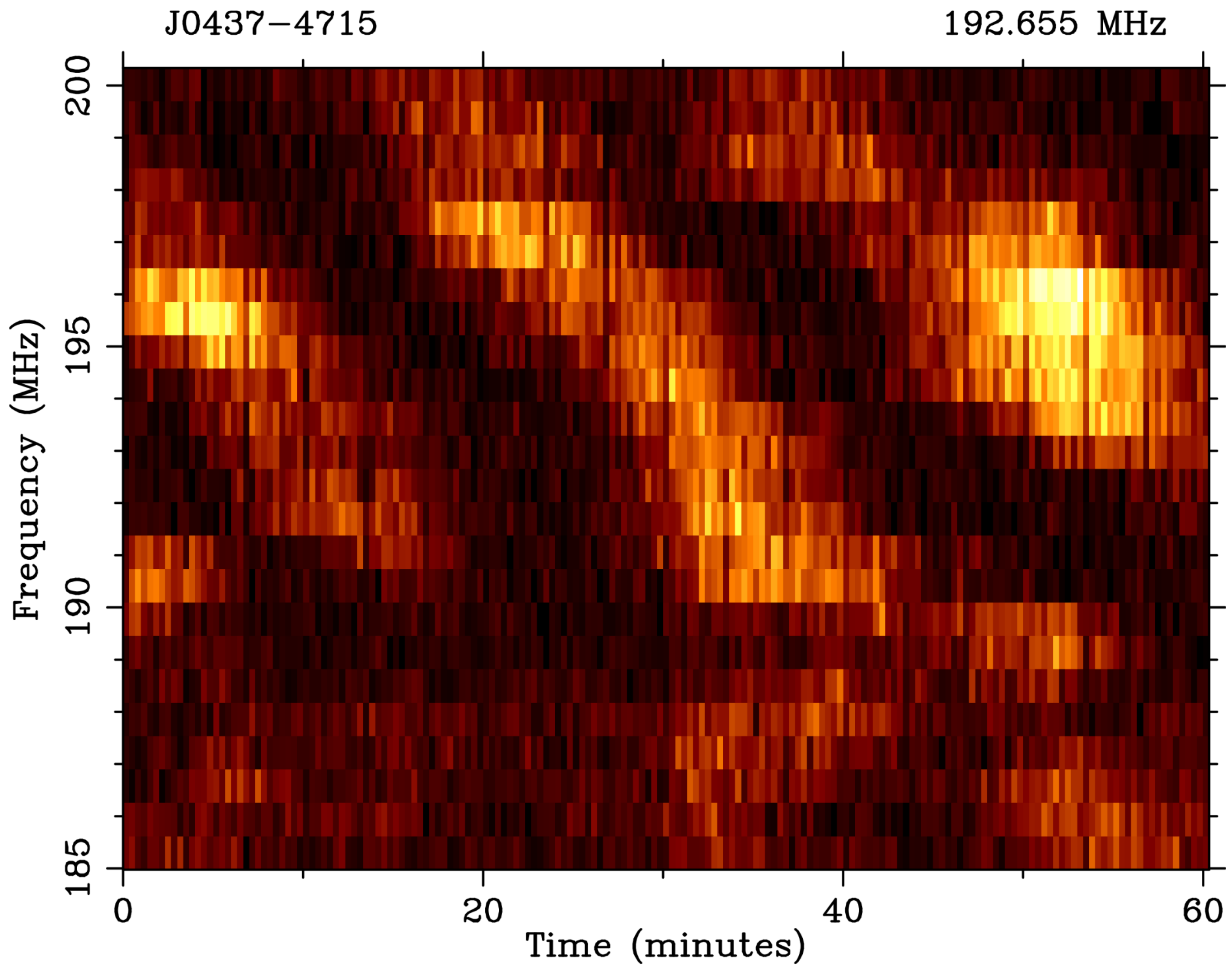
(Kolmogorov spectrum, thin screen approximation and same-sized inhomogeneities)

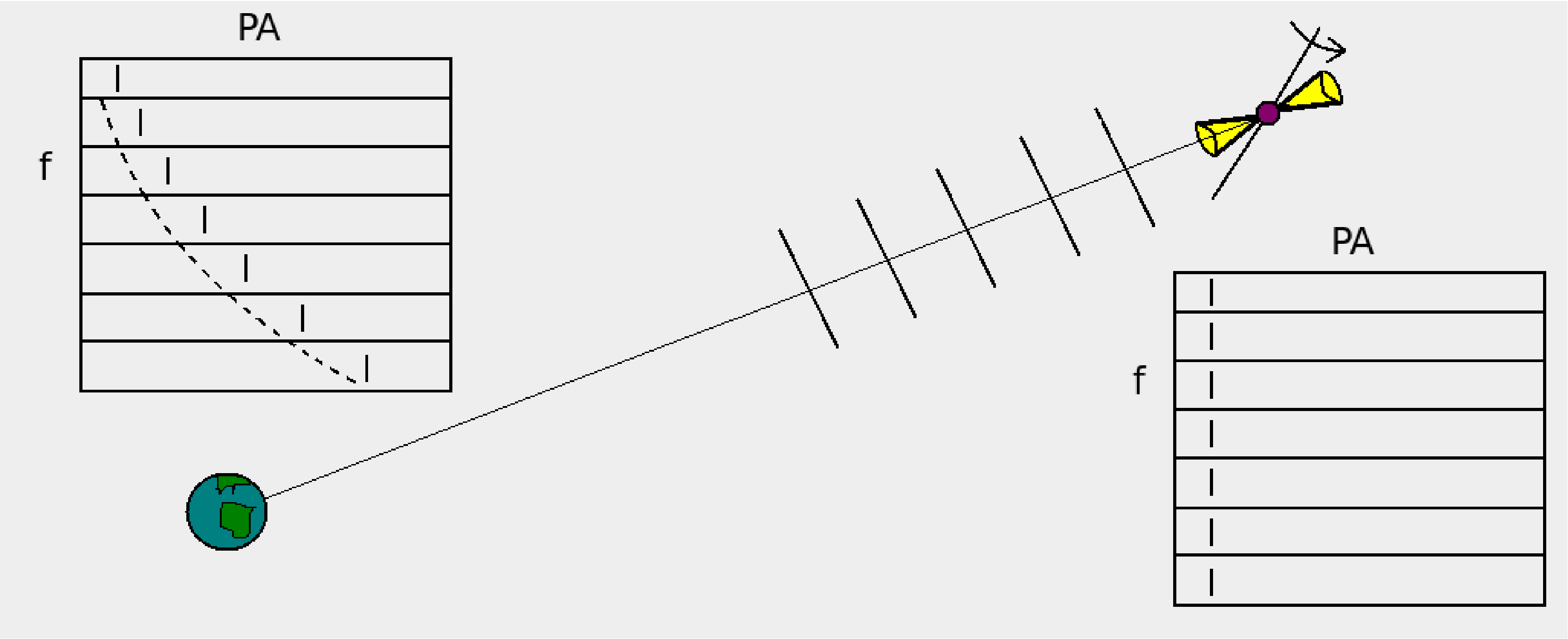
(And your friend is...
the dynamic spectrum and its ACF)

Scintillation



Credits: Bhat et al. 2014

Faraday Rotation

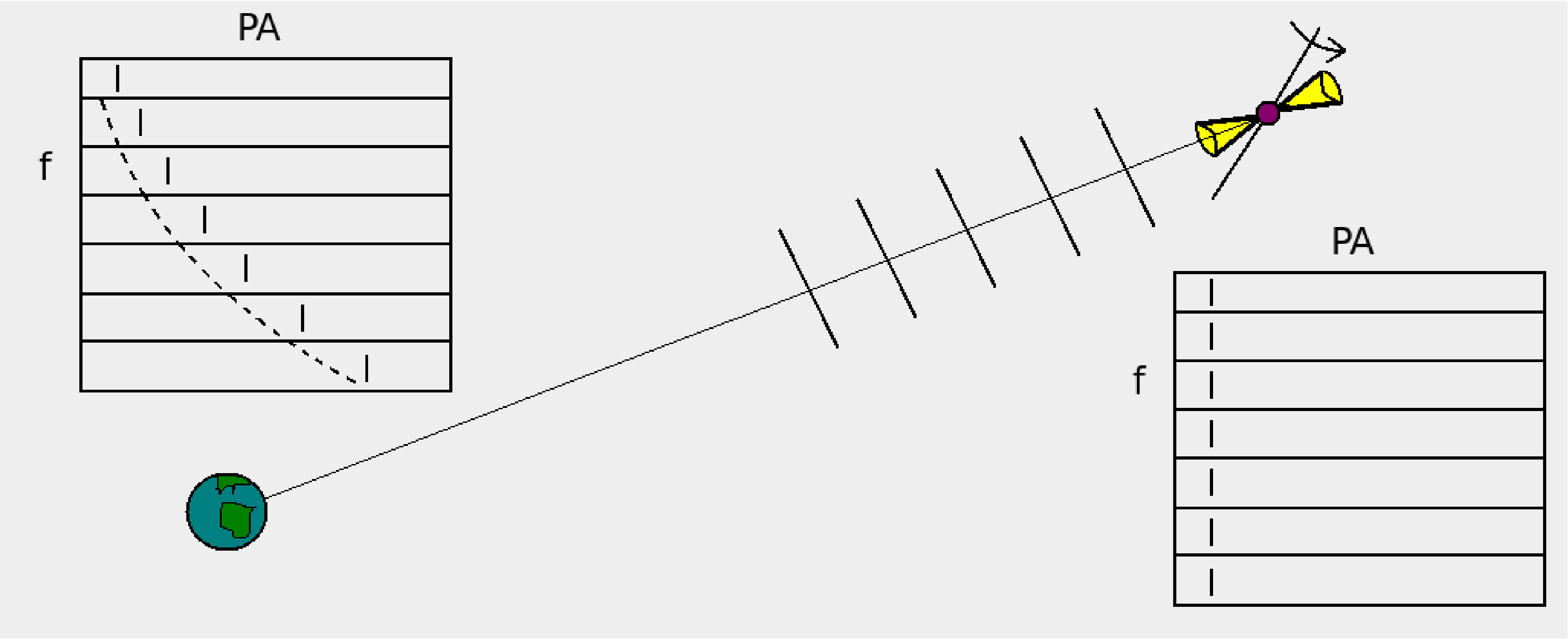


$$\Delta PA = \frac{e^3}{2\pi m_e c^2} \int_0^d n_e B_\| \; dl = c^2 \frac{RM}{f^2}$$

(And your friend is...

$$RM = \frac{e^4}{2\pi m_e} \int_0^d B_\| n_e \, dl$$

Faraday Rotation

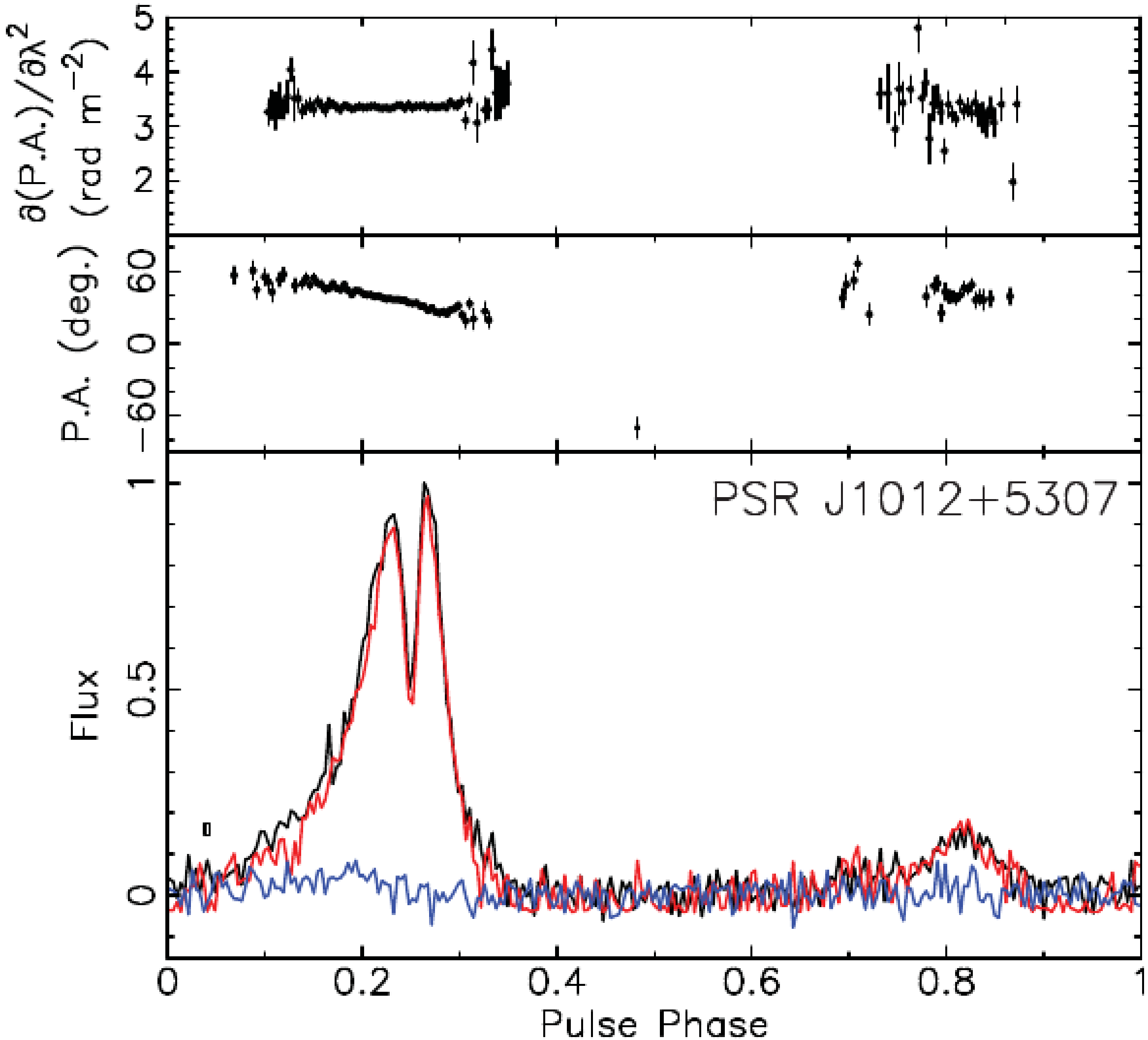


$$\Delta PA = \frac{e^3}{2\pi m_e c^2} \int_0^d n_e B\| \; dl = c^2 \frac{RM}{f^2}$$

$$RM = \frac{e^4}{2\pi m_e} \int_0^d B\| n_e \, dl$$

(And your friend is...
RM SYNTHESIS)

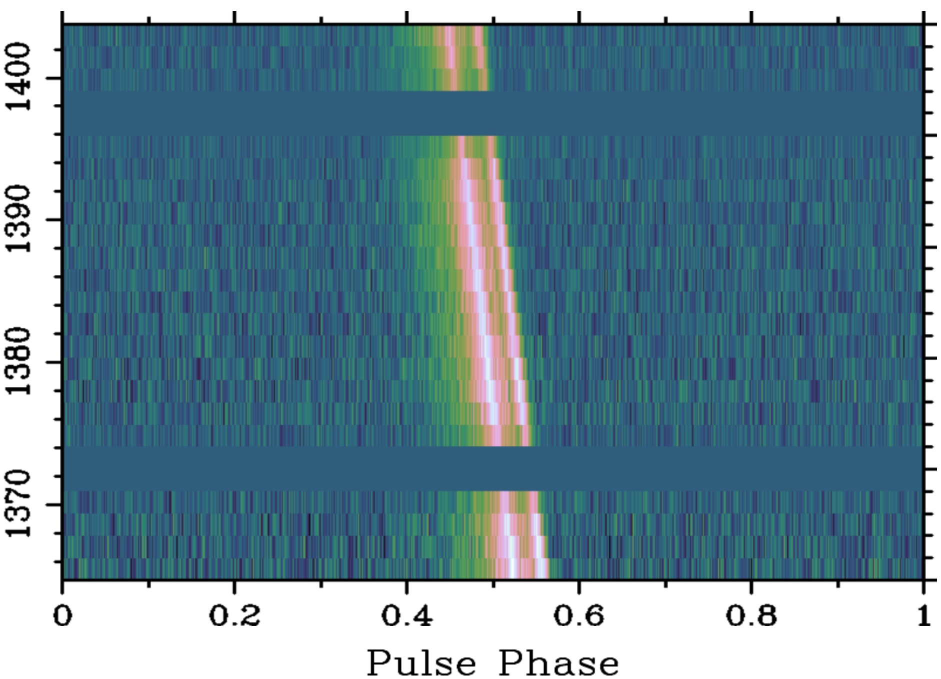
Faraday Rotation



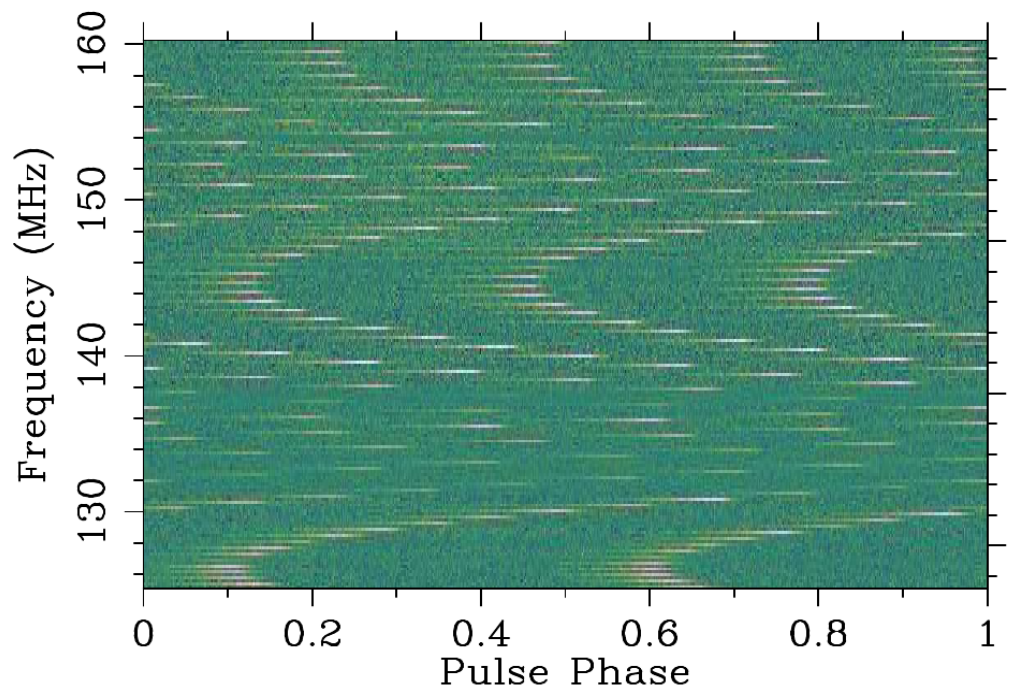
Credits: Noutsos et al. 2015

Low frequencies vs. high frequencies

J1022+1001

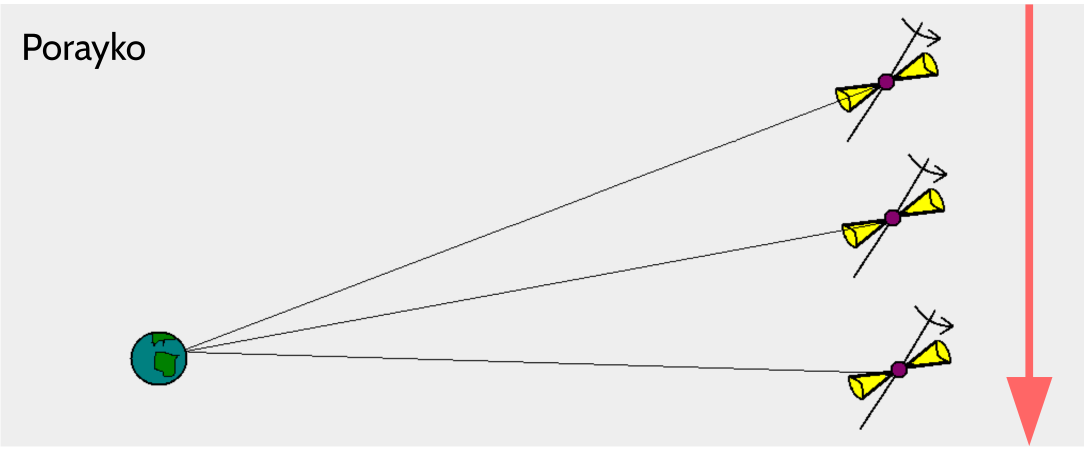


1385 MHz



142 MHz

Tracking DM variations

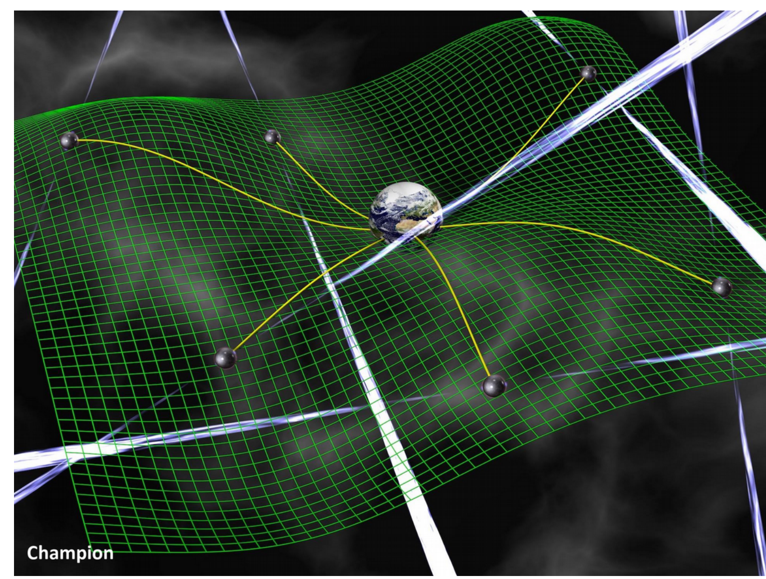


As a pulsar moves in the sky, its line-of-sight crosses different portions of the ionised interstellar medium (IISM), and its DM can vary

DM variations tell us about the structure of the IISM

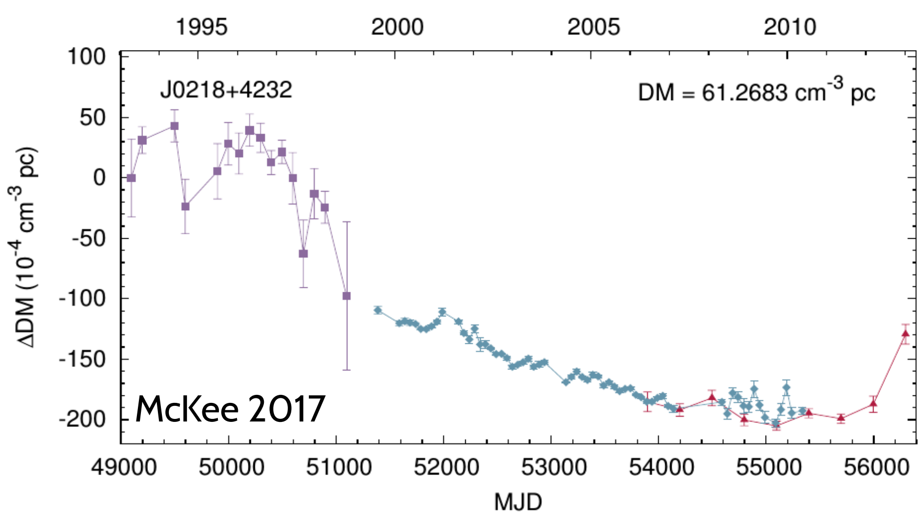
For ***Pulsar Timing Arrays*** it is necessary to characterise the red noise in the timing residuals

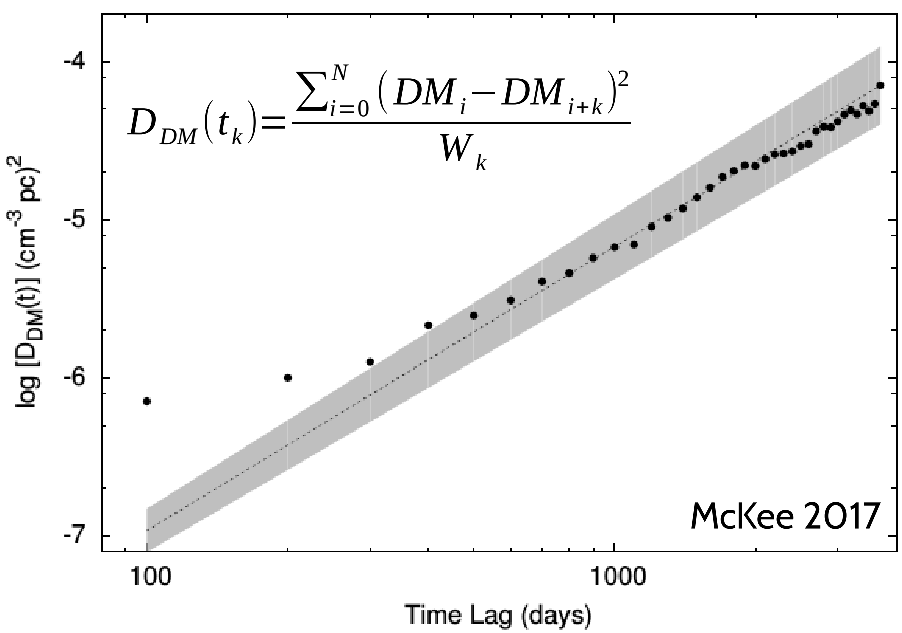
DM variations are one of the main sources of red noise in pulsar timing!



DM variations from 31 MSPs from the EPTA

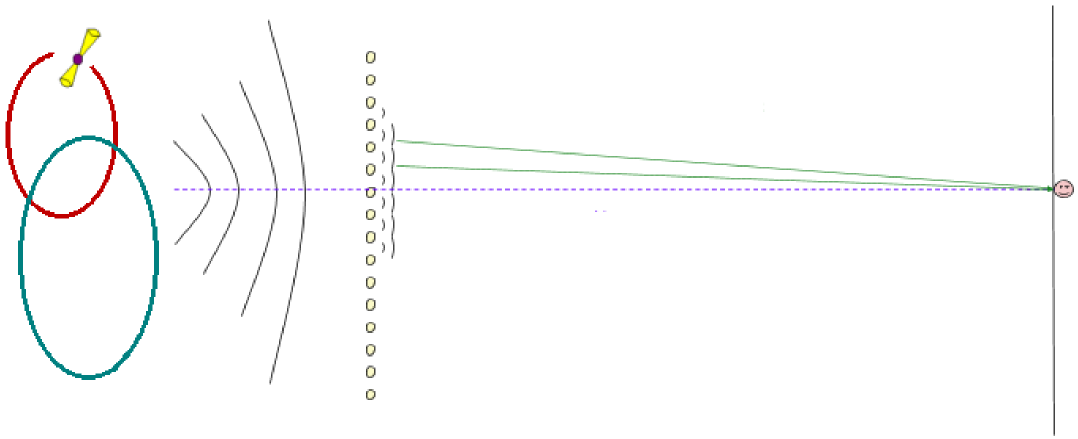
(McKee, PhD thesis 2017; Janssen, McKee et al. in prep)





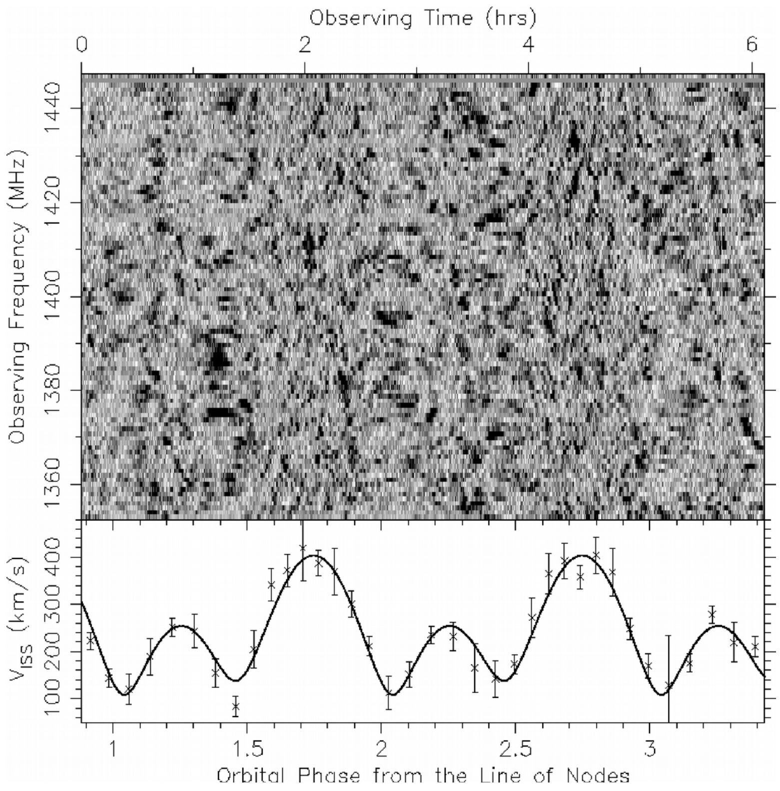
- 31 EPTA MSPs searched for DM variations in multifrequency data;
- Average DM values obtained over time windows from 50 to 500 days;
- Structure functions;
- Minimum detected DM variation size of 10^{-4} pc/cm^3
- Attempted back-correction of the timing residuals using DM derived from low-f data;
- Low-frequency data allow precise DM measurements, and an improvement of the rms in timing residuals.

Scintillation speed



$$V_{ISS} = A \frac{\sqrt{d[kpc] \;\; \Delta f_{DISS}[MHz]}}{f[GHz] \;\; \Delta t_{DISS}[s]}$$

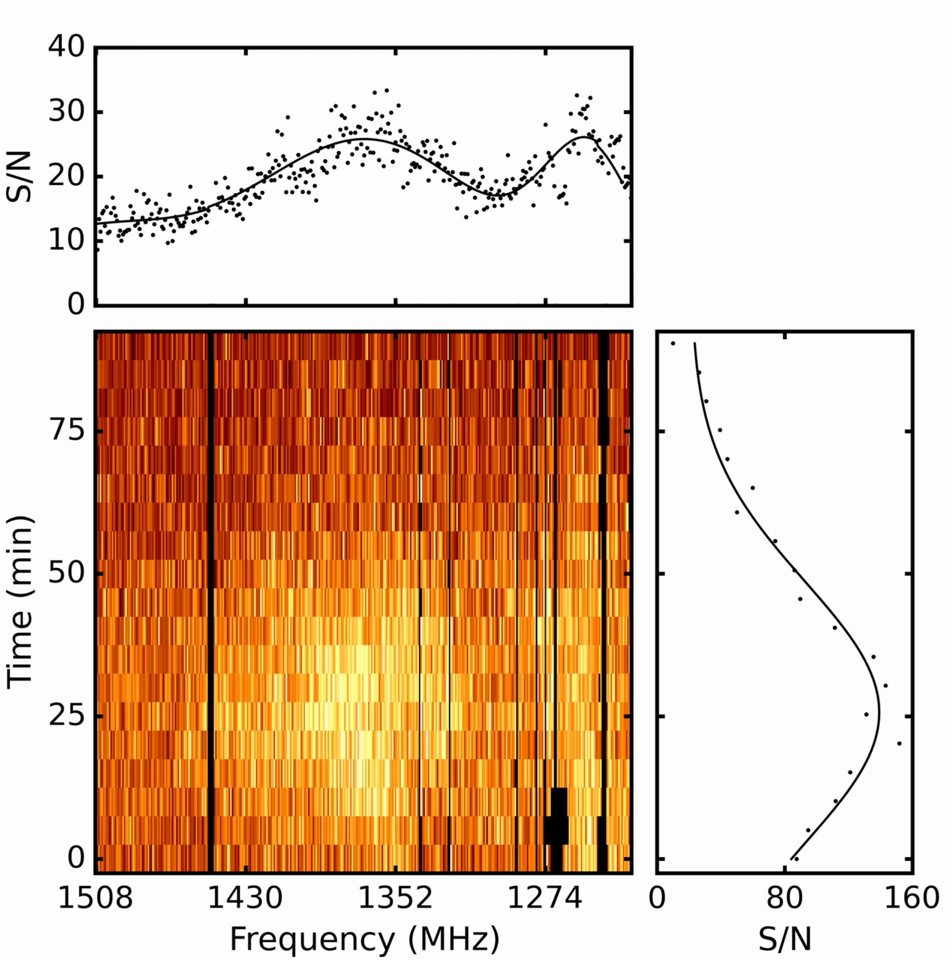
- Dynamic spectrum at regular intervals during the orbit;
- V_{ISS} as a function of orbit (expressed in terms of the true anomaly);
- V_{ISS} can be encapsulated in a geometrical model and expressed in terms of 4 free parameters, including the ***inclination of the orbital plane***



Ransom et al. 2004; Coles et al. 2005

Limits on the mass, velocity and orbit of PSR J1933-6211

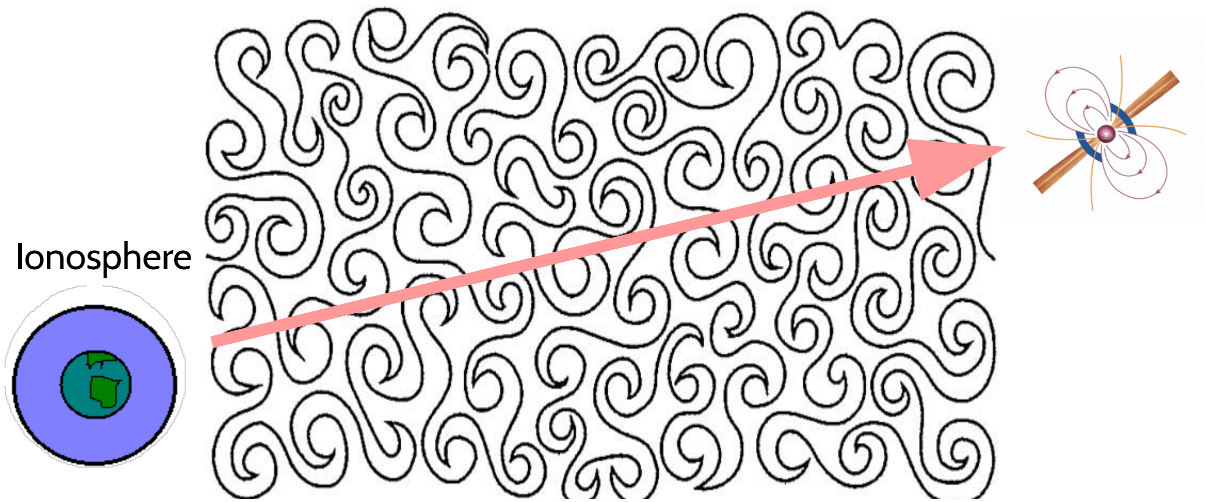
(Graikou et al. 2017)



Graikou et al., 2017

- Data from the Parkes radio telescope ;
- 2 complete scintles measured at the same orbital phase;
- V_{ISS} ~ 36 km/s;
- Orbital inclination limited to be below 32 degrees or between 61 and 75 degrees;
- Mass of the companion lower than 0.44 Solar masses.

RM determination and magnetic field



Credits: Porayko

RM and DM values allow to compute the ***average component of the magnetic field along the line of sight***

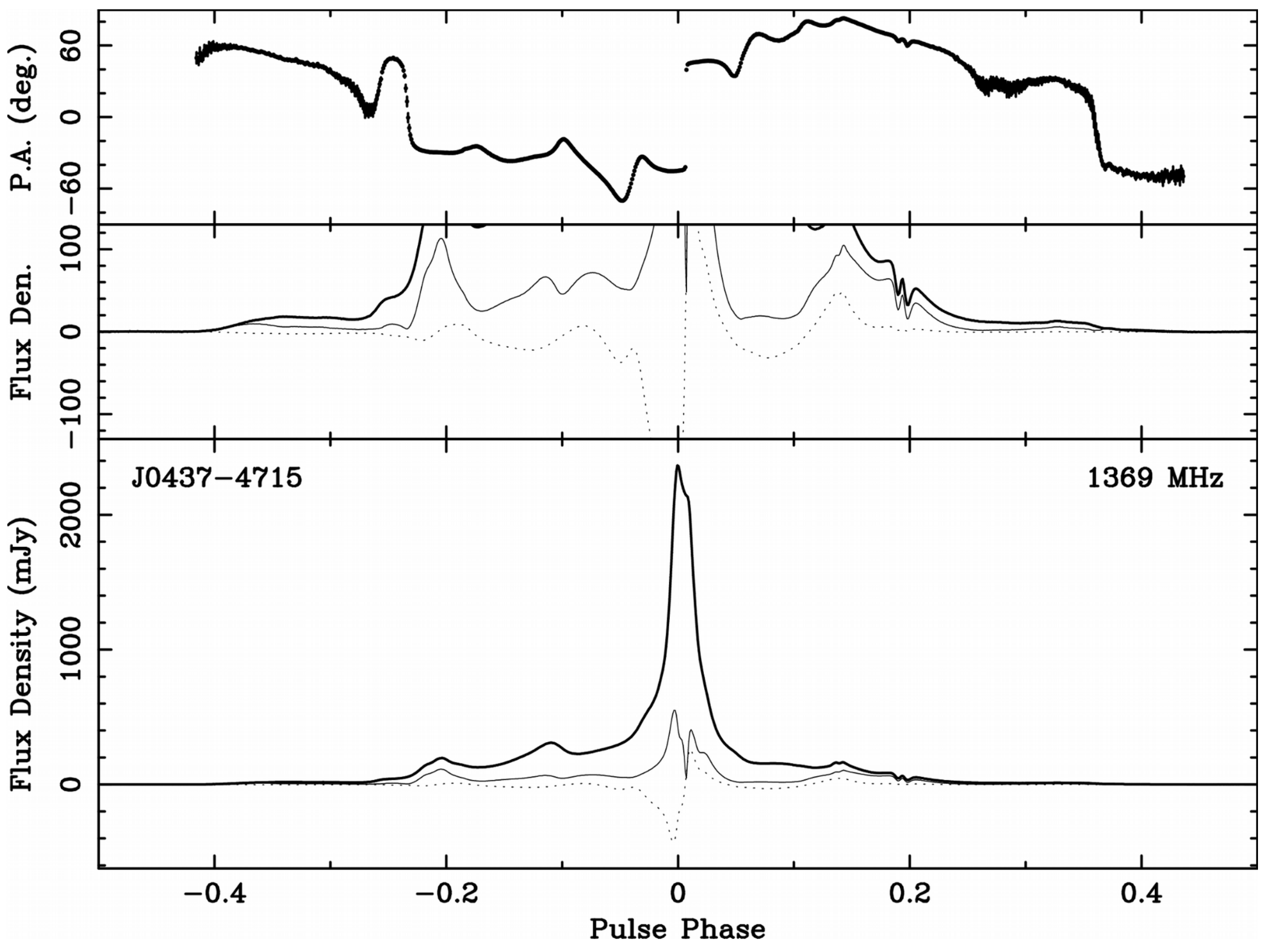
$$B||_{avg} \propto RM / DM$$

The ionosphere needs to be considered to infer the interstellar RM. ***Predicting the ionospheric RM***, through geomagnetic field models and TEC maps, ***is a very tricky task***

MSPs are disadvantaged in polarimetric studies, as ***less bright***, on average, than long period pulsars

Polarization observations of 20 MSPs

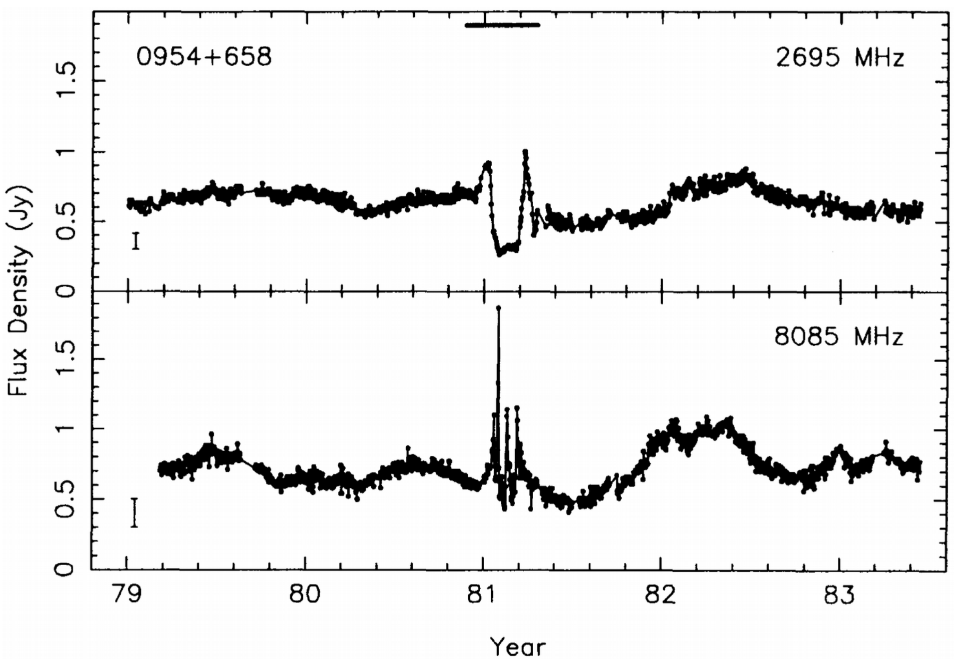
(*Yan et al.* 2011)



Yan et al., 2011

- Data from the Parkes radio telescope ;
- Ionospheric RM corrected with the FARROT sw;
- RM computed by applying the Faraday rotation equation to the polarisation angles in two halves of the band;
- 8 new RMs

Extreme scattering events



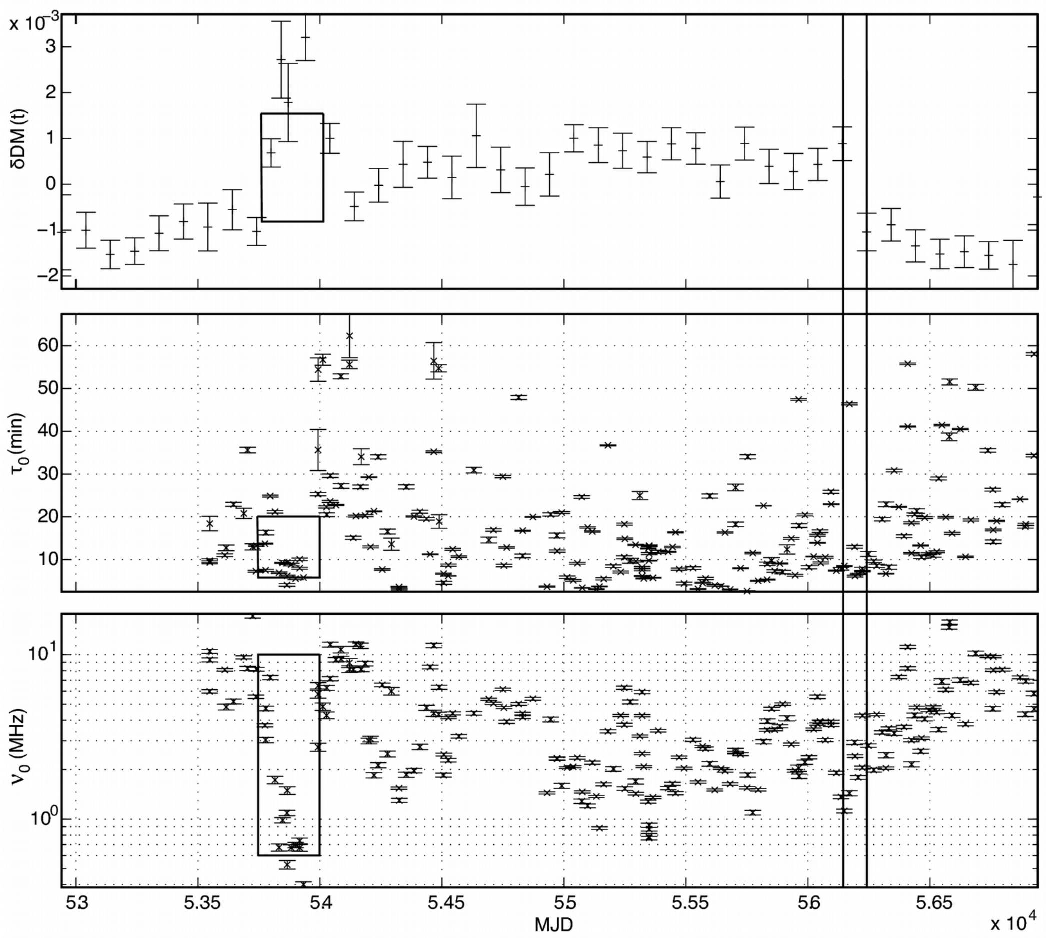
Fiedler et al. 1987

Strong flux variations happening on a month time-scale, ***associated with the passage of a dense, refractive lensing structure***.

With pulsars, the refraction of the radiation path and the increased electron density can broaden the pulse profile and induce structures in the timing residuals

Pulsar observations of ESE

(Coles et al. 2015)



Coles et al., 2015

- Data from the PPTA monitoring at the Parkes radio telescope ;
- ESEs identified in two MSPs, J1603-7207 and J1017-7156;
- In the first case, the scattering agent is likely to be located midway and shell-like
- In the second case, it is closer to the pulsar and also likely shell-like

See also...

DM variations of MSPs

Keith et al. 2013; Lam et al. 2016; Jones et al. 2017

Scintillation studies of MSPs

Coles et al. 2005; Bhat et al. 2014, 2016; Archibald et al. 2014

Polarimetry of MSPs

Keith et al. 2012; You et al. 2012; Burgay et al. 2013; Dai et al. 2015

Scattering analyses of MSPs

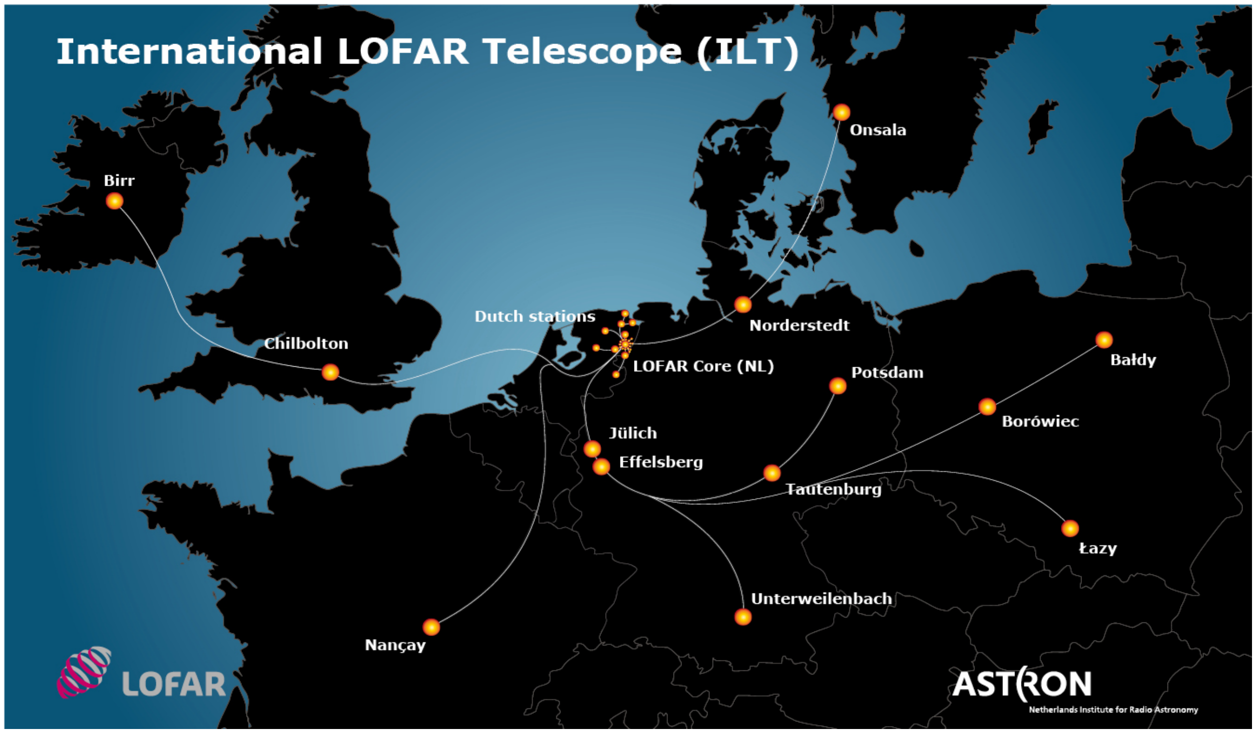
Walker et al. 2013; Levin et al. 2016

Pulsars as Solar wind trackers

C. **Tiburzi**, J. **Verbiest**, W. **Coles**, N. **Porayko**,
G. **Janssen**, G. **Shaifullah** and R. **Fallows**

- Pulsars can probe the Solar wind at large angular distances from the Solar disk (You et al. 2007/2012);
- The Solar magnetic field is obtained independently of electron content models;
- Pulsars can probe different lines of sight at the same time;
- Pulsars can be used to track coronal mass ejection (Howard et al. 2016).

LOFAR



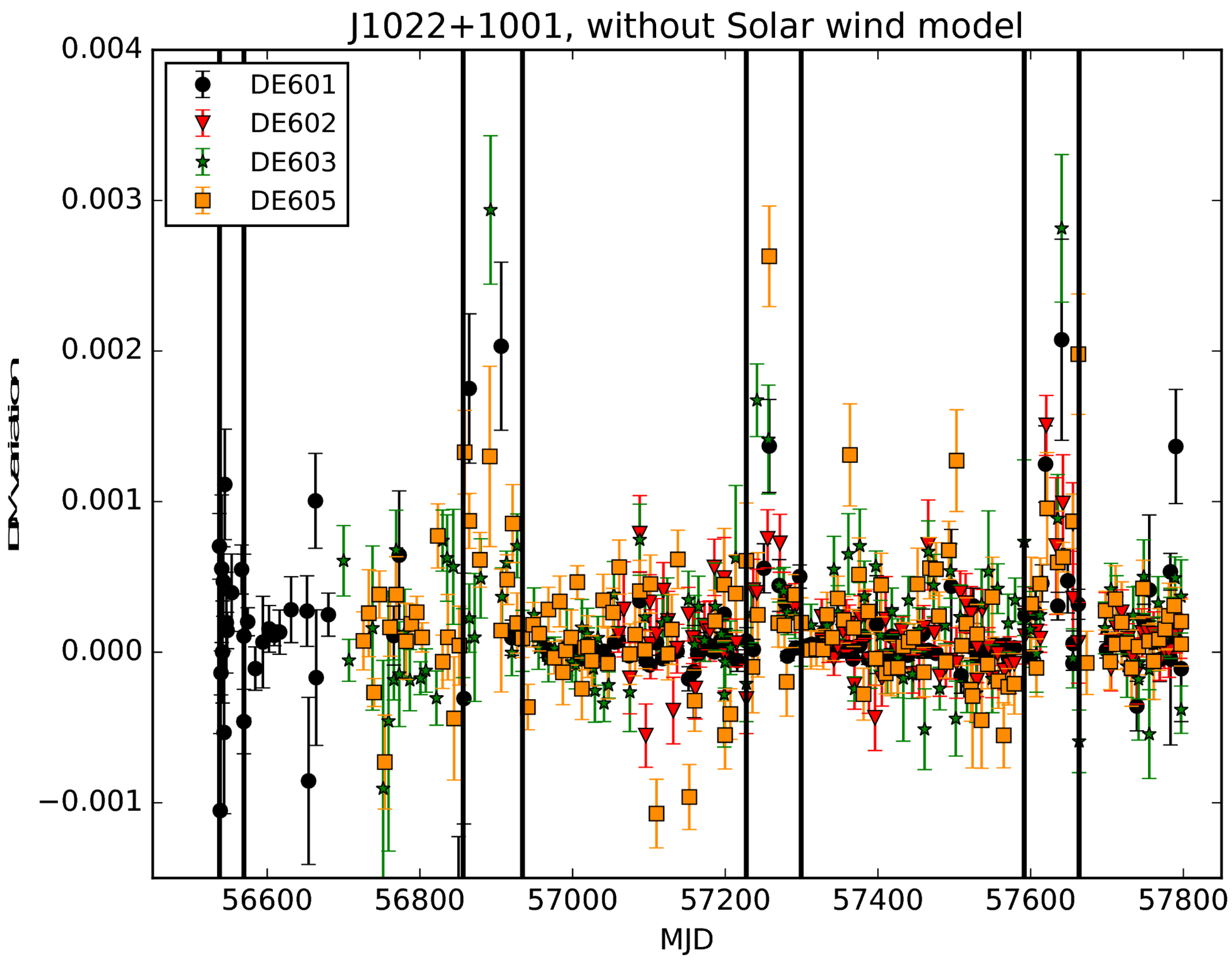
- Frequency range from 10 to 240 MHz, divided in Low band (10-90 MHz) and **High band (110-240 MHz)**;
- 24 + 14 stations in the Netherlands;
- 13 international stations;
- **Germany hosts 6** of them, mainly dedicated to pulsar monitoring;
- Campaign started in 2013;
- >100 pulsars observed per week

Credits: ASTRON

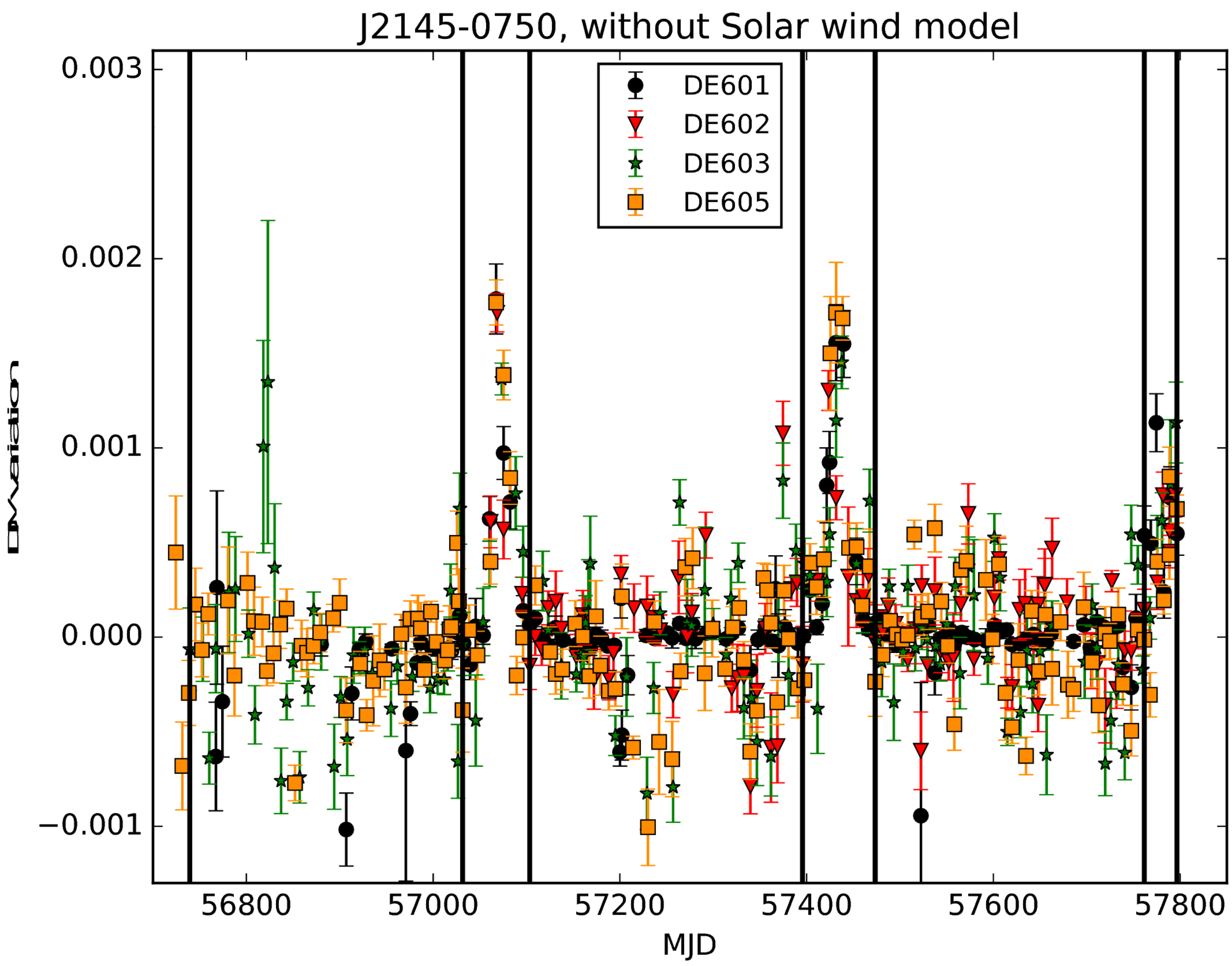
Pulsars

Pulsar	Period [s]	DM [pc/cm^3]	RM [rad/cm^2]	Elat [deg]	Observing stations
J1022+1001	0.0164	10.2521	-0.6	-0.06	DE601 DE602 DE603 DE605
J2145-0750	0.0161	8.9977	-1.3	5.31	DE601 DE602 DE603 DE605
J0034-0534	0.0019	13.76517	-	-8.53	DE601 DE602 DE603 DE605

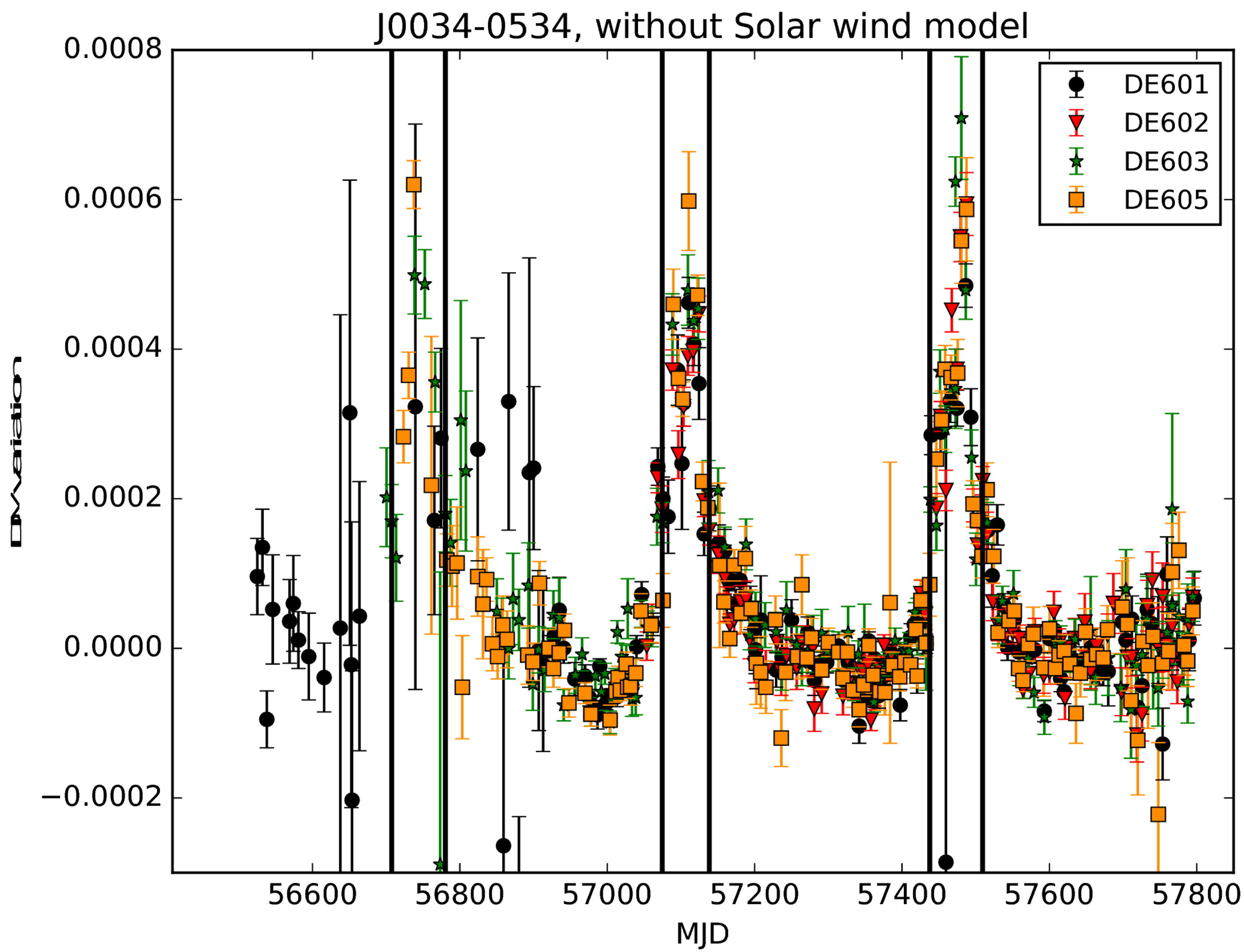
J1022+1001, DM variations



J2145-0750, DM variations



J0034-0534, DM variations



RM analysis, a challenge

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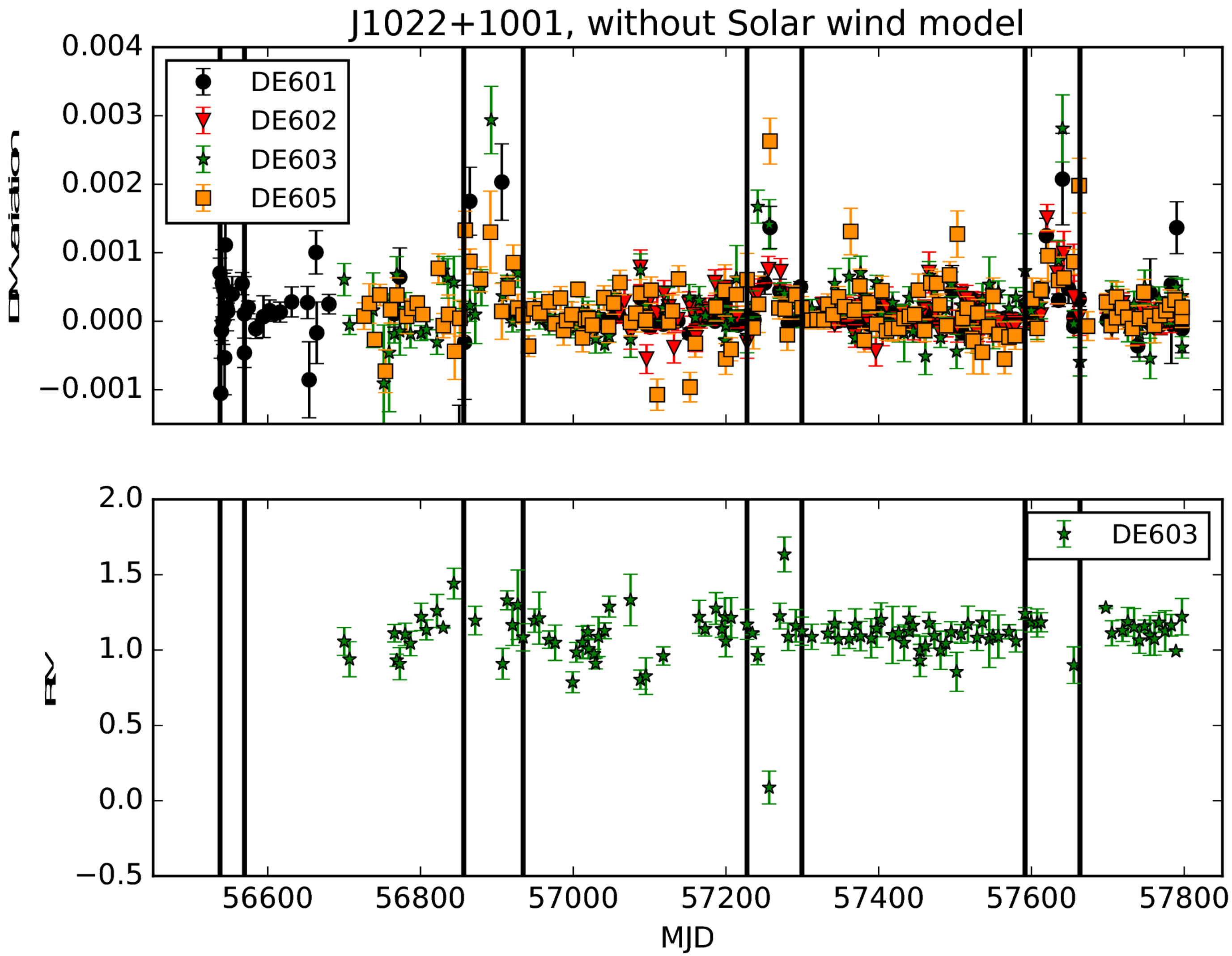
- Modified Rmsynthesis (Porayko et al., in prep)
- Ionospheric contribution (Porayko et al., in prep);
- Difficult for RMsynthesis because of the small RM value, that is absorbed by the instrumental bias;
- Weak pulsars!
- Not enough polarization?

J1022+1001, DM and RM variations



Tiburzi

Porayko

- We have summarised the classical propagation effects and seen examples of their effects on MSPs
- Low-frequency is the way to go to monitor interstellar and interplanetary media!
- The most important effect that MSPs can pin is the variation in electron content along the line-of-sight
- Pulsars are effective Solar wind trackers
- MSPs are invaluable tools to probe the Solar signature in DM
- … not so great to probe the Solar signature in RM
- Still working on it!

Thank you for your attention