Studies of interstellar scintillation and scattering of pulsars using polish LOFAR stations

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The interstellar medium (ISM)

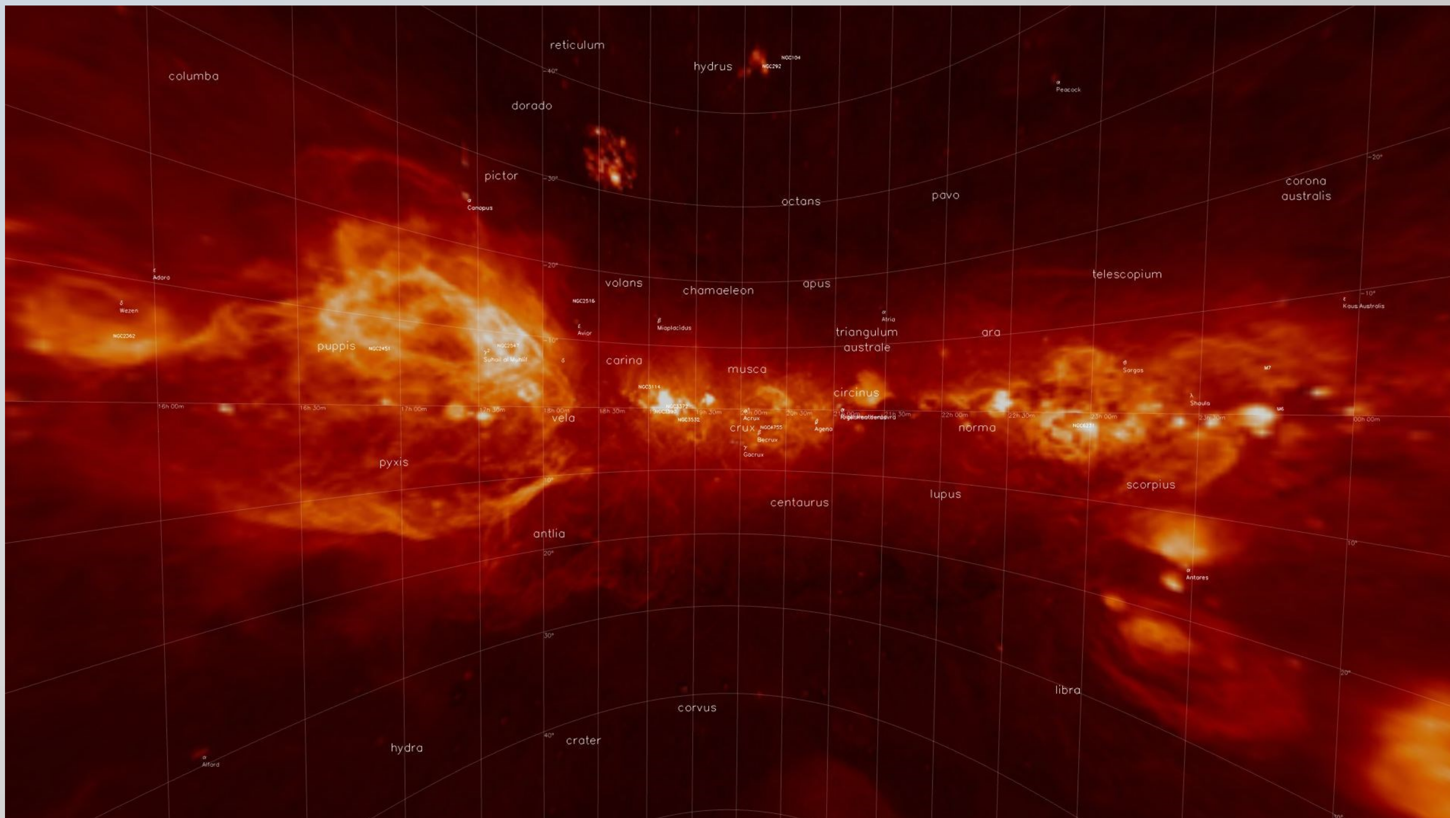
- **Molecular clouds**
- **Dust clouds (dark nebulae)**
- **Emission nebulare (ionized matter)**

Ionized medium

(and free electrons) in the ISM:

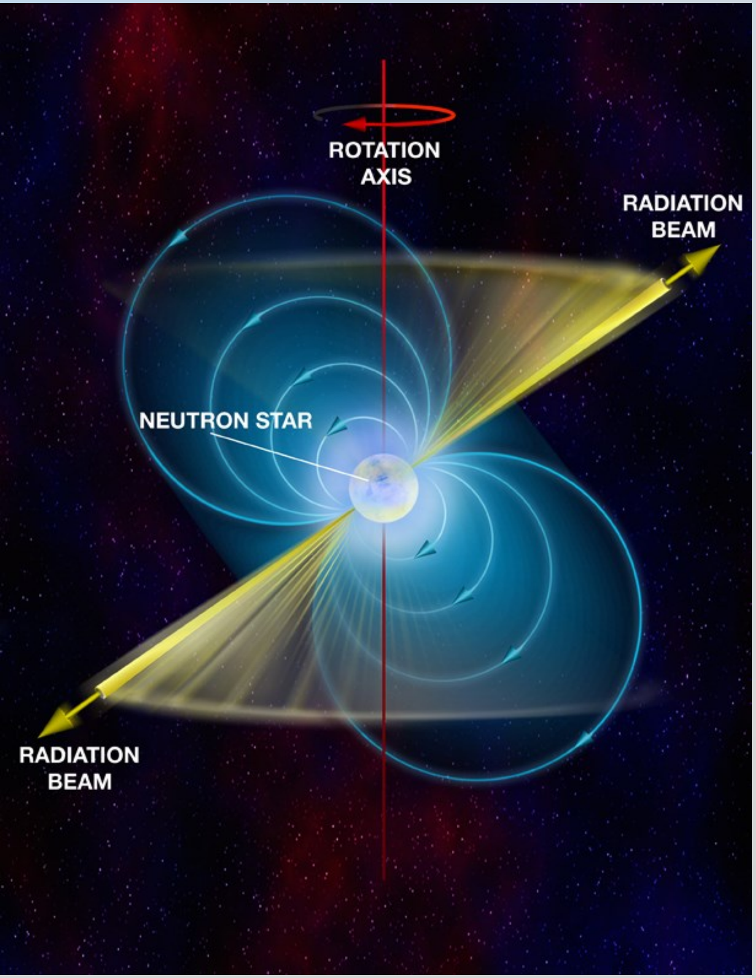
- Supernova remnants
- *HII* regions
- Galactic Disk component

The Milky Way galaxy in *Hα* – an indicator of the ionized medium



Composite of the Virginia Tech Spectral line Survey (VTSS)

The basics of pulsars

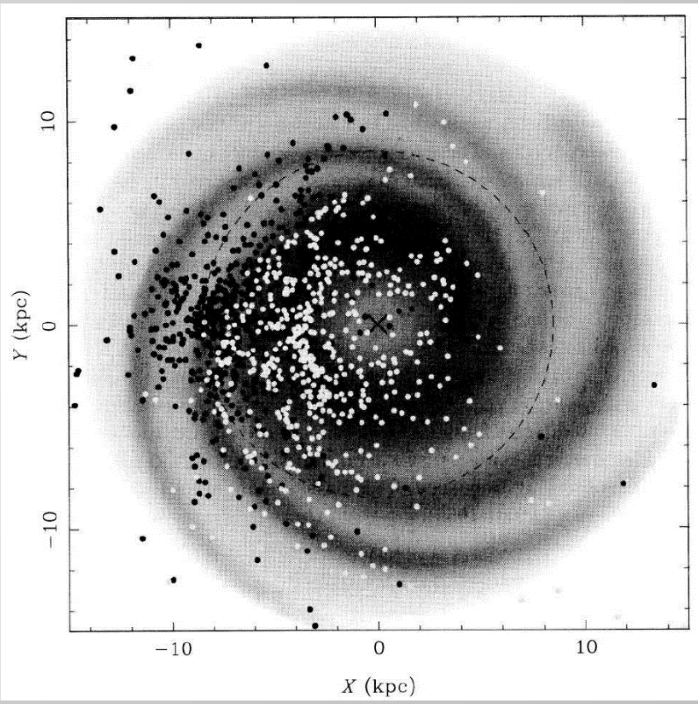


Pulsars are rapidly rotating neutron stars…. etc., and so on… ***You've heard it a zillion times before.***

For the purposes of this talk the only important thing is that:

We receive sharp pulses of radiation from pulsars.

The pulsars are observed all over the Galaxy (or actualy the "our half" of it).



The interaction of pulsar radiation with the ionized ISM:

Interstellar dispersion

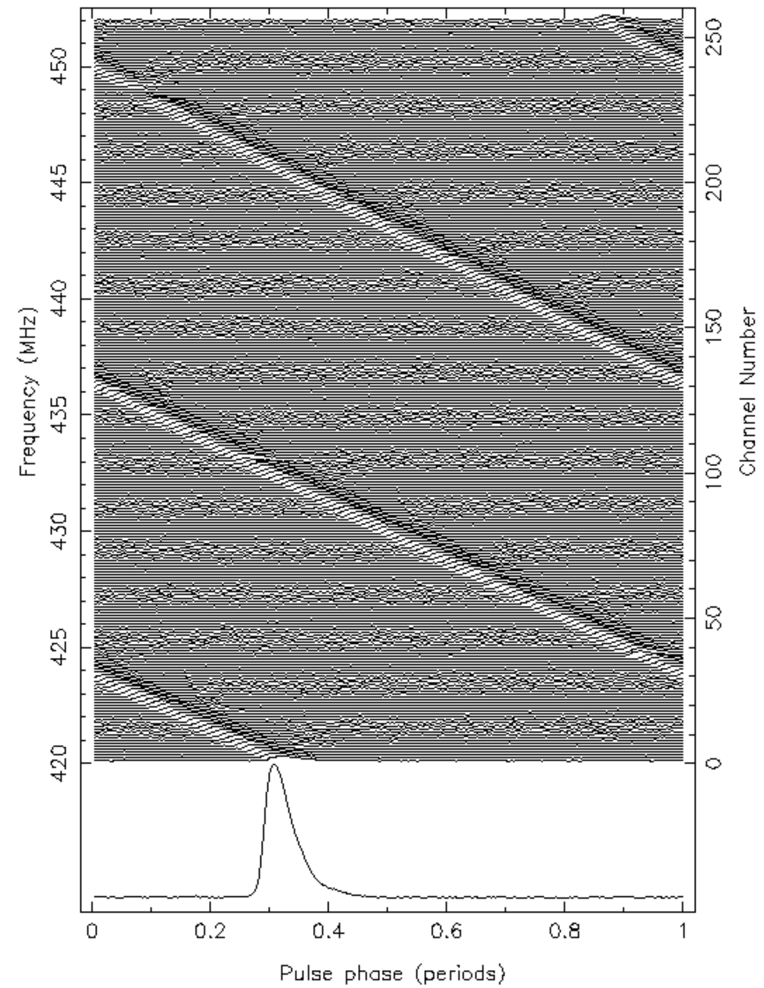
The ionized matter is a dispersive medium for radio waves. The propagation velocity will depend on frequency, because the refractive index does.

This will introduce different delays to propagation times at different frequencies

$$\Delta t \simeq 4.15 \times 10^6 \text{ ms } \times (f_1^{-2} - f_2^{-2}) \times \text{DM}.$$

The Dispersion Measure (DM) is a column density of electrons along the LoS.

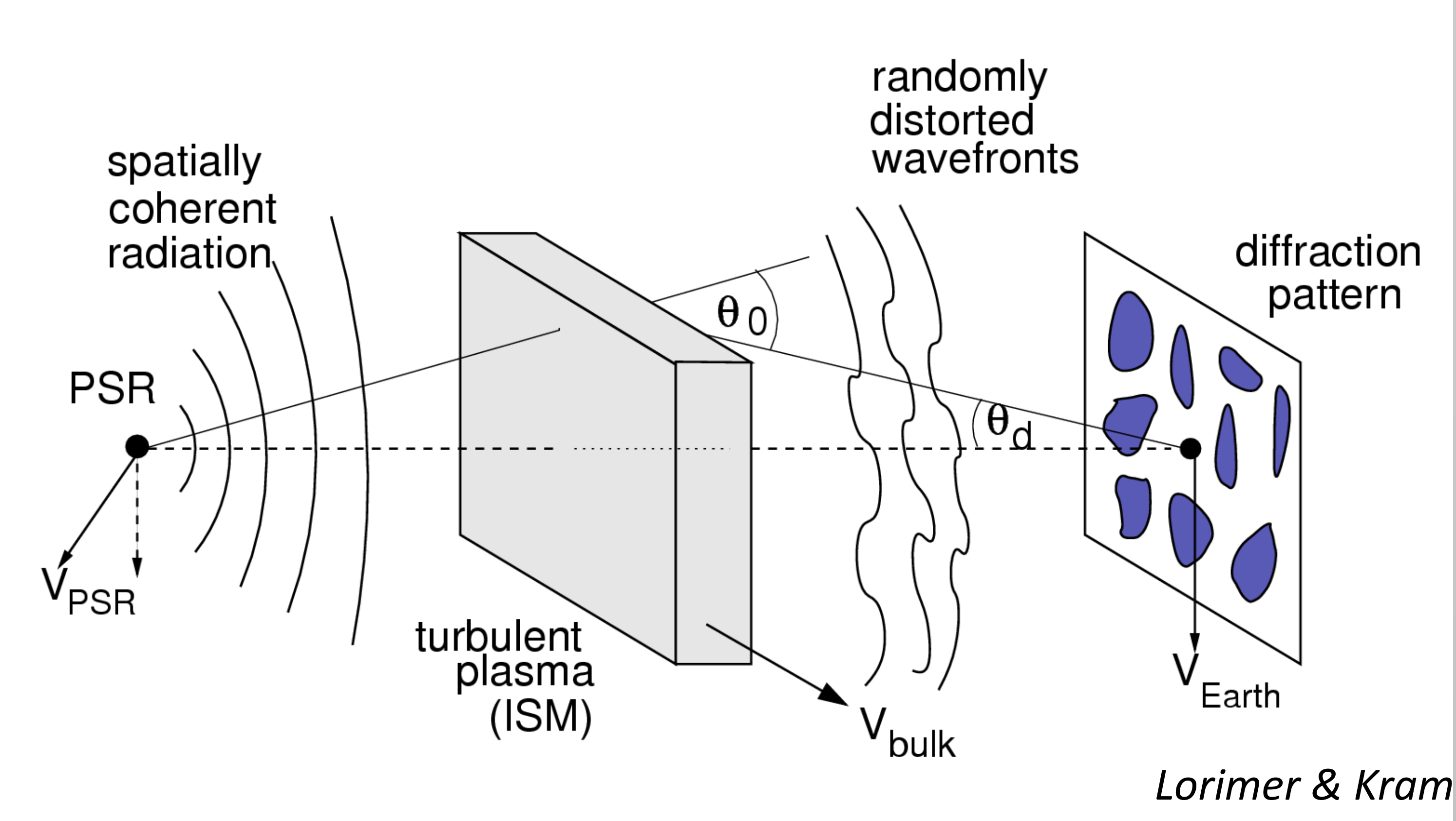
$$\text{DM} = \int_0^d n_e \, \mathrm{d}l$$



The interaction of pulsar radiation with the ionized ISM:
Interstellar Scattering

The **Interstellar Medium (ISM)** is neither uniform nor isotropic.

The presence of **free electrons** cause the radio waves to **disperese**, and fluctuations in the electron density give rise to ***interstellar scattering*** and ***scintillation***.

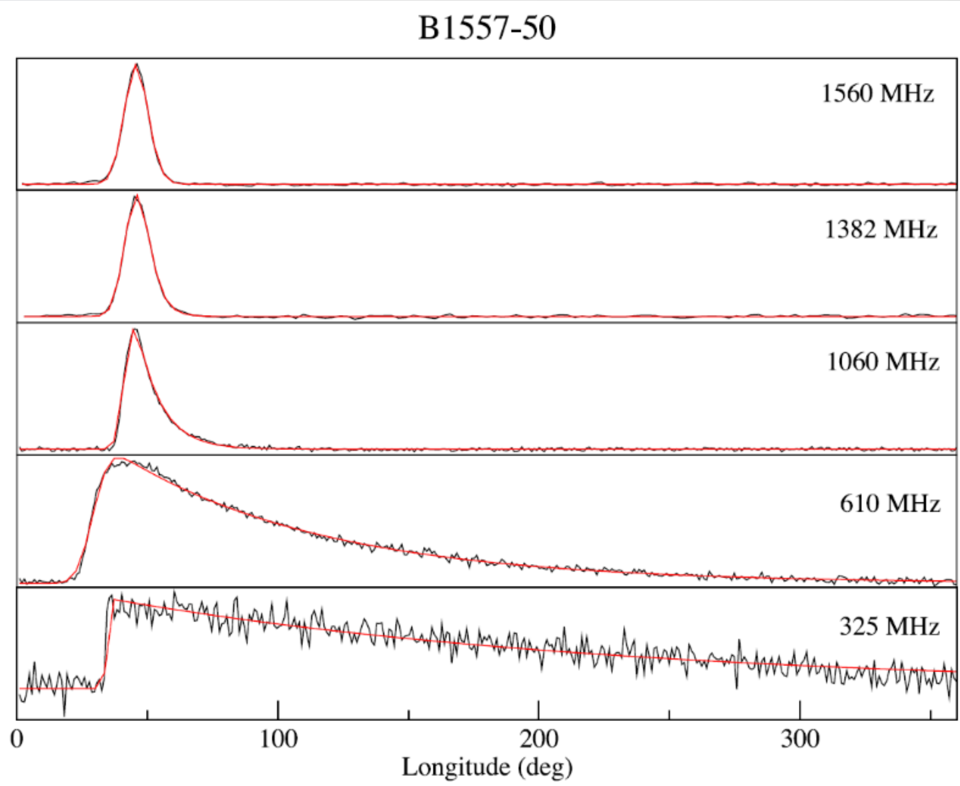


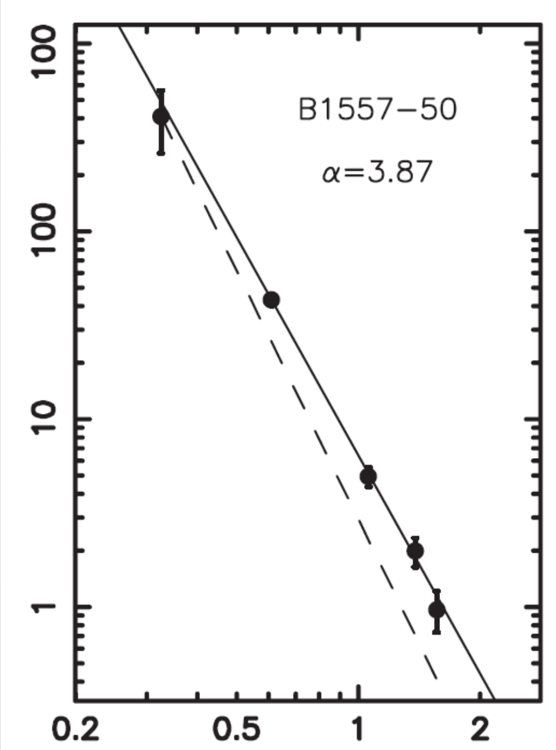
Lorimer & Kramer (2005)

Interstellar Scattering (cont.)

Scattering is frequency dependant, and is clearly more noticeable at lower frequencies. This frequency dependance gives us a way to estimate the energy spectrum of the turbulence in the ISM.

$$P_{n_e}(q) = C_{n_e}^2 q^{-\beta},$$





Lewandowski et al. (2013), MNRAS

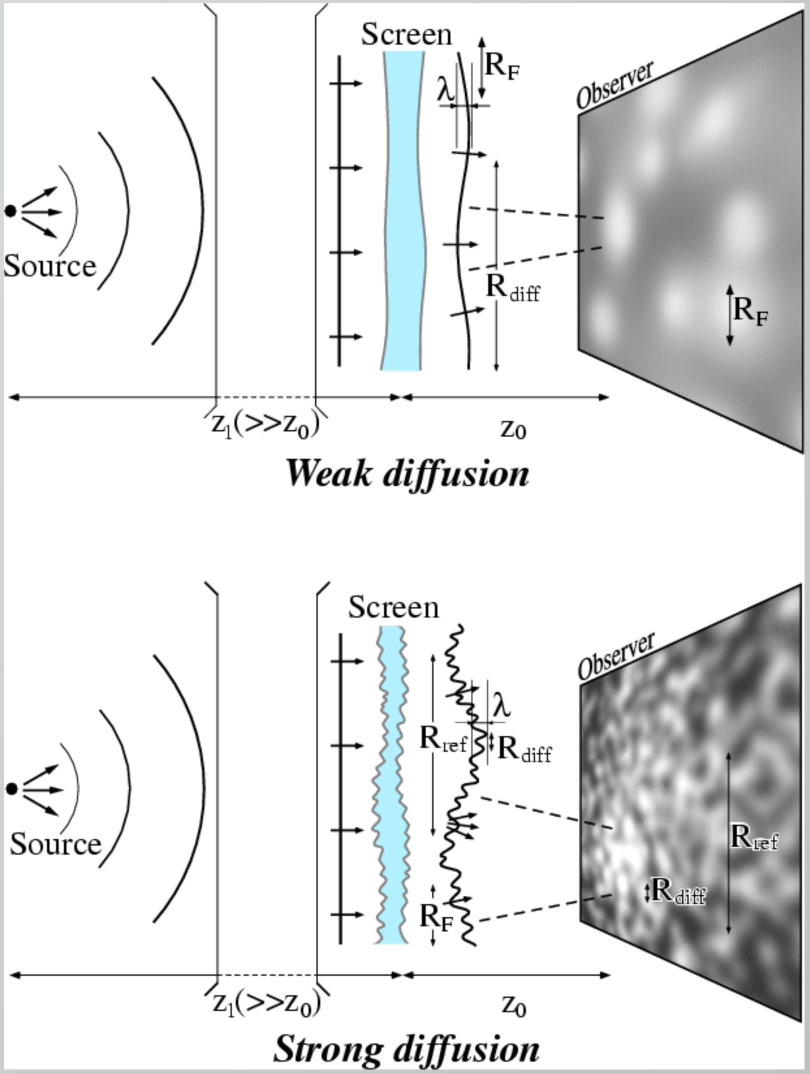
$$\beta = 2\alpha/(\alpha - 2)$$

For Kolmogorov's turbulence spectrum (β=**11/3**) the expected α=**4.4**.

The interaction of pulsar radiation with the ionized ISM:

Interstellar Scintillation

As in the case of the scattering phenomenon it is (for simplicity) assumed, that the **density fluctuations are localized in a "thin screen".**



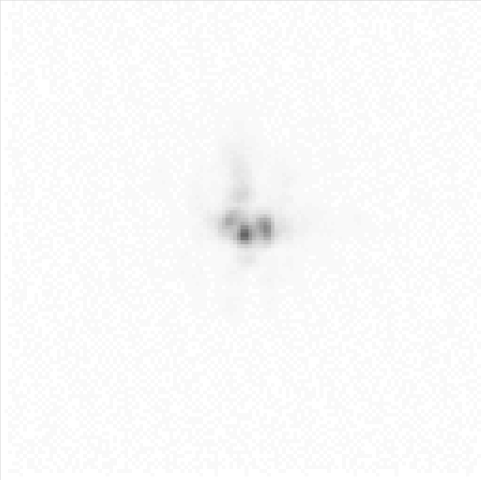
The pulsar signal **wavefront is disturbed** by the density fluctuations and interferes with itself.

In the strong scintillation regime one has to take into account bouth the **diffraction** as well as **refraction** of the signal.

This corresponds to two linear/angular scales involved in the process, and two time scales.

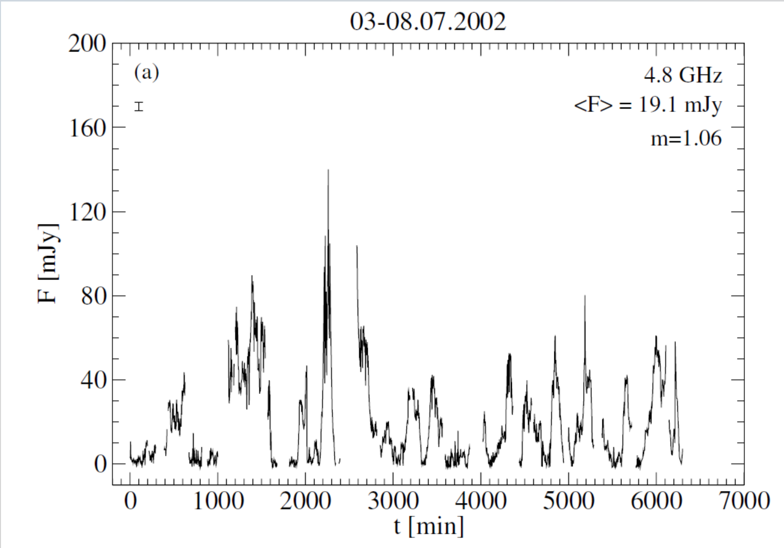
Interstellar Scintillation

In principle the **scintillations** of the pulsar signal is very similar to the **"twinkling star"** phenomenon.

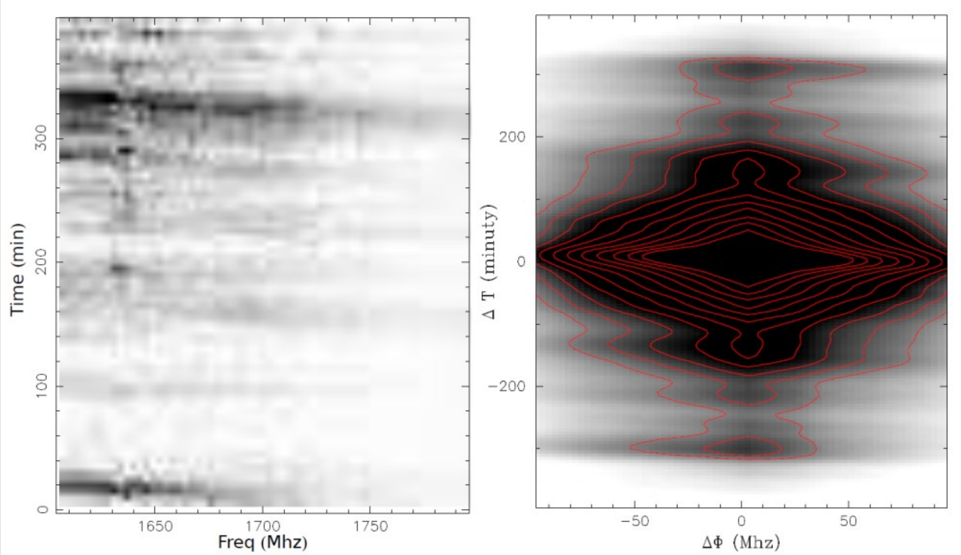


The differences are in the wavelength of the radiation *(radio versus visual)*, the medium *(ionized ISM versus neutral gas)* and place where it happens *(ISM instead of Earth's atmosphere)*.

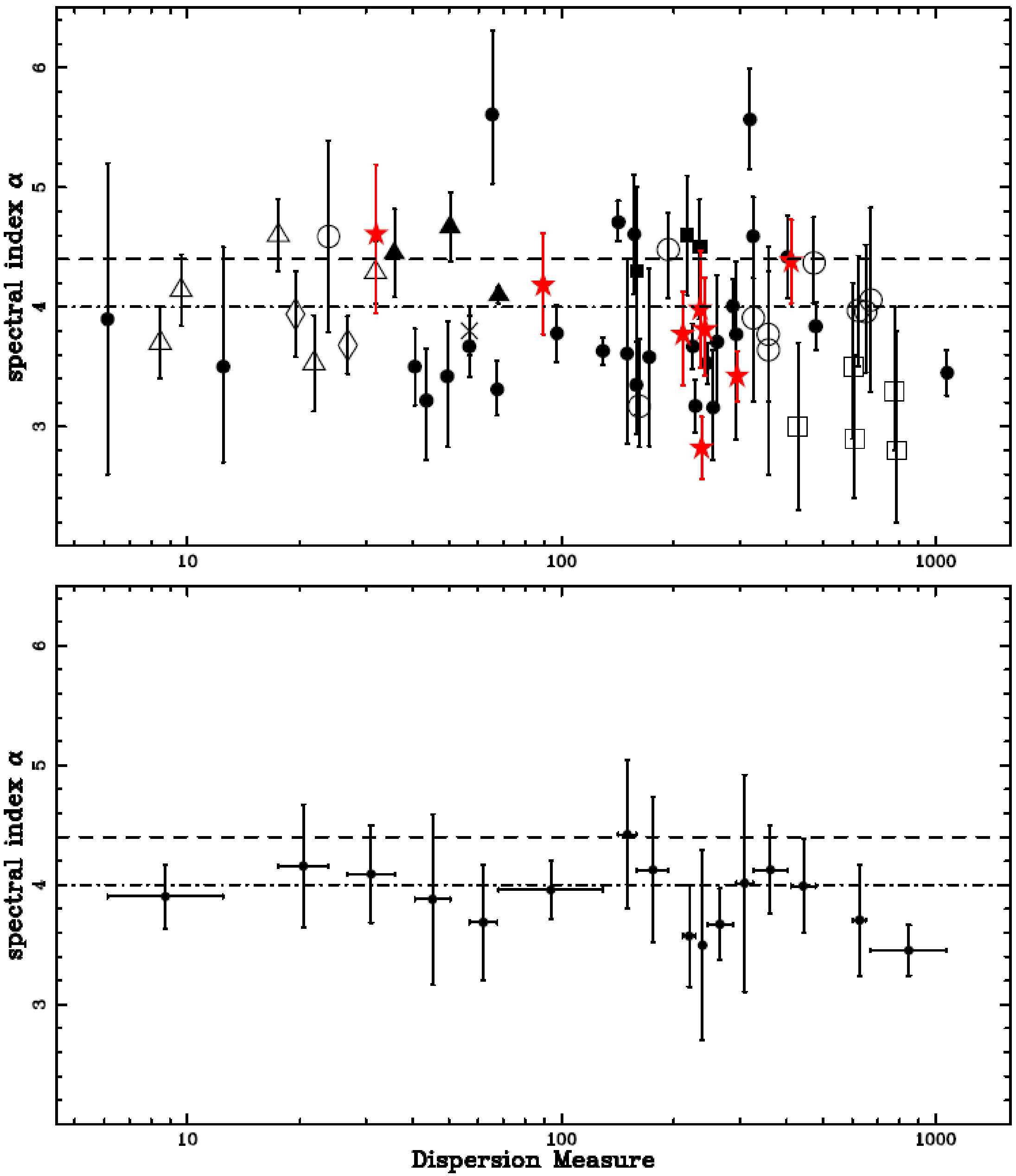
The net effect is the same – radio telecopes see the pulsars "twinkling" (i.e. varying in intensity).



Lewandowski, Kijak, Gupta & Krzeszowski, 2011, A&A



Daszuta, Lewandowski & Kijak, 2013, MNRAS



Scatter time frequency scaling index vesrus the dispersion measure.

Theory predicts the values of α between **4.0** (the critical spectrum) and **4.4** (Kolmogorov's spectrum).

Most of the pulsars lie beyond this range, and lower values of α dominate!

Strangely, the average values for the whole population are relatively close to 4.0.

Only for sources with the largest DM (the most distant objects) a significant deviation can be seen.

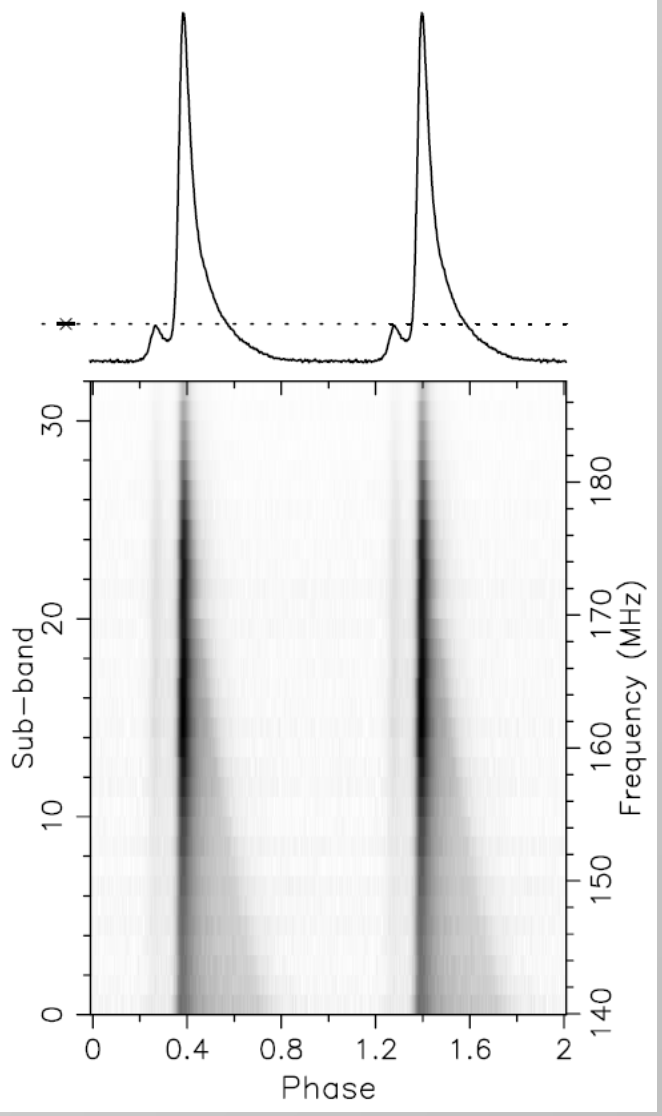
Advantages of using LOFAR for ISM studies:

Scattering is significantly stronger at lower frequencies, even for nearby pulsars.

Relative bandwidth is large: evolution of scattering strength within the bandwidth – easy way for checking the scatter time vs frequency dependence.

Long term monitoring of DM and scattering strength variations – search for anisotropy and inhomogeneity effects (should be detectable with timescales of weeks to months).

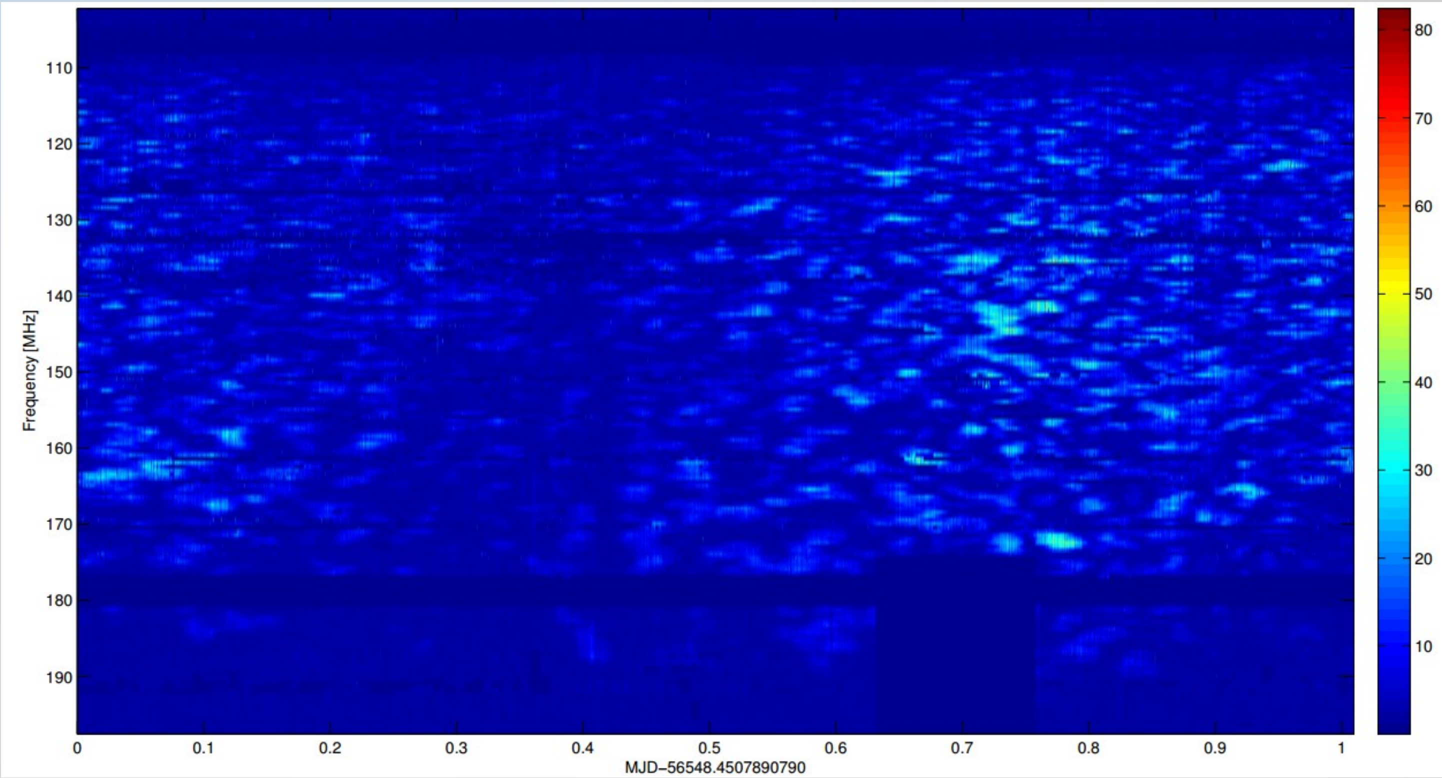
PSR B2111+46



From a presentation by J. Hessels

Disadvantages of using LOFAR for ISM studies:

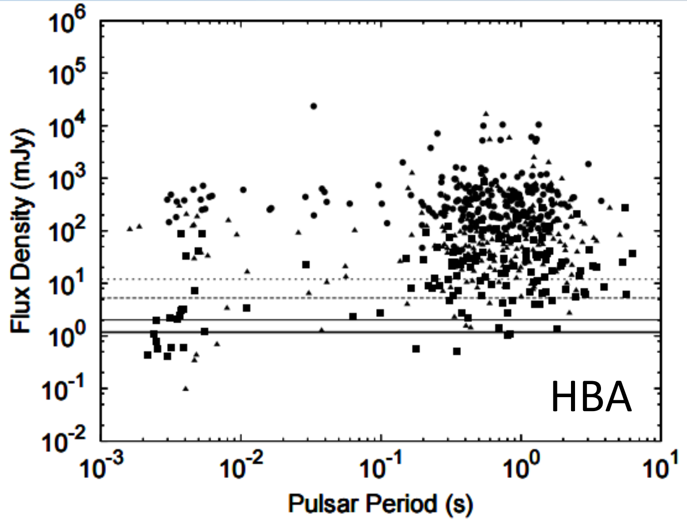
At LOFAR frequencies both the timescales of scintillation and the decorrelation bandwidth are very small: timescales below 1 minute and decorrelation bandwidth of a few kHz.

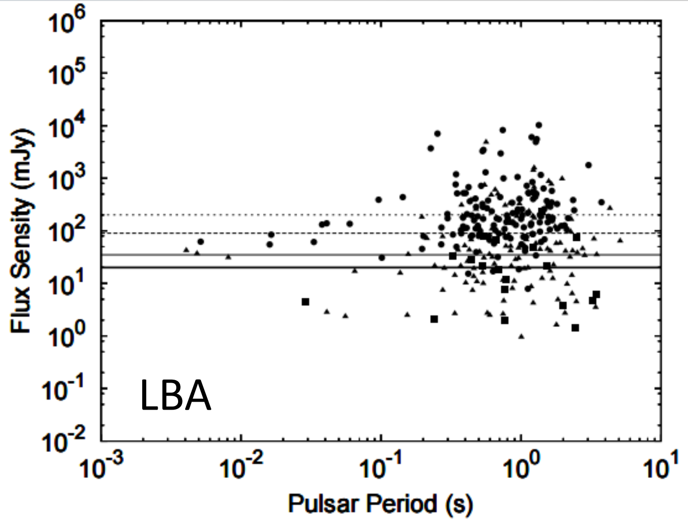


Dynamic spectrum of PSR B0809+74 using single station observationss (from batchelor thesis of Hauke Jung, Uni-Bielefeld)

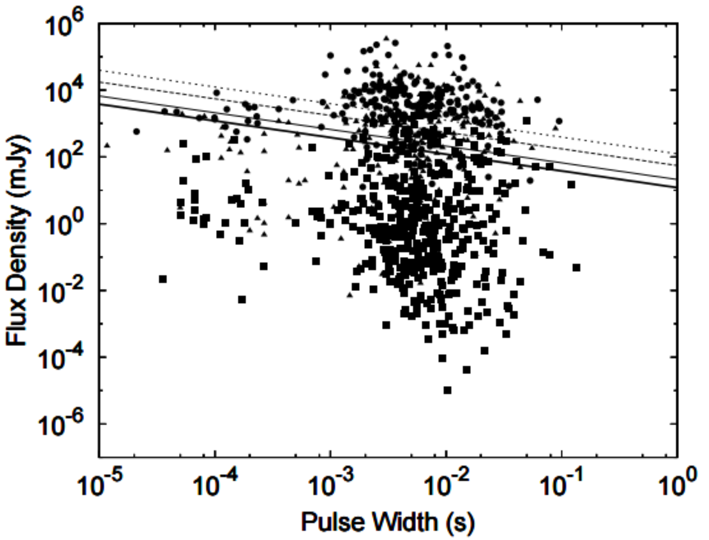
Large relative bandwidth (!) – as for scattering it means evolution of scintillation parameters within the band, this time however it's actually a problem.

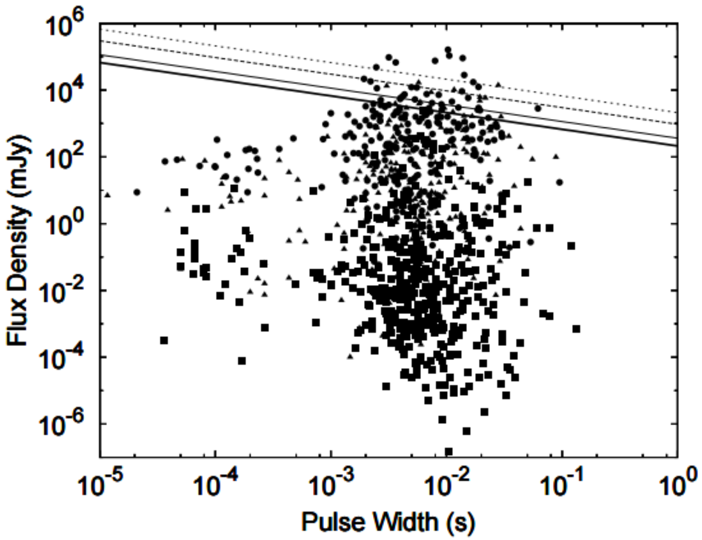
Sensitivity plots for LOFAR (Stappers et al. 2007) – highest, dashed line represents single station sensitivity





Integrated profiles





Single pulses

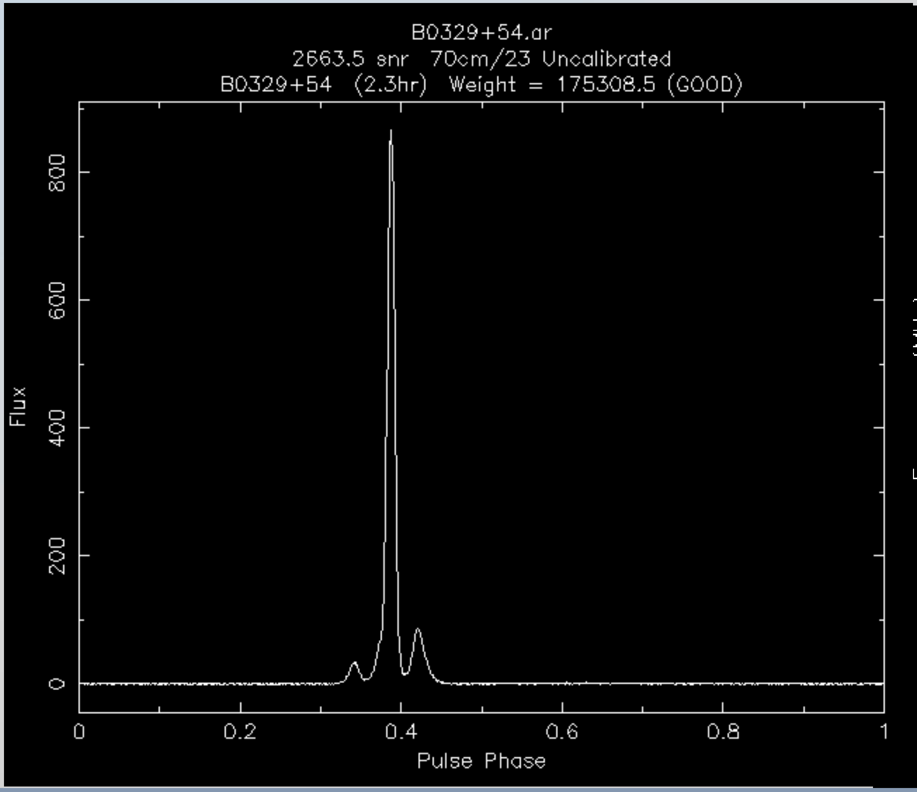
PL612 – Bałdy near Olsztyna – observations of PSR B0329+54, May 28/29 2016

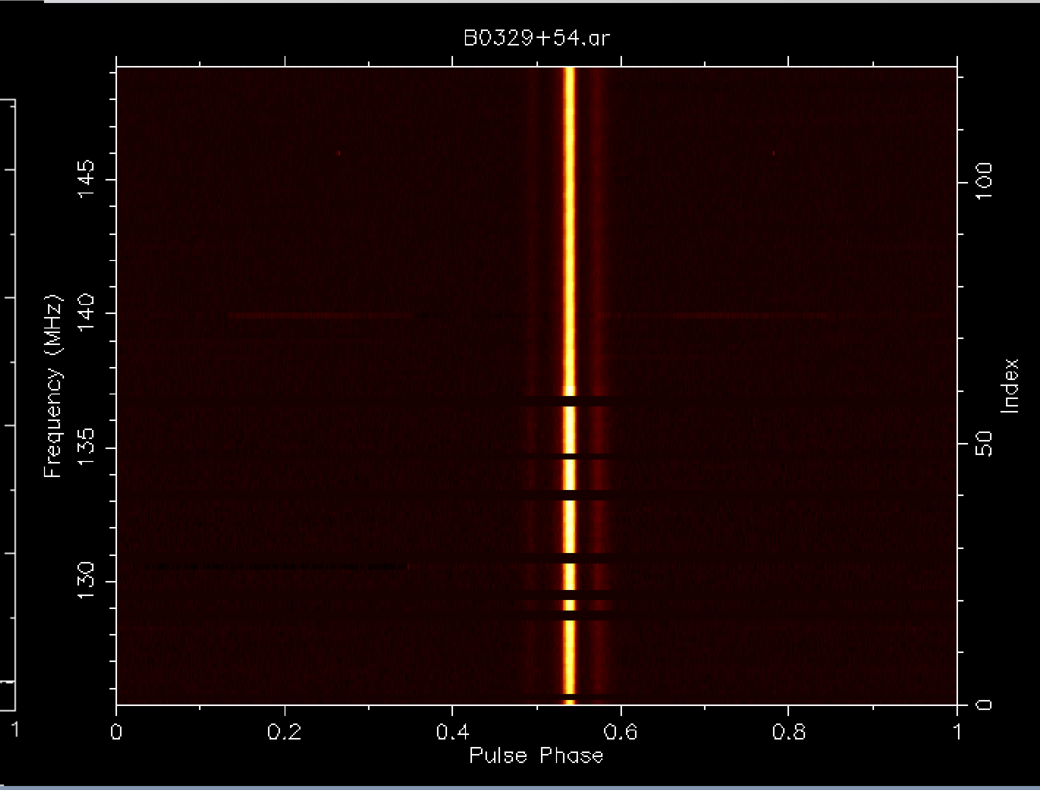
by

Tomasz Sidorowicz, Leszek Błaszkiewicz (UWM)

observations performer using the LUMP recording system

(set up with the help of S. Osłowski, Uni-Bielefeld/GLOW)





The study of the Interstellar Medium is vital to our understanding of the Milky Way structure.

We still don't fully understand the sources and the distribution of energy in the ISM, and the studies of the ionized fraction of the ISM can hold the key.

Without it we will never fully understand how the stars and planetary systems are formed.

Thank you for your attention.