Scintillometry 2019

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Book of Abstracts

Contents

1

Characterisation of pulsar emission and timing variabilities

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Neutron Stars are compact stellar remnants of the massive main sequence stars. Pulsars are highly magnetized rotating neutron stars that emit a coherent beam of electromagnetic radiation along its magnetic axis. The typical spin periods range anywhere from a few milliseconds to a few seconds. In the simplest scenario, the emitted electromagnetic radiation along the magnetic axis of the pulsar is similar to the emission of magnetic dipole radiation. However, even after 50 years of their discovery the pulse evolution and morphology along with the detailed physics of the broadband pulsar emission are not well understood. Depending upon the spin period, the pulsar population can be broadly classified into two categories, viz., normal pulsars, and millisecond pulsars. Using the 'the psrqpy' package, which is a python tool for interacting with the ATNF(Australia Telescope National Facility) pulsar catalog, we generate the P-Pdot diagram which is helpful in studying the lifecycle and population properties of different classes of pulsars. During this project, we construct the pulse profiles and examine the properties of two different types of pulsars. Since individual pulsar signals are weak and usually get lost in the RFI(Radio frequency interference), we use the software PRESTO to build a detectable signal through the folding of data at a specific period. To construct the pulses we have used radio data from the Parkes radio telescope. For a set of normal and millisecond pulsar, we use PRESTO to generate pulse profiles and look for their evolution in time and frequency. The profiles and their evolution shed light on the emission properties as well as other derived properties of the pulsar, eg., magnetic field, characteristic age, dispersion measure, spin-down power.
Keywords: Neutron star, Pulsars, Pulse profile, P-Pdot diagram, PRESTO

3

Holography via Dynamic Cyclic Spectroscopy

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Holographic approaches to pulsar signal processing have great potential for improving our understanding of the ISM and the pulsar emission process - goals that are valuable in their own right, and which in turn will help to reduce the systematic errors of pulsar timing experiments. However, holographic processing is not yet a routine procedure. I will describe recent progress towards that goal, using a new algorithm that can solve for a sparse wavefield given a dynamic spectrum, but modified to take a dynamic cyclic spectrum as the input. This approach allows the wavefield phases to be fixed by the explicit phase information in the cyclic spectra insofar as possible, and otherwise to prefer the sparsest wavefield that is consistent with the data.

5

Compact structures of interstellar plasma in the Galaxy revealed by RadioAstron

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The presentation is given on behalf of Radioastron Pulsar Working Group (RPWG). Firstly, we present the main parameters of RadioAstron Mission relevant to pulsar studies with the full list of scientific proposals and objects observed at 324 MHz and 1650 MHz. Using direct measurements of scattering angles made at space ground baselines we estimated distances to the scattering screens for dozens of pulsars. Several methods of such estimation are discussed, compared and illustrated. We concluded that scattering is produced mainly by compact plasma layers, and the uniform model of inhomogeneity distribution along the line of sight is not applicable. Particular attention is given to such peculiarities of scattering as anisotropic scattering in the direction to the PSR B0833-45 (Vela), and abnormal scattering event observed in the direction to the PSR B0834+06.

6

Pulsar interstellar scintillation study using FAST

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Pulsars shine through the Galaxy like beacons and they scintillate due to the relative motion between the pulsar, the scattering medium and the observer. A small sample of about 30 bright pulsars are known to show interstellar scintillation (ISS) arcs, from which we can measure the scale, location and velocity for the scattering medium and velocity for the pulsar. When the scintillation bandwidth and the scintillation timescale are resolvable, the detectability of ISS arcs rely mainly on the telescope's sensitivity, where FAST has a significant comparative strength. Using FAST's high sensitivity observation in L-band, We have already successfully detected new scintillation arcs from several pulsars, including both single pulsars and pulsars in binary systems. By detecting scintillation arcs for more pulsars, the FAST observations will allow us to find the astrophysical structure that dominate the scattering of pulsars, study the position and structure of the Galactic spiral arms, measure the boundary of the local bubble (LB), and open the doors to plasma lensing study for interesting pulsar systems, such as double neutron stars, and millisecond pulsar binaries. For binary systems, scintillation observation can put constraint on the inclination angle that enable us to measure the masses precisely.

7

Rate annual cycles for two new IDVs and their implications for scattering plasma

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Annual cycles in the scintillation rates for two Intra-Hour Variable quasars, J1819 and PKS B1257, indicate an alignment of the scattering plasma with hot stars close to their lines of sight. The TAILS team have now tracked the variation rates for two newly discovered IHVs, PKS B1322 and J1726, for over a year with ATCA, and analysed their annual cycles. Both look strongly anisotropic and the former appears to be associated with the nearby B-star Spica, although the orientation of the anisotropy is not well constrained; the latter is more interesting. I will present results for both of these new scintillating quasars.

8

FAST pulsar search and scintillation observations

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In this talk, I would like to report some results from pulsar survey and scintillation observations using the Five-hundred-meter Aperture Spherical Telescope (FAST), to showcase the excellent sensitivity of the telescope and its prospect in discovering pulsars and studying the ISM.

9

IISM studies with low-frequency pulsar observations

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I will present the various ways in which low-frequency pulsar observations can and have been used to study the ionised interstellar medium (IISM). Specifically, I will briefly highlight the power of dispersion monitoring towards a large sample of pulsars for e.g. ISM studies. Subsequently, I will show several investigations of pulsar scintillation, caused by phase variations introduced in the wave-front by slight density variations; as well as monitoring studies of so-called "scintillation arcs": higher-order refractive effects that are detectable in the 'secondary spectrum' (i.e. the 2D Fourier Transform of the dynamic spectrum). These studies allow the detection and monitoring of fine-scale structures in the IISM that are highly complementary to the larger-scale structures probed by dispersion monitoring.

10

Effects of wave optics in gravitational microlensing

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The geometric limit of wave optics allows one to investigate problems in gravitational lensing that would otherwise be analytically and numerically intractable. However, for non-extended, coherent sources of radiation (e.g. pulsars and FRBs), many effects of interest only appear in the full wave-optics regime. In this talk, we will introduce the formalism for computing these additional diffractive effects and explore their possibility of being used as novel means of detecting objects such as free-floating planets or gravitational waves. We will also introduce techniques from Picard-Lefschetz theory that can be used to ameliorate the so-called "sign problem" in computing diffraction integrals.

11

The Morphology of Scintillation Arcs: Observation and Theory

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In pulsars scintillation arcs are recognized from their observed secondary spectra. I will discuss their morphologies from both published pulsar observations and from a survey at Green Bank by Stinebring et al (in preparation 2019). These will be compared with theoretical calculations for both random plasma screen models (eg Kolmogorov) and from some specific discrete plasma concentrations (lenses). The over-riding goal is to quantify any spatial anisotropy in the concentrations of the responsible interstellar plasma.

12

Detecting higher-order frequency-dependent time delays using B0329+54's microstructure

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Dispersive time delays, proportional to $1/\nu^2$, are a well-known effect. However, under some circumstances, small additional delays with higher-order frequency dependency, proportional to $1/\nu^4$ or higher, can arise. I will discuss these circumstances, describe how fine microstructure in pulse profiles can be a powerful tool to detect such higher-order variations, and then present preliminary evidence for the existence of higher-order delay components in 400–800 MHz data of the very bright pulsar PSR B0329+54.

13

Using scintillation as a tool to search for off-pulse emission from short period pulsars

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Pulsars typically exhibit radio emission in the form of narrow pulses originated from confined regions of their magnetospheres. A potential presence of magnetospherically originated emission outside these confined regions, the so-called off-pulse emission, would challenge the existing theories. While there have been several attempts to detect off-pulse emission, few have been successful. Moreover, several previous claims of detection of off-pulse emission later turned out to be emission from an independent source in the same sky direction or that from a pulsar wind nebula (PWN). The only convincing detections of off-pulse emission using gated interferometric imaging have been from pulsars B0525+21 and B2045-16, at 325 and 610 MHz. However, more recent studies of these pulsars using the European VLBI Network indicate that the claimed off-pulse emission might have been originated from compact PWNe (Marcote, Maan, et al. 2019). Hence, even large radio interferometers may not suffice to resolve any off-pulse emission from pulsar magnetospheres and that from compact PWNe. A recent study (Ravi and Deshpande, 2018) suggests exploiting effects of interstellar scintillation to probe any off-pulse emission from pulsars. Even with single dish observations, this technique effectively uses interstellar baselines to potentially achieve spatial resolutions comparable to the typical pulsar magnetosphere extents at appropriately selected observing frequencies. We have recently embarked upon a survey for off-pulse emission from short period pulsars using this scintillation-based search method. In addition to the details and updates on this survey, I will also provide a detailed account of the probes of off-pulse emission from B0525+21 and B2045-16 and the current state of this field.

14

Echo Morphology in the Crab Pulsar

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The Crab Pulsar is known to exhibit events during which additional components in its radio profile trail the Main Pulse and the Interpulse. From its long history of observation, such echoes in the Crab emission have been seen to evolve over a wide range of timescales, from a few days to many months. These echoes likely relate to clouds of diffuse scattering material which pass by the pulsar line of sight. Additional signal is then either reflected or refracted off bubbles of ionized gas which are either denser or oriented more favourably relative to the line of sight. As this scattering material sees the pulsar from slightly different angles, better understanding these echoes may allow us to better resolve the radio-emitting regions of the Crab Pulsar. Different configurations of these structures relative to the nebular scattering screen can lead to a range of different echo morphologies which depend on how delayed the echo is from the regular pulse components. Therefore, by studying the morphology of these echoes as they evolve, we can learn more about these structures. I will present the shapes expected for various scenarios and discuss which ones seem to best match observations.

15

Using giant pulses to descatter pulsar emission

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Giant pulses are bright, narrow spikes of emission which can be thought of as impulses. An observed giant pulse is then a noisy measurement of the impulse response function of the interstellar medium along the line of sight. In our observations of PSR B1937+21, we detect thousands of giant pulses and model this impulse response function over our observation. This model can then be used to descatter recorded baseband data to acquire the intrinsic emission of the pulsar. We hope to use this technique to study emission phenomena at low frequencies where scattering effects normally wash away the details. Additionally, this technique can aid pulsar timing studies as well as further our understanding of scattering screens in the ISM.

16

Monitoring the scattered image of PSR B0834+06 over time with multi-epoch VLBI and Arecibo observations

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Evidence of highly-anisotropic scattering in pulsar observations, including parabolic arcs in pulsar secondary spectra and the remarkably linear scattered image of PSR B0834+04, have led to the development of a number of potential models that describe the responsible interstellar plasma lenses. These models, which include inclined plasma sheets and filaments, can predict the frequency and temporal evolution of the scattered image and thus the secondary spectrum. I will discuss the results of multi-epoch VLBI and Arecibo observations that aim to characterize the temporal evolution of the secondary spectrum of PSR B0834+06. I will show how these observations support lens models with asymmetric lens profiles, and then discuss the comparison of these observations to the corrugated plasma sheet model. Investigations of this sort serve not only to further our understanding of the ionized interstellar medium on scales < 1 AU, but also advance our ability to treat pulsar scintillation as a deterministic process that can be predicted and accounted for in timing observations.

17

Anisotropy in Weak and Strong Scintillation

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The effects of anisotropy on scintillation are quite different in weak and strong scintillation. In weak scintillation the intensity autocovariance (ACF) is quite different in the parallel and perpendicular directions and the orientation can easily be determined by the shape of the ACF alone. In the secondary spectrum fine forward parabolic arcs are observed, regardless of anisotropy, provided the scattering medium is compact. However the distribution of energy inside the primary arc can be used to determine the orientation. I will show that this behavior persists well into strong scintillation, i.e to coherence bandwidths < 10%. This explains the observation of very fine forward parabolic arcs in pulsars such as J0437-4715 which scintillate somewhat more strongly than has been considered "weak". In contrast the strong scintillation ACF has the same shape in regardless of orientation and the secondary spectrum will display a forest of reverse sub-arcs if the observed brightness distribution is highly anisotropic. However this can also result from isotropic scattering in a highly inhomogeneous medium which appears linear to the observer, and this is probably the case with pulsar B0834+06. Thus the evidence for highly anisotropic plasma turbulence in the ISM is somewhat weaker than has been thought.

18

Imaging Vela with LBA data: combining Simultaneous Single dish with VLBI

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Pulsar scintillation patterns reveal information about small-scale plasma structures in the interstellar medium. With VLBI techniques, the scattering geometry can be solved if a single, highly-anisotropic (essentially linear) scattering screen dominates the scintillation (Brisken 2010). By combining VLBI and simultaneous single dish data, more complex scattering geometry can be solved (Simard et al. 2018). This is based on the fact that, when considering a pair of sub-images on the sky, the visibilities are sensitive to the sum of the image angular positions, while the cross-correlated intensities are sensitive to the difference.
We applied this technique to the Vela Pulsar, B0833-45. The dominant screen is localized to be 22 pc from the pulsar. We also measure the Faraday rotation by cross-correlating the intensity dynamic spectra of left and right polarization in Fourier space. This gives a delay of 6.5 µs, which is consistent with the measured Faraday Rotation of 31.38 rad/m^2.

19

Giant Pulse Emission Regions of the Crab Pulsar

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The Crab pulsar's radio profile is dominated by two pulse components, the main pulse and the interpulse, comprised entirely of giant pulses. The alignment of the components from radio to gamma observations suggests that the emissions occur near the Crab pulsar's light cylinder radius. It should be possible to verify this through the study of the Crab pulsar's scintillation properties. Scattering from structures in the Crab Nebula create scintillation effects which can be used as a lens with a resolution at the pulsar of ~1000 km, comparable to the light cylinder radius. To achieve high sensitivity, we resolve the radio-bright nebula using multiple telescopes at large baselines as an interferometer. We develop a method to align baseband data of individual telescopes using giant pulses to create a coherent tied-array beam. We look at 4 European VLBI Network datasets taken over a span of 2 years. Correlations of giant pulse spectra between the two pulse components in frequency and time can be used to determine the separation between

the two emission regions on the sky. We find a significant offset in time in these correlations which suggests that the pulse components arise from distinct physical locations. We compare the correlations between observations and find differences in scattering properties from which we construct a picture of what the geometry of the emission regions can look like on the sky.

20

The curious DM events of PSR J1713+0747

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The NANOGrav collaboration observed two “dips” in the Dispersion Measure (DM) time series of PSR J1713+0747 in its 12.5+ years of observations, each lasting about ~100-200 days. The dips are possibly due to a single lensing structure in the ISM, and the profiles of the dips are consistent with the underdense sheet model of the ISM of Simard & Pen, which aims to explain observed features in the scintillation of pulsars. However, we did not observe echoes or interference predicted by the model. Instead, we discovered an unexplained minute ($< 5\%$ of pulse flux) profile change associated with the DM events that is not uniform across the pulse. As the dip is likely to reoccur, baseband recording and VLBI campaigns during similar future events will provide invaluable data to constrain models of ISM plasma lenses.

21

Mapping and fitting 1d scattering screens

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Scattering screens are often anisotropic and sometimes almost one-dimensional. Taking this for granted, each point in the secondary spectrum corresponds to exactly one pair of interfering subimages. We can transform the coordinates to produce a matrix of correlations of subimages with the positions as axes. If the assumed arc curvature (given by distances and velocity projections) is correct, structures nicely align horizontally and vertically. Any deviations will show up as shear so that we can measure curvatures quite accurately. Deviations from the 1d assumption can also be detected.
In a more ambitious approach we can then try to fit the 1d scattering field coherently to the entire dynamic spectrum, which potentially allows extreme precision in the determination of curvatures (or binary orbits). In this talk I will present the theory and some preliminary results and discuss the yet-to-be-solved difficulties.

22

The scattering screens towards PSR B1508+55 - the view from a 10000-km baseline

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We report simultaneous Giant Metrewave Radio Telescope (GMRT) and Algonquin Radio Observatory radio frequency observations at 550-750 MHz of the scintillation of PSR B1508+55 on two days, resulting in a ∼ 10,000-km baseline on both days. We use an intensity correlation technique to measure a systematic delay in the arrival of the scintillation pattern at the two stations and hence measure the speed of ∼200 km/s of the scintillation pattern in the direction of the pulsar's proper motion. We find evidence for the evolution of the scintillation dynamic spectrum from one observatory to the other as well as infer a distance of ∼390 pc to the scattering screen from which the correlated scintillation arises, but find that this screen is not associated with the dominant parabola seen in the high S/N secondary spectrum observed with the GMRT. The measured scintillation time of ∼120 s independently constrains the effective scintillation velocity of the screen responsible for the main parabola, and equivalently places it closer than the screen detected on the long baseline. We propose the presence of at least two distinct scattering screens, the closer of which is possibly also associated with a detected lensing event observed at ∼100 MHz with the German Long Wavelength (GLOW) Consortium of the Low Frequency Array (LOFAR) at ∼125 pc. We note that the edge of the local bubble at similar distance towards PSR B1508+55 could possibly explain the presence of the scattering screen that causes scintillation associated with the dominant parabola, in which enhanced local structure is responsible for the pulse echoes at low frequencies.

23

Upward Drift in Crab Giant Pulses

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Emission from the Crab Pulsar is predominantly in the form of giant pulses, which are known to have many surprising properties. We recorded tens of thousands of giant pulses in the 400-800 MHz frequency band at the Algonquin Radio Observatory, and will describe some particularly peculiar ones that we believe hold promise for understanding some of the underlying physics. In particular, the dynamic spectrum of one bright pulse associated with the main pulse shows discrete bands that appear to drift upward over 30 MHz in about 720 microseconds. Though superficially similar to what Hankins et al. (2016) observed in the dynamic spectrum for a main giant pulse at 43 GHz which appeared to sweep upward over 2 GHz in 2 microseconds, the drift must have physically distinct origin, since it occurs over much longer time scales, set by the scattering in the Crab nebula rather than the intrinsic durations of giant pulses. We characterize this pulse and other bright pulses in detail, and show that the observed sweep cannot be due to instrumentation defects or effects from interplanetary scintillation and de-dispersion. We conclude that the observed phenomenon results from intrinsic emission physics combined with propagation effects in the Crab nebula. We present a possible physical model for the drift and discuss what this implies for the properties of the material emitting giant pulses.

24

Update on J1509+5531 and eclipses of J2051-0827

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Regular LOFAR observations of J1509+5531 revealed a remarkable wide-angle refractive extreme scattering event. Regular monitoring pulsar timing observations revealed a presence of new components which changed in amplitude and location as a function of time. These can be interpreted as reflections of the pulse profile due to the ISM. In this talk, I'll present a summary

of observational properties of this ESE, based on standard pulsar timing observations, including its temporal and spectral characteristics. The timing observations predict that the pulsar is now near its closest angular approach to the source of the extreme scattering event.
J2051-0827 is one of the first black widows discovered and has now been observed for decades. Aside from its interesting timing properties, such as orbital variability, it also shows interesting eclipses, visible due to favourable viewing angle of the orbit. Here, I'll discuss the properties of the eclipses, including evidence of anisotropic scattering, magnetic properties fo the eclipsing material, and implications for the eclipse mechanism.

25

Scintillation arcs in PTA Pulsars using LEAP

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The Large European Array for Pulsars (LEAP) coherently adds the largest dishes in Europes to form an effective telescope with a diameter as large as 192 m^2, and has been observing many pulsars monthly since 2012. The coherently added baseband data are stored, allowing one to re-reduce the data with frequency and time resolution sufficient to resolve the scintillation; 8 of these sources show scintillation arcs, some showing clear annual variation and systemic changes of their scattering. I will also show early results using the German LOFAR stations mapping scattering screens and hoping to measure binary inclinations.

26

The Interstellar Medium of the Magellanic Clouds

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The Magellanic Clouds are two of our closest neighbor galaxies, and currently the only external galaxies where we have observed radio pulsars. By studying the pulsars in the clouds, we can analyse how they interact with their local interstellar medium, from analyses of dispersion measures, scattering, polarisation properties and rotation measure. The TRAPUM survey on the MeerKAT telescope will observe the clouds with significantly increased sensitivity and in a full survey we will be able to increase the current population of 30 pulsars by a factor of eight. This will contribute to a much more complete picture of the internal structure of the clouds, through mapping both the interstellar medium and the magnetic fields across the clouds. I will give an overview of ISM studies that have been done of the Magellanic Clouds to date, and look forward to what we will be able to do with MeerKAT data.

27

Solving pulsar binary orbits using scintillation

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The interstellar scintillation patterns of radio pulsars vary with their transverse velocity on the sky. These variations can therefore be modelled to measure parameters of pulsar's binary orbit. If annual variations are also observed in long-term data, these can break model degeneracies to allow unique measurements of the orbital inclination angle, transverse velocity and orbital orientation

in celestial coordinates, and the anisotropy of the scattering. Some of these pulsar parameters are difficult to measure even with precision pulsar timing, but are important for fundamental physics, such as the role of the inclination angle in constraining the system masses. In this talk I will present results from the long-term modelling of diffractive scintillation in the relativistic binary PSR J1141-6545, and scintillation arc curvature variations in the millisecond pulsar PSR J0437-4715.

28

Frequency Dependence of Scintillation Arcs

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I will review what we know observationally about the frequency development of scintillation arcs, focusing on various morphological features and the depth of the valley along the f_D = 0 axis. In one case (Stinebring, Ocker, and Rickett 2019), we have detailed modeling that points toward an extremely anisotropic scattering disk for B1133+16. I will examine more general trends in a wider sample of pulsars with low ($0 < DM < 50$) to moderate ($50 < DM < 100$) dispersion measure. To what extent can we extract information about the anisotropy of the image from single dish observations? What do existing single-dish observations tell us about the underlying physical model (e.g. inclined sheet vs. “noodles” vs. anisotropic scattering) that gives rise to scintillation arcs?