Scintillometry Meeting 2022: Book of Abstracts

University of Toronto

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Contents

Overview Talks

Scintillation Arc Survey Overview

Dan Stinebring
Oberlin College

By providing information about the location of scattering material along the line of sight (LoS) to pulsars, scintillation arcs are a powerful tool for exploring the distribution of ionized material in the interstellar medium. Here, we present observations that probe the ionized ISM on scales of $\sim 0.001 - 30$ au. We have surveyed pulsars for scintillation arcs in a relatively unbiased sample with DM $< 100\,\mathrm{pc\,cm^{-3}}$. We present multi-frequency observations of 22 low to moderate DM pulsars. Many of the 54 observations were also observed at another frequency within a few days. We detect definite or probable scintillation arcs in 19 of the 22 pulsars and 34 of the 54 observations, showing that scintillation arcs are a prevalent phenomenon. The arcs are better defined in low DM pulsars. We show that well-defined arcs do not directly imply anisotropy of scattering. Only the presence of reverse arclets and a deep valley along the delay axis, which occurs in about 20% of the pulsars in the sample, indicates substantial anisotropy of scattering. The survey demonstrates substantial patchiness of the ionized ISM on both au size scales transverse to the line of sight and on ~ 100 pc scales along it. We see little evidence for distributed scattering along most lines of sight in the survey.

Analysis of Arc Structures in the Scintillation Arc Survey

Barney Rickett
University of California San Diego

Stinebring et al. (submitted to ApJ 2022) present the results of our survey for scintillation arcs in observations of 22 pulsars with dispersion measures (from $5.7 - 84\,\mathrm{pc\,cm^{-3}}$). Hour-long observations were made at $1 - 3$ frequencies from $330 - 1400$ MHz. In the first talk we describe the observations and how the presence of parabolic arcs in the Secondary Spectra is defined and recognized. Parameters such as curvature, width and asymmetry were estimated for each observation. Here we analyze arc detectability as a function of frequency and dispersion measure, finding that arcs become wider and less distinct at greater DM and lower frequencies. An interpretation is suggested as arc-causing plasma concentrations located at the interfaces between interstellar bubbles similar to the Local Bubble with a typical spacing of $100 - 500$ pc.

Waves, Rays, Noodles, and Snowballs

Carl Gwinn

University of California Santa Barbara

I will discuss how optics provides insights into the physical parameters of the "noodle" and "snowball" models for interstellar scattering material. Although the wave equation governs wave propagation, the stationary-phase approximation allows straightforward solutions for many optics problems. Primal experience motivates the closely-related ray approximation. The geometry and physics of the propagation medium, and properties of source and observing instrument, determine whether these approximations apply. I will introduce the mathematics of the stationary-phase approximation and discuss its relation to the ray approximation. I will describe how they relate to the signal and noise of radio-astronomical observations, and the physical conditions they imply for the "noodle" and "snowball" models of the material responsible for interstellar scattering.

Fantastic Beasts and Where to Hear Them: An Adaptation of Radio Interferometry and Scintillation Analysis Techniques to Bioacoustics

Jim Lovell

Astro Acoustics

Acoustic recorders are commonly used for biological research on a wide range of species including insects, birds, mammals, and bats. These passive devices provide data that can be used for species identification, occupancy and some limited population studies. Open source/hardware models are gaining popularity given their low cost compared to commercial offerings. There has also been significant advance in machine learning and artificial intelligence techniques for automated identification. However these single-microphone units have limitations, particularly when it comes to number counts, identification of individuals, and studies of behaviour and movement. There are also difficulties in identifying different species that have similar call signatures. Recording with multiple microphones in an array can help address many of these problems and add significant value to observations. Can scintillometry help in species identification, behaviour and localisation? I will describe the work I have been undertaking to develop a multi-microphone bioacoustics recorder and adapted radio interferometry techniques. Initial studies have concentrated on bats given that they are readily detected and distinguished, and that their movement and echolocation calls reveal information about behaviour.

Refraction and Scattering by Neutral Gas Clouds

Mark Walker
Manly Astrophysics

Cold, self-gravitating gas clouds emit very little radiation and a large population of such objects could exist in the Galaxy yet remain undetected. Refraction and scattering of radio-waves in the neutral gas presents novel opportunities for constraining the properties of dense gas clouds, or perhaps detecting them. I'll describe the signatures that are expected based on what we currently understand about the cloud physics.

Parabolic Arcs

Scintillation Arcs in B1508+55

Tim Sprenger

Max Planck Institute for Radio Astronomy

The pulsar B1508+55's scintillation shows unusual stripe-like features and echoes in its pulse profile that correspond to scattering regions it was predicted to cross around late 2020. I will present observations at the Effelsberg 100-m telescope spanning from early 2020 to 2022 that indeed show a sudden transition in the scintillation arcs to parabolic arclets. To infer a geometric model of the scattering, the effects of the annual velocity curve of Earth, of the relative movement of the line of sight, and of the projection of points on a second scattering screen were measured. The latter phenomenon was observed for the first time and strongly indicates a two-screen scattering geometry. As shown by parameter fits as well as simulations, an analytical two-screen model can be successfully applied to explain the observations by interpreting the transition as a change of relative amplitudes of images as well as a shift in the orientation of anisotropy.

Progenitors of Parabolic Arcs in Secondary Spectra of Pulsars

Vladimir Soglasnov

Lebedev Physical Institute

Instead tradition "phase screen" model we suggest "phase membrane" model, which can produce time delays of large amount, a very probable physical reason is resonant processes in a pulsar wind region.

Scintillation of PSR J0437−4715 with MeerKAT

Daniel Reardon

Swinburne University of Technology

The MeerKAT radio telescope was used to observe the brightest millisecond pulsar, PSR J0437−4715. The first observation revealed many scintillation arcs originating from independent scattering screens along the line-of-sight, including one extremely low-curvature arc. A long observing campaign followed, to measure the change in curvature of the arcs with the orbital velocity of the pulsar. The lowest-curvature arc varies strongly with orbital phase, and its distance is consistent with the pulsar's bow shock. Here I present the MeerKAT observations and the modelling efforts for this collection of scintillation arcs.

Multiple Scattering Screens in Six Pulsars

James McKee

Canadian Institute for Theoretical Astrophysics

I will report on our FAST monitoring campaign of 6 nearby pulsars which are known to have multiple scattering screens along their lines of sight. By modelling the variation in arc curvatures throughout the year, we are able to find precise distances to these screens, and associate them with boundaries in the Local Bubble.

Properties of the Scintillation Frequency Structure and Constraints on Interstellar Interferometry

Norbert Bartel

York University

We investigated the scintillation pattern of 12 bright pulsars at 324 MHz and analyzed the frequency section of their dynamic spectra. All inner parts of the autocorrelation functions (ACFs) of these sections could be well fit by predictions of thin-screen and extended-screen scattering models with a range of power-law spectral indices of the interstellar plasma turbulence of $3.5 < \alpha < 4$. Inspection down to $\sim 10\%$ of the ACF maximum and analysis of the Fourier transforms of the ACFs down to $\sim 0.1\%$ of the maximum could not distinguish between the models and instead indicated sometimes large discrepancies. The average scintle profile has a pronounced spike toward the origin for the smaller values of α and a moderately decaying function for the larger values of α. One of the pulsars, B1237+25, was investigated in more detail by analyzing the frequency sections of the dynamic spectra at different pulse longitudes. We found that they smoothly changed as a function of longitude but the change was not a signature of having spatially resolved the pulsar magnetosphere. We address technical constraints that need to be considered for interstellar interferometry.

Scintillometry Techniques

Non-Stationary Spectroscopy With or Without Correlations?

Olaf Wucknitz
Max Planck Institute for Radio Astronomy

Scintillation/scattering can be studied in two domains: In the time domain, we can exploit the "timing signal" provided by pulsars and do gated imaging or observe scattering tails directly. In the frequency domain, on the other hand, the pulsar's variability is only used to subtract background noise from the signal and apply weighting to increase the SNR of dynamic spectra. Most of the sophisticated methods to study secondary spectra do not use the additional information explicitly. Cyclic spectroscopy tries to combine the advantages of both approaches, but the assumption of exact periodicity still wastes invaluable information, particularly in slow pulsars. I try to develop a technique for non-cyclic processes, that takes the variability into account for a frequency-domain analysis. The correlation matrices, which are explicitly computed in cyclic spectroscopy, quickly explode in size for such an approach, because the relevant time span is not the pulse period, but the subintegration time. In this talk I discuss possible solutions to this problem. This is work in progress, and there is no guarantee for success.

Phase Retrieval in VLBI Using the $\theta - \theta$ Transform

Daniel Baker
Canadian Institute for Theoretical Astrophysics

Very Long Baseline Interferometry offers the opportunity to study not only the general properties of the screens responsible for pulsar scintillation, but also the behavior of individual images. This makes it an invaluable tool in determining the nature of these screens. However, using the standard dynamic spectra and visibilities can make it difficult to isolate individual images sitting at the peaks of arclets from the extended arclet itself. We present a method using the $\theta - \theta$ transform to achieve simultaneous phase retrieval at multiple dishes to preserve relative phases and localize images in the conjugate wavefield.

Path Integrals for Radio Astronomy

Job Feldbrugge

University of Edinburgh

With the advent of new radio telescopes and the discovery of fast radio bursts, the study of interference phenomena in wave optics is becoming increasingly important. However, unfortunately, up to recently, the evaluation of lens systems and scintillation in wave optics was very difficult in most physical systems. In this talk, I will use Picard-Lefschetz theory to evaluate the path integral for radio astronomy for general plasma lenses, the binary gravitational lens problem, and multi-lens systems. These systems show intricate interference patterns in the vicinity of the caustics. I will also show how these techniques can be applied when the lens is a realization of a Gaussian random field.

A New Method for Phase Retrieval in Pulsar Spectroscopy

Stefan Osłowski

Manly Astrophysics

A pulsar dynamic spectrum is an inline digital hologram of the interstellar medium; it encodes information on the propagation paths by which signals have travelled from source to telescope. To decode the hologram it is necessary to "retrieve" the phases of the wavefield from intensity measurements, which directly gauge only the field modulus, by imposing additional constraints on the model. We present a new method for phase retrieval in the context of pulsar spectroscopy. Our method makes use of the Fast Iterative Shrinkage Thresholding Algorithm (FISTA) to obtain sparse models of the wavefield in a hierarchical approach with progressively increasing depth. Once the tail of the noise distribution is reached the FISTA optimisation is terminated and the remaining structure is estimated in a single step. The result is a fully dense model of the complex wavefield that permits the discovery of faint signals by appropriate averaging. We illustrate the performance of our method on synthetic test cases and on real data.

A New Method to Estimate Pulsar DM in the Presence of Scatter-Broadening

Jaikhomba Singha

Indian Institute of Technology Roorkee

Pulsars are rotating neutron stars emitting a beam of radio light from their magnetic axis. As the pulsar signal passes through the interstellar medium (ISM), it gets smeared due to the variation of the group velocity of the radiation with wavelength caused by the electrons in the line of sight. This smearing can be due to dispersion by the integrated column density of electrons or multipath propagation due to inhomogeneities in the electron distribution across the line of sight. The dynamic nature of the ISM makes both these effects vary with observation epochs. This variation can mimic a slowly varying noise in ToA covariant with GW signature of an isotropic stochastic gravitational wave background (SGWB). We present a new method to estimate the DM accurately in presence of scatter broadening in the pulse profile by compensating for variable scatter broadening, estimated using $300-500$ MHz wide-band upgraded Giant Metrewave Radio Telescope (uGMRT) measurements. We evaluate this method in comparison with traditional DM estimation methods, ignoring such effects, using simulated data. We also present results from this method using the Indian Pulsar Timing Array (InPTA) data set on PSR J1643$-$1224 and discuss implications of our results.

A Two Screen Analysis of a 36 Epoch Observation of B1737+13

Sammy Siegel

Oberlin College

We present an analysis of pulsar B1737+13's varying scintillation from observations obtained from Arecibo telescope from April 2006 to January 2007. In July of 2006, the scintillation arcs in the pulsar's secondary spectrum changed markedly from arcs showing inverted arclet substructure to broad and diffuse arcs without inverted arclets. A recent analysis by Sprenger et. al. (2022) demonstrated that a two scattering screen model of the interstellar medium could account for comparable long-term changes in the scintillation behavior of pulsar B1508+55. We employ similar techniques in our analysis of pulsar B1737+13, with preliminary results from arc curvature measurement through linearizing the secondary spectrum showing evidence of two arcs.

Lensing

Regimes in Astrophysical Lensing: Refractive Optics, Diffractive Optics, and the Fresnel Scale

Dylan Jow
Canadian Institute for Theoretical Astrophysics

The scattering of radio sources in the ISM is thought to occur in two distinct regimes: diffractive and refractive optics. In the early days of pulsar astronomy, scintillation was thought to be primarily caused by diffractive scattering off of a turbulent ISM. However, in recent decades, a refractive formalism has been used to explain the appearance of parabolic arcs in the secondary spectrum of scintillation observations. The recent success of this purely refractive formalism may be somewhat surprising given the early emphasis on diffractive interstellar scintillation (DISS). In this talk, I will attempt to delineate the different regimes of astrophysical lensing, and argue that refractive optics holds for a much wider range of parameter space than has previously been assumed. In particular, I will argue that the scale which has been assumed to separate the diffractive and refractive regimes, the Fresnel scale, is modified in the presence of strong lenses. Indeed, this modification can be arbitrarily large. By applying the mathematical framework of Picard-Lefschetz theory, which was recently introduced to the study of lensing, I will utilize new tools to answer old questions.

Investigating Plasma Lensing Structures by Simulating the Propagation of Radio Wavefronts

Kelvin Au
University of Manitoba

We simulate the propagation of radio wavefronts through spatially varying continuous media to gain insight into the nature and structure of plasma lenses thought to produce extreme scattering events (ESEs). By first ray-tracing through spatially varying media, we then construct the propagation of wavefronts. We form a mapping between the source and the image to produce intensity maps. With this approach, we have produced the resulting light curves through turbulence generated by Fourier methods, as well as turbulence generated using PythonMHD, an MHD simulation code developed by Delica Leboe-McGowan at the University of Manitoba. Future explorations of wavefront propagation through plasma structures of various dimensionality such as spheres, cylinders, and sheets are planned.

What Plasma Microlensing Can Tell About Tiny-Scale Structures in the ISM

Xun Shi
Yunnan University

Gravitational microlensing has become a mature technique for discovering small gravitational lenses in the Universe that are otherwise beyond our detection limits. Similarly, plasma microlensing can help us explore the small compact plasma lenses in the ionized interstellar medium whose astrophysical correspondence remains a mystery. We demonstrate that plasma microlensing events by these plasma lenses recorded in the form of wide-band dynamic spectra are a powerful probe of their nature, that the size, strength, and shape of the plasma lens can be measured from the location of the cusp point and the shape of spectral caustics, respectively, with a combination of distances and the effective velocity known a priori or measured from the widths of the interference pattern.

Double-Lensing Event in PSR B0834+06

Hengrui Zhu
Princeton University

In extreme scattering events, the brightness of a compact radio source drops significantly, as light is refracted out of the line of sight by foreground plasma lenses. Despite recent efforts, the nature of these lenses has remained a puzzle, because any roughly round lens would be so highly overpressurized relative to the interstellar medium that it could only exist for about a year. This, combined with a lack of constraints on distances and velocities, has led to a plethora of theoretical models. In this talk, we present observations of a dramatic double-lensing event in pulsar PSR B0834+06 and use a novel phase-retrieval technique to show that the data can be reproduced remarkably well with a two-screen model: one screen with many small lenses and another with a single, strong one. We further show that the latter lens is so strong that it would inevitably cause extreme scattering events. Our observations show that the lens moves slowly and is highly elongated on the sky. If similarly elongated along the line of sight, as would arise naturally from a sheet of plasma viewed nearly edge-on, no large over-pressure is required and hence the lens could be long-lived. Our new technique opens up the possibility of probing interstellar plasma structures in detail, leading to understanding crucial for high-precision pulsar timing and the subsequent detection of gravitational waves.

Origins of Scintillation

A Long-Baseline View of B1508+55: A Two-Screen System

Visweshwar Ram Marthi
Tata Institute of Fundamental Research

I will describe the results of the two-station measurements of the scintillation of PSR B1508+55 in August 2017 with the GMRT and ARO. While the experiment was only partially successful, even the limited scope provided by a single baseline allowed us to infer the presence of two screens. A low scintillation cross-correlation on the GMRT-ARO baseline suggested a highly anisotropic but 2D screen. This pulsar transitioned from weak to strong scattering in late 2020, aiding in the modelling of the two-screen system. Continued wideband low-frequency campaigns on this pulsar and a few other interesting candidates are well-justified for capitalizing on the early success of the reconnection sheet model and could lead to a paradigm shift in our understanding of “diffractive” scintillation.

Tracing Transient Features in the Solar Wind with MWA IPS Observations

Angie Waszewski
Curtin Institute of Radio Astronomy

Our society is heavily reliant on infrastructure such as power grids and Satellite Navigation Systems. A major space weather event, like the Carrington event, could put these technologies at risk, and therefore predicting the severity of such events in advance is of great importance. Interplanetary scintillation (IPS) is the variability of compact radio sources caused by turbulence in the solar wind, and by making measurements of IPS it is possible to probe the solar wind. By adapting this technique for modern low-frequency instruments such as the Murchison Widefield Array, we have opened up new possibilities in solar physics. The key advance we have made is to exploit the enormous field of view of the MWA, which allows us to monitor all IPS sources across a field of view 30 degrees, leading to an unprecedented density of measurements. We have conducted a blind search of 49 days of MWA IPS observations from mid 2019, with overlapping daily observations approximately East and South-East of the Sun at an elongation of 30 degrees. This search has revealed a number of interesting transient features characterised by higher than usual scintillation levels (in spite the observations being taken at solar minimum). None

have (yet) been linked to any known solar events (such as coronal mass ejections). However, one solar wind enhancement is captured in two observations several hours apart, allowing the plane-of-sky velocity to be inferred. In this talk I will give a quick overview of IPS, how it is studied using the MWA, as well as how our IPS observations can be used to study the solar wind and other solar events. I will also be discussing the observed feature in our observations, as well as the multiple avenues of analysis that are possible with IPS in conjunction with other circumstances of this discovery.

Scintillation in Multiwavelength Observations of PSR J1744−1134

Lydia Guertin
Haverford College

As a low-DM isolated millisecond pulsar, J1744−1134 is uniquely positioned to indirectly probe the local interstellar medium (ISM) via the scattering and scintillation of its emission. Over two months, we collected data with the Low-Frequency ARray (LOFAR) and the Effelsberg Radio Telescope during simultaneous sessions earlier this year, with the hope of constraining and tracking changes in the power law relation between scattering measurements and frequency on the cadence of weeks. This study is primarily focused on contributing to pulsar timing array (PTA) efforts, but each observation was carried out with sufficient length and bandwidth to search for discrete structures and properties of the ISM in the direction of the source. Preliminary results will be presented, as well as a status update of an open-source software package aimed at creating a smooth introduction to the field of scintillation for aspiring astronomers.

Bow Shocks of Scintillating Pulsars

Stella Ocker
Cornell University

Neutron star bow shocks form at the interface of the stellar wind and the interstellar medium, and their stand-off radii can be inferred from H-alpha observations to directly probe interstellar density fluctuations. While only 9 neutron star bow shocks have been observed in Hα, bow shocks likely form around many supersonic pulsars at stand-off radii ranging from 10s to 1000s of au, depending on the pulsar's velocity and the interstellar density. I will discuss the feasibility of using scintillation arcs as a tool for bow shock detection, and potential constraints on bow shock physics and the ionization content of the ISM from combined searches for bow shocks in both scintillation and Hα. I will also describe an observing campaign conducted at FAST in 2021, which yielded long-track scintillation observations of seven pulsars with known or likely bow shocks. These observations will help constrain whether scintillation from pulsar bow shocks is a common phenomenon, informing both future bow shock studies and pulsar timing applications.

Scintillation Structures in Pulsar Signals: Insights from Quantum Dynamics and Branched Flow

Tobias Kramer

Johannes Kepler University Linz

Scintillation arcs seen in pulsar signals are thought to be related to the occurrence of multi-path interference, for instance by deflections from the ionized interstellar medium. Similar arcs can be observed in the propagation of quantum mechanical wave packets over disorder potentials. I discuss the relationship between both physical systems in terms of the principle of stationary action and "branched flow". The connection between both areas of physics might help to establish new perspectives on the observed phenomena and provide insights into the properties of the scattering medium.

New Facilities

Scintillation with the MeerKAT Thousand Pulsar Array: First Results

Robert Main
Max Planck Institute for Radio Astronomy

The Thousand Pulsar Array (TPA) is part of the Large Survey Project 'MeerTime' on the MeerKAT telescope, which has observed > 1270 pulsars in the southern sky in a wide band from $856-1712$ MHz. The TPA provides a rich dataset for studying scintillation over a large sample of pulsars - in this talk I will describe the first results. Over 100 of the sources show measurable scintillation arcs, primarily low-DM, high velocity sources. Among these are several clear detections of multiple arcs, sources with inverted arclets, and with clumps of power at fixed position across frequency. One highlight is J1731−4744 for which the extremely rapid scintillation implies a local < 10 pc screen, confirming its association with the supernova remnant RCW 114. Almost half of the sources show some degree of measurable scintillation, but detections of arcs are limited by the short observation durations and ~ 1 MHz channels. The large sample will be useful in building and improving galactic electron models, studying the distribution of screens in the Milky Way, and many of these sources will be interesting candidates for targeted followup observations.

CHIME Overview

Emmanuel Fonseca
West Virginia University

The timing of radio pulsars is a uniquely powerful technique for probing fundamental aspects of physics in extreme environments. However, most premier single-dish observatories only observe a small fraction of the known pulsar population with several-month cadences due to limited and competitive resources. In this talk, I will describe the development and ongoing operation of a pulsar-timing backend constructed for the Canadian Hydrogen Intensity Mapping Experiment (CHIME). The CHIME/Pulsar backend tracks up to 10 different sky positions at any instant in time, and observes all Northern pulsars within a several-week timespan with a range of uniquely high cadence. I will also present brief overviews of its science capabilities and several recent/ongoing efforts.

Scintillation Across Two Decades of Frequency

Kathryn Ross
Curtin University

Determining the origins of low-frequency (∼MHz) variability of extragalactic sources has, until recently, largely been limited to small populations and/or single frequencies. However, with the advent of radio telescopes like the Murchison Widefield Array (MWA), variability surveys of large populations with significant temporal coverage have now become a reality. Using two epochs of the Galactic and Extragalactic All-sky MWA (GLEAM) survey, we have conducted a variability analysis of over 23,000 sources across 100 − 231 MHz over a year-long timescale, the only spectral variability study of its kind. We identify a population of over 300 variable AGN and monitor 15 of these sources simultaneously with the MWA and the ATCA several times over the course of one year. With the large spectral coverage, we are able to distinguish between variability caused by interstellar scintillation and intrinsic processes relating to the source itself. In this talk, I will outline the importance of spectral coverage in scintillation studies to ensure a reliable population of scintillating sources for analysis. Furthermore, I will demonstrate the advantages of detecting low-frequency variability to identify IDV candidates and present recent results following up a sample of these candidates using the ATCA to measure their timescale and annual cycle of variability.

Orbital Studies

Scintillometry Studies of Pulsar Triple System PSR J0337+1715

Nina Gusinskaia
Canadian Institute for Theoretical Astrophysics

PSR J0337+1715 is the only known pulsar in a stellar triple system. Long-term timing analysis of this system enabled the most accurate test of the Strong Equivalence Principle to date, but it also provided very precise measurements of the orbital elements of this system, including inclination and longitude of the ascending node. This makes PSR J0337+1715 an excellent test case for pulsar scintillometry techniques using which information about pulsar orbit orientation, distance to the pulsar as well as interstellar screen parameters can be independently retrieved. We used new high-frequency resolution GBT timing data of PSR J0337+1715, newly developed $\theta-\theta$ techniques of retrieving systems' effective velocities and 1D-screen model of the scintillation. We found that timing and scintillometry results are in perfect agreement in the pulsar triple system. Furthermore, we show that our scintillometry techniques and results can potentially be used to improve precision of timing and VLBA parallax measurements.

PSR B1744−24A Eclipses

Dongzi Li
California Institute of Technology

Radio emission from pulsars in close orbit with a companion can be modulated rapidly by the electron and magnetic field of the companion. PSR B1744−24A is a millisecond pulsar in a 1.8 hr orbit with a low mass companion. When it ablates the material from the companion, its radio wave experiences irregular eclipses from the ablated plasma. Our polarization study of this radio pulsar has revealed the magneto-active environment around it. Abrupt rotation measure (RM) changes of $\sim 100\,\mathrm{rad\,m^{-2}}$ happening at a time interval less than 20 sec are seen on random orbital phases, indicating $B > 10\,\mathrm{mG}$ in the remote wind of the companion. The circular polarization reverses its sign near the inferior conjunction of the pulsar at 2 GHz. This is best explained by the pulsar light experiencing Faraday conversion between linear and circular polarization during the large-scale magnetic field reversal in the companion magnetosphere, limiting the magnetic field $B > 10\,\mathrm{G}$ in the

companion magnetosphere. The pulsar flux is partially eclipsed near the inferior conjunction. The profile of total and circular flux across the frequency requires the eclipse mechanism to be circularly polarized. Our measurement provides new constraints on the eclipse mechanisms, the companion magnetic field, and a new possibility to infer the orbit inclination angle. Moreover, the fast RM variation and significant circular polarization changes are reminiscent of some Fast radio bursts, suggesting the possibility that those FRBs are also observed through the turbulent plasma of a nearby companion.

Lensing Around the PSR B1957+20 Eclipses

Fang Xi Lin

Canadian Institute for Theoretical Astrophysics

Recently, several eclipsing millisecond pulsars have been shown to experience strong and apparent weak lensing from the outflow of their ionized companions. Lensing can be a powerful probe of the ionized plasma, with the strongest lenses potentially resolving emission regions of pulsars, and understanding lensing in the 'laboratory-like' conditions of an eclipsing pulsar may be analogously applied to fast radio bursts, which reside in dense, magnetized environments. We discover clear evidence of the two regimes of lensing, strong and apparent weak, and find variable dispersion measure (DM), absorption, scattering, and flux density in the original Black Widow pulsar PSR B1957+20 through an eclipse at the Arecibo Observatory at 327 MHz. We show that the flux density variations in the apparently weak lensing regime can be modeled directly from variations of DM. The mean effective velocities of the lensing material cannot be explained by orbital motions alone, but are consistent with significant outflow velocity of material from the companion. We also show that geometric optics can predict when and where the lensing regime-change between apparent weak and strong occurs, and argue that the apparent weak lensing to be due to averaging of many images.

Scintillation of the Double Pulsar

Ashley Stock

University of Toronto

The physical nature of interstellar scintillation screens remains an open question with only a handful of pulsars having a screen associated with a known structure in the interstellar medium. Measurements of scintillation can provide estimates on the screen distance, orientation, and velocity which can be compared with measurements of interstellar medium tracers. I will present on my work in understanding the scintillation screen of the double pulsar, J0737−3039A, from measurements of its scintillation timescale and foreground interstellar medium. J0737−3039A is a useful pulsar for this type of study as its orbital parameters have been measured precisely from pulsar timing, leaving few unknowns to measure through scintillation. This

pulsar is also located near the Galactic plane and behind the Gum Nebula, so its line of sight probes a complex mix of interstellar medium structures and environments. Understanding the source of J0737−3039A's scintillation can give insight into both the structures that cause scintillation and those that do not.

Probing the Orbit of J0621+1002 Using New Techniques for Precise Measurement of Scintillation Arc Curvatures

Geetam Mall
Canadian Institute for Theoretical Astrophysics

PSR J0621+1002 is a 28.8 ms pulsar in a binary system with a WD companion. It has an orbital period of 8.3 days. A Shapiro delay detection has loosely constrained the pulsar mass to $1.7^{+0.59}_{-0.63}\,\mathrm{M}_{\odot}$. In this project, we aim to measure the inclination of the binary system. Using the inclination and mass of the companion, we can measure the mass of the pulsar precisely. Constraining the mass of this binary will contribute to probe the EoS. Measuring the arc curvatures in a secondary spectrum becomes difficult when the power is not distributed along a thin parabola, but is convolved with inverted arclets, resulting in a diffused parabola. We use $\theta-\theta$ transform technique to avoid this issue. In my talk, I will present the current progress in this project.

Giant Pulses and Fast Radio Bursts

Scintillometry of the Crab: Evidence for Highly Relativistic Motion

Marten van Kerkwijk
University of Toronto

The Crab Pulsar's radio emission is unusual, consisting predominantly of giant pulses, with durations of about a micro-second but structure down to the nano-second level, and extreme brightness temperatures. It is unclear how giant pulses are produced, but they likely originate near the pulsar's light cylinder, where corotating plasma approaches the speed of light. I discuss observations where we use scattering in the Crab nebula to resolve the emission region, showing that the giant pulses originate in an extended emission region. We suggest that the simplest explanation for being able to resolve the emission region is (apparent) superluminal motion, and infer that the plasma producing the giant pulses moves highly relativistically, with a Lorentz factor of about 10000.

Using Giant Pulses to Measure the Impulse Response of the Interstellar Medium

Nikhil Mahajan
University of Toronto

Any sufficiently short radio burst looks like an impulse over a correspondingly narrow bandwidth. If this signal then propagates through a linear and relatively time-invariant system, we observe a noisy but direct measurement of the interstellar medium's impulse response. Using this idea, we use Arecibo observations of PSR B1937+21, a giant pulse emitting millisecond pulsar, to measure and model the ISM's impulse response along the line of sight. We can then use this technique to coherently decouple intrinsic pulsar emission from scintillation/scattering effects so that they can be studied separately.

Scintillometry with Radio Giant Pulses from the Crab Pulsar

Natalia Lewandowska

State University of New York in Oswego

The Crab pulsar has been a numerously studied object since its detection more than 50 years ago. It is a well known, albeit not understood source of radio giant pulses, single pulses that are apparently irregular and much brighter than their regular counterparts. In this talk I will focus on what we can learn from the Crab and its newly discovered trend between peak brightness and dispersion measure in the case of High Frequency Interpulses with the approach of scintillometry.

DM-Power: An Algorithm for High Precision Dispersion Measure and Application to Fast Radio Bursts

Hsiu-Hsien Lin

Academia Sinica Institute of Astronomy and Astrophysics

We present a new technique, DM-power, to measure the uncertainty of dispersion measure (DM) of single pulses up to the order of $\sim$0.01 pc cm^{-3}, which is typically 10 times more precise than other methods. DM-power maximizes the substructure energy of single pulses in different Fourier frequencies in the power spectrum. We apply DM-power to bursts of Fast Radio Bursts (FRBs) 20180916B and Pulsar (PSR) B0329+54. FRB 20180916B shows DM variation. In contrast, PSR B0329 does not show DM variation. The DM variation of FRB 20180916B can be due to the intrinsic, the propagation, and the Doppler effects, which are indistinguishable.

Scattering Variations Detected from a Repeating Fast Radio Burst

Stella Ocker

Cornell University

Fast radio bursts (FRBs) are millisecond-timescale radio transients, whose predominantly extragalactic sources appear to include highly magnetized compact objects. FRBs undergo multipath propagation, or scattering, from electron density fluctuations on sub-parsec scales in ionized gas along the line-of-sight. Scattering observations have been used to locate plasma structures within FRB host galaxies, probe Galactic and extragalactic turbulence, and estimate FRB redshifts. Scattering can also inhibit FRB detection and biases the observed FRB population. Here we report the detection of scattering delays from the repeating FRB 20190520B that vary by up to a factor of two or more on minutes to days-long timescales. In one notable case, the scattering delay varied from 7.9 ± 0.4 ms to less than 3.1 ms (95% confidence) over 2.9 minutes at 1.45 GHz. The scattering times appear to be uncorrelated between different bursts and uncorrelated with variations in the line-of-sight

integrated electron density or magnetic field. Scattering variations are attributable to dynamic, inhomogeneous plasma around the FRB, and analogous variations have been observed from the Crab pulsar. 9 Under such circumstances, the frequency dependence of scattering can deviate from the typical power-law used to measure scattering. Similar variations may be detectable from other FRBs that previously showed minimal evidence of scattering, offering an empirical window into small-scale processes within FRB source environments.

Gravitational Lensing and Scattering of FRB Radio Waves

Pawan Kumar
University of Texas at Austin

I will describe how gravitational lensing of FRBs is affected by a plasma screen in the vicinity of the lens or somewhere between the source and the observer. The wave passage through a turbulent medium affects gravitational image magnification, lensing probability (particularly for strong magnification events), and the time delay between images. These effects will be discussed in this talk.

Multipath Propagation of FRBs as a Tool for Uncovering the Properties of Extragalactic Plasma

Paz Beniamini
Open University of Israel

The interaction of FRB radio waves with the intervening plasma between us and the sources is viewed, at times, as a nuisance for probing intrinsic FRB properties. At the same time, it offers unique ways to probe interstellar matter at large redshifts and the intervening intergalactic medium. In particular, due to multi-path propagation, a magnetized plasma screen can cause temporal broadening of the FRB, lightcurve variability, spectral decoherence, depolarization and induced circular polarization. I will describe how these different properties are directly inter-related, how they manifest in FRB and pulsar observations and how this can already be used to constrain the nature of the intervening plasma in some bursts.

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