Abstracts for Krabi 2013 science week

Stanislav Babak stba@aei.mpg.de

In this work we present a search for monochromatic gravitational wave (GW) signals from individual sources. Numerous massive black hole binaries will form a stochastic GW background, while some nearby binaries might produce a resolvable GW signal. If binary is slowly evolving, the pulsar and earth terms in the response function could fall within the same Fourier frequency bin. In this work we search specifically for such GW signals (from "non-evolved" circular binaries) using frequentist and Bayesian approaches. We will report on the preliminary results of the search on EPTA data.

Cees Bassa bassa@jb.man.ac.uk

The Large European Array for Pulsars is a project within the European Pulsar Timing Array to facilitate the direct detection of gravitational waves through pulsar timing. By combining the signals from the five 100m class telescopes in Europe into a tied array telescope, we are creating an instrument with a collecting area equivalent to a 200m circular dish. This will improve the accuracy of the EPTA pulsar timing project and increase the sensitivity to the perturbations that gravitational waves insert into the pulse arrival times. I will present an overview of the project and discuss the latest results.

Ramesh Bhat ramesh.bhat@curtin.edu.au

Observing PPTA pulsars with the MWA. MWA will make a promising instrument for conducting low-frequency observations of PPTA pulsars, which will enable detailed characterisations of the ISM effects on timing data through dispersion and scattering measurements. A high time resolution data recorder is currently under development for this array and it will enable pulsar observations via capture of voltage data from all 128 array elements and processing to form coherent beam data. I will describe the status and timeline of this system, pulsar observations from ongoing commissioning, and the observing plans and strategies for monitoring PPTA pulsars with the MWA.

Anna Bilous hanna.bilous@gmail.com

Timing of millisecond pulsars at low frequencies with LOFAR LOFAR is a new leading-edge radio telescope operating at the very low frequency range of 10-240 MHz, thus covering the lowest 4 octaves of the observable radio window. We have started an observing campaign of millisecond pulsars (MSPs) with LOFAR and have already detected 34 MSPs out of 50 observed so far. This unique low-frequency data set allows us to study with unmatched precision both the interstellar medium (dispersion, rotation measure and scattering) and the spectral evolution of average pulse profiles. Characterising and correcting these systematic effects will potentially improve pulsar timing precision at higher observing frequencies, where the influence of interstellar medium is generally more subtle yet still capable of biasing timing solutions. The data we are acquiring will also give us new knowledge about the physics of MSPs themselves.

Paul Brook `paul.brook@astro.ox.ac.uk`
Pulsars are expected to have very stable average pulse profiles. There have been, however, a steadily growing number of exceptions to this generalisation. An understanding of the nature and magnitude of profile variability is valuable for improvements in pulsar timing. We have conducted an investigation into the average profile stability for a range of canonical and millisecond pulsars and present the results.

Sarah Burke-Spolaor (I) `sarahbspolaor@gmail.com`
Status of and predictions from electromagnetic observations of PTA continuous wave sources
We will speak about the use of both electromagnetic observations and pulsar timing's limits on gravitational waves to constrain, support, or disprove the binary supermassive black hole hypothesis in candidate systems. We will review electromagnetic signatures of PTA-detectable binaries, and present the results of ongoing electromagnetic studies to investigate the presence of a binary supermassive black hole in candidate systems. We will also consider the near-term prospects of Pulsar Timing Arrays to place physically interesting gravitational wave limits on these and other nearby targets. Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Bill Coles `bcoles@ucsd.edu`
Fitting for the quadrupolar signature of a single GW source
Any single GW source provides a distinctive spatial signature in a PTA that depends on the direction of the source and the locations of the pulsars, regardless of the temporal behavior of the GW source. In order to facilitate searches for burst, continuous, and memory signals we have implemented auxiliary functions Ax(t) and A+(t) in TEMPO2. These functions act as spatial matched filters for the two polarizations of a single GW source, by analogy with a radio signal one can think of them as the result of phasing the array to point in a certain direction. These auxiliary functions are complete statistics for the Earth component of the quadrupolar signal from a given direction, i.e. they carry all the information in the timing residuals that is relevant for this component.

Jim Cordes jmc33@cornell.edu

Timing Precision and Spin Stability in MSPs

This talk gives a progress report on the timing precision of MSPs, including empirical studies of noise contributions and their physical cause. The results include a breakdown of empirical noise into the relative contributions of the ISM, intrinsic pulsar effects, and radiometer noise. Results are based primarily on recent studies of published NANOGrav timing data by NANOGrav's Noise Budget Task Force. Projections to current wider bandwidth systems will be made. A brief summary of state switching seen in canonical pulsars will report on modeling using Markov processes and will speculate about whether similar effects are manifested by MSPs.

Xihao Deng xud104@psu.edu

Bayesian nonparametrics analysis is a novel data analysis method that is powerful to extract signals with unknown shapes. Instead of inferring the parameters that characterize the signals, it directly infers the shapes of the signals by taking advantage of our prior information. We apply this novel method to detect and characterize gravitational wave bursts and non-Gaussian gravitational wave background via pulsar timing array. We have found that Bayesian nonparametrics methodology can not only investigate if the gravitational wave is present in the data set, but also precisely infer the important properties of the gravitational waves, such as the sky location of the burst sources, the duration of the burst sources, the strain amplitude of the background, etc.

Timothy Dolch tdolch@oberlin.edu

A Systematic Evaluation of Deconvolution with Cyclic Spectroscopy on Simulated Data

The deconvolution methodology outlined in recent cyclic spectroscopy (CS) papers (Demorest 2011; Walker, Demorest, and van Straten 2013, submitted) can be used to measure the interstellar scattering (ISS) of millisecond pulsars. Correcting times-of-arrival for ISS is of interest for detecting gravitational waves with pulsar timing arrays. We present an analysis of simulated data to test the performance of CS deconvolution over a range of scattering and signal-to-noise parameters. We show that the inherent biases and scatter of the pulse-broadening function recovery must be taken into account when interpreting pulsar data through CS. Consequently, we set boundary conditions in the space of pulsar and ISS parameters within which the CS deconvolution technique can be effectively applied.

Justin Ellis (I) justin.ellis18@gmail.com

Pulsar timing arrays (PTAs) offer a unique opportunity to detect low frequency GWs in the near future. In this frequency band, the expected source of GWs are Supermassive Black Hole Binaries (SMBHBs) and they will most likely form in an ensemble creating a stochastic GW background with the possibility of a few nearby/massive sources that will be individually resolvable. The data analysis problem for detecting GWs with PTAs is not dominated by the complexity of the GW waveform as these sources are far from merger and more complex corrections to the waveform are negligible. Instead the difficulty lies in the PTA data itself which is irregularly sampled, and may contain many artifacts related to a deterministic timing model that must be subtracted from the data as well intrinsic pulsar behavior that is not well understood. Here we will discuss the development of a robust continuous GW pipeline aimed at detection and characterization. We will discuss our sampling methods including parallel adaptive MCMC and parallel tempering adaptive MCMC algorithms aimed at efficient parameter estimation and calculation of the Bayesian evidence. Finally, we will show preliminary results of this search on the International Pulsar Timing Array (IPTA) datasets.

Emmanuel Fonseca efonseca@phas.ubc.ca

A comprehensive study of relativistic gravity using PSR B1534+12

We present updated analyses of pulse profiles and their arrival-times from PSR B1534+12, a 37.9-ms pulsar in an eccentric orbit with another neutron star. A high-precision timing model is derived from twenty-two years of timing data, and accounts for all astrophysical processes that systematically affect pulse arrival-times. Five post- Keplerian parameters are measured that represent relativistic corrections to the standard Keplerian quantities of the pulsars binary orbit. These relativistic parameters are then used to test general relativity by comparing the measured values with those predicted by general relativity. We conclude that relativity theory is confirmed to within 0.38% of its predictions. The measurement of orbital decay contains a kinematic bias due to relative acceleration in the Galactic potential, and cannot be corrected for at this time due to an unreliable measure of distance; however, we can use this excess of orbital decay as a means to constrain the distance the pulsar should be in order for general relativity to be the correct theory of gravity. We find this distance to be d_GR = 1.035pm0.012 kpc. We also present evidence for pulse jitter in PSR B1534+12, which indicates short-term magnetospheric activity and has significant implications for the long- term improvement of timing precision. As a secondary study, we present an analysis on pulse-profile evolution that has been previously linked to relativistic spin precession. (More will be added soon!)

Jonathan Gair jrg23@cam.ac.uk

The effect of background discreteness on non-Einsteinian gravitational wave polarization constraints

When a gravitational wave background is detected using pulsar timing, it will be possible to test general relativity by placing a constraint on the presence of non-general relativity polarization states of the background. Previous analyses have focussed on isotropic backgrounds, but in practice the GW background is most likely to be dominated by emission from supermassive black hole binaries and will therefore be comprised of a number of discrete point sources. We investigate the effect of finiteness of the background on the polarisation constraints and show that these constraints are not adversely affected by the presence of discreteness in the background.

George Hobbs (I) george.hobbs@csiro.au
Pulsar-based time scales
I will provide an update on the IPTA project for developing a pulsar-based time scale from the IPTA data sets. I will discuss issues with applying the algorithm to the current IPTA data, show simulations of our expected time scale and present initial results. I will conclude by describing the IAU working group that has been set up to consider how to combine pulsar-based time scales with atomic time scales.

Gemma Janssen (I) gemma.janssen@manchester.ac.uk
The IPTA Data sets
This talk will be an overview of the data sets that are now available on the IPTA wiki, and the work that has been done to combine the data sets from the EPTA, NANOGrav and PPTA.

Antoine Lassus antoine.lassus@cnrs-orleans.fr
Searching for individual Massive Black Hole binaries in EPTA data : detection and upper limit in Bayesian approach
Pulsar timing arrays (PTAs) might detect gravitational waves (GWs) from massive black hole (MBH) binaries within this decade. The signal is expected to be an incoherent superposition of several nearly-monochromatic waves of different strength. The brightest sources might be individually resolved, and the overall deconvolved, at least partially, in its individual components. In this talk I will report on part of the work done in EPTA data analysis working group for searching these individual sources. I will present a Bayesian approach developed as part of the pipeline of the EPTA group. I will concentrate on parallel tempering MCMC made for characterization of single source parameters and upper limit on the amplitude of the signal (others talks will present other approaches) and I will present the preliminary results obtained by this method.

Patrick Lazarus (I) plazarus@mpifr-bonn.mpg.de
Solar system studies
By virtue of being extremely stable cosmological clocks, millisecond pulsars can be used to study the Solar System. The data sets produced by the IPTA will be used to search for small deviations in the position of the Solar System Barycenter as pre-

dicted by the Solar System Ephemeris used. At present, specialized techniques are being developed, and tested, within the IPTA to quantify the presence of such offsets with the aim to weigh Solar System bodies, search for unknown masses in the Solar System, compare Solar System ephemeris models, and constrain alternative theories of gravity that predict time-variations of the Earth-Sun separation.

Kejia Lee (I) kjlee007@gmail.com

Making the IPTA data challenge more realistic

As we know, the first IPTA data challenge has finished and the second is in the finalization state. Three major topics are included in this talk. I will start with reviewing the submitted results of the first data challenge, where the results will be presented in a overview fashion. A few high lights for the progress in the analyzing algorithm will be also mentioned. The second major part of the talk presents on the feedback and comments we received from the fist challenge. Accordingly, I will introduce the second data challenge and mention the improvements compared to the previous one. The third part will discuss the possible future planning of the challenge and its relation with the under-going data analysis of IPTA dataset.

Lindley Lentati ltl21@cam.ac.uk

TempoNest and beyond - A Bayesian approach to pulsar timing

A new Bayesian software package for the analysis of pulsar timing data is presented in the form of TempoNest that allows for the robust determination of the pulsar timing solution simultaneously with a range of additional stochastic parameters including both red spin noise and dispersion measure variations using either power law descriptions of the noise, or through a model-independant method that parameterises the power at individual frequencies in the signal. We will show that in scenarios where the noise is characteristic of pulsars being observed today (1 microsecond rms), the linear approximation to the timing model can underestimate the uncertainties in the timing model parameters by up to an order of magnitude compared to a non-linear analysis. We will show how TempoNest can be used to perform model selection between timing model and stochastic parameters, and how, even when only an initial, phase disconnected guess to the timing model is available, such as when new pulsars are discovered, TempoNest can be used to trivially perform the initial parameter estimation with minimal manual interaction. Finally we will introduce the concept of generative pulsar analysis, that allows for the simultaneous Bayesian parameterisation of the timing solution, stochastic processes and pulse profiles.

Lina Levin lina.s.levin@gmail.com

Interstellar Medium effects on NANOGrav pulsars

Scintillation in the interstellar medium affects the pulsar signal by scattering the pulses on their way to Earth. We calculate scattering delays for the NANOGrav

MSPs by creating dynamic spectra of the standard GUPPI and PUPPI timing observations and investigate whether we can use these to correct the TOAs to achieve a higher timing precision. We also analyse the long term variations of the scattering delays for several pulsars at the 20/30 day cadence of the NANOGrav timing data.

Kuo Liu kliu.psr@gmail.com
Measuring pulse time-of-arrival from broad-band pulsar observation
With the development of instrumentation, broad band pulsar observation has become available. Therefore, further investigation to improve the classic pulsar time-of-arrival technique is required. For the purpose of high precision timing, the new technique is supposed to account for effects from both interstellar medium scintillation and dispersion measure variation. In this talk, I will discuss two potential approaches and present simulation results as well as attempt of application.

Duncan Lorimer duncan.lorimer@mail.wvu.edu
The Galactic millisecond pulsar population
The current sample of pulsars with $P < 20$ ms is now 200 and at the level where meaningful statistics can be made. Following a short summary of this sample. I will present recent progress in our understanding of Galactic MSP demographics based on various generations of Parkes multibeam surveys. The talk will conclude with a discussion of suggestions for future progress in this area.

Jing Luo luojing1211@gmail.com
This talk describes the current design of a new completely TEMPO-independent pulsar timing data simulator, its capabilities and limitations, and well as the results of preliminary tests of the TEMPO2 package. The new simulation is based on SPICE, the solar system ephemeris reading software, developed at NASA's Jet Propulsion Laboratory. Currently, the analysis and simulation of pulsar timing data has been predominantly carried out using either the TEMPO or TEMPO2 software packages. This simulator will enable full end-to-end testing of these packages as well as the data analysis pipe-lines, which include those for gravitational waves detection and studying, based on these packages.

Dustin Madison (I) drm252@cornell.edu
Gravitational wave bursts with memory (BWMs) in IPTA data sets.
A burst of gravitational radiation contains non-oscillatory contributions which permanently deform the spacetime surrounding the source. These contributions are commonly referred to as "memory". In the merger of two supermassive black holes, the memory is produced primarily in the time interval immediately preceding the final plunge when the gravitational interaction is strongest. Memory is forbiddingly difficult to detect with ground-based laser interferometers. In pul-

sar timing experiments, a burst with memory (BWM) causes a sudden apparent change in the period of a pulsar; this creates a signal in the timing residuals which grows with the time baseline of the data set. With the largest number of well-timed pulsars, the most nearly-isotropic distribution of pulsars, and the longest available timing baselines, the IPTA is the best tool available for detecting memory. In this talk I will discuss memory, techniques for detecting it with pulsar timing, and the vital role the IPTA will play in its eventual detection.

Maura McLaughlin `maura.mclaughlin@mail.wvu.edu`
I will review the population of MSPs found in recent surveys at the GBT and Arecibo and discuss their properties and suitability for inclusion in PTAs. I will also discuss the MSP population expected to be discovered in these surveys over the next few years and, finally, the outreach programs which involve students in these searches and form an important pipeline for pulsar astronomy and gravitational wave science.

Chiara Mingarelli `chiara@star.sr.bham.ac.uk`
Pulsar Timing Arrays are currently the only way to search for gravitational radiation in the nanohertz band. The main sources of interest are gravitational wave backgrounds generated by supermassive black hole binaries or processes in the early universe. Several limits on this background have been set in recent years and searches of increasing sensitivity are currently ongoing. All the searches so far have only been done for isotropic backgrounds. However, a level of anisotropy may be present in the background radiation, and if a stochastic signal is detected it is important to characterise its power at different angular scales. We decompose a generic anisotropic background into spherical harmonics and compute and characterise the overlap reduction functions for any pulsar pair, which is an essential element for the evaluation of the likelihood function used in searches.

Chiara Mingarelli (I) `chiara@star.sr.bham.ac.uk`
IPTA outreach efforts
Outreach is becoming evermore important in today's society– people are demanding to know why their taxes should fund things like gravitation wave research. Here I present the various outreach activities across the IPTA, and provide a list of resources currently available to IPTA members who wish to further engage in outreach. This includes ready made video games, apps, podcasts and successful outreach grant applications.

David Nice `niced@lafayette.edu`
NANOGrav Millisecond Pulsar Timing Observations
We will give a status report on the NANOGrav millisecond pulsar timing effort using the Arecibo Observatory and the Green Bank Telescope. Observing cadence is 20 to 30 days. Observations are dual-frequency at each epoch, 800/1400 MHz

at Green Bank and generally 430/1400 or 1400/2030 at Arecibo. Observations use the 800 MHz GUPPI/PUPPI coherent dedispersion backends. We presently observe 18 pulsars at Green Bank and 19 sources at Arecibo, with an overlap of two sources.

Stefan Oslowski `stefan.oslowski@gmail.com`
Timing, polarimetry and physics of J0437-4715. In this talk I'd like to present a single-pulse perspective on timing, polarimetry, and physics of J0437-4715, a bright nearby millisecond pulsar. I'll discuss polarimetry of single pulses and their evolution with amplitudes relative to the mean. Strong dependence of polarisation emerges from such a study and I'll discuss its implications for physics and models of this MSP. Finally, I'll review the relation of single pulses to the timing properties of this pulsar.

Nipuni Palliyaguru `npalliya@mix.wvu.edu`
Single pulse properties of NANOGrav MSP J1713+0747
We investigate single pulse properties of MSPs in order to quantify their effect on timing. Jenet et al. (1997) presented the polarization properties and morphologies of single pulses from PSR J0437-4715 and concluded that the radio emission mechanism of MSPs is similar to that of canonical pulsars. Furthermore, single pulses of some MSPs such asJ1713+0747 and J0437-4715 are known to show phase jitter (Cordes & Shannon 2010). We explore the single-pulse properties of selected NANOGrav MSPs and present our results. We also investigate the possibility of using composite profiles consisting of bright single pulses, to improve timing.

Tim Pennucci `pennucci@virginia.edu`
Developments in wideband timing of millisecond pulsars
Millisecond pulsars are very sensitive to stochastic and secular changes of the dispersion measure, which may change on short timescales. The recent development of wideband receiver and backend systems has produced challenges for conventional timing methods due to profile variability originating from the pulsar and the interstellar medium. The development of improved methods should provide opportunities to not only obtain better timing for MSPs, but to also better study the ISM. I will present our progress on a new wideband timing algorithm that combines a simple extention of the Taylor (1992) TOA fit procedure and an empirically-based, frequency-dependent model of the pulsar's profile to produce timing and DM measurements. The results of its application to several MSPs will also be included.

Antoine Petiteau `petiteau@apc.univ-paris7.fr`
Searching for individual Massive Black Hole binaries in EPTA data : detection and upper limit in frequentist approach
Pulsar timing arrays (PTAs) might detect gravitational waves (GWs) from massive black hole (MBH) binaries within this decade. The signal is expected to be an incoherent superposition of several nearly-monochromatic waves of different strength.

The brightest sources might be individually resolved, and the overall deconvolved, at least partially, in its individual components. In this talk I will report on part of the work done in EPTA data analysis working group for searching these individual sources. I will briefly describe the pipeline which is currently developed for detection and for setting an upper limit on amplitude and distance of potential binaries. I will mainly concentrate on Fstatistic using Earth term only within a frequentist approach (others talks will present other approaches). Finally I will present the preliminary results obtained by applying this pipeline on EPTA data.

Scott Ransom `sransom@nrao.edu`
Millisecond Pulsar in a Stellar Triple System.
Just over one year ago, we uncovered a fast, bright, and so-far unique millisecond pulsar in the GBT 350MHz Driftscan survey which has two stellar-mass companions. Since that time, using a variety of telescopes and a huge number of observations, we have managed to fully "solve" the system. Gravitational interactions between the orbits and the relativistic transverse doppler effect of the pulsar are detected with extremely high precision, providing masses and inclinations to several decimal points of precision. Fitting the data with a 3-body integrator, the pulsar now "times" with microsecond-level or better precision, and with further refinement (and a "proper" timing model), this may become an excellent IPTA pulsar. Beautiful optical observations of at least one of the companions and a forthcoming VLBA measurement of a precise distance and proper motion will allow the system to be used as a calibrator for low-mass Helium white dwarfs. Finally, the exquisitely measured properties of the system will allow detailed investigations into its likely very strange evolutionary history.

Vikram Ravi `v.vikram.ravi@gmail.com`
Interesting astrophysical implications of current (I)PTA GW results
An IPTA detection of gravitational waves (GWs) will rely on an identification of an observed phenomenon in pulsar timing data with an unambiguous GW signal model. Ruling out such models with data also offers interesting scientific possibilities. GW signal models, clearly, are important. I will outline the effects of varying the most influential parameters that determine the GW signals expected from models of the binary super-massive black hole (SMBH) population, including binary orbital eccentricities and the SMBH formation mechanism. I will then compare the predicted signals with constraints from pulsar timing data and the algorithms used to compute them, and discuss the implications of these constraints.

Siraprapa Sanpa-arsa `ss8dy@virginia.edu`
After Fermi launched in 2008, it has revolutionized gamma-ray pulsar astronomy, by enabling the discovery of many new millisecond pulsars (MSPs). The Fermi Pulsar Search Consortium (PSC) has organized hundreds of radio observations of pulsar-like Large Area Telescope (LAT) unassociated gamma-ray sources. In less than 3 years, the PSC has discovered 49 new MSPs. These new discoveries num-

ber more than all MSPs in the first 20 years (from 1982 to 2002) of MSP searching combined. Notably, among the 46 new MSPs, there are at least 10 black widows and 4 redbacks (the rare populations of eclipsing pulsar binaries). As one of the PSC radio telescopes, the Green Bank Telescope (GBT) has, outstandingly, helped uncover 25 new MSPs. Here we report the properties and timing analysis of the 2 MSPs most recently discovered with the GBT: PSR J0621+25, PSR J2042+02 and PSR J1135+75. By searching more Fermi unassociated sources from the LAT 1-year, 2-year and soon 3-year Point Source Catalog, the GBT will almost certainly discover additional MSPs. The newly discovered MSPs will provide more potential additions to the pulsar timing arrays (like NANOGrav) as well as improve the understanding of MSP formation and evolution.

Alberto Sesana (I) `alberto.sesana@aei.mpg.de`
Modelling the expected PTA GW signal from massive black hole binaries
Pulsar timing arrays (PTAs) provide a promising tool to probe massive black hole binaries in the low redshift Universe. The strength of the emitted gravitational wave signal depends on several crucial parameters of the binary population, namely their masses and space density, but also their dynamical evolution, eccentricity and coupling with gaseous/stellar environment. I will discuss how these ingredients affect the expected GW signals qualitatively and quantitatively, presenting predictions consistent with theoretical models and observation of massive galaxy evolution in the low redshift Universe.

Ryan Shannon (I) `ryan.shannon@csiro.au`
Obtaining an upper bound on the GW background using IPTA data
Until the detection of gravitational waves, limits on the strength of the gravitational wave background (GWB) will be the most astrophysically relevant outcomes of the International Pulsar Timing Array (IPTA) project. In this talk, I will review an algorithm developed to place limits on the amplitude of GWBs. I will present limits derived from the Parkes Pulsar Timing (PPTA) dataset, derived for both Gaussian and non-Gaussian GWBs. and briefly discuss the astrophysical implications. I will then apply the algorithm to the IPTA dataset to calculate a preliminary limit on the amplitude of the GWB. I will discuss improvements that can be made to the datasets and prospects for placing more stringent limits on the amplitude of the GWB.

Xavier Siemens `siemens@gravity.phys.uwm.edu`
I will discuss how our ability to confidently detect a stochastic background of gravitational waves with pulsar timing arrays depends on various PTA properties like number of pulsars, cadence, RMSs, and observation time.

Ben Stappers (I) ben.stappers@manchester.ac.uk

The role of the IPTA in the SKA pulsar science team

The Square Kilometre Array will be the largest radio telescope ever built. It will be built in two phases and the first phase should be operational early next decade. Using pulsars to test theories of gravity in a number of different ways is one of the two key science goals for this first phase. The search for, and study of, gravitational waves forms an important part of this key science goal. I'll present the current construction of the pulsar science working group for the SKA and the areas in which it is currently contributing. I will also look forward to the future of this group. There is already representation from the IPTA on this SWG and I will highlight that and then enter into a discussion of this construction and how/if we think that this needs to be changed.

Dan Stinebring dan.stinebring@oberlin.edu

Correcting for Interstellar Delays: a NANOGrav Update

I will review the status of NANOGrav efforts to correct for ISM delays at the sub-microsecond level given our particular assets (large collecting area at Arecibo and the GBT; wideband observations with GUPPI/PUPPI) and our challenges (dual-frequency, as opposed to N>2 frequencies; and relatively low observing cadence of every 3-4 weeks). I will report on our method for correcting for dispersion measure variations and also on our R&D efforts to correct for scattering delay variations using a variety of techniques including cyclic spectroscopy.

Stephen Taylor staylor@ast.cam.ac.uk

The First PTA Search For Anisotropy In The Gravitational-Wave Background

The field of Gravitational-Wave (GW) detection via pulsar-timing arrays (PTAs) now has several mature techniques aimed at placing tighter, and ever more astrophysically interesting, constraints on the presence of an isotropic stochastic GW-background (GWB). However, if discretness of the emitting source-population leads to the stochastic approximation breaking down at higher GW frequencies, or local inhomogeneity leads to significant deviations of the GW-source distribution from isotropy, then an anisotropic search-pipeline will be necessary. Additionally, there may be a source-number regime between which single-source and isotropic codes are sub-optimal, and an anisotropic search becomes the optimal search algorithm. We have developed a suite of Tempo2 plugins to perform injections of GWBs whose constituent source-population has user-specified anisotropy. Via repeated injection and recovery of GWBs with anisotropic source-distribution, we have successfully developed the first pipeline capable of searching for anisotropy in the GWB. We will present the results of our injections, and conclude with preliminary results of the first ever PTA search for an anisotropic GWB.

Rutger van Haasteren (I) vhaasteren@gmail.com
Searching for Isotropic GW background using the IPTA data
One proposed IPTA project aims to perform a search for an isotropic background of gravitational waves. Since many independent and published methods designed to do this exist, this project would be an effort to apply many/all currently available methods to the IPTA combined data release. I will provide a summary of how the project is proposed to be managed. Because similar and similarly managed project is currently ongoing within the EPTA, the discussion of the IPTA project will be supplemented with experiences and results from its EPTA counterpart.

Rutger van Haasteren vhaasteren@gmail.com
Bayesian common mode mitigation: Time standards and DM variations
Common modes are stochastic signals shared between multiple datasets. Dispersion measure variations and clock errors both fall in that category. General Bayesian methods exist that deal with these kind of common modes, by treating it as stochastic signal. Such a procedure explicitly avoids estimating the waveform of the common mode(s), resulting in more accurate propagation of the uncertainties for subsequent analysis. This makes it an ideal addition to Bayesian searches for a stochastic gravitational-wave background signals. The common modes can be reliably reconstructed. I will present current efforts to apply this to DM variations and time standard reconstruction.

Jingbo Wang wangjingbo@xao.ac.cn
Bursts of gravitational waves produced by supermassive black hole mergers will leave a permanent imprint on space-time. It has been shown that such gravitational wave memory signals are, in principle, detectable by pulsar timing arrays as a glitch event would seem to occur simultaneously for all pulsars. Here, we describe an algorithm that can search for gravitational wave memory signals and limit the maximum size of possible gravitational wave memory event that could remain undetectable in a data set. We apply this algorithm to the Parkes Pulsars Timing Array data set. No significant gravitational wave memory signal is founded in the data set. We place upper bound on the amplitude of the gravitational wave memory signal. We discuss the astrophysical implication of the upper bound of the gravitational wave memory signal.

Yan Wang yan.wang.fire@gmail.com
Modified F-statistic for the continuous wave search
In this talk, I will report the recent progress on the continuous wave search pipeline by utilizing the modified F-statistic. The modified F-statistic is a variant of the standard F-statistic, it can include the pulsar terms and add the contributions from each pulsar coherently. And we take advantage the Particle Swarm Optimization (PSO) method to search for the parameters of the model from the statistic.

Linqing Wen linqing.wen@uwa.edu.au
Angular resolution and directional sensitivity of a pulsar timing array to detect individual gravitational-wave sources
I will present analytical solutions to (1) the angular resolution of a pulsar timing array to detect individual gravitational-wave sources and, (2) the relative contributions of different pulsar data to the overall signal-to-noise ratio for a coherent analysis and their dependence on pulsars' relative geometrical directions. I will discuss the implications of the result.

Weiwei Zhu zhuww@phas.ubc.ca
We report the analysis of a 19-year span of timing data on PSR J1713+0747 taken by the Arecibo and Green Bank telescopes. PSR J1713+0747 is one of the best high-timing-precision pulsars monitored by the NANOGrav project for the purpose of detecting gravitational waves. The timing precision of this pulsar can be regarded as the benchmark of NANOGrav timing instruments. We show the precision improvement achieved by multi-generation instruments including the Green Bank Ultimate Pulsar Processing Instrument (GUPPI) and its counterpart in Arecibo. The new timing solution we found improves the measurement of the pulsars mass, its orbital and geometric parameters, sets new limits on alternative gravitational theories.

Xingjiang Zhu xingjiang.zhu@uwa.edu.au
Title: Search for continuous gravitational wave signals in Parkes Pulsar Timing Array data Abstract: The talk includes some updates (e.g., the method, new results, etc.) on an all-sky blind search in latest PPTA data sets for continuous gravitational wave signals, such as those produced by nearby binary supermassive black hole systems.

Posters

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The Northern High Time Resolution Universe (HTRU-North) pulsar survey is a large-scale, L-band search for pulsars and fast transients using the 100-m Effelsberg radio telescope. Using state-of-the-art hardware that provides unprecedented time and frequency resolution, we are probing the northern hemisphere deeper than ever before in the search for precisely timing millisecond pulsars (MSPs). The discovery of such pulsars is, and will continue to be, of vital importance to the effectiveness of current and future pulsar timing arrays. So far, the survey has focused on observations at mid-Galactic latitudes (—b—¡15 deg, 3-minute integrations). With 13% of this survey region observed, we are happy to report that the survey

has discovered 15 pulsars. Of particular note, the first MSP of the HTRU-North survey, J1946+3414, is a member of a high-eccentricity binary. As J1946+3414 is a Galactic-field pulsar, the origin of this eccentricity is not well understood, with a possible explanation being found in a formation scenario involving a hierarchical triple star system. In this poster, I present an overview of the HTRU-North survey with particular focus on newly discovered MSP, J1946+3414.

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The new 64-m Sardinia Radio Telescope
The Sardinia Radio Telescope (San Basilio, CA, Italy) is a new 64-m dish now in its commissioning phase. Its active surface, made of 1008 separate alluminium panels, will allow to observe at frequencies up to 100 GHz. At the moment three receivers, one per focal positions, have been installed and tested: a 7-beam K-band receiver, a monofeed C-band receiver and a coaxial dual feed L-P band receiver. The latter will be the main instrument for pulsar observations and, with both an ATNF dual band Digital Filterbank backend and a Roach Board based backend, it will be extensively used for timing observations of pulsar for the European Pulsar Timing Array (EPTA) and for the LEAP (Large European Array for Pulsars) experiments. Tests of the pulsar instrumentation are now underway.

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Status of the EPTA timing
We present an overview of the EPTA dataset, which consists of data for 41 millisecond pulsars from four telescopes: the Effelsberg 100-m Telescope, the Nançay Radio Telescope, the Lovell telescope and the Westerbork Synthesis Radio Telescope. The dataset is based on the EPTA legacy data and date as back as 1996. Also, key features of the new generation backends currently used are presented as well as a glimpse into future EPTA instrumentation. Additionally, we present an overview of current work carried out using the data.

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LOTAAS: The LOFAR Tied-Array All-Sky Survey for Pulsars and Fast Transients
LOTAAS is an all-northern-sky survey for pulsars and fast transients using the LOFAR high-band antennas. LOTAAS takes advantage of LOFAR's unparalleled field-of-view and multi-beaming capabilities to perform the deepest all-sky survey ever undertaken for pulsars and other sub-second radio bursts. The survey is in many ways different from previous pulsar surveys (e.g., much longer dwell times and lower frequency) and the potential for the serendipitous discovery of new source classes and physical phenomena is high, especially because of the unprecedented total on-sky time the survey will achieve. Each point on the sky will be covered for 1 hr at full sensitivity and for 3 hours at moderate sensitivity. We have demonstrated the potential of LOTAAS through two pilot surveys performed during LOFAR's commissioning period and have recently started acquiring and

processing new data. Here we present an overview of the novel survey approach and early results from the search processing.

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Pulsar polarisation as a diagnostic tool.
High precision timing may be ultimately limited by subtle affects in the pulsar magnetosphere. Understanding these effects is therefore essential to remove intrinsic variations of the pulsar clock. These effects can be best studied in normal pulsars in order to estimate their impact for millisecond pulsars. Here we study the interplay between the geometry of pulsars and magnetospheric propagation and switching effects.
The geometry is one of the intrinsic neutron stars properties, governing the pulse-profile phenomenon and other aspects of pulsar astronomy. With a number of pulsars in our dataset, the geometry is derived from the polarisation position angle (PPA) using the hollow-cone and rotating vector models (RVM), in which the solutions can hardly be constrained or are failed to be consistent because of the limitations of the model itself. The inconsistency issues in the results suggest that the initial PPAs can be strongly perturbed from additional parameters after the emission altitude, such the plasma medium or rotational aberration effects, in which their characteristics shape is no longer related to the geometry via the RVM. We investigate further into the effects of wave propagation in the pulsar magnetosphere, and found an indication that in most cases the RVM-originated PPAs are likely to be affected by plasma effects.
In recent years, there have been an increasing number of intermittent and mode-switching pulsars, observed to have their radio pulse profiles correlating with changes in the pulsars spin frequency derivative. It is understood that the two phenomena are related via different states of plasma in the magnetosphere. One such pulsar with known geometry and moding behaviour, PSR B1822−09, is studied in detailed and compared to the classical intermittent pulsars, PSRs B1931+24, J1841+0500 and J1832+0029.

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In this poster, we show a remarkable dataset spanning ~25 years of high cadence data from the bright southern pulsar J0738−4042. The data challenge our understanding of pulsar radio emission at many levels. They show smooth and abrupt variability on long time scales, a dramatic change in the spin down rate, and changes in the polarization properties. We present these findings in the context of a growing population of radio-variable pulsars with correlated timing irregularities, including the intermittent pulsars, state-changing pulsars and other individual examples.

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The ASTERIX pulsar instrument
ASTERIX is the most recent addition to the suite of pulsar instruments at the Ef-

felsberg 100m Radio Telescope. The large bandwidth offered by ASTERIX and the possibility to deal with radio frequency interference is producing arrival times with higher precision than the previous instruments. This greatly improves the already high quality and broad range of results capable with the Effelsberg 100m. The design and features of the instrument are presented in the poster.

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Analysis of relativistic binary pulsars is currently the best means by which to test theories of gravity in strong gravitational fields. We have developed a four-dimensional Hough transformation capable of detecting sinusoids in noisy images. This hough transformations can by applied to Dynamic Power Spectra to detect the sinusoidal sift in observed spin frequency from binary pulsars in approximately circular orbits. We examine the power of this search method in relation to other standard search techniques. These types of transformation are computationally intensive and can take prohibitive amounts of time to run. We present four alternative GPU accelerated implementations of a Sinusoidal Hough transformation algorithm, which we apply to synthesized and real Dynamic Power Spectra to determine the GPU kernel that provides the best acceleration.

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Polarization calibration for LEAP
Polarization calibration is crucial for high precision pulsar timing experiments as well as many other astronomical observation. The Large European Array of Pulsars (LEAP) is the first phase array dedicated to pulsar timing observations. Phase array combines the baseband data coherently to increase the telescope sensitivity. There are many types of telescopes used in LEAP observing, where Effelserberg , Jodrell bank and Sardinia telescope are altazimuthal mounted, WSRT is equatorial mounted, and Nancy works as a transient telescope. Such mounting varieties introduce different polarization-time dependence. In this way, we need to calibrate the polarization of each telescope individually before the coherent addition. In this poster, we will present the technique we developed to calibrate the telescope polarization properties using pulsar itself. In our method, 7 system parameters per frequency channel are used to fully characterize the all possible linear deviation of the receiver system from the perfect feed and are measured using least square fitting method. We will show the results of PSR J1022-1001 as an example, where the calibrated pulse profile, and coherent addition between Effelsberg and WSRT is given. As a remark, we will also show that such algorithm is capable of calibrating the historical pulsar data without corresponding calibrator observations, where the system parameters can be measured from a ensemble of bright pulsars.

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The nature of pulsars is still unknown because of non-perturbative effects of the fundamental strong interaction, and different models of the inner structures are

then suggested, either conventional neutron stars or quark stars. Besides, a state of quark-cluster matter is conjectured for cold matter at supranuclear density, as a result pulsars could thus be quark-cluster stars. Besides understanding different manifestations, the most important issue is to find an effective way to observationally differentiate those models. X-ray polarimetry would play an important role here. In this letter, we focus on the thermal X-ray polarization of quark/quark-cluster stars. While the thermal X-ray linear polarization percentage is usually higher than 10% in normal neutron star models, the percentage of quark/quark-cluster stars is almost zero. It could then be an effective method to identify quark-cluster stars by X-ray polarimetry. We are therefore expecting to detect X-ray polarization in the coming decades.

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PRESTO is one of the best pulsar searching softwares in the world. It is fast in the searching. And now we are working to make it even faster, with the help of GPU. I will present out current work and the latest progress. The future work will also be discussed.

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A new method to search for supermassive black hole binaries.
We present a new technique to search for low redshift supermassive black hole binaries (MBHB), which are expected to be the main gravitational wave (GW) sources for pulsar timing arrays (PTAs). Using mock galaxy catalogues from the Millennium Simulation, we investigate the peculiar properties of merging galaxies. We find that they are biased towards larger masses and redshifts, and have a distinct distribution of neighbouring galaxies below approximately 10 Mpc. Using machine learning algorithms, we demonstrate that such information can efficiently recover MBHBs in mock galaxy catalogues, as well as in catalogues adapted to the observational limitations of a real galaxy survey (namely the Sloan Digital Sky Survey, SDSS). We then apply the same technique directly to the spectroscopic SDSS catalogue, assigning to each galaxy a probability of containing a MBHB. The result is a probability sky map that can be used both to perform targeted searches in particular directions of the sky (the ones with higher probability of hosting a MBHB), and to study the properties of the overall background (i.e., deviation from Gaussianity, anisotropy, etc.). The spectroscopic SDSS covers less than a quarter of the sky and becomes severely incomplete at z>0.1; however, this technique can be applied in the future to larger catalogues, to obtain detailed observationally based information of the expected GW signal detectable by PTAs.

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The LEAP pipeline
The Large European Array for Pulsars (LEAP) involves coherently combining the five EPTA-telescopes to make the equivalent of a fully steerable 194-m dish. This results in 35 tera-bytes of data from each of the 5 participating telescopes that needs

to be transferred, coherently added and reduced to average profiles from which the TOAs can be extracted. A pipeline has been developed that allows complete reduction of all data-streams in only a few days.
The pipeline consists of C-code, python-code and shell scripts to allow for both extensive automation as well as great flexibility. The correlations and addition run on a 32-node cluster. Each node can run 4 jobs at a time, which is an optimal trade-off between processor capacity and data-transfer rates. The code includes polarization calibration, rfi filtering and bandpass corrections, aswell asthe option to correlate on the gated pulsar signal itself.

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A Population PDF for PALFA MSPs Using the "Snapshot Method"
Using results from the PALFA precursor (P1944) survey, we put constraints on the Galactic MSP population using the "snapshot method" – extrapolating the form of an underlying pulsar population given the inferred spatial and intrinsic parameter distributions of known pulsars. By varying the size of a simulated MSP population, we compute probabilities of detecting N MSPs for each population size and constrain the Galactic population with the resulting PDFs. Since the P1944 Survey detected one MSP, simulations loosely constrain the Galactic population to N_G on the order of 10^4 MSPs. Using similar techniques, we estimate the number of MSPs that will likely be detected by the full PALFA survey and show how the scale-up is likely to further constrain N_G for MSPs. We perform this analysis using PsrPopPy, a new Python implementation of PSRPOP that takes advantage of object-oriented features of Python and improves on the modularity of the initial Fortran code. Prewritten scripts are provided for running standard population simulations but the code is flexible enough to accommodate customized scripts and pulsar parameter distributions. PsrPopPy is open source and available on GitHub at `https://github.com/samb8s/PsrPopPy`.

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Limits on GWs from high–cadence observations of PSR B1937+21
We present new timing results on PSR B1937+21, which we observed with the Lovell telescope at Jodrell Bank Observatory with almost daily cadence. We used multi-frequency timing data from the Westerbork Synthesis Radio Telescope to correct for the dispersion measure variations. The high cadence timing enables us to set an upper limit of individual GWs from 2.5×10^8 Hz to 5×10^6 Hz. The post-fit residuals show unmodeled noise, which is periodic and can be fitted with sinusoidal wave along with the second harmonic. The fundamental frequency is 3.4yr^{-1}. We are investigating different possible origins of the noise but have no confirmed explanation yet.