The International Pulsar Timing Array

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Abstract

The International Pulsar Timing Array (IPTA) is an organization whose *raison d’être* is to facilitate collaboration between the three main existing PTAs (the EPTA in Europe, NANOGrav in North America and the PPTA in Australia) in order to realize the benefits of combined PTA data sets in reaching the goals of PTA projects. Currently, shared data sets for 50 pulsars are available for IPTA-based projects. Operation of the IPTA is administered by a Steering Committee consisting of six members, two from each PTA, plus the immediate past Chair in a non-voting capacity. A Constitution and several Agreements define the framework for the collaboration. Web pages provide information both to members of participating PTAs and to the general public. With support from an NSF PIRE grant, the IPTA facilitates the organization of annual Student Workshops and Science Meetings. These are very valuable both in training new students and in communicating current results from IPTA-based research.

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(Some figures may appear in colour only in the online journal)

1. Introduction

Pulsar timing arrays (PTAs) exploit the great period stability of millisecond pulsars (MSPs) to explore a range of phenomena that produce correlated timing variations among the pulsars in the array. There are three main sources of correlated variations that can be investigated.

- Irregularities in reference time standards.
- Errors in the planetary ephemerides used for transferring observed pulse arrival times to the solar-system barycentre.
- Gravitational waves (GWs) passing over the pulsars and the Earth.

These three source categories have different spatial signatures, i.e., the correlated variations have different dependencies on the positions of the pulsars. Consequently, to separate these different source categories, a PTA must have a wide distribution of pulsars on the sky (e.g., Foster and Backer 1990).

All pulse times of arrival (ToAs) are with reference to a time standard, normally based on an international network of atomic frequency standards. For example, ‘Temps atomique
international’ (TAI) is a uniform timescale, defined by the Bureau International des Poids et Mesures (BIPM) in Paris, that is based on a weighted average of data from several hundred atomic frequency standards around the world. Normally time derived from a local observatory frequency standard is referred to TAI using global navigation systems to effect the time transfer. TAI has a stability of order $10^{-15}$ over intervals of months to years (Arias et al 2011), comparable to the stability of MSPs (Verbiest et al 2009). Consequently it is feasible to use a PTA to identify irregularities in TAI and similar atomic timescales. Such irregularities will affect the period of all pulsars in the array in the same way; if the reference timescale is running slow, all pulsars will appear to be running fast and vice versa. In terms of a spatial pattern, this is a monopole signature.

To remove the effects of motion of the Earth from pulsar ToAs, all pulsar timing analyses use a planetary ephemeris to calculate corresponding ToAs at the barycentre of the solar system, assumed to be inertial (unaccelerated) with respect to the local standard of rest. Any error in the ephemeris results in an error in the computed position of the Earth and hence residuals which are positive for pulsars in the direction of the error and negative for pulsars in the opposite direction. Such errors therefore have a dipole signature on the sky.

Because of the quadrupolar nature of gravitational radiation, correlated residuals resulting from a GW passing over the Earth have a different signature, positive for pulsars separated on the sky by angles near zero and $\pi$ and negative for separations near $\pi/2$ (Hellings and Downs 1983).

These different spatial signatures allow the different effects to be separated. The significance of any detection depends in a complicated way on the details of the signal, the distribution on the sky of pulsars in the array, and the precision, cadence and span of the ToA measurements. Figure 1 illustrates this for the case of detection of an isotropic stochastic GW background with a set of idealized PTAs. While real PTAs may not reach these ideal assumptions, the general trends remain valid. Clearly the most dramatic improvement in detection significance is obtained by increasing the number of pulsars in the PTA, with sensitivity approximately linearly proportional to the number of pulsars in the array at a given
GW amplitude. This is the core rationale for creation of the International Pulsar Timing Array (IPTA).

There are three main PTAs currently operating: the European Pulsar Timing Array (EPTA), the North American pulsar timing array (NANOGrav) and the Parkes Pulsar Timing Array (PPTA)—see articles in this Focus issue by Michael Kramer and David Champion, Maura McLaughlin and George Hobbs, respectively. Each of these has been operating consistently since 2005 although earlier data from related pulsar timing programs are frequently included in analyses. As is discussed in more detail in section 3 below, data are available for 50 pulsars, of which 11 are observed by two PTAs and eight by all three PTAs.

The benefits of combining data sets from the various PTAs have long been recognized. However, the first concrete steps toward setting up a framework to facilitate this were taken by Andrea Lommen and colleagues when they organized the first IPTA meeting in Arecibo on 1–2 August, 2008. This meeting was very successful and resulted in a draft Data Sharing Agreement between the three main PTAs. Informal contact was maintained between representatives of the three PTAs over the next couple of years and this led to the second IPTA Meeting, held in Leiden in June 2010. This meeting, the first supported by the NSF PIRE grant awarded to West Virginia University, was in two parts, a student workshop with pedagogical lectures and tutorial sessions, and a science meeting with both invited and contributed talks and posters. Following this meeting a representative IPTA Steering Committee (IPTASC) was formed and this first met (by teleconference) in February 2011. In its subsequent meetings, the IPTASC formalized the goals and modus operandi of the IPTA as described in section 2 below.

One of the most important functions of the IPTA is to make available to the wider community carefully calibrated combined data sets. As a first step, data files have been made available by the three PTAs and these are described in section 3. Another important function is to coordinate and facilitate what have now become regular annual IPTA student workshops and science meetings and to encourage outreach programs related to IPTA objectives. These aspects of the IPTA are discussed in section 4.

An early description of the IPTA was presented by George Hobbs at the 8th Edoardo Amaldi GW Conference held in New York in June 2009 (Hobbs et al 2010). The pulsars being observed by the three PTAs and the expected ToA precisions were listed along with the expected GW detection sensitivity for a combined IPTA data set.

2. IPTA organization

The IPTA in an organization whose role is to facilitate cooperation between the main existing PTAs in order to optimize progress toward the mutual goals of PTA projects. It does this in several different ways. Firstly it sets up projects with lead members from each of the PTAs for specific goals related to use of combined data sets. One of the most important of these projects has the goal of producing combined data sets in a carefully calibrated and user-friendly form. Secondly the IPTA facilitates the organization of annual student workshops and science meetings on PTA-related topics. Thirdly it provides a framework for the establishment of working groups on topics of interest to PTA researchers, including outreach programs and data challenges.

Operation of the IPTA is administered by a Steering Committee, the IPTASC, which was formally established in February 2011. Each participating PTA has two members on the Committee and the immediate past Chair has ex-officio non-voting status. Table 1 gives the past and present membership of the IPTASC. The IPTA meets approximately every two months by teleconference or at the annual Science Meeting, and urgent matters are discussed via email.
Table 1. Members of the IPTA Steering Committee.

| Year | Chair          | Members                                                                 |
|------|----------------|-------------------------------------------------------------------------|
| 2011 | Andrea Lommen  | Dick Manchester, Scott Ransom, Ben Stappers, Gilles Theureau, Willem van Straten |
| 2012 | Dick Manchester| Scott Ransom, Ingrid Stairs, Ben Stappers, Gilles Theureau, Willem van Straten |
| 2013 | Ben Stappers   | Jim Cordes, Jason Hessels, George Hobbs, Scott Ransom, Willem van Straten |

The main vehicle for communication of IPTA-related issues between PTA researchers is a set of wiki-based web pages at www.ipta4gw.org/wiki/. These are accessible only to registered users who are normally members of a participating PTA, although a ‘friend’ category with limited access exists. Currently there are 95 registered users. A new user can request access to the wiki from the login page and such requests are normally promptly approved by the IPTASC. The wiki has pages for policies and agreements, projects, working groups, shared data, IPTASC Minutes and outreach. Registered users have read and write access to most of these pages; friends have this access only for the outreach page. IPTASC members and a few other people have administration access to the wiki allowing them to modify permissions, create new pages, approve user requests etc.

The IPTA operates under a Constitution that was ratified by the IPTASC in March 2012 and consists of the following items.

1. The International pulsar timing array (IPTA) is a consortium of existing pulsar timing array (PTA) collaborations.
2. The aims of the IPTA are to facilitate collaboration between participating PTA groups and to promote progress toward PTA scientific goals.
3. The IPTA will host annual student workshops and science meetings open to both members and non-members.
4. An IPTA Steering Committee (IPTASC) consisting of one or two representatives of each participating PTA will establish policy guidelines for data sharing, publication of results based on shared data and other matters as the IPTASC decides.
5. New PTA collaborations may be admitted to the IPTA with the approval of the IPTASC. Depending on size, new collaborations may have either one or two representatives on the IPTASC.
6. Members of the IPTASC will normally serve two-year terms.
7. The Chair of the IPTASC will be elected by the IPTASC members, normally from within the IPTASC membership, and will serve a one-year term as Chair and a further one-year term as an ex-officio non-voting member.
8. The IPTASC will meet at regular intervals and at least three times per year to discuss and formulate IPTA policy.
9. Policy will normally be agreed by consensus within the IPTASC, but in the event of disagreement, a policy decision can be made with one dissension.
10. The IPTASC will establish policy documents on topics as agreed necessary.
11. The IPTASC will establish and maintain a list of IPTA projects. Each project will have a title, abstract and a list of lead authors for the associated publication. The Project list will be made available to all IPTA members through a password-protected website.
12. Projects can be proposed to the IPTASC at any time and will be reviewed at (or if urgent, before) the next IPTASC meeting.
(13) The IPTASC will review the Project list at agreed intervals and, if deemed necessary, revise the goals or lead authorship of previously approved projects with not less than three months notice to the existing lead authors.

(14) This Constitution may be amended by unanimous vote of the IPTASC not less than three months after notification of IPTA members of any proposed changes.

The next most important document governing the operation of the IPTA is the Data Sharing Agreement, ratified by the ad hoc IPTA Committee in June 2009 following discussion at the Arecibo IPTA Meeting in August 2008, which has the following terms and conditions.

(1) The data is made available to the PTAs for doing PTA work only. This could be GW work, ephemerides or new time standards, but it is not for studying the properties of individual sources.

(2) Nothing is to be published from these data by people who didn’t take the data without the participation of people from the group that did take the data, in both the analysis process and in any resulting publications.

(3) IPTA-wide projects led by graduate students will be protected from prior publication by others. Such projects must be agreed to by the IPTA collaboration and the protection will be reviewed annually by the collaboration.

(4) We share calibrated pulse profile data, timing template profiles and ToAs, but raw data files will be made available on request.

(5) Shared data (including a summary table), lists of members of each PTA collaboration and lists of agreed collaborative projects will be made available on a server accessible only to members of the IPTA collaboration.

(6) Data will be made available within six months of the date of observation.

(7) Within a year of the date of this agreement and under the terms of this agreement, we commit to making available data obtained as part of the PTA projects. Access to earlier data will be by negotiation with the relevant group.

(8) The status and terms of this agreement will be reviewed annually.

The IPTA Publication Policy is another important document governing the operation of the IPTA. It was ratified by the IPTASC in March 2012 and has the following items.

(1) Projects using or interpreting shared non-public IPTA data, hereafter ‘IPTA projects’ must be approved by the IPTA Steering Committee and listed on the password-protected IPTA Projects website with a provisional title, abstract and list of principal authors for associated papers. IPTA data (hereafter ‘data’) is any previously unreleased pulsar timing data from two or more PTA members of the IPTA.

(2) Each PTA will recommend who among its members will be an author on an IPTA paper. Authorship order will be determined by the IPTASC considering any recommendation by the group of principal authors. There may be a small lead group of authors followed by a larger group of other authors listed alphabetically, or it may be a fully alphabetical list. Authorship will include at least everyone who contributed significantly to obtaining, processing, managing and/or interpreting the data discussed in the paper. Other contributions may also be worthy of authorship.

(3) Any member of an IPTA PTA can request inclusion in the group of principal authors for a given project. Such requests will be decided by the IPTASC considering any recommendation by the existing group of principal authors.

(4) Any member of the proposed author list for a paper may elect to opt out of authorship on that paper at any time prior to submission.

(5) IPTA projects, including graduate student projects, will be protected from prior publication by others provided the project is completed in timely manner.
Table 2. IPTA Projects.

| Project title                  | Lead person  | Date approved |
|-------------------------------|--------------|---------------|
| Pulsar timescale              | George Hobbs | 2012 June     |
| Solar system studies          | Patrick Lazarus | 2012 September |
| IPTA combined data release    | Joris Verbiest | 2012 September |

(6) The status of all unpublished IPTA papers, including graduate student projects, will be reviewed at regular intervals by the IPTASC and, if deemed necessary by the SC, modifications made to the lead authorship group.

(7) The IPTA encourages the early circulation of mature manuscript drafts to the entire author list. When the principal authors deem a manuscript ready for submission it will be circulated to all co-authors and the IPTASC for a review and comment period of at least two weeks.

(8) Following the review and comment period, the revised manuscript, with a cover note addressing the comments received and their disposition, will be submitted to and reviewed by the IPTASC. Following IPTASC approval the corresponding author will simultaneously submit the final manuscript for publication and to all co-authors.

(9) Upon receipt, all editorial correspondence (reviewer comments, acceptance/rejection notices, notices of on-line or other publication) related to a submitted IPTA manuscript will be circulated by the corresponding author to the IPTASC and to all co-authors. When the principal authors have prepared a response it will be circulated to the IPTASC and all co-authors. The IPTASC will decide whether the response requires a review and comment period and, if so, its duration. (Ordinarily, minor revisions will require no review and comment period, but major revisions will involve a review and comment period of at least one week.)

IPTA Projects operate under the terms contained in the Constitution and the Publication Policy. Current projects that have been approved by the IPTASC are listed in table 2 along with the lead proposer and the date of approval by the IPTASC.

The pulsar timescale project aims to use the IPTA combined data sets to establish a realization of terrestrial time, TT(IPTAxx) where 20xx is the year of the realization, that is of comparable or better precision compared to the best long-term atomic timescales. This work is a follow-up to the PPTA project that established TT(PPTA11) as described by Hobbs et al (2012).

The solar system studies project builds on the work of Champion et al (2010) who used a subset of the PPTA data set plus archival data from the Arecibo and Effelsberg telescopes to determine the masses of solar system planetary systems. The best result was obtained for the Jupiter system where the mass was obtained with a precision of $2 \times 10^{-10} \, M_\odot$, comparable to the best available measurements. In addition to improving planetary-system masses, the IPTA project aims to search for solar-system bodies that are not included in the solar-system ephemerides used for current timing analyses and to constrain variations in the astronomical unit over the past 20 yr.

The remaining approved project is described in section 3 below. There are several proposed projects that are currently awaiting discussion and approval by the IPTASC.

3. IPTA Data sets

Provision of combined data sets that contain well-calibrated results from all three participating PTAs is in a convenient form is fundamental to the goals of the IPTA. This task is an IPTA project
in its own right (table 2) and all other IPTA projects depend on it. Data sets from the different PTAs cover different pulsars, different frequency bands, have different random and systematic noise properties, different cadences and different data spans. Combining these data sets in a consistent way with optimal weighting and including corrections for dispersion variations is a non-trivial problem and is a work-in-progress. Based on the EPTA, NANOGrav and PPTA papers in this CQG Focus issue, table 3 lists the 50 pulsars for which data are currently (or soon will be) available on the IPTA website. The pulsar name, period, dispersion measure and mean flux density at 1400 MHz are given in the first four columns. The next six columns give the data span in years and the number of ToA epochs1 for each pulsar observed by each of the three main PTAs. The final column gives the total span of the combined data sets expressed as a range of Modified Julian Dates.

Figure 2 shows the distribution on the sky of pulsars being observed by the PTAs participating in the IPTA and figure 3 shows the time coverage of ToAs for the combined data sets. Not unexpectedly, the sky distribution is somewhat uneven with fewer observed pulsars in the northern hemisphere and a concentration in the central regions of the Galaxy around 18h right ascension where the density of pulsars is greater. The optimal sky coverage is a complex issue dependent on the application. For example, for the pulsar timescale project it is irrelevant, whereas for detection of an isotropic background of GW a wide range of angular separations on the sky is required but sky position itself is not important. For detection of an isolated source of GW, the optimal distribution depends on the direction of the source (see, e.g., Boyle and Pen 2012). Of the 50 IPTA pulsars, 12 are being observed by all three PTAs and ten by two PTAs. While some overlap is desirable, in fact essential, the current degree of overlap seems somewhat excessive. Scheduling of PTAs with multiple telescopes while ensuring adequate observation cadence and frequency coverage is not trivial (Lee et al 2012), but it is likely that addressing the issue would result in some improvement in the overall efficiency and effectiveness of the IPTA.

1 Multi-channel ToAs from a single observation are counted as one ToA epoch.
Table 3. Parameters of the PTA and IPTA Data Sets.

| Pulsar | $P_0$ (ms) | DM (cm$^{-3}$ pc) | $S_{1400}$ (mJy) | Span (yr) | ToAs | Span (yr) | ToAs | Span (MJD) |
|--------|-----------|------------------|------------------|-----------|------|-----------|------|-----------|
| J0023+0923 | 3.05 | 14.3 | – | – | 1.9 | 56 | – | – | 55 730–56 438 |
| J0030+0451 | 4.87 | 4.3 | 0.6 | 12.8 | 737 | 15.5 | 324 | – | – | 50 787–56 438 |
| J0340+4130 | 3.29 | 49.6 | – | – | 1.3 | 41 | – | – | 55 971–56 432 |
| J0437−4715 | 5.76 | 2.6 | 149.0 | – | – | 17.0 | 5160 | 15.5 | 324 | 49 373–56 396 |
| J0613−0200 | 3.06 | 38.8 | 2.3 | 14.2 | 1192 | 8.4 | 217 | 13.3 | 799 | 50 931–56 432 |
| J0645+5158 | 8.85 | 18.2 | – | – | 2.0 | 53 | – | – | 55 699–56 432 |
| J0711−6830 | 5.49 | 18.4 | 3.2 | – | – | 19.2 | 729 | 49 373–56 396 |
| J0751+1807 | 3.48 | 30.2 | 3.2 | 15.3 | 3199 | 5.9 | 68 | – | – | 50 363–55 948 |
| J0931−1902 | 4.64 | 41.5 | – | – | 0.2 | 8 | – | – | 56 439–56 438 |
| J1012+5307 | 5.26 | 9.0 | 3.0 | 15.2 | 1192 | 8.8 | 233 | – | – | 50 362–56 432 |
| J1017−7156 | 2.34 | 94.2 | 0.9 | – | – | – | – | 2.6 | 248 | 55 456–56 395 |
| J1022+1001 | 16.45 | 10.2 | 61.5 | 813 | 15.5 | 10.3 | 755 | 50 361–56 432 |
| J1024−7191 | 5.16 | 6.5 | 1.5 | 15.0 | 432 | 3.7 | 120 | 17.2 | 626 | 50 931–56 432 |
| J1045−4509 | 7.47 | 58.2 | 2.7 | – | – | 19.1 | 714 | 49 405–56 396 |
| J1103−2234 | 3.16 | 18.4 | 2.0 | 15.0 | 517 | 15.5 | 279 | – | – | 50 459–56 438 |
| J1143−1224 | 4.62 | 62.4 | 4.8 | 14.9 | 659 | 8.8 | 236 | 19.1 | 799 | 50 931–56 432 |
| J1203−2452A | 3.05 | 120.5 | 2.0 | – | – | – | – | 7.9 | 398 | 53 518–56 394 |
| J1239+1303 | 4.09 | 30.6 | 0.4 | 5.9 | 75 | 8.4 | 126 | – | – | 53 786–56 438 |
| J1235+0943 | 5.36 | 13.3 | 15.0 | 289 | 27.4 | 853 | 9.1 | 416 | 49 421–56 395 |
| J1303−0327 | 2.15 | 297.5 | 1.3 | – | – | 4.7 | 134 | – | – | 54 723–56 432 |
| J1317+0747 | 4.57 | 16.0 | 10.2 | 18.4 | 1144 | 21.2 | 857 | 19.1 | 683 | 48 737–56 436 |
| J1350−2304 | 8.12 | 9.6 | 3.9 | 14.2 | 191 | 4.2 | 21 | 19.1 | 754 | 50 361–56 432 |
| J1403−7200 | 3.51 | 56.8 | 1.7 | – | – | – | – | 17.4 | 590 | 50 026–56 395 |
| J1414−2230 | 3.15 | 34.5 | – | – | 1.9 | 8 | – | – | 54 971–56 432 |
| J1430+2224 | 16.45 | 10.2 | 61.5 | 813 | 15.5 | 10.3 | 755 | 50 361–56 432 |
Figure 3. Distribution of ToAs for the combined data sets. The band centre frequencies (ν) are colour encoded as follows: black: ν < 500 MHz, red: 500 MHz < ν < 750 MHz, green: 750 MHz < ν < 1000 MHz, blue: 1000 MHz < ν < 1500 MHz, aqua: 1500 MHz < ν < 2000 MHz and pink: 2000 MHz < ν < 4000 MHz.

Four IPTA pulsars have data spans longer than 20 yr: PSR J1713+0747 (21.2 yr), PSR J1857+0943 (PSR B1855+09, 27.4 yr), PSR J1939+2134 (PSR B1937+21, 28.6 yr) and PSR J1955+2908 (PSR B1953+29, 28.2 yr). The early observations for all four of these pulsars were made at Arecibo (Foster et al. 1993, Kaspi et al. 1994, Rawley et al. 1988). Unfortunately, except for J1713+0747, there are substantial gaps between the early and later data, and so arbitrary jumps are generally required between the data sets and pulse counting ambiguities are possible, significantly reducing the value of the early data. Since 2005 (MJD ∼ 53400) the cadence of observations has improved dramatically and there is more overlap of data at different frequency bands or with different instruments. However, the long data spans are important for detection of the red signals expected from GW and other sources despite the reduced cadence. For three pulsars: J0751+1807, J1732−5049 and J1911+1347, data-taking appears to have ceased a year or two ago. The PPTA dropped J1732−5049 since its ToAs had much larger uncertainties than those of other nearby pulsars.

4. Meetings and outreach

One of the important roles of the IPTA is to facilitate communication between the members of the participating PTAs, with the broader scientific community and with the general public. Aside from the wiki pages described in section 2, the main avenue for communication between
PTA members is the series of now-annual science meetings and the associated student workshops. Since 2010, these meetings have been generously supported by the National Science Foundation’s ‘Partnerships for International Research and Education’ (PIRE) grant, awarded to West Virginia University and NANOGrav in 2010 with Maura McLaughlin as Principal Investigator.

The first ‘IPTA’ meeting was held in Arecibo on 1–2 August, 2008. The meeting was attended by about 35 people representing all three PTAs and the larger GW community and including seven or eight students. It included a celebratory dinner in honour of Don Backer’s 65th birthday. There were four sessions on, respectively, the status of the three PTAs, techniques to improve timing precision, connections between the laser-interferometer projects and PTAs, and the future development of PTA projects. All sessions had extensive discussion periods during which many of the ideas that were later realized with the formation of the IPTA were discussed.

The second IPTA meeting\(^2\) was held at the Lorentz Center in Leiden between 21 June and 2 July 2010, supported by the NSF PIRE grant. The meeting was attended by about 65 people, nearly half of whom were students. This was the first IPTA meeting to have a pedagogical student workshop; this extended over five days (21–25 June) and included lectures by experts and practical tutorial sessions on GW basics, pulsar timing basics, the effects of the interstellar medium, and data analysis techniques for GW detection (two days). The Science Meeting was held on the following week and followed a similar set of session headings on each of the first four days with both invited and contributed talks and a discussion session at the end of each day. On the fifth day, there were presentations on each of the three main PTAs followed by discussion sessions to end the meeting.

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The 2012 meeting\(^4\) was hosted by the PPTA. The Student Workshop was held at Sydney University on 18–22 June and the Science Meeting was held at Kiama, a seaside town about 100 km south of Sydney, on 25–29 June. A total of 84 people, including 29 students and eight participants from China, attended the meetings with most attending both the Workshop and the Science Meeting. The Workshop followed a similar format to previous meetings with highlights being a session of live observing on the Parkes 64 m radio telescope using the Pulse@Parkes system (Hobbs et al 2009) and a talk on aboriginal astronomy by Ray Norris. The Science Meeting began with reviews of the current status of the three main PTAs and then presentations and discussions on data analysis, including several talks on cyclic spectroscopy, GW detection algorithms, implications of limits on GW signals, other applications of PTA data

\(^2\) www.lorentzcenter.nl/\{\{\}\}/web/2010/388/info.php3?wsid=388&venue=Oort.
\(^3\) http://ipta.phys.wvu.edu/ipta-2011/.
\(^4\) http://ipta.phys.wvu.edu/ipta-2012/.
sets, optimization of PTA/IPTA observing strategies and future telescopes and instrumentation, including a presentation by Di Li on the Chinese FAST project.

The 2013 IPTA meetings were held 17–28 June in Krabi, Thailand, approximately equidistant from all participating PTA centres, with Busaba Kramer playing a major role in the local organizing. About 90 people attended the meeting, including more than 30 students. These included many who had not previously attended an IPTA meeting. The Student Workshop was very successful, concentrating on signal processing for GW detection, and was a little more relaxed than previous years with more time for informal discussions (and relaxing by the pool!). Highlights of the Science Meeting included the first analyses of real IPTA data sets and extensive discussions on data analysis methods, especially considering the effects of red and white timing noise. Presentations and discussions on the nature of the nanohertz GW background, especially its likely anisotropy, and projections of GW sensitivity for future IPTA data sets were also of great interest.

The terms of the PIRE grant require that the IPTA meetings be formally evaluated; this is achieved by means of questionnaires distributed at the meeting. Summaries of these evaluations may be found in the Quarterly Newsletters on the PIRE website.

Plans are already coming together for the 2014 IPTA meetings, to be organized by NANOGrav and held at the University of Calgary (Workshop) and Banff National Park (Science Meeting). We plan to have the 2015 meetings in South Africa, to be organized by the PPTA in collaboration with Sarah Buchner, probably Durban for the Workshop and Kruger National Park for the Science Meeting. Note that participation in the IPTA Workshops and Meetings is not restricted to members of the participating PTAs and attendance by others from the larger astronomy and astrophysics community is encouraged.

The IPTA has a Working Group led by Ryan Lynch that focusses on outreach to the general public. The internal web page, accessible to group members, lists the outreach activities of the three PTAs and also acts as a forum for discussion of ideas related to IPTA outreach. The public website also has an outreach page giving links to PTA outreach sites.

Detection of GW signals in pulsar timing data is a complex task, with many possible approaches. To provide some confidence in the techniques being used by various groups around the world, not all associated with one of the three main PTAs, the IPTA has hosted a Data Challenge with a small Working Group led by Rick Jenet. This Data Challenge has made several simulated PTA data sets publically available as part of Data Challenge 1 and invited interested groups to analyse them. There are two classes of data set, Open and Closed, both of which are somewhat idealised and lacking all the complications of real data sets. Parameters of the injected GW signal were provided for the open data sets, but were hidden for the closed sets. A total of 12 analyses of the closed data sets were submitted by the deadline of 28 September, 2012, most of which obtained results consistent with expectations. Further, more realistic, data challenges are planned for the future.

Over the past few years, pulsar timing has been increasingly recognized as an important tool in the quest to detect GW, complementary to the various laser-interferometer systems, existing and planned. Stan Whitcomb, as Executive Secretary of the Gravitational Wave International Committee (GWIC), attended the 2008 Arecibo IPTA meeting, and promoted the idea of the PTAs joining GWIC. Shortly after this meeting, GWIC invited representatives of the three PTAs to join the 21 representatives of 11 GW detector projects and related bodies on the Committee. This invitation was accepted on 22 November, 2008, with Michael Kramer,

5 http://ipta.phys.wvu.edu/
6 http://nanograv-pire.wvu.edu/pire.html#evaluation.
7 http://www.ipta4gw.org.
8 See the Data Challenge pages at www.ipta4gw.org and the article by Rick Jenet in this special issue.
Andrea Lommen and Dick Manchester representing the EPTA, NANOGrav and the PPTA respectively. The current PTA representatives are Michael Kramer, Rick Jenet and George Hobbs. Among other activities, GWIC organises an annual GWIC Thesis Prize, typically with 20 or so theses submitted each year. The 2011 prize was awarded to Rutger van Haasteren, a member of the EPTA, for his thesis ‘Gravitational Wave detection and data analysis for Pulsar Timing Arrays’, a notable first for the PTA community.

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