Jodrell Bank Crab Pulsar Timing Results

Monthly Ephemeris

February 23, 2018

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Notes

1. If you intend to use this data in a publication, we request that you acknowledge use of the Crab ephemerides by giving this resource's web address and by referencing (Lyne, Pritchard & Smith 1993).

2. Modified Julian Date (MJD) is the Julian Date - 2400000.5.

3. The arrival times given are those of the centre of the first main pulse after midnight at infinite frequency at the barycentre of the solar system, in seconds. The timescale is now quoted in terms of T.D.B. To convert to T.A.I. 32.184 seconds must be subtracted, as well as the gravitational clock correction.
   The assumed pulsar position used in the reductions is:

R.A.(1950.0)	05 31 31.40500	DEC.(1950.0)	+21 58 54.3900
R.A.(J2000)	05 34 31.97232	DEC.(J2000)	+22 00 52.0690

   t_{MIT} is the barycentric arrival time obtained using the M.I.T.(PEP311) ephemeris (Ash,M.E.,Shapiro,I.I.,& Smith,W.B.,1967. Astr.J.,72,338).
   t_{JPL} is the barycentric arrival time obtained using the JPL (DE200) ephemeris (Standish 1982).

4. The quoted accuracy t_{acc} is that with which the ephemeris defined from these numbers is believed to describe the observed arrival times during the whole calendar month, using the DE200 ephemeris. If the M.I.T. (PEP311) ephemeris is used, then the difference in frequency ν is approximately 1 part in 10^{-10}, corresponding to a maximum arrival time difference over a month of less than 250 $\mu\, secs$.

5. The observed barycentric frequency ν and its first derivative $\dot{\nu}$ are given at the quoted arrival time, using the DE200 ephemeris.

6. The dispersion measure DM, as observed, is usually given, the error being typically $0.005\, pc\, cm^{-3}$. If the value given is in parenthesis, then this is an assumed value, extrapolated from adjacent data.

7. The assumed delay due to interstellar scattering is given for 408 Mhz. Where measured at other frequencies, the amount of scattering is assumed to scale as ν^{-4}.

8. There was a significant glitch on MJD 46664.0 (22 AUG 1986) (Lyne & Pritchard 1987). This date is taken as the end of the fit for AUG 1986 and the beginning of the fit for SEP 1986.

9. There was a significant glitch on MJD 47767.4 (29 AUG 1989) (Lyne, Smith & Pritchard 1992). This date is taken as the end of the fit for AUG 1989.

10. The fits immediately following the glitch (29 AUG 1989), with epochs 2 SEP, 11 SEP and 23 SEP 1989, cover the dates 29 AUG 09:30 to 7 SEP 00:00, 7 SEP 00:00 to 15 SEP 00:00 and 15 SEP 00:00 to 1 OCT 00:00 1989 respectively.

11. The MIT ephemeris only covers the dates up to Feb 1990.

12. There was a significant glitch on MJD 48945.8 (19 NOV 1992) (Espinoza et al. 2011b). This date is taken as the end of the fit for NOV 1992 and the beginning of the fit for DEC 1992.

13. There was a significant glitch on MJD 50259.9 (25 JUN 1996) (Espinoza et al. 2011b). This date is taken as the end of the fit for JUN 1996 and the beginning of the fit for JULY 1996.

14. There was a significant glitch at MJD 51452.3 (1 OCT 1999) (Espinoza et al. 2011b). The beginning of the fit for OCT 1999 is taken as 3 OCT 1999.

15. There was a significant glitch at MJD 51739.4 (14 JUL 2000) (Espinoza et al. 2011b). This date was taken as the end of the fit for JUL 2000 and the beginning of the fit for AUG 2000.

16. There was a significant glitch at MJD 51804.9 (17 SEP 2000) (Espinoza et al. 2011b). This date was taken as the end of the fit for SEP 2000 and the beginning of the fit for OCT 2000.

17. There was a significant glitch at MJD 52083.8 (24 JUN 2001) (Espinoza et al. 2011b). This date was taken as the end of the fit for JUN 2001.

18. There was a significant glitch at MJD: 52146.0 (24 AUG 2001) (Espinoza et al. 2011b). This date was taken as the end of the fit for AUG 2001.

19. There was a small glitch at MJD 52497.3 (12 AUG 2002).

20. There was a very small glitch at MJD 52587.1 (9 NOV 2002).

21. There was large glitch at MJD 53067.1 (3 MAR 2004) (Espinoza et al. 2011b). The fits with epochs 7 MAR ,15 MAR and 26 MAR 2004 cover the dates 3 MAR 00:00 to 10 MAR 00:00, 10 MAR 00:00 to 20 MAR 00:00 and 20 MAR 00:00 to 1 APR 00:00 2004 respectivly.

22. The fits with epochs 5 APR, 15 APR and 25 APR 2004 cover the dates 1 APR 00:00 to 10 APR 00:00, 10 APR 00:00 to 20 APR 00:00 and 20 APR 00:00 to 1 MAY 00:00 2004 respectivly.

23. There was a significant glitch at MJD 53254.2 (6 SEP 2004) (Espinoza et al. 2011b). The start of the fit for SEP 2004 is taken as MJD 53258.2 (10 SEP 2004).

24. There was a small glitch at MJD 53331.1 (22 NOV 2004) (Espinoza et al. 2011b).

25. There was a significant glitch at MJD 53970.0 (23 AUG 2006) (Espinoza et al. 2011b). This date was taken as the end of the fit for AUG 2006.

26. There was a significant glitch at MJD 54580.0 (24 APR 2008) (Espinoza et al. 2011b). This date was taken as the end of the fit for APR 2008.

27. A significant enhancement of dispersion measure occurred during SEP 2011. For this reason there are two fits for SEP 2011.

28. There was a significant glitch at MJD 55785 (10 NOV 2011). The fits with epochs 5 NOV, 13 NOV and 24 NOV 2011 cover the dates 31 OCT to 10 NOV, 11 NOV to 17 NOV and 17 NOV to 30 NOV 2011 respectively (Espinoza et al. 2011a).

29. Data fits from 1 DEC 2011 may include a term for DMDot (the first time derivative of the dispersion measure). An extra column has been added to the table.

30. There was a glitch at MJD 57839 (27 MAR 2017) This date was taken as the end of the fit for MAR 2017 (Espinoza et al. 2011a).

31. There was a significant glitch at MJD 58065 (8 NOV 2017). The fits with epochs 4 NOV, 11 NOV and 22 NOV 2017 cover the dates 1 NOV to 6 NOV, 8 NOV to 13 NOV and 14 NOV to 1 DEC 2017 respectively. The fits with epochs 8 DEC and 24 DEC 2017 cover the dates 1 DEC to 15 DEC and 16 DEC 2017 to 1 JAN 2018 respectivly. The fits with epochs 8 JAN and 24 Jan 2018 cover the dates 1 Jan to 15 Jan and 16 JAN to 1 FEB 2018 respectivly Note the large values for σ_ν. For more precise ephemerides we advise using the .gro format.

Examples of reduction of site arrival times to the Solar System barycentre and infinite frequency using the JPL Ephemeris DE200. (Revised 13th August 2002)

Pulses were observed at the following place, frequencies and times(UTC):-

JODRELL	1396.000 MHz.	27 SEPT 2001 02:21:39.018353
JODRELL	1396.000 MHz.	09 DEC 2001 21:29:42.031314
JODRELL	1396.000 MHz.	25 MAR 2002 15:46:39.092186
JODRELL	1396.000 MHz.	31 JULY 2002 07:10:25.075001

The telescope site co-ordinates are

	r×cos(lat)	r×sin(lat)	long(hours west)
Jodrell	3825.684	5086.391	0.153740

The corrections applied are as follows :-

	27 SEPT 2001 02:21:39.018353	09 DEC 2001 21:29:42.031314
UTC to TAI	+32.000000	+32.000000
TAI to TDT	+32.184000	+32.184000
TDT to TDB	-0.001609	-0.000686
Jodrell to Earth centre	0.014783	0.014746
Earth centre to Barycentre	+1:23.447712	+8:05.548384
observed freq to infinite freq	-0.120912	-0.120891
Gravitational propogation delay	0.000002	0.000007
Corrected BC arrival time	02:24:06.542329	21:38:51.656874
BC arrival time from ephemeris	02:24:06.542365	21:38:51.656901

	25 MAR 2002 15:46:39.092186	31 JUL 2002 07:10:25.075001
UTC to TAI	+32.000000	+32.000000
TAI to TDT	+32.184000	+32.184000
TDT to TDB	+0.001611	-0.000697
Jodrell to Earth centre	+0.016959	+0.016643
Earth centre to Barycentre	-1:35.139340	-6:8.132720
observed freq to infinite freq	-0.120864	-0.120905
Gravitational propogation delay	-0.000002	-0.000012
Corrected BC arrival time	15:46:08.034550	07:05:21.021310
BC arrival time from ephemeris	15:46:08.034566	07:05:21.021324

FORTRAN CODING TO OBTAIN THE ARRIVAL TIME OF A PULSE AT THE BARYCENTRE OF THE SOLAR SYSTEM AT INFINITE FREQUENCY FROM THE SUPPLIED EPHEMERIS.

The following example can be used to find the Arrival Time of a pulse nearest to a given time:-

```
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER LINE*120
   20 WRITE (5,9507)
       READ (5,*) EPOCH
      WRITE (5,9508)
       READ (5,*) SECS
      EPOCH=EPOCH+SECS/86400D0
      WRITE (5,9505)
       READ (5,*) V
      WRITE (5,9506)
       READ (5,*) VDOT
   30 WRITE (5,9522)
       READ (5,*) TD,TH,TM,TS
C
C CALCULATE ARRIVAL TIMES
C
      TREQ  = TD+TH/24D0+TM/1440D0+TS/86400D0
      TI    = (TREQ-EPOCH)*86400D0
      P     = 1D0/V
      PDOT  = -VDOT/(V*V)
      VDDOT = 2D0*PDOT*PDOT/(P*P*P)
      FREQ  = V + TI*VDOT + TI*TI/2D0*VDDOT
      TURNS = V*TI + VDOT*TI*TI/2D0 + VDDOT*TI*TI*TI/6D0
        IF(TREQ-EPOCH.LT.0D0) TURNS=TURNS-1D0
      PMEAN = 1D0/FREQ
      TARR  = TREQ - DMOD(TURNS,1D0)*PMEAN/86400D0
C
C WRITE RESULTS
C
      WRITE (5,9510) TD,TH,TM,TS
      TDI=AINT(TARR)
      TH =24D0*(TARR-TDI)
      THI=AINT(TH)
      TM =60D0*(TH-THI)
      TMI=AINT(TM)
      TS =60D0*(TM-TMI)
      WRITE (5,9511) TDI,THI,TMI,TS
      WRITE (5,9520)
       READ (5,9001) LINE
        IF (LINE(1:1).EQ.'Y') GOTO 20
      WRITE (5,9521)
       READ (5,9001) LINE
        IF (LINE(1:1).NE.'Y') GOTO 100
```

```
      GOTO 30
 9001 FORMAT (A80)
 9505 FORMAT (/$,' FREQUENCY = ?  HZ           (D-FORMAT) ')
 9506 FORMAT (/$,' FREQDOT   = ?  E-15/SEC**2  (D-FORMAT) ')
 9507 FORMAT (/$,' EPOCH       ?  MJD                     ')
 9508 FORMAT (/$,' EPOCH    ?  SECS     (D-FORMAT) ')
 9510 FORMAT (/$,8X,'TREQ = ',F6.0,3X,F3.0,3X,F3.0,3X,F9.6)
 9511 FORMAT (/$,8X,'TARR = ',F6.0,3X,F3.0,3X,F3.0,3X,F9.6)
 9520 FORMAT (/$,' DO YOU WANT A NEW EPOCH ? [YES/NO] ')
 9521 FORMAT (/$,' DO YOU WANT ANOTHER ARRIVAL TIME ?
     &        [YES/NO] ')
 9522 FORMAT (/$,' REQUIRED ARRIVAL TIME ? '/
     &        /$,' MJD, HOURS, MINS, AND SECS ')
  100 STOP 'OK'
      END
```

```
/*-------------------------------------------------------------*/
/* C CODING TO OBTAIN THE ARRIVAL TIME OF A PULSE AT          */
/* THE BARYCENTRE OF THE SOLAR SYSTEM AT INFINITE FREQUENCY */
/* FROM THE SUPPLIED EPHEMERIS.                               */
/*                                                            */
/* The following example can be used to find the Arrival     */
/* Time of a pulse nearest to a given time:-                  */
/*                                                            */
/* a c translation of the Jodrell Bank Observatory            */
/* pulse arrival time program from Crab Notes                 */
/* compile using eg. gcc -o getarrtime getarrtime.c           */
/*                                         caj June 2004      */
/*-------------------------------------------------------------*/

#include <stdio.h>
#include <math.h>
#include <string.h>

int main ()
{

  double  epoch, secs, v, vdot,freq;
  double treq, ti, p, pdot, vddot;
  double turns, preq, tarr;
  char q='y',eph[20];

  printf("Enter values from pulsar ephemeris...... \n");

  printf("Epoch of ephemeris (MJD)       :");
  scanf("%lf",&epoch);
```

```
  printf("Epoch of ephemeris (secs)      :");
  scanf("%lf",&secs);
  epoch = epoch + secs/86400.0;

  printf("Frequency (nu) in Hz           :");
  scanf("%lf",&v);
  printf("Freqdot   (nudot) in e-15Hz/sec:");
  scanf("%lf",&vdot);
  vdot = vdot* 1e-15;

  while (q=='y') {
    printf("\nRequired arrival time (mjd):");
    scanf("%lf",&treq);

    /* Calculate arrival time */
    ti = (treq-epoch)*86400.0;
    p = 1.0/v;
    pdot = -vdot/(v*v);
    vddot = 2.0*pdot*pdot/(p*p*p);
    freq = v + ti*vdot + ti*ti/2.0*vddot;
    preq = 1.0/freq;

    turns = v*ti + vdot*ti*ti/2.0 + vddot*ti*ti*ti/6.0;

    /*printf("ti=%lf, p=%lf, pdot=%f, vddot=%lf, freq=%lf\n",
          ti,p,pdot,vddot,freq);
    printf("turns %lf\n",turns);
    */

    turns = turns - (int)turns;
    tarr = treq + (1.0 - turns) *preq/86400.0;

    /*    printf("tarr = %lf\n",tarr); */
"\n1st arrival time after required epoch(mjd sec):%d %lf\n",
        (int)tarr, (tarr - (int)tarr)*86400.0);
    printf("Preq(secs) and nu(Hz): %.9lf %.9lf\n\n",preq,freq);

    /* Clear input buffer! */
    q=getchar();

    printf("Another epoch (n/y):");
    q=getchar();

    q=tolower(q);
    }
  exit(0);

  }
```

References

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