The curious case of J1022+1001
Or
How I learned to stop worrying and love MSP profile instabilities

The Pledge

- Discovered in the Arecibo declination strip survey by Camilo et al. in 1996
- 21 new pulsars discovered; 2 new MSPs including J1022+1001
- Unusual profile shape changes noticed in first few months of follow up.. Timescale of minutes
- Mass of companion > 0.73 solar masses
- IMBP; Mostly a CO WD

TABLE 4

PARAMETERS OF THE BINARY PULSARS

Parameter	PSR J0621+1002	PSR J1022+1001
Right ascension, α (J2000)	06 21 22.1103(6)	10 22 58.06(6)
Declination, δ (J2000)	+10 02 38.79(4)	+10 01 54(3)
Period, P (ms)	28.85386072615(4)	16.452929681440(7)
Period derivative, $\dot{P}$	$<8 \times 10^{-20}$	$4.2(3) \times 10^{-20}$
Epoch of period (MJD)................	49950.0	49780.0
Dispersion measure (cm^{-3} pc)	36.60(1)	10.25(1)
Orbital period, P_b (days)...............	8.31867514(4)	7.80513015(1)
Projected semimajor axis, x (s)	12.032077(5)	16.765411(2)
Eccentricity, e	0.0024575(6)	$9.76(2) \times 10^{-5}$
Longitude of periastron, ω (deg)......	188.769(16)	97.54(15)
Time of periastron, T_0 (MJD)	49954.8334(4)	49778.4057(30)

Optical counterpart discovered! (Lundgren et al. 1996)

Discovered with HST; Mass of companion is 0.87 solar masses

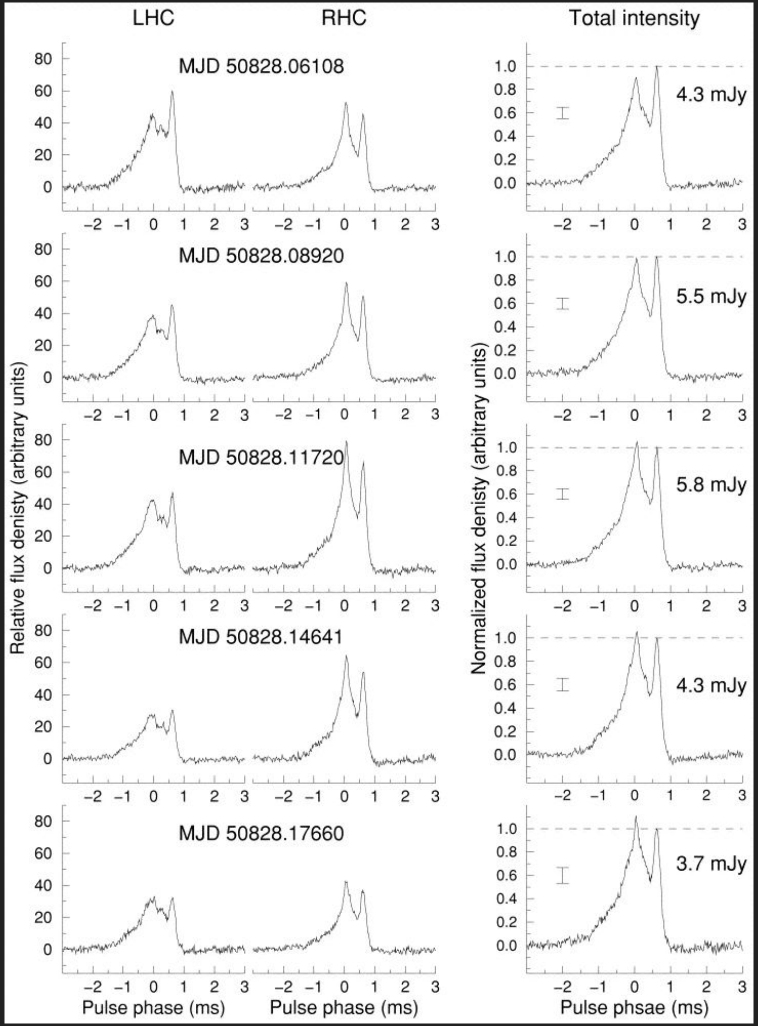
Table 2. Photometry*

Parameter	J0034−05	J1022+10	J1640+22	J1713+07	J2019+24	J2145−07
pos'n offset (″)	0.6	1.0	0.8	0.5	0.3	0.9
m_B	—	—	—	>27.1	—	23.89(11)
m_V	>26.8	23.09(4)	26.0(3)	26.0(2)	26.4(4)	23.70(10)
m_I	24.8(3)	22.665(7)	24.6(2)	24.1(1)	25.0(3)	22.97(7)
$B-V$	—	—	—	>1.1	—	0.18(14)
$V-I$	>2.0	0.43(4)	1.4(4)	1.9(2)	< 1.1	0.73(10)
$m-M$	10.0(5)	8.9(5)	10.4(5)	10.2(5)	9.8(5)	8.5(5)
E_{B-V}	0.00(2)	0.00(2)	0.05(2)	0.08(2)	> 0.2	0.03(2)
T(K)	<3800	6925(200)	4200(300)	3700(100)	> 4500	5800(300)
$\log(L/L_\odot)$	−4.2(2)	−3.8(2)	−3.8(2)	−3.8(2)	> −4.4	−4.1(2)
$m_2/M_\odot$	0.23(20)	0.83(25)	0.25(10)	<0.32	0.6(3)	0.87(25)
t_{cool}(Gyr)	>4.5	3.7(9)	7(2)	8(2)	< 8	5.5(7)
P_i(ms)	—	10(2)	>2.5(2)	—	> 3.2	10(2)
$\dot{M}/\dot{M}_{edd}$	—	0.007(2)	0.005(1)	—	<0.002	0.010(3)

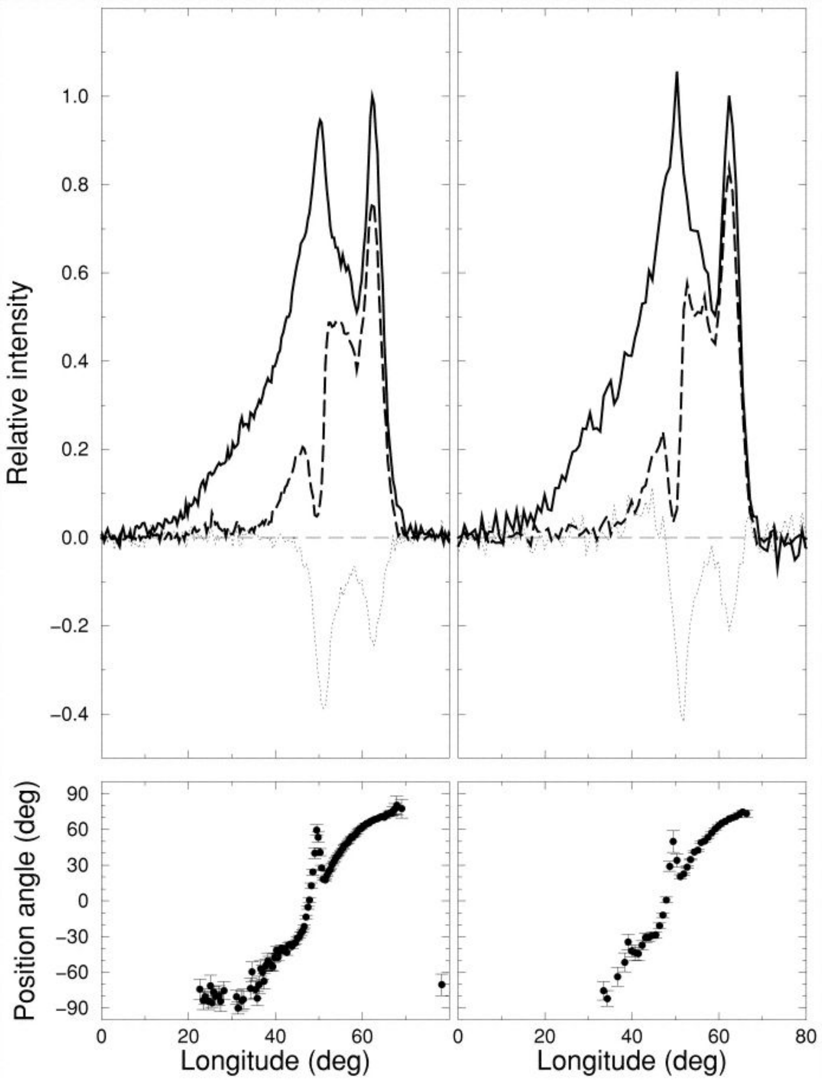
* The numbers in parentheses represent the uncertainty in the last digits quoted.

Profile highly unstable ! (Kramer et al. 1998)

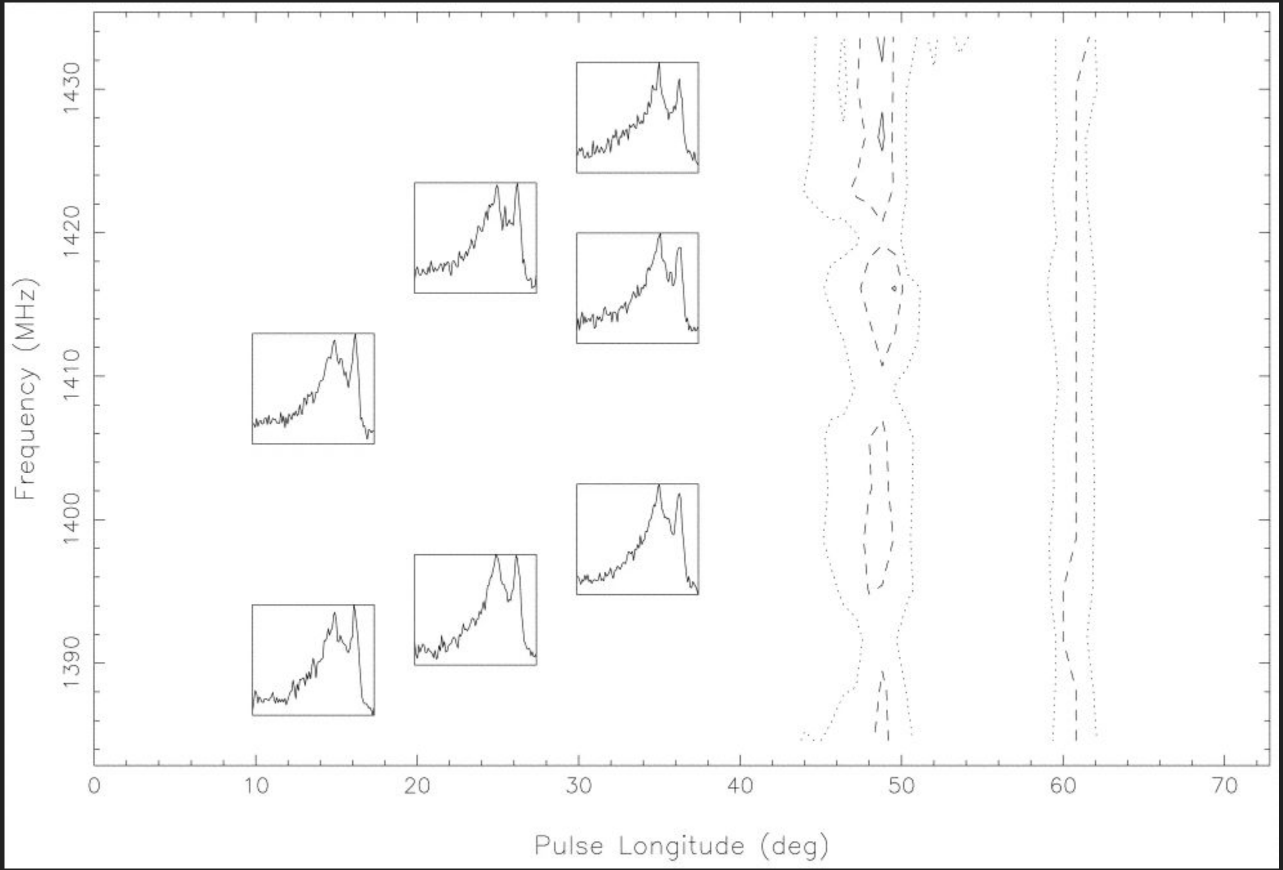
- Profile changes across long time scales unlike moding
- Specific parts of profile vary ; implies intrinsic variability



- Linear Polarization stable but circular polarization changes sense
- PA swing mostly S shaped; But has a notch!



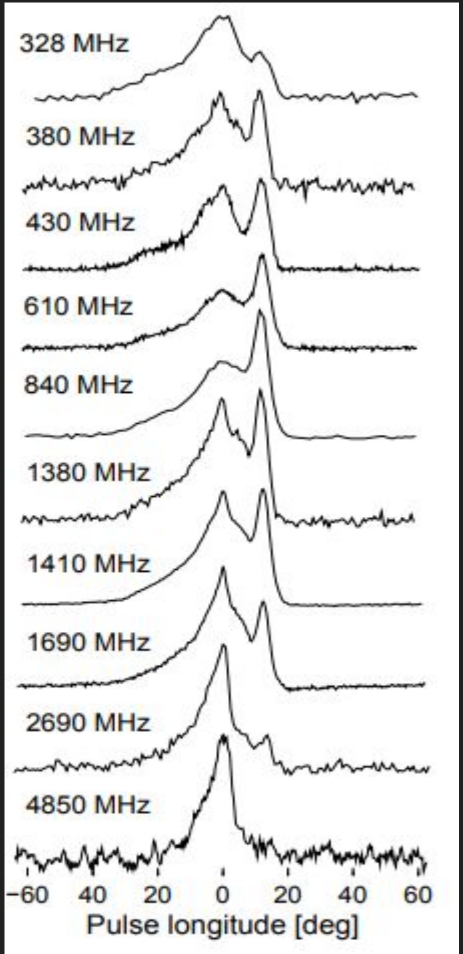
- Profile changes across frequency too. Order of every 8 MHZ



- Gaussian components fit to profile. 5 in number. Trailing component observed to be more stable than leading.
- Each component relates to a particular polarization feature
- Timing residuals despite fitting : 15-20 microseconds
- Proper motion measured : 50 km/s
- DM distance : 600 kpc
- Possibly magnetosphere effects?

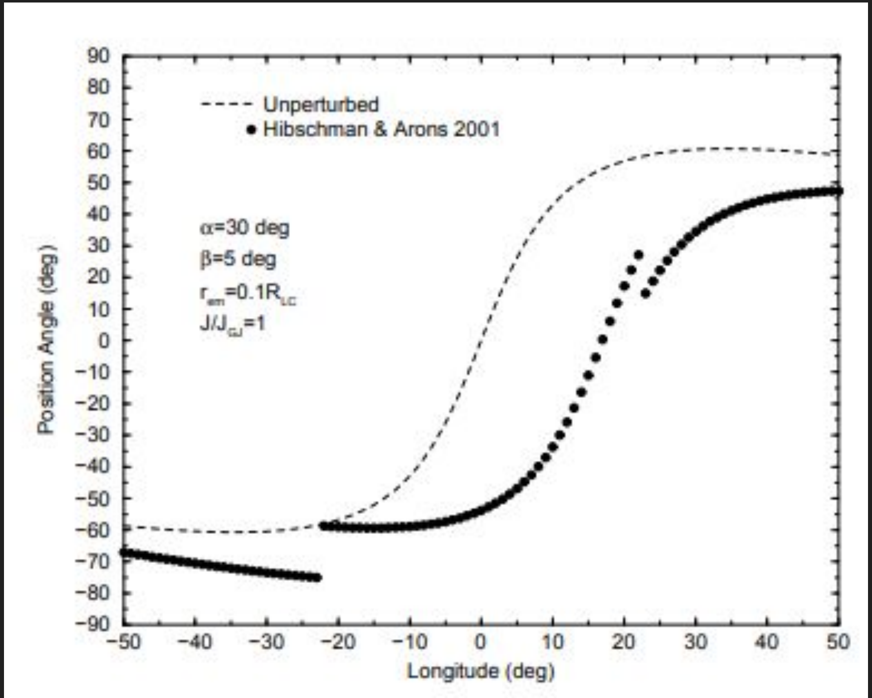
Magnetospheric return currents: Ramachandran & Kramer 2003

- Observed with Westerbork ; thus no effect of parallactic angle on polarization calibration
- Reinstated what Kramer et al. 1998 found w.r.t profile changes in frequency and time.
- No particular characteristic frequency and time scale of variations found.



2 possible explanations for PA ‘jumps’.

1) 2 polarisation emission modes; 2 different emission heights.
2) Polar cap current flows which shift PA upwards. Hibschman & Arons 2001



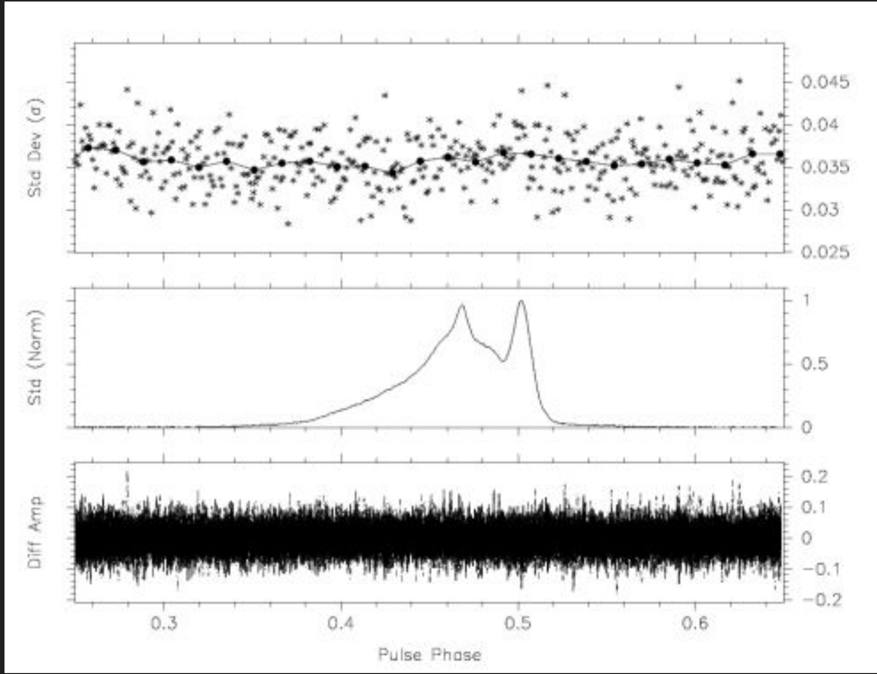
The Turn

J1022+1001 has no unusual behaviour whatsoever:

Hotan et al. 2004

xsProfile stable with time:

- New technique of flux normalisation and differencing amplitudes showed white noise like behaviour



Some other turns...

- It's a great timer; RMS of 2.27 microseconds.
- Parallax distance off from DM distance by half (300 pc)
- No characteristic BW dependence for profile variation.

Parameter	Value
Ecliptic Lon. (λ) (deg)	153.86589029 (4)
Ecliptic Lat. (β) (deg)	-0.06391 (6)
Proper Motion in λ (mas yr^{-1})	-17 (2) *
Parallax (mas)	3.3 (8)
Period (ms)	16.4529296931296 (5)
Period Derivative (10^{-20})	4.33 (1)
Period Epoch (MJD)	52900
Dispersion Measure (cm^{-3}pc)	10.25180 (7)
Projected Semi-Major Axis (lt-s)	16.7654148 (2)
Eccentricity	0.00009725 (3)
Time of Periastron Passage (MJD)	52900.4619 (3)
Orbital Period (days)	7.805130160 (2)
Angle of Periastron (deg)	97.73 (1)
Right Ascension (α)	10:22:58.015 (5)
Declination (δ)	+10:01:53.2 (2)
Number of TOAS	555
Total χ^2	545.74
RMS Timing Residual (μs)	2.27
MJD of first TOA	52649
MJD of last TOA	53109
Total Time Span (days)	460

- Constrain on inclination angle through Shapiro delay contour map.
- 37 < i <56
- Mass of WD > 0.9 solar masses
- Xdot measured

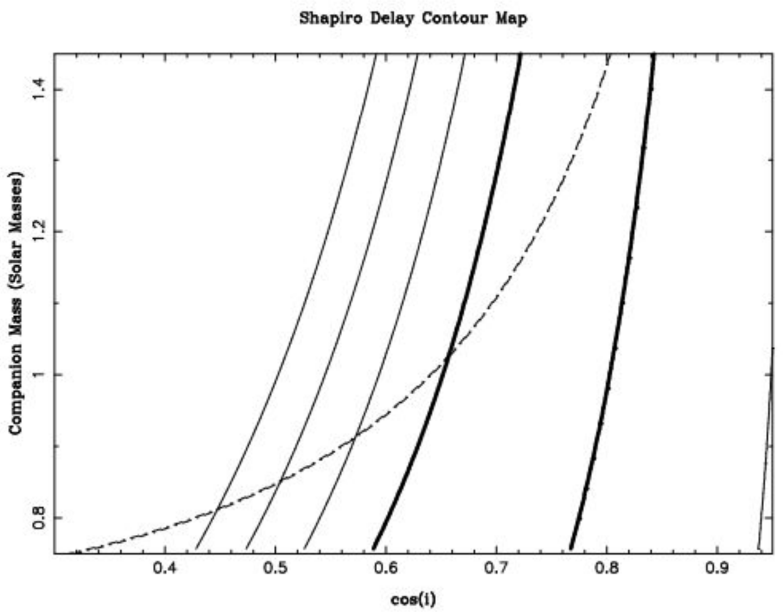


Figure 12. Shapiro delay χ^2 map. The thick lines represent 1-σ contours, followed by 2,3 and 4-σ contours on the left hand side. The dashed line represents the mass function constraint, assuming a 1.35 $M_\odot$ neutron star.

The Prestige

Single pulse studies of J1022+1001 - Liu et al. 2015

- 14000 subpulses seen in 35 hour long observation time. Most seen in trailing component.
- The occurence is correlated. Trailing component as preferred pulse width.
- 700 ns upper limit on jitter
- **Polarization calibration cannot be sole reason for instability.**

VLBI Measurements

Deller et al. 2016

- VLBI Measurement yields distance of approx. 700 pc.
- Shows that Timing model not perfect; possibly for not incorporating solar wind.
- Many parameters better constrained (Show tables in paper)