Status of the EPTA

Grégory Desvignes[1] on behalf of the EPTA

[1]MPIfR Bonn

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The EPTA (Est. 2005)

Goal of the EPTA: Perform high-precision timing to study pulsar binaries, theories of gravity and to detect gravitational waves

The observations

- MPIfR: Effelsberg Telescope - 100m
- Univ. of Manchester / Jodrell Bank: Lovell Telescope - 76m
- ASTRON: WSRT - 94m equivalent
- CNRS / Obs. de Paris: Nancay - 94m equivalent
- INAF: Sardinia - 64m

Theory

- University of Birmingham
- University of Cambridge
- APC / Univ. Paris 7
- Kavli institute Beijing
- Albert Einstein Institute
- JPL / Caltech

Similar collaborations: NANOGrav (McLaughlin 2013), PPTA (Hobbs 2013)

Past Results

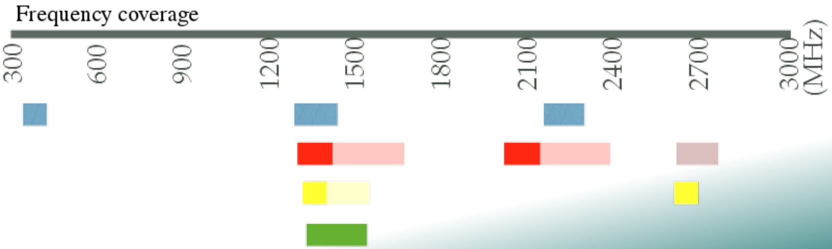
- Generic tests of the existence of the gravitational dipole radiation and the variation of the gravitational constant (Lazaridis et al. 2009)
- Long-term timing of four millisecond pulsars (Janssen et al. 2010)
- Evidence for gravitational quadrupole moment variations in the companion of PSR J2051-0827 (Lazaridis et al. 2011)
- Placing limits on the stochastic gravitational-wave background using European Pulsar Timing (van Haasteren et al. 2011)

A new EPTA Data Release

- 4 telescopes (EFF, JBO, NRT, WSRT)
- 5 backends (EBPP, DFB, BON, PUMA1, DDS@NRT: J1939+2134)
- Archival data for 42 MSPs up to May 2014
- Between 7 and 18 years of data
- Multi-frequency dataset

The EPTA dataset: details

	WSRT	Nançay	Effelsberg	Jodrell
N(MSPs)	19	42	18	39
Cad.	30d	7-14d	30d	10-30d
Obs	~30m	30-60m	~30m	30-60m
Dur	6-9yrs	~9yrs	~18yrs	~6yrs (~21 yr)



The EPTA dataset: Combination and Timing

- Diff backends, diff RFI, diff templates, diff algorithm for TOAs
- Apply white noise correction factors (EFAC and EQUAD) to each set of backends/observing bands
- Terestrial Time TT(BIPM)
- Solar Sytem Ephemeris: DE421
- Bayesian timing analysis with TempoNest (Lentati et al. 2014)
- DM Model: TempoNest DM Model (power-law model)
- Red noise Model: TempoNest red noise Model (power-law model)
- Error checking by comparing different telescope data

Output of the EPTA dataset

- EPTA limits on an isotropic stochastic GWB (Lentati et al. 2015) See talk by L. Lentati in this session
- EPTA limits on anisotropy in the Nanohertz Stochastic GWB (Taylor et al. 2015) See talk by L. Lentati in this session
- EPTA limits on continuous gravitational waves from individual supermassive black hole binaries (Babak et al. accepted) See talk by A. Lassus in this session
- Results of the timing analysis of 42 MSPs: astrometric, distance and mass measurements (Desvignes et al., submitted)
- Dispersion Measure analysis (Janssen et al. in prep)
- Noise properties and impact on the GW search (Caballero et al., submitted)

Timing results: Summary 1/2

PSR JName	Obs.	N_{TOA}	T_{span} (yr)	RMS (μs)	Period (ms)	P_{orb} (d)	S_{1400} (mJy)
J0030+0451	E, N	857	15.1	4.43	4.9	—	1.0 (0.4)
J0034−0534	N, W	276	13.5	4.00	1.9	1.59	0.1 (0.3)
J0218+4232	E, J, N, W	1151	17.5	7.40	2.3	2.03	0.7 (0.3)
J0610−2100	J, N	947	6.8	6.56	3.9	0.29	0.4 (0.2)
J0613−0200	E, J, N, W	1286	16.1	1.69	3.1	1.20	2.0 (0.4)
J0621+1002	E, J, N, W	609	11.8	13.44	28.9	8.32	1.4 (0.5)
J0751+1807	E, J, N, W	720	17.6	2.40	3.5	0.26	1.3 (0.8)
J0900−3144	J, N	845	6.9	3.13	11.1	18.74	3.6 (0.3)
J1012+5307	E, J, N, W	1421	16.8	1.61	5.3	0.60	4.3 (3.6)
J1022+1001	E, J, N, W	825	17.5	2.28	16.5	7.81	3.9 (3.6)
J1024−0719	E, J, N, W	505	17.3	7.67	5.2	—	1.6 (1.2)
J1455−3330	J, N	515	9.2	2.86	8.0	76.17	0.8 (1.0)
J1600−3053	J, N	496	7.7	0.45	3.6	14.35	2.2 (0.4)
J1640+2224	E, J, N, W	525	16.7	2.20	3.2	175.46	0.7 (0.8)
J1643−1224	E, J, N, W	718	17.3	1.63	4.6	147.02	4.3 (0.7)
J1713+0747	E, J, N, W	1188	17.7	0.68	4.6	67.83	8.0 (8.7)
J1721−2457	N, W	150	12.8	13.04	3.5	—	1.0 (0.4)
J1730−2304	E, J, N	217	16.6	1.35	8.1	—	3.7 (3.1)
J1738+0333	N	262	7.3	2.84	5.9	0.35	0.3 (0.3)
J1744−1134	E, J, N, W	501	17.3	0.80	4.1	—	2.7 (2.9)
J1751−2857	N	107	8.3	2.66	3.9	110.75	0.4 (0.1)

Timing results: Summary 2/2

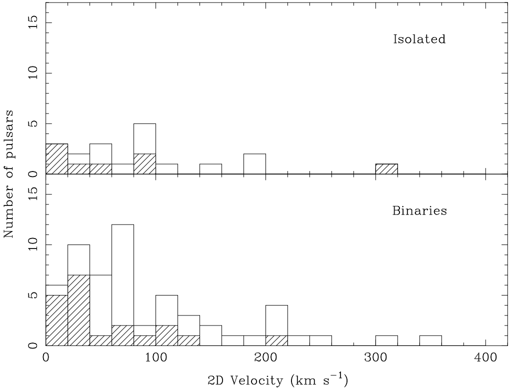
PSR JName	Obs.	N_{TOA}	T_{span} (yr)	RMS (μs)	Period (ms)	P_{orb} (d)	S_{1400} (mJy)
J1801−1417	J, N	102	6.8	2.44	3.6	—	1.3 (0.6)
J1802−2124	J, N	503	7.0	2.81	12.6	0.70	1.0 (0.1)
J1804−2717	J, N	89	8.1	2.24	9.3	11.13	1.2 (0.9)
J1843−1113	N, W	220	9.9	0.78	1.8	—	0.6 (0.3)
J1853+1303	J, N	90	8.2	1.50	4.1	115.65	0.6 (0.5)
J1857+0943	E, J, N, W	444	17.3	1.74	5.4	12.33	4.2 (2.0)
J1909−3744	N	425	9.4	0.13	2.9	1.53	1.9 (1.9)
J1910+1256	J, N	92	8.2	1.63	5.0	58.47	0.5 (0.1)
J1911+1347	N	71	7.4	0.86	4.6	—	0.8 (0.5)
J1911−1114	J, N	95	8.0	4.34	3.6	2.72	0.7 (0.5)
J1918−0642	J, N, W	236	12.8	2.02	7.6	10.91	1.4 (0.7)
J1939+2134	E, J, N, W	3174	24.1	34.50	1.6	—	10.6 (4.6)
J1955+2908	J, N	130	8.1	5.65	6.1	117.35	0.6 (0.3)
J2010−1323	J, N	349	7.4	1.90	5.2	—	0.6 (0.3)
J2019+2425	J, N	112	9.1	10.33	3.9	76.51	0.3 (0.4)
J2033+1734	J, N	166	7.9	13.92	5.9	56.31	0.1 (0.0)
J2124−3358	J, N	522	9.4	3.17	4.9	—	3.4 (2.1)
J2145−0750	E, J, N, W	758	17.2	1.70	16.1	6.84	7.2 (6.6)
J2229+2643	E, J, N	289	8.2	4.22	3.0	93.02	0.4 (0.5)
J2317+1439	E, J, N, W	509	17.3	2.61	3.4	2.46	0.7 (0.9)
J2322+2057	J, N	240	7.9	6.31	4.8	—	0.2 (0.4)

Timing results: New parameters

- 9 new proper motions (additional 7 PM improved by a factor 10)
- 7 new parallaxes and improvement on a few others
- All Px corrected from the Lutz-Kelker bias
- 6 new apparent $\dot{x}$
- new Shapiro measurement in PSR J1918-0642
- good Shapiro measurement in PSR J1600-3053
- update on the masses of PSR J0751+1807

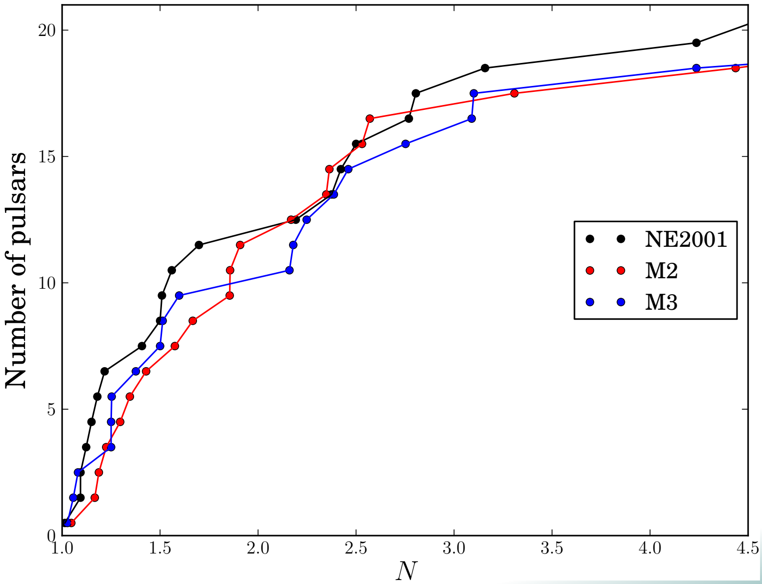
PSR JName	DM	Distance via NE2001 (kpc)	Prev. published parallax (mas)	Parallax (mas)	Corrected parallax (mas)	Distance via parallax (kpc)
J0030+0451	4.33	0.32	4.1 ± 0.3	2.78 ± 0.22	$2.70^{+0.22}_{-0.22}$	$0.36^{+0.03}_{-0.03}$
J0613−0200	38.78	1.71	0.8 ± 0.35	1.14 ± 0.13	$1.09^{+0.13}_{-0.13}$	$0.84^{+0.11}_{-0.09}$
J0751+1807	30.25	1.15	1.6 ± 0.8	0.84 ± 0.18	$0.76^{+0.18}_{-0.17}$	$1.04^{+0.23}_{-0.16}$
J0900−3144	75.70	0.54	—	0.93 ± 0.50	$0.36^{+0.37}_{-0.17}$	$0.71^{+0.33}_{-0.18}$
J1012+5307	9.02	0.41	1.22 ± 0.26	0.76 ± 0.17	$0.74^{+0.16}_{-0.15}$	$1.10^{+0.23}_{-0.16}$
J1022+1001	10.25	0.45	1.8 ± 0.3	0.74 ± 0.20	$0.72^{+0.18}_{-0.17}$	$1.06^{+0.25}_{-0.18}$
J1024−0719	6.49	0.39	1.9 ± 0.8	0.81 ± 0.17	$0.75^{+0.17}_{-0.16}$	$1.07^{+0.23}_{-0.16}$
J1455−3330	13.56	0.53	—	1.04 ± 0.35	$0.50^{+0.35}_{-0.24}$	$0.81^{+0.30}_{-0.19}$
J1600−3053	52.32	1.63	0.2 ± 0.15	0.63 ± 0.08	$0.60^{+0.08}_{-0.08}$	$1.52^{+0.21}_{-0.16}$
J1643−1224	62.41	2.40	2.2 ± 0.4	1.11 ± 0.26	$0.92^{+0.27}_{-0.27}$	$0.79^{+0.20}_{-0.14}$
J1713+0747	15.99	0.89	0.94 ± 0.05	0.90 ± 0.03	$0.90^{+0.03}_{-0.03}$	$1.11^{+0.04}_{-0.03}$
J1738+0333	33.80	1.43	0.68 ± 0.05	—		
J1744−1134	3.13	0.41	2.4 ± 0.1	2.33 ± 0.08	$2.32^{+0.08}_{-0.08}$	$0.43^{+0.01}_{-0.01}$
J1843−1113	59.95	1.70	—	0.69 ± 0.33	$0.11^{+0.16}_{-0.04}$	$1.11^{+0.67}_{-0.32}$
J1853+1303	30.65	2.08	1.0 ± 0.3	—	—	
J1857+0943	13.30	1.17	1.1 ± 0.2	0.70 ± 0.26	$0.20^{+0.31}_{-0.10}$	$1.10^{+0.44}_{-0.25}$
J1909−3744	10.39	0.46	0.79 ± 0.02	0.87 ± 0.02	$0.87^{+0.02}_{-0.02}$	$1.15^{+0.03}_{-0.03}$
J1910+1256	38.10	2.33	—	1.47 ± 0.71	$0.11^{+0.12}_{-0.04}$	$0.55^{+0.43}_{-0.18}$
J1939+2134	71.02	3.56	0.13 ± 0.07	0.22 ± 0.08	$0.19^{+0.07}_{-0.06}$	$3.27^{+1.02}_{-0.66}$
J2124−3358	4.58	0.27	3.1 ± 0.6	2.50 ± 0.35	$2.31^{+0.36}_{-0.36}$	$0.38^{+0.06}_{-0.05}$
J2145−0750	8.98	0.57	1.6 ± 0.3	1.57 ± 0.11	$1.55^{+0.11}_{-0.11}$	$0.63^{+0.05}_{-0.04}$
J2317+1439	21.90	0.83	—	0.83 ± 0.33	$0.61^{+0.28}_{-0.21}$	$0.88^{+0.31}_{-0.19}$

2D Velocities



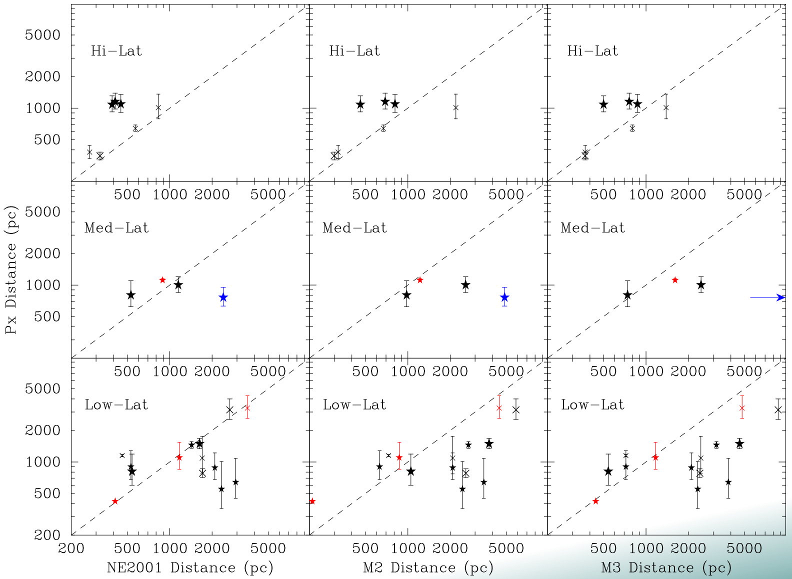
All pulsars, $V_{iso} = 88 \pm 17\text{km s}^{-1}$, $V_{bin} = 93 \pm 13\text{km s}^{-1}$
MSPs with Px: $V_{iso} = 75 \pm 10\text{km s}^{-1}$, $V_{bin} = 56 \pm 3\text{km s}^{-1}$

Comparison of Gal. e^- density models: NE2001 / M2 / M3

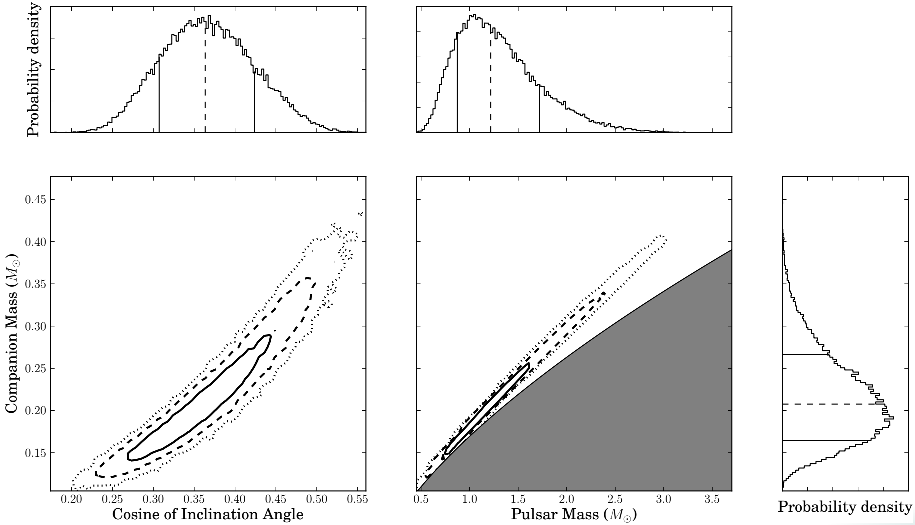


NE2001: 80% mean uncertainty, M2-M3: $\sim$ 100% mean uncertainty

Comparison of Gal. e^- density models: NE2001 / M2 / M3



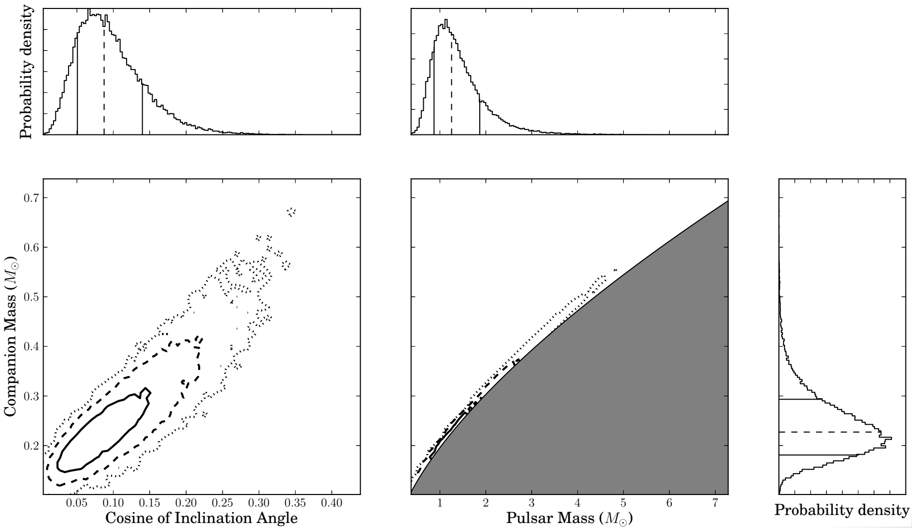
J1600-3053: Mass-Mass diagram



$$M_p = 1.27^{+0.54}_{-0.37}\ M_\odot$$

$$M_c = 0.214^{+0.063}_{-0.045}\ M_\odot$$

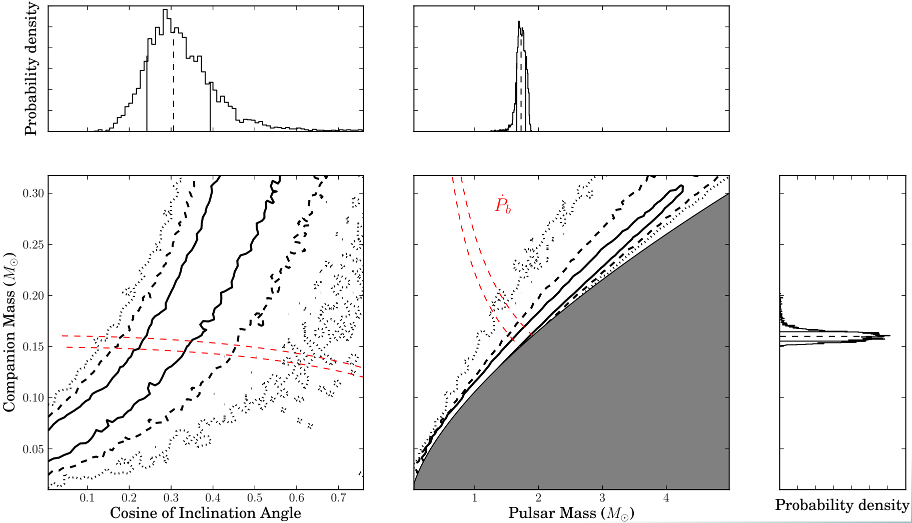
J1918-0642: Mass-Mass diagram



$$M_p = 1.33^{+0.67}_{-0.41}\ M_\odot$$
$$M_c = 0.23^{+0.07}_{-0.05}\ M_\odot$$

J0751+1807: Mass-Mass diagram

PSR JName	D_π (kpc)	$\dot{P}_b$ $(\times 10^{-13})$	$\dot{P}_{b\_kin}$ $(\times 10^{-13})$	$\dot{P}_{b\_kz}$ $(\times 10^{-13})$	$\dot{P}_{b\_dgr}$ $(\times 10^{-13})$	$\dot{P}_{b\_GR}$ $(\times 10^{-13})$	$D_{\dot{P}_b}$ (kpc)
J0751+1807	1.0(2)	-0.350(25)	+0.103(21)	-0.0101(11)	+0. 0117(24)	—	—



$$M_p = 1.72^{+0.07}_{-0.07}\ M_\odot$$

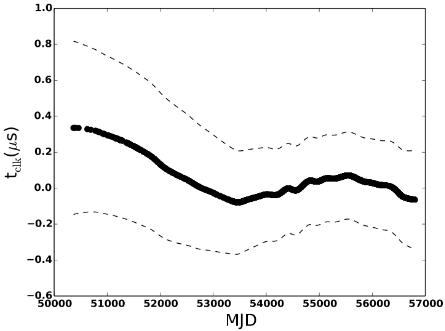
$$M_c = 0.160^{+0.005}_{-0.005}\ M_\odot$$

EPTA Dataset: Noise analysis

Two methods: Bayesian and frequentist noise analysis

- 25 MSPs: significant measurement of the noise properties
- 17 MSPs: upper-limits (covariance between DM and TN)
- Noise due to errors in TT standard < 10%
- Noise in individual pulsars reduces sensitivity in isotropic stochastic GWB by > 12.5

Caballero et al. (submitted)



The EPTA in the IPTA

The EPTA Data Release has been shared to the International Pulsar Timing Array (IPTA)

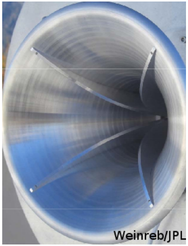
- Data combination project (Verbiest et al. submitted)
- Noise analysis (Lentati et al. to be submitted)
- Solar System study: mass measurements (Lazarus et al. in prep.)
- Pulsar based time-scale (Hobbs et al.)
- GW science projects: isotropic and anisotropic GWB, continuous sources

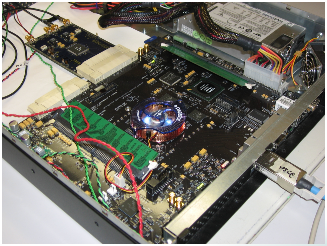
Prospects: new receivers and instrumentations

New generation of pulsar backends:

∼2-4x more bandwidth

- PuMaII (WSRT)
- PSRIX (Effelsberg)
- NUPPI (Nancay)
- ROACH (Jodrell)



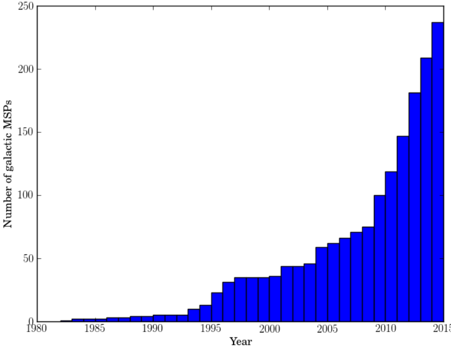


New receivers:

Effelsberg: UBB (0.6-2.5 GHz, ERC BEACON P.Freire), C+ (4-9 GHz)

Prospects: more and better data

- LEAP (ERC Advanced grant, PI M. Kramer): coherent addition of the signals from the 5 EPTA telescopes, equivalent to a 200m dish for more precise TOAs. (See Kuo Liu's talk on LEAP at 17:35 in room 3, level 0)
- New MSPs from pulsar surveys: FERMI, PALFA, HTRU N&S, GBT
- Monitoring with LOFAR: unprecedented precision for DM



More MSPs, more precise TOAs and better DM measurements (to disentangle between intrinsic and extrinsic noise sources)

Questions?

Any questions?