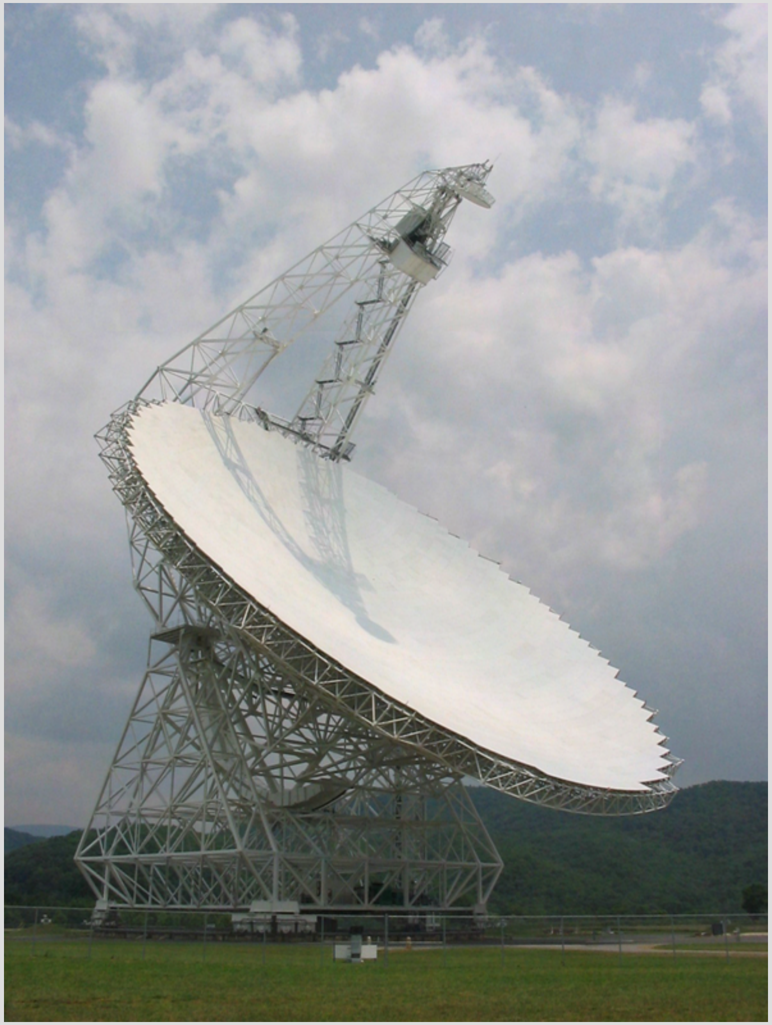
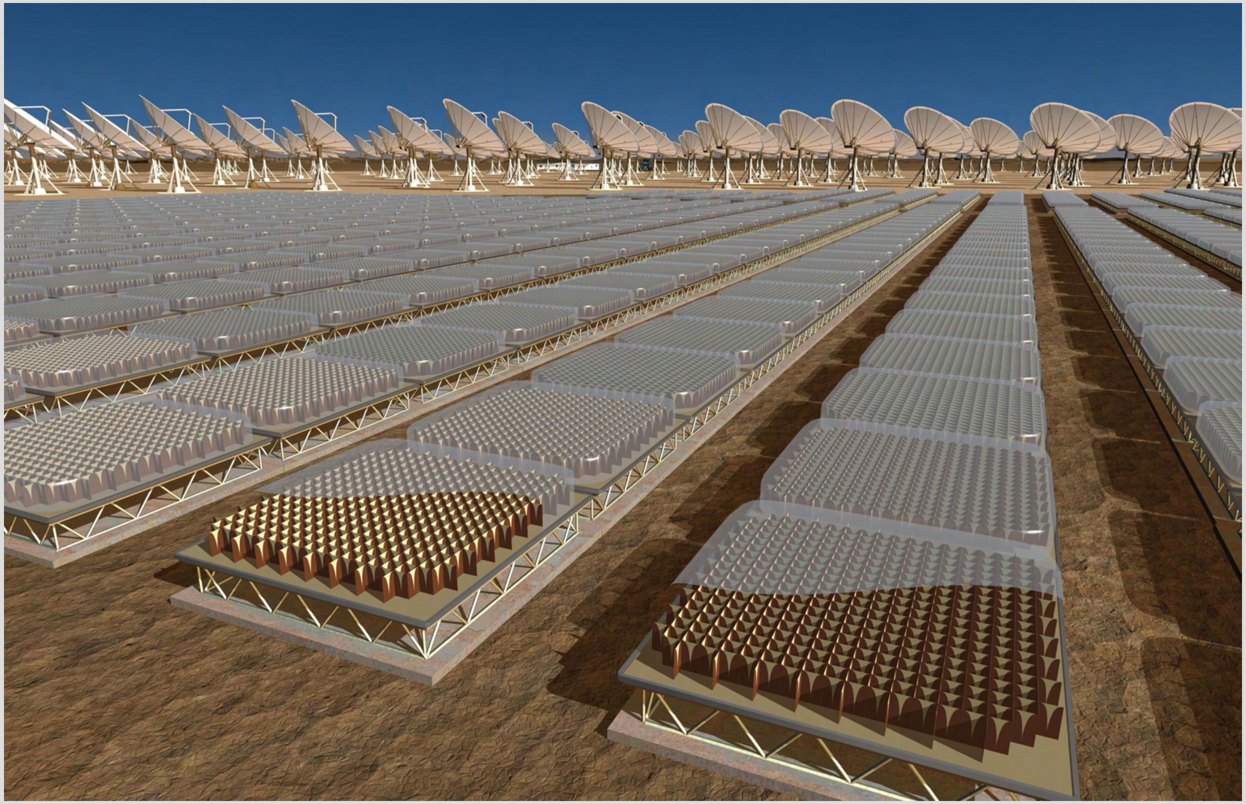
Present and future of pulsar observations From current large radiotelescopes to SKA



Green Bank, US

SKA reference design



Radioastronomie Basses Fréquences : Instrumentation, Thématiques scientifiques, Projets
Goutelas, 4-8 juin 2007

Cognard I., LPCE Orléans, icognard@cnrs-orleans.fr

Plan

Recent pulsars results

- Magnetar
- Giant pulses
- ISM study
- RRATs
- Intermittent pulsars
- Relativistic binary pulsars
- Gravitational wave background
- ISM study

Pulsars with SKA

Conclusion

Present large radiotelescopes

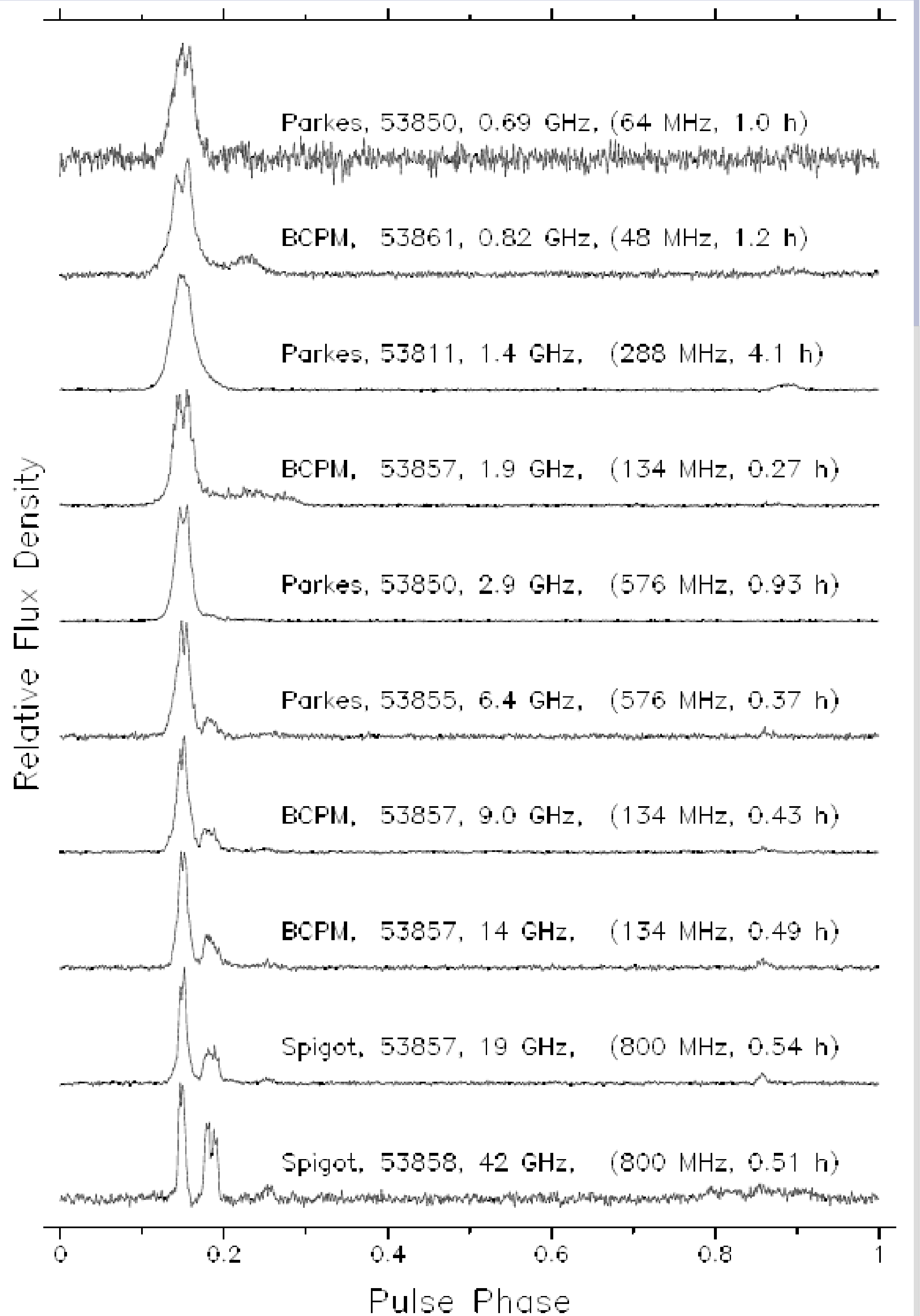
Magnetar XTE1810-197

a transient AXP (Anomalous X-Ray Pulsar)
detected early 2003 in X-Ray
with pulsations of periodicity 5.54sec

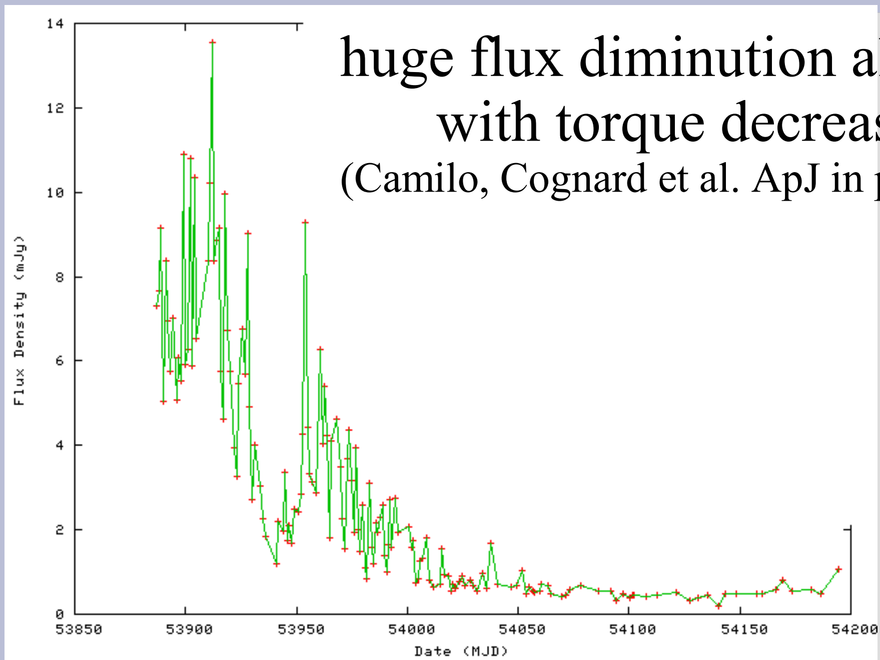
an AXP is powered by the decay of
its ultra-strong magnetic field
(when a radio pulsar is powered
by its rotational energy loss)

for the first time in 2006,
a magnetar was detected in radio
(Camilo et al., *Nature* 442, 892)

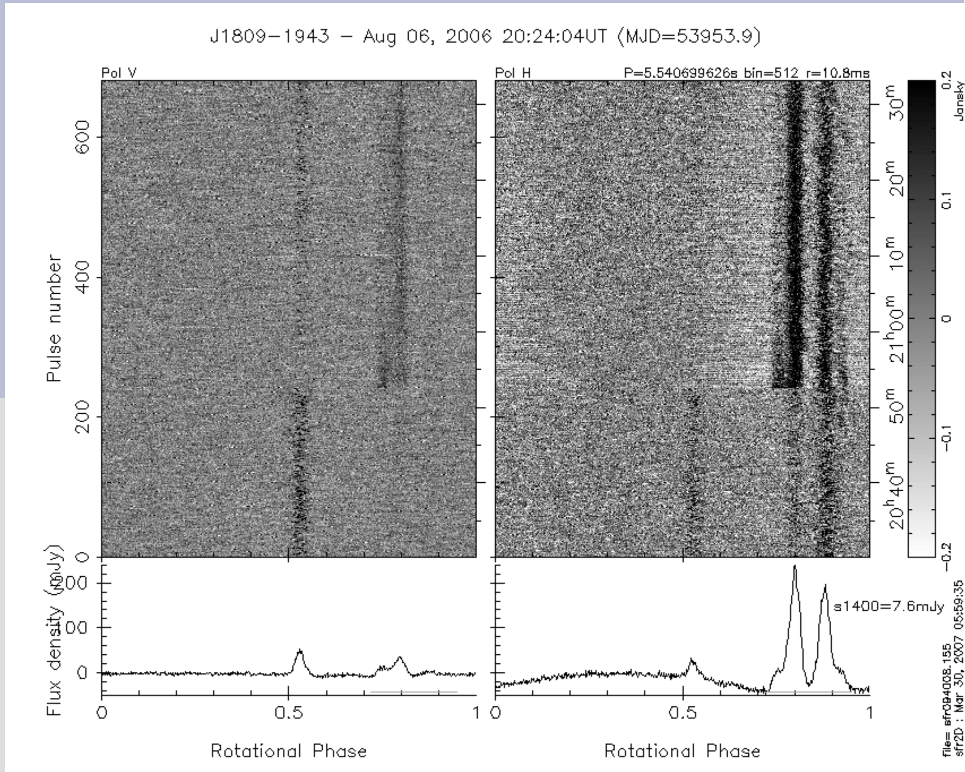
a daily monitoring was started at Nançay...



Magnetar XTE1810-197

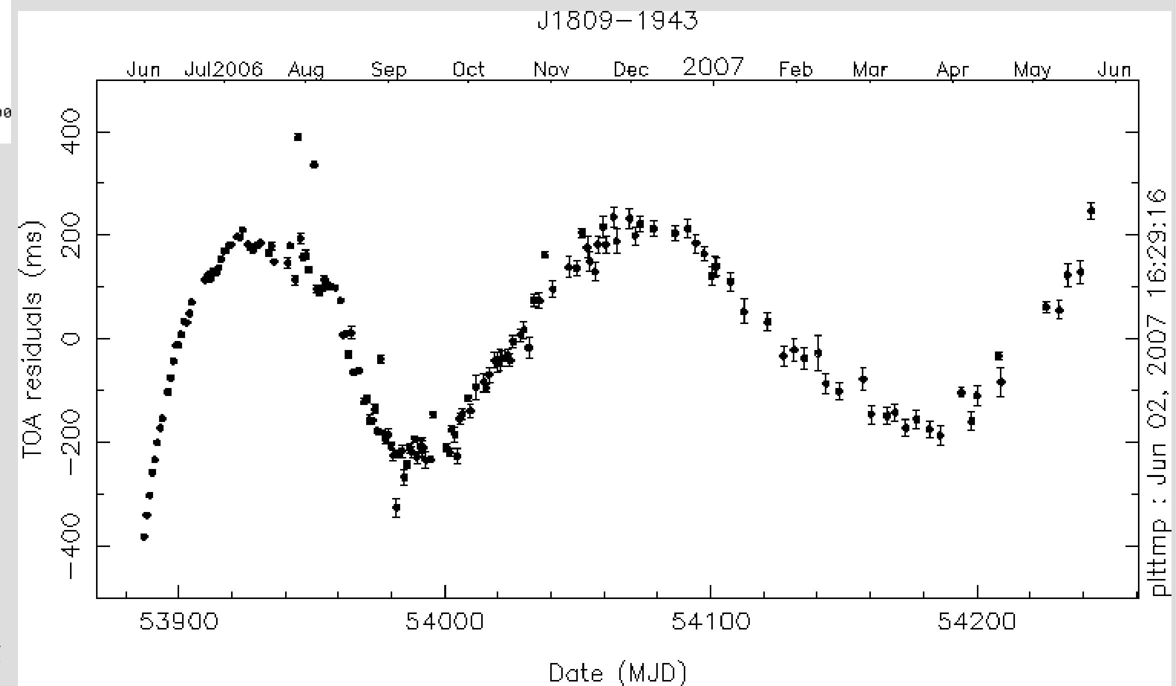


huge flux diminution along
with torque decrease
(Camilo, Cognard et al. ApJ in press)



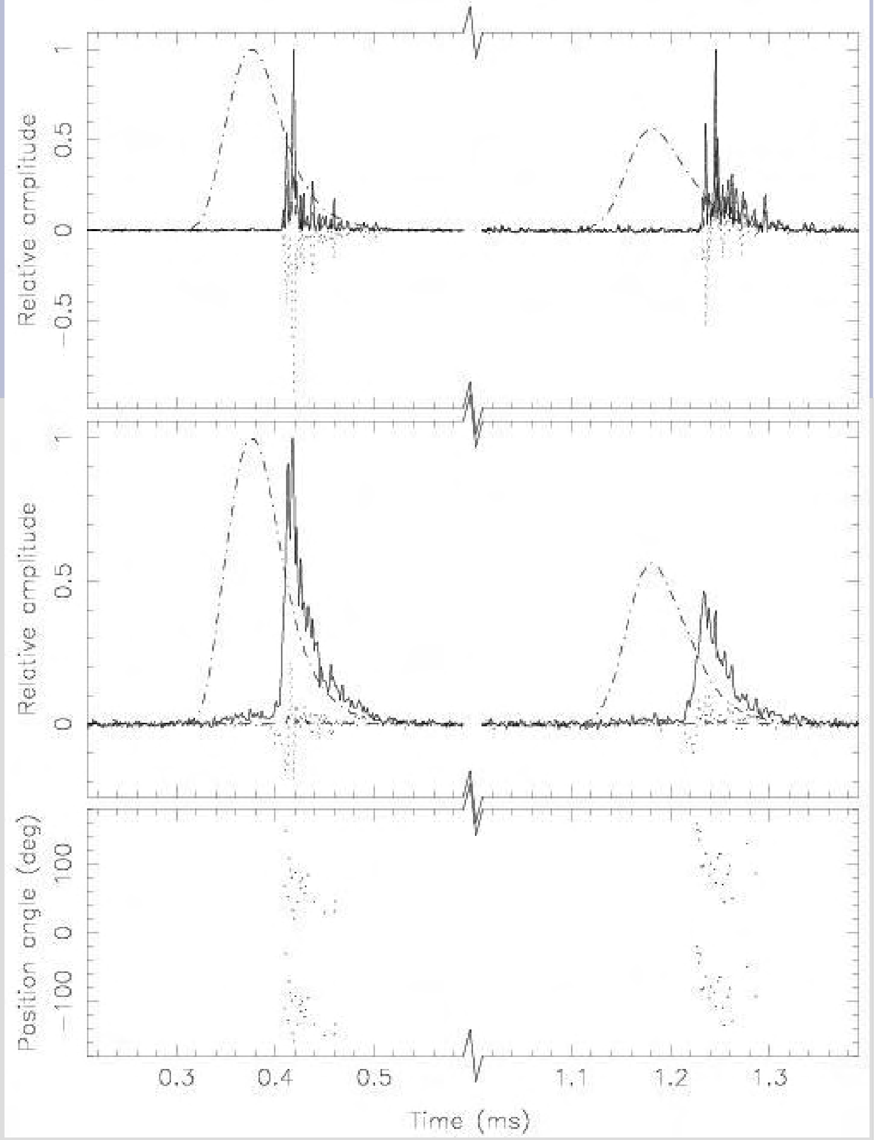
individual pulses study in progress...

If magnetars are so low in radio quiescent mode... then SKA will help a lot!



daily monitoring at Nançay 1.4GHz

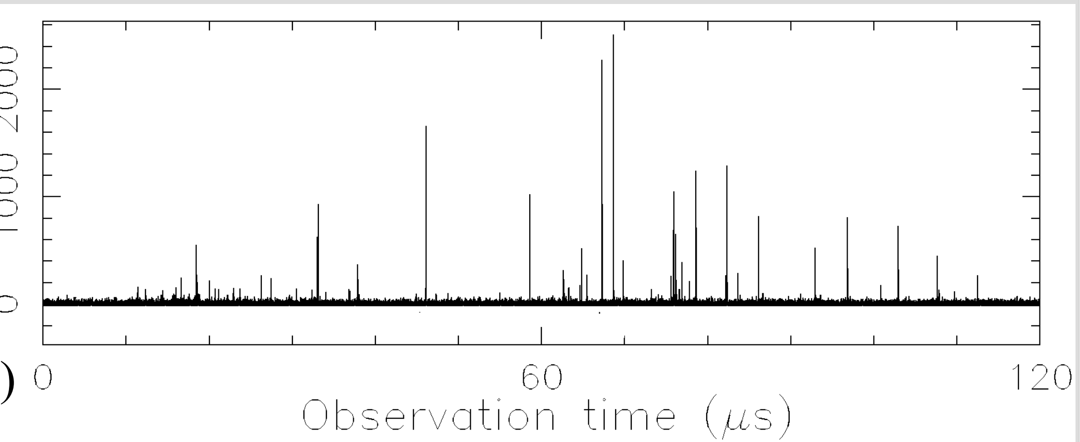
Giants pulses



Crab pulsar was discovered
through its dispersed giant pulses (Gps)

a giant pulse is a single pulse
with flux density 10-20 times above the average

Millisecond pulsar B1937+21
was the second known to show GPs
(Sallmen & backer 1995, Cognard et al. 1996)



Usually the phases of the GPs are coincident
with the high energy emission

bursts of emission less than 15ns for B1937+21
and even 1ns for the Crab pulsar (Hankins 2003)

Giants pulses

GPs are now detected for a handfull of pulsars

PSR	Freq MHz	S_{GP} kJy	S_{GP}/S_{AP}	T_B K	E_{GP} Jy × ms	E_{GP}/E_{AP}	B_{LC} G	References
B0031–07	40	1.1	400	$\geq 10^{28}$	6600	15	6.9	1
	111	0.5	120	$\geq 10^{26}$	2600	8		2
J0218+42	610				1.3	51	3×10^5	3
B0531+21	146		300				9×10^5	4
	594	150	6×10^4	$\geq 10^{36}$	75	10		5
	2228	18	5×10^5	$\geq 10^{34}$	9	80		5
	5500	1		$\geq 10^{37}$				6
B0540–69	1380		$> 5 \times 10^3$				3×10^5	7
B1112+50	111	0.18	80	$\geq 10^{26}$	900	10	4.1	8
J1752+2359	111	0.11	260	$\geq 10^{28}$	920	200	4.6	9
B1821–24	1517				0.75	81	7×10^5	10
J1823–3021A	685	0.045	680			64	2.5×10^5	11
	1405	0.02	1700			28	2.5×10^5	11
B1937+21	111	40	600	$\geq 10^{35}$	400	65	9.8×10^5	12
	1650	65	3×10^5	$\geq 5 \times 10^{39}$	1	60		13
B1957+20	400				0.9	129	4×10^5	3

References: 1) Kuzmin & Ershov 2004, 2) Kuzmin et al. 2004, 3) Joshi et al. 2004, 4) Argyle & Gower 1972, 5) Kostyuk et al. 2003, 6) Hankins et al. 2003, 7) Johnston & Romani 2003, 8) Ershov & Kuzmin 2003, 9) Ershov & Kuzmin 2005, 10) Romani & Johnston 2001, 11) Knight et al. 2005, 12) Kuzmin & Losovsky 2002, 13) Soglasnov et al. 2004.

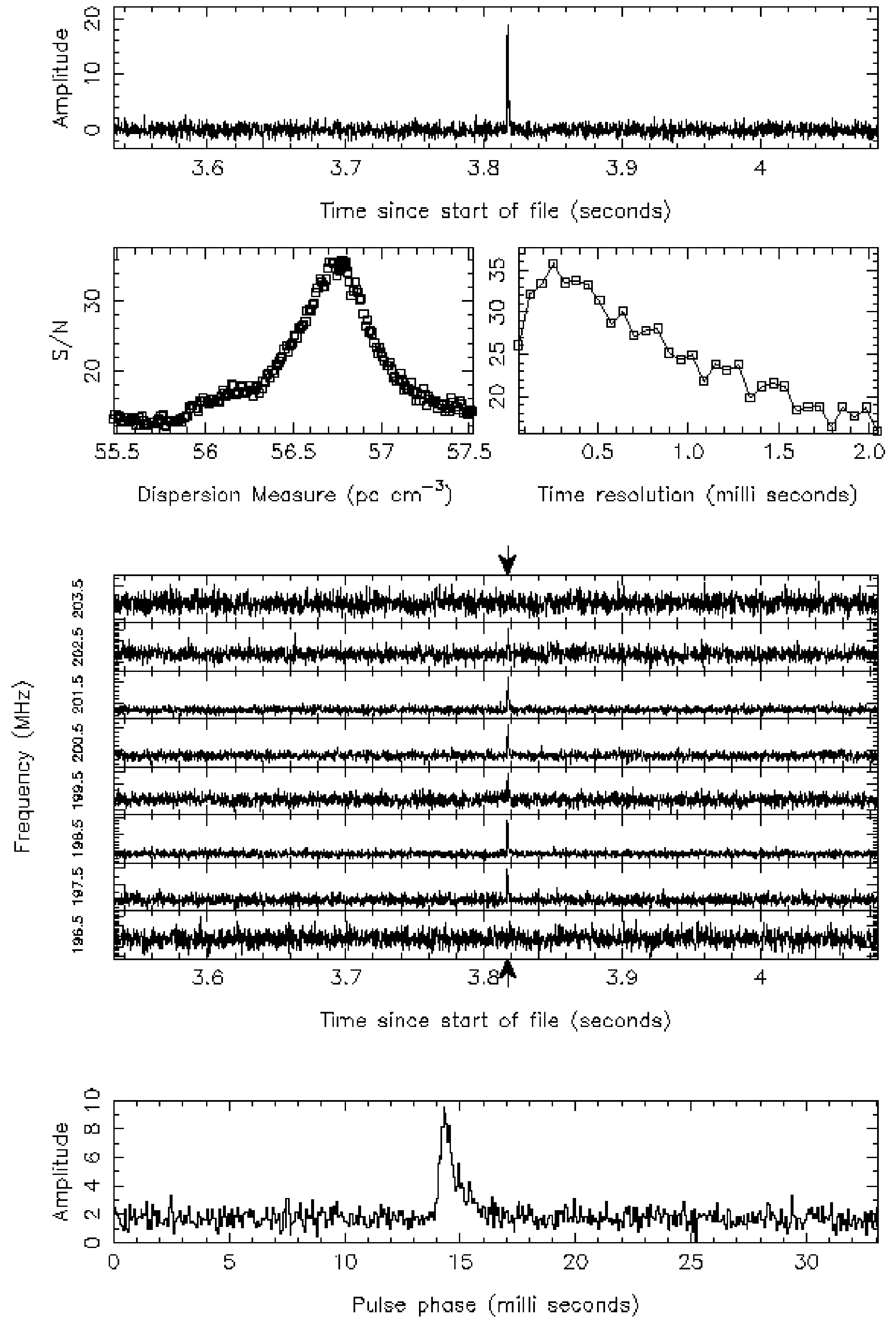
Kuzmin, Hanas Symposium, Chin. J. Astron. Astrophys. Vol6 (2006), Suppl 2, 34-40 http://www.chjaa.org

Giants pulses

GPs are now searched towards
lower and lower radio frequency

Crab pulsar GPs detected at 200MHZ
by MWA-LFD, Australia
baseband sampled
8MHz bandwidth, 8bits

31 GPs in 3.5hrs

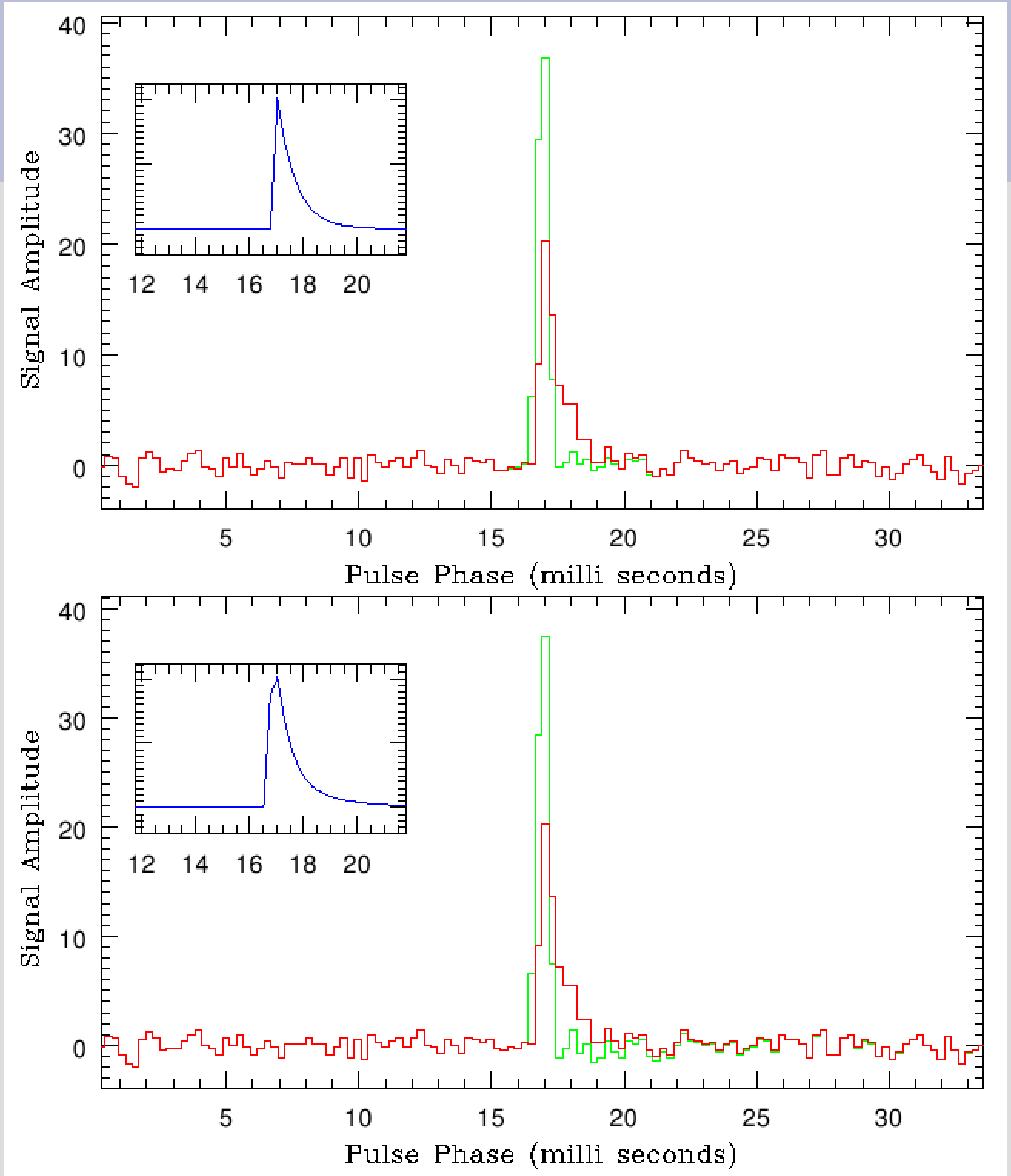


Bhat et al. astro-ph/0705.0404

Giants pulses

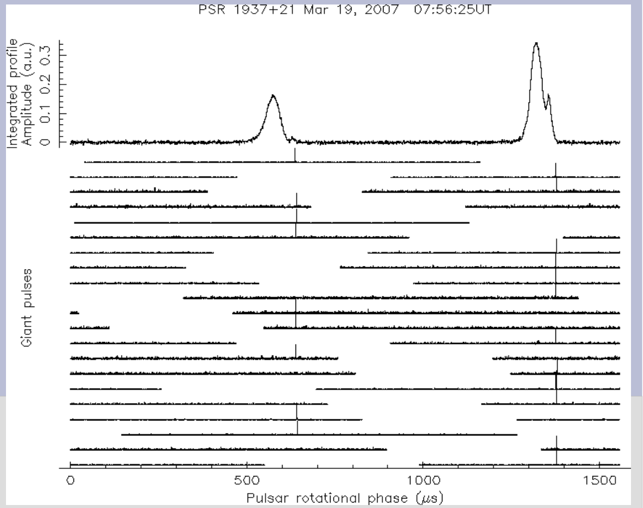
MWA-LFD Crab observation
after deconvolution,
pulse broadening
is estimated to 0.7ms

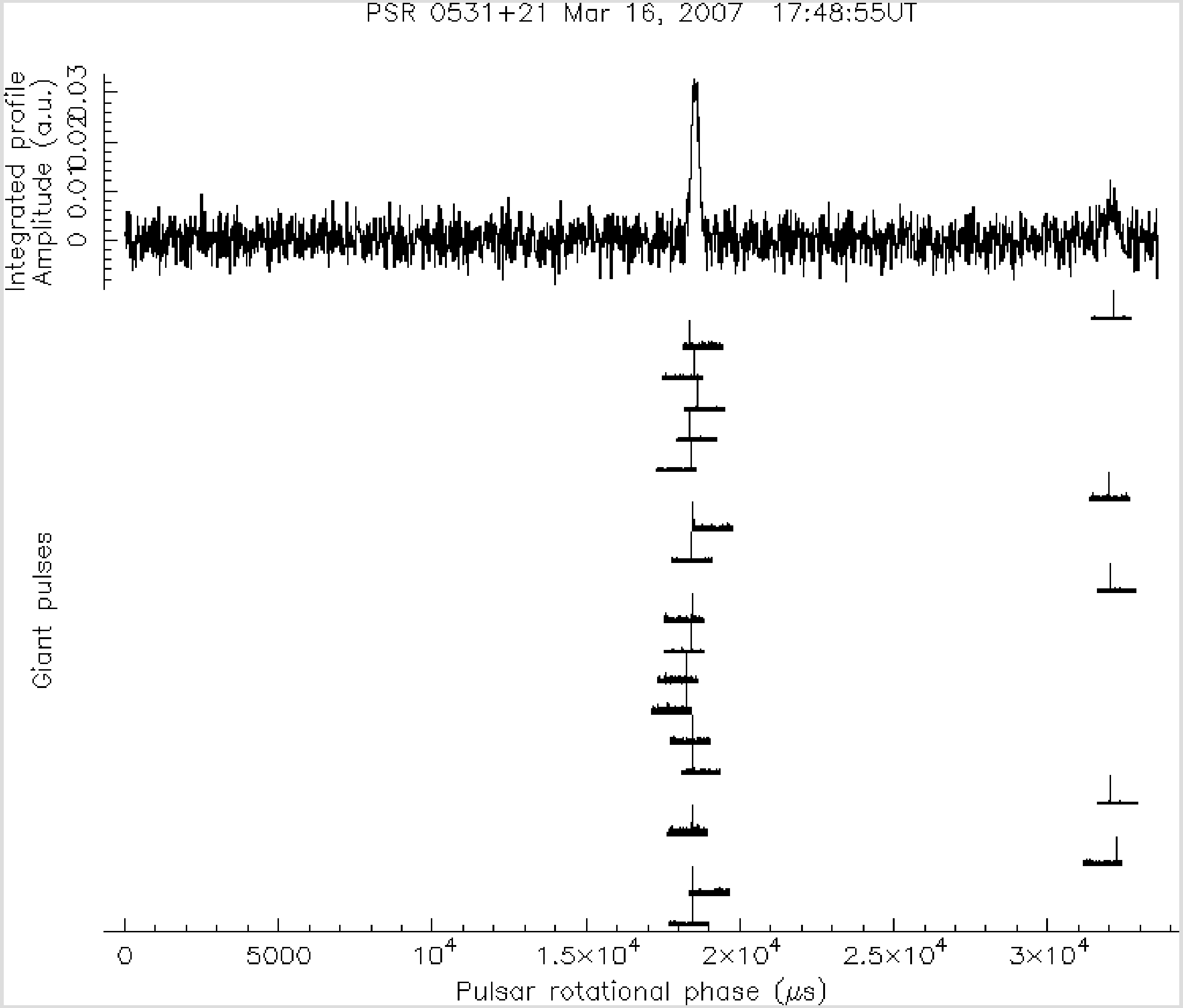
multipath scattering
is a severe problem
at low frequency



Giants pulses

Crab and B937+21 GPs are routinely observed and archived with coherent pulsar BON instrumentation

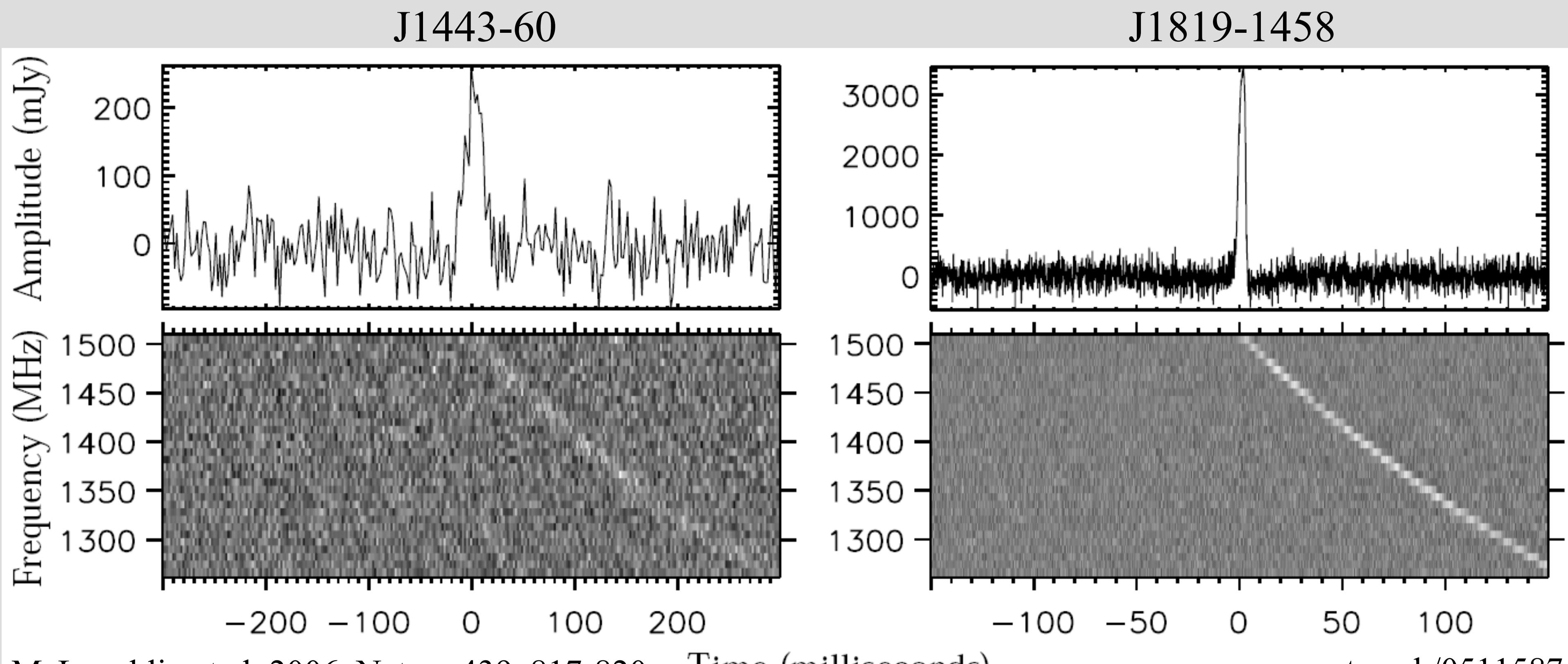




Just before folding, each dedispersed data chunck is searched for outlines, if something above a given threshold is found, then data chunck is saved... Search is done in 4MHz channel time resolution is 250ns

RRATs Rotating Radio Transients

Discovered in the 35-minute pointings of the Parkes Multibeam Pulsar Survey …..
during a **Transient Event Search** (single, dispersed events like giant pulses!)

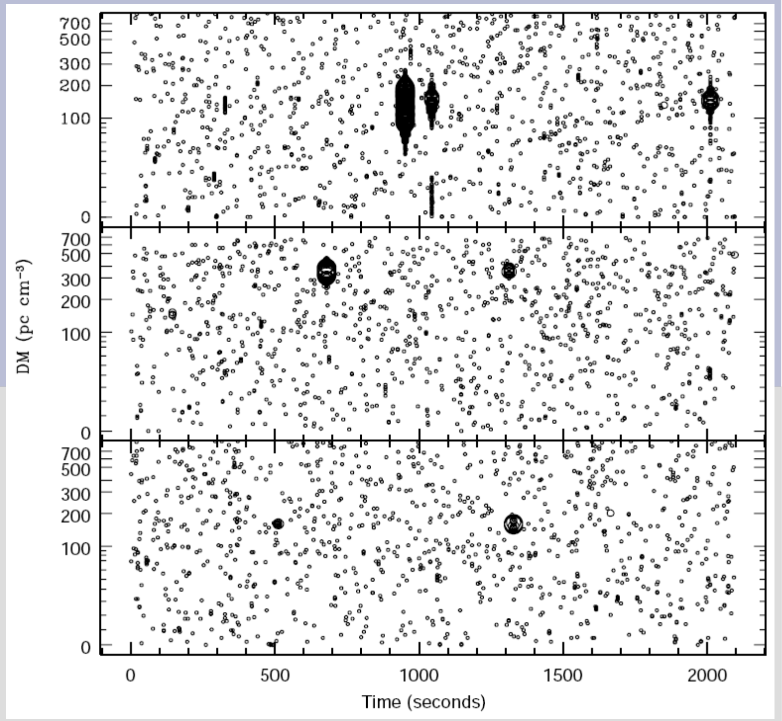


McLaughlin et al. 2006, Nature 439, 817-820

astro-ph/0511587

RRATs Rotating Radio Transients

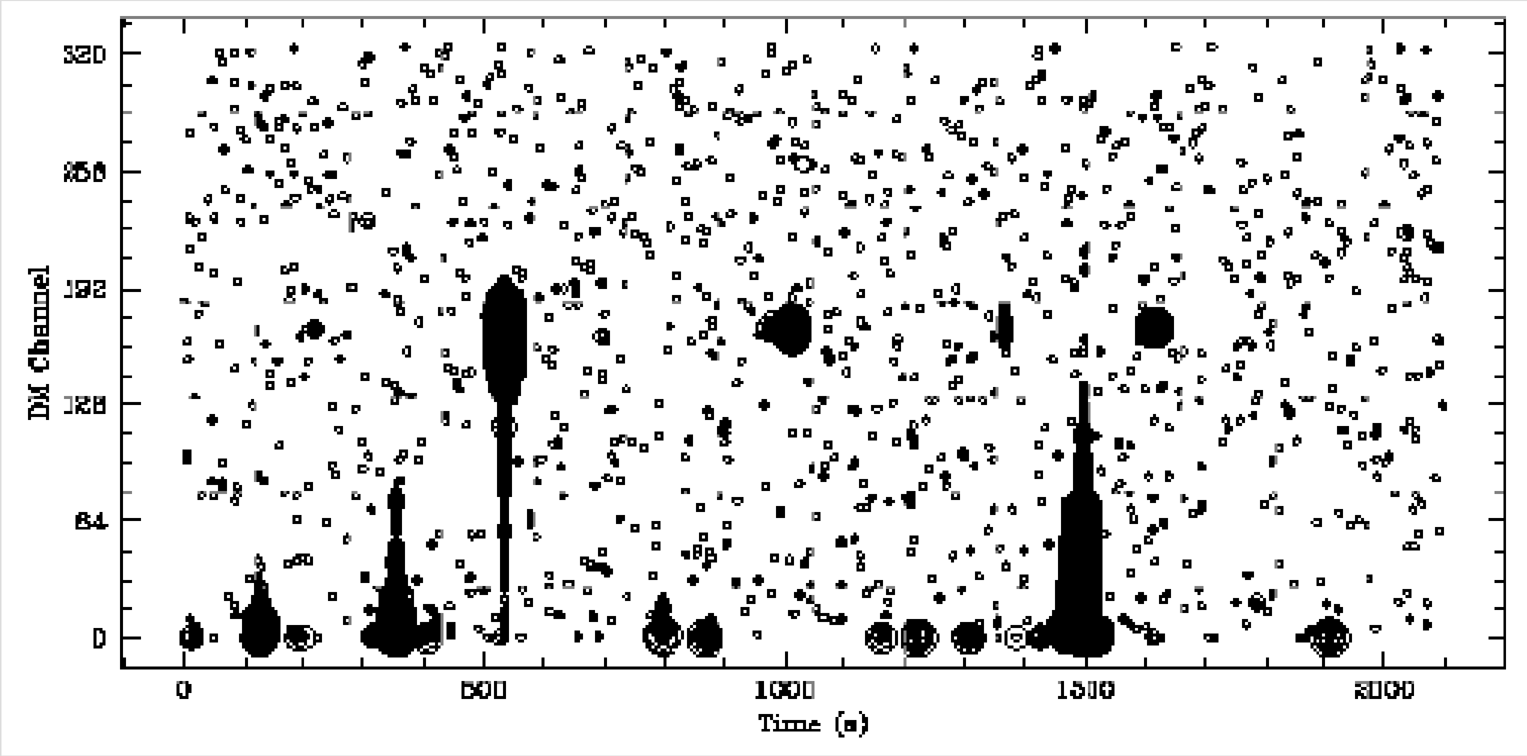
11 confirmed sources
FFT searches showed no periodicity
Time difference analysis shows periodicity in all 11 sources



J1317-5759, J1443-60, J1826-14

J1819–1503
DM = 194 pc cm^{-3}

periodicity 4.26s



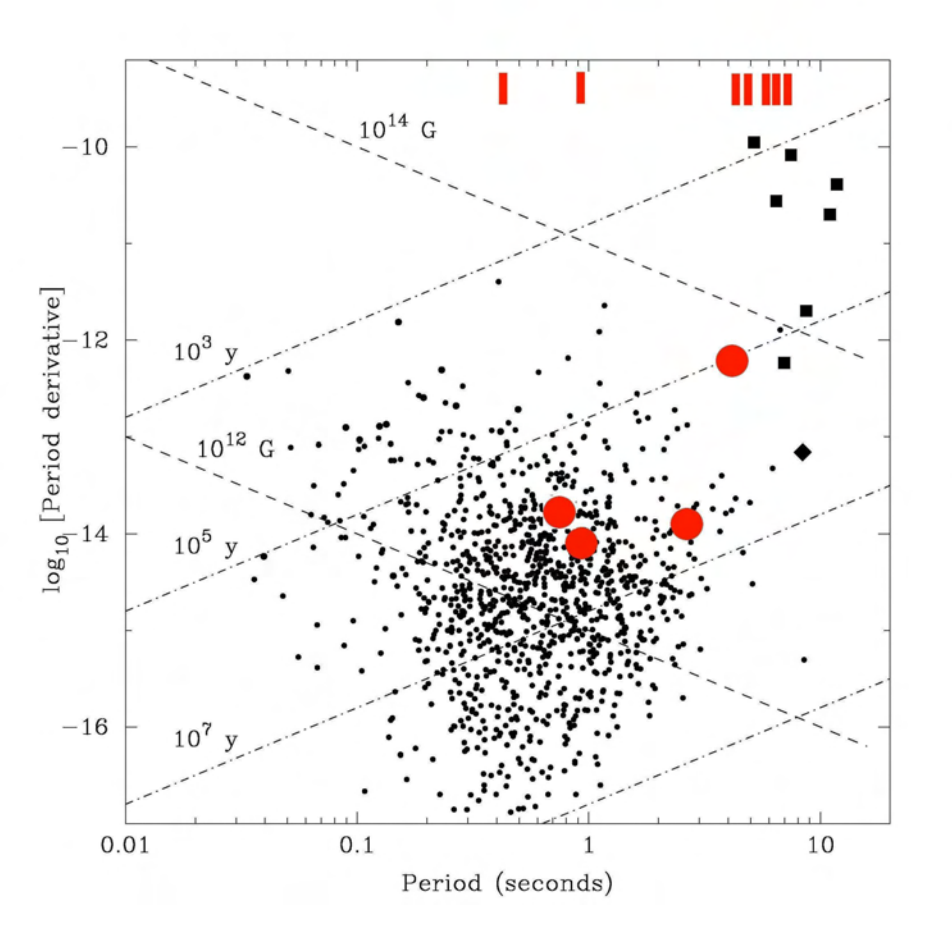
RRATs Rotating Radio Transients

Single bursts of length 2-30ms
maximum brust Flux Density 0.1-4Jy
Mean interval between bursts 4min-3hrs
Periods 0.4-7sec <P>=3.6sec

Periodicity suggests rotating Neutron Stars
can be timed like normal pulsars,
but using single pulses

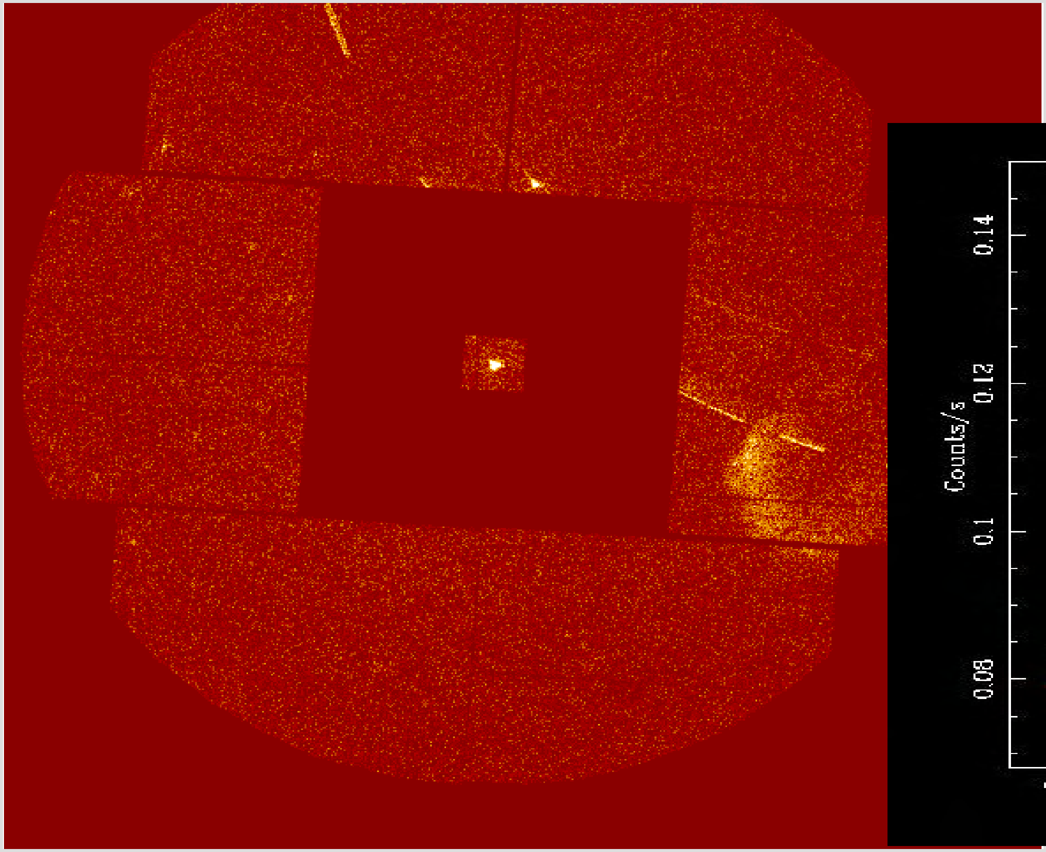
For 4 of the 10 RRATs with periods,
coherent timing solutions have
been obtained from burst arrival times
With Period Derivatives,
4 RRATs can be put in P-Pdot diagram

one of them, J1819-1458 close to magnetars

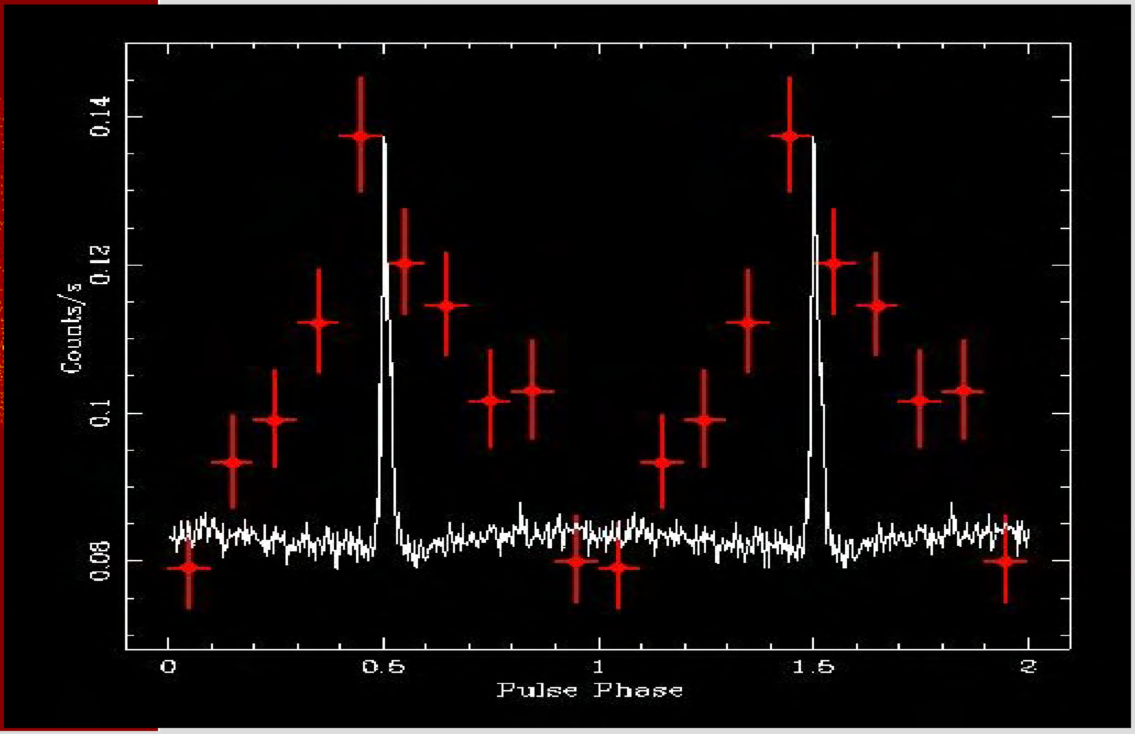


RRATs Rotating Radio Transients

Serendipitous detection of J1819-1458 in 30ks Chandra observation of Reynolds 2006's field
New detection in 40ks XMM Epic PN observation



McLaughlin et al., 2007, in preparation



RRATs Rotating Radio Transients

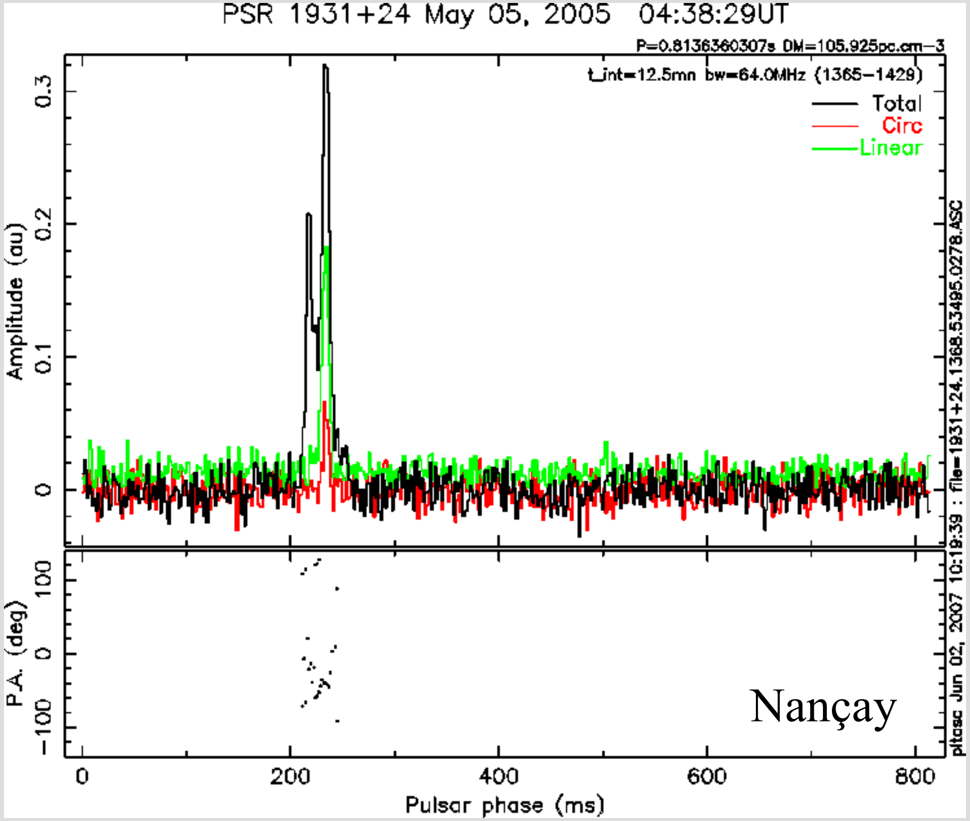
11 objects which only radiate for typically 0.1-1.0 sec/day
Not detectable in periodicity searches or by folding
Probably rotatinf neutron stars
Ages 0.1-3Myr
Young cooling Neutron Stars ?

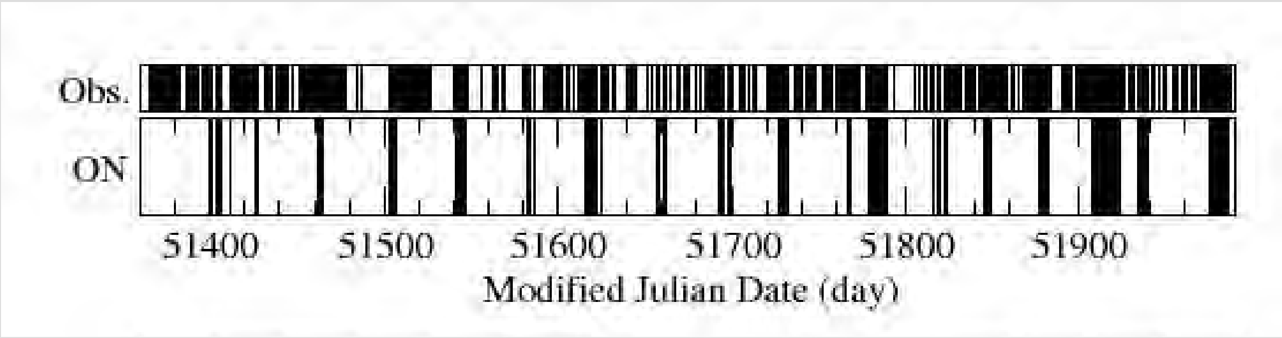
Large previously unknown galactic population ?
- huge selection effects in standard survey
  - only long observing times can detect them
  - terrestrial impulsive interference is severe (small DMs)

Intermittent pulsars

PSR B1931+24
discovered years ago at Green Bank

ON for ~1 week, OFF for ~1 month
visible only 20% of time
relatively strong when ON
deep observations do not show
any emission when OFF
broadband phenomenon
radio emission is shut off is less than 10sec
to remain off for ~1 month





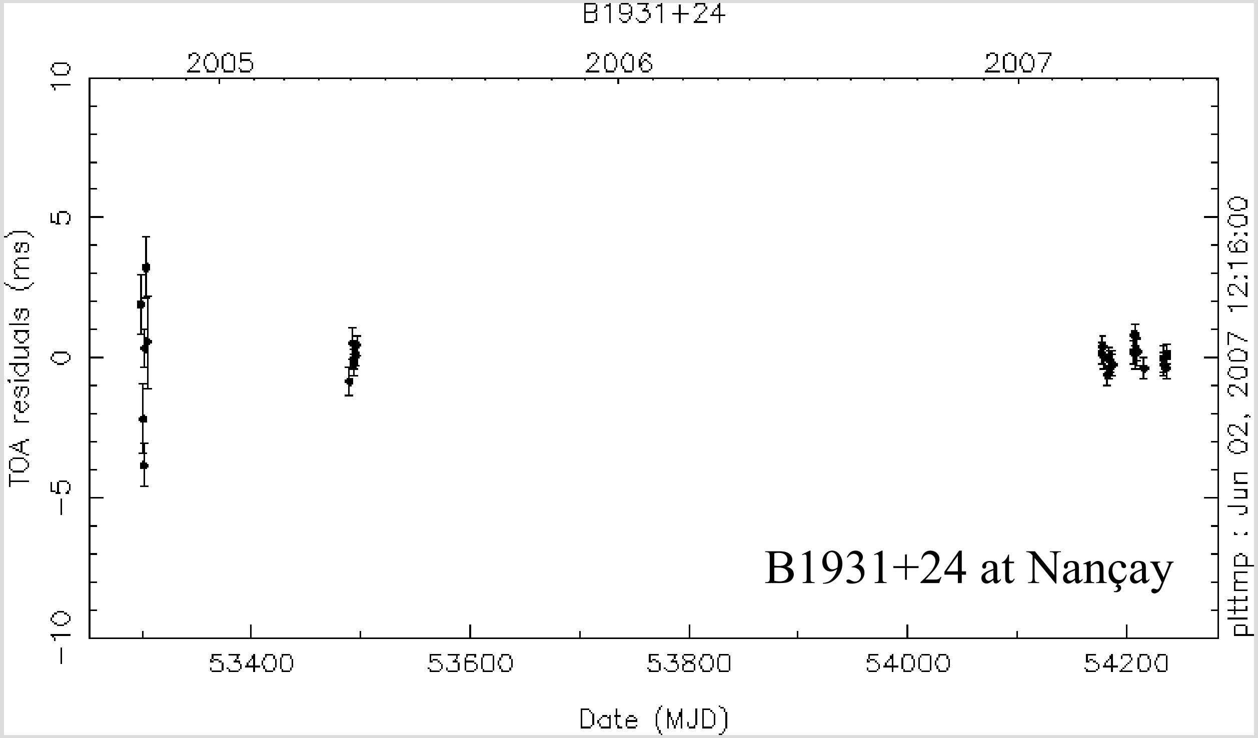
Intermittent pulsars

Nulling ? NO...

nulling duration of typically a few pulse periods
no nulls during ON phases

Precession ? NO...

switch time is less than 10sec
no continuous profile changes



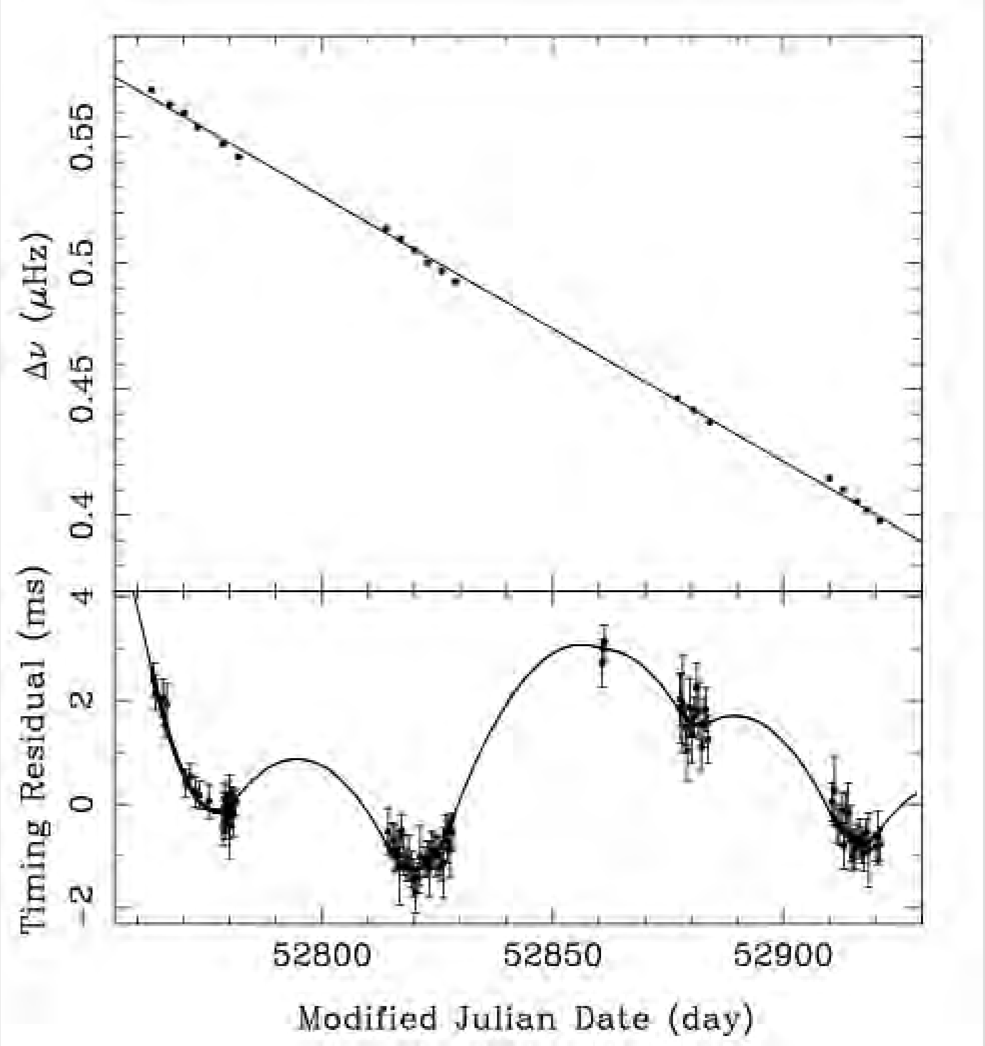
Intermittent pulsars

50% increase in Pdot !
the spin down is faster when ON

braking is greatest when ON
braking is less when OFF

both braking and radio emission
arise in currents
the plasma creating the radio emission
provides the expected extra torque
when the plasma is absent,
braking is less strong

Good agreement with Pacini and
Goldreich & Julian models



Kramer et al. Science 312, 549 (2006)

Intermittent pulsars

Systematic search was done in Parkes survey

4 more intermittent pulsars

J1107-5907

P=253ms, 3 different emission states

J1717-4054

ON 20% of time, no periodicity yet

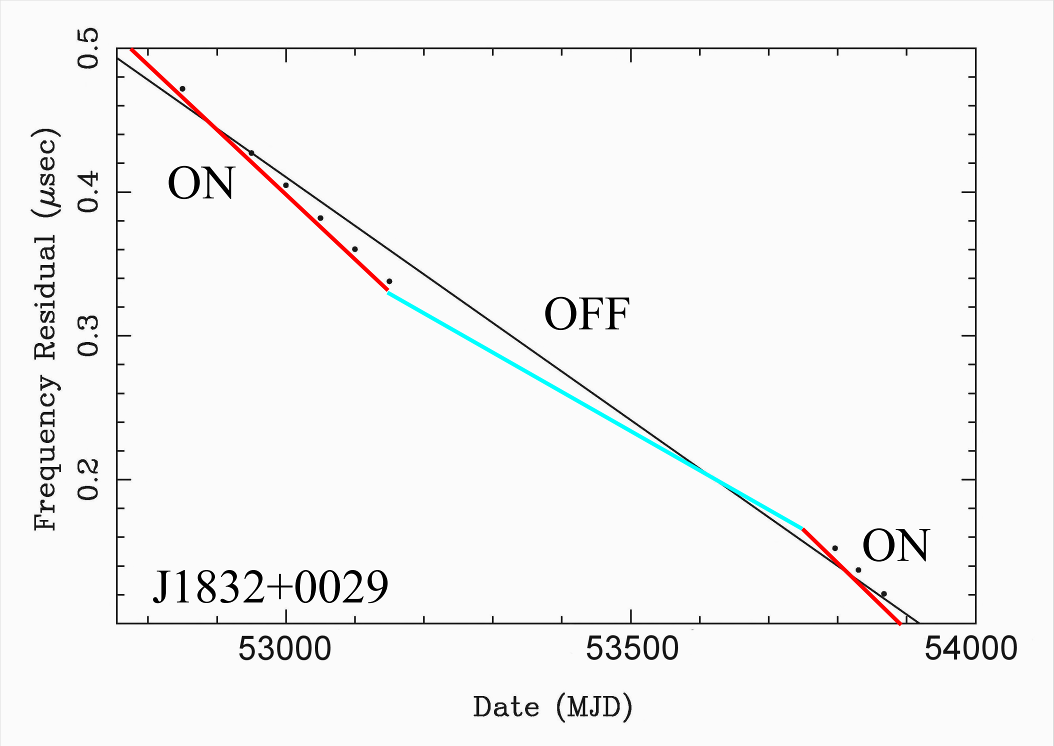
J1634-5107

strong ON, ~10days quasi-periodicity

J1832+0029

ON for >300days, OFF for ~600days!

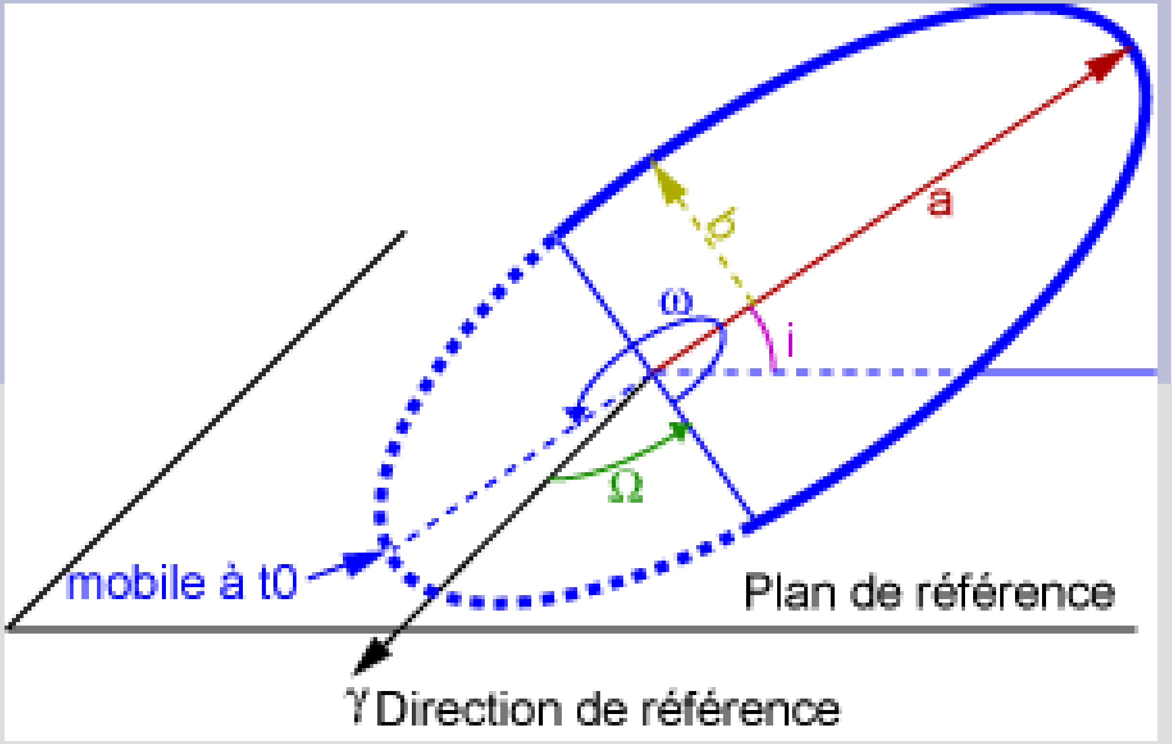
$Pdot_{ON}/Pdot_{OFF}$ ~ 1.8+/-0.1



Could all NULLING associated with failure of particule flow
and only testable in pulsars with switch timescales much greater than a day ?

Relativistic binary pulsar

two neutron stars orbiting
around each other

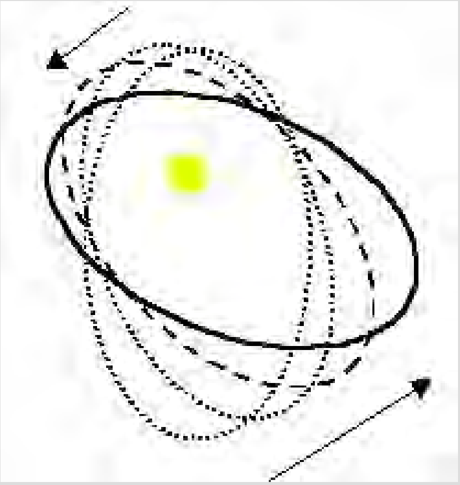


5 Keplerian parameters :

projected semi-major axis	a.sin(i)
eccentricity	e
orbital period	Porb
periastron angle	w
periastron date	Tpa

masses of the two stars remain unknown and non measurable !

Relativistic binary pulsar



with the extreme rotational stability of neutron stars,
it is possible to detect General Relativity effects

post-Keplerian (PK) parameters

periastron advance	dw/dt
orbital period decrease	dP/dt
Shapiro delay	r, s
gravitational delay	g

As the two masses remain to be determined,
any determination of 3, or more, post-kepkerian parameters
provide a test of the different Gravitation theories

Relativistic binary pulsar

Relations between M_A, M_B and the post-keplerian parameters in General Relativity

$$\dot{\omega} = 3T_{\odot}^{2/3} \left(\frac{P_b}{2\pi}\right)^{-5/3} \frac{1}{1-e^2} (M_A + M_B)^{2/3},$$

$$\gamma = T_{\odot}^{2/3} \left(\frac{P_b}{2\pi}\right)^{1/3} e \frac{M_B(M_A + 2M_B)}{(M_A + M_B)^{4/3}},$$

$$\dot{P}_b = -\frac{192\pi}{5} T_{\odot}^{5/3} \left(\frac{P_b}{2\pi}\right)^{-5/3} \frac{\left(1 + \frac{73}{24}e^2 + \frac{37}{96}e^4\right)}{(1-e^2)^{7/2}} \frac{M_A M_B}{(M_A + M_B)^{1/3}},$$

$$r = T_{\odot} M_B,$$

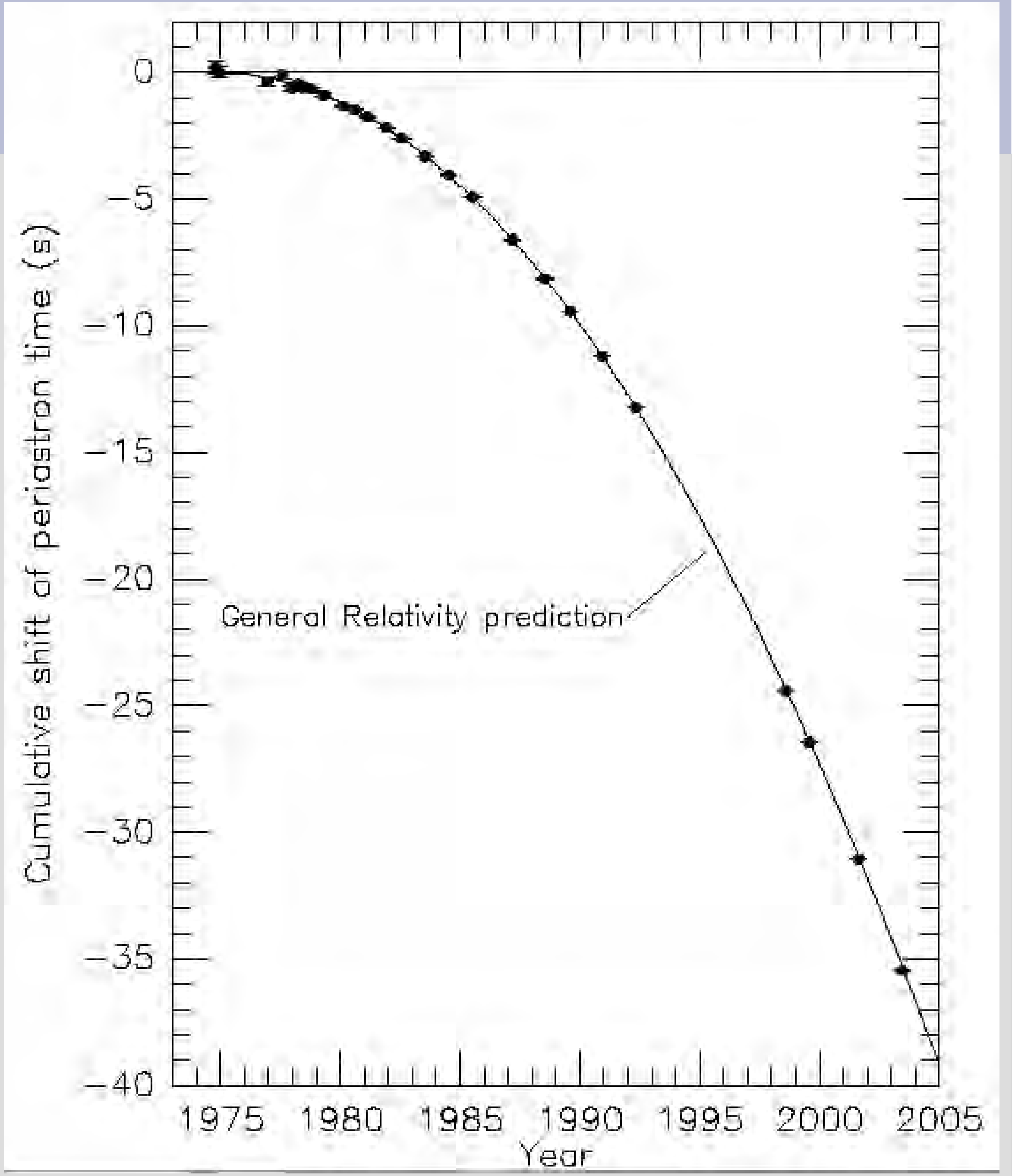
$$s = T_{\odot}^{-1/3} \left(\frac{P_b}{2\pi}\right)^{-2/3} x \frac{(M_A + M_B)^{2/3}}{M_B}.$$

Relativistic binary pulsar

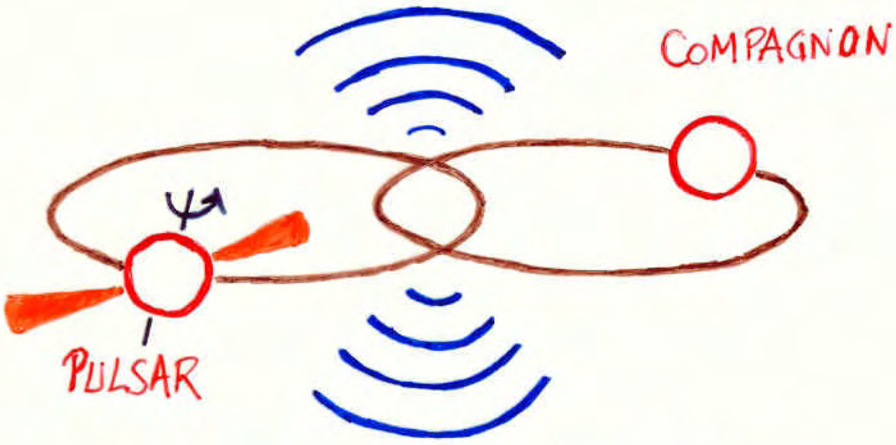
PSR B1913+16
Taylor & Hulse

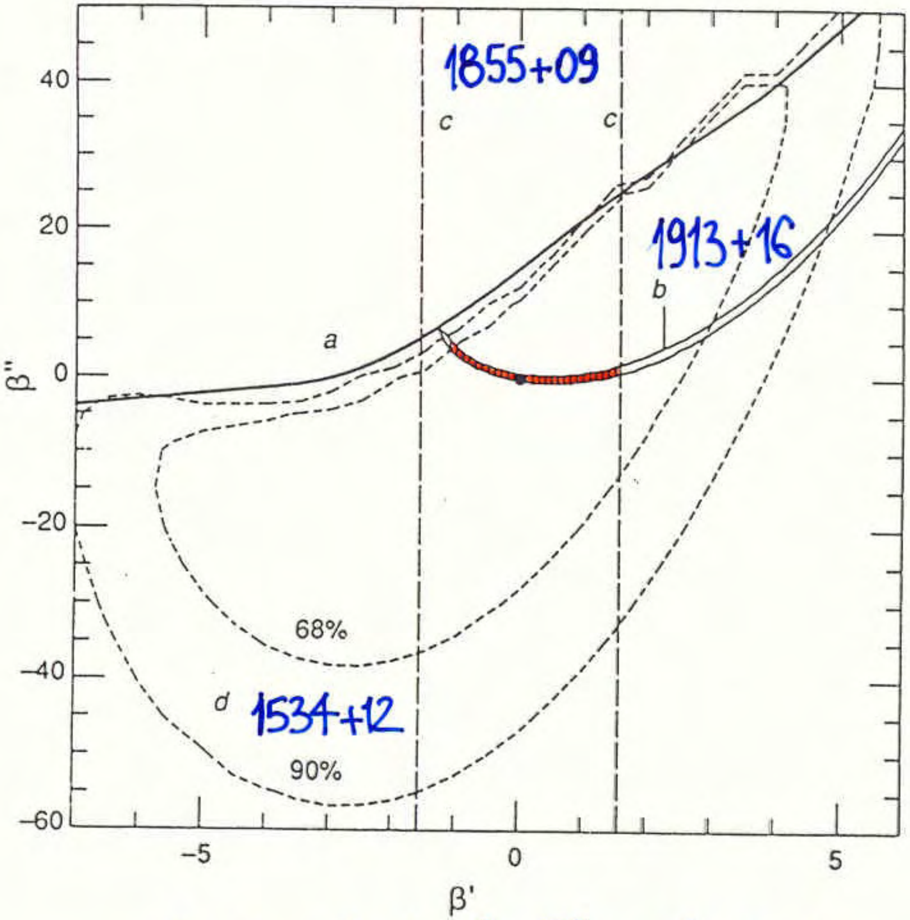
two PK parameters are used to determine M_A and MB
and the $P_b$dot calculated in the frame of the General Relativity with the M_A and M_B values
is compared to the measured one

agreement with GR is 0.2%



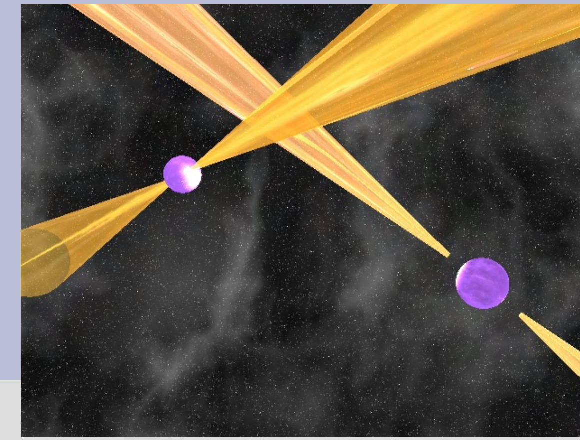
Relativistic binary pulsar





PLAN β'-β" des THEORIES de la GRAVITATION

Relativistic binary pulsar



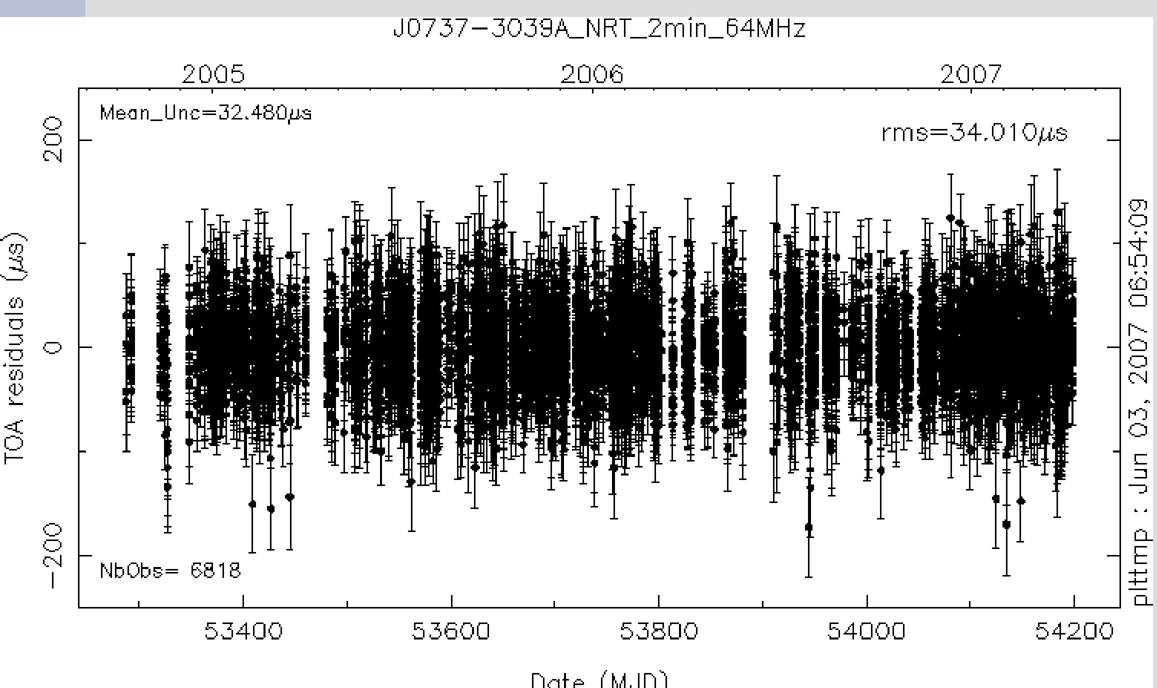
Double pulsar 0737-3039A/B

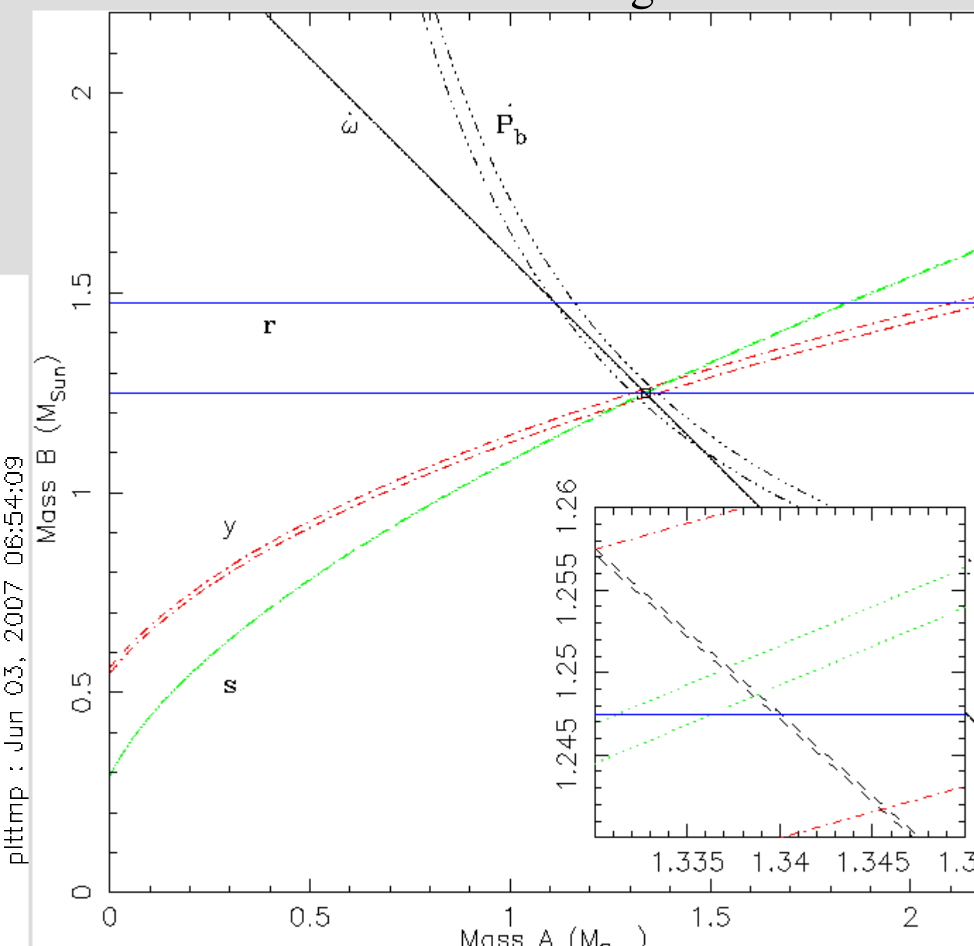
two neutron stars seen as radio pulsars of periods 22ms and 2.8s

mass-mass diagram

Nançay 0737-3039A observations

dense monitoring and high precision





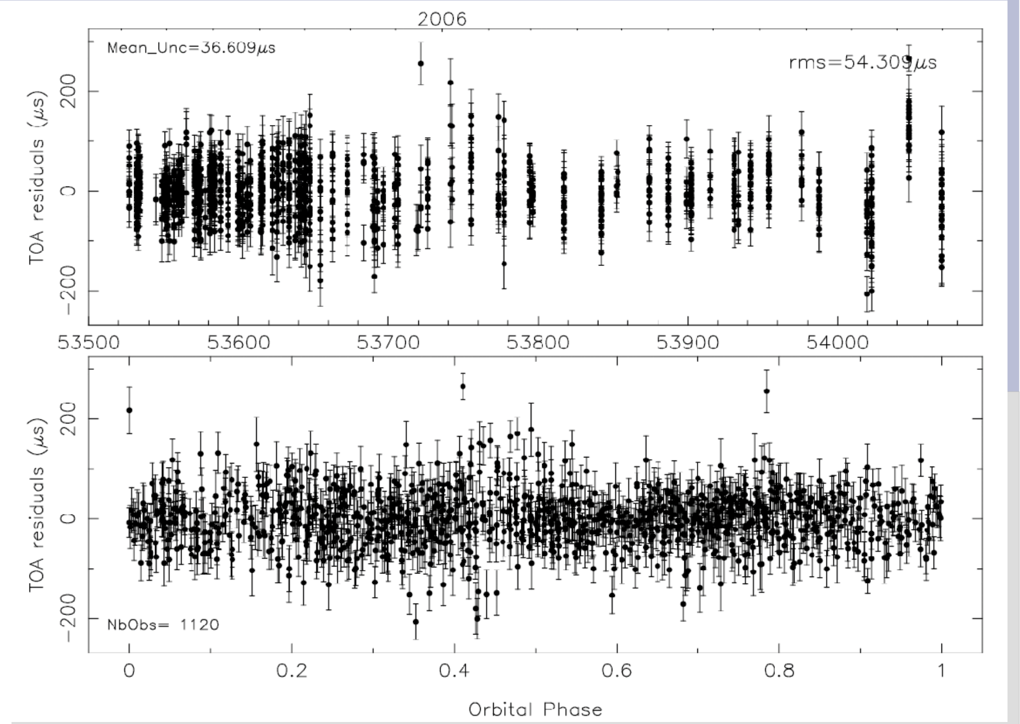
Relativistic binary pulsar

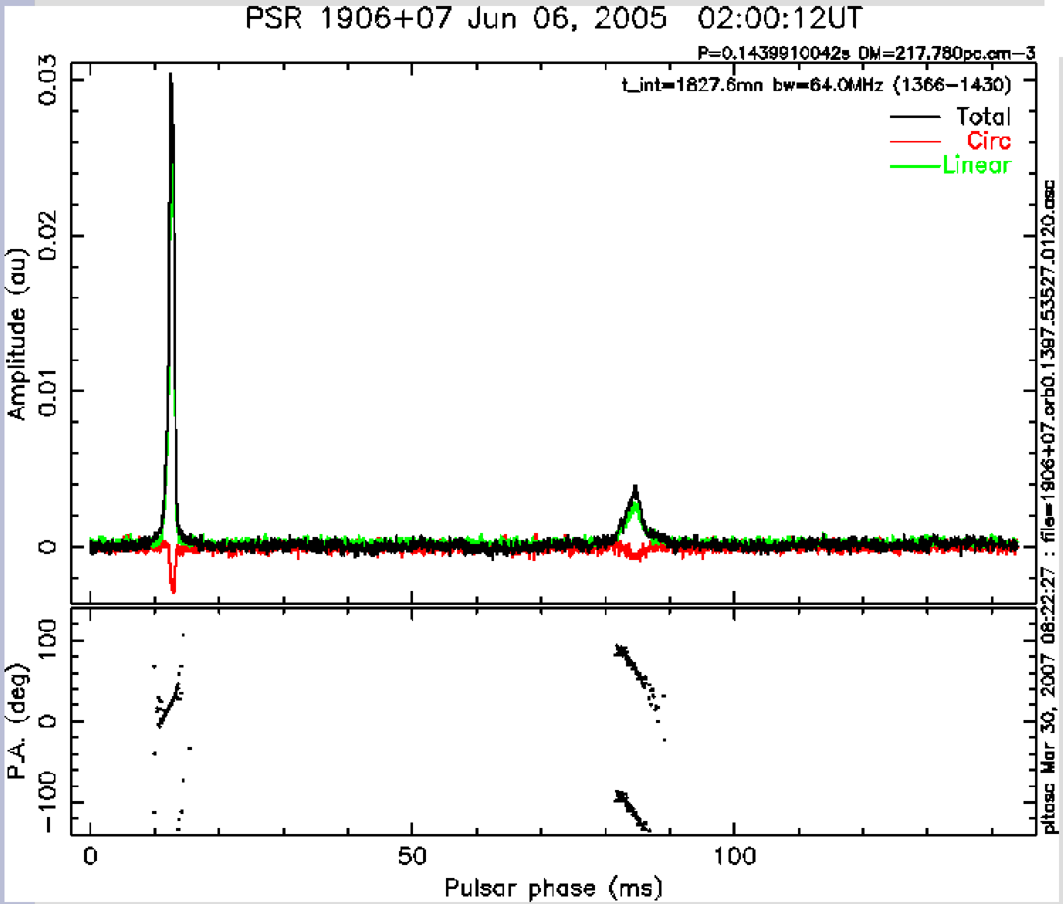
PSR J1906+0746 P=144ms

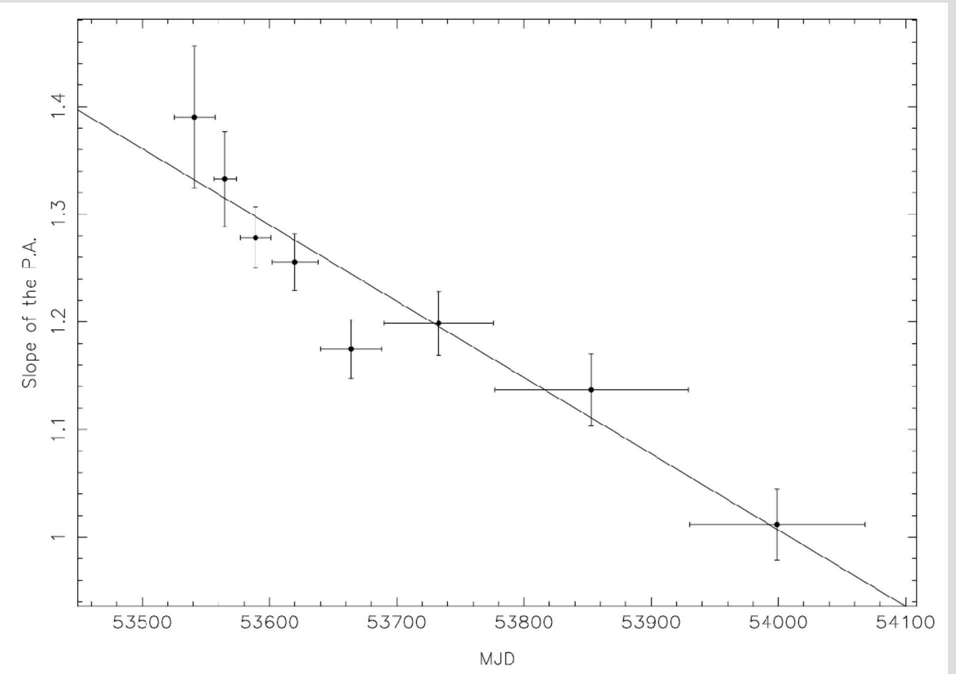
components separation change ~1.5deg/yr

slope of the PA swing change

Desvignes et EPTA (in preparation)



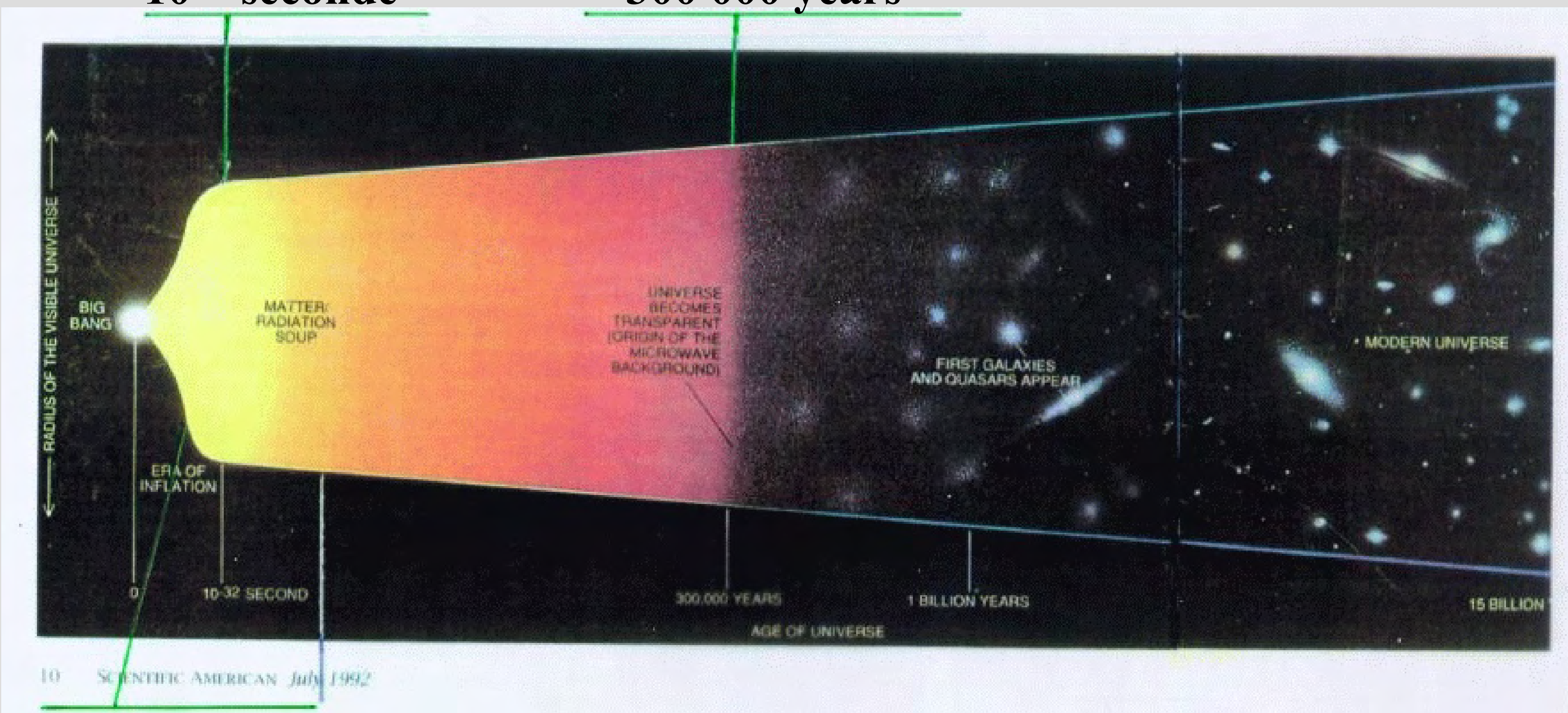




Gravitational Wave background

gravitational
wave background
10^{-32} seconde

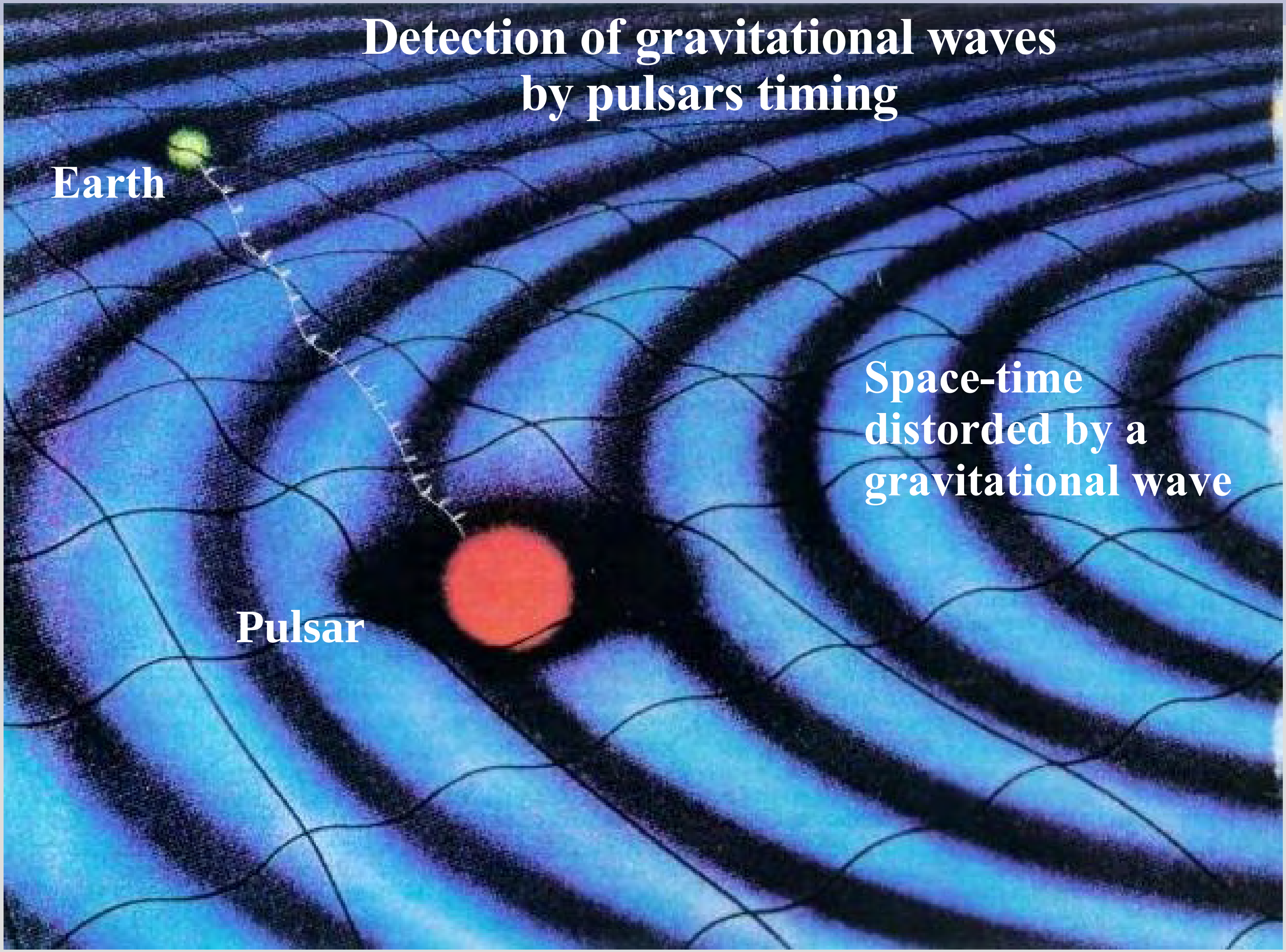
electromagnetic wave
background (radio)
300 000 years



inflation

acceleration - deceleration
oscillations cosmic strings
⇒
emission of
gravitational waves

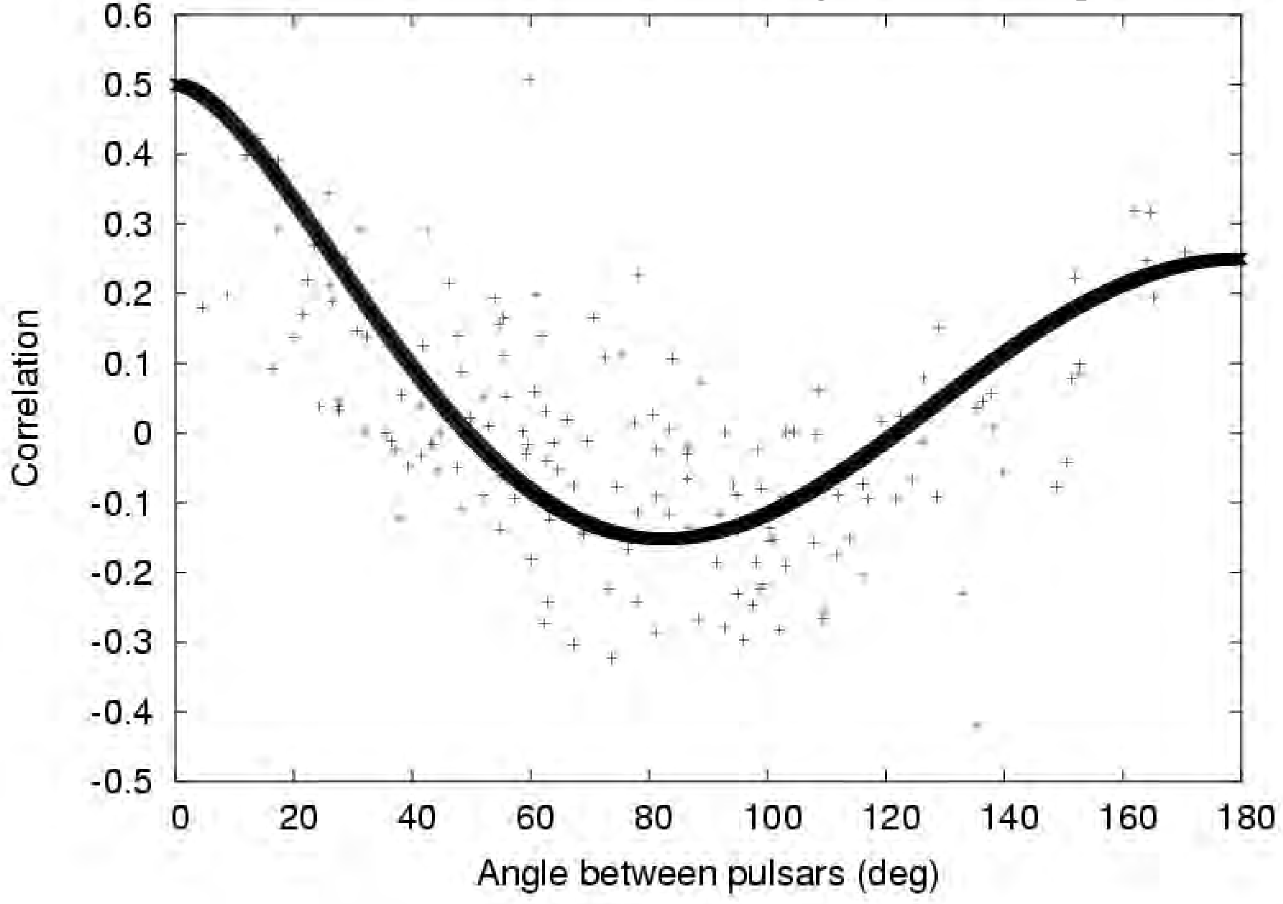
Gravitational Wave background



Gravitational Wave background

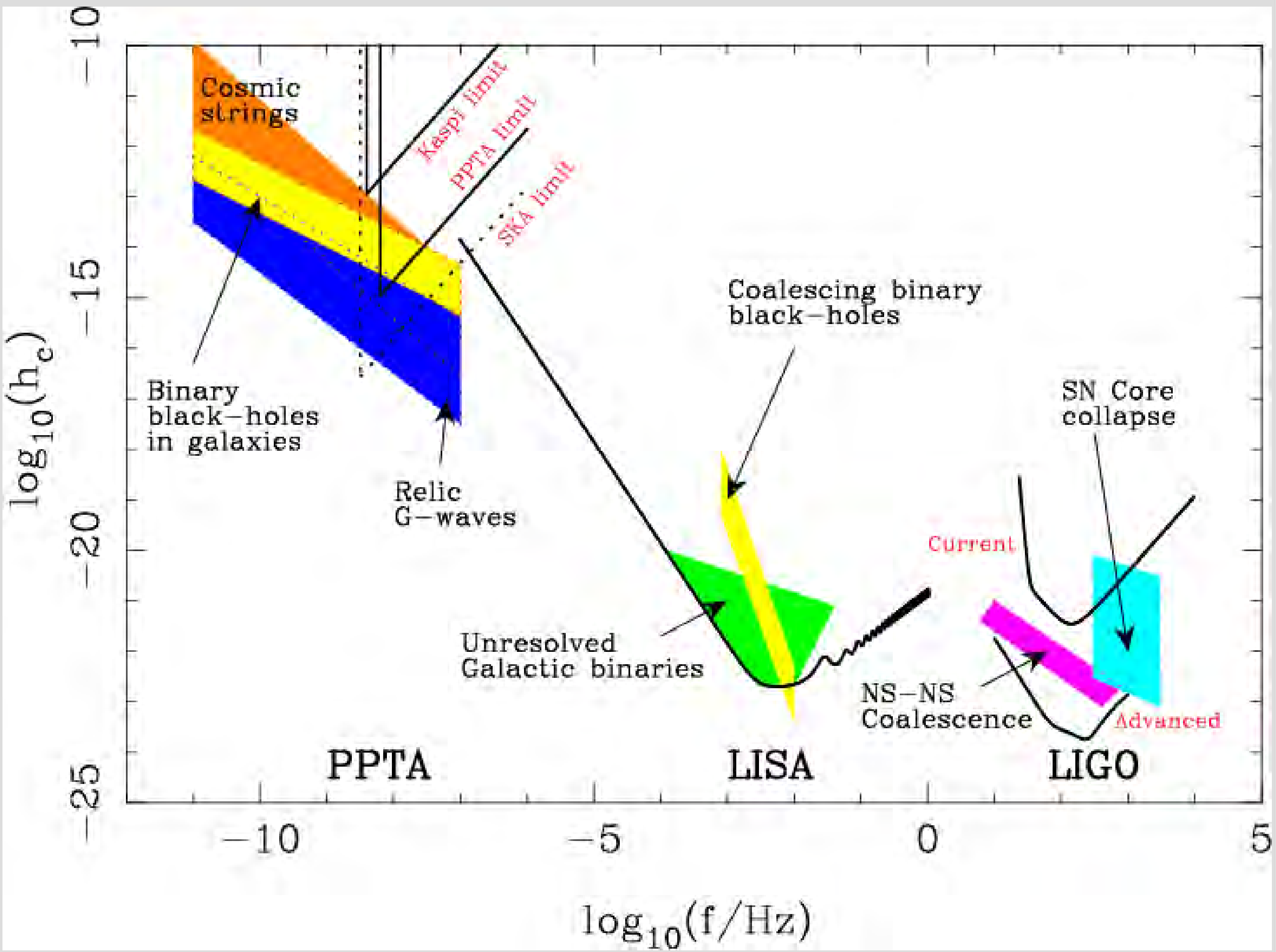
Search for correlation in timing noise among TOAs residuals from a set of stable pulsars

Hellings-and-Downs angular correlation curve
Hellings & Downs, ApJ 265, L39 (1983)



Gravitational Wave background

Different Limits on the GW background

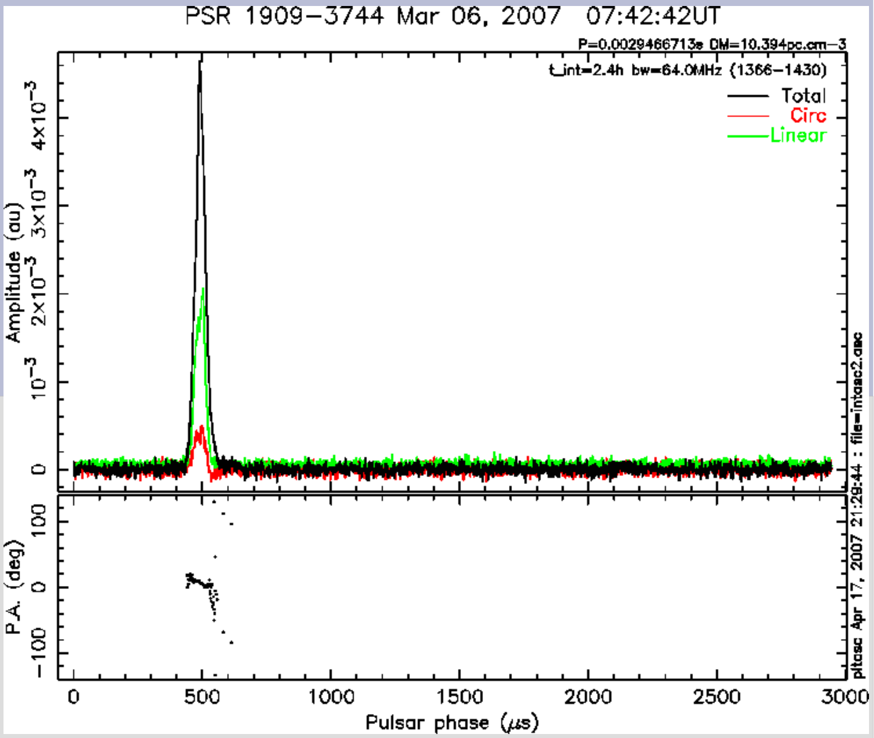


Gravitational Wave background

Parkes PTA (Pulsar Timing Array)

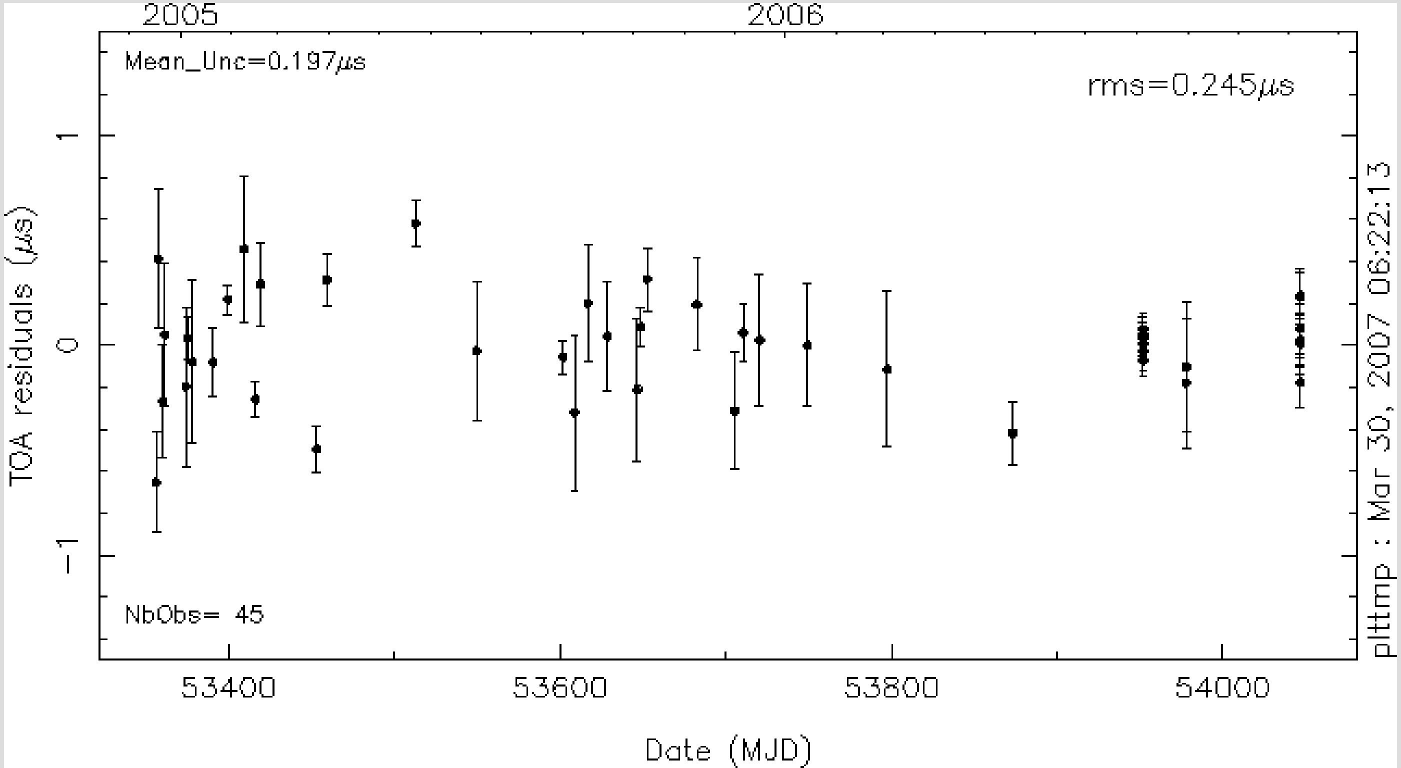
PSR	length(yrs)	TOAs rms	Tint
J0437-4715	9.9	200 ns	1 h
J1909-3744	3.8	224 ns	15 m
J1713+0747	4.1	282 ns	5 m
J144-1134	11.2	629 ns	1 h
J0613-0200	3.6	1.155 μs	15 m
J1939+2134	3.8	1.787 μs	15 m
	with F2	536 ns	
J1600-3053	3.3	3.092 μs	15 m

Gravitational Wave background



PSR J1909-3744 P=2.947ms

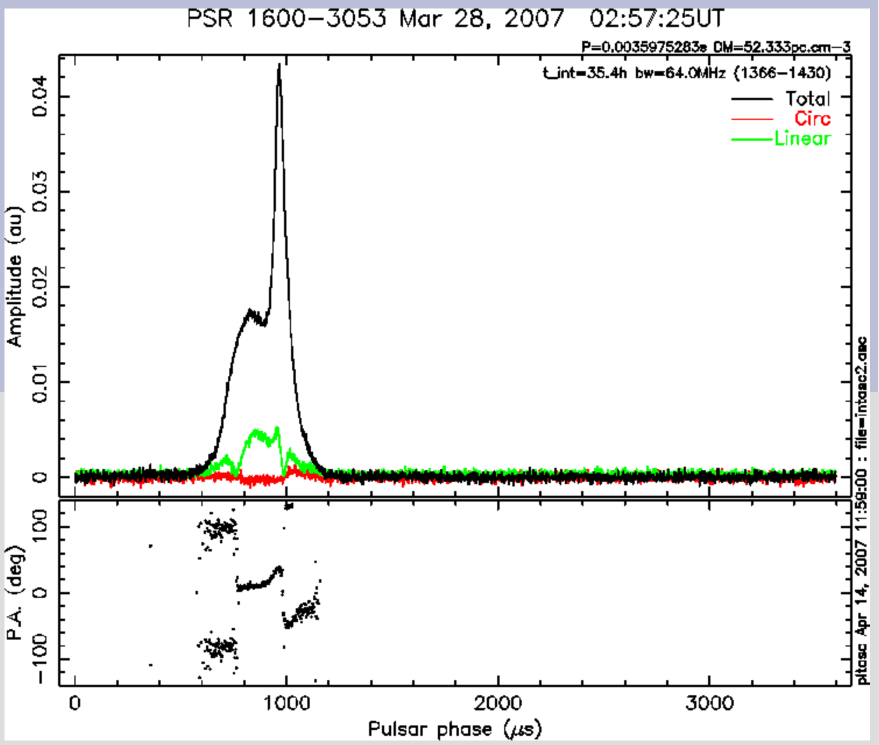
Nançay	mean uncertainty (2')	200ns
	residuals rms	245ns
Parkes	residuals rms	~220ns

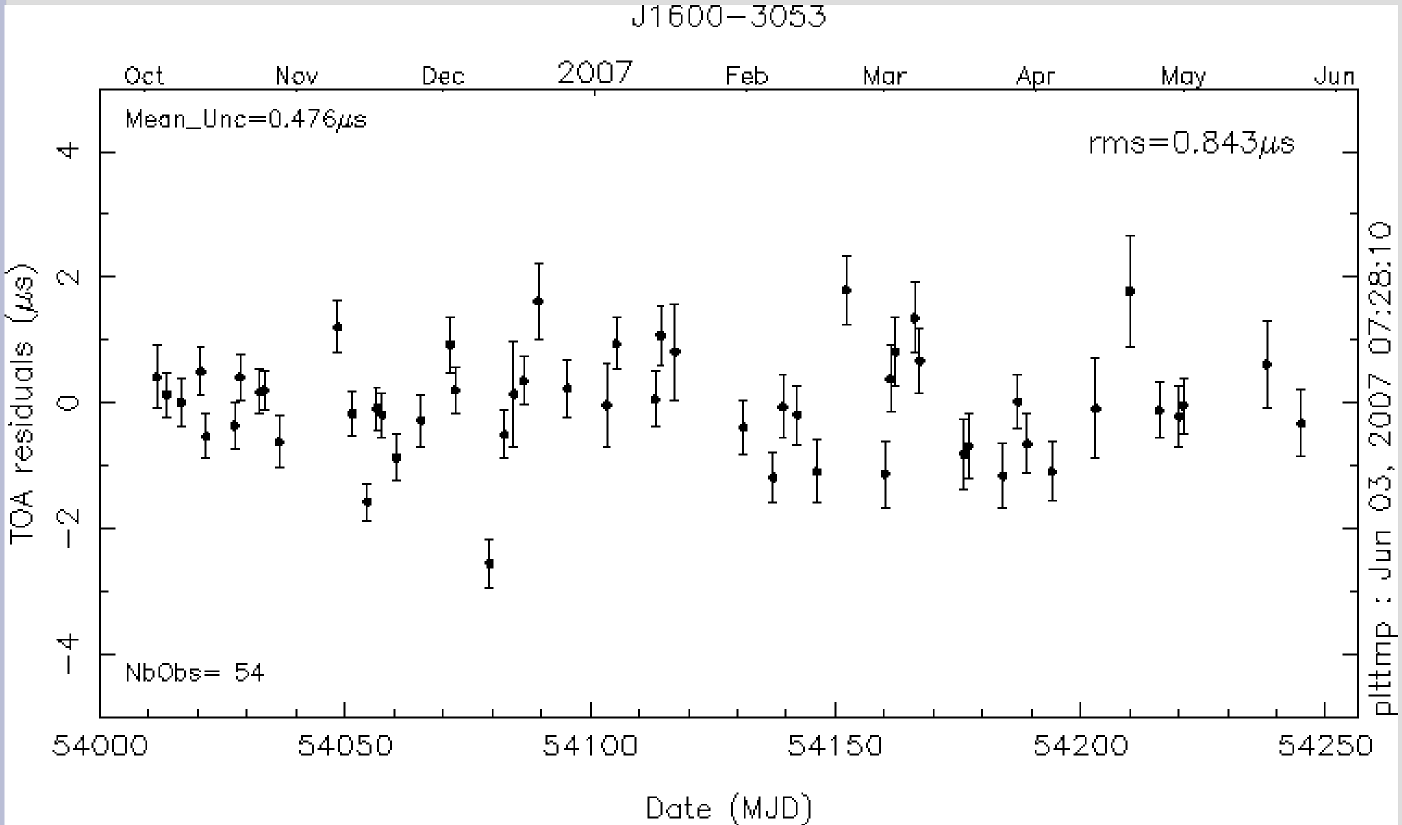


Gravitational Wave background

PSR J1600-3053 P=3.598ms

Nançay	mean uncertainty	470ns
	residuals rms	840ns
Parkes	residuals rms	~3µs



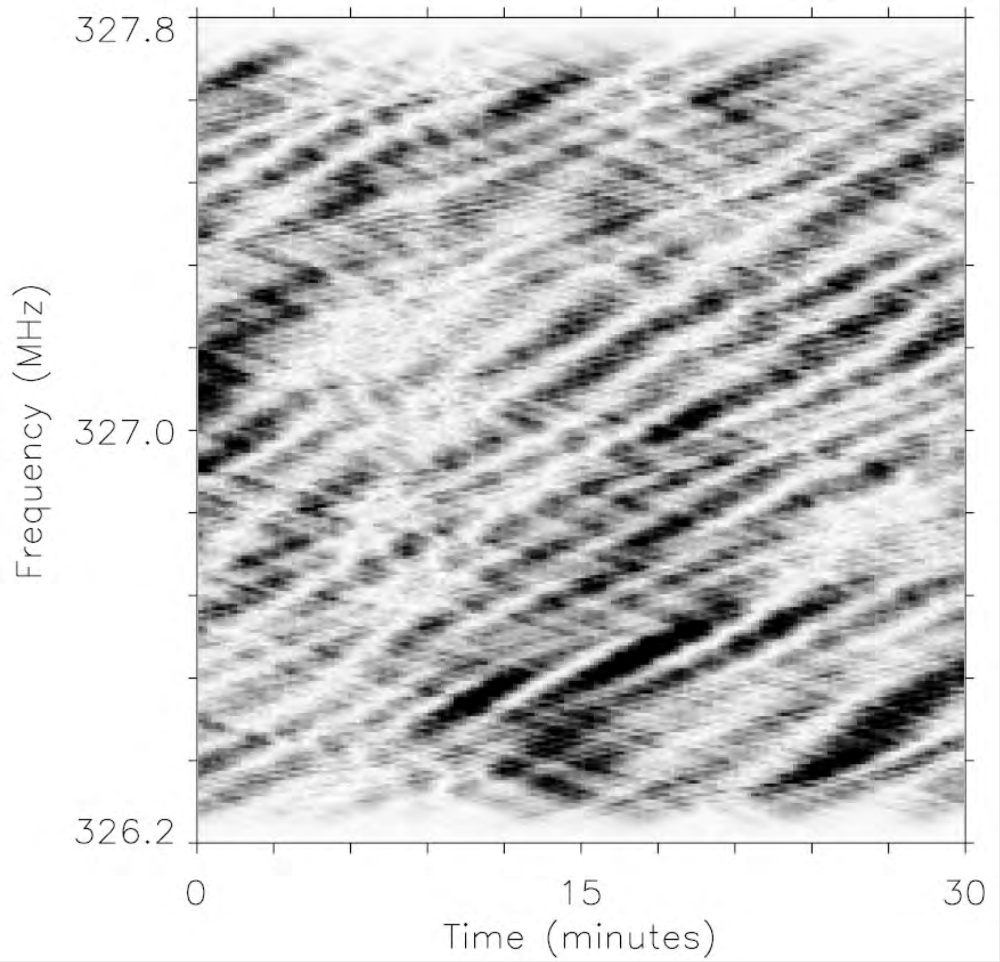


ISM study

arc curvature is dependent on the location of the scattering screen
arclets related to discrete lens-like structure in the screen are moving along the main arc

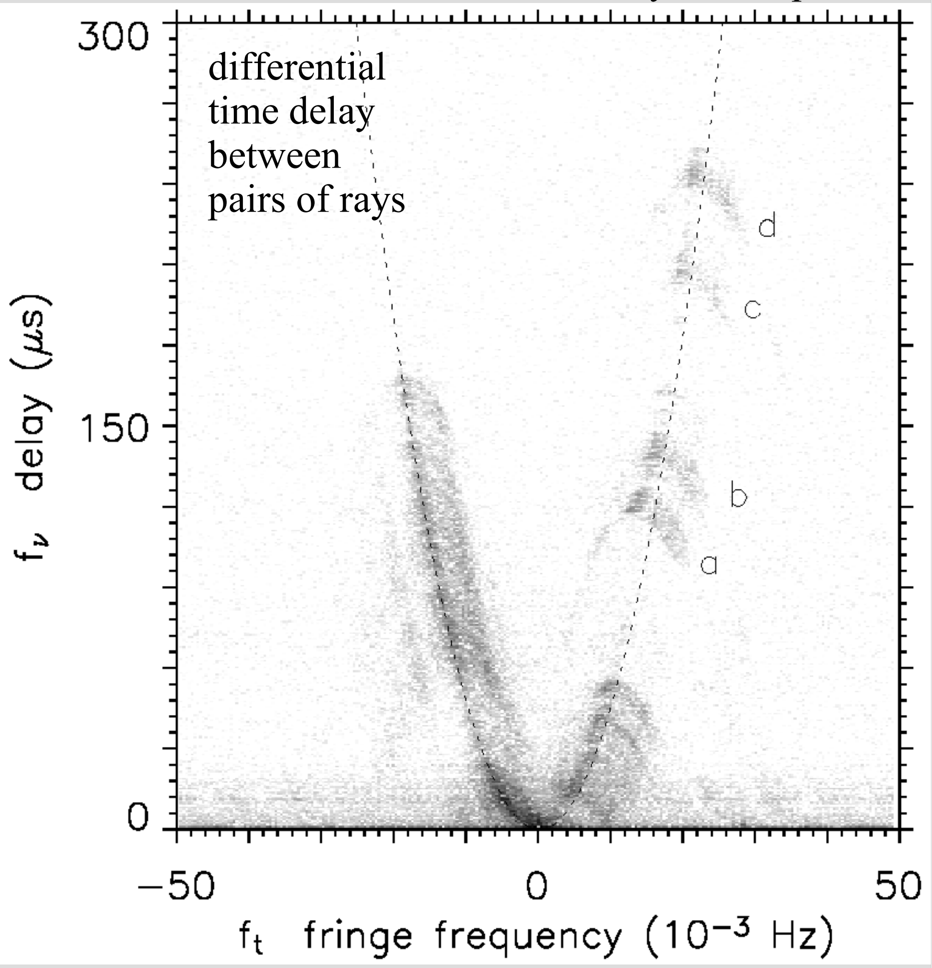
PSR B0834+06, Arecibo

dynamic spectra



secondary spectra

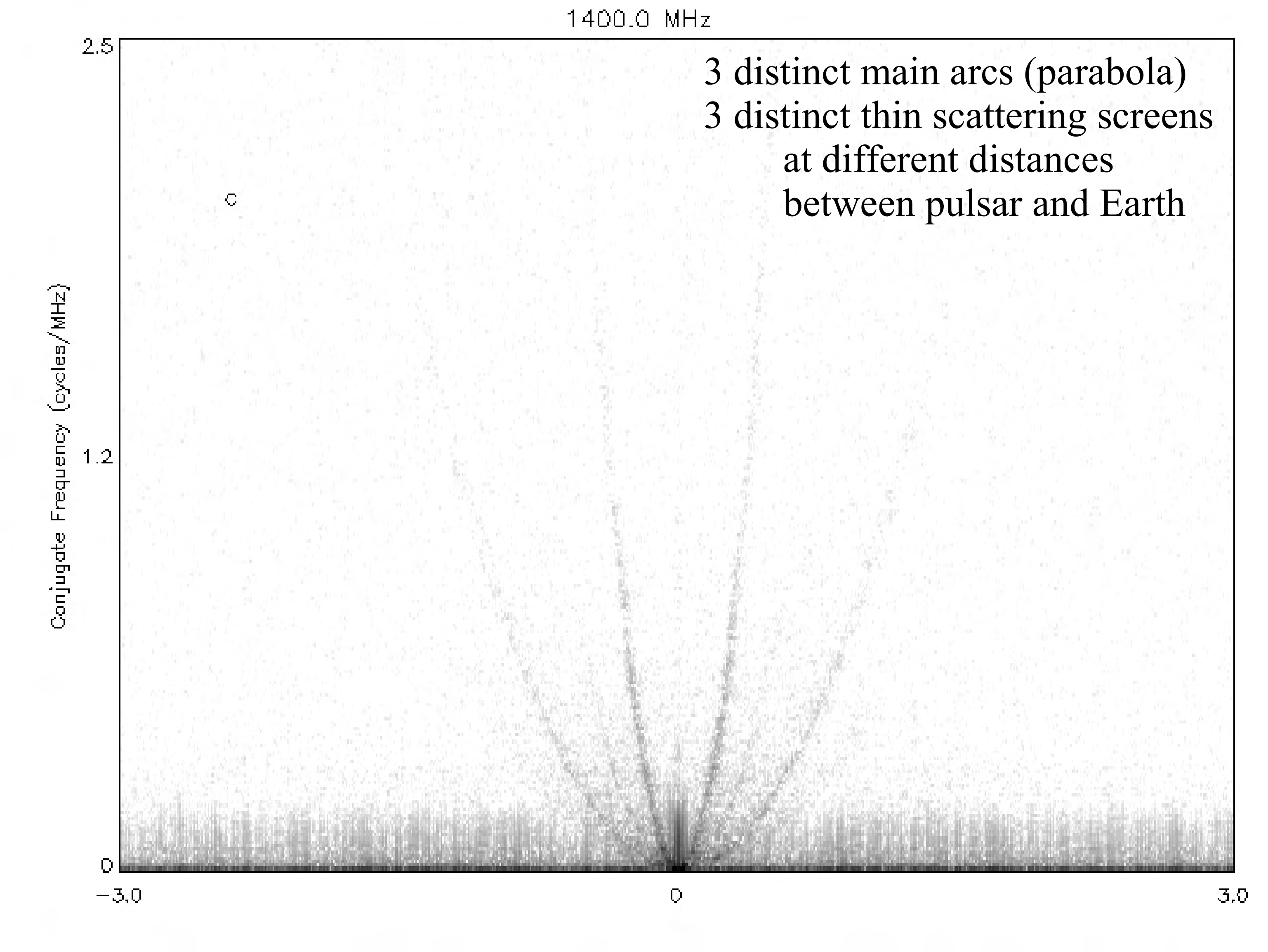
squared modulus of the Fourier transform of the dynamic spectrum



Hill et al., ApJ 619, L171 (2005)

ISM study

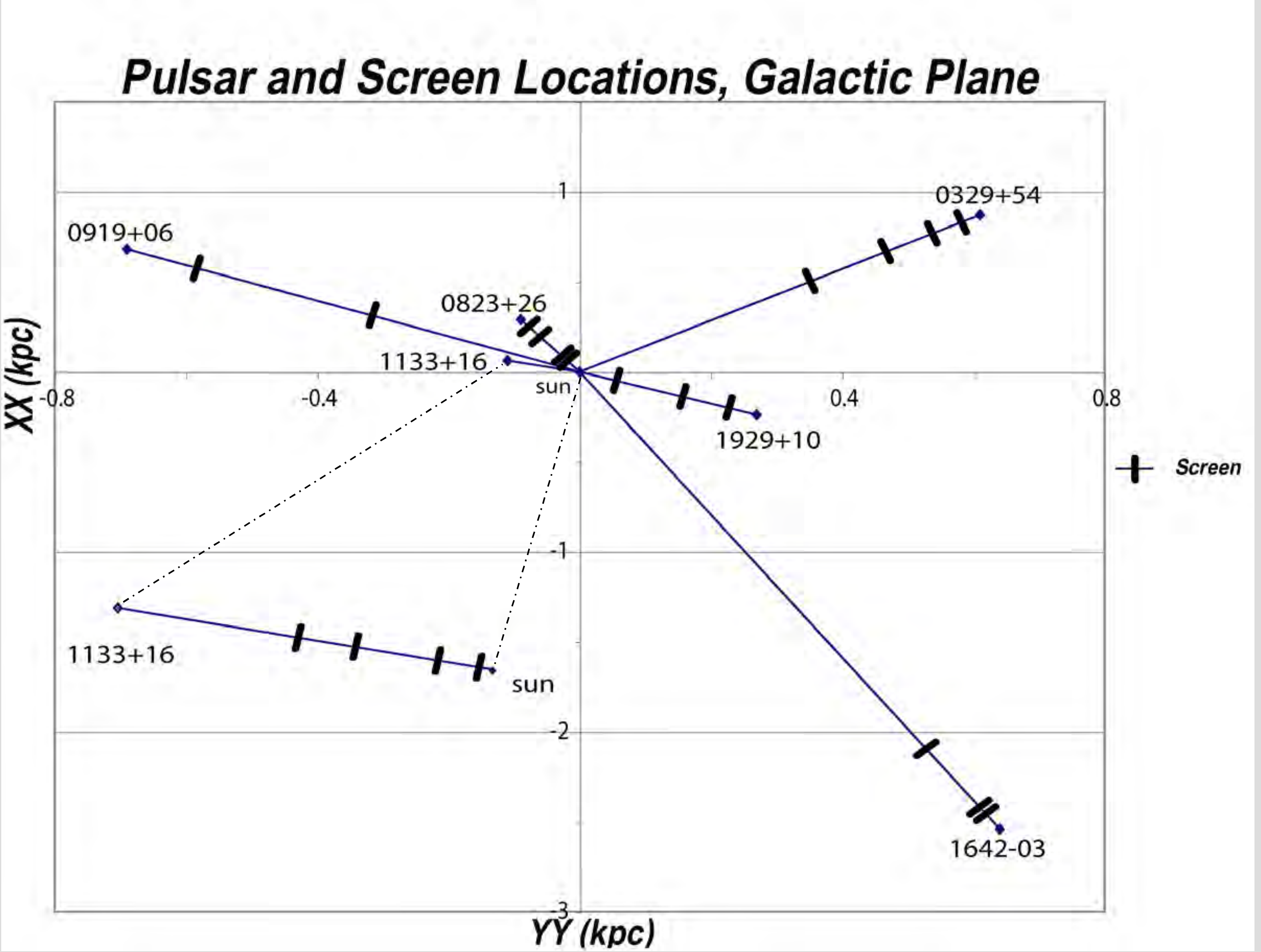
PSR B1133+16
Arecibo



Stinebring, Krabi

ISM study

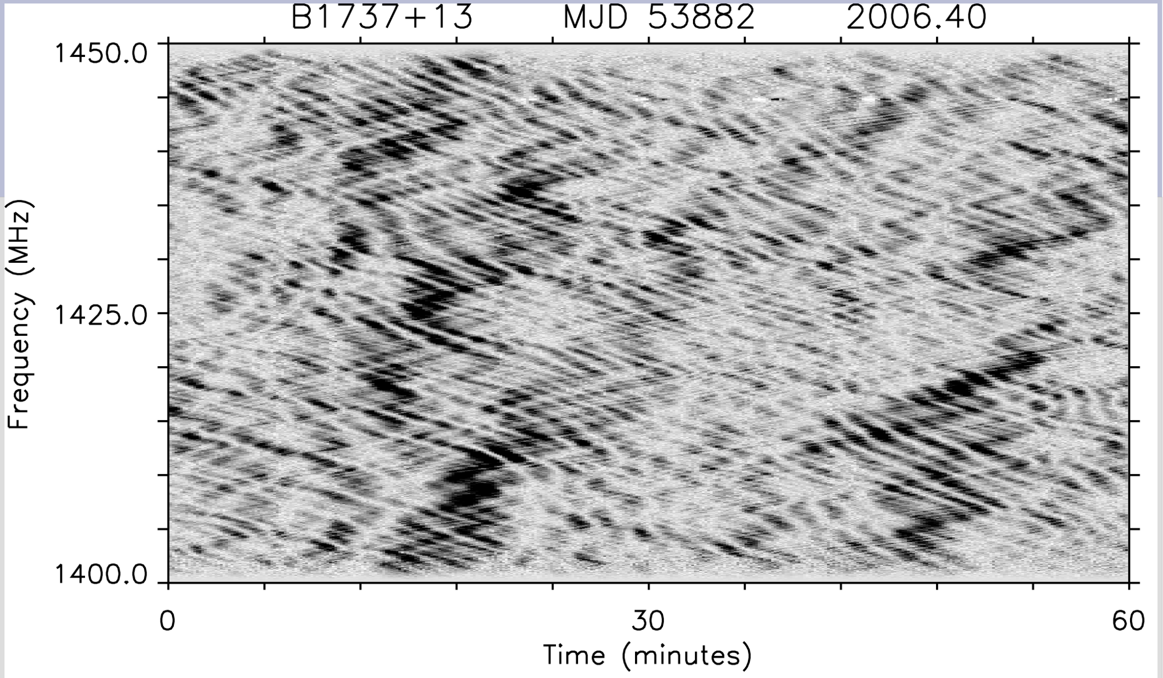
map of the different scattering screens on different lines of sight



Stinebring, Krabi

ISM study

Multipath produces varying scattering tails, tiny changes in the shape of daily profiles yield to systematics in TOAs
How much is the mean pulse affected by low level contribution of delayed pulses ?
Should we routinely produce a secondary spectrum to be able to correct TOAs ?



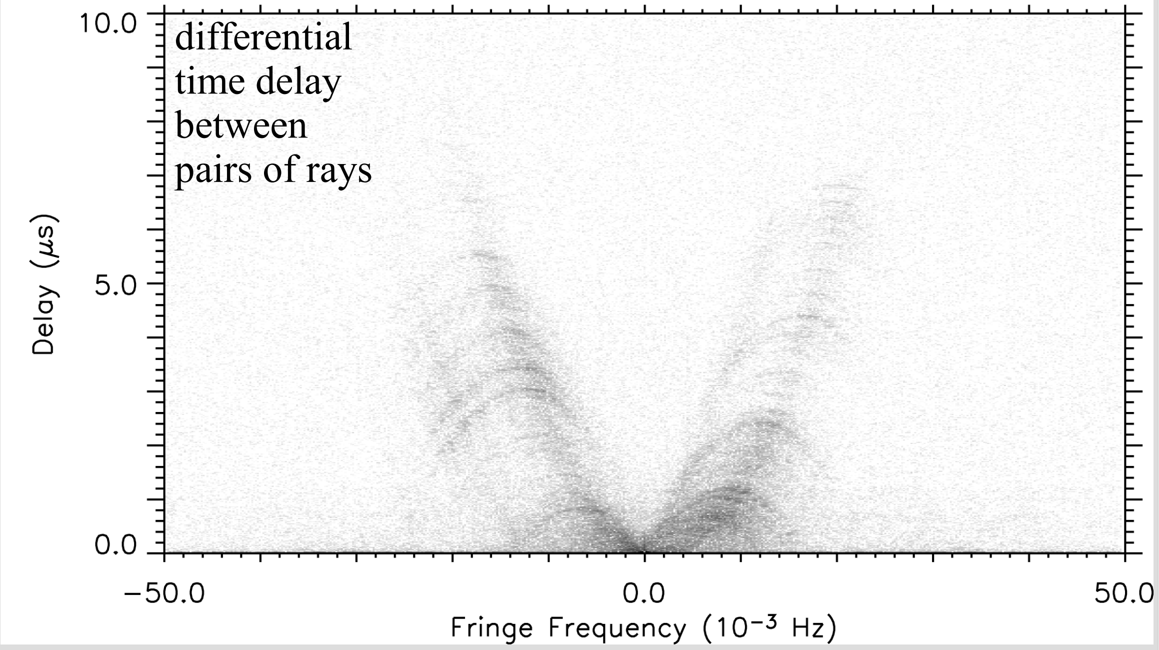
A systematic study is being done
at Arecibo on PSR B1737+13

it's seems promising...

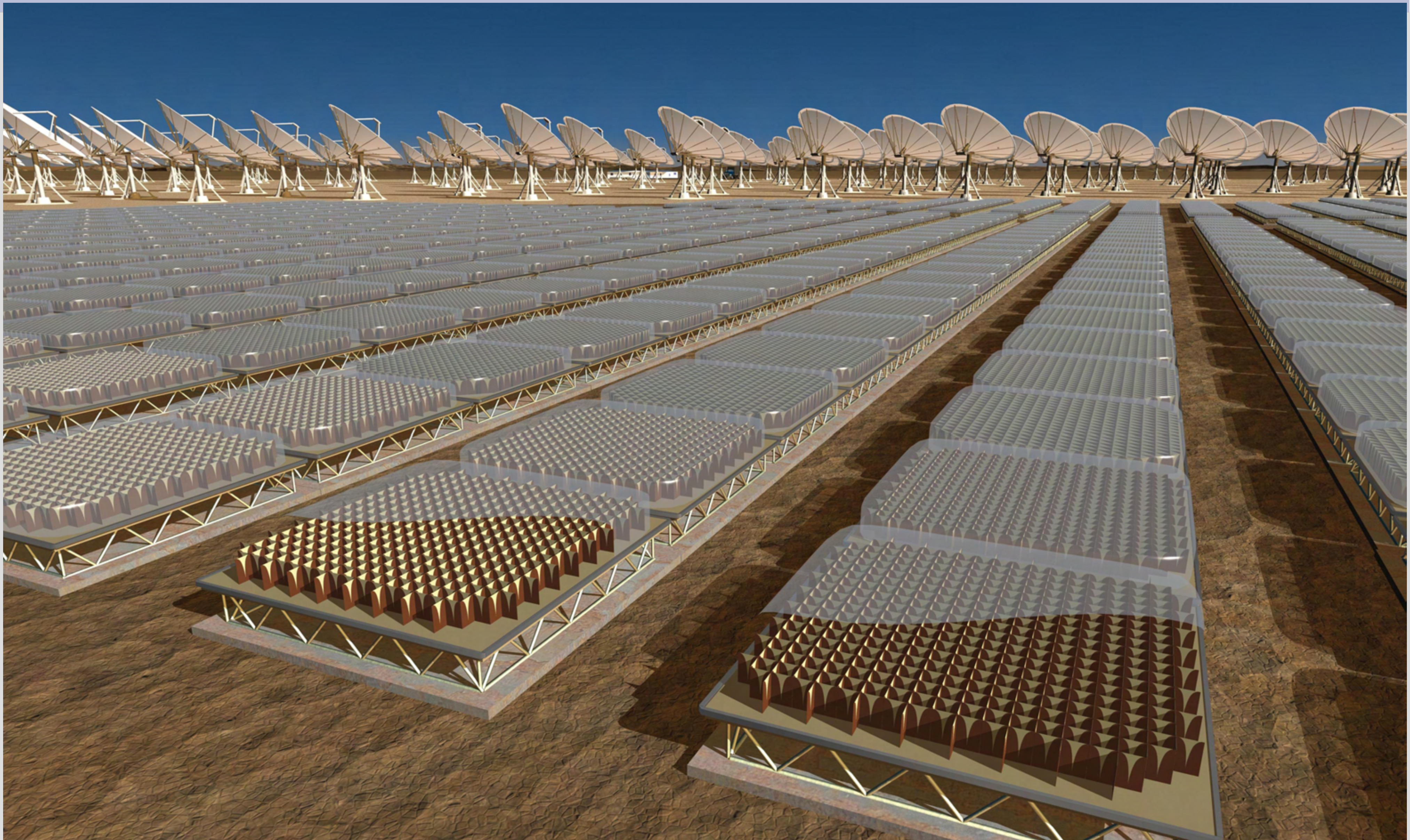
Could this be done on
much fainter millisecond pulsars ?

with SKA for sure !

Stinebring, Krabi



SKA Square Kilometer Array



SKA timing capability

generaly, the timing uncertainty can be estimated by :

$$\sigma \propto \frac{W}{\mathrm{SNR}} \propto \frac{T_{sys}}{A_{eff}} \times \frac{1}{\sqrt{2\ \Delta\nu\ t}} \times \frac{W^{3/2}}{S_{psr}}$$

where W is the profile width

just on Tsys/Aeff, SKA can improve timing accuracy
by a factor 10 over Arecibo
by a factor 100 over others 100meters radiotelescopes

SKA searching capability

SKA should find many pulsars !...

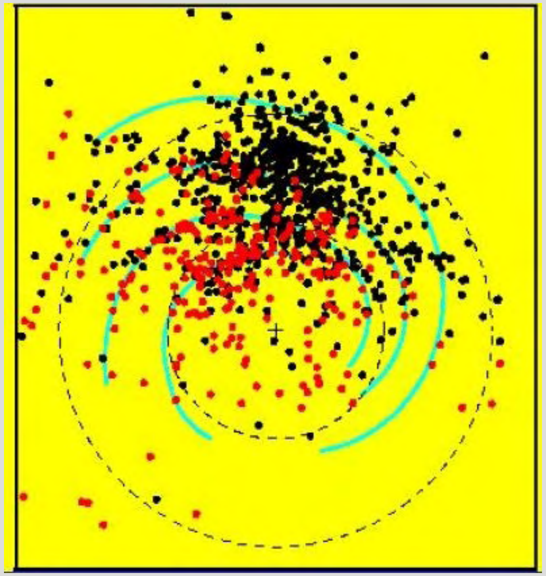
with a sensitivity of 1.4mJy (1min integration, 8sec, Tsys=25K, Df=0.5f)
at a distance of 25kpc (on the other side of the Galaxy)
this corresponds to a luminosity of 0.8mJy.kpc^2
actual distribution : 0.01 < 25.0 (median) < 10000 mJy.kpc^2

a fairly complete census of the Galactic population is possible

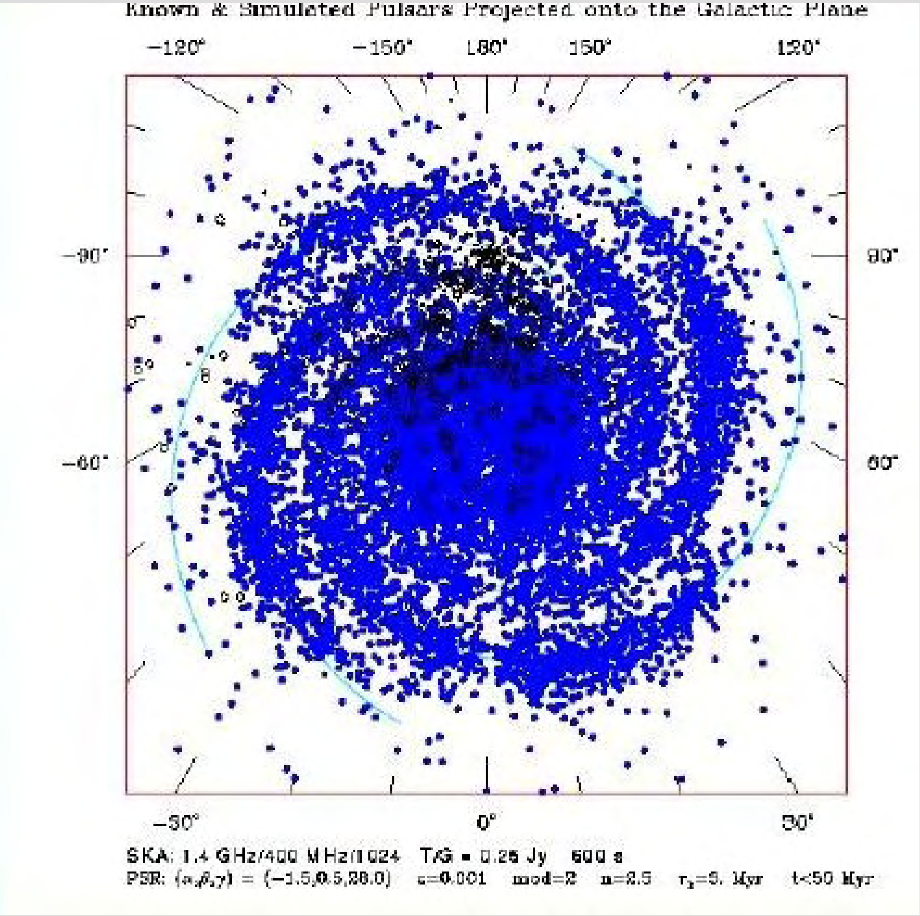
with a large Field Of View, better chance to catch RRATs and intermittent pulsars

through GPs, pulsars should be found in distant galaxies up to 5-10Mpc

SKA searching capability



today ~1800



with SKA ~20000
and ~1000 msPSR

Conclusion

with SKA,

in **survey** mode

we should have ~ 20000 pulsars (complete census of the Galaxy)

among them around 1000 millisecond pulsars

and some very exotic systems

~100 NS-NS, few NS-BH, magnetars, ...

large FOV : many RRAT and intermittent pulsars

in **timing** mode

we should be able to simultaneously time dozens and hundreds of pulsars with an uncertainty better by a factor 10 or more

important for PTA and GWB study!

in **observation** mode

Weltevrede just showed that ~50% of pulsars exhibit drifting

secondary spectra corrections for multipath

maps of discrete scattering screens

giant pulses on much more pulsars