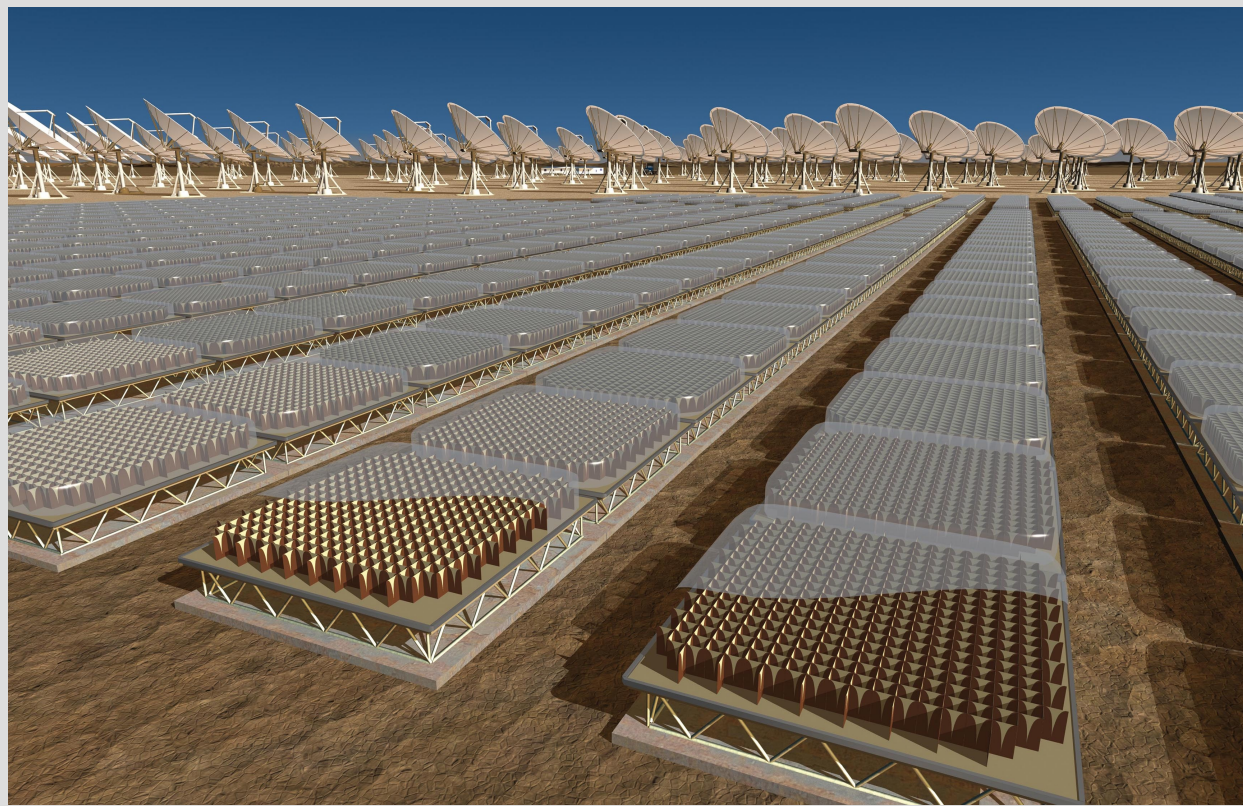# Present and future of pulsar observations
From current large radiotelescopes to SKA

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
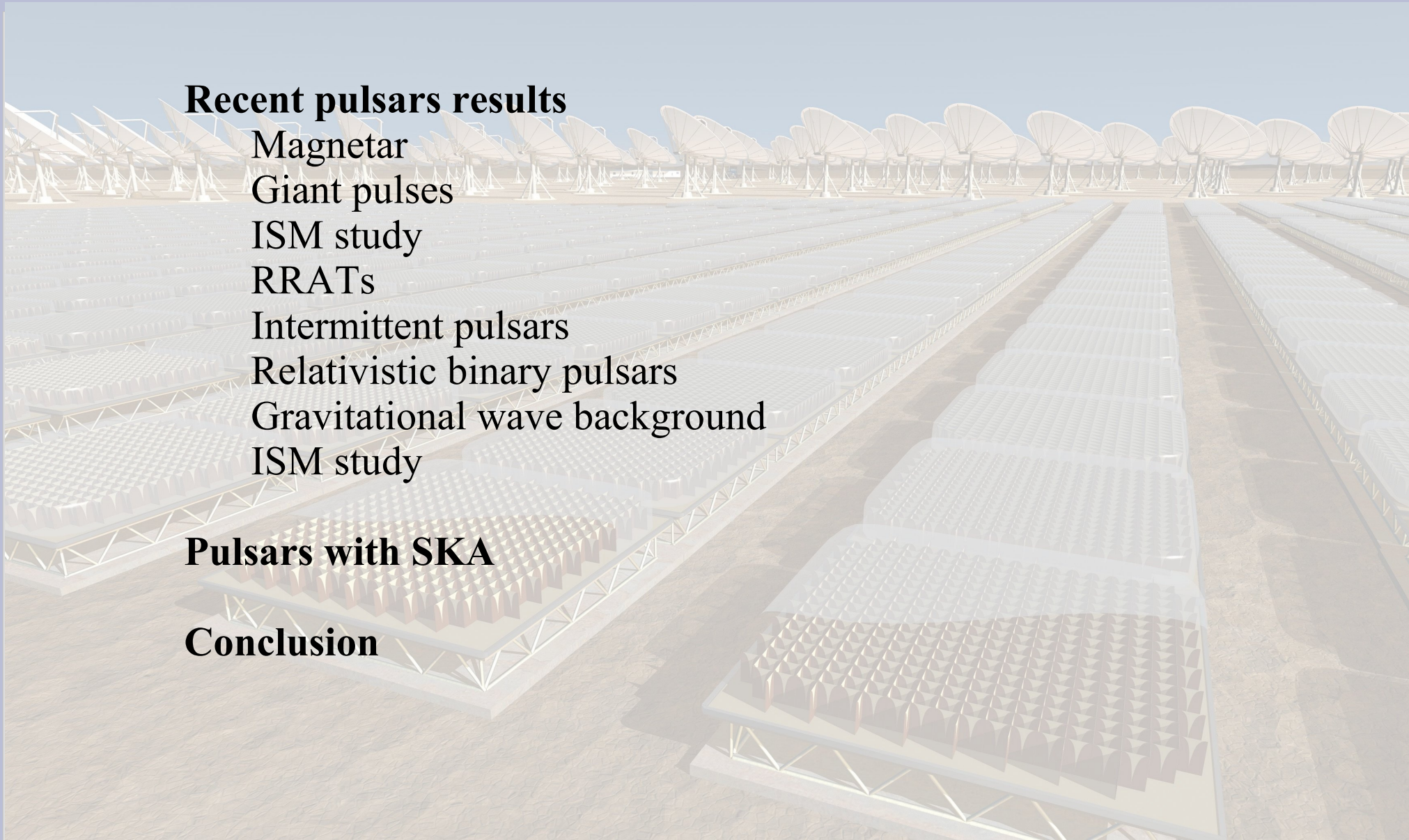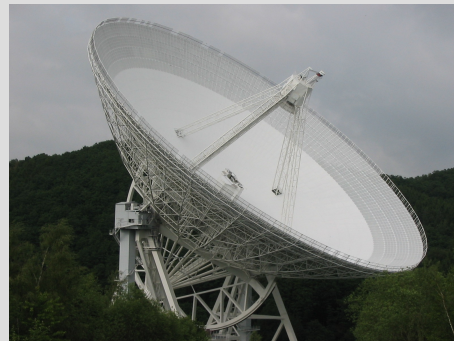   Relativistic binary pulsars
    Gravitational wave background
    ISM study

Pulsars with SKA

Conclusion
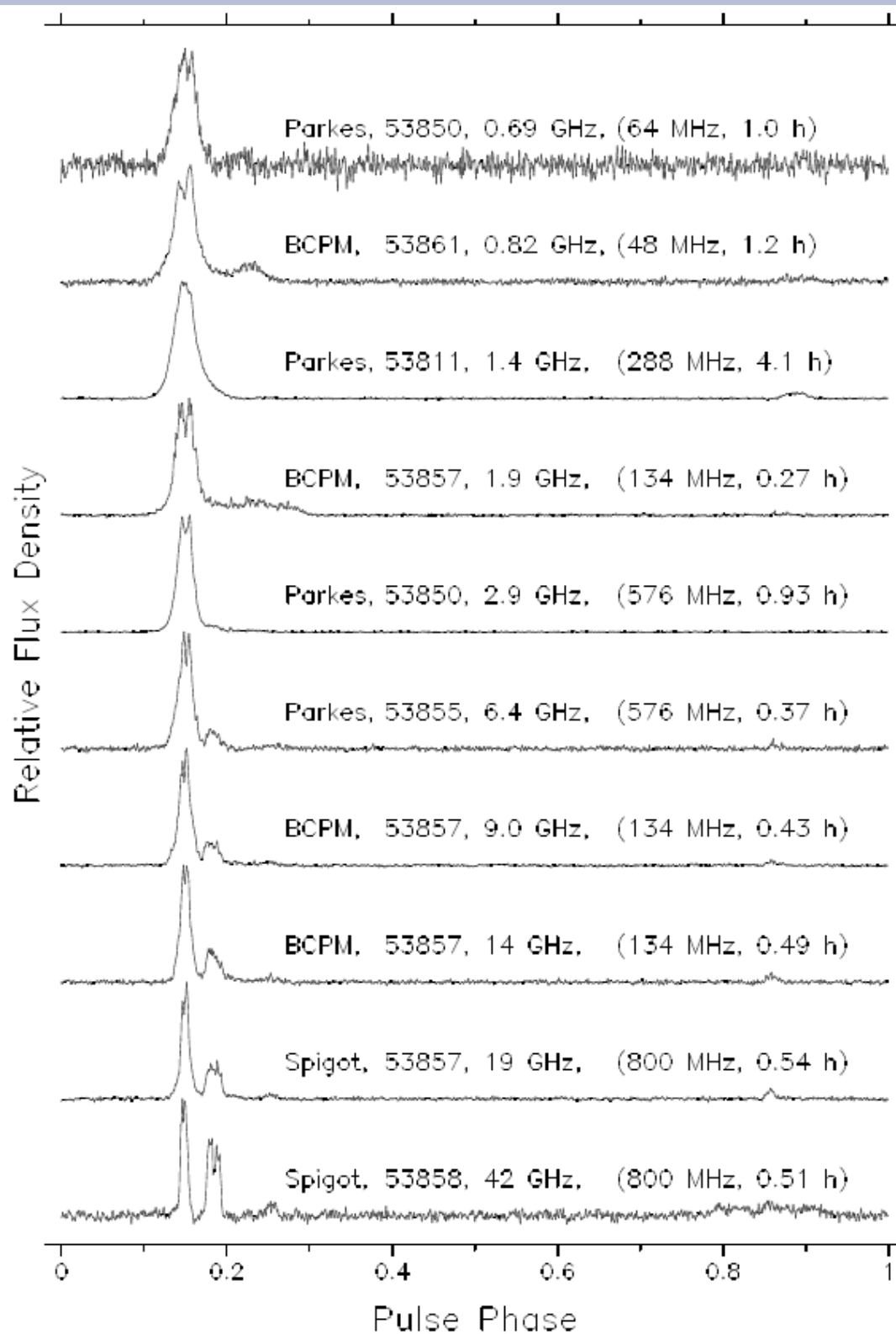
Present large radiotelescopes

Magnetar XTE1810-197

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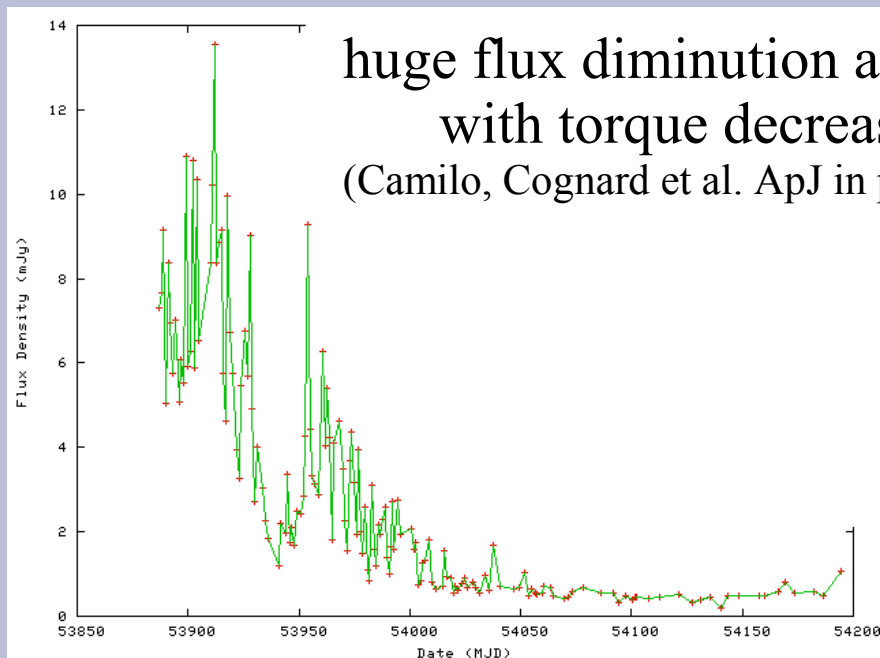   with pulsations of periodicity 5.54sec

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)

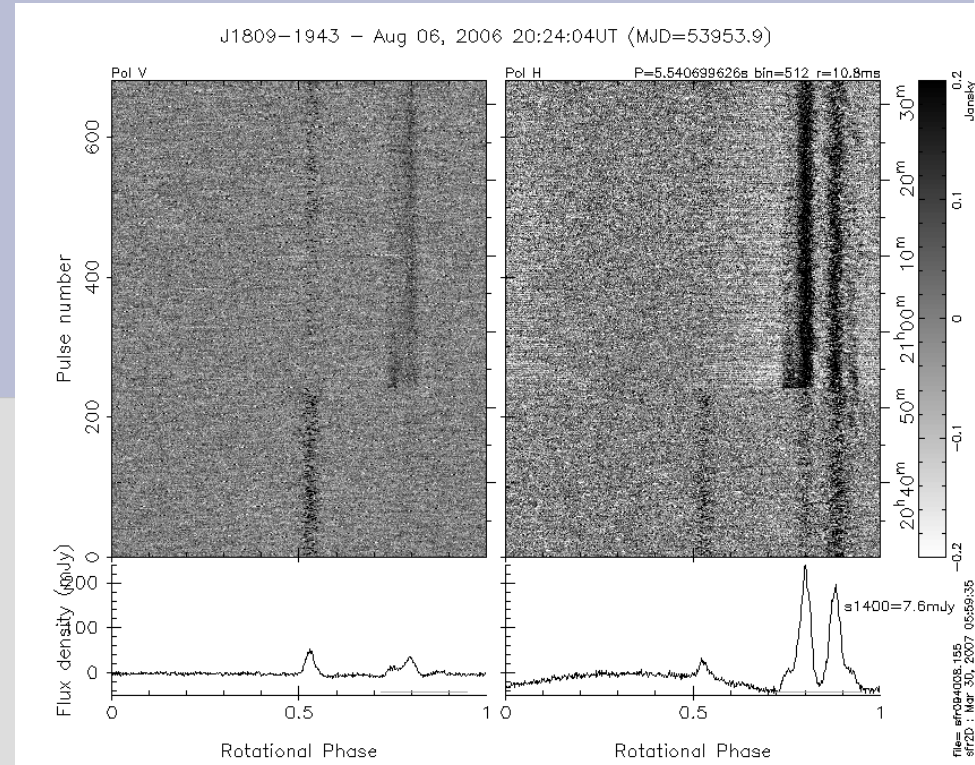a daily monitoring was started at Nançay...

Parkes, 53850, 0.69 GHz, (64 MHz, 1.0 h)

BCPM, 53861, 0.82 GHz, (48 MHz, 1.2 h)

Parkes, 53811, 1.4 GHz, (288 MHz, 4.1 h)

BCPM, 53857, 1.9 GHz, (134 MHz, 0.27 h)

Parkes, 53850, 2.9 GHz, (576 MHz, 0.93 h)

Parkes, 53855, 6.4 GHz, (576 MHz, 0.37 h)

BCPM, 53857, 9.0 GHz, (134 MHz, 0.43 h)

BCPM, 53857, 14 GHz, (134 MHz, 0.49 h)

Spigot, 53857, 19 GHz, (800 MHz, 0.54 h)

Spigot, 53858, 42 GHz, (800 MHz, 0.51 h)

Magnetar XTE1810-197

J1809-1943 – Aug 06, 2006 20:24:04UT (MJD=53953.9)

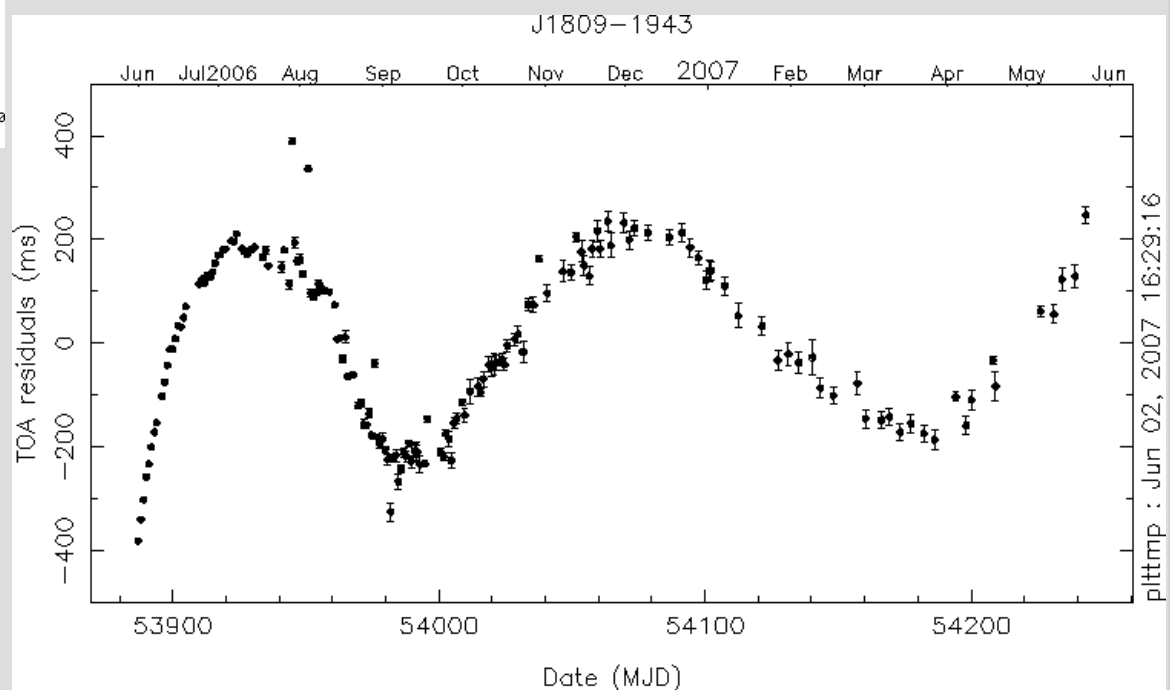individual pulses study in progress...

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

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

J1809-1943
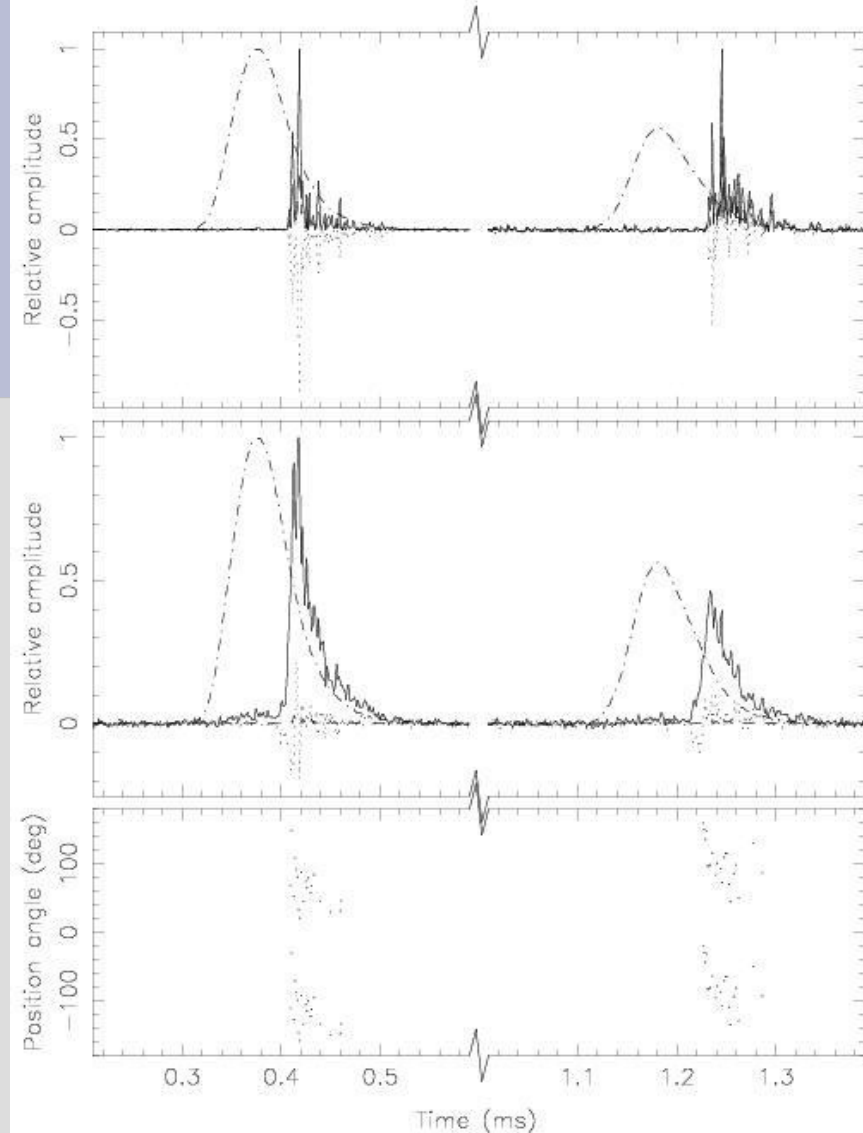
daily monitoring at Nançay 1.4GHz

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)
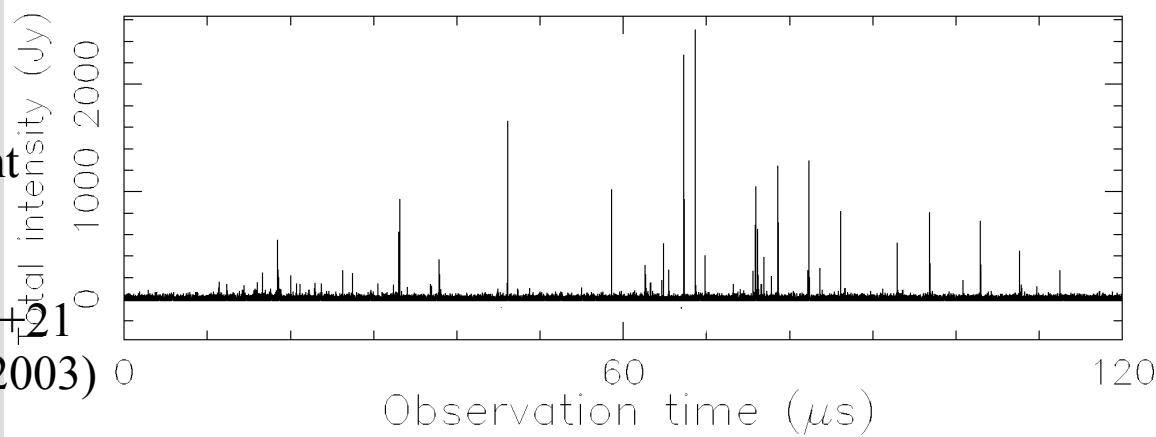
Giants pulses

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.

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

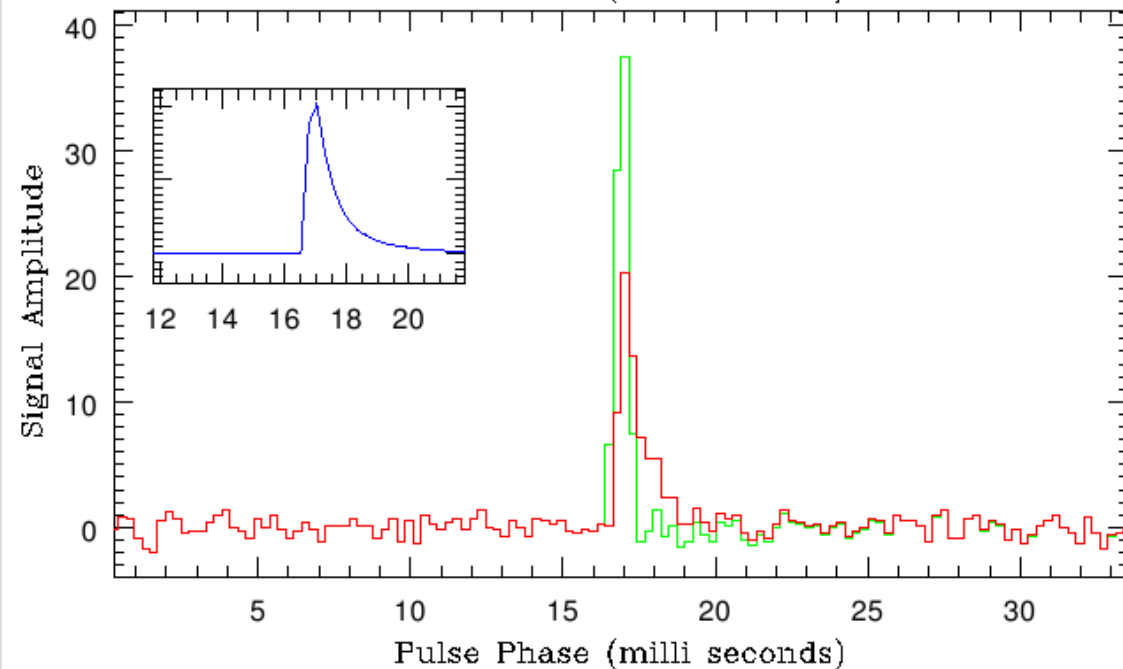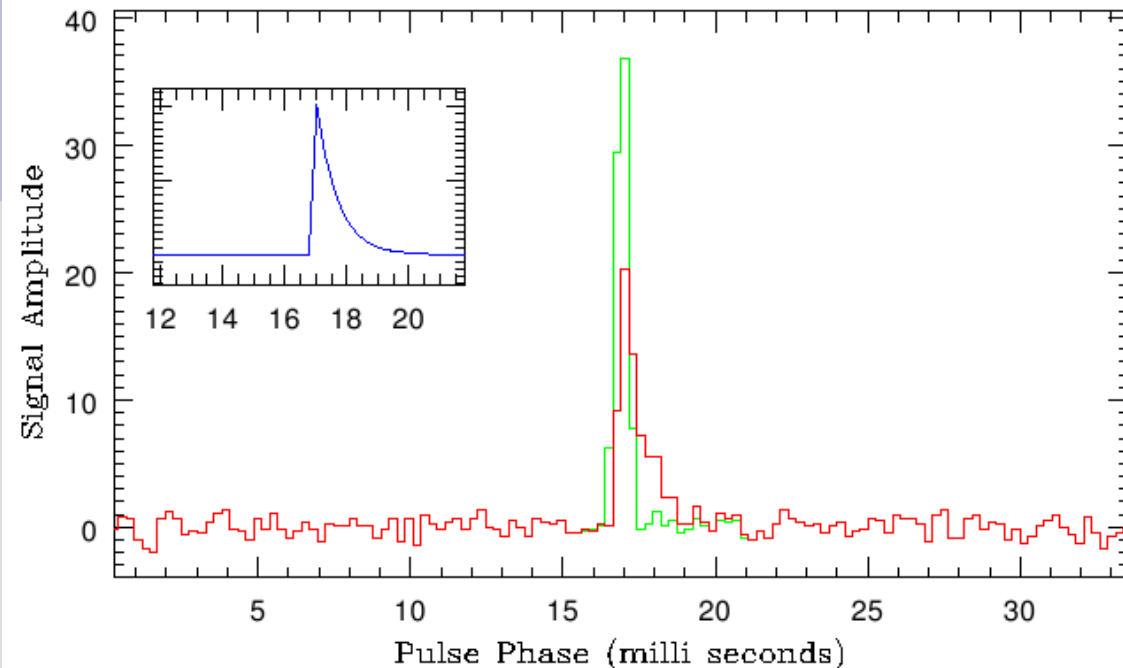Bhat et al. astro-ph/0705.0404
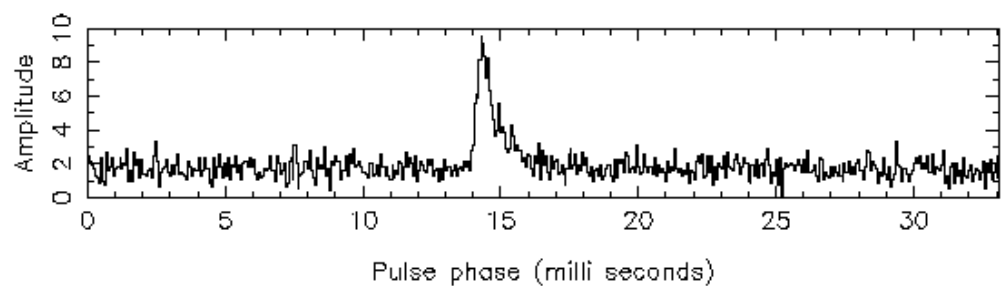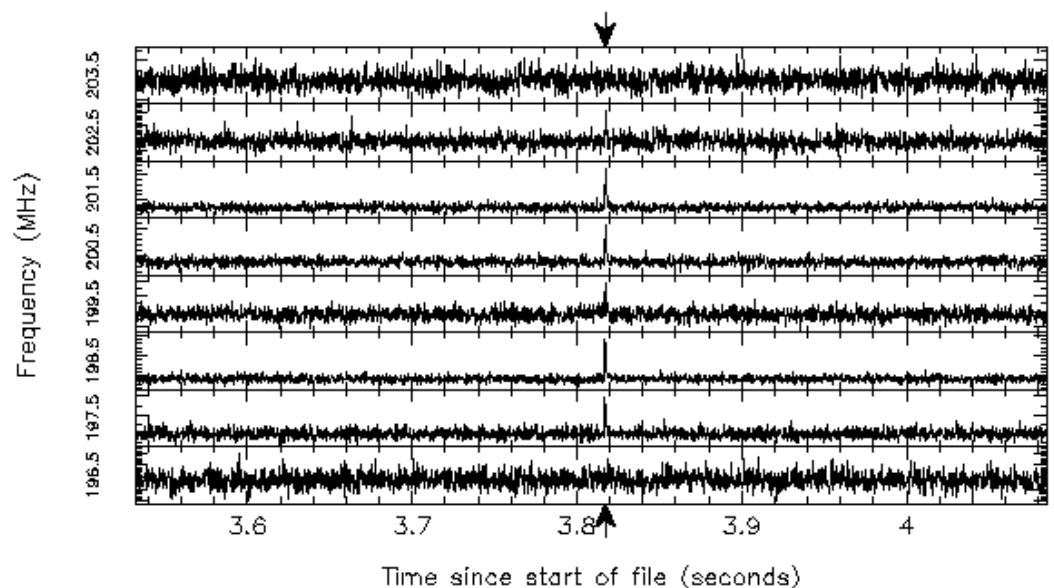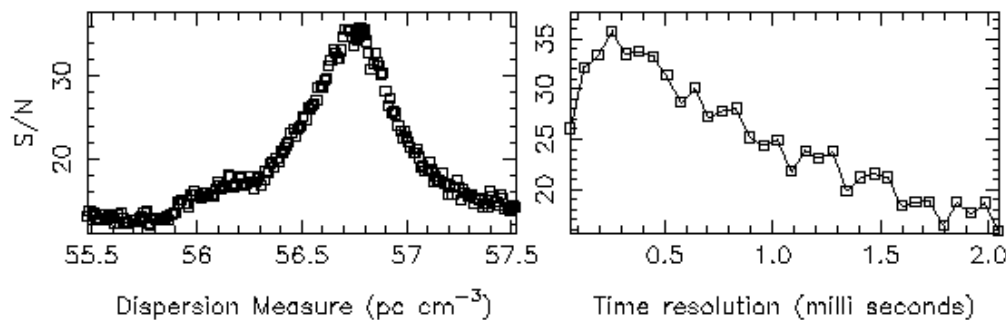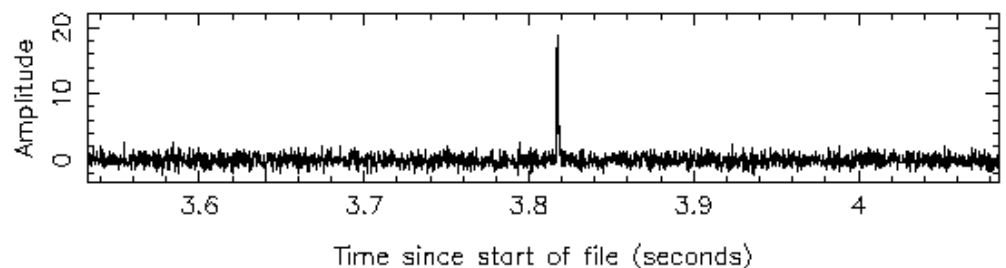
Giants pulses

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
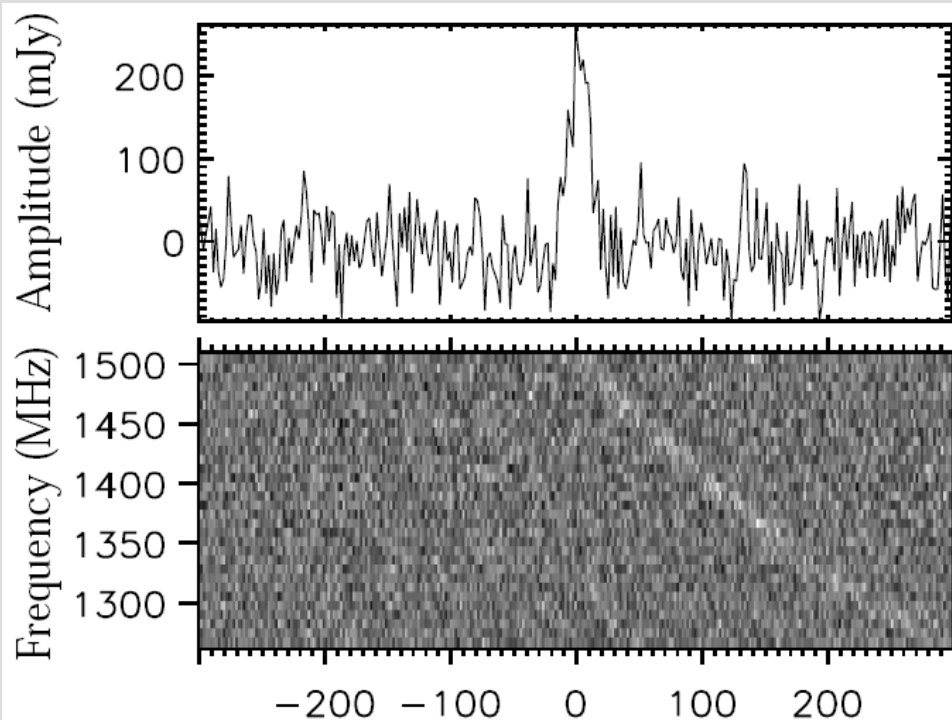   pulsar BON instrumentation

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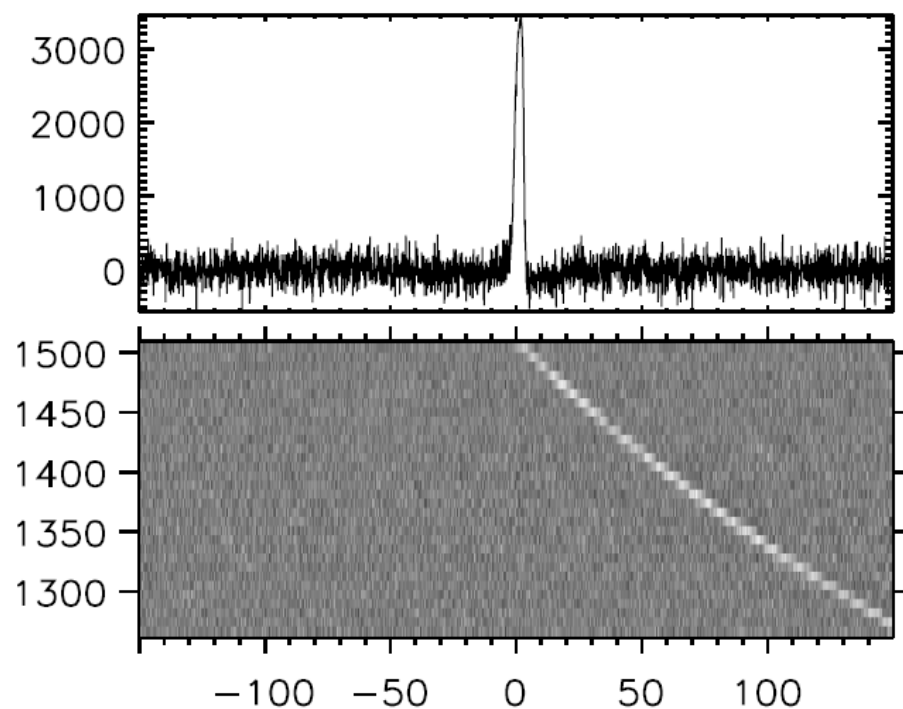Search is done in 4MHz channel
time resolution is 250ns
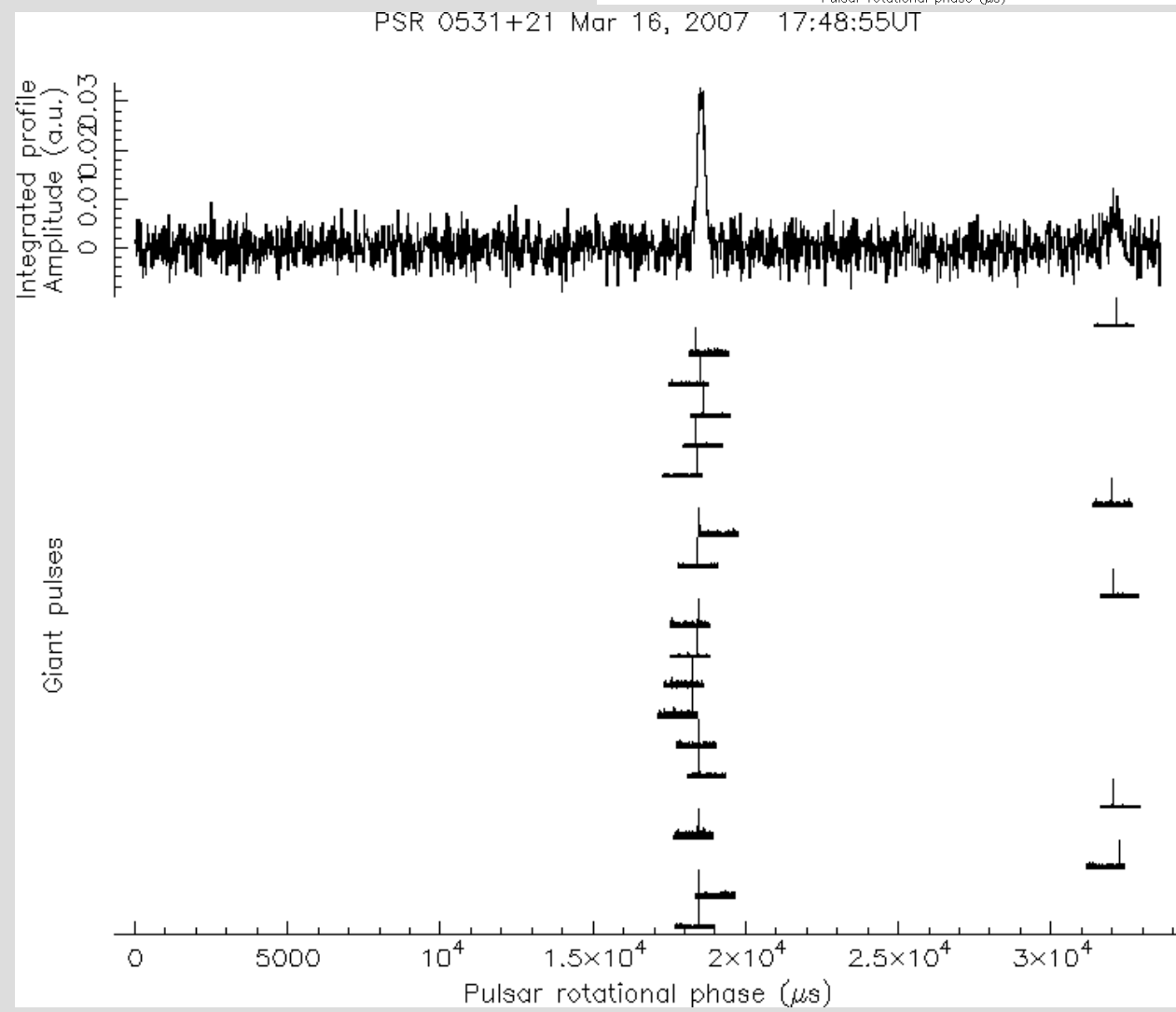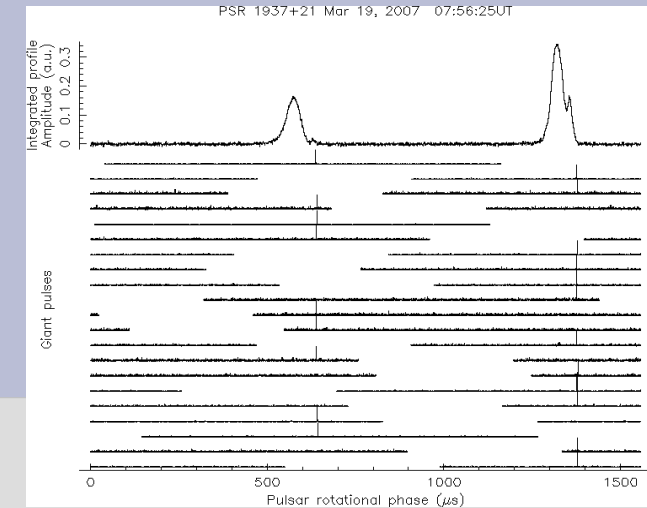
RRATs Rotating Radio Transients

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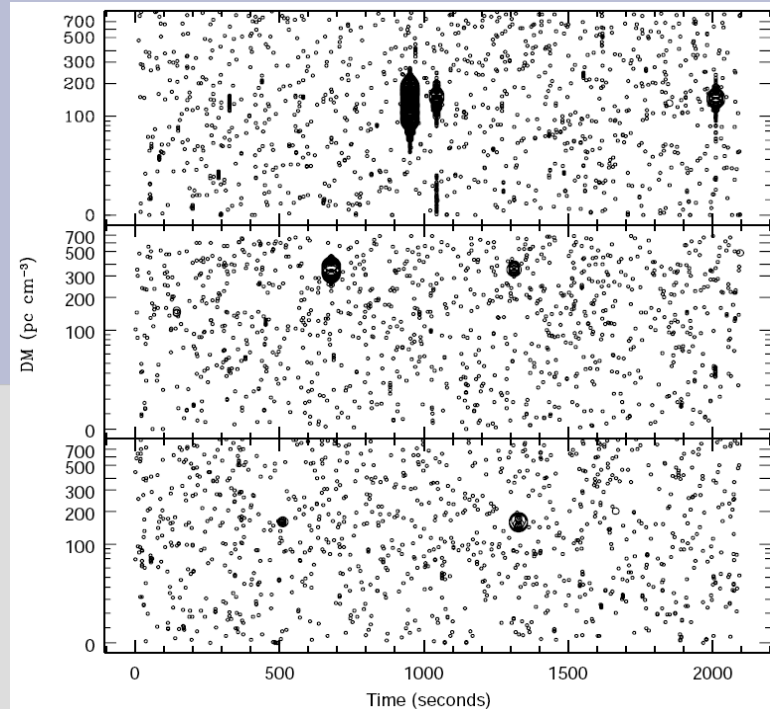during a **Transient Event Search** (single, dispersed events like giant pulses!)

J1443-60   J1819-1458

McLaughlin et al. 2006, Nature 439, 817-820   Time (milliseconds)   astro-ph/0511587
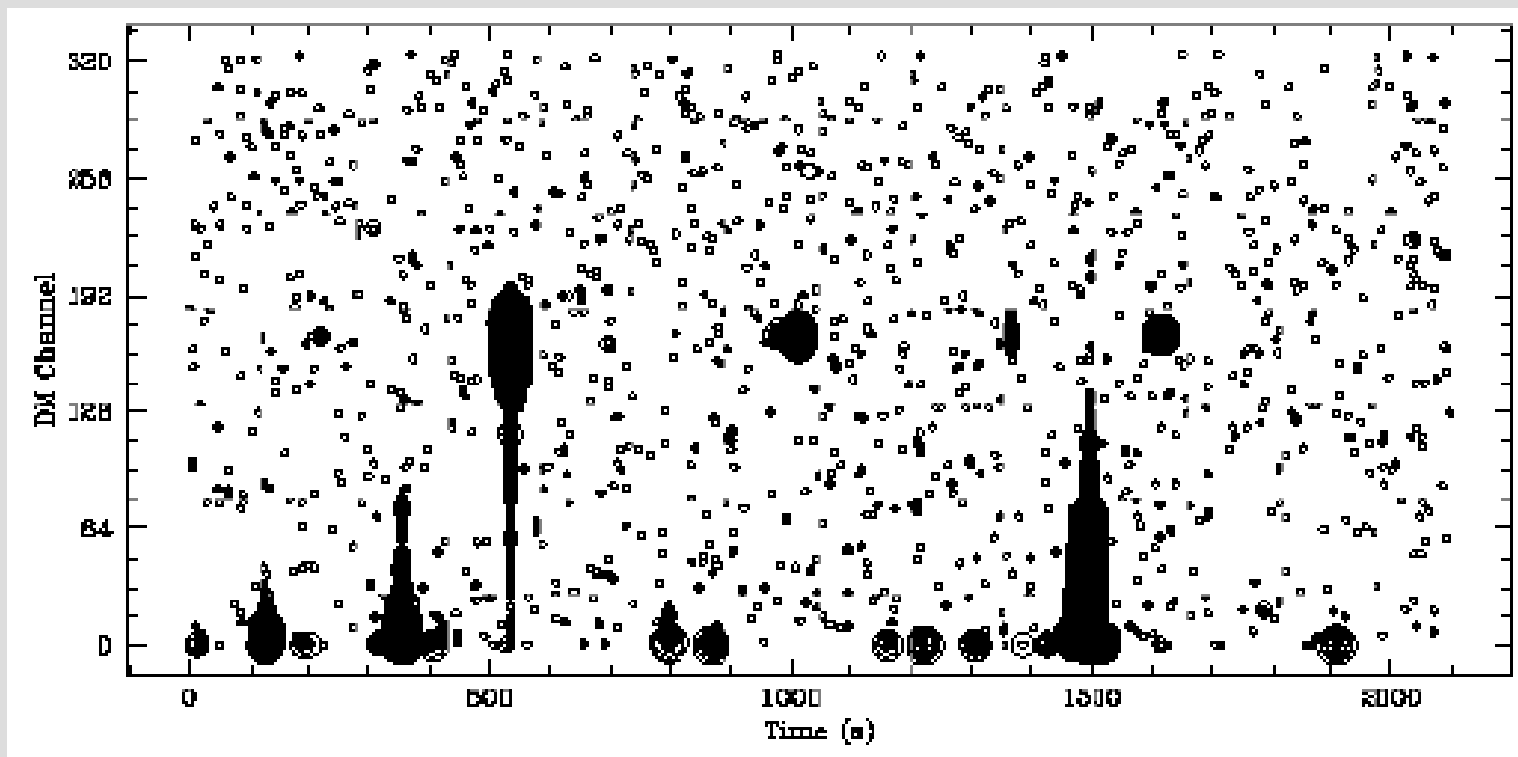
RRATs Rotating Radio Transients

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

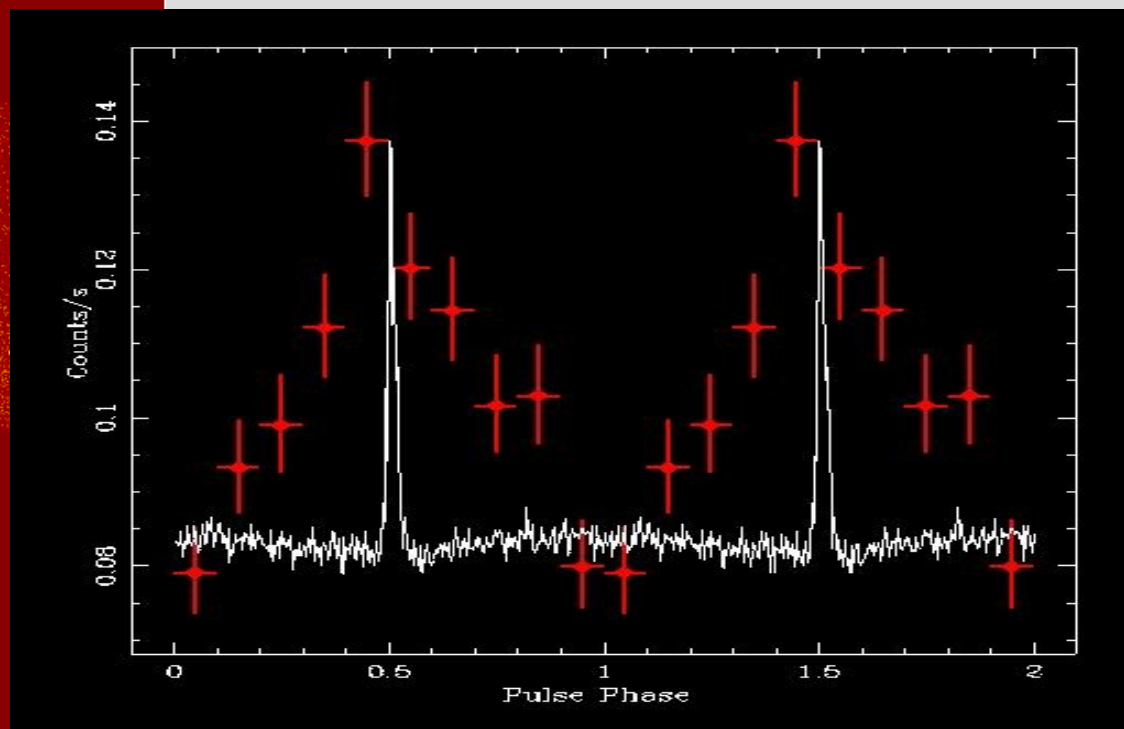one of them, J1819-1458 close to magnetars
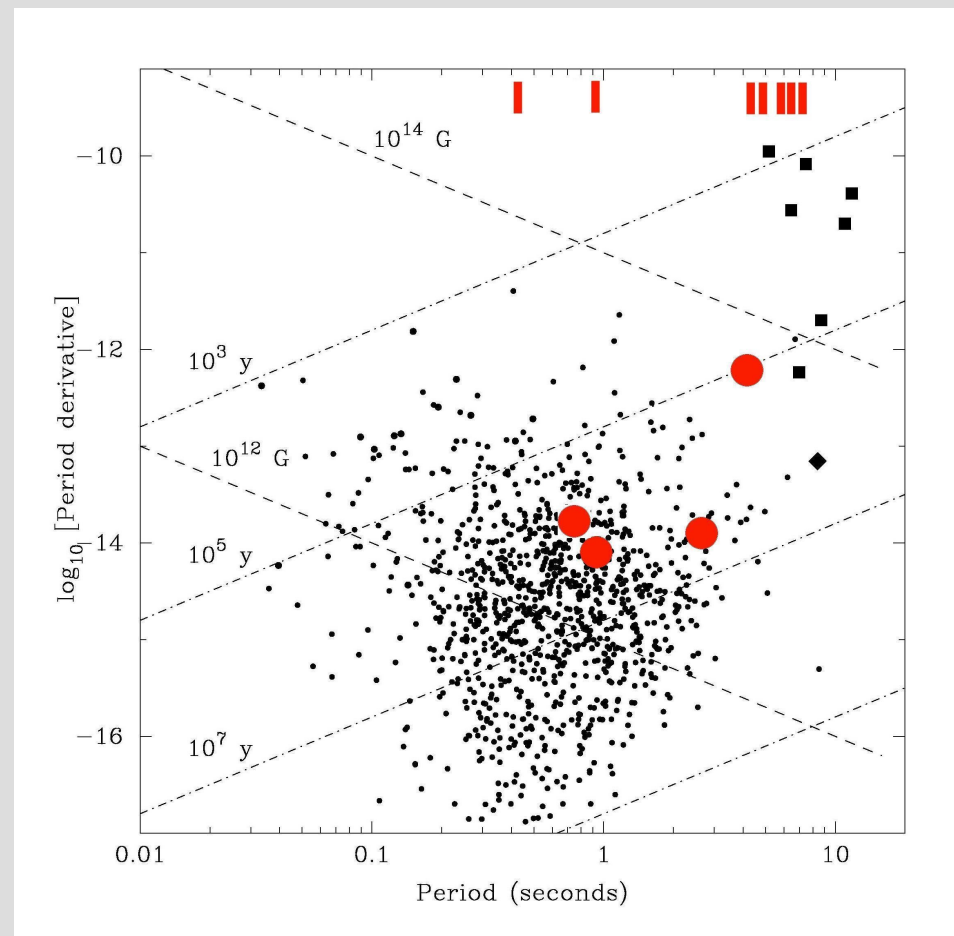
RRATs Rotating Radio Transients

Serendipitous detection of J1819-1458 in 30ks Chandra observation of Reynolds 2006's field
New detection in 40ks XMM Epic PN observation
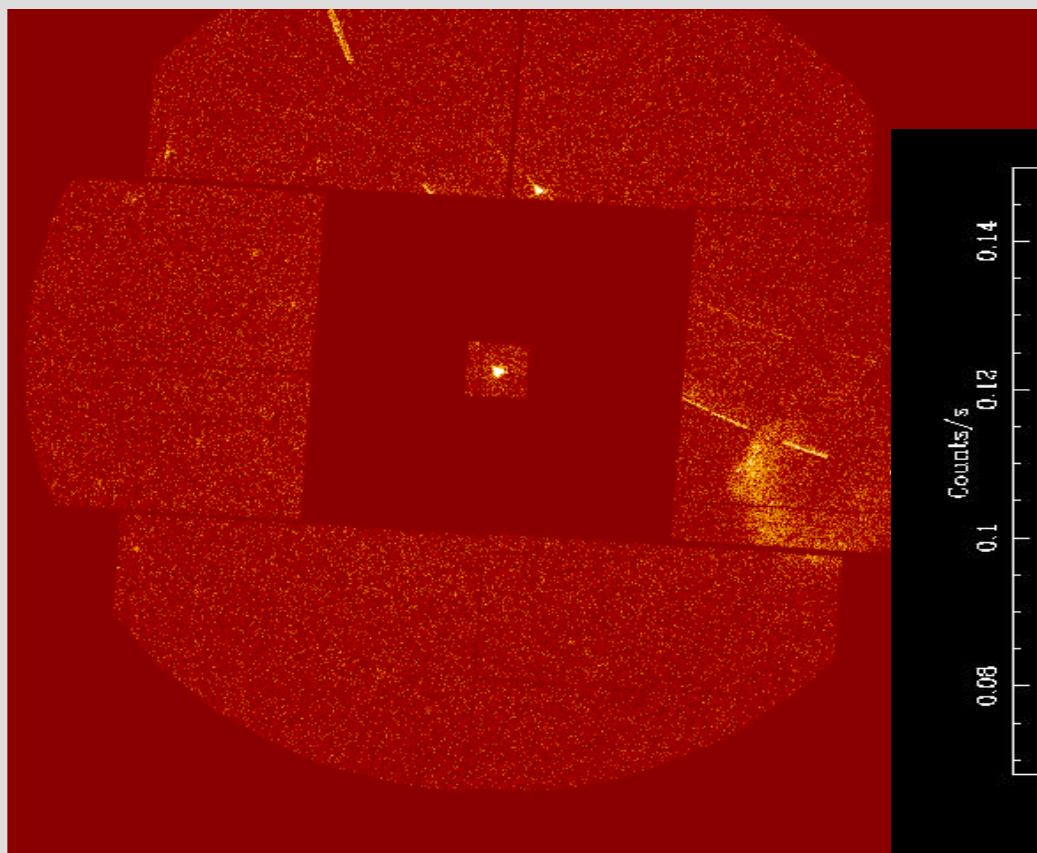
McLaughlin et al., 2007, in preparation

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

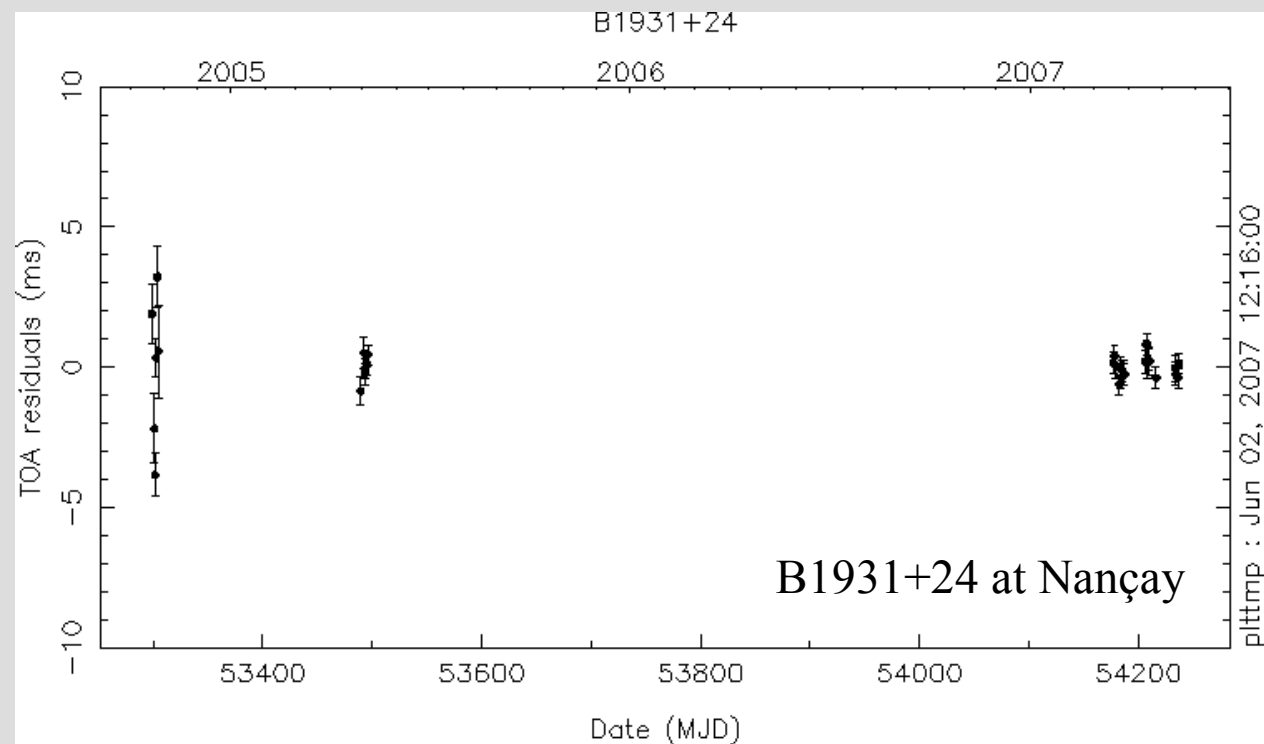PSR 1931+24 May 05, 2005 04:38:29UT

Nançay
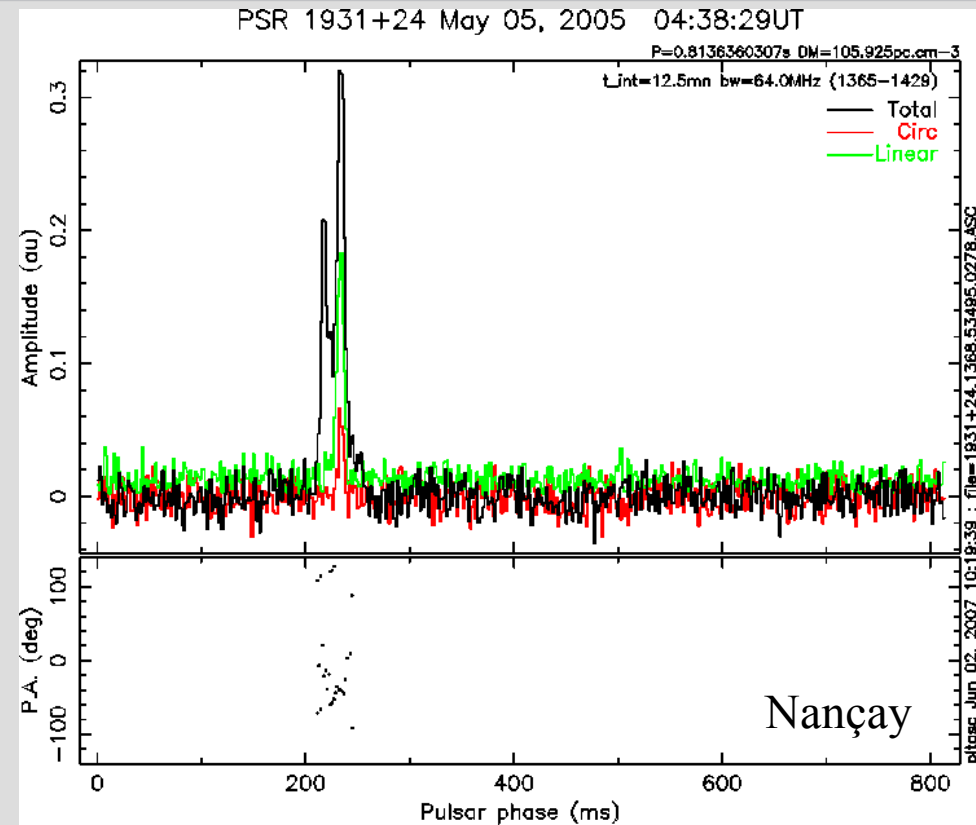
Intermittent pulsars

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

B1931+24 at Nançay

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
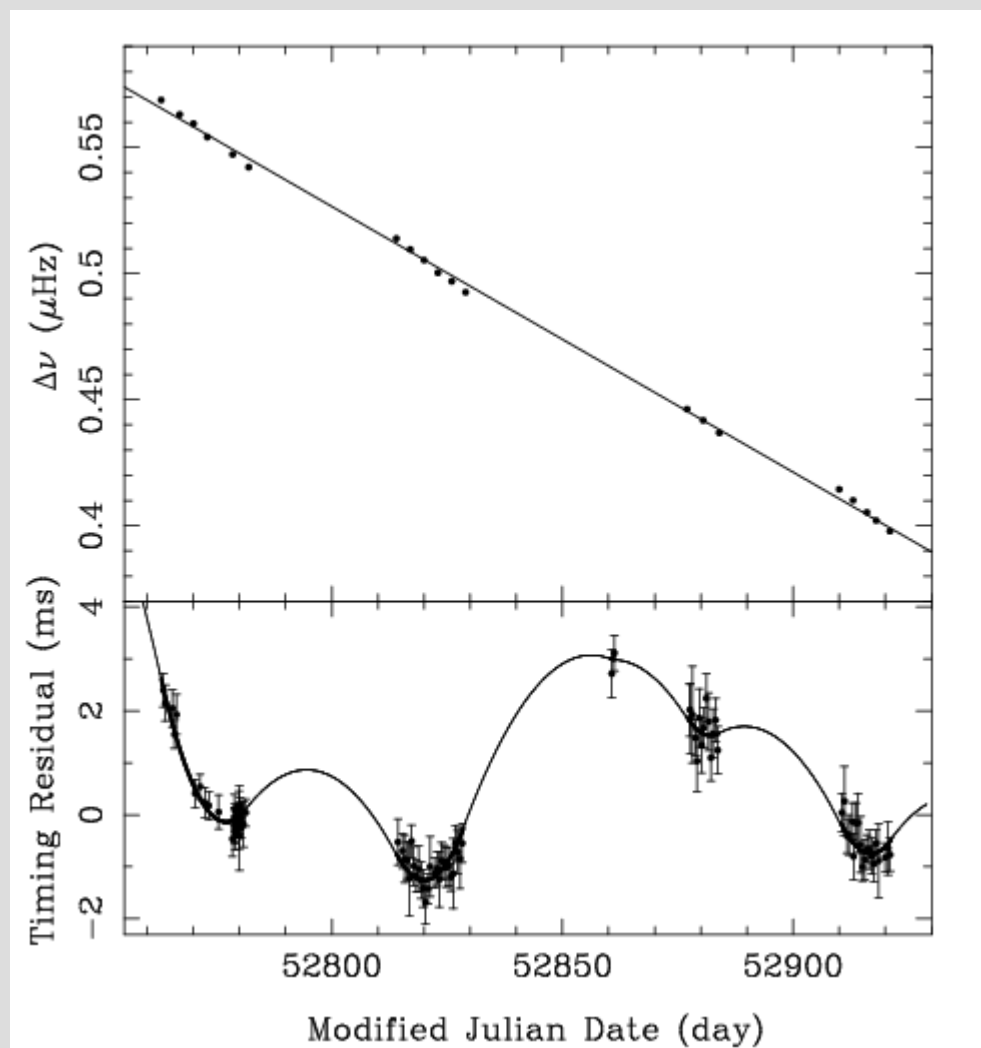
Kramer et al. Science 312, 549 (2006)

Intermittent pulsars

Systematic search was done in Parkes survey

4 more intermittent pulsars

J1107-5907
  P=253ms, 3 different emission states
J1717-4054
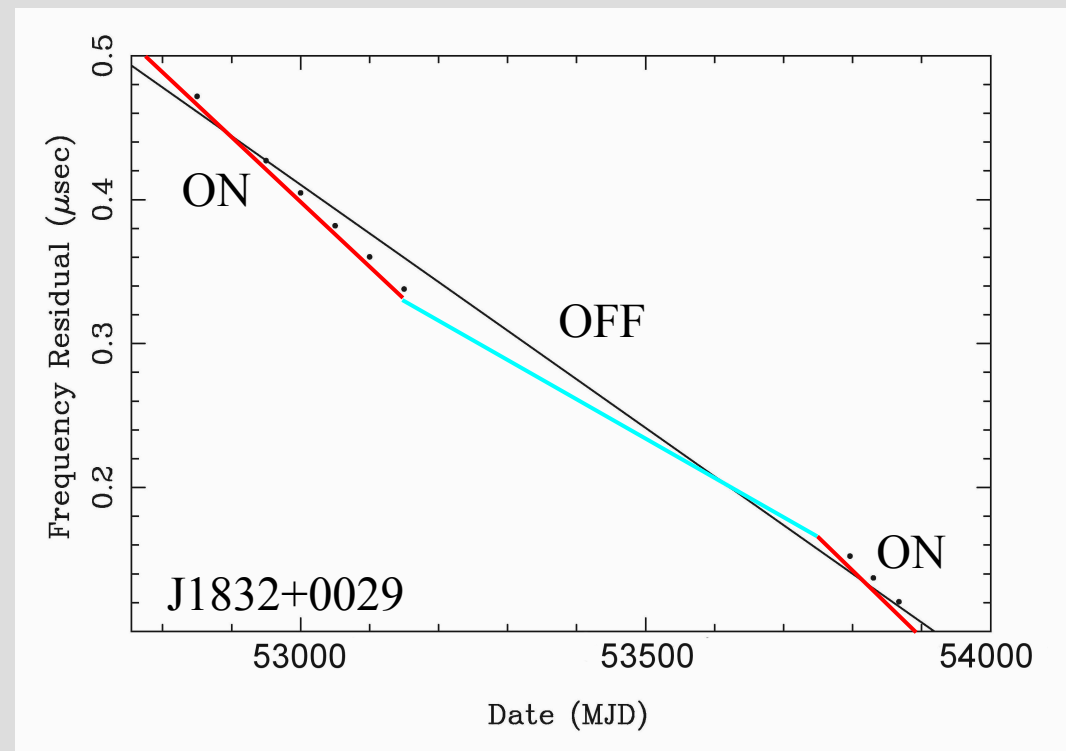 ON 20% of time, no periodicity yet
J1634-5107
  strong ON, ~10days quasi-periodicity
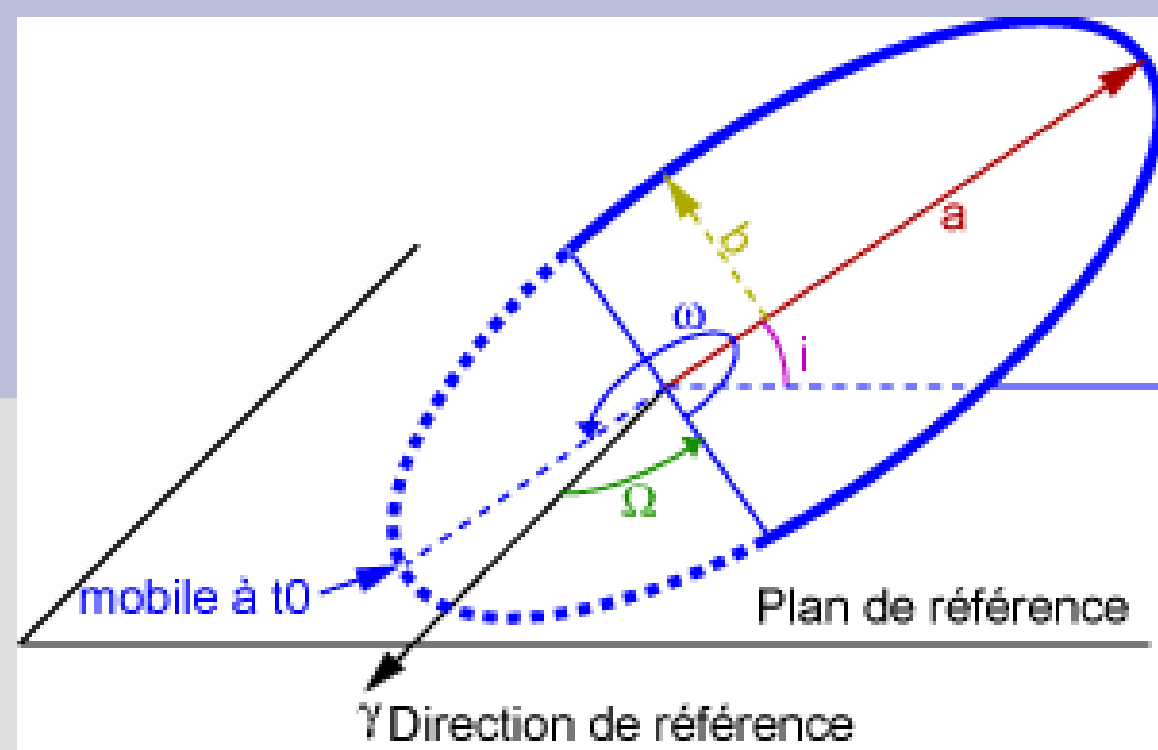**J1832+0029**
  ON for >300days, OFF for ~600days!
  $Pdot_{ON}/Pdot_{OFF} \sim 1.8+/-0.1$

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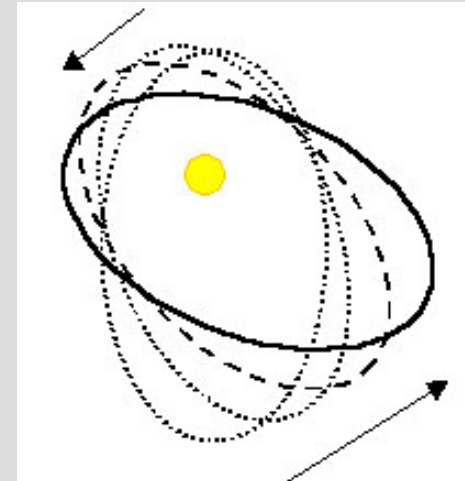orbital period decrease   dP/dt
Shapiro delay   r, s
gravitational delay   g

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

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

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

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

$$
r = T_\odot M_B,
$$

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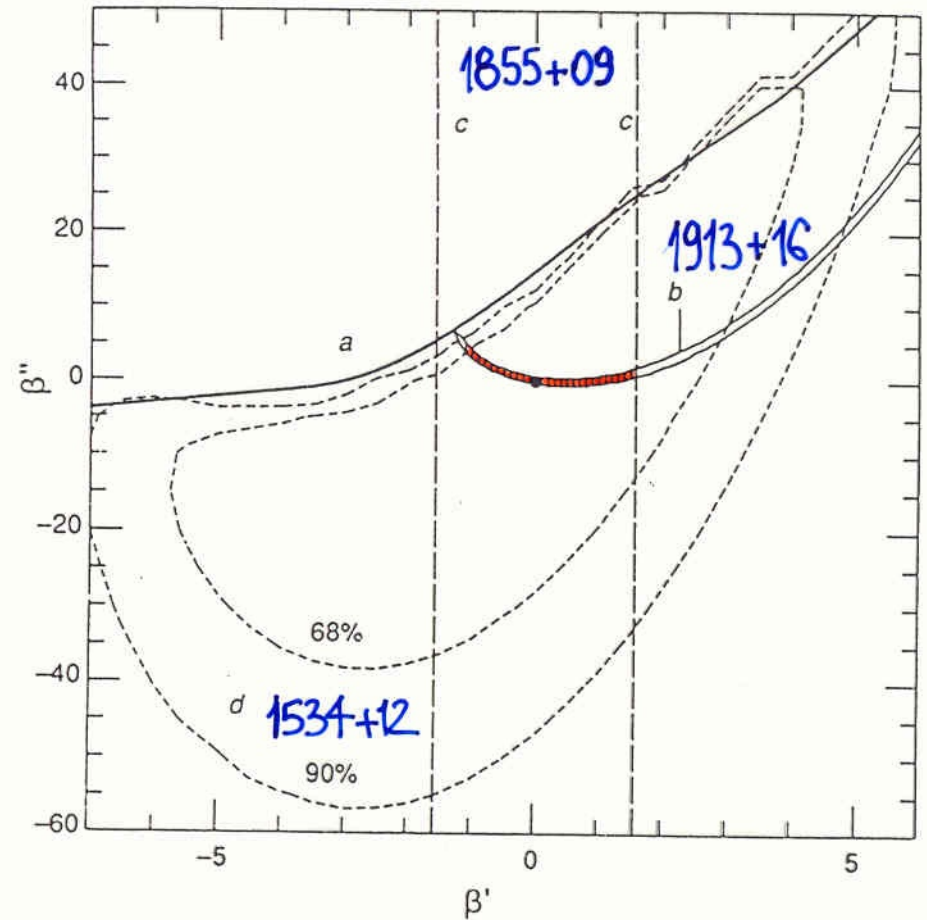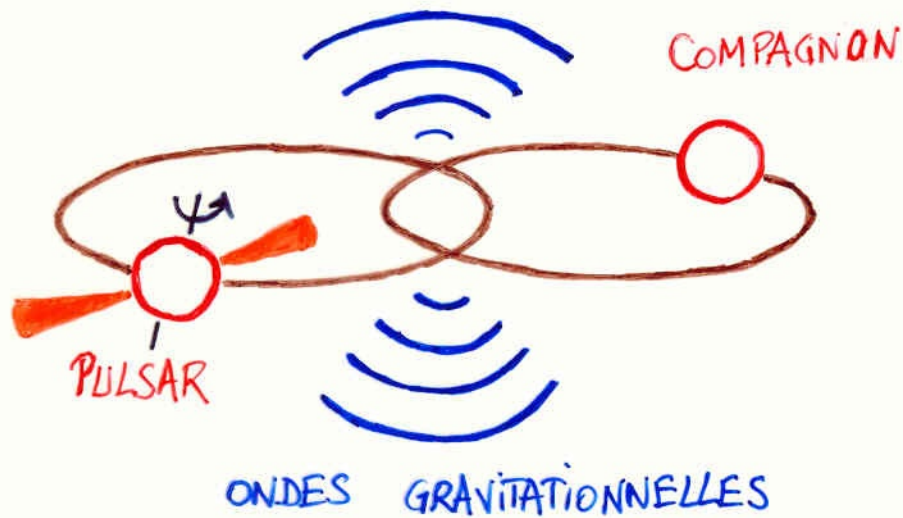$$

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
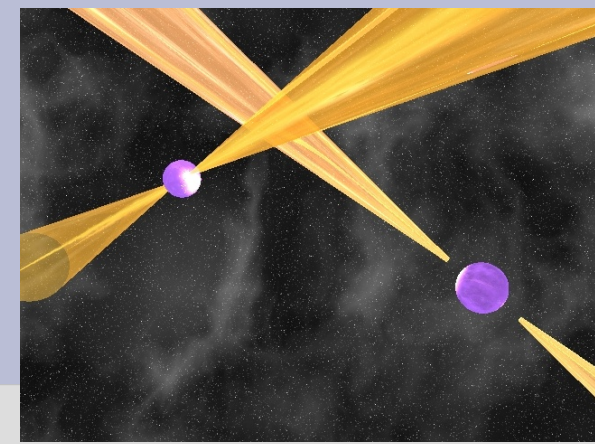is compared to the measured one

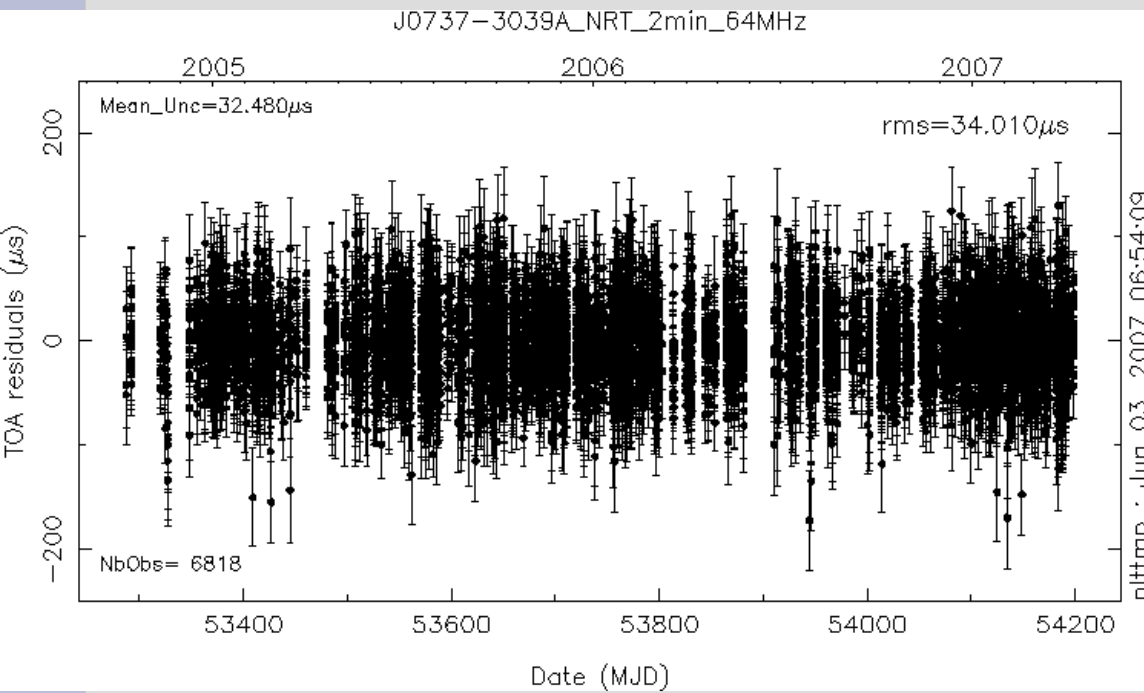agreement with GR is 0.2%
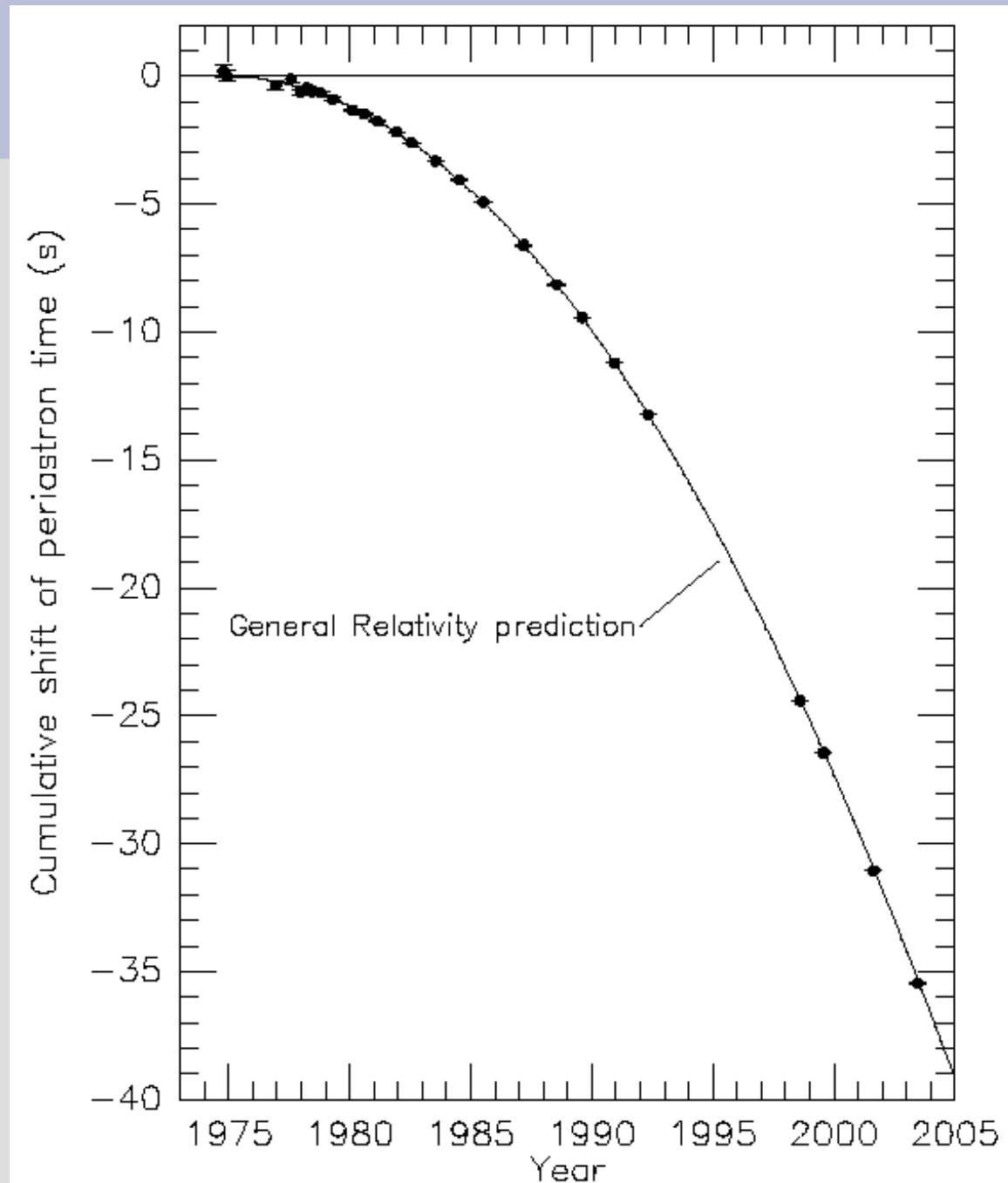
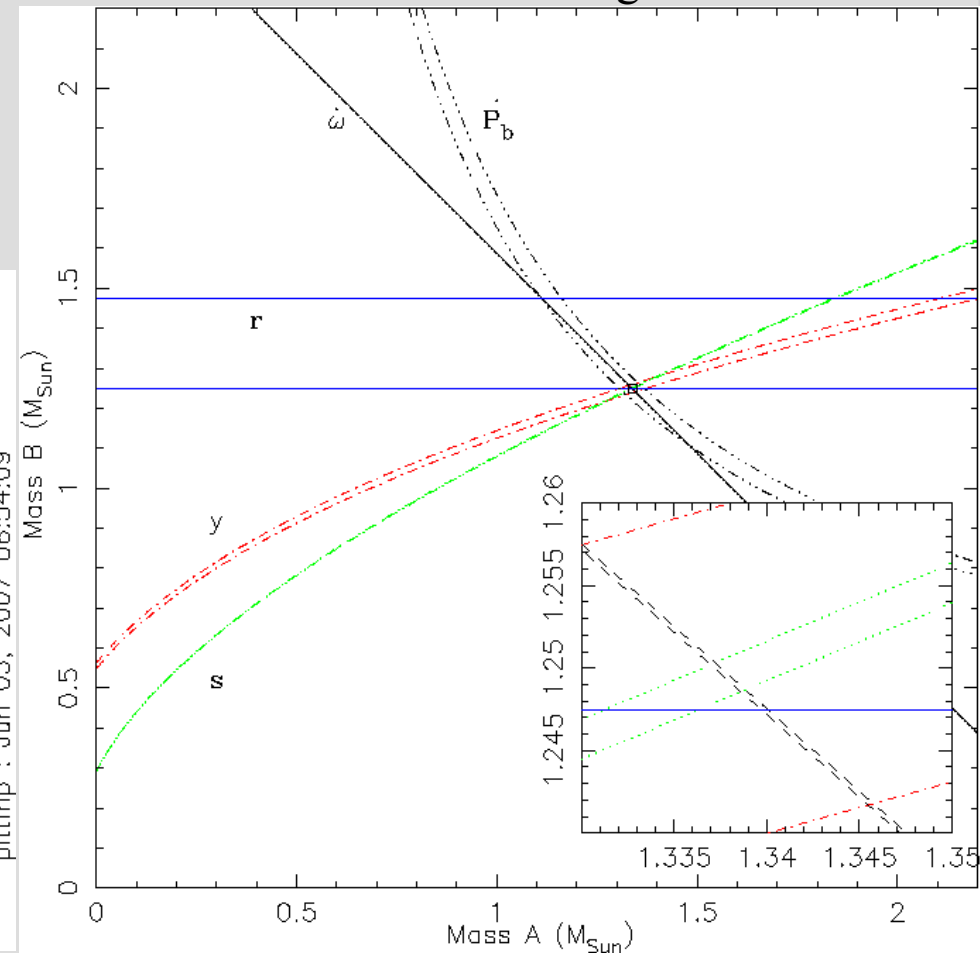# Relativistic binary pulsar

Relativistic binary pulsar

Double pulsar 0737-3039A/B
  two neutron stars seen as radio pulsars of periods 22ms and 2.8s

Nançay 0737-3039A observations
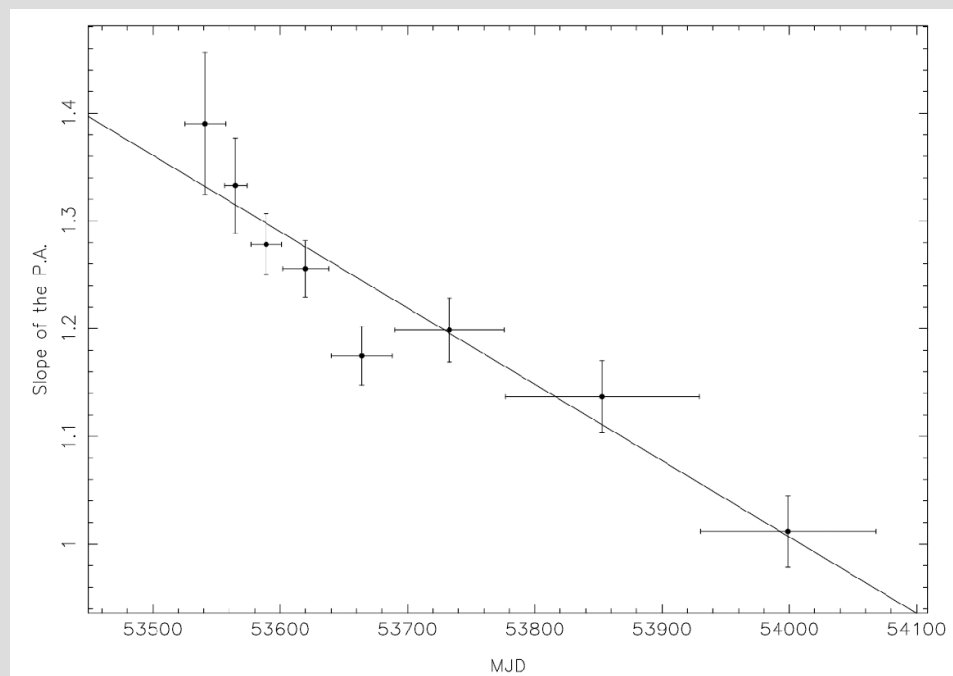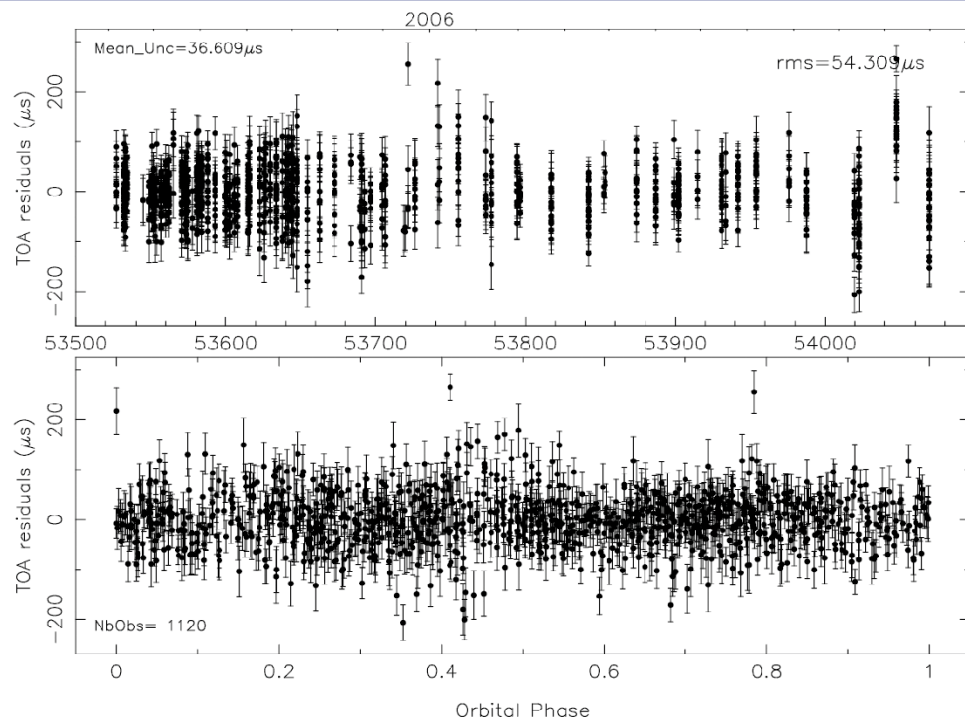 dense monitoring and high precision
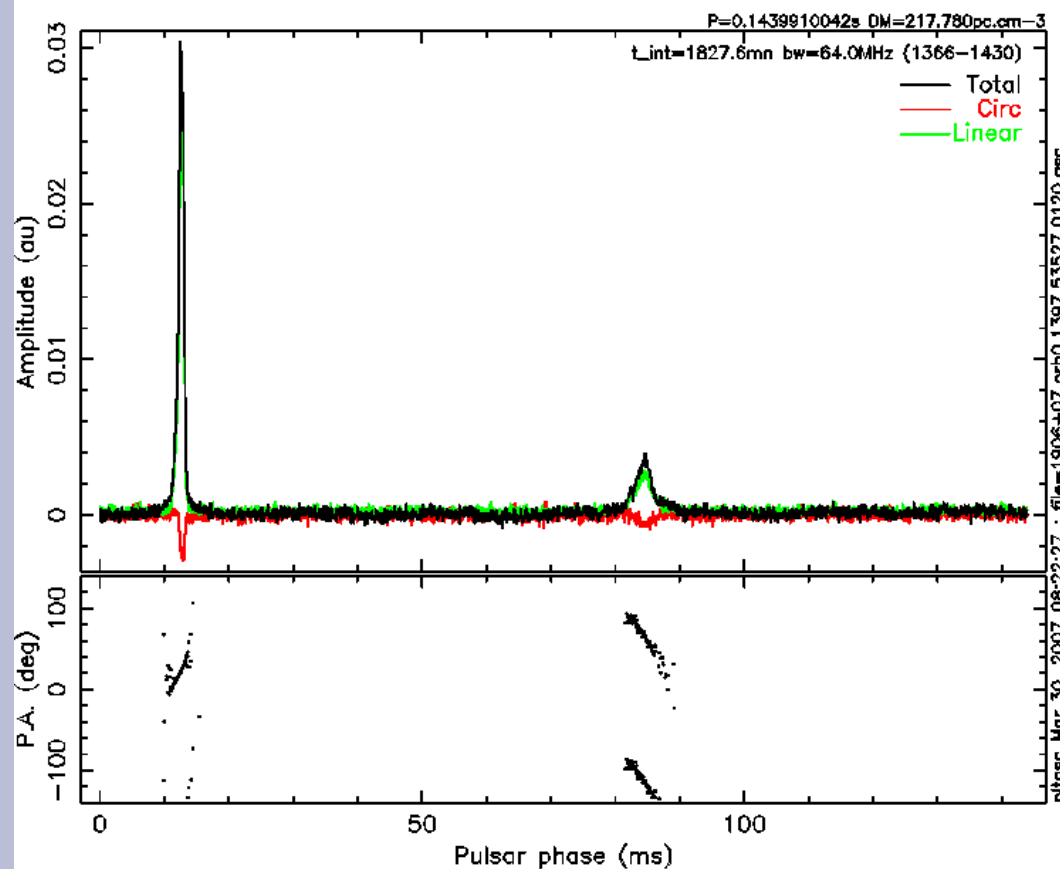
mass-mass diagram

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
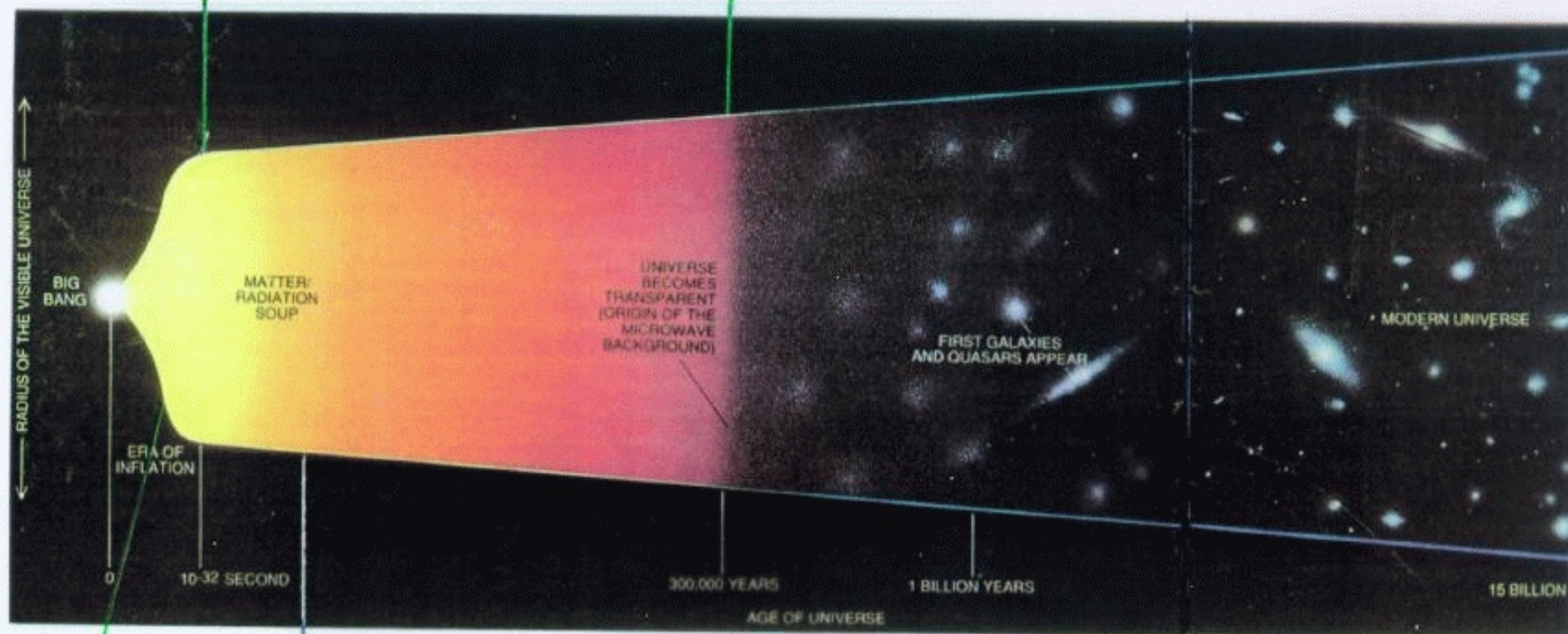

gravitational
wave background
10^{-32} seconde

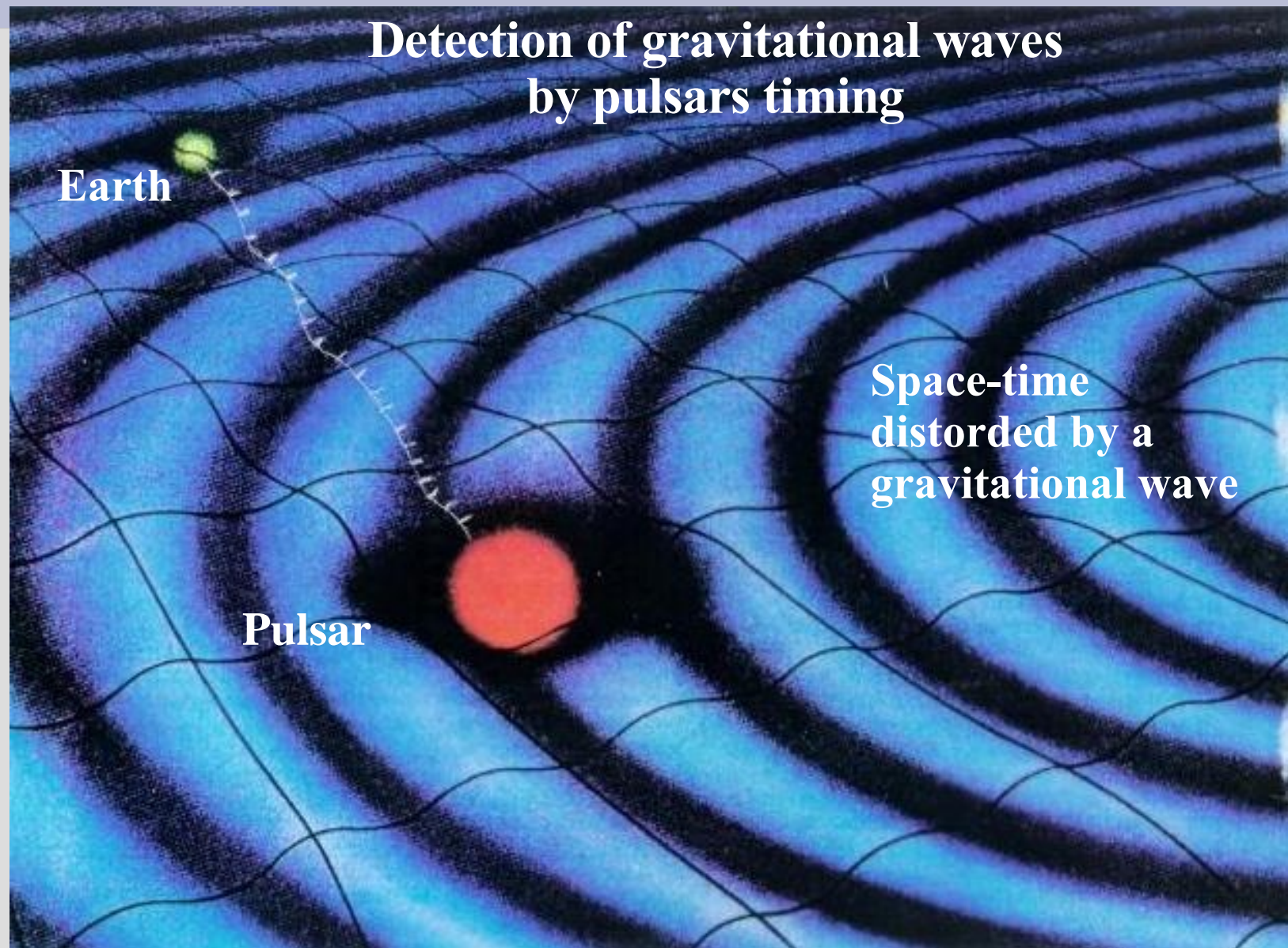electromagnetic wave
background (radio)
300 000 years

inflation

acceleration - deceleration
oscillations cosmic strings $\Rightarrow$ emission of
gravitational waves

Gravitational Wave background

Detection of gravitational waves by pulsars timing

Earth

Pulsar

Space-time distorded by a gravitational wave

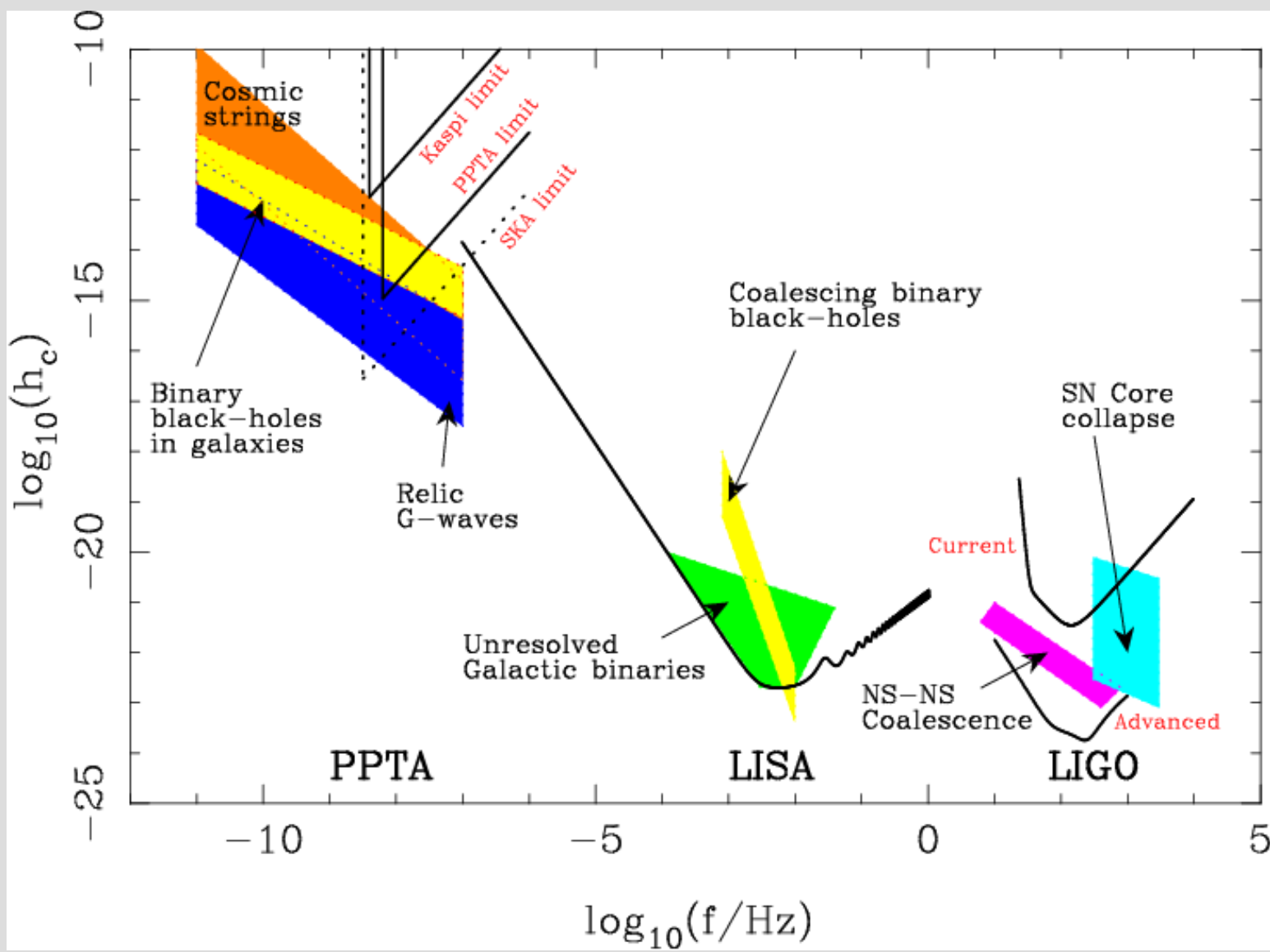# Gravitational Wave background

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)
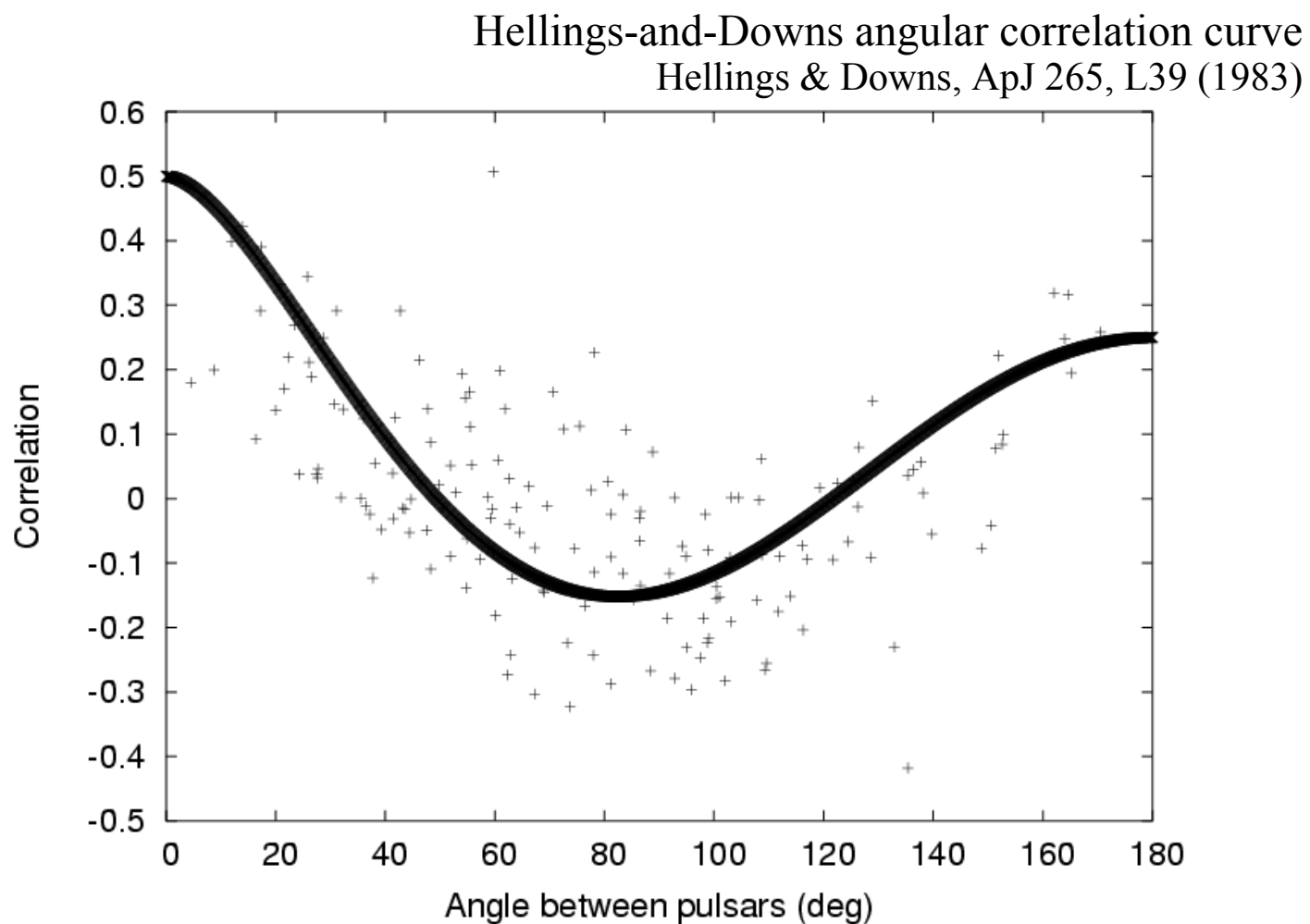
Gravitational Wave background

Different Limits on the GW background

Gravitational Wave background

Parkes PTA (Pulsar Timing Array)

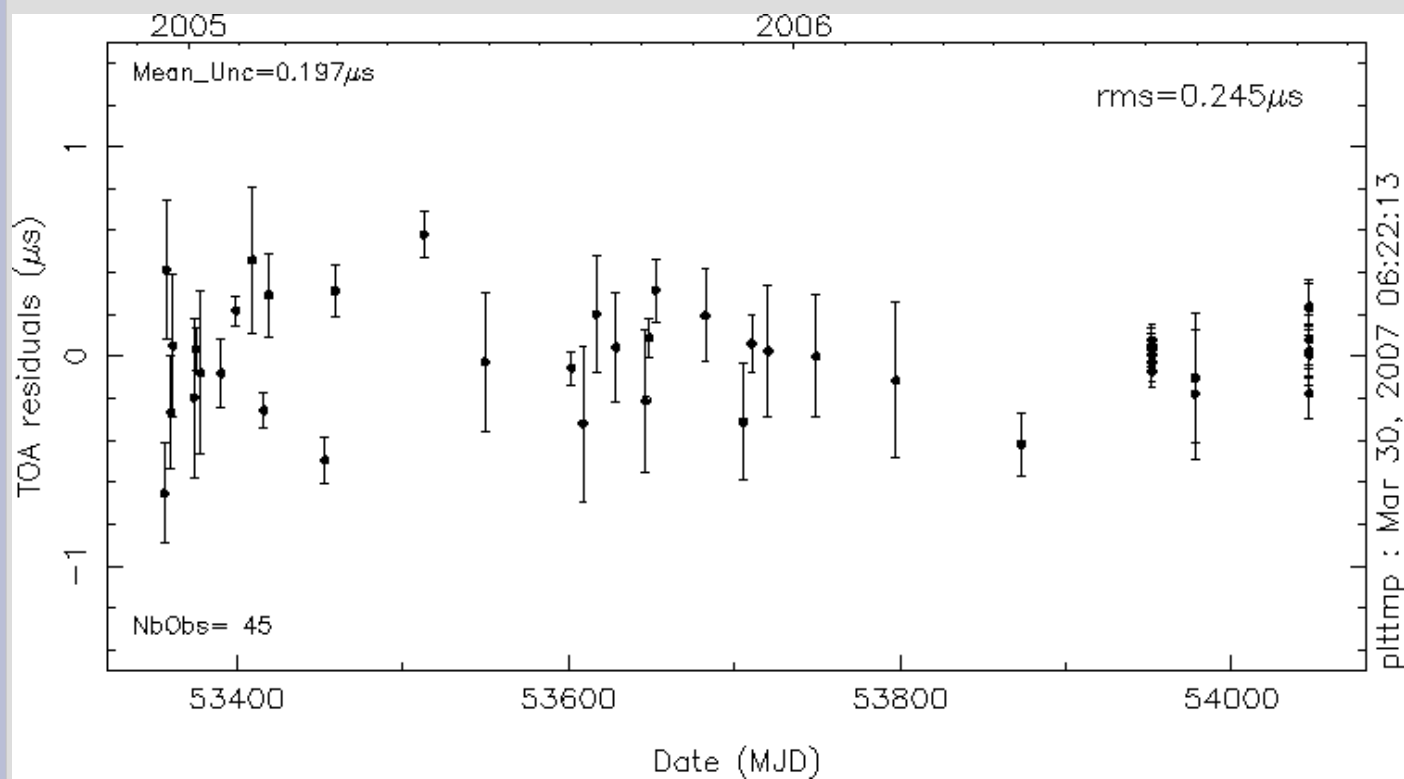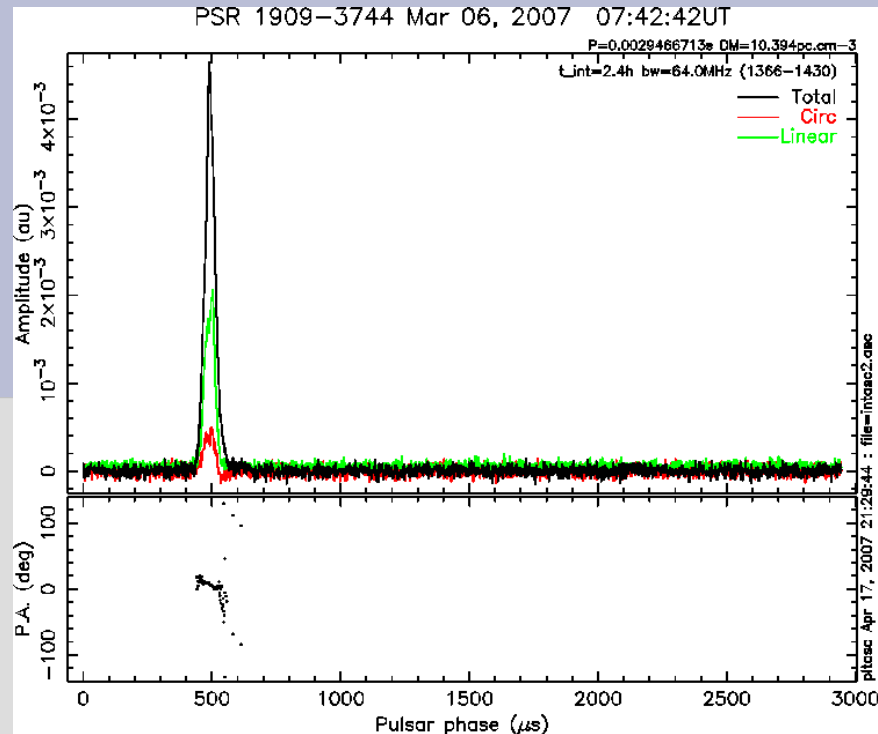| PSR	length(yrs)	TOAs rms	Tint
J0437-4715	9.9	200 ns	1 h
J1909-3744	3.8	224 ns	15 m
J1713+0747	4.1	282 ns	5 m
J144-1134	11.2	629 ns	1 h
J0613-0200	3.6	1.155 μs	15 m
J1939+2134	3.8	1.787 μs	15 m
	with F2	536 ns	
J1600-3053	3.3	3.092 μs	15 m

Gravitational Wave background

PSR J1909-3744   P=2.947ms

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

Parkes   residuals rms   ~220ns
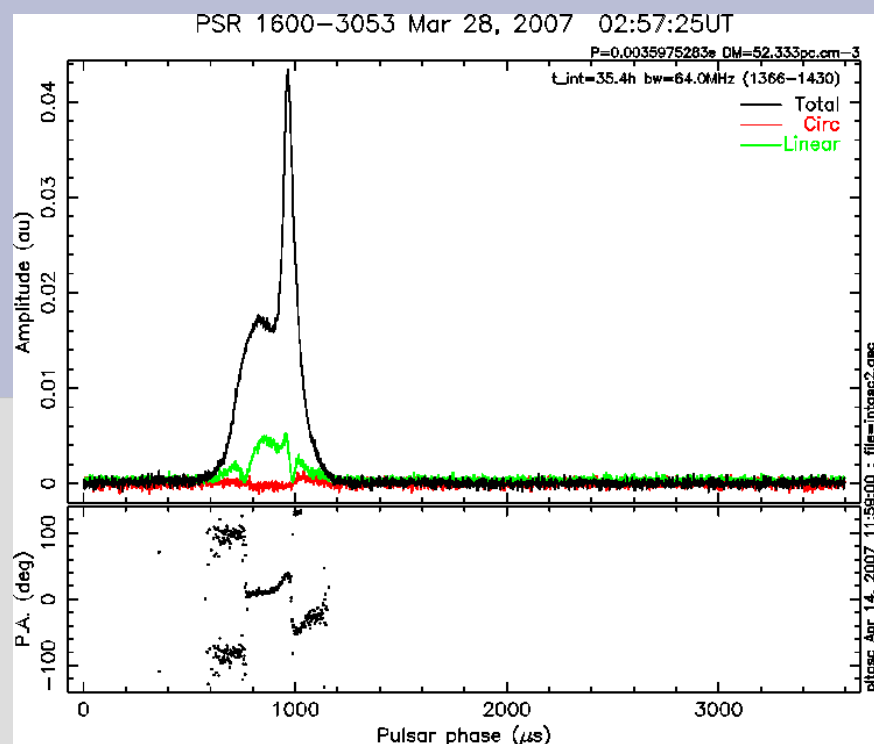
Gravitational Wave background
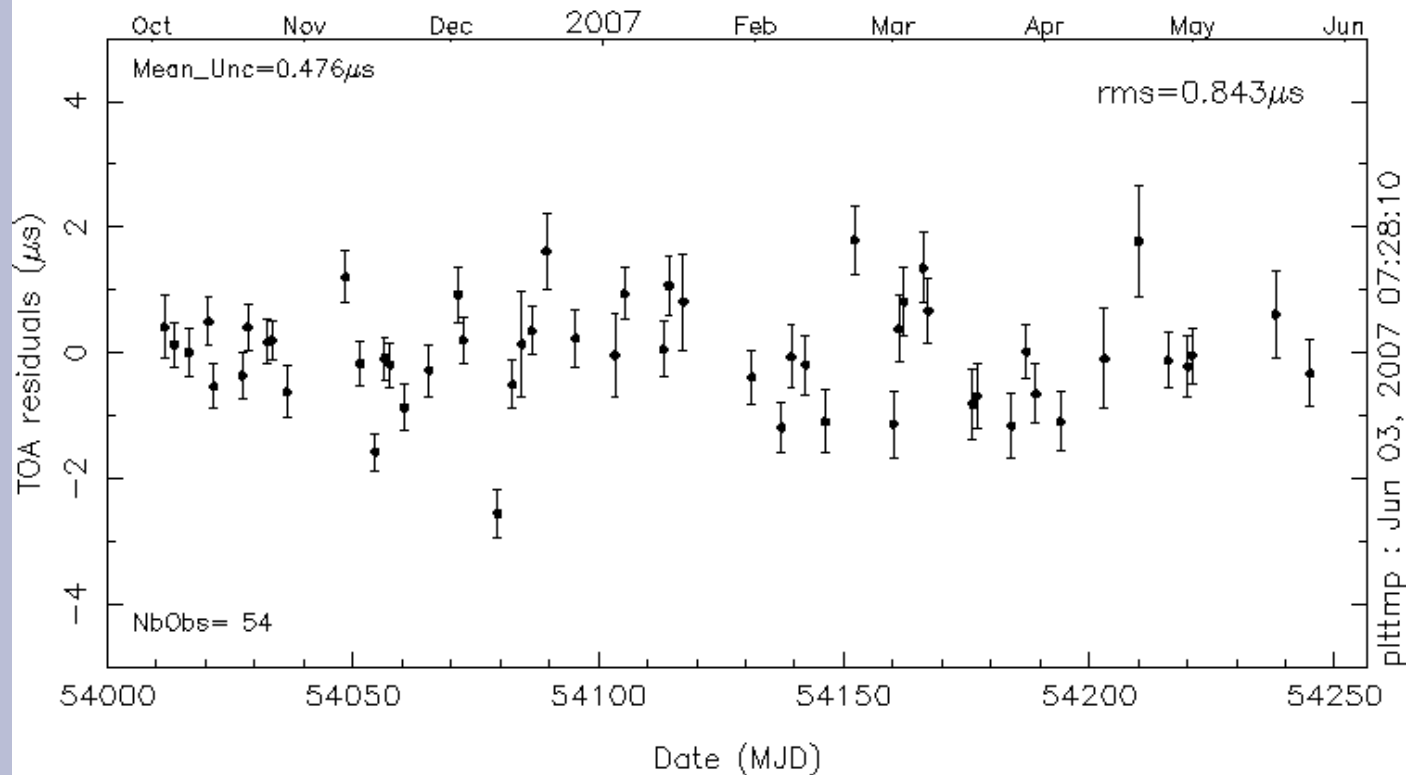
PSR J1600-3053   P=3.598ms

| Nançay | mean uncertainty | 470ns |
| | residuals rms | 840ns |

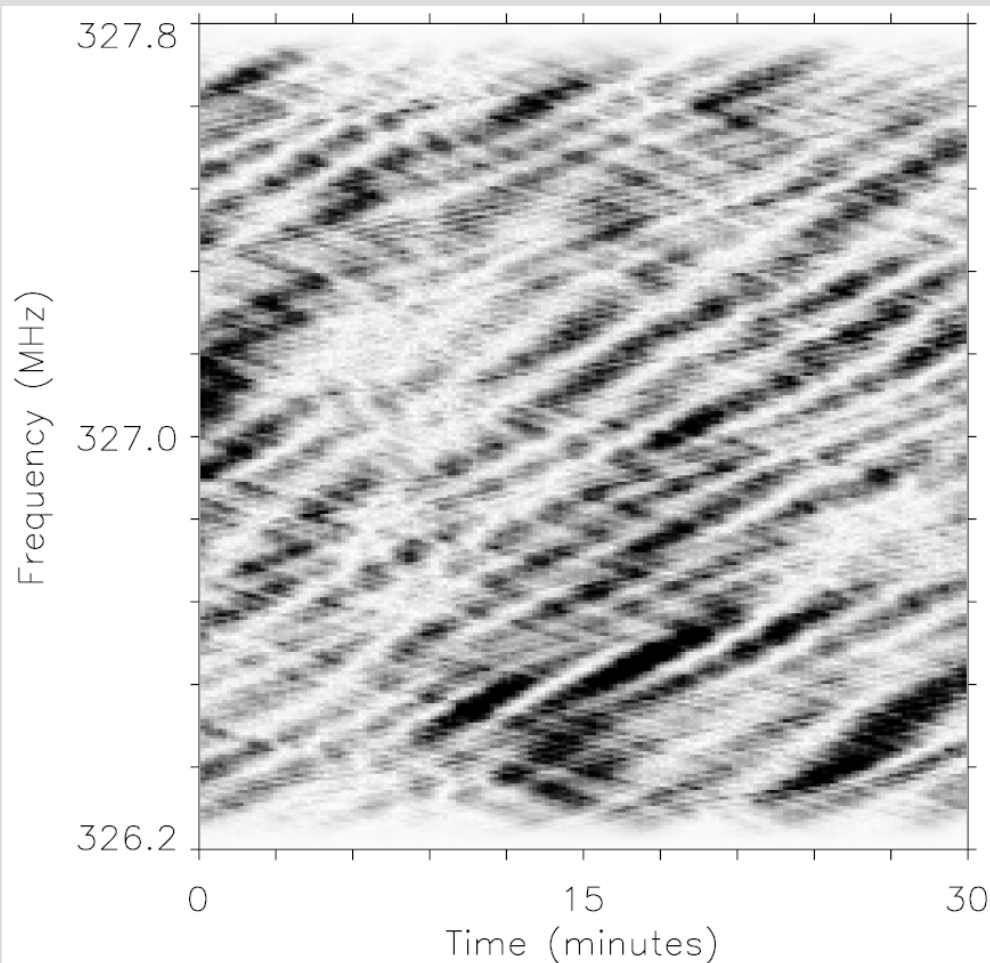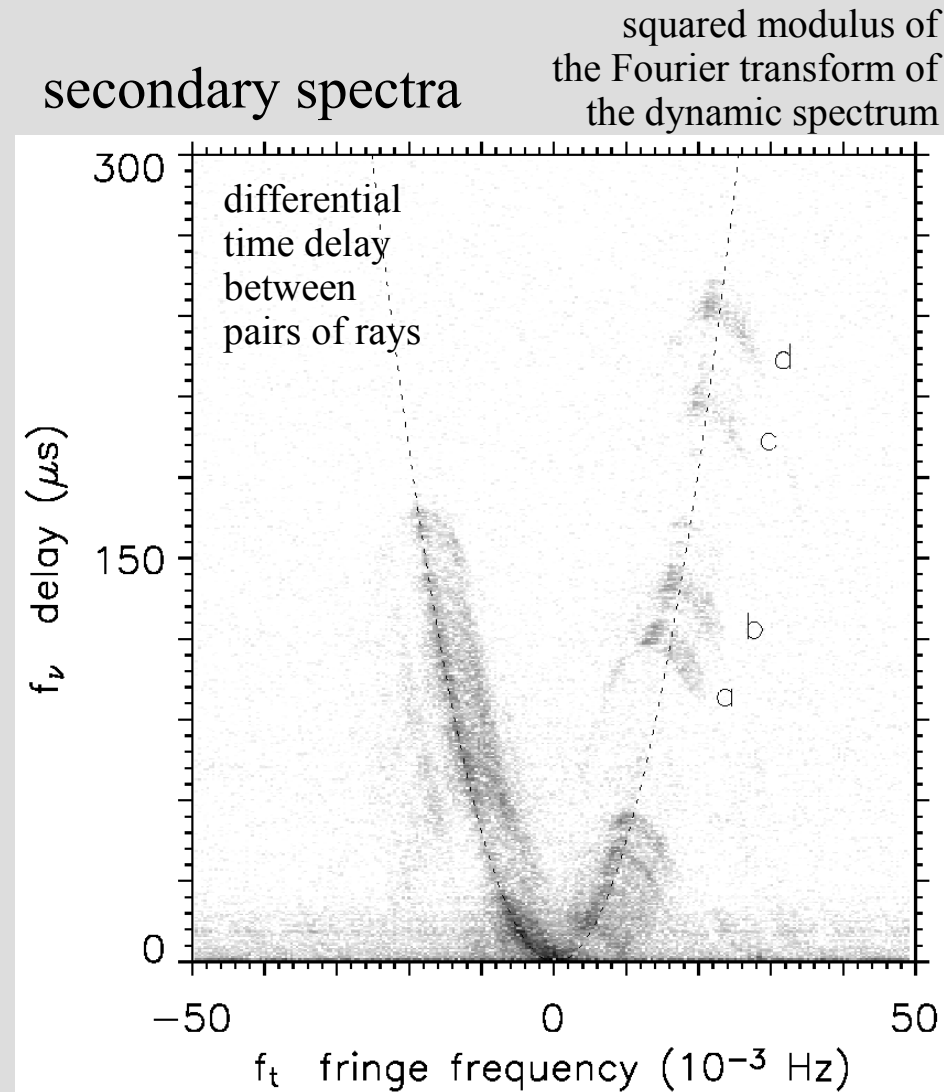| Parkes | residuals rms | ~3µs |

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

differential
time delay
between
pairs of rays

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

ISM study

PSR B1133+16 Arecibo

3 distinct main arcs (parabola)
3 distinct thin scattering screens
   at different distances
   between pulsar and Earth

Stinebring, Krabi
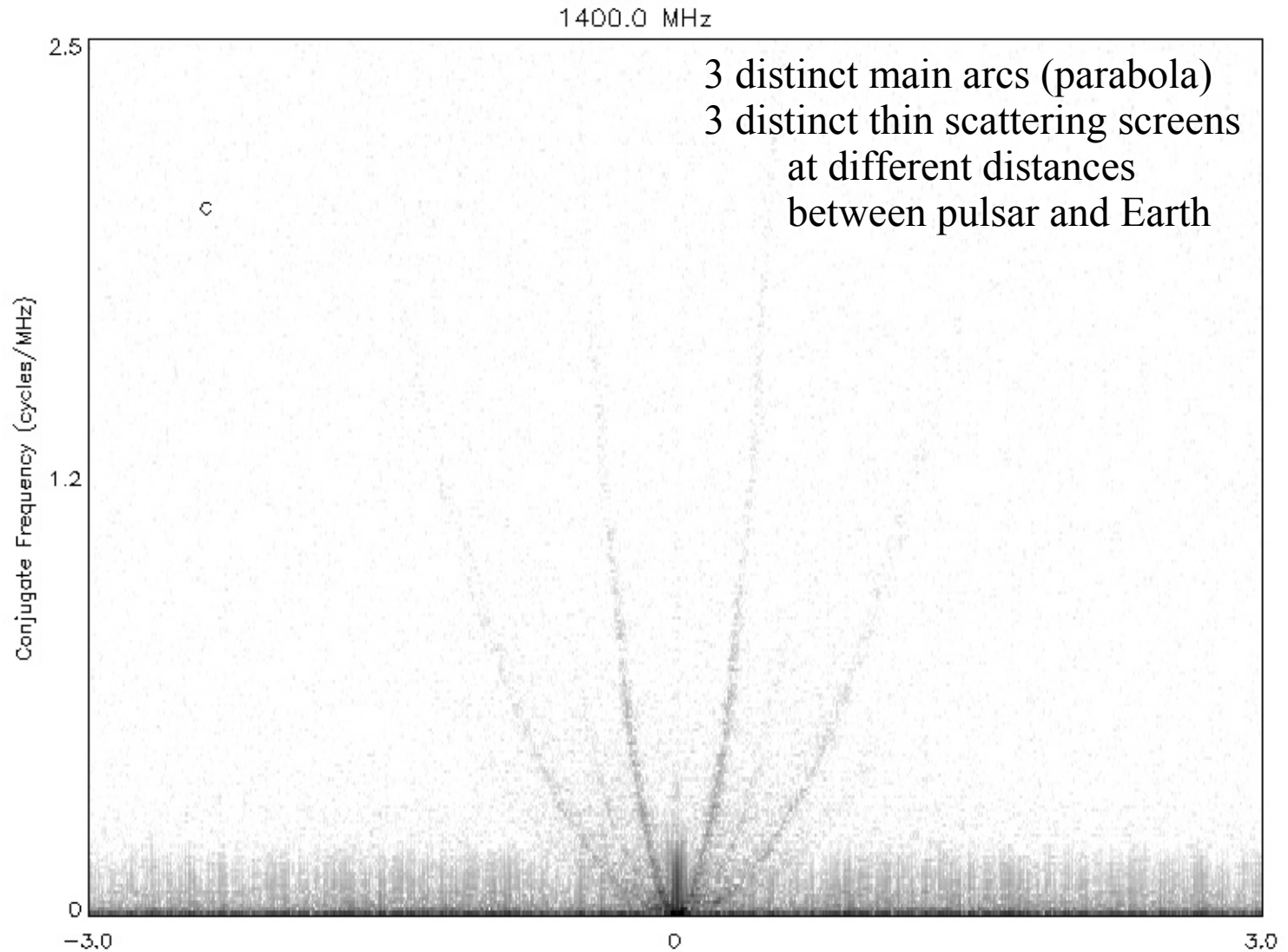
ISM study

map of the
different scattering
screens on
different
lines of sight

Pulsar and Screen Locations, Galactic Plane

Stinebring, Krabi
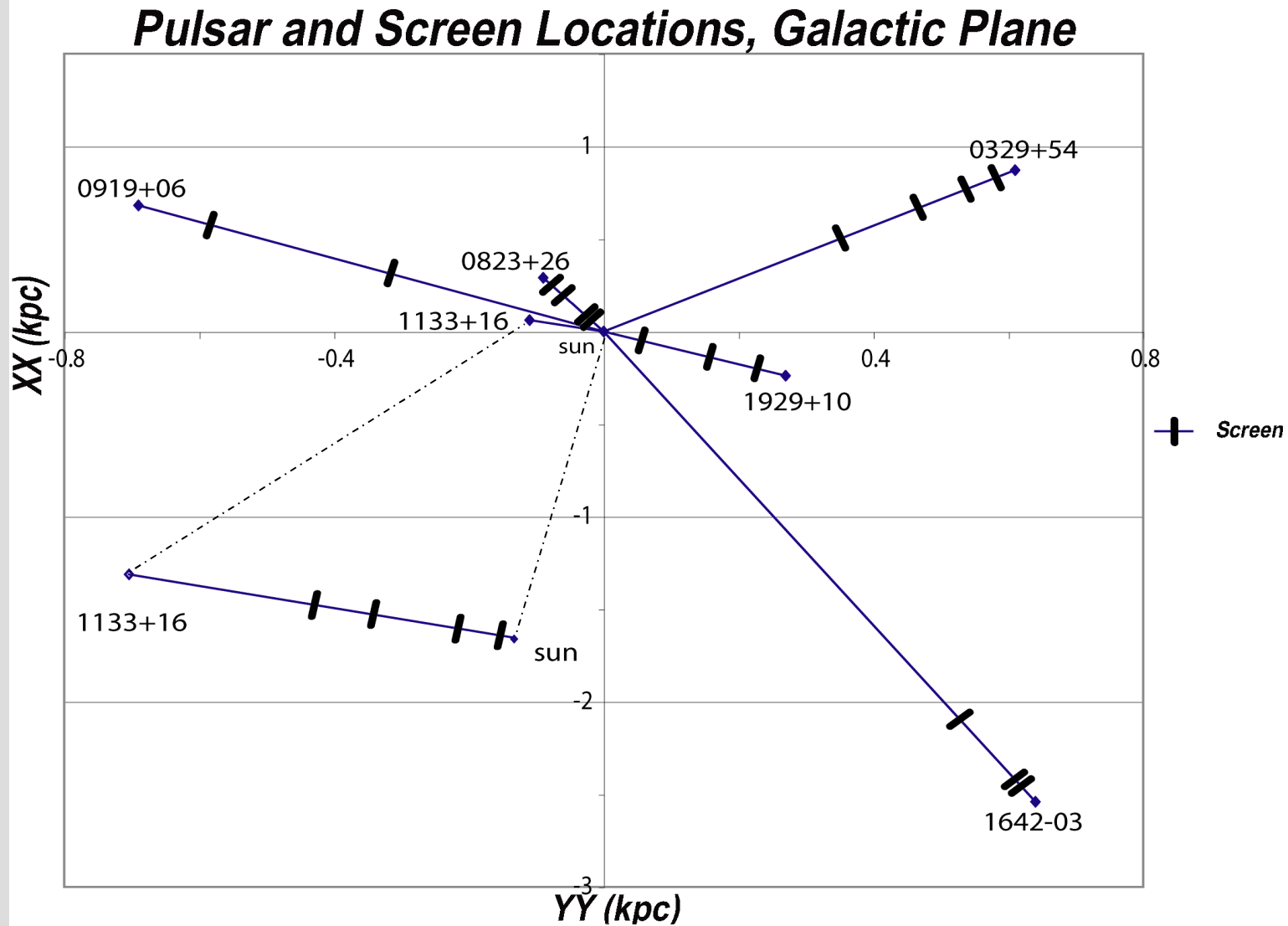
ISM study

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 ?
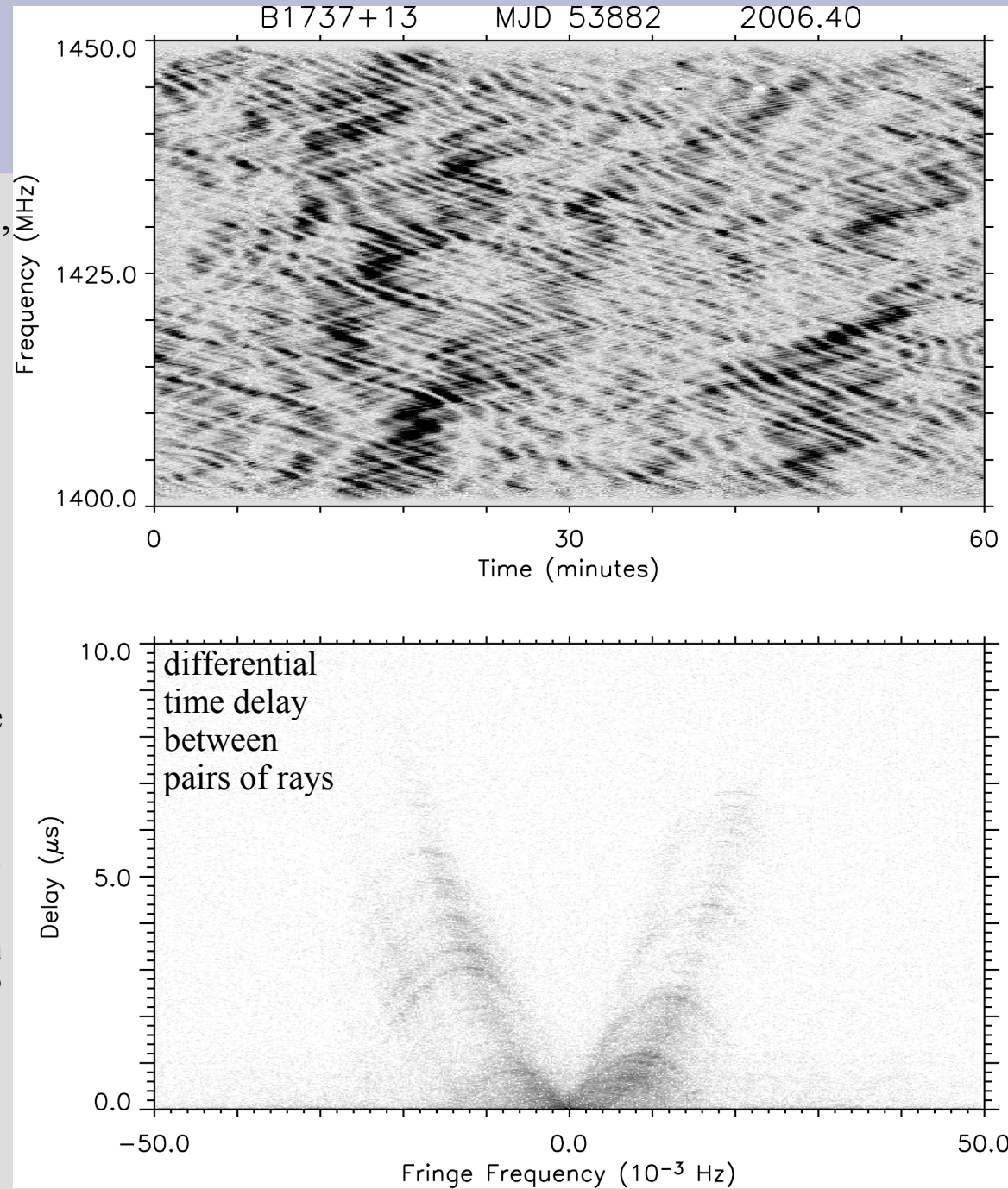Should we routinely produce a secondary spectrum to be able to correct TOAs ?

A systematic study is being done at Arecibo on PSR B1737+13
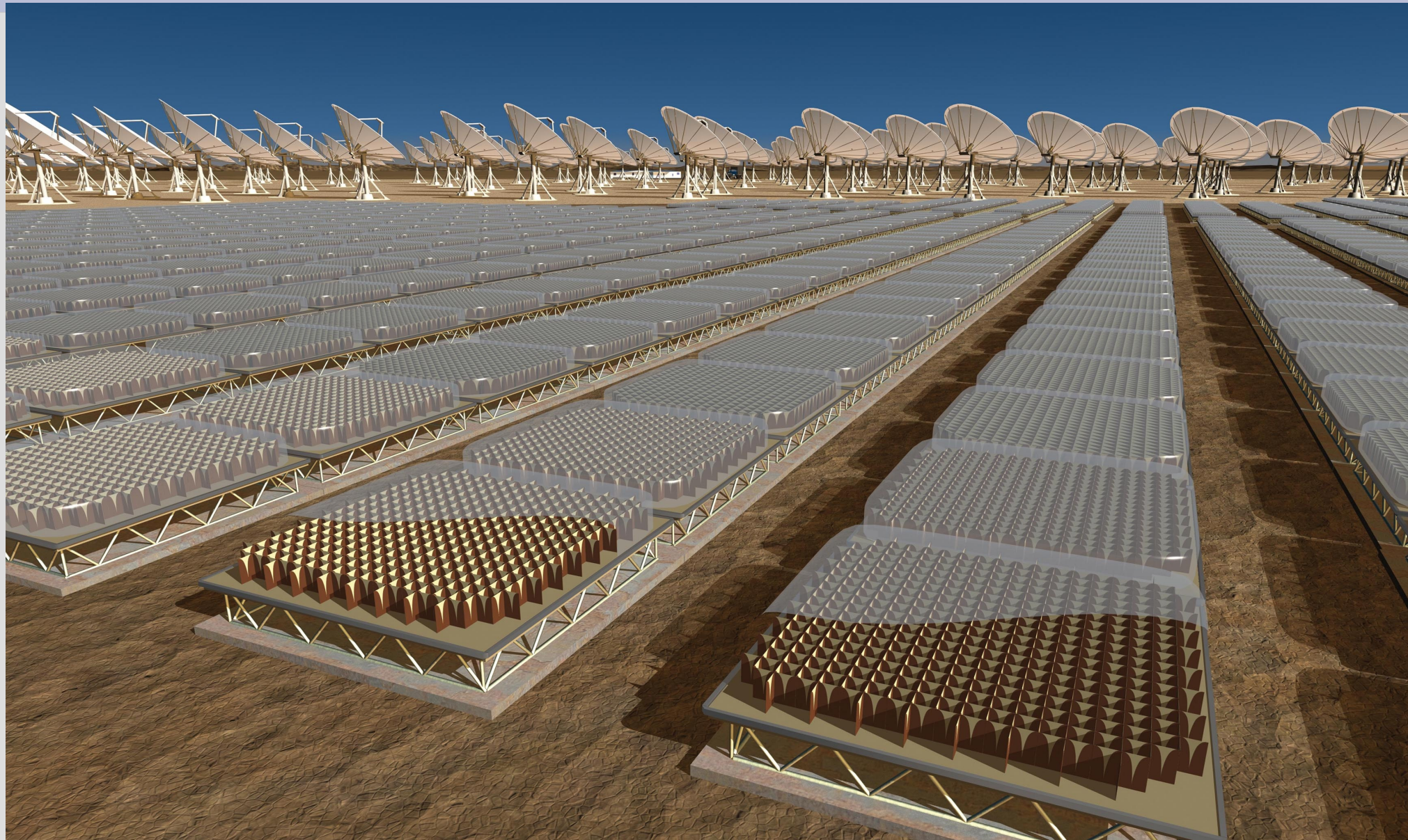
it's seems promising...

Could this be done on much fainter millisecond pulsars ?

with SKA for sure !

Stinebring, Krabi

B1737+13   MJD 53882   2006.40

differential time delay between pairs of rays

SKA Square Kilometer Array

SKA timing capability

generaly, the timing uncertainty can be estimated by :

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

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
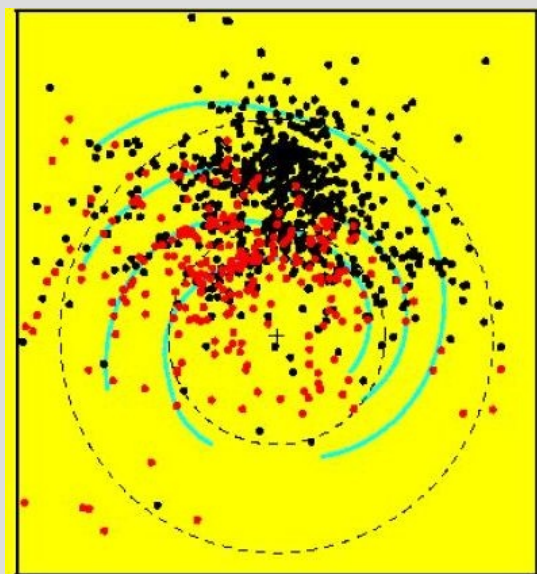
a fairly complete census of the Galactic population is possible

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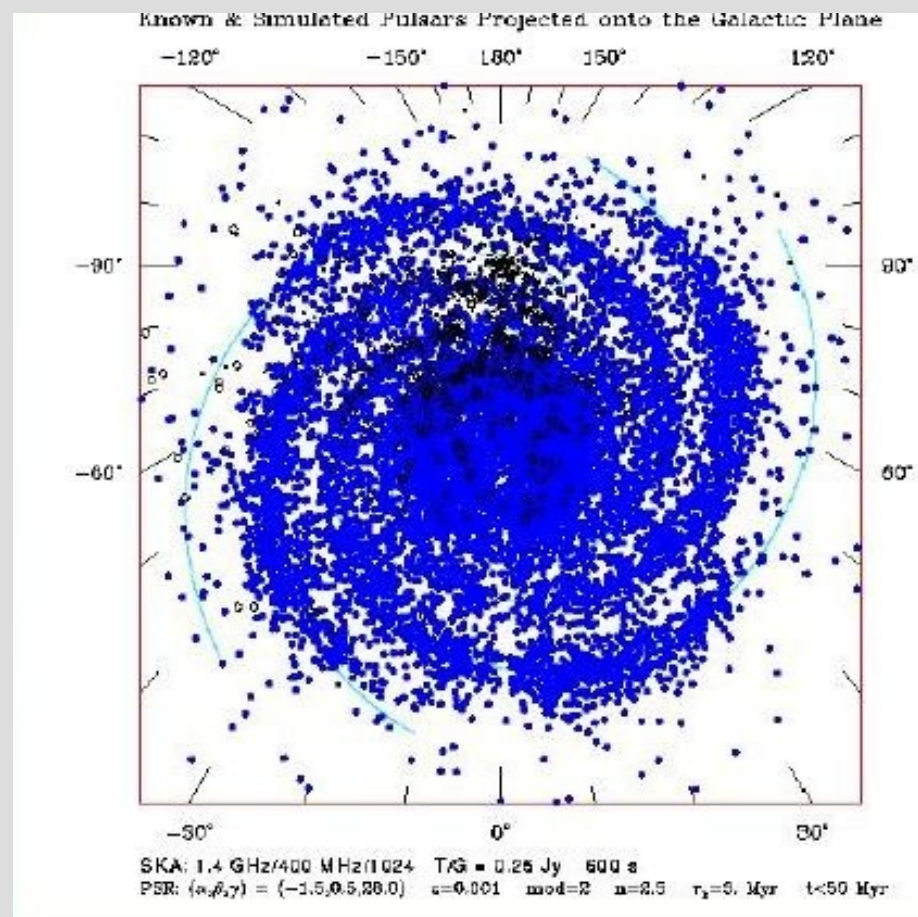   pulsars

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

SKA searching capability

today ~1800

Known & Simulated Pulsars Projected onto the Galactic Plane

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