Pulsar Stability

(and A New Limit on the GWB* from Pulsar Timing)

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*: GWB = Gravitational Wave Background

Outline

- High precision timing of MSPs*
- Long-term timing stability
- Simple GWB limit technique
- Conclusions

*: MSP = Milli-Second Pulsar

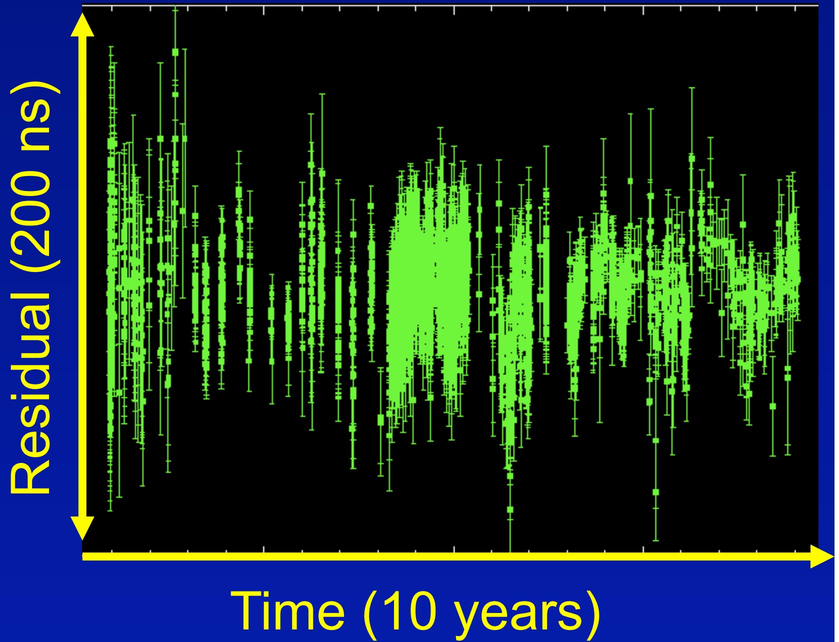
Quick Basics of Pulsar Timing

- Basic Method:

  Theoretical Model

  <u>– Actual Pulse Arrival Time</u>

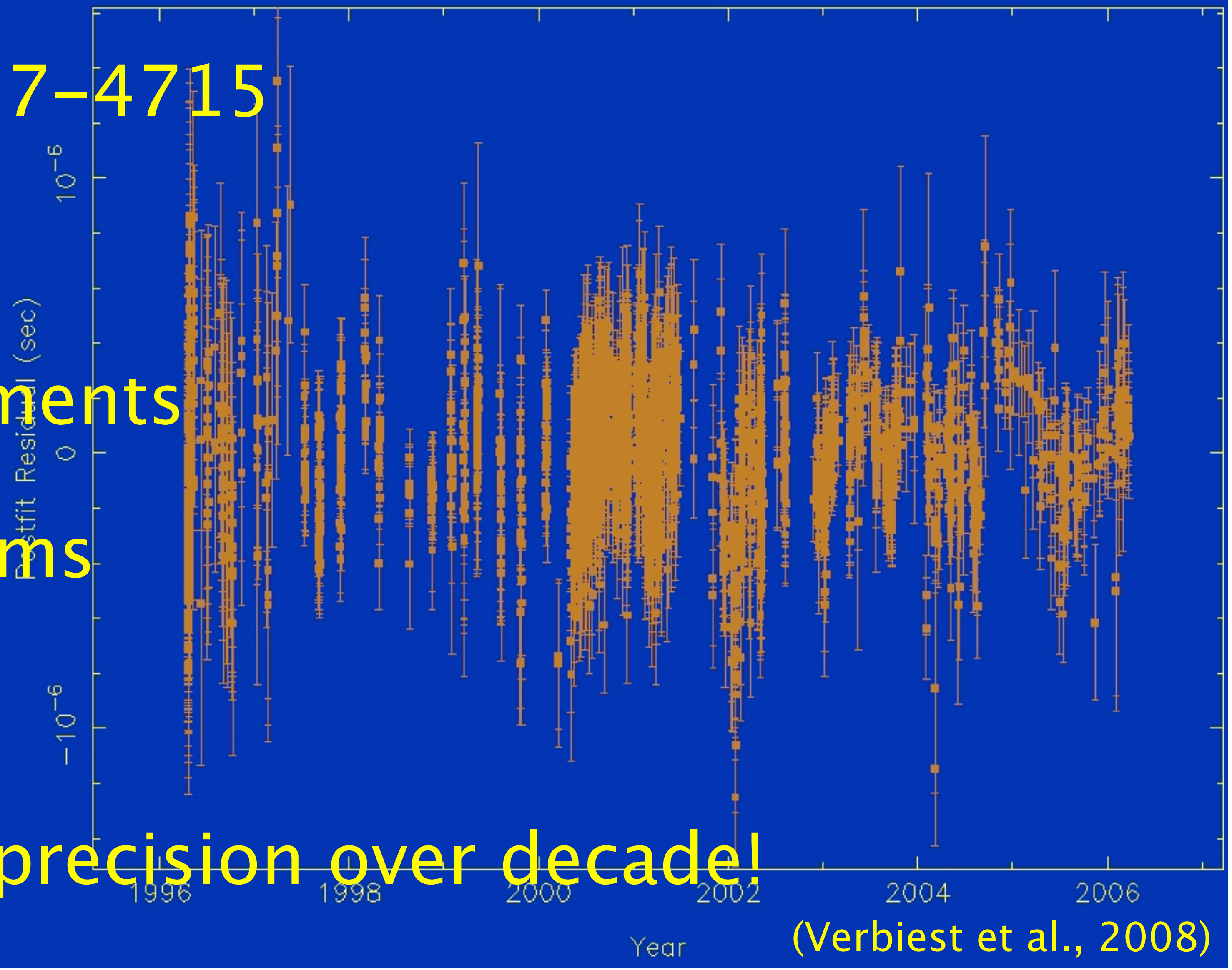
  = Timing **Residual**



$$T_{th} = \nu t + \tfrac{1}{2}\dot{\nu}t^{2} + D\,\frac{\int_{0}^{d} n_{e}\,dl}{f^{2}} - \tfrac{1}{c}(\vec{r}\cdot\hat{s}) + \frac{V_{T}^{2}t^{2}}{2cd} - \frac{(\vec{r}\times\hat{s})^{2}}{2cd} + \ldots$$

Precision Timing State-of-the-Art

- PSR J0437-4715
- 10 years
- 4 instruments
- 200 ns rms
- Highest precision over decade!



(Verbiest et al., 2008)

Long-term Stability of MSPs

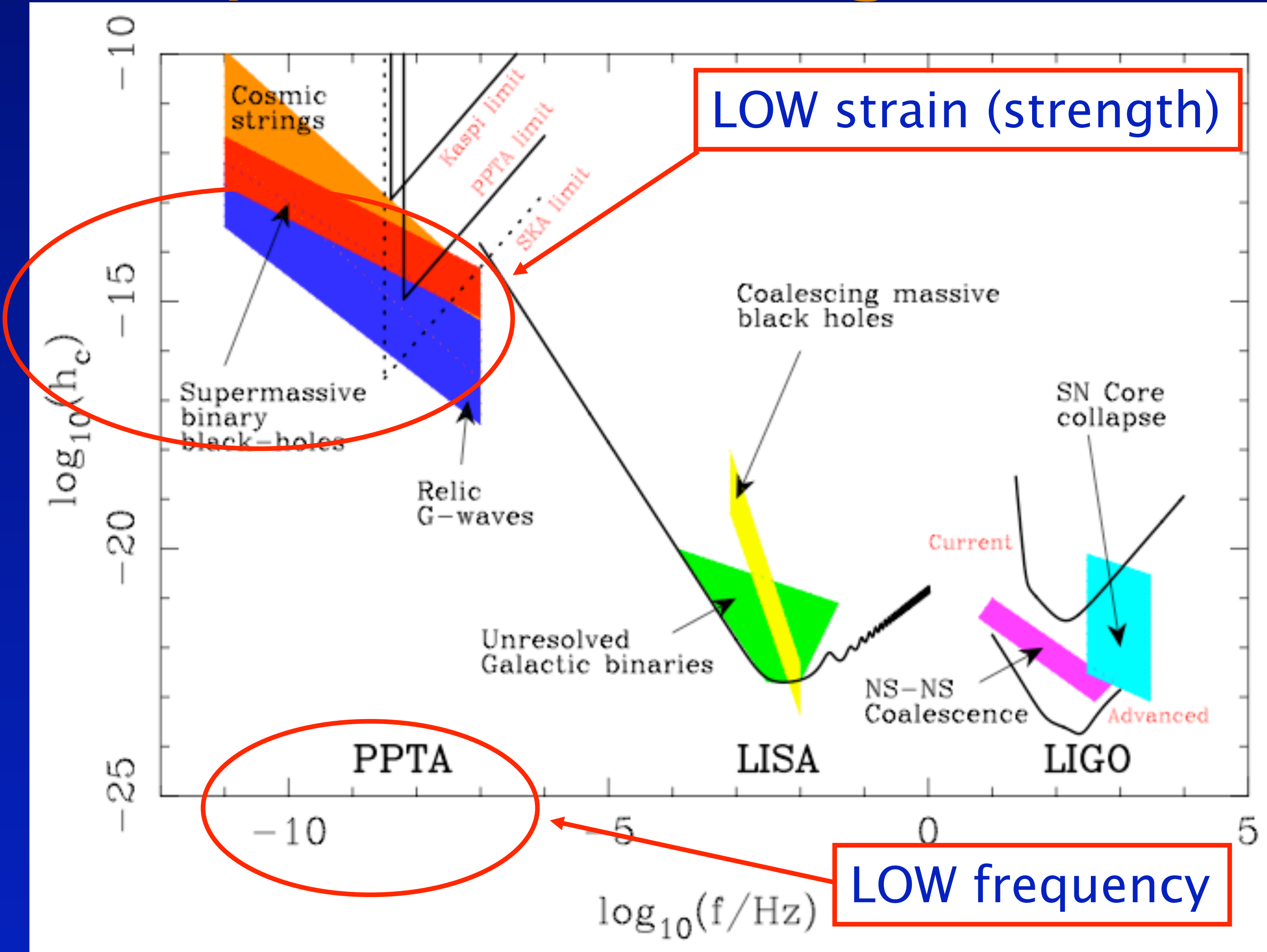
GWB sensitivity requires:

(Jenet et al., 2005)

- High timing precision ($\sim 10^2$ ns)
- Long observing campaigns ($\sim 10^1$ yrs)

$\Rightarrow$ Highly stable MSPs

Expected GWB signature



(Figure courtesy of G. Hobbs)

Stability: Observations

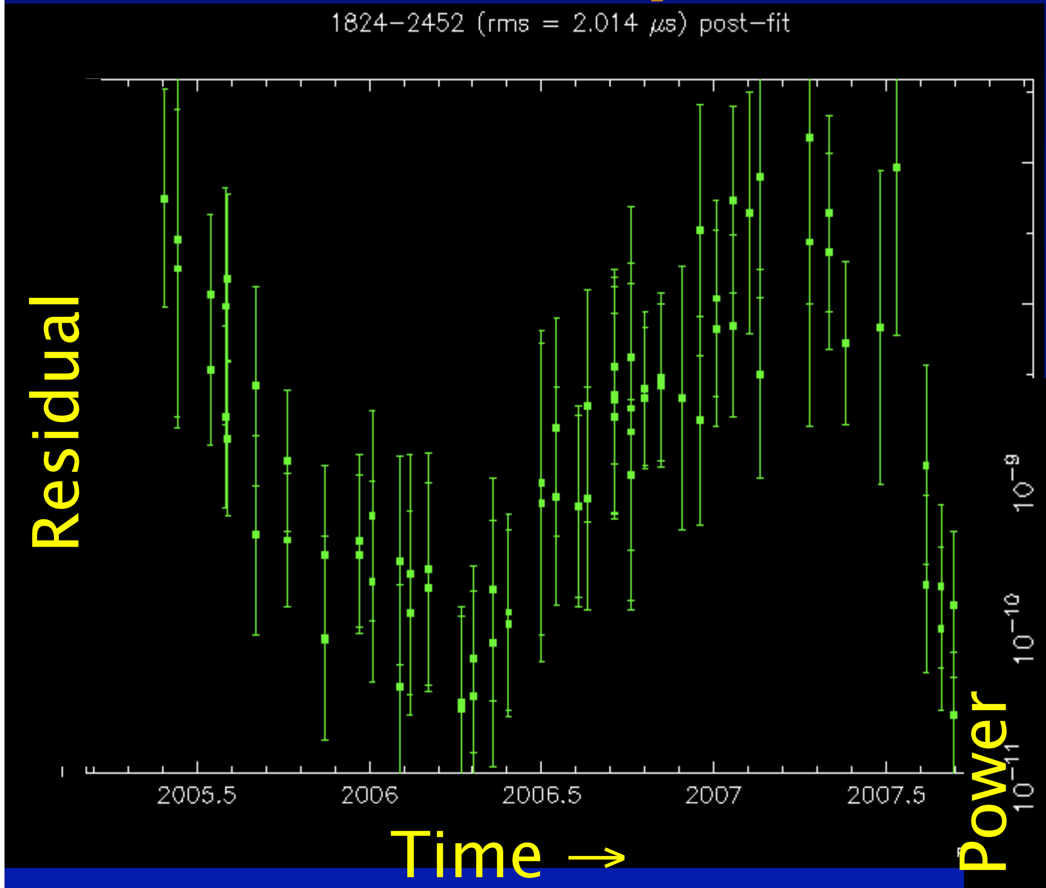
- 12 years (avg.) on 20 PPTA* pulsars

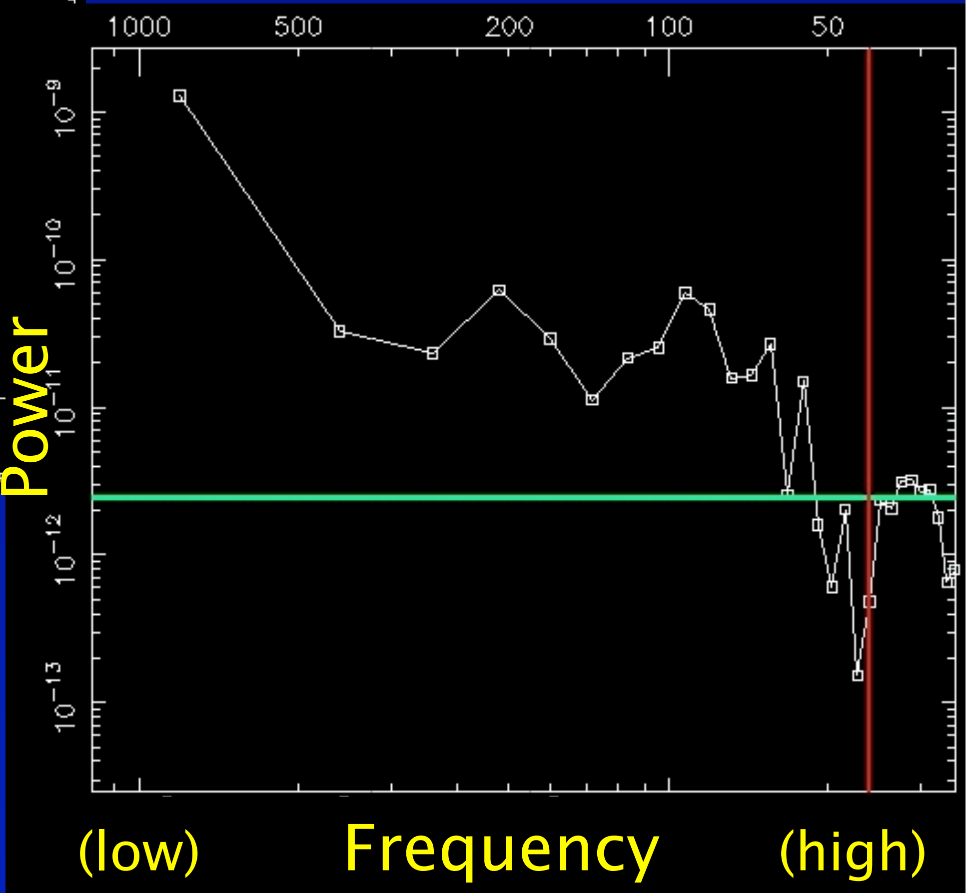
*: PPTA = Parkes Pulsar Timing Array

Stability: Examples: 1824

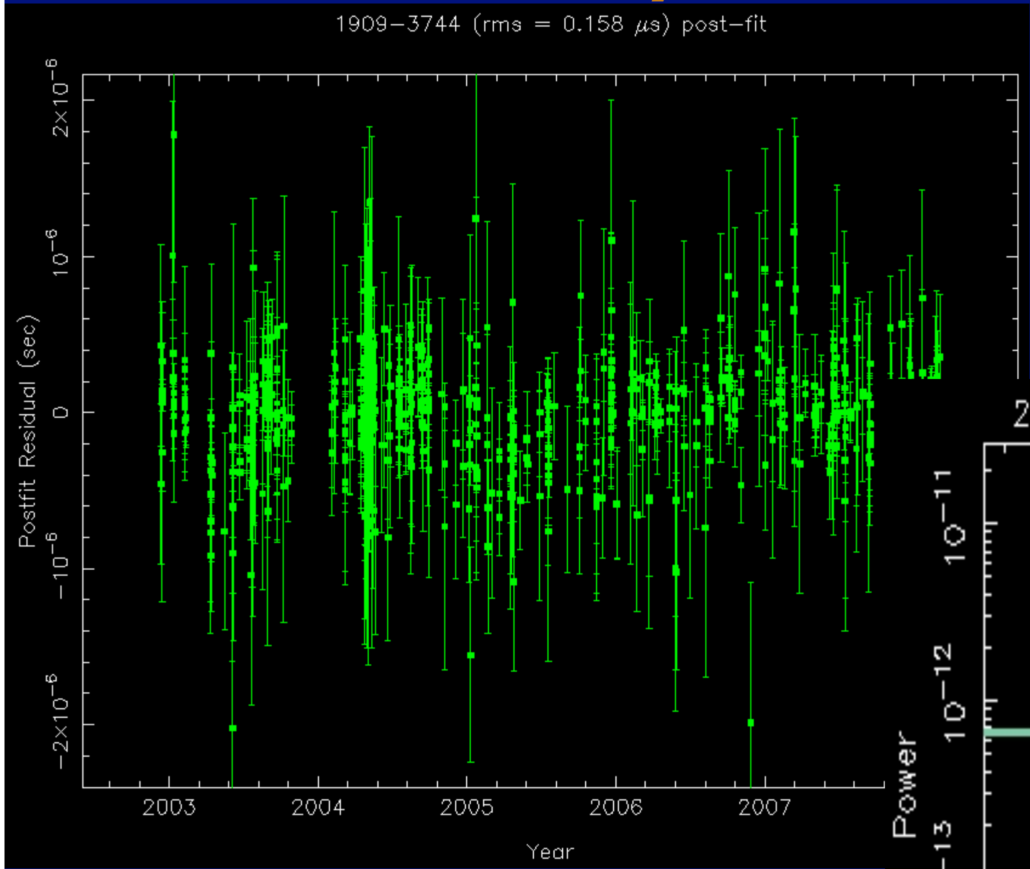
PSR J1824-2452

(in Globular Cluster M28)



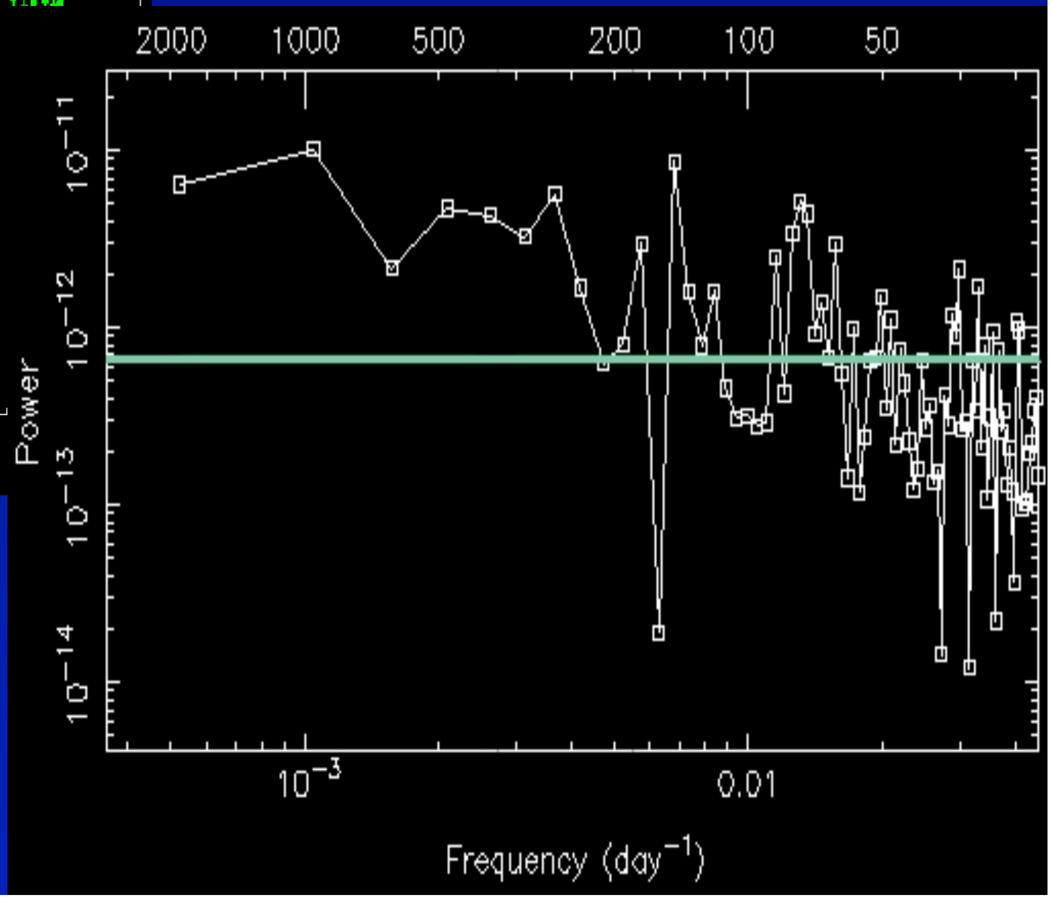


Stability: Examples: 1909



PSR J1909-3744:

158 ns over 5 yrs



Stability: Observations

- 12 years (avg.) on 20 PPTA* pulsars
  - 2: clear timing noise (J1939+2134, J1824-2452)
  - 2: some evidence for timing noise
    (J0613-0200, J1024-0719)
  - 4: sub-μs timing
    (J0437-4715, J1909-3744, J1713+0747, J1744-1134)
  - 12 remaining: white noise, μs-level rms
  - average: 2.2 μs rms

*: PPTA = Parkes Pulsar Timing Array

Stability: Conclusion & Prospects

- Mostly stable, but high noise levels

Detection prospects look good, provided:

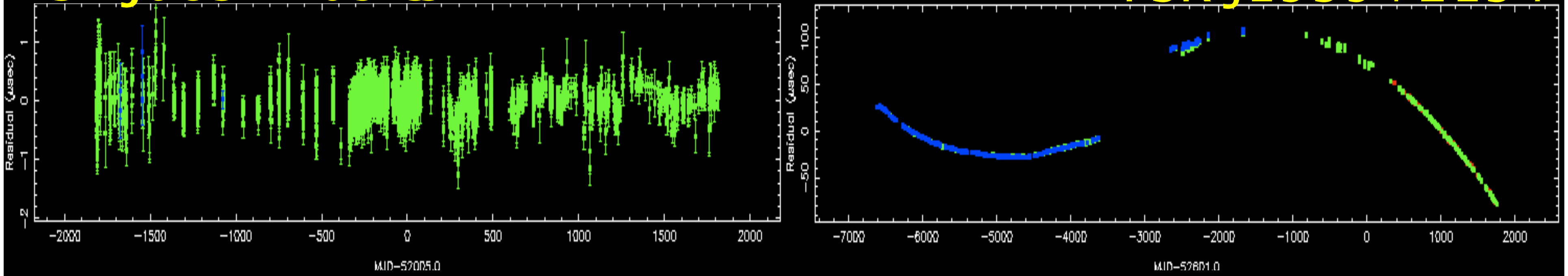
- New instruments (bandwidth, resolution)
- New calibration methods
- New software
- New pulsars (surveys)
- Collaboration (more, bigger telescopes)

PTAs need to “see” the GWs

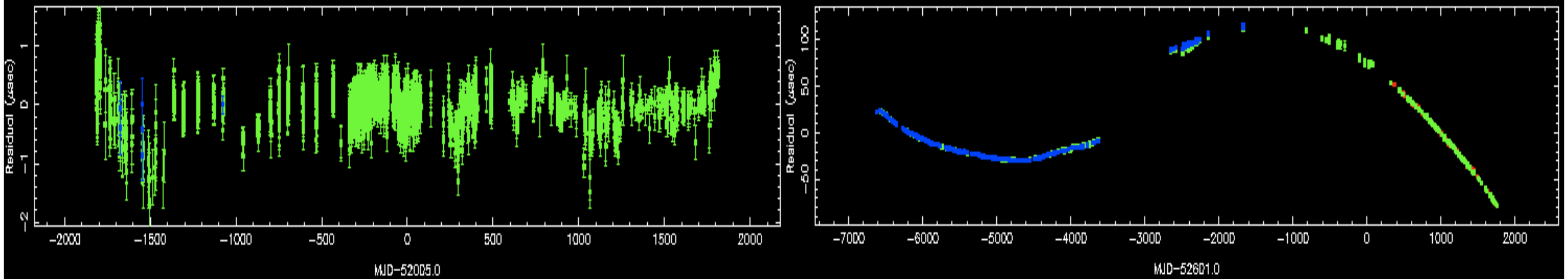
PSR J1857+0943 / PSR J0437-4715

True Residuals

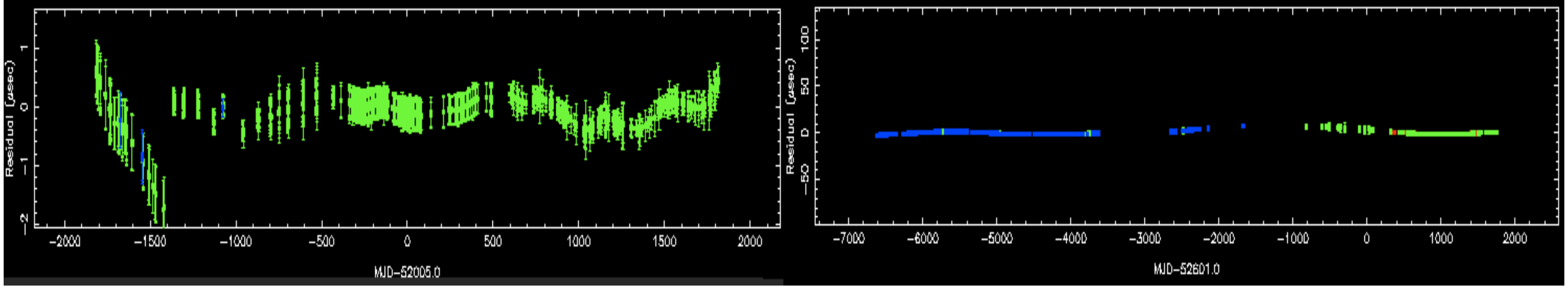
PSR J1939+2134



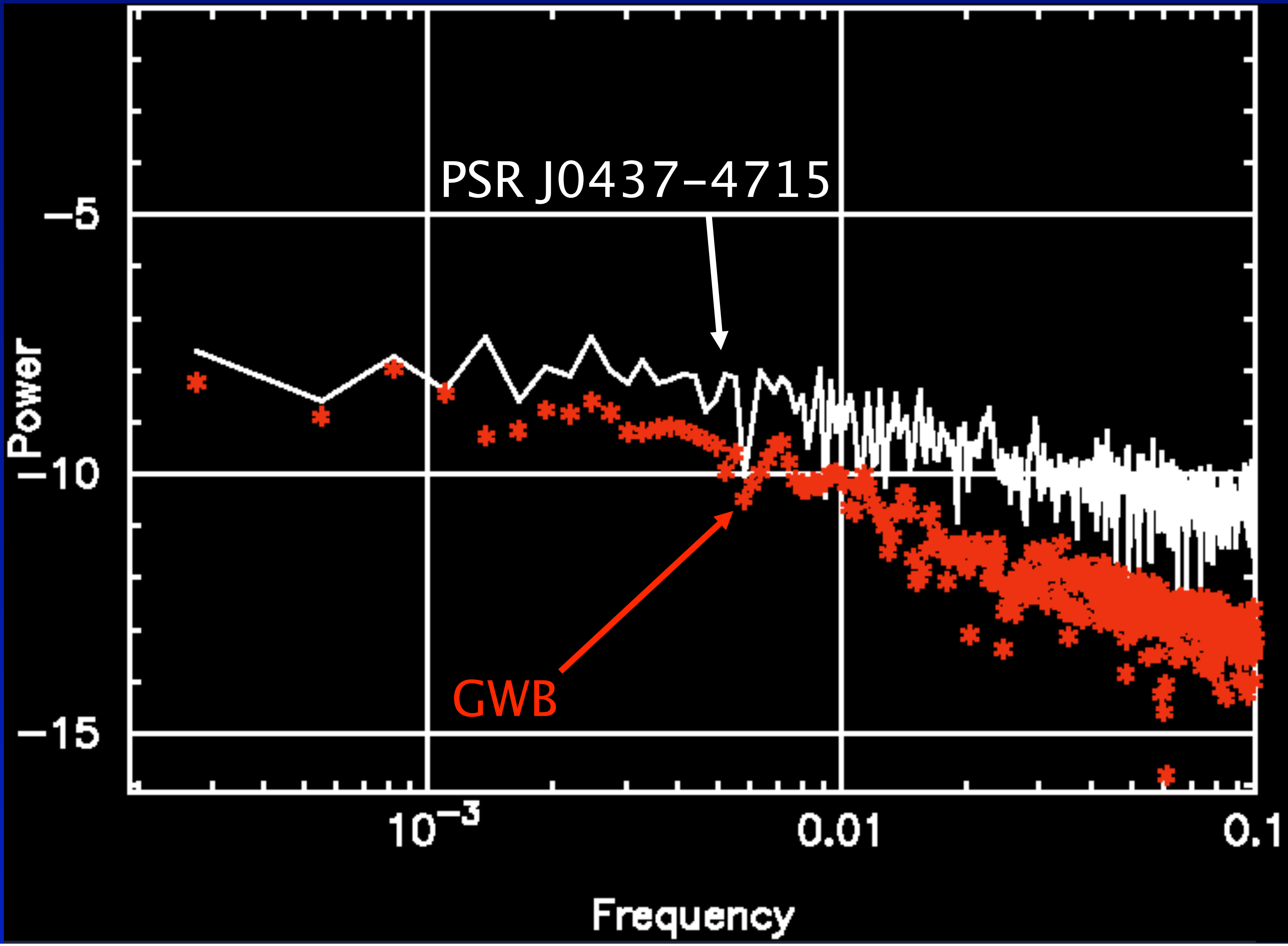
True Residuals + simulated GWB



Simulated GWB



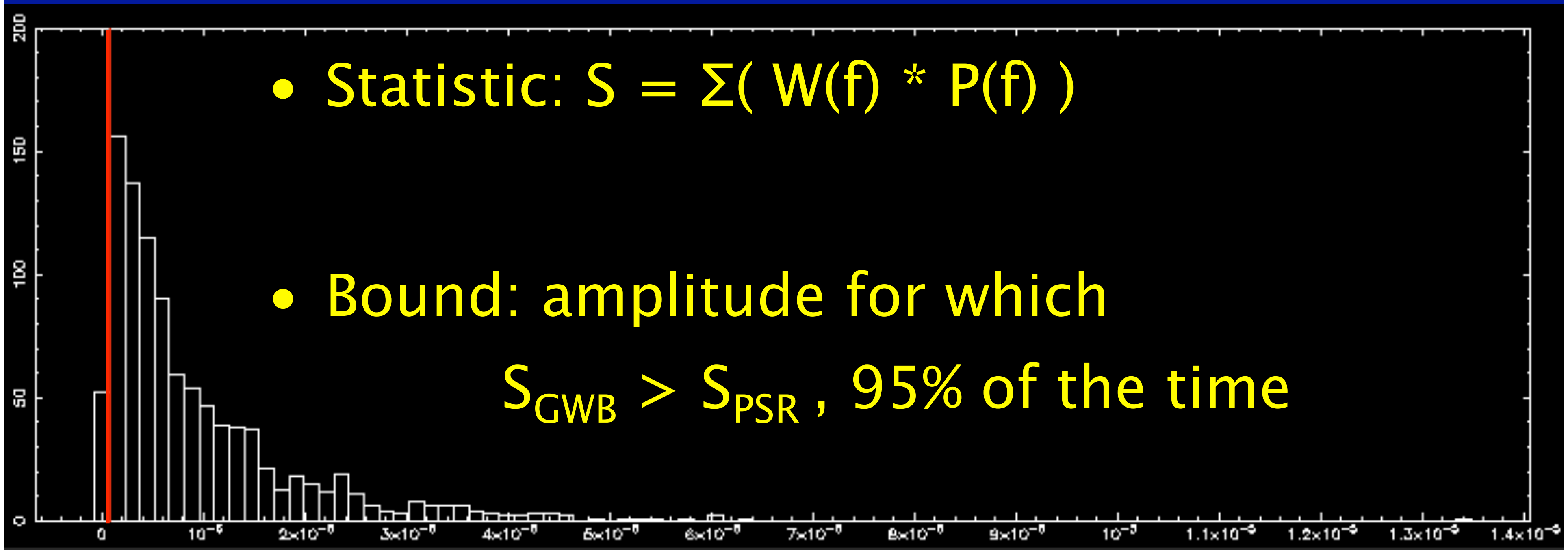
GWB vs. Pulsar Spectrum



A Very Simple GWB Limit

- Spectrum of Pulsar Residuals: $P_{PSR}(f)$
- Monte-Carlo GWB Spectrum: $P_{GWB}(A,f)$
- Statistic: $S = \Sigma(\ W(f) * P(f)\ )$
- Bound: amplitude for which

  $S_{GWB} > S_{PSR}$, 95% of the time



Previous Limits in Literature

- Kaspi, Taylor & Ryba, ApJ, 1994
- Thorsett & Dewey, Ph. Rev. D, 1996
- McHugh et al., Ph. Rev. D, 1996
- Jenet et al., ApJ, 2006

Earlier Limit Problems

Then

- No GWB simulations – all analytic
  - Fitting, jumps & sampling effects
  - Hard Statistics
- White residuals required (Jenet et al., 2006)

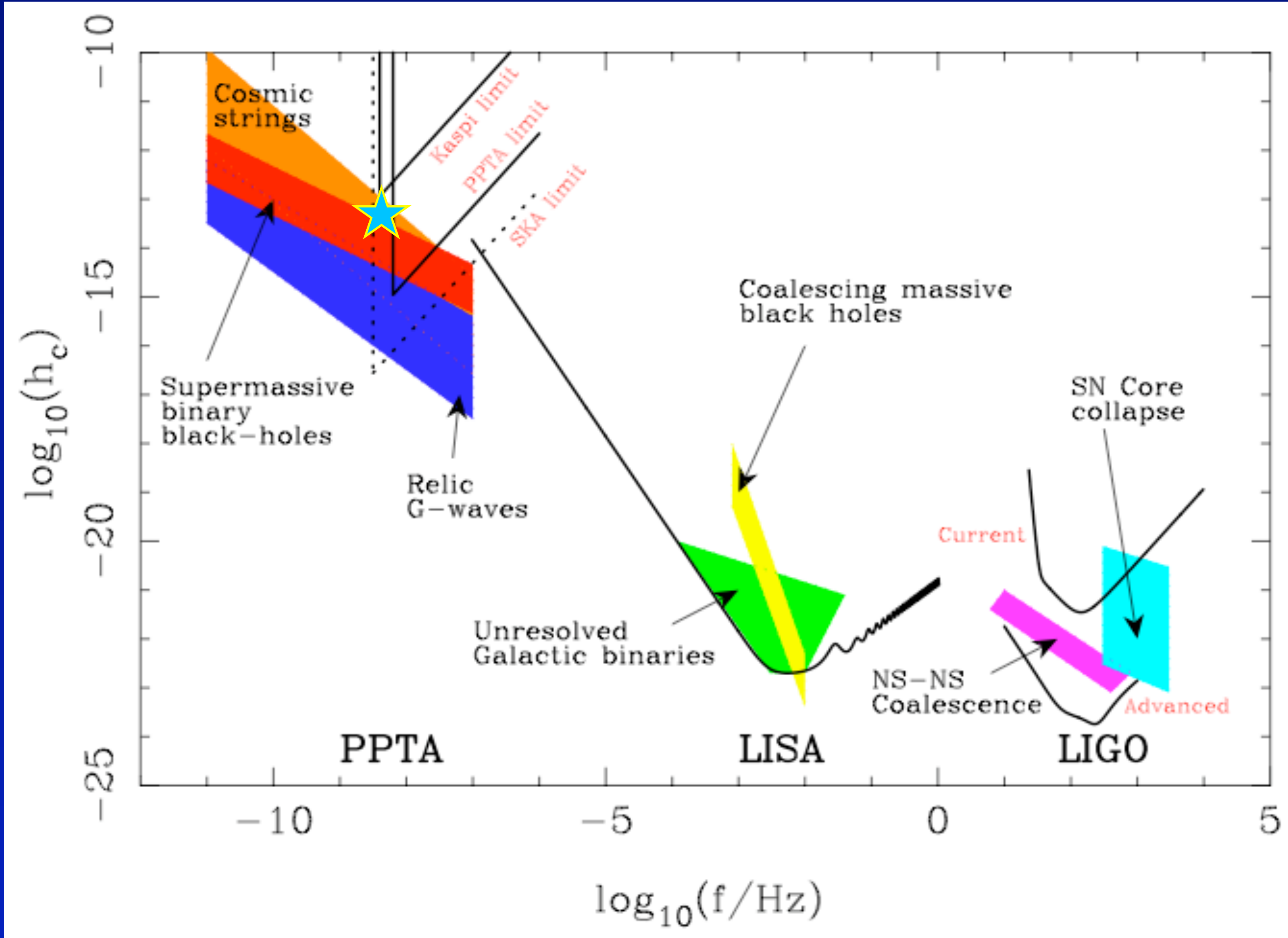
Now

- GWB simulation software
  (Hobbs et al., 2008)
  - Monte-Carlo simulations
- Red noise allowed

Details to be Worked Out

- Precise weighting
  (i.e. combination of frequencies)
- Combination of Pulsars
- Spectral leakage
- Steep spectra

No (New) Limit

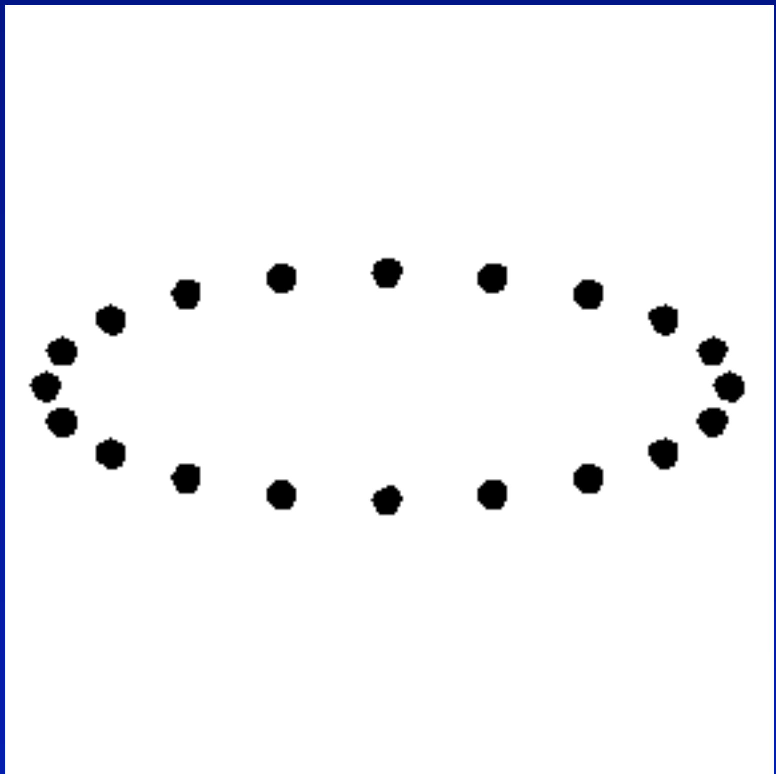


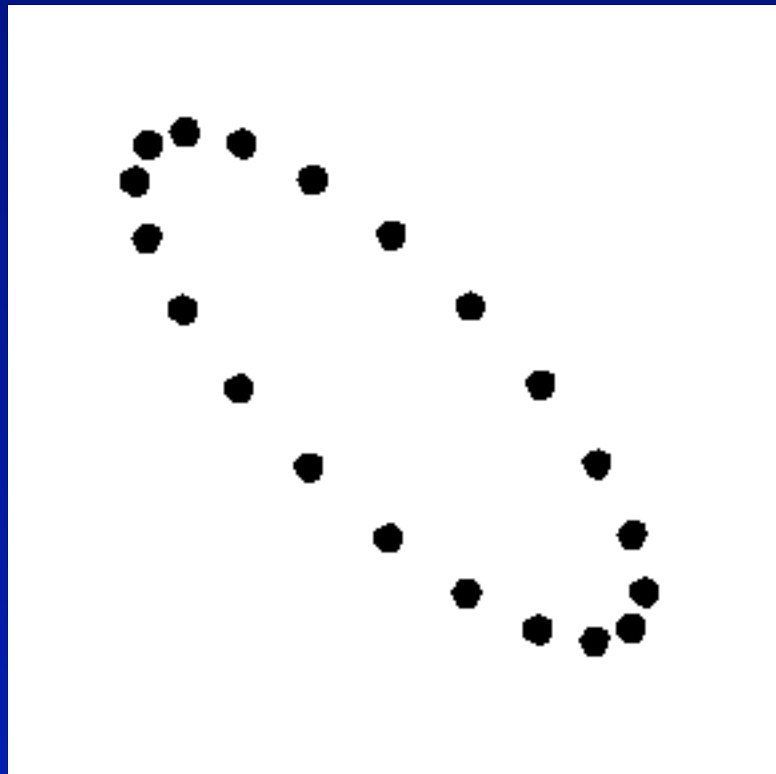
Cosmic strings
Kaspi limit
PPTA limit
SKA limit
Supermassive binary black−holes
Relic G−waves
Coalescing massive black holes
Unresolved Galactic binaries
SN Core collapse
Current
Advanced
NS−NS Coalescence
PPTA
LISA
LIGO
log10(hc)
log10(f/Hz)
−10
−15
−20
−25
−10
−5
0
5

Conclusions

- MSPs are intrinsically stable
- Limits are useful too
- Promising new limit coming soon

Gravitational Wave Effect





Source: Wikipedia

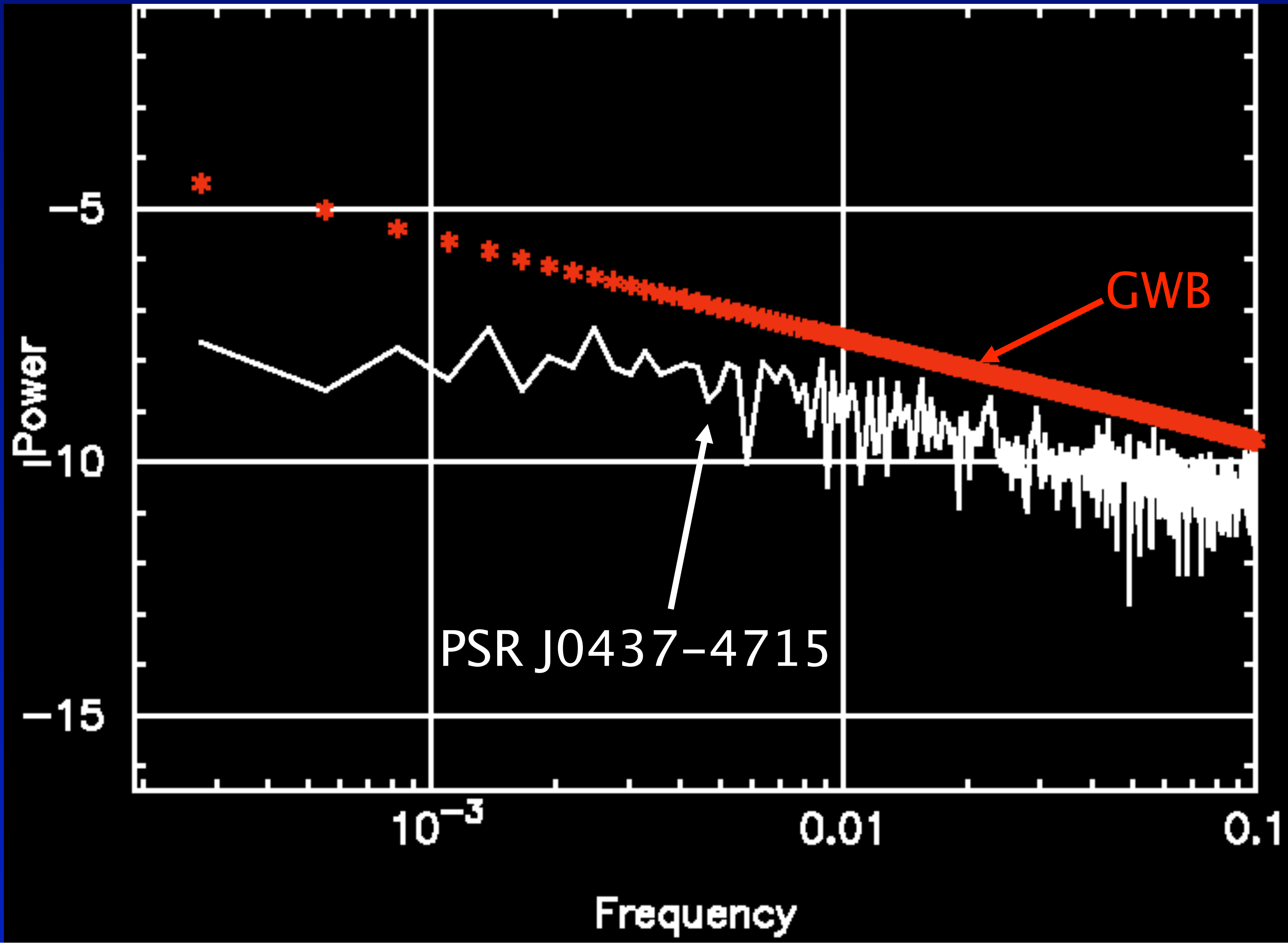
Results (Summary)

No.	JName	rms	Timespan	Npts
1	J1909-3744	167 ns	5.2 yrs	893
2	J0437-4715	199 ns	9.9 yrs	2847
3	J1713+0747	360 ns	14.0 yrs	380
4	J1744-1134	622 ns	13.2 yrs	369
5	J1600-3053	1.19 μs	6.8 yrs	478
6	J1857+0943	1.22 μs	22.2 yrs	382
7	J0613-0200	1.54 μs	8.2 yrs	190
8	J1022+1001	1.61 μs	5.1 yrs	260
9	J2145-0750	1.81 μs	13.8 yrs	377
10	J1824-2452	2.01 μs	2.3 yrs	76
11	J1603-7202	2.09 μs	12.4 yrs	242
12	J2129-5721	2.28 μs	12.5 yrs	179
13	J1730-2304	2.51 μs	14.0 yrs	180
14	J1643-1224	2.58 μs	14.0 yrs	276
15	J1732-5049	3.39 μs	6.8 yrs	129
16	J0711-6830	3.61 μs	14.2 yrs	236
17	J1024-0719	4.18 μs	12.1 yrs	262
18	J2124-3358	5.42 μs	13.8 yrs	423
19	J1045-4509	6.31 μs	14.1 yrs	364
20	J1939+2134	20.1 ns	23.3 yrs	654

GC

Timing Noise

GWB vs. Pulsar Spectrum



Stability: Examples: 1713

PSR J1713+0747:

362 ns over 14 yrs