Long-term Timing at Arecibo and Green Bank

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Goals and Strategies of the Program

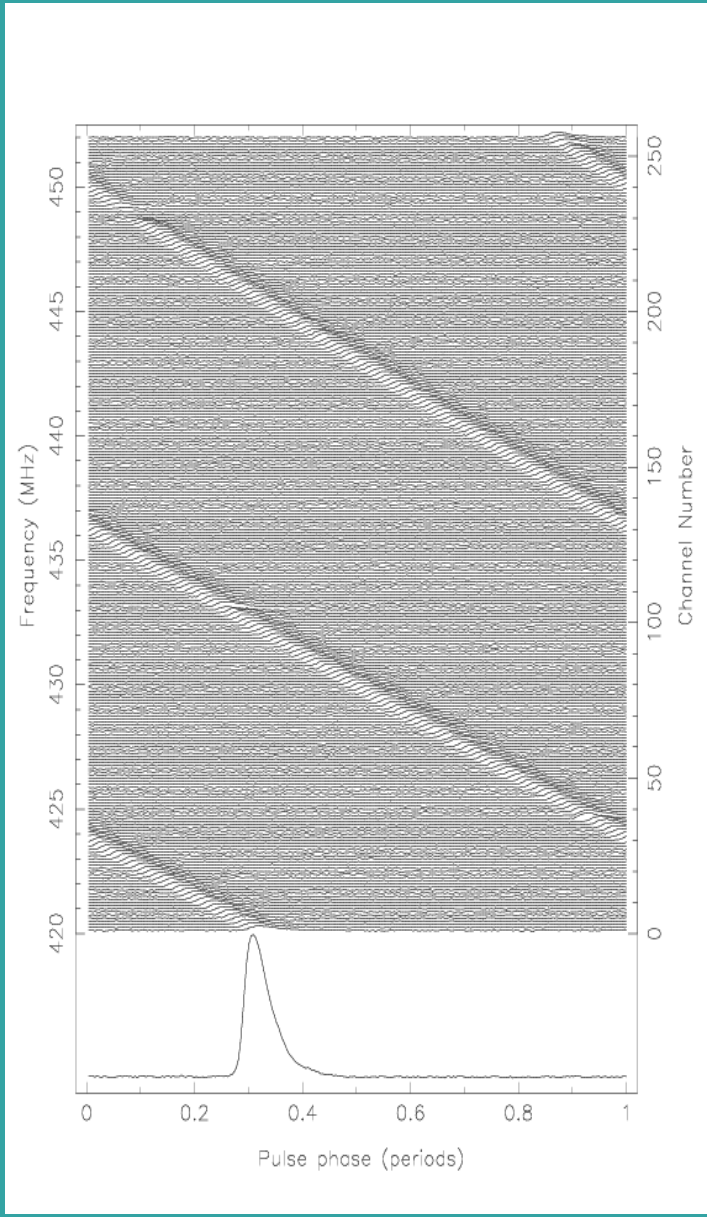
We want to:

- Set limits on (or detect!) a gravitational-wave background
- Investigate pulsar evolution, masses, velocities, etc.
- Learn about the variations in the ISM
- Investigate intrinsic pulsar timing stability

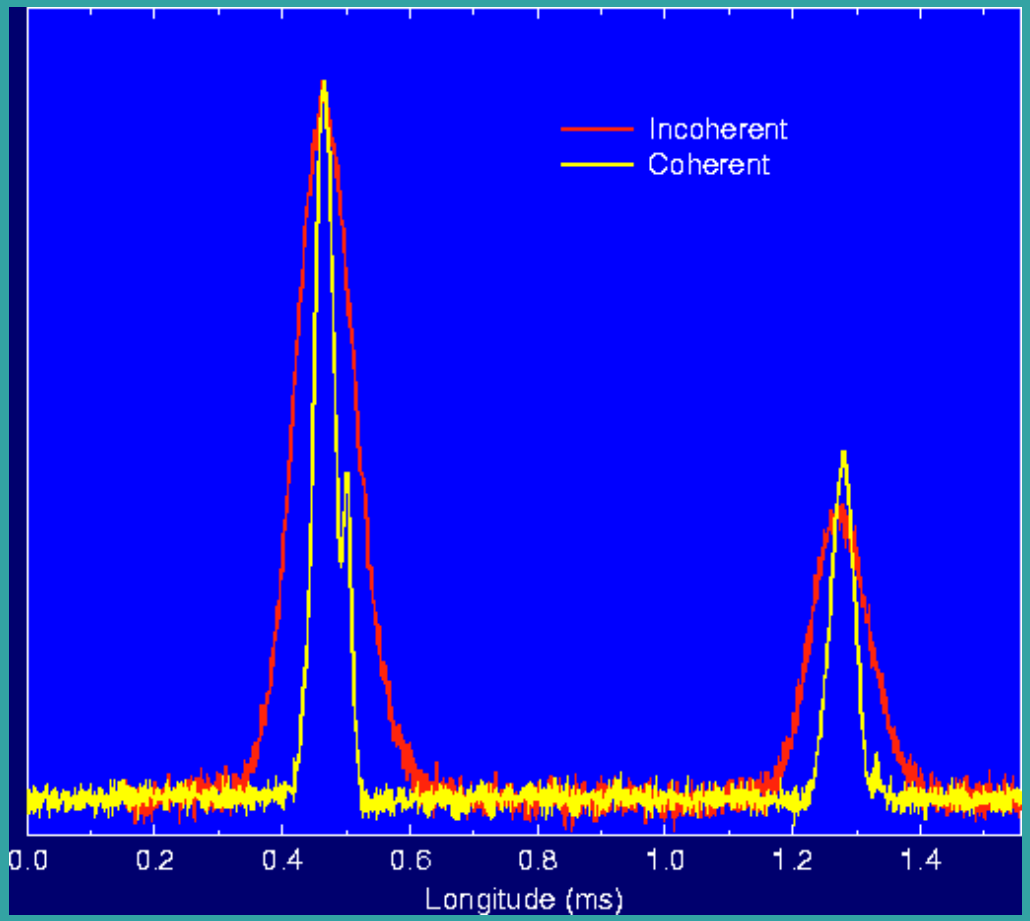
Therefore we:

- Monitor a large set of millisecond (some binary) pulsars at different positions on the sky
- Sample every 2—4—6 weeks
- Observe at 2+ frequencies for each pulsar
- Use state-of-the-art data acquisition equipment

Dispersion and its Removal



Filterbank: residual smearing in channels



Coherent Dedispersion: computationally intensive, but sharper profiles ⇒ better timing

ASP and GASP

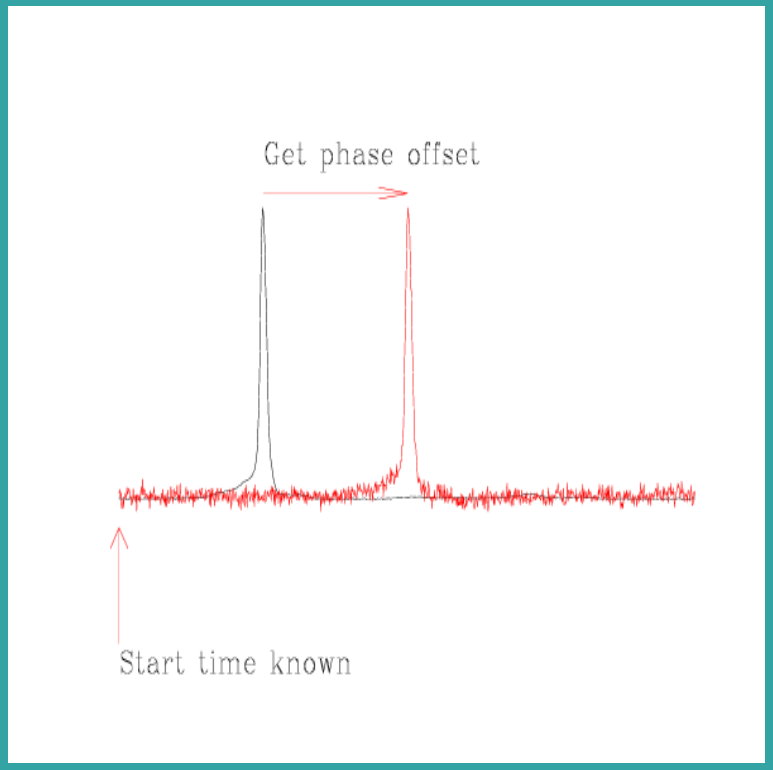
ASP (Arecibo Signal Procesor) and GASP (Green-Bank Astronomical Signal Processor):

- Wideband (64—128 MHz) coherent dedispersion (16—32 4-MHz channels)
- 8-bit sampling for excellent profile fidelity
- Linux beowulf clusters perform dedispersion and folding including Stokes in real time
- Possibility to dump dedispersed time series, also full-Stokes
- Funding from NSERC and NSF

ASP at Arecibo

High-precision Timing

Cross-correlation with standard profile: Time-of-Arrival (TOA)



- Transform to Solar System Barycentre
- Fit spin and astrometric parameters, and binary parameters if needed.

Secret to success:
count every rotation
of the neutron star!

Issues in Precision Timing

- Need to eliminate (as far as possible) machine- and RFI-related systematics
- Need a good solar system ephemeris – DE405 is now our standard – and timescale – we use TT(BIPM).
- Need to be careful in subtracting out all relevant solar-system effects; TEMPO2 will be an improvement over standard TEMPO for these purposes
- Need to be sure of identifying and fitting all pulsar-related parameters, such as timing noise, proper motion, Shapiro delay...
- Need to keep track of DM variations and separate these from timing noise and proper motion!

Source Lists

Arecibo

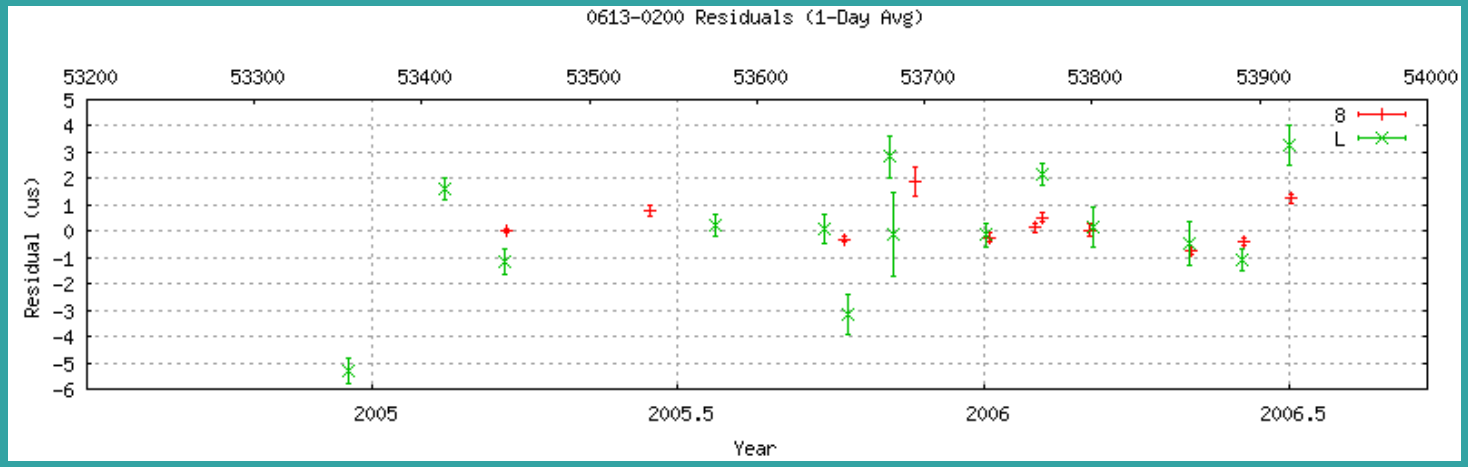
J1640+2224
J1713+0737
B1855+09
B1937+21
J2019+2425
J2033+1734
J2317+1439
J0030+0450

GBT

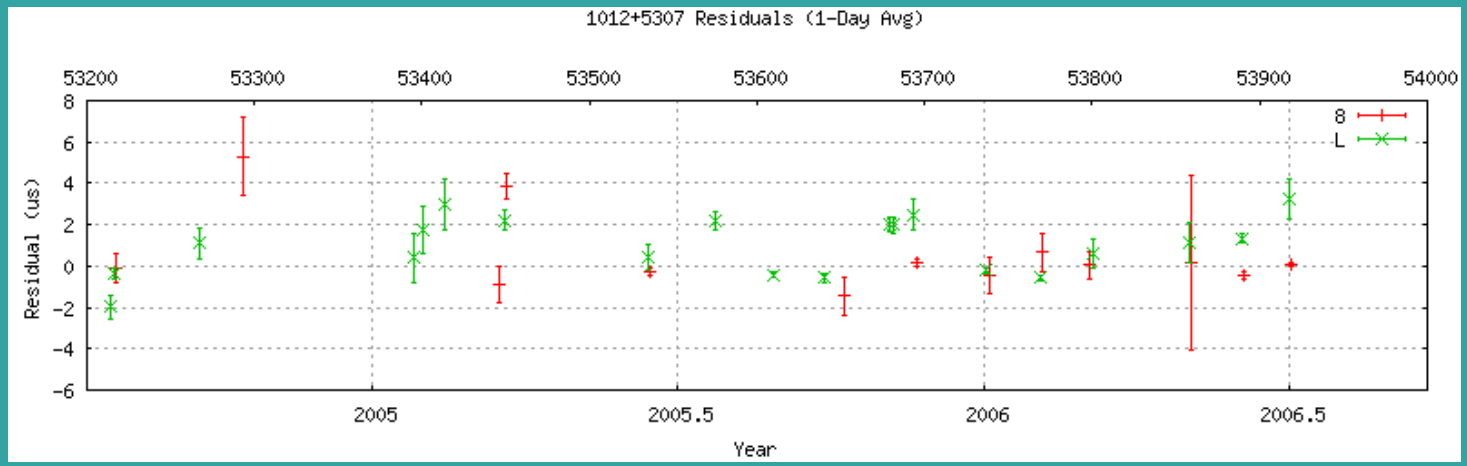
J0281+4232
J0613-0200
J1012+5307
J1455-3330
J1642-1224
J1713+0747
J1744-1134
B1821-24
J1909-3744
J1918-0642
B1937+21
J2124-2258
J2145-0750

Some (Preliminary) GBT Residuals...

J0613-0200:
1.2-day binary

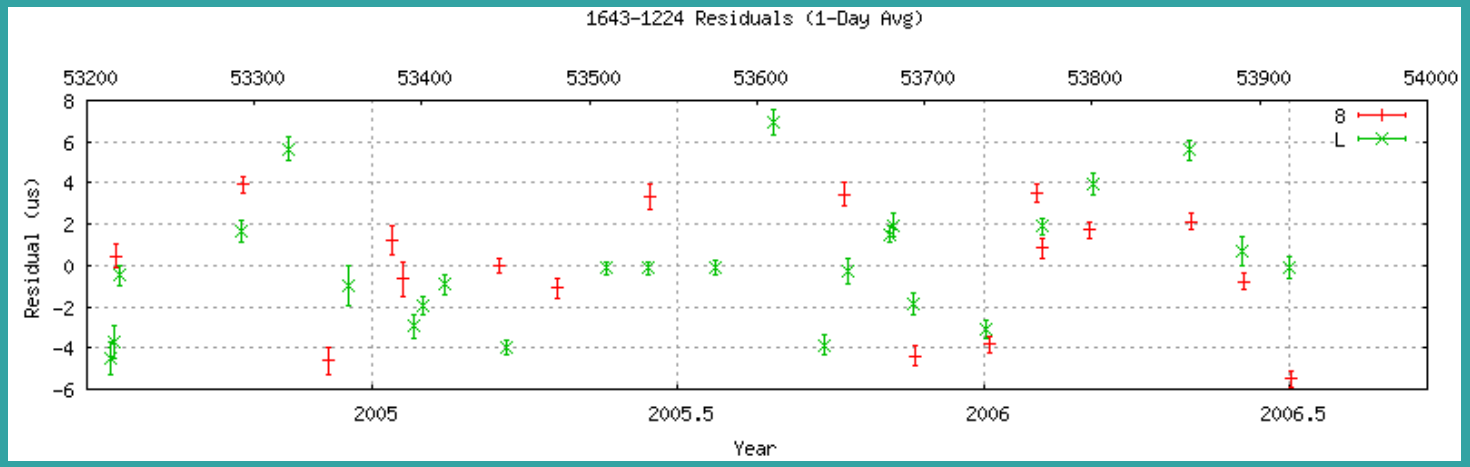


J1012+5307:
16-hour
binary



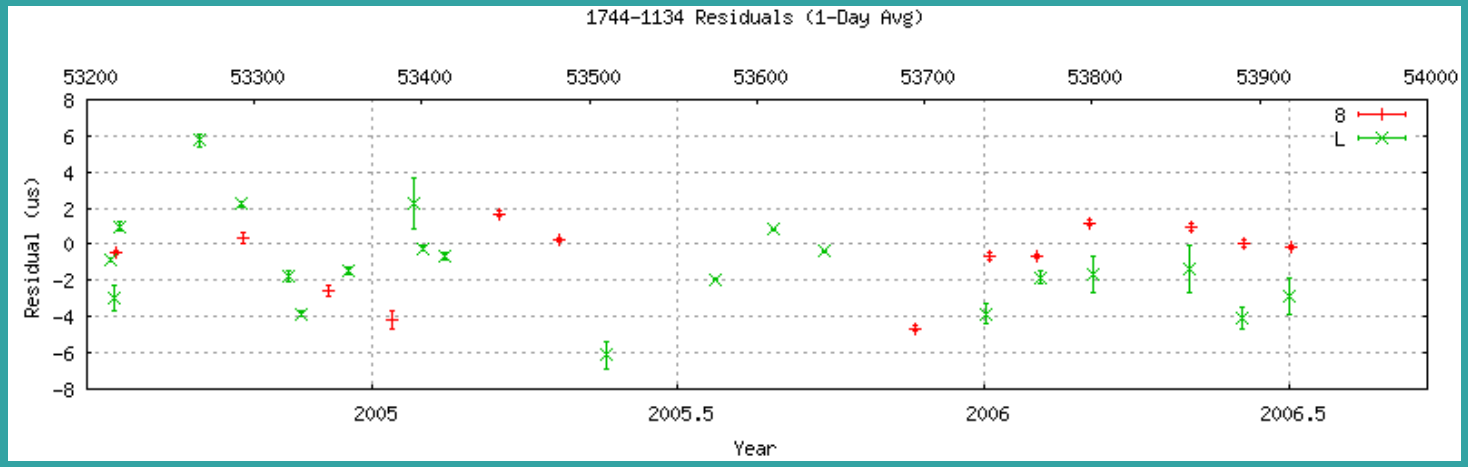
Some More (Preliminary) GBT Residuals...

J1643-1224:
147-day binary



J1744-1134:
isolated.

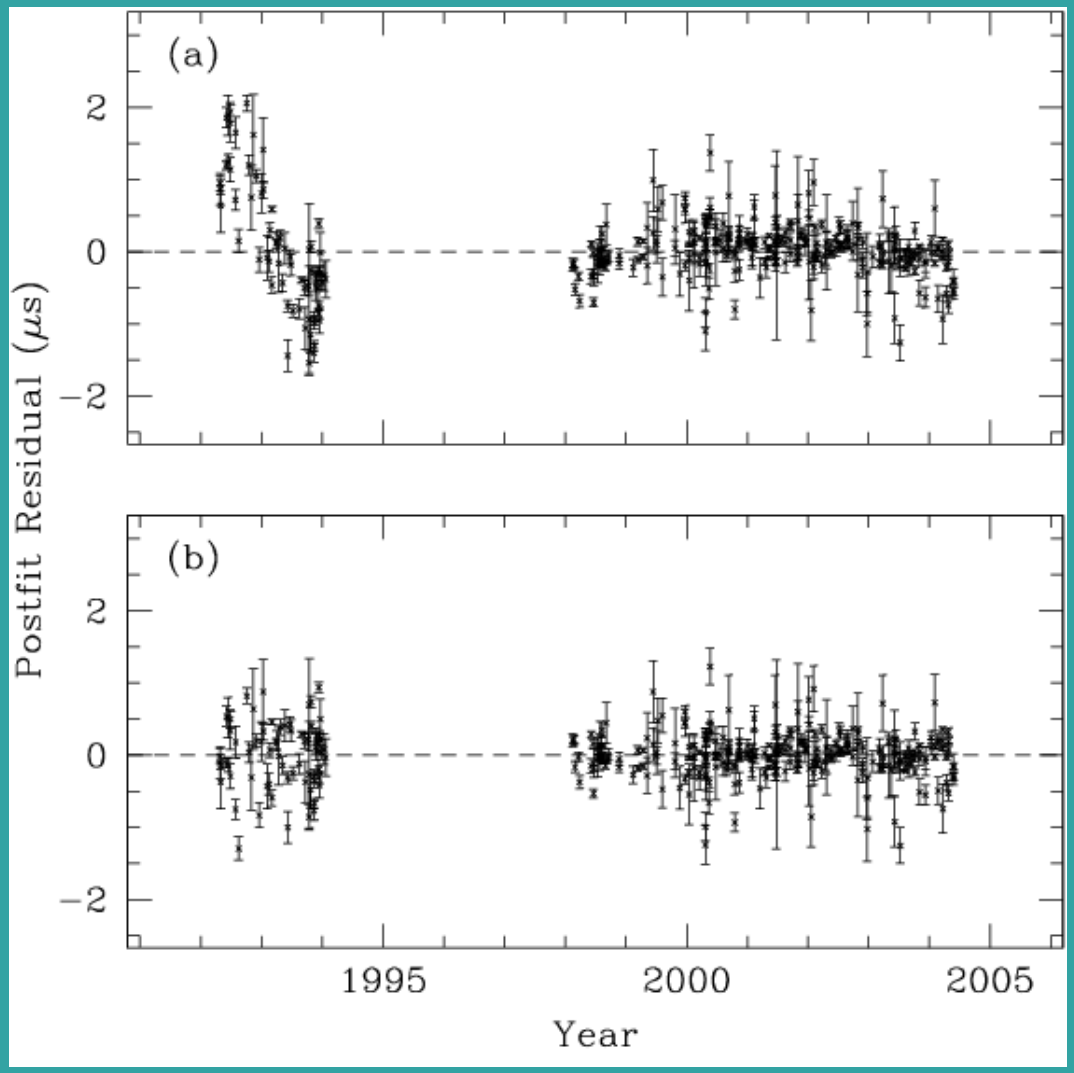
Note parallax signature (cf Toscano et al 1999).



Arecibo Timing: J1713+0747

A success story: Splaver et al. 2005

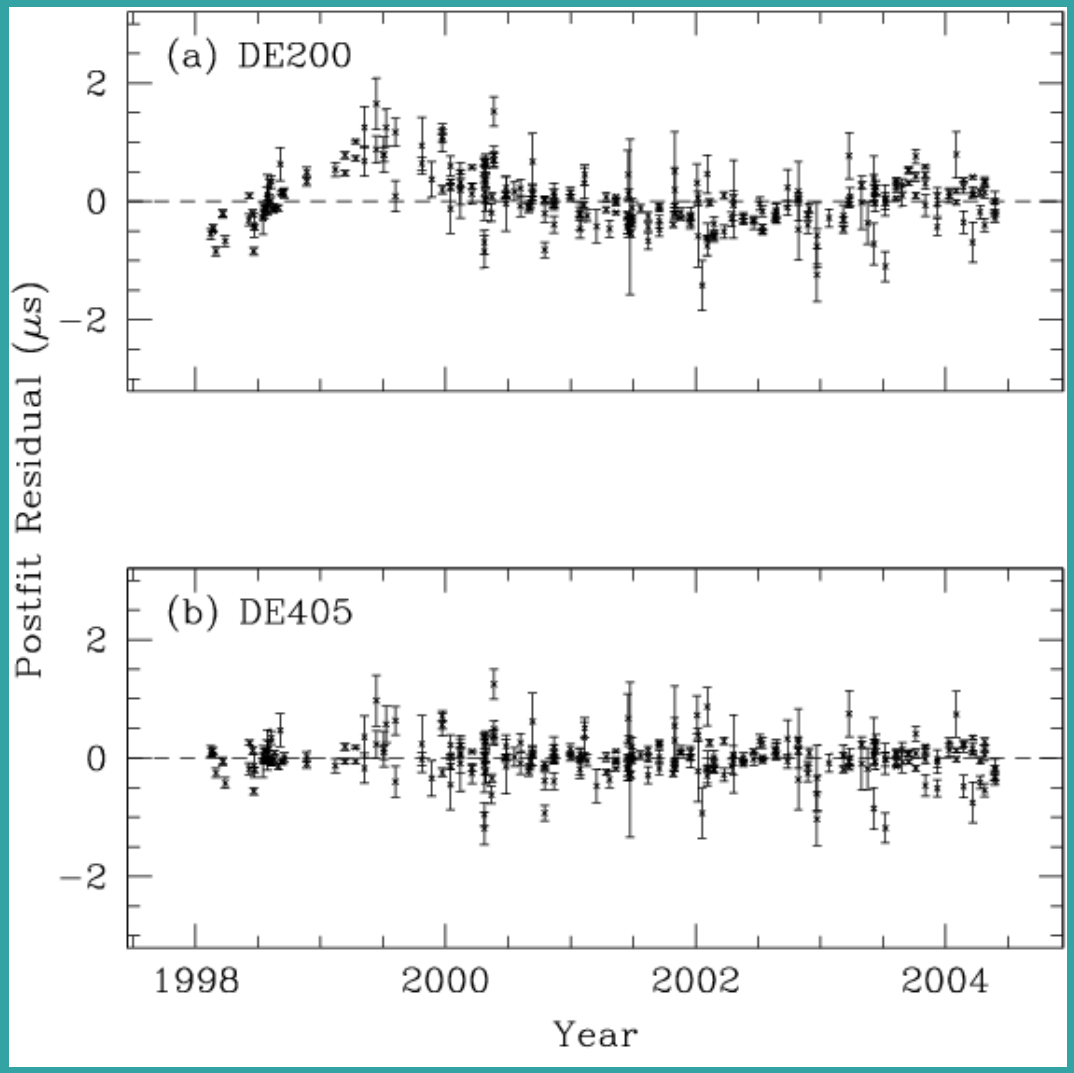
Residuals show timing noise (8 frequency dericatives needed!) but we were still able to determine accurate binary parameters and investigate stability and ephemeris quality.



Arecibo Timing: J1713+0747 2.

Demonstration that DE405 is a far better ephemeris to use than DE200.

Better mass measurements of the outer planets account for the difference.



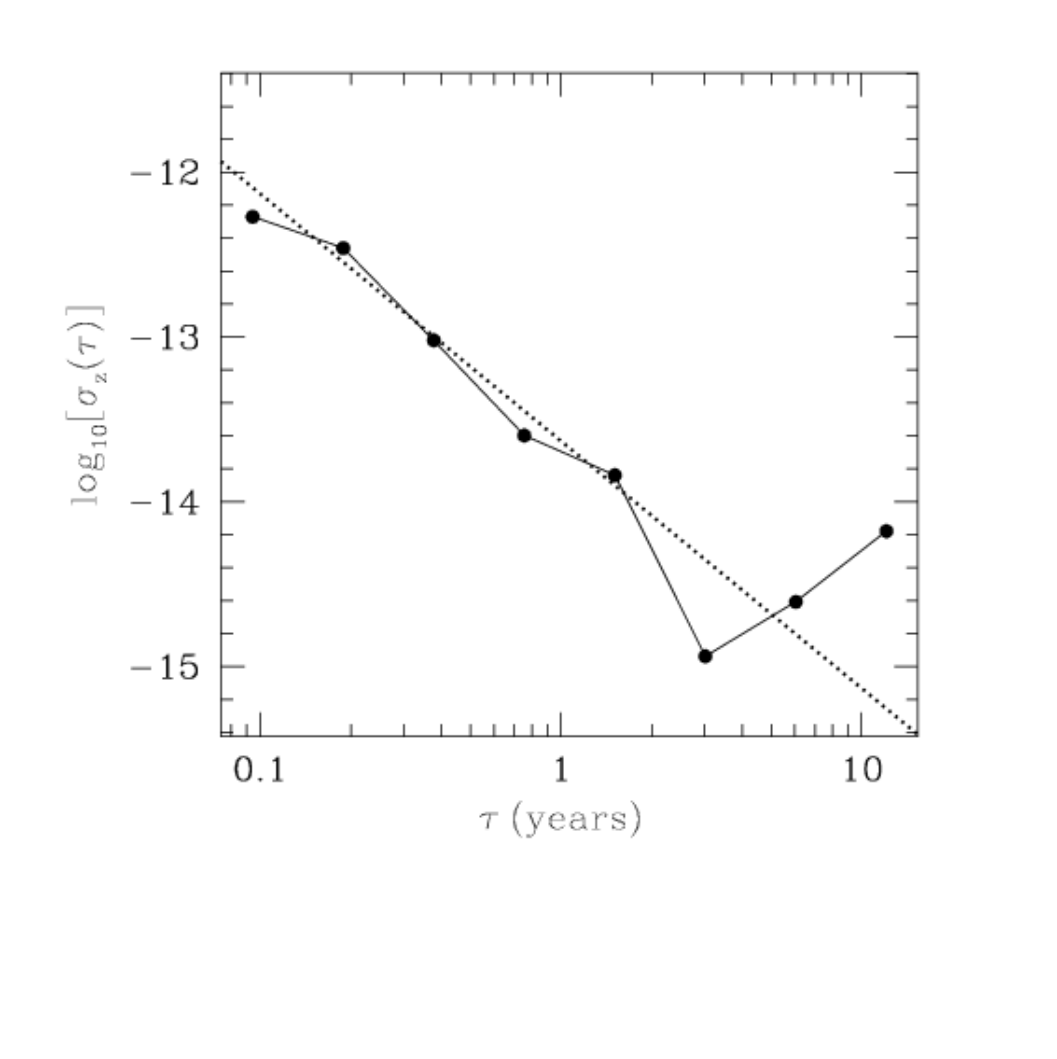
Splaver et al. 2005

Arecibo Timing: J1713+0747 3.

σ_z statistic (Matsakis et al. 1997) for J1713+0747.

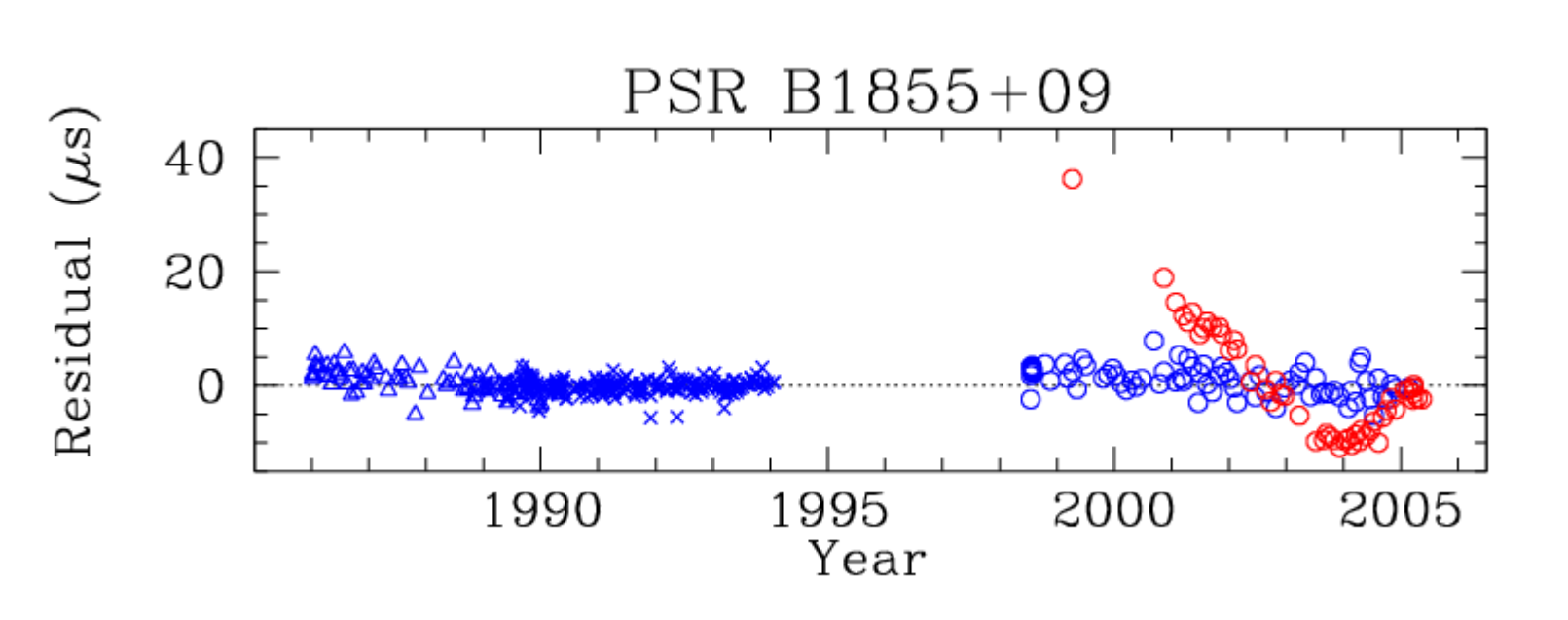
Short-timescale: stable, consistent with random noise.

Longer timescales: timing noise increases the statistic. (NB we also fit an arbitrary offset between pre- and post-upgrade data.)



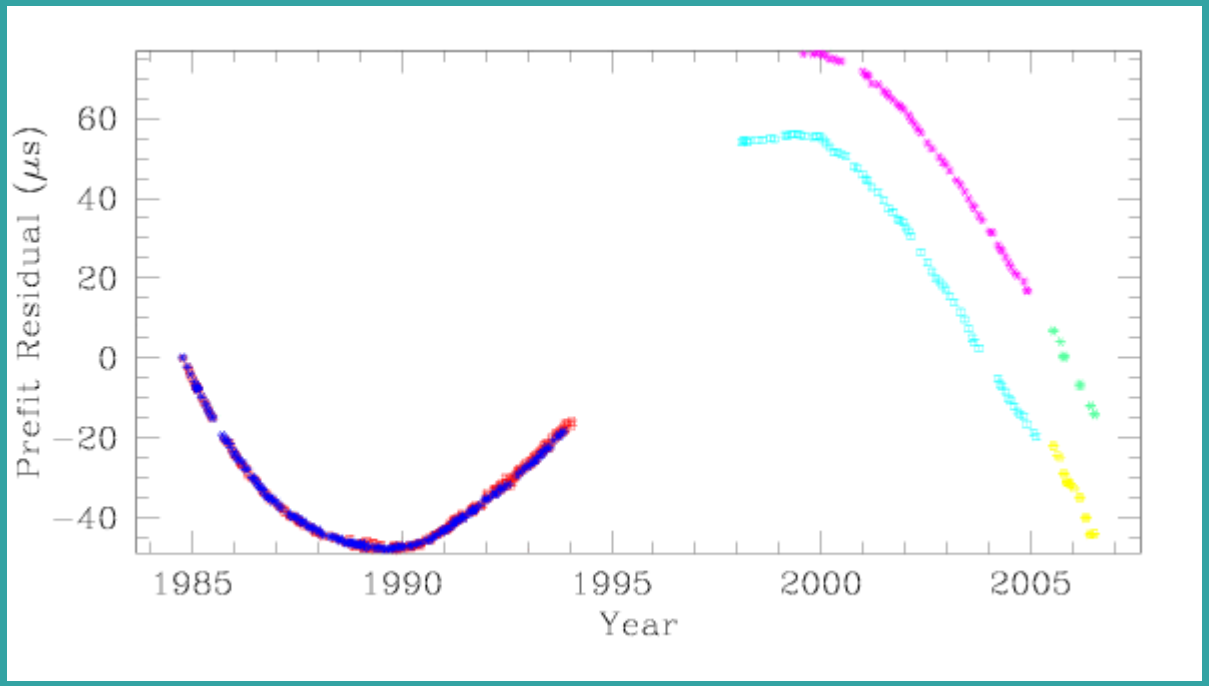
Splaver et al. 2005

Arecibo Timing: B1855+09



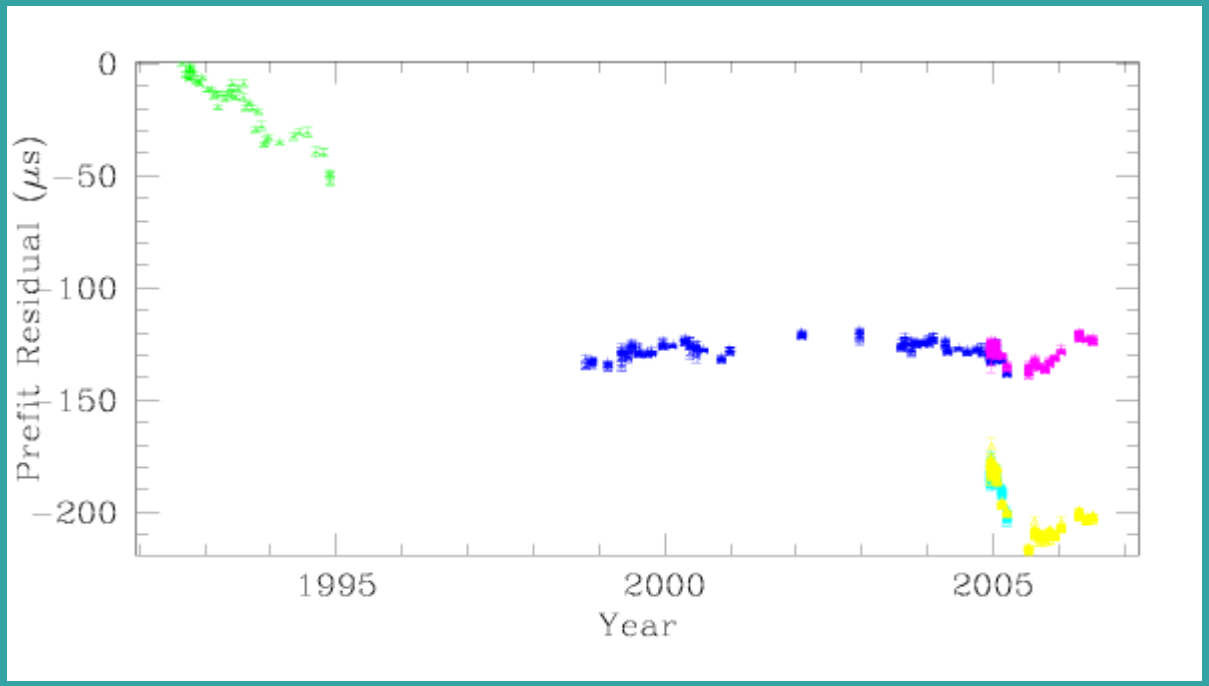
From David Nice's talk in JD02 on Pulsar Astronomy.
Blue = 1400 MHz, red = 430 MHz.
Large DM variations are measurable in the post-upgrade era, but are impossible to include in pre-upgrade (Kaspi et al 1994) data. This will complicate the interpretation of the pulsar's stability!

Arecibo Timing: B1937+21



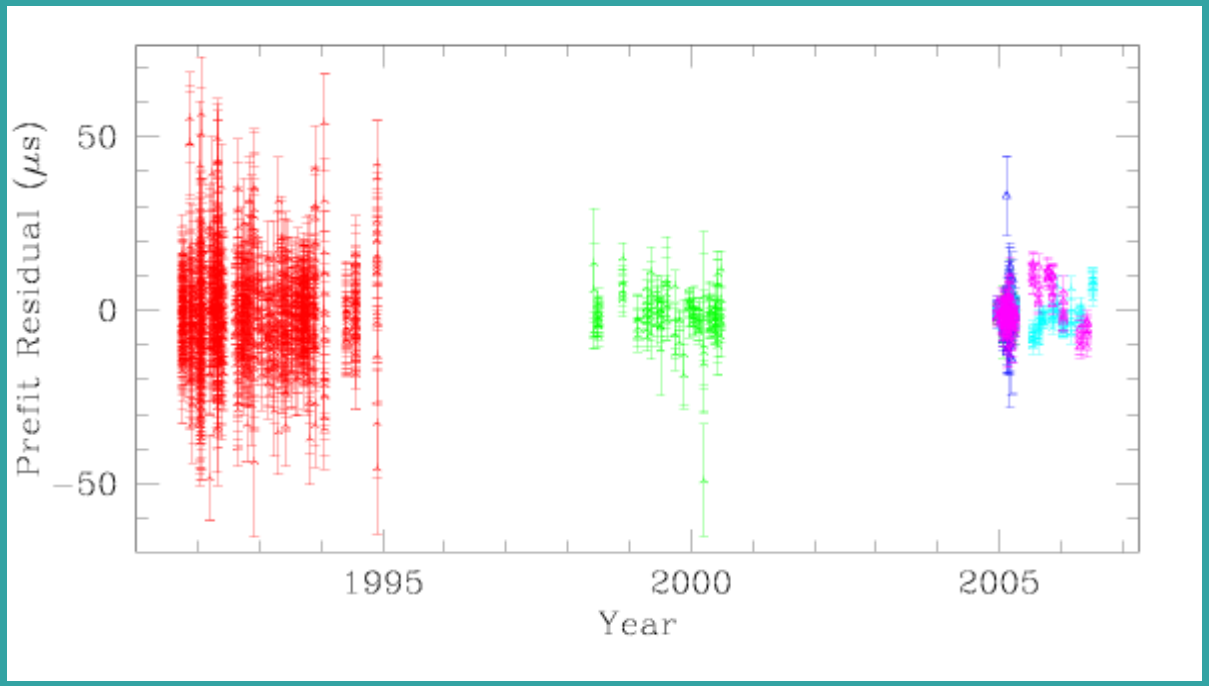
Blue/red: pre-upgrade, individual-day DMs included
Cyan/yellow: Mark IV/ASP 1410 MHz
Magenta/green: Mark IV/ASP 2380 MHz
Large DM variations are present, in addition to very significant timing noise.

Arecibo Timing: J2317+1439



Green: pre-upgrade, 430 MHz
Blue/magenta: Mark IV/ASP 430 MHz
Cyan/yellow: Mark IV/ASP 327 MHz
Large DM variations and timing noise are present.
Lack of dual-frequency data before late 2004
is problematic.

Arecibo Timing: J2019+2425



Red: pre-upgrade, 430 MHz
Green/magenta: Mark IV/ASP 430 MHz
Blue/Cyan: Mark IV/ASP 327 MHz
Again DM variations are important!
Lack of dual-frequency data before late 2004 is problematic.

Conclusions

- Even the best millisecond pulsars exhibit timing noise on timescales of 5+ years and DM variations on much shorter timescales.
- Do not trust timing stability claims based on single-frequency data!
- With good time and frequency coverage, we can fit out DM variations and investigate timing stability.
- Given that all pulsars seem to show timing noise if we observe long enough, a pulsar-based time standard is likely impractical.