Pulsar timing noise

implications for GW searches

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What is timing noise?

- The spins of *all* pulsars evolve in a remarkably predictable manner characterised by their spin frequency, n , and spindown rate, $\dot{n}$, measured at some reference time.
- However, some (particularly young) pulsars show small departures from this simple timing model that can impact on GW searches.
- These departures appear as *timing noise* and *glitches*, both of which seem to be tracers of irregularities in the rotation of the neutron star, probably related to changes in the moment of inertia of the pulsar and/or the transfer of angular momentum from the fluid core.
- As a rule-of-thumb, pulsars with high spindown rates (which are by definition young) also show high timing instabilities.

Timing noise characterisation

- We can model the rotational phase of the pulsar as

$$f(t) = f_0 + n t + \tfrac{1}{2}\dot{n} t^2 + \tfrac{1}{6}\ddot{n} t^3 + \ldots$$

Initial phase

Initial frequency

Initial spindown rate

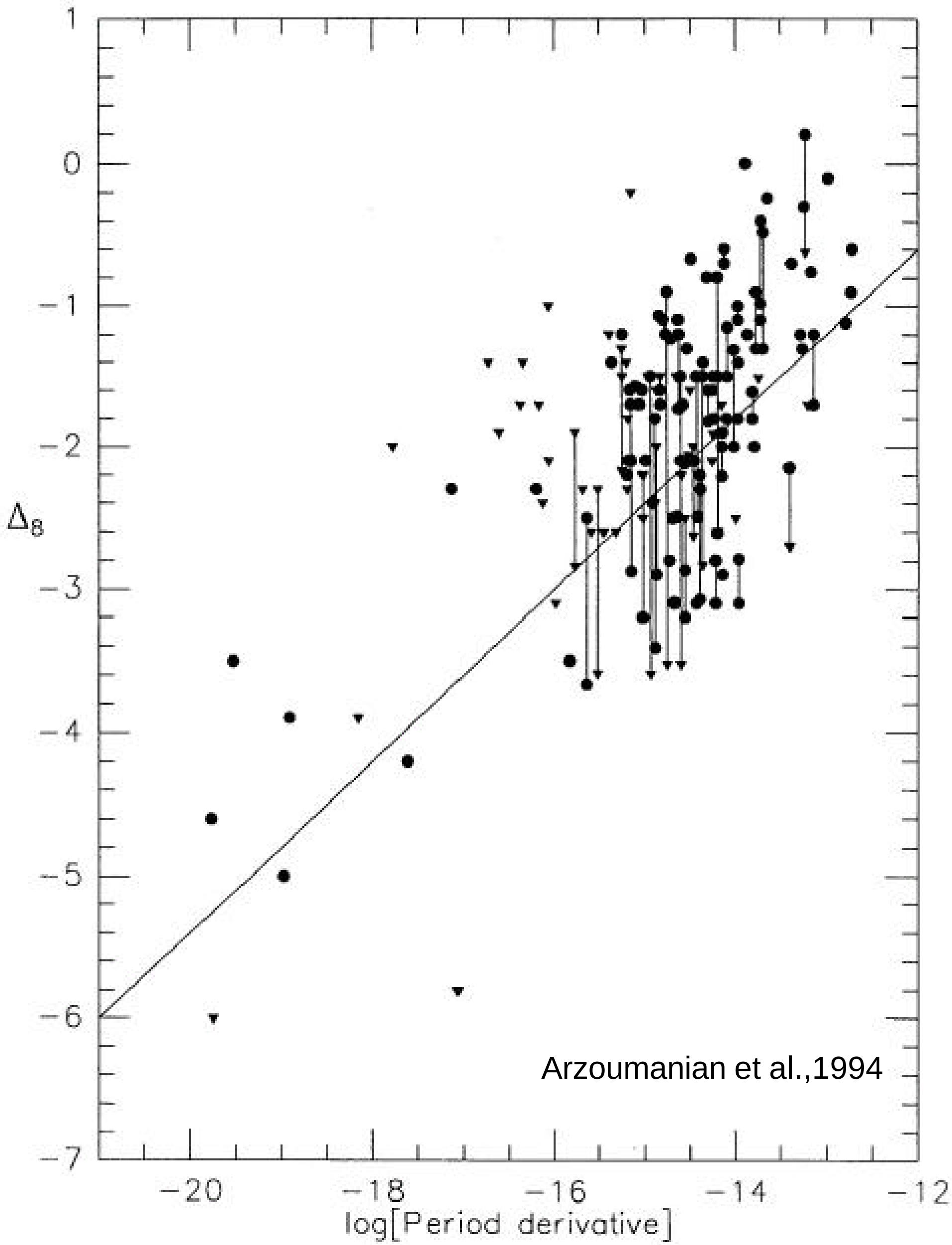
First term containing significant timing noise

and characterise the timing noise as $\Delta_8 = \log_{10}\left(\frac{1}{6n}|\ddot{n}|\, t^3\right)$, with $t = 10^8$s (Arzoumanian et al. 1994)

- Δ_8 is approximately (the log of) the pulsar timing error, in seconds over a sampled (or extrapolated) ~3 year period.

- Note that a finite $\ddot{n}$ is also expected from the simple magnetic dipole spindown model, but this component is usually swamped by the timing noise, particularly in older pulsars. Indeed, stable values exist for only about 5 pulsars (including the Crab and Vela).

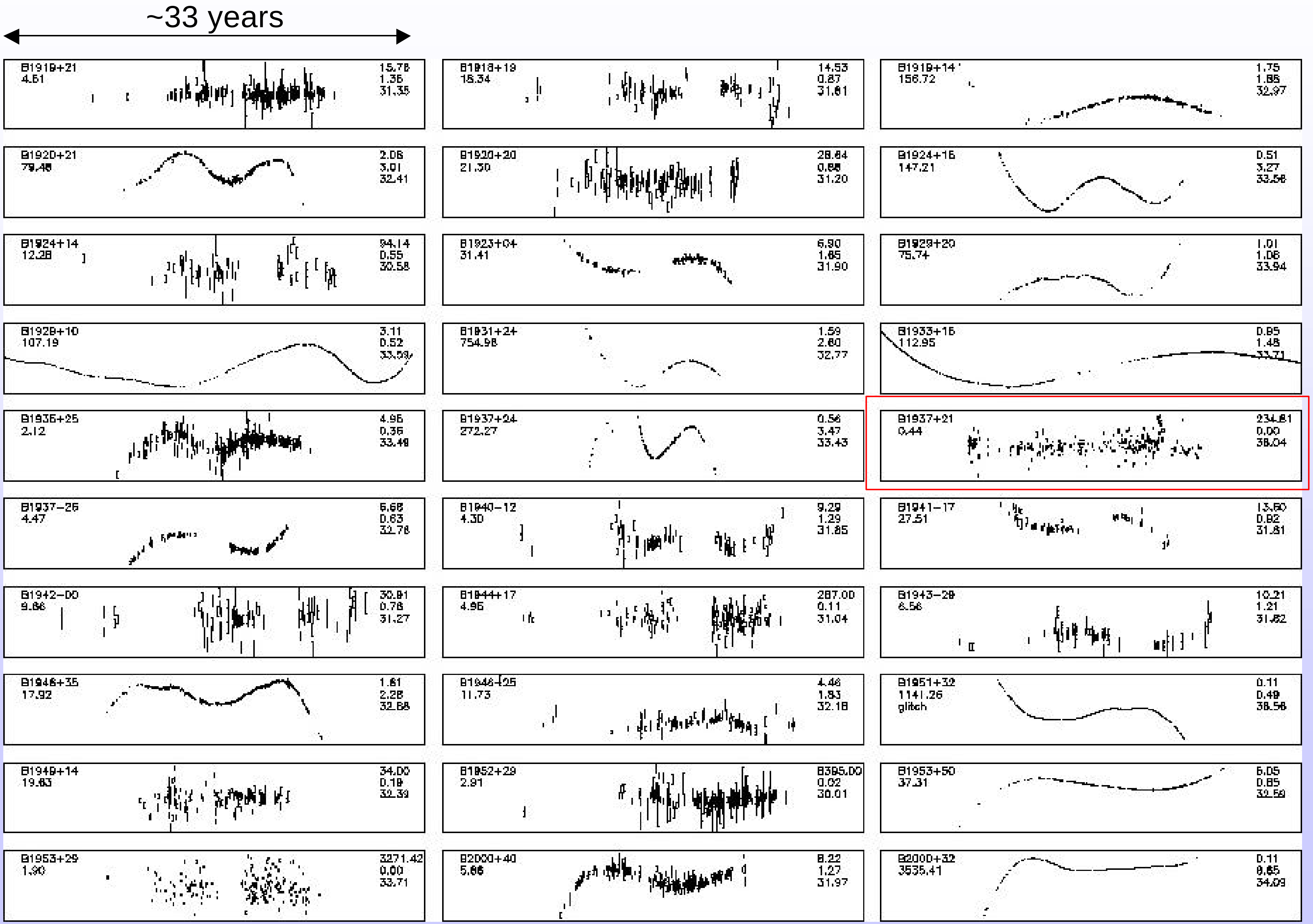
Dependence on period derivative



- There is a reasonable correlation between stochastic timing noise and spindown rate, with young pulsars (high Pdot) tending to be noisier. These may also be the most promising candidates for GW sources.
- For millisecond pulsars (low Pdot) it can be difficult to distinguish true timing noise from data reduction errors introduced by uncertainties in the solar system ephemeris and in atomic time.

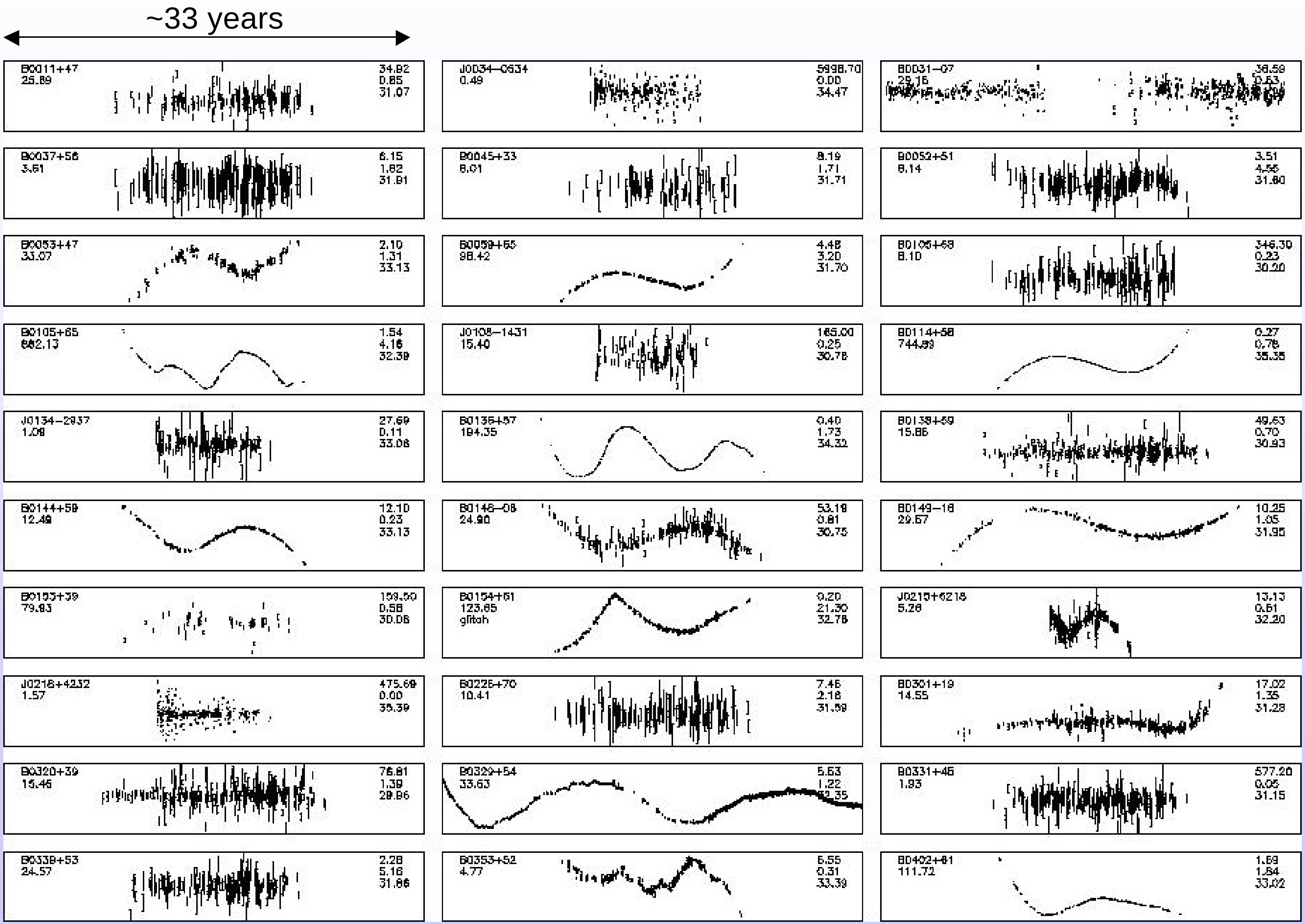
Examples of timing noise

(Hobbs, 2003)



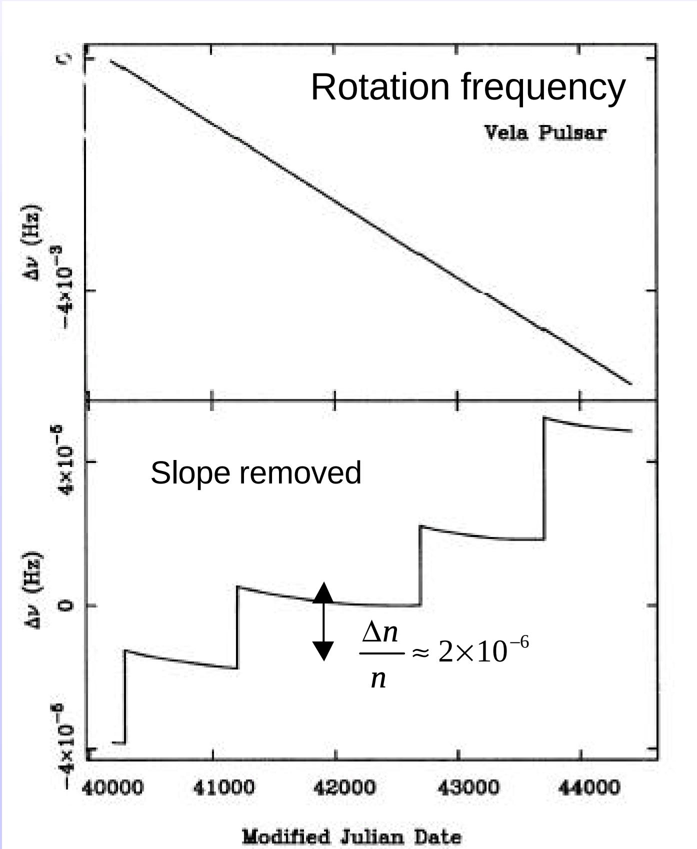
Examples of timing noise

(Hobbs, 2003)

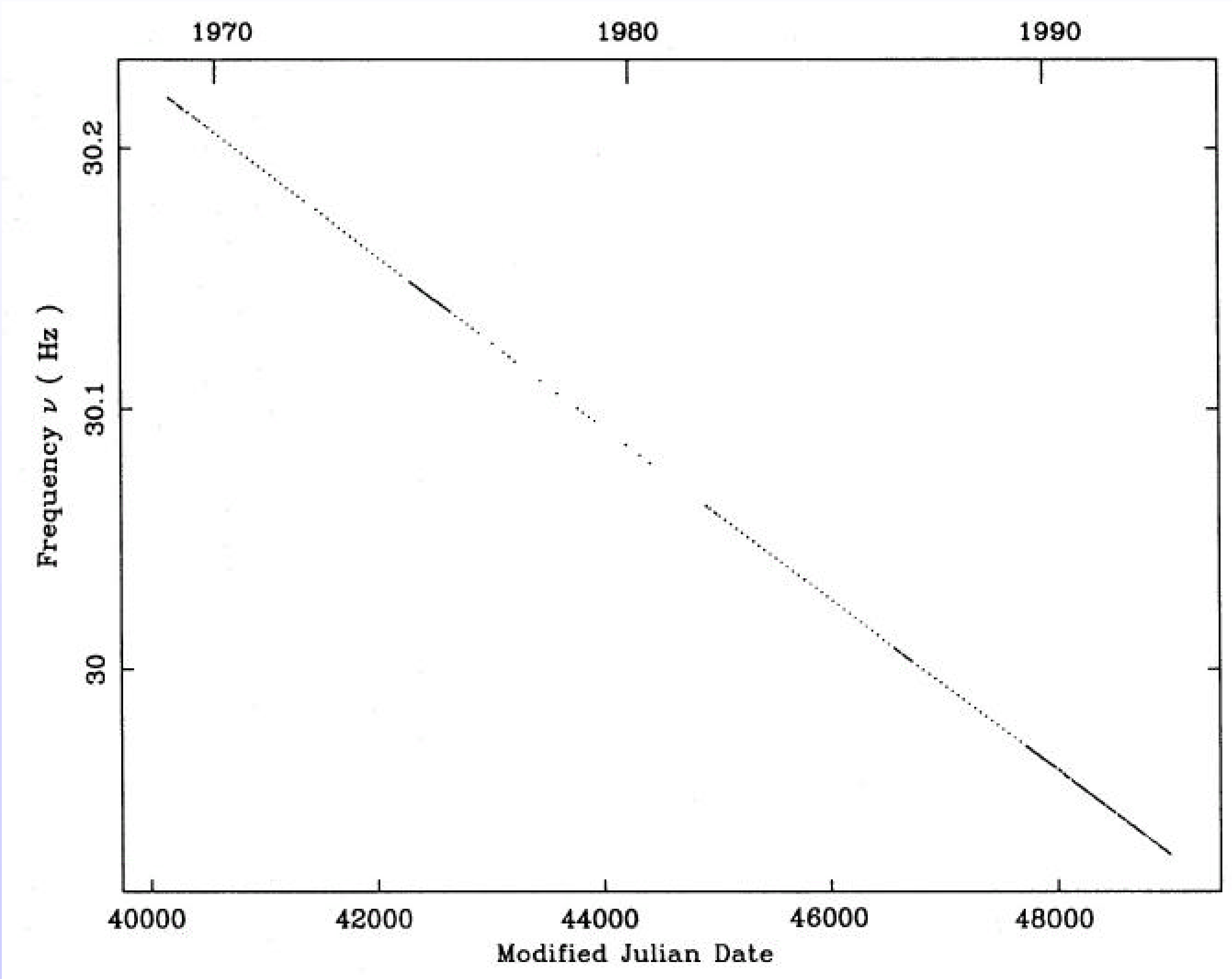


Glitches

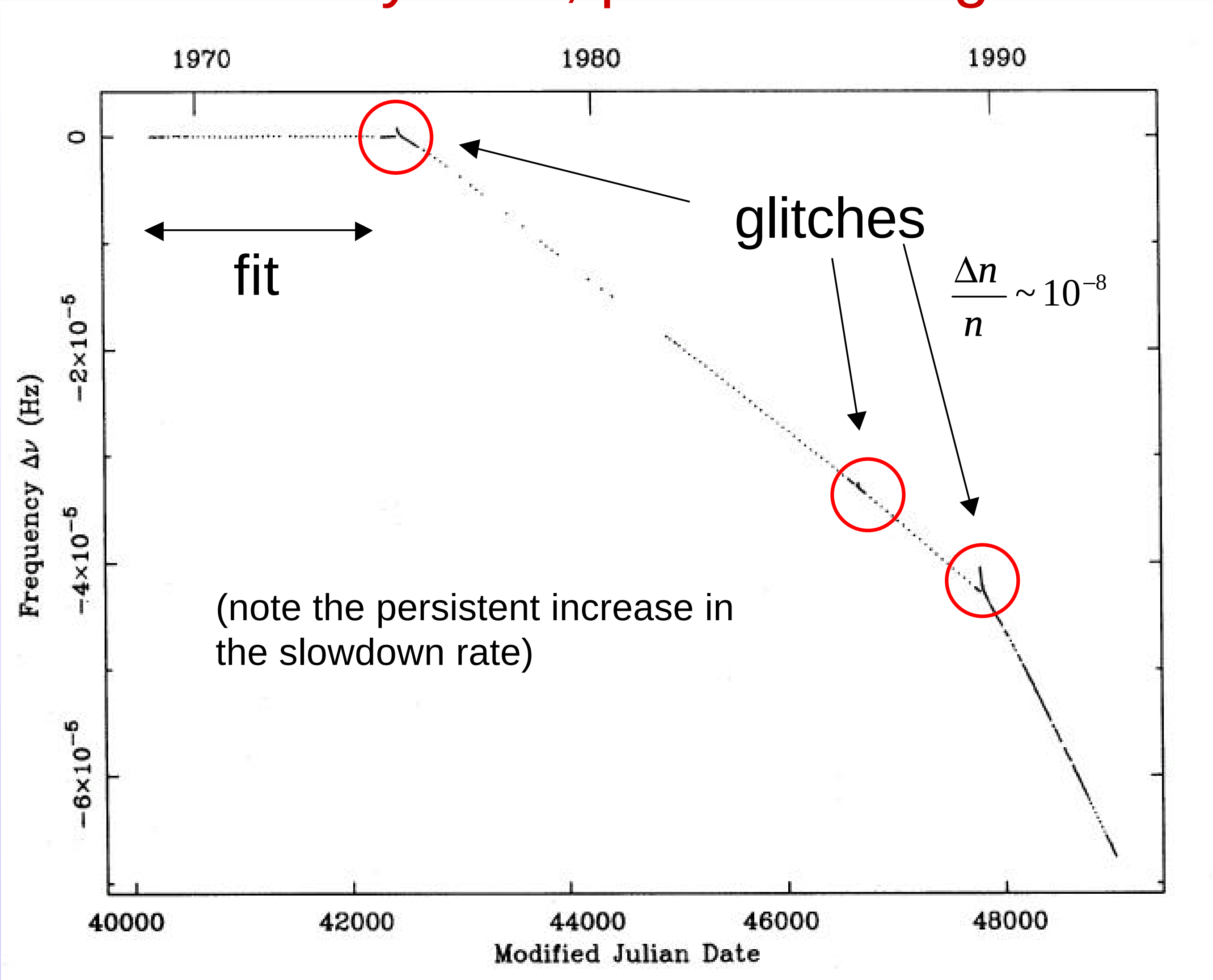
- Sudden change (increase) in rotation rate, followed by an exponential recovery.
- Seen in only ~21 (~3%) pulsars, mostly young. Only 5 have been seen to glitch more than twice.
- Timing noise *may* simply be a superposition of many small glitches.



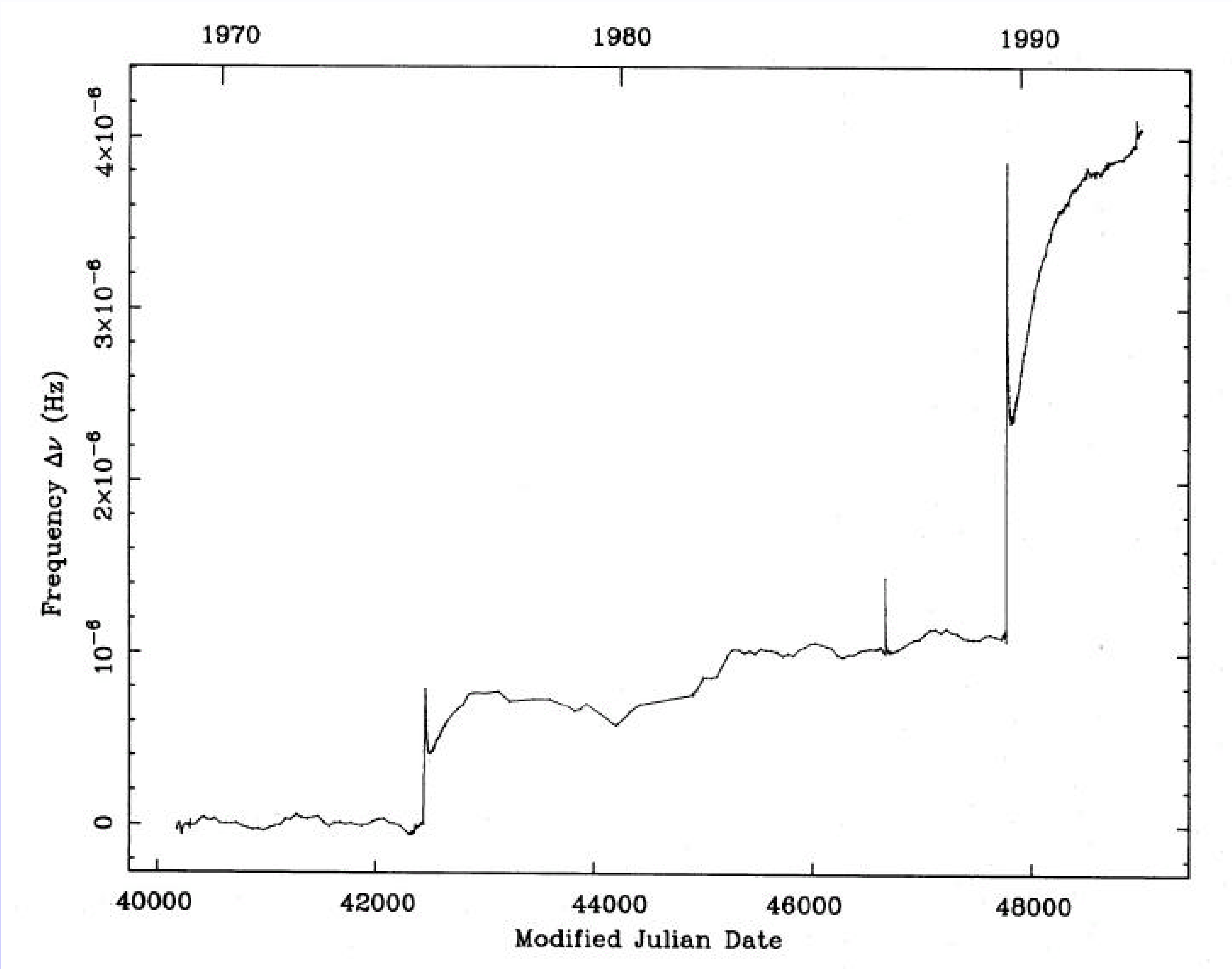
Crab pulsar rotation rate 1969-1993 (Lyne et al 1993)



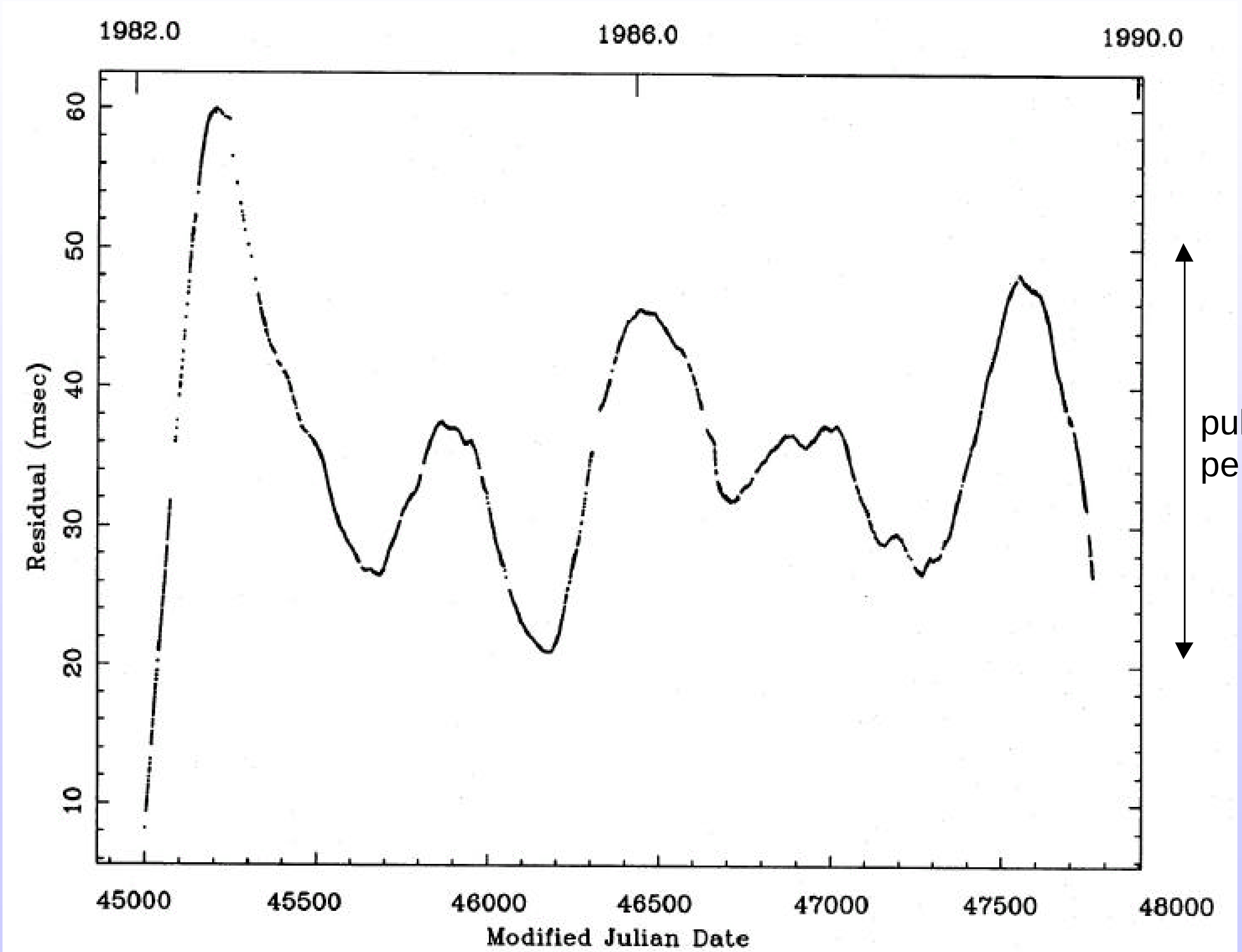
Deviation from a 3rd order polynomial fit to the early data, prior to first glitch



After fitting for post-glitch steps in slowdown rate

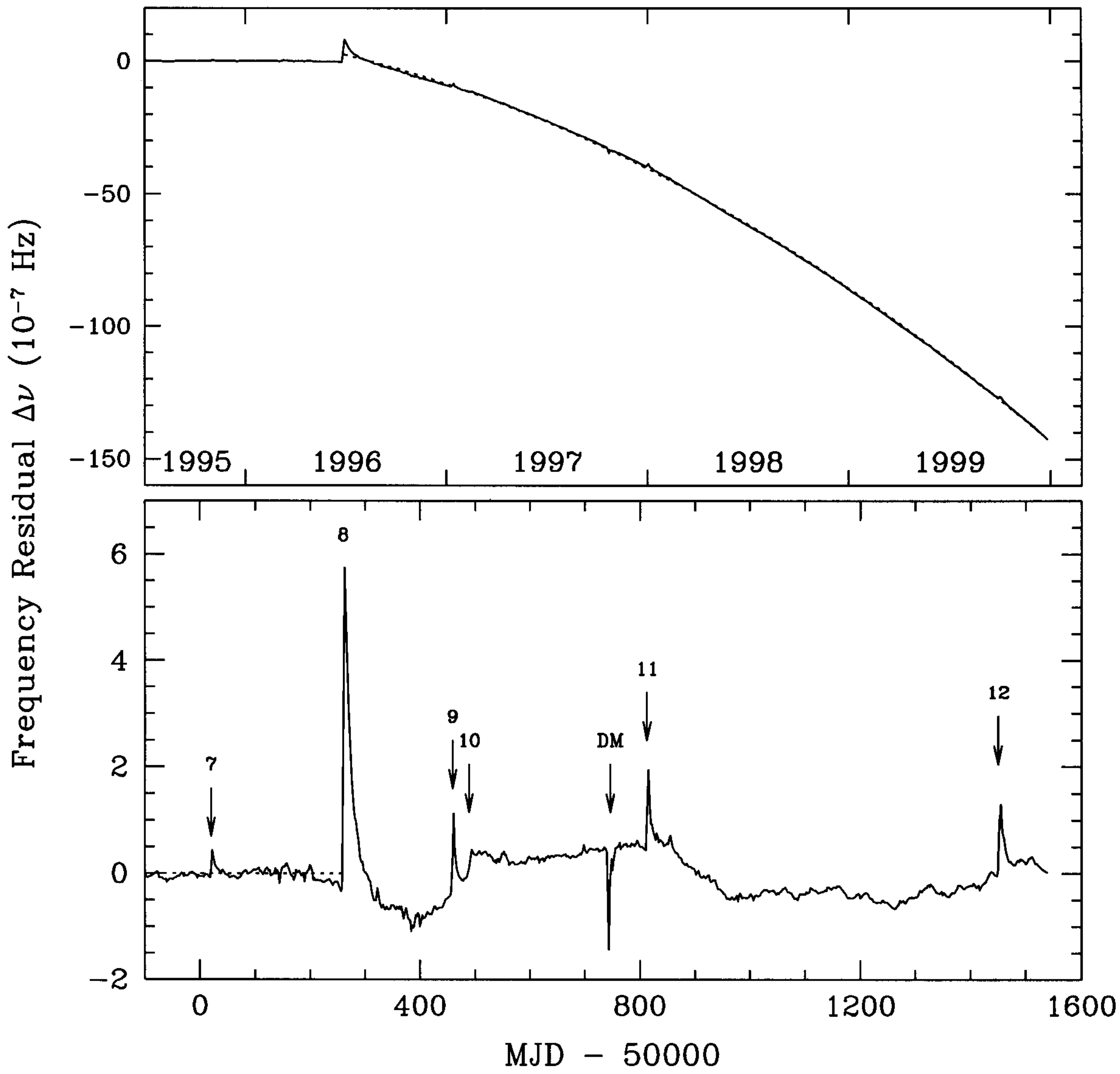


Time of arrival residuals 1981-1989 (fit includes 1986 glitch)



pulsar period

More recent Crab glitches



Wong, Backer & Lyne, 2001

Are these effects important for GW searches?

YES

- Pulsars are not fully coherent sources, so for non-targeted searches over very long time periods (~years) we should consider searching over coherence time in addition to the normal parameters.

- Even for targeted searches we need to be careful: old catalogue data will not necessarily reflect the present pulsar parameters. An assessment programme is currently underway.

- Some glitches probably correspond to step changes in the quadrupole moment of the neutron star, and timing noise may correspond to a more gradual evolution. Crab timing noise is consistent with this, so we need to consider the relationship between EW and GW phase.

Are these effects important for GW searches?

- Timing noise is generally red, so coherence times are generally long. Only the youngest pulsars show timing noise that would significantly effect our present search algorithms, and of these only the Crab pulsar is within the GW band. We are targeting the Crab with a flexible search that tracks the radio phase.
- We can do follow-up radio observations to re-time all catalogued pulsar GW candidates (there are only ~50).