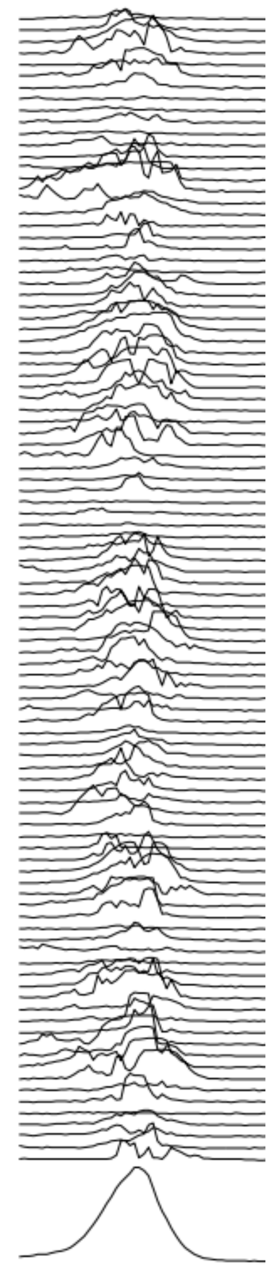
Radio pulsars can be used as accurate reference clocks to detect GWs

Radio pulsars are rapidly rotating, highly magnetized neutron stars. Their radio beams sweep the sky like lighthouses, and are recorded by radiotelescopes as *regularly spaced pulses*.

Individual pulse shapes vary greatly, but 100-fold integrated profiles are very stable, and can be timed accurately. Their times of arrival (TOAs) are shifted by the integrated spacetime-metric perturbations along the lines of sight to the pulsars, providing a way to detect GWs.

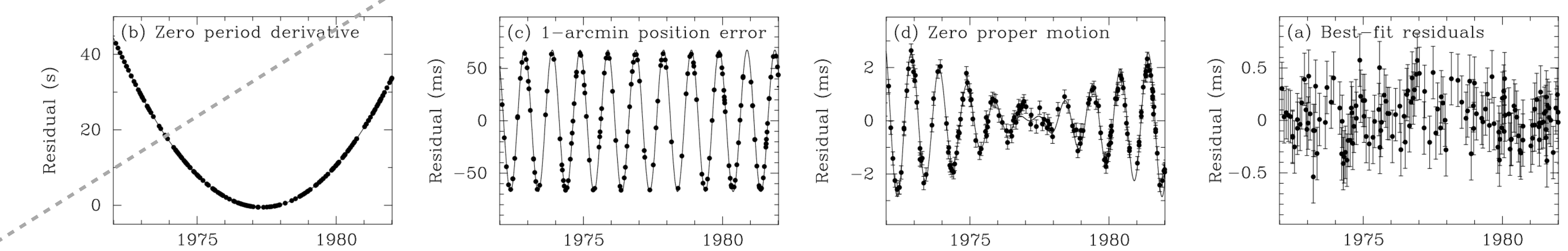
The idea of using pulsar timing to detect GWs was first explored in the late 1970s [Sazhin 1978, Detweiler 1979]



individual and integrated pulses from B0950+08, with P = 253 ms [Stairs 2003]

The long-time evolution of pulse sequences can be fit coherently, providing accurate pulsar parameters

Integrated TOAs are affected by EM dispersion, Earth–pulsar relative motions, GR delays, orbital dynamics (for pulsars in binaries), and intrinsic period drifts. After these effects are fit, the best-timed pulsars reach fractional stabilities of a few parts in 10^{14}. The final *timing residuals* are searched for GWs.



B1133+16 TOAs: fit and remove period derivative

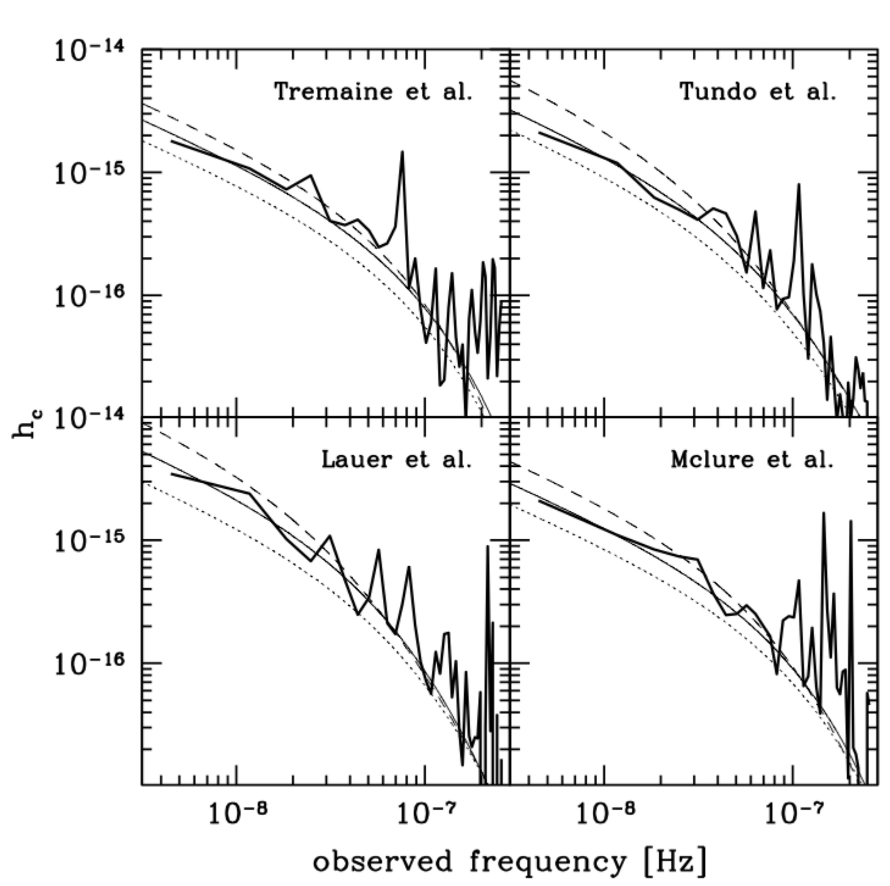
fit sky position and remove apparent yearly modulation

fit proper motion and remove modulation

final best-fit residuals [Lorimer 2008]

Massive–black-hole binaries at the center of merged galaxies produce a stochastic GW background $h_c \sim 10^{-15}$ at 10^{-8} Hz

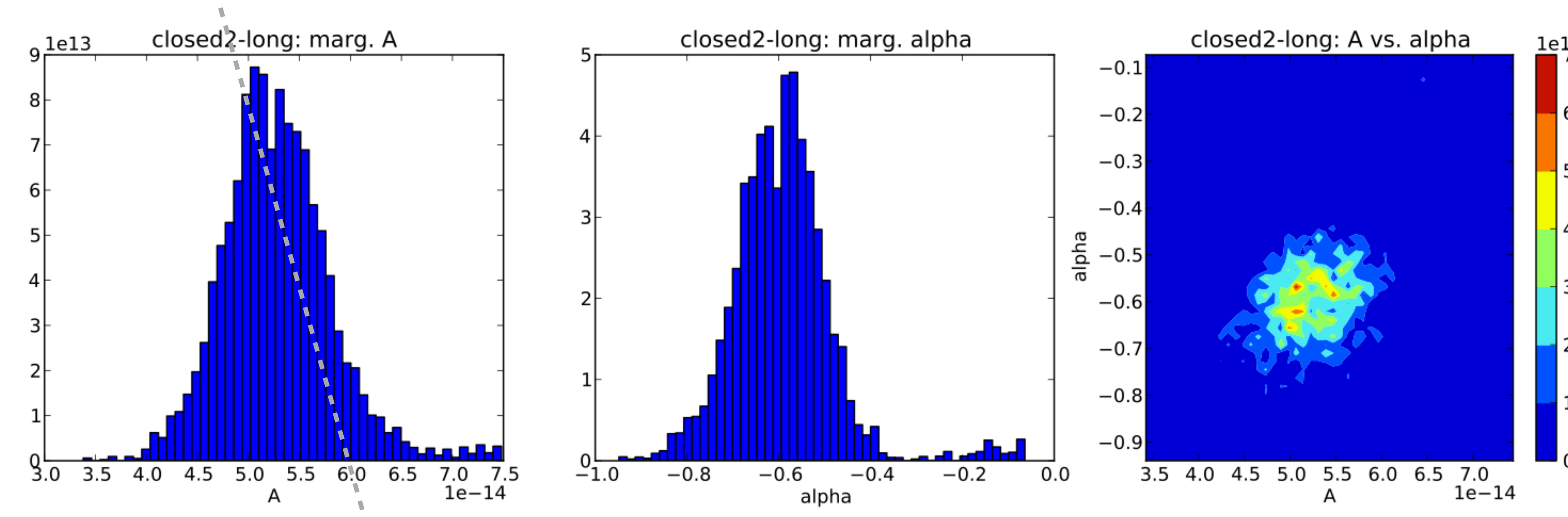
We search for this background by *correlating* the timing residuals between all pulsar pairs in an *array* (PTA). Sensitivity is limited at low *f* by the span of observations, and decays linearly at higher *f* due to intrinsic pulsar timing noise.



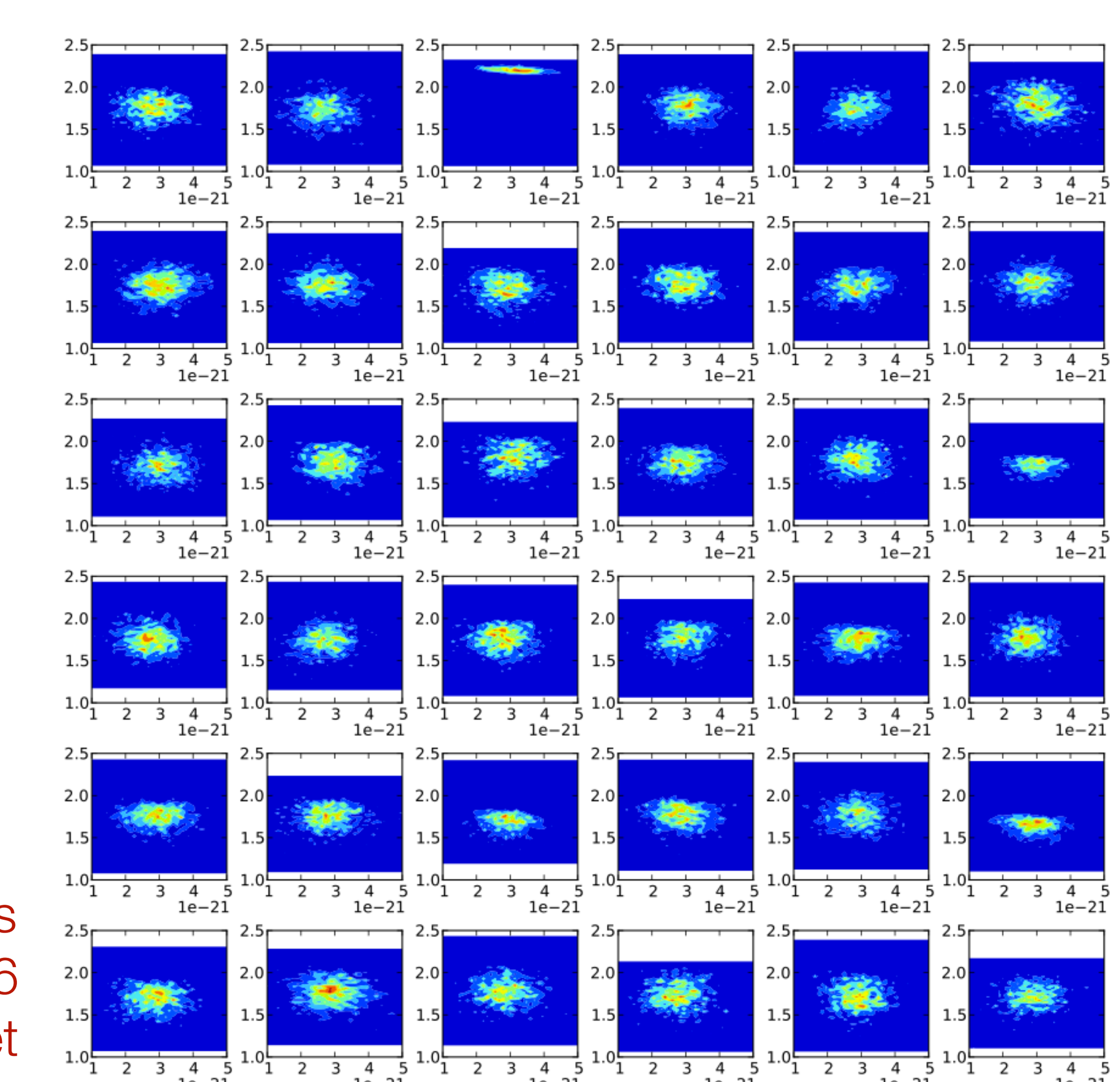
predicted GWB spectra for a variety of MBH-mass and accretion models [Sesana and Vecchio 2010]

We implement Markov-Chain Monte Carlo Bayesian inference to extract GW-background parameters from time-of-arrival correlations

MCMC realizes a controlled random walk across parameter space that follows the posterior probability distribution of GW-background *and* pulsar-noise parameters. *Affine invariant* MCMC [Goodman and Weare 2010], which evolves a large cloud of walkers, scales up well to parallel computers.



posterior distribution of GW parameters [A and α for $h_c = A \times (f\,\mathrm{yr})^{\alpha}$] for the second blind dataset in the 2012 International Pulsar Timing Array data challenge [work in collaboration with J. Lazio and S. Burke–Spolaor]



distribution of intrinsic red-noise parameters [*x*: amplitude, *y*: spectral slope] for the 36 pulsars in the IPTA data-challenge dataset