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Extracting physics from the randomness in neutron star rotation

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Rotational irregularities in neutron stars, principally glitches and timing noise, are often regarded as nuisance phenomena which are subtracted from electromagnetic pulsar timing data in order to reveal the underlying, secular rotational evolution. This represents a missed opportunity. Glitches and timing noise excite internal degrees of freedom in the star impulsively and stochastically. The internal response leaves a distinctive imprint on pulsar timing data. Here we review two new data analysis techniques, which track rotational irregularities as a specific realization of a random process, whose physical parameters can be inferred within a Bayesian framework. The first technique tracks timing noise with a Kalman filter and can be used to infer the parameters of the classic, two-component, crust-superfluid model of a neutron star. The second technique tracks glitches with a hidden Markov model and can be used to infer the parameters of superfluid vortex pinning and mutual friction. Both techniques operate without human supervision and perform well on synthetic and real data. We show that automated measurements of glitch sizes and waiting times are a powerful tool to falsify theories of the stick-slip, stress-relax physics of glitches. We also show that contemporaneous gravitational-wave and electromagnetic timing experiments have the power to resolve important physical and parametric degeneracies in the future.

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