Z120a Bayesian inference for the inclination of stars, brown dwarfs, and exoplanets using time-series spectroscopy

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When a rotating star's surface hosts inhomogeneous features, its spectral line profiles become distorted. As the star rotates, the line-of-sight velocities of these features change, and the resulting Doppler effect causes the distortions to migrate across the line profile. Analyzing these variations to map the surface brightness distribution is known as Doppler Imaging. Because this problem is linear — time-series observations d can be expressed as a linear operator $W(v, i)$ acting on the surface map vector a — we can analytically marginalize over the map and efficiently obtain posterior distributions for the nonlinear parameters, namely the rotation velocity v and the inclination angle i.

In this study, we construct the design matrix W for Doppler Imaging in JAX to verify its linearity, and then establish a novel method that uses NumPyro's NUTS sampler to perform a joint Bayesian inference of the stellar rotation velocity v and inclination i. This new approach allows us to estimate the inclination without relying on external information such as the star's rotation period or radius, and it also provides quantitative uncertainty estimates. Furthermore, the framework can be extended to simultaneously infer the surface map and the intrinsic line profile. In this presentation, we will describe the underlying principles of the method and discuss its applicability to real observational data.