Mass-ratio distribution of contact binary stars

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ABSTRACT: When the mass ratio of a contact binary system drops below the critical value $q_{\rm min}$, the binary undergoes the tidal Darwin instability, leading to a rapid merger and observable brightening. So far, the minimum mass ratio has not been experimentally measured on a sufficiently large population of contact binary stars, because the determination of the mass ratio of a single contact binary typically requires spectroscopy. However, it is possible to infer the mass-ratio distribution of an entire population of contact binaries simply from the observed distribution of their light curve amplitudes. Employing Bayesian inference, we obtain a sample of contact-binary candidates from the Kepler Eclipsing Binary Catalog combined with Gaia EDR3 and estimates of effective temperature. Each candidate is assigned a probability of being a contact binary of either early or late type. Altogether, our sample includes about 300 late-type and 340 early-type contact-binary candidates with probabilities higher than 50%. We model the mass ratio distribution as a power law with a cut off at $q_{\rm min}$, and obtain the posterior distributions for the parameters. Our preliminary results constrain $q_{\rm min}$ to between 0.05 and 0.1 for late-type contact binaries with periods longer than 0.3 days. For binaries with shorter periods, we find $q_{\rm min}$ between 0.15 and 0.3, but the sample is small. For early type contact binary stars with periods shorter than 1 day, we find $q_{\rm min} \leq 0.07$. These results are broadly compatible with theoretical predictions. In addition, our method can be easily extended to large samples of contact binaries from TESS and other space-based surveys, and we expect that $q_{\rm min}$ obtained from these samples might put some constraints on tidal-interaction models of close stellar binaries.

Method

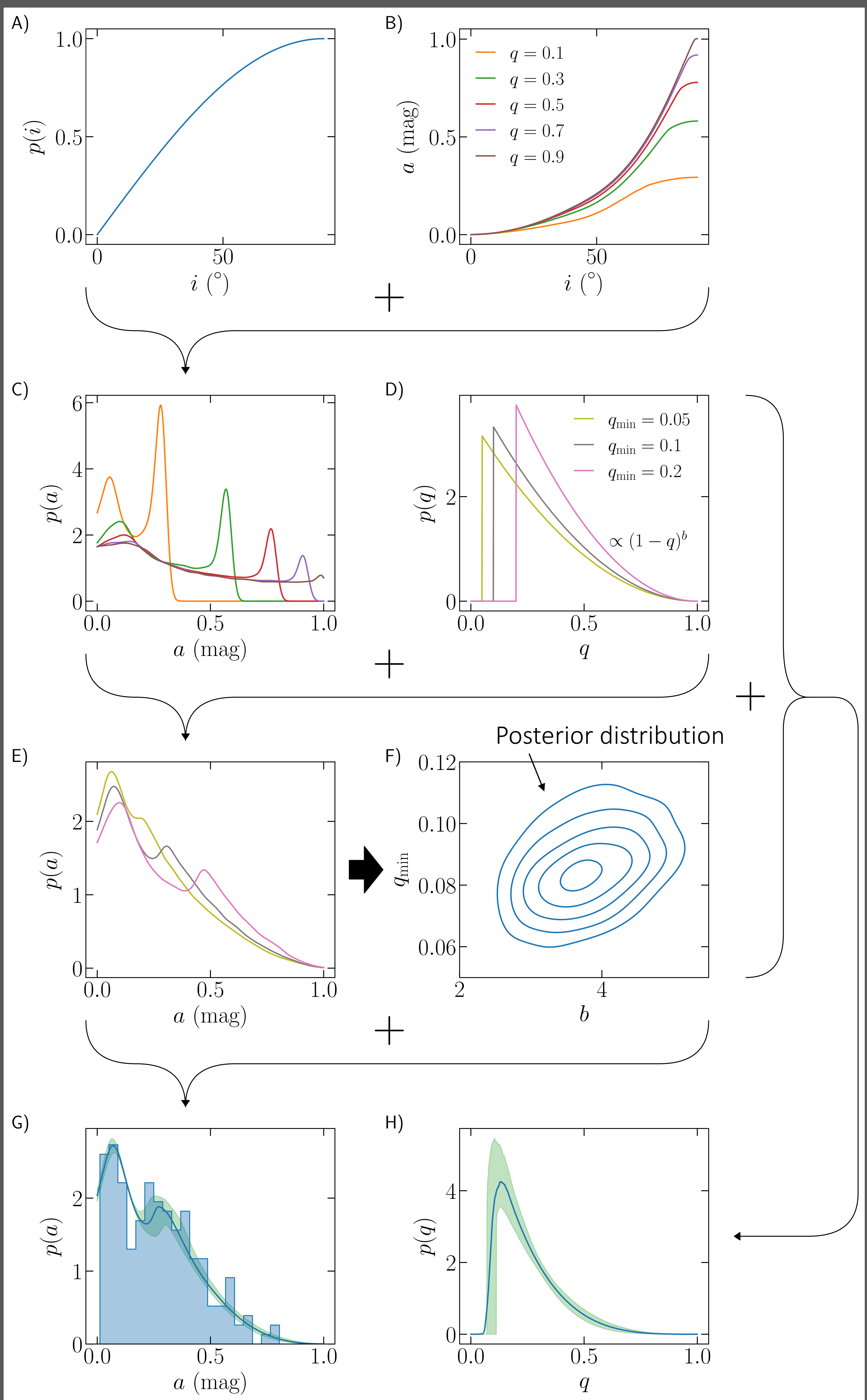

Figure 1. An infographic describing the employed method. A) Assuming that the orbits of contact binary systems are isotropically distributed in space, the probability of observing a system with an inclination i is proportional to $\sin i$. B) The dependence of the contact-binary photometric amplitude a on the inclination for different values of the mass ratio. C) By sampling the inclination distribution while keeping the mass ratio constant, we obtain the photometric amplitude as a function of the mass ratio. D) The mass-ratio distribution can be approximated by a power law with a sharp cut off at the minimum mass ratio $q_{\rm min}$. The existence of $q_{\rm min}$ is implied by the Darwin instability, which occurs when the spin angular momentum of the more massive component exceeds 1/3 of the orbital angular momentum of the whole system. E) By sampling the power-law prescription for the mass ratio distribution, we arrive at the full photometric amplitude distribution, with its shape strongly depending on the value of $q_{\rm min}$. F) By fitting the amplitude distribution to a sample of contact binary stars (see Figure 2) within the framework of Bayesian inference, we obtain the posterior distribution for the two parameters of the power law. G) Once the posterior is obtained, one can marginalize over it and estimate the mean photometric amplitude distribution (solid blue line) and its 1σ-credible interval (green strip). H) When applied to the power-law, the procedure described in G) yields the mean mass-ratio distribution (solid blue line) and the corresponding 1σ-credible interval (green strip).

Sample construction

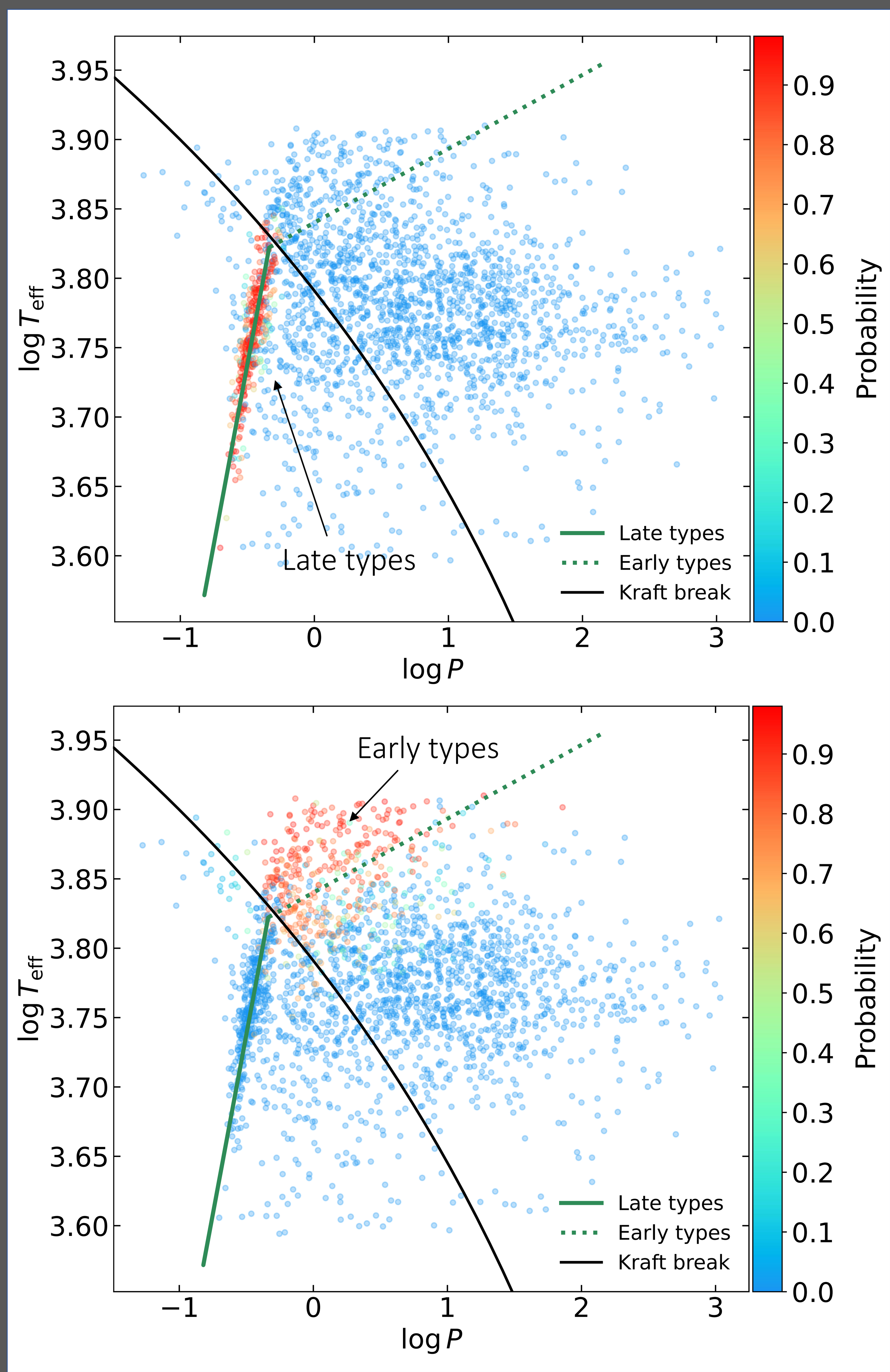

Figure 2. A log-period vs. log-effective temperature scatter plot of a sample of binary stars. The sample is constructed by combining the Kepler Eclipsing Binary Catalog and Gaia EDR3, yielding a mixture of contact binaries and noise (detached and semi-detached binaries, and possibly other types of variable stars). The solid and dashed green lines represent the projections of the period-effective temperature-luminosity relation of late type and early type contact binary stars respectively into the 2D sub-space of the scatter plot. The difference between the two types is in their position relative to the Kraft break (solid black line). Utilizing Bayesian inference, we model the noise as Gaussian, and we assume that the contact binaries in the sample are scattered around the period-effective temperature-luminosity relation, which makes it possible to assign a probability of being a contact binary star of either late (top panel) or early type (bottom panel) to each object in the sample. Adopting different probability and period cut offs, we obtain a number of different contact-binary samples with varying sizes.

Conclusions

- Method for mass-ratio distribution inference with no need for spectroscopy
- Possible dependence of $q_{\rm min}$ on structure and mass of components:
  - Late types
    - Period ≤ 0.3 days: $q_{\rm min} = 0.25^{+0.03}_{-0.05}$
    - Period > 0.3 days: $q_{\rm min} = 0.088^{+0.023}_{-0.016}$
  - Early types
    - Period < 1 day: $q_{\rm min} = 0.027^{+0.019}_{-0.020}$
- Results compatible with theoretical predictions
- Method easily extendable to larger samples expected from TESS and other space-based surveys