Modeling Stellar Microflares

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1 Overview

An open question in the field of Solar and stellar astrophysics is the source of heating that causes stellar coronae to reach temperatures of millions of degrees. One possibility is that the coronae are heated by a large number of small flares (see Audard *et al.* (2000), Drake *et al.* (2000)). On the Sun, microflares are distributed with energy as a power-law of the form $\frac{dN}{dE} = k \cdot E^{\alpha}$, with $\alpha = 1.8$, and α appears to increase to values 2.2-2.9 for flares of lower energy (cf. Aschwanden *et al.* (2000)). If the slope exceeds the critical value of 2, then in principle the entire coronal energy input may be ascribed to flares that are increasingly less energetic, but are more numerous. We have developed a new method to model these weak flares in photon arrival-time data.

2 Method

Model: Because flare onset is stochastic in nature, the light curves cannot be modeled directly. Instead we compare the distribution of **arrival-time differences** between the data and the model. We consider a 3-parameter model $\mathbf{M} = \{\alpha, r_F, r_B\}$ where α is the index of the power-law, r_F is the average count rate due to flares, and r_B is a constant "background" component. The Poisson-distributed model counts in an interval dt, $c(t)\,dt \;\sim\; \phi(t)\; Poisson[r_B(t)\,dt \;+\; f(t)\,dt]$, where $\phi(t)$ is a correction factor that takes into account Primbsch, dead-time, and GTIs, and the flare component, $f(t) = \sum_{j=1}^{N_f} \Theta(t - t_j) F_j e^{-(t-t_j)/\tau}$. Here τ is a fixed flare decay timescale, F_j are flare peak intensities sampled from the power-law distribution, and $\Theta(x)$ is a step function to represent instantaneous flare onset. Note that not only will the placement t_j and intensity F_j of the flares vary for each simulation, but so will the total number of flares N_f. Within the bounds of Poisson statistics, we expect that for any given

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simulation, $\sum_{j=1}^{N_f} F_j\,\tau \approx r_F \cdot \Delta T$ where ΔT is the total duration of the observation. The model parameter r_F fixes the normalization k by equating the total counts due to the flare component with the counts expected from the power-law distribution.

Algorithm: We follow a Bayesian formalism and derive the joint posterior probablity of the model parameters, $p(\mathbf{M}|D,I) \propto p(\alpha|I)p(r_F|I)p(r_B|I) \cdot p(D|\mathbf{M},I)$ where D represents the data. The prior distributions are taken to be non-informative and flat over the limited parameter ranges considered. The likelihood is computed as the probability density of obtaining the observed χ^2 value for N degrees of freedom (see Eadie et al. 1971, Equation 4.22), $p(D|\mathbf{M}) = \frac{\frac{1}{2}\left(\frac{\chi}{2}\right)^{\frac{N}{2}-1} e^{-\frac{\chi}{2}}}{\Gamma(N/2)}$. The basic steps of the algorithm are: First, derive the distribution of photon arrival-time differences $f_D(\delta t) \propto \sum_i \rho_i \lambda_i e^{-\lambda_i \delta t}$, where ρ_i is the fraction of the time that a source spends at the intensity λ_i; then obtain realizations of the photon event list over a grid of parameter values; and compare the simulated $f_M(\delta t)$ with $f_D(\delta t)$.

Limitations: Unlike existing methods that rely on detection of flares, this method is best-suited to investigate the effects of very weak flares on stellar coronal emission. However, in the process of deriving $f(\delta t)$, the sequential information inherent in the light-curve is lost. For example, we cannot take advantage of the known fact that flares decay in intensity. Further, because the model is stochastic, a large number of simulations are necessary to obtain a stable result, leading to very lengthy computations. Finally, the method loses sensitivity for $\alpha \sim 3$ as the model approaches the limiting case of constant emission.

Results: We find strong evidence in favor of the slope of the flare distribution to be greater than 2 for active stars such as FK Aqr, Wolf 630, AD Leo, β Per. We find that $\alpha_{FKAqr} = 2.68 \pm 0.25$, $\alpha_{V1054Oph} = 2.62 \pm 0.21$, $\alpha_{ADLeo} = 2.17 - 2.3$, and $\alpha_{\beta\ Per} = 2.84 (> 2.41)$ The flare component contributes to 70%, 85%, 80%, and 75% respectively.

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