Optical Variability in the Candidate Transitional Millisecond Pulsar 3FGL J0427.9-6704

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Abstract

The gamma-ray source 3FGL J0427.9-6704 has been associated with the nearby LMXB 1SXPS J042749.2-670434, making it unique among the known LMXBs due to the presence of a gamma-ray eclipse (Strader et al. 2016). The optical light curve of the source suggests the binary is accreting, and the system has been proposed to belong in the transitional millisecond pulsar (tMSP) class. We have recently obtained a high time resolution multi-band optical light curve of the source using ULTRACAM on ESO's New Technology Telescope. There is a deep optical eclipse present in the light curve, alongside flickering which is most likely coming from the accretion disc. There is evidence for significant heating of the secondary star, and modeling of the light curve constrains the inclination to be 84±3°, in line with the required inclination to produce a gamma-ray eclipse. We are unable to tightly constrain the primary mass (whose nature is still unclear), and do not find any evidence for a bi-modality in the systems optical flux (whose presence would have been the smoking gun for a tMSP classification). Finally, we find weak evidence for a ~21 min quasi-periodic oscillation in the light curve, we which attribute to a transient structure in the accretion disc.

Fig 1:

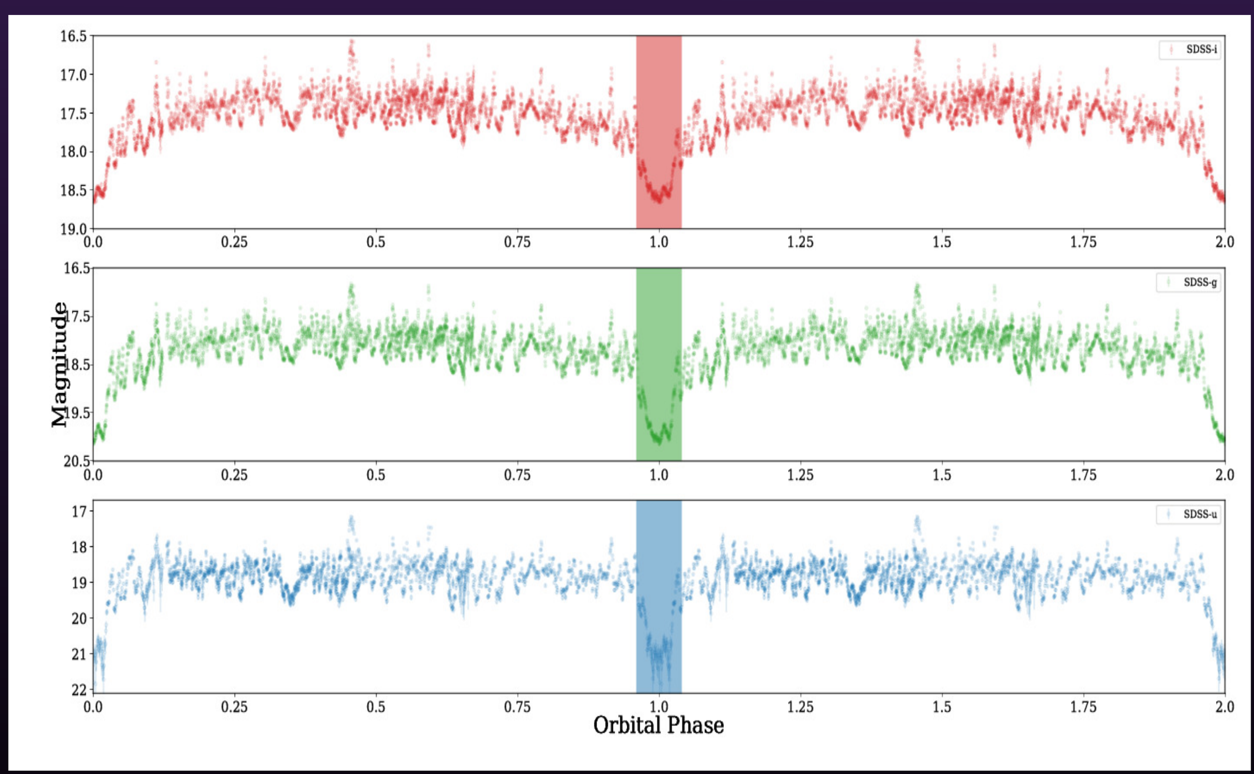


Fig 2:

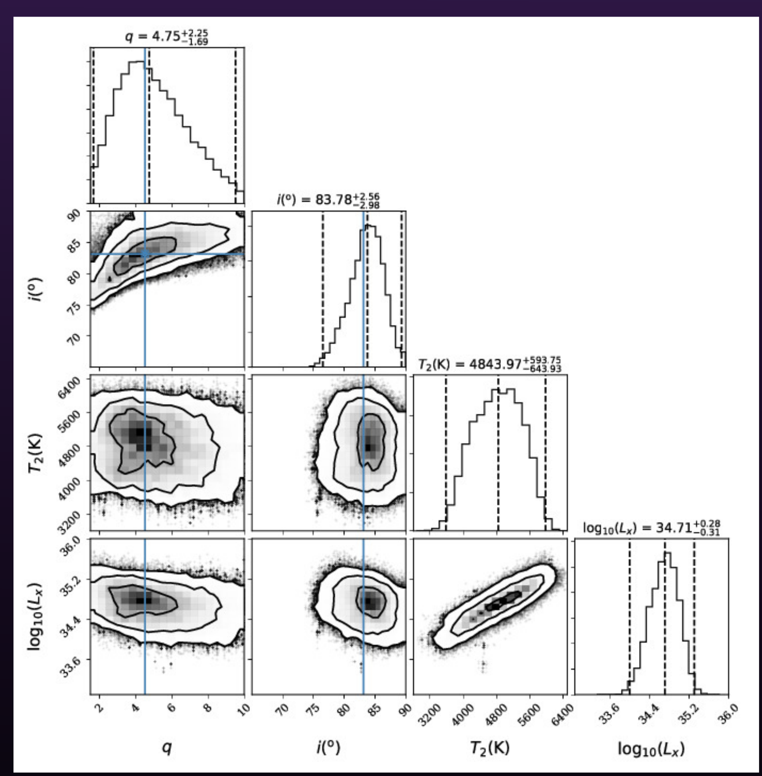
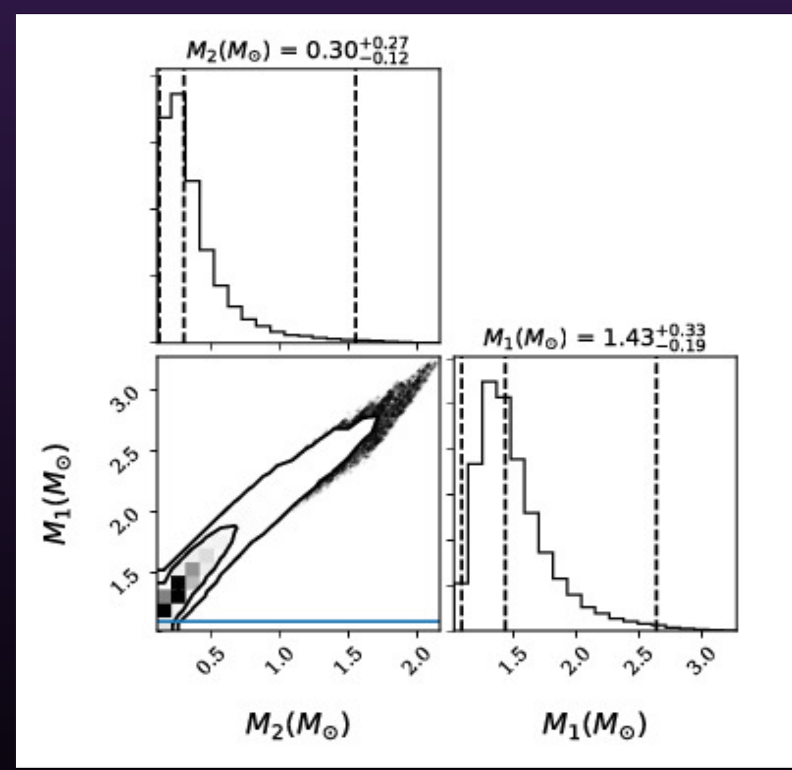


Fig 3:



Light Curve Modelling

Fig 1 shows the optical light curve of 3FGL J0427 obtained over three separate nights in 2017, phase on the orbital period of 8.88 hours. There are three important features to the light curve - a significant curvature to the i' light curve, a deep eclipse in all three bands (deepest in u'), and extreme variability on a time scale of order 2 minutes. A binned version of this light curve was analysed using the Eclipsing Light Curve code. In Fig 2, we show the corner plot of several of the parameters which were fit using this code. The inclination of the system is well constrained, as is the average temperature of the secondary star and the amount of heating which the secondary experiences. Fig 3 shows the mass constraints from our modelling.

Timing Analysis

After subtracting the best fit model light curve obtained using ELC, the residual data were subjected to a Lomb Scargle periodogram to search for any periodicities in the data. Fig 3 shows the periodogram from our second night of data, which had the strongest peaks of any of our data. The periodogram suggests there is a periodic signal present with a period of ~21 mins. The confidence level here was found by simulating data which had a power law power spectrum with α=-1. This signal is not present on any other night, leading us to believe it is quasi periodic, and most likely related to transient structures with in the accretion disc.

Fig 3:

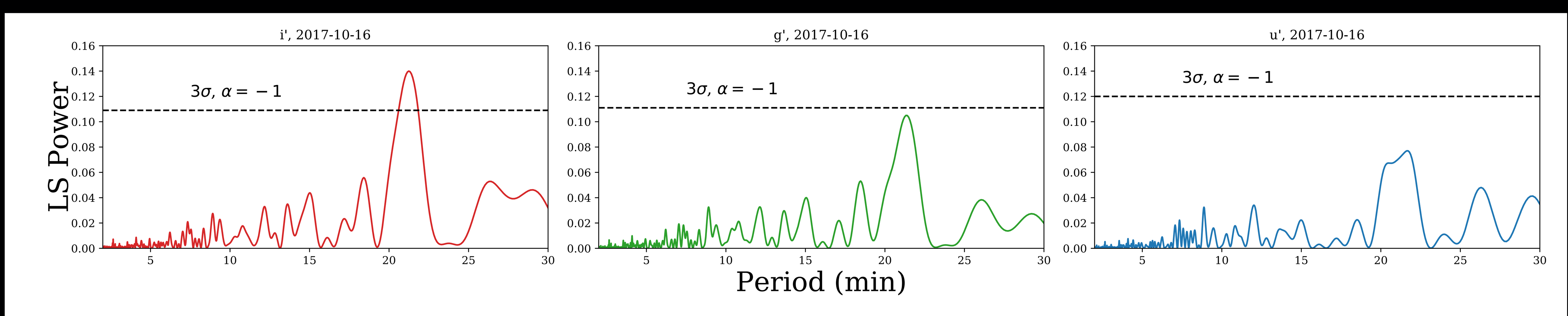
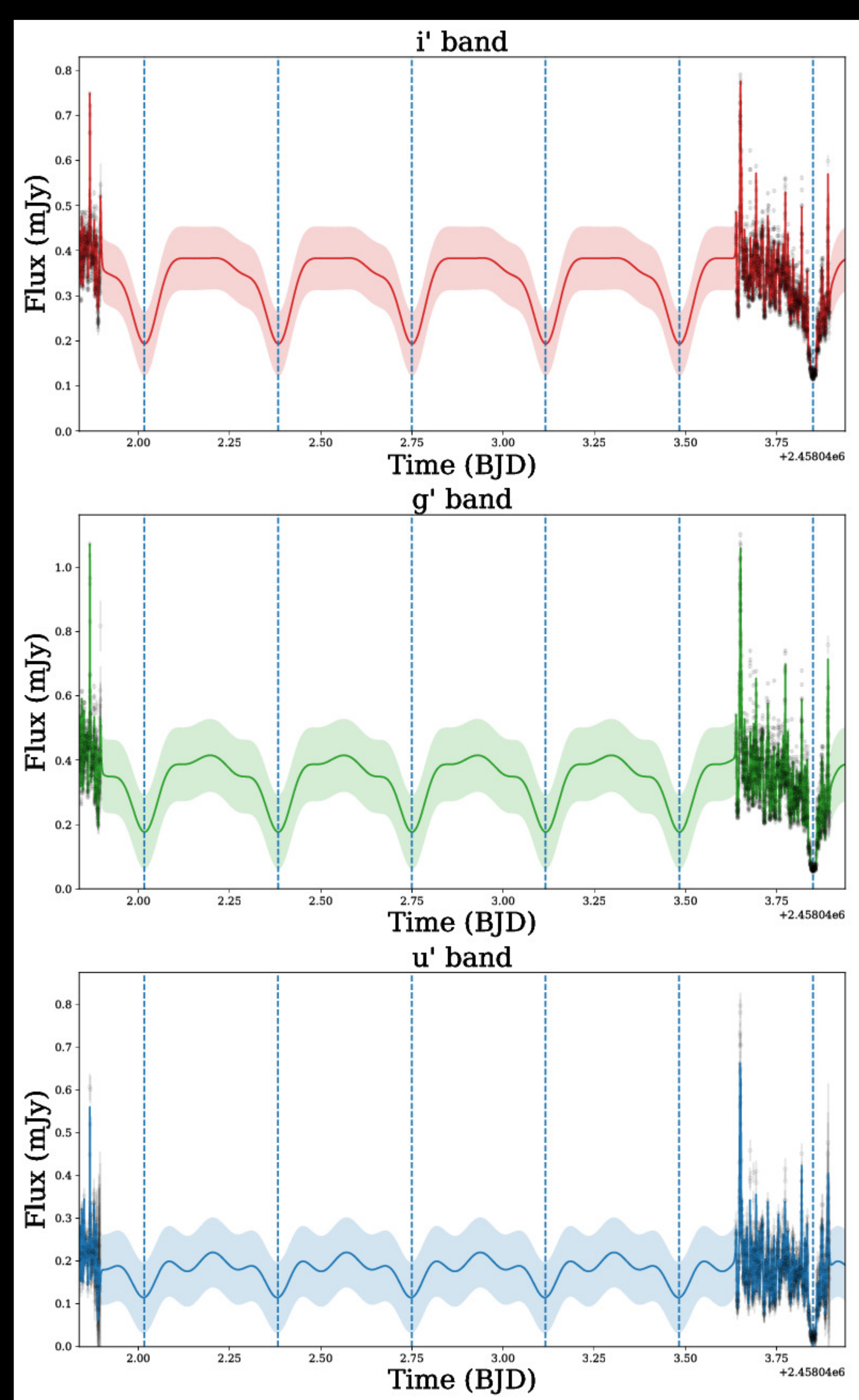


Fig 4:



Gaussian Process Modelling

We also attempted to model the light curve using Gaussian Process Modelling. This type of modelling uses a user defined kernel to model the covariances between each data point. We used a kernel composed of a Matern kernel to account for the flickering in the light curve and a periodic kernel with a period equal to the orbital period to account for periodic covariances in the data. Fig 4 shows our trained model along with data from two nights. We find that the flickering in the light curve is well modelled by the Matern component, and has a length scale of 2 minutes. The model was used to predict the light curve shape joining the two sets of data, and correctly predicts the times of minimum light (plotted in dashed blue and found using the known orbital ephemeris) but, due ot the 2 minute length scale of the Matern kernel, quickly loses the ability to predict any fine detail in the light curve. A periodic component with a period close to 20 minutes was not needed to adequately model the data.

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