Reverberation Mapping of the Binary Quasar Candidate PG 1302-102

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INTRODUCTION

Graham et al. (2015) reported the discovery of a "strong, smooth periodic signal in the optical variability of the quasar PG 1302-102 with a mean observed period of 1,884 ± 88 days" (Fig.1). This kind of variation is suggestive of a binary system of orbiting supermassive black holes with subparsec separation (Fig. 2). The optical brightness could be linked to their orbit through variations in accretion rate or Doppler boosting (e.g., D' Orazio et al. 2013). Of course, out of hundreds of thousands of light curves searched, some will show periodic signals by chance (Davis et al. 2024). Liu et al. (2018), in a paper with the fun title "Did ASAS-SN Kill the Supermassive Black Hole Binary Candidate PG1302-102?" used additional photometry to extend the light curve found that the statistical significance of the periodic variation decreased, but did not actually kill the binary hypothesis (Fig. 3).

REVERBERATION MAPPING

One experiment suggested to investigate the nature of binary supermassive black hole candidates is reverberation mapping. Spectroscopic monitoring is used to determine the response of a broad emission line, typically Hβ, to continuum variability. The time lag between the two characterizes the size of the broad line region (BLR) and, in conjunction with the velocity width, can be used to measure the central black hole mass under the assumption that the motions are virial.

We started observing PG 1302-102 in 2016 with the 2.3m telescope at the Wyoming Infrared Observatory (WIRO). Fig. 4 shows sample spectra of the Hβ+[O III] region taken with the longslit spectrograph and a 5 arcsecond slit oriented North-South. See Du et al. (2018) for details.

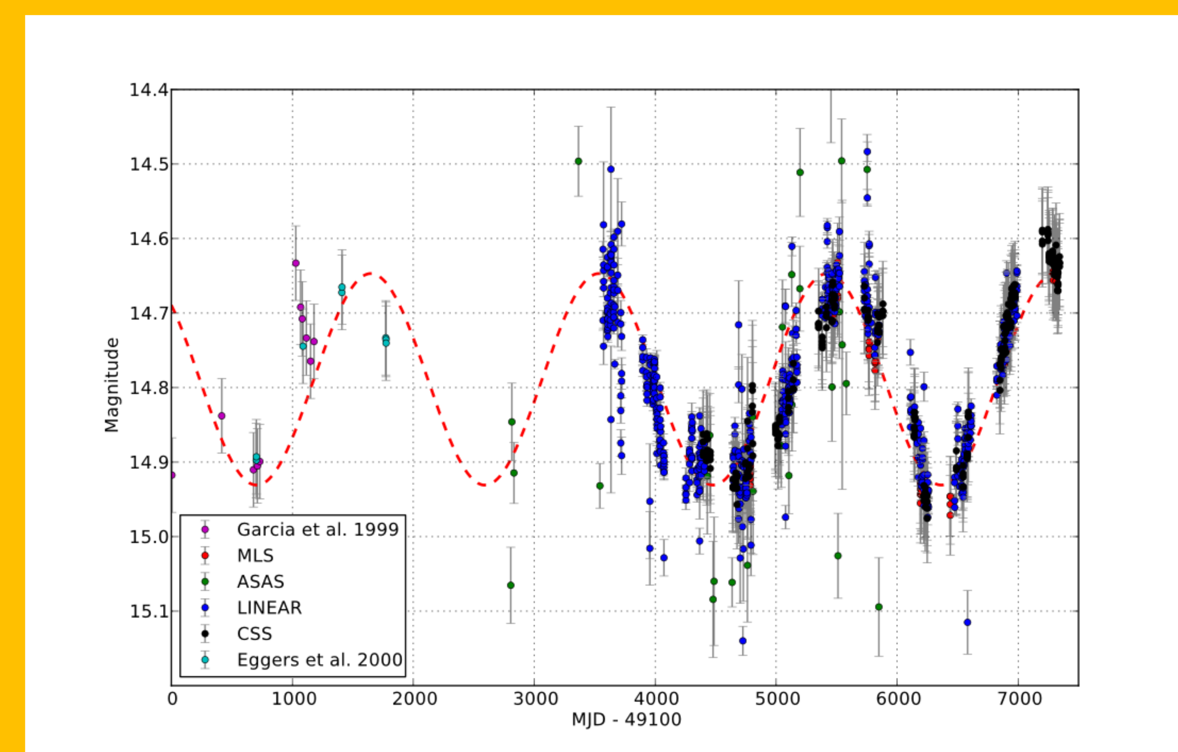
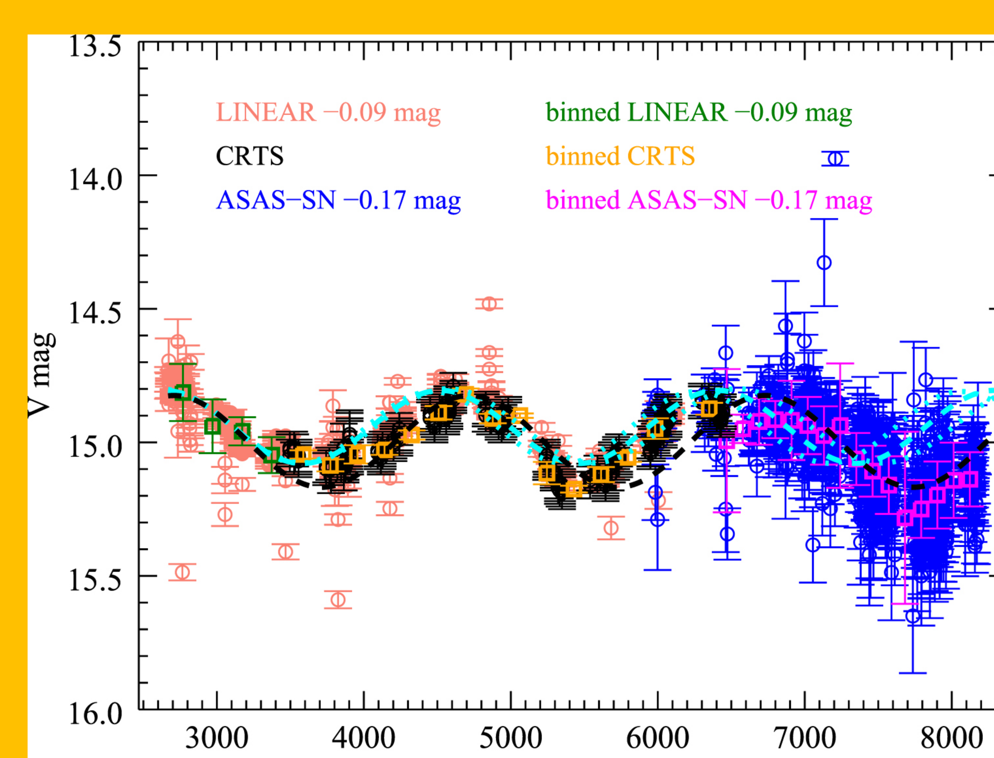
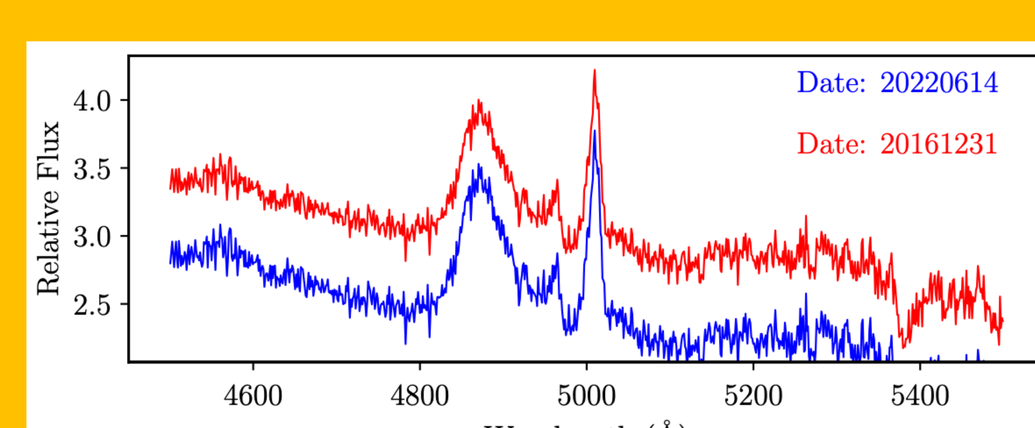


Figure 1. Light curve of PG 1302-102 from Graham et al. (2015).

Figure 2. An artist's conception of a black hole binary in a heart of a quasar, with the data showing the periodic variability superposed. Credit: Santiago Lombeyda/Caltech Center for Data-Driven Discovery



Fig, 3. Light curve of PG 1302-102 from Liu et al. (2018)



Fig, 4. Observed-frame, low- resolution WIRO spectra at two epochs.

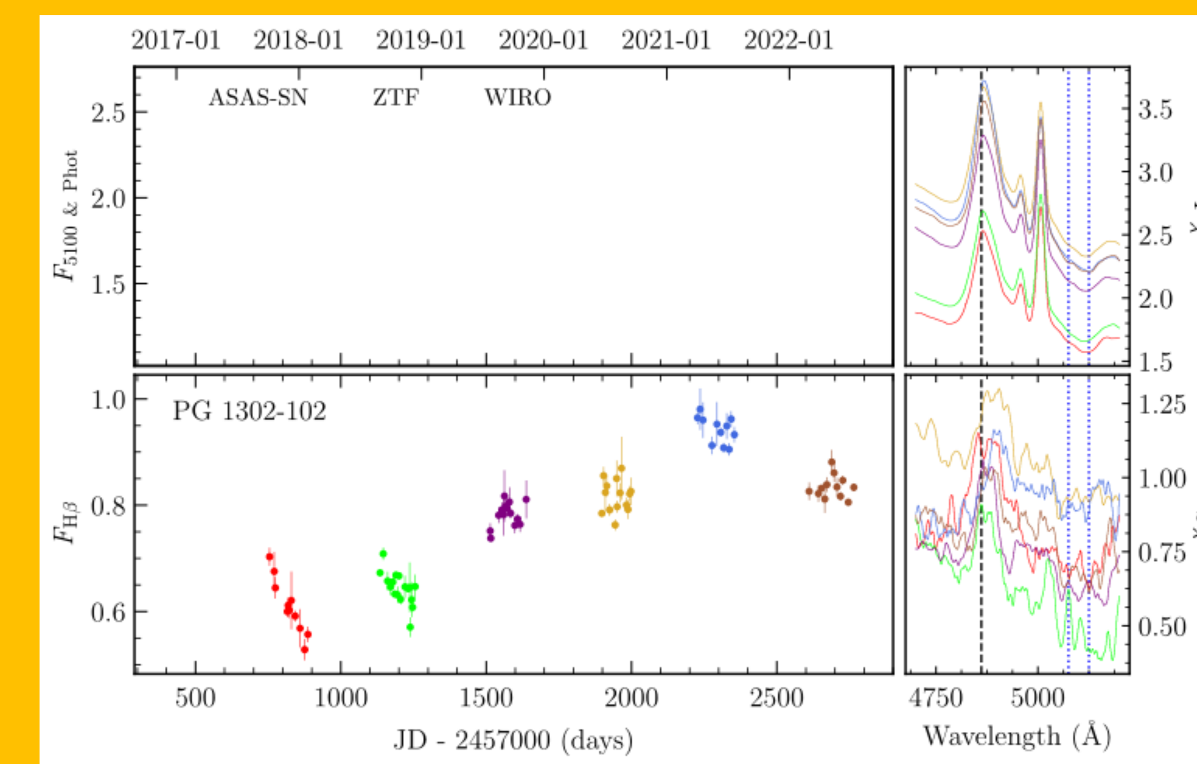


Figure 5. Left, Top: Continuum using WIRO, ASAS-SN, and ZTF photometry; Bottom, Hβ light curve. Right, Top: Mean Hβ spectra for each season; Bottom, rms Hβ profiles for each season.

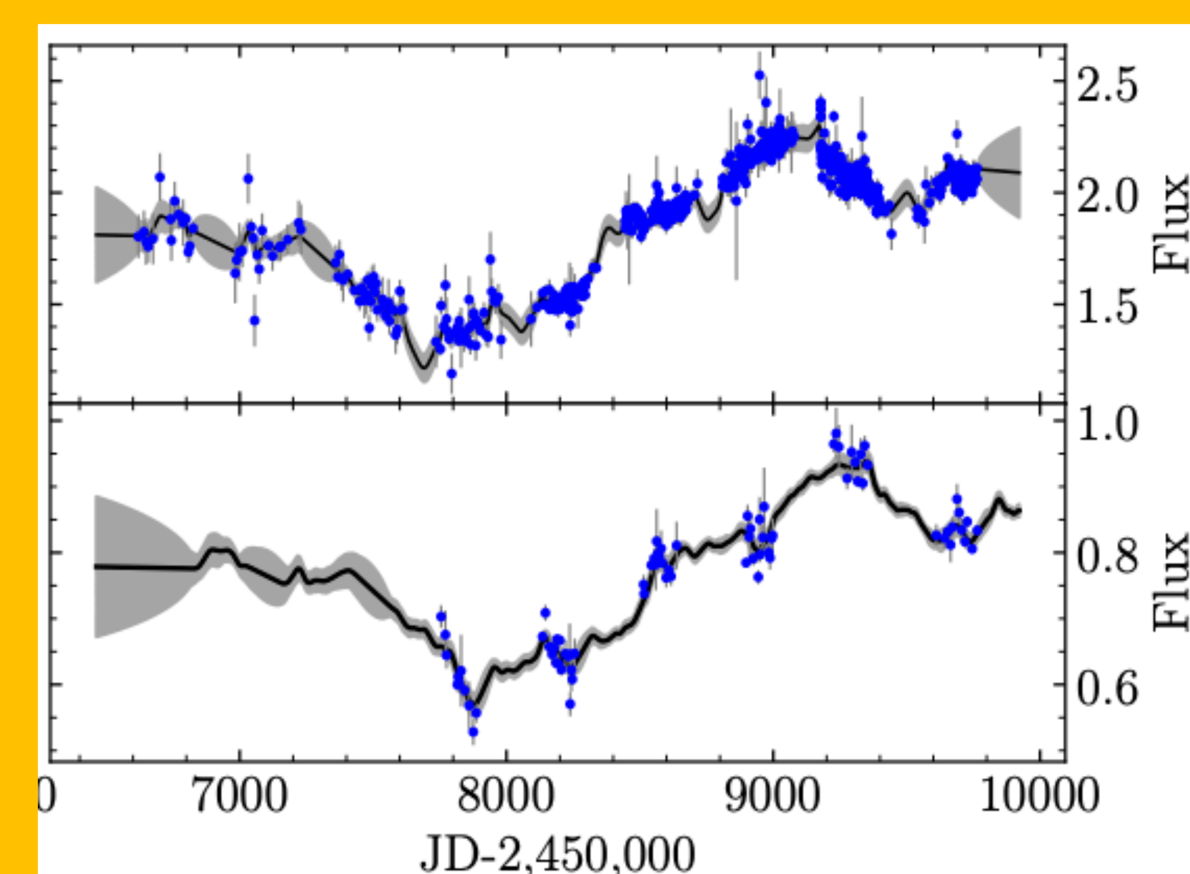


Figure 6. Modeling of the continuum and Hβ light curves using MICA (Li et al. 2016), a Bayesian code using a damped random walk helpful for intelligently interpolating across the seasonal gaps and determining time lags.

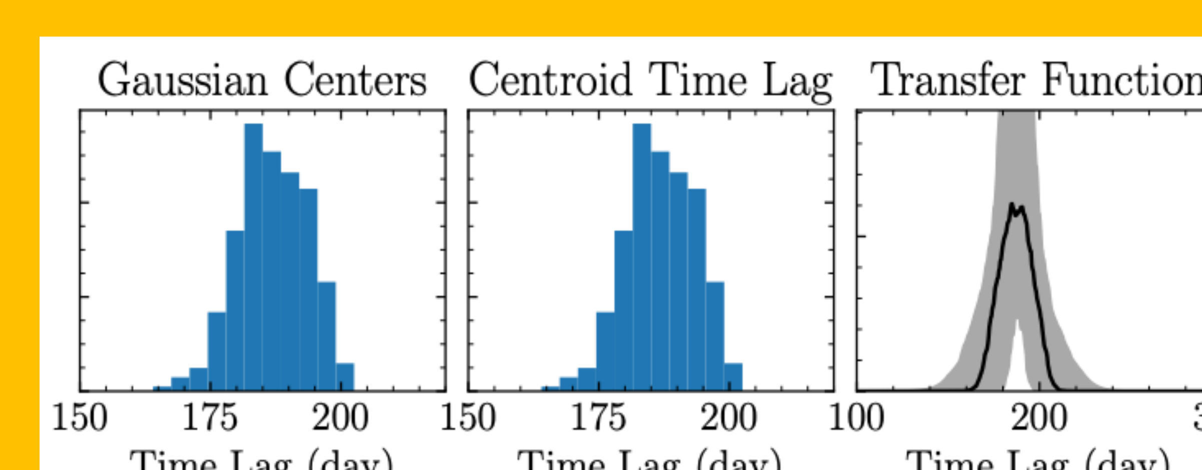


Figure 7. MICA results for the time lags and transfer function for the model shown in Fig. 6 above. The Hβ time lag is 187.0 +7.7 -6.8 days in the observed frame. PG 1302-102 has z = 0.2784.

RESULTS & CONCLUSIONS

Figure 5 shows our continuum and Hβ light curves spanning six seasons. The Hβ profile does not show any large changes. There are no correlations within single seasons, only when considering the entire data set. Figures 6 and 7 show our results determining a time lag of ~146 days in the rest frame. For FWHM = 4300 km/s and f = 1.1, PG 1302-102 has a conventionally determined mass of 590 million solar masses. For logL5100 = 45.9 (erg/s) (Vestergaard & Peterson 2006) we might expect a time lag of 151 days for the most up-to-date radius-luminosity relationship (Wang & Woo 2024). For this mass and luminosity, the Eddington fraction is about unity. At this level of analysis, PG 1302-102 appears to be a conventional luminous quasar without any strong indicators of being a binary system.

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