

The Search for a Counterpart to *NuSTAR* J053449+2126.0

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ABSTRACT

(Tumer et al. 2022, ATel #15171) have recently reported the discovery of an X-ray source, *NuSTAR* J053449+2126.0, during a calibration observation which took place on 25 April 2020. We scan the Zwicky Transient Facility (ZTF) alerts and archival photometry to determine the nature of the source. Palomar Gattini-IR is searched as well. We identify no obvious counterpart candidate. Follow-up X-ray and optical studies are needed to determine the true counterpart.

1. INTRODUCTION

The confirmation of an optical or infrared counterpart to an X-ray source is often needed to confirm the nature of the source. Accreting systems are among the most common X-ray sources: galactic sources include compact object binaries such as cataclysmic variables (CVs) and neutron star (NS)/black hole (BH) binaries (e.g. Bradt & McClintock 1983) while extragalactic sources are often active galactic nuclei (AGN) (e.g. Rosswog & Brüggen 2007).

ATel #15171 (Tumer et al. 2022) has recently reported the discovery of an X-ray source, *NuSTAR* J053449+2126.0, but it is unclear whether the source is an X-ray transient or persistent X-ray source from the ATel alone. The authors report the extraction of a 1 arcmin spectrum centered on the object positioned at (05:34:49.20, +21:26:02.9). The spectrum is fitted with a power-law with photon index ~ 2.46 in the 3.0–20.0 keV band. With a flux of $\sim 4 \times 10^{-13}$ erg/s/cm² in the 3.0–10.0 keV band, assuming the source at $z = 0.1$ would put its X-ray luminosity at $\sim 5 \times 10^{42}$ erg/s. Assuming it to be a galactic X-ray source at 1 kpc would put its X-ray luminosity at $\sim 3 \times 10^{31}$ erg/s. The Galactic coordinates (ℓ :185.0864077, b :-6.0382378) of this source are a few degrees away from the Crab nebula, leading us to speculate it may be a Galactic source.

2. ZTF SEARCH

The Zwicky Transient Facility (ZTF) is a photometric survey that uses a wide 47 deg² field-of-view camera on the Samuel Oschin 48-inch telescope at Palomar Observatory with g , r , and i filters (Bellm et al. 2019; Graham et al. 2019; Dekany et al. 2020; Masci et al. 2019).

We use ZTF Data Release 5 (DR5) with forced photometry provided for the ZTF collaboration through the Infrared Processing and Analysis Center¹ (IPAC; Masci et al. 2019). The forced photometry calculates photometry of the object on all available frames by forcing the location of the PSF to remain fixed according to the ZTF absolute astrometric reference.

2.1. ZTF and Palomar Gattini-IR Alerts

We first searched the ZTF Alerts catalog and found two sources within a 1 arcmin radius. Two alerts were discovered, ZTF21aaxwqyj and ZTF21aaxwtmr, which we attribute to the same source: an asteroid or other Solar System object. Both alerts appear only once and are consistent with a moving object.

The Palomar Gattini-IR (De et al. 2020) infrared telescope alerts were also searched within a 1 arcmin radius of *NuSTAR* J053449+2126.0, and one source was found to have some infrared variability, 2MASS J05344864+2125080. The ZTF light curve does not show any periodicity or significant outbursts.

2.2. ZTF light curves

We then downloaded all light curves within 1 arcmin of *NuSTAR* J053449+2126.0 within the ZTF Data Release 5 (DR5) catalog. We found 202 light curves, searching between both *r* and *g* filters. The two criteria we searched for were either: 1) an outburst in the light curve or 2) a strong periodic signal indicative of a binary system. No (>1 mag) outbursts were found within a 2 day window of 25 April 2020. Strong outbursts *anywhere* in the light curves were then searched. Two objects with significant (>2 mag) outbursts in their light curves were found, ZTFJ053452+212605 and ZTFJ053450+212603.

To search for periodic signals, we applied the Lomb-Scargle algorithm (Scargle 1982) to the forced photometry of all 202 light curves using *gatspy* (Vanderplas 2015). We searched periods of 2 minutes to 10 days. We quantified the significance of a detected period by dividing the Lomb-Scargle power of the best-fit period by the median Lomb-Scargle power of all searched periods. We found three sources with periods significant in the 90th percentile.

3. ANALYSIS OF POTENTIAL CANDIDATES AND OTHER CONSTRAINTS

All 6 candidates (summarized in Table 1) were queried on CDS Portal and all featured unremarkable spectral energy distributions (SEDs) with the possible exception of ZTFJ053447+212605, which features a slight infrared excess in its SED. SED data was compiled from *Gaia*, SDSS, Pan-STARRS, UKIDSS, and WISE photometry. Cataclysmic variables are Galactic X-ray emitters which may also have infrared excesses (Hoard et al. 2009). This would then attribute *NuSTAR* J053449+2126.0 to the X-ray counterpart to a CV. Both non-magnetic and magnetic CVs can have X-ray luminosities $L_X \sim 10^{31}$ erg/s (Mukai 2017), but we did not find a CV orbital period in the data.

None of the candidates stand out as an obvious counterpart to a hard X-ray source. The candidates identified through their long-term light curve behavior do

not show sustained or exceptionally high-amplitude outbursts. The candidates identified through periodicity do not show highly significant periods (i.e. > 95 th percentile) and feature variation on the order of the error bars of each photometric data point.

Since *NuSTAR* J053449+2126.0 is located close to the Crab nebula in the sky, we suspect it is a Galactic source. The extinction to this source is obtained from the NASA/IPAC Extragalactic Database, which derives its results from Schlafly & Finkbeiner (2011). We find the extinction in the direction of *NuSTAR* J053449+2126.0 to be $A_V \sim 1.37$.

Galactic sources that would have shown strong optical periodicity at high >1 mag amplitudes would be attributed to “spider variables”. These are systems where a pulsar irradiates a companion low-mass star or brown dwarf and the resulting shock emits in X-rays. Cyclotron beaming from magnetic CVs known as polars also lead to high-amplitude periodic variability. Since no folded light curves with amplitudes >1 mag were found in the ZTF archive, we can exclude polar CVs and spider variables from the possible Galactic associations with *NuSTAR* J053449+2126.0.

4. DISCUSSION AND CONCLUSION

X-ray imaging with a telescope with a sharper point spread function such as *Swift* or *Chandra* is needed. This would provide better spatial resolution of the *NuSTAR* J053449+2126.0 1 arcmin region as well as provide the soft X-ray coverage when comparing to the *NuSTAR* spectrum. Additional X-ray data would also inform us if *NuSTAR* J053449+2126.0 is a persistent or transient source.

We have found no obvious counterpart to *NuSTAR* J053449+2126.0 after searching ZTF and Palomar Gattini-IR alerts as well as long-term photometry. Our limited knowledge of the temporal behavior of *NuSTAR* J053449+2126.0 motivates the need for further observations within the 1 arcmin region to determine the nature of the source.

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Table 1. Candidate Counterparts to *NuSTAR* J053449+2126.0

Name	RA (J2000)	DEC (J2000)	Distance from <i>NuSTAR</i> source (arcsec)	Notes
2MASS J05344864+2125080	05 34 48.644	+21 25 8.04	55.4	Palomar Gattini-IR detection
ZTFJ053452+212605	05 34 52.004	+21 26 5.74	39.3	ZTF > 2 mag burst
ZTFJ053450+212603	05 34 50.700	+21 26 3.44	21.0	ZTF > 2 mag burst
ZTFJ053450+212634	05 34 50.264	+21 26 34.18	34.6	ZTF periodicity
ZTFJ053449+212632	05 34 49.888	+21 26 32.22	30.8	ZTF periodicity
ZTFJ053447+212605	05 34 47.499	+21 26 5.78	23.9	ZTF periodicity

No obvious optical or infrared counterpart to *NuSTAR* J053449+2126.0 was identified. The above objects are identified as the most likely candidates based on outbursts or periodicity seen in their light curves.

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