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Gemini Speckle Imaging of Dual Quasar Candidates

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Abstract

We observed the candidate dual quasar J2122−0026 with speckle interferometric imaging at the Gemini-North Observatory. Results of our one-hour high resolution 'Alopeke imaging observation agree with and confirm Hubble Space Telescope imaging of the pair separated at ~0.″5. These observations show that sub-arcsec dual quasar candidates as faint as $r \sim 19$ can be observed and detected using speckle imaging at Gemini.

"Do not go where the path may lead, go instead where there is no path and leave a trail."

Ralph Waldo Emerson

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1. Introduction and Observations

The population of ~kpc-scale dual supermassive black holes (SMBHs) at $z > 1$ is poorly explored given the stringent requirement on spatial resolution (Shen et al. 2021). Faint candidate dual quasars (with both SMBHs being active) are usually selected with indirect methods and resolved/confirmed with high-resolution observations with Hubble Space Telescope (HST) (Chen et al. 2021). Ground-based, nearly diffraction-limited optical imaging will open a new venue to the confirmation and detailed studies of high-z dual quasars, which in turn will improve our understanding of this elusive population.

We used one-hour of engineering time to observe the dual quasar candidate J2122−0026 (Chen et al. 2021) on 2021 August 8 UT using the 'Alopeke speckle instrument mounted on the 8 m Gemini-North telescope located on Maunakea, HI.[6] 'Alopeke (Scott & Howell 2018) uses a dichroic to split the optical light at 674 nm and obtains simultaneous blue and red images with two EMCCD detectors. The observations reported herein were obtained using SDSS r and i filters at an airmass between 1.0 and 1.09 with seeing of 0.″45 and in dark time.

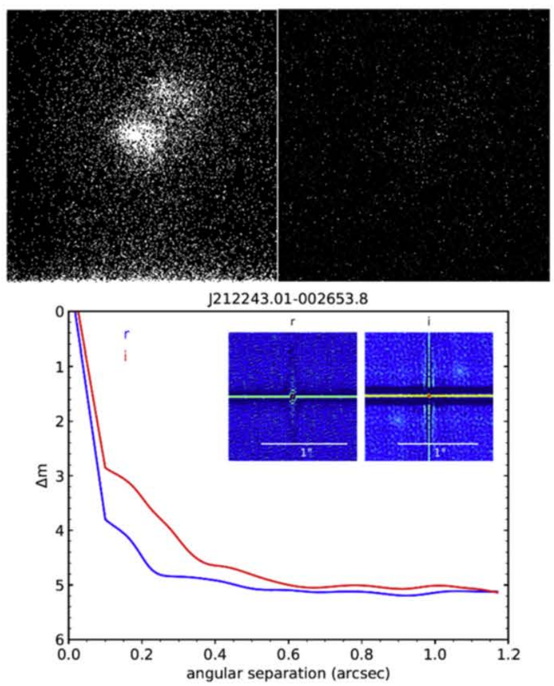
The speckle observation consisted of a total on-source time of 45 minutes bracketed by observations of the point-spread function (PSF) standard star HR 8199. Speckle imaging collects many 60 ms images which are then subjected to Fourier analysis and used to search for close companions, determine their properties, and provide reconstructed high resolution images (Howell et al. 2011). Observations of HR 8199 consisted of 3 sets of 1000 60 ms images with an EMCCD gain near 0 while the $r \sim 19$ quasar J2122−0026 observations used 45 sets of 1000 60 ms images and an EMCCD gain of 1000. The HR 8199 ($V = 5.5$) observations obtained through the broad-band SDSS filters, even at EM gain = 0, contained a ghost due to internal reflections within the instrument. This ghost raised the speckle image background in a non-symmetric manner, producing a low-level ghost in the Fourier output and obscuring the companion image from detection. Thus, in reducing the data, we used 'Alopeke archival speckle images of HR 7040 in the blue and HR 7086 in the red observed at airmass 1.02 on 2021 June 26 UT and using our standard narrow band filters. In future observations of this type, we would reduce the integration time/frame for the bright standard star observed in the SDSS filters.

2. Results

Even though the excellent seeing on the night of observation and the wide separation (~0.″5) of this

Even though the excellent seeing on the night of observation and the wide separation (~0″.5) of this quasar pair, allowed us to directly observe the dual QSO pair, the purpose of this experiment was to subject the target to speckle interferometric analysis. Speckle observations would allow us to resolve close quasar pairs as faint as $m \sim 18$–19 and as close as the diffraction limit of Gemini (~20 mas) limit not possible with other telescopes.

Figure 1 presents our imaging results. We show a one-minute co-added direct and one of the 60 ms speckle frames taken in SDSS *i*. In addition, we present our final reduced speckle imaging results showing our 5σ contrast limits for each filter and the resultant reconstructed speckle images. The banding in the reconstructed images is due to a difference in the background level of the broad-band J2122 images and the narrow-band PSF standard star image we used, and is only present in the reconstructed images not in the Fourier analysis. Our analysis revealed the companion (in SDSS *i*) as well as the usual Fourier 180° ghost. Our data reduction process uses bi-spectral fitting routines to determine with high likelihood the true position angle of any companion (see Howell et al. 2011).



Zoom In Zoom Out Reset image size

Figure 1. Four images of the candidate dual quasar J2122−0026 at $z \approx 2$ (Chen et al. 2021). The top row presents 'Alopeke images in the SDSS *i* filter; a (non-shifted) co-added one-minute raw integration (left) and a single 60 ms speckle frame (right) revealing the tens of signal photons gathered in each speckle integration. The pattern "noise" in the 1 minute observation is due to the electron multiplier amplifier. The bottom panel presents our final 5σ contrast curves, that is the limiting magnitude reached in each filter as a function of angular distance. The insets show the two speckle interferometric reconstructed images in which the brighter component is at the center. The faint companion is seen in the upper right quadrant of the SDSS *i* image. The SDSS *r* band image only revealed the brighter component. The banding is an artifact of the mismatched filter widths/backgrounds that occurs in the image reconstruction process. The top panel images are 2″.4 on a side and all images have N up and E to the left.

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Standard image High-resolution image

From the observations, we formed an average real image using the entire 45 minutes data set. Applying aperture photometry to this image, we estimate that the two sources have magnitude differences in the SDSS *r* and *i* bands of ~0.66 ± 0.25 and ~1.4 ± 0.4 mag respectively. Using Fourier analysis, the SDSS *i* speckle analysis detected the fainter companion. SDSS *r* band speckle images also revealed the quasar pair, but with only about 25 photons/speckle image for the brighter source. This was too few to allow Fourier analysis to detect fringes above the background. In general, speckle imaging analysis degrades as one observes into the blue region of the optical due to atmospheric coherence times and seeing stability.

The candidate quasar pair is separated by 0″.49 ± 0″.03 at a position angle of 306° ± 7° and have an estimated magnitude difference in SDSS *i* of 2.4 ± 0.8. For faint companions, the magnitude contrast is the hardest value to measure and often uncertain, being overestimated by 0.5–1.0 mag. Previous HST observations (Chen et al. 2021) found a separation of 0″.52 at the same position angle.

3. Discussion

3. Discussion

Speckle imaging of sources brighter than $r \sim 15$ can be done in bright time, with seeing of less than 1.″2, and with airmass values below 1.4. However, in order to obtain speckle imaging for faint targets such as J2122, certain observing conditions are required. The observations were performed in dark time, the seeing was excellent (~0.″5), and the airmass remained between 1.0 and 1.09. The total integration time required for the target depends on these conditions but will be close to 45–60 minutes for sources with similar total brightness (SDSS $r \sim 18$–19) and magnitude contrast to J2122. Note that in speckle interferometry, the detection contrast is proportional to $1/\text{seeing}^2$ while the angular resolution is unaffected. This is in contrast to IR/AO in which the final image resolution is affected by the native seeing.

J2122 is the first dual quasar candidate observed by 'Alopeke and the faintest target ever observed by speckle interferometry. Earlier speckle interferometry imaging observations for quasars, even with 6 m telescopes, were limited to brighter ($m \lesssim 16$) targets (e.g., Hege et al. 1981). The raw data and final reduced data products are available at the Gemini archive.

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Footnotes

6 https://www.gemini.edu/instrumentation/alopeke-zorro

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