A Mid-infrared Flare in the Seyfert Galaxy NGC 3786: A Changing-look Event Triggered by an Obscured Tidal Disruption Event?

Suyeon Son1, Minjin Kim1, Luis C. Ho2,3, Dohyeong Kim4, and Taehyun Kim1

1 Department of Astronomy and Atmospheric Sciences, Kyungpook National University, Daegu 41566, Republic of Korea; smkim.astro@gmail.com
2 Kavli Institute for Astronomy and Astrophysics, Peking University, Beijing 100871, People’s Republic of China
3 Department of Astronomy, School of Physics, Peking University, Beijing 100871, People’s Republic of China
4 Department of Earth Sciences, Pusan National University, Busan 46241, Republic of Korea

Received 2022 June 10; revised 2022 August 6; accepted 2022 August 16; published 2022 September 15

Abstract

We report an exceptional mid-infrared flare in the Seyfert 1.8 NGC 3786. In the multiepoch data from the Wide-field Infrared Survey Explorer, the nuclear mid-infrared brightness of NGC 3786 appears to vary substantially up to 0.5–0.8 mag around mid-2020. However, there is no evidence of significant variation in the corresponding light curve of the optical band from the Zwicky Transient Facility. This implies that the flare may have been heavily obscured by nuclear dust. Through follow-up spectroscopic observations with Gemini-North after the flare, we find that broad emission lines in Paα and Paβ newly appear, while the broad Hβ emission is marginally detected in the postflare spectrum. In addition, their central wavelengths are systematically redshifted up to 900 km s⁻¹ with respect to the narrow emission lines. This reveals that the flare is associated with the changing-look phenomenon from type 1.8 to type 1. Based on these findings, we argue that the flare is likely to originate from an obscured tidal disruption event, although extreme variation in the accretion rate may not be ruled out completely.

Unified Astronomy Thesaurus concepts: Active galactic nuclei (16); Tidal disruption (1696); Supermassive black holes (1663)

1. Introduction

Supermassive black holes (SMBHs) are ubiquitous, at least at the center of massive galaxies (e.g., Kormendy & Ho 2013). A majority of SMBHs remain dormant. If a wandering star approaches an SMBH sufficiently close to be tidally disrupted, an accretion disk with a super-Eddington ratio is suddenly formed from the tidal debris of the star and a large amount of energy is emitted through X-rays and ultraviolet (UV) radiation. This phenomenon is known as a tidal disruption event (TDE; Hills 1975; Rees 1988). TDEs can probe the demography of SMBHs in quiescent galaxies and the physical properties of central stars in galactic nuclei (e.g., Stone & Metzger 2016; Graur et al. 2018; French et al. 2020).

To date, a few tens of TDEs have been observed using multiepoch data in the X-ray and UV/optical bands (e.g., Komossa & Greiner 1999; Gezari et al. 2006; Gezari 2021; van Velzen et al. 2021). Although observed TDE rates appear to be lower than those that are theoretically predicted, the origin of this discrepancy is unknown (e.g., Magorrian & Tremaine 1999; Holoiien et al. 2016). One possibility is that TDEs that occur in the obscured nucleus may be difficult to discover in the existing data set using current detection methods (e.g., Tadhunter et al. 2017; Kool et al. 2020). Therefore, to examine TDE phenomena fully, it is essential to investigate the occurrence rate and the physical properties of obscured TDEs.

Similar to an active galactic nucleus (AGN), a TDE can exhibit IR emission radiated from the circumnuclear dust heated by the X-ray/UV continuum from the accretion disk (e.g., Komossa et al. 2009; Jiang et al. 2016; Lu et al. 2016; van Velzen et al. 2016). Such IR echoes in the optically selected TDEs have been studied systematically using the light curves of the Wide-field Infrared Survey Explorer (WISE; e.g., Jiang et al. 2021). Jiang et al. (2021) argued that the dust covering factor is less than 0.01 and reported that known TDEs are substantially biased toward those that are minimally obscured.

TDEs are occasionally reported to be accompanied by a changing-look (CL) phenomenon in AGNs, wherein the appearance or disappearance of broad emission lines and thermal continuum from the accretion disk occurs (e.g., Eracleous et al. 1995; Merloni et al. 2015; Chan et al. 2020; Ricci et al. 2020). Although the origin of CL AGNs is unknown, the dramatic change in the accretion rate may be responsible for the type change (e.g., Penston & Perez 1984; Elitzur et al. 2014). Indeed, fallback stellar debris can be a primary driver for enhancing accretion. For example, Merloni et al. (2015) and Li et al. (2022) argued that the width and central wavelength of the broad Hα emission changed substantially in some CL AGNs, possibly due to eccentric tidal debris originating from TDEs.

In this study, we report an exceptional IR-only flare occurring in NGC 3786, which may have originated from a TDE. This IR flare is highly obscured by circumnuclear dust and associated with the CL AGN phenomenon. The initial identification of the flare, along with follow-up observations, is described in Section 2. The physical properties derived from various observational data sets are summarized in Section 3. Finally, the physical origin of this flare is discussed in Section 4. Throughout the study, we assume a cosmology with $H₀ = 67.4$ km s⁻¹ Mpc⁻¹, $Ω_m = 0.315$, and $Ω_{λ} = 0.685$ (Planck Collaboration et al. 2020).
2. Observation and Data

2.1. IR Flare in NGC 3786

Initially, we used multiepoch photometric data from WISE (Wright et al. 2010) and available in IRSA (Wright et al. 2019) to investigate the mid-IR variability of nearby galaxies within 50 Mpc. Because WISE observes certain targets multiple times during a few days of each visit, we calculate the representative magnitude of each visit as described in Son et al. (2022b) following the method of Lyu et al. (2019). The 1σ uncertainty of the magnitude is defined as the rms sum of the measurement errors and the standard deviation of the measured brightnesses in the multiple observations of each visit. By comparing this data set with light curves in the optical band, we serendipitously discovered an IR-only flare in NGC 3786, which appeared to have occurred around mid-2020. The amplitude of the bright IR flare was ∼0.5 and 0.8 mag in W1 and W2, respectively. These values are 6–8 times larger than σ of W1 and W2 before the flare.

However, no significant increase in brightness was observed in the optical monitoring data from 2019 to 2021 obtained from the Zwicky Transient Facility (ZTF; Bellm et al. 2019; Figure 1). The rms value of the g-band magnitude during 2020 is ∼0.1 mag, which is substantially less than the amplitude of the IR flare. This indicates that a corresponding flare is not observed in the optical band. As NGC 3786 has long been classified as an intermediate-type Seyfert (i.e., 1.8 or 1.9; Goodrich & Osterbrock 1983) with no detection of power-law continuum and broad Hβ emission in the optical band, it is natural to suspect that an optical flare could be obscured by the dusty torus (e.g., Goodrich 1990). Note that a significant flux variation during 2014–2016 may reveal that another weak flare occurred. However, it is unclear if that event is directly associated with the IR flare in 2020. Interestingly, optical flares occasionally occurred in NGC 3786 over the past decades (e.g., Nelson 1996; Koshida et al. 2014).

2.2. Follow-up Observations

To clarify the nature of the flare, we obtained optical and near-infrared (NIR) spectroscopic data using GMOS-N and GNIRS, respectively, at Gemini-North. Both spectra were taken on 2022 February 2, at an airmass of 1.1–1.2. The position angle was set to the parallactic angle to minimize light loss. The skies were clear and the seeing was measured as 0.75–0.8. For the optical data with GMOS-N, we used the B600 grating and a 0.75 slit to cover HeII, Hα, Hβ, and Hγ simultaneously and achieve a spectral resolution of ∼1100 to properly measure the width of the emission lines. Two individual observations with an exposure time of 280 s were obtained via spectral dithering to fill the gap between the chips. The final optical spectrum covers a range of 4600–6861 Å.

For the NIR spectrum with GNIRS, we adopted the cross-dispersed mode to obtain a wide spectral coverage from 0.8 to 2.5 μm. A 32 lines mm⁻¹ grating and 0.75 wide slit were used to achieve a spectral resolution of 1800. From this instrument setup, a slit with a length of 7″ is insufficiently long to obtain the sky spectrum for optimal sky subtraction. Therefore, we additionally acquired sky data in the blank field through target-sky-target nodding.

Before the flare, the optical spectrum of NGC 3786 was obtained with the Perkins 1.8 m telescope through a 2″ wide slit on 2010 April 6 (Koss et al. 2017). The spectrum covers 3900–7500 Å with a spectral resolution of ∼1050. In addition, the preflare NIR spectrum obtained with the IRTF telescope is available, which was obtained on 2017 March 5. It was taken with a SpeX Spectrograph and a ShortXD grating through a 0.8 wide slit at an airmass of 1.2–1.4. The spectrum covers from 0.7 to 2.55 μm with a resolution of ∼750.

2.3. Data Reduction

The optical spectra were processed in a standard way, including bias subtraction, flat-field correction, and cosmic-ray removal, using the Gemini/GMOS IRAF package. After performing wavelength calibration using arc images, we subtracted the sky emission sampled from the blank sky during the spectral extraction. The 1D spectrum is extracted from an area of 0″75 × 5″ centered at the nucleus. Finally, flux calibration was performed using the spectrum of Feige 66, an O-type subdwarf (sdO).

The NIR spectrum was reduced using the Gemini/GNIRS IRAF package. For flat-fielding correction, we used two types of flat images obtained with different rams to recover the response functions in low and high orders, simultaneously. Distortion correction was performed using pinhole spectra. The wavelength solution was determined using arc images obtained with the Argon lamp. After sky subtraction and spectral extraction with a diameter of 3″, we performed flux calibration and telluric correction using the standard star HIP 57239 (A2V) by adopting the method from Vacca et al. (2003). The preflare NIR spectrum from the IRTF telescope was reduced in the same manner. Owing to a relatively large airmass difference (∼0.8) between the standard star and the target galaxy in the IRTF observation, the telluric correction was imperfect and highly degraded the data quality in the spectral region of Paα.
To compare the spectral properties before and after the flare, optical spectra obtained with a 1.8 m Perkins telescope and GMOS-N were fitted using the following procedure. First, we simply modeled the local continuum using a first-order polynomial, which provides sufficiently reasonable results for the spectral measurements of the emission lines in AGNs (e.g., Denney et al. 2009). The [S II] λ6716, 6731 doublet was fitted with four Gaussian components (i.e., two components for each line) to account for the putative outflow in the narrow-line region (NLR; e.g., Kim et al. 2006) and used as a template profile to model other narrow lines (i.e., [N II], Hα). To fit the narrow emission lines for [O III] and Hβ, we also used two Gaussian components for each line. Both of the narrow lines were assumed to be represented by the same profile. Where necessary, the broad lines of Hβ and Hα were fitted with multiple Gaussian components. The optical spectrum obtained on 2010 April 6 exhibited a broad emission only in Hα. It is still possible that the weak broad Hβ emission is buried by the noise in the continuum. We calculated the upper limit of the broad Hβ flux (∼0.9 × 10^{-14} erg s cm^{-2}), using the 3σ of the underlying continuum and FWHM (∼2695 km s^{-1}) obtained from the postflare spectrum. However, after the flare, the broad Hα emission was enhanced and a broad Hβ emission appeared to be weakly present (Figure 2). More interestingly, the broad Hβ emission was shifted toward longer wavelengths by ∼900 km s^{-1}. Furthermore, the broad Hα emission was also observed to be redshifted by ∼600 km s^{-1} with respect to the narrow emission line. Broad He II λ4686 emission is often detected in the TDEs. However, we find no evidence of the broad He II for both optical spectra. The upper limit of He II is calculated using the 3σ of the continuum and the FWHM (∼2695 km s^{-1}) of the broad Hβ emission in the GMOS spectrum, which yields the flux ratio of He II to Hβ is less than 0.92 in the GMOS spectrum. Fitting results are summarized in Table 1.

We note that the narrow emission lines (e.g., Hβ, [O III], Hα, and [S II]) in the postflare spectrum appear to be enhanced compared to those from the preflare spectrum. It is unclear if this is due to either the intrinsic variation of the narrow-line region or the difference in the observing conditions. The former is further discussed in Section 3.3. One caveat is that the intensity from the extended region can be slightly overestimated due to the fact that the slit size is comparable and smaller than the seeing (Lee & Park 2006). As the flux calibration is performed using the standard star (i.e., the point source), the light loss owing to the small width of the slit can naturally lead to overestimating the flux of the extended emission in the science target. Therefore, the underlying continuum from the host stars and the emission from the narrow-line region can be slightly underestimated, while the fluxes of the broad emission lines originates from the unresolved nucleus is relatively free from this bias.

For the fitting of Paα and Paβ in the NIR spectra for GNIRS, we used a fitting method similar to that used for the optical spectra, except that narrow emission lines were simply fitted with a single Gaussian as their shapes appear to be distinctive from the broad emission lines. From this analysis, we found that the broad emission lines were clearly detected but significantly redshifted with respect to the narrow lines by ∼800 km s^{-1}, which is in good agreement with the velocity shift in Hβ. Using the NIR spectrum obtained with the IRTF telescope on 2017 March 5, we found that a broad component was not present, at least in Paβ, before the flare. The upper limit of the broad Paβ was calculated using the 3σ of the continuum and the FWHM measured from the postflare NIR spectrum, that is significantly smaller than the flux of the broad Paβ emission from the postflare spectrum. It indicates that the broad Paα is likely to newly appear after the flare. Note that the IRTF spectrum around Paα was heavily affected by telluric absorption, which made it difficult to detect the broad component in Paα (Figure 3).

### 3.2. 2D Imaging Decomposition

To estimate the black hole (BH) mass of NGC 3786, we use the scaling relation between BH mass and bulge stellar mass. For this purpose, we conducted a 2D imaging decomposition of a 3.6 μm image obtained with the Spitzer Space Telescope Infrared Array Camera (IRAC) using GALFIT ( Peng et al. 2002). The imaging data were obtained from the Spitzer Survey of Stellar Structure in Galaxies (S4G). The point-spread function (PSF) adopted from Salo et al. (2015) was used for the convolution of the image and to model the tentative nucleus. Note that the PSF was properly rotated according to the orientation of the science image. The companion objects were masked using the masking image provided by Salo et al. (2015).

Based on the visual inspection, we attempted to model the host with three components (bulge, oval, and disk). While a range of Sérsic indices from 1 to 6 was used to fit the bulge component, we found that the bulge was represented best by a Sérsic with n = 1. Finally, the host galaxy was fitted with three Sérsic components: one for the bulge with Sérsic index n = 1, one for an oval with free n, and one for a disk with n = 1 (Figure 4). In addition, to quantify the effect of the oval component on the bulge magnitude, we modeled the oval with the Ferrer function instead of the Sérsic component, which yielded results in terms of bulge brightness that were similar to within 0.04 mag. This result is consistent with the morphology (SABa) of NGC 3786 (de Vaucouleurs et al. 1991). Because of the nonnegligible amount of sky background, the sky value was simultaneously determined during the fitting procedure. The decomposition results are summarized in Table 2.

The absolute magnitude of the bulge was estimated to be −18.72 mag. The typical uncertainty in the bulge luminosity is ∼5% (Salo et al. 2015). However, if the PSF mismatch is severe, the uncertainty can be increased up to ∼30% (e.g., Kim et al. 2008, 2017; Son et al. 2022a). To compute the stellar mass of the bulge, we used the mass-to-light ratio given by Muñoz-Mateos et al. (2013). It yields \( M_{\text{bulge}} \approx 10^{9.62} M_\odot \), where the total stellar mass of the host is \( \sim 10^{10.08} M_\odot \). The bulge-to-total light ratio (\( B/T \)) is \( \sim 0.09 \).

### 3.3. AGN Properties

As the physical properties of the target galaxy are essential for investigating the physical origin of the flare, we estimated BH masses, bolometric luminosities, and Eddington ratios using various methods. For a type 1 AGN, BH masses can be computed using the virial method from the equation \( M_{\text{BH}} \approx \frac{v^2 R}{G} \), where \( R \) and \( v \) are the radius and velocity dispersion of the broad-line region (BLR), respectively. From
the empirical relation between AGN luminosity and $R$, the BH mass can be inferred using the single-epoch spectrum (e.g., Bentz et al. 2013). Note the broad-line luminosity instead of the optical continuum luminosity to estimate the BLR radius, which is needed to calculate the BH mass, because the AGN continuum is not detected in the spectrum. Note that the BH mass from the virial method is associated with an uncertainty, namely a scaling factor ($f$), which may depend on the geometry and kinematics of the BLR.

Conversely, BH mass can be measured independently by adopting the tight correlation between the BH mass and bulge mass ($M_{BH}-M_*$). Therefore, we estimated the BH mass before the flare using the following two measurements: using the 3.6 $\mu$m bulge luminosity (Section 3.2) and the broad H$\alpha$ emission. It is known that the $M_{BH}-M_*$ relation as well as the
The Astrophysical Journal, 937:3 (pp.), 2022 September 20

Son et al.

Table 1

| Line (1) | Date (2) | Flux (3) | FWHM (4) | Center (5) | Velocity Shift (6) |
|----------|----------|----------|----------|------------|-------------------|
| Broad He II | b ≤ 0.8 | ... | ... | ... | ... |
|           | a ≤ 1.1 | ... | ... | ... | ... |
| Narrow Hβ | b 1.1  | 383  | 4859.4 | ... | ... |
|           | a 2.1  | 243   | 4860.8 | ... | ... |
| Broad Hβ | b ≤ 0.9* | ... | ... | ... | ... |
|           | a* 1.2 | 2695 | 4875.8 | +928 | ... |
| [O III]λ5007 | b 7.5 | 383   | 5006.4 | ... | ... |
|           | a 16.2 | 243   | 5006.6 | ... | ... |
| Narrow Hα | b 5.2 | 224   | 6560.6 | ... | ... |
|           | a 11.7 | 174   | 6562.2 | ... | ... |
| Broad Hα | b 5.8  | 2854 | 6567.1 | +297 | ... |
|           | a 1.0  | 1647 | 6567.7 | +324 | ... |
|           | a 4.8  | 3938 | 6565.5 | +224 | ... |
|           | a 30.2 | 2303 | 6575.3 | +598 | ... |
|           | a 14.0 | 1831 | 6574.3 | +553 | ... |
|           | a 12.0 | 3421 | 6583.5 | +973 | ... |
|           | a 4.2  | 1571 | 6526.9 | −1613 | ... |
| [S II]λ6717,6731 | b 4.5 | 224* | 6713.3* | ... | ... |
|           | a 9.4  | 174* | 6715.4* | ... | ... |
| Narrow Paβ | b 0.94 | ... | ... | ... | ... |
|           | a 1.27 | 298  | 12819.0 | ... | ... |
| Broad Paβ | b ≤ 4.70* | ... | ... | ... | ... |
|           | a 7.30 | 3108 | 12853.9 | +816 | ... |
|           | a 0.52 | 688  | 12854.9 | +840 | ... |
|           | a 6.78 | 5025 | 12843.8 | +580 | ... |
| Narrow PaOα | b 2.60 | ... | ... | ... | ... |
|           | a 7.53 | 2398 | 18769.8 | +306 | ... |
| Broad PaOα | b ... | ... | ... | ... | ... |
|           | a 6.54 | 1831 | 18802.8 | +834 | ... |
|           | a* 0.81 | 543 | 18806.3 | +890 | ... |
|           | a* 5.73 | 2398 | 18769.8 | +306 | ... |

Notes. Column (1): emission line. Column (2): observation epoch: “b” = before the flare, “a” = after the flare. Column (3): line flux in units of 10^{-14} erg s^{-1} cm^{-2}. Column (4): FWHM of the emission line in units of km s^{-1}. Column (5): rest-frame central wavelength of the emission line in units of Å. Column (6): velocity shifts of the broad emission lines relative to the narrow emission lines in units of km s^{-1}.

* Upper limit of the emission line derived from 3σ of the underlying continuum and FWHM measured from the spectra taken after the flare.
* Single Gaussian component is used to fit the broad Hβ.
* Measurements for [S II]λ6717.
* The line is not resolved due to the low spectral resolution of the IRTF spectrum (R ~ 750).
* Measurements for each Gaussian component.

scaling factor in the virial method depends on the bulge type of the host galaxies (e.g., Kormendy & Ho 2013; Ho & Kim 2014). For the purpose of consistency, we adopted the $M_{BH} - M_*$ relation and the virial estimates derived from all galaxies regardless of the bulge type (Greene & Ho 2005; Kormendy & Ho 2013; Ho & Kim 2015). We obtained the value of log $M_{BH}/M_*$ = 6.70 and 6.68, respectively. The BH mass from the virial method is consistent with that from the $M_{BH} - M_*$ relation, despite the fact that the BLR can be moderately obscured. Additionally, we also used the correlation between the BH mass and the stellar velocity dispersion ($M_{BH} - \sigma_*$ relation) to derive the BH mass. We used two measurements of the stellar velocity dispersion. Nelson & Whittle (1995) reported $\sigma_* \sim 142 \pm 13$ km s^{-1}, based on the spectral fitting around Ca II triplet absorption. We also utilized the preflare optical spectrum to independently estimate the stellar velocity dispersion as it covers Ca H+K stellar absorption, which helps to robustly constrain the kinematics of the stars. By applying the Penalized PiXel-Fitting (pPXF) method (Cappellari & Emsellem 2004) to the spectrum, we found $\sigma_* \sim 105 \pm 59$ km s^{-1}. As a result, the black hole masses inferred from the $M_{BH} - \sigma_*$ relation of all types of bulges from Kormendy & Ho (2013) are log $M_{BH}/M_* = 6.83$ and 7.54.

We applied the same methods to calculate the BH mass after the flare, wherein broad emissions from the NIR spectrum were additionally used. From the viral methods, BH masses were estimated as log $M_{BH}/M_* = 6.82, 6.76,$ and 7.23 from the Hα, Paα, and Paβ emissions, respectively (Kim et al. 2010), without the extinction correction. By comparing the observed line ratios among Hα, Paα, and Paβ with the intrinsic values from Kim et al. (2010), we found that $E(B-V)$ ranges from 0 to 0.51 (Kim et al. 2018). We again calculated the BH masses using the extinction-corrected luminosity by adopting the color excess $E(B-V) \sim 0.35$ derived from the flux ratio of Paα to Hα, yielding a slight increase in the BH masses (log $M_{BH}/M_* = 6.97, 6.79,$ and 7.28 from the Hα, Paα, and Paβ emissions, respectively).

Although those estimates are in good agreement with that derived from the bulge mass within the uncertainty (0.4–0.5 dex in the viral methods; Park et al. 2012; Shen 2013), the BH masses estimated after the flare appear to be systematically larger than those estimated before the flare. If the newly appeared broad emission lines originated from the TDE, it is possible that the gas in the BLR is not virialized, which can introduce a systematic bias in the BH mass estimation (e.g., Li et al. 2022). Therefore, we use log $M_{BH}/M_* = 6.70$, derived from the bulge mass, as the best estimate because of the unknown bias in the virial estimates. Nevertheless, the majority of the BH mass measurements (log $M_{BH}/M_* \sim 6.5–7.5$) from various methods are in broad agreement within the typical uncertainties (0.3–0.5 dex).

The bolometric luminosity ($L_{bol}$) can be inferred either from monochromatic luminosities at various bands or line luminosities with the proper bolometric conversion. For a type 2 or intermediate-type AGN, the [O III] emission line is often used as an estimator of bolometric luminosity because the featureless continuum and broad emission are not detected. The conversion from the [O III] luminosity to the bolometric luminosity can be carried out in two different ways: (1) using the conversion factor computed from the observed [O III] luminosity not corrected for the extinction (e.g., Heckman et al. 2004); (2) using the conversion factor derived from the extinction-corrected [O III] luminosity (e.g., Lamastra et al. 2009). By adopting the conversion factor from Heckman et al. (2004) along with the [O III] luminosity ($L_{bol} = 10^{40.50}$ erg s^{-1}) after the flare, the bolometric luminosity was estimated to be $10^{44.04}$ erg s^{-1}. From the extinction-corrected [O III] luminosity with the Balmer decrement ($f_{bol}/f_{Pa\beta} \approx 5.6$), we found $L_{bol} = 10^{43.44}$ erg s^{-1} by adopting the conversion factor from Lamastra et al. (2009).
Note that the [O III] luminosity appeared to be enhanced after the flare. However, the observing conditions (e.g., slit width, position angle, and extraction aperture) in both observations, which can easily affect the flux measurements in the extended narrow-line region, are not identical to each other. Additionally, [O III] fluxes measured from past observations carried out during the last ~40 yr appeared to vary by a factor of ~5 (e.g., Goodrich & Osterbrock 1983; Keel et al. 1985; Dahari & De Robertis 1988; Cruz-Gonzalez et al. 1994; Koss et al. 2017), although it is again difficult to determine the origin of this flux variation as the observing conditions are not the same. Narrow-line flux is generally believed to be invariant on years timescale, but the flux variations in [O III] emission have been reported in CL AGNs and TDEs (e.g., Denney et al. 2014; Barth et al. 2015; Li et al. 2022). Previous studies have also shown that NGC 3786 has undergone extreme flux variations.

Figure 3. Fitting results for NIR spectra obtained before and after the IR flare. Spectra obtained with IRTF before the flare (left) and with Gemini-North after the flare (right), for Paβ (top) and Paα (bottom). Note that Paα data from IRTF are heavily compromised due to the imperfect telluric correction. Therefore, the emission-like feature around 18750 Å in the IRTF spectrum is an artifact caused by incomplete removal of the telluric features rather than Paα emission.
Figure 4. Results of 2D imaging decomposition of MIR imaging data obtained with Spitzer IRAC1 (3.6 μm). (a) Top panel shows surface brightness profiles of original data (open circles), nucleus (dotted line), bulge (solid red line), oval (dotted-dashed green line), and disk (dashed blue line) component. The residuals are displayed in the bottom panel. (b) Original image. (c) Best-fit model for only the host components. (d) Residuals.

Table 2

| Component | \(m_{1.6\mu m}\) | \(n\) | \(R_e\) |
|-----------|-----------------|------|--------|
| Nucleus   | 13.22           | ...  | ...    |
| Bulge     | 14.30           | 1.00 | 3.42   |
| Oval      | 13.68           | 0.08 | 19.29  |
| Disk      | 12.43           | 1.00 | 32.37  |

Note. Column (1): component. Column (2): AB magnitude in the IRAC1 band. Column (3): Sérsic index. Column (4): effective Radius in the unit of arcsec.

Table 3

| Property | Data Before the Flare | After the Flare |
|----------|-----------------------|-----------------|
| \(M_{BH}\) | \(L_{bol,6.68}\) | 6.70            | ...            |
| \(\sigma_e\) | ... | 6.83–7.54 | ... |
| \(L_{H\alpha}\) | 6.68 | 6.82 | ... |
| \(L_{Pa\alpha}\) | ... | 7.67 | ... |
| \(L_{Pa\beta}\) | ... | 7.23 | ... |

| Property | Data Before the Flare | After the Flare |
|----------|-----------------------|-----------------|
| \(L_{bol}\) | \(L_{H\alpha}\) | 43.70           | 44.04           |
| \(L_{Pa\alpha}\) | 43.14 | 43.44 | ... |
| \(L_{Pa\beta}\) | 42.66 | 43.27 | ... |
| \(M_{Pa\alpha}\) | ... | 43.35 | ... |
| \(M_{Pa\beta}\) | 42.88 | 43.52 | ... |
| \(M_{Pa\gamma}\) | 43.47 | 43.75 | ... |

| Property | Data Before the Flare | After the Flare |
|----------|-----------------------|-----------------|
| \(L_{bol}/L_{bol}\) | \(L_{H\alpha}\) | \(-1.10\) | \(-0.76\) |
| \(L_{Pa\alpha}\) | \(-1.66\) | \(-1.36\) | ... |
| \(L_{Pa\beta}\) | \(-2.14\) | \(-1.53\) | ... |
| \(M_{Pa\alpha}\) | ... | \(-1.28\) | ... |
| \(M_{Pa\beta}\) | \(-1.92\) | \(-1.45\) | ... |
| \(M_{Pa\gamma}\) | \(-1.33\) | ... | ... |

Notes. Column (1): AGN properties. Column (2): observational data used to estimate the AGN property. Column (3): estimates based on the data obtained before the flare. Column (4): estimates based on the data obtained after the flare.

2 W1 magnitude derived from the SED fit.

3 W1 magnitude derived from the imaging decomposition of the Spitzer 3.6μm data taken in 2004.

4 Extinction-corrected.

(e.g., Nelson 1996; Koshida et al. 2014) and type transition from type 1.8 (e.g., Goodrich & Osterbrock 1983; Osterbrock & Martel 1993) to 1.9 (e.g., Trippe et al. 2010; Koss et al. 2017) over the past decades. Moreover, NGC 5548, one of the nearest AGN, exhibits the flux variation of [O III] emission with a timescale of a few years possibly due to the fact that the ionized gas in NLR is highly concentrated in the center and the gas density is significantly higher than expected so that the recombination timescale becomes smaller than a year (Peterson et al. 2013). Therefore, the genuine change of the narrow-line region could also be responsible for the [O III] flux variation of NGC 3786. In any case, the [O III] luminosity is not suitable for an immediate trace of the bolometric luminosity due to its uncertainty in the measurements and a relatively long response timescale with respect to the variation of the AGN continuum.

Alternatively, we used W1 mag for the estimation of \(L_{bol}\) using the conversion equation in Son et al. (2022b). To properly remove the host contribution in the W1 band, we performed spectral energy density fitting using the template spectra of host galaxies and AGNs (Son et al. 2022b). From this experiment, we determined that \(L_{bol} = 10^{42.89}\) erg s\(^{-1}\) before the flare. Alternatively, the MIR magnitude of the nucleus can be simply estimated from the imaging decomposition of the Spitzer data (Section 3.2). The nuclear magnitude (~13.2 mag) from this method is significantly smaller (brighter) than that (~14.7 mag) from the spectral energy distribution (SED) fitting, yielding that \(L_{bol} = 10^{43.46}\) erg s\(^{-1}\). It is uncertain what causes this discrepancy. But the PSF mismatch can severely introduce systematic uncertainties not only for the bulge magnitude but also for the nuclear magnitude. Moreover, the Spitzer data were taken after 2004 December 17, while the WISE data were taken after 2010. Therefore, the long-term variation in MIR brightness can be also responsible for this discrepancy.

Finally, from the luminosity of the H\(\alpha\) emission before the flare, \(L_{bol} = 10^{42.66}\) erg s\(^{-1}\) (Greene & Ho 2005; Richards et al. 2006). After the flare, by applying the same methods, \(L_{bol} = 10^{43.27}\) and \(10^{43.35}\) erg s\(^{-1}\) were estimated from H\(\alpha\) and W1 mag, respectively. Additionally, we used the Pa\(\alpha\) luminosity to compute the bolometric luminosity \((L_{bol} = 10^{43.52}\) erg s\(^{-1}\)) by adopting the conversion factor from Kim et al. (2022). Based on the above measurements, the Eddington ratio was calculated under the assumption that \(\log M_{BH}/M_\odot = 6.70\) (Table 3).
4. Physical Origins of the Flare

Here, we discuss the physical origin of the MIR-only flare in NGC 3786. Variations in MIR color can be used as a probe for flares. W1-W2 became redder as it brightened in the W1 band (Figure 1), which is in broad agreement with canonical CL AGNs and low-luminosity AGNs (e.g., Yang et al. 2018, 2019; Son et al. 2022b), and distinctive from the color variability in supernovae (SN). Therefore, the flare is likely to originate from nuclear activity rather than SN.

An intriguing result from the follow-up observations was that the newly appearing broad emission lines were redshifted up to 900 km s\(^{-1}\). Such a high-velocity offset is often observed in CL AGNs, possibly resulting from the eccentric tidal debris generated from the TDE phenomenon (e.g., Merloni et al. 2015; Li et al. 2022). In this light, it is natural to suspect that the MIR flare was caused by radiation of circumnuclear dust, which is heated by the enhanced light from the accretion disk due to the TDE.

However, He II λ4686, which is most commonly found in ordinary TDEs (e.g., Arcavi et al. 2014), was not detected in the GMOS spectrum obtained after the flare. In general, He II is known to be more luminous than Hβ in TDEs. However, the flux ratio between the two lines and its variation over time substantially varies among TDEs (e.g., Hung et al. 2017). Given that the follow-up observation was performed at least ~2 yr after the flare, it may not be surprising that He II dimmed and was not detected. Alternatively, it is also possible that the gas density is not yet sufficiently low for He II to emerge after Hα enhancement (Li et al. 2022). In addition, dust obscuration may not be negligible, which can lead to significant attenuation of He II flux.

It is well known that a TDE preferentially occurs in low-mass BHs (≤10\(^{-3.5}\)M\(_{\odot}\)) because at high-mass BHs (>10\(^{-7.5}\)M\(_{\odot}\)) the tidal radius of low-mass stars becomes less than the Schwarzschild radius (e.g., Stone & Metzger 2016). NGC 3786 (M\(_{BH}\) ~ 10\(^{-7.0}\)M\(_{\odot}\)) appears to meet the BH mass range for a high TDE occurrence rate, which implies that the TDE scenario is still favorable. Note that the BH masses derived from the M\(_{BH}\)–σ relation are slightly larger (M\(_{BH}\) ~ 10\(^{6.83\pm0.54}\)M\(_{\odot}\)). However, even with these values we still cannot completely rule out the TDE scenario, accounting for the intrinsic scatter of the M\(_{BH}\)–σ relation (~0.3 dex). In addition, at a given stellar velocity dispersion, galaxies with pseudobulges systematically have a smaller BH mass compared to ellipsoidal or galaxies with classical bulges. Our imaging decomposition results indicate that the NGC 3786 can be well fit with a pseudobulge represented by the small Sérsic index and B/T. Therefore, BH mass inferred from the M\(_{BH}\)–σ relation can be somehow overestimated.

In contrast, the CL AGN phenomenon can originate from the transition of the accretion mode (e.g., Guolo et al. 2022). For example, in the AGN with the low Eddington ratio, the BLR can physically disappear in the disk-wind driven BLR model due to the low efficiency in the accretion disk or the lack of an ionizing photon (e.g., Elitzur & Ho 2009; Elitzur et al. 2014). This transition between the standard thin accretion disk model and a radiatively inefficient accretion flow (RIAF) can occur at the critical Eddington ratio (~1%; e.g., Ho 2008). Interestingly, the Eddington ratio of the nucleus of NGC 3786 before and after the flare (~0.7%–3.5%) is in broad agreement with the critical value. Even if we adopt the BH masses derived from the M\(_{BH}\)–σ relation, the estimated Eddington ratios range from ~0.1% to 0.5%, which is still comparable to the critical value for the transition. This suggests that the flare and the CL AGN phenomenon can be driven simply by accretion mode transition, although the velocity offset of the broad emission lines may not be naturally explained by this mechanism.

In summary, while the increase of the accretion rate cannot be entirely excluded as the physical origin of the IR flare, the TDE is more favorable to explain the velocity shifts in the broad emission lines (e.g., Merloni et al. 2015; Li et al. 2022). In this scenario, the reddish broad emission lines are likely to arise from the tidal debris on eccentric orbits (e.g., Guillochon et al. 2014). To further determine the nature of the flare, multiepoch spectroscopic data will be essential because the BLR can be shifted on a scale of ~ month if the BLR is generated from tidal debris (e.g., Zabludoff et al. 2021; Li et al. 2022). For the systematic studies of the heavily obscured flares, the future IR multiepoch survey, such as SPHEREx, will play a crucial role by extensively detecting MIR flares in the galactic nuclei (e.g., Doré et al. 2018; Kim et al. 2021).

We thank the anonymous referee for constructive comments that helped to improve the manuscript. L.C.H. was supported by the National Science Foundation of China (11721303, 11991052, and 12011540375) and the China Manned Space Project (CMS-CSST-2021-A04 and CMS-CSST-2021-A06). This work was supported by the National Research Foundation of Korea (NRF) grant (Nos. 2020R1A2C4001753 and 2022R1A4A3031306) funded by the Korean government (MSIT) and under the framework of the international cooperation program managed by the National Research Foundation of Korea (NRF-2020K2A9A2A06026245). D.K. was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT: No. 2021R1C1C1013580). T.K. was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) grants (Nos. 2019R11A3A02062242) funded by the Ministry of Education, and grants (WISEST 2021-541) funded by the Korea Foundation for Women In Science, Engineering and Technology. This work was supported by K-GMT Science Program (PID: GN-2022A-FT-203) of Korea Astronomy and Space Science Institute (KASI). Based on observations obtained at the international Gemini Observatory, a program of NSFs NOIRLab, which is managed by the Association of Universities for Research in Astronomy (AURA) under a cooperative agreement with the National Science Foundation, on behalf of the Gemini Observatory partnership: the National Science Foundation (United States), National Research Council (Canada), Agencia Nacional de Investigación y Desarrollo (Chile), Ministerio de Ciencia, Tecnología e Innovación (Argentina), Ministério da Ciência, Tecnologia, Inovações e Comunicações (Brazil), and Korea Astronomy and Space Science Institute (Republic of Korea).

ORCID iDs
Suyeon Son @ https://orcid.org/0000-0002-5346-0567
Minjin Kim @ https://orcid.org/0000-0002-3560-0781
Luis C. Ho @ https://orcid.org/0000-0001-6947-5846
Dohyeong Kim @ https://orcid.org/0000-0002-6925-4821
Taehyun Kim @ https://orcid.org/0000-0002-5857-5136
