Photometric Stellar Variability in the Galactic Center

M. Rafelski1, A. M. Ghez1,2, S. D. Hornstein1, J. R. Lu1, M. Morris1

1 Division of Astronomy and Astrophysics, UCLA, Los Angeles, CA 90095-1547
2 Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095-1565
E-mail: marcar, ghez, seth, jlu, morris@astro.ucla.edu

Abstract. We report the results of a diffraction-limited, photometric variability study of the central 5'' × 5'' of the Galaxy conducted over the past 10 years using speckle imaging techniques on the W.M. Keck I 10 m telescope. Within our limiting magnitude of $m_K < 16$ for maps made from a single night of data, we find a minimum of 25 variable stars out of 131 monitored stars. Among 46 stars brighter than $m_K < 14$ which have roughly uniform photometric uncertainties, there are 16 variable stars. This suggests a minimum variable star frequency of 34%. We see no evidence of flares or dimming of the 7 stars that have known 3-dimensional orbits in our study, which greatly limits the possibility of a cold, geometrically-thin, inactive accretion disk around the supermassive black hole, Sgr A*. While large populations of binaries have been posited to exist in this region both to explain the presence of young stars in the vicinity of a black hole and because of the high stellar densities, only one eclipsing binary is identified. The only periodic source in our sample is the previously identified variable IRS 16SW (P=19.448 ± 0.002 days). In contrast to recent results, our data show an asymmetric phased light curve with a much steeper fall-time than rise-time. IRS 29N shows variability on time scales of ≈ 5 years and has a known spectral type of WC9. This variation is likely due to episodic dust production, which may suggest that this source is a binary star system. Only 2 of the LBV candidates in our sample (16NW, 16SW) show variability and none of the 4 show the characteristic large increase or decrease in luminosity. However, our time baseline is too short to rule them out as LBVs. Our study has shown that photometric variability provides a useful handle on the unusual massive star population surrounding our Galaxy’s supermassive black hole and its local environment.

1. Introduction

The cluster of stars at the Galactic center (GC) presents a unique opportunity to study the evolution and properties of stars within the influence of the $\sim 3.7 \times 10^6 M_\odot$ supermassive black hole (SMBH), Sgr A* [1, 2]. These stars are composed of a mix of older giants and young massive stars in transient phases of evolution whose variability characteristics and mechanisms are not well understood. Some of the massive young stars have been spectroscopically identified as blue supergiants (O & B spectral type), luminous blue variables (LBVs), and Wolf-Rayet (WR) stars [3], while some of the older population is composed of asymptotic giant branch (AGB) and cool supergiant stars [4, 5]. The LBVs, WR, and AGB stars are expected to show photometric variability. Determining which stars are variable and the characterization of their time variability can improve our understanding of the circumnuclear material of the SMBH, the rare transitional stars associated with regions of star formation, and the Galactic center stars.
2. Identifying Variable Stars

Over the last 10 years, K-band ($\lambda_0 = 2.2 \mu m$, $\Delta \lambda = 0.4 \mu m$) speckle imaging observations within the central 5" $\times$ 5" of the Galaxy's central stellar cluster were obtained with the W. M. Keck I 10 m telescope. For this study, data from each night of observations were combined to produce 50 diffraction limited images. StarFinder [8] was run on all the images to extract the relevant photometric information.

There are a wide range of methods for testing photometric variability and the challenge for these various approaches is to avoid false identifications on the basis of a few outlying data points [6]. We therefore have chosen to use the Kolmogorov-Smirnov (K-S) test, to calculate the probability that a distribution of data points is consistent with a model of a distribution of measurements for a non-variable source. This approach is less sensitive to outlying data points than the commonly used $\chi^2$ test. Stars are classified as variable if they lie more than 3$\sigma$ from a gaussian distribution of a non variable.

Among the 131 stars in our sample, 25 are identified as photometric variables in this study (see Figure 1). Since the relative photometric uncertainties are roughly uniform down to a $m_K$ magnitude of $\sim 14$ and then increase at fainter magnitudes, we limit our statistical study to those stars brighter than 14 mag. Within this brighter sample of 44 stars, there are 15 variable stars, suggesting a minimum frequency of variable stars of 34%. There is no evidence for radial, magnitude, or type dependence of the variable stars.

3. Variability of stars near closest approach

The photometry of stars near Sgr A* constrain the properties of a possible cold geometrically-thin inactive accretion disk around Sgr A* [9, 10]. In the presence of such a disk we would expect to see nearby stars significantly flaring in the near infrared NIR at times and eclipsed at others due to their interaction with the material in the disk. The time-scales vary based on the geometry of the disk, but are on the order of a year for the eclipses and months for flares. Due to the high stellar densities and the flaring of Sgr A* in the infrared [11, 12], the photometry of the...
central sources sometimes vary due to stellar confusion with each other or with Sgr A* during their closest approach. Observations averaging multiple nights of data also show additional stars close enough to cause confusion with some of the stars identified in this survey [1]. An optically thin disk may not fully eclipse stars and our gaps in observations would allow different geometries of the disk to account for any one star not showing eclipses or flares in the light curves as was done for S0-2 [12]. We have not observed any flares in the 7 central arcsecond sources that have known 3-dimensional orbits (S0-2, S0-16, S0-19, S0-20, S0-1, S0-4, S0-5). Also, no noticeable eclipses are detected in any of these sources, although three of these (S0-16, S0-19, S0-20) can not be used to constrain the flares since they are all fainter than the others and have missing measurements due to insufficient map sensitivity (see Figure 2). S0-2 and S0-16 are still considered variable stars according to their K-S probability after discarding points affected by well understood confusion, however we attribute this low level variation to confusion with faint unrecognized stars. While optically thin disks may not fully eclipse stars and flares can be missed between observations, the lack of such effects indicate that such a disk probably does not exist around Sgr A*.

![Figure 2. Light curves of 7 central arcsecond sources that have known 3-dimensional orbits. Large tick-marks on y-axis designate 1 magnitude in range. The X’s mark observations that are rejected due to confusion with other sources, and the boxes are areas where the nightly maps have missing measurements that are due to insufficient map sensitivity and are detected in monthly averaged images.](image1)

![Figure 3. Light curves of the four stars in our sample that are classified as candidate LBVs (IRS 16SW, 16NW, 16NE, 16C). Large tick-marks on y-axis designate 1 magnitude in range. Lines indicate the median magnitude.](image2)

4. Luminous Blue Variables
Luminous Blue Variables (LBVs) are rare high mass stars in a transient phase of evolution. Massive O stars go through the LBV phase before becoming Wolf-Rayet stars [13]. During this phase, they are well known for giant eruptions and obscuration events [14]. The presence of LBVs along with Wolf-Rayet stars in the Galactic center would suggest two distinct star formation events occurred due to their differing evolutionary time-scales. Our sample includes 4 of the 23 candidate LBV stars in our Galaxy (IRS 16NE, 16C, 16NW, 16SW) [15, 16]. These 4 stars are cited as possible LBVs based on IRS 34W’s (a similar nearby star) categorization as an LBV, their brighter luminosity, and narrower emission lines [15]. If these stars are LBVs,
we expect to see eruptions of $\Delta M_V \simeq 1 - 2$ mag occurring on time scales of 10-40 years with minima and maxima that may last several years and have smaller variations superimposed [14].

Two of these stars (16NW and 16SW) show variability (see Figure 3), but these variations are not characteristic of LBV variations; 16NW is an Ofpe/WN9 star with a flat light curve and a decrease in brightness from 1997 to 1999 of $\Delta m_K \simeq 0.2$ and 16SW has periodic variability (see §5). The apparent dimming in 16NW can be explained by ejected circumstellar material obscuring the star, with the smaller amplitude representing a smaller ejection than an LBV, and does not require it to be an LBV. In the case of 16SW, it has been suggested that it might not be an LBV due to its periodic nature, although its spectrum resembles that of the other IRS 16 cluster sources that are Ofpe/WN9 stars [15, 3]. If 16SW consists of two eclipsing LBVs then they show no significant variation evidenced by the smooth phased light curve. The other two LBV candidates(16NE and 16C) are non-variable over a ten-year time frame. LBVs may look like Of/WN9 stars during a quiescent state [14], so these stars may be such LBVs. While none of these stars show the classic characteristics of LBVs, our time baseline is too short to rule them out completely as LBVs.

5. Periodic Variables
IRS 16SW is the only star in our sample with a detectable period. We find a period of $19.448 \pm 0.002$ days, which is consistent with other studies’ second harmonic for this star [17, 18]. As noted by Depoy et al., if the star is an eclipsing binary with two equal mass systems then the actual period would be the second harmonic as the star would have equal primary and secondary minima [18]. Figure 4 shows the phased light curve of IRS 16SW at 19.448 days. The light curve is asymmetric with a shorter fall-time than rise-time, a short minimum, and a possible period of constancy at maximum brightness. Our light curve is similar to the light curve presented by Ott et al., although asymmetry was not reported there [17]. This is in contrast to Depoy et al. who see an almost symmetric light curve with a slightly shorter rise-time than fall-time and no evidence of any part of the light curve remaining constant [18]. The most recent results presented in these proceedings show a period of 19.4 days in the radial velocity data, which matches our photometric period and suggests that 16SW is an eclipsing binary [19]. We suggest that the asymmetry may be due to hot spots on the stars.

**Figure 4.** The phased light curve of IRS 16SW at its period of 19.448 ± 0.002 days.

**Figure 5.** Light curve of IRS 29N.
6. Wolf-Rayet type WC stars

Wolf-Rayet stars of spectral type WC9 are dust producers although the mechanism for this production is still not well understood due to the hostile environment of the stellar winds at the dust condensation radius [20, 21]. One mechanism for dust formation is wind colliding binaries (WCB), and all seven observed (prior to this study) WC stars that variably produce dust are believed to be WCBs [22, 23]. When the dust forms, the stars exhibit enhancements in their infrared fluxes followed by fading emission when dust formation stops and is dispersed by the stellar winds [22]. Light curves of these variable dust producers are presented by van der Hucht in L'-band (λo = 3.8μm) [24] and are similar to the light curve of IRS 29N (see Figure 5). IRS 29N is spectroscopically identified as a WC9 star [3], while we show it photometrically varying with a gradual drop and then rise in brightness of ΔmK ≃ 0.7 over a time scale of ≈ 5 years. We propose that IRS 29N is a periodic or episodic dust producer and probably a WCB based on its light curve and spectral classification.

Acknowledgments

The W. M. Keck Observatory is operated as a scientific partnership among the California Institute of Technology, the University of California and the National Aeronautics and Space Administration. The Observatory was made possible by the generous financial support of the W. M. Keck Foundation. Support for this work was provided by NSF grant AST-0406816.

References

[1] Ghez, A. M., Salim, S., Hornstein, S. D., Tanner, A., Lu, J., Morris, M., Becklin, E. E., Duchêne, G. 2005, ApJ, 620, 744
[2] Schödel, R., Ott, T., Genzel, R., Eckart, A., Mouawad, N., & Alexander, T. 2003, ApJ, 596, 1015
[3] Paumard, T., et al. 2006, ApJ, 643, 1011
[4] Blum, R. D., Ramírez, S. V., Sellgren, K., & Olsen, K. 2003, ApJ, 597, 323
[5] Figer, D.F. et al. 2003, ApJ, 599, 1139
[6] Welch, D.L., & Stetson, P.B. 1993, AJ, 105, 1813
[7] Ghez, A. M., et al. 2006 (in prep)
[8] Diolaiti, E., Bendinelli, O., Bonaccini, D., Close, L., Currie, D., & Parmegiani, G. 2000, A&A, 147, 335
[9] Nayakshin, S., & Sunyaev, R. 2003, MNRAS, 343, L15
[10] Cuadra, J., Nayakshin, S., & Sunyaev, R. 2003, A&A, 411, 405
[11] Genzel, R., Schödel, R., Ott, T., Eckart, A., Alexander, T., Lacombe, F., Rouan, D., & Aschenbach, B. 2003, Nature, 425, 934
[12] Ghez, A.M., Wright, S.A., Matthews, K., Thompson, D., Le Mignant, D., Tanner, A., Hornstein, S.D., Morris, M., Becklin, & Soifer, B. T. 2004, ApJ, 601, L159
[13] Massey, P. 2003, ARA&A, 41, 15
[14] Humphreys, R. M., & Davidson, K. 1994, PASP, 106, 1025
[15] Clark, J. S., Larrisonov, V. M., & Arkharov, A. 2005, A&A, 435, 239
[16] Paumard, T., Genzel, R., Maillard, J. P., Ott, T., Morris, M. R., Eisenhauer, F., & Abuter, R. 2004, Proc. of XXXIXth Rencontres de Moriond, Eds: A. Chalabaev, T. Fukui, et al., (Paris: Frontieres), p 377
[17] Ott, T., Eckart, A., & Genzel, R. 1999, AJ, 523, 248
[18] DePoy, D. L., Pepper, J., Pogge, R. W., Stutz, A, Pinsonneault, M., & Sellgren, K. 2004, ApJ 617, 1127
[19] Ott, T. et al. 2006, these proceedings
[20] Williams, P. M., van der Hucht, K. A., & Rauw, G. 2005, Massive Stars and High-Energy Emission in OB Associations, p 65
[21] Williams, P. M., van der Hucht, K. A., & The, P. S. 1987, A&A, 182, 91
[22] Williams, P. M., & van der Hucht, K. A. 2000, MNRAS, 314, 23
[23] Lefèvre, L., et al. 2005, MNRAS, 360, 141
[24] van der Hucht, K. A., Williams, P. M., & Morris, P. W. 2001, ESA SP-460: The Promise of the Herschel Space Observatory, p 273