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The Spectrum of the Optical Transient in NGC 5775

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On 2012 April 25, we acquired spectra and images of NGC 5775 OT PSN J14535395+0334049, classified as a calcium transient similar to NGC 300 OT and SN 2008S in NGC 6496. The Russian 6-m telescope and the SCORPIO focal reducer were used. The spectral range was $\lambda\lambda 4070 - 5830$ Å and the spectral resolution, 5.4 Å. The spectrum is noisy and shows a continuum with an H_β emission line . The line has a two-component profile containing a narrow component, with FWHM $\approx$ 300 km s^{-1}, and a broad one, with FWHM $\approx$ 4000 km s^{-1}. The object is located at the front of the edge-on galaxy disk, it is weakly reddened. We estimate its M_V as $-13\overset{m}{.}7$ on the date of observation, typical of a calcium-type supernova impostor.

1 INTRODUCTION

Intermediate-luminosity optical transients are the eruptive stars that hit the peak-luminosity gap between classical novae and core-collapsed supernovae (SNe). The gap ranges between absolute magnitudes $-8^{\rm m}$ and $-17^{\rm m}$ (Berger et al., 2009). This family of astrophysical objects includes heterogeneous groups of stars: (1) Luminous Blue Variables that experienced large outbursts (η Car, SNe 1961V and 1954J); (2) the so-called calcium transients (SN 2008S in NGC 6496, NGC 300 OT); and (3) red novae (V1006/7 in M31, V838 Mon). Outburst spectra of the first two groups resemble SNe IIn, where "n" reflects presence of narrow hydrogen and other emission lines. SNe IIn have absolute magnitudes $M_V = -17.5 \div -18\overset{m}{.}0$, typical of core-collapsed SNe II (Schlegel, 1990). Van Dyk et al. (2000) called lower-luminosity SNe IIn (group 1) "supernova impostors", i.e. stars that feign their being supernovae. Later, the term "SN impostor" was applied also to group 2 transients (Berger et al., 2009; Smith et al., 2009).

In the group of calcium transients, NGC 300 OT2008-1 got the peak absolute magnitude M_V of $-12\overset{m}{.}9 \div -13\overset{m}{.}1$ and developed a late F-type absorption spectrum with hydrogen emissions, the CaII emission triplet at λ8498, 8542, and 8662 Å, the [CaII] doublet at λ7291 and 7323 Å, and the strong CaII H&K absorption doublet at λ3933 and 3968 Å (Bond et al., 2009; Humphreys et al., 2011). There are also the OI λ8446 Å absorption, [O I] λ6300 and 6363 Å emission lines. The temperature derived from continuum energy distribution was 4670 K (Berger at al., 2009). The spectrum is similar to that of the cool Galactic hypergiant IRC+10420. The emission lines had a complex double-peak structure suggesting development of a bipolar outflow. Another calcium transient, SN 2008S in NGC 6496, had a peak magnitude $M_R = -13\overset{m}{.}9$ and a spectrum similar to NGC 300 OT (Smith et al., 2009). Its temperature in the outburst was measured as 7500 K from the continuum light distribution. Progenitors of both transients were identified in far infrared using the Spitzer Space Telescope.

The progenitor of NGC 300 OT was detected in all five bands of Spitzer IRAC and MIPS images in the wavelength range from 3.6 to 24 μm (Berger et al., 2009). Its spectral energy distribution can be fitted by a black body with the temperature 338 K and bolometric luminosity $5.8 \times 10^4\ L_\odot$. The progenitor of SN 2008S was clearly seen in the IR bands at 4.5, 5.8, and 8.0 μm and did not vary during three years. Its blackbody temperature was $T = 440$ K (Prieto et al., 2008; Wesson et al., 2010). The source had a bolometric luminosity of $3.5 \times 10^4\ L_\odot$. Both progenitors were not seen in optical bands over the limits of the deepest frames of the Hubble Space Telescope. It becomes clear that both progenitors are OH/IR stars. In the Temperature − Luminosity diagram they are located at the AGB sequence, being extremely cool and luminous (super-AGB) stars. Khan et al. (2010) measured archival images of Spitzer IRAC of four nearby galaxies, M 33, NGC 300, M 81, and NGC 6946, and found that such objects occured very seldom, there were only a few of them in each galaxy. In NGC 300 and NGC 6496, such super-AGB stars were single, and both exploded. They are considered as dusty-enshrouded luminous stars with masses of $10 - 15\ M_\odot$. Wesson et al. (2010) show that the radius of dust shell may reach 10^5 AU, and the region of the dust evaporated by the flash will expand in the shell as a light echo. The presence of narrow lines in spectra is the prime evidence of dense gas-and-dust medium. Ohsawa et al. (2010) observed NGC 300 OT with the IR camera of the AKARI satellite at $2 - 5\ \mu$m on days 398 and 582 after the discovery and detected radiation of hot dust with temperatures 810 and 610 K, respectively.

Another calcium transient, PSN J17592296+0617267, was discovered in NGC 6509 (Kelly et al., 2011; Silverman et al., 2011).

Recently, a new object of such type, identified as PSN J14535395+0334049 in NGC 5775, was discovered by Howerton et al. (2012). It was detected by the Catalina Sky Survey (CSS) on 2012 March 27.49 UT at $V = 18\overset{\mathrm{m}}{.}7$ and was not seen in CSS data on March 17.39 to $V > 19\overset{\mathrm{m}}{.}5$. Howerton et al. report that, besides the Hα line well fitted by a Lorentzian profile with FWHM ≈ 650 km s^{-1}, its spectrum contains CaII and [CaII] emission lines and also strong CaII H&K and NaI D absorptions. The spectrum resembles early-time spectra of SN 2008S and NGC 300 OT. The observed absolute magnitude of this object, $-13\overset{\mathrm{m}}{.}9$, is consistent with those of the calcium transients. Additionally, Berger et al. (2012) found a potential progenitor in the image of NGC 5775 with the F625W filter in the HST ACS archive at the AB magnitude of $25.5 \div 26^{\mathrm{m}}$. With the NGC 5775 distance, this corresponds to an absolute magnitude $-6\overset{\mathrm{m}}{.}1 \div -6\overset{\mathrm{m}}{.}6$.

The nature of calcium-type transients and energy sources of their explosions are still disputable.

Fox et al. (2011) studied with Spitzer the remnants of 68 SNe IIn and found that 15 per cent of such objects displayed late-time emission of warm dust. The dust-shell properties indicate that the progenitor winds and mass-loss rates are most consistent with the properties of LBVs. An LBV has already been directly identified as a likely progenitor of SN 2005gl, and LBVs are considered likely progenitors of many other SNe IIn. So, dust-obscured LBVs may be progenitors of such transients and the LBV phenomenon is accompanied with great explosions. Recently, Rest et al. (2011), taking spectra of light echoes of η Car generated by its 19th-century Great Eruption, found it unexpectedly cool in the outburst, with the same calcium features.

Humphreys et al. (2011) argue that such transients are most likely evolved intermediate-mass stars in post-AGB or post-RGB transition to higher temperatures that had recently experienced large mass loss. Having shed a lot of mass, these stars are at the Eddington limit for their luminosities or close to it. Humphreys et al. think that the progenitors of these transients are not classical or normal LBV/S Dor variables, and although they have experienced "giant eruptions", these eruptions are not examples of the LBV giant eruptions. The progenitors of these transients are less luminous. Observations showed that these eruptions produced a cool dense envelope and a two-component bipolar outflow.

Kashi, Frankowski, and Soker (2010) suggest that most (but probably not all) intermediate-luminosity optical transients are accretion-powered events. The outbursts may be caused by tidal disruption in stellar approaches or by merging stars. These transients are expected to produce bipolar ejecta as a result of the geometry of the accretion process.

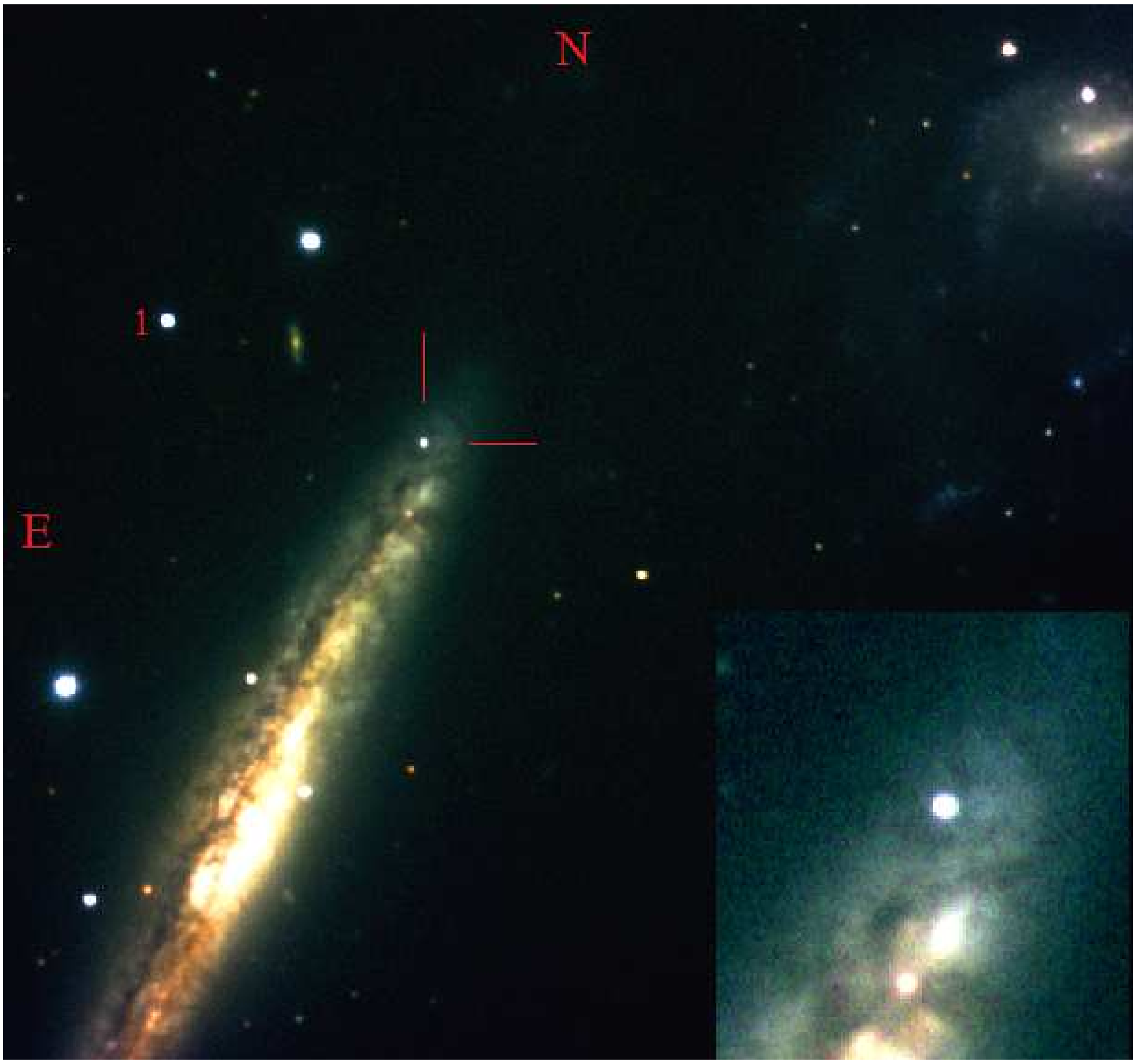

Figure 1. The color image of the NGC 5775 transient, formed from BTA/SCORPIO B, V, and R frames. The size of the image is $4'.1 \times 4'.1$. The comparison star is marked "1". Bottom right: an enlarged fragment of the star's environment, $0'.8 \times 0'.6$ in size.

Having in mind the scientific interest in such objects, we have carried out observations of the NGC 5775 transient.

2 OBSERVATIONS AND DATA REDUCTION

The spectra and images of NGC 5775 OT were taken with the 6-m BTA telescope and SCORPIO focal reducer (Afanasiev & Moiseev, 2005) on 2012 April 25.

In the photometric mode, we obtained CCD frames with standard B, V, and Cousins R filters. A color image based on these frames is shown in Fig. 1. It appears that the star is located at the front edge of the galactic disk, in a low-absorption region. Dark nebulae are located close to the star, to the north and south of it, but they do not cover the star. To perform relative photometry, we used the comparison star No. 1. Its SDSS position is $14^h53^m57^s.9$, $+3°34'42''.5$, J2000.0, and its SDSS magnitudes are $ugriz = (17.238 \pm 0.009,\ 16.235 \pm 0.003,\ 15.711 \pm 0.004,\ 15.857 \pm 0.004,\ 15.664 \pm 0.007)$. These magnitudes were transferred to BVR_C magnitudes by interpolation using $ugriz$ and UBV AB_{95} magnitudes of α Lyr calculated by Fukugita et al. (1996, Table 8). As a result, the BVR_C magnitudes of the star 1 were derived as follows: (16.57, 16.01, 15.61). The measured magnitudes of NGC 5775 OT are $BVR_C = (18.82 \pm 0.06,\ 18.26 \pm 0.05,\ 17.89 \pm 0.04)$, the mean Julian date of the observation is 2456043.40. The color indices are $B - V = 0^m.56 \pm 0^m.08$, $V - R_C = 0^m.37 \pm 0^m.06$; the estimated uncertainties are mainly formed by inhomogeneities of surrounding background. The photometry available to date is collected in Table 1.

In the spectroscopic long-slit mode, the camera was equipped with a VPHG 1200G grism (the nominal spectral range $\lambda 4000 - 5700$ Å, resolution 5 Å, dispersion 0.88 Å per pixel). Due to technical problems, the observations were done without guiding. The spectra are noisy due to small exposures and insufficient signal accumulation. The signal-to-noise ratio in the continuum was about 5. During the observations, the seeing was estimated between $1''.2$ and $1''.5$. Spectra were reduced using standard ESO MIDAS procedures for the long-slit mode. Basic parameters of the spectra are given in Table 2.

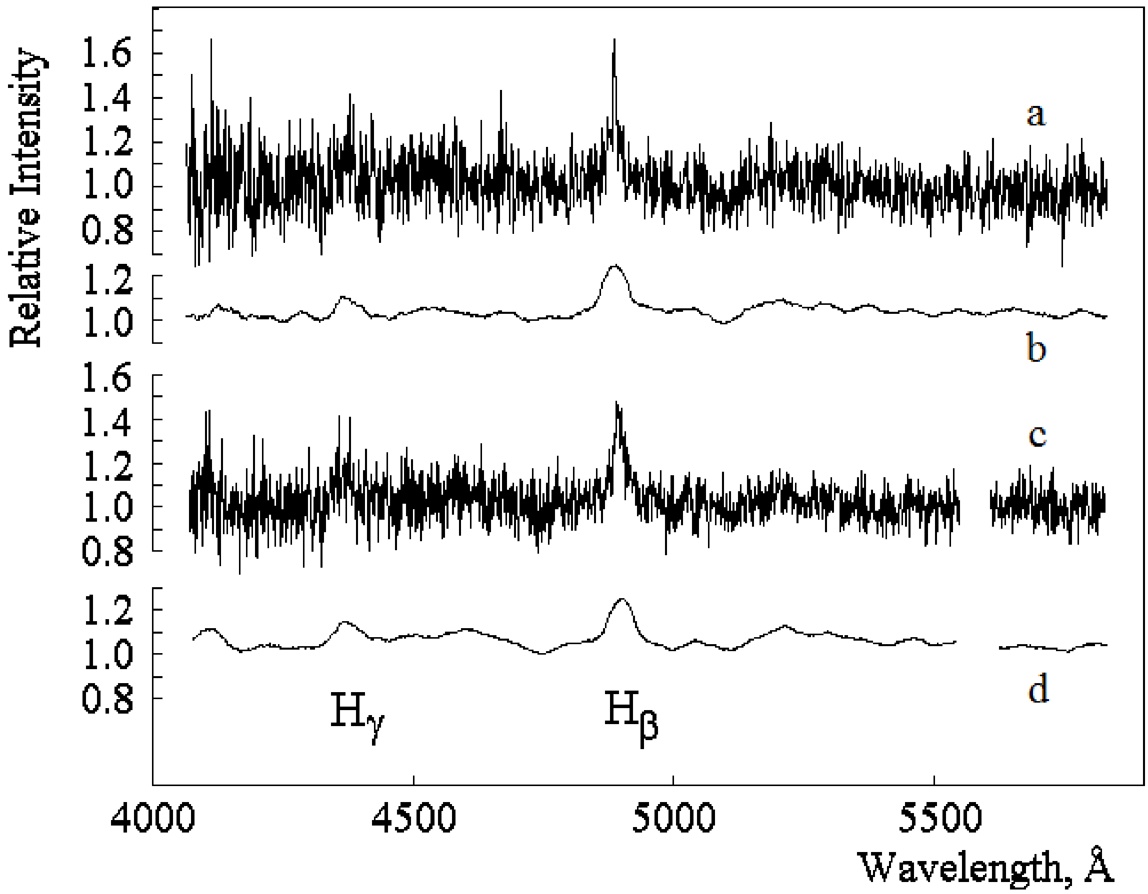

Figure 2. Spectra of NGC 5775 OT taken with BTA/SCORPIO. (a): The 600 s spectrum with the resolution of 5.4 Å. (b): The same spectrum smoothed with a Gaussian filter. (c): The 1200 s spectrum with the resolution 17 Å. (d): The same spectrum smoothed with a Gaussian filter.

To display general features of these noisy spectra, we smoothed them with a Gaussian filter, its width being $\sigma = 30$ Å. The original and smoothed spectra are shown in Fig. 2.

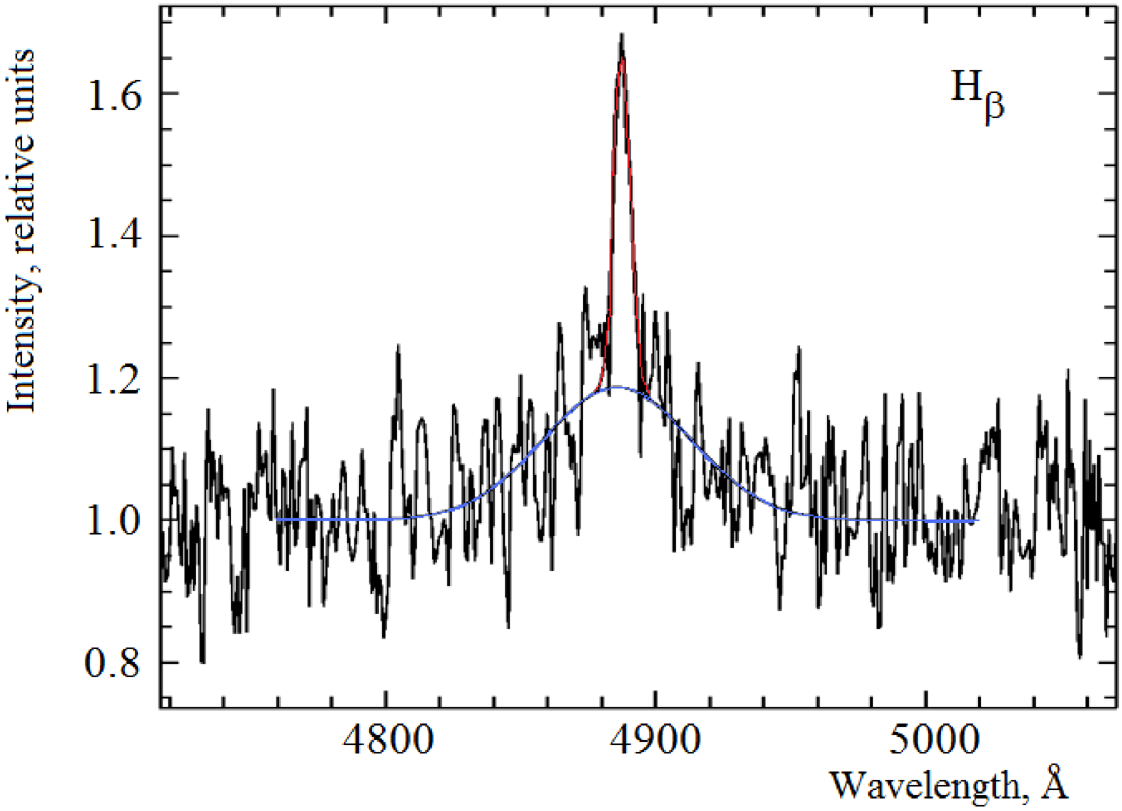

Figure 3. The H_β line profile. Two components of Gaussian approximation are also shown. The narrow component is red, the broad component is blue.

3 RESULTS

In the spectra ranged between λ4070 and 5830Å, only the H_β line is seen well enough. There are no strong calcium lines in this range. In both smoothed spectra, H_γ emission can also be identified. The spectrum of higher resolution reveals a two-component H_β profile (Fig. 3). It consists of a narrow component with FWHM $= 7.0 \pm 0.8$ Å centered at $\lambda 4887.55 \pm 0.32$ Å and a broad component with FWHM $= 64.6 \pm 6.5$ Å centered at $\lambda 4885.74 \pm 2.5$ Å. Taking into account the instrumental profile (FWHM $= 5.4$ Å), we have a half width of the narrow component about 300 km s^{-1}. The FWHM of the broad one is about 4000 km s^{-1}, and the total width of this component at zero level can be about 8600 km s^{-1}. The radial velocity of the narrow component is 1620 ± 10 km s^{-1}.

The radial velocity of the galaxy NGC 5775 is 1681 ± 5 km s^{-1} (NED). The difference of $\sim (-60)$ km s^{-1} may be attributed to the galaxy's rotation. Using the new HST estimate of the Hubble constant, 73.8 km s^{-1} Mpc^{-1} (Riess et al., 2011), we find the distance to NGC 5775 to be 22.8 Mpc. With this distance and taking into account only the Galactic extinction of $A_V \approx 0\overset{\mathrm{m}}{.}14$ (NED), our brightness measurement $V = 18\overset{\mathrm{m}}{.}26$ corresponds to the absolute magnitude $M_V = -13\overset{\mathrm{m}}{.}7$. This is a value typical of calcium transients.

In the color images of NGC 5775, it is visible that the star is surrounded with young population of blue stars and dark nebulae, located at the edge of the galactic disk where the star-forming rate is relatively high. No star-like object or HII region brighter than $24^{\rm m}_{.}1$ B is visible at the place of the explosion in the deep VLT/FORS frame taken on 2006 April 28. Balmer-line profiles that consist of narrow and broad components are sometimes observed in the spectra of SNe IIn. Ordinarily, broad components of SNe IIn display neither absorption details nor P Cyg profiles. Explaining similar structures of Balmer lines in SN IIn 1988Z, Chugai & Danziger (1994) suggested that the broad Balmer emission was formed by dynamic interaction of the expanding ejecta with a relatively rarefied circumstellar wind previously ejected by the progenitor. Narrow lines originate from the radiation-shocked dense wind component. Thus, the progenitor's wind either had a dense disk-like structure or there were dense clumps in a rarefied radially symmetric wind. Whatever the case, the progenitor underwent a stage of extensive mass loss before the explosion, and the star had a stage of super-Eddington mass outflow. The velocity of the ejecta measured in NGC 5775 OT, 4000 km s^{-1}, is smaller than typical SN envelope velocities, and it is comparable to the velocities of the most rapid classical novae. The broad component of the H_β line does not have a P Cygni profile as distinct from profiles in spectra of SNe II or classical novae at maxima of their outbursts.

4 CONCLUSIONS

The results of the multicolor photometry and spectroscopy of the calcium-type transient PSN J14535395+0334049 in the galaxy NGC 5775 with the Russian 6-m telescope are reported. The star appeared in the edge region of the galaxy, rich in young stellar population and dark dust nebulae. Its absolute magnitude was $-13^{\rm m}_{.}7$ at the time of the observation. The H_β line has a two-component profile containing a broad and a narrow emission components.

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Table 1: Available photometry of NGC5775 OT

Date	JD	mag	Filter	Source
2006.04.28	2453853.74	>24.1	*B*	VLT/FORS
2012.03.17	2456003.89	>19.5	*V*	Howerton et al. (2012)
2012.03.27	2456013.99	18.7	*V*	Howerton et al. (2012)
2012.04.15	2456033	~17.7	*V*	Drake, A.J., private comm.
2012.04.25	2456043.401	18.26	*V*	BTA/SCORPIO
2012.04.25	2456043.403	17.83	R_C	BTA/SCORPIO
2012.04.25	2456043.404	18.82	*B*	BTA/SCORPIO

Table 2: Spectra of NGC 5775 OT taken with BTA/SCORPIO

UT	λ, Å	Exposure, s	S/N	Resolution, Å
2012 Apr 25.912	4070 - 5828	1200	5.0	17*
2012 Apr 25.966	4067 - 5830	600	5.3	5.4

* Camera out-of-focus.

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