A LARGE BRIGHTNESS ENHANCEMENT OF THE QSO 0957+561 A COMPONENT

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ABSTRACT

We report an increase of more than 0.2 mag in the optical brightness of the leading image (A) of the gravitational lens Q0957+561, detected during the 2000 September to 2001 June monitoring campaign (2001 observing season). The brightening is similar to or even greater than the largest change ever detected during the 20 yr of monitoring of this system. We discuss two different provisional explanations of this event: intrinsic source variability or microlensing (either short-timescale microlensing or cessation of the historical microlensing). An exhaustive photometric monitoring of Q0957+561 is needed until the summer of 2002 and during 2003 to discriminate between these possibilities.

Subject headings: gravitational lensing --- quasars: individual (QSO 0957+561)

1. INTRODUCTION

The first gravitational lens system discovered, Q0957+561 (Walsh, Carswell, & Weymann 1979), has become the most observed gravitational mirage. This system has been the target of continuous monitoring in optical and radio wavelengths. The early works by Florentin-Nielsen (1984), Schild & Cholfin (1986), Lehár, Hewitt, & Roberts (1989), Vanderriest et al. (1989), Schild (1990), and Roberts et al. (1991) were followed by other recent monitoring, such as those by Beskin & Oknyanskij (1992), Kundić et al. (1995, 1997), Oscoz et al. (1996, 1997), Haarsma et al. (1999), and Serra-Ricart et al. (1999).

Three outstanding events can be noticed during these 20 yr of monitoring. The first is the existence of a large-timescale microlensing (of several years). The analysis made by Pelt et al. (1998) with data corresponding to the period 1979–1996 clearly shows its presence. Next, a strong 0.13 mag intrinsic brightening of Q0957+561 in 2 months was detected by Kundić et al. (1995). And finally, Schild (1996) noticed a possible microlensing event with maximum amplitude of 0.05 mag and a timescale of 90 days. The sharp drop detected by Kundić et al. allowed them to solve the long-standing problem concerning the “short” (~410 days) and “long” (~530 days) time delays between the A and B components of the system. The observations confirmed that the short value was the correct one (Oscoz et al. 1996; Kundić et al. 1997), constraining the time delay between 410 and 440 days. Moreover, this feature allowed us to obtain a first accurate value for the delay (417 ± 3 days: Kundić et al. 1997; 424 ± 3 days: Oscoz et al. 1997). This robust estimate led to searches for the existence of possible microlensing events (Gil-Merino et al. 1998; Goicoechea et al. 1998), but no other event of the type reported by Schild (1996) has been detected (see Gil-Merino et al. 2001).

The Instituto de Astrofísica de Canarias (IAC) gravitational lensing project started a long-term monitoring program on this system in 1996, with the 0.82 m IAC-80 telescope at the Observatorio del Teide in Tenerife, Spain. Our set of almost 500 individual observations in the \( R \) band, together with several hundred points in the \( V \) band, constitutes one of the largest photometric databases of a gravitational lens system. The application of a new data reduction method (to improve the original aperture photometry), and the development of a new procedure to estimate the time delay, gave a value of \( \Delta T_{Q0957} = 425 \pm 4 \) days (Serra-Ricart et al. 1999). The accuracy in the time delay was further improved by including data from other groups in the period 1984–1999 and by using several statistical methods for the calculations. A new value of 422.6 ± 0.6 days was derived (Oscoz et al. 2001).

2. THE 2000 AND 2001 MONITORING CAMPAIGNS

To date, we have only published the data corresponding to the campaigns from 1996 to 1999 (Oscoz et al. 2001). A summary of the last two observing campaigns (1999 October to 2000 June and 2000 September to 2001 June) are shown in Table 1. Each data point is the result of averaging several individual measurements. The reduction procedure was done by means of the PHO2COM IRAF task (for a complete description of PHO2COM, see Serra-Ricart et al. 1999). Once the final light curves were obtained, the data were checked to eliminate inconsistent measurements: some points are affected by systematic effects and show strong and simultaneous (non-time-shifted) variations in both components. These points are the result of bad weather conditions or problems with the CCD and/or the telescope. The number of discarded data points was always small (18 out of 401).

The final light curves of our monitoring campaign ranging from 1996 February 25 to 2001 June 6 in the \( R \) and \( V \) bands are presented in Figure 1. The apparent magnitudes of the A and B components were derived by comparing the instrumental fluxes with those of two reference stars (D and H; see Serra-Ricart et al. 1999). From the scatter in the comparison star differential light curve, we estimate that the photometry is accurate to 2%–3%. In Figure 1, a delay of 422.6 days has been applied to the B component, but no magnitude correction has been applied to the data set; both the A and B magnitude are the real ones. It is obvious that the behavior of the light curves shows epochs in which both components fade, followed by epochs in which they brighten, in a quasi-periodic way. This is the general trend observed during the 2000 campaign. However, a conspicuous behavior can be seen in the 2001 campaign, where a brightening of more than 0.2 mag in component A can be observed

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1 Full data corresponding to all the observing campaigns—dates, brightness, and errors of the individual data—can be found at http://www.iac.es/project/quasar/mserra/meth.html.

2 IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
reduce the noise and to clearly show the trend of both components. This behavior is evident when only the points corresponding to the 2001 campaign are represented. This is shown in the top panel of Figure 2, where the B component is not responding to the 2001 campaign are represented. This is shown in the top panel of Figure 2, where the B component is not responding to the 2001 campaign.

3. DISCUSSION

Every year, when the observing season for Q0957+561 is finished, the obtained data are reduced by the IAC group together with the data from previous campaigns. A possible explanation of the trend appearing in component A during the 2001 campaign is that the data have been badly obtained and/or reduced, leading to a wrong magnitude estimate. However, a mistake in the reduction procedure would lead to changes in the whole data, not only in the points corresponding to the latest year. Moreover, only component A points show this variation, while the B data remain almost constant (see Fig. 2, top panel). These facts demonstrate that a wrong reduction process or a failure in data acquisition cannot be the explanation for this trend in the image A light curve.

Differential photometry between both comparison stars (see § 2) has been performed in order to check for their stability. No significant variability in the differential light curve is observed, as can be seen in the bottom panel of Figure 2. So, the brightening of component A is certainly not due to any change of the reference stars.

Two different explanations for the monotonous increase in the brightness of the A component of Q0957+561 are proposed: (1) it is intrinsic variability of the source; (2) it is due to a microlensing event, either a short-time one (months to a few years) or the cessation of the historical microlensing (about 20 yr; see Pelt et al. 1998).

3.1. Intrinsic Variability of the Source

Figure 1 shows that there have been several epochs of remarkable intrinsic variability in the last 5 yr. However, these changes are always less than 0.15 mag: for example, ∼0.14 mag between JD 2,450,300 and JD 2,450,500 or ∼0.12 mag between JD 2,451,100 and JD 2,451,300. Note that the sharp drop detected by Kundic et al. (1995) had an amplitude of 0.13 mag. So, if the trend found in the 2001 observing campaign is the consequence of intrinsic variability of the source, it would be the largest intrinsic variation ever found, with an optical flux increase of at least 0.2 mag. The large brightening now detected would make it relatively easy to obtain a final confirmation of the time delay between both components of Q0957+561. In addition, and perhaps even more important, it would allow us to obtain this delay independently of the method selected, finally solving the controversy of the last few years. Thus, a monitoring of Q0957+561 until 2004 would be crucial to improve our knowledge of both the time delay and the robustness of several statistical methods.

3.2. Microlensing

As stated before, a microlensing event of more than 10 yr is being produced in Q0957+561. Pelt et al. (1998) made a statistical analysis of the Q0957+561 light curves from the first 17 yr (1979–1996) with data from R. E. Schild et al.3 Princeton University (Kundic et al. 1997), and the IAC group’s first observing campaign (Oscoz et al. 1996). These observational data led them to obtain a time delay of 416.3 ± 1.7 days and then to calculate the differential light curve between both components of Q0957+561 (taking into account this value for the time delay). Pelt et al. (1998) finally concluded the existence of a first variation of 0.25 mag in about 6 yr, followed by a quiet phase of about 8 yr without variability over 0.05 mag. The historical differential light curve is presented in Figure 3, where only data from Schild et al. and the first four campaigns of the IAC group campaigns have been used. A time delay of 422.6 days has been applied to component B data, and only the annual averages are presented. The analysis made by Pelt et al. (1998) shows that objects with mass of less than $10^{-5} M_\odot$ can explain the 0.25 mag event. They also stated that the existence of objects with a mass as high as $1 M_\odot$ was possible, although they are quite unlikely. A remarkable fact since the beginning of this event is that component B remains brighter than component A. However, the differential light curve does not clearly lead to the interpretation of long-term microlensing. The shape of this curve does not match the one expected for a microlensing event, and it is difficult to explain.

3 See http://cfa-www.harvard.edu/~rschild.
The dip between day 5000 and day 6000. A point favoring the historical microlensing interpretation is that component A is brighter than B in the line emission (Angonin-Willaime & Vanderriest 1995), which is supposed to be unaffected by microlensing.

In any case, a point against the explanation of the observed variability in the 2001 campaign as the end of the historical microlensing is the fact that this long-timescale microlensing took 6 yr (~1983–1988) to vary 0.25 mag, while about the same variation has been measured now in only a year.

Another interesting explanation of this large change in brightness is that it can be produced by a short-timescale (from several months to a few years) microlensing event. Until now, no short-timescale microlensing event has been completely confirmed in Q0957+561, although some observing campaigns with several participating observatories have been carried out (Colley et al. 2002). Even the possible microlensing event reported by Schild (1996) is not entirely convincing. This author, with his own data and a time delay of 404 days, found amplitude peaks of 0.05 mag and 90 days long in the microlensing curves. This phenomenon was interpreted as short-timescale microlensing due to objects with $10^{-3}$ $M_\odot$ mass.

Refsdal et al. (2000) employed the microlensing light curve by Pelt et al. (1998) to restrict the microlens mass. These authors concluded that the lens mass could be restricted to values in the interval $10^{-8}$ to $5 M_\odot$. Another analysis was performed by Schmidt & Wambsganss (1998) with data in the g band by Kundic et al. (1997; two observing campaigns: 1994 December to 1995 May and 1995 November to 1996 July) and a time delay of 417 days. No variation larger than 0.05 mag was found in the differential light curve. Two conclusions were derived: (1) MACHOs with masses in the interval $10^{-5}$ to $10^{-3} M_\odot$ can be excluded for a quasar with a radius less than $10^{-4} h_{100}^{-1/2}$ pc; and (2) there was no evidence of short-timescale events. Lately, Wambsganss et al. (2000) added to the previous light curves the data obtained until 1998 in the same band and with the same telescope, detecting again no microlensing with amplitude larger than 0.05 mag. They could extend the previous limits, excluding a halo made only by MACHOs with masses between $10^{-6}$ and $10^{-2} M_\odot$ for a quasar with radius less than $10^{-4} h_{100}^{-1/2}$ pc.

Finally, Gil-Merino et al. (2001) performed an exhaustive analysis of the microlensing signal obtained with the IAC 1996, 1997, and 1998 observing campaigns in the R band. They selected a delay of $\Delta t_{Q0957} = 425 \pm 4$ days (Serra-Ricart et al. 1999). Gil-Merino et al. concluded that (1) no 3 month duration and 0.05 mag amplitude events are found in the microlensing light curves, so these events do not occur in a continuous way; (2) from a conservative point of view, the amplitude of any microlensing signal must be in the interval between $-0.05$ and $+0.05$ mag (the same limit found by Pelt et al. 1998 and Wambsganss et al. 2000); and (3) the small variability observed in the differential light curves could be originated, in a natural way, by observational noise mechanisms.

4. FINAL REMARKS

We present in this Letter a large, $|\Delta m| \geq 0.2$ mag, brightening of component A of the gravitational lens system Q0957+561. The event occurs between approximately JD 2,451,500 and approximately JD 2,452.065, our last observing date, so its amplitude could be even larger. Two different alternatives are offered to explain this variation: intrinsic variability or microlensing.

The historical light curve of Q0957+561 presents several large variations in amplitude. Some of them are fast, such as the 0.13 mag sharp drop detected by Kundic et al. (1995), whereas others, larger in magnitude (but always below 0.15 mag), are relatively slow (see Fig. 1). However, the detected 2001 variability in component A, if intrinsic, would be the largest one ever reported in this quasar, allowing us to obtain a confirmation of the time delay independently of the method employed.

Alternatively, the observed brightening could be due to a microlensing event. As a possible explanation, it could correspond to short-timescale microlensing (months to years). Microlensing events of this type have been detected in several gravitational lenses, especially in Q2237+0305, where they are almost routinely detected (a noticeable 0.15 mag micro-

**Fig. 2.** Top panel: 2000 and 2001 campaigns of Q0957+561 in the R band averaged into 10 day bins. Components A (filled circles) and B (not shifted in time; open squares) are shown. Note the almost monotonous brightening of component A between days 2500 and 3000. Bottom panel: Difference light curve of the two comparison stars (H and D) to check their stability.

**Fig. 3.** Differential light curve of Q0957+561A ($t - t_Q0957+561B$ vs $|\Delta t|$ of Q0957+561 from data from R. E. Schild and IAC. Component B data are delayed by 422.6 days. The data corresponding to each year have been averaged.
lensing in component A of Q2237+0305 has been recently reported; Wozniak et al. 2000; Alcalde et al. 2002). On the contrary, in Q0957+561 it would be the first secure event of this type detected (see Schild 1996; Gil-Merino et al. 2001). Another possibility is that it could indicate the end of the historical microlensing, which started in 1983 (Pelt et al. 1998). However, the variation seems too fast to correspond to the cessation of such a microlensing event.

In any case, the definitive answer will only come after the observation of component B during 2002. So, an exhaustive monitoring of Q0957+561 from several observing groups is necessary from now until summer of 2002 to study the behavior of component B (if the variability is intrinsic, the same behavior will appear in component B from approximately JD 2,452,000, 2001 April, until approximately JD 2,452,600, 2002 August), and at least during 2003 to cover all the event.

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