Compact object detection in self-lensing binary systems with a main-sequence star

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ABSTRACT
Detecting compact objects such as black holes, white dwarfs, strange (quark) stars and neutron stars by means of their gravitational lensing effect on an observed companion in a binary system has already been suggested almost four decades ago. However, these predictions were made even before the first observations of gravitational lensing, whereas nowadays gravitational microlensing surveys towards the Galactic bulge yield almost 1000 events per year where one star magnifies the light of a more distant one. With a specific view to those experiments, we therefore carry out simulations to assess the prospects for detection of the transient periodic magnification of the companion star, which lasts typically only a few hours in binaries involving a main-sequence star. We find that the effect is practically independent of the distance of the binary system from the observer, but a limit to its detectability is given by the achievability of dense monitoring with the required photometric accuracy. In sharp contrast to earlier expectations by other authors, we find that main-sequence stars are not substantially less favourable targets to observe this effect than white dwarfs, not only because of a better achievable photometry on the much brighter targets, but even more due to the fact that there are \( \gtrsim 10^4 \) times as many objects that can be monitored. The requirement of an almost edge-on orbit leads to a probability of the order of \( 3 \times 10^{-4} \) for spotting the signature of an existing compact object in a binary system with this technique. Assuming an abundance of such systems of about 0.4 per cent, a high-cadence monitoring every 15 min with 5 per cent photometric accuracy would deliver a signal rate per target star of \( \gamma \sim 4 \times 10^{-7} \) yr\(^{-1} \) at a recurrence period of about 6 months. With microlensing surveys having demonstrated the capability to monitor about \( 2 \times 10^8 \) stars, one is therefore provided with the chance to detect roughly semi-annually recurring self-lensing signals from several compact objects in a binary system. These must not be mistaken for similar signatures that arise from isolated planetary mass objects that act as gravitational lens on a background star. If the photometric accuracy was pushed down to 0.3 per cent, 10 times as many signals would become detectable.

Key words: black hole physics – gravitational lensing: micro – binaries: general.

1 INTRODUCTION
Despite the successful observation of the bending of light by the Sun (Dyson, Eddington & Davidson 1920), following the suggestion by Einstein (1911), it required many decades of advance in technology for enabling the detection of this effect for another star, given that ‘there is no great chance of observing this phenomenon’ (Einstein 1936). Only following the call by Paczyński (1986) to apply ‘gravitational microlensing’ to measure the abundance of potential massive compact halo astrophysical objects (MACHOs) in the Galactic halo, the first related experiments were carried out. In fact, a decade of observations of the Large and Small Magellanic Clouds now reveal that there are not enough MACHOs in the Galactic halo to account for the observed flat rotation curve for the Galactic disc (Milsztajn & Lasserre 2001; Popowski et al. 2005; Moniez 2009). The gravitational microlensing effect has evolved into an important astrophysical tool not only for studying stellar atmospheres (e.g. Albrow et al. 1999; Alfonso et al. 2001; Gould...
2001; Abe et al. 2003), but also for studying populations of extrasolar planets (Mao & Paczyński 1991; Gould & Loeb 1992; Dominik 2010).

In this paper, we assess the suggestion to detect compact objects (COs), namely black holes (BHs), strange (quark) stars (QSs) and neutron stars (NSs), by means of their gravitational bending of light received from an observed star that forms a binary system together with the CO in the context of current experiments. The lens action within a binary system of stars or stellar remnants has been discussed in great detail by Maeder (1973). This effect shares many characteristics with the meanwhile common gravitational microlensing events where a foreground star magnifies the light of an unrelated background star, which gets aligned on the sky with respect to the observer just by chance. However, the typical duration of the transient brightening is substantially shorter, of the order of a few hours, and the signal repeats periodically (albeit with periods that can be as large as decades). Maeder (1973) moreover found that the smaller the radius of the source star, the larger is the lens effect and its probability of occurrence. As a consequence, main-sequence (MS) stars were considered unfavourable candidates as compared to white dwarfs (WDs), where however the prospects for MS–BH pairs are substantially better than for MS–NS and MS–WD pairs. As a consequence, Beskin & Tuntsov (2002) have more recently evaluated the detectability of COs in a binary system with an observed WD due to gravitational lensing, and in particular looked at the prospects for observing this effect in the Sloan Digital Sky Survey (SDSS), while not considering MS source stars.

However, the chances of success in both cases depend on a number of various factors. First, there is the existing number of respective pairs of binary systems, on which we are currently forced to rely on the best available understanding of stellar evolution. Observations of star-forming regions show that 70–90 per cent of stars form in the clusters and almost two out of three stars reside in binary systems (Mathieu 1994). Models of stellar evolution predict that 0.4 per cent of the binary systems will see one of the companions turning into a CO (Hurley, Pols & Tout 2000; Belczynski, Bulik & Kluzniak 2002), whereas 0.2 per cent of stars end up in a binary system composed of two COs. Secondly, the probability for a signature to be ongoing at any time is given by the product of the probability for the monitored target to show a signal and the ratio between the signal duration and the orbital period. Thirdly, the number of suitable targets that can be monitored plays a crucial role. Fourthly and finally, it cannot be neglected that high-precision photometry on MS as far as the Galactic bulge is possible, whereas such an opportunity does not arise for the much fainter WDs.

Gravitational lensing of a star gravitationally bound to a CO has also been proposed by Campbell & Matzner (1973) as an interpretation of the Weber experiment (Weber 1970) for the gravitational radiation from the centre of the Galaxy, where they used the optical approach for calculating the lensing effect in a Schwarzschild metric when the source star is aligned with the massive BH of the Galaxy and the observer. In the optical approach, the variation of light bundle along the null geodesic describes the intensity of the light. In the extension of this work, Cunningham & Bardeen (1973) obtained the gravitational lensing of a source star rotating around a maximal Kerr metric. The main physical difference between the lensing in the work by Campbell & Matzner (1973) and eclipsing microlensing proposed in this paper is that in the former case the source star is orbiting around the BH with the orbital size of the order of Schwarzschild radius, while in the latter case the source is located at a distance of the order of astronomical unit. In this case, the line between the source lens and the optical axis (line connecting lens to the observer) is small (Bozza & Mancini 2005).

In contrast to Beskin & Tuntsov (2002), we focus on self-lensing within binaries that are composed of a CO and an observed MS star and on the observability of this effect with current or upcoming microlensing monitoring efforts.

In Section 2, we discuss the arising binary self-lensing light curves, and subsequently in Section 3 we evaluate the detection probability of such signals using strategies similar to ongoing microlensing efforts by means of Monte Carlo simulations. In Section 4, we briefly discuss the extraction of parameters from the observed data, before finally summarizing our conclusions in Section 5.

2 SELF-MICROLENSING WITHIN BINARY SYSTEMS

As illustrated in Fig. 1, the self-lensing binary system involving the CO is characterized by its inclination angle $\varphi$ with respect to the observer–lens axis (the lens being the CO), the orbital radius $a$ (assuming circular orbits for simplicity) and the Einstein radius

$$R_E = \sqrt{2 R_S a},$$

where

$$R_S = \frac{2GM}{c^2}$$

denotes the Schwarzschild radius of the (lensing) CO of mass $M$, which evaluates to

$$R_E = 1.73 \times 10^4 \left(\frac{R_S}{1 \text{ km}}\right)^{1/2} \left(\frac{a}{1 \text{ au}}\right)^{1/2} \text{ km}.$$

Given that the difference between lens and source distance as compared to their distance from the observer can comfortably be neglected, the Einstein radius becomes a function solely of the lens mass and the orbital radius of the binary system, which means that the observed signature does not depend on its distance from the observer.

With a CO as lens, we should however be aware of several possible corrections to standard gravitational microlensing light curves: (i) the strong gravitational field of the lensing CO leads to relativistic images, (ii) geometrical corrections due to strong fields, (iii) the perturbation effect of the source on the light deflection and (iv) the finite-size effect of the source star.

For a BH, light rays can enter regions with strong gravitational fields near the Schwarzschild radius and reach the observer after a quite complicated track (Chandrasekhar 1992). Such light rays correspond to relativistic images that exist in addition to the usual weak-field images, and in principle affect the total magnification

![Figure 1. Geometrical configuration of lens and source in a binary system.](https://academic.oup.com/mnras/article-abstract/410/2/912/1029484/1029484)
pattern of the observed source star. For these relativistic images, the relation between the source, image and deflection angle do not satisfy the small-angle approximation, but the lens equation for this configuration is rather given by

\[ \tan \beta = \tan \theta - \frac{D_{ls}}{D_s} [\tan \theta + \tan(\alpha - \theta)], \]  

(4)

where \( \theta \) and \( \beta \) are the position angles of image and source, respectively, and \( \alpha \) is the deflection angle. Integration over the path yields the deflection angle as

\[ \alpha(x_0) = \int_{x_0}^{\infty} \frac{2dx}{x \sqrt{(x/x_0)^2(1-1/x_0) - (1-\beta^2)}} - \pi, \]  

(5)

where all distances are in units of the Schwarzschild radius \( R_s \) and \( x_0 \) marks the closest approach of the light ray to the deflector. If \( \alpha \) is the ratio between the angular radius \( R_s/\alpha \) of the order of one-tenth of astronomical unit, the gravitational lensing effect. Considering a linear perturbation in the small-angle regime.

The proximity of the source star to the lens may also perturb the gravitational lensing effect. Considering a linear perturbation around the Schwarzschild metric in the weak-field limit, the perturbation on the deflection angle relates to the Newtonian potentials as

\[ \frac{\delta \alpha}{\alpha} = \frac{\Phi_S}{\Phi_L}, \]  

(6)

where \( \Phi_S \) and \( \Phi_L \) are the Newtonian gravitational potentials of the source star and the lens, respectively. For a light ray passing near the Einstein radius \( R_E \), source and lens objects being separated by an astronomical unit, one finds a relative perturbation on the deflection angle of

\[ \frac{\delta \alpha}{\alpha} \simeq \frac{m_\star}{M} \frac{R_E}{1 \text{ au}}, \]  

(7)

where \( m_\star \) and \( M \) are the mass of source star and the lens, respectively. With equation (3) one finds a numerical value of \( \sim 10^{-4} \), so that the perturbation effect of the companion star does not play a significant role.

Finally we look at the influence of the finite size of the observed source star, which was discussed in detail by Witt & Mao (1994). The relevant parameter \( \rho_s \) is the ratio between the angular radius of the source star and the angular Einstein radius, which simplifies to \( \rho_s = R_s/R_E \), given that the lens and source distances practically coincide. Eliminating the stellar radius in favour of the stellar mass, using \( R_s/R_\odot \simeq (m_\star/M_\odot)^{0.8} \) (Demircan & Kahraman 1991) and equation (3), one finds

\[ \rho_s = 22.7 \left( \frac{m_\star}{M_\odot} \right)^{0.8} \left( \frac{M}{M_\odot} \right)^{-1/2} \left( \frac{a}{1 \text{ au}} \right)^{-1/2}. \]  

Given that the magnification is limited to

\[ \mu_{\text{max}} = \sqrt{1 + \frac{4}{\rho_s^2}}, \]  

(9)

which is realized for perfect alignment, the signal amplitude is quite substantially suppressed due to the finite size of MS source stars, unless the star is of low mass and/or the CO is a massive BH. As pointed out by Maeder (1973), WDs come with a clear advantage of smaller radii, so that larger magnifications occur regularly.

For general separations between lens and source stars, where \( u \) denotes the angular separation in units of the angular Einstein radius, the magnification for \( u \neq \rho_s \) is given by

\[ A(u, \rho_s) = \frac{1}{2\pi} \left[ \frac{u + \rho_s}{\rho_s^2} \sqrt{4 + (u - \rho_s)^2} E(k) \right. \]  

\[ \left. - \frac{u - \rho_s}{\rho_s^2} \frac{8 + u^2 - \rho_s^2}{\sqrt{4 + (u - \rho_s)^2} K(k)} \right] + \frac{4(u - \rho_s)^2}{\rho_s^2(u + \rho_s)} \frac{1 + \rho_s^2}{\sqrt{4 + (u - \rho_s)^2}} \Pi(n; k), \]  

(10)

where \( E(k) \), \( K(k) \) and \( \Pi(n; k) \) are the complete elliptic integral of first, second and third kinds, respectively, and

\[ n = \frac{4 \mu u \rho_s}{(u + \rho_s)^2} k = \sqrt{\frac{4n}{4 + (u - \rho_s)^2}}, \]  

(11)

whereas for \( u = \rho_s \), one finds (Maeder 1973; Dominik 1996)

\[ A(\rho_s; \rho_s) = \frac{2}{\pi} \left[ \arcsin \frac{1}{\sqrt{1 + 1/\rho_s^2}} + \frac{1}{\rho_s} \right]. \]  

(12)

The centre of the source star is within the angular Einstein radius of the lens star for angles \( \varphi \lesssim \varphi_{\text{max}} \). Therefore, this condition can be used as a reference for the magnification to be substantial. We note that the characteristic inclination angle \( \varphi_{\text{max}} \) is independent of the distance of the binary system to the observer. We find an order estimate for the fraction of the binary systems with significant magnification signature in their light curves as \( f = 2 \varphi_{\text{max}}/\pi \). We further find \( f \sim (2/7\pi)(R_E/a) \sim (2/\pi) \sqrt{2R_E/a} \). Using the numerical values for the Schwarzschild radius of the order of a few kilometres and \( a \) of the order of one-tenth of astronomical unit, the fraction of self-lensing binaries with COs that provide a signature becomes \( f \sim 10^{-4} \). Taking 0.4 per cent of binary stars with compact star companions, the probability for the effect to show up amongst all observed stars turns out to be \( f_{\text{all}} \sim 4 \times 10^{-7} \). This number is tiny, but one needs to be aware of the fact that the prospects for observing such an effect crucially depend on the viability of regular monitoring of a huge number of targets, as well as on the frequency of such events to occur.

For a binary system, the angular velocity is given by

\[ \omega = \sqrt{\frac{G(m_\star + M)}{a^3}}, \]  

(13)

so that the relative transverse velocity of the source with respect to the lens follows as

\[ v_\perp = \omega a = \sqrt{\frac{G(m_\star + M)}{a}}, \]  

(14)

and is therefore determined with the choices of the masses \( m_\star \) and \( M \) of the components and the orbital radius \( a \). This defines an event time-scale

\[ t_E \equiv R_E/v_\perp = \frac{2a}{c} \sqrt{\frac{M}{m_\star + M}}. \]  

(15)
within which the source moves by $R_E$. In fact, the motion can be approximated as uniform, where

$$u(t) = \sqrt{u_0^2 + \left(\frac{t - t_0}{t_E}\right)^2},$$

with the closest angular approach between lens and source star being

$$u_0 = \frac{a}{R_E} \varphi = \sqrt{\frac{a}{2 R_s}} \varphi$$

for a small $\varphi$, which occurs at epoch $t_0$. Therefore, the signal of eclipsing microlensing resembles a normal extended-source standard microlensing light curve, described by the four parameters $t_E, t_0, u_0$ and $\rho_\star$.

For reference, the light curve of a binary system with the parameters of $M = 8.5 \, M_\odot$, an MS star with the mass of $m_\star = 0.35 \, M_\odot$, $a = 17$ au and $\varphi = 0.33$ arcsec is shown in Fig. 2. This system has the finite-size parameter $\rho_\star = 0.81$ and the period of this system is about 23 yr. MS are again disfavoured due to their long periods in detectable systems, whereas substantial signals can arise in systems with WDs with much shorter periods.

### 3 DETECTION PROBABILITY

Let us now investigate the prospects for detecting COs by means of binary self-lensing for specific observational strategies. Modelled upon the characteristics of current or upcoming microlensing campaigns, and giving us a hint on the roles of both photometric accuracy and sampling rate, we consider regular monitoring with

For MS, we adopt the mass function $\xi(m_\star) = dN/\Delta[\log(m_\star/M_\odot)]$ proposed by Chabrier (2003), namely

$$\xi(m_\star) = \begin{cases} 0.093 \exp \left\{ -\frac{[\log(m_\star/M_\odot) - \log(0.2)]^2}{2 \times 0.55^2} \right\} & \text{for } m_\star < 1 \, M_\odot, \\ 0.041 (m_\star/M_\odot)^{-1.35} & \text{for } m_\star \geq 1 \, M_\odot, \end{cases}$$

which covers the range of $m_\star \in [0.1, 2] \, M_\odot$, while we assume a mass–radius relation $R_\star/R_\odot \simeq (m_\star/M_\odot)^{0.8}$ (Demircan & Kahraman 1991).

For the COs, we adopt the product of the evolution of the zero-age mass function to the final stage of stars (Belczynski et al. 2002) with the mass range of $M \in [1.2, 15] \, M_\odot$. To estimate the fraction of binary systems with one CO and one MS star, we do a rough calculation for stars in the binaries with the initial masses in the range of $M < 1 \, M_\odot$ for the first star and $M > 8 \, M_\odot$ for the companion star. The star with larger mass has a relatively short lifetime and will evolve to a CO, while the smaller star stays in the MS if we do not have mass transfer between the two stars. For the binaries located at far enough distances from each other (i.e. stellar size should be smaller than the Roche lobe), we obtain that almost 0.4 per cent of the stars will end to the binary systems with one CO and a companion MS star.

For the orbital distance within the binary system, we assume a logarithmic distribution in the range of $d \in [0.01, 50]$ au, in accordance with Opik’s law, while the inclination angle is drawn uniformly from $\varphi \in [0, \pi/2]$.

Using these parameter distributions, we generated synthetic light curves by means of Monte Carlo simulations, see Fig. 3 for an example. With a detection criterion of three consecutive data points being larger than three times the standard deviation from the baseline, we obtain not only the fraction of systems for which the CO is detectable, but also the distribution of parameters of the expected eclipsing microlensing events.

Fig. 4 shows the detection efficiency for the three considered monitoring strategies. One finds that it depends only weakly on the mass of the lens. This is a consequence of the relation

\begin{figure}
\centering
\includegraphics[width=\columnwidth]{figure2}
\caption{Gravitational self-microlensing light curve arising from a binary system that involves a BH lens of mass $M = 8.5 \, M_\odot$ and an observed MS star of mass $m_\star = 0.35 \, M_\odot$. The orbit is $\varphi = 0.33$ arcsec from an edge-on configuration, and the orbital radius is $a = 17$ au. This yields a finite-size parameter $\rho_\star = 0.81$ and an orbital period $P \sim 23$ yr.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\columnwidth]{figure3}
\caption{Example synthetic light curve as arising from the Monte Carlo simulation. The adopted parameters are $M = 13.28 \, M_\odot$, $m_\star = 0.2 \, M_\odot$, $d = 30$ au and $\varphi = 0.01$ arcmin, so that $\rho_\star = 0.32$ and $t_E = 5.95$ h.}
\end{figure}
between the lens mass $M$ and the event time-scale $t_\text{E} = R_\text{E}/v$. With $R_\text{E} \propto \sqrt{M}$ and $v \propto \sqrt{m_*/(M+m_*)}$, one finds a weakly varying $t_\text{E} \propto \sqrt{M/(M+m_*)}$. A larger mass $m_*$ of the MS source star implies a larger radius $R_\text{E}$, which diminishes the magnification due to the finite-size effect. Moreover, the event time-scale becomes smaller. On the other hand, a larger source radius $R_\text{E}$ enables us to get a signal from a wider range of inclination angles, and the effective signal duration is increased. The gain from a longer signal duration plays a larger role for sparser sampling, while for an inferior photometry the signal drops below the detection threshold earlier.

The effect of the orbital radius of the two companion stars on the observability eclipsing microlensing signal is a function of three factors, namely (i) the dependence of the Einstein radius on the orbital radius as $R_\text{E} \propto \sqrt{a}$, (ii) the relative transverse velocity of the binary system $v \propto 1/\sqrt{a}$, hence $t_\text{E} \propto a$ and (iii) $\psi_{\text{max}} = R_\text{E}/a \propto 1/\sqrt{a}$. The wider range of suitable inclination angles increases the prospects for a detection in systems with smaller orbital radius. Smaller event time-scales however let signals fall into the gap between subsequent observations. Consequently, we find a rise in the detection efficiency towards smaller orbital radii (and thereby shorter periods) until the signals become too short to be detectable.

With the detection efficiency and the distribution functions of the adopted parameters, we find the overall probability for detecting binary self-microlensing events. In particular, by multiplying the detection efficiency with the mass function of the lens stars, we obtain the expected distribution of lens masses revealed from observed eclipsing microlensing signals, which is shown in Fig. 5. The mass function of the lens stars were normalized to the overall number of stars. Integrating these histograms results in the total probability of observing eclipsing microlensing events. For our three variants of the adopted observing strategy, we find $f_{\text{all}} = 1.45 \times 10^{-7}$, $6.50 \times 10^{-8}$ or $9.97 \times 10^{-7}$, respectively. With the latter value being close to our earlier thumb estimate, we find a rather good efficiency of the adopted strategy.

We further weigh each detection efficiency $\varepsilon$ with the frequency of the signal, which equals the inverse of the orbital period $P$, i.e. we calculate an average $\langle \varepsilon/P \rangle$ over the realizations arising from the Monte Carlo simulation, in order to obtain the event rate per observed star as $\gamma = \langle \varepsilon/P \rangle$. The results are shown in Table 1. As an example, we find $\gamma = 3.71 \times 10^{-7}$, $2.08 \times 10^{-8}$ or $3.28 \times 10^{-6}$ yr$^{-1}$ for our three adopted monitoring strategies, which typically find COs in binaries with orbital periods of $P \sim 0.39$, $3.12$ or $0.30$ yr, respectively, which equals the period of recurrence of the signals. Naturally, systems with shorter periods dominate the events due to their higher recurrence rate, and the goal of an observational strategy has to be to keep these detectable. The findings of our simulations are summarized in Table 1.

### Table 1. Fraction of observed systems with a detectable compact companion

| Accuracy $\sigma$ | Sampling rate $\Delta t$ (min) | Detectability $f_{\text{all}}$ | Event rate $\gamma$ (yr$^{-1}$) | Period $P$ (yr) |
|-------------------|-------------------------------|-------------------------------|-------------------------------|----------------|
| 5                 | 15                            | $1.45 \times 10^{-7}$         | $3.71 \times 10^{-7}$         | 0.39           |
| 2                 | 120                           | $6.50 \times 10^{-8}$         | $2.08 \times 10^{-8}$         | 3.12           |
| 0.3               | 15                            | $9.97 \times 10^{-7}$         | $3.28 \times 10^{-6}$         | 0.30           |

### 4 EXTRACTION OF PARAMETERS

The observed light curve allows us to extract the four standard parameters $t_\text{O}, t_\text{D}, t_\text{E}$ and $\rho_\text{m}$, but with $t_\text{O}$ not carrying any relevant information about the binary system, we are one parameter short of reconstructing the masses of the components $m_\text{L}$ and $M$, the orbital radius $a$ and the inclination angle $\psi$. Only in the limit $m_\text{L} \ll M$,...
equation (17) yields

\[ a = \frac{ct_e}{2} \sqrt{\frac{M + m_\star}{M}} \approx \frac{ct_e}{2}. \]  \hspace{1cm} (21)

In order to go further, one needs to exploit the periodicity of the signal. This again stresses the need for events with shorter periods, not longer than a few years. In fact, any attempt to obtain information by measuring astrometric shifts of the observed source star due to its wobble around the CO or its radial velocity by means of Doppler shifts of spectral lines relates to the orbital period. Withstanding the difficulties in obtaining such measurements for faint stars, the fundamental properties already follow with the orbital period itself.

Kepler’s third law

\[ P = 2\pi \sqrt{\frac{a^3}{G(M + m_\star)}} \]  \hspace{1cm} (22)

would allow us to find

\[ \varphi = \frac{2\pi t_0}{P} \]  \hspace{1cm} (23)

with equations (17) and (19), and one would be able to obtain iteratively

\[ M = \frac{4\pi^2}{GP^2} a^3 - m_\star \approx \frac{\pi^2 c^3 t_e^2}{2GP^2}, \]  \hspace{1cm} (24)

as well as

\[ R_\star = \frac{2\rho_\star c}{\sqrt{GMa}} \approx \frac{\pi \rho_\star c t_e^2}{P}, \]  \hspace{1cm} (25)

so that with the mass–radius relation for MS is

\[ m_\star = M_\odot \left( \frac{R_\star}{R_\odot} \right)^{5/4} \approx M_\odot \left( \frac{\pi \rho_\star c t_e^2}{P R_\odot} \right)^{5/4}. \]  \hspace{1cm} (26)

5 CONCLUSIONS

Given that the signal amplitude of self-lensing due to a CO in a binary system is less suppressed by the much smaller finite radius of a WD as compared to an MS star, and moreover the orbital period of detectable systems is smaller (given that the relevance of finite-source effects is quantified by \( \rho_\star \propto 1/\sqrt{a} \)), and thereby the frequency of signals is larger, Maeder (1973) concluded that WDs are the favourable targets for observing this effect, whereas the prospects for binaries involving MS are rather bleak. However, the fortune changes substantially if one looks at the observability of suitable systems. Beskin & Tuntsov (2002) considered the SDSS as most favourable for observing WDs, and in fact, it has dramatically increased the number of known WDs. However, with the sample containing about 15,000 objects (Kleinman, Nitta & Koester 2009), it is \( \sim 10^4 \) times smaller as compared to the \( 2 \times 10^8 \) stars regularly monitored by current microlensing surveys (Udalski 2003).

For \( N_{\text{obs}} \sim 2 \times 10^4 \) monitored stars with an event rate per observed star of \( \gamma \sim 4 \times 10^{-7} \text{ yr}^{-1} \) (for 5 per cent photometric accuracy and 15-min sampling cadence), one finds a total event rate of \( \Gamma \sim 74 \text{ yr}^{-1} \), where \( \kappa < 1 \) is a coverage factor accounting for the visibility of the Galactic bulge from the respective sites over the year, any losses due to weather or technical downtime and imperfect cadence or data quality. In contrast to earlier work, we therefore conclude that the detection of COs (in fact, predominantly BHs) in binary systems due to self-lensing of an observed MS star companion is possible, provided that a high-cadence sampling substantially below 2 h is realized. The upcoming Korea Microlensing Telescope Network (KMTNet) has in fact been designed as a wide-field survey of the Galactic bulge with 10-\( \text{min} \) cadence (Hwang & Han 2010). Moreover, the Microlensing Observations in Astrophysics (MOA) survey already monitors some of its fields at that cadence (Sumi et al. 2010). Higher photometric accuracies of 0.3 per cent, achievable with space-based observations (Bennett & Rhie 2002; Bennett et al. 2003) or lucky-imaging cameras (Jørgensen 2008), could result in 10 times as many observable signals due to self-lensing in binaries with COs, whereas lower accuracies of 20 per cent would lead to about 10 times less objects being detected.

Given that the duration of the expected self-microlensing signals is of the order of a few hours, we issue a note of caution that such is not mistaken for evidence of planetary mass bodies that pass the line of sight to a background star. In fact, the MOA survey appears to show an excess of short-duration peaks as compared to expectations from stellar populations and the kinematics of the Milky Way (Kamiya, private communication).

In practice, one faces a rather hard job to distinguish between usually poorly covered spikes of different origin. The self-lensing binary signals repeat in principle, but on an initially unknown timescale of months to years and are rather easy to miss. The discriminating power of the criterion of achromaticity of gravitational microlensing as opposed to stellar variability is also limited due to the lack of detail on the shape of the signal. Only if a period of the binary system can be established, its physical characteristics can be determined.

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