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On the probability of microlensing in gamma-ray burst afterglows

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ABSTRACT

The declining light curve of the optical afterglow of gamma-ray burst (GRB) GRB000301C showed rapid variability with one particularly bright feature at about $t - t_0 = 3.8$ d. This event was interpreted as gravitational microlensing by Garnavich, Loeb & Stanek and subsequently used to derive constraints on the structure of the GRB optical afterglow. In this paper, we use these structural parameters to calculate the probability of such a microlensing event in a realistic scenario, where all compact objects in the universe are associated with observable galaxies. For GRB000301C at a redshift of $z = 2.04$, the a posteriori probability for a microlensing event with an amplitude of $\Delta m \geqslant 0.95$ mag (as observed) is 0.7 per cent (2.7 per cent) for the most plausible scenario of a flat Λ-dominated Friedmann–Robertson–Walker (FRW) universe with $\Omega_{\rm m} = 0.3$ and a fraction $f_* = 0.2$ (1.0) of dark matter in the form of compact objects. If we lower the magnification threshold to $\Delta m \geqslant 0.10$ mag, the probabilities for microlensing events of GRB afterglows increase to 17 per cent (57 per cent). We emphasize that this low probability for a microlensing signature of almost 1 mag does *not* exclude that the observed event in the afterglow light curve of GRB000301C was caused by microlensing, especially in light of the fact that a galaxy was found within 2 arcsec from the GRB. In that case, however, a more robust upper limit on the a posteriori probability of ≈5 per cent is found. It does show, however, that it will not be easy to create a large sample of strong GRB afterglow microlensing events for statistical studies of their physical conditions on microarcsec scales.

Key words: gravitational lensing – dark matter – gamma-rays: bursts.

1 INTRODUCTION

Gravitational microlensing offers a way to study the structure of high-redshift sources on microarcsecond scales, besides being able to constrain the mass fraction and mass function of compact objects in the universe. In strong gravitational lens systems (i.e. systems with multiple images of a single background source), the microlensing optical depth is of the order of unity (e.g. Chang & Refsdal 1979; Gott 1981; Young 1981). Precisely because of this high optical depth, these systems are perfect for resolving microarcsec structure in the lensed cosmologically distant source if it crosses a caustic created by the stellar-mass compact objects in the lens mass distribution (e.g. Chang & Refsdal 1984; Grieger, Kayser & Refsdal 1988; Wambsganss, Paczyński & Schneider 1990; Woźniak et al. 2000). Moreover, because of the presence of multiple images, one can in principle separate intrinsic source fluctuations from microlensing variability.

For example, ongoing microlensing of the lensed (optical) images in the system Q2237+0305 (Huchra et al. 1985) has been observed ever since its discovery (e.g. Irwin et al. 1989; Corrigan et al. 1991; Østensen et al. 1996; Lewis et al. 1998; Woźniak et al. 2000). To a smaller degree and on longer time-scales, microlensing in Q0957+561 has been detected as well (Pelt et al. 1998; see also Refsdal et al. 2000). The time-scale of microlensing in both cases is defined by the relative transverse velocity between the source, lens and observer, which is given by the bulk velocity of the lensing galaxy plus the random motions of compact objects in the line-of-sight to the stationary quasar images, and is typically of the order of several hundred km s^{-1}. This results in microlensing time-scales of the order of months to years for solar-mass objects (e.g. Wambsganss 2000).

Besides these optical sources, the first case of radio-microlensing was recently reported in the lens system B1600+434 (Koopmans et al. 2000a,b; Koopmans & de Bruyn 2000), suggesting an extremely compact relativistic substructure in the lensed radio source. If this microarcsec-scale substructure is part of a relativistic jet, the time-scale of microlensing variability by stellar-mass objects reduces to several weeks (Koopmans &

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de Bruyn 2000), allowing one to probe compact objects of up to $\sim 10^5\,M_\odot$ on time-scales of several years, as well as the substructure of the relativistic jet. Indications of optical microlensing in B1600+434 with similar time-scales have also been found (Burud et al. 2000). Clearly, microlensing is a promising field of future research regarding the study of high-z sources at microarcsec scales.

In addition to testing the structure of active Galactic nuclei (AGNs), Loeb & Perna (1998) more recently proposed the use of microlensing to probe into the internal structure of GRB afterglows on microarcsec scales. Garnavich, Loeb & Stanek (2000) indeed interpreted an anomalous event in the light curves of the optical afterglow of GRB000301C (Masetti et al. 2000; Sagar et al. 2000; Berger et al. 2000; Jensen et al. 2001; Smette et al. 2000) as being caused by microlensing of the GRB afterglow. They subsequently derived constraints on its structure, which appear to be in good agreement with theoretical blast-wave models. The inferred mass of the lensing object is $\sim 0.5\,M_\odot$, if its redshift is optimal for microlensing (i.e. about half way; Garnavich et al. 2000).

However, one needs to be cautious here, because no multiple images are present – as in the case of strong gravitational lenses – to confirm that this is indeed a non-intrinsic event. The fact that the event occurs within only a few days after the burst and has an amplitude of ≈ 1 mag suggests that the burst must have occurred close to the Einstein radius of an intervening massive compact object (Garnavich et al. 2000). To have a significant probability of observing such a GRB microlensing event, the Universe requires a surface density in compact objects close to the critical surface density (e.g. Press & Gunn 1973; Blaes & Webster 1992). The situation is partly similar to the case of variability in single quasars (i.e. not multiply imaged), which cannot easily be proven to be due to microlensing either (e.g. Hawkins & Taylor 1997; Hawkins 1998), although the freedom to model the GRB afterglow light curve (mostly dominated by self-similar expansion resulting in power-law behaviour) is significantly less than that for quasars.

In this paper, we investigate the probability of microlensing in GRB afterglows for a flat, Λ-dominated cosmological model and with the distribution of massive compact objects connected to visible galaxies, particularly focusing on the strong event seen in the GRB000301C afterglow. Our conclusions, however, are independent of this particular GRB. In Section 2, we describe numerical microlensing simulations of GRB afterglow light curves, extended to high microlensing optical depths. In Section 3, the a posteriori probability of the observed event in GRB000301C is calculated. Section 4 summarizes our results and states our conclusions.

2 MICROLENSED GRB LIGHT CURVES

To calculate the microlensing probability of GRBs, we simulate microlensing magnification patterns for a range of shears and dimensionless surface densities in compact objects (i.e. γ and κ; see chapter five of Schneider, Ehlers & Falco 1992 for the definitions). A similar analysis for the microlensing variability in Q2237+0305 was performed by Rauch & Blandford (1991) and Jaroszynski, Wambsganss & Paczynski (1992), placing constraints on its accretion-disc models.

As a first-order model, we here assume that (i) galaxies in the universe can be described as a singular isothermal sphere mass distribution (SIS; e.g. Binney & Tremaine 1987) for which $\kappa = \gamma$ (e.g. Kormann, Schneider & Bartelmann 1994), (ii) the fraction of mass in compact objects $f_* = 1$, although in Section 3.3 we will consider the case of $f_* < 1$, and (iii) the mass spectrum of compact objects is narrow ($\Delta m/m < 1$) such that we can assume that all objects have nearly the same mass (for example the average or median value). Magnification patterns for $\kappa = \gamma = 0.005$, 0.01, 0.025, 0.05, 0.1 and 0.25 are calculated on a grid of 1024×1024 pixels using the ray-shooting algorithm of Wambsganss (1999). Each pixel has a size of 0.1 Einstein radius.

For the structure of the GRB, we take the results from Garnavich et al. (2000), who model the GRB as an expanding ring with a width W times the ring radius $R(t)$. No jet structure is assumed in the model. The ring radius evolves as function of time as $R(t) = R_0 \times t^{5/8}$ (e.g. Waxman 1997), where t is time in days and R_0 is the ring radius on day one. Their best fit to the combined optical data sets suggests $W = 0.16 \pm 0.02$ and $R_0 = 0.49 \pm 0.02$ Einstein radius. A constant surface brightness inside the ring is

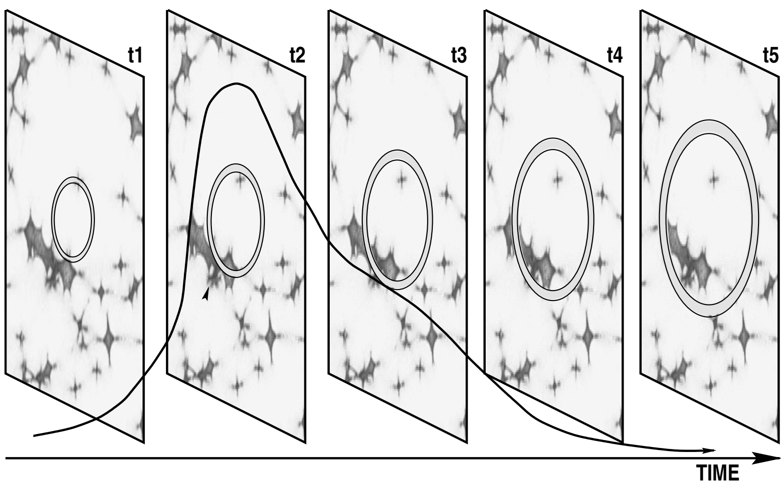

Figure 1. A cartoon of how we determine the microlensing magnification as a function of time for the expanding shell source superimposed on the magnification patterns caused by massive compact objects. The five panels indicate five different epochs (in practice, we consider 100 epochs). The superimposed curved line indicates the microlensing magnification as a function of time, corresponding to this particular example. The arrow points to a particular high magnification structure that is passed by the ring source at epoch t_2.

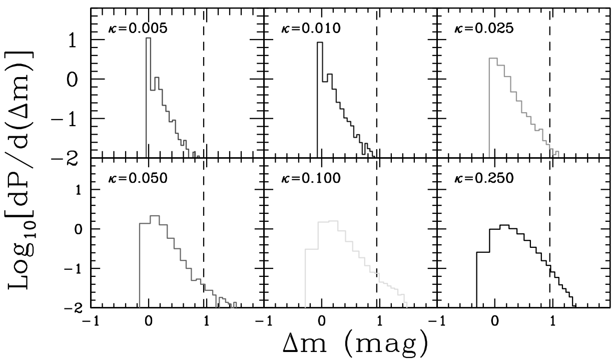

Figure 2. The probability distribution function of microlensing magnifications as function of $\kappa = \gamma$. From upper left to lower right, $\kappa = \gamma = 0.005$, 0.01, 0.025, 0.05, 0.1 and 0.25, respectively. The dashed line indicates a peak magnification of 0.95 mag or $\mu_o = 2.4$.

Table 1. The a posteriori probability that GRB000301C shows a microlensing event with magnitude greater than approximately 0.10 and 0.95 mag, respectively. The errors indicate the Poisson error, due to the finite number (i.e. 10^4) of simulated light curves. The equal probability for $\kappa = 0.1$ and 0.25 in the second column is coincidental, but illustrates the rapid break from $P \propto \kappa$ (see text) in the probability of strong events for high optical depth regimes.

$\kappa = \gamma$	P($\Delta m \geqslant 0.95$ mag)	P($\Delta m \geqslant 0.10$ mag)
0.005	0.0043 ± 0.0007	0.181 ± 0.004
0.010	0.0063 ± 0.0008	0.224 ± 0.005
0.025	0.0150 ± 0.001	0.441 ± 0.006
0.050	0.0340 ± 0.002	0.617 ± 0.008
0.100	0.0530 ± 0.002	0.729 ± 0.009
0.250	0.0530 ± 0.002	0.781 ± 0.009

assumed and no emission comes from either inside or outside of the ring structure.

Although the redshift and the mass of the possible lensing object is unknown, this is of no consequence to our calculations, because we can express the properties of lensing objects in dimensionless units of critical surface density, shear and Einstein radius. For intermediate redshifts, the mass of the possible lensing object of the GRB000301C afterglow would be $\sim 0.5\,M_\odot$ (Garnavich et al. 2000), which agrees well with Galactic (e.g. Alcock et al. 2000) as well as extragalactic constraints on halo-mass objects (Refsdal et al. 2000; Wambsganss et al. 2000).

To obtain simulated GRB microlensing light curves, we convolve the magnification patterns with the time-variable GRB source structure for each epoch t. We then store the 'convolved' magnifications from 10^4 random grid points. We repeat this procedure for 100 epochs from day 0.5 to day 35 (approximately the period during which the afterglow light curve of GRB000301C was sampled; Garnavich et al. 2000), each step evolving the GRB afterglow structure and taking the magnifications from the same 10^4 grid points (the procedure is illustrated in Fig. 1). The sampling epochs for our simulated microlensing light curves are logarithmically spaced, to avoid undersampling during the initial GRB afterglow phase, where one might expect the highest magnifications. The light curves are normalized to show only the microlensing magnification of the GRB afterglow (as in Mao & Loeb 2001). In Fig. 2, we show the probability-density distributions of the peak magnification of the normalized GRB microlensing light curves, from which it is immediately clear that strong $\approx$1 mag events are relatively rare. We will discuss this in more detail in the next section.

3 PROBABILITIES

In this section we consider the probability of observing the event seen in GRB000301C, within the microlensing hypothesis. First, we calculate the probability of the event as function of the dimensionless surface density in compact objects. Secondly, we determine the probability of actually observing GRB000301C through a dimensionless surface density, κ, as function of a cosmological model and distribution of compact objects. Thirdly, we combine these probabilities to arrive at an a posteriori probability for the feature in the afterglow light curve of GRB000301C being a microlensing event, as suggested by Garnavich et al. (2000).

3.1 Event-amplitude probability

The microlensing event seen in GRB000301C has a maximum amplitude of 0.95 mag or a magnification $\mu_o = 2.4$ (see fig. 2 in Garnavich et al. 2000). To calculate the probability of at least such a strong event, we need to measure the fraction of simulated light curves (Section 2) that show an event stronger than μ_o (see Fig. 2). These numbers are listed in Table 1. We find that even in the higher optical depth regimes, the probability does not significantly exceed $\approx$5 per cent but levels off in the high optical depth regime, because of averaging of the GRB afterglow over multiple caustics. At low surface-densities, one expects the probability of microlensing ($\tau_{\mu l}$) to asymptotically behave as $\tau_{\mu l} \propto \kappa$.

Let us now make a simple analytical fit through these probabilities, using the following function

$$P_A(\kappa) \approx \frac{P_c \kappa}{\sqrt{1 + (\kappa/\kappa_c)^2}}. \quad (1)$$

This function is by no means the correct functional form, that might be expected from a detailed theoretical analysis, but it has the correct asymptotic behaviour for $\kappa \to 0$. We find that $P_c \approx 0.82$ and $\kappa_c \approx 0.072$ fit the results in Table 1 best. This empirical function provides a good enough representation of the probability of the observed event in the region $0 < \kappa \leqslant 0.25$ for the purposes of this paper. The value $\kappa = 0.25$ is the highest through which any source can be seen without being multiply imaged in case of a SIS mass distribution (e.g. Kormann et al. 1994). In Table 1, we also list the results for events with amplitudes greater than 0.1 mag (i.e. $\mu_o = 1.1$). In that case, we find $P_c \approx 22.7$ and $\kappa_c \approx 0.034$. We defer a discussion of these events to Section 3.3.

For the high-magnification events ($\geqslant$0.95 mag), Table 1 shows that $P \lesssim \kappa$. Because the probability of multiple imaging by compact objects is equal to κ (in the case of $\kappa \ll 1$), this result implies that the GRB needs to lie very close to the Einstein radius of the compact object as found for GRB000301C (Garnavich et al. 2000). Conversely, one could thus conclude: the fact that the microlensing event in GRB000301C requires the GRB to lie close to the Einstein radius implies a probability of the event close to the average dimensionless surface density $\langle\kappa\rangle$ of the Universe in compact objects.

3.2 Surface density probability

To obtain the final probability of this event being observed, we have to multiply equation (1) with the probability that the GRB is seen through a region of sky that has a dimensionless surface density between κ and $\kappa + d\kappa$.

For a constant comoving density of SIS lens galaxies, which distribution follows the Schechter luminosity (i.e. mass) function, we find from Turner, Ostriker & Gott (1984), Turner (1990) and Fukugita & Turner (1991) that the optical depth for multiple imaging is

$$\tau_{\rm GL}(z_{\rm s}) = \frac{16\pi^3}{30} n_0^* \left(\frac{c}{{\rm H}_0}\right)^3 \left(\frac{\sigma_\parallel^*}{c}\right)^4 \Gamma\left[\alpha + \frac{4}{\gamma} + 1\right] G(z_{\rm s}), \qquad (2)$$

where n_0^* and $\sigma_\parallel^*$ are the local-density and central-velocity dispersion of L_* galaxies, respectively. The parameters in the Γ-function describe the Schechter luminosity function (see Fukugita & Turner (1991) for a detailed description of this equation). Furthermore

$$G(z_{\rm s}) = \left[\int_1^{1+z_{\rm s}} \frac{{\rm d}w}{\sqrt{\Omega_{\rm m} w^3 - \Omega_{\rm m} + 1}}\right]^3, \qquad (3)$$

for a flat FRW universe with $\Omega_{\rm m} + \Omega_\Lambda = 1$ and a GRB redshift $z_{\rm s}$. For definiteness, we assume here that $\Omega_{\rm m} = 0.3$ and $\Omega_\Lambda = 0.7$, which seem to agree best with most recent cosmic microwave background (CMB), SNe Ia and cluster-abundance observations.

The optical depth $\tau_{\rm GL}(z_{\rm s})$ indicates the fraction of sky covered by regions in which sources are multiply imaged (i.e. regions inside the Einstein ring). It is easy to show that the brightest image, in the case of multiple imaging of the source, always lies in the region $\kappa = 0.25$–0.50 (between 1–2 Einstein radii from the lens centre) for a SIS mass distribution ($\kappa = 1/2x$, with x being the radius in Einstein radii). This region projects one-to-one back onto a disc of one Einstein radius in the source plane (see Schneider et al. 1992, chapter 8). Hence the probability of observing a GRB through a patch of sky that has a dimensionless surface density $>\kappa$ (but smaller than $\kappa = 0.5$) is given by

$$P(>\kappa) = \tau_{\rm GL}(z_{\rm s}) \left(\frac{1}{2\kappa} - 1\right)^2, \qquad (4)$$

in which case the region $\kappa = 0.25$–0.50 has exactly the probability $\tau_{\rm GL}(z_{\rm s})$, as required. We do not take the magnification bias into account here, because the majority of GRB will be seen through regions with $\kappa \ll 1$. In Section 4, we will come back to the magnification bias in more detail. Finally, we need to normalize $P(>\kappa)$ to unity, which requires us to put a lower limit on the allowed κ. We find $\kappa_{\rm l} = \frac{1}{2}(1 + 1/\sqrt{\tau_{\rm GL}})^{-1}$ for which $P(>\kappa_{\rm l}) = 1$. For surface densities smaller than $\kappa_{\rm l}$, galaxies will start to significantly overlap. In that case, equation (4) will clearly break down and $\kappa_{\rm l}$ is therefore a natural limit on the probability distribution of κ.

3.3 Probability of the GRB000301C event

The overall probability that a GRB with the properties of GRB000301C shows a microlensing event with an amplitude of ≈0.95 mag (i.e. $\mu_{\rm o} = 2.4$) then becomes

$$P_{\rm e} = \int_{0.5}^{\kappa_{\rm l}} \frac{{\rm d}P(>\kappa)}{{\rm d}\kappa} P_{\rm A}(\kappa|\mu_{\rm o})\,{\rm d}\kappa. \qquad (5)$$

If we now use the values $n_0^* = 0.61 \times 10^{-2}\,h^3\,{\rm Mpc}^{-3}$, $\alpha = -1$, $\gamma = 4$ and $\sigma_\parallel^* = 225\,{\rm km\,s}^{-1}$ for the Schechter luminosity function describing the population of elliptical lens galaxies, which presumably dominates the lensing cross-section and mass in the universe (see also Kochanek 1996; Falco, Kochanek & Munoz 1998), we find

$$\tau_{\rm GL}(z_{\rm s}) \approx 9 \times 10^{-4} \times G(z_{\rm s}). \qquad (6)$$

Evaluating equation (6) for the redshift of the burst $z_{\rm GRB} = 2.04$ (Jensen et al. 2001; see also Smette et al. 2000), we find the probability that GRB000301C could have been multiply imaged to be

$$\tau_{\rm GL/GRB} \approx 2.2 \times 10^{-3}, \qquad (7)$$

for $\Omega_{\rm m} = 0.3$ in a flat FRW universe. Hence the probability of seeing the observed microlensing event becomes

$$P_{\rm e} \approx \tau_{\rm GL/GRB} \int_{0.5}^{\kappa_{\rm l}} \frac{(2\kappa - 1)P_{\rm c}}{2\kappa^2\sqrt{1 + (\kappa/\kappa_{\rm c})^2}}. \qquad (8)$$

For GRB000301C at $z_{\rm z} = 2.04$, we furthermore find $\kappa_{\rm l} \approx 0.022$ (Section 3.2). Evaluating equation (8) for $P_{\rm c} \approx 0.82$ and $\kappa_{\rm c} \approx 0.072$ (Section 3.1), we finally find that the a posteriori probability of the event seen in GRB000301C is $P_{\rm e}(f_* = 1) \approx 0.027$.

However, this calculation assumes that all mass is in the form of compact objects. Recent results from the Massive Astrophysical Compact Halo Object (MACHO) collaboration indicate that $f_* = 0.08$–0.50 with 95 per cent confidence (Alcock et al. 2000). The most likely value is $f_* \approx 0.2$. In that case, we have to modify equation (1) such that $\kappa \rightarrow f_*\kappa$. In other words, the probability of an event goes down by a factor $\sim f_*$. This scaling of the numerical simulation is allowed, because for $\kappa = \gamma \ll 1$, the influence of the shear on lensing properties is small (see also Mao & Loeb 2001). Similarly, changing a fraction $(1 - f_*)$ of the surface density in compact objects to a smooth mass distribution is nearly similar to completely removing this fraction for $\kappa \ll 1$. Thus for a more realistic scenario, the probability reduces to $P_{\rm e}(f_* = 0.2) \approx 0.007$.

For microlensing events with an amplitude $\Delta m \geqslant 0.1$ mag (much weaker events than the one seen in the GRB000301C afterglow), we find $P_{\rm e} \approx 0.56$ and 0.17, respectively, for $f_* = 1.0$ and 0.2. One might therefore expect many high-z (i.e. $z \gtrsim 2$) GRB afterglows to show evidence for microlensing at a low level, assuming their physical properties are similar to those inferred from GRB000301C by Garnavich et al. (2000).

4 DISCUSSION

If the event seen in the optical light curve of the GRB000301C afterglow is caused by microlensing, the opportunities to study the structure and evolution of GRB afterglows on microarcsec scales are potentially very exciting (Loeb & Perna 1998; Garnavich et al. 2000; Mao & Loeb 2001).

However, in this paper we have shown that the a posteriori probability of this particular event is actually small, i.e. 0.7–2.7 per cent for a fraction $f_* = 0.2$–1.0, respectively, of dark-matter in the form of compact objects. The main assumptions in this calculation are: (i) a constant comoving density population of galaxies which follow a Schechter luminosity (i.e. mass) function, (ii) a flat Λ-dominated FRW universe with $\Omega_{\rm m} = 0.3$, (iii) all matter in the universe traces galaxies, which can be described as singular isothermal spheres, (iv) the mass spectrum of compact objects is ‘narrow’, in which case they can be parametrized by a single value for their mass, (v) a typical GRB optical afterglow has similar properties to GRB000301C and has a redshift of $z \approx 2$ and (vi) there is no significant magnification bias. The magnification bias, however, is unlikely to be a problem. Even in the case where this bias increases the number of observed GRBs by a factor of 10 for high microlensing optical depths ($\kappa \gtrsim 0.25$), Table 1 and equation (7) show that the overall probabilities are increased by only $10 \times P(\Delta m \geqslant 0.95^{\mathrm{m}}|\kappa \gtrsim 0.25) \times \tau_{\mathrm{GL/GRB}} \sim 0.1$ per cent. A detailed calculation should consistently take into account both the magnification distribution of galaxies *and* that of compact objects (e.g. Pei 1993a,b). In light of the very uncertain redshift distribution and luminosity function of GRB afterglows this is, however, not yet warranted.

Moreover, even in the case that the *whole* sky has a surface mass density of $\kappa_{*} \lesssim 0.25$ (normalized by the 'critical' surface mass density for lensing, e.g. Schneider et al. 1992) our simulations (see Table 1) indicate that the probability of such an event does not significantly exceed ≈5 per cent. Clearly, the latter situation is unrealistic, but it does place a very robust upper limit on the probability of this event (see also Press & Gunn 1973 and Blaes & Webster 1992).

The plausibility to actually observe such a fraction of GRB afterglow light curves with a microlensing event of about one magnitude also depends on the typical mass of compact objects. However, even if the mass goes up or down by a factor of ten from the assumed $0.5\,\mathrm{M}_{\odot}$, to first approximation that would just mean a 'broadening' in time of the microlensing event by about a factor of three (since the length/time-scale is proportional to the square root of the mass). However, if most compact objects have masses *much* smaller than that inferred for GRB000301C, the fraction of GRB afterglows with microlensing signatures will obviously decrease. In that case the effect of the 'shrunk' caustics will average out over the much larger angular size of the emission region of the GRB afterglow. This case, however, seems unlikely in light of the stringent lower limit ($\sim 10^{-2}\,\mathrm{M}_{\odot}$) placed on low-mass compact objects in 0957+561 (Schmidt & Wambsganss 1998; Refsdal et al. 2000; Wambsganss et al. 2000). The fraction of microlensed GRB afterglows would also decrease if the typical redshift of GRBs is significantly lower than $z = 2$. A somewhat lower typical redshift is supported by the average redshift $\langle z \rangle_{\mathrm{GRB}} \approx 1.3$, with an rms spread of ≈1, that we find from Bloom, Kulkarni, & Djorgovski (2000). In case of a broad mass spectrum of the compact objects or a large spread in the physical properties of the GRB optical afterglows, one has to convolve the microlensing probabilities with these properties. This, however, is not expected to change the results significantly.

We emphasize that our results *do not exclude* that the event seen in the light curve of the optical afterglow of GRB000301C is in fact due to gravitational microlensing, especially in light of the fact that a galaxy was found at 2 arcsec from the GRB (Garnavich et al. 2000). Each event should be treated on its own merit (and it is a posteriori anyway). In any case, in the sample of ~20 known GRBs with observed optical afterglows (e.g. Bloom et al. 2000), the probability of one such event would be around 14 per cent. But our results predict that it is unlikely to find many strongly microlensed GRB afterglow soon, and it emphasizes the difficulties one will encounter in creating a large sample of these strong (i.e. $\Delta m \gtrsim 1$ mag) events, with the aim to statistically study the physical properties of GRB afterglows on microarcsec scales. For example, to get 10 additional microlensing events of comparable strength, one would require ≈1500 GRB afterglow optical light curves. Even for the *Swift* satellite (Parsons et al. 1999; see also Mao & Loeb 2001) this provides a challenging task.

On the bright side, if the event in GRB000301C was due to microlensing, we can expect a significant fraction of high-z GRB afterglow light curves to show microlensing events stronger than 0.1 mag (see also Mao & Loeb 2001), although these will be hard to distinguish from intrinsic variations and will also not really be able to probe the GRB afterglow structure on microarcsec scales. We conclude that the best cases to unambiguously study microarcsec structure in GRB afterglows will probably be those GRBs that are multiply imaged (about 1–2 per cent expected, see, e.g. Paczyński 1987; Mao 1992, 1993; Narayan & Wallington 1992; McBreen, Plunkett & Metcalfe 1993; Wambsganss 1993; Nowak & Grossman 1994; Williams & Wijers 1997; Holz et al. 1999; Komberg, Kurt & Kuznetsov 1999; Marani et al. 1999). Those (soon to be discovered!) will almost certainly (see Table 1) show microlensing events ≳0.1 mag, which can easily be separated from intrinsic variations by comparison with the other lensed GRB images, after correcting for the respective time delays. A smaller fraction (≈5 per cent) will also show events ≳1 mag, although this might increase due to the magnification bias. So the prospects of doing science with (micro-)lensed gamma-ray bursts and afterglows remain promising.

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