Microlensing of collimated Gamma-Ray Burst afterglows

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1 INTRODUCTION

Whether the gamma-ray bursts (GRBs) are collimated or not is one of the most important questions in GRBs, since the jet configuration is crucial for almost all aspects of GRBs, such as the energetics, statistics, and central engine models of GRBs. There are several suggestions for the collimation of GRBs. When the Lorentz factor of the ejecta drops below the inverse of the opening angle, the ejecta begins to spread sideways, and we expect a break in the light curve of the afterglow (see e.g. Sari 2000). Such breaks have been observed in several GRBs, such as GRB 990510 and GRB 991216. The rapid decline rate (e.g., GRB 980519) or the unusually slow decline rate of GRB 980425 also suggests the collimation of GRBs. However, in order to establish that the afterglows are jets, other observations are indispensable, such as early afterglow observations at radio frequencies. Microlensing of the afterglows has a potential to be one of such observations. The emission region of the afterglow seen by an external observer occupies a size of $\sim 10^{17}$ cm on the sky which is comparable to the lensing zone of a solar mass lens located at the cosmological distance (Loeb & Perna 1998). Therefore microlensing can resolve the afterglow, and hence we can expect that some features of jets can be obtained by the observations of the microlensed afterglows.

On the other hands, afterglows will be useful to constrain the cosmological density parameter of stellar mass objects $\Omega_\star$ through microlensing. As a result of the relativistic motion, the emission region appears to expand superluminally, so that the microlensing time is only ~ 1 day (Loeb & Perna 1998). This is much shorter than that of common sources, $\gtrsim 10$ years. The microlensing probability of a source at a redshift $z_s \sim 3$ is $\sim 0.3\Omega_\star$. Since the known luminous stars amount to $\Omega_\star \gtrsim 4 \times 10^{-3}$, roughly 1 in $\sim 10^3$ GRBs would be within the lensing zone. If some fraction of the dark matter is made of massive compact halo objects (MACHOs), as Galactic microlensing searches suggest, we can expect higher probability. Remarkably, the microlensed afterglow may have been already observed in the light curve of GRB 000301C as the achromatic bump (Garnavich, Loeb & Stanek 2000). Since new GRB satellites such as *HETE-2* and *SWIFT* will provide many opportunities to monitor afterglows frequently, it is important to study the jet effects on the microlensing of the GRB afterglows.

2 SUMMARY AND DISCUSSIONS

We have investigated stellar microlensing of collimated GRB afterglows taking into account of the jet effects. Using the analytical expressions for the evolution of the jet, we have first calculated the surface brightness distribution of the jet. We find that the image is "disk-like" after the jet break time, rather than "ring-like" before the break time. We have further analyzed the microlensing signal in the light curve of the afterglow observed at frequencies far below and far above the typical synchrotron frequency ν_m, where the radio is in the low frequency for about 1 month,[1] and the optical is in the high frequency after about 1 day. If the edge of the image crosses the lens before the break time, the microlensing signal appears as an achromatic amplification peak in the light curve (Loeb & Perna 1998). We find that, after the break time, the amplification peak becomes lower and broader because of the "disk-like" image. Although the exact peak shape may be relevant to more detail calculations, the amplification peak disappears at frequencies $\nu \gg \nu_m$ but remains at $\nu \ll \nu_m$. This means that only optical observation is not sufficient for constraining $\Omega_\star$. At the break time, the peak amplitude depends on the lens position.

Microlensing also induces the proper motion and the polarization of the afterglow in coincidence with the maximum amplification. The magnitude of the proper motion does not depend on the image profile so much, which might be detected by upcoming missions, such as *SIM*, with positional accuracy down to $\sim 1\mu$as. From the proper motion we can estimate the apparent size of the afterglow explicitly. The maximum polarization due to microlensing is comparable to the polarization which is expected around the jet break time (Sari 2000), even if the image is "disk-like".

A low amplification peak in the optical can be used to test whether the afterglows are jets or not, if we can confirm that the afterglow is microlensed by other observations, such as radio, proper motion and polarization observations, since a low peak in the optical means that the image is "disk-like".

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references

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[1]The radio scintillation is suppressed at $\nu \gtrsim 10$ GHz.