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LETTERS

Is the Variable X-ray Source in M82 due to Gravitational Lensing?

Da-Ming Chen ⋆

National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012

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Abstract We explore the possibility of attributing the recent discovery of the variable hard X-ray source CXO M82 J095550.2+694047 in M82 to the gravitational magnification by an intervening stellar object along the line of sight acting as a microlens. The duration of the event (> 84 days) allows us to set robust constraints on the mass and location of the microlensing object when combined with the dynamical properties of the Galactic halo, M82 and typical globular clusters. Except for the extremely low probability, the microlensing magnification by MACHO in either the Galactic halo or M82 halo is able to explain the X-ray variability of CXO M82 J095550.2+694047. It is hoped that the lensing hypothesis can be tested soon by measurement of the light curve.

Key words: X-rays: stars — Galaxies: individual: M82 — gravitational lensing

1 INTRODUCTION

Observations of the most famous starburst galaxy M82 with the High-Resolution Camera on board the *Chandra X-Ray Observatory*, showed that there are nine sources in the central $1' \times 1'$ region, but no source was detected at the galactic center (Matsumoto et al. 2001). Comparing the observations on 1999 October 28 and those on 2000 January 20, the authors found an extremely large time variability of the source CXO M82 J095550.2+694047, which is located $9''$ away from the galactic center. They concluded that this source is the origin of the hard X-ray time variability of M82 detected with ASCA (Advanced Satellite for Cosmology and Astrophysics). Assuming a spectral shape obtained by the ASCA observation, its luminosity in the 0.5–10 keV band changed from 1.2×10^{40} erg s^{-1} on 1999 October 28 to 8.7×10^{40} erg s^{-1} on 2000 January 20.

It is difficult to explain such a short-term variability in terms of a supernova remnant. If the spectral shape of the source is described by an absorbed thermal bremsstrahlung model, the observations show that the probability of such a bright source existing in the $1' \times 1'$ field is 0.3%. Consequently, this source is probably not a background AGN.

⋆ E-mail: dmchen66@263.net

CXO M82 J095550.2+694047 may be a medium-massive black hole (Matsumoto et al. 2001), and the possibility of an X-ray binary source whose jet is strongly beamed towards us cannot be excluded. In this Letter, we explore an alternative possibility that the time variability of the source is produced by the microlensing effect of MACHO along the line of sight.

2 MICROLENSING EXPLANATION

The source CXO M82 J095550.2+694047 is $9''$ away from the center of M82 (its distance from us is 3.9 Mpc). It may be located in a star cluster with typical size of 2.34–10 pc (de Grijs et al. 2001) and typical velocity dispersion of member stars of 15 km s^{-1}.

If a foreground star is traversing across the line of sight, the apparent magnitude of the source would be magnified according to microlensing theory. The duration of the crossing time is $T = 2a_{\rm E}/v$, in which $a_{\rm E}$ is the Einstein radius defined as

$$a_{\rm E} = \left(\frac{4GM}{c^2} \frac{D_{\rm ds} D_{\rm d}}{D_{\rm s}} \right)^{1/2}, \tag{1}$$

where $D_{\rm d}$, $D_{\rm s}$ and $D_{\rm ds}$ are the angular diameter distances to the lens, to the source and from the lens to the source, respectively, v is the relative velocity perpendicular to the line of sight between the source and the lens.

The mass of microlens is related to the crossing time by (Wu 1996)

$$M = \frac{c^2}{32G} \frac{D_{\rm s}}{D_{\rm d} D_{\rm ds}} \frac{v^2 T^2}{0.4919}, \tag{2}$$

where we have chosen the total maximum magnification to be $\mu_T = 7.0$, since the luminosity of the source in the 0.5–10 keV band changed from 1.2×10^{40} erg s^{-1} on 1999 October 28 to 8.7×10^{40} erg s^{-1} on 2000 January 20.

A microlens of mass of $\sim M_\odot$ could lie at any point between the source and the observer, and different positions would lead to different crossing time. For the source CXO M82 J095550.2+694047, the observed time duration should already exceed 84 days. For simplicity, we take $T = 2 \times 84$ days for an approximate estimate. The microlens mass versus its distance is plotted in Fig. 1 for three lensing models, with the microlens located in our Galaxy with a typical velocity of 200 km s^{-1}, in M82 with a typical velocity of 100 km s^{-1} and in a star cluster of the source itself with a velocity of 15 km s^{-1}.

At the three different positions, the same microlens mass would lead to different crossing time durations, as shown in Fig. 2. We set $D_{\rm s} = 3.9$ Mpc in all the situations. Because of the symmetry between $D_{\rm d}$ and $D_{\rm ds}$ in Equation (2), the first and second panels of both Fig. 1 and Fig. 2 look very similar.

3 DISCUSSION AND CONCLUSIONS

Given a definitive value of the crossing time or the distance of lens from us, the source–lens–observer system must align appropriately to produce the correct results. The typical value of the microlens mass is of $\sim M_\odot$, the crossing time duration is about ~ 200 days, and the distance of microlens should be chosen such that the microlens is within our Galaxy, in M82 or in the star cluster of the source, with typical size of 50 kpc, 30 kpc and 10 pc, respectively.

It can be seen clearly from Fig. 1 and Fig. 2 that the microlens object, if any, should be located either in M82 or in the Galactic halo. However, we can exclude the possibility of the

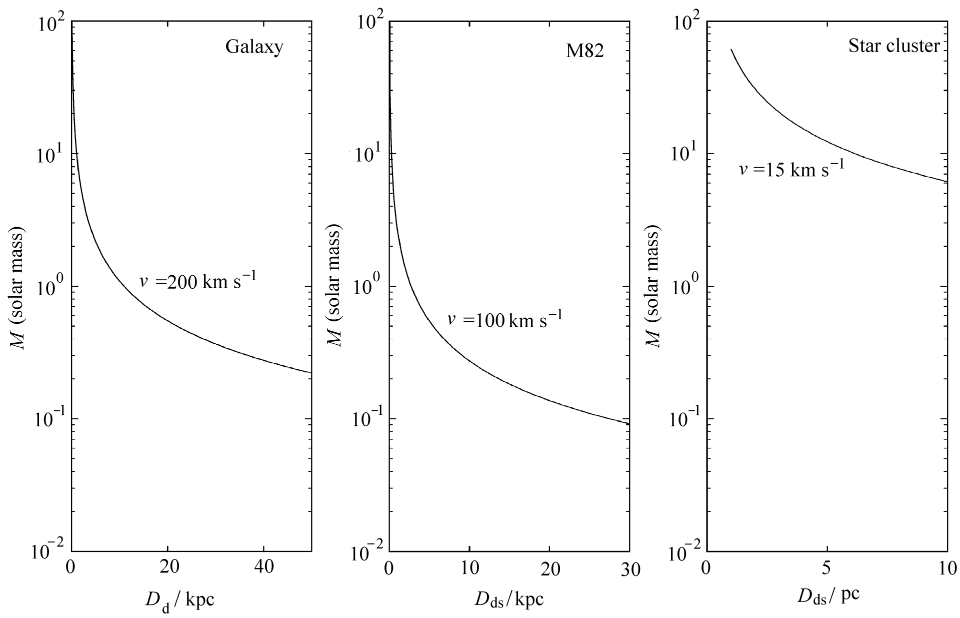

Fig. 1 The mass of microlens as a function of $D_{\rm d}$ or $D_{\rm ds}$. The three panels from left to right refer to the location of lens in our Galaxy, in M82 and in a star cluster, respectively. The corresponding typical velocity of the microlens is clearly marked

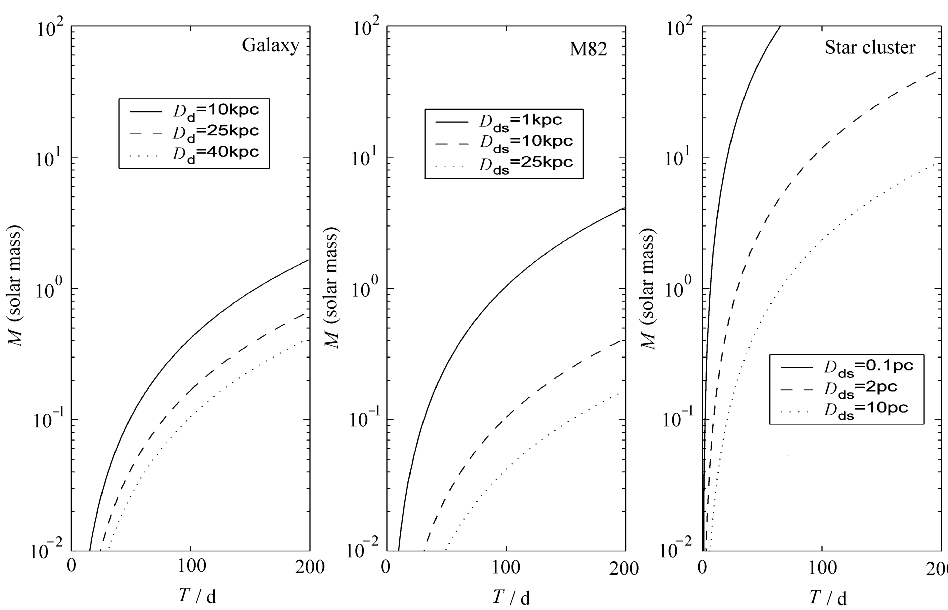

Fig. 2 The mass of microlens as a function of crossing time duration T. The three panels from left to right refer to the location of lens in our Galaxy, in M82 and in a star cluster, respectively. The position of the microlens in each case is indicated

self-lensing by a star in the star cluster that harbors CXO M82 J095550.2+694047 if the typical size of a star cluster is smaller than $\sim 10\,\mathrm{pc}$.

The probability that a source is gravitationally lensed by MACHOs in either the Galactic halo or in the halo of M82, is described by the optical depth which amounts to $\sim 10^{-6}$. Indeed, the event like the variable hard X-ray source CXO M82 J095550.2+694047 seen in M82 is very rare if it is due to microlensing. A conclusive resolution needs a detailed sample of the light curve of CXO M82 J095550.2+694047. Whether or not the light curve demonstrates the time-symmetry around the maximum intensity will be a crucial test for the lensing hypothesis.

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