Dark Matter in Galaxies
IAU Symposium, Vol. 220, 2004
S.D. Ryder, D.J. Pisano, M.A. Walker, and K.C. Freeman, eds.

Quasar Mesolensing as a Probe of CDM Substructures

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1. Introduction

Currently, the CDM scenario has met a crisis that the number of substructures presented by cosmological N-body simulations based on the scenario is much larger than the observed amount. If such substructures do not really exist, it must be an actual crisis for the CDM scenario. In contrast, if the reason for the overproduction of substructures in simulations is some observational bias, and many substructures are invisible or not detectable due to very low star formation efficiency by some feedback processes (e.g., Nishi & Susa 1999), the CDM scenario will survive. Thus, it is crucial for the resolution of this crisis to discriminate between these two possibilities.

For this purpose, gravitational lensing phenomena can be an ideal tool because neither the luminosity nor brightness but the mass of objects is responsible for the phenomena. Moreover, multiply-lensed quasars can be ideal targets since the lines of sight to images automatically intersect the lens galaxy and part of them also intersect in the vicinity of a substructure around the lens galaxy.

When an image of multiply-lensed quasars is gravitationally lensed by a substructure in the strong lens regime, the image can be split into more than two images. Even if we cannot resolve such additional multiple images, we will be able to find substructures from echo-like signals[1]. If the typical size of the lens is considered to be larger than for quasar microlensing and smaller than for quasar macrolensing, then the expected quantities should be medium scale, and we call them quasar mesolensings. Here, we investigate possibilities to find substructures via quasar mesolensing.

2. Expected Phenomena

We adopt standard CDM cosmology, and set the lens and the source redshifts to 1 and 2, respectively. We consider substructures as singular isothermal sphere lenses and the range of velocity dispersions to be $11 - 110\ \mathrm{km\,s^{-1}}$. The velocity

[1]Quasars have stochastic flux variations, and there are time delays between additional multiple images. If we observe such additional multiple images as one image, we should observe echo-like signals in the flux variations.

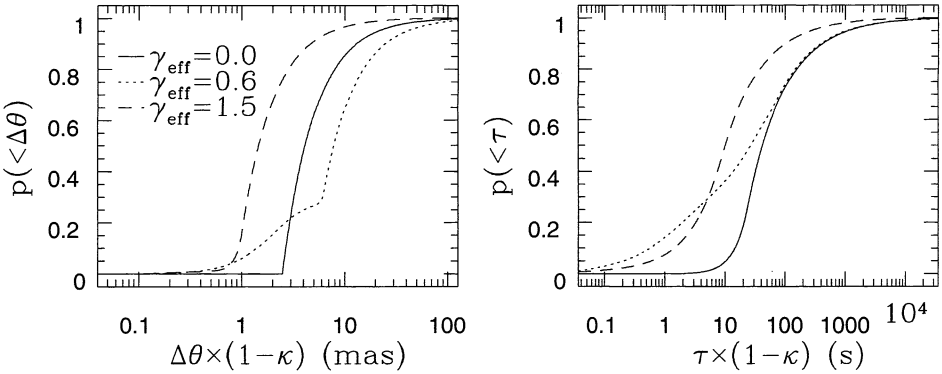

Figure 1. Cumulative probability distribution for expected image separations and time delays between further multiple images. Here, $\gamma_{\rm eff}$ is equal to $\gamma/\left(1-\kappa\right)$.

distribution of the substructures is also taken into account. Additionally, the effects of the lens galaxy itself are not negligible and we include such effects as external shear (γ) and convergence (κ). If the second brightest image is too faint, we will not be able to detect signals from additional multiple images. To include such observational constraints, we only consider the case that the second brightest image is brighter than 20% of the brightest image.

Following the above setting and performing some calculations, we determine that the probability for quasar mesolensing to occur is $1.2\times\left[(1-\kappa)^2-\gamma^2\right]^{-1}$ %. The term in parentheses corresponds to the magnification factor of the multiple images. Since multiple quasars are magnified by a factor of several to ten, the probability becomes roughly 10%.

Furthermore, expected image separations ($\Delta\theta$) and time delays (τ) between additional multiple images due to quasar mesolensing are also calculated. By using Monte-Carlo simulations, we obtained cumulative probability distributions for them. The results are shown in Figure 1. From these results, we can conclude that the typical scale of quasar mesolensing is expected to be $1-30$ mas for image separations, and $1-500$ s for time delays.

There are still some ambiguities for our evaluations due to the unknown nature of substructure such as density profiles, but quasar mesolensings will provide us with important information for structure formation in the near future. More details are shown in Yonehara, Umemura, & Susa (2003).

This work is supported in part by the Japan Society for the Promotion of Science (09514, 13740124).

References

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