Fuluctuation of Extragalactic Reference Frame
Due to Gravitational Lensing

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Abstract

Expectation values of the position shift and its variation of the quasars due to the gravitational lensing by the stars and MACHOs in our galaxy are calculated. Typical values of these are the order of 10 microarcsecond and several microarcsec/year. When constructing highly accurate reference flame, these will cause the aging of the frame and we have to take these effects into account. At the same time, the detection of these effects might be useful for probing the contents of our galaxy.

1. Introduction

Thanks to the technical developments of VLBI and optical interferometer, the measurement accuracy of the position of the stars is increasing. It is said to be 10 μas in some plans on the differential VLBI and satellite on-board the optical interferometer [1]. They will resolve many unknown facts such as the rotation curve of our galaxy, the measurement of the mass of single star [2]. On the other hand, in such accurate observation, the measured values include various effects and we have to distinguish what we want to measure from what we measure. Here we examine an effect that has been hitherto ignored, the fluctuation of the position of extra galactic objects due to the gravitational lensing by compact objects in our galaxy. At present, the most reliable reference frame is constructed by the position of the quasars. These objects are considered to be very far from our galaxy, and therefore, their proper motions are negligible. Hence, the reference frame constructed by them has been considered to show no aging. Even if the real proper motions of quasars are negligible, however, we have to observe them through our galaxy, the space filled with stars and MACHOs. Then, the light ray from a quasar is deflected slightly by their gravitational field of these matter and its observed position would be different from that in the case of no lensing. Moreover, the deflection angle would change according to the relative motion between the line of sight

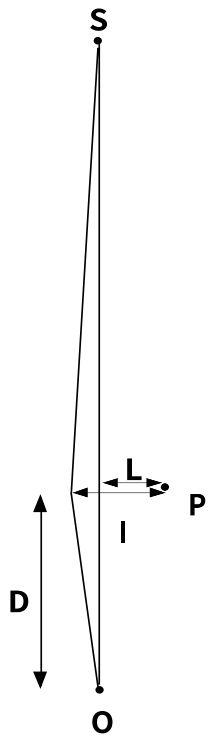

Fig. 1

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and the deflectors. Therefore, apparent proper motion of the quasars would be induced by these deflections. In this paper, we show a brief review of these phenomena. For the detail of the calculation and discussion, see Ref. 3.

2. Theory and assumptions

The simplest configuration of the gravitational lensing (GL) is shown in Fig.1. The source is located at a distance D_S from the observer O and a point mass deflector P is at a distance D from O. The line OS is the line of sight from O to S, the path of light ray in the absence of lensing. The distance between P and OS is denoted by L. The distance between P and the lensed light ray, the impact parameter, is denoted by I. The deflection angle is given as [4]:

$$\alpha = m/I\,, \tag{1}$$

where $m \equiv 4GM/c^2$ and M is the mass of the deflector P. If the number density and the mass distribution of the deflectors are obtained, the mean square of angular shift of the quasars is evaluated as

$$<\alpha^2> = \int n(m,\mathbf{r})\,\alpha^2\,dm\,dV \tag{2}$$

where $n(m, \mathbf{r})\,dm\,dV$ shows the number of the stars which locate at $\mathbf{r}$, within the volume dV, and whose masses are between m and $m + dm$. In the integration with respect to dV, Eq.(1) shows that the main contribution comes from the region close to the line of sight. In the same way, the mean square of the induced proper motion is obtained.

$$<(d\alpha/dt)^2> = \int n(m,\mathbf{r})(d\alpha/dt)^2\,dm\,dV \tag{3}$$

On the relation between proper motion of the deflector and quasar's induced proper motion, see Fig. 2 [2].

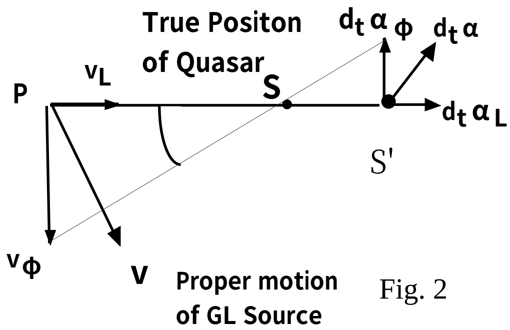

Fig. 2

Here we consider only two kind of matters, the disk stars and MACHOs. For the distribution of each kind of matter, we adopt the following model.

1. Disk Star (M_{sun}, Exponential Disk model) [5,6]

Σ_0 = 46 M_{sun}/pc^2 : Column Density of Disk Stars

R_0 = 8.5 kpc2 : Distance to Galactic Center

z_h = 300 pc : Disk Thickness

v_0 = 220 km/s : Flat rotaition curve [Fig. 3]

2. MACHO (0.1 M_{sun}, Isothermal model) [6,7]

a : Core Radius of MACHO , 2000 pc

ρ_0 : Local Density of DM, 8×10^{-3} M_{sun}/pc^3

$\langle v_{MACHO}\rangle$ = 180 km/s : Random Direction

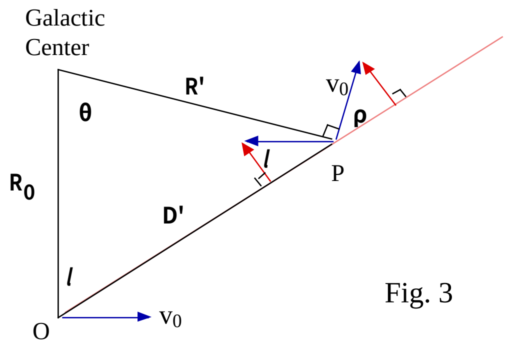

Fig. 3

The results are shown in Fig. 4 and Fig. 5. We can see that near the galactic plane, the positions of the quasars are expected to be fluctuated more than 10 μas by the gravitational lensing due to the stars in our galaxy. If the typical mass of MACHOs are 0.1 M_{sun} or less, the fluctuation due to these is very small. This is because the mean square of the fluctuation is approximately proportional to the number density times square of the typical mass. On the induced proper motion of the quasars, that due to the disk stars is more than 5 μas/year near the galactic plane, $| l | < 60°$ [Fig. 3]. Contrary to the case of angular shift, MACHOs' contribution is not negligible in the induced proper motion. If MACHO exist, the expectation value of the induced proper motion is larger than 4 μas/year in every direction [Fig. 4]. This is because the mean square of the induced proper motion is proportional to the density and the square of the velocity.

3. Discussion

Here we will discuss on some properties of these effects. On the galaxy core parameter *a*, certain value has not been found yet. The value of *a* is now considered as between 2000pc and 8000 pc. We have checked what differences will occur between *a* is 2000 pc and 8000 pc. The difference is found mainly in the direction near the galactic center. The results of numerical calculations are shown in Fig. 6.

We made another numerical calculation of the induced proper motion in that the effect of the orbital motion of the Earth was taken into account. Compared to the rotation speed of the disk star, about 220 km/s , the speed of that, 30 km/s, is not so small [2,8]. The calculation is done by simply adding or subtracting a speed of 30 km/s to the disk star's relative velocity to the line of sight [Fig. 7]. In order to detect the annual variation of the expectation value of the induced proper motion, the accuracy of 1 μas will be needed.

The expectation values obtained in the previous section will be important when we construct a reference frame with the accuracy of better than 10 μas based on the position of many quasars. On the other hand, the distribution of these are far different from Gaussian. Therefore when we observe each quasar, the probability of observing the position shift or proper motion as or grater than the expectation values will not be so high. We also calculate the optical depth [7] of the induced proper motion at 1 μas/year [Fig.8]. They are not so high. In such case, the optical depth can be regard as the probability of such event. When the probability of induced proper motion is low enough, that can be corrected by regarding almost all neighbor quasars are not induced any proper motion. In the smaller proper motion level where the optical depth is the order of unity or more, the situation is complicated and that will give us an accuracy limit of constructing the reference frame.

To summarize, we have to pay attention to the fluctuation of the position of the quasars due to the gravitational lensing caused by the matters in our galaxy when we observe their positions with the accuracy of 10 μas. The apparent proper motion induced by such lensing will make the aging of the reference frame. Also, statistical analysis of such induced proper motion would be useful for the search of the contents of our galaxy, such as the existence and the density distribution of MACHO.

References

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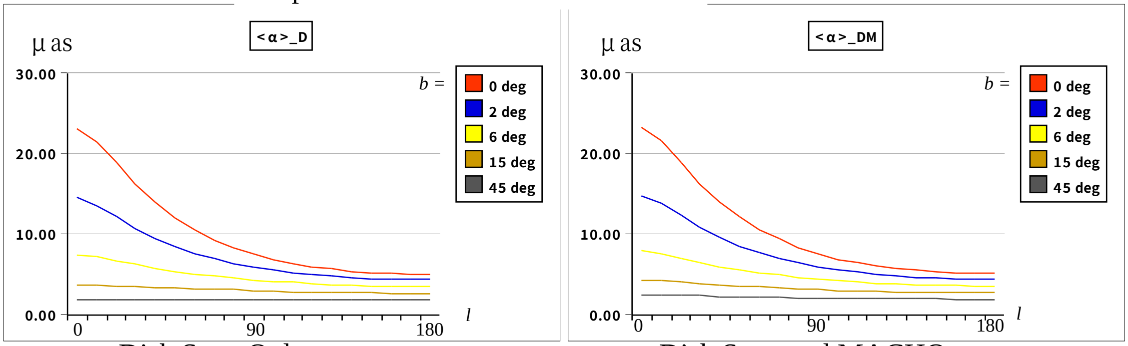
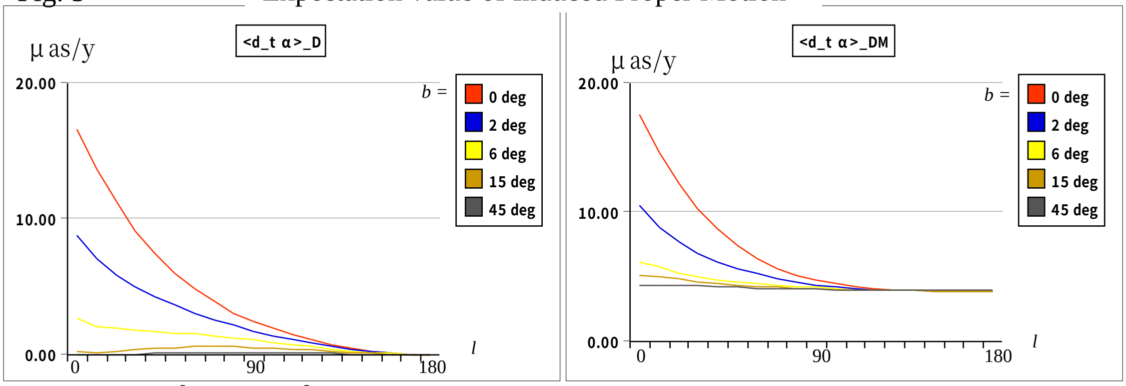
Fig. 4 Expectation value of Position Shift



Disk Stars Only

Disk Stars and MACHOs

Fig. 5 Expectation value of Induced Proper Motion



Disk Stars Only

Disk Stars and MACHOs

Fig. 6 Galaxy core parameter *a* and Induced proper motion

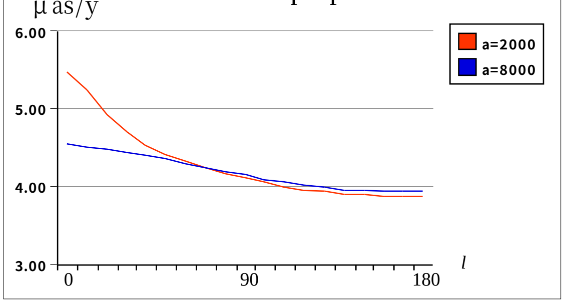


Fig. 7 effect of the orbital motion of the Earth

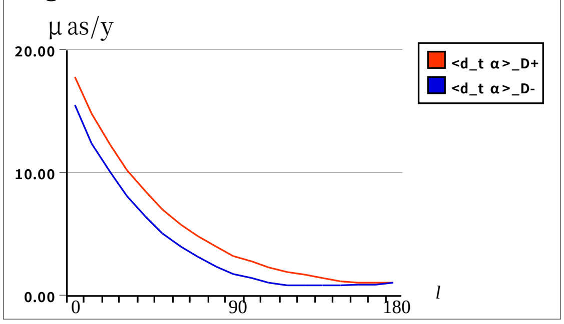
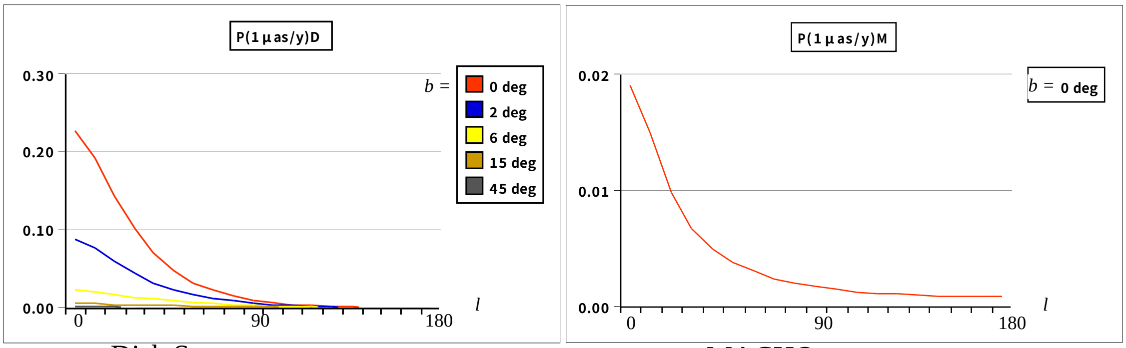


Fig. 8 Induced proper motion at 1 μas/year



Disk Stars

MACHOs

Disk Stars

MACHOs