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Macro lens toward the Galactic Center

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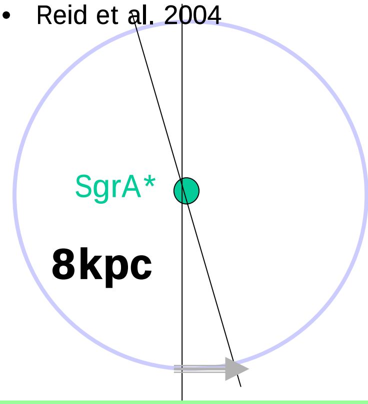
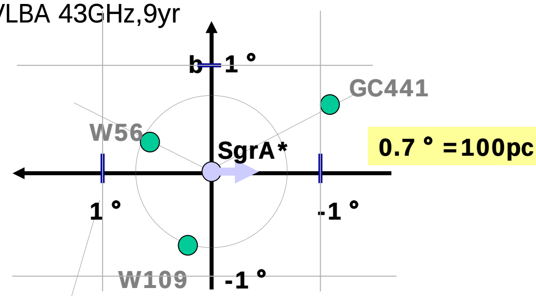
1. Introduction

1-1 Detection of Galactic Rotation of Solar System

phase-referenced to QSOs J1748-291(W109) J1745-283(W56)

- Reid et al. 1999 VLBA 43GHz,2yr
- Backer & Sramek 1999 VLA 4.9GHz, 17yr
- Reid et al. 2004 VLBA 43GHz,9yr





$$6mas/yr = \frac{220km/s}{8kpc}$$

VLBI observation of SgrA* =>6mas/y

1. Introduction

1-2 Various effect in the apparent motion

Table 1. Various effects in the apparent motion

	Sgr A*		QSOs	
Nature	Secular	Periodic	Secular	Random
Magnitude	6 mas/yr	250μas/yr	0.6μas/yr	10μas/yr
Cause	Galactic Rotation	Annual Parallax	Macro Lens	Microlensing

1. Introduction

1-2 Gravitational Lens effect to the G.C.

Micro Lens effect

of reference QSOs
by the star near the line of sight to G.C

Individual Star

Astrometric Microlensing

(Hosokawa,et al 2002)

Macro Lens effect

of reference QSOs
by galactic potential
near the line of sight to G.C

Group of Stars

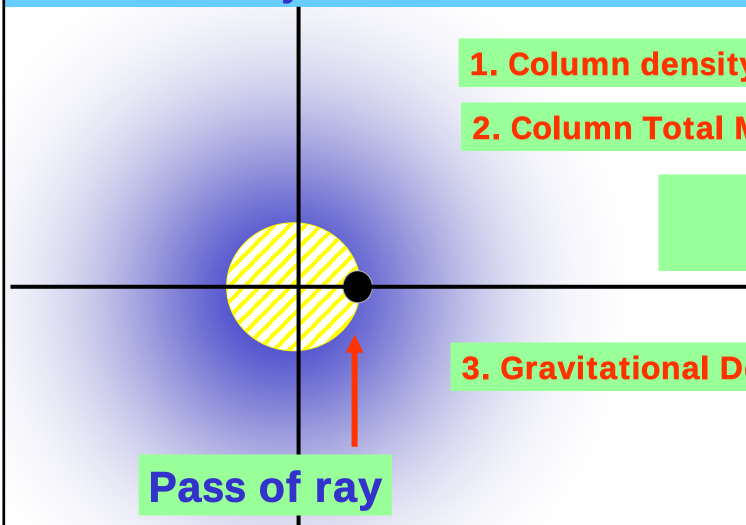
(1) SgrA* (Massive BH)
(2) Core
(3) Bulge

Macro Lens

(Ohnishi, et al. 2003)

2. Astrometric Macro-lens

2-1 Gravitational Deflection by Axis Symmetric Mass Distribution



1. Column density $\Sigma(L)$

2. Column Total Mass within *L*

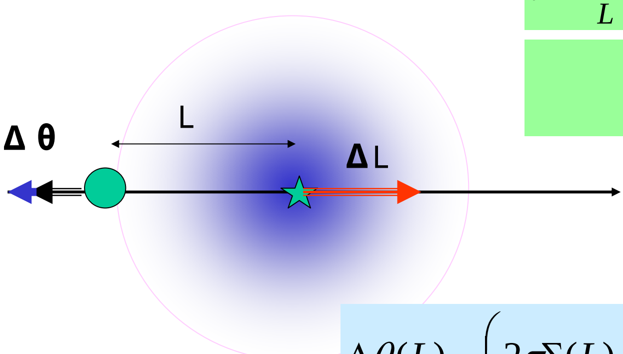
3. Gravitational Deflection

$$\theta = \frac{m}{L}$$

2. Astrometric Macro-lens

2-2 Gravitational Deflection

$$\theta = \frac{m}{L}$$

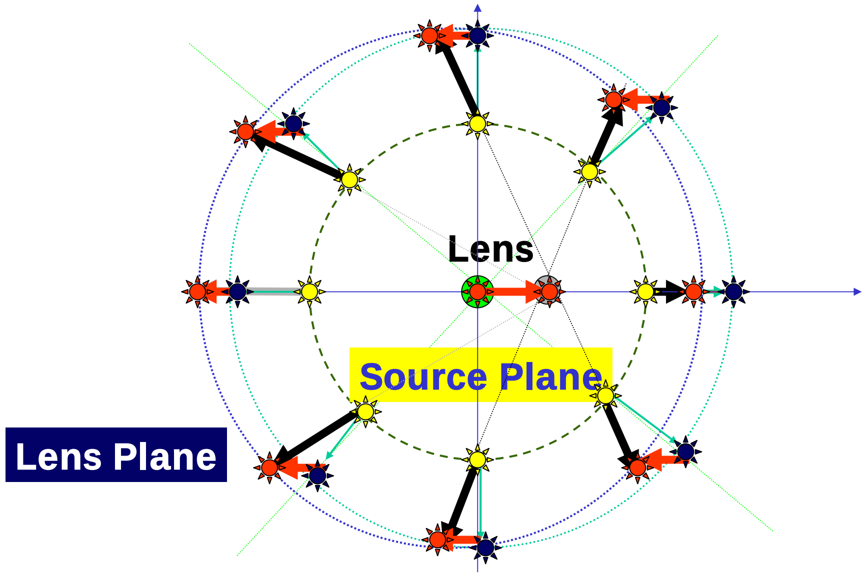


$$\Delta\theta(L) = \left(2\pi\Sigma(L) - \frac{m(L)}{L^2}\right)\Delta L$$

If $\Sigma =$ Constant $\Delta\theta(L) = \pi\Sigma_0 \Delta L$

2. Astrometric Macro-lens

2-3 Illustration of Shift by Bulge Motion



3. Astrometric Macro-lens in our Galaxy

3-1 Adopted Galactic Model

Alexander & Sternberg (1999)

Core+Bulge+Disk

Characteristic Length Scale

Core	Bulge	disk
0.38pc	667pc	3kpc

$$\rho_{core}(r) = \frac{\rho_o}{1+3(r/r_c)^2}$$

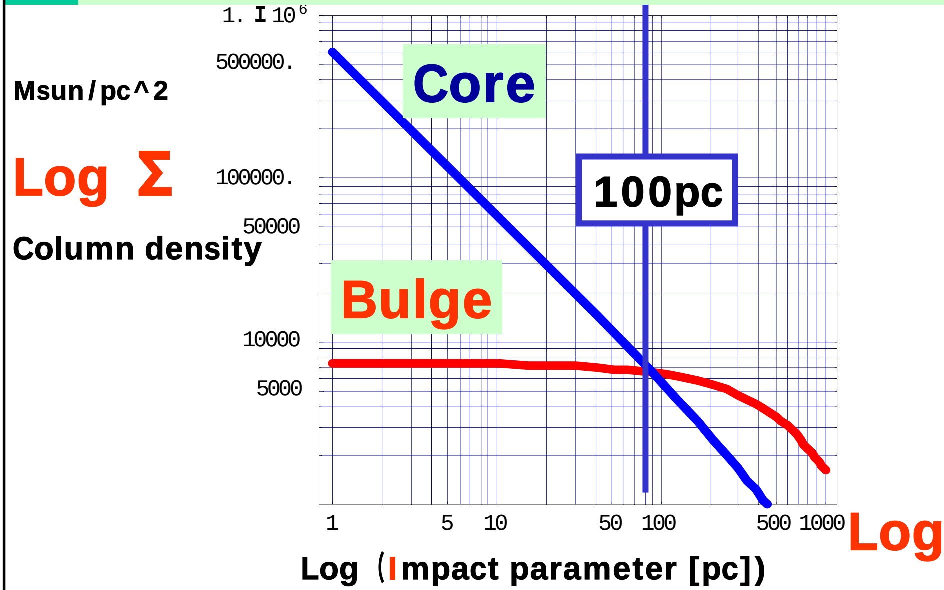
$$\rho_o = 4\times10^6 M_{SUM}\, pc^{-3}, r_c = 0.38\, pc$$

$$r_b = 3000\, pc$$

Disk and Halo contribution is negligible

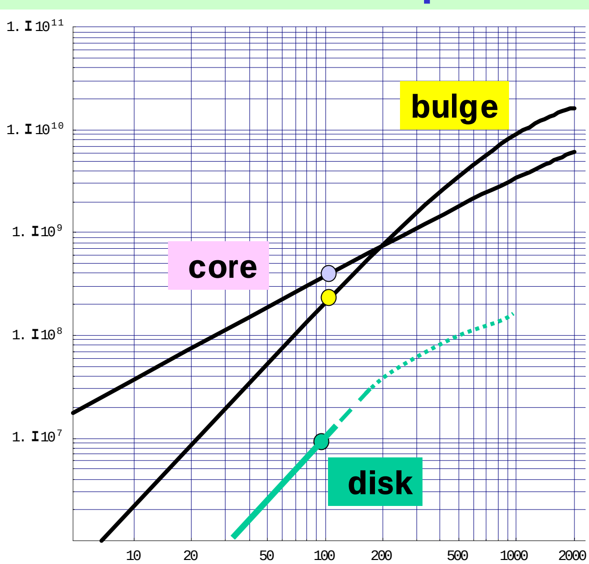
A. Astrometric Macro-lens in our Galaxy

A-1 Column Density of Core and Bulge



A. Astrometric Macro-lens in our Galaxy

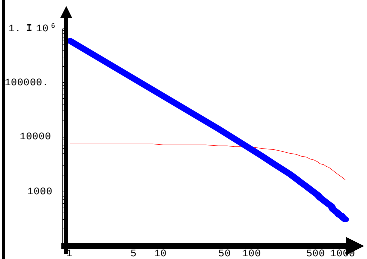
A-2 Total Mass inside the Impact Parameter



3. Astrometric Macro-lens in our Galaxy

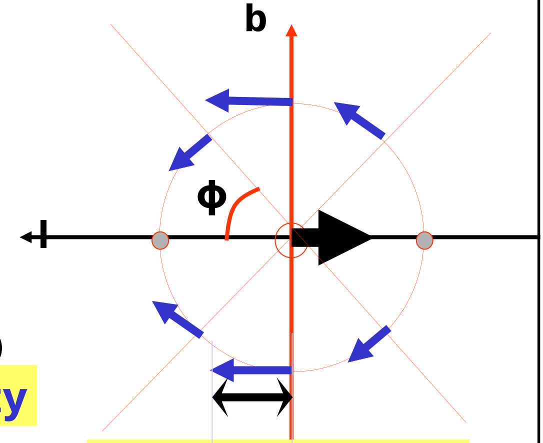
3-2 Effect of Core Motion

Log Σ Msun/pc^2



Log (Impact parameter [pc])

Core column density



~4μas/10yr @100pc

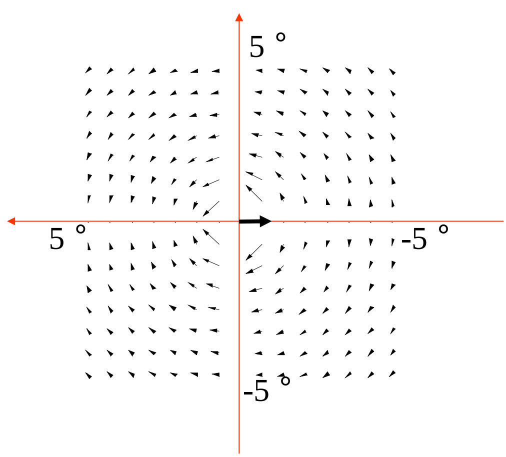
$$\overline{\mu_l} = \mu_c(1-\cos 2\phi)$$

$$\overline{\mu_b} = \mu_c(-\sin 2\phi)$$

$$\mu_c = 2\mu as/10yr\left(\frac{L}{100pc}\right)\left(\frac{\rho_c}{4\times10^6 M_{sun}/pc^3}\right)\left(\frac{a}{0.38pc}\right)^2\left(\frac{V}{220km/s}\right)$$

3. Astrometric Macro-lens in our Galaxy

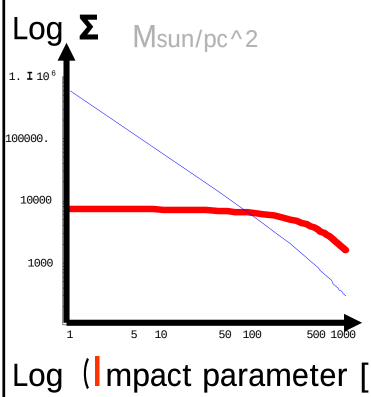
3-3 Effect of Core Motion



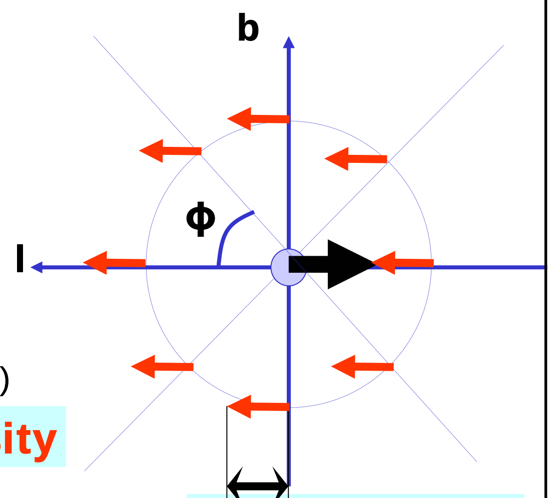
$$\mu_{cx} = 0.027\left(\frac{1-\cos 2\phi}{d}\right)\mu\text{as}, \quad \mu_{cy} = -0.027\left(\frac{\sin 2\phi}{d}\right)\mu\text{as}.$$

3. Astrometric Macro-lens in our Galaxy

3-4 Effect of Bulge Motion



Bulge column density



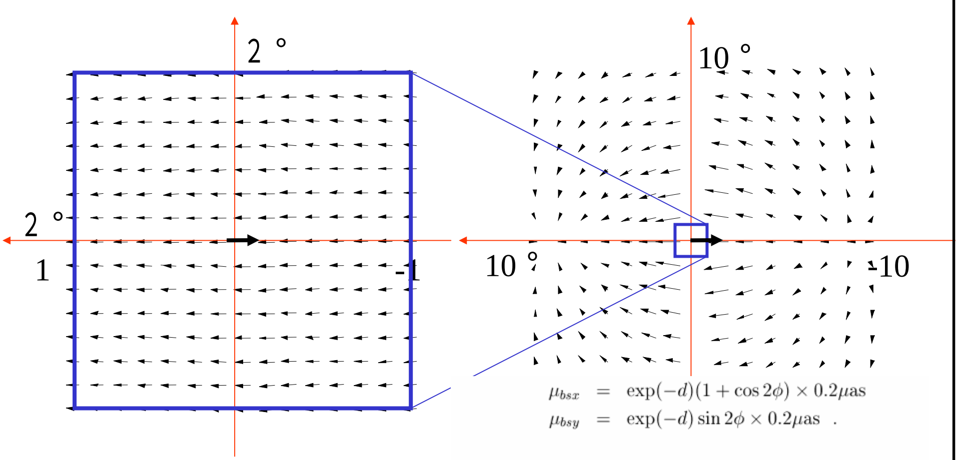
$$\overline{\mu}_l = \mu_B$$
$$\overline{\mu}_b = 0$$

$$\mu_B = 2\,\mu as/10\,yr\left(\frac{\Sigma(100\,pc)}{6\times 10^6 M_{sun}/pc^2}\right)$$

~2 μ as/10yr

3. Astrometric Macro-lens in our Galaxy

3-5 Effect of Bulge Motion



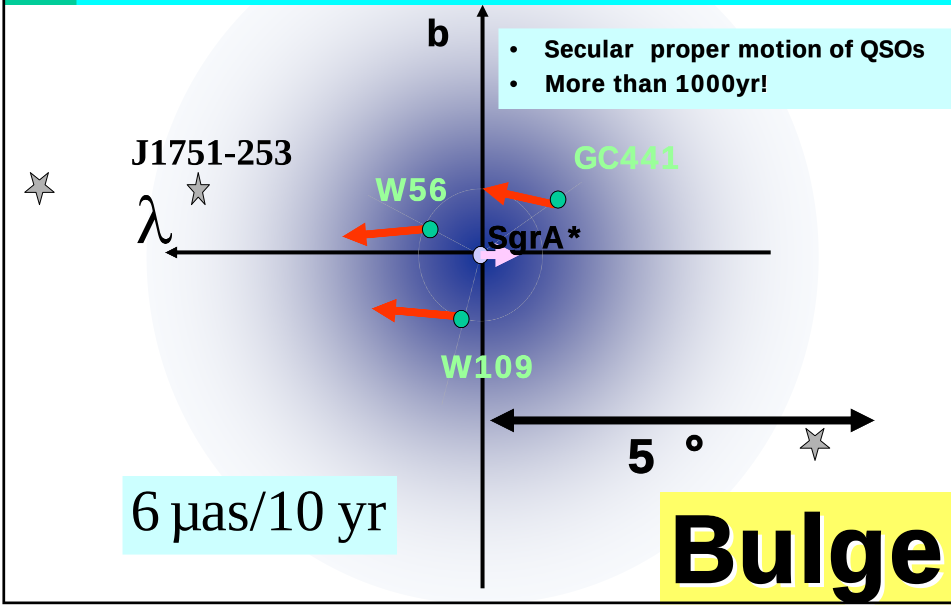
$$\mu_{bsx} = \exp(-d)(1+\cos 2\phi)\times 0.2\mu\text{as}$$
$$\mu_{bsy} = \exp(-d)\sin 2\phi \times 0.2\mu\text{as} \quad .$$

$$\mu_{bmx} = -\left(\frac{(1-(1+d))e^{-d}}{d^2}\right)\cos 2\phi \times 0.2\mu\text{as}$$
$$\mu_{bmy} = -\left(\frac{(1-(1+d))e^{-d}}{d^2}\right)\sin 2\phi \times 0.2\mu\text{as} \;.$$

3. Astrometric Macro-lens in our Galaxy

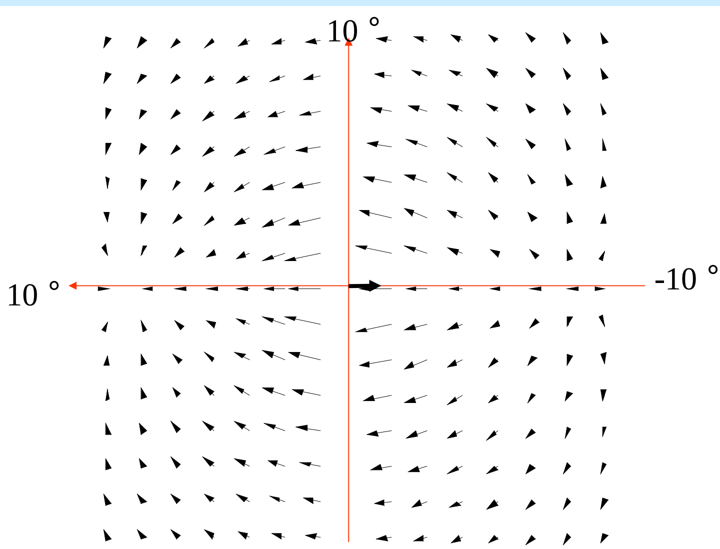
3-7 Collective Motion

- Secular proper motion of QSOs
- More than 1000yr!



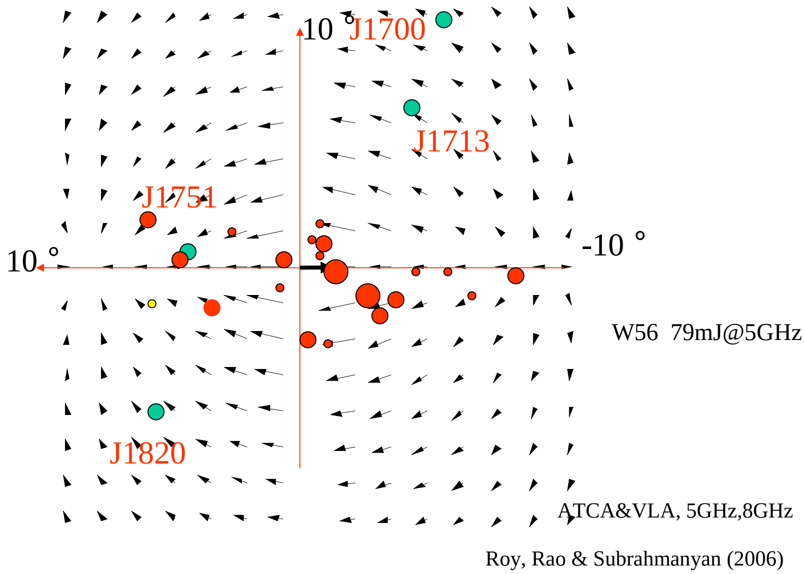
3. Astrometric Macro-lens in our Galaxy

3-6 Total Effect



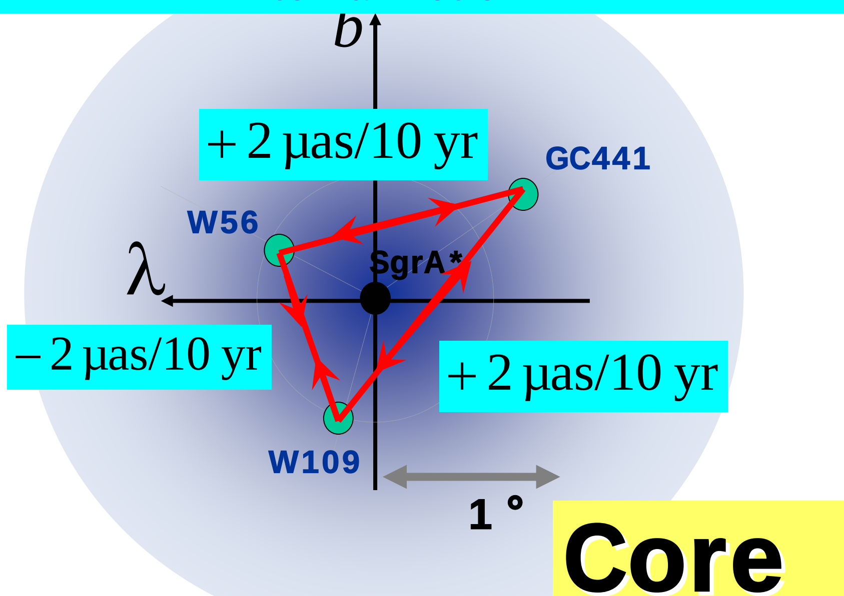
3. Astrometric Macro-lens in our Galaxy

3-6 Total Effect



3. Astrometric Macro-lens in our Galaxy

3-8 Internal Motion



3. Astrometric Macro-lens in our Galaxy

3-6 Total Effect

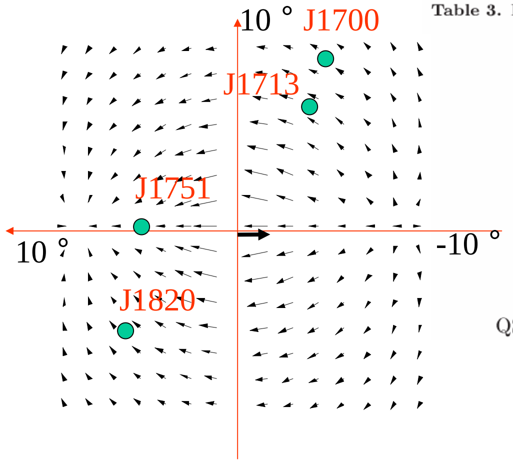


Table 3. Internal motion of the apparent places of QSOs

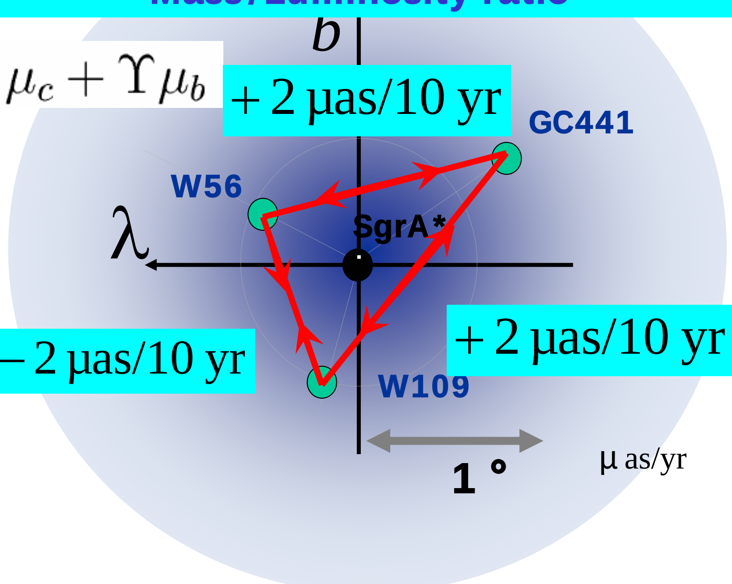
Name	μ_1
W56-W109	-0.20
W109-GC441	0.19
GC104-W56	0.15
J1751-W59	-0.21
J1751-J1713	0.05
J1751-J1820	-0.08

QSO 2 点間の離角の変化 (μas/yr.)。

3. Astrometric Macro-lens in our Galaxy

3-9 Mass/Luminosity ratio

$$\mu = \mu_c + \Upsilon \mu_b$$



3. Astrometric Macro-lens in our Galaxy

3-9 Mass/Luminosity ratio

$$\mu = \mu_c + \Upsilon \mu_b$$

Table 6. Υ

Name	μ_1	μ_5	μ_{10}
W56-W109	-0.20	0.47	1.16
W109-GC441	0.19	-0.19	-0.66
GC104-W56	0.15	0.42	1.08
J1751-W59	-0.21	-0.64	-1.25
J1751-J1713	0.05	0.37	0.77
J1751-J1820	-0.08	0.40	0.82

QSO 2 点間の離角の変化 (μas/yr.)。

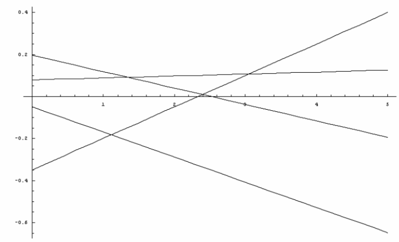


Fig. 7. MASSLUMI.

5. Conclusion

5-1 Summary of MACRO Lens

Macro lens effect of Galaxy is important

Apparent Motion of QSOs

Internal	Collective
Core	Core + Bulge
2 µas/10yr	2-6 µas/10yr

The collective gravitational deflection by the bulge, that is called **MACRO-Lens**, are observable magnitude. This effect reaches 0.6 micro-arcsecond/yr and it has a secular component.

The measurement of these effects will provide us valuable information on the visible and dark matter density and mass function of the Galactic Center.

5. Conclusion

5-2 Summary of MACRO Lens

SgrA*	QSOs
Secular **6 mas/yr** **Galactic Rotation**	**Secular** **0.6 μas/yr** **Macro Lens**
Periodic **250 μas/yr** **Annual Parallax**	**Random** **(several years)** **10 μas/yr** **Microlensing**

3. Astrometric Macro-lens in our Galaxy

3-8 Collective Motion

Table 3. Internal motion of the apparent places of QSOs

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QSO 2点間の離角の変化 (μas/yr.)。