長野ブラックホール天文教育研究会（銀中祭り）
2014年11月15日

銀河系中心方向の重力レンズ現象

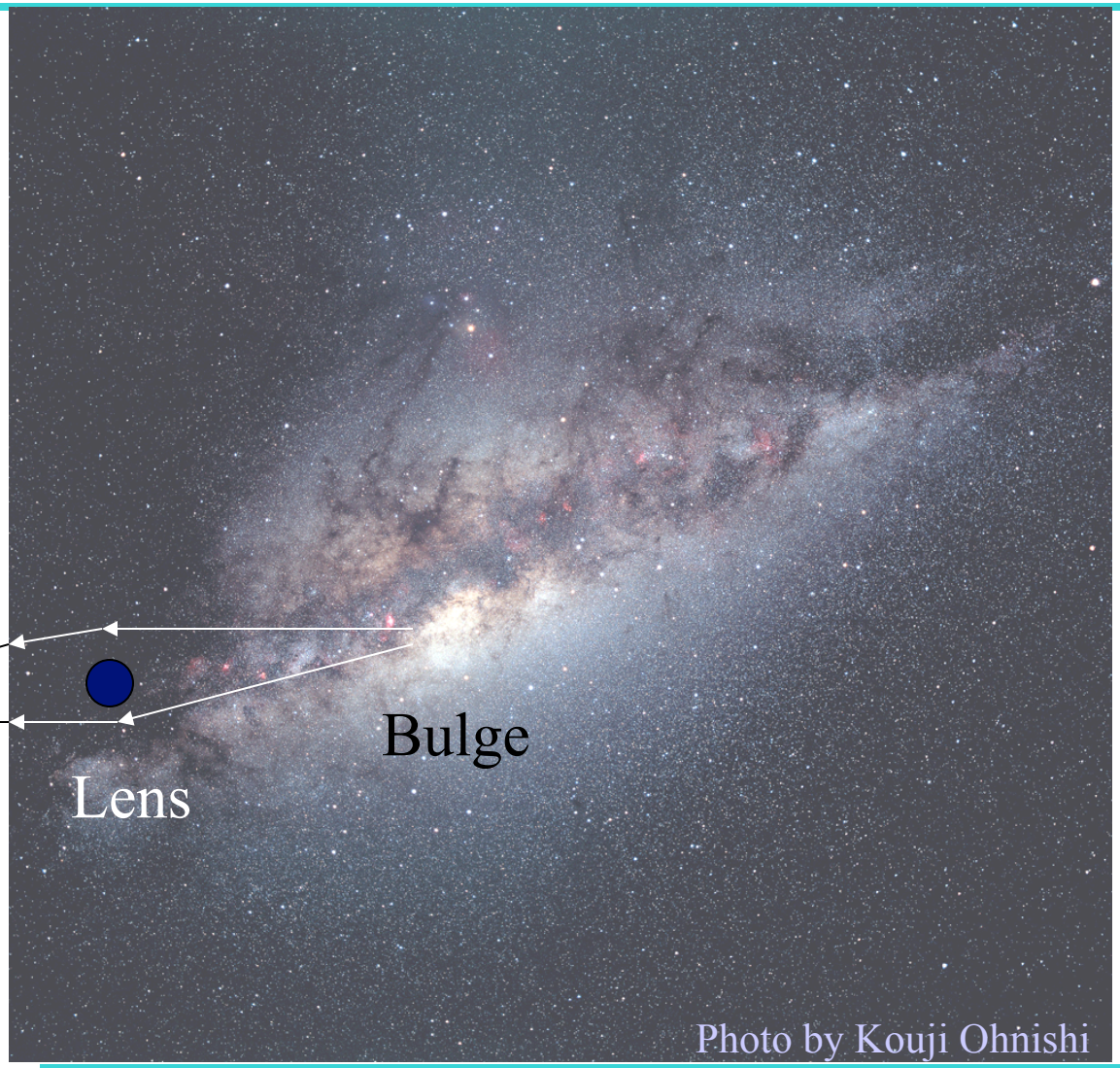
大西浩次 (長野高専)

0. Introduction

0-1

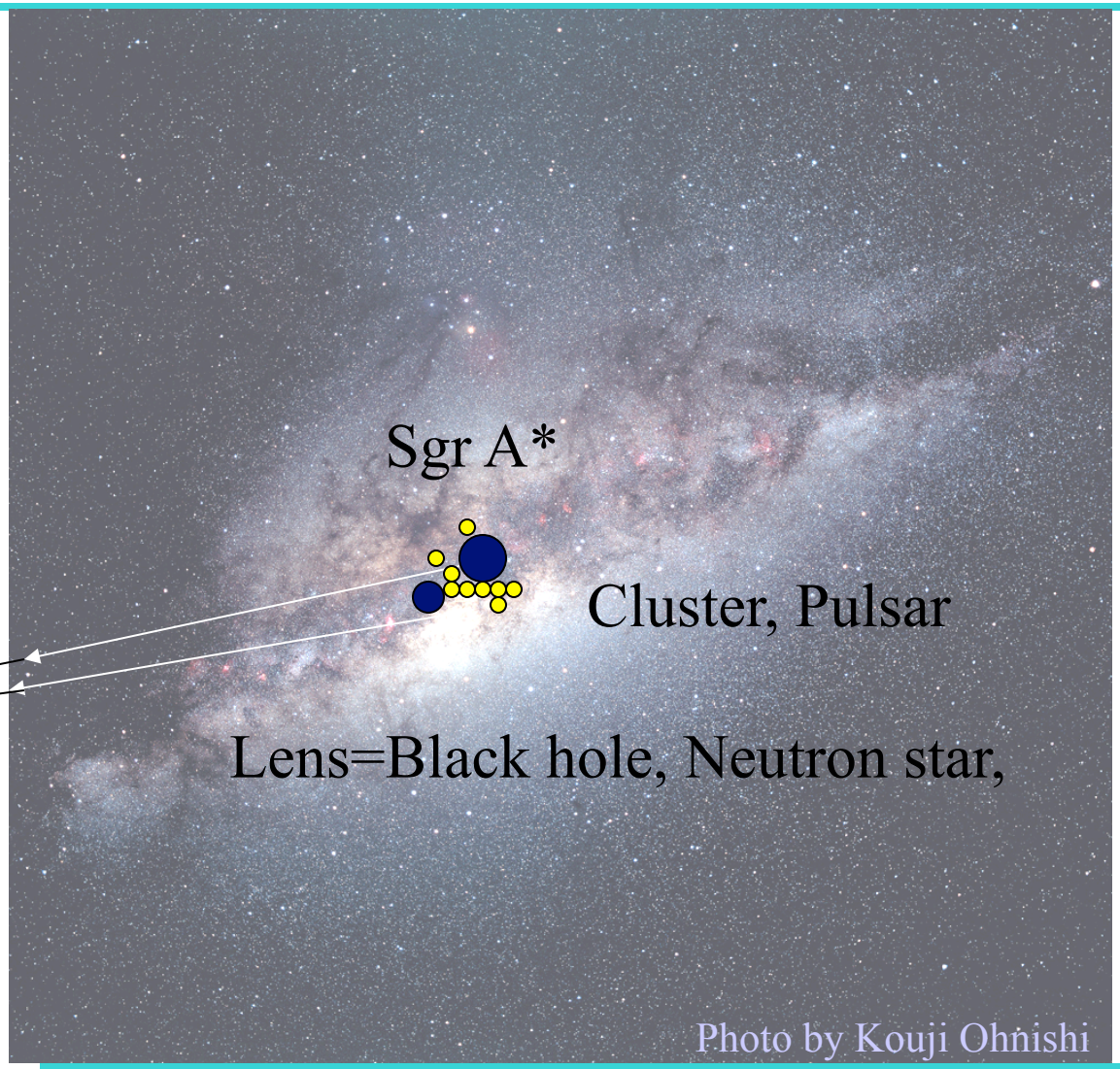
Lensing toward Galactic Center I

Microlensing

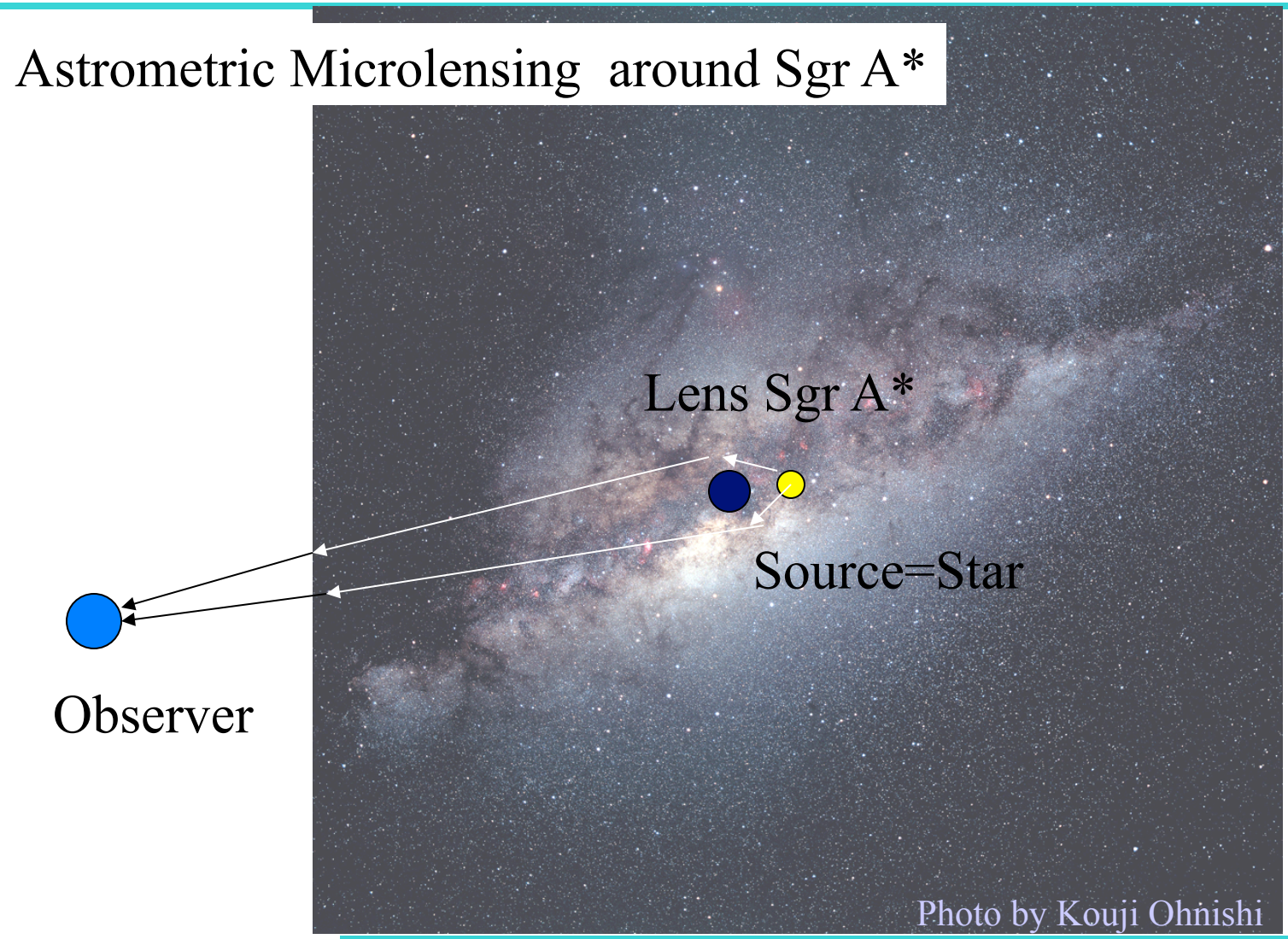


Lensing toward Galactic Center II

Microlensing

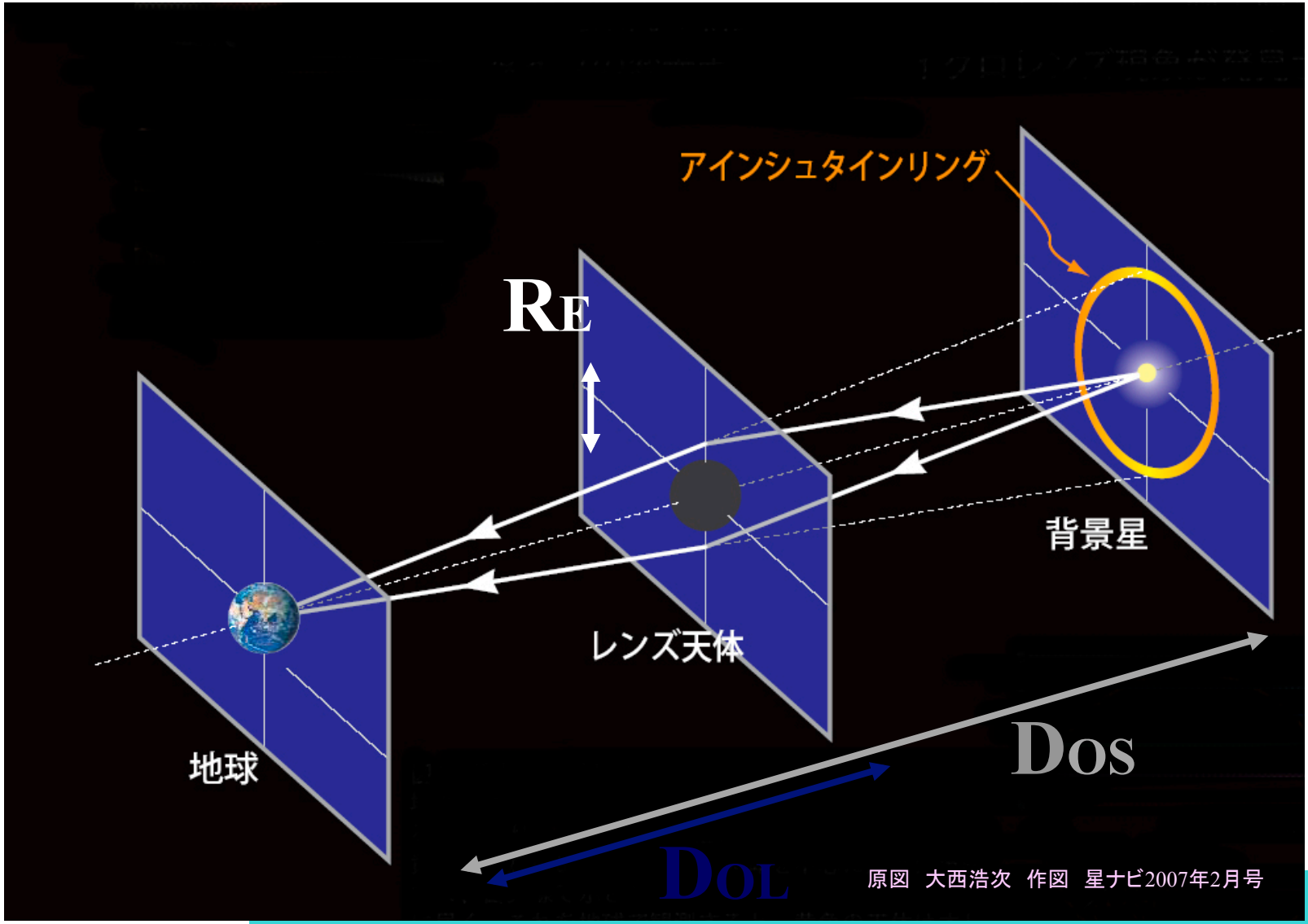


Lensing toward Galactic Center IV



2. Gravitational Lens by Sgr A*

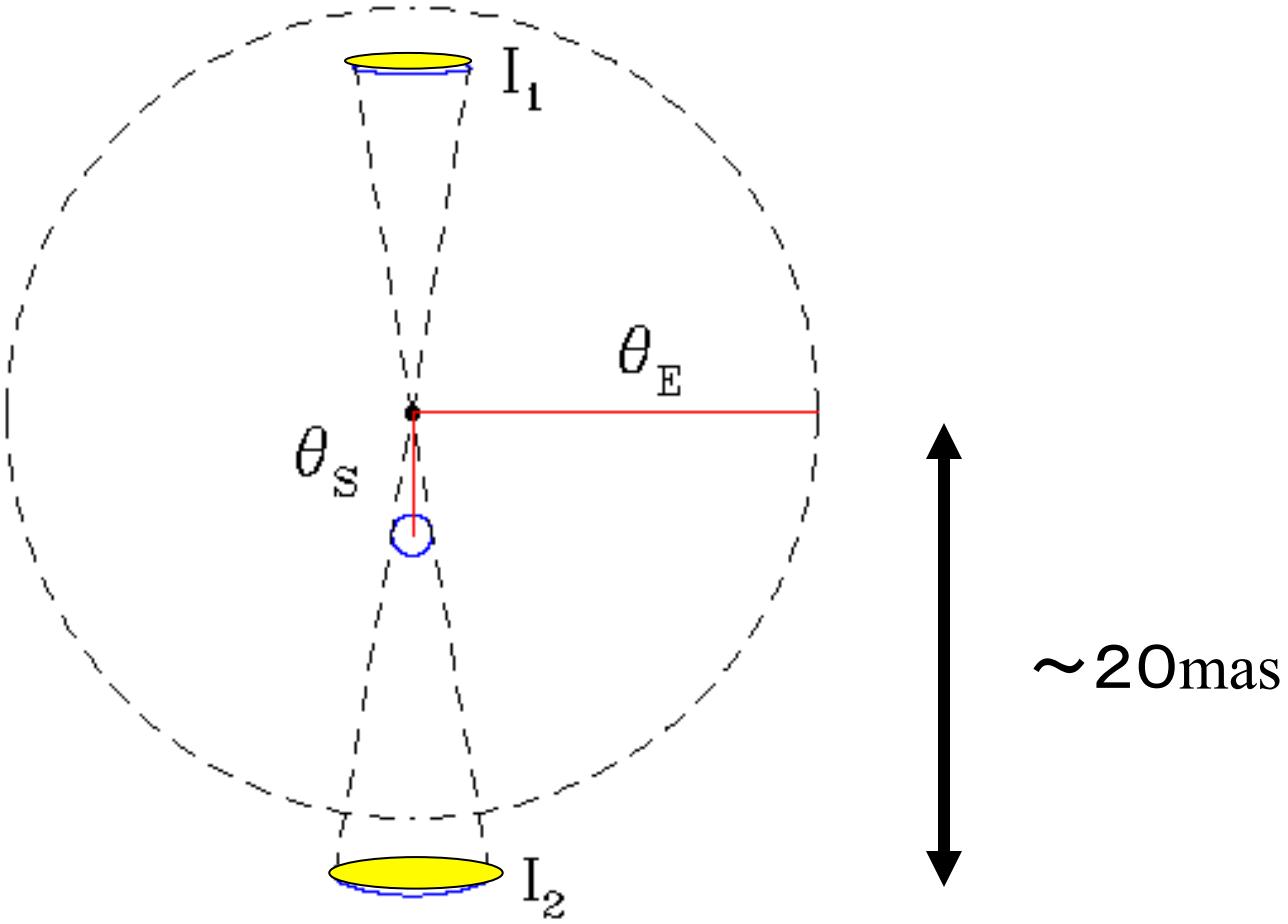
2-1 Einstein Ring



2. Gravitational Lens by Sgr A*

2-2

Lens images



2. Gravitational Lens by Sgr A*

2-3 Sgr A* の重力レンズの特徴的なサイズ

Sgr A*

$M = 4 * 10^6 M_{sun}$

$R_0 = 8kpc$

Photo by Kouji Ohnishi

Schwarzschild半径

$R_s = 2GM / c^2 = 15 R_{sun} = 6 * 10^{-2} AU$

$\Theta_s = R_s / R_0 = 9 \mu as$

Einstein Ring

$\Theta_E = (2 R_s (D_{LS}/D_S D_L))^{1/2}$

= 1.7″ (13600AU @SgrA) @ $D_{LS} \rightarrow \infty$

= 20 mas (160AU @SgrA) @ D_{LS}=1pc

= 0.4 mas (3AU@SgrA) @ D_{LS}=100AU

2. Gravitational Lens by Sgr A*

2-3 Sgr A* の重力レンズの特徴的なサイズ

Photo by Kouji Ohnishi

Sgr A*

$M = 4 * 10^6 M_{sun}$

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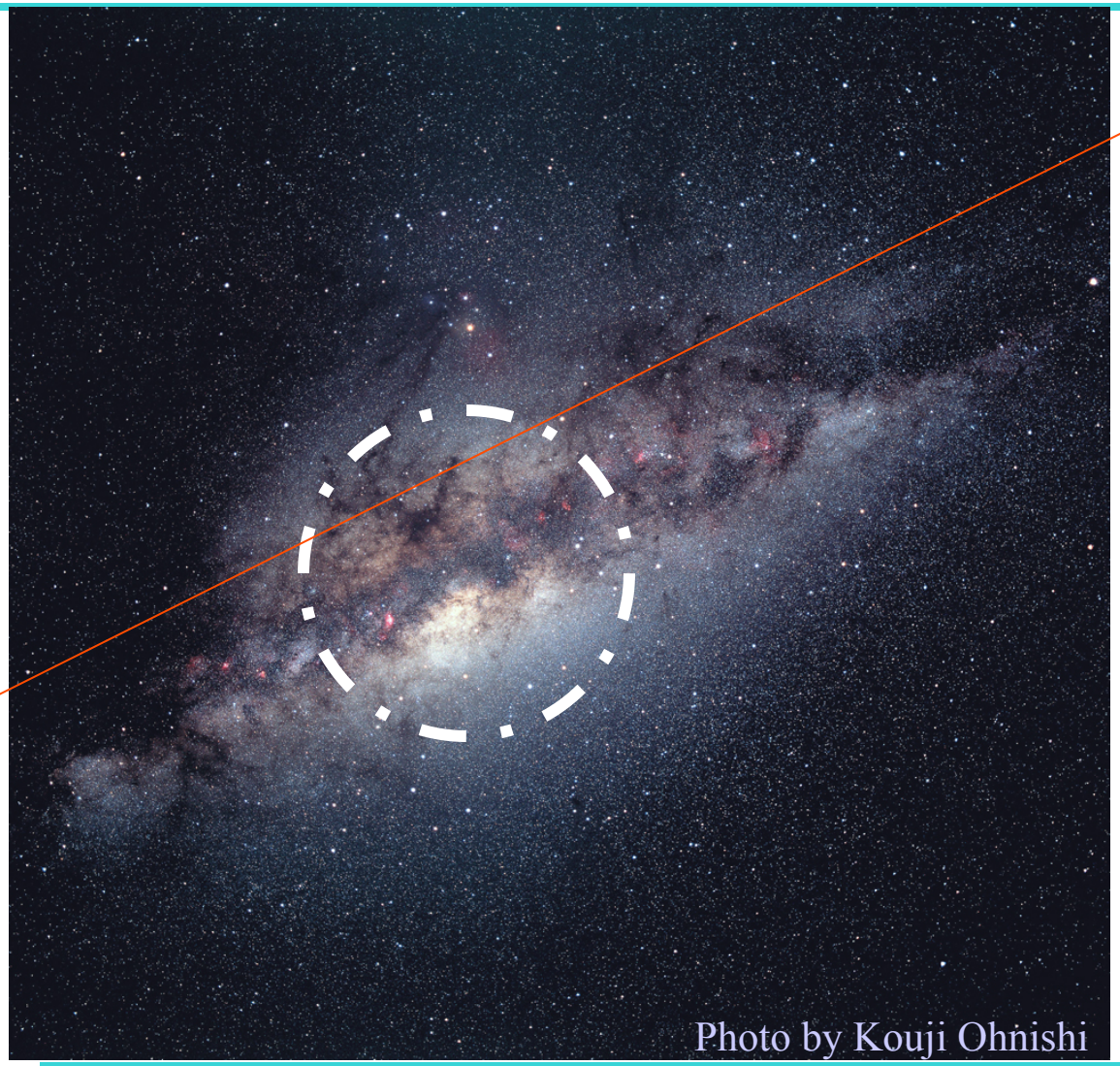
Idea! Like a Exoplanet Search by microlensing

6. Lensing toward Galactic Center V

6-1 Macrolens of the Galaxy



QSOs

Observer

What is Macro Lens?

Gravitational Deflection in Galactic Center

Individual Star	Group of Stars
Astrometric Microlensing	Macro Lens
0-4”	This Talk

Lensing toward Galactic Center III

0-4"

Astrometric Microlensing @ Distance Measurement

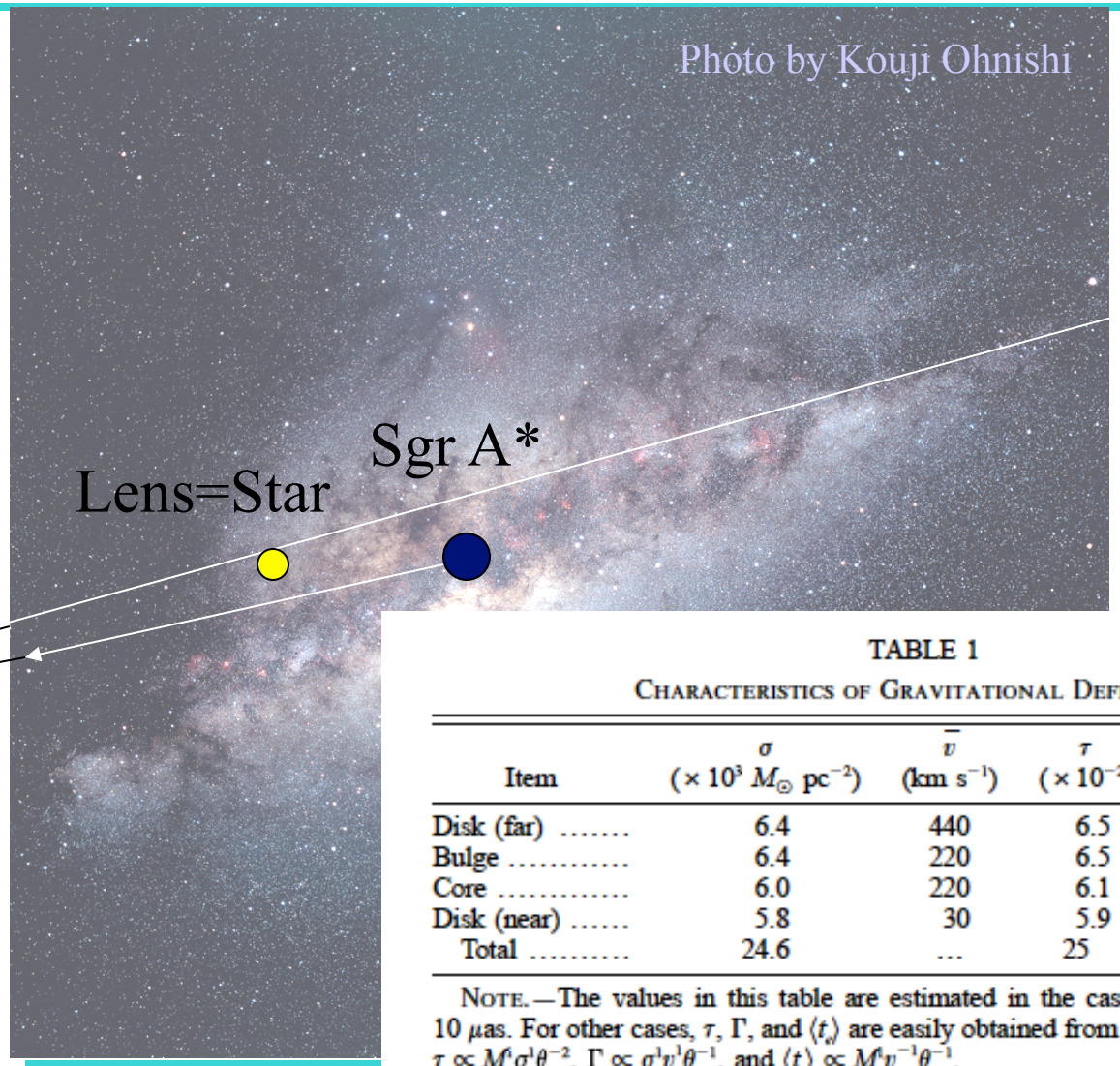


TABLE 1

CHARACTERISTICS OF GRAVITATIONAL DEFLECTION

Item	σ ($\times 10^3\ M_\odot\ \mathrm{pc}^{-2}$)	$\bar{v}$ (km s^{-1})	τ ($\times 10^{-2}$)	Γ ($\times 10^{-2}\ \mathrm{yr}^{-1}$)	$\langle t_* \rangle$ (yr)
Disk (far)	6.4	440	6.5	2.3	3.2
Bulge	6.4	220	6.5	1.2	5.6
Core	6.0	220	6.1	1.1	5.7
Disk (near)	5.8	30	5.9	0.14	42
Total	24.6	...	25	4.7	5.5

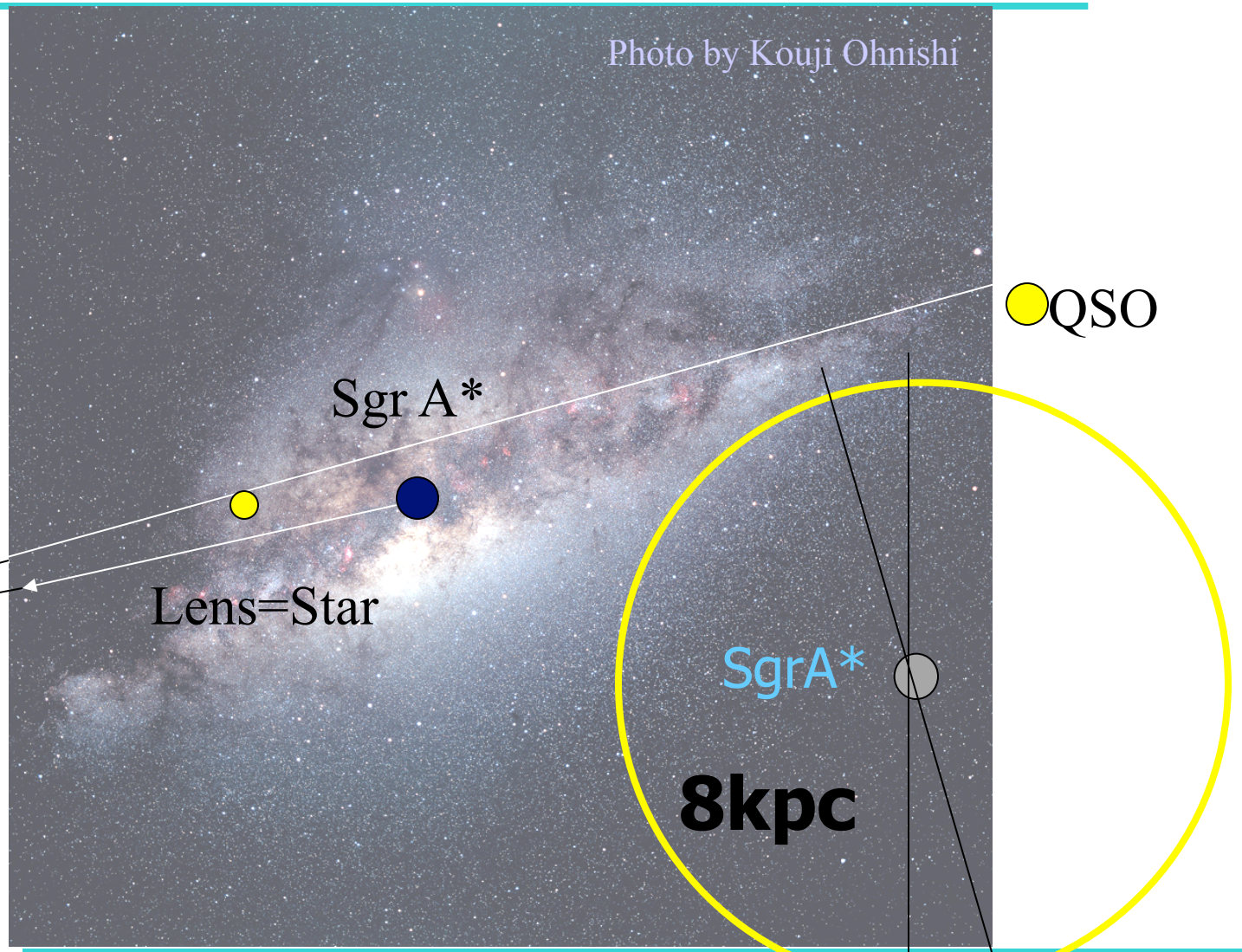
NOTE.—The values in this table are estimated in the case $M = 0.2\ M_\odot$ and $\theta = 10\ \mu$as. For other cases, τ, Γ, and $\langle t_* \rangle$ are easily obtained from this table and the relations $\tau \propto M^1\sigma^1\theta^{-2}$, $\Gamma \propto \sigma^1 v^1 \theta^{-1}$, and $\langle t_* \rangle \propto M^1 v^{-1}\theta^{-1}$.

Hosokawa,Jauncey,Reynolds, Toioumis, Ohnishi, Fukusima ApJ(2002)

Lensing toward Galactic Center III

0-4

Astrometric Microlensing @ Distance Measurement



Reid et al. ApJ(1999) et al.

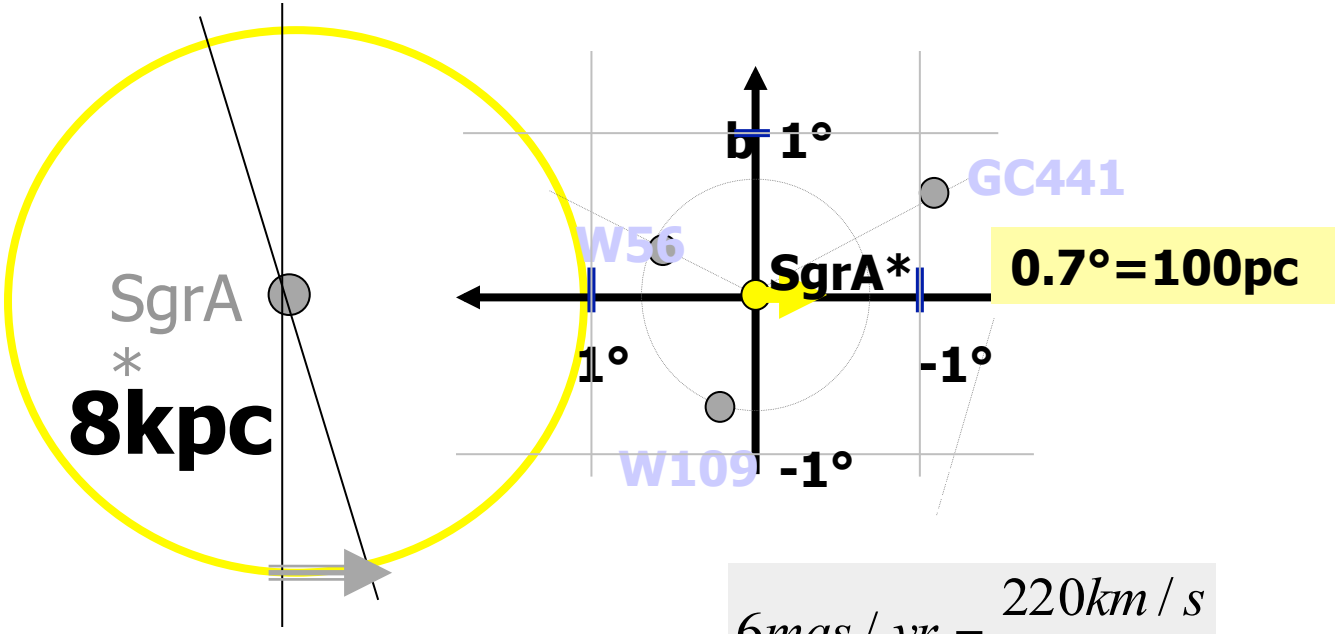
Lensing toward Galactic Center III

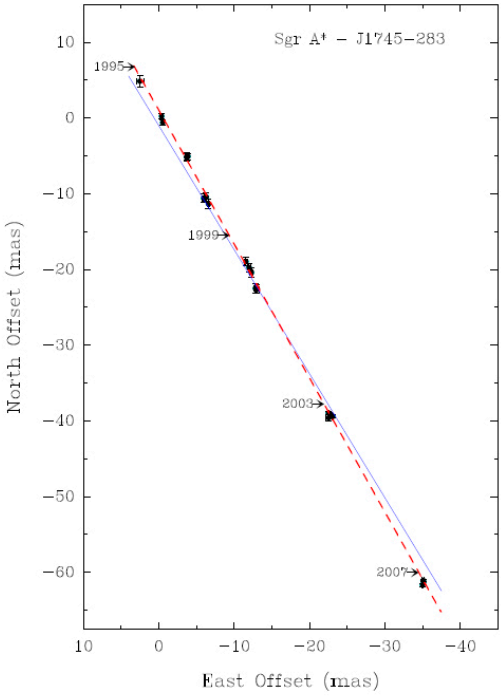
0-4`

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

Gravitational Deflection by Axis Symmetric Mass Distribution

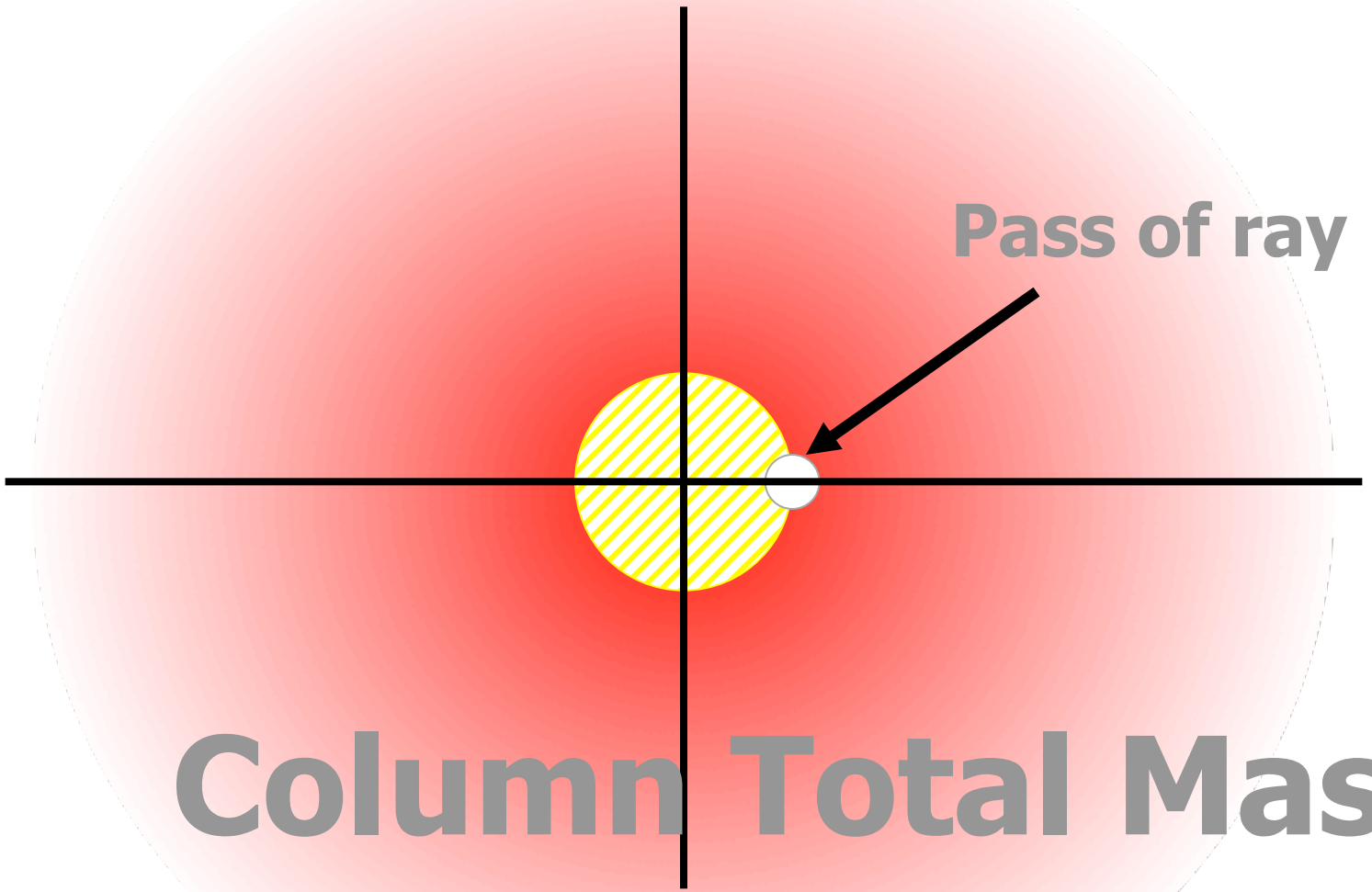
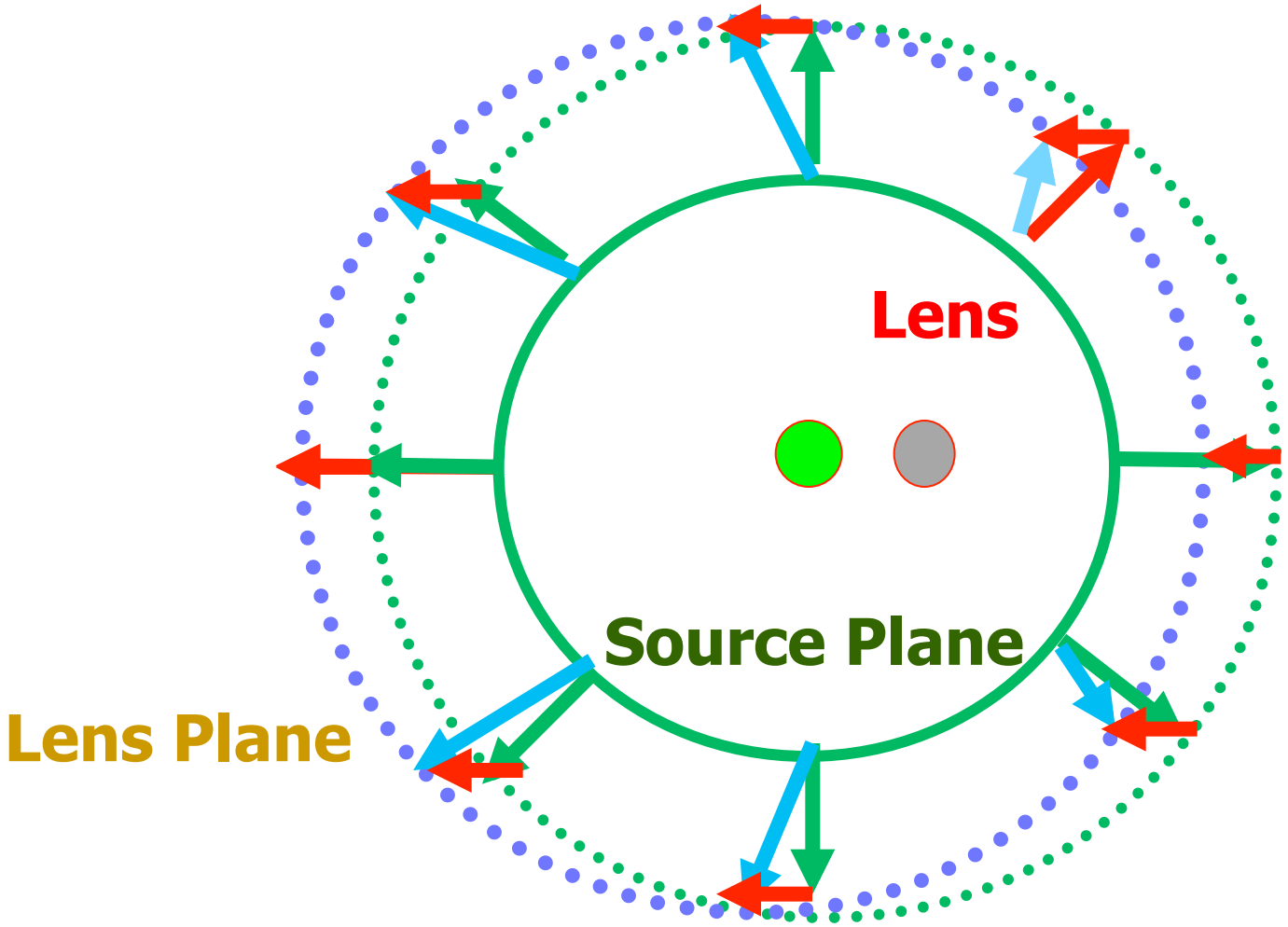


Illustration of Shift by Bulge Motion



Adopted Galactic Model

Alexander & Sternberg (1999)

Core+Bulge+Disk

Characteristic Length Scale

Core	Bulge	disk
0.38pc	667pc	3kpc

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

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

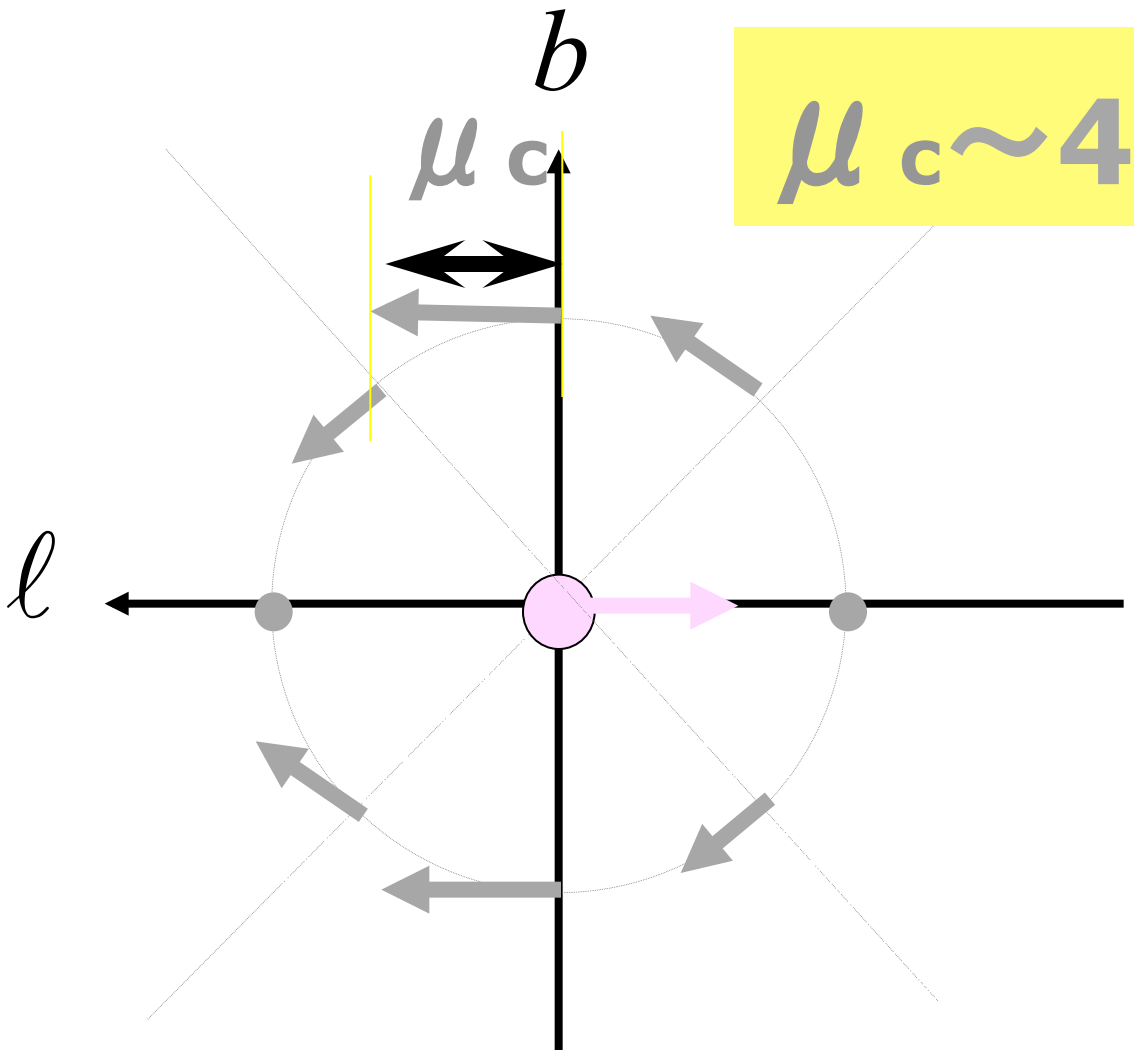
$$r_c = 0.38\, pc$$

$$\rho_{bulge} = 3.53 K_0(\tfrac{r}{r_b}),$$

$$r_b = 3000\, pc$$

Disk contribution is negligible

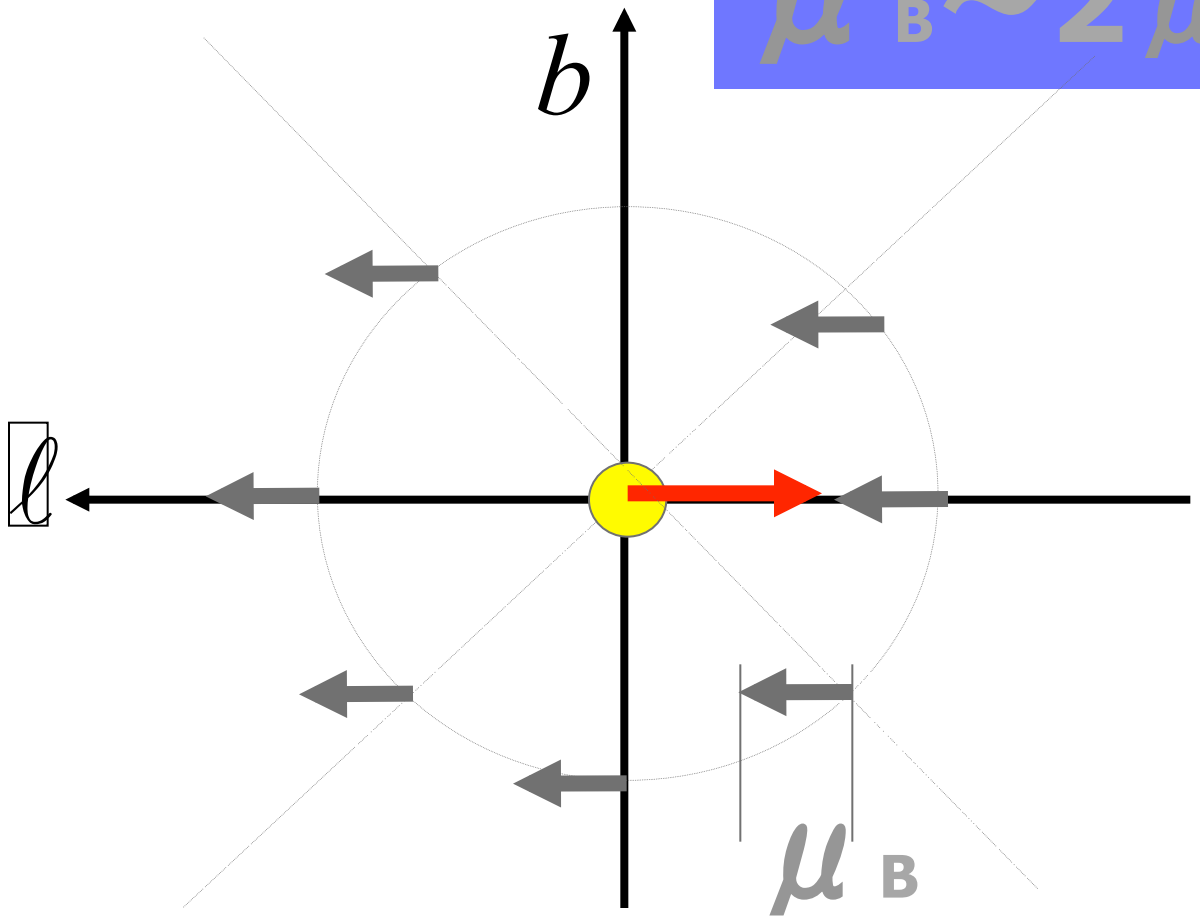
Effect of Core Motion



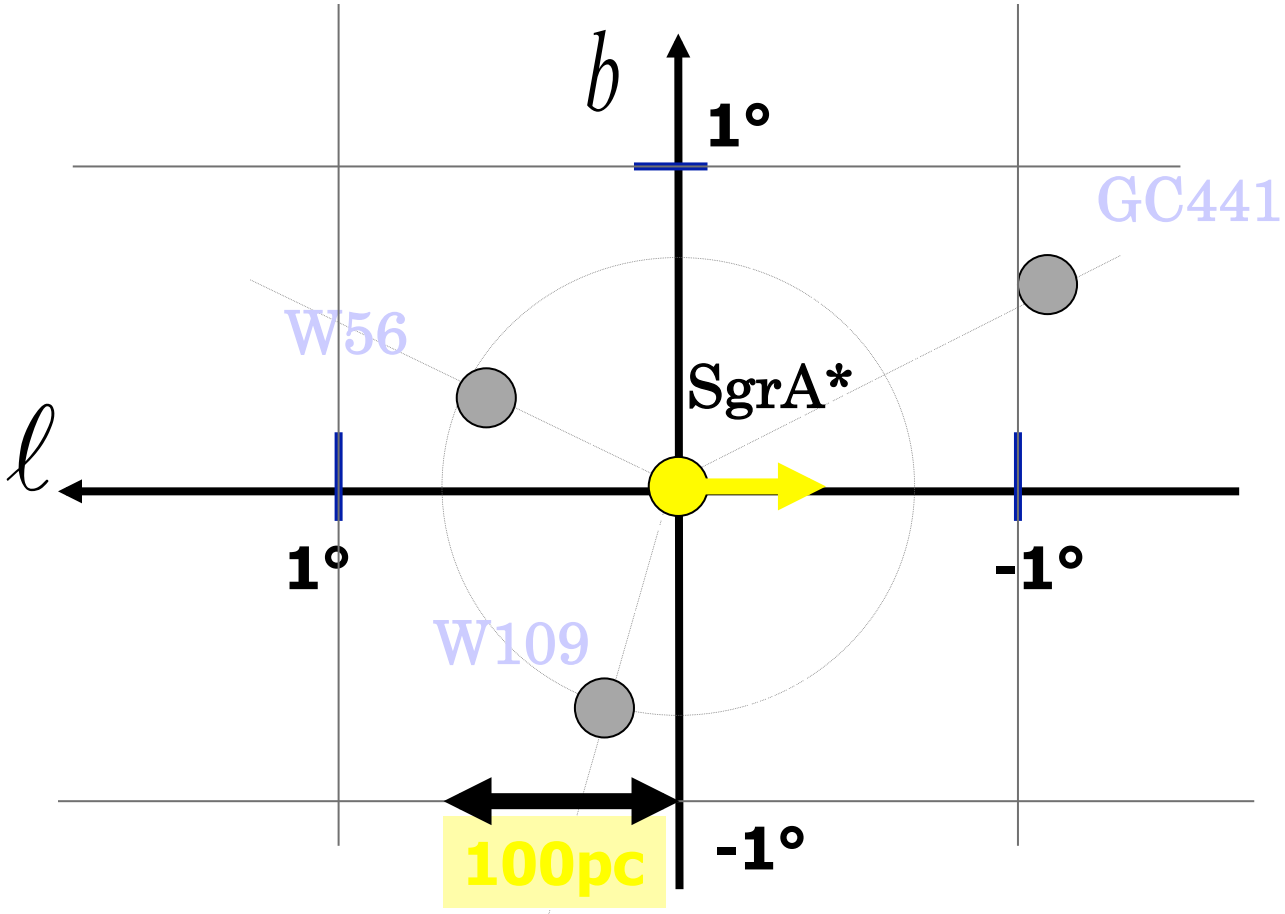
$\mu_c \sim 4\,\mu\mathrm{as/10yr}$

Effect of Bulge Motion

$\mu_B \sim 2\,\mu as/10yr$



3 Motion of SgrA* referred to QSOs



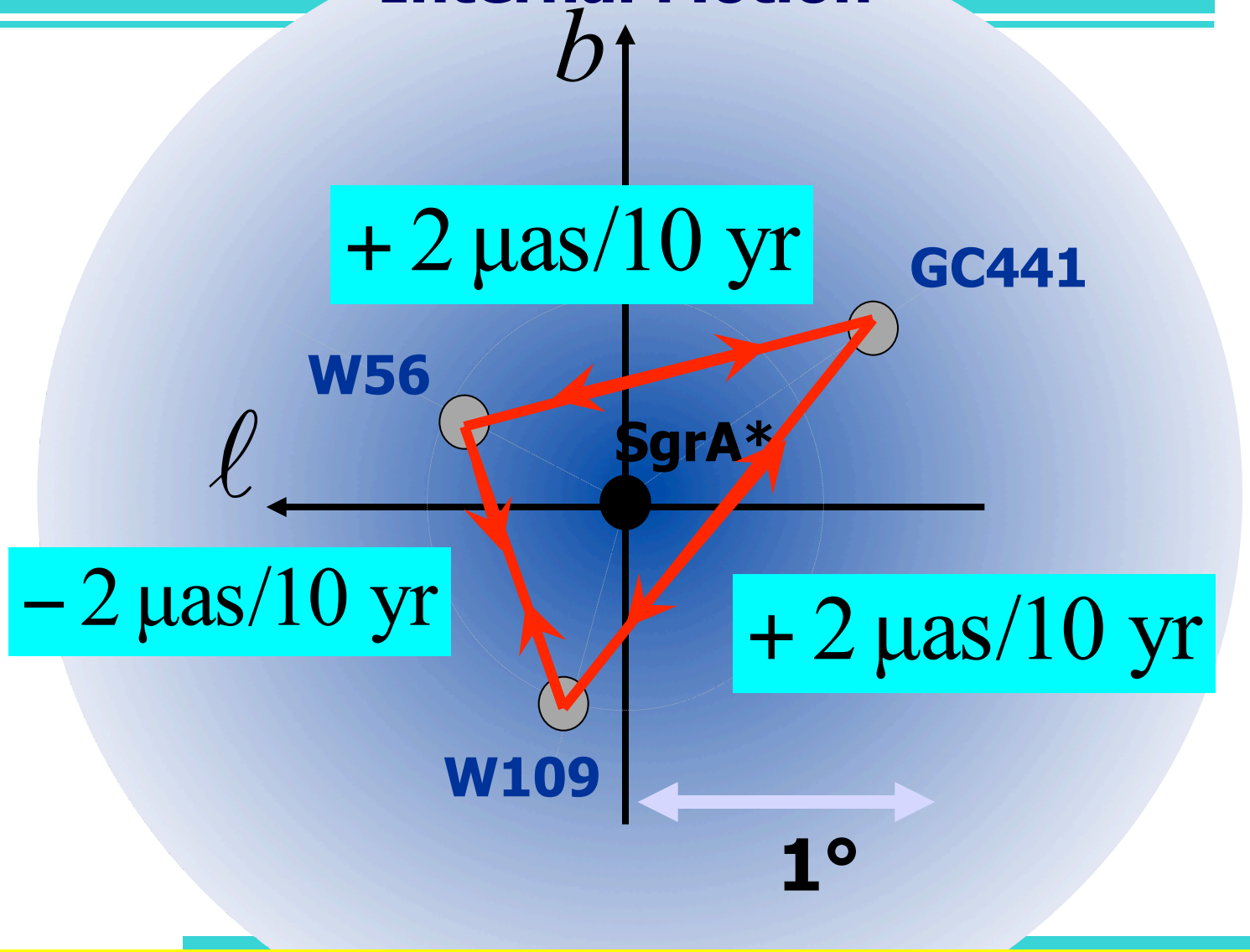
$$6\,\mathrm{mas/yr} = \frac{220\,\mathrm{km/s}}{8\,\mathrm{kpc}}$$

← Galactic Rotation

6. Lensing toward Galactic Center V

6-6

Internal Motion



コメント：Sgr A*近傍にQSOが見つかると、非常に楽しい。

Parameter Dependence

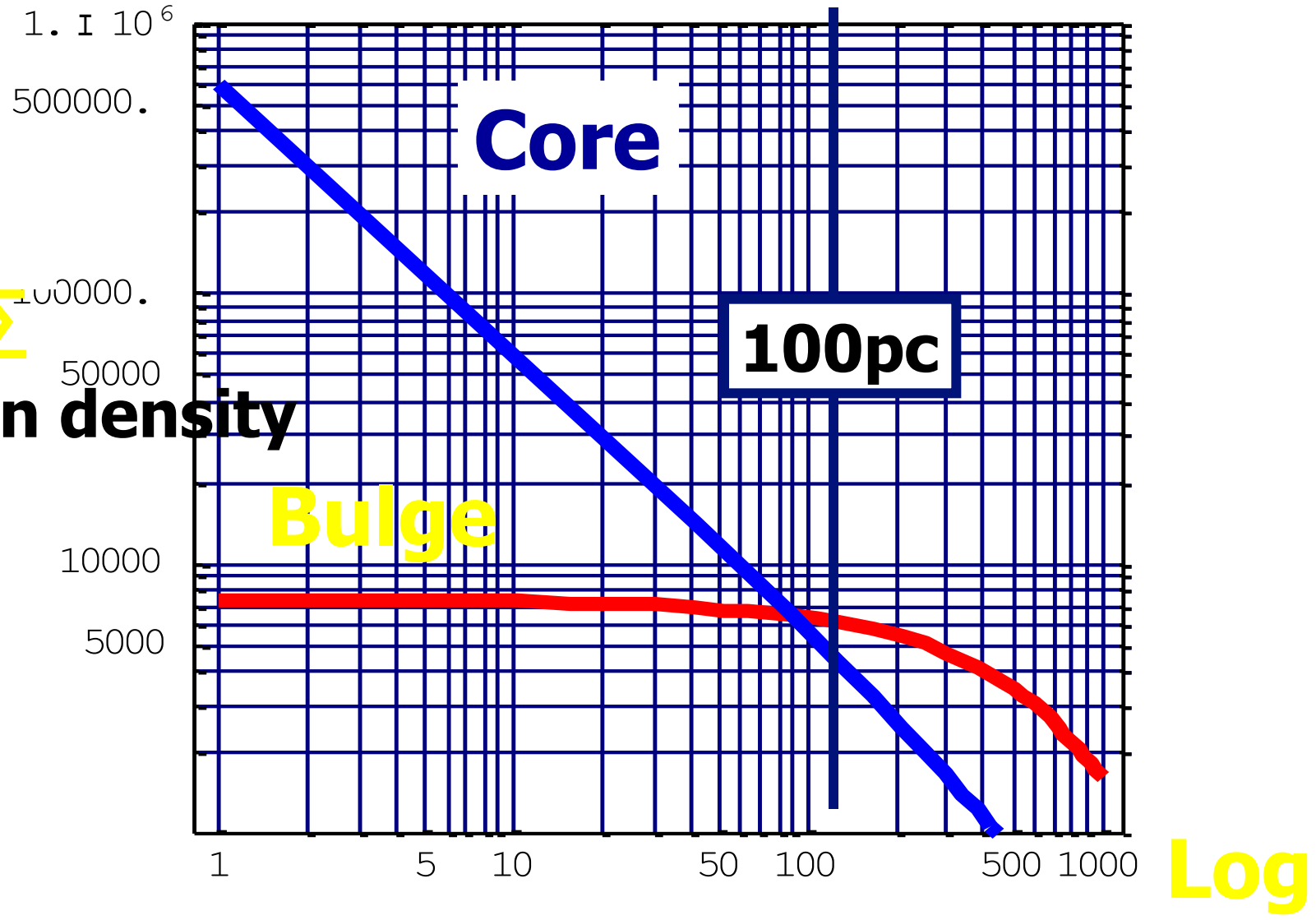
Effect of Core Motion

$$\mu_c = 4\mu\text{as/10yr}\left(\frac{L}{100\text{pc}}\right)^{-1}\left(\frac{\rho_c}{4\times10^6\,\text{M}_{\text{sun}}/\text{pc}^3}\right)\left(\frac{a}{0.38\text{pc}}\right)^{2}\left(\frac{V}{220\text{km/s}}\right)$$

Effect of Bulge Motion

$$\mu_B = 2\mu\text{as/10yr}\left(\frac{\Sigma_0}{6\times10^6\,\text{Msun/pc}^2}\right)\left(\frac{V}{220\text{km/s}}\right)$$

Column Density of Core and Bulge



Msun/
pc^2

Log Σ

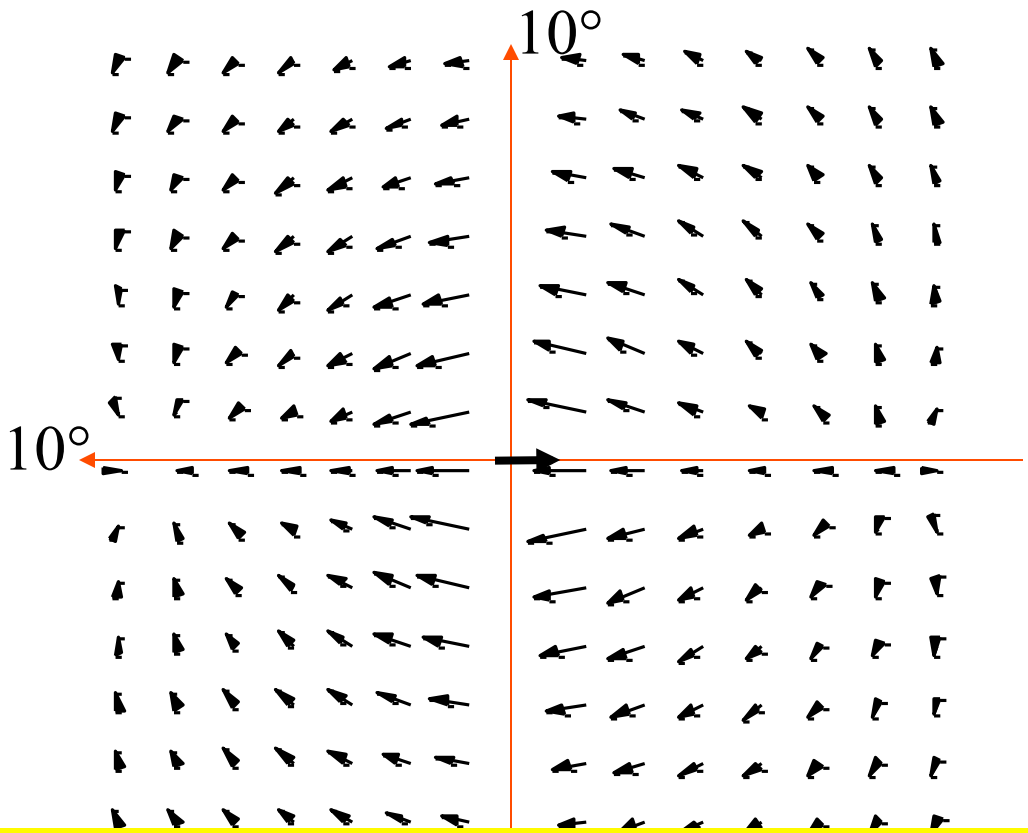
Column density

Log (Impact parameter [pc])

6. Lensing toward Galactic Center V

6-4

Total Effect



0.7°=100pc

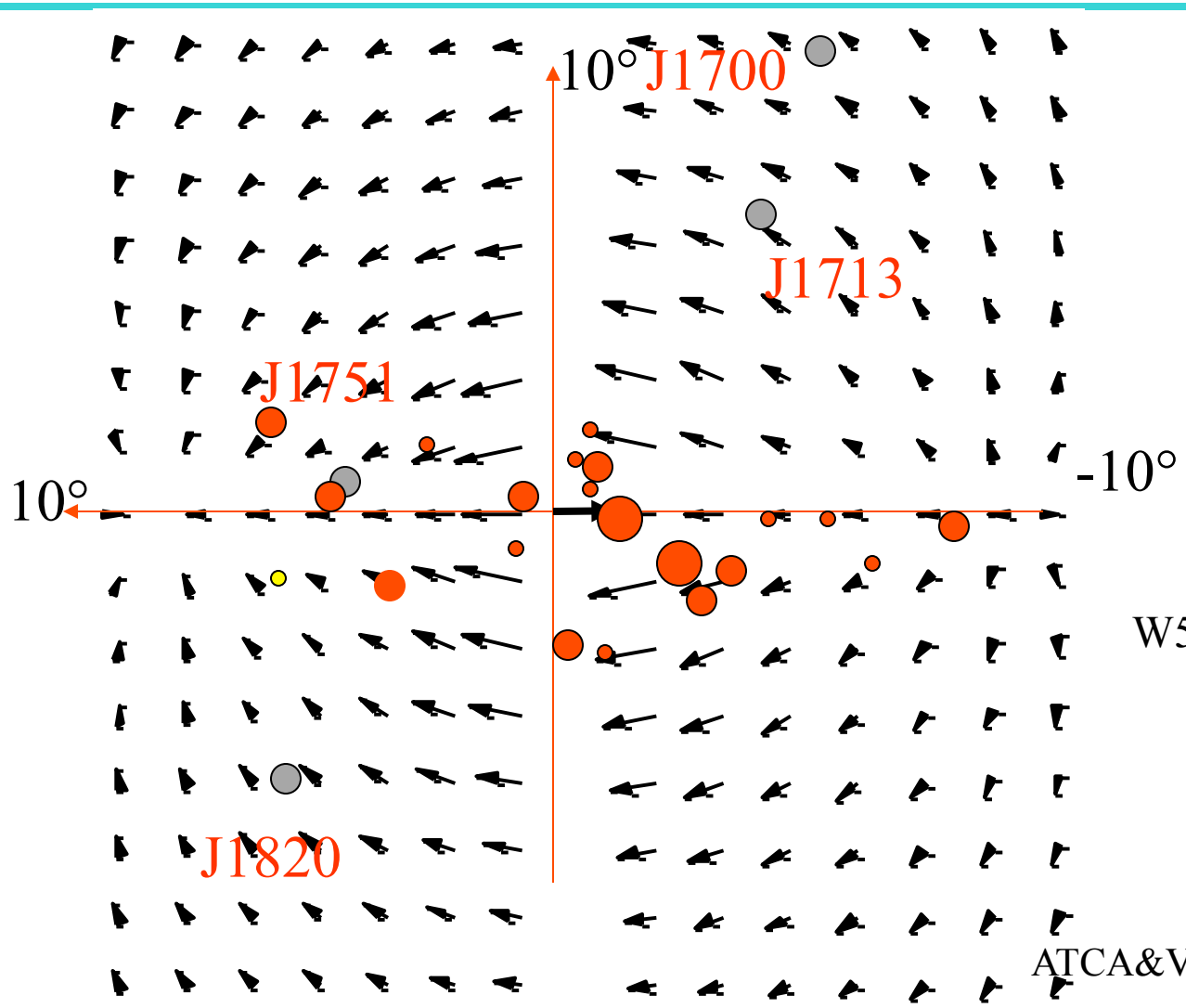
$$\mu_c = 2\mu as/10yr\left(\frac{L}{100pc}\right)\left(\frac{\rho_c}{4\times10^6 M_{sun}/pc^3}\right)\left(\frac{a}{0.38pc}\right)^2\left(\frac{V}{220km/s}\right)$$

$$\mu_B = 2\mu as/10yr\left(\frac{\Sigma(100pc)}{6\times10^6 M_{sun}/pc^2}\right)$$

6. Lensing toward Galactic Center V

6-5

Total Effect



W56 79mJ@5GHz

ATCA&VLA, 5GHz,8GHz

Roy, Rao & Subrahmanyan (2006)

Apparent Motion

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

7. Summery

7-1 銀河系中心方向の重力レンズ効果

1. マイクロレンズ効果・・・・MOA Project

➔Dark matter, 系外惑星探査

2. SgrA*近傍の星質量BH,中性子星、・・によるレンズ。

➔ SgrA*のDark matterの量、・・・

3.銀河系内の星によるAstrometric microlensingでQSO基準座標系が揺らぐ➔意外と高いOptical Depth

4. SgrA*による弱重力近似のレンズ

5. SgrA*による強重力場近似のレンズ

6. 銀河系によるマクロな重力レンズ

Photo by Kouji Ohnishi