JD7P011

Fluctuation of Extragalactic Reference Frame Due to Gravitational Lensing

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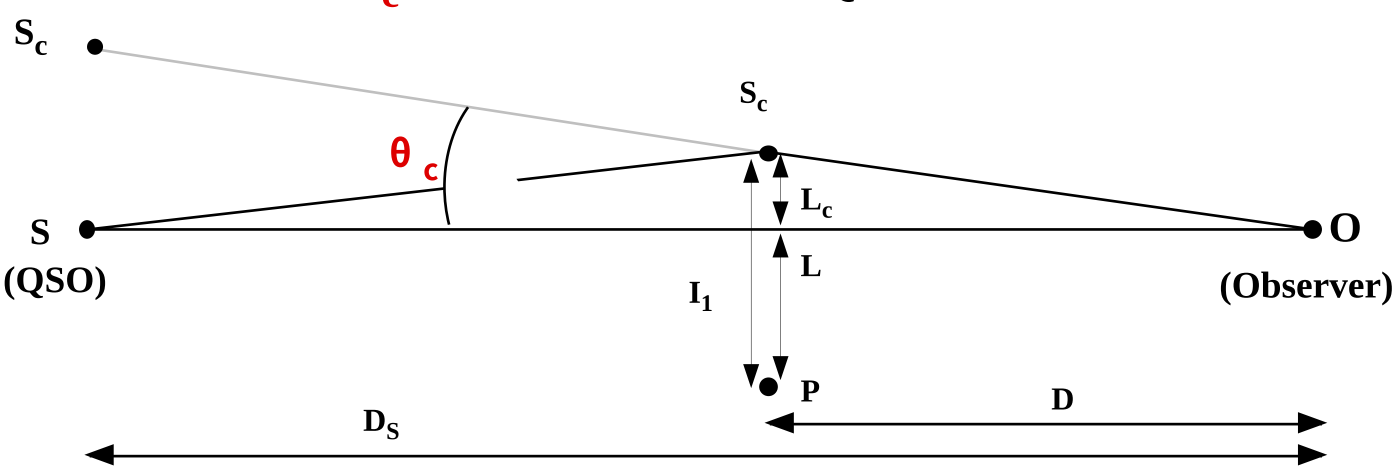
Observation of QSOs through our galaxy

Observed position of QSOs are shifted,
apparent proper motion of QSOs are induced
due to gravitational lensing of the matters in our galaxy.

θ_c : Positional Shift of QSO due to GL



$\theta_c = mL/(L^2 + 2mD)$: Angular Shift of Light Centroid

where $m \equiv 4GM/c^2$

Our Model

1. Disk Star (1 M_{sun} , Exponential Disk model)

$$\rho_{\rm D}(x,y,z) = \frac{\Sigma_{\rm D}}{2z_{\rm D}} \exp\left[-\left(\frac{\sqrt{x^2+y^2}-R_0}{R_{\rm D}}\right) - \left(\frac{z}{z_{\rm D}}\right)\right]$$

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

R_0 = 8.5 kpc^2 ： Distance Galactic Center

z_h = 300 pc ： Disk Thickness

v_0 = 220 km/s ： flat rotaition curve

2. MACHO (0.1 M_{sun} , Isothermal model)

$$\rho_{\rm M} = \rho_0 \frac{a^2+R_0^2}{a^2+R^2}$$

a ： Core Radius of MACHO , 2000 pc

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

v = 180 km/s ： Random Direction

We cannot see QSO beyond bulge.

Expectation Values of QSO positional Shift

Root Mean Square of positional shift θ_c

$$\left\langle \theta_c^2 \right\rangle = \int n(m,\mathbf{r})\{\theta_c(m,L)\}^2\, dm\, dV$$

$$= \sum_{i={\rm D,M}} \int\int 2\pi\rho_i(D)\frac{L^3 m_i}{(L^2+2m_iD)^2} dL\, dD$$

∝ Mass × Density

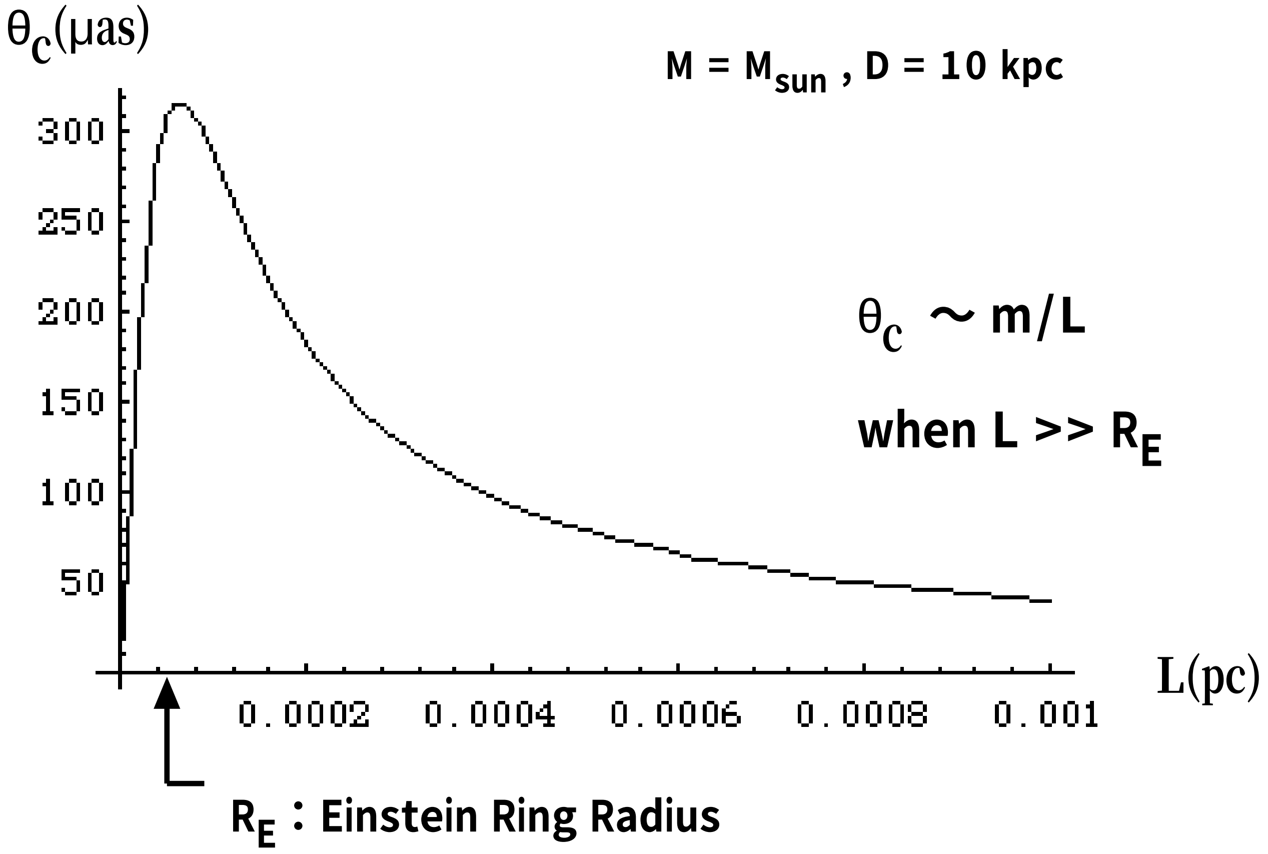
where $n_{\rm D} = \frac{\rho_{\rm D}}{m_{\rm D}}\delta(m_{\rm D})$, $n_{\rm M} = \frac{\rho_{\rm M}}{m_{\rm M}}\delta(m_{\rm M})$

Results of numerical calculation

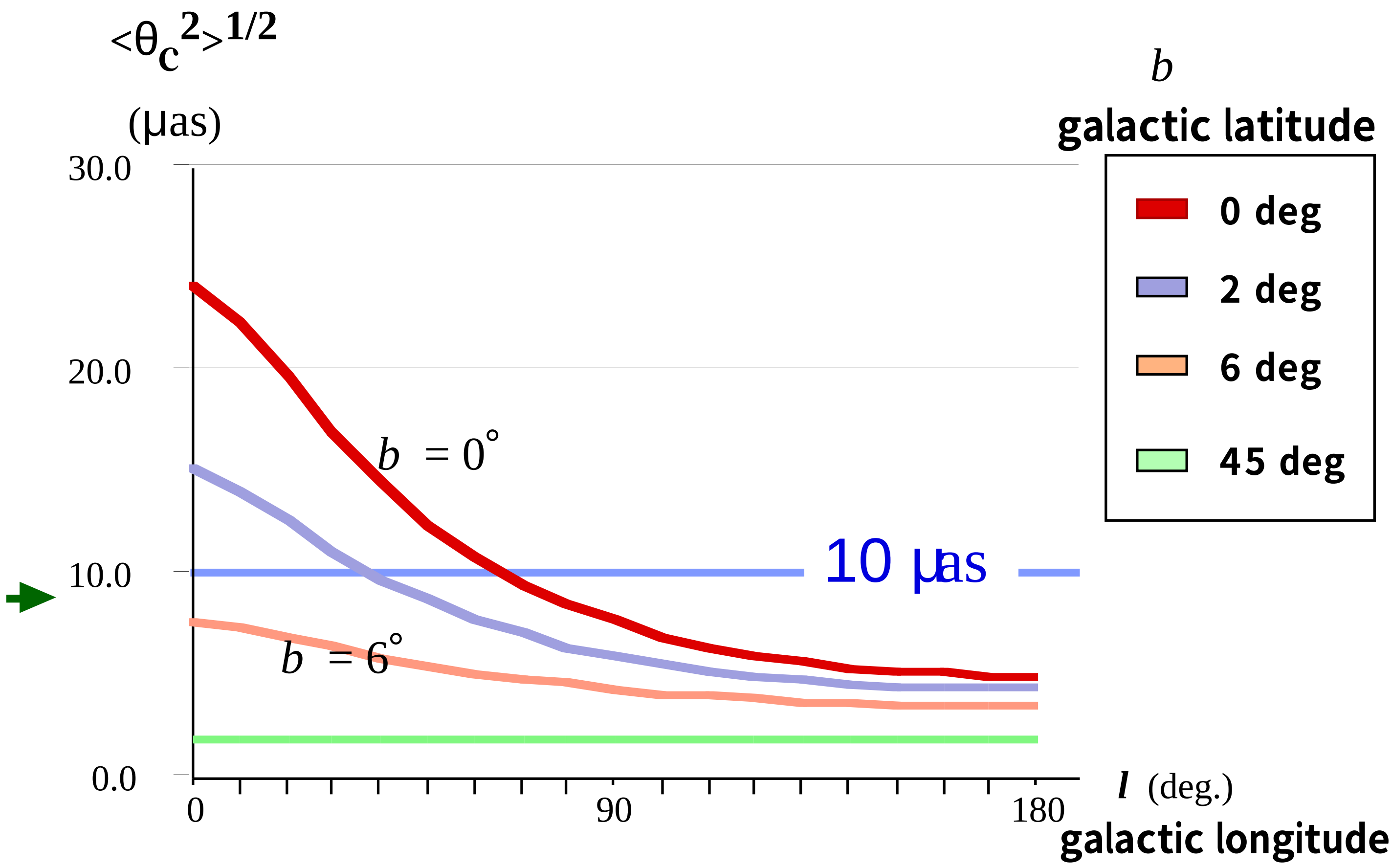
Due to disk stars, mainly.

MACHOs' contribution ：very small (under 0.1 M_{sun} assumption)

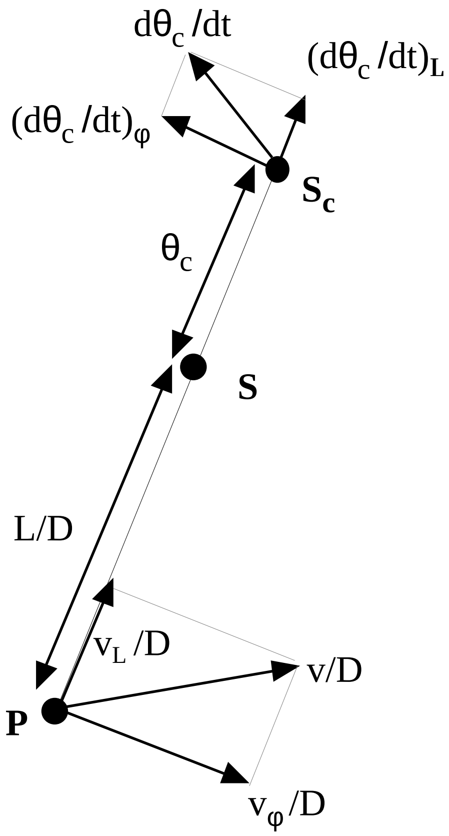
Impact parameter vs. Positional Shift of QSOs



Expectation Values of Positional Shifts of QSOs



Proper motion of Lensing Matter will induce the apparent proper motions of QSOs



$$\left\langle \left(\frac{d\theta_c}{dt}\right)^2 \right\rangle = \int n(m,\mathbf{r}) \left(\frac{d\theta_c}{dt}\right)^2 dm\, dV$$

$$= \sum_{i=\mathrm{D,M}} \frac{\pi m_i}{3} \int_{D_{\min}}^{\infty} \frac{n_i \langle {v_i}^2 \rangle}{D}\, dD$$

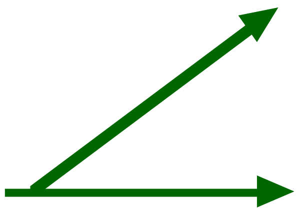
$\propto$ **Density**

Motion of the Images seen from Observer

Disk stars：Flat rotation

MACHOs：random transversal velocity

Results **of the numerical calculations**



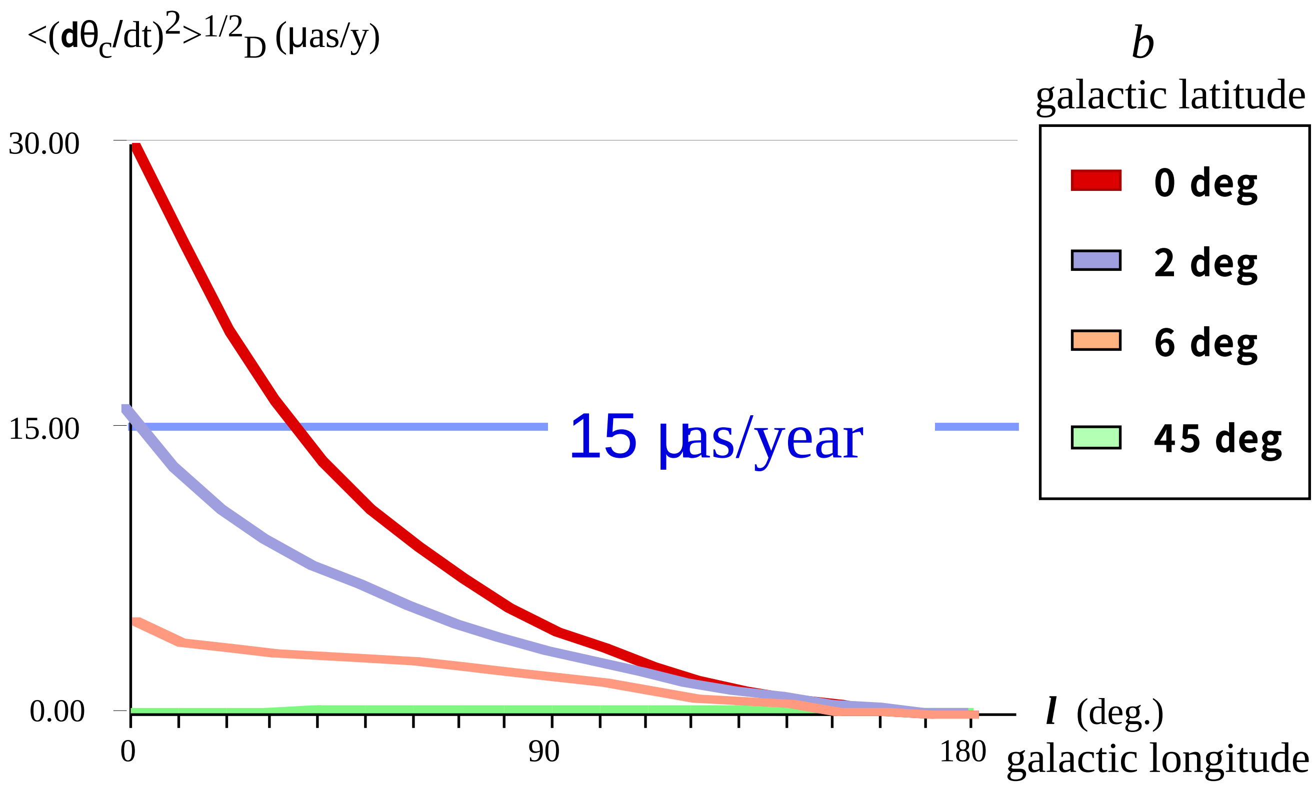
Positional Shifts due to GL ∝ Mass × Density

MACHOs' contribution is small

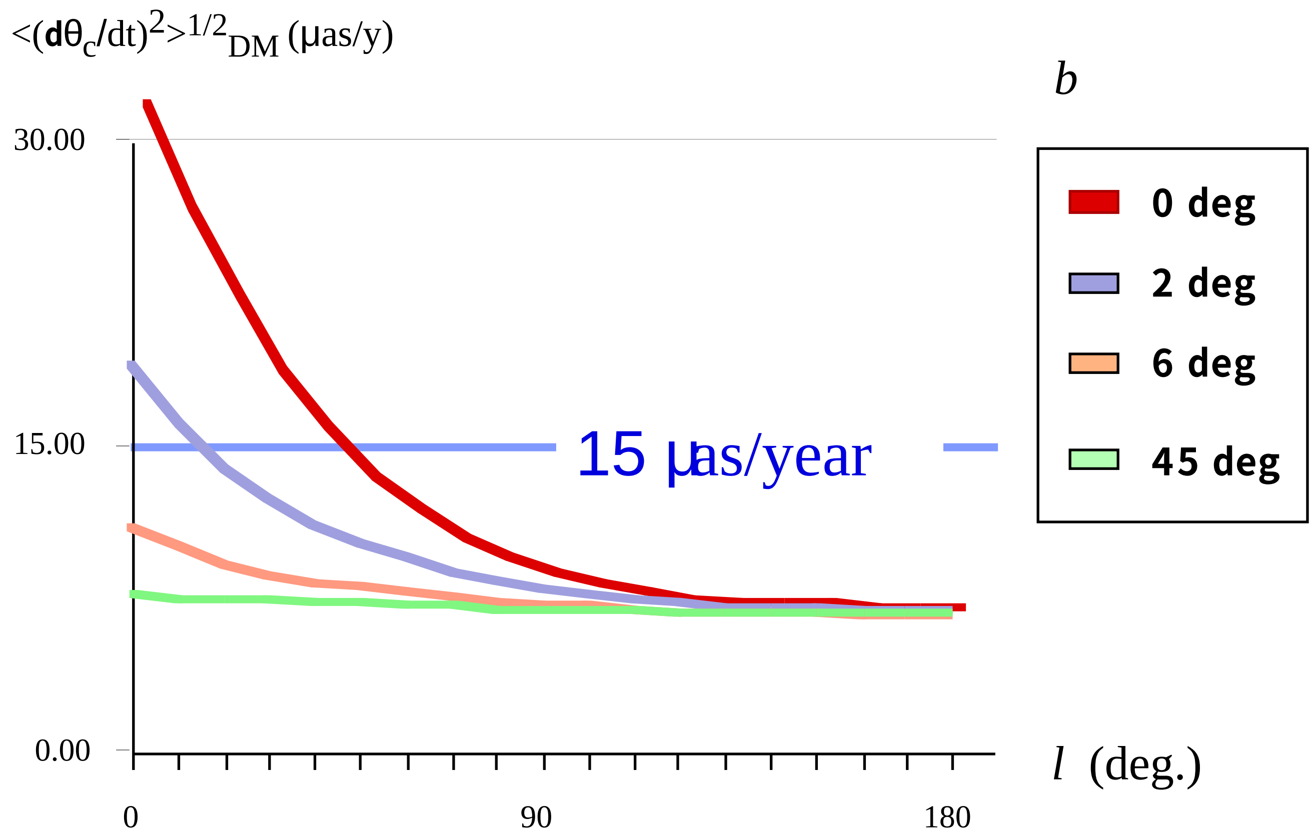
Induced Proper Motion ∝ Density

MACHOs' contribution is NOT so small (***if exist !*** **)**

Expectation Values of Induced Proper Motion of QSOs



Due to Disk Stars



Due to Disk Stars and MACHOs

Optical depths

Distribution of Pos. Shift and Induced Prop. Motion

→ Far from Gaussian

Optical depths are also useful and important

$\sigma_{\mathrm{pos},\ i}(\theta_c)$ **: Optical depth for positional shift grater than θ_c**

$\sigma_{\mathrm{mot},\ i}\left(\frac{d\theta_c}{dt}\right)$ **: that for induced proper motion grater than $d\theta_c/dt$**

Scaling laws

$\theta_c \sim m/L$ and $d\theta_c/dt \sim mv/L^2$

when $L >> R_E$

$$\sigma_{\mathrm{pos},\ i}(k\theta_c) = \frac{\sigma_{\mathrm{pos},\ i}(\theta_c)}{k^2}$$

Accuracy ×2 → Opt. depth ×4

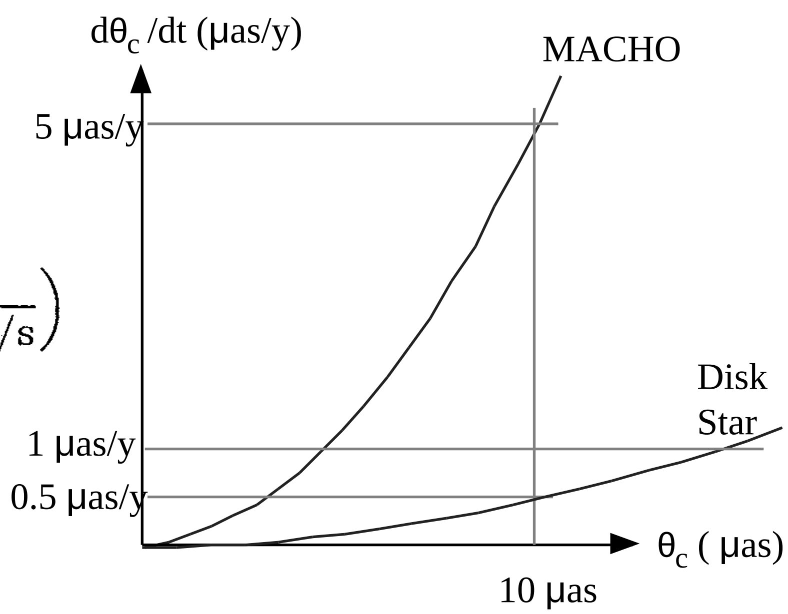
$$\sigma_{\mathrm{mot},\ i}\left(k\frac{d\theta_c}{dt}\right) = \frac{\sigma_{\mathrm{mot},\ i}(d\theta_c/dt)}{k}$$

Accuracy ×2 → Opt. depth ×2

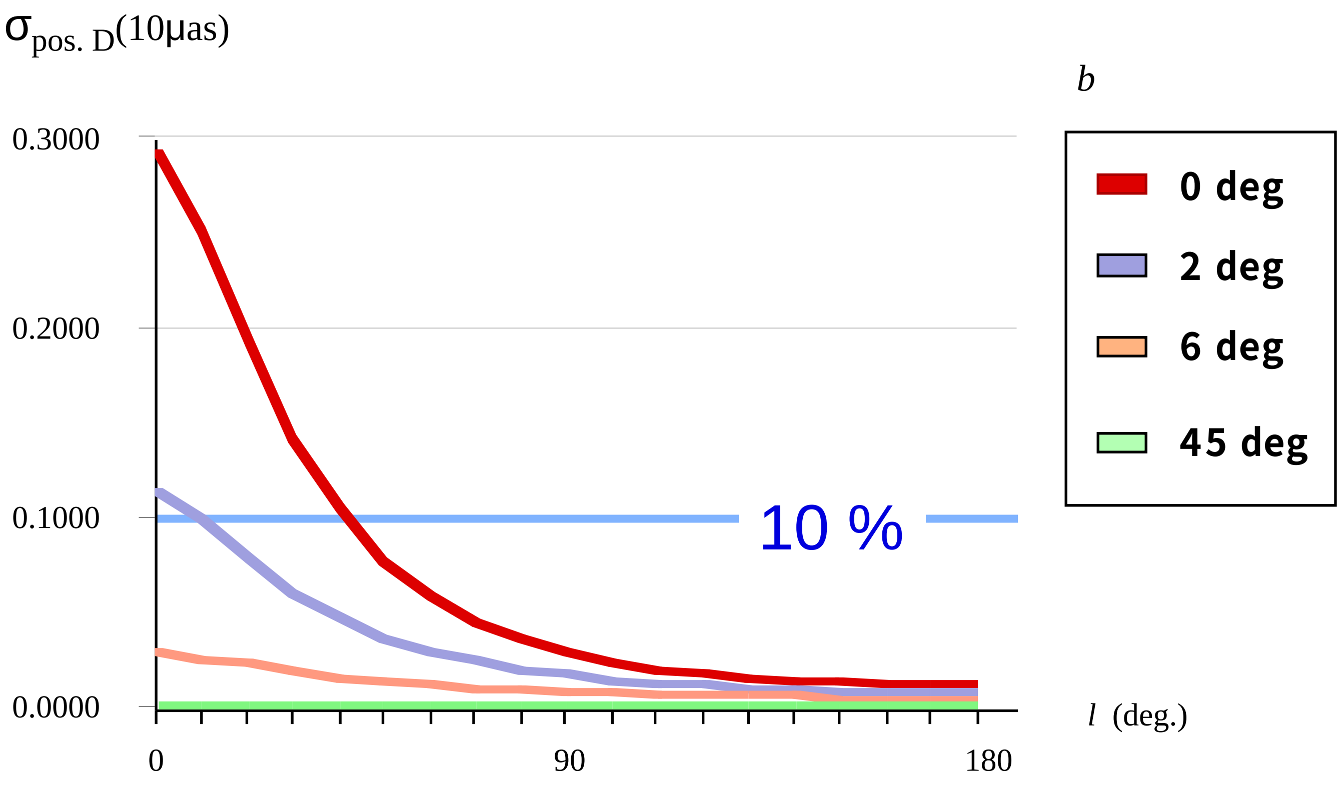
Relation between

θ_c (μas) and $\frac{d\theta_c}{dt}$ (μas/y)

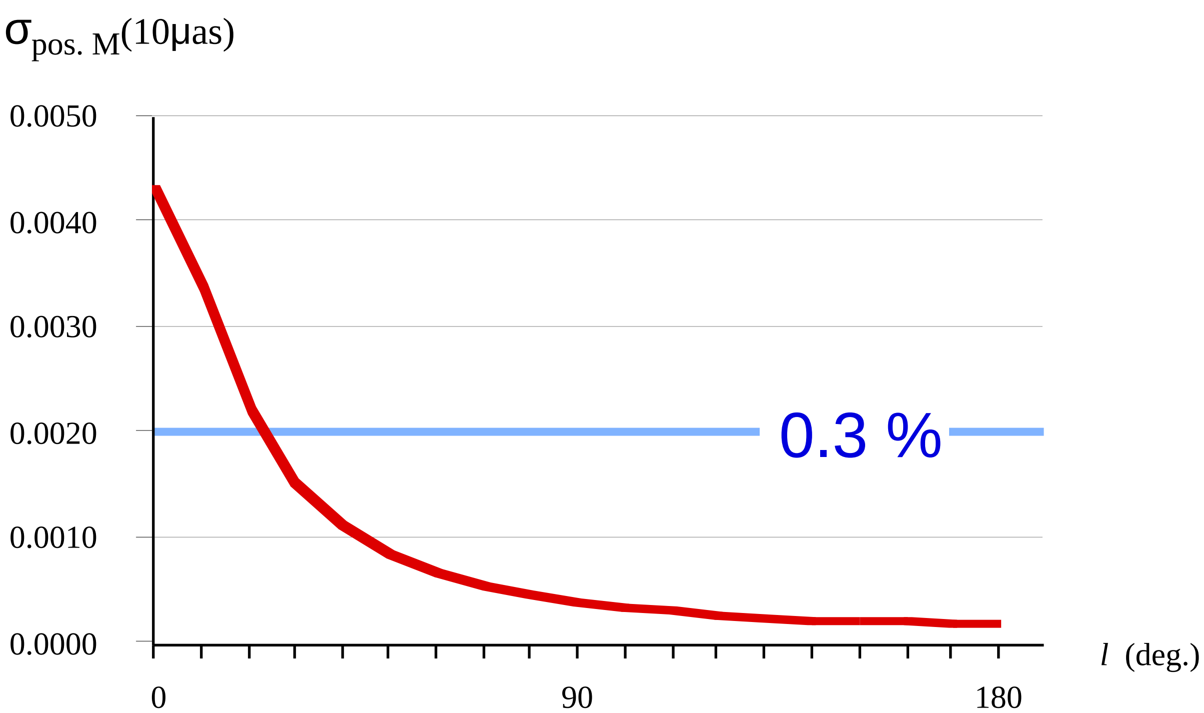
$$\frac{d\theta_c}{dt} = 0.005\ \theta_c^2\left(\frac{1M_{\mathrm{sun}}}{M}\right)\left(\frac{\langle v\rangle}{180\mathrm{km/s}}\right)$$



Optical depth (10 μas Positional Shift)

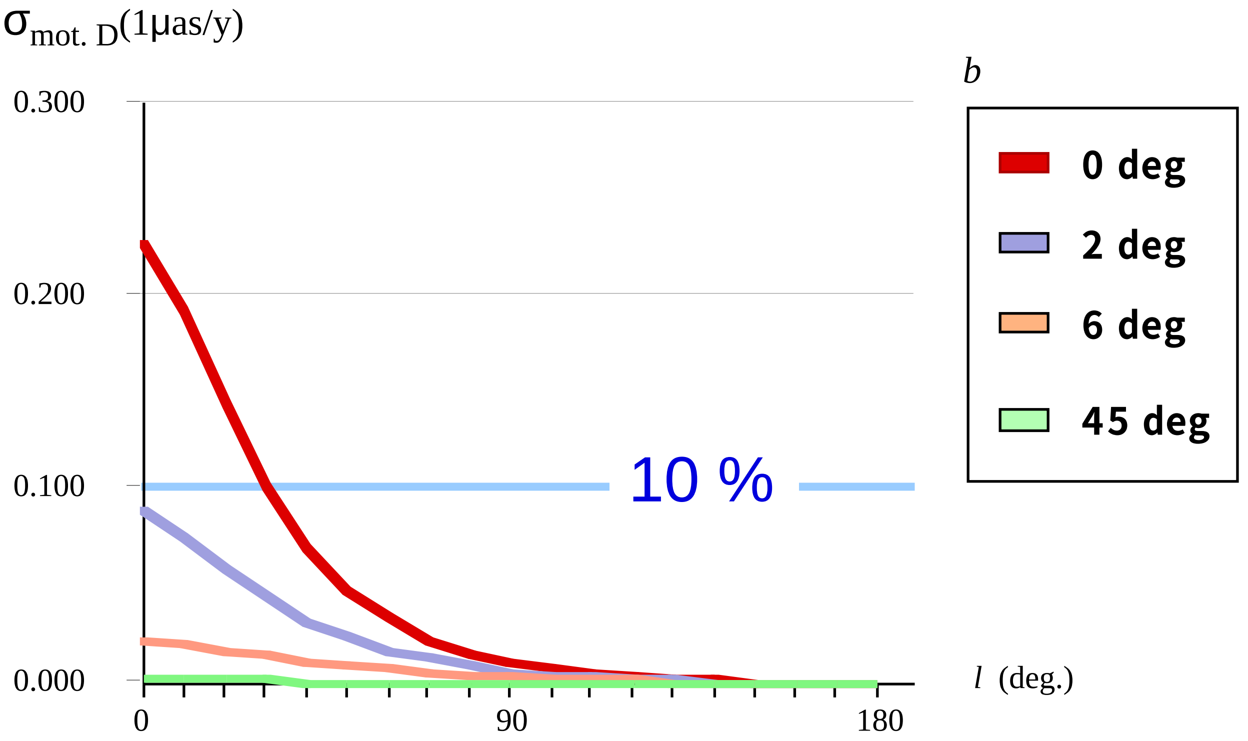


Due to Disk Stars

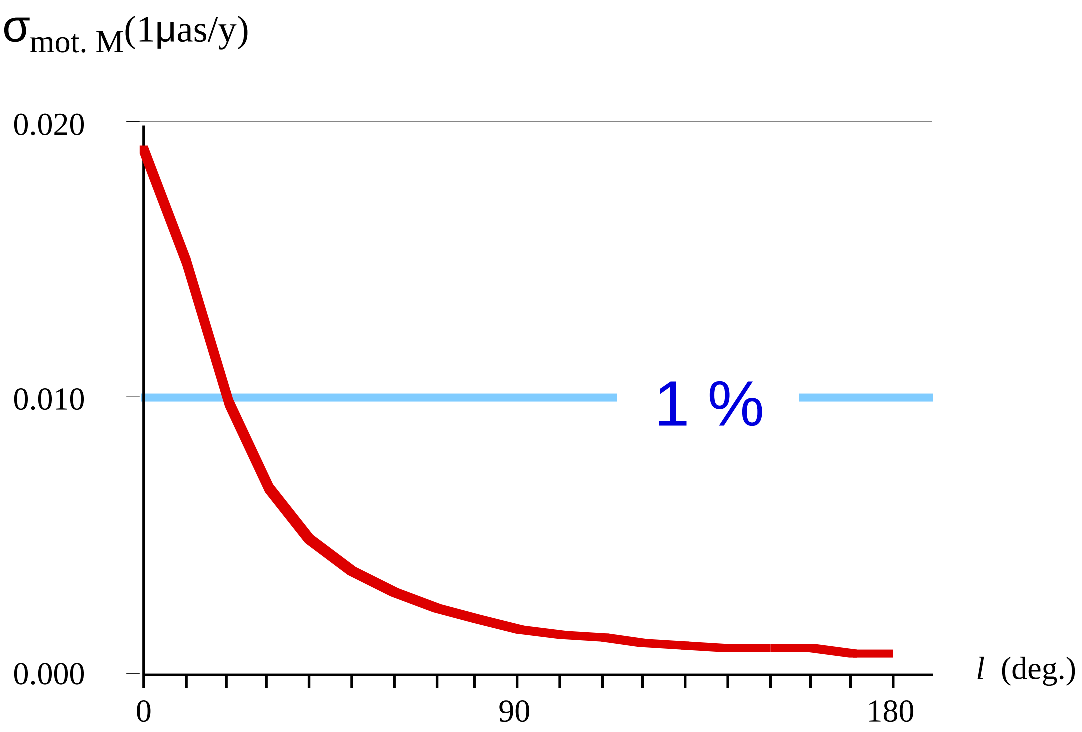


Due to MACHOs

Optical depth (1 μas/year Induced Proper Motion)



Due to Disk Stars



Due to MACHOs

Discussions and Summary

Accuracy limit of Extragalactic Reference Frame

when the optical depths $\geq$ 1,
almost all positions of QSOs are fluctuated,
affected by multiple sources

Scaling laws tell us that σ_{pos}(1 μas) and σ_{mot}(0.1 μas/y) $\geq$ 1
in the vast region of the celestial sphere

→ Difficulty in finding an reference frame
covering the entire celestial sphere

The AGING of Reference Frame will be observed

when the QSOs' positions are measured
with the accuracy of *10 μas*,

New Way to prove the structure of

Disk Stars and Galactic Dark Matter

See the paper (Astron.J. Vol. 114. No.4 October '97)

on the detail of the calculation, MACHOs' core parameter,
effects of the Orbital Motion of Earth, and

See the poster in S183(Ohnishi, Hosokawa and Fukushima)

MACHOs detection and MACHOs' core parameter