Influence of the Galactic gravitational field on the positional accuracy of reference sources of ICRF

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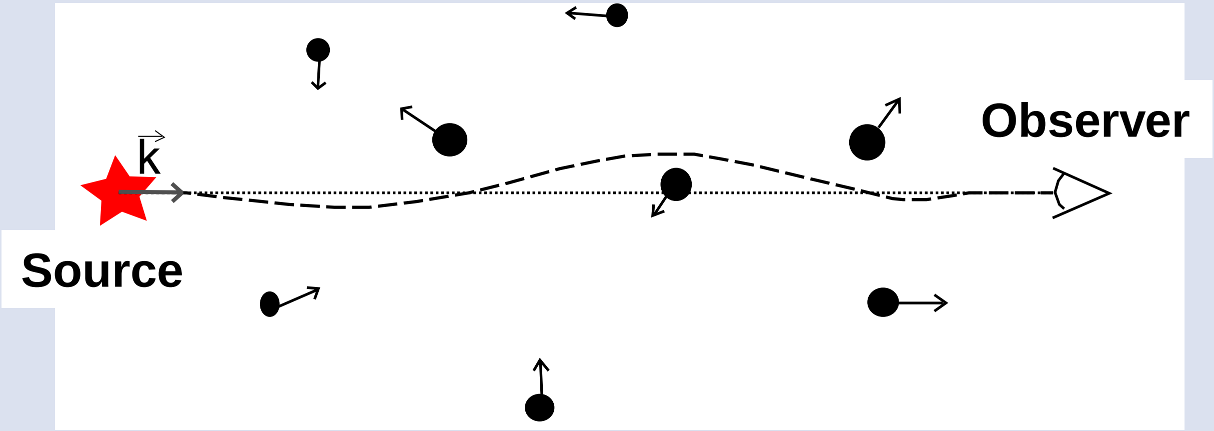
We consider an influence of the non-stationary gravitational field of the Galaxy on the apparent positions of extragalactic sources, including reference sources of the International Celestial Reference Frame (ICRF).

A contribution of the galactic baryonic matter including the hidden component in the form of brown dwarfs is taken into account. As a result we obtain a 2D distribution of the standard deviation of the angular shifts in positions of ICFR sources with respect to their true positions.

For different matter density distributions in the Galaxy we show that in the direction to the Galactic center the standard deviation of the offset angle can reach several tens of microarcseconds, decreasing down to 2-3 μas at high galactic latitudes.

The obtained results place physical limits on the accuracy of absolute astrometric measurements and can be important for highly precise navigation measurements as well as for space missions, like a Gaia, Millimetron, etc.

The light propagation in the gravitational field of the arbitrarily moving system of N point-like bodies with different masses



The deflection angle in the gravitational field of the arbitrarily moving system bodies is a random function of the time, coordinates and velocities of these bodies.

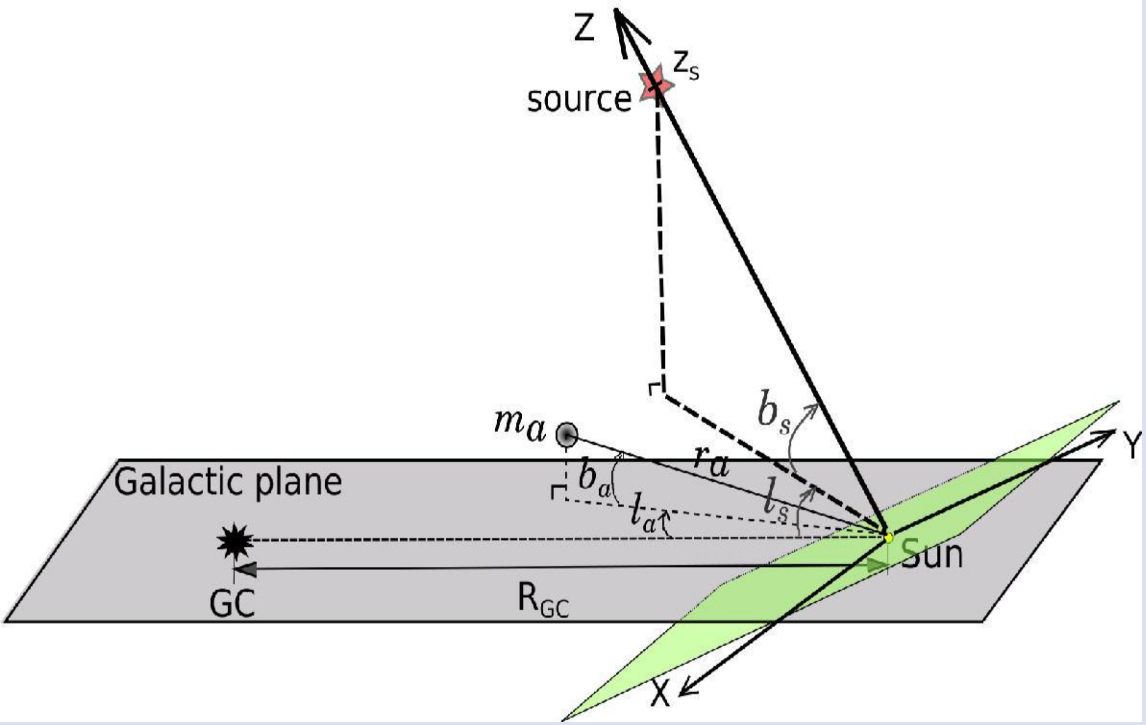
$$\alpha_a^i(t) = \frac{4Gm_a}{c^2} \frac{1 - \vec{k}\vec{v}_a / c}{\sqrt{1 - \vec{v}_a^2 / c^2}} \frac{P_j^i r_a^j}{\left|P_j^i r_a^j\right|^2}$$

$$v_a = const$$

$$\vec{r}_a = \vec{x}(t) - \vec{x}_a$$

$$P_{ij} = \delta_{ij} - k_i k_j$$

(Kopeikin, Schafer 1999)



Function $\alpha(t, m_a, \vec{x}_a, \vec{v}_a)$ describes realizations of the random stochastic process of the light ray deflection in the Galaxy.

$\langle \alpha \rangle = const$, therefore the considered random process is stationary.

$$\sqrt{\langle \alpha^2 \rangle} = \sqrt{\int dm_a d\vec{x}_a d\vec{v}_a \, f(m_a, \vec{x}_a, \vec{v}_a) \alpha^2 (m_a, \vec{x}_a, \vec{v}_a)}$$

$$\Re(\tau) = \int dm_a d\vec{x}_a d\vec{v}_a \, f(m_a, \vec{x}_a, \vec{v}_a) \alpha \, (t, m_a, \vec{x}_a, \vec{v}_a) \alpha \, (t + \tau, m_a, \vec{x}_a, \vec{v}_a)$$

$$f(m_a, \vec{x}_a, \vec{v}_a) = Af(m_a) f(\vec{x}_a) f(\vec{v}_a)$$

$$S(\omega) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \exp(-i\omega\tau) \Re(\tau) d\tau$$

Key assumptions:

1. A velocity distribution is a truncated Maxwellian function

2. A present day mass function for different galactic components

Disk
(brown dwarfs included)

Bulge (m<1 M_{sun})

$$\xi_{PDMF}(m) = k\frac{1}{\log M_s pc^3}\begin{cases} 0.158m^0, 0.01 \le m < 0.08 \\ 0.158\exp\left[-\frac{\left(\log\left(\frac{m}{0.079}\right)\right)^2}{0.9577}\right], 0.08 \le m < 1.0 \\ 0.044m^{-4.37}, 1.0 \le m < 3.47 \\ 0.015m^{-3.53}, 3.47 \le m < 18.2 \\ 0.00025m^{-2.11}, 18.2 \le m < 63 \end{cases}$$

Halo

$$\xi_{PDMF}(m) = k \cdot 0.004 \cdot \left(\frac{m}{0.1M_s}\right)^{-1.7}, 0.01 \le m < 0.8$$

3. A space distribution:
   1) a multicomponent model of the Galaxy *(Dehnen & Binney 1998)*
   2) a multicomponent model of the Galaxy *(Bahcall & Soneira 1980)*

Galaxy model BS

Disk:

$$\rho_d(x,z) = \rho_{0,d} \exp\left(-\frac{x - R_{GC}}{3.5kpc} - \frac{|z|}{z_d} \right)$$

$\rho_{0,d} = 0.04 \frac{M_s}{pc^3}$ $\quad z_d = 0.125kpc$

Bulge:

$$\rho_b = \rho_{0,b} \left(\frac{r}{1kpc} \right)^{-1.8} \exp\left(-\frac{r}{1kpc} \right)^3$$

$\rho_{0,b} = 3 \frac{M_s}{pc^3}$ $\quad R_{GC} = 8kpc$

Spheroid:

$$\rho_{sph}(r) = \rho_{0,sph} \exp\left(-b \left(\frac{r}{2.8kpc} \right)^{1/4} \right) \Big/ \left(\frac{r}{2.8kpc} \right)^{7/8}$$

$\rho_{0,sph,l} = \frac{1}{500} \rho_{0,d}$ $\quad b = 7.669$

Halo:

$$\rho_h(r) = \rho_{0,h} \frac{a^2 + R_{GC}^2}{a^2 + r^2}$$

$\rho_{0,h} = 0.010 \frac{M_s}{pc^3}$ $\quad a = 2kpc$

Galaxy model DB

Disk

$$\rho_d(R,z) = \frac{\Sigma_d}{2z_d} \exp\left(-\frac{R_m}{R} - \frac{R}{R_d} - \frac{|z|}{z_d} \right)$$

$R_d = 2.4kpc$ $\quad z_{d(thin\_d)} = 180pc$ $\quad z_{d(thick\_d)} = 1kpc$

Bulge:

$$\rho_b = \rho_{0,b} \left(\sqrt{R^2 + \frac{z^2}{q^2}} \Big/ 1.0kpc \right)^{-1.8} \exp\left(-\left(R^2 + \frac{z^2}{q^2} \right) \Big/ (1.9kpc)^2 \right)$$

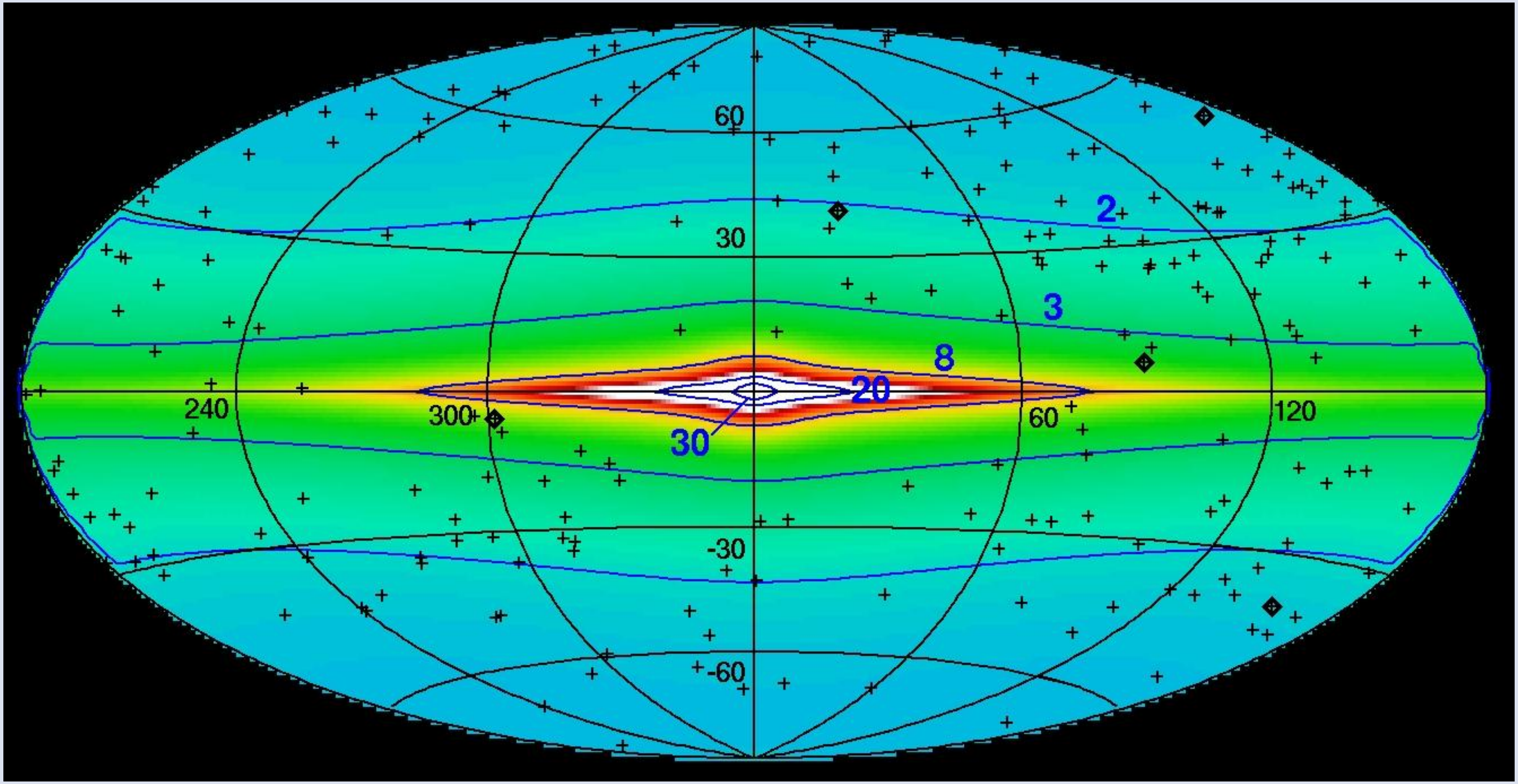
$\rho_{0,b} = 0.756 \frac{M_s}{pc^3}$ $\quad q = 0.6$

Halo:

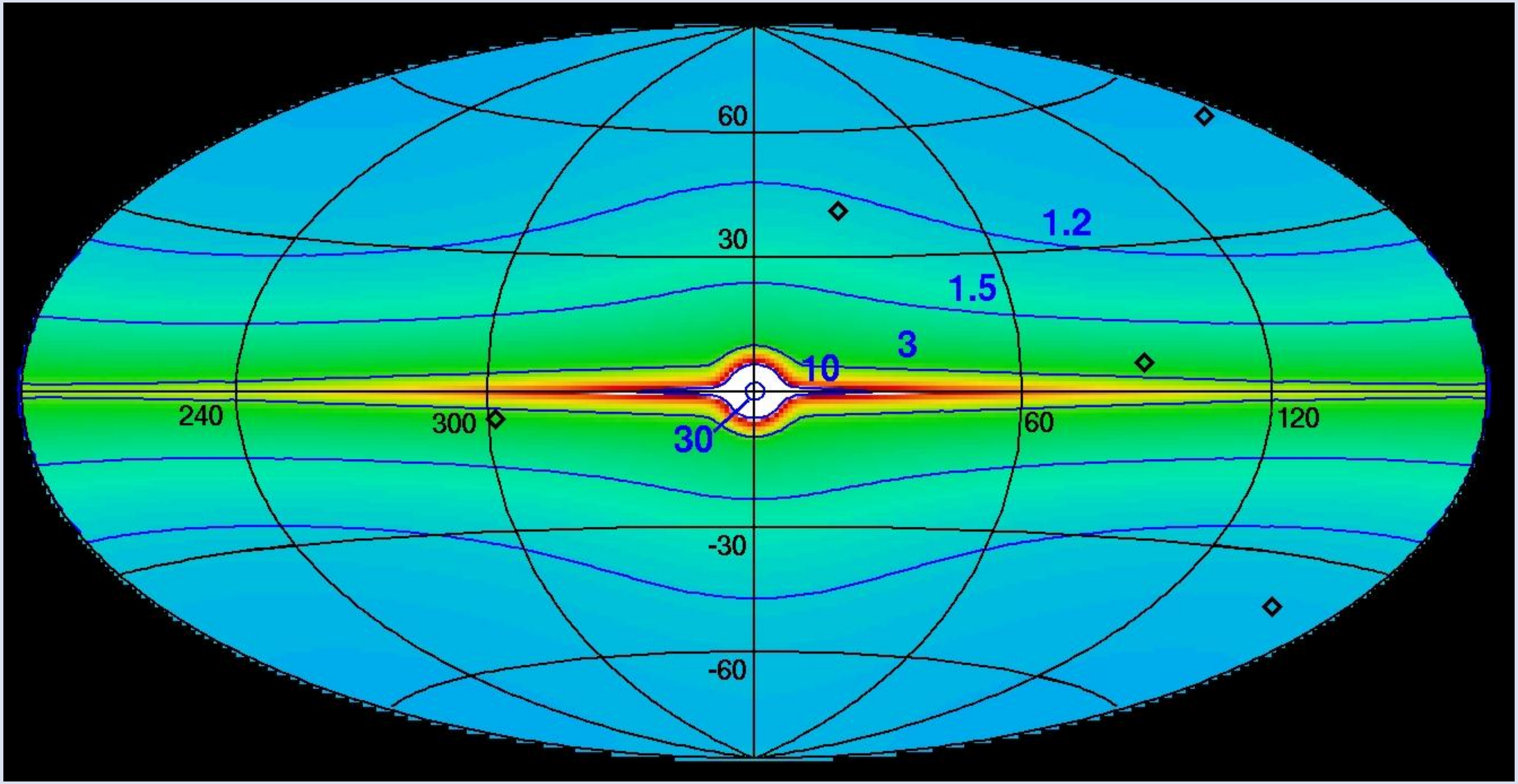
$$\rho_h = \rho_{0,h} \left(\left(R^2 + \frac{z^2}{q^2} \right) \Big/ (1.09)^2 \right) \left(1 + \sqrt{R^2 + \frac{z^2}{q^2}} \Big/ (1.09) \right)^{-4.207}$$

$\rho_{0,h} = 1.263 \frac{M_s}{pc^3}$ $\quad q = 0.8$

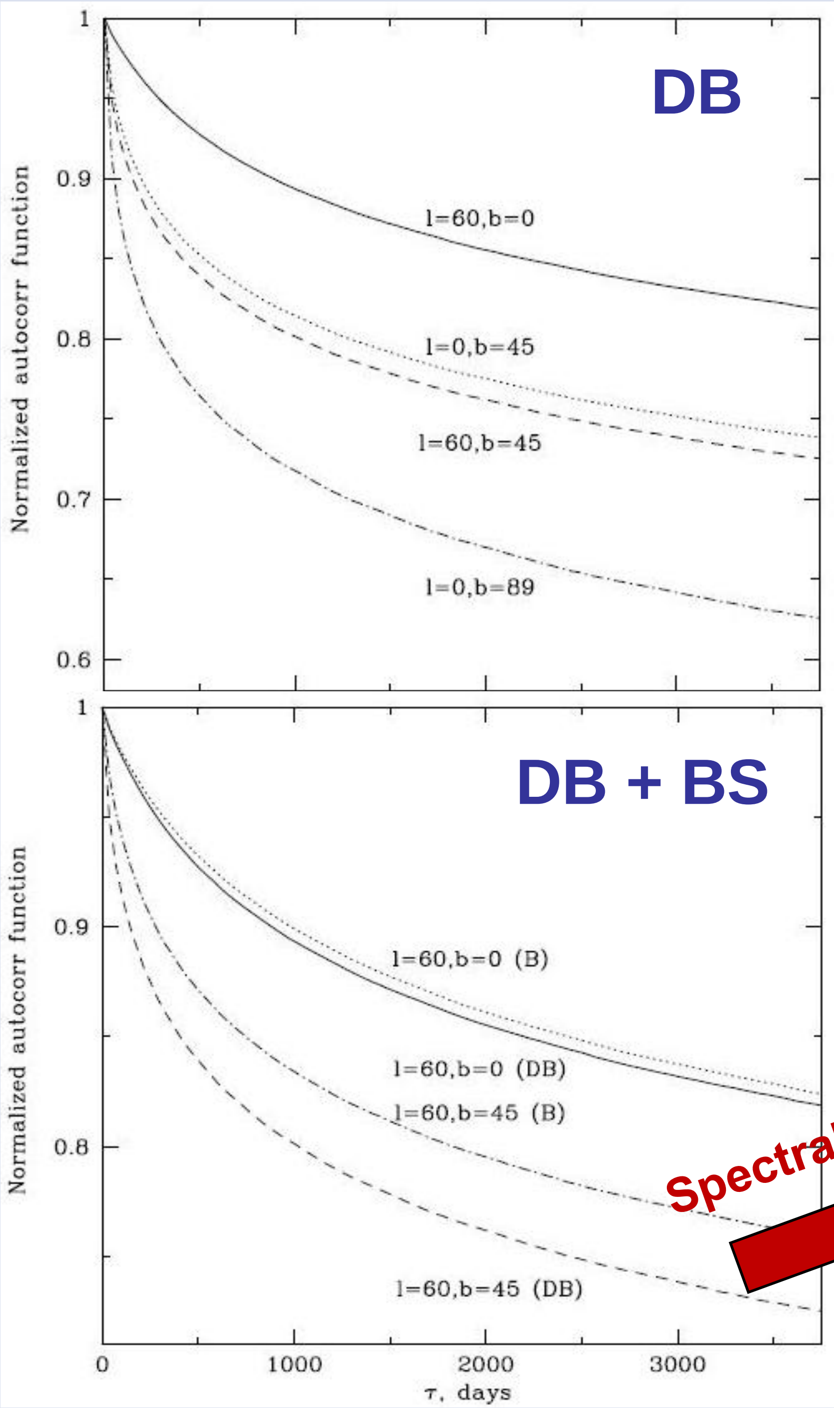
$\sqrt{\langle \alpha^2 \rangle}$ in microarcseconds for the DB model



$\sqrt{\langle \alpha^2 \rangle}$ in microarcseconds for the BS model



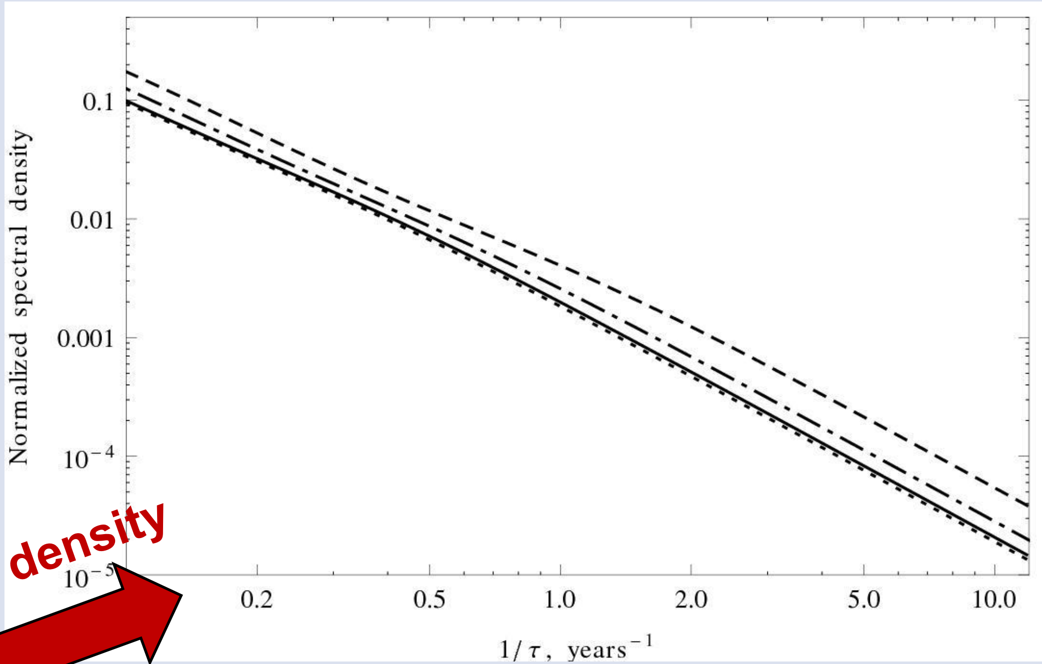
Autocorrelation function and power spectrum



$$\Re(\tau) = \sum_i N_i \exp\left(-\frac{\tau}{T_i}\right)$$

T_i ~400, 2000, 15000 days for τ=70 yr

Spectral density



Spectral index n ≈ 2 for τ ≤ 1 yr and n ≈ 1.6-1.7 for τ > 1.5 yrs

Conclusions

Major moment characteristics of the stochastic process (moments of a first order and autocorrelation function), arising due to non-stationary gravitational filed of the Galaxy were calculated for different directions on the sky.

We constructed the 2D distribution of the standard deviation of the angular shifts in positions of ICFR sources with respect to their true positions and found that the offset angle can reach several tens of microarcseconds, decreasing down to 2-3 μas at high galactic latitudes.

Relative changes of the autocorrelation function are about 5-20% for one year and about 20-40% for ten years depending on the coordinates.

The obtained results place physical limits on the accuracy of absolute astrometric measurements.