Galactic masers: kinematics and the state of the thin disk

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Abstract: We analyze the structure and kinematics of the currently most extensive sample of 123 Galactic maser sources associated with young stars and with published trigonometric parallaxes, radial velocities, and proper motions measured using VLBI technique (BESSEL and VERA surveys). We use a modification of the statistical-parallax technique based on the maximum-likelihood method to validate the trigonometric-parallax based distance scale (which we find to be correct within the errors) and determine (1) the solar Galactocentric distance Ro ~ 8.3 ± 0.3 kpc, (2) the parameters of the Galactic rotation curve in the Galactocentric distance range spanning from 1 kpc to the outskirts of the Galactic thin disk (about 15 kpc), (3) velocity of the residual solar motion, (4) Galactocentric distance dependent components of the velocity dispersion tensor, (5) the radial disk scale length, and (6) the parameters of the perturbations induced by the spiral density wave (the pitch angle, the amplitudes of the radial and tangential perturbations, and the phase of the Sun).

Technique:

Maximum-likelihood method (Murrey 1986) with the allowance for all measurement errors.

Particularities:

(1) Axial ratio of velocity ellipsoid depends on Galactocentric distance R in accordance with Lindblad's relation:

$$\frac{\sigma_T(R)}{\sigma_R(R)} = \sqrt{1 - \frac{A(R)}{\omega(R)}}$$

(2) Radial axis of the velocity ellipsoid σR depends on R in accordance with Toomre's condition for marginally stable exponential disk with radial scale HD:

$$\frac{\kappa(R)\cdot\sigma_R(R)}{3.36\cdot G\cdot\Sigma(R)} \approx const \quad \Rightarrow \quad \frac{\sigma_R(R)}{\sigma_R^0} \approx \frac{\kappa_0}{\kappa(R)}\cdot\exp\left(-\frac{R-R_0}{H_D}\right)$$

(3) σZ ≈ const (constant disk thickness)

Data: Compilation of ~130 Galactic masers with published trigonometric parallaxes, proper motions, and radial velocities measured using VLBI technique within the framework of VERA and BeSSeL projects (Reid et al. 2009; Honma et al. 2012; Reid et al. 2014).

Results: 1. Pure circular rotation, no spiral perturbations. Sixth-order expansion of angular velocity ω(R), 123 masers:

Ro = 8.43 ± 0.26 kpc (distance to the Galactic center)

(Uo,Vo,Wo) = (-8.46,-16.98,-8.09) ± (1.27,1.22,0.69) km/s

(σUo,σW) = (11.66, 5.83) ± (0.86,0.62) km/s

ω0 = 29.14 ± 0.60 km/s/kpc

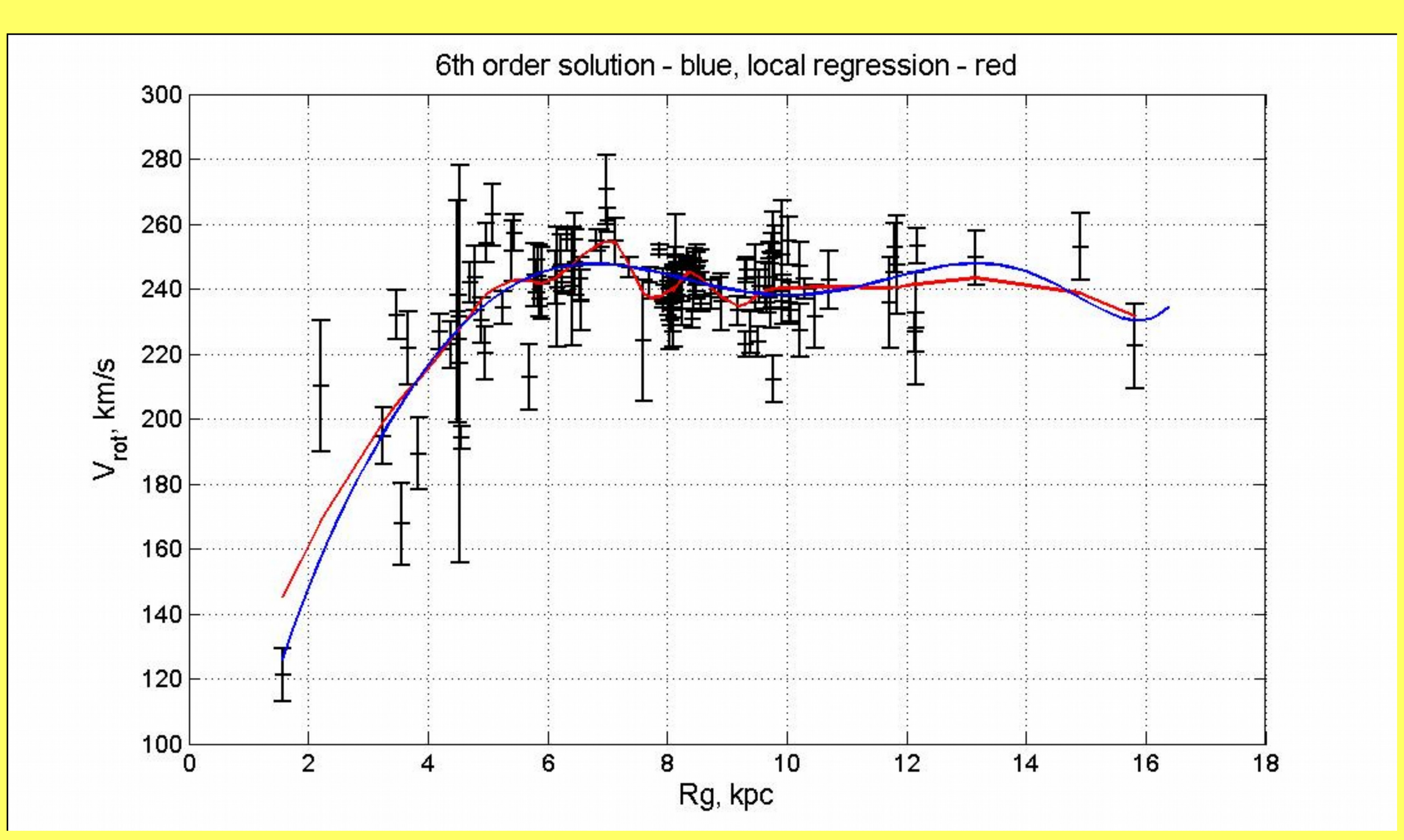
dω/dR = -3.98 ± 0.22 km/s/kpc^2

Hd = 3.24 ± 0.35 kpc (radial disk scale)

Vo = 245 ± 10 km/s

true parallax = (0.987 ± 0.038) x measured parallax

MILKY WAY ROTATION CURVE



Results: 2. Circular rotation plus spiral perturbations (4 arms). Fourth-order expansion of angular velocity ω(R), 119 masers:

Ro = 8.21 ± 0.29 kpc (distance to the Galactic center)

(Uo,Vo,Wo) = (-6.28,-17.08,-8.32) ± (1.17,1.14,0.81) km/s

(σUo,σW) = (9.31, 6.17) ± (0.77,0.71) km/s

ω0 = 28.13 ± 0.59 km/s/kpc

dω/dR = -3.81 ± 0.27 km/s/kpc^2

Hd = 3.50 ± 0.35 kpc (radial disk scale)

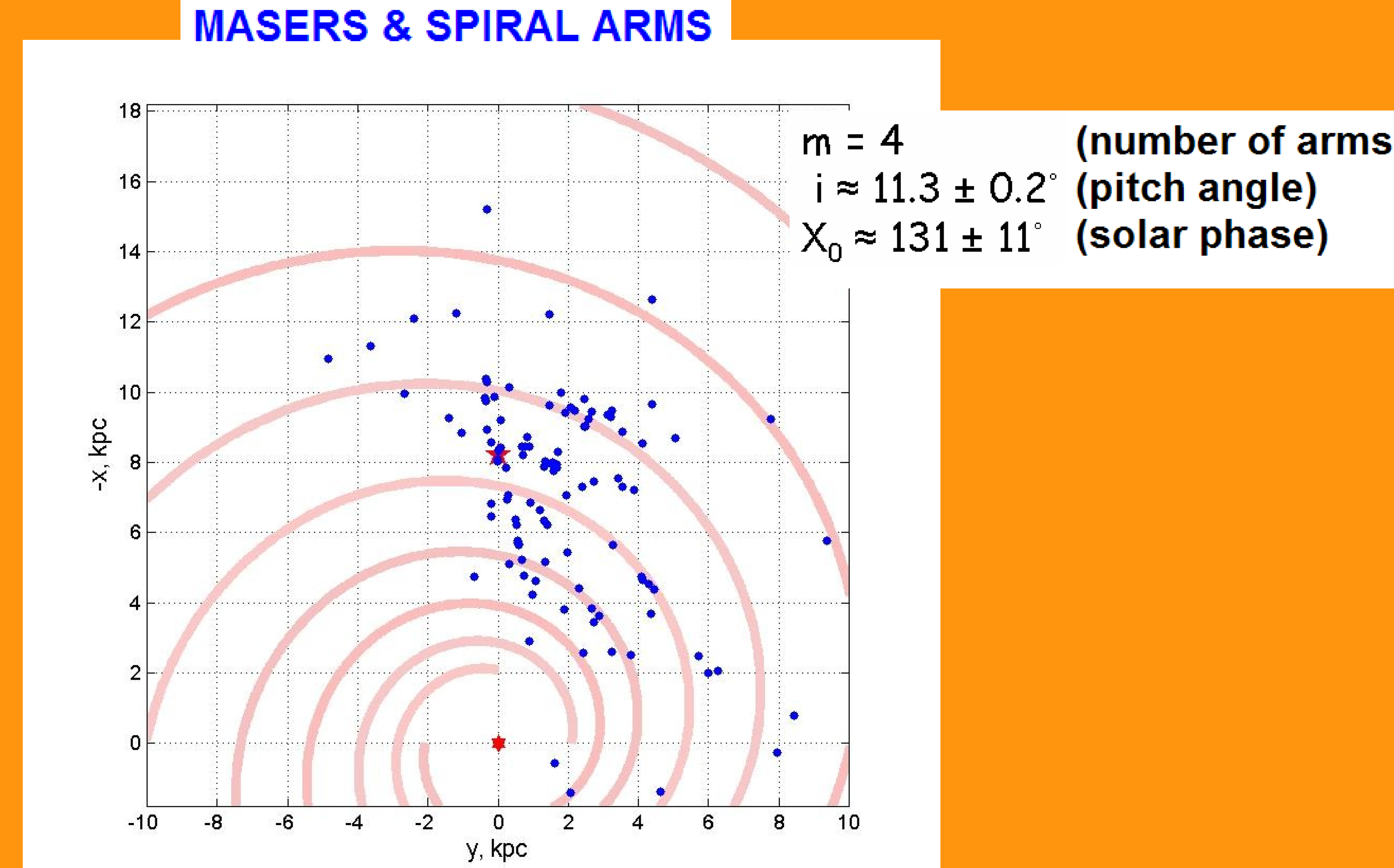
Vo = 231 ± 10 km/s

true parallax = (0.957 ± 0.025) x measured parallax

f_R = -7.10 ± 1.26 km/s (radial perturbation amplitude)

f_T = +1.48 ± 1.23 km/s (azimuthal perturbation amplitude)

MASERS & SPIRAL ARMS



Kinematic pitch angle lies halfway between the estimates

(1) $i = -13.1 \pm 0.6^\circ$ obtained by Vallée (ApJS V.215, id.1, 2014) by analyzing tangents to arms

(2) $i = -9.1 \pm 0.1^\circ$ obtained by Dambis et al. (arXiv:1505.01782) from the space distribution of classical Cepheids