Could very low-metallicity stars with rotation-dominated orbits have been shepherded by the bar?

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Introduction

Very low-metallicity stars were discovered more than two thousands

Several hundred stars are rotation-dominated and prograde

In particular, these stars are close to the Sun's orbit.

Where did these very low-metallicity prograde stars come from?

(1) accreted from small satellites with specific orbits through minor mergers;

(2) brought in during the early assembly of the proto-Milky Way disc;

(3) formed in-situ from pockets of pristine gas at early times pushed into the solar neighborhood;

(4) originally in the inner Galaxy, that gained rotation and moved outwards due to the bar resonances.

Data

LOMST DR3 VMP catalog + Pristine sample + UMP sample → 2290 stars

$[Fe/H] \le -2.5$

↓

2D dust map 、3D dust map and Bayesian approach

→ posterior probability distribution of distance (get 6D kinematic measurements)

↓

AGAMA → The actions (J_ϕ, J_r, J_z) →

$0.5 \le J_\phi / J_{\phi,sun} \le 1.0$

$0.5 \le J_z / J_{z,sun} \le 1250$

(Sestito et al. 2020)

↓

284 prograde planar stars → random → 284 x 500 particles

Models

AGAMA use the potential to model dynamical evolution

- the potential
  - the axisymmetric background → given by AGAMA
  - the non-axisymmetric perturbation
    - a central bar
      - steadily rotating bar
      - decelerating bar
    - spiral arms

Models

The potential of the bar:

$$\Phi_b(r,\theta,\phi,t) = \Phi_{br}(r) sin^2\theta cos m(\phi - \Omega_b t - \phi_b)$$

only consider the $m = 2$ quadrupole term
Ω_b : the pattern speed ϕ_b : the phase angle, $t = 0$
Φ_{br} : the radial dependence of the bar potential

$$\Phi_{br}(r) = -\frac{AV_C^2}{2}\left(\frac{r}{r_{CR}}\right)^2\left(\frac{b+1}{b+r/r_{CR}}\right)^5$$

A : the potential strength of the bar
V_c: the circular velocity in the solar vicinity
$b = r_b/r_{CR}$: the bar's scale length r_b / the co-rotation radius r_{CR}

The steadily rotating bar: $\Omega_b = -35\ kms^{-1}kpc^{-1}$

The decelerating bar: $\Omega_b = -88\ kms^{-1}kpc^{-1}$ at $t = -6Gyr$, $\Omega_b = -38\ kms^{-1}kpc^{-1}$ at $t = 0$

Models

The potential of the spiral arms: (two-arm model)

$$\Phi_s(R,\theta,z) = -4\pi G\Sigma_0 e^{-R/R_s} \sum_n \frac{C_n}{K_n D_n} cosn\gamma[\cosh(\frac{K_n z}{\beta_n})]^{-\beta_n}$$

Σ_0: the central surface density

$C_n(\mathrm{n} = 1,2,3)$: the amplitudes of the three harmonic terms, $C_1 = \frac{8}{3\pi}, C_2 = \frac{1}{2}, C_3 = \frac{8}{15\pi}$

The functional parameters:

$$K_n = \frac{nN}{Rsin\alpha}$$

$$D_n = \frac{1}{1+0.3K_n h_s} + K_n h_s$$

$$\beta_n = K_n h_s(1 + 0.4K_n h_s)$$

$$\gamma = N[\phi - \frac{\ln\left(\frac{R}{R_s}\right)}{tan\alpha} - \Omega_p t - \phi_0]$$

N: the number of arms

h_s : the scale height

α: the pitch angle

ϕ_0 : the phase

Models

Bar	Ω_b	A	v_c	b	r_{CR}	ϕ_b	
Values	-35	0.02	235	0.28	6.7	28°	
Spiral arm	Ω_p	R_s	h_s	N	α	ϕ_0	Σ_0
Values	-18.9	1.0	0.1	2	9.9°	26°	2.5×10^9

four different perturbation setups:

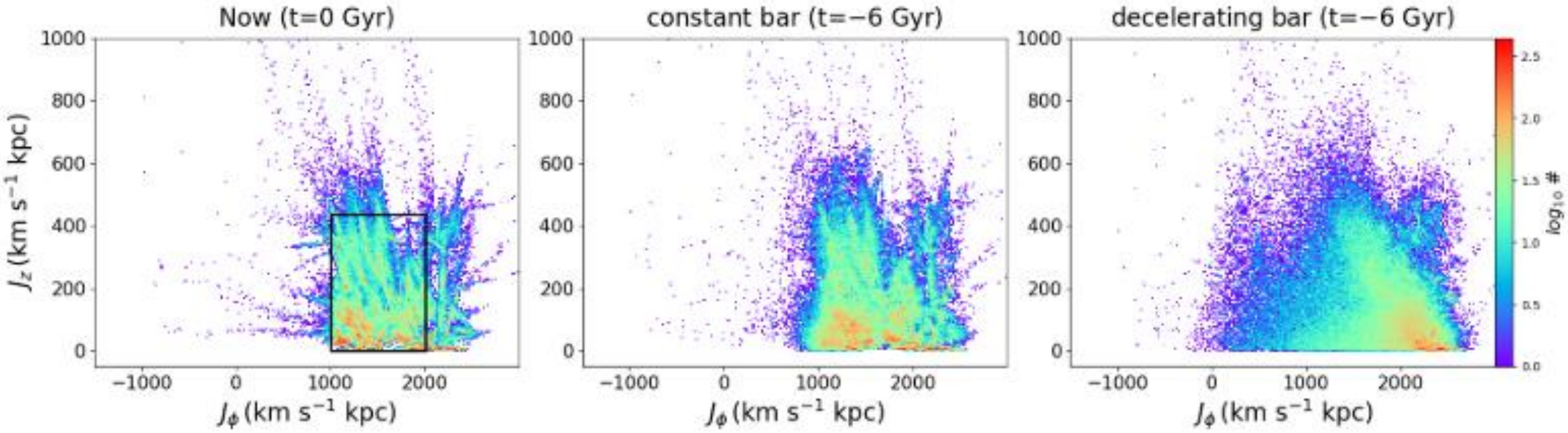
(i) constant bar only,

(ii) constant bar + spiral arms,

(iii) decelerating bar only,

(iv) decelerating bar + spiral arms

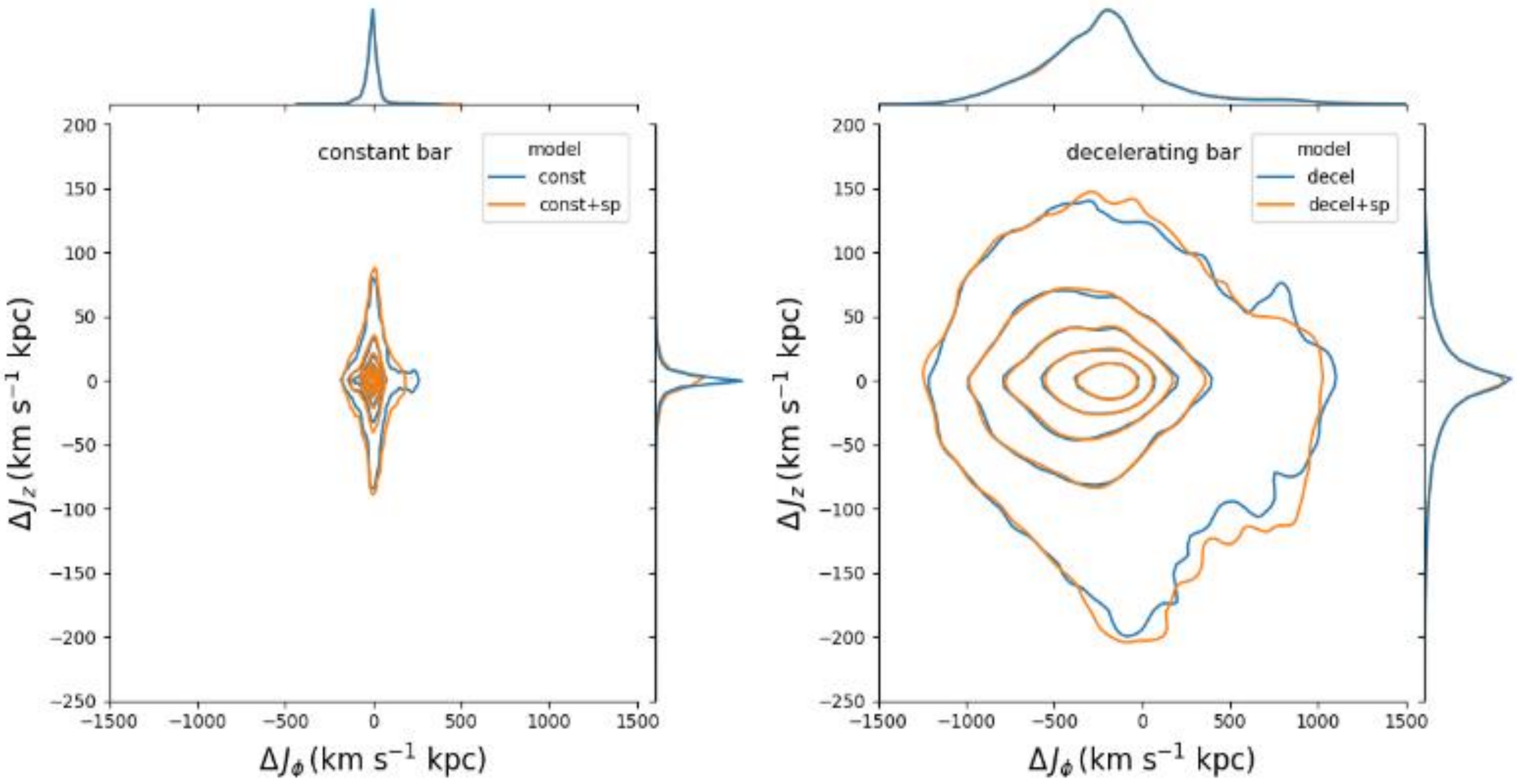
Results



In the model of steadily rotating bar:
No significant change.

In the model of decelerating bar:
The particles with $J_\phi \leq 1000kms^{-1}$have gained stronger rotations, but as long as 8%.

Results



The density contour plot of the change in the $(\Delta J_\phi, \Delta J_z)$ space for all particles

(1) spiral arms have little effect on the actions of the particles.

(2) The majority of the particles in fact lose rotation within the 6 Gyr and only a small fraction of them (19%) gain rotation from interactions with the decelerating bar.

the bar's corotation resonance-trapped regions

Summary & Discussions

- A rotating bar cannot be a robust mechanism to explain the existence of these observed stars.

- These old prograde planar stars that are currently present in the solar neighborhood possibly have varied origins.

  They were either born in-situ in the proto-MW disc, came from accreted systems that merged onto the MW with very prograde orbits, or were brought in with the clumps that formed the proto-MW.

- From the modeling aspect, there are key limitations:

(a) The decelerating bar model is only a toy model that cannot represent the true evolution history of the bar in the Galaxy.
(b) The test-particle simulation method does not include any response of the stellar systems to the perturbations by the bar and the spiral arms that is due to the self-gravity of the system itself.
(c) the method does not take into account the evolution/increase of the background potential of the Galaxy.

- On the observational side, the strong selection effect of different ground-based survey samples used in this work may lead to misunderstanding their true distribution.