Origin of a Massive Hyper-runaway Subgiant Star LAMOST-HVS1: Implication from Gaia and Follow-up Spectroscopy

Hattori et al., The Astrophysical Journal, Volume 873, Issue 2, article id. 116, 19 pp. (2019)

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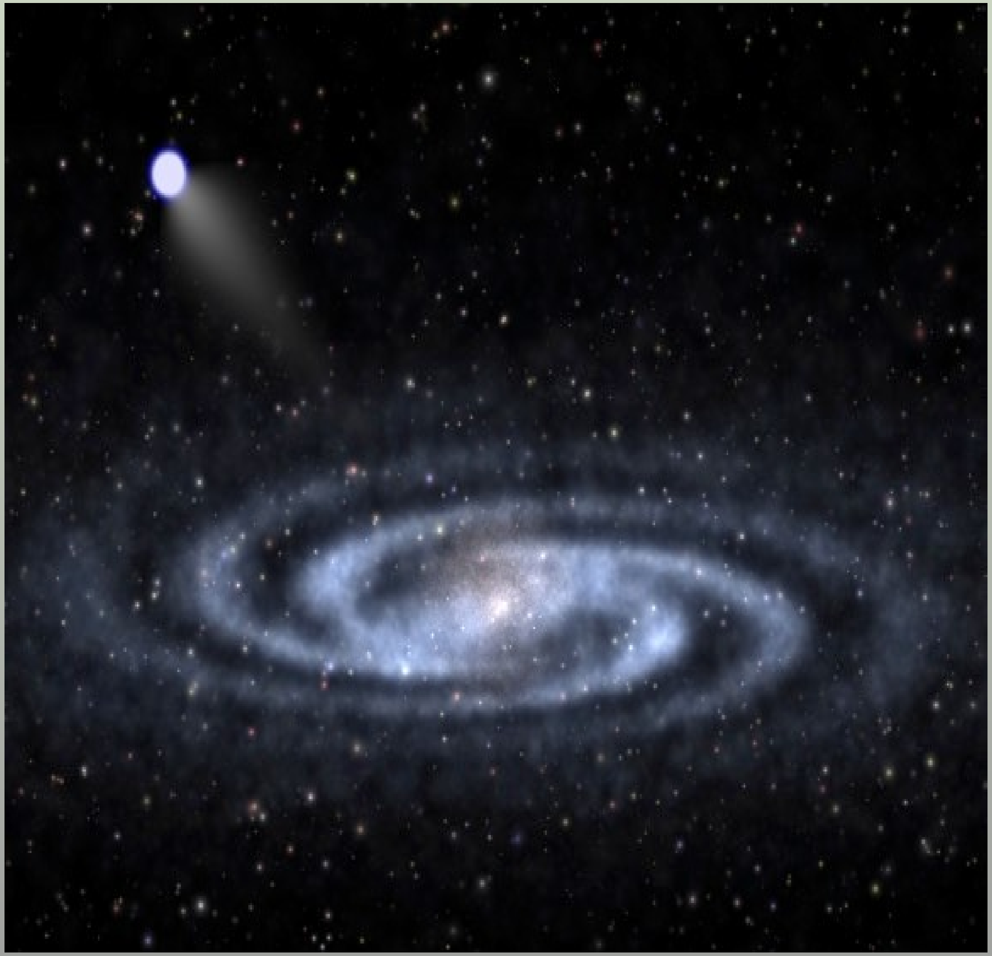

An astrophysicist-artist’s conception of a hypervelocity star speeding away from the visible part of a spiral galaxy like our Milky Way.
Image credit: Ben Bromley, University of Utah

Origin of a Massive Hyper-runaway Subgiant Star LAMOST-HVS1: Implication from Gaia and Follow-up Spectroscopy

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- Investigation of the properties of a massive hyper-runaway star using GAIA + spectroscopy.

Basic Results

- LAMOST-HVS1 (L-HVS1) is a massive hyper-runaway subgiant star
- $M = 8.3M_{sun}$
- Super – solar metallicity
- $T_{ejection}$ = ~33Myrs ago
- $V_{int,ejection} = 568\ ^{+19}/^{-17}$ km/s
- Probably ejected by a three- or four-body dynamical interaction with more massive objects in a high-density environment such as a YMC, $M_{YMC} \geq 10^4 M_{Sun}$
- Ejection agent might be: IMBH ($\geq 100M_{Sun}$), VMS ($\geq 100M_{Sun}$), multiple ordinary massive stars ($\geq 30M_{Sun}$)
- Ejection agent may be currently located near the Norma spiral arm
- Natal cluster of L-HVS1 may be an undiscovered YMC near the Norma spiral arm

YMC: Young massive cluster
IMBH: intermediate black hole
VMS: Very massive star

Basics

Runaway stars: Young O- and B-type stars with large peculiar velocities (>~40 km/s) or with large vertical excursion from the Galactic disk plane (>~1 kpc)

BEM: Binary ejection mechanism
DEM: Dynamical ejection mechanism

Two proposed mechanisms for ejecting massive runaway stars:

- BEM: A runaway star is ejected as a result of the supernova explosion of its binary companion ($v_{ej,max}$~400km/s)
- DEM: Three-or four-body interaction of stars (and black holes) in high-density environment ejects a runaway star ($v_{ej,max}$~1000km/s)

Large ejection velocity is attained when some extreme conditions are met, e.g. small separation of stars in binary to be disrupted by a massive compact object.

Massive runaway stars lith large $v_{ejection}$ can be probes for the extreme environments where massive stars form.

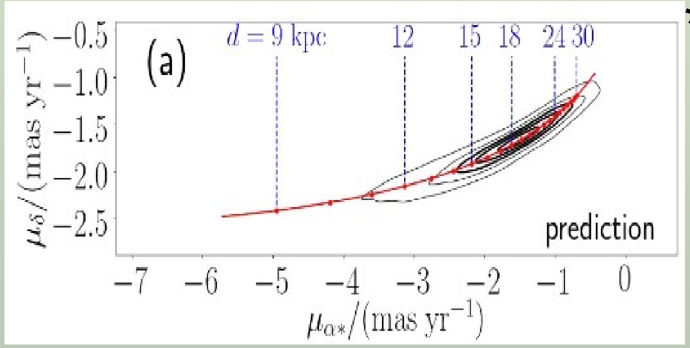
Methods ’n stuff

Table 1
Basic Properties of LAMOST-HVS1

Gaia Data	LAMOST-HVS1
Gaia DR2 source_id	590511484409775360
ℓ	221°.099505130
b	35°.407214626
α	138°.027167145
δ	9°.272744019
G/mag	13.06
$(G_{\rm BP} - G_{\rm RP})$/mag	−0.2316
ϖ/mas	−0.044
σ_{ϖ}/mas	0.067
$\mu_{\alpha *}/(\mathrm{mas\ yr^{-1}})$	−3.54
$\sigma_{\mu,\alpha *}/(\mathrm{mas\ yr^{-1}})$	0.11
$\mu_{\delta}/(\mathrm{mas\ yr^{-1}})$	−0.62
$\sigma_{\mu,\ \delta}/(\mathrm{mas\ yr^{-1}})$	0.09
Spectroscopic Data	
$T_{\rm eff}$	18100 ± 400 K
$\log(g)$	3.42 ± 0.065
$v_{\rm los}$	615 ± 5 km s^{-1}
$v\ \sin(i)$	130 ± 20 km s^{-1}
$v_{\rm macro}$	164 ± 30 km s^{-1}
$v_{\rm micro}$	6 ± 1 km s^{-1}
age τ	$37.4^{+4.0}_{-3.7}$ Myr
(Current mass) M_*	$8.3^{+0.5}_{-0.4}\ M_\odot$
(Current radius) R_*	$9.3^{+1.0}_{-0.9}\ R_\odot$
DM	$16.40^{+0.52}_{-0.48}$
$d_{\rm spec}$	$19.1^{+5.1}_{-3.8}$ kpc
Result of Orbital Analysis	
d	$13.3^{+1.7}_{-1.5}$ kpc

Is L-HVS1 a hyper-runaway star?

SMBH ejection?



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Hattori, K. et al., 2018, ApJ, 869, 33

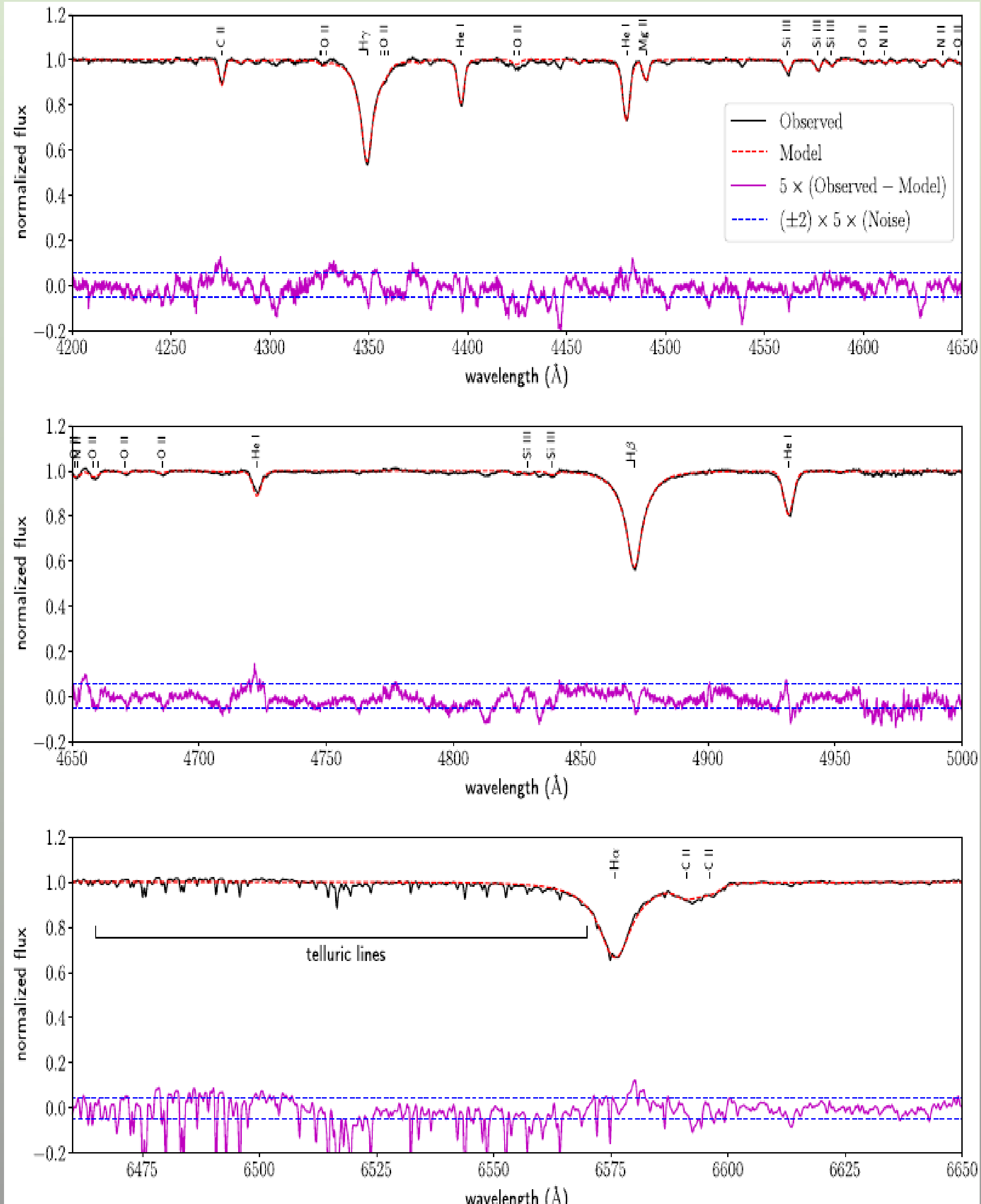
Age of star: ~30 Myrs (Hattori et al. 2018)

→ Most probably L-HVS1 was born in the galactic disk and ejected to reach current location.

Large velocity → L-HVS1 is almost unbound to the Milky Way.

* **Figure 4.** (a) Predicted 2D proper motion ($\mu_{\alpha *}$, μ_δ) of LAMOST-HVS1 based on the assumption that this star originates from the Galactic center. In estimating proper motion, we use $d = 18.00^{+5.59}_{-4.03}$ kpc and $v_{\rm los} = 611.65 \pm 4.63$ km s^{-1}; and we consider the uncertainties in the solar position/velocity and the Galactic potential. The outer thin contours enclose 90% and 70% of the probability; while the inner thick contours enclose 50%, 30%, and 10% of the probability. The red line indicates the predicted proper motion for the fiducial model where only d is varied. Along this red line, the prediction for d/kpc = 9, 10, ⋯, 30 are shown with red dots.

Spectroscopic data



Spectroscopic Data	
T_{eff}	18100 ± 400 K
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DM	$16.40^{+0.52}_{-0.48}$
d_{spec}	$19.1^{+5.1}_{-3.8}$ kpc

L-HVS1 is a massive hyper-runaway subgiant star!

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v_{los} is consistent with preveious measurements by LAMOST → probably not a binary

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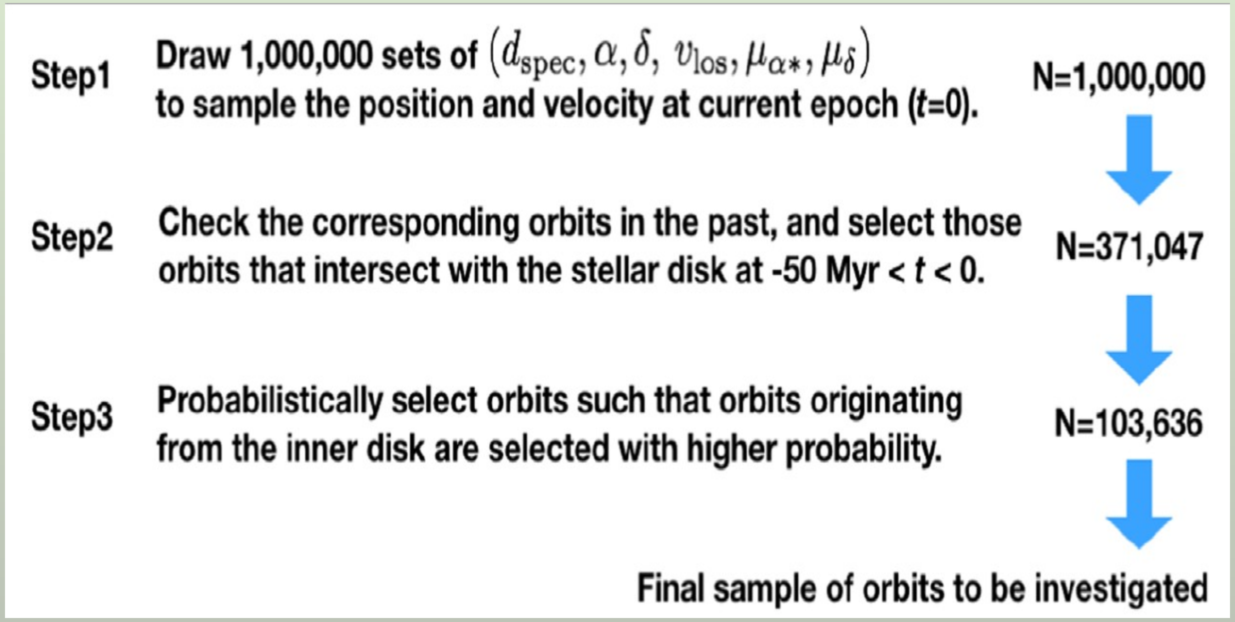
Analysis of the orbit



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If d_{spec}, age_{spec}, GAIA pm are correct maybe L-HVS1 did not originate from the disk
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- Chemical abudunce pattern is consistent with disk origin

Table 2
Chemical Abundances of LAMOST-HVS1

	LAMOST-HVS1		B stars		Sun
X	[X/H][a]	A(X)	$\langle A_{\rm B}^{3\,\rm kpc}({\rm X})\rangle$	$\langle A_{\rm B}^{8\,\rm kpc}({\rm X})\rangle$	$A_\odot$(X)
Si	0.60 ± 0.06	$8.11^{+0.05}_{-0.05}$	7.73 ± 0.05	7.50 ± 0.05	7.51 ± 0.03
Mg	0.33 ± 0.10	$7.93^{+0.06}_{-0.12}$	7.76 ± 0.05	7.56 ± 0.05	7.60 ± 0.04
C	0.26 ± 0.07	$8.69^{+0.05}_{-0.06}$	8.85 ± 0.10	8.33 ± 0.04	8.43 ± 0.05
N	0.35 ± 0.07	$8.18^{+0.05}_{-0.05}$	8.22 ± 0.11	7.79 ± 0.04	7.83 ± 0.05
O	0.17 ± 0.07	$8.86^{+0.05}_{-0.05}$	8.94 ± 0.05	8.76 ± 0.05	8.69 ± 0.05

Notes. A(X) denotes the abundance of LAMOST-HVS1 derived from our analysis. $\langle A_{\rm B}^{3\,\rm kpc}({\rm X})\rangle$ and $\langle A_{\rm B}^{8\,\rm kpc}({\rm X})\rangle$ denote the mean abundance of the B stars located at $R = 3$ kpc and 8 kpc, respectively, derived from Table 9 of Nieva & Przybilla (2012) and the literature values of the radial abundance gradient therein. $A_\odot$(X) denotes the abundance of the Sun taken from Asplund et al. (2009).
[a] Note that $[{\rm X/H}] = A({\rm X}) - A_\odot({\rm X})$ depends not only on A(X) but also on an external quantity $A_\odot$(X). Thus, any systematic error on $A_\odot$(X) can affect [X/H].

Results

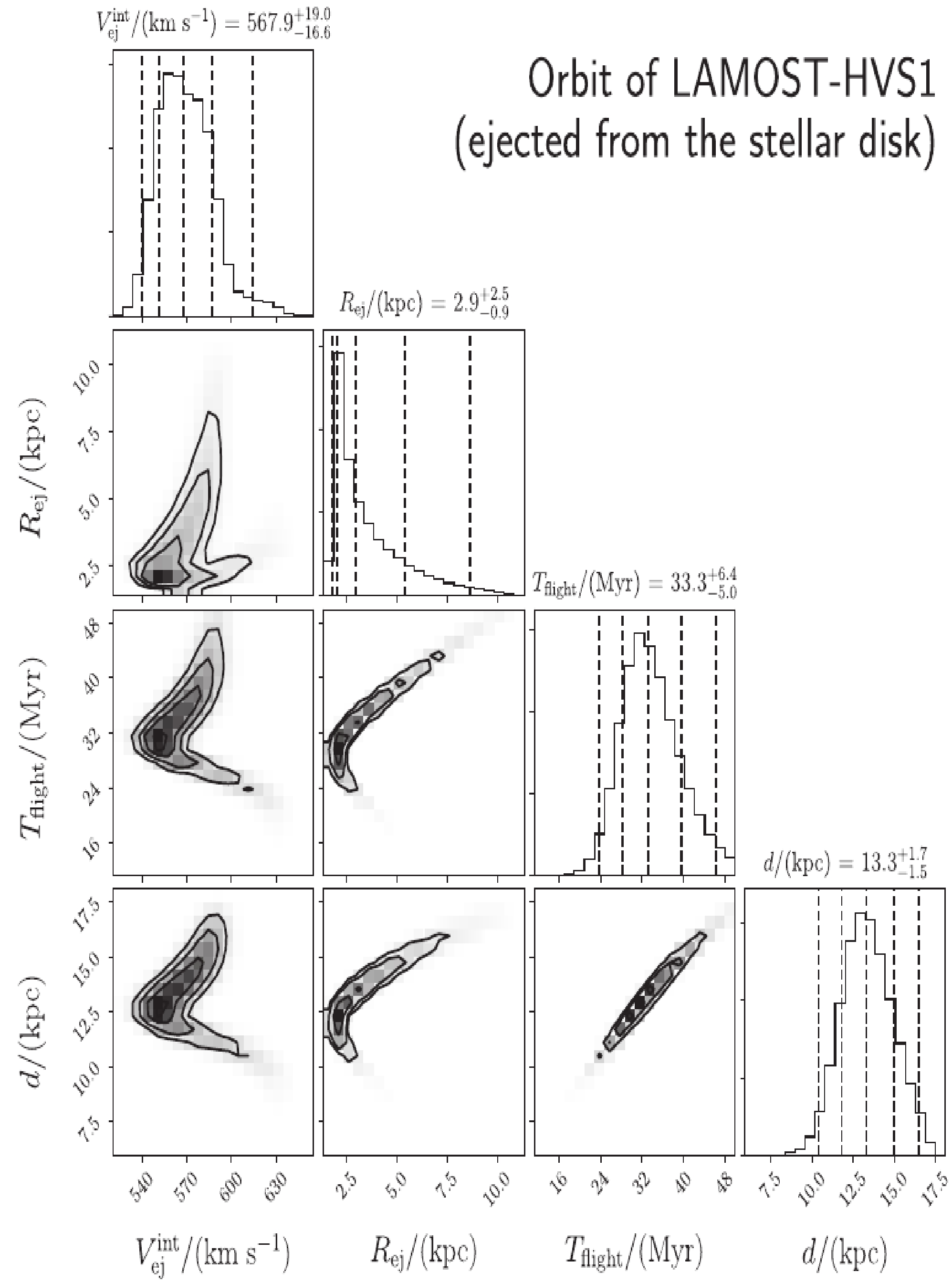

Figure 3. The probability distribution of the orbital properties of LAMOST-HVS1 represented by 103,636 orbits sampled from our analysis. The uncertainty in these orbital parameters are almost exclusively explained by the distance uncertainty, as described in Section 5.1. The dashed vertical lines in the histograms represent the 2.5th, 16th, 50th, 84th, and 97.5th percentiles of the distributions.

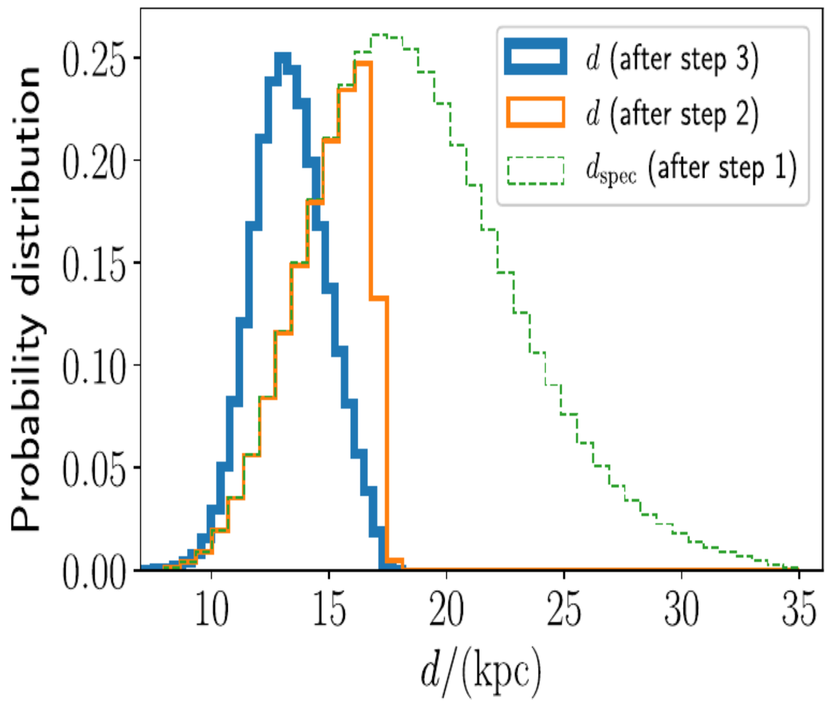

Figure 4. The probability distribution of the distance to LAMOST-HVS1. The distance distribution of the sampled orbits after (step 1), (step 2), and (step 3) in Figure 2 are shown by the green dashed, orange thin, and blue thick histograms, respectively. We see that the spectroscopic distance (green-dashed histogram) is comparatively uncertain by itself, and our belief in the distance is improved after we take into account the orbital information (blue-solid histogram). The blue-thick and orange-thin histograms are normalized to unity; while the green-dashed histogram is scaled so that the difference from the orange-thin histogram can be clearly seen.

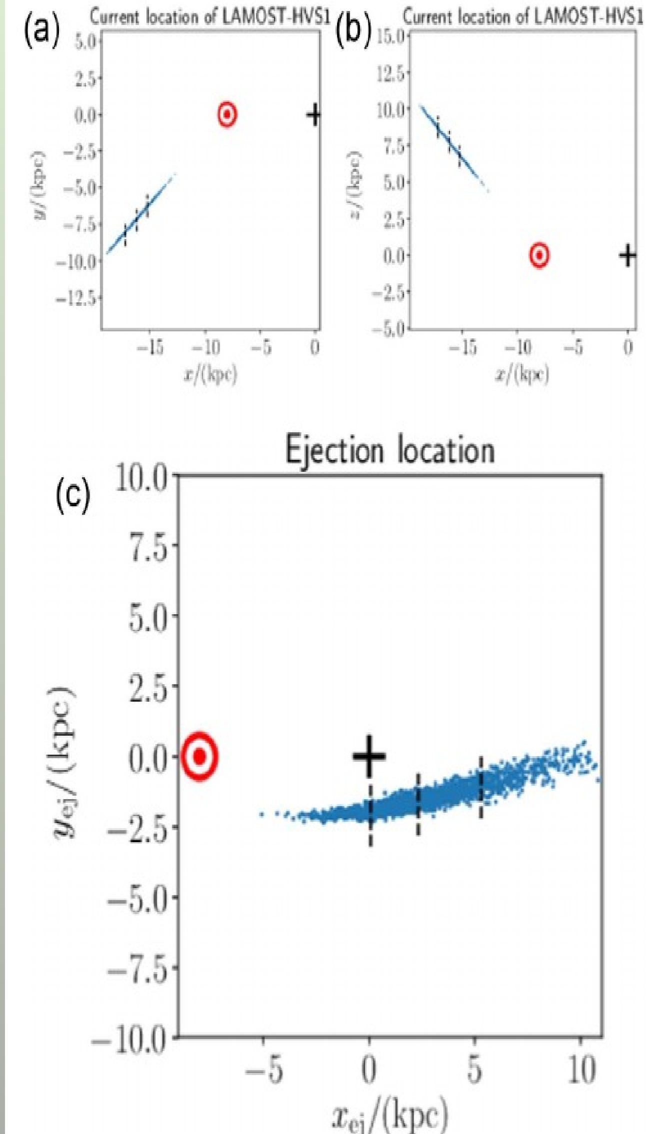

Figure 5. The probability distribution of the current location of LAMOST-HVS1 (upper two panels) and the location when it was ejected from the stellar disk (bottom panel) represented by the 103,636 sample orbits. (Only 2% of them are shown for clarity.) The black plus and red dot correspond to the Galactic Center and the current solar position, respectively. In panels (a) and (b), the vertical dashed lines indicates the 16th, 50th, and 84th percentiles of the current x coordinate of LAMOST-HVS1, which are shown to provide a rough idea of the distance uncertainty. In panel (c), the vertical dashed lines indicate the 16th, 50th, and 84th percentiles of the x coordinate of the ejection location, x_{ej}.

Notes on results

- T_{flight} (~33Myrs) < τ_{spec}(~37Myrs) → Star ejected right after it was born
- Ejection location (R_{ej}~3 kpc) is very active recently in terms of star formation
- L-HVS1 is the only well-confirmed massive hyper-runaway star ejected from the disk with an extreme $v_{ejection}$ ~ 600 km/s

Current location of the ejection agent

- Assume that rotation is confined to the disk.
- Ejection agent may not exist now but natal YMC probably does (if M_{YMC}~10^3 – 10^4 M_{sun}.)
- Location is around Norma spiral arm.
- Location consistent with the idea that YMC are located close to spiral arms.
- Existing YMCs near Norma are younger than flight time of L-HVS1, also abundances not consistent.
- Maybe natal YMC is still undiscovered.

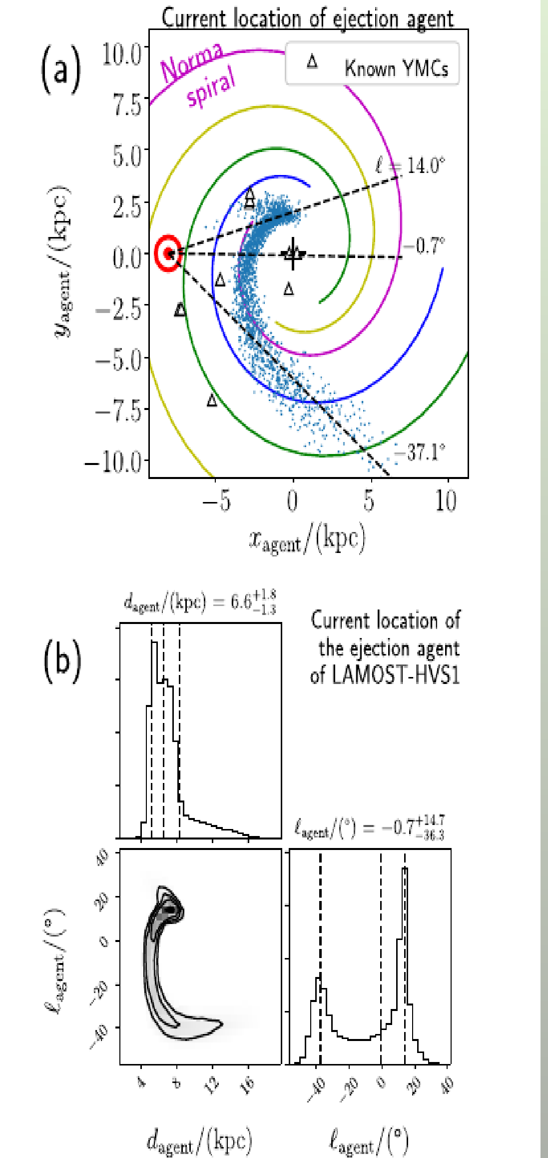

Figure 7. The probability distribution of the current position of the ejection agent of LAMOST-HVS1 (the object that ejected LAMOST-HVS1; this may be an IMBH, a VMS, or ordinary massive stars in the natal star cluster). (a) The distribution in the Galactic disk plane is represented by the 103,636 Monte Carlo sample. (Only 2% of them are shown for clarity.) We note that the spatially elongated distribution arises from the uncertainty in the current heliocentric distance to LAMOST-HVS1. The distribution appears to have a significant overlap with the Norma spiral arm. The three dashed lines indicate the 16th, 50th, and 84th percentiles of the Galactic longitude. The open triangles show the locations of the known young massive clusters (Portegies Zwart et al. 2010). (b) This panel shows the same information, but in the distance (d_{agent}) and Galactic longitude (ℓ_{agent}) space. The three vertical dashed lines in the bottom right panel indicate the 16th, 50th, and 84th percentiles of the Galactic longitude, which are also shown in panel (a).

Summary

- L-HVS1 is a hyper-runaway subgiant star, $M \sim 8.3 M_{Sun}$ and super-solar metallicity
- Was ejected from the inner stellar disk $R_{ejection} \sim 3$kpc with $v_{ejection} \sim 600$ km/s ~33Myrs ago
- Chemical abundance is consistent with the ejection location
- Large $v_{ejection}$ rules out BEM as an ejection mechanism and favors few-body dynamical interaction
- If natal YMC is $\sim 10^3 - 10^4 M_{Sun}$ it may survive until today and be near the Norma spiral arm and is still undiscovered
- L-HVST1 is the first well-confirmed early B-type massive hyper-runaway star with so large $v_{ejection}$

Thank you!