IAUS395: Stellar populations in the Milky Way and beyond

# Exploring the Milky Way with LAMOST Survey

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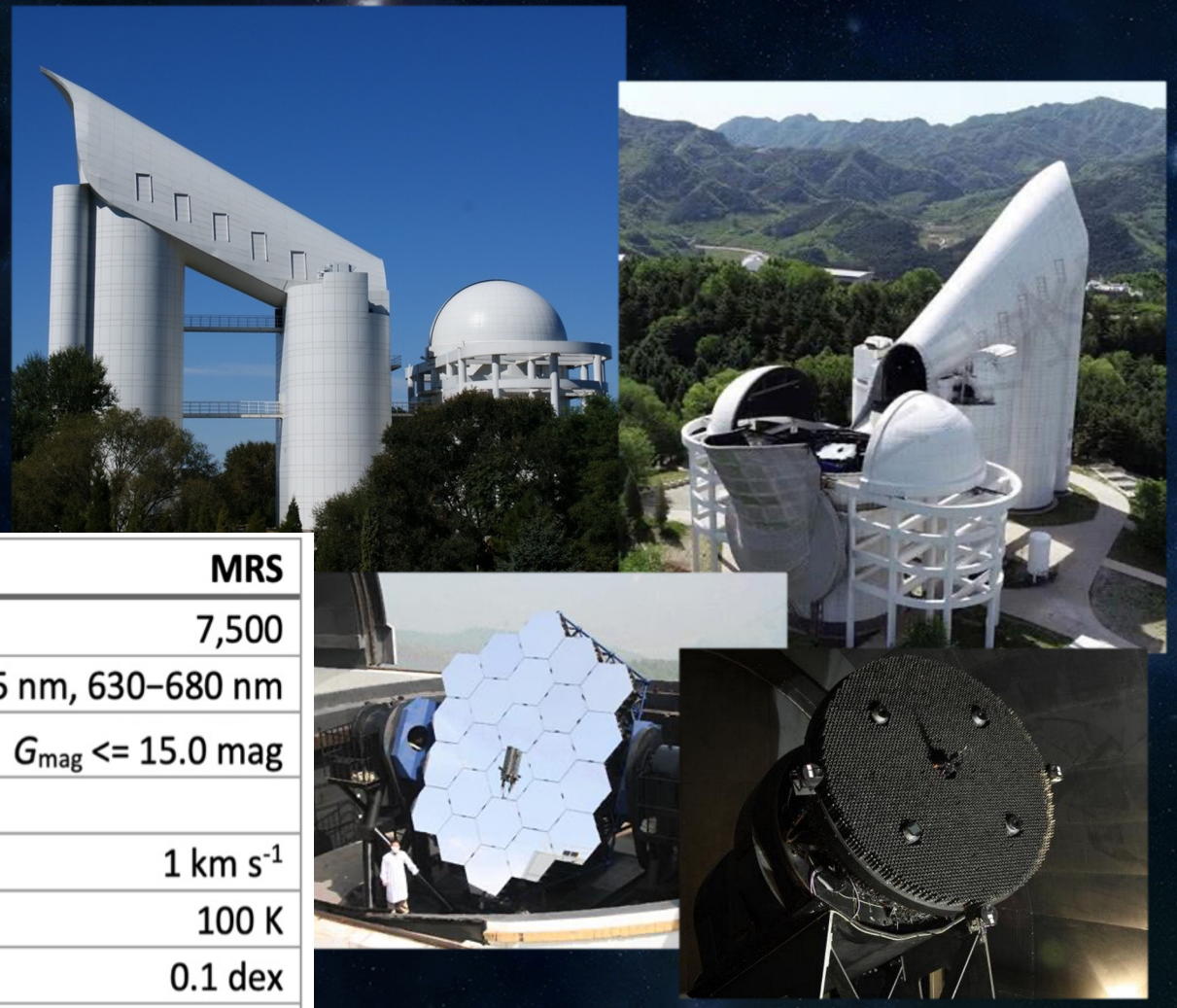
# LAMOST: the design

- Large Sky Area Multi-Object fiber Spectroscopic Telescope
- Located at Xinglong, Hebei Province
- 4m aperture + 5deg FoV
- 4000 fibers

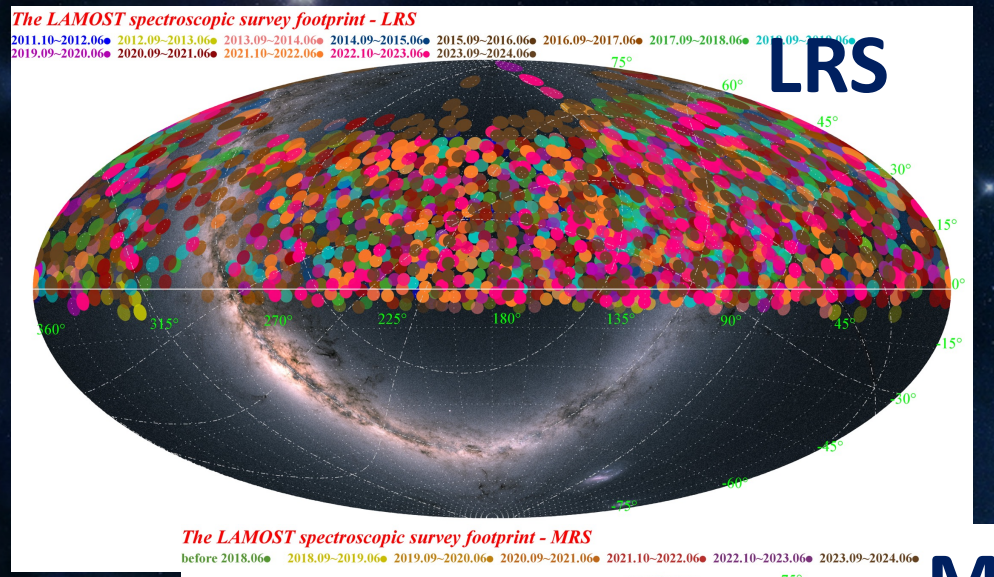


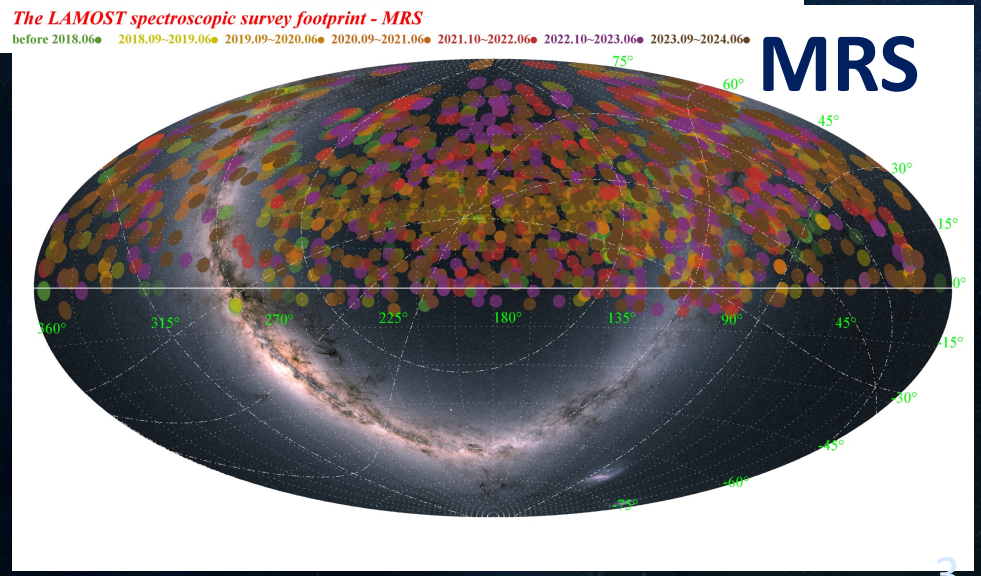
| Parameters | LRS | MRS |
|---|---|---|
| Resolution | 1,800 | 7,500 |
| Wavelength Coverage | 370–900 nm | 495–535 nm, 630–680 nm |
| Limiting Magnitude | $r_{mag}$ <= 17.8 mag | $G_{mag}$ <= 15.0 mag |
| Expected Precision | | |
| RV | 5 km $s^{-1}$ | 1 km $s^{-1}$ |
| $T_{eff}$ | 300 K | 100 K |
| *logg* | 0.2 dex | 0.1 dex |
| [Fe/H] | 0.2 dex | 0.1 dex |

Yan et al. 2022 The Innovation

# LAMOST: the survey

- Phase I: 2012.09 – 2017.06 (LRS only)
- Phase II: 2018.09 – 2023.06 (LRS + MRS)
- LRS survey
  - ✓ disk (anti-Galactic center) + halo + extragalactic area (very small)
- MRS survey
  - ✓ time domain, including Kepler area

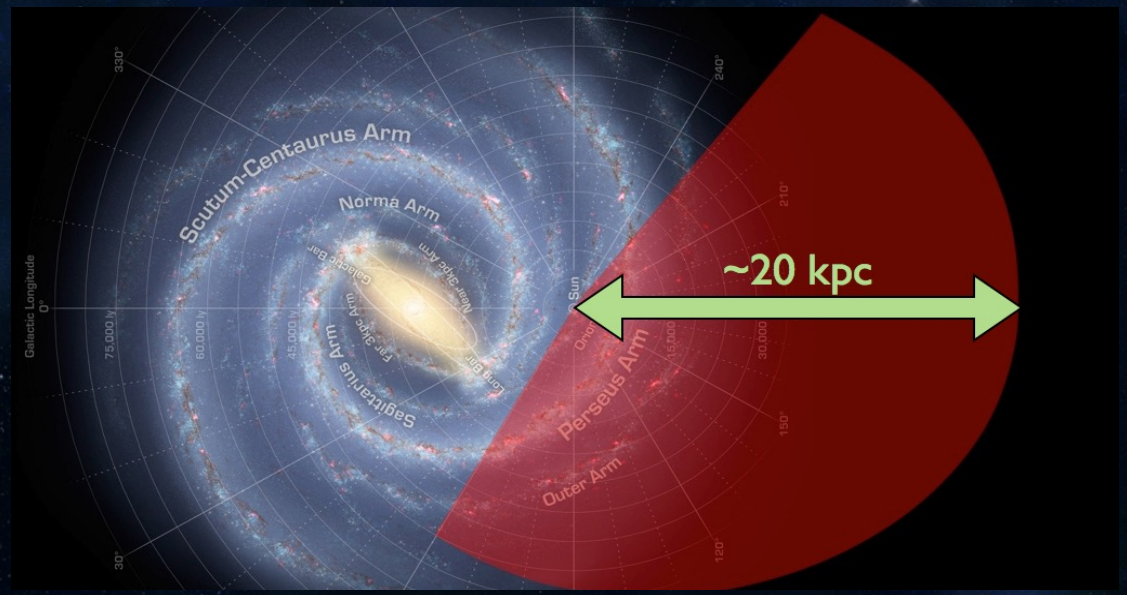


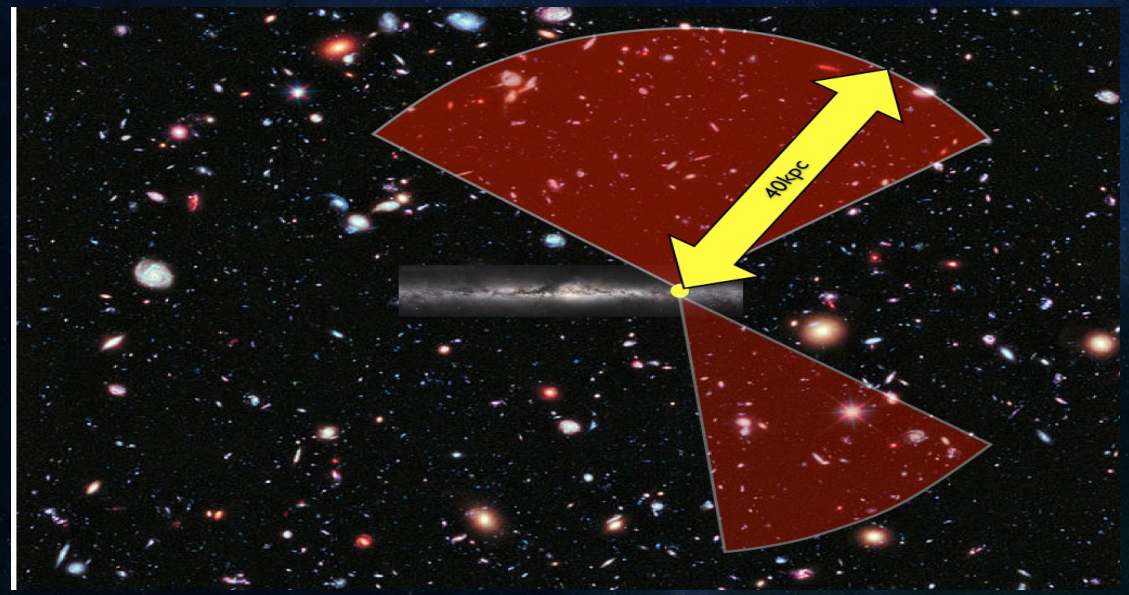



# LAMOST: the survey

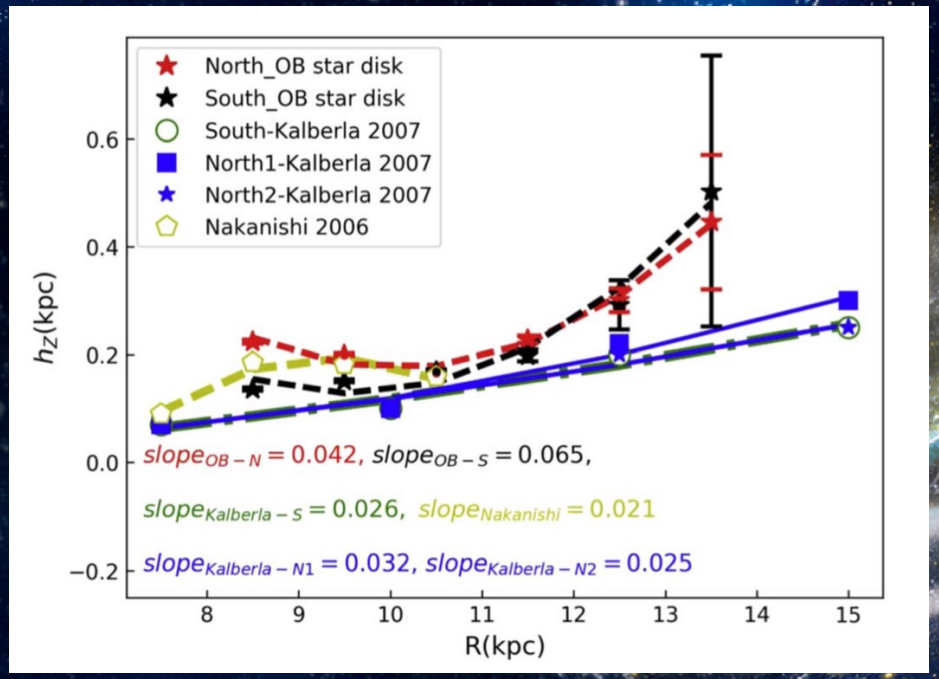
- large area
  - ✓ disk: cover 20 kpc (from the Sun)
  - ✓ halo: reach 40 kpc (from the Sun)
- huge database of stellar spectra

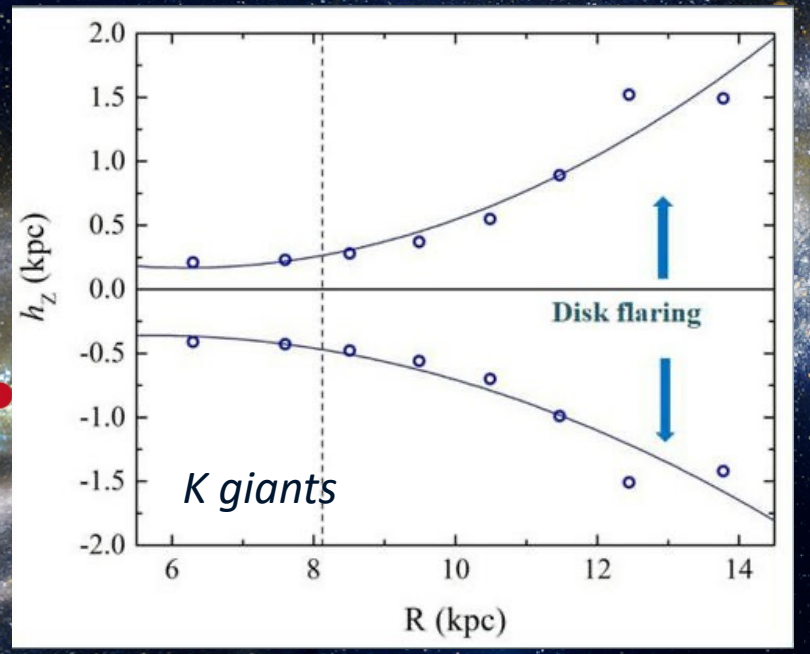
| DR11 | LRS | MRS |
|---|---|---|
| spectra | 11.94 million | 13.18 million |
| parameter | 7.78 million | 2.59 million |



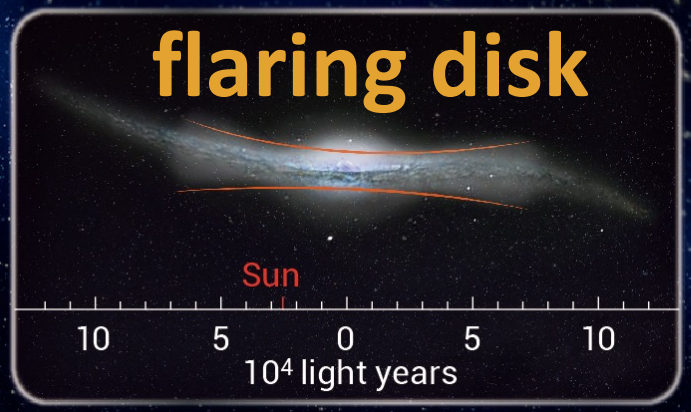



# Exploring the Galactic structures



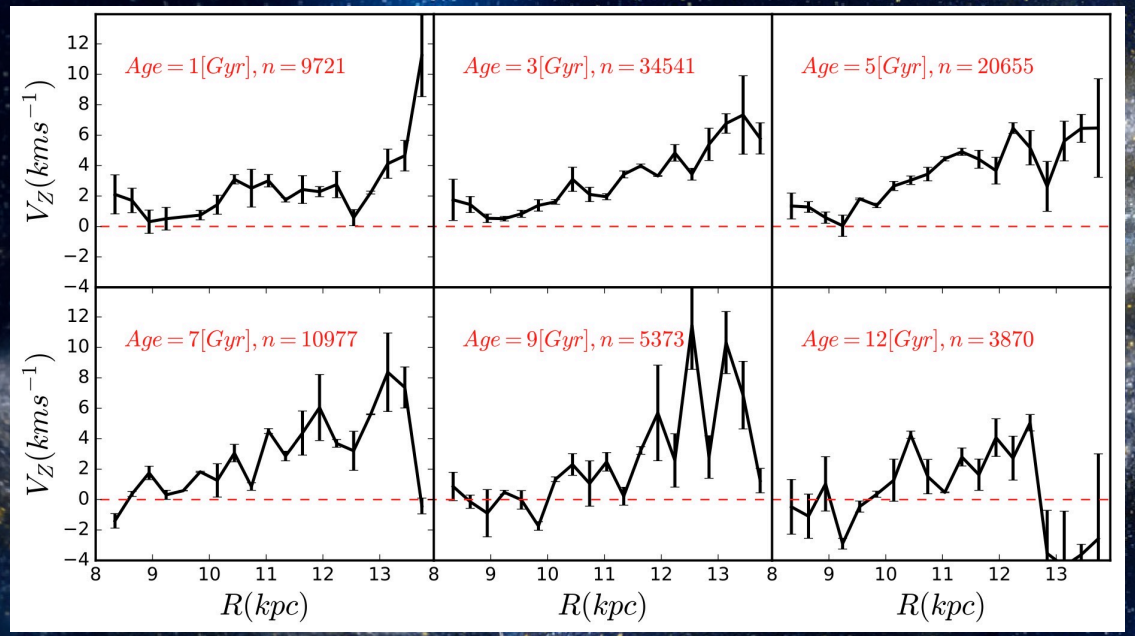




*Wang+2018, MNRAS, 478, 3*
*Yu+2021, ApJ, 922, 80*
*Ding+2021, AJ, 162, 112*

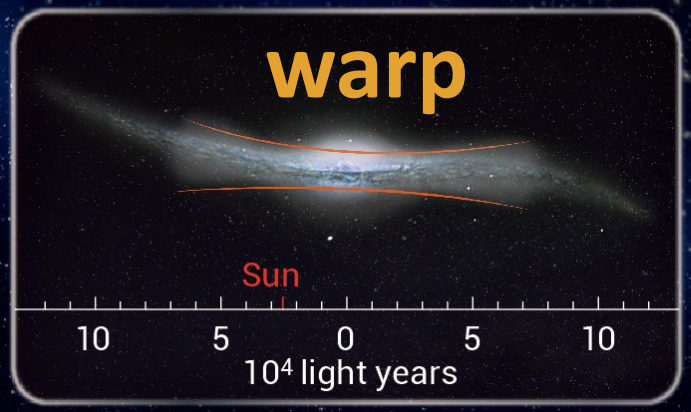



- OB stars traces similar flares as K giants
- Possibly originated from external disturb, e.g, a dwarf galaxy

# Exploring the Galactic structures



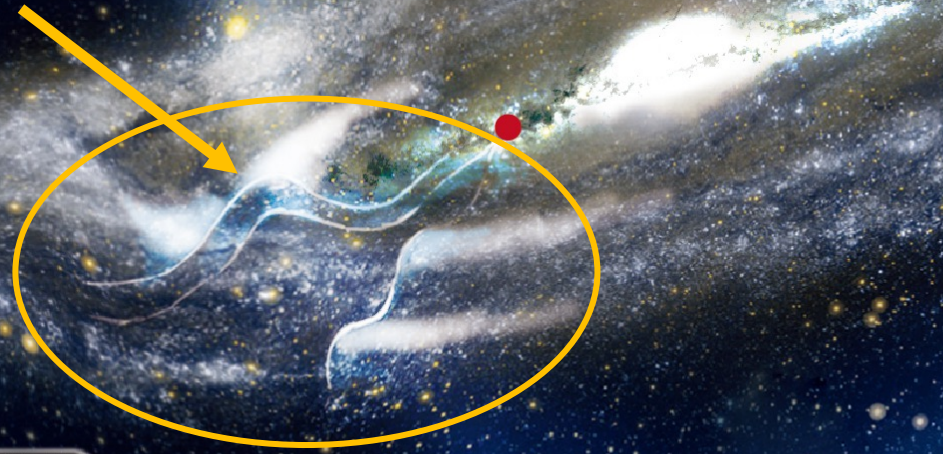

*Wang+2020, ApJ, 897, 119*
*Yu+2021, ApJ, 922, 80*



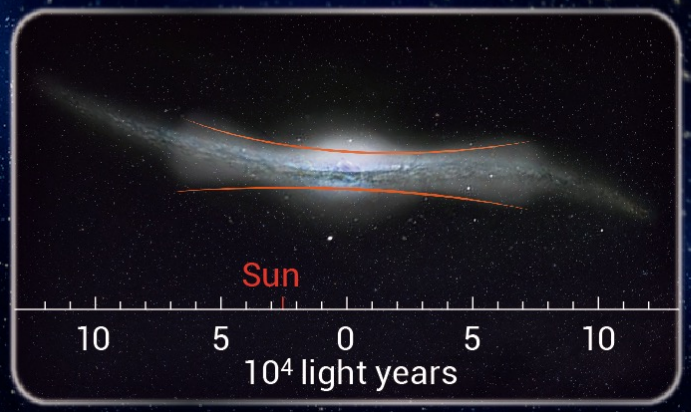

- red clump stars
- strength decreases when the age increases
  - ✓ non-gravitational interaction, e.g., gas infall onto the disk

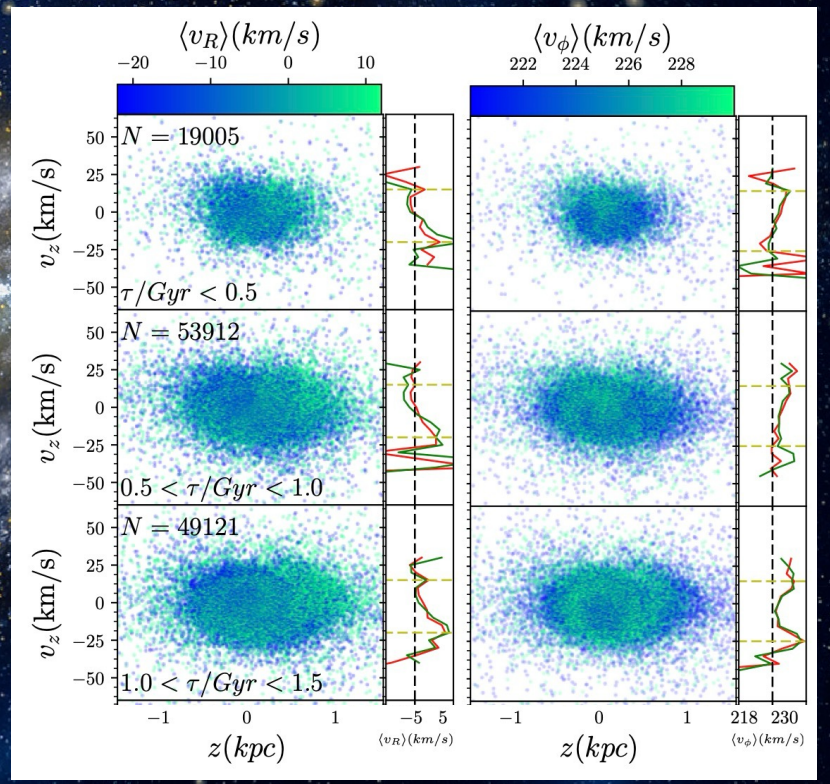
# Exploring the Galactic structures

**perturbed disk**



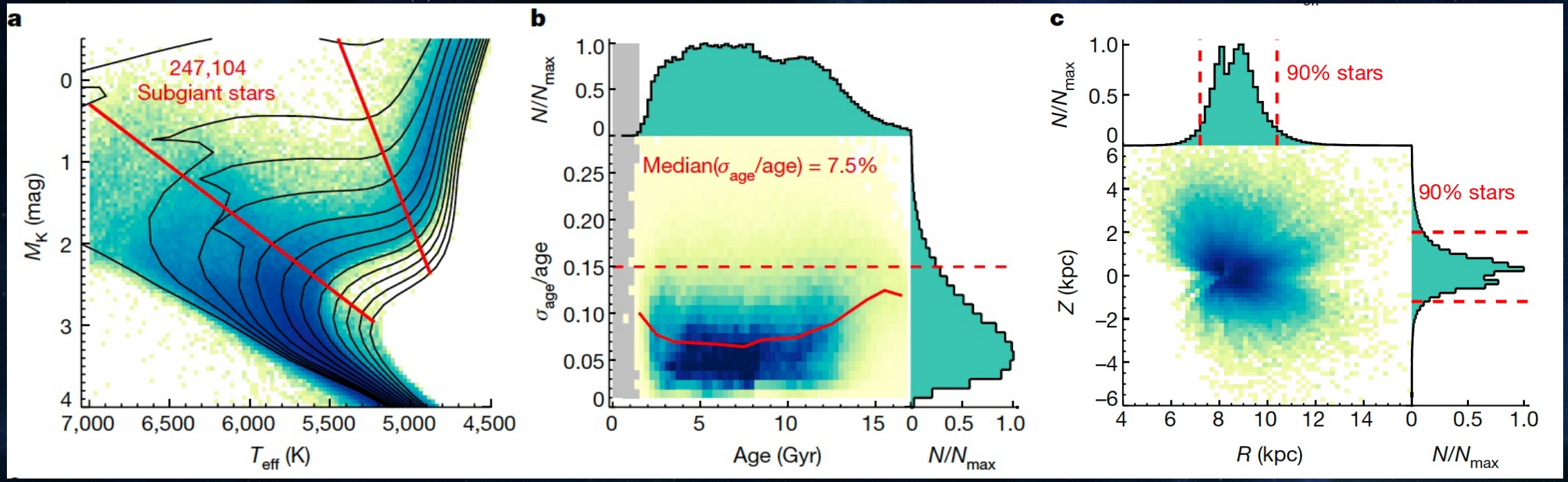
*Tian+2018, ApJ, 865, L19*
*Li+2021, ApJ, 910, 46*
*Xu+2023, ApJ, 956, 13*




- oscillating asymmetry in star counts on either side
- rippled structures appear in stars with all ages
  - ✓ vertical perturbation by a dwarf galaxy within ~0.5 Gyr

# Dating the early Galaxy




250,000 subgiants: LAMOST + Gaia + isochrone age precision to 8%

*Xiang & Rix, 2022, Nature*

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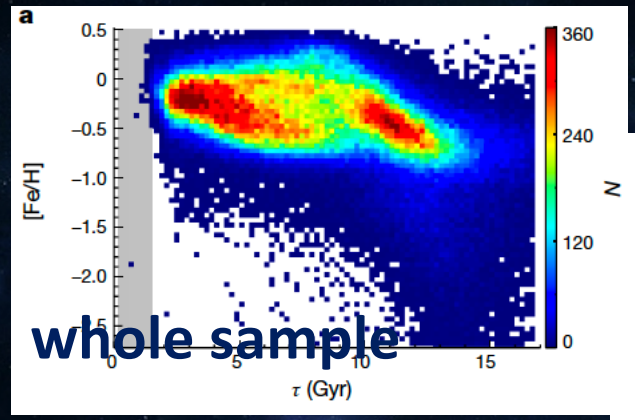
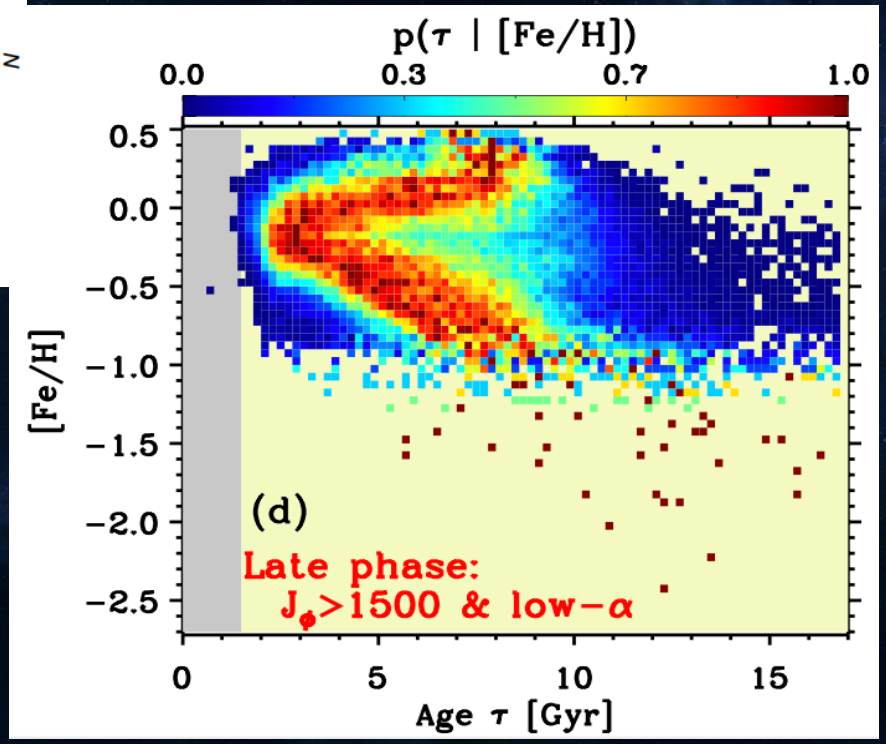
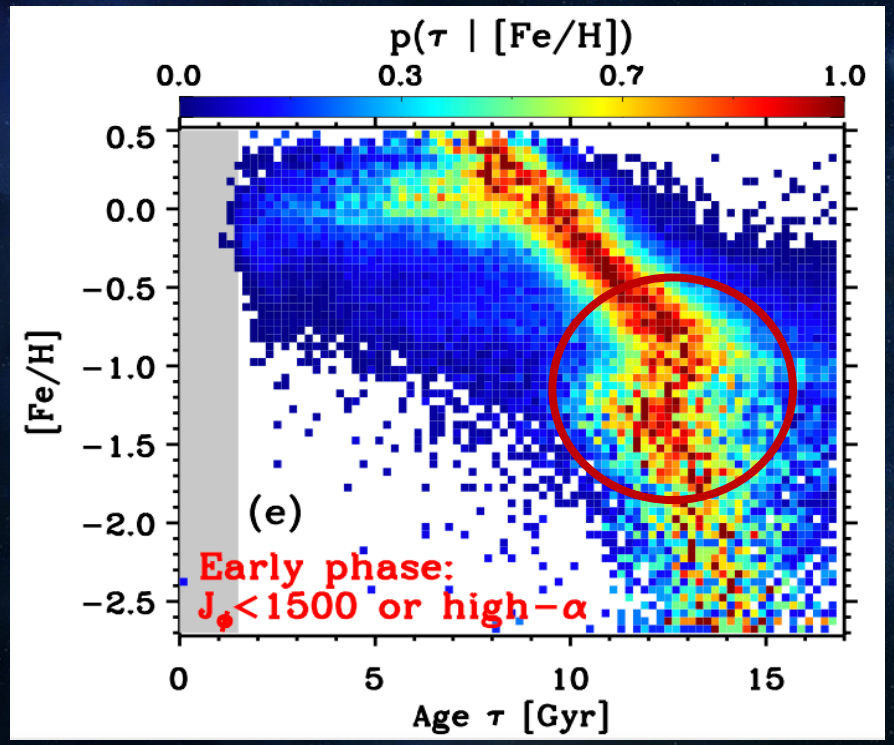



distinct phases of disk formation



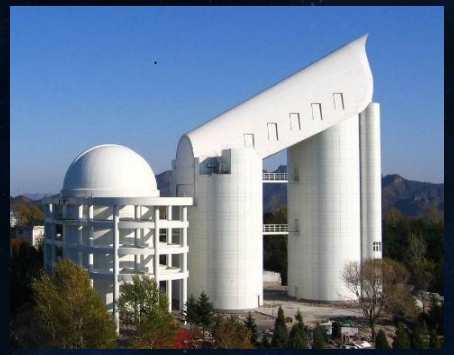

low-α disk: secular evolution, dynamically quiescent (stellar migration)




old/high-α disk: formed around 13Gyr, earlier than the inner halo

*Xiang & Rix, 2022, Nature*

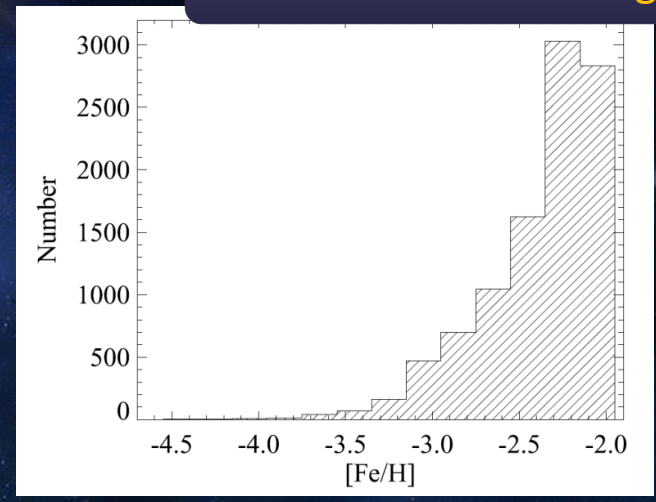
# Dating the early Galaxy

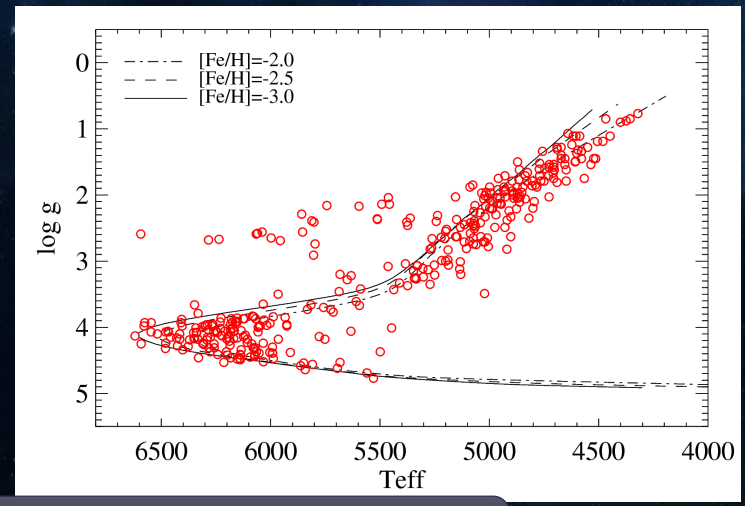


*Li+2018, ApJS*
*Aoki+2022, ApJ*
*Li+2022, ApJ*

- LAMOST target selection
  - ✓ the largest bright 10,000 very metal-poor (VMP) star catalogues
- Subaru/HDS high-resolution follow-up
  - ✓ R>36,000 from 2014-2019
  - ✓ Uniform analysis on ~400 stars for over 20 species

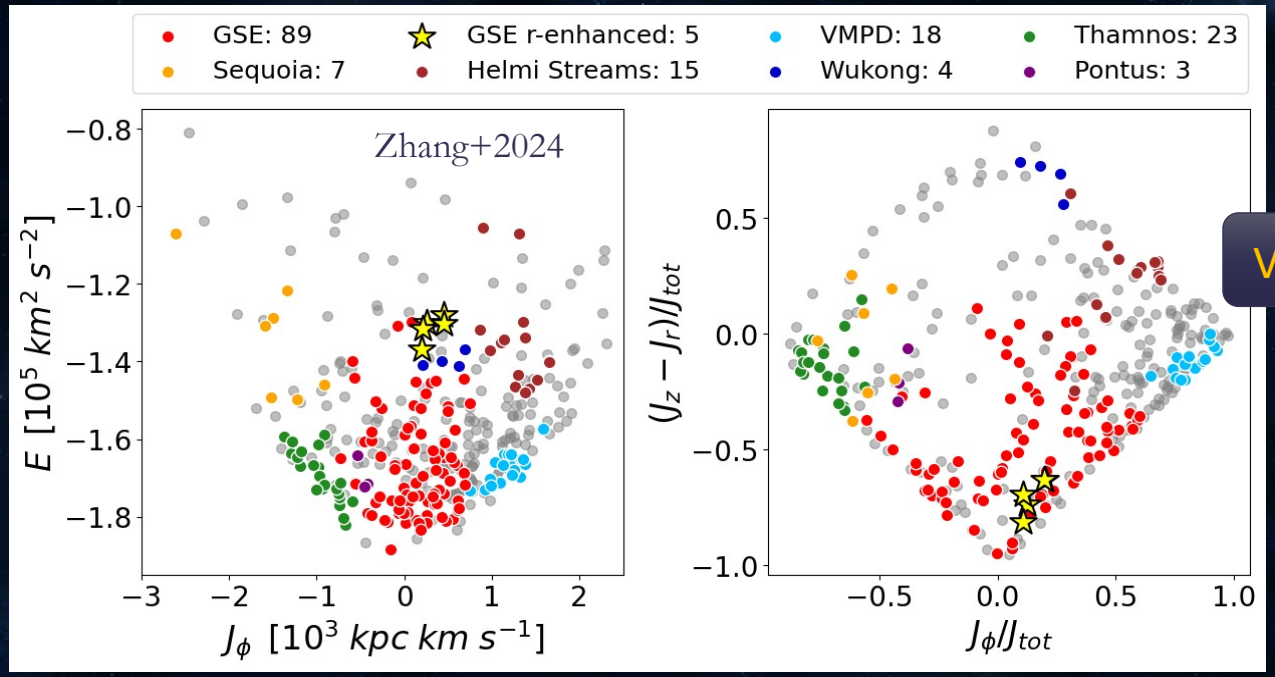
LAMOST VMP catalogue



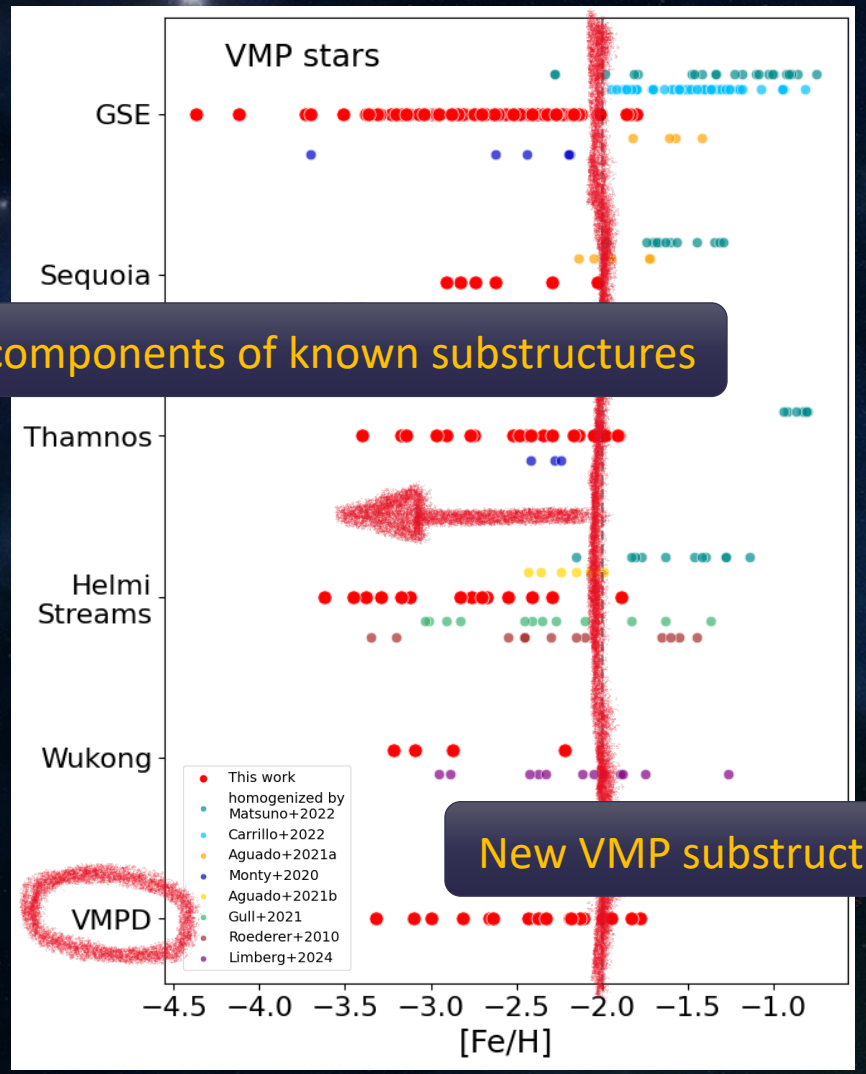




LAMOST/Subaru sample

# Dating the early Galaxy




Over 130 VMP substructures identified using the friend-of-friend algorithm

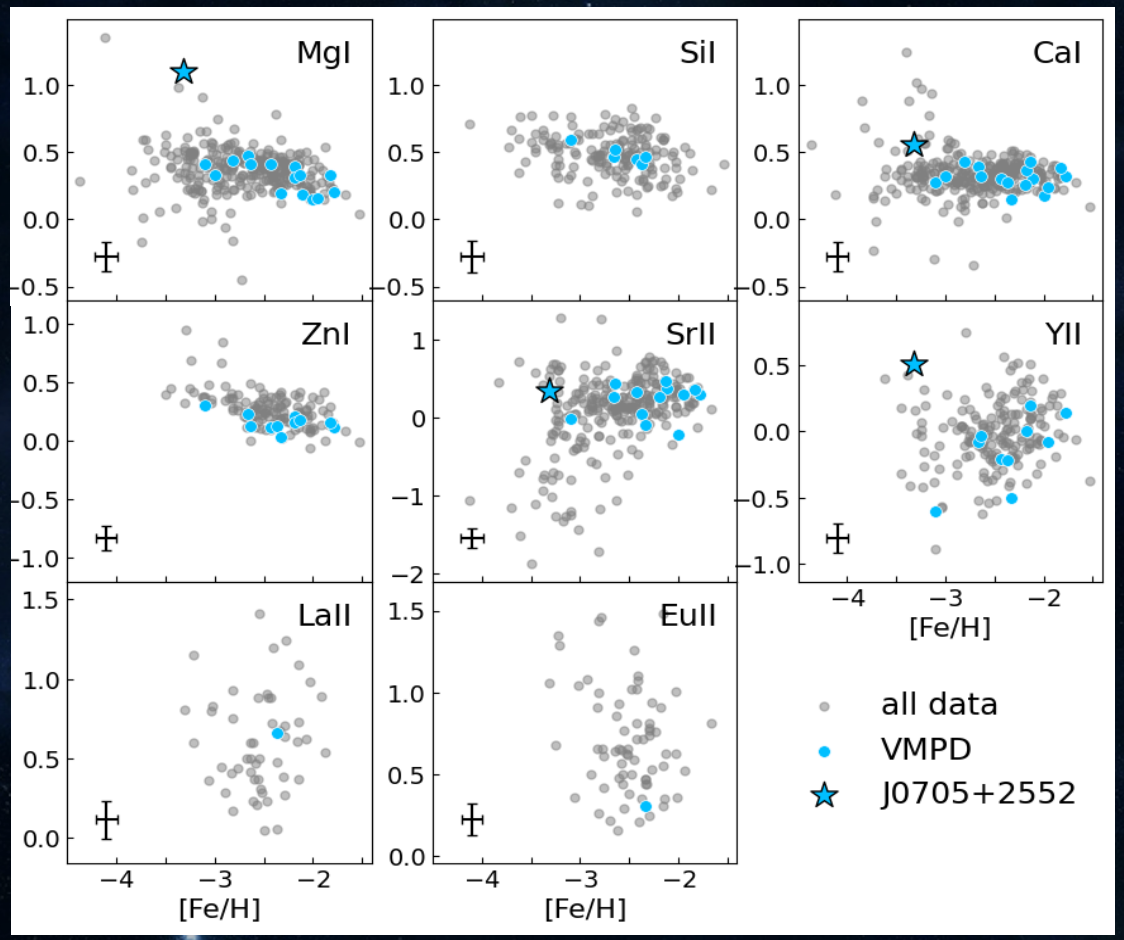



VMP components of known substructures

New VMP substructure

*Zhang+2024, ApJ*

# Dating the early Galaxy

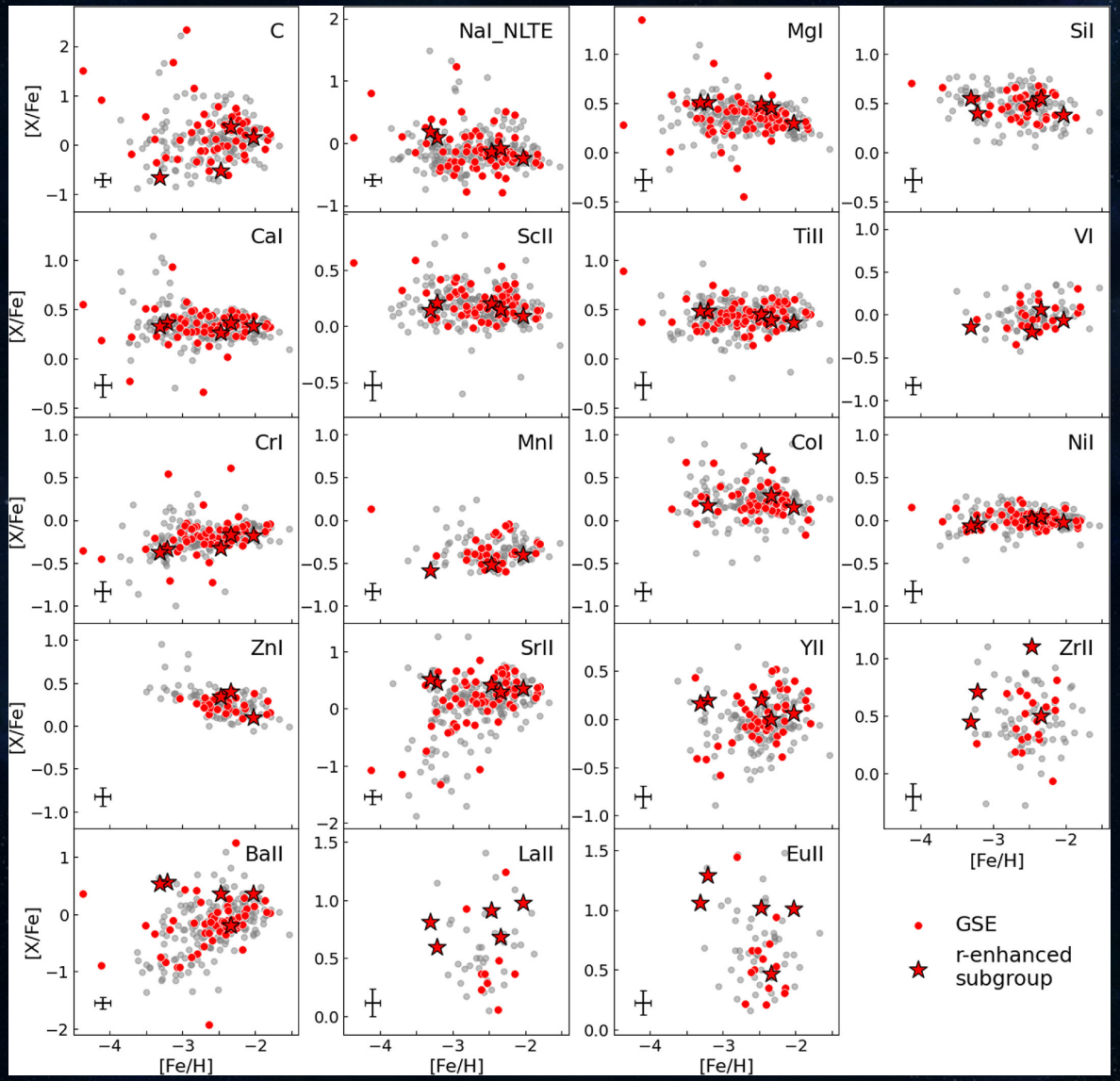



*Zhang+2024*

VMPD (very metal-poor disk)

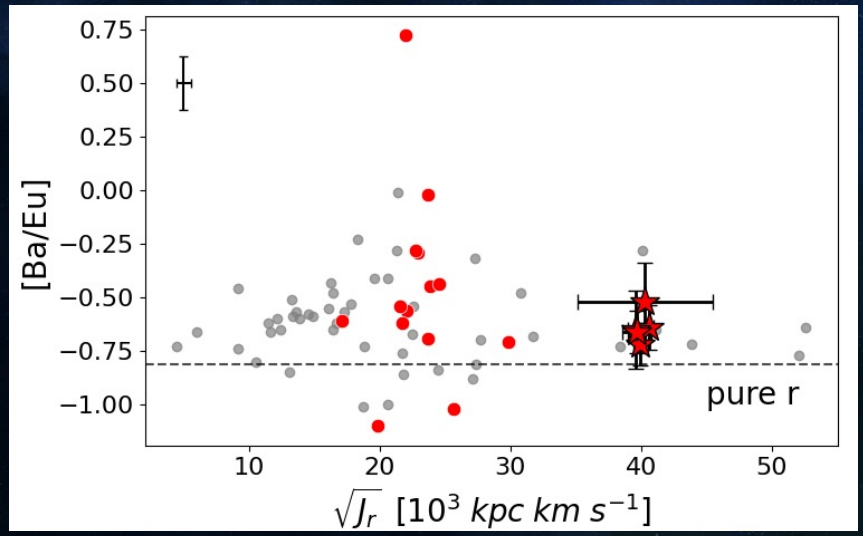
- disk-like kinematics
  - ✓ $v_\phi \sim 130 \pm 40\ km/s$
  - ✓ $z_{max} < 3\ kpc$; $0.25 < ec < 0.60$
- abundances
  - ✓ small scatter
  - ✓ low Zn/Fe
- Low-mass building block of the proto-Galaxy?

# Dating the early Galaxy

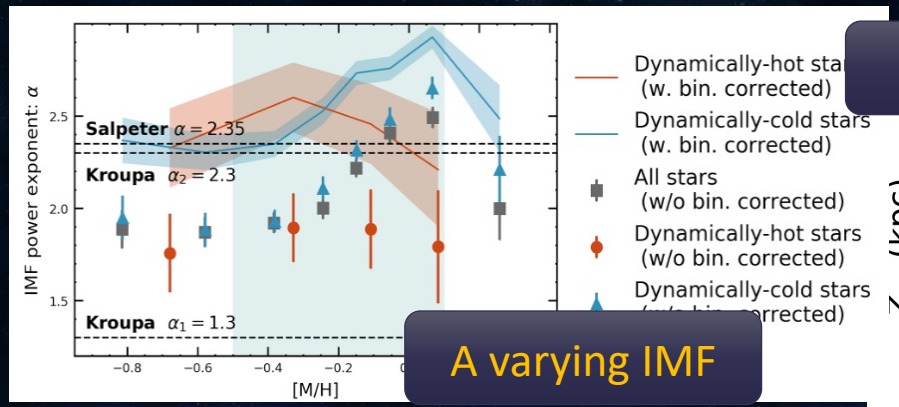



GSE

- Complicated evolution
- An interesting dynamical subgroup
  - ✓ small scatter in abundances
  - ✓ extremely r-process enhanced

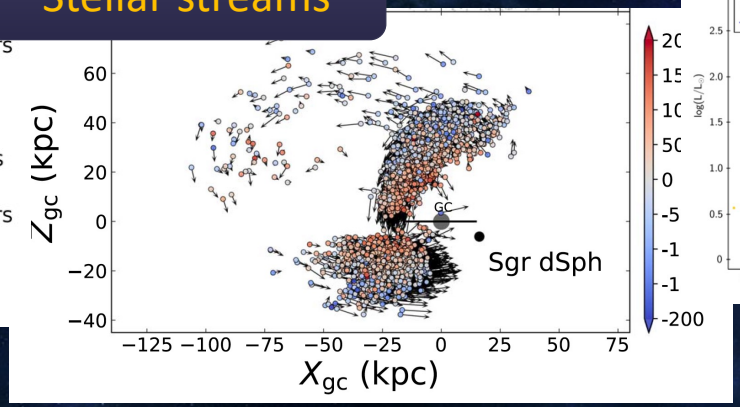


# A lot more to tell …

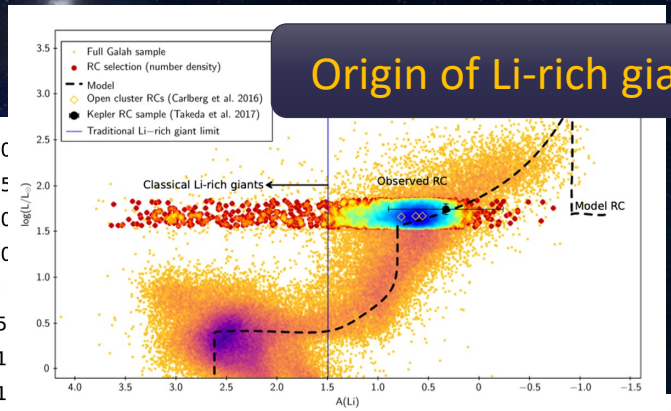


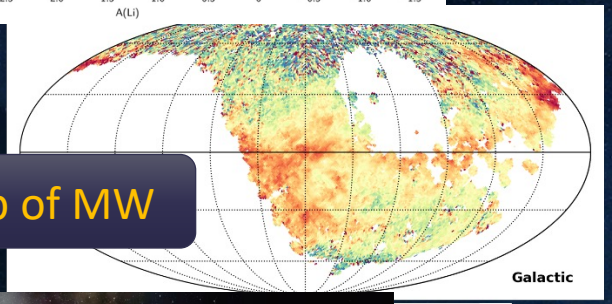

A varying IMF

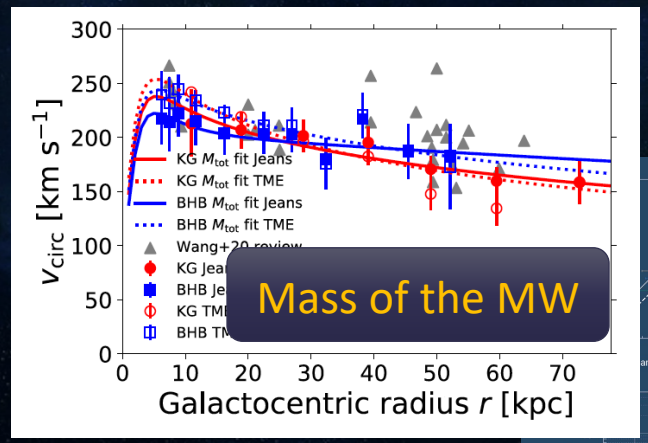
Stellar streams




Origin of Li-rich giants

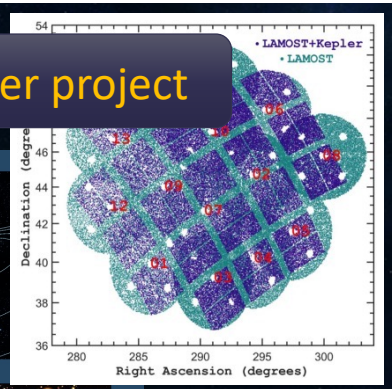


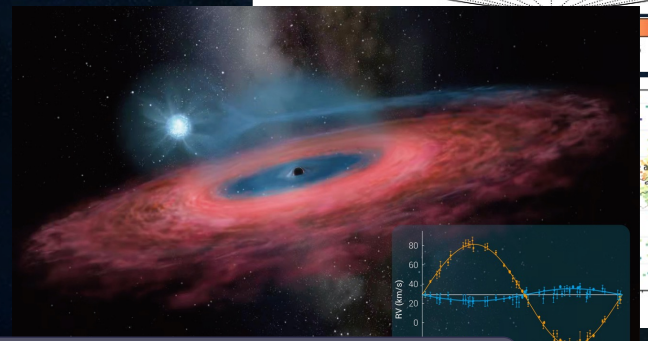



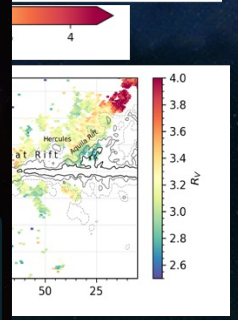




Mass of the MW

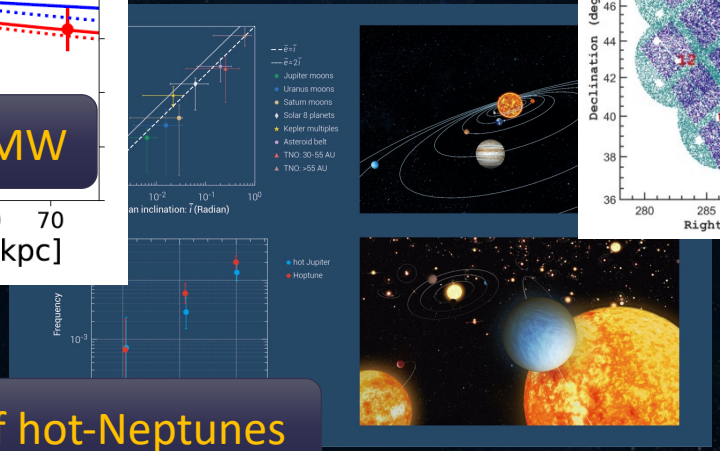
LAMOST-Kepler project






Discovery of massive black-hole

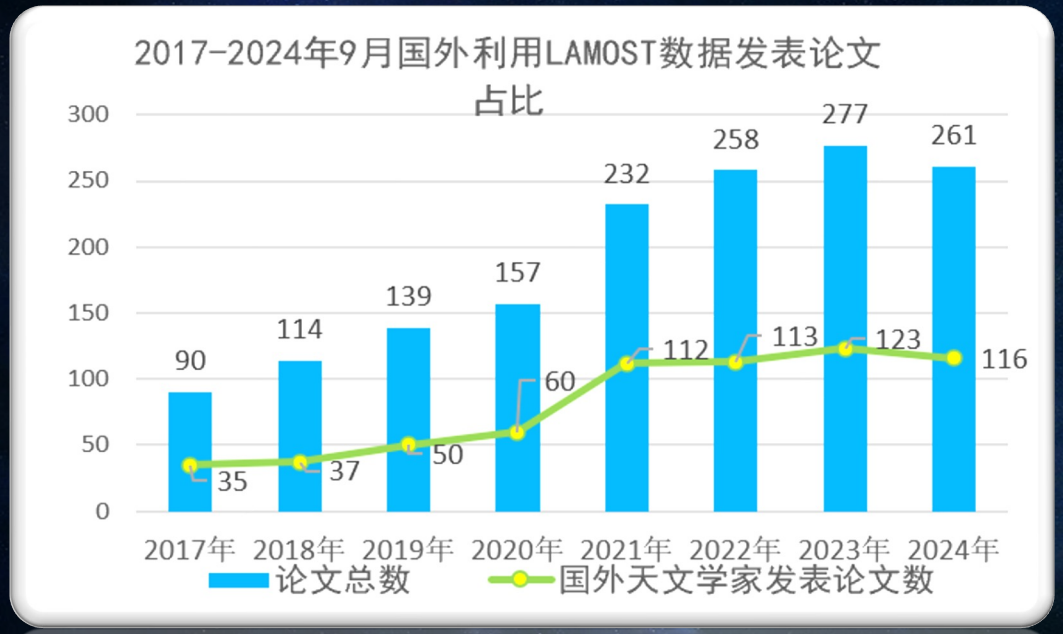



Discovery of hot-Neptunes

# Summary and Prospect

- LAMOST surveying the Milky Way
  - ✓ disk + halo
  - ✓ large number of bright stars
  - ✓ over 20 million stellar spectra

- LAMOST phase III (2023Nov - )
  - ✓ Targets including metal-poor stars, distant giants, young objects, etc.
  - ✓ open to add-on projects and external collaborations




Astronomers from other countries contributed over 40% of LAMOST publications