New insights into the radial and vertical stationary structure of the Milky Way galaxy

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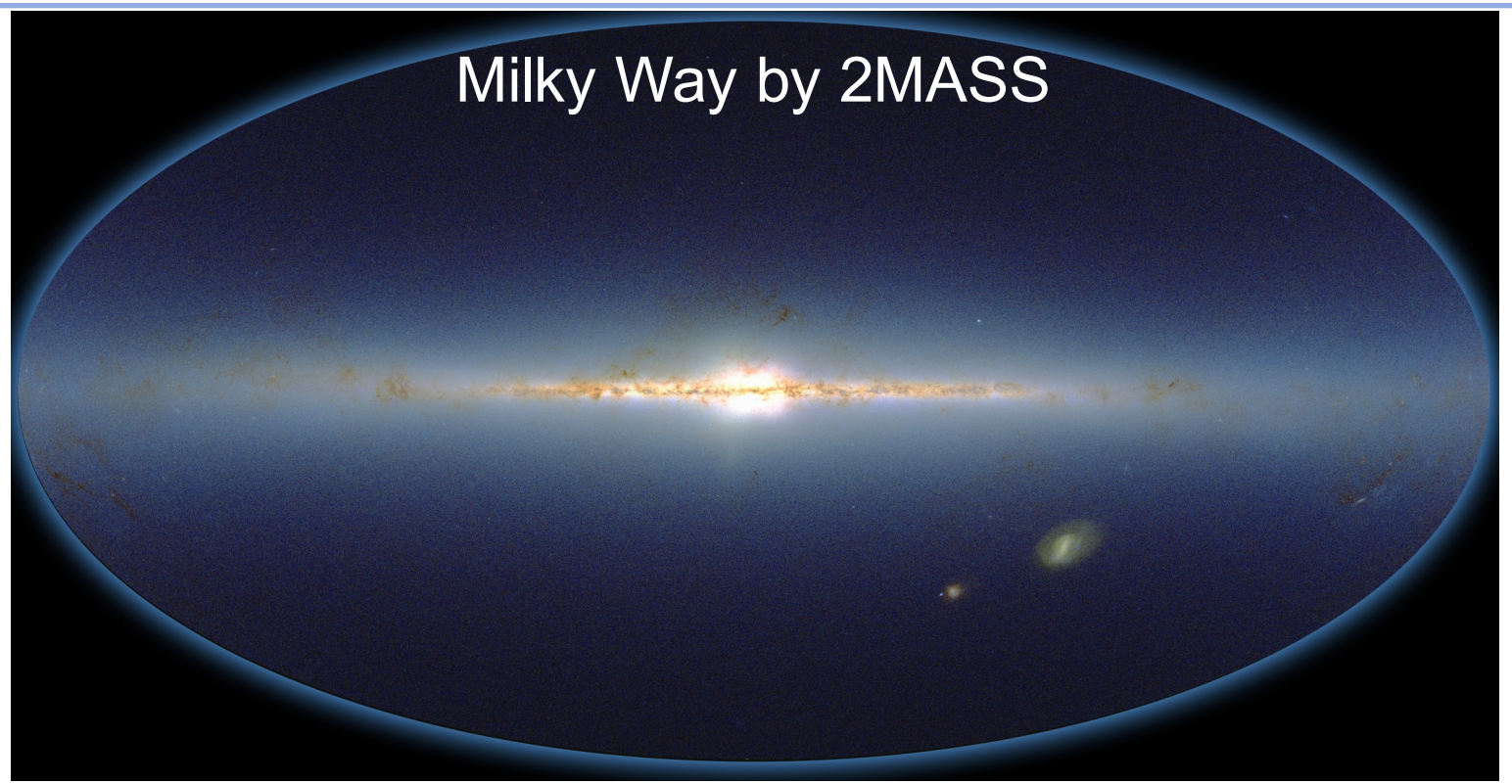
2024-09-14，Milky Way Group Meeting

MW's structure inferred from photometric obs.



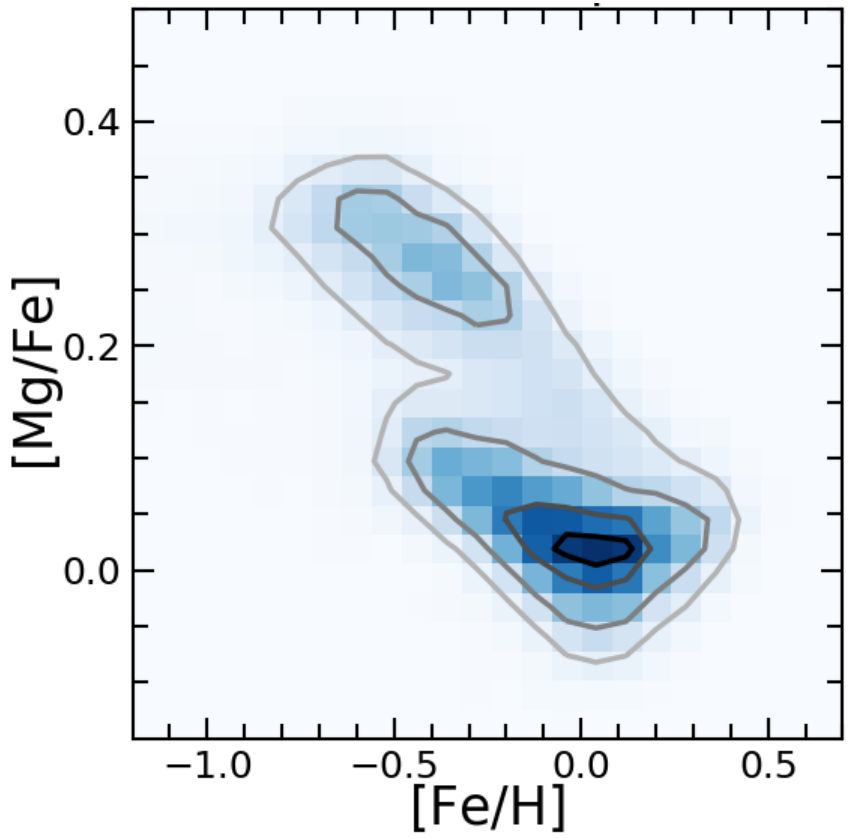
- Bar dominated pseudo bulge
- Dual disk configuration: Thin disk, h_r~2-3 kpc, h_z~300pc;
  Thick disk, h_r~2 kpc, h_z~1kpc. (Bland-Hawthorn & Gerhard ARA&A2016)

MW's structure inferred from spectroscopic obs.

from perspective of mono-abundace populations

Precise distance

+



Forward modelling approach

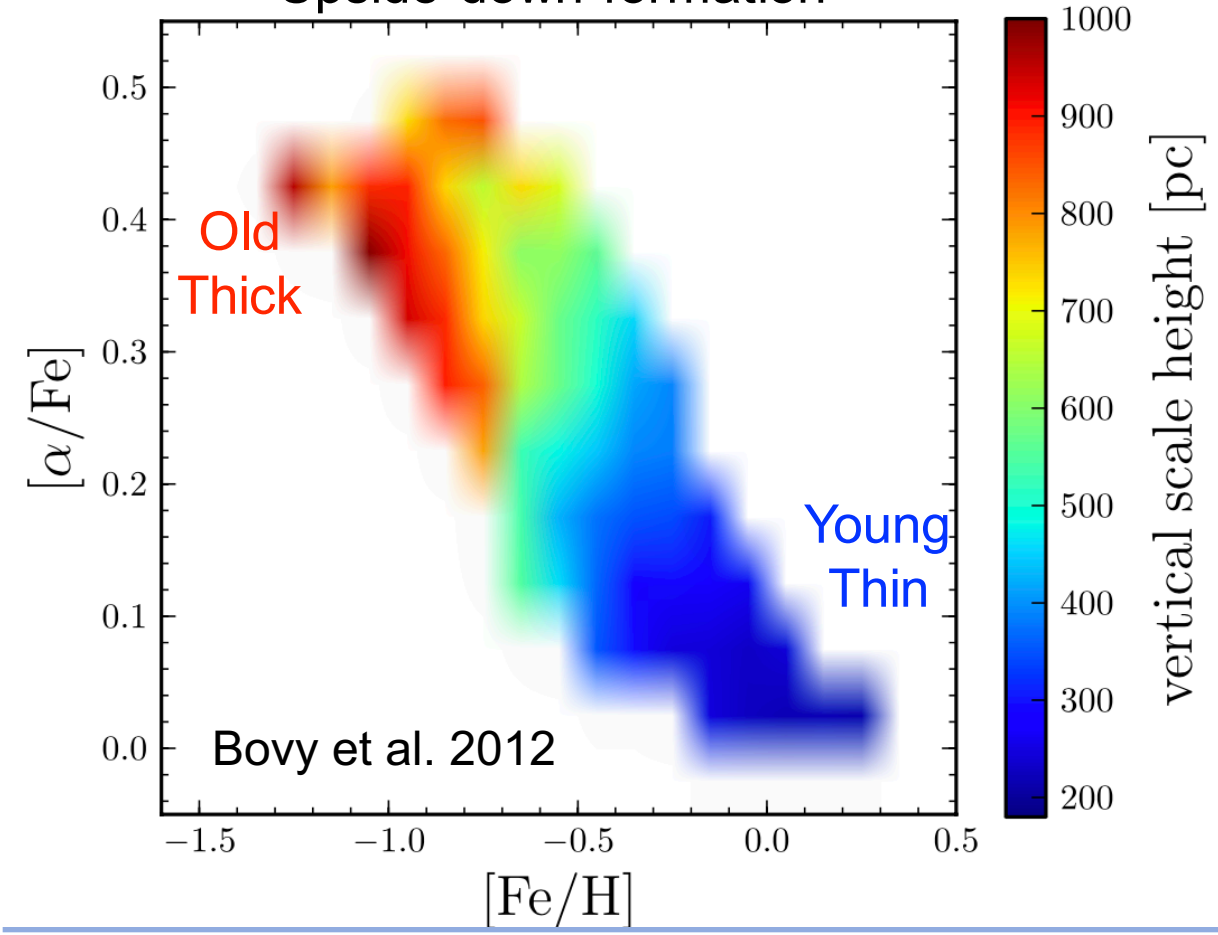
Density model: $\nu_* \propto e^{\frac{R}{h_{R,i}}} e^{\frac{|Z|}{h_Z}}$

Convolving selection function → Predicting observed distribution

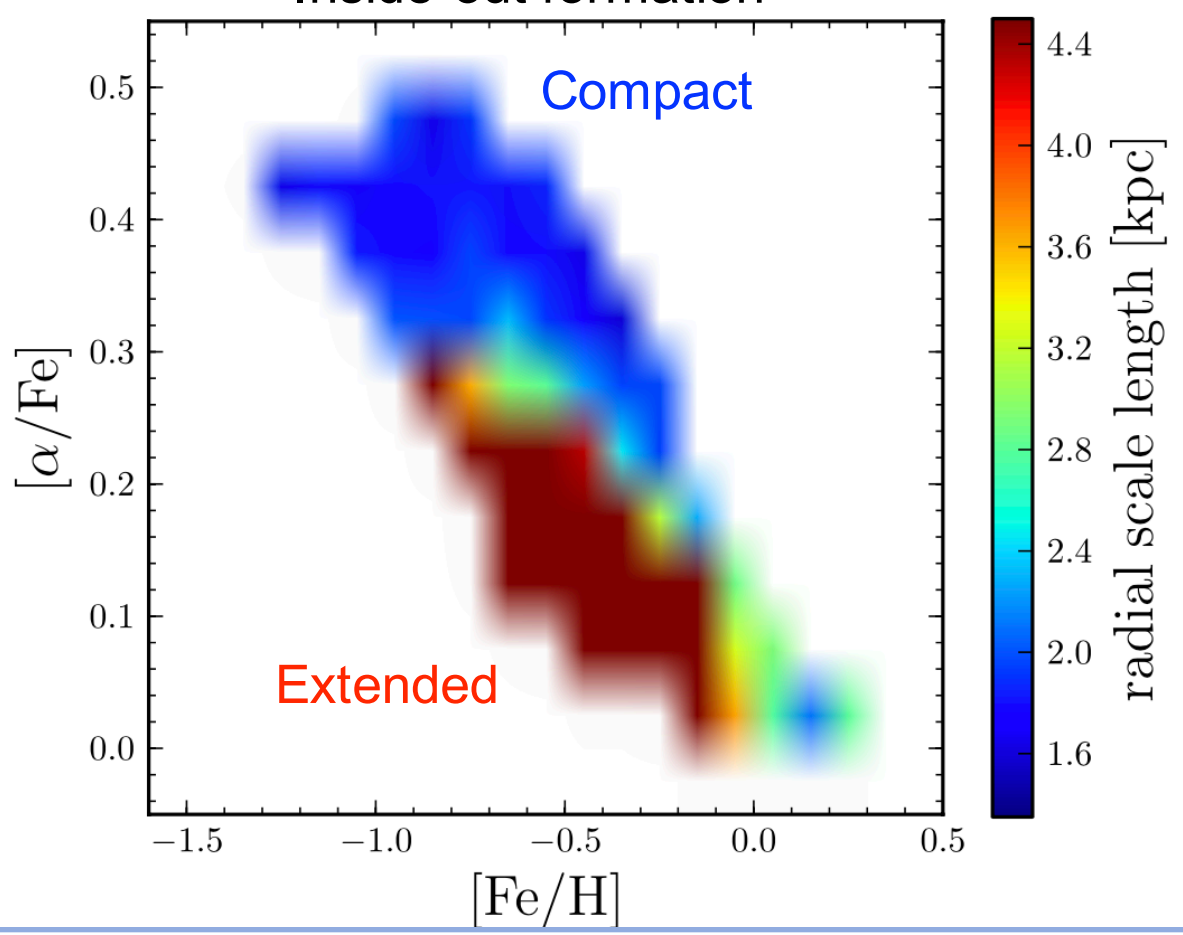
MW's structure inferred from spectroscopic obs.

- High-α: Old/compact/thick, chemical thick disk
- Low-α: Young/extended/thin, chemical thin disk

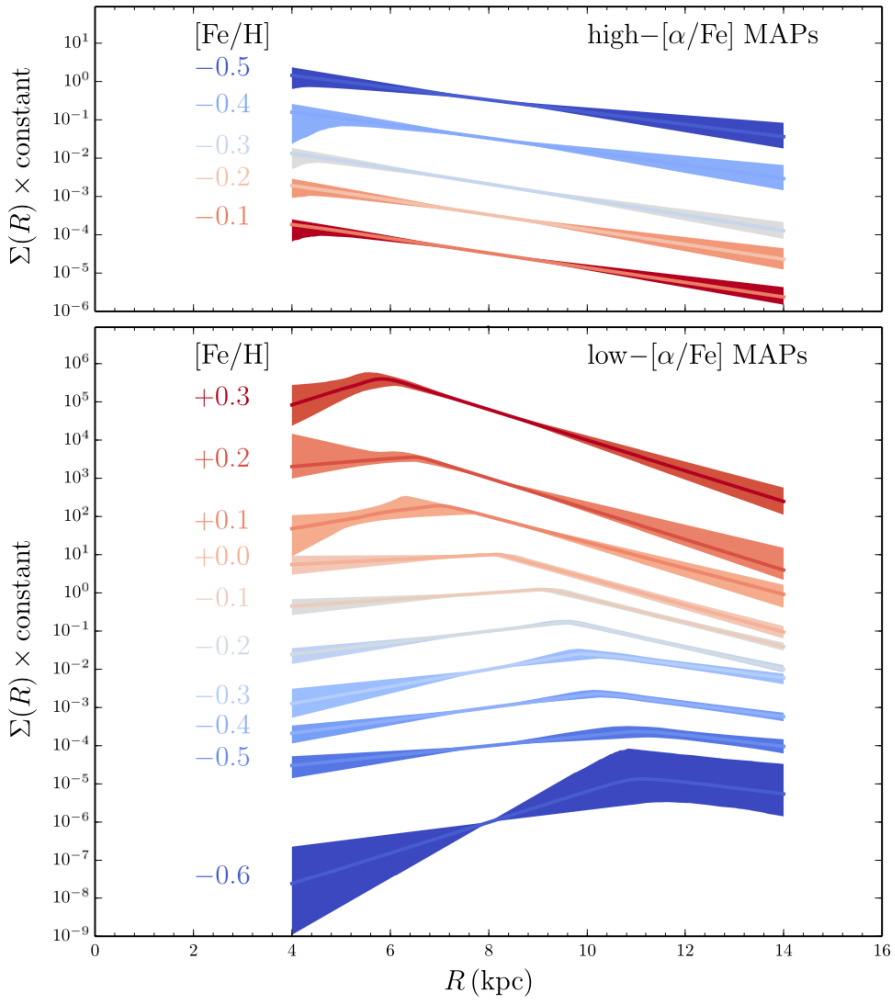
Upside-down formation



Inside-out formation



MW's structure inferred from spectroscopic obs.



Bovy et al. 2016

Broken radial profile:

$$\nu_*(R,Z) \propto \begin{cases} e^{\frac{R}{h_{R,i}}} e^{\frac{|Z|}{h_Z(R)}}, R < R_b \\ e^{\frac{R}{h_{R,o}}} e^{\frac{|Z|}{h_Z(R)}}, R > R_b \end{cases}$$

Flaring disk (Alard 2000, Yusifov 2004, Kalberla et al. 2014, Lopez-Corredoira+20014, Minchev et al. 2015):

$$h_Z(R) \propto e^{R_{flare}^{-1} R}$$

APOGEE selection function

Direct approach:

$\rho_{\mathrm{APOGEE}}(\alpha, Fe, glon, glat, r)$ → (Correct f_{eff}) → $\rho_{\mathrm{intrinsic}}(\alpha, Fe, glon, glat, r)$

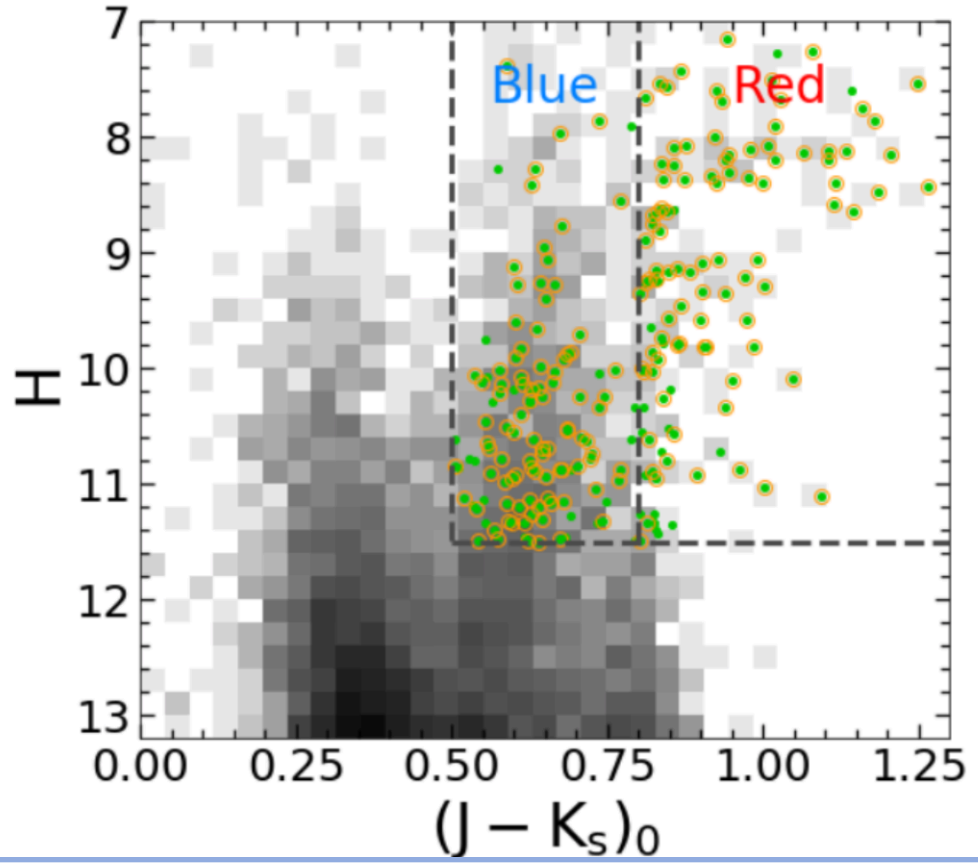
Observations

Goal

For a given MAP at a given 3D position:

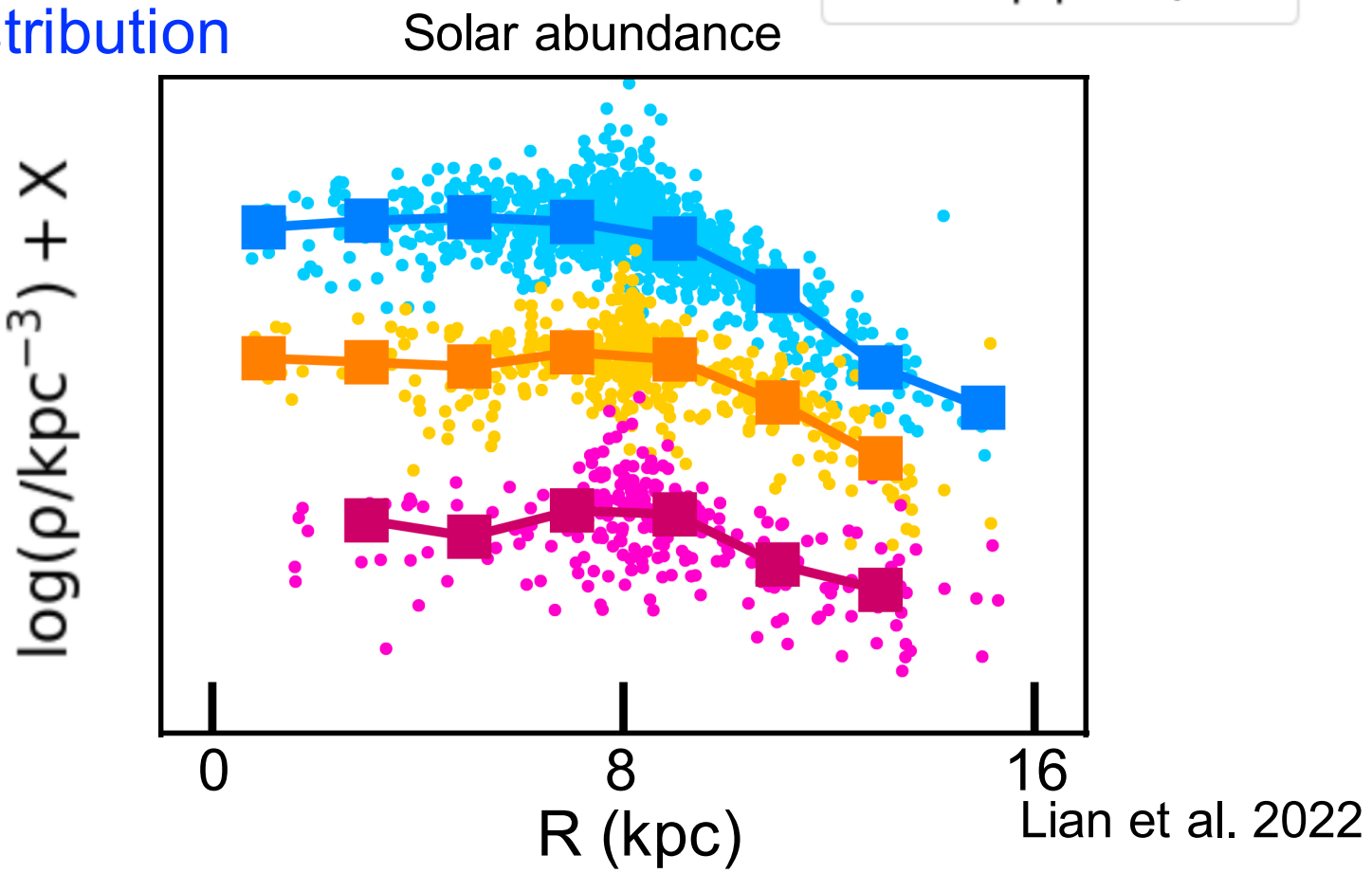
$$f_{eff} = f_{CMD} \times f_{random}$$

$$\rho_{intrinsic} = \rho_{APOGEE} / f_{eff}$$



Radial structure of mono-abunance populations

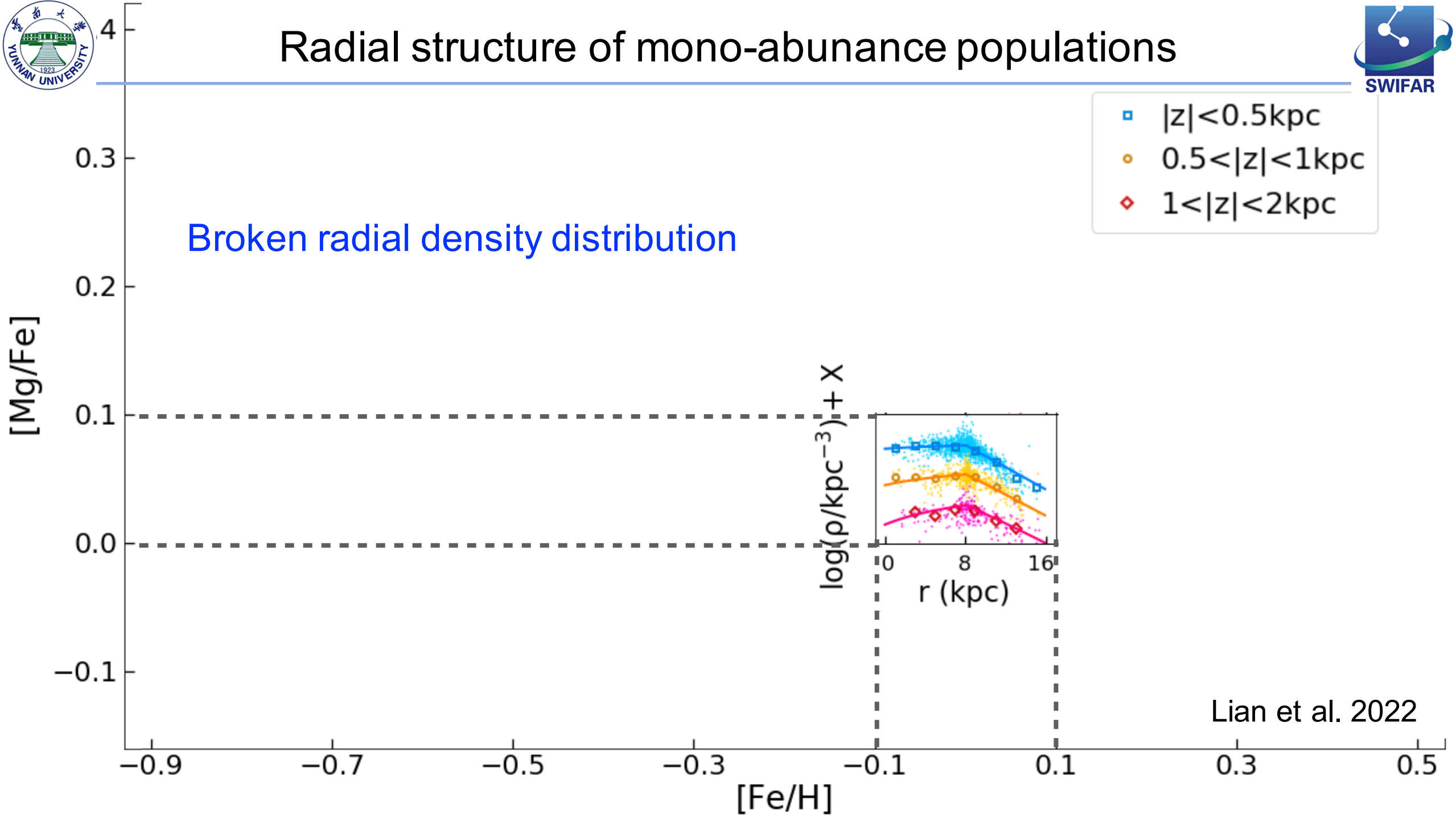
Broken radial density distribution

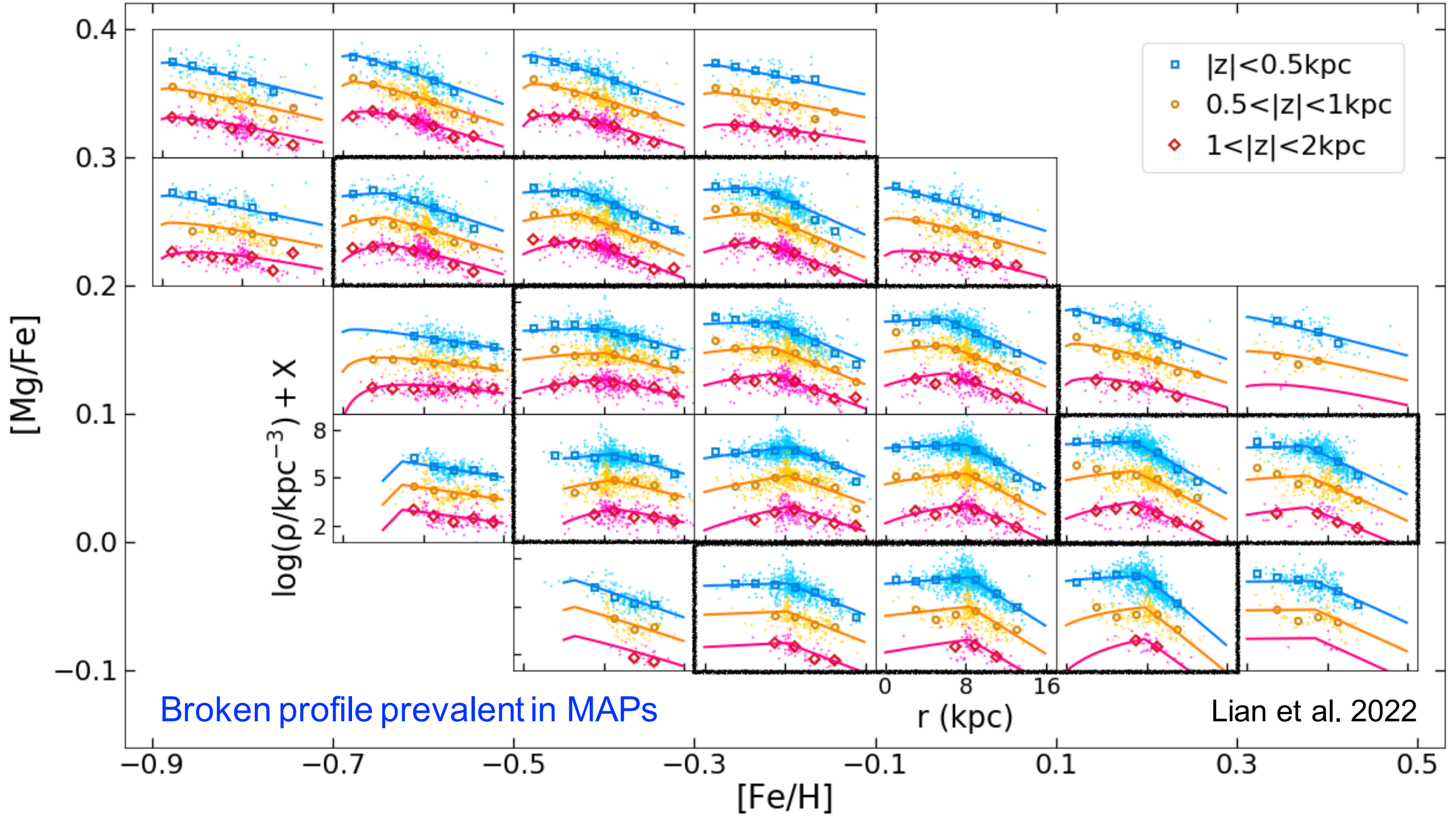


Lian et al. 2022

Radial structure of mono-abunance populations

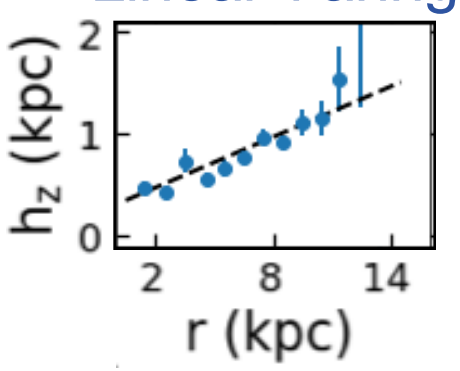
Broken radial density distribution




|z|<0.5kpc
0.5<|z|<1kpc
1<|z|<2kpc
[Mg/Fe]
[Fe/H]
log(ρ/kpc^{-3}) + X
r (kpc)
Broken profile prevalent in MAPs
Lian et al. 2022

Vertical structure of mono-abunance populations

Linear flaring

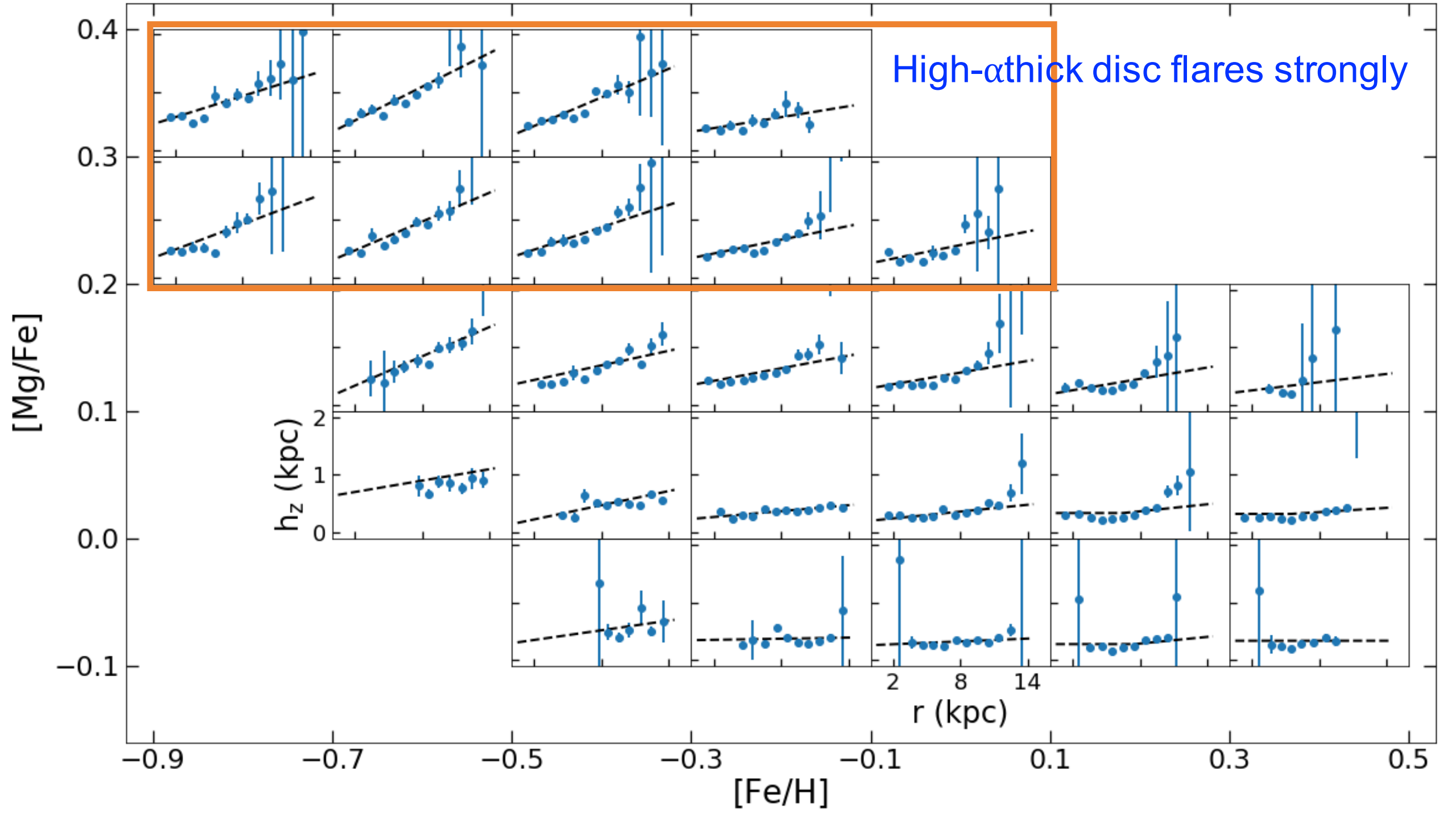


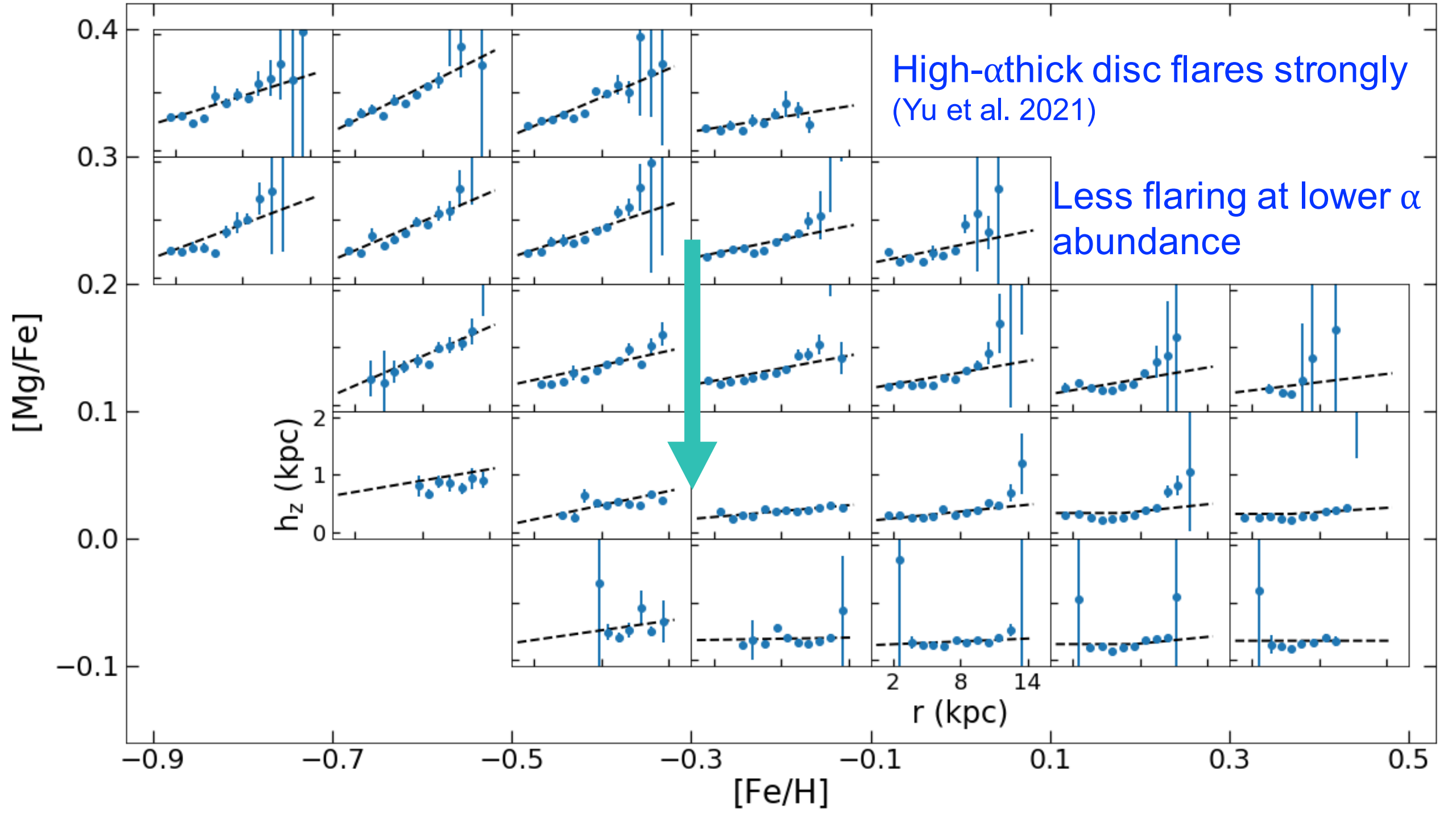
[Mg/Fe]

0.4
0.3
0.2
0.1
0.0
−0.1

−0.9 −0.7 −0.5 −0.3 −0.1 0.1 0.3 0.5

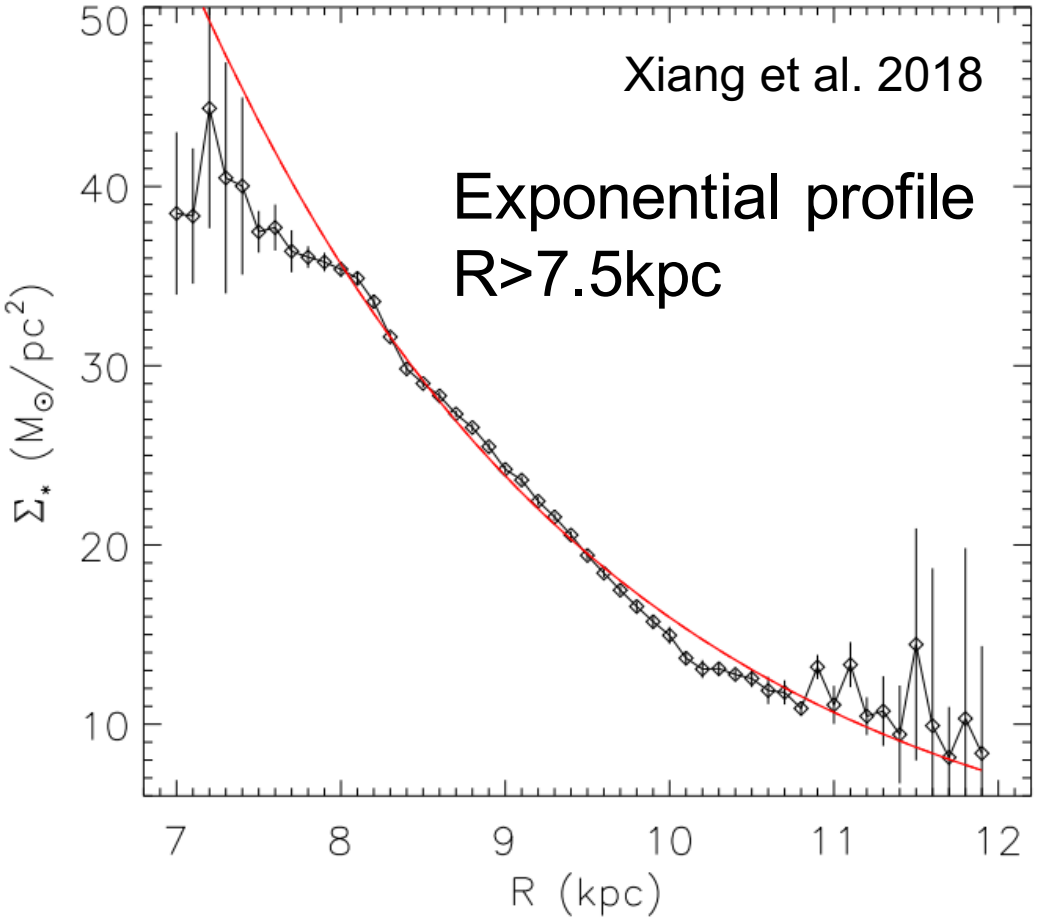
[Fe/H]


High-αthick disc flares strongly
[Mg/Fe]
[Fe/H]
h_z (kpc)
r (kpc)
0.4
0.3
0.2
0.1
0.0
−0.1
−0.9
−0.7
−0.5
−0.3
−0.1
0.1
0.3
0.5
2
1
0
2
8
14

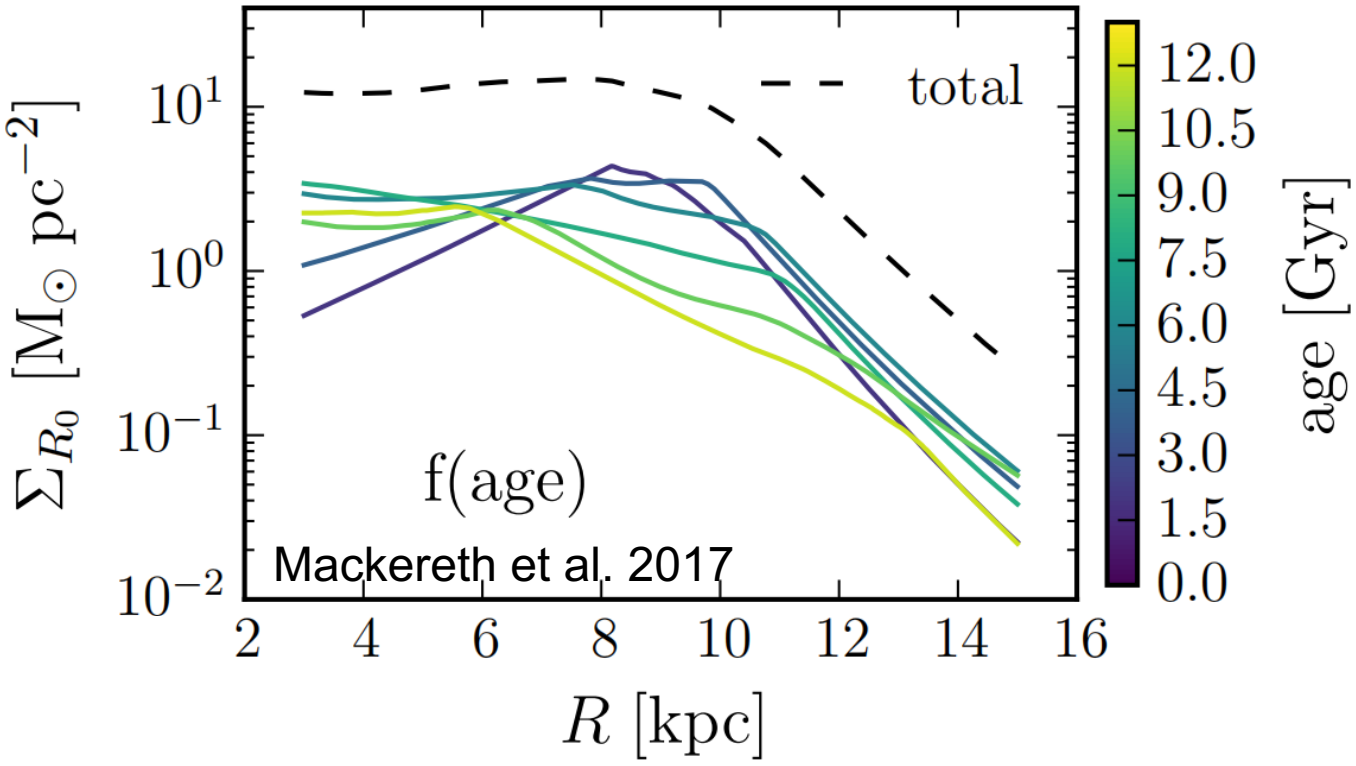

High-αthick disc flares strongly
(Yu et al. 2021)
Less flaring at lower α abundance
[Mg/Fe]
[Fe/H]
r (kpc)
h_z (kpc)
0.4
0.3
0.2
0.1
0.0
−0.1
−0.9
−0.7
−0.5
−0.3
−0.1
0.1
0.3
0.5
2
8
14
0
1
2

Milky Way's surface brightness profile (previous works)

LAMOST data

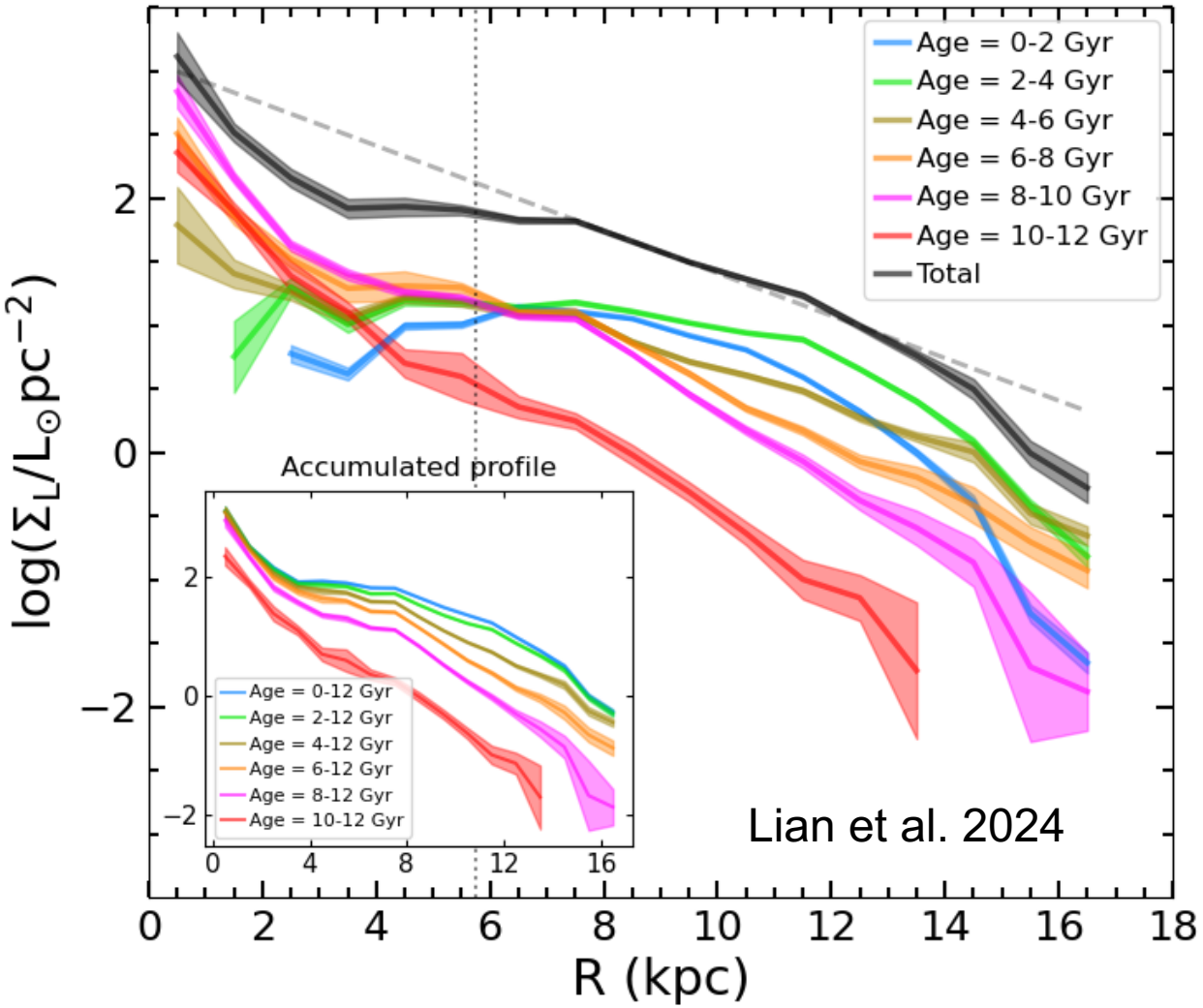


APOGEE early data + forward modelling



Inner flattening, R > 3kpc
Model dependent

Milky Way's surface brightness profile (our work)



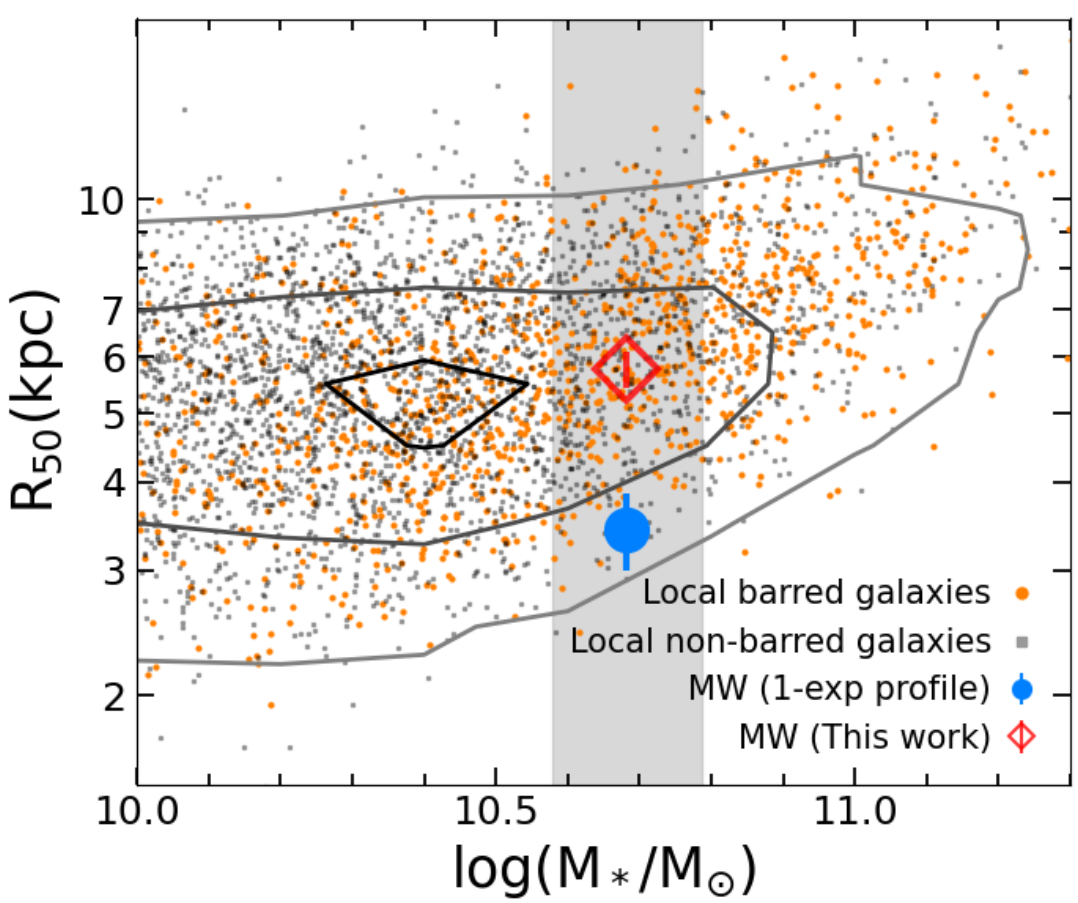
- Complete from R=0-17 kpc
- Inner flattening in 3.5-7.5 kpc
- Exponential of old pop.
- More extended of younger pop. (inside-out growth)

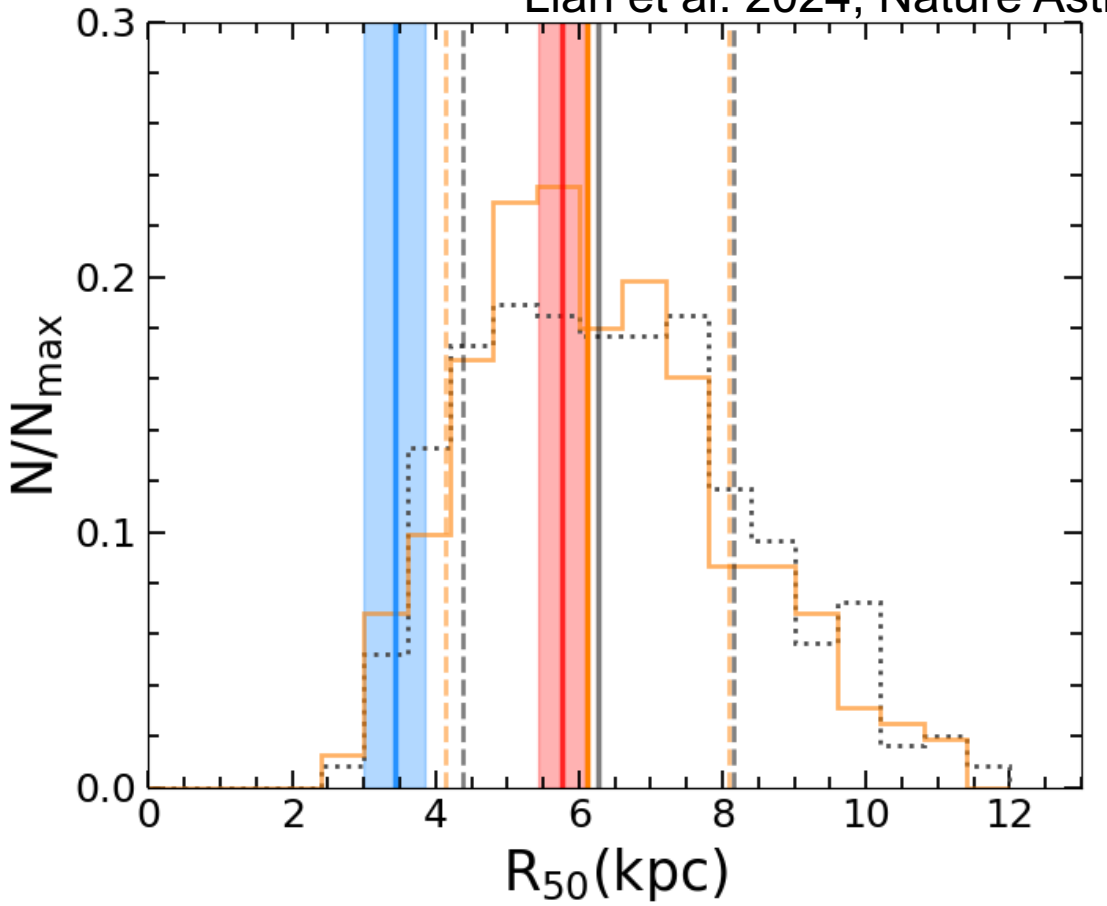
Scale length is invalid, half-light radius, R_{50}, is a better quantity for galaxy size

Milky Way in mass-size plane

- Milky Way half light radius, R_{50} = 5.75 ± 0.38 kpc.
- Previously thought compact, but normal in this work.

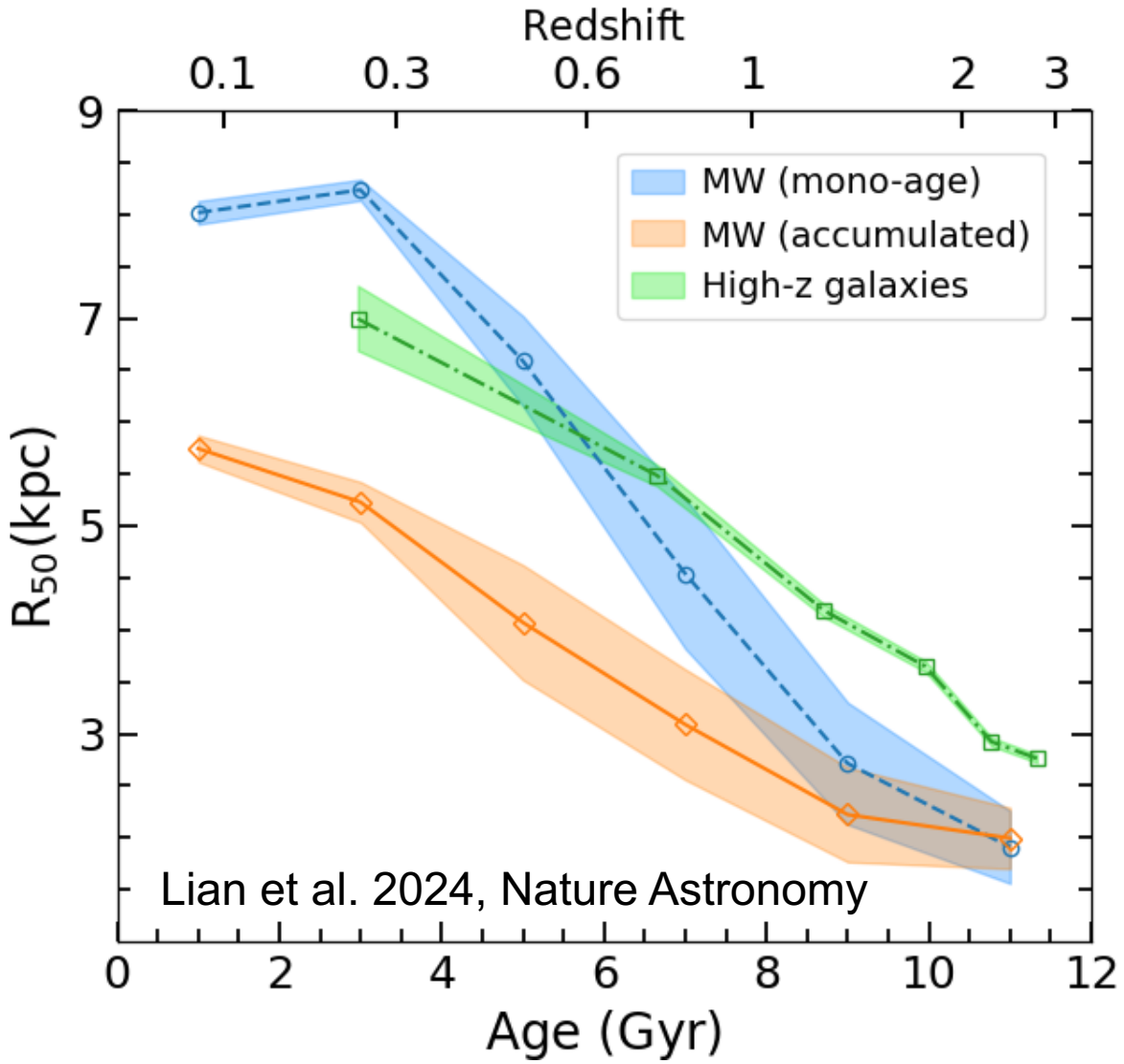
Lian et al. 2024, Nature Astronomy



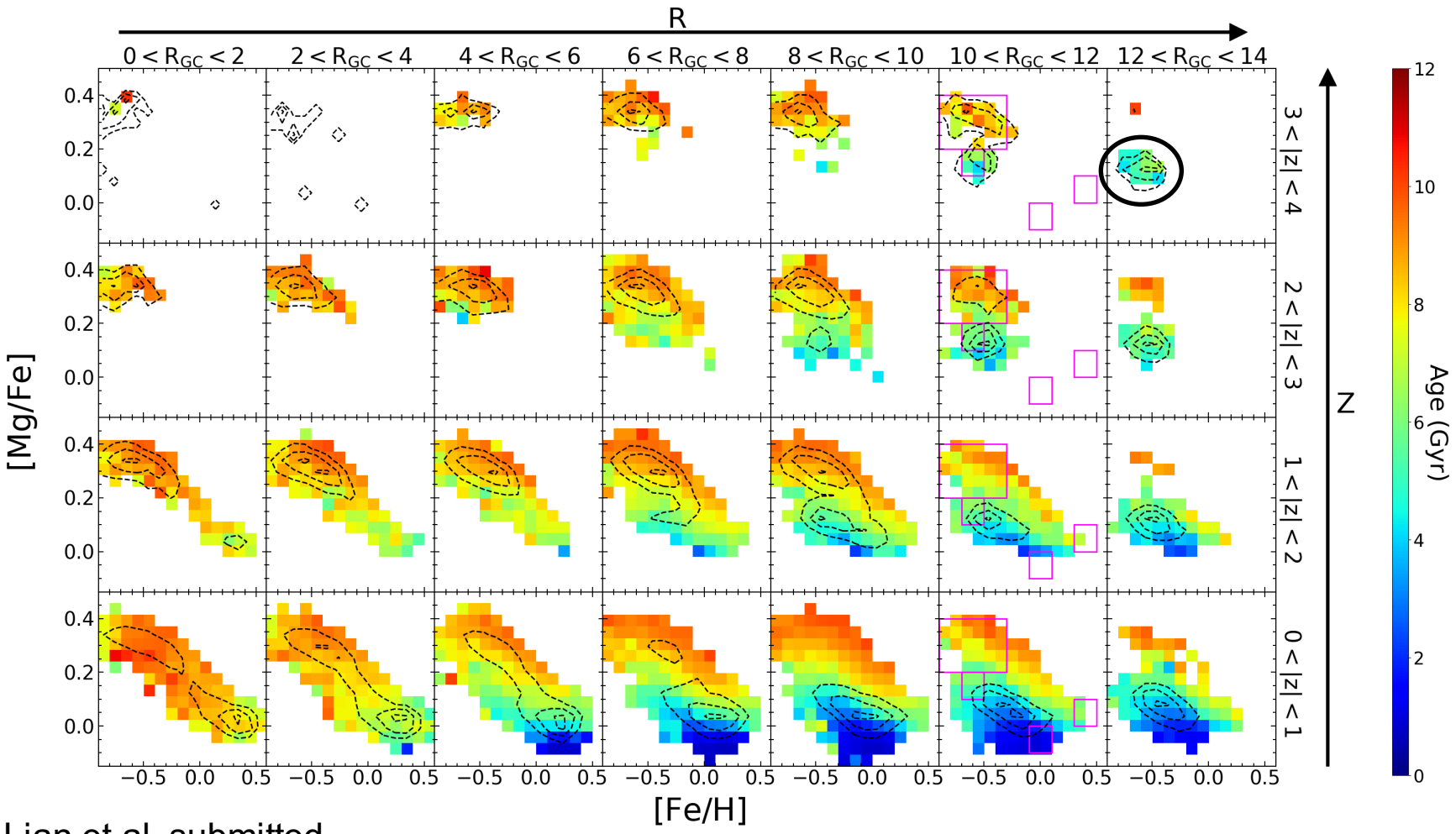


Milky Way size growth history

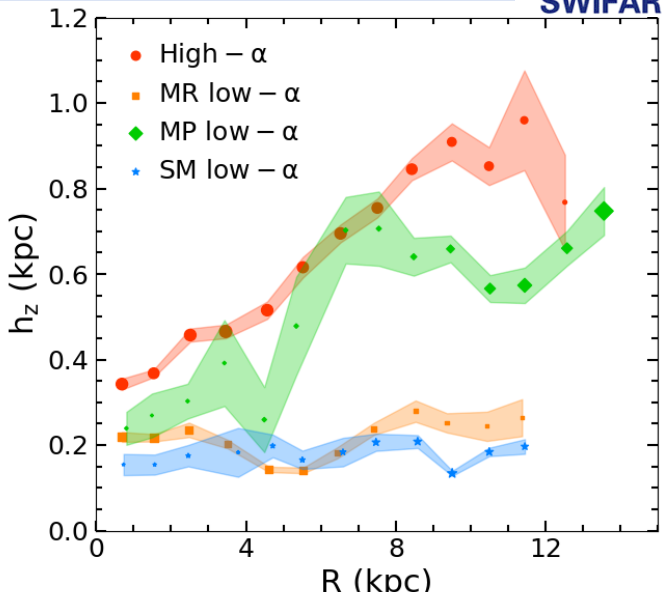
- Consistent size growth history, but systematically smaller
- Stop of inside-out growth several Gyr ago

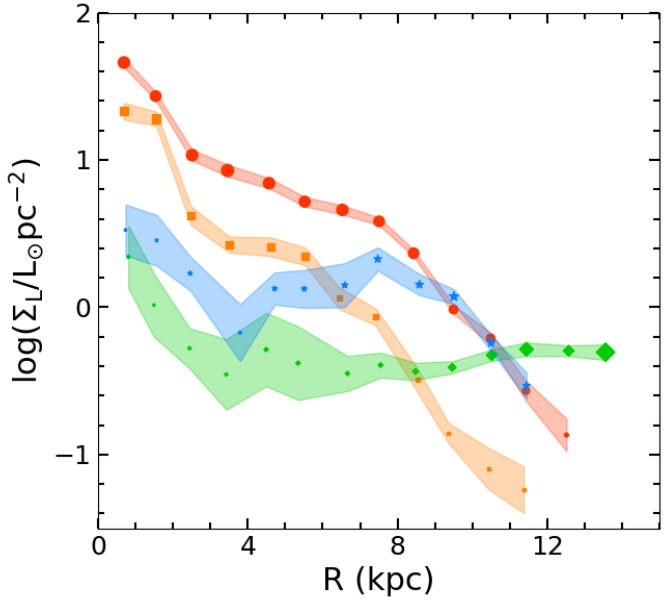


Unveailing a young thick disk in the Milky Way



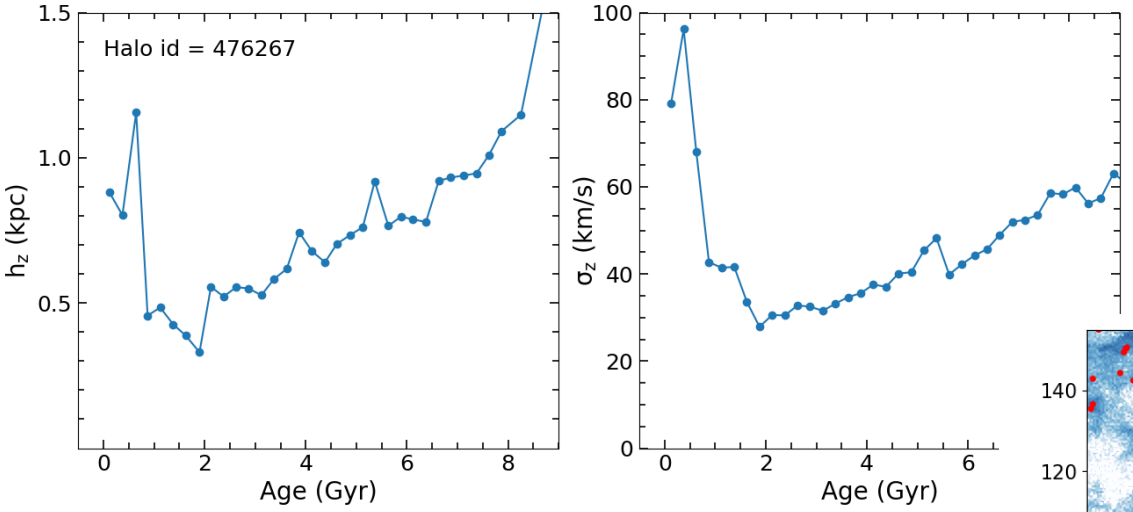
Lian et al. submitted





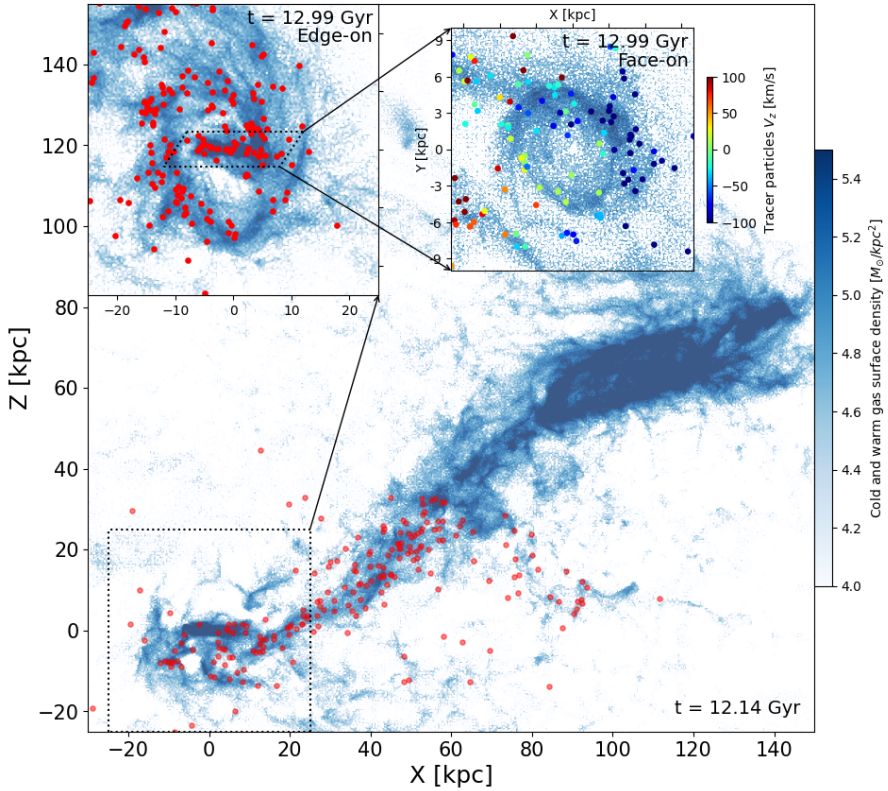
Metal-poor end of low-α(~6.6 Gyr):
a young thick disk population?

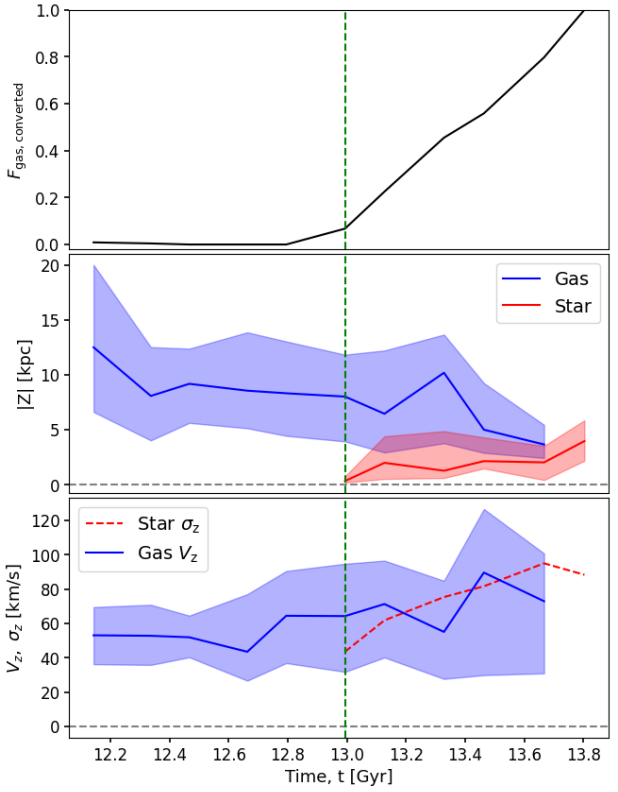
A young thick disk in a TNG50 galaxy



Large h_z and velocity dipersion caused by disturbance by infalling gas with large Vz

Sgr dwarf galaxy likely supply the gas with larger Vz and form the young thick disk.



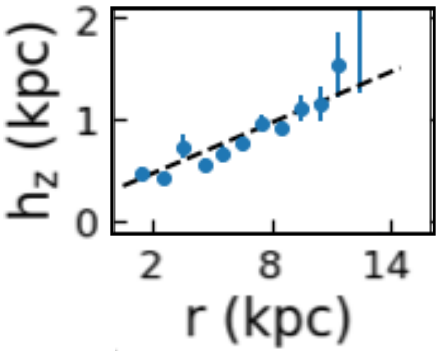


Summary

- Milky Way's disc structure varies dramatically with abundances.

  The (high-α) thick disc is compact with strong flaring

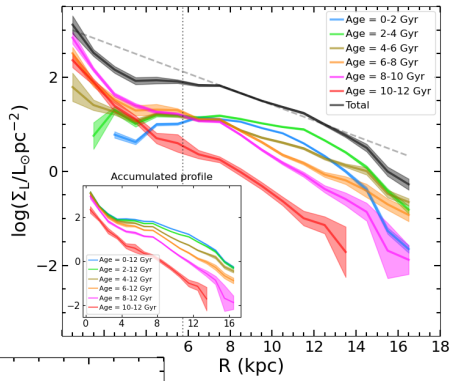
  The (low-α) thin disc is more extended with weak to mild flaring



- Broken radial profile and larger size of the Milky Way.

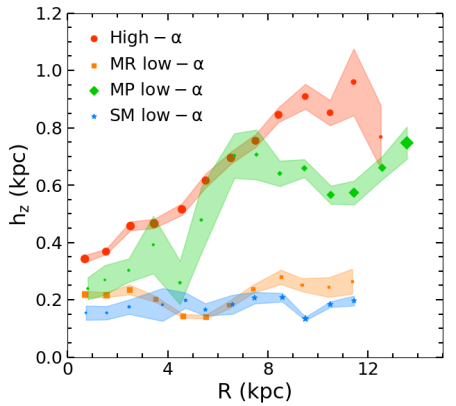
  Inner flattening within 3.5-7.5 kpc

  Half light radius of 5.75 kpc, larger than previously expected but normal in similar mass disk galaxies.

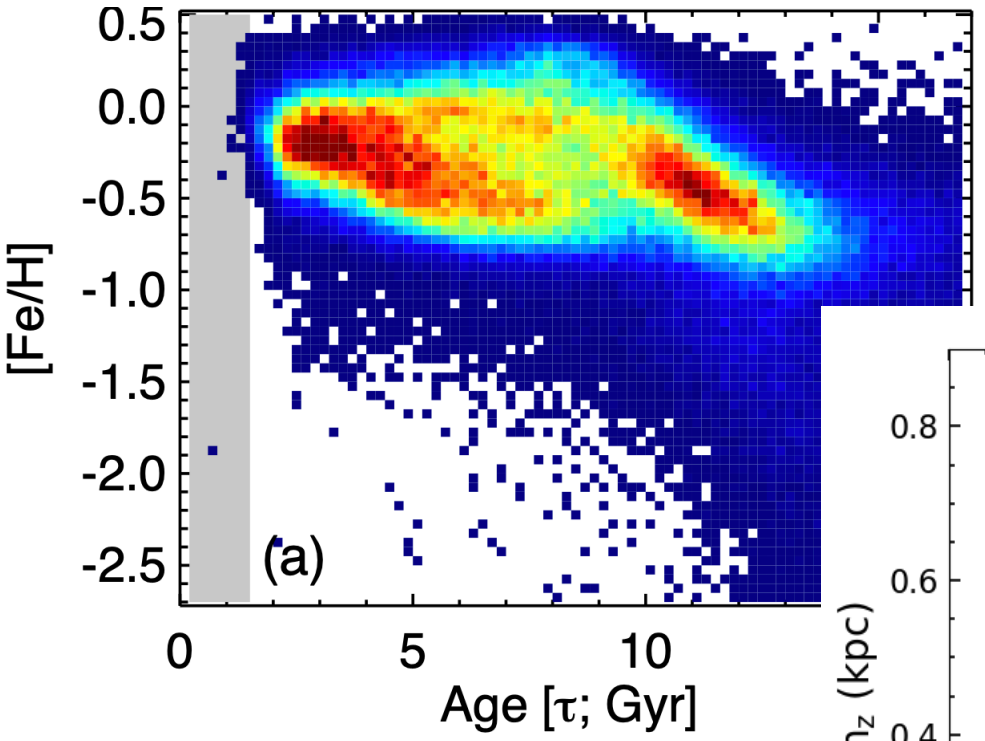


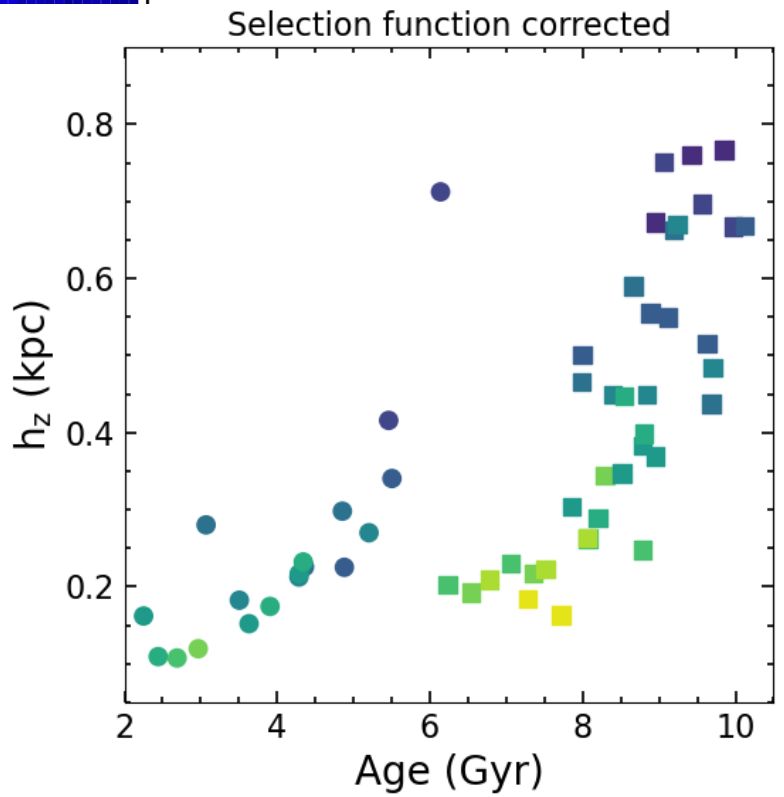
- Unveiling a young thick disk population of the Milky Way.

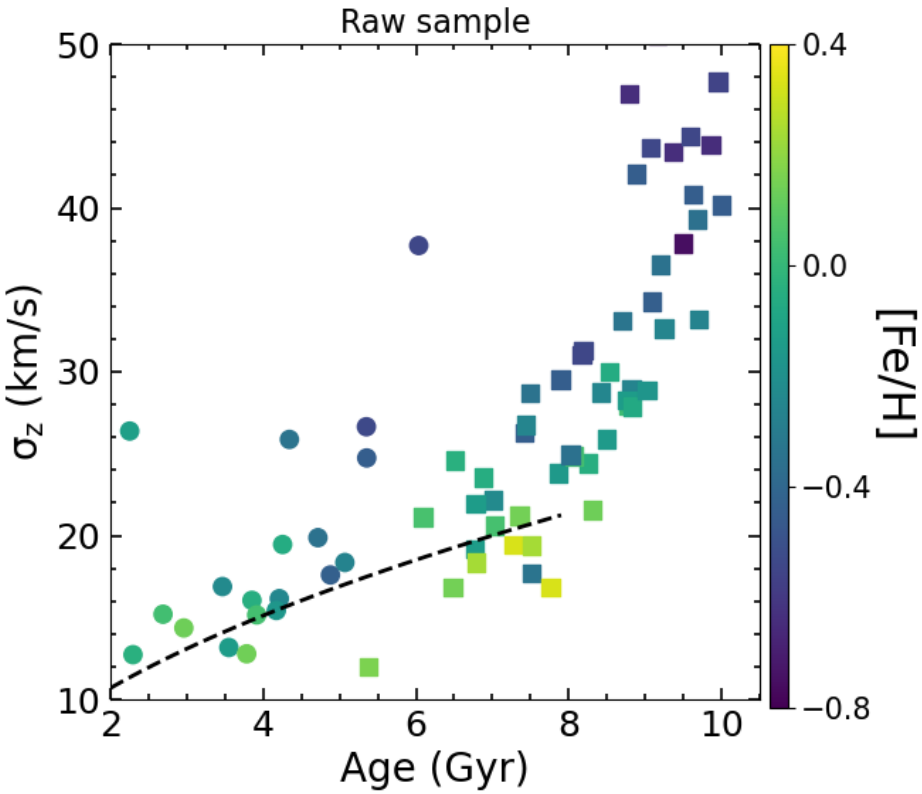
  Likely born within a turbulent and bursty environment triggered by Sgr first close passage.

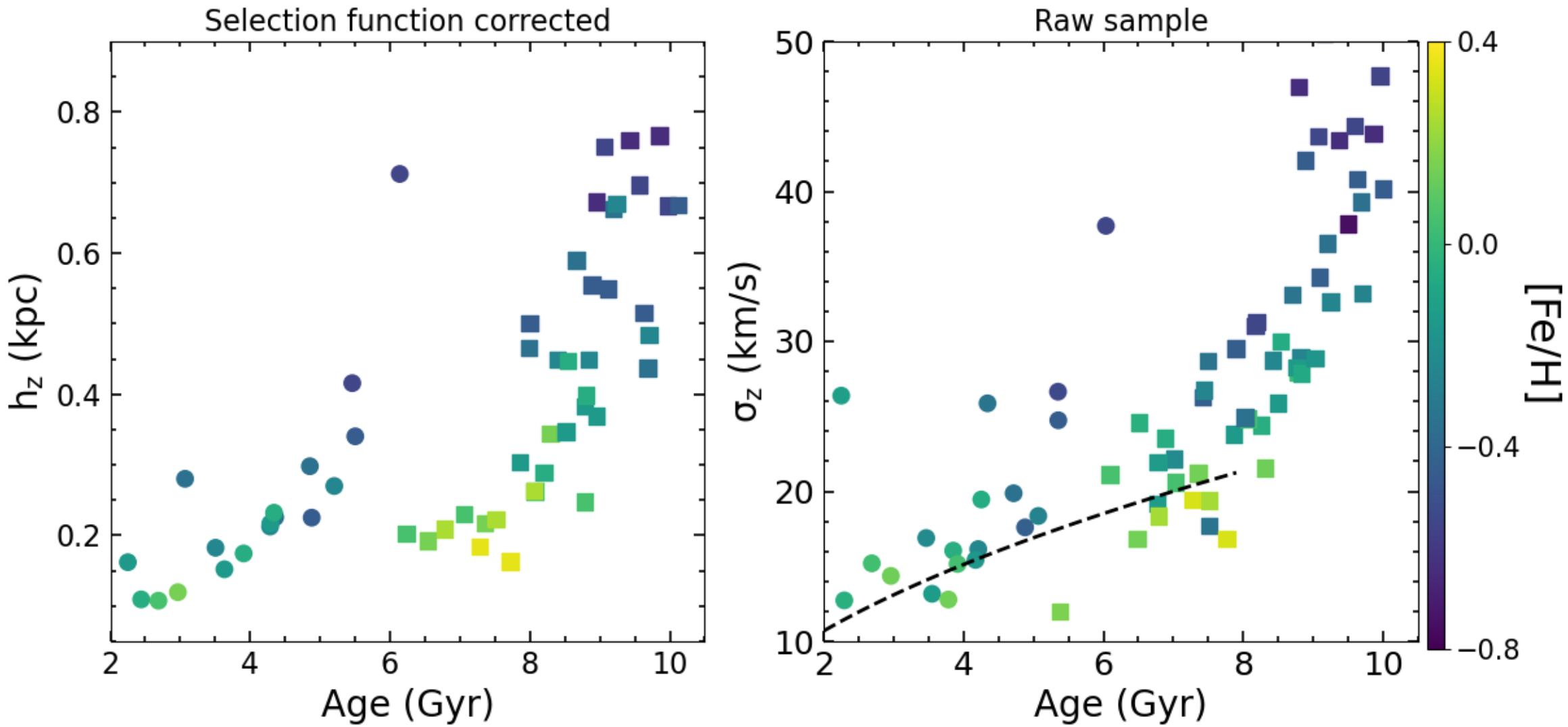


Evidence in kinematics





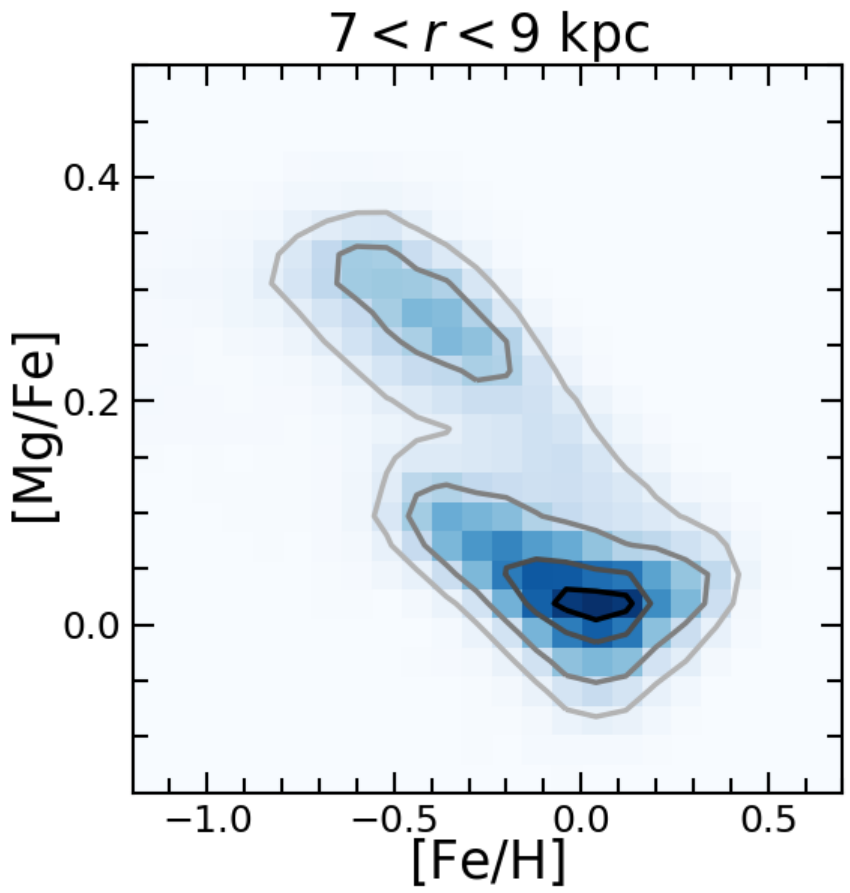



Selection function corrected
Raw sample
h_z (kpc)
σ_z (km/s)
Age (Gyr)
Age (Gyr)
[Fe/H]
0.2
0.4
0.6
0.8
10
20
30
40
50
2
4
6
8
10
0.4
0.0
−0.4
−0.8

Early knowledge of MW's structure from spectroscopic obs.

from perspective of mono-abundace populations

α-dichotomy



Direct approach

Intrinsic density distribution

$$\rho_{\rm intrinsic}(\alpha, Fe, glon, glat, r)$$

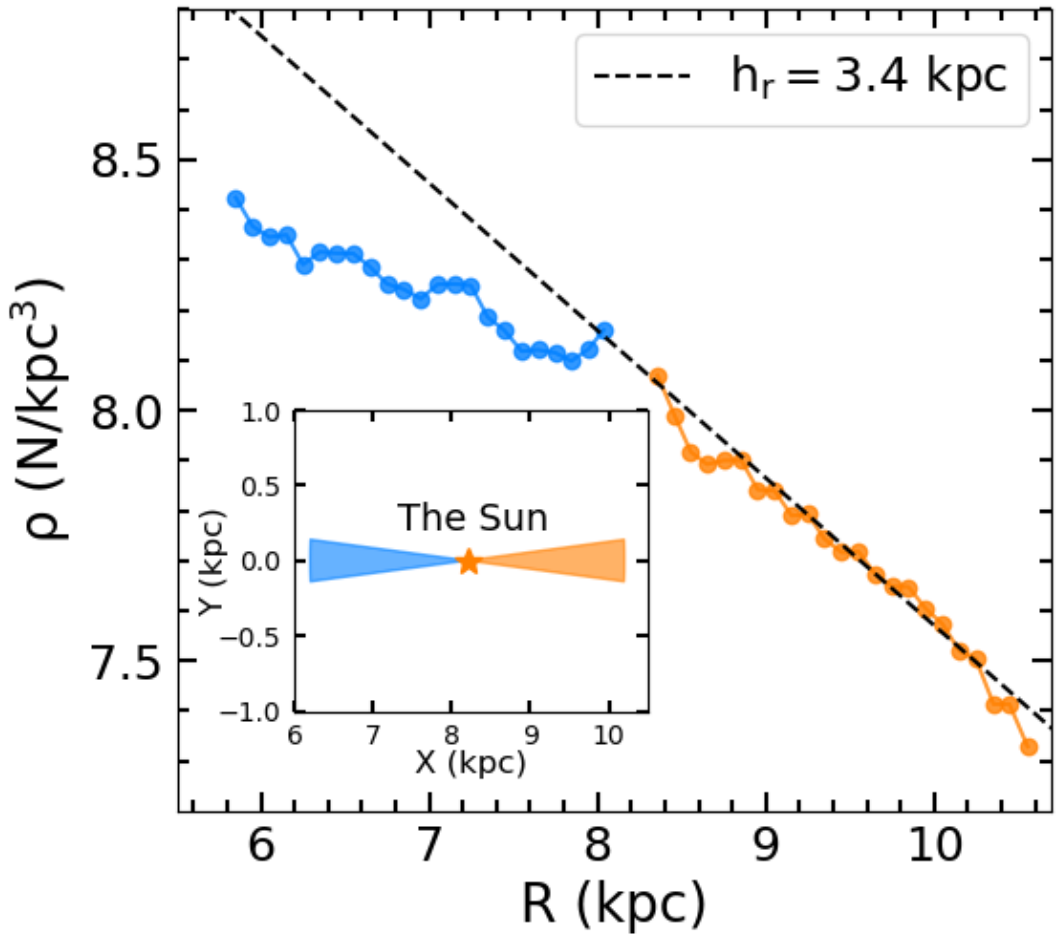
Correcting for selection function

Observed distribution

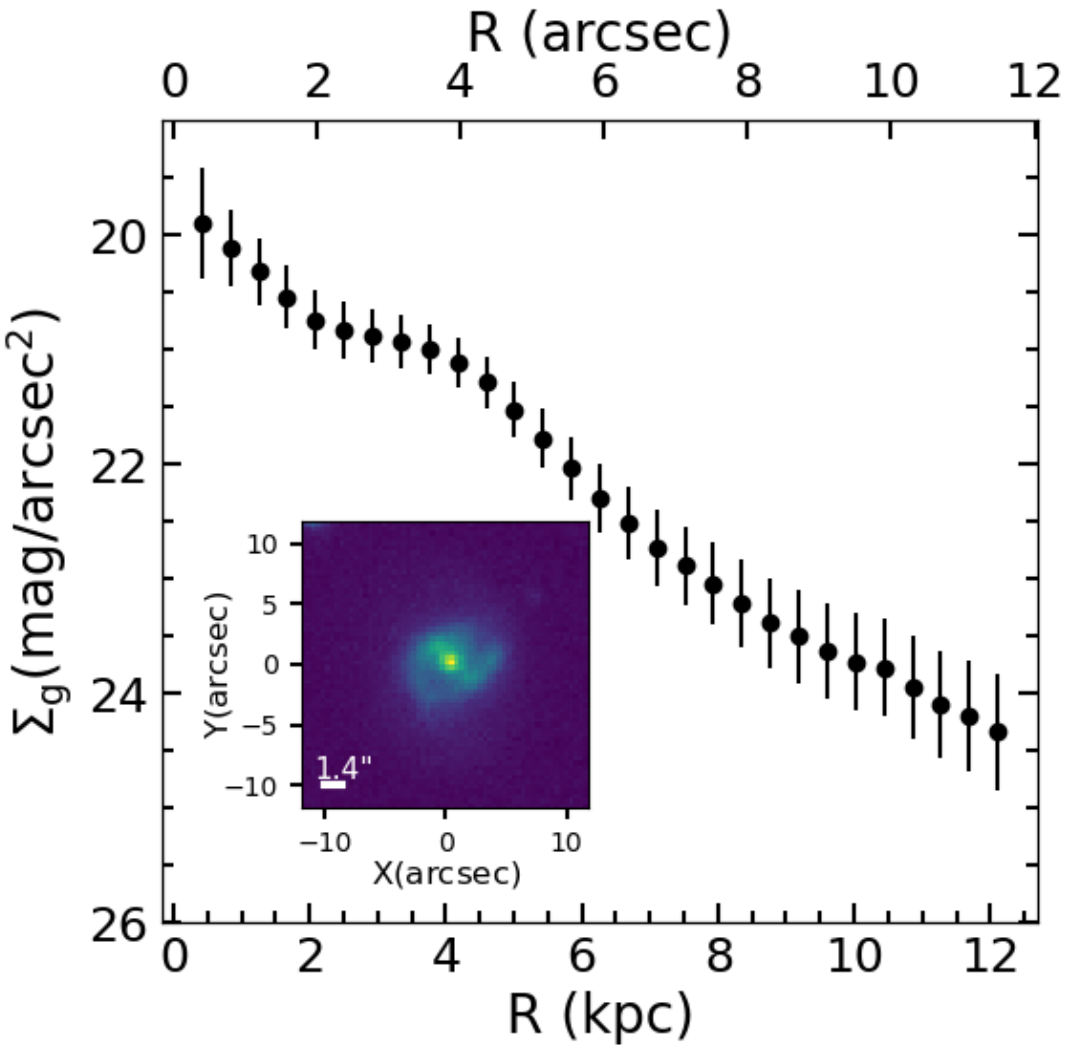
$$\rho_{\rm APOGEE}(\alpha, Fe, glon, glat, r)$$

Sanity check

Break confirmed by Gaia

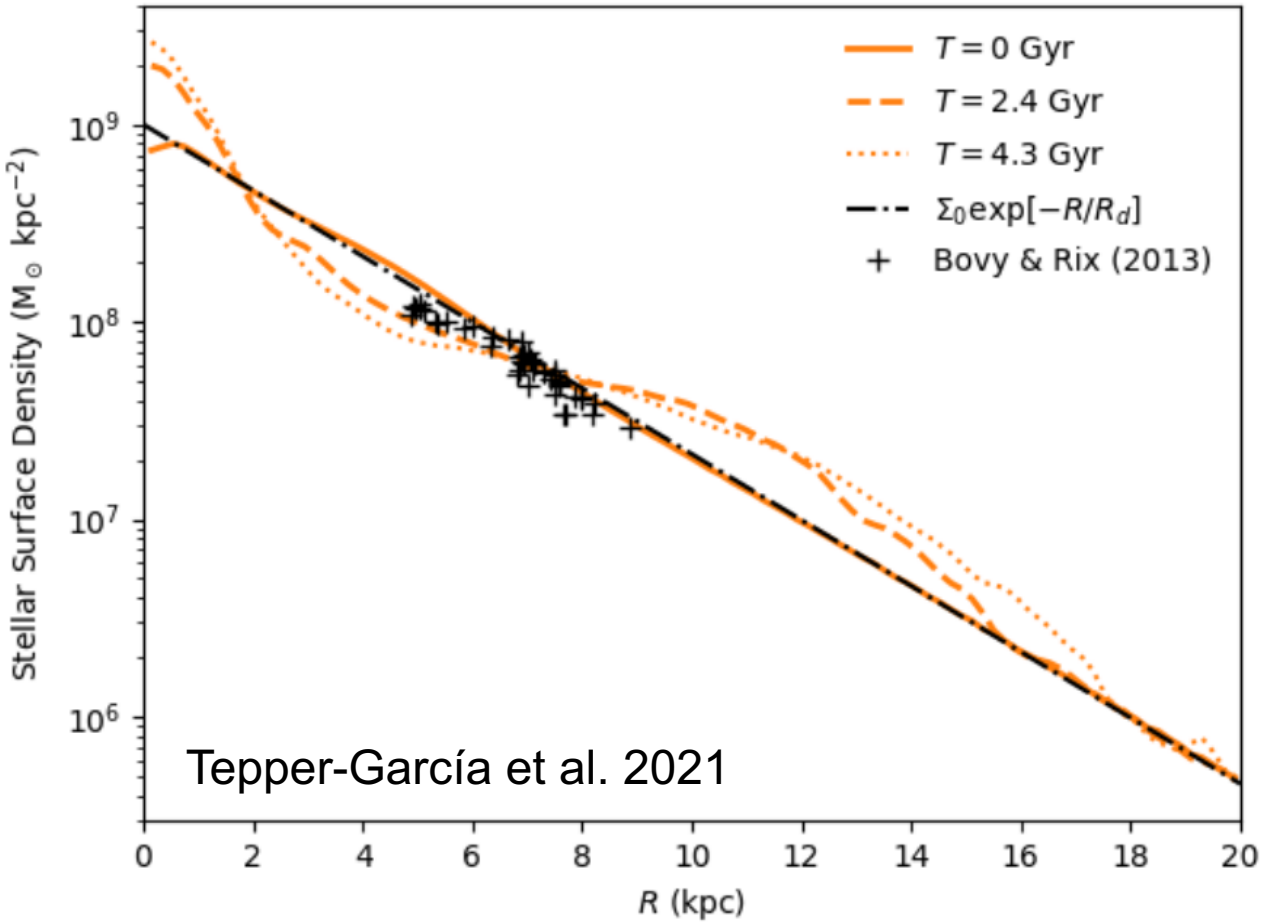


Similar profile seen in galaxies



Origin of inner break

N-body simulation



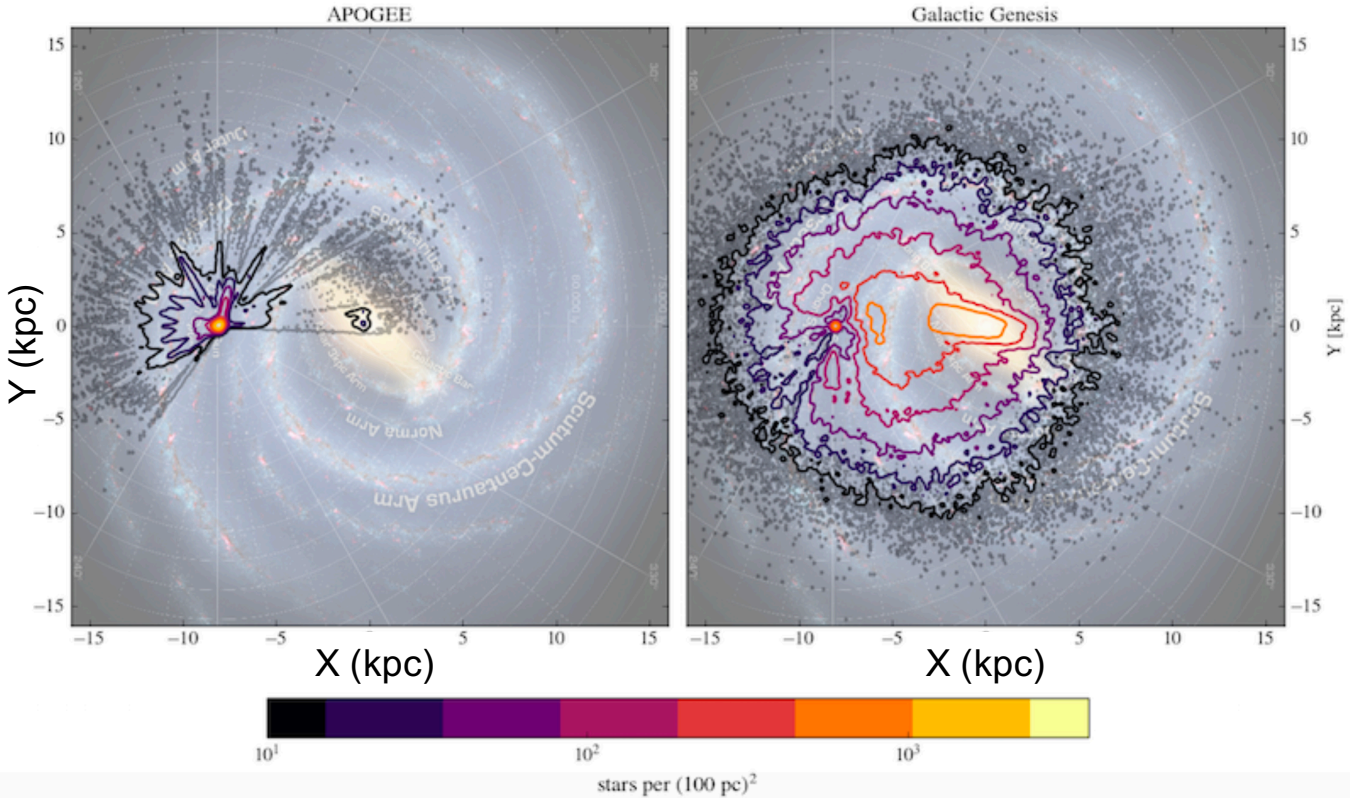
Possible origin:

1. Bar formation size effect
2. Spiral arms

Next generation of stellar spectroscopic survey

SDSS-V (2022-2027)

SDSS-V/Milky Way Mapper survey (R~22000): 6M stars



4MOST (2024-2029)

Disc+bulge (R~6500-20000) Survey: ~20M stars