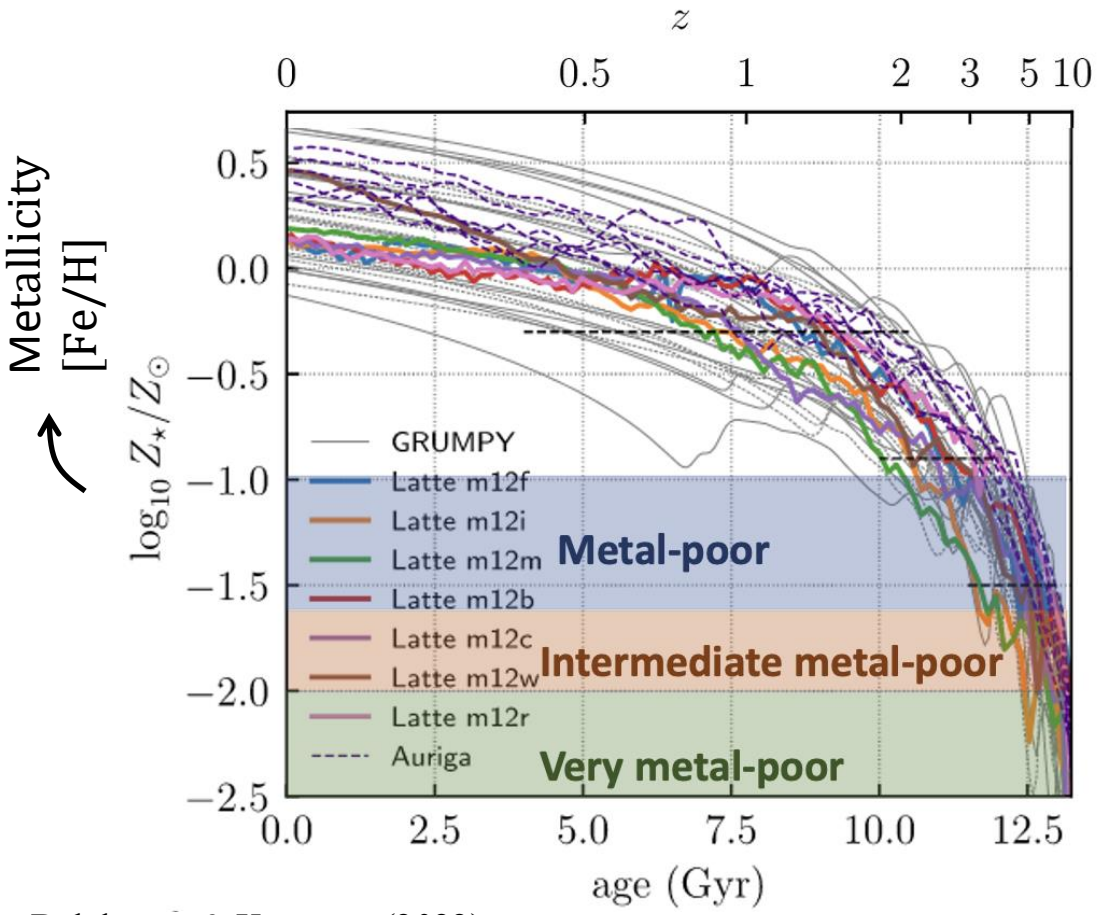
Do we have an early disc in the Milky Way?

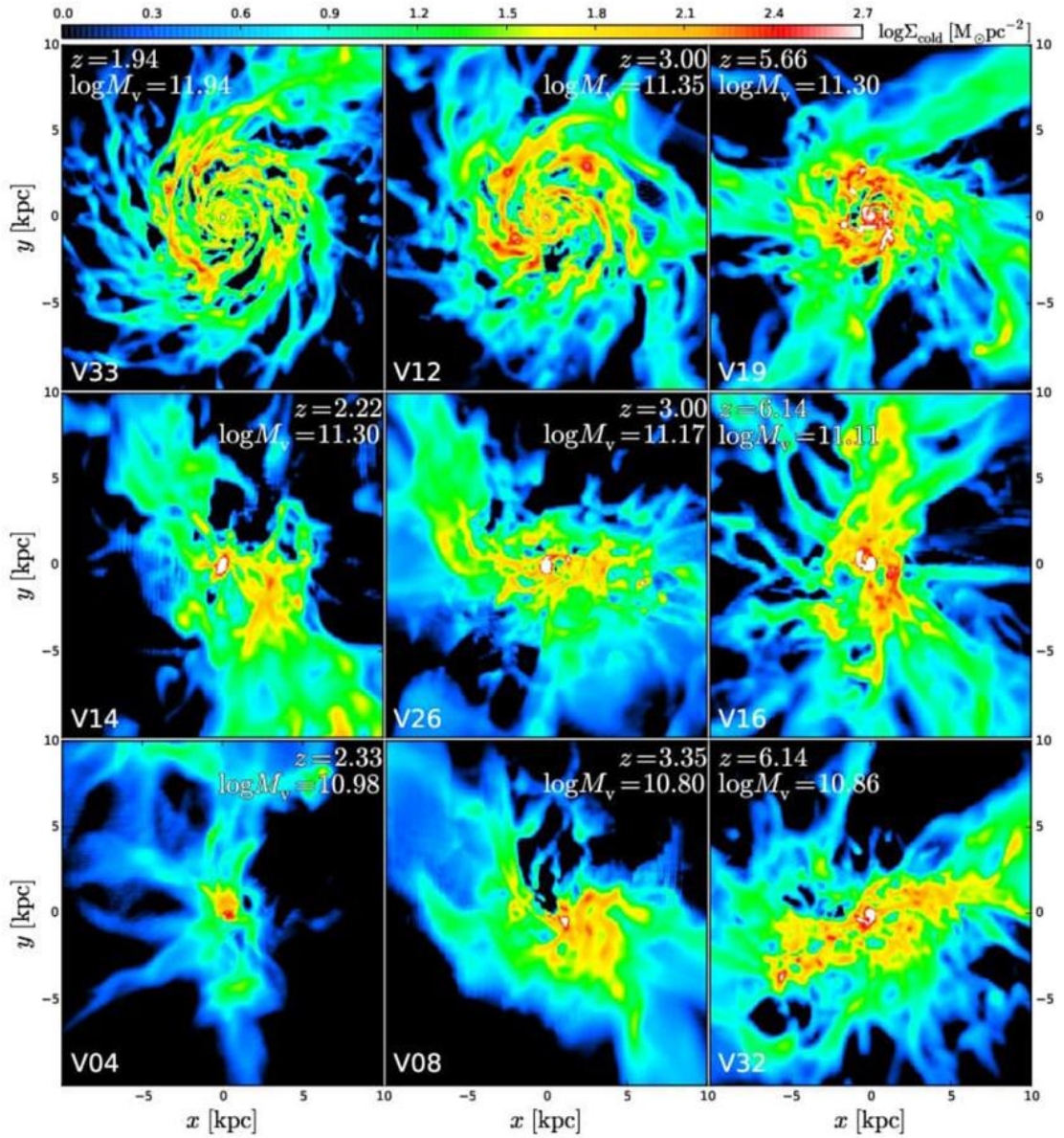
Hanyuan Zhang

Collaborators: Anke Arentsen, Vasily Belokurov

How early is it?



Belokurov & Kravtsov (2022)

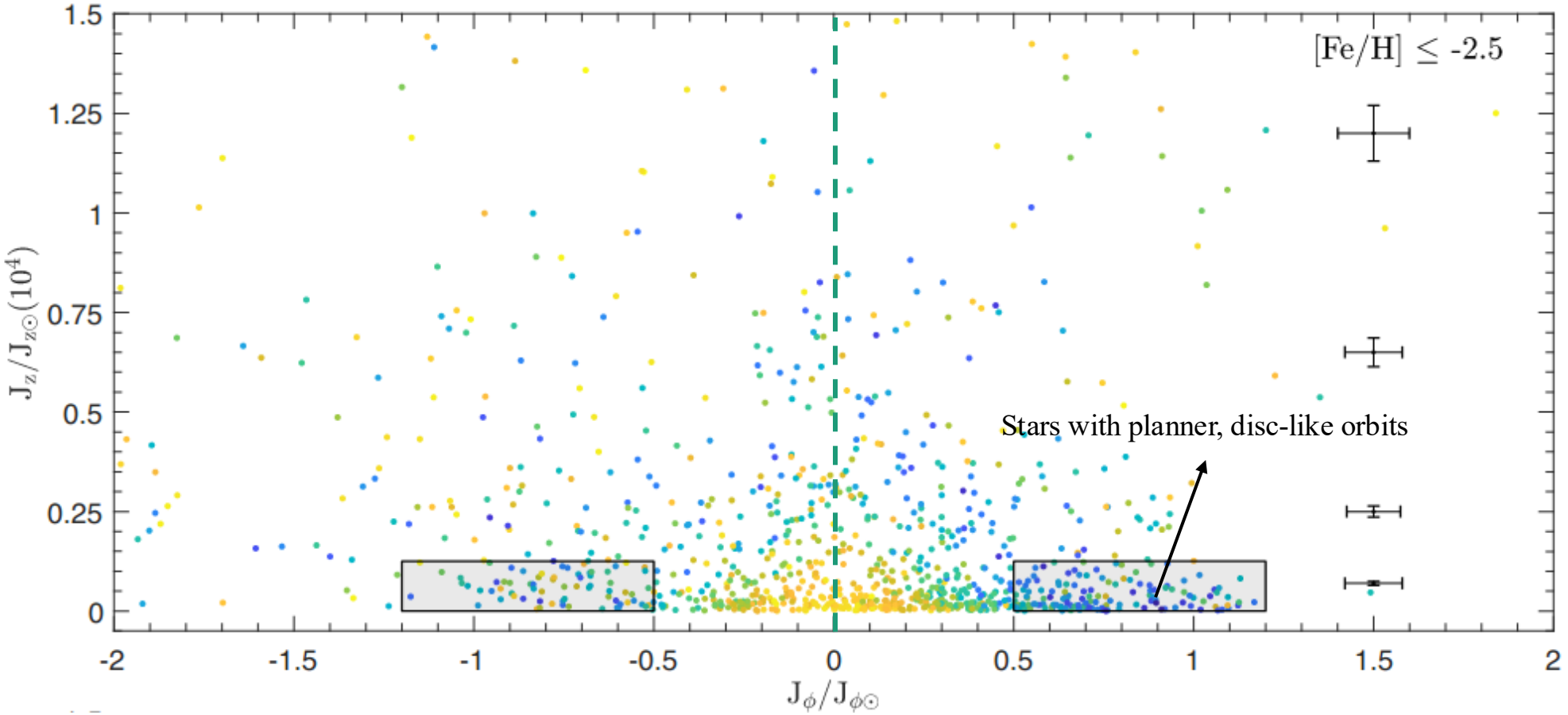


Dekel *et al.* (2020)

Recent studies revived this controversy

Very metal-poor stars born at high redshift, (Z~5)

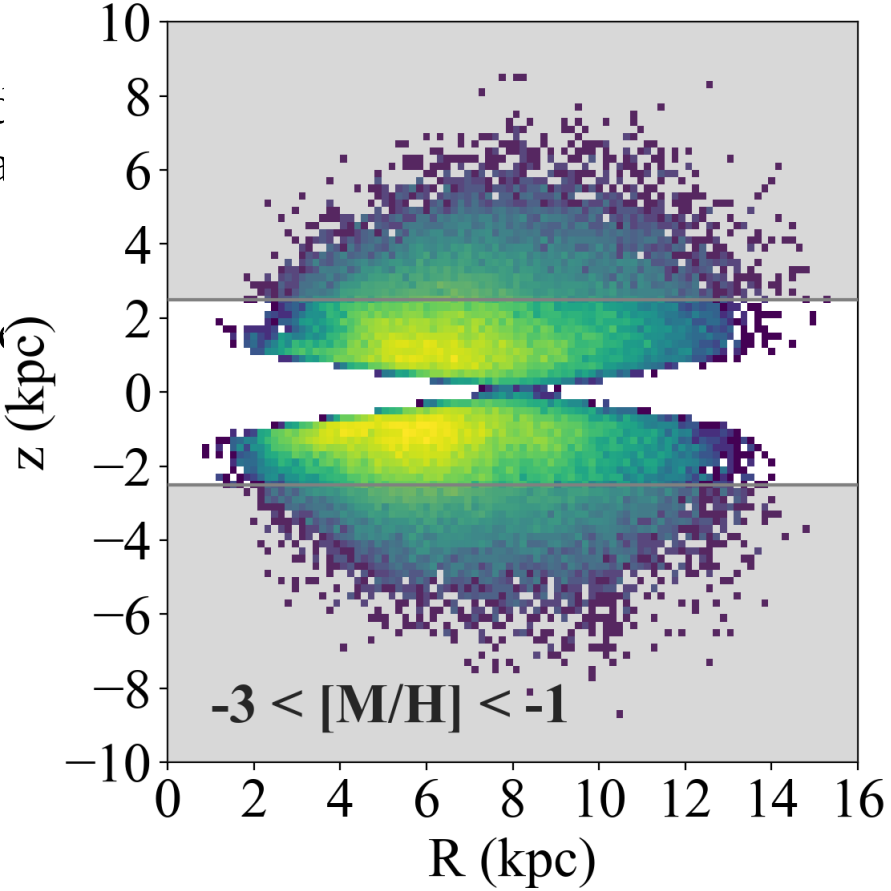
Sestito et al. 2020



Many subsequent works follow the early disc scenario and argue that a stable disc formed in the early life stage of the Milky Way, e.g. Di Matteo *et al.* (2020); Sotillo-Ramos *et al.* (2023); Hong *et al.* (2023); etc.

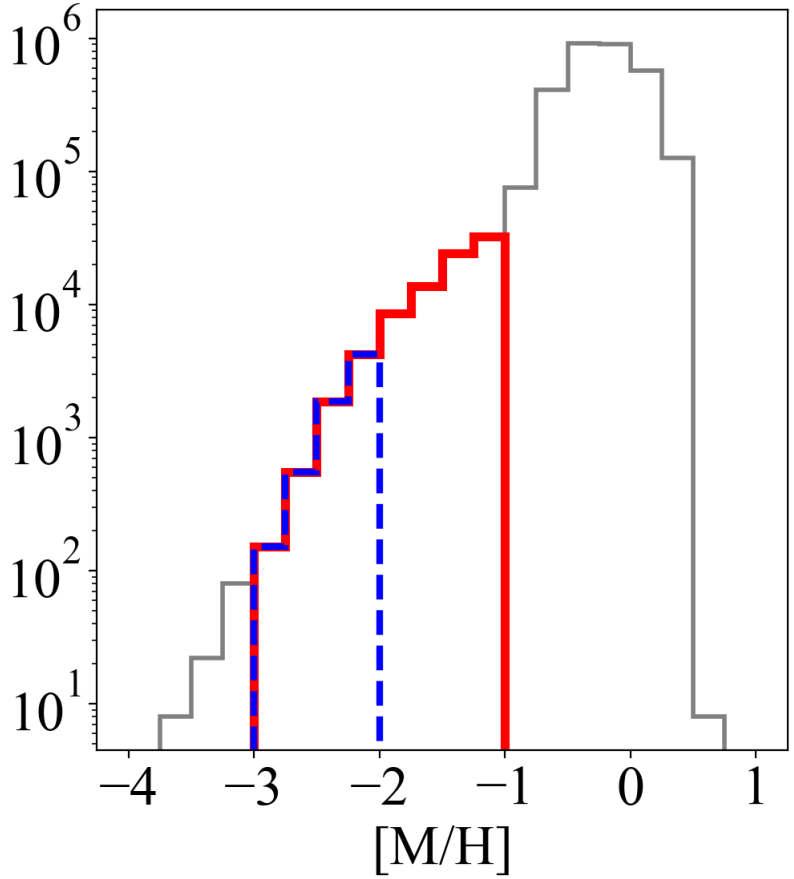
Sample construction

- Gaia DR3 release XP spectrum parameters for ~220 million stars
- Anc
  data
- A v
  and

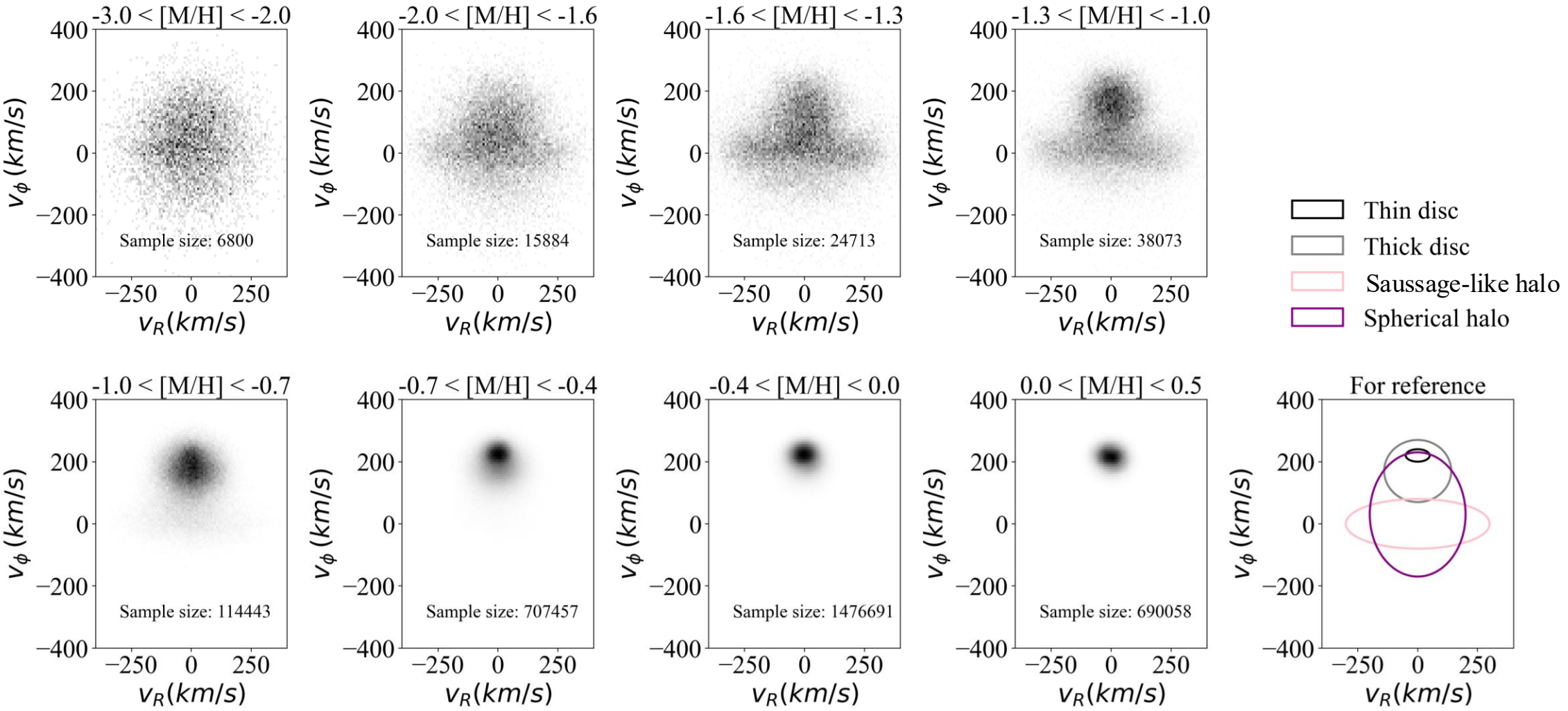


rs using

selected,

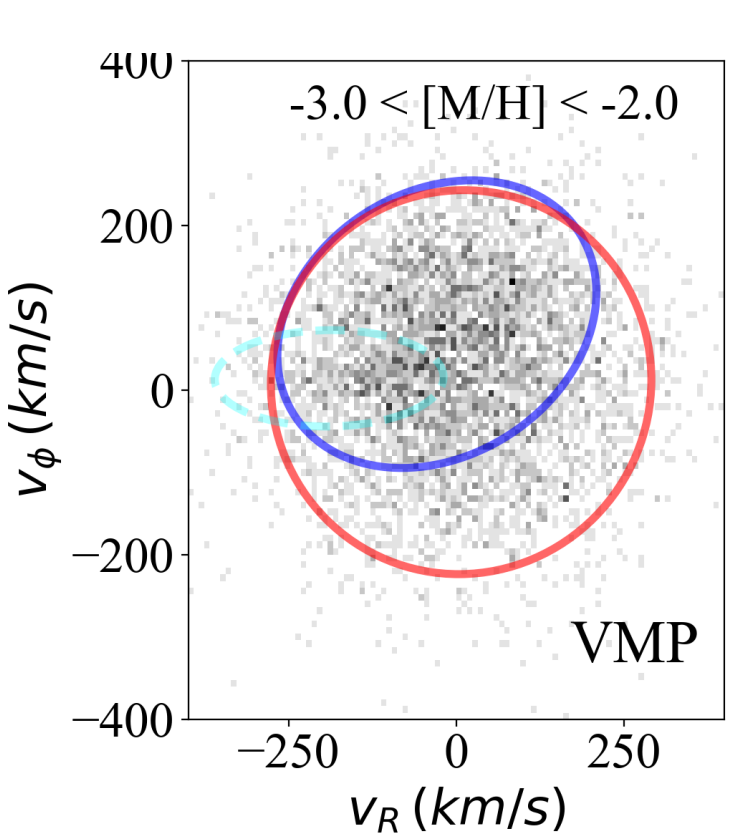


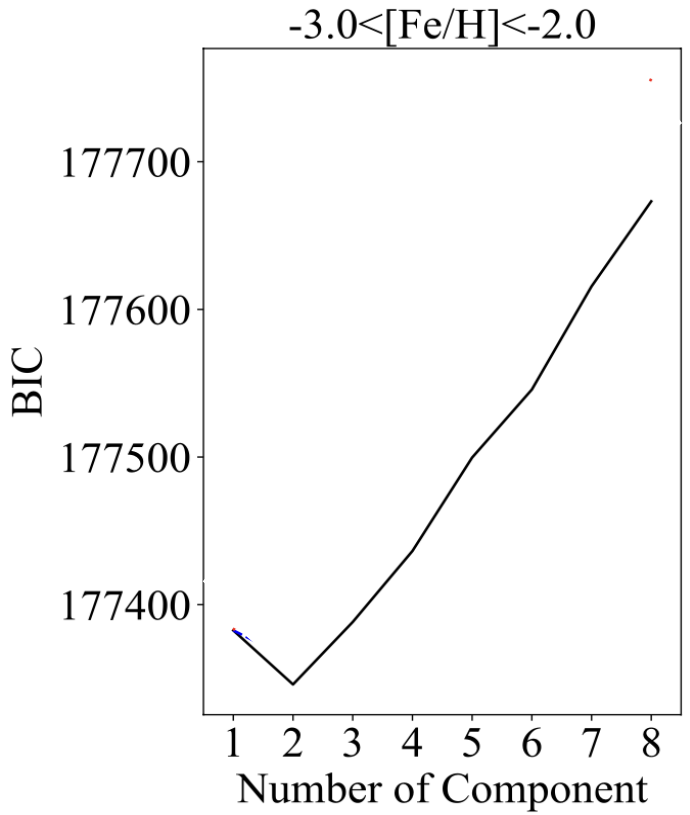
Distribution in velocity space



Gaussian Mixture Model (GMM)

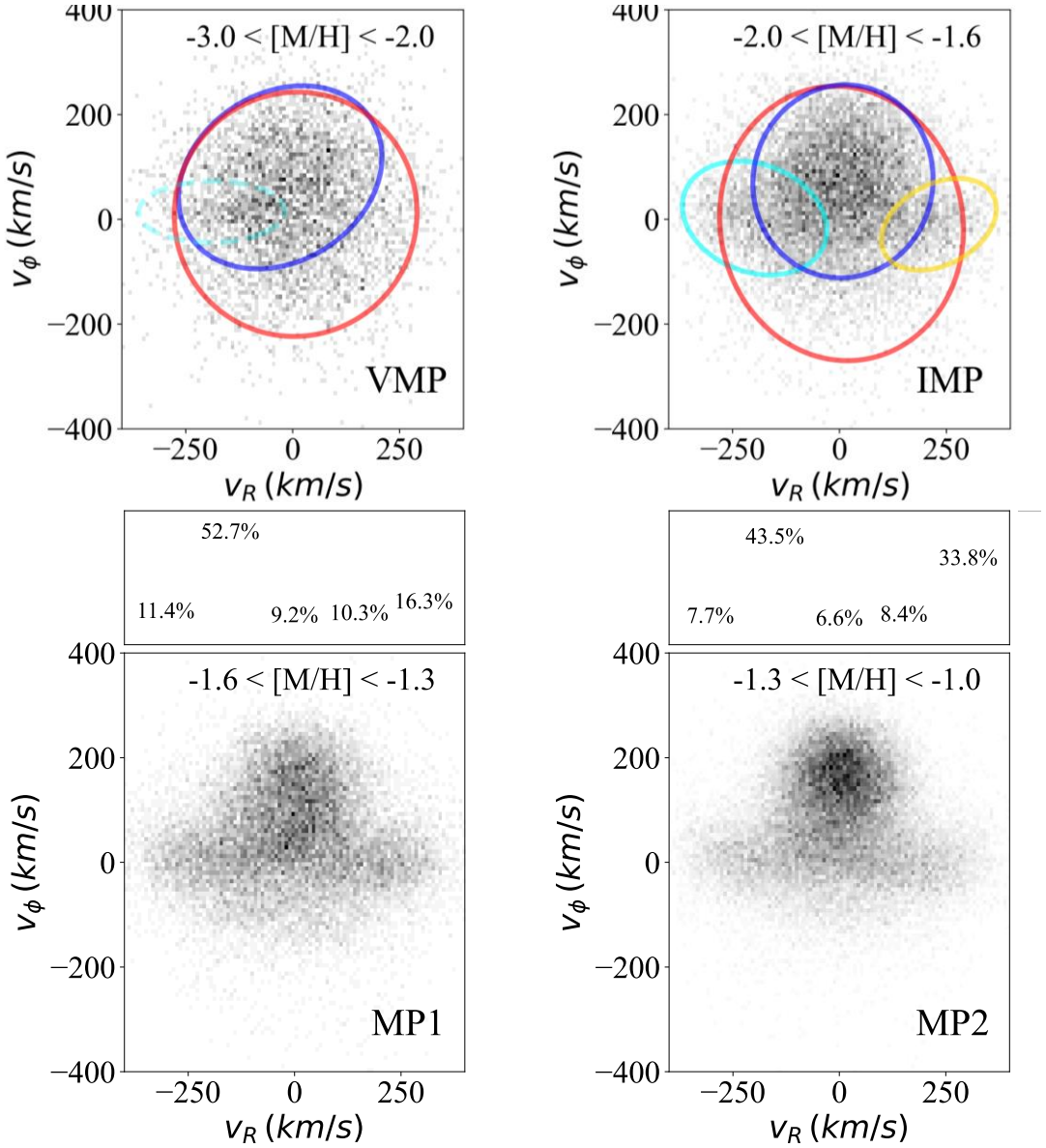
An unsupervised classification algorithm by assuming the whole population is the mixture of N Gaussian population

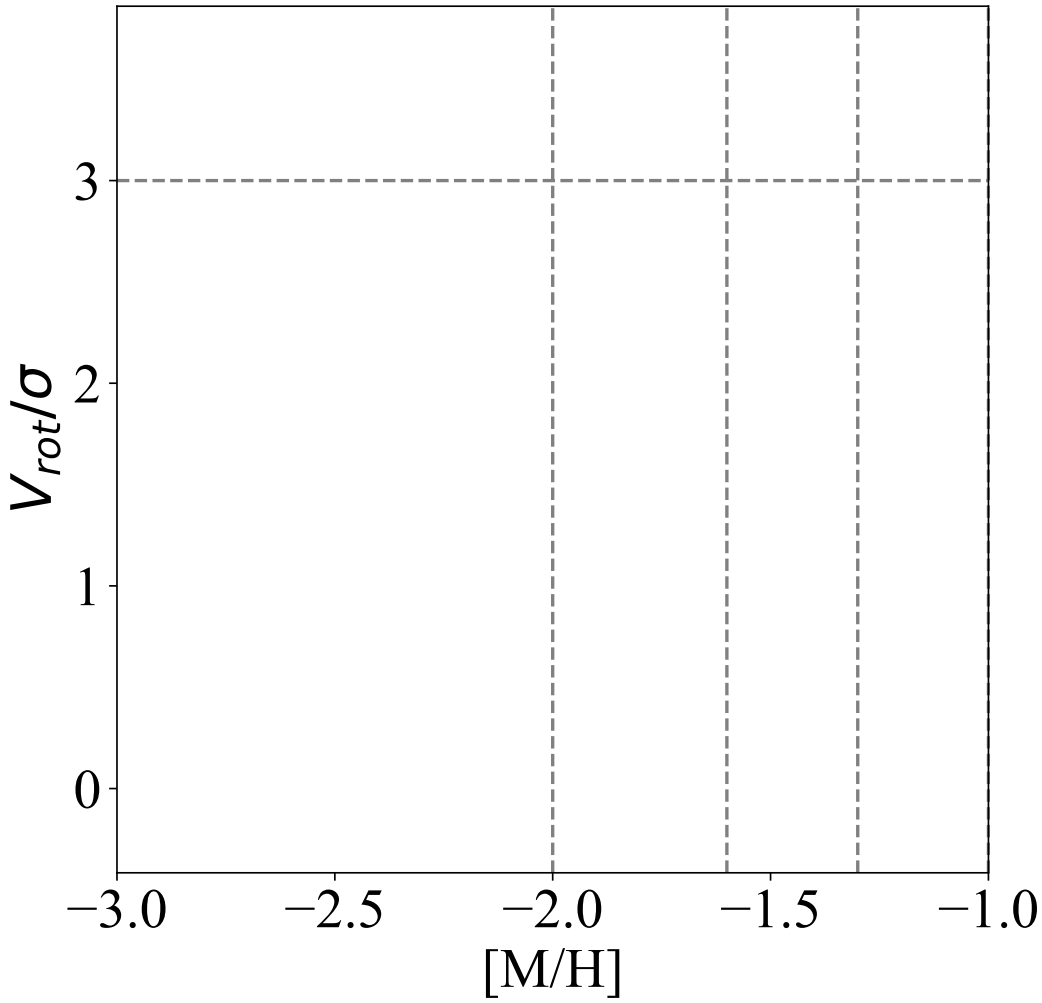




Bayesian Information Criteria (BIC) $= k \ln(n) - 2 \ln L$

Gaussian Mixture Model (GMM)



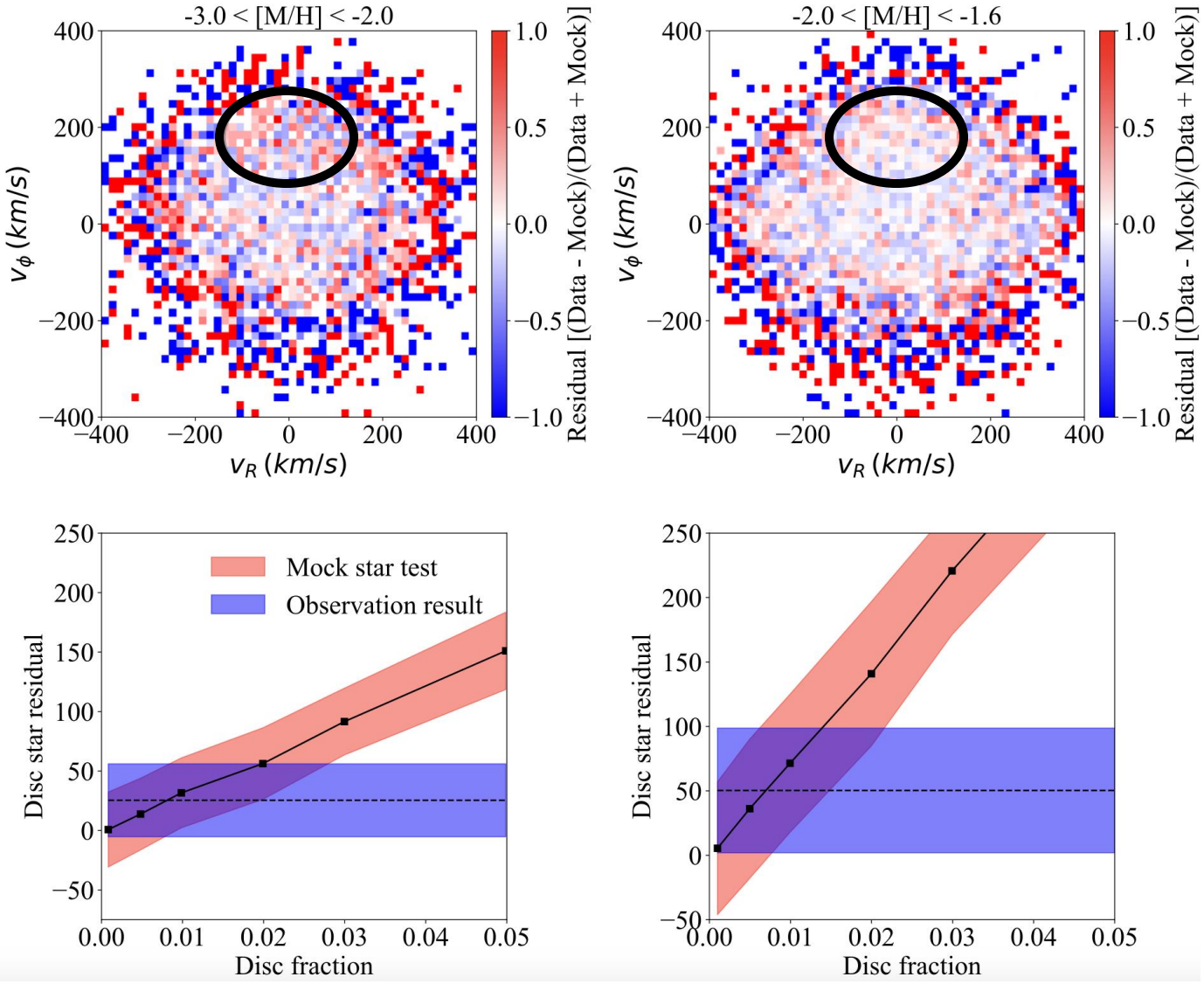


Testing the robustness of GMM (Residual)

$\sim 0 - 3\%$ disc fraction in the VMP and IMP regime !

Disc residual: Subtract observation by the GMM model; count residual in the grey ellipse

Mock sample: Manually insert disc stars, so there is a known disc star fraction

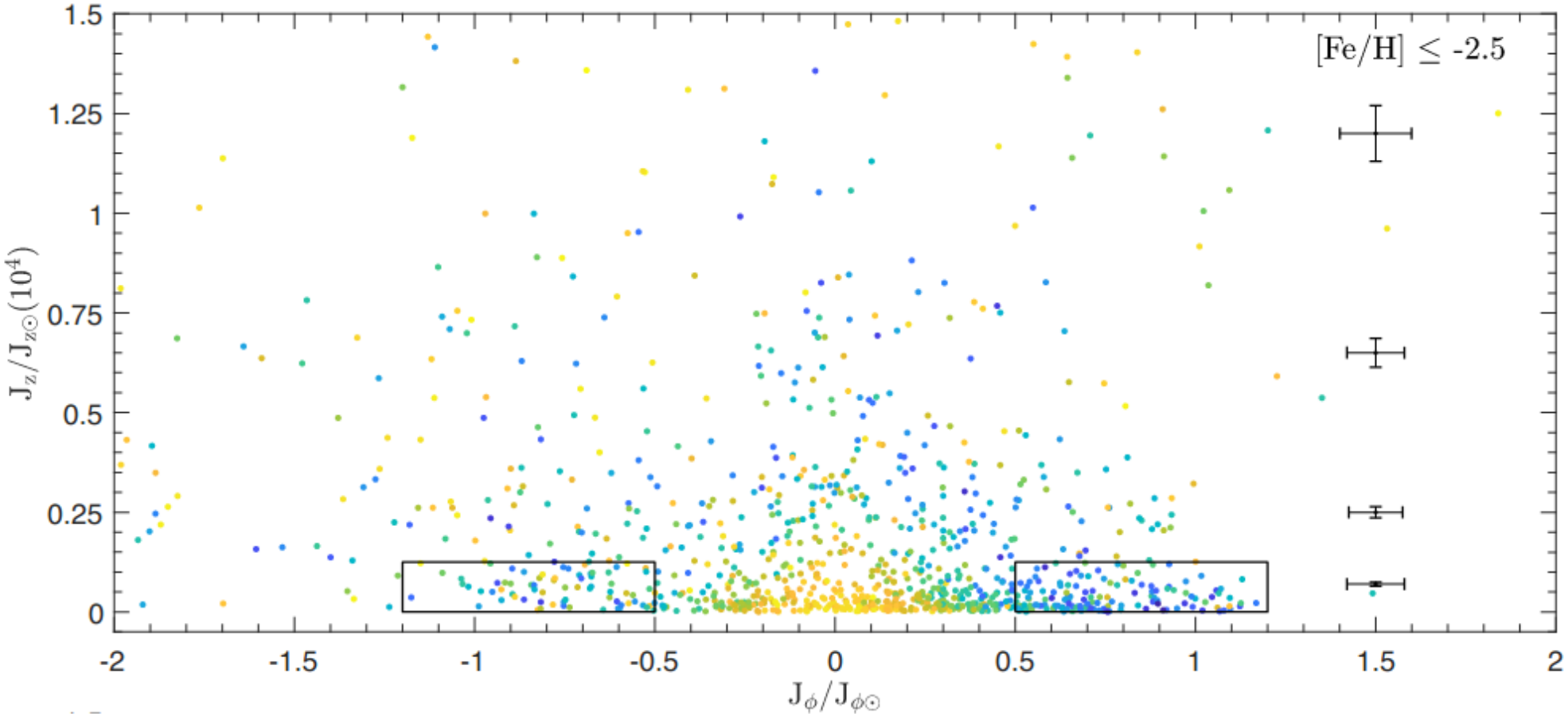


Interpretation & Conclusion

- No statistically significant evidence can claim for an early-formed disc in the Milky Way
  - $0 - 3\%$ disc population fraction in the very metal-poor regime
  - Disc emerged at [Fe/H]~-1.3, which agrees better with simulation

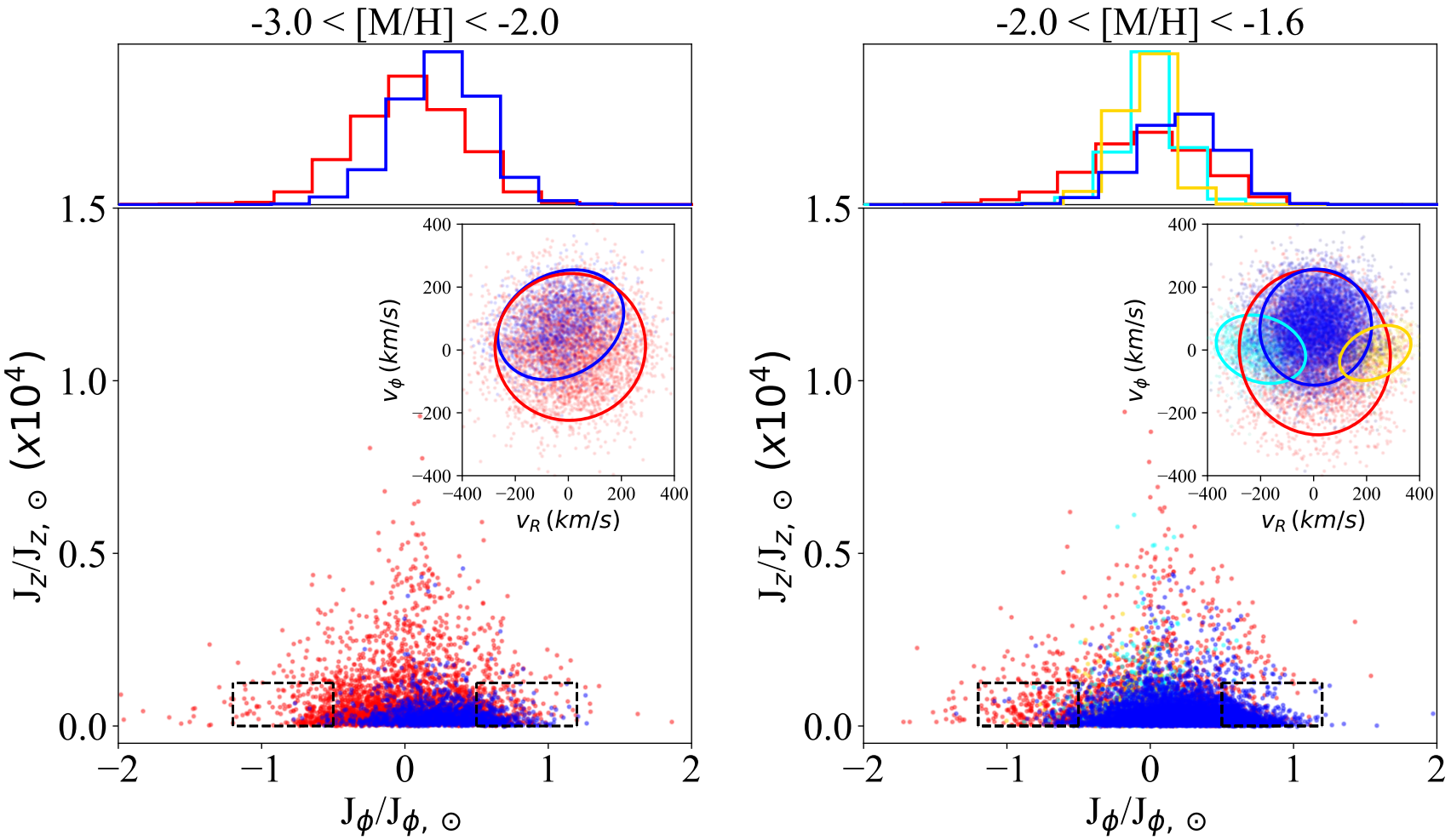
- The early Milky Way is still halo-dominated, but some prograde signature is clued
  - The prograde signature is also found in many simulations, and other observations, but it is new to see this prograde signature is still there in the very early phase of the Milky Way
  - The kinematics of the prograde halo in the -1.3<[Fe/H]<-1.0 regime is similar to *Aurora*/Proto-Galaxy

Justification of the VMP planner stars



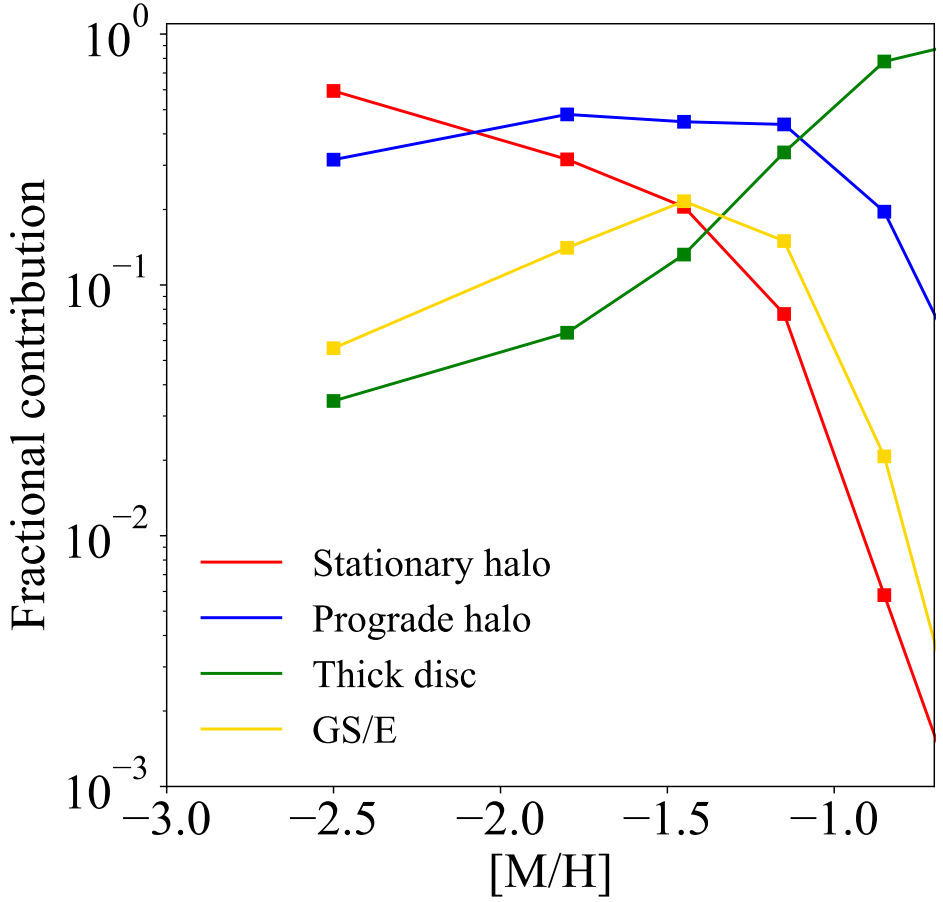
Justification of the VMP planner stars

Classify stars by their position in the $v_R - v_\phi$ plane



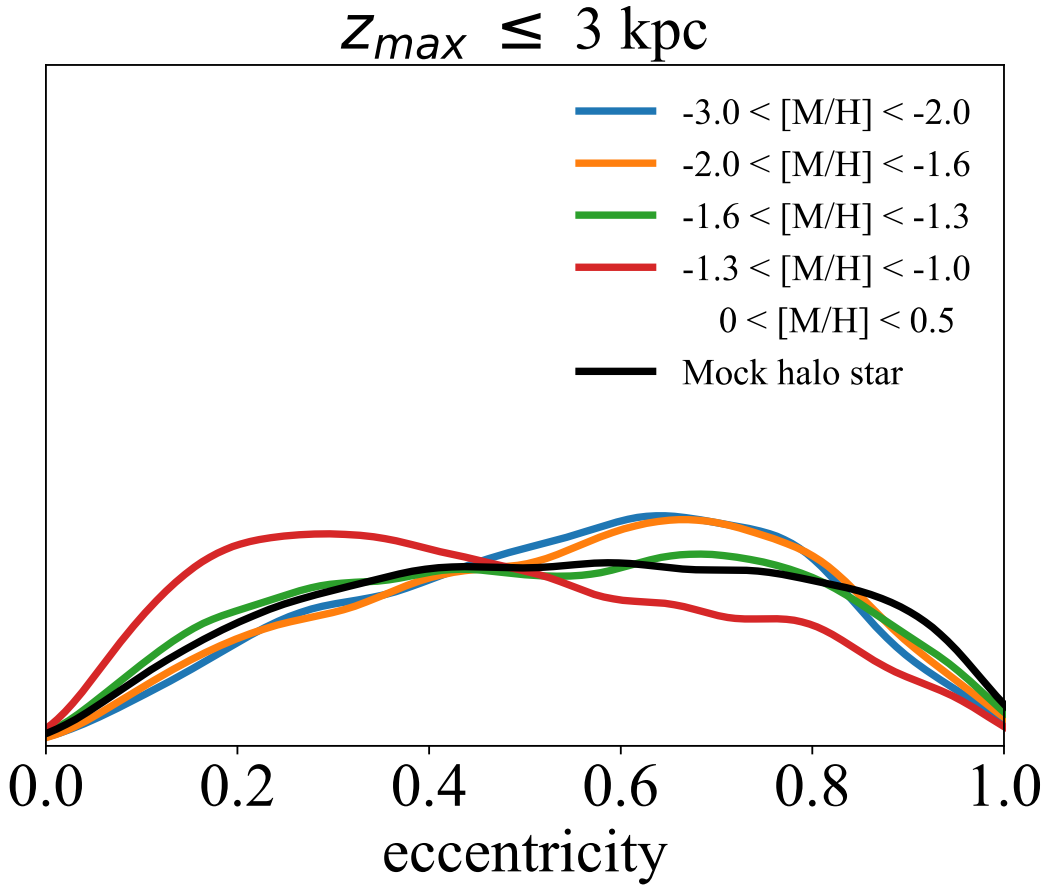
The prograde halo could be responsible for those prograde planner stars !

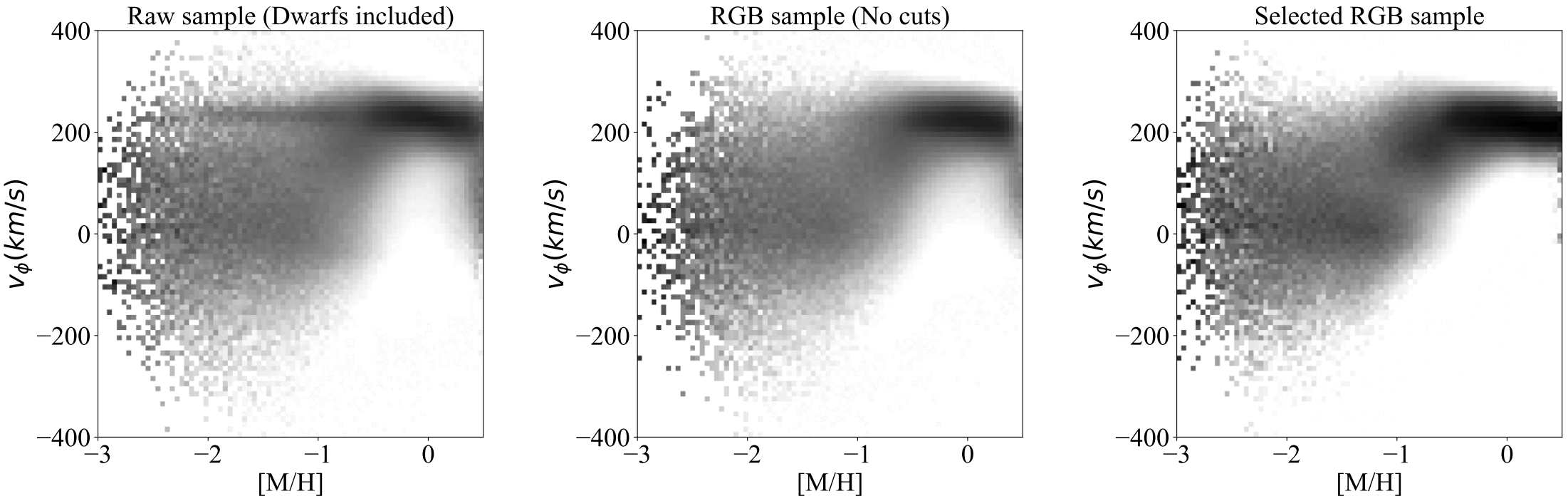
Testing the robustness of GMM (Frozen componet)



Justification of the VMP planner stars

- Some studies also use a population of low eccentricity as argument for the VMP disc
- We test that argument by
    a) generating stars from an isotropic NFW distribution function;
    b) integrate these stars in the McMillan17 potential to get the eccentricity
    c) apply the same selection function in R and z coordinate to the mock stars




Raw sample (Dwarfs included)
RGB sample (No cuts)
Selected RGB sample
$v_\phi(km/s)$
[M/H]
400
200
0
−200
−400
−3
−2
−1
0

Testing the robustness of GMM (Residual)

$\sim 0 - 3\%$ disc fraction in the VMP and IMP regime !

Validation procedure:

Generate N stars according the GMM fitting

↓

Subtract the number of observed stars in each pixel

↓

Count residual in the grey ellipse (disc region)

Generate N_{GMM} stars according the GMM fitting

+

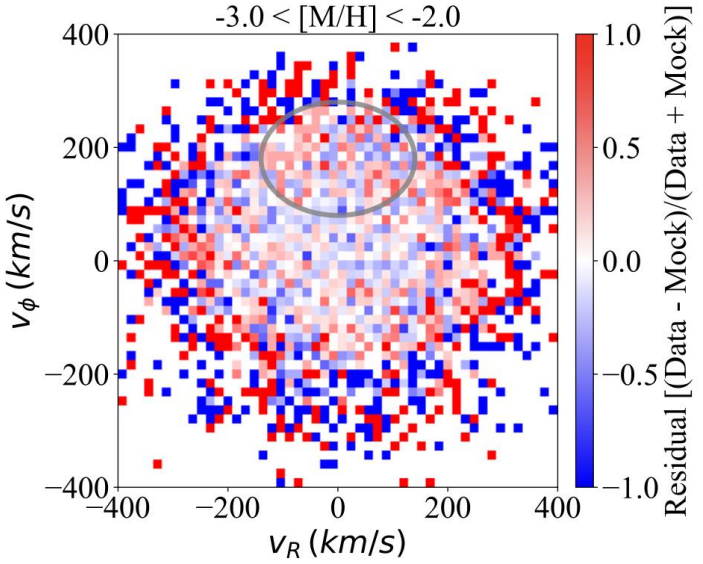
Generate N_{disc} stars according the grey ellipse

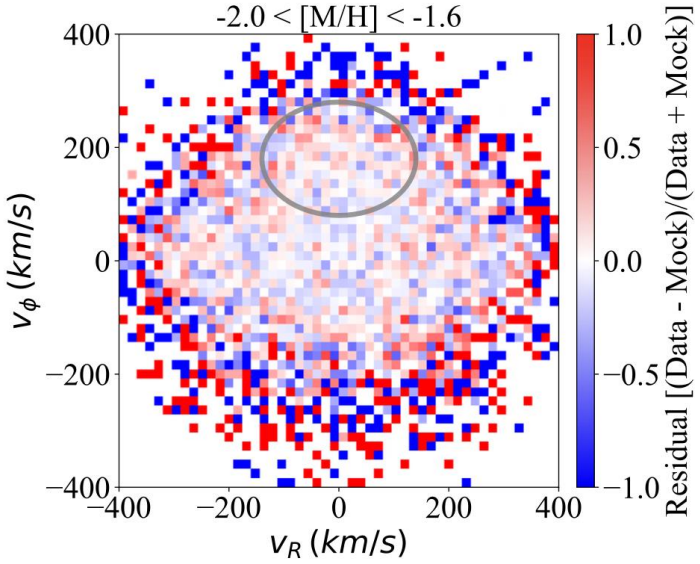
↓

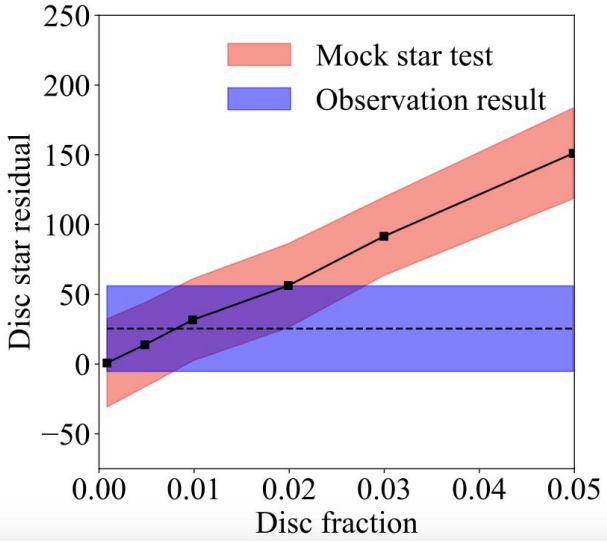
Generate $N_{GMM} + N_{disc}$ stars according the same GMM

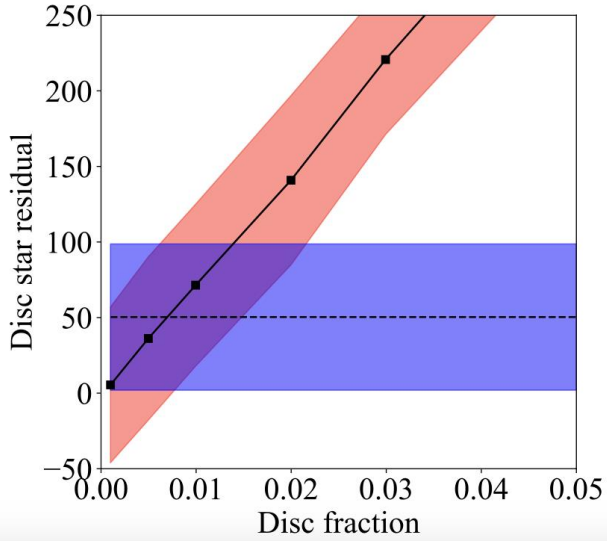
↓

Subtract two mock population and find disc residual









Justification of the VMP planner stars

Classification routine:

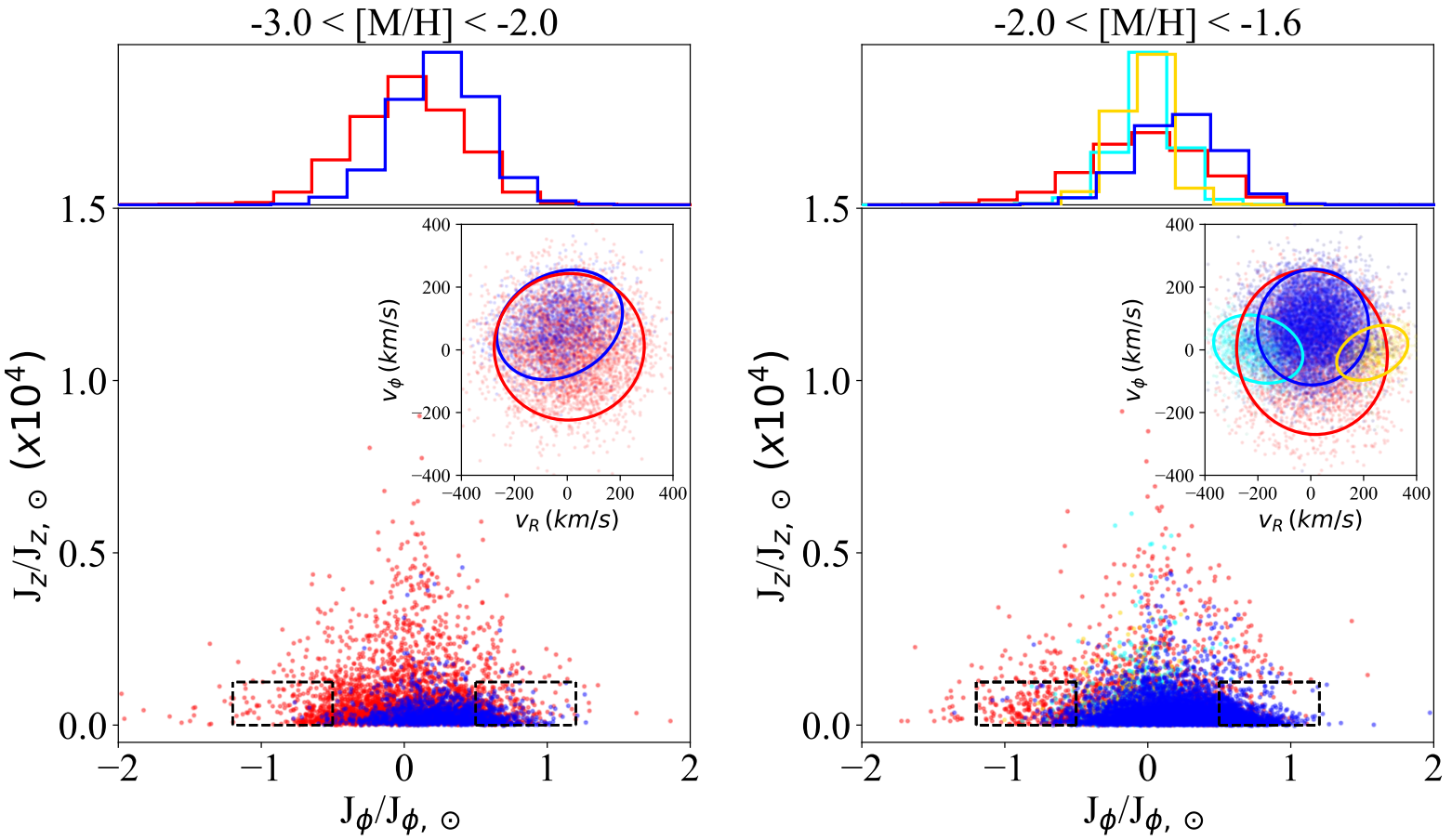
Generate N stars according to the GMM model

↓

For observed star, finding the closest match of the generated stars in the $v_R - v_\phi$ plane

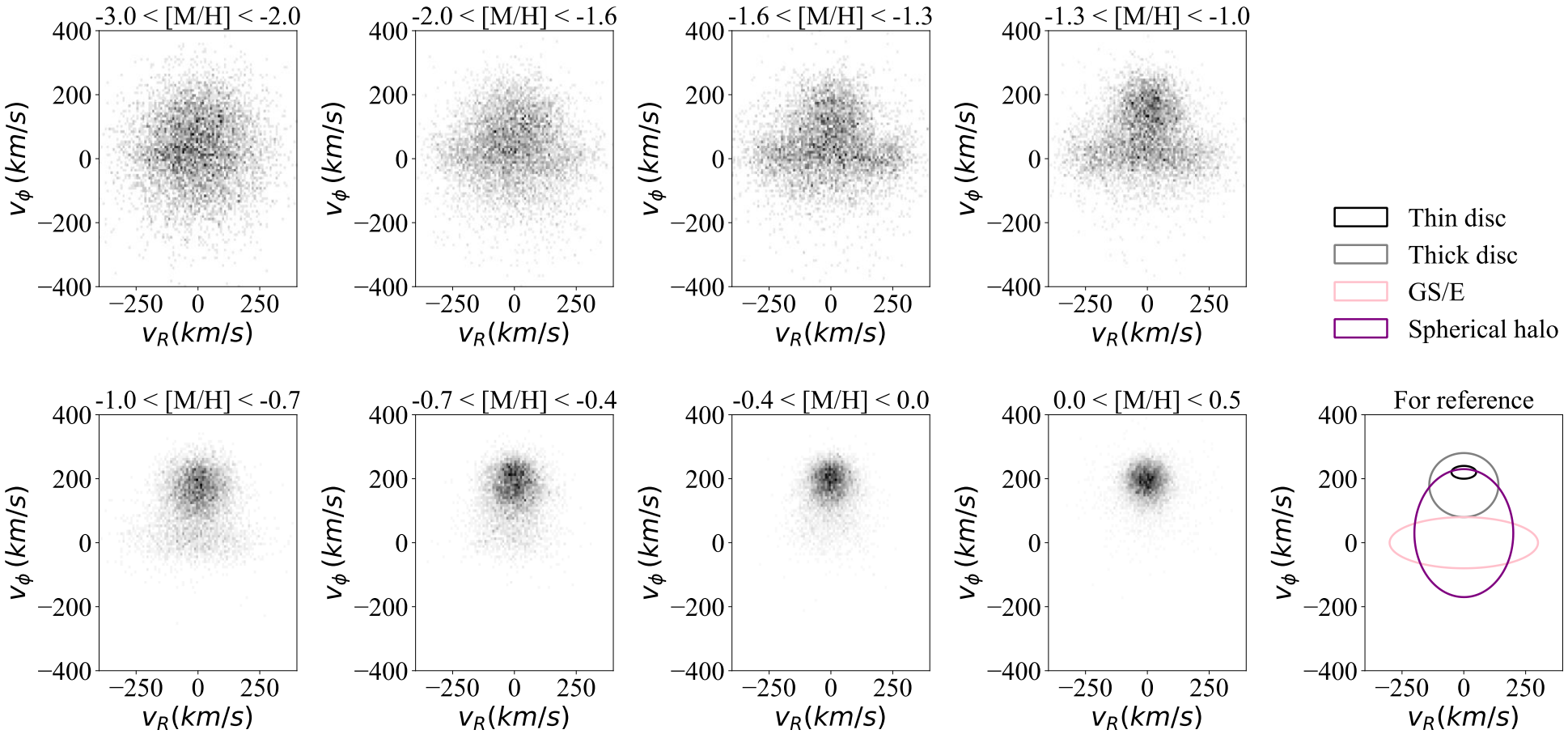
↓

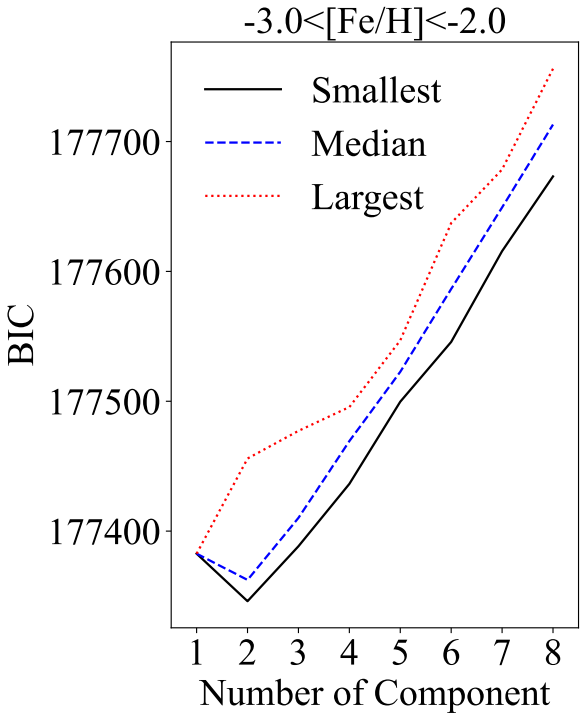
Assign the membership of the generated star to the observed star

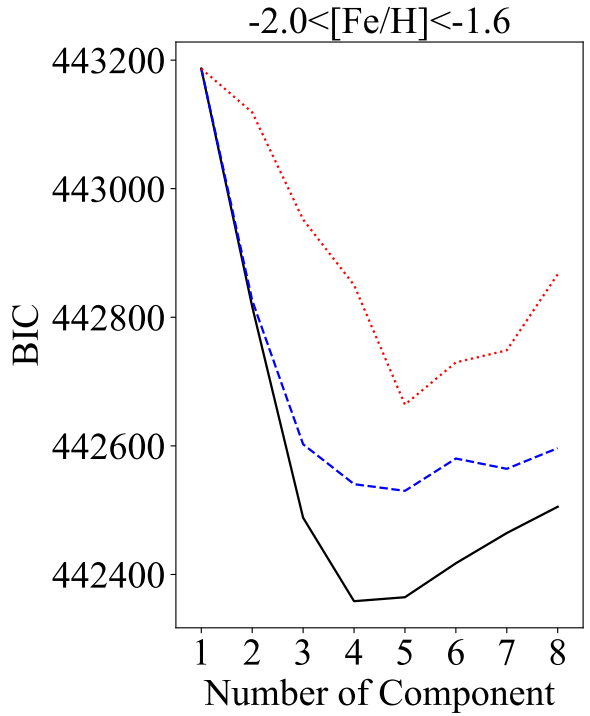


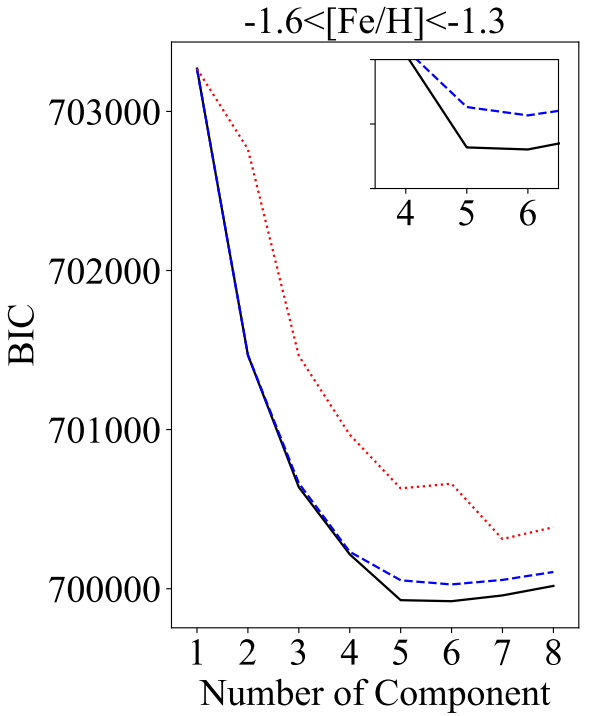
The prograde halo could be responsible for those prograde planner stars !

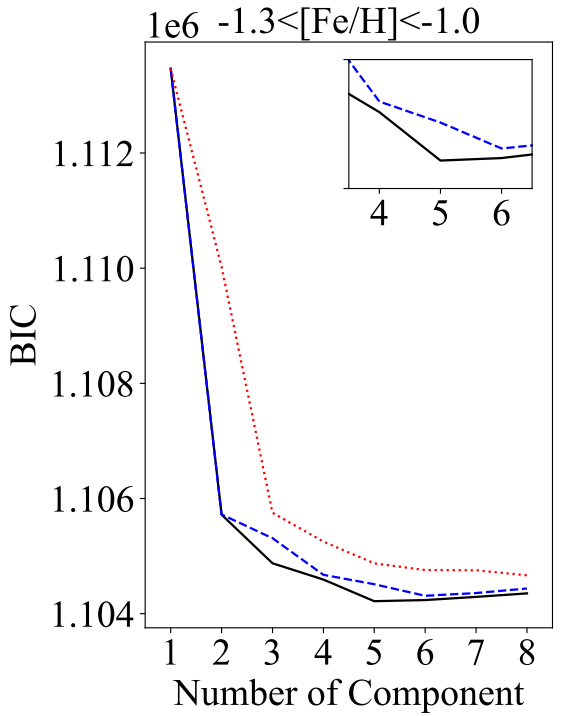
How robust the result is against the selection function

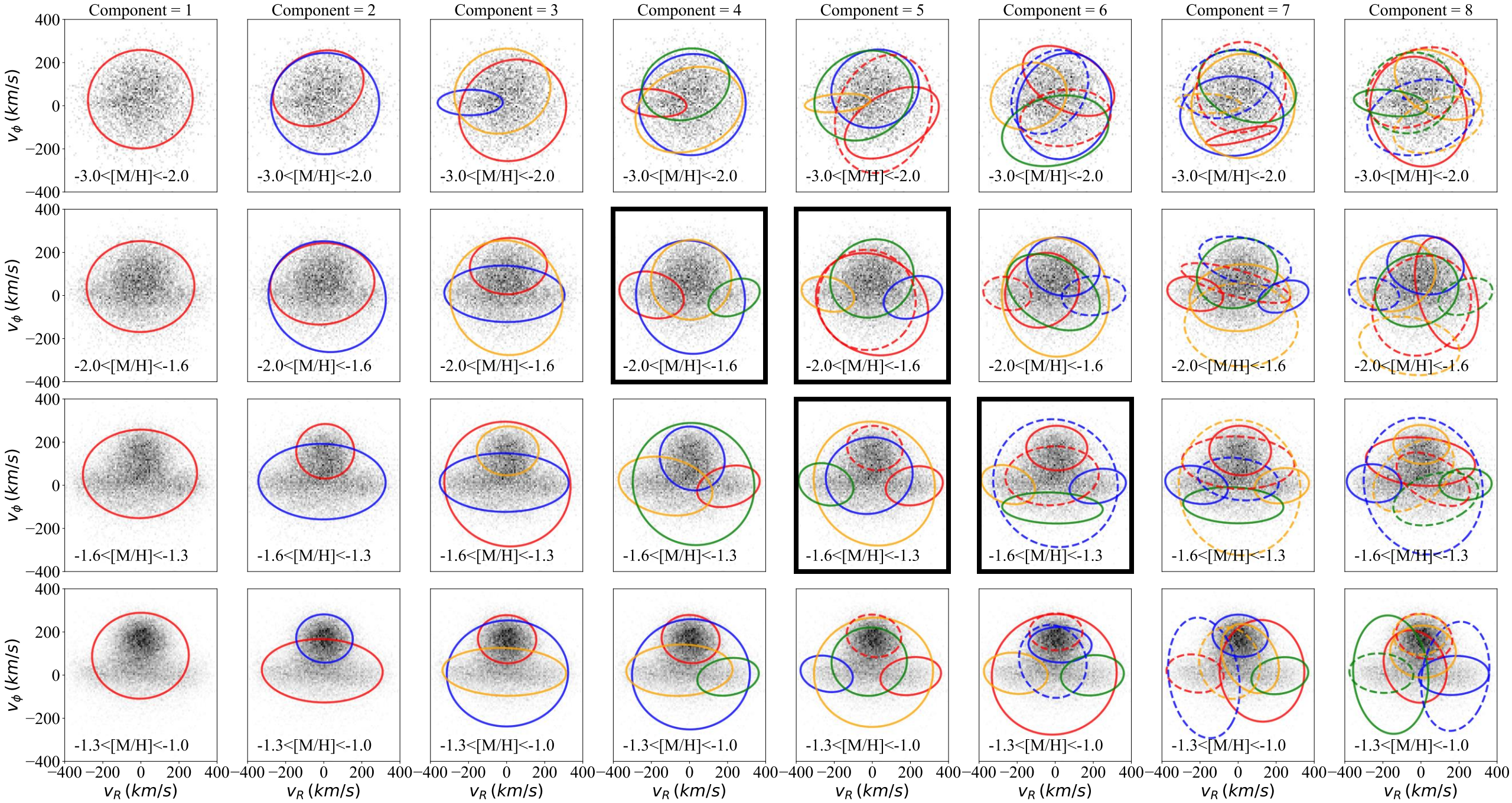



-3.0<[Fe/H]<-2.0
Smallest
Median
Largest
BIC
177700
177600
177500
177400
1 2 3 4 5 6 7 8
Number of Component


-2.0<[Fe/H]<-1.6
BIC
443200
443000
442800
442600
442400
1 2 3 4 5 6 7 8
Number of Component


-1.6<[Fe/H]<-1.3
BIC
703000
702000
701000
700000
4 5 6
1 2 3 4 5 6 7 8
Number of Component


1e6
-1.3<[Fe/H]<-1.0
BIC
1.112
1.110
1.108
1.106
1.104
4 5 6
1 2 3 4 5 6 7 8
Number of Component


Component = 1
Component = 2
Component = 3
Component = 4
Component = 5
Component = 6
Component = 7
Component = 8
-3.0<[M/H]<-2.0
-2.0<[M/H]<-1.6
-1.6<[M/H]<-1.3
-1.3<[M/H]<-1.0
v_ϕ (km/s)
v_R (km/s)
400
200
0
−200
−400