Environmental effects on the assembly of dynamically cold disks in cluster galaxies -- Fornax vs. TNG50

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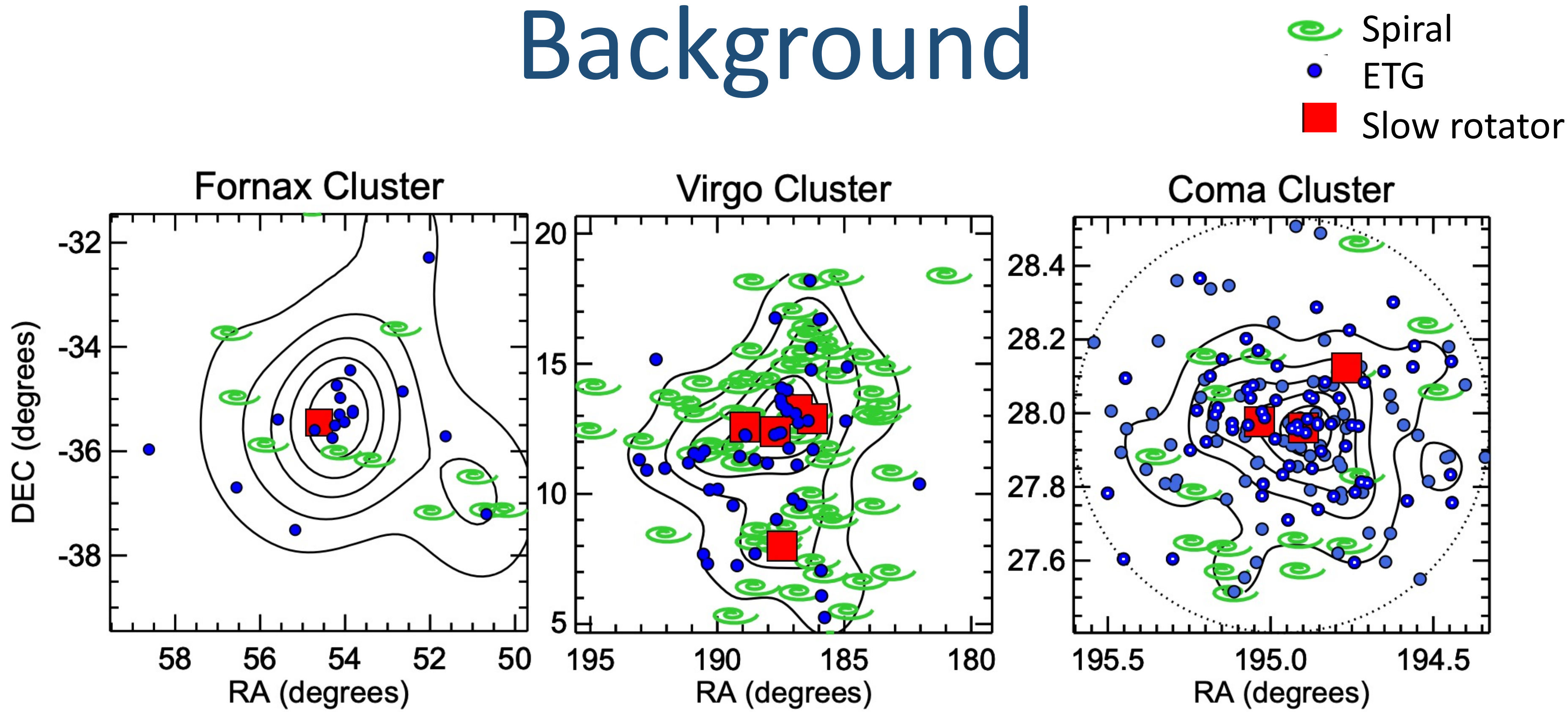
Collaborators:

Ling Zhu, the Fornax3D team

Background

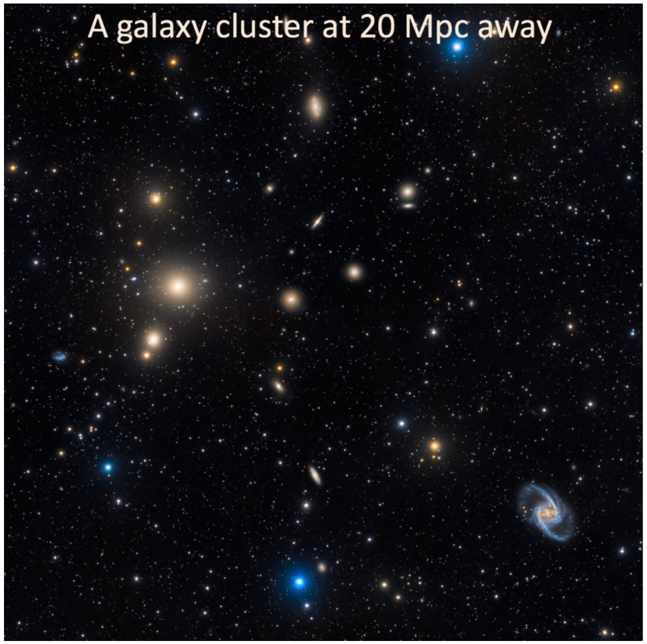


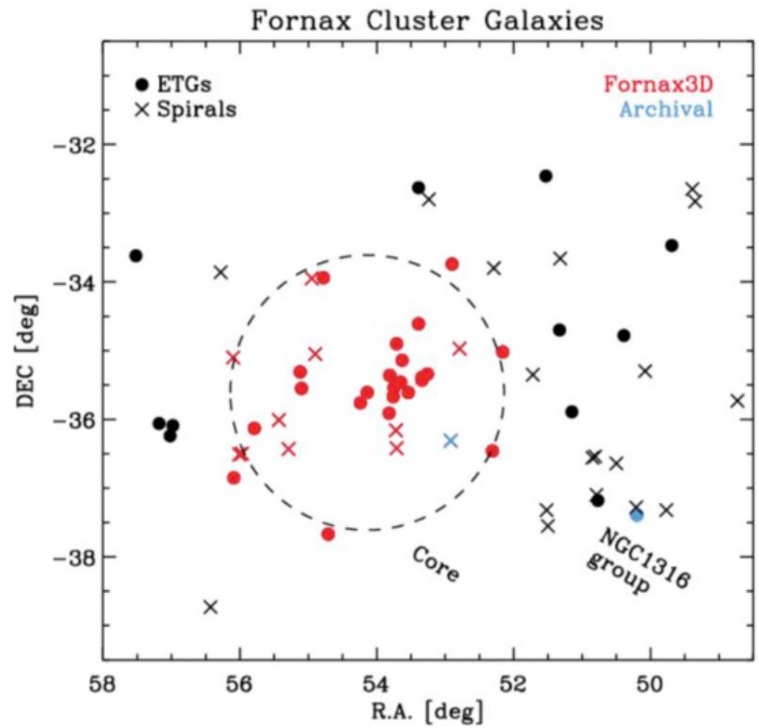
Cappellari+2016

- Environment affects the star-formation of galaxies.
- Environment affects the internal dynamical structure of galaxies, but hard to quantify.

The Fornax3D survey

Fornax cluster





Sarzi+2018

- Deep IFU using MUSE/VLT, FOV:1’x1’, pixel size:0.2’’x0.2’’
- 23 ETGs, 10 LTGs within R_v of the Fornax cluster.
- Cover the outer faint regions

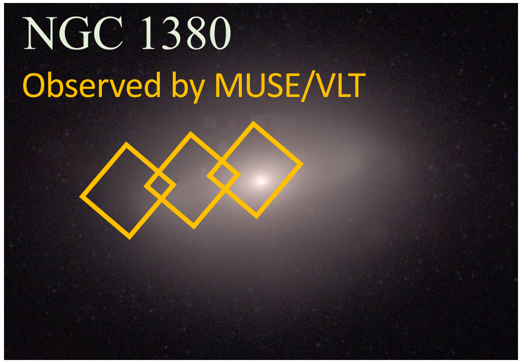
Outline

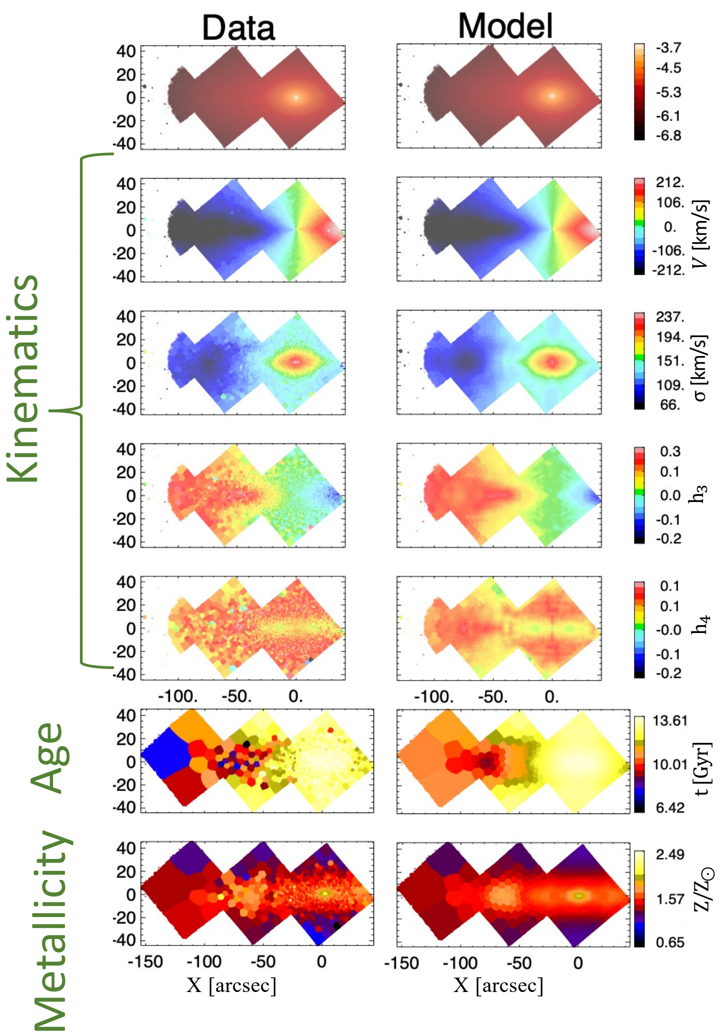
- Cold disk -- chemo-dynamical decomposition via a population-orbital superposition model

- Environment -- obtaining t_{infall} of each galaxy by using a correlation of t_{infall} vs. t_{cold} obtained from TNG50.

- Environmental effects on the cold disk formation. (Fornax vs. TNG50 cluster)

Chemo-dynamical decomposition via a Population-orbital superposition model





Zhu+2020, Zhu+2022b

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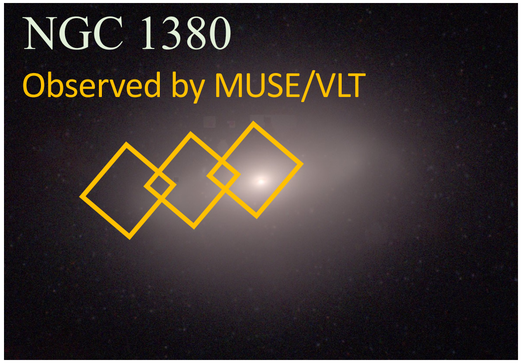
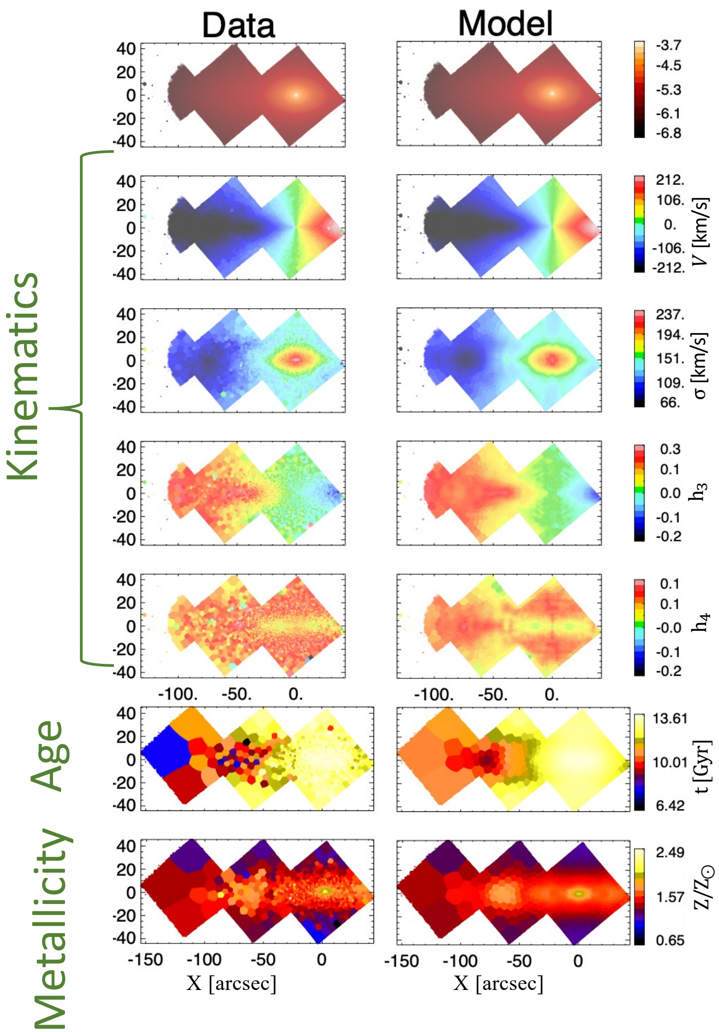


Gravitational potential=
$M_*/L \times$ MGE + DM + …



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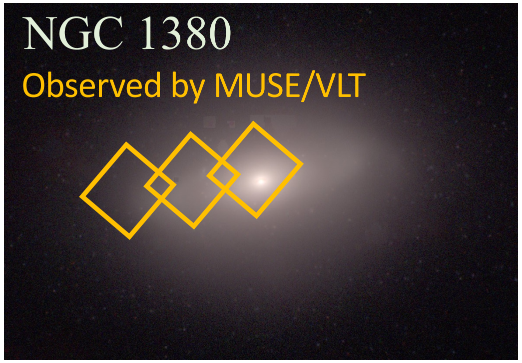

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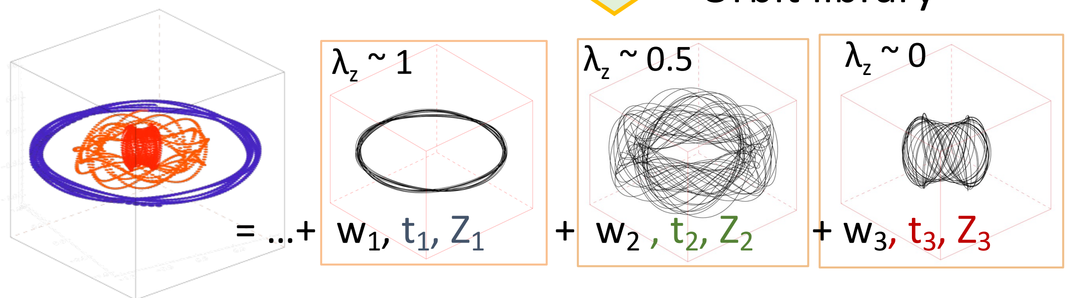
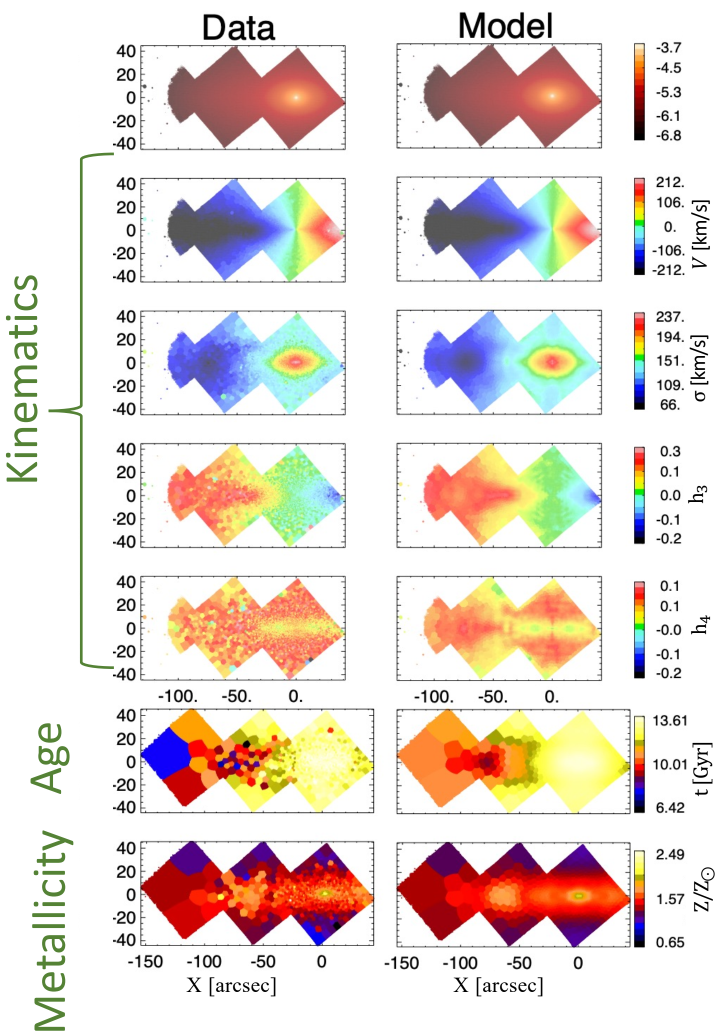
Orbit library





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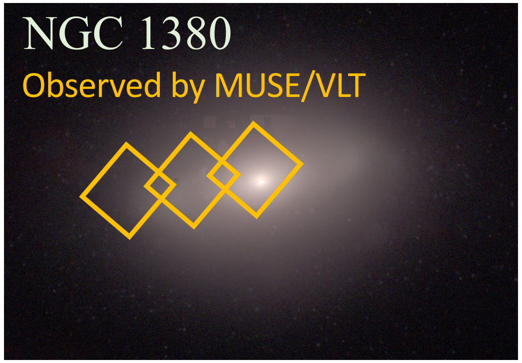

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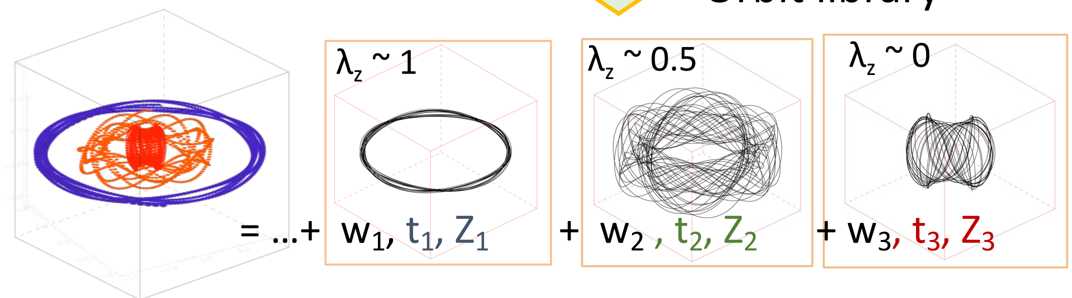
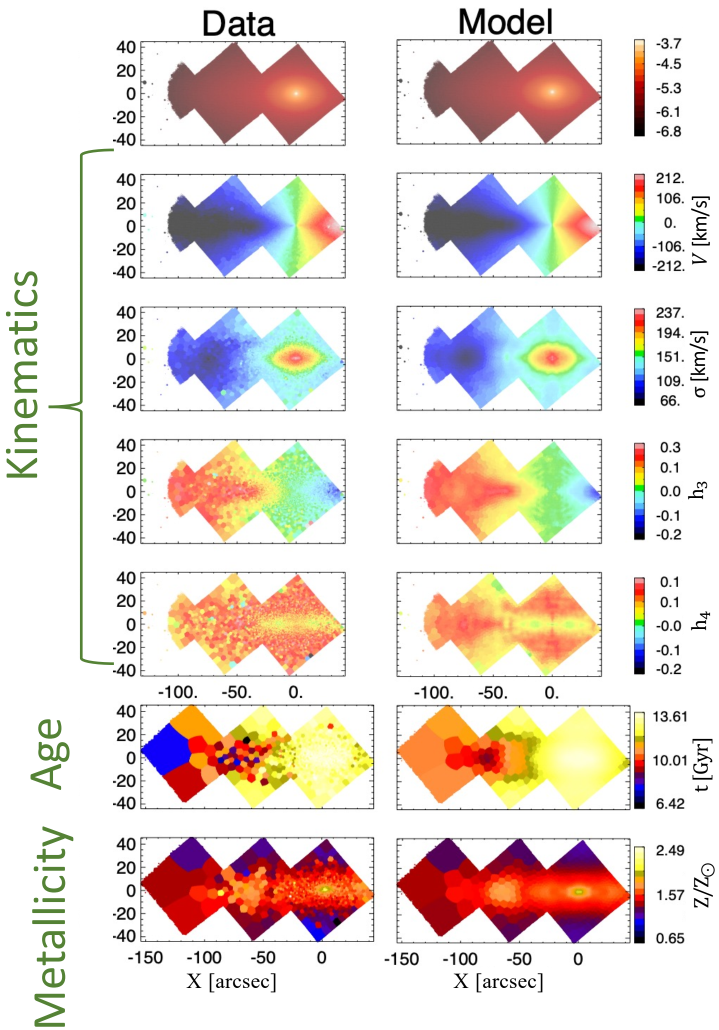
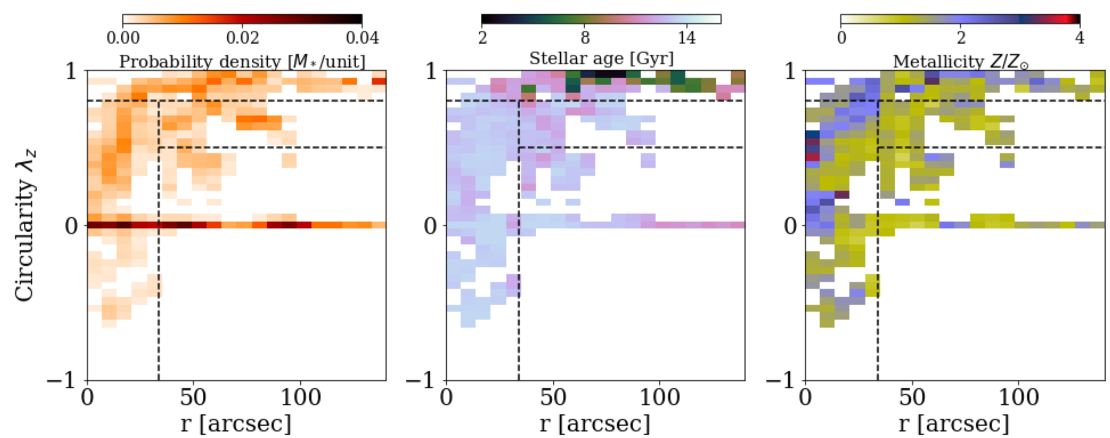


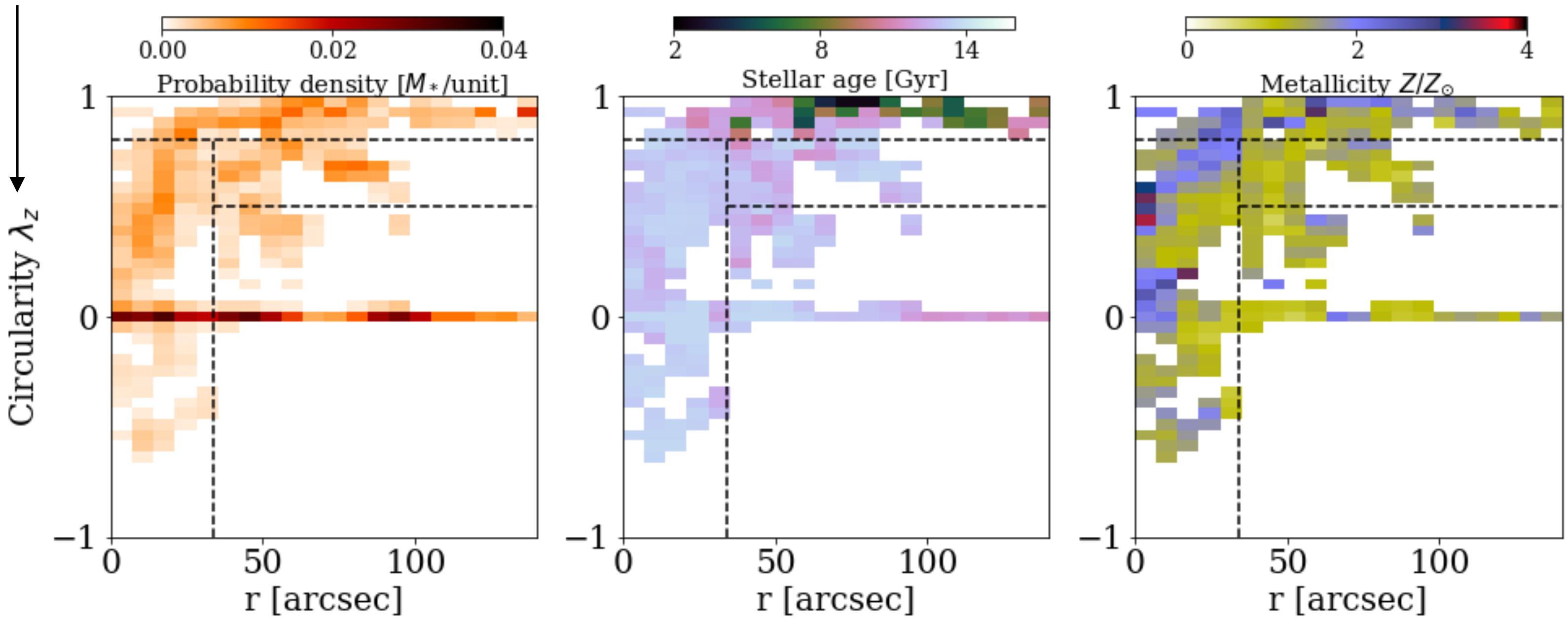




Zhu+2020, Zhu+2022b

Orbital structure decomposition

$\lambda_z = L_z/J_c$



- Define structures in a flexible and physical-motivated way.
- Quantify the morphology, kinematics, age and metallicity of each component.
- Direct comparison to simulations.

Orbital structure decomposition

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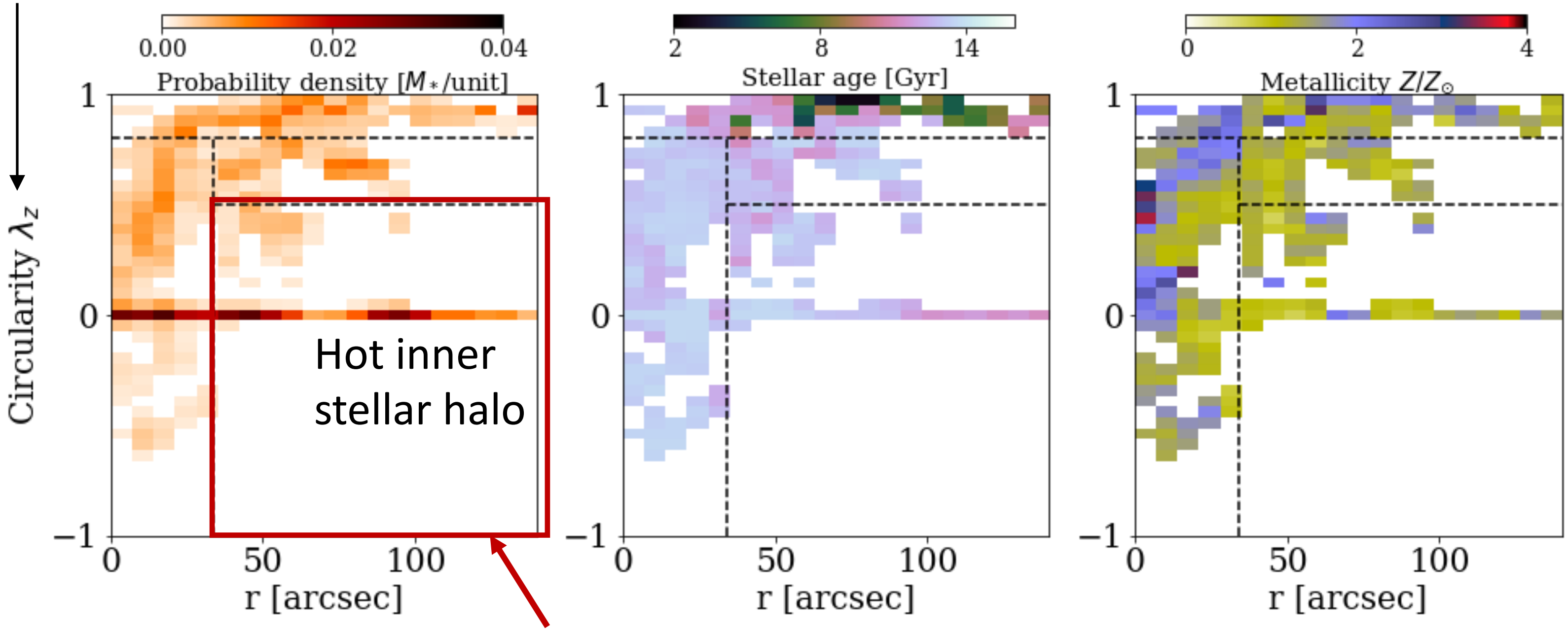

A good indicator of past massive mergers (see Zhu+2022a,b)

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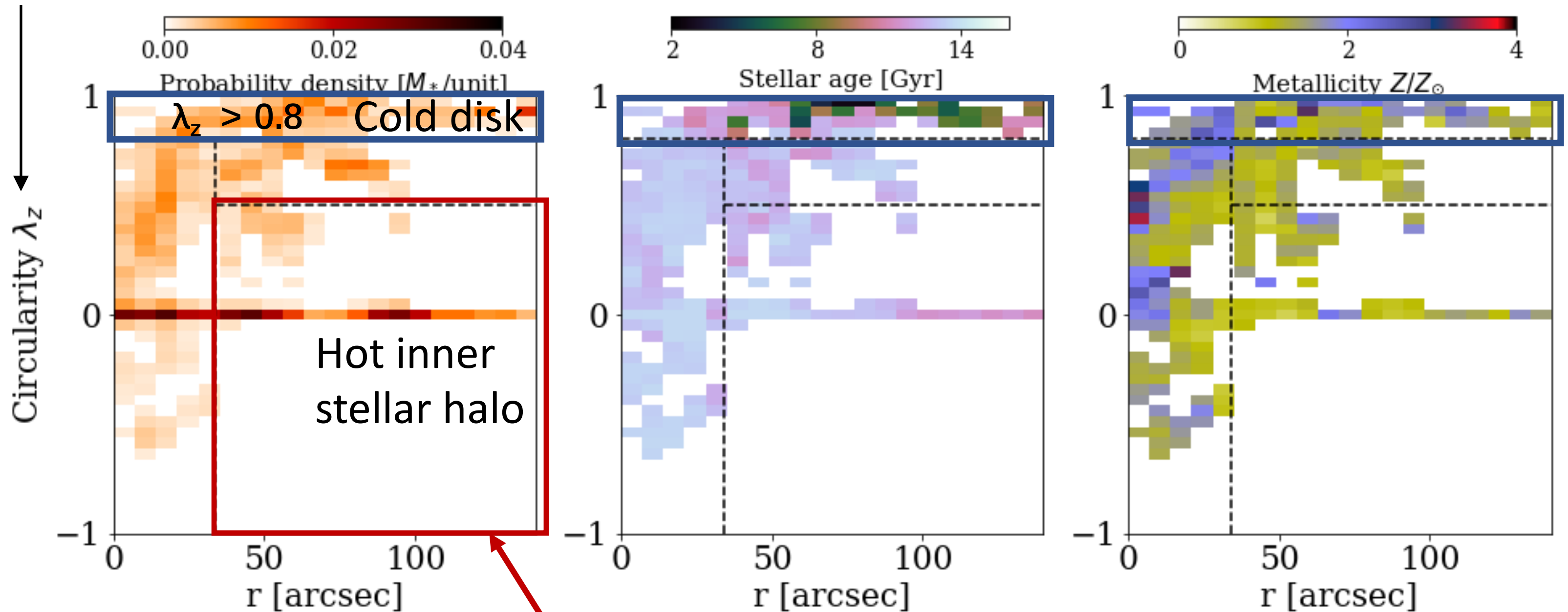

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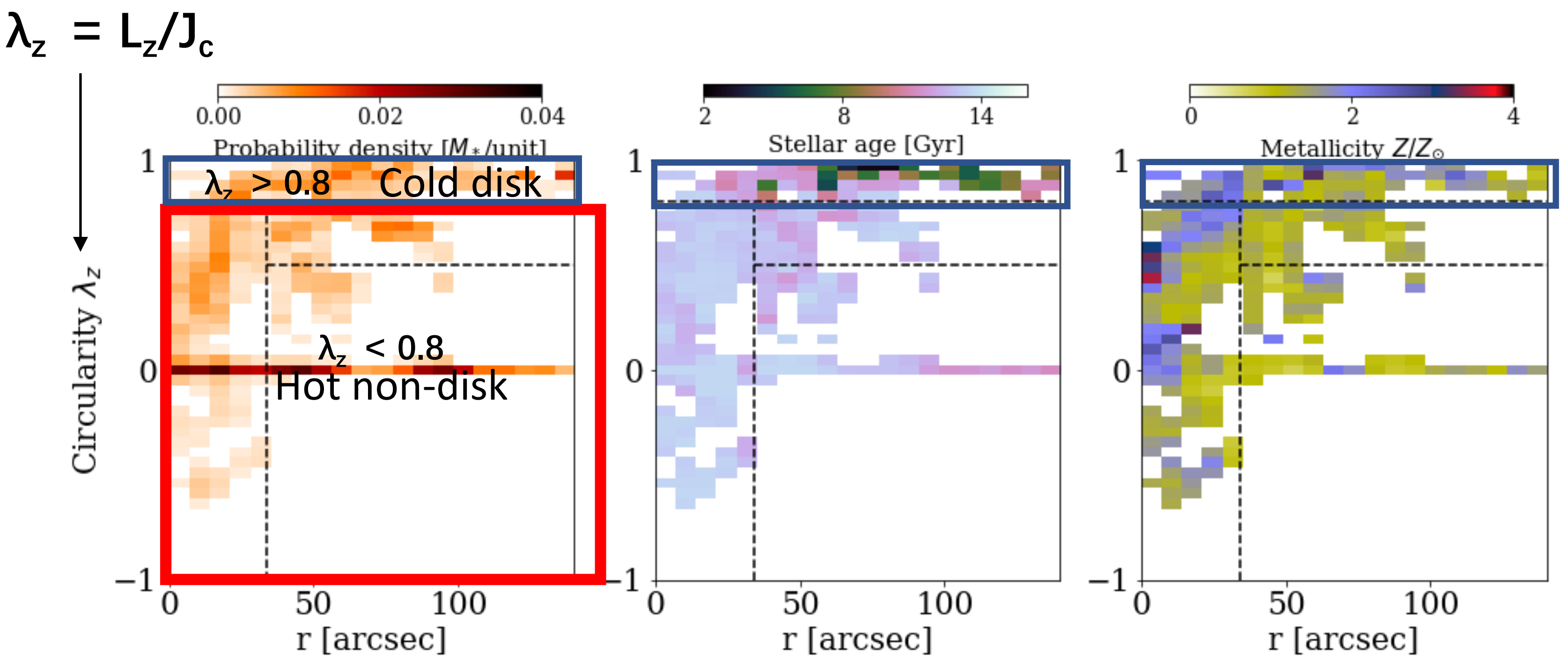

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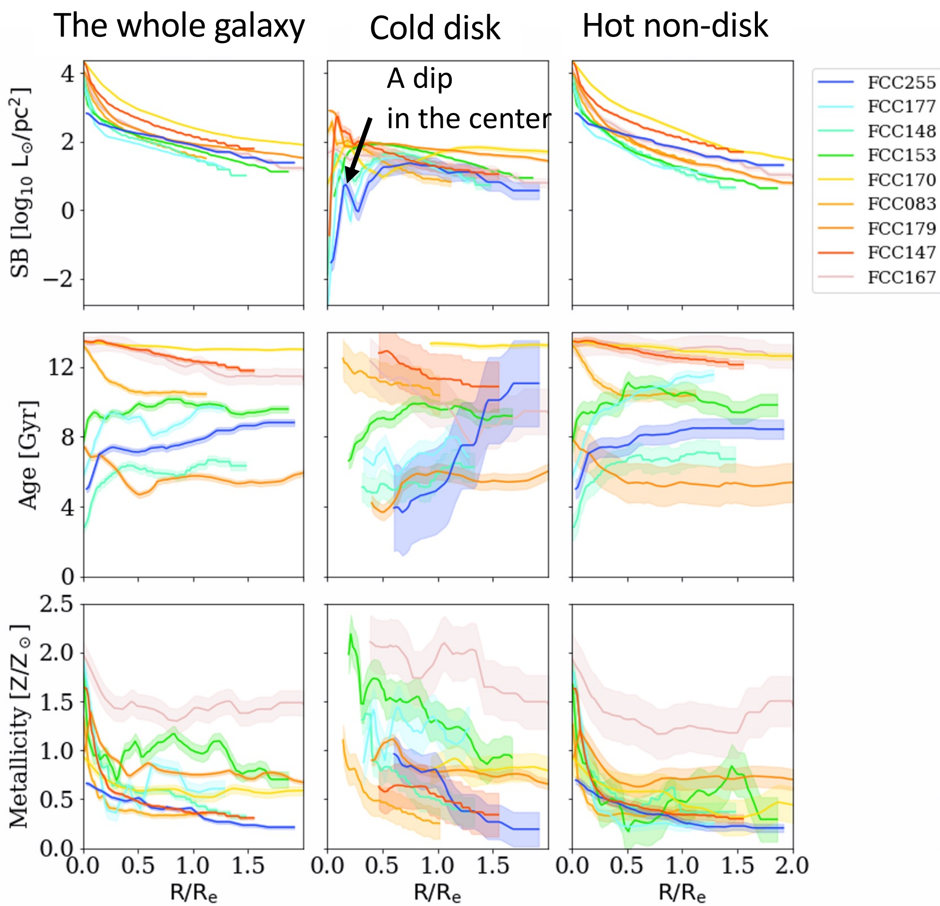
Orbital decomposition of cold disk and hot non-disk components



Ding+2023

Key parameters

For all 16 galaxies:

f_{cold} : Cold disk fraction

t_{cold} : Cold disk age

Z_{cold} : Cold disk metallicity

For 9 galaxies with extended disks:

∇t_{cold}: Cold disk age gradient

∇Z_{cold}: Cold disk metallicity gradient

And the corresponding parameters for the hot components.

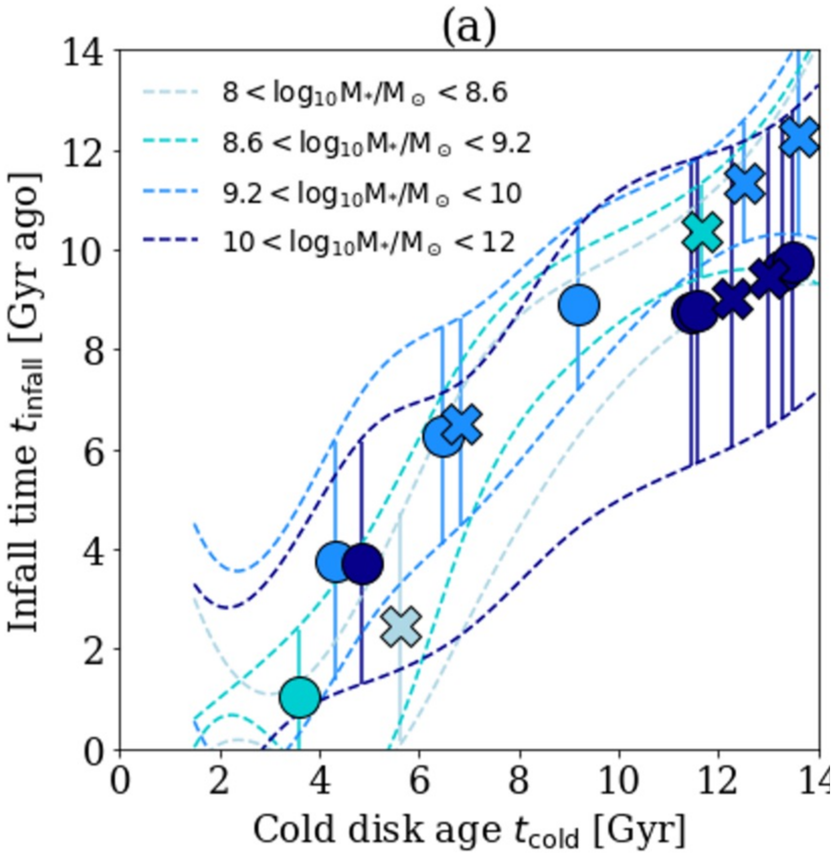
Outline

- Cold disk -- chemo-dynamical decomposition via a population-orbital superposition model

- Environment -- obtaining t_{infall} of each galaxy by using a correlation of t_{infall} vs. t_{cold} obtained from TNG50.

- Environmental effects on the cold disk formation. (Fornax vs. TNG50 cluster)

Infer the infall time of each galaxy in the Fornax cluster



- Tight correlations between t_{cold} vs. t_{infall} from TNG50
- For Fornax cluster galaxies, with t_{cold} known, we infer t_{infall} from these correlations

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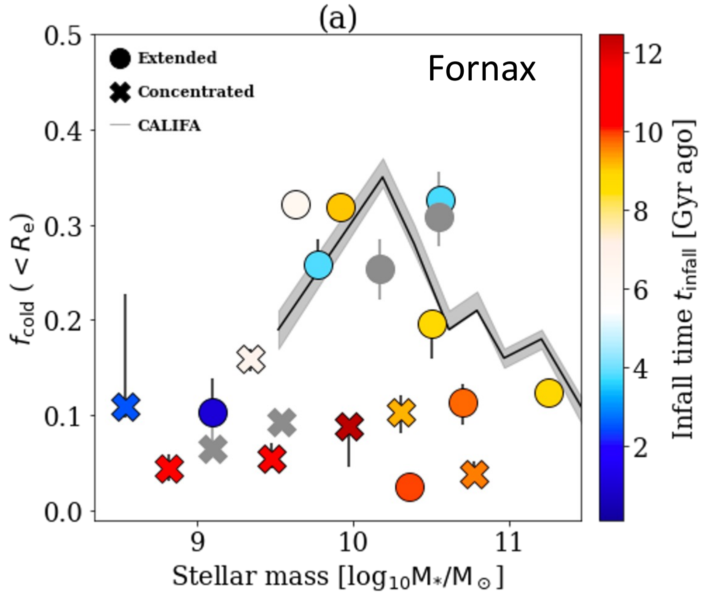
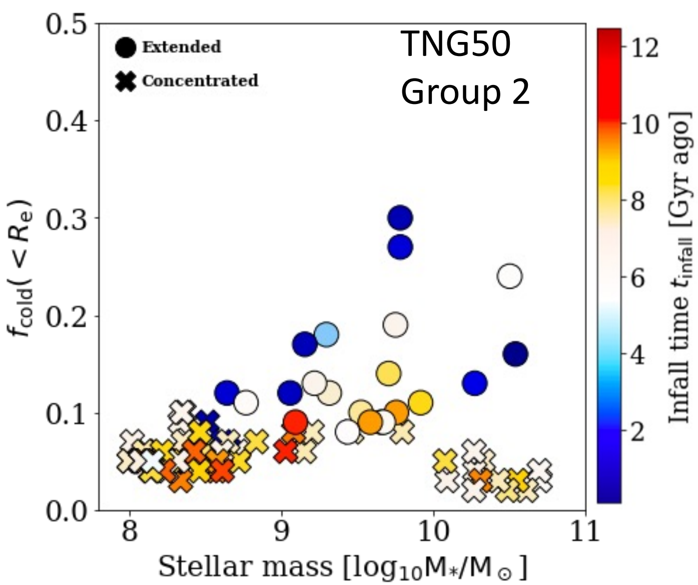
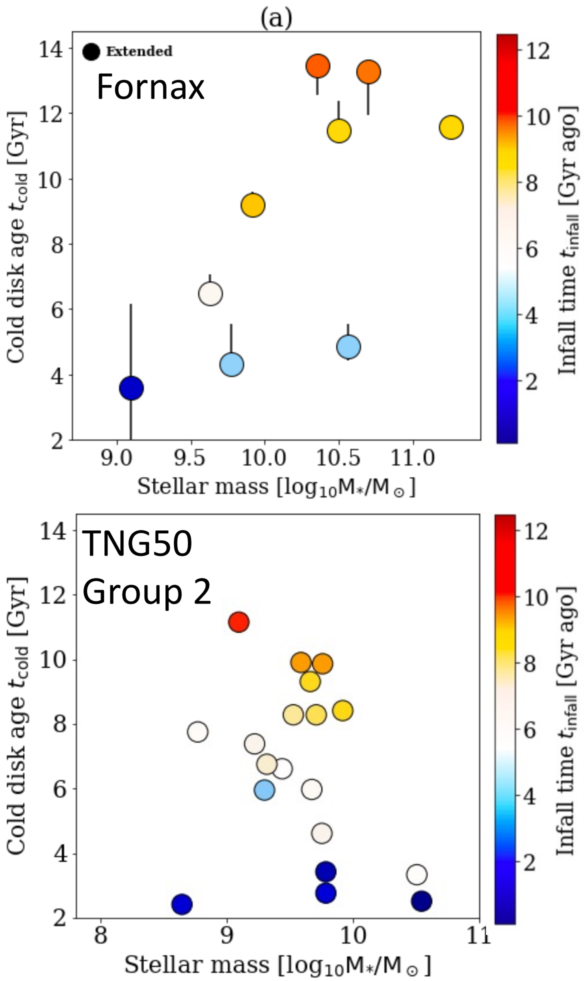
Environmental effects on the cold disk fraction





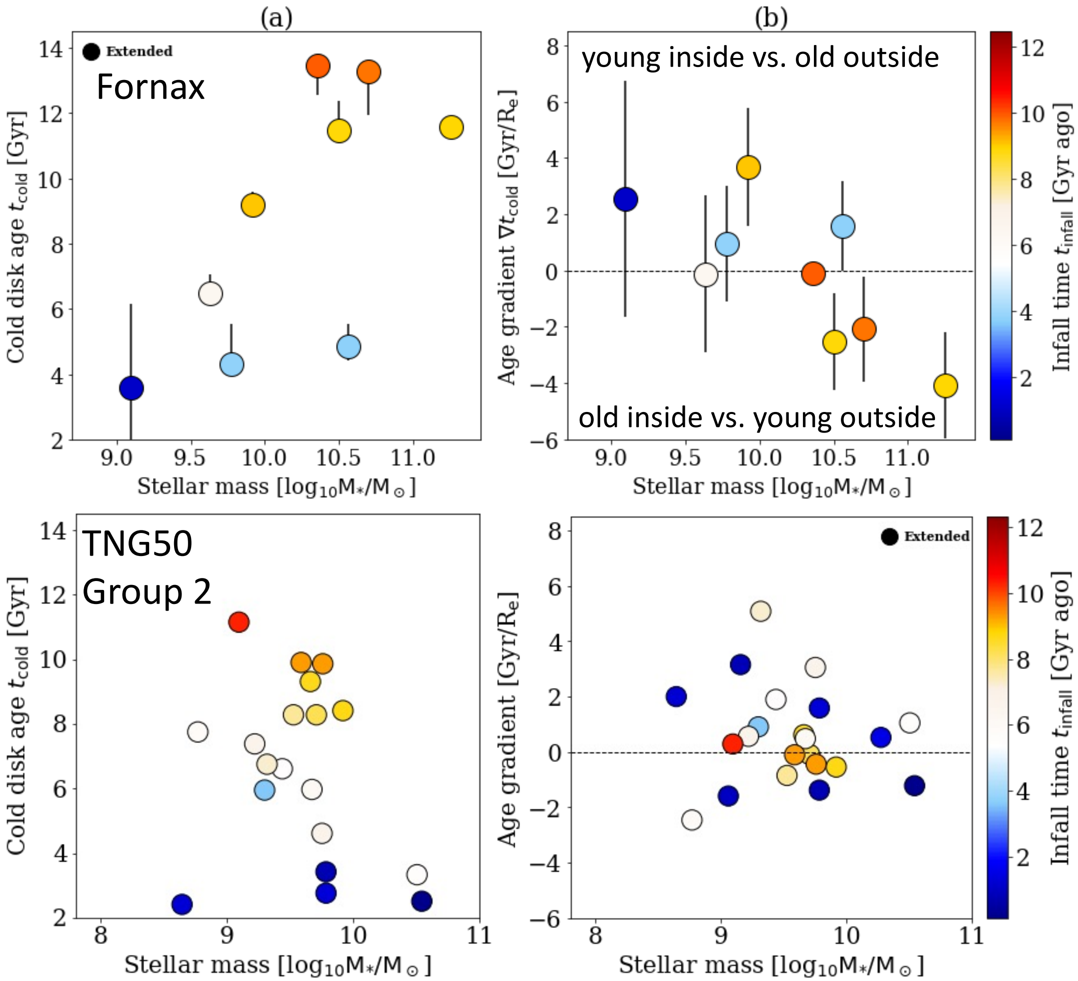
- Ancient infallers tend to have lower $f_{\rm cold}$ at all mass region.
- $f_{\rm cold}$ of recent and intermediate infallers is consistent with CALIFA field galaxy.

Environmental effects on the cold disk age & age gradient



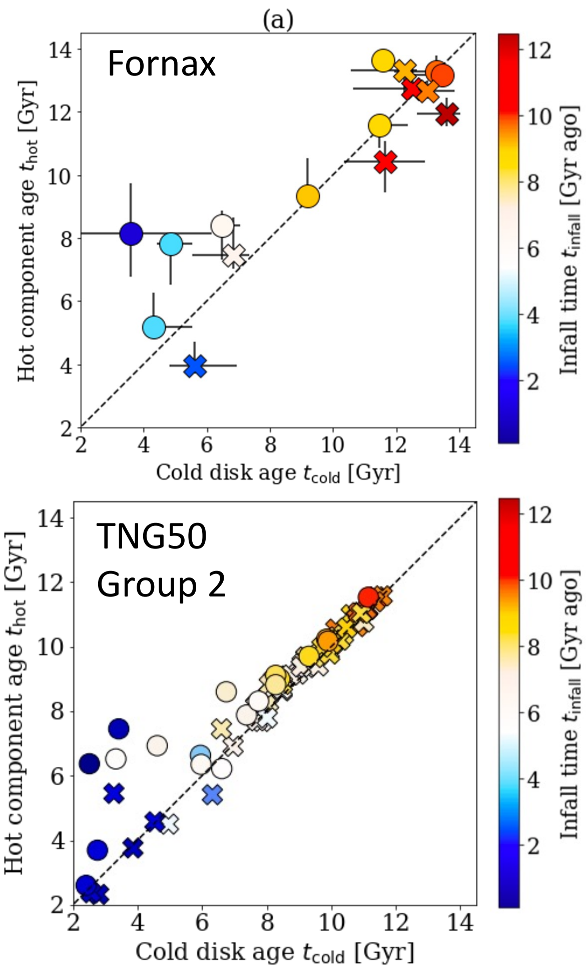
- Cold disks are old in the ancient infallers, which happen to be the most massive galaxies in Fornax cluster.

Environmental effects on the cold disk age & age gradient



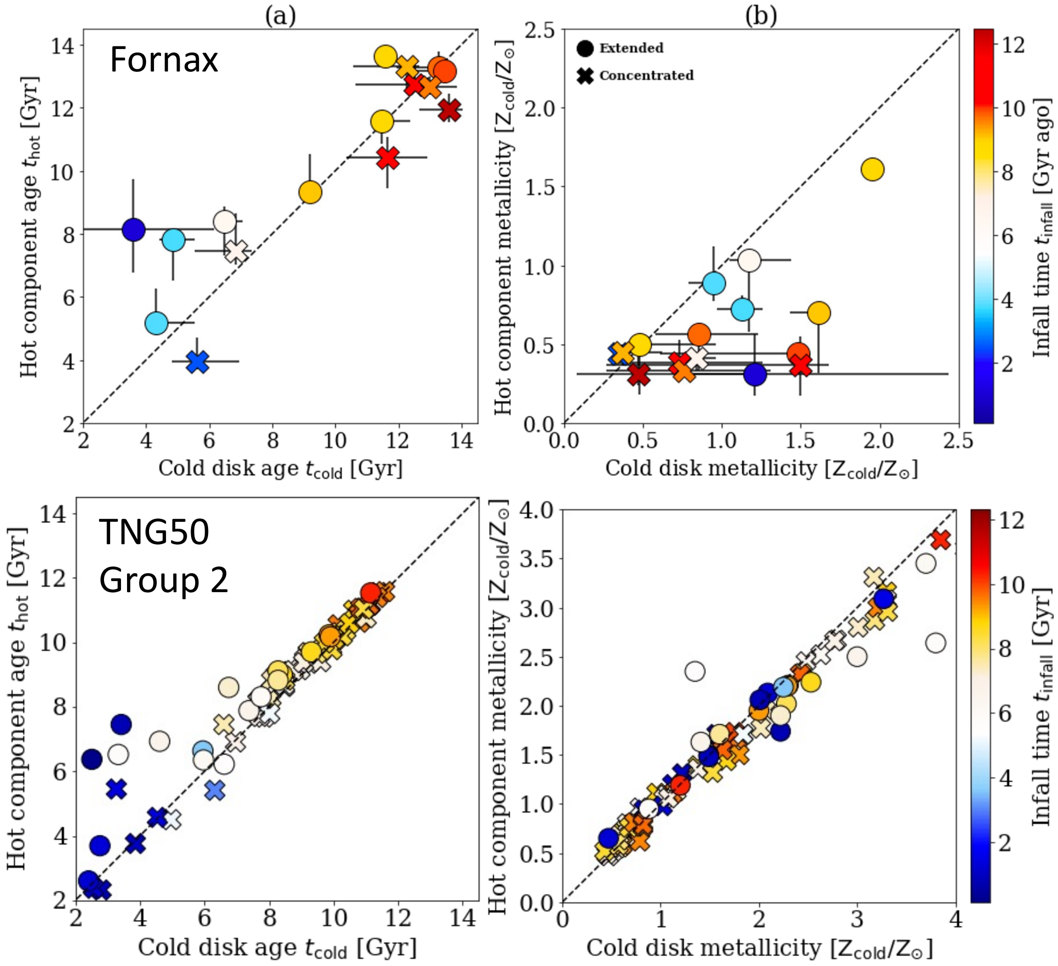
- Cold disks are old in the ancient infallers, which happen to be the most massive galaxies in Fornax cluster.
- Low mass galaxies show positive age gradient while high mass galaxies show negative gradient in Fornax.
- Positive age gradient is found in both Fornax and TNG50.

Cold vs. hot



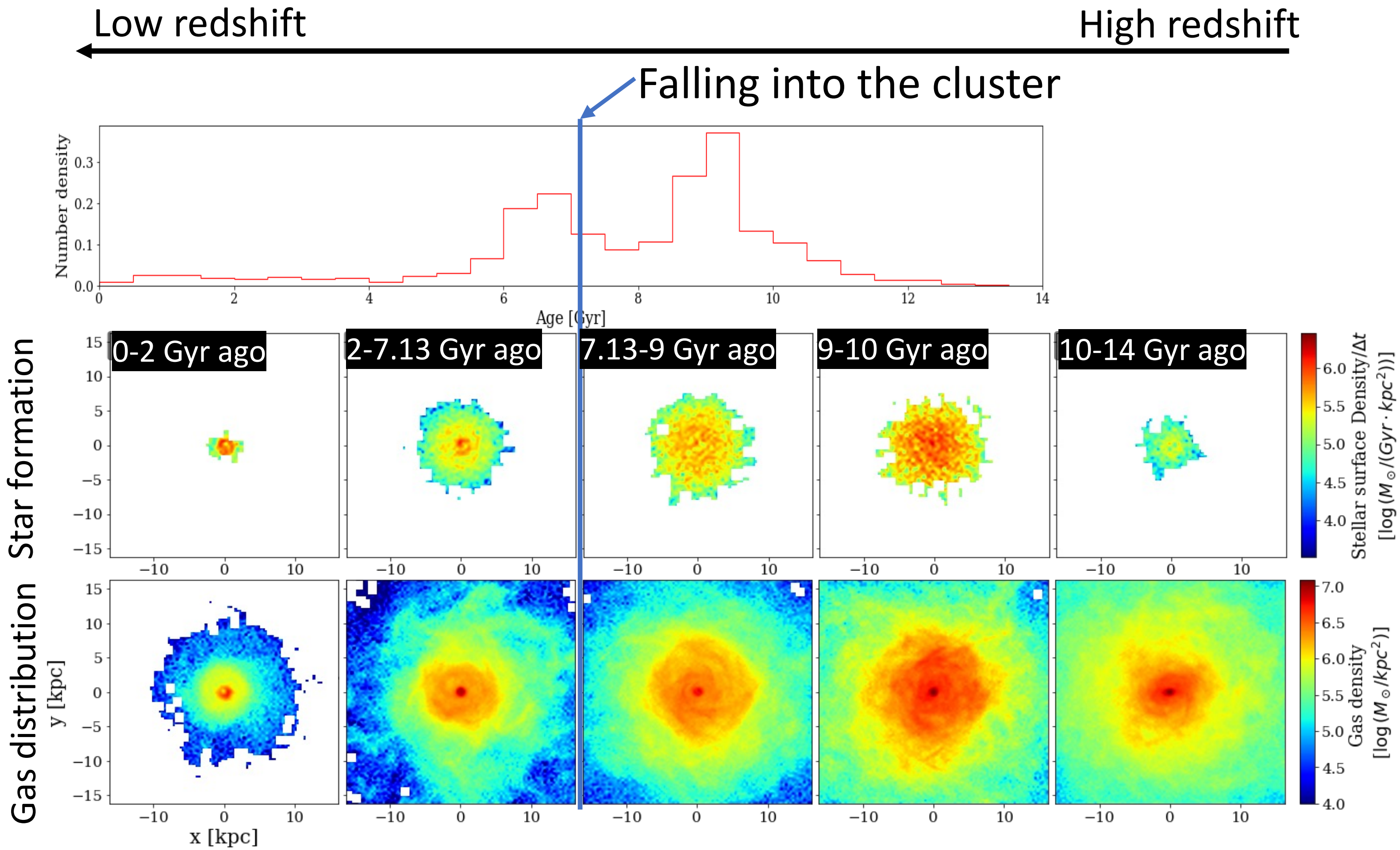
- Ancient infallers: hot and cold components have similar age.
- Recent infallers: cold component is significantly younger.

Cold vs. hot



- Ancient infallers: hot and cold components have similar age.
- Recent infallers: cold component is significantly younger.
- The cold disks are more metal-rich that the hot component in Fornax, not seen in TNG50.

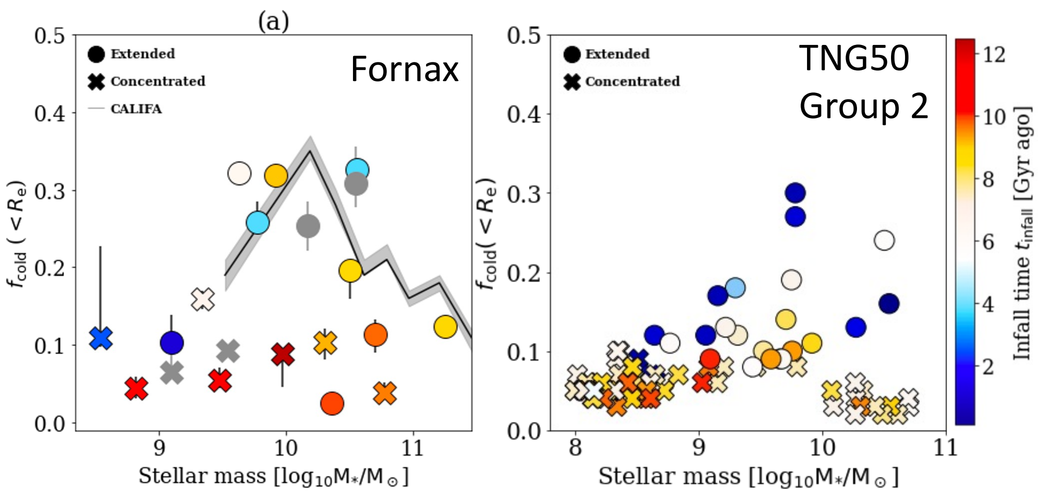
Infalling into the cluster changes galaxies' gas distribution:
(1) gas in the outer disk is stripped
(2) gas left is concentrated in the center



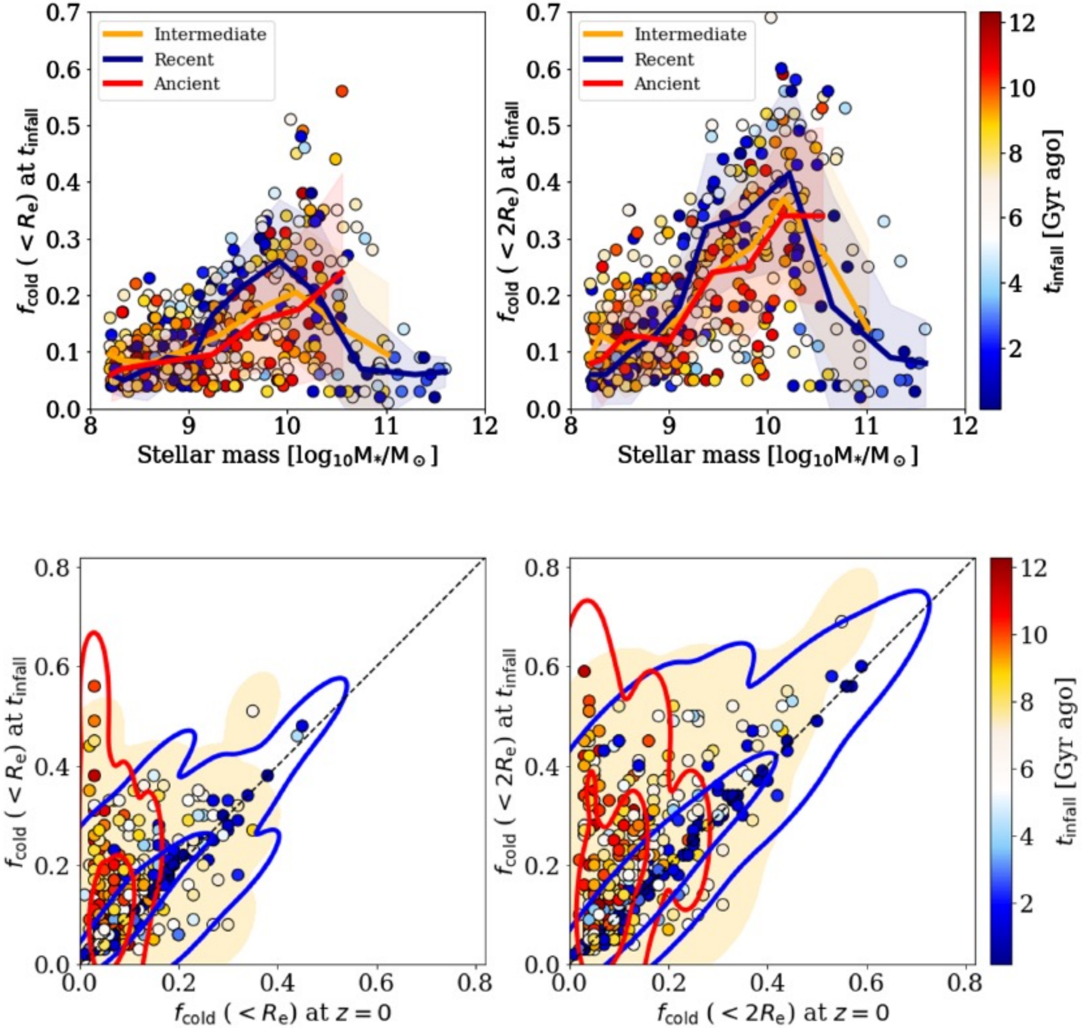
Galaxies in TNG50: falling into cluster stops the star-formation in extended disks and causes the new star-formation in the center, thus leading to low cold-disk fraction and old stellar disk in ancient infallers.

Summary

- We create population-orbital superposition models to 16 Fornax galaxies, thus we can quantify the luminosity fraction, age, and metallicity of the dynamical cold disk of each galaxy.
- We find the ancient infallers have a significantly lower cold disk fraction (~3 times lower), regardless of stellar mass. The recent and intermediate infallers have consistent cold disk fraction as a function of stellar mass with CALIFA field galaxies.
- We find ancient infallers have old cold disks, and some galaxies have positive age gradients.
- We find consistent results in TNG50 and these are direct results of gas removing in the outer disk of galaxies when falling into the cluster.

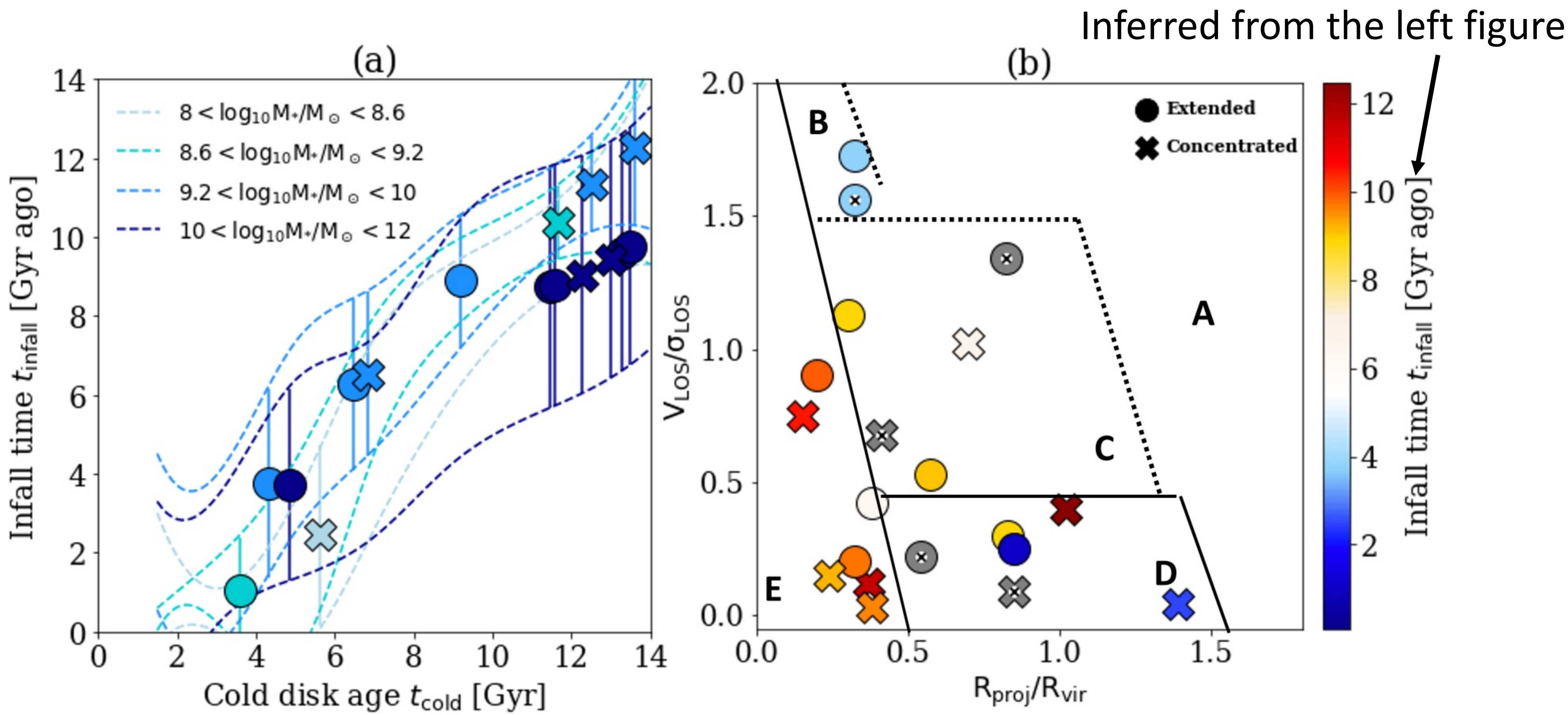


Cold disk fraction at z=0 vs. infall



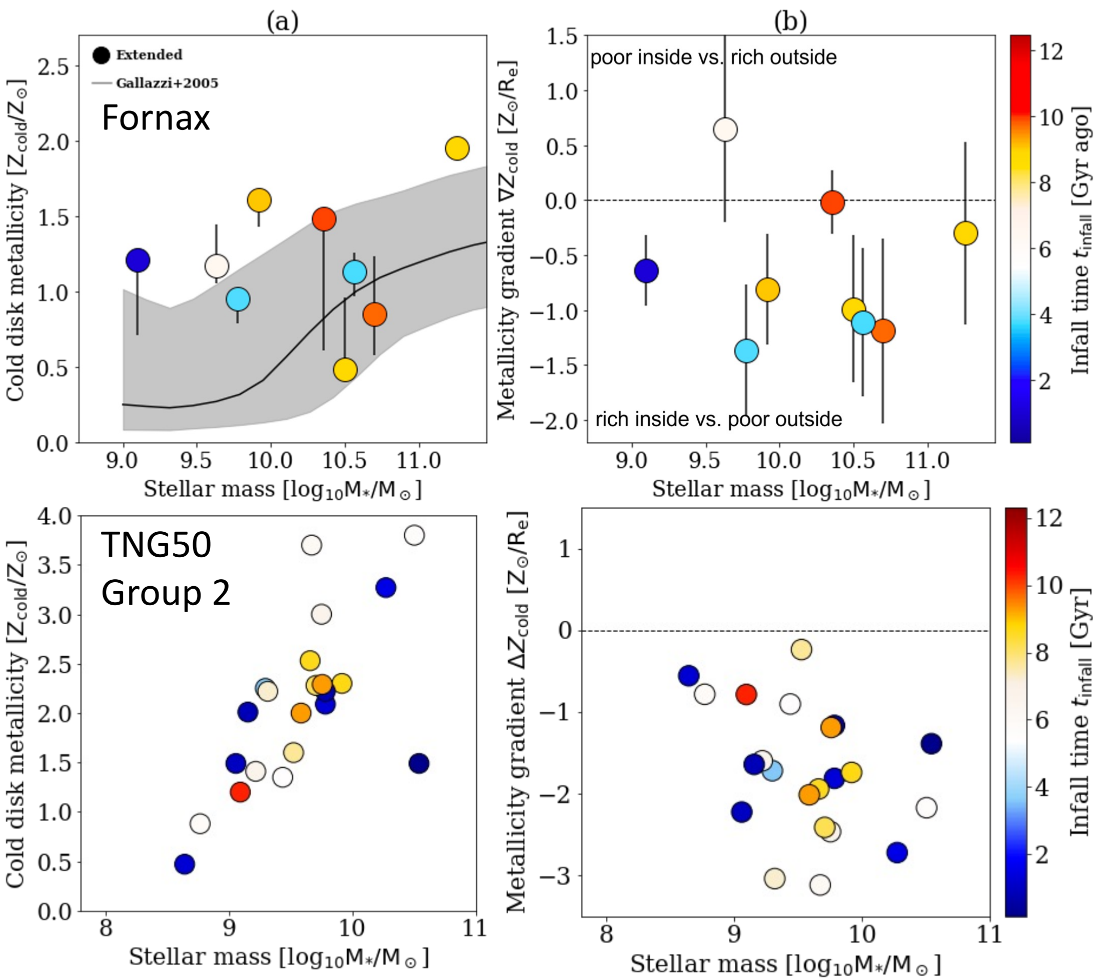
- At t_{infall} , ancient and intermediate infallers had slightly lower cold-disk fraction than that of recent infallers.
- Cold-disk is strongly disrupted after galaxies fall into the cluster due to the tidal shocking near the pericentric passages.

Infer the infall time of each galaxy in the Fornax cluster



- Tight correlations between t_{cold} vs. t_{infall} from TNG50
- For Fornax cluster galaxies, with t_{cold} known, we infer t_{infall} from these correlations
- t_{infall} obtained in this way consistent with galaxies' phase-space positions in the cluster

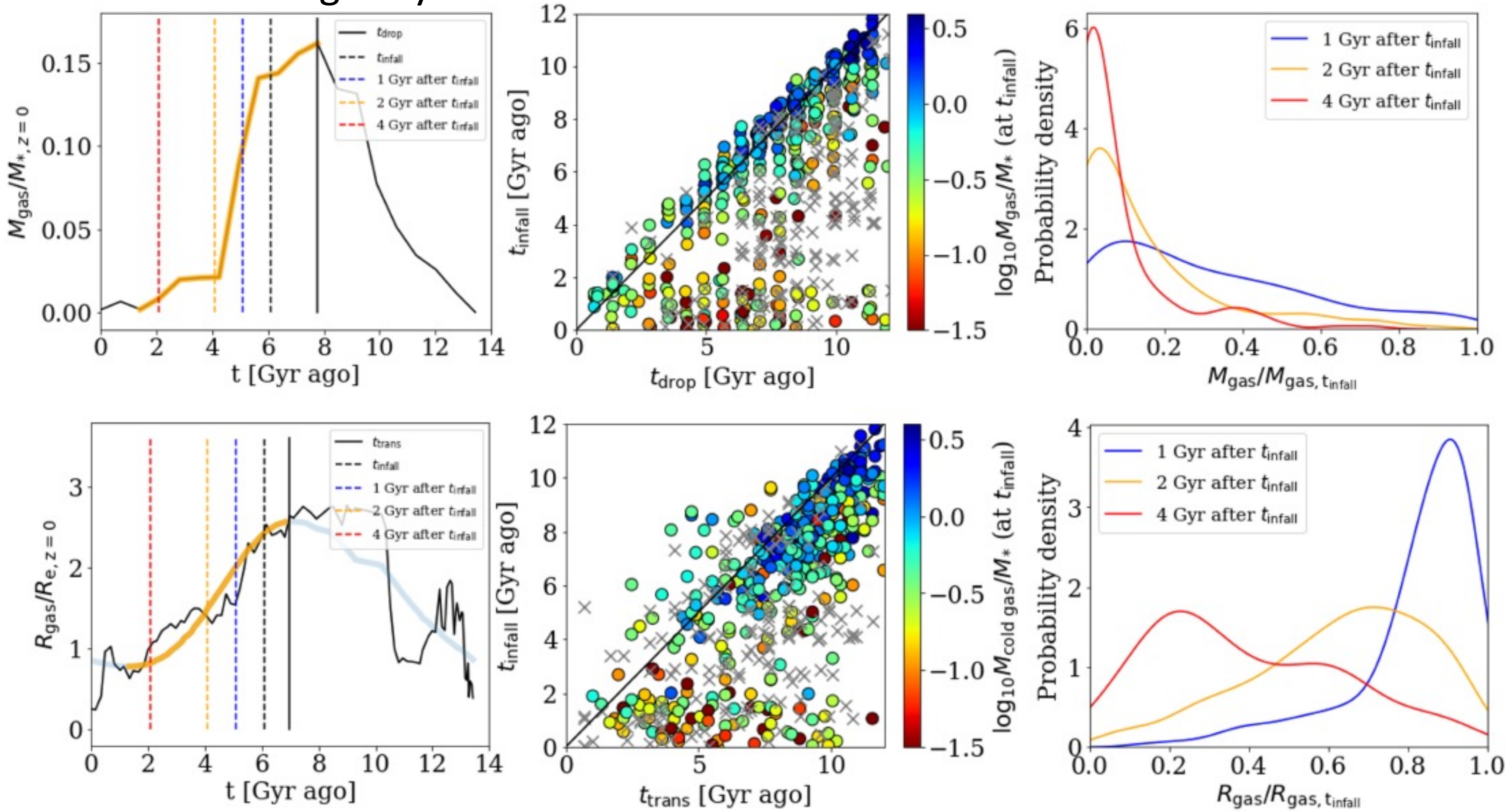
Environmental effect on the cold disk metallicity & metallicity gradient



- Cold disk metallicities of Fornax galaxies are slightly higher than the general mass-metallicity relation (Gallazzi+2005).
- Most galaxies show negative metallicity gradient in the cold disks.
- Cold disk metallictiy in TNG50 is much higher.

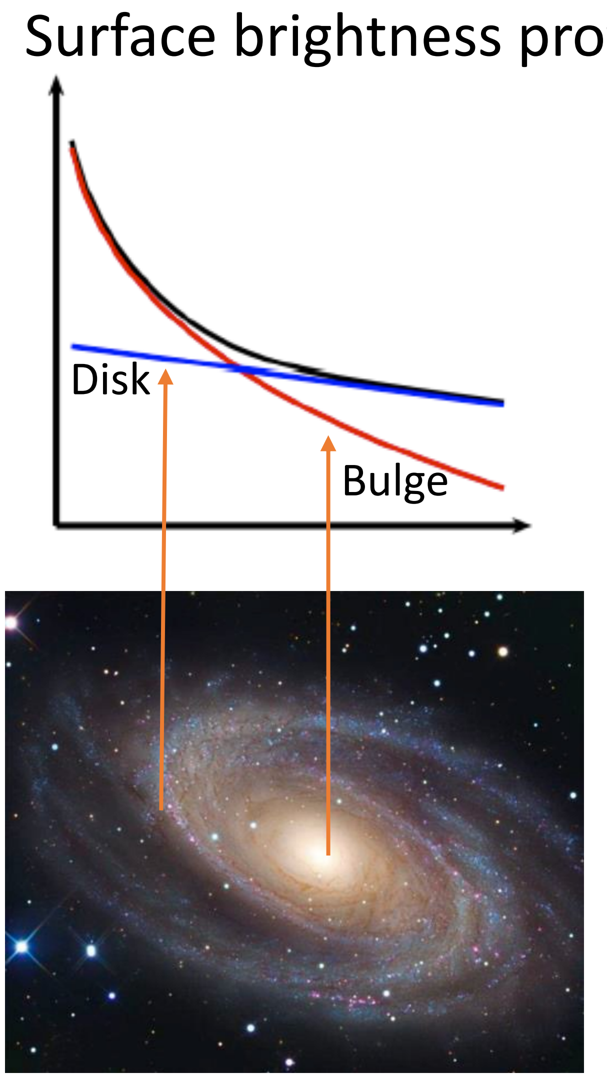
Environmental effect on gas and gas distribution

A TNG50 galaxy



After the infall, the star-formation radius shrinks.
The mass of cold gas decreases.

Background

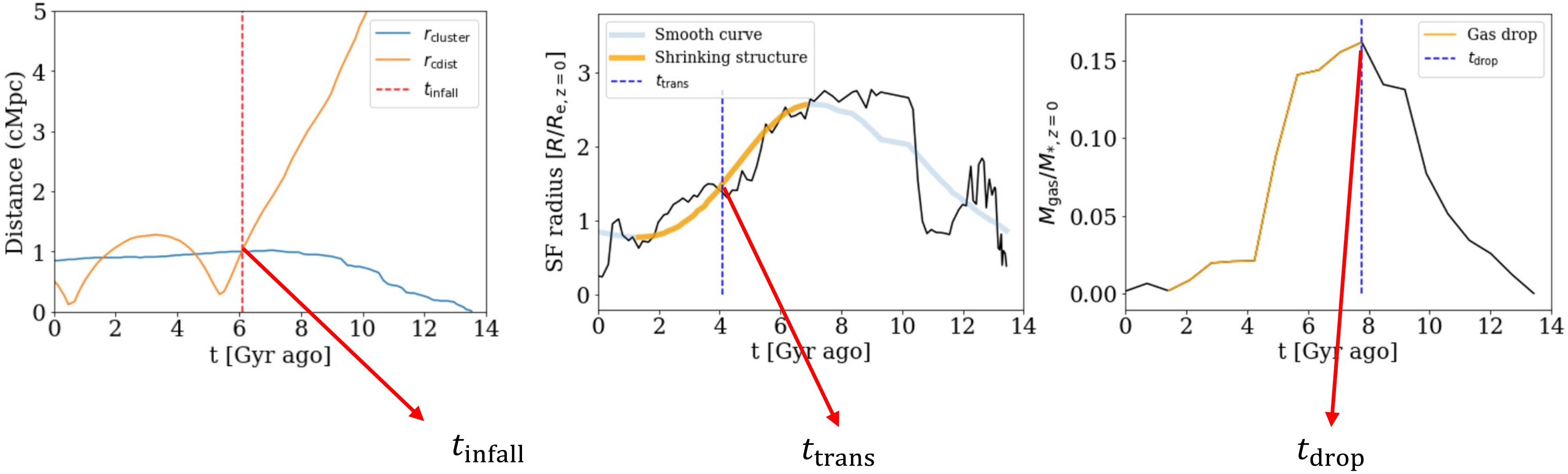


Weakness of photometrical bulge-disk decomposition:

- Model dependent
- Not physically motivated
- Disk may not be exponential

Environmental effect on star-formation radius and gas

A TNG50 galaxy



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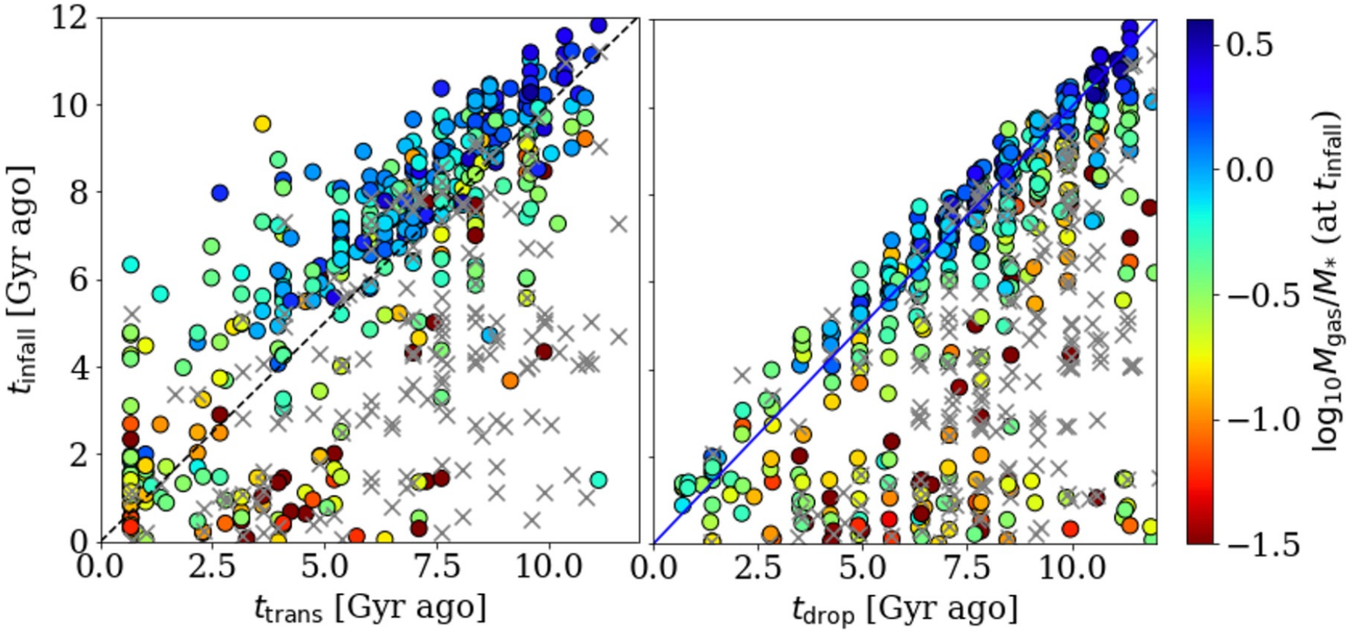
The mass of cold gas decreases.

In TNG50

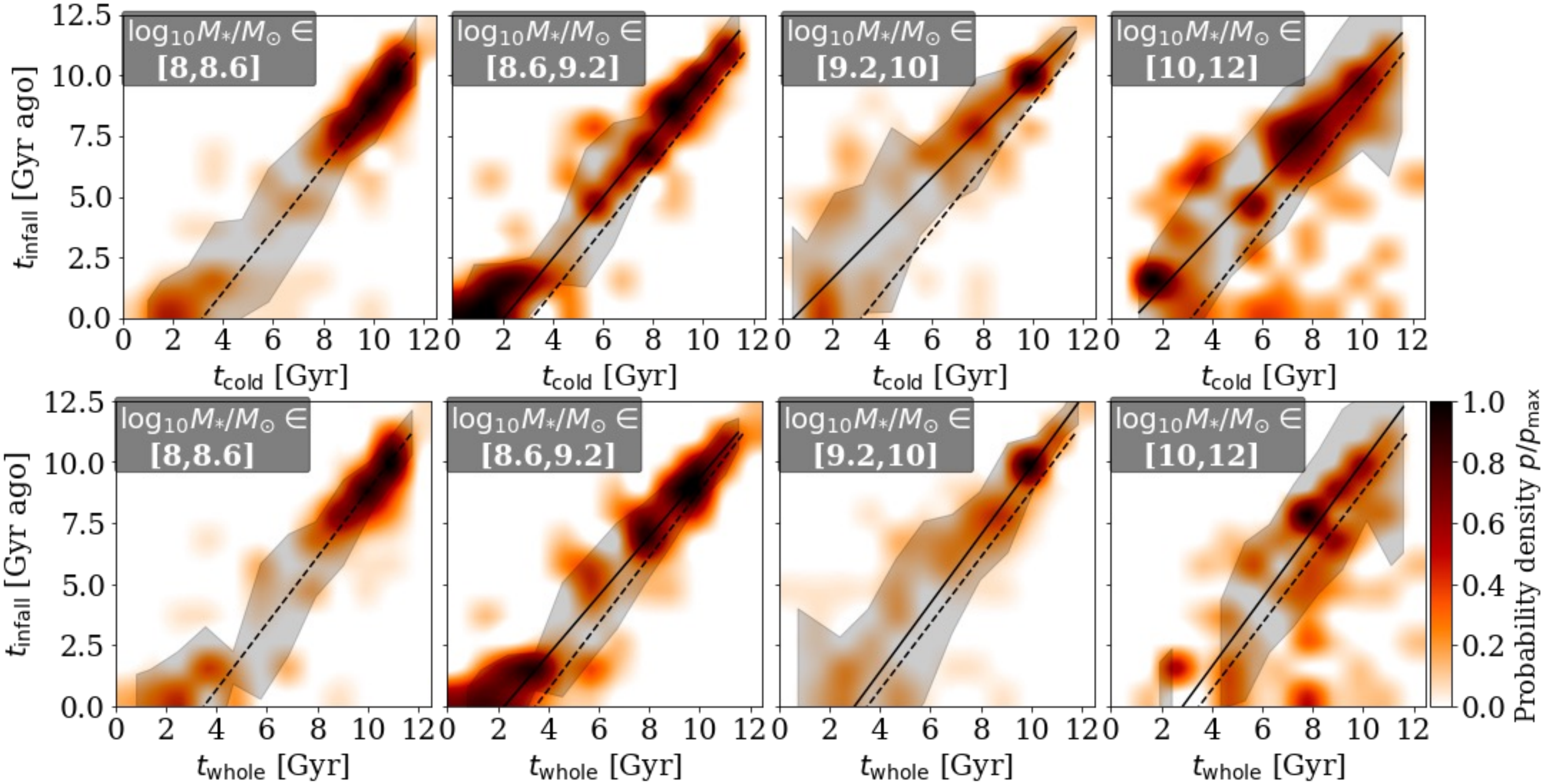
Select cluster viral mass $\log_{10} M_{200c}/M_{\odot} > 13.3$
galaxy stellar mass $\log_{10} M_{*}/M_{\odot} \in [8,12]$, Re>0.5 kpc



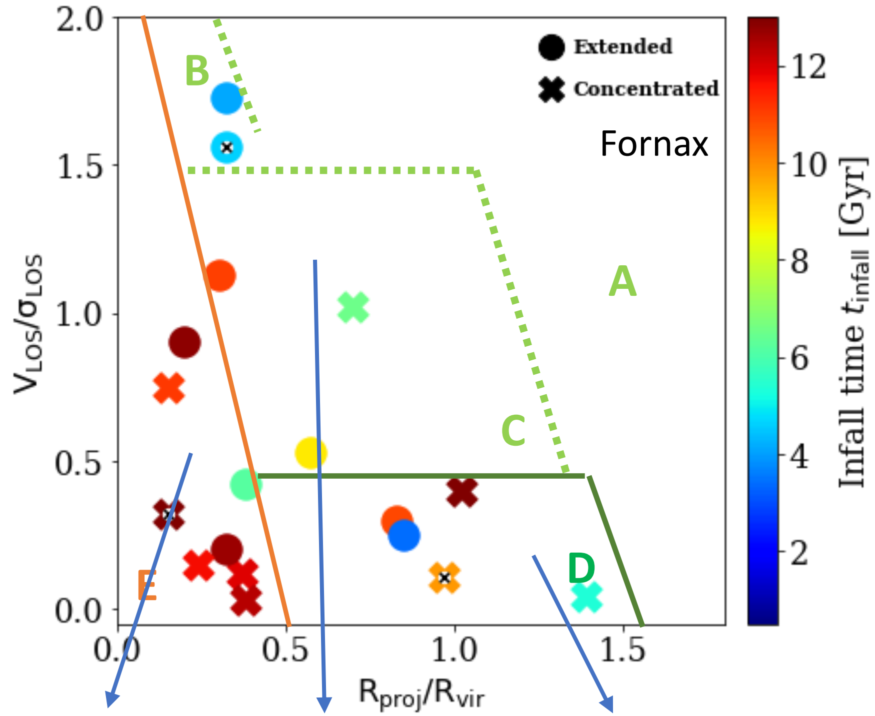
Environment should cause:

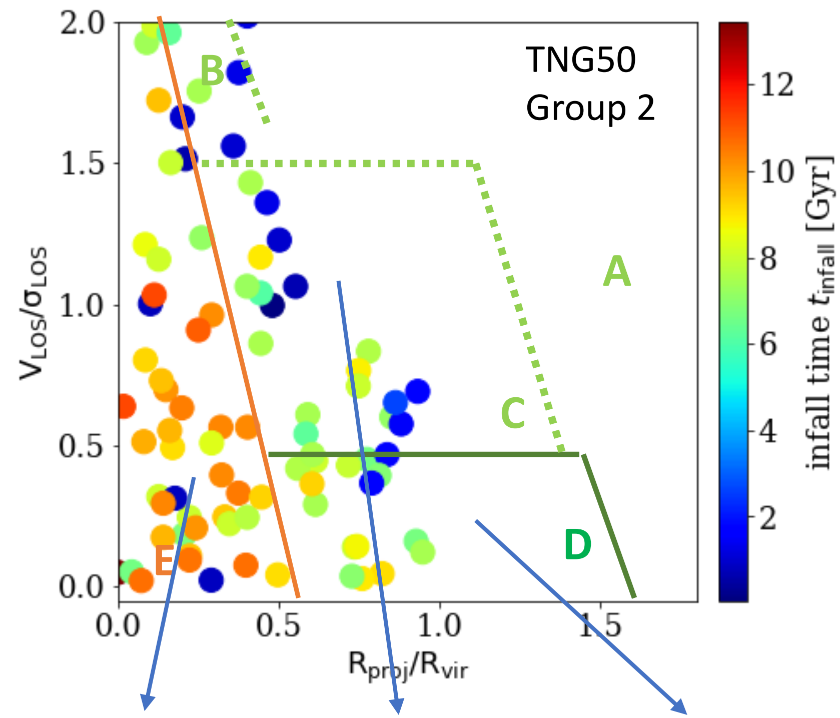
- Low disk fraction
- Old disk
- Positive age gradient

t_{infall} vs. t_{cold} vs. t_{whole}



A phase-space check on t_{infall}





Region E
Ancient: 87.5%
Intermediate: 12.5%

Region B,C
Recent: 40%
Intermediate: 40%
Ancient: 20%

Region D
Ancient: 60%
Intermediate: 20%
Recent: 20%

Region E
Ancient: 73.2%
Intermediate: 26.7%
Recent:7.1%

Region B,C
Recent: 50%
Intermediate: 41.7%
Ancient: 8.3%

Region D
Intermediate: 82.3%
Recent: 11.8%
Ancient: 5.9%