Chemical evolution of galaxies and the role of feedback

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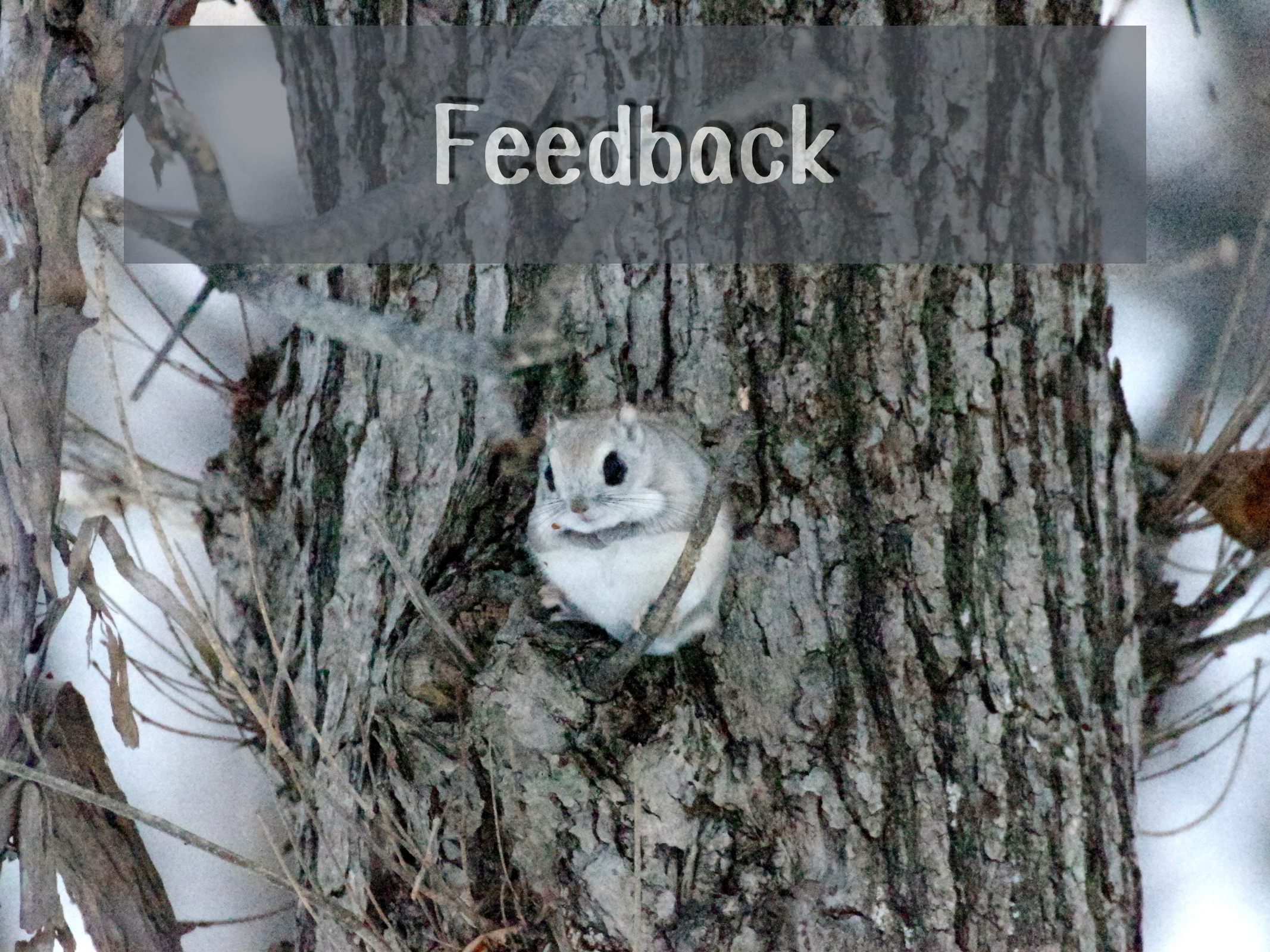
Masahiro Nagashima (Bunkyo),
Carlos Frenk (Durham), Cedric Lacey (Durham)


Feedback

Feedback

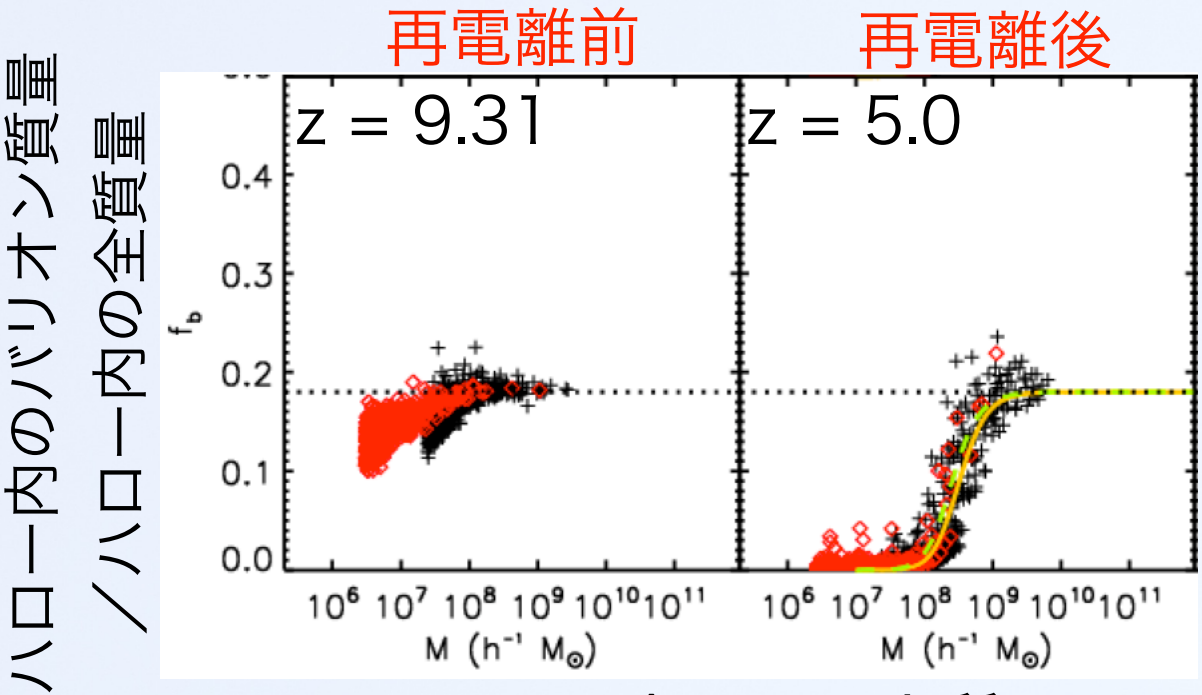
- **External**
  - Reionization
  - UV background

Feedback

- **External**
  - Reionization
  - UV background

- **Internal**
  - <u>Stellar feedback</u>
    - SNe
    - Stellar radiation
    - Stellar winds
  - <u>AGN feedback</u>
    - Quasar-mode
    - Radio-mode

Reionization and UVB



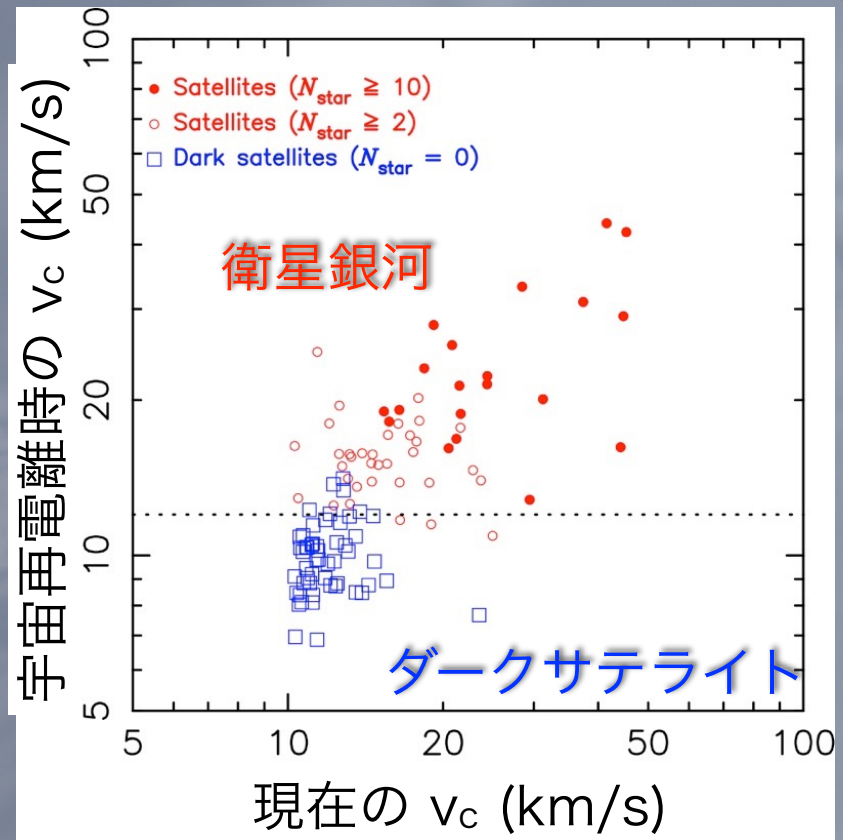
Okamoto, Gao, & Theuns '08

- 再電離後は，baryon rich と baryon poor を分ける特徴的なハロー質量 (M_c) が存在

(e.g. Gnedin '00)

Reionization and UVB

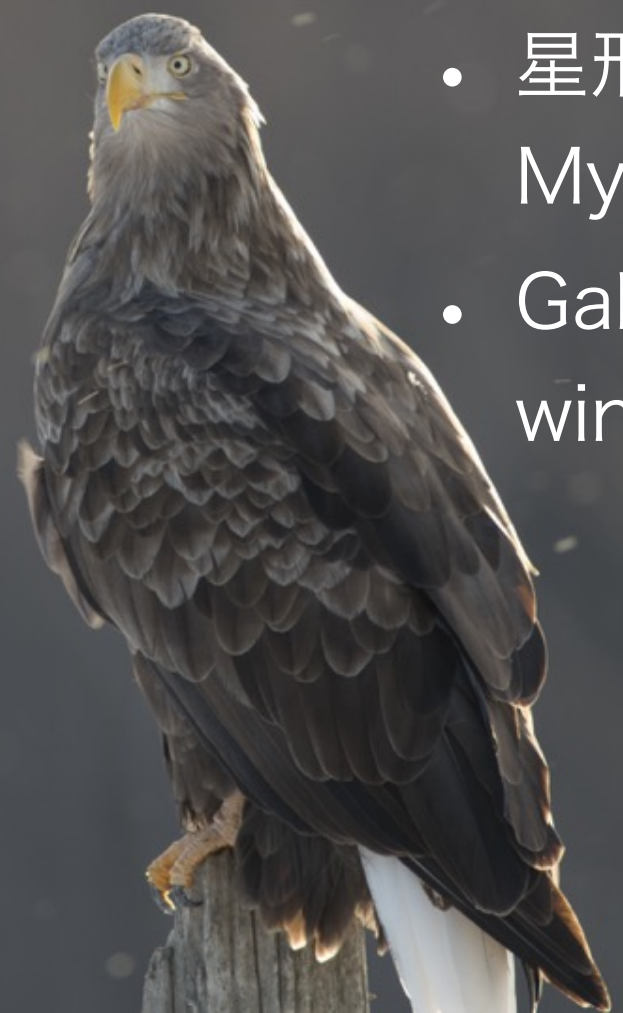
Okamoto & Frenk '09



衛星銀河になれるものとなれないもの（ダークサテライトになるもの）を分ける再電離時の回転速度が存在

Stellar feedback

- **Radiation**
  - 星形成直後 ~ 10 Myr
    - photo-ionization
      - HII region
      - 星形成の抑制
    - Radiation pressure
      - dust が多いほど効く
      - Galactic winds?



- **Supernova**
  - 星形成から ~ Myr程度後
  - Galactic winds?

Stellar feedback

Stellar feedback
はポテンシャルが
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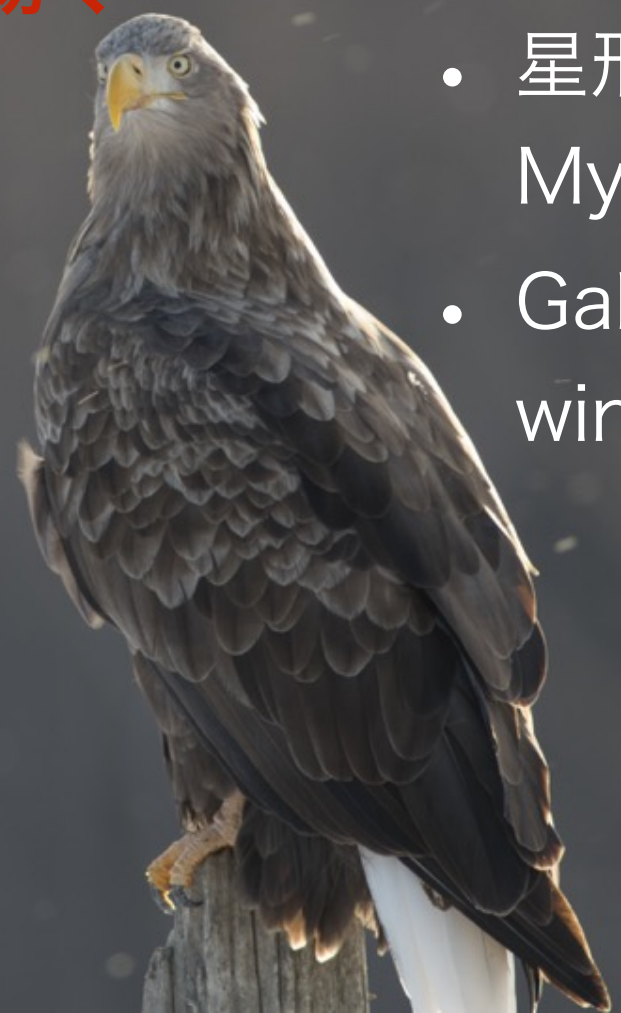

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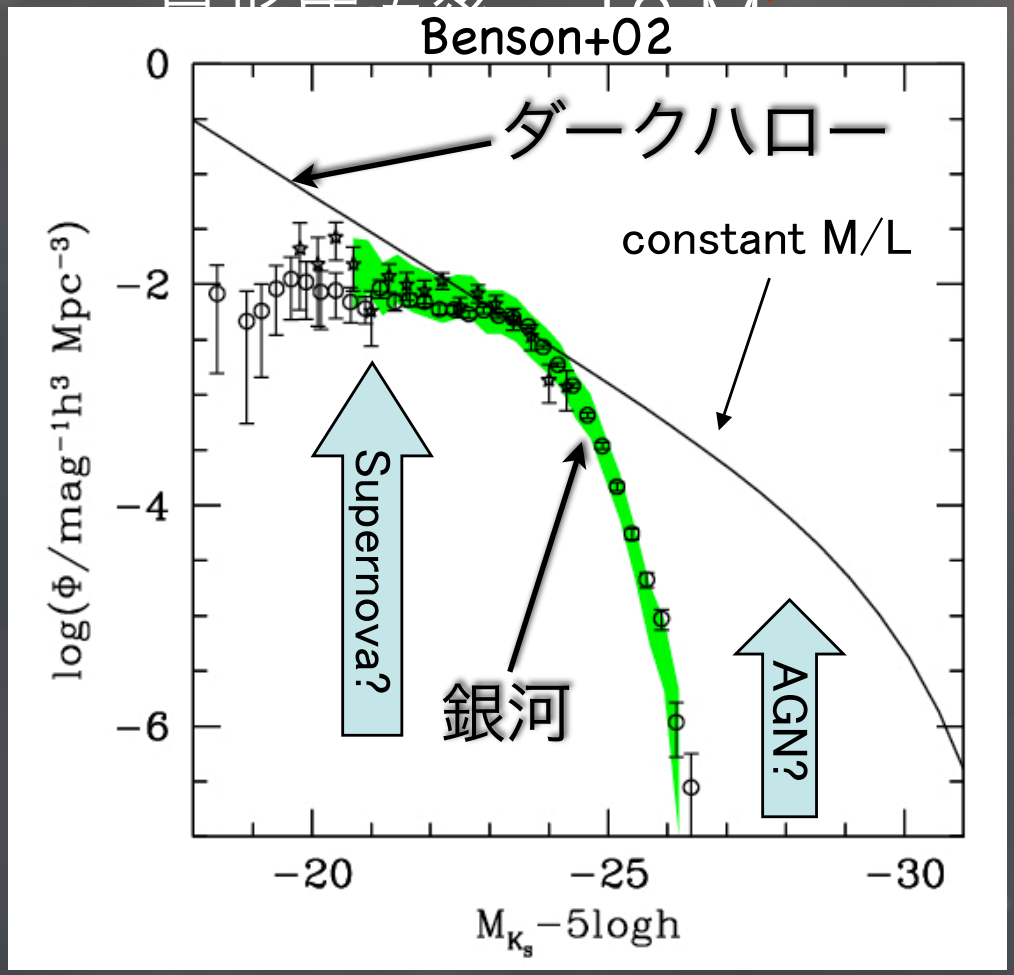

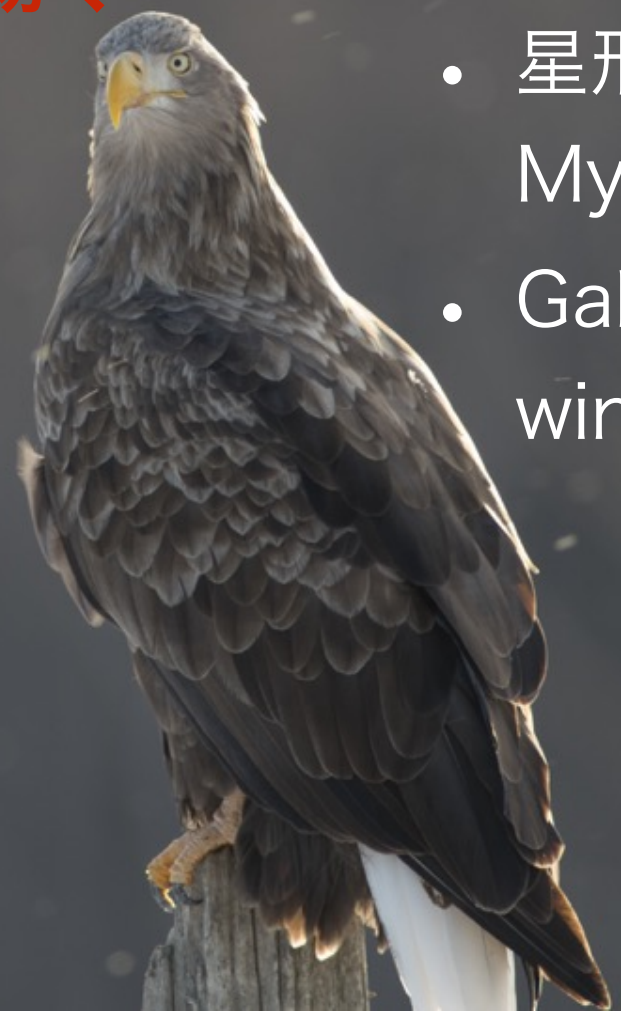

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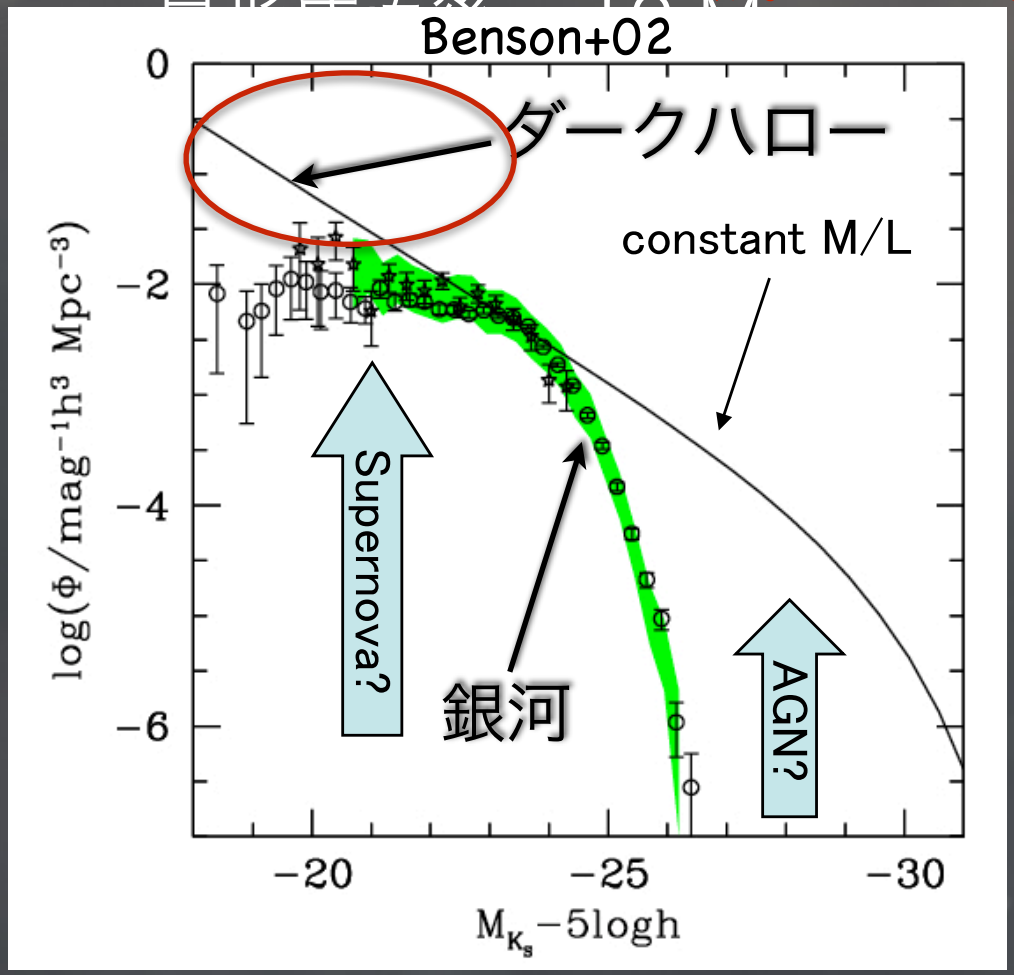

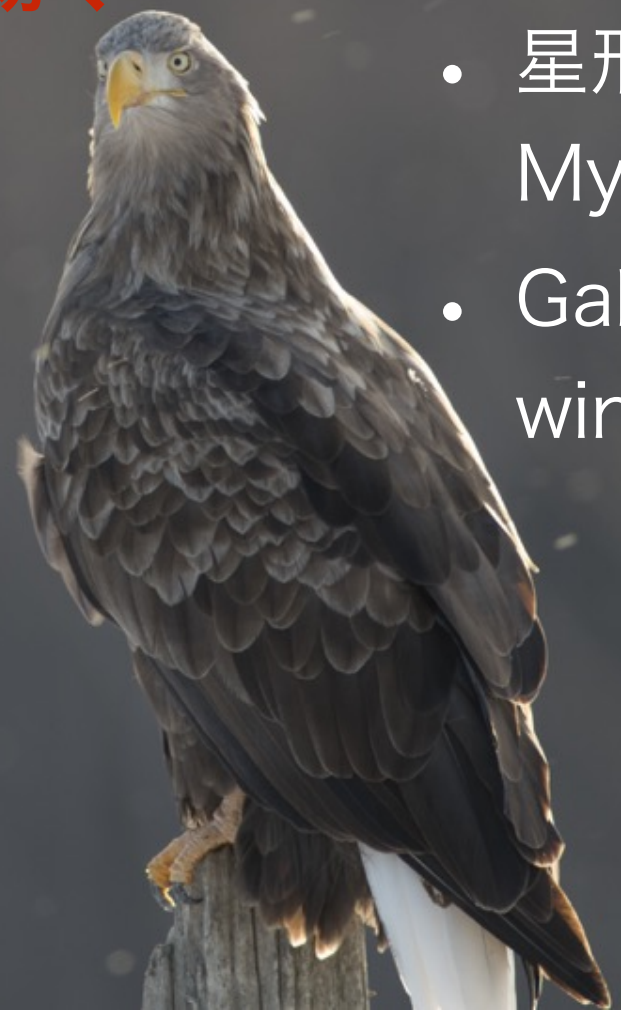

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Stellar feedback

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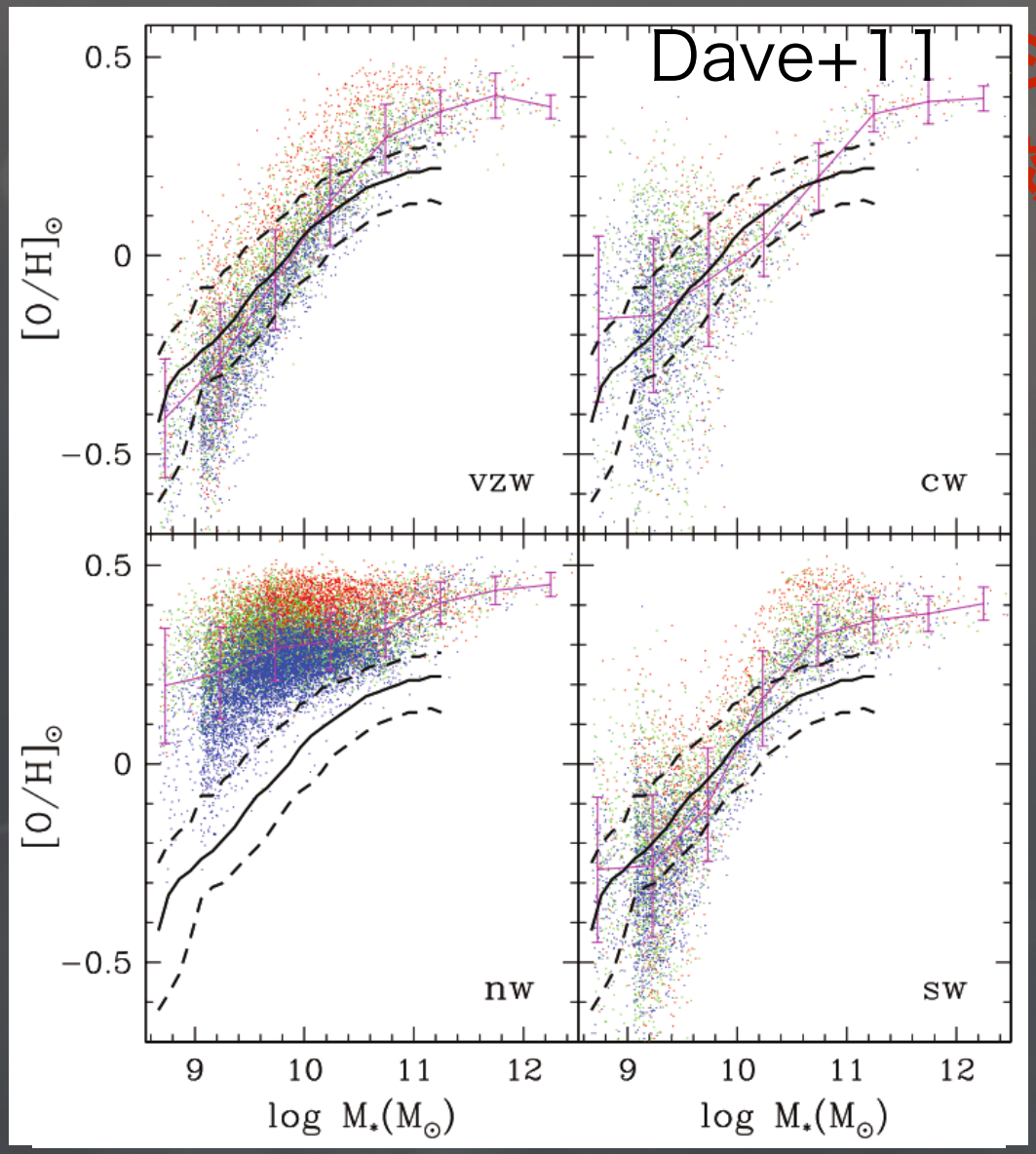

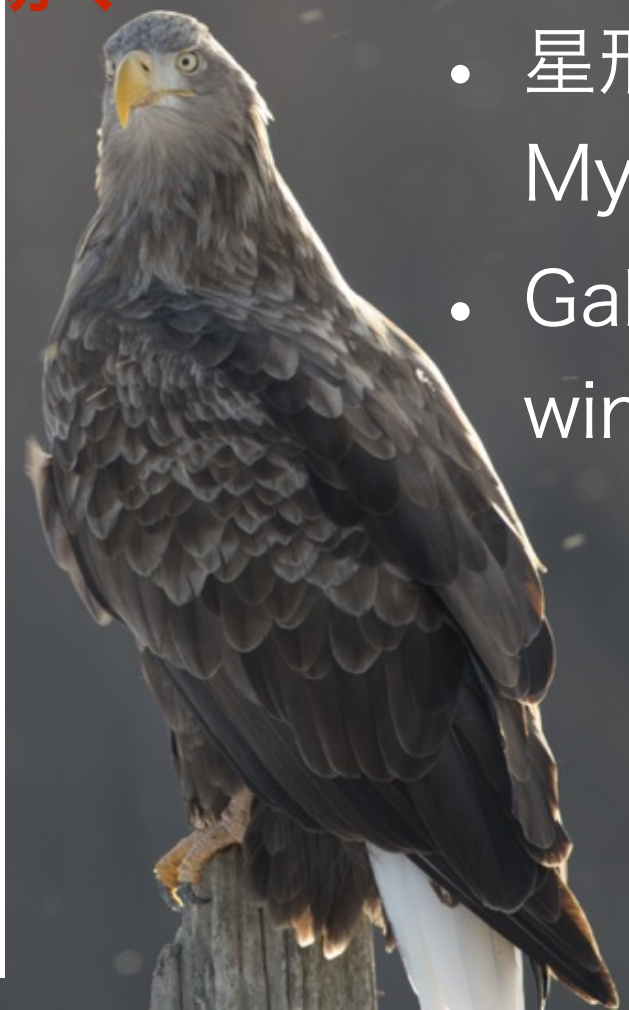

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AGN feedback

- **Quasar mode**
  - L_{AGN}/c を運動量として周囲のガスに与える or L_{AGN} を dE/dt として周囲のガスの加熱に使う
  - $\dot{M}_{\rm BH} \sim \dot{M}_{\rm Edd}$あたりで効く
  - 役割: M-σ関係を作る
- **Radio mode**
  - Jet/outflow が直接銀河団ガスを加熱 (bubbles/radio lobes)
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AGN feedback

異なるガス降着のモードが異なるフィードバックのモードに対応

(Sijacki+'07; Okamoto+'08)

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- bubbles/
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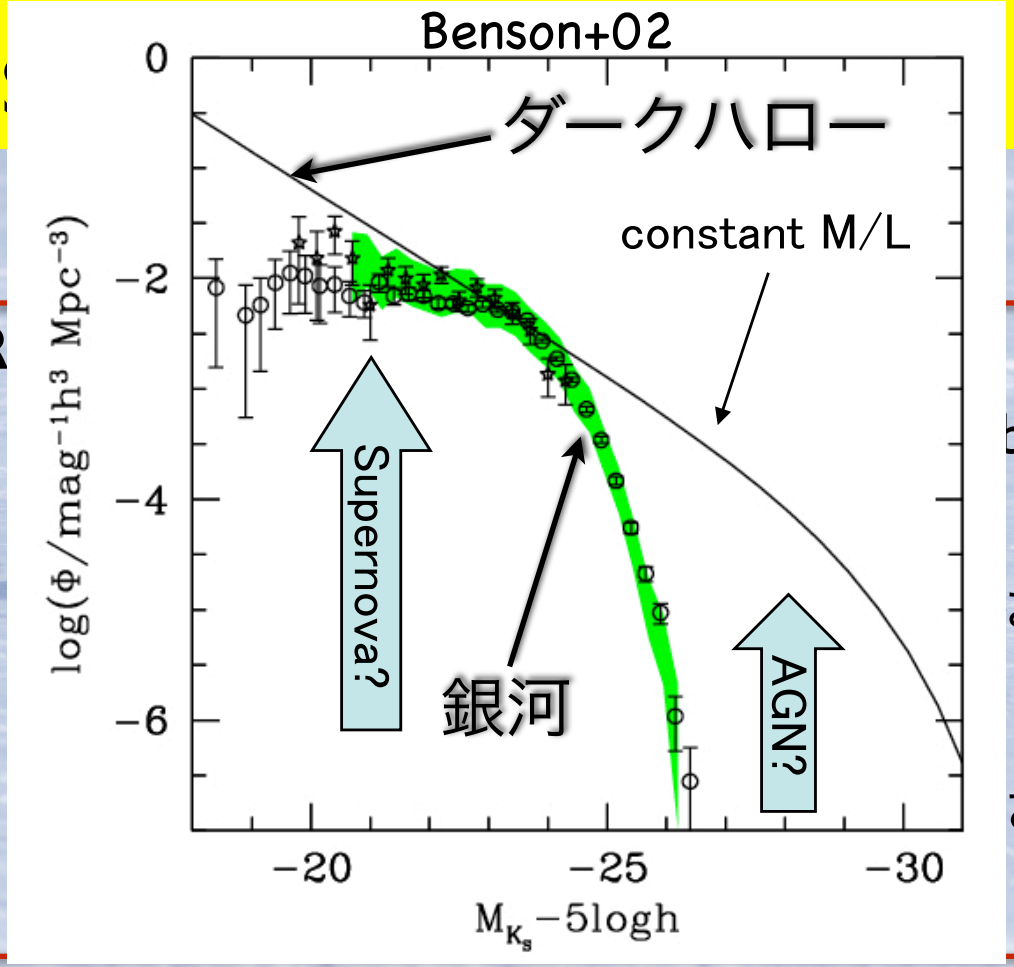

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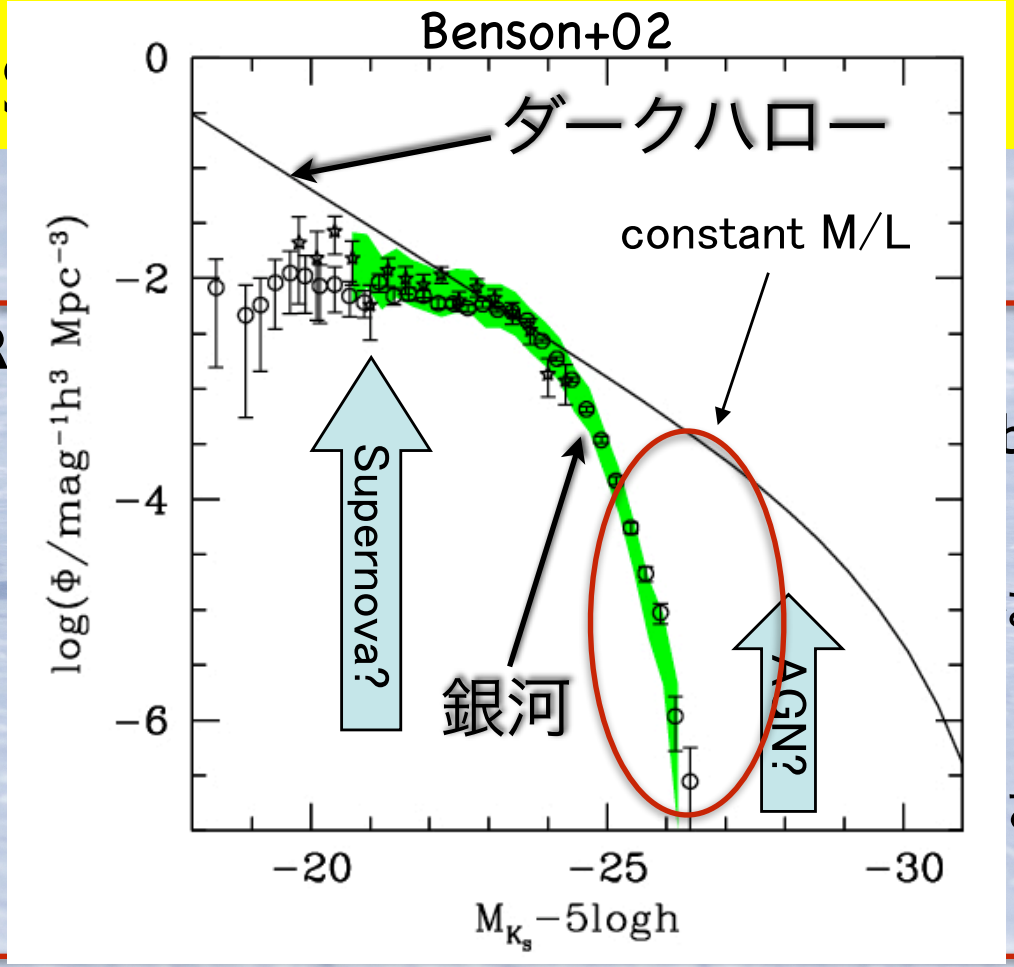
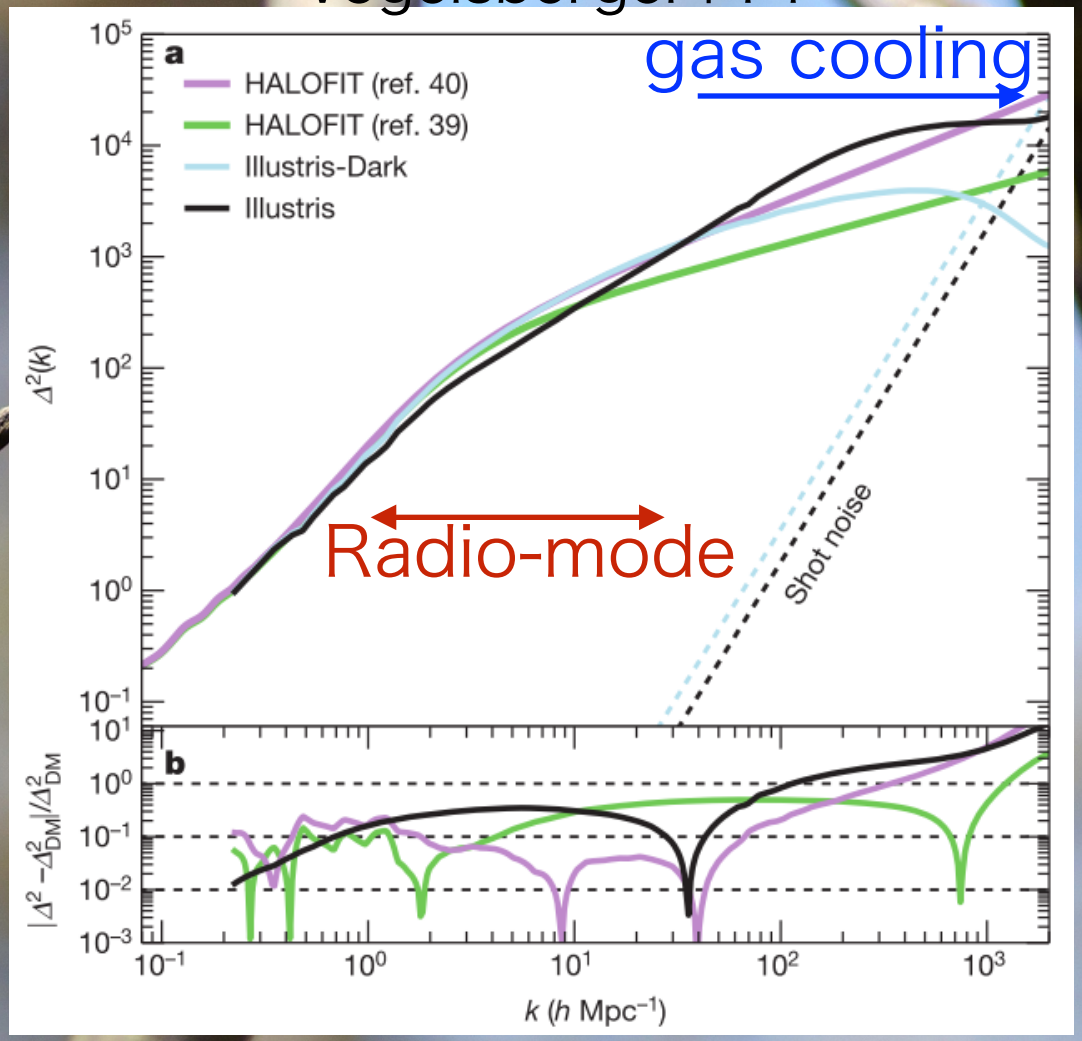


Impact on DM

Vogelsberger+14



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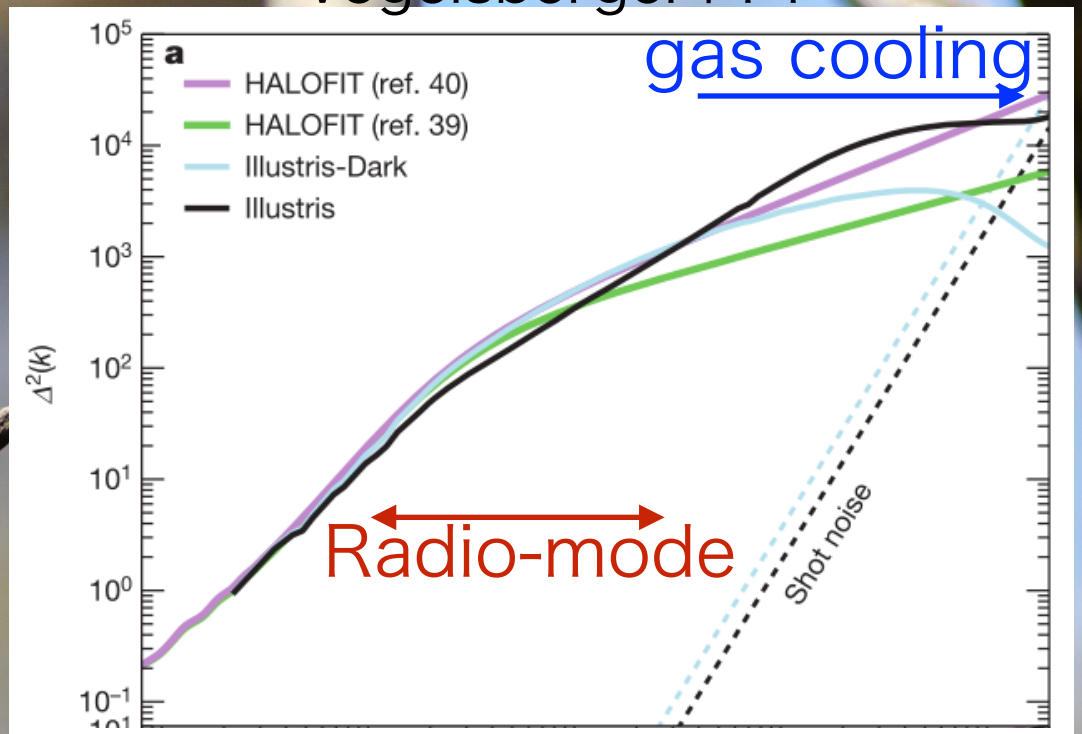
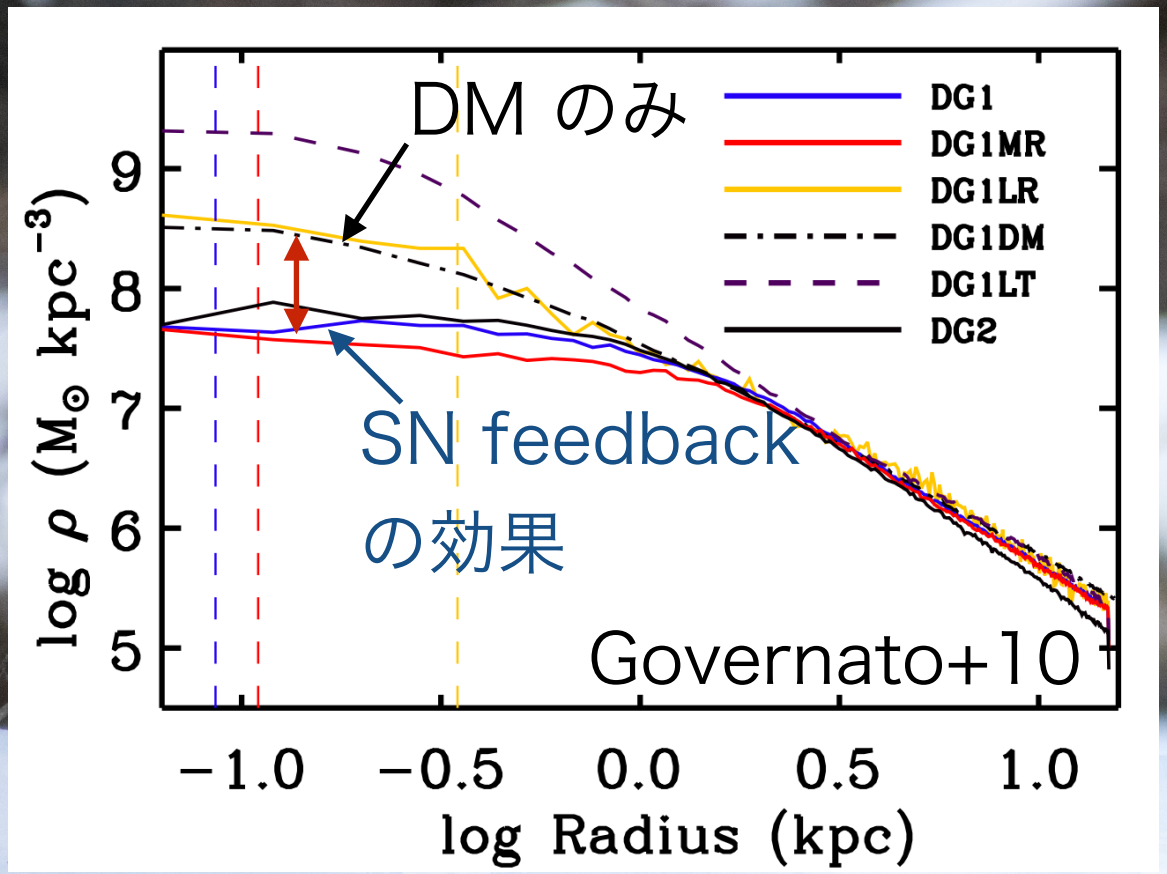
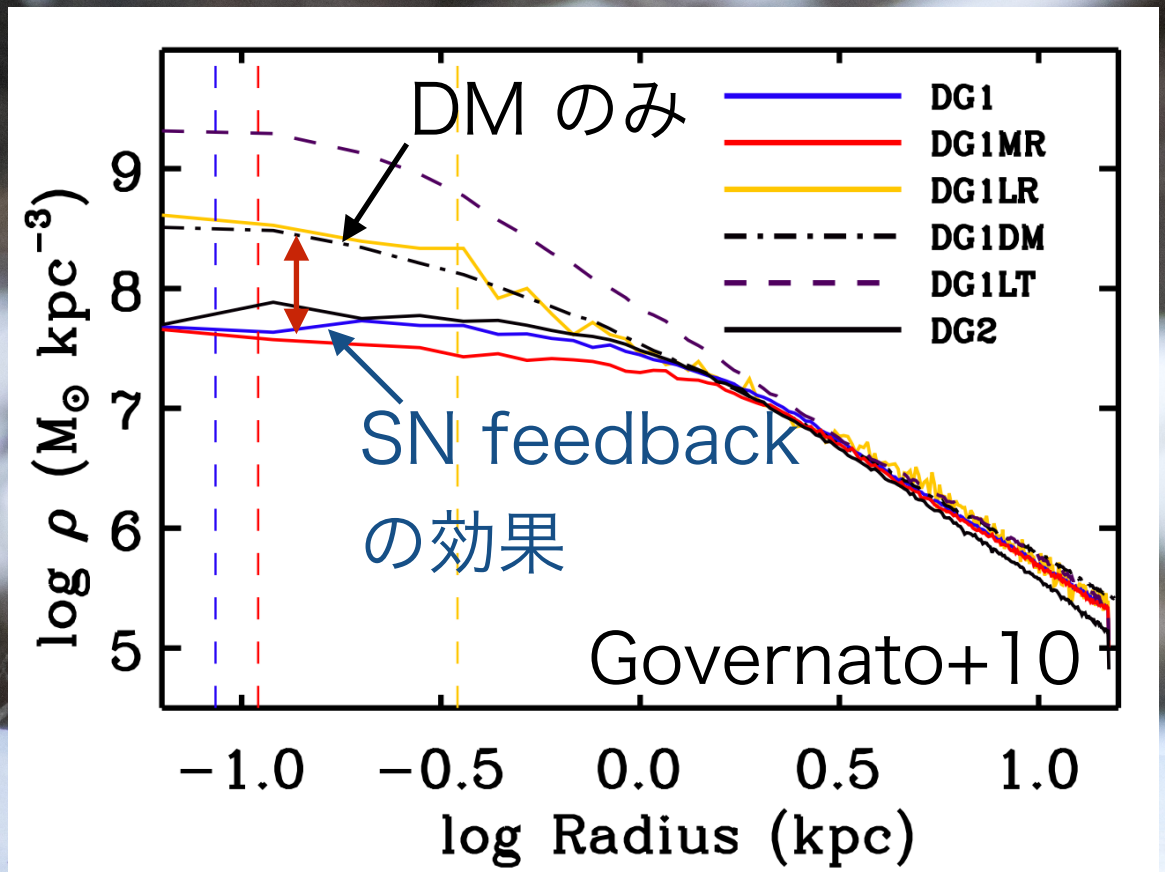


AGN feedback は k > 1 h^{-1} Mpc のスケールでパワースペクトルを弱める (van Daalen+11, Vogelsberger+14)

Impact on DM


DM のみ
SN feedback
の効果
Governato+10
DG1
DG1MR
DG1LR
DG1DM
DG1LT
DG2
log ρ (M⊙ kpc⁻³)
log Radius (kpc)
9
8
7
6
5
−1.0
−0.5
0.0
0.5
1.0

Impact on DM



Repeated energetic feedback turns a DM cusp into a core (Pontzen & Governato'12, Ogiya & Mori'14)

何がいつ何処で効いてるの？

- **Quenching**
  - AGN feedback だとして **quasar mode**? それとも **radio mode**?

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Passive 銀河の chemical abundances を見ることでフィードバックについて何かわかる?

Chemical enrichment with outflows

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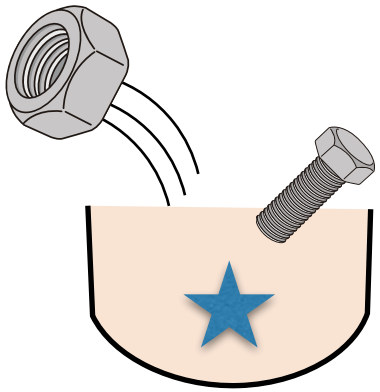

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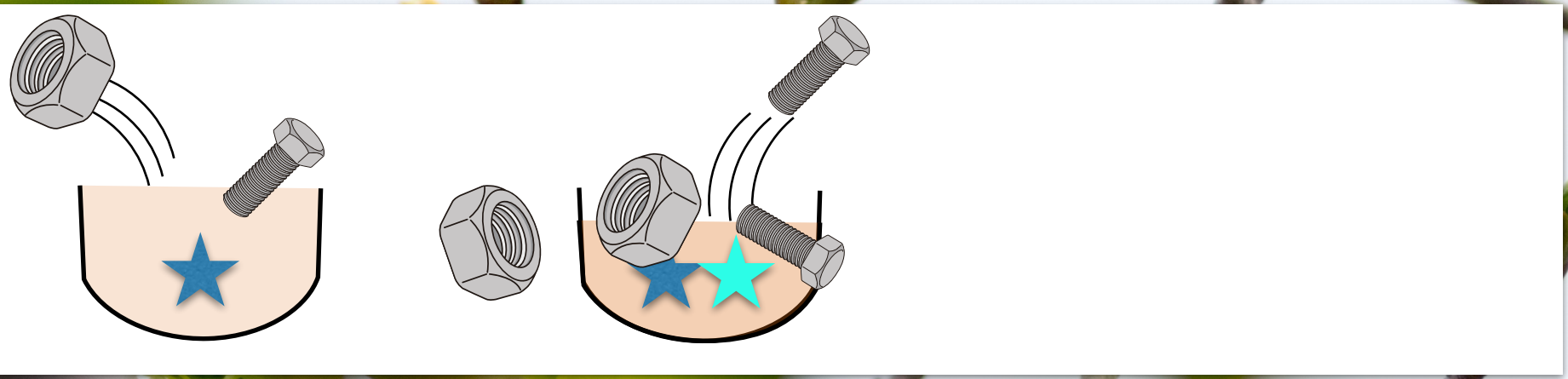

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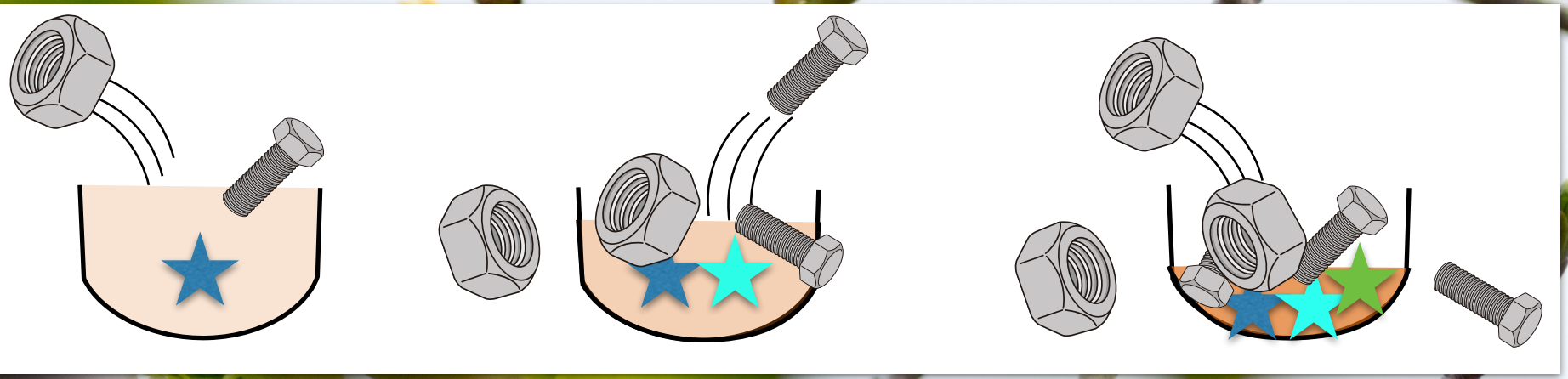

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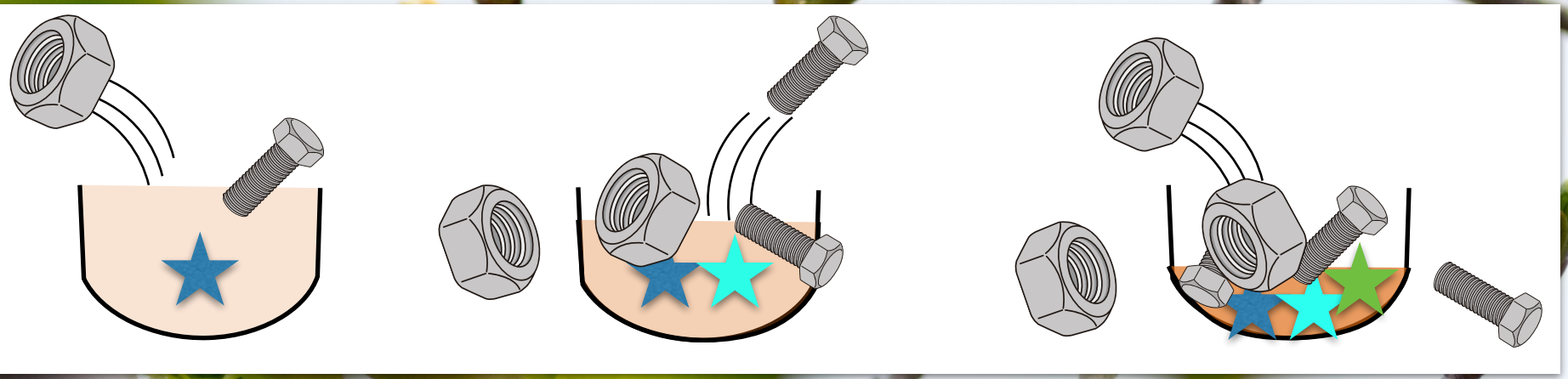

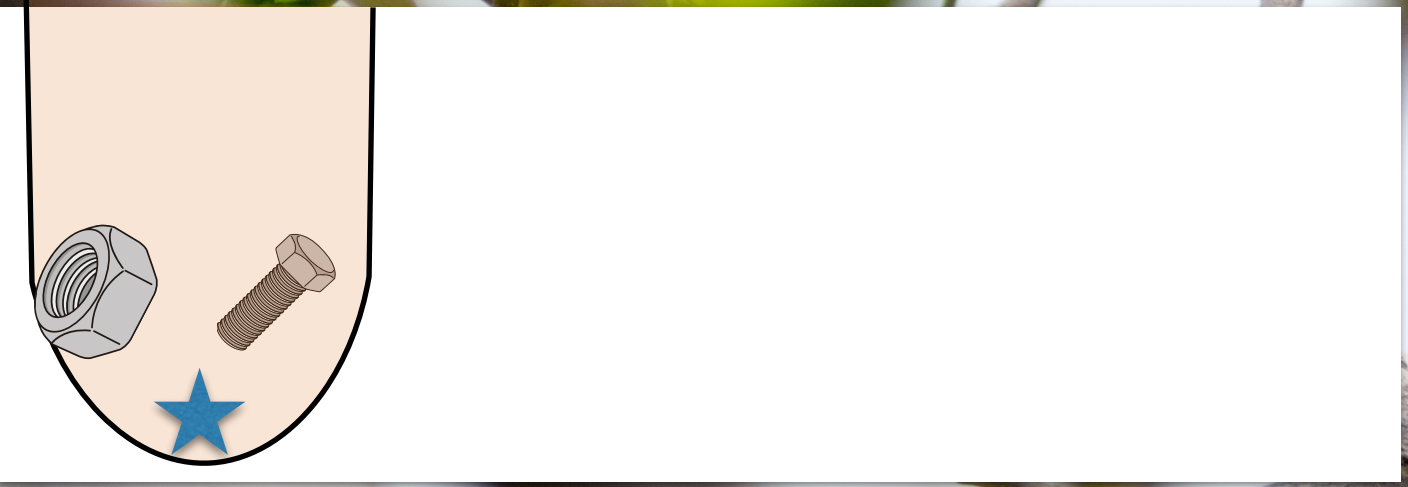

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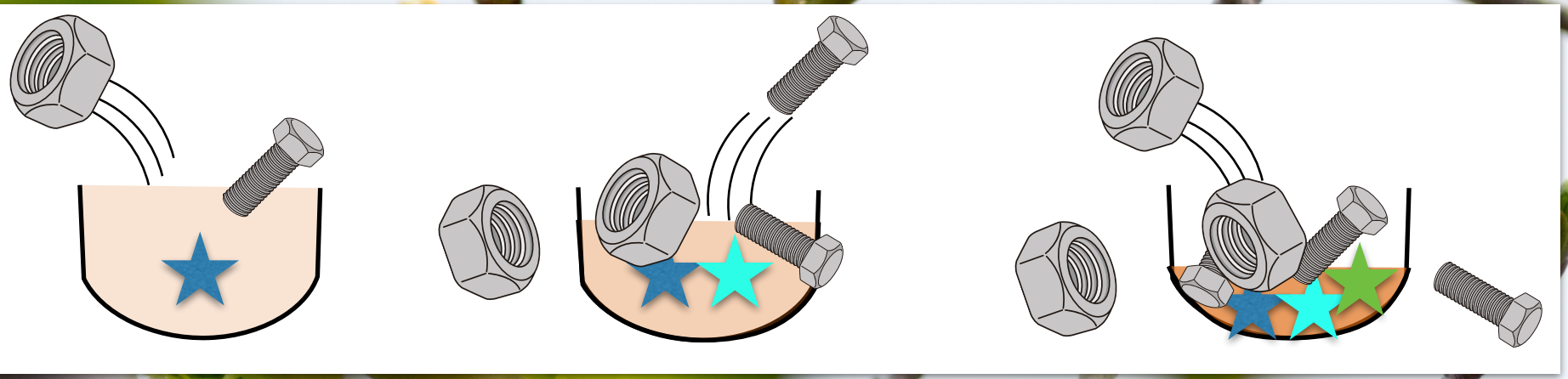

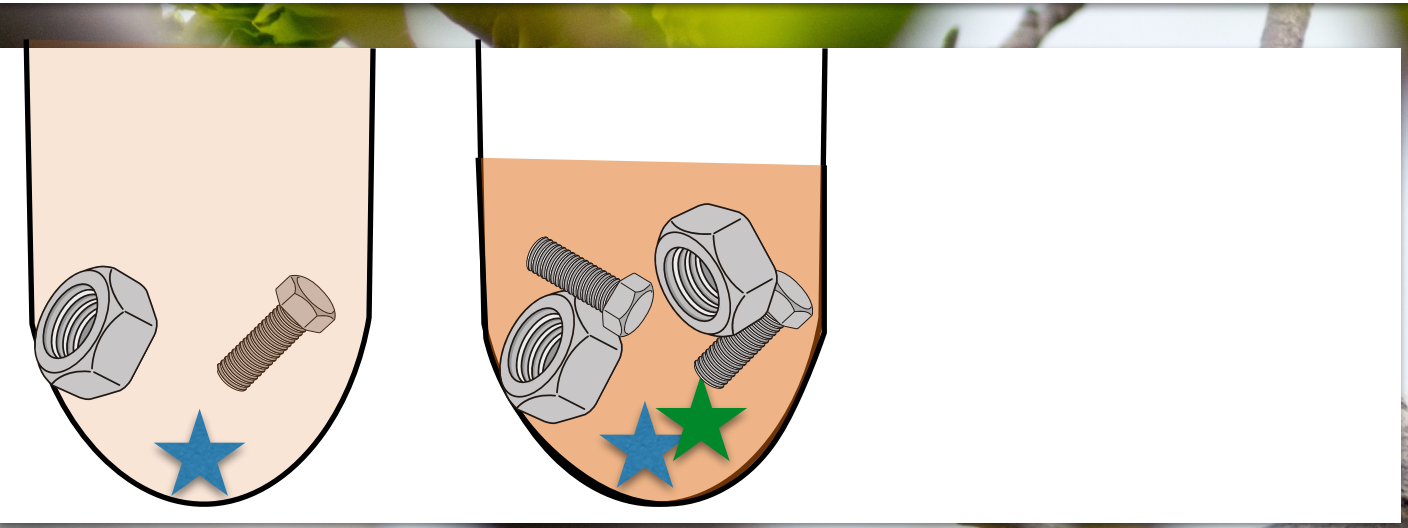

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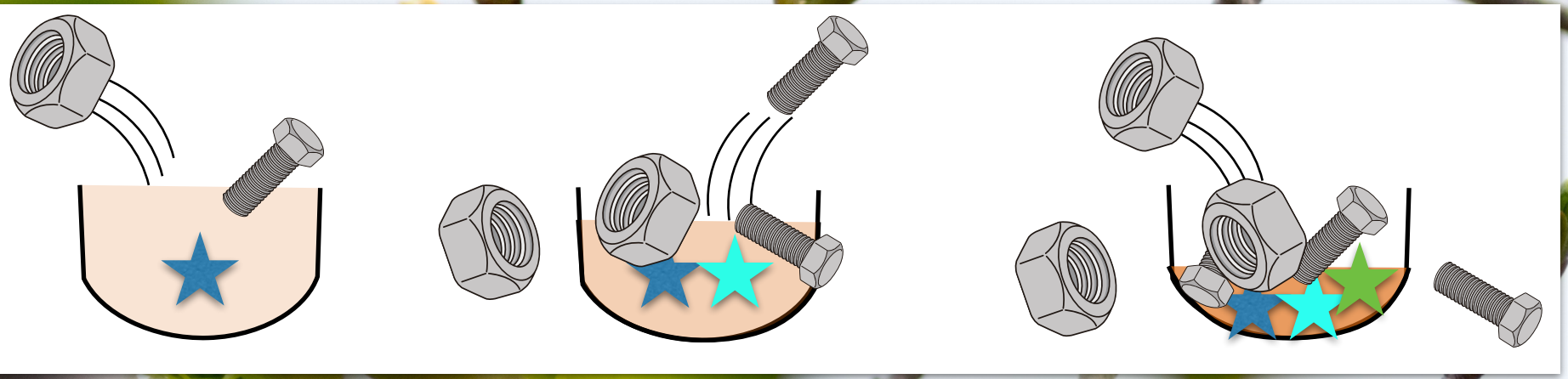

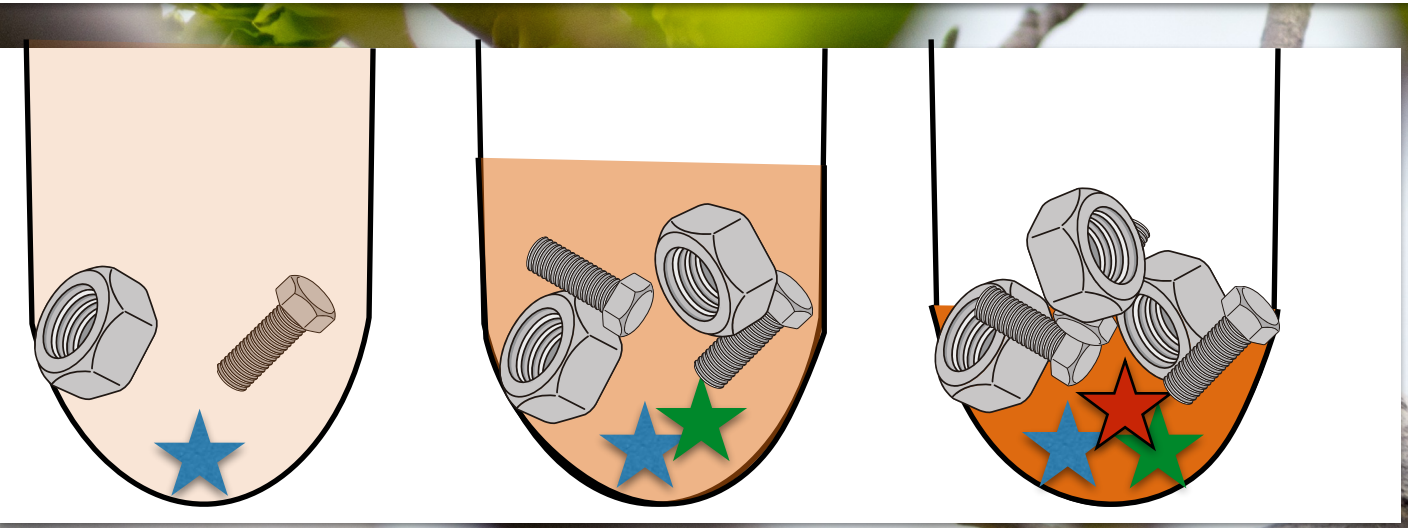

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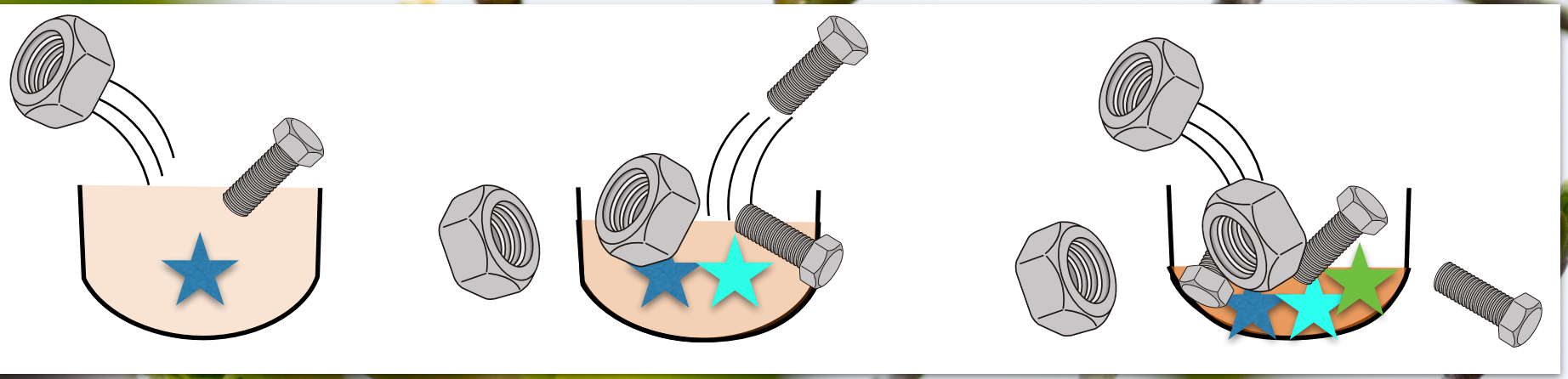

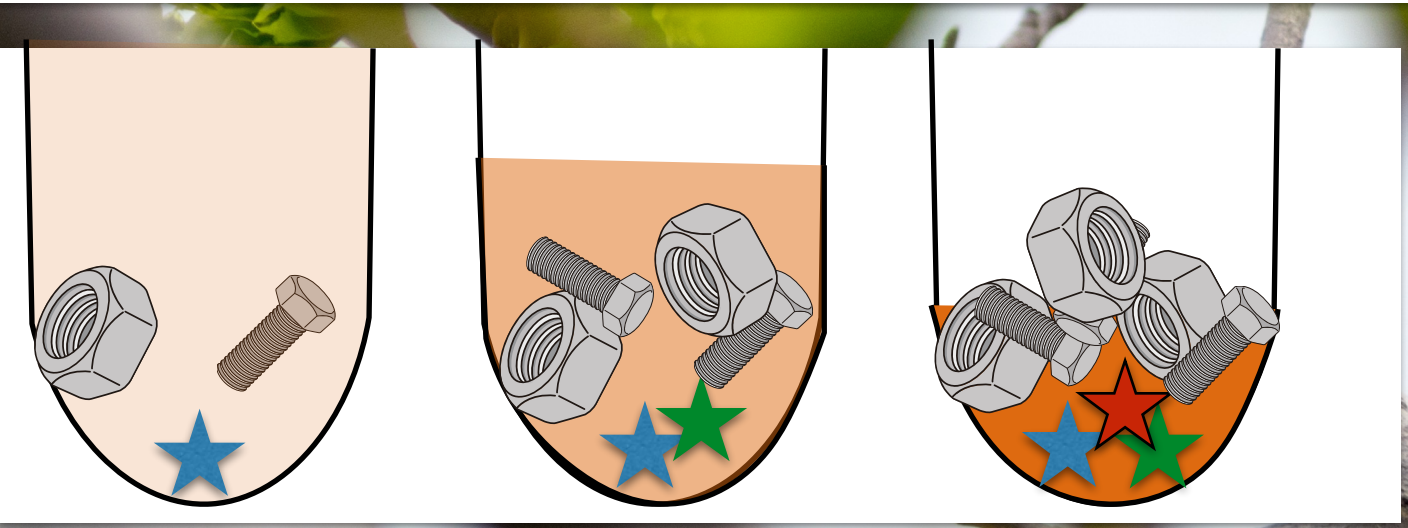

More massive galaxies have higher metallicity

- **Quasar mode**
  - Outflow をともなう
- **Radio mode**
  - Cooling (inflow) を止めるだけ
  - Strangulation と一緒

Types of supernovae

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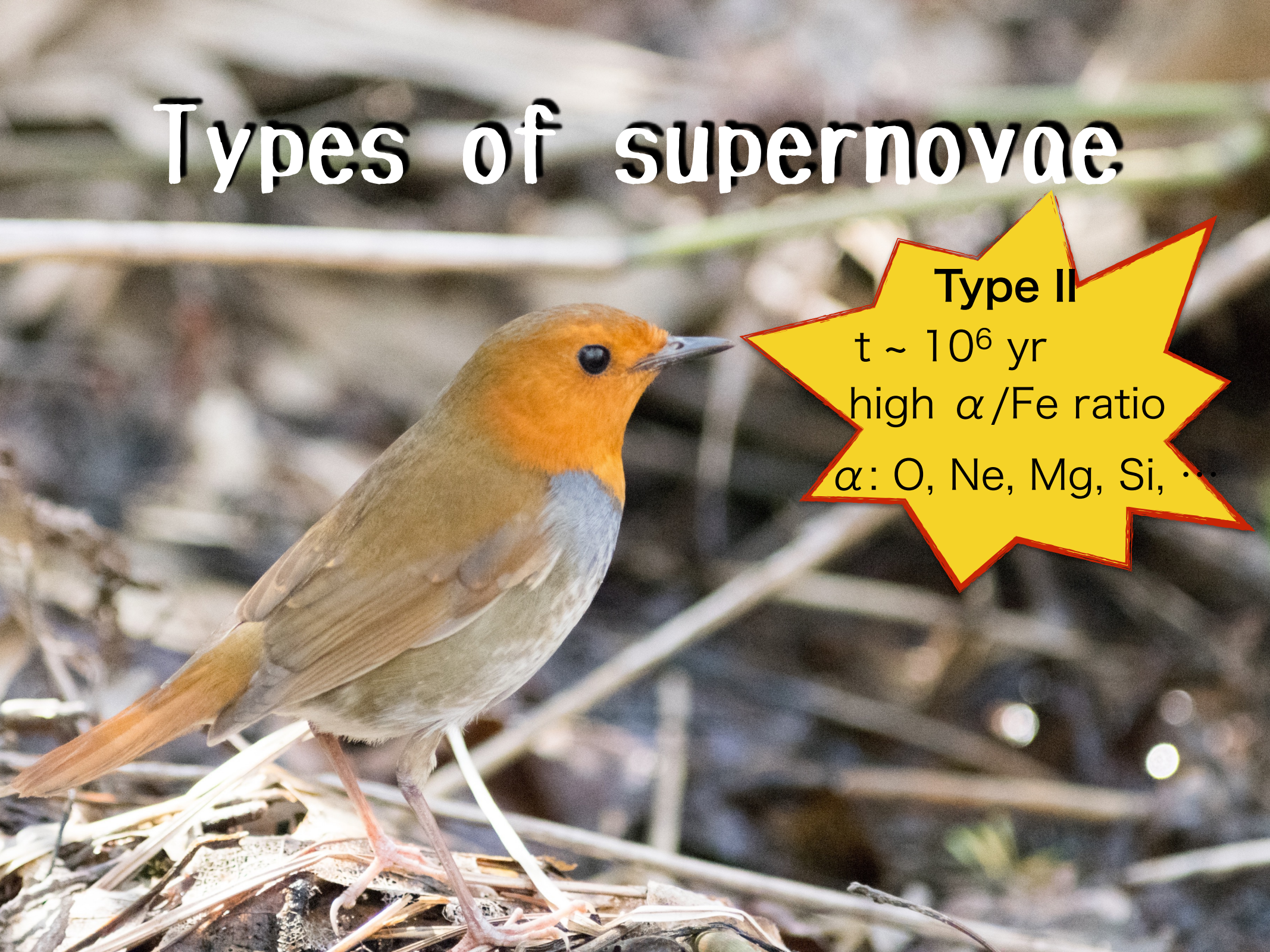

Type II

t ~ 10^6 yr

high α/Fe ratio

α: O, Ne, Mg, Si, ⋯

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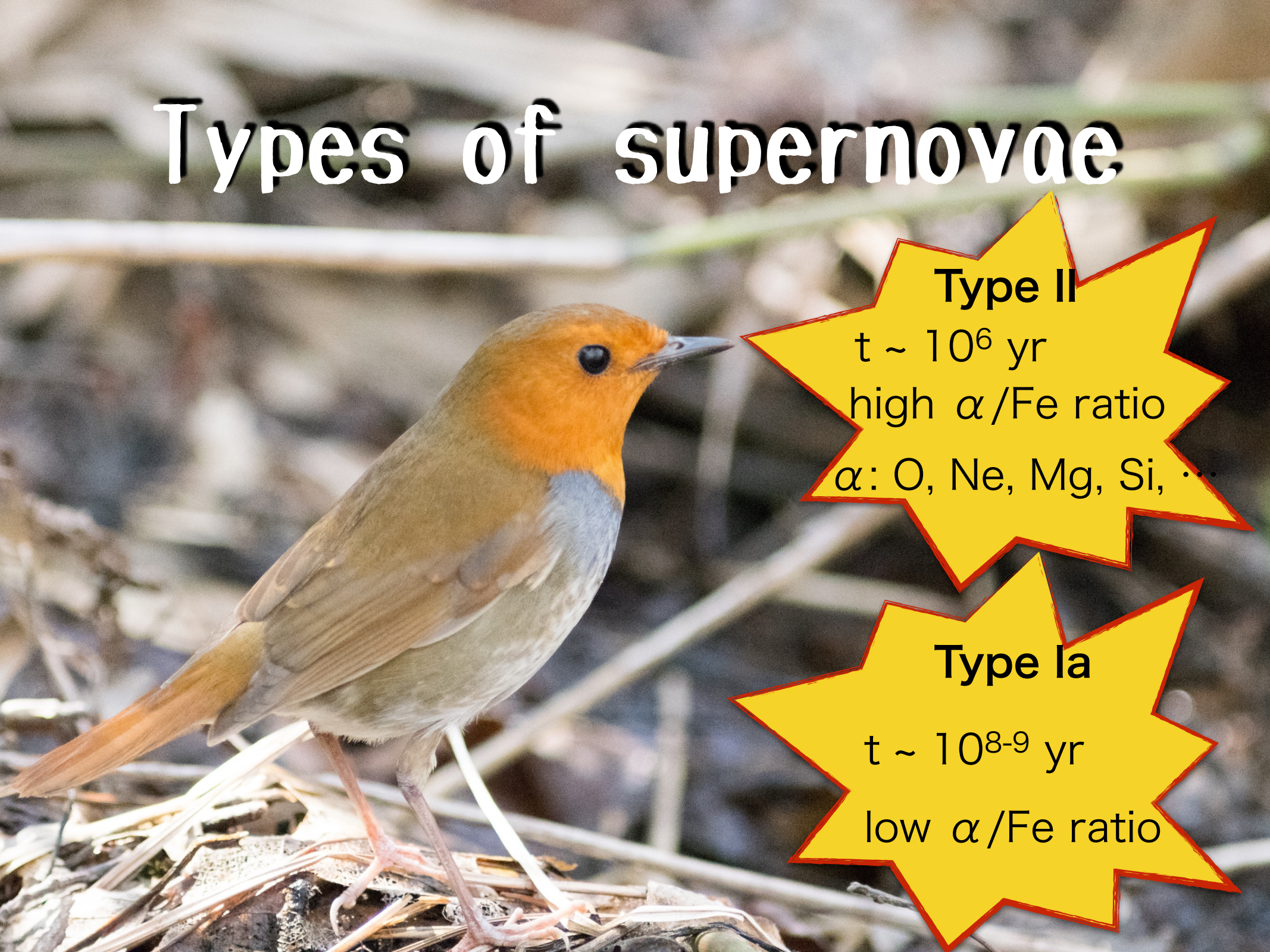


Type II

t ~ 10^6 yr

high α/Fe ratio

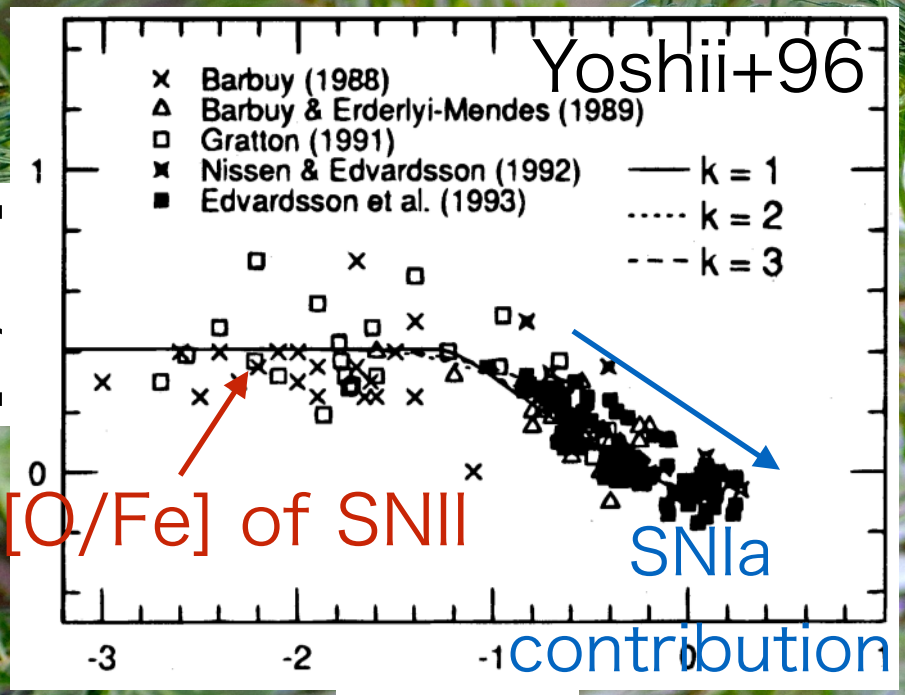
α: O, Ne, Mg, Si, ⋯

Type Ia

t ~ $10^{8\text{-}9}$ yr

low α/Fe ratio

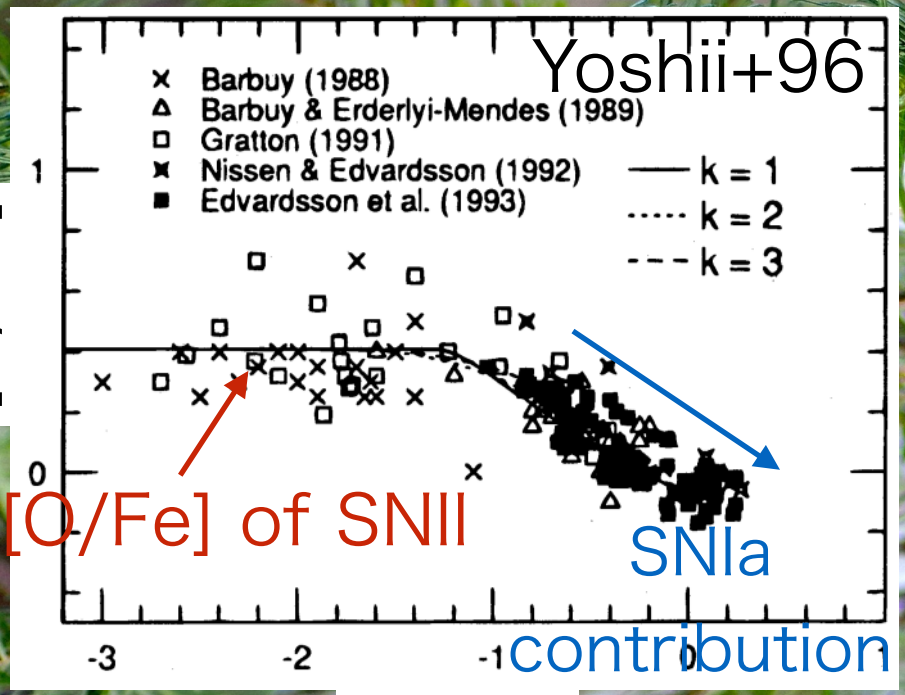
[α/Fe] vs [Fe/H]



Z

time

[α/Fe] vs [Fe/H]



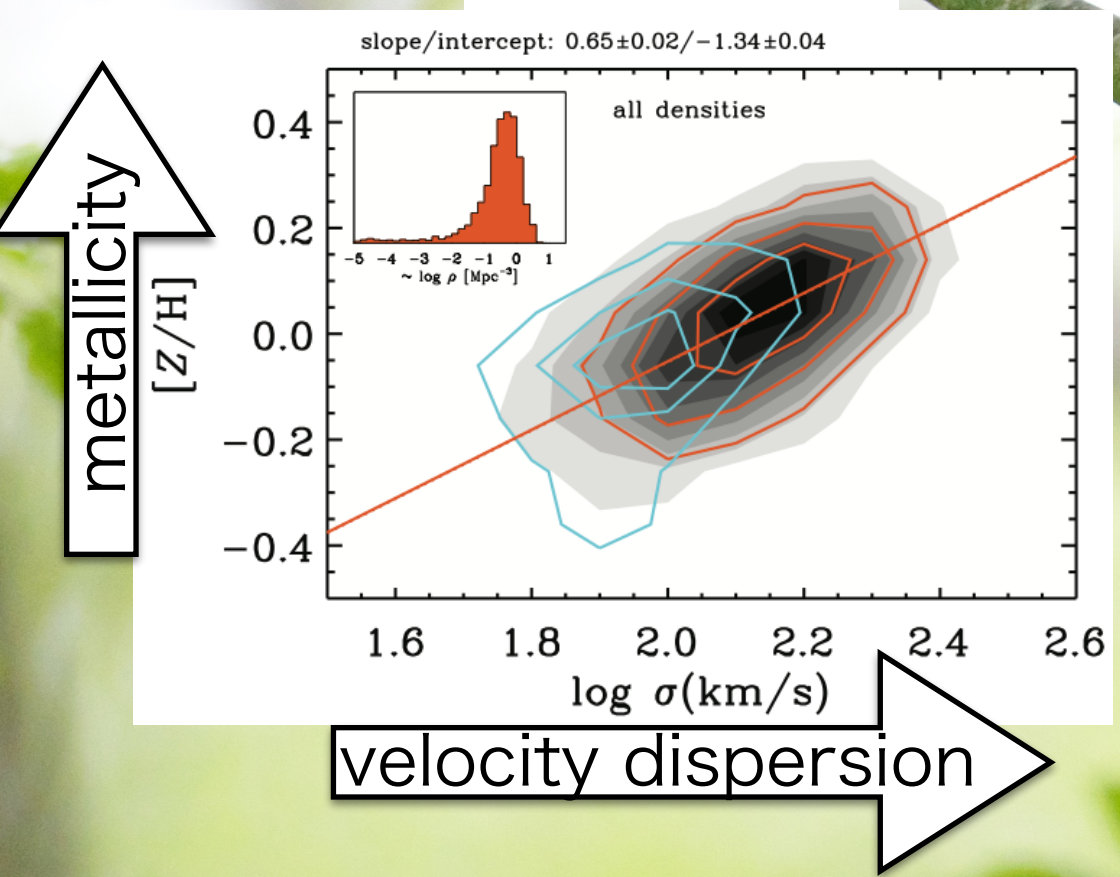
Z

time

[α/Fe] tells about star formation timescale

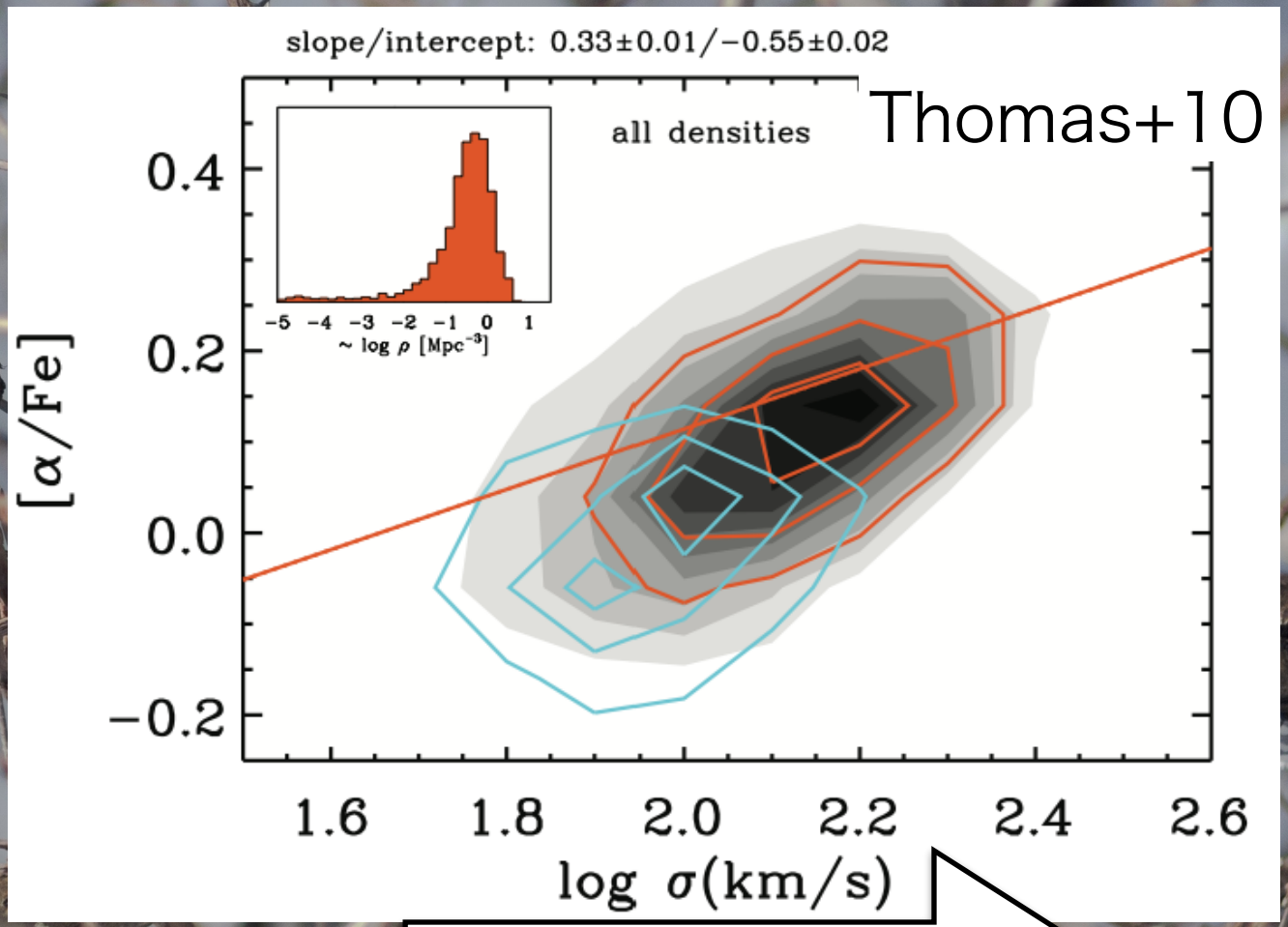
Metallicity

Thomas+10



More massive early-type galaxies have higher metallicity

[α/Fe] -σ



velocity dispersion

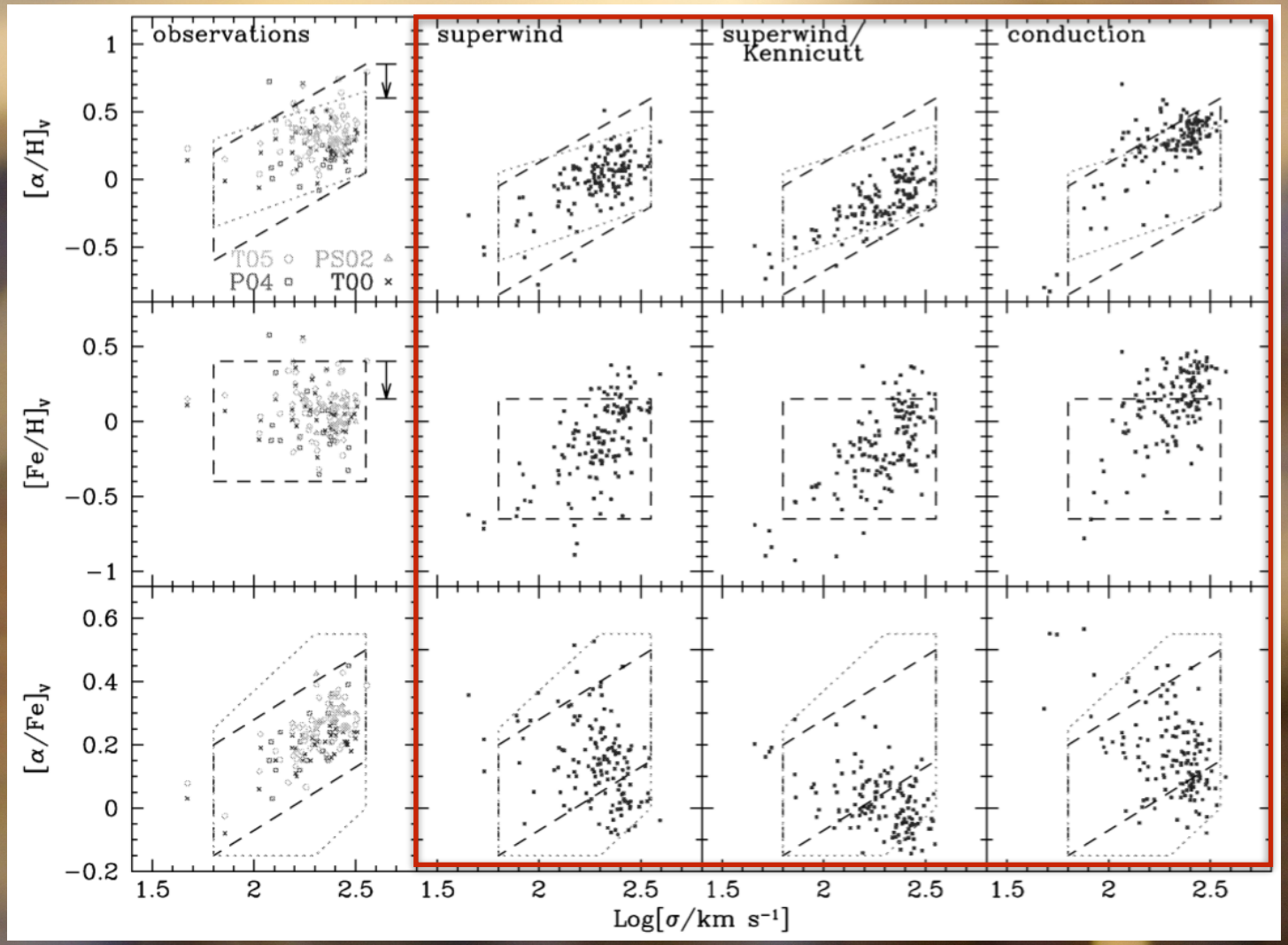
More massive early-type galaxies have higher [α/Fe]

Summary of Obs.

- Higher M_* or σ
  - Redder
  - Higher Z
  - Higher [α/Fe]
  - Older

Models

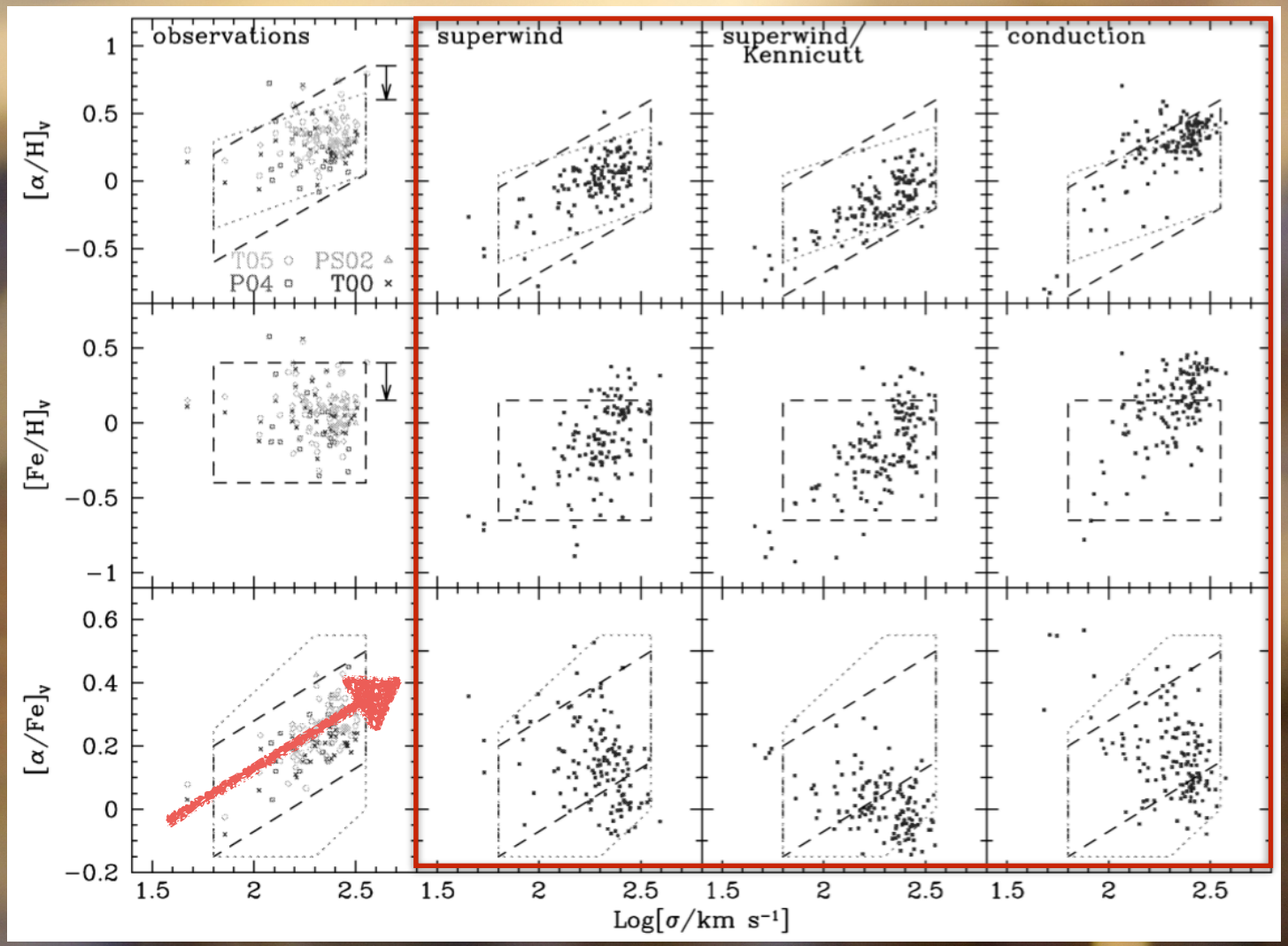
Obs. Models



Nagashima+05 (GALFORM)

Models

Obs. Models



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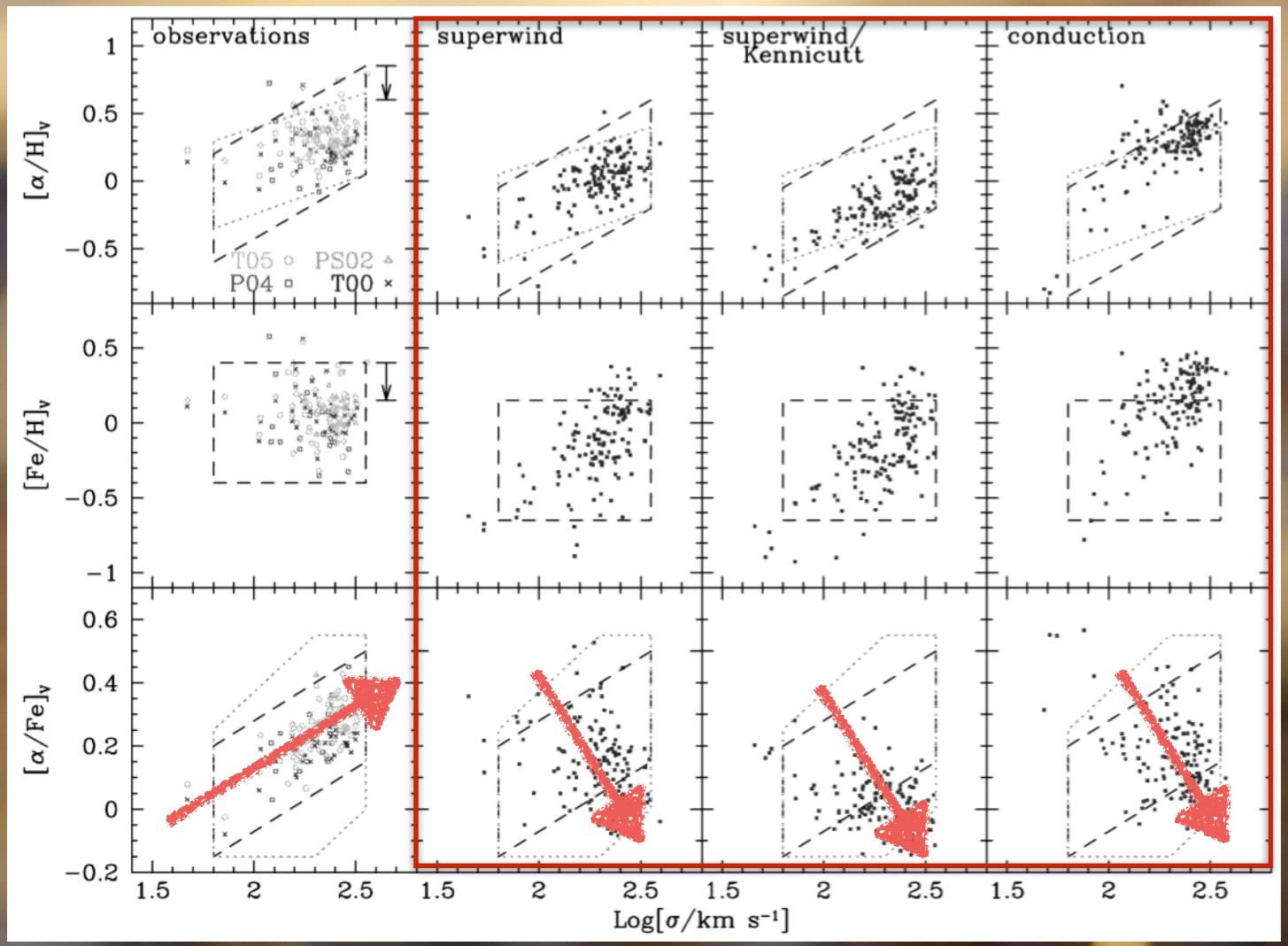

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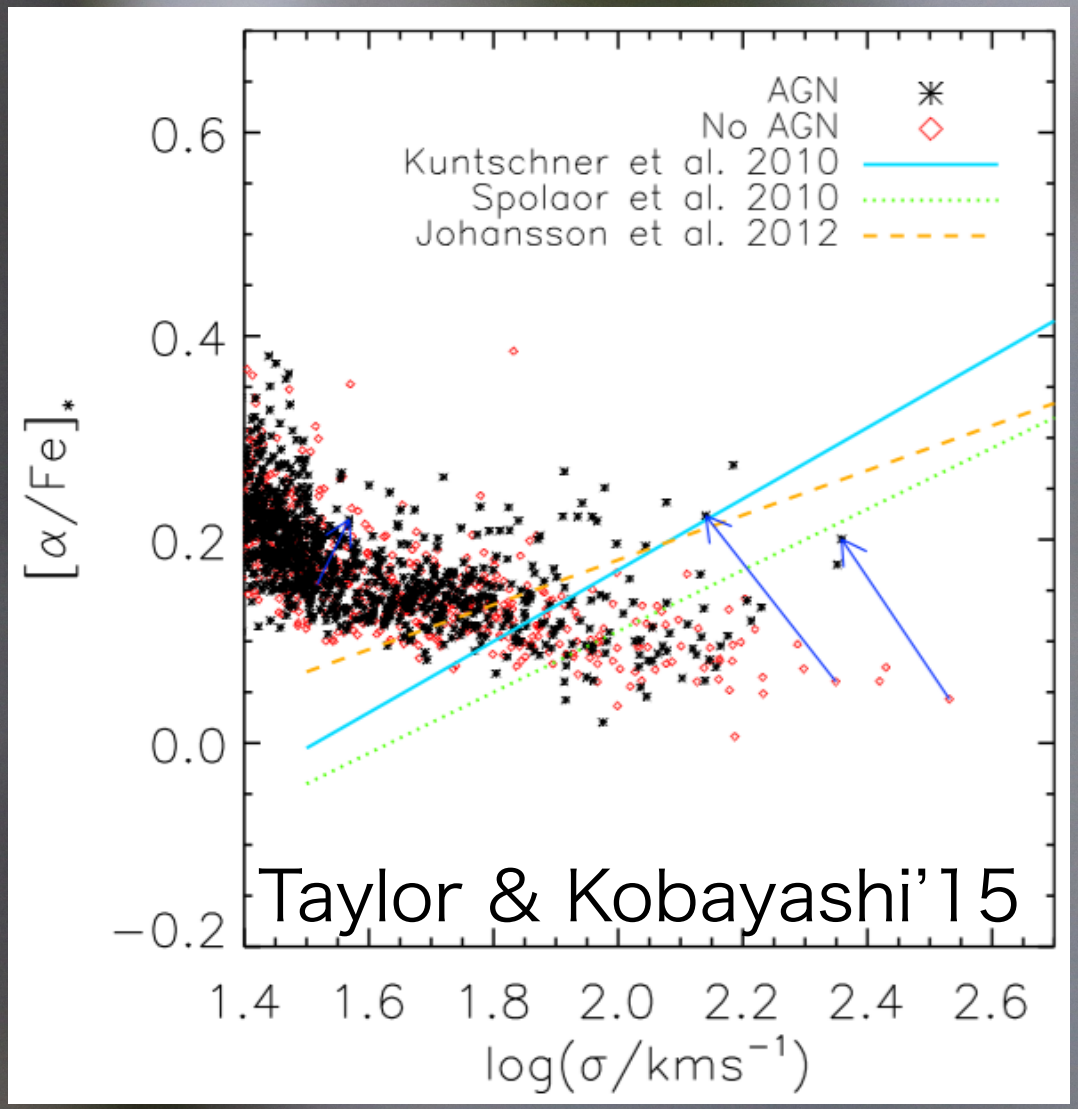
Simulations



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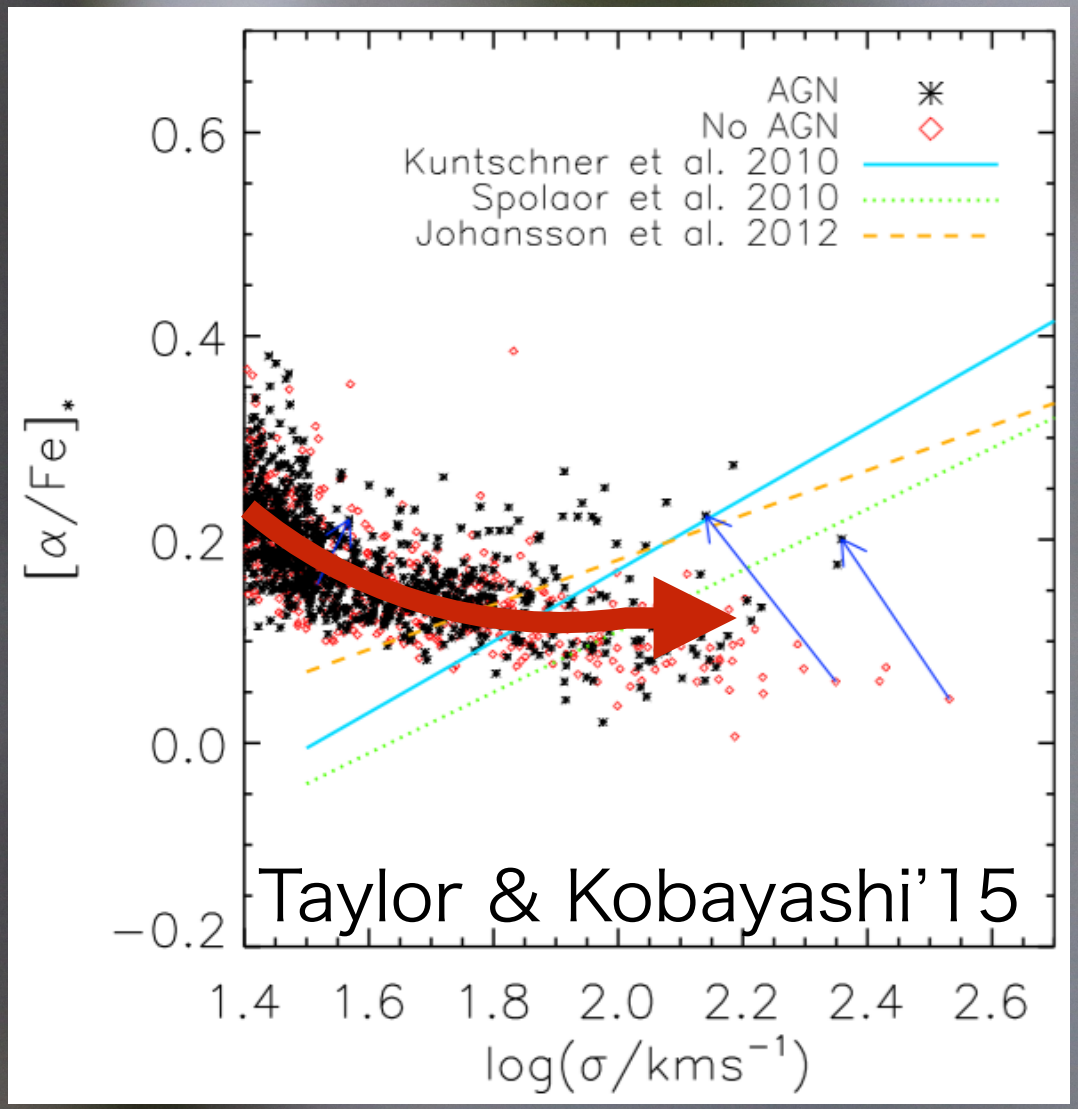
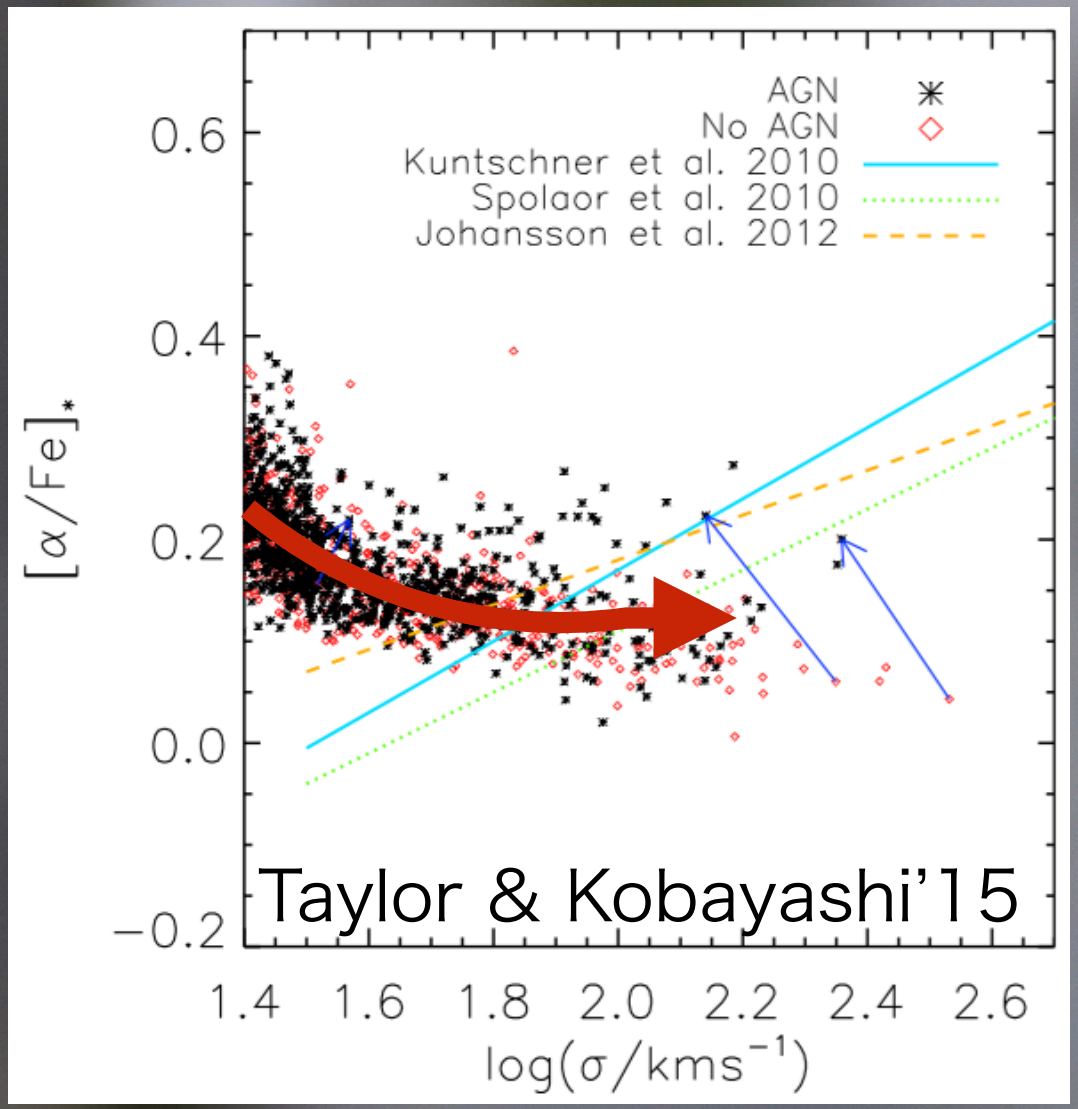
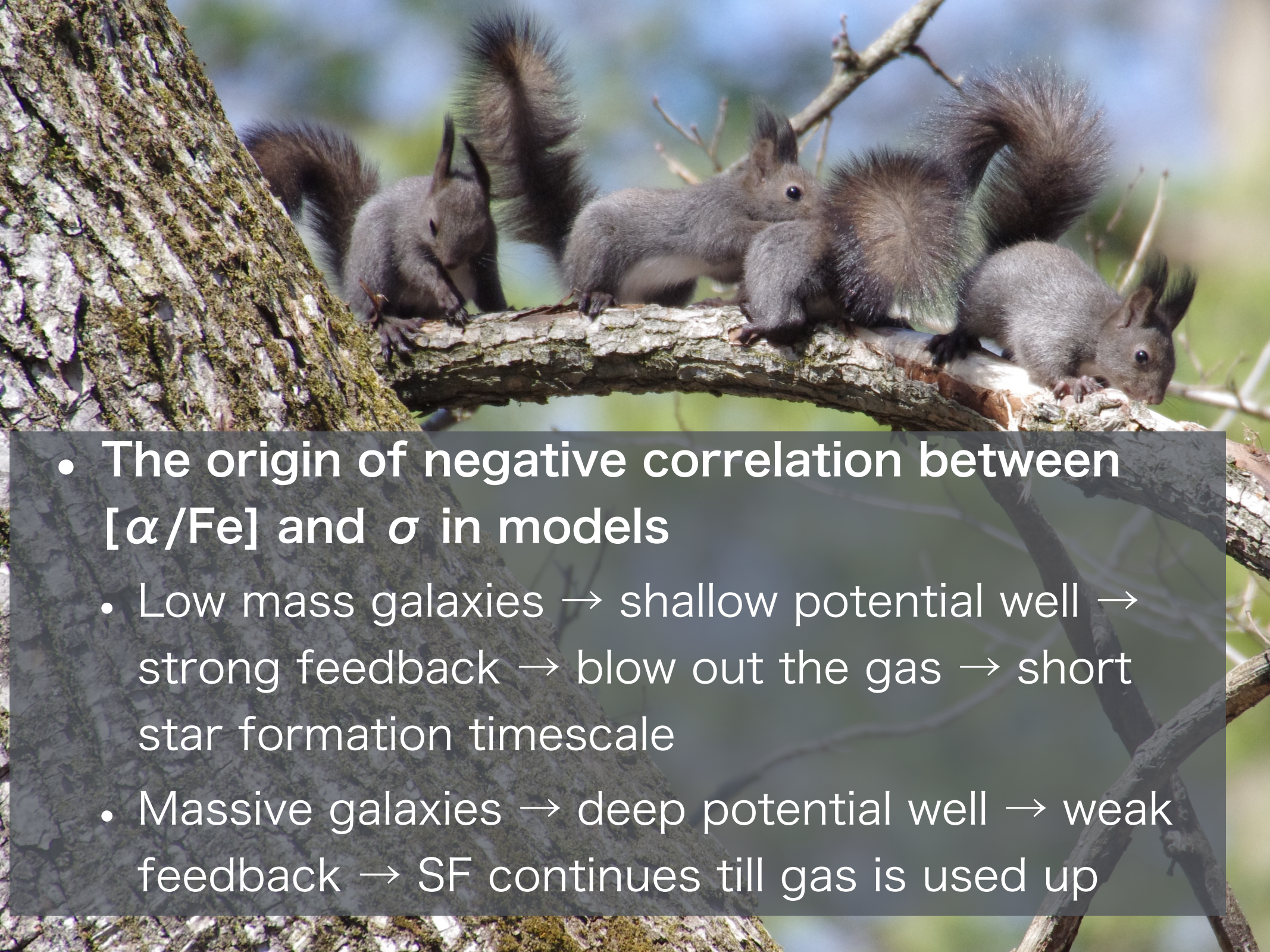


Simulations



Decreasing [α/Fe] with increasing σ.

AGN feedback may help.



- **The origin of negative correlation between [α/Fe] and σ in models**
  - Low mass galaxies → shallow potential well → strong feedback → blow out the gas → short star formation timescale
  - Massive galaxies → deep potential well → weak feedback → SF continues till gas is used up

Our simulations

- Okamoto+14
  - Reproduce many observed properties of gals from z = 4 to 0.
  - stellar mass functions, star formation rate, gas phase metallicity, galaxy downsizing, etc.

Our stellar feedback

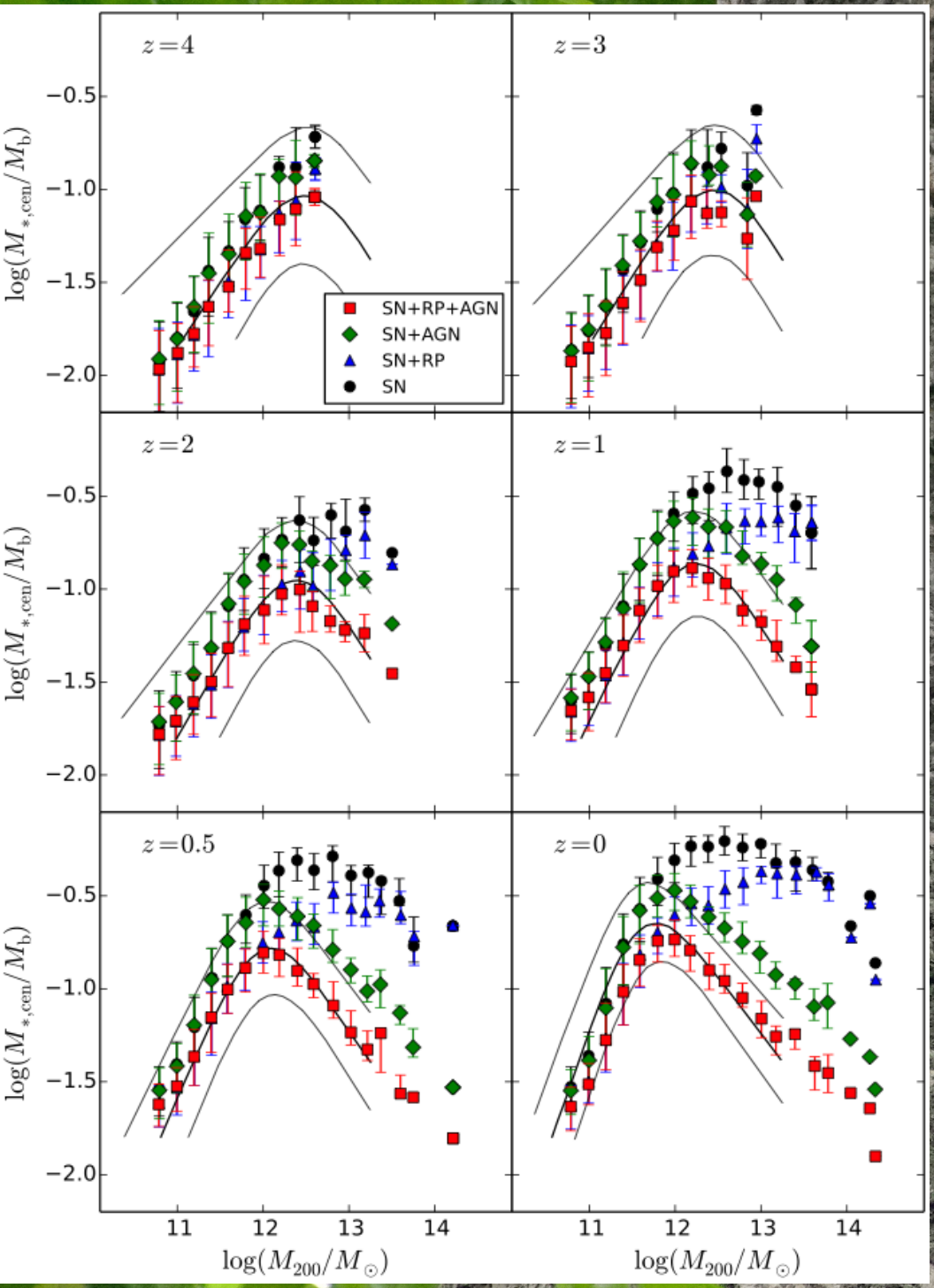
- **Stellar feedback**
  - modeled as winds $v_{\rm w} \propto \sigma$
  - Energy driven winds by SNII $\dot{M}_{\rm w} \propto \sigma^{-2}$
  - Momentum driven winds by stellar radiation $\dot{M}_{\rm w} \propto \sigma^{-1}$

AGN radio mode-like feedback

- **Radio mode**
  - 要するに大きなハローで cooling を止めるプロセス
  - Shutting-off cooling if $\sigma > \sigma_{\rm crit}$.

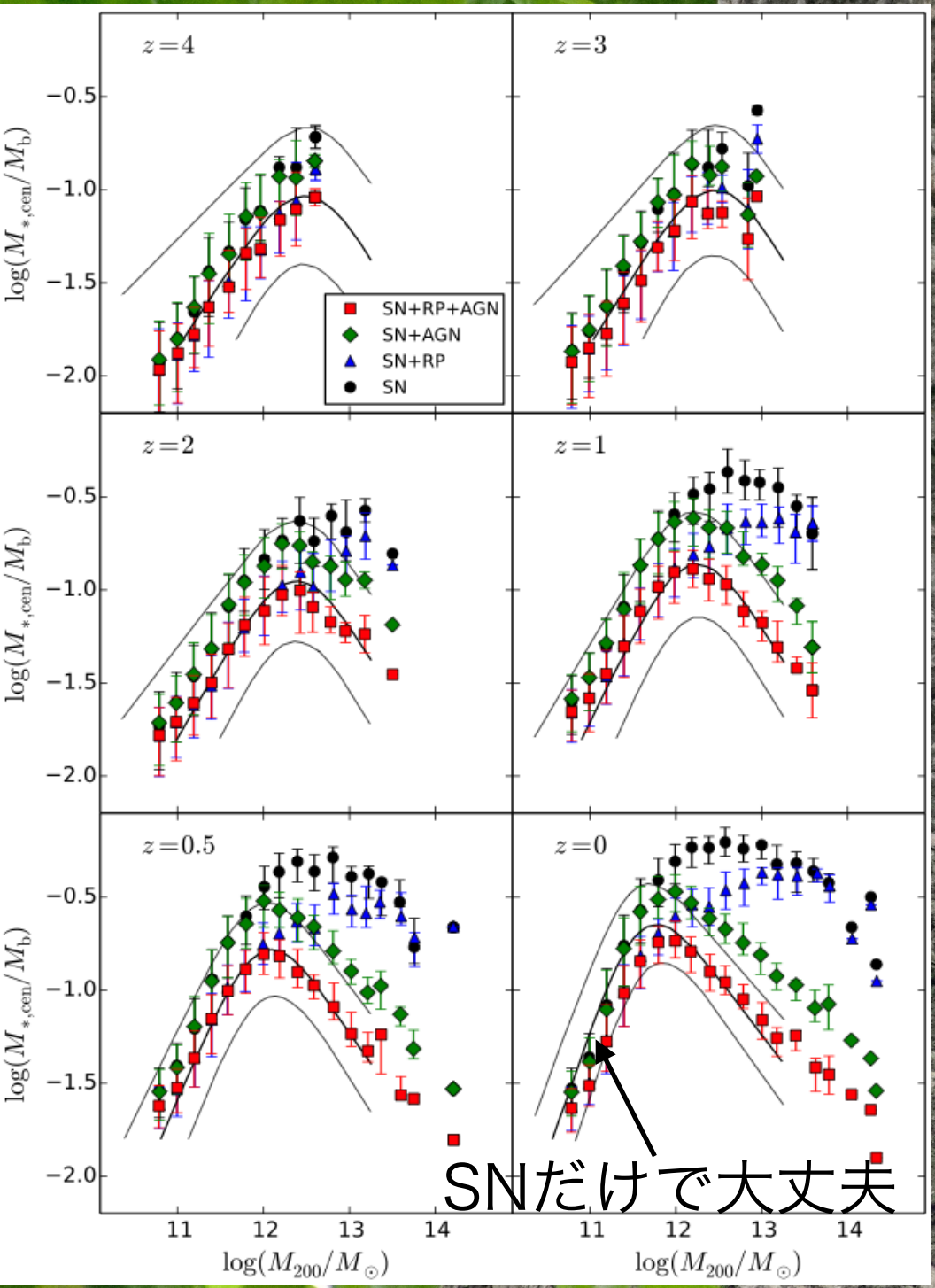
    $$\sigma_{\rm crit} = \sigma_0 (1+z)^{\alpha}$$
  - α = 0.75
  - Cooling in high-σ halos is quenched earlier than low-σ counterparts.

Galaxy formation efficiency



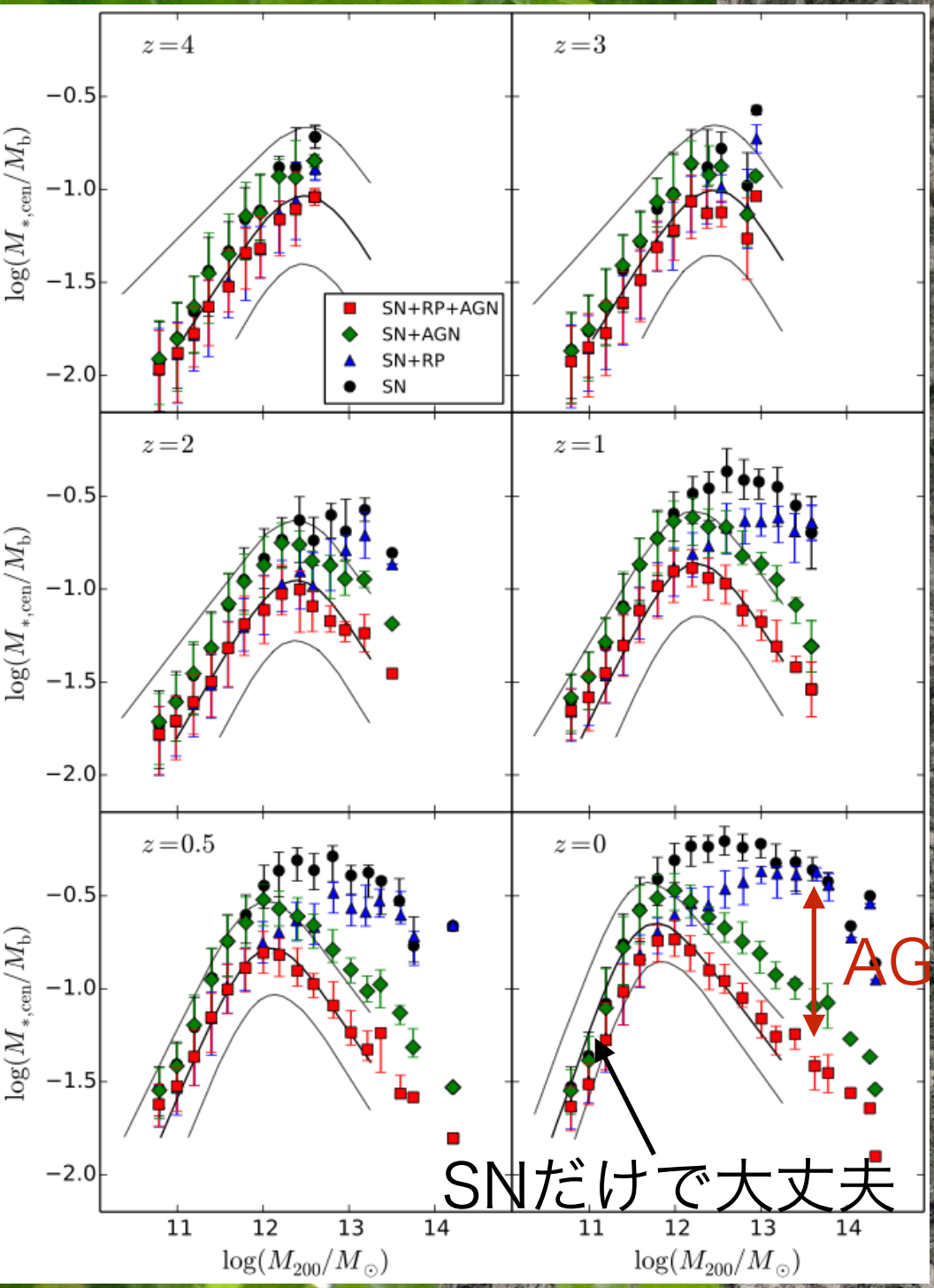
- SN + RP + AGN
- SN + AGN
- SN + RP
- SN

Galaxy formation efficiency



- SN + RP + AGN
- SN + AGN
- SN + RP
- SN

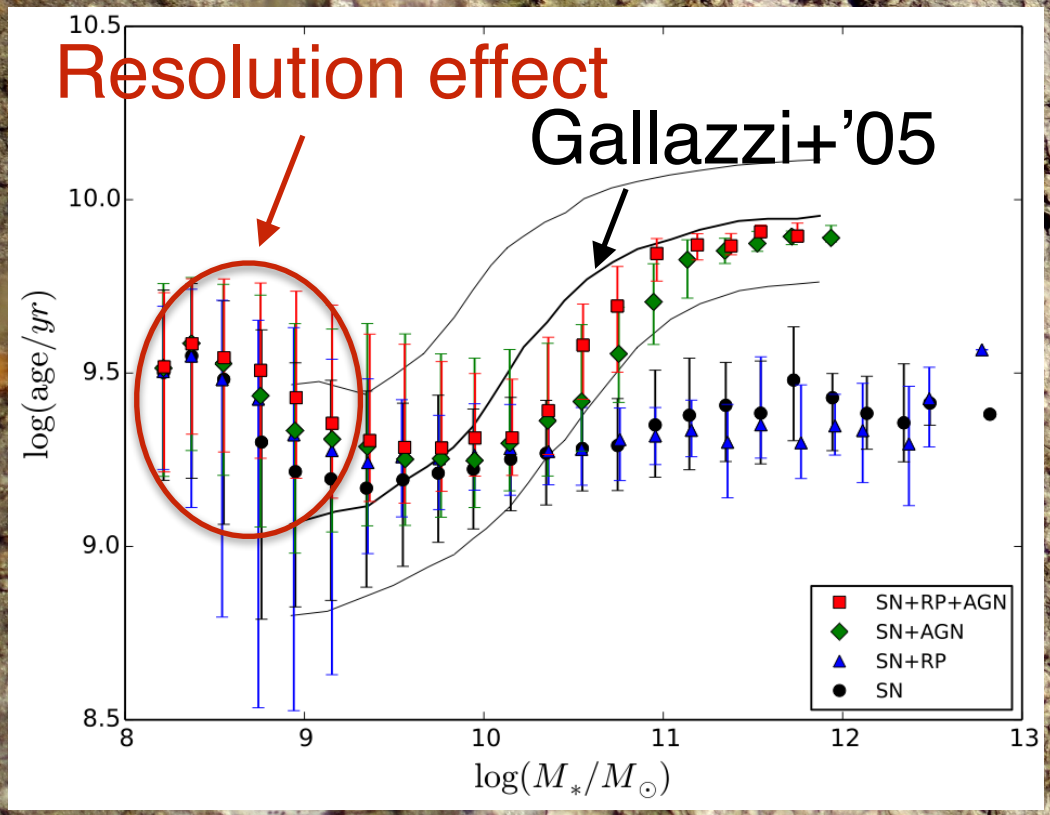
Galaxy formation efficiency



- SN + RP + AGN
- SN + AGN
- SN + RP
- SN

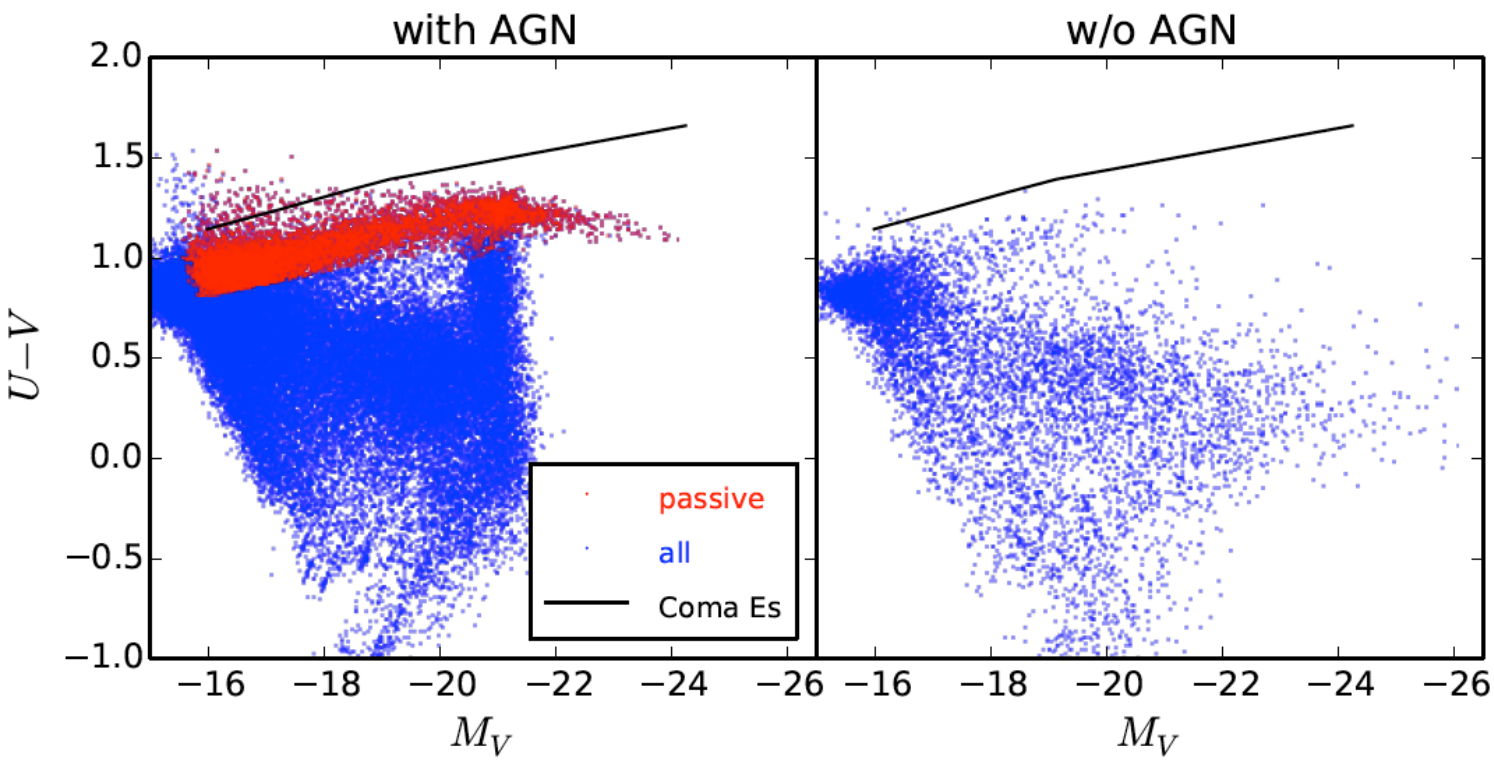
Galaxy downsizing

AGN FB is essential for the galaxy downsizing



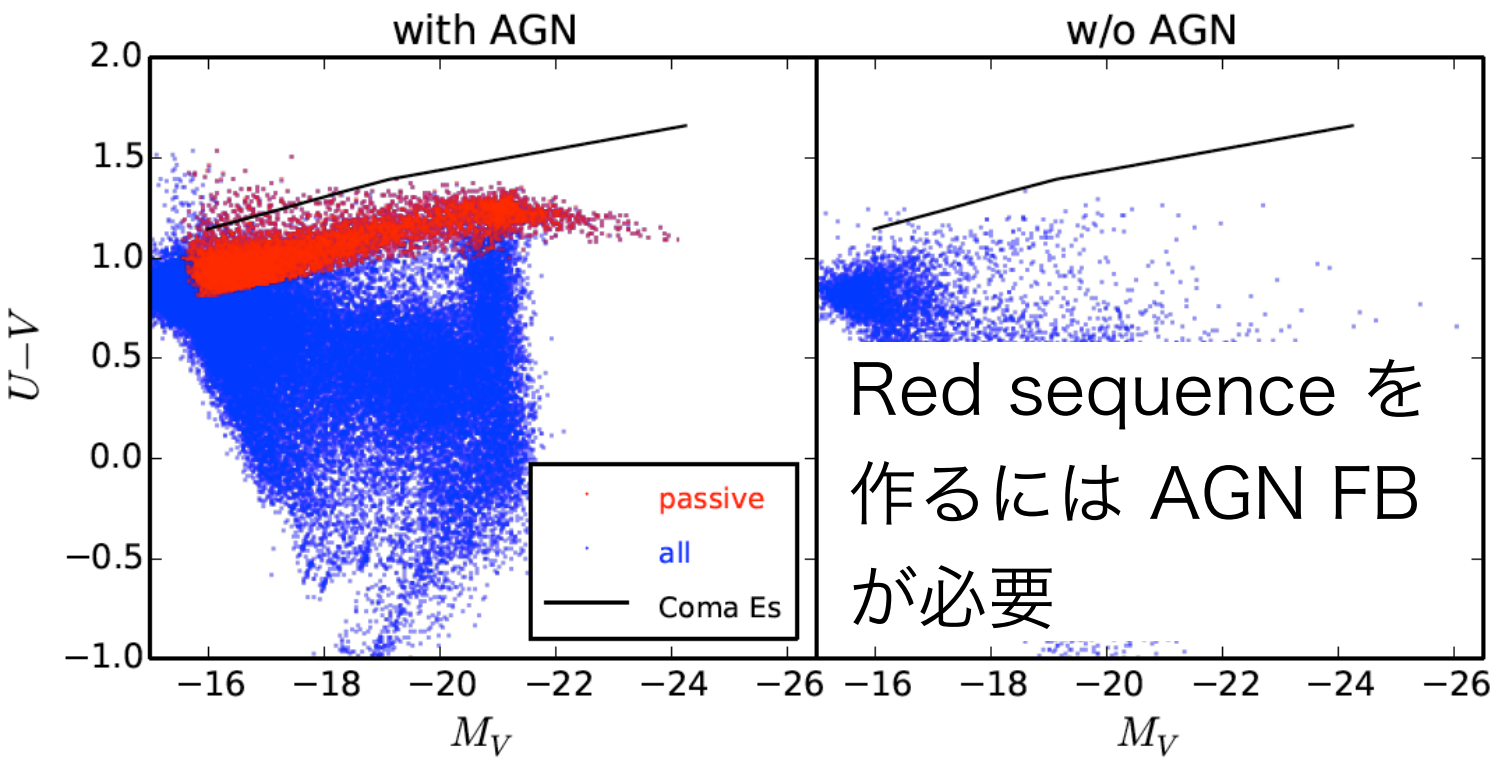
Simulated passive galaxies

Color-magnitude diagram



Simulated passive galaxies

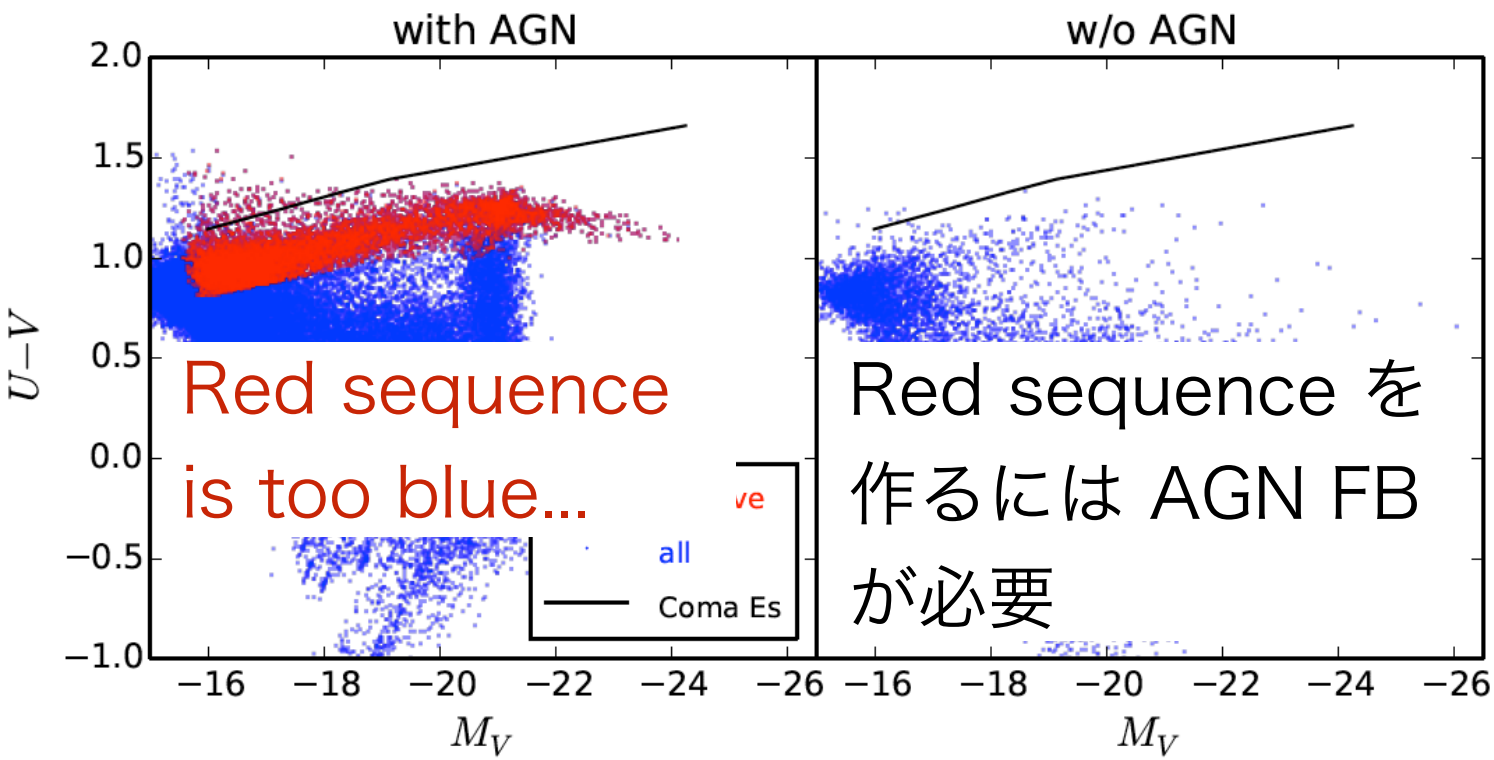
Color-magnitude diagram



Red sequence を作るには AGN FB が必要

Simulated passive galaxies

Color-magnitude diagram



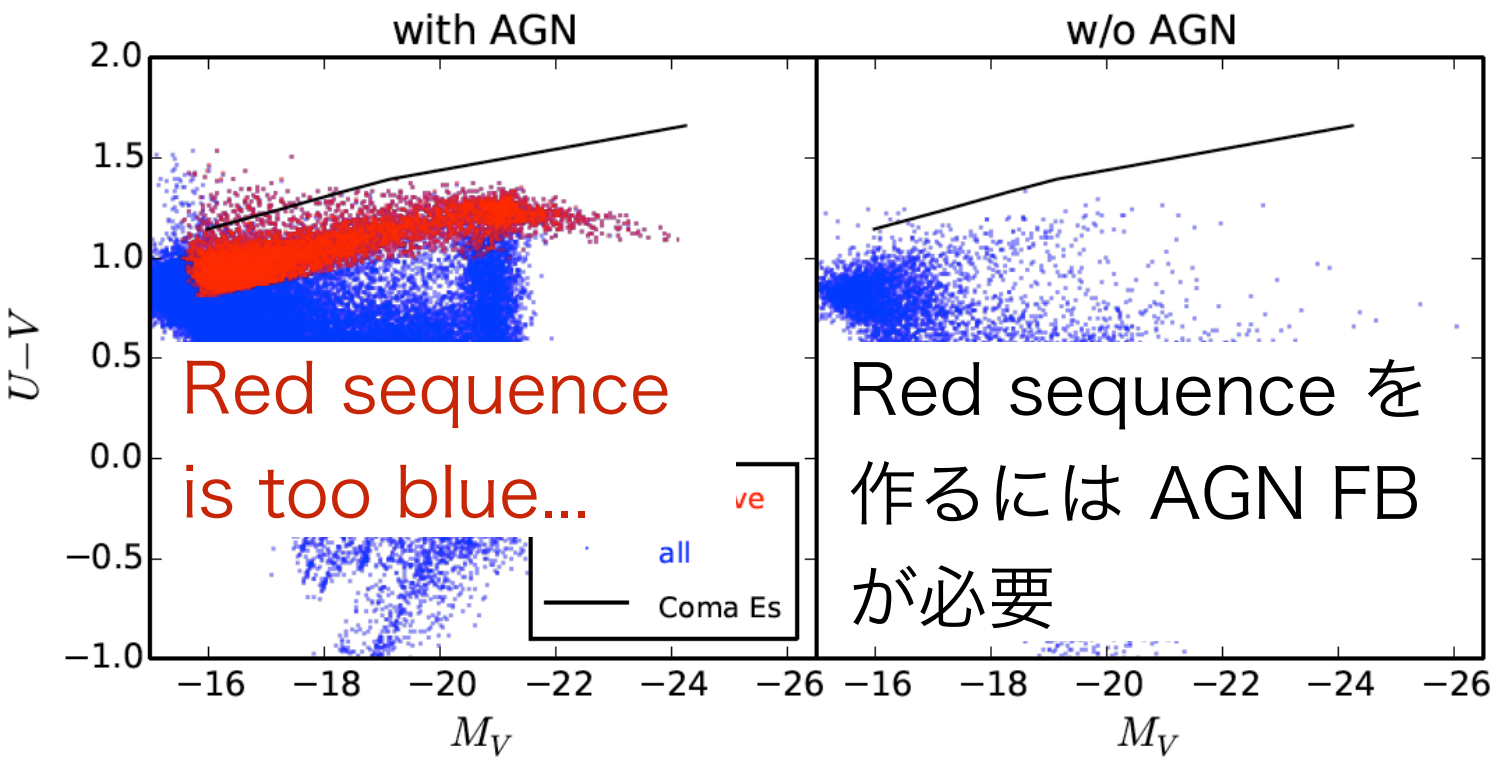
Red sequence is too blue...

Red sequence を作るには AGN FB が必要

Simulated passive galaxies

無理やり合わせるには Z を 2~3 倍してやる必要あり (Top-heavy IMF?)

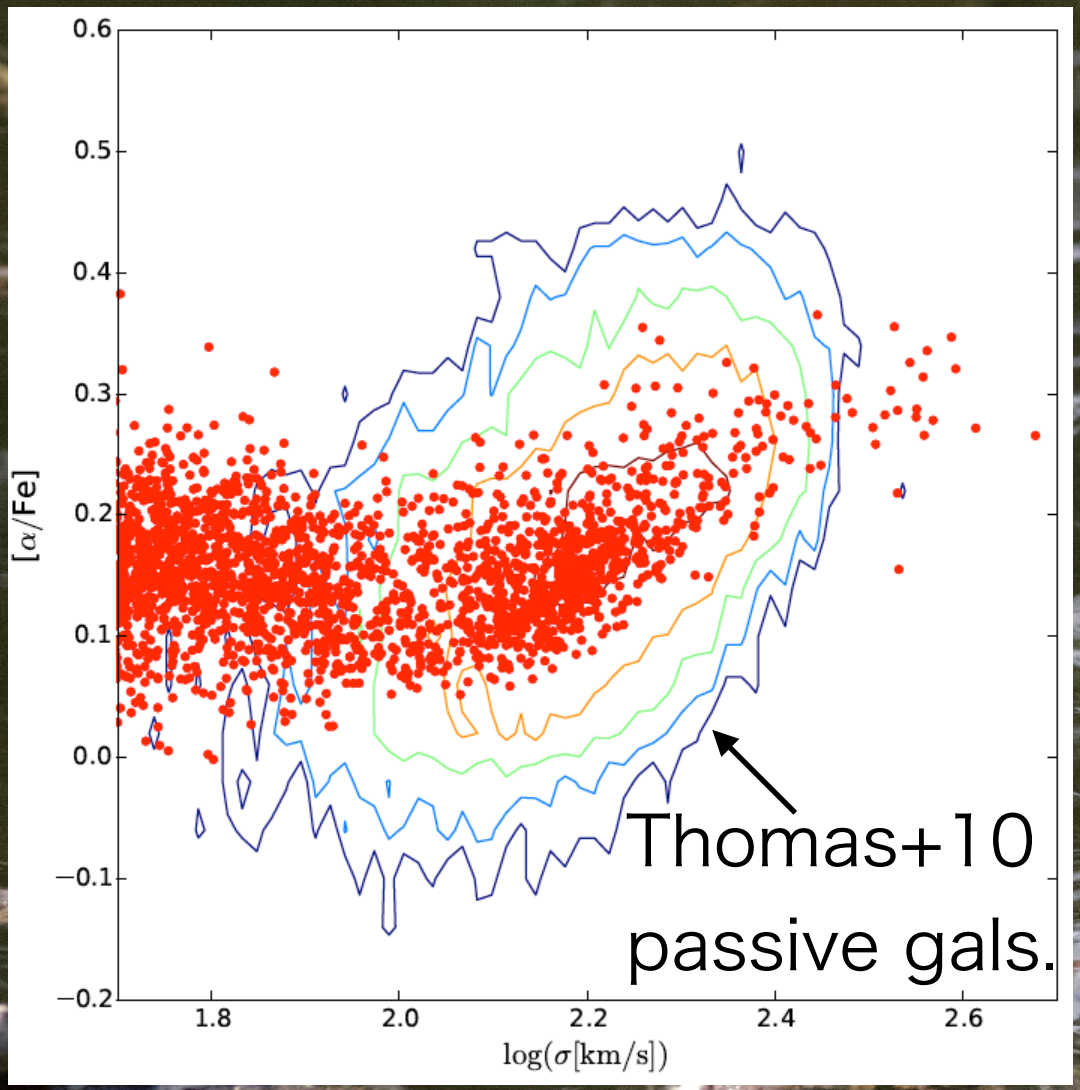
Color-magnitude diagram



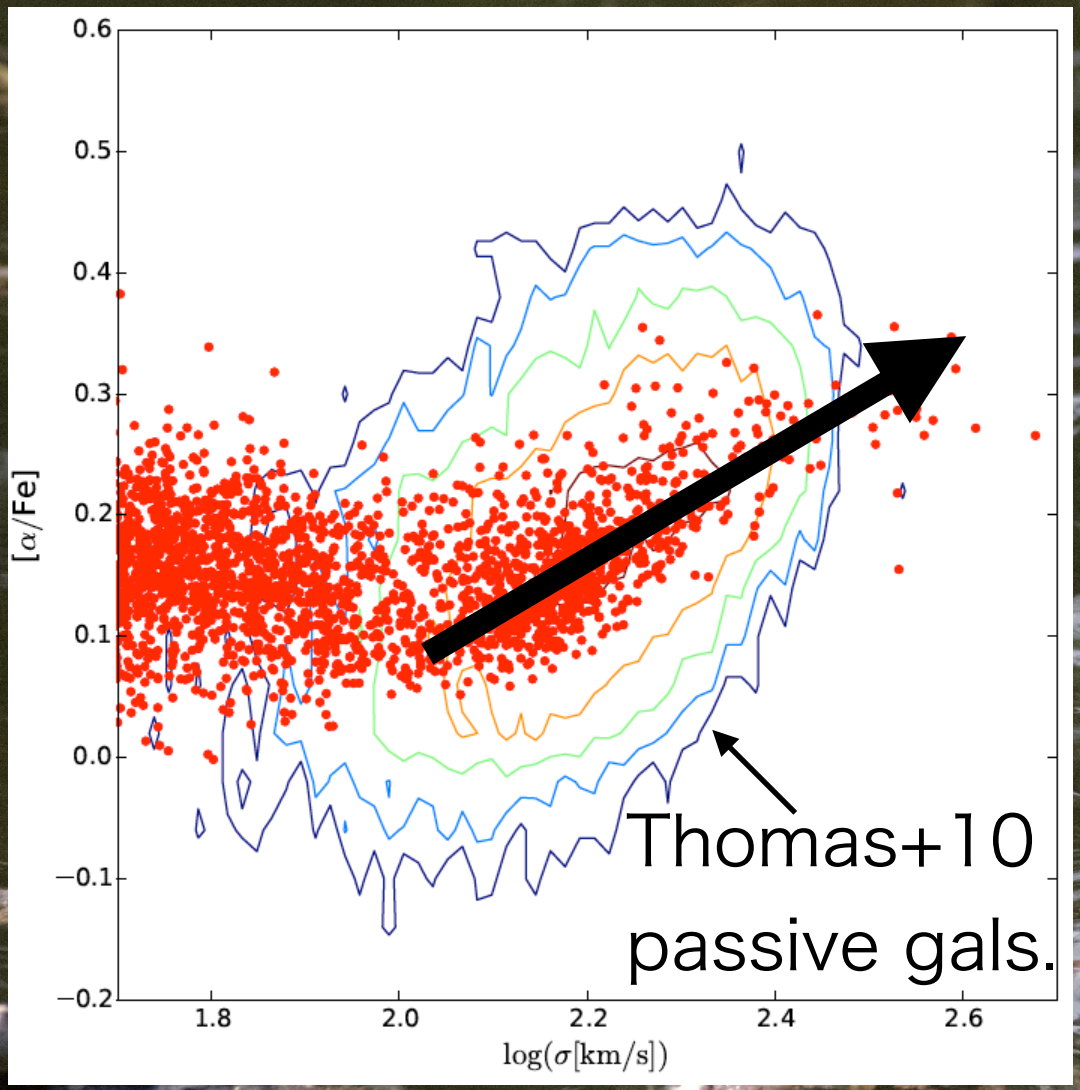
Red sequence is too blue...

Red sequence を作るには AGN FB が必要

[α/Fe] vs σ


0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
[α/Fe]
1.8
2.0
2.2
2.4
2.6
log(σ[km/s])
Thomas+10
passive gals.

[α/Fe] vs σ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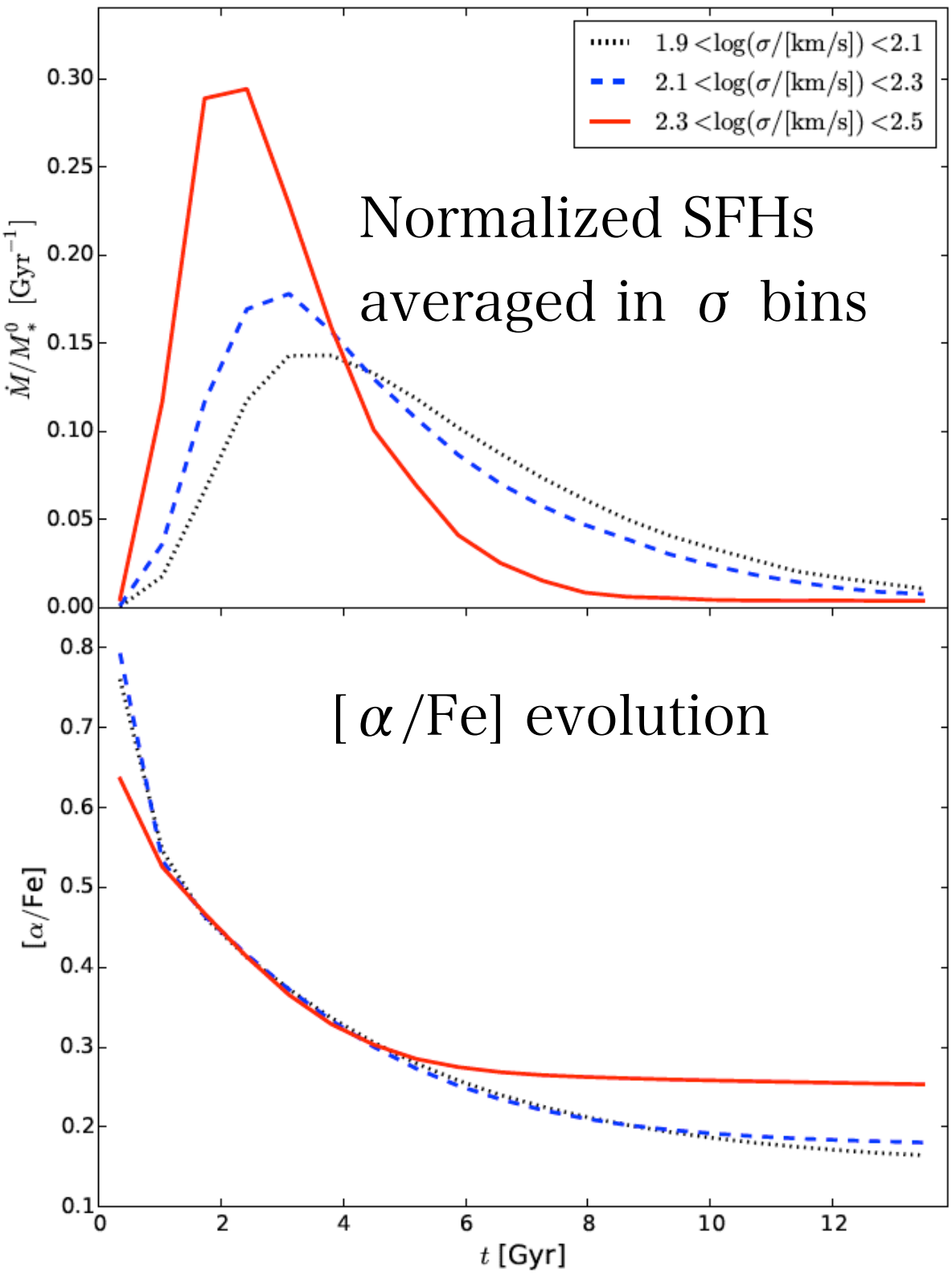
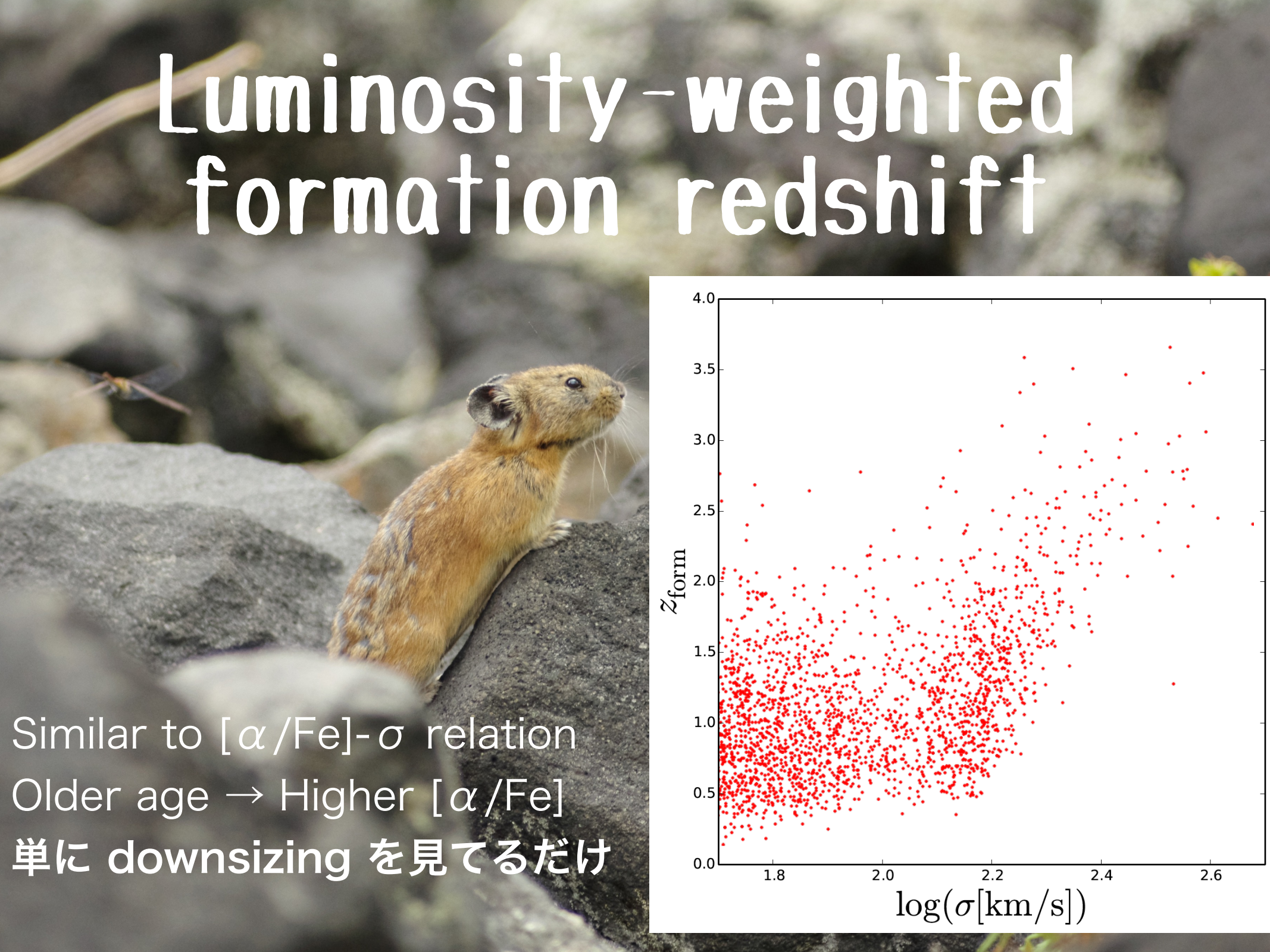
−0.2
[α/Fe]
1.8
2.0
2.2
2.4
2.6
log(σ[km/s])
Thomas+10
passive gals.

The origin of [α/Fe]-σ relation



Luminosity-weighted formation redshift



Similar to [α/Fe]-σ relation

Older age → Higher [α/Fe]

単に downsizing を見てるだけ

Roles of feedback

- SN feedback

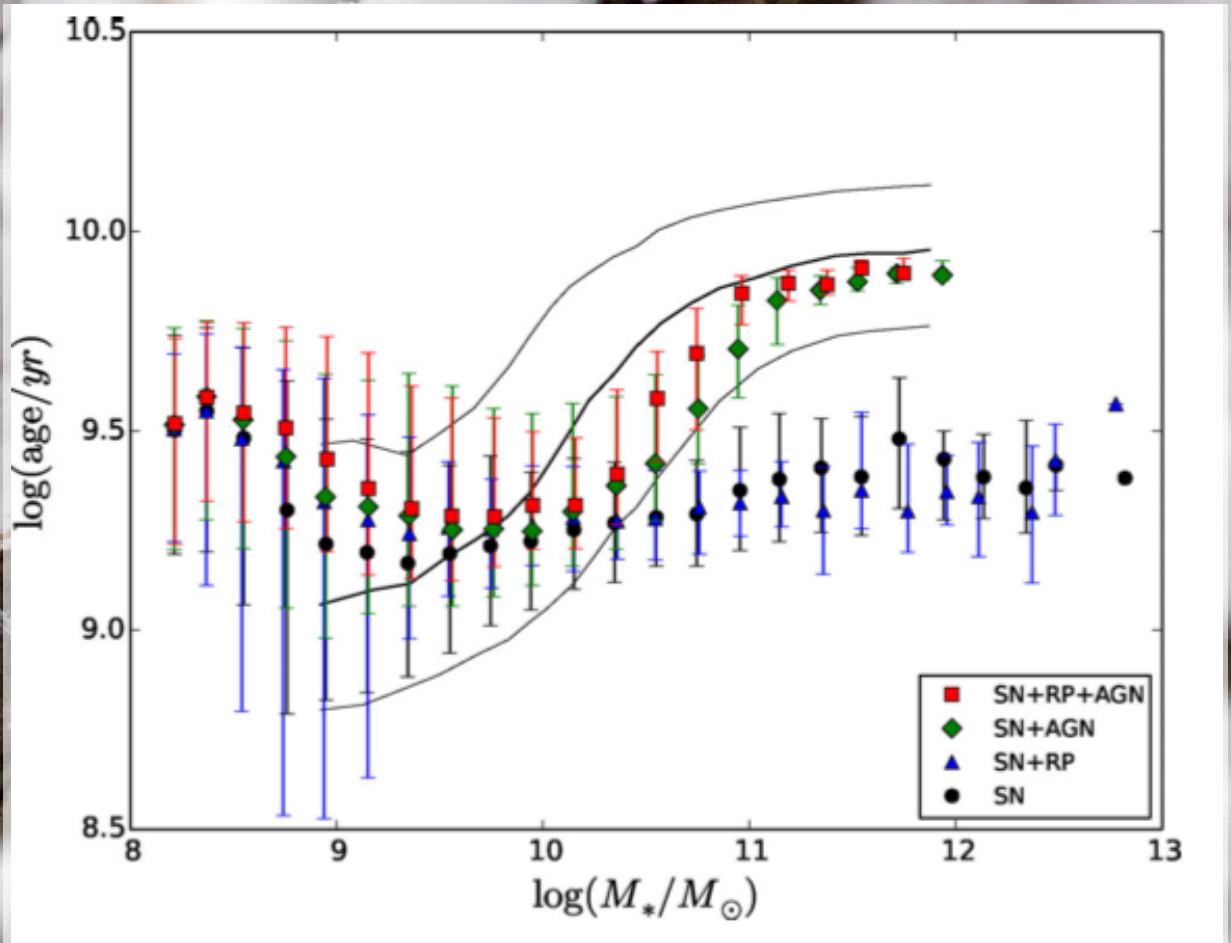
$$\dot{M}_{\rm w} = \eta_{\rm w} \dot{M}_*$$

$$v_{\rm w} \propto \sigma$$

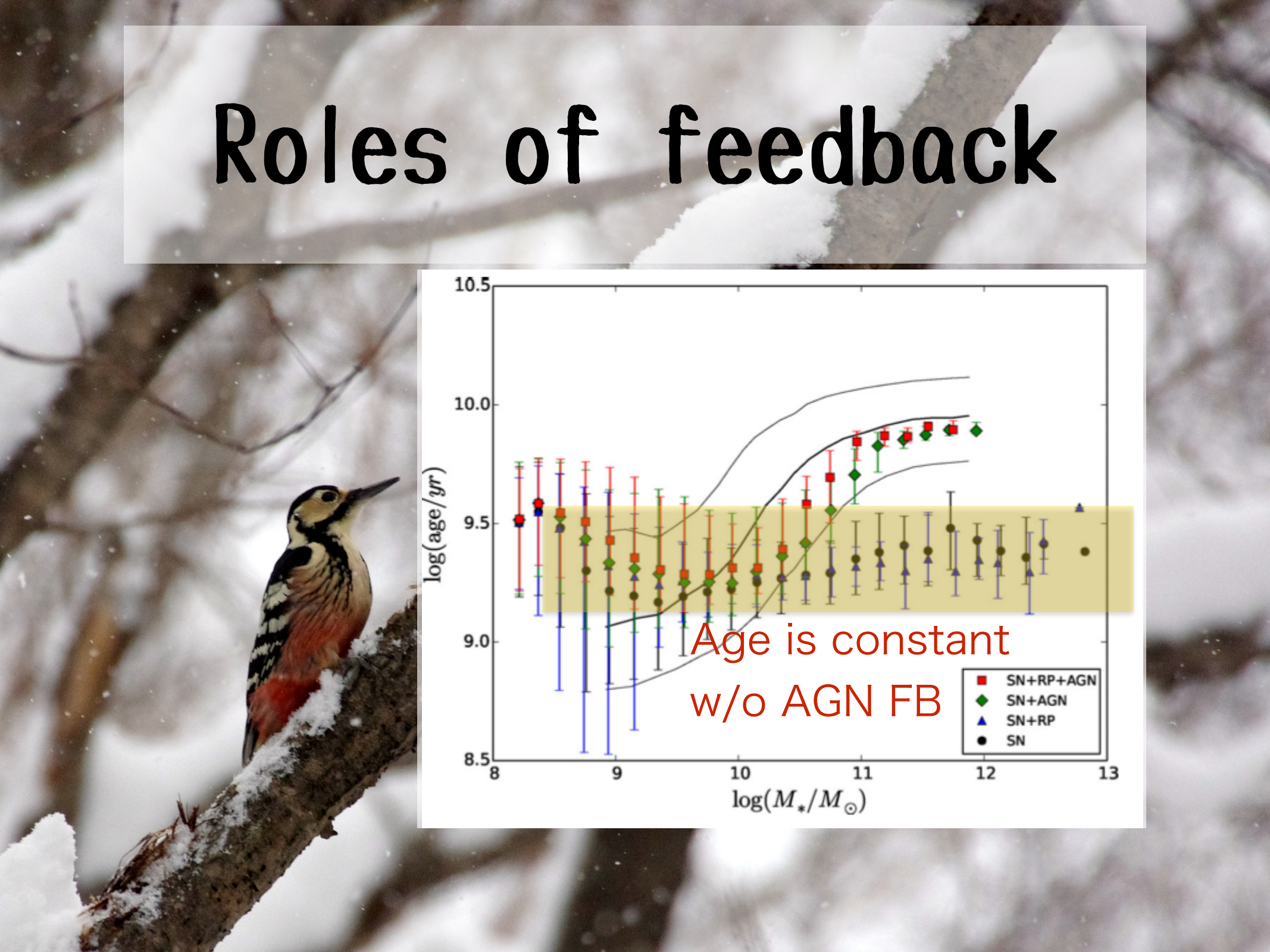
$$\eta_{\rm w} \propto \sigma^{-2}$$

- More winds are generated in low mass galaxies
- The ejected gas can return to the galaxy → long t_{SF}

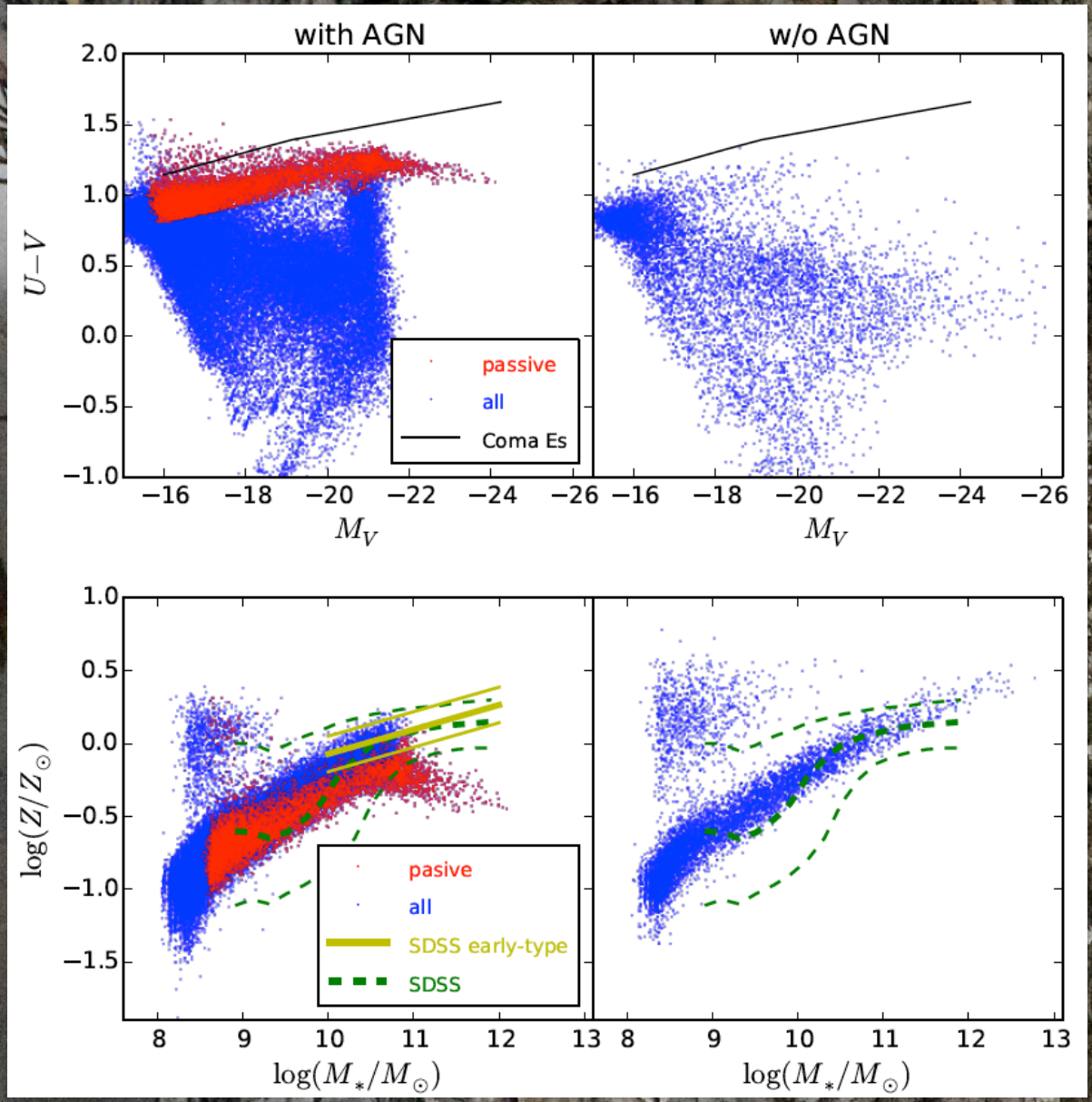
Roles of feedback



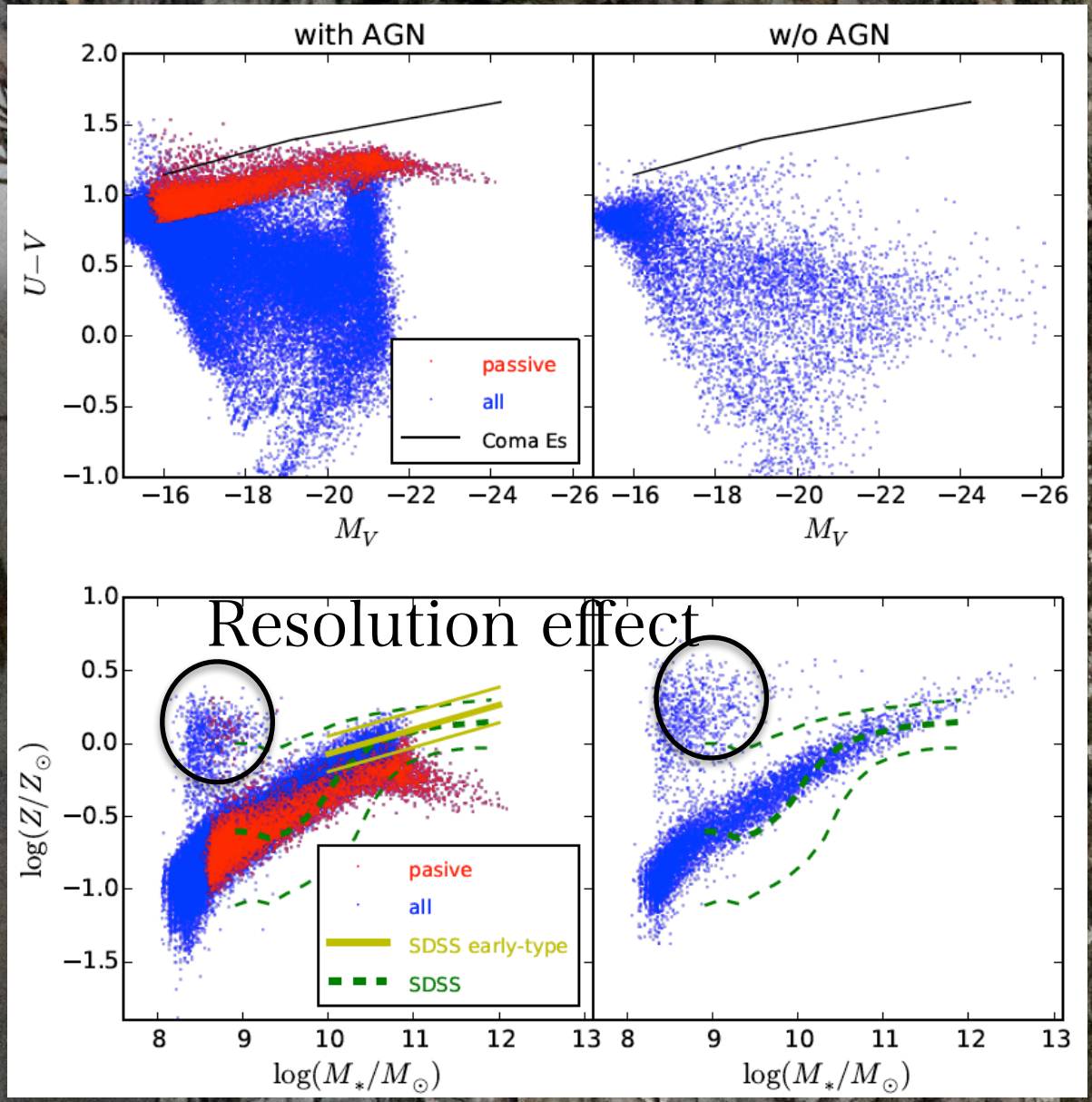
Roles of feedback



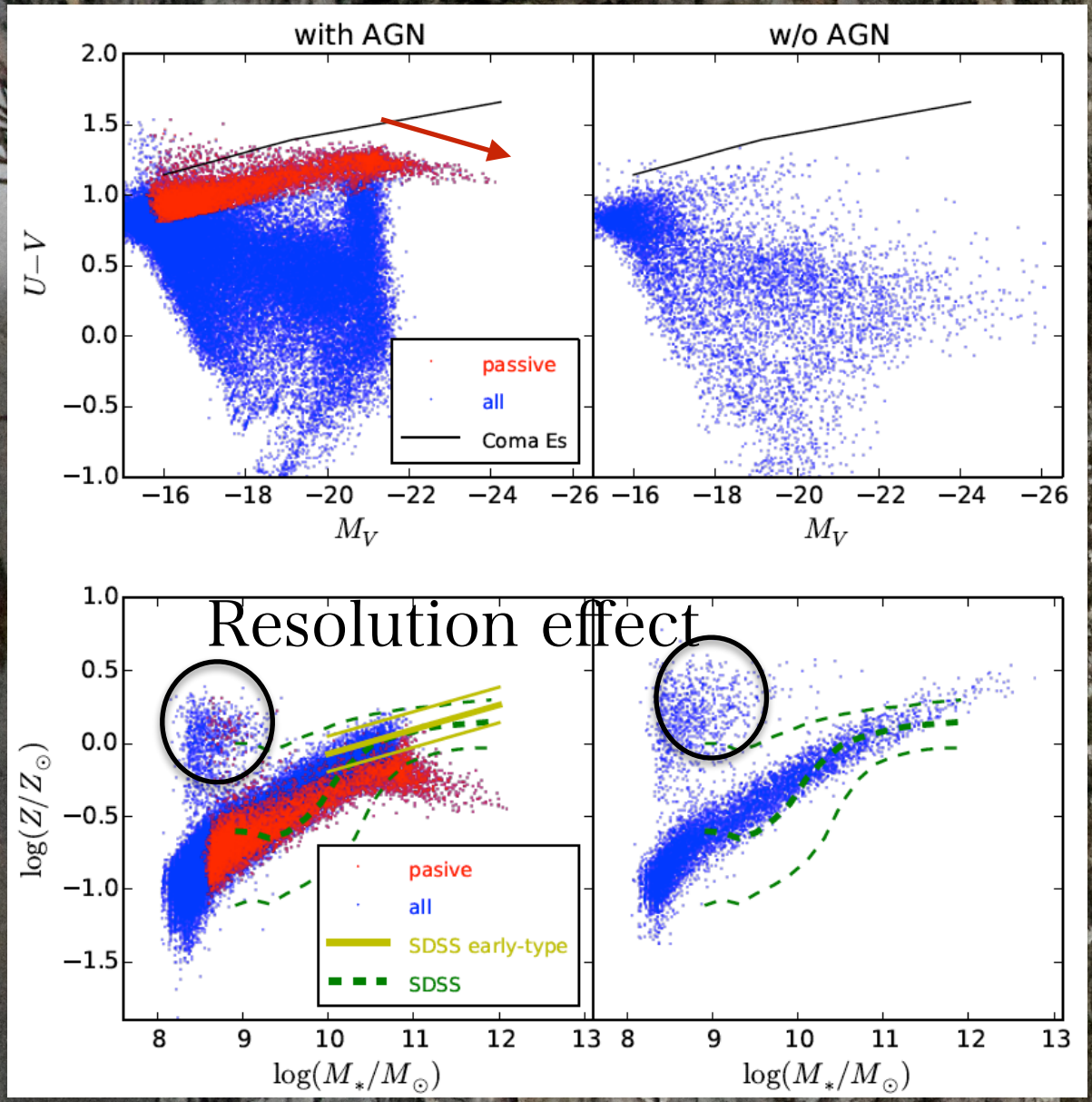
Problems in MZR



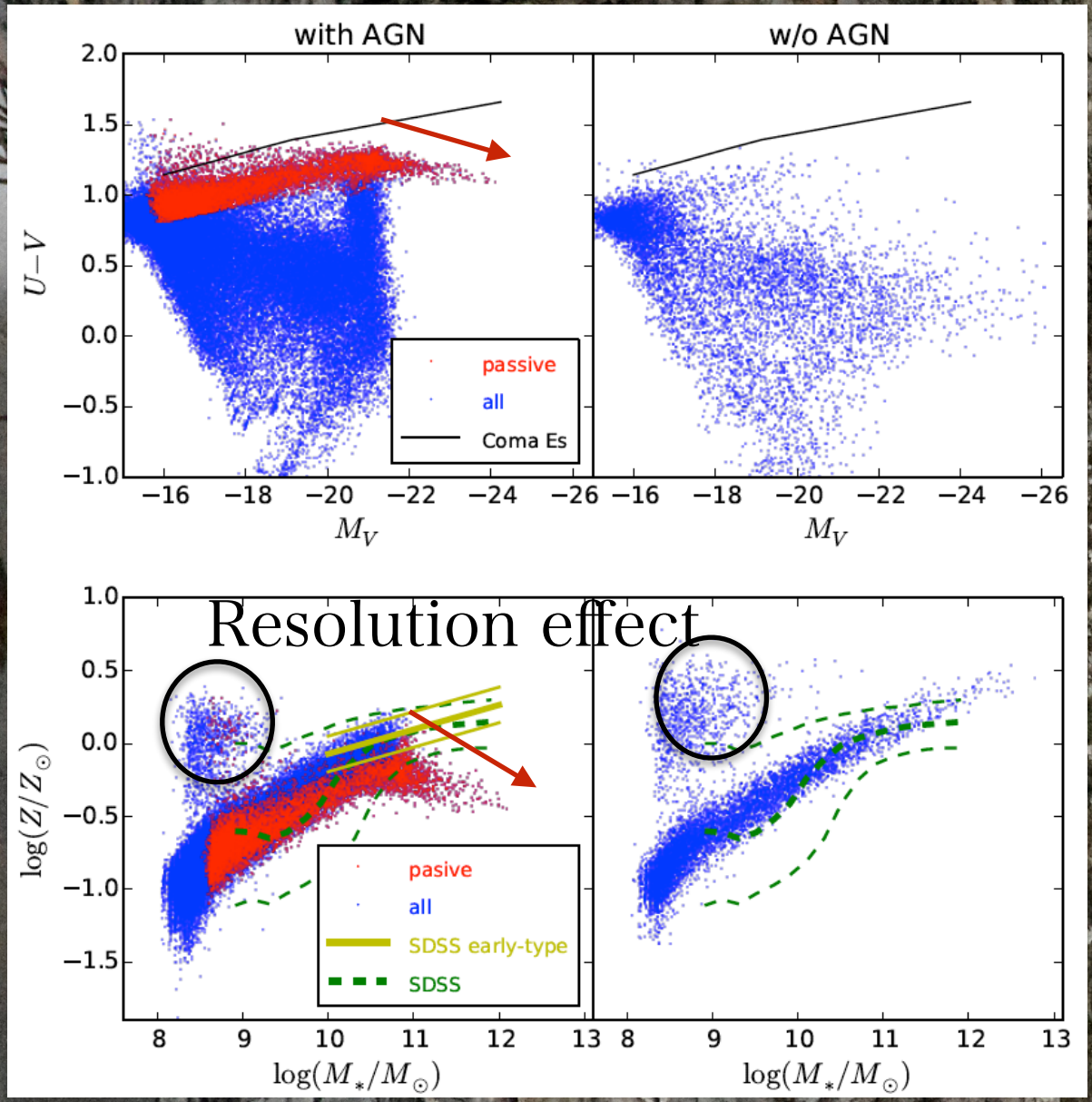
Problems in MZR



Problems in MZR

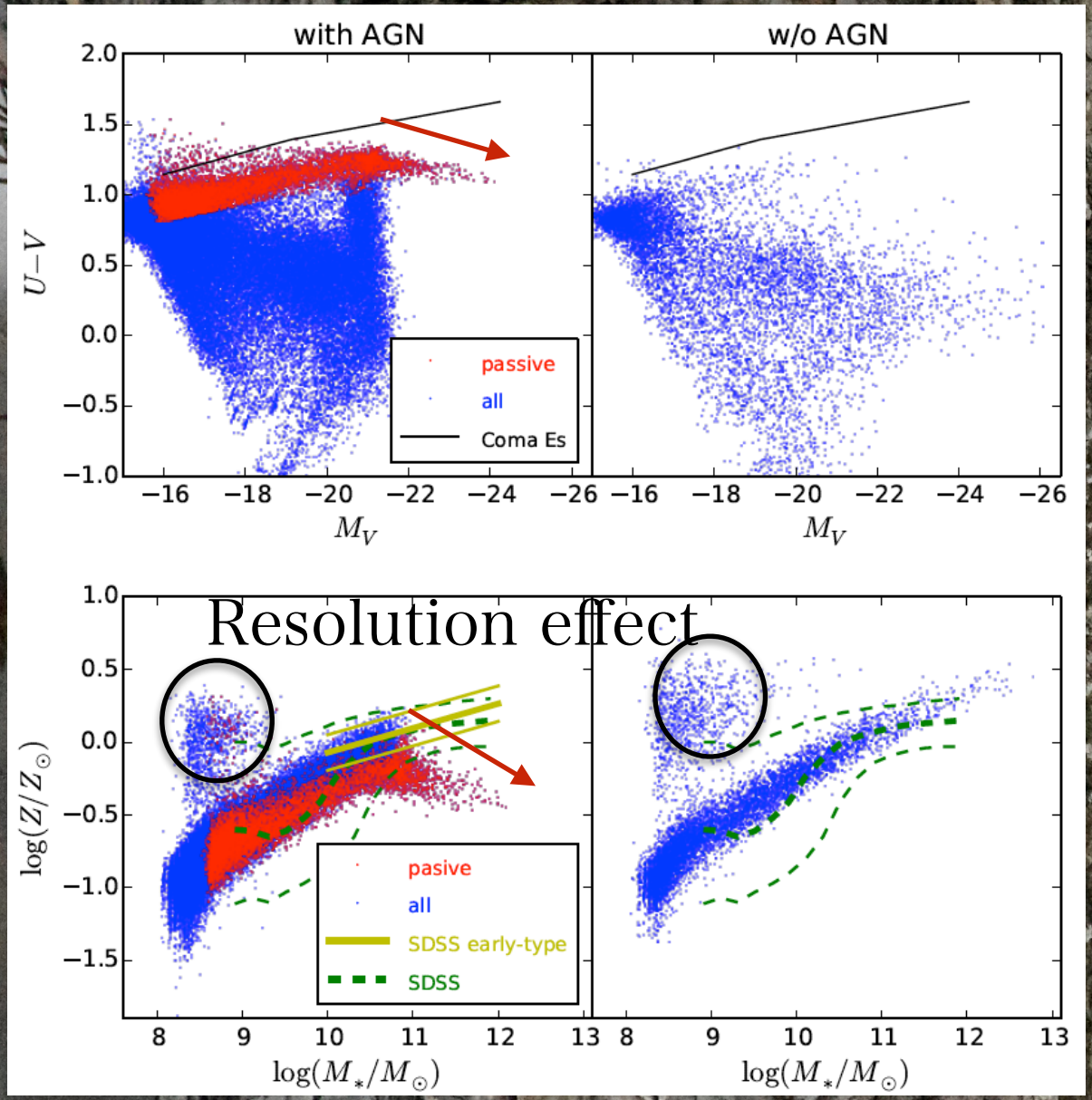


Problems in MZR



Problems in MZR

Stellar feedback in massive galaxies is too strong.



Problems in MZR

Stellar feedback in massive galaxies is too strong.

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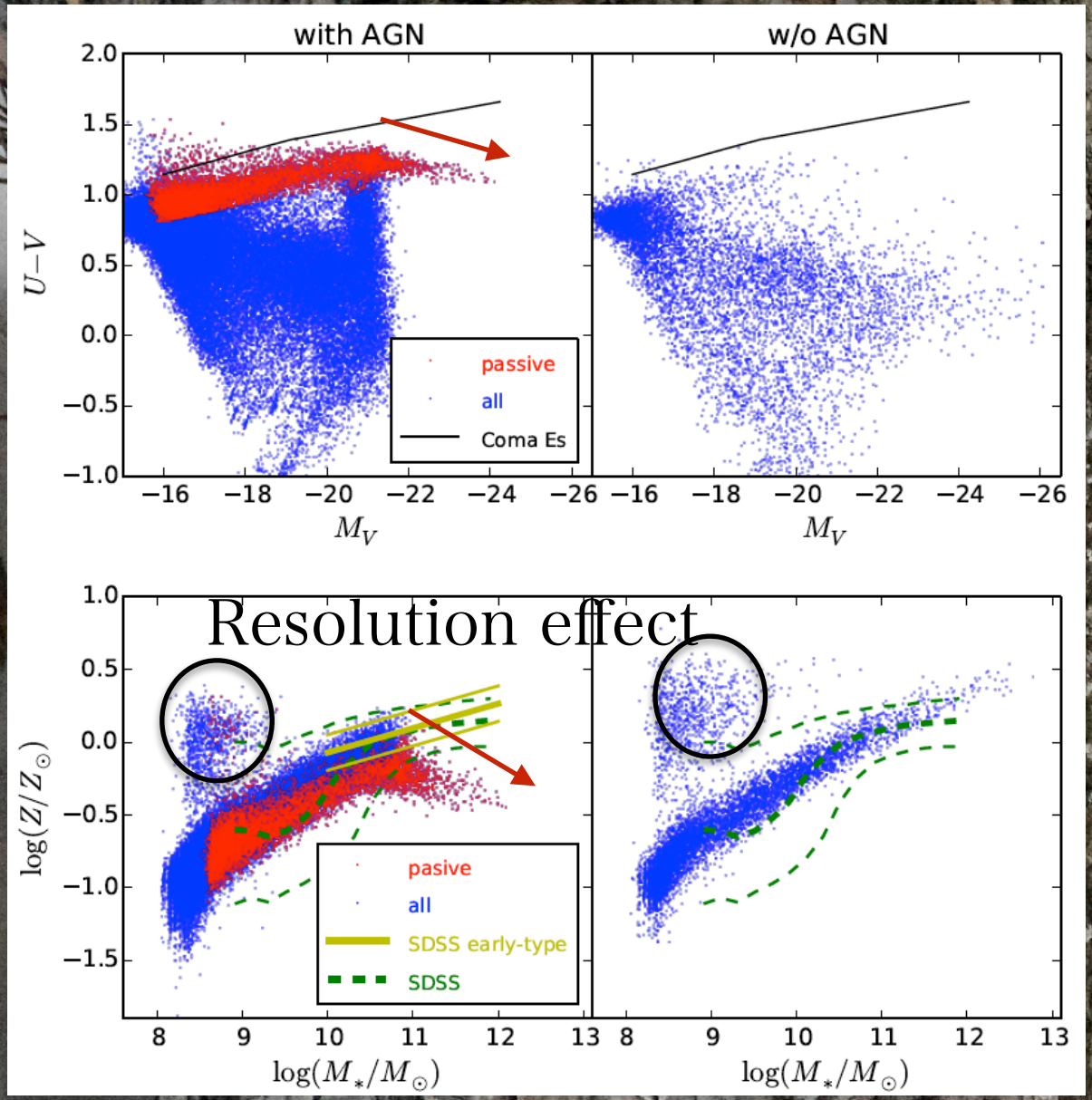
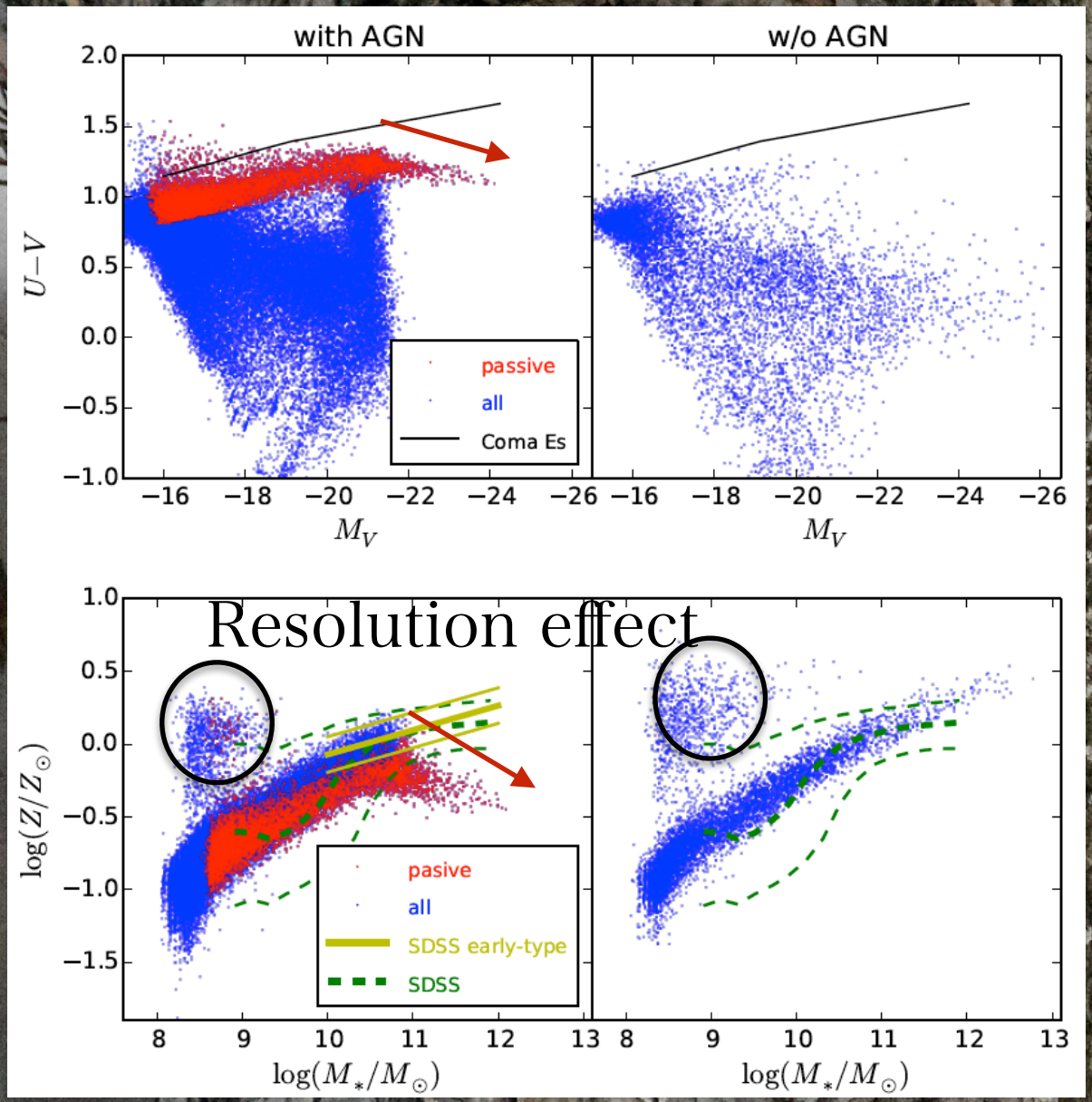


Problems in MZR



Stellar feedback in massive galaxies is too strong.

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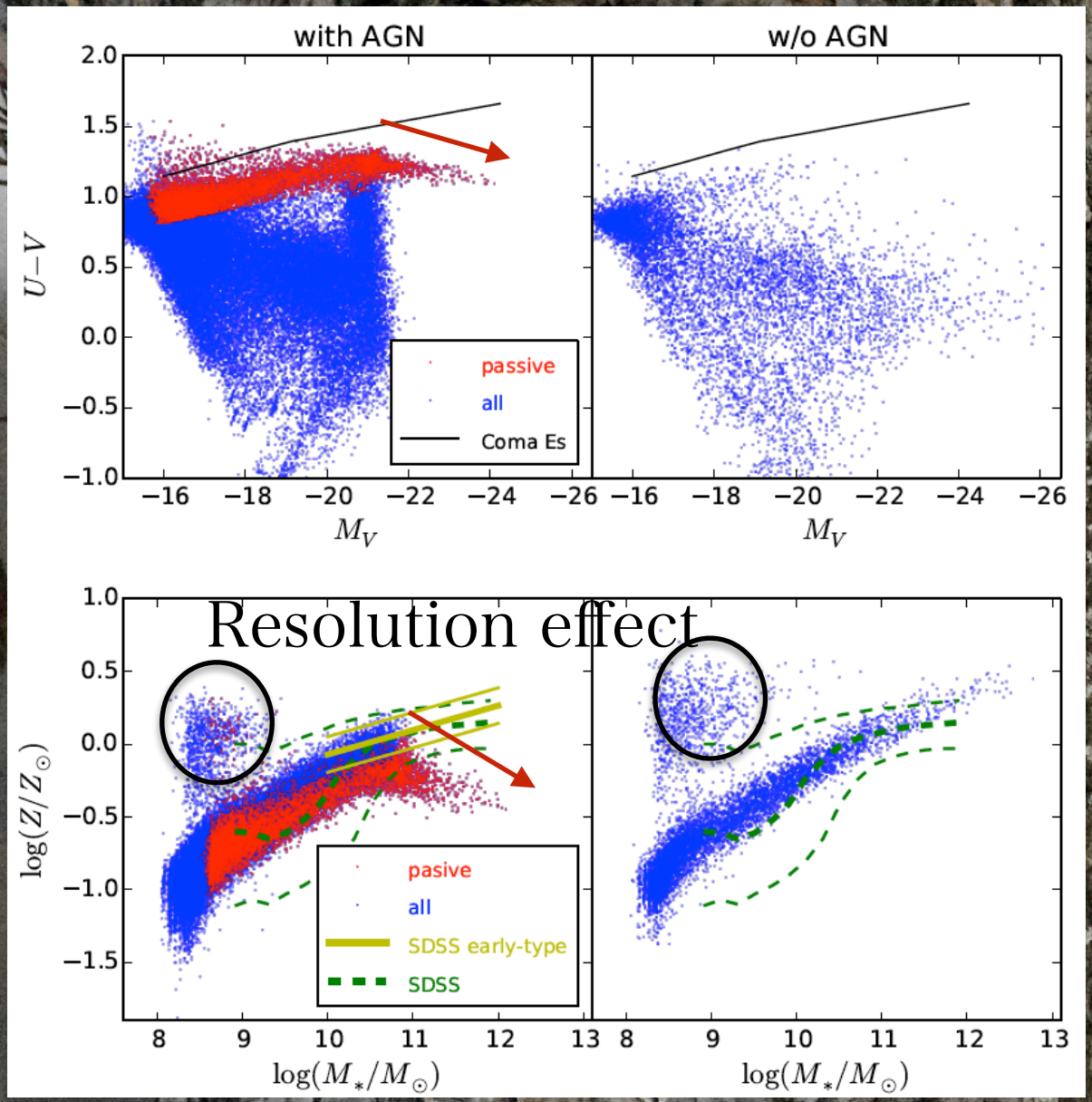
For a given stellar mass, passive gals are less metal rich

Problems in MZR



Stellar feedback in massive galaxies is too strong.

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For a given stellar mass, passive gals are less metal rich

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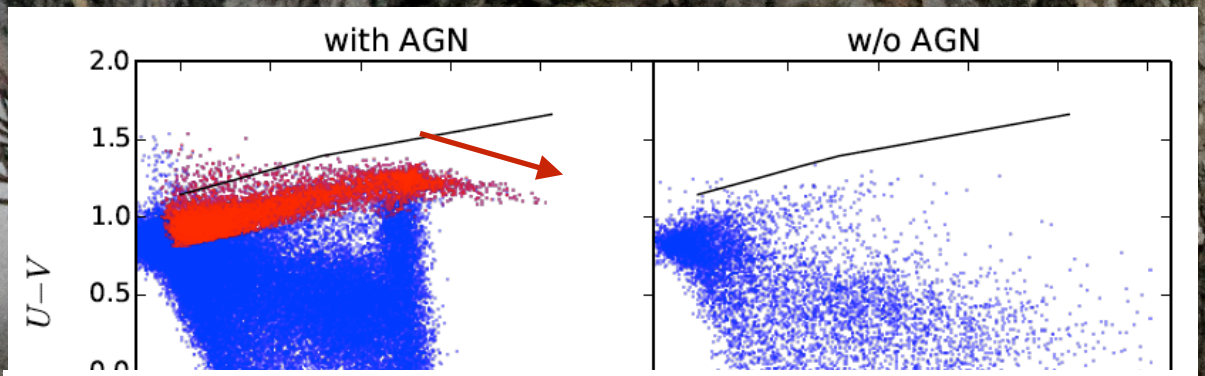
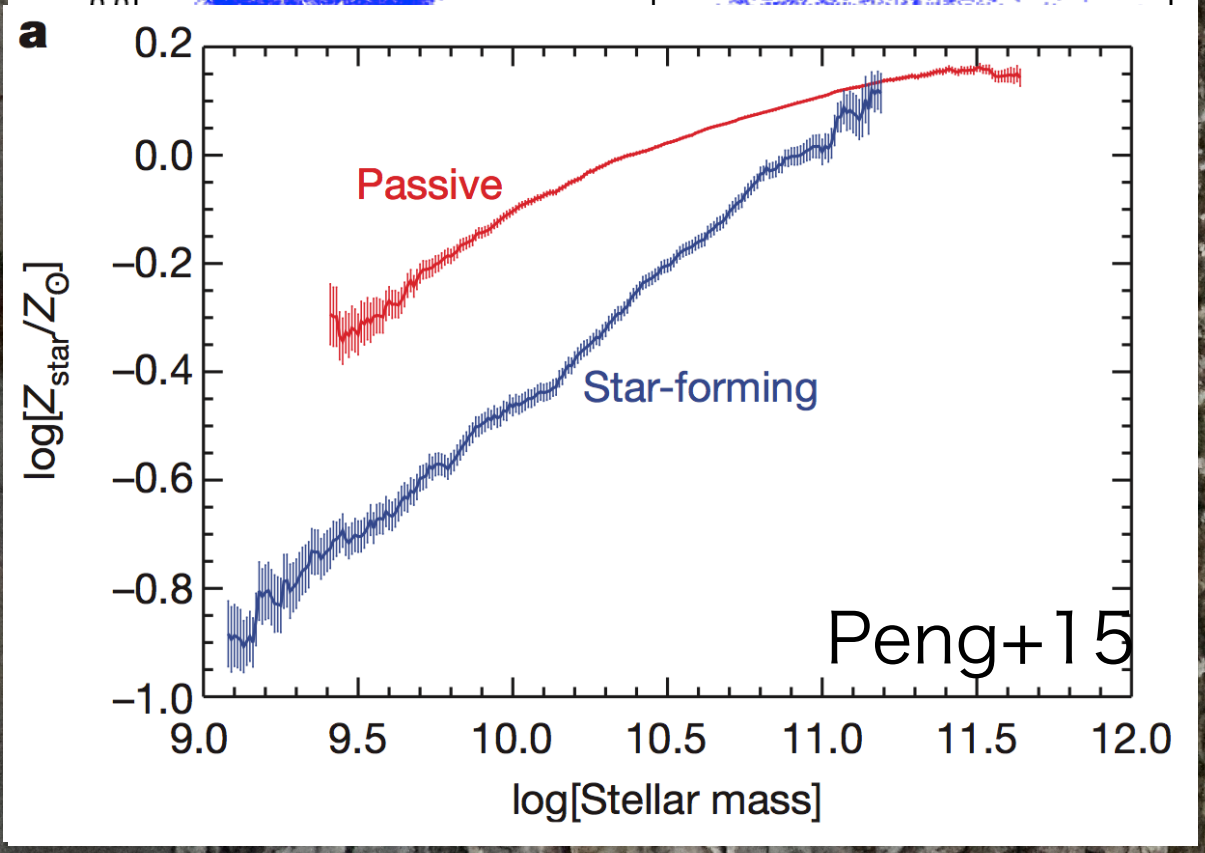
Problems in MZR





Stellar feedback in massive galaxies is too strong.

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For a given stellar mass, passive gals are less metal rich

ナントモナラナイ

原因と対策

- High-σ で metal poor
  - 大きな σ の halo から星形成が止まり enrich する時間がない
  - Outflow が無ければ単なる closed-box → yield の値まで上がる
  - 他の観測量は？

- Passive が metal poor
  - v_c が小さいうちに星を作っているから
  - Burst の時は feedback が弱くなるとか？ もしくは IMF?

Summary

- Radio-mode 的なもので [α/Fe]-σ は説明可能
- Massive gals の metallicity が低くなりすぎる (stellar FB が強すぎる)
- 同じ質量だと passive の方が star-forming よりも metal poor に><
- Outflow がポテンシャルに依存するせい（準解析的モデルでも起こる）
- 高解像度の simulation で outflow の生成を直接見て調べる必要あり（それから考えたい）