EWASS 2015
22-26 June 2015, La Laguna, Tenerife, Spain

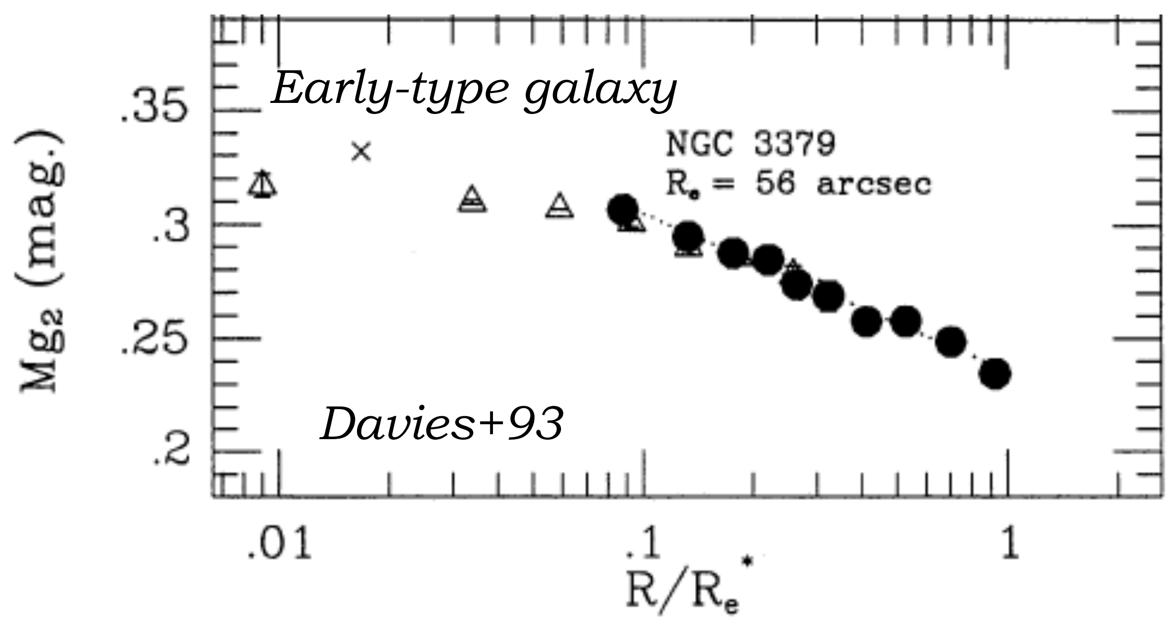
The impact of mergers & energetic phenomena on stellar metallicity gradients in massive galaxies

Michaela Hirschmann *(IAP-CNRS, France)*

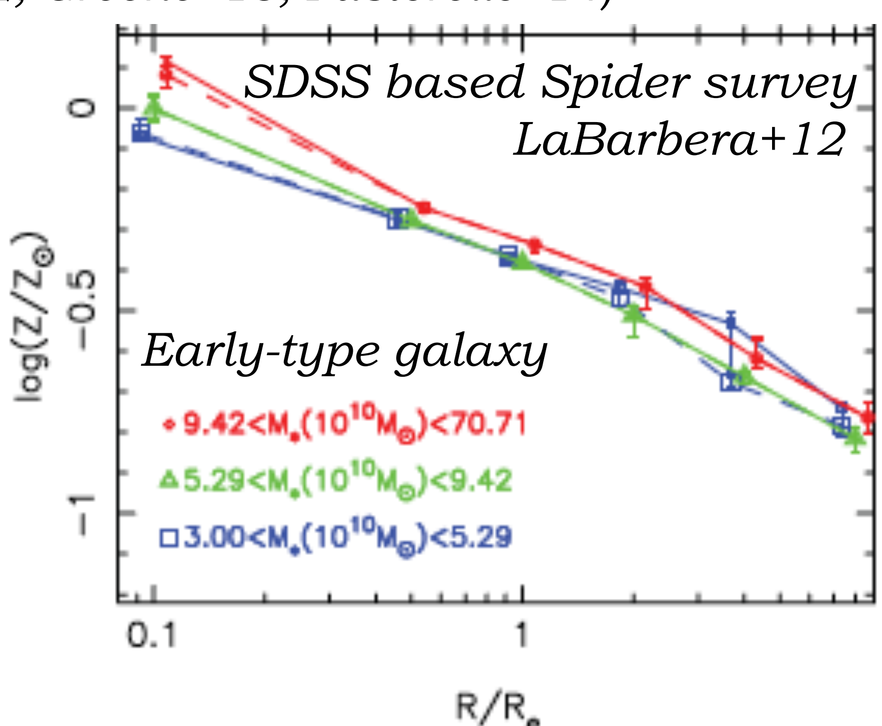
Collaborators: T. Naab, J. P. Ostriker, L. Oser, P.-A. Duc, D. Forbes, E. Choi, S. Charlot

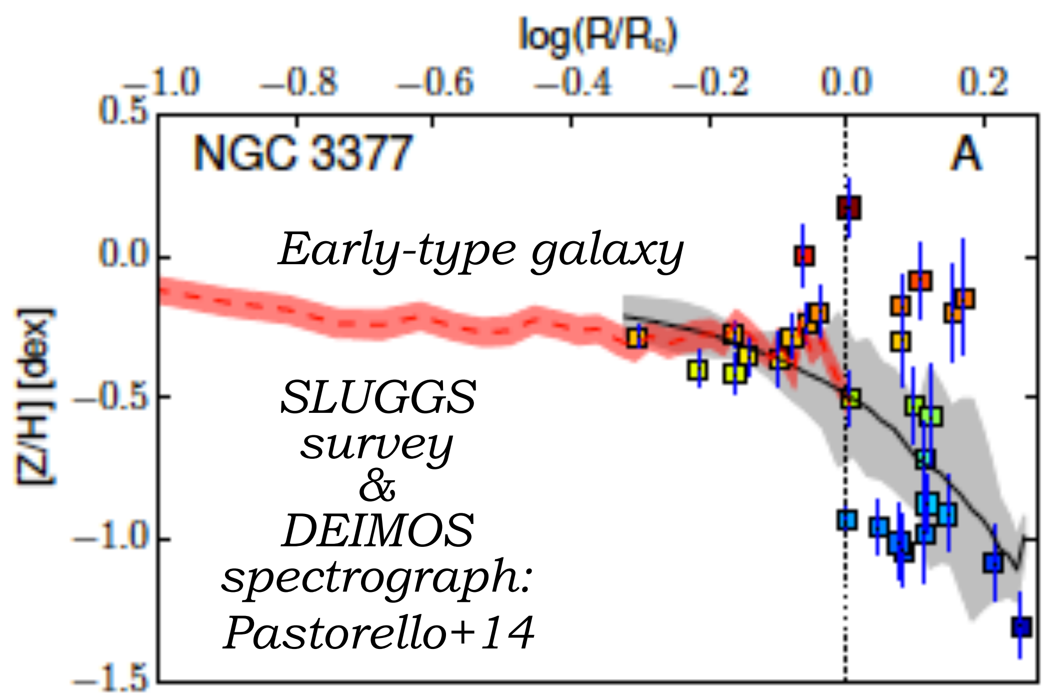
Observational evidence

More than 20 years ago, negative metallicity gradients were discovered in both early- & late-type galaxies (e.g. Davies+93, Carollo+93, Wyse&Silk89, Vila-Costas+92)



Nowadays, thanks to more elaborated techniques, metallicity gradients in early-type galaxies can be measured out to large radii, > 1 R_{eff}, (e.g. LaBarbera +12, Greene+13, Pastorello+14)





Theoretical work

Metallicity gradients can emerge from

Late-type, disk galaxies galaxies:

- *Insitu star formation* due to continuous infall of metal-poor gas onto the disk, which can be turned into metal-poor stars, inside-out growth *(e.g. Steinmetz&Mueller+94, Chiappini+01, Pilkington+12)*

Massive, early-type galaxies:

- *Insitu star formation* dominant at higher z
- *Late-time accretion* of stellar material at large radii in collisionless minor mergers (e.g. Villumsen+83, HOD: *Moster+13, Behroozi+12*, SAMs: *DeLucia+07*, Guo&White08, *Hirschmann+12,* Sims: *Oser+10, Lackner+12, Gabor+12, Hirschmann+13*)
  - "Minor merger picture" successful in predicting a strong size evolution, increasing Sersic index and higher DM fractions (e.g. Naab+09, Oser+12, Hilz+12, Hilz+13)
  - Stellar systems accreted onto already formed early-type galaxies may affect metallicity gradient? *To be tested!*

Theoretical work

Metallicity gradients can emerge from

Late-type, disk galaxies galaxies:

- *Insitu star formation* due to continuous infall of metal-poor gas onto the disk, which can be turned into metal-poor stars, inside-out growth *(e.g. Steinmetz&Mueller+94, Chiappini+01, Pilkington+12)*

Massive, early-type galaxies:

- *Insitu star formation* dominant at higher z
- *Late-time accretion* of stellar material at large radii in collisionless minor mergers (e.g. Villumsen+83, HOD: *Moster+13, Behroozi+12*, SAMs: *DeLucia+07*, Guo&White08, *Hirschmann+12*, Sims: *Oser+10, Lackner+12, Gabor+12, Hirschmann+13*)
  - "Minor merger picture" successful in predicting a strong size evolution, increasing Sersic index and higher DM fractions (e.g. Naab+09, Oser+12, Hilz+12, Hilz+13)
  - Stellar systems accreted onto already formed early-type galaxies may affect metallicity gradient? *To be tested!*

Use high-resolution cosmological zoom simulations to understand the origin of observed gradients of massive gal's:

Can we see an effect of the stellar accretion in minor mergers?

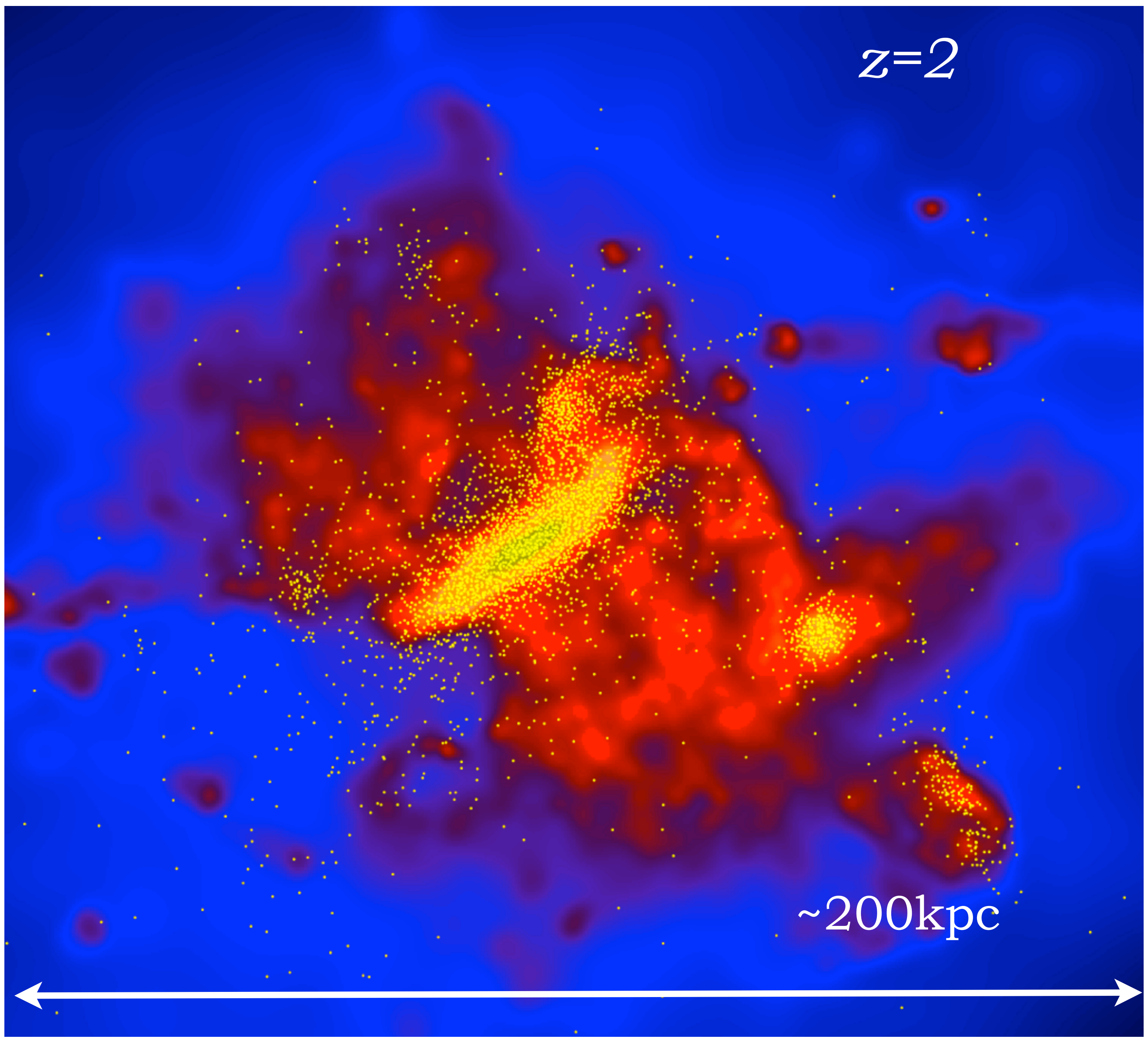
What is the differential impact of environment and feedback?

Can a comparison with observations help to constrain uncertain models for feedback processes?

Model for stellar-driven winds

Impact of stellar-driven galactic outflows on massive galaxies (>2e11 $M_\odot$)

in cosmological zoom simulations of massive galaxies
with $x_{spatial}$= 400pc, $m_{dm} = 2.5*10^7 M_\odot$ & $m_{gas} = 4.2*10^6 M_\odot$



Hirschmann+13/15

Empirically motivated model for momentum driven winds

(Oppenheimer & Dave, 2006/08, Murray+05, Martin'05)

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

$$\dot{M}_{\rm wind} \times v_{\rm wind} \propto \dot{M}_{\rm stellar}$$

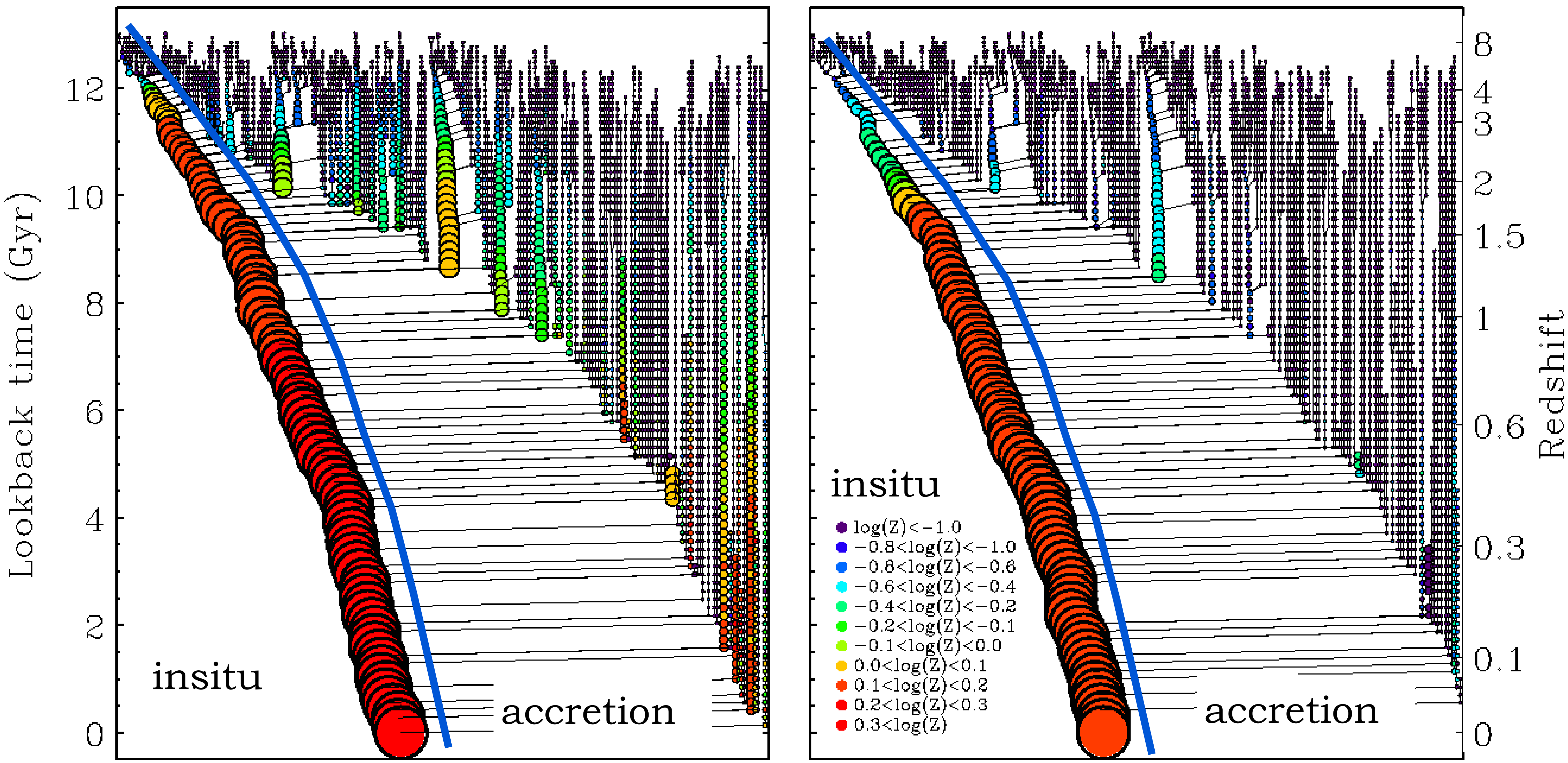
$$\eta \propto \frac{M_{\rm wind}}{M_{\rm stellar}} \propto \frac{1}{v_{\rm wind}} \propto \frac{1}{\sigma}$$

Gas density of a $3*10^{11}$ $M_\odot$ galaxy
$x_{spatial}$ = 200pc,
$m_{gas} = 5.2*10^5 M_\odot$

Stellar accretion history

of massive galaxies (>2e11 $M_\odot$)

No galactic, stellar-driven winds — *With galactic outflows*

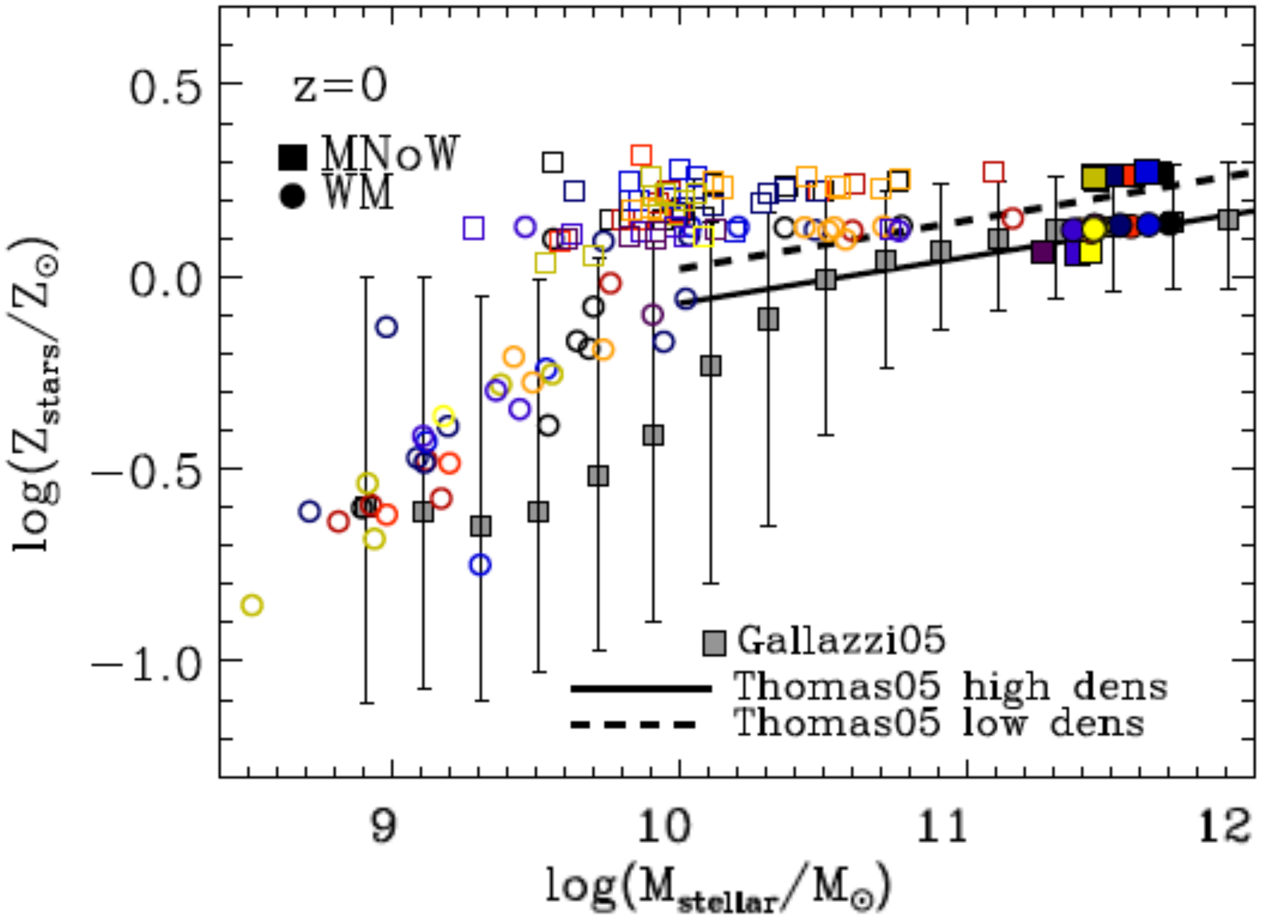


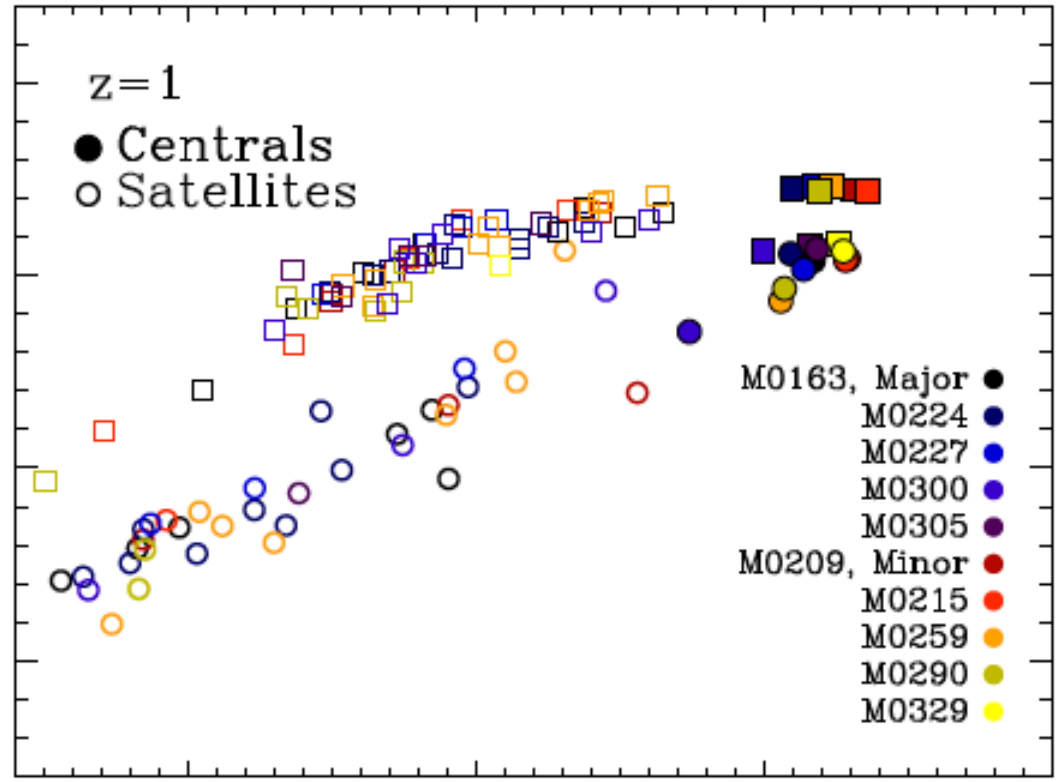
Hirschmann+13/15

They assemble *through (minor) mergers with smaller galaxies* which are *strongly affected by stellar feedback*

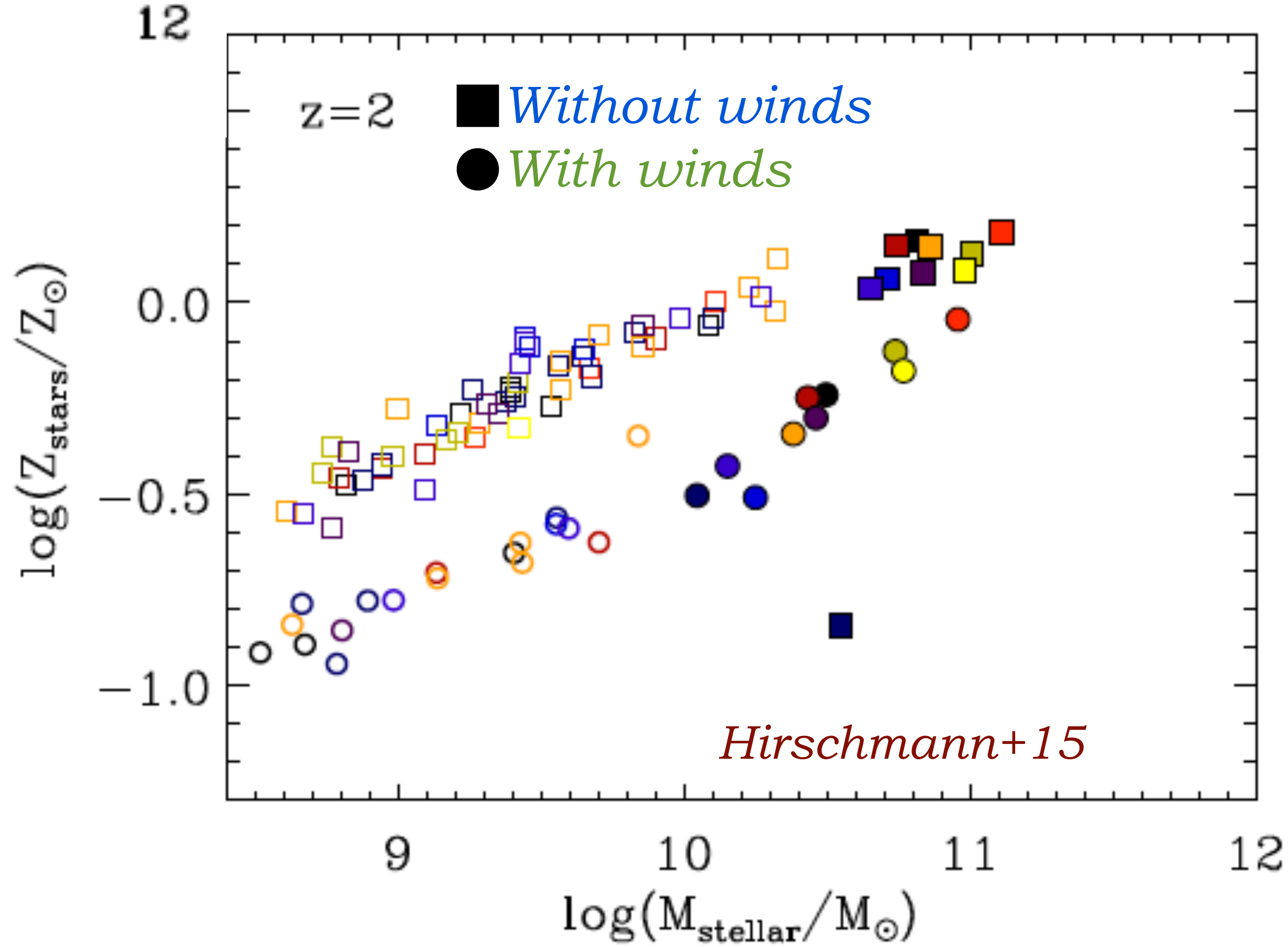
- delayed star formation
- smaller stellar masses
- lower metallicity
- smaller amount of accreted stellar mass

Stellar mass-metallicity relation



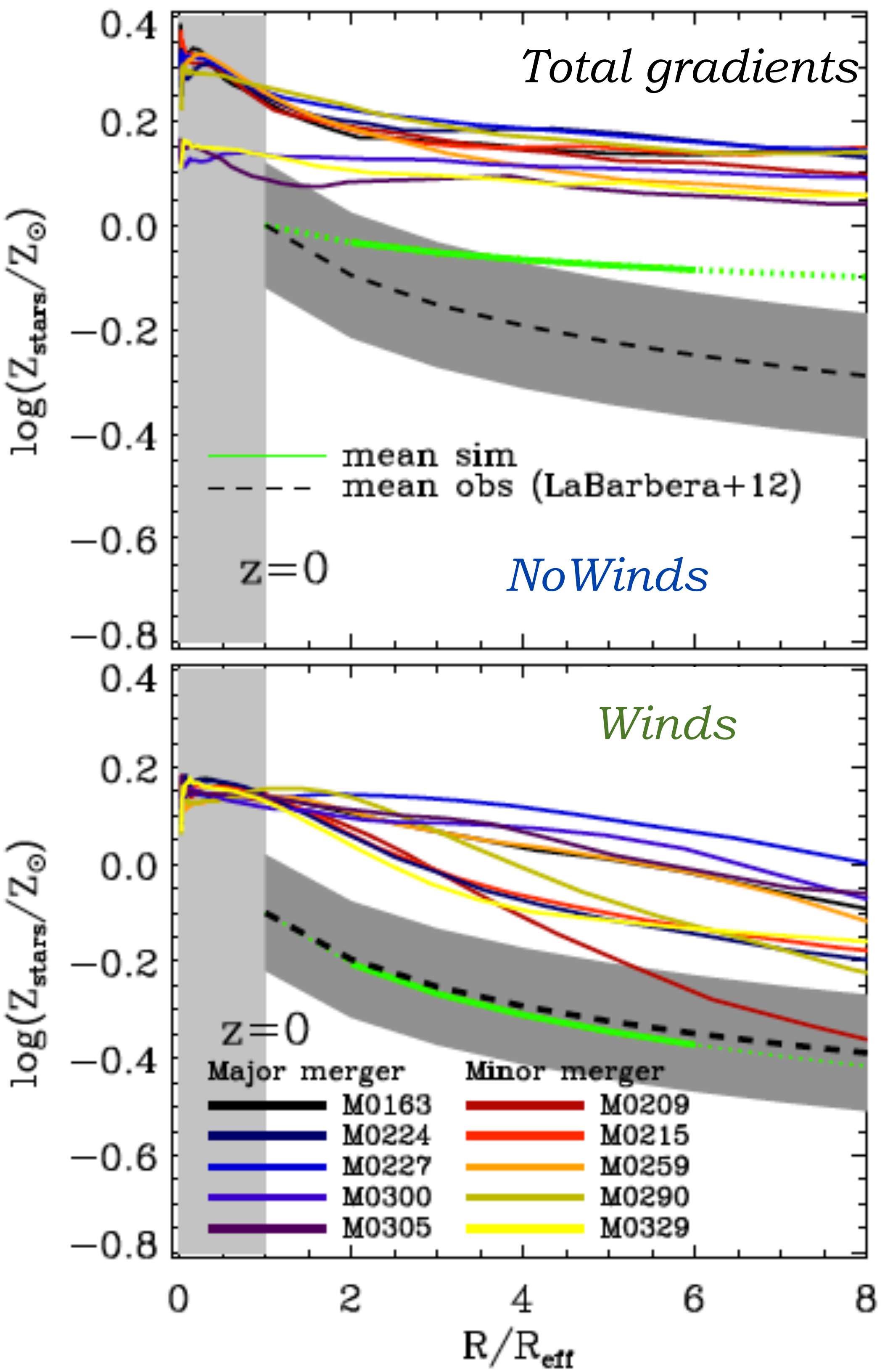


- Galactic outflows delays metal enrichment in all galaxies
- Low mass galaxies in stellar feedback models have lower stellar metallicities
- *Good agreement with observations*



Stellar metallicity profiles

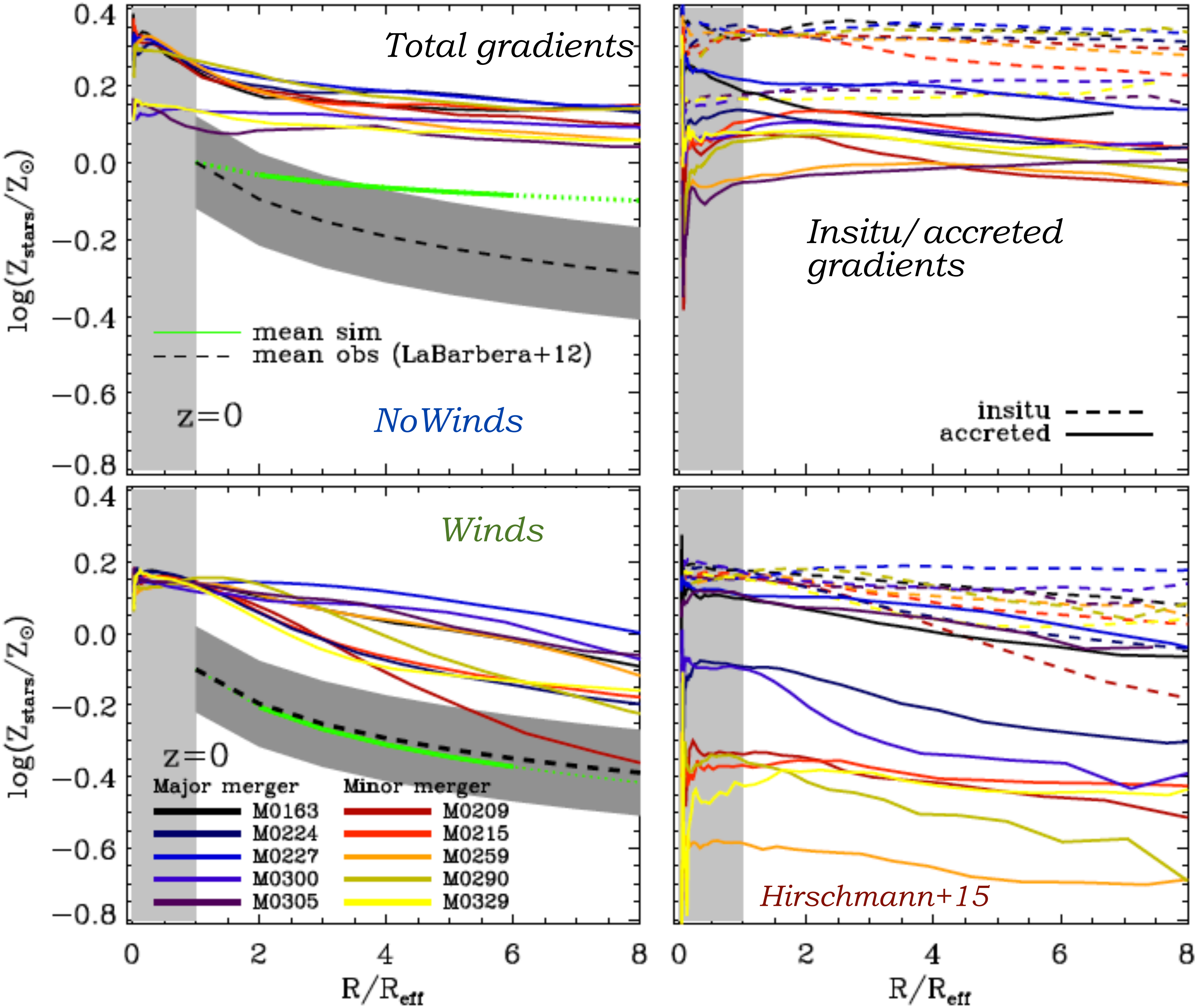
of massive galaxies (>2e11 $M_\odot$)



- Steeper metal gradients in the wind model (-0.3 dex/dex) due to accretion of more metal-poor stars
- Good agreement with observations for wind model
  (e.g. LaBarbera+12, Pastorello +14 etc)
- *Strong outflows necessary for steepening outer metallicity grads*
- Different behaviour for major/minor mergers
  (see e.g. Villumsen+83, Kobayashi+04)
- *Minor mergers steepen the gradients*

Stellar metallicity profiles

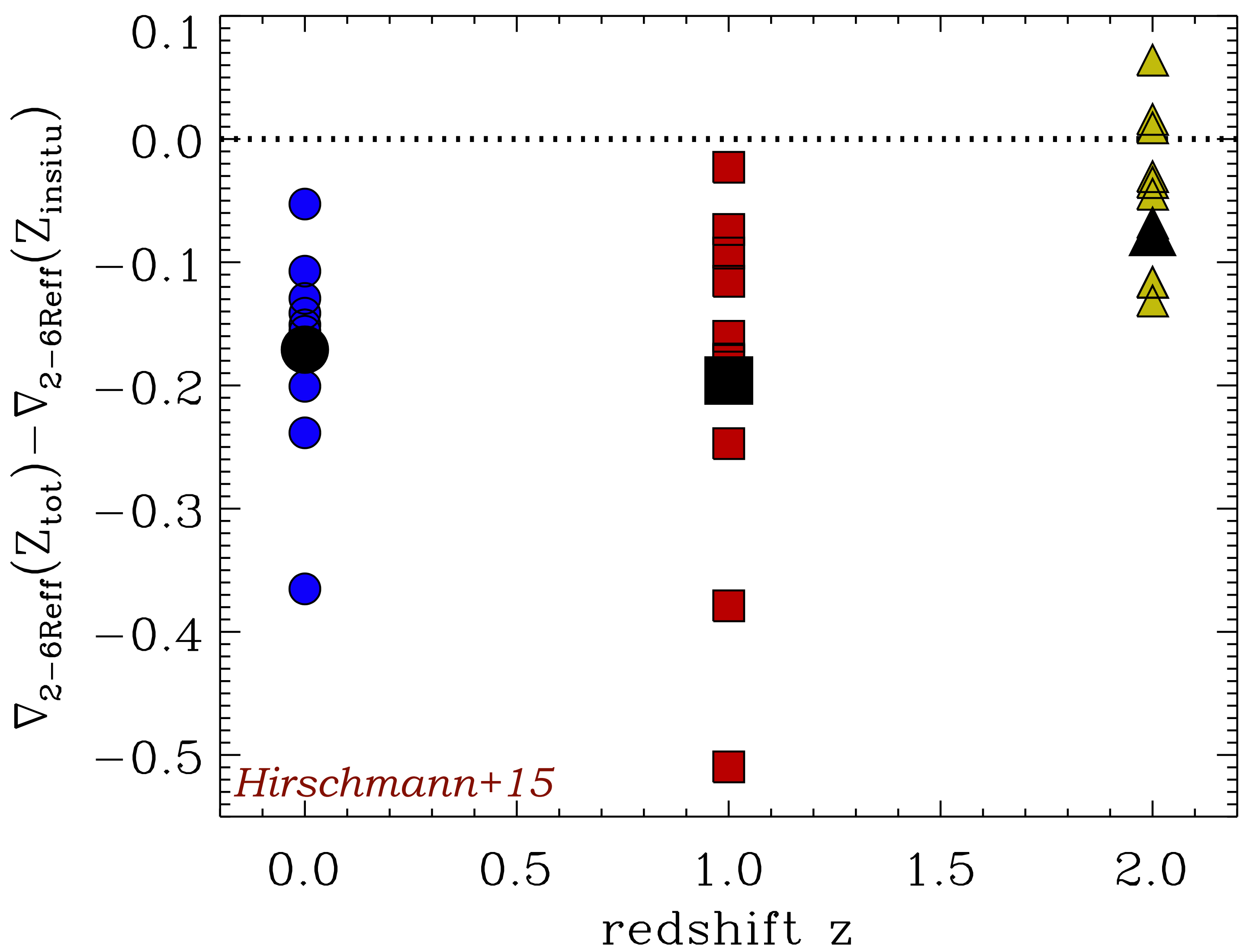
of massive galaxies (>2e11 $M_\odot$)



- Steeper metal gradients in the wind model (-0.3 dex/dex) due to accretion of more metal-poor stars
- Good agreement with observations for wind model
  (e.g. LaBarbera+12, Pastorello +14 etc)
- *Strong outflows necessary for steepening outer metallicity grads*
- Different behaviour for major/minor mergers
  (see e.g. Villumsen+83, Kobayashi+04)
- *Minor mergers steepen the gradients*

The role of stellar accretion

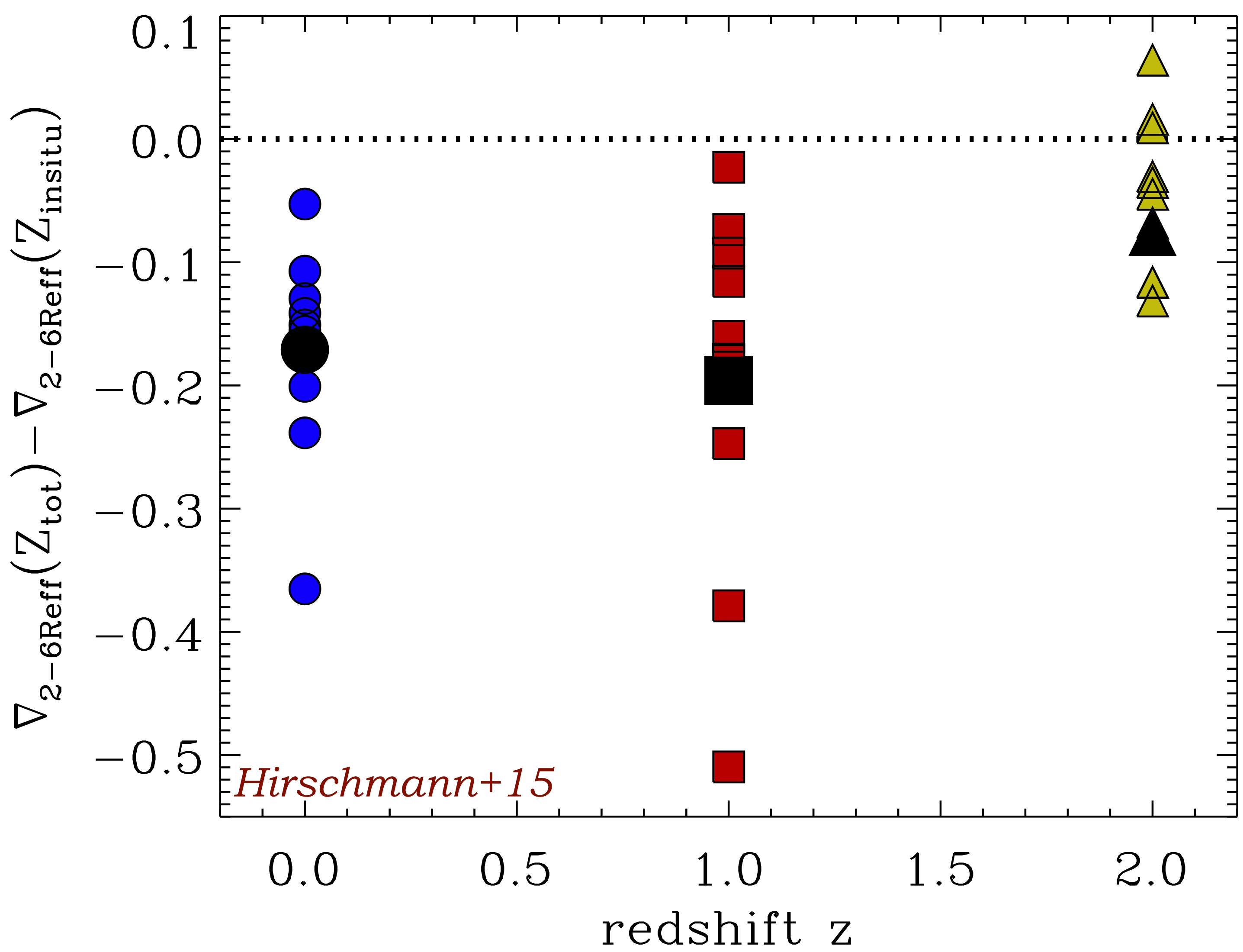
…for steepening stellar metallicity profiles in the stellar-driven feedback model



- Existing insitu gradients are *steepened by -0.2 dex/dex at z<1* through accretion of metal-poor stars
- *The same applies to present-day color gradients* which are mostly influenced by metallicity
- Towards higher redshifts, stellar accretion less significant due to stronger gas-dissipative processes

The role of stellar accretion

...for steepening stellar metallicity profiles in the stellar-driven feedback model

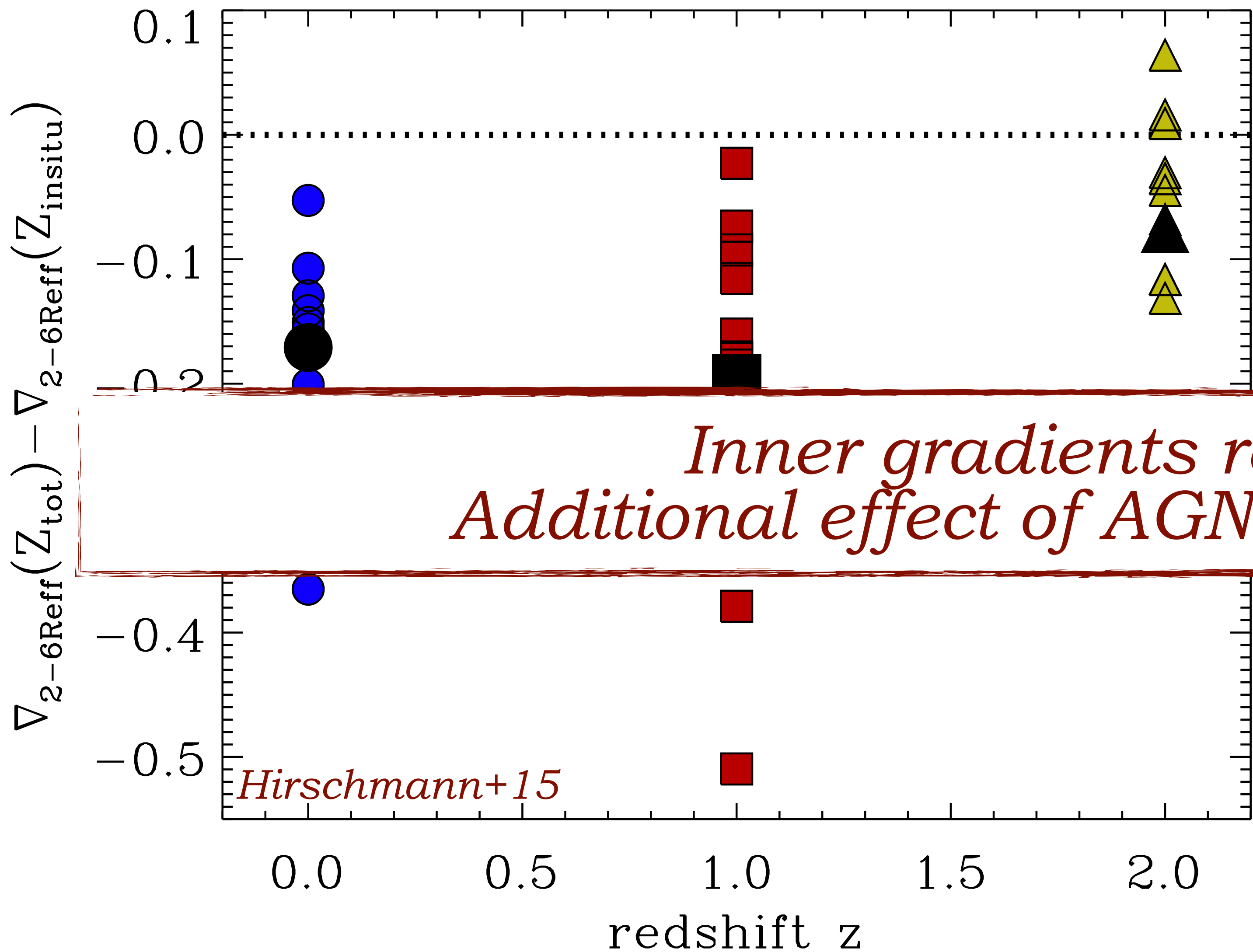


- Existing insitu gradients are *steepened by -0.2 dex/dex at z<1* through accretion of metal-poor stars
- *The same applies to present-day color gradients* which are mostly influenced by metallicity
- Towards higher redshifts, stellar accretion less significant due to stronger gas-dissipative processes

Superposition of internal and environmental effects are shaping the stellar population (metallicity & color) gradients at large radii

The role of stellar accretion

…for steepening stellar metallicity profiles in the stellar-driven feedback model



- Existing insitu gradients are *steepened by -0.2 dex/dex at z<1* through accretion of metal-poor stars
- *The same applies to* … metallicity
- Towards higher redshifts, stellar accretion less significant due to stronger gas-dissipative processes

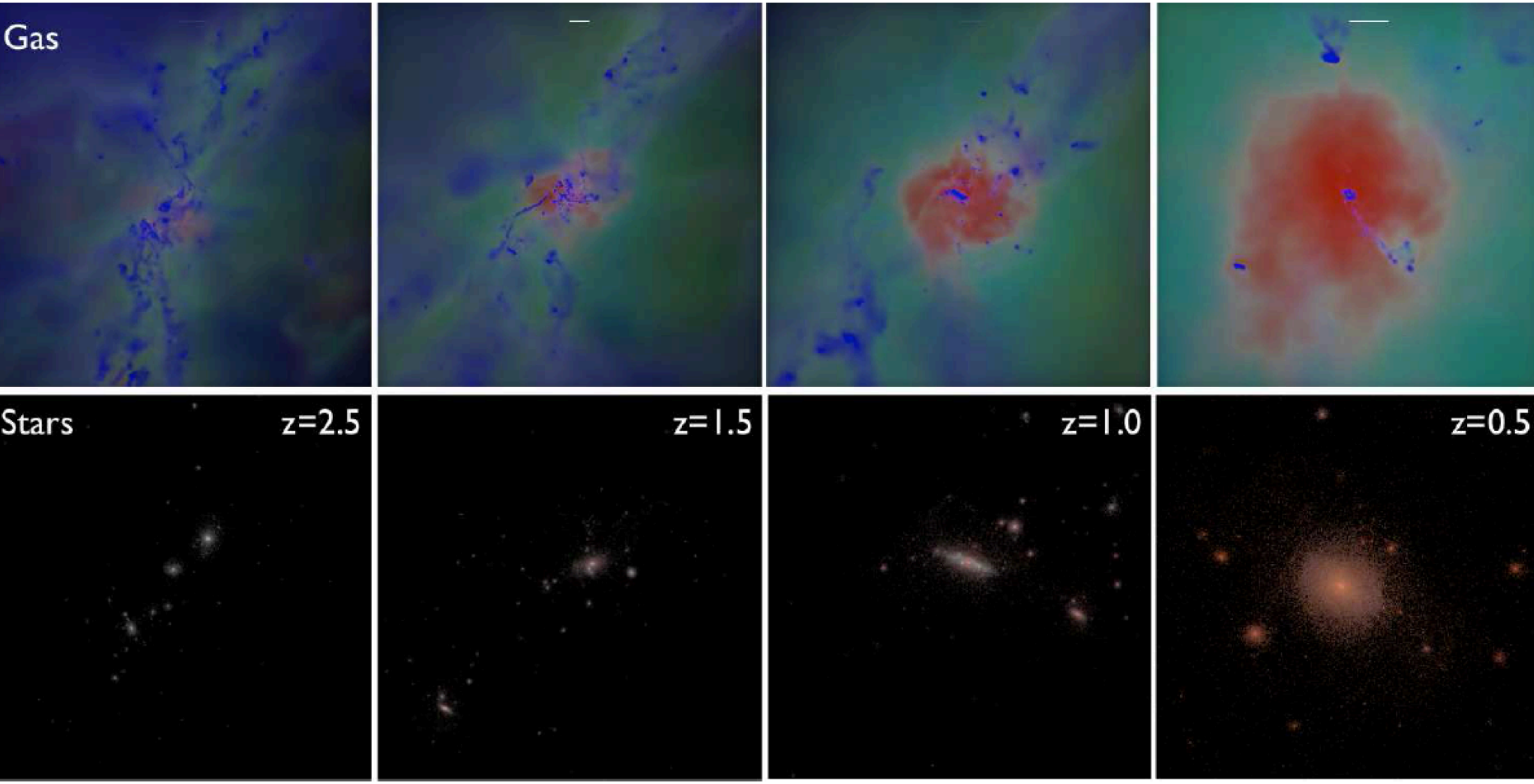
Inner gradients realistic?
Additional effect of AGN-driven winds?

Superposition of internal and environmental effects are shaping the stellar population (metallicity & color) gradients at large radii

Model for AGN-driven winds

preliminary

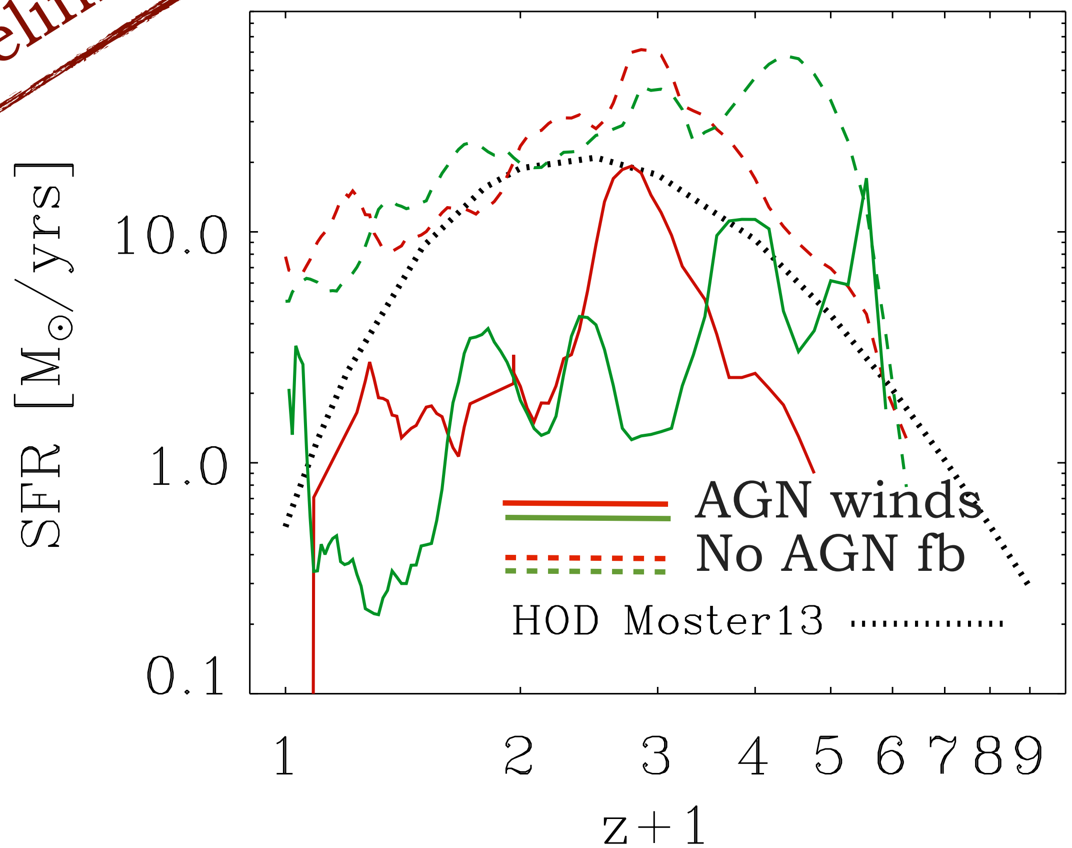
Mass, momentum and energy input (conservation) into the surrounding gas motivated by observations of broad absorption line winds,
v_w = 10,000km/s, $\epsilon_f = 0.005$
Ostriker+10, Choi+13/14



So far, two zooms of massive halos with M_{halo}~1e13 $M_\odot$ ($x_{spatial}$ = 100pc, m_{gas}=6.6e4 $M_\odot$)

Stellar metallicity & age profiles

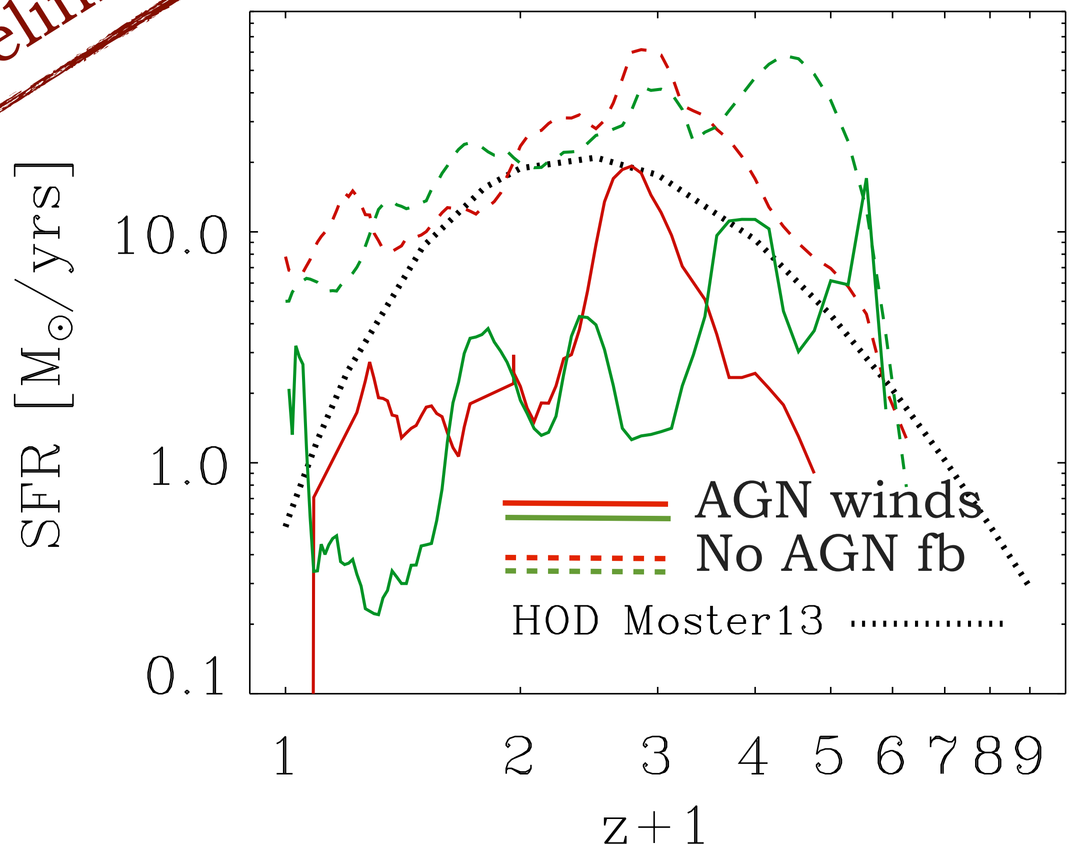
preliminary



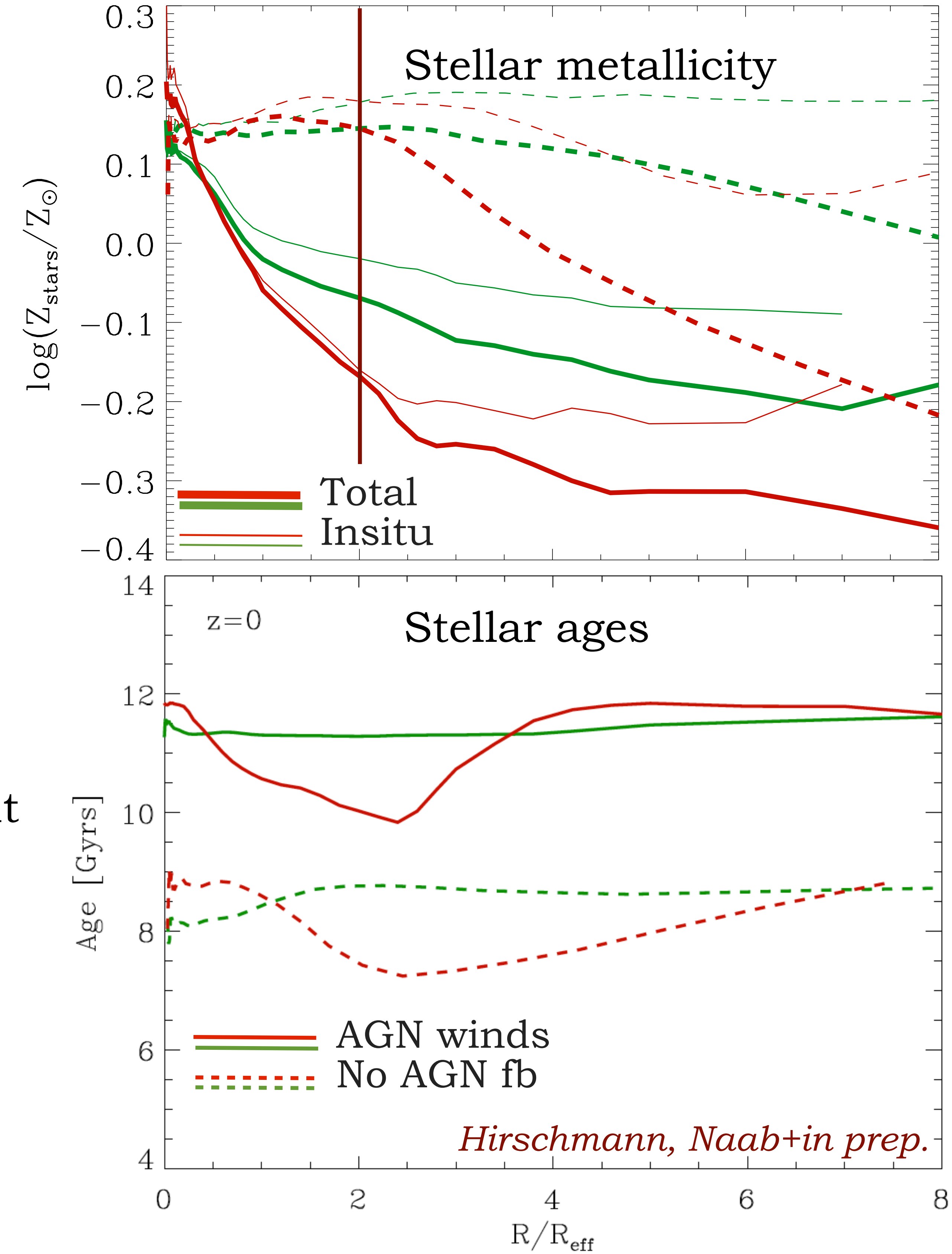
- By up to one order of magnitude reduced SFRs
- AGN winds can affect stellar, stellar metallicities and ages out to 8 R_{eff}
- Older stellar populations
- Steeper inner gradients (-0.1- -0.2 dex/dex at $<1R_{eff}$) due to inside-out growth & AGN fb
- Stellar accretion still steepens the outer metallicity gradients

Stellar metallicity & age profiles

preliminary



- By up to one order of magnitude reduced SFRs
- AGN winds can affect stellar, stellar metallicities and ages out to 8 R_{eff}
- Older stellar populations
- Steeper inner gradients (-0.1--0.2 dex/dex at $<1R_{eff}$) due to inside-out growth & AGN fb
- Stellar accretion still steepens the outer metallicity gradients



Conclusions

Energetic phenomena are essential for forming realistic galaxies with respect to stellar population profiles

- Stellar feedback can strongly influence massive galaxies wrt integrated and spatially resolved the stellar populations at large radii (> 2 R_{eff})
- AGN feedback affects stellar populations in massive galaxies, particularly strongly the central region within 2 R_{eff}
- Superimposed effect of environment, in form of mergers, at large radii, "minor merger picture" confirmed
- Individual merger history responsible for the diversity in the gradients: flattening by major mergers (in agreement with Kobayashi+04), but steepening by minor mergers

Conclusions

Energetic phenomena are essential for forming realistic galaxies with respect to stellar population profiles

- Stellar feedback can strongly influence massive galaxies wrt integrated and spatially resolved the stellar populations at large radii (> 2 R_{eff})
- AGN feedback affects stellar populations in massive galaxies, particularly strongly the central region within 2 R_{eff}
- Superimposed effect of environment, in form of mergers, at large radii, "minor merger picture" confirmed
  - Individual merger history responsible for the diversity in the gradients: flattening by major mergers (in agreement with Kobayashi+04), but steepening by minor mergers

Future:

- *Construction of a statistically complete sample of cosmological zoom simulations of massive galaxies (>3e11 $M_\odot$) with unprecedented high resolution*
- *Including further AGN feedback mechanisms (radiative-X-ray)*
- *Gas metallicity gradients, creating synthetic emission line maps by coupling zooms to new-generation stellar evolution models (w. S. Charlot)*