Astro@TS 2019

June 24th

New analytic solutions for galaxy evolution:

Gas, Stars, Metals and Dust in local ETGs and in their high-z Starforming Progenitors

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Overview

I. INTRODUCTION
- ETGs and their high-z starforming progenitors
- Emerging scenarios for galaxy evolution
- How to model galaxy formation and evolution

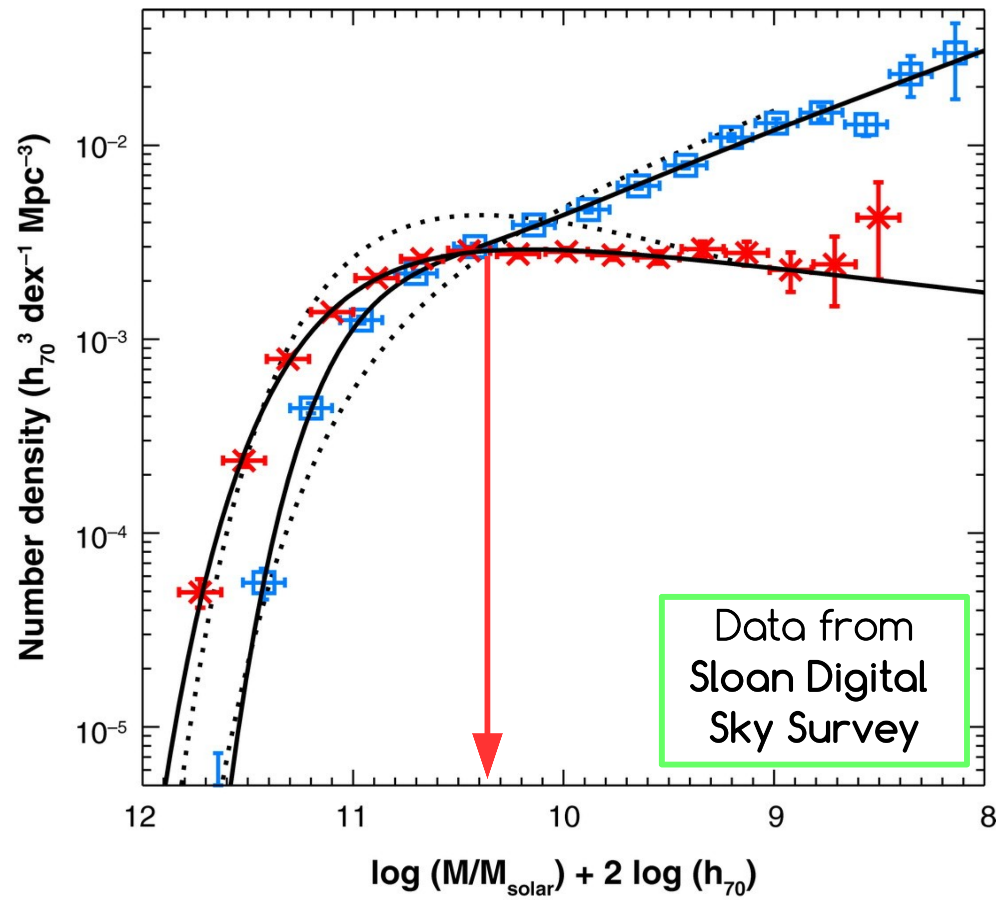
II. THE ANALYTIC MODEL
- Aims and assumptions
- Analytic solutions
- Reproducing the observed statistical relations

III. CONCLUSIONS
- Is this model a good tool to investigate ETG formation and evolution?

ETGs: mass and stellar population

LOCAL GALAXY STELLAR MASS FUNCTIONS

- Prevail in number at $M_{star} \gtrsim 3 \times 10^{10} M_{Sun}$



Renzini A. 2006.
Annu. Rev. Astron. Astrophys. 44:141–92

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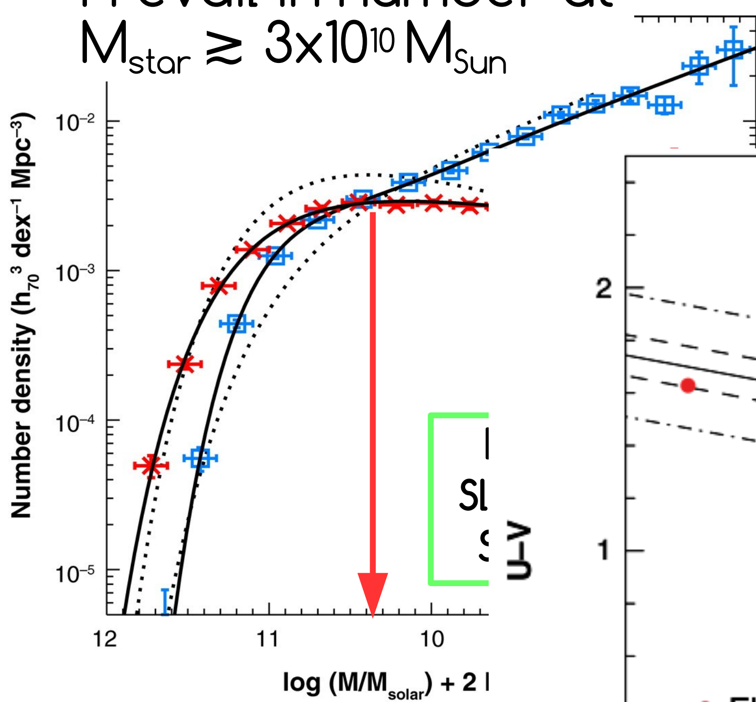

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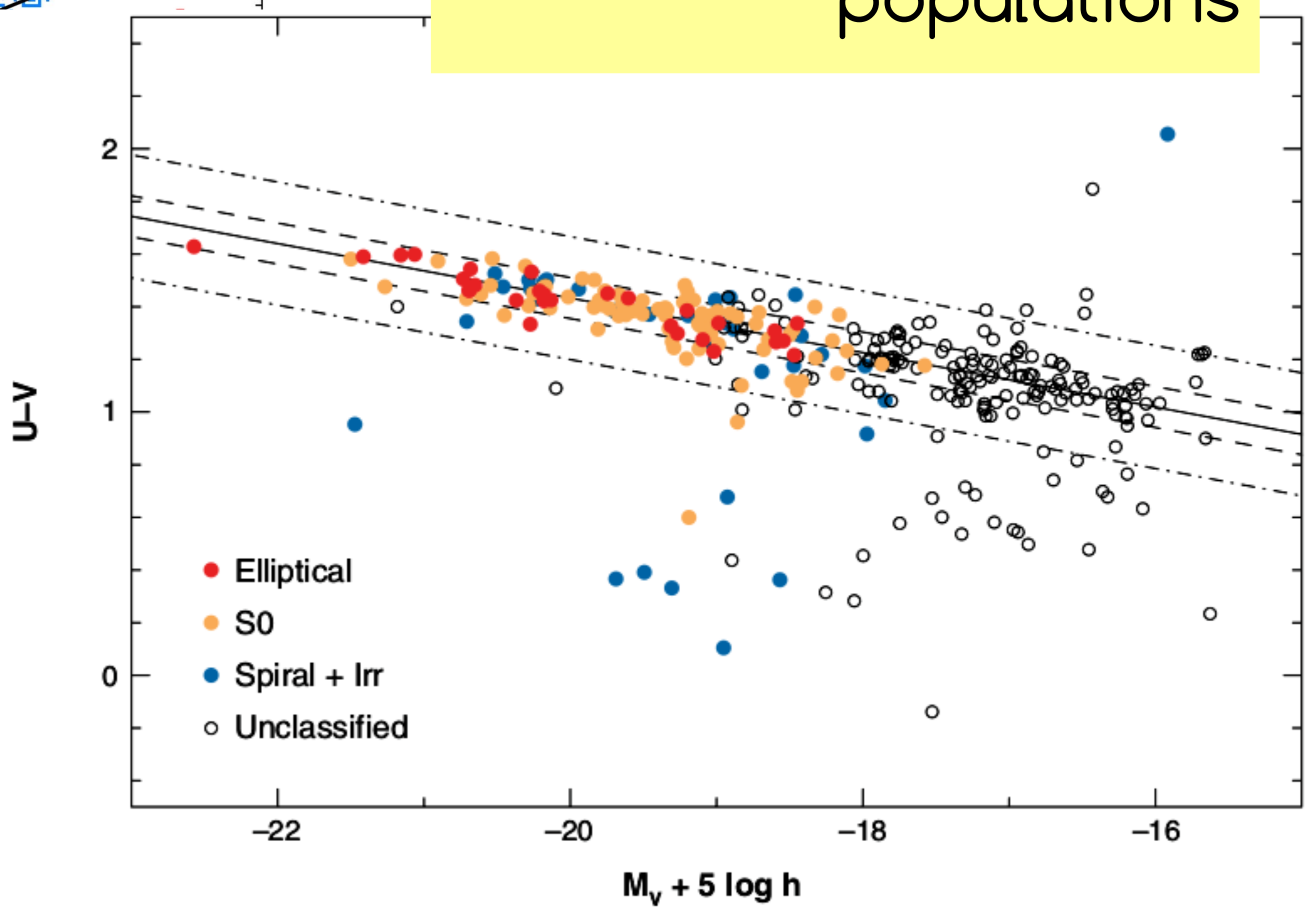
- Homogeneous stellar populations



ETGs:
mass and stellar population

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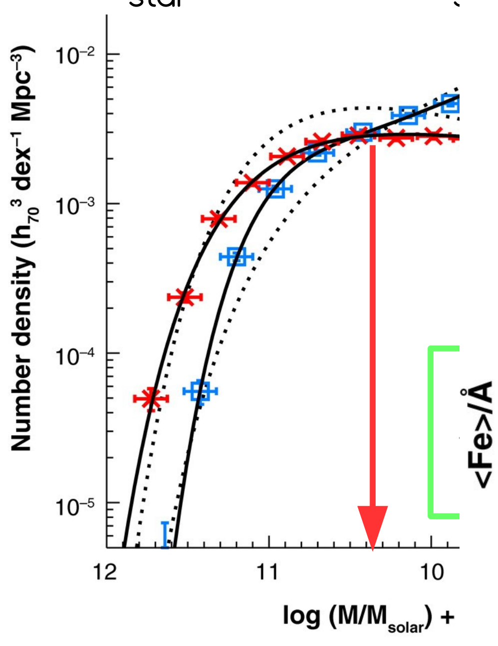

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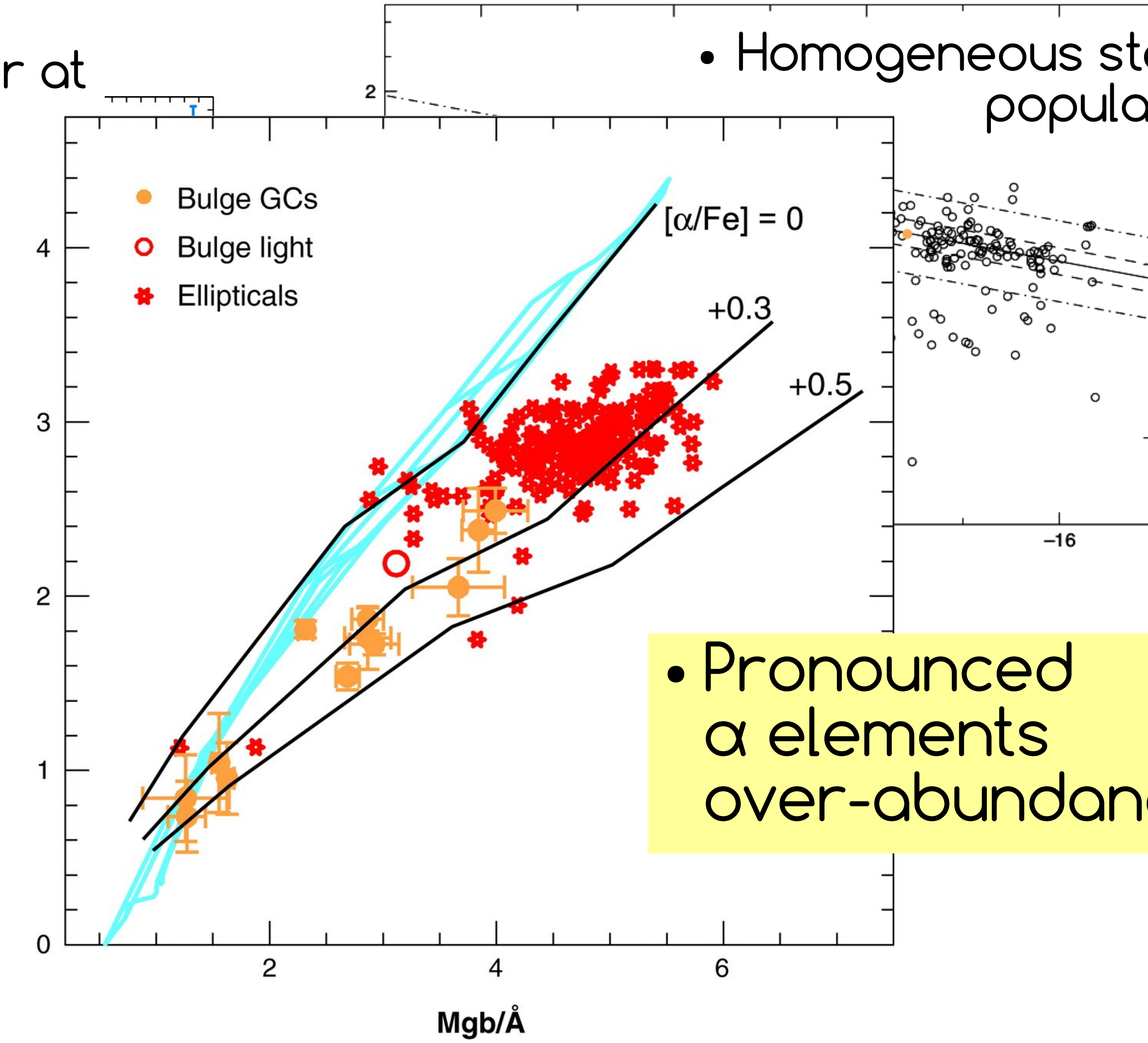

- Pronounced α elements over-abundance

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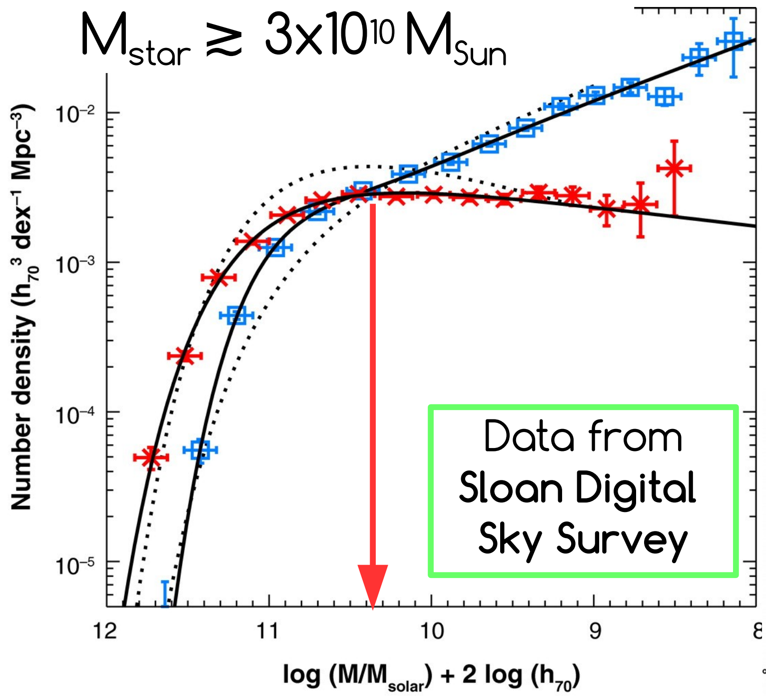

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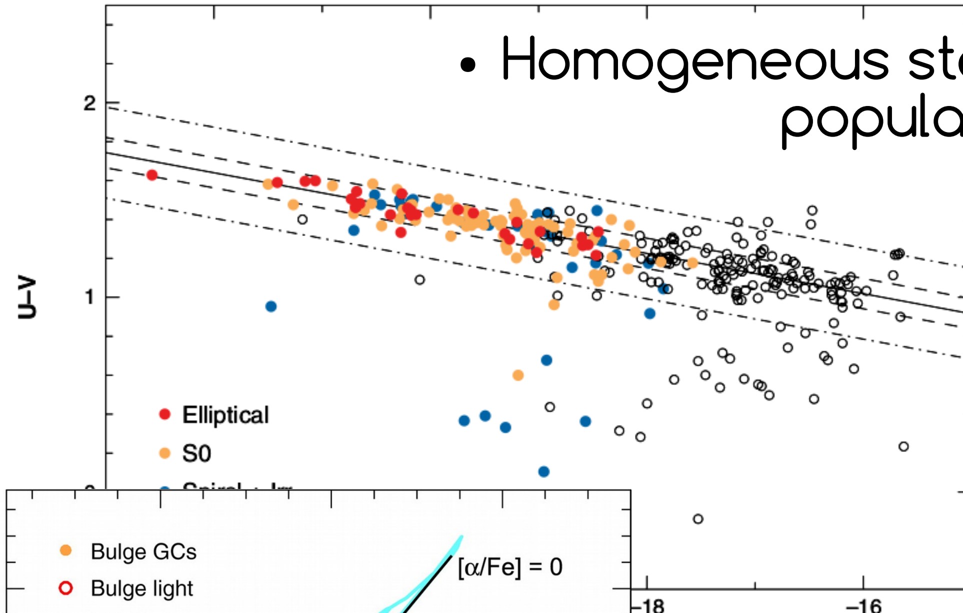

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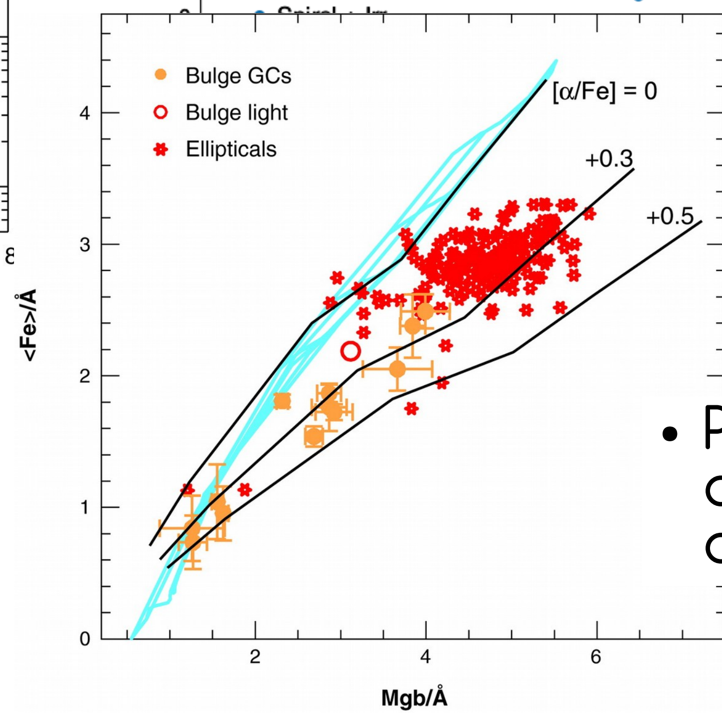
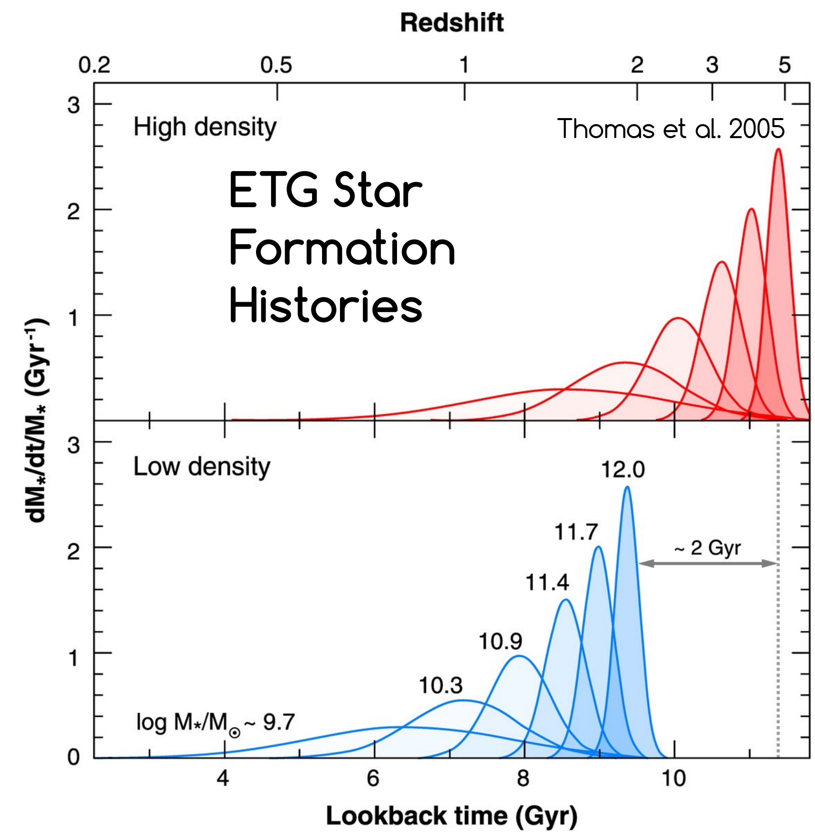


ETGs: downsizing

- The **bulk of stars** formed at $z_{form} > 1$
- **Short** SF timescale
- The **duration** of SF phase **decreases with increasing galaxy mass:**

$M_{star} \gtrsim 10^{11} M_{Sun} \longrightarrow \tau_{burst} < 1$ Gyr



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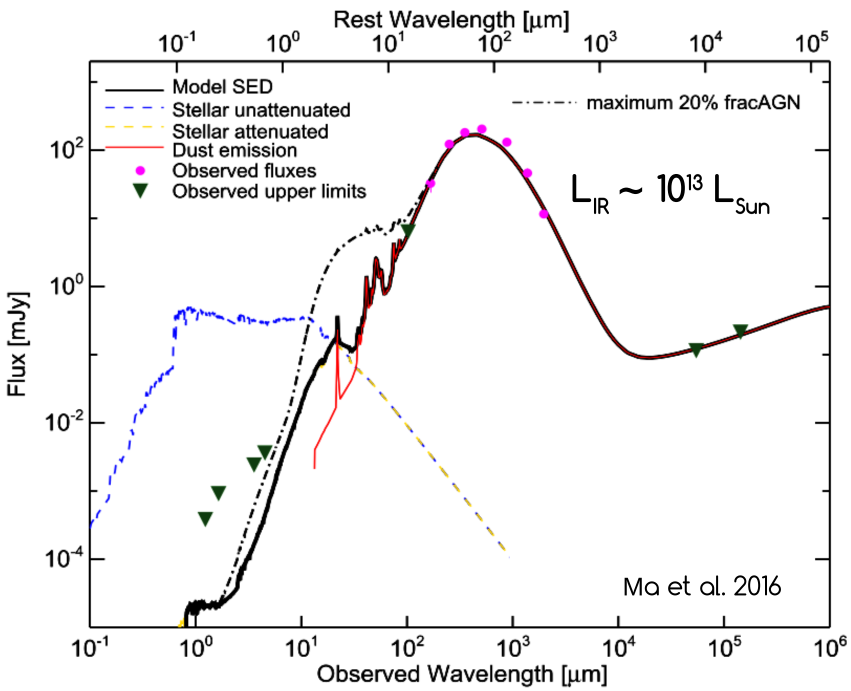
Moving towards high-z Universe: ETG starforming progenitors

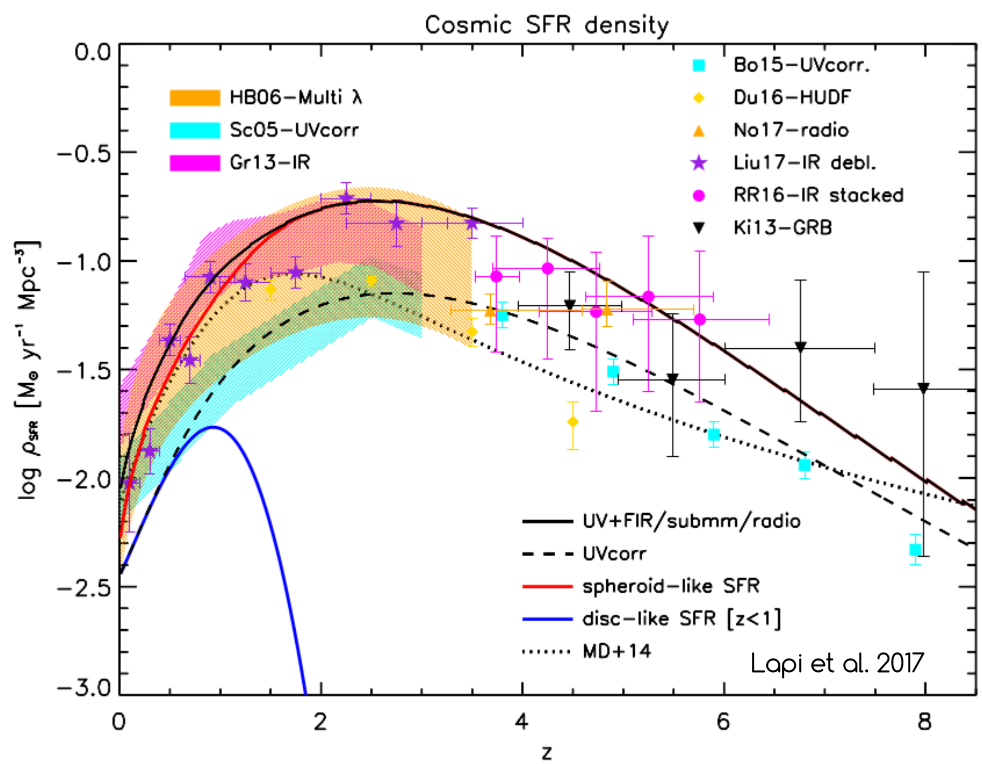
Abundant population of **Dusty Starforming Galaxies** (DSFGs) observed at z≳1



EXAMPLING SED OF A HIGH-z DSFG

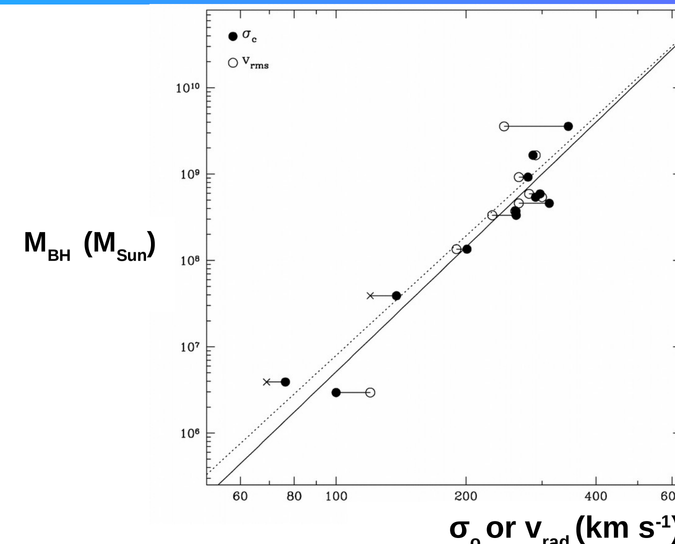
SPT0346-52
z = 5.656
Best-fit SED (black) from CIGALE PYTHON

- Responsible for the bulk of Cosmic SFH
  (e.g., Gruppioni et al. 2015, Dunlop et al. 2017)

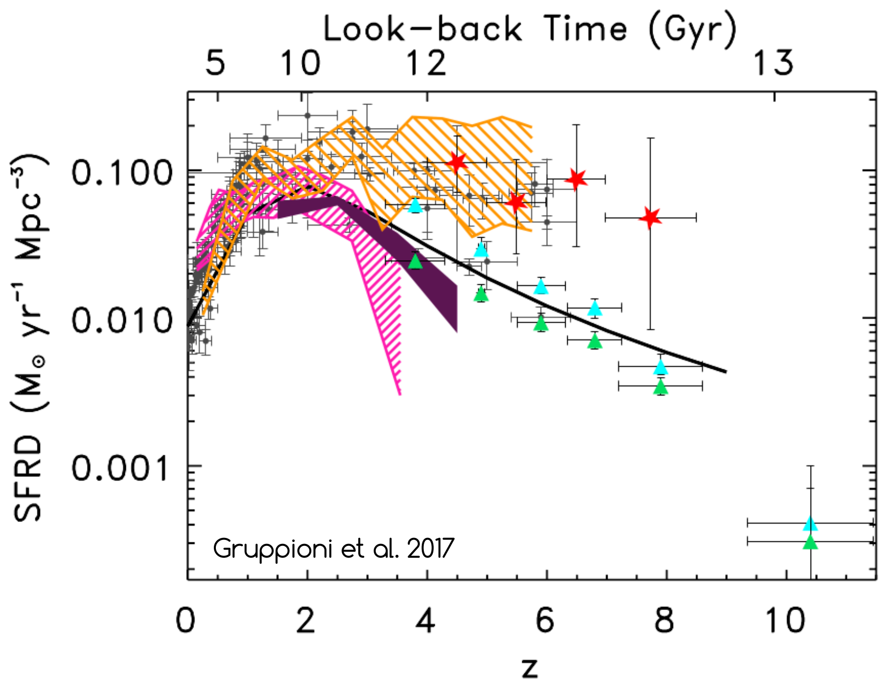


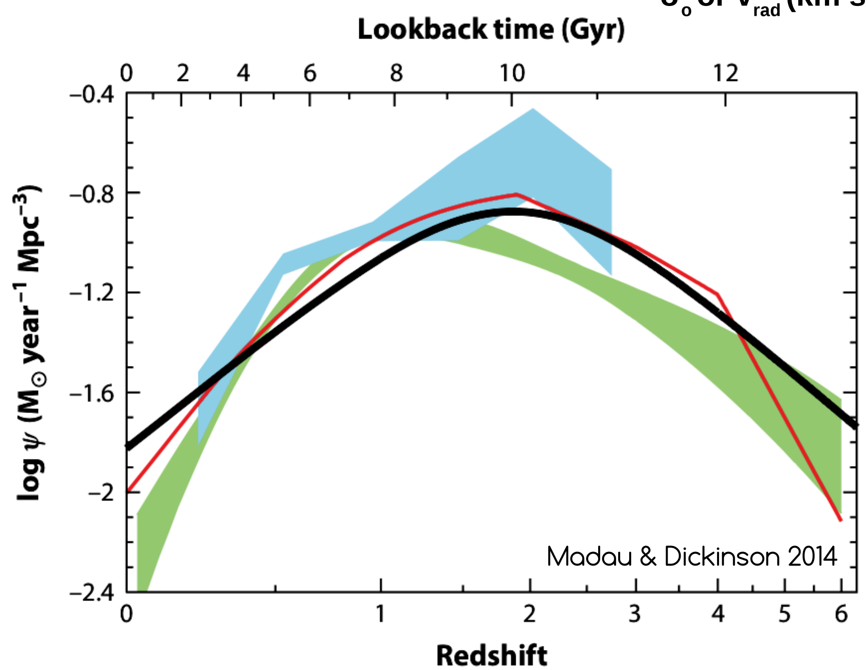
Galaxy – BH coevolution

- **BH mass** is tightly correlated with the **velocity dispersion σ** of stars (Ferrarese & Merritt 2000)



- Central SMBH mass accretion history is linked to the formation and evolution of their hosts → **AGN feedback**

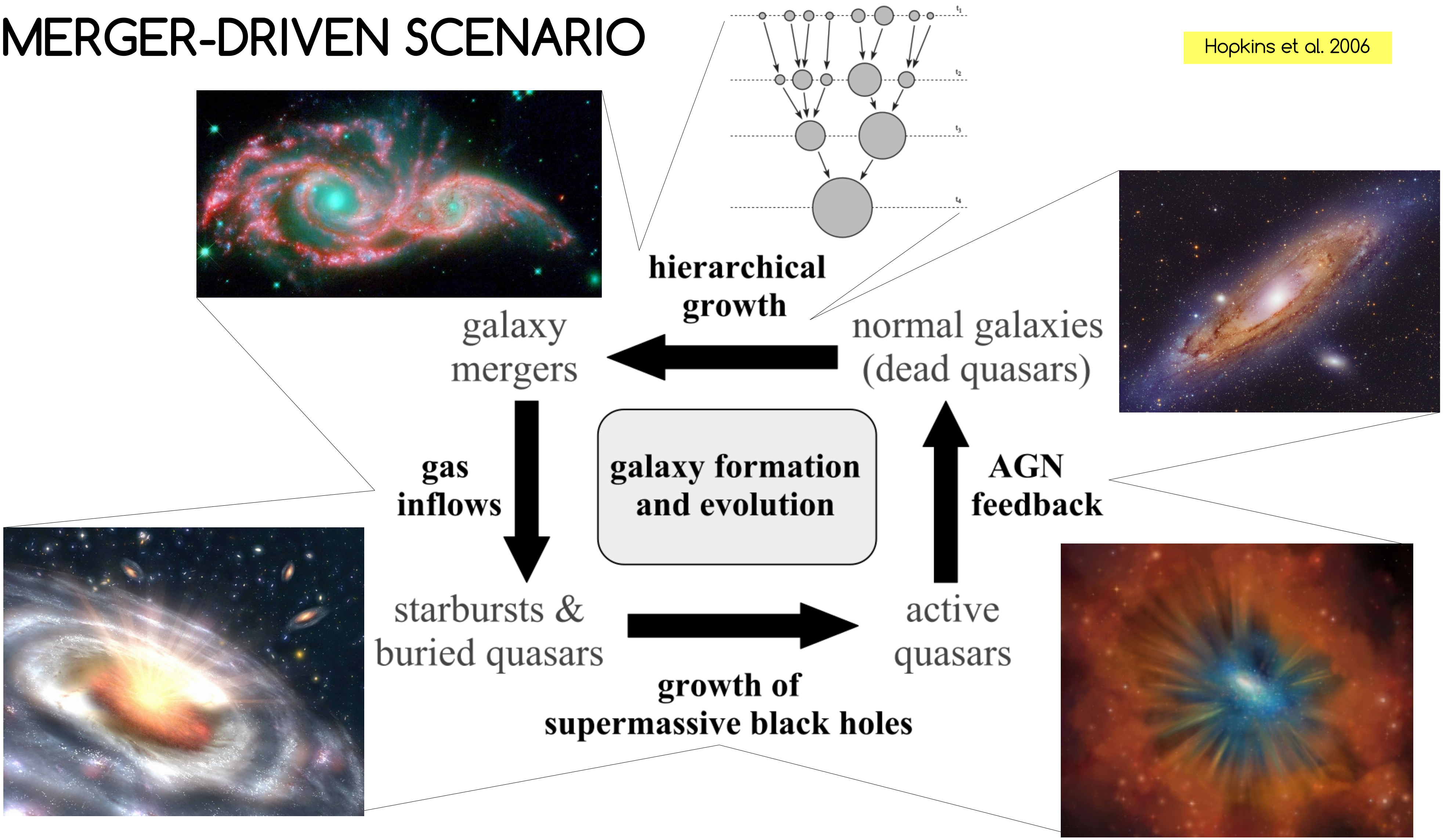




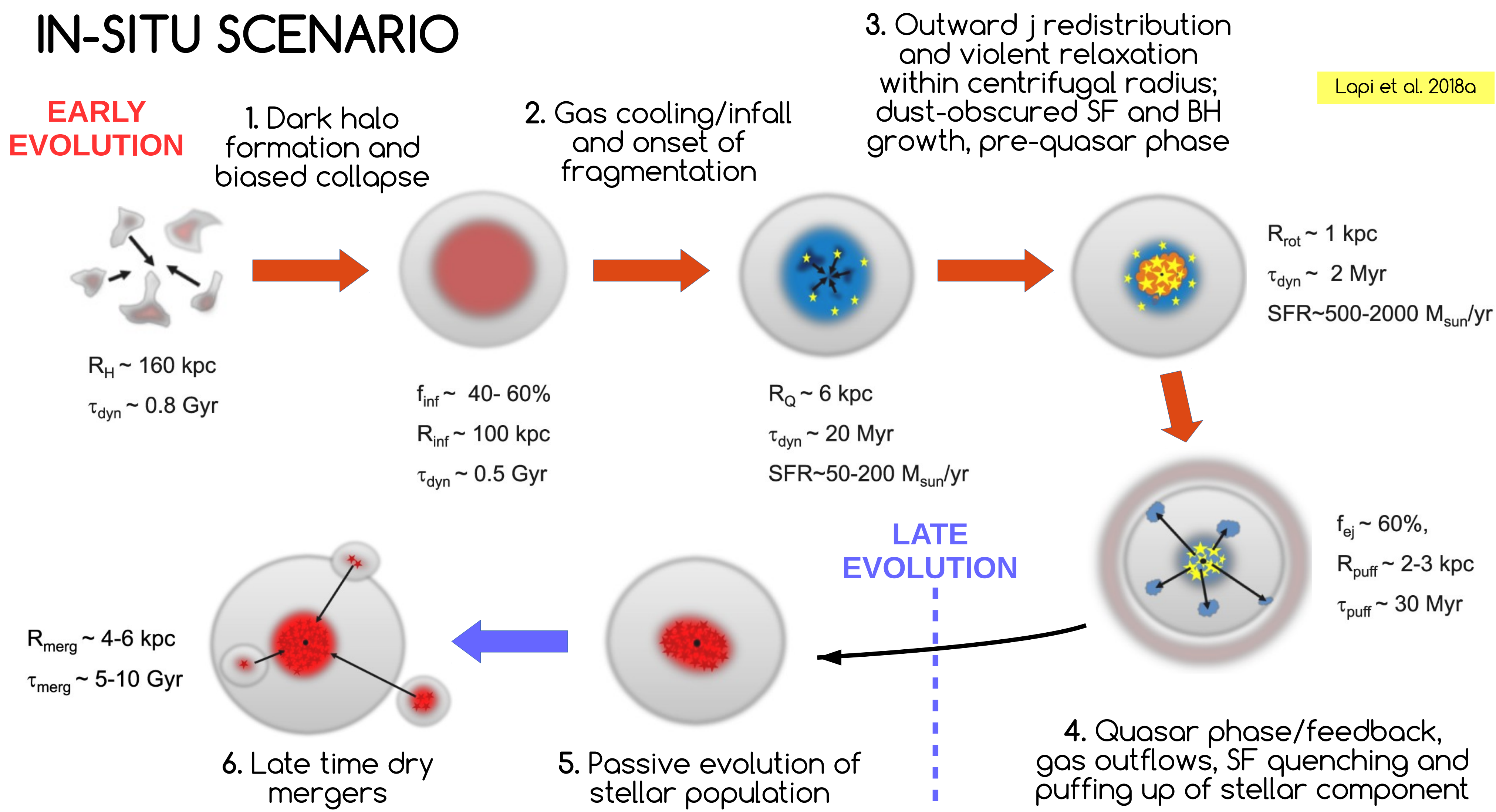
ETGs formation and evolution: two emerging scenarios

MERGER-DRIVEN SCENARIO

Hopkins et al. 2006



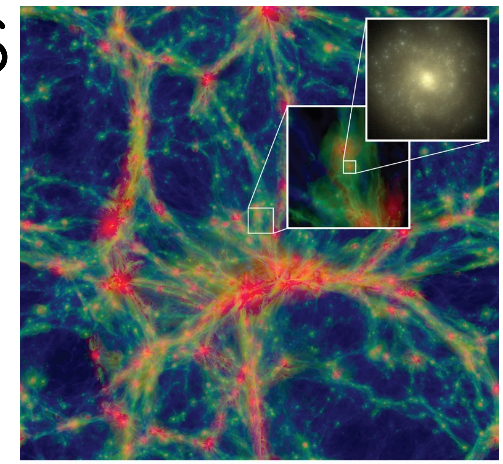
ETGs formation and evolution: two emerging scenarios



Modelling galaxy evolution: different approaches

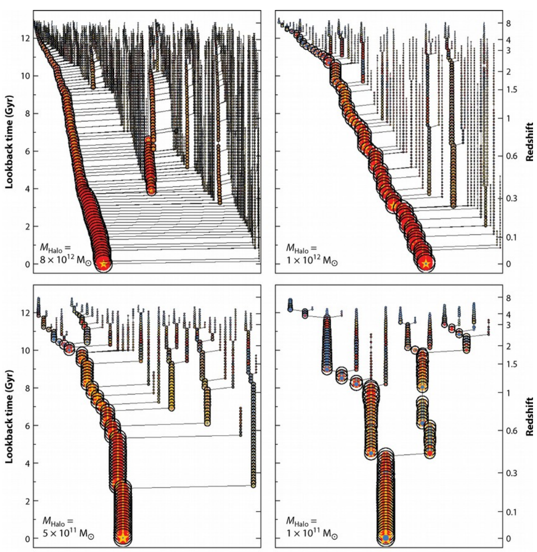
SISSA

1. NUMERICAL HYDRODYNAMIC SIMULATIONS



Somerville RS, Davé R. 2015. Annu. Rev. Astron. Astrophys. 53:51–113

- Direct simulation of galaxies via numerical code ✓
- **Resolution limited** ✗
- **Sub-grid physics??** ✓
- **High** computational cost ✗



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2. SEMI-ANALYTIC MODELS

- **DM merger trees** from N-body simulations ✓
- **Parametric expression** tuned to match a subset of observations to model **baryonic physics** ✗
- **Low** computational cost ✓
- Relative role of the various physical processes under **control** ✓

3. ANALYTIC MODELS

- **Averaged** and **approximate** description of astrophysical processes ✓
- **Deep understanding** of the underlined mechanisms ✓

Analytic model: aims and basic assumptions

AIMS:

- **General** and **self-consistent** description of gas, stars, metal and dust evolution with galaxy proper time τ
- Reproducing the **main statistical relationships** followed by ETG progenitors
- Providing a basis to improve **subgrid physical recipes**

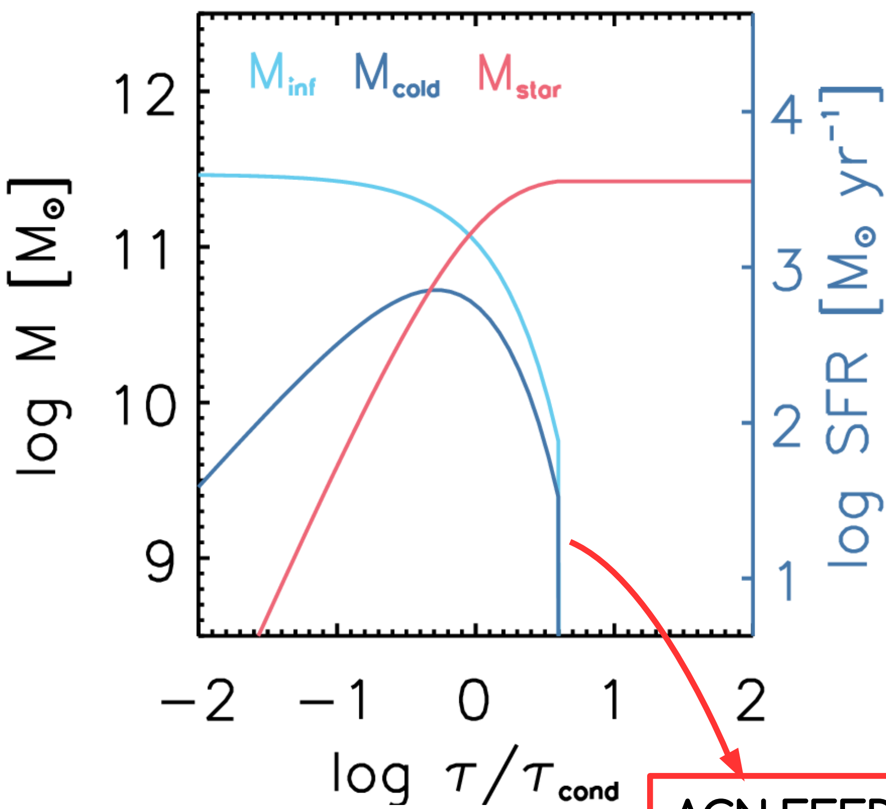
BASIC ASSUMPTIONS:

- Galaxy as an **open, one zone** system
- Istantaneous mixing
- Istantaneous recycling
- $M_{\rm inf}(0) = f_{\rm inf}\, M_{\rm b}\,, \quad M_{\rm cold}(0) = M_\star(0) = 0,$
  $Z_{\rm cold}(0) = Z_\star(0) = 0\,,\; D_{\rm core}(0) = D_{\rm mantle}(0) = 0$

Analytic solutions

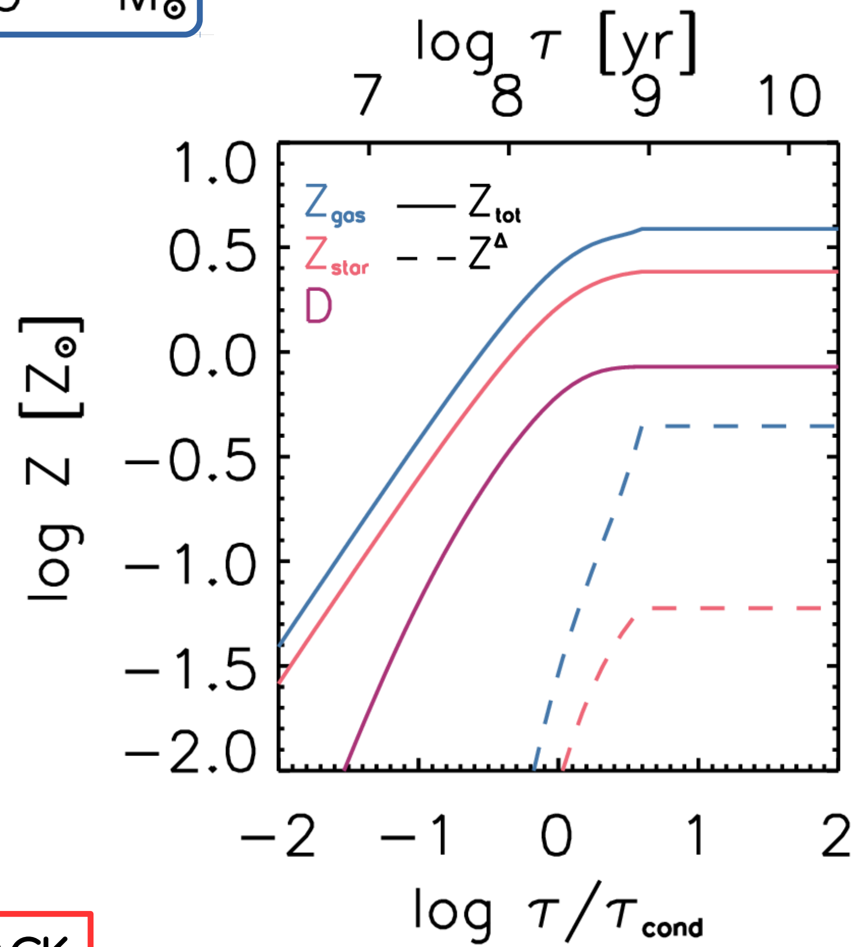
$z_{form} = 3$

$M_H = 10^{12.5}\ M_\odot$



AGN FEEDBACK

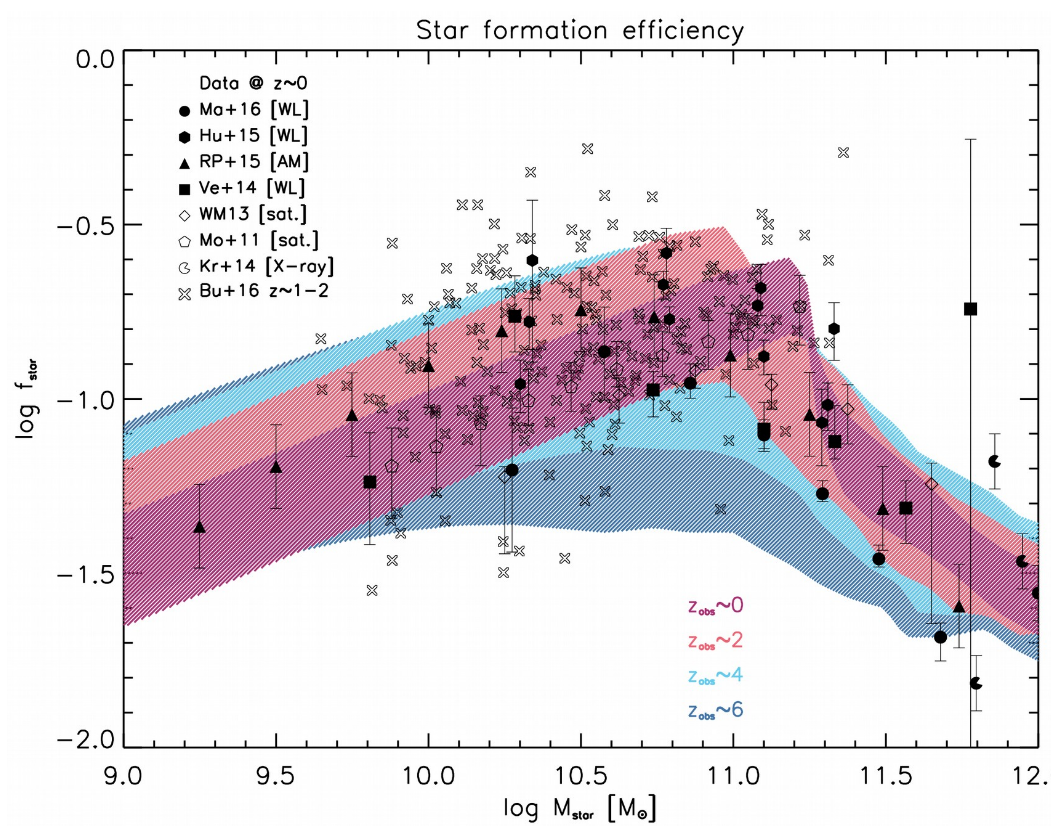
$\tau_{burst} \sim 2\times10^8$ yr



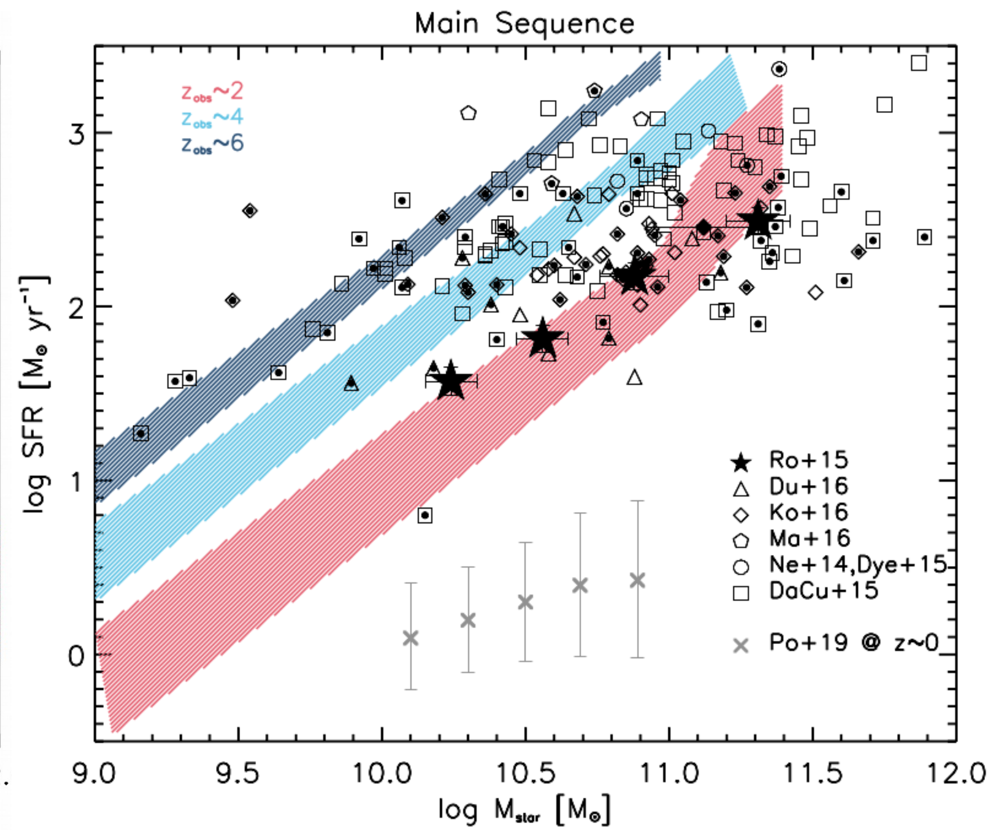
Pantoni et al. 2019 (accepted)

Statistical relations: SF efficiency and galaxy MS

STAR FORMATION EFFICIENCY



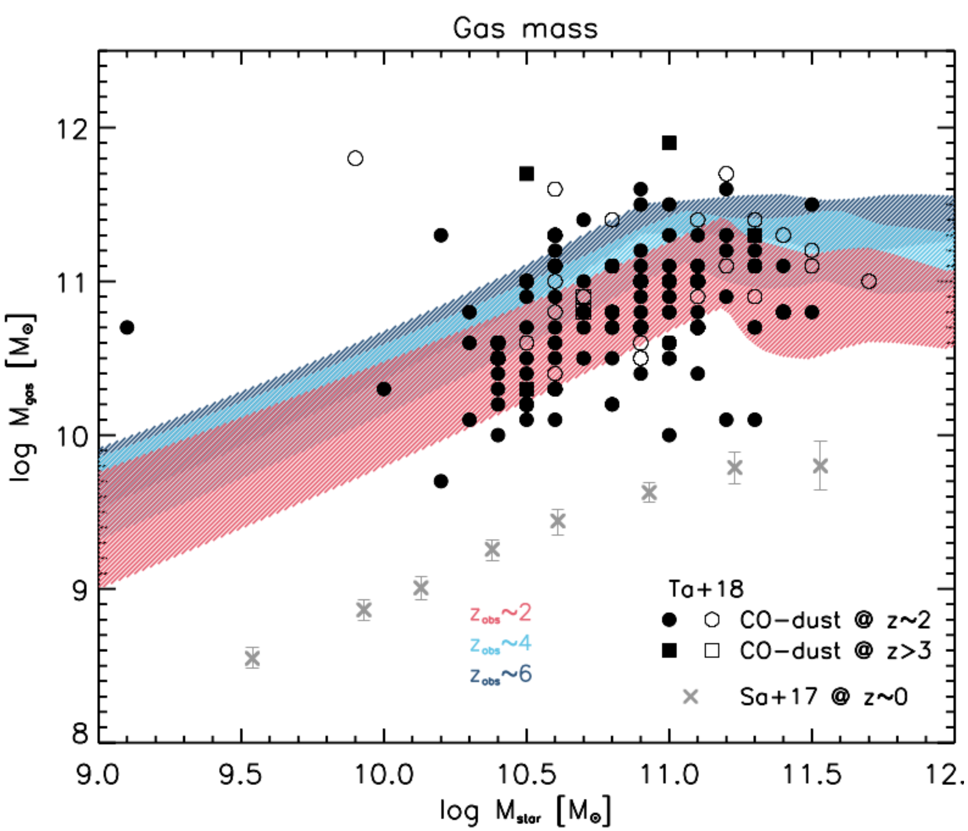
STARFORMING GALAXY MAIN SEQUENCE



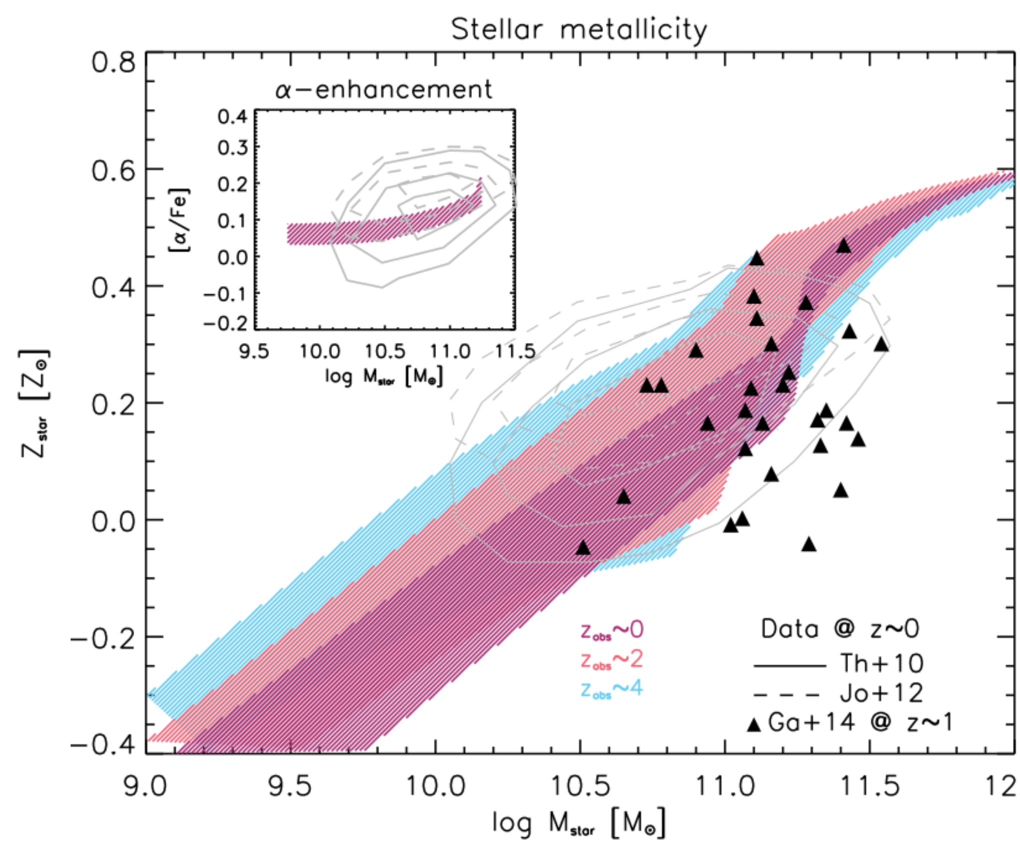
Pantoni et al. 2019 (accepted)

Statistical relations: M_{gas} - M_{star} and Z_{star} - M_{star}

M_{gas} - M_{star} RELATION



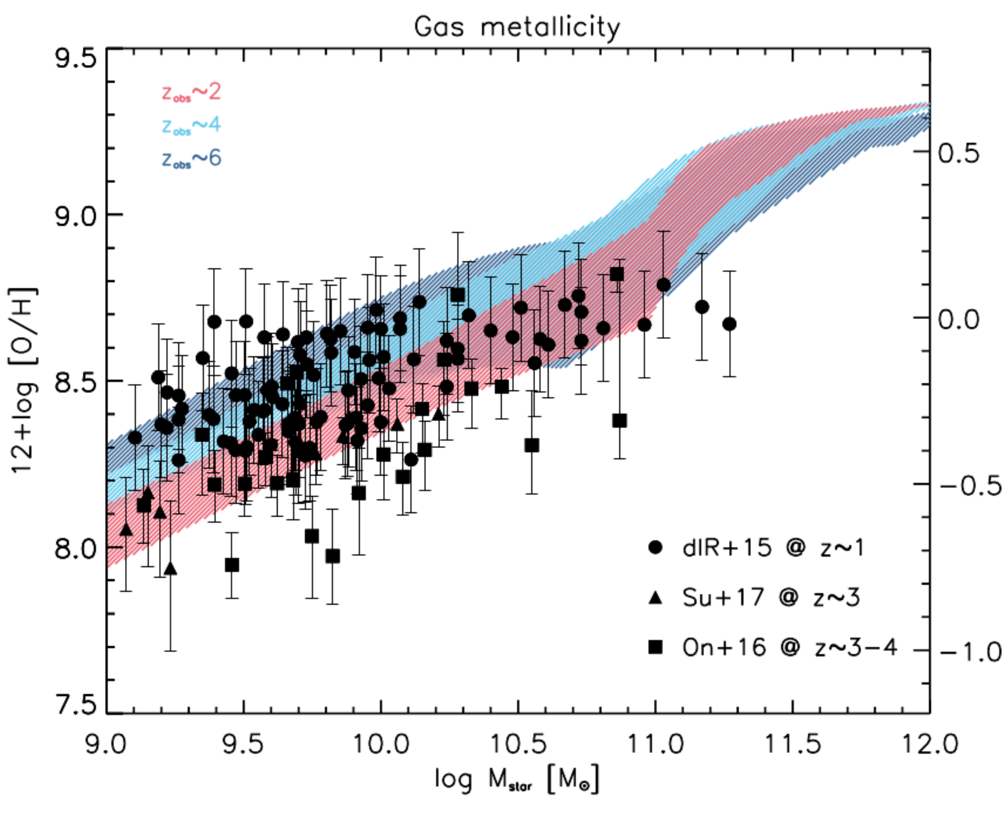
Z_{star} - M_{star} RELATION



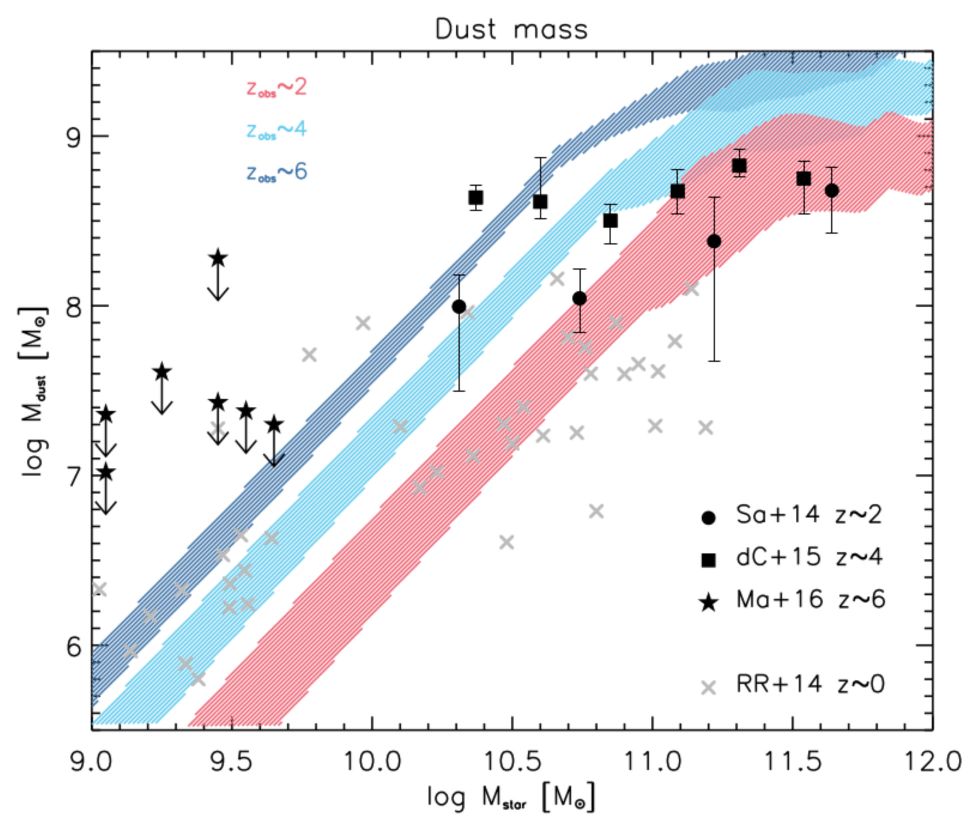
Pantoni et al. 2019 (accepted)

Statistical relations: FMR and M_{dust} - M_{star}

FUNDAMENTAL METALLICITY RELATION



M_{dust} - M_{star} RELATION



Pantoni et al. 2019 (accepted)

Conclusions

The model suxceed in reproducing the main galaxy statistical relationships at different redshifts

- Averaged description of the physical quantities does not affect dramatically the final results

- Powerful tool to improve the sub-grid physics recipes in hydrodynamical simulations

FUTURE PERSPECTIVES

Specialize the analytic solutions to local disk-dominated/spiral galaxies, including: **galactic fountains**, **radial** gas **flows**, differential galactic winds, **multi-zonal structure** and **stellar mixing**.

Thank you!