Strong stellar-driven outflows shape the evolution of high-redshift galaxies

Fontanot, Hirschmann, De Lucia, 2017, ApJL, 842, 14

Fabio Fontanot

GEE5 16/11/17

Strong stellar-driven outflows shape the evolution of high-redshift galaxies ...

... what about AGN-driven winds?

Fabio Fontanot

GEE5 16/11/17

OSSERVATORIO ASTRONOMICO DI TRIESTE

INAF ISTITUTO NAZIONALE DI ASTROFISICA

Outline

- New Semi-analytical Model of Galaxy Formation and Evolution
  - GAEA

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- Evolution of high-z galaxies
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- New Semi-analytical Model of Galaxy Formation and Evolution
  - GAEA
- Evolution of high-z galaxies
  - Critical test of stellar feedback
- Role of AGN in galaxy evolution
  - What can we learn from the BH-Bulge relation?

GAlaxy Evolution and Assembly

GAEA

- Evolution of the De Lucia & Blaizot 2007 SAM

GAEA

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- Detailed Chemical Enrichment De Lucia+14

GAEA

- Evolution of the De Lucia & Blaizot 2007 SAM
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  - No IRA
  - Explicit timescales for SNIa SNII and AGB stars

GAEA

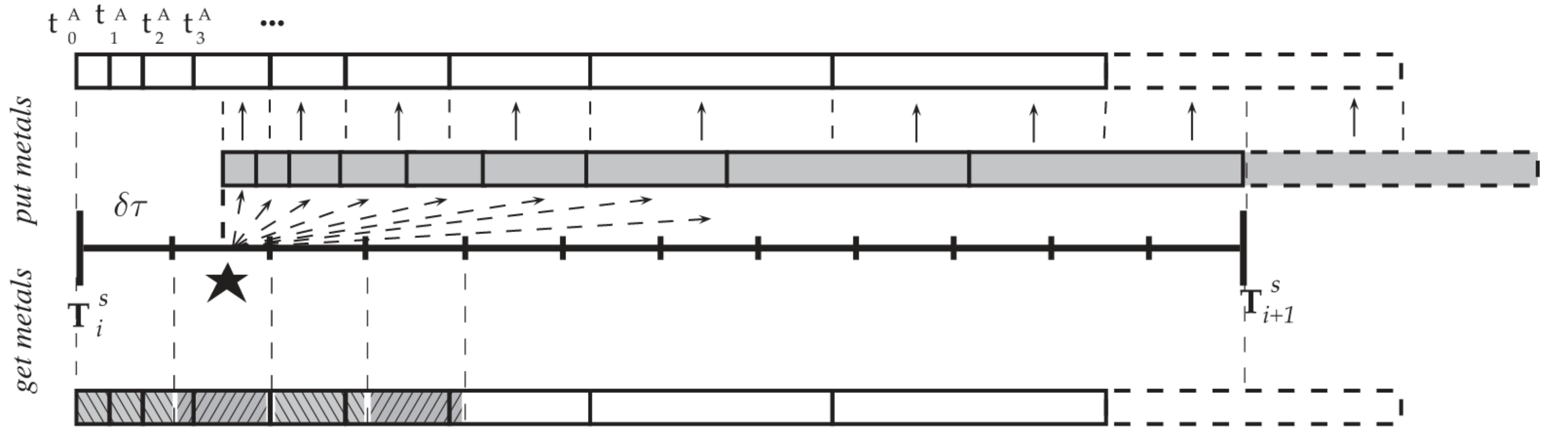
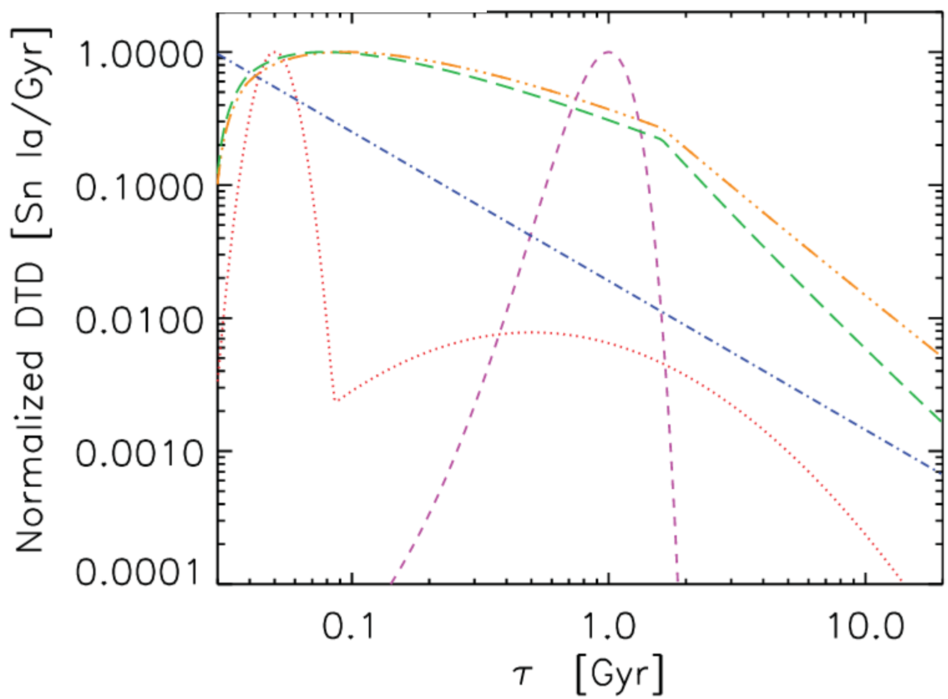


Figure 2. Schematic illustration of the method adopted to store the contributions from different types of stars in the future, and incorporate the metals in the baryonic gaseous phase of model galaxies during their evolution. The thick line shows the time interval between two subsequent snapshots. The two arrays at the top and at the bottom of the figure represent a 'metal restitution array' (RETURNEDMET) that is associated with each model galaxy and contains the mass of elements returned, at any time in the future, by the SSPs that constitute the model galaxy under consideration. At each time-step, the code computes the elements produced and adds them to the future bins (in case there is an episode of star formation), and then reads from the array RETURNEDMET the amount of metals that needs to be re-incorporated. The grey array shown in the figure is a 'virtual array' used to project metals in the appropriate bins.

DeLucia+14



GAEA

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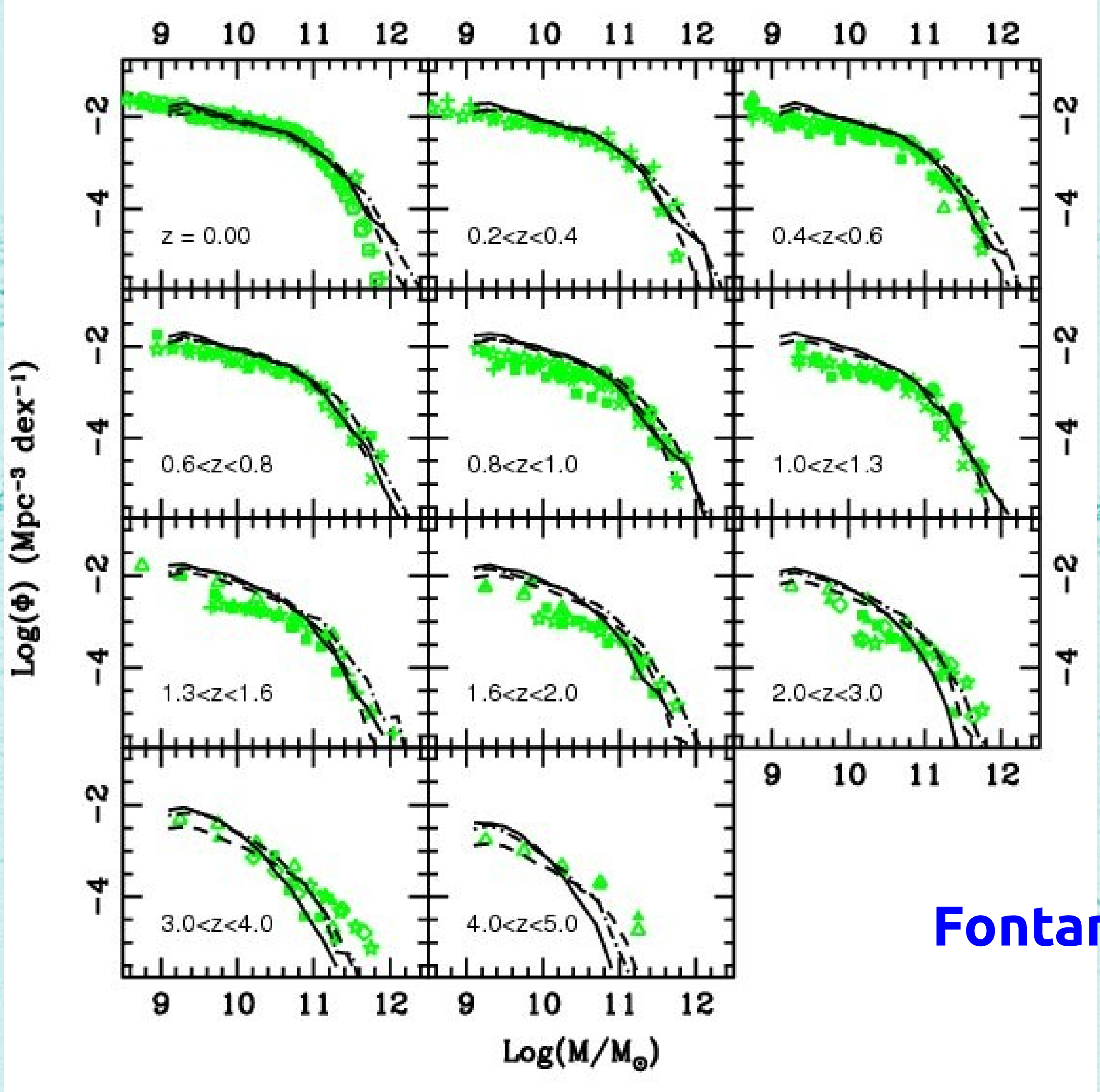
- Updated treatment of stellar feedback

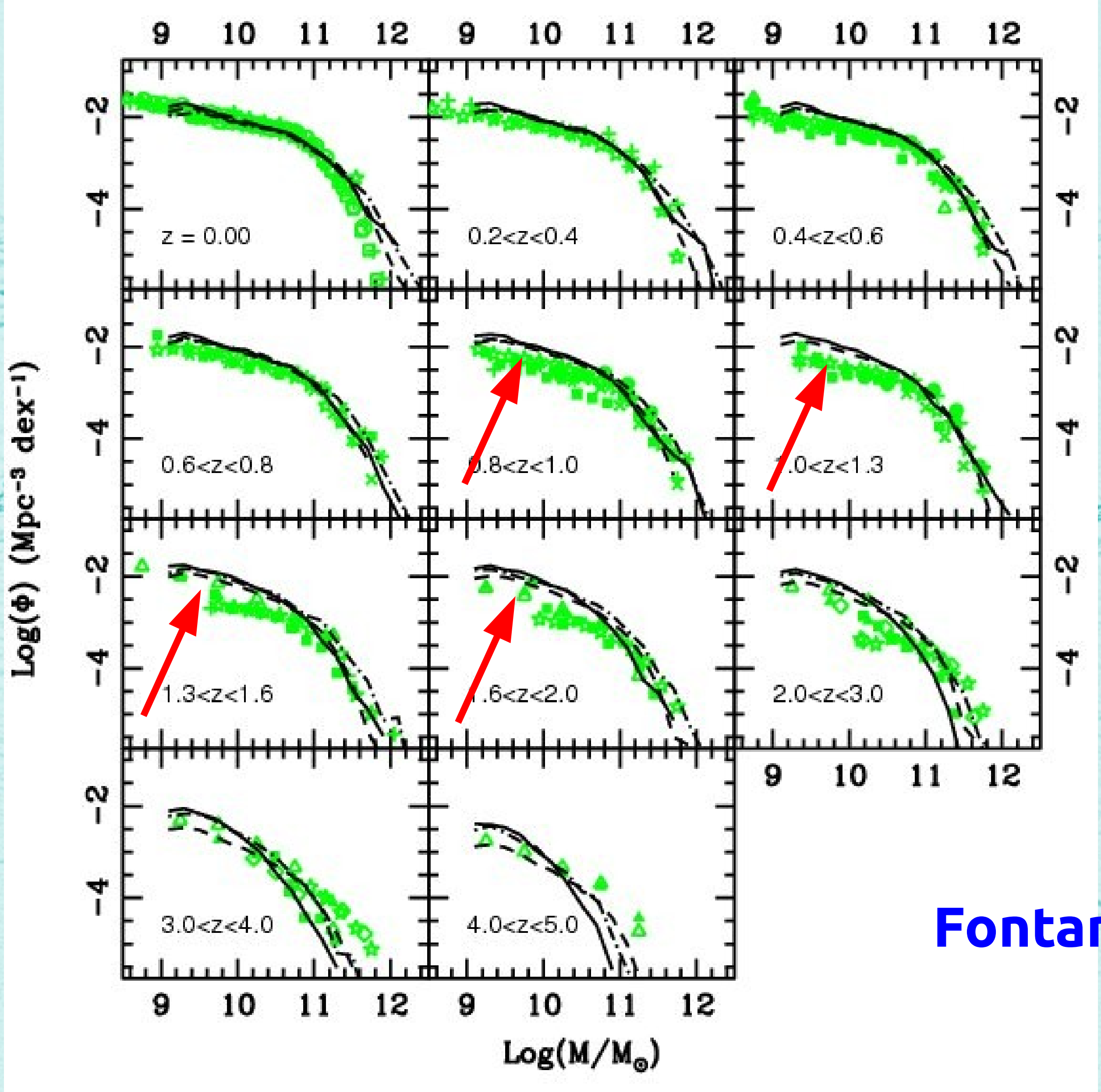
  Hirschmann De Lucia & Fontanot 2016

GSMF



Fontanot+09

GSMF



Fontanot+09

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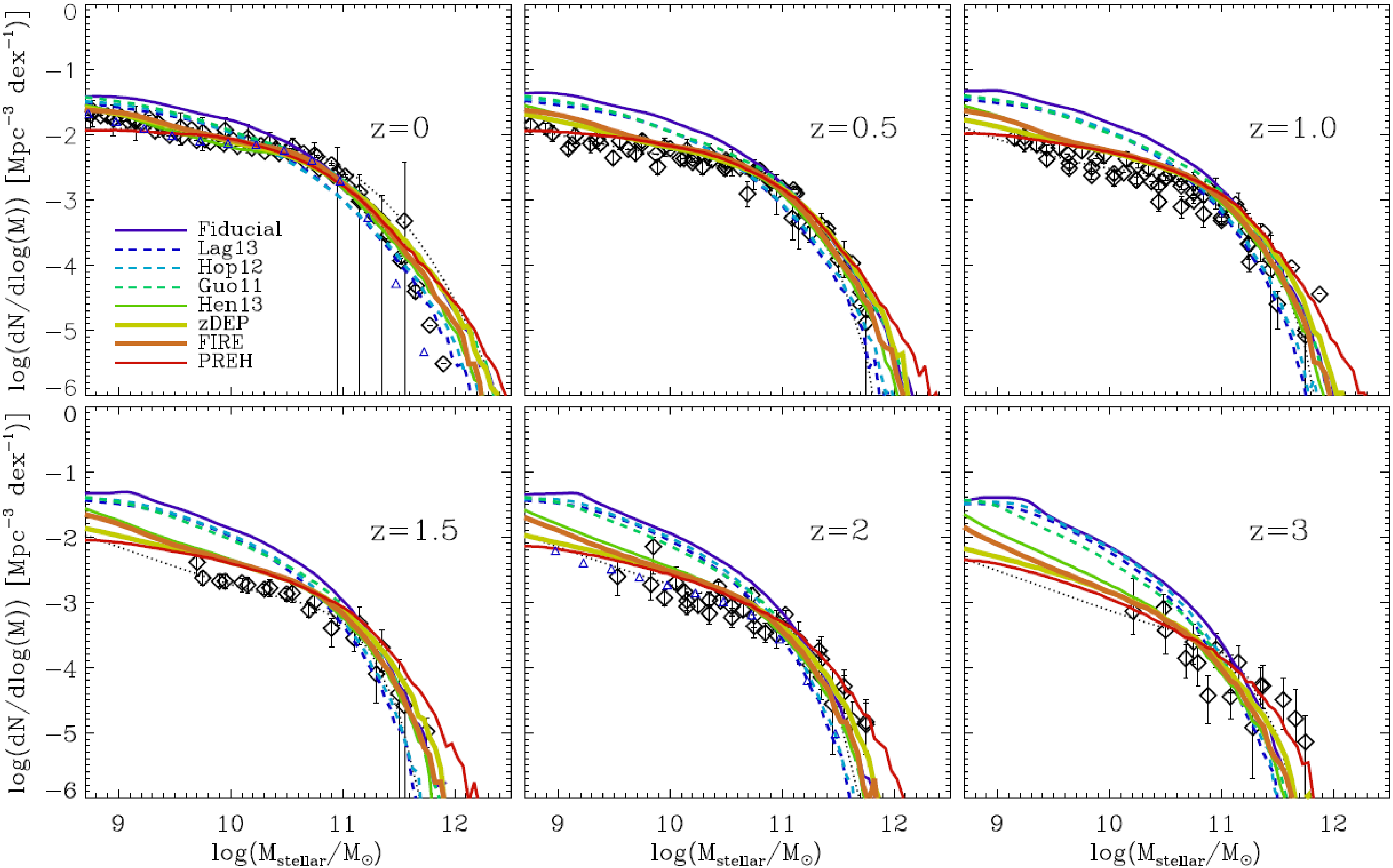
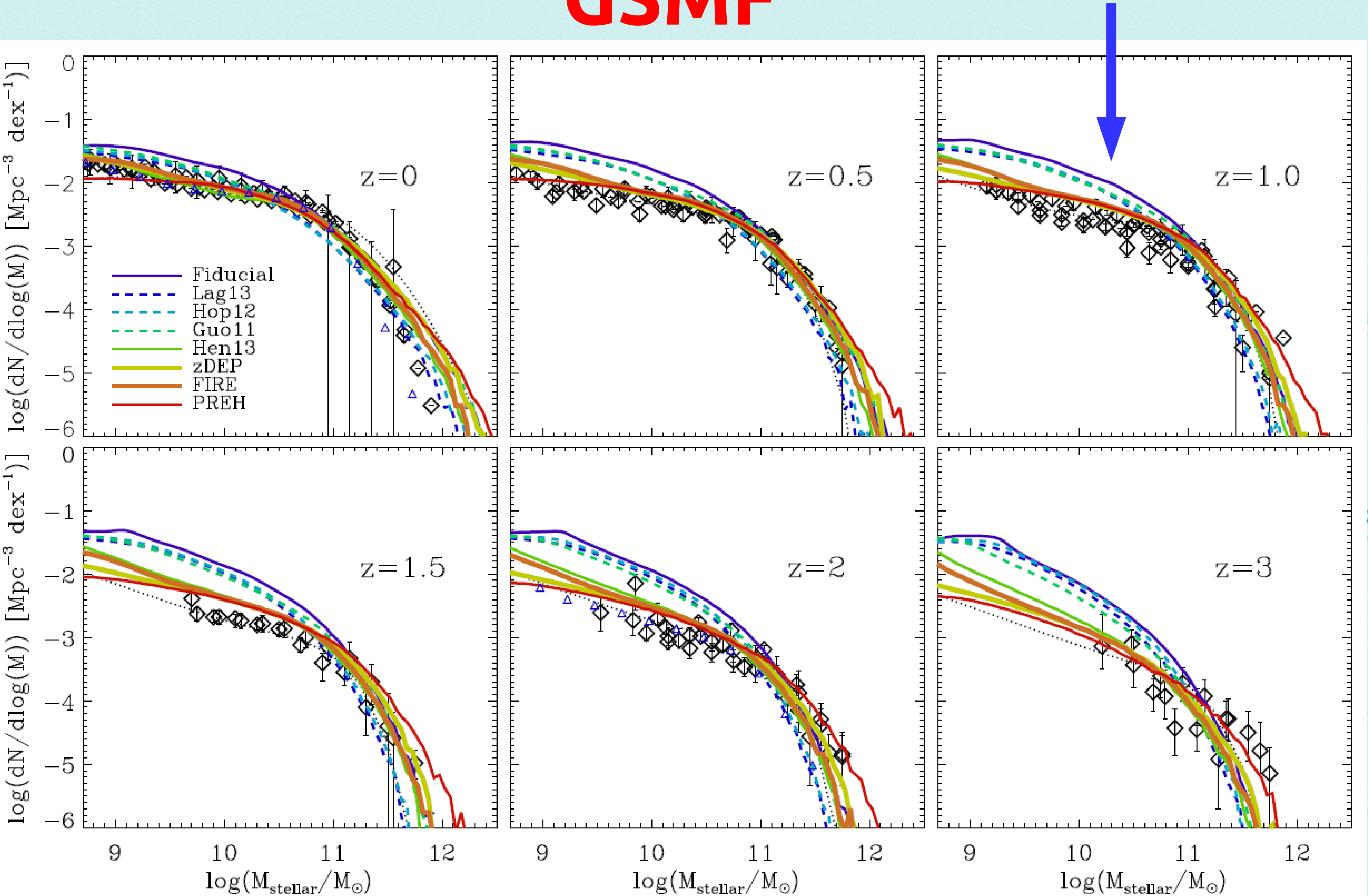


Hirschmann, De Lucia & Fontanot 2016 (see also Henriques+13 or White+14)

GSMF

"Old" feedback schemes



GSMF

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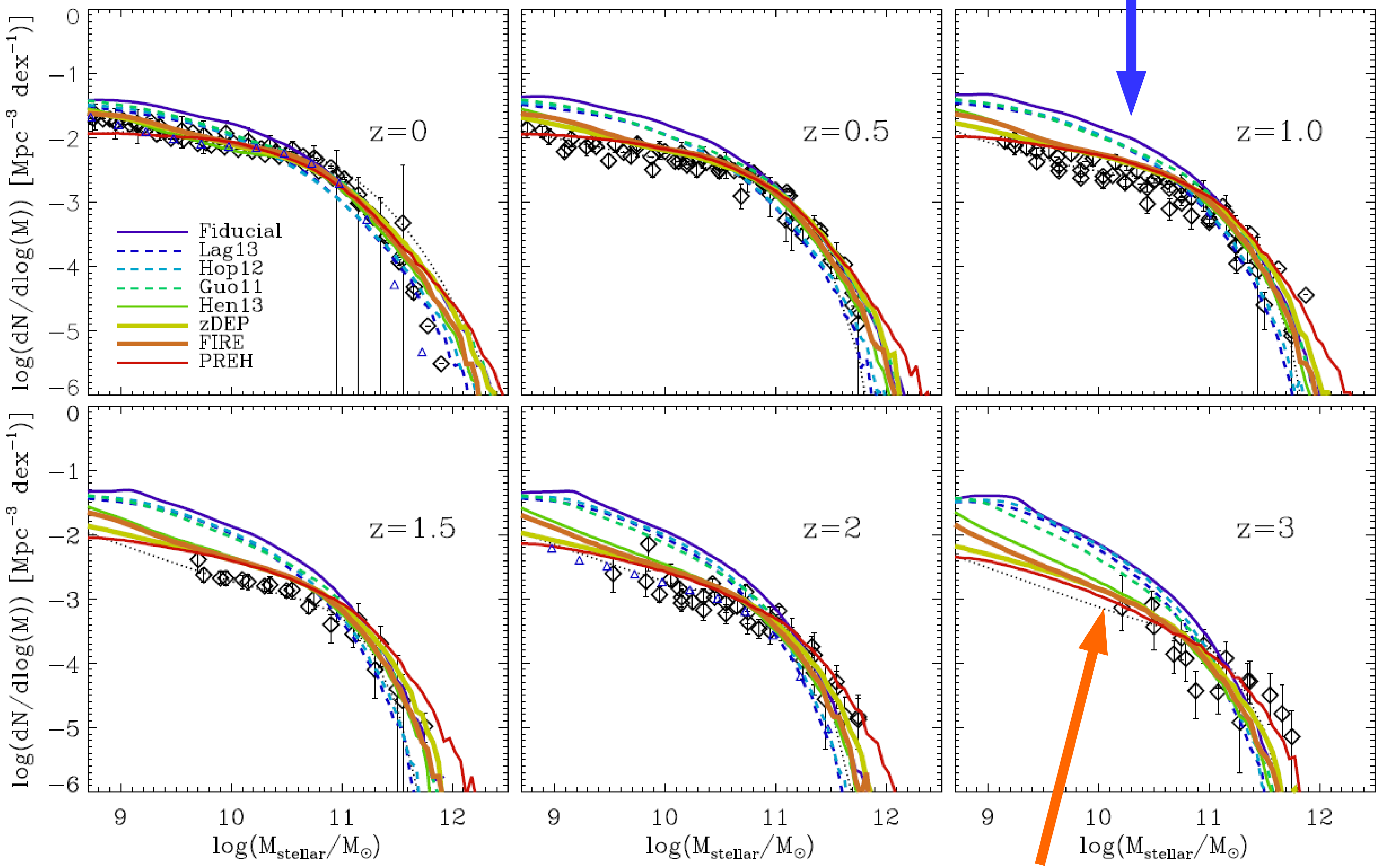

Ejective/Preventive feedback

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- Evolution of the De Lucia & Blaizot 2007 SAM
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- Updated treatment of stellar feedback =>
  Ejective (or preventive) feedback (H16F)

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  - Modelling Reheating

$$\dot{M}_{\rm reheat} = \epsilon_{\rm reheat}(1+z)^{1.25}\left(\frac{V_{\rm max}}{60\ {\rm km\,s^{-1}}}\right)^{\alpha} \times \dot{M}_{\rm star}$$

"FIRE" simulations
Muratov+15

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"FIRE" simulation suite
Muratov+15

  - Modelling Ejection

$$\dot{E}_{\rm FB} = \epsilon_{\rm eject}(1+z)^{1.25}\left(\frac{V_{\rm max}}{60\ {\rm km\,s^{-1}}}\right)^{\alpha} \times 0.5\dot{M}_{\rm star}V_{\rm SN}^2$$

$\longrightarrow$

$$\dot{M}_{\rm eject} = \frac{\dot{E}_{\rm FB} - 0.5\dot{M}_{\rm reheat}V_{\rm vir}^2}{0.5V_{\rm vir}^2}$$

As in Guo+11

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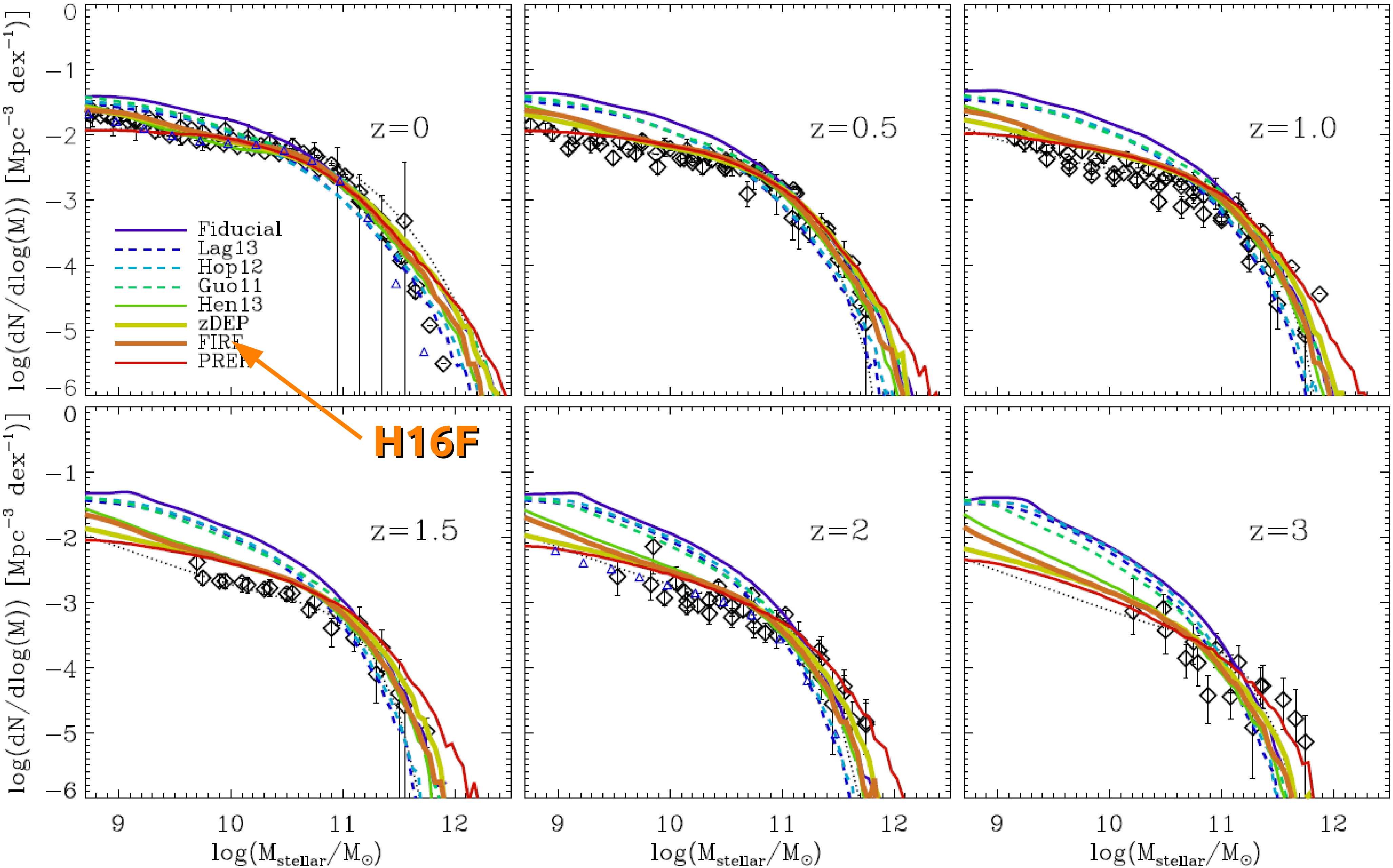
As in Guo+11

  - Mass dependent reincorporation

$$M_{\rm reinc} = \gamma\frac{M_{\rm eject}}{t_{\rm reinc}},\ \ \text{with}\ t_{\rm reinc} = \frac{10^{10}\,{\rm M}_\odot}{M_{\rm vir}} \times yr$$

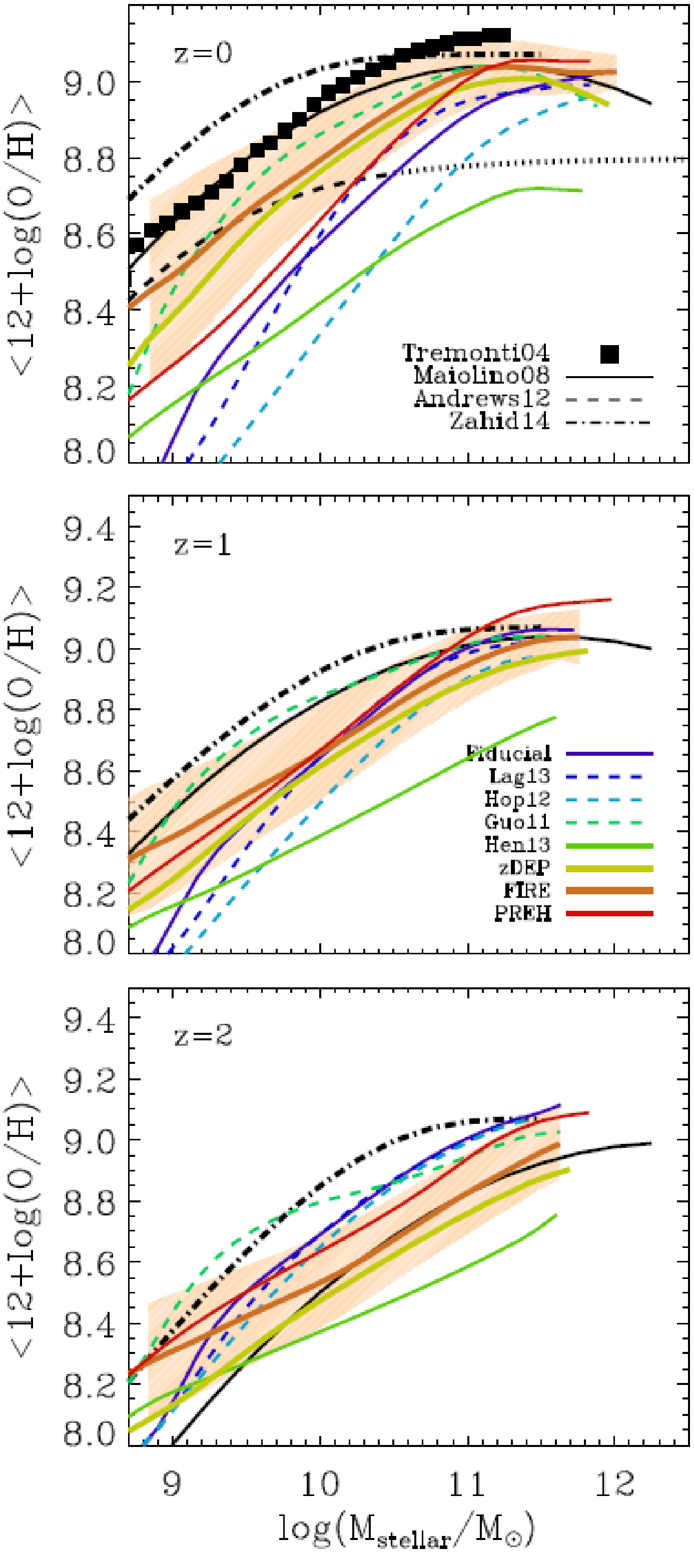
As in Henriques+13

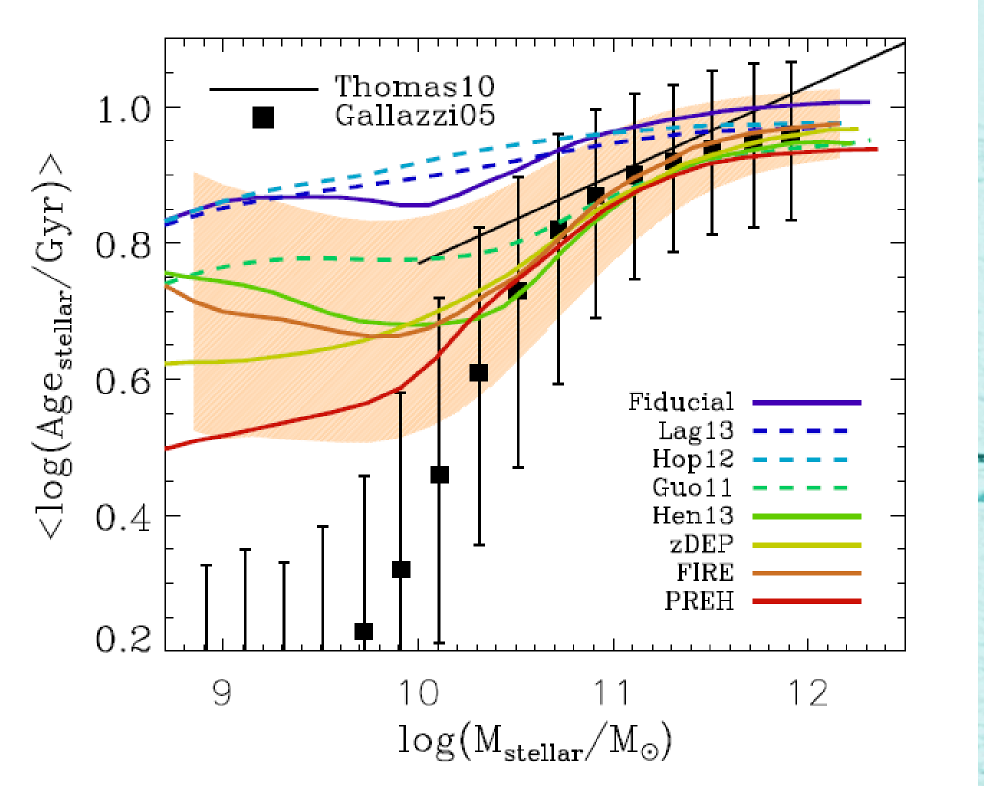
GAEA



Hirschmann, De Lucia & Fontanot 2016 (see also **Henriques+13** or **White+14**)

GAEA





Hirschmann, De Lucia & Fontanot 2016

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- Other projects

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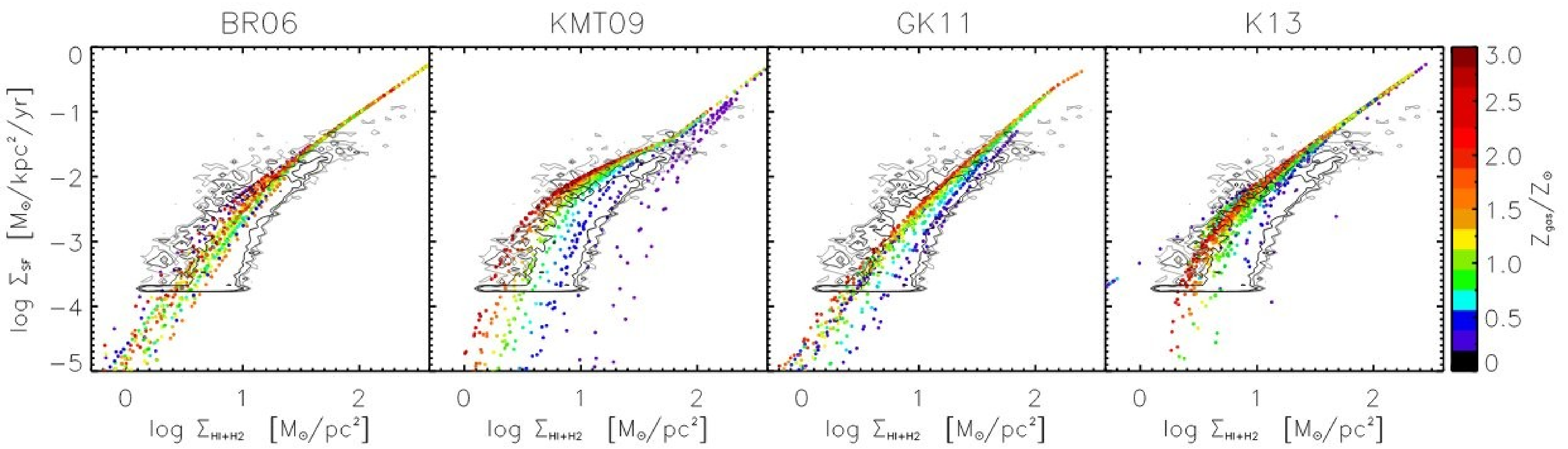

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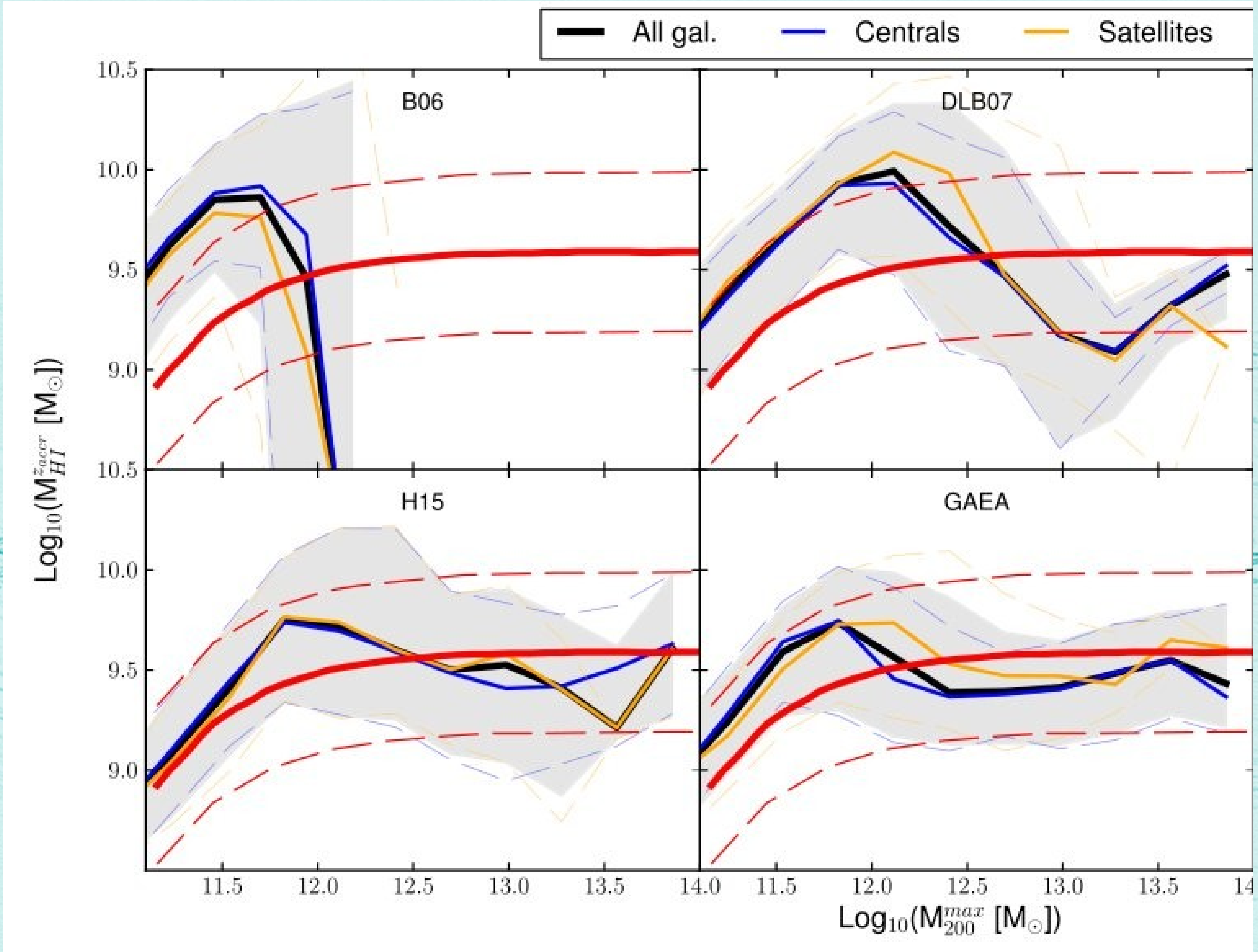

All gal.
Centrals
Satellites
B06
DLB07
H15
GAEA
10.5
10.0
9.5
9.0
11.5
12.0
12.5
13.0
13.5
14.0
$Log_{10}(M_{HI}^{z_{accr}}\ [M_{\odot}])$
$Log_{10}(M_{200}^{max}\ [M_{\odot}])$

GAEA

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  Hirschmann De Lucia & Fontanot 2016

- Other projects
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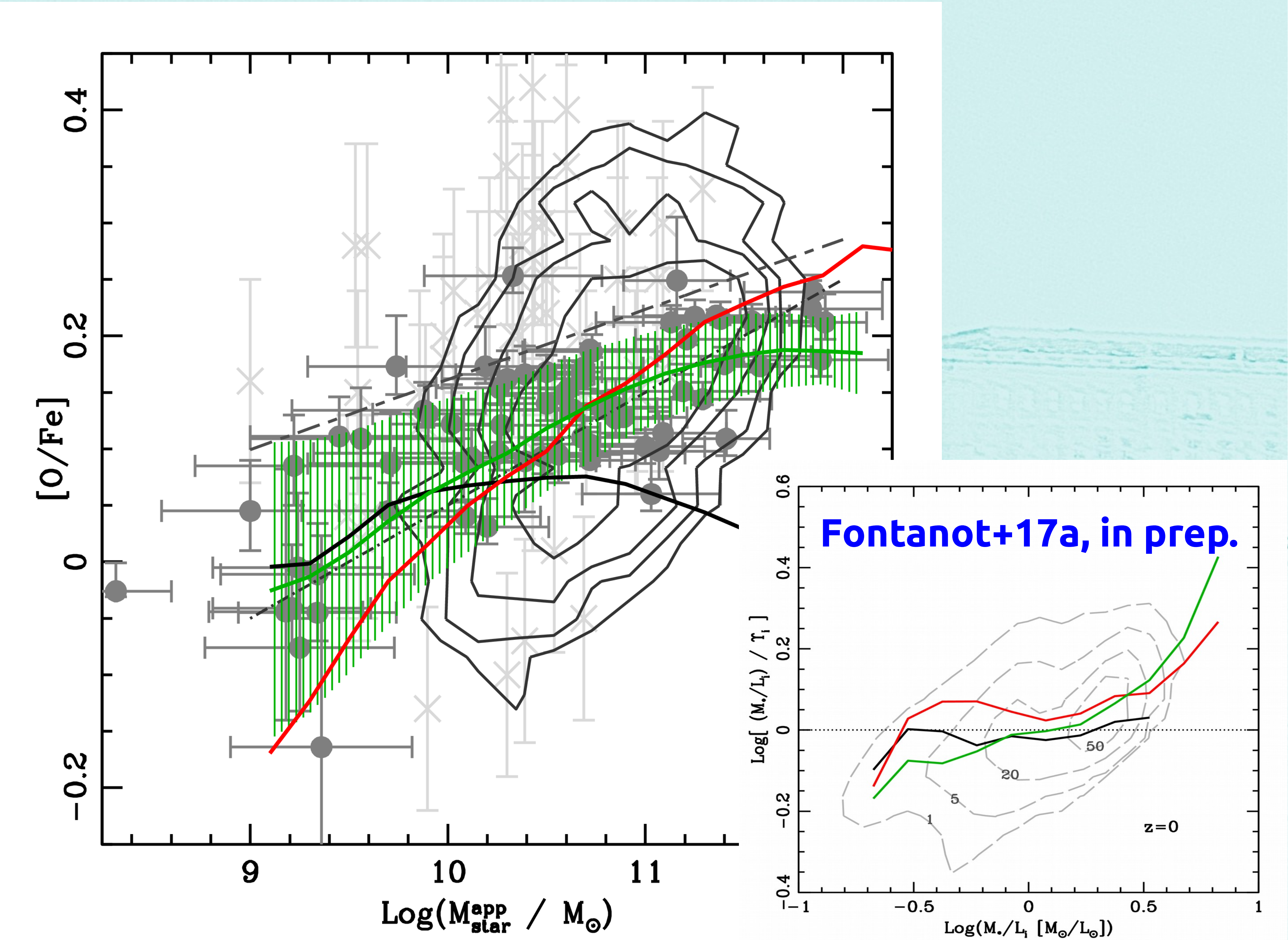
  - HI content of DMHs Zoldan+17
  - Variable IMF Fontanot+17a



[O/Fe]
0.4
0.2
0
−0.2
9
10
11
$Log(M_{star}^{app} / M_{\odot})$
Fontanot+17a, in prep.
$Log[(M_*/L_i) / \Upsilon_i]$
$Log(M_*/L_i\ [M_{\odot}/L_{\odot}])$
z=0
50
20
5
1
0.6
0.4
0.2
0
−0.2
−0.4
−1
−0.5
0
0.5
1

Properties of high-z galaxies

GAEA high-z runs

- Different Feedback Schemes
  - FIDUCIAL => standard scheme as in De Lucia+04, +14
  - H16F => strong stellar-driven winds Hirschmann+16

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- Different Feedback Schemes
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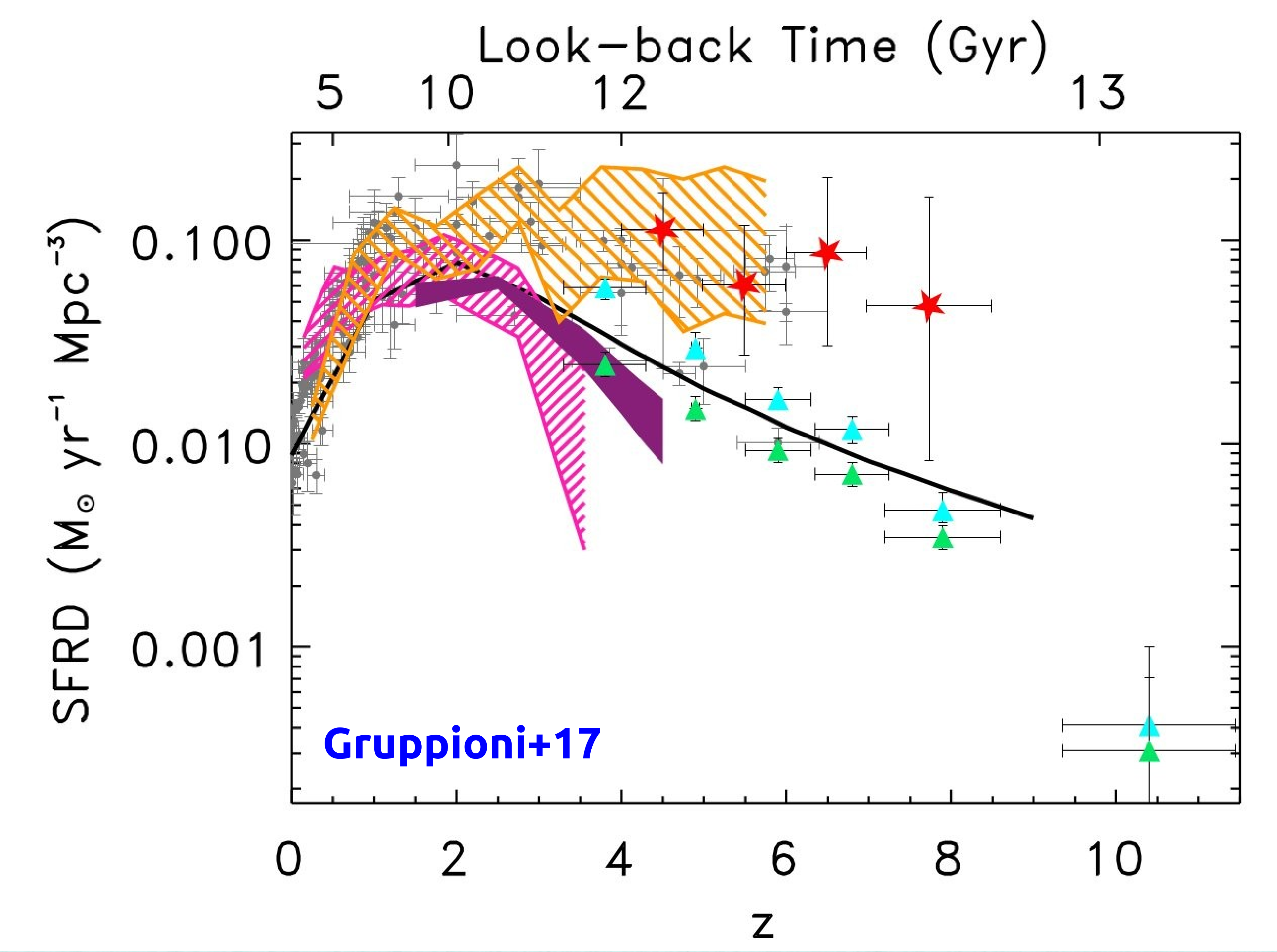
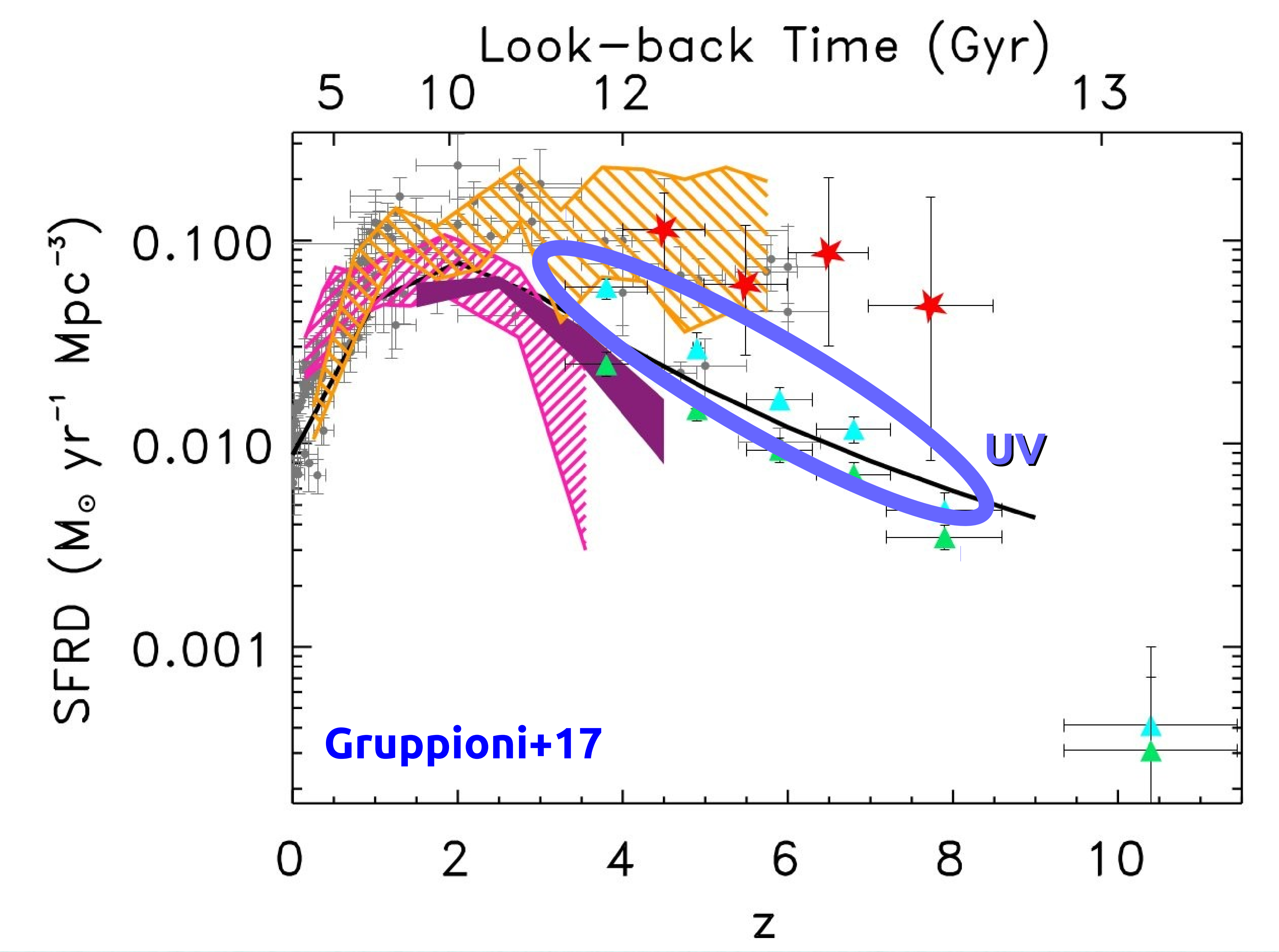
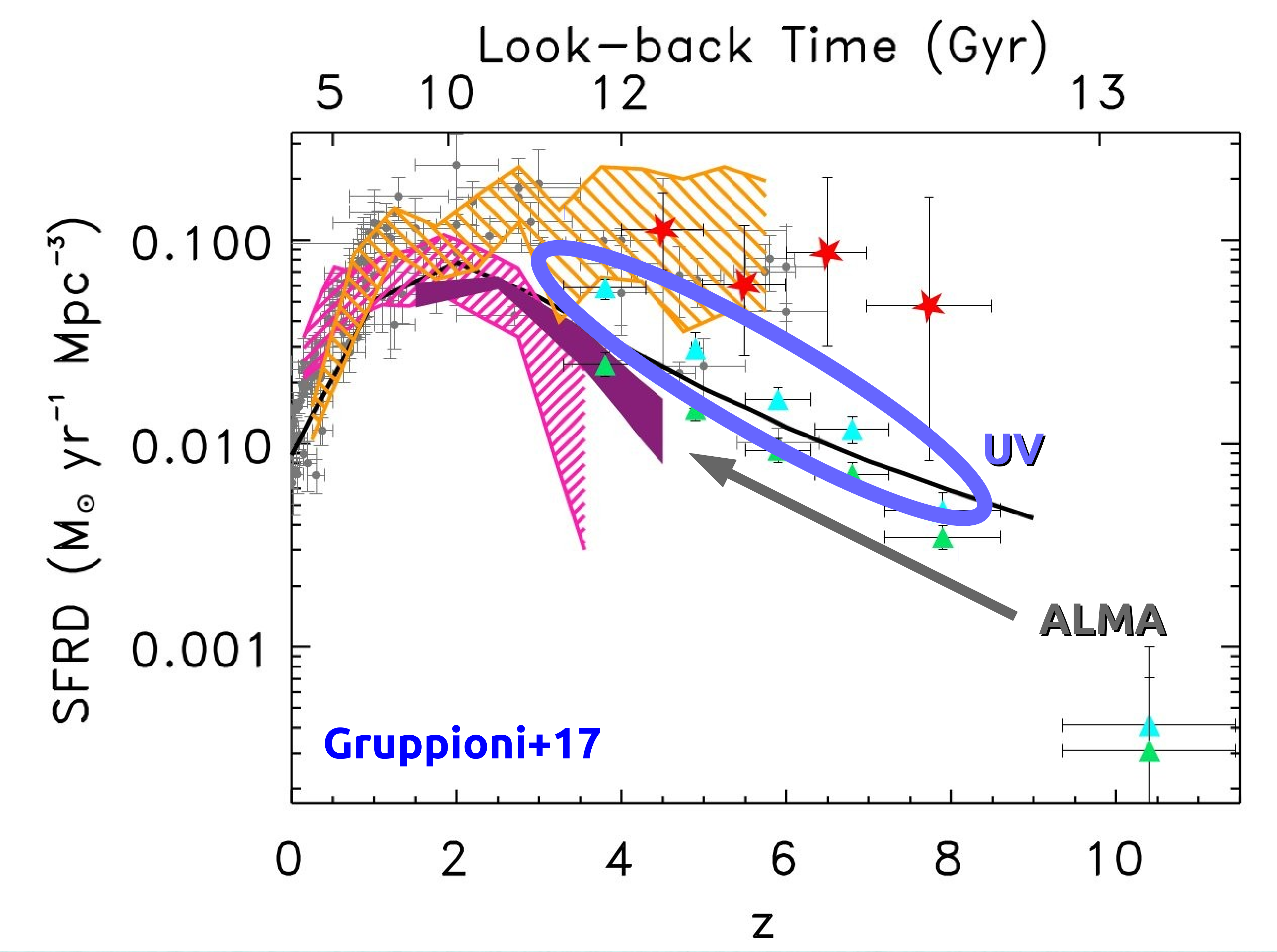
- Different Dust Treatment

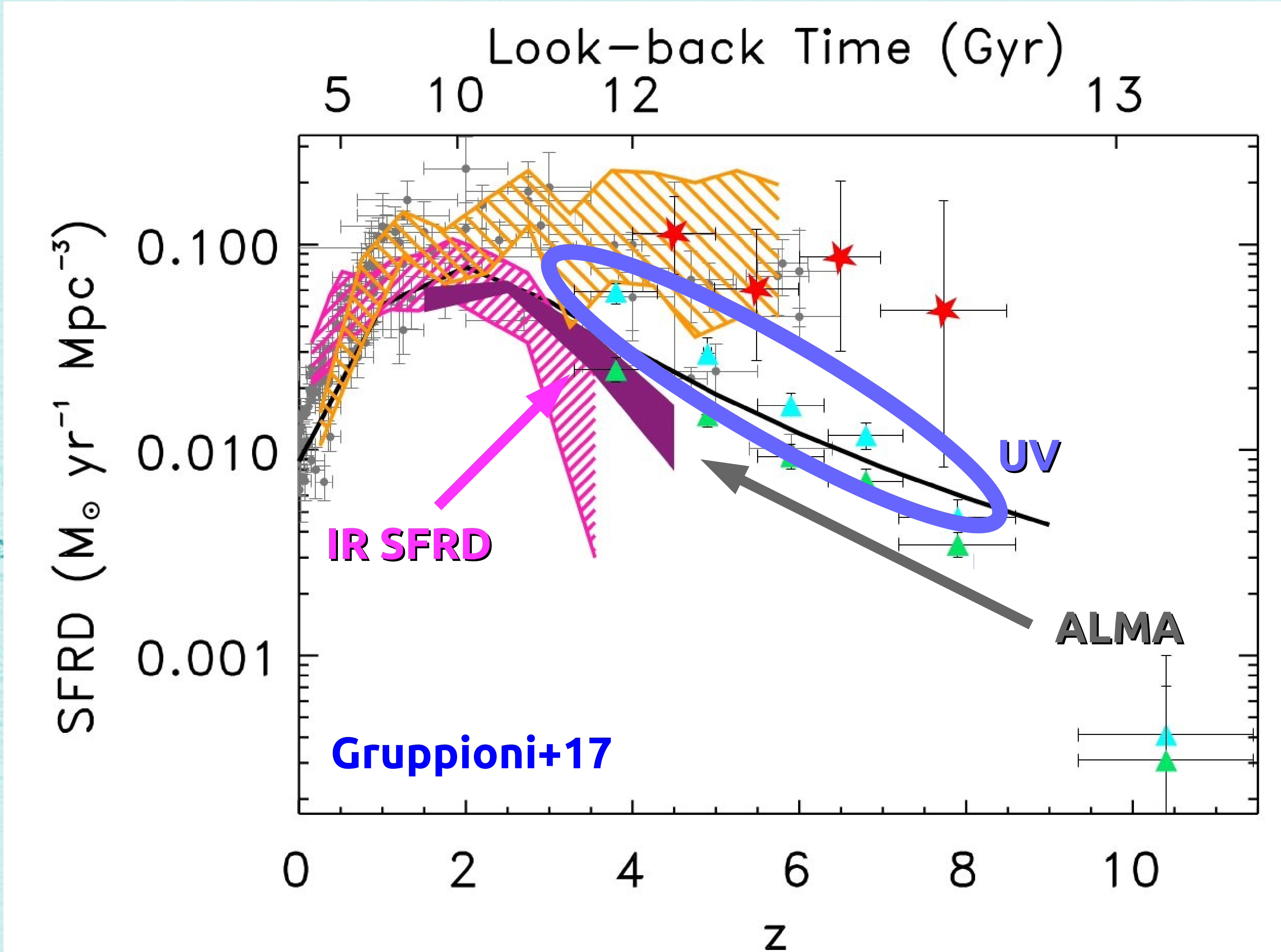


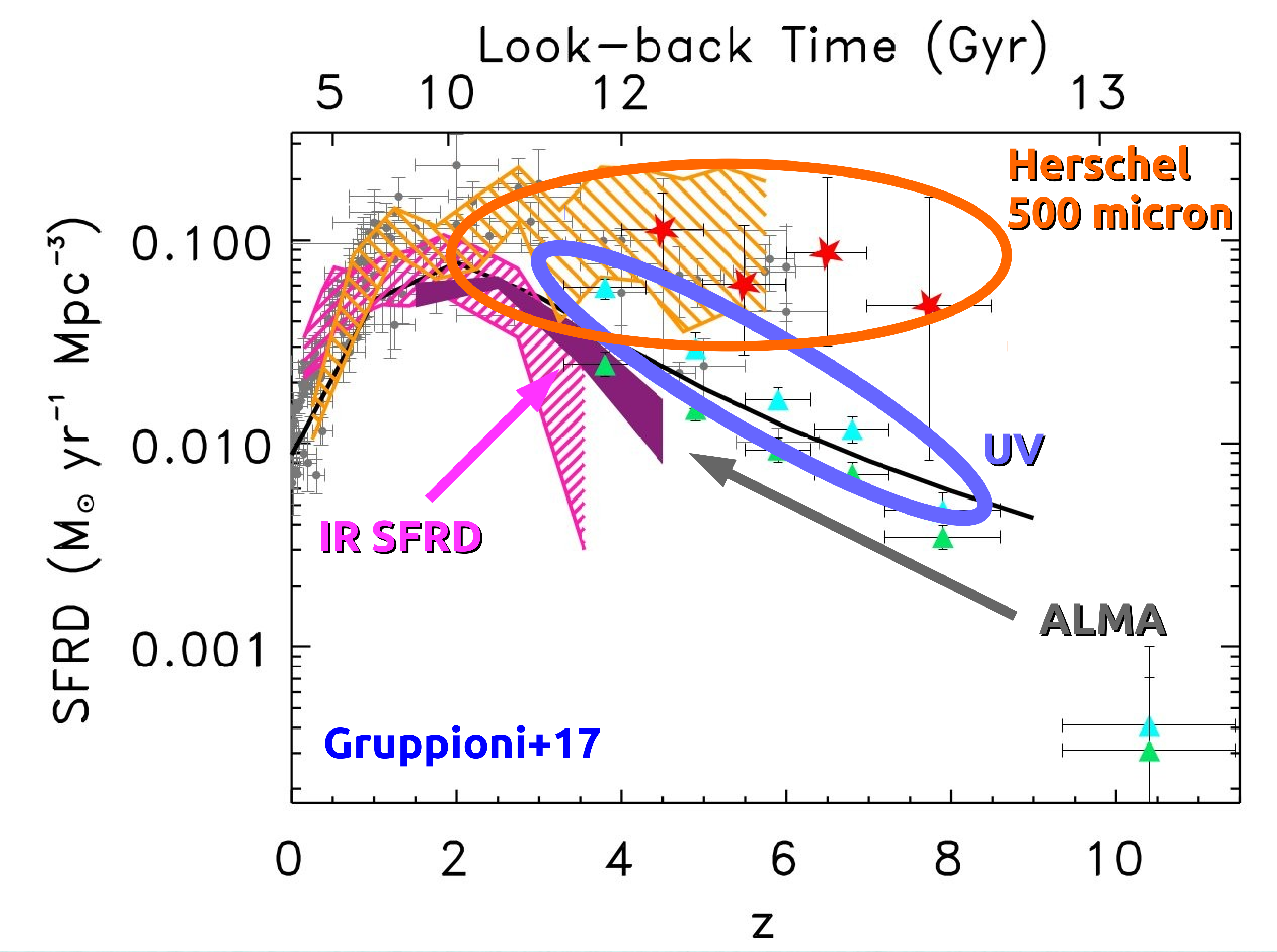
Look-back Time (Gyr)
5
10
12
13
SFRD (M⊙ yr⁻¹ Mpc⁻³)
0.100
0.010
0.001
Gruppioni+17
0
2
4
6
8
10
z



Look-back Time (Gyr)
5
10
12
13
SFRD (M⊙ yr⁻¹ Mpc⁻³)
0.100
0.010
0.001
UV
Gruppioni+17
0
2
4
6
8
10
z


Look-back Time (Gyr)
5
10
12
13
SFRD (M⊙ yr⁻¹ Mpc⁻³)
0.100
0.010
0.001
UV
ALMA
Gruppioni+17
0
2
4
6
8
10
z


Look-back Time (Gyr)
5
10
12
13
SFRD (M⊙ yr⁻¹ Mpc⁻³)
0.100
0.010
0.001
0
2
4
6
8
10
z
UV
IR SFRD
ALMA
Gruppioni+17



Look-back Time (Gyr)
5
10
12
13
SFRD (M⊙ yr⁻¹ Mpc⁻³)
0.100
0.010
0.001
0
2
4
6
8
10
z
Herschel
500 micron
UV
IR SFRD
ALMA
Gruppioni+17

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- Different Feedback Schemes
  - FIDUCIAL => standard scheme as in De Lucia+04, +14
  - H16F => strong stellar-driven winds Hirschmann+16
- Different Dust Treatment
  - No-Dust
  - Standard dust prescription as in De Lucia&Blaizot07 (see also Charlot&Fall00)

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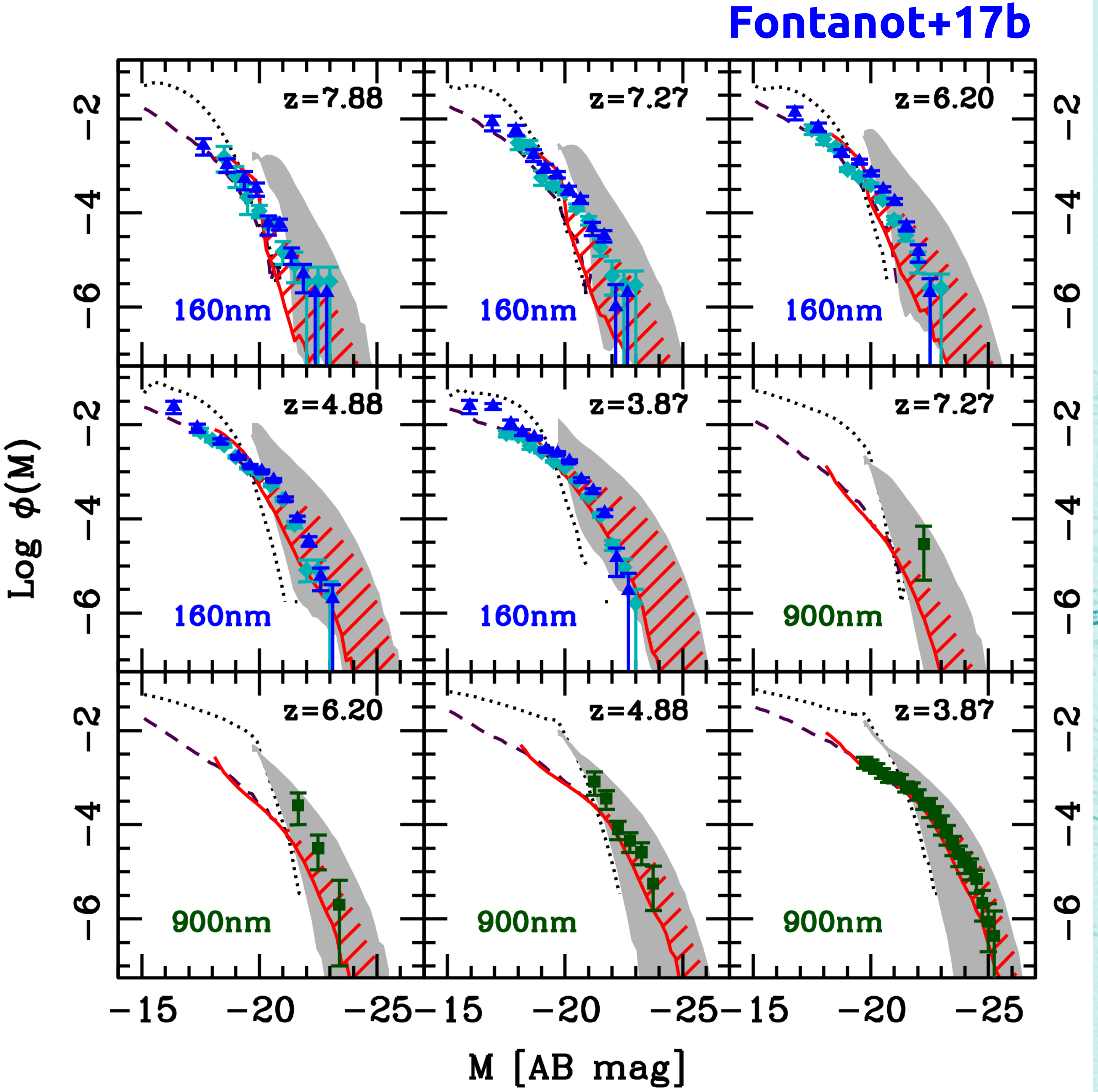
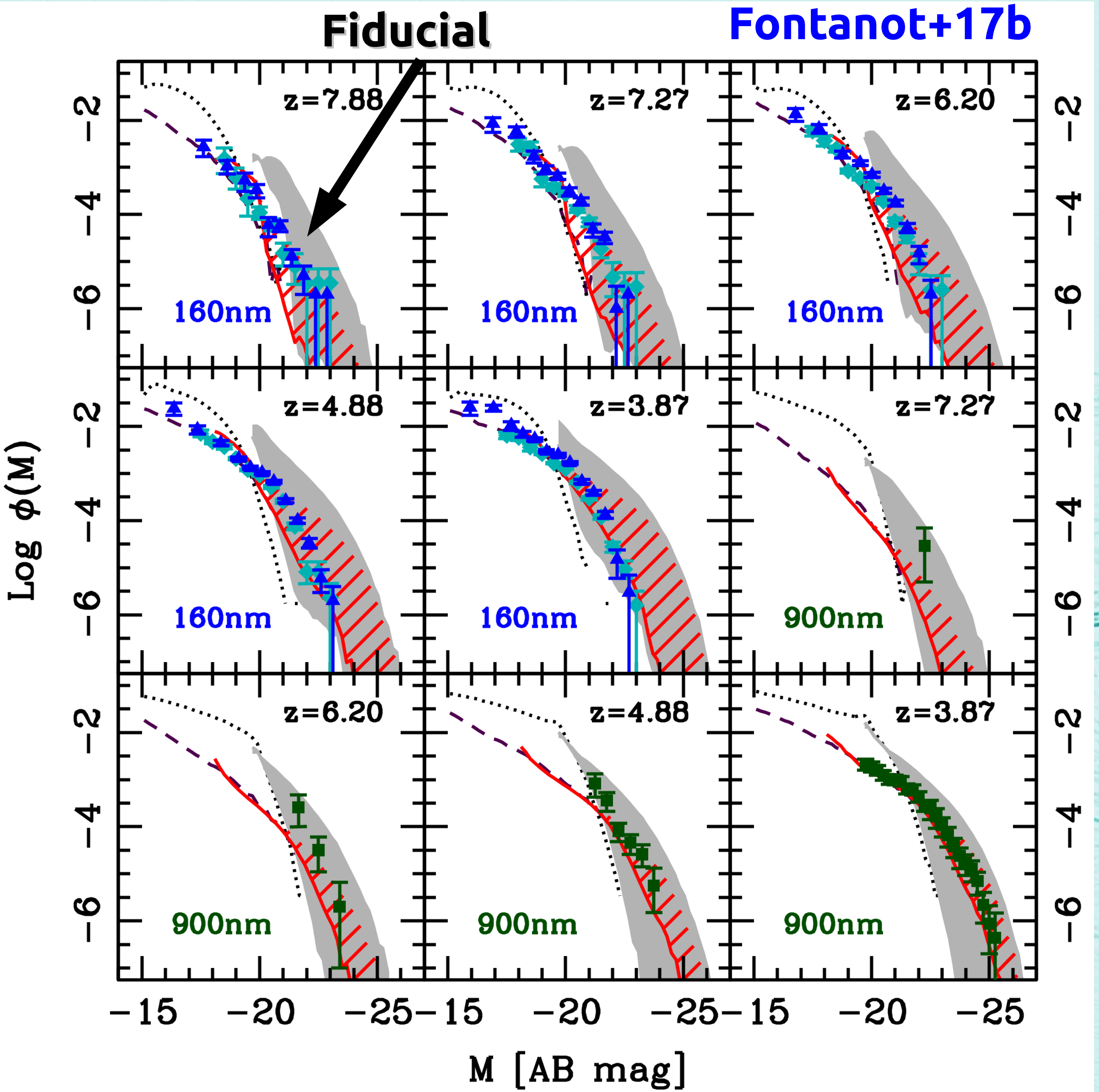
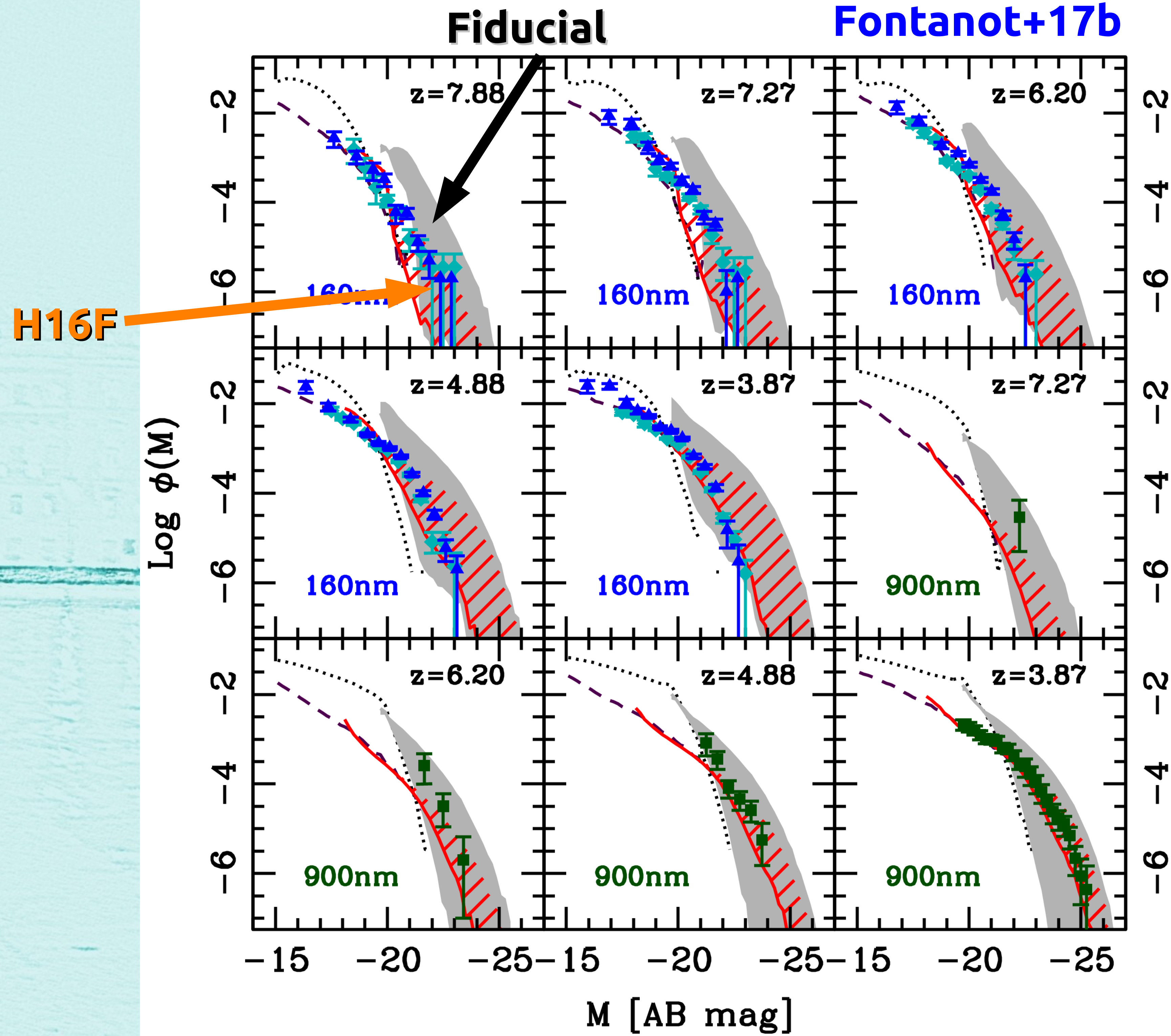
- Different Dust Treatment
  - No-Dust
  - Standard dust prescription as in De Lucia&Blaizot07 (see also Charlot&Fall00)
- Reference simulations (different resolution)
  - MS
  - MSII

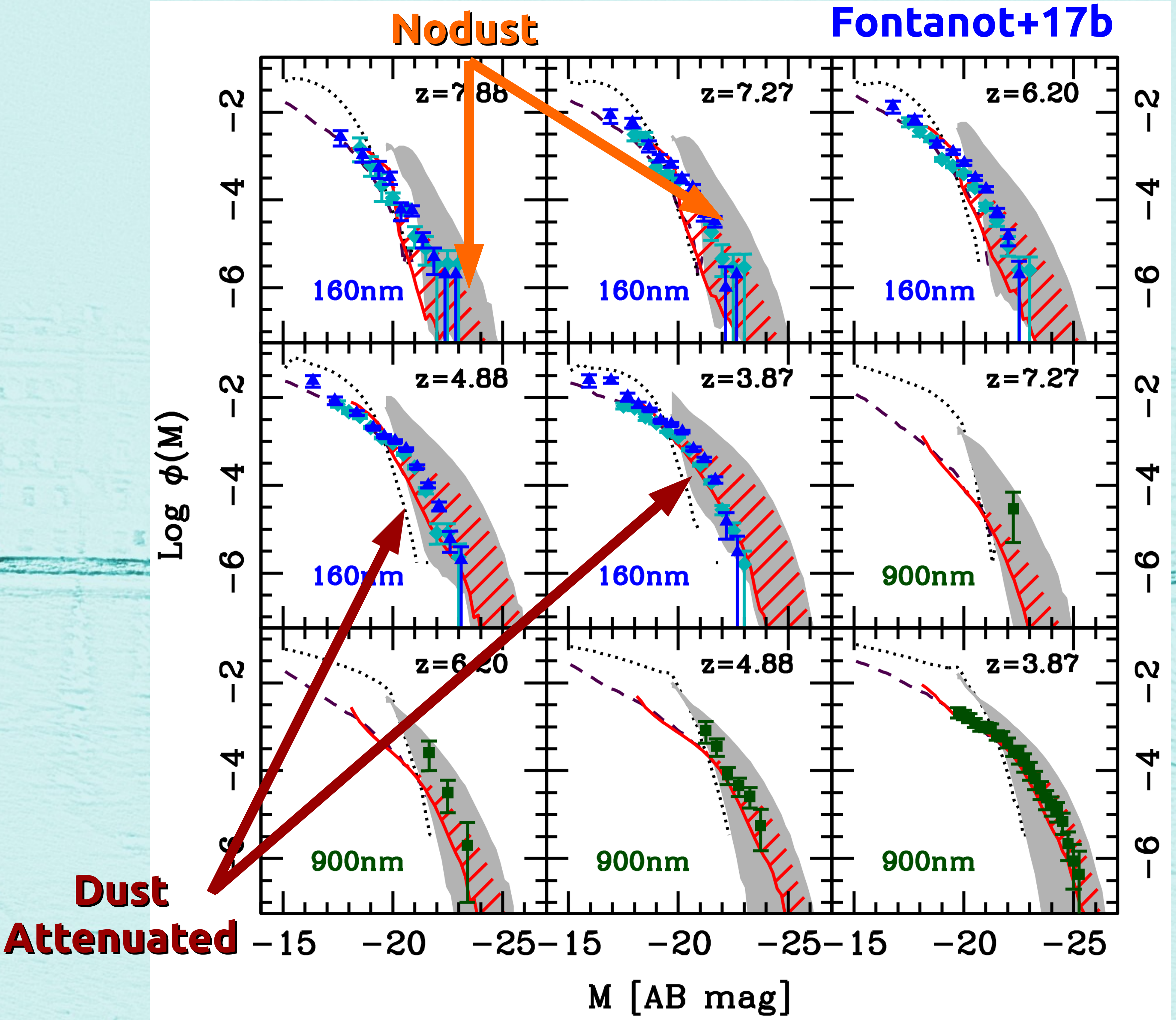


Fontanot+17b
z=7.88
z=7.27
z=6.20
z=4.88
z=3.87
z=7.27
z=6.20
z=4.88
z=3.87
160nm
900nm
Log ϕ(M)
M [AB mag]
−2
−4
−6
−15
−20
−25

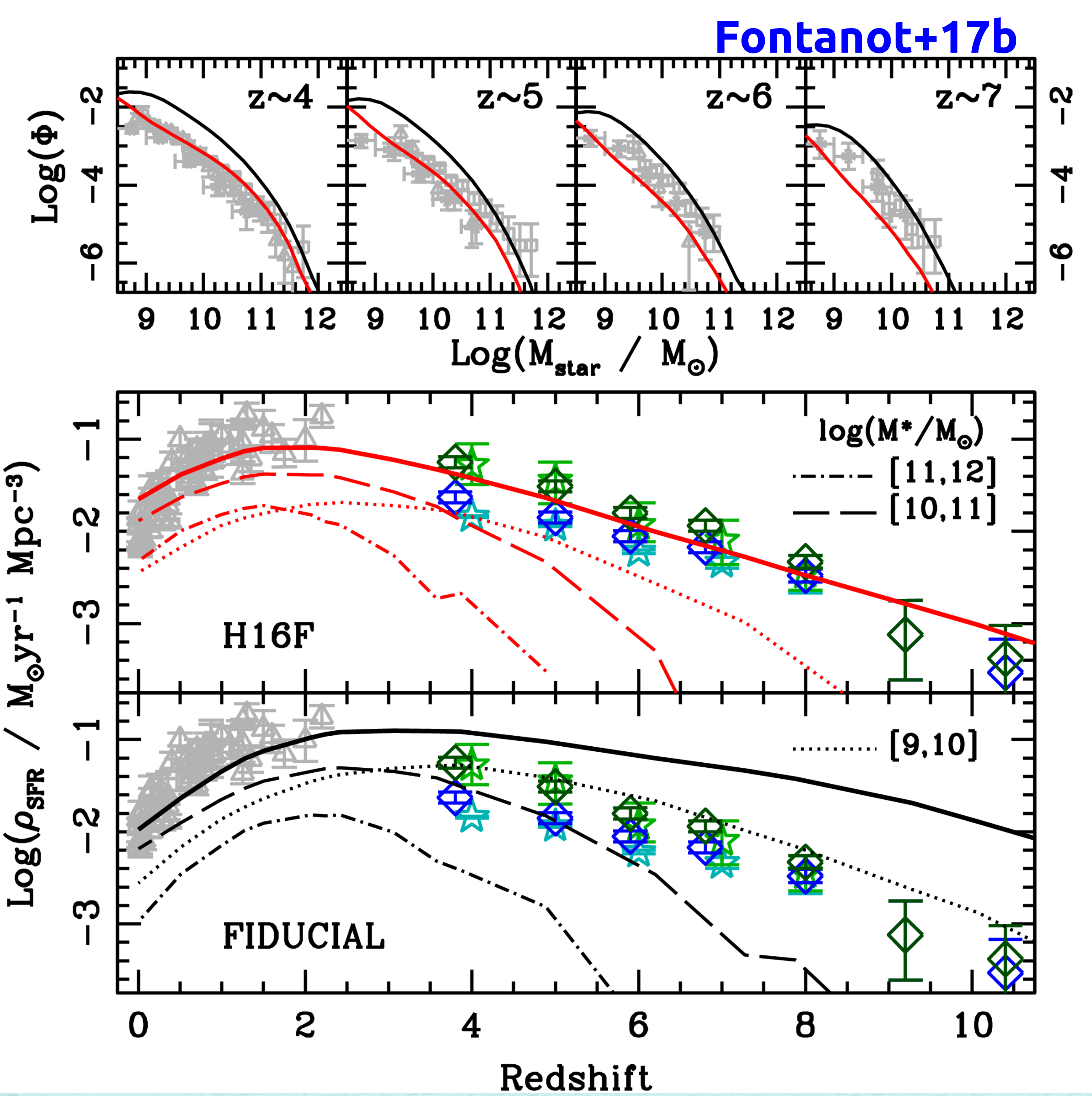


Fiducial
Fontanot+17b
z=7.88
z=7.27
z=6.20
z=4.88
z=3.87
z=7.27
z=6.20
z=4.88
z=3.87
160nm
900nm
Log φ(M)
M [AB mag]
−15
−20
−25
−2
−4
−6


Fiducial
Fontanot+17b
H16F
z=7.88
z=7.27
z=6.20
z=4.88
z=3.87
z=7.27
z=6.20
z=4.88
z=3.87
160nm
900nm
Log φ(M)
M [AB mag]



Nodust
Fontanot+17b
z=7.88
z=7.27
z=6.20
z=4.88
z=3.87
z=7.27
z=6.20
z=4.88
z=3.87
160nm
900nm
Log φ(M)
M [AB mag]
Dust Attenuated



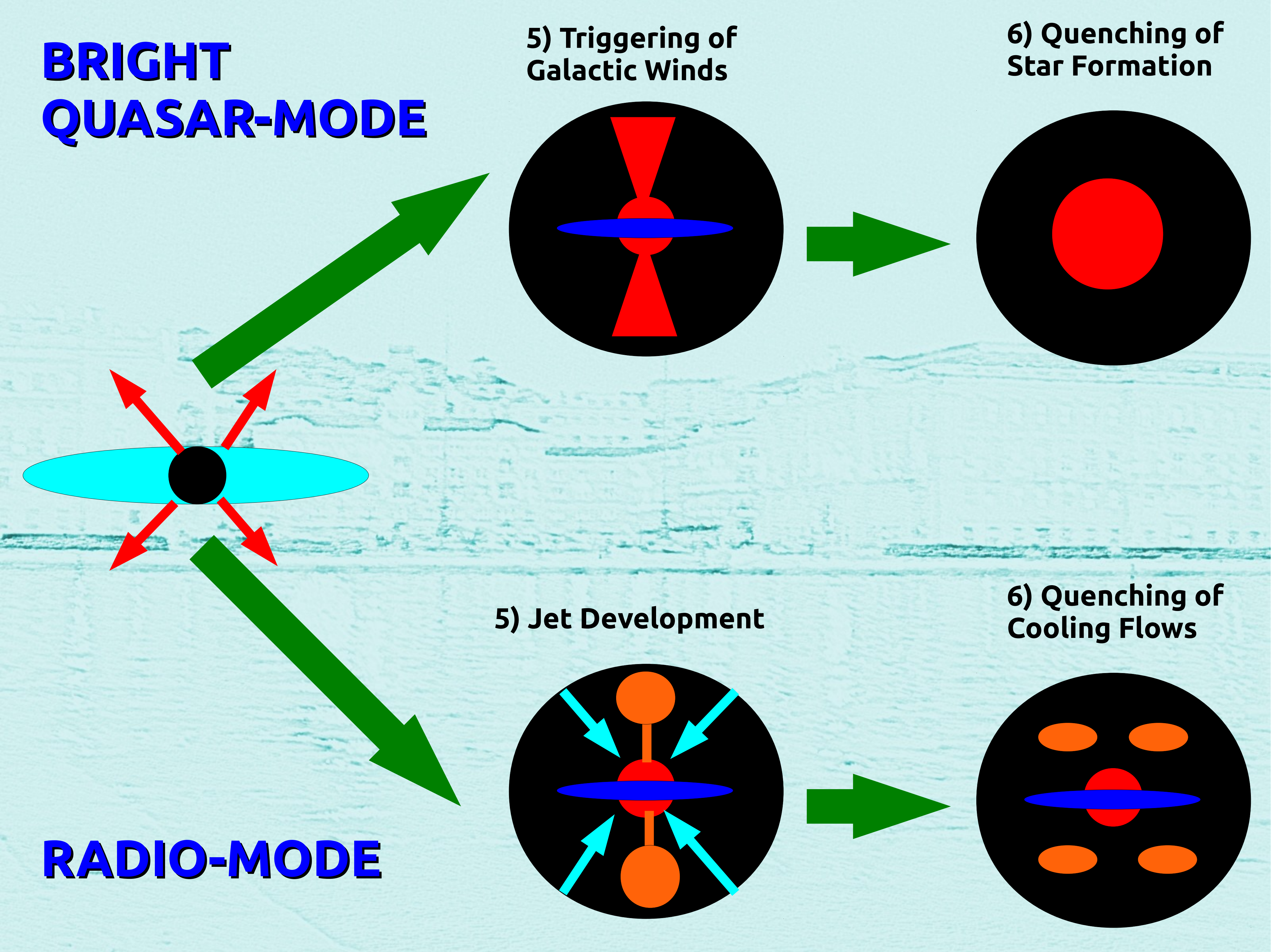
Fontanot+17b
z~4
z~5
z~6
z~7
Log(Φ)
Log(M_star / M_⊙)
log(M*/M_⊙)
[11,12]
[10,11]
[9,10]
H16F
FIDUCIAL
Log(ρ_SFR / M_⊙yr^-1 Mpc^-3)
Redshift

Conclusions I

- Strong stellar-driven outflows coupled with mass-dependent re-accretion timescales are able to recover the evolution of the rest-frame UV and optical LFs over the redshift range $4<z<7$
- GAEA provides a self consistent picture of galaxy evolution at $z<10$
- Beware Dust!
  - GAEA in qualitative agreement with UV-selected samples
  - Self-consistent models of dust still missing
  - Powerful discriminant between different stellar feedback schemes

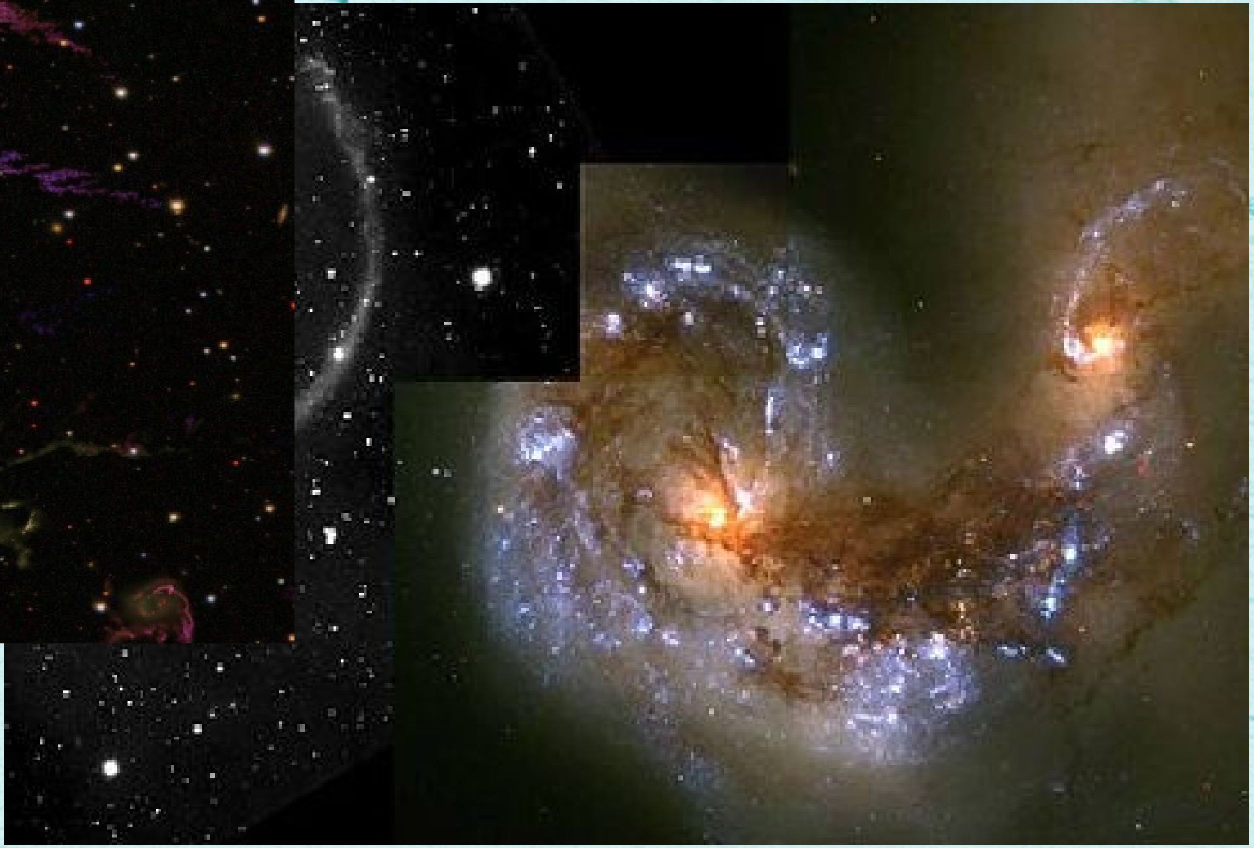
AGN activity in theoretical models of galaxy formation

- Represents a viable "solution" for a number of long-standing theoretical problems
- Properties of AGN and Galaxy population are "similar"
- Joint evolution of Galaxies and AGNs


BRIGHT
QUASAR-MODE
5) Triggering of
Galactic Winds
6) Quenching of
Star Formation
5) Jet Development
6) Quenching of
Cooling Flows
RADIO-MODE

Different regimes

- **"Quasar"-mode**
- **High-accretion**
- **Bright-phase**
- **Galaxy Mergers**



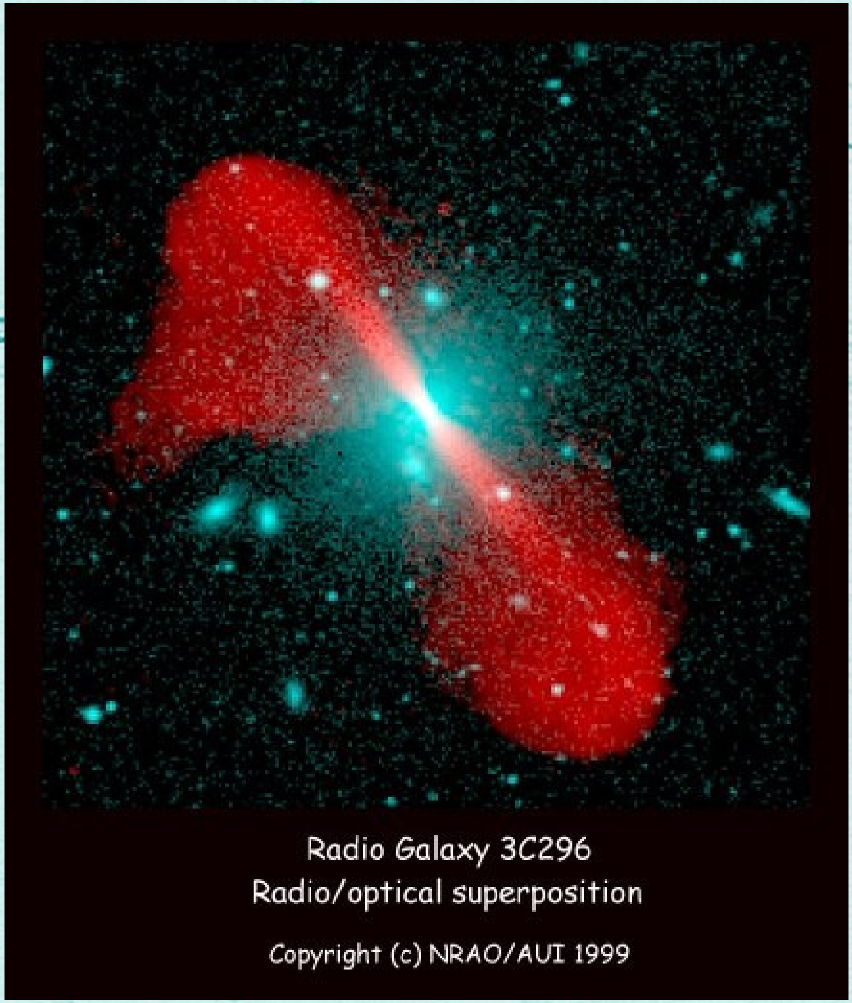
Springel+05

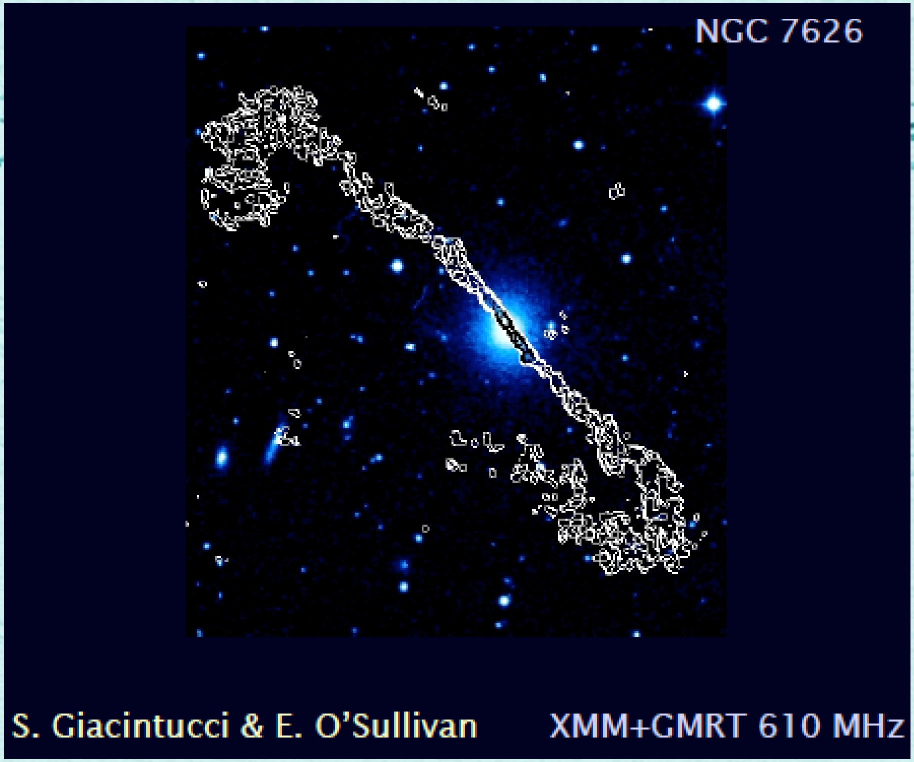
Different regimes

- “Quasar”-mode
- High-accretion
- Bright-phase
- Galaxy Mergers
  - Secular processes?

Different regimes

- "Radio"-mode
- Low-accretion
- Development of radio jets





Different regimes

- “Radio”-mode
- Low-accretion
- Development of radio jets
- Keep massive galaxies red
- Hot Haloes
  - Dry Mergers?
- LargeScales (DMH)
- Long
  - Steady state accretion rate or cyclic behaviour?
- Regulates stellar mass

- “Quasar”-mode
- High-accretion
- Bright-phase
- From blue to red
- Galaxy Mergers
  - Secular processes?
- Small Scales (~kpc)
  - Triggering galactic winds?
- Rapid
- Regulates BH mass

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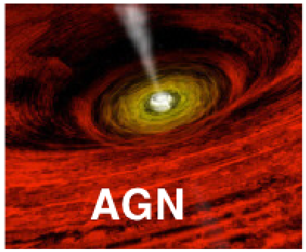
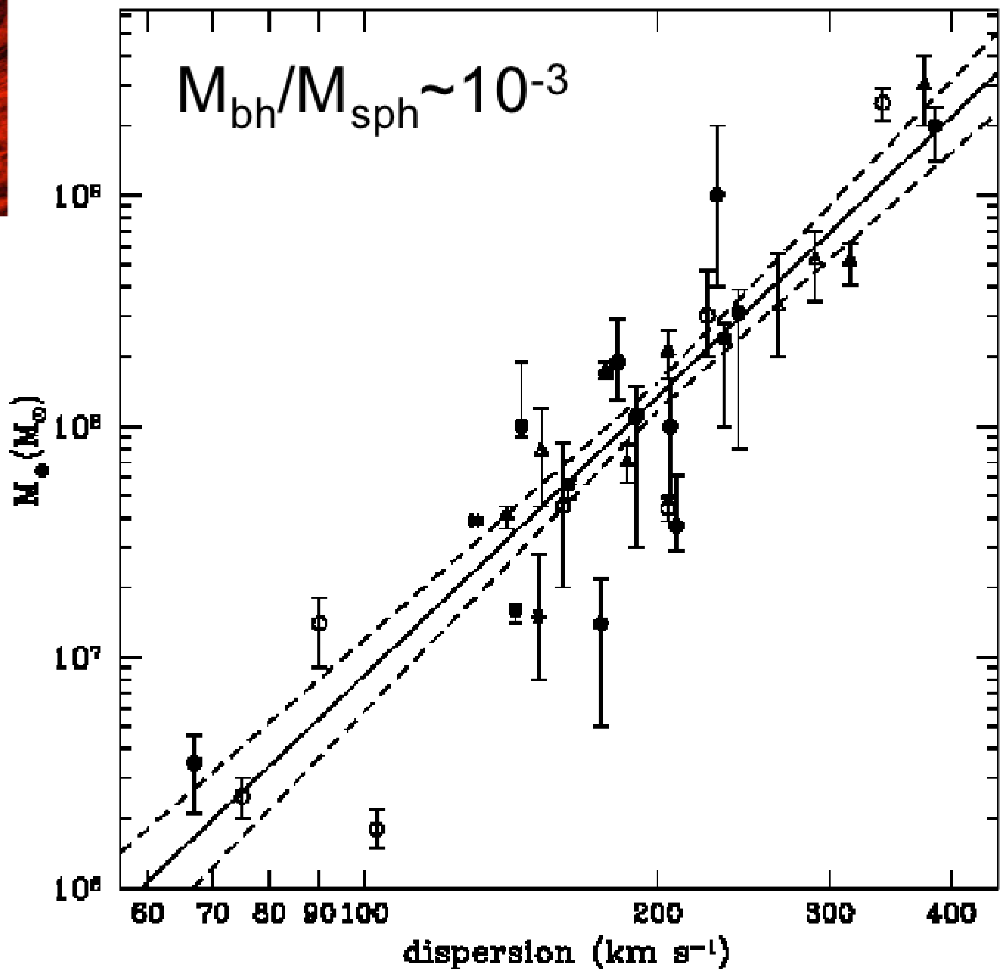
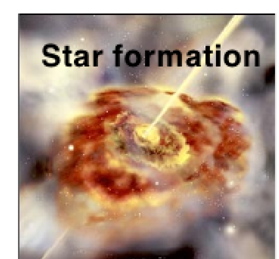
BH-bulge relation



Driver: AGN activity

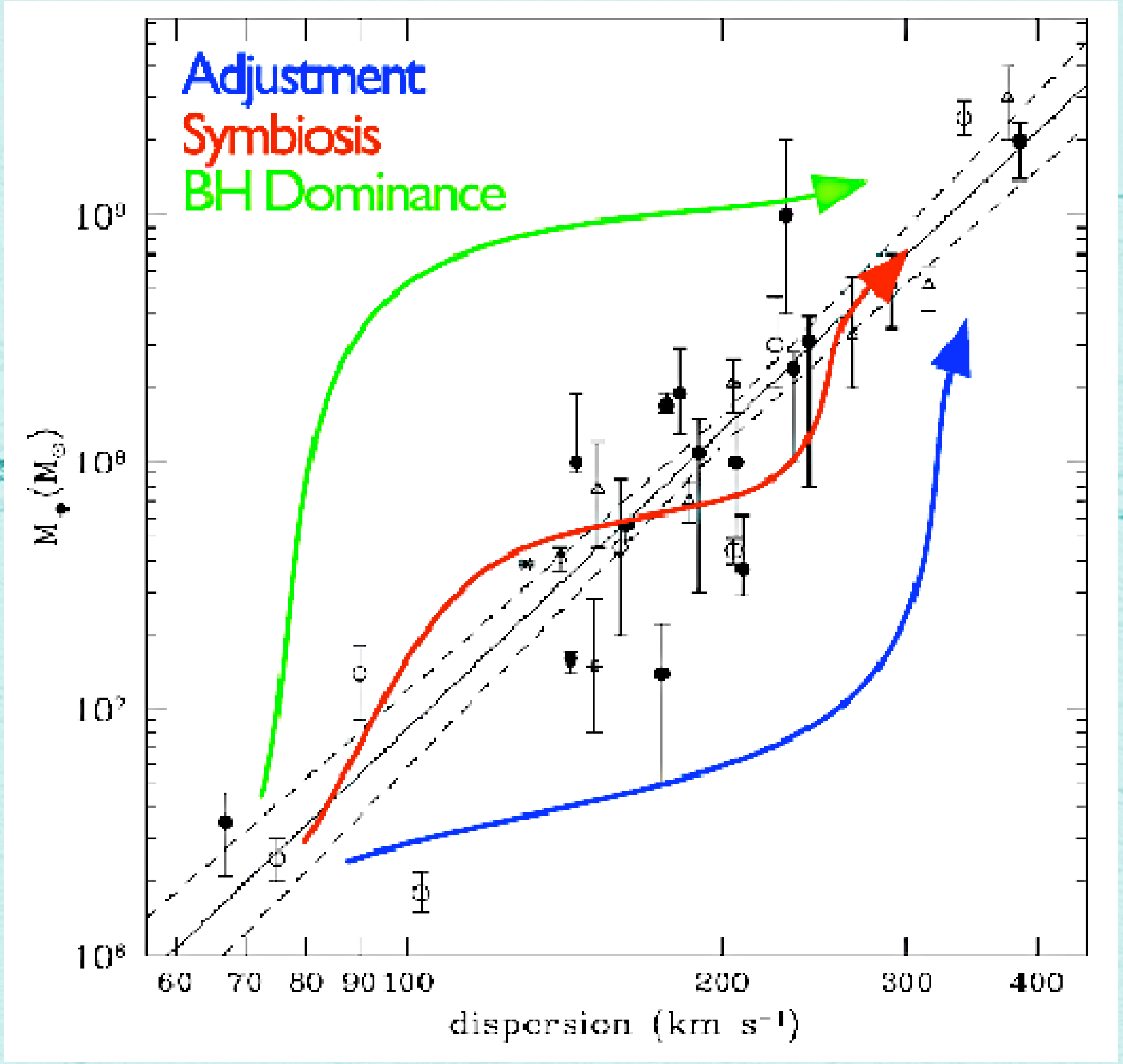




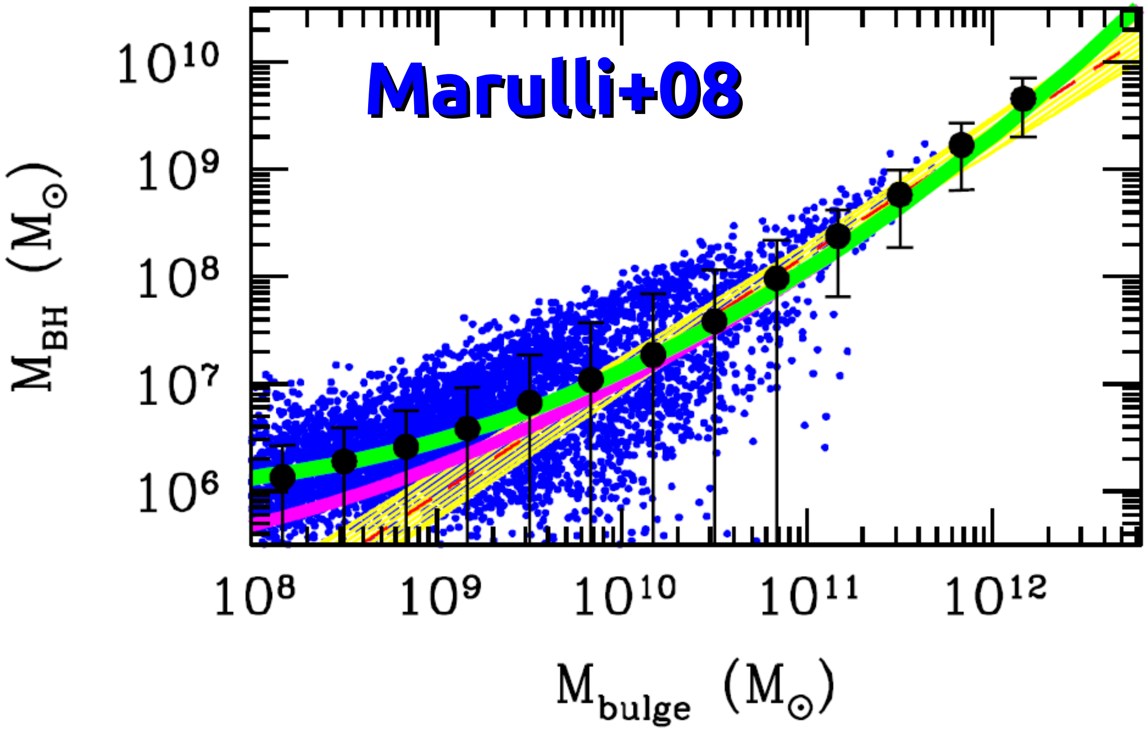
Driver: Star formation (gas accretion/mergers)

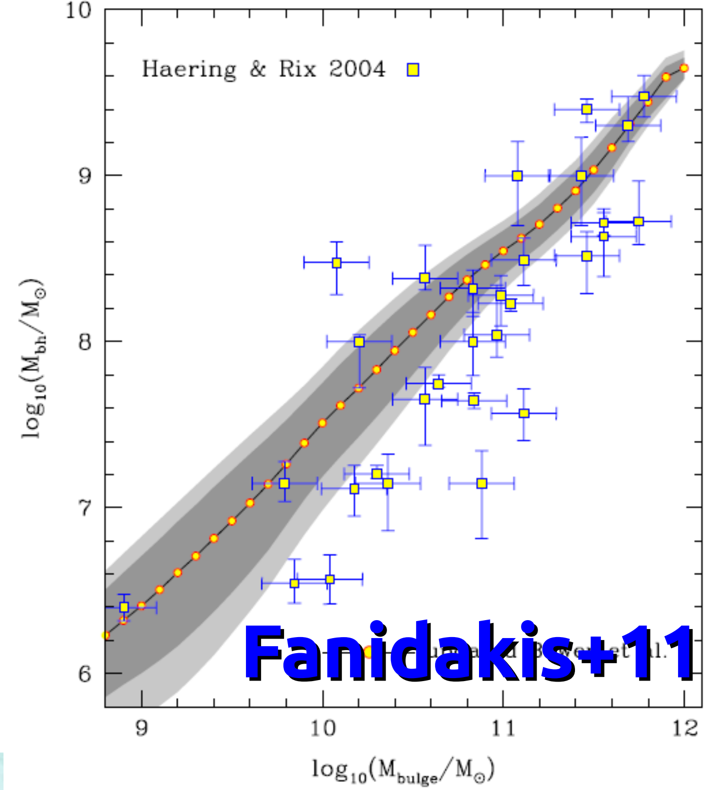
Credits **Dave Alexander**

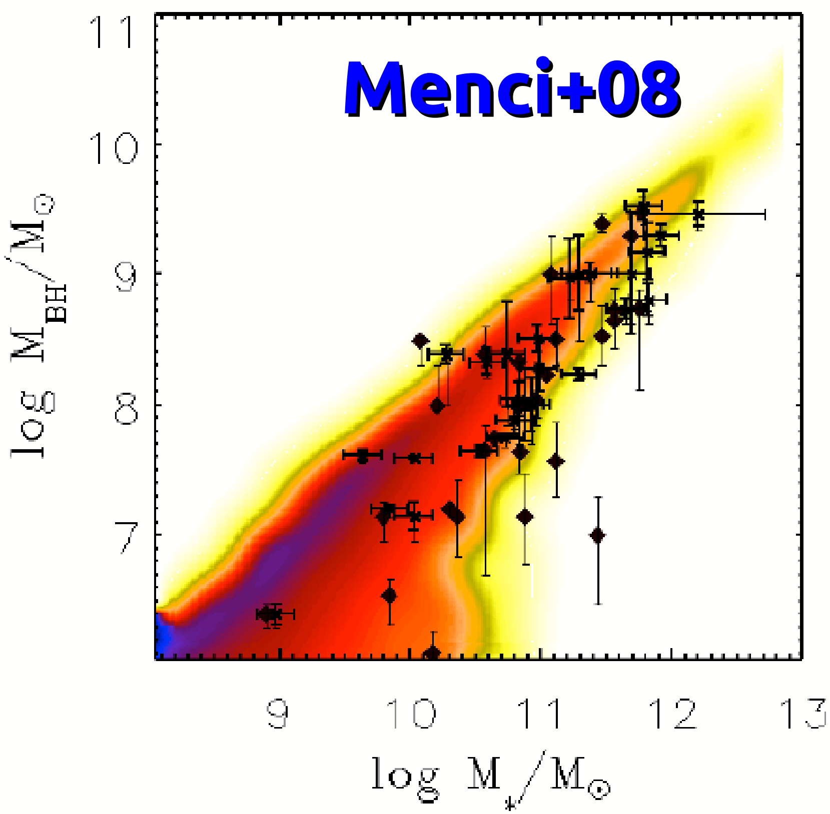
Assembly of BH-bulge relation

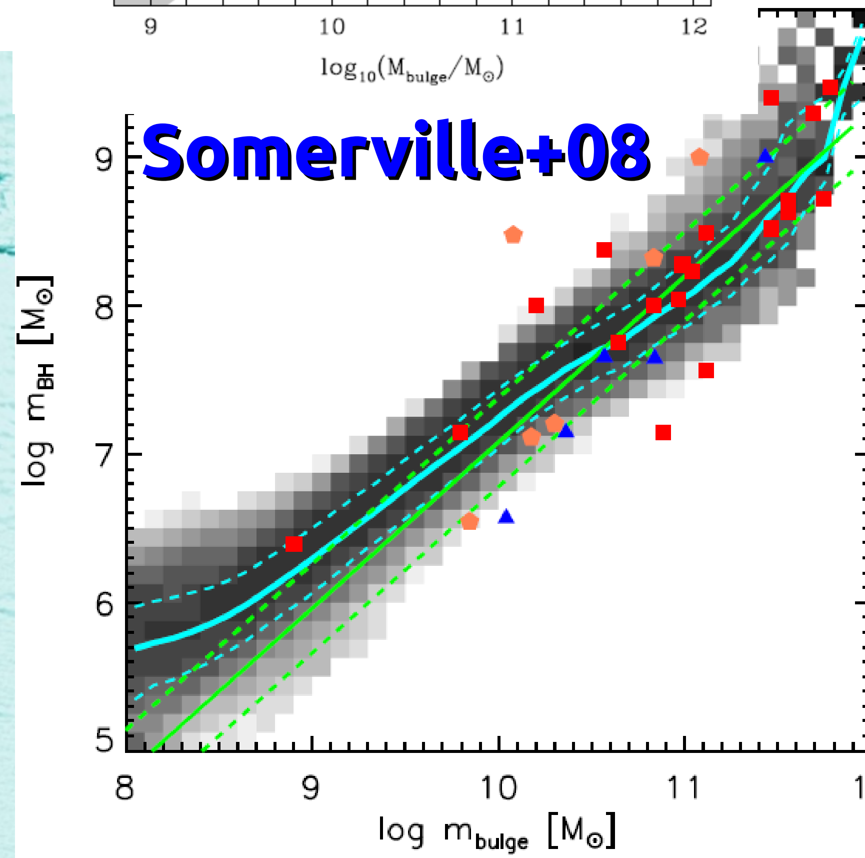


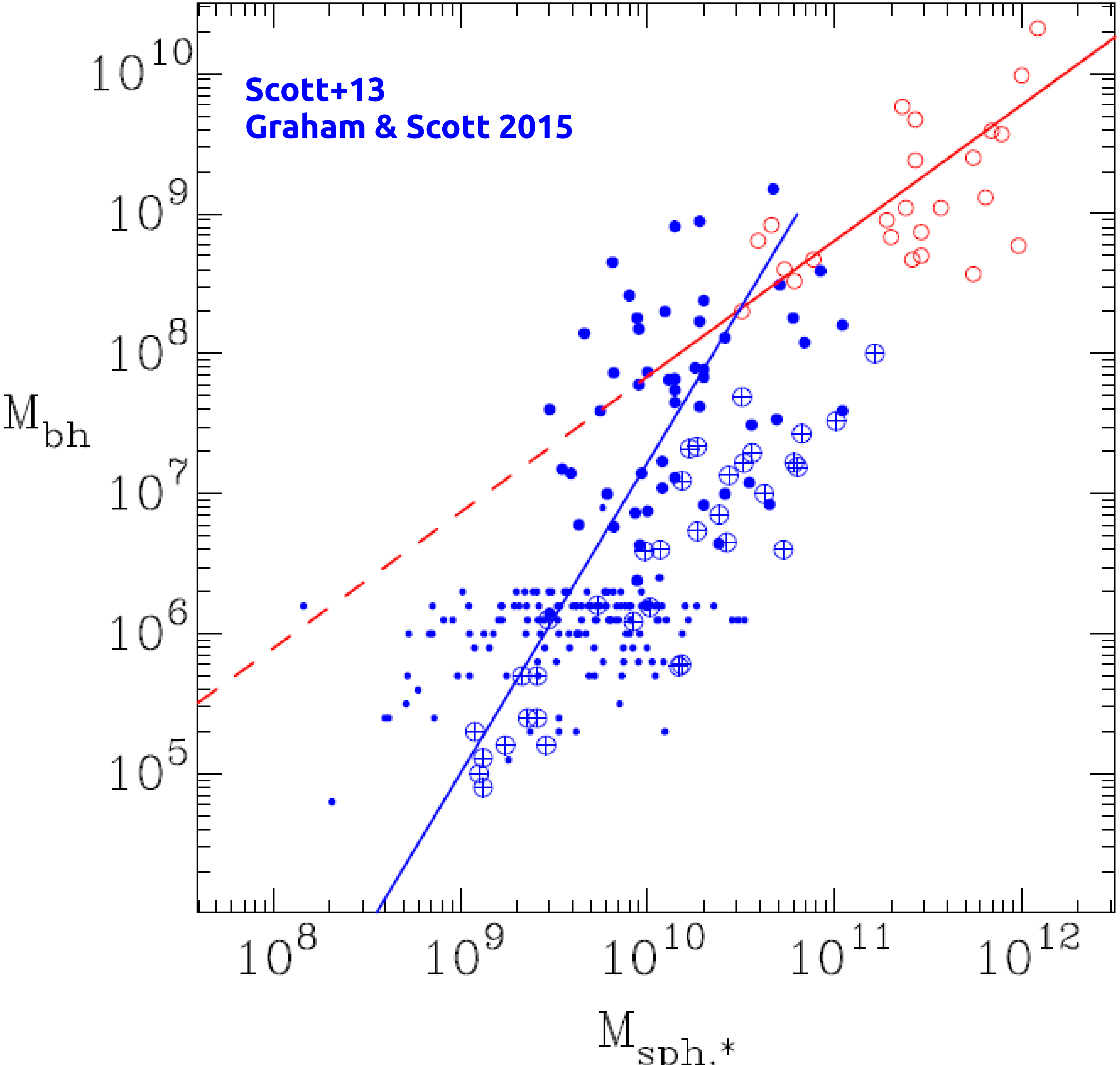
Colpi+07
Volonteri+10


Marulli+08
M_{BH} ($M_\odot$)
M_{bulge} ($M_\odot$)
10^{6} 10^{7} 10^{8} 10^{9} 10^{10}
10^{8} 10^{9} 10^{10} 10^{11} 10^{12}

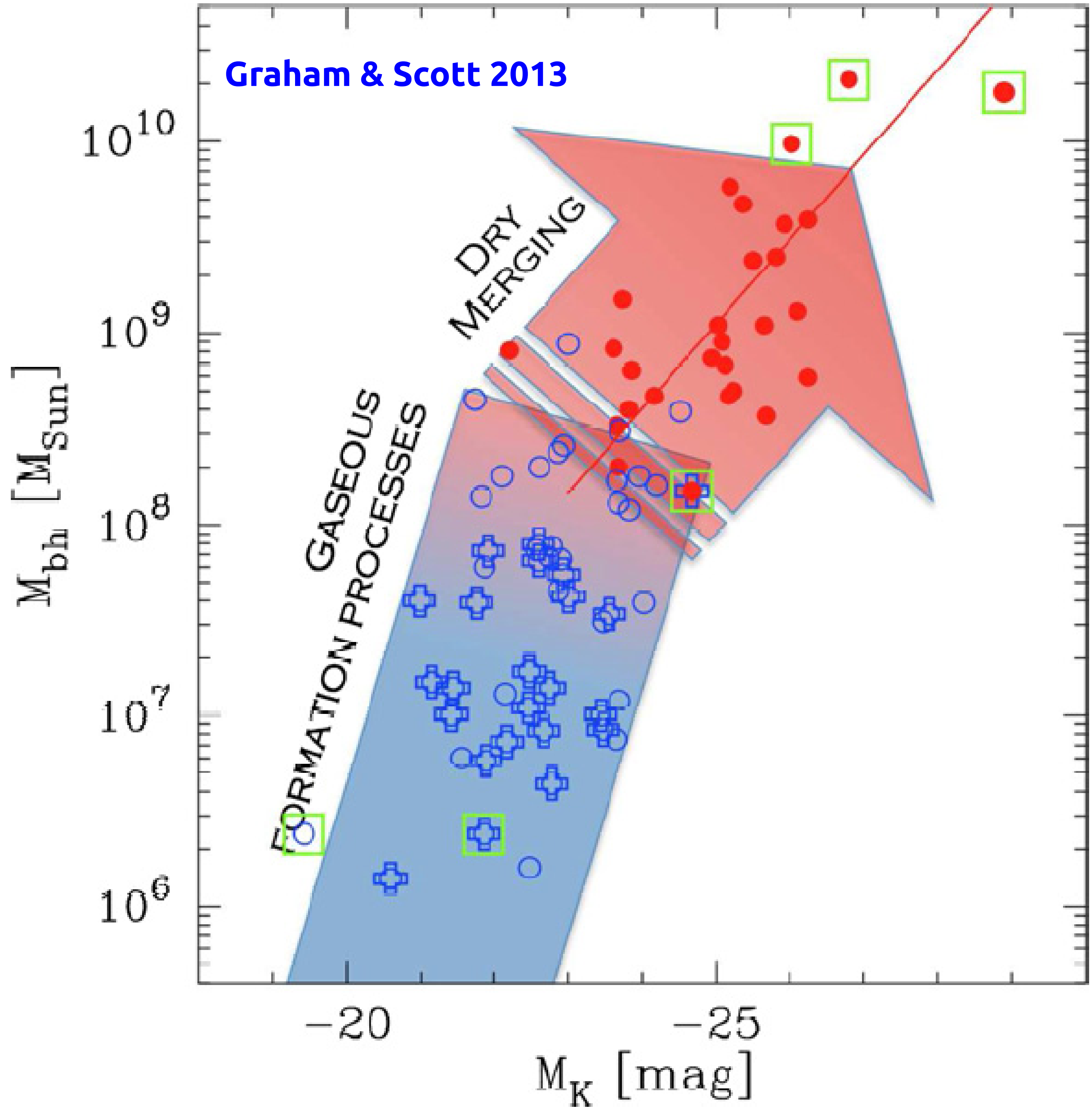

Haering & Rix 2004
Fanidakis+11
$\log_{10}(M_{bh}/M_\odot)$
$\log_{10}(M_{bulge}/M_\odot)$
6 7 8 9 10
9 10 11 12


Menci+08
log $M_{BH}/M_\odot$
log $M_*/M_\odot$
7 8 9 10 11
9 10 11 12 13

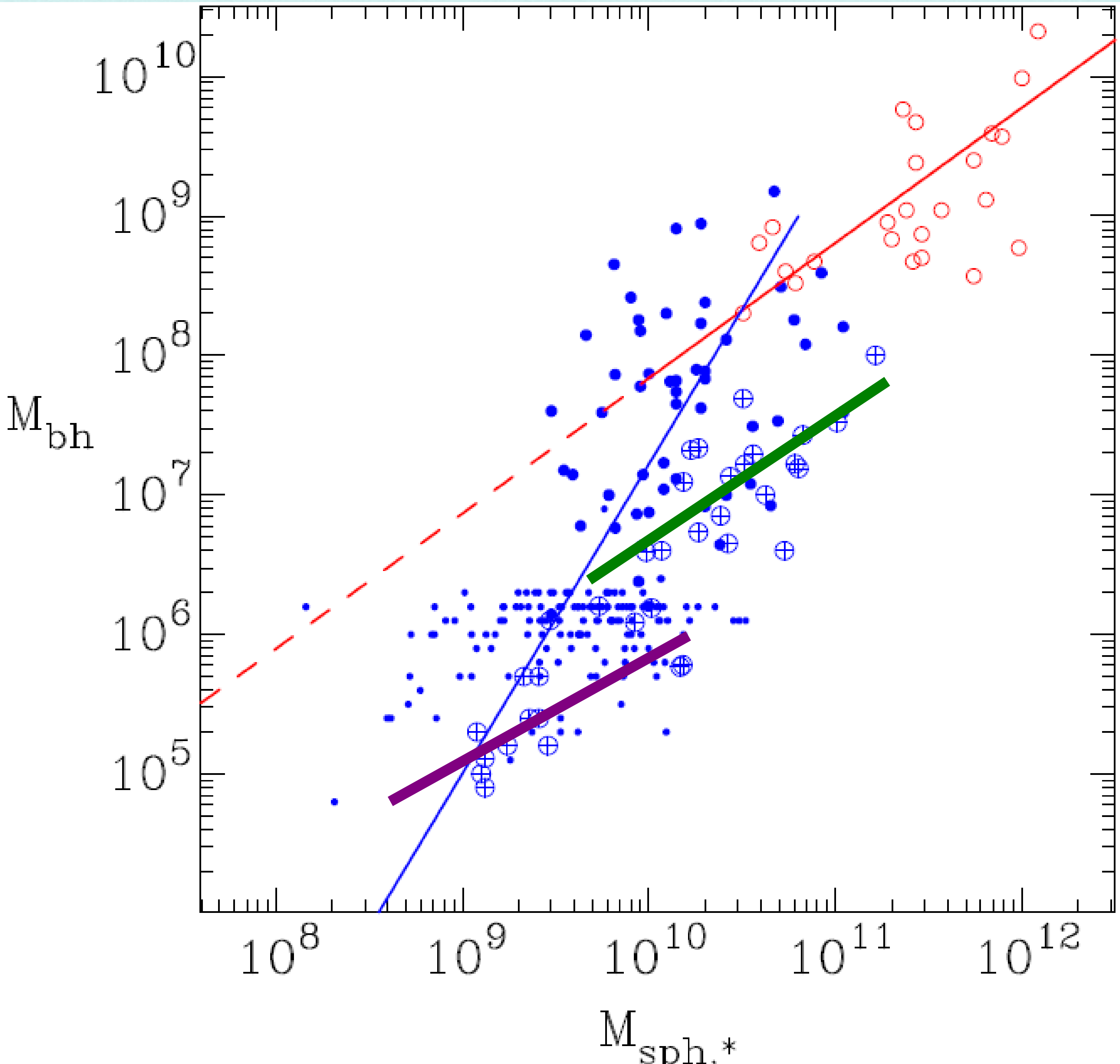

Somerville+08
log m_{BH} [$M_\odot$]
log m_{bulge} [$M_\odot$]
5 6 7 8 9
8 9 10 11 12



Scott+13
Graham & Scott 2015
M_{bh}
$M_{sph,*}$
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}

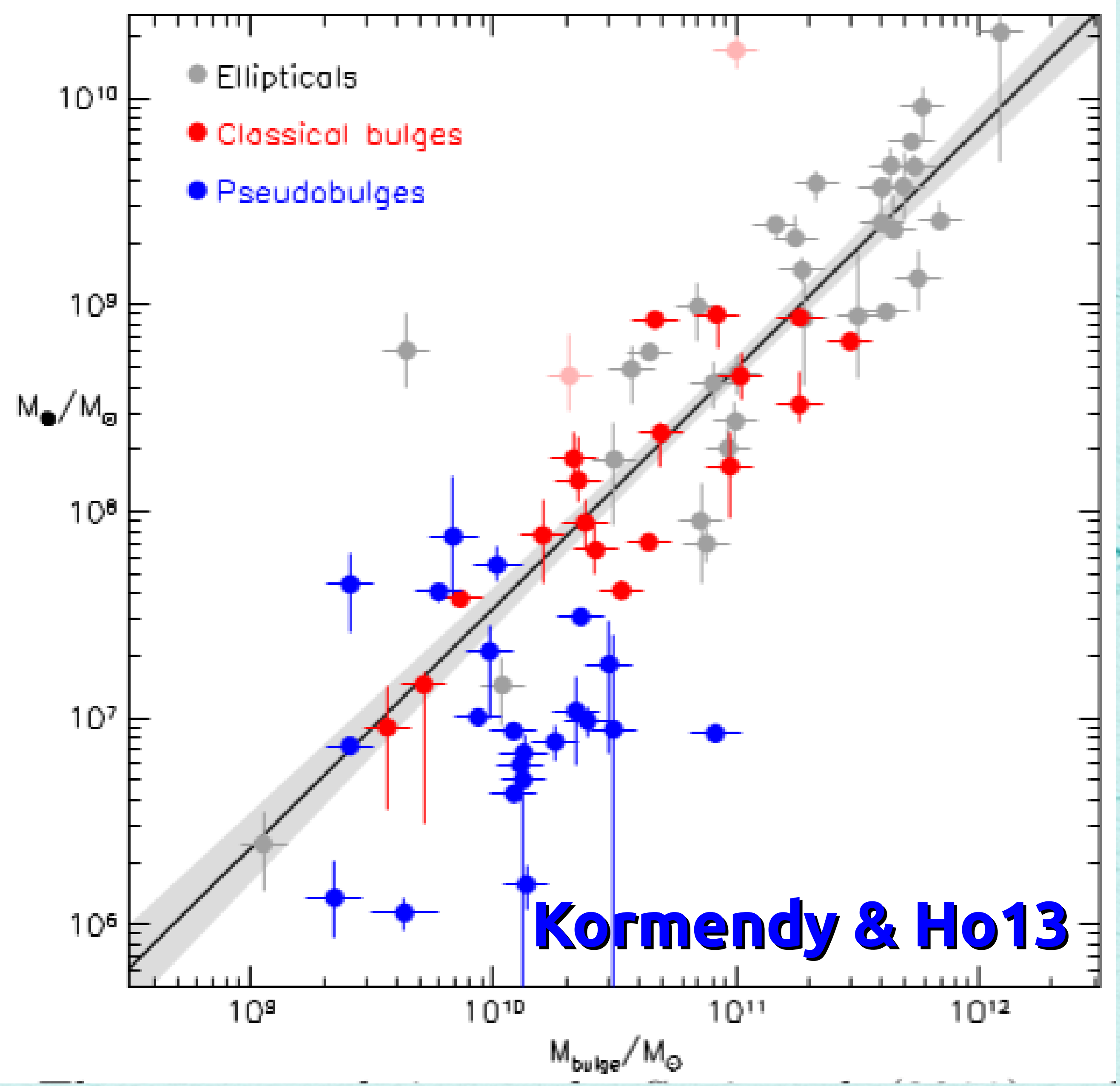


Graham & Scott 2013
DRY MERGING
GASEOUS FORMATION PROCESSES
10^{10}
10^9
10^8
10^7
10^6
M_{bh} [M_{Sun}]
−20
−25
M_K [mag]

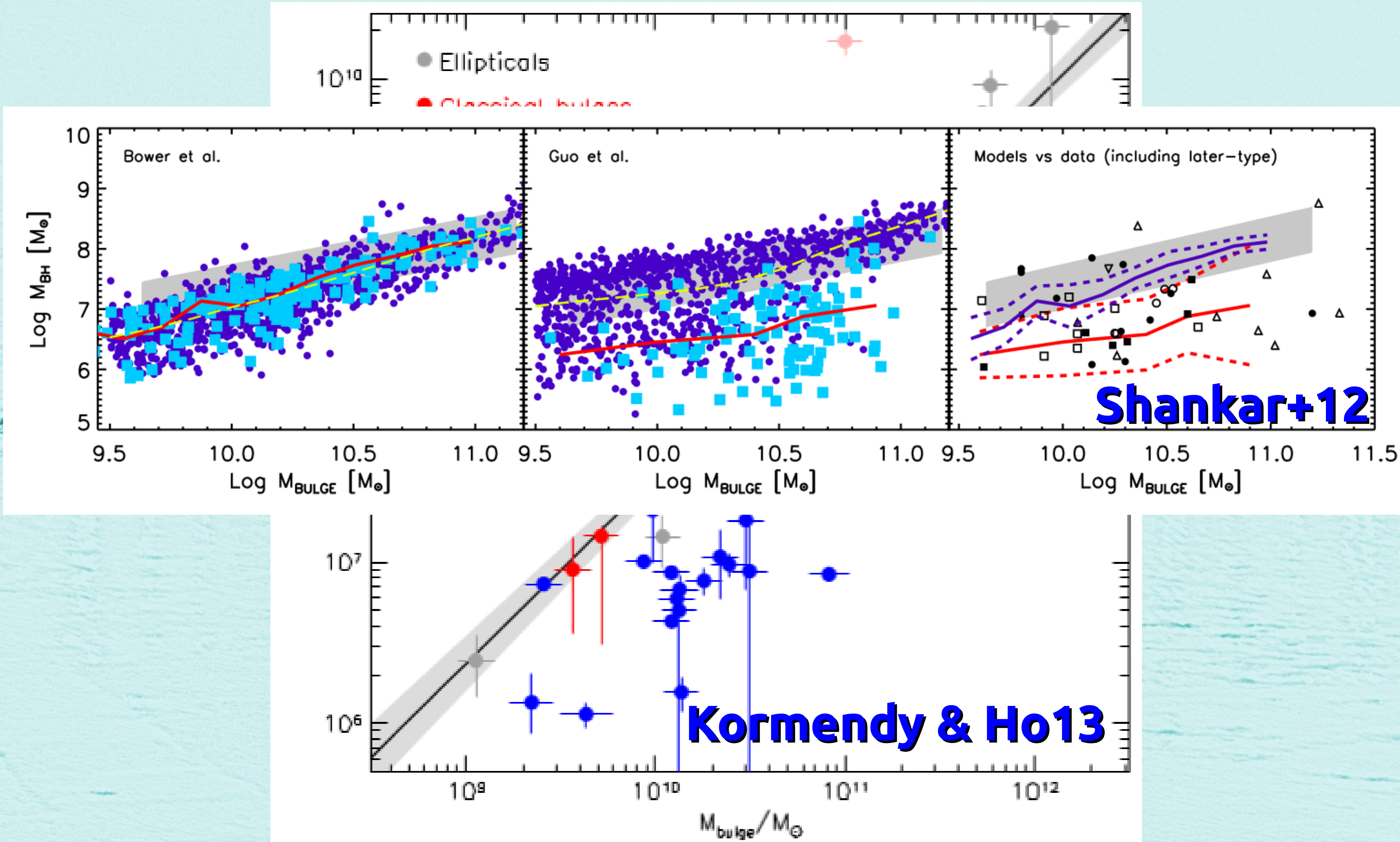


M_{bh}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
$M_{sph,*}$

Mergers vs Secular

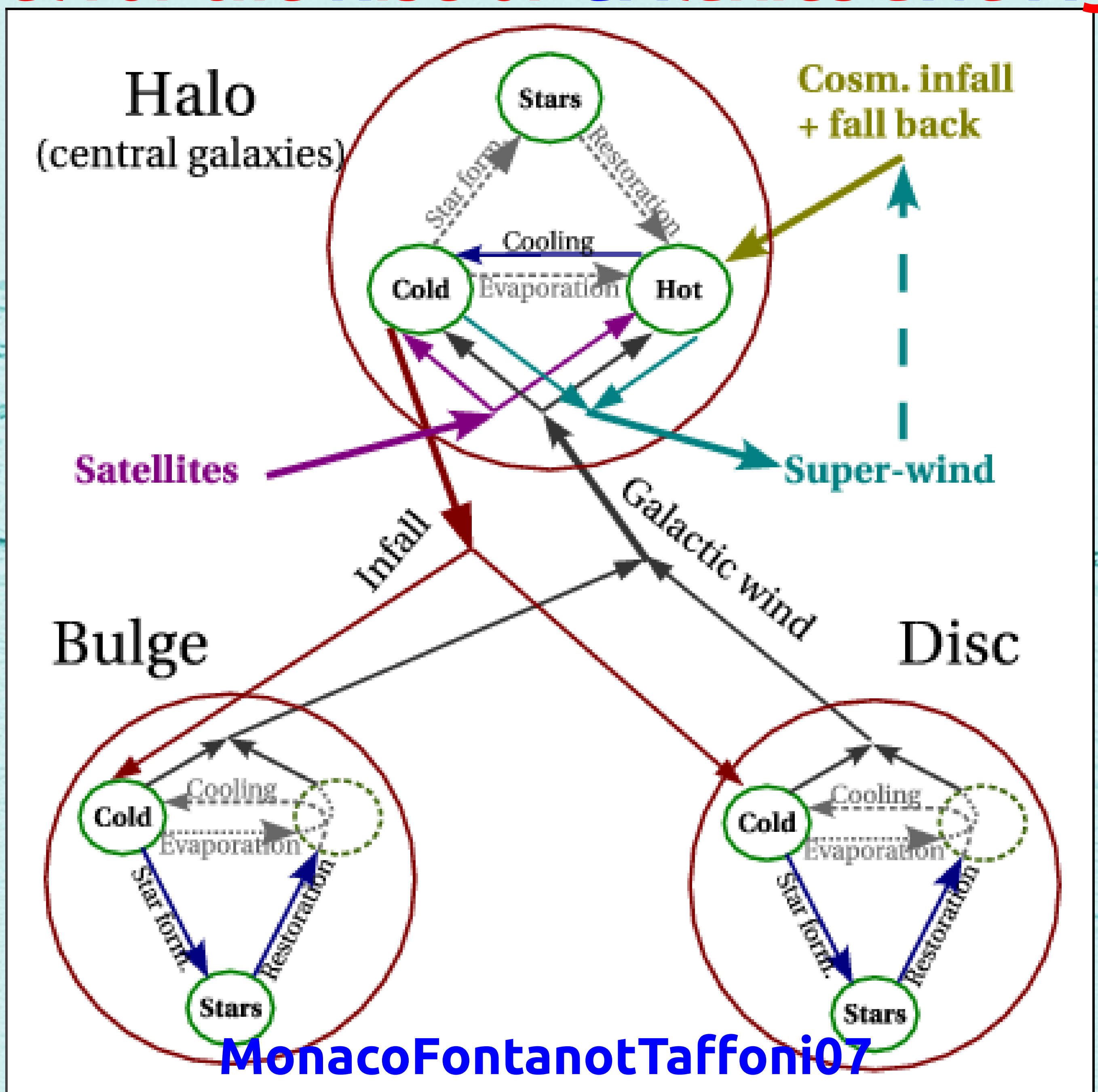


Mergers vs Secular



MORGANA

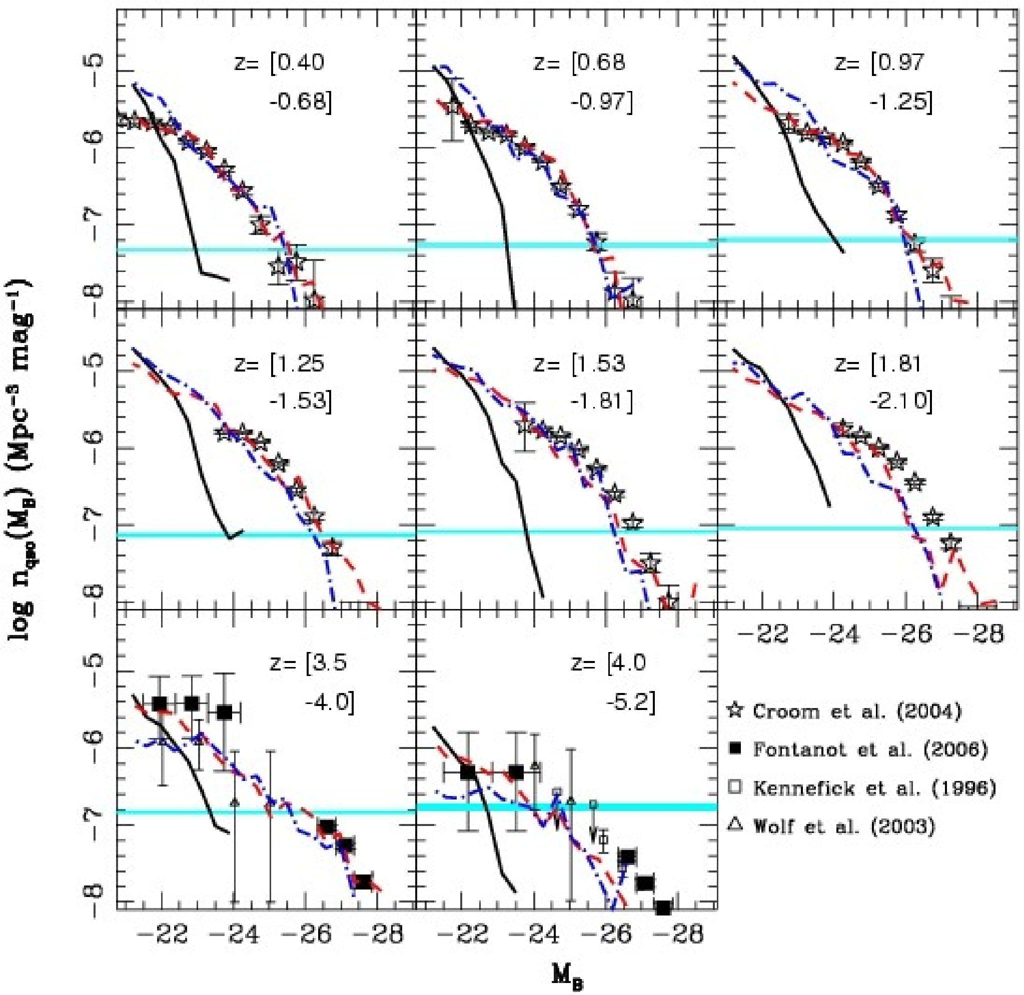
MOdel for the Rise of GAlaxies aNd Agns



MonacoFontanotTaffoni07

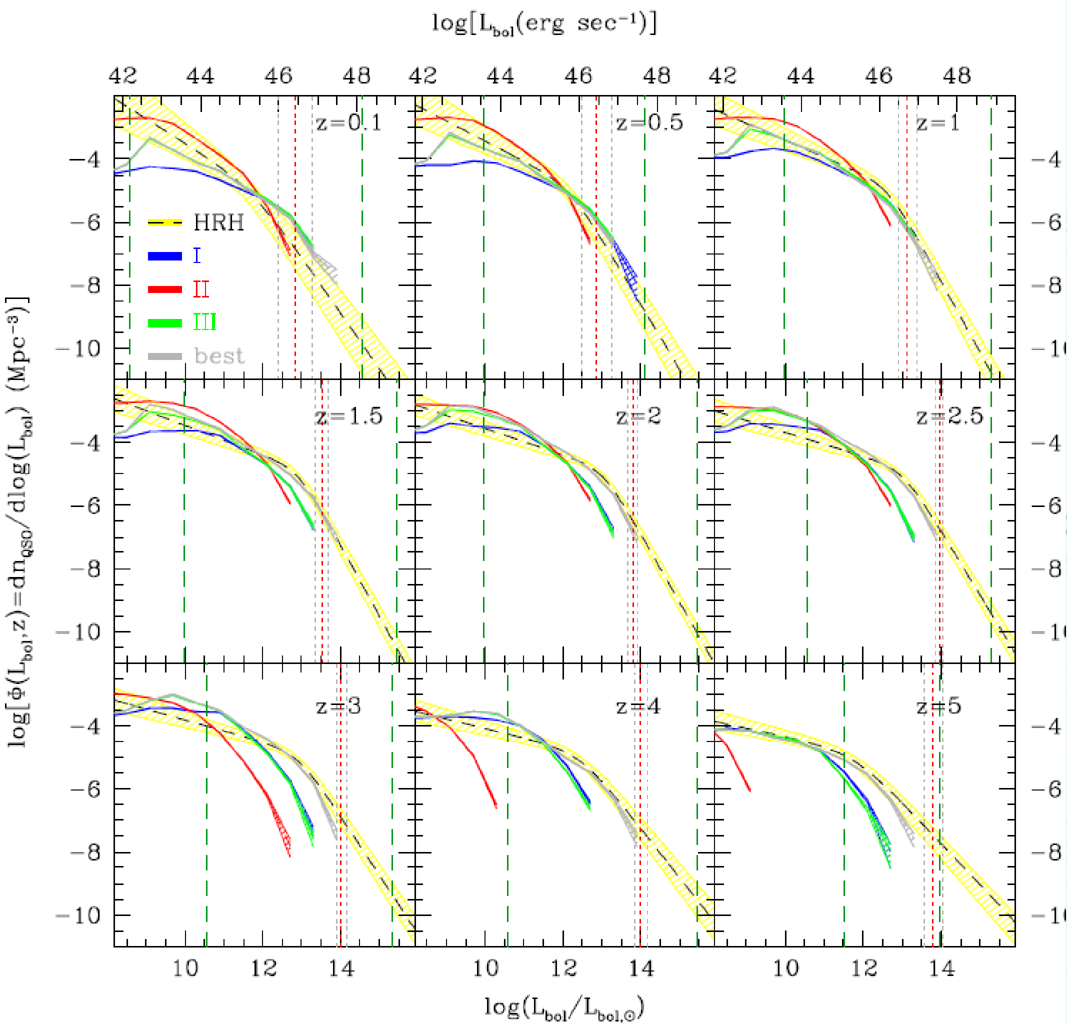
QSO-LF evolution

MORGANA: Optical



Fontanot+06

DLB07: Bolometric

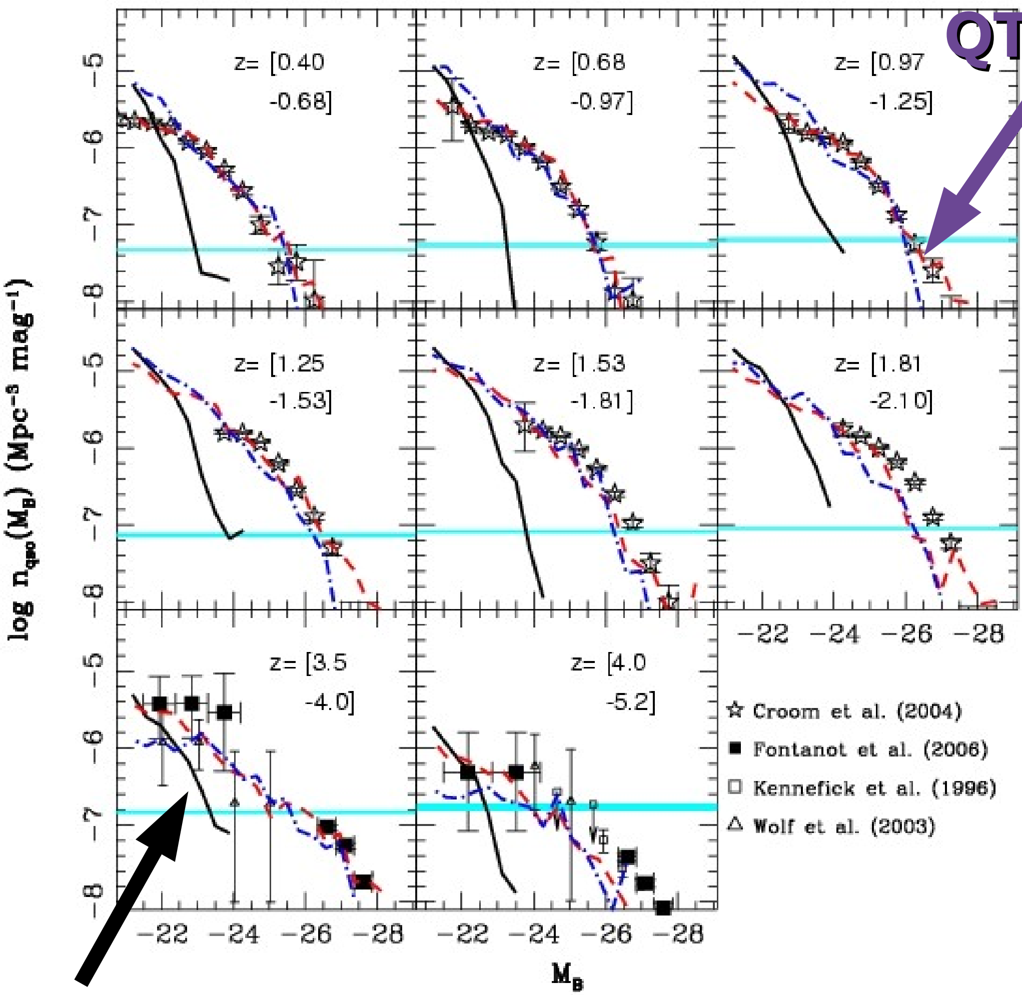


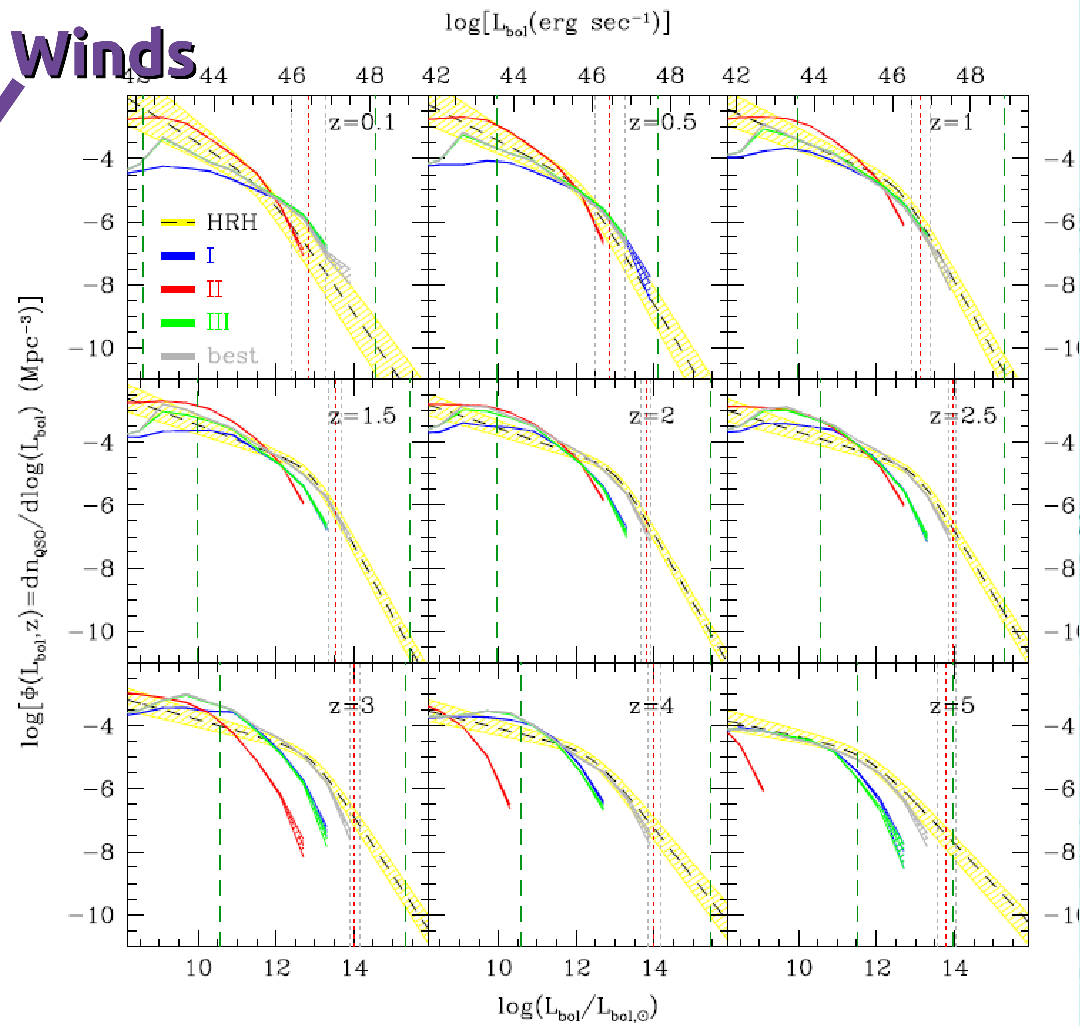
Marulli+08

QSO-LF evolution

MORGANA: Optical

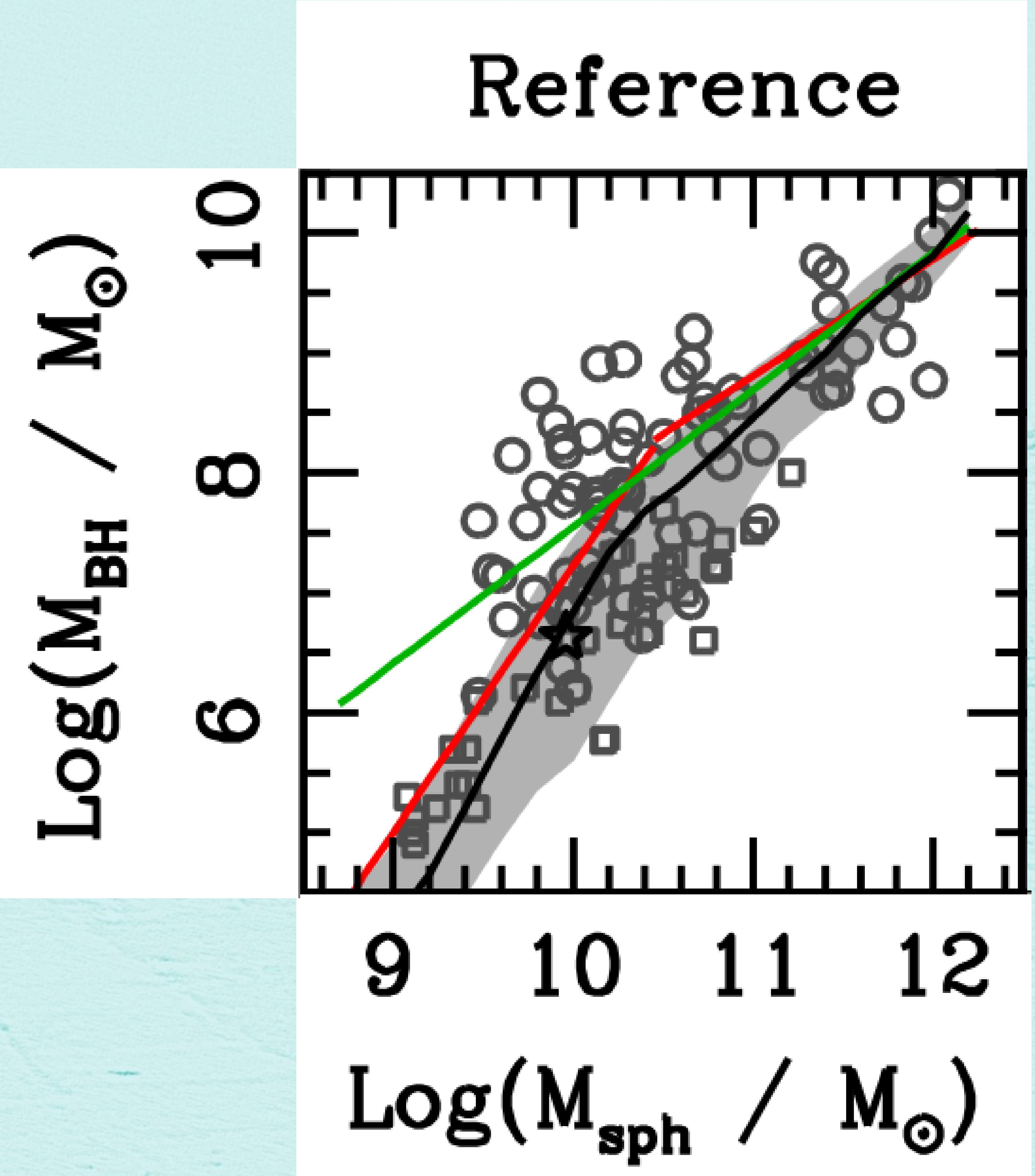
DLB07: Bolometric





Fontanot+06

Marulli+08



MORGANA prediction (back 2006)

QSO evolution in MORGANA

- Cold gas in Bulges fuels BH accretion
  - Galaxy Mergers - Disc Instabilities - direct inflow

$$\dot{M}_{\rm RS}^{+} = f_{\rm BH}\phi_{\rm B}\left(\frac{\phi_{\rm B}}{100\,{\rm M}_{\odot}\,{\rm yr}^{-1}}\right)^{\alpha-1}$$

- Explicit modeling of cold gas “reservoir” around the central SMBH
  - Reservoir viscosity regulates SMBH accretion
    Umemura01 Granato+04

$$\dot{M}_{\rm RS}^{-} = \dot{M}_{\rm BH} = 0.001\frac{\sigma_B^3}{G}\left(\frac{M_{\rm RS}}{M_{\rm BH}}\right)^{3/2}\left(1+\frac{M_{\rm BH}}{M_{\rm RS}}\right)^{1/2}$$

QSO evolution in MORGANA

- **Cold gas in Bulges fuels BH accretion**
  - **Galaxy Mergers - Disc Instabilities - direct inflow**

$$\dot{M}^{+}_{\rm RS} = f_{\rm BH}\phi_{\rm B}\left(\frac{\phi_{\rm B}}{100\,{\rm M}_{\odot}\,{\rm yr}^{-1}}\right)^{\alpha-1}$$

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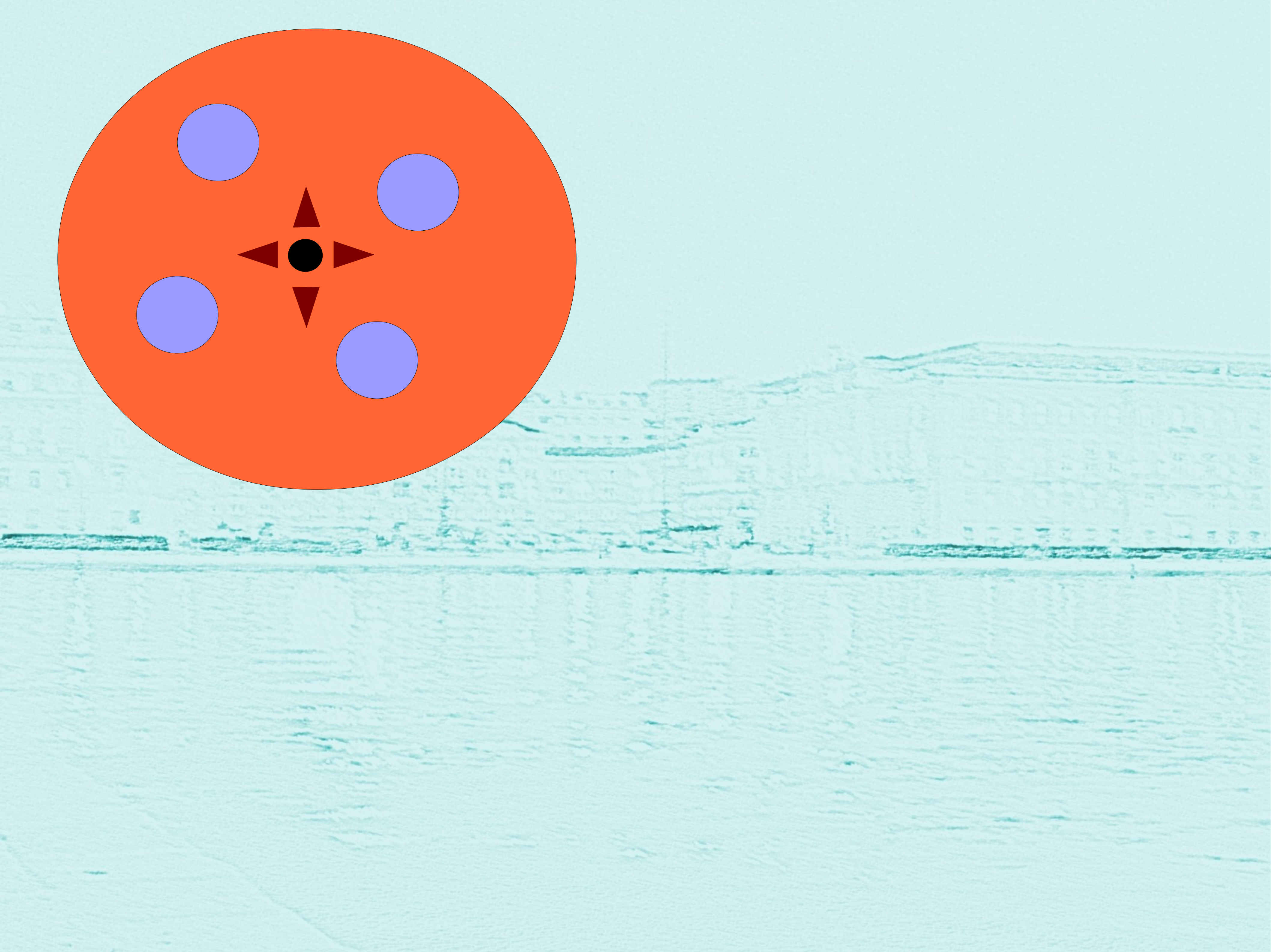
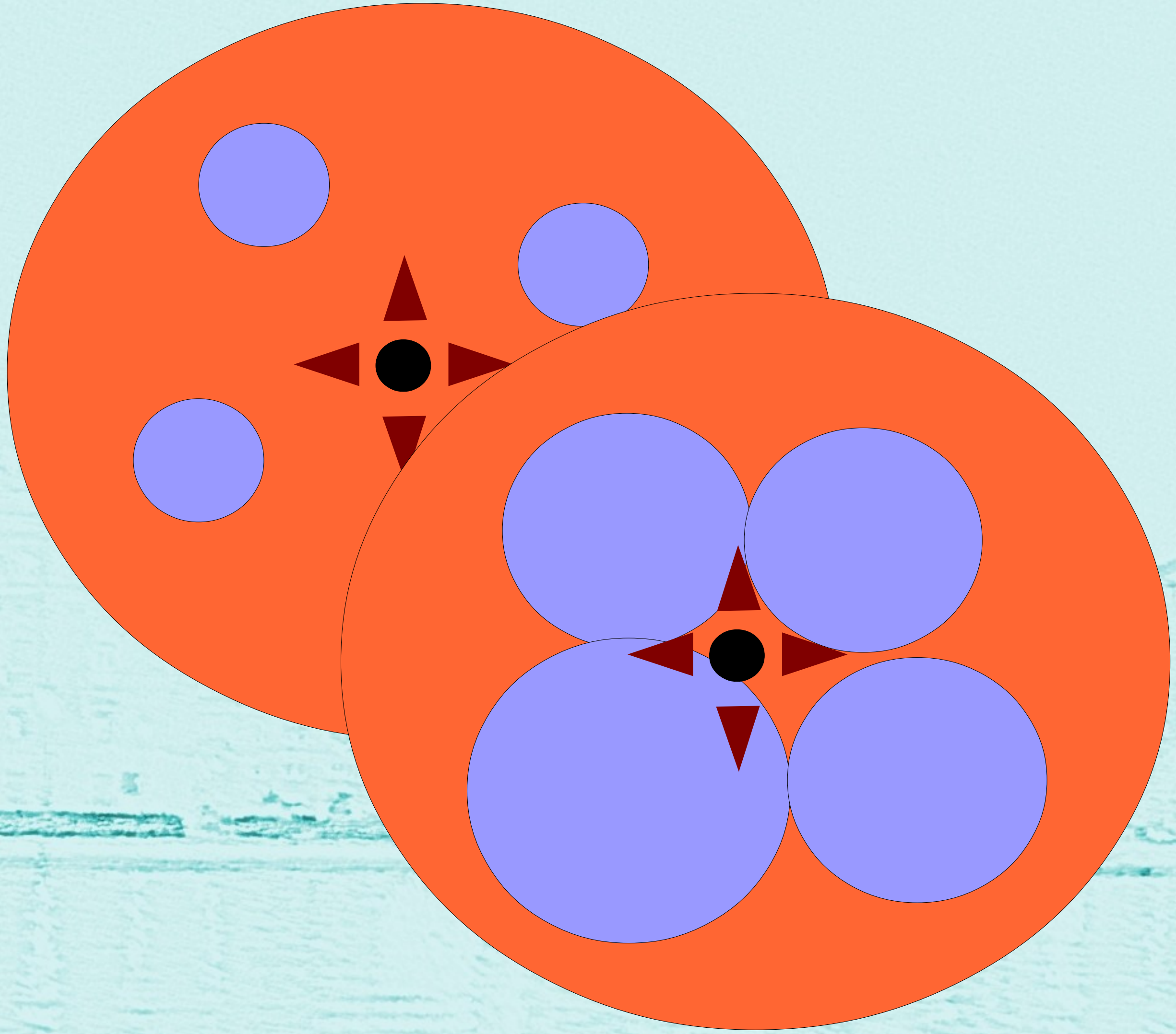
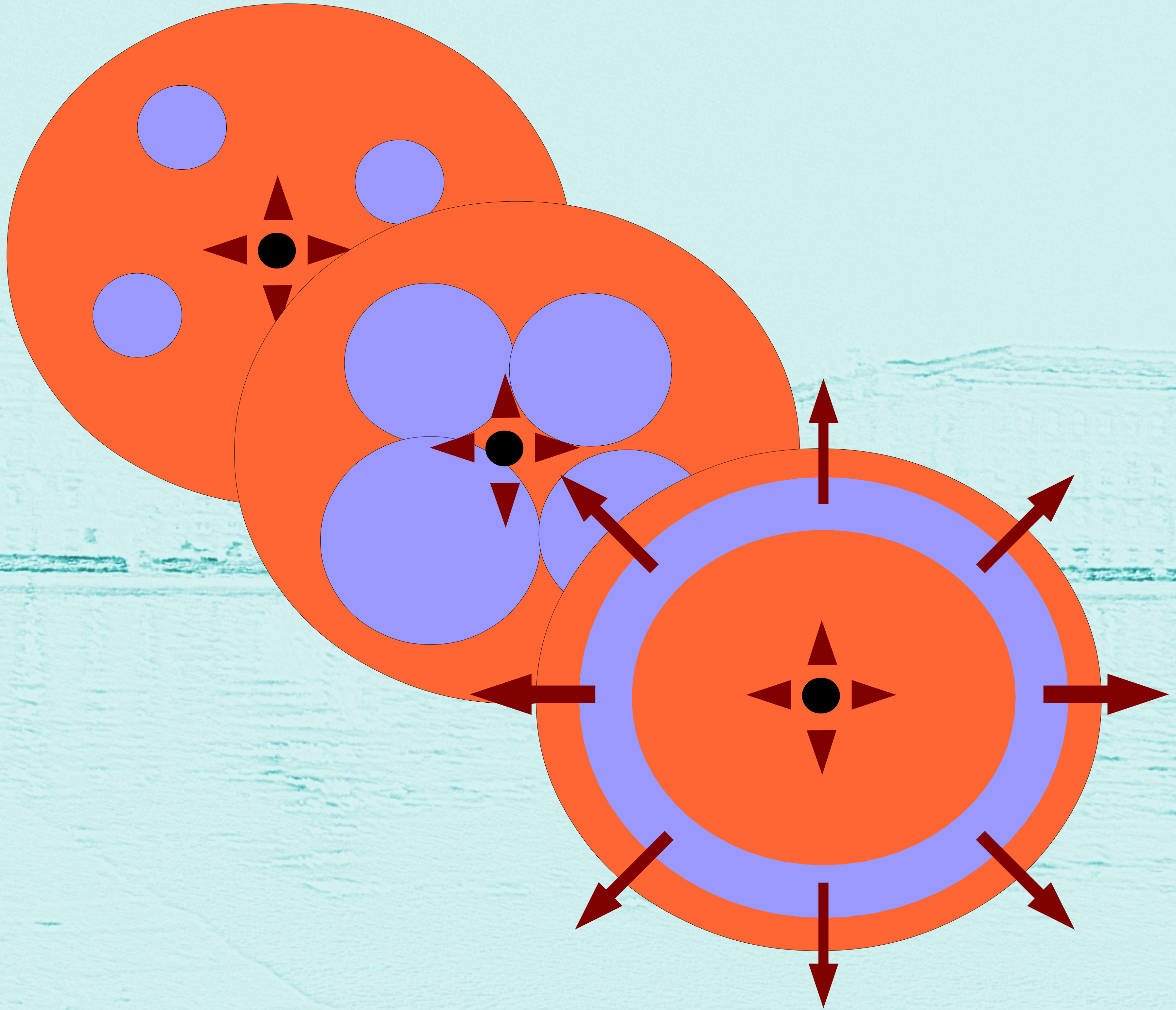
$$\dot{M}^{-}_{\rm RS} = \dot{M}_{\rm BH} = 0.001\frac{\sigma_B^3}{G}\left(\frac{M_{\rm RS}}{M_{\rm BH}}\right)^{3/2}\left(1+\frac{M_{\rm BH}}{M_{\rm RS}}\right)^{1/2}$$

- **Interplay between stellar and AGN feedback**
  - **Kinetic Stellar Feedback**

$$\sigma_{\rm cg} = \zeta_0\left(\frac{t_\star}{1\,{\rm Gyr}}\right)^{-1/3}\,{\rm km\,s^{-1}}$$







QSO evolution in MORGANA

- Cold gas in Bulges fuels BH accretion
  - Galaxy Mergers - Disc Instabilities - direct inflow

$$\dot{M}_{\rm RS}^{+} = f_{\rm BH}\phi_{\rm B}\left(\frac{\phi_{\rm B}}{100\,{\rm M}_\odot\,{\rm yr}^{-1}}\right)^{\alpha-1}$$

- Explicit modeling of cold gas "reservoir" around the central SMBH
  - Reservoir viscosity regulates SMBH accretion

$$\dot{M}_{\rm RS}^{-} = \dot{M}_{\rm BH} = 0.001\frac{\sigma_B^3}{G}\left(\frac{M_{\rm RS}}{M_{\rm BH}}\right)^{3/2}\left(1+\frac{M_{\rm BH}}{M_{\rm RS}}\right)^{1/2}$$

- Interplay between stellar sand AGN feedback
  - Kinetic Stellar Feedback

$$\sigma_{\rm cg} = \zeta_0\left(\frac{t_\star}{1\,{\rm Gyr}}\right)^{-1/3}\,{\rm km\,s^{-1}}$$

QSO evolution in MORGANA

- Cold gas in Bulges fuels BH accretion
  - Galaxy Mergers - Disc Instabilities - direct inflow

$$\dot{M}_{\rm RS}^{+} = f_{\rm BH}\phi_{\rm B}\left(\frac{\phi_{\rm B}}{100\,{\rm M}_\odot\,{\rm yr}^{-1}}\right)^{\alpha-1}$$

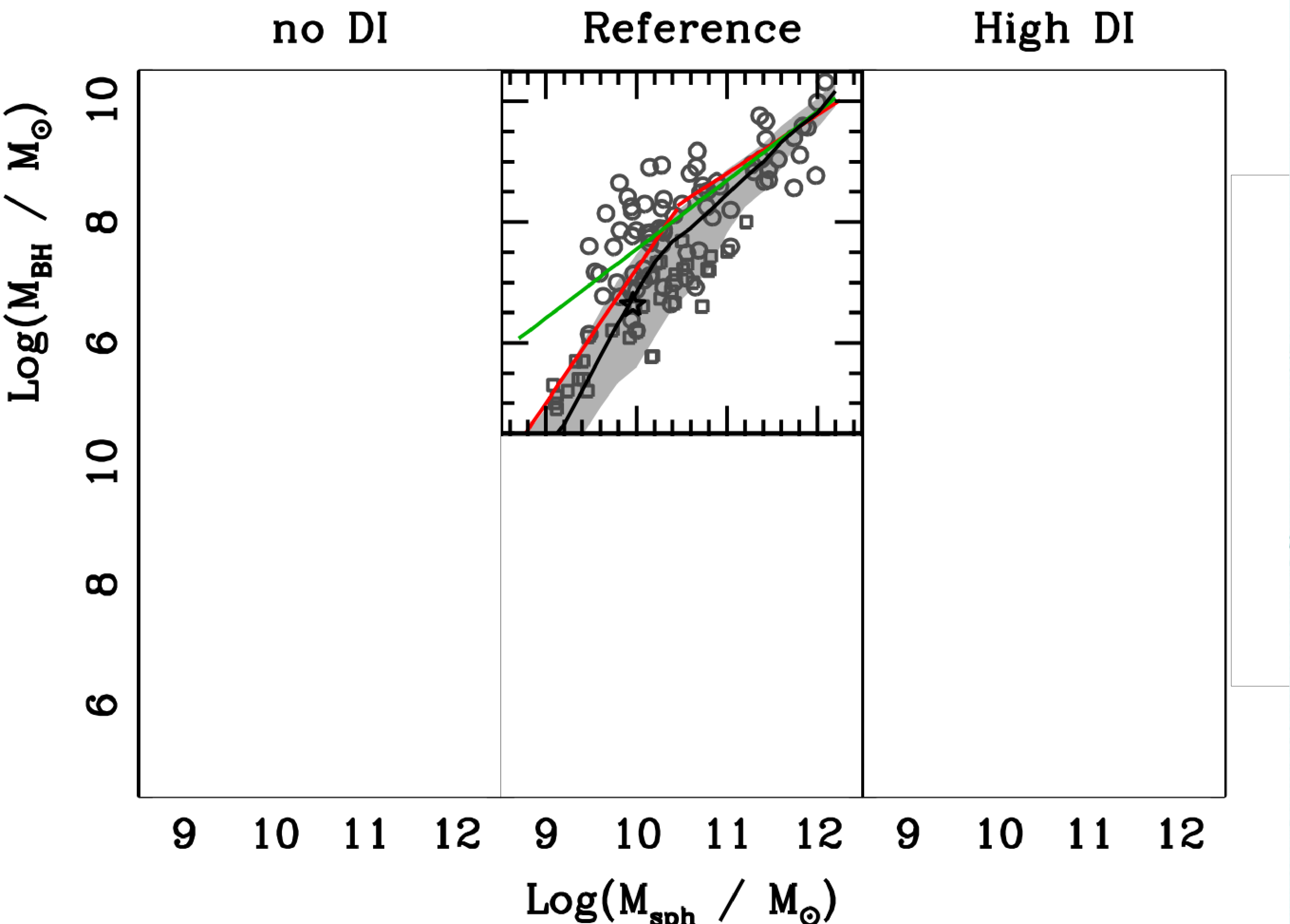
- Explicit modeling of cold gas "reservoir" around the central SMBH
  - Reservoir viscosity regulates SMBH accretion

$$\dot{M}_{\rm RS}^{-} = \dot{M}_{\rm BH} = 0.001\frac{\sigma_B^3}{G}\left(\frac{M_{\rm RS}}{M_{\rm BH}}\right)^{3/2}\left(1+\frac{M_{\rm BH}}{M_{\rm RS}}\right)^{1/2}$$

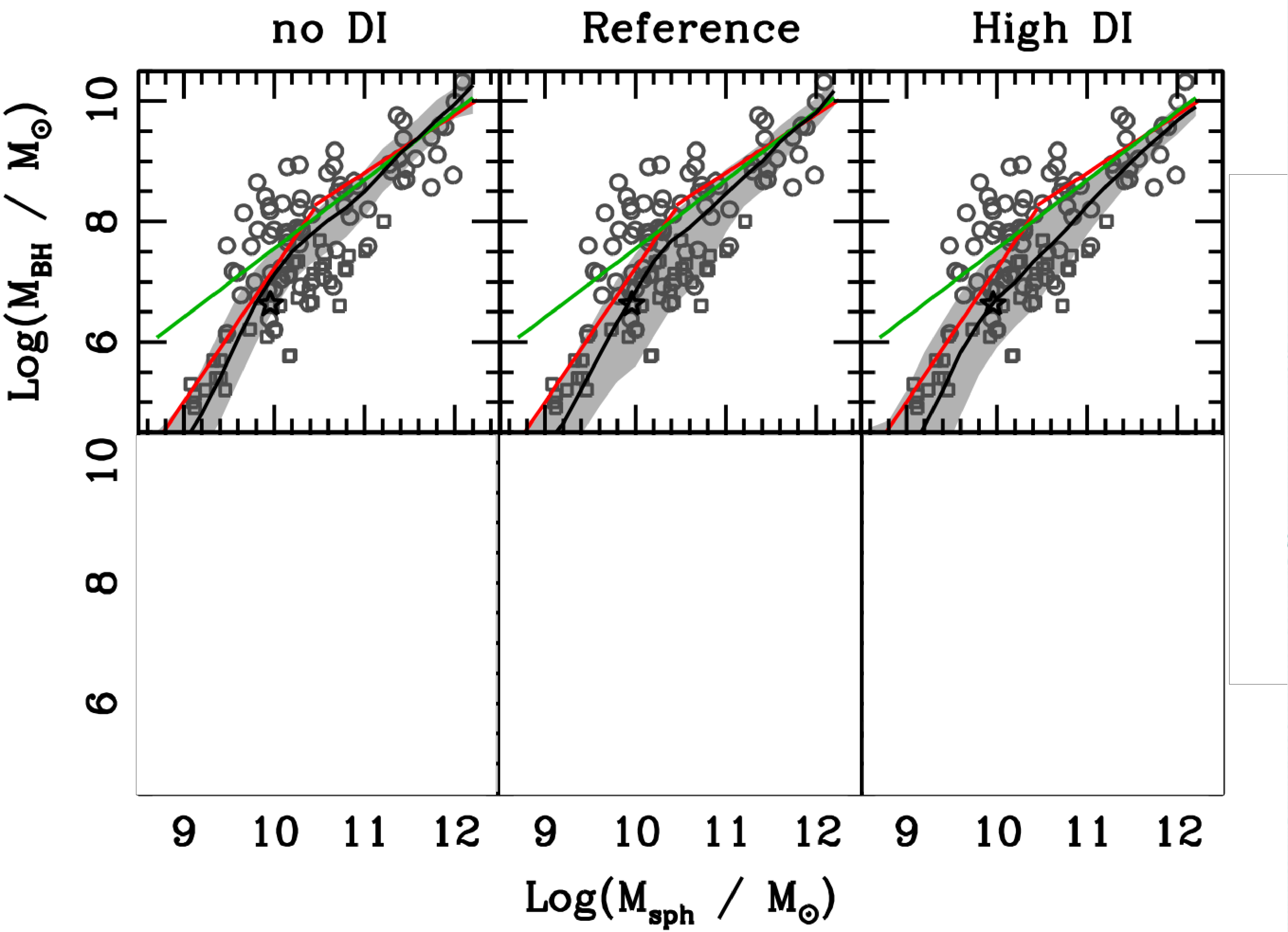
- Interplay between stellar and AGN feedback
  - Kinetic Stellar Feedback
  - Triggering of galactic winds

$$\sigma_{\rm cg} = \zeta_0\left(\frac{t_\star}{1\,{\rm Gyr}}\right)^{-1/3}\ {\rm km\,s}^{-1}$$

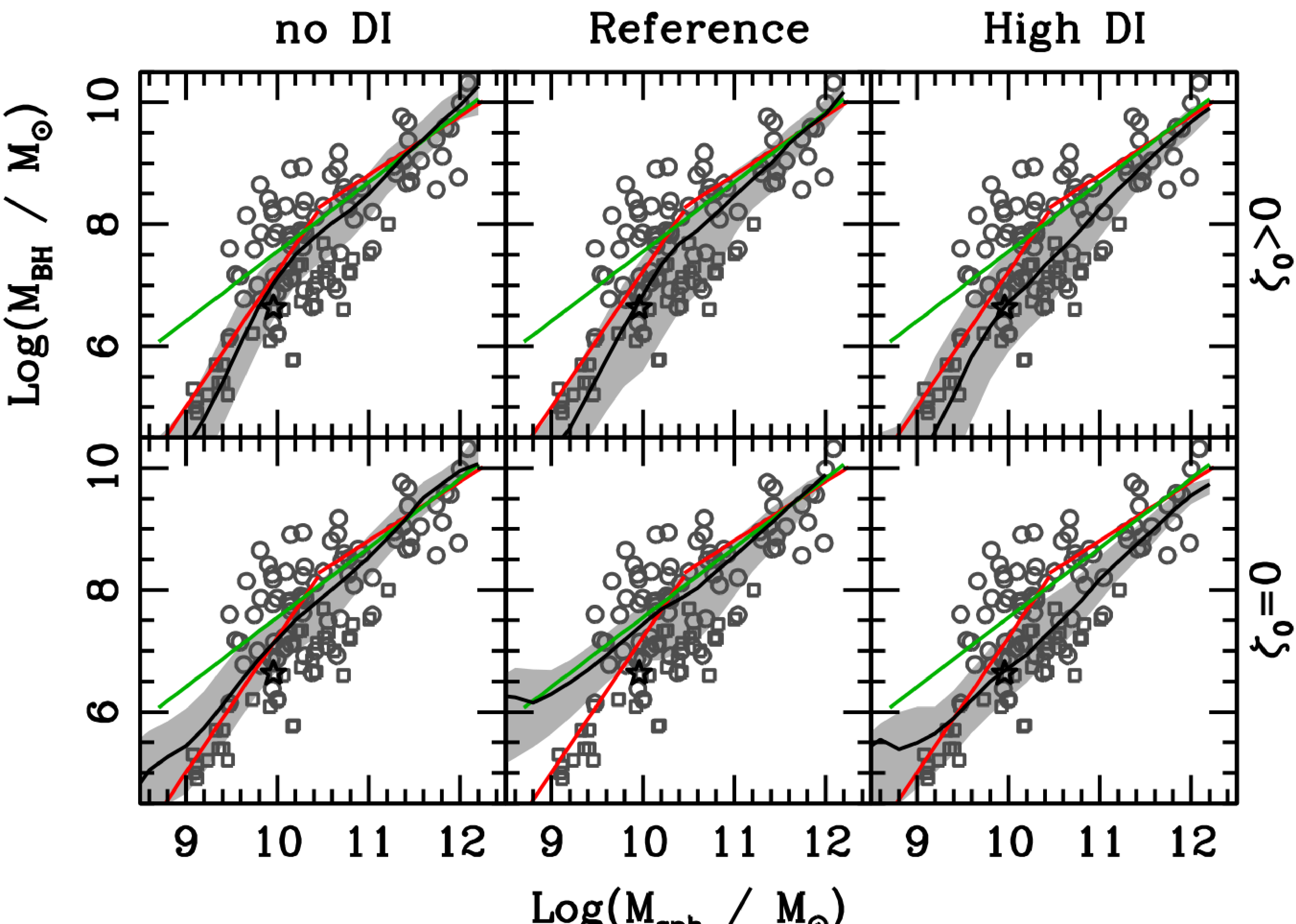
Fontanot+06



no DI
Reference
High DI
Log(M_BH / M_⊙)
10
8
6
10
8
6
9
10
11
12
9
10
11
12
9
10
11
12
Log(M_sph / M_⊙)



no DI
Reference
High DI
Log(M_BH / M_⊙)
10
8
6
10
8
6
9
10
11
12
9
10
11
12
9
10
11
12
Log(M_sph / M_⊙)


no DI
Reference
High DI
$\zeta_0>0$
$\zeta_0=0$
$\mathrm{Log}(M_{BH}\ /\ M_\odot)$
$\mathrm{Log}(M_{sph}\ /\ M_\odot)$
6
8
10
9
10
11
12

Conclusions II

- Steepening of BH-Bulge relation favours co-evolution
  - Self-regulation of BH and Bulges
- MORGANA view: interaction between stellar and AGN feedbacks
  - Kinetic stellar feedback affects small bulges heavily by removing cold gas content and limiting BH growth
  - Prediction: normalization of BH-Bulge relation evolves with redshift (but its shape does not)