An Introduction to AGNs and IMF in GAEA

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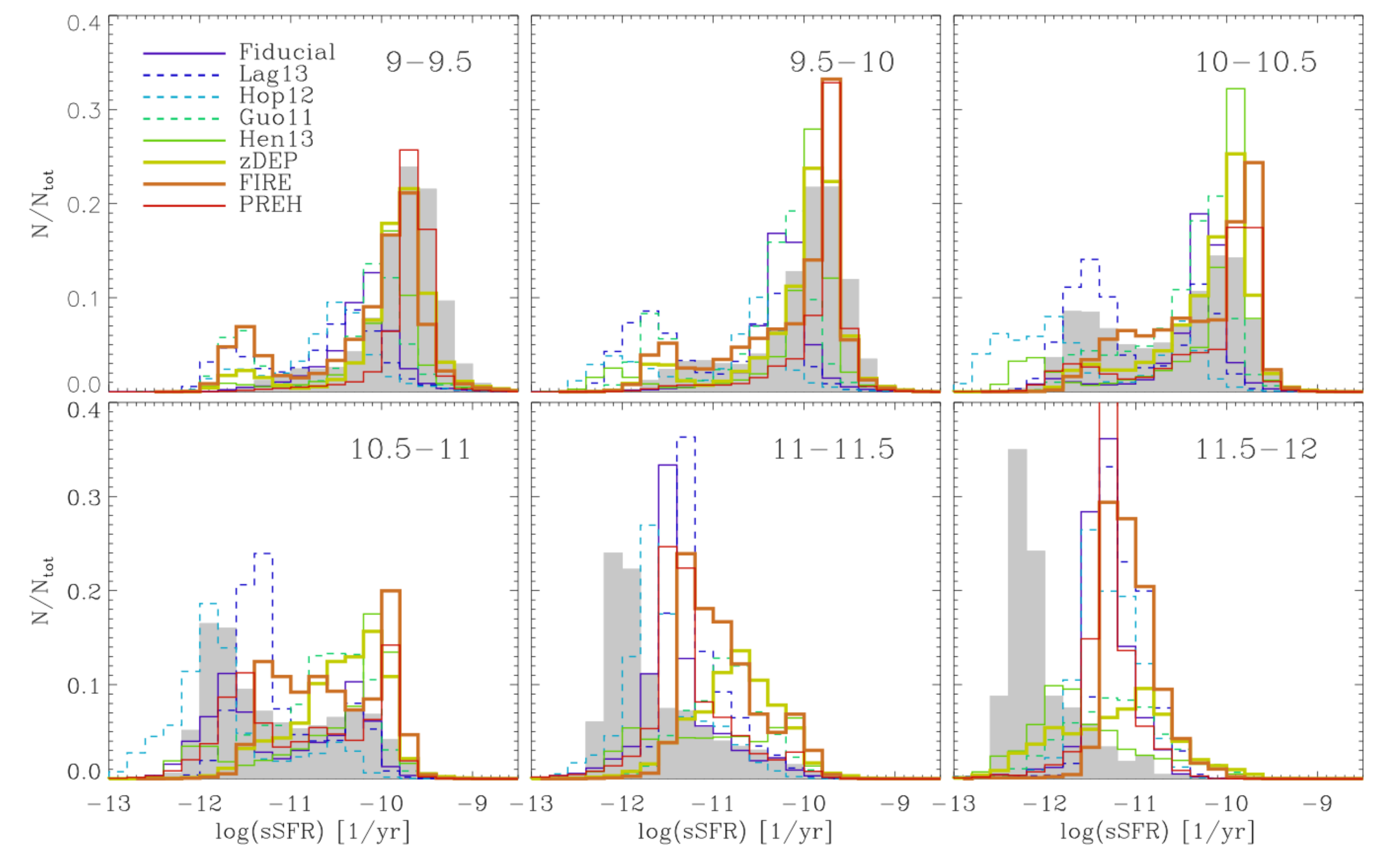
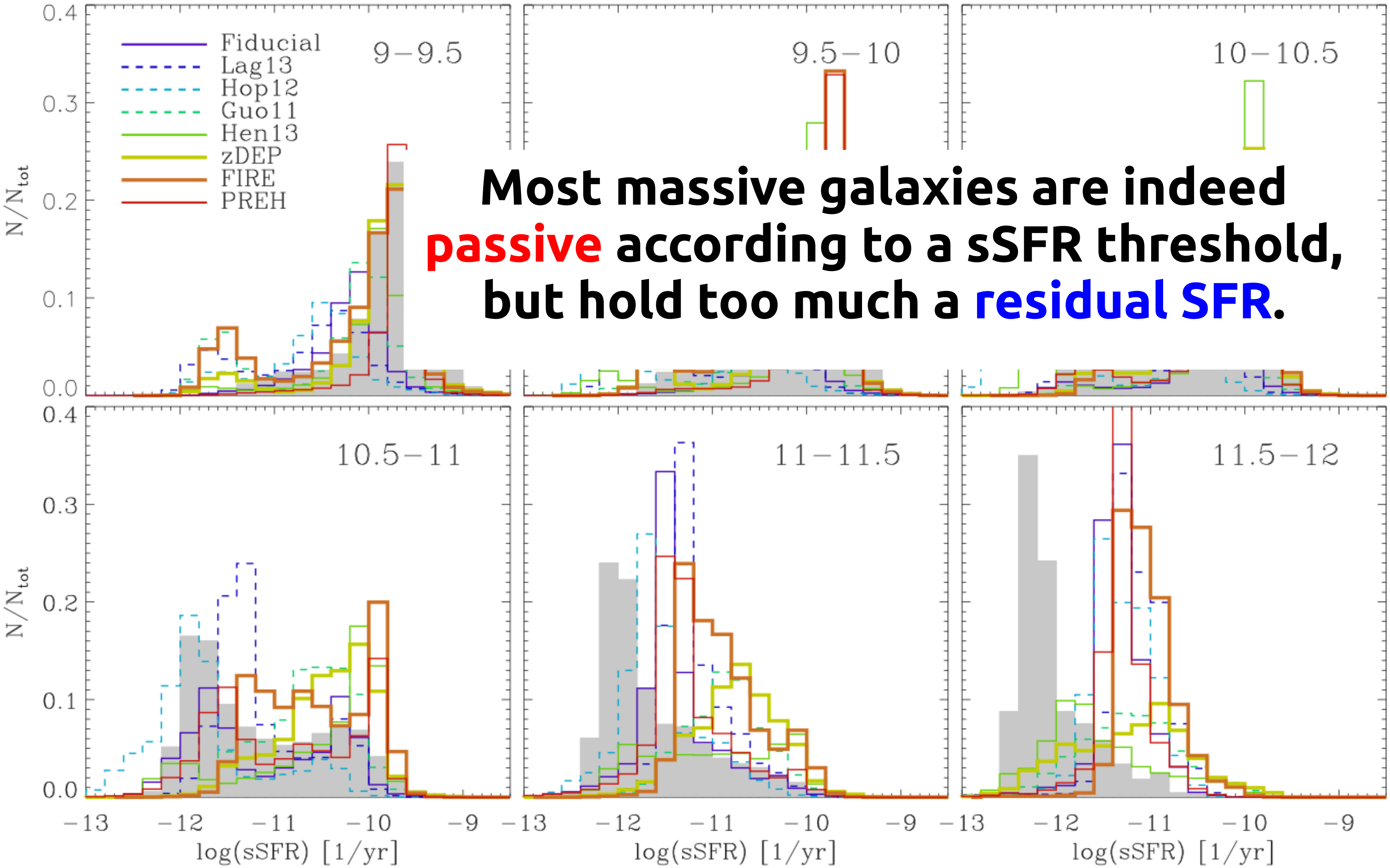
Trieste 05/06/23

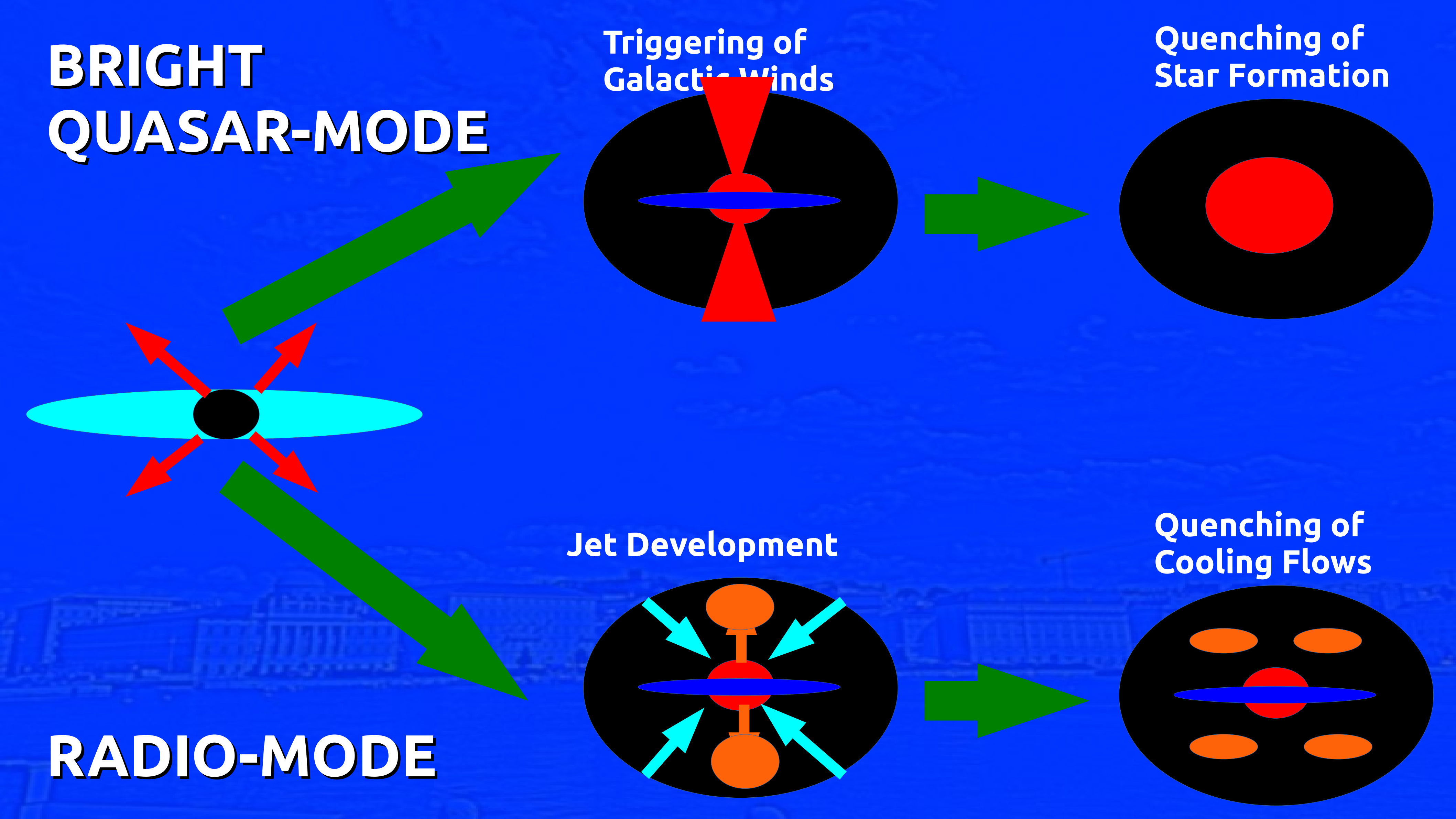
AGN accretion



Fiducial
Lag13
Hop12
Guo11
Hen13
zDEP
FIRE
PREH
9−9.5
9.5−10
10−10.5
10.5−11
11−11.5
11.5−12
N/Ntot
0.0
0.1
0.2
0.3
0.4
−13
−12
−11
−10
−9
log(sSFR) [1/yr]



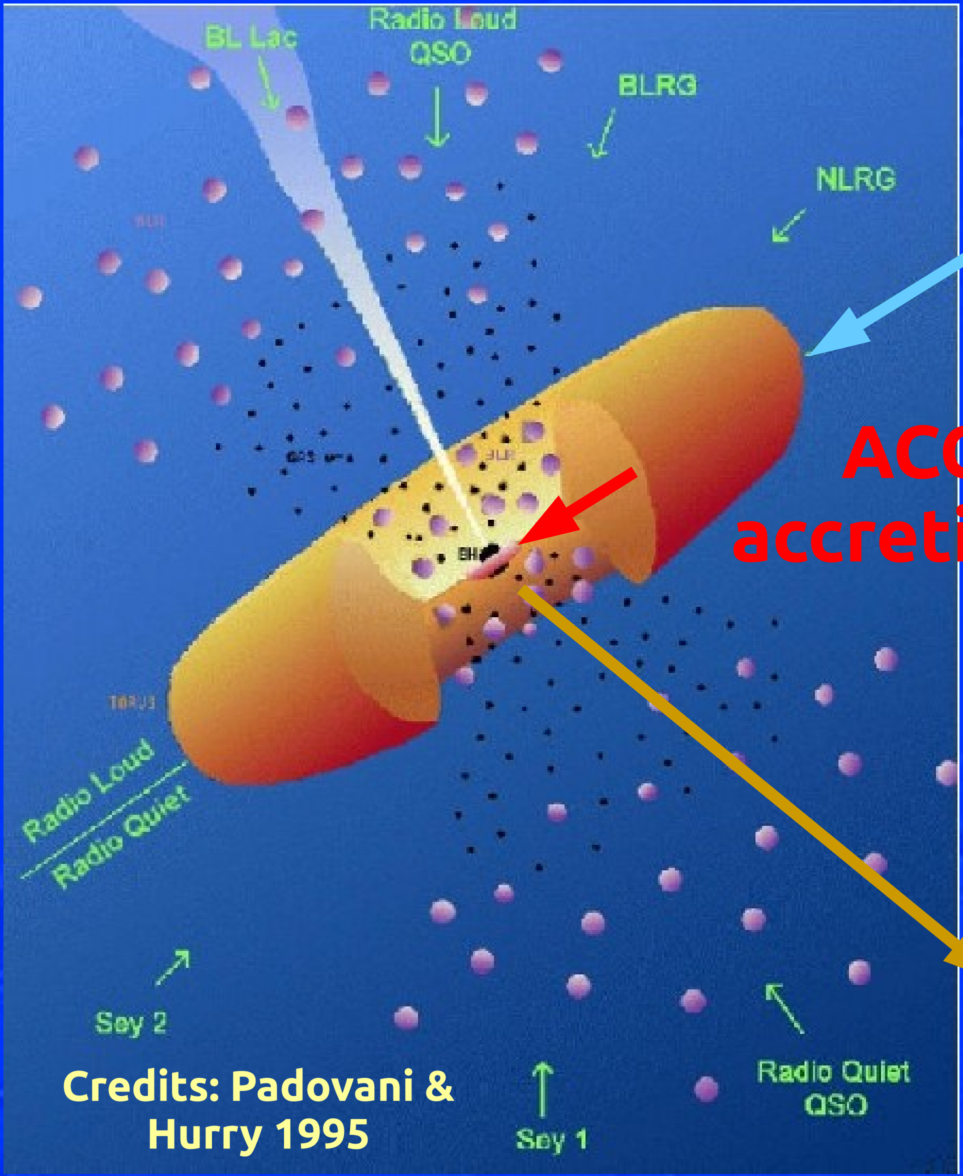
Most massive galaxies are indeed passive according to a sSFR threshold, but hold too much a residual SFR.


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

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



Credits: Padovani & Hurry 1995

INFLOW: from the cold gas component to the accretion disc

ACCRETION: from the accretion disc to the central SMBH

OUTFLOW:
of cold gas to the reheated/ejected component

Prescriptions

- **INFLOW** (driven by mergers and DIs)
  - SFR-driven (Granato+04)
  - Analytic model + Simulations (Hopkins & Quaetert 11)
- **ACCRETION**
  - Viscous timescale (Umemura+00)
  - Light curve model (Hopkins+07)
- **OUTFLOW**
  - Empirical model (Fiore+17)
  - Analytical model (Menci+19)

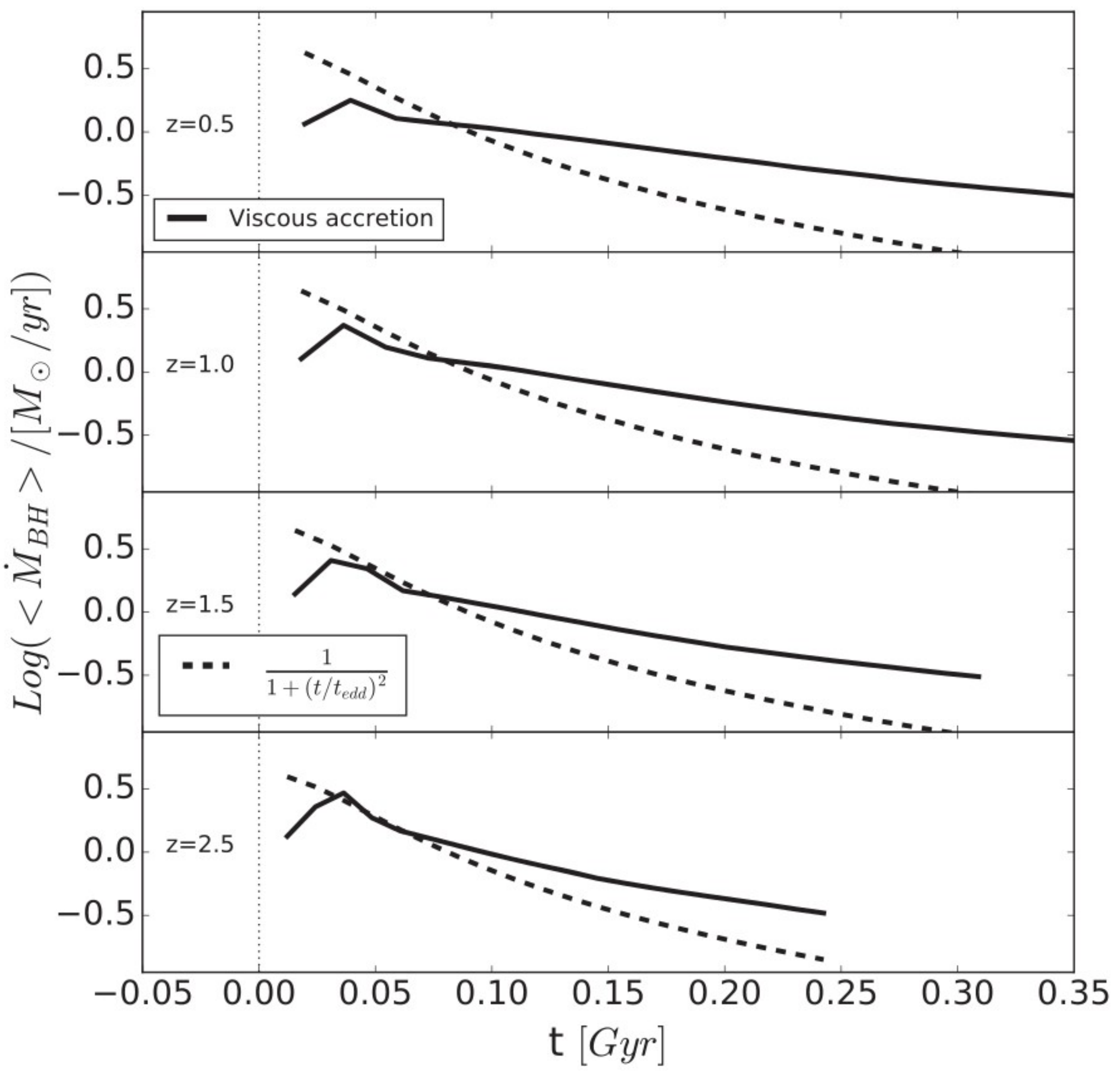
Other important aspects to remember:

1) **TRIGGERS**: mergers and disc instabilities

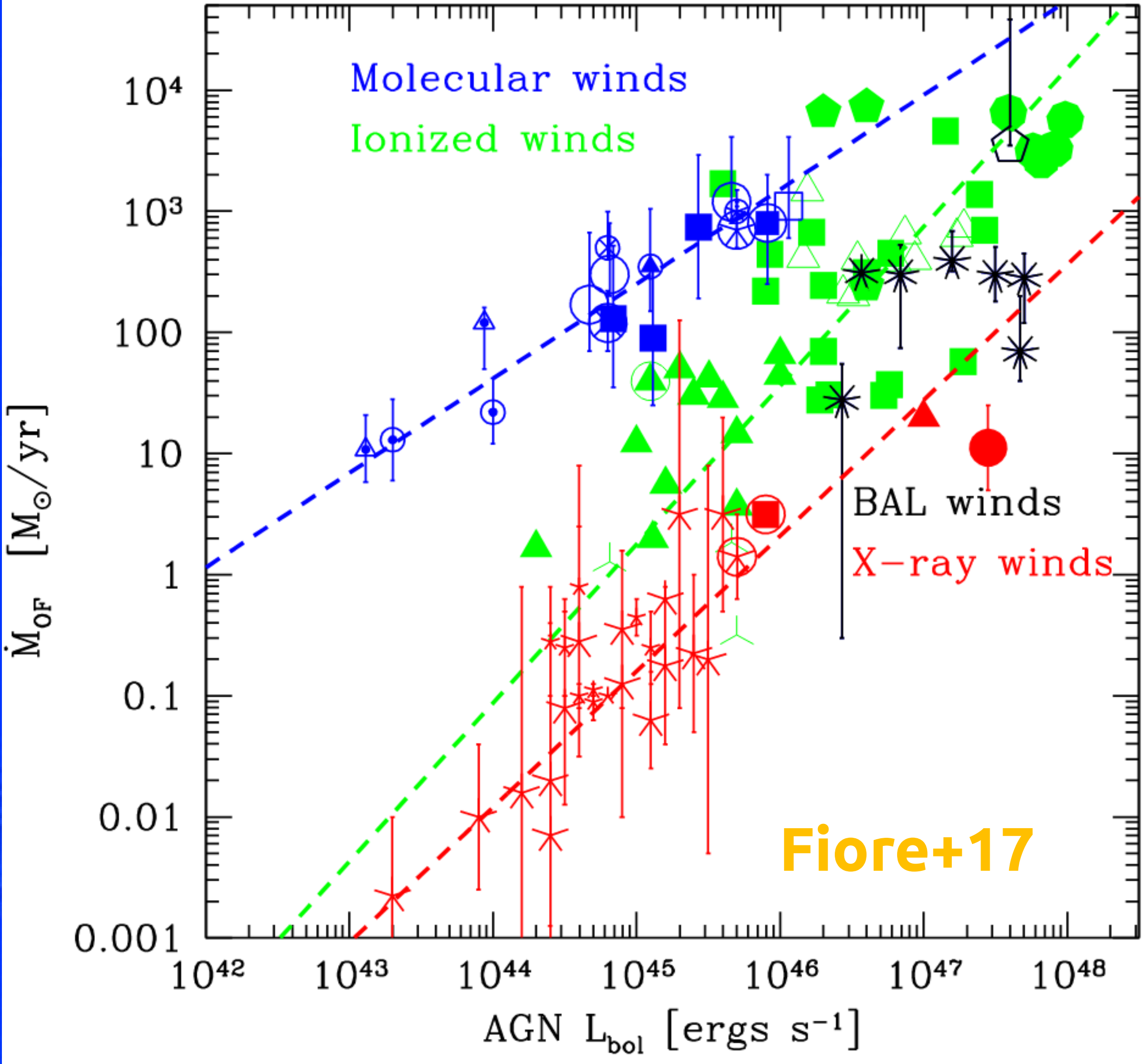
2) Rad. Efficiency 15%

3) Ed. limit: $L/L_{edd} = 10$

4) BH seeding: $10^3 - 10^5$ Msun

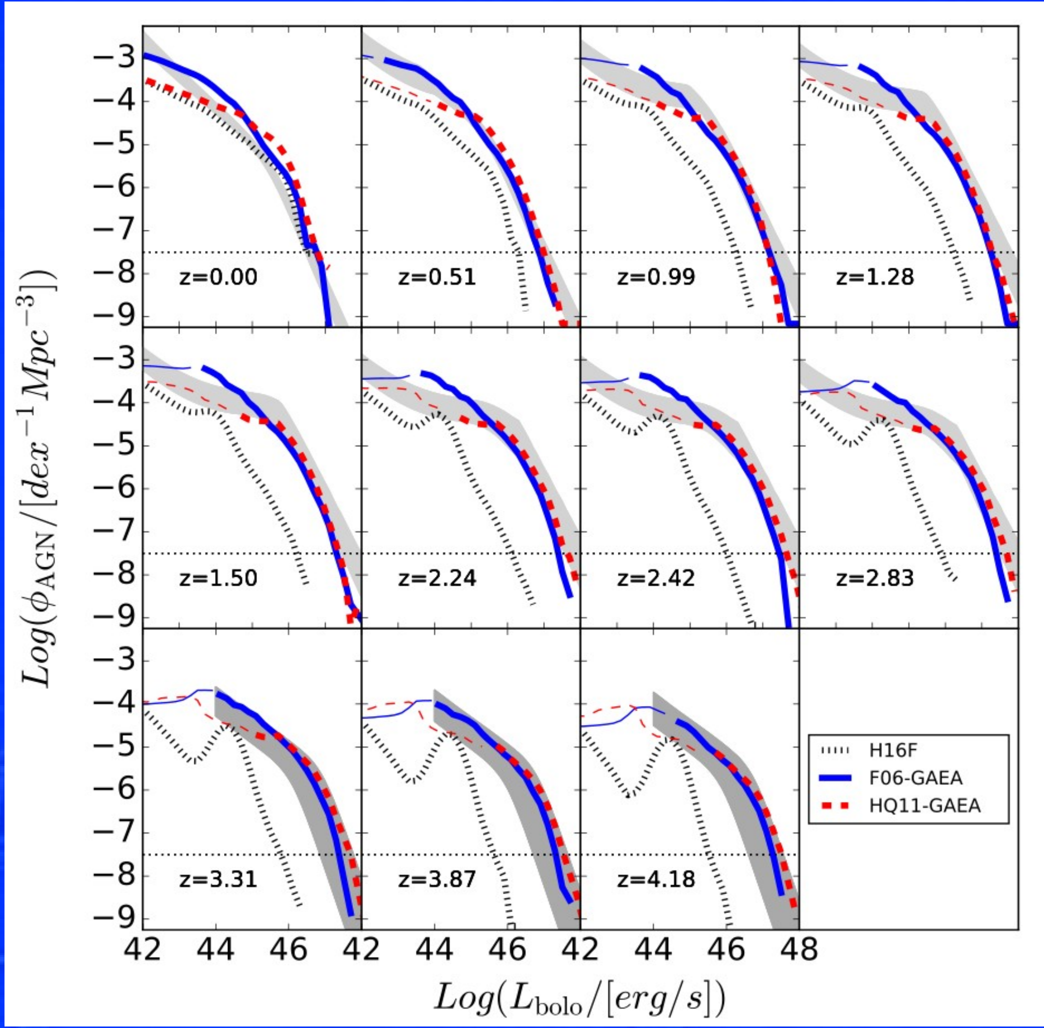


z=0.5
z=1.0
z=1.5
z=2.5
Viscous accretion
$\frac{1}{1+(t/t_{edd})^2}$
$Log(<\dot{M}_{BH}>/[M_\odot/yr])$
t $[Gyr]$

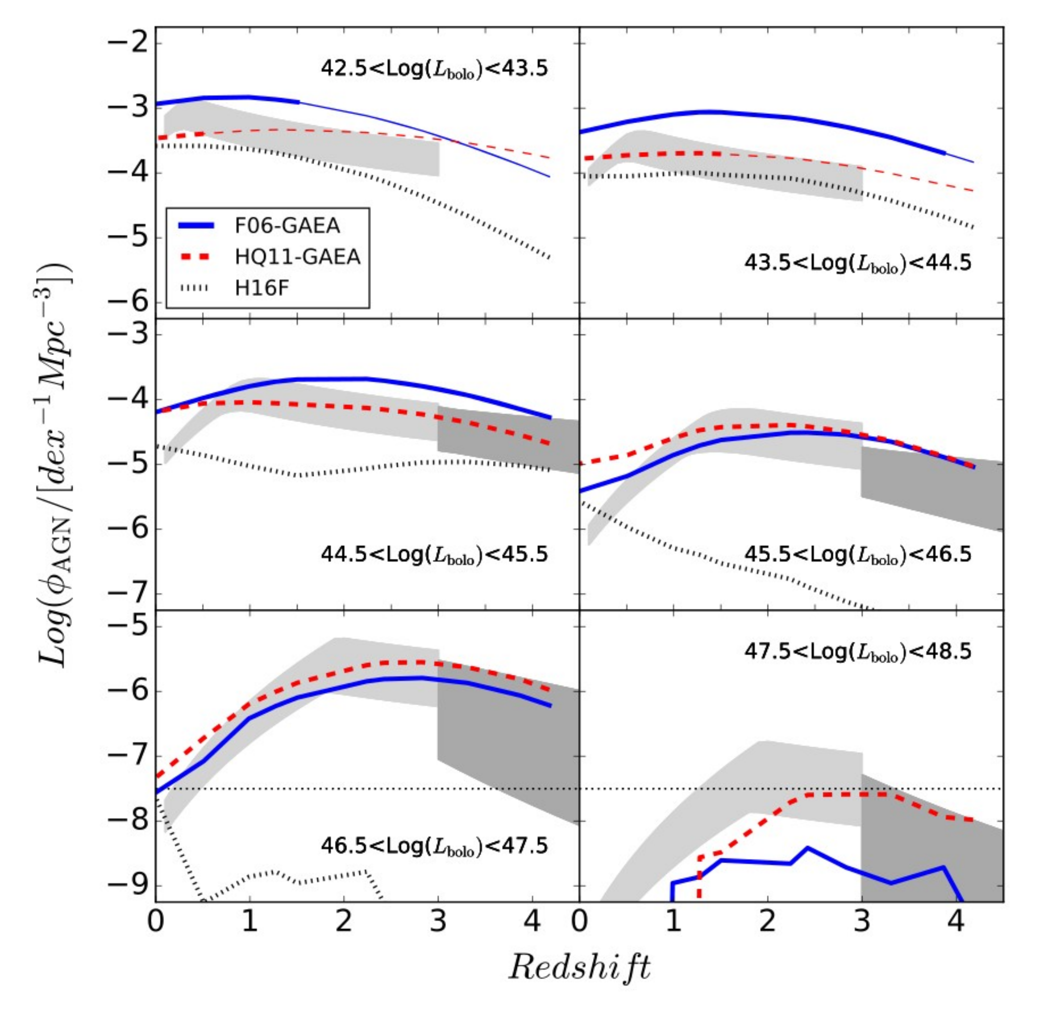


Molecular winds
Ionized winds
BAL winds
X-ray winds
Fiore+17
$\dot{M}_{OF}$ [$M_\odot$/yr]
AGN L_{bol} [ergs s^{-1}]
10^4
10^3
100
10
1
0.1
0.01
0.001
10^{42}
10^{43}
10^{44}
10^{45}
10^{46}
10^{47}
10^{48}

Fontanot+20

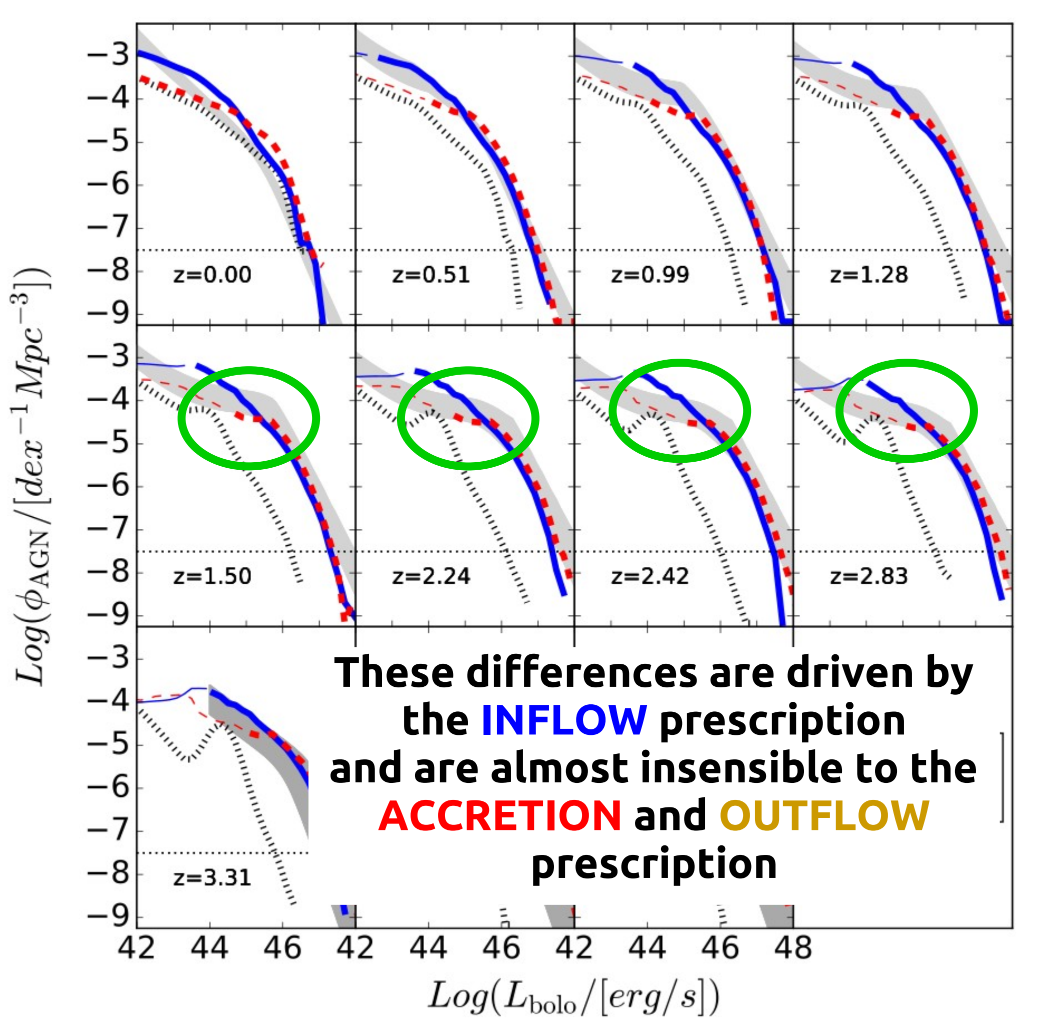


z=0.00
z=0.51
z=0.99
z=1.28
z=1.50
z=2.24
z=2.42
z=2.83
z=3.31
z=3.87
z=4.18
H16F
F06-GAEA
HQ11-GAEA
$Log(\phi_{\rm AGN}/[dex^{-1}Mpc^{-3}])$
$Log(L_{\rm bolo}/[erg/s])$

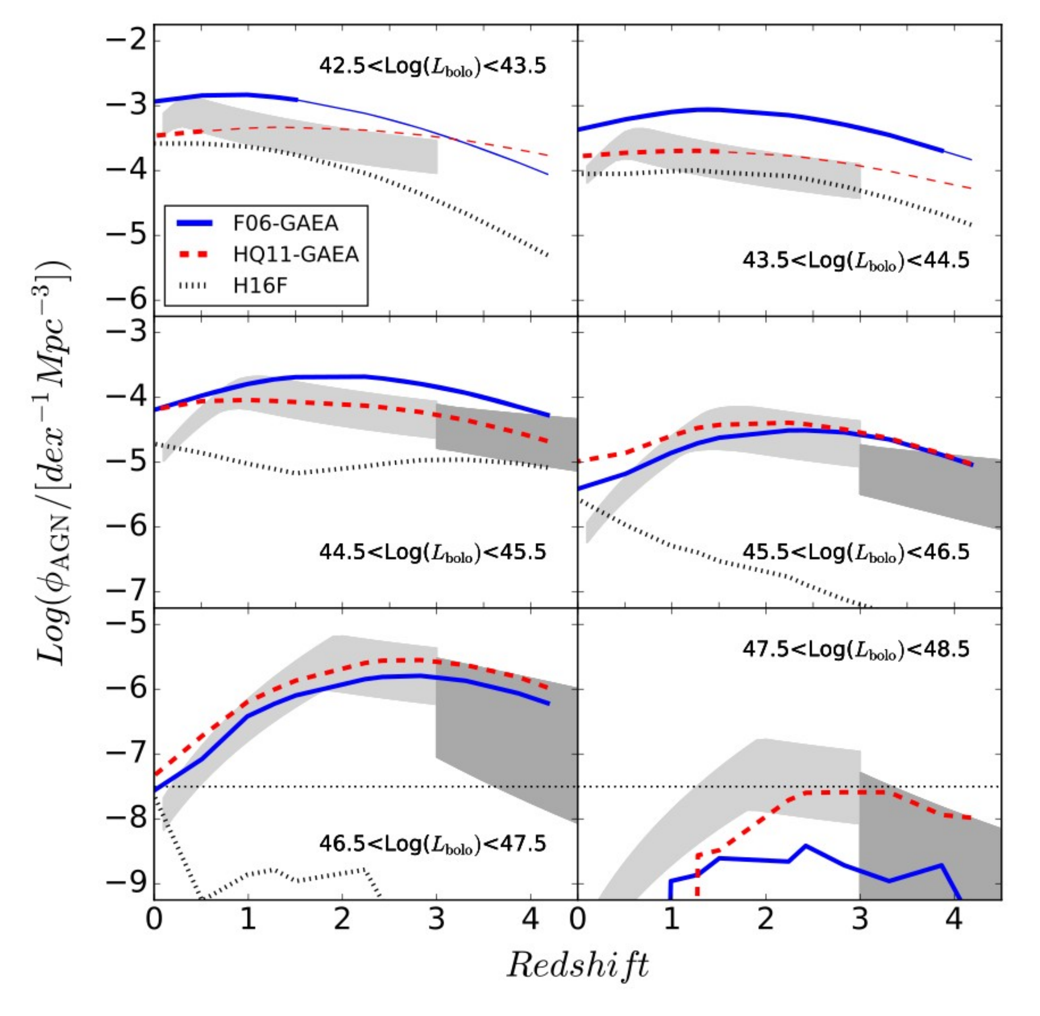


42.5<Log($L_{\rm bolo}$)<43.5
43.5<Log($L_{\rm bolo}$)<44.5
44.5<Log($L_{\rm bolo}$)<45.5
45.5<Log($L_{\rm bolo}$)<46.5
46.5<Log($L_{\rm bolo}$)<47.5
47.5<Log($L_{\rm bolo}$)<48.5
F06-GAEA
HQ11-GAEA
H16F
$Log(\phi_{\rm AGN}/[dex^{-1}Mpc^{-3}])$
$Redshift$

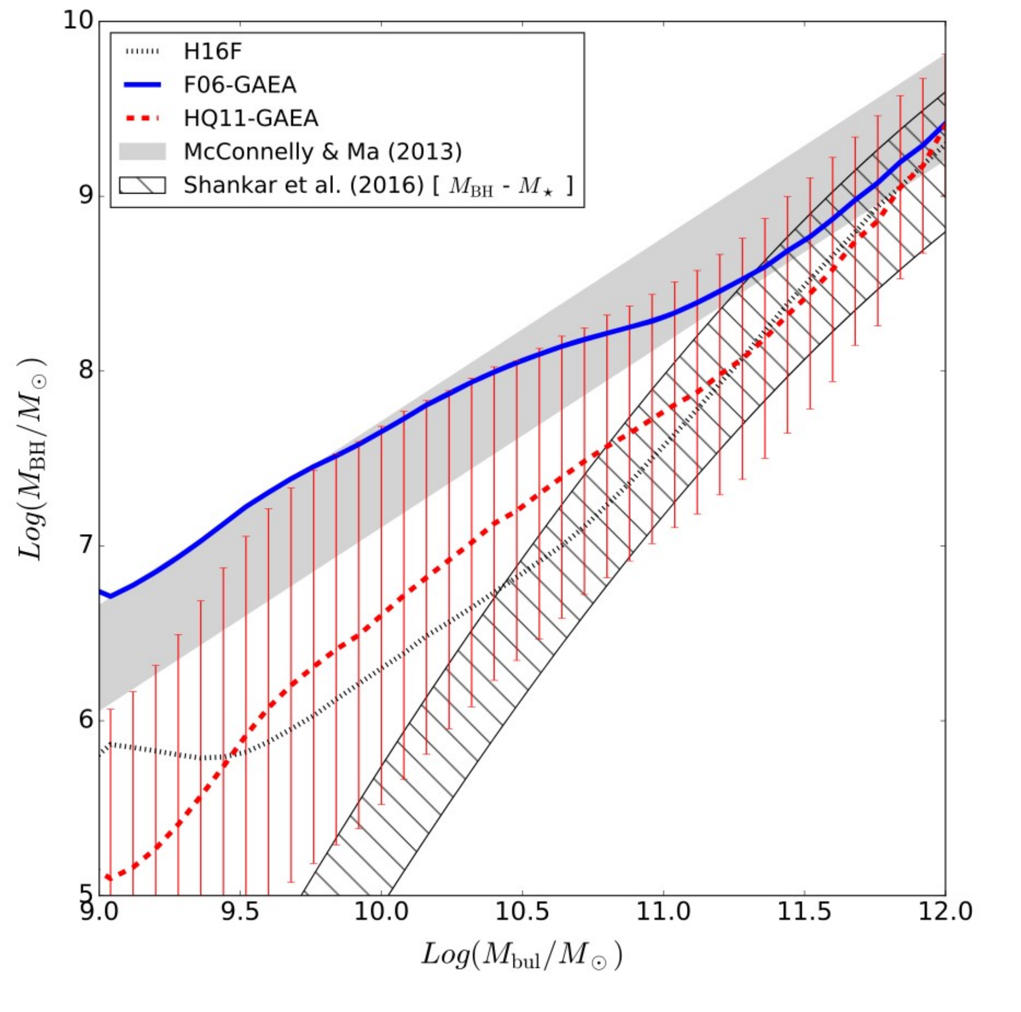
Fontanot+20

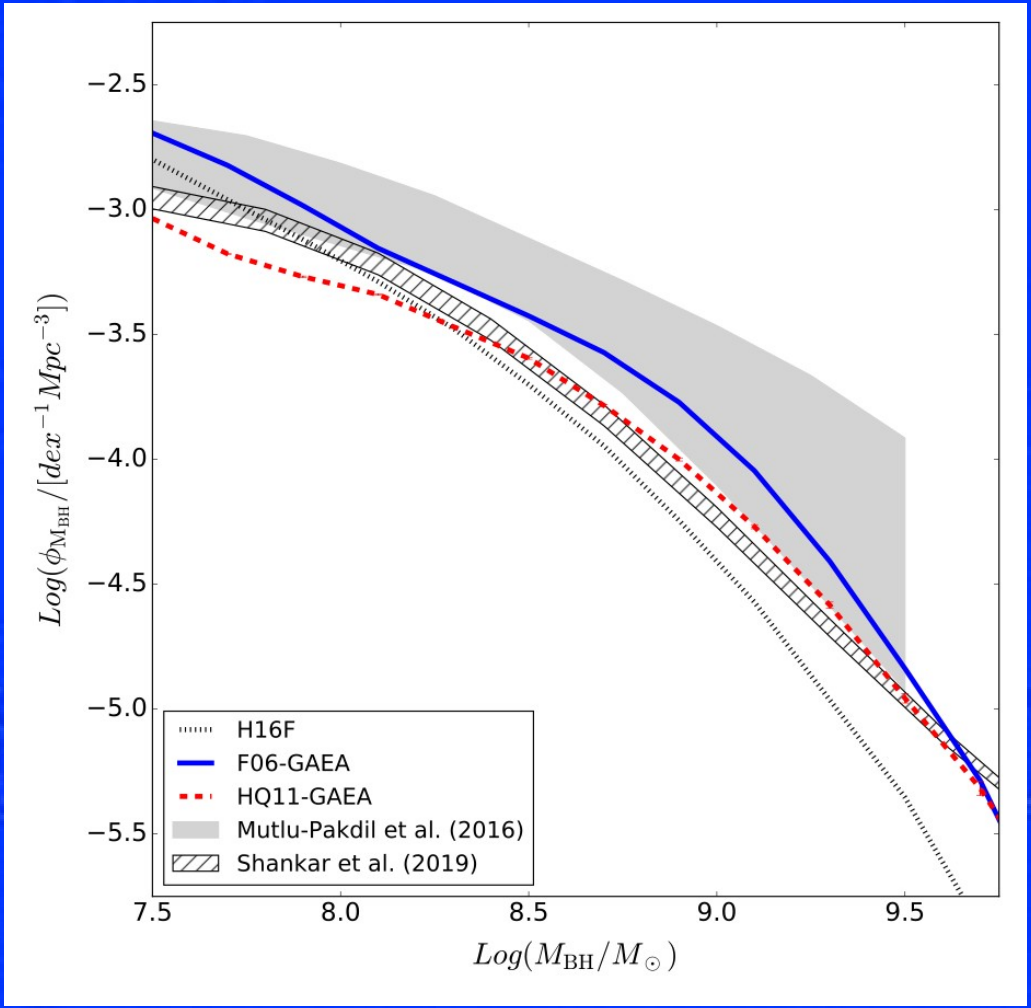


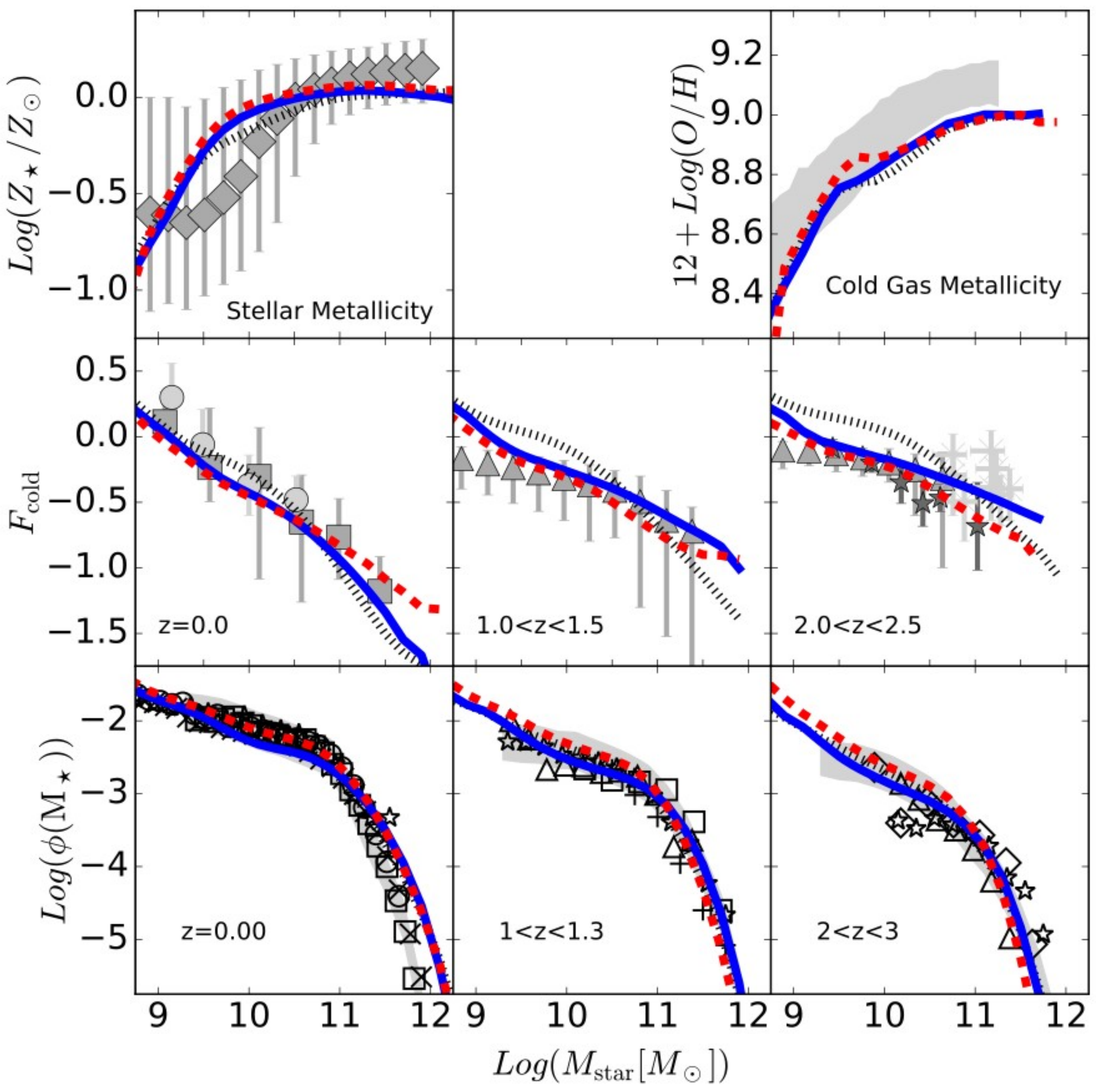
These differences are driven by the INFLOW prescription and are almost insensible to the ACCRETION and OUTFLOW prescription



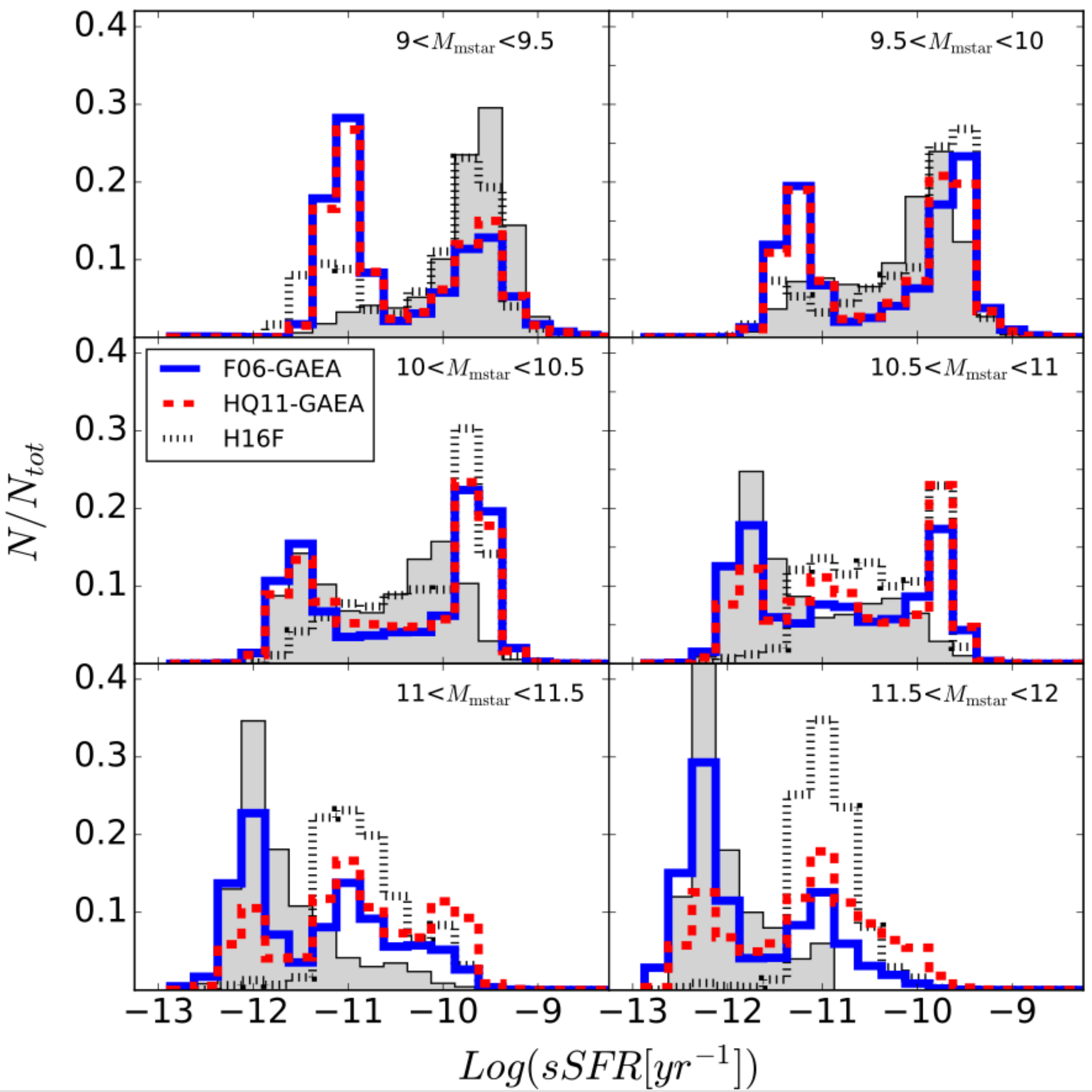
Fontanot+20


H16F
F06-GAEA
HQ11-GAEA
McConnelly & Ma (2013)
Shankar et al. (2016) [M_{BH} - $M_\star$]
$Log(M_{BH}/M_\odot)$
$Log(M_{bul}/M_\odot)$
10
9
8
7
6
5
9.0
9.5
10.0
10.5
11.0
11.5
12.0

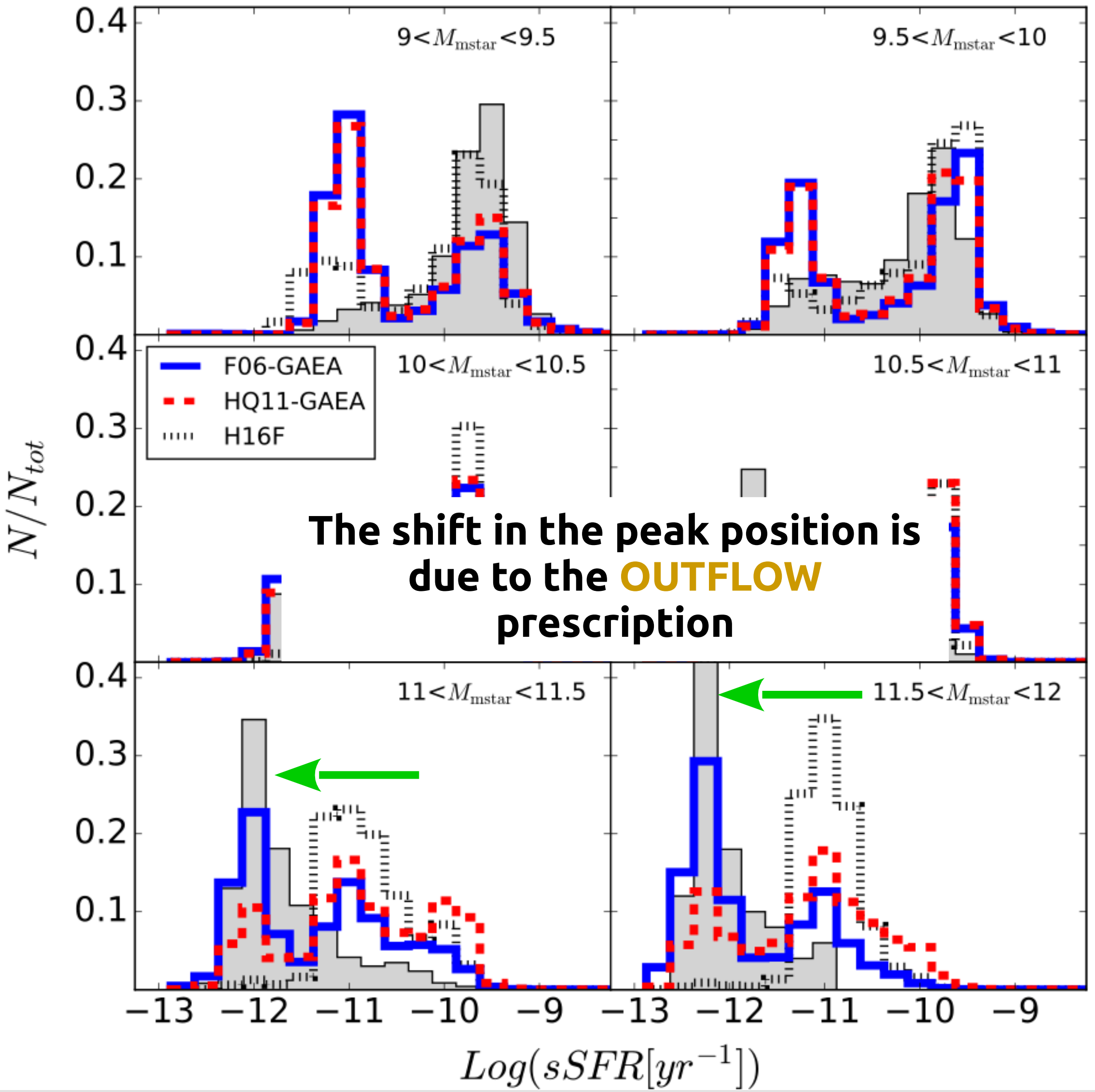

H16F
F06-GAEA
HQ11-GAEA
Mutlu-Pakdil et al. (2016)
Shankar et al. (2019)
$Log(\phi_{M_{BH}}/[dex^{-1}Mpc^{-3}])$
$Log(M_{BH}/M_\odot)$
−2.5
−3.0
−3.5
−4.0
−4.5
−5.0
−5.5
7.5
8.0
8.5
9.0
9.5



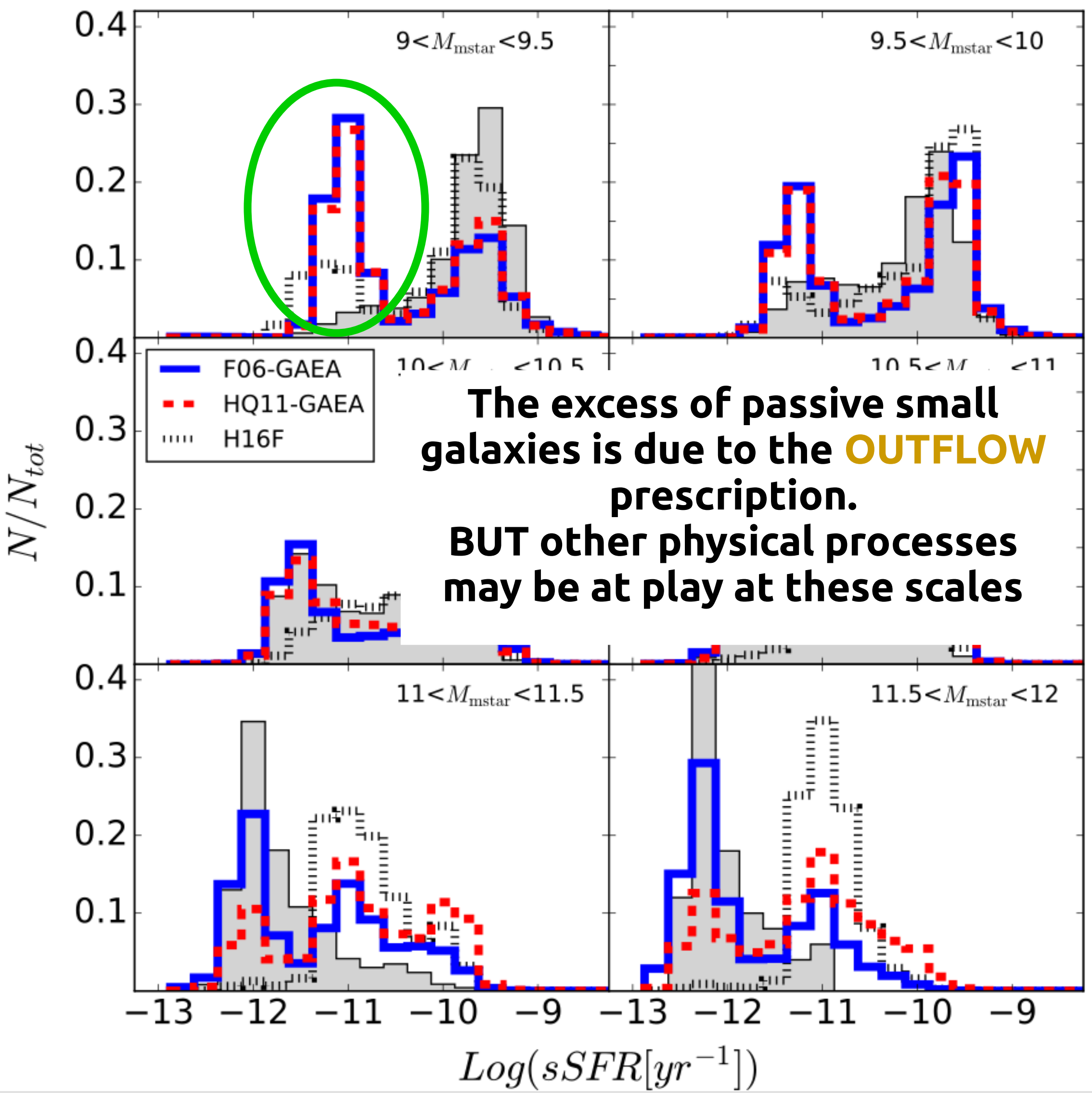
Stellar Metallicity
Cold Gas Metallicity
z=0.0
1.0<z<1.5
2.0<z<2.5
z=0.00
1<z<1.3
2<z<3



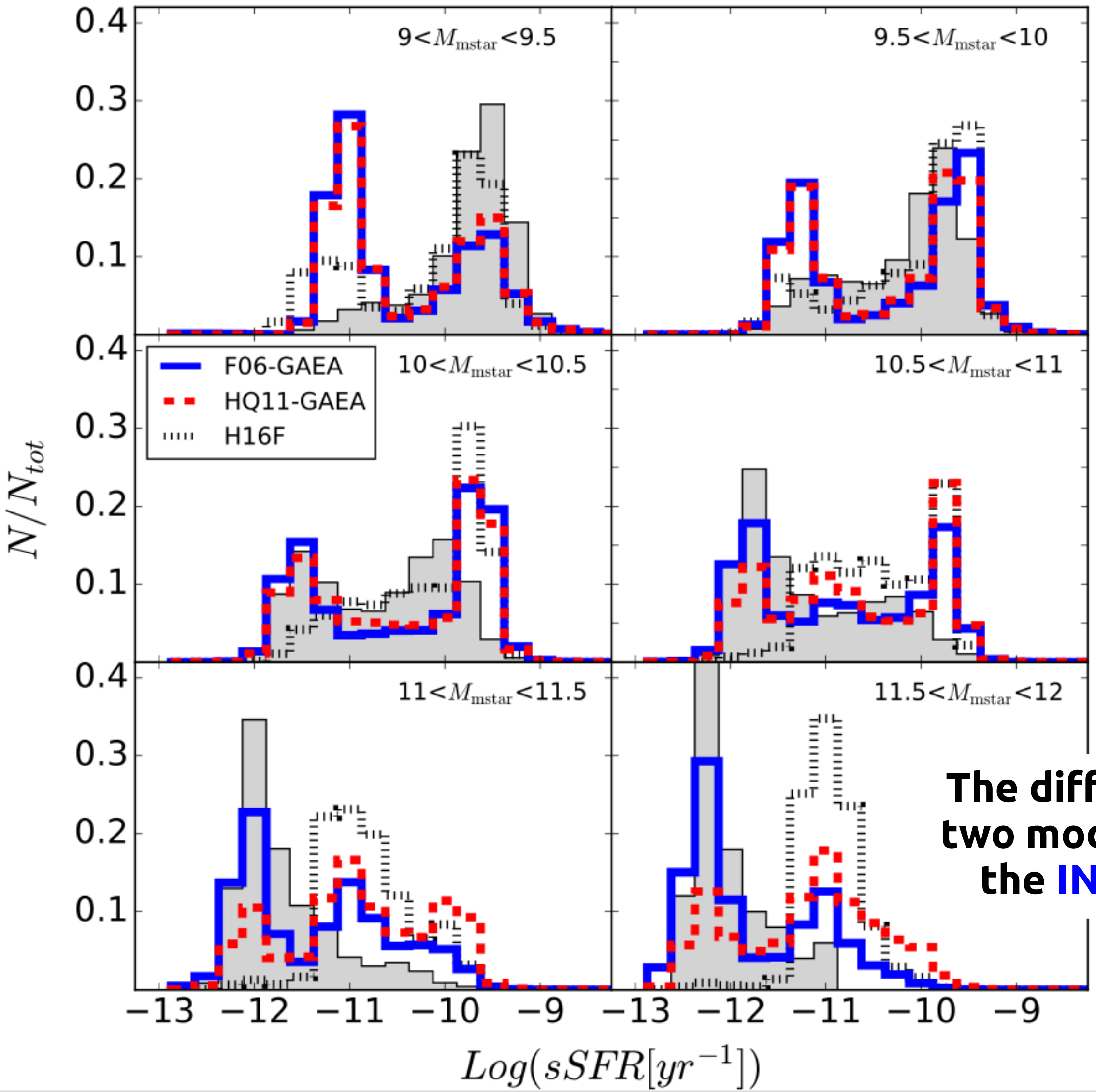
9<$M_{\rm mstar}$<9.5
9.5<$M_{\rm mstar}$<10
10<$M_{\rm mstar}$<10.5
10.5<$M_{\rm mstar}$<11
11<$M_{\rm mstar}$<11.5
11.5<$M_{\rm mstar}$<12
F06-GAEA
HQ11-GAEA
H16F
N/N_{tot}
$Log(sSFR[yr^{-1}])$
0.1
0.2
0.3
0.4
−13
−12
−11
−10
−9



9<M_{mstar}<9.5
9.5<M_{mstar}<10
10<M_{mstar}<10.5
10.5<M_{mstar}<11
11<M_{mstar}<11.5
11.5<M_{mstar}<12
F06-GAEA
HQ11-GAEA
H16F
N/N_{tot}
$Log(sSFR[yr^{-1}])$
The shift in the peak position is due to the OUTFLOW prescription



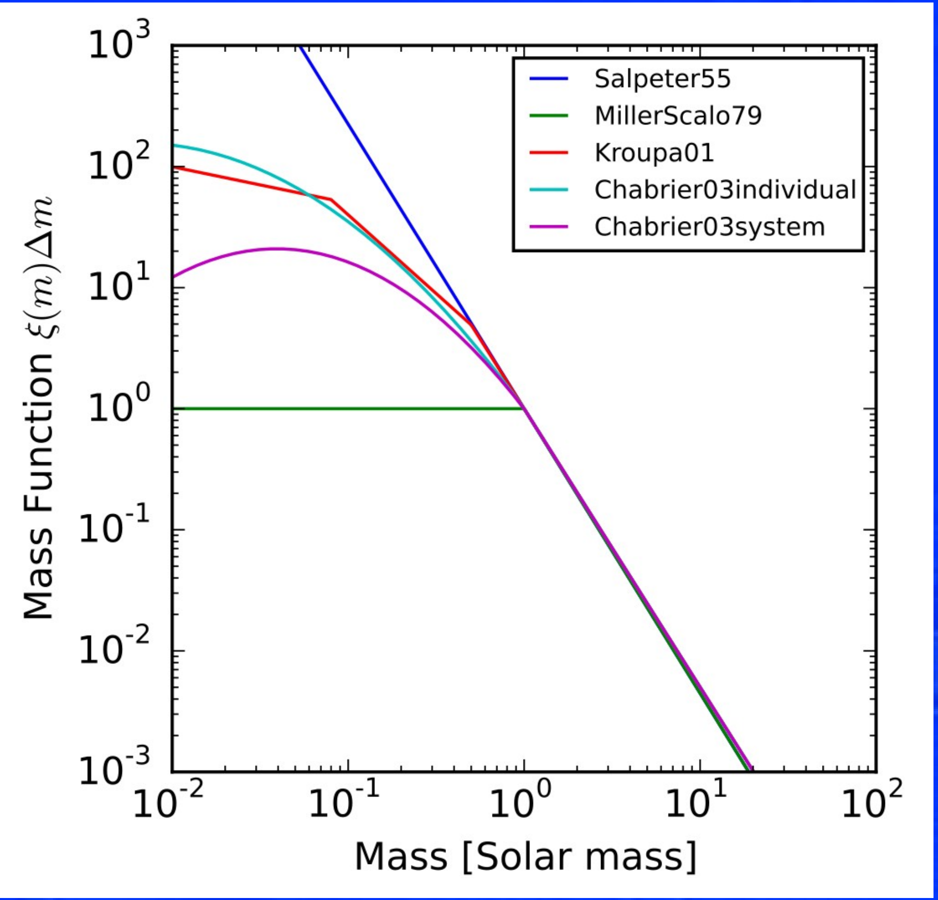
9<M_{mstar}<9.5
9.5<M_{mstar}<10
F06-GAEA
HQ11-GAEA
H16F
11<M_{mstar}<11.5
11.5<M_{mstar}<12
N/N_{tot}
$Log(sSFR[yr^{-1}])$
0.4
0.3
0.2
0.1
−13
−12
−11
−10
−9
The excess of passive small galaxies is due to the OUTFLOW prescription.
BUT other physical processes may be at play at these scales

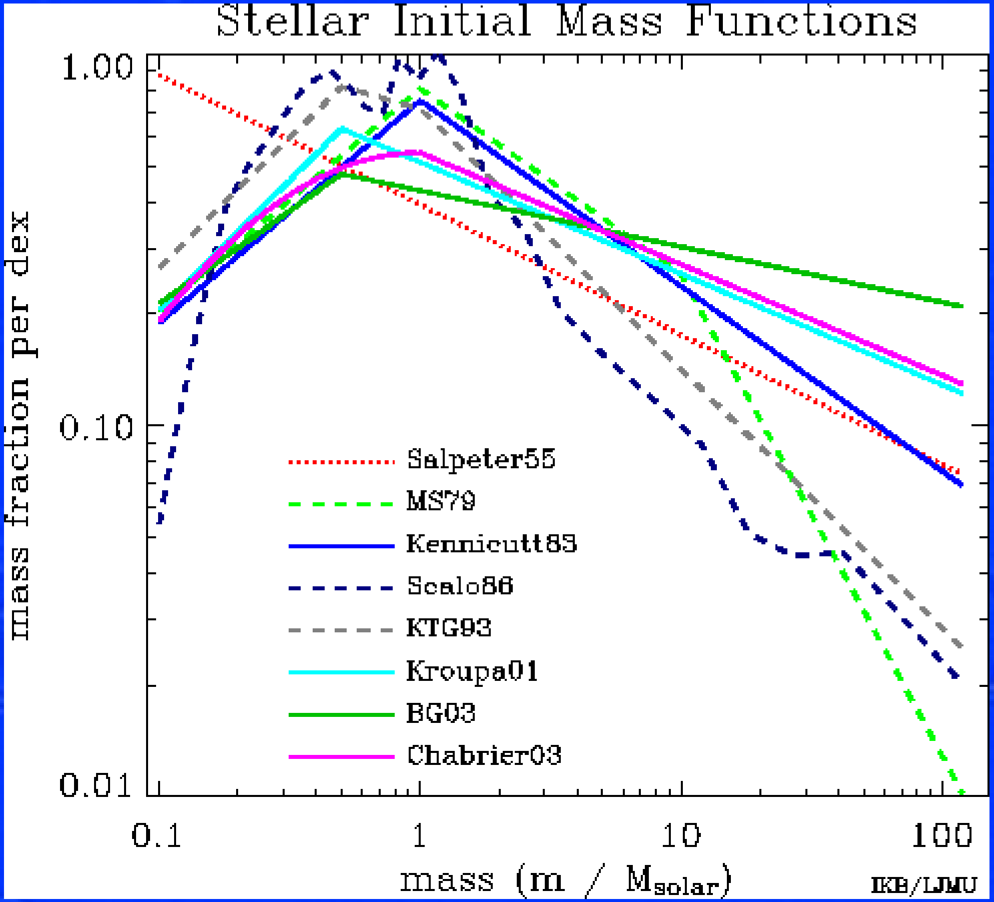


The differences between the two models are mainly due to the INFLOW prescription.

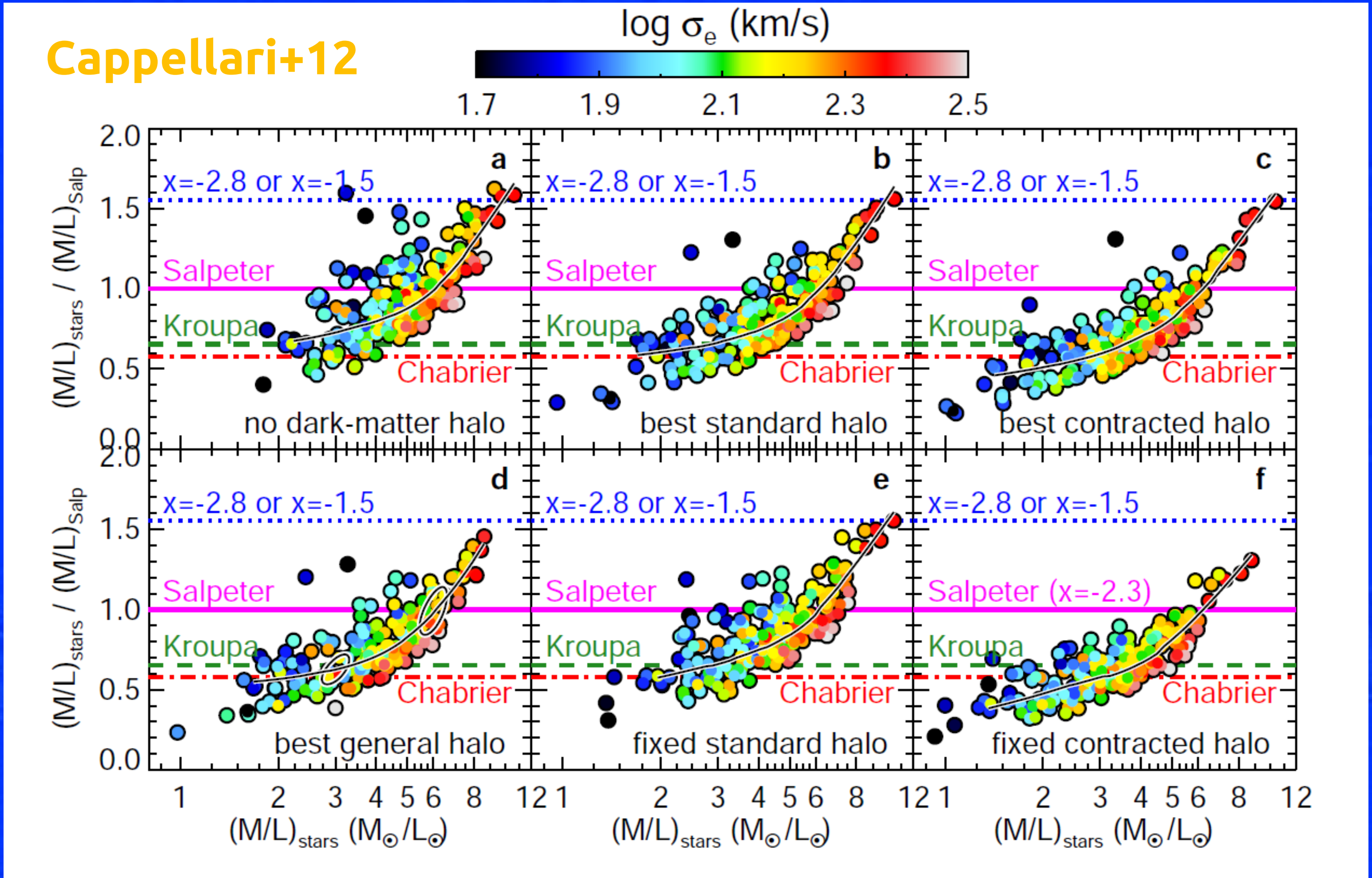
Variable **IMF**

Universal IMF ?

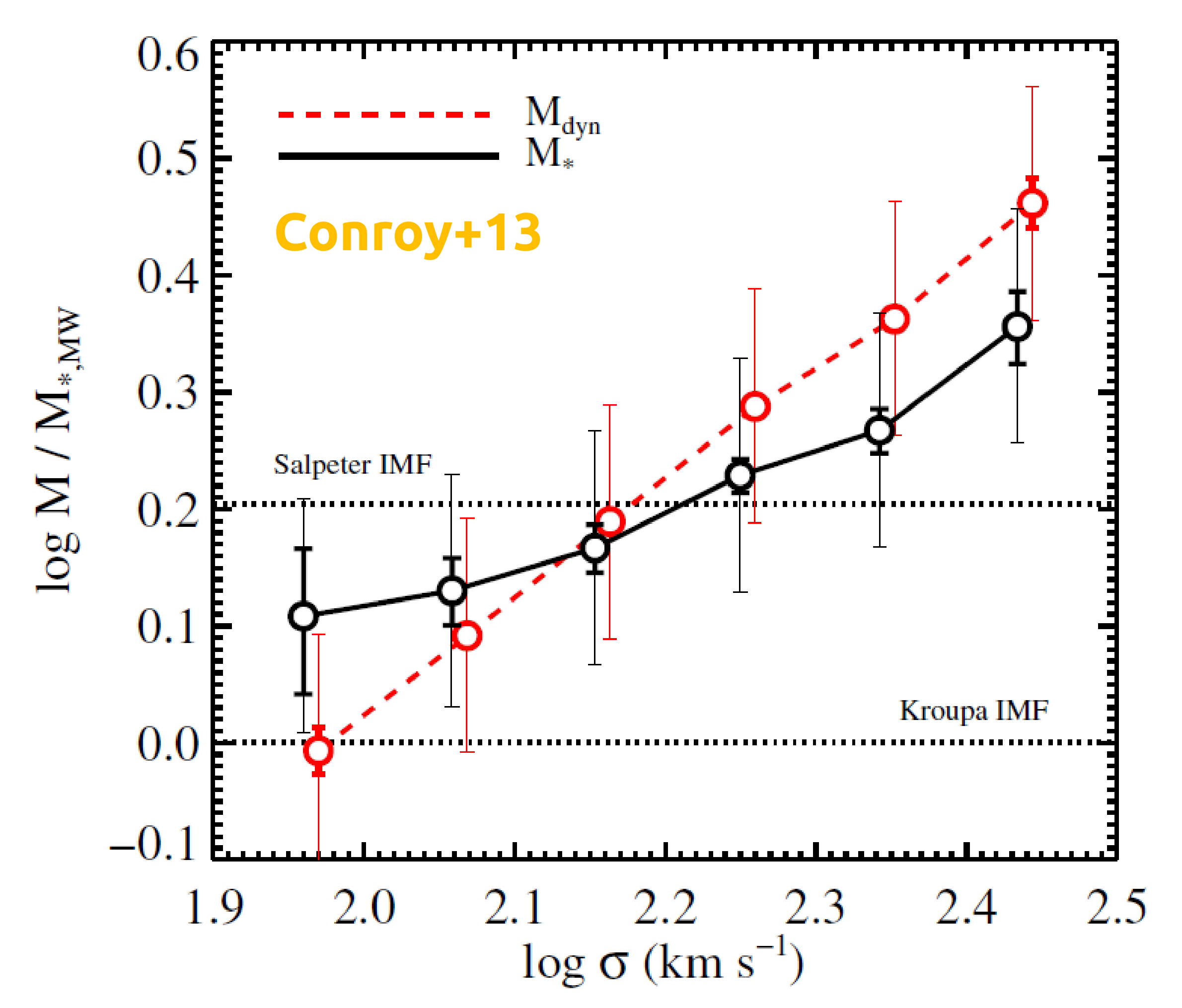




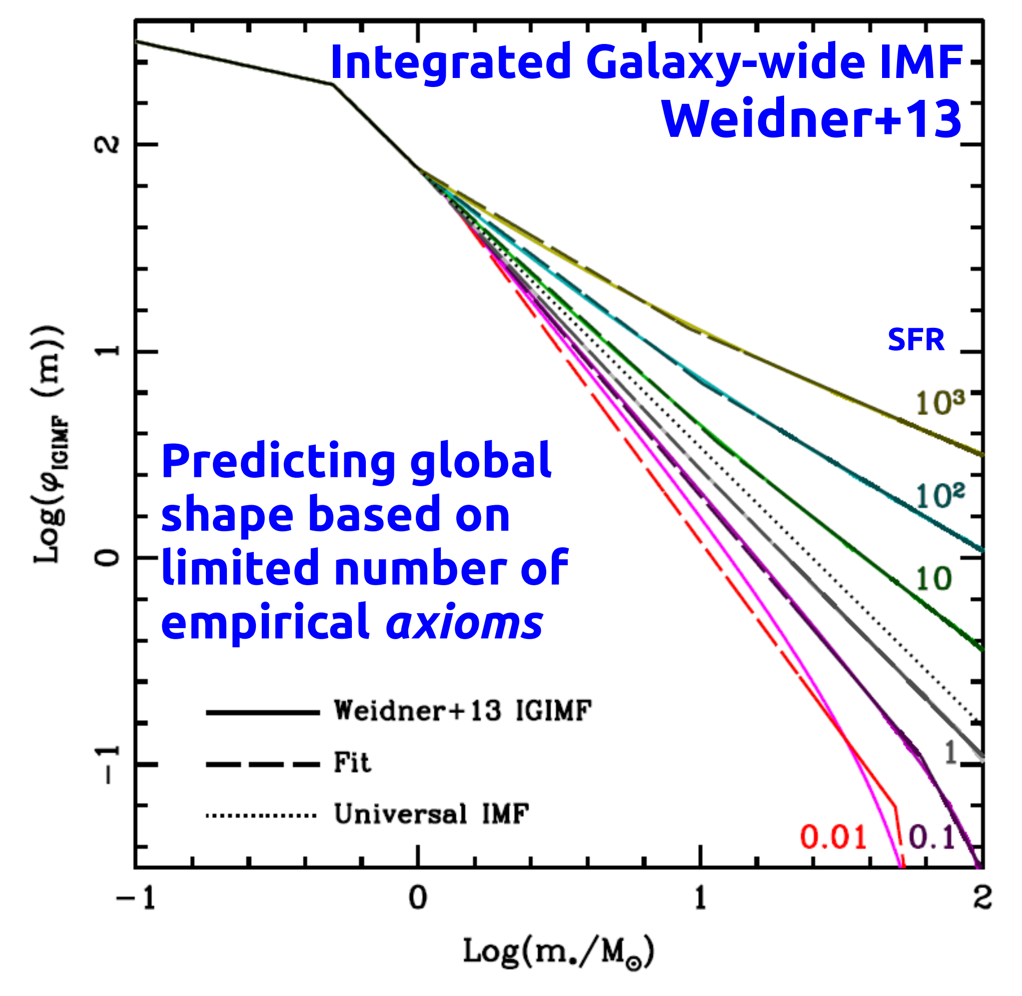
Variable IMF: Observations (dynamical)



Variable IMF: Observations (Spectroscopic)



Variable IMF: Theory



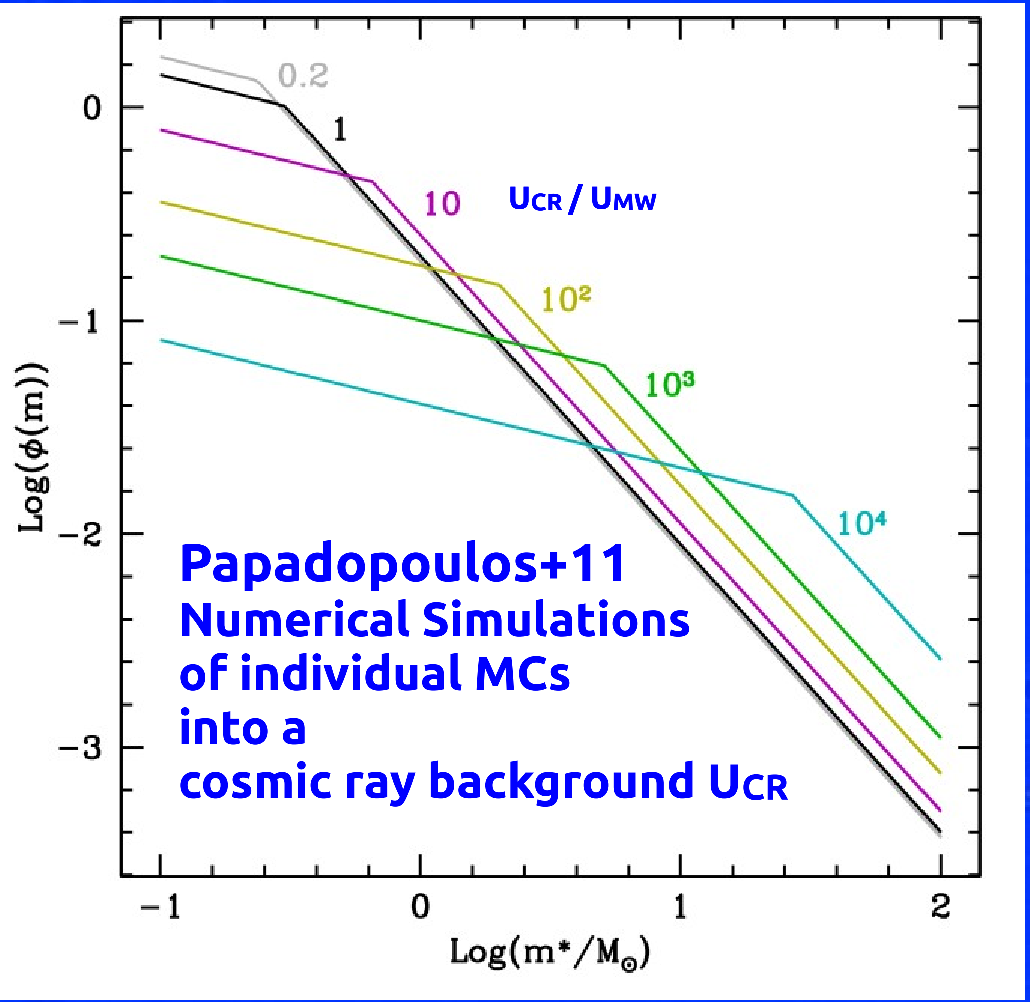
Variable IMF 1

- IGIMF = Integrated Galaxy-wide IMF
  WeidnerKroupa03 Weidner+13
- Based on a limited number of axyoms
  1. Universal IMF for individual MC → Kroupa IMF
  2. High-mass end evolution → $\alpha_3 = \begin{cases} 2.35 & \rho_{\rm cl} < 9.5 \times 10^4 M_\odot/pc^3 \\ 1.86 - 0.43 \log(\frac{\rho_{\rm cl}}{10^4}) & \rho_{\rm cl} \geqslant 9.5 \times 10^4 M_\odot/pc^3 \end{cases}$
  3. MC core density → $\log \rho_{\rm cl} = 0.61 \log M_{\rm cl} + 2.85$
  4. MC-MF → $\varphi_{\rm CL}(M_{\rm cl}) \propto M_{\rm cl}^{-\beta},$
  5. Power law index → $\beta = \begin{cases} 2 & SFR < 1 M_\odot/yr \\ -1.06 \log SFR + 2 & SFR \geqslant 1 M_\odot/yr \end{cases}$
  6. Maximum MC mass → $\log M_{\rm cl}^{\rm max} = 0.746 \log SFR + 4.93.$
  7. Maximum stellar mass → $\log m_\star^{\rm max} = 2.56 \log M_{\rm cl} \times [3.82^{9.17} + (\log M_{\rm cl})^{9.17}]^{1/9.17} - 0.38.$
- Estimate of IGIMF as a function of SFR

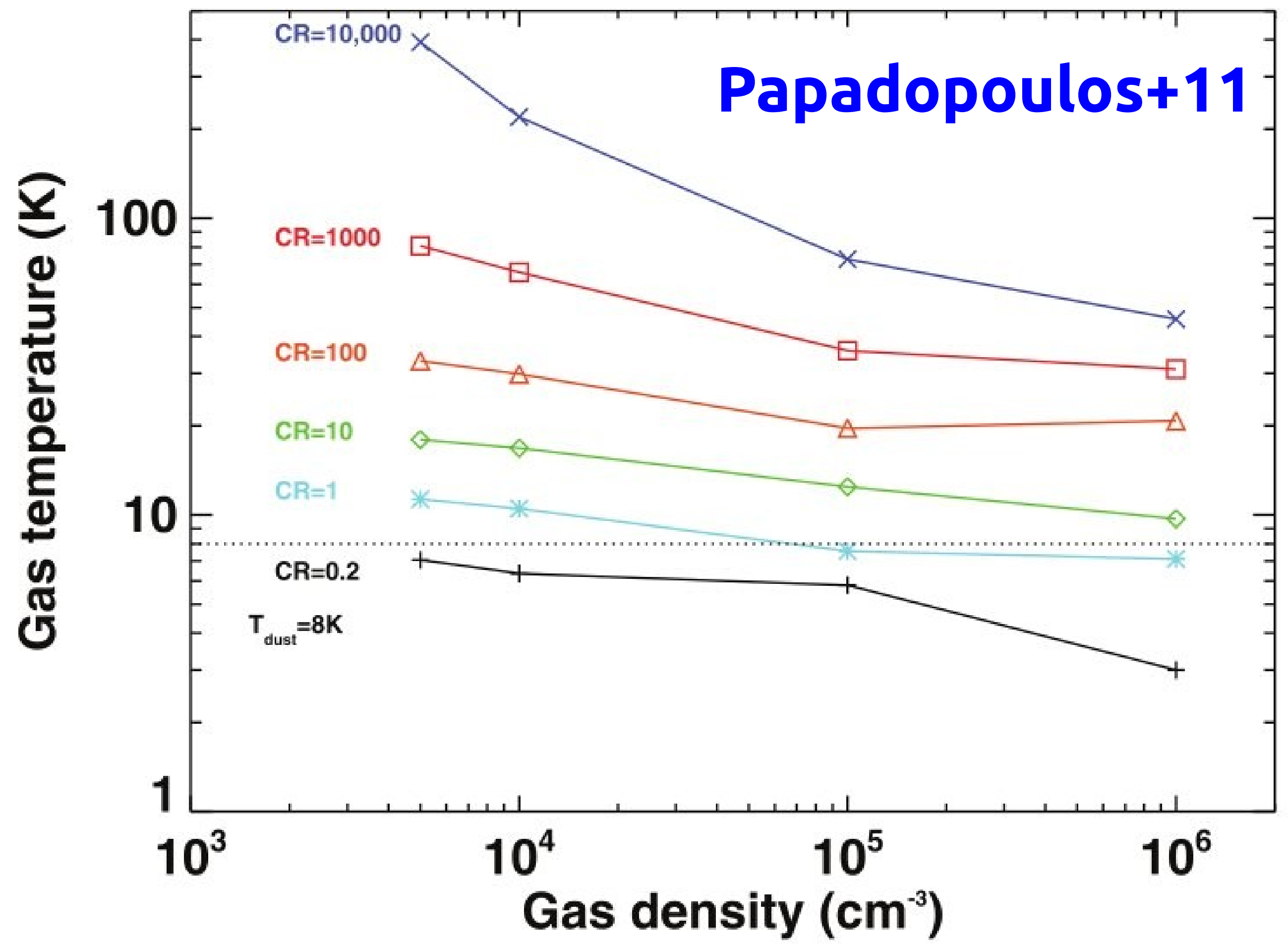
$$\varphi_{\rm IGIMF}(m) = \int_{M_{\rm cl}^{\rm min}}^{M_{\rm cl}^{\rm max}} \varphi_\star(m \leqslant m_\star^{\rm max}(M_{\rm cl}))\varphi_{\rm CL}(M_{\rm cl}) dM_{\rm cl}$$

Variable IMF: Theory

SFR

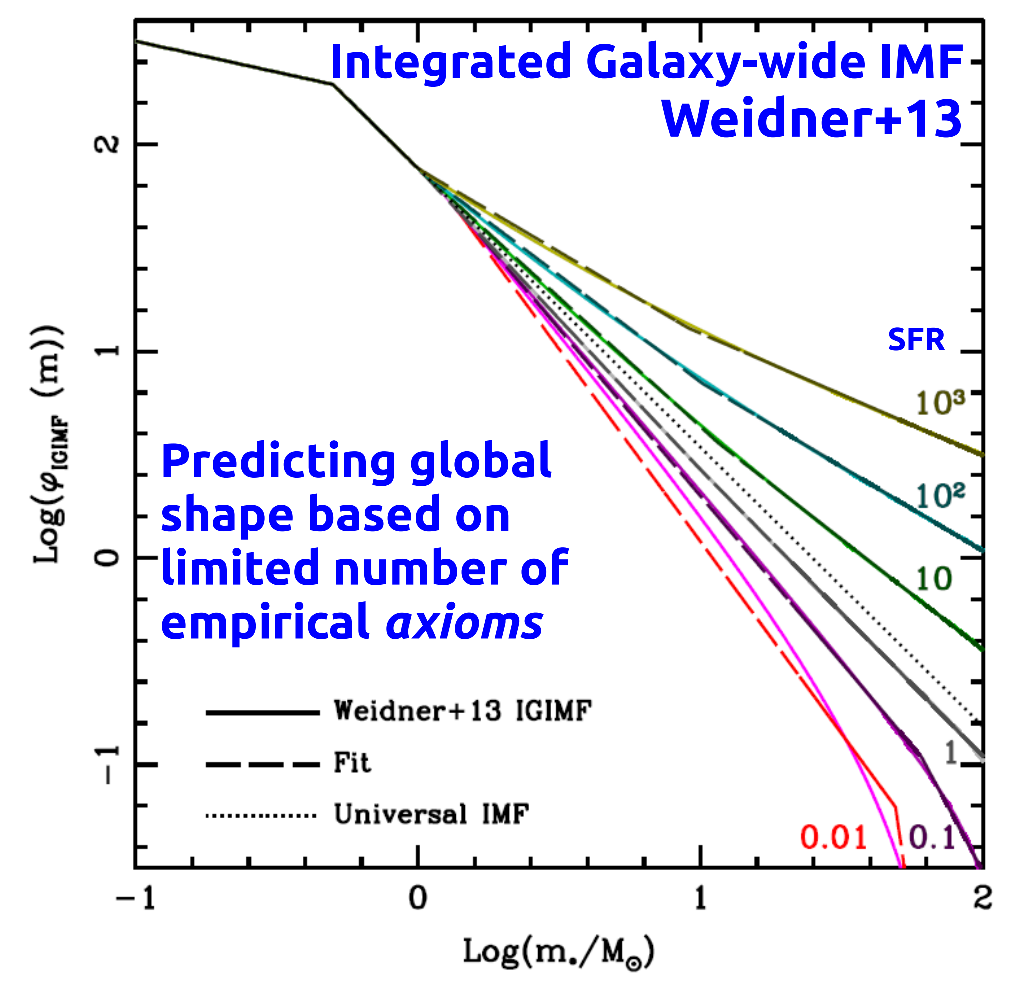


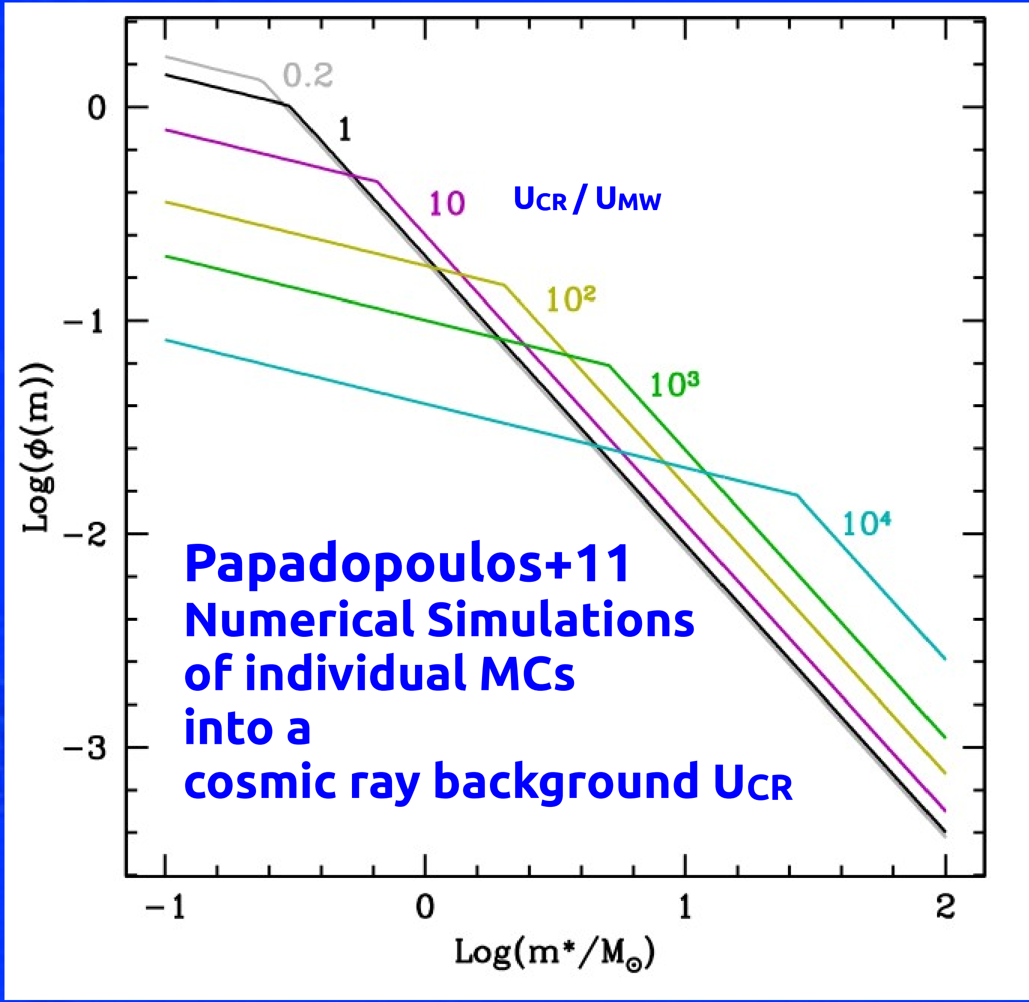
Variable IMF 2



$$M_J^{(c)} = \left(\frac{k_B T_k}{G \mu m_{H_2}}\right)^{3/2} \rho_c^{-1/2}$$
$$= 0.9 \left(\frac{T_k}{10\,K}\right)^{3/2} \left[\frac{n_c(H_2)}{10^4\,cm^{-3}}\right]^{-1/2} M_\odot,$$

Variable IMF: Theory





Strategy

- Variable IMF prescription has been implemented into the GAlaxy Evolution and Assembly (GAEA) semi-analytic code

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- Intrinsic properties cannot be compared directly with observational estimates

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- We derive self-consistent synthetic photometry to compare
  - Intrinsic Galaxy Properties

Strategy

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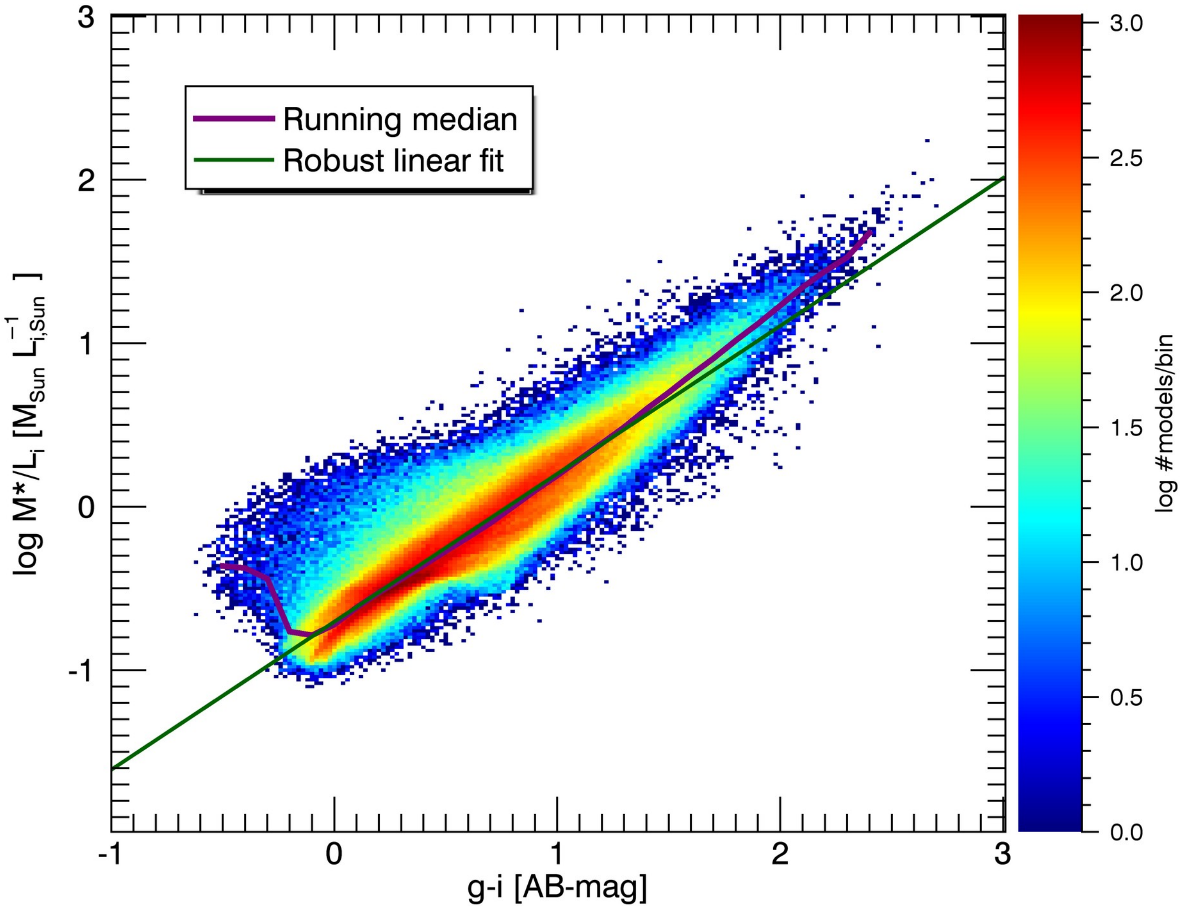
- Intrinsic properties cannot be compared directly with observational estimates

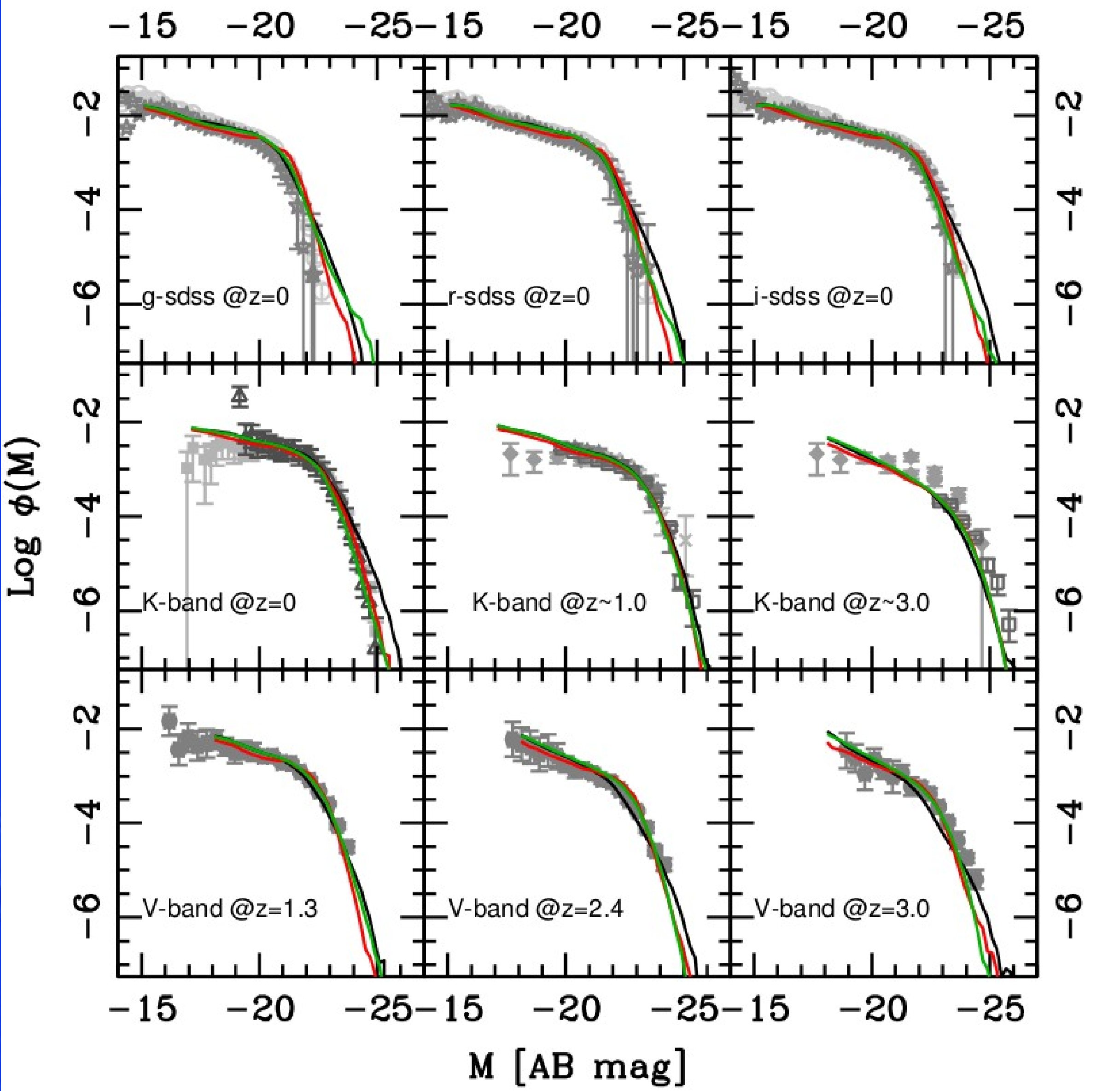
- We derive self-consistent synthetic photometry to compare
  - Intrinsic Galaxy Properties
  - Photometrically derived Galaxy Properties ("What an observer would estimated from synthetic photometry assuming universal IMF")

Intrinsic properties cannot be compared directly with observational estimates



Zibetti+17

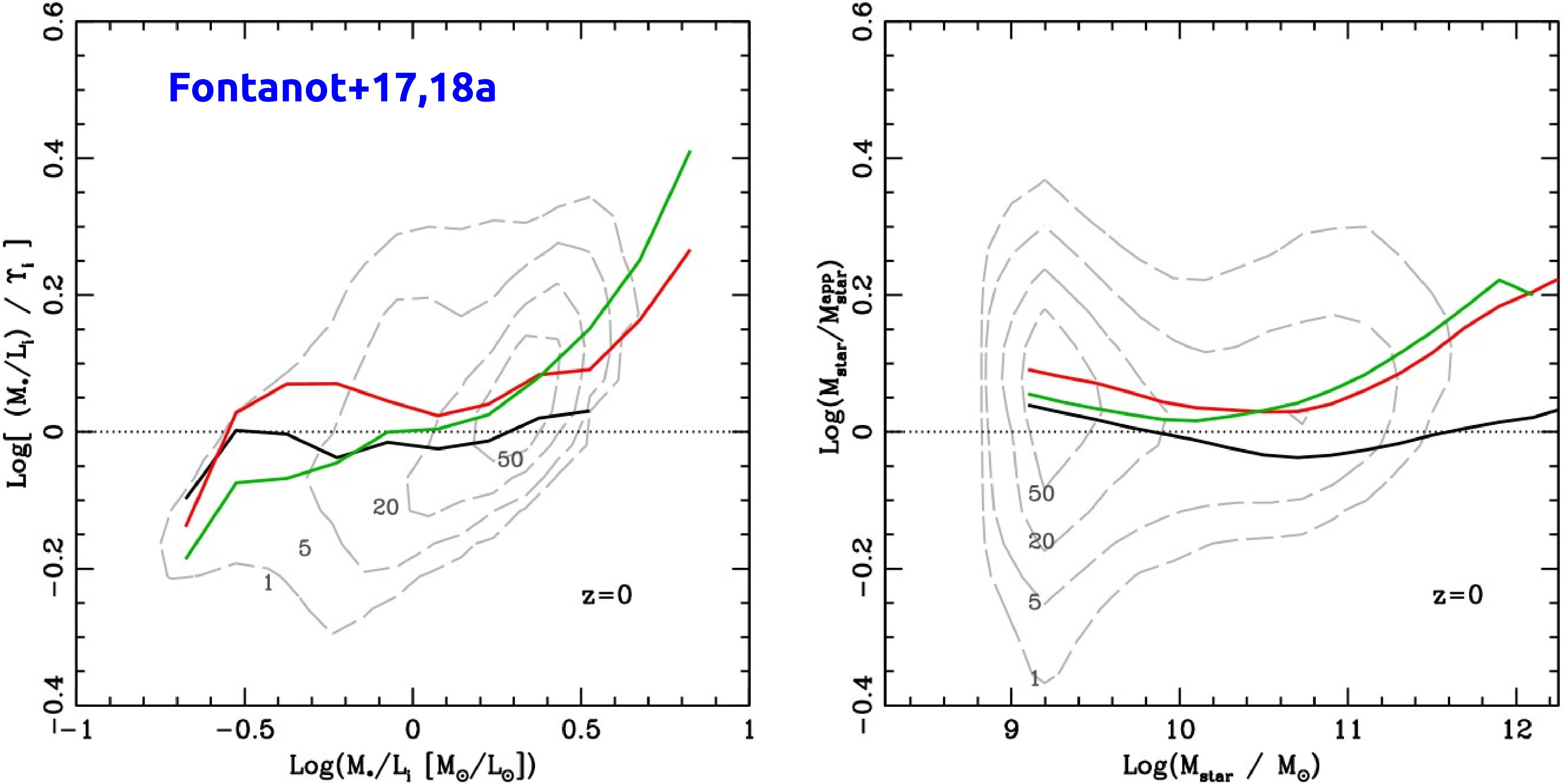
$$\log \Upsilon_i = v(g-i) + \delta$$

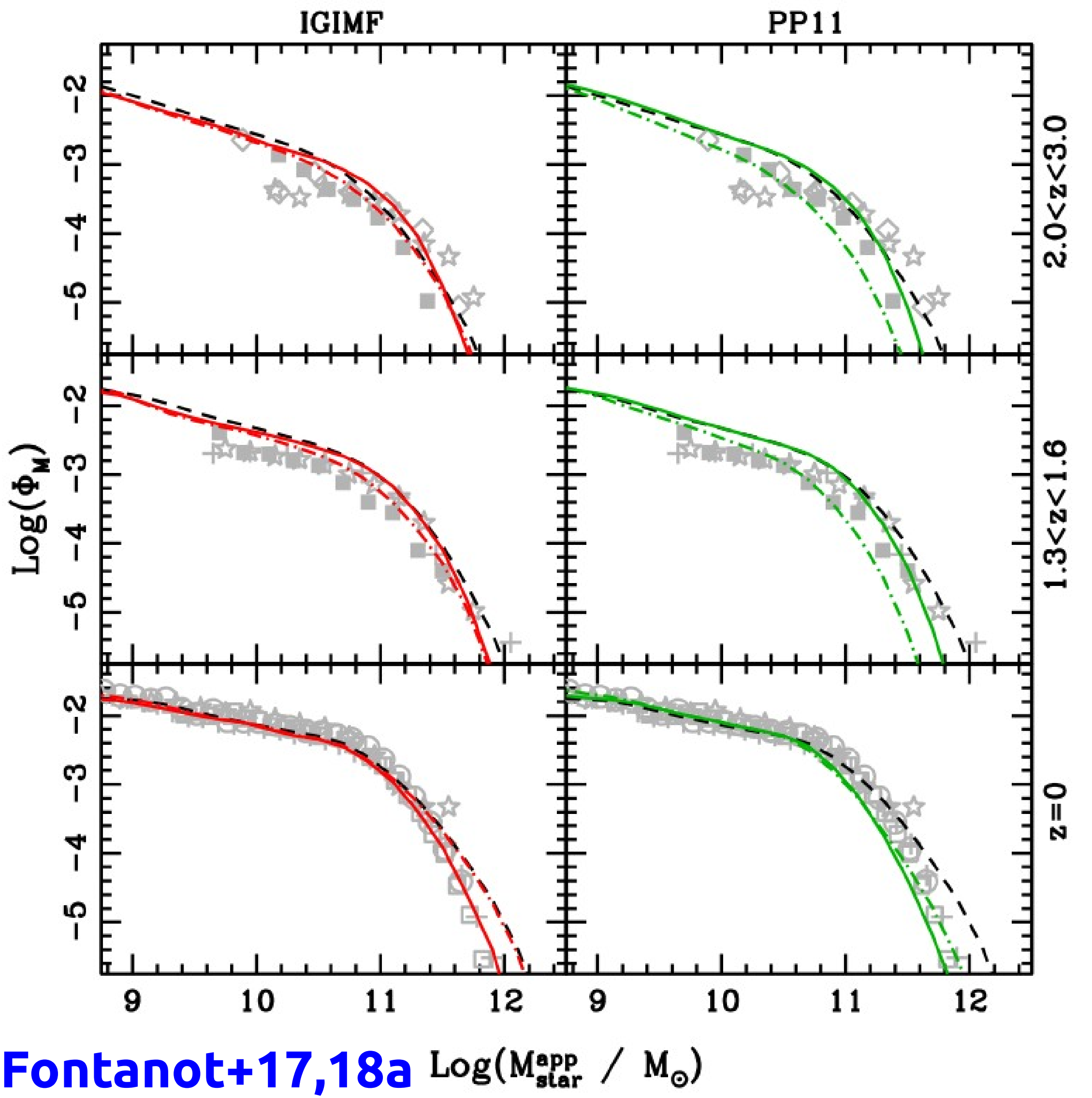


Log φ(M)
M [AB mag]
g-sdss @z=0
r-sdss @z=0
i-sdss @z=0
K-band @z=0
K-band @z~1.0
K-band @z~3.0
V-band @z=1.3
V-band @z=2.4
V-band @z=3.0

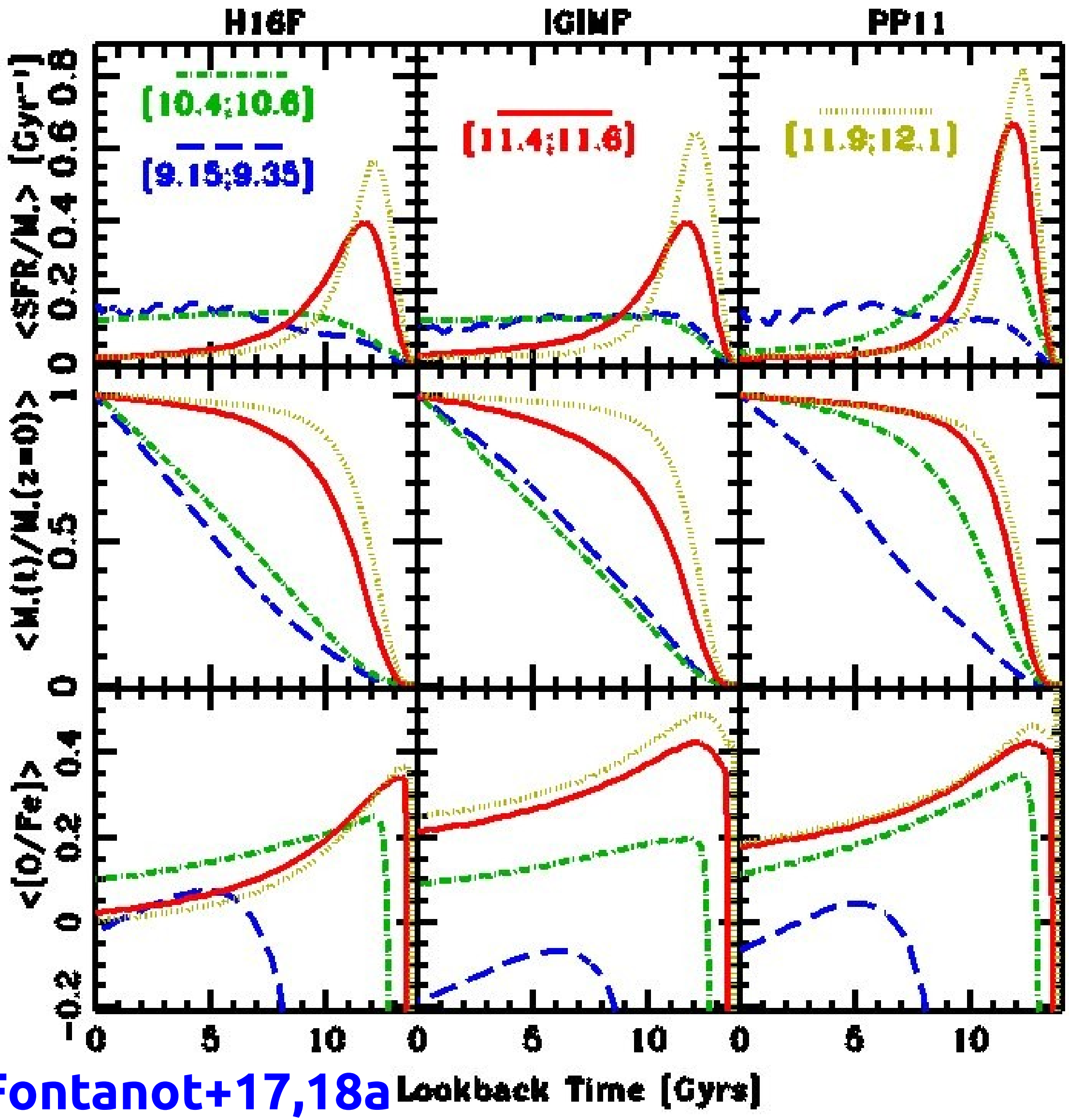
Fontanot+17

Fontanot+17,18a

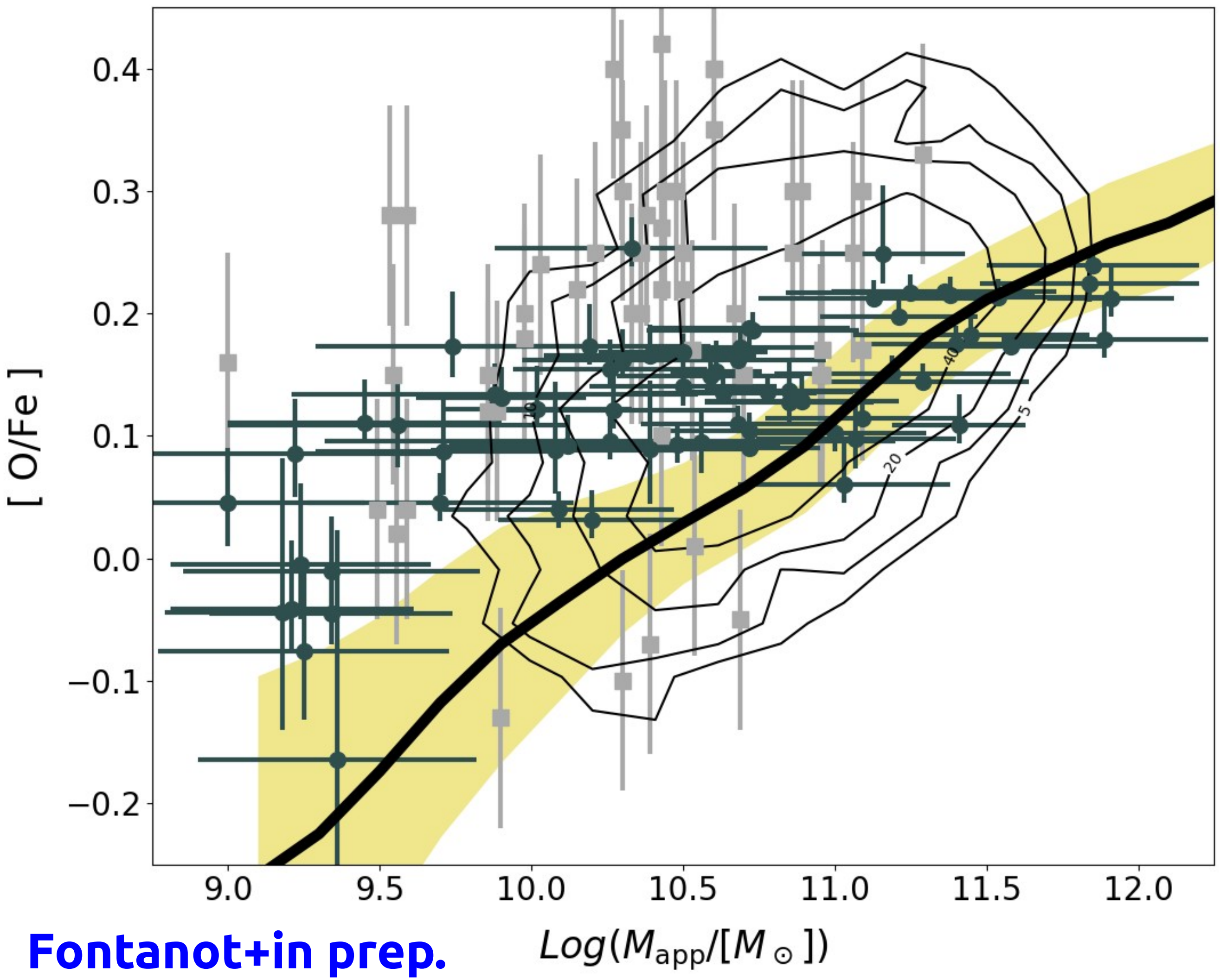




Fontanot+17,18a

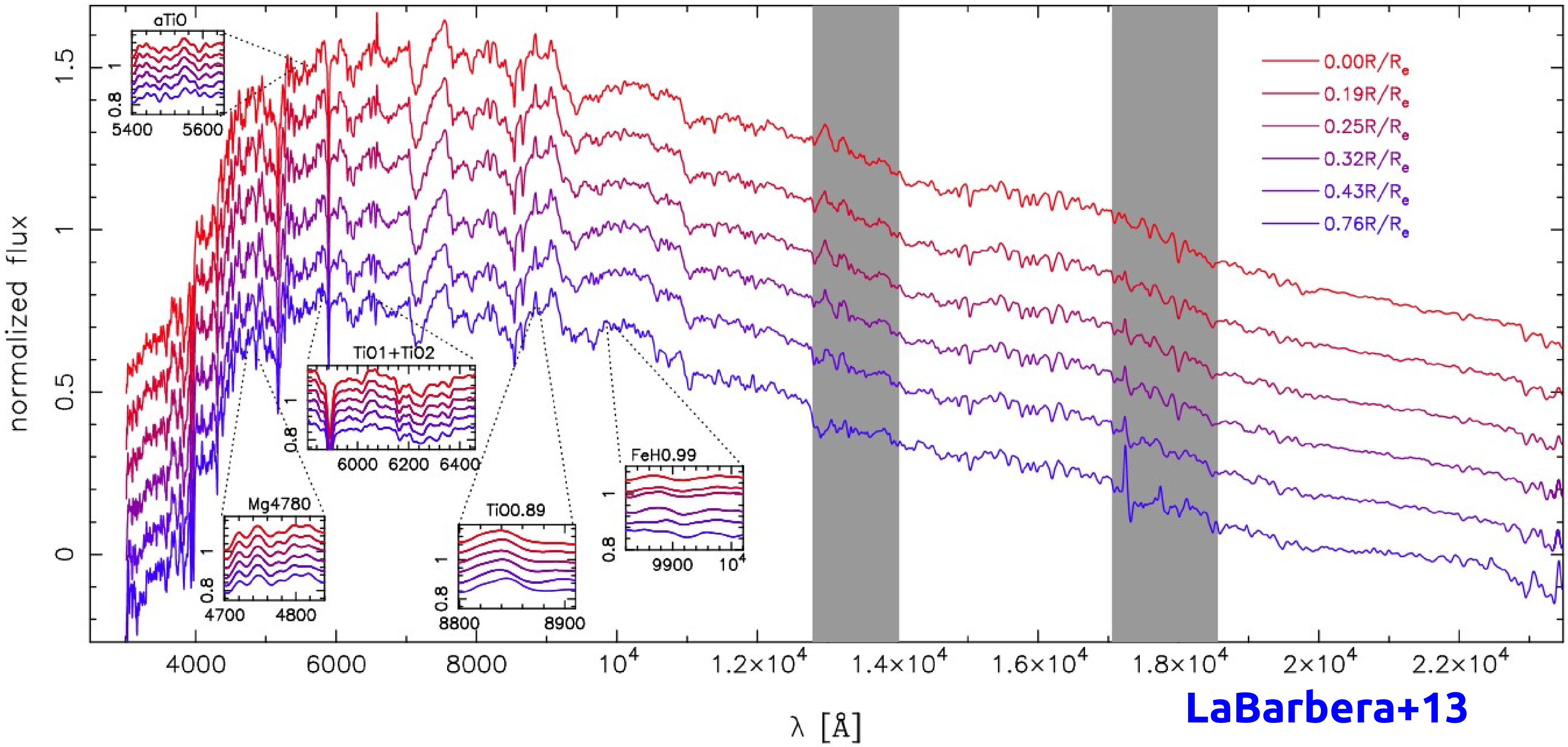


Fontanot+17,18a

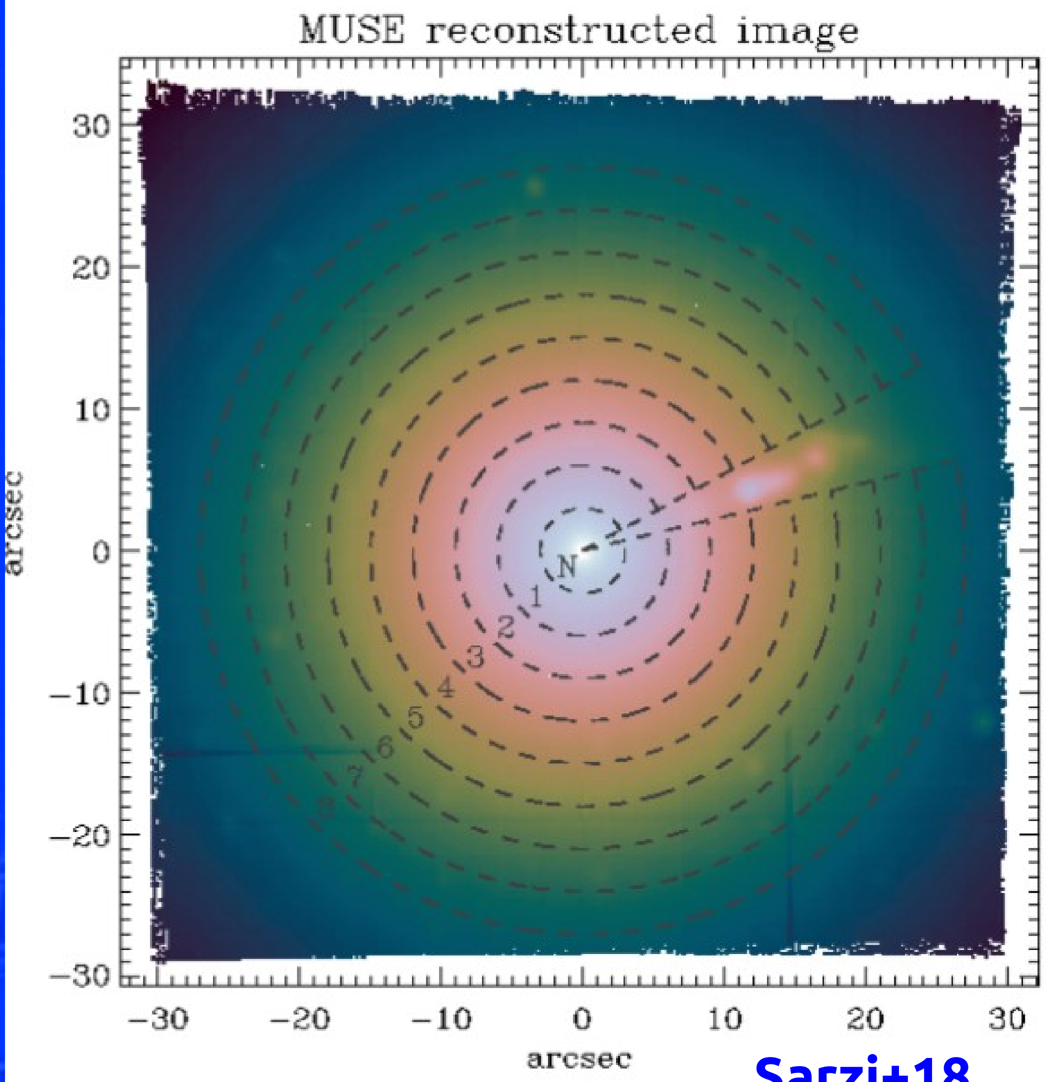


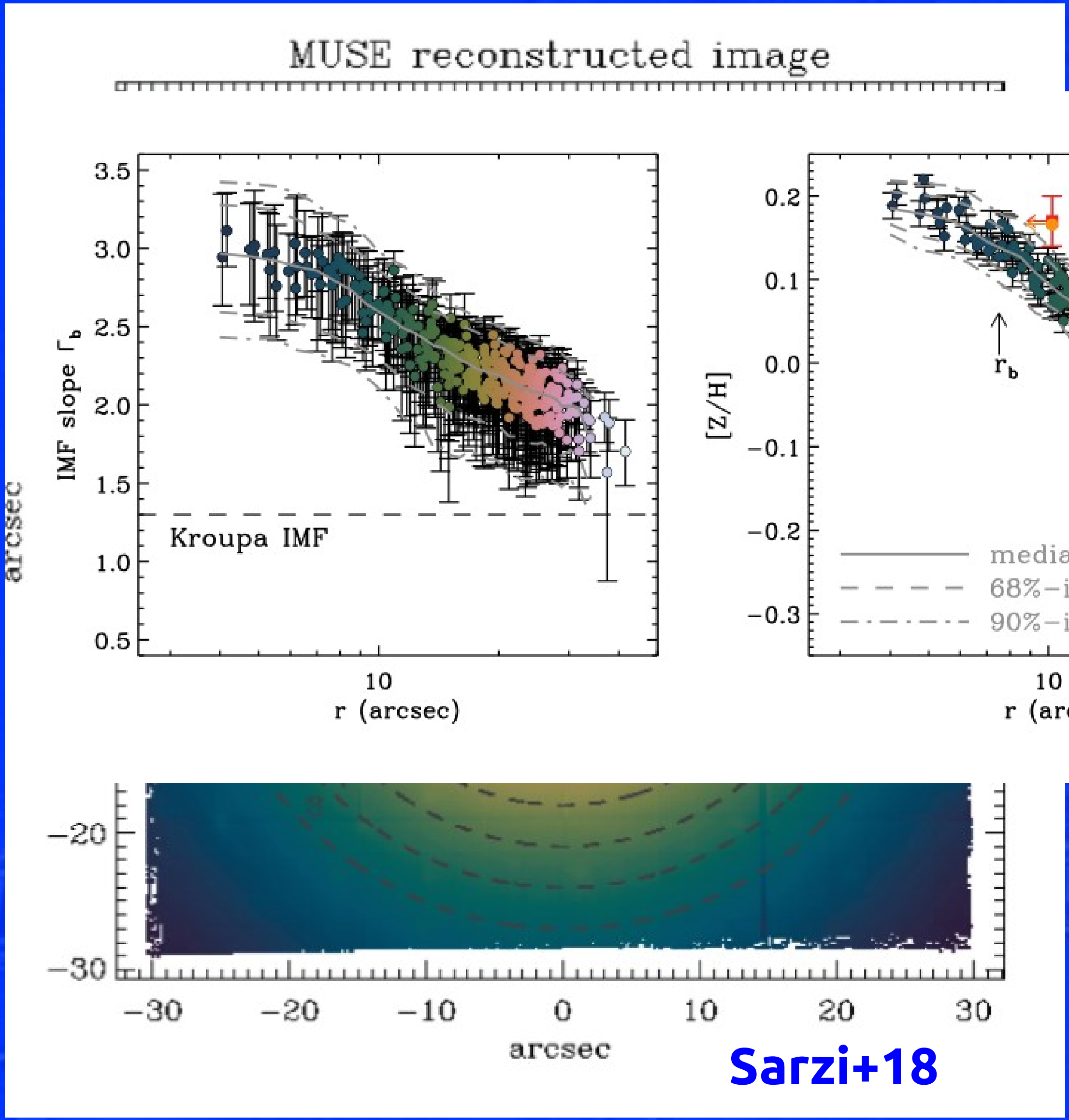
Fontanot+in prep.

Variable IMF: Observations (Spectroscopy again)



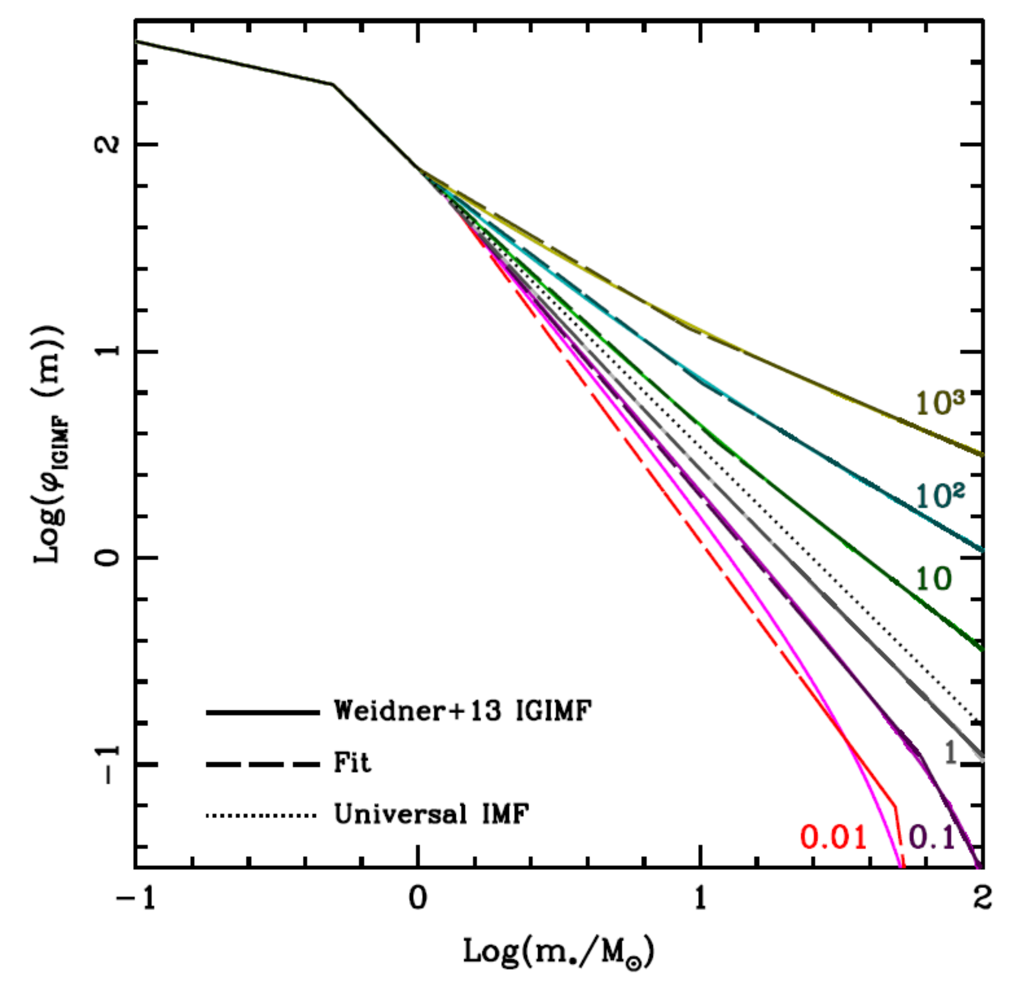
LaBarbera+13

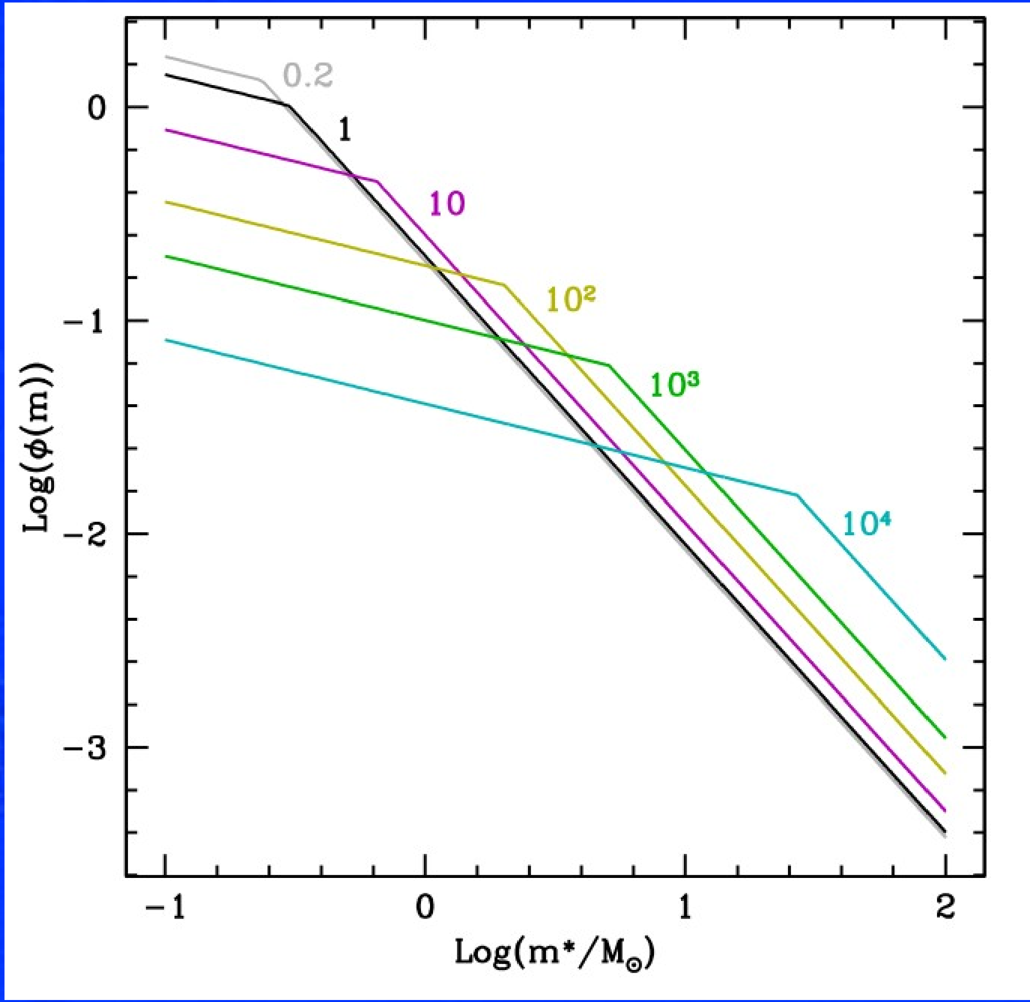

MUSE reconstructed image
arcsec
arcsec
30
20
10
0
−10
−20
−30
−30
−20
−10
0
10
20
30
N
1
2
3
4
5
6
7
8
Sarzi+18



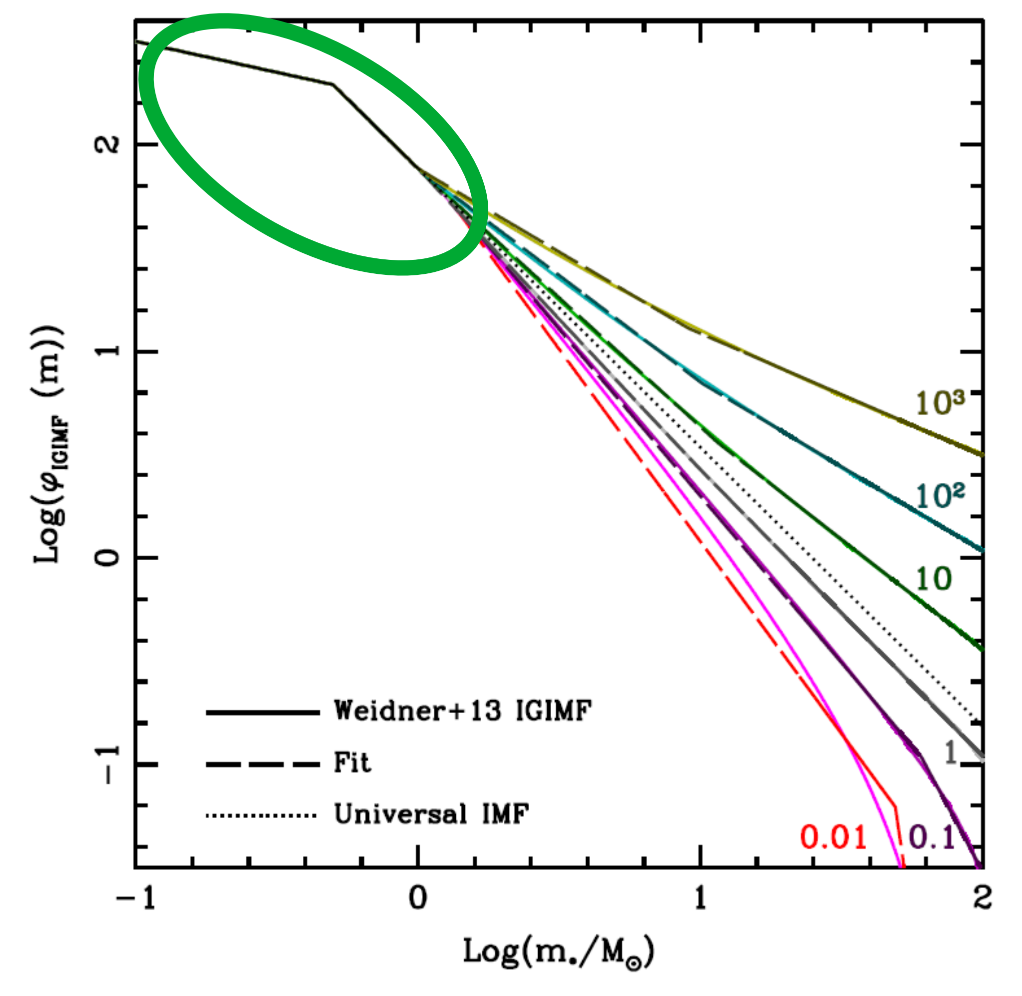
MUSE reconstructed image
IMF slope Γb
Kroupa IMF
r (arcsec)
[Z/H]
rb
median
68%-ile
90%-ile
[α/Fe]
McDermid et al. (2015)
this work
arcsec
Sarzi+18

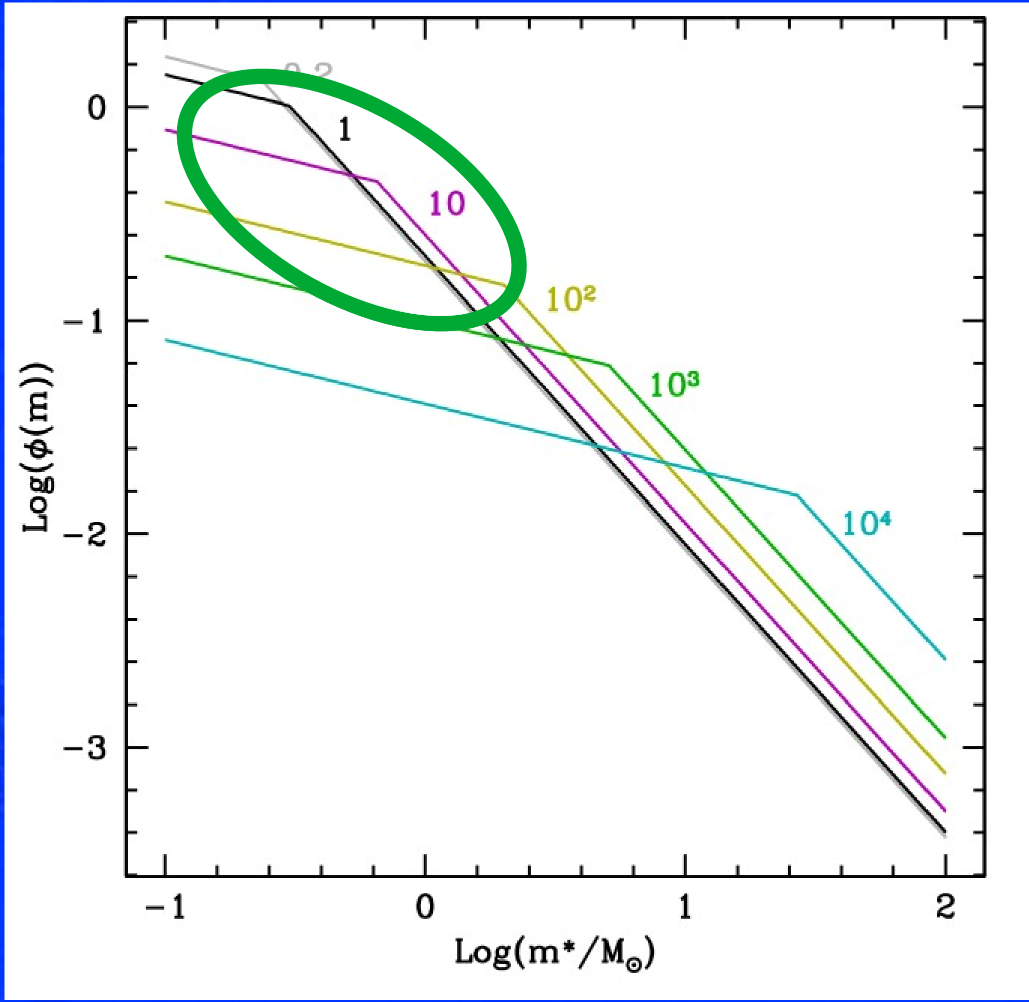
Variable IMF: Theory



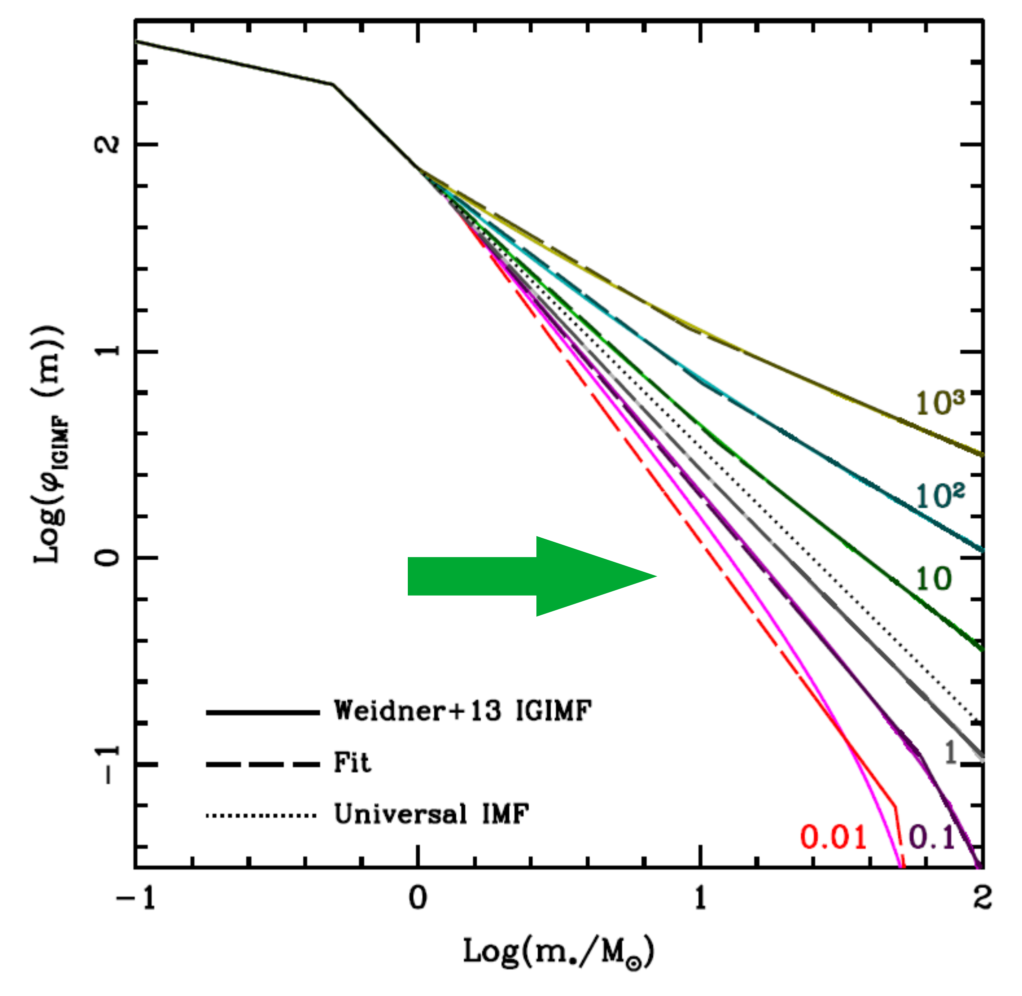


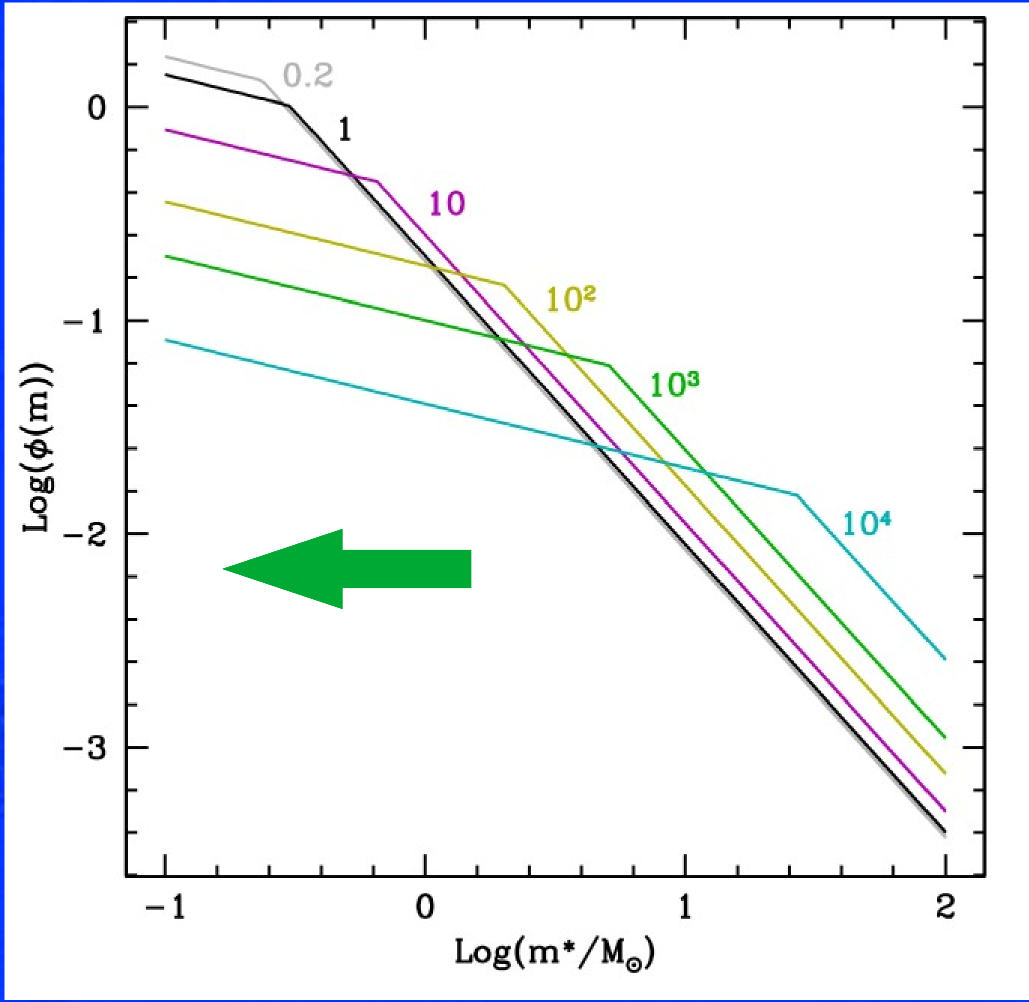
Variable IMF: Theory

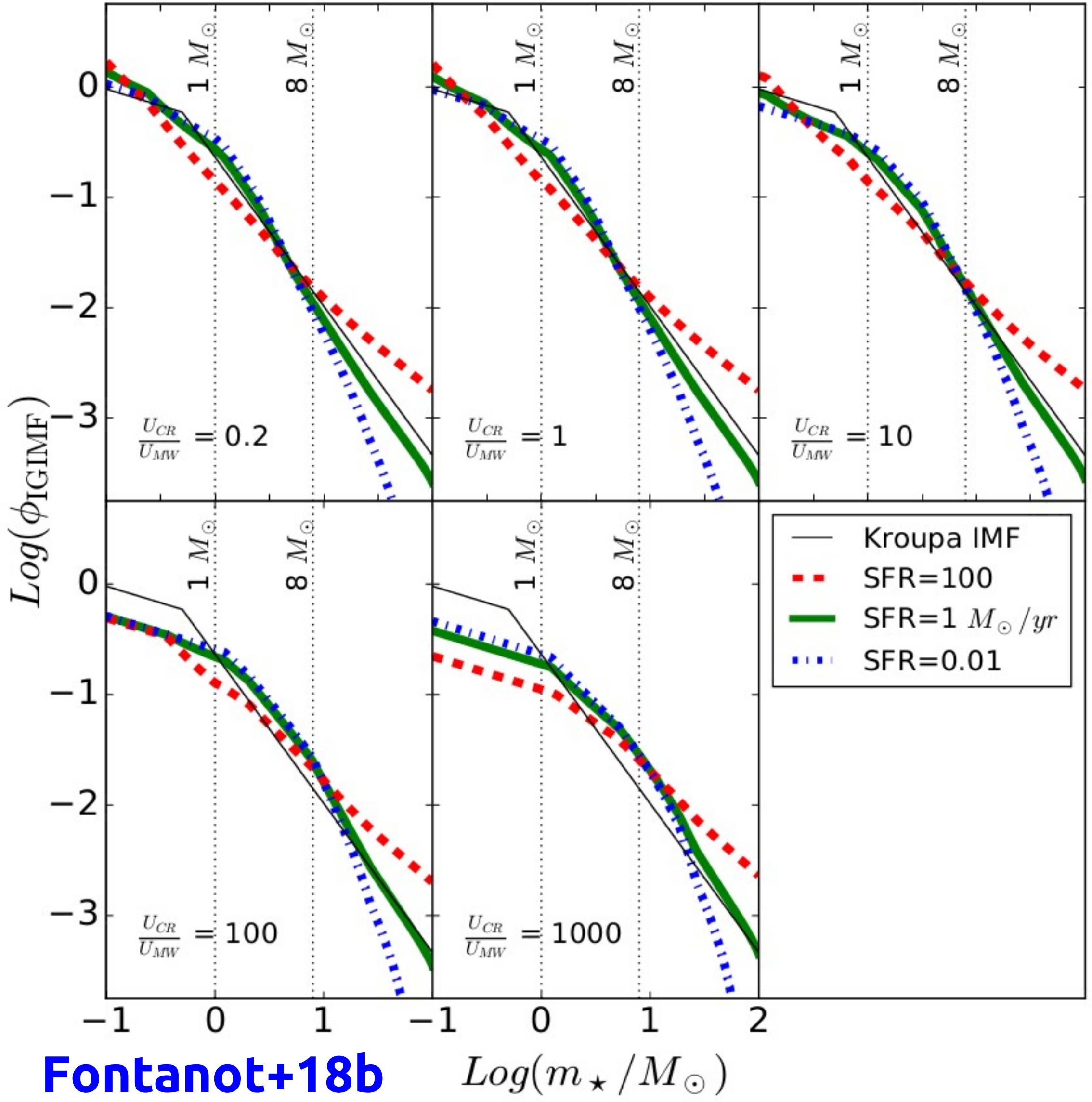




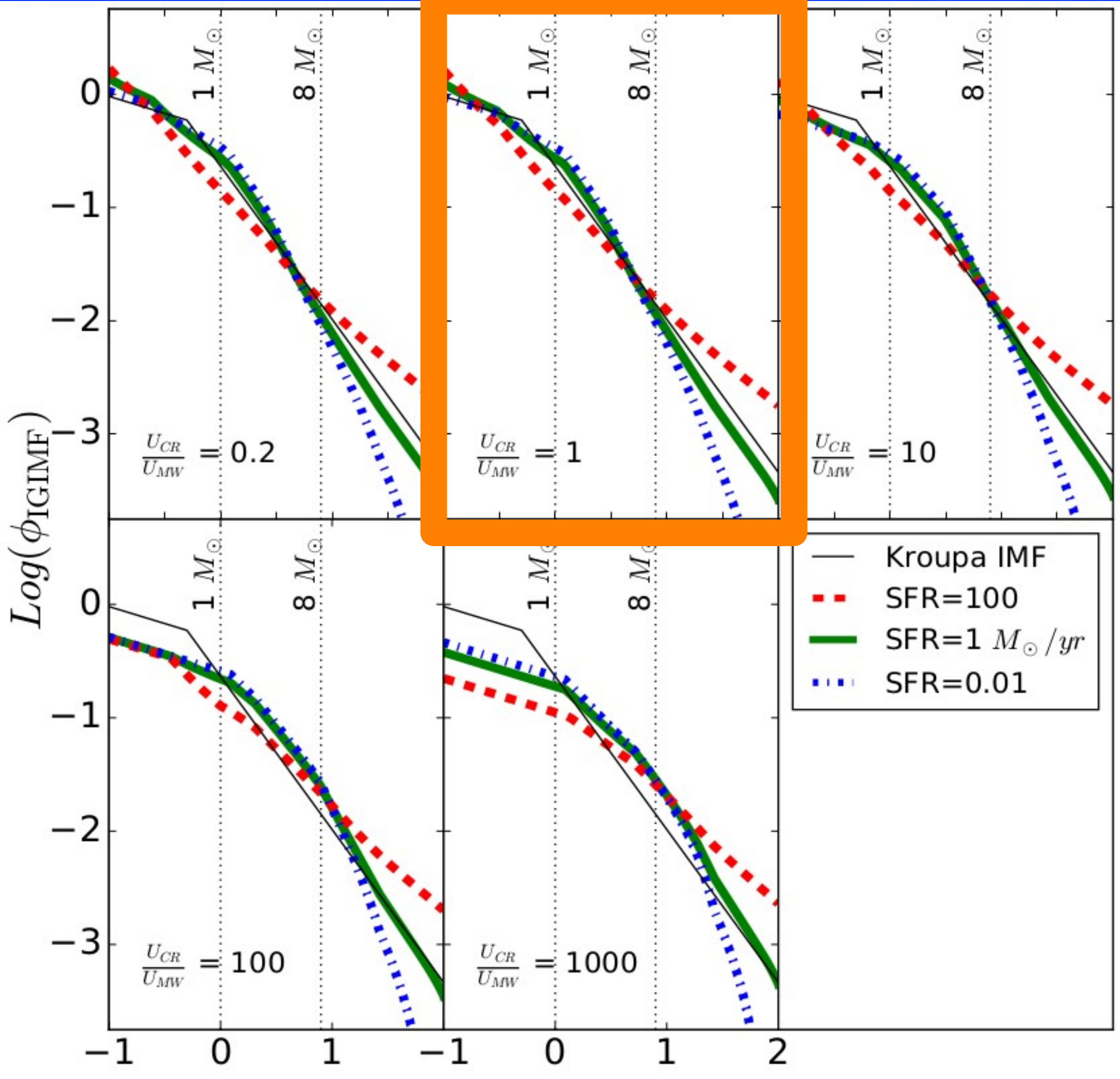
Variable IMF: Theory



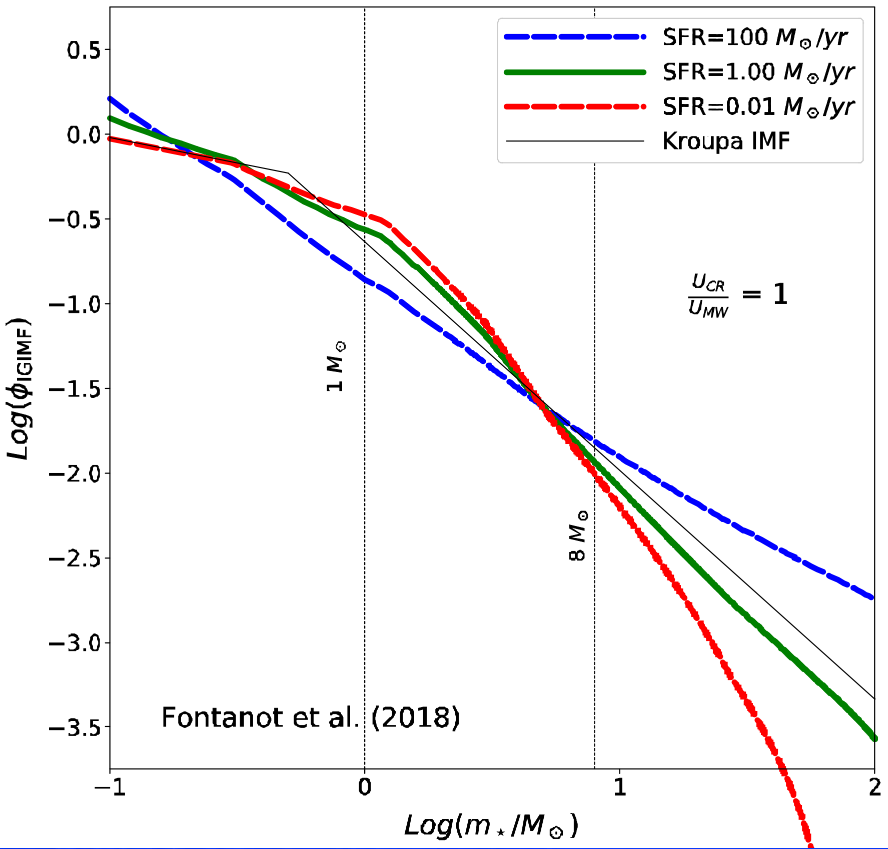




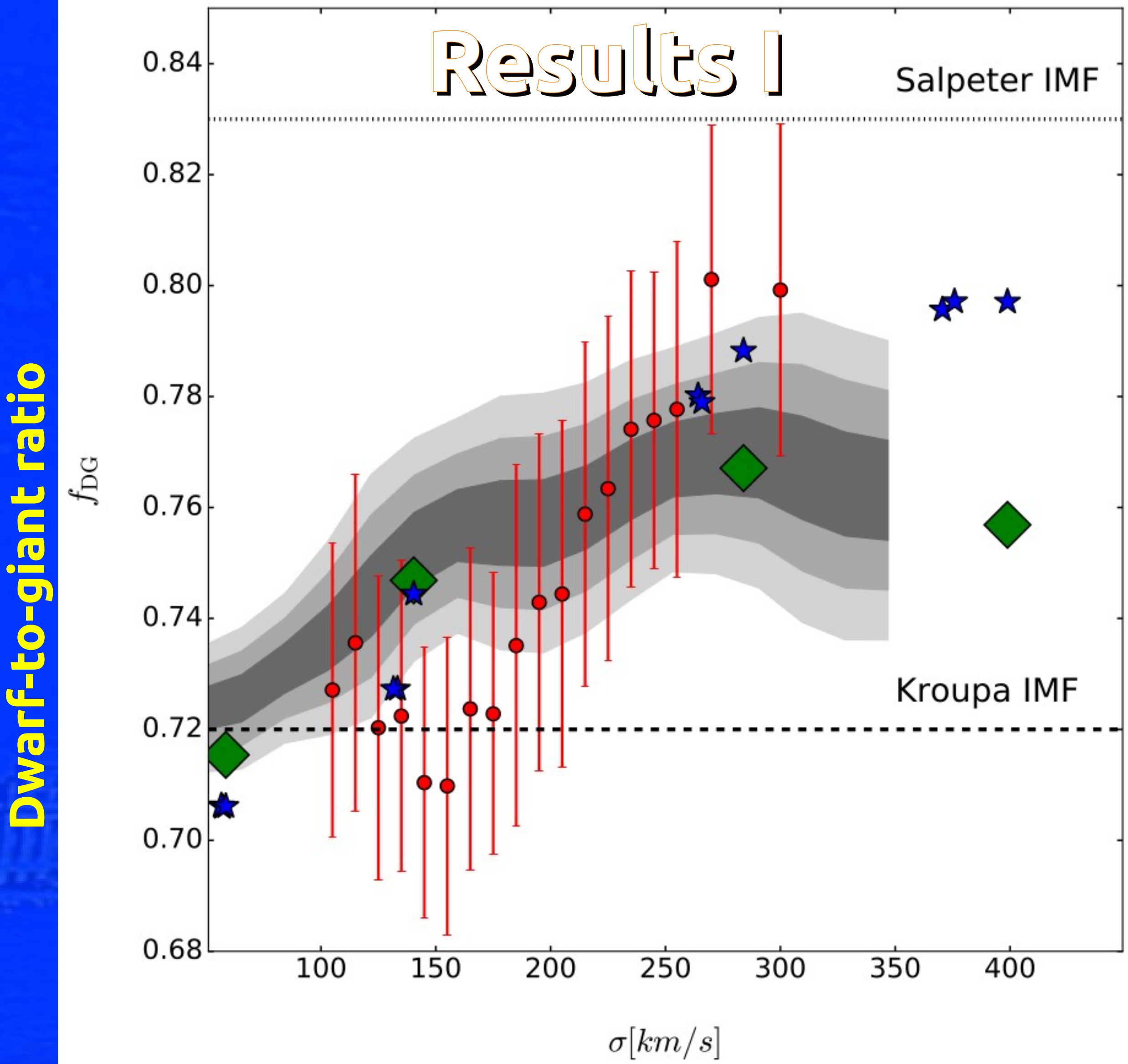
Fontanot+18b



Fontanot+18b

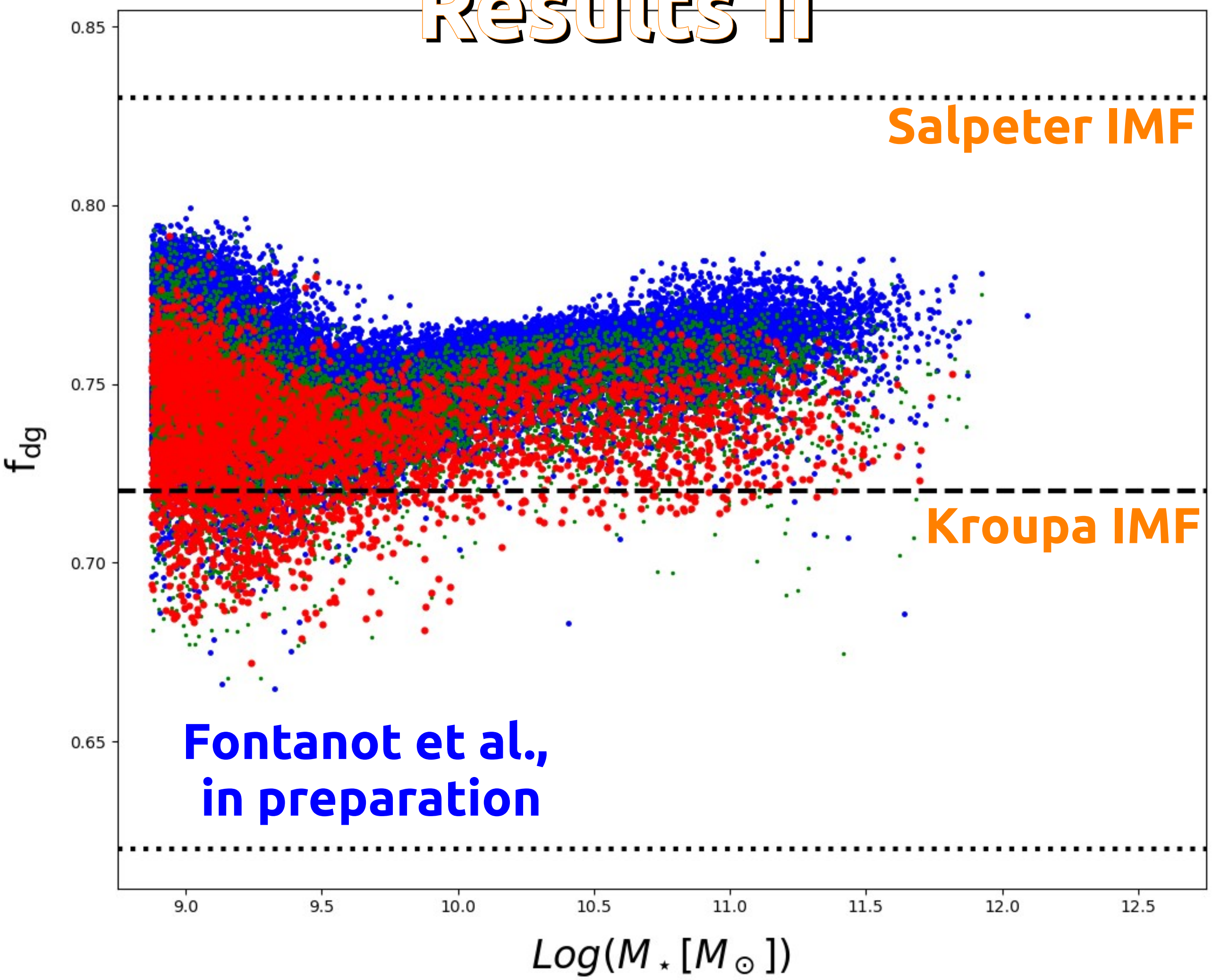


Results I



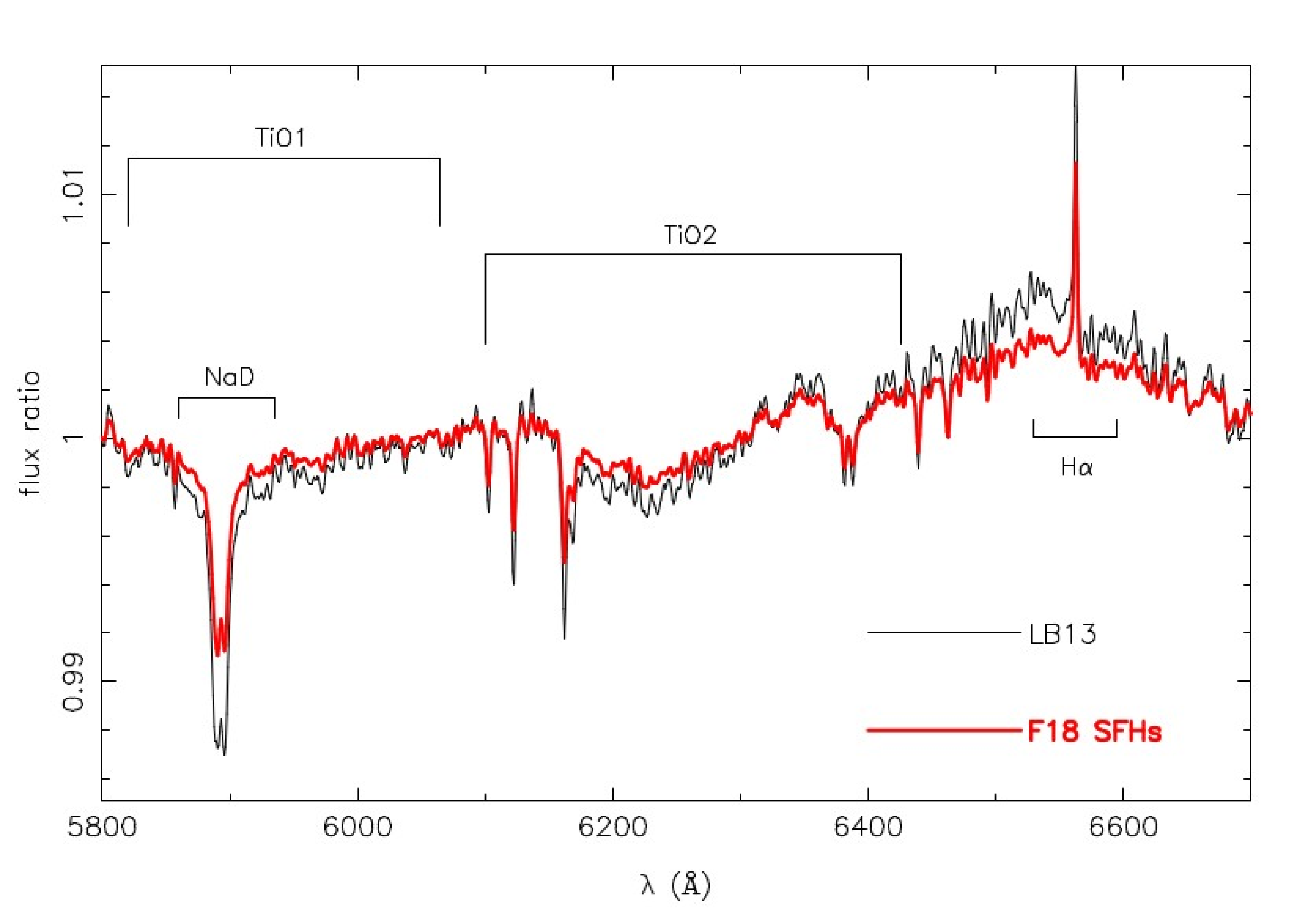
Dwarf-to-giant ratio
Salpeter IMF
Kroupa IMF
f_{DG}
0.84
0.82
0.80
0.78
0.76
0.74
0.72
0.70
0.68
100
150
200
250
300
350
400
$\sigma[km/s]$

Results II



Dwarf-to-giant ratio

Results II



TiO1
TiO2
NaD
Hα
LB13
F18 SFHs
flux ratio
1.01
1
0.99
5800
6000
6200
6400
6600
λ (Å)

Conclusions

- Variable IMF prescriptions in SAMs are a tool to interpret dynamical & spectral deviations from universal IMF
  - Easy way to test (different) IMF variability as a function of galaxy physical properties and/or redshift
- Dual IMF deviations from MW-like at the high- & low-mass end are required to explain at the same time the chemical, dynamical and spectroscopic observations Fontanot+18
  - Intrinsic Galaxy Properties might be drastically different from photometrically estimated values