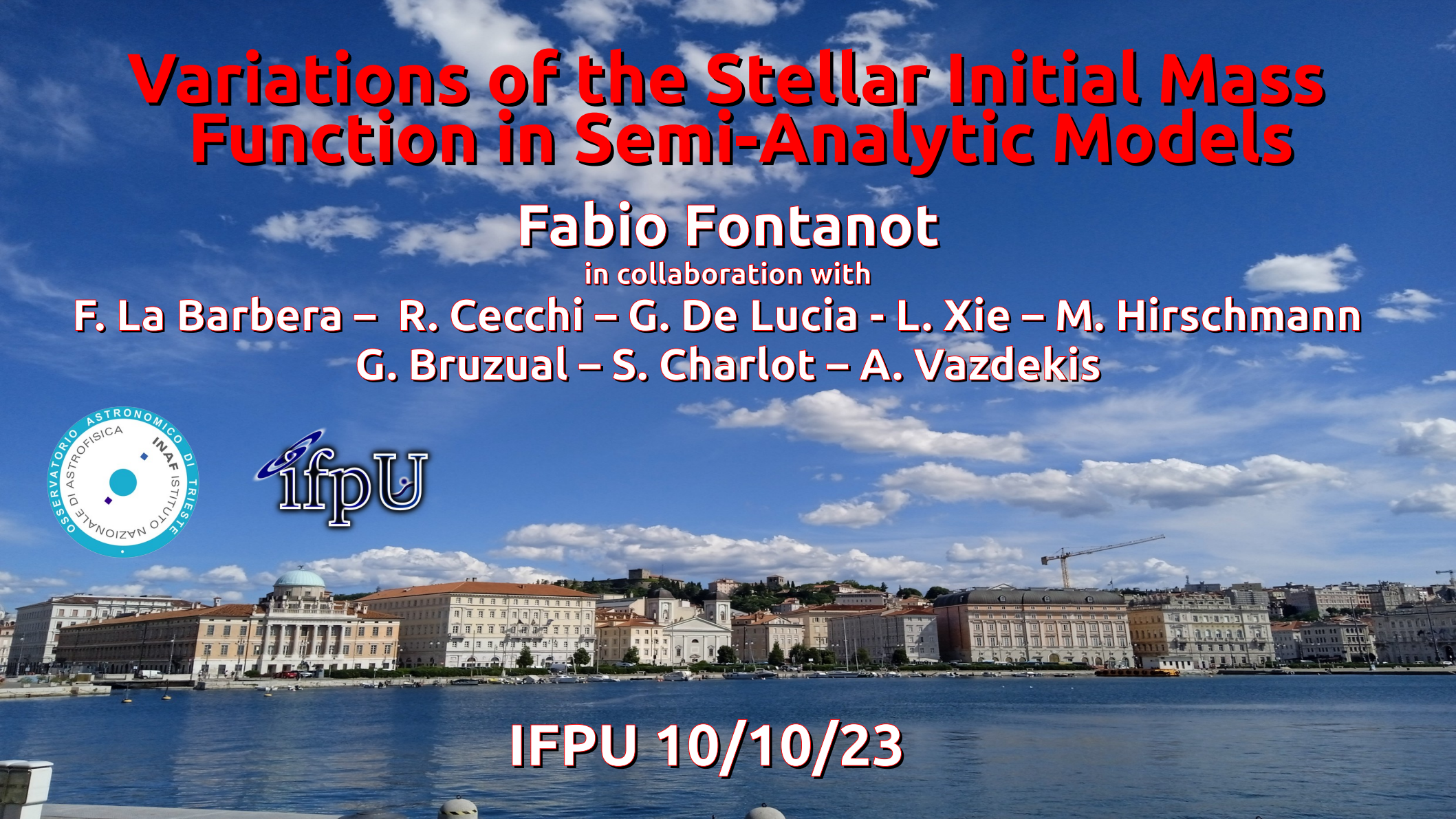
Variations of the Stellar Initial Mass Function in Semi-Analytic Models

Fabio Fontanot

in collaboration with

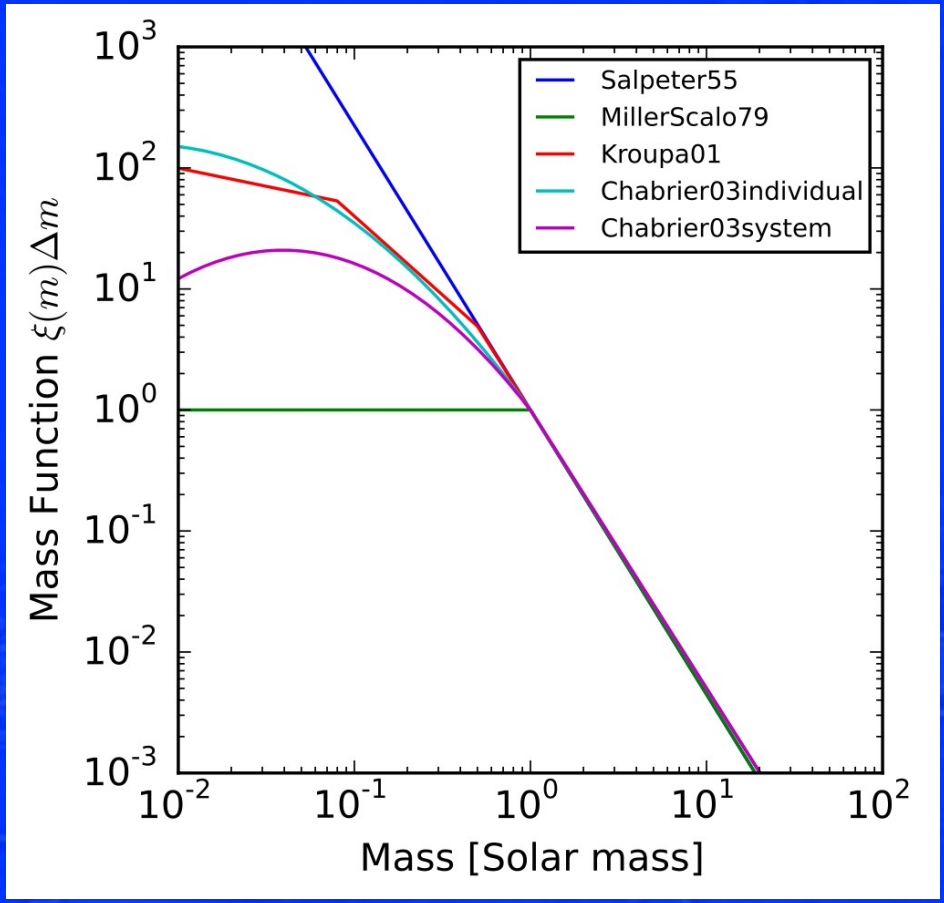
F. La Barbera – R. Cecchi – G. De Lucia - L. Xie – M. Hirschmann

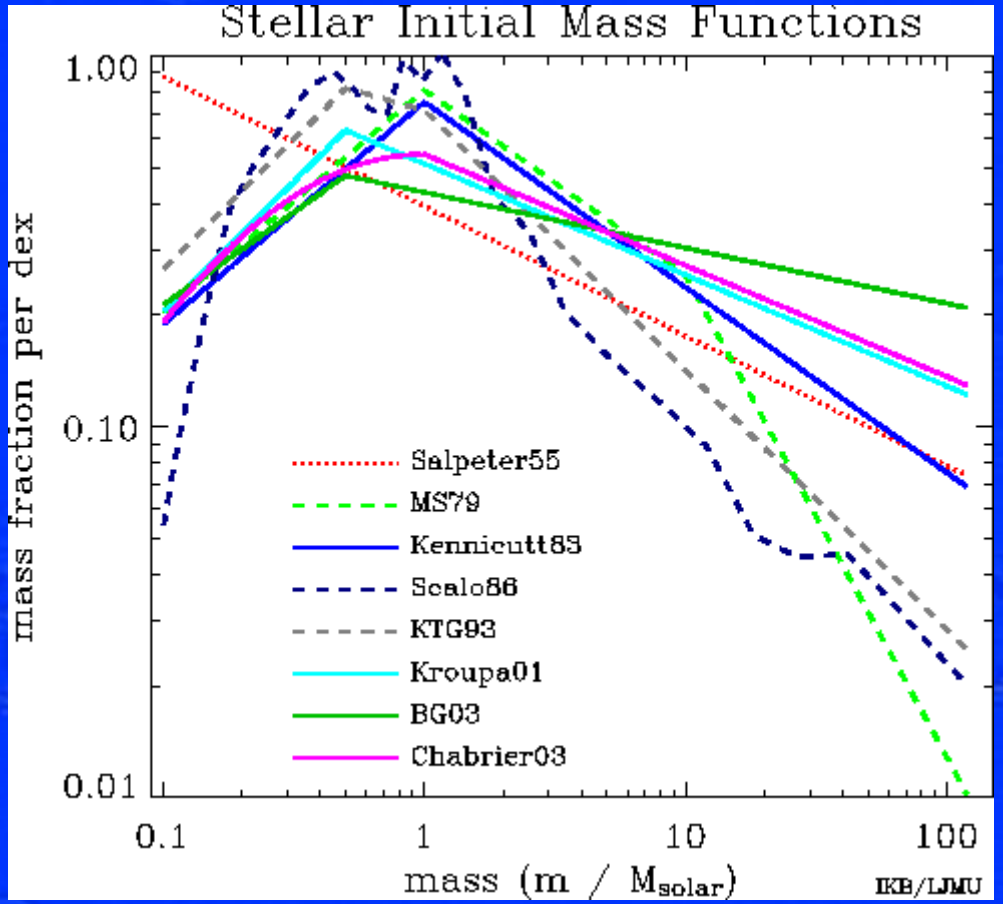
G. Bruzual – S. Charlot – A. Vazdekis



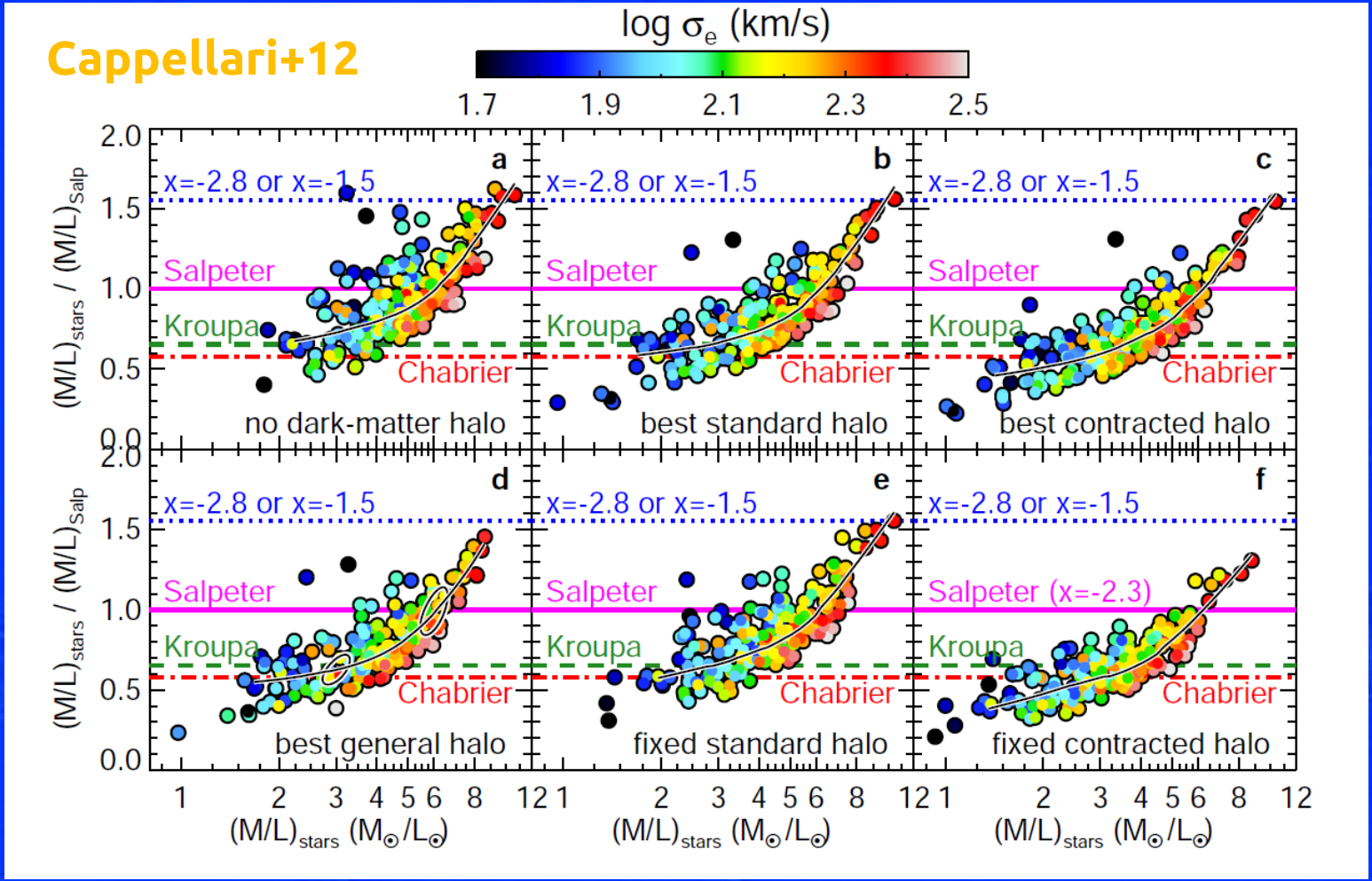
IFPU 10/10/23

Universal IMF ?

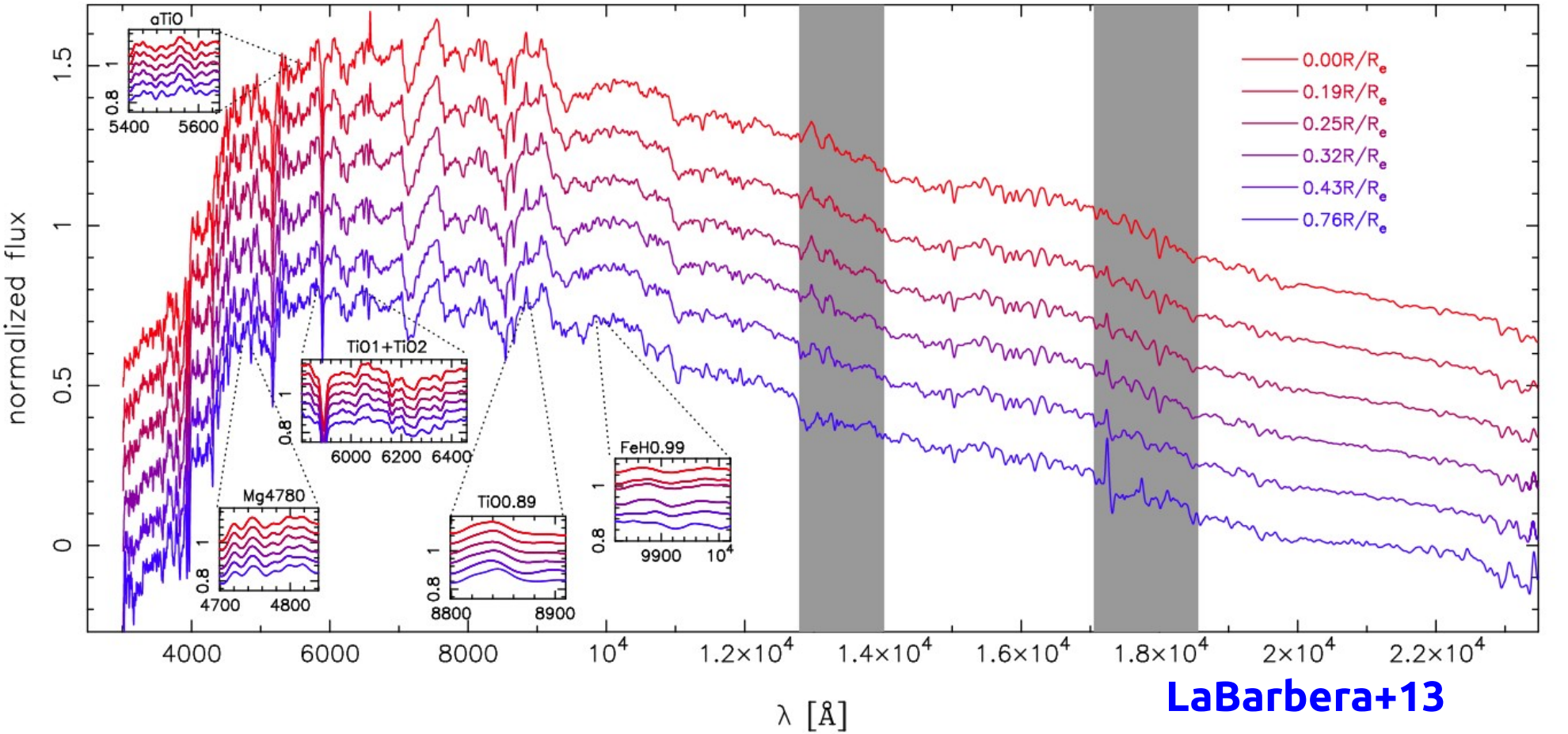




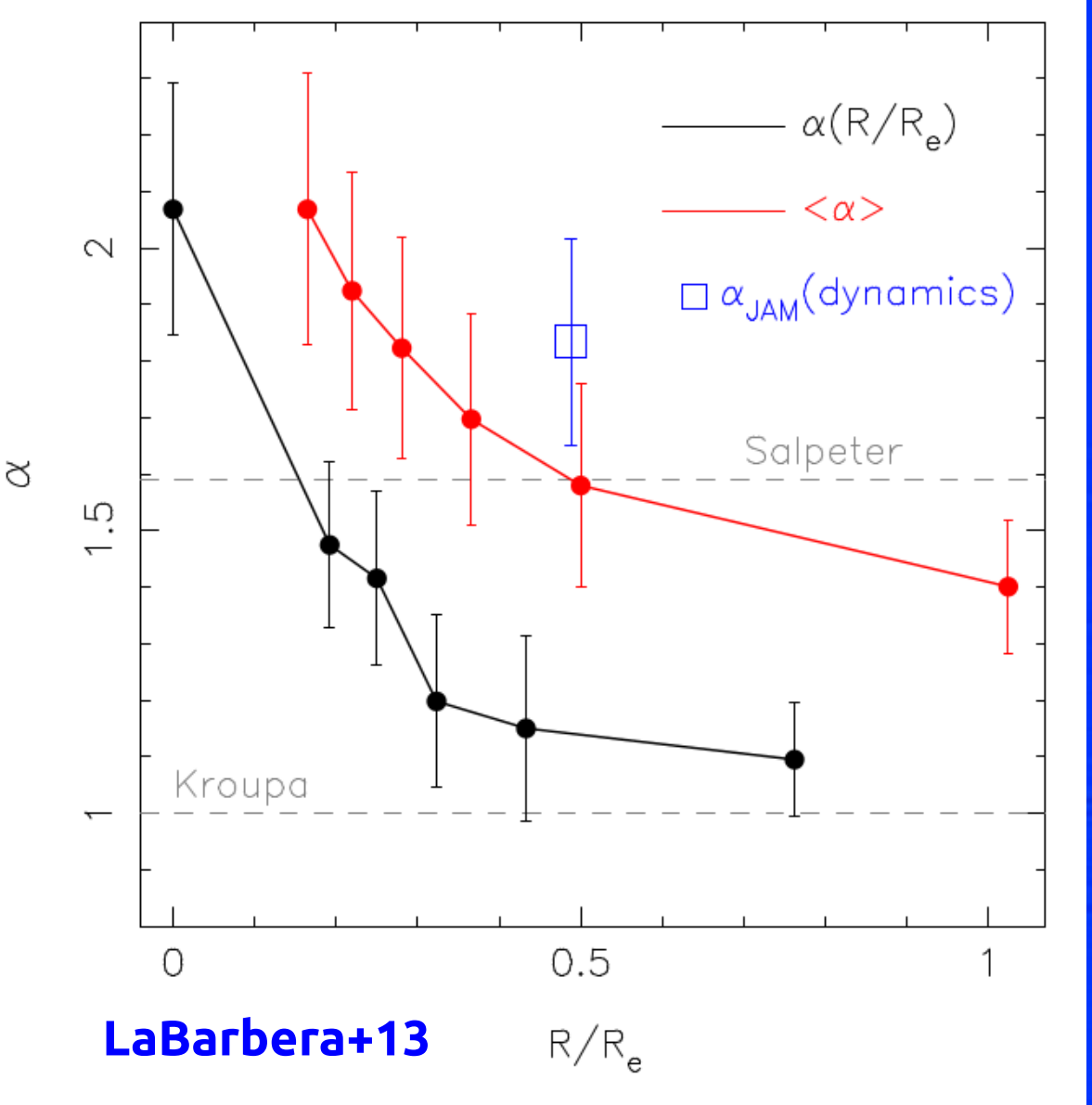
Variable IMF: Observations (dynamical)



Variable IMF: Observations (Spectroscopy again)

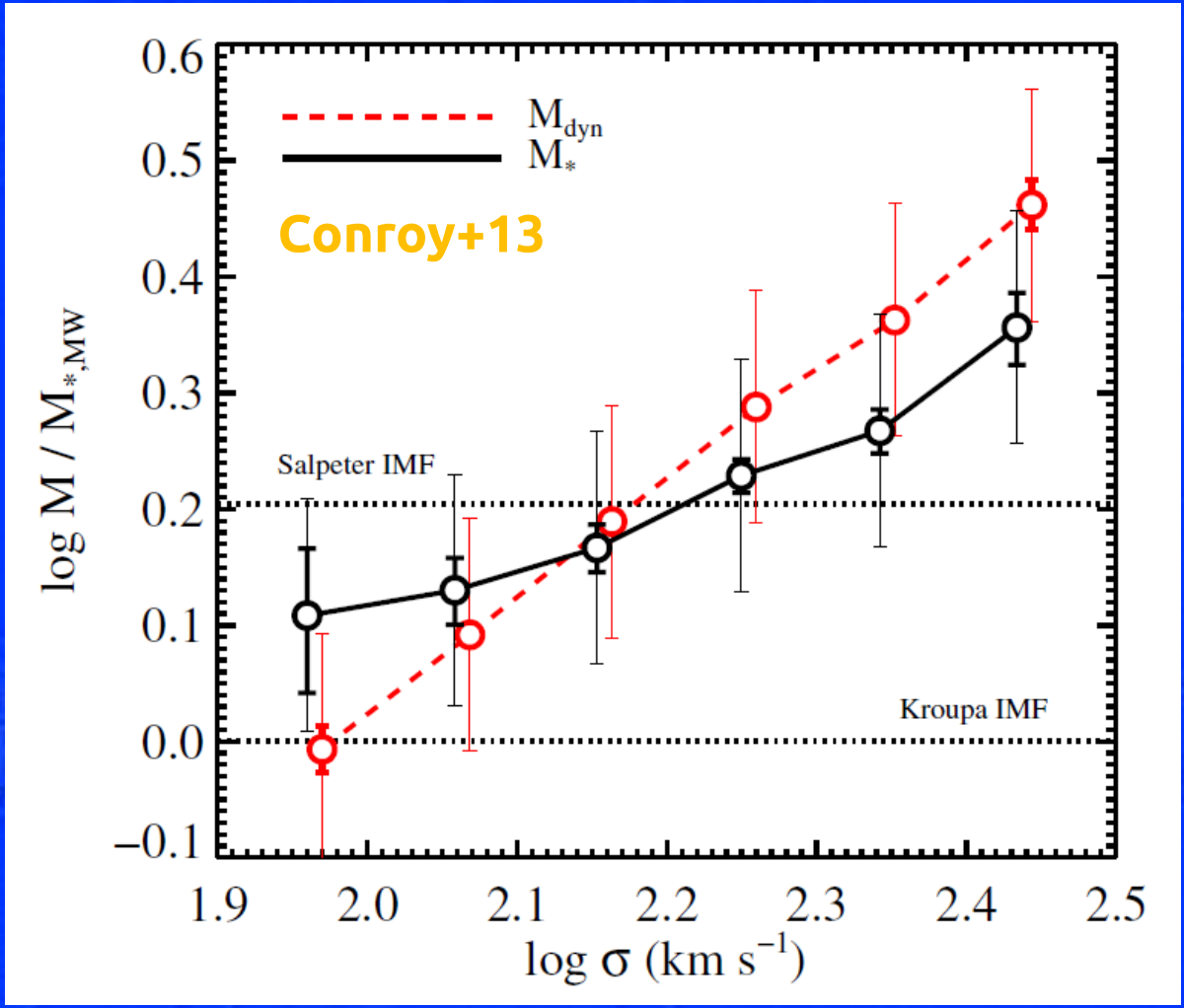


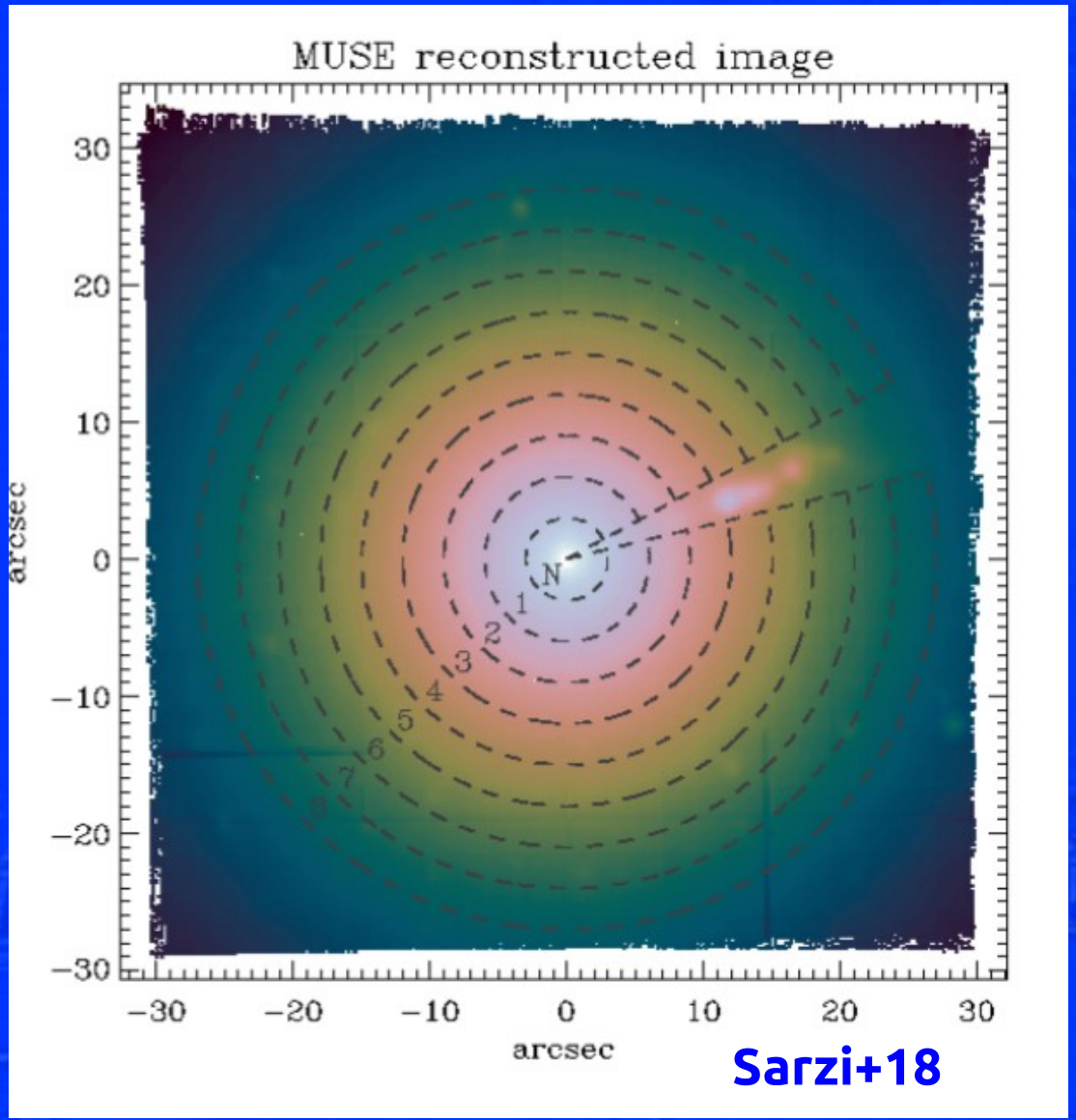
LaBarbera+13

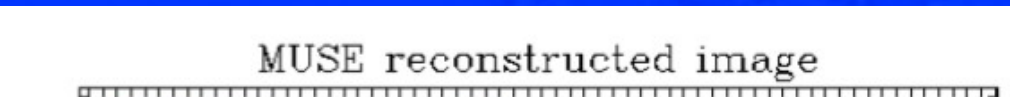


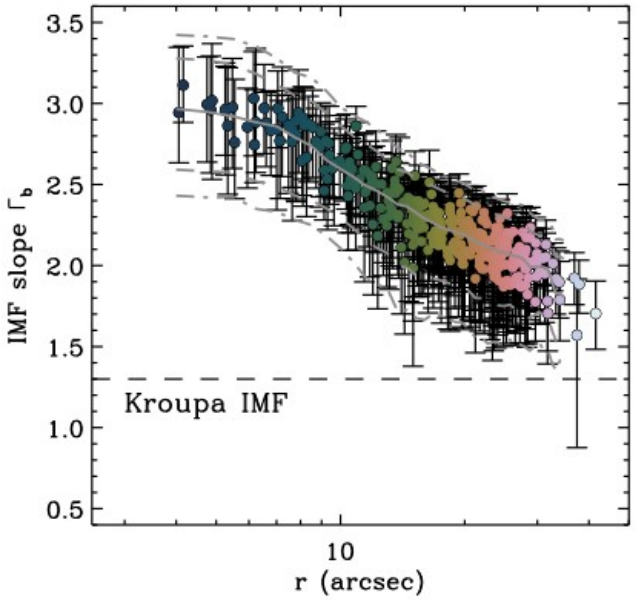
LaBarbera+13

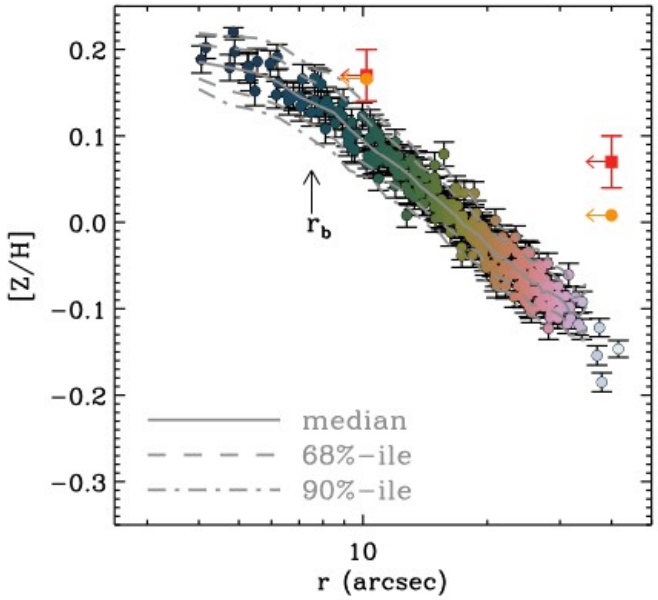
Variable IMF: Observations (Spectroscopic)

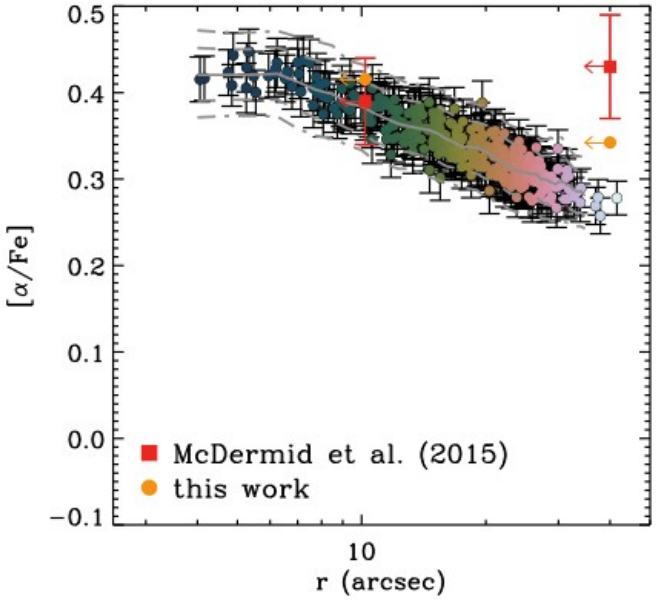


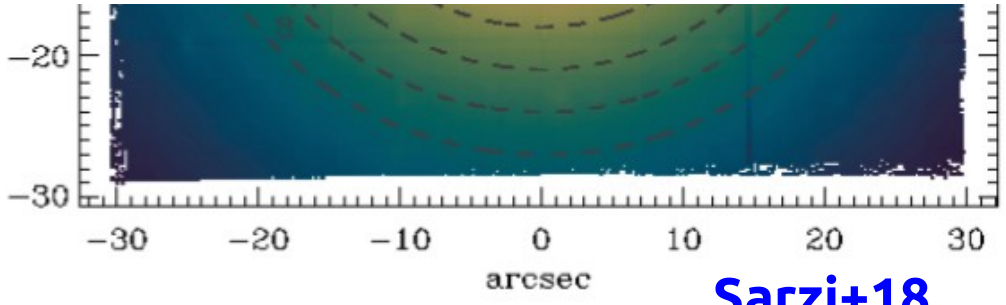

MUSE reconstructed image
30
20
10
0
−10
−20
−30
arcsec
−30
−20
−10
0
10
20
30
arcsec
N
1
2
3
4
5
6
7
Sarzi+18


MUSE reconstructed image


IMF slope Γ_b
Kroupa IMF
r (arcsec)


[Z/H]
r_b
median
68%−ile
90%−ile
r (arcsec)


[α/Fe]
McDermid et al. (2015)
this work
r (arcsec)

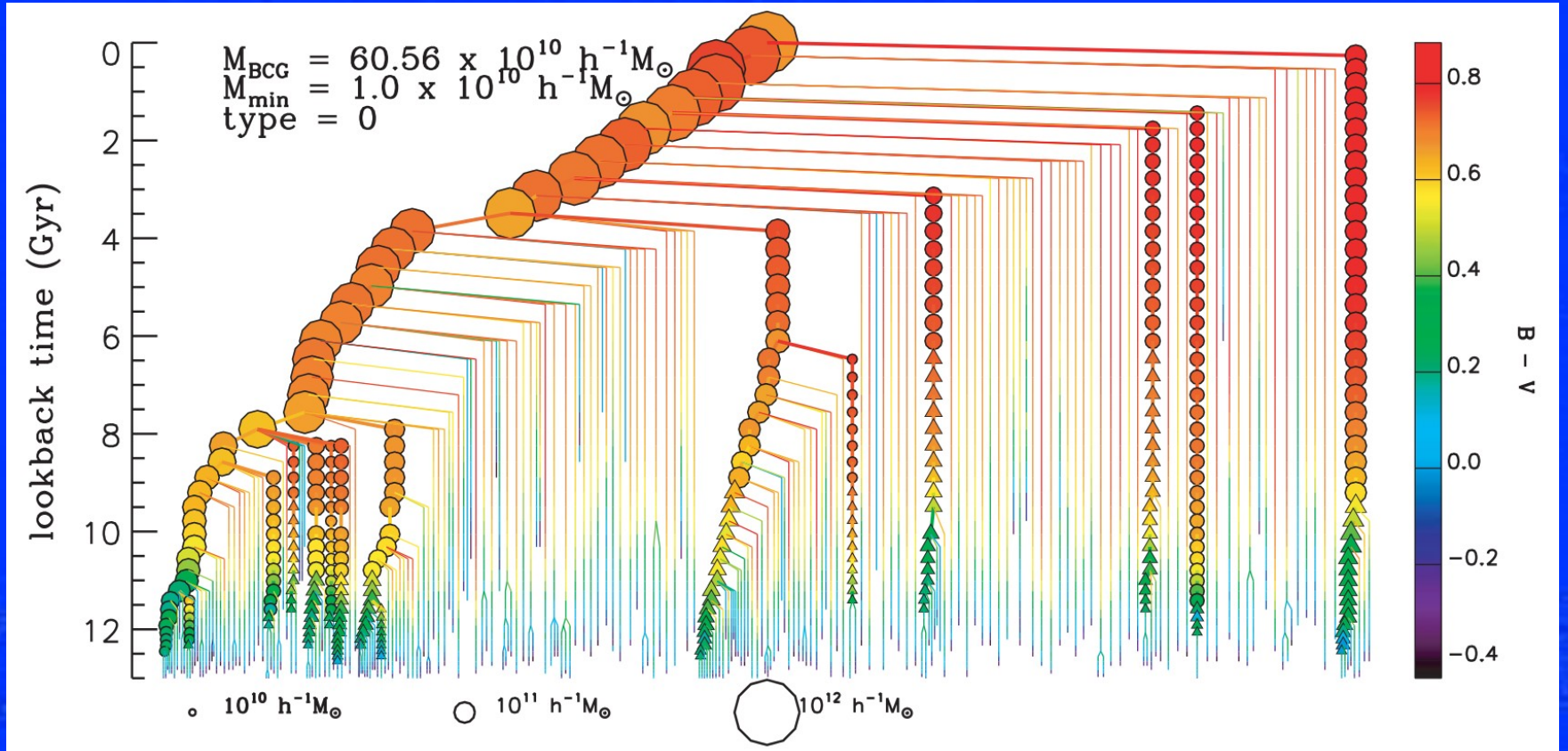

arcsec
arcsec

Sarzi+18

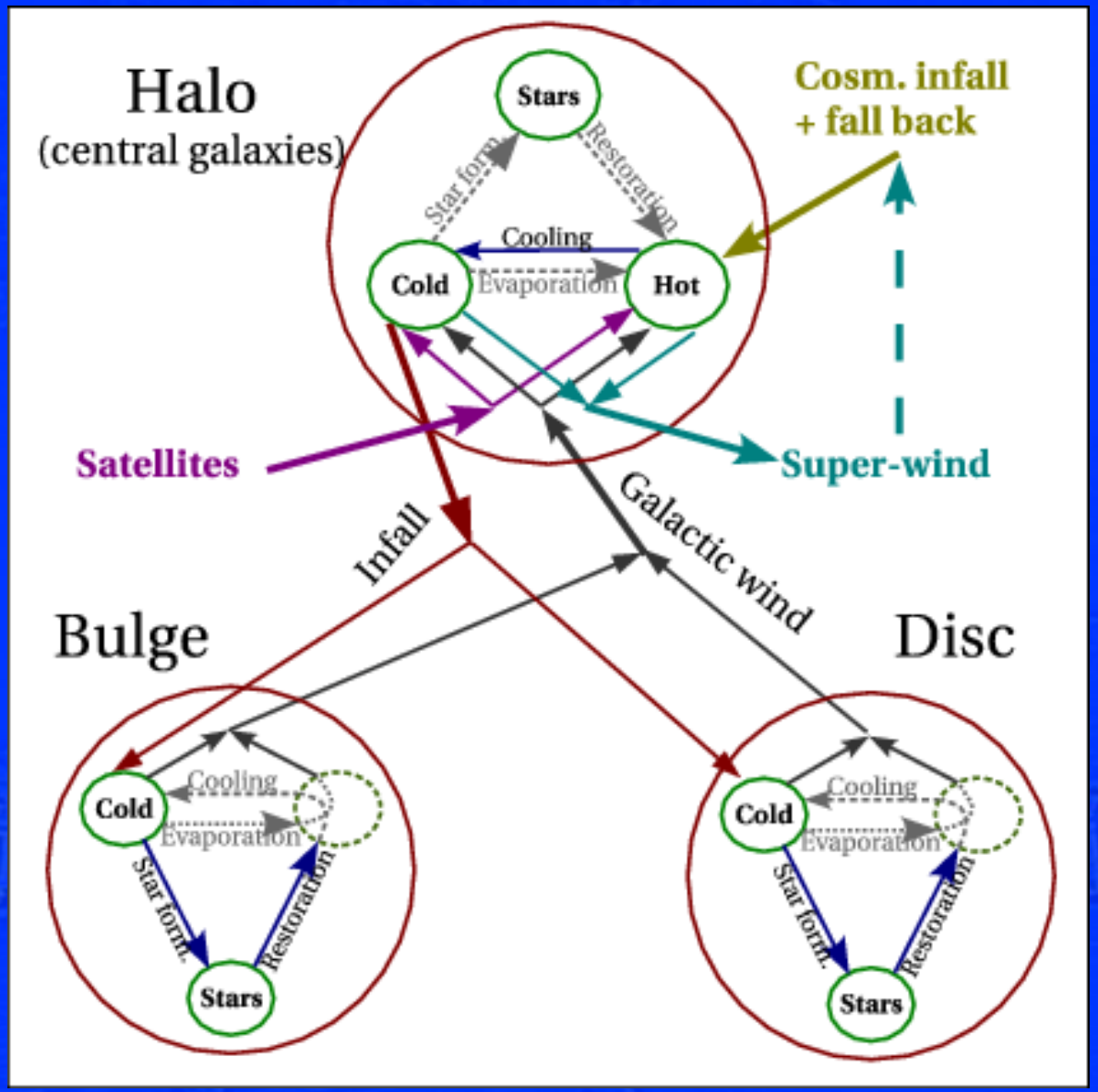
Strategy

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

GAEA semi-analytic model



SAMs are a fast tool **to solve the complex interplay of physical processes at an** affordable computational costs**, but relying on a** statistical approach.


Halo
(central galaxies)
Stars
Star form.
Restoration
Cooling
Cold
Evaporation
Hot
Cosm. infall
+ fall back
Satellites
Super-wind
Infall
Galactic wind
Bulge
Disc
Cold
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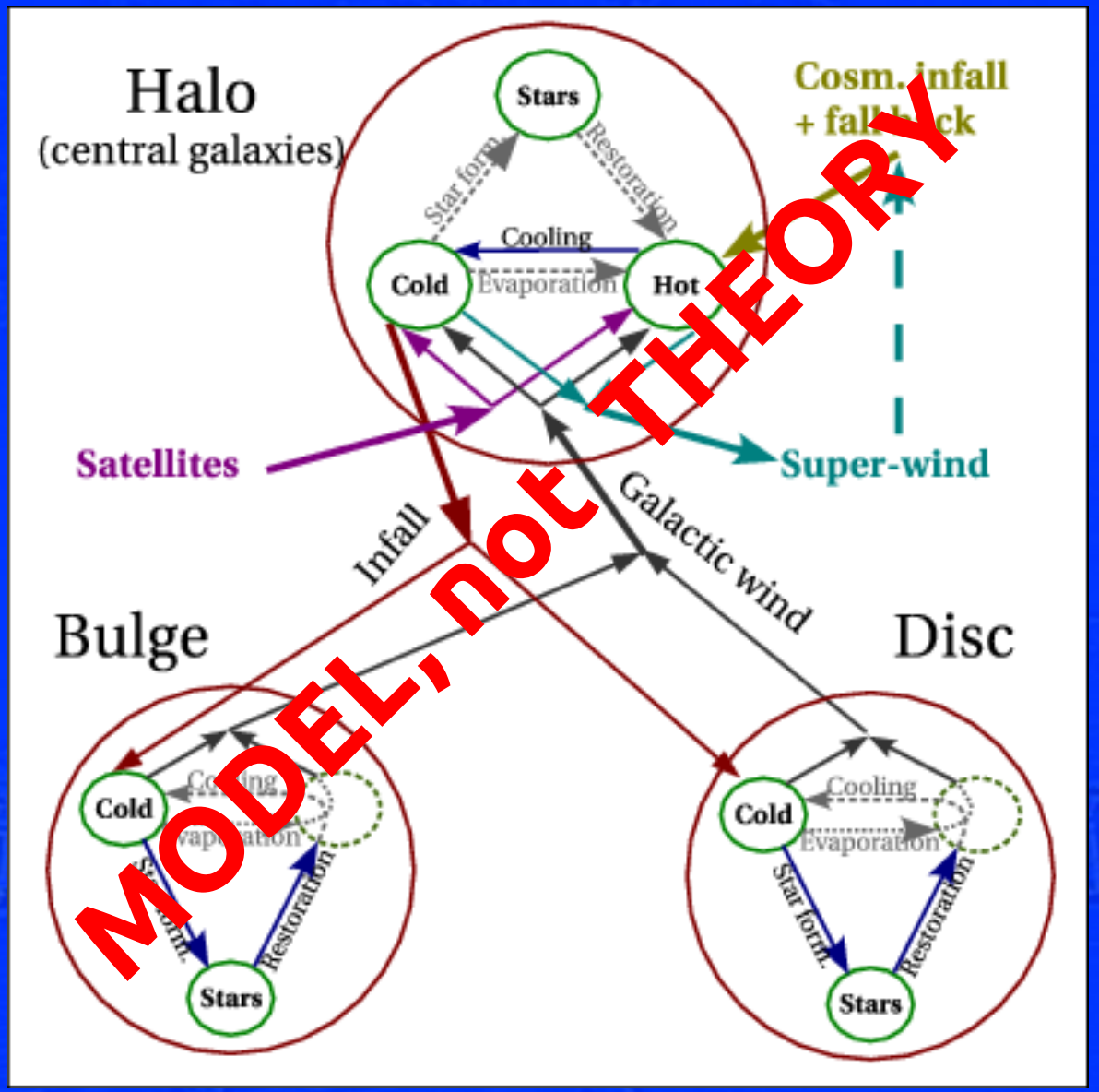
Evaporation
Star form.
Restoration
Stars
Cold
Cooling
Evaporation
Star form.
Restoration
Stars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Stars
MODEL, not THEORY

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

- Intrinsic properties cannot be compared directly with observational estimates

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

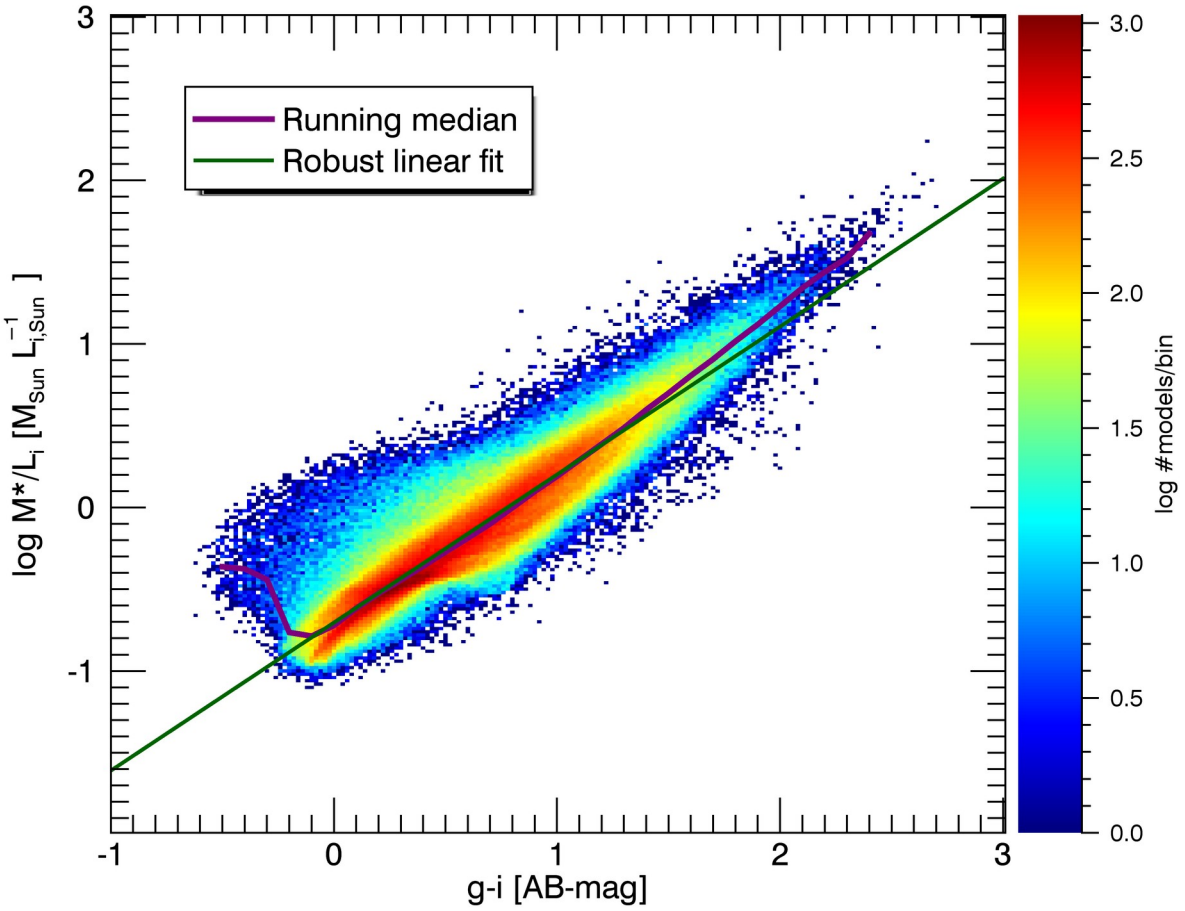
Strategy

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

- 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

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

Strategy

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

- Intrinsic properties cannot be compared directly with observational estimates

- We derive self-consistent synthetic photometry to compare
  - Intrinsic Galaxy Properties
  - Photometrically derived Galaxy Properties
  - Synthetic SEDs (MILES SSPs in variable IMF)

The Problem:
which kind of variable IMF?

Fontanot+17,18a

Variable IMF 1

- **IGIMF = Integrated Galaxy-Wide IMF** WeidnerKroupa13 Kroupa13
- **Based on a limited number of *axyoms***

1) Universal IMF for individual MCs → **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) MCMF →
$$\varphi_{\rm CL}(M_{\rm cl}) \propto M_{\rm cl}^{-\beta},$$

5) Power-law index →
$$\beta = \begin{cases} 2 & SFR < 1 M_\odot/yr \\ -1.06 \log SFR + 2 & SFR \geqslant 1 M_\odot/yr \end{cases}$$

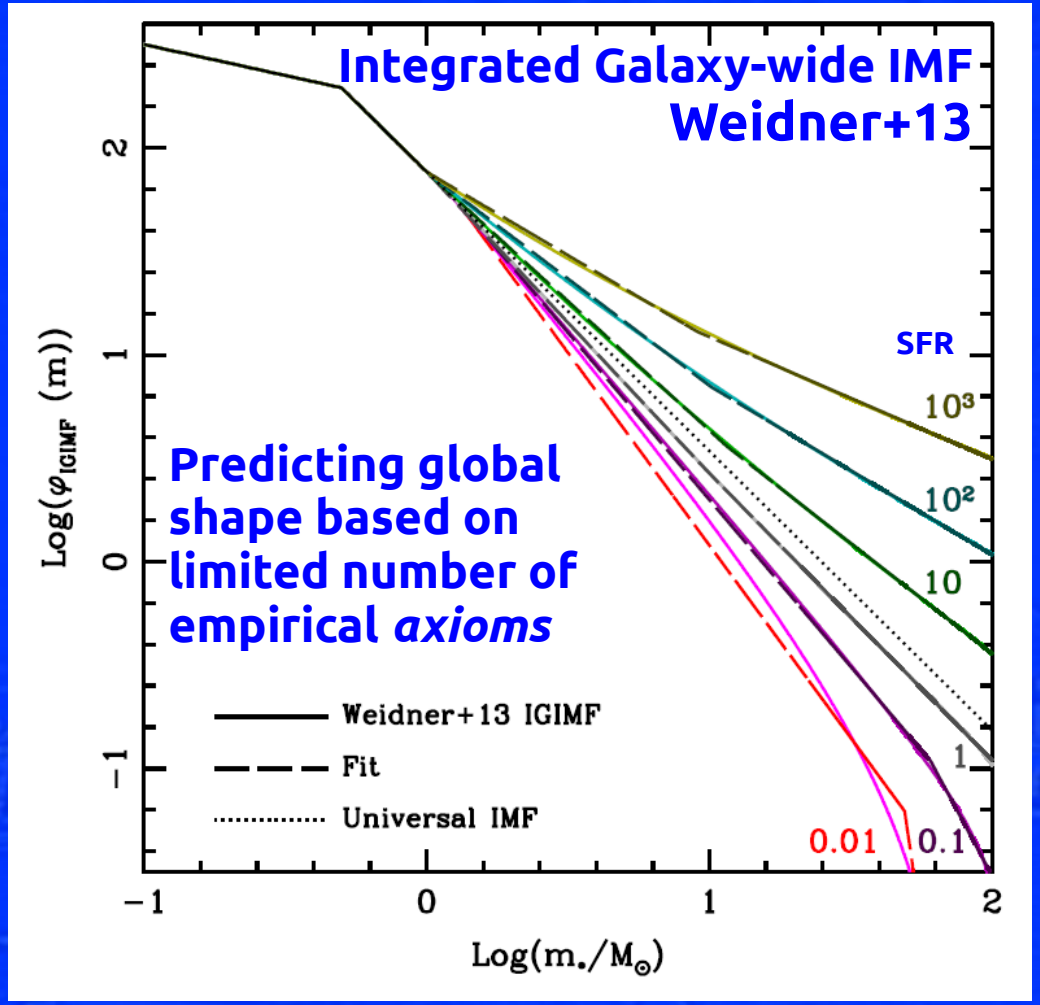
6) Maximum MC mass →
$$\log M_{\rm cl}^{\rm max} = 0.746 \log SFR + 4.93.$$

7) Maximum stellar mass →
$$\log m_\star^{\rm max} = 2.56 \log M_{\rm cl} \times [3.82^{9.17} + (\log M_{\rm cl})^{9.17}]^{1/9.17} - 0.38.$$

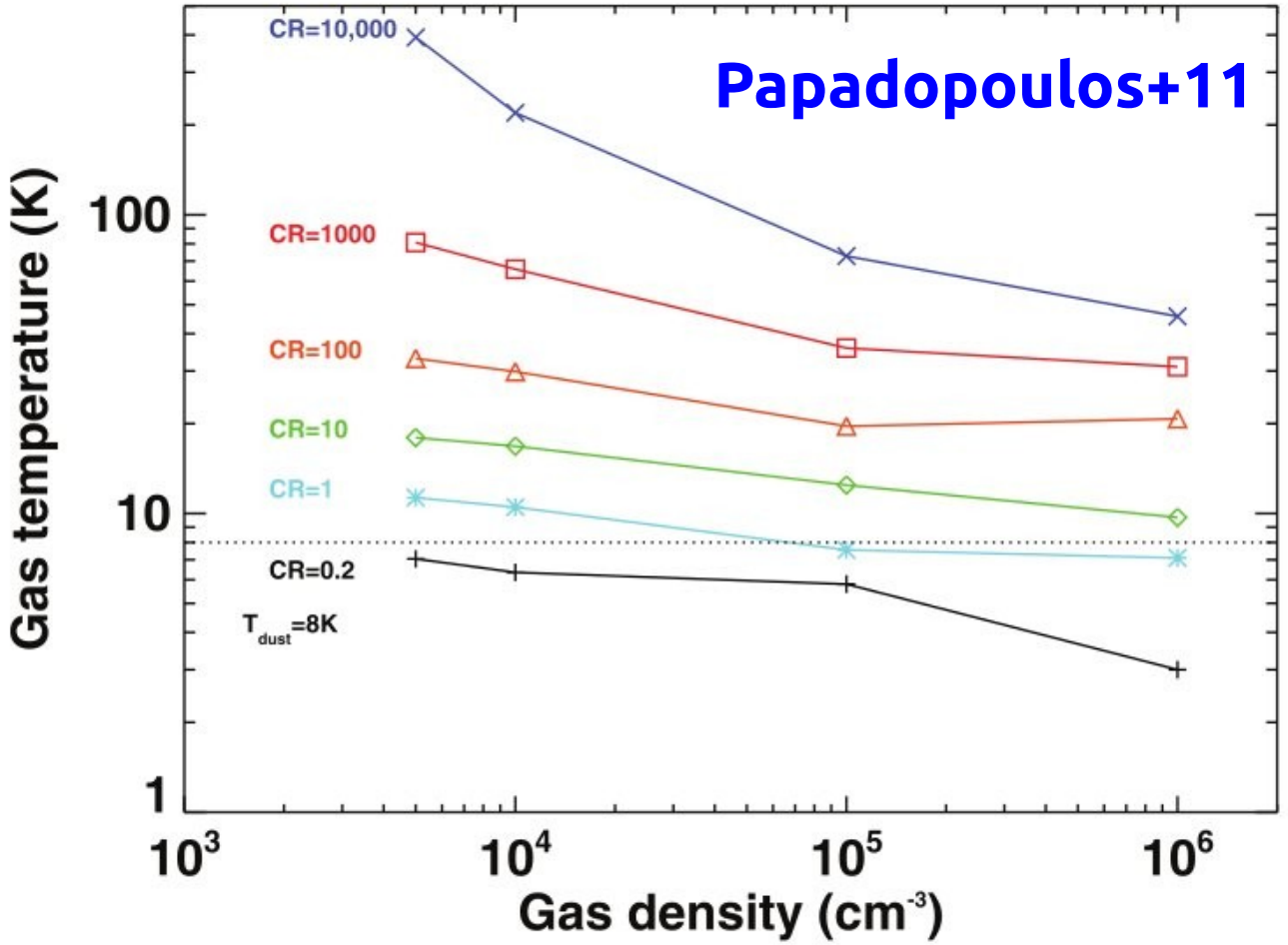
- **Estimate of IGIMF as a function of SFR**

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

Variable IMF: Theory

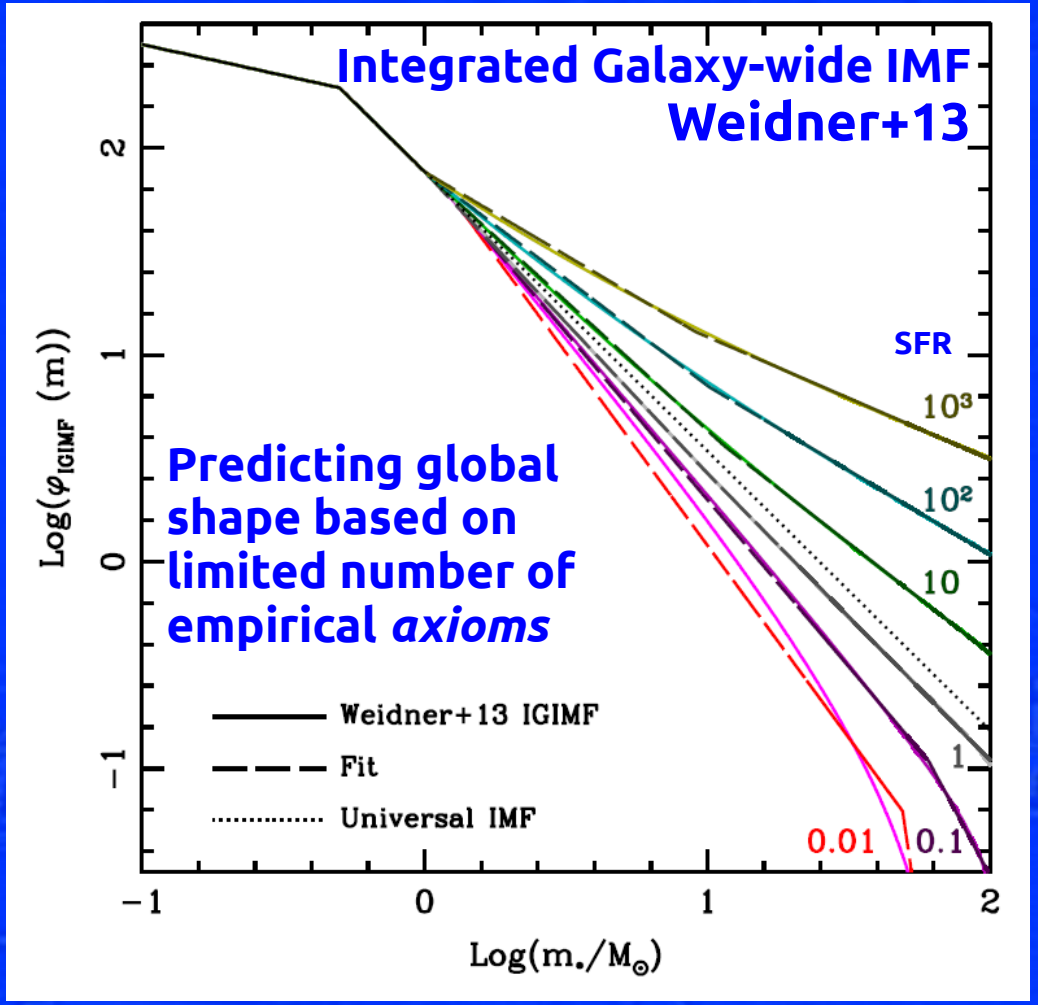


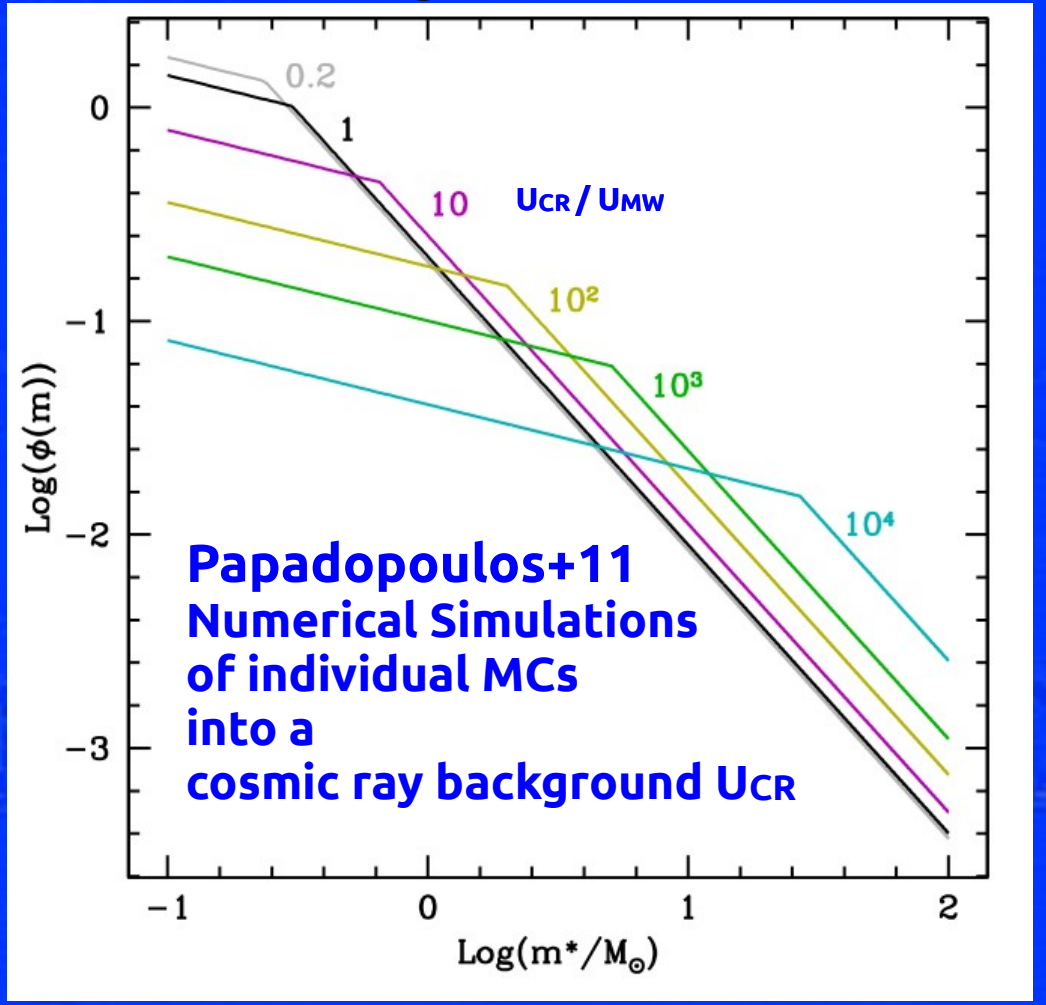
Variable IMF 2

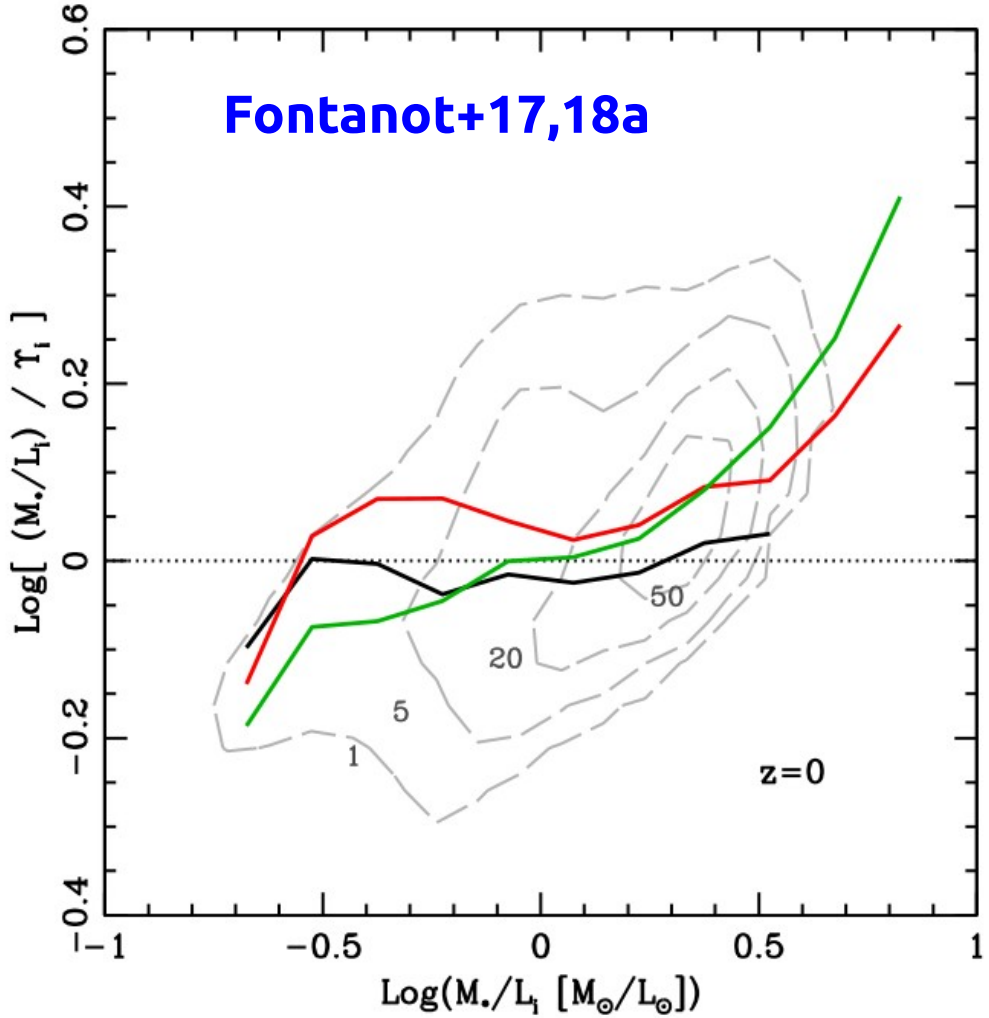


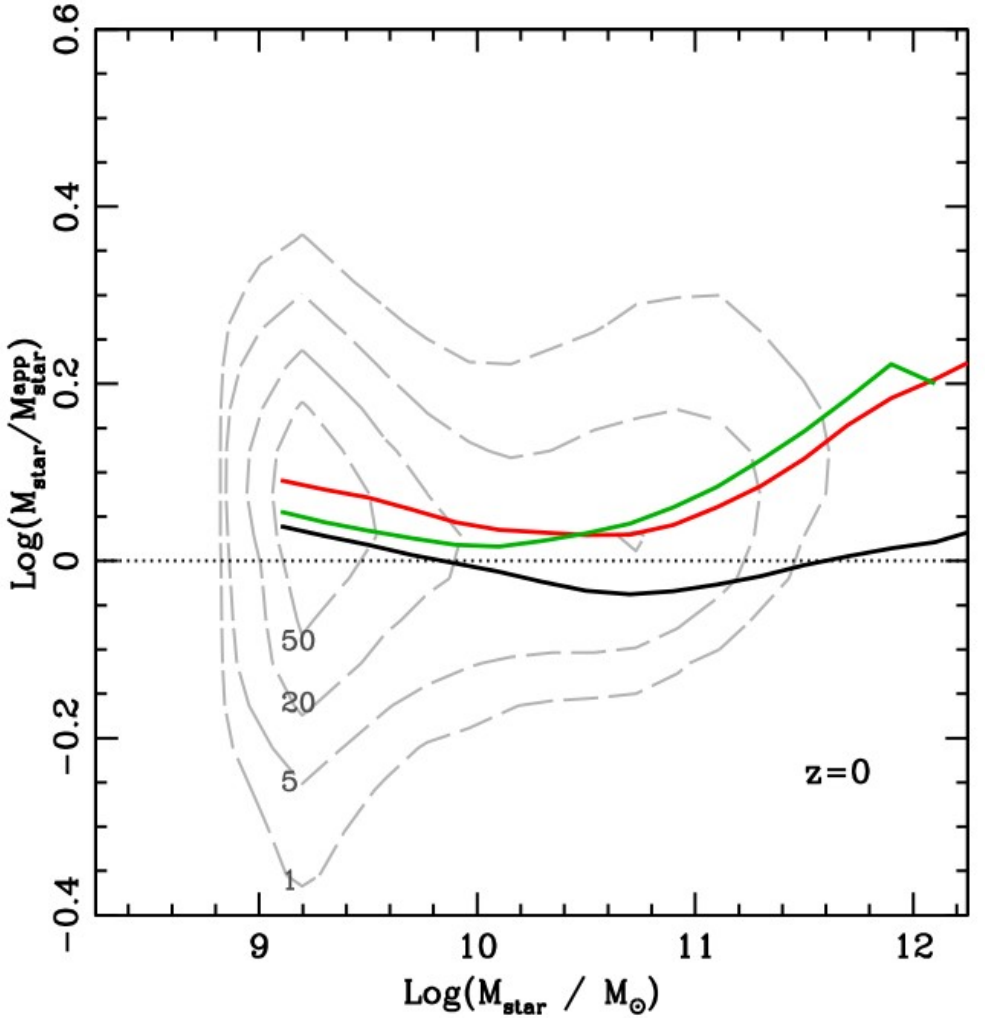
$$M_{\rm J}^{(\rm c)} = \left(\frac{k_{\rm B}T_{\rm k}}{G\mu m_{\rm H_2}}\right)^{3/2} \rho_{\rm c}^{-1/2}$$
$$= 0.9 \left(\frac{T_{\rm k}}{10\,{\rm K}}\right)^{3/2} \left[\frac{n_{\rm c}({\rm H_2})}{10^4\,{\rm cm^{-3}}}\right]^{-1/2} {\rm M}_\odot,$$

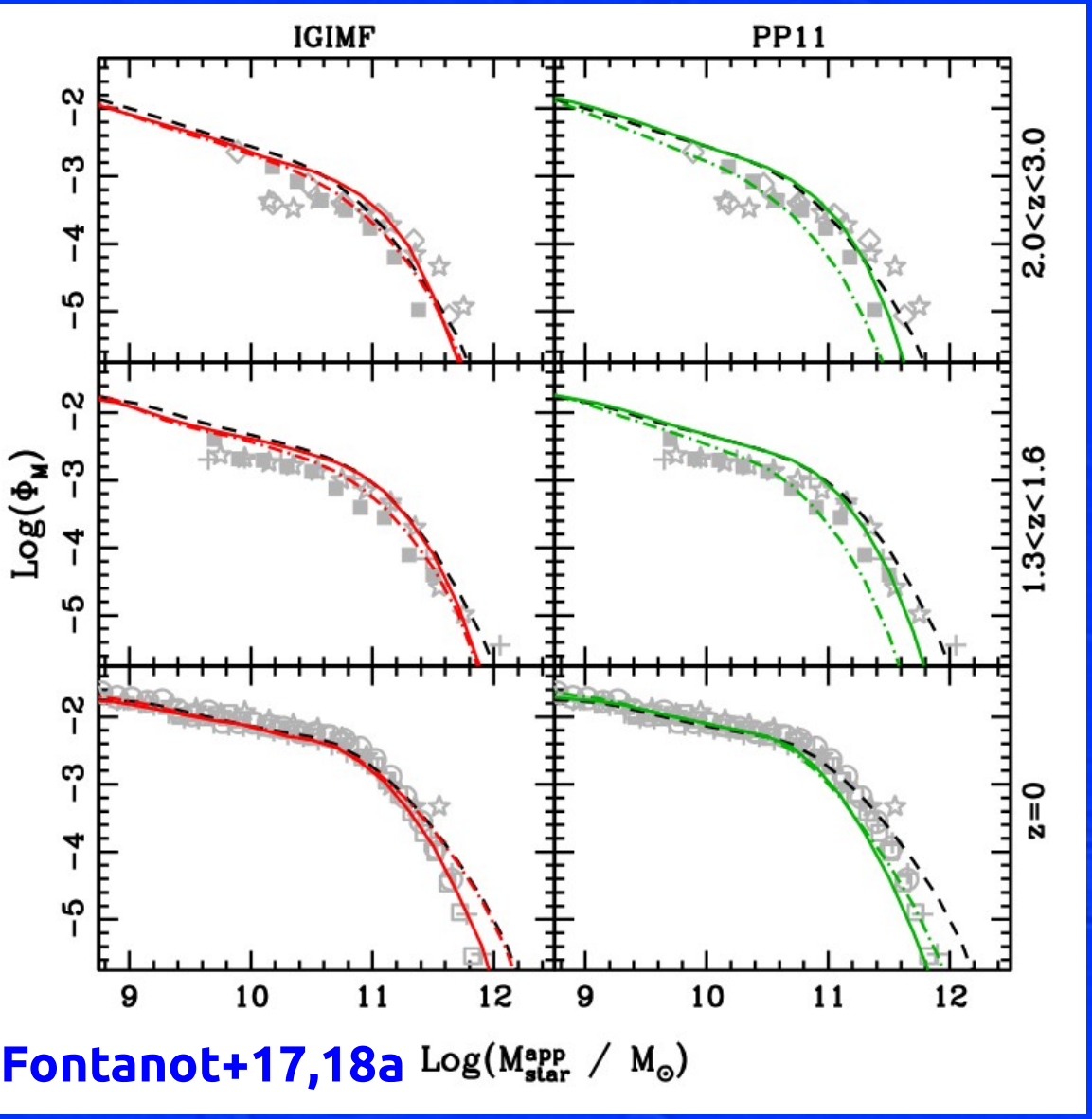
Variable IMF: Theory






Fontanot+17,18a
Log[(M*/L_i) / Υ_i]
Log(M*/L_i [M⊙/L⊙])
z=0
50
20
5
1


Log(M_star/M_star^app)
Log(M_star / M⊙)
z=0
50
20
5
1



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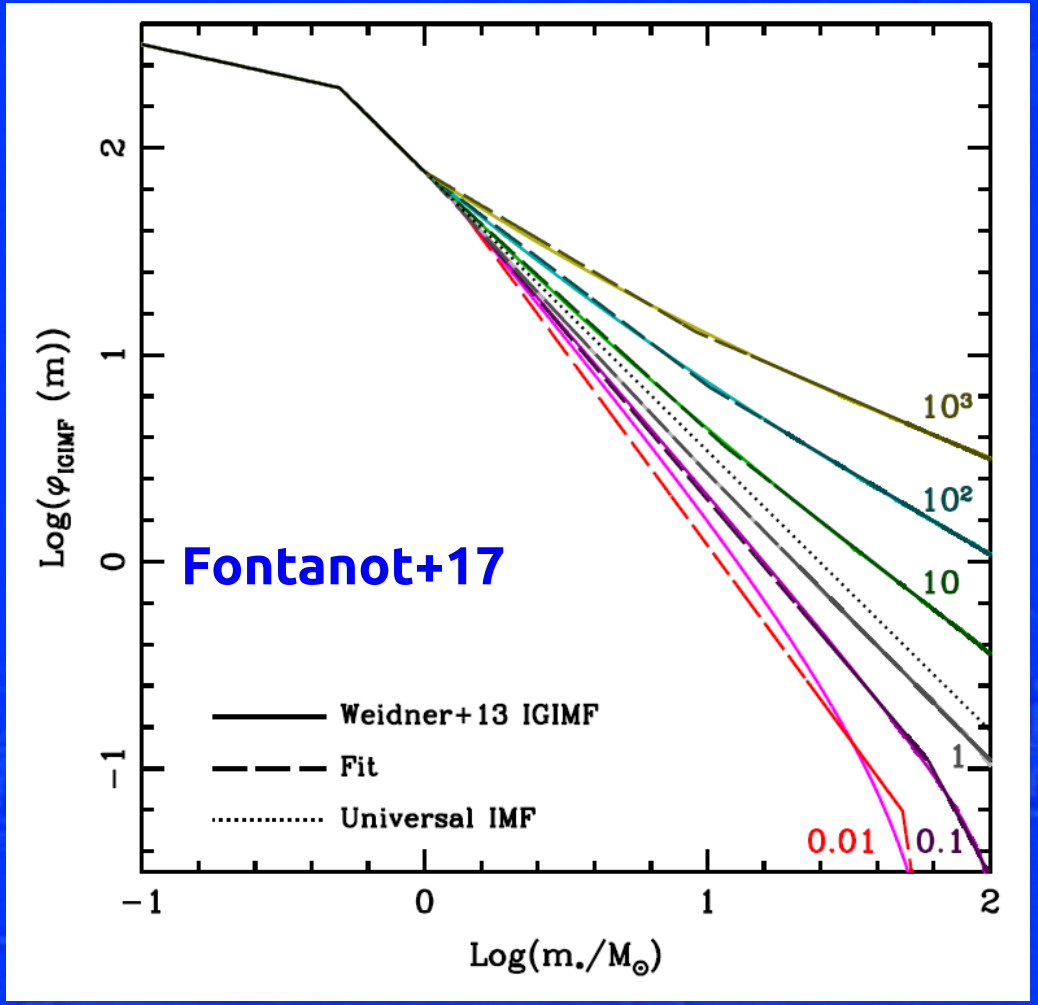

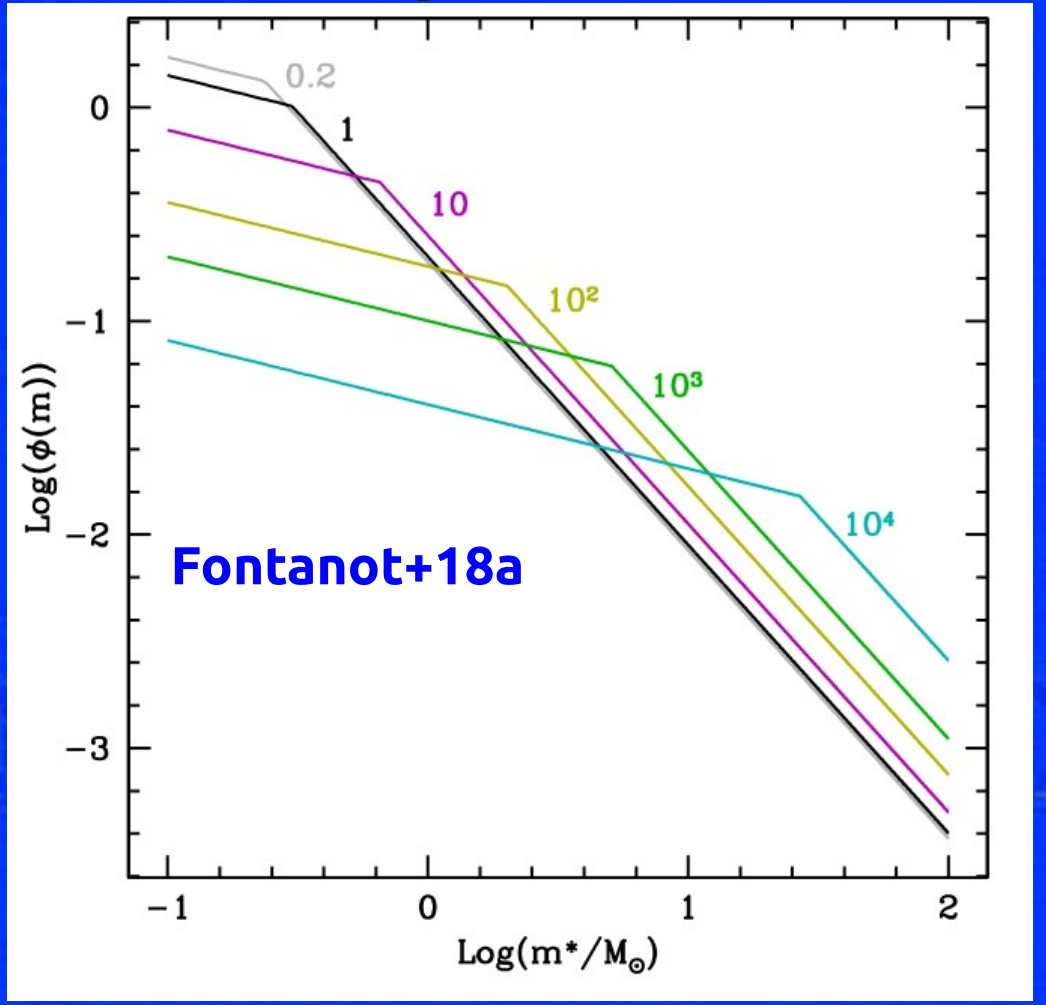

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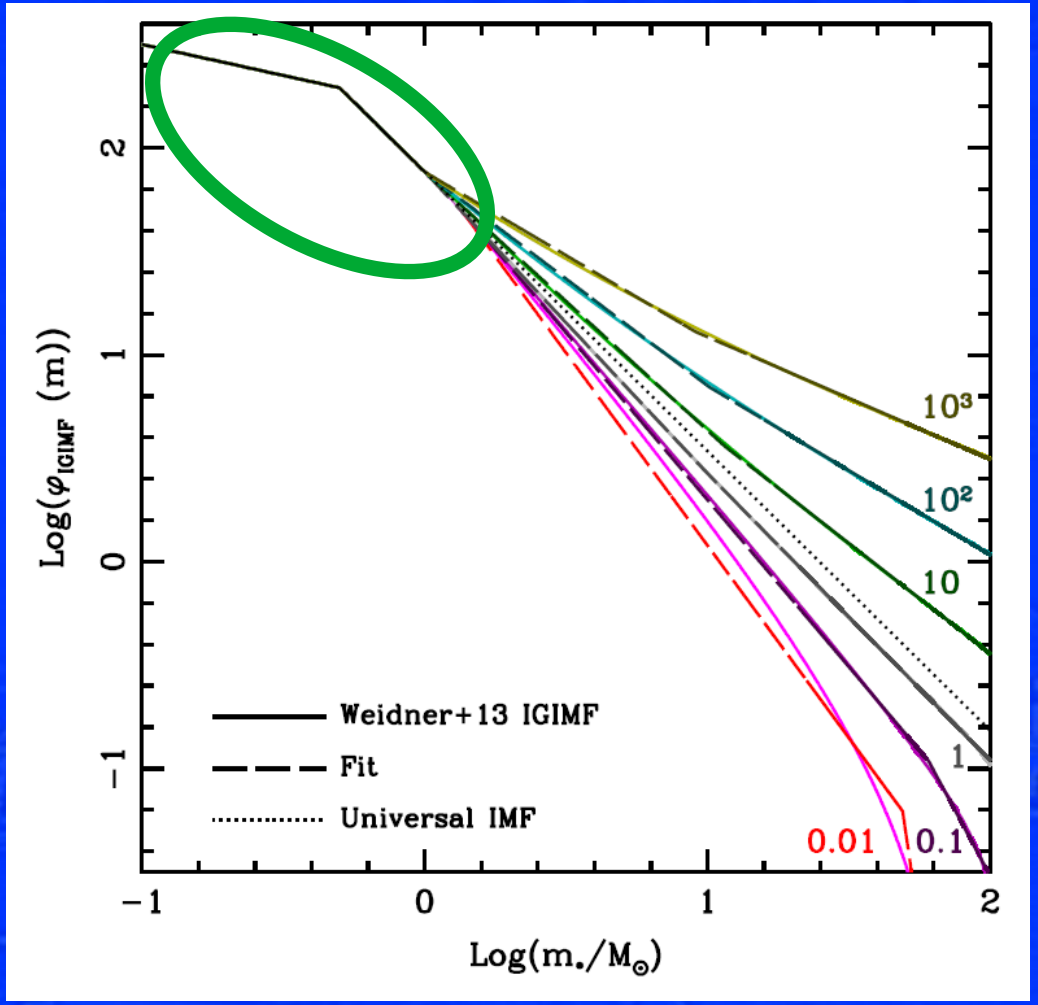

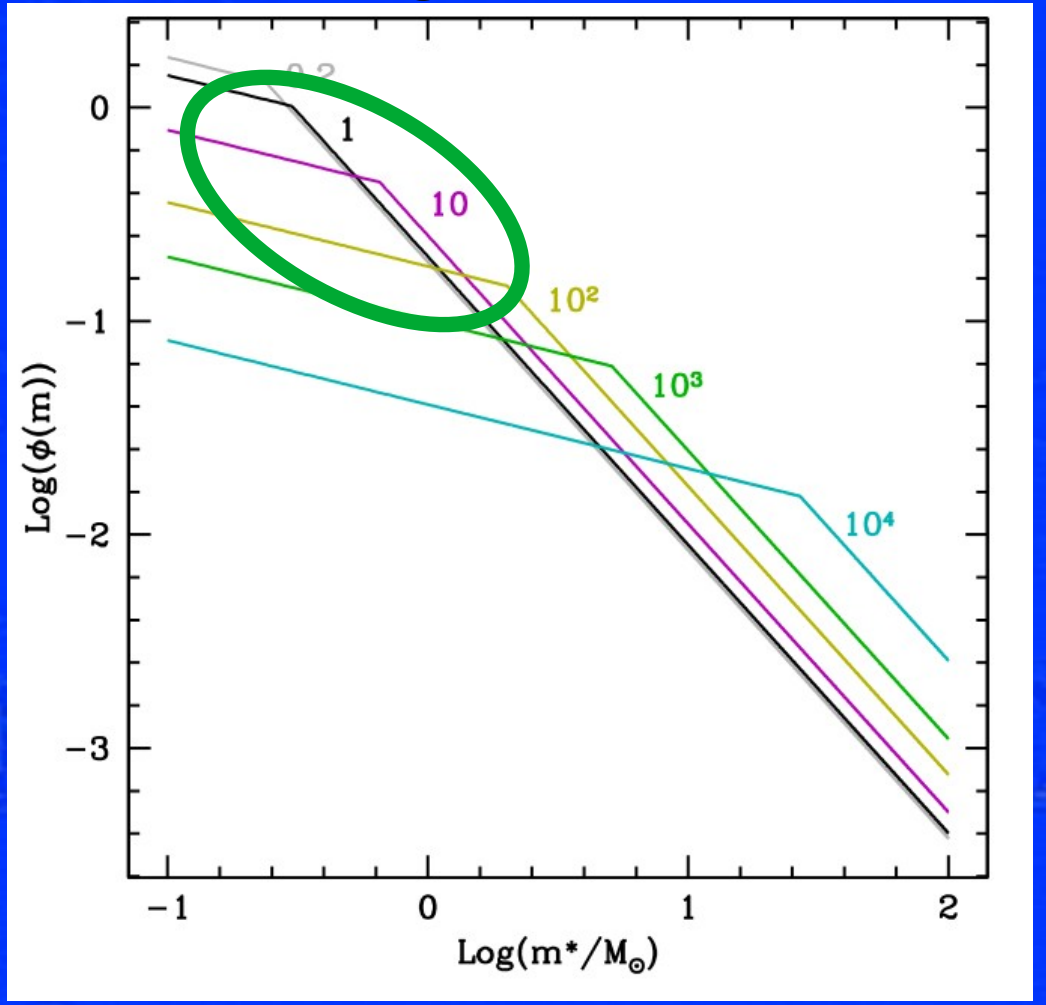

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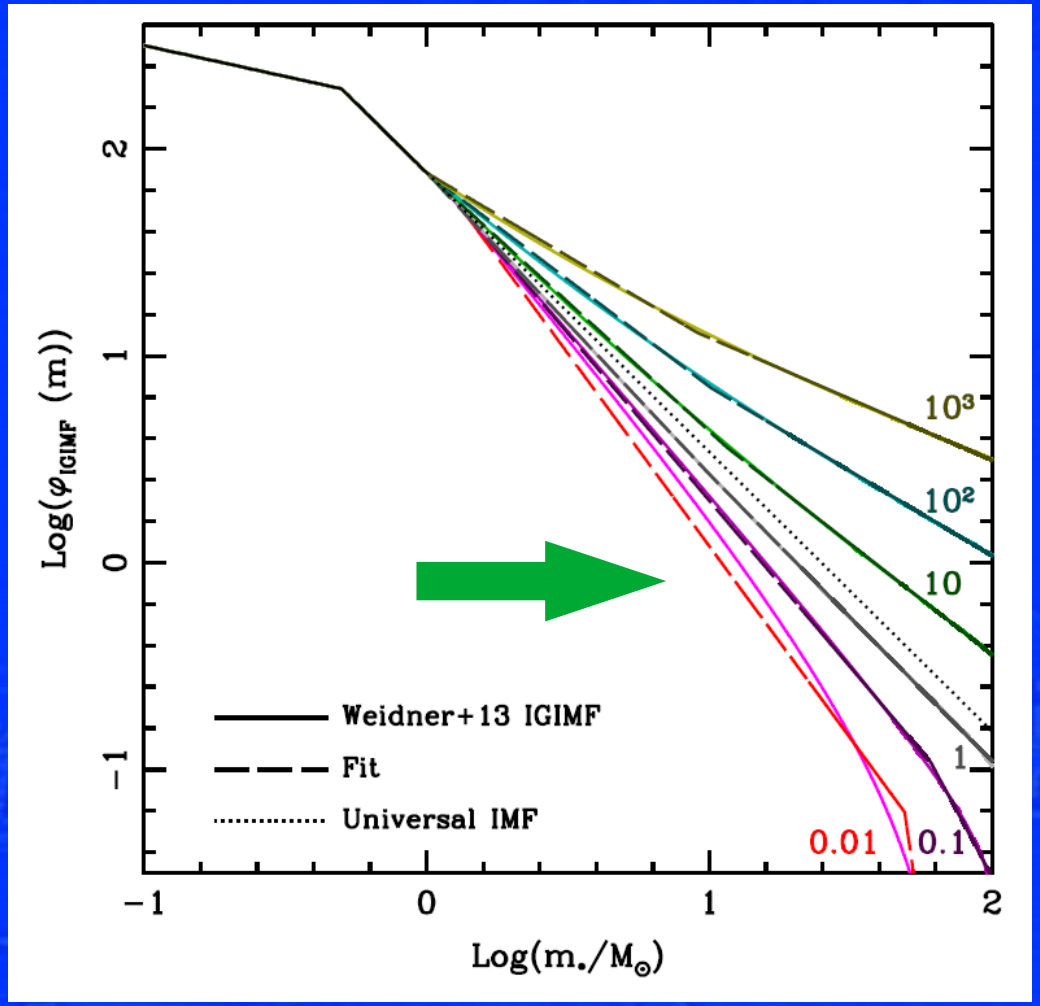

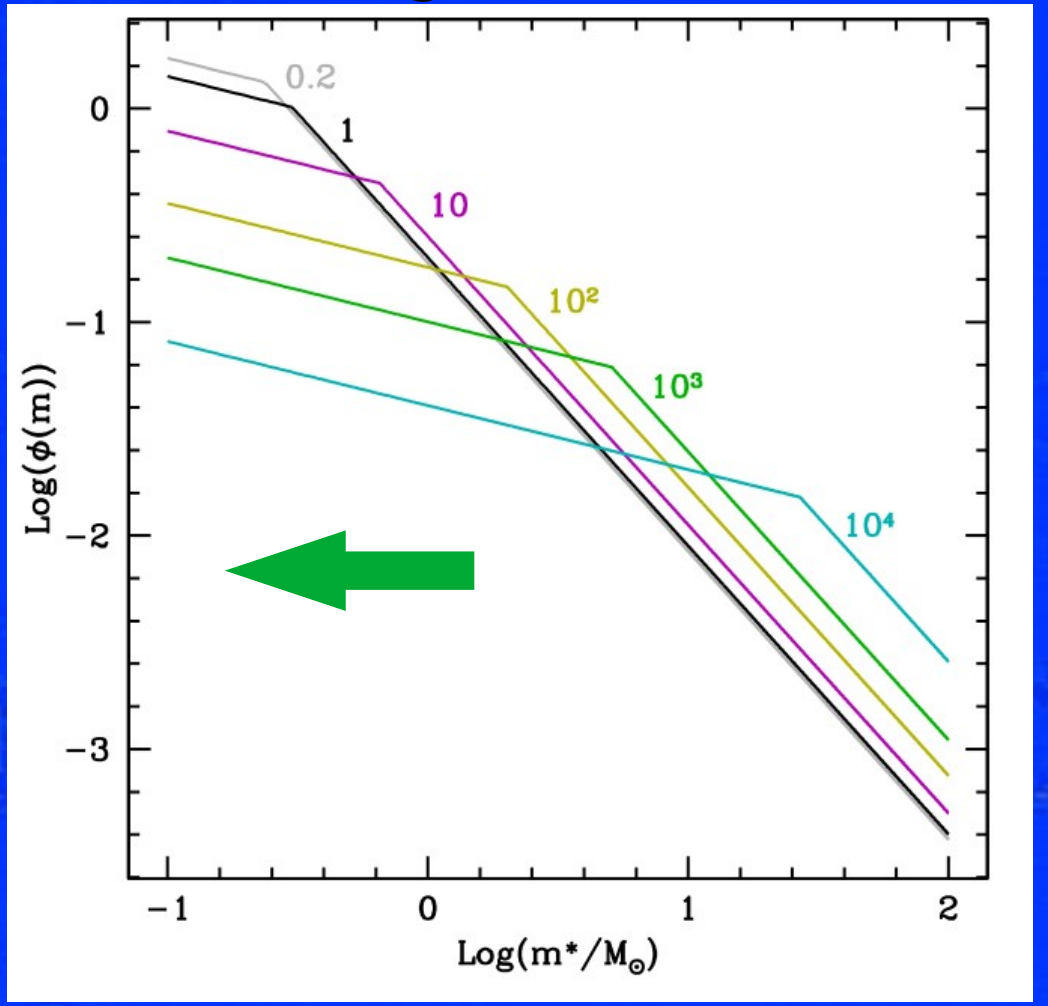

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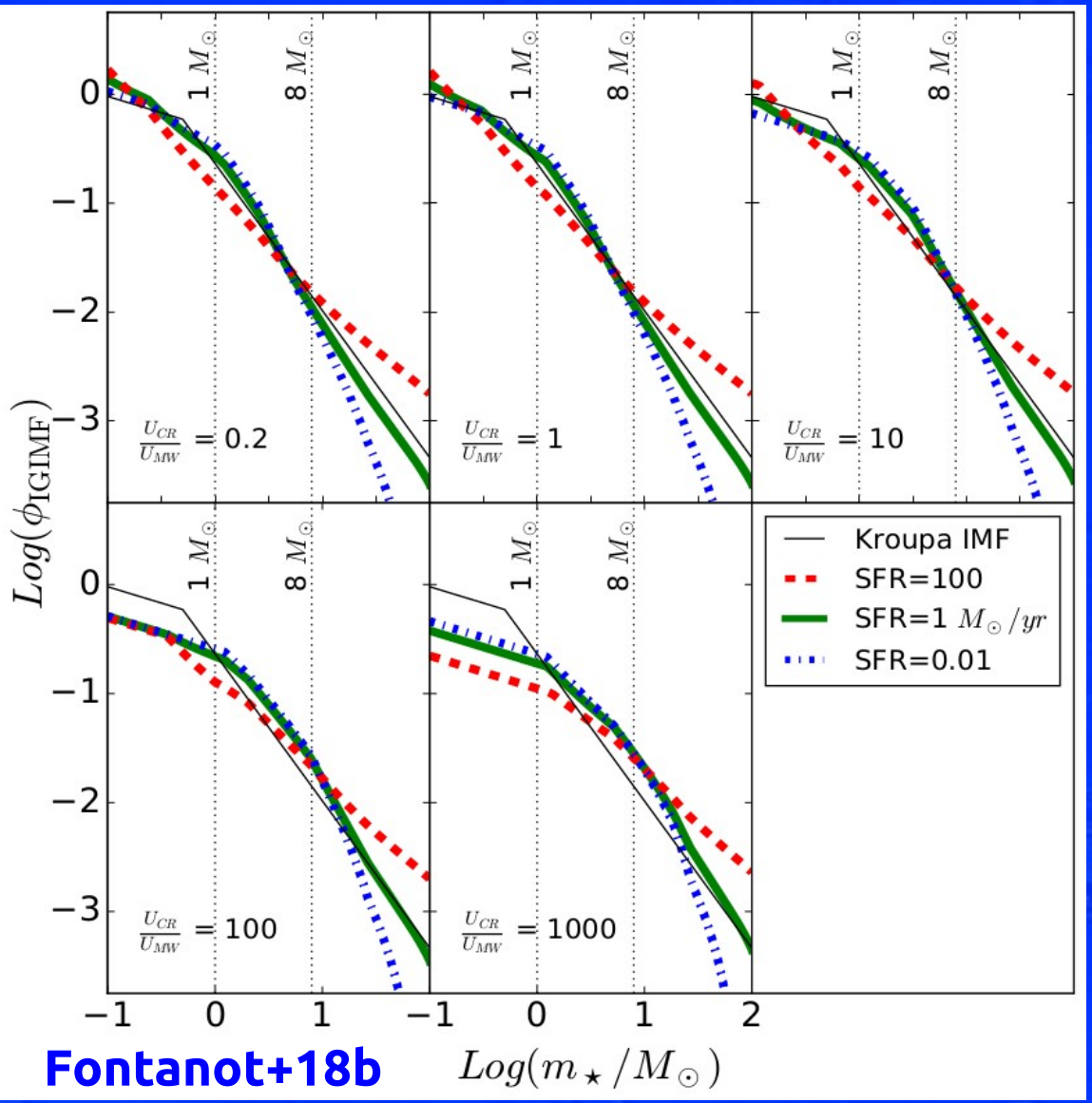
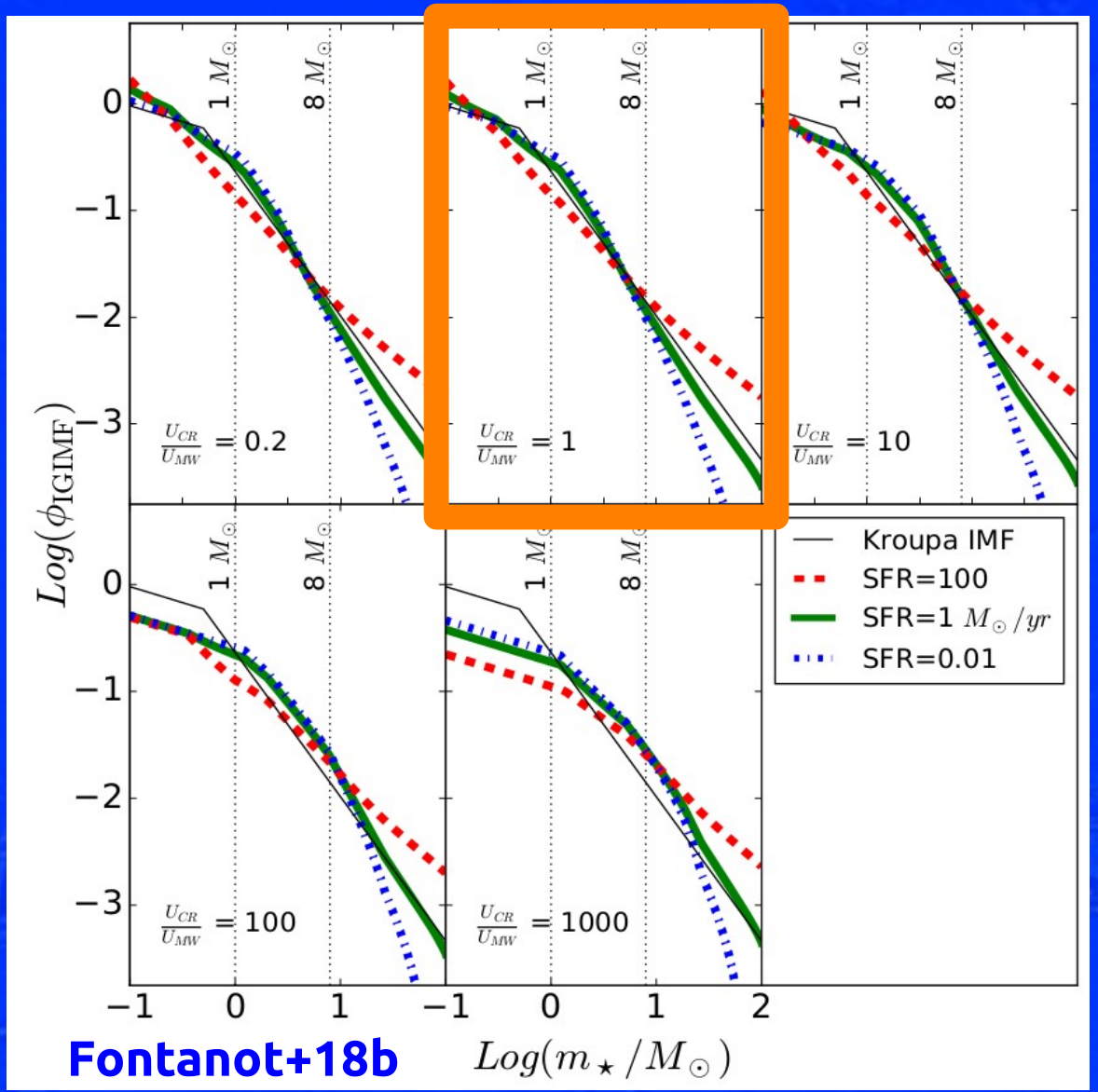
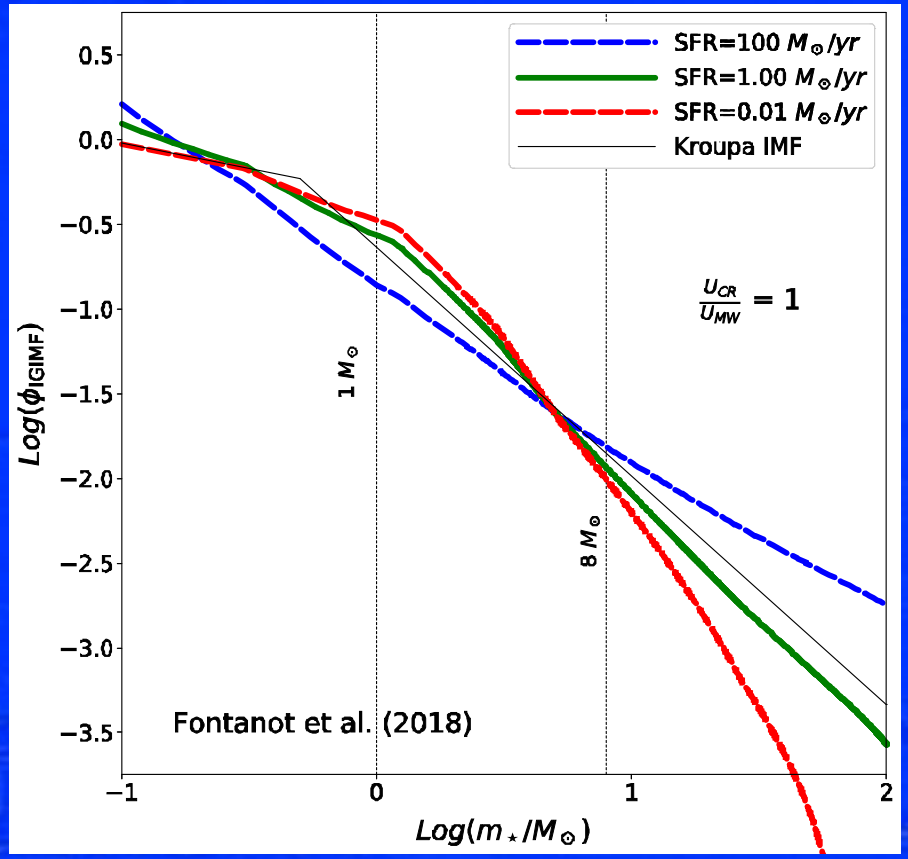
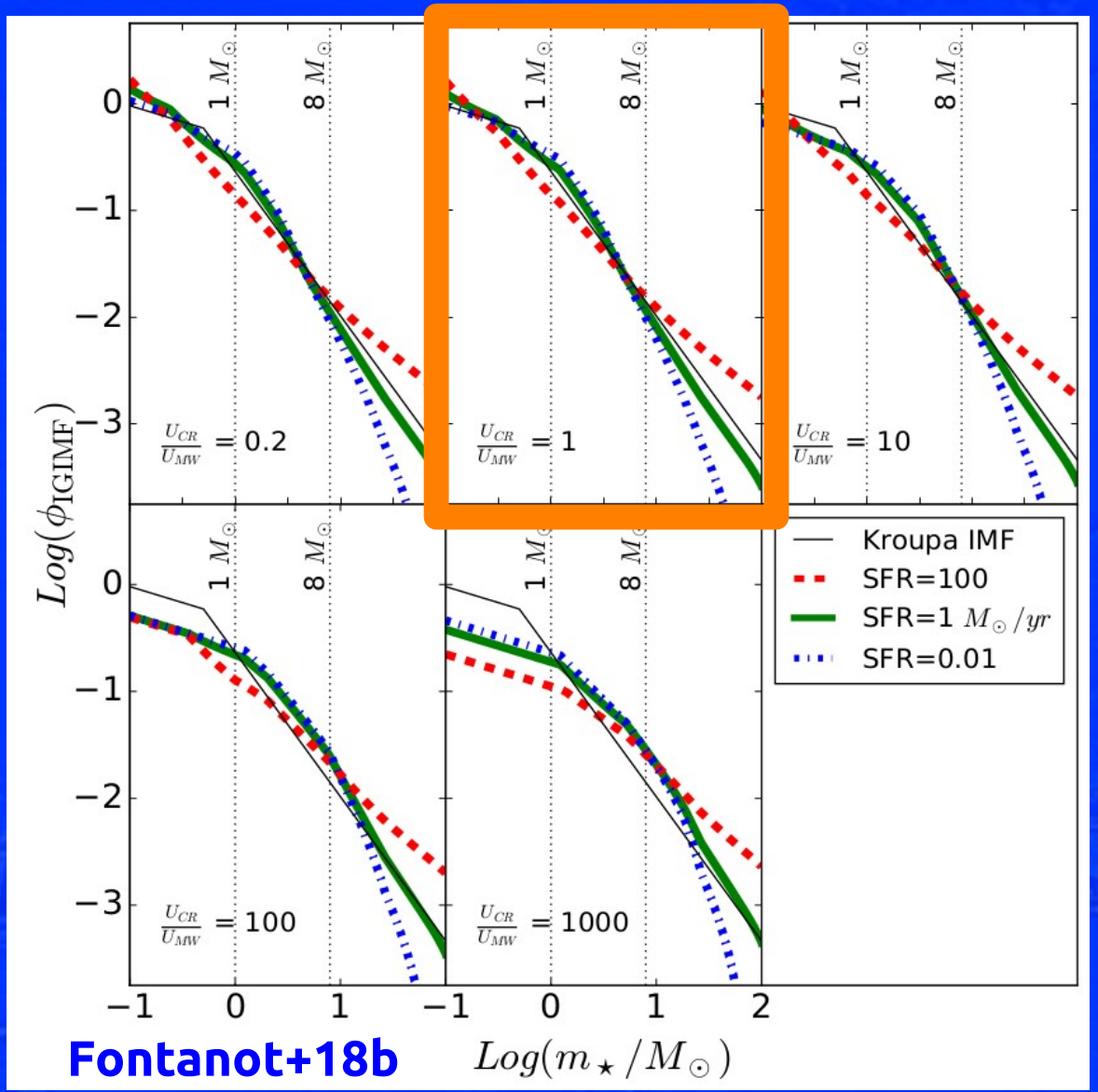


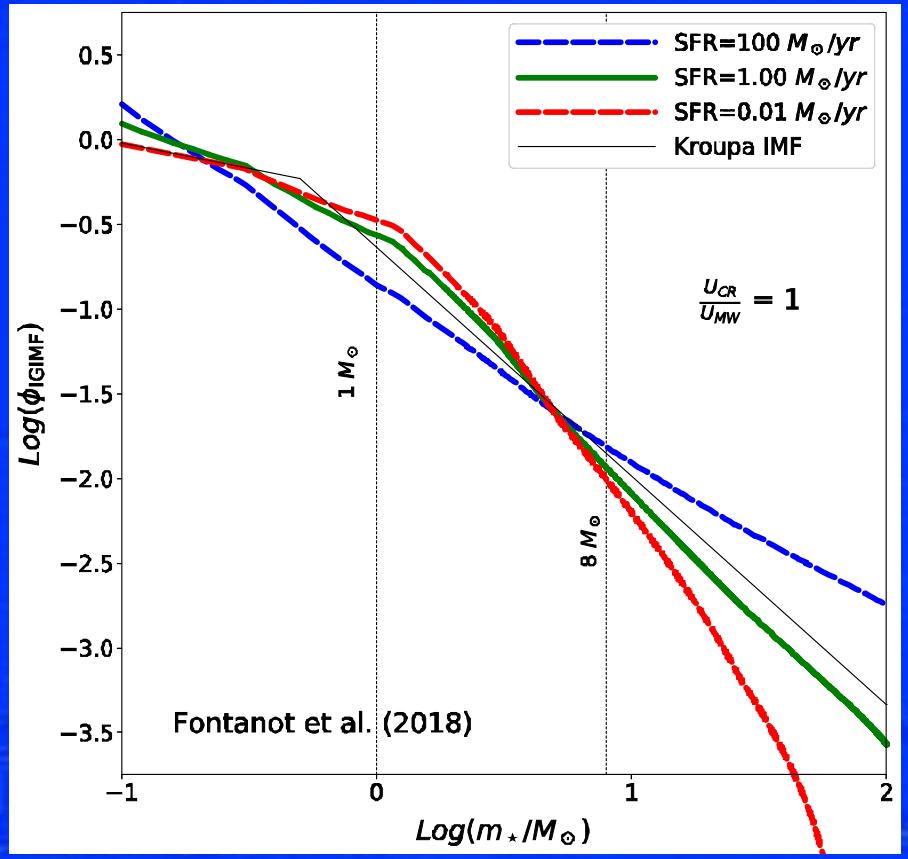
Fontanot+18b


$Log(\phi_{\rm IGIMF})$
$1\ M_\odot$
$8\ M_\odot$
$\frac{U_{CR}}{U_{MW}} = 0.2$
$\frac{U_{CR}}{U_{MW}} = 1$
$\frac{U_{CR}}{U_{MW}} = 10$
$\frac{U_{CR}}{U_{MW}} = 100$
$\frac{U_{CR}}{U_{MW}} = 1000$
Kroupa IMF
SFR=100
SFR=1 $M_\odot/yr$
SFR=0.01
$Log(m_\star/M_\odot)$
Fontanot+18b

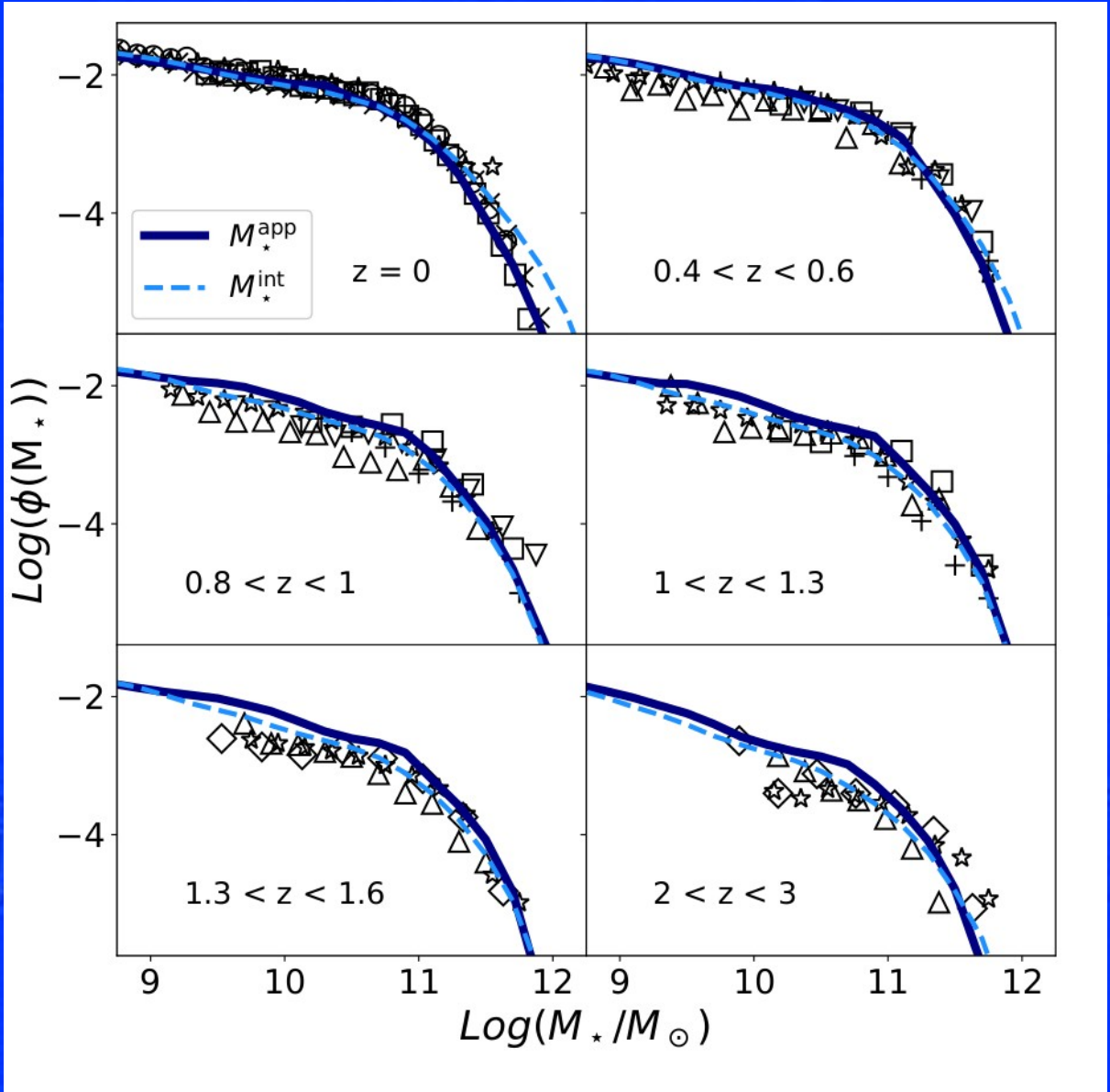

SFR=100 $M_\odot$/yr
SFR=1.00 $M_\odot$/yr
SFR=0.01 $M_\odot$/yr
Kroupa IMF
$\frac{U_{CR}}{U_{MW}} = 1$
$1\ M_\odot$
$8\ M_\odot$
$Log(\phi_{\rm IGIMF})$
Fontanot et al. (2018)
$Log(m_\star/M_\odot)$

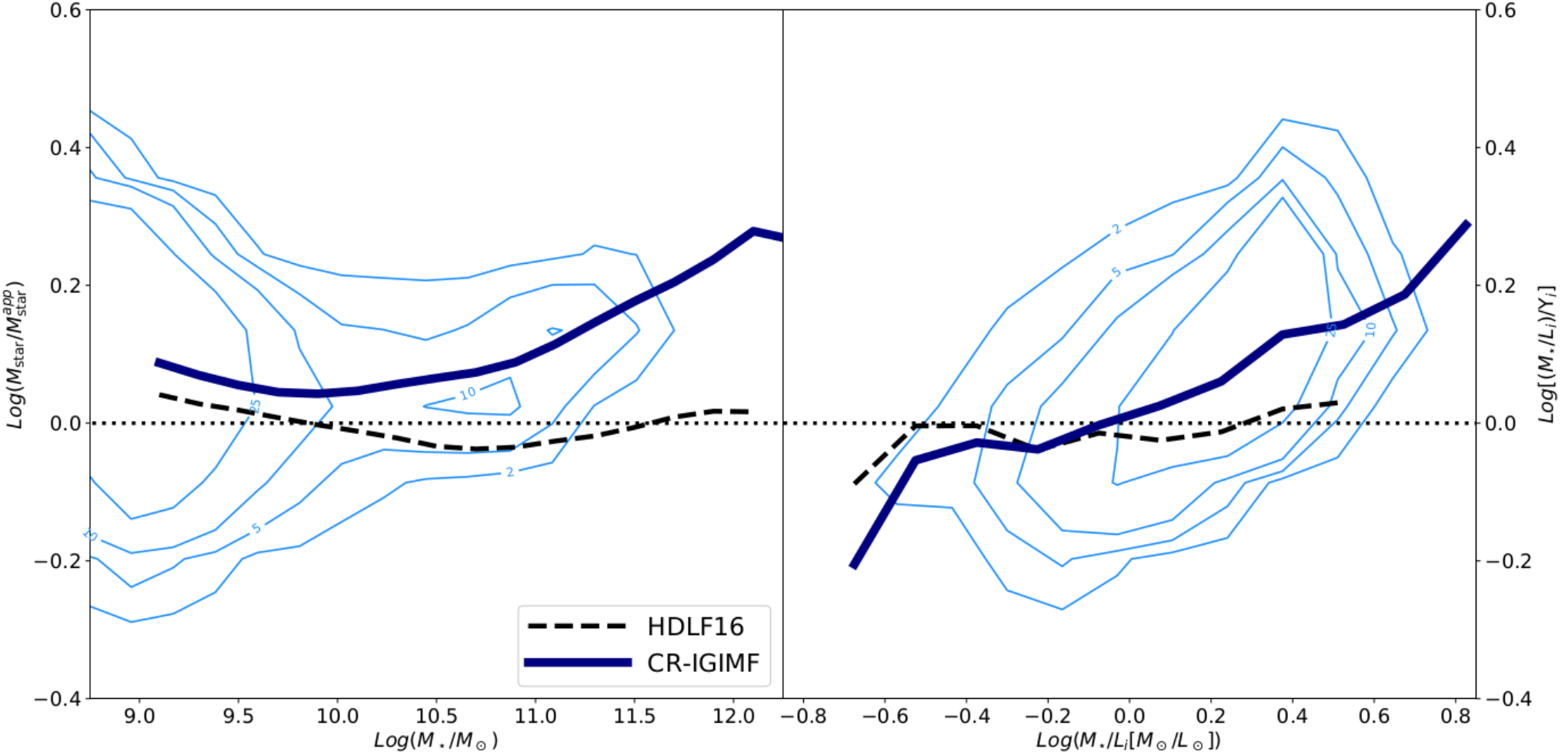


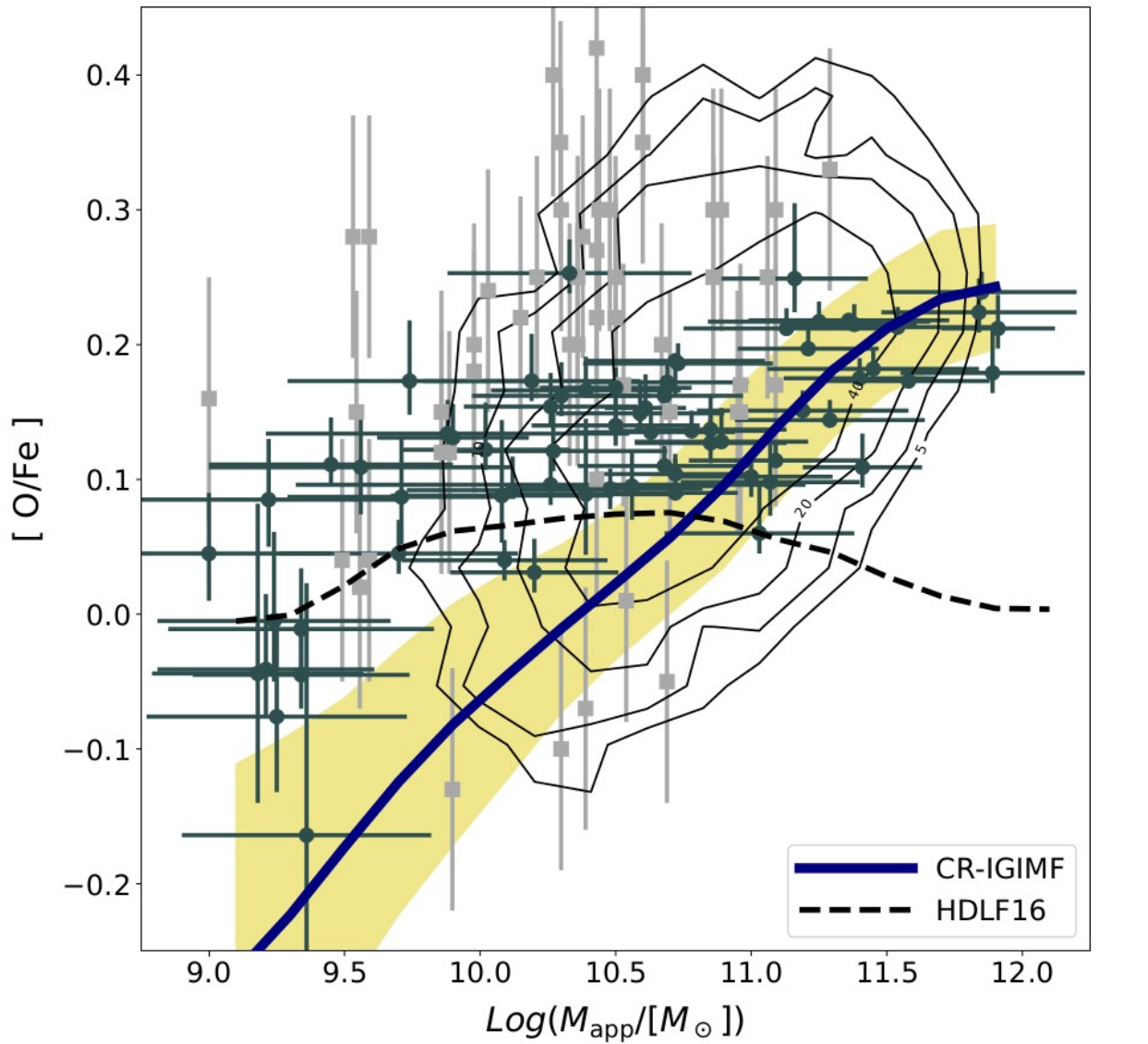
Fontanot+18b

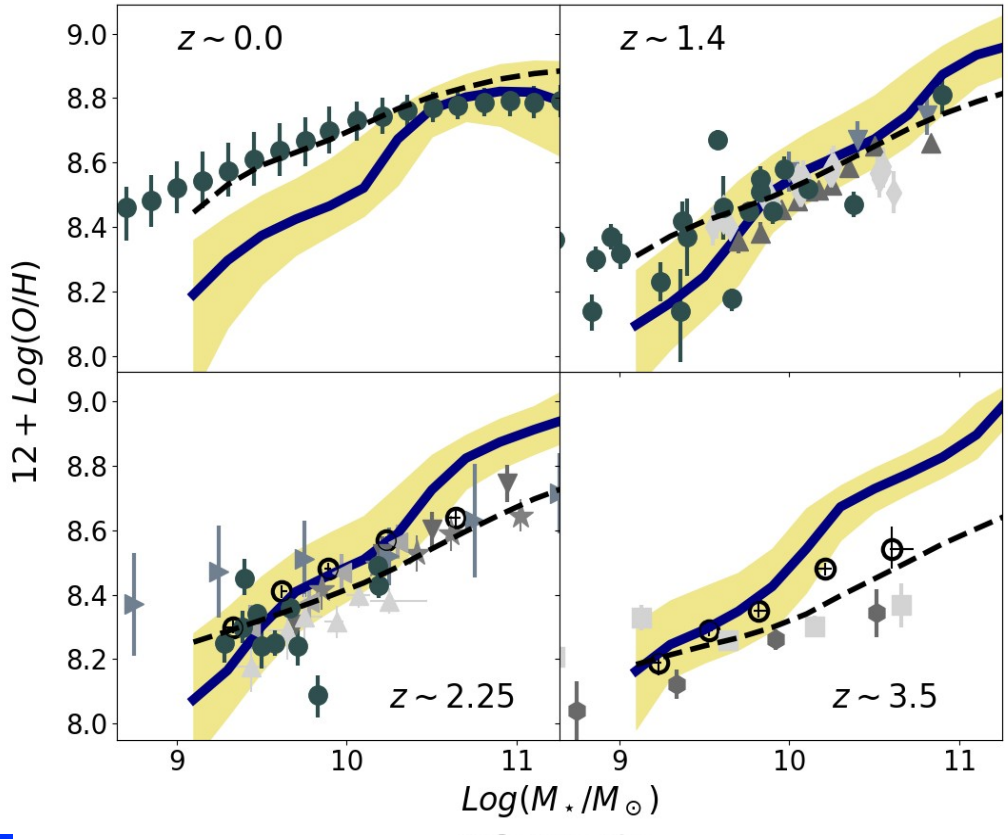


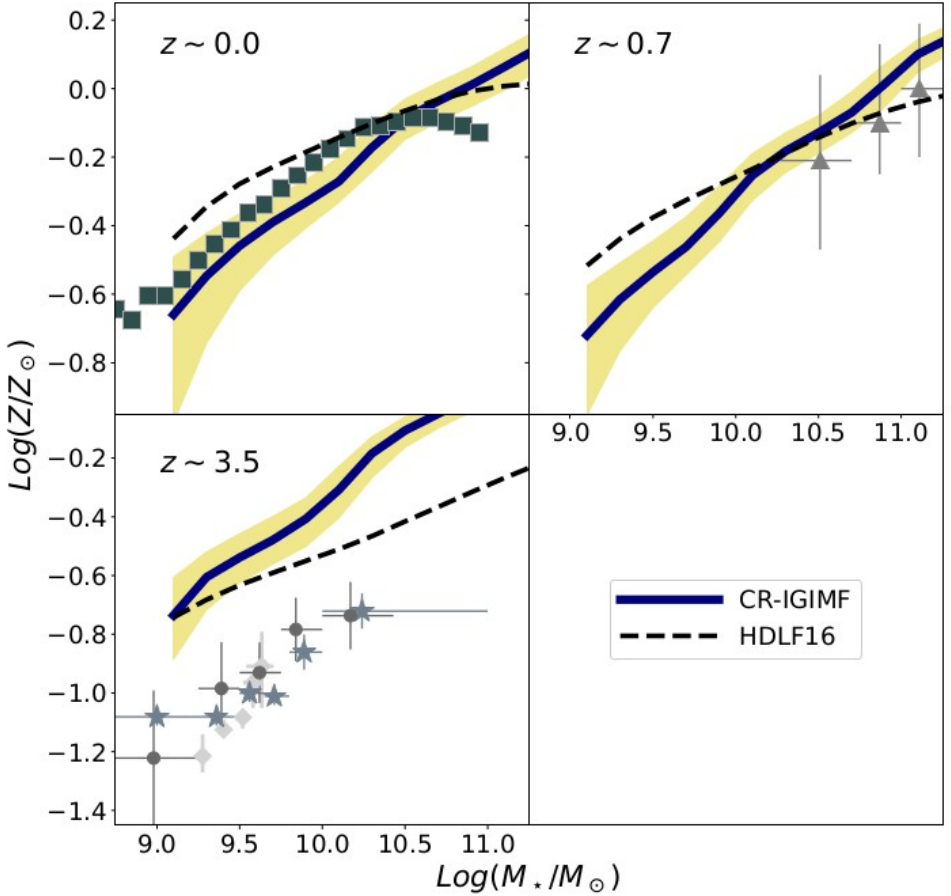
see also Jerabkova+18

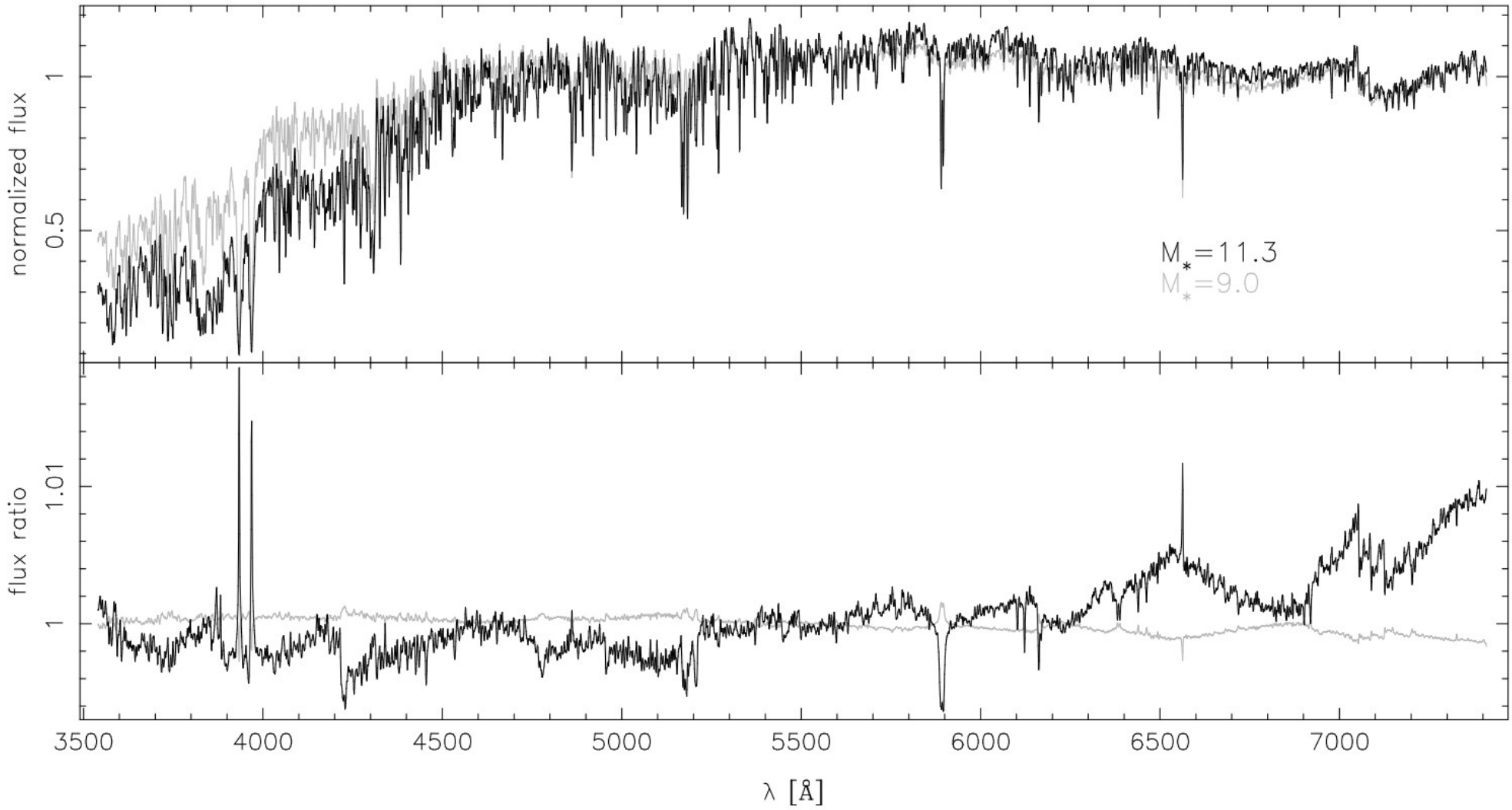

$M_\star^{app}$
$M_\star^{int}$
z = 0
0.4 < z < 0.6
0.8 < z < 1
1 < z < 1.3
1.3 < z < 1.6
2 < z < 3
−2
−4
9
10
11
12
$Log(\phi(M_\star))$
$Log(M_\star/M_\odot)$

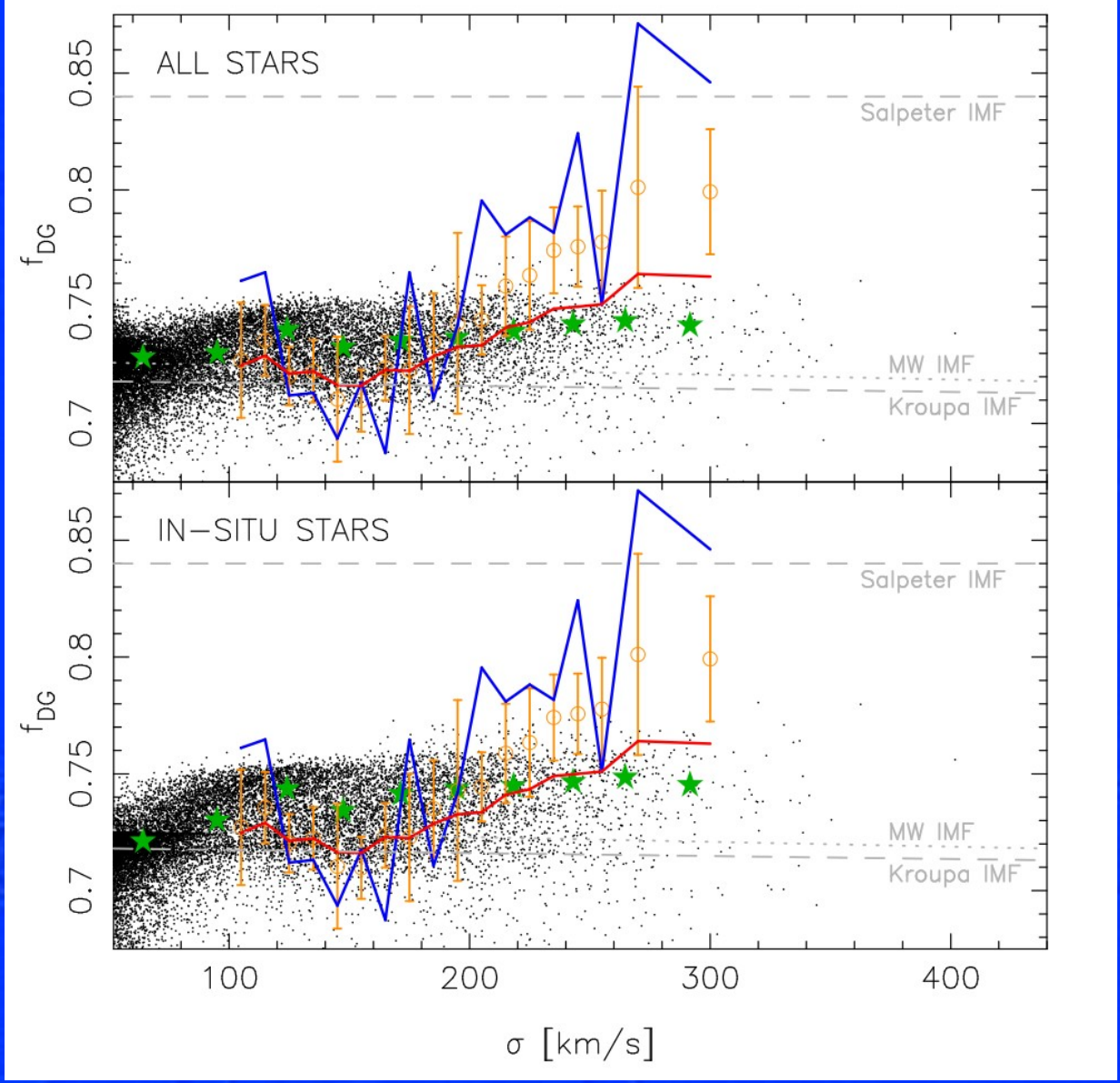

0.6
0.4
0.2
0.0
−0.2
−0.4
$Log(M_{star}/M^{app}_{star})$
$Log(M_\star/M_\odot)$
9.0
9.5
10.0
10.5
11.0
11.5
12.0
HDLF16
CR-IGIMF
2
5
10
15
−0.8
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
$Log(M_\star/L_i[M_\odot/L_\odot])$
$Log[(M_\star/L_i)/Y_i]$

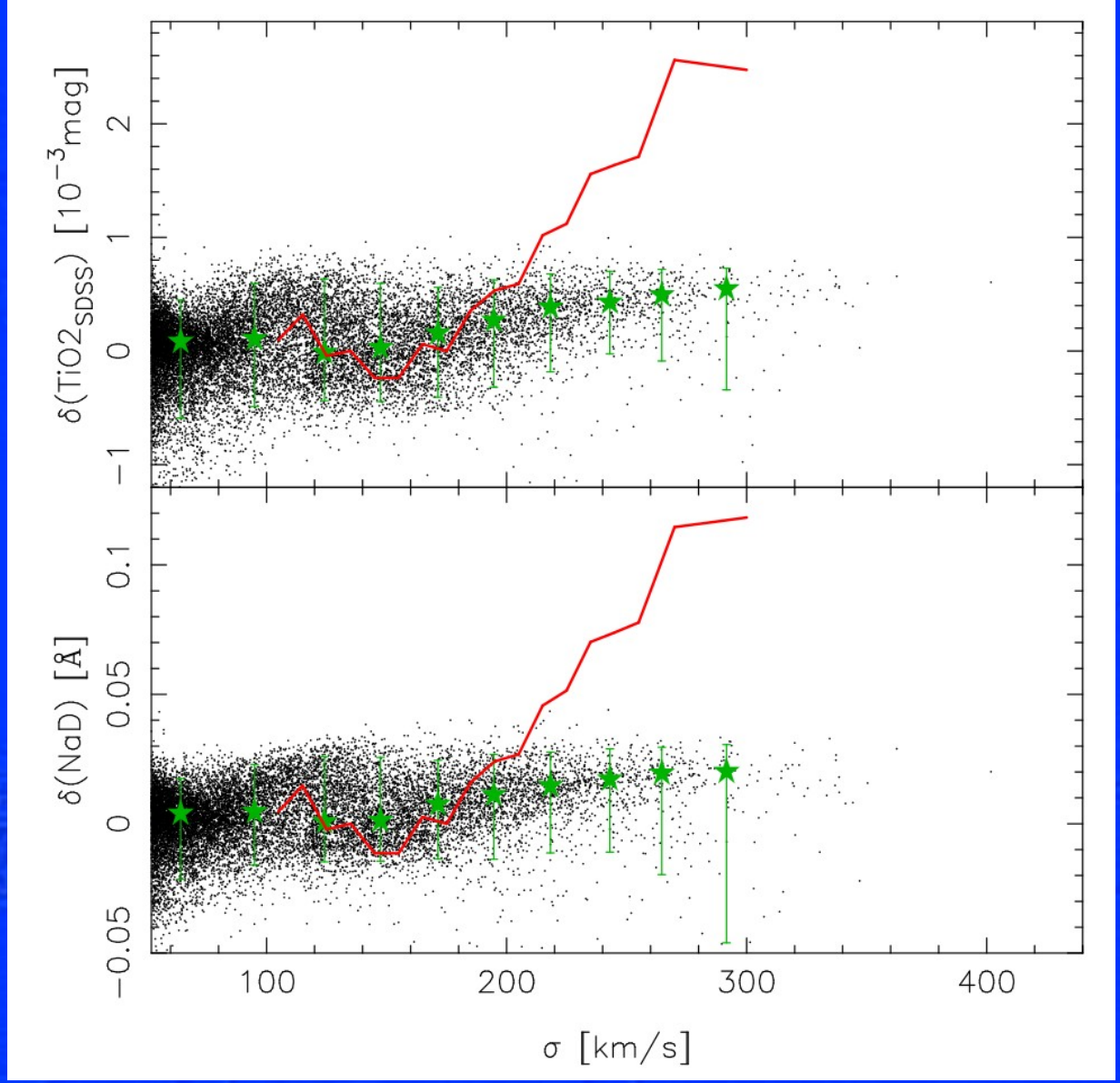

0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
[O/Fe]
9.0
9.5
10.0
10.5
11.0
11.5
12.0
$Log(M_{app}/[M_\odot])$
40
5
20
CR-IGIMF
HDLF16


$z \sim 0.0$
$z \sim 1.4$
$z \sim 2.25$
$z \sim 3.5$
$12 + Log(O/H)$
$Log(M_\star/M_\odot)$


$z \sim 0.0$
$z \sim 0.7$
$z \sim 3.5$
CR-IGIMF
HDLF16
$Log(Z/Z_\odot)$
$Log(M_\star/M_\odot)$


normalized flux
1
0.5
M*=11.3
M*=9.0
flux ratio
1.01
1
3500
4000
4500
5000
5500
6000
6500
7000
λ [Å]


ALL STARS
Salpeter IMF
MW IMF
Kroupa IMF
IN−SITU STARS
Salpeter IMF
MW IMF
Kroupa IMF
f_{DG}
0.7
0.75
0.8
0.85
100
200
300
400
σ [km/s]


δ(TiO2SDSS) [10−3mag]
2
1
0
−1
δ(NaD) [Å]
0.1
0.05
0
−0.05
100
200
300
400
σ [km/s]

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
  - Intrinsic Galaxy Properties might be drastically different from photometrically estimated values