The UV Luminosity Function of high-z galaxies using z-Z dependent IMF

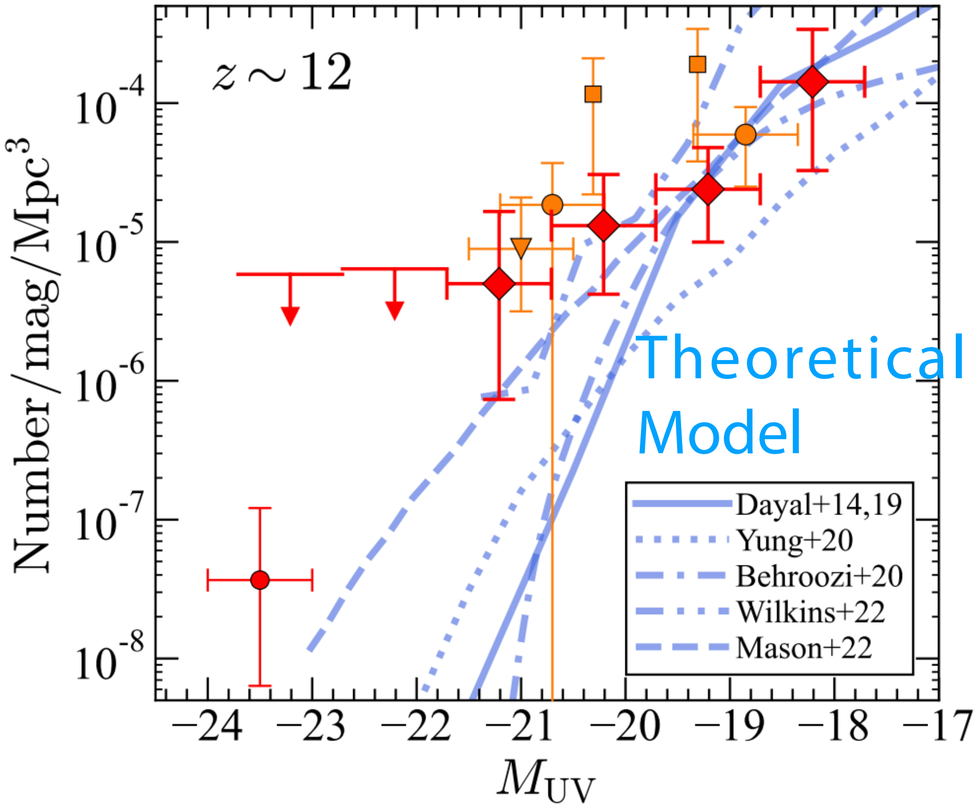
Keita Fukushima (Seoul National University)

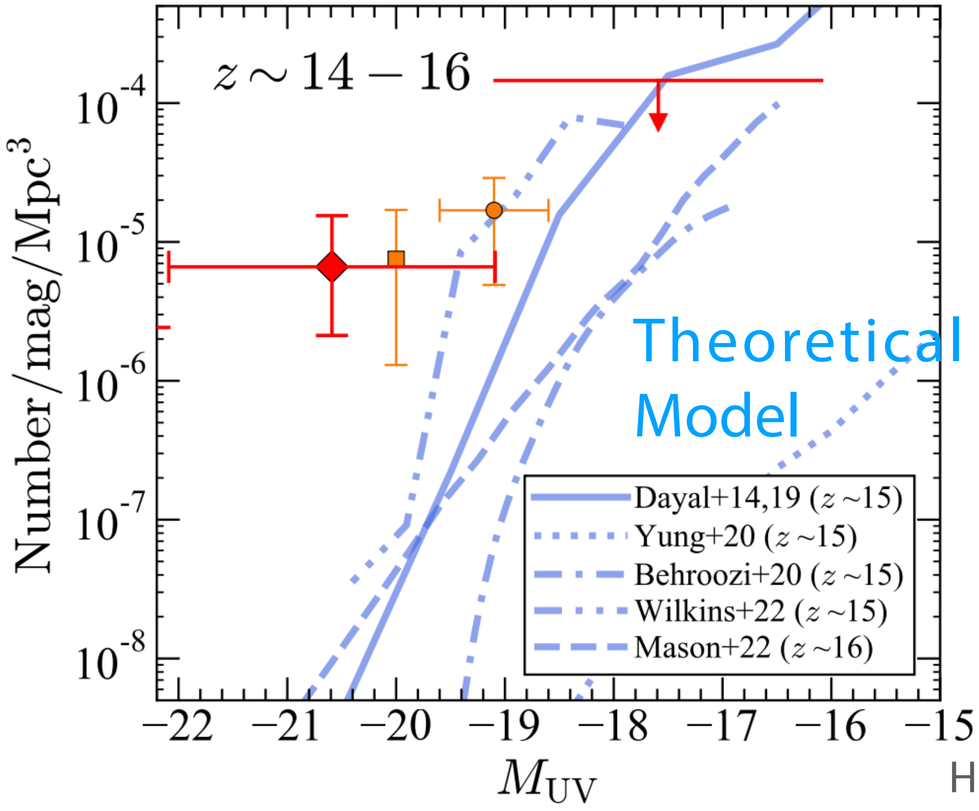
Shuya Kitagawa, Akio Inoue (Waseda), Tomoaki Ishiyama (Chiba),
Sunmyon Chon (Tohoku, MPA), Kazuyuki Omukai (Tohoku)

11KIAS Workshop on Cosmology & Structure Formation, OCT 29, 2024

UV Luminosity function (UVLF)

Discrepancy with Observations at z>10





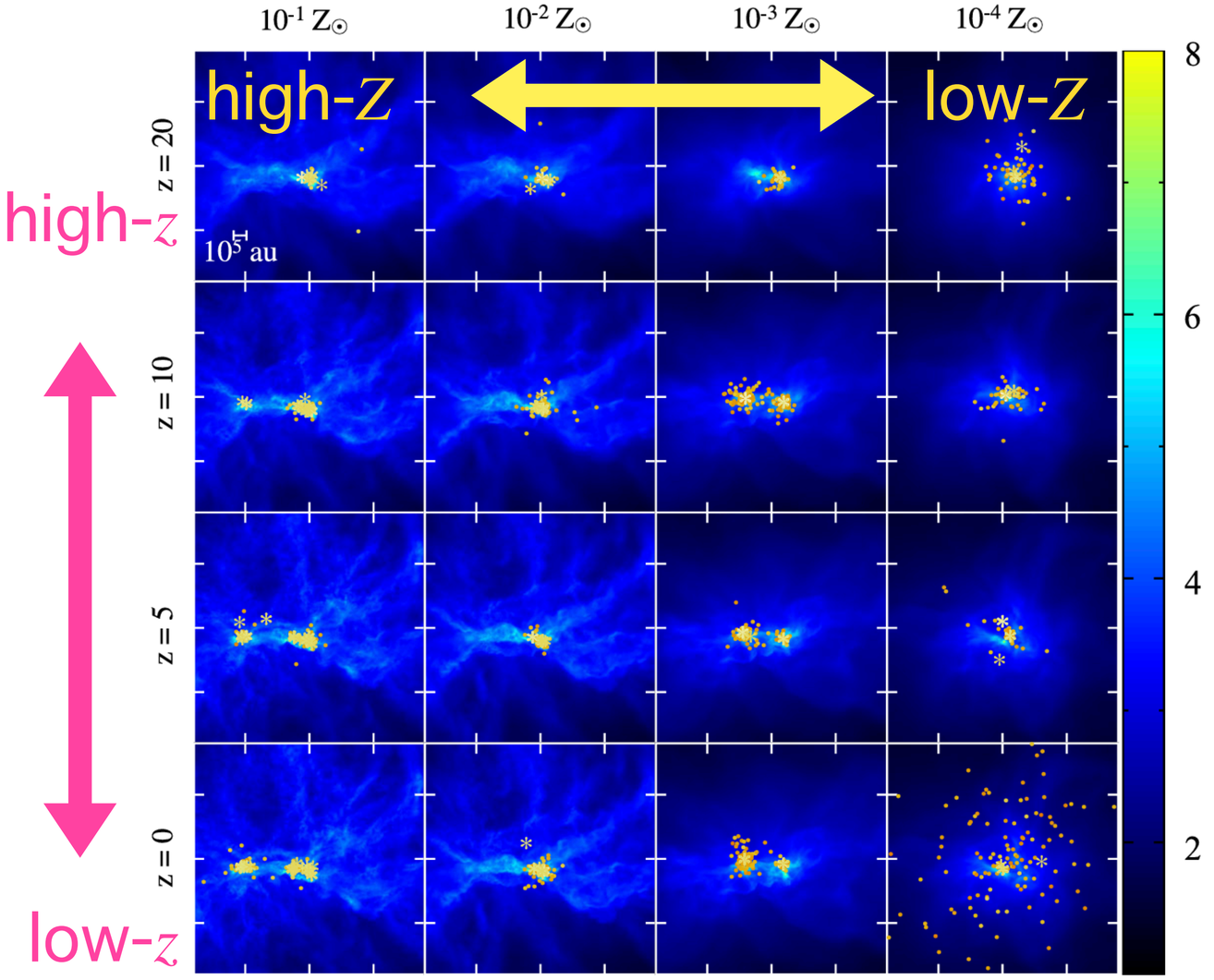
Harikane+23

- Increase in the star formation efficiency (SFE) of galaxies at higher redshift
- Highly stochastic star formation activity
- Low dust attenuation
- Top-heavy IMF (increases the UV luminosity per SFR)

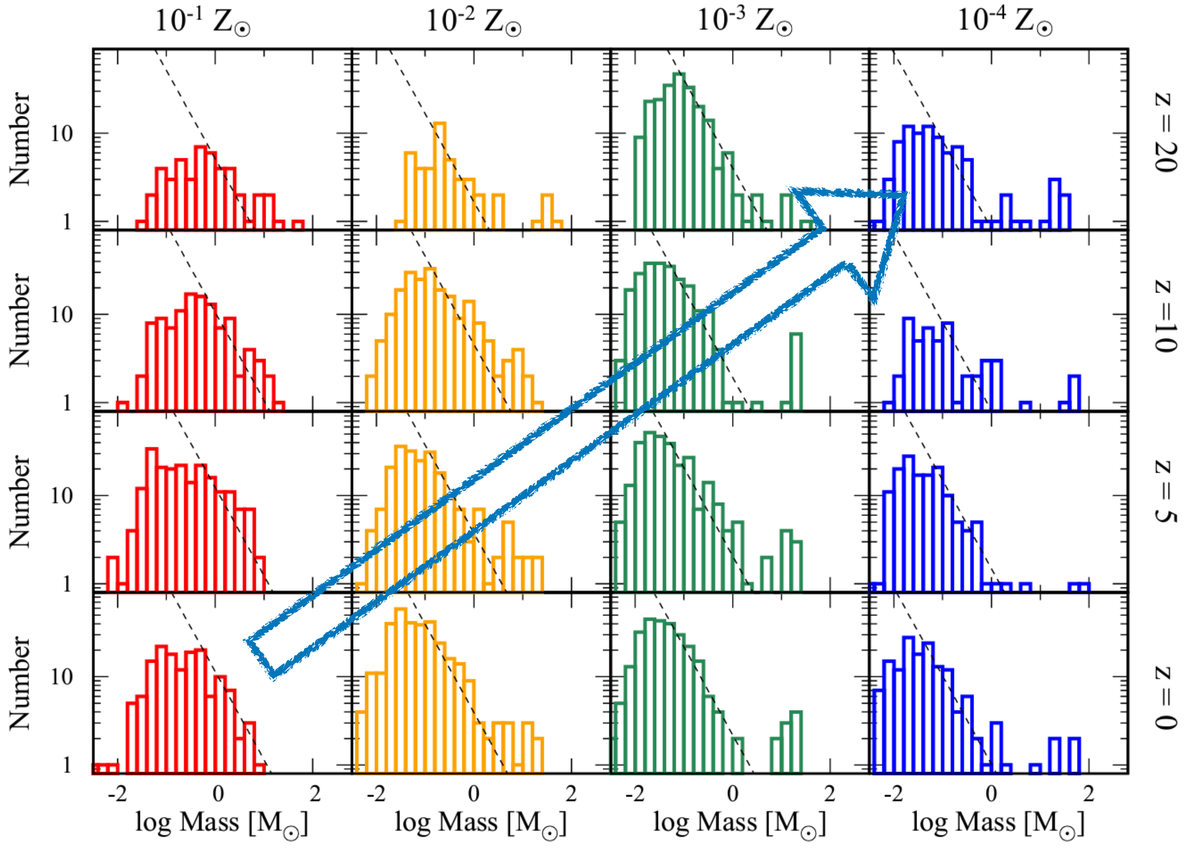
Our study: Developed a **semi-analytic model** that incorporates a **top-heavy IMF**, and **metallicity evolution**, applied to a large-box N-body simulation to generate the UVLF

Top heavy IMF (z-Z dependent IMF)

High-resolution 3D hydrodynamical simulation (Chon+'22)



Top heavy



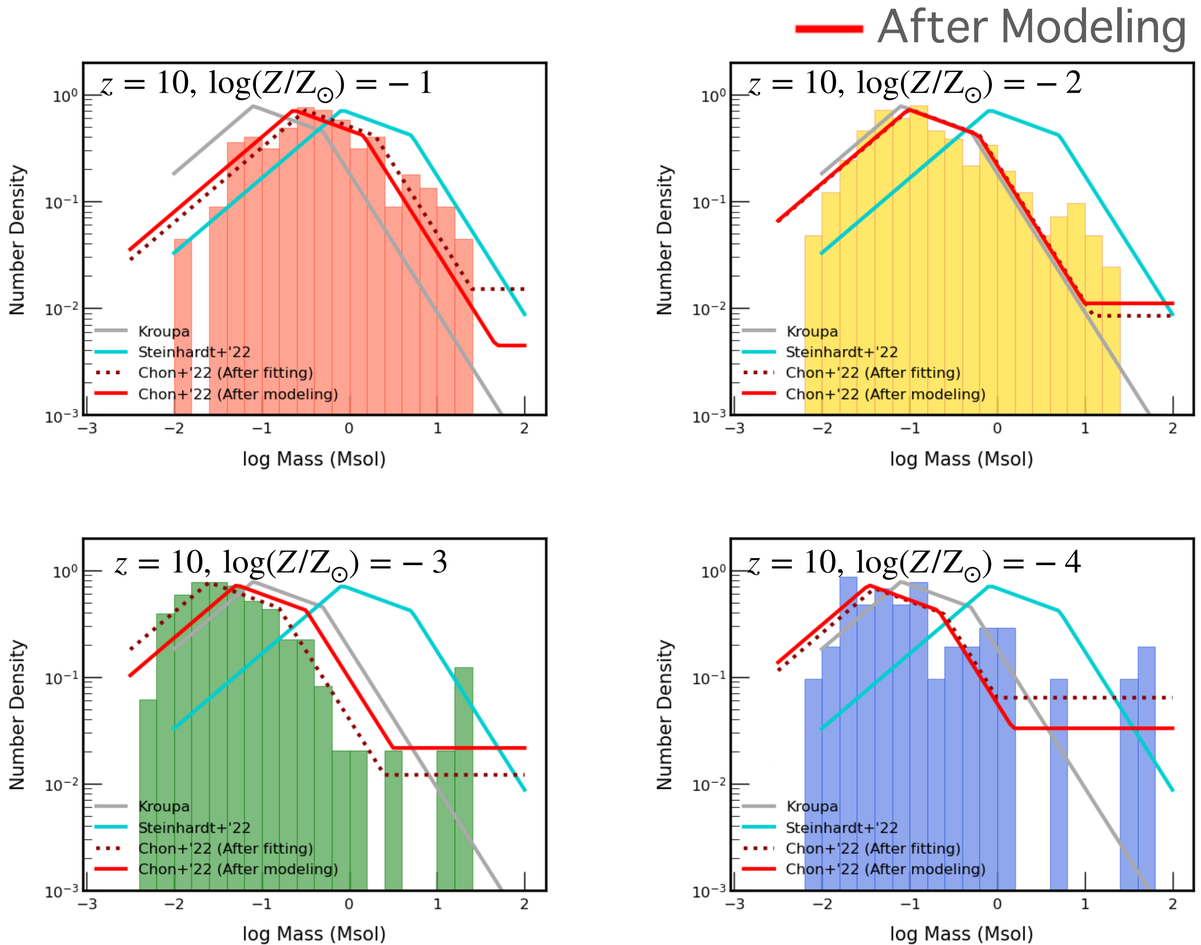
Strategy

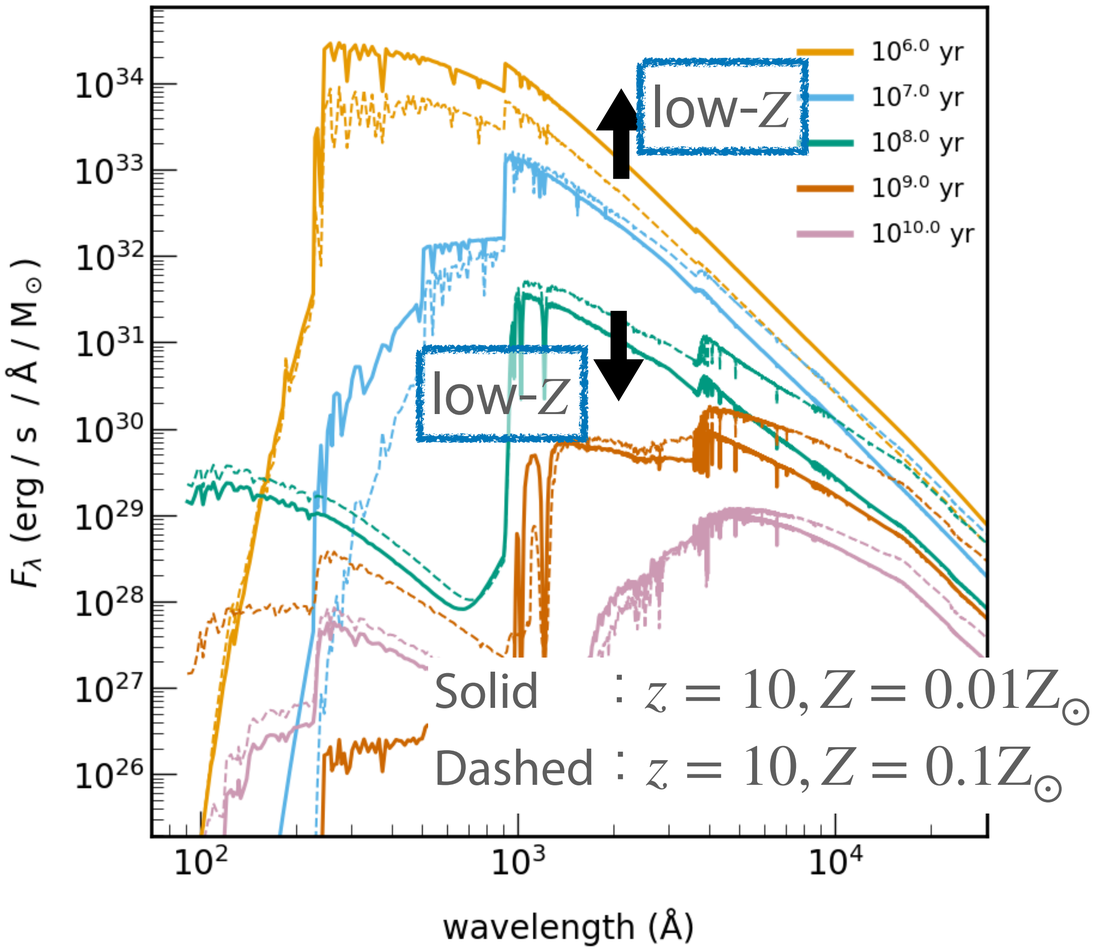
- Top heavy IMF (redshift-Metallicity dependent) (Chon+'22)
- SED model (FSPS; Conroy, Gunn, & White 2009, Conroy & Gunn 2010)
- Semi-analytic model (Shin-Uchuu simulation; Ishiyama+21)

→ UV Luminosity function

Strategy

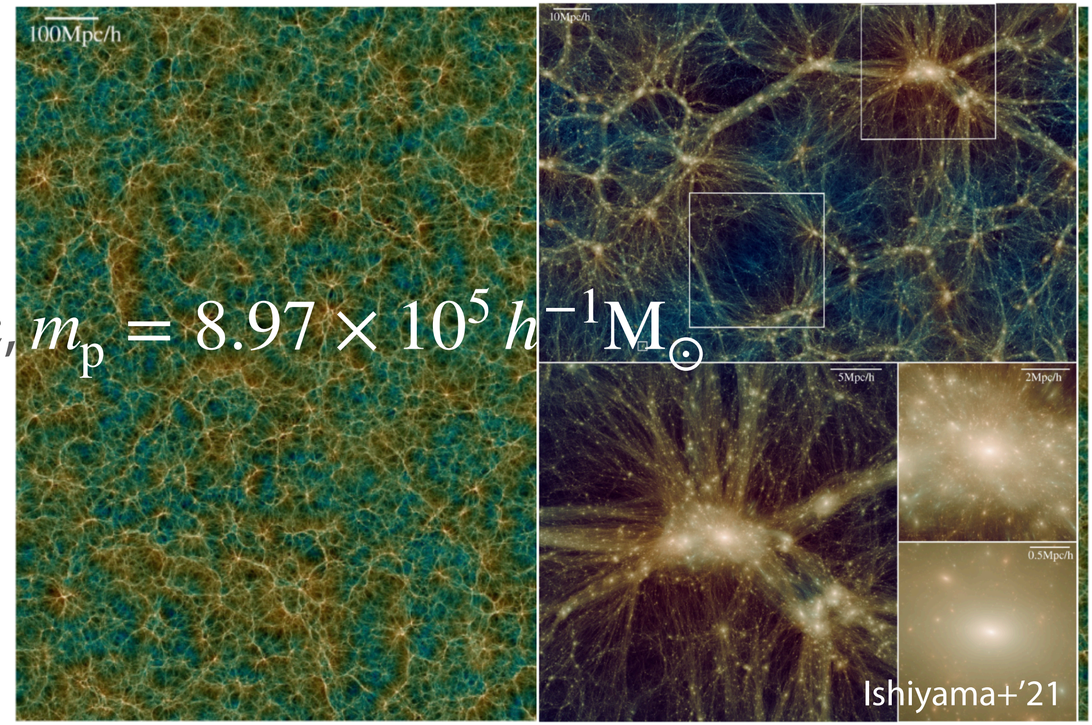
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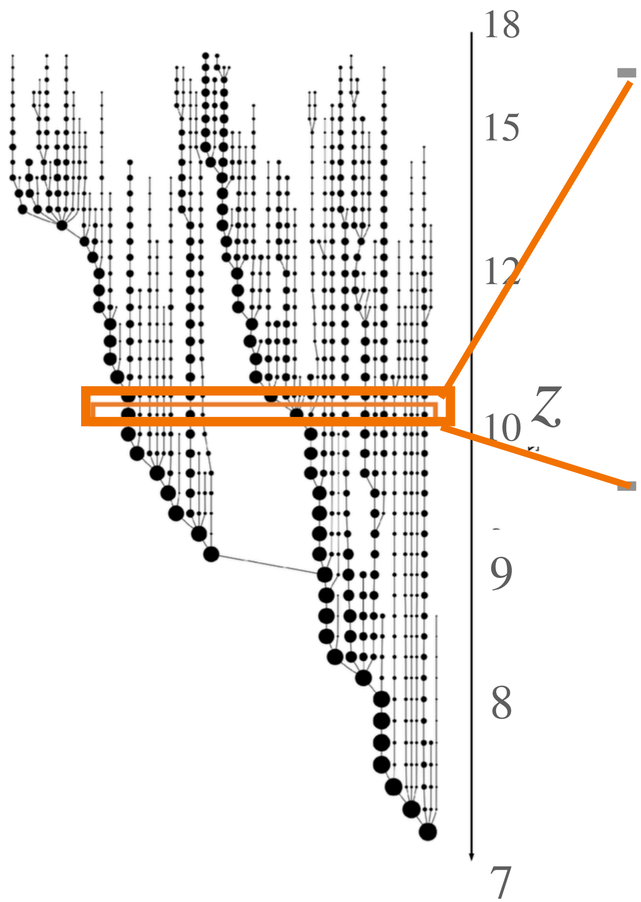


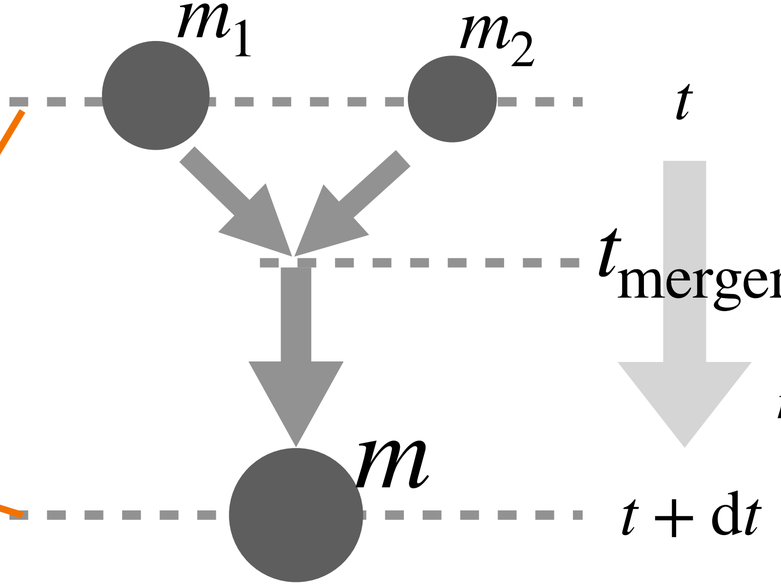


Semi-analytic model

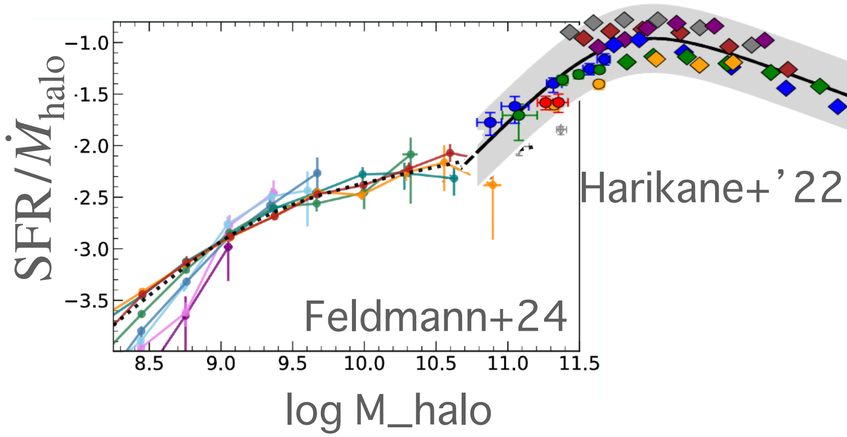
- N body simulation (Ishiyama+'21)
  - Shin-Uchuu : $L = 140\,h^{-1}\mathrm{Mpc}, \epsilon = 0.4\,h^{-1}\mathrm{kpc}, m_\mathrm{p} = 8.97 \times 10^5\,h^{-1}\mathrm{M}_\odot$







$$\dot{m} = \frac{m - m_1}{\mathrm{d}t}$$



$$\mathrm{SFR} = f(m) * \dot{m}$$ Harikane+22, Feldmann+24

$$\dot{m}_\mathrm{gas} = f_\mathrm{b}\,\dot{m} - \eta\,\mathrm{SFR} - (1 - f)\,\mathrm{SFR}$$

$$\dot{m}_Z = Z_\mathrm{yield}\,\mathrm{SFR} - Z\,\eta\,\mathrm{SFR} - Z\,(1 - f)\,\mathrm{SFR}$$

$$f_\mathrm{UV} = \frac{1-\delta}{2}(1 + e^{-\tau_\mathrm{d}}) + \frac{\sigma}{\tau_\mathrm{d}}(1 - e^{-\tau_\mathrm{d}}) \qquad \tau_\mathrm{d} = \frac{3\Sigma_\mathrm{d}}{4 a_\mathrm{d} s} \qquad \Sigma_\mathrm{d} = e_\tau \frac{M_\mathrm{metal}}{\pi r_\mathrm{half}^2}$$ Shimizu+14

η: mass loading factor

f: mass loss rate

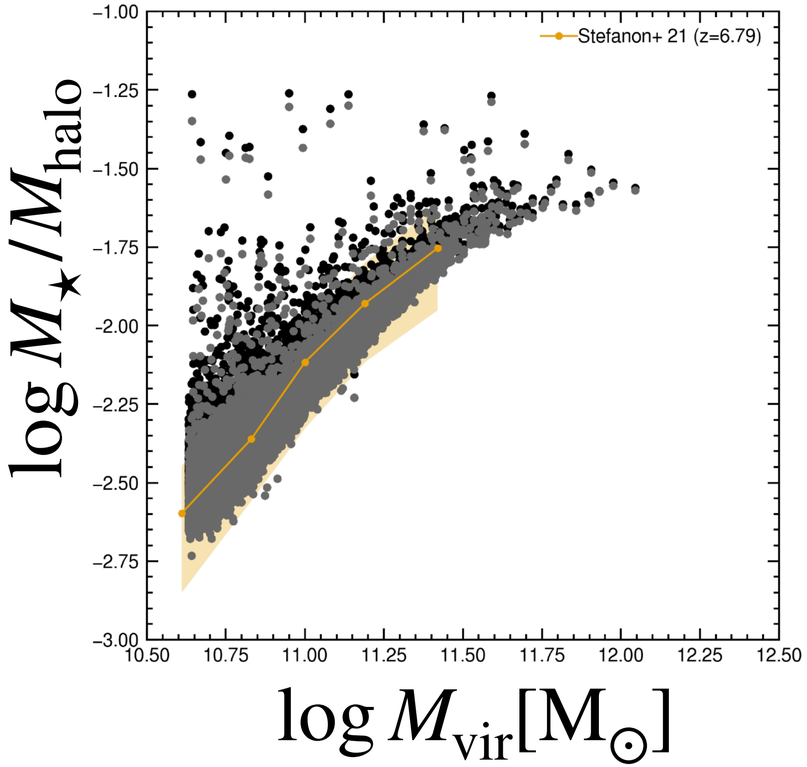
$e_\tau = e_{M_\mathrm{d}} / e_\mathrm{rd}^2$

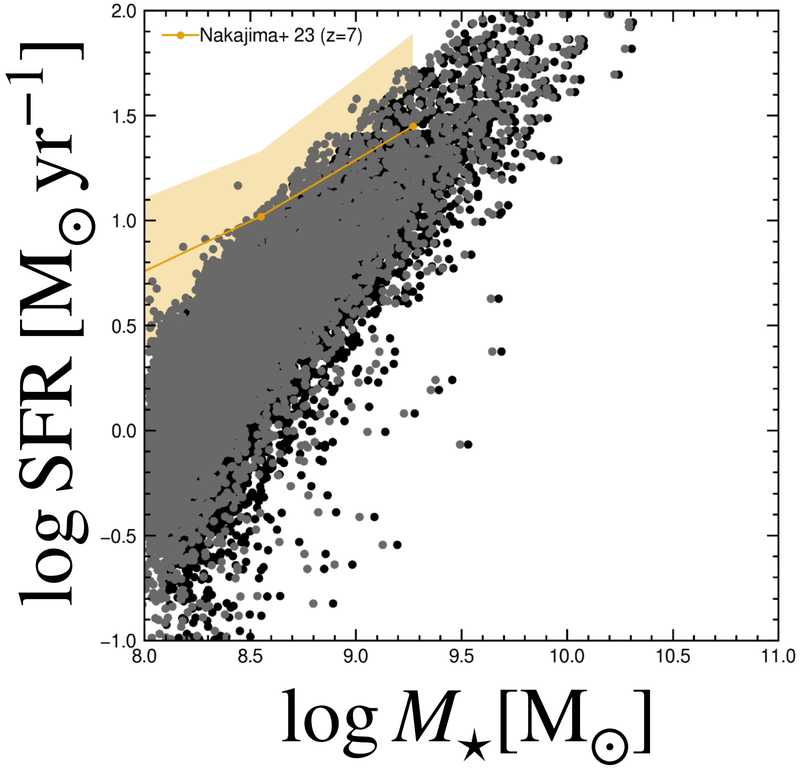
Semi-analytic model

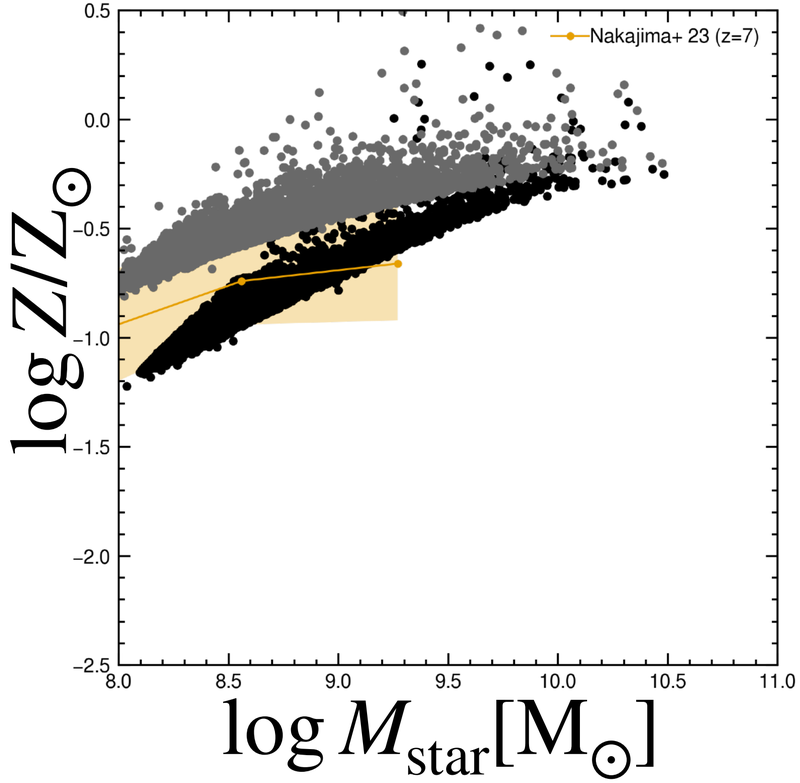
Model	SF History	SED	Metal evolution	Dust Calibration
Kroupa IMF	Same	Kroupa IMF	Kroupa IMF	Kroupa IMF at z=7
zZ IMF (Z: Kroupa)		zZ IMF		
zZ IMF (Z: zZ)			zZ IMF	zZ IMF at z=7

SHMR, SFMS, & MZR at z=7

- Kroupa IMF
- zZ IMF (Z: zZ)

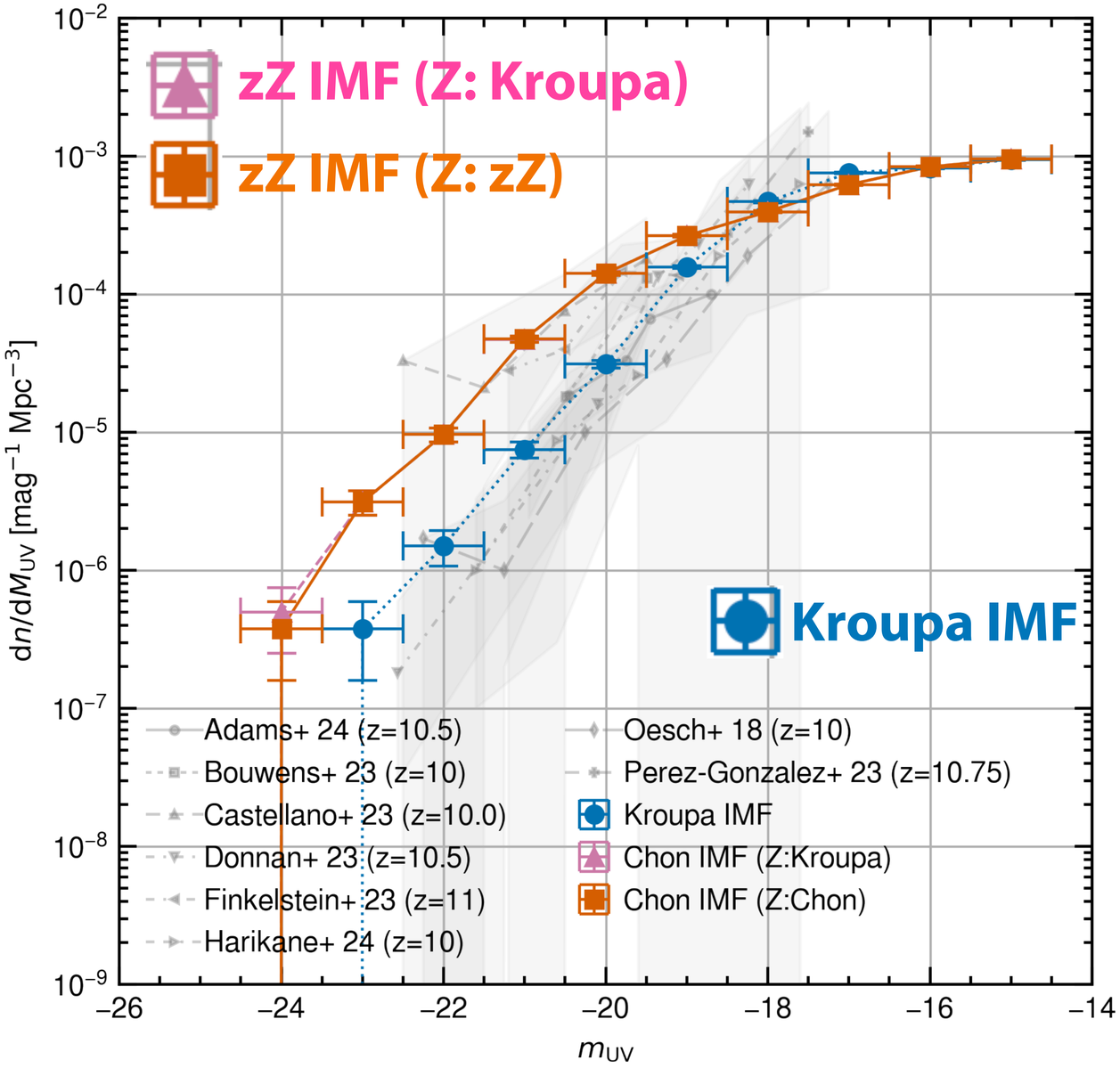






- Our SHMR is reproduce observed SHMR
- SFMS is lower than observations on the low-mass end

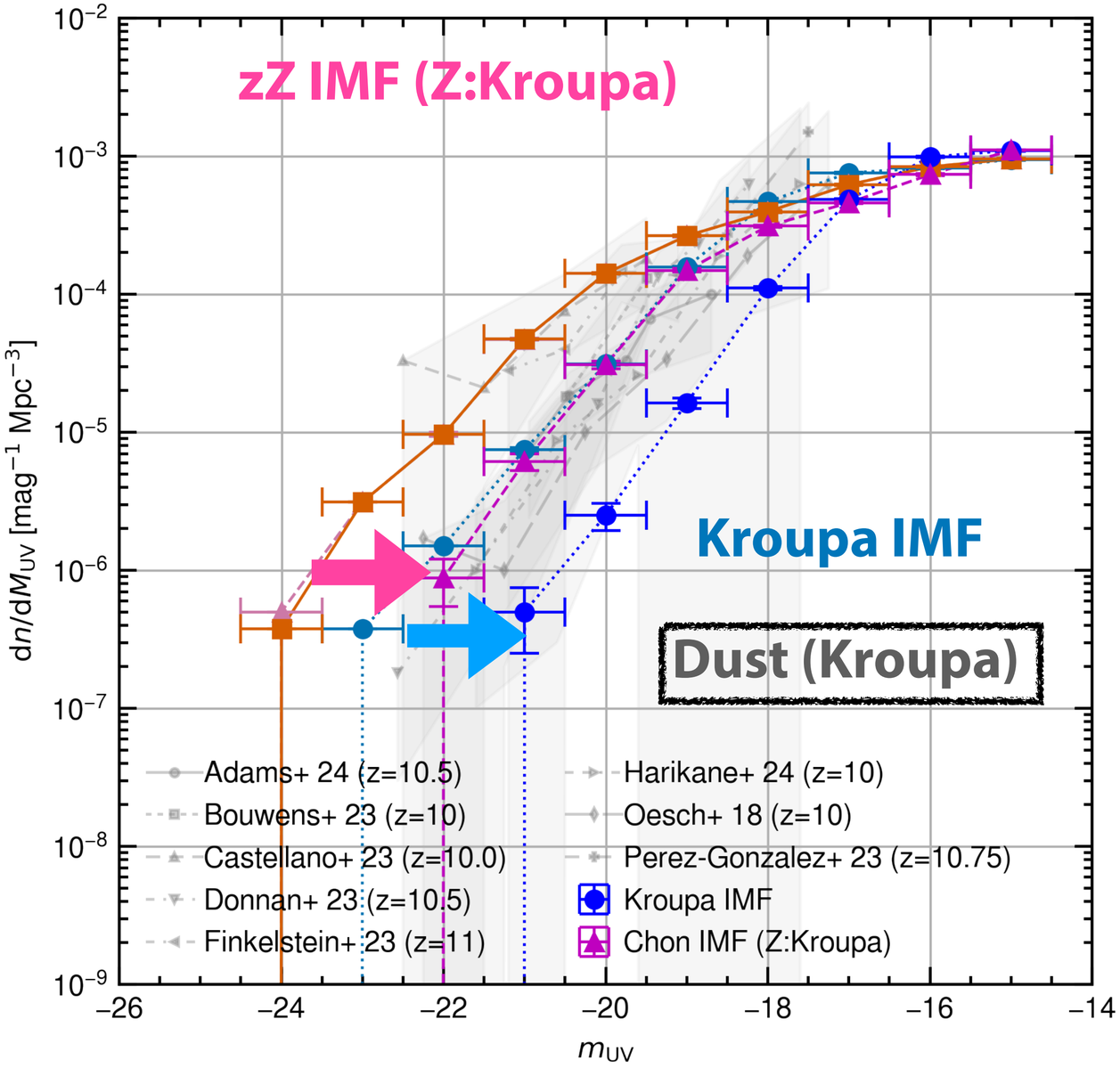
UVLF without dust attenuation @ z=10



No Dust Attenuation

UVLF of zZ IMF (Z:zZ) is almost same to that with zZ IMF (Z:Kroupa)

UVLF with dust attenuation @ z=10

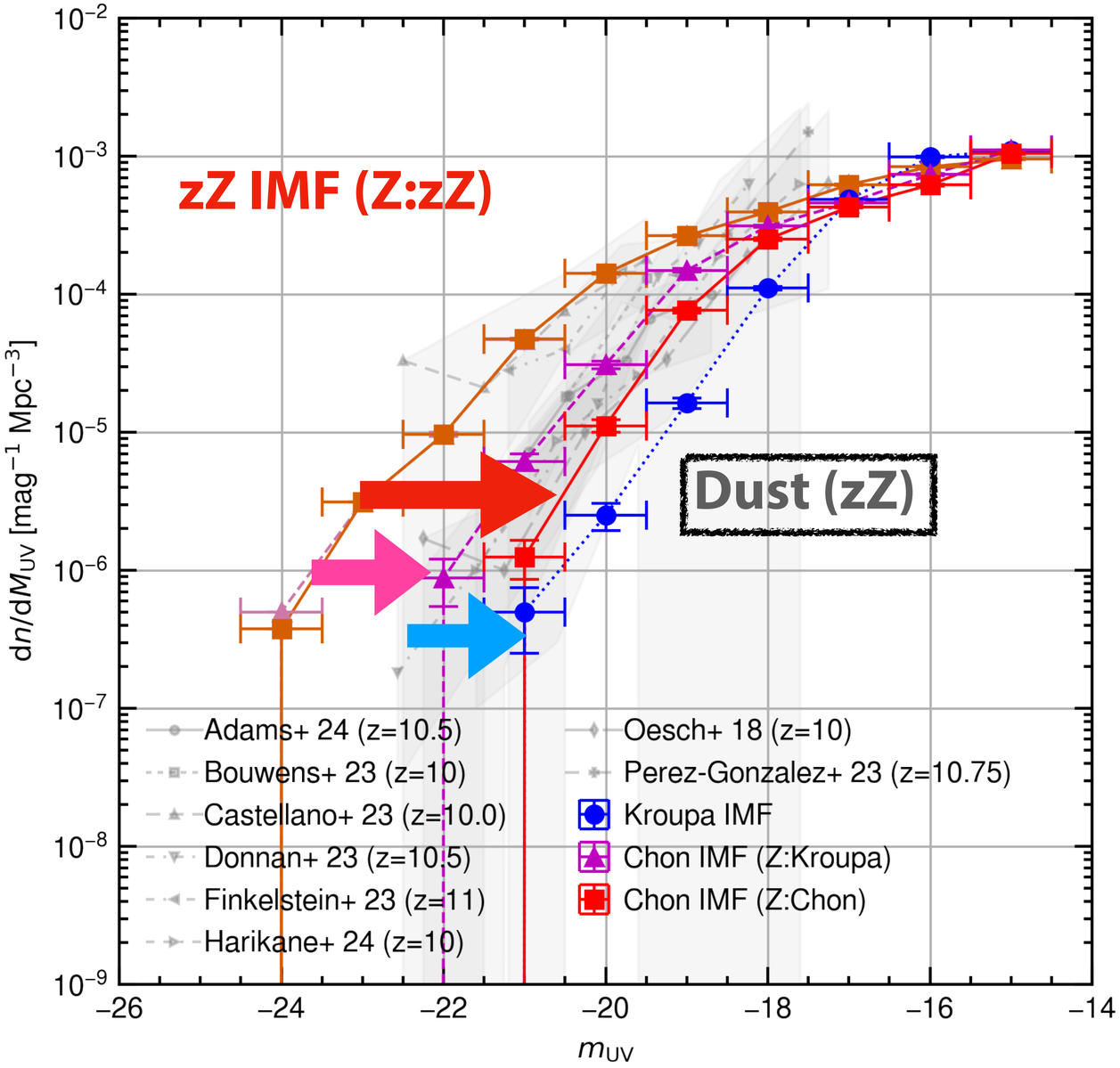


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UVLF of zZ IMF (Z:zZ) is almost same to that with zZ IMF (Z:Kroupa)

Dust Attenuation

UVLF with dust attenuation @ z=10



No Dust Attenuation

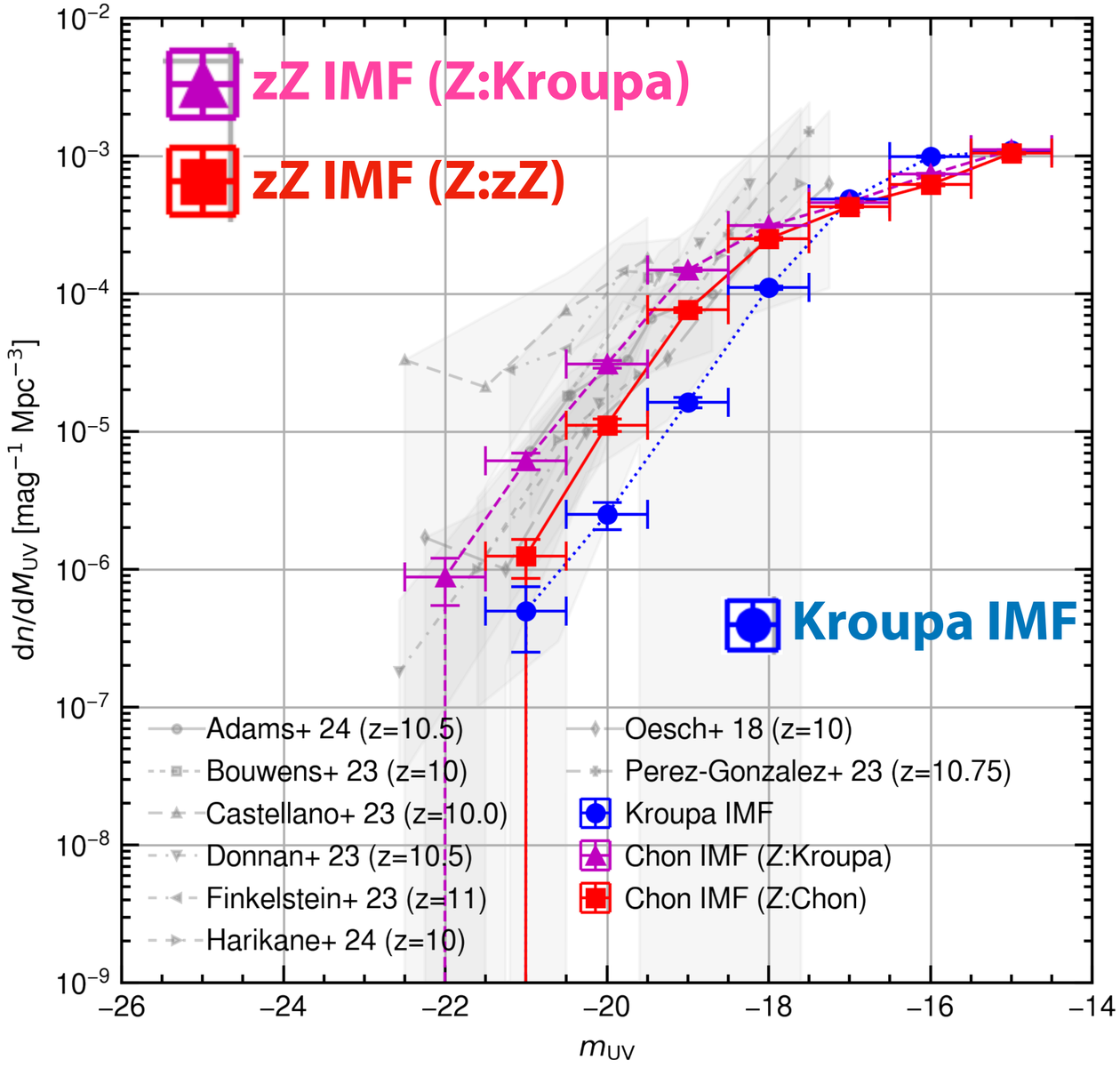
UVLF of zZ IMF (Z:zZ) is almost same to that with zZ IMF (Z:Kroupa)

Dust Attenuation

Metal enrichment occurs more rapidly with the zZ IMF than with the Kroupa IMF

→ Dust absorption more effective

UVLF with dust attenuation @ z=10



No Dust Attenuation

UVLF of zZ IMF (Z:zZ) is almost same to that with zZ IMF (Z:Kroupa)

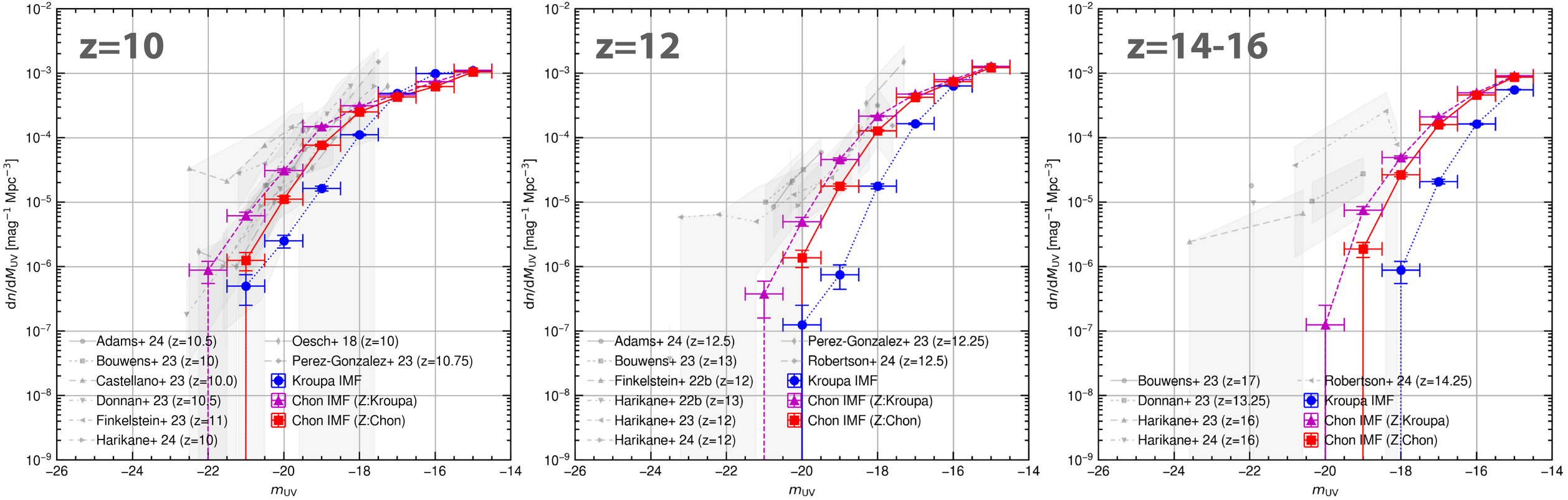
Dust Attenuation

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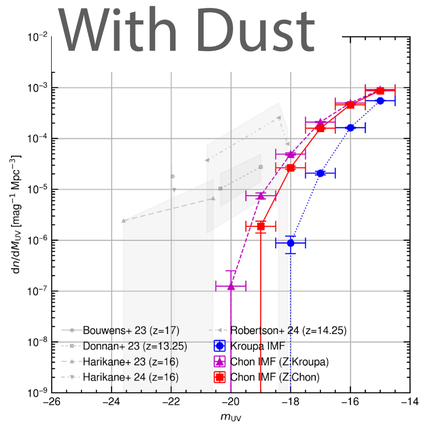
With the zZ IMF, UVLF is higher than with the Kroupa IMF, but dust attenuation limits its contribution

UVLF with dust attenuation @ z=10, 12, 14



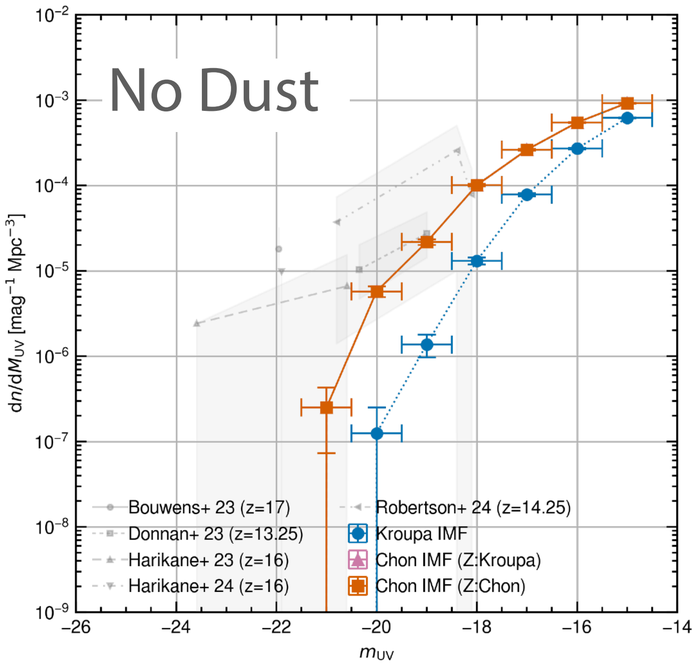
- zZ IMF (Z: zZ) is not as high as zZ IMF (Z: Kroupa)
- At z = 12 and 14, even the zZ IMF is still insufficient

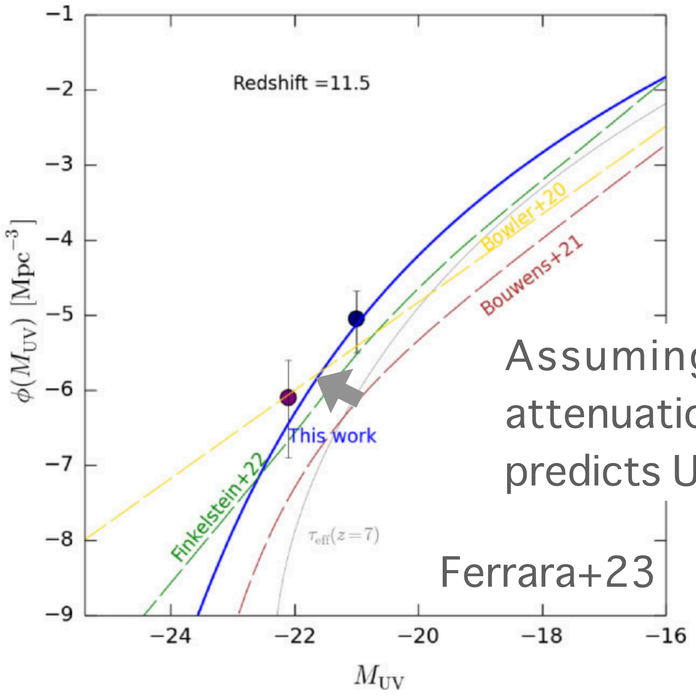
How to reproduce UVLF @ z=14



Low dust attenuation (Ferrara et al. 2023)

- Special relative distribution of stars and dust
- Low dust-to-stellar mass ratio





Assuming a negligible dust attenuation at z=11.5, model predicts UV Luminosity Function

No-attenuation hypothesis may be consistent with the very blue UV slope ($\beta \leq 2.5$) of high-z galaxies

Summary

Investigation of UV Luminosity Function for Galaxies at $z > 10$ using semi-analytic model

- Developed **zZ-dependent IMF** model dependent on redshift (z) and metallicity (Z)
- Developing a galaxy evolution model based on the Shin-Uchuu Simulation
- **With the zZ IMF, UVLF is higher than with the Kroupa IMF, but dust attenuation limits its contribution**
- A low dust attenuation model may be needed for $z > 12$