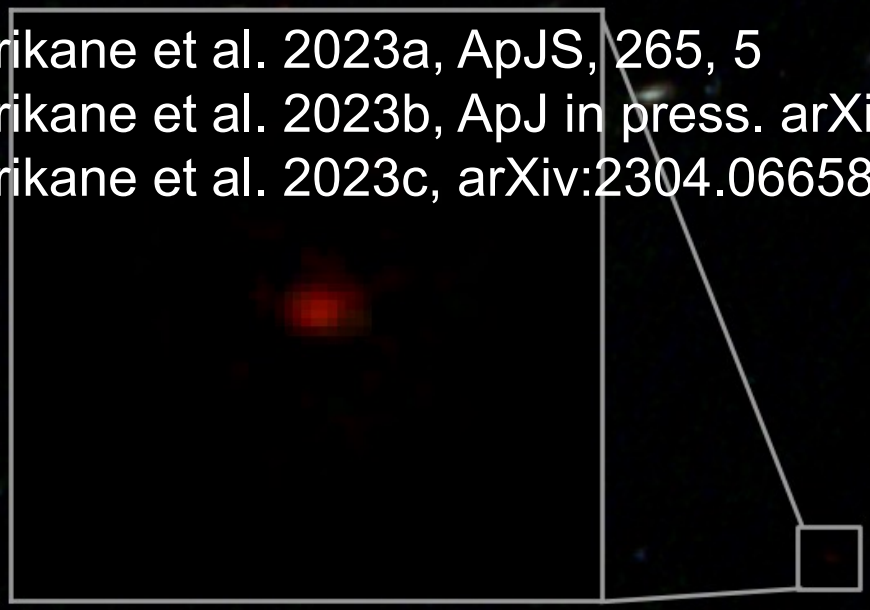
JWSTで探る宇宙星形成史と
マルチメッセンジャー天文学への展望

Harikane et al. 2023a, ApJS, 265, 5
Harikane et al. 2023b, ApJ in press. arXiv:2303.11946
Harikane et al. 2023c, arXiv:2304.06658



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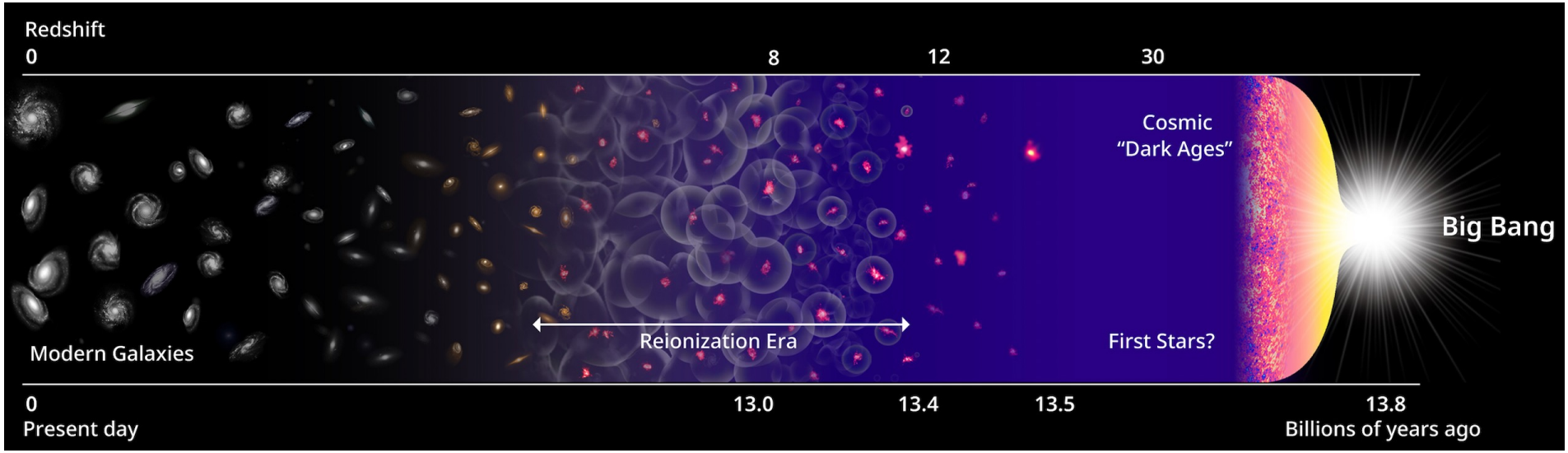
Goal of Galaxy Formation Study

- Understanding how galaxies form and evolve in the 13.8 billion-year cosmic history.

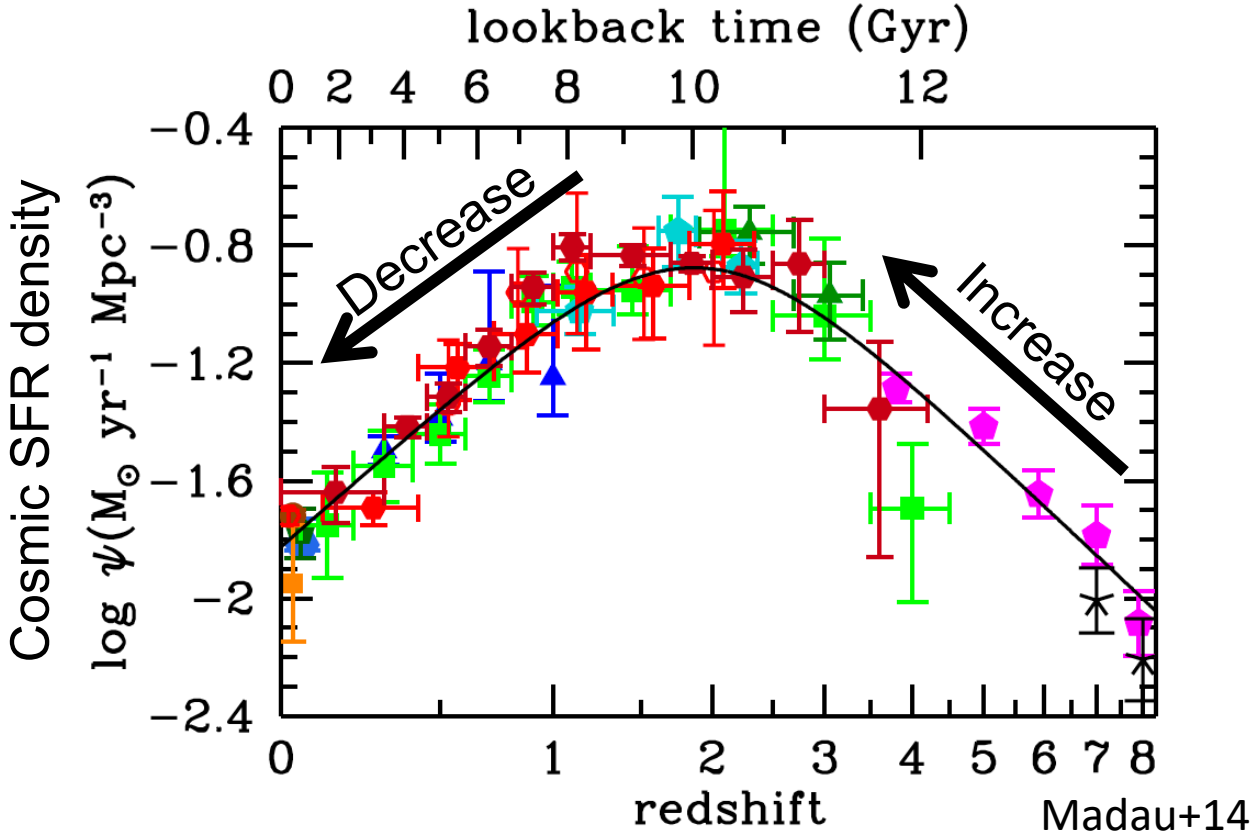


Harikane et al.

Research topics
- When the first stars (Pop-III) and galaxies form?
- Properties of high redshift galaxies (e.g., initial mass function).
- Co-evolution between galaxies and supermassive black holes (豊内さんtalk).

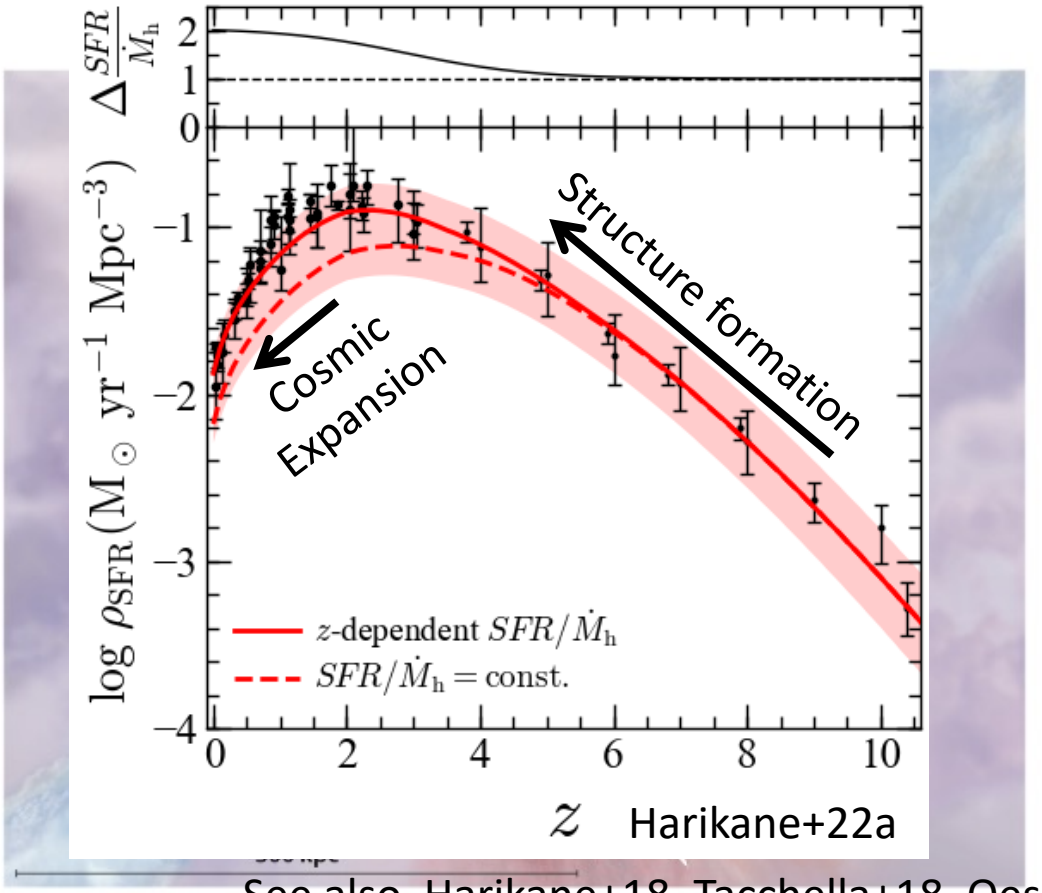
Cosmic Star Formation Rate Density

- Redshift evolution of the SFR density
  - Structure formation, star formation efficiency
  - Related to SN neutrino background, GRB rate, etc…



Constant Efficiency Model

- Constant star formation efficiency model (**SFR/(dM$_h$/dt)**)
  - Reproducing evolution at z=0-10

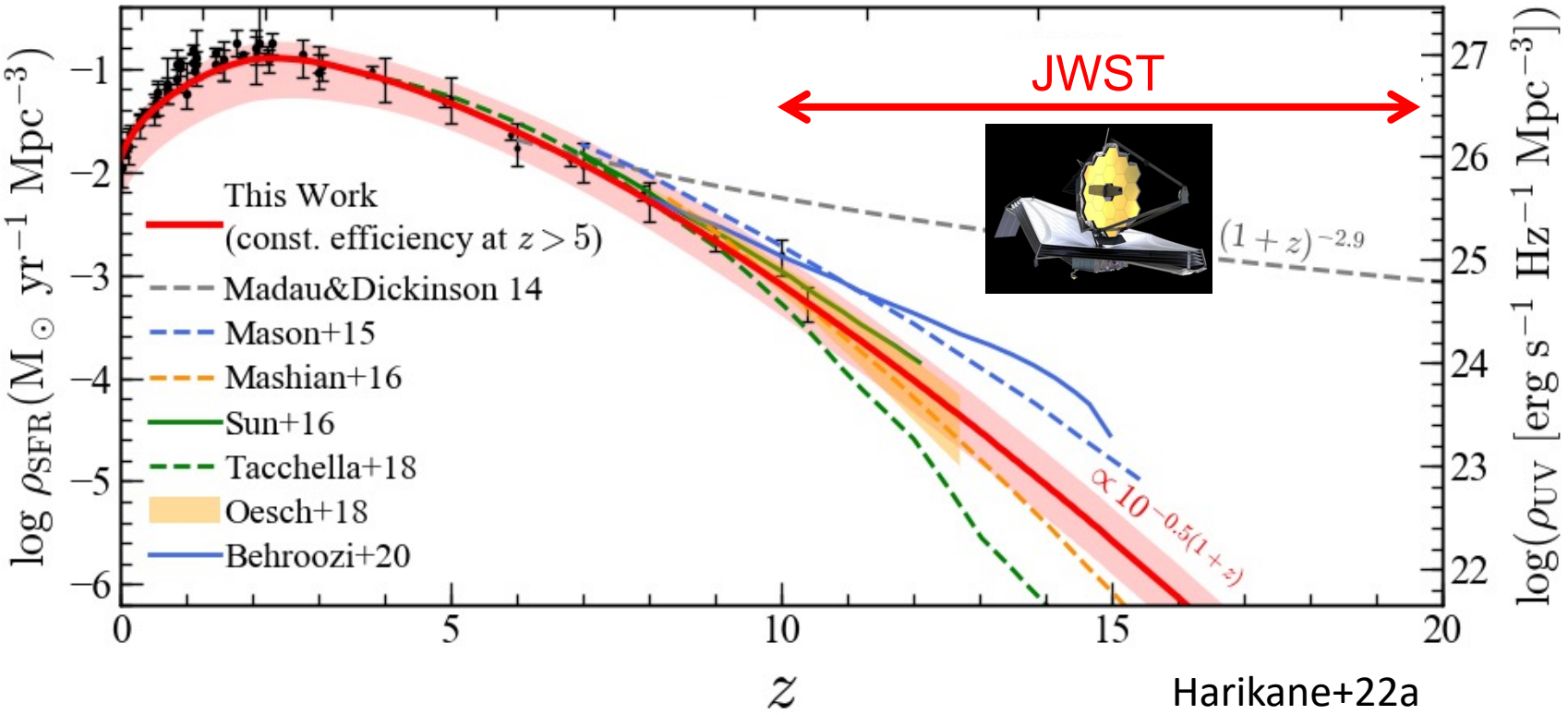


Tumlinson17

See also, Harikane+18, Tacchella+18, Oesch+18, Mason+22…

Prediction at z>10

- Steep decrease at z>10 w/ $10^{-0.5(1+z)}$
  - Consistent with other galaxy formation models
  - Expectation: only a few z>10 galaxies in the first data



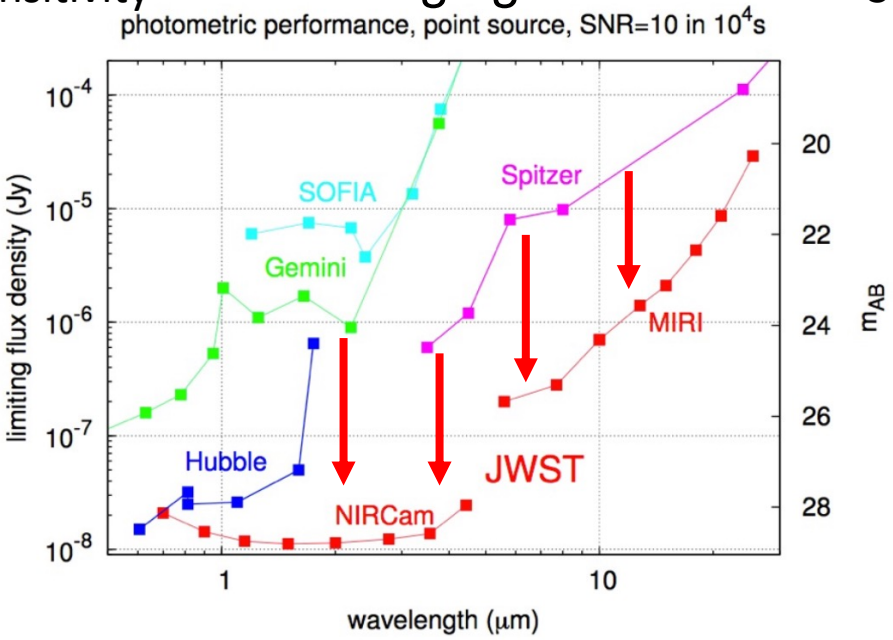
Harikane+22a

James Webb Space Telescope (JWST)

- Sensitivity >10x improved at infrared
  - Detect faint & redshifted high-z galaxy

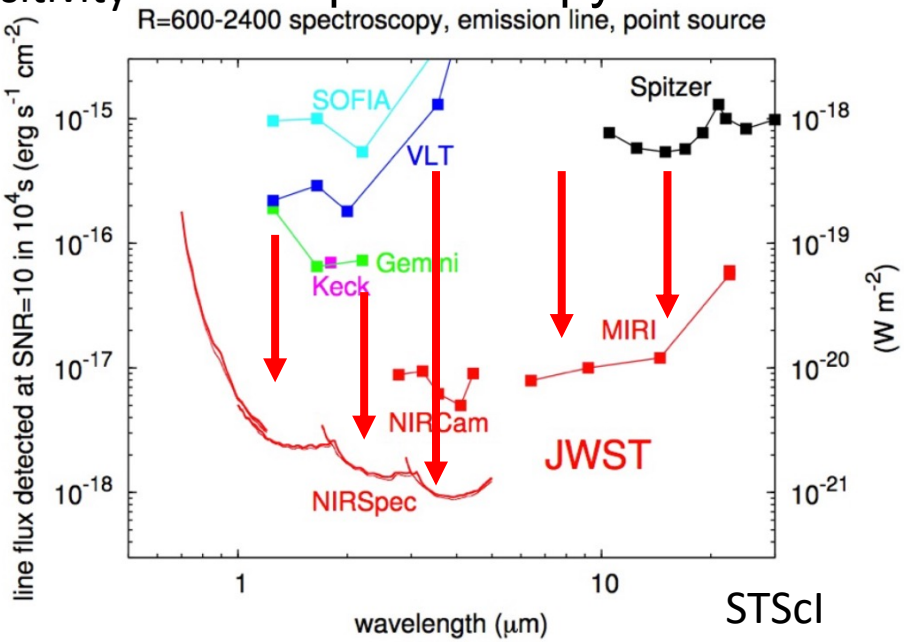
NASA

Sensitivity



Wavelength [μm]

Sensitivity



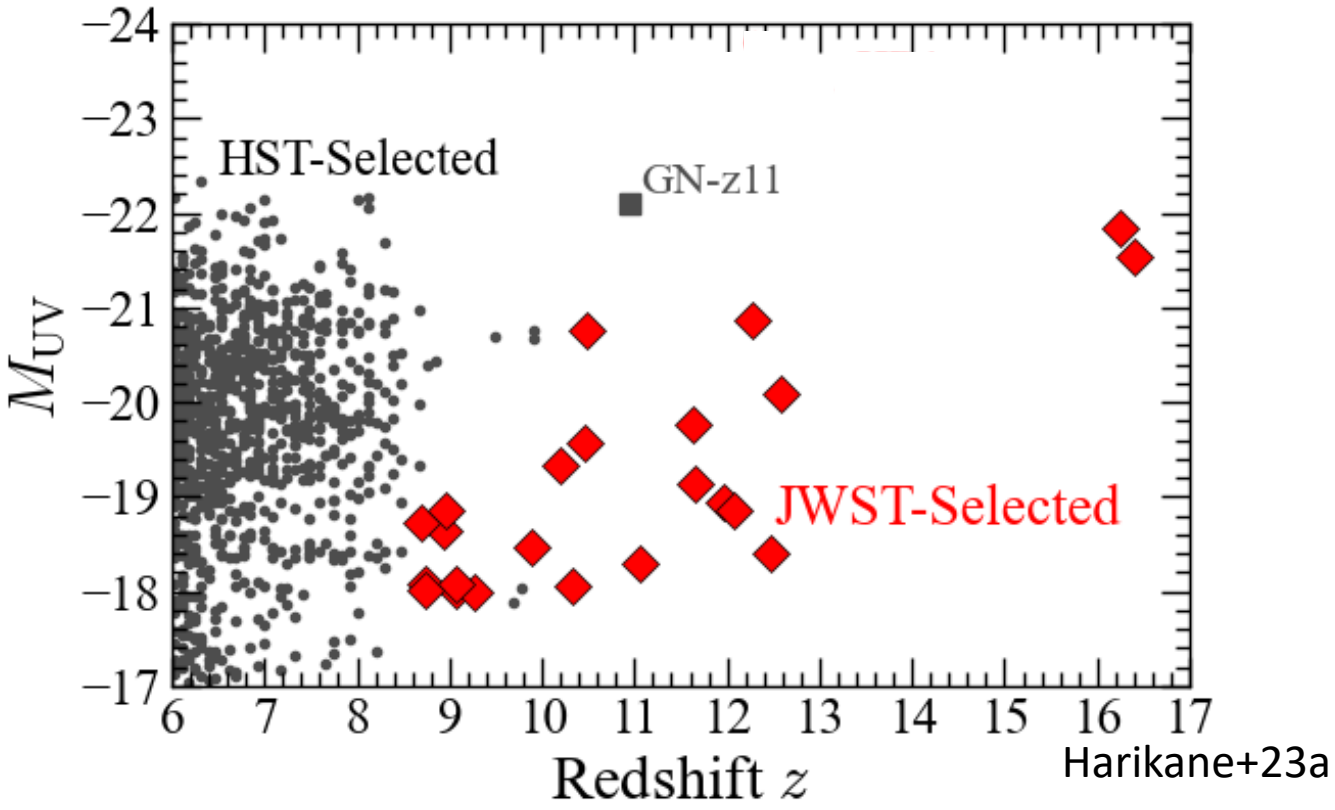
STScI

Wavelength [μm]

https://www.stsci.edu/jwst/about-jwst/history/historical-sensitivity-estimates

JWST Galaxy Sample at z~9-16

- 23 galaxy candidates at z~9-16 in 90 arcmin^2
  - Expectation before JWST: a few galaxies at z>10

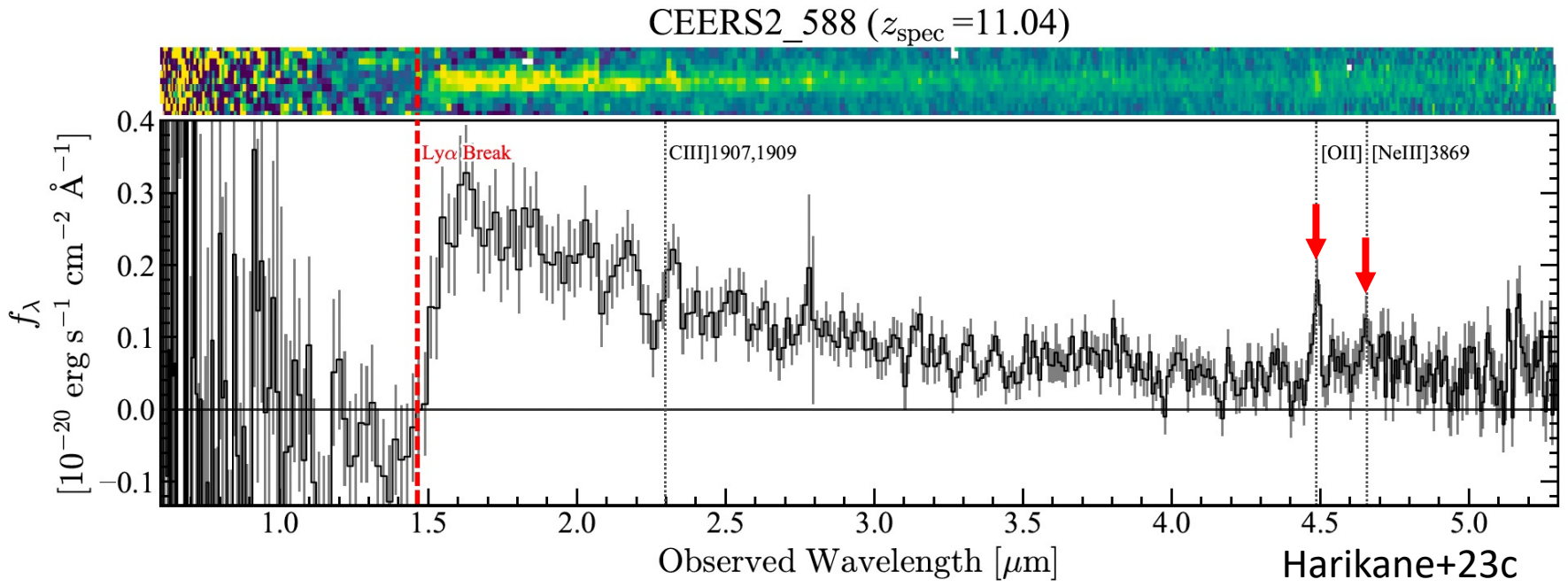


Harikane+23a

See also, Naidu+22, Castellano+22, Finkelstein+22, Donnan+23, Bouwens+23, …

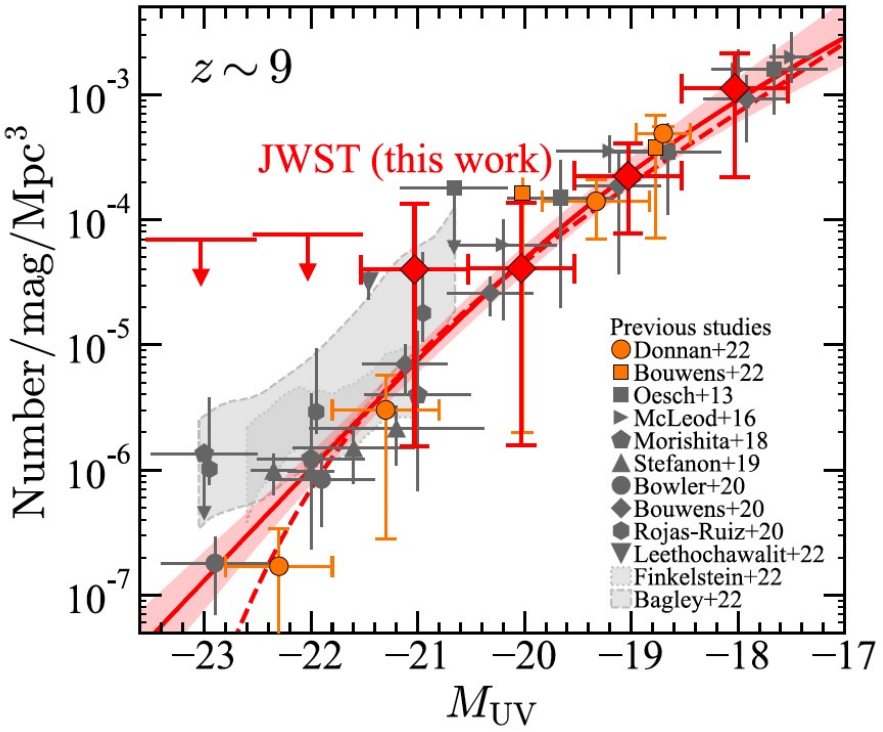
JWST Spec-z Sample

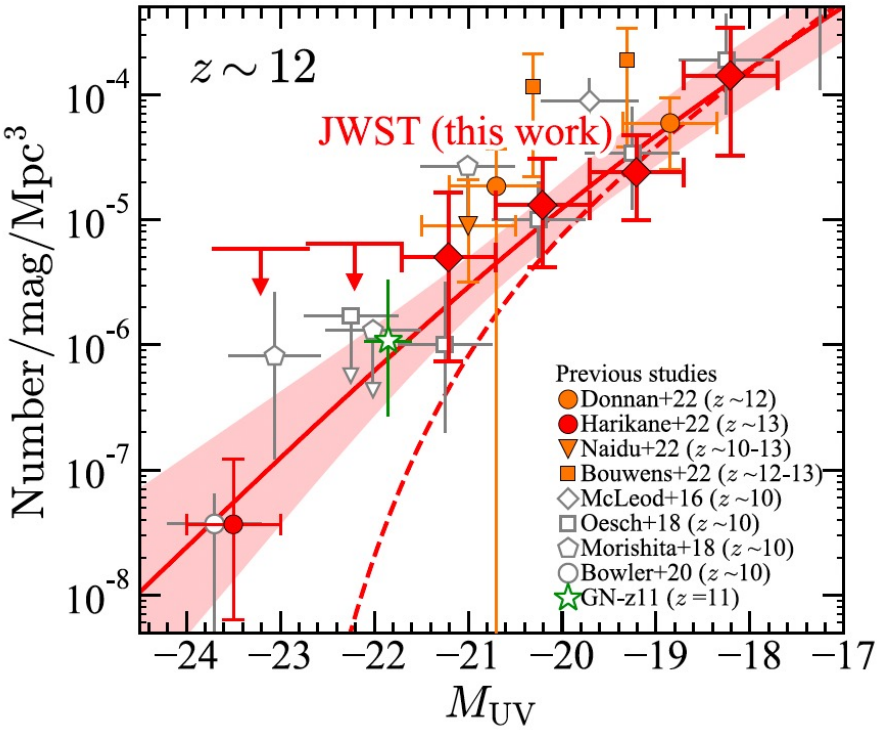
- 25 galaxies at z=8.61-13.20 confirmed w/ NIRSpec



UV Luminosity Function

- Consistent w/ other HST&JWST results at z~9,12





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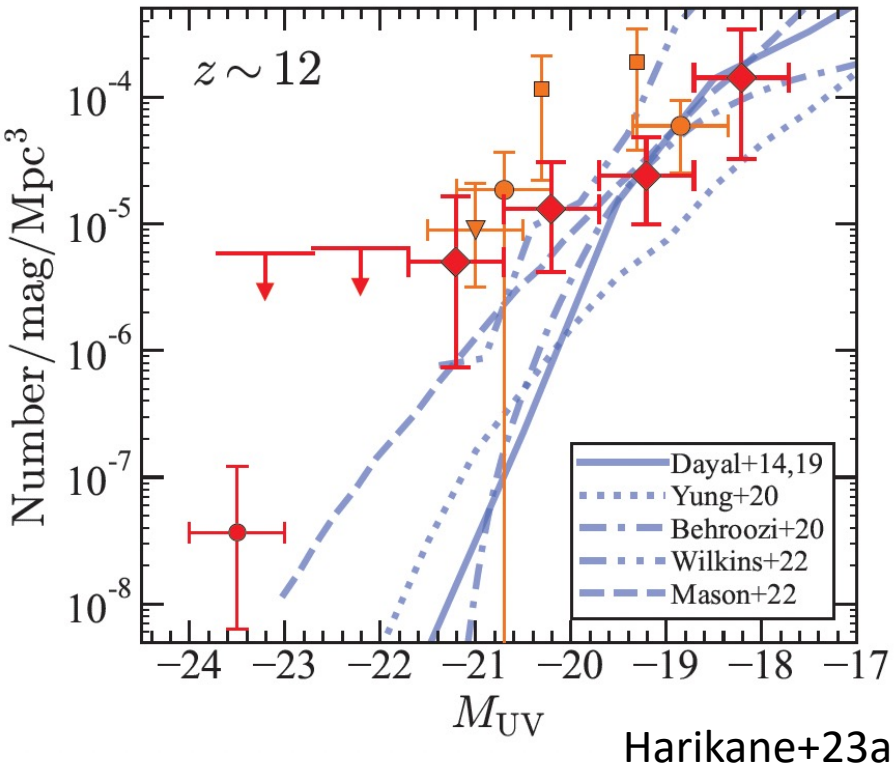
Comparison with Models

- Surprisingly larger number of galaxies than models



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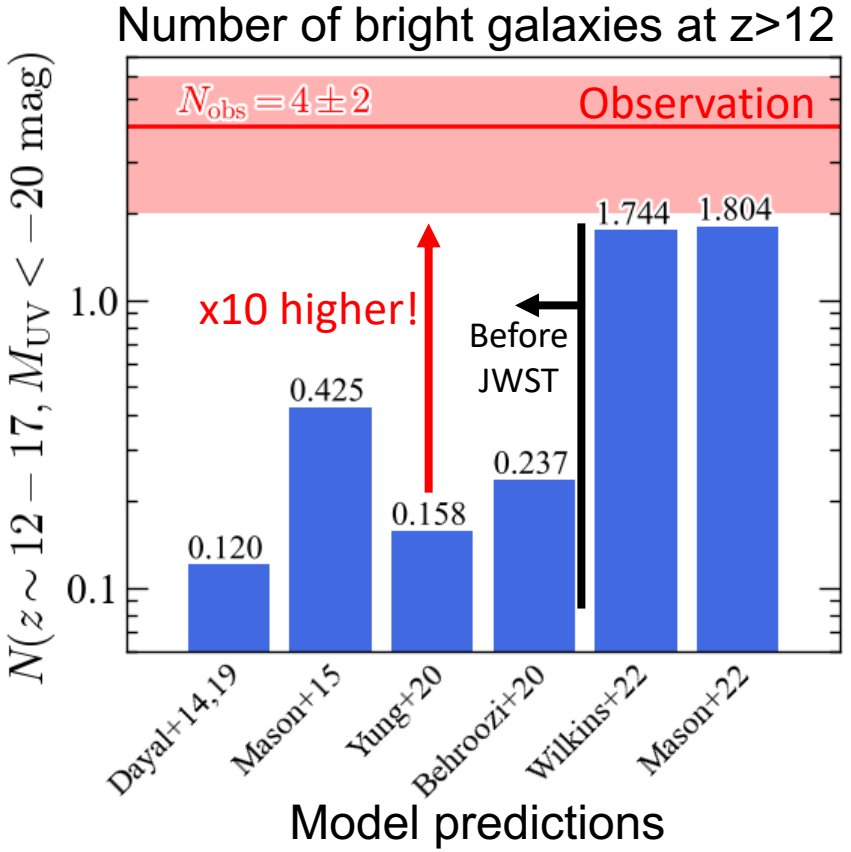

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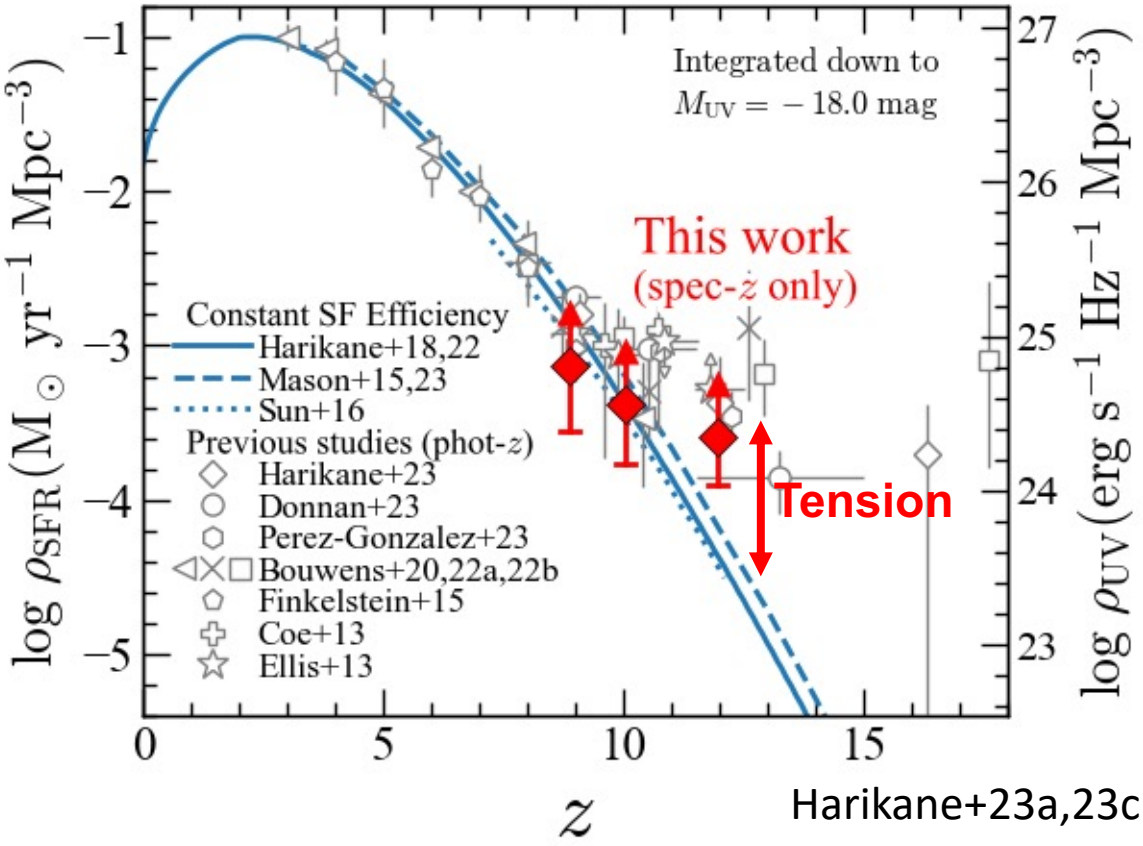
Spec-z Cosmic SFR Density at z>10

- UV→SFR: $SFR(M_\odot\ \mathrm{yr}^{-1}) = \mathcal{K}_{\mathrm{UV}} L_{\mathrm{UV}}(\mathrm{erg\ s^{-1}\ Hz^{-1}})$

$$\mathcal{K}_{\mathrm{UV}} = 1.15 \times 10^{-28}\ M_\odot\,\mathrm{yr}^{-1}/(\mathrm{erg\ s^{-1} Hz^{-1}})$$

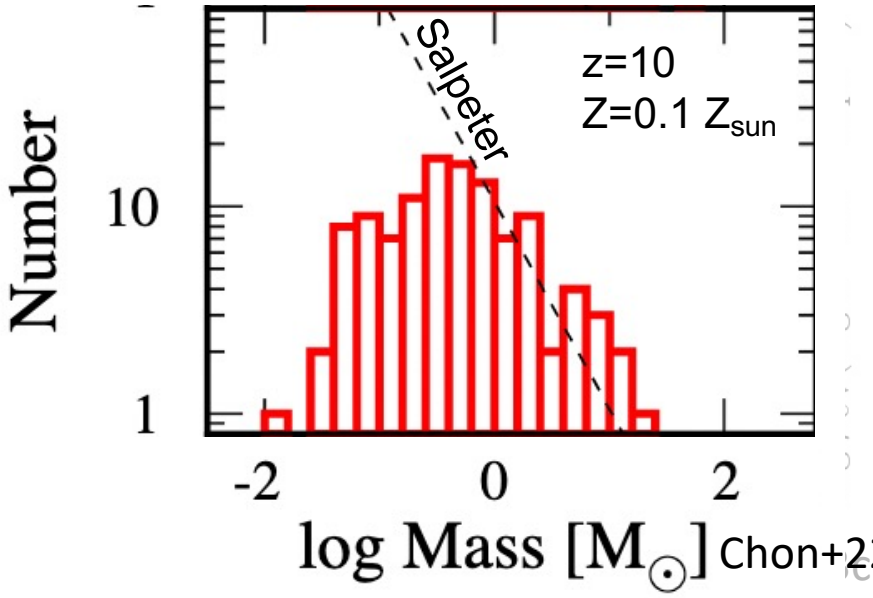
- Tension with constant efficiency models at z>10



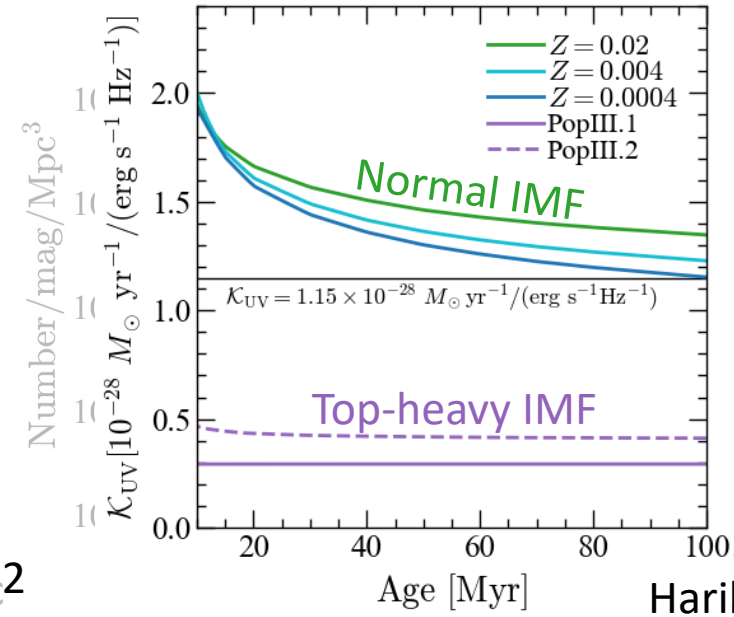
Harikane+23a,23c

Physical Interpretations

- High SFR density at z>10 can be explained by
  1. High efficiency (>5%) at pre-EoR (e.g., Fukushima+22)
  2. Many AGN populations? (discussed later)
  3. A top-heavy IMF w/ CMB and/or low-Z (Pop III?)



Chon+22

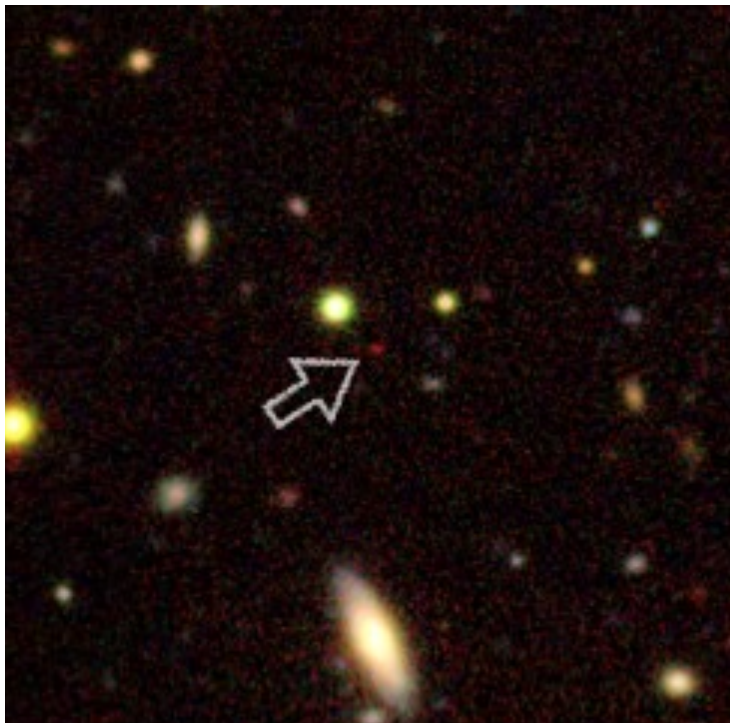


Harikane+23a

See also Inayoshi,YH+22, Lovell,Harrison,YH+22

How About AGNs?

- Before JWST: quasars at z~4-7 w/ M_{BH}~10^9 M_{sun}
- Quasar luminosity function at z~4-7
  - Flat slope at faint end → N<0.1 obj. expected in JWST



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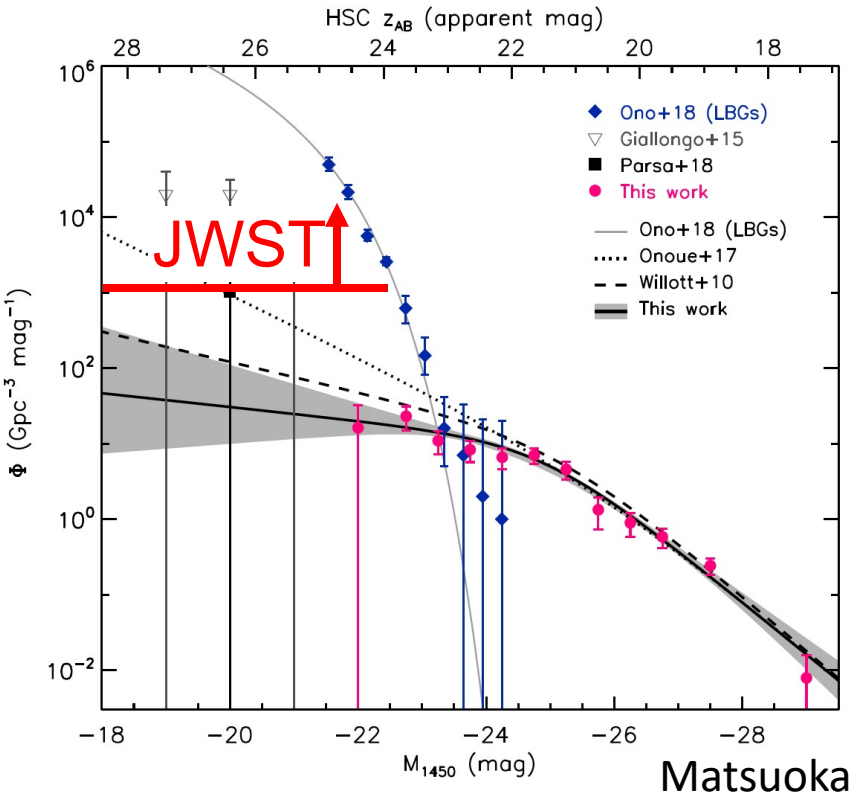
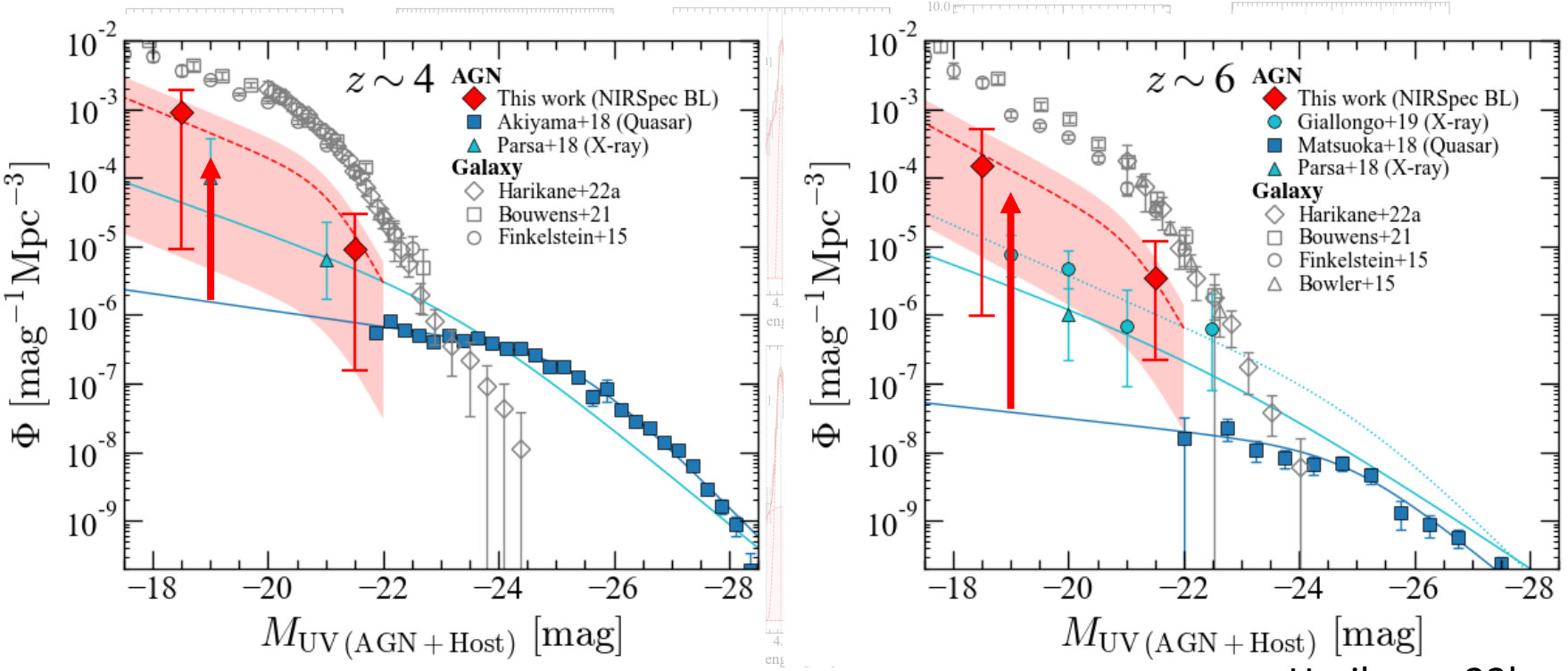


Matsuoka+18

Many AGNs at z>4 from JWST!

- 10 AGNs at z=4-7 (JWST/NIRSpec Spectra)
  - Broad Ha (FWHM~1000-6000 km/s), narrow [OIII] (<1000 km/s)
  - From 185 galaxies at z_{spec}>3.5, ~5% (~1-2% at z~0)

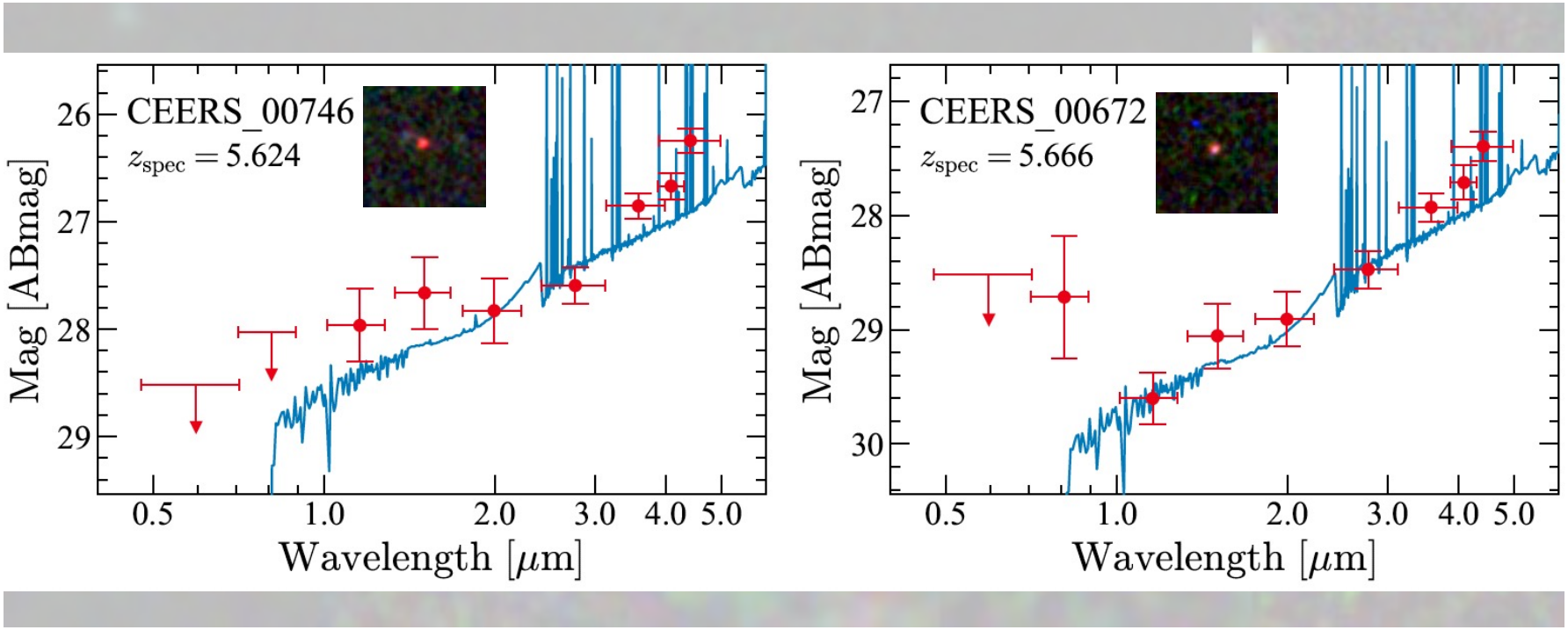


Harikane+23b

see also Kocevski+23, Ubler+23, Larson+23, Maiolino+23ab, Matthee+23, Labbe+23

Many AGNs at z>4 from JWST!

- 7/10 show extended morphologies
  - Dominated by host galaxies, Seyfert galaxies at z>4
  - Two compact & red AGNs (Av>3): “little red dots”

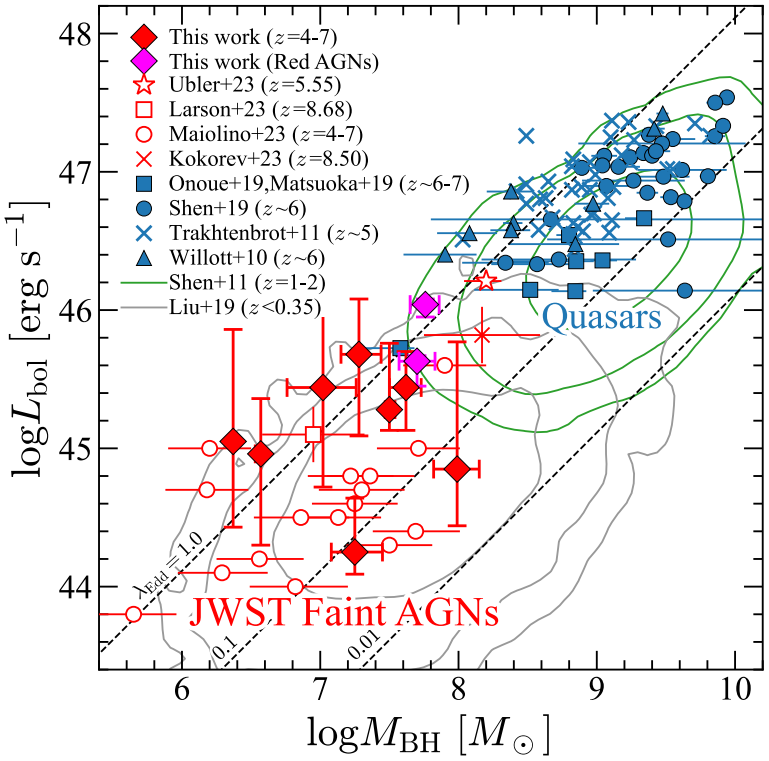


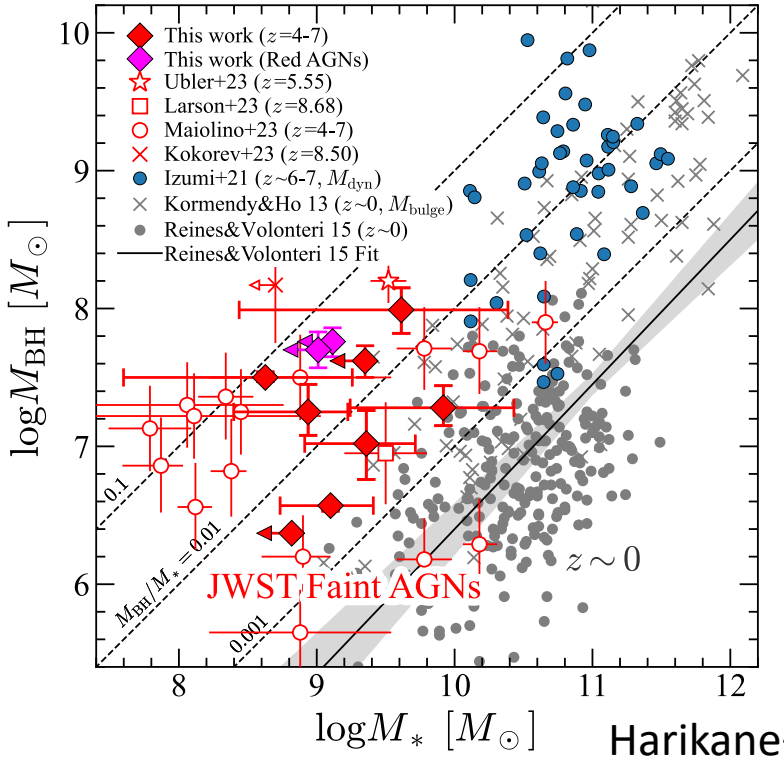
Harikane+23b

see also Kocevski+23, Ubler+23, Larson+23, Maiolino+23ab, Matthee+23, Labbe+23

Many AGNs at z>4 from JWST!

- M_{BH}~10^6-10^8 M_{sun} higher than z~0 M_*-M_{BH} relation
  - Significantly lower M_{BH} than quasars at z>4
  - Two red compact AGNs with relatively large M_{BH}



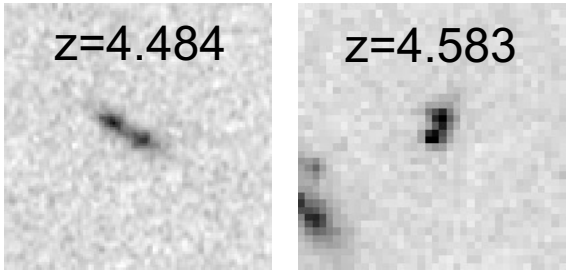


Harikane+23b

see also Kocevski+23, Ubler+23, Larson+23, Maiolino+23ab, Matthee+23, Labbe+23

Dual AGN Candidates

- Multiple compact components in some AGNs at z>4
  - Dual AGN candidates?
  - Separation of 0.2” → 1 kpc



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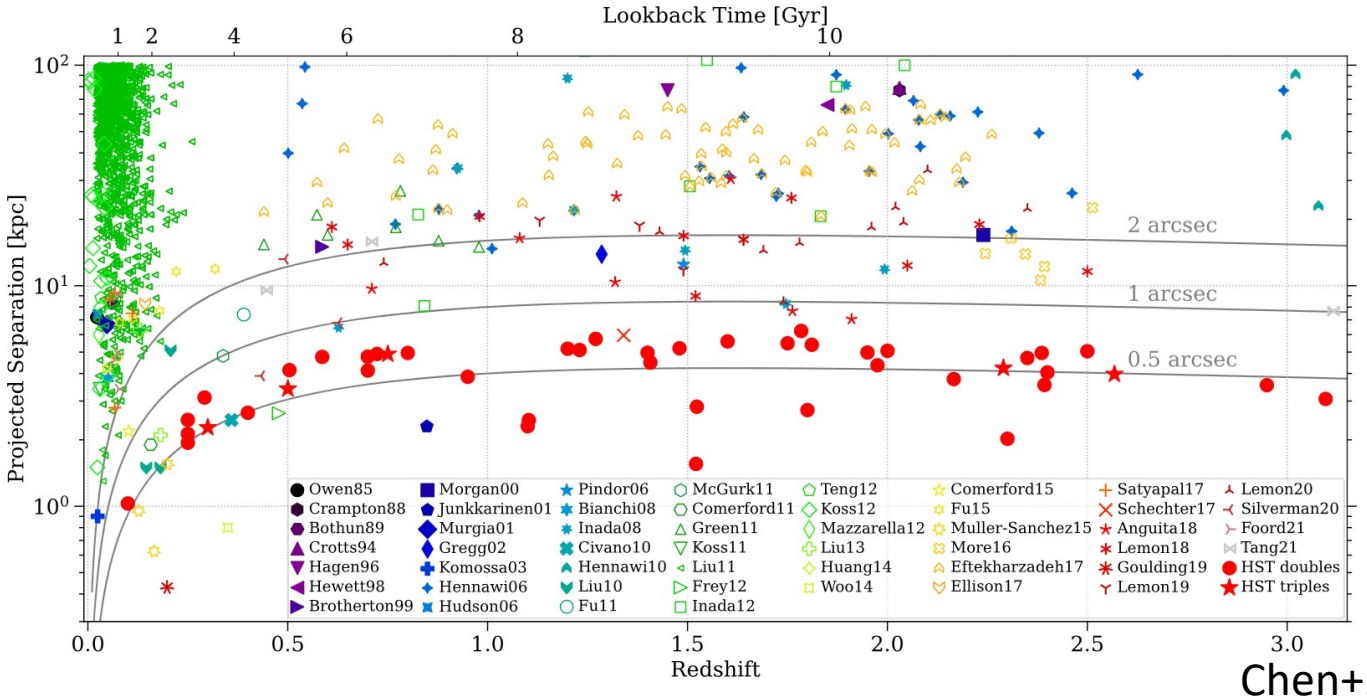
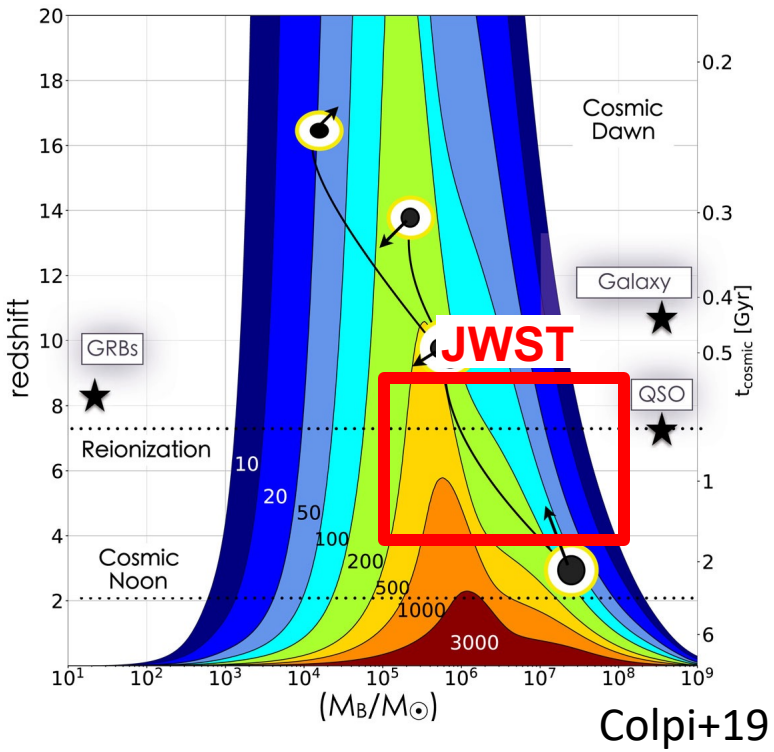


Chen+22

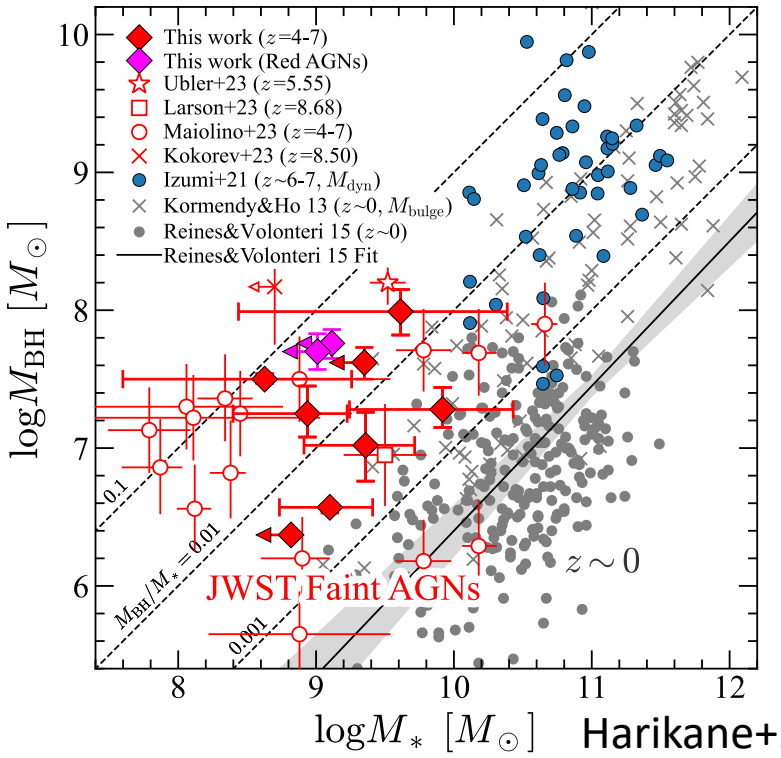
z~4.5
~1 kpc

Gravitational Wave from BH-BH Merger?

- M_{BH}~10^6 M_{sun} at z>4: parameter range of LISA
- Sky localization accuracy: ~0.01-1 deg^2 (Mangiagli+22)
  - Density of z~4 galaxies: 4000/deg^2 (<27 mag, dz=0.1)



Colpi+19

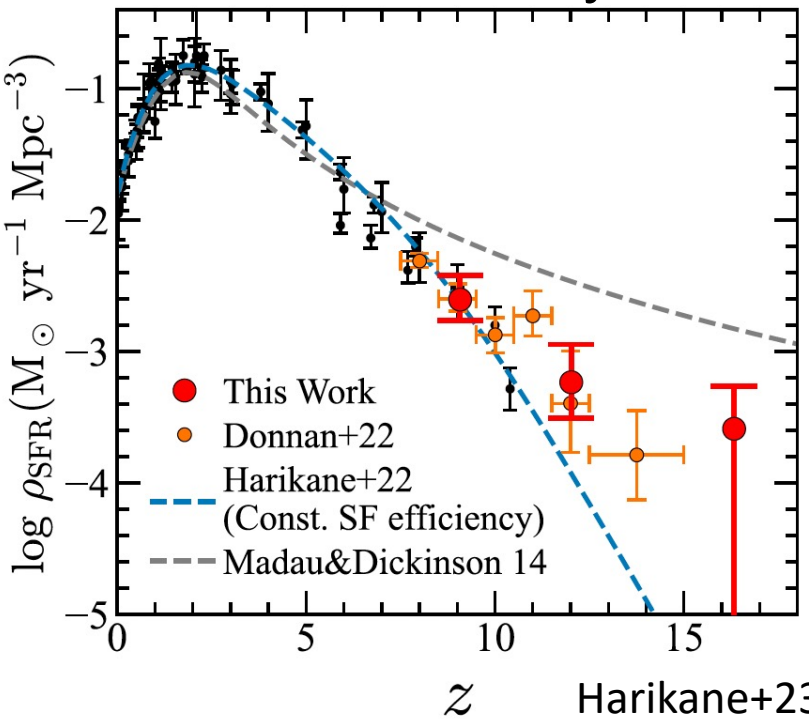


Harikane+23b

Future Prospect: High-z GRB

- HiZ-GUNDAM: >10 GRBs/yr at z=9-14 (津村さんtalk)
- GRB: direct probe to high-z **star** formation/evolution
  - z>10 GRB rate may be higher than previous estimates

SFR density



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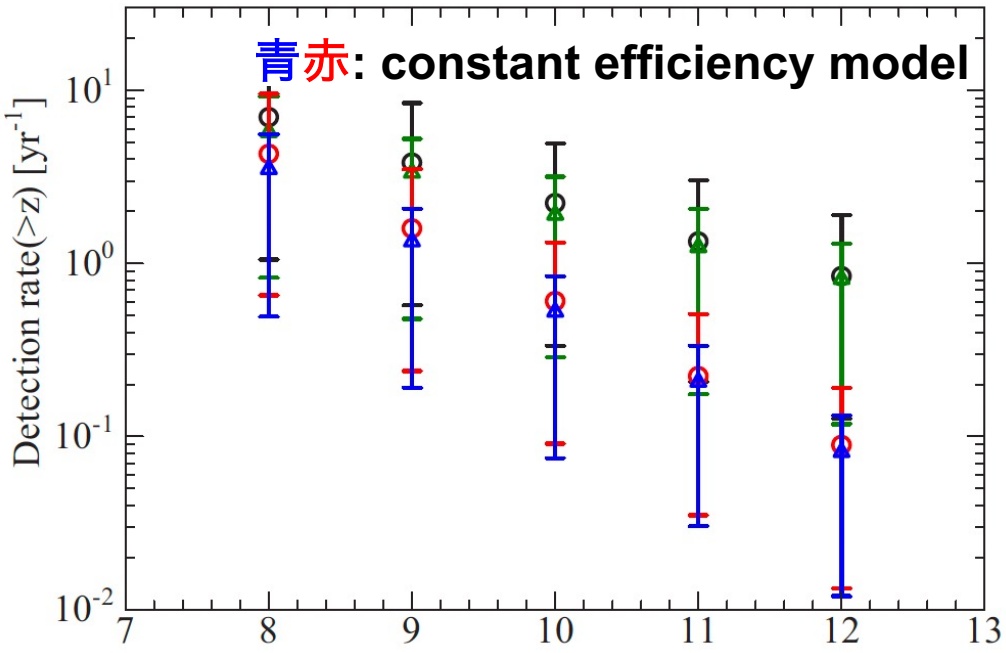
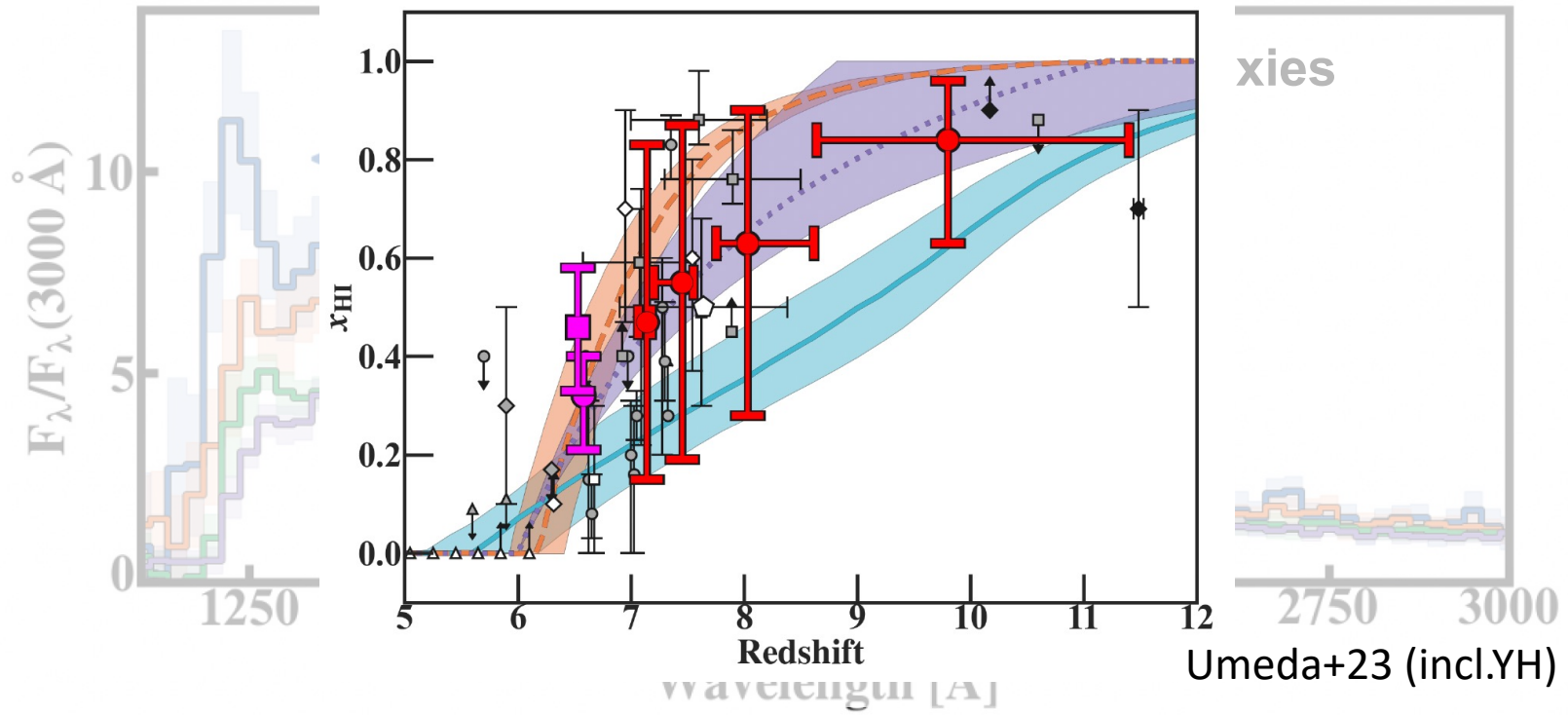
GRB Rate



Kinugawa, YH, Asano 19

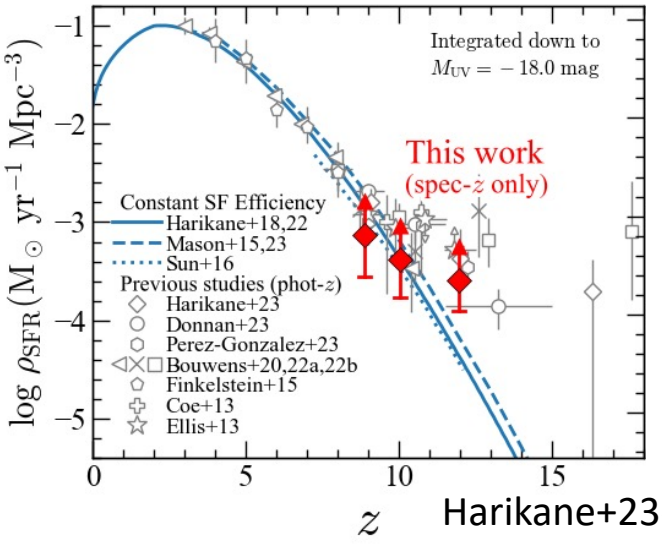
Constraints on Cosmic Reionization

- Lya damping wing: powerful tool to measure the neutral hydrogen fraction, xHI
  - Galaxy: complicated w/ ISM emission/absorption
  - GRB: bright & simple spectrum (power law)

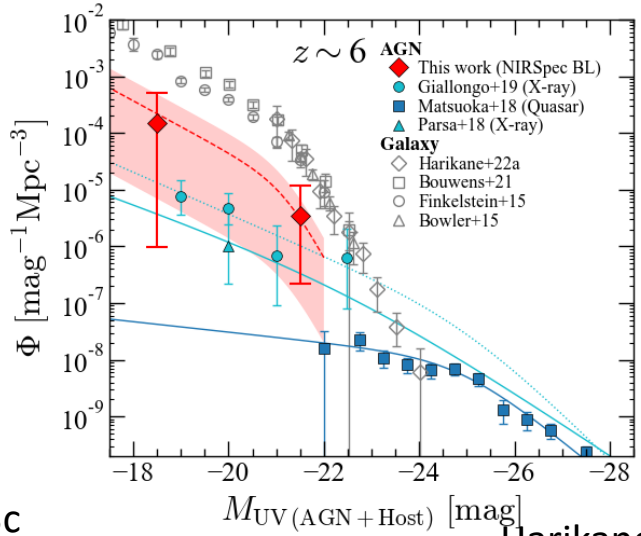


Summary

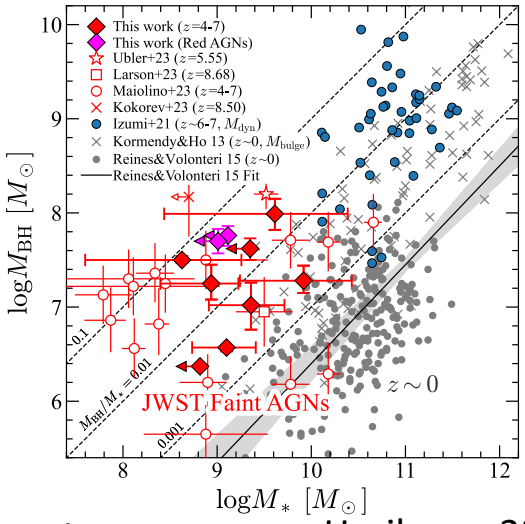
- JWST studies on high-z galaxies
  - Large number of z>10 galaxies, more than theoretical model predictions, from photo-z and spec-z
  - Excess in SFR densities at z>10, high SF efficiency, AGN, top-heavy IMF at high-z?
  - Many AGNs at z=4-7 with M_{BH}~10^6-10^8 M_{sun}
  - Future prospects on HiZ-GUNDAM, LISA



Harikane+23c



Harikane+23b



Harikane+23b