第2回 TMTウェビナー on October 2, 2025

TMTで挑む、
初代星・初代銀河天文学の展望

中島 王彦　Kimihiko Nakajima

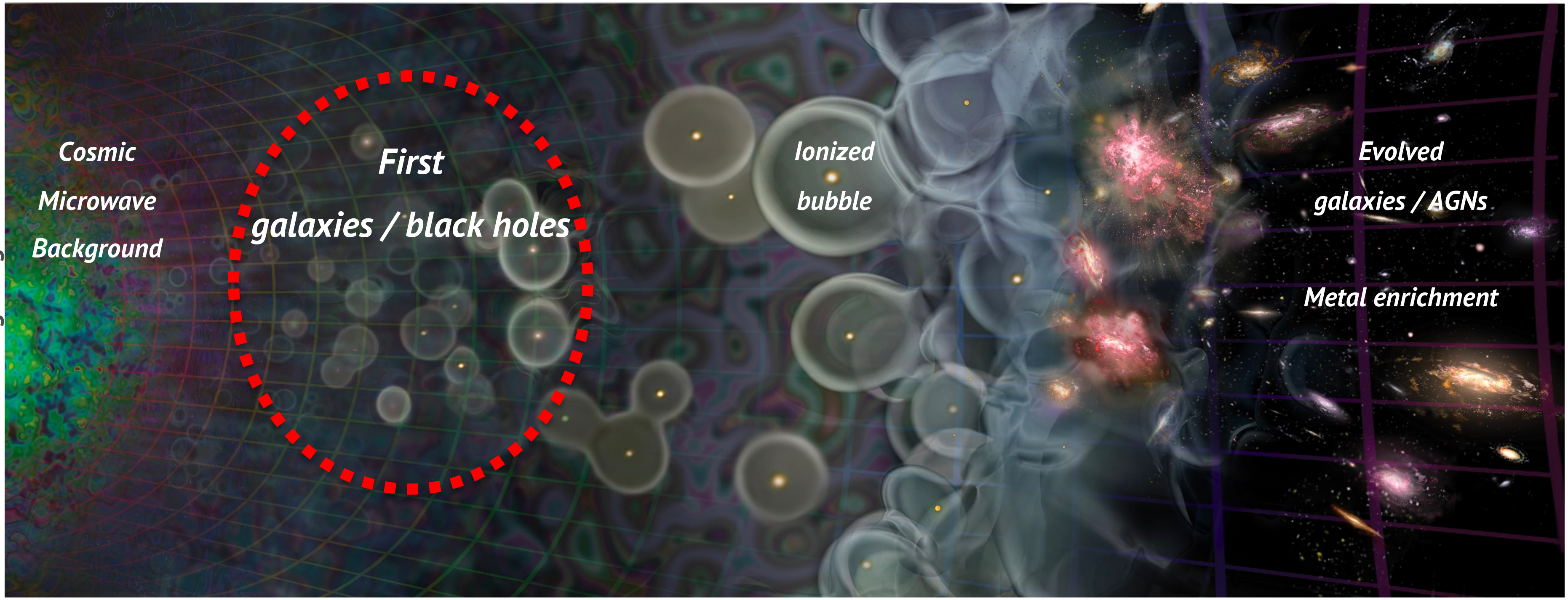
金沢大学　Kanazawa Univ.

ISDT Member of TMT w/ focus on Early Universe

Key Science of TMT: First Sources of light in Early Universe

Cosmic Dark Ages | Cosmic Dawn | Epoch of Reionization | Peak of Cosmic Star-Formation

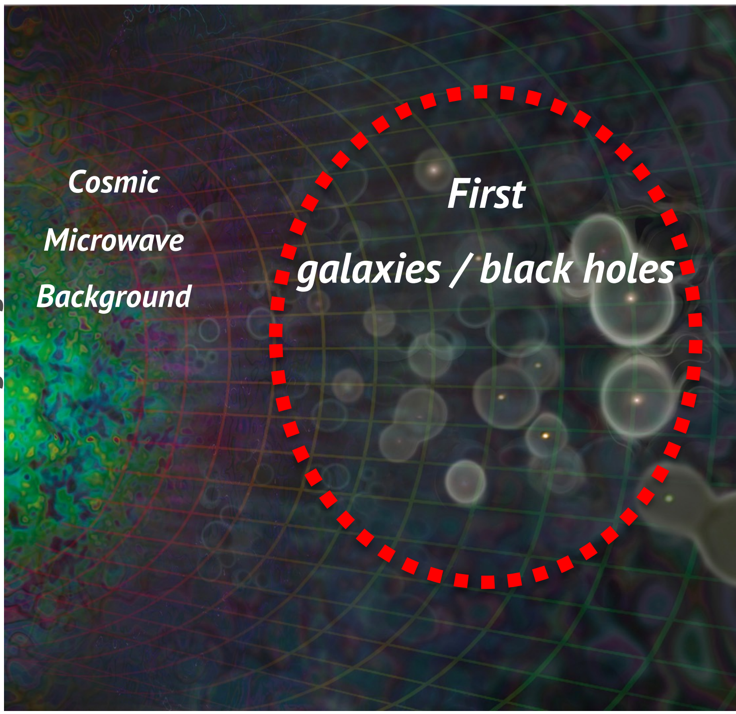
Big Bang



380,000 yr	~100-300 Myr	-- Age of Universe --	1 Gyr	3 Gyr
z=1,100	z~15-25	-- Redshift --	z=6	z=2

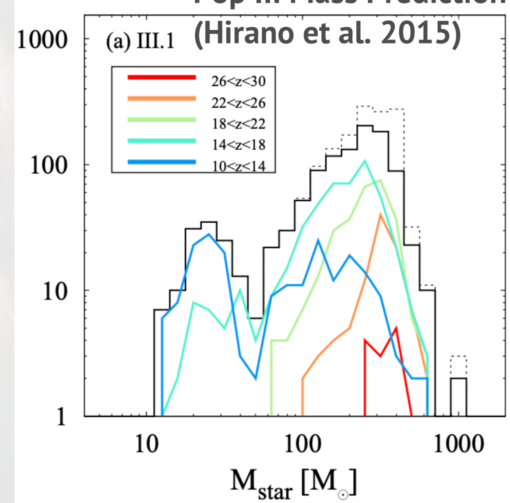
Key Science of TMT: First Sources of light in Early Universe

Cosmic Dark Ages | Cosmic Dawn | Epoch of Reionization | Peak of Cosmic Star-Formation



- Pop III IMF ?
- Chemical enrichment by Pop III stars ?
- Pop III star vs. Black hole (DCBH) ?
- ...

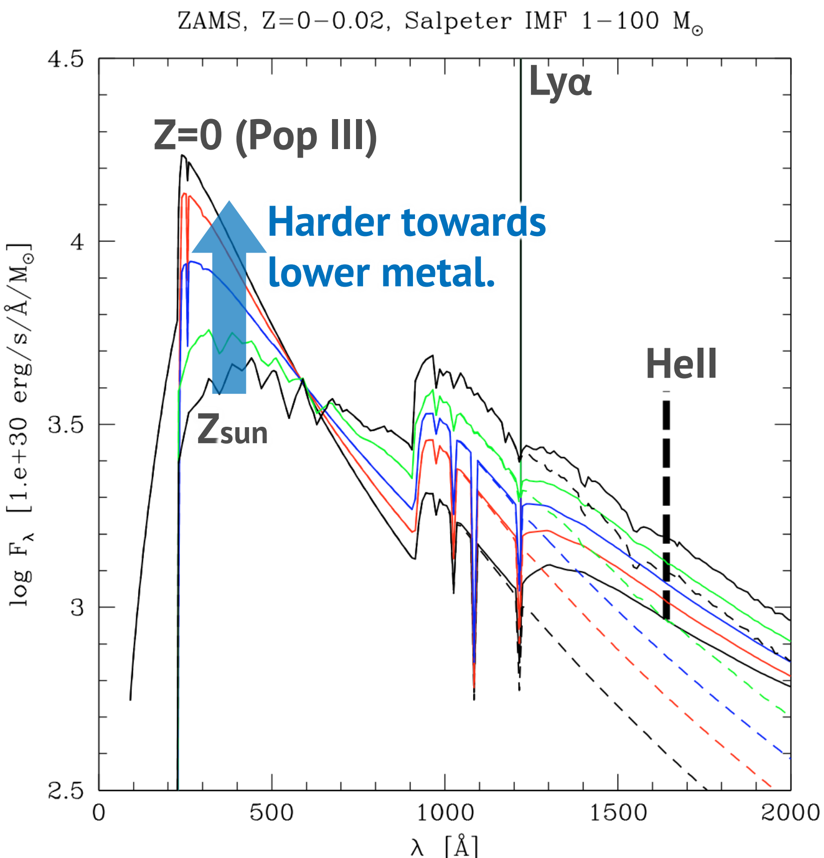
Pop III Mass Prediction (Hirano et al. 2015)



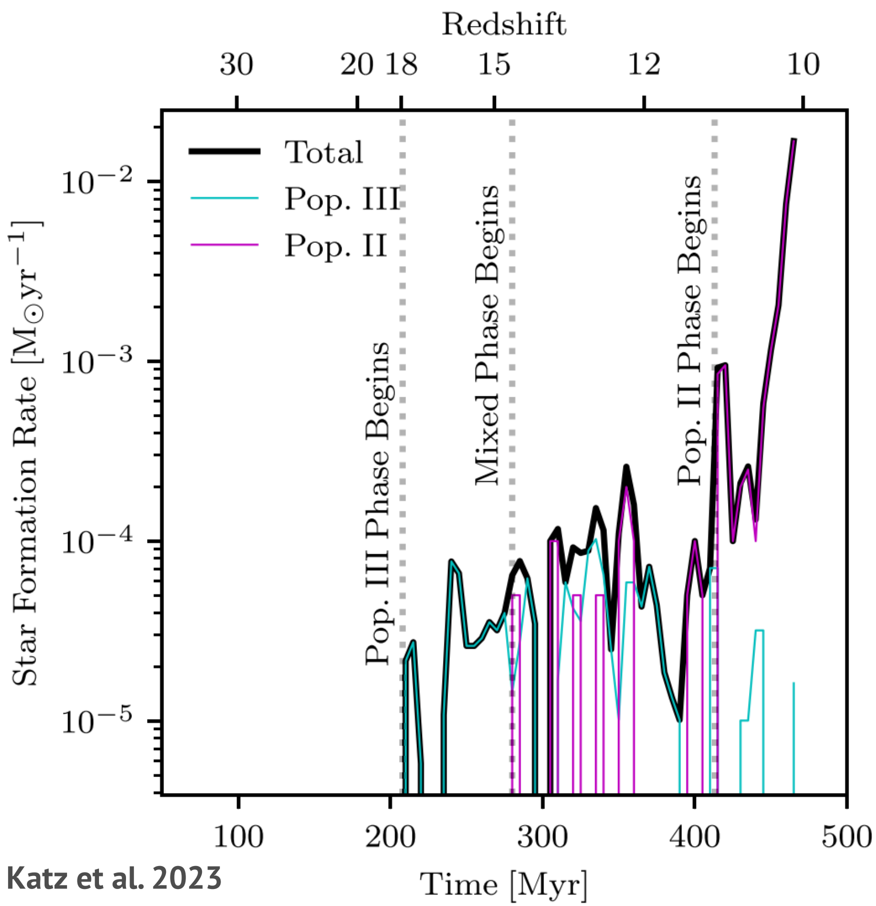
380,000 yr | ~100-300 Myr | -- Age of Universe -- | 1 Gyr | 3 Gyr

z=1,100 | z~15-25 | -- Redshift -- | z=6 | z=2

Predicting Observational Signatures of Population III Galaxies: Hard spectrum & Ext. low metallicity



Schaerer 2003



Katz et al. 2023

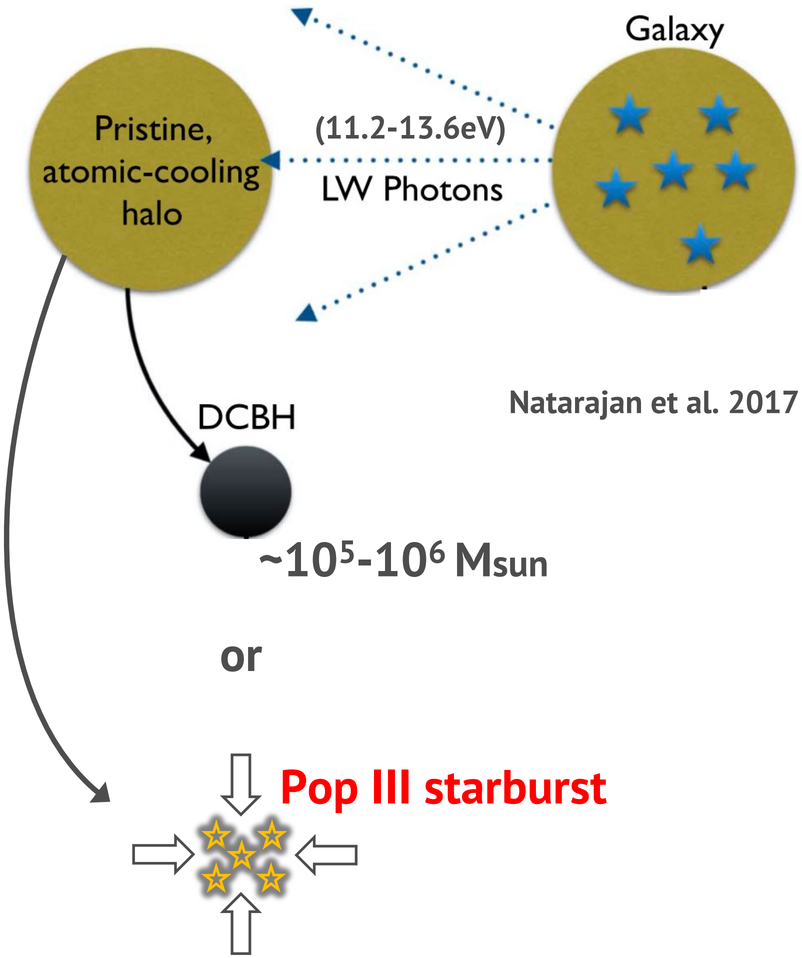
Quick metal enrichment (see: Wise et al. 2012)

+ One PISN to enrich Z~10^{-3} Zsun (10^6 Msun halo)

Pop III stars and ISM metals coexist

See also: Tumlinson+2000, 2001, Schaerer 2002, Raiter+2010, Inoue 2011, Zackrisson+2011, Nakajima & Maiolino 2022, Rusta+2025

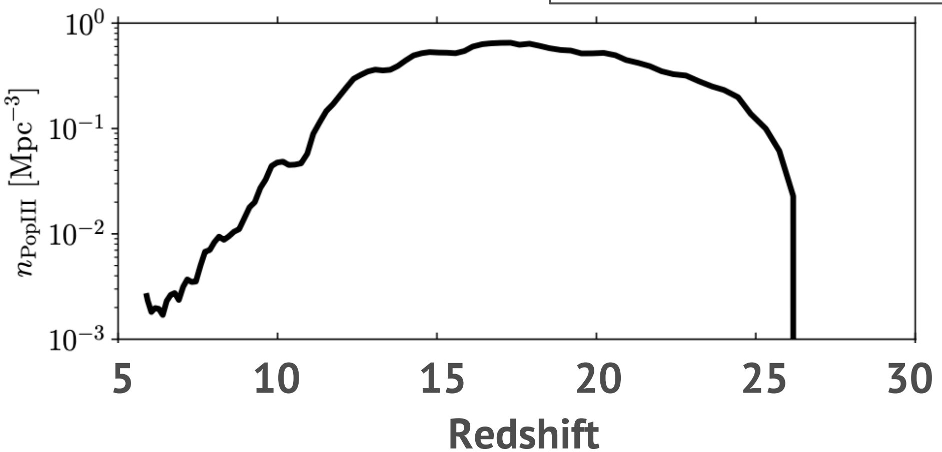
Predicting Observational Signatures of Population III Galaxies: Possibly in Vicinity of Luminous Obj at Moderate-Redshift



Natarajan et al. 2017

Theoretical predictions for Abundance of Pop III sources

+ LW feedbacks
+ External metal-enrichment
+ Reionization feedbacks



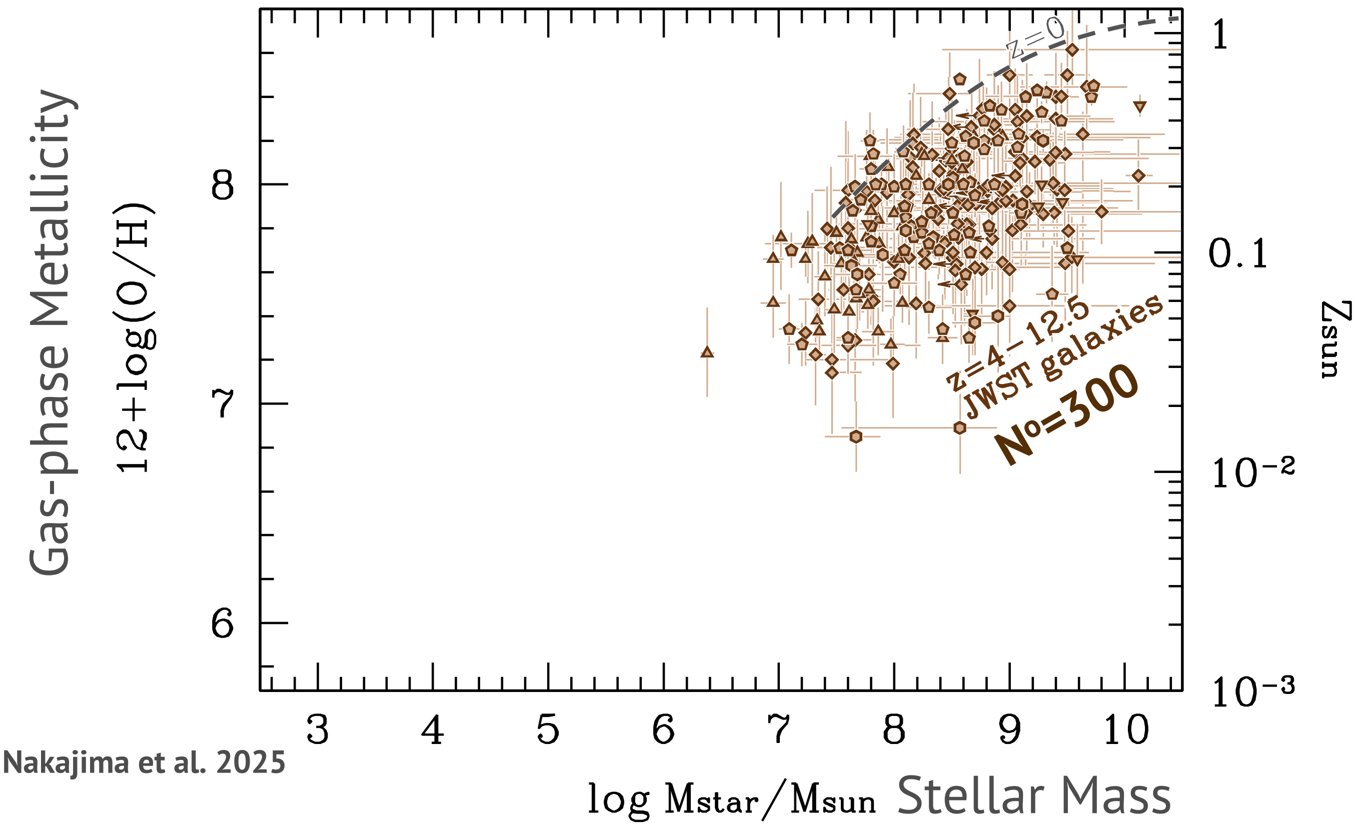
Visbal et al. 2025

We have chances to catch Pop III star formation in later epochs (in ~1st Gyr, down to z~6)

See also: e.g. Haiman et al. 1997, Machacek et al. 2001, O'Shea & Norman 2008, Stiavelli & Trenti 2010, Johnson & Aykutalp 2019

See also: e.g. Skinner & Wise 2020, Liu & Bromm 2020, Jaacks et al. 2019, Visbal et al. 2020, Venditti et al. 2023

Recent Progress w/ JWST
(0) Absence of likely Pop III cand in “typical” high-redshift sample



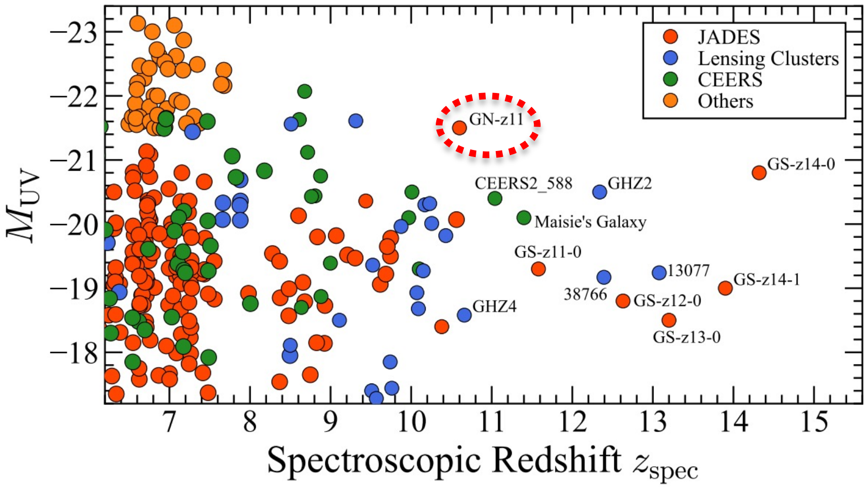
Adapted from Nakajima et al. 2025

No metal-deficient galaxies are found below ~1% Z_{sun} among continuum-selected galaxies at z=4-12.5 down to 10^7 M_{sun}

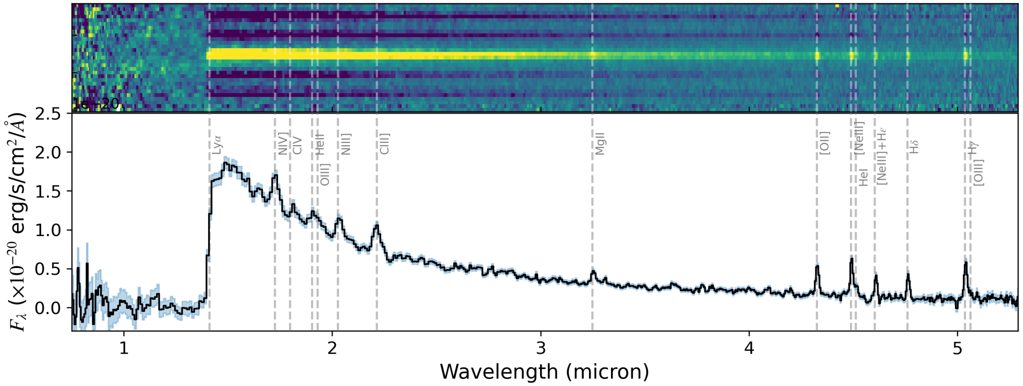
→ Dedicated searches are needed for Pop III

See also: Nakajima+2023, Curti+2024, Morishita+2024, Sarkar+2025

Recent Progress w/ JWST
(i) HeII clump in Vicinity of Luminous GN-z11



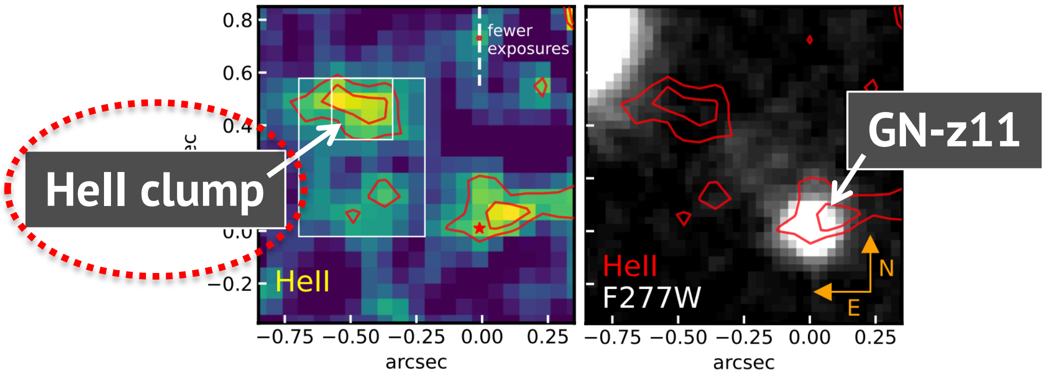
Harikane et al. 2025



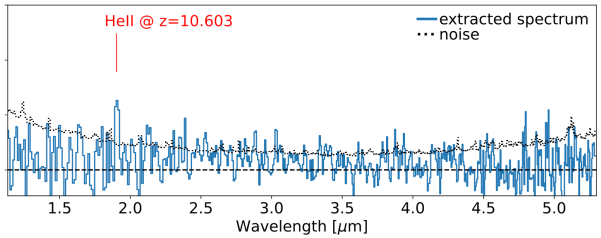
Bunker et al. 2023

Recent Progress w/ JWST
(i) HeII clump in Vicinity of Luminous GN-z11

NIRSpec-IFU uncovers Halo of GN-z11 at z=10.6

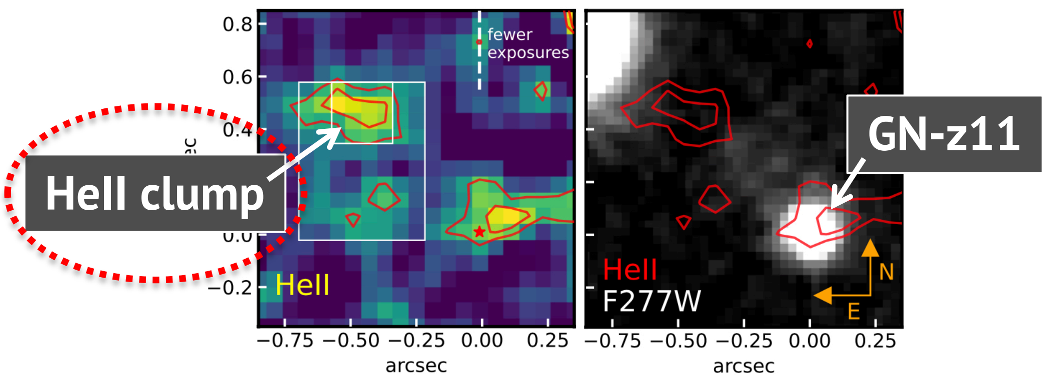


Maiolino, .., Nakajima et al. 2024

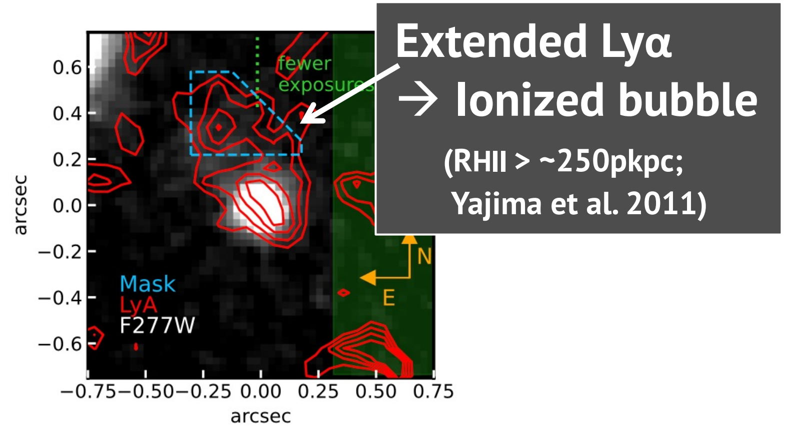


Recent Progress w/ JWST
(i) HeII clump in Vicinity of Luminous GN-z11

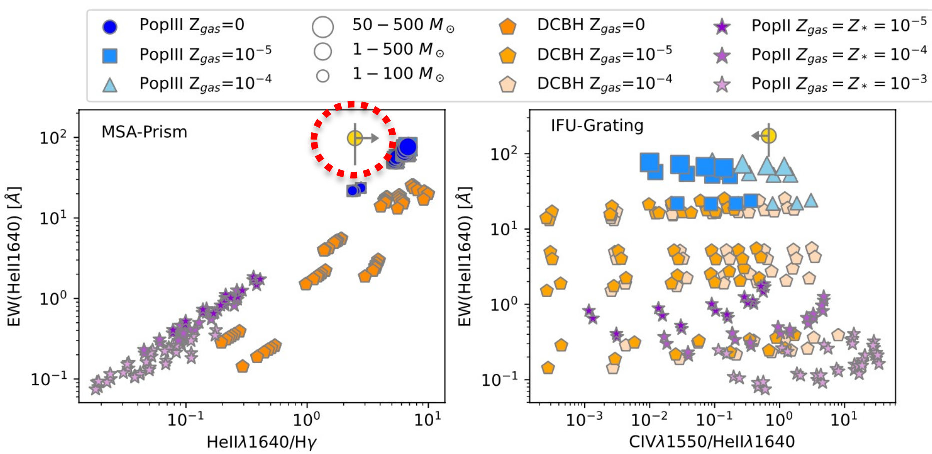
NIRSpec-IFU uncovers Halo of GN-z11 at z=10.6

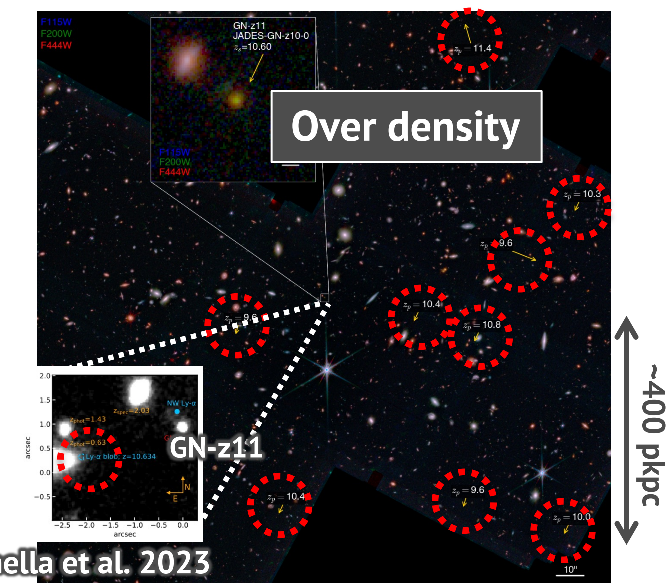


Maiolino, .., Nakajima et al. 2024



Scholtz et al. 2024



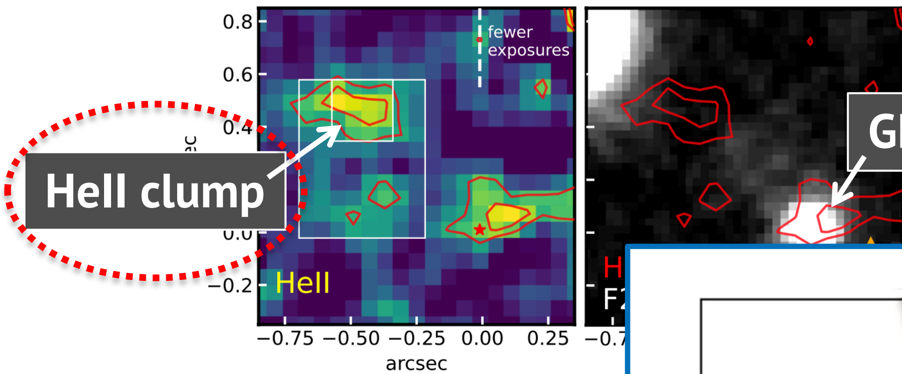


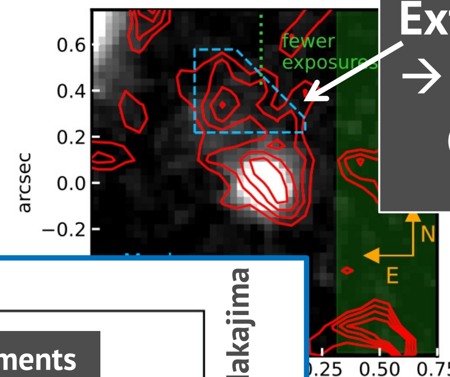
Tacchella et al. 2023

Intense HeII: consistent w/ hosting very massive PopIII stars (>100Msun)
(Nakajima&Maiolino 2022)

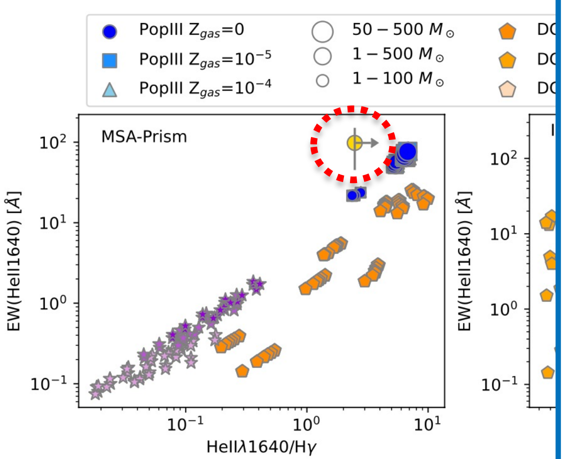
Recent Progress w/ JWST
(i) HeII clump in Vicinity of Luminous GN-z11

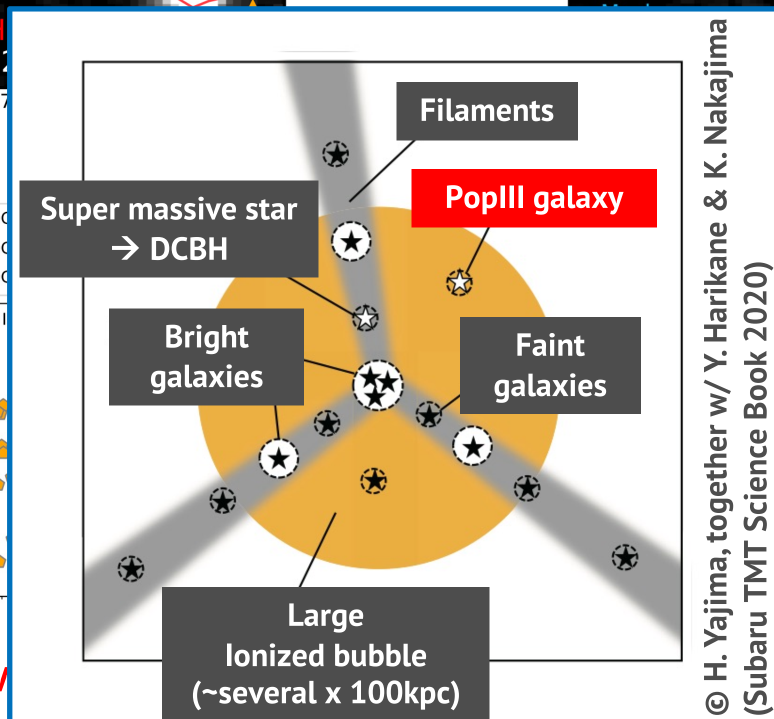
NIRSpec-IFU uncovers Halo of GN-z11 at z=10.6

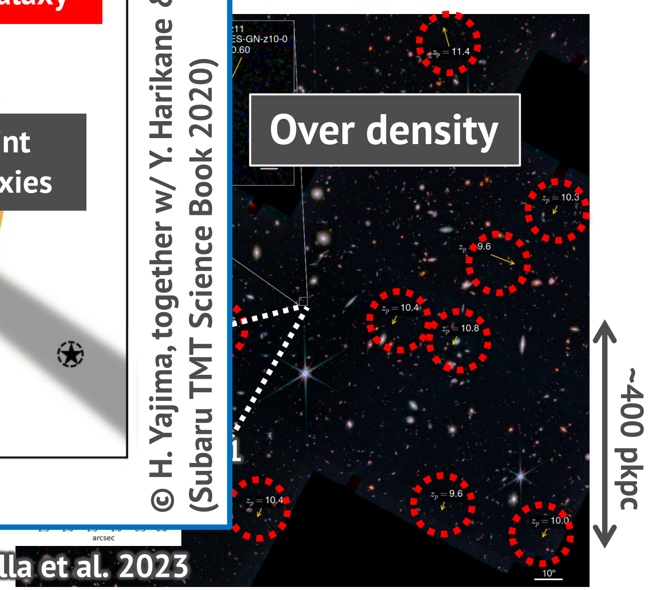




Maiolino, .., Nakajima et al. 2024





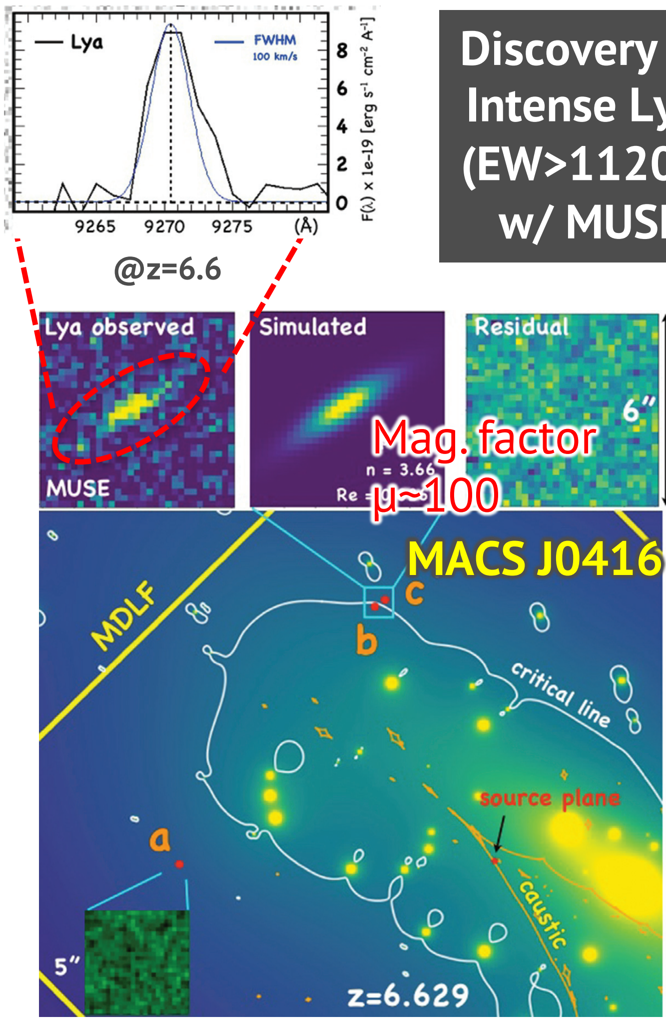


Tacchella et al. 2023

Intense HeII: consistent w/ very massive PopIII stars (>100Msun)
(Nakajima&Maiolino 2022)

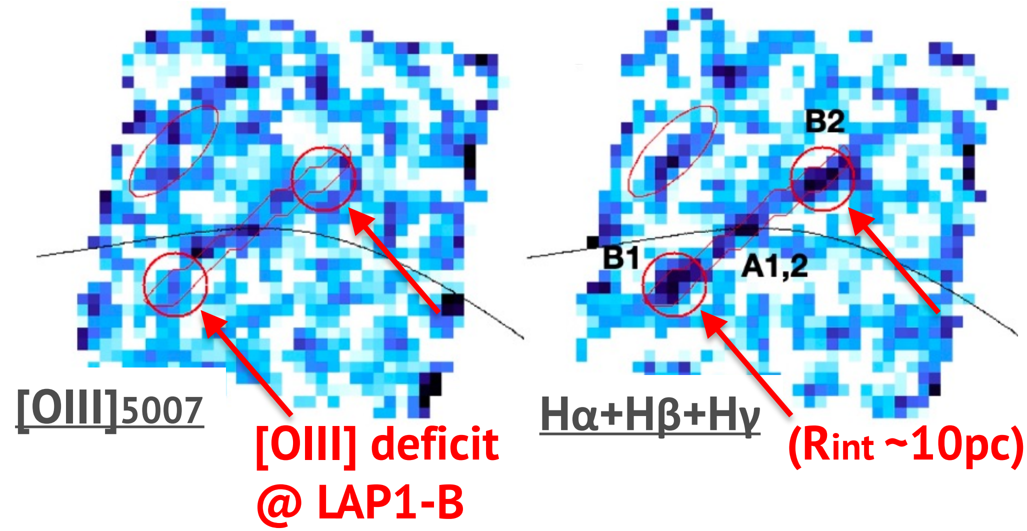
Recent Progress w/ JWST
(ii) LAP1-B: Hard Spec. & Ext. Low- M⋆, Low-Metallicity

Discovery of Intense Lyα (EW>1120A) w/ MUSE



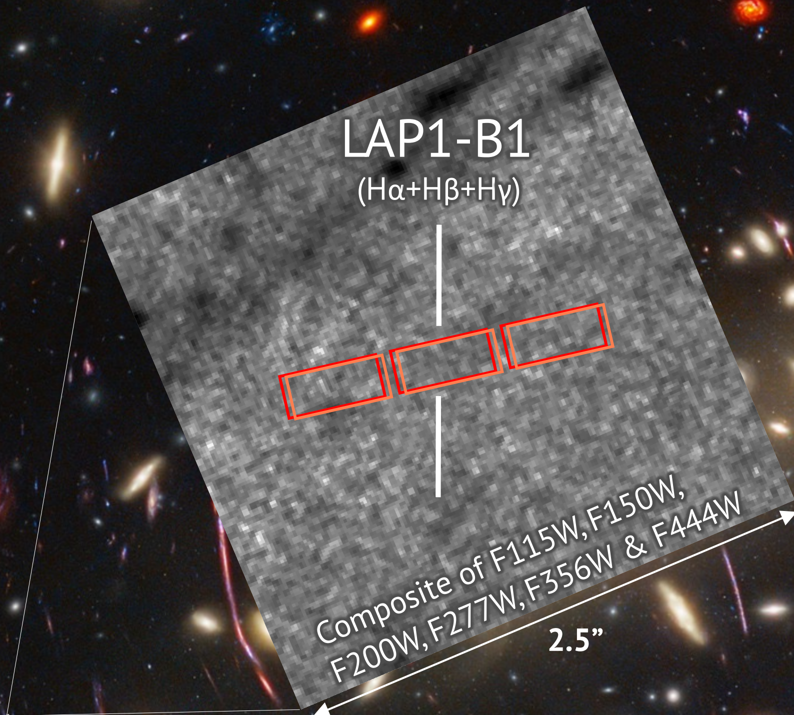
Vanzella et al. 2020

Weak [OIII] suggested by JWST/NIRSpec IFU



Vanzella et al. 2023

Deep JWST/NIRSpec MSA Medium-grating Observations targeting LAP1-B



JWST PID: 4750 (Cycle 3 GO) a.k.a.
DREAMS

> Deep Reconnaissance of
> Early Assemblies with
> Metal-poor Star formation

PI: K. Nakajima

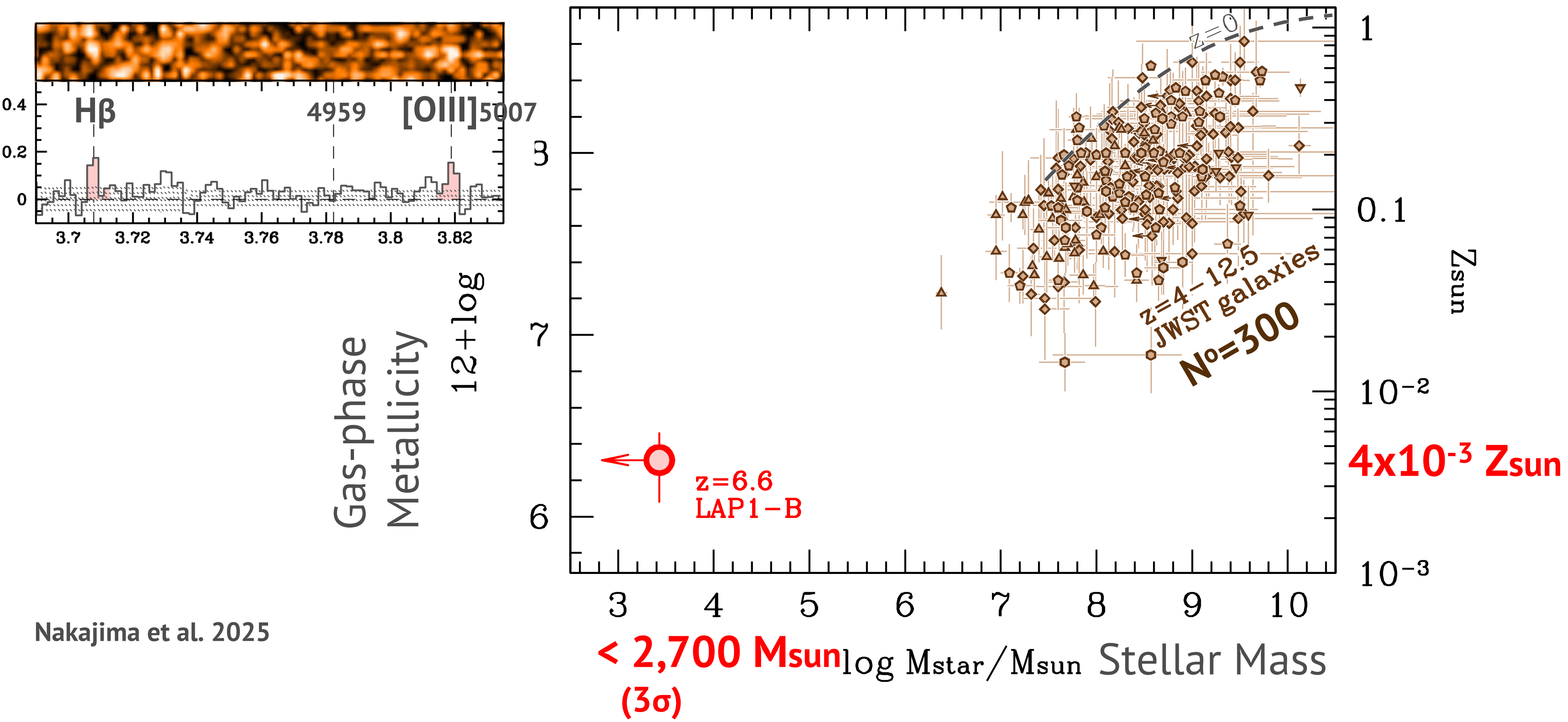
Allocated Time: 63 hours

ExpTime for LAP1-B:

> 16.4 hr (G140M; 0.8-1.8um)
> 16.4 hr (G395M; 2.9-5.2um)

Nakajima et al. 2025, arXiv:2506.11846

Recent Progress w/ JWST
(ii) LAP1-B: Hard Spec. & Ext. Low- M★, Low-Metallicity

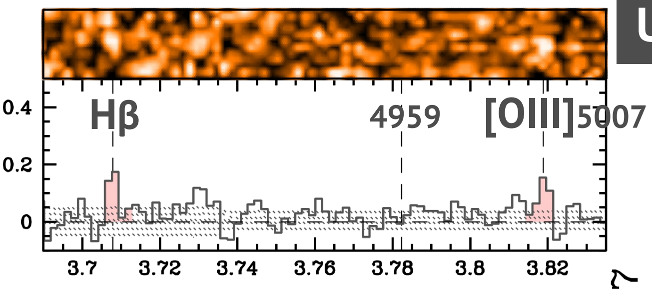


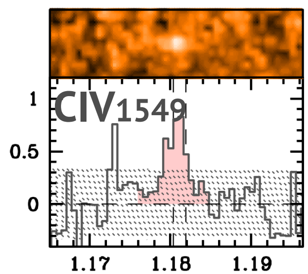
Nakajima et al. 2025

Extremely low metallicity is revealed by deep NIRSpec-MSA observations
→ Nascent, chemically-primitive galaxy
What kinds of stars are currently shining?

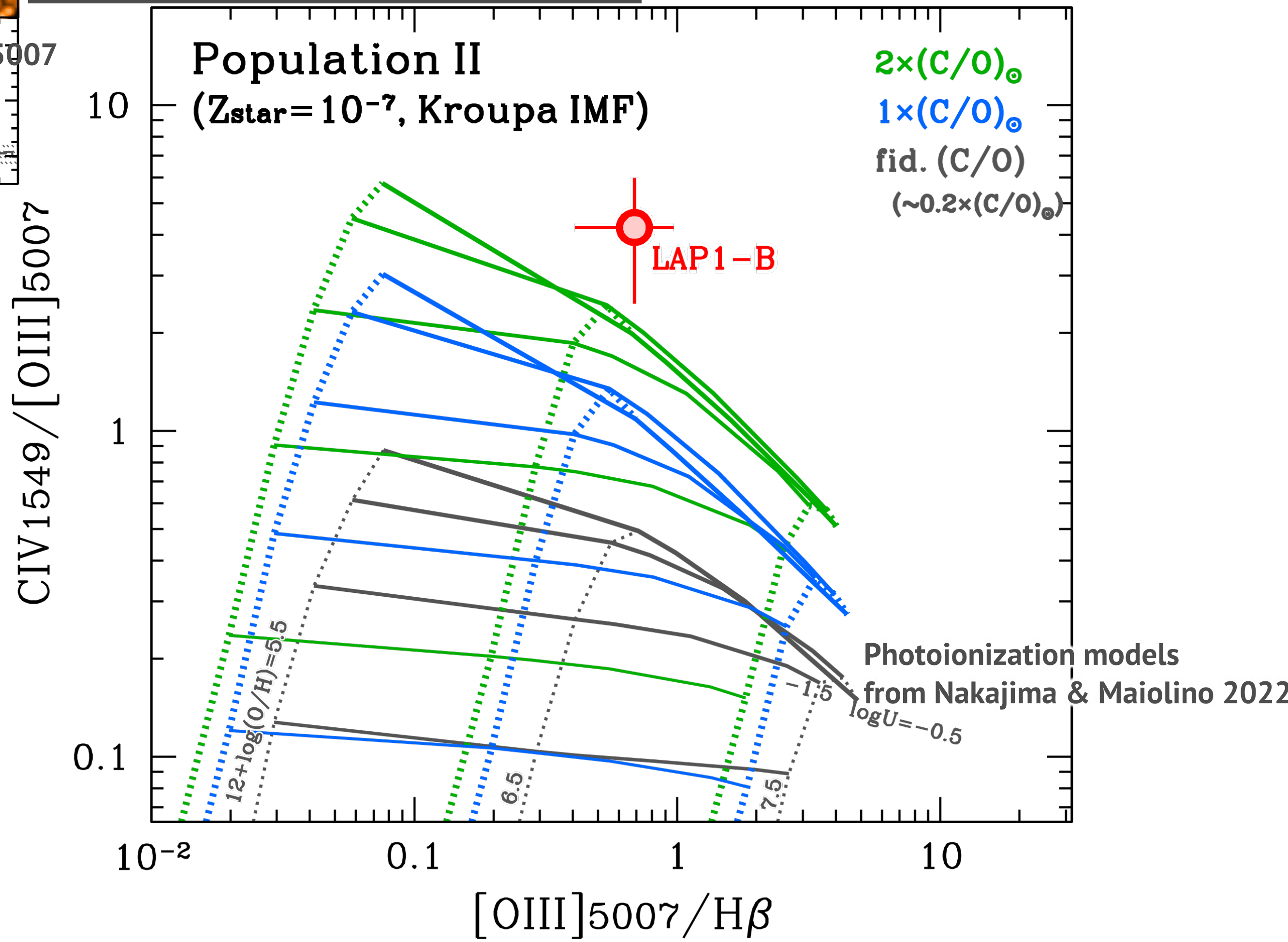
See also: Vanzella+2023

Recent Progress w/ JWST
(ii) LAP1-B: Hard Spec. & Ext. Low- M⋆, Low-Metallicity





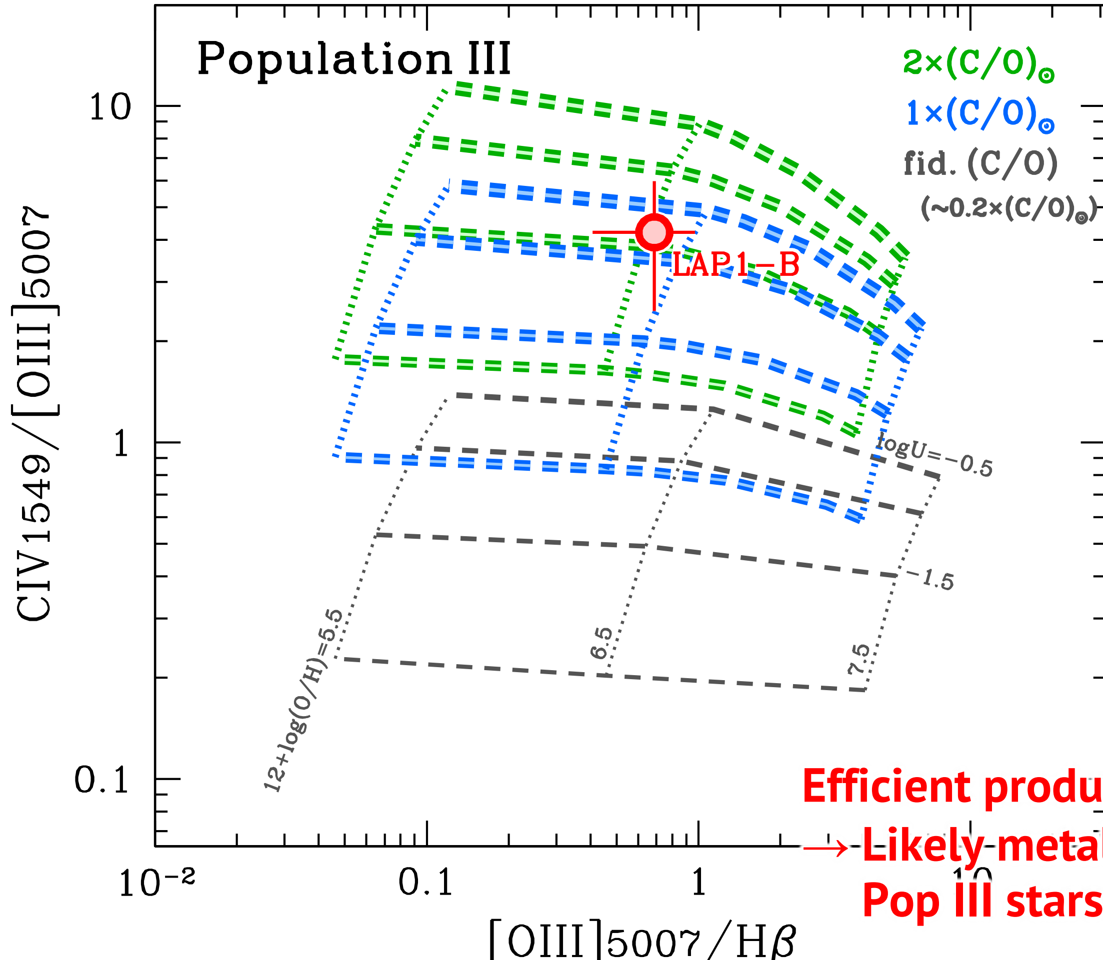
UV emission line Diagnostics



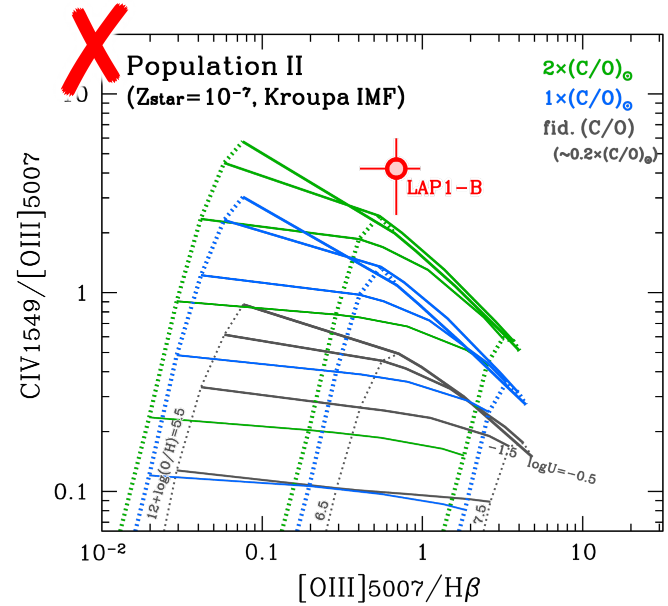
Nakajima et al. 2025

Recent Progress w/ JWST
(ii) LAP1-B: Hard Spec. & Ext. Low- M★, Low-Metallicity

UV emission line Diagnostics



Nakajima et al. 2025

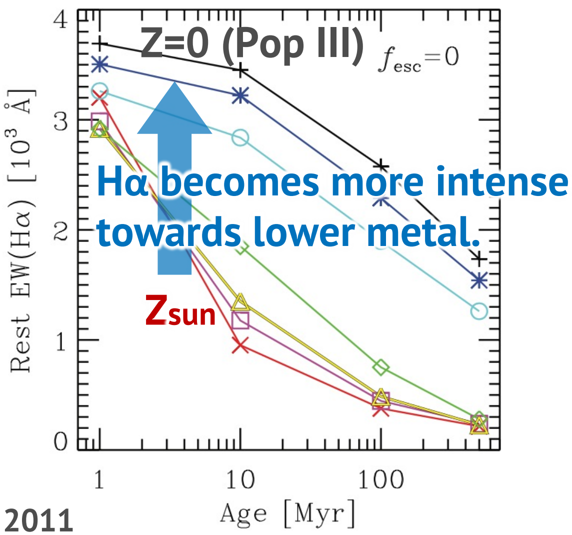


Photoionization models
from Nakajima & Maiolino 2022

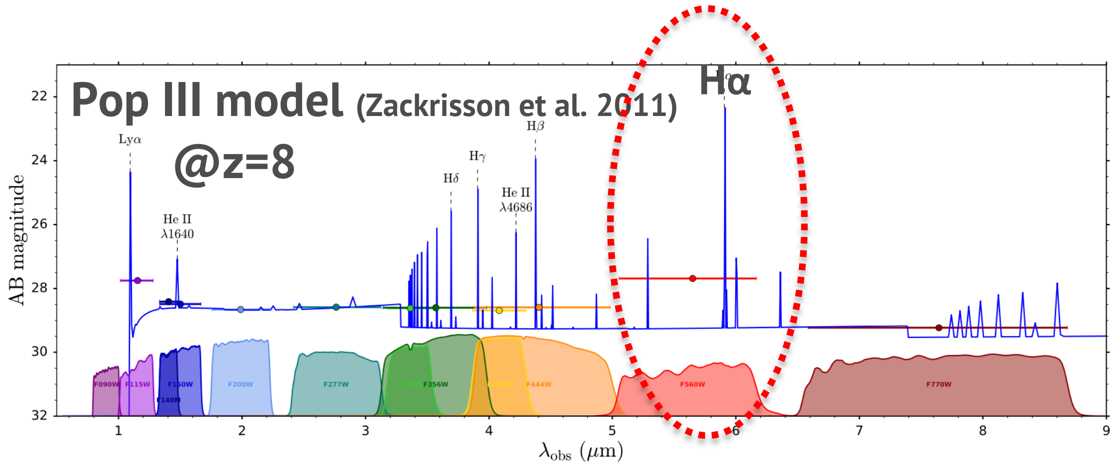
Efficient production of photons (>~50eV)
→ Likely metal-deficient ionizing source
Pop III stars and ISM metals coexist ?

cf. High C/O is consistent w/ Pop III SNe enrichment

Recent Progress w/ JWST
(iii) Intense Hydrogen Line Emitters (w/ Weak Metal Lines)



Inoue 2011



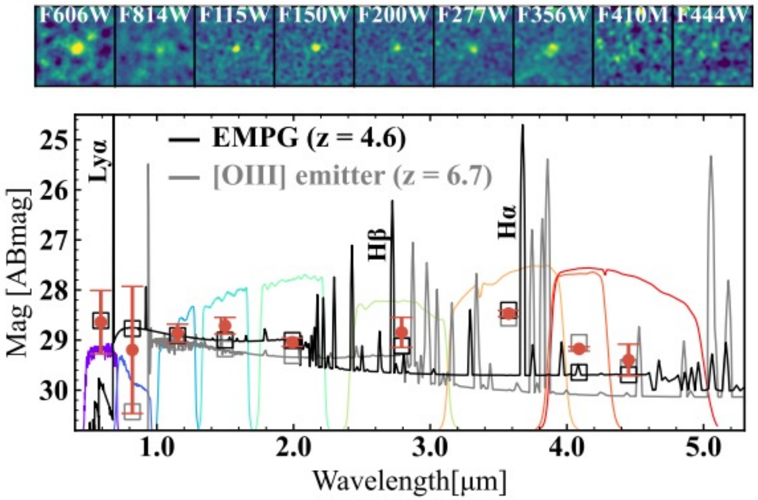
Trussler, .., Nakajima et al. 2023

cf. LAP1 is also originally discovered by intense Lyα

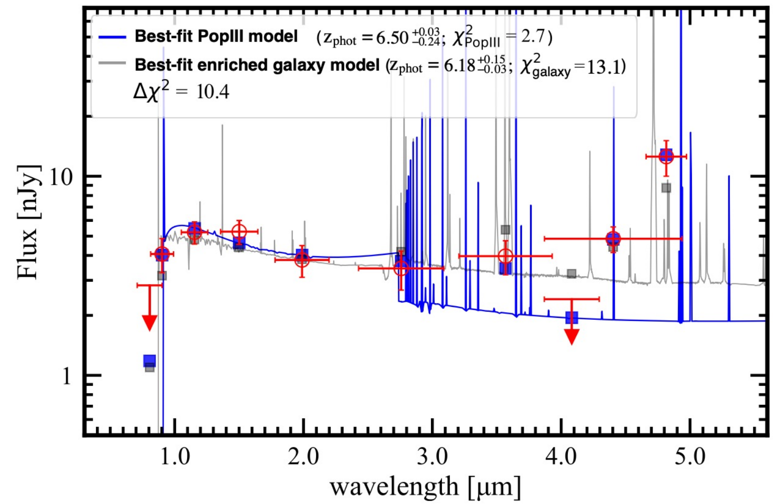
See also: Cai+2025

NIRCam + MIRI Imaging to search for Pop III cand w/ strong Balmer lines & Weak metal lines

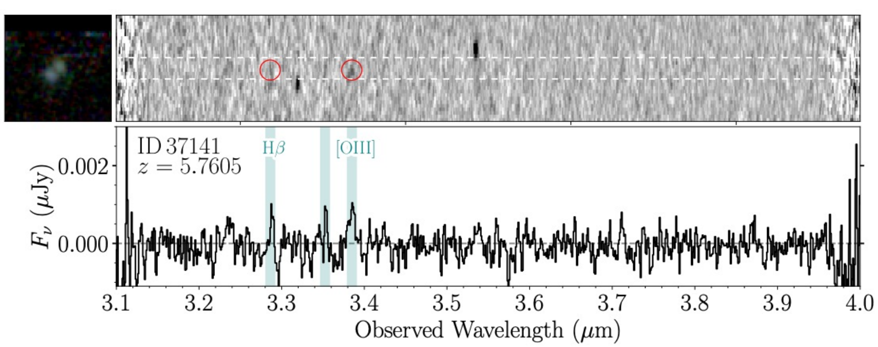
Recent Progress w/ JWST
(iii) Intense Hydrogen Line Emitters (w/ Weak Metal Lines)

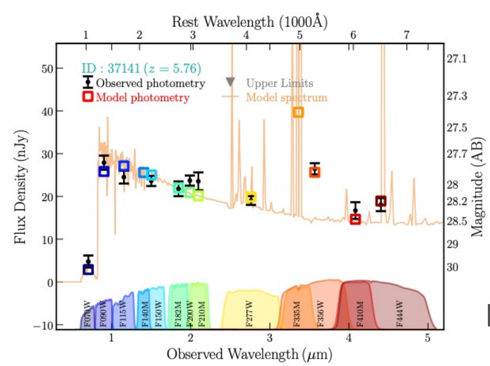


[Pilot study] 17 extremely metal-poor candidates at z=4-5 selected based on NIRCam photometry
(Nishigaki,.., Nakajima et al. 2023)



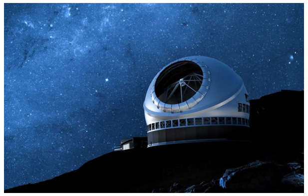
Fujimoto et al. 2025





Hsiao et al. 2025

See also: Morishita+2025, Maiolino+2025

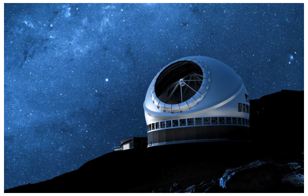


Prospects for Research of Primordial Obj in TMT Era
Spectroscopic characterizations of Pop III cand

Search Strategies for Pop III cand

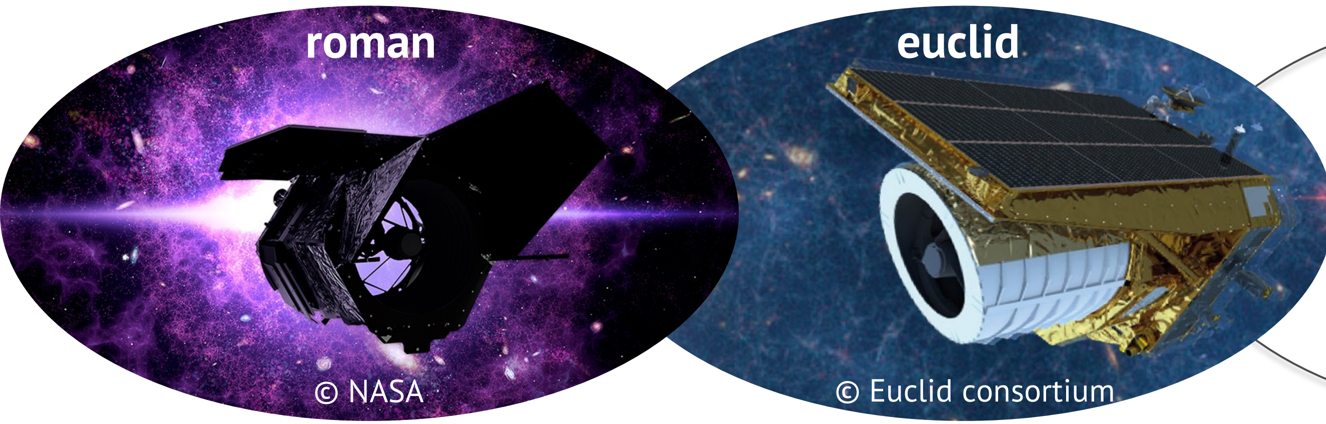
+ **Spectral Signatures:** Find intense H-line emitters (w/ weak/no metal lines)
+ **Proximity Searches:** Target regions near luminous, (moderate-) high-redshift obj
+ **Explosive Transients:** Detect their deaths as PISNs/GRBs

  (Tanaka+13, de Souza+13, Hartwig+18, Moriya+22)
+ Etc.
+ **Future Surveys:** Utilize next-generation wide-field imaging & spectroscopy



Prospects for Research of Primordial Obj in TMT Era
Spectroscopic characterizations of Pop III cand

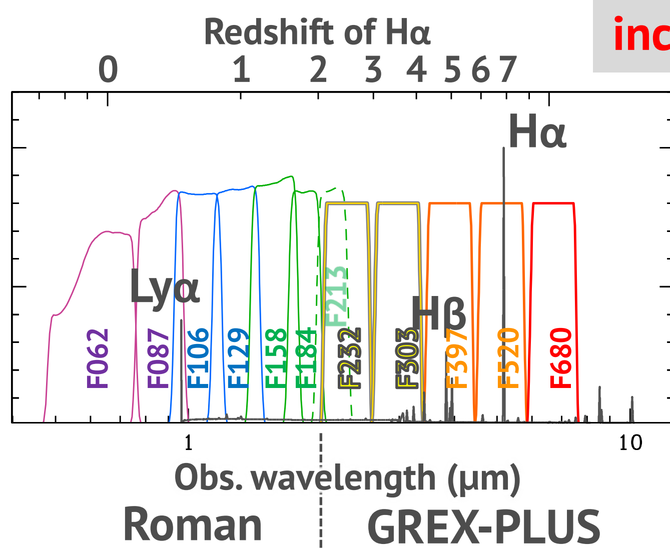
+ **Future Surveys:** Utilize next-generation wide-field imaging & spectroscopy

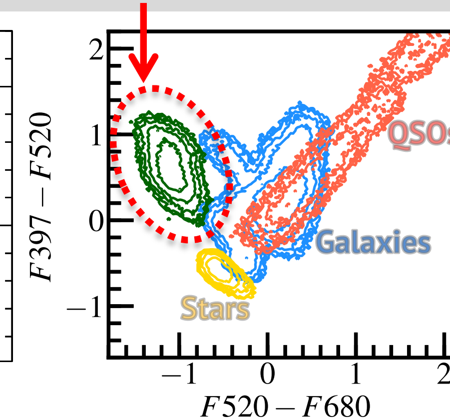


Future IR space missions
e.g. GREX-PLUS
(Inoue et al. 2022)

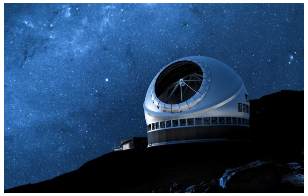
- TMT's follow-up IFU spec. around luminous obj found by Euclid/Roman
- Slitless *blind* spectroscopy for intense Lyα, Hα+
- Photometric selection of obj w/ intense Hα, weak/no metal lines

z~7 metal-poor galaxies incl. PopIII galaxies



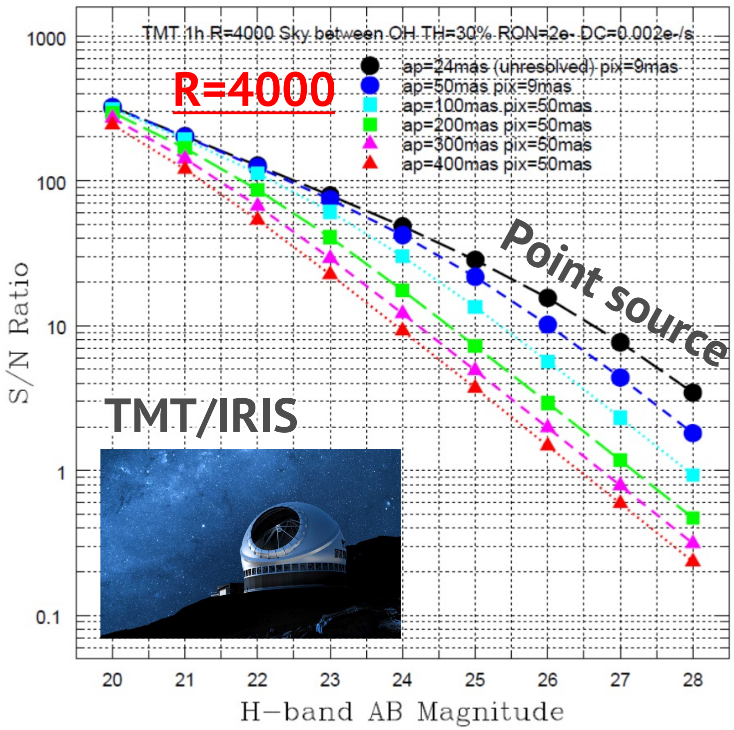


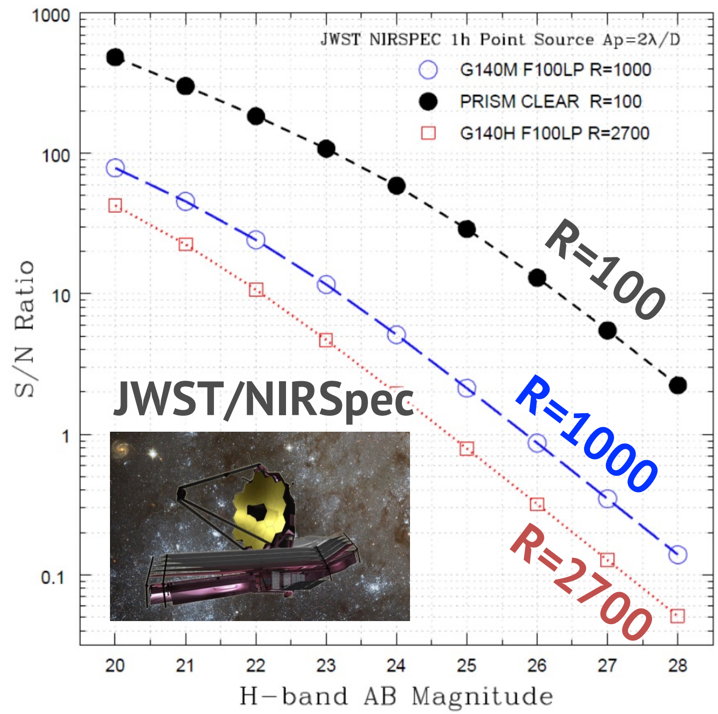
GREX-PLUS Science Book



Prospects for Research of Primordial Obj in TMT Era
Spectroscopic characterizations of Pop III cand

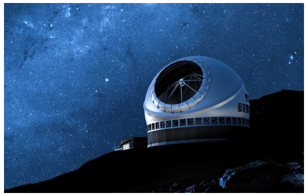
Better Sensitivity



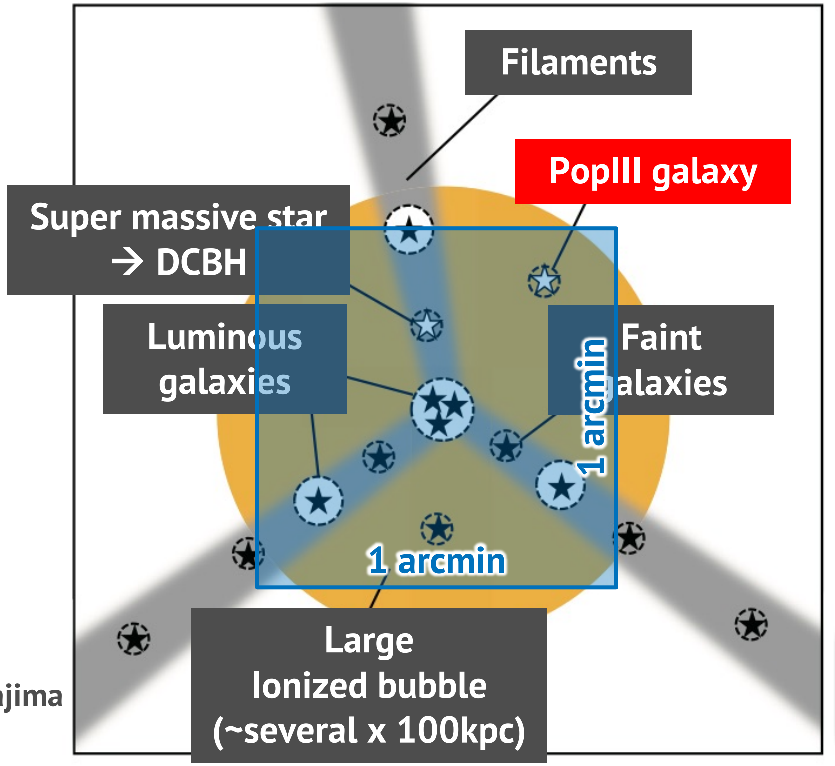


Why TMT is Crucial:

TMT will offer **sensitivity (higher than JWST) at high spec. resolution** (esp. for point src) to de-blend HeII from OIII], examine HeII's spectral profile for Wolf-Rayet features, etc.



Prospects for Research of Primordial Obj in TMT Era
A Vision for Future Primordial Surveys



© H. Yajima, together w/ Y. Harikane and K. Nakajima (Subaru TMT Science Book 2020)

Dedicated NIR IFU capable of surveying large areas for faint, primordial sources

+ **Map large areas** by providing FoV ~1 arcmin^2 (~100x100 kpc^2 @z=10)
+ **Directly detect** faint recombination line signatures (HeII, Lyα), allowing for discovery of primordial sources without prior knowledge of their exact locations

Summary

Search strategies for primordial candidates in TMT era: Lessons from JWST

Spectral Signatures: Find intense H-line emitters (w/ weak/no metal lines)
(Vanzella+2023, Nakajima+2025, Nishigaki+2023, Fujimoto+2025, see also: Inoue 2011)

Proximity Searches: Target regions near luminous, (moderate-) high-redshift obj
(Maiolino+2024, see also: Visbal+2020, 2025)

And More (incl. Explosive Transients: Detect their deaths as PISNs/GRBs)

Future Surveys: Utilize next-generation wide-field imaging & spectroscopy

Key role of TMT

Superior Spec Sensitivity: Higher sensitivity than JWST at high spectral resolution

Instrument Flexibility: Ability to host powerful new instruments (e.g. wide-field NIR IFU)

⇩

Definitive Diagnoses: Confirming primordial nature of sources
w/ hard ionizing spectrum and extremely low metallicity

Efficient "Blind" Surveys: Systematically exploring primordial sources
w/o needing to know their exact locations in advance