“A needle in a haystack: Catching Population III stars during the Epoch of Reionization”

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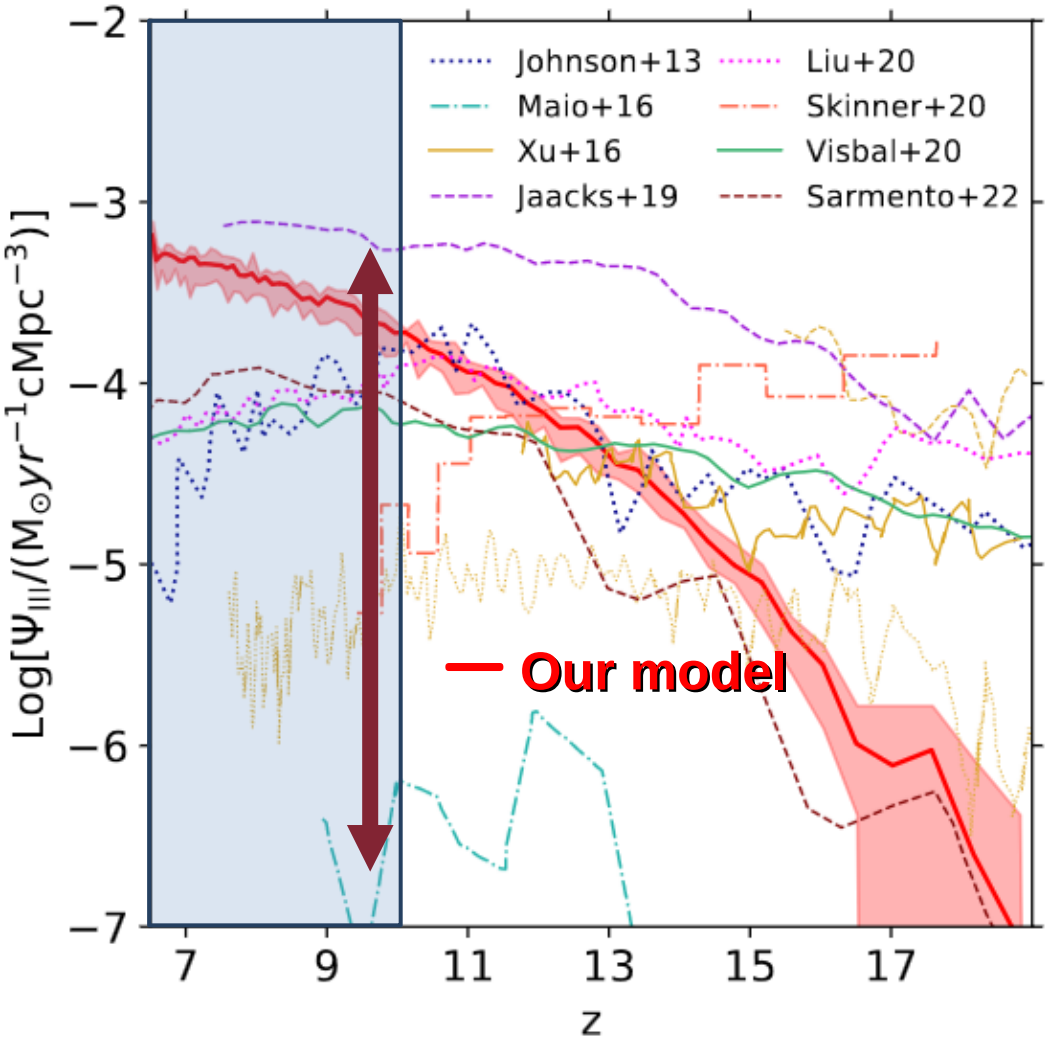
Finanziato dall'Unione europea
NextGenerationEU

Pop III star formation during the EoR



- **Large scatter** between theoretical predictions
- One thing in common: **late Pop III SF**, down to the EoR, due to inhomogeneous enrichment
- <u>BUT</u> small simulated volumes: we want to study a **full cosmological context**

[cMpc/*h*] [$10^5 M_\odot/h$]

	Code	Scheme	L	m_{DM}
This work	dustyGadget	SPH	50	353.00
Sarmento+18	RAMSES	AMR	12	0.99
Pallottini+14	RAMSES	AMR	10	4.70
Trinca+23	CAT	SAM	-	-
Xu+16	ENZO	AMR	4.3	0.21
Jaacks+19	GIZMO	MFM	4	0.29
Liu+20	GIZMO	MFM	4	0.36
Sarmento+22	RAMSES-RT	AMR	3	0.12
Johnson+13	Gadget-2	SPH	2.84	0.04
Visbal+20	-	SAM	2.01	0.05
Skinner+20	ENZO	AMR	0.67	0.01
Maio+16	Gadget-3	SPH	0.5	0.04

Our simulation suite

(Graziani et al. 2020)

dustyGadget simulations including self-consistent dust production and evolution.

×8

Box size [cMpch^{-1}]	$m_{\rm DM}$ [M$_\odot h^{-1}$]	$m_{\rm b}$ [M$_\odot h^{-1}$]	N. of particles
50	3.53×10^7	5.56×10^6	2×672^3

- Largest available simulations including a model for Pop III
- Resolving the SF environments of massive galaxies ($M_* \gtrsim 10^{7.5}$ M$_\odot$)

+ Pop III model:

- Stellar populations of ~10^6 M$_\odot$ formed in a gas < 10^{-4} Z$_\odot$
- Salpeter IMF [100 – 500] M$_\odot$
- Mass-dependent yields from stars in the PISN range [140 – 260] M$_\odot$
  (Heger&Woosley 2002, Schneider et al. 2004)
  → following six metals + dust (C, O, Mg, S, Si and Fe)

[cMpc/h] [10^5M$_\odot/h$]

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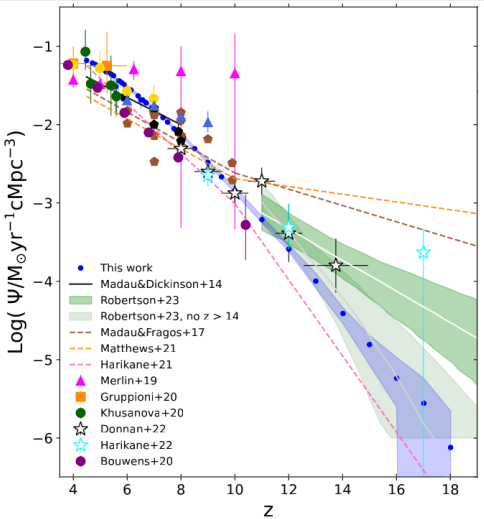
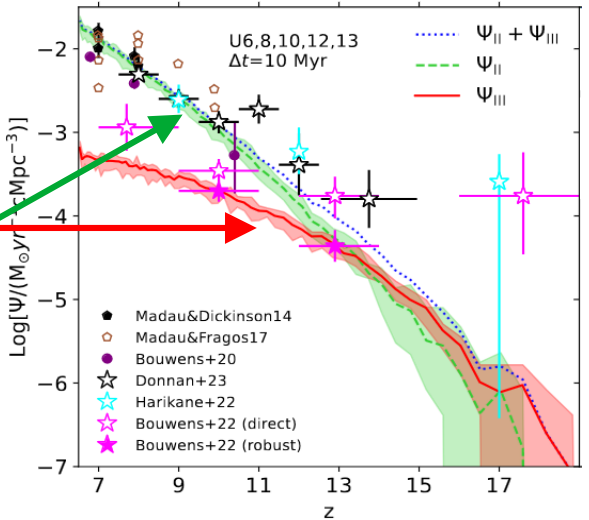
LARGE SCALE

Harnessed to study the build-up of M_* and M_{dust} at $z > 4$

Di Cesare et al. (2023), MNRAS, 519, 4632

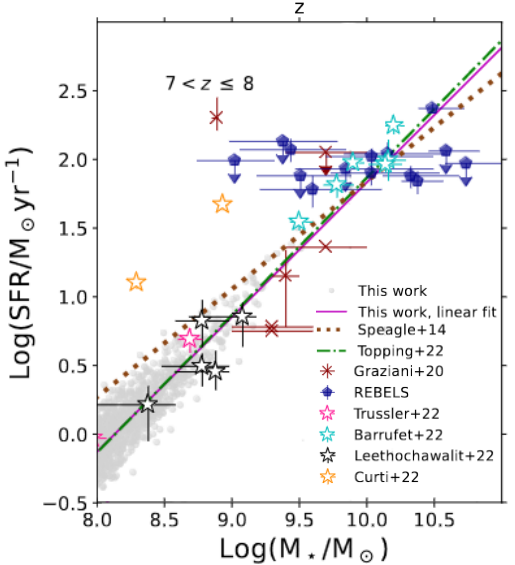


Cosmic SFRD/SMD

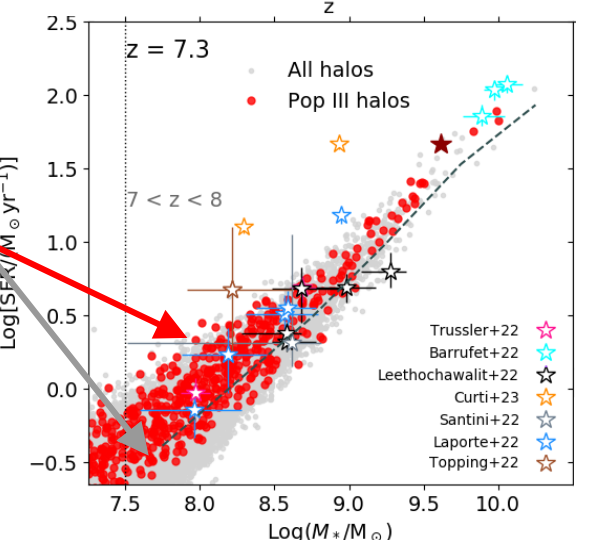


+ We can decompose in **Pop III/II** contribution

Moderate Pop III SF down to z ~ 6



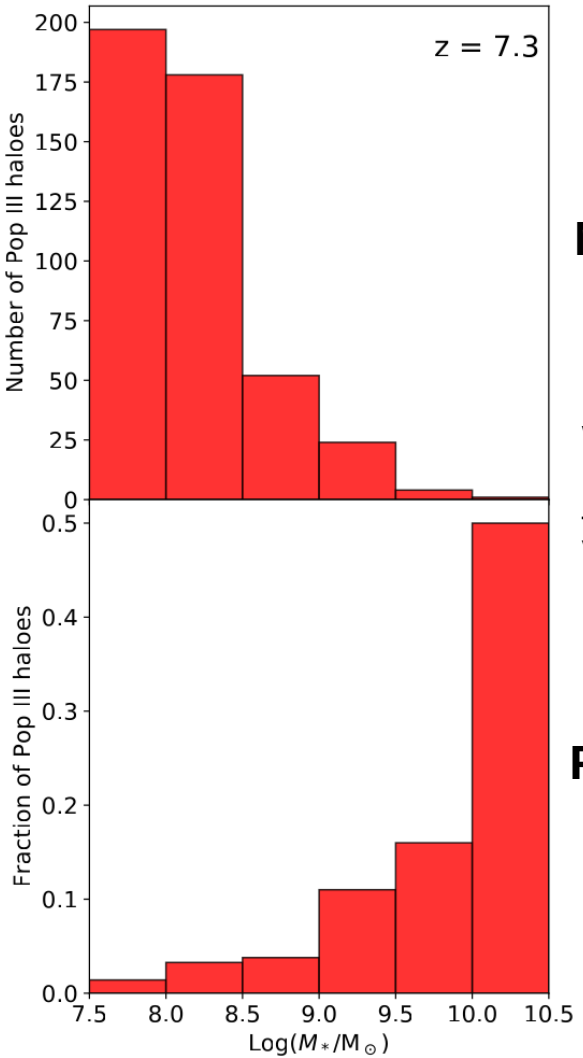
Main scaling relations (e.g. MS)



In galaxies all over the MS, even in massive galaxies, at high SFRs

Venditti et al. (2023), MNRAS, 522, 3809

LARGE SCALE



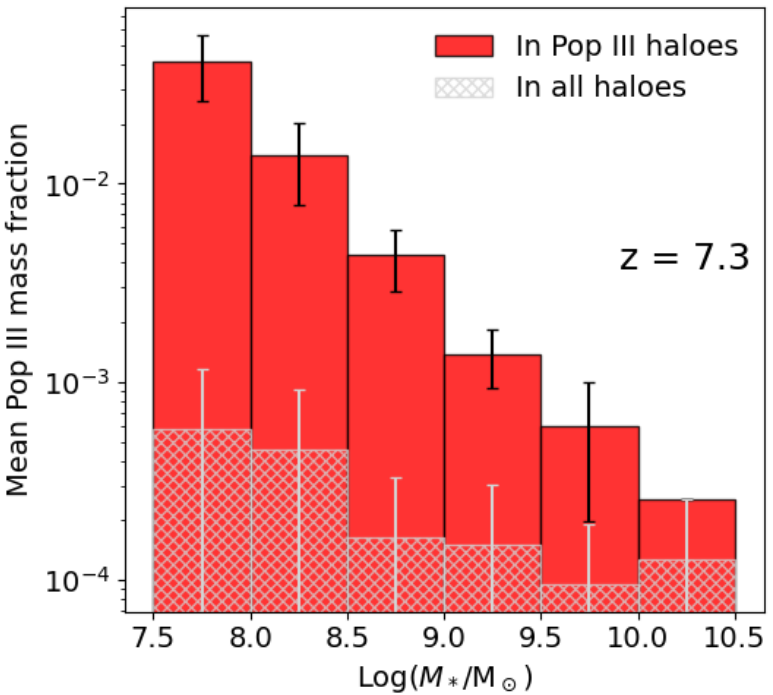
N. of Pop III haloes ↓ with M*

We can target <u>bright, massive galaxies</u>: rarer, but Pop III in their vicinity with higher probability

Frac. of Pop III haloes ↑ with M*

<u>BUT</u> all mixed systems, co-existing with Pop II!
+ **Pop III mass frac.** ↓ with M*

Important to look at the resolved <u>SF environments</u>



Venditti et al. (2023), MNRAS, 522, 3809

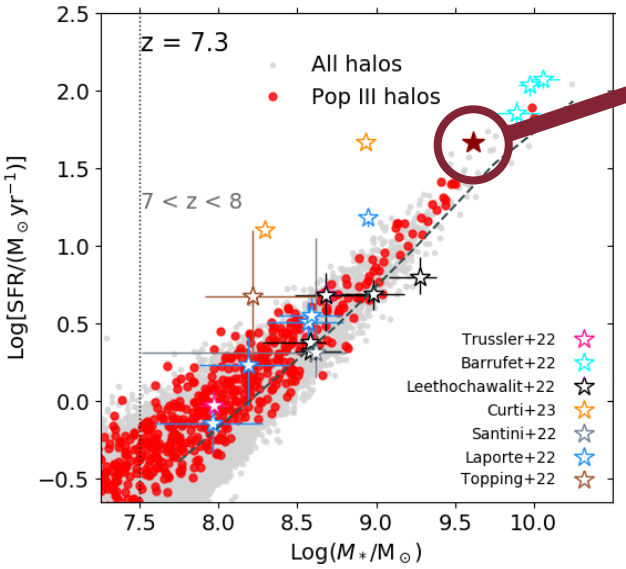
SF ENVIRONMENTS

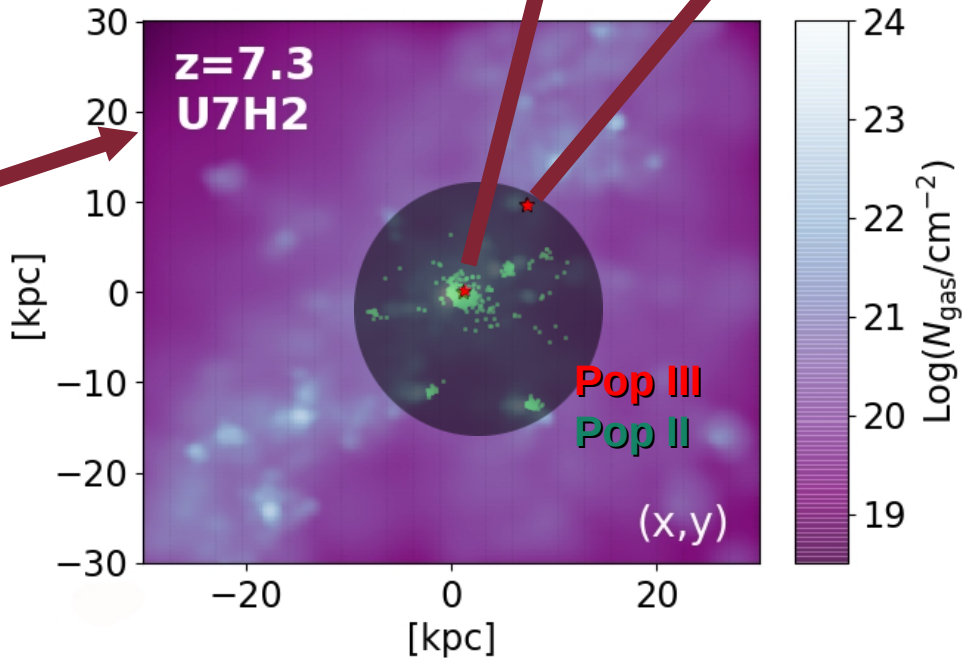
Venditti et al. (2023), MNRAS, 522, 3809

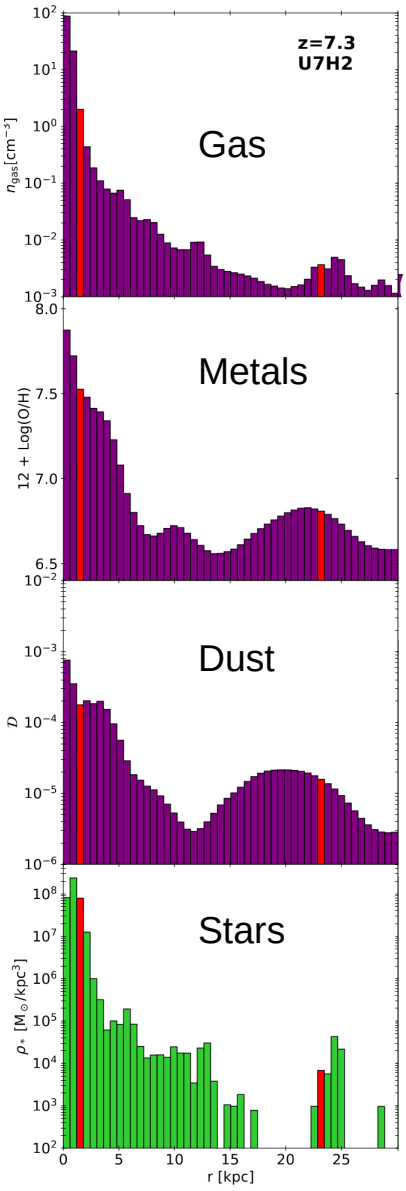
With enough **spatial resolution**, we can tell apart Pop III stellar populations even in/around Pop II-dominated galaxies

Pop III in the outskirts of metal-enriched regions

Pop III in isolated, pristine gas clouds

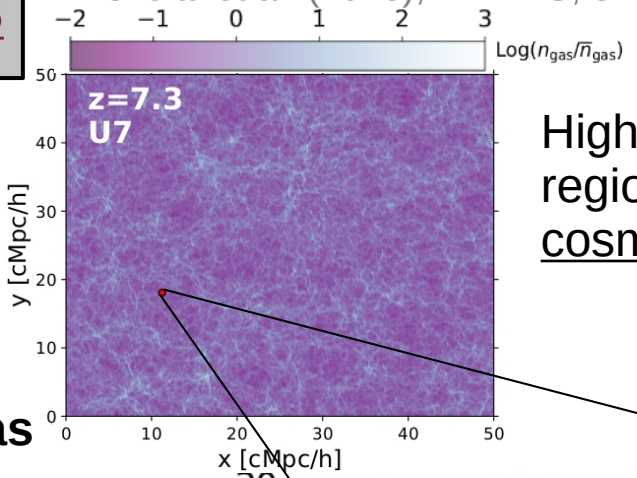






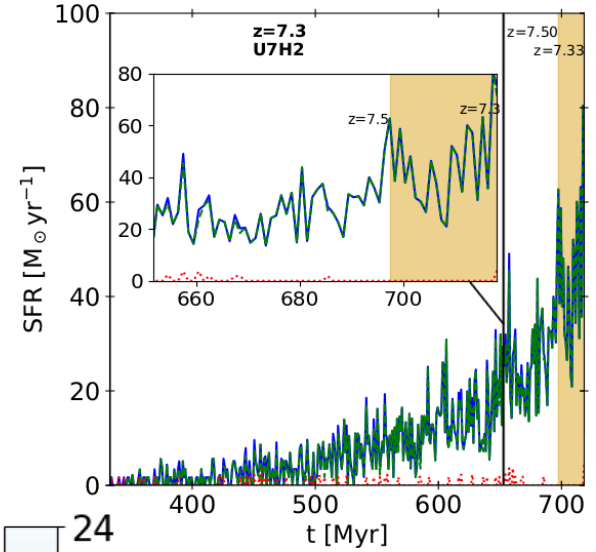
SF ENVIRONMENTS

Venditti et al. (2023), MNRAS, 522, 3809

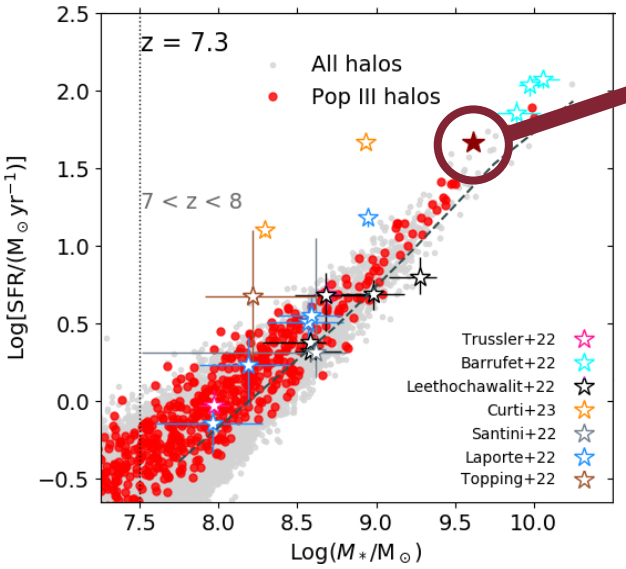


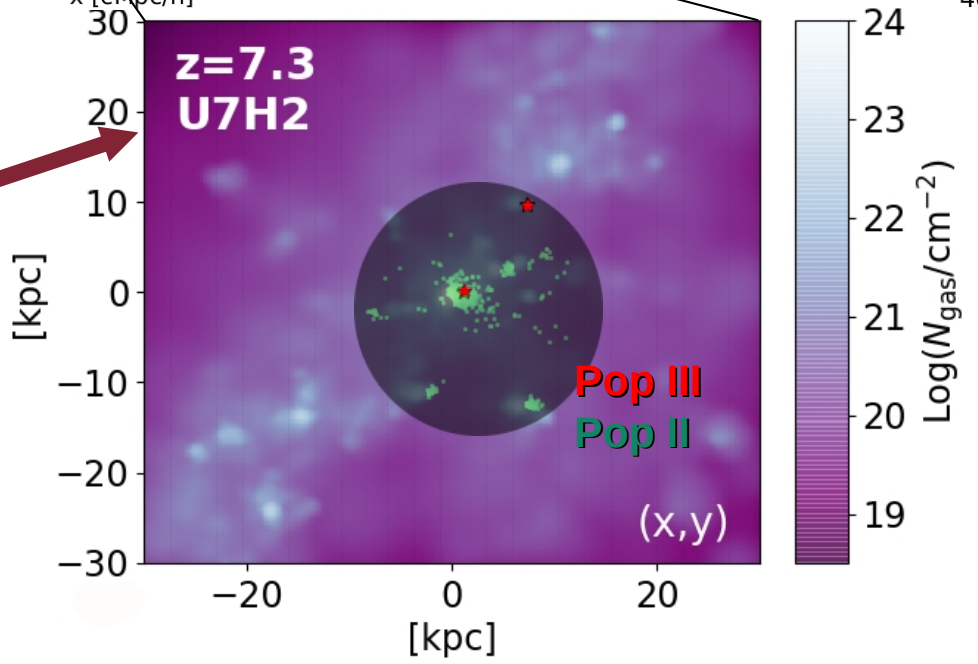
High-density regions of the cosmic web

High SFRs possibly induced by a sustained **accretion of pristine gas**

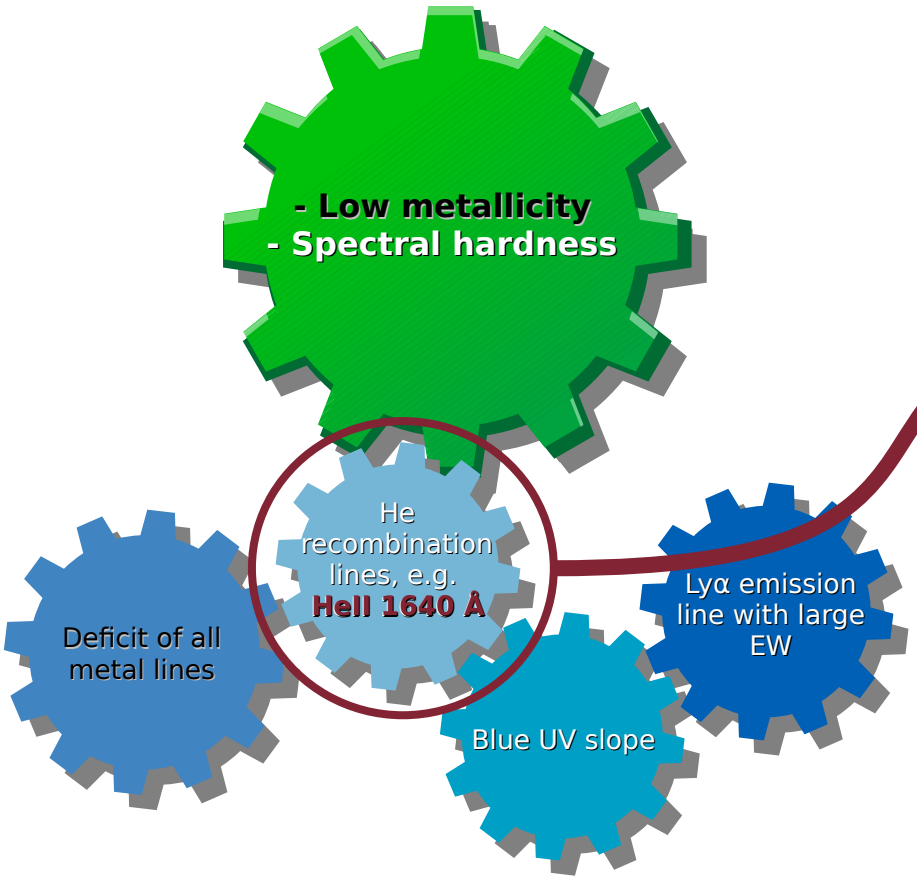


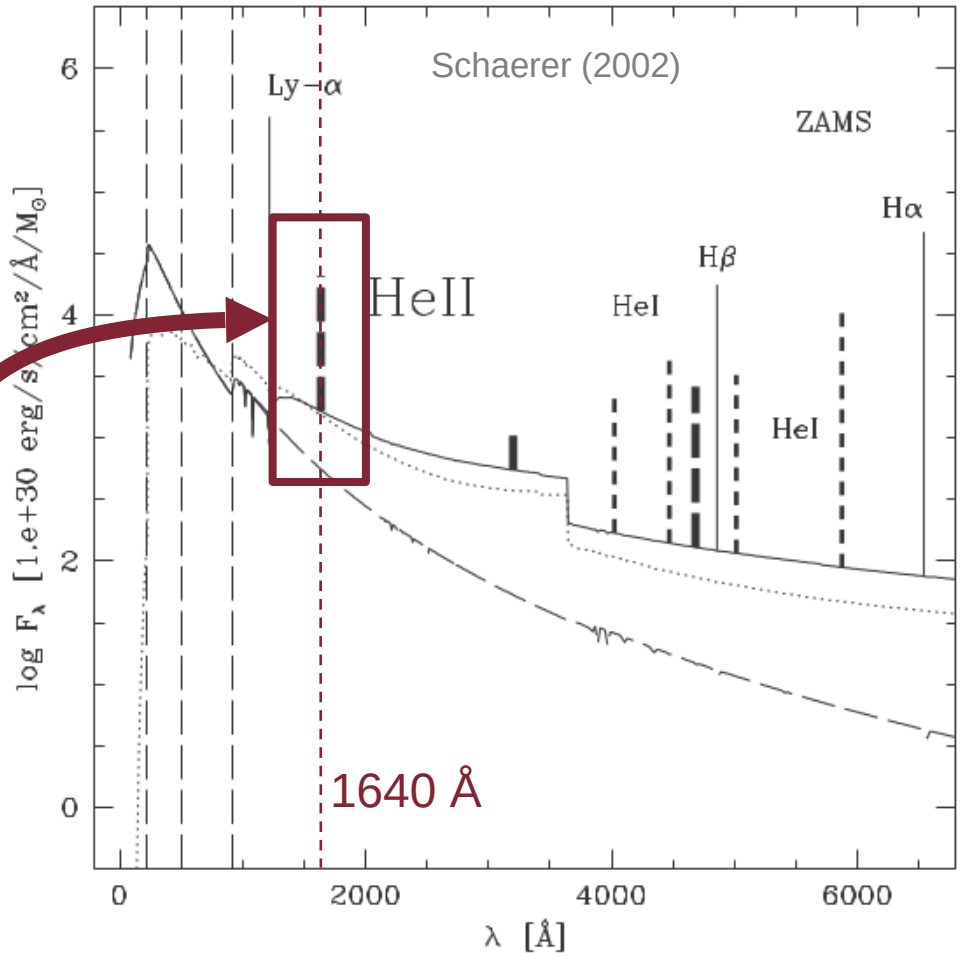
Increasing SFHs





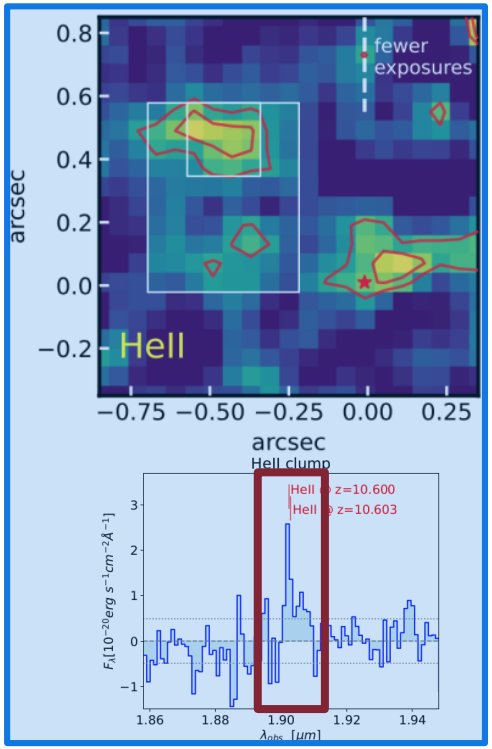
Identifying Pop III in high-z galaxies





HeII1640: hide-and-seek game?

Venditti et al. (2024b), arXiv:2405.10940

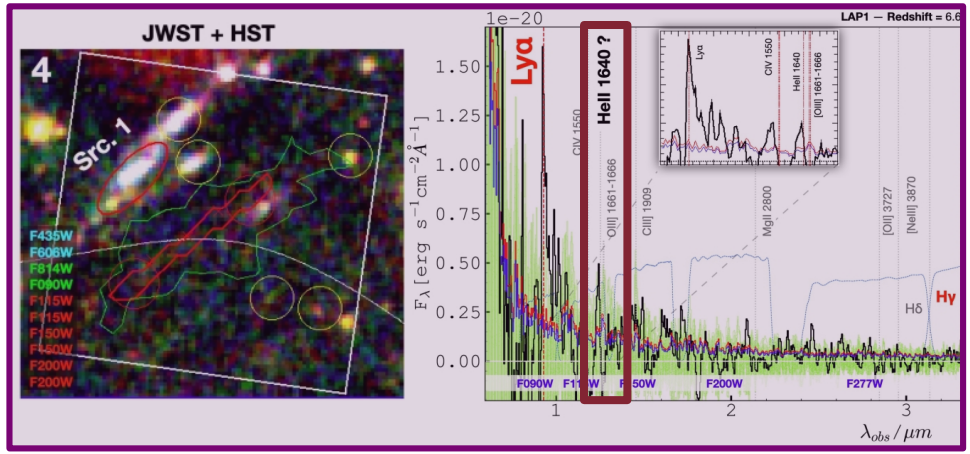


GN-z11 (z~10.6)
Maiolino et al. 2023

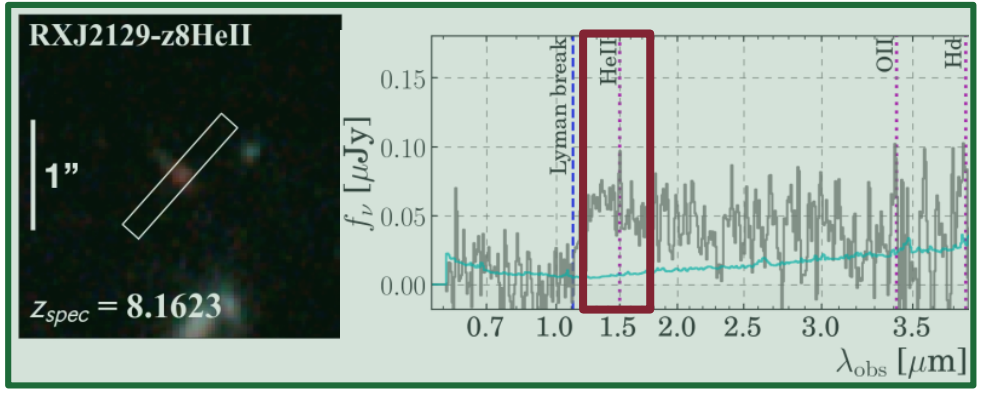
- Not enough **sensitivity**?
- Not large enough **FoV**?

+ Short lifetime (~ Myr)
+ Dust absorption
+ Confusing hard sources

LAP1 (z~6.6)
Vanzella et al. 2023



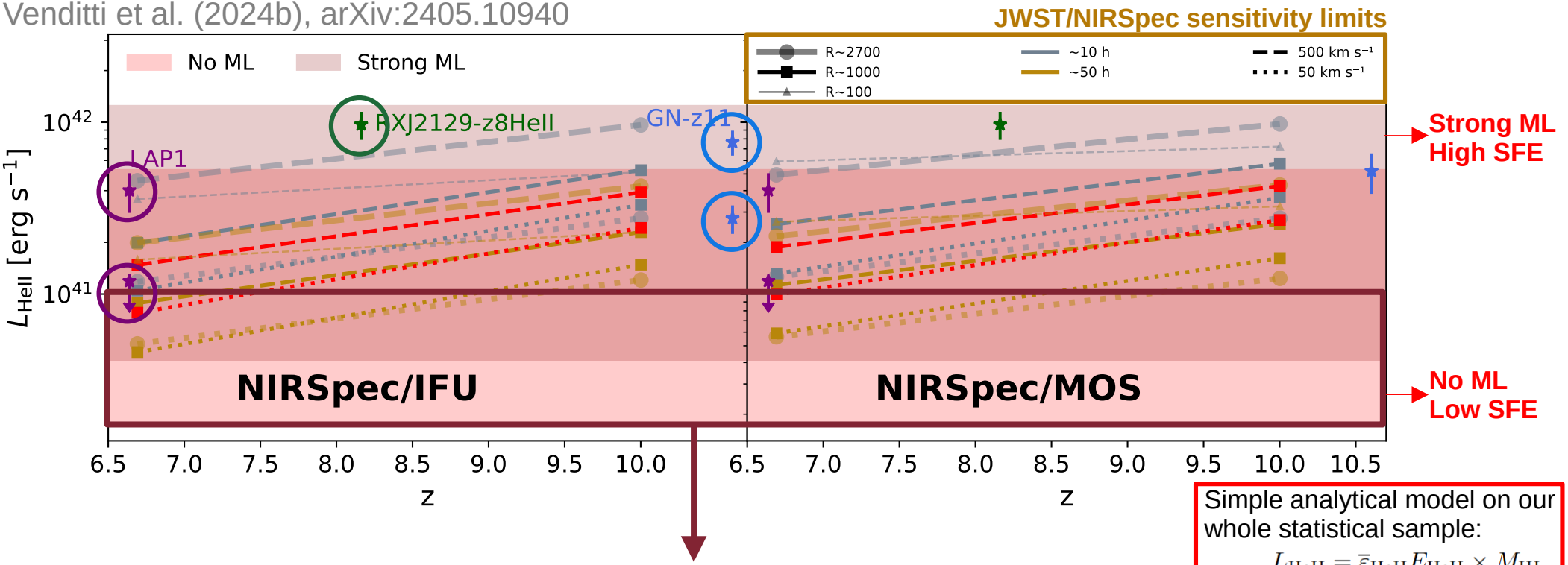
Why not even more?



RXJ2129-z8HeII (z~8.1)
Wang et al. 2024

Not enough sensitivity?

Venditti et al. (2024b), arXiv:2405.10940



Long exposures needed to capture low-luminosity systems

Simple analytical model on our whole statistical sample:

$$L_{\rm HeII} = \bar{\varepsilon}_{\rm HeII} E_{\rm HeII} \times M_{\rm III}$$

$$\bar{\varepsilon}_{\rm HeII} = \frac{\int_{m_{\rm low}}^{m_{\rm up}} \varepsilon_{\rm HeII}(m)\,\phi(m)\,{\rm d}m}{\int_{m_{\rm low}}^{m_{\rm up}} \phi(m)\,{\rm d}m}$$

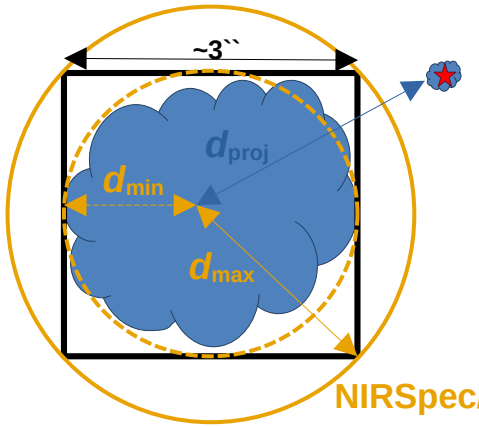
$$M_{\rm III} = \eta_{\rm III} M_{\rm III,res}$$

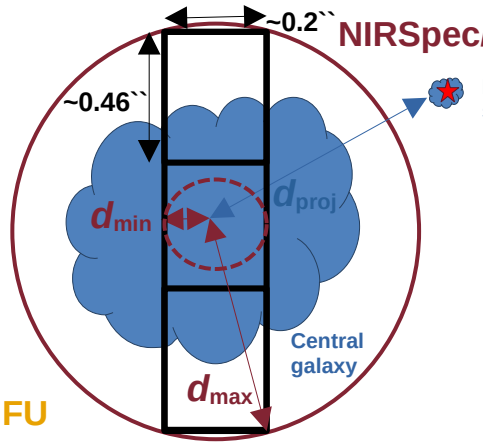
HeII emissivity from Schaerer 2002 (for no/strong ML)

Pop III SFE parameter

Not large enough FoV?

Venditti et al. (2024b), arXiv:2405.10940

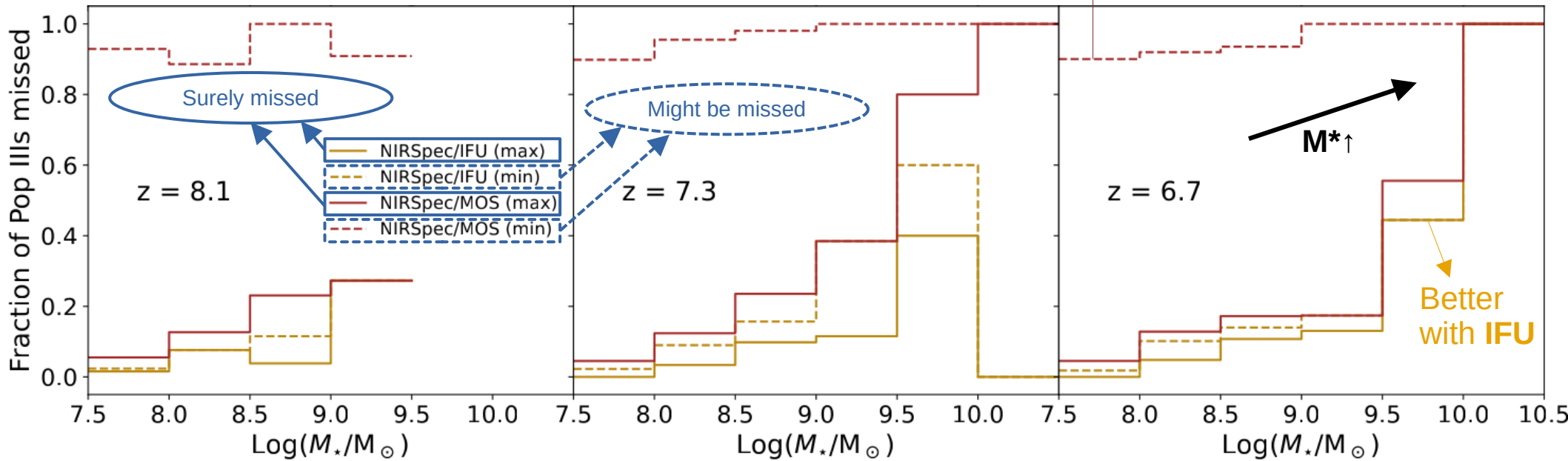




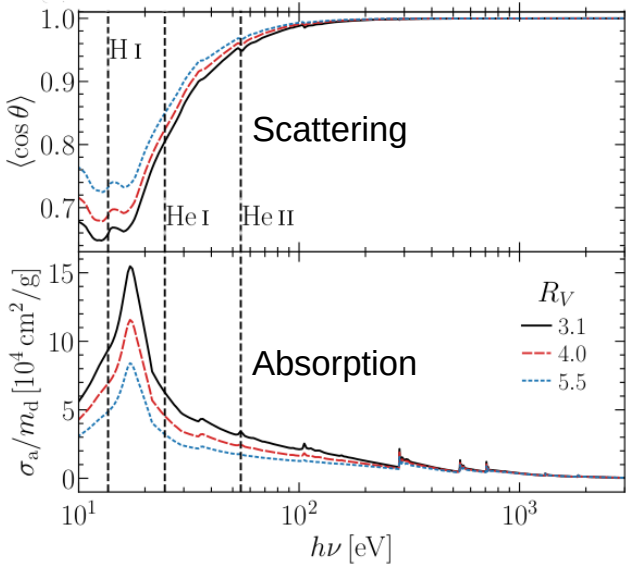
Pop III system → **up to ~20 kpc from center!**

Many Pop III systems missed with a **single pointing**

especially with **MOS**

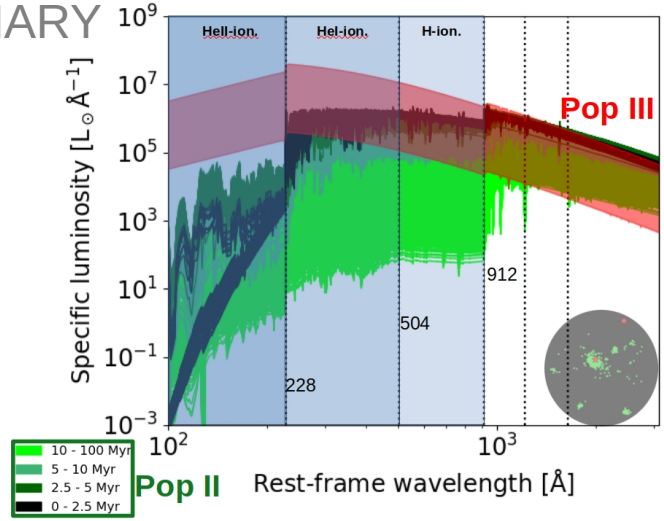


HeII1640 prospects: dust/confusing sources



Glatzle et al. 2019

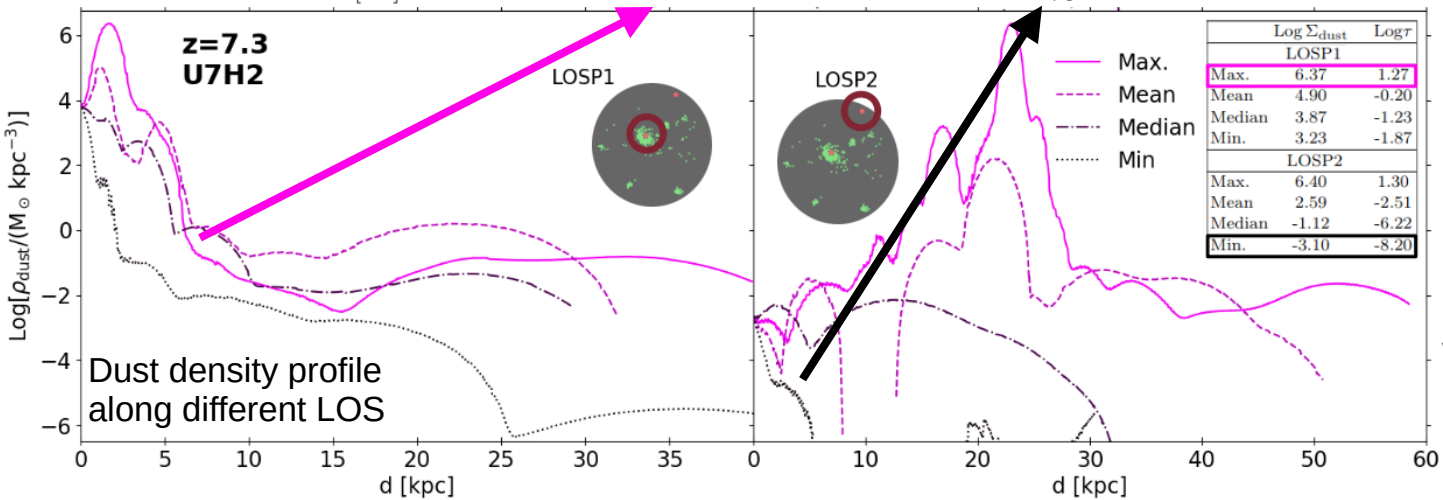
PRELIMINARY



HeII line can be both absorbed and scattered by **dust**
→ Depending on the LOS

Worst-case scenario:
$\Sigma_{dust} \gtrsim 10^6\ M_\odot\ kpc^{-2}$
$\tau \gtrsim 10$

Best-case scenario:
$\Sigma_{dust} \lesssim 10^{-3}\ M_\odot\ kpc^{-2}$
$\tau \lesssim 10^{-8}$



	Log Σ_{dust}	Logτ
LOSP1		
Max.	6.37	1.27
Mean	4.90	-0.20
Median	3.87	-1.23
Min.	3.23	-1.87
LOSP2		
Max.	6.40	1.30
Mean	2.59	-2.51
Median	-1.12	-6.22
Min.	-3.10	-8.20

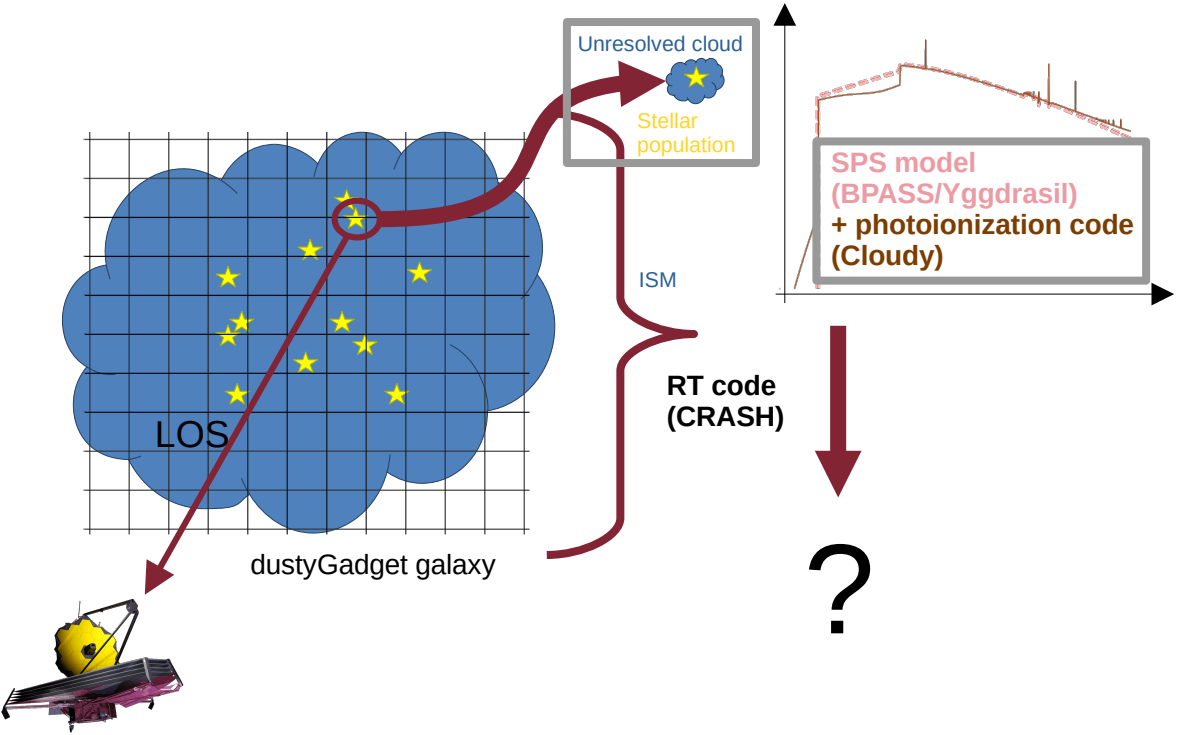
Confusing hard sources, e.g. **Pop II binaries**

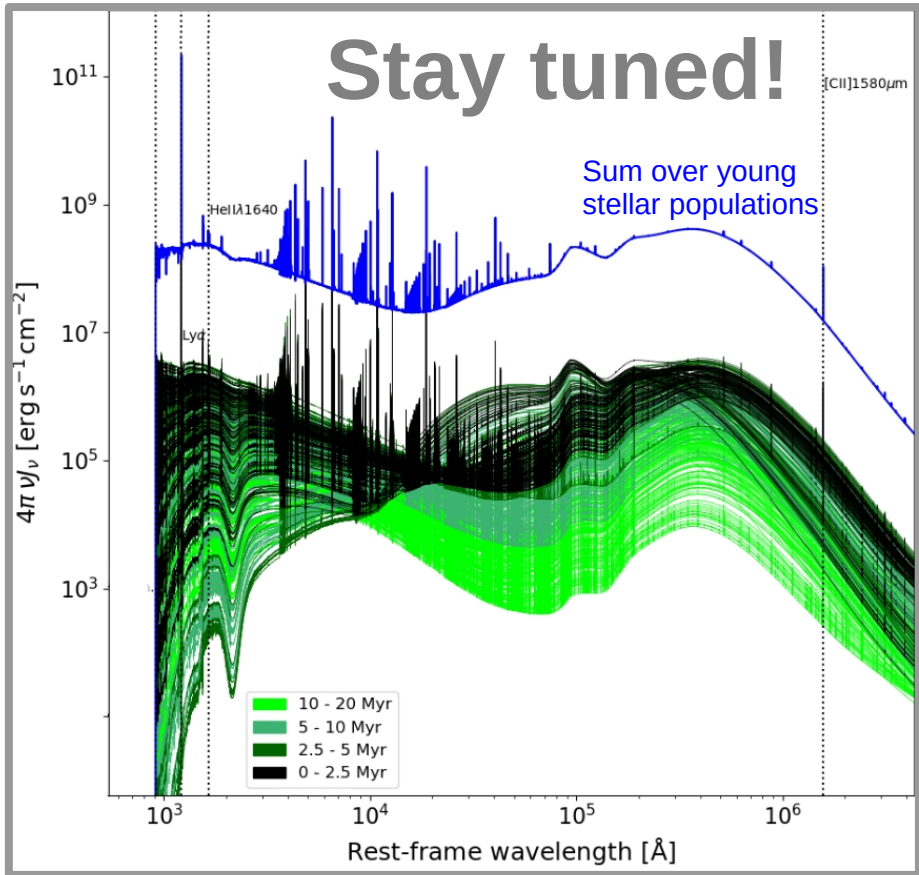
Venditti et al. (2023), MNRAS, 522, 3809

HeII1640 prospects: detailed spectral modeling

Simple analytical modelling in our statistical sample… vs tailored galaxy-by-galaxy approach ($\gtrsim 10^9\,M_\odot$)

→ **Detailed syntetic spectra** of selected massive Pop III galaxies PRELIMINARY





Another channel: PISNe

Venditti et al. (2024a), MNRAS, 527, 5102

Markers of massive Pop IIIs

Evolved massive He core

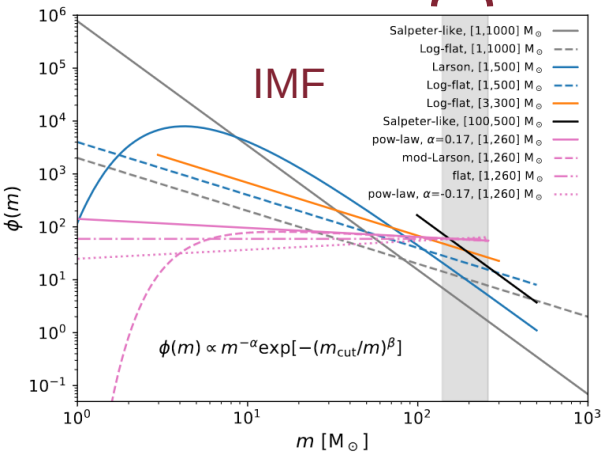
Pair production
$(Z+)\gamma \rightarrow e^- + e^+$

Loss of pressure support
⇒ collapse

Explosive O ignition

PISN with
complete
disruption

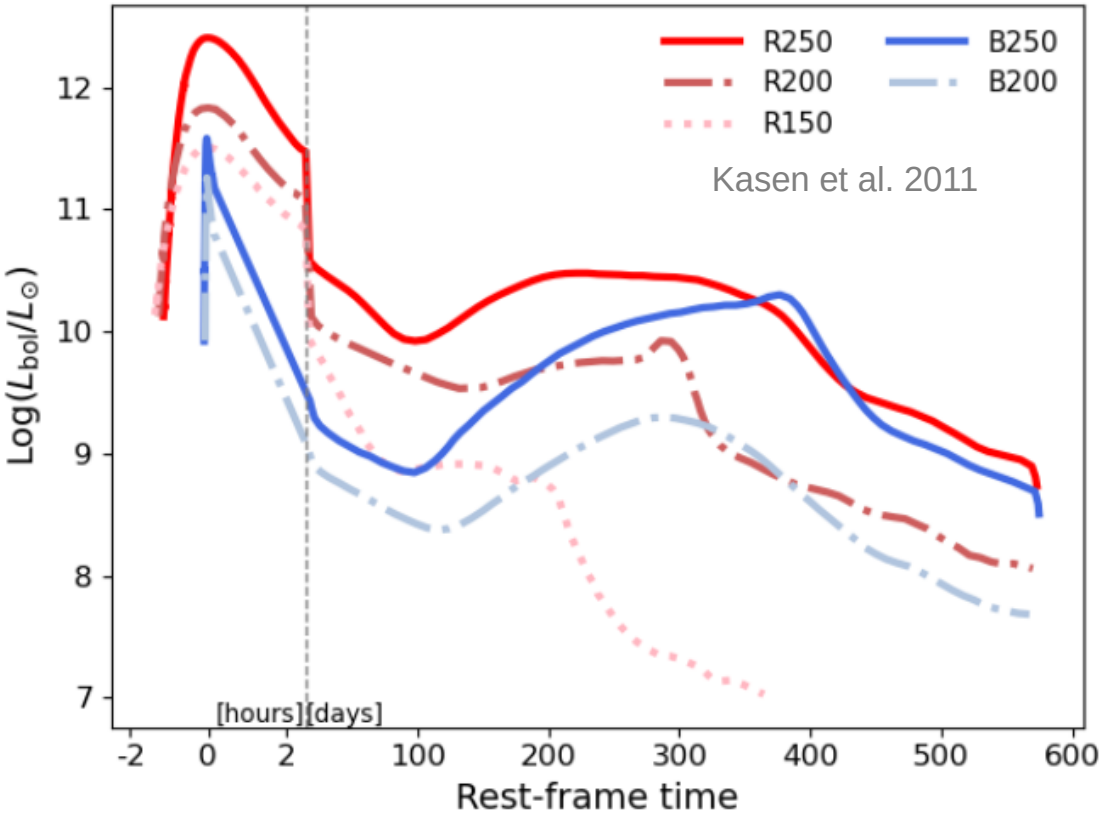
~ [140, 260] $M_\odot$



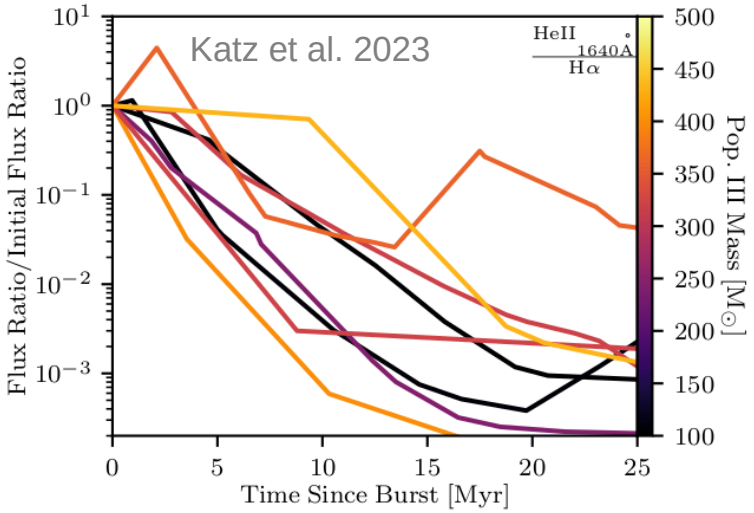
Very bright...

Venditti et al. (2024a), MNRAS, 527, 5102

PISNe can be seen up to very **high distances**



<u>BUT</u> **brief lifetime** ~ 1 yr

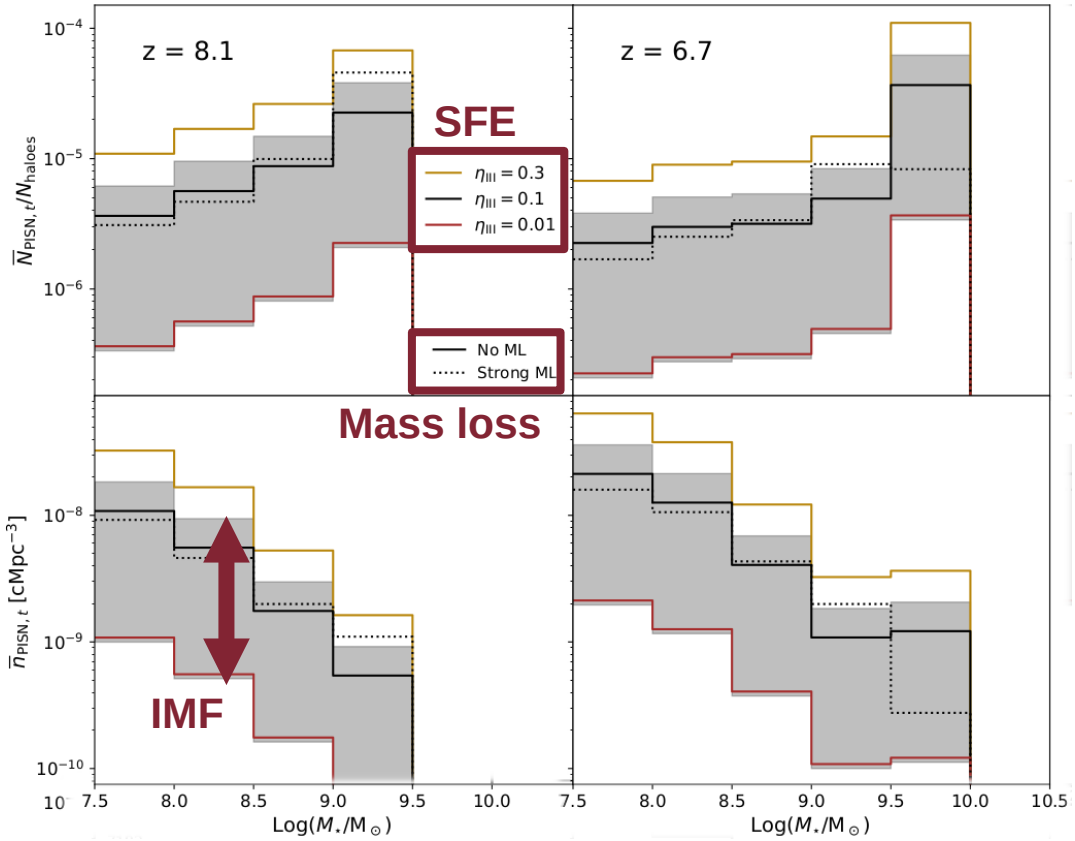


vs HeII line:
lifetime ~ 10 Myr,
x10^7 times longer!

... but rare

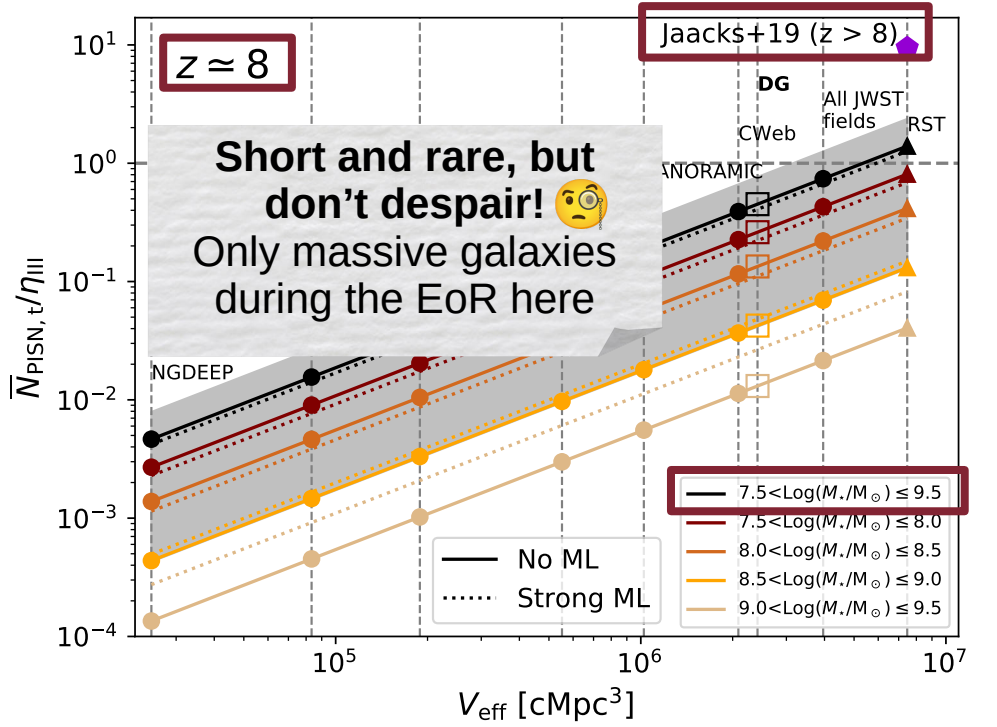
Venditti et al. (2024a), MNRAS, 527, 5102

Av. n. of PISNe per halo/unit volume among galaxies with different M_* and z



- < 1 PISN in JWST surveys
- Better chance with Roman

Tot. n. of PISNe up to Cosmic Dawn (1 yr survey of ~1 deg^2)



- Statistically relevant population of **pristine pockets in massive EoR galaxies** (z ~ 6 - 10).
  Venditti et al. (2023), MNRAS, 522, 3809

- Direct probes, e.g. **HeII line at 1640 Å**, provided
  - enough sensitivity;
  - large enough FoV;

  } **Venditti et al. (2024b), arXiv:2405.10940**

  - negligible dust absorption / confusing sources; → **in prep.**

- Also indirect probes, e.g. **PISNe**: short and rare, but don't despair!
  Venditti et al. (2024a), MNRAS, 527, 5102

Thank you for your attention!

SAPIENZA
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NextGenerationEU

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