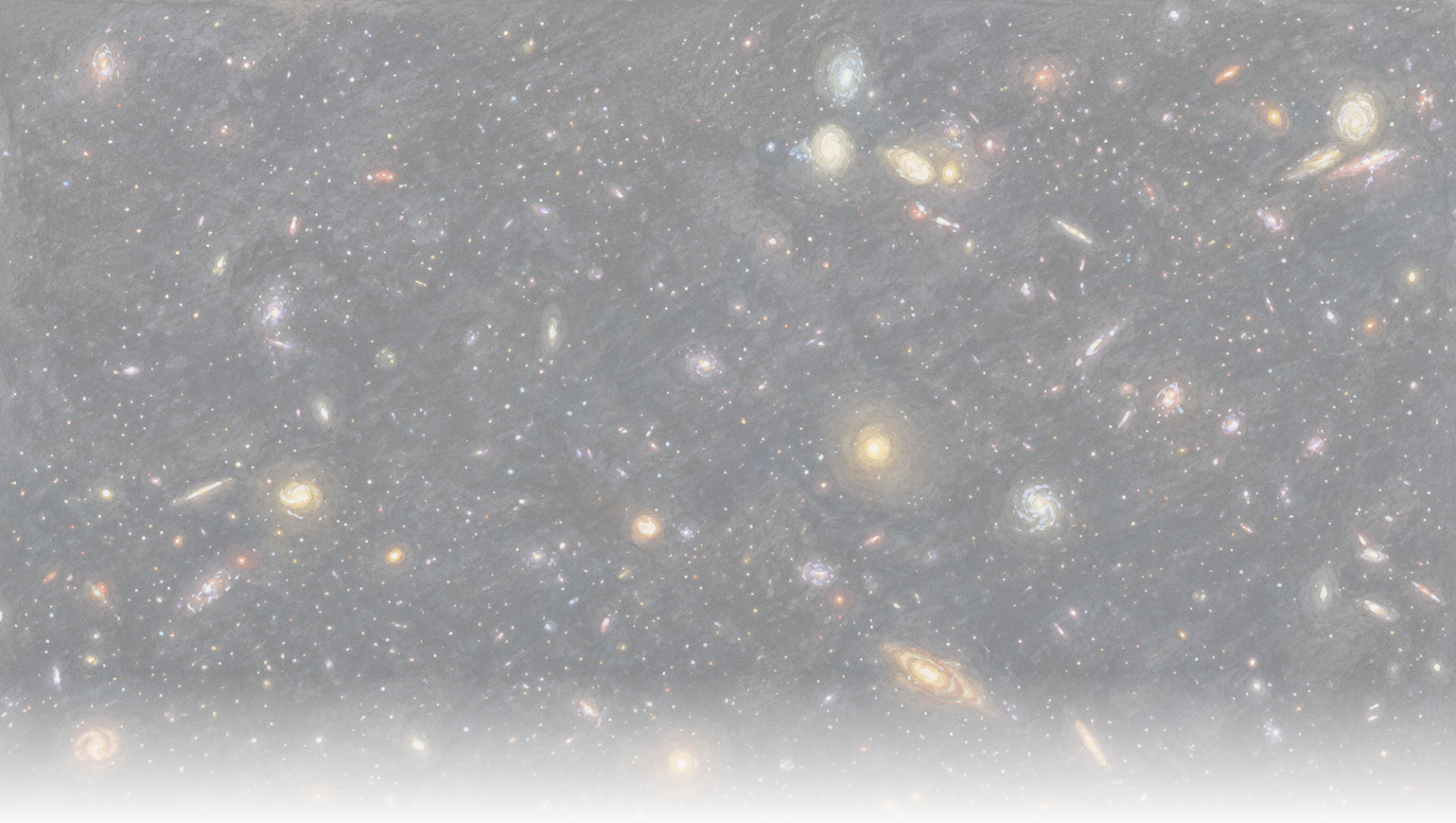

The Clean Paper

WHAT THE PAPER SAYS · WHAT IT DOESN'T · WHY IT MATTERS

Galaxy mafi nisa da aka kama tana barin ionizing light ɗinta ya tsere

Masana taurari sun yi amfani da JWST da Hubble don kama ionizing ultraviolet da ke tserewa daga galaxy guda kusan shekaru miliyan 250 bayan cosmic reionization — leakage mafi nisa da aka taba gani kai tsaye. Escape fraction na 50–100% da zai iya zama headline yana da asali amma reconstruction ne ta models, ba measurement kai tsaye ba; sakamakon da ya fi shiru shi ne gwajin high-redshift na farko na yadda za a gano leakage ɗin lokacin da ba za a iya ganinsa kai tsaye ba.

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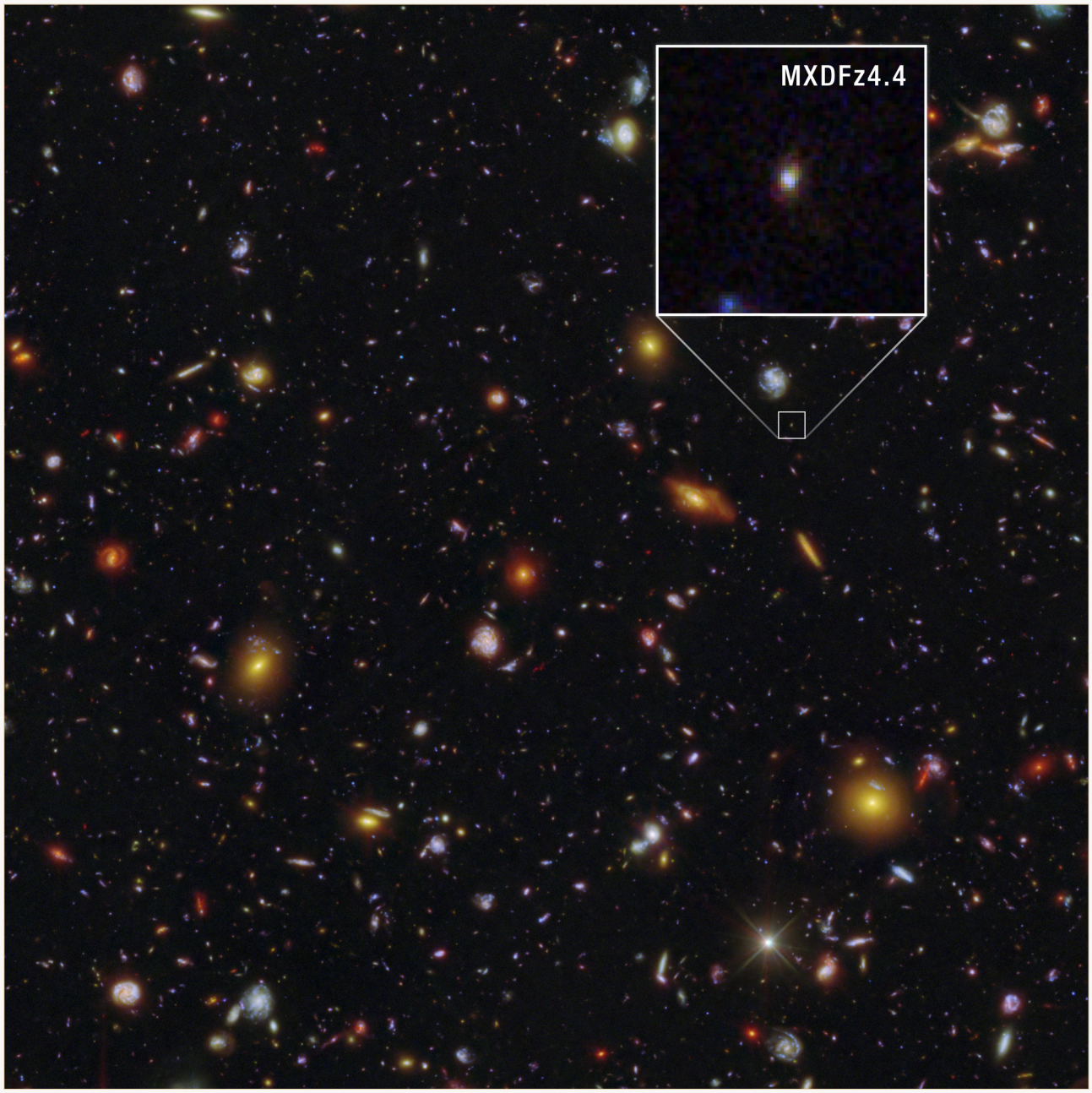
Paper: *MXDFz4.4: A LyC emitter 250 Myr after the epoch of reionization and a first test of Lyman-alpha morphology as a tracer of LyC escape at high redshift*, Ilias Goovaerts, Marc Rafelski, Alexander Beckett, Grecco Oyarzun, Annalisa Citro, Farhanul Hasan, Kalina V. Nedkova, Calum Hawcroft, Anton M. Koekemoer, Mitchell Revalski, Matthew J. Hayes, Claudia Scarlata, Ray A. Lucas, Norman A. Grogin, David V. Stark, Paolo Sun, Nor Pirzkal, and Louis-Gregory Strolger, The Astrophysical Journal (accepted, 2026) · DOI: 10.3847/1538-4357/ae75b0

Hasken da ya kawar da hazo

A cikin ɗaruruwan miliyoyin shekarunsa na farko, sararin samaniya ba ya barin haske ya ratsa sosai. Sarari ya cika da hydrogen mai tsaka-tsaki — atoms da electrons ɗinsu har yanzu suna makale da su — kuma neutral hydrogen yana sha *ionizing* ultraviolet sosai: haske mai gajeren wavelength, ƙasa da 912 ångström (*Lyman limit*), wanda ke da isasshen kuzari don cire electron daga hydrogen atom. Ba duk ultraviolet ne yake yin wannan ba — ultraviolet mai tsawon wavelength ba a sha shi ta hanya ɗaya, kuma muna ganin da yawa daga galaxies na farko — don haka musamman wannan ionizing light ne sararin samaniya na ƙuruciya ya riƙe. Sannan, cikin kusan biliyan ɗaya na shekaru da suka biyo baya, wani abu ya cika cosmos da isasshen irin wannan haske har ya sake cire waɗannan electrons, ya ionize hydrogen, kuma ya bar haske ya yi tafiya cikin ’yanci. Masana taurari suna kiran wannan **epoch of reionization**, kuma waɗanda aka fi zargi su ne galaxies na farko: taurari masu zafi, masu girma kuma masu gajeren rai a cikinsu suna fitar da ionizing ultraviolet da yawa, kuma idan isasshen kashi ya tsere zuwa intergalactic space, za su iya yin aikin.

Matsalar tana cikin kalmar *tserewa*. Mafi yawan ionizing light da galaxy ke samarwa ba ya fita — hydrogen ɗin da ke cikin galaxy ɗin da taurarin suke ƙoƙarin ionize shi ne ke sha shi. Wani kashi kaɗai ne yake fita zuwa sarari, kuma wannan kashi, **escape fraction**, shi ne lamban da ya fi wahalar ɗaurewa a cikin dukan labarin. Mafi muni, a lokacin reionization da kansa hasken da ya tsere kusan ba zai yiwu a kama shi ba: hazo na intergalactic hydrogen da hasken yake taimakawa wajen sharewa yana shan sa tun kafin ya isa gare mu. Saboda haka, don nazarin leakage ɗin, masana taurari dole su duba galaxies da ke zuwa *jim kaɗan bayan* hazo ya ragu, amma har yanzu kusa da zamanin sosai da za su iya zama wakilai.

Kungiyar da Ilias Goovaerts ke jagoranta yanzu ta kama irin wannan leak kusan mafi nisan baya da aka taɓa gani. Ta amfani da deep imaging daga Hubble da JWST, sun ba da rahoton wata galaxy guda mai rauni — MXDFz4.4 — wadda ionizing ultraviolet da ke tserewa daga cikinta ya bayyana a matsayin ɗan tabon haske a cikin wani Hubble filter. Galaxy ɗin tana redshift 4.442, kusan shekaru miliyan 250 bayan reionization ya ƙare: ita ce “leaker” mafi nisa da aka taɓa gano kai tsaye.



MXDFz4.4 (an nuna ta a faɗaɗa a inset) ƙaramin tabon haske ne a wannan deep field na Hubble da JWST — galaxy mafi nisa da aka taba kama kai tsaye tana barin ionizing ultraviolet ɗinta ya tsere, kusan shekaru miliyan 250 bayan cosmic reionization ya ƙare.

Lambar da za ta fi yawo daga wannan takarda ita ce escape fraction, kuma tana da girma — wani wuri tsakanin rabin da kusan dukan ionizing light na galaxy. Wannan lamba tana da asali a bayanai, amma ya dace a yi hankali da abin da “na gaske” yake nufi a nan. Ba a karanta ta kai tsaye daga hoton ba; an sake gina ta ne ta hanyar jerin models, kuma faɗin range ɗin yana da dalili mai gaskiya. Labarin da ya fi amfani yana da ɓangarori biyu: abin da leak ɗin galaxy guda ɗaya da aka kama zai iya faɗa mana da abin da ba zai iya ba, sannan wani sakamako mai natsuwa — gwaji na farko a wannan nisan don duba wata hanya ta *kai tsaye ba* ta gano leakage, kafin mu shiga zamanin da hanyar kai tsaye ta daina aiki gaba ɗaya.

Menene “escape fraction”, kuma me ya sa yake da wuyar auna shi?

Taurari — musamman manya, mafi zafi kuma mafi ƙuruciya — suna fitar da ultraviolet mai isasshen kuzari don cire electrons daga hydrogen atoms. Masana taurari suna kiran wannan ionizing radiation, ko kuma a wavelengths ɗin da ake magana a kai, *Lyman-continuum* light. Wannan shi ne kamar kuɗin reionization: sararin samaniya ya zama transparent lokacin da aka saki isassun photons irin waɗannan don ci gaba da riƙe intergalactic hydrogen a ionized state.

Amma galaxy ma cike take da hydrogen. Mafi yawan ionizing light da galaxy ke samarwa ana sha kafin ya fita — yana ƙarewa yana ionize gas ɗin galaxy ɗin kanta. **Escape fraction** shi ne rabon da ya iya fita zuwa intergalactic space, inda zai iya taimakawa wajen reionize sararin samaniya mai faɗi. Wannan shi ne zuciyar tambayar, kuma yana da wahalar aunawa saboda dalilai biyu.

Na farko, a lokacin reionization intergalactic medium har yanzu yana cike da neutral hydrogen, wanda yake sha daidai hasken da kake son ganowa — saboda haka leaked light yawanci ba ya iso gare mu kwata-kwata. Na biyu, ko da lokacin da *za ka iya* ganin wani ɓangare nasa (jim kaɗan bayan zamanin, ta hanyar wani unusually bayyananne line of sight), canza wannan detection zuwa escape fraction yana nufin raba abin da ka gani da abin da galaxy ta samar — kuma wannan abin da ta samar ma ba ka ganinsa kai tsaye. Dole ne a model shi daga sauran hasken galaxy, inferred star-formation history ɗinta, da assumptions game da taurarin kanta.

Shi ya sa escape fractions suke zuwa da manyan error bars, kuma shi ya sa — idan har absorption na intergalactic medium ma dole a model shi — detection ɗaya na iya goyon bayan answers masu faɗi sosai. Lambar reconstruction ce, ba reading kai tsaye ba.

Abin da marubutan suka yi

- Sun tabbatar da nisan galaxy da deep spectroscopy daga MUSE instrument a VLT, wanda ya kama emission line guda — Lyman-alpha — mai lopsided profile da aka saba gani ga wannan line a high redshift, ya sa redshift ya zama z = 4.442. Sun kiyasta yiwuwar chance foreground alignment da 0.0076%.
- Sun gano escaping ionizing (Lyman-continuum) light a wani deep Hubble F435W image — filter wanda, a wannan redshift, yake ganin kawai hasken ƙasa da 912 ångström da za a iya kirga a matsayin “escaped.” Detection ɗin yana 5.2–5.3σ (sigma yana nuna yadda signal ya tashi sama da expected noise; 5σ threshold ne mai tsauri sosai a statistics, ba hujja ce cewa interpretation ɗin dole ne ya zama gaskiya ba — jagora), kuma sun kwatanta flux ɗin da patches na sararin sama miliyan ɗaya marasa abu don tabbatar da cewa ba noise ba ne.
- Sun kawar da classic trap na irin wannan da’awa — cewa “escaping” light ɗin a gaskiya galaxy ce mai low redshift da ta faɗo a gaban target ɗin bisa sa’a — ta amfani da resolved shape na source da custom de-blending na wata faint neighbour.
- Sun model taurarin galaxy ta fitting cikakken Hubble-plus-JWST colours ɗinta (da CIGALE code da stellar-population models da dama), wanda ya nuna recent burst of star formation ’yan miliyoyin shekaru da suka wuce.
- Sun model adadin ionizing light da intergalactic medium zai sha a hanya, a kan simulated sightlines 10,000, sannan suka haɗa komai don derive escape fraction.
- A karo na farko a wannan nisan baya, sun gwada wata hanyar *indirect* ta ganin escape — shape da extent na Lyman-alpha line (“halo fraction” ɗinta) — da direct detection ɗin.

Abin da suka gano

- Lyman-continuum emitter mafi nisa da aka taɓa gano kai tsaye zuwa yanzu, a z = 4.442.
- Detection na gaske na escaping ionizing light ɗin kansa — ba inference ba, signal ne a image a 5.2–5.3σ.
- Escape fraction mai girma, a range na 50–100%, gwargwadon assumptions — babba, amma model-dependent. (Wani separate *relative* estimate ma ya wuce 100%. Wannan sakamakon yadda aka ayyana shi ne — yana kwatanta escaping ionizing light da ultraviolet na galaxy ba tare da fara gyara dust ba — ba yana nufin haske fiye da wanda taurari suka samar ya tsere ba.)
- Shaida daga fitted starlight cewa recent burst of star formation yana jagorantar duka samarwa da tserewar ionizing light.
- “Cautious support,” a kalmomin marubutan, ga amfani da shape na Lyman-alpha line a matsayin tracer na escape a high redshift.

Abin da wannan ba ya tabbatar

- Ba ya gano “galaxies da suka reionize sararin samaniya.” Galaxy guda ce, kuma tana kusan shekaru miliyan 250 *bayan* reionization ya ƙare, ba a lokacin ba. Mataki ne zuwa zamanin, ba hoto na abin da ya faru ba.
- Escape fraction **ba measurement kai tsaye ba ne**. Ana reconstruction ɗinsa ne ta raba observed light da *modelled* estimate na hasken da aka samar, sannan a gyara da *modelled* amount na intergalactic absorption — kuma marubutan sun zaɓi favourable line of sight da gangan, domin duk galaxy wadda leaked light ɗinta ya iso gare mu dole ta kasance a direction mai tsabta fiye da matsakaici. Faɗin range ɗin (50–100%, da fiye a relative terms) alama ce mai gaskiya ta wannan model dependence.
- Ba ya tabbatar da inganci sabon Lyman-alpha tracer. “Cautious support” daga object guda na farko test ne, ba confirmation ba.
- Ba ya, da kansa, tabbatar cewa bursty star formation ne ya jagoranci reionization. Wannan interpretation ne mai ma’ana daga galaxy guda plus tracer nazari, ba doka da aka nuna kai tsaye ba.

Yaya ƙarfin shaidar yake?

- **Mai ƙarfi** inda shaidar take kai tsaye: redshift (Lyman-alpha line mai shape na musamman, tare da 0.0076% chance na foreground contamination) da detection na escaping light (5.2–5.3σ, an duba da empty apertures miliyan ɗaya, kuma an rufe foreground-interloper trap da hankali — matsalar da ta rushe wasu high-redshift escape ikirarai a baya).
- **Mai rauni fiye, kuma marubutan sun bayyana hakan**, inda abubuwa suke modelled: *darajar* escape fraction (wadda ta dogara da stellar model da chosen intergalactic sightline), “significance” ga reionization (object guda plus interpretation), da sabon tracer (na farko cautious test).
- Gaskiyar takardar tana cikin ranges ɗinta. Ta ba da spans maimakon single numbers, ta kira support ga tracer “cautious,” har ma ta ƙi yarda da wani estimate nata na intergalactic transmission. Takarda ce mai hankali wadda ba ta overstating kanta; haɗarin hype yana daga wajen takardar ne.

Me ya sa yake da muhimmanci

Direct detections na escaping ionizing light yanzu sun kusanto epoch of reionization kusan iyakar inda har hasken zai iya, da ƙyar, ratsa. Wannan yana da daraja da kansa. Amma sakamakon da ya fi shiru na iya zama mafi muhimmanci: da zarar ka shiga *cikin* reionization, direct method ta daina aiki gaba ɗaya, kuma komai ya dogara da indirect tracers da aka calibrate da galaxies na kusa masu sauƙin gani. Gwada ɗaya daga cikin waɗannan tracers a nan, inda har yanzu za ka iya kwatanta shi da real detection, shi ne yadda za ka samu dalilin yarda da shi daga baya, inda ba za ka iya duba kai tsaye ba. Darajar MXDFz4.4 ba sosai “mun gano galaxy da ta reionize sararin samaniya” ba ce; ta fi zama “muna koyon yadda ake karanta leakage, kuma muna fara duba kayan aikinmu kafin duhu.”

Takaitaccen bayani mai tsabta

Masana taurari da suka yi amfani da Hubble da JWST sun gano kai tsaye ionizing ultraviolet da ke tserewa daga galaxy guda a redshift 4.442 — detection mafi nisa irin wannan zuwa yanzu, kusan shekaru miliyan 250 bayan cosmic reionization ya ƙare. Detection ɗin kansa yana da ƙarfi. Escape fraction na 50–100% da zai iya zama kanun labarai ba measurement ba ne, reconstruction ne ta models na taurarin galaxy da intergalactic absorption a deliberately favourable sightline, shi ya sa range ɗinsa ya yi faɗi. Tare da detection ɗin, ƙungiyar ta yi gwajin high-redshift na farko na wata indirect method don gano escaping light — shape na Lyman-alpha line — kuma ta samu “cautious support” gare ta. Sakamako ne mai hankali daga object guda: real catch na leakage, lamba mai gaskiyar uncertainty a haɗe da shi, da mataki na farko zuwa kayan aikin da masana taurari za su buƙata lokacin da leakage ɗin ba zai sake kasancewa abin gani kai tsaye ba.

Binciken No-BS

Abin da takardar ta nuna: Direct detection a 5.2–5.3σ na escaping ionizing (Lyman-continuum) light daga galaxy a z = 4.442 — highest-redshift detection irin wannan zuwa yanzu — tare da foreground-contamination trap da aka kawar da shi da hankali.

Abin da yake yiwuwa amma ba a tabbatar ba: Cewa escape fraction na galaxy yana 50–100%. Detection na gaske ne; fraction reconstruction ne ta stellar-population da intergalactic-absorption models (a favourable sightline), shi ya sa yake da range mai faɗi. Haka kuma mai yiwuwa amma ba a tabbatar ba: cewa shape na Lyman-alpha line yana aiki a matsayin escape tracer a wannan nisan — takardar tana ba da “cautious support” daga object guda.

Abin da ba ya nuna: Cewa wannan galaxy ce “da ta reionize sararin samaniya” (tana bayan zamanin, kuma object guda ce), ko cewa bursty star formation ne ya jagoranci reionization (interpretation ne, ba demonstration ba).

Babban limitations: Sample na object guda; escape fraction da ya dogara da model choices da deliberately bayyananne sightline; na farko cautious test na sabon tracer; da wahalar nazarin escaping ionizing light kusa da zamanin inda yake zama invisible.

Nawa ne amincewar da mai karatu na gama gari ya kamata ya yi? Mai girma cewa escaping light ɗin an

gano shi da gaske, kuma wannan shi ne detection mafi nisa irin wannan zuwa yanzu. Kasa zuwa matsakaici kan ainihin escape fraction — a ɗauki “50–100%” a matsayin modelled range, ba measurement ba. Matsakaici kan sabon tracer: promising na farko check ne, ba settled tool ba.

Sabuntawa bayan wallafawa

- **Gyara · 2026-07-28**

  Bayan feedback daga Ilias Goovaerts, ɗaya daga marubutan paper, an gyara farkon article ɗin ya gabatar da ionizing light tun daga farko maimakon ultraviolet gaba ɗaya, tare da bayyana cewa ultraviolet mai gajeren wavelength — kasa da Lyman limit na 912 ångström — ne kaɗai ke ionizing, yayin da ultraviolet mai tsawon wavelength ba ionizing ba ne kuma ana ganinsa akai-akai daga high-redshift galaxies.

Majiyoyi

Goovaerts et al., arXiv:2603.04517 (accepted in The Astrophysical Journal)
https://arxiv.org/abs/2603.04517

The Astrophysical Journal (2026), DOI 10.3847/1538-4357/ae75b0
https://doi.org/10.3847/1538-4357/ae75b0