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Solving reionization with HWO

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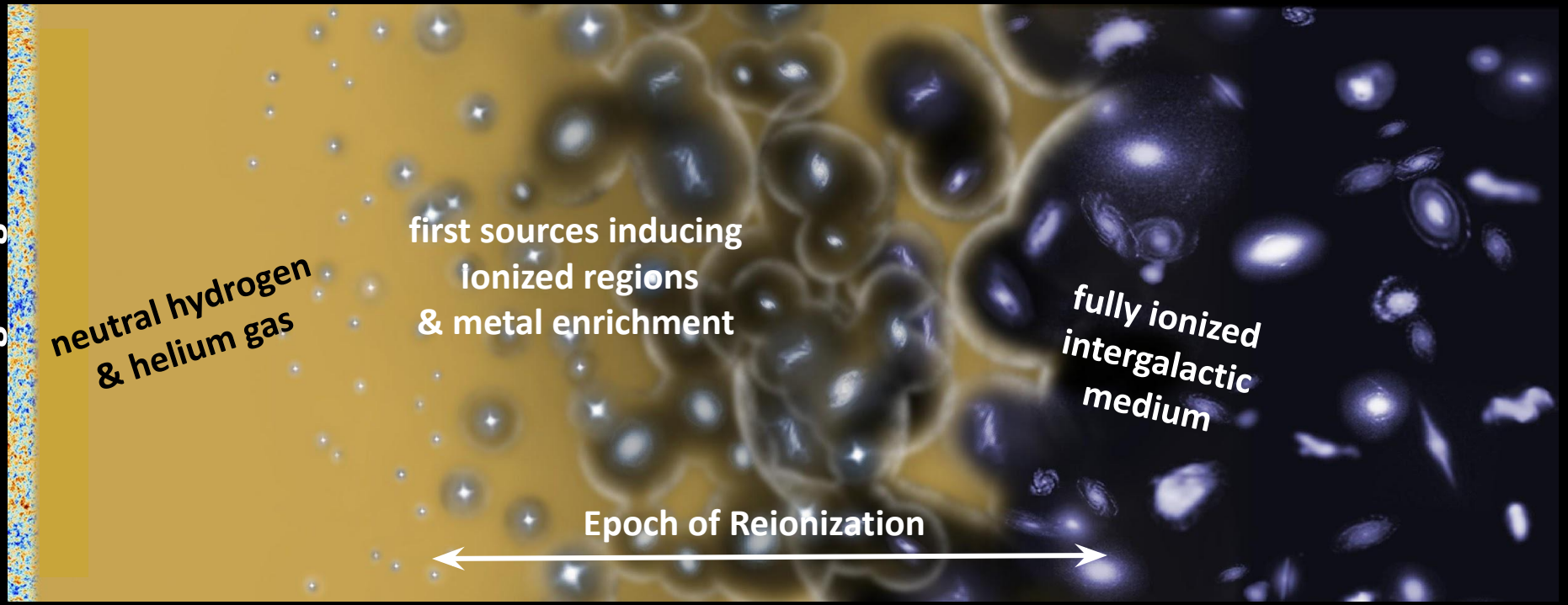
NATIONAL INSTITUTE FOR ASTROPHYSICS

SHAPING THE ITALIAN CONTRIBUTION TO HWO

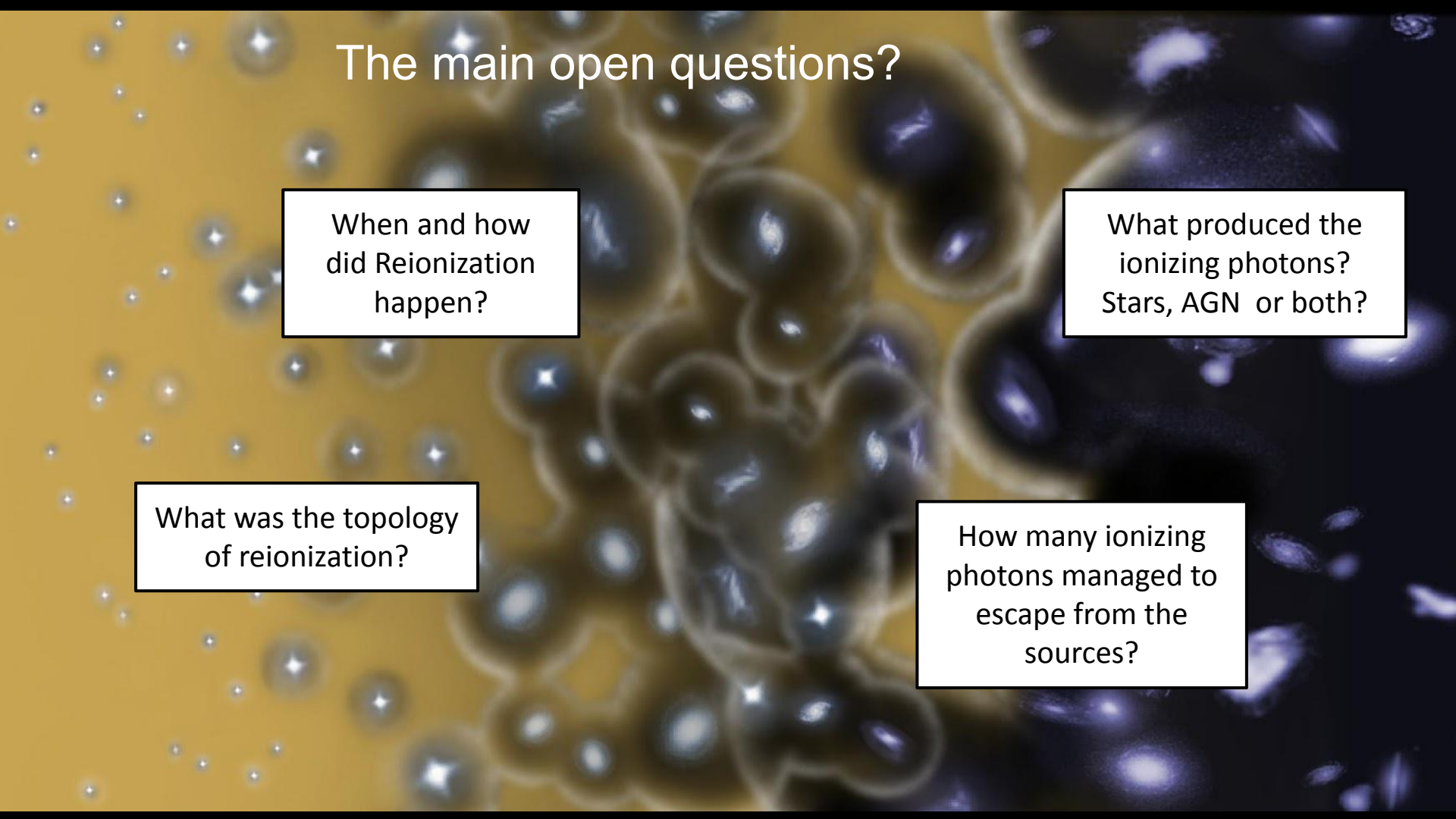
OAR

Our Universe: 13.8 billion years of history in a picture



Credit: ESA

The main open questions?



The equations governing reionization:

$$\frac{dQ_{\rm HII}}{dt} = \frac{\dot{n}_{\rm ion}}{\langle n_H \rangle} - \frac{Q_{\rm HII}}{t_{\rm rec}},$$

ionization

recombination

$$\bar{t}_{\rm rec} = [(1+2\chi)\bar{n}_p \alpha_B \, C]^{-1}$$

$$C \equiv \langle n_p^2 \rangle / \bar{n}_p^2$$

clumping

Reionization is completed when:

$$\dot{n}_{\rm ion} \bar{t}_{\rm rec} \gtrsim \bar{n}_{\rm H},$$

The total ionizing radiation $\dot{n}_{ion}$: the "ingredients"

$$\dot{n}_{ion} = \rho_{UV}\, \xi_{ion}\, f_{esc}$$

ϱ_{UV}= the total density of UV photons

↓

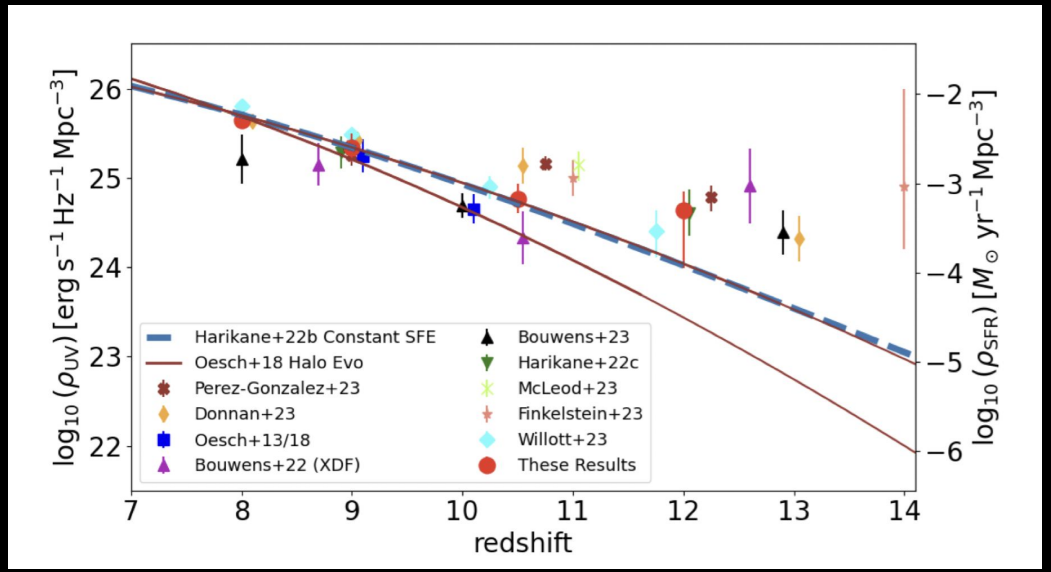
combined from galaxies and AGN

ξ_{ion} = the photon production efficiency (how many ionizing photons per UV photon)

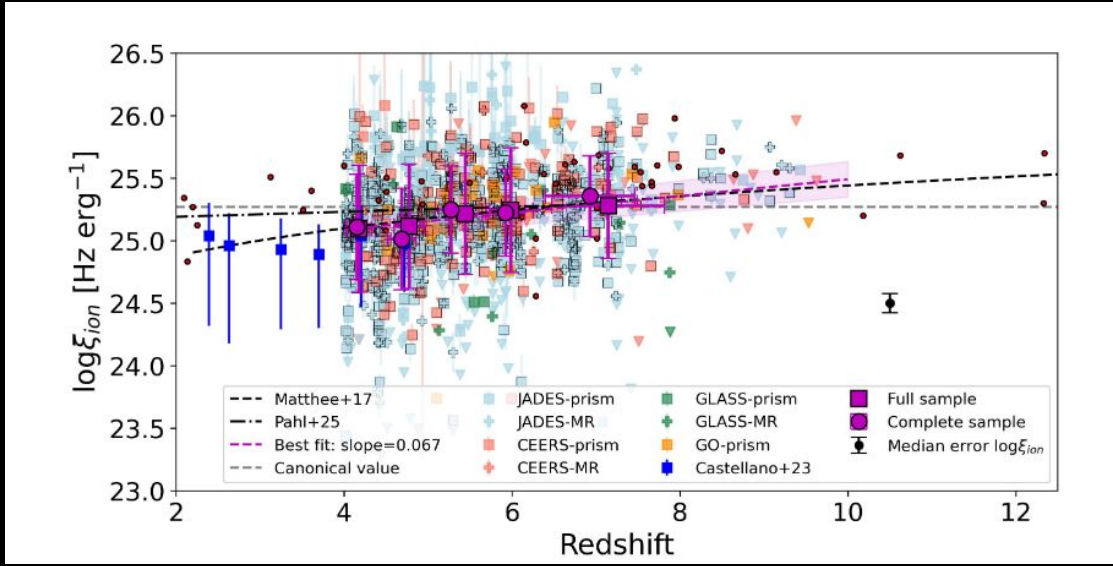
f_{esc} = the fraction of ionizing photon escaping to the IGM

$$\rho_{UV} = \int_{Lmin}^{Lmax} L\,\Phi\,(L) dL$$

ϱ_{UV}= the total density of UV photons



Adams+25 with results from Harikane+23, Perez-Gonzalez+23 Donnan+23, Willlot+23 and other programs



Llerena+24
see also
Simmonds+24
Phal+25

$$\xi_{\rm ion} = \frac{N({\rm H}^0)}{L_{\rm UV,cor}} [{\rm s}^{-1}/{\rm erg\ s}^{-1}\ {\rm Hz}^{-1}].$$

$$N({\rm H}^0)[{\rm s}^{-1}] = \frac{1}{1.36} \times 10^{12}\, L_{\rm H\alpha,cor}[{\rm erg\ s}^{-1}].$$

ξ_{ion} = the photon production efficiency

The total ionizing radiation $\dot{n}_{ion}$: the "ingredients"

$$\dot{n}_{ion} = \rho_{UV}\ \xi_{ion}\ f_{esc}$$

??

f_{esc} = the fraction of ionizing photon escaping to the IGM

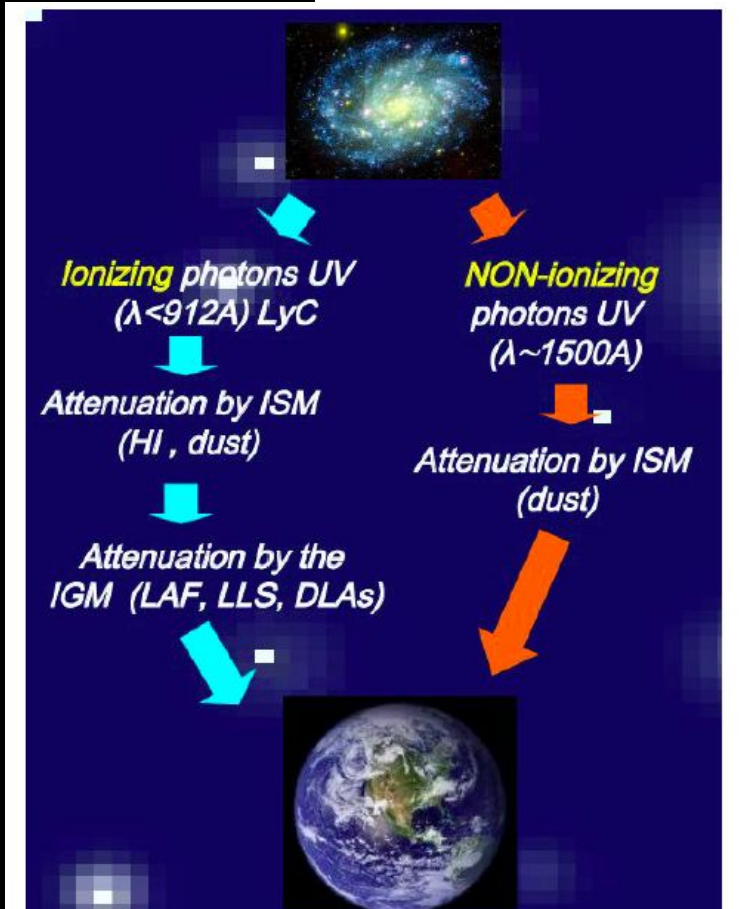
ϱ_{UV}= the total density of UV photons

ξ_{ion} = the photon production efficiency

The escape fraction of LyC radiation

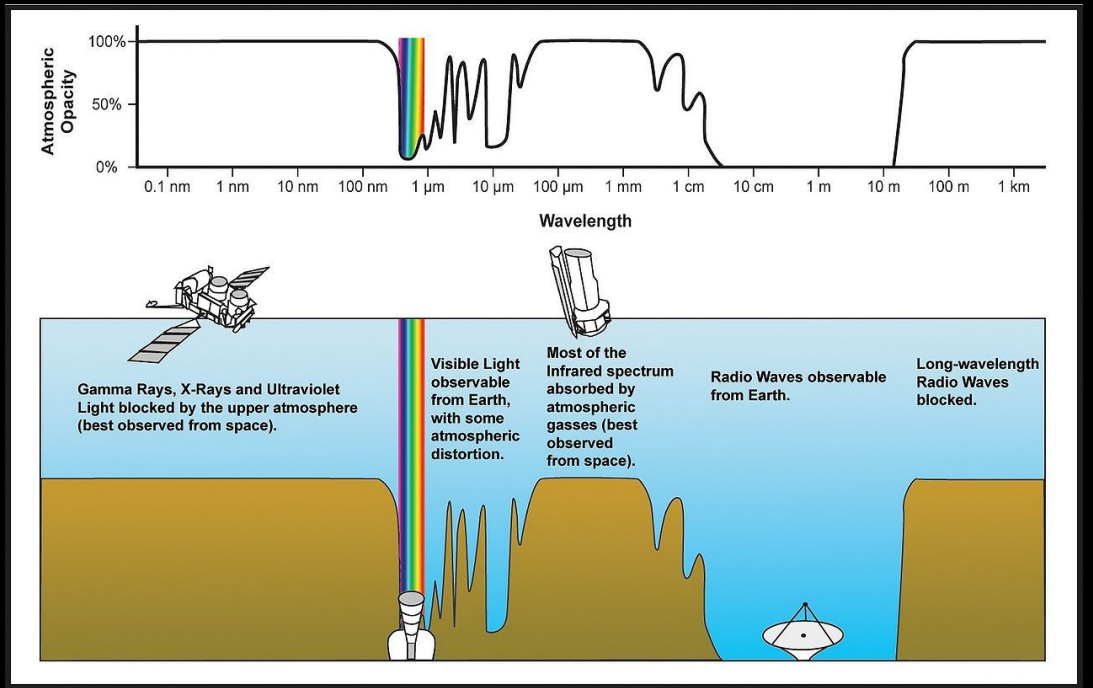
$$\dot{n}_{ion} = \rho_{UV}\, \xi_{ion}\, f_{esc}$$

→ In galaxies usually a tiny fraction of the produced ionizing photons can escape since the dust and gas effects within ISM/CGM/IGM are very important



1st challenge: our atmosphere

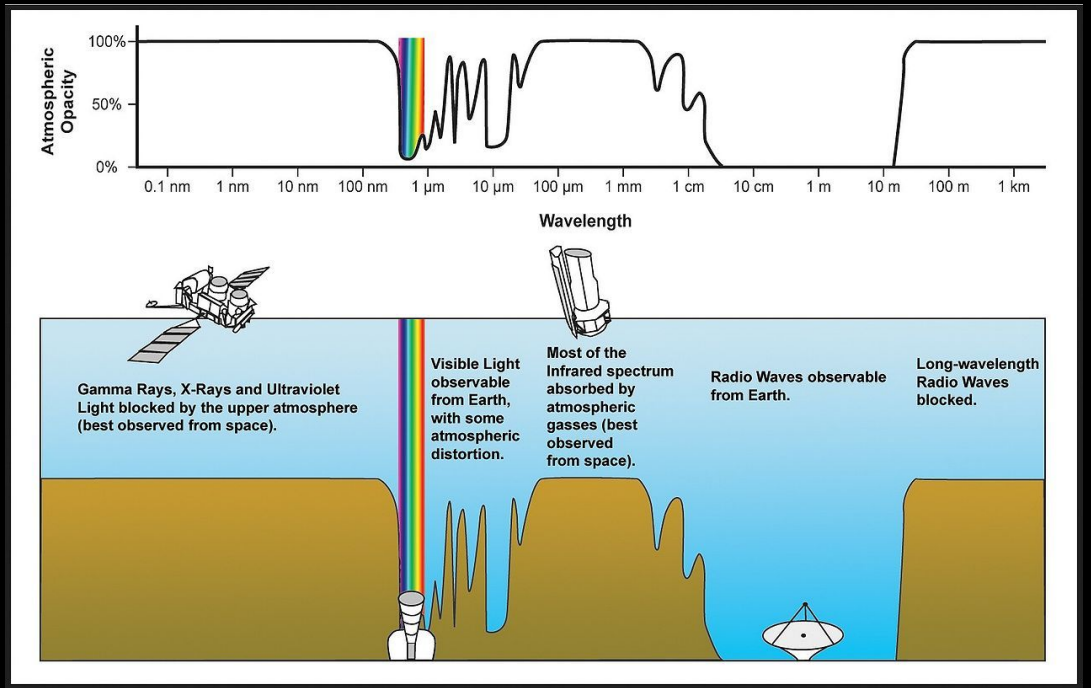
The restframe range of Lyman continuum emission (800-910 Å) is NOT observable from Earth for z<2.5



1st challenge: our atmosphere

The restframe range of Lyman continuum emission (800-910 Å) is NOT observable from Earth for $z<2.5$

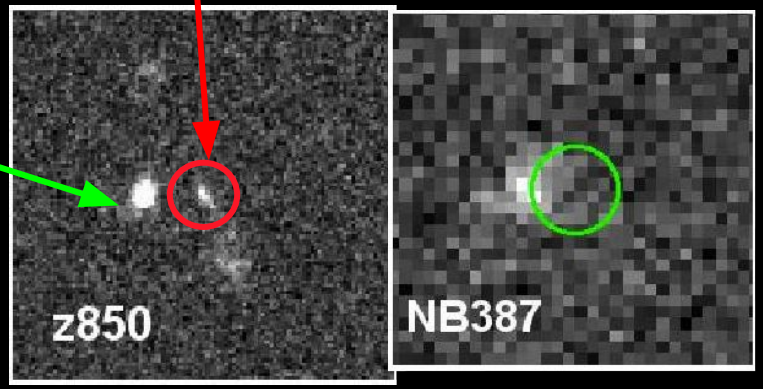
for **low redshift** galaxies we need a UV space telescope



2nd Challenge: confusion
a**t intermediate redshift,** the presence
of interlopers can mimic the LyC flux

redshift 3 galaxy

the flux in NB387 band
actually comes from the nearby
galaxy at another redshift
(so it is NOT lyC radiation)



band with
non -ionizing
continuum

band with
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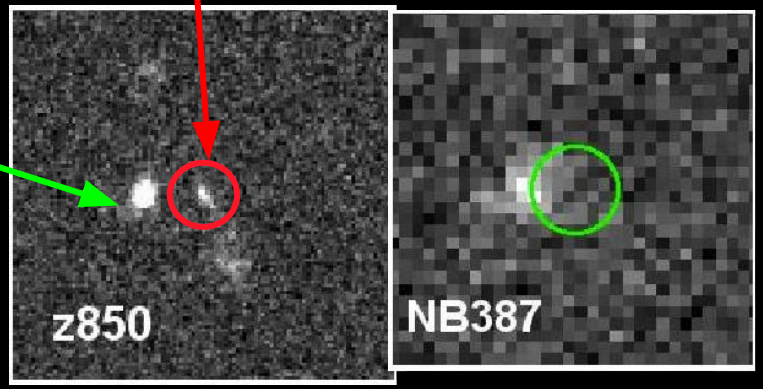

band with
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continuum

band with
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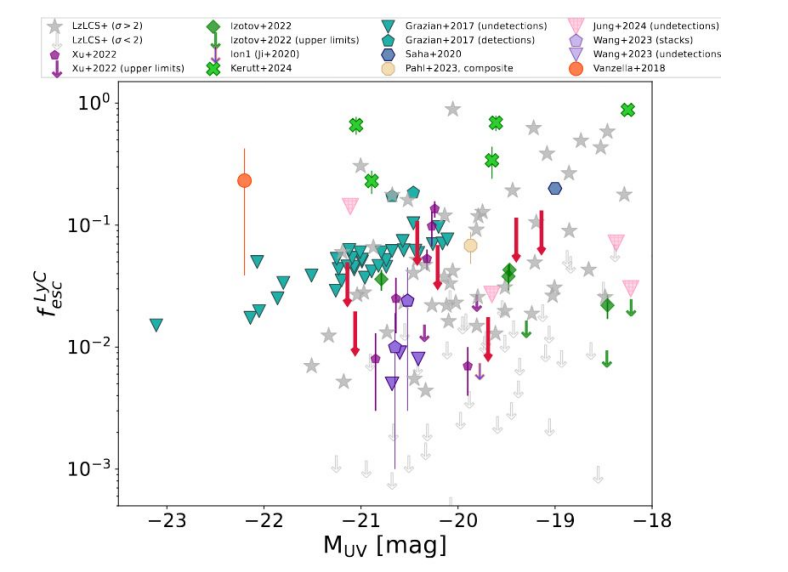
we need high spatial
resolution
(a big space telescope)

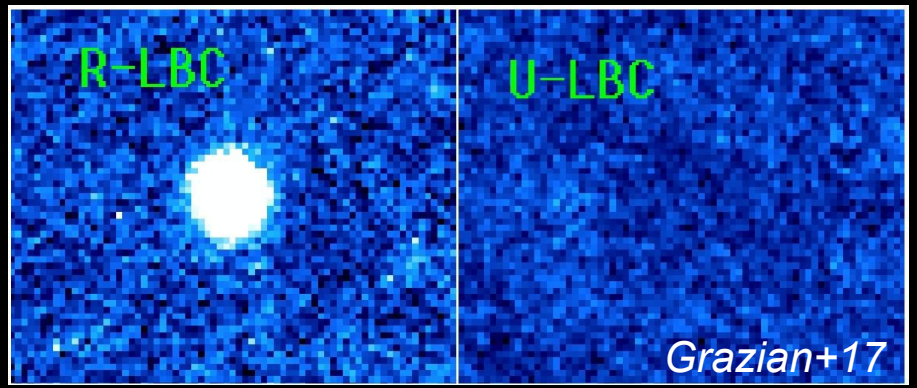
3rd challenge: LyC flux is very faint since most sources have very low f_{esc}(LyC)



Flury+22, see also Grazian+17, Marchi+17, Guaita+15,Liu+23, Begley+22, Saxena+20 Smith+20, Jung+24 etc

Stringent constraints from stacking analysis

stack of 69 3.27<z<3.40 galaxies



non -ionizing ionizing

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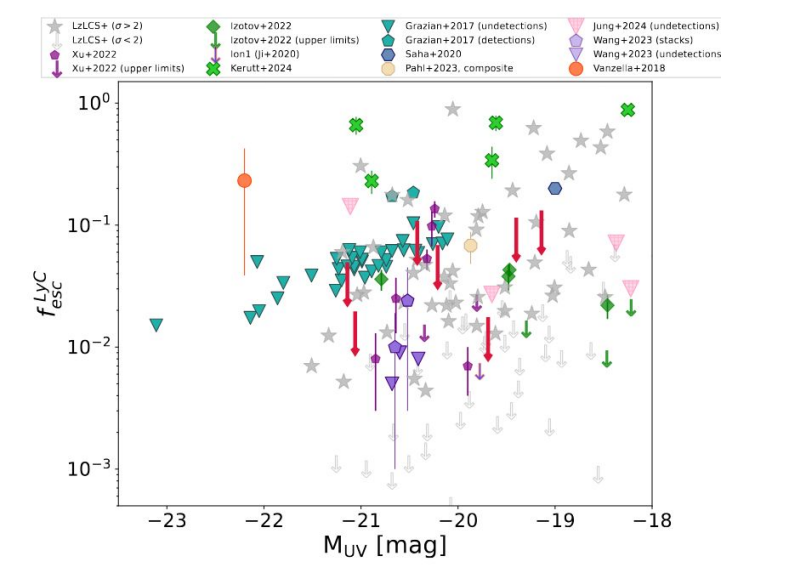

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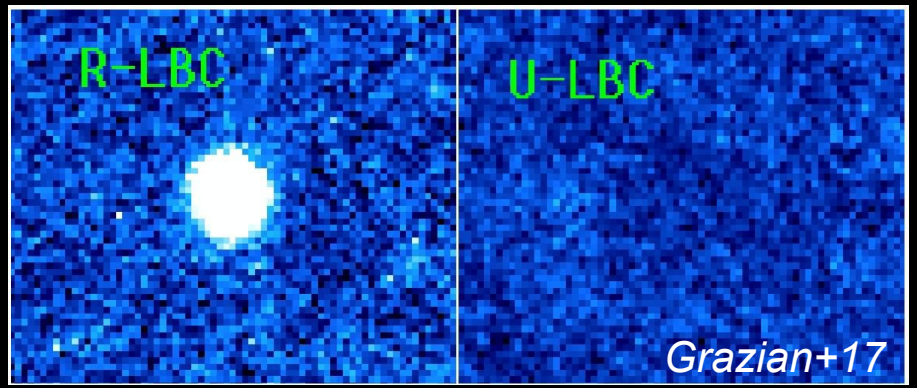
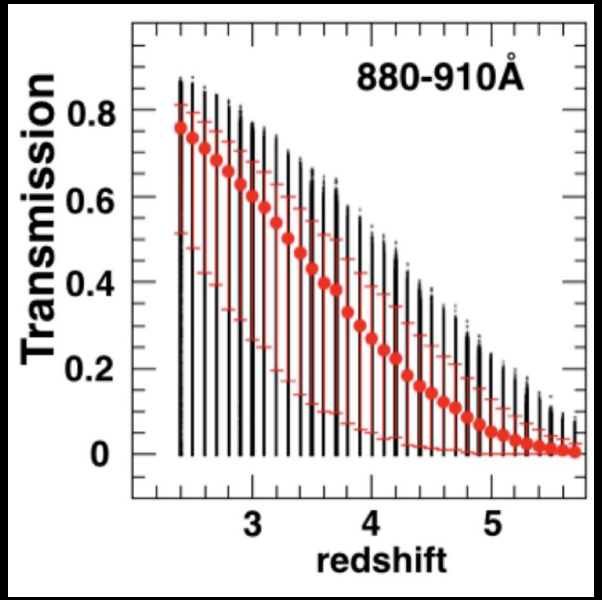


non -ionizing ionizing

we need sensitivity
(a big telescope)

The final challenge!!

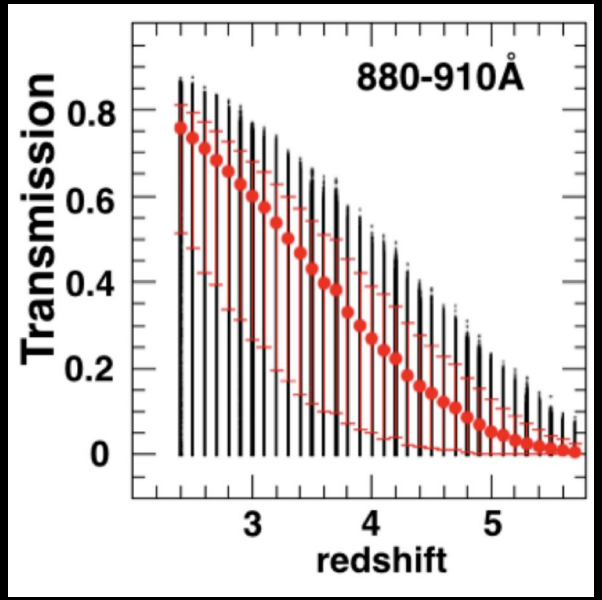


Vanzella+16

Direct detection of ionizing radiation is <u>impossible</u> at z>4.5 given the very high IGM opacity

By definition we are not able to measure a key ingredient of reionization for the galaxies in this epoch

The final challenge!!



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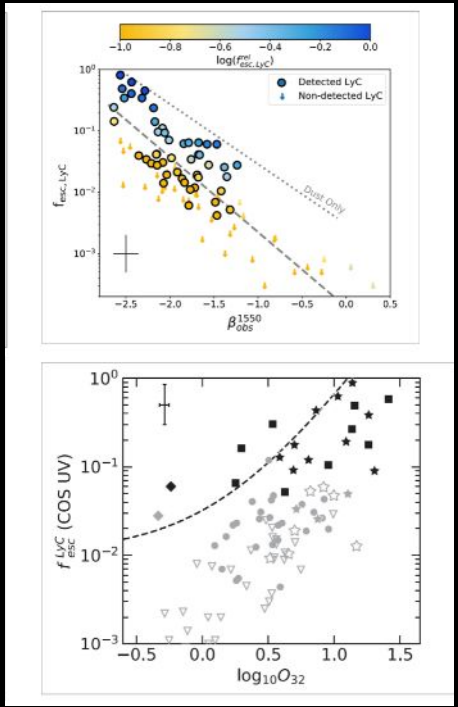
we need to understand the physical mechanism of LyC escape

indirect tracers of Lyman Continuum emission

At low redshift, many properties correlate (or anti-correlate) with LyC emission



The connection between f_{esc}(LyC) and indirect indicators :

f_{esc}(LyC) correlates to Lyα, OIII/OII, ΣSFR, CIV …

f_{esc}(LyC) anti-correlates with UV size, UV slope, dust…

all correlations are very scattered: complex problem

Chisholm+22, Flury+22, Citro+25

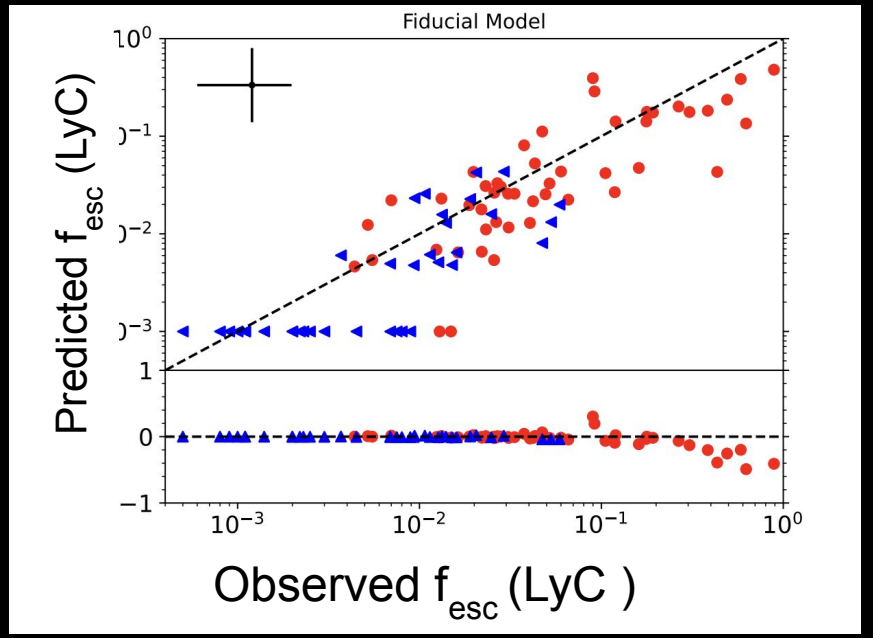
Multi-variate diagnostics of Lyman Continuum emission

- To predict the LyC emission we use a combination of several physical and spectroscopic parameters that show strong (anti) correlations with LyC

  We use Cox proportional hazards models (a survival analysis technique to best incorporate also upper limits)

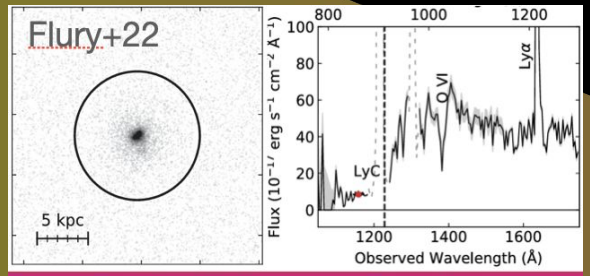
Jaskot+24a,b see also Mascia+23,Mascia+24, Lin+24, Chisholm+22, Chustikov+24, Chustikov+23

Model based on log(O32), UV-β and ΣSFR (Jaskot+24a)

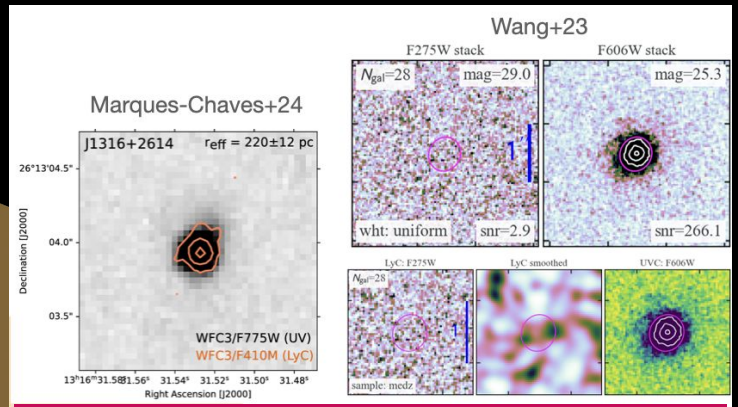


The escape of LyC radiation over cosmic time
- state of the art -

IGM transmission



About **90** galaxies with accurate f_{esc}(LyC) measurements and physical properties (Flury+22a,b)



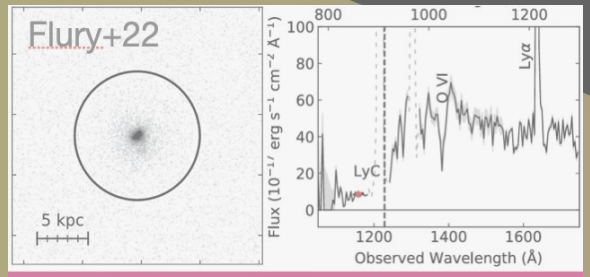
About **10** solid Individual detections of LyC leakers (Sunburst arc, Ion1, Ion2, J1316…) or limits from stacks

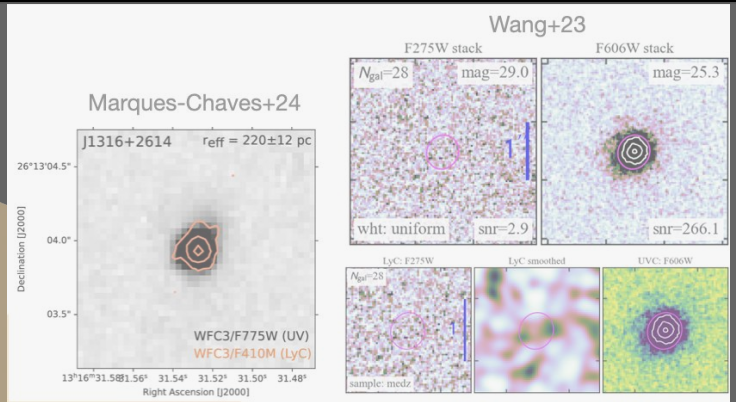
indirect tracers based on low-z

low redshift — cosmic noon — reionization

The escape of LyC radiation over cosmic time
- wish list -

IGM transmission





Spatially resolved studies to understand the physics

A much larger statistics to understand evolutionary trends in the LyC escape mechanisms

Predictions from solid models

low redshift

cosmic noon

reionization

What could HWO do with a UV spectrometer ?

CURRENT

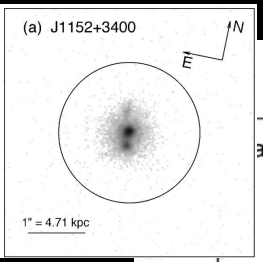
WISH

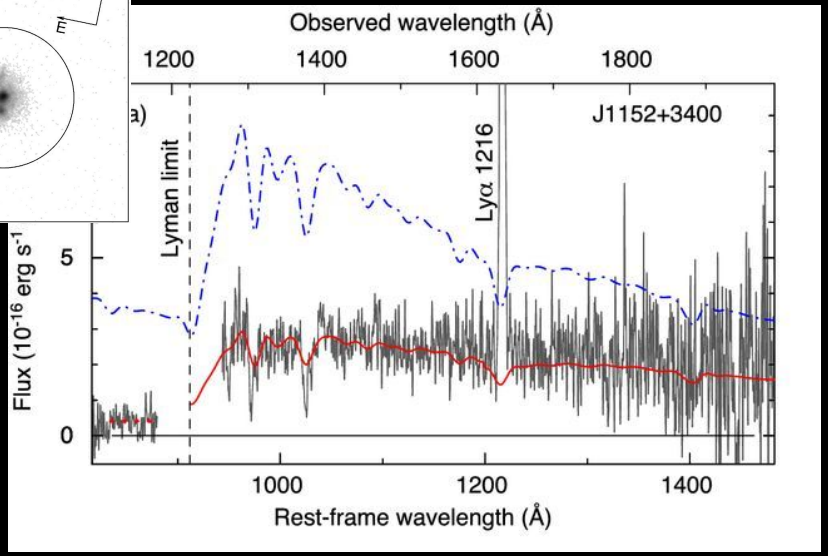
Table 1: Progress in galaxy sample and UV luminosity.

Physical Parameter	**State of the Art**	**Incremental Progress (Enhancing)**	**Substantial Progress (Enabling)**	**Major Progress (Breakthrough)**
Number of galaxies in the studied sample	~ 90	~ 400 ($\sim$ 2-fold S/N increase)	~ 2000 ($\sim$ 5-fold S/N increase)	~ 40000 ($\sim$ 20-fold S/N increase)
UV luminosity (*in L^* units*)	$L \sim L^*$ ($M_{UV} \sim -18$)	$L \sim 0.5L^*$ ($M_{UV} \sim -17.2$)	$L \sim 1/10L^*$ ($M_{UV} \sim -16.5$)	$L \sim 1/100L^*$ ($M_{UV} \sim -13$)
Apparent m_{UV} at $z \sim 0.1$	20	21	22.5	25

Citro+25

LyC-leaking starburst J115205 + 340050
z=0.3 f_{esc}(LyC) =13% S/N=10





Izotov+17

12 HST obits with COS

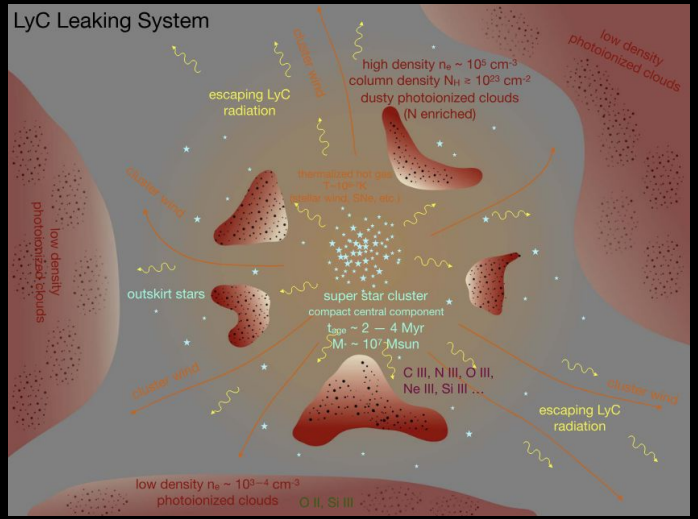
with the FUV channel of POLLUX spectrometer
-27 minutes with an 8m telescope
-45 minutes wth a 6m

Carr+25

What could HWO do with a UV IFU ?

Spatially resolved studies (UV to optical) of low redshift leakers
→ understand the physics of LyC escape

- map the sites of ionizing photon production
- map the channels through which the photons can escape
- map the conditions facilitating the lyC escape



A cartoon illustrating a physical picture for the LyC leaking star cluster of Sunburst Arc derived from joint analysis of photometry and spectroscopy data (Pascale+23)

Further science objectives

- What is the dominant source of feedback governing LyC escape across different galaxy populations?
- How does feedback (mechanical vs. radiation) shape the distribution of neutral gas and dust in galaxies to allow LyC escape?
- How does the LyC escape fraction evolve relative to the star formation episode or baryon cycle?
- What is the appropriate timeline for LyC escape?
- What are the roles of different stellar population

Some recent papers on these science cases with HWO: Citro+25 arXiv:2507.03171
Carr+25 arXiv:2506.23105
Xu+25 arXiv:2507.01312
McCandliss+25 arXiv:2507.02178