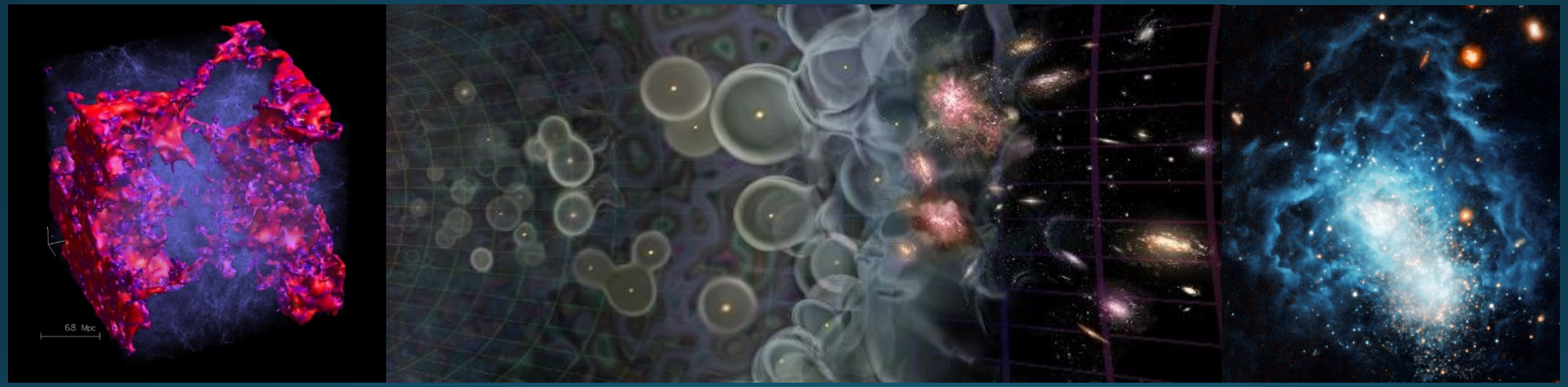
JWST as a probe of Lyman continuum leakage from galaxies in the reionization epoch



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Punchline

Did galaxies reionize the Universe?

- Are there enough star-forming galaxies at high z?
- *Were the ionizing photons able to escape into the IGM?*

New science case for spectroscopy with JWST/NIRSpec:

Indirect measurements of the escape of ionizing radiation from galaxies at redshift z ≈ 6-9

Zackrisson et al. 2013, ApJ, 777, 39

What caused cosmic reionization?

IGM studies (e.g. Lyα, 21 cm, CMBR) can reveal *when* reionization happened, but where did the ionizing photons come from?

Star-forming galaxies at $z > 6$ are the prime suspects, but how do we prove that they did it?

A few alternatives: Population III stars, miniquasars, microquasars, annihilating dark matter…

CMBR

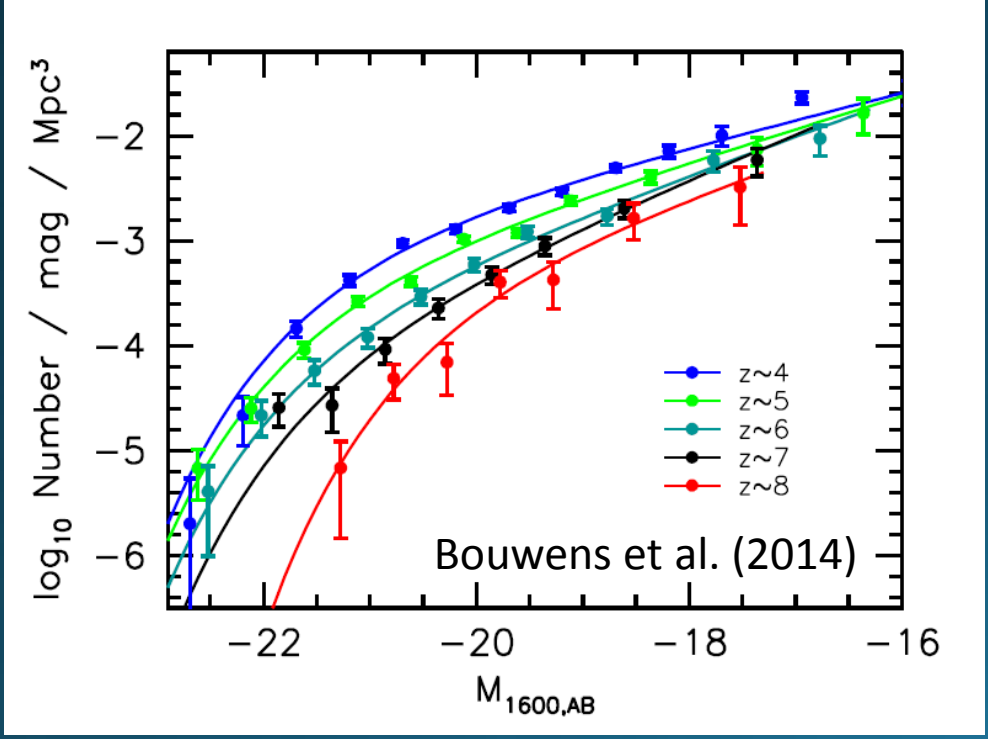
Reionization
($z \approx 6$-14)

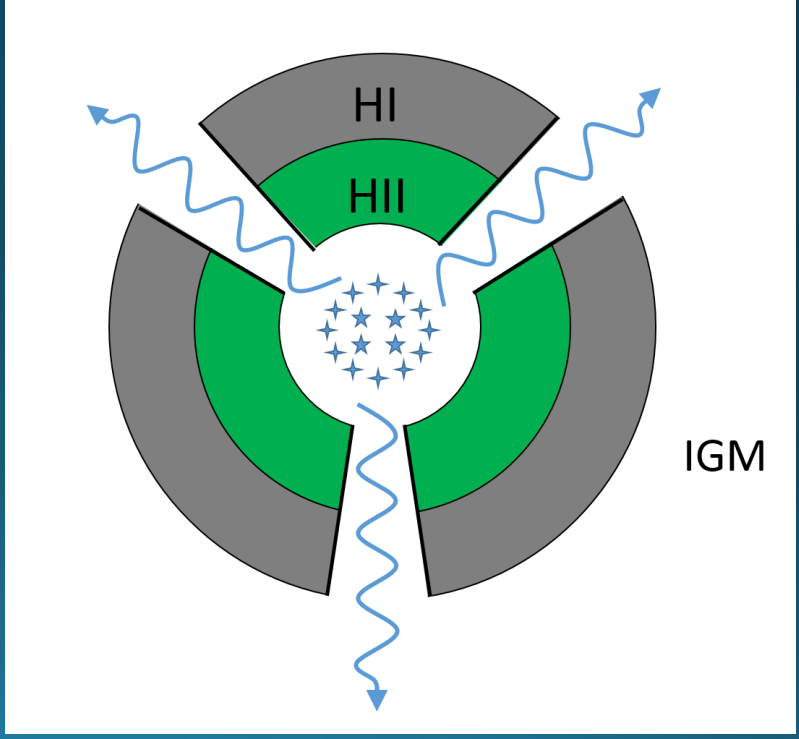
Today

Ionizing photon budget relevant for reionization: $\dot{N}_{\rm ion} \propto \rho_{\rm UV} f_{\rm esc}$

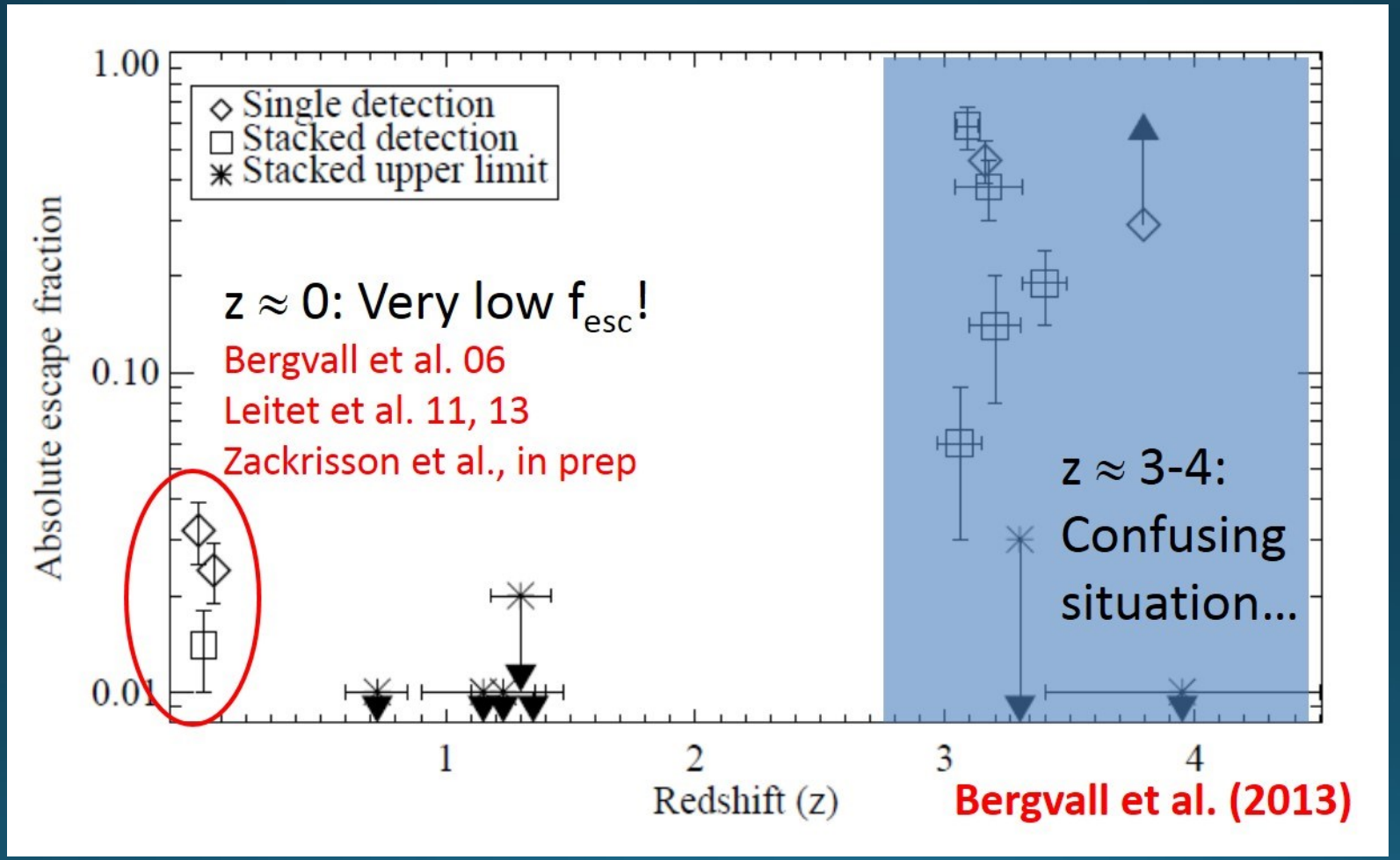
$\rho_{\rm UV}$: From observed z > 6 galaxy luminosity function

$f_{\rm esc}$: Escape fraction of ionizing photons (Lyman continuum)





Escaping ionizing radiation – our current view



Serious problem: At z > 4-5, the IGM opacity prevents direct detection of escaping Lyman continuum (Inoue & Iwata 2008)

Escaping ionizing radiation – the future

Two approaches:

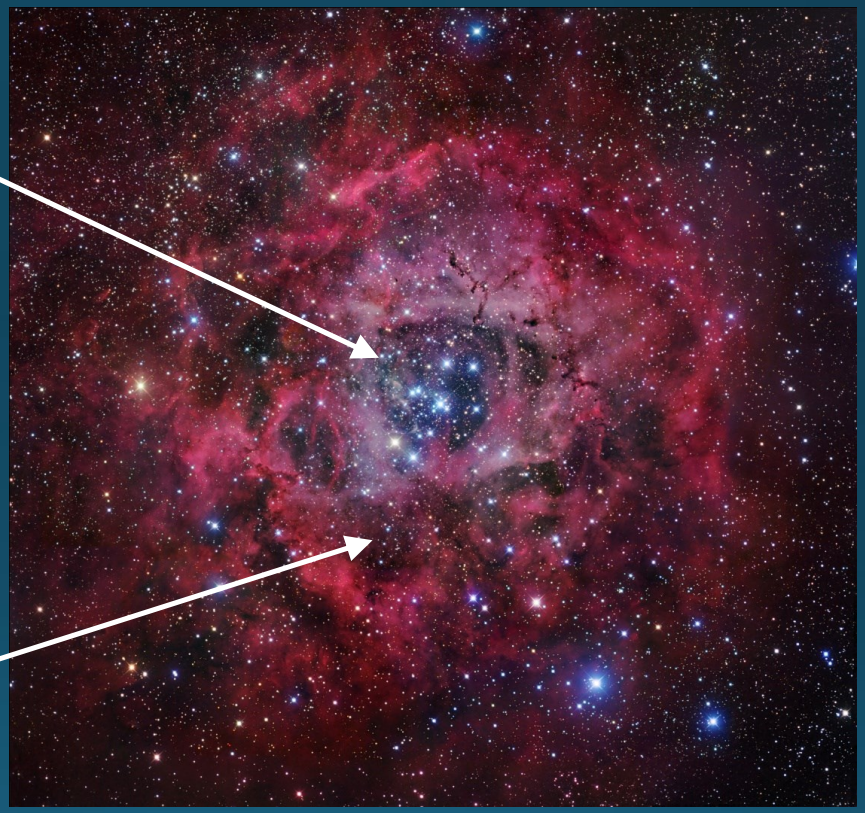
1. Measure f_{esc} at low redshift ($z \approx 0$-4) and extrapolate (somehow) into the reionization epoch ($z>6$)
2. Use indirect methods to constrain f_{esc} at $z > 6$
   Ono et al. (2010), Fernandez et al. (2012), Pirzkal et al. (2012, 2013)

New science case for JWST/NIRSpec:

Indirect measurements of f_{esc} for galaxies @ $z \approx 6$–9
Zackrisson et al. 2013, ApJ, 777, 39

How does this work?

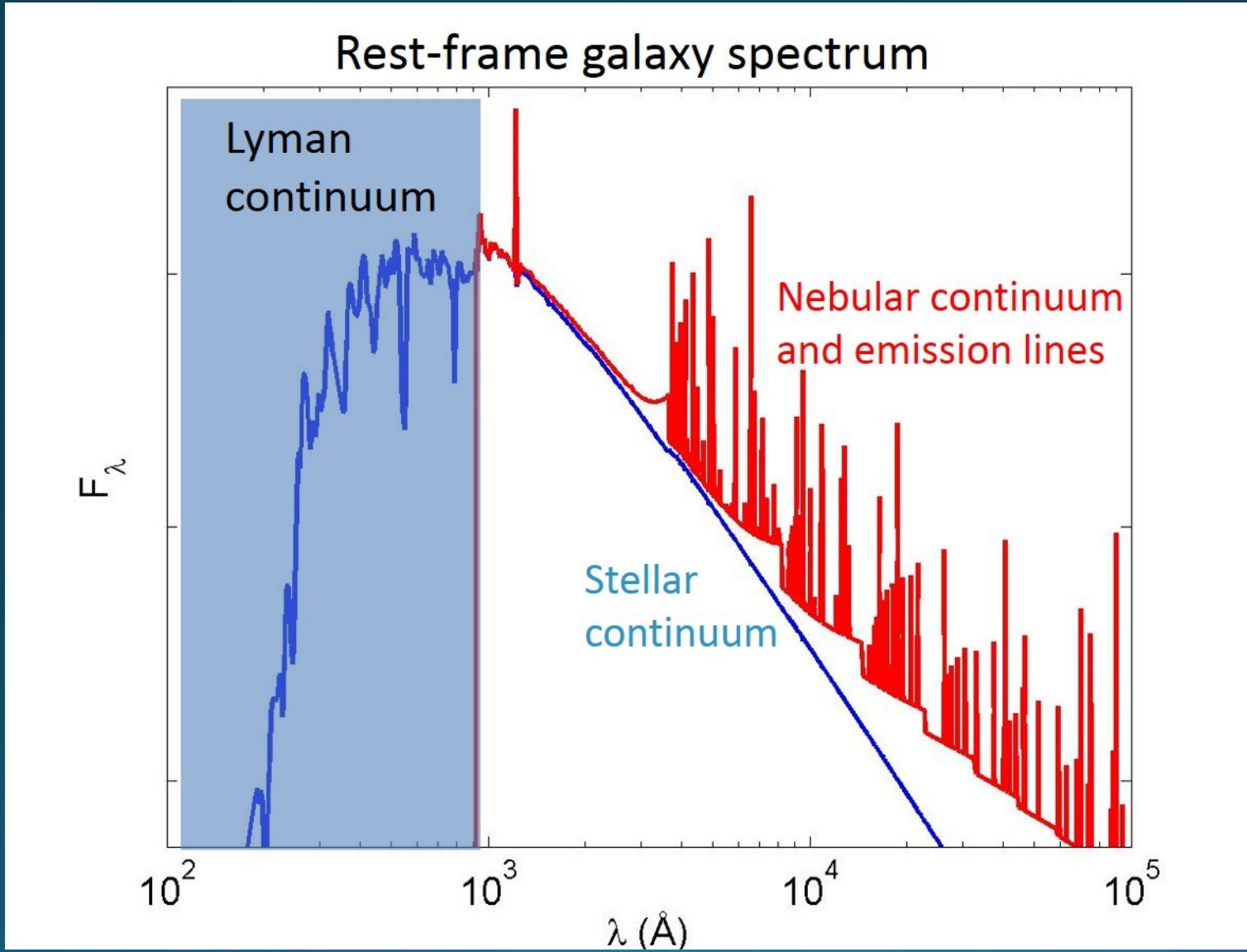
Young stars



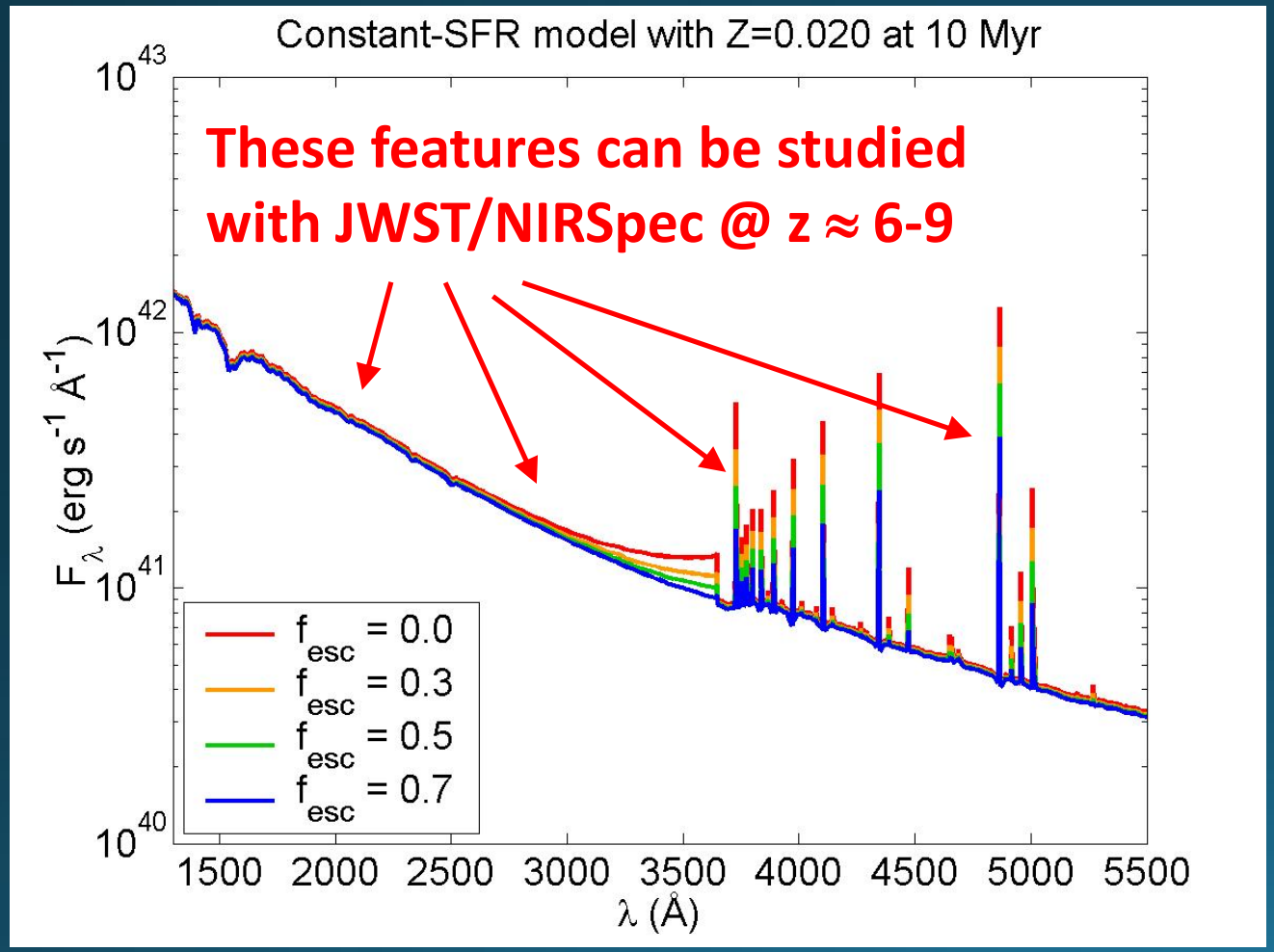
Lyman continuum photons from young stars captured by gas
→ Nebular emission

If some of the Lyman continuum photons escape without ionzing the ISM → Less nebular emission!

Nebular emission made simple



Spectral signatures of Lyman continuum leakage



The f_{esc} information is imprinted in the spectrum – you just have to find some clever way of extracting it!

Zackrisson et al (2013)

- Pop I, II, III stars
- Nebular emission (Cloudy)
- Rest-frame SEDs (far-UV to near-IR)
- SDSS/HST/Spitzer/JWST/ WISH broadband fluxes @ z = 0-15

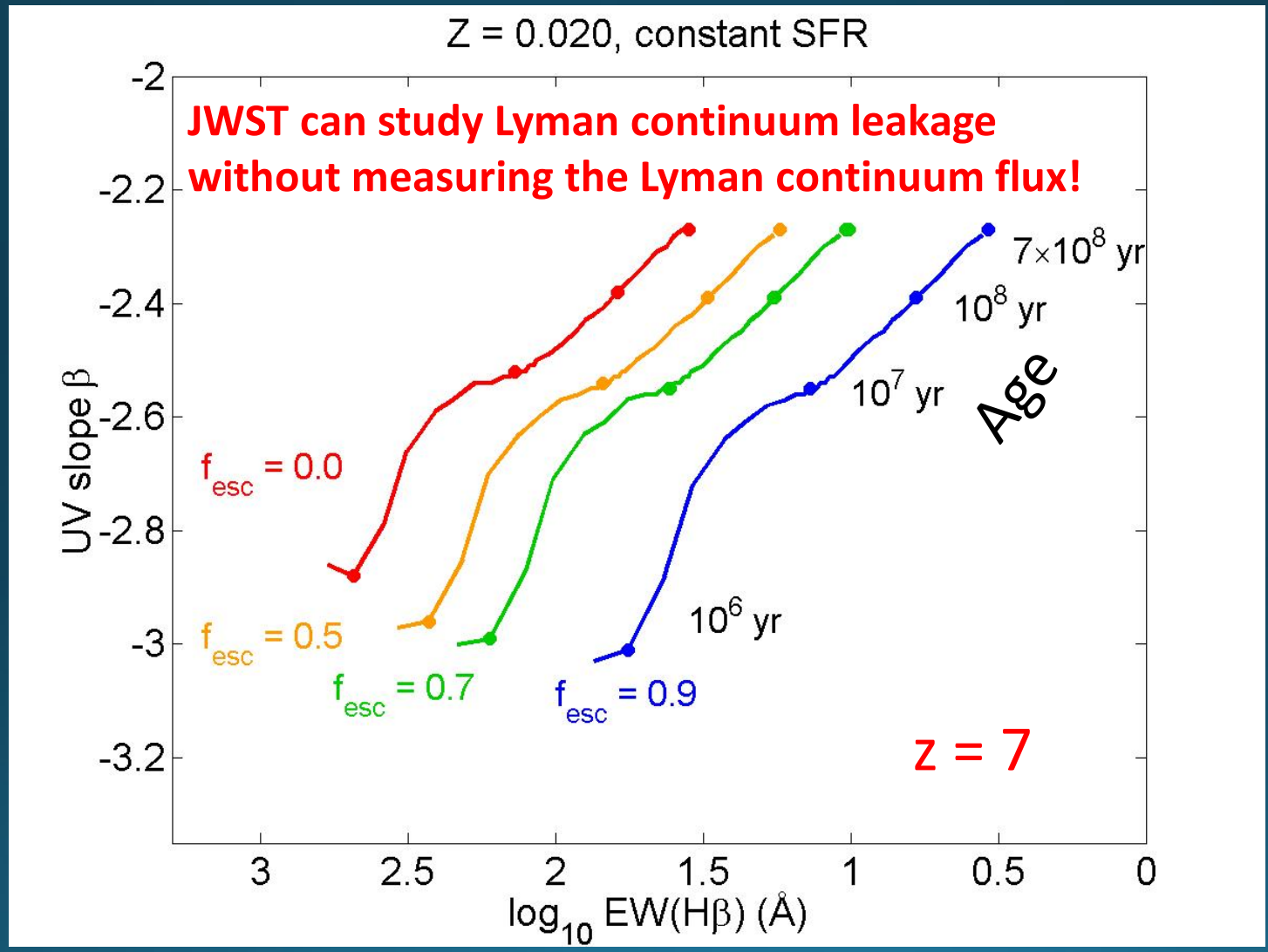
The Yggdrasil code

A spectral synthesis model for the first galaxies

Model grids available at: www.astro.su.se/~ez

Zackrisson et al. 2011, ApJ, 740, 13

Simple diagnostics: UV slope & EW(Hβ)

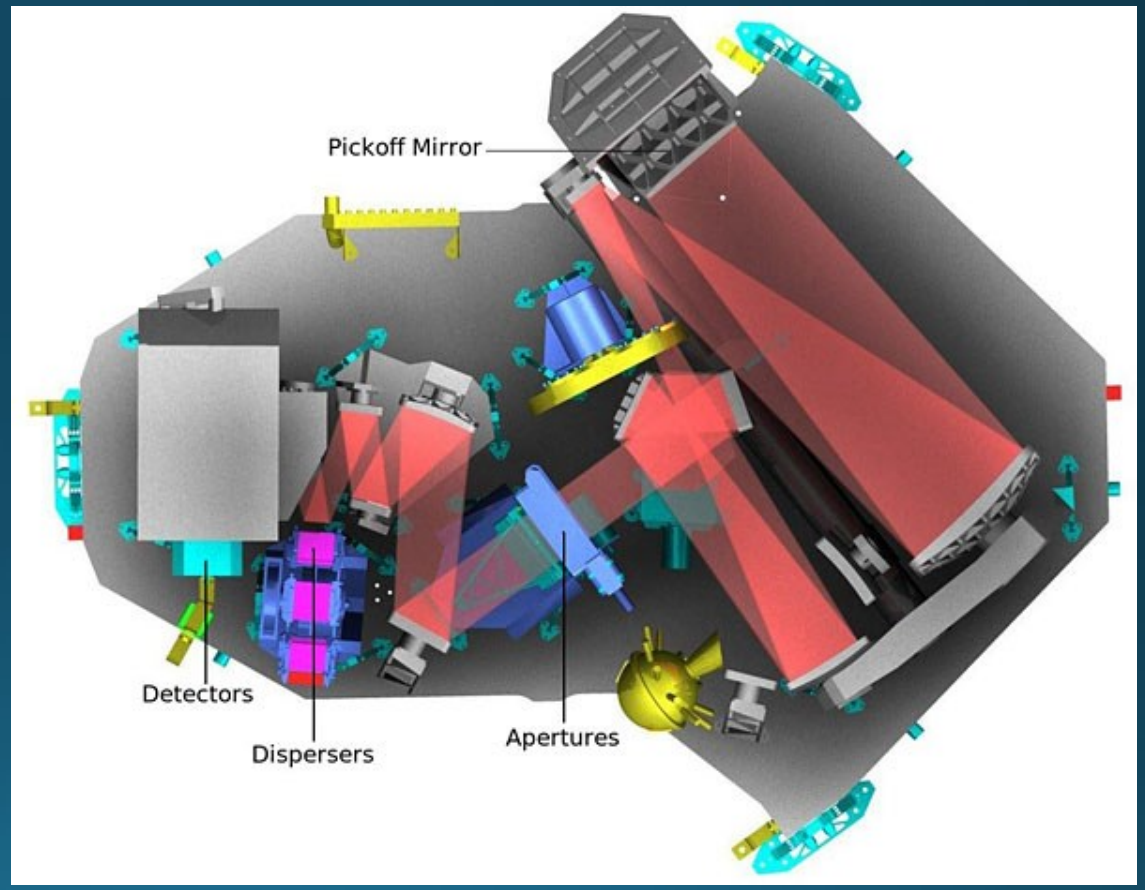


Zackrisson, Inoue & Jensen 2013, ApJ, 777, 39

Spectroscopy with JWST/NIRSpec

NIRSpec wavelength range
0.7-5 μm →

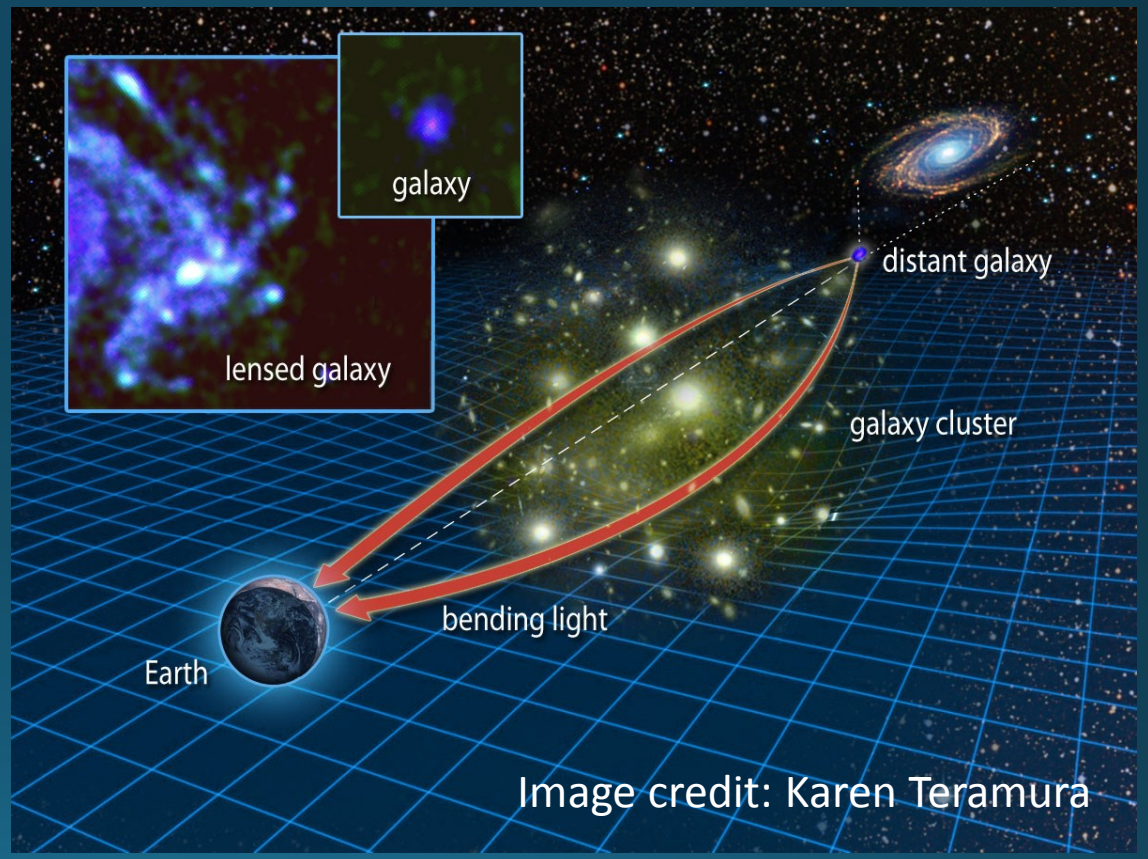
Can get UV continuum slope, Hβ, Hγ, Hβ continuum, [NeIII]3869, [OII]3727 and [OIII]4959, 5007 for objects up to $z \approx 9$



Lensed galaxies make the best targets

Low-mass galaxies more relevant for reionization than high-mass ones → We need to probe as far down the luminosity function as possible

In 10 h, NIRSpec can get a sufficiently good spectrum for a $z \approx 7$ galaxy with stellar mass $\sim 10^7$ Msolar ($M_{1500} \approx -16$) if the gravitational magnification is $\mu \approx 30$



How well can we measure f_{esc}?

LYman Continuum ANalysis project:

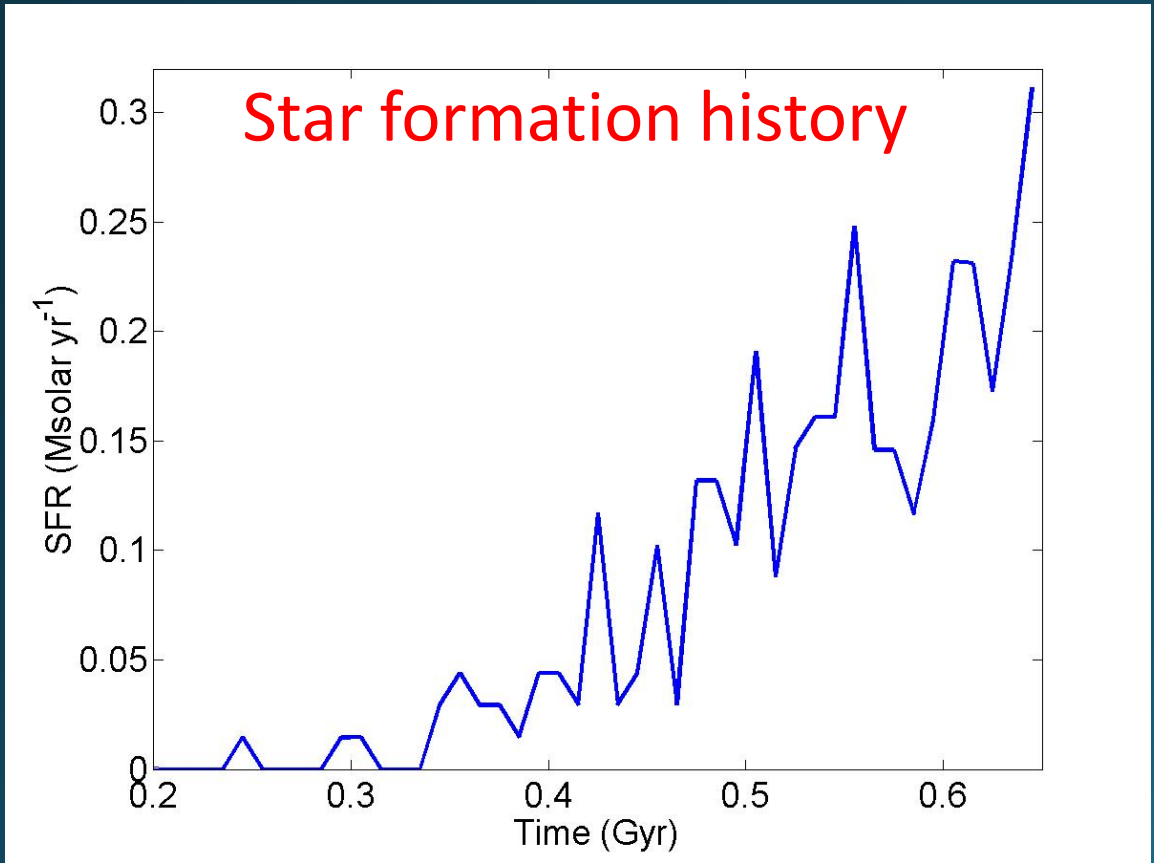
SPH/RT simulations + Yggdrasil + observational errors →

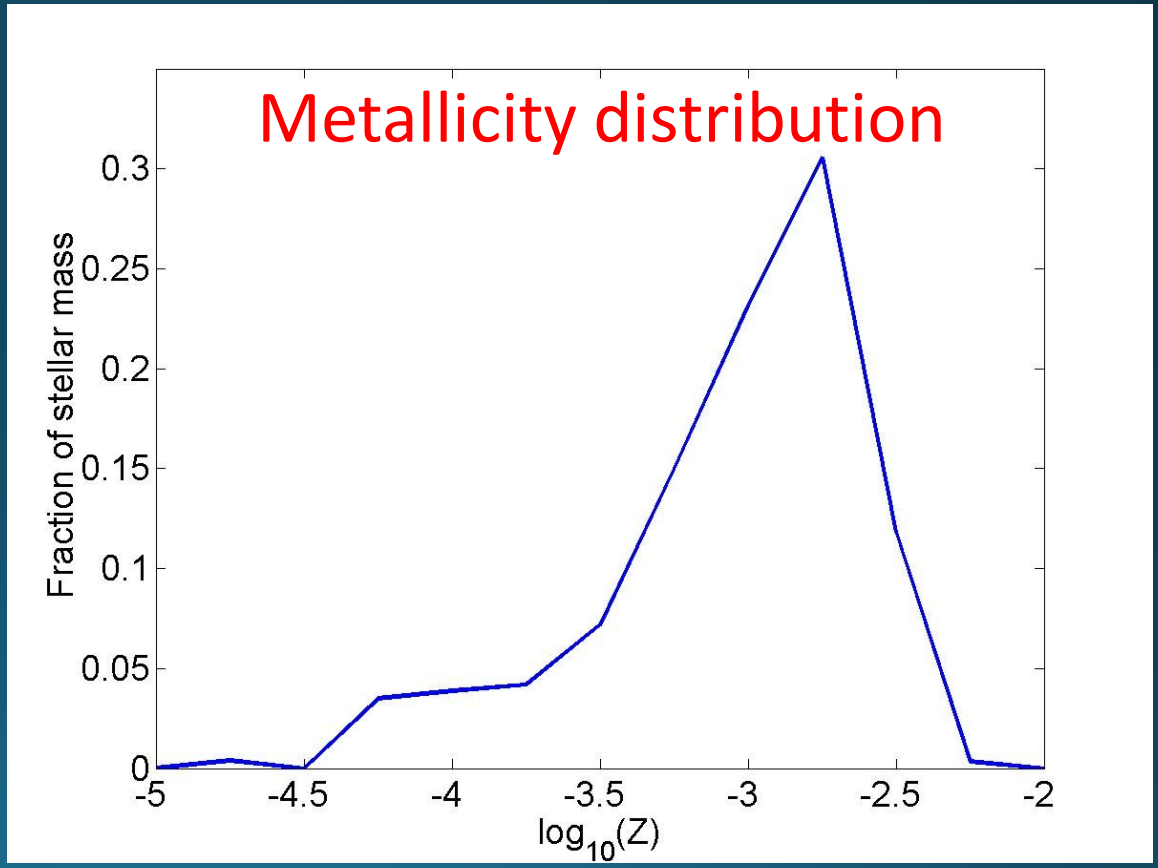
Mock spectra of high-z galaxies with Lyman continuum leakage

SPH simulations from:

Finlator et al. (2012)
Paardekooper et al. (2013)
Shimizu et al. (2014)

Challenge I: Complicated SFR(t) and wide metallicity distribution



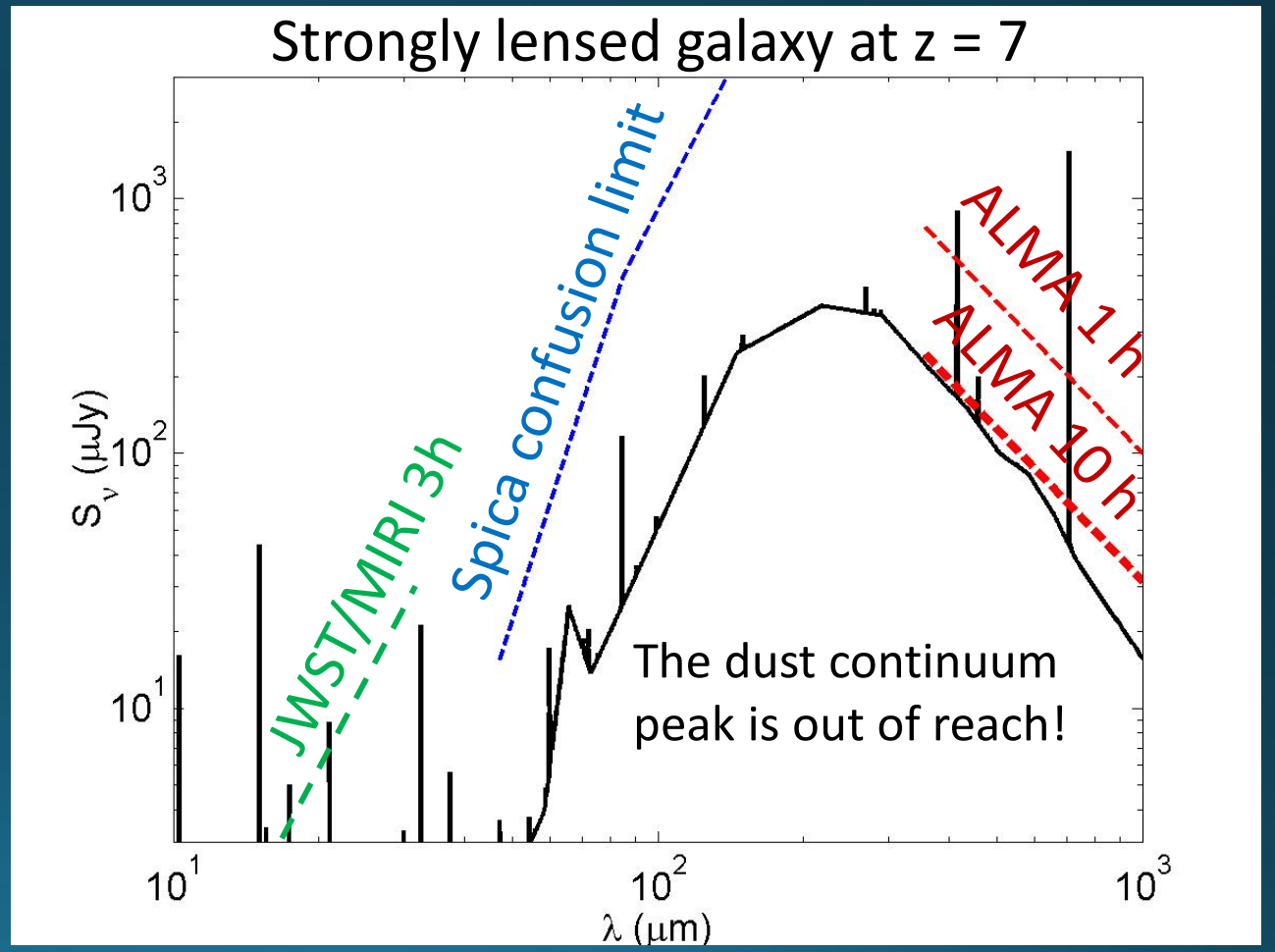


Typical model galaxy with stellar mass 4×10^7 Msolar at $z \approx 8$

Challenge II: Dust

- Rest-frame UV/optical attenuation
  Not that problematic – just apply a correction based on Balmer emission lines

- Direct extinction of LyC photons
  (e.g. Inoue 01, Hirashita+03)
  If this mechanism is significant, the relevant observables are redshifted out of reach at z ≈ 7-9



Zackrisson & Inoue (2013)

Summary

- The role of galaxies during reionization depends not only on the galaxy luminosity function, but also on the escape of ionizing radiation into the intergalactic medium
- Spectroscopy with NIRSpec can help us constrain the escape of ionizing radiation from galaxies up to $z \approx 9$
- Lensed galaxies are the best targets for this
- The LYCAN simulation project will provide a handle on the uncertainties