

Hunting down the galaxies that reionized the Universe

Erik Zackrisson
Stockholm University



Akio Inoue, Ikkoh Shimizu, Kristian Finlator, Hannes Jensen,
Nils Bergvall, Jan-Pieter Paardekooper, Claes-Erik Rydberg,
Genoveva Micheva, Sadegh Khochfar, Claudio Dalla Vecchia

Fingerprints



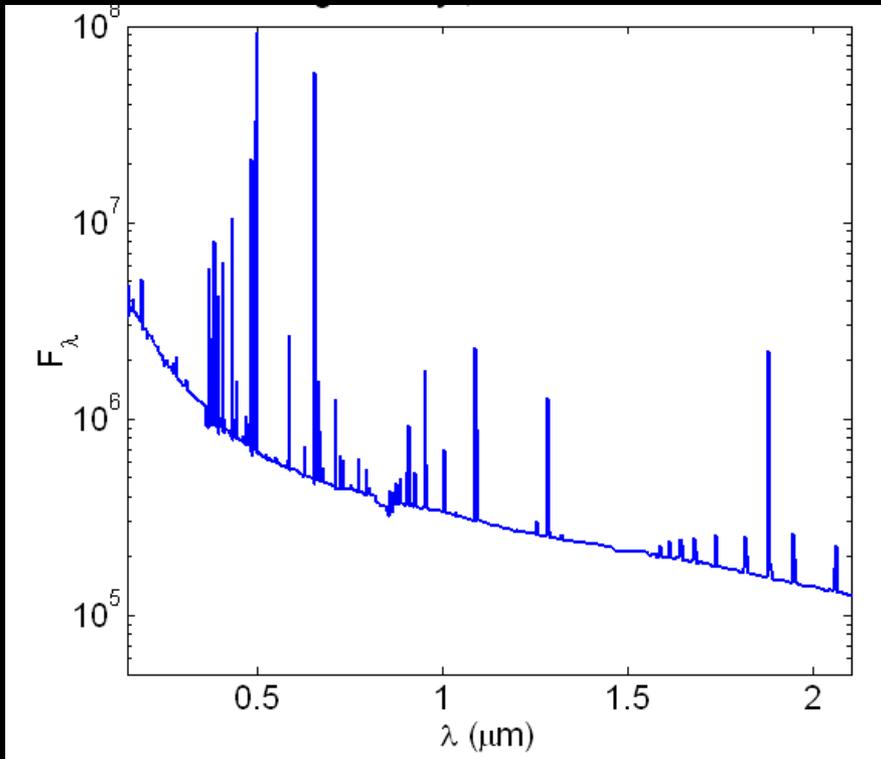
Classical use:

- Whorls, arches, loops in fingerprint pattern → **Identification**

The next frontier:

- Chemical analysis of fingerprint → **Drug habits, medication**

Galaxy Spectra



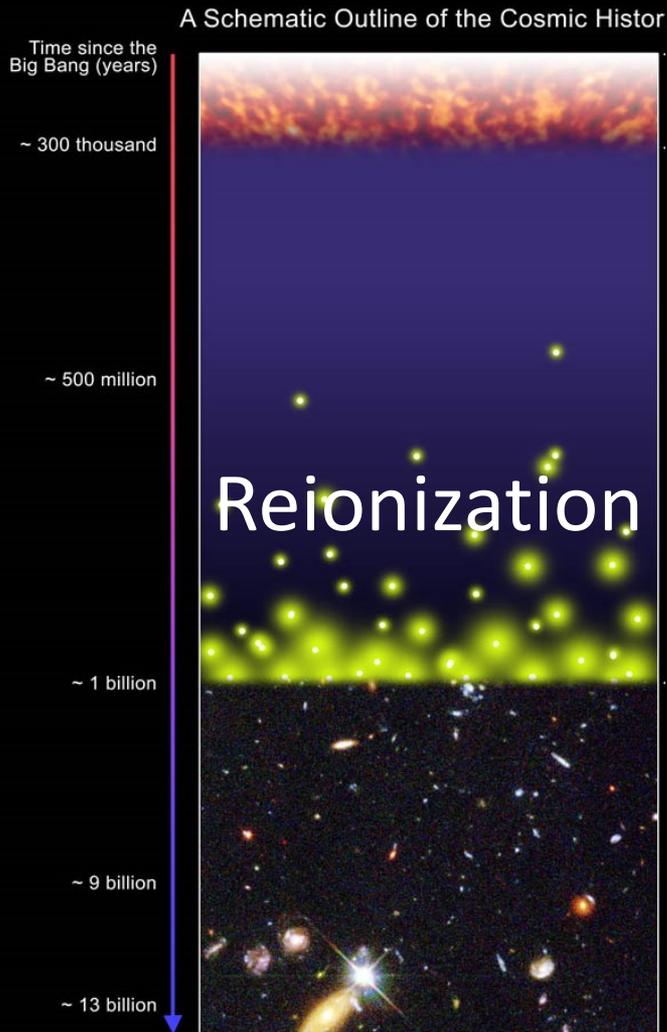
Classical use:

- Template fitting → **Galaxy type, redshift**
- SED modelling → **SFR, Z , $E(B-V)$, M_{stars} , SF history, IMF**

The next frontier:

- SED modelling → **Escape Fraction (f_{esc}) of ionizing photons from galaxies @ $z > 6$**

Did Galaxies Reionize the Universe?



S.G. Djorgovski et al. & Digital Media Center, Caltech

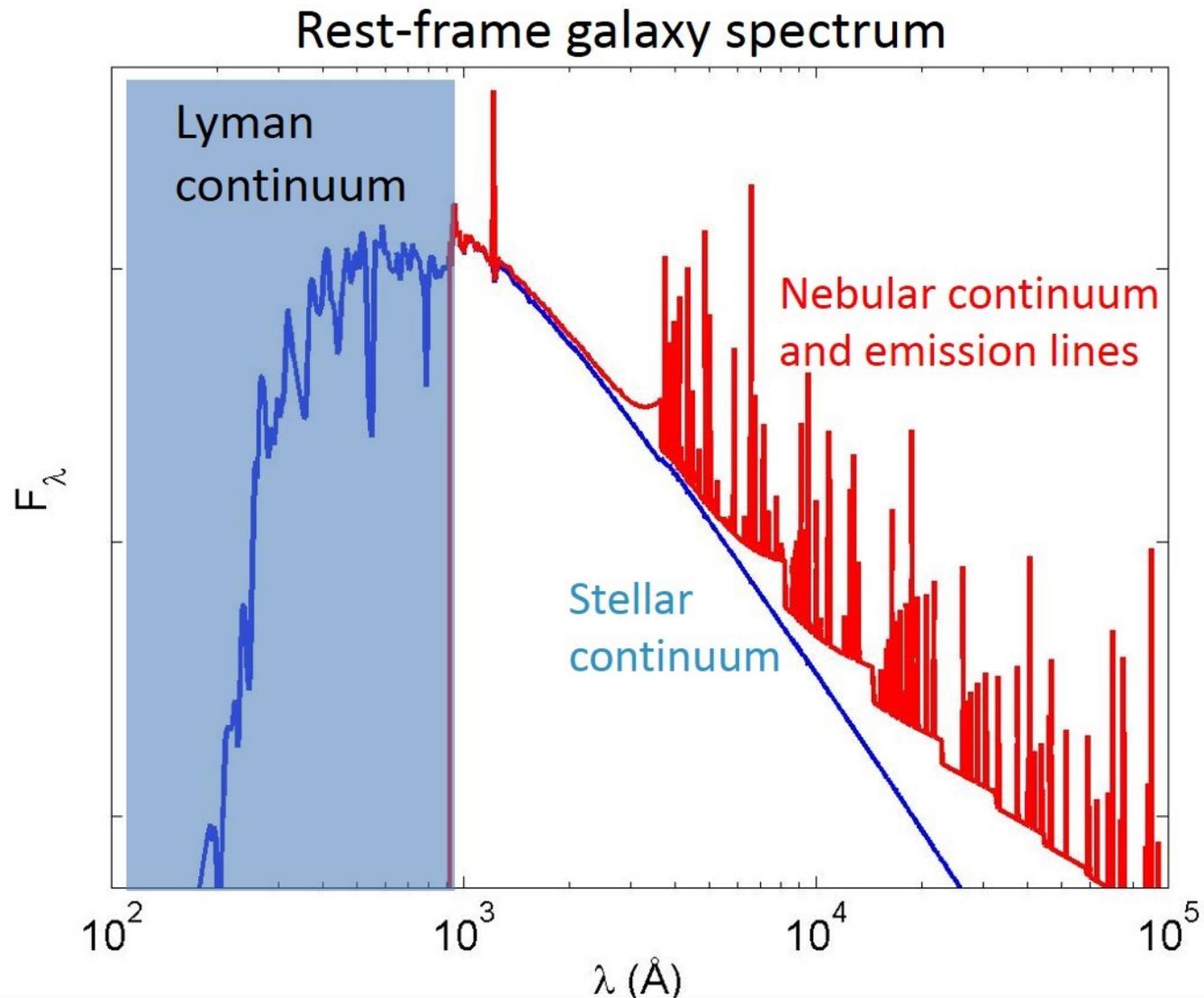
Ionizing photon budget relevant for reionization:

$$N_{\text{ion}} \propto \rho_{\text{UV}} f_{\text{esc}}$$

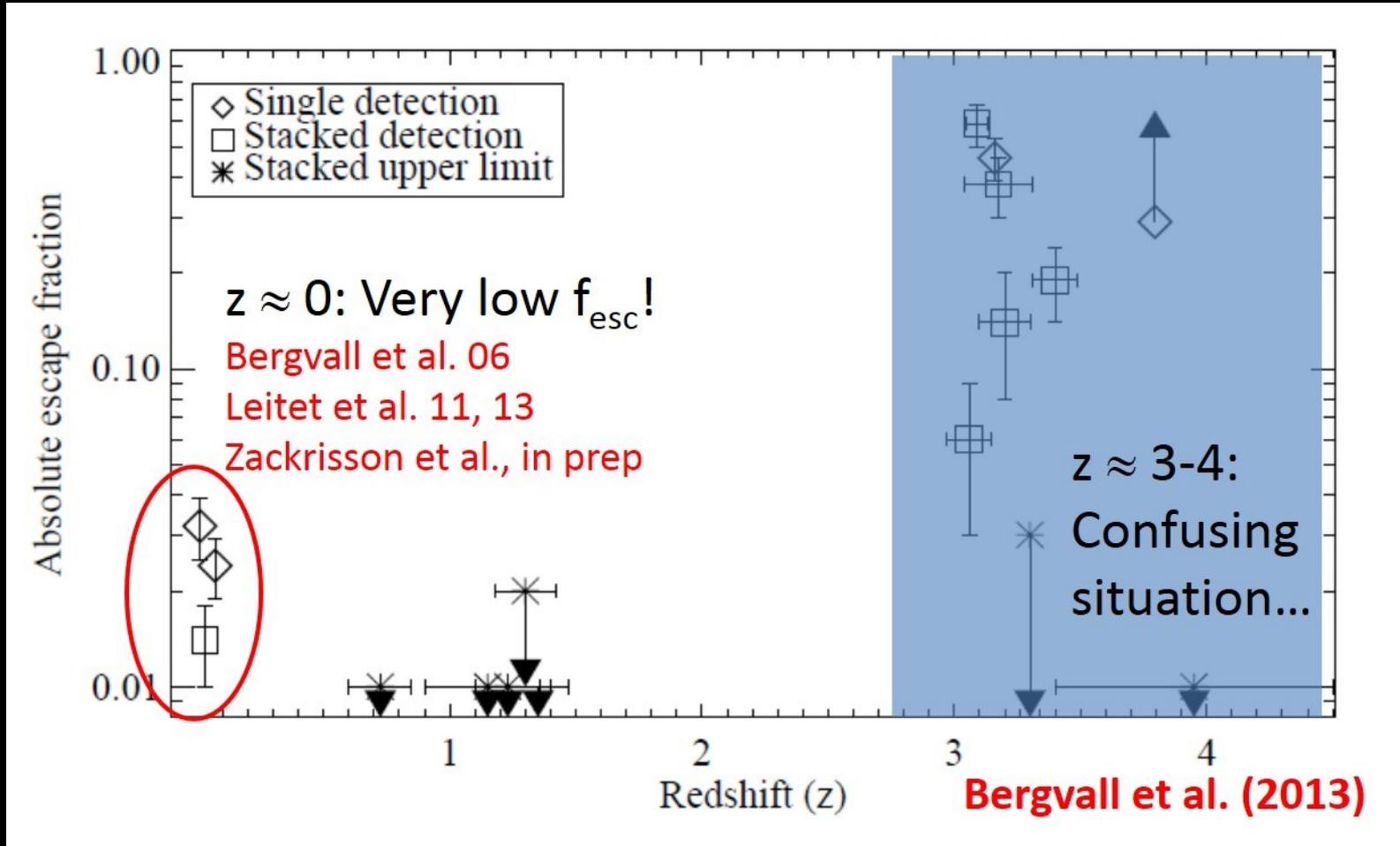
From observed galaxy luminosity function at $z > 6$

Escape fraction of ionizing photons (Lyman continuum)

Lyman Continuum Radiation



The Lyman Continuum Escape Fraction

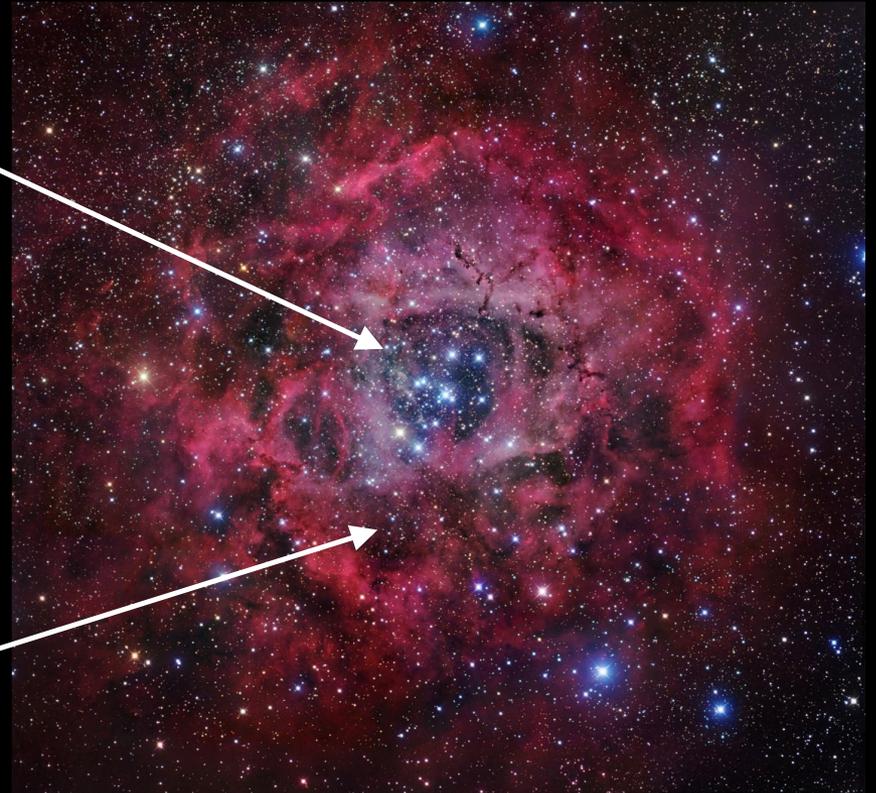


At $z > 4-5$, the IGM opacity prevents direct detections of escaping Lyman continuum (Inoue & Iwata 2008) – **Indirect methods needed!**

How Lyman Continuum Leakage Affects the Spectra of Galaxies

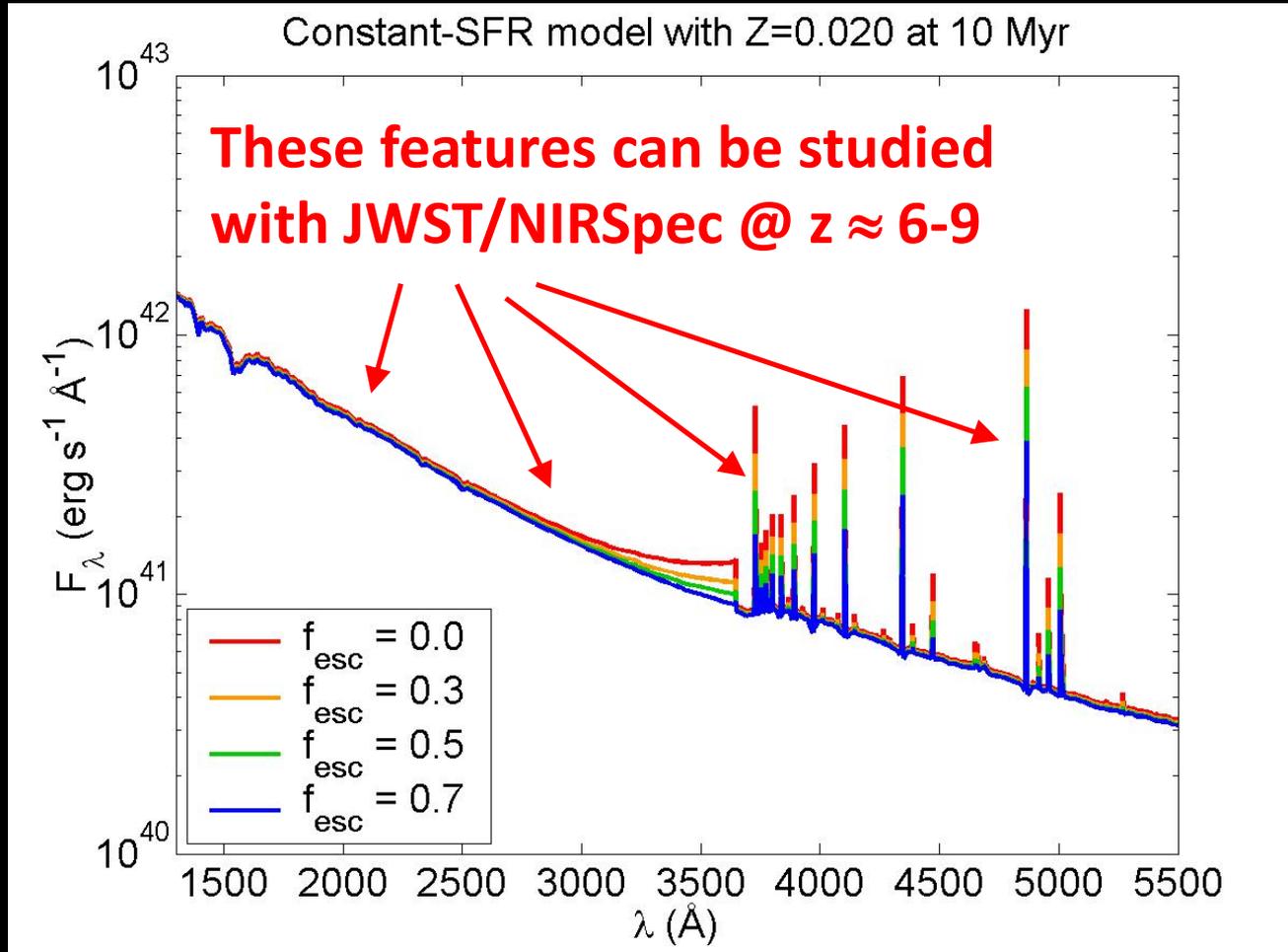
Young stars

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

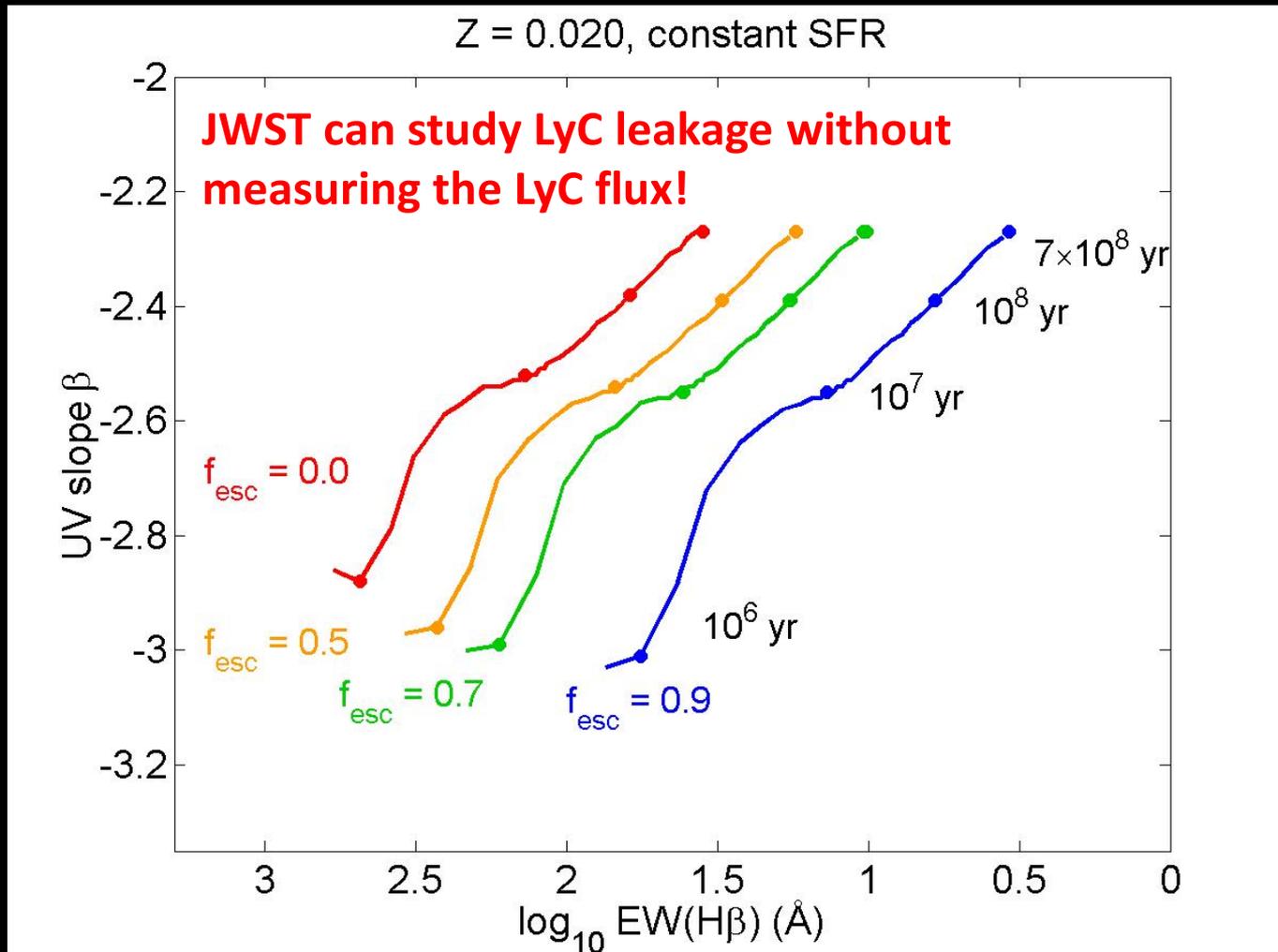


If some of the LyC photons escape without ionizing the ISM → ***Less nebular emission!***

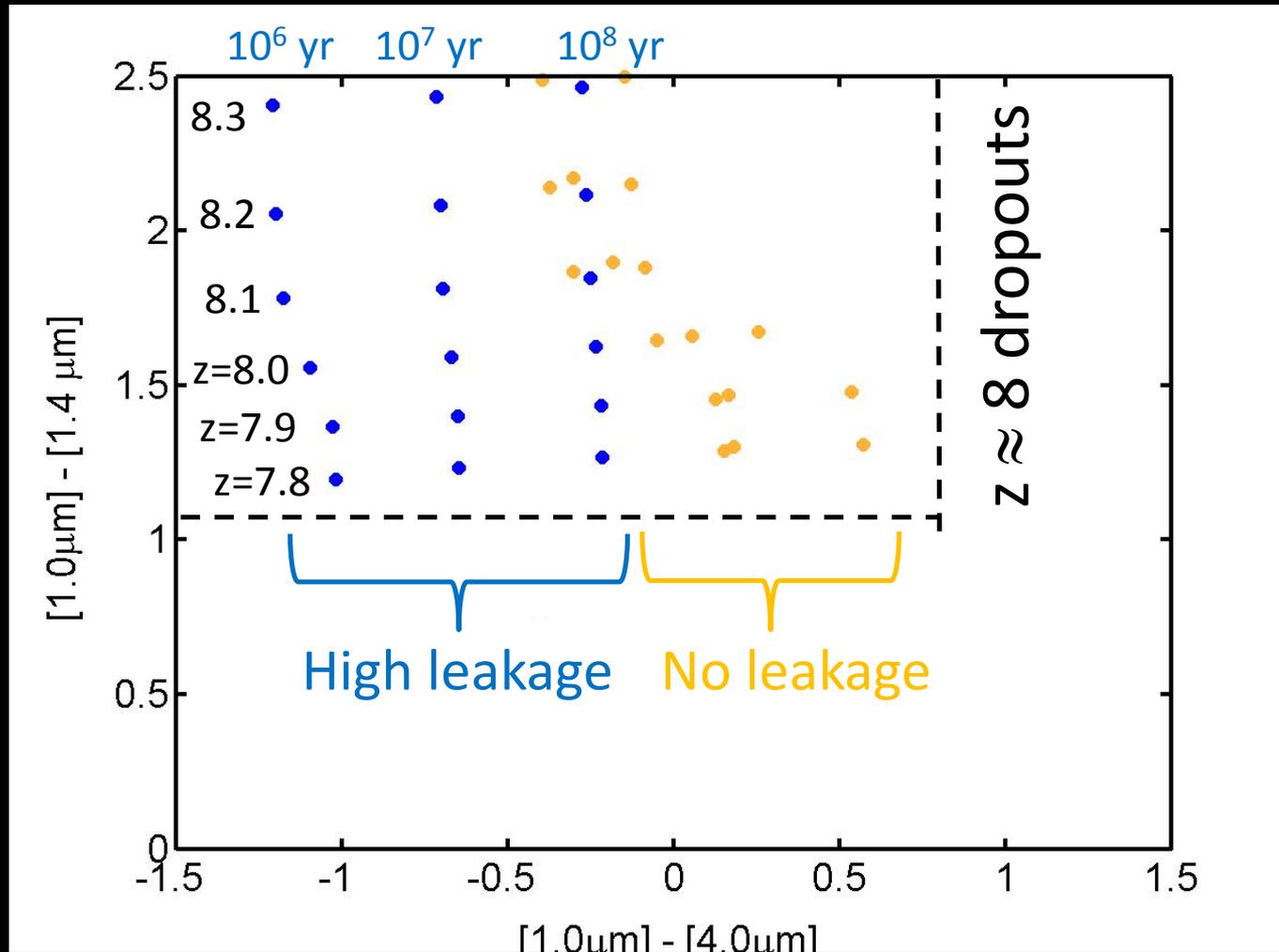
Studying Lyman Continuum Leakage in the Reionization Epoch



Indirect Constraints on f_{esc} for Galaxies at $z \approx 6-9$



LyC leakage candidates in WISH surveys



LyC leakage candidates found through WISH imaging can then be followed up with JWST/ELT spectroscopy



- Pop I, II, III stars
- Nebular emission (Cloudy)
- SDSS/HST/Spitzer/JWST/
WISH fluxes @ $z=0-15$

The ggdrasil 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

Galaxy models for WISH

http://ttt.astro.su.se/~ez/ Erik Zackrisson

Arkiv Redigera Visa Favoriter Verktyg Hjälp

- [Main page](#)
- Current projects:
 - [The first stars and galaxies](#)
 - [Dark matter subhalos](#)
 - [The faint outskirts of galaxies](#)
- Model access:
 - [Yggdrasil](#)
 - [Other models](#)
- [Scientific publications](#)
- [Brief CV](#)
- [Teaching](#)
- [Students](#)
- [Talks](#)
- [Fiction](#) (in Swedish)

- JWST/NIRCam (AB)
- SDSS (AB)
- Spitzer (AB)
- HST (AB)
- WISH (AB)
- Lyman-alpha transmission factor
 - $f_{\text{Ly}\alpha} = 0$
 - $f_{\text{Ly}\alpha} = 0.1$
 - $f_{\text{Ly}\alpha} = 0.3$
 - $f_{\text{Ly}\alpha} = 0.5$
- Redshift coverage
 - Full coverage, $z=0-15$, step 0.25
 - Low redshift, $z=0-0.5$, step 0.01
 - High redshift, $z=5-11$, step 0.1

Choose metallicity, star formation history, redshift resolution etc.

Then click here!

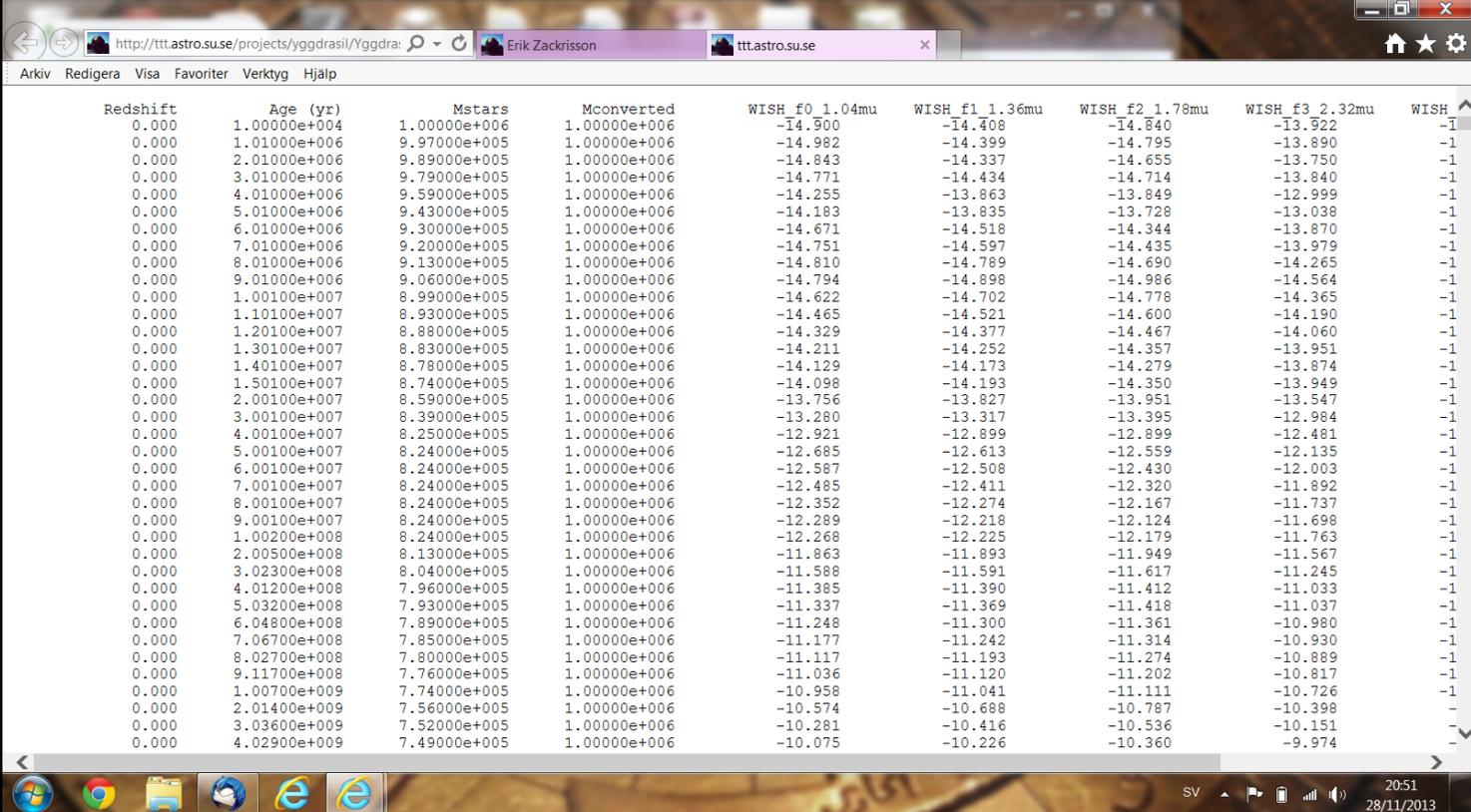
Get magnitudes

Webmaster: [Claes-Erik Rydberg](#)

Yggdrasil models: www.astro.su.se/~ez

Galaxy models for WISH

... and you immediately get AB magnitudes in WISH filters as a function of galaxy age and redshift!



The screenshot shows a web browser window displaying a table of galaxy model parameters and AB magnitudes for WISH filters. The table has the following columns: Redshift, Age (yr), Mstars, Mconverted, WISH f0 1.04mu, WISH f1 1.36mu, WISH f2 1.78mu, WISH f3 2.32mu, and WISH. The data is organized into rows, with the first row representing a redshift of 0.000 and an age of 1.00000e+004 years. The magnitudes are listed in AB magnitude format, ranging from approximately -14.900 to -9.974. The browser's address bar shows the URL <http://ttt.astro.su.se/projects/yggdrasil/Yggdra> and the user name Erik Zackrisson. The browser's taskbar at the bottom shows the date 2013/11/28 and the time 20:51.

Redshift	Age (yr)	Mstars	Mconverted	WISH f0 1.04mu	WISH f1 1.36mu	WISH f2 1.78mu	WISH f3 2.32mu	WISH
0.000	1.00000e+004	1.00000e+006	1.00000e+006	-14.900	-14.408	-14.840	-13.922	-1
0.000	1.01000e+006	9.97000e+005	1.00000e+006	-14.982	-14.399	-14.795	-13.890	-1
0.000	2.01000e+006	9.89000e+005	1.00000e+006	-14.843	-14.337	-14.655	-13.750	-1
0.000	3.01000e+006	9.79000e+005	1.00000e+006	-14.771	-14.434	-14.714	-13.840	-1
0.000	4.01000e+006	9.59000e+005	1.00000e+006	-14.255	-13.863	-13.849	-12.999	-1
0.000	5.01000e+006	9.43000e+005	1.00000e+006	-14.183	-13.895	-13.728	-13.038	-1
0.000	6.01000e+006	9.30000e+005	1.00000e+006	-14.671	-14.518	-14.344	-13.870	-1
0.000	7.01000e+006	9.20000e+005	1.00000e+006	-14.751	-14.597	-14.435	-13.979	-1
0.000	8.01000e+006	9.13000e+005	1.00000e+006	-14.810	-14.789	-14.690	-14.265	-1
0.000	9.01000e+006	9.06000e+005	1.00000e+006	-14.794	-14.898	-14.986	-14.564	-1
0.000	1.00100e+007	8.99000e+005	1.00000e+006	-14.622	-14.702	-14.778	-14.365	-1
0.000	1.10100e+007	8.93000e+005	1.00000e+006	-14.465	-14.521	-14.600	-14.190	-1
0.000	1.20100e+007	8.88000e+005	1.00000e+006	-14.329	-14.377	-14.467	-14.060	-1
0.000	1.30100e+007	8.83000e+005	1.00000e+006	-14.211	-14.252	-14.357	-13.951	-1
0.000	1.40100e+007	8.78000e+005	1.00000e+006	-14.129	-14.173	-14.279	-13.874	-1
0.000	1.50100e+007	8.74000e+005	1.00000e+006	-14.098	-14.193	-14.350	-13.949	-1
0.000	2.00100e+007	8.59000e+005	1.00000e+006	-13.756	-13.827	-13.951	-13.547	-1
0.000	3.00100e+007	8.39000e+005	1.00000e+006	-13.280	-13.317	-13.395	-12.984	-1
0.000	4.00100e+007	8.25000e+005	1.00000e+006	-12.921	-12.899	-12.899	-12.481	-1
0.000	5.00100e+007	8.24000e+005	1.00000e+006	-12.685	-12.613	-12.559	-12.135	-1
0.000	6.00100e+007	8.24000e+005	1.00000e+006	-12.587	-12.508	-12.430	-12.003	-1
0.000	7.00100e+007	8.24000e+005	1.00000e+006	-12.485	-12.411	-12.320	-11.892	-1
0.000	8.00100e+007	8.24000e+005	1.00000e+006	-12.352	-12.274	-12.167	-11.737	-1
0.000	9.00100e+007	8.24000e+005	1.00000e+006	-12.289	-12.218	-12.124	-11.698	-1
0.000	1.00200e+008	8.24000e+005	1.00000e+006	-12.268	-12.225	-12.179	-11.763	-1
0.000	2.00500e+008	8.13000e+005	1.00000e+006	-11.863	-11.893	-11.949	-11.567	-1
0.000	3.02300e+008	8.04000e+005	1.00000e+006	-11.588	-11.591	-11.617	-11.245	-1
0.000	4.01200e+008	7.96000e+005	1.00000e+006	-11.385	-11.390	-11.412	-11.033	-1
0.000	5.03200e+008	7.93000e+005	1.00000e+006	-11.337	-11.369	-11.418	-11.037	-1
0.000	6.04800e+008	7.89000e+005	1.00000e+006	-11.248	-11.300	-11.361	-10.980	-1
0.000	7.06700e+008	7.85000e+005	1.00000e+006	-11.177	-11.242	-11.314	-10.930	-1
0.000	8.02700e+008	7.80000e+005	1.00000e+006	-11.117	-11.193	-11.274	-10.889	-1
0.000	9.11700e+008	7.76000e+005	1.00000e+006	-11.036	-11.120	-11.202	-10.817	-1
0.000	1.00700e+009	7.74000e+005	1.00000e+006	-10.958	-11.041	-11.111	-10.726	-1
0.000	2.01400e+009	7.56000e+005	1.00000e+006	-10.574	-10.688	-10.787	-10.398	-
0.000	3.03600e+009	7.52000e+005	1.00000e+006	-10.281	-10.416	-10.536	-10.151	-
0.000	4.02900e+009	7.49000e+005	1.00000e+006	-10.075	-10.226	-10.360	-9.974	-

Yggdrasil models: www.astro.su.se/~ez

The Lyman Continuum Analysis Project



Logo: Genoveva Micheva

SPH/RT simulations +
Yggdrasil + obs. errors →

Mock spectra of high- z
galaxies with LyC leakage

Can tackle:

- How well can f_{esc} be retrieved from JWST/ELT spectra?
- How well can high- f_{esc} candidates be selected from WISH imaging data?

Lyman Continuum Leakage and Cosmic Reionization

13-15 August 2014

AlbaNova University Center, Stockholm University, Stockholm, Sweden

[Home](#)



The contribution from star-forming galaxies to the reionization of the Universe depends on the galaxy luminosity function *and* on the Lyman continuum (LyC) escape fraction of galaxies at redshifts greater than $z \sim 6$. While most activity in this field has so far focused on quantifying the luminosity function, this 3-day workshop focuses on current and future efforts to constrain the LyC escape fraction of galaxies at both low and high redshift, and the impact that this is likely to have on our understanding of cosmic reionization.

Topics to be explored include:

- Direct and indirect methods to constrain LyC leakage (from the local to the high-redshift Universe)
- Observations of LyC leakage
- Theoretical perspectives on LyC leakage mechanisms
- Simulations and observational probes of reionization: How can empirical data on LyC escape fractions help? Is it necessary to know the galaxy LyC escape fraction to prove that galaxies reionized the Universe?
- Complications: Anisotropic leakage, IGM clumping factors, gravitational lensing etc.

Stockholm, Sweden, August 13-15, 2014

Summary

- WISH imaging can help us find galaxies leaking ionizing radiation into the IGM at $z > 6$
- Follow-up spectroscopy can constrain the ionizing escape fraction
- WISH fluxes for Yggdrasil model galaxies at redshifts $z = 0 - 15$: www.astro.su.se/~ez

