Cutting through the Clouds
Comparing Indirect Tracers of Ionizing Photon Escape

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Orthodox Academy of Crete
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Collaborators: *Danielle Berg, John Chisholm, Simon Gazagnes, + CLASSY collaboration*

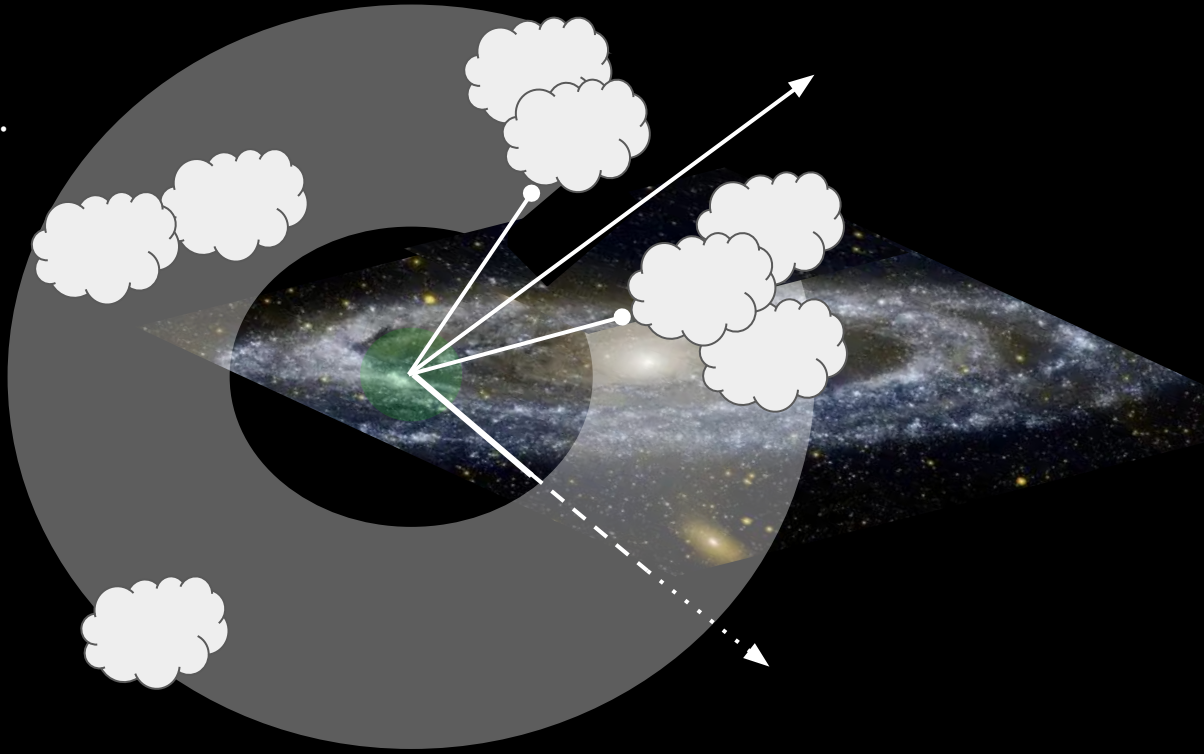
The amount ionizing radiation that can escape depends on…

how much is produced

determined by the stellar populations present + other ionizing sources (ex: AGN, HMXB)

characteristics of the neutral gas

geometry, densities, kinematics, quantity, + dust content



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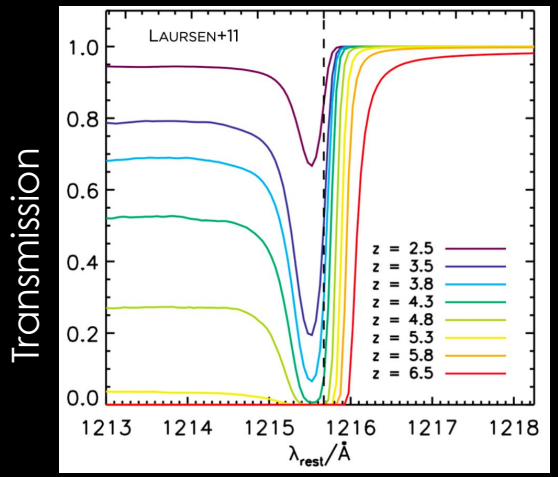
but it is often not possible to directly observe the escaping LyC from galaxies at high-z



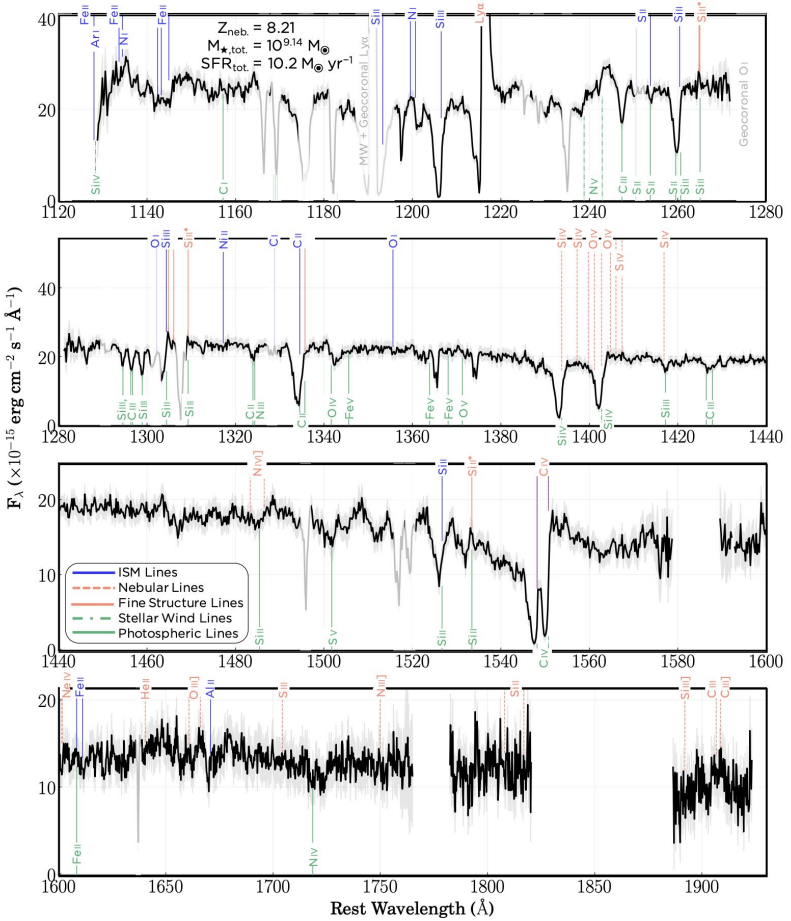
A variety of methods have been developed to indirectly estimate f_{esc}

CLASSY

COS **L**egacy **A**rchive **S**pectroscopic **S**urve**Y**

45 nearby (z < 0.3) star-forming galaxies
- high-S/N and high-resolution (R ~ 15000)
- FUV *HST/COS* spectra
- broad wavelength coverage (~1100-2000Å)
- span a large ranges of galaxy properties

Berg+22



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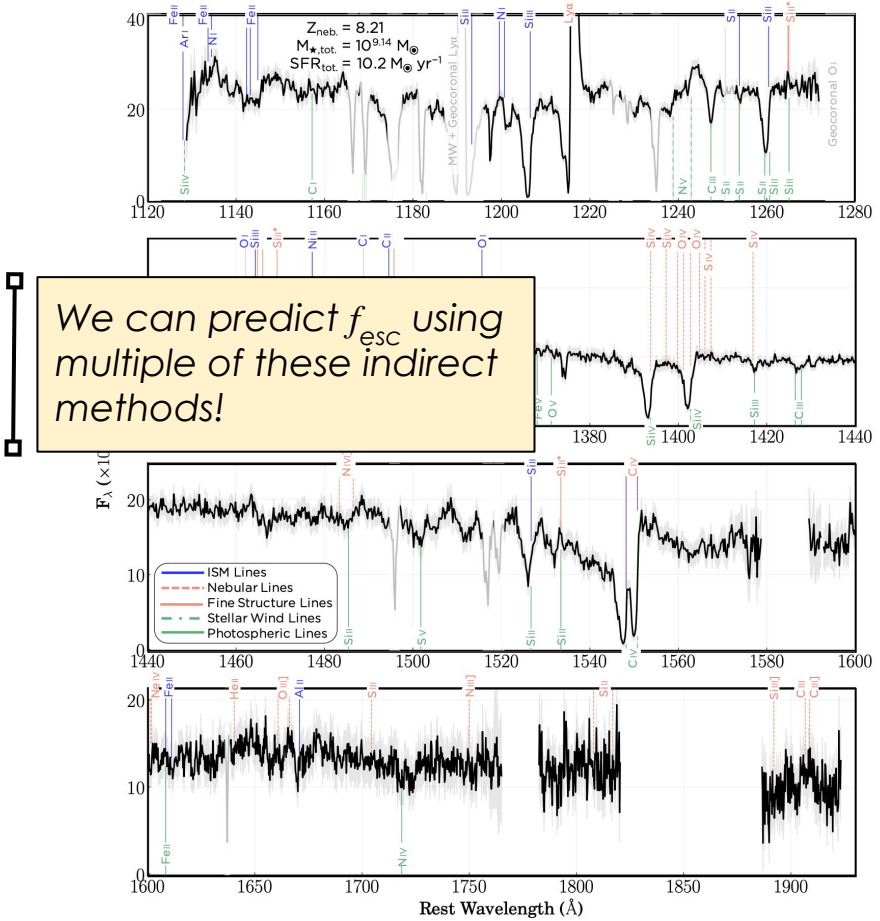

We can predict f_{esc} using multiple of these indirect methods!

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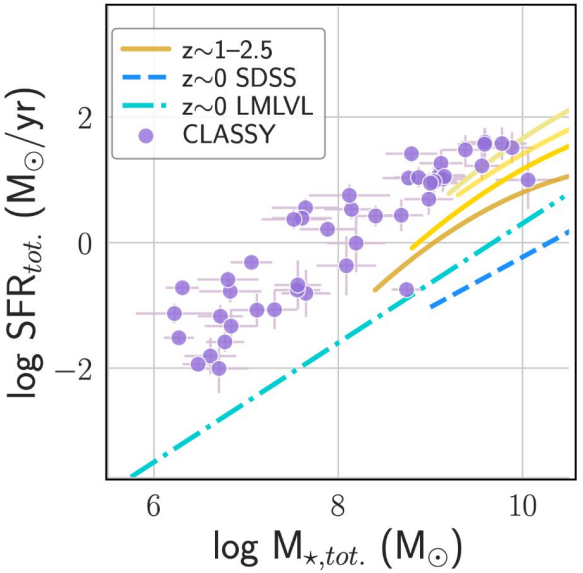
SFRs similar to galaxies at z ~ 2

Berg+22



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21-cm HI measurements

Parker+24

Galaxy	$\log(M_{HI})$ $(M_\odot)$
J0036–3333	8.77±0.02
J0127–0619	8.16±0.05 8.21±0.07
J0144+0453	8.66±0.01 8.63±0.02
J0337–0502	9.07±0.08 8.69±0.18
J0405–3648	7.83±0.01
J0808+3948	< 8.10
J0823+2806	10.19±0.08 10.09±0.04
J0926+4427	< 10.45 < 11.49
J0934+5514	7.88±0.02
J0938+5428	< 8.07
J0940+2935	7.40±0.01 7.40±0.05
J0942+3547	< 6.56
J0944–0038	9.09±0.02
J0944+3442	9.69±0.01
J1016+3754	7.86±0.01 8.00±0.11
J1024+0524	< 8.28
J1044+0353	8.36±0.04
J1105+4444	9.84±0.01

• • •

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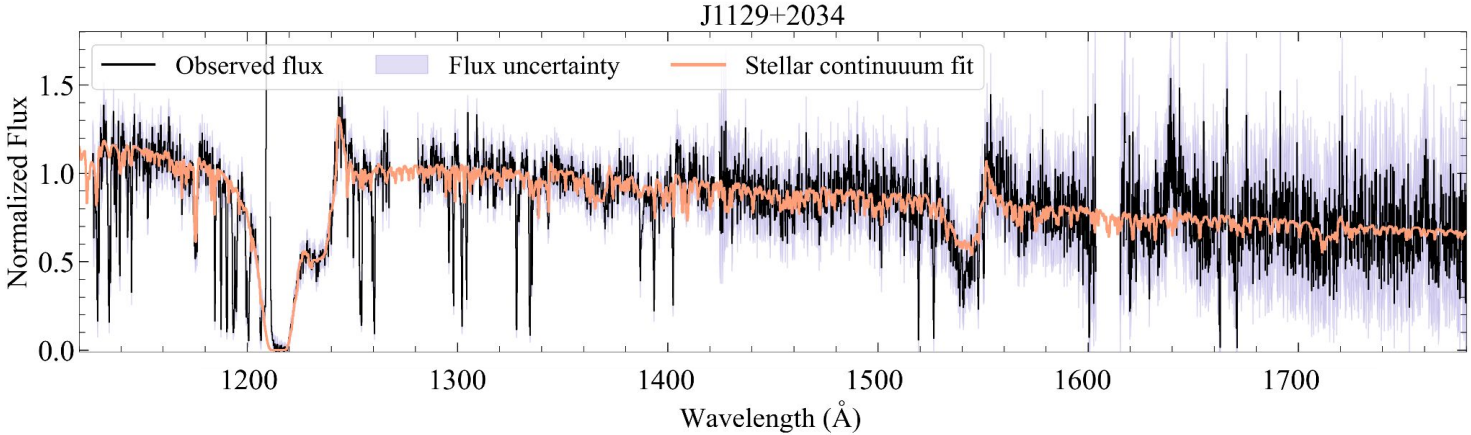
SPS fits (Starburst99)

Parker+(in prep.)



We indirectly predicting f_{esc} through 5 approaches:

1. LIS covering fraction
2. UV beta-slope
3. peak separation of Lyα
4. `LyCsurv`
5. `RAMSES-RT` simulation

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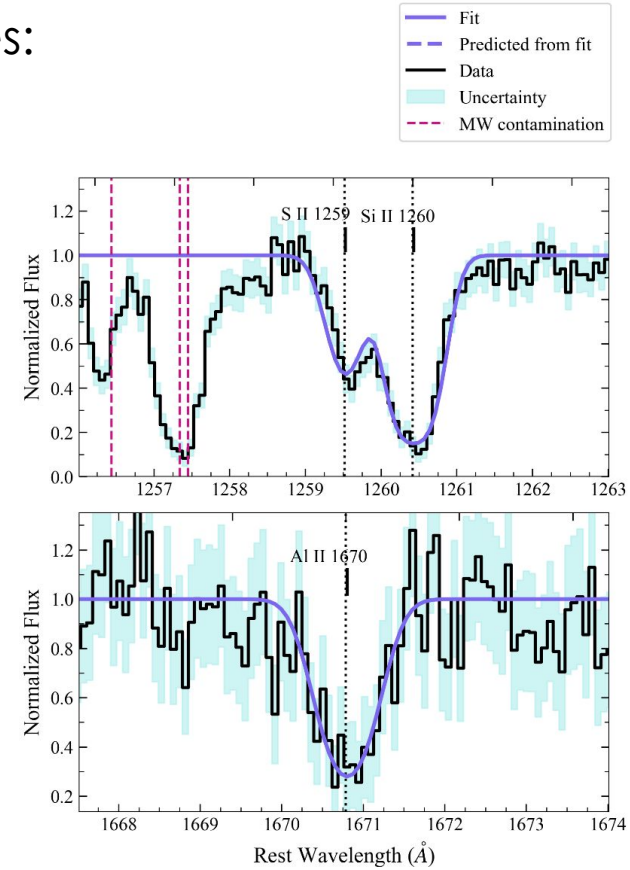
$$f_{\rm esc}^{C_f} = 10^{-0.4 k_{912} E_{\rm B-V}} \times (1 - C_f({\rm H\,I}))$$

(Chisholm+18)

Using neutral and low-ionization covering fractions from Parker+24



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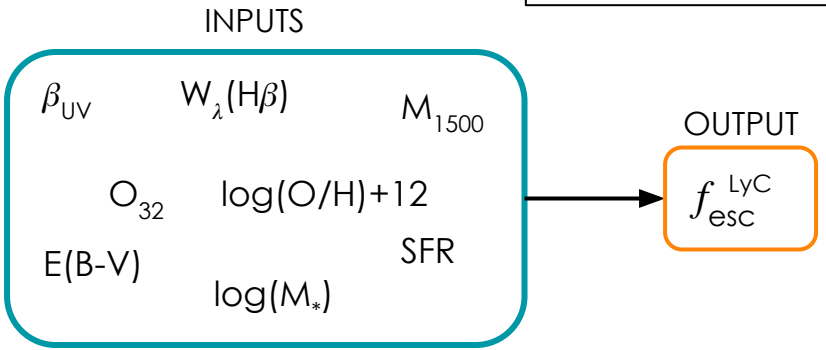
4. **`LyCsurv`**
5. `RAMSES-RT` simulation

`LyCsurv` (Jaskot+24a,b)

Multivariate estimator of f_{esc}
- using properties of LzLCS+ (Flury+22a,b)
- incorporates both detections and non-detections of f_{esc}

Code on Github: https://github.com/sflury/LyCsurv



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1. LIS covering fraction
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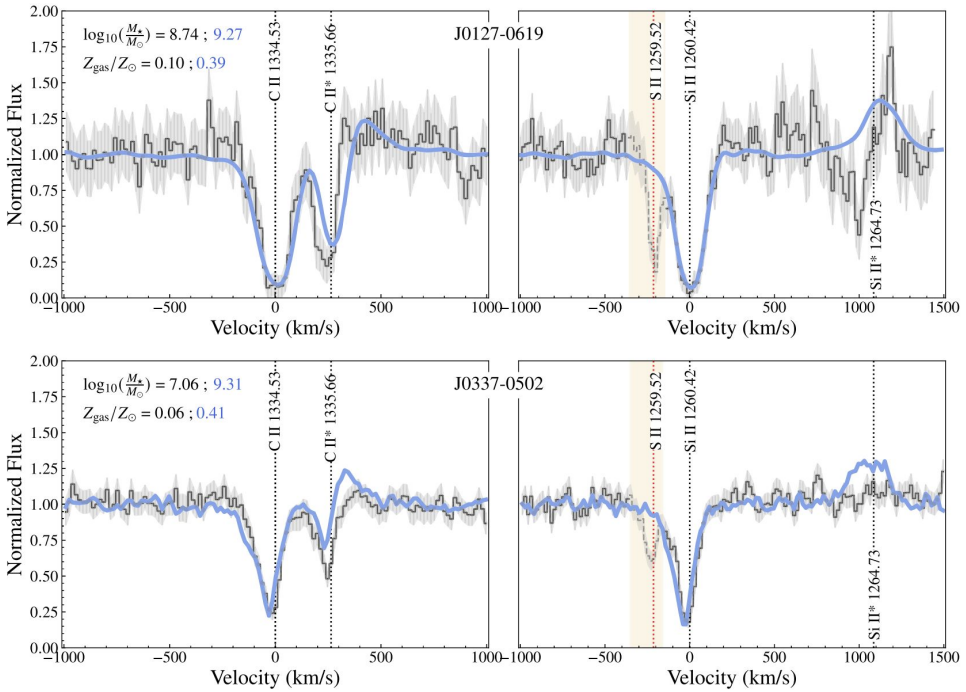
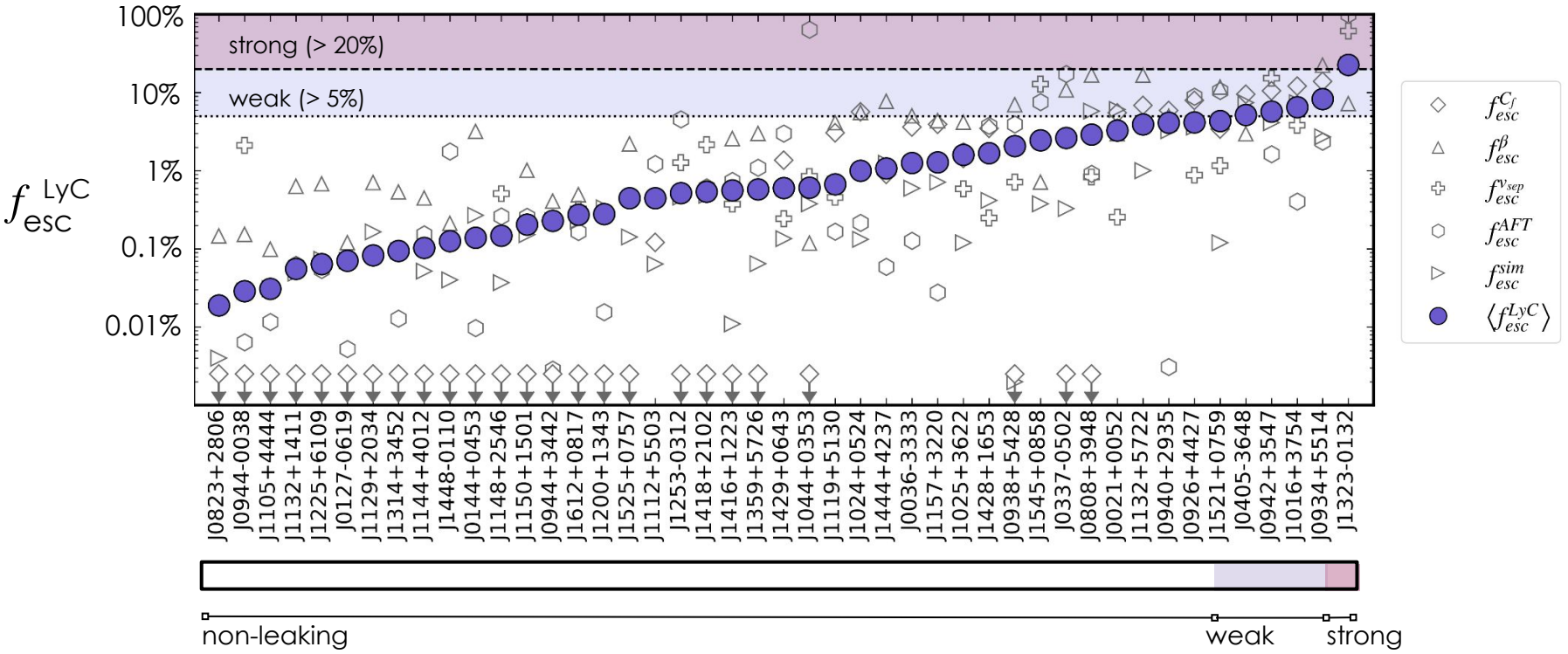
5. **`RAMSES-RT` simulation**

Used the intrinsic f_{esc} from the Gazagnes+23 best-fits for CLASSY

→ using ~22500 spectra from a hydrodynamical (`Ramses-RT`) galaxy (Mauerhofer+21)




100%
10%
1%
0.1%
0.01%
f_{esc}^{LyC}
strong (> 20%)
weak (> 5%)
$f_{esc}^{C_f}$
f_{esc}^{β}
$f_{esc}^{v_{sep}}$
f_{esc}^{AFT}
f_{esc}^{sim}
$\langle f_{esc}^{LyC} \rangle$
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J1150+1501
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J1612+0817
J1200+1343
J1525+0757
J1112+5503
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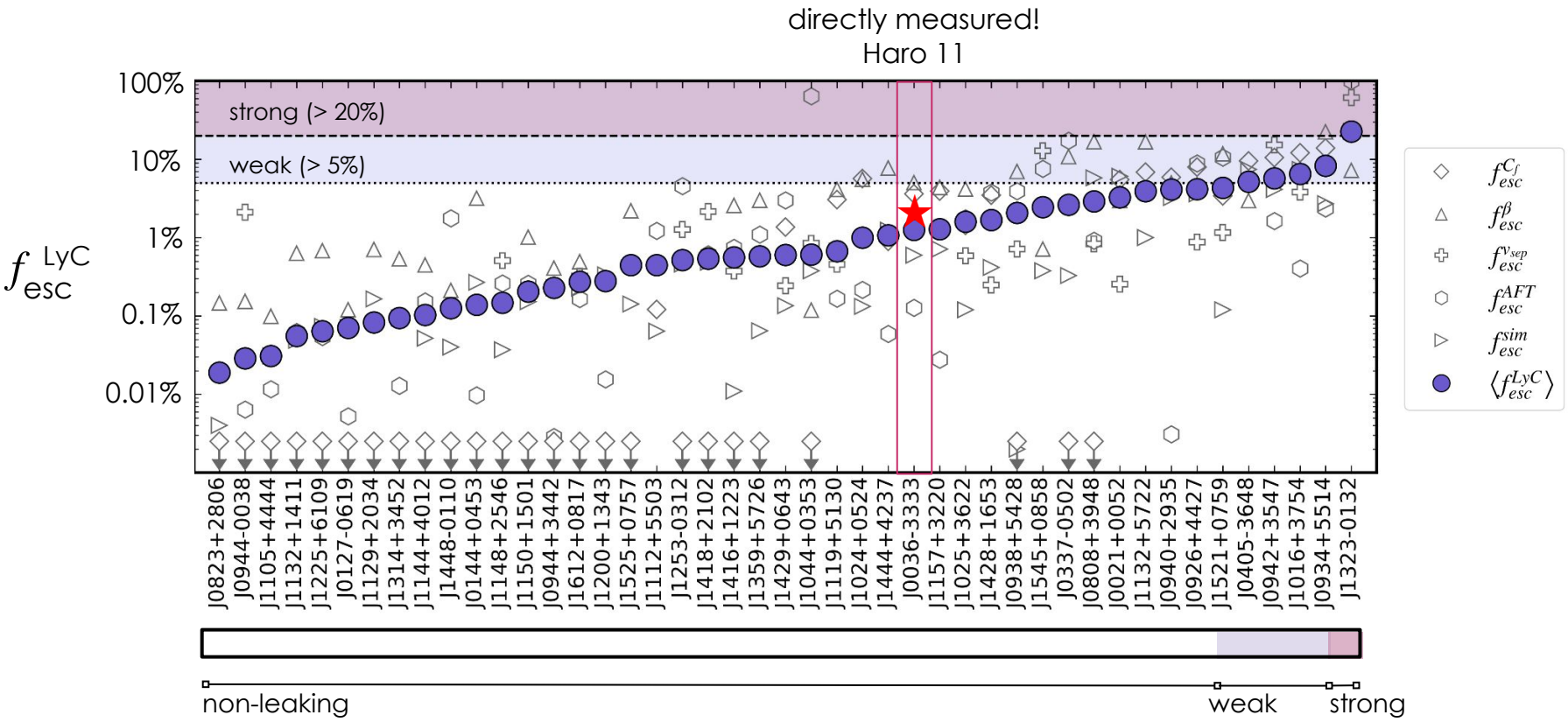
non-leaking
weak
strong


directly measured!
Haro 11
100%
10%
1%
0.1%
0.01%
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strong (> 20%)
weak (> 5%)
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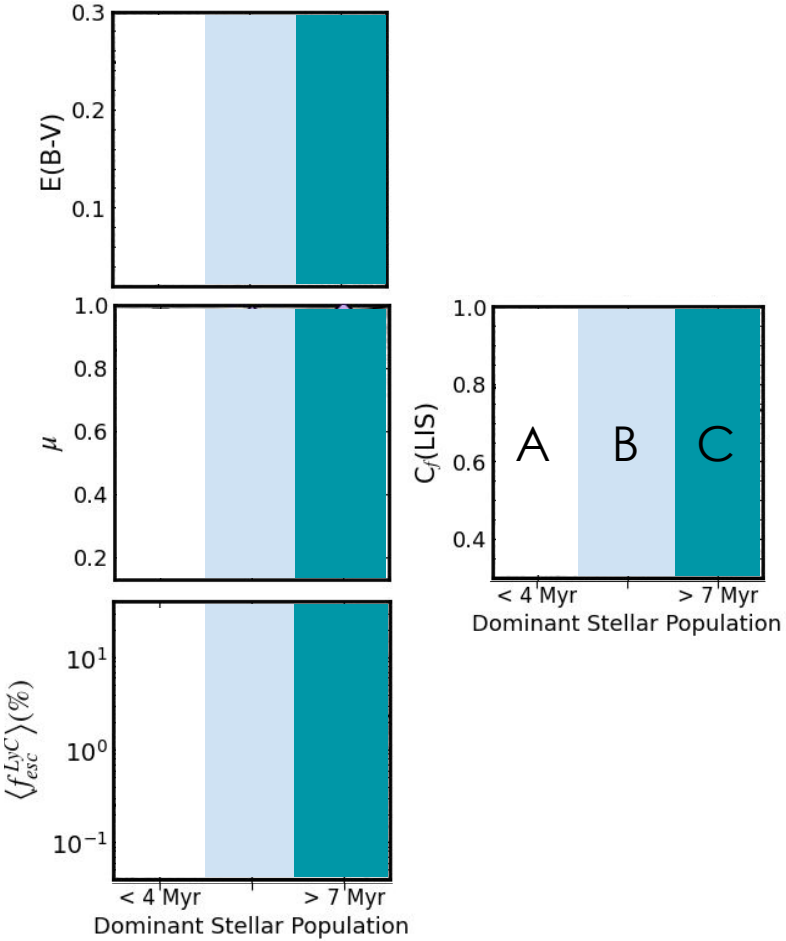
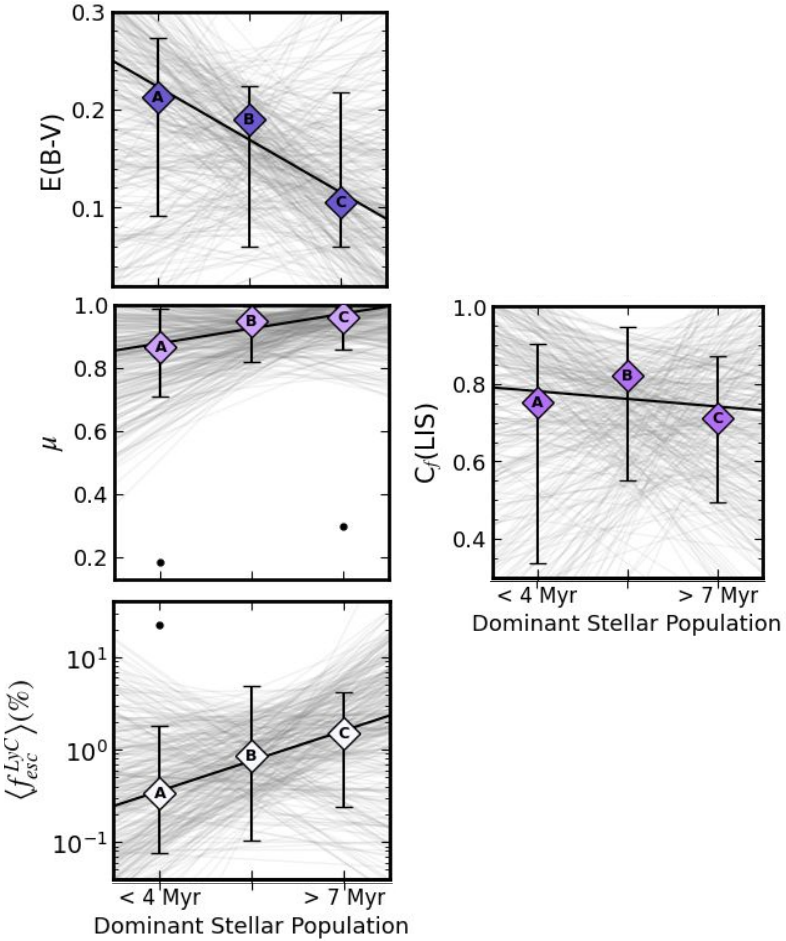


Binning by stellar populations

	$\langle t_{SP} \rangle$	N	Threshold
A	$2.4^{+1.5}_{-0.8}$ Myr	8	$F(< 4\,\mathrm{Myr}) \geq 0.75$
B	$5.1^{+3.0}_{-2.1}$ Myr	12	$F(< 4\,\mathrm{Myr}) < 0.75$ and $F(> 7\,\mathrm{Myr}) < 0.25$
C	$11.3^{+4.2}_{-5.5}$ Myr	25	$F(> 7\,\mathrm{Myr}) \geq 0.25$

← O-stars dominate

← significant contributions are possible from SN



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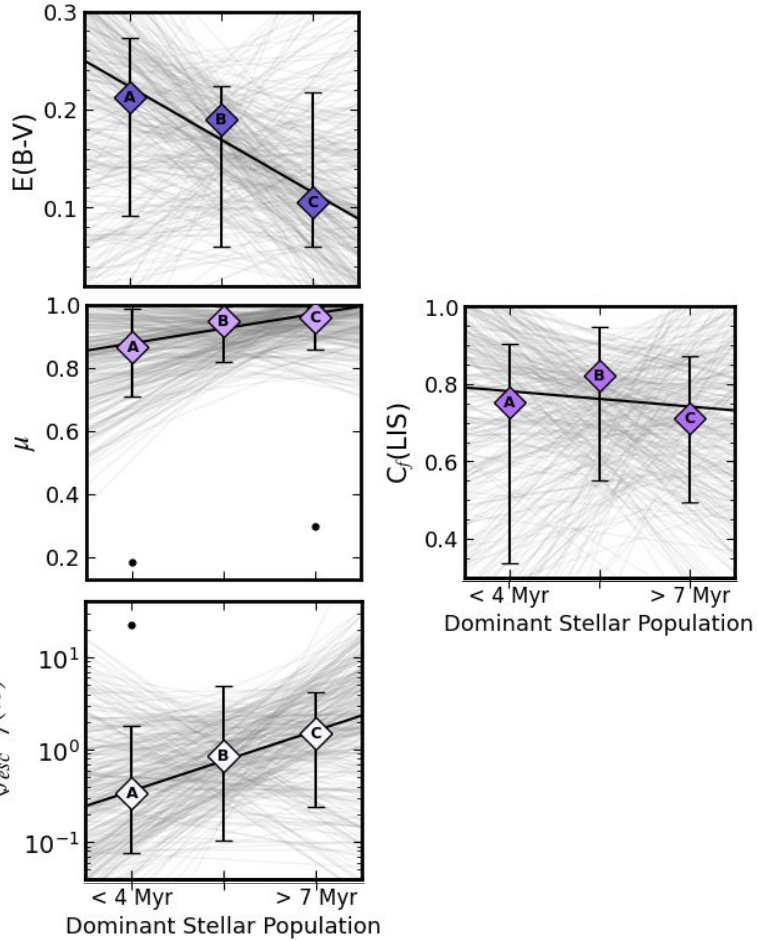
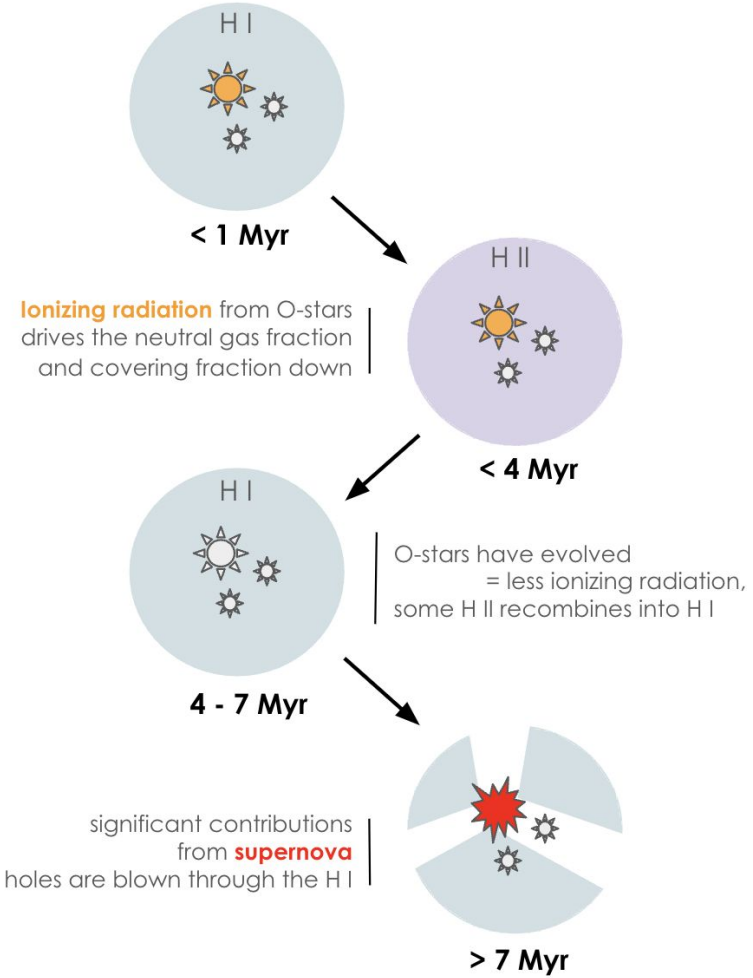
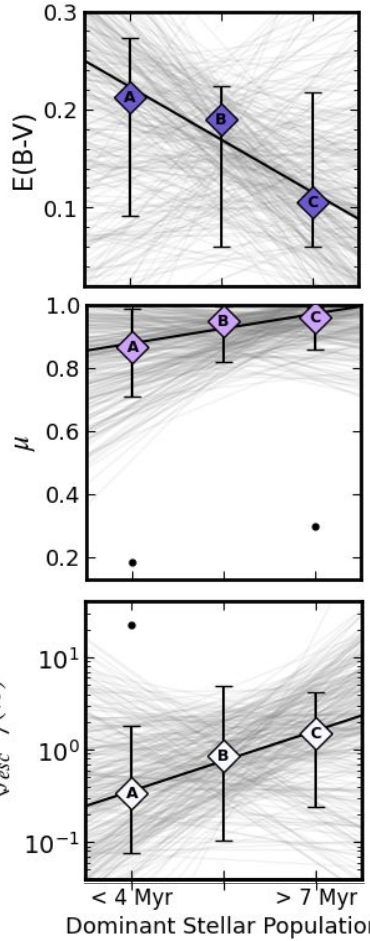
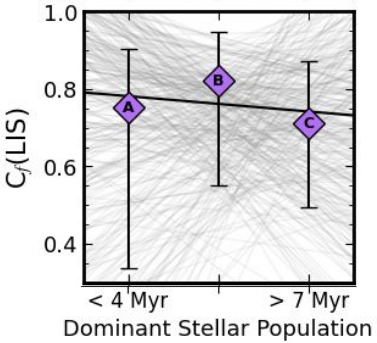

E(B-V)
μ
$\langle f_{esc}^{LyC} \rangle$(%)
A
B
C
< 4 Myr
> 7 Myr
Dominant Stellar Population

C_f(LIS)
A
B
C
< 4 Myr
> 7 Myr
Dominant Stellar Population

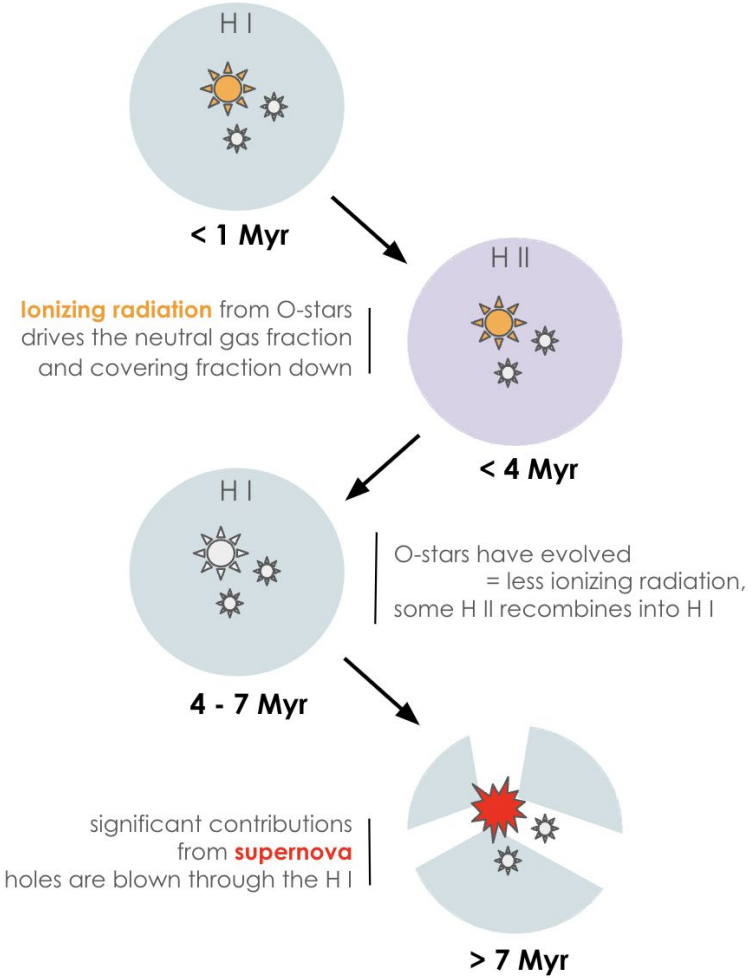

H I
< 1 Myr
Ionizing radiation from O-stars drives the neutral gas fraction and covering fraction down
H II
< 4 Myr
H I
O-stars have evolved
= less ionizing radiation,
some H II recombines into H I
4 - 7 Myr
significant contributions from supernova holes are blown through the H I
> 7 Myr



destruction of dust?



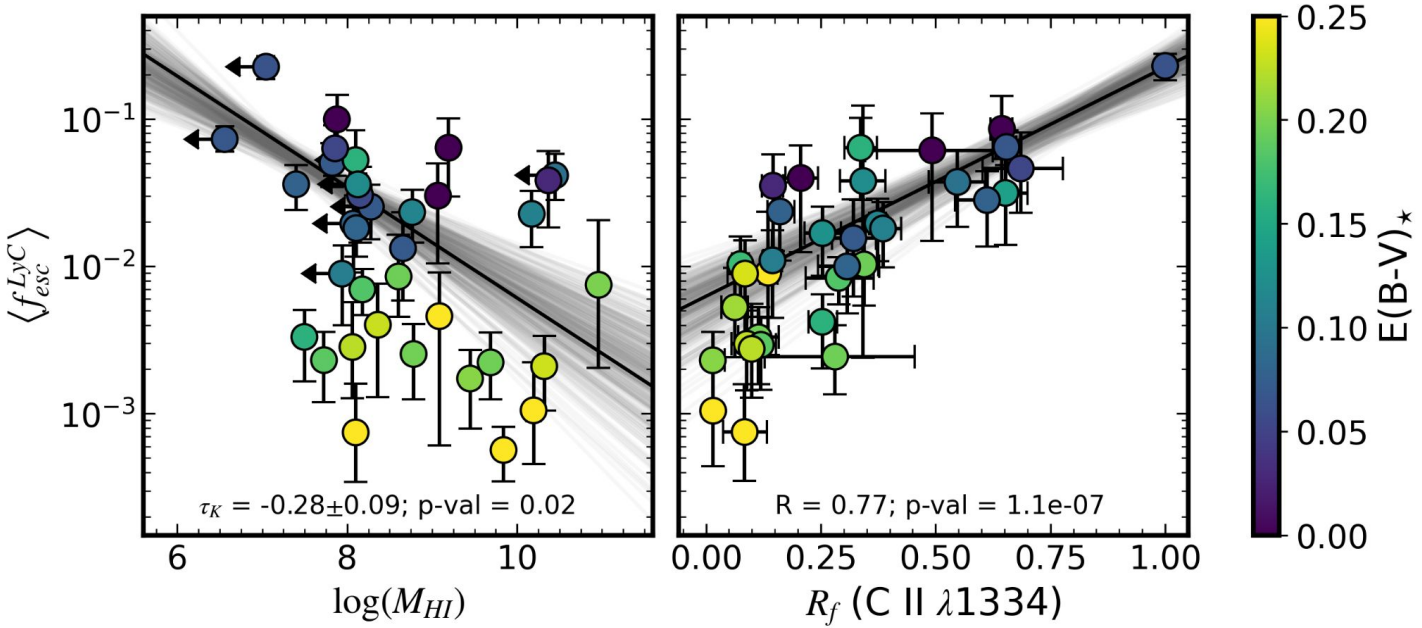
The onset of supernova are essential for increasing f_{esc} in CLASSY



Our f_{esc} predictions correlate with properties of the dust and gas

global + line-of-sight
HI + low-ionization

error-weighted average of indirect methods



In Summary

Keep an eye out for these results in Parker et al. (in prep.)

With the high-resolution nearby CLASSY galaxies, we found:

- general agreement between five indirect methods of predicting f_{esc}
  - *with some systematic differences*
- multiple LyC-leaker candidates among the CLASSY sample
- the onset of supernova is a main driver for high escape fractions in CLASSY
- correlations between escape fraction and
  - the **total** amount of HI gas present, $\log(M_{HI})$
  - line-of-sight LIS gas absorption, R_f
  - line-of-sight dust attenuation, E(B-V)