Probing Lyman Continuum Escape: Bayesian SED Modeling of Low-Redshift Analogues

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Sandro Tacchella, Charlotte Simmonds, Ben Johnson

Escape Fraction

$$\dot{n} = \rho_{UV} \times \xi_{ion} \times f_{esc}^{LyC}$$

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Escape Fraction with Prospector

Prospector:

- Bayesian
- Self consistently fit photometry & emission lines
- Nested sampling: can find multimodal solutions!

Data:

- High-z analogues, LzLCS (Flury+22)

Stellar Population & IMF

- **IMF:** Kroupa (2001)
- **Libraries:** MILES, MIST
- **Metallicity:** Fitted as $\log(Z / Z_{\odot})$

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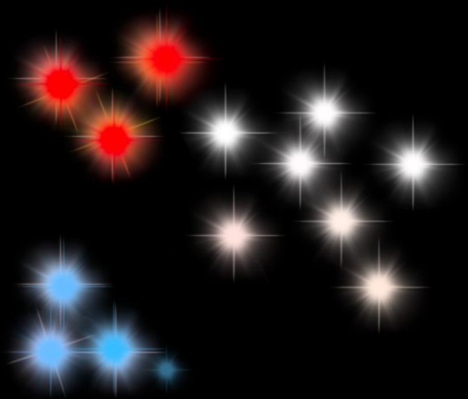
Star Formation History (SFH)

- **Non-parametric SFH**
- 8 time bins
- First two: fixed at 5 Myr and 10 Myr
- Remaining: log-spaced up to z = 20
- **SFR parameterization:** $\log(SFR_n / SFR_{n+1})$ between bins



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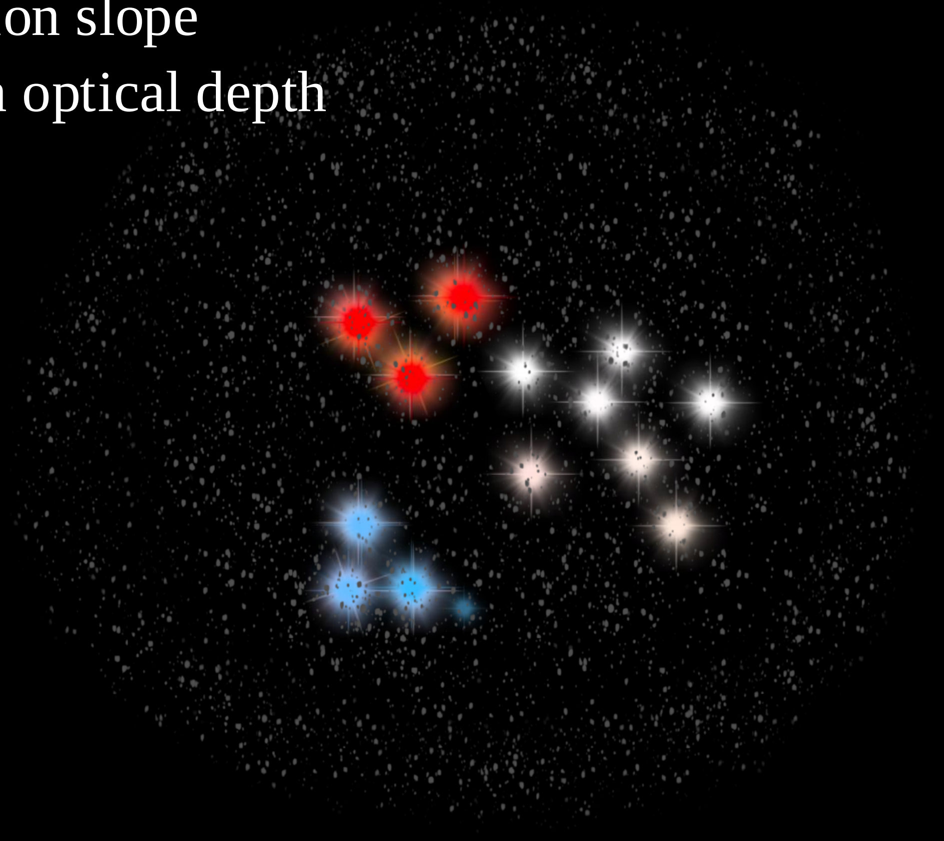
Dust Attenuation: 2-component model

- Law: Kriek & Conroy (2013)

Parameters:

- dust_index: attenuation slope
- τ_2: global dust screen optical depth

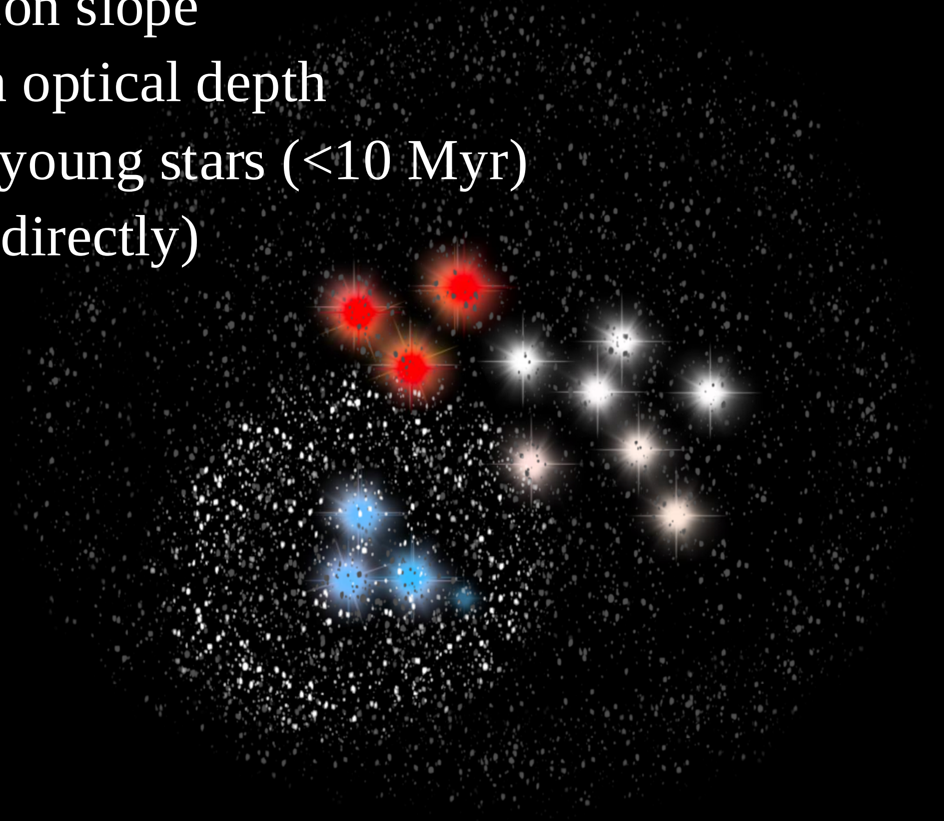


Dust Attenuation: 2-component model

- Law: Kriek & Conroy (2013)

Parameters:

- dust_index: attenuation slope
- τ_2: global dust screen optical depth
- τ_1: local dust around young stars (<10 Myr)
- Fit for: τ_2 / τ_1 (not τ_1 directly)



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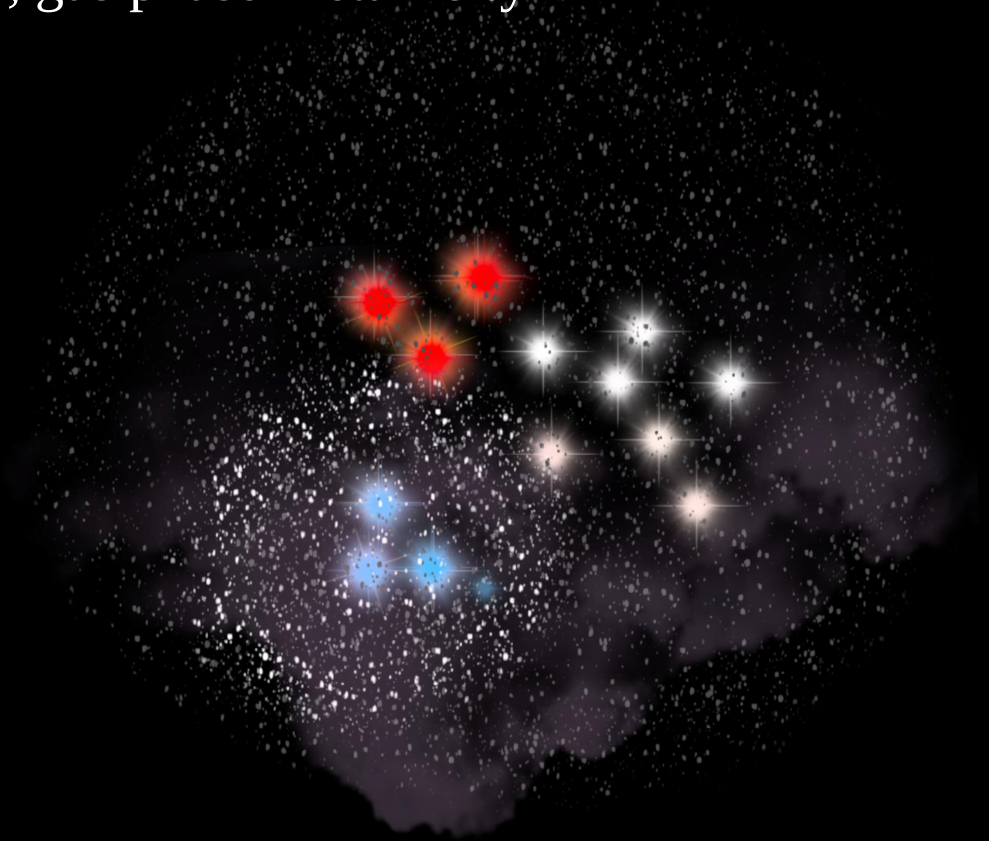
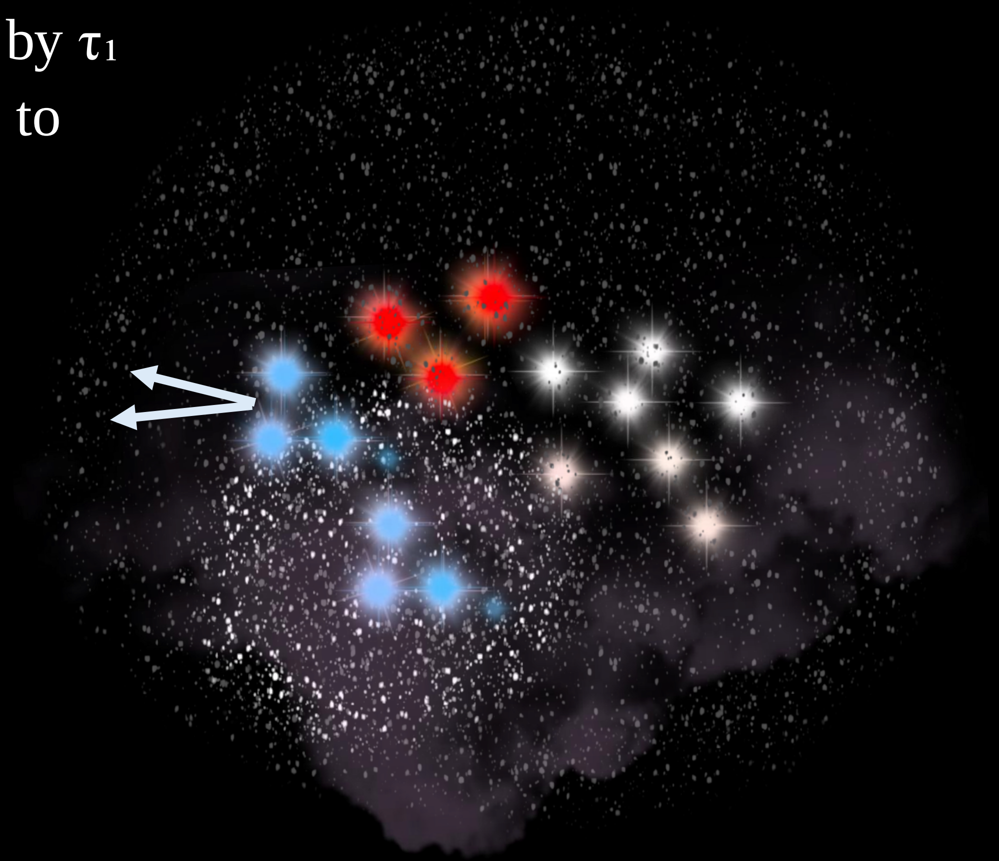
Nebular Emission

- Models: CLOUDY-based (Byler et al. 2017)
- Includes: Line + continuum emission
- ionization parameter, gas phase metallicity



Fraction of Runaway Stars

- Parameter: frac_obrun
- Fraction of light from young stars not attenuated by τ_1
- Does not contribute to emission lines




Dust 1
Gas

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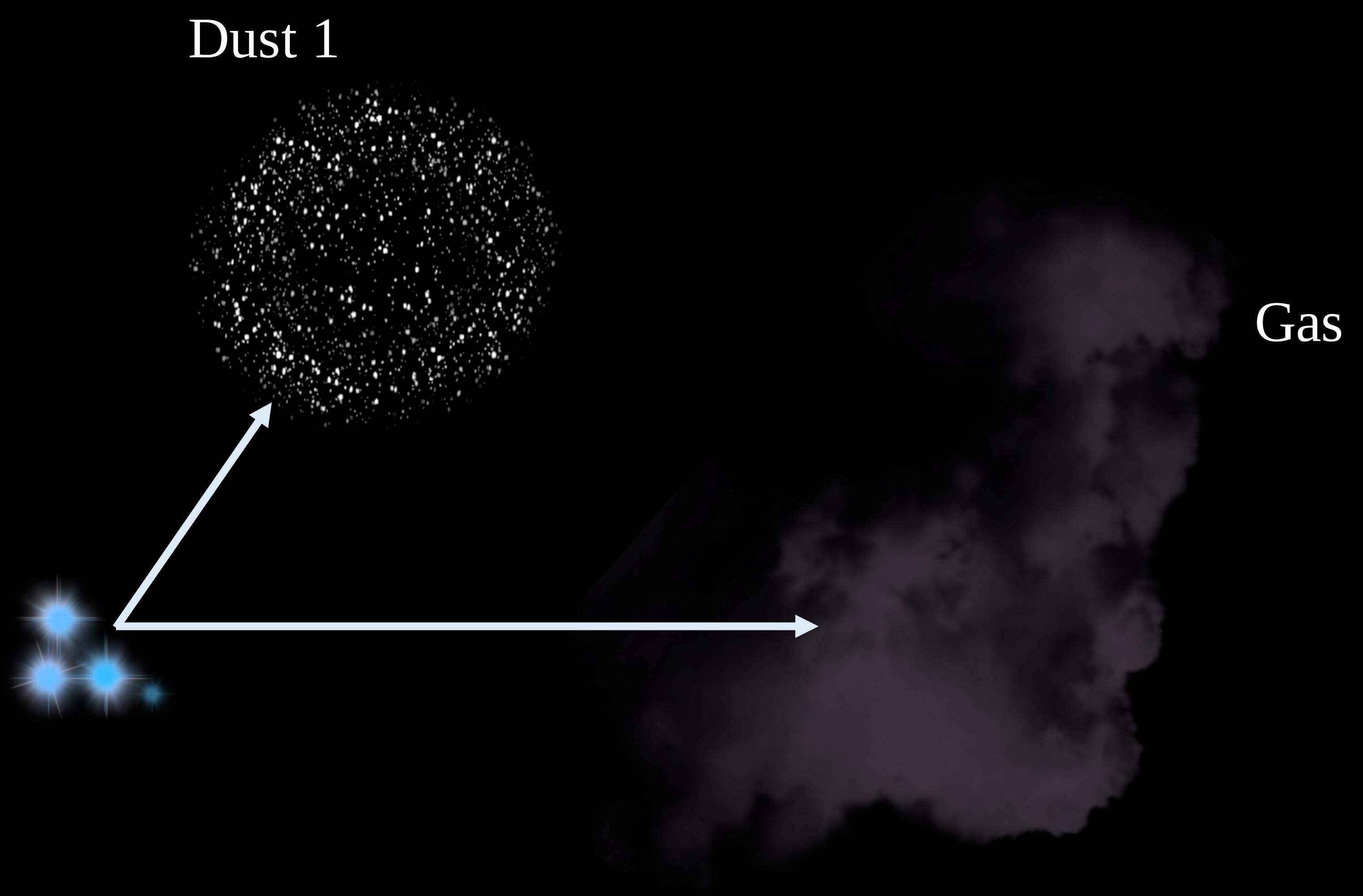

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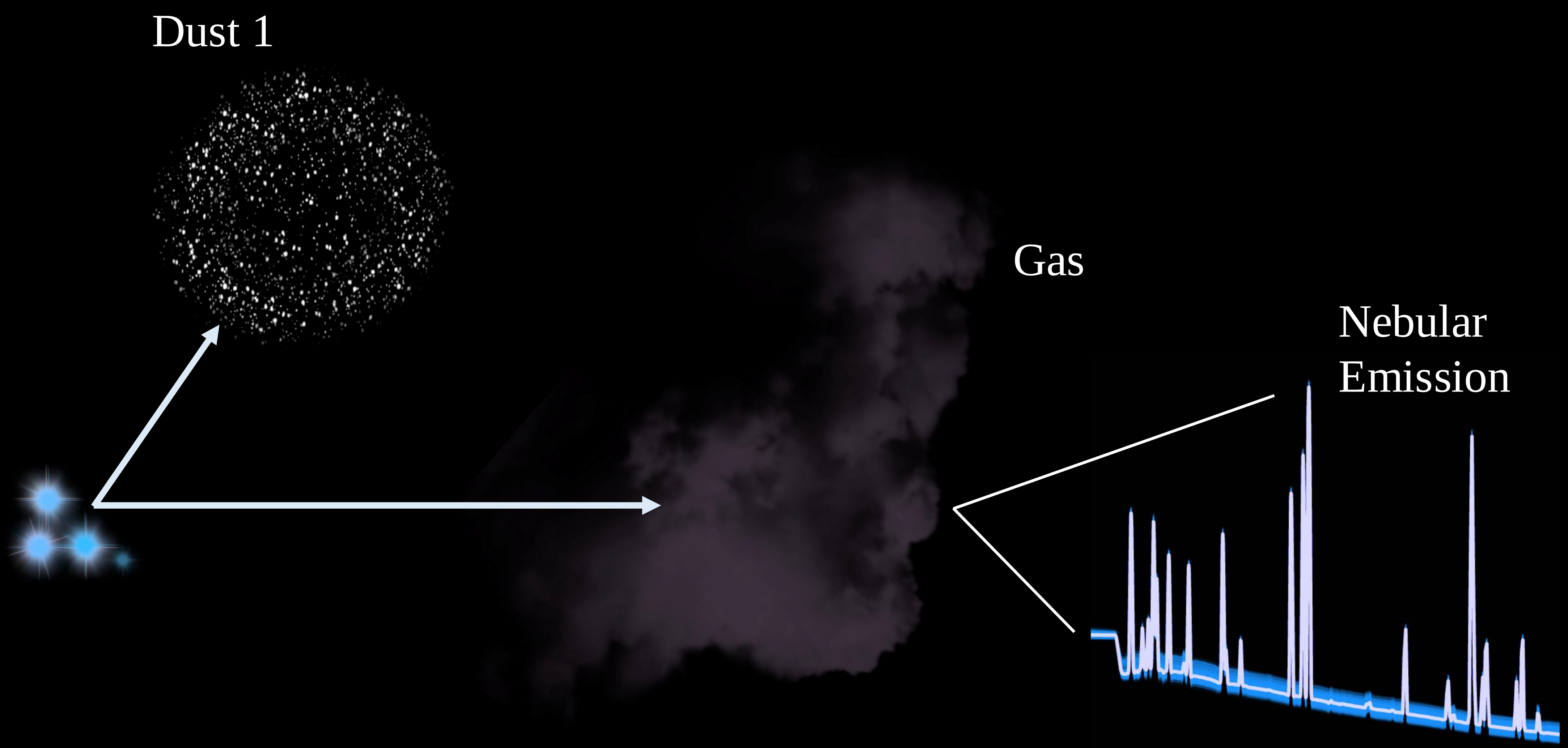

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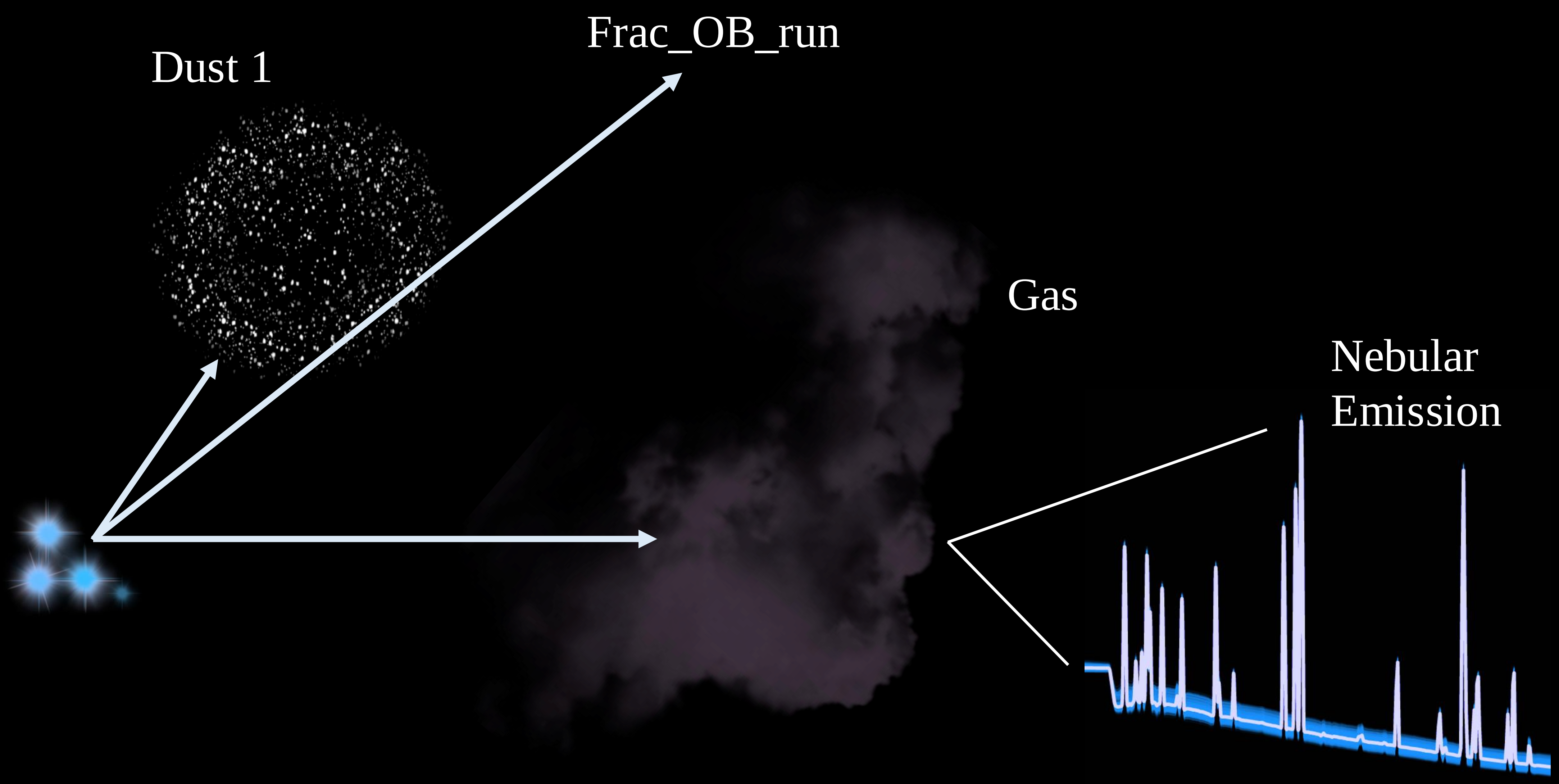

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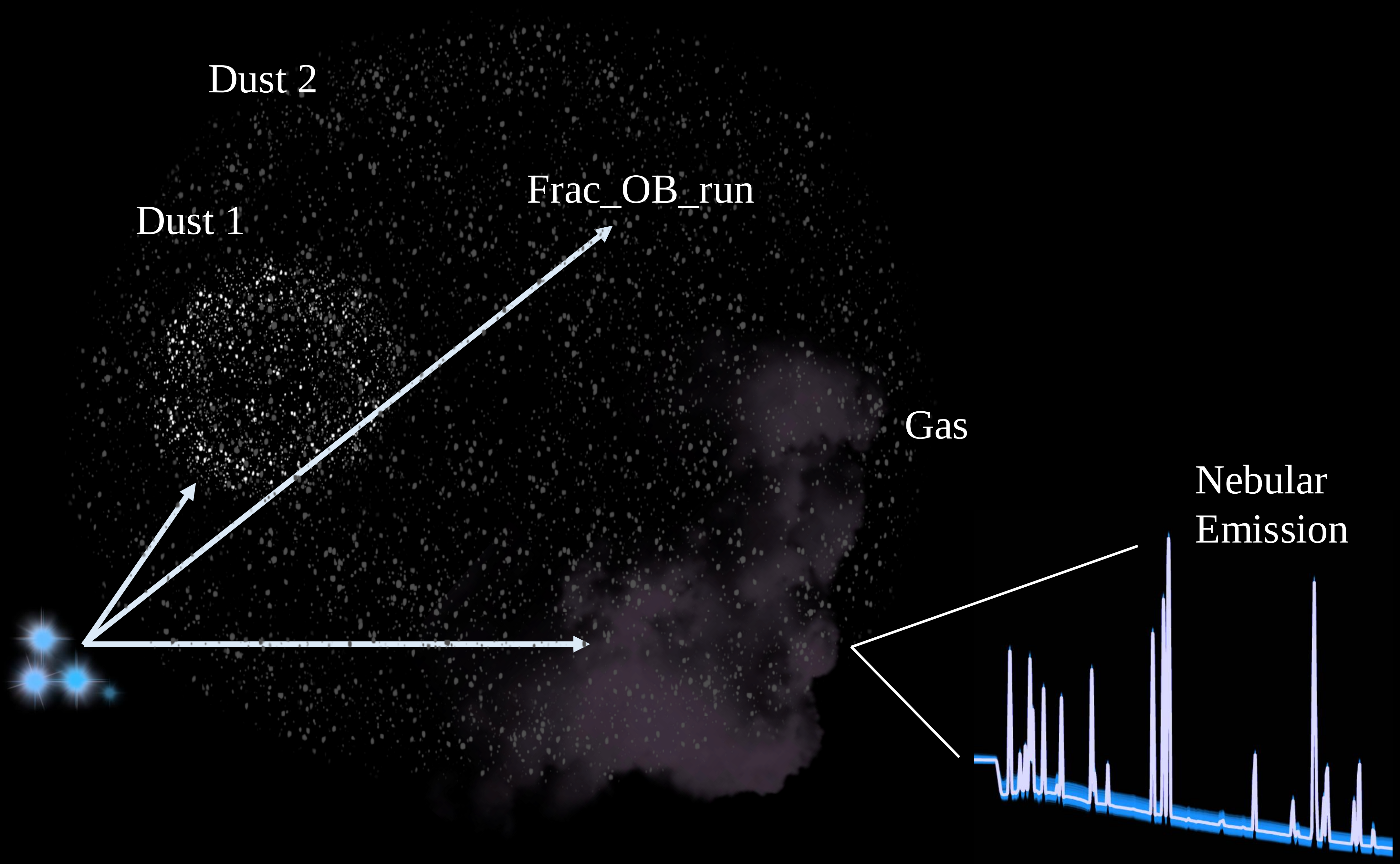
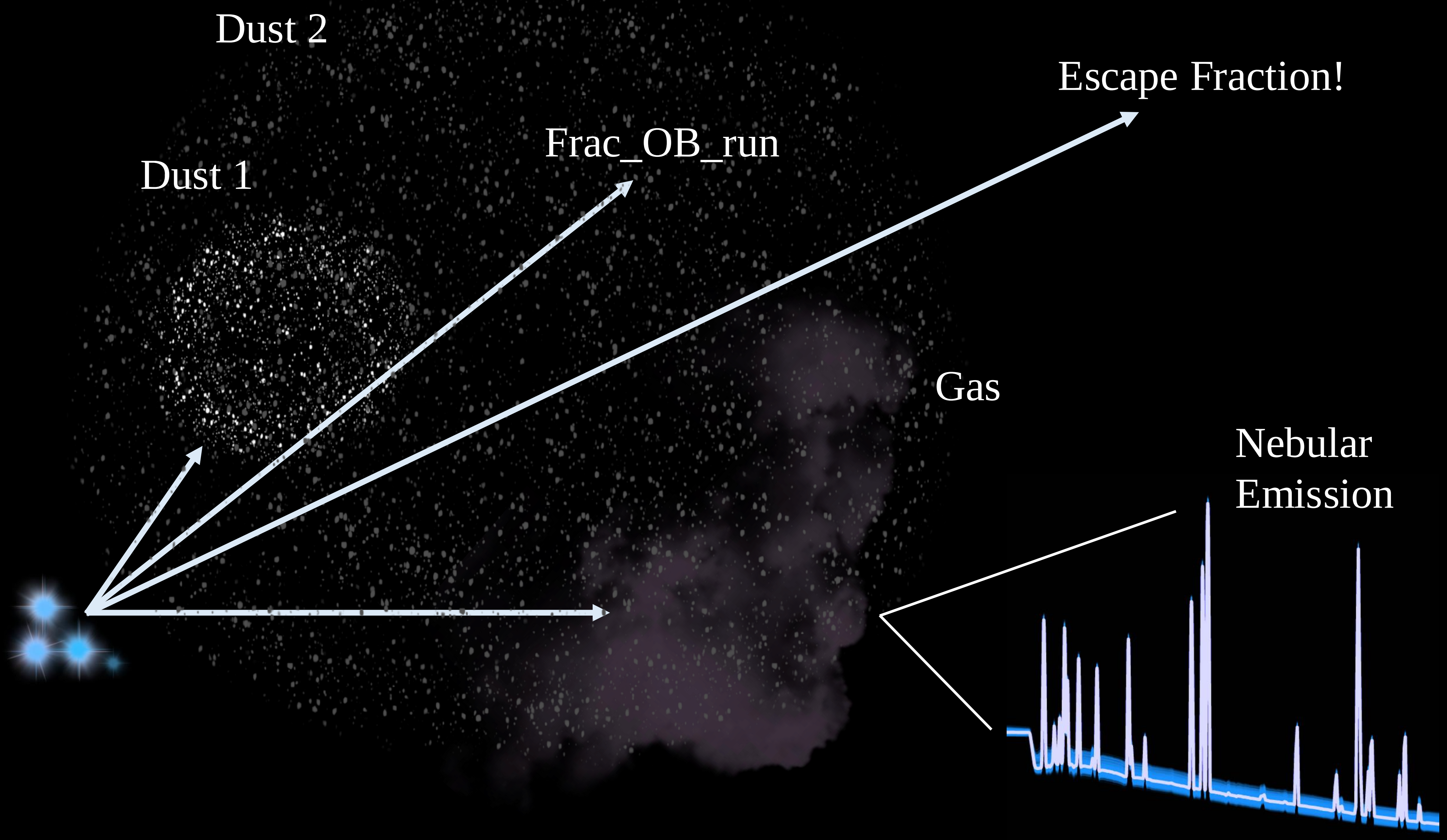

Dust 2
Dust 1
Frac_OB_run
Gas
Nebular
Emission



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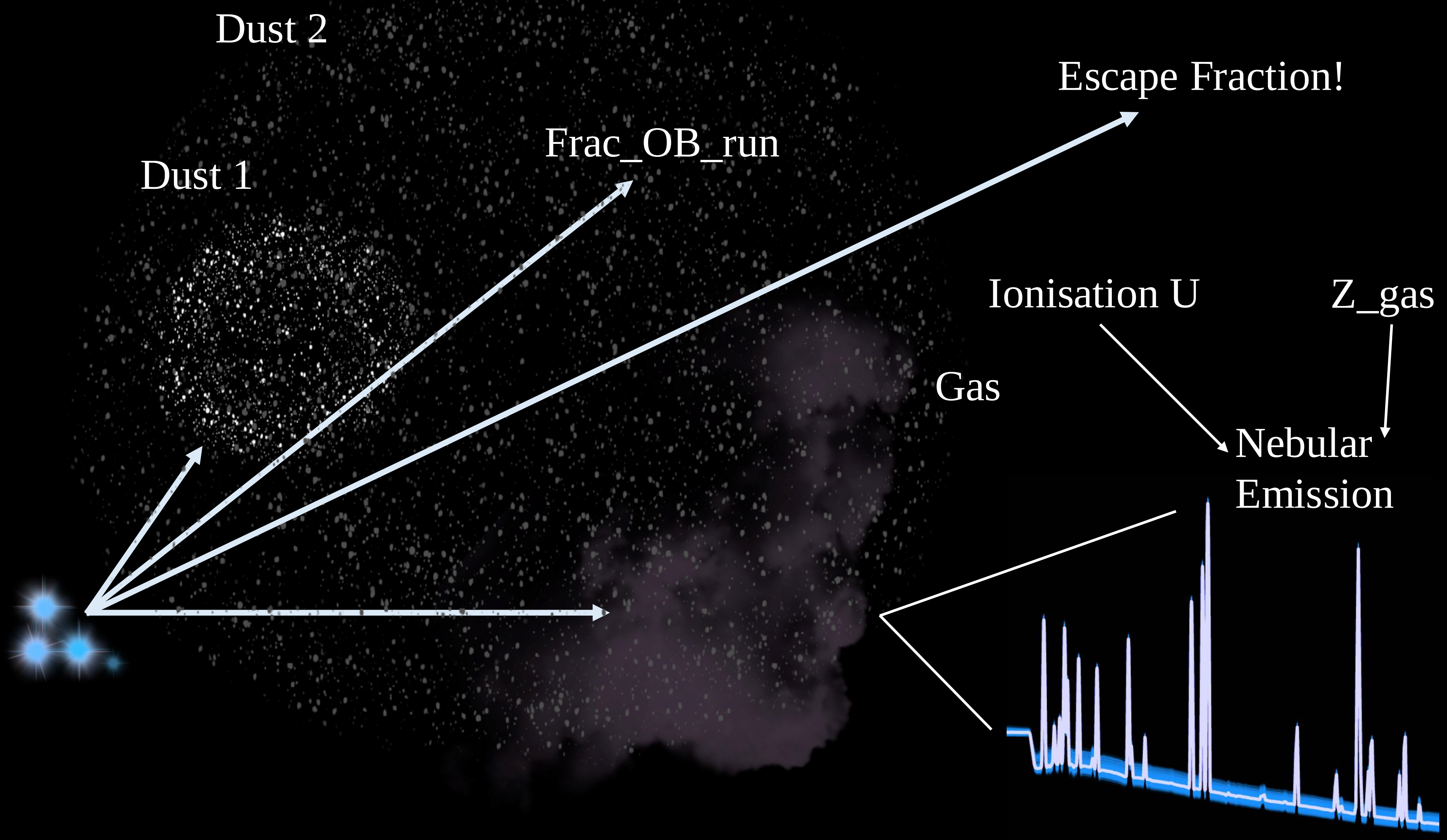
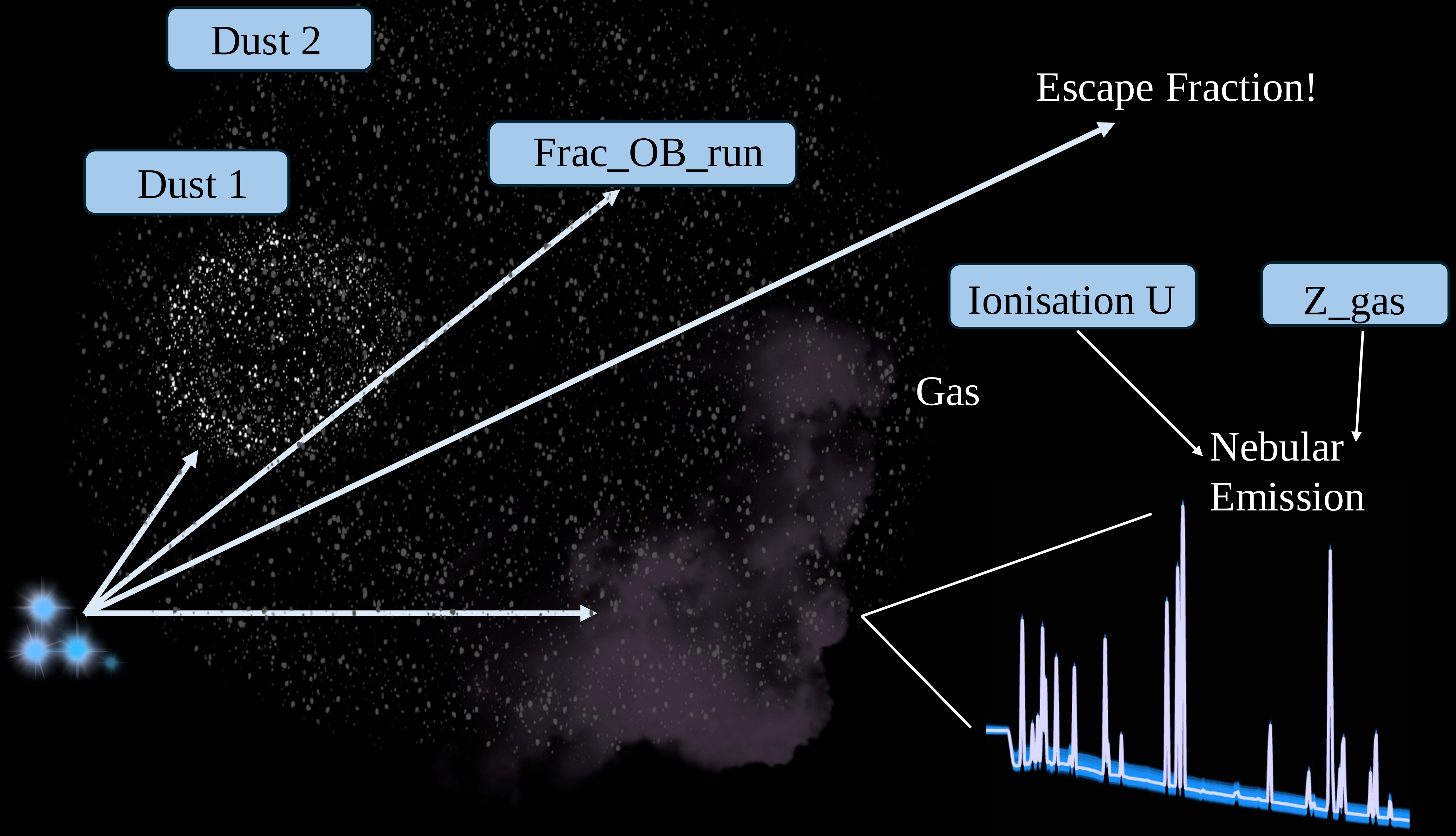
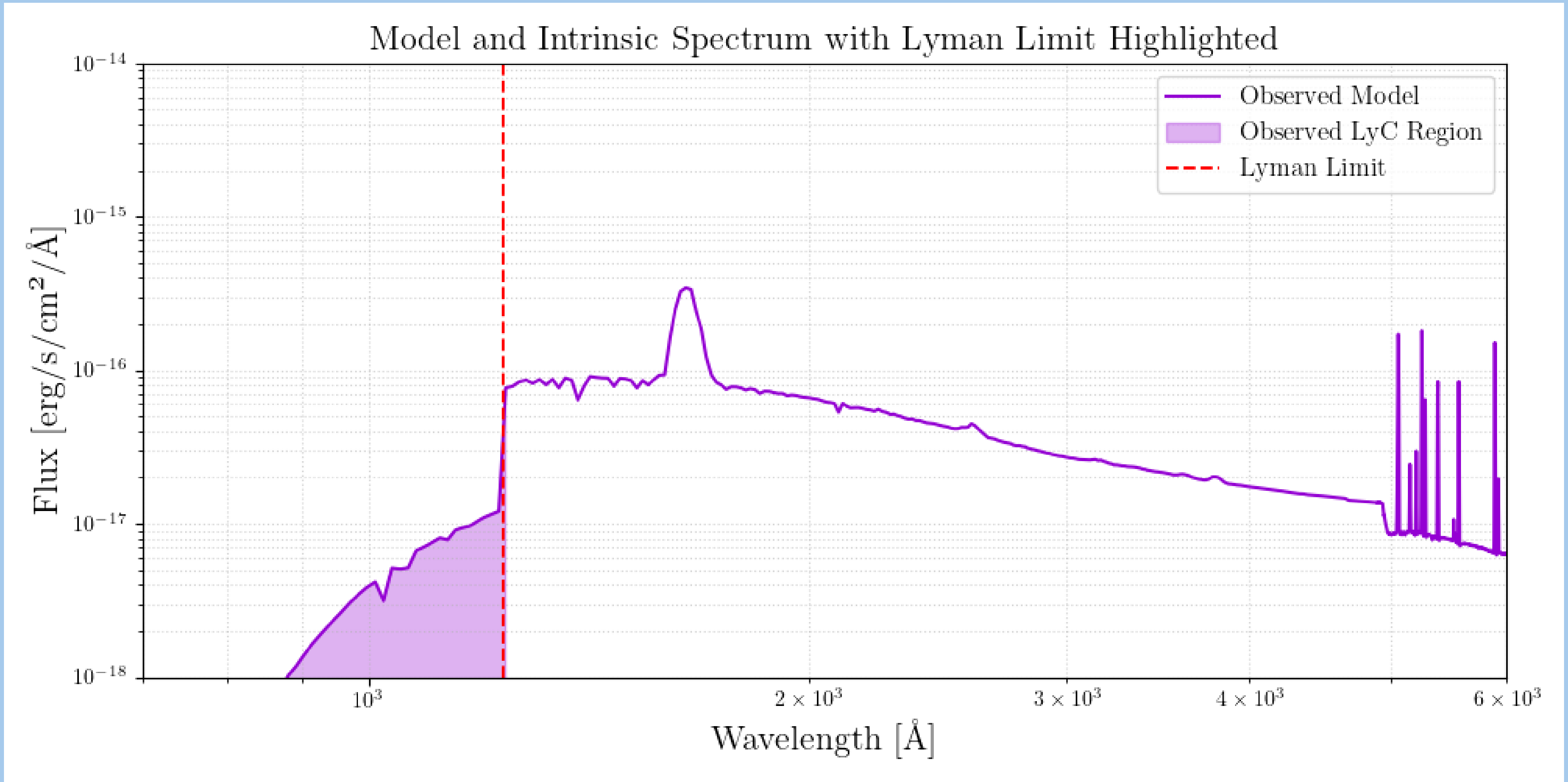

Dust 2
Escape Fraction!
Frac_OB_run
Dust 1
Ionisation U
Z_gas
Gas
Nebular
Emission

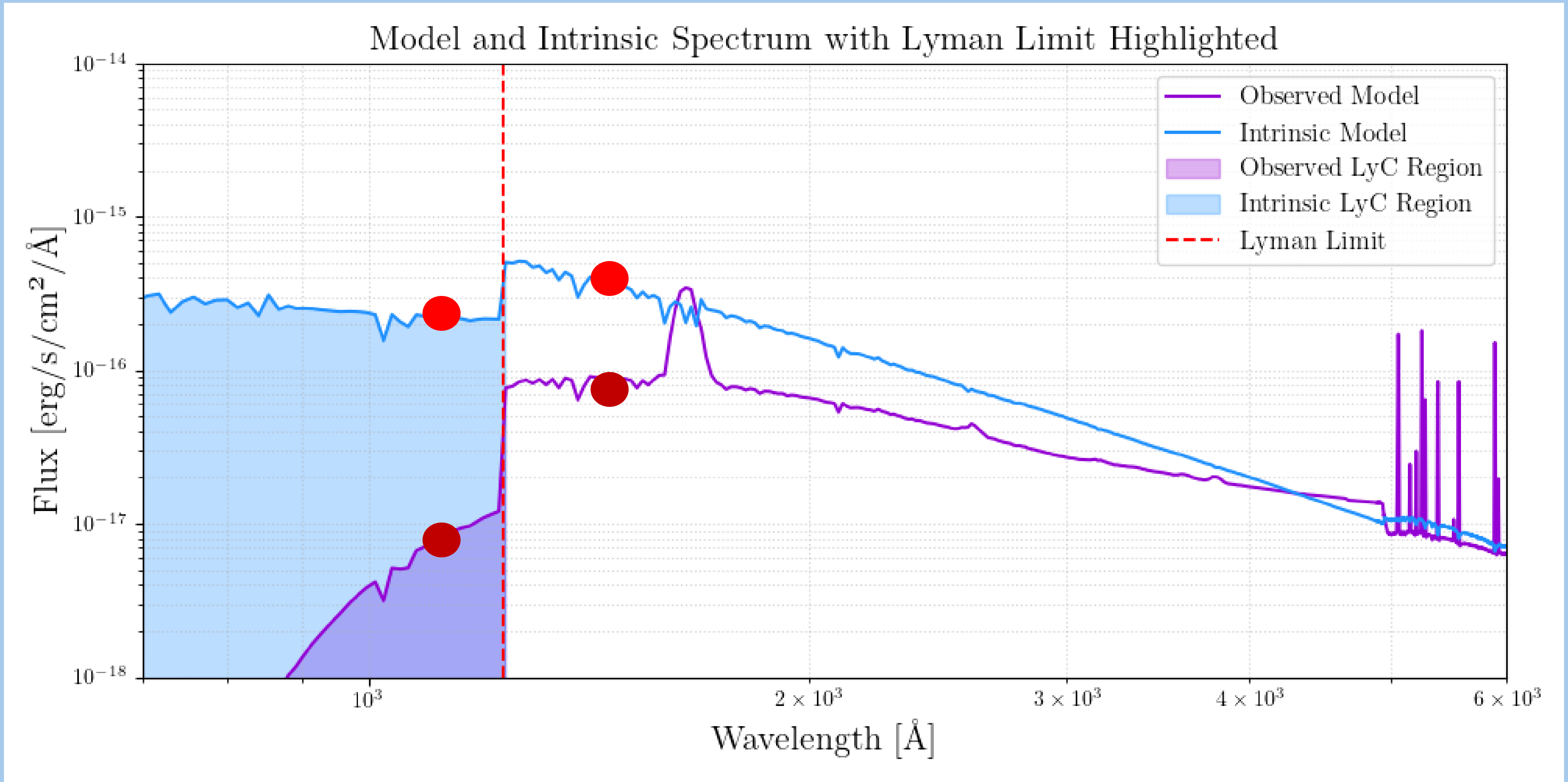

Dust 2
Dust 1
Frac_OB_run
Escape Fraction!
Ionisation U
Z_gas
Gas
Nebular
Emission

The Escape I Talk About



$$f_{esc,integrated} = \frac{n_{ion}^{obs}}{n_{ion}^{intr}}$$

$$f_{esc,ratio} = \frac{F_{LyC}^{obs} / F_{1100}^{obs}}{F_{LyC}^{intr} / F_{1100}^{intr}}$$



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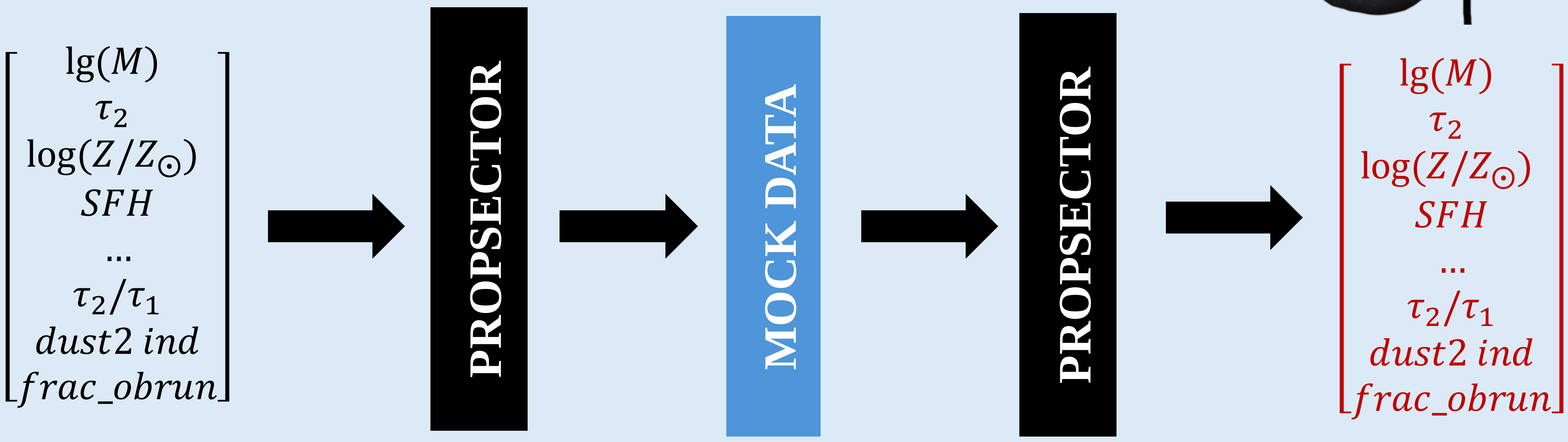
Recovery Test



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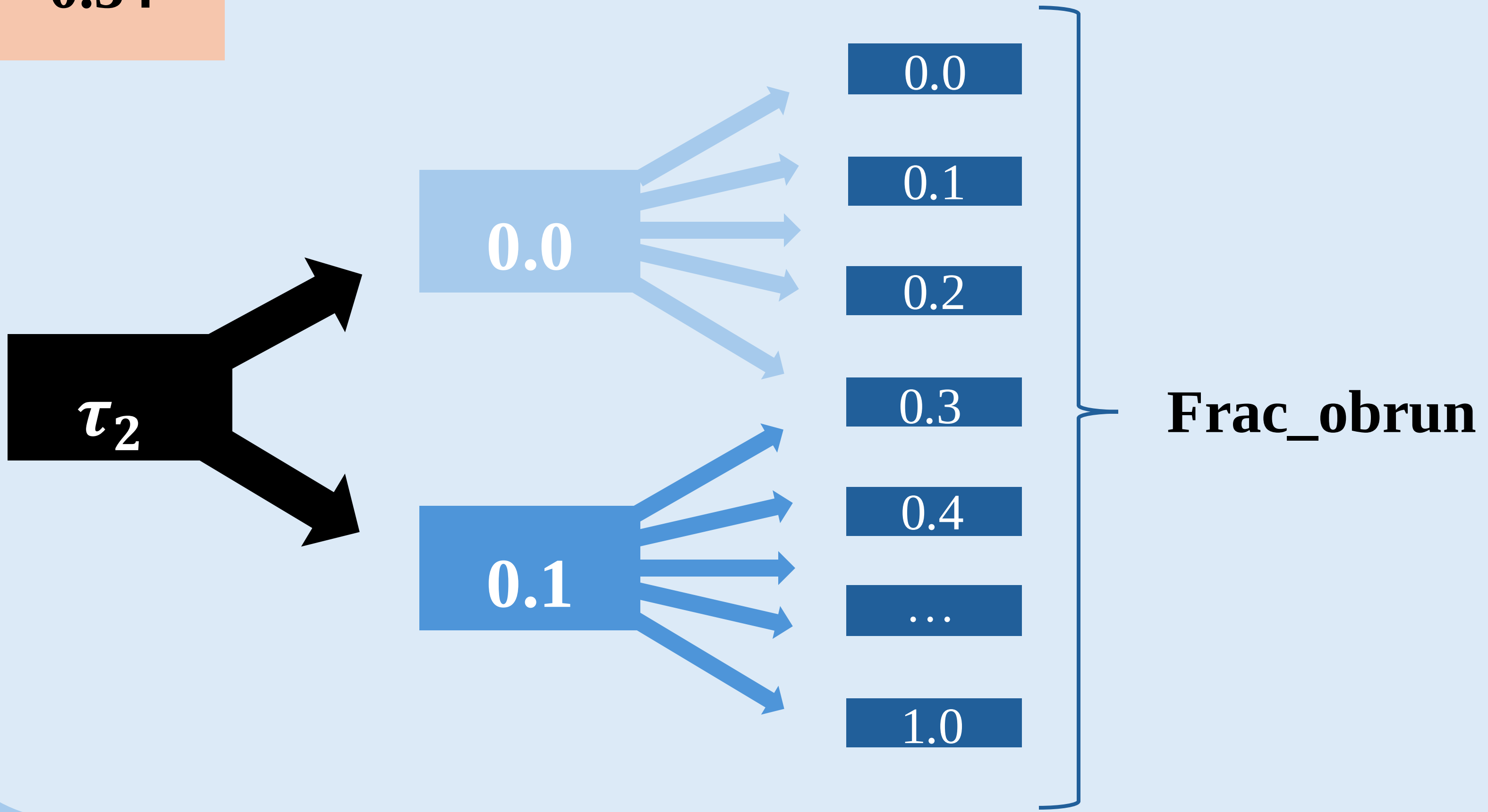
Recovery Test

$$\begin{bmatrix} \lg(M) \\ \tau_2 \\ \log(Z/Z_\odot) \\ SFH \\ \dots \\ \tau_2/\tau_1 \\ dust2\ ind \\ frac\_obrun \end{bmatrix}$$

z = 0.34



+ Noise

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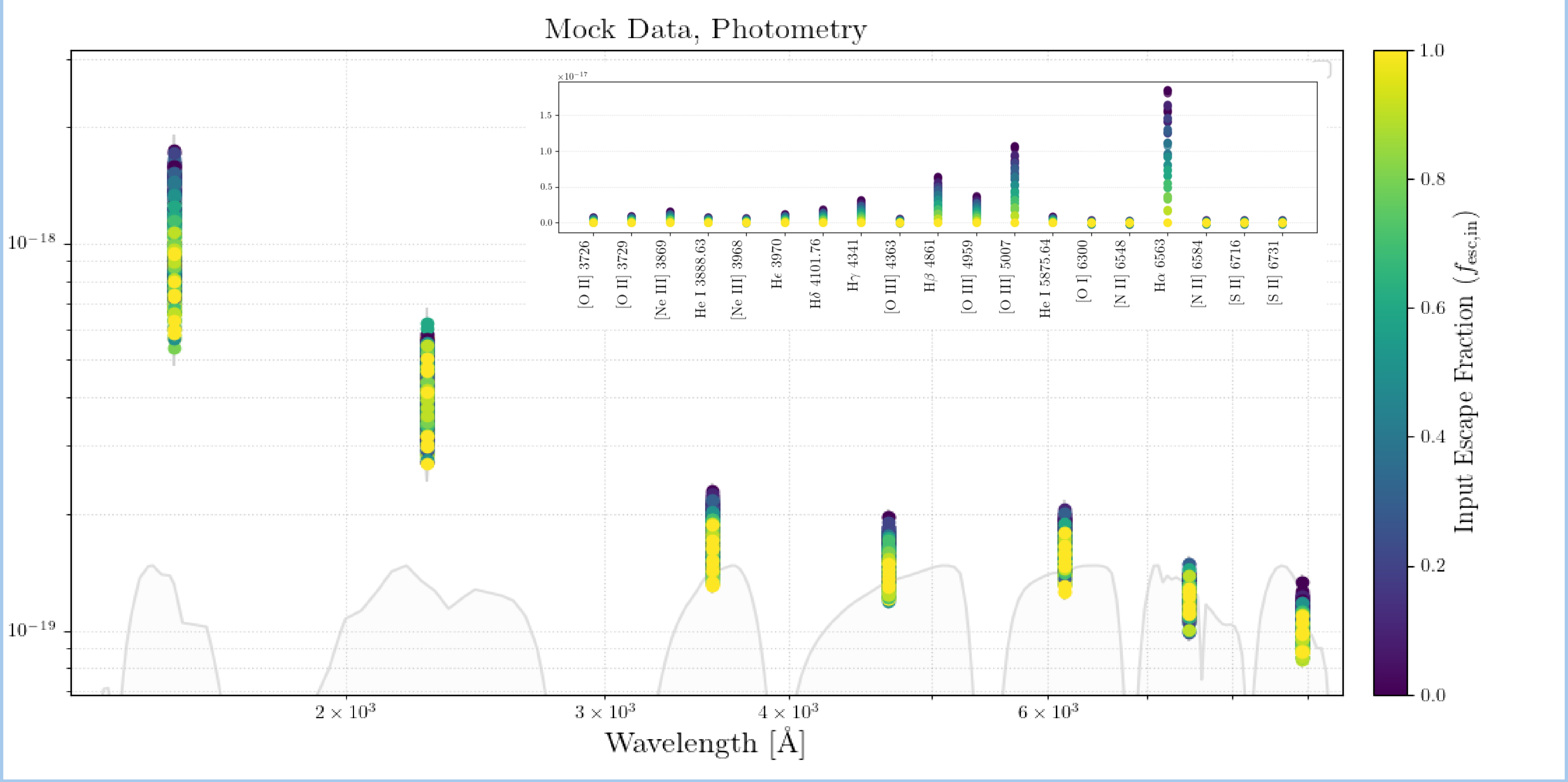
Mock Data



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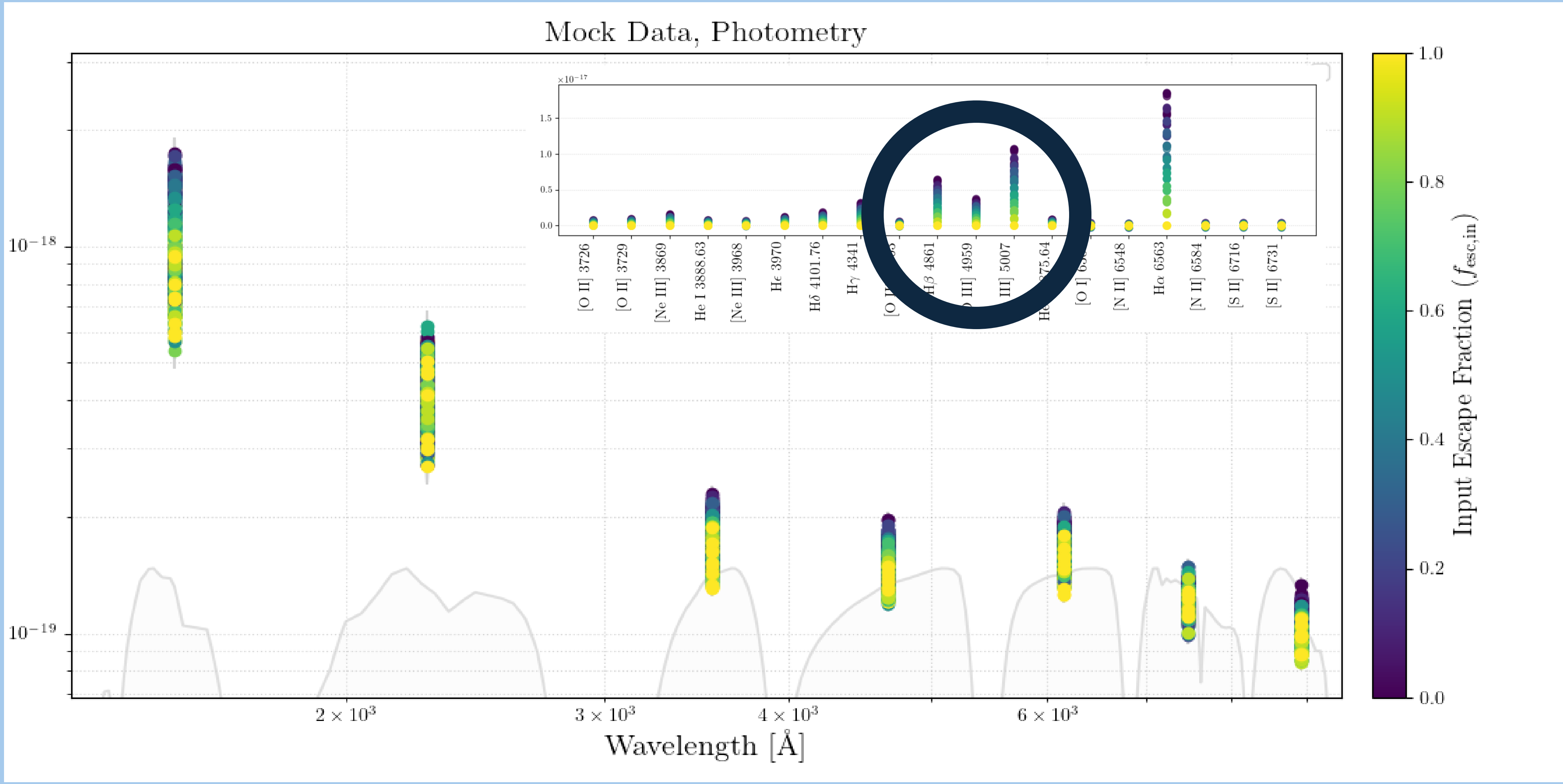
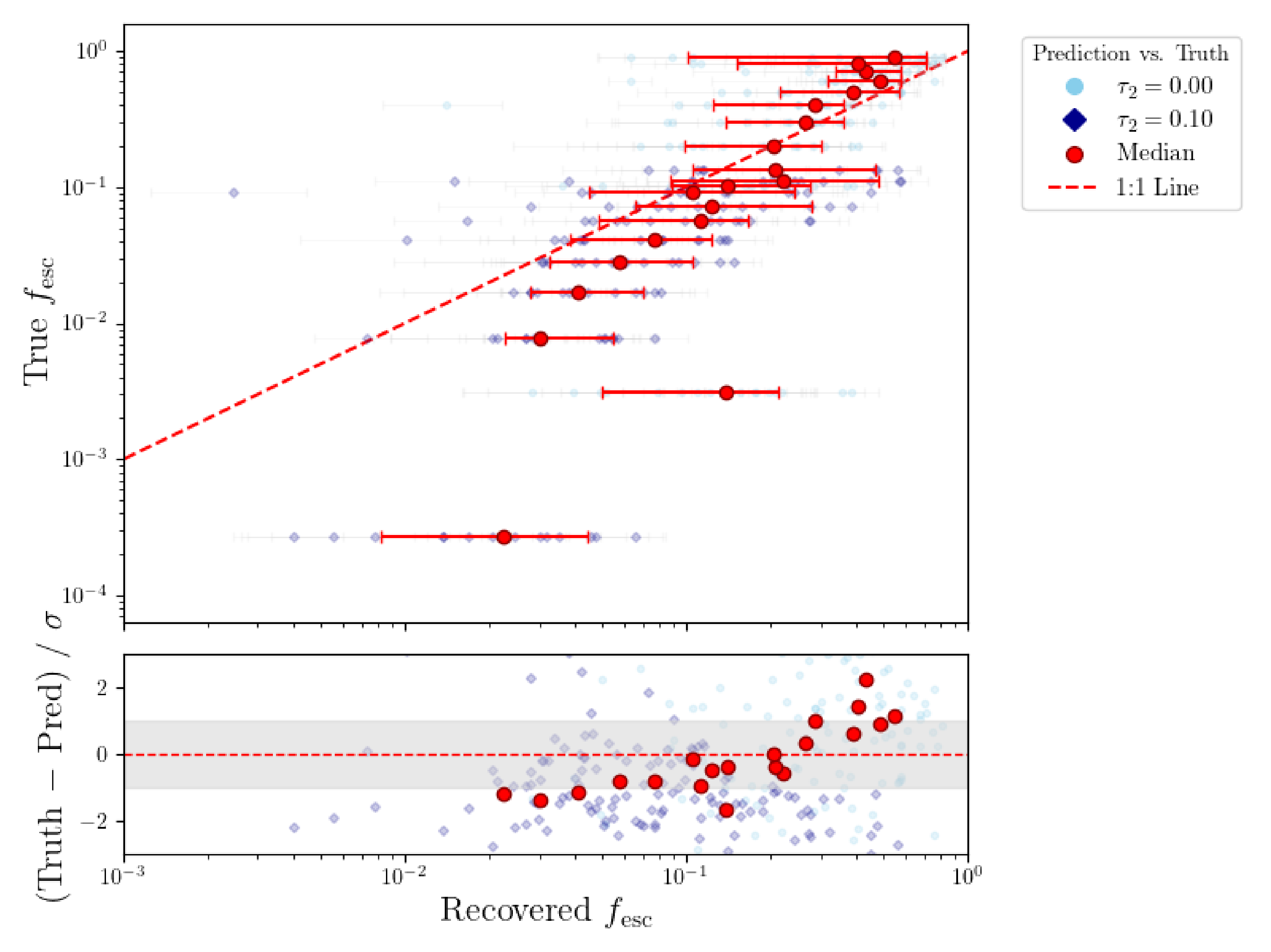


Mock Data, Photometry
Wavelength [Å]
Input Escape Fraction ($f_{esc,in}$)
[O II] 3726
[O II] 3729
[Ne III] 3869
He I 3888.63
[Ne III] 3968
Hε 3970
Hδ 4101.76
Hγ 4341
Hα 6563
[N II] 6548
[N II] 6584
[S II] 6716
[S II] 6731

Mock test results



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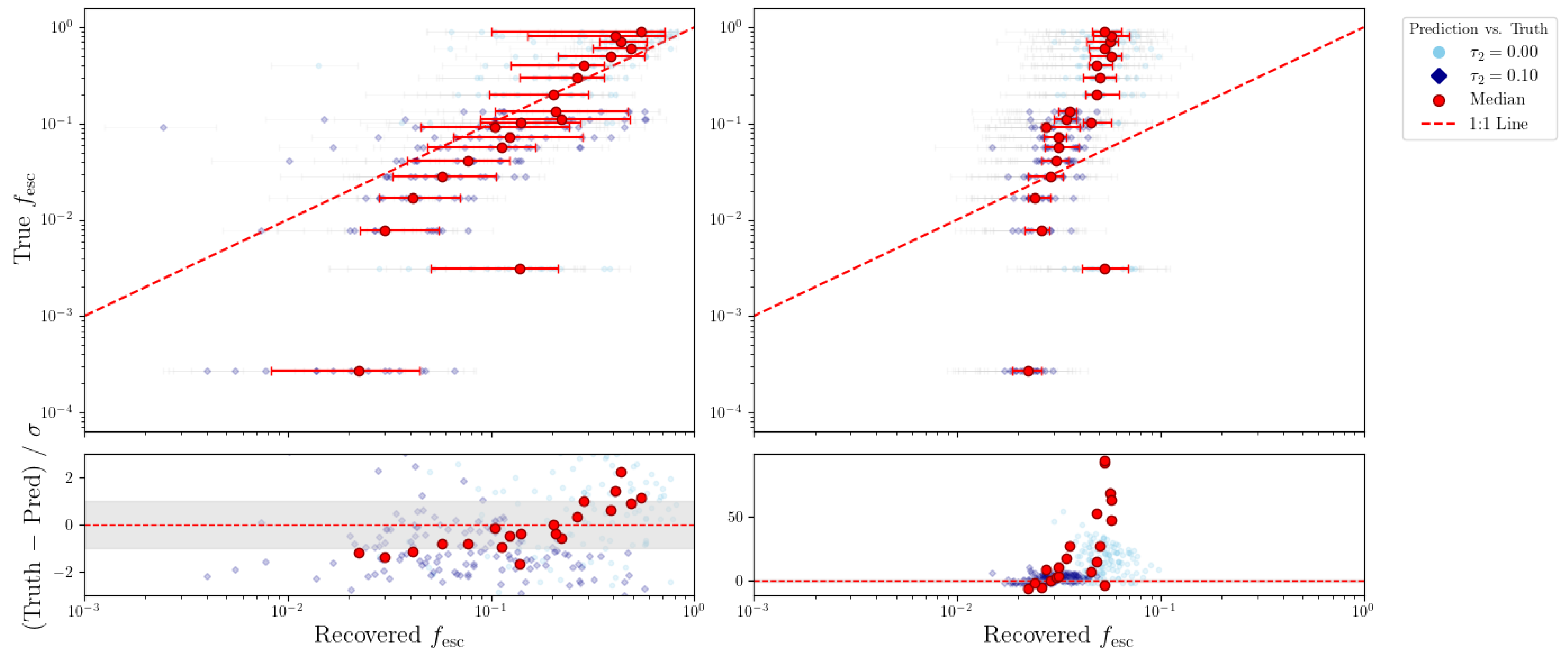
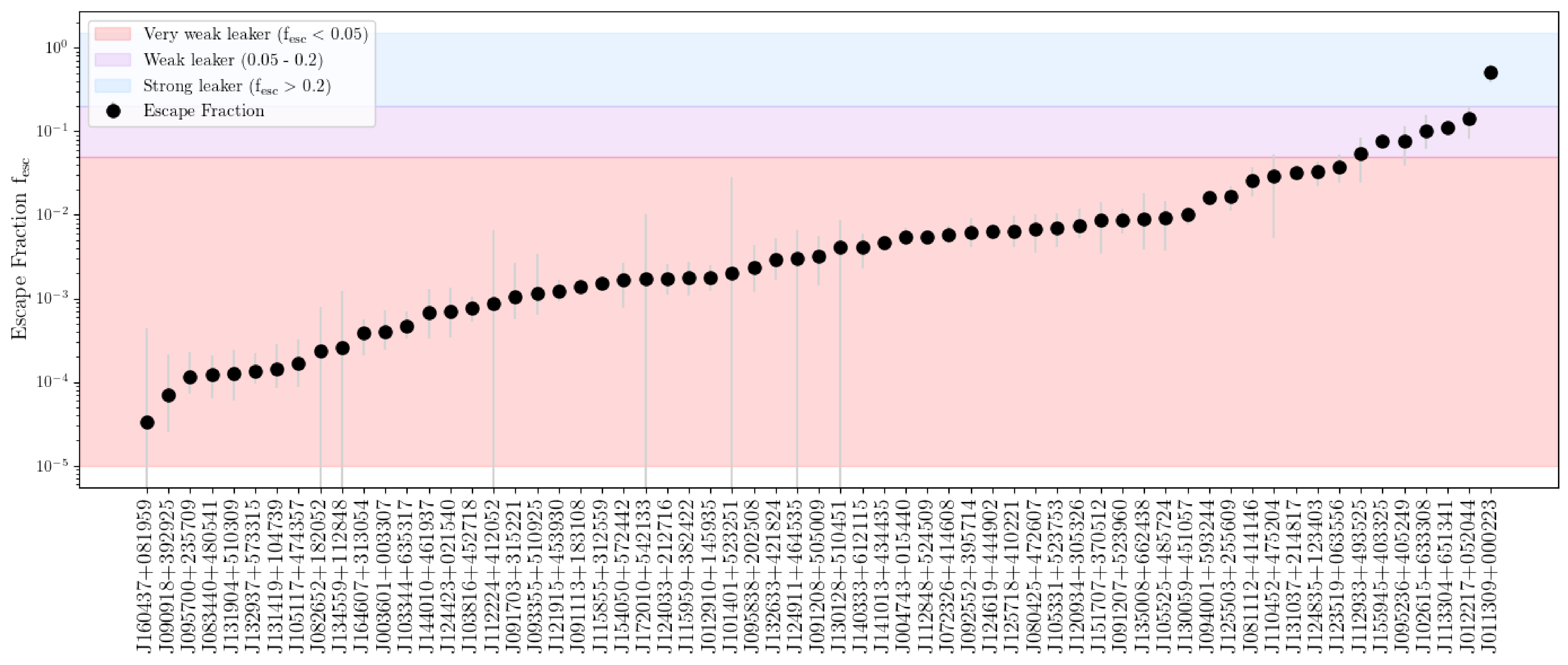
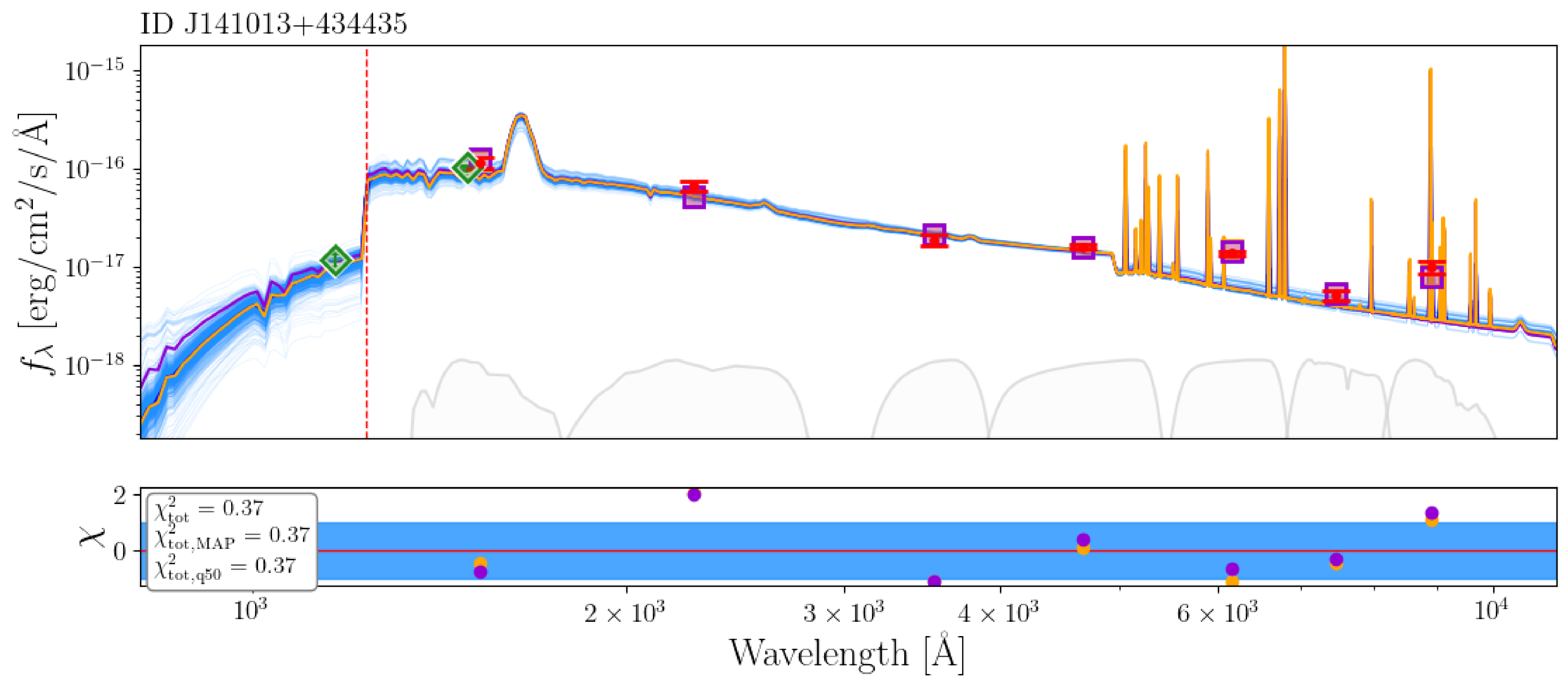


LzLCS



Very weak leaker (f_{esc} < 0.05)
Weak leaker (0.05 - 0.2)
Strong leaker (f_{esc} > 0.2)
Escape Fraction
Escape Fraction f_{esc}
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
J160437+081959
J090918+392925
J095700+235709
J083440+480541
J131904+510309
J132937+573315
J131419+104739
J105117+474357
J082652+182052
J134559+112848
J164607+313054
J003601+003307
J103344+635317
J144010+461937
J124423+021540
J103816+452718
J112224+412052
J091703+315221
J093355+510925
J121915+453930
J091113+183108
J115855+312559
J154050+572442
J172010+542133
J124033+212716
J115959+382422
J012910+145935
J101401+523251
J095838+202508
J132633+421824
J124911+464535
J091208+505009
J130128+510451
J140333+612115
J141013+434435
J004743+015440
J112848+524509
J072326+414608
J092552+395714
J124619+444902
J125718+410221
J080425+472607
J105331+523753
J120934+305326
J151707+370512
J091207+523960
J135008+662438
J105525+485724
J130059+451057
J094001+593244
J125503+255609
J081112+414146
J110452+475204
J131037+214817
J124835+123403
J123519+063556
J112933+493525
J155945+403325
J095236+405249
J102615+633308
J113304+651341
J012217+052044
J011309+000223

LzLCS



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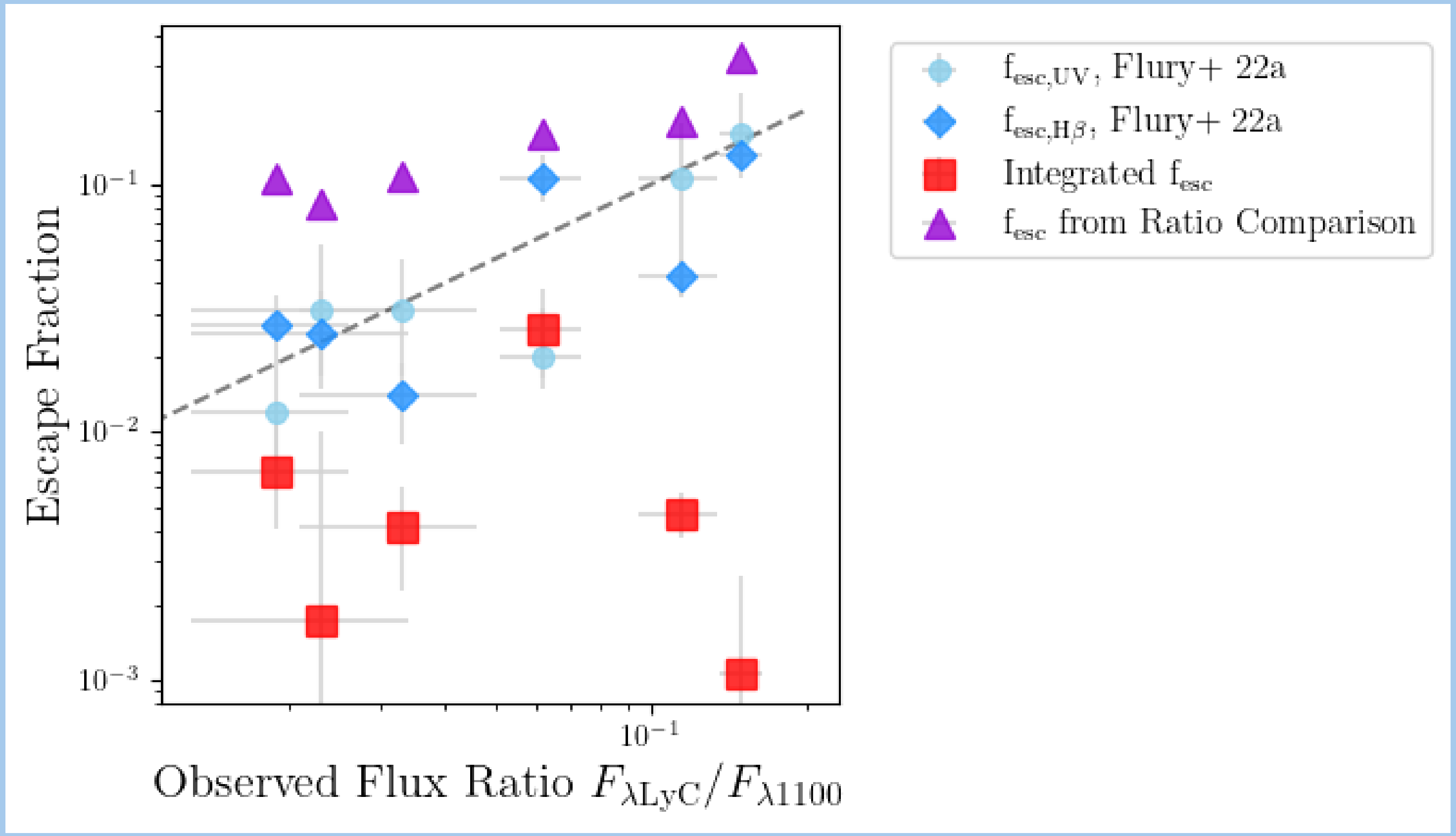
Compare to Observables



$$f_{esc,ratio} = \frac{F_{LyC}^{obs} / F_{1100}^{obs}}{F_{LyC}^{intr} / F_{1100}^{intr}}$$

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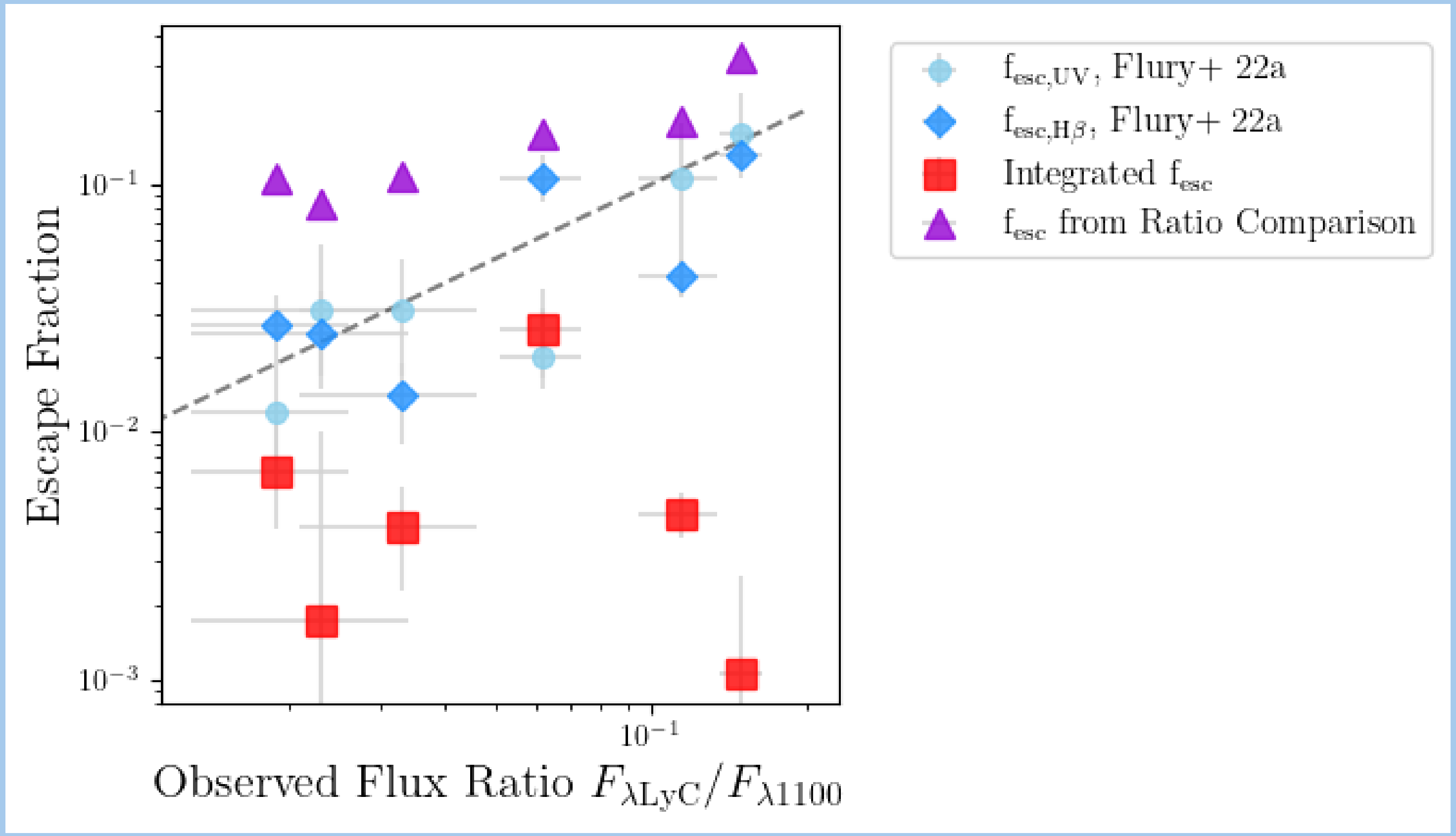
Compare to Observables



$$f_{esc,ratio} = \frac{F^{obs}_{LyC} / F^{obs}_{1100}}{F^{intr}_{LyC} / F^{intr}_{1100}}$$

$$f_{esc,integrated} = \frac{n^{obs}_{ion}}{n^{intr}_{ion}}$$

Ideas

- So far only ionization bounded
  - No escape contribution from nebular continuum
- Different SSPs – BPASS!
- Compare to less contaminated UV regions
- More detailed tests: in which parameter regions do which beta slope and other indirect estimators work?

CERIDWEN – SED Fitting with HMC

- Matrix based
- Fully differentiable
- JAX
  - GPU
  - Fast!
- Hamiltonian Monte Carlo
  - Fast!
- More parameters
- “Continuous” SFH!
- Metallicity history
- SFH connected to alpha abundances
- Dust per population age
- Photoionization with...
  - CUE
  - Cloudy

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Coming to a GitHub near you
—by the end of this year!
(hopefully)

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Summary

- Prospector is able to recover escape fractions within uncertainties
- Cloudy model is restricting escape fraction

Future

- CERIDWEN: combine alpha abundances to find detailed SFH
- Photoionization:
  - Use higher-dimensional Cloudy grids
  - Use emulator CUE (Yijia Li 24)

Error Boosting

Boost uncertainties of f_esc by 2.09