# Probing the Halos of Primordial Galaxies

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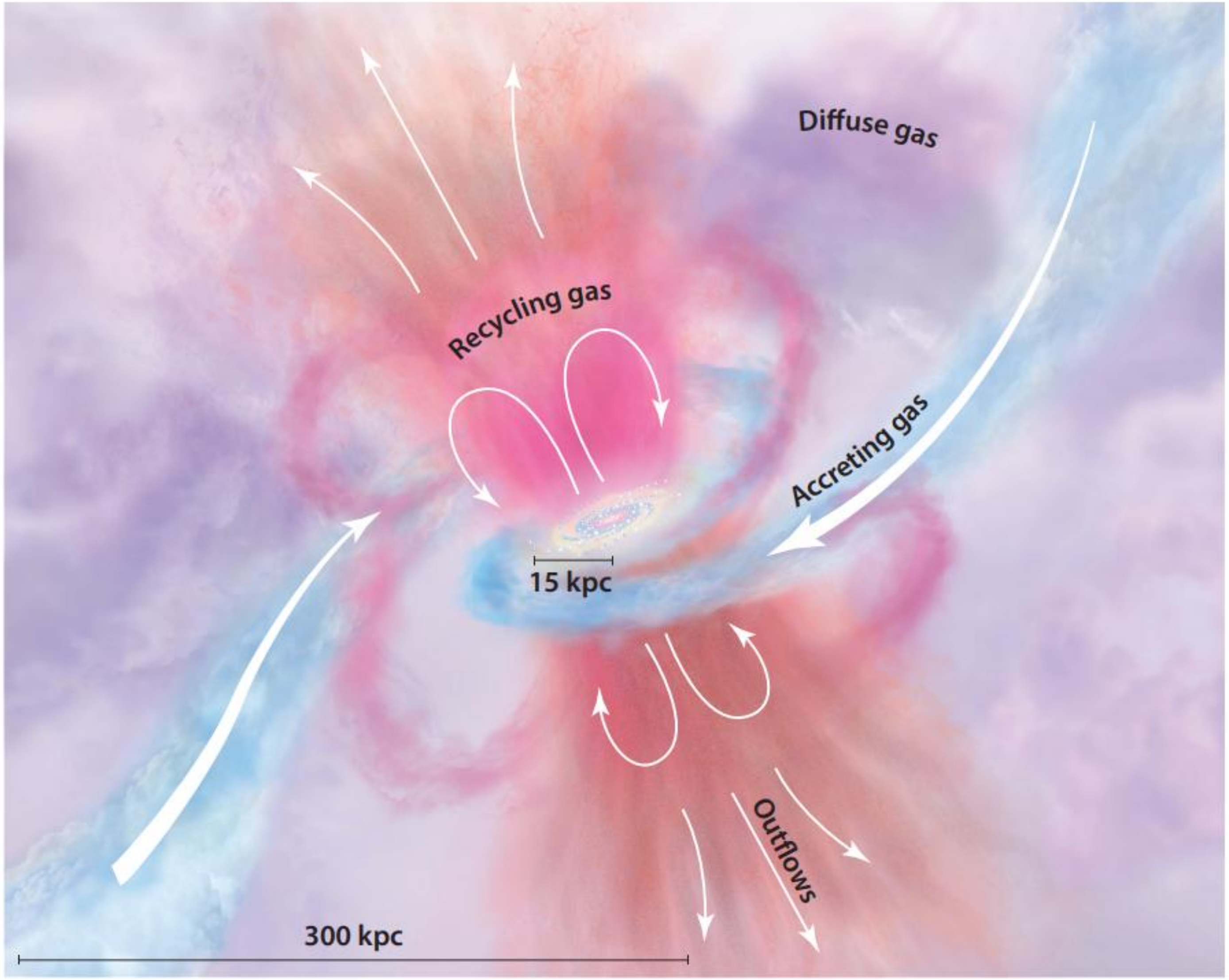
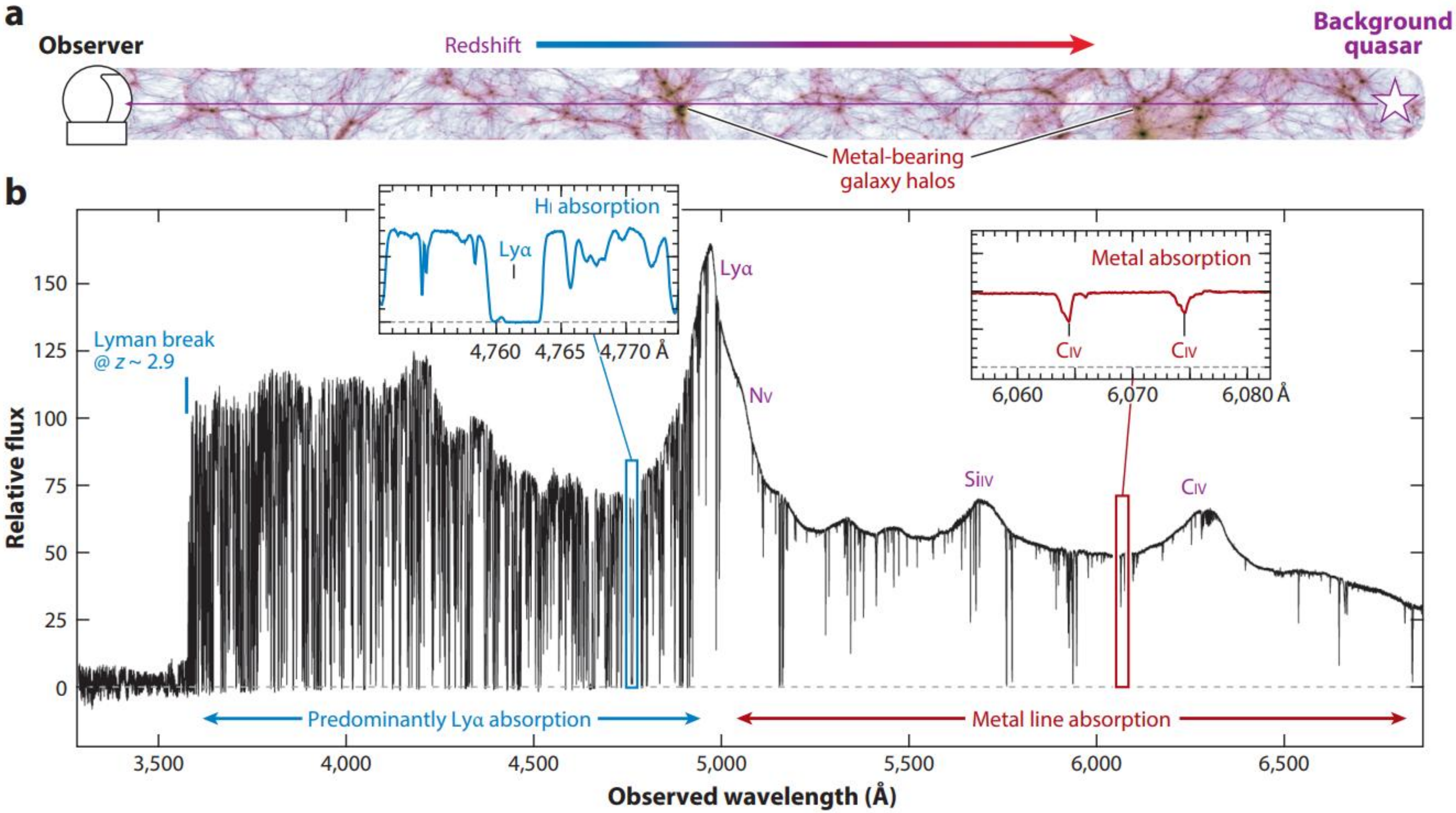
# Why Study The Circumgalactic Medium?




- Baryon Reservoir
- Galaxy Fuelling
- Feedback Engine
- Metal Repository
- Angular Momentum Transfer
- Evolutionary Link

Credits: Jason Tumlinson et al. (2017)

# Probing Diffuse Universe


Credit:
Péroux & Howk (2020)

A&A 680, A82 (2023)
https://doi.org/10.1051/0004-6361/202347943


Astronomy & Astrophysics

# Metal enrichment and evolution in four $z > 6.5$ quasar sightlines observed with JWST/NIRSpec

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Received 11 September 2023 / Accepted 11 October 2023

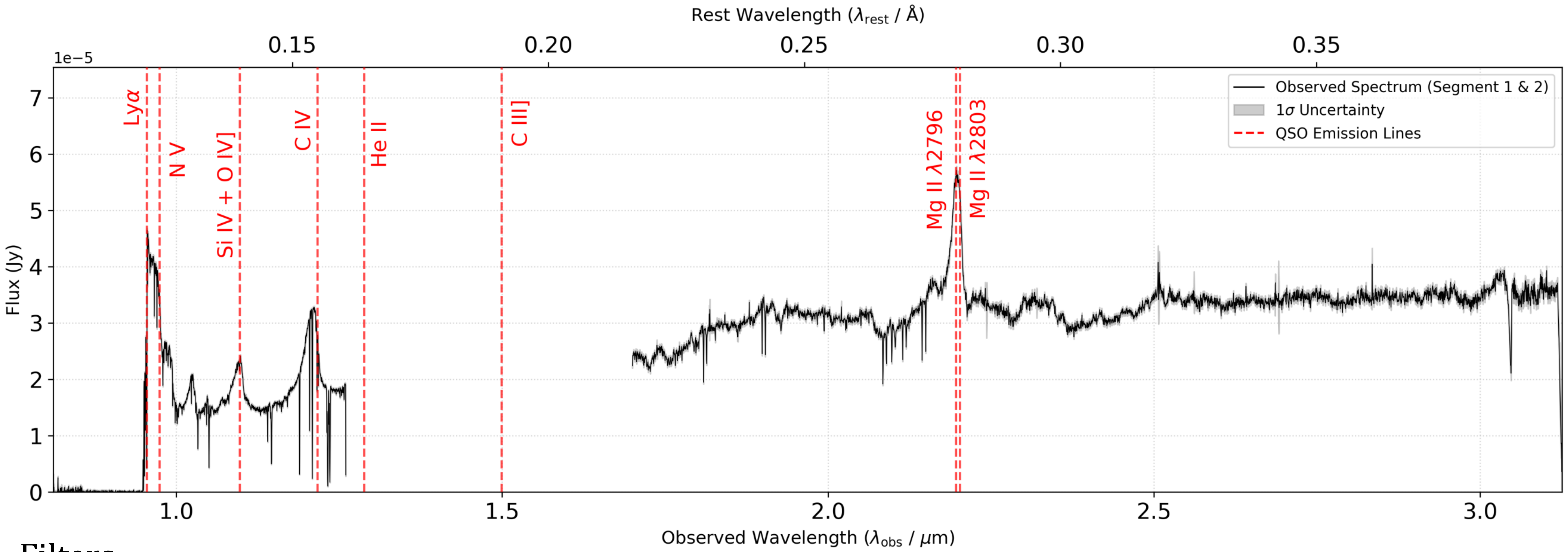
## ABSTRACT

We present JWST/NIRSpec $R \simeq 2700$ spectra of four high-redshift quasars: VDES J0020–3653 ($z = 6.860$), DELS J0411–0907 ($z = 6.825$), UHS J0439+1634 ($z = 6.519$), and ULAS J1342+0928 ($z = 7.535$). The exquisite data quality, signal-to-noise ratio of 50–200, and large $0.86\,\mu m \leq \lambda \leq 5.5\,\mu m$ spectral coverage allowed us to identify between 13 and 17 intervening and proximate metal absorption line systems in each quasar spectrum, with a total number of 61 absorption-line systems detected at $2.42 < z < 7.48$ including the highest redshift intervening O I $\lambda$1302 and Mg II systems at $z = 7.37$ and $z = 7.44$. We investigated the evolution of the metal enrichment in the epoch of re-ionisation (EoR) at $z > 6$ and found the following: *i)* a continued increase in the low-ionisation O I, C II, and Si II incidence, *ii)* decreasing high-ionisation C IV and Si IV incidence with a transition from predominantly high- to low-ionisation at $z \approx 6.0$, and *iii)* a constant Mg II incidence across all redshifts. The observations support a change in the ionisation state of the intergalactic medium in the EoR rather than a change in metallicity. The abundance ratio of [Si/O] in five $z > 6$ absorption systems show enrichment signatures produced by low-mass Pop III pair instability supernovae, and possibly Pop III hypernovae. In the Gunn-Peterson troughs, we detected transmission spikes where Ly$\alpha$ photons can escape. From 22 intervening absorption line systems at $z > 5.7$, only a single low-ionisation system out of 13 lies within 2000 km s$^{-1}$ from a spike, while four high-ionisation systems out of nine lie within ~2000 km s$^{-1}$ from a spike. Most spikes do not have associated metal absorbers close by. This confirms that star-forming galaxies responsible for producing the heavy elements that are transported to the circumgalactic medium via galaxy winds do so in predominantly high-density, neutral environments, while lower density environments are ionised without being polluted by metals at $z \approx 6$–7.

**Key words.** cosmology: observations – intergalactic medium – galaxies: high-redshift – quasars: absorption lines – dark ages, reionization, first stars

Christensen et al. (2023), A&A 680, A82

# JWST NIRSpec/Slit Spectrum of VDES J0020-3653 (z = 6.855)




Filters:

F070LP, G140H

F170LP, G235H

# Mg II λλ 2796, 2803
## Absorption Line Systems

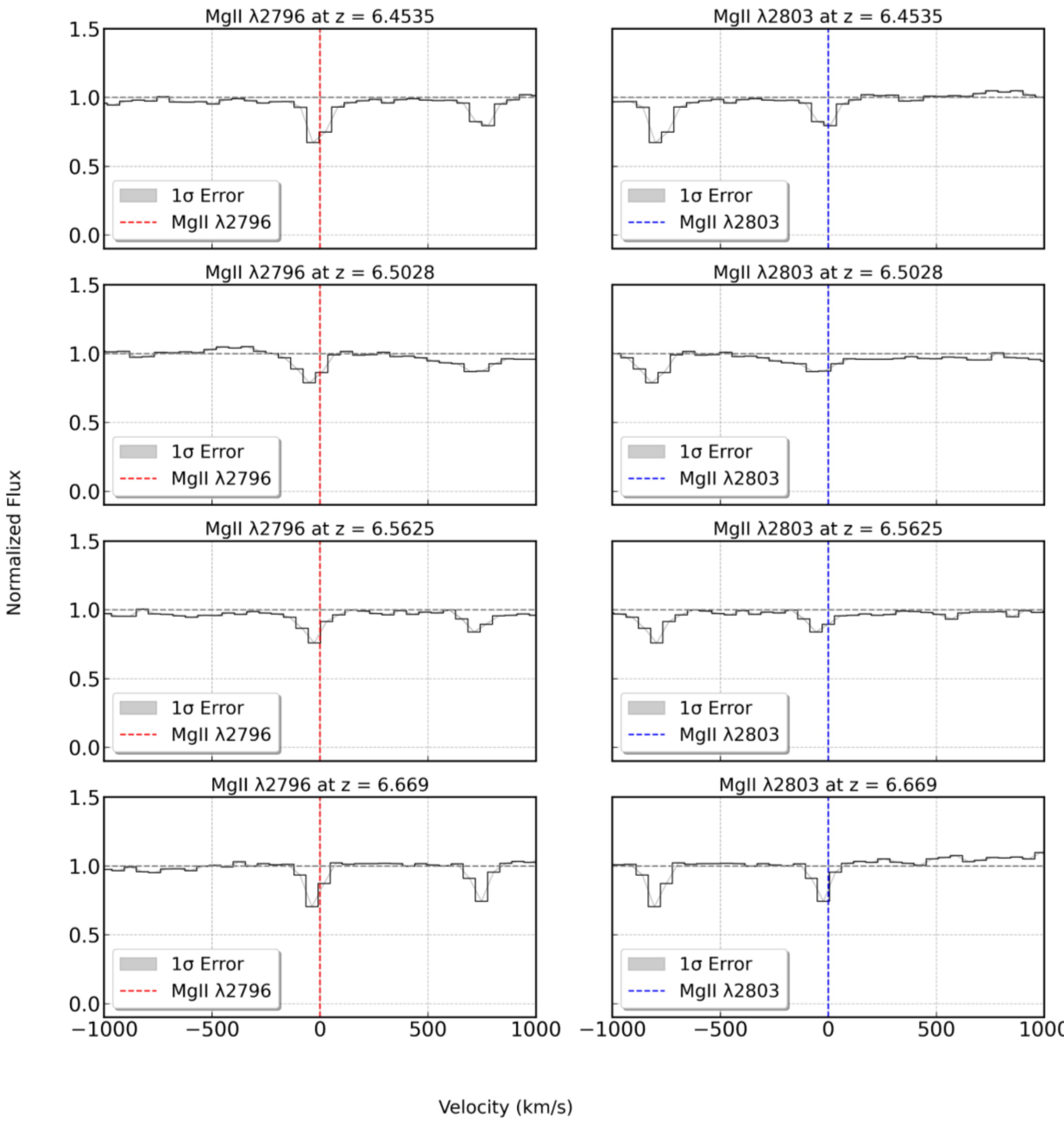
| $z_{absorber}$ | $W_{r\,2796}$ | $W_{r\,2803}$ |
|---|---|---|
| 6.4535 | 0.4590 ± 0.0025 | 0.2545 ± 0.0027 |
| 6.5028 | 0.2400 ± 0.0026 | 0.3498 ± 0.0024 |
| 6.5625 | 0.3278 ± 0.0024 | 0.2862 ± 0.0034 |
| 6.6690 | 0.1855 ± 0.0024 | 0.1215 ± 0.0023 |

$$W_r = \int_{\lambda_1}^{\lambda_2} \left(1 - \frac{F_\lambda}{F_c}\right) d\lambda$$

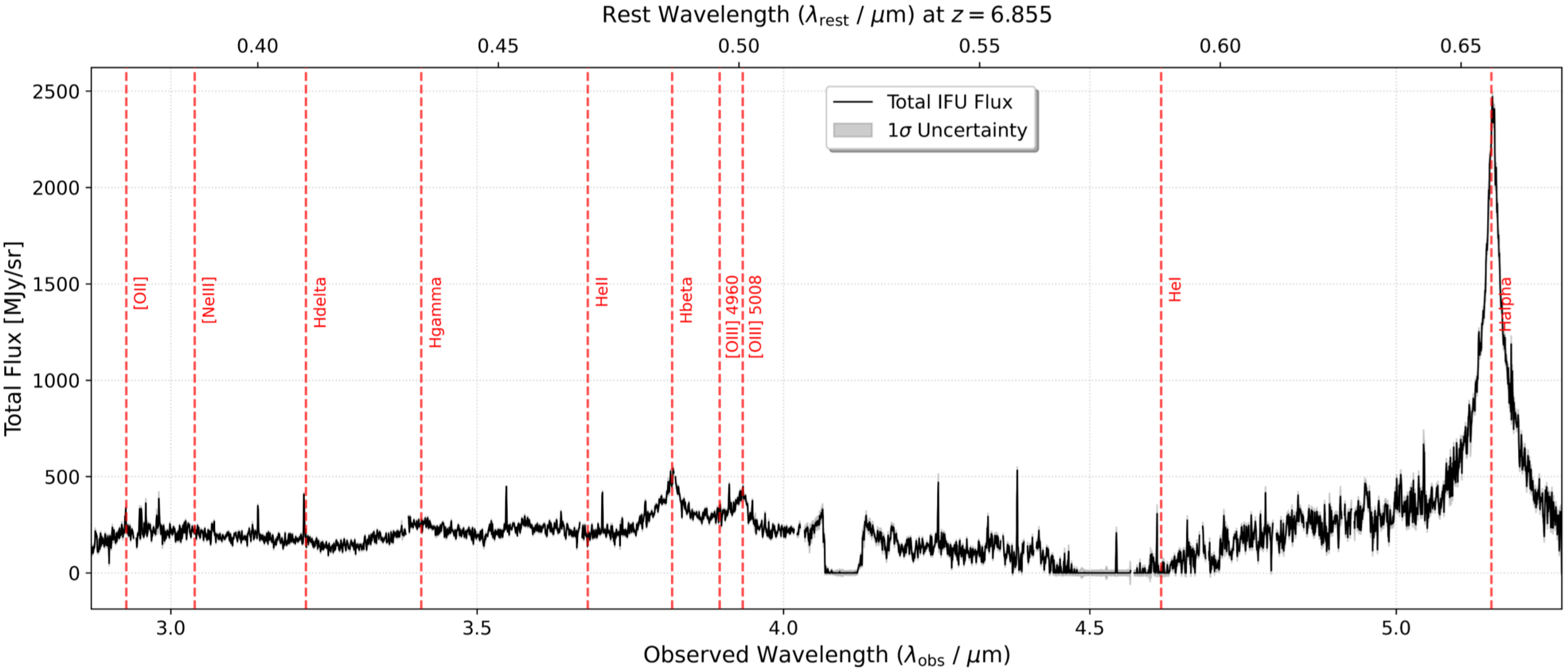
$$\tau_a(v) = \ln\left(\frac{F_c(v)}{F(v)}\right)$$

$$N_a(v) = 3.768 \times 10^{14} \times (f\lambda)^{-1} \times \tau_a(v)$$

... Savage & Sembach(1991)



# JWST NIRSpec/IFU Spectrum of VDES J0020-3653 ($z = 6.855$)




Filters: F290LP, G395H

# Na I λλ 5890, 5895
## Absorption Line Systems

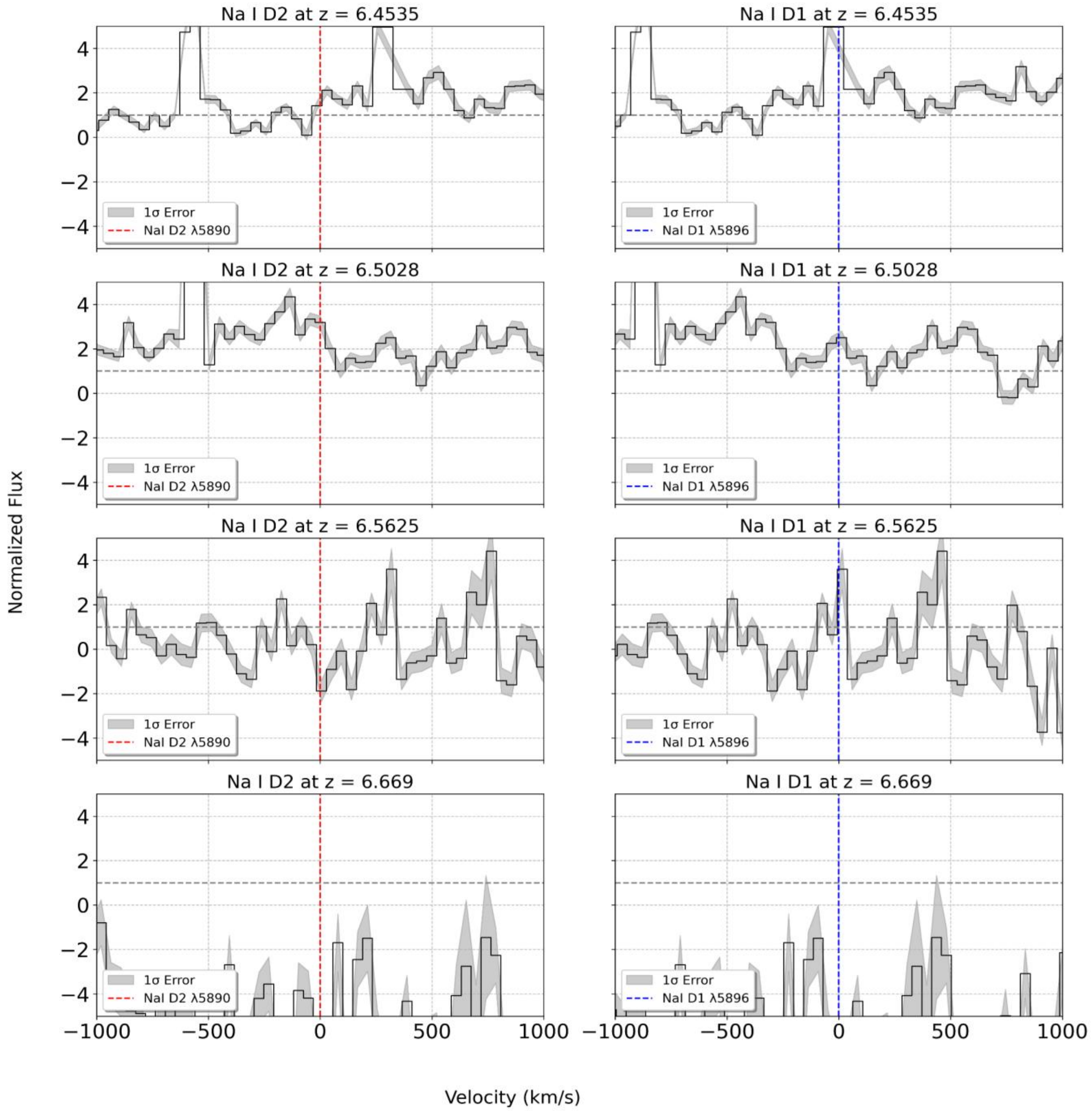
| $z_{absorber}$ | $W_r$ |
|---|---|
| 6.4535 | -- |
| 6.5028 | -- |
| 6.5625 | -- |
| 6.6690 | -- |

$$W_r = \int_{\lambda_1}^{\lambda_2} \left(1 - \frac{F_\lambda}{F_c}\right) d\lambda$$

$$\tau_a(v) = \ln\left(\frac{F_c(v)}{F(v)}\right)$$

$$N_a(v) = 3.768 \times 10^{14} \times (f\lambda)^{-1} \times \tau_a(v)$$

… Savage & Sembach(1991)



# Ca II λλ 3934, 3969
## Absorption Line Systems

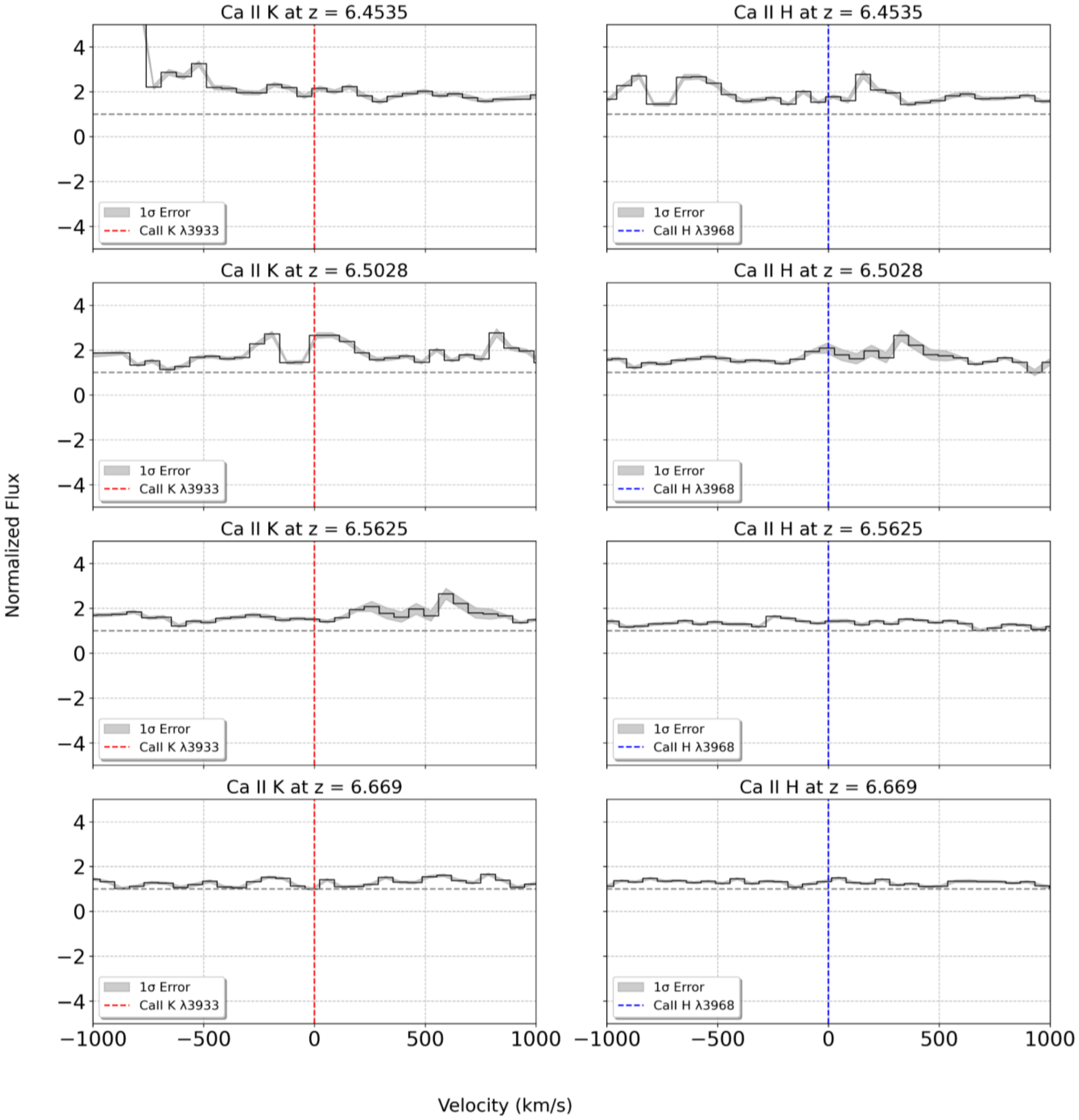
| $z_{absorber}$ | $W_{r\ 3934}$ | $W_{r\ 3969}$ |
|---|---|---|
| 6.4535 | < 0.5625 | < 0.6446 |
| 6.5028 | < 0.6466 | < 1.2251 |
| 6.5625 | < 0.4278 | < 0.3676 |
| 6.6690 | < 0.3204 | < 0.3027 |

$$W_r = \int_{\lambda_1}^{\lambda_2} \left(1 - \frac{F_\lambda}{F_c}\right) d\lambda$$

$$\tau_a(v) = \ln\left(\frac{F_c(v)}{F(v)}\right)$$

$$N_a(v) = 3.768 \times 10^{14} \times (f\lambda)^{-1} \times \tau_a(v)$$

... Savage & Sembach(1991)



Thank You