The Connection between Reddening, Gas Covering Fraction, and the Escape of Ionizing Radiation at High Redshift

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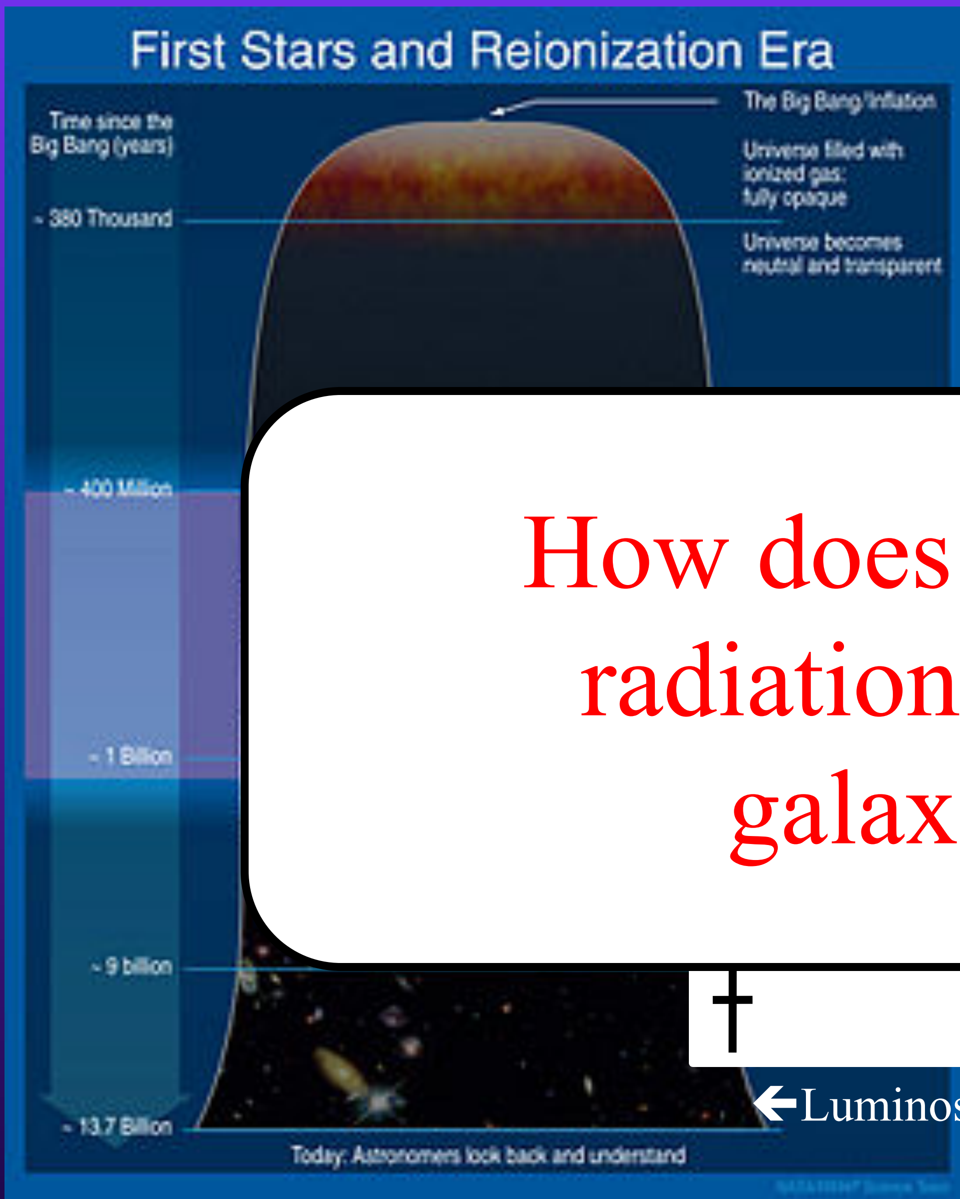
Dark Ages 2016; Heidelberg, Germany, 28 June 2016

Important Period in History of Universe: Reionization



ield

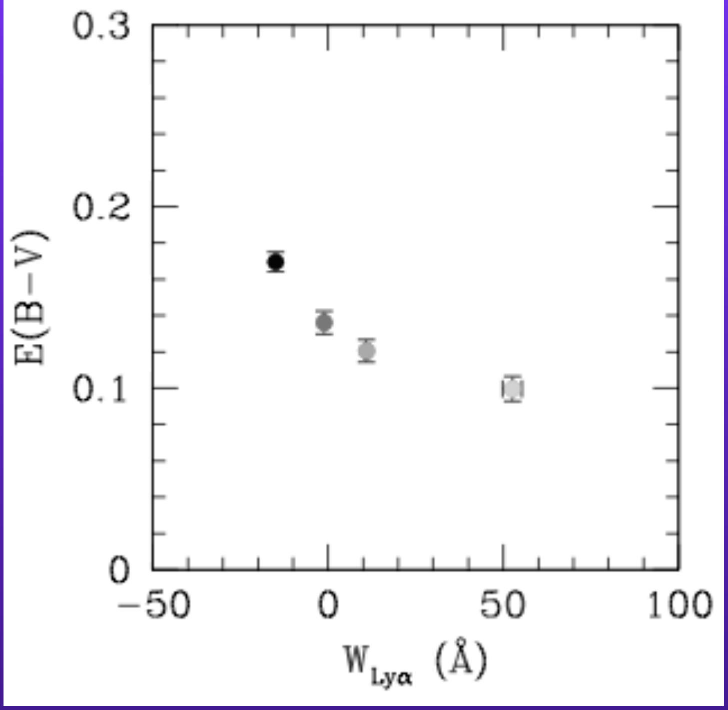
How does ionizing radiation escape galaxies?

←Luminosity

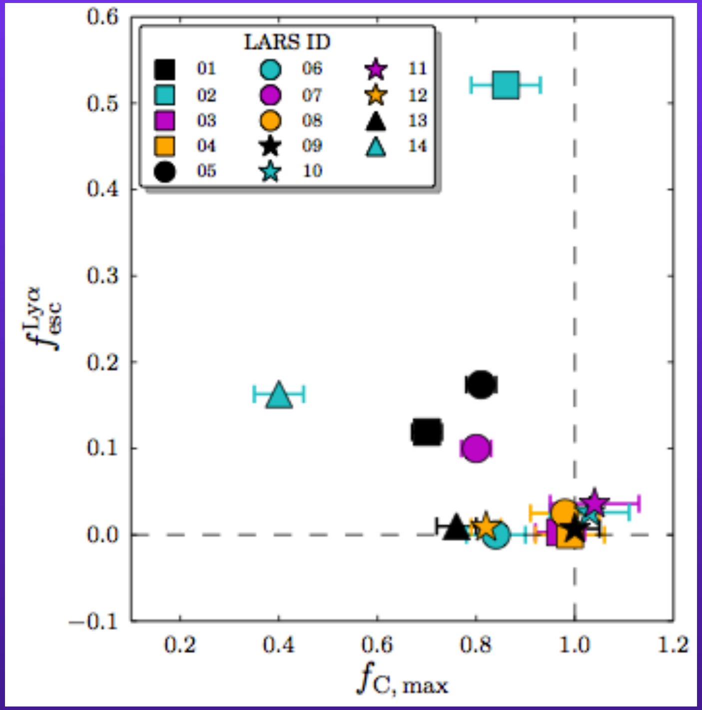
What does it take: lots of galaxies/AGN?

Evidence for a Connection between Reddening and Gas Covering Fraction

Shapley+03



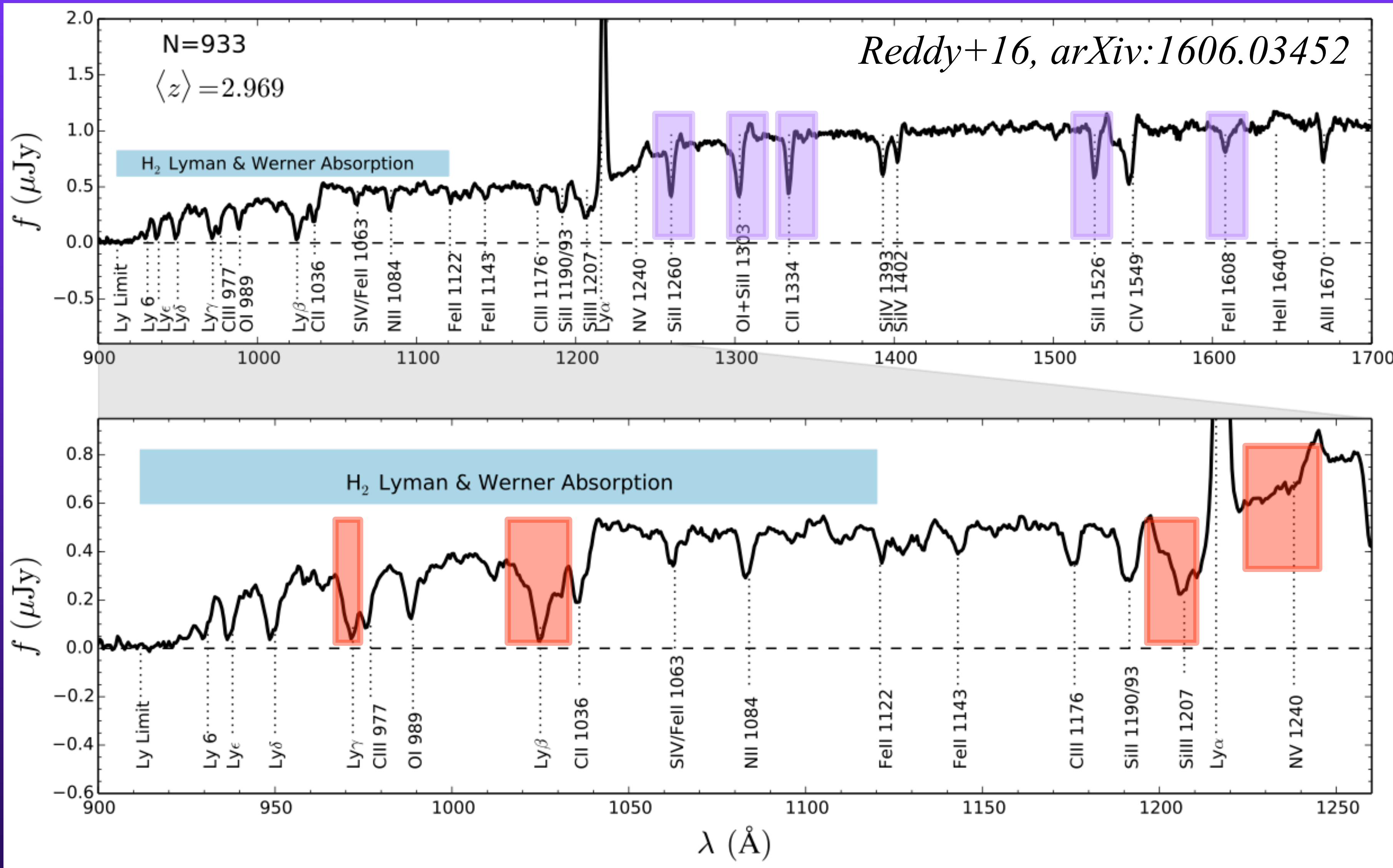
Rivera-Thorsen+15



-low ions may trace higher τ gas than required to deplete ionizing photons

- ideally one must directly trace the HI: requires deep far-UV observations blueward of Lyα and large samples to average over variations in the Lyα forest

Composite Spectrum of 933 z~3 LBGs: fcov(HI) < 1

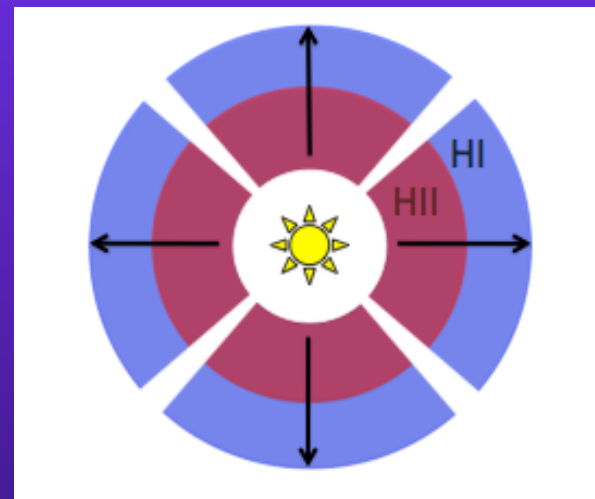


(1) Blue-shifted HI; (2) damping wings of Ly series lines; (3)non-zero residual flux at line centers: fcov(HI) < 1

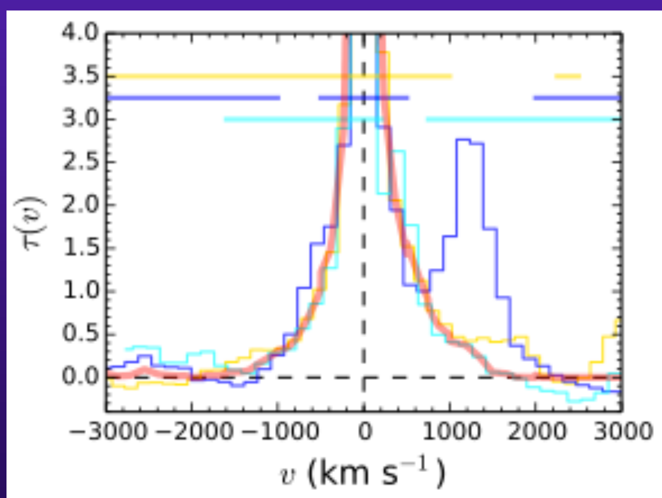
Spectral Modeling

Details of Our "Two Component" Model:

- Intrinsic Spectrum: Rix+S99, $0.28Z_o$, neb. continuum emission; constant SF

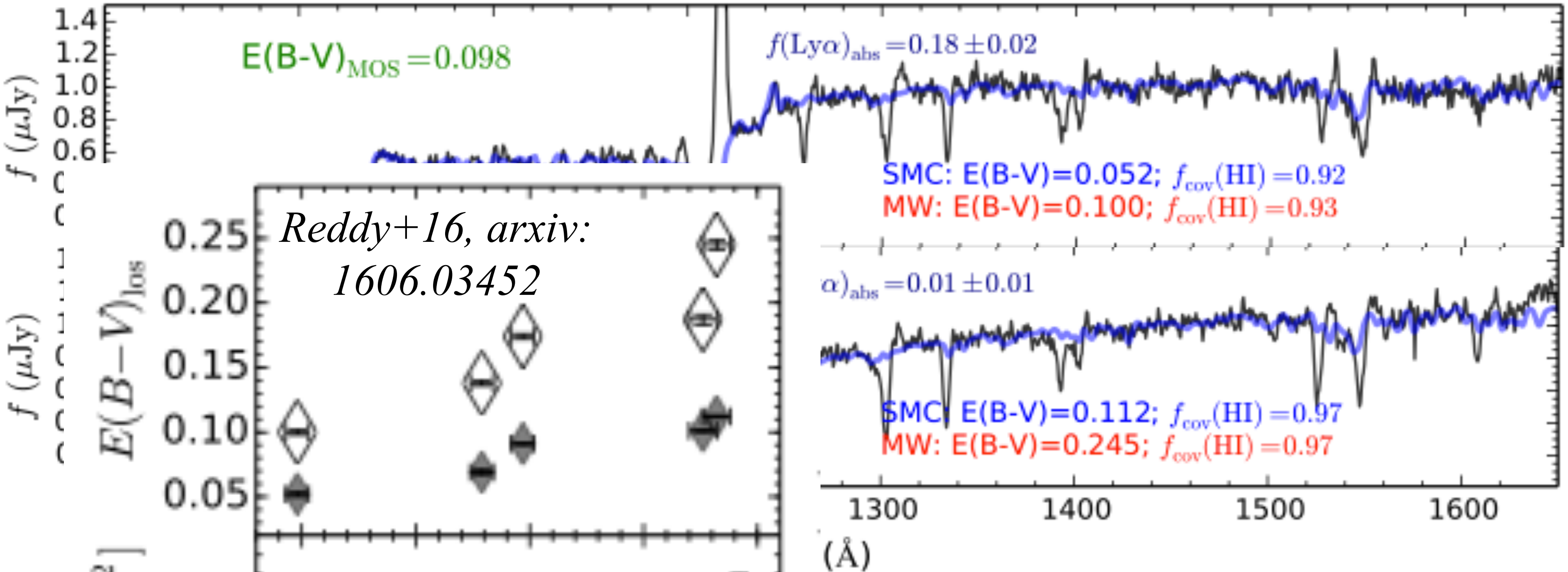


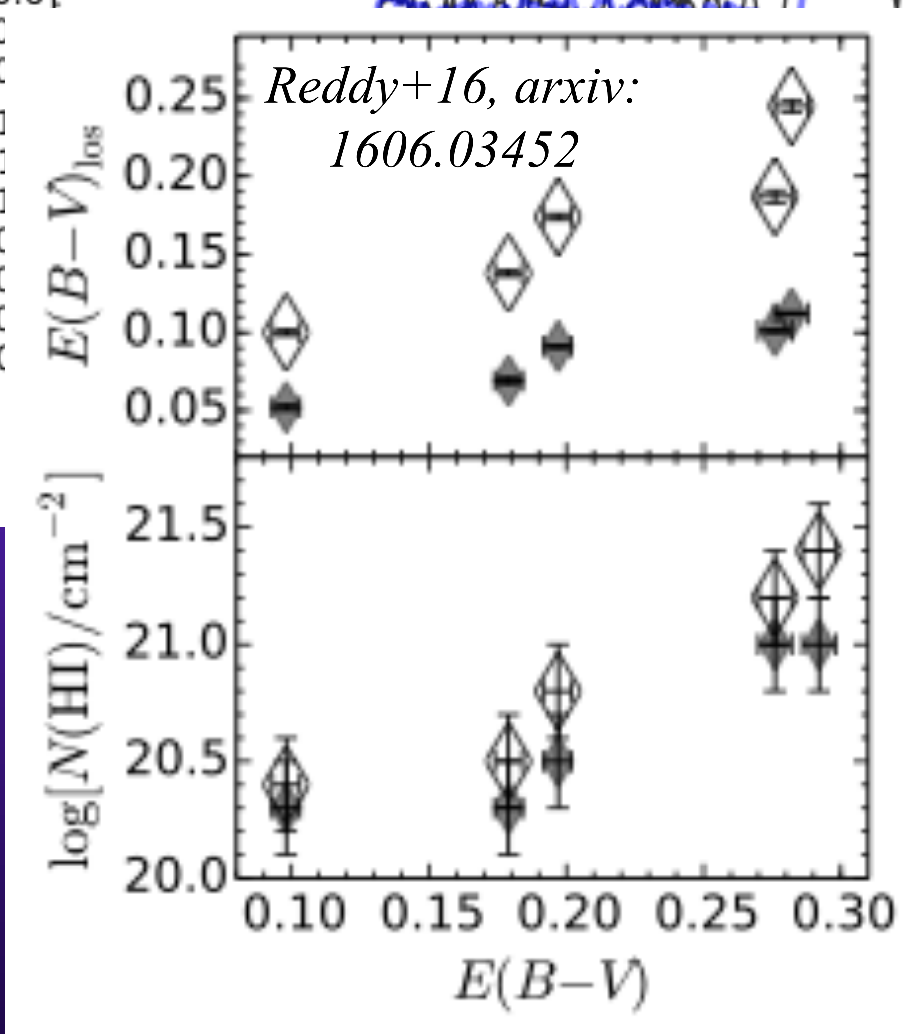
Reddened, and HI+H2 Absorbed spectrum



Fit to composites in bins of UV continuum reddening, while varying fcov

Spectral Modeling

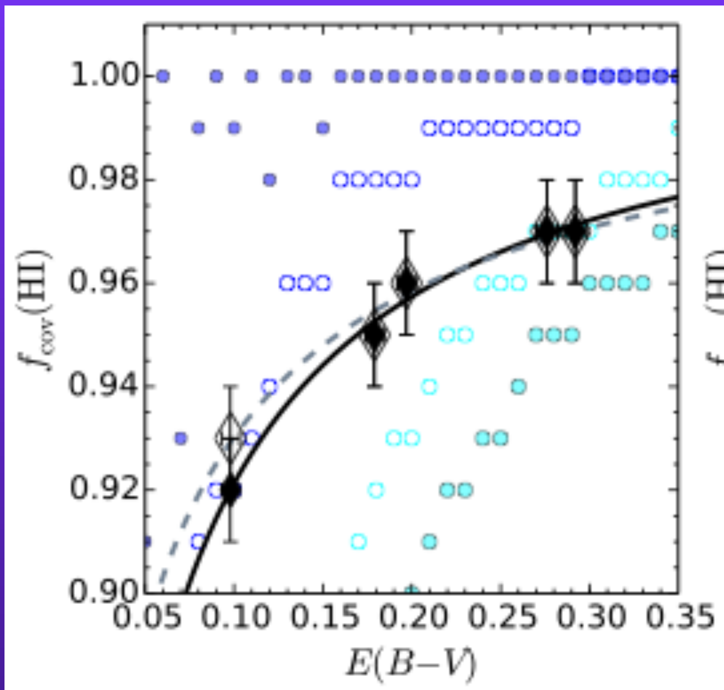




Relationships between continuum and line-of-sight reddening/N(HI)

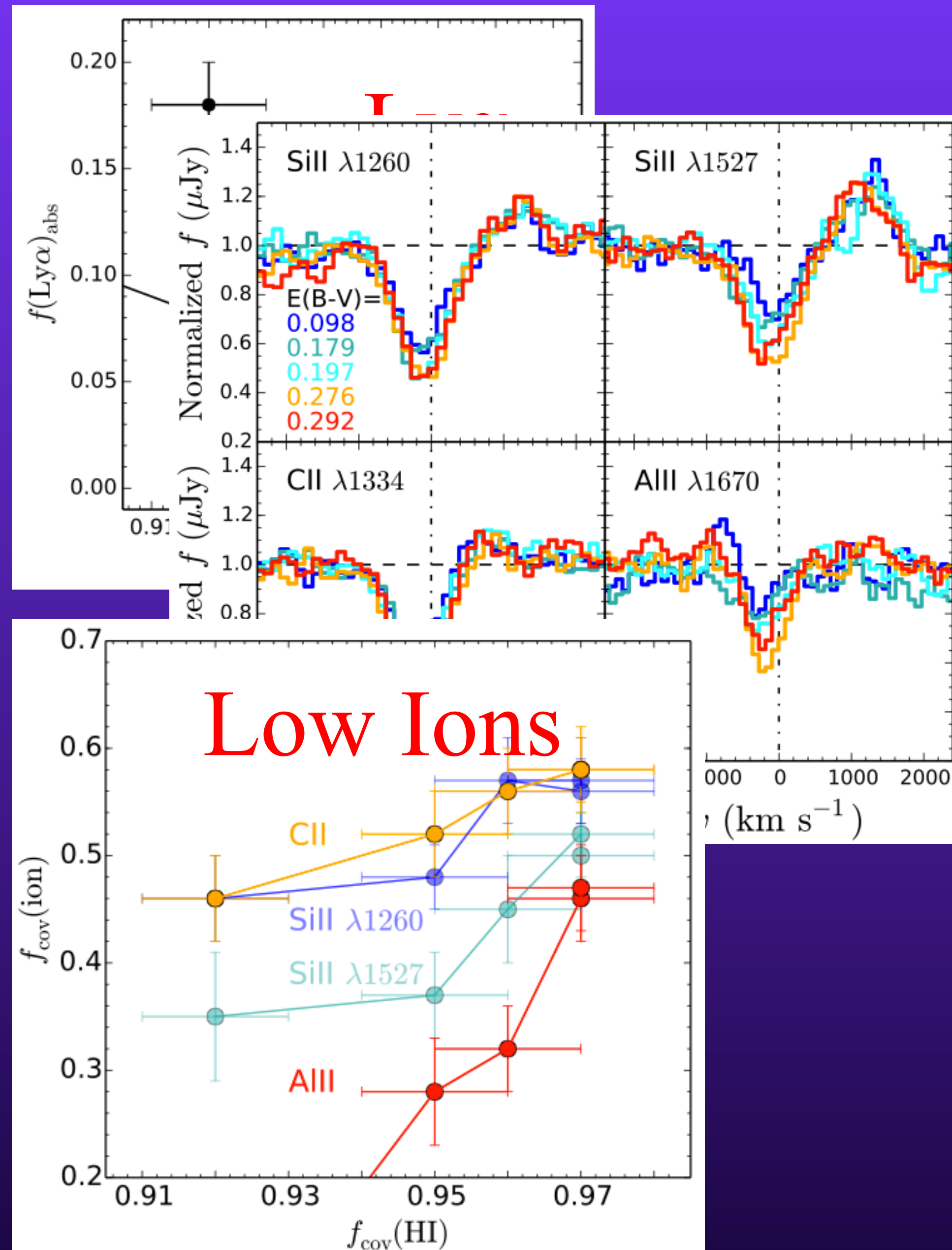
Galaxies with redder UV slopes are characterized by redder line-of-sight reddening, higher N(HI), and higher fcov

Relationship between Reddening and Covering Fraction



Reddy+16, arxiv: 1606.03452

Low-ionization interstellar absorption lines systematically *underpredict* covering fraction.



Relationship between Reddening and Covering Fraction

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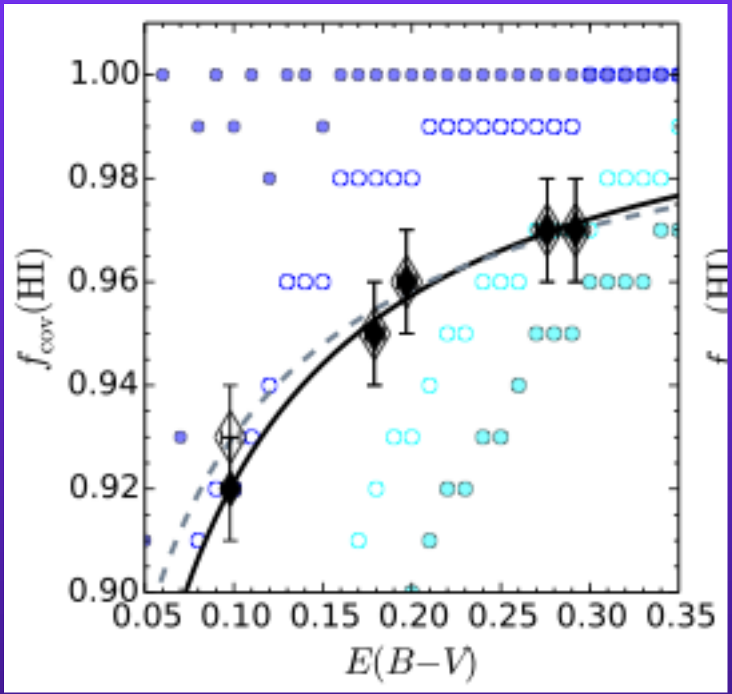


$$f(\mathrm{LyC})_{\mathrm{abs}} \approx 1 - f_{\mathrm{cov}}(\mathrm{H\ I}).$$

+

$$f_{\mathrm{cov}}(\mathrm{H\ I}) = 1 - \exp[a \times E(B-V)^b],$$

||

$$\frac{S(\mathrm{LyC})_{\mathrm{obs}}}{S(\mathrm{UV})_{\mathrm{obs}}} = \frac{S(\mathrm{LyC})_{\mathrm{int}}}{S(\mathrm{UV})_{\mathrm{int}}} \times \exp[-\tau_{\mathrm{IGM}}(\mathrm{LyC})] \times \exp[-\tau_{\mathrm{CGM}}(\mathrm{LyC})] \times \left[\frac{\exp[a \times E(B-V)^b]}{10^{-0.4k(\mathrm{UV})E(B-V)}}\right]$$

Empirical Constraints on the Intrinsic LyC-to-UV Ratio

$(f900/f1500)_{obs} \sim 0.019 \pm 0.002$

IGM/ CGM

$(f900/f1500)_{cor} \sim 0.047 \pm 0.005$

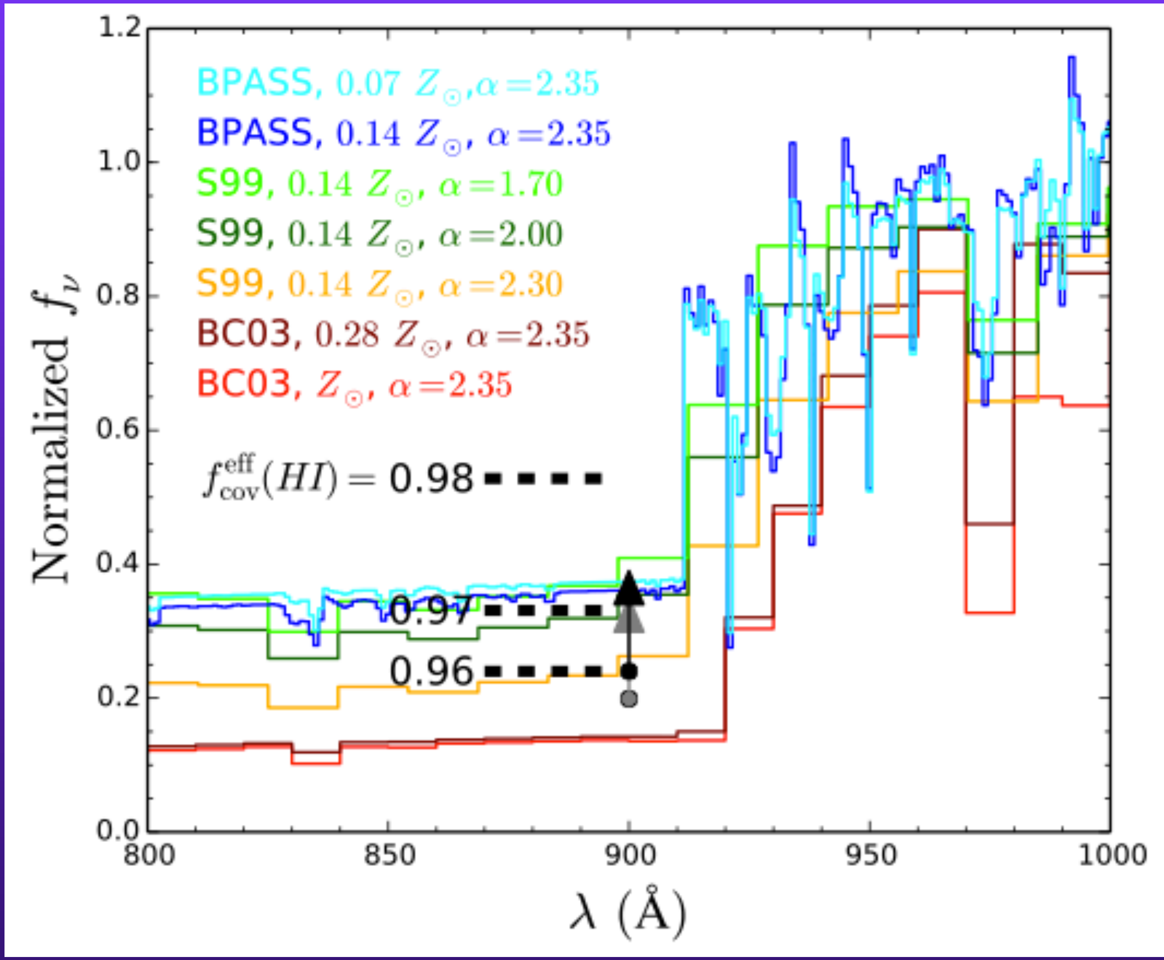
$E(B\text{-}V) \sim 0.197 \pm 0.005$

Model Prediction

$f_{cov}(HI) \sim 0.955 \pm 0.010$

$(f900/f1500)_{int} \sim 0.240 \pm 0.047$

Comparison with Stellar Population Models

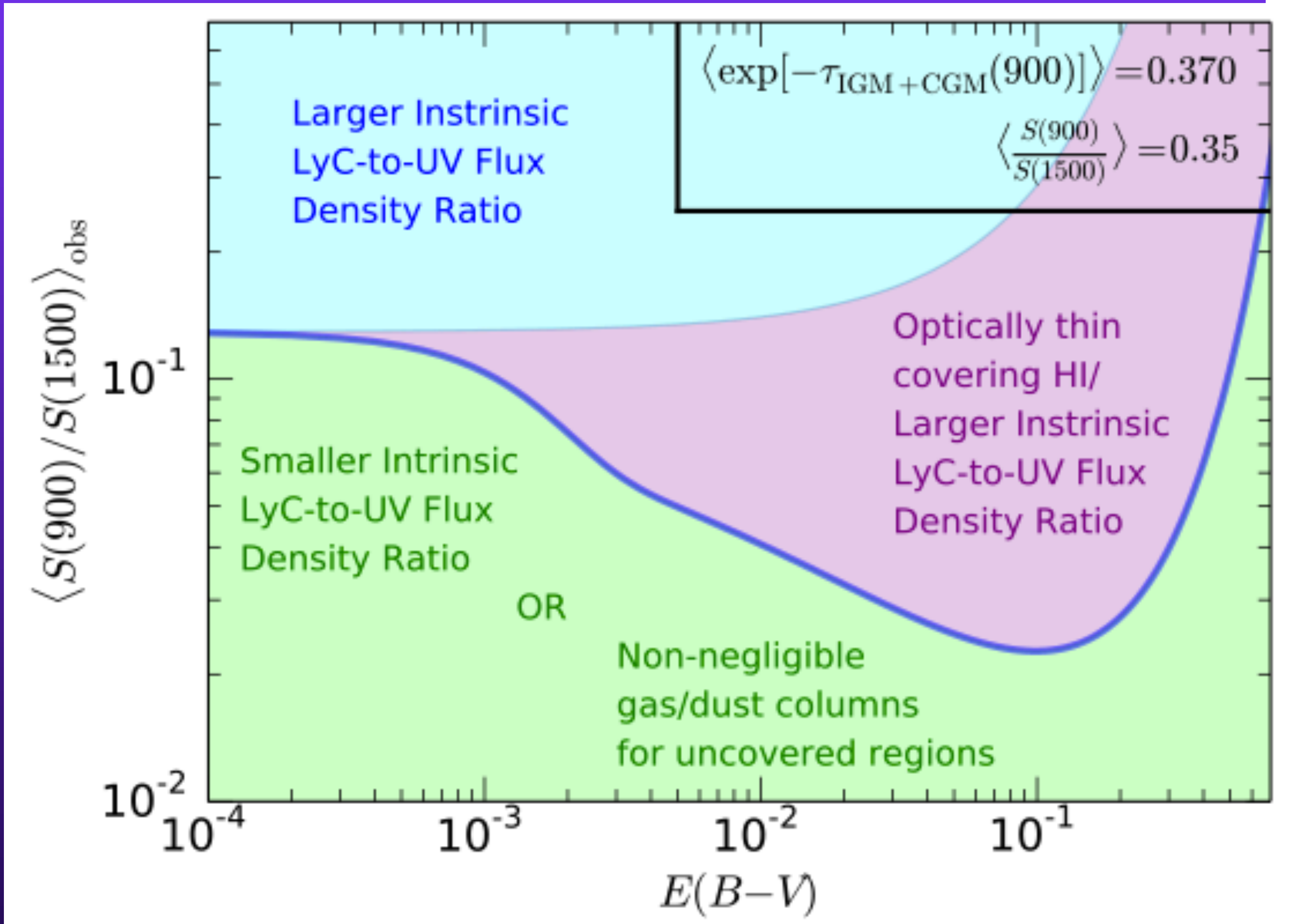


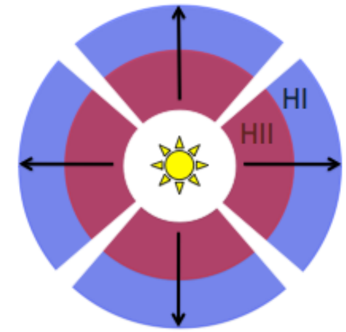
Galaxies with *large* covering fractions provide the most sensitive constraints on the intrinsic LyC production rate

Reddy+16, arxiv:1606.03452

Limit favors models that include weaker stellar winds, a shallower IMF, and/or stellar rotation/binarity

Investigating Deviations in "Geometry" of Escaping Ionizing Radiation





Reddy+16, arxiv:1606.03452

Summary of Results

- Evidence for optically-thick HI with $f_{cov} < 1$ in $\sim L^*$ galaxies at z~3; photoelectric absorption (not dust) dominates depletion of LyC photons
- Galaxies with bluer UV slopes have lower neutral gas covering fractions
- Establish model to relate f_{cov} and E(B-V): applications for predicting observed or intrinsic escape fractions
- Model predicts a limit on f(900)/f(1500) that favors models that include a flatter IMF and/or stellar rotation/binarity

Reddy+16, arxiv:1606.03452