

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

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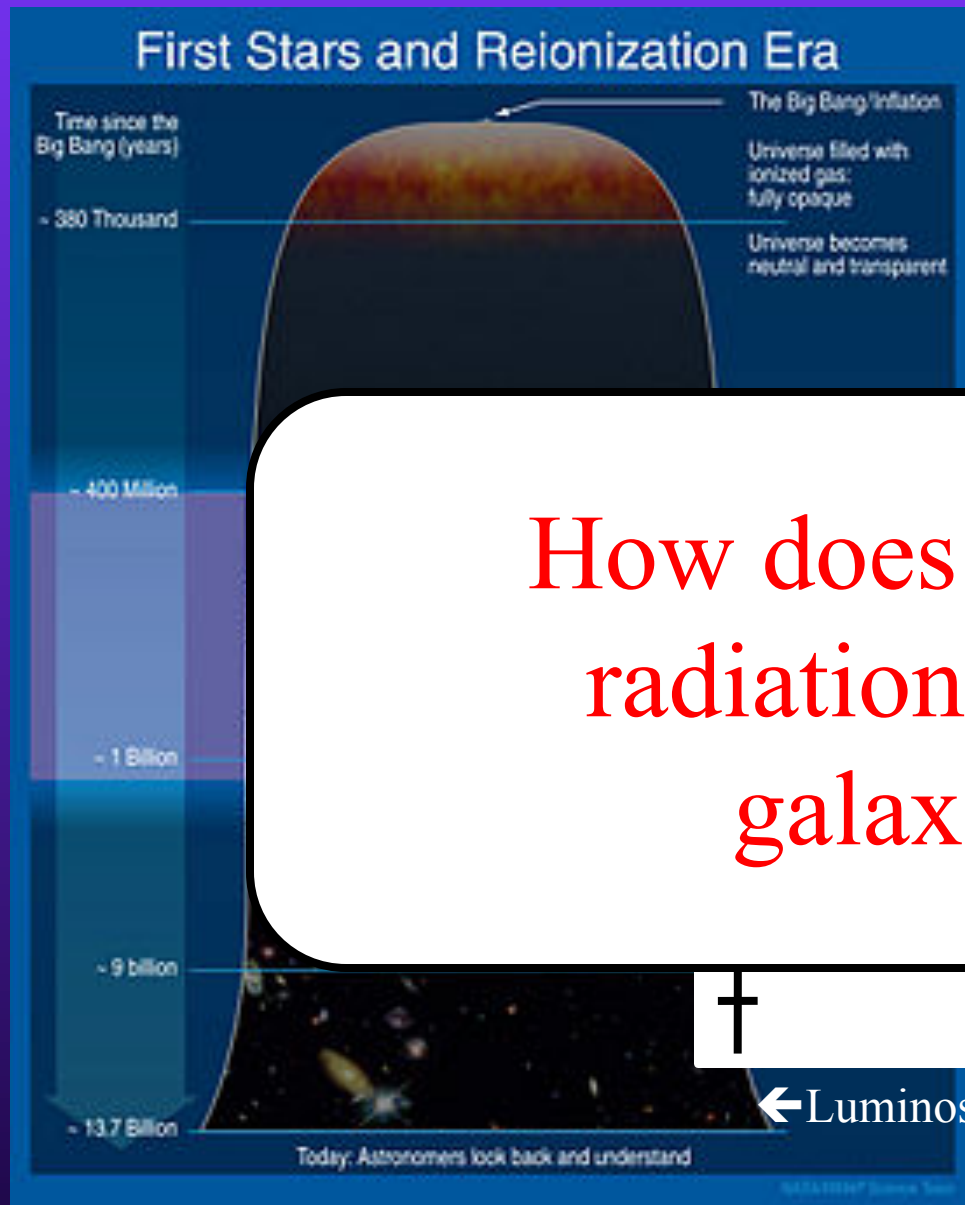
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Alice Shapley (UCLA)



IAP 2016; Paris, France, 23 June 2016

Important Period in History of Universe: Reionization

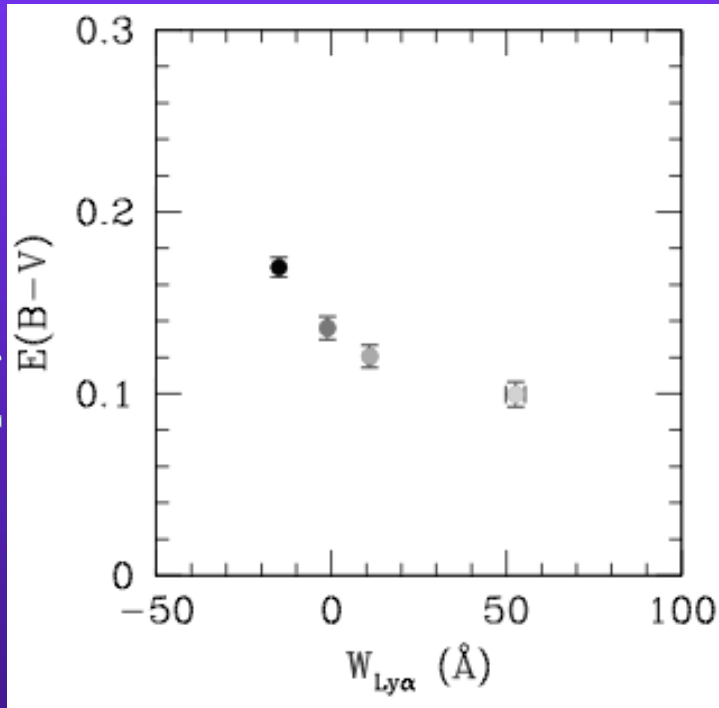


How does ionizing radiation escape galaxies?

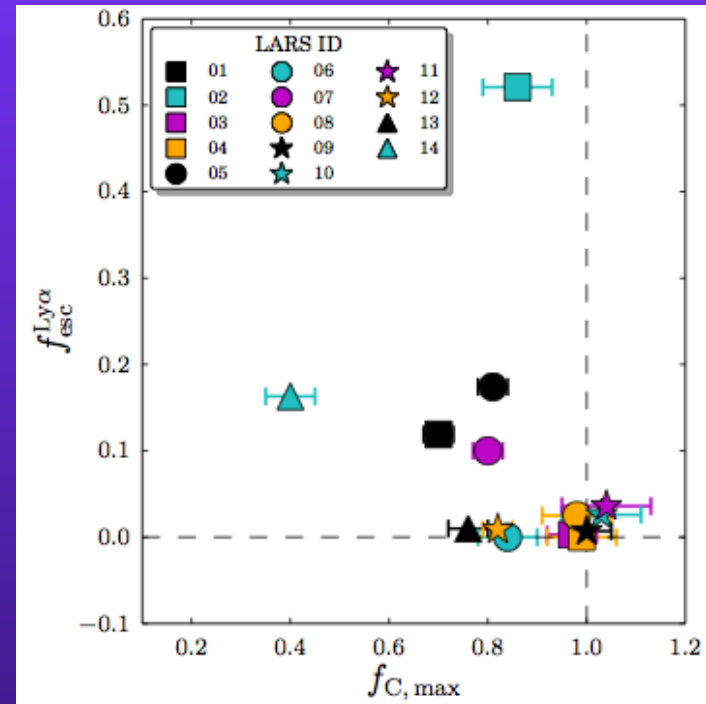
What does it take: lots of galaxies/AGN?

Evidence for a Connection between Reddening and Gas Covering Fraction

Shapley+03

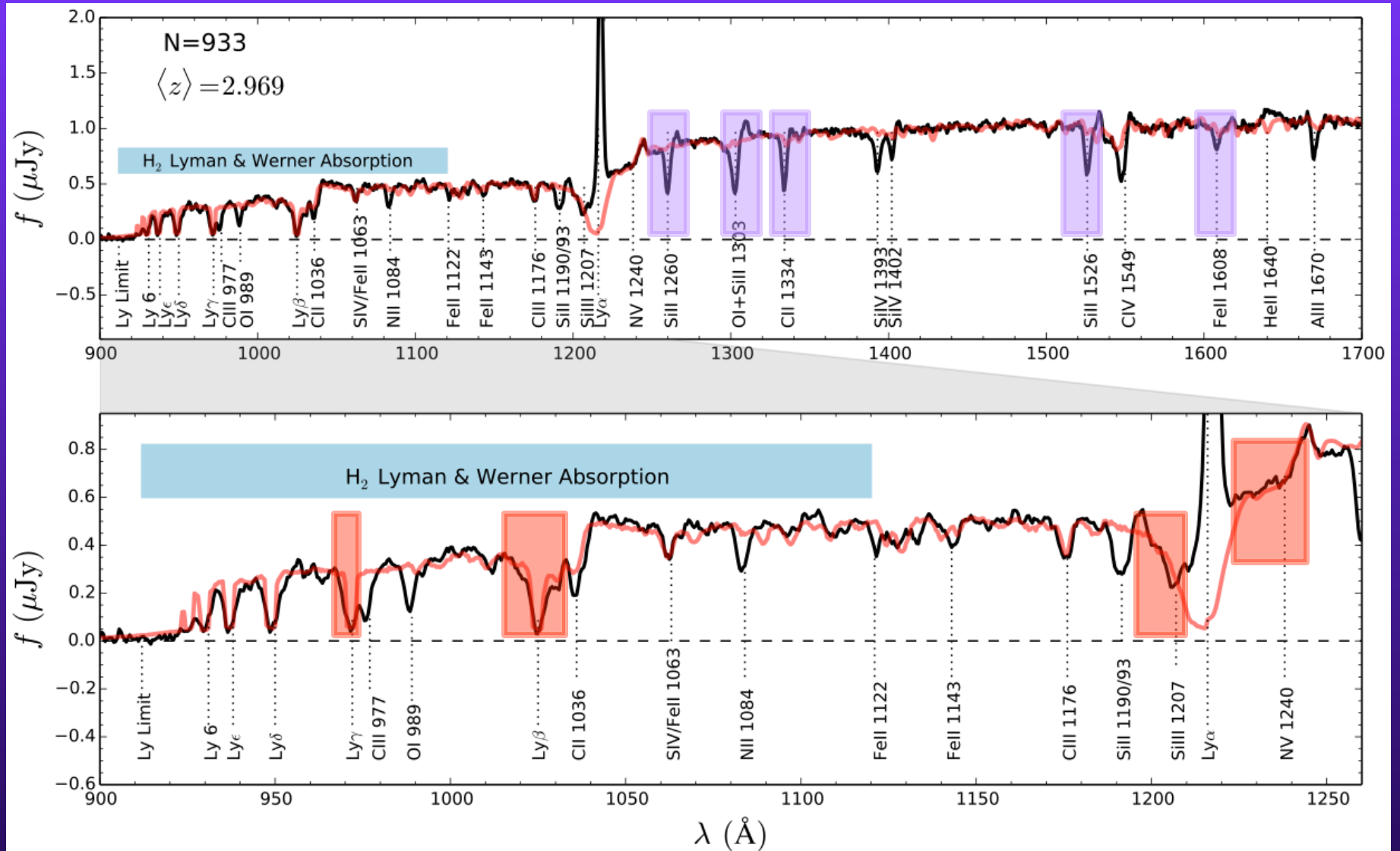


Rivera-Thorsen+15



- 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 Ly α and large samples to average over variations in the Ly α forest

Composite Spectrum of 933 $z \sim 3$ LBGs: $f_{\text{cov}}(\text{HI}) < 1$



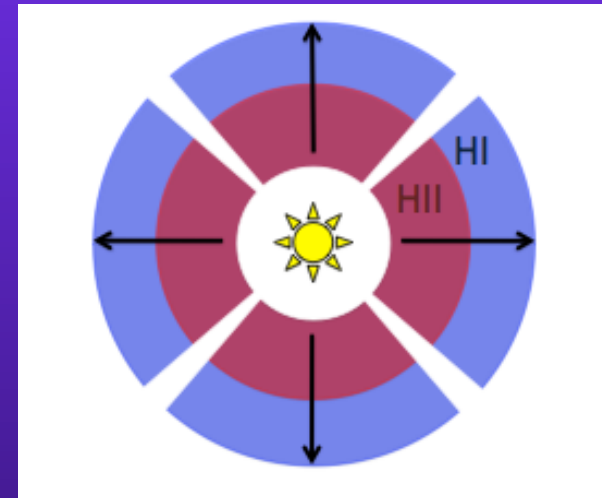
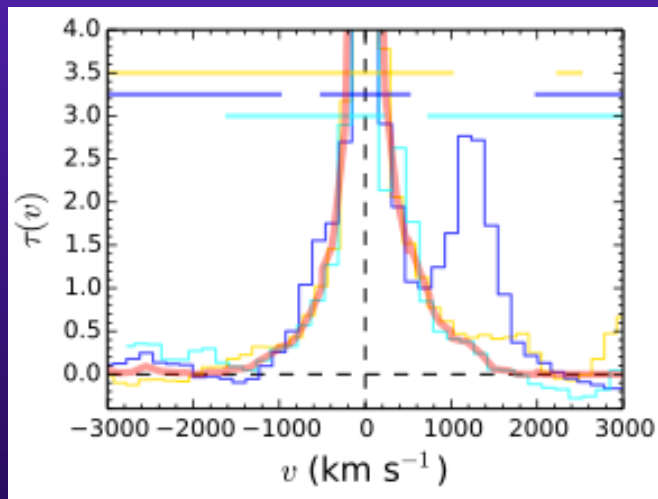
(1) Blue-shifted HI; (2) damping wings of Ly series lines; (3) non-zero residual flux at line centers: $f_{\text{cov}}(\text{HI}) < 1$

Spectral Modeling

Details of Our “Two Component” Model:

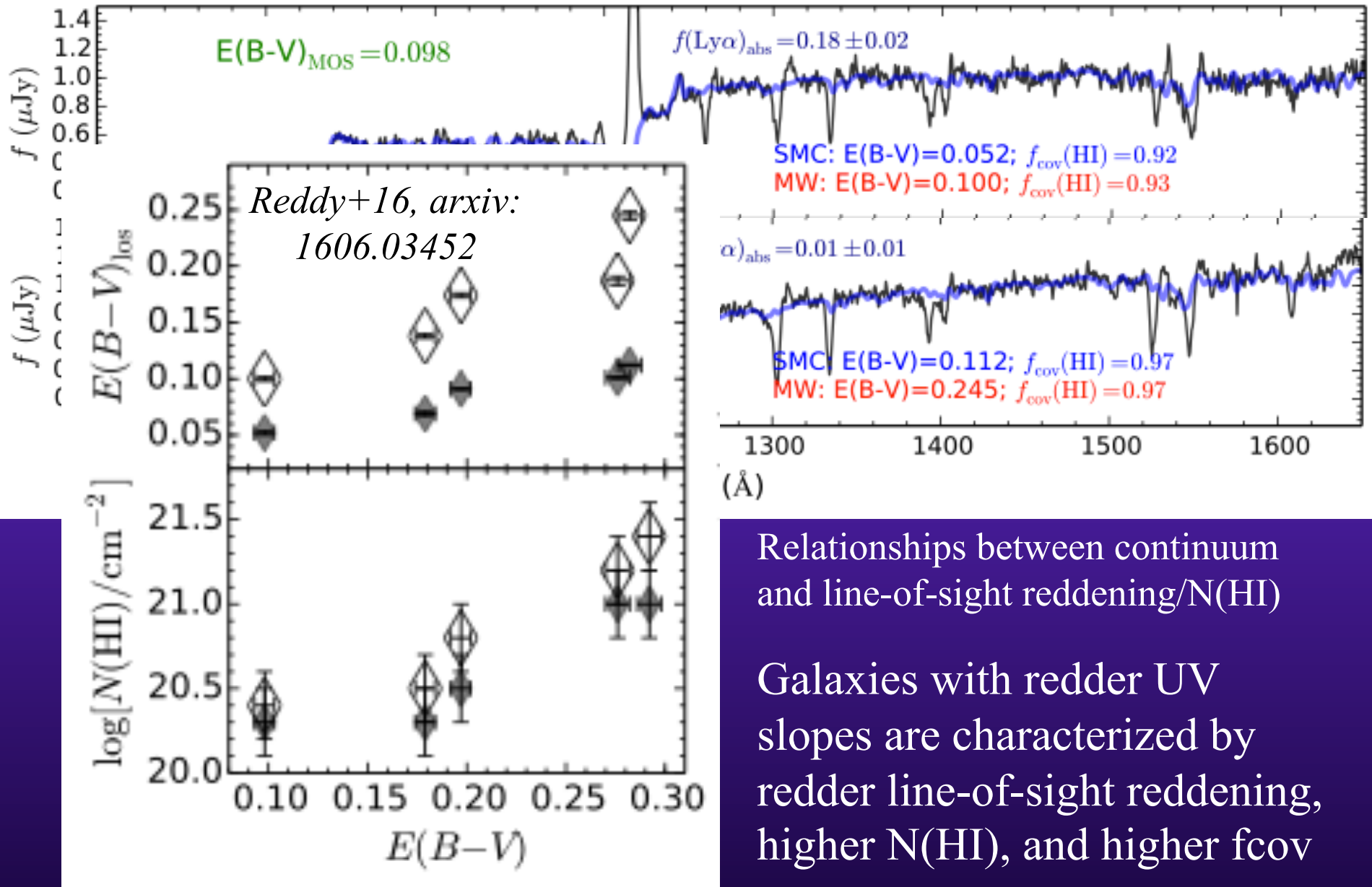
- Intrinsic Spectrum: Rix+S99, $0.28Z_{\odot}$, neb. continuum emission; constant SF

Reddened, and HI+H2
Absorbed spectrum



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

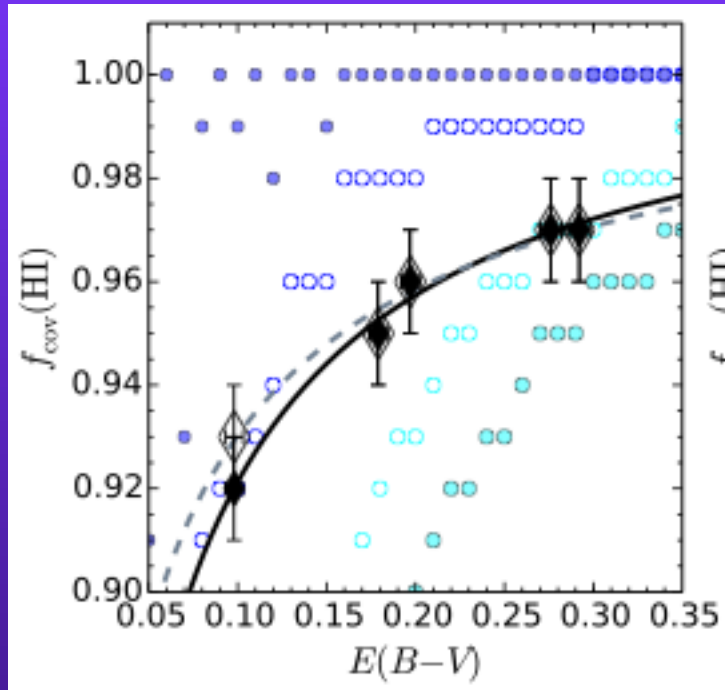
Spectral Modeling



Relationships between continuum and line-of-sight reddening/ $N(\text{HI})$

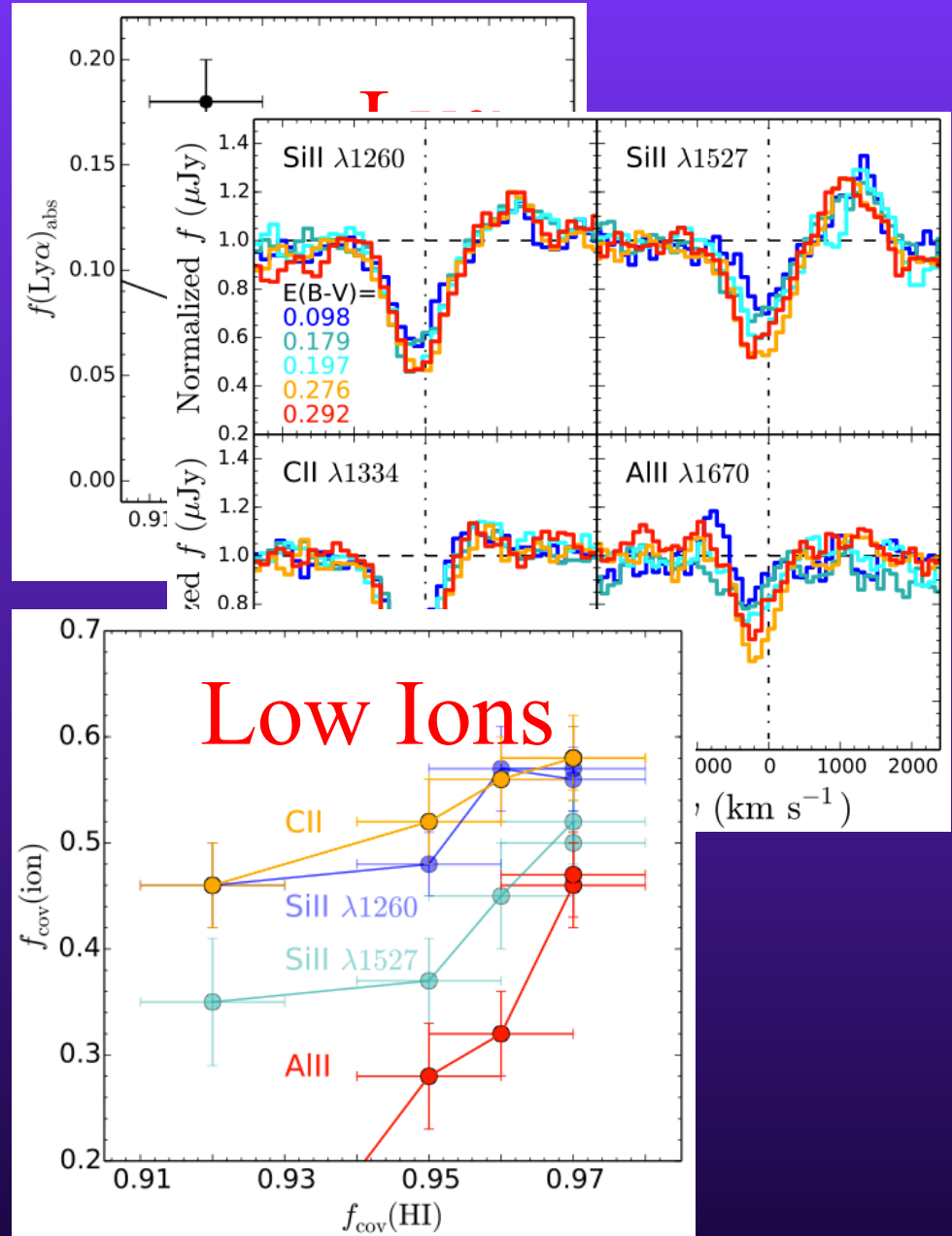
Galaxies with redder UV slopes are characterized by redder line-of-sight reddening, higher $N(\text{HI})$, and higher f_{cov}

Relationship between Reddening and Covering Fraction



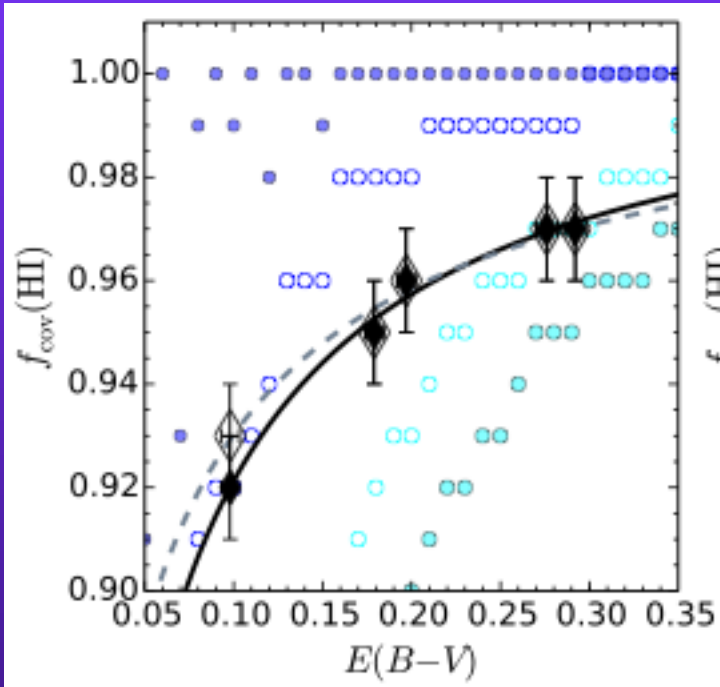
Reddy+16, arxiv: 1606.03452

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



Relationship between Reddening and Covering Fraction

Reddy+16, arxiv:1606.03452



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

+

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

||

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

Empirical Constraints on the Intrinsic LyC-to-UV Ratio

$$(f_{900}/f_{1500})_{\text{obs}} \sim 0.019 \pm 0.002$$



$$(f_{900}/f_{1500})_{\text{cor}} \sim 0.047 \pm 0.005$$



$$(f_{900}/f_{1500})_{\text{int}} \sim 0.240 \pm 0.047$$

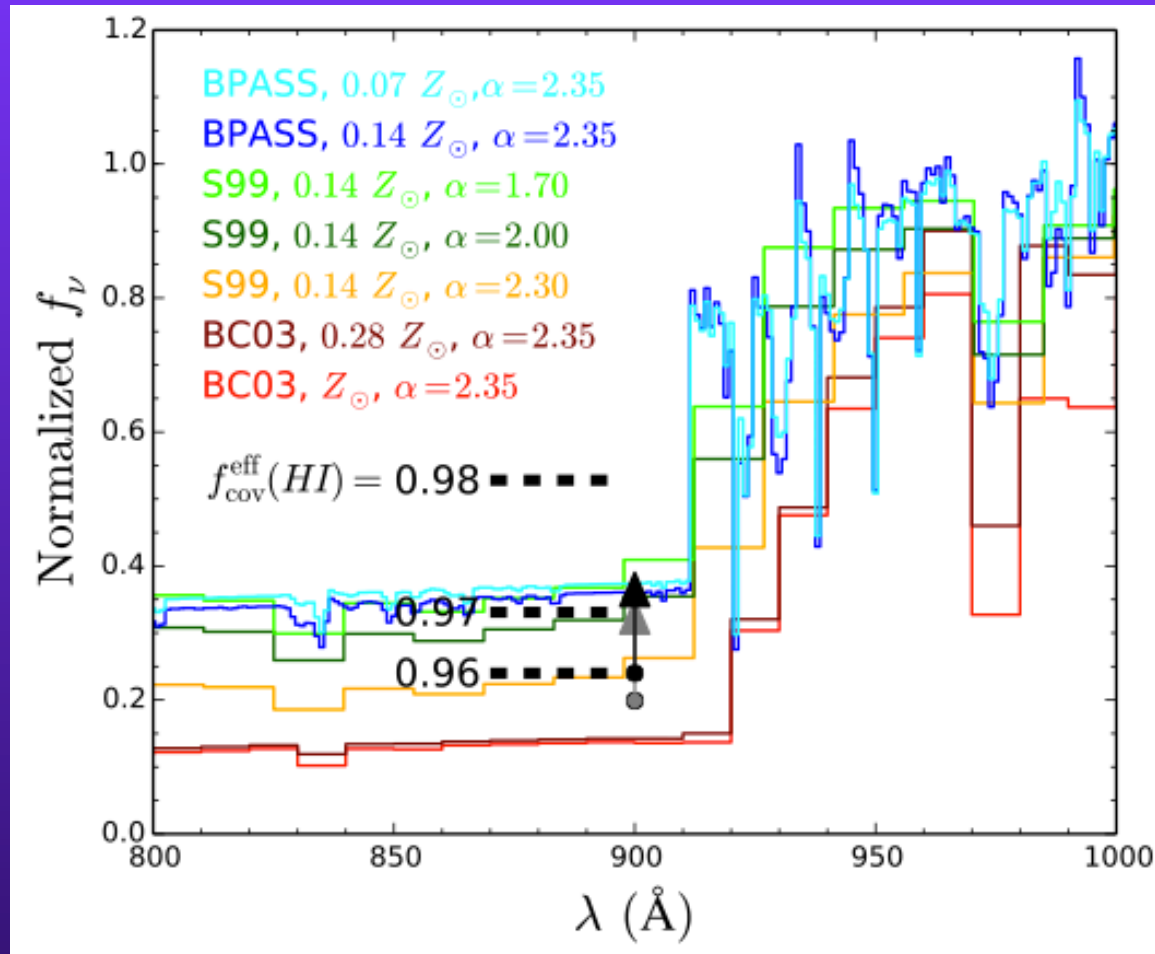
$$E(B-V) \sim 0.197 \pm 0.005$$



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



Comparison with Stellar Population Models

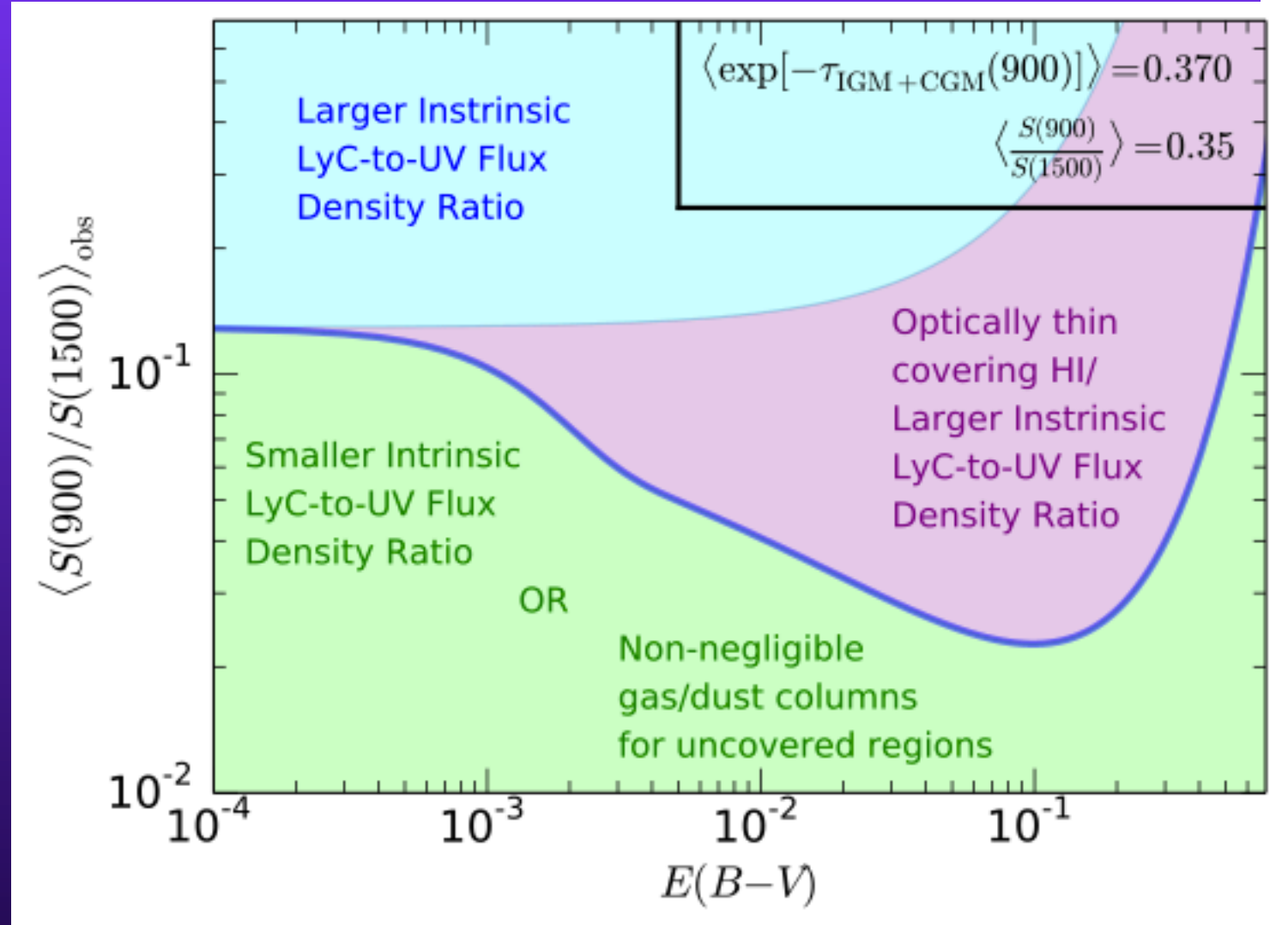
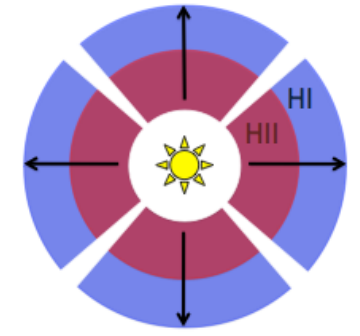


Reddy+16, arxiv:1606.03452

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

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

Investigating Deviations in “Geometry” of Escaping Ionizing Radiation



Summary of Results

- Evidence for optically-thick HI with $f_{\text{cov}} < 1$ in $\sim L^*$ galaxies at $z \sim 3$; photoelectric absorption (not dust) dominates depletion of LyC photons
- Galaxies with redder UV slopes have higher f_{cov} with higher line-of-sight reddening
- f_{cov} derived from low ions systematically lower than those derived from HI
- 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