Revealing the Second Epoch of Reionization with UV-Bright z =3–4 Quasars

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&

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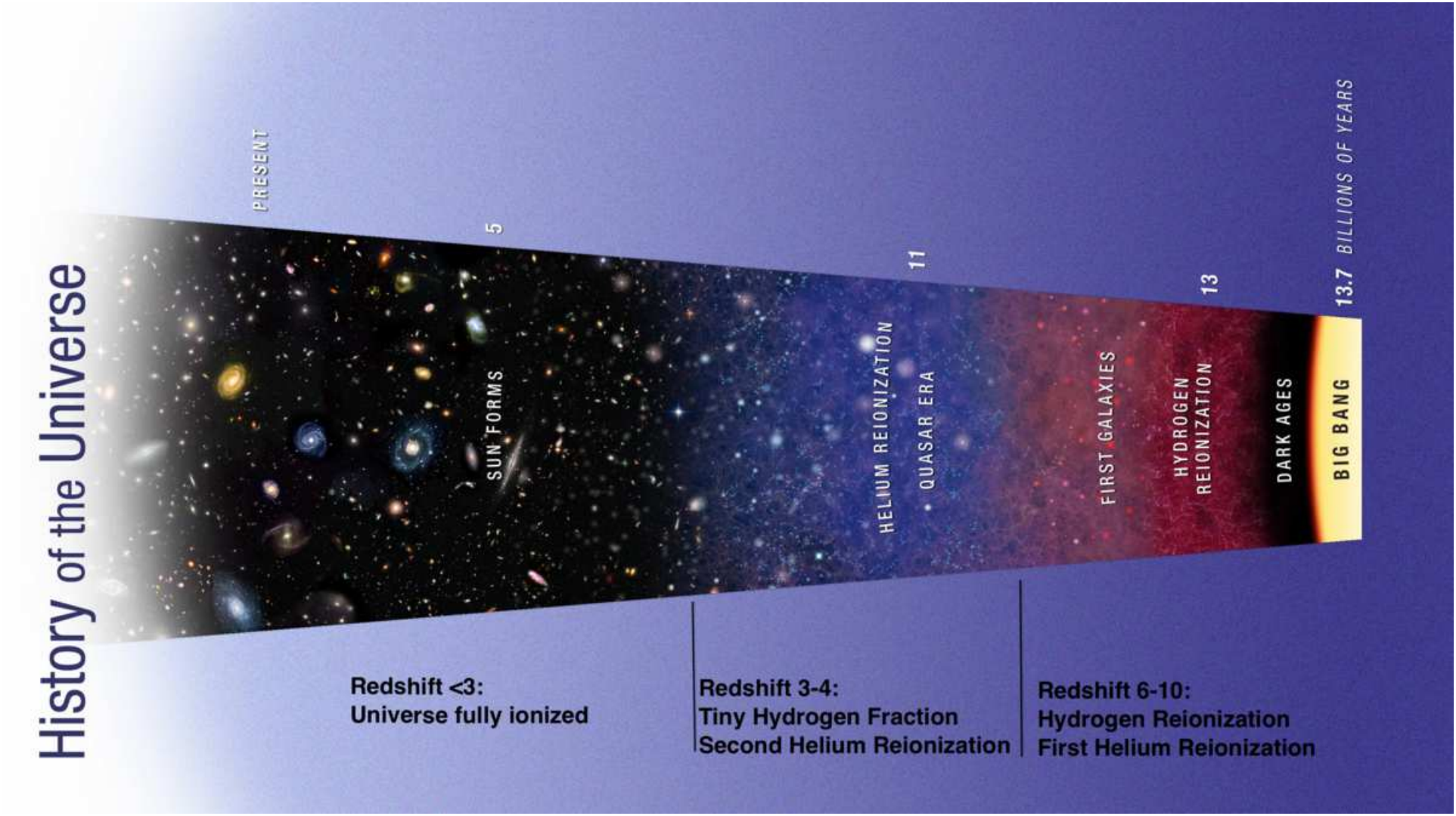
Exploiting VST Atlas and its Sister Surveys

Durham, 14–16 April 2014

Reionization Events – Two Baryonic Phase Transitions



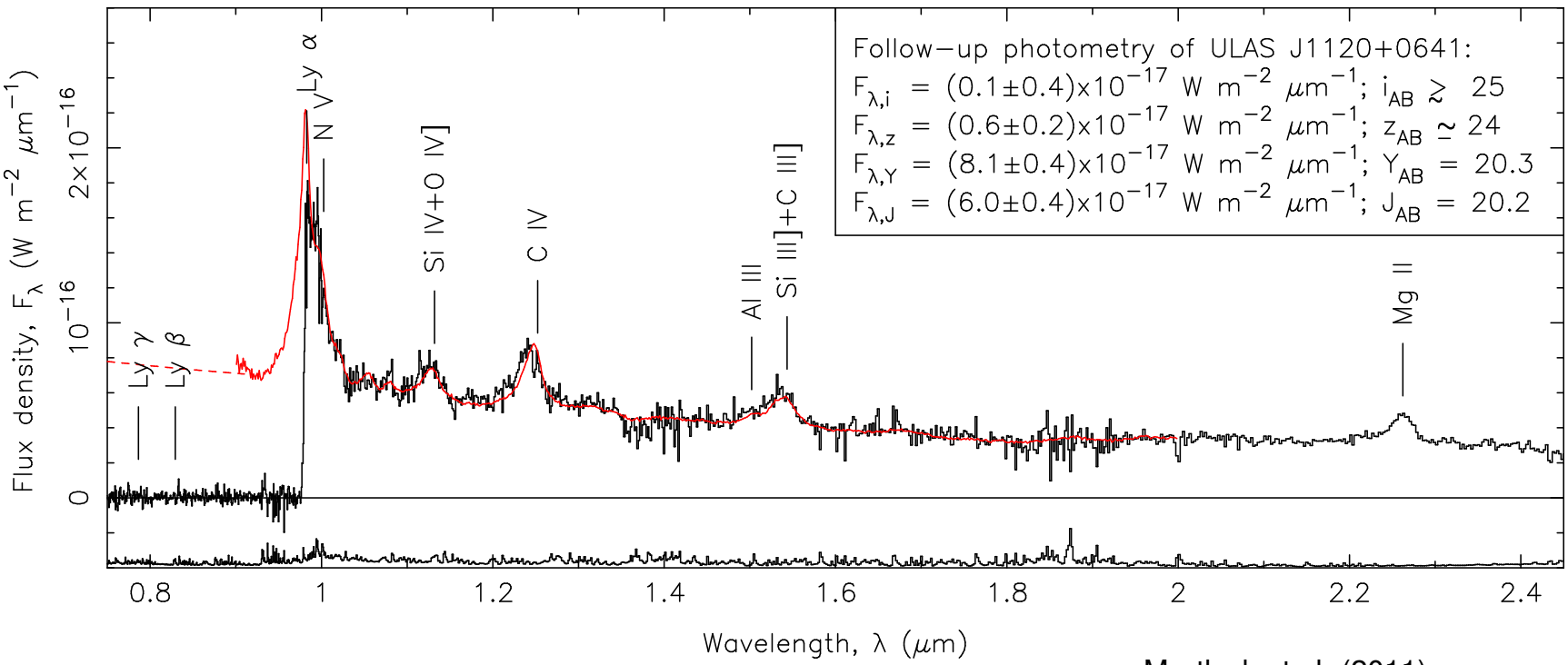
Credits: NASA

Redshift $z > 6$: H I Gunn-Peterson Trough

- Quasi-continuous H I Lyα absorption
- H I Lyα saturates at neutral fractions $\gtrsim 10^{-4}$

  $\longrightarrow$ insensitive test

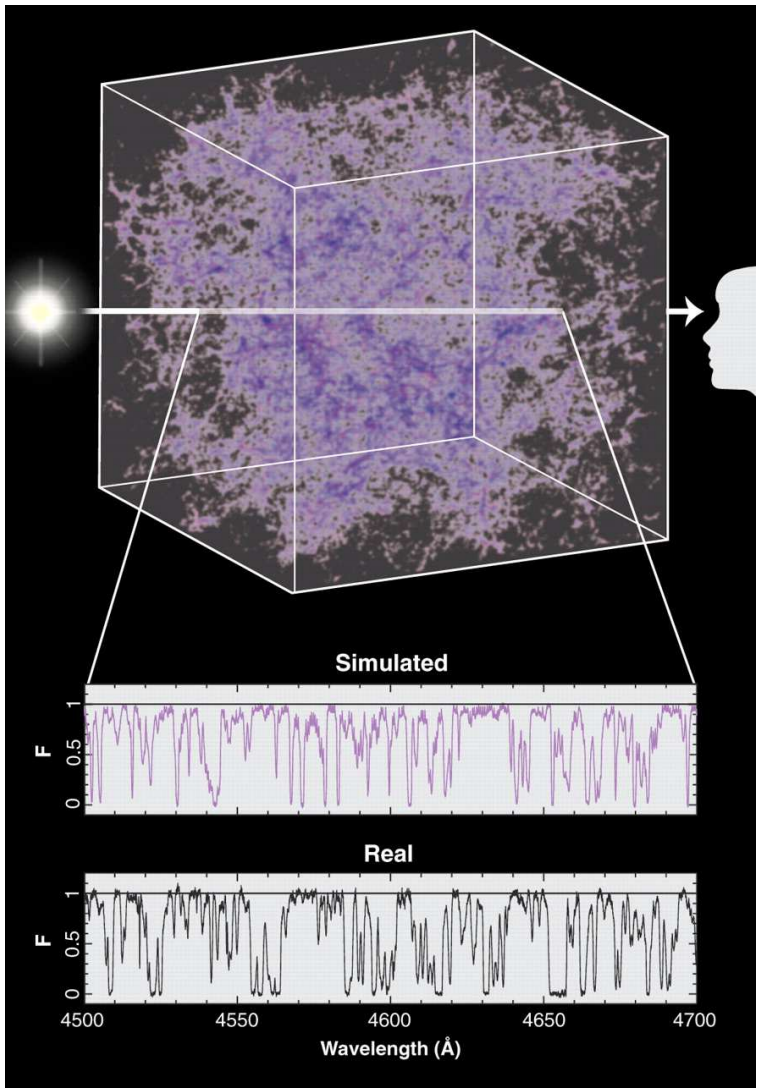
  $\longrightarrow$ additional probes (Ly series, metals, 21cm...)



Mortlock et al. (2011)

The Post-Reionization ($z < 5$) Intergalactic Medium

- Cosmic Web in photoionization equilibrium with UV background



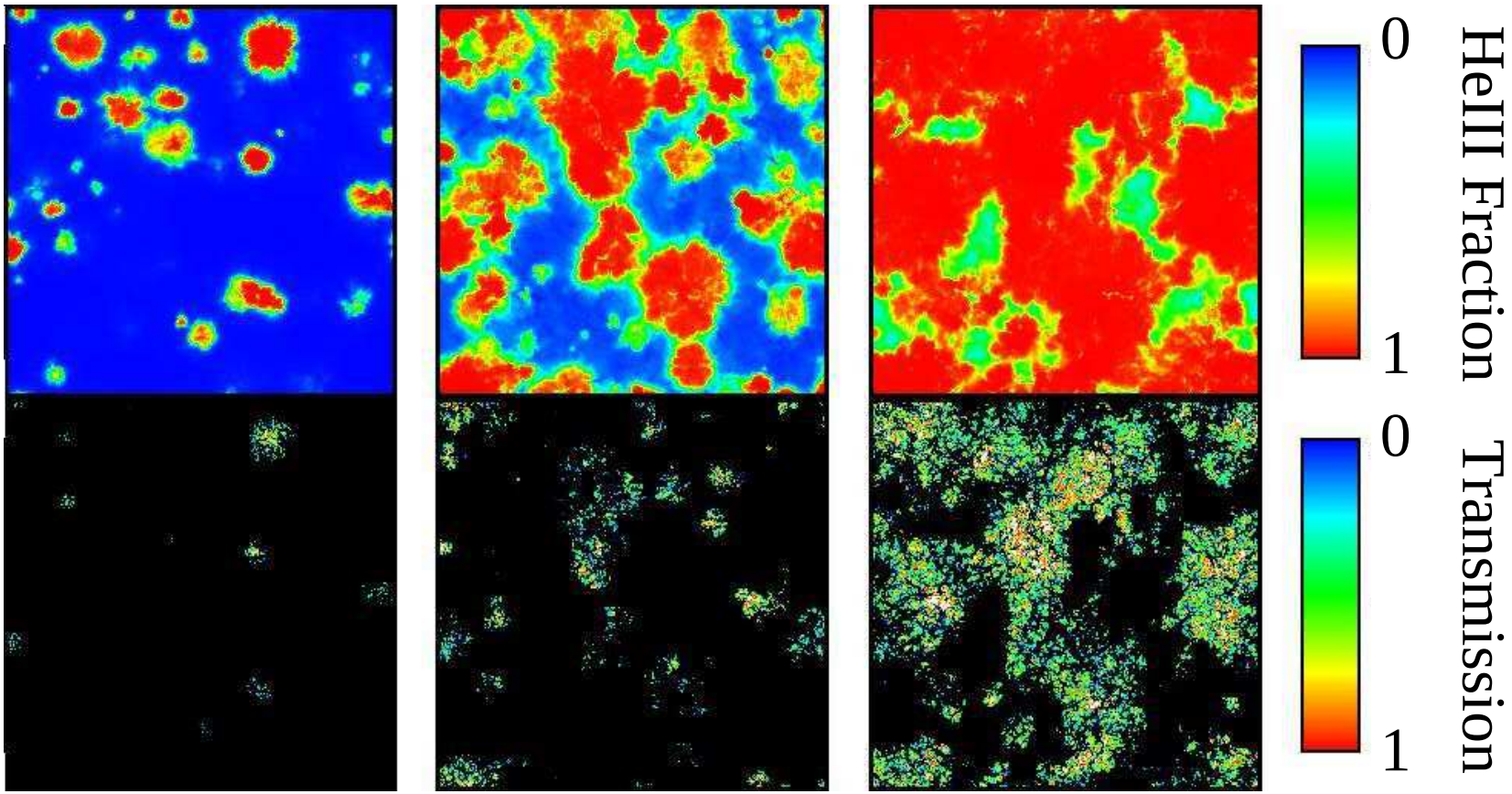
Faucher-Giguère et al. (2008)

Basics of Helium Reionization ($3 \lesssim z \lesssim 4$)

- After reionization: H and He in photoionization equilibrium with UV background
- He reionization likely two-step process:
  1. He I $\longrightarrow$ He II @ $z \sim 6$ ($h\nu > 24.6$ eV required)
  2. He II $\longrightarrow$ He III @ $z \sim 3$ ($h\nu > 54.4$ eV required)
- Reason: hard UV photons only produced by quasars, full He reionization delayed until quasars sufficiently abundant
- Tracers of He II reionization:
  - indirect: IGM temperature
  - direct: He II Lyα absorption at $\lambda_{\rm rest} = 303.78$ Å (analogous to H I Lyα at $z \sim 6$)

Simulations: He III Bubbles around Quasars

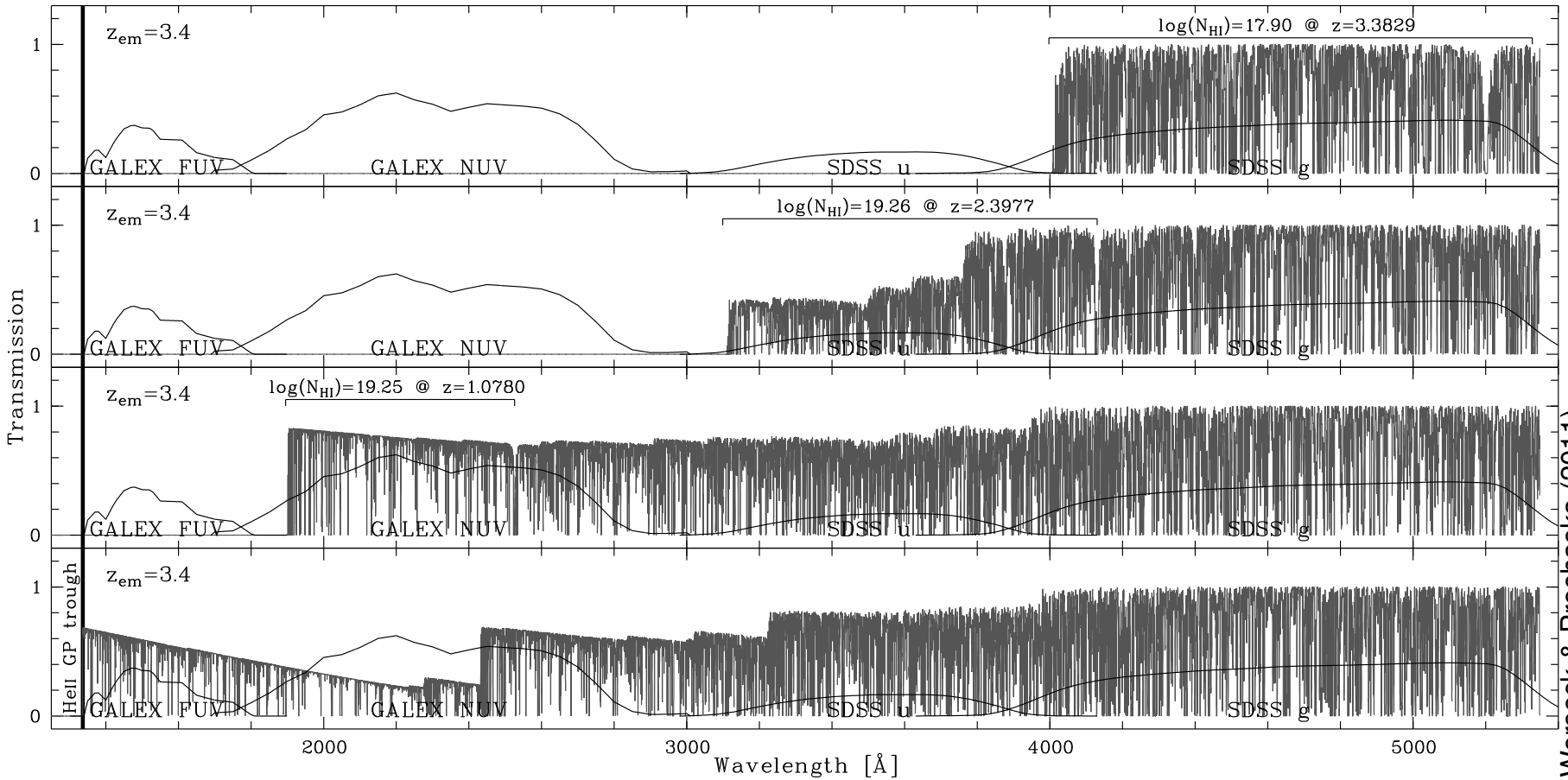
- Semi-analytic models and radiative transfer simulations
- Prediction: inhomogeneous and extended He II reionization ($\sim$ 1Gyr, $3 \lesssim z \lesssim 4$)



McQuinn et al. (2009)

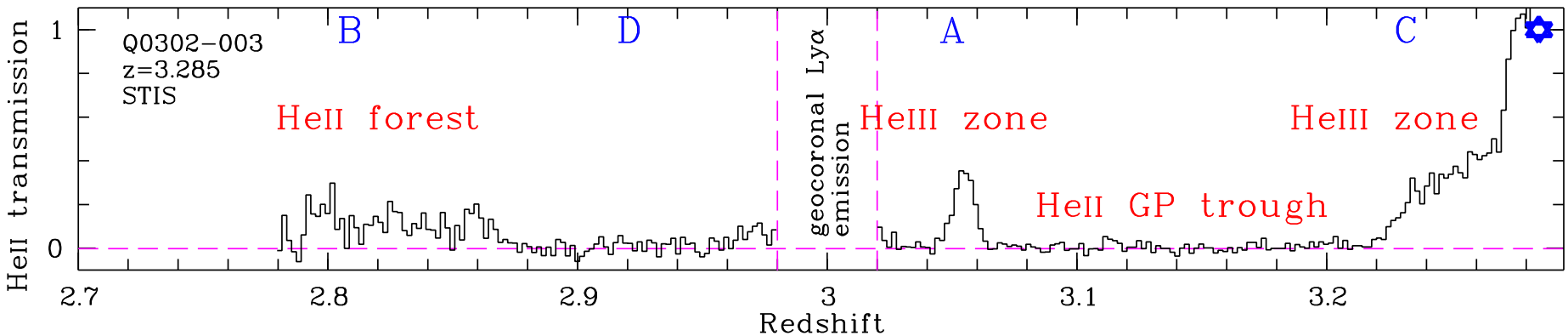
Challenge for He II Lyα: H I Lyman Continuum

- High-z H I Lyman limit systems
  $\longrightarrow$ strong cumulative Lyman continuum absorption
- A few percent of $z_{\rm em} > 3$ QSO sightlines "clear" at $\lambda_{\rm rest} = 304$Å
  $\longrightarrow$ GALEX Far UV selection



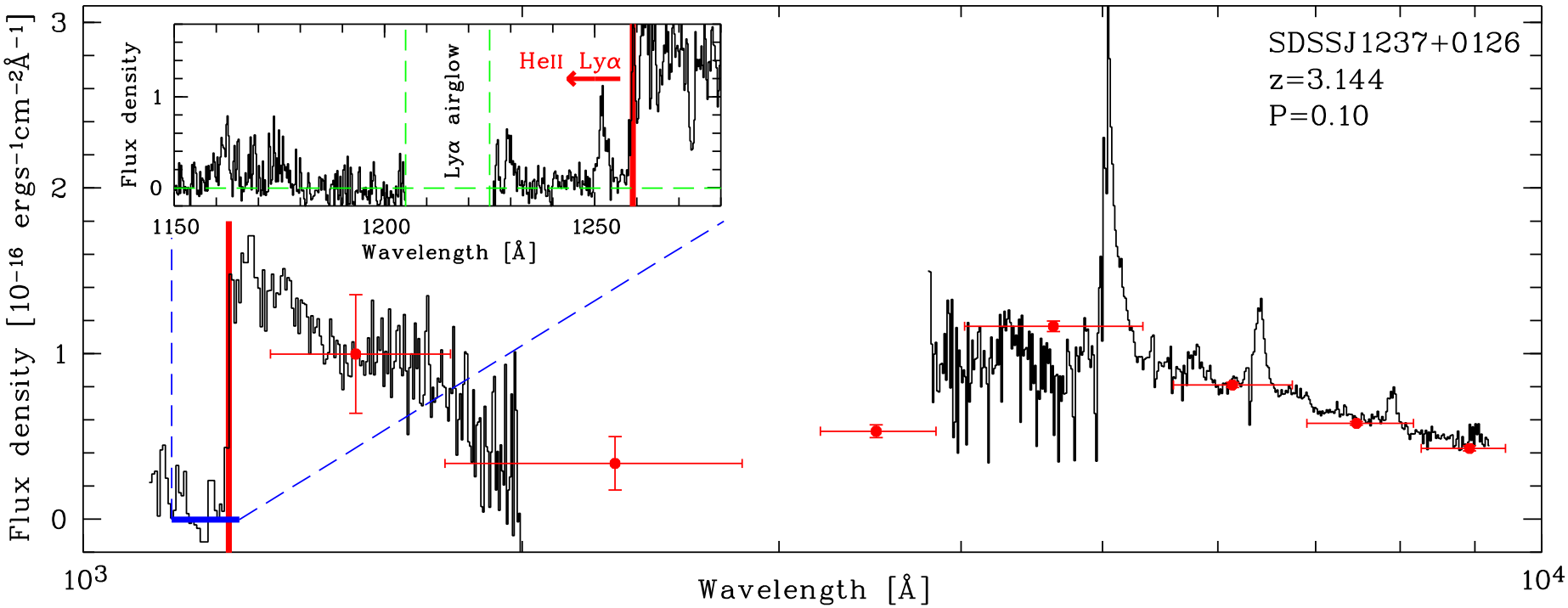
Handful of Historic He II Sightlines: $z_{\rm reion} \sim 3$

- Before GALEX: 5 sightlines
- Main features: Gunn-Peterson trough at $z > 3$, patchy He II absorption at $2.7 < z < 3$, forest at $z < 2.7$
- He III zones around background and foreground quasars
- Statistical sample lacking



The GALEX + HST/COS Revolution

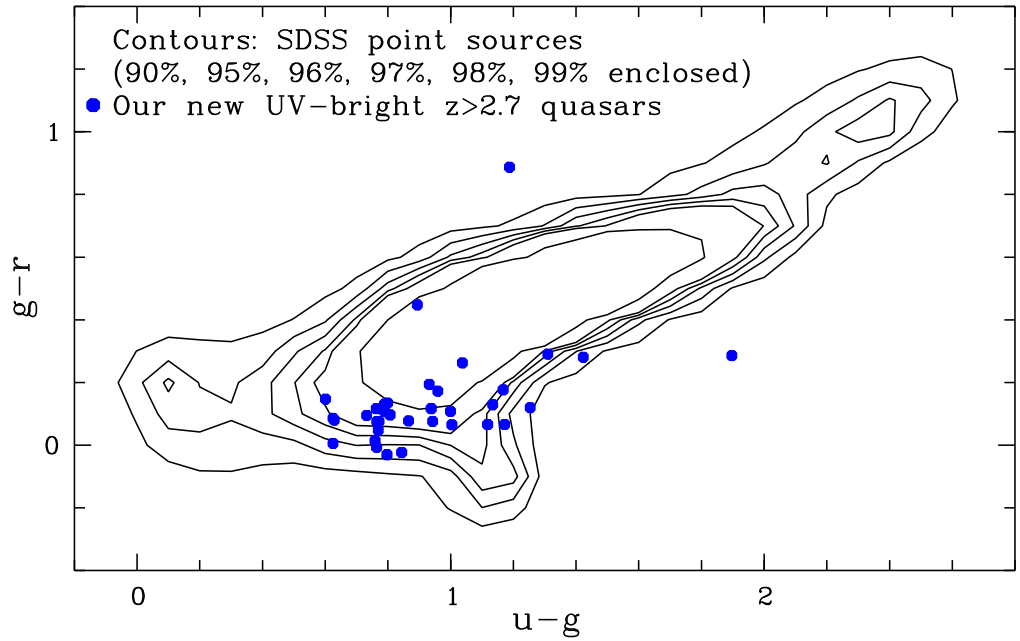
- GALEX: pre-selection of UV-transparent sightlines
- HST/COS follow-up spectroscopy
- Cycles 17: 6 new science-grade He II sightlines
- SDSS is biased at $z \sim 3$ (Worseck & Prochaska 2011)

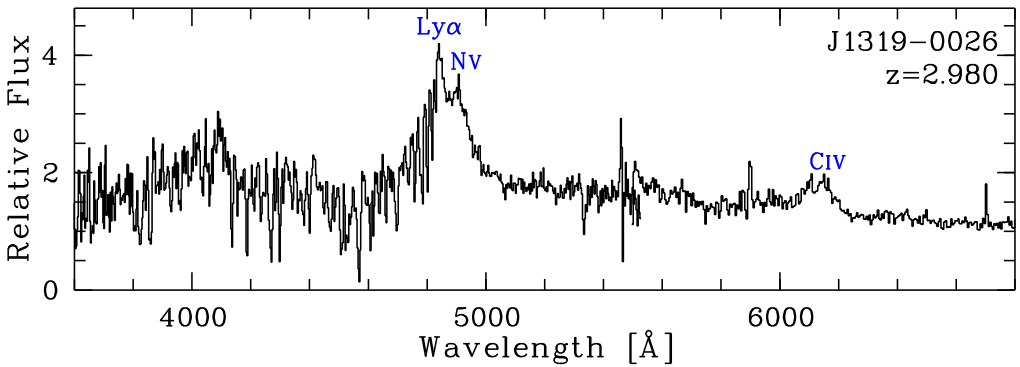


A Dedicated Survey for UV-bright $z > 2.7$ Quasars

- Multi-wavelength selection
  - GALEX+SDSS+WISE
  - GALEX+PS1+WISE
  - GALEX+ATLAS+WISE
- Follow-up spectroscopy at 2–3 m tel.

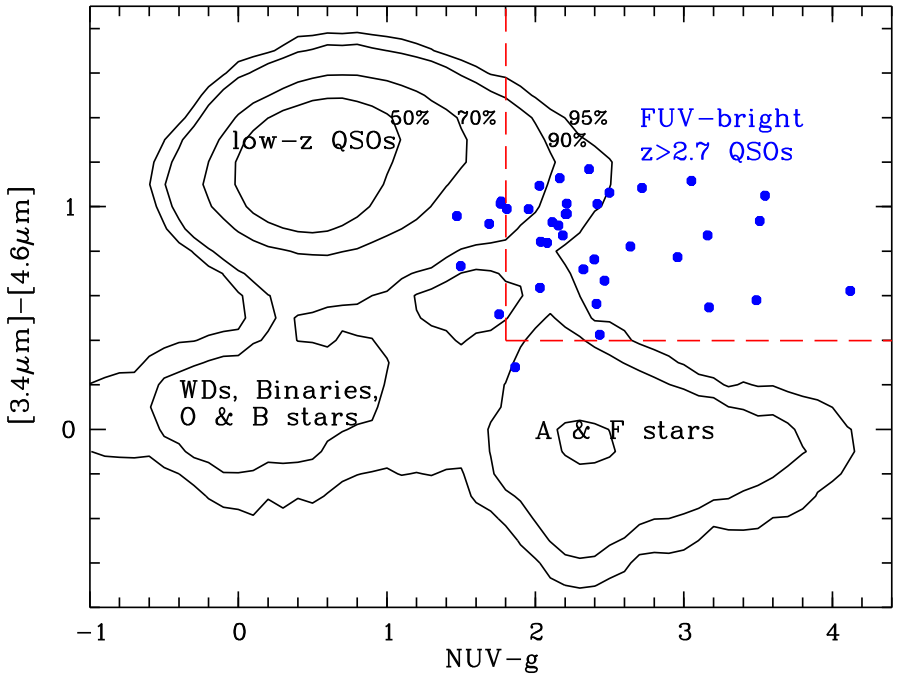
  (CAHA, Lick, Las Campanas)
- 2011–14: $\sim$ 60 nights

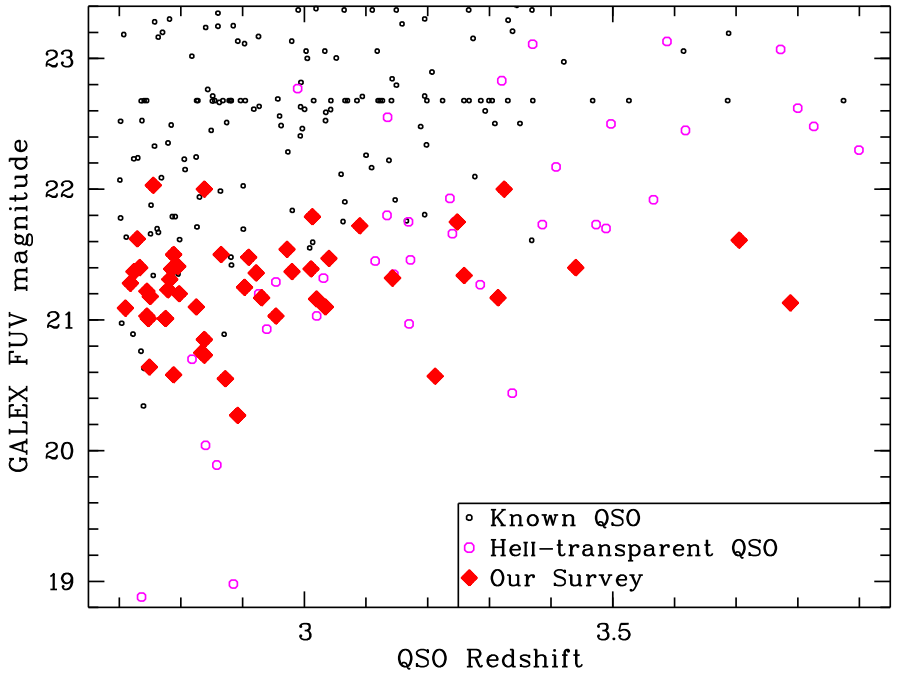




Pan-STARRS1: Access to 3π

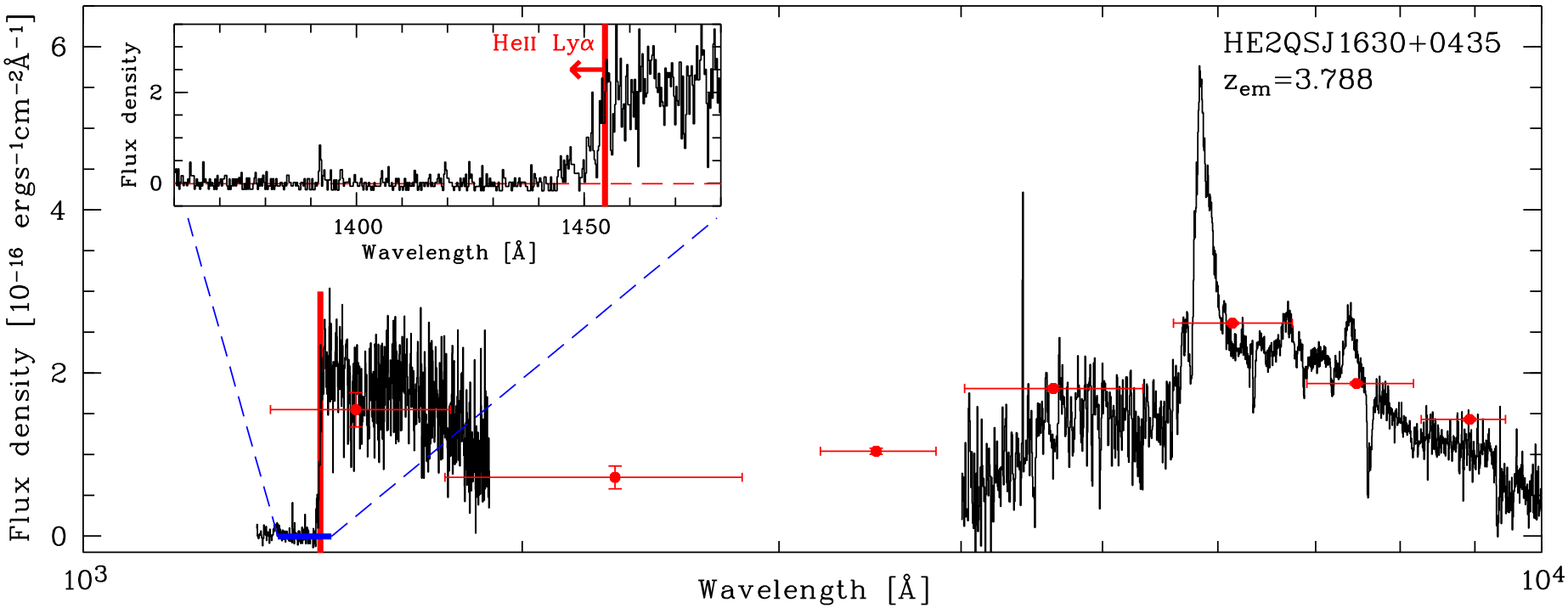
- PS1: No *u* band, large contamination from low-*z* quasars
- Total: > 50 UV-bright ($m_{\mathrm{FUV}} < 21.5$) quasars at $z > 2.7$





We build the HST/COS He II Legacy Sample

- HST Cycle 20: HST/COS follow-up of 7 $z > 3.1$ quasars
- HE2QS J1630+0435: brightest He II quasar at $z > 3.5$
- Ongoing survey in 3π PS1 footprint + VST (south)



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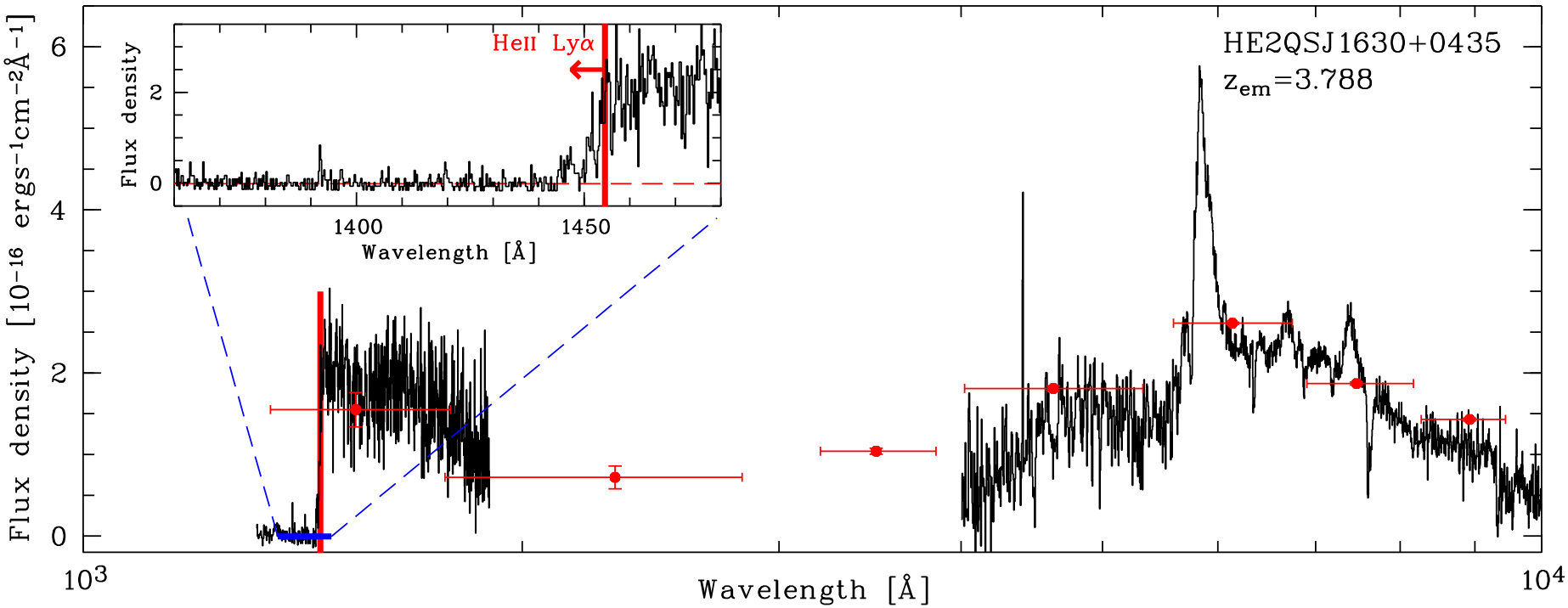
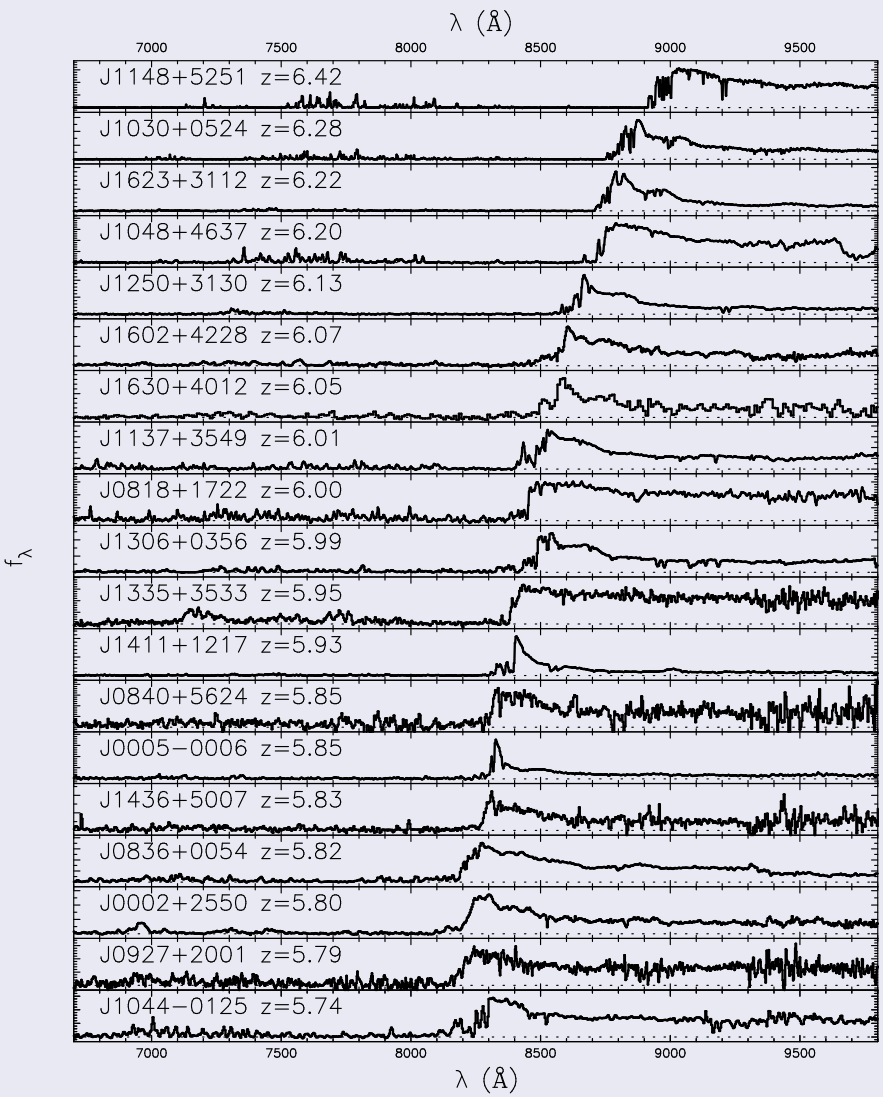


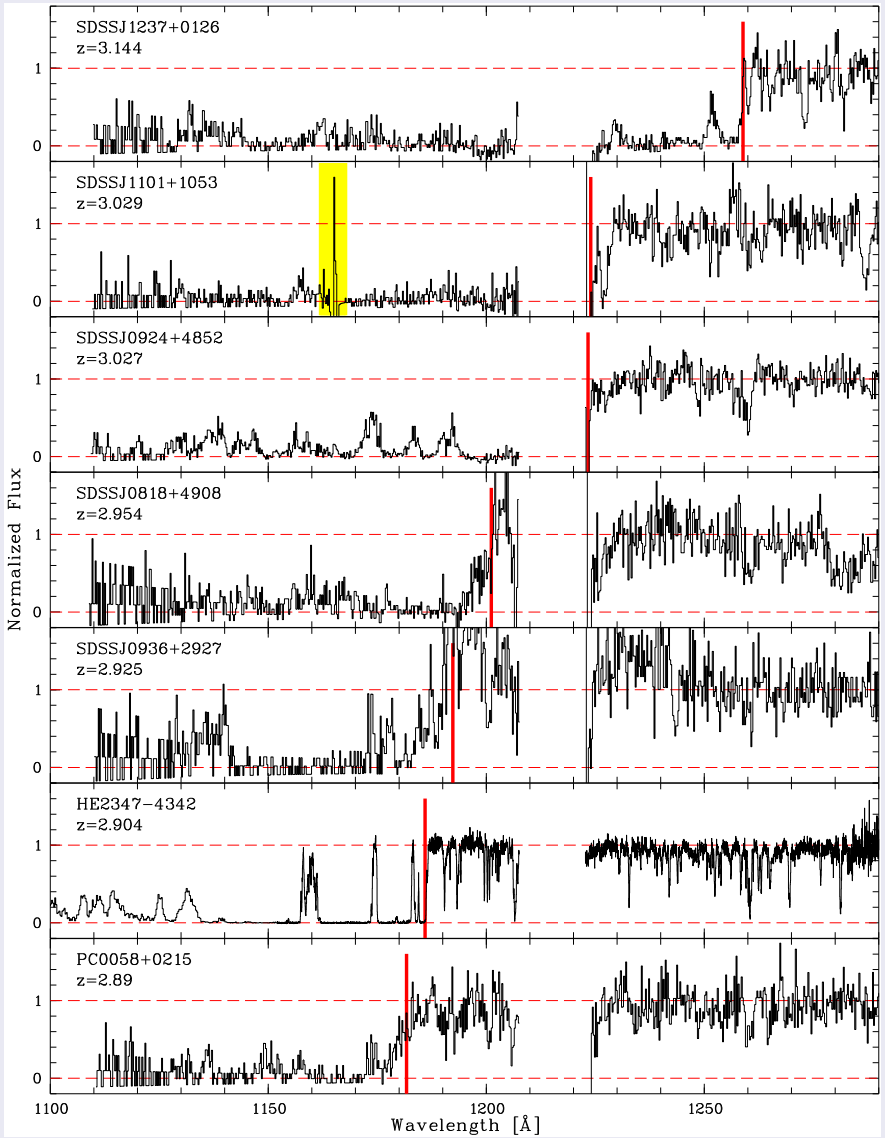
Fluctuating Gunn-Peterson Troughs

Ground: Hydrogen at $z \sim 6$



Fan et al. (2006)

Far UV: Helium (He II) at $z \sim 3$



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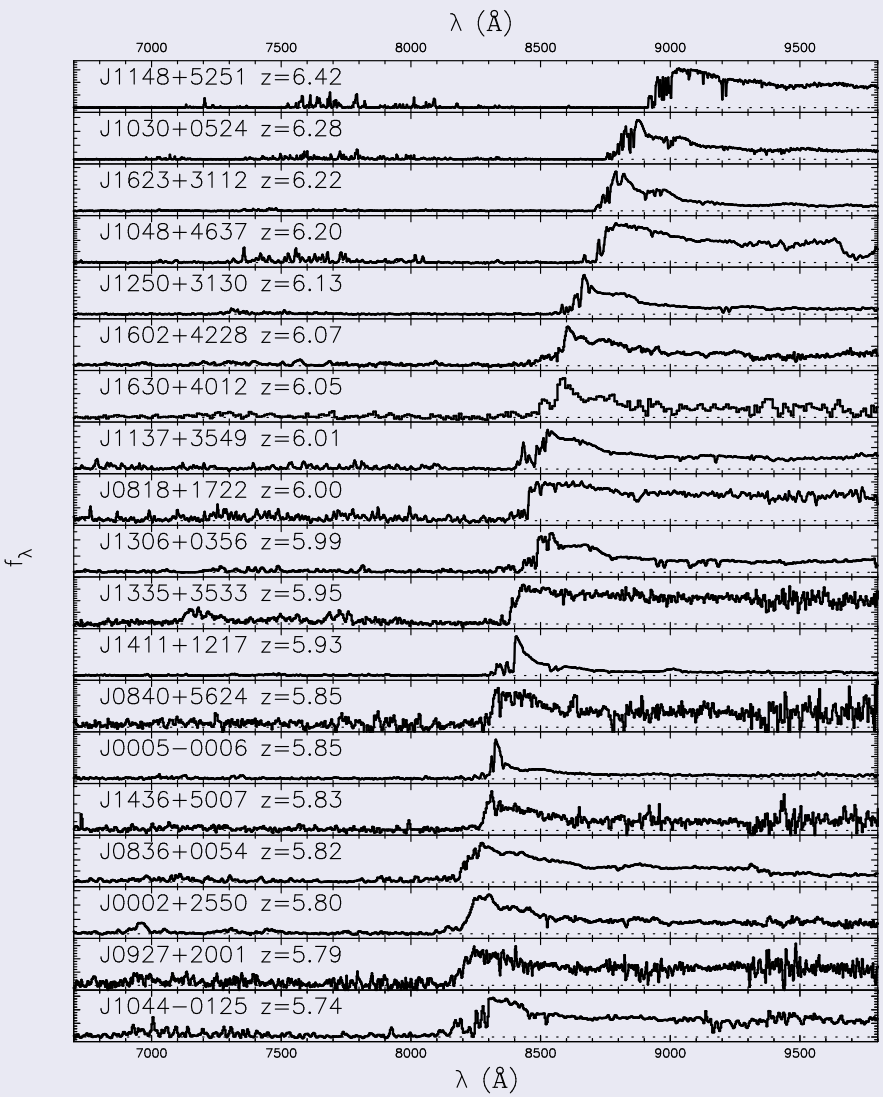

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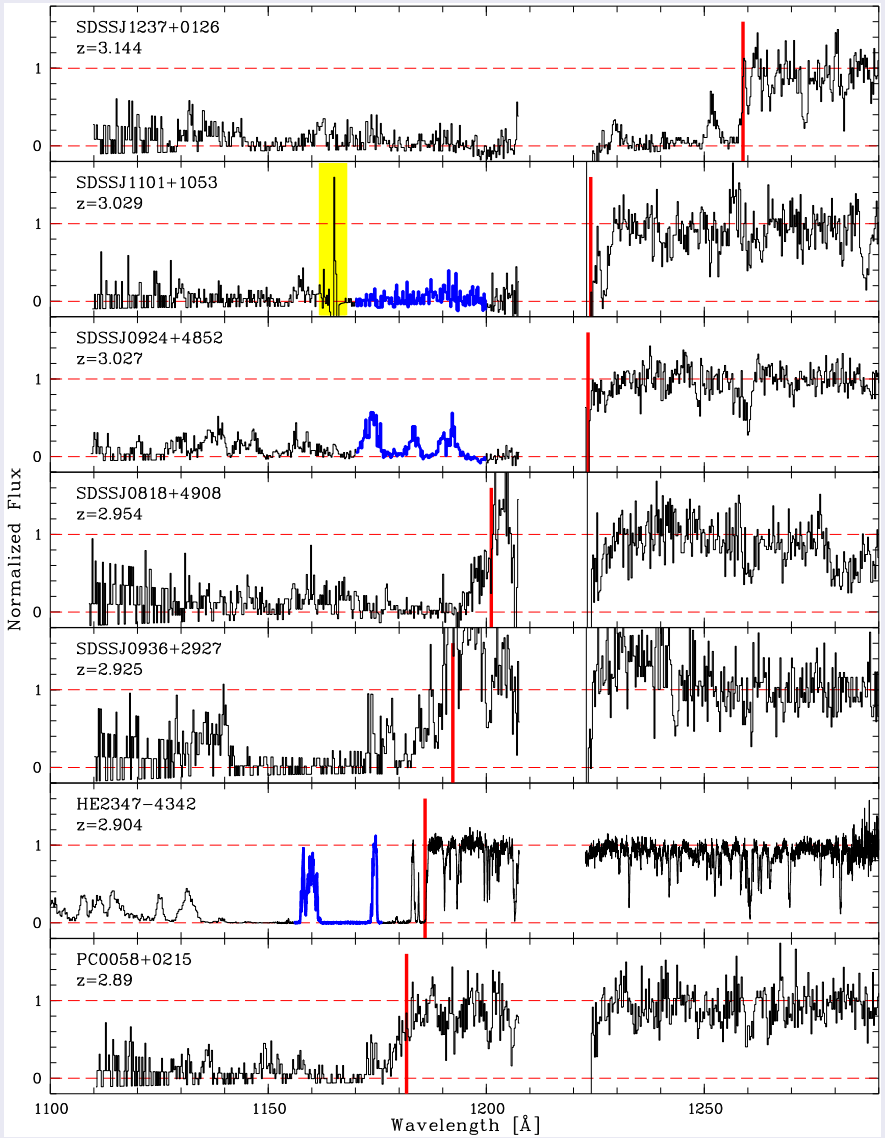

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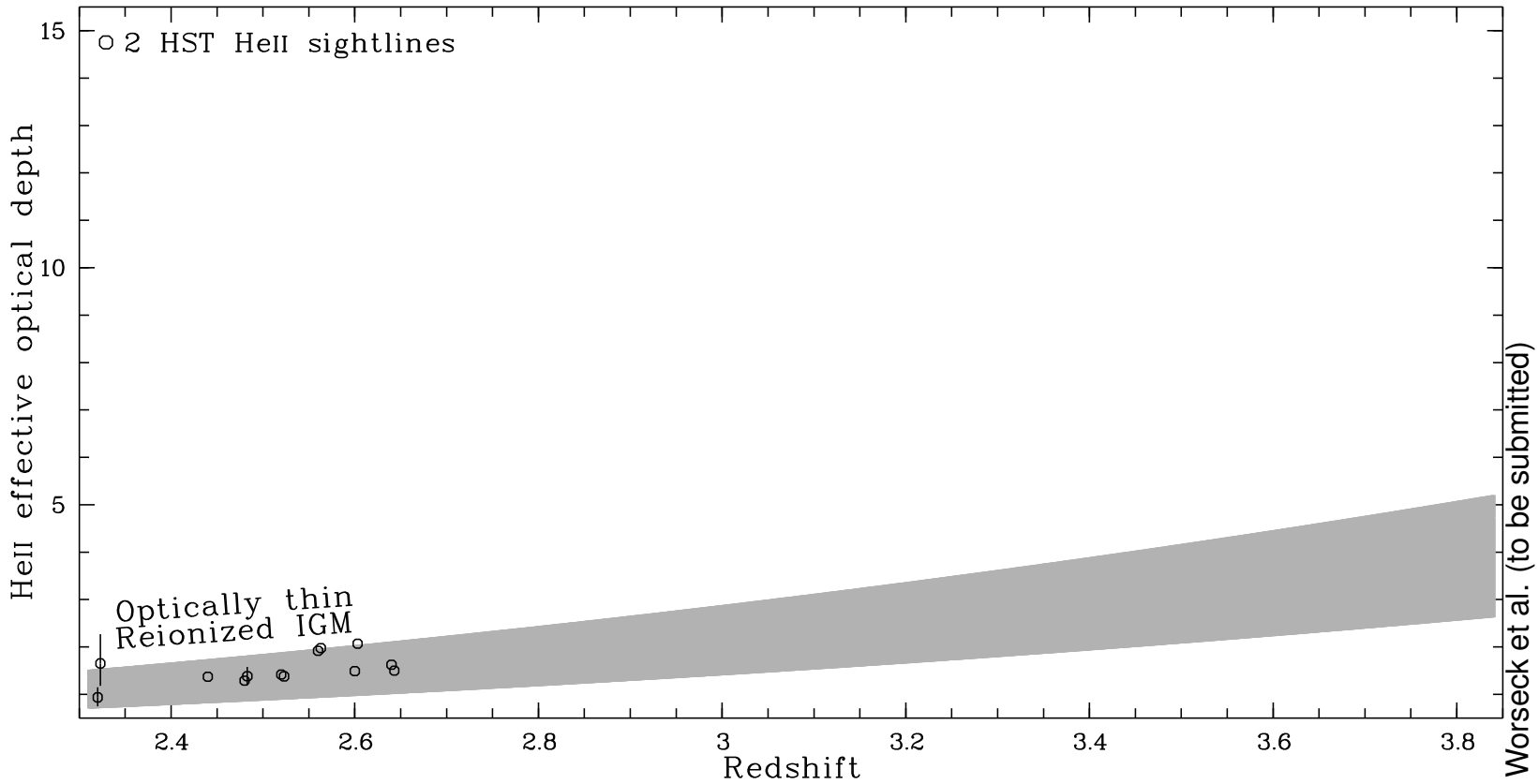
Extended He II Reionization ends at $z_{\rm reion} \simeq 2.7$

- Measurements: He II effective optical depth on ~ 10 proper Mpc
- $z \lesssim 2.7$: agreement with semi-analytic model of photoionized IGM



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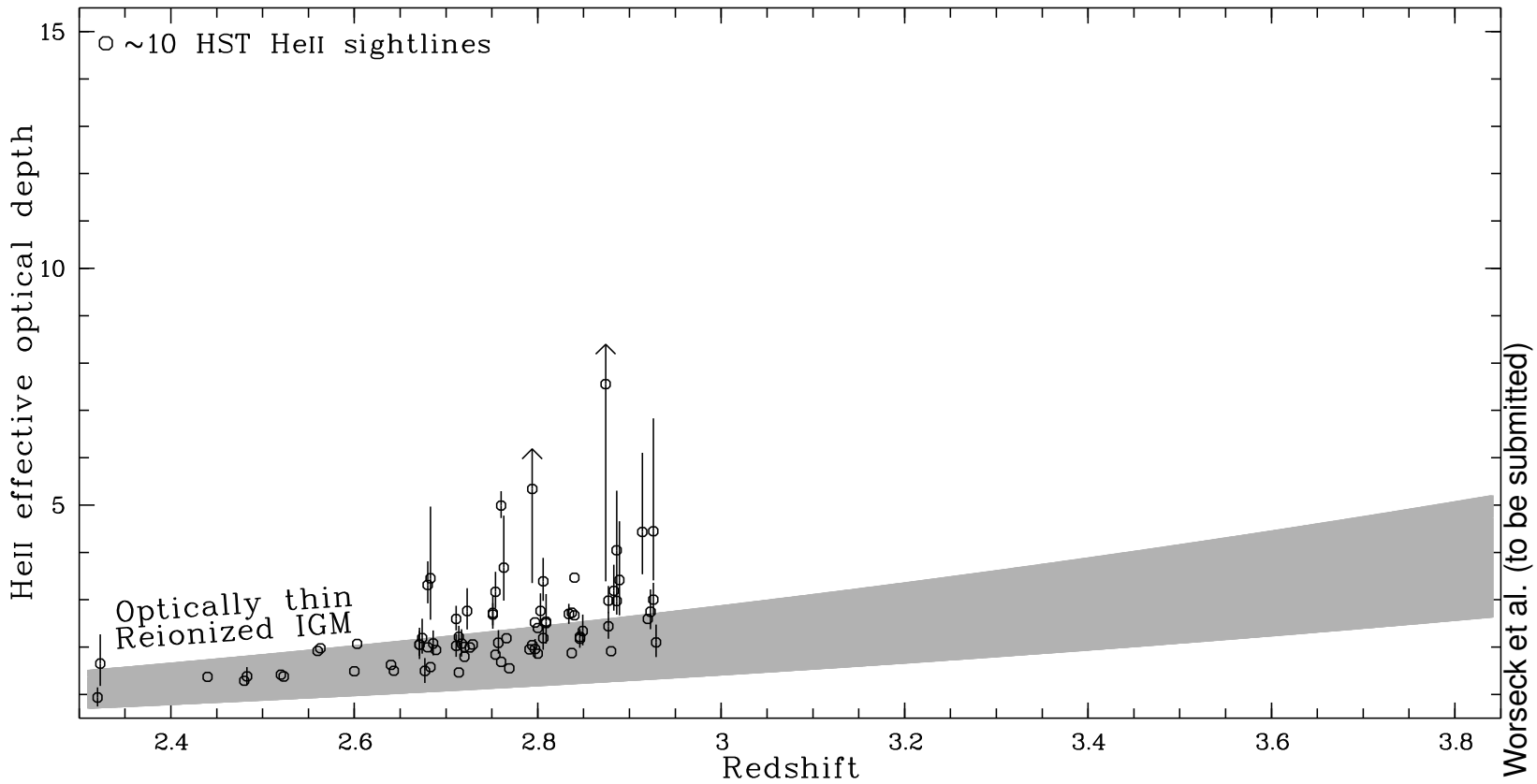

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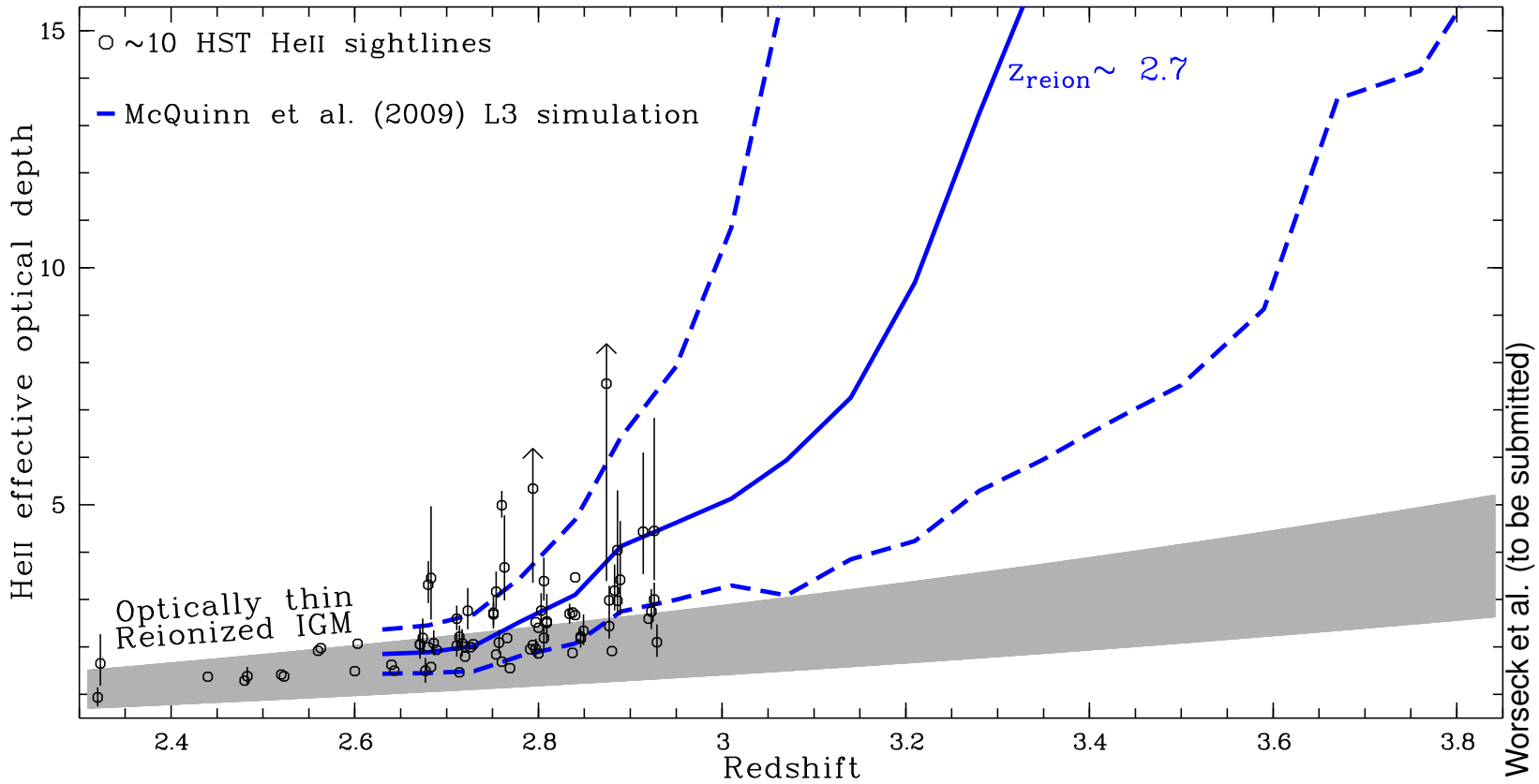

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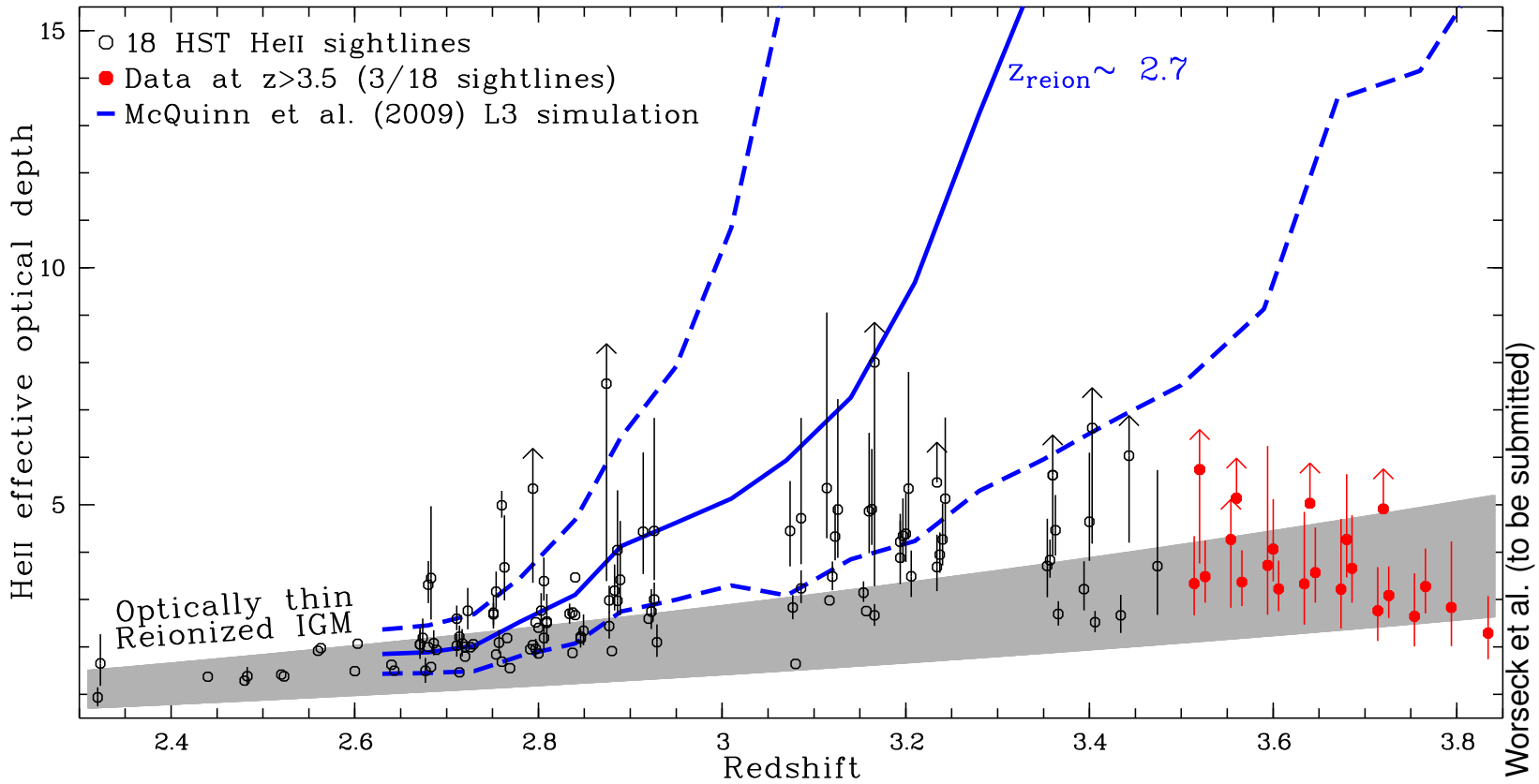
- $z > 3$: dispersion not reproduced, low opacity at $z \sim 3.8$



Finding Lighthouses in the UV Fog

- The 2nd Epoch of Reionization
  - Helium reionized by quasars at $z \sim 3 \longrightarrow$ Gunn-Peterson test
  - He II Lyα at 304 Å$\longrightarrow$ HST FUV spectroscopy
- We find rare He II-transmitting quasars
  - A few percent of all $z \sim 3$ quasars usable for He II studies
  - Multi-wavelength selection in large-area surveys
  - Optical follow-up: $>$ 50 UV-bright quasars at $z > 2.7$
- A Now or Never survey
  - Ground-based 3 m telescopes are closing
  - No sensitive UV mission after HST for the next $>$ 20 years
  - Our goal: $22 + X$ He II sightlines