Observational Constraints on Cosmic Reionization

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Overview

- Previous papers discuss reionization from a theoretical P.O.V.
- This paper focuses on observational constraints
  - QSO spectroscopy
    - Gunn-Peterson troughs
  - High-z galaxies
  - CMB
- Sources of reionization
- Future in 21cm observations

Cosmic Stromgren spheres

1. Introduction

- Three phases of IGM evolution
  - z<1100 ← Probed with CMB
    - PGM hot, fully ionized
  - z=1100 – z=14
    - Neutral
  - z=14 – z=6
    - Reionization

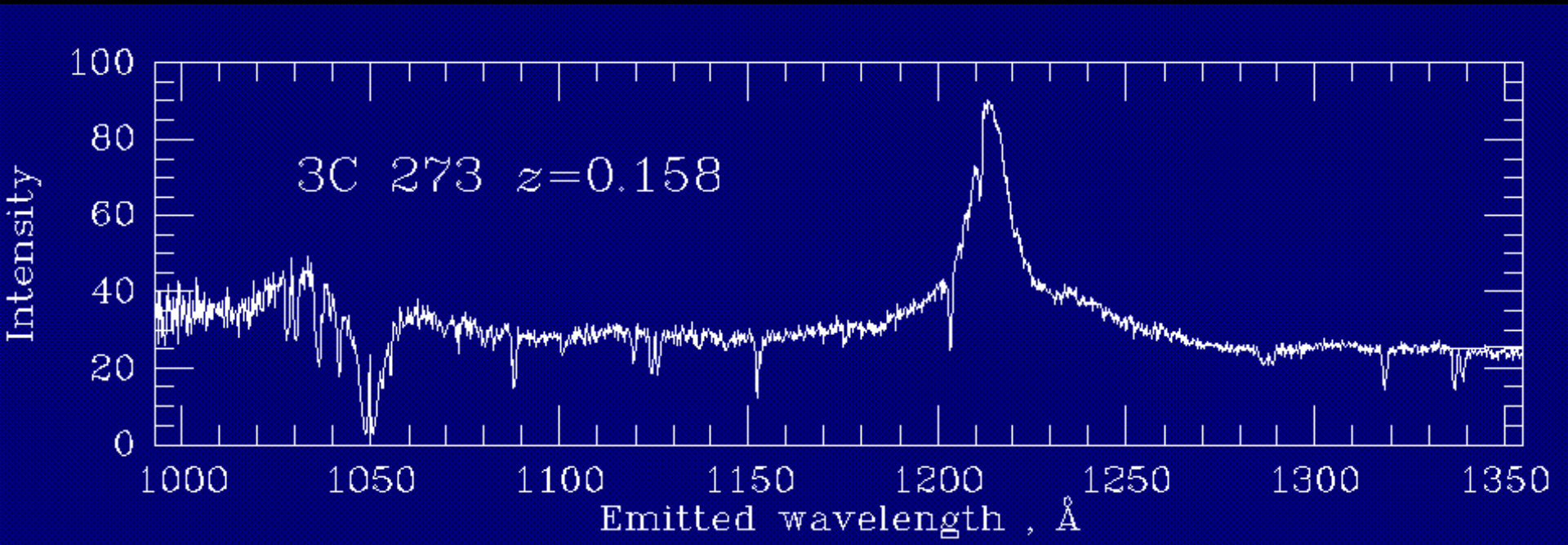
    } Last evolution regime to be characterized
  - z=6 – z=0 ← Probed with nearby QSOs
    - Ionized IGM

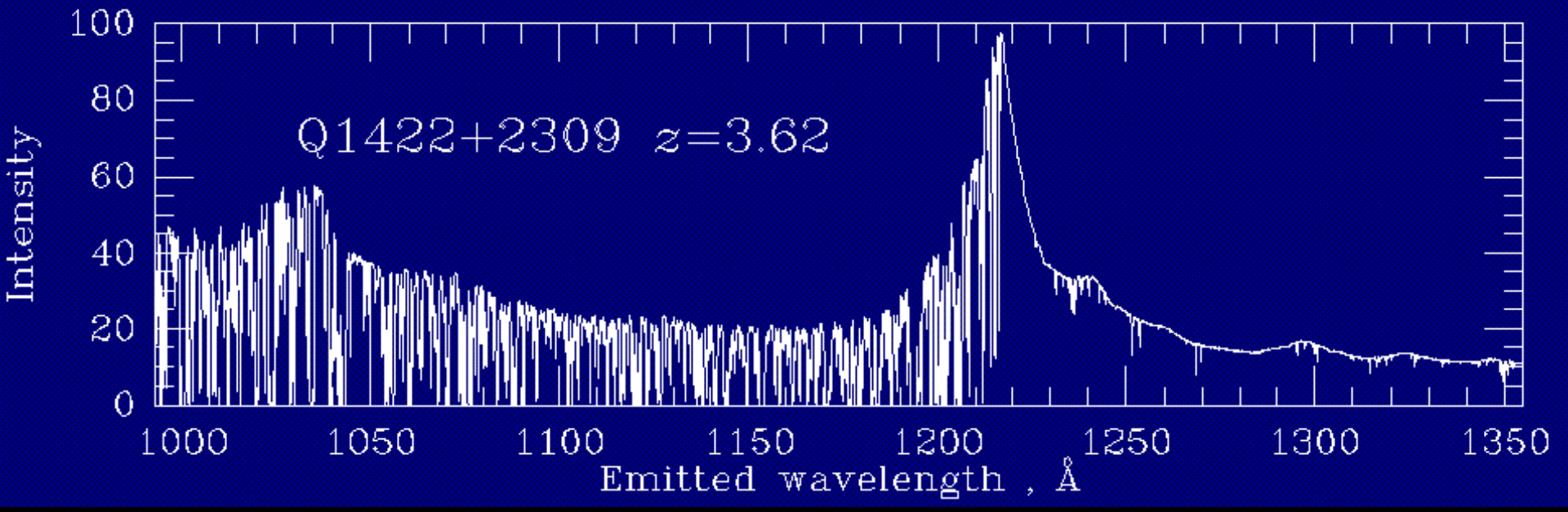
2. Basic Model of Reionization

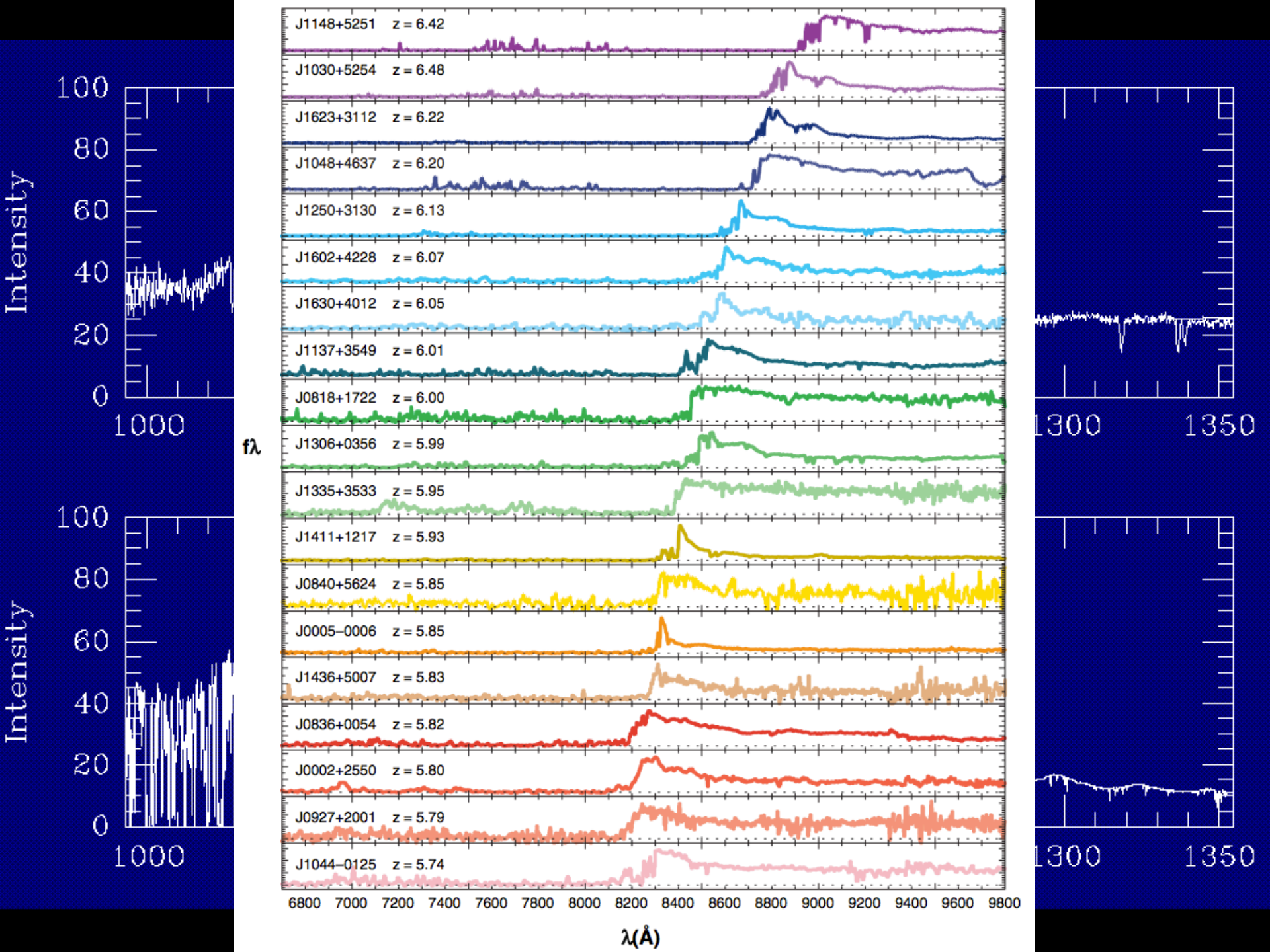
- 3 phases of reionization
  - (slow) isolated Stromgren spheres
  - (fast) “overlap” or “percolation” phase
  - (slow) etching away of dense filaments
- Caveats/open issues
  - Minimum for fast phase?
  - Recomb. time of IGM > Hubble time at z>8
  - Inside out or outside in reionization?
  - What if reion. from part. decay or X-rays?

3. Observations of Gunn-Peterson Effect

- Definition: absorption blueward of Ly-alpha in high-z QSO spectra due to intervening neutral hydrogen


3C 273 z=0.158
Intensity
100
80
60
40
20
0
1000
1050
1100
1150
1200
1250
1300
1350
Emitted wavelength , Å


Q1422+2309 z=3.62
Intensity
100
80
60
40
20
0
1000
1050
1100
1150
1200
1250
1300
1350
Emitted wavelength , Å


J1148+5251 z = 6.42
J1030+5254 z = 6.48
J1623+3112 z = 6.22
J1048+4637 z = 6.20
J1250+3130 z = 6.13
J1602+4228 z = 6.07
J1630+4012 z = 6.05
J1137+3549 z = 6.01
J0818+1722 z = 6.00
J1306+0356 z = 5.99
J1335+3533 z = 5.95
J1411+1217 z = 5.93
J0840+5624 z = 5.85
J0005−0006 z = 5.85
J1436+5007 z = 5.83
J0836+0054 z = 5.82
J0002+2550 z = 5.80
J0927+2001 z = 5.79
J1044−0125 z = 5.74
fλ
λ(Å)
6800 7000 7200 7400 7600 7800 8000 8200 8400 8600 8800 9000 9200 9400 9600 9800
Intensity
0 20 40 60 80 100
1000
1300 1350

3. Observations of Gunn-Peterson Effect

- How would we estimate optical depth for Ly-alpha photons?

$$\tau_{\rm GP} = \frac{\pi e^2}{m_e c} f_\alpha \lambda_\alpha H^{-1}(z) n_{\rm HI},$$

Absorption cross-section

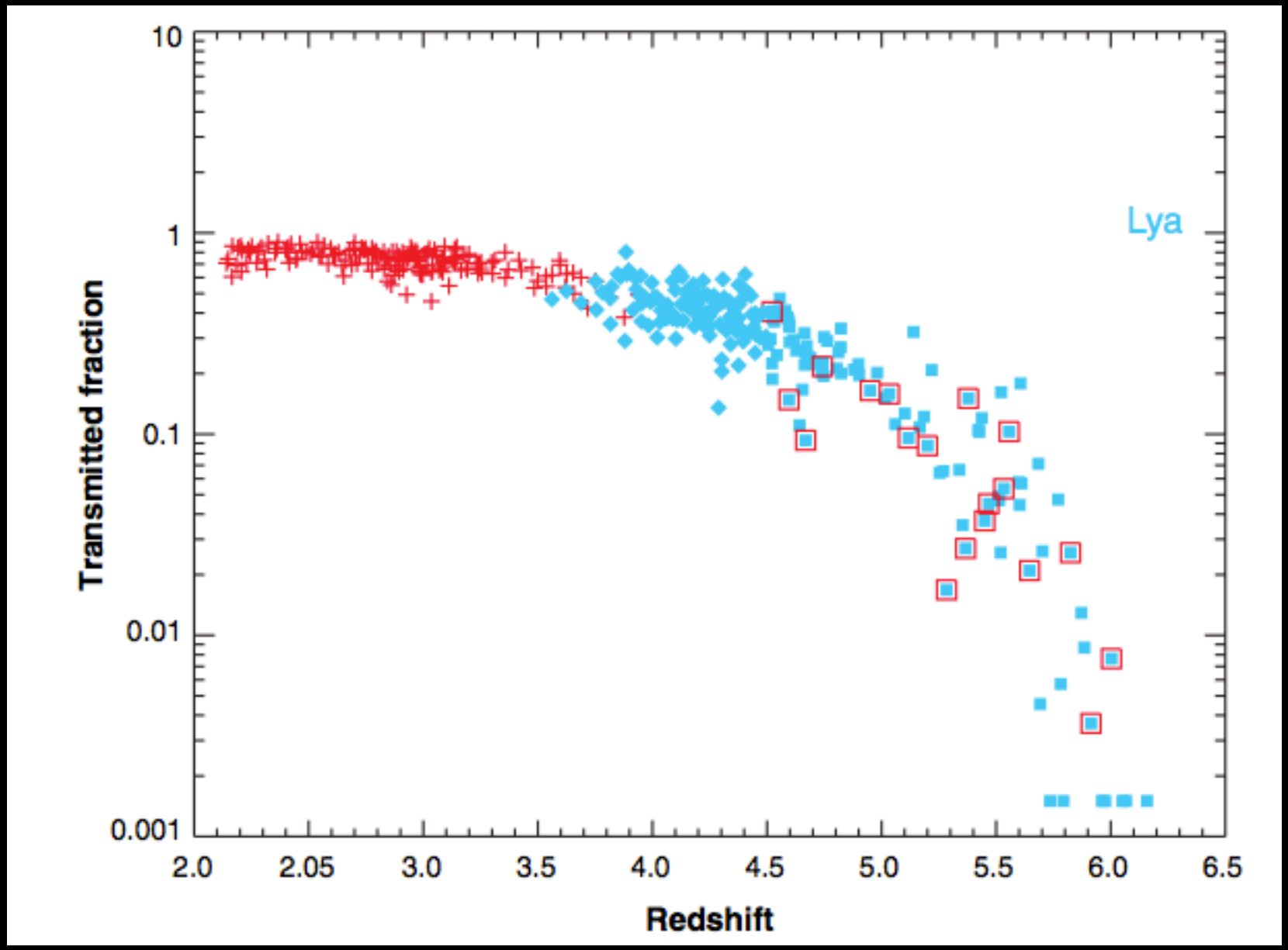
- What is the effect of such a large prefactor?
- Why is it so large?

$$\tau_{\rm GP}(z) = 4.9 \times 10^5 \left(\frac{\Omega_m h^2}{0.13}\right)^{-1/2} \left(\frac{\Omega_b h^2}{0.02}\right) \left(\frac{1+z}{7}\right)^{3/2} \left(\frac{n_{\rm HI}}{n_{\rm H}}\right)$$

- How does transmitted flux depend on tau?

$$I/I_0 = e^{-\tau}$$

3. Observations of Gunn-Peterson



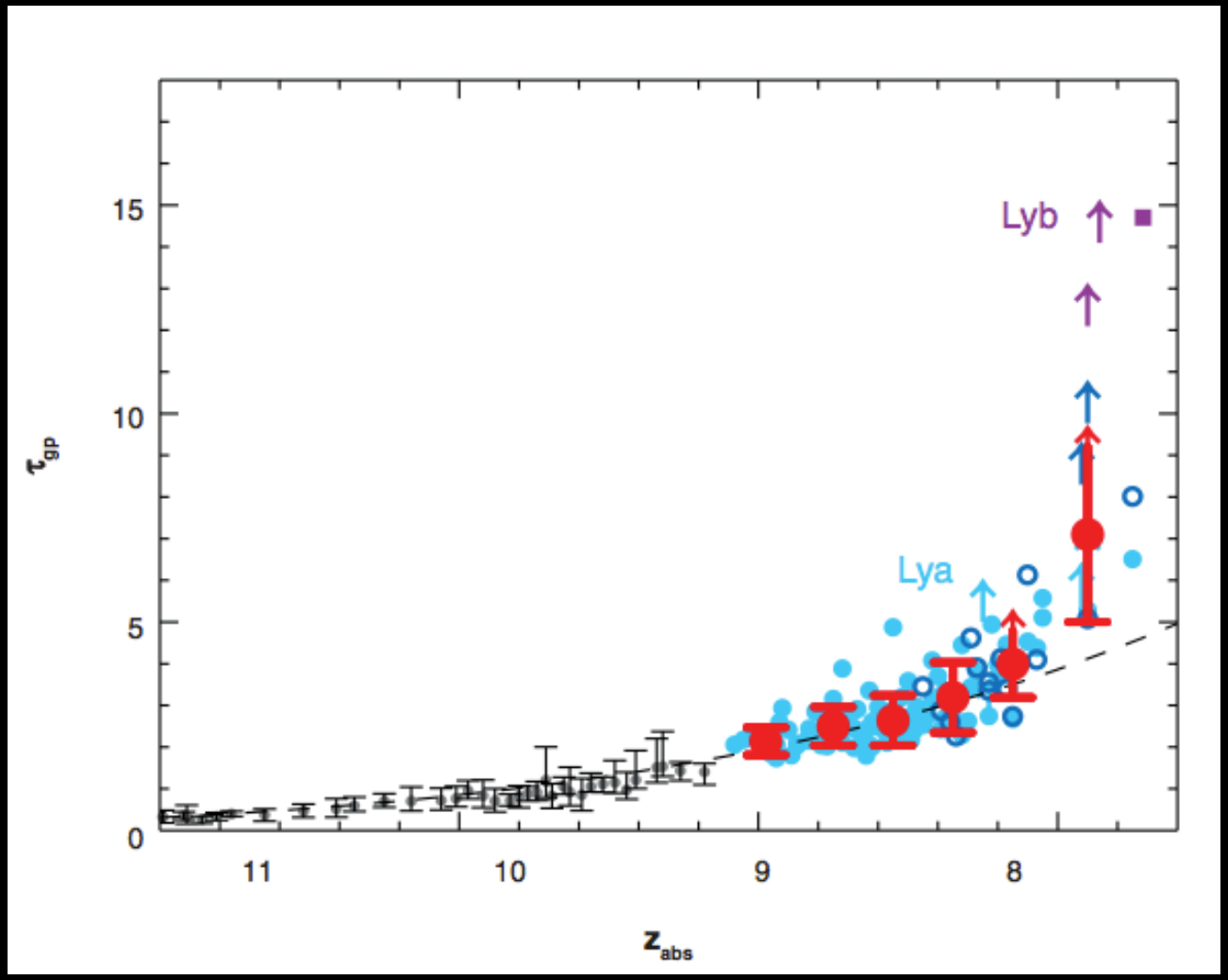
3. Observations of Gunn-Peterson Effect

- Strong evolution of transmitted flux blueward of Lyman alpha for z>5
- How can we get stronger constraints on neutral fraction?
  - Tau >>1 problematic for strong constraints

$$\tau_{\rm GP} = \frac{\pi e^2}{m_e c} f_\alpha \lambda_\alpha H^{-1}(z) n_{\rm HI},$$

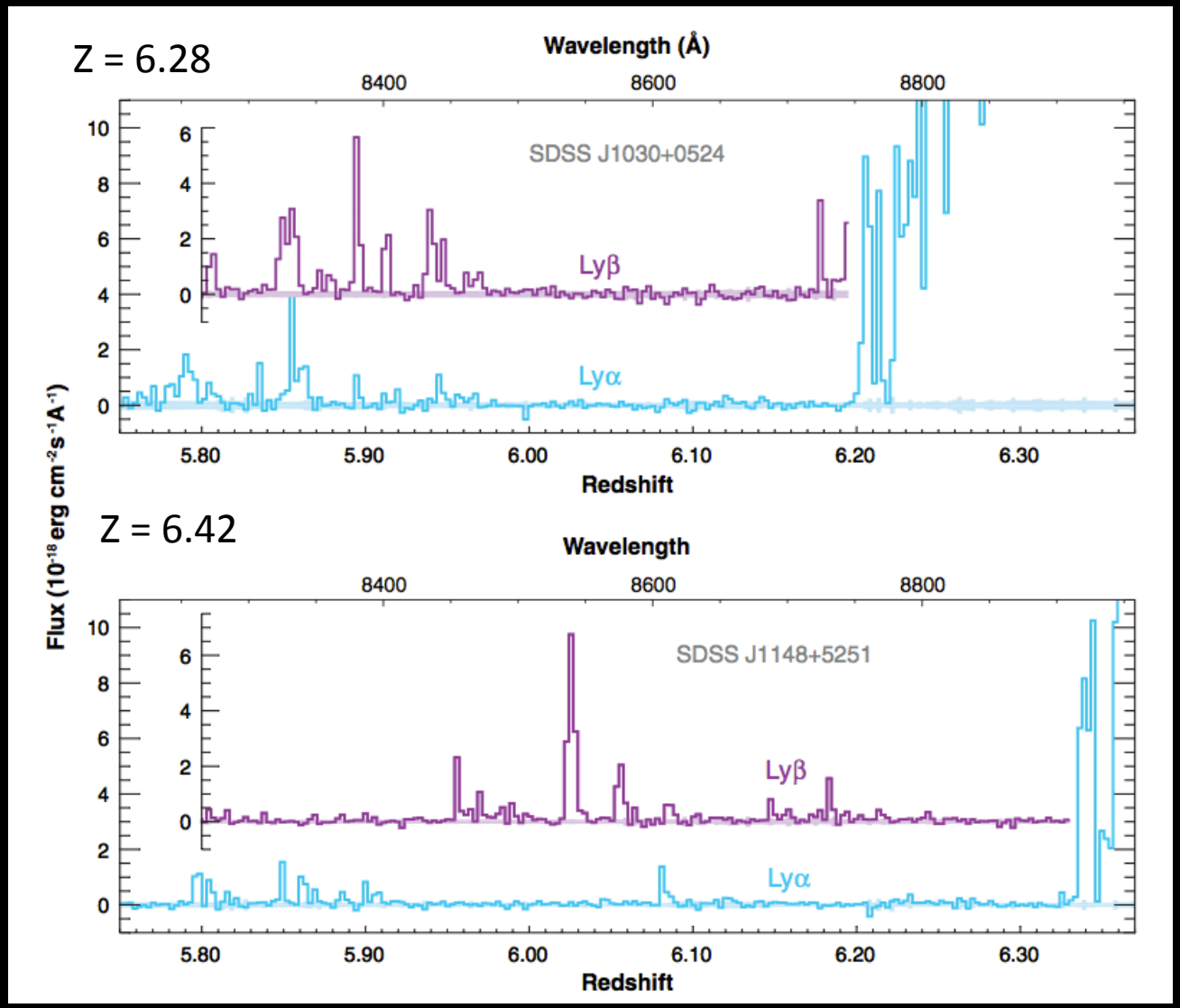
  - Other lines in the Lyman series

3. Observations of Gunn-Peterson Effect



What is this plot?

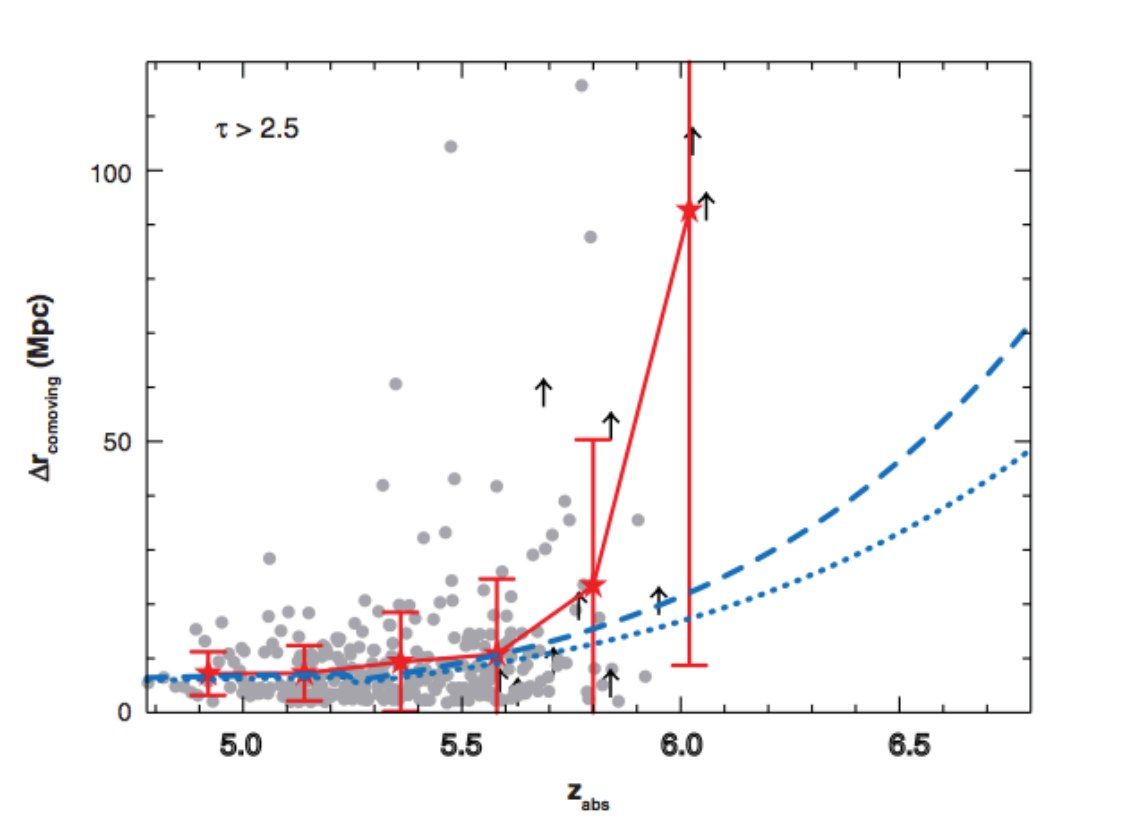
3. Observations of Gunn-Peterson Effect



What do we see when comparing these two objects?

3. Observations of Gunn-Peterson Effect

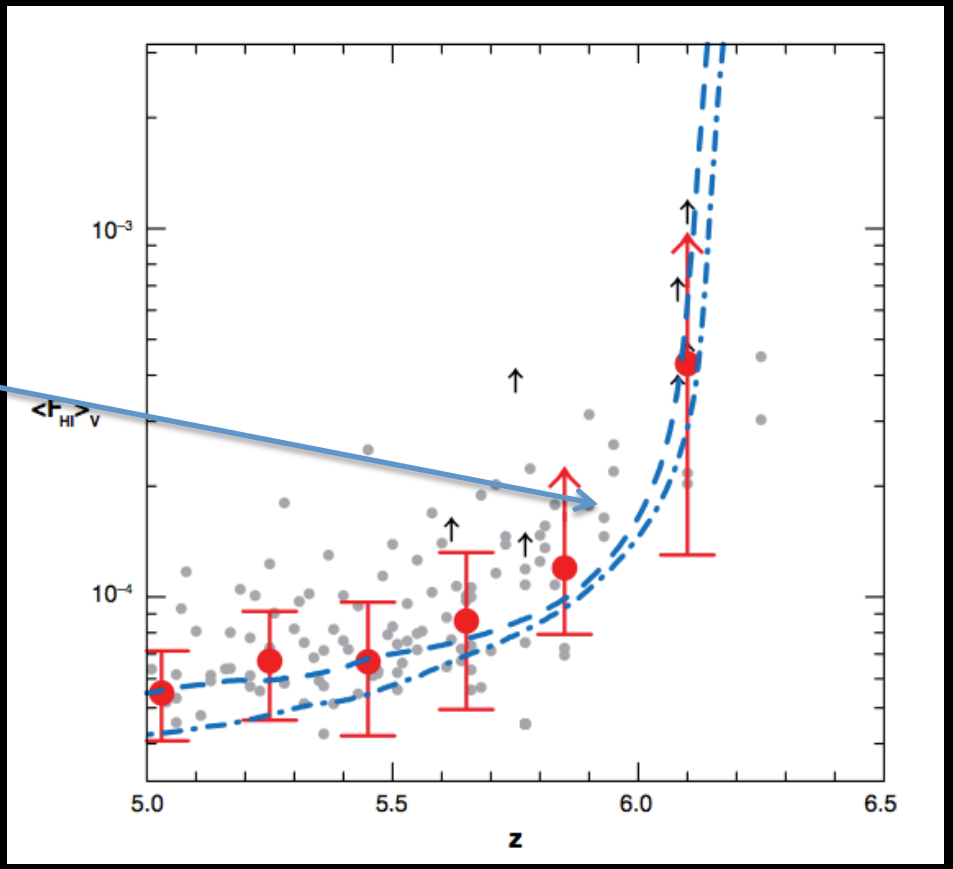
- Constraints from dark gaps?
  - Avg. length of dark gaps evolve at z>6



3. Observations of Gunn-Peterson Effect

- Deriving neutral fractions and comparing to cosmological simulation predictions

What does this knee correspond to?



4. Cosmic Stromgren Spheres

- What are cosmic Stromgren spheres?
- How can we learn about the size of Stromgren spheres from QSO spectra?