The Spectrum Analysis of a New Quasar at z=6.61

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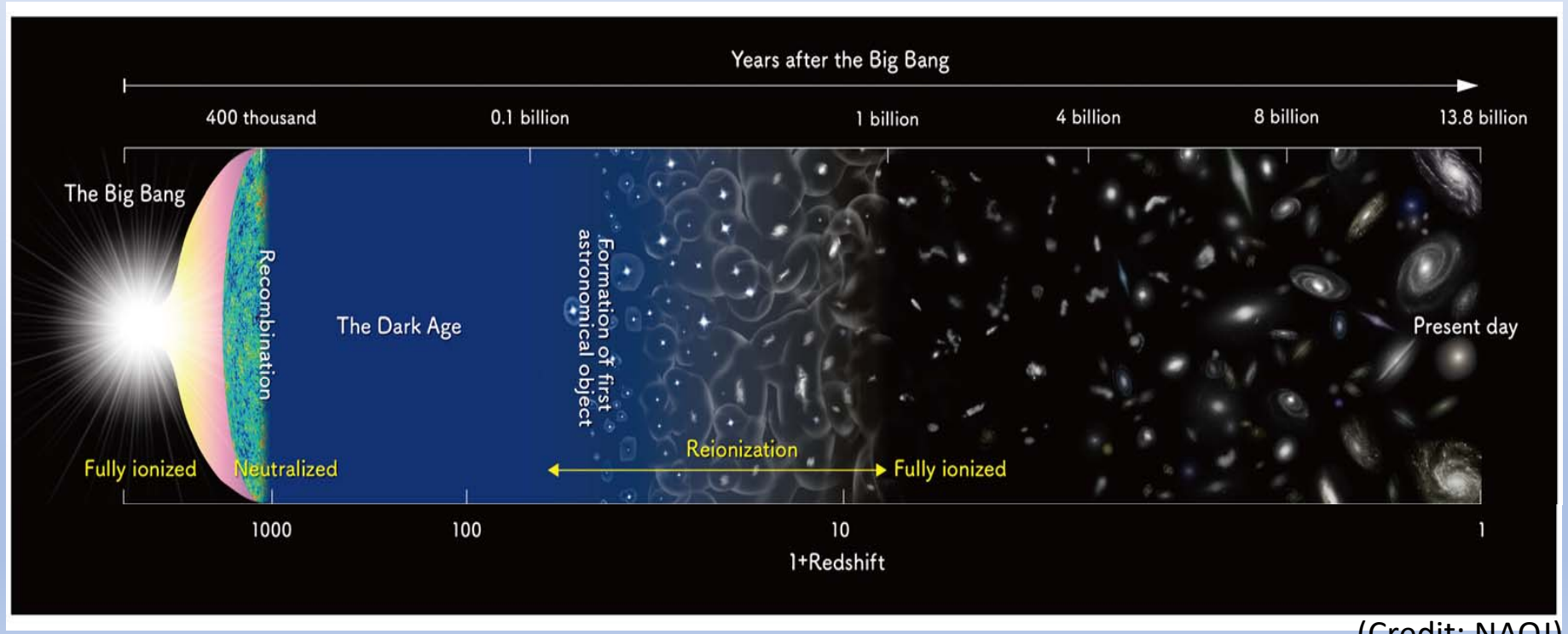
Why High Redshift (z>6) Quasars Are Important?

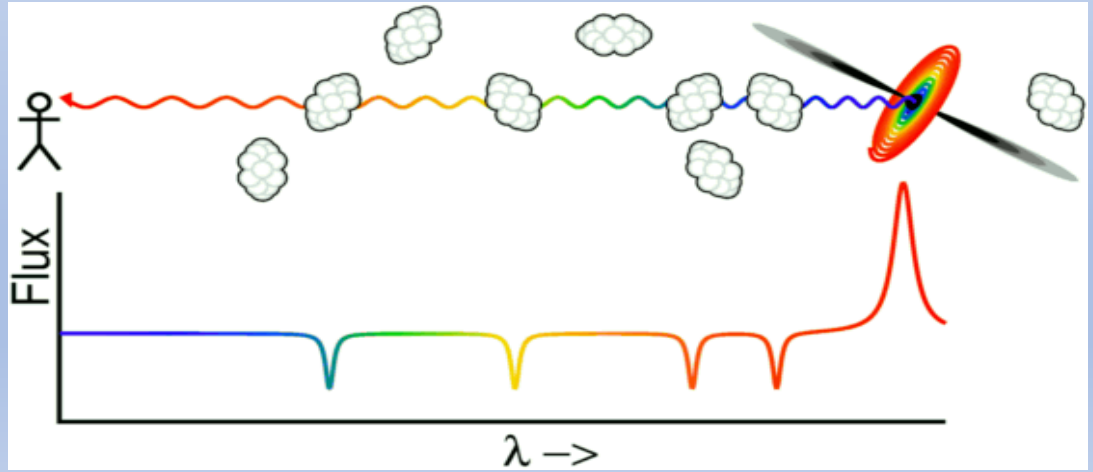
- Reionization epoch



(Credit: NAOJ)

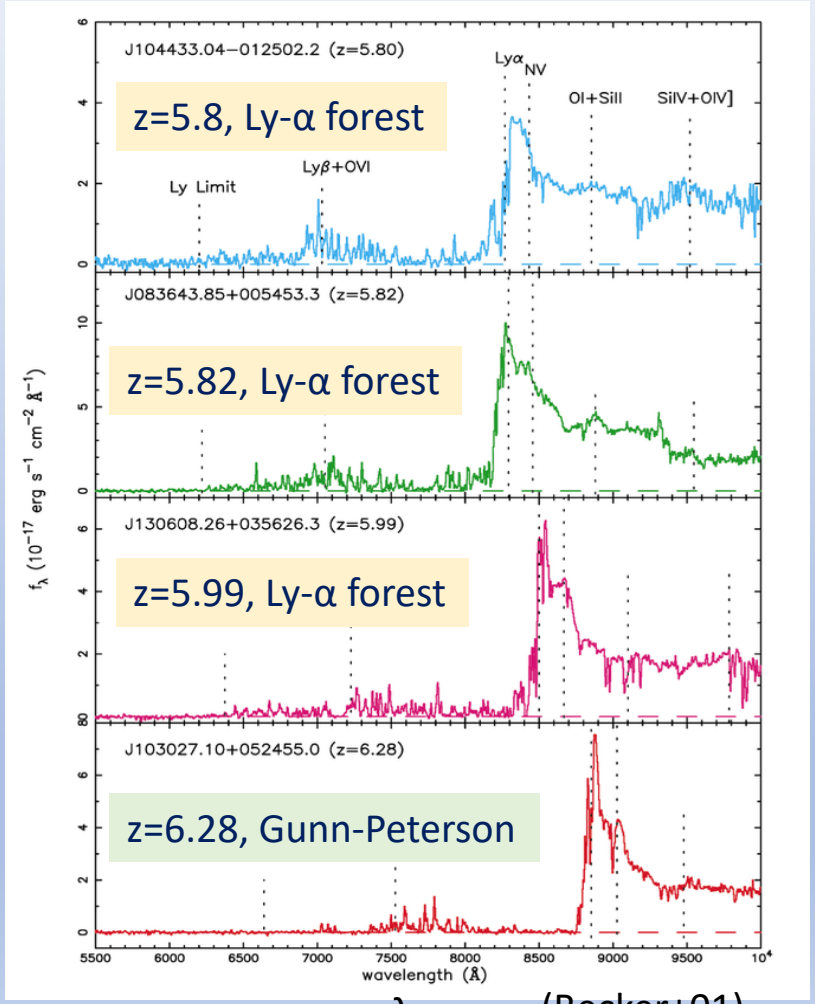
What Can the Spectrum of the High Redshift Quasar Tell Us About the Reionization Epoch?

- The information along the line of sight
- Larger scale-neutral hydrogen
  - Lyman-alpha forest or Gunn-Peterson effect
  - Neutral hydrogen fraction



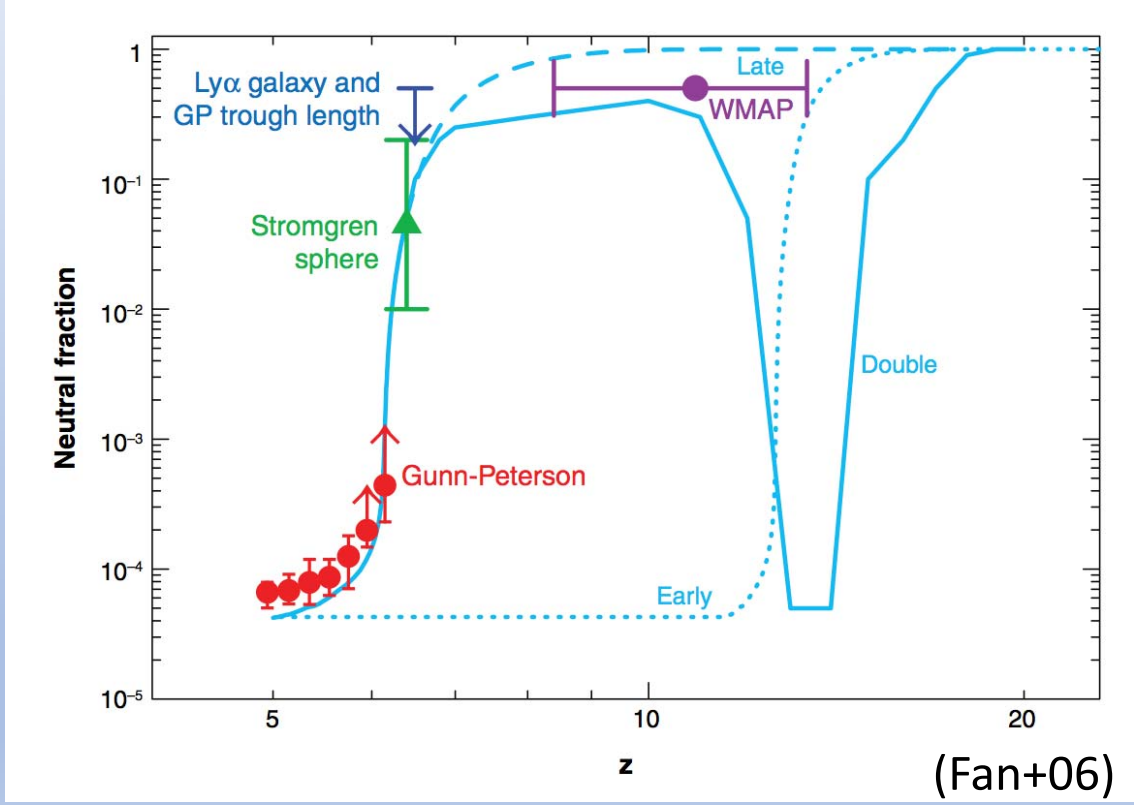
(Credit from http://www.astro.ucla.edu/~wright/Lyman-alpha-forest.html)

Reionization Epoch - Neutral Hydrogen Fraction



λ (Becker+01)

Reionization Epoch - Neutral Hydrogen Fraction



(Fan+06)

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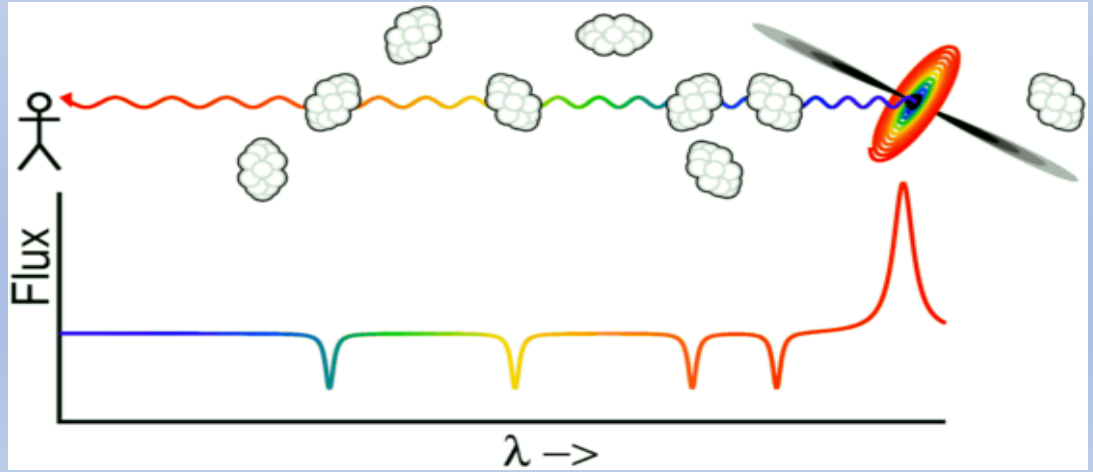

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What Can the Spectrum of the High Redshift Quasar Tell Us About the Reionization Epoch?

- The information along the line of sight
- Larger scale-neutral hydrogen
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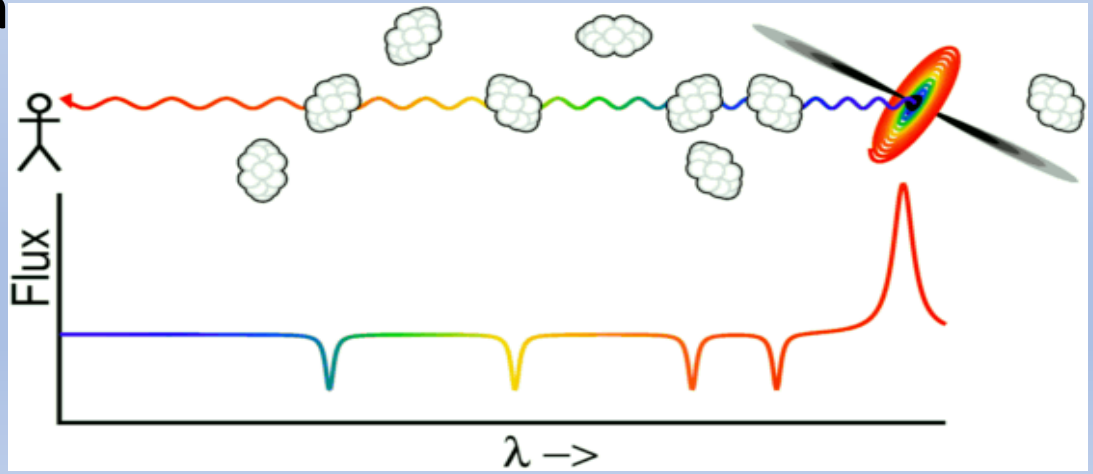
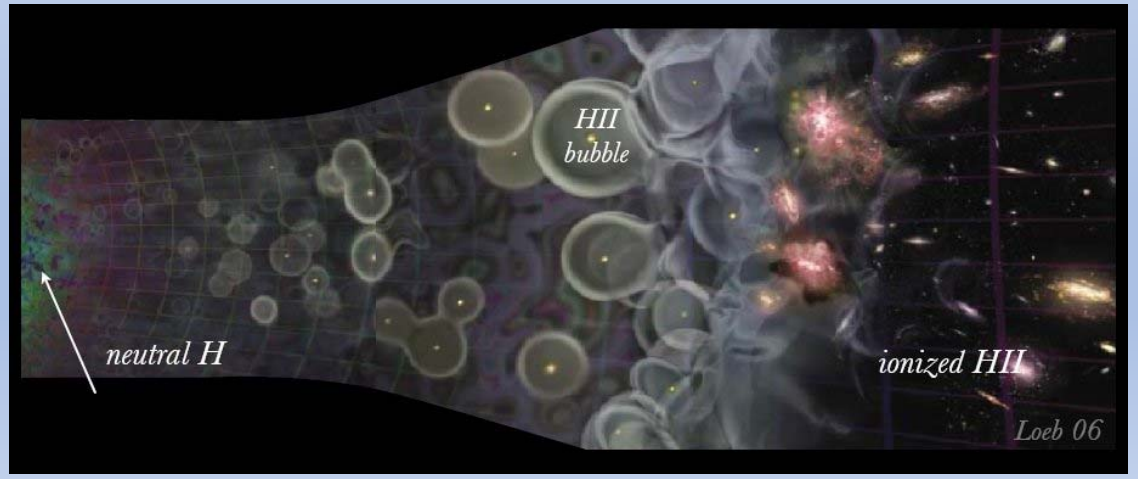
  - Neutral hydrogen fraction
- Smaller scale-ionized hydrogen
  - Near-zone region



(Credit from http://www.astro.ucla.edu/~wright/Lyman-alpha-forest.html)

Reionization Epoch - Near Zone Region

- Show how much a QSO can ionize
- Ly-α emission line emits from the quasar
- The “HII bubble” ionized by the quasar
- Transmitted through the bubble
- A few Mpc

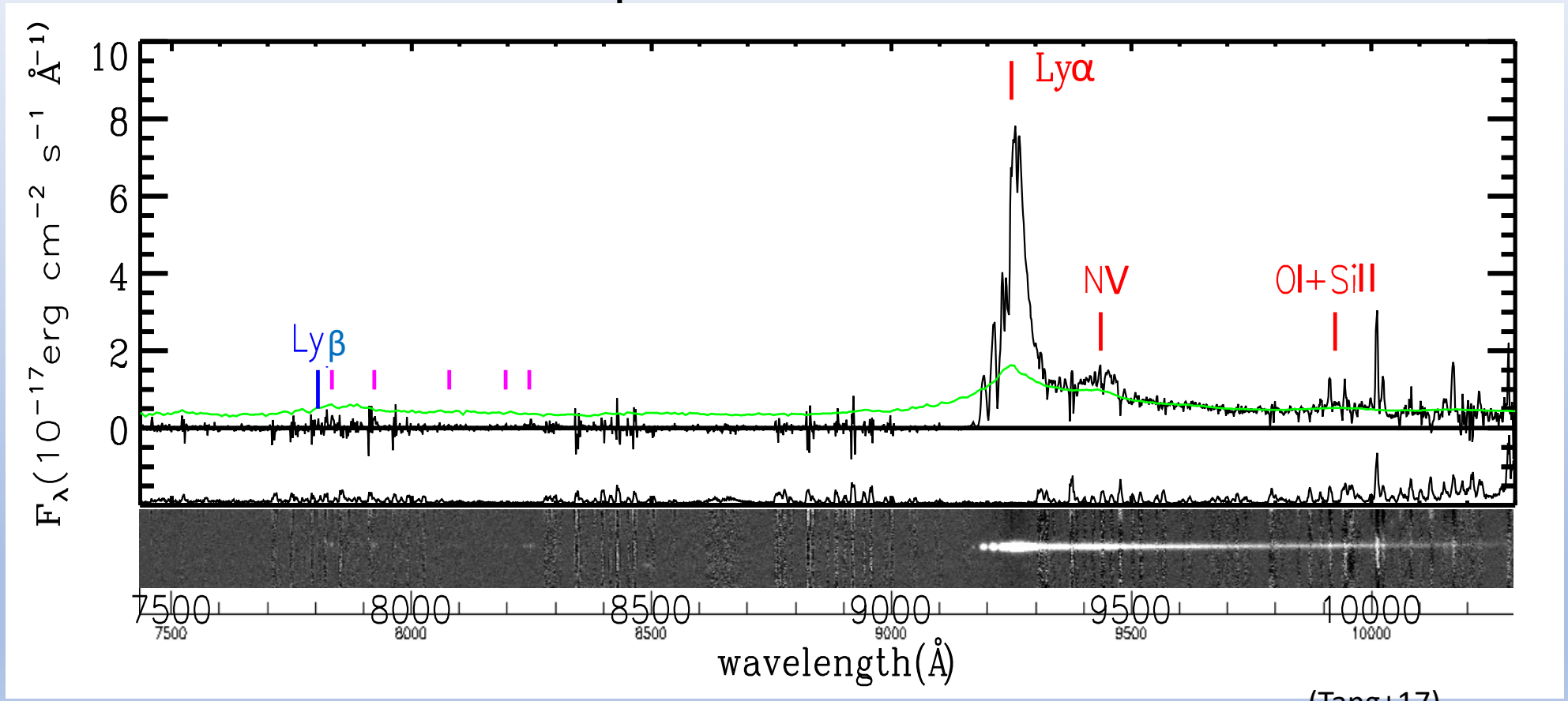


(Loeb+06)

The Quasar Discovered at z=6.61 from Pan-STARRS1

- Quasar J006+39
- Subaru-FOCAS spectroscopic observation
  - 2015.11.02, seeing~0.75”
  - Slit width:0.8”
  - Resolution~600
  - 1000sec exposure X 5 times
  - VPH900 grating, O58 order cut
  - 7434Å~10582Å with 1.48Å pixel resolution

Quasar J006+39 Spectrum



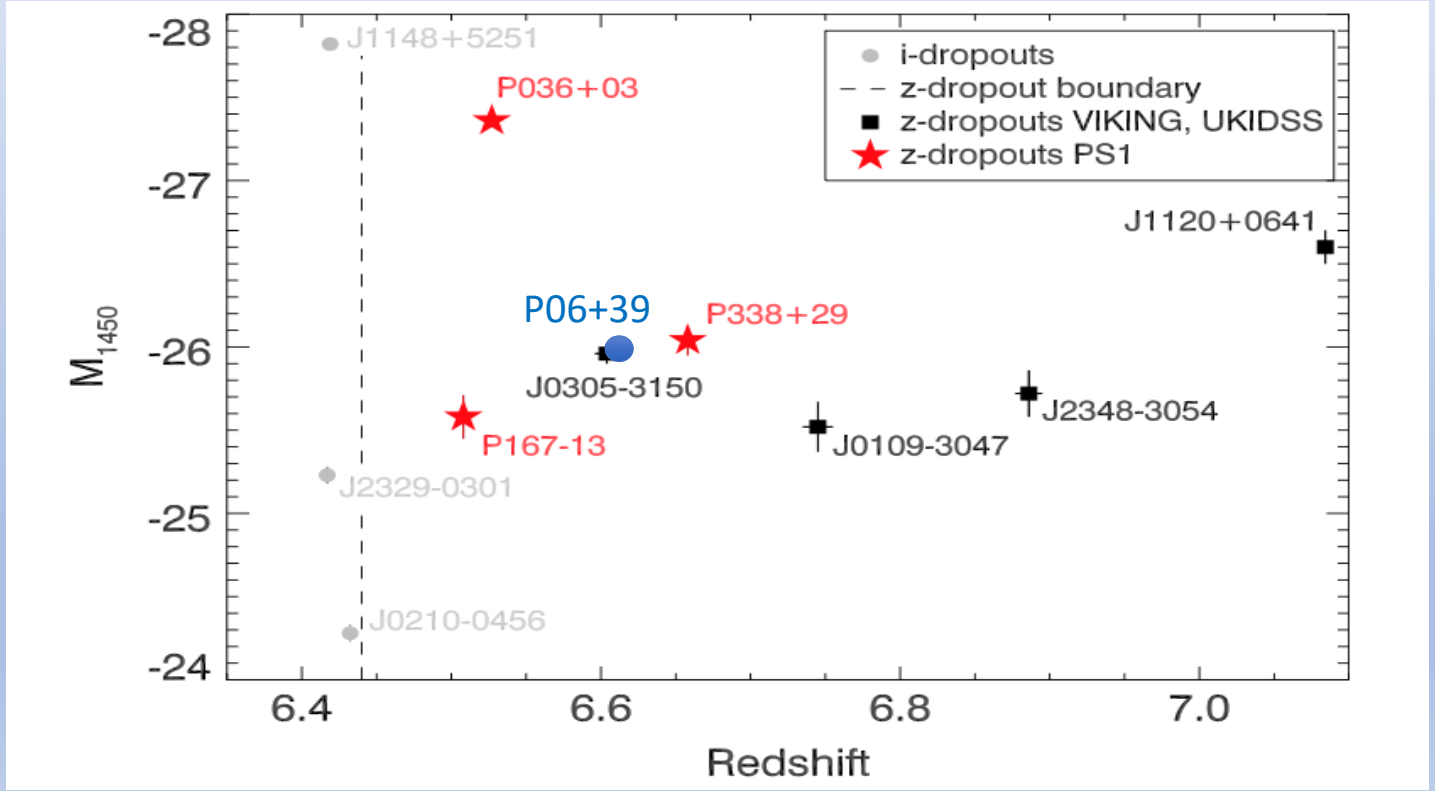
(Tang+17)

Quasar J006+39

- Redshift: 6.61 ± 0.02
- 7th farthest quasars known so far
- Number of quasars discovered above $z > 6.5$(z-dropout): nine

Quasar J006+39

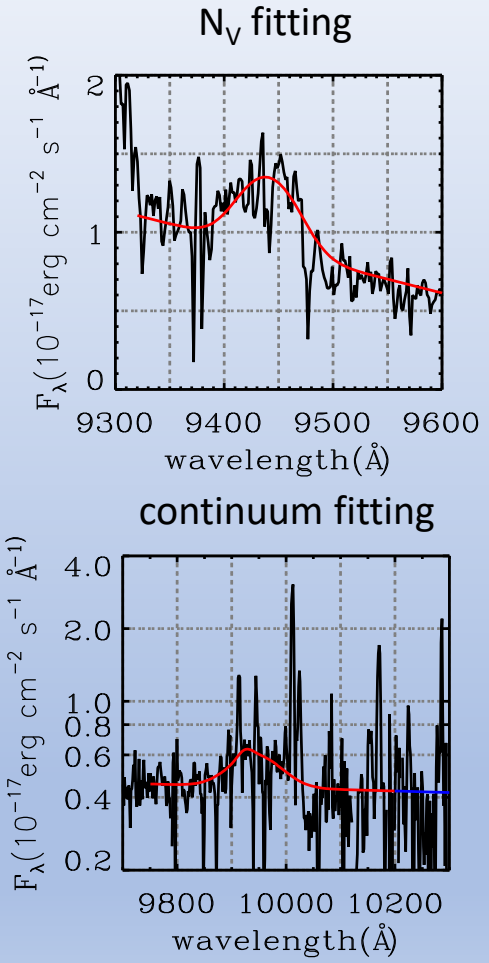
- Compare to other z-dropout Quasars



(Venemans+15)

Quasar J006+39 Fitting

- NV fitting
  - Double Gaussian + linear continuum
  - Redshift measurement
- Continuum fitting
  - Double Gaussian (OI+SiII) + power-law
  - Luminosity estimation
    - Extrapolate to redshifted 1450Å

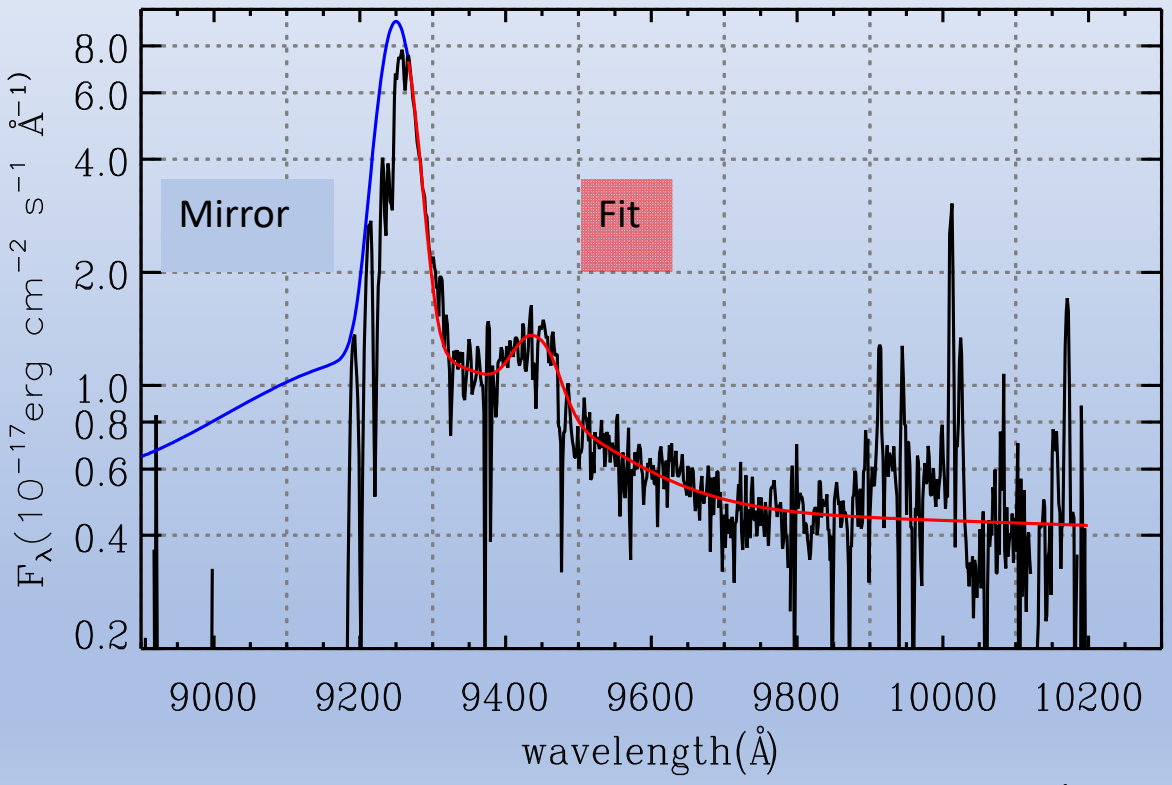


(Tang+17)

Quasar J006+39 Fitting

- Ly-alpha fitting
  - Compensate for absorption
  - Transmission measurement

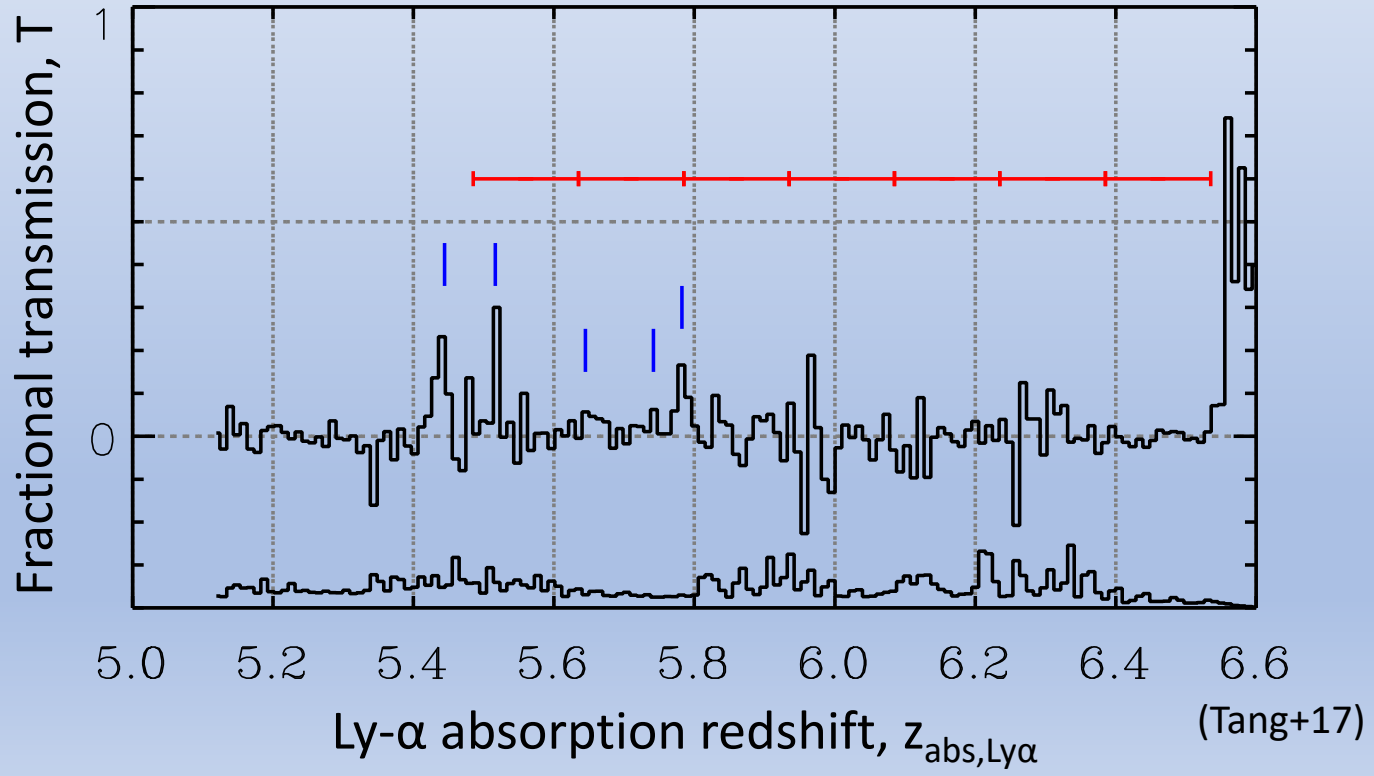
$$Transmission = \frac{Observed\ spectrum}{Fitted\ spectrum}$$



(Tang+17)

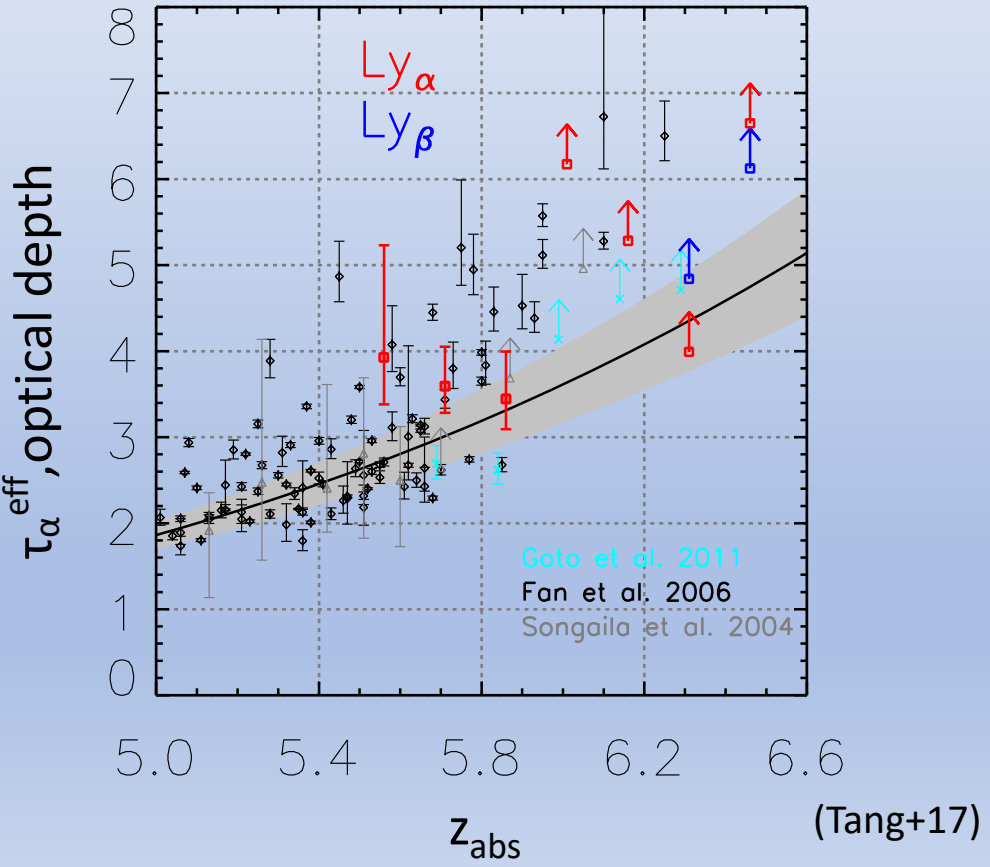
Transmission Measurement - Optical Depth

- Gunn-Peterson effective Optical Depth



Transmission Measurement - Optical Depth

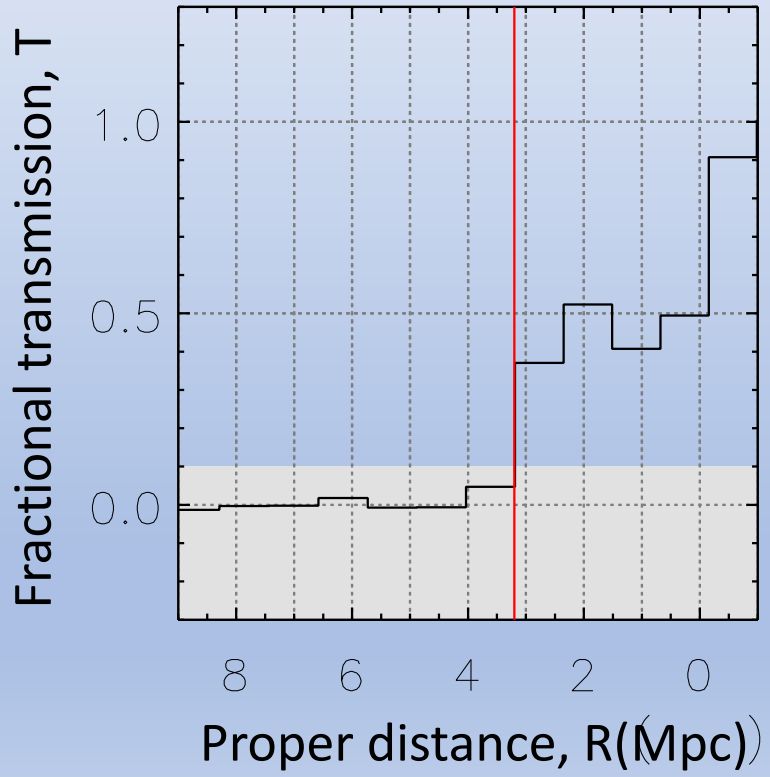
- Compare to previous optical depth measurement
  - Ly-α
  - Ly-β



(Tang+17)

Transmission Measurement - Near Zone Region

- Near zone region:
  - $R_{p,NZ} = 3.2 \pm 1.1$Mpc
- Corrected near zone region:
  - $R_{NZ,corr} = 4.3 \pm 1.5$Mpc
  - corrected for luminosity



(Tang+17)

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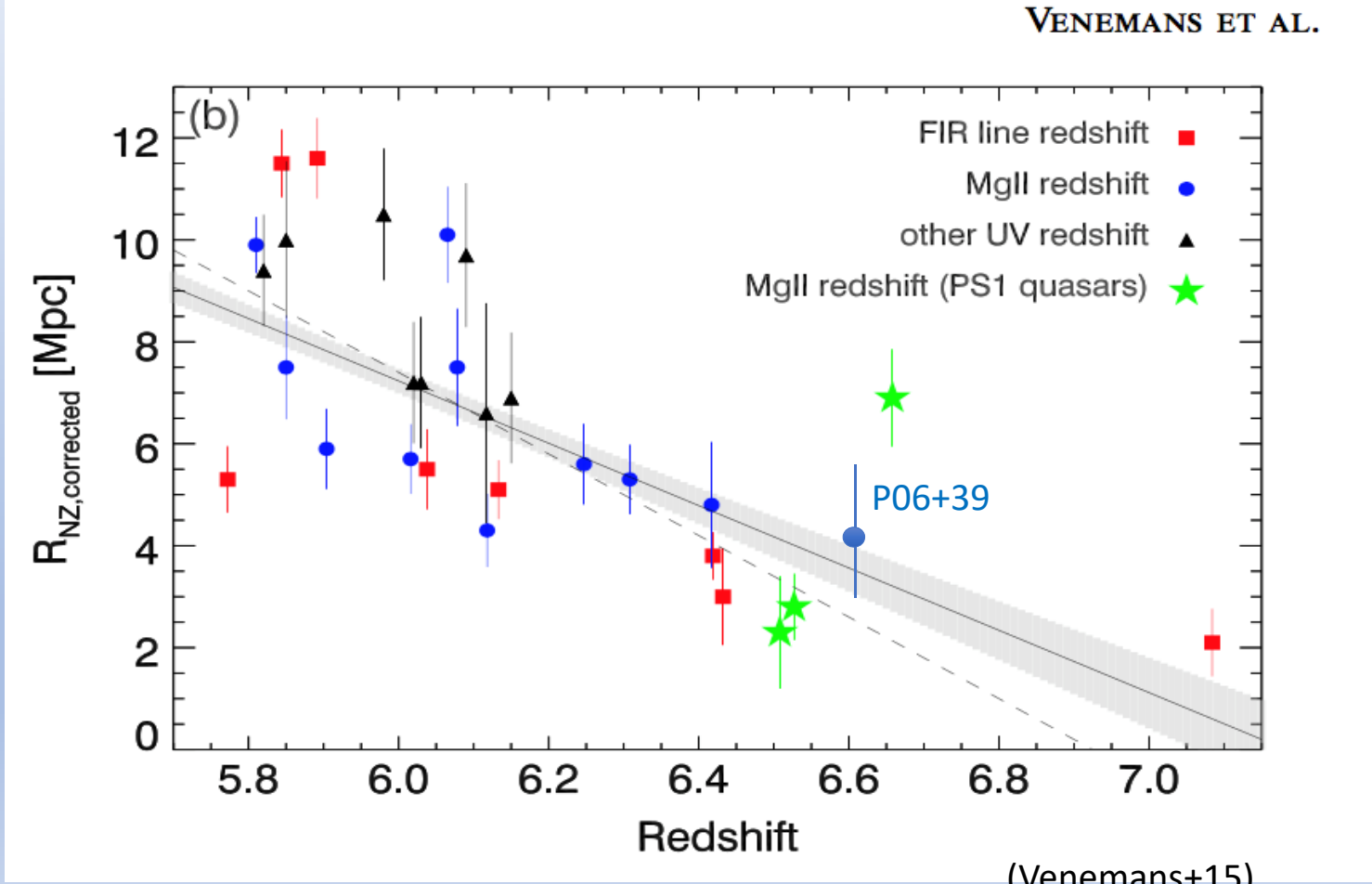

(Venemans+15)

Summary

- Found a QSO at Redshift 6.61 (7^{th} farthest quasars known so far)
- Gunn-Peterson optical depth measurement provides more data of neutral hydrogen fraction at high-z universe
- Near-zone region follows the trend: Ionization ability is similar to other high-z quasars

Transmission Measurement - Near Zone Region

- Near-zone Region
  - Transmission $T < 0.1$ (z_{GP})
  - $R_{p,NZ} = \left(D_Q - D_{GP}\right) / \left(1 + z_Q\right)$
  - The D_{Q} and D_{GP} are the comoving distances of the redshift of the quasar host galaxy (z_Q) and the redshift where the transmission drops below 0.1 (z_{GP}), respectively.
  - 3.2 ± 1.1Mpc
- Corrected Near-zone region
  - Consider Luminosity
  - $R_{NZ,corr} = 10^{0.4\times\left(27+M_{1450,AB}\right)/3} R_{NZ}$
  - 4.3 ± 1.5Mpc

Transmission Measurement - Optical Depth

- Convert Transmission into effective optical depth: $\tau_{eff} = -ln(T)$
- Ly-alpha optical depth (τα)
  - $5.56 < z < 6.46$ (Avoid Ly-alpha & beta emission)
- Ly-beta optical depth (τβ)
  - Estimate Ly-alpha absorption:
    - $\tau\alpha = (0.85 \pm 0.06) \times \left(\frac{1+z}{5}\right)^{(4.3\pm0.3)}$ from (Fan+06)
  - below 1017 Å (Avoid Ly-beta emission)
- $\tau_\alpha / \tau_\beta = 2.25$