(HI) Reionisation at z=7.1 from ULASJ1120+0641?

Bradley Greig

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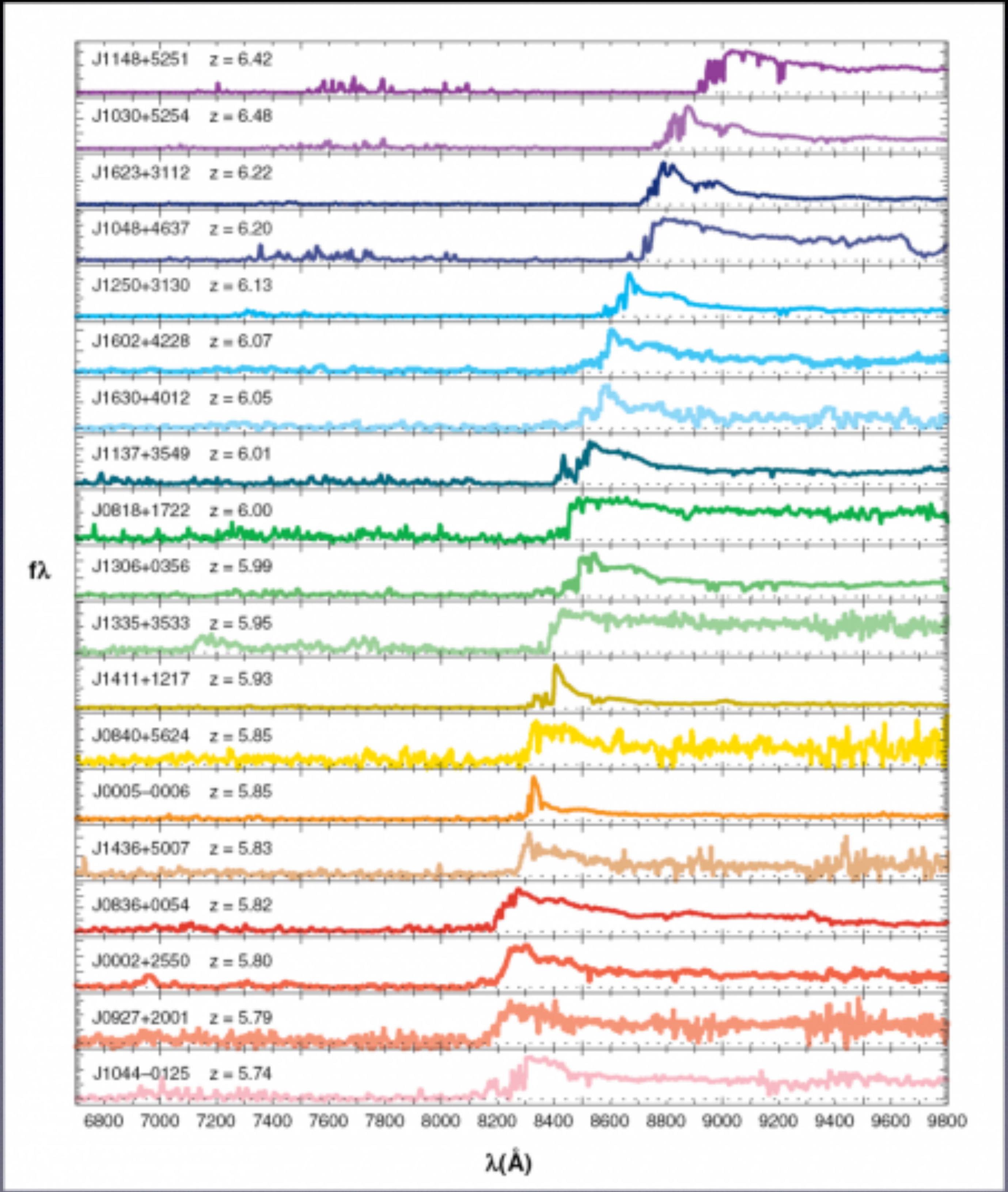
Illuminating the Dark Ages, Heidelberg, June 28th

European Research Council

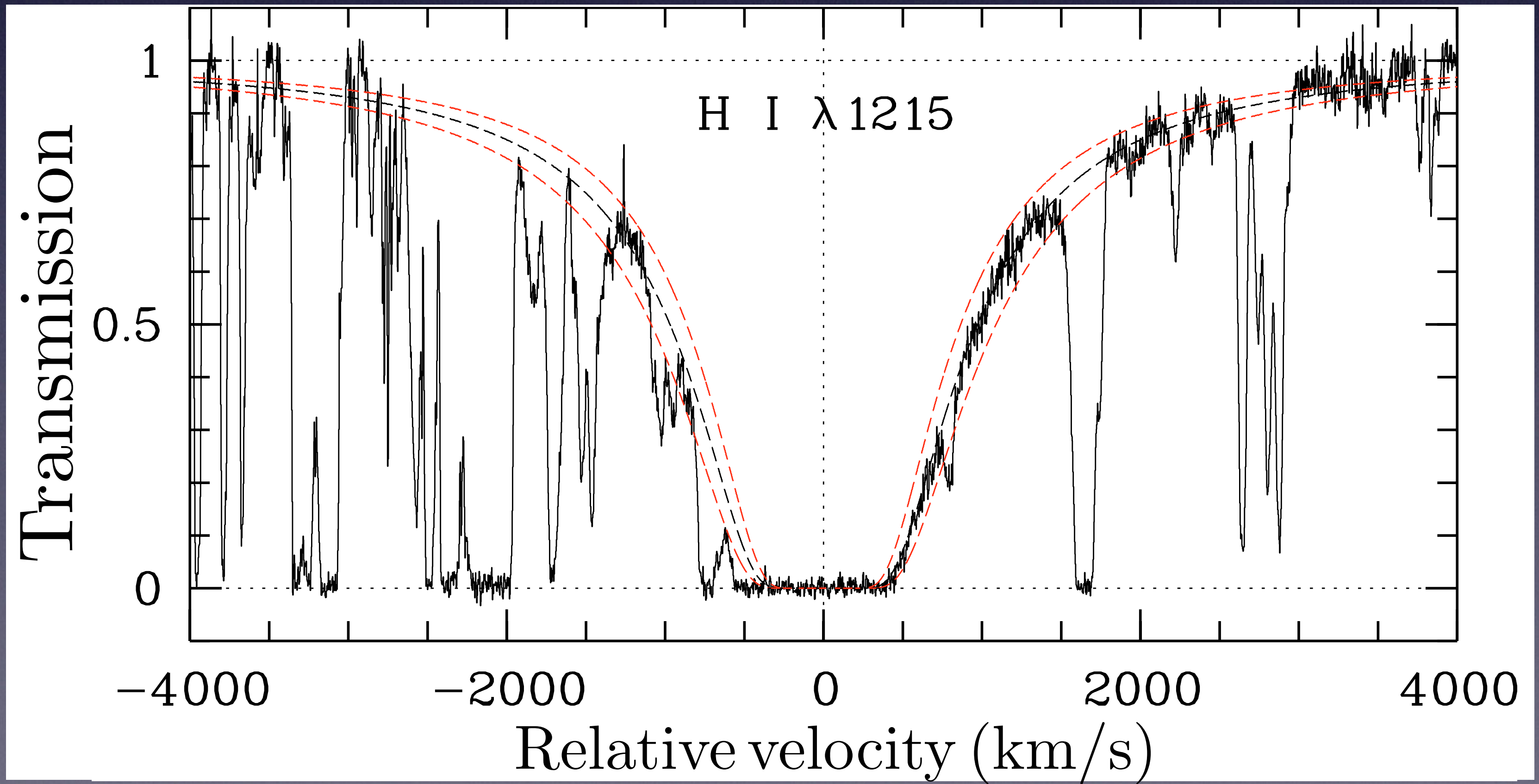
Evidence for reionisation



Fan et al., 2006

Saturated Lyα absorption

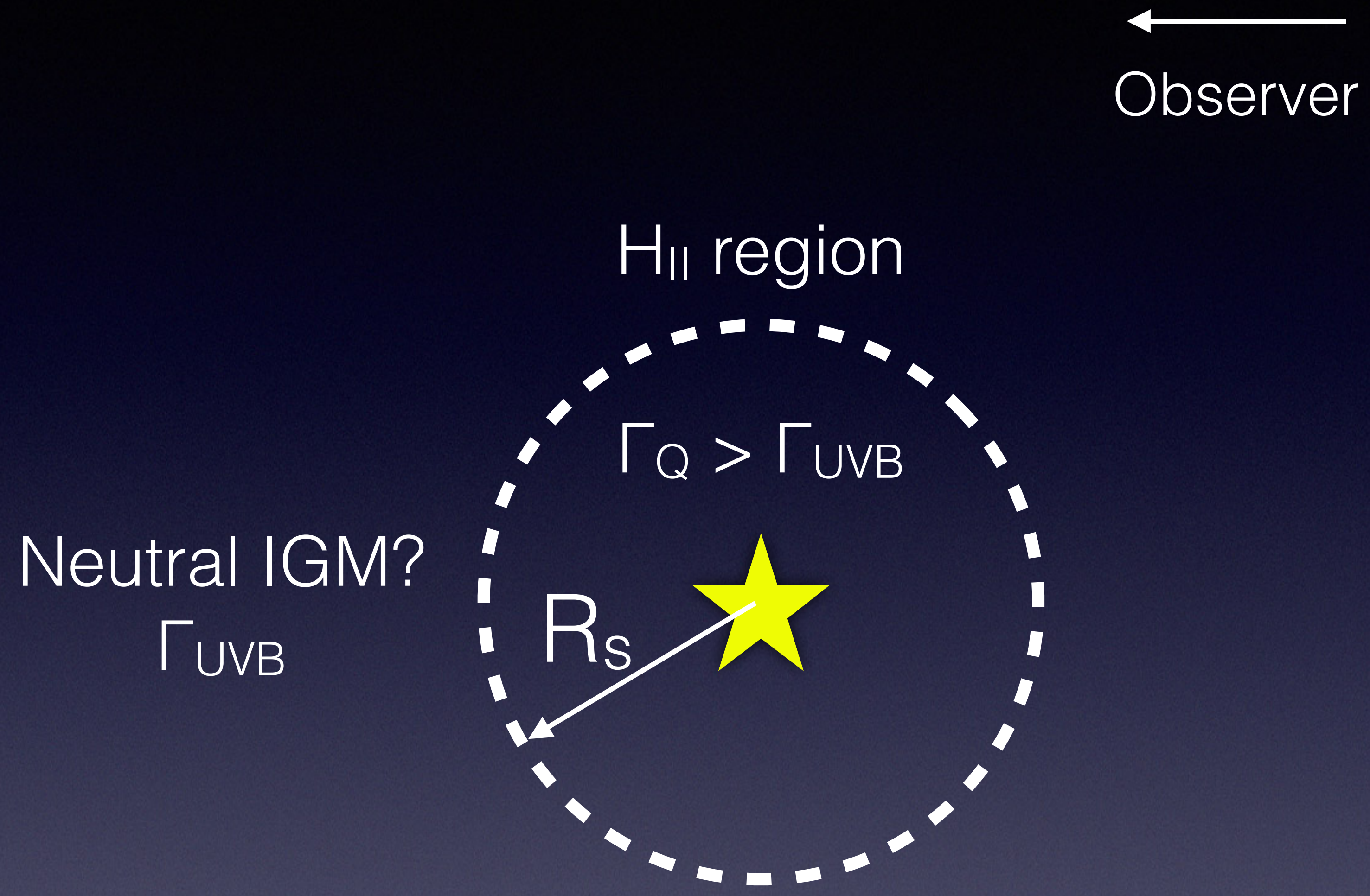
- Absorption profiles are Lorentzian not Gaussian
- High column densities allow significant absorption in the "wings"
- Absorption wings are sensitive to neutral fractions of ~1
- Adds a "smooth" component to Lyα absorption
- Produced by DLAs or the neutral IGM itself



Noterdaeme et al. 2007

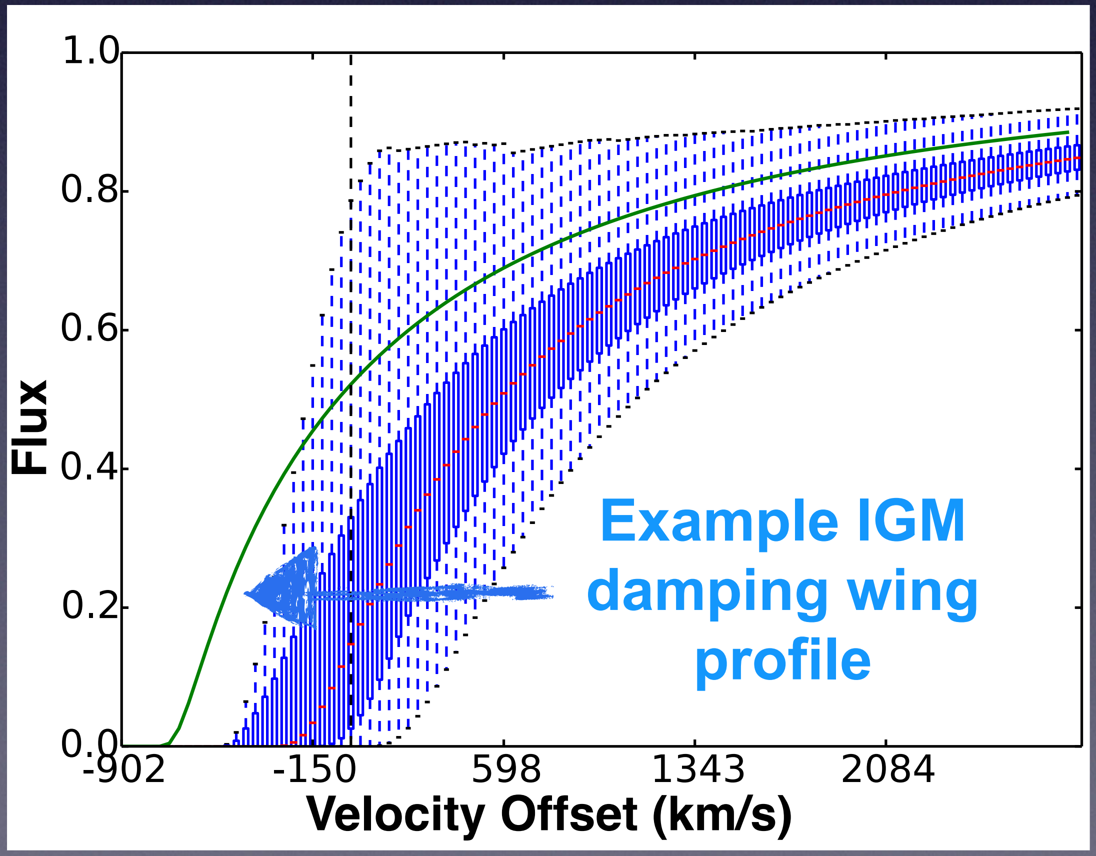
QSO proximity zone

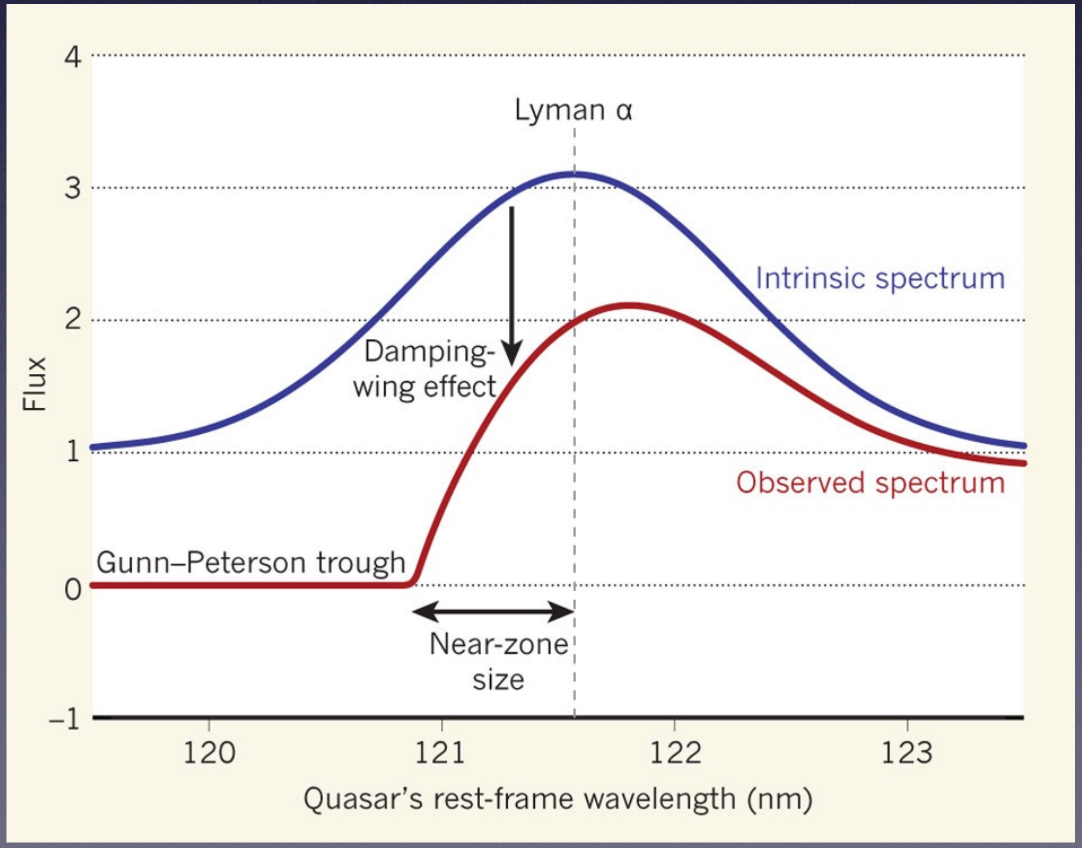
- R_s dependent on intrinsic QSO luminosity and lifetime
- Typically 5-6 proper Mpc
- Proximity zone alone does not probe IGM neutral fraction
- Search for the “smooth” imprint of the IGM neutral fraction within the QSO proximity zone



Impact of the IGM damping wing

- Produces a smooth component on top of the fluctuating Lyα forest
- Significantly affects the size/shape of the observed Lyα line profile
- Requires a method to extract the intrinsic QSO luminosity and profile shape

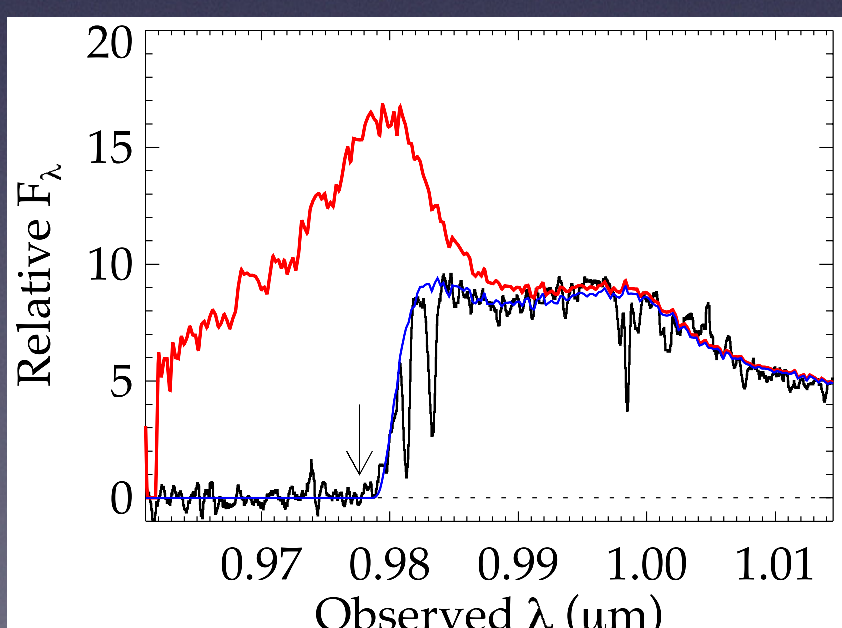




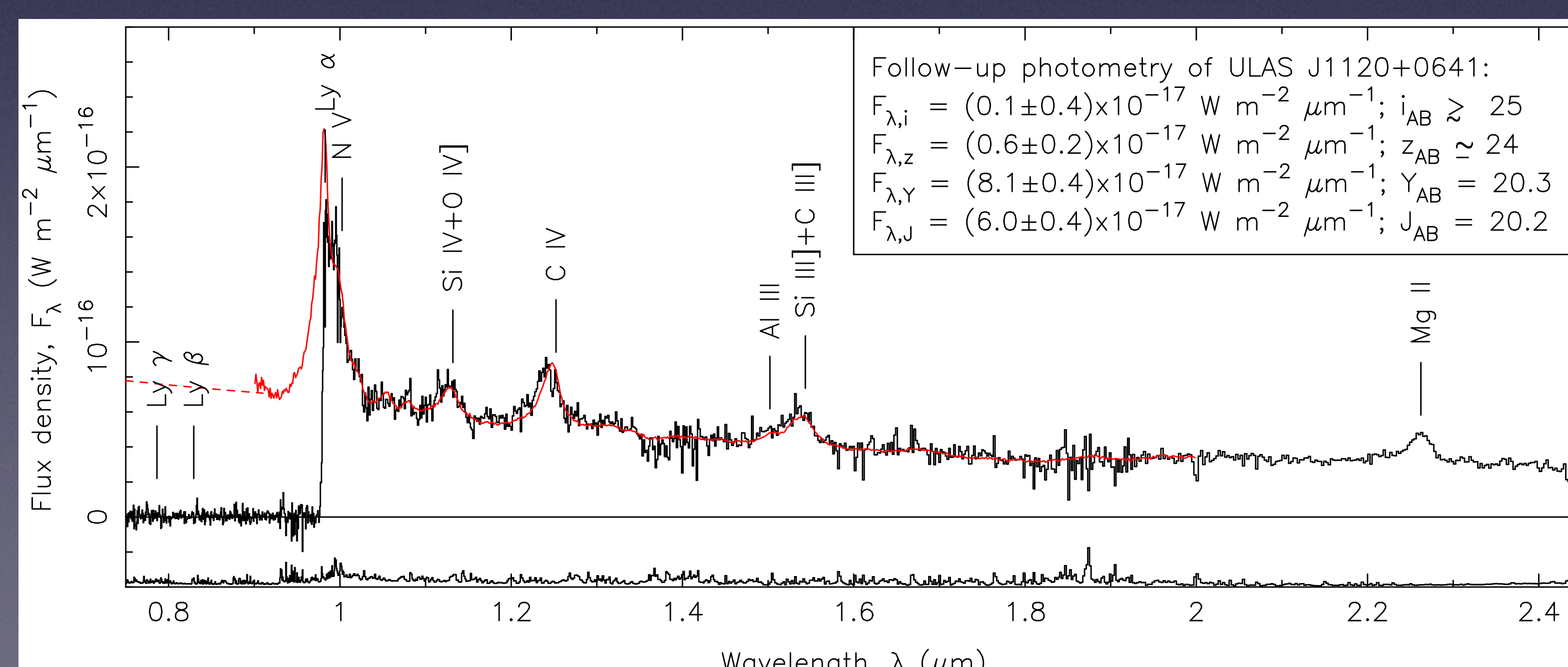
Willott 2011

ULAS J1120+0641

- Highest redshift QSO to date (z = 7.0842; Mortlock et al., 2011, Venemans et al. 2012)
- Luminous (bright), with smaller than expected proximity zone (~2 pMpc)
- Could be due to short QSO lifetime, nearby DLA or incomplete reionisation (Mortlock et al., Bolton et al., 2011, Keating et al., 2015)
- Short proximity zone complicates the detection of a full damping wing imprint
- The damping wing could extend sufficiently redward of Lyα hindering existing approaches to estimate the intrinsic QSO profile

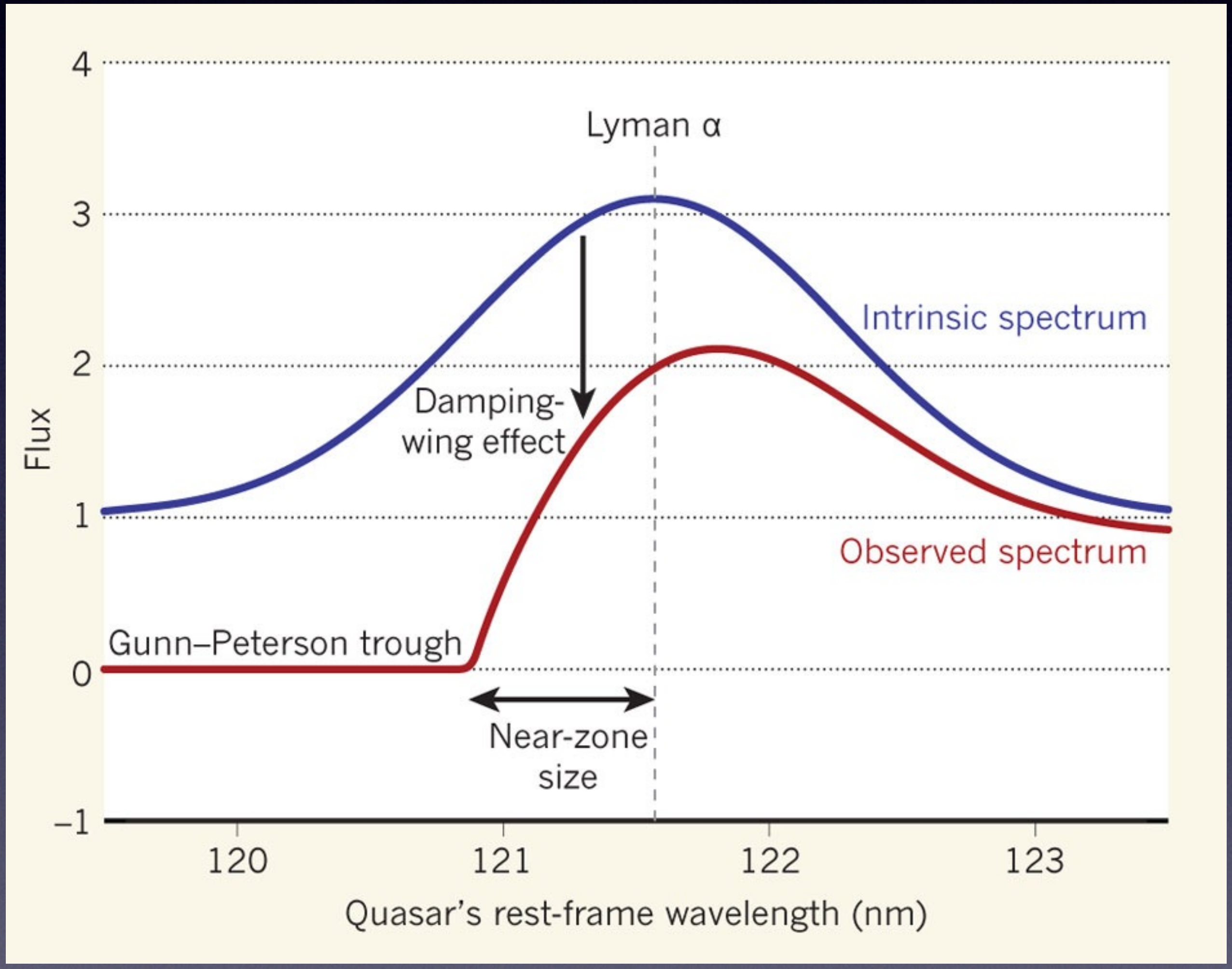


Simcoe et al. 2012



Mortlock et al. 2011

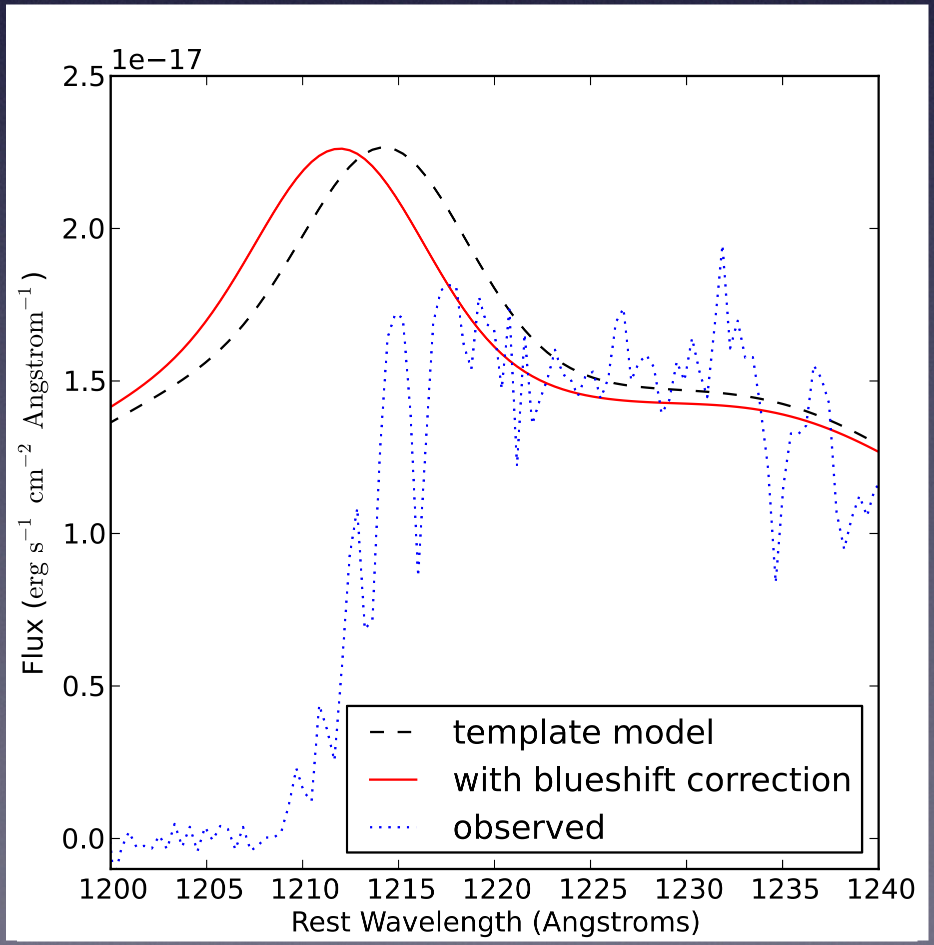
Impact of the IGM damping wing



Willott 2011

Further complications for ULAS J1120+0641

- Shows extremely large blueshifts for high ionisation lines (e.g. CIV and CIII])
- An observed correlation exists between the Lyα and CIV peak blueshift
- Various treatments of the blueshift can alter the analysis of ULAS J1120+0641 (e.g. Mortlock et al., Bolton et al., 2011, Bosman & Becker, 2015)



Method: The idea

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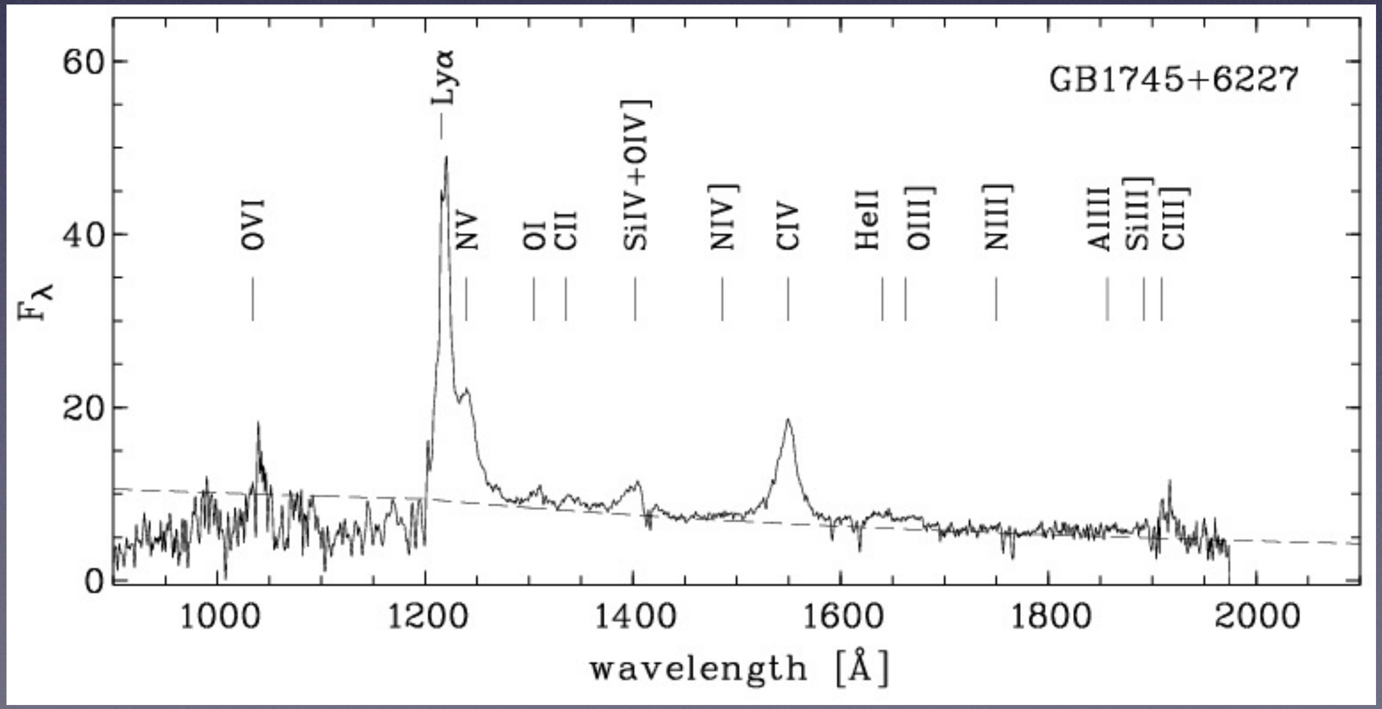
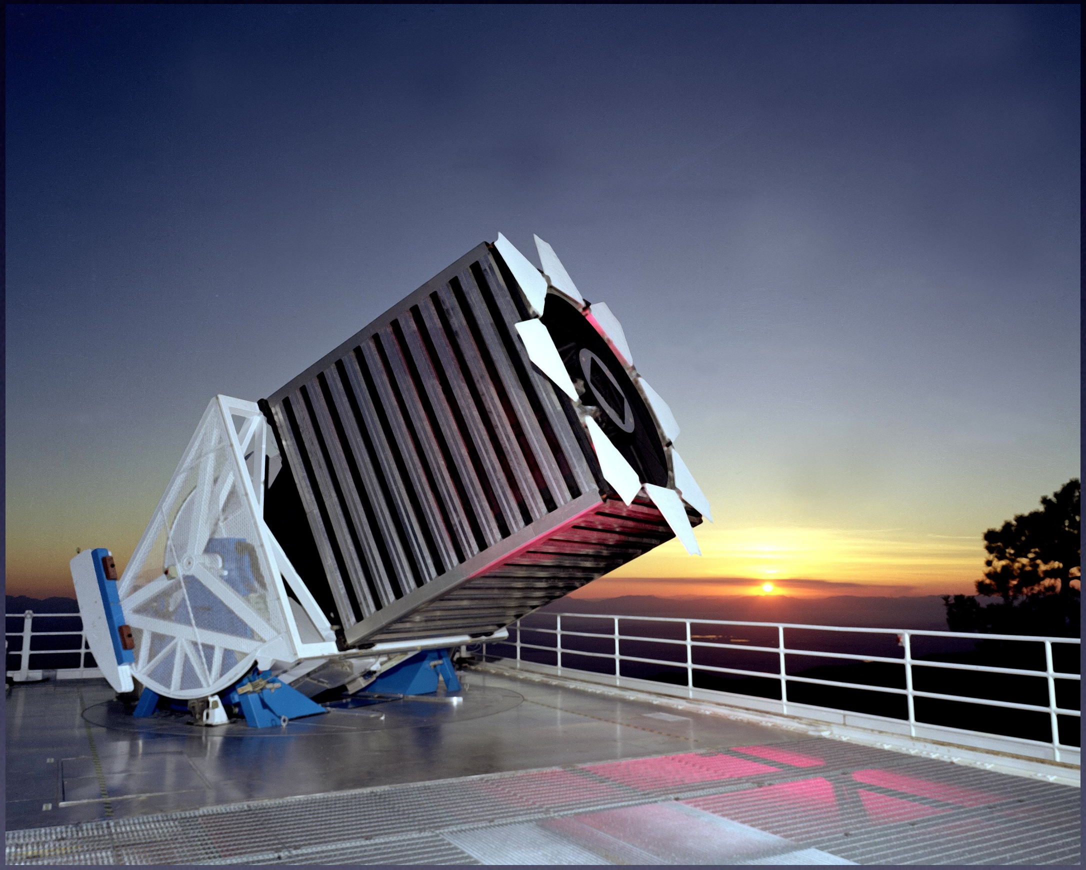
- Can the intrinsic Lyα profile be reconstructed from (strong) correlations between Lyα and other strong emission lines?
- Construct a moderate z, high S/N sample of QSOs, building a database of strong QSO emission lines
- Construct a covariance matrix characterising all correlations
- Reconstruct the intrinsic Lyα emission profile from a redward fit (λ > 1275 Å) to the QSO spectrum and the covariance matrix



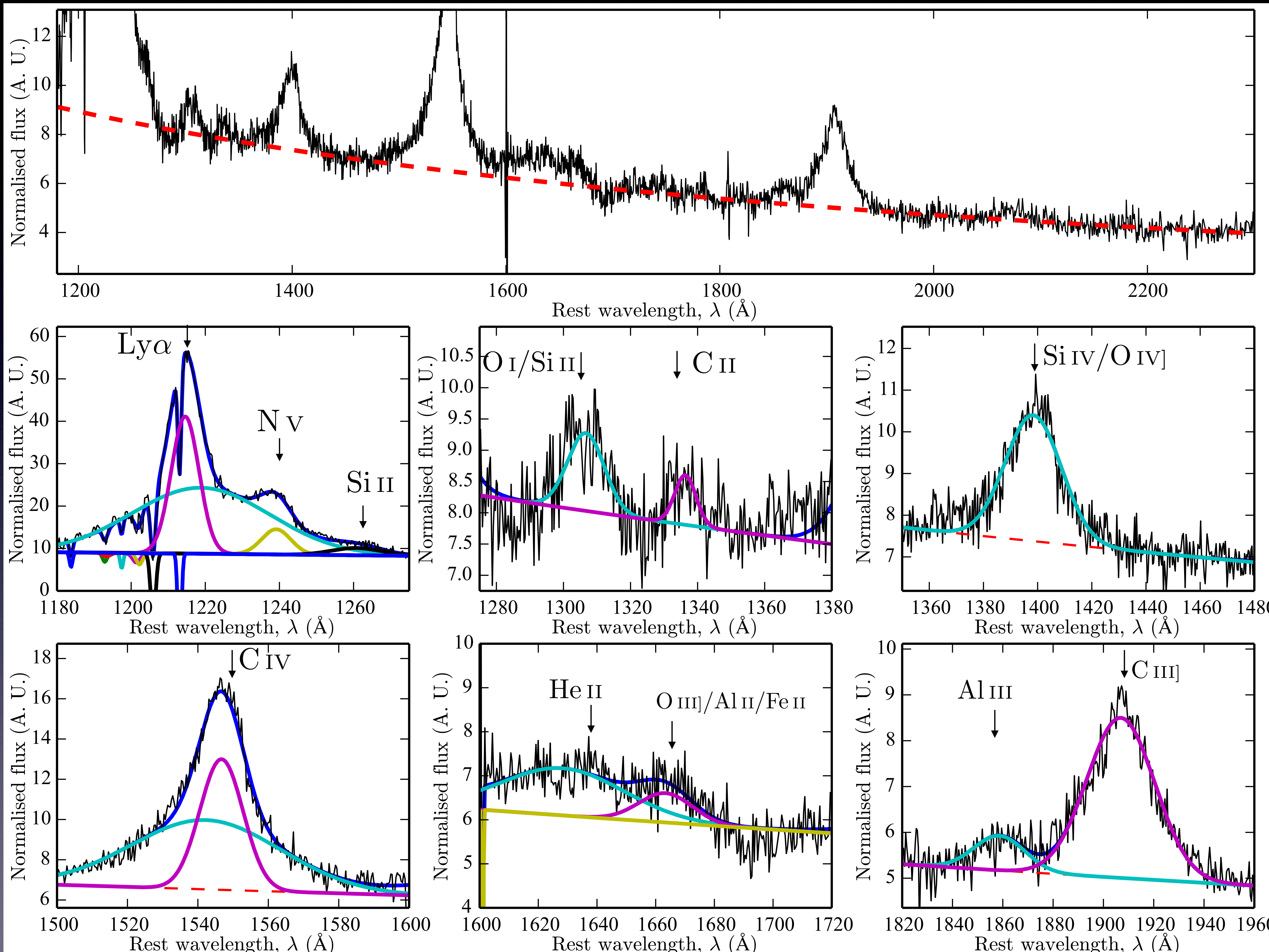
Data sample

- QSOs from publicly available SDSS DR12 (BOSS)
- QSO selection:
  - S/N > 15
  - 2 < z < 2.5
  - Remove BALs
- Total sample ~ 3926 QSOs
- Perform a by-eye quality assessment on QSOs
  - Obtain a high-quality subsample of 1673 QSOs
  - Remove contaminants (non QSOs), unflagged BALs, strong absorption, bad continuum, missing chunks of spectrum etc.



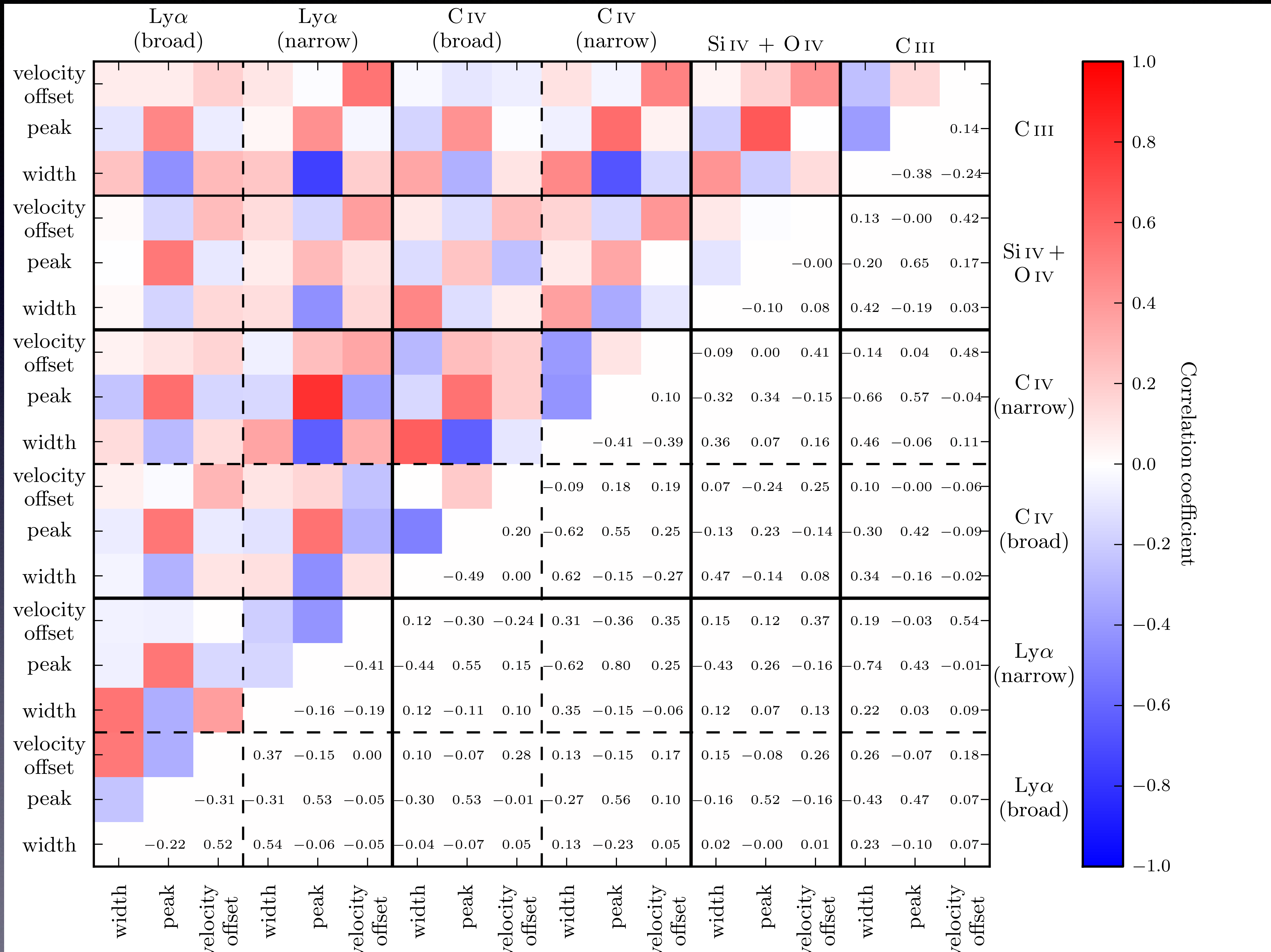
QSO fitting

- Fit a single continuum component (amplitude and spectral index)
- Fit a series of known emission lines assuming each is a Gaussian
- Each Gaussian defined by three parameters (peak amplitude, width and velocity offset)
- Model strong lines as the sum of two Gaussians profiles (broad and narrow)
- Improve QSO template by fitting a variable number of `absorption features’
- Perform a MCMC maximum likelihood fit (CosmoHammer; Akeret et al. 2012)



Greig et al., (arXiv: 1605.09388)

The Correlation Matrix



Bradley Greig (SNS), Illuminating the Dark Ages, Heidelberg, June 28th

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Reconstructing the intrinsic Lyα emission profile

- Construct a N-dimensional likelihood function (normal distribution)

$$\mathcal{L} = \frac{1}{(2\pi)^{N/2}|\boldsymbol{\Sigma}|}\exp\left(-\frac{1}{2}(\boldsymbol{x}-\boldsymbol{\mu})^{\mathsf{T}}\boldsymbol{\Sigma}^{-1}(\boldsymbol{x}-\boldsymbol{\mu})\right)$$

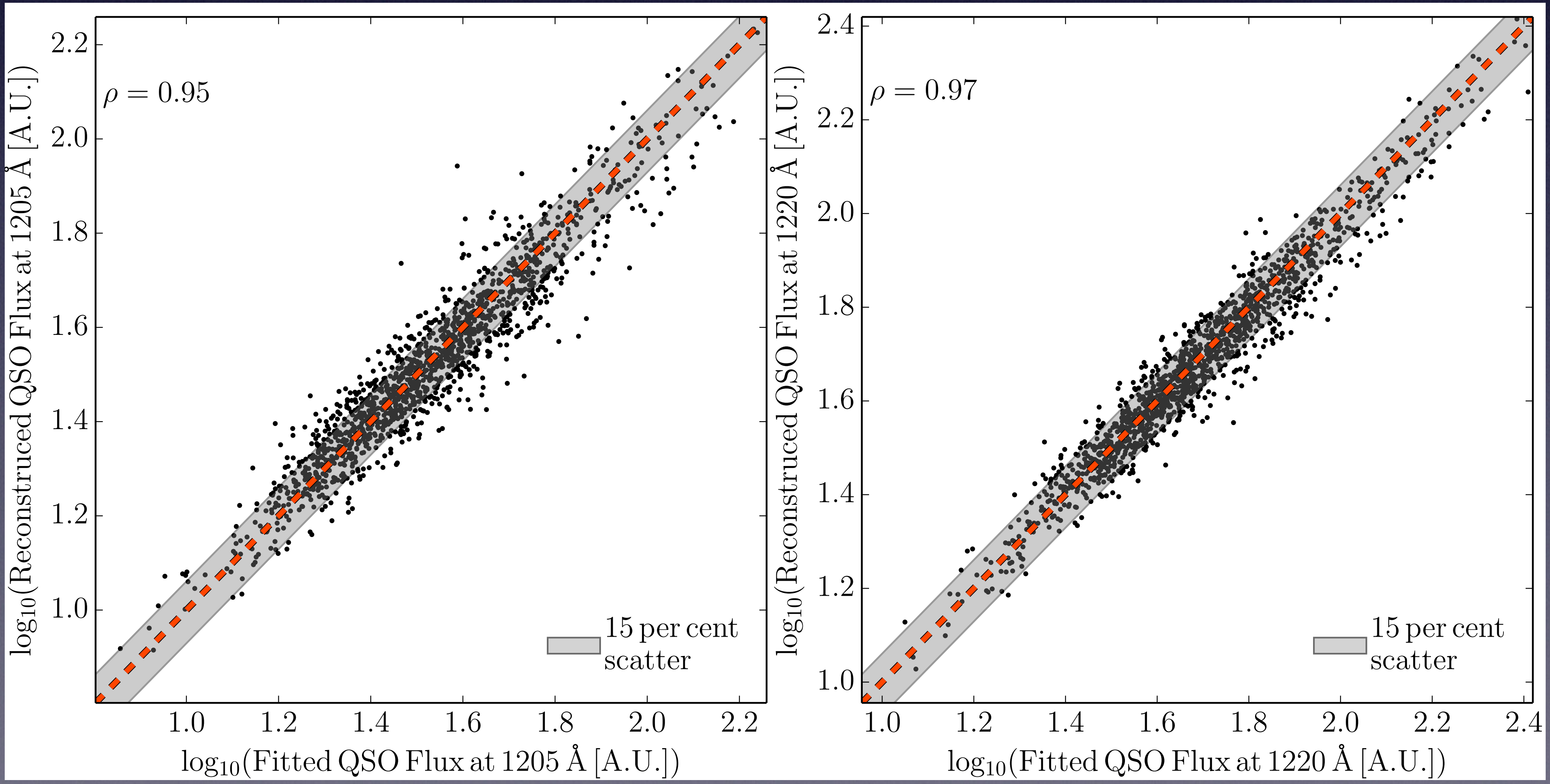
- Reconstruct Lyα by creating an 18 dimensional model
  - 6 Lyα parameters (double component)
  - 3 strong emission lines (CIV double component, Si IV+O IV and CIII single component: 4x3 = 12 parameters)

- Obtain a 6x6 covariance matrix for Lyα (marginalising over all other remaining parameters)

Performance of Reconstruction Method

- Compare the reconstructed QSO flux against the observed QSO flux
- Find the reconstructed flux to be within 15% of the original flux in 85% (90%) of the QSOs in our sample at 1205Å (1220Å)

Blueward of Lyα (1205Å) Redward of Lyα (1220Å)



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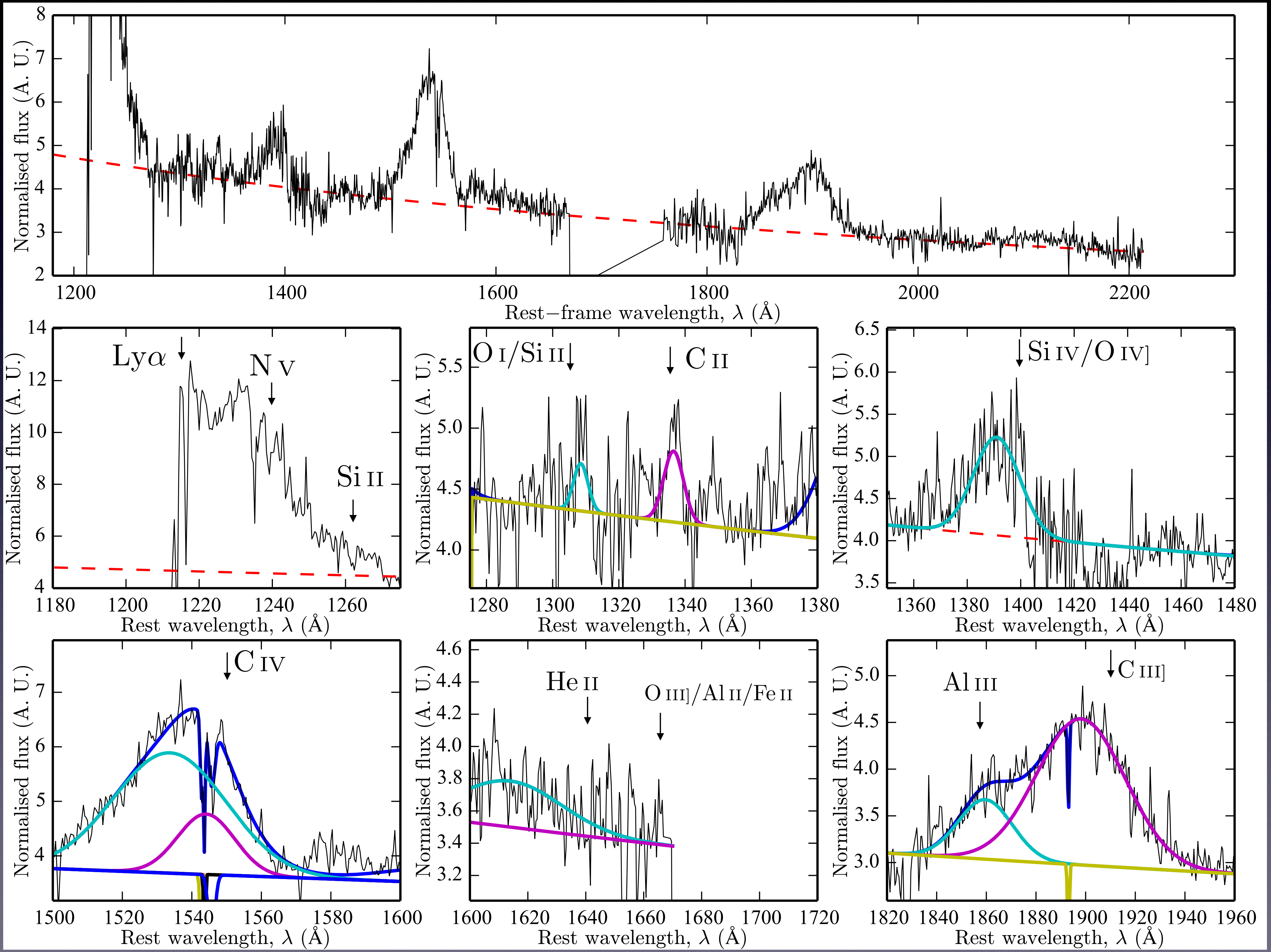
Returning to ULAS J1120+0641

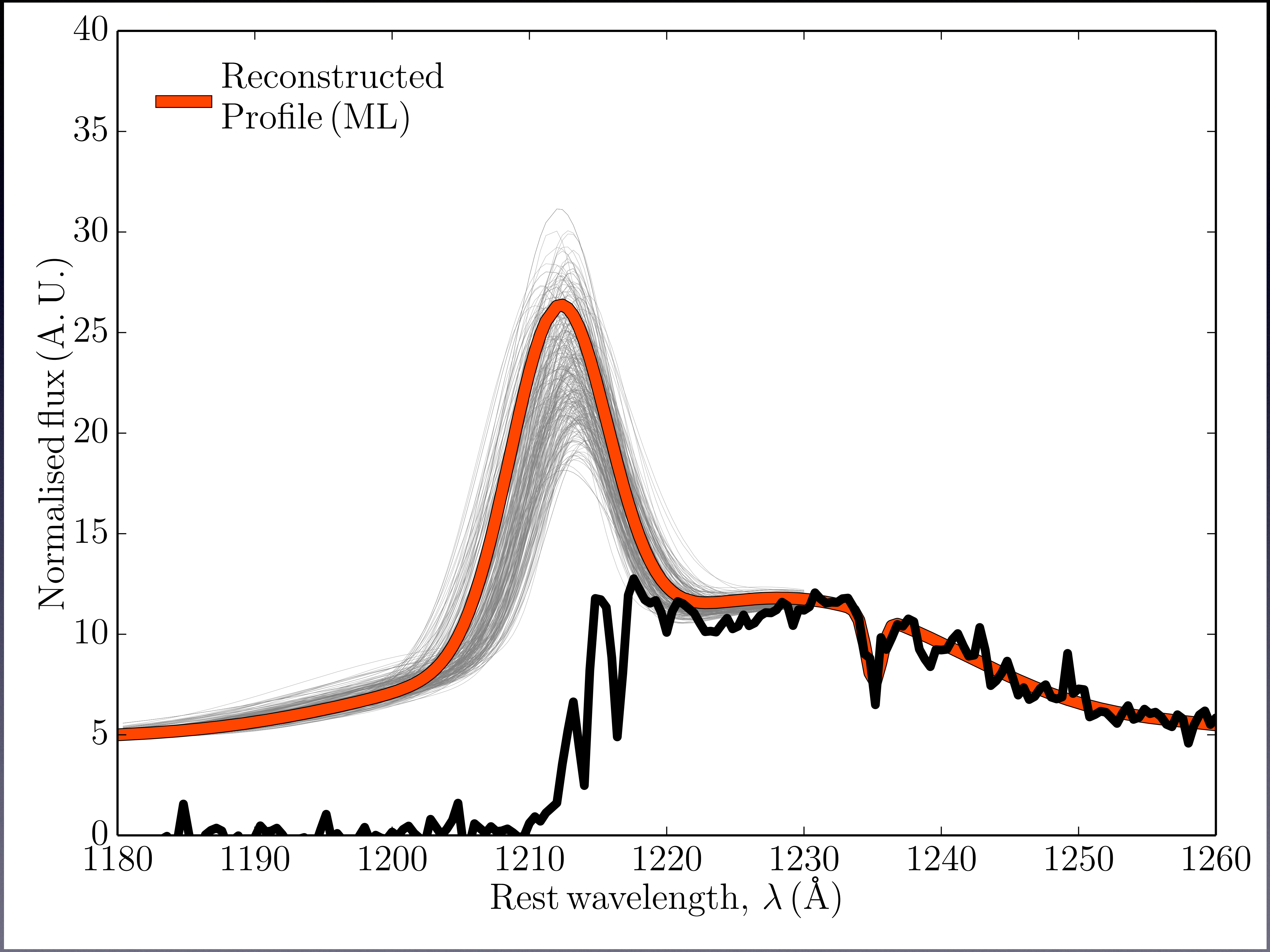
Mortlock et al. 2011

Fitting method applied to ULAS J1120



Greig et al. (arXiv:1606.00441)

Reconstructed Lyα profile of ULAS J1120



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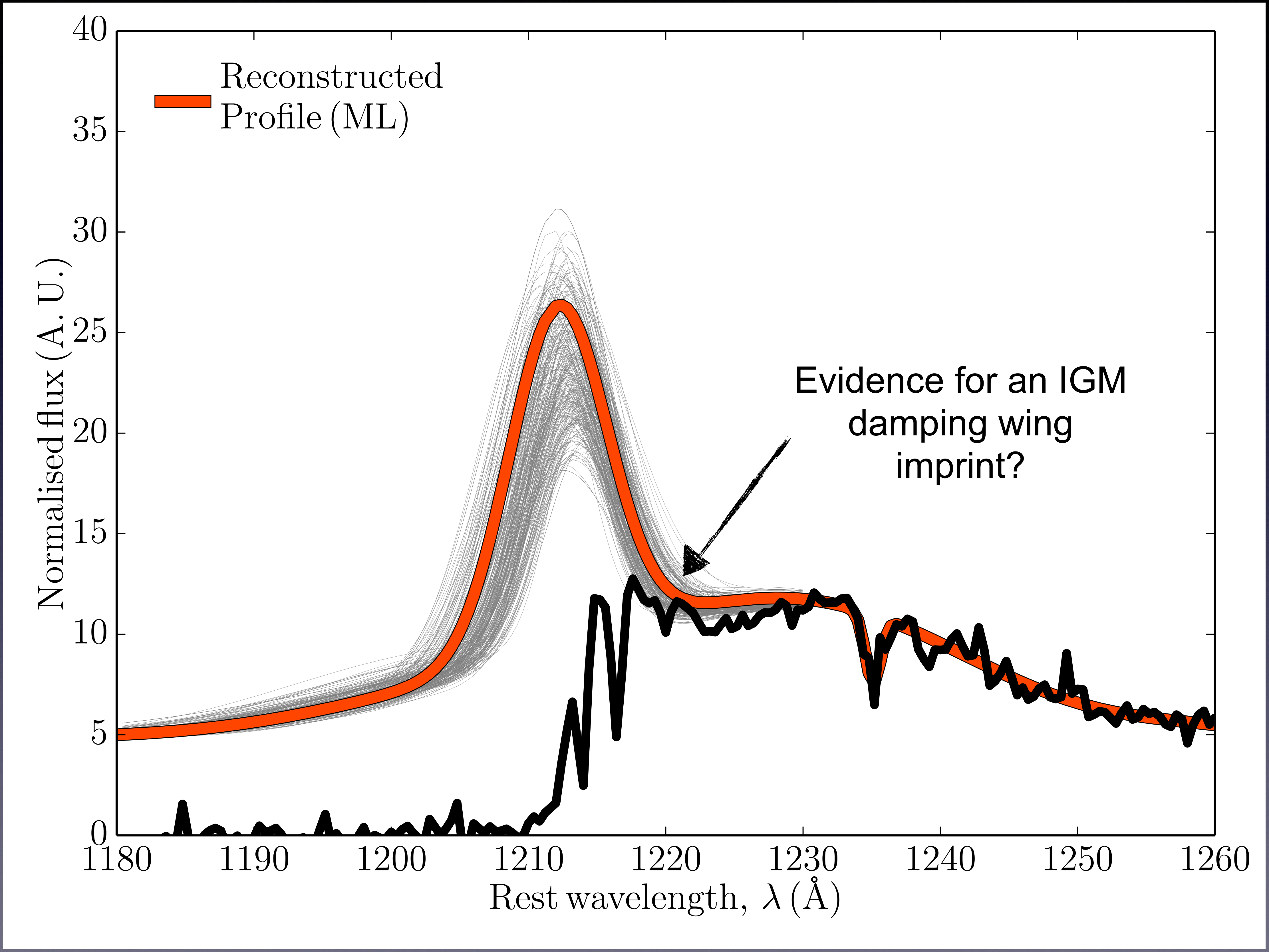

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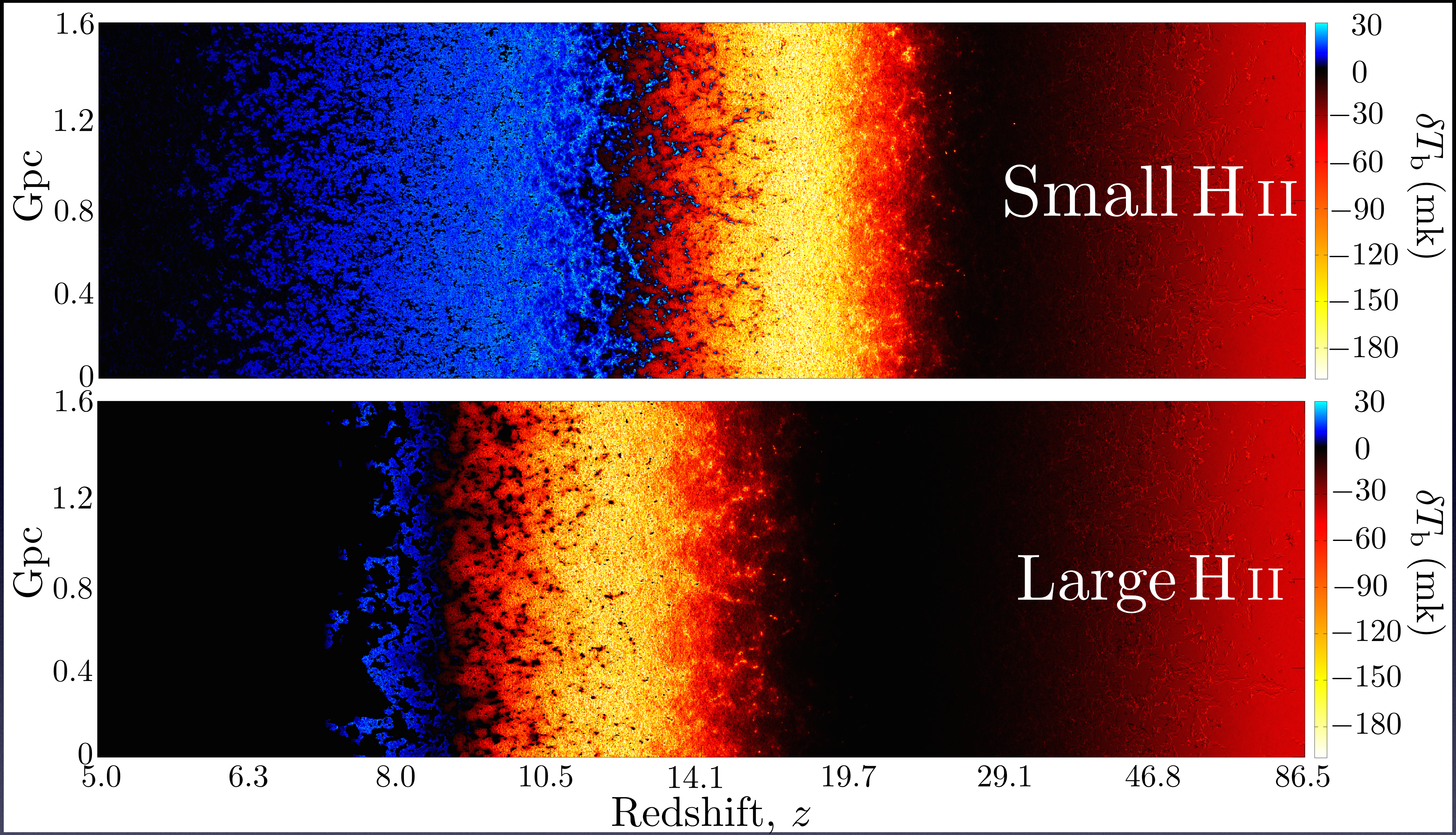
IGM neutral fraction constraints at z = 7?

- Perform χ^2 minimisation to recover the damping wing imprint
- Extract 100,000 sightlines from an EoR simulation (EOS, Mesinger et al., 2016)
- Consider two reionisation simulations:
  (i) by bright galaxies (large HII)
  (ii) by faint galaxies (small HII)



Mesinger et al. (2016)

- Includes state of the art sub-grid modelling of inhomogeneous recombinations and photoheating feedback
- Simulation size allows sightlines to probe ~$10^{12} M_{\odot}$ haloes (i.e. biased regions)
- These two models bracket the range of physically-motivated EoR morphologies

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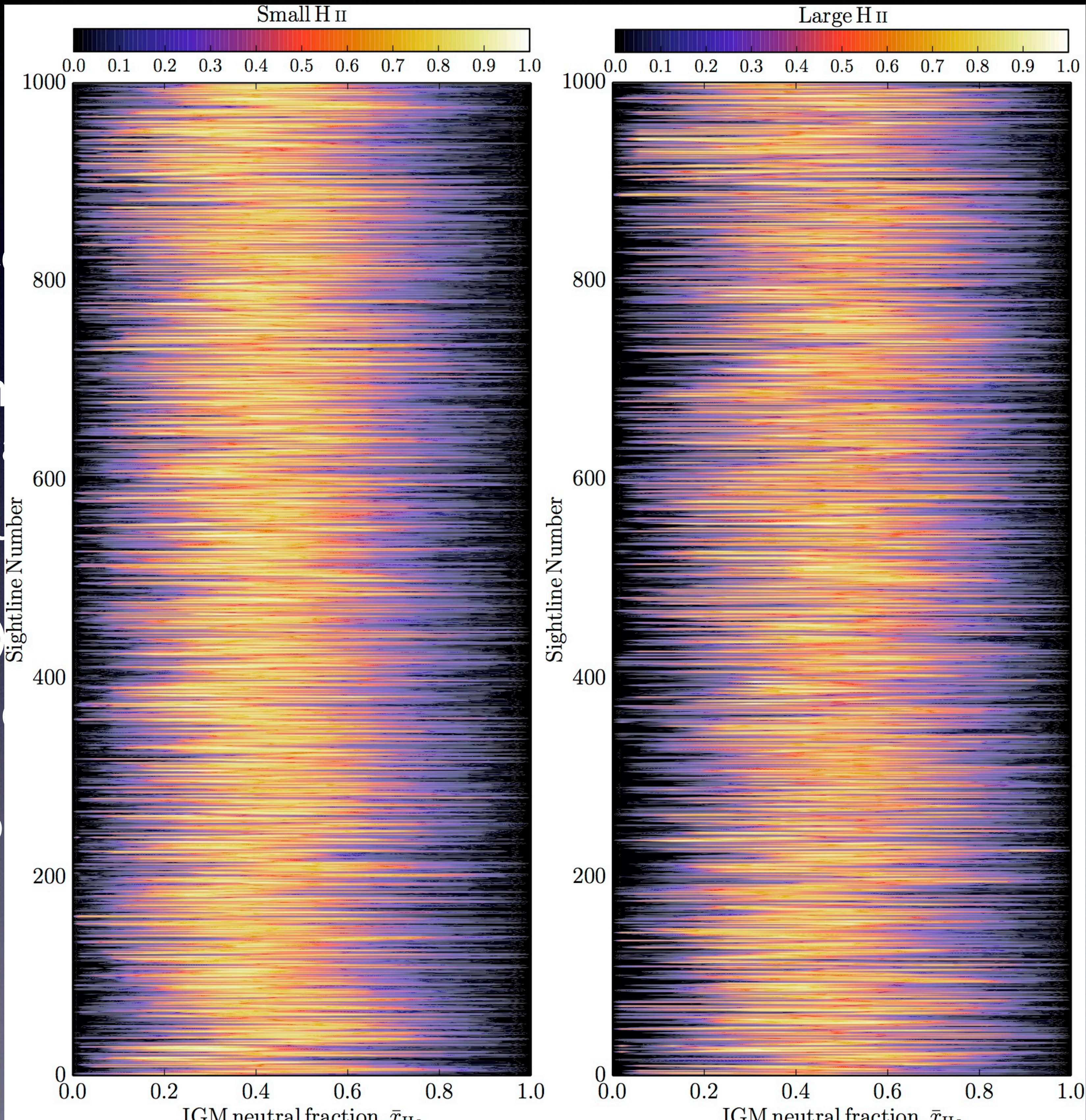

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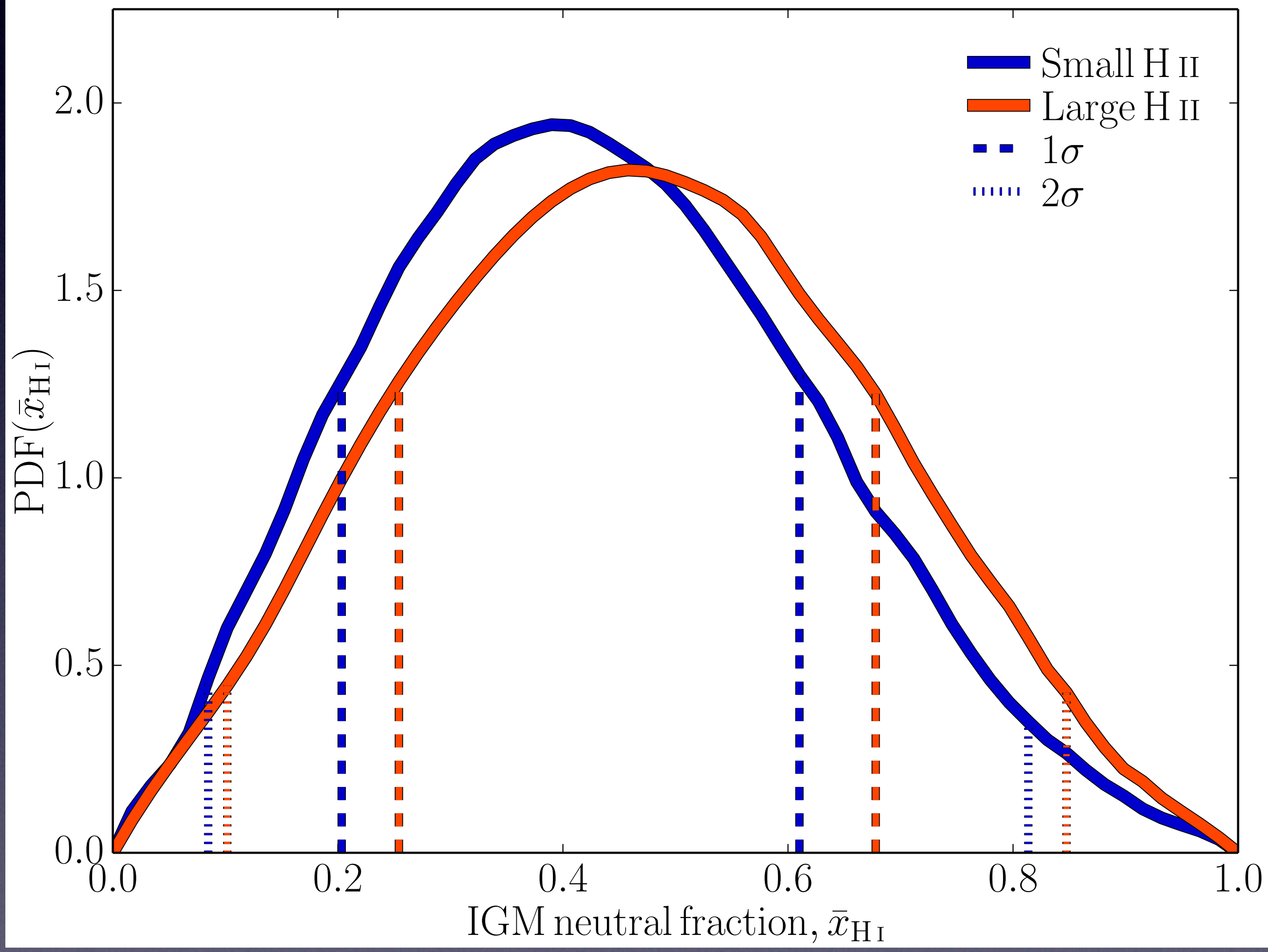

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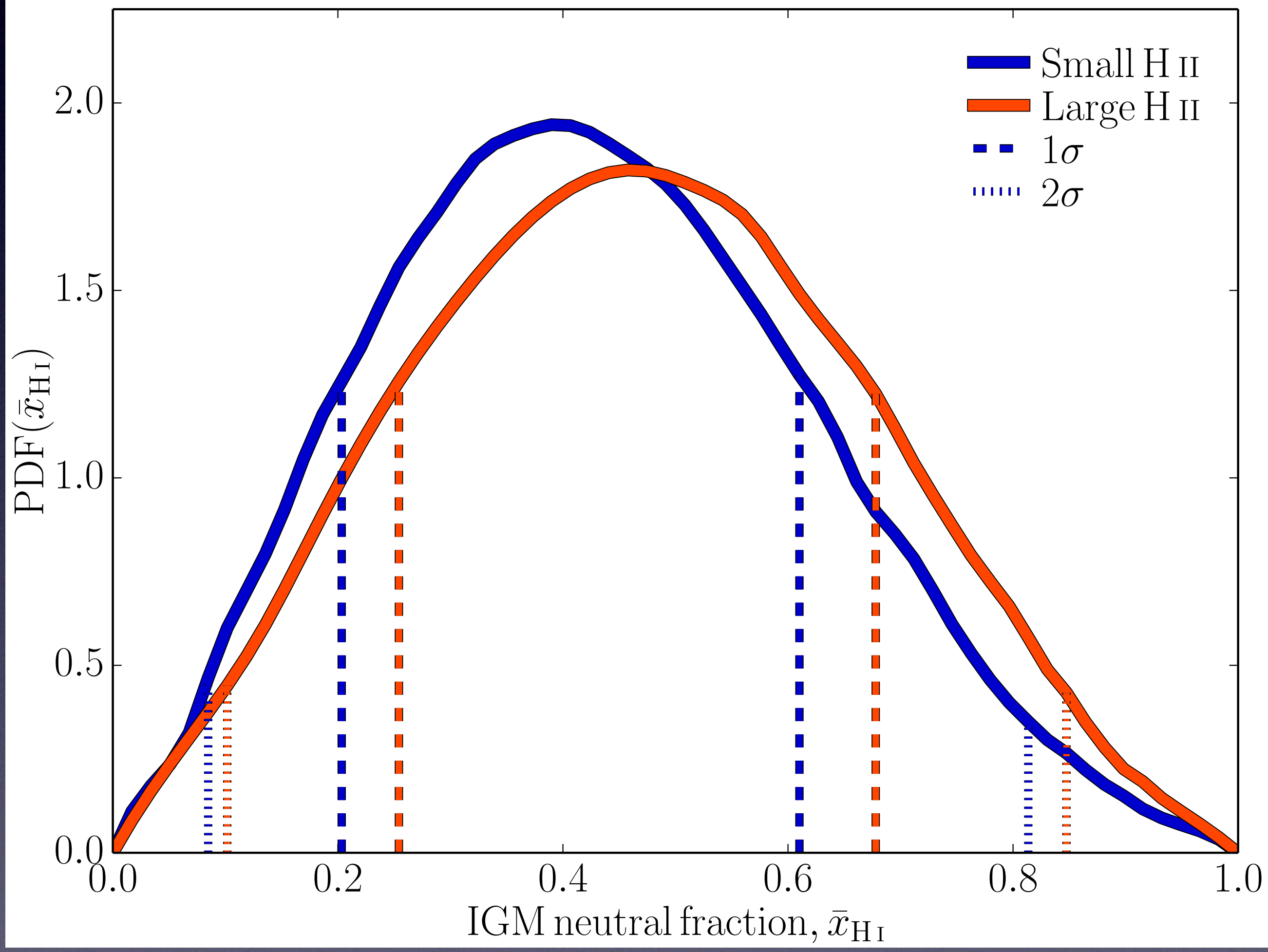

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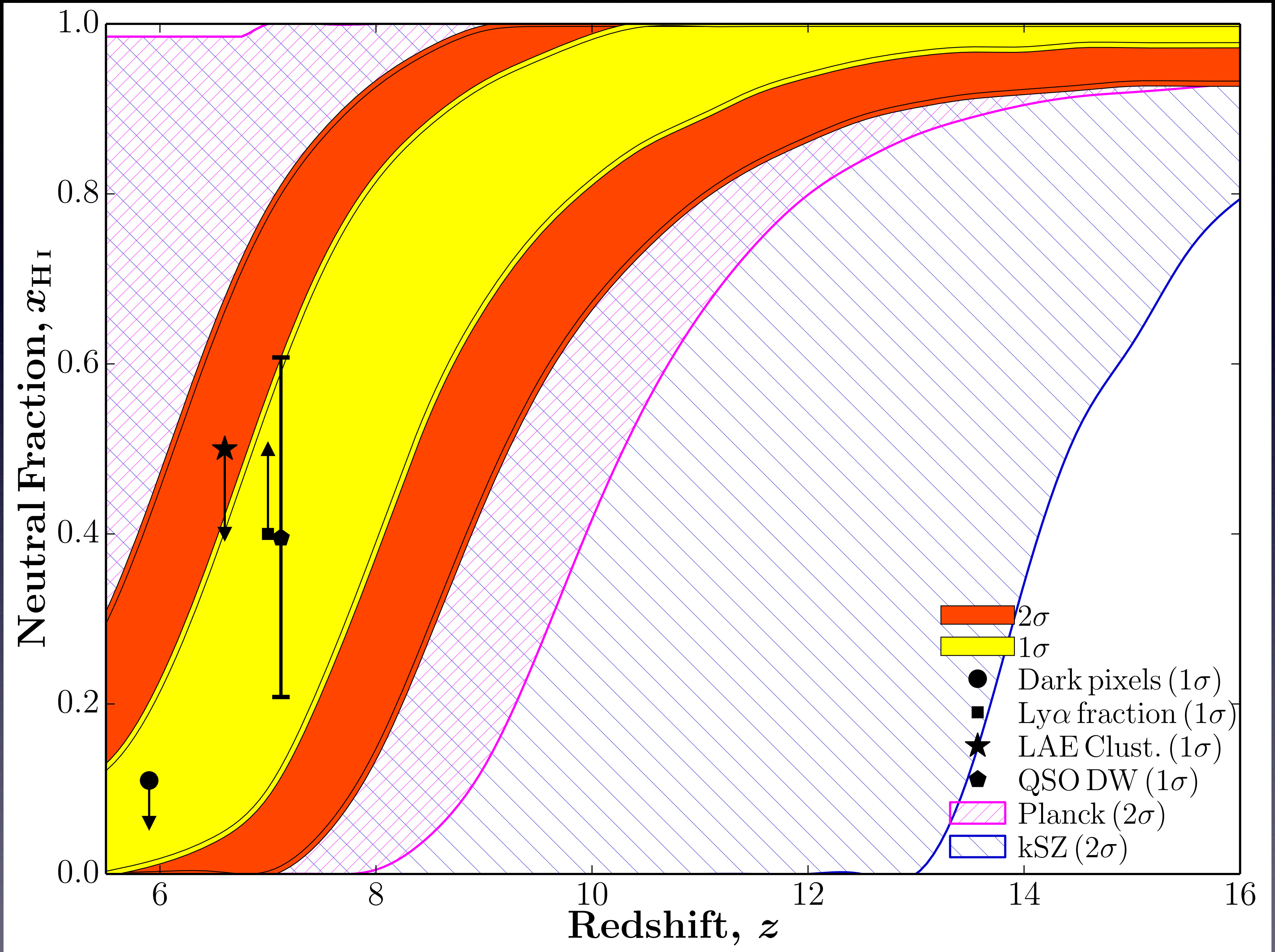
Recover:

$$\bar{x}_{\rm H\,I} = 0.40^{+0.21}_{-0.19}\ (1\sigma)\ \text{and}\ \bar{x}_{\rm H\,I} = 0.40^{+0.41}_{-0.32}\ (2\sigma)$$

The Global History of Reionisation



BG & Mesinger (arXiv:1605.05374)

Conclusion

- Showed a reconstruction method for the intrinsic Lyα emission line profile for high-z QSOs
- Important for studies of the QSO proximity effect, DLAs, IGM damping wing, reionisation…
- Applied this approach to the z=7.1 QSO ULAS J1120+0641
- Found evidence of an IGM damping wing
- First Bayesian framework jointly sampling uncertainties in (i) the intrinsic QSO emission and (ii) Lyα damping wing absorption in the EoR
- Recovered constraints:

$$\bar{x}_{\rm H\,I} = 0.40^{+0.21}_{-0.19}\ (1\sigma)\ \text{and}\ \bar{x}_{\rm H\,I} = 0.40^{+0.41}_{-0.32}\ (2\sigma)$$

- More z > 7 QSO would be nice!