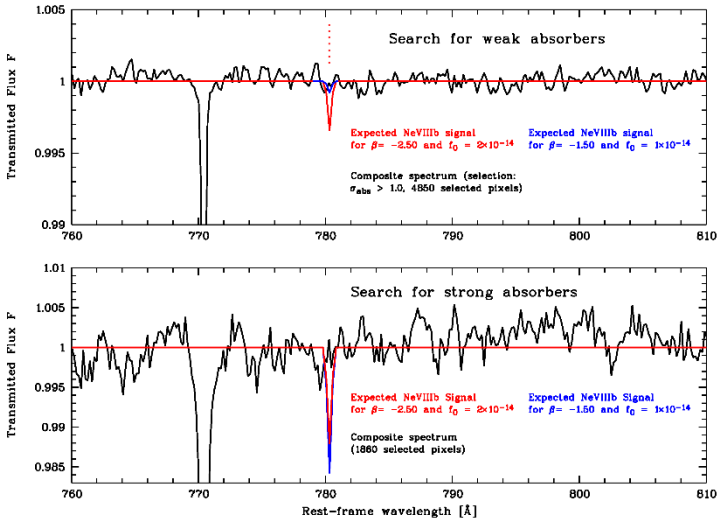
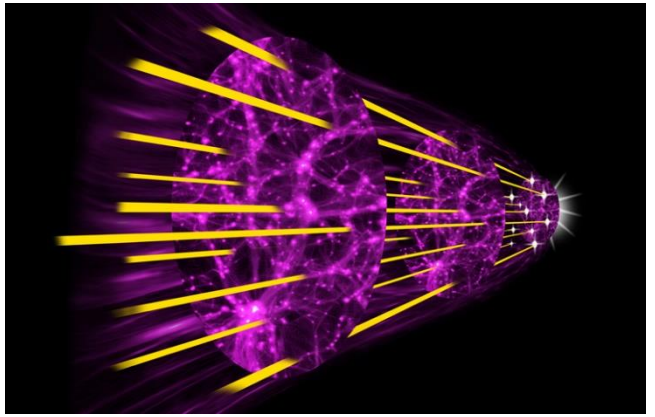
Assessing the z≈0.9 NeVIII absorber population via ***Agnostic Stacking***





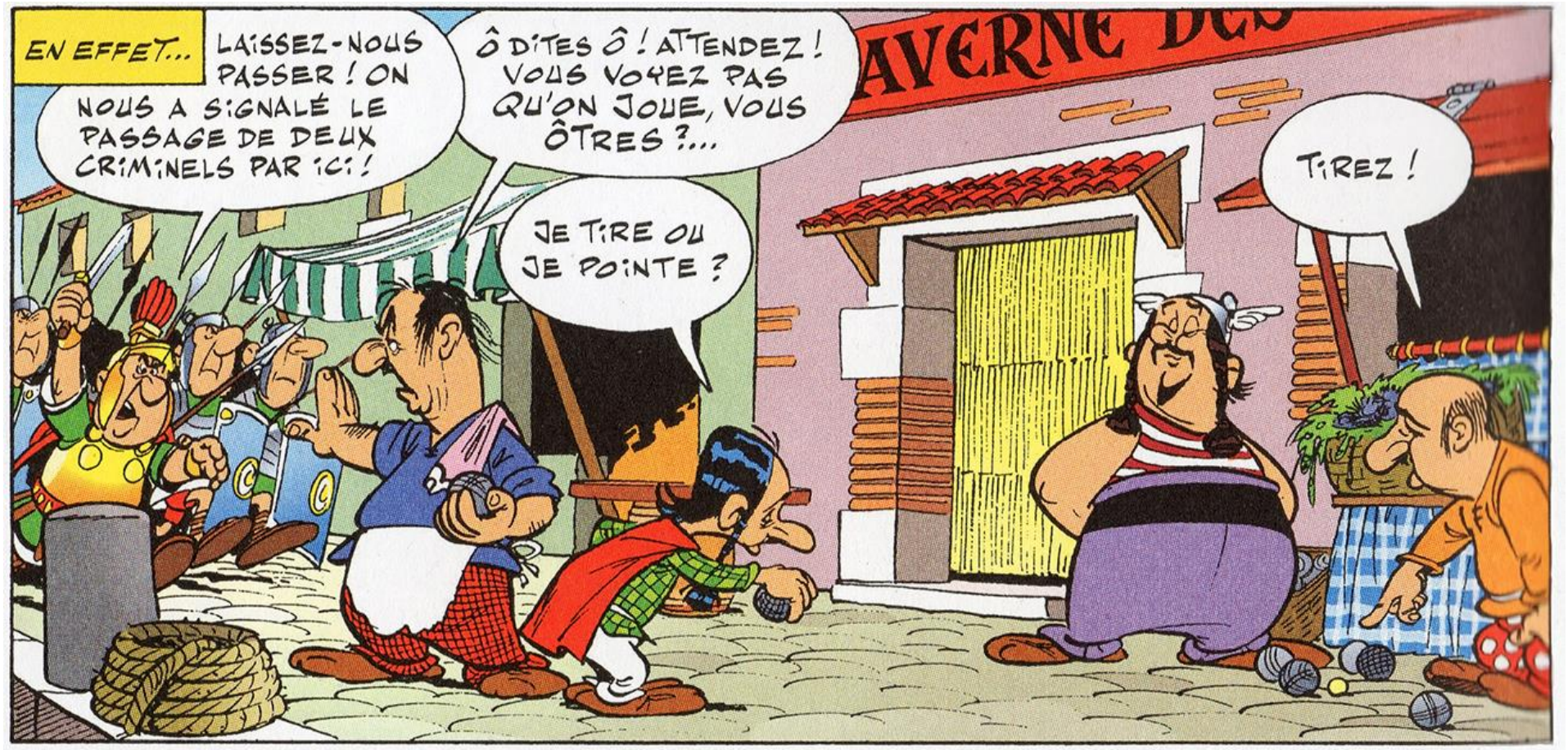
Stephan Frank , Matthew Pieri, Charles Danforth,

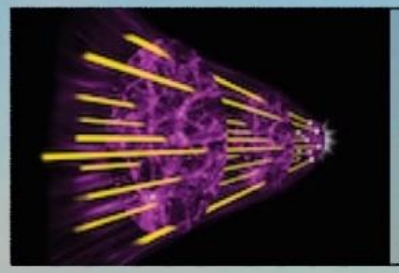
Smita Mathur, Michael Shull

Frank et al., 2018 MNRAS, 476, 1356

Marseille, Intergalactic Interconnections Conference, July 9th 2018

My suggestion : Take some time to enjoy this marvelous city (and its surroundings) !





Intergalactic Interconnections

9th-13th July 2018 Marseille, France

The 12th Edition of the Marseille Cosmology Conference Series

igm-inter2018.sciencesconf.org

o Diffus

o Circur

o Interg

o Interg

opulations

operties

Smita Mathur
Rob Crain
Peng Oh
Chris Martin
Clothilde Laigle

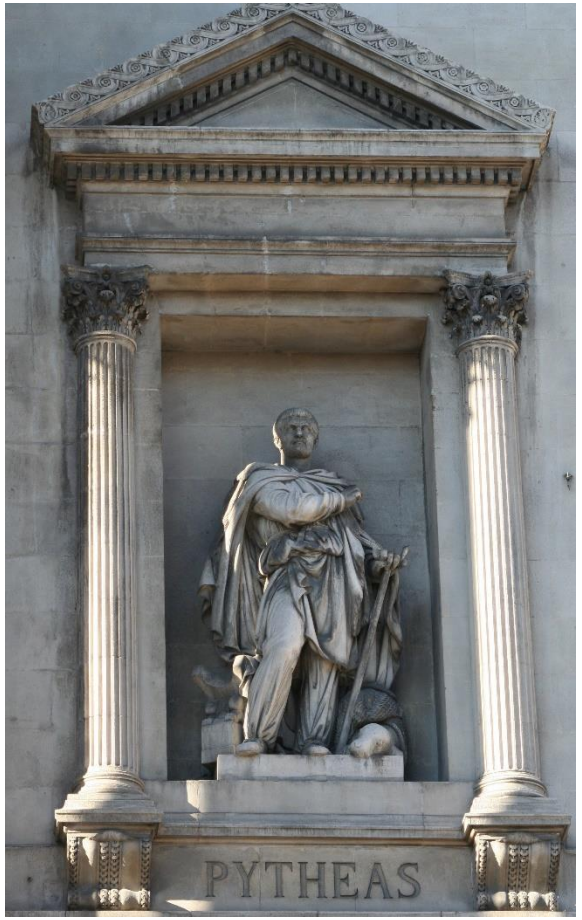
Michael Blomqvist
Jordi Miralda-Escudé
Nathalie Palanque-Delabrouille
Joe Hennawi

SOC: Mat Pieri, Celine Peroux, Dusan Keres, Juna Kollmeier, Gwen Rudie, Joop Schaye, Mike Shull, Matteo Viel

LOC: Vincent Le Brun, Mat Pieri, Michael Blomqvist, Cecile Gry, Bruno Milliard, Sean Morrison, Ignasi Perez Rafols, Celine Peroux, Debopam Som

LAM
A*Midex
PNCG
Aix*Marseille université

Astronomical Research has a long tradition here in Marseille.



Statue outside of Palais de la Bourse

Pytheas of Massalia / Πυθέας ὁ Μασσαλιώτης
4th century BC Greek 'scientist' :

- Measures Latitude of Massalia (Marseille)
- First Greek to describe the 'Land of the Midnight Sun'
- First to suggest Moon (phases?) related to tides

In the next 15 minutes you will….

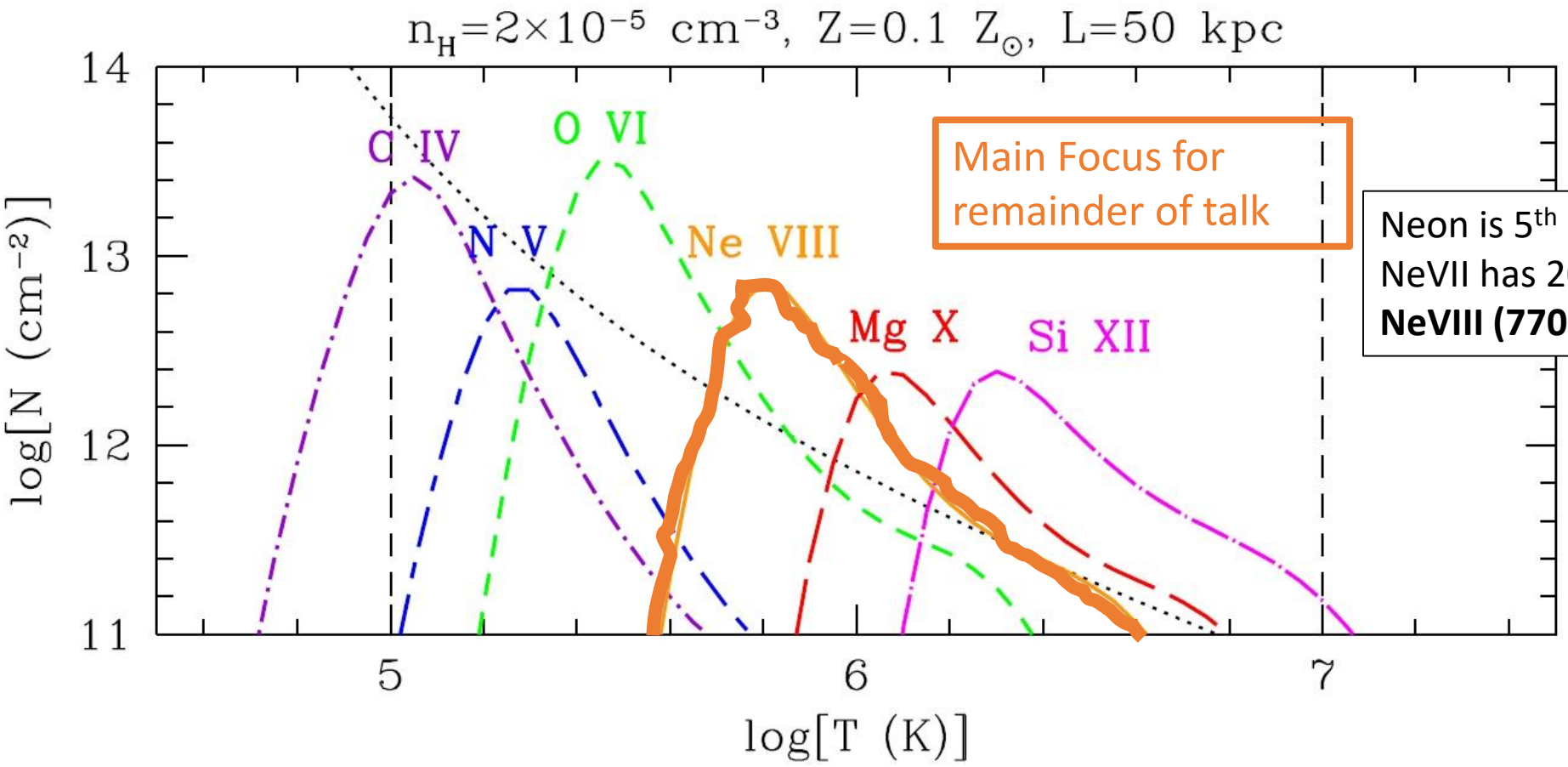
- ……be introduced to a **novel method : Agnostic Stacking**

  - blind search for doublet intergalactic metal absorption
  - selects apparent absorption without requiring knowledge of its source
  - stacking this mixed population dilutes doublet features in composite spectra in a deterministic manner

- ……see the results of applying this method to the **characterization of the NeVIII absorber population** in COS-data at z~0.9

  - Danforth sample of 26 high quality COS data
  - probing to an unprecedented low limit of log N>12.3 at 0.47<z<1.34
  - pathlength $\Delta z = 7.36$
  - dn/dz (log N>13.7) = 1.38 (+0.97,-0.82)
  - Ω(NeVIII) significantly lower than predicted by recent simulations
  - Inferred baryon density of this gas phase : 4% of total baryonic mass

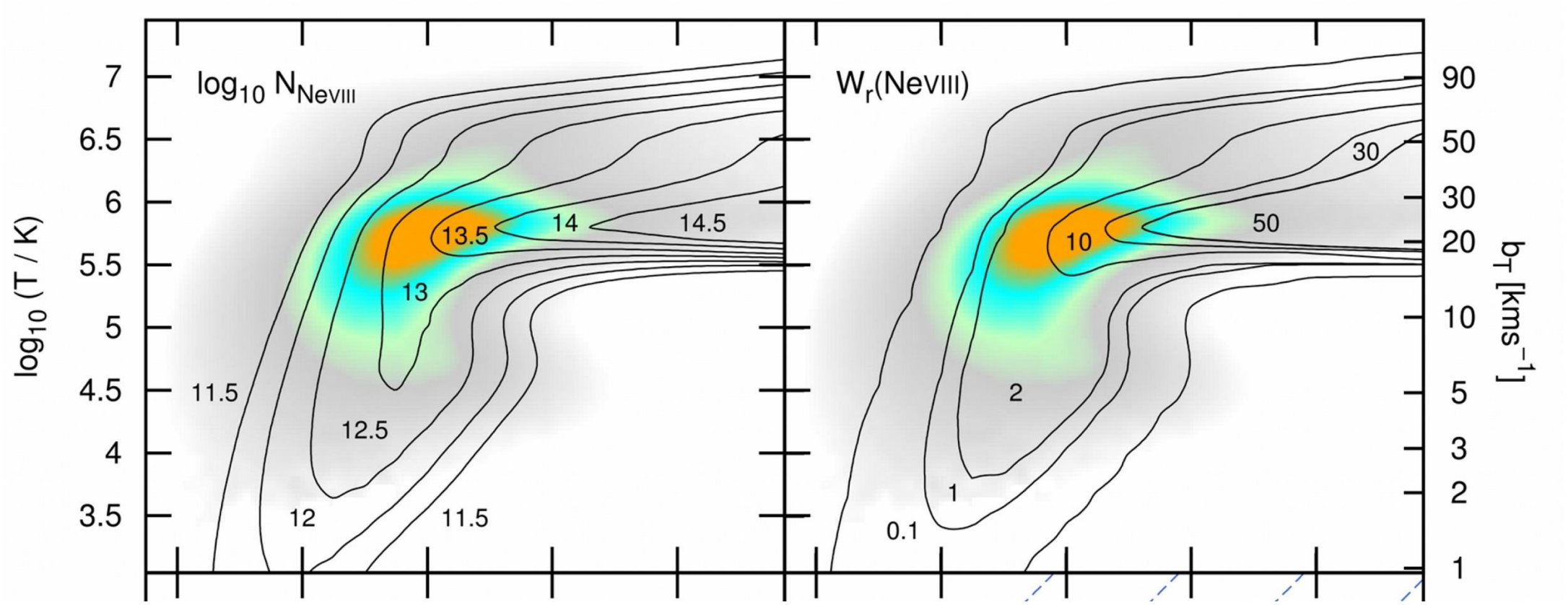
Highly ionised metals are tracers of hot gas between 10^5 and 10^7 K ("WHIM")



Neon is 5th most abundant element
NeVII has 207 eV ionization energy
NeVIII (770 / 780 Å) is a doublet !

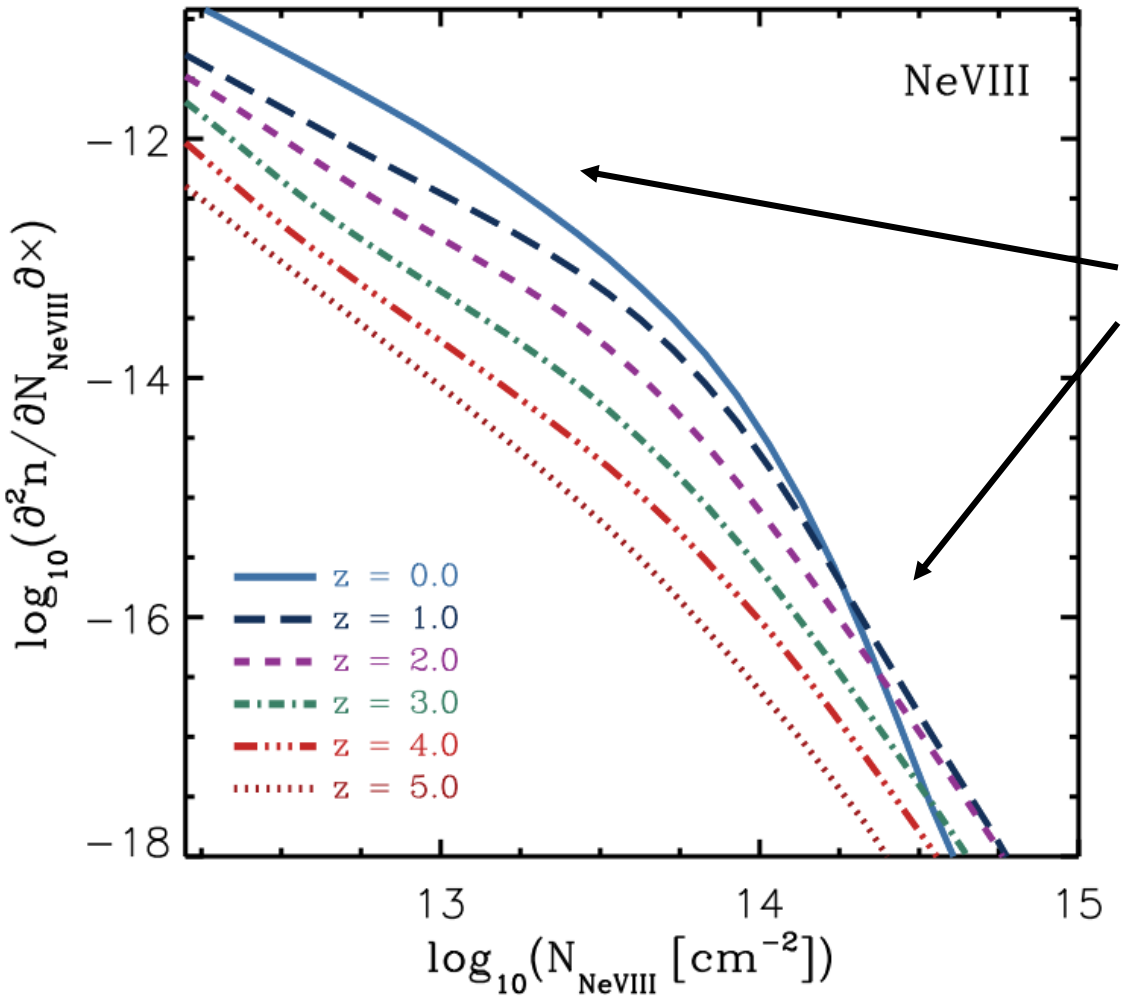
Pieri et al. 2010,
HST Archival Proposal 2010
→ but see e.g. :
Tepper-Garcia 2013,
Oppenheimer & Schaye 2013

The bulk of NeVIII absorbers are predicted to produce weak features.



Tepper-Garcia 2013, OWLS Simulation

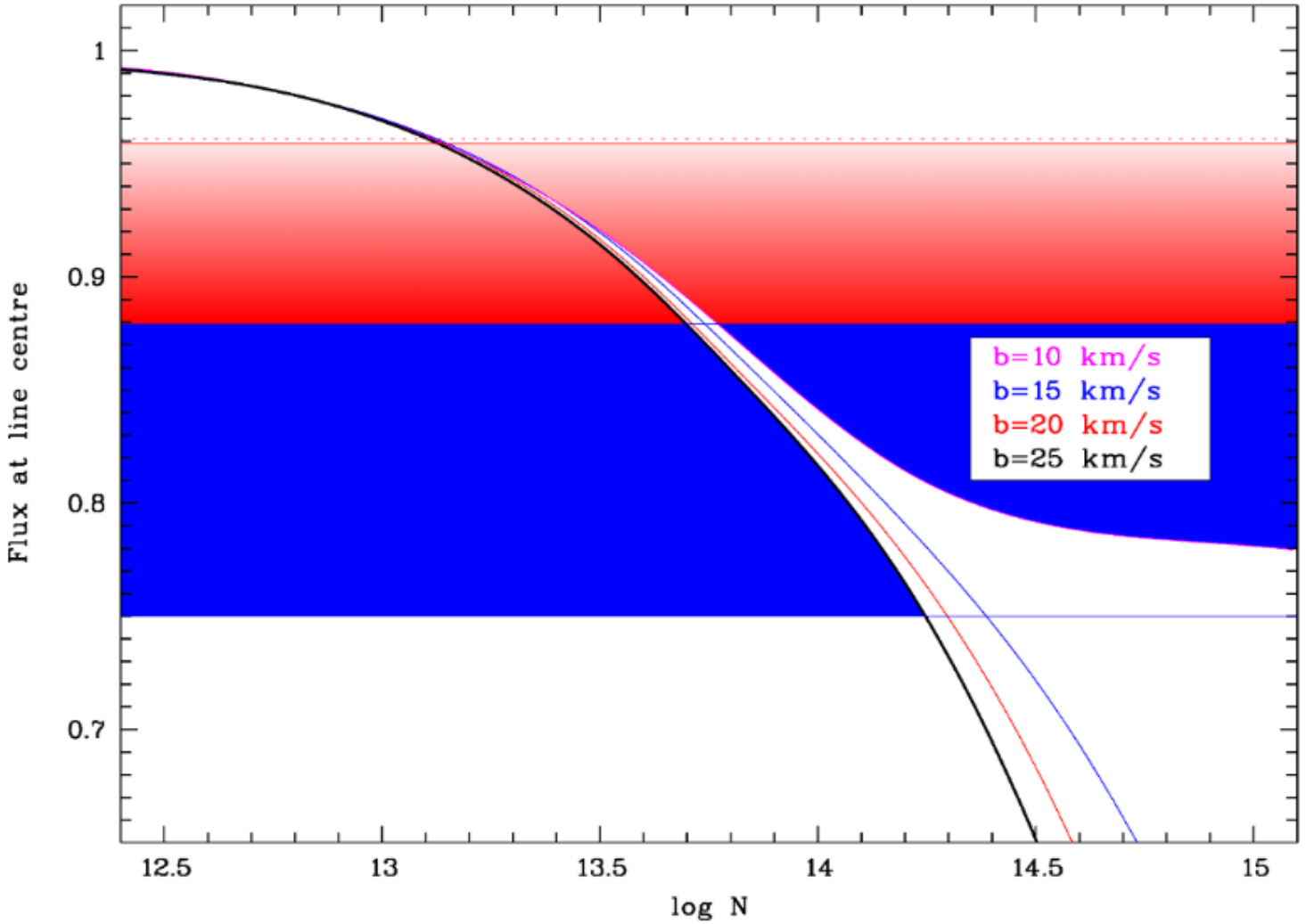
In other words, the CDDF is steep !

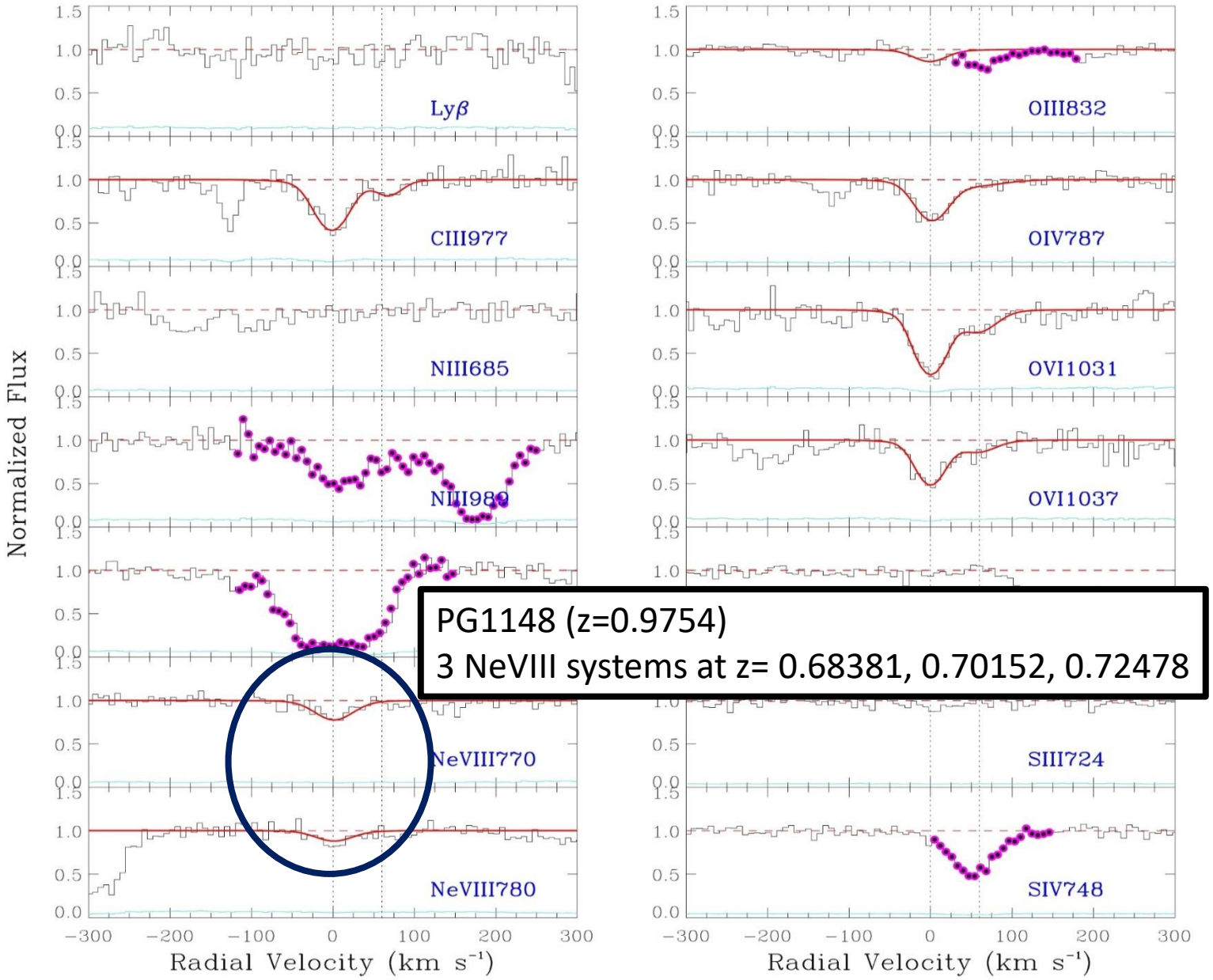


There are may more
Weak (log N<13.7) than
Strong Absorbers predicted.

Rahmati et al., 2016
EAGLE simulation

Low column density systems are really weak (doh !)





PG1148 (z=0.9754)
3 NeVIII systems at z= 0.68381, 0.70152, 0.72478

Meiring 2013

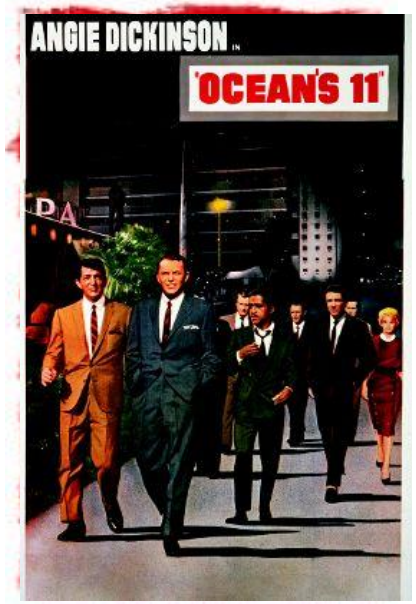
Ocean's Eleven (running out of movies puns here)

11 (!) direct detections in FUSE or COS spectra

Savage 2005
Narayanan 2009
Narayanan 2011
Narayanan 2012
Meiring 2013
Savage 2011
Tripp 2011

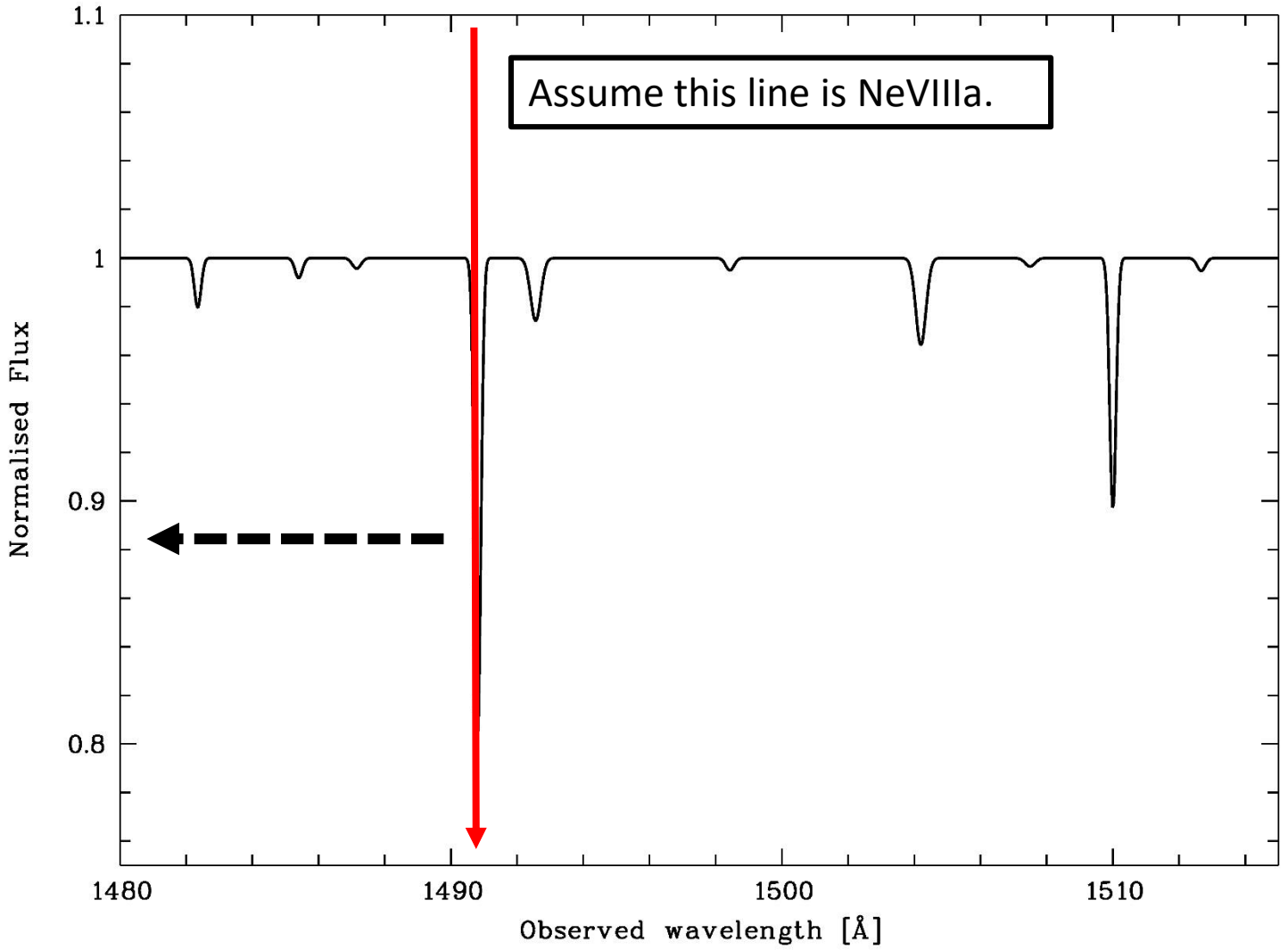
Hussain 2015

Pachat 2017

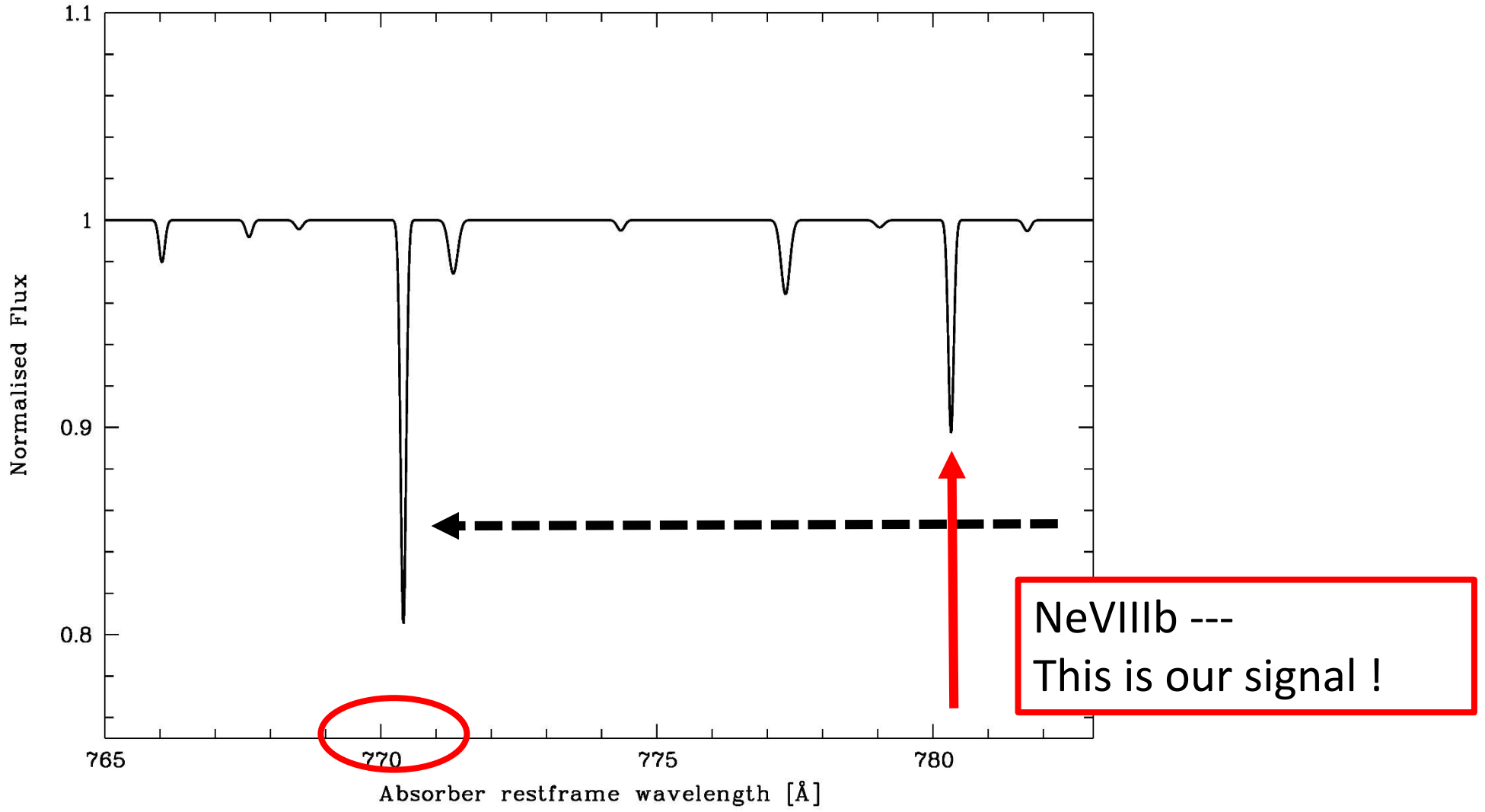


-- stark contrast to OVI
(>100 known systems at low-z)

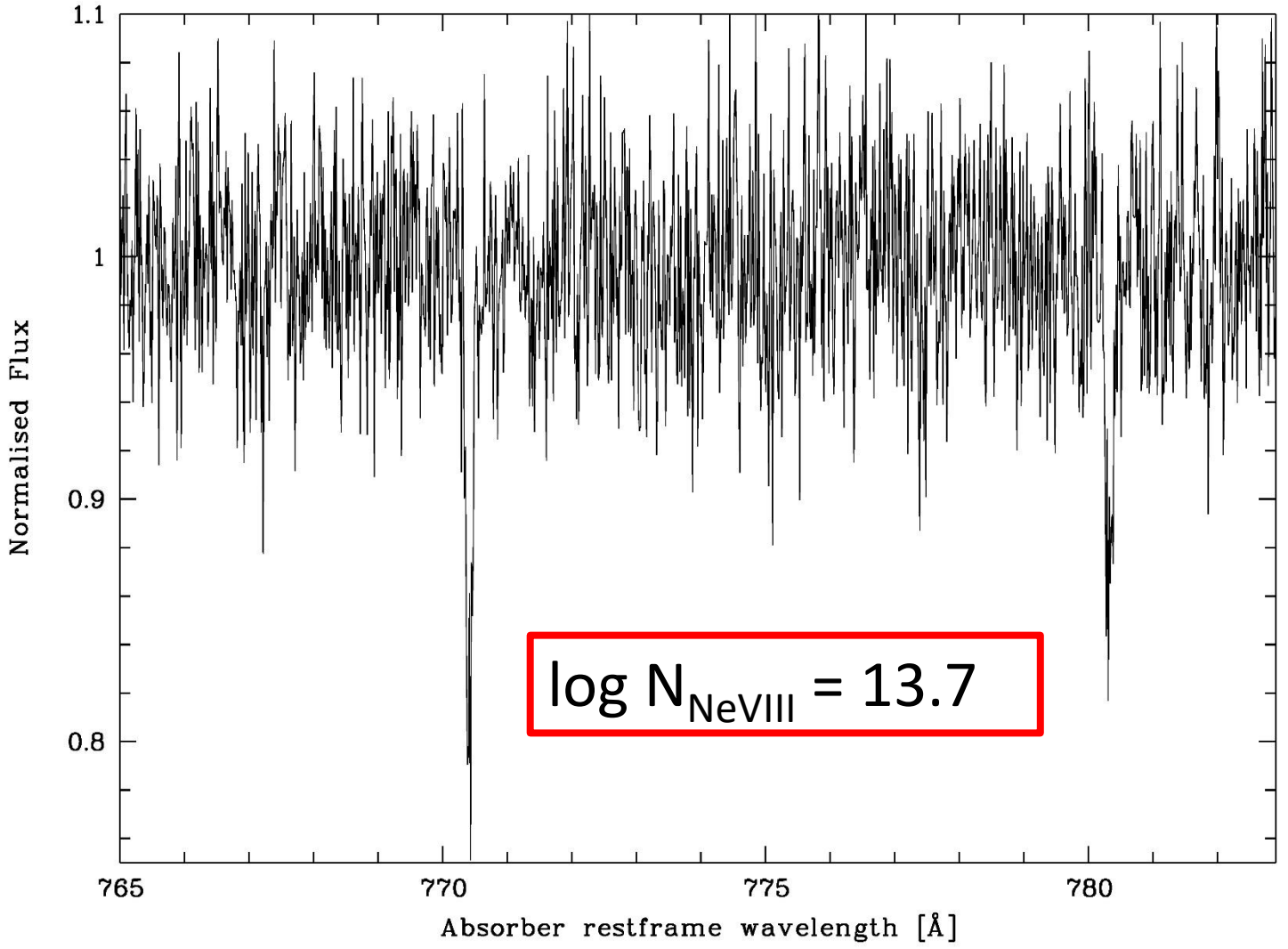
The agnostic approach to stacking



Back to the NeVIII absorber restframe.

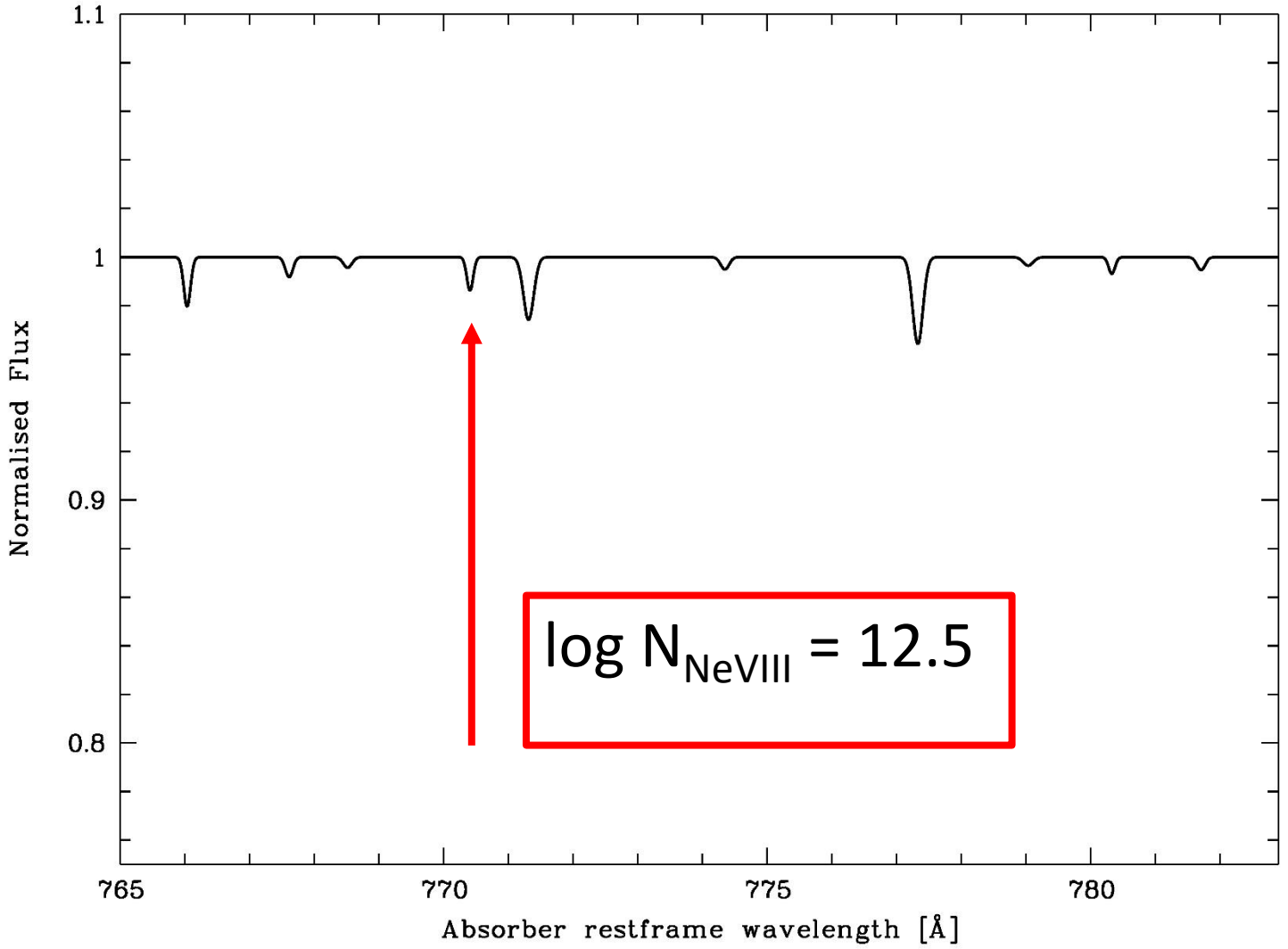


But wait. Real data are noisy !

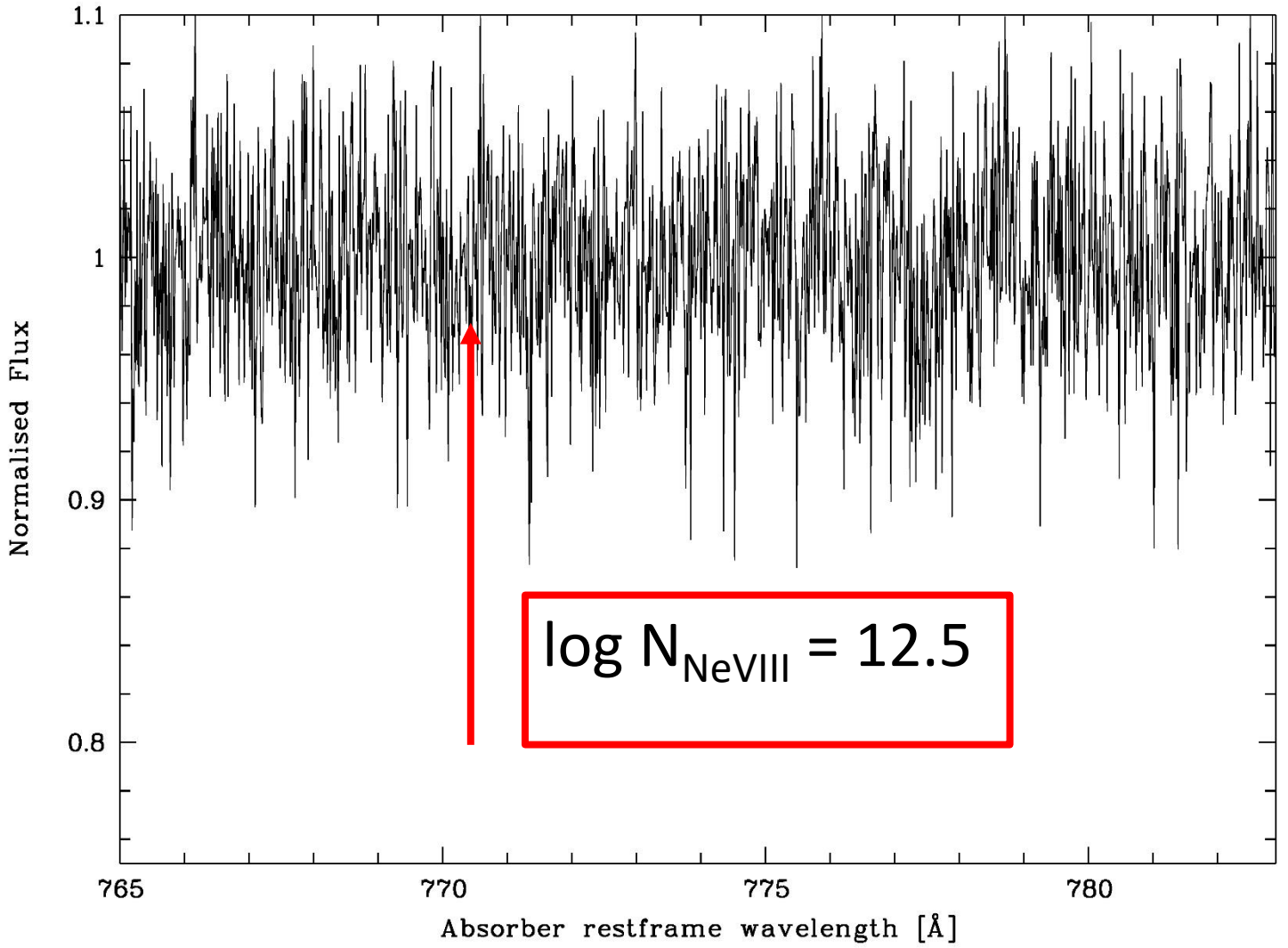


S/N for a typical COS sightline (after rebinning to our purposes).

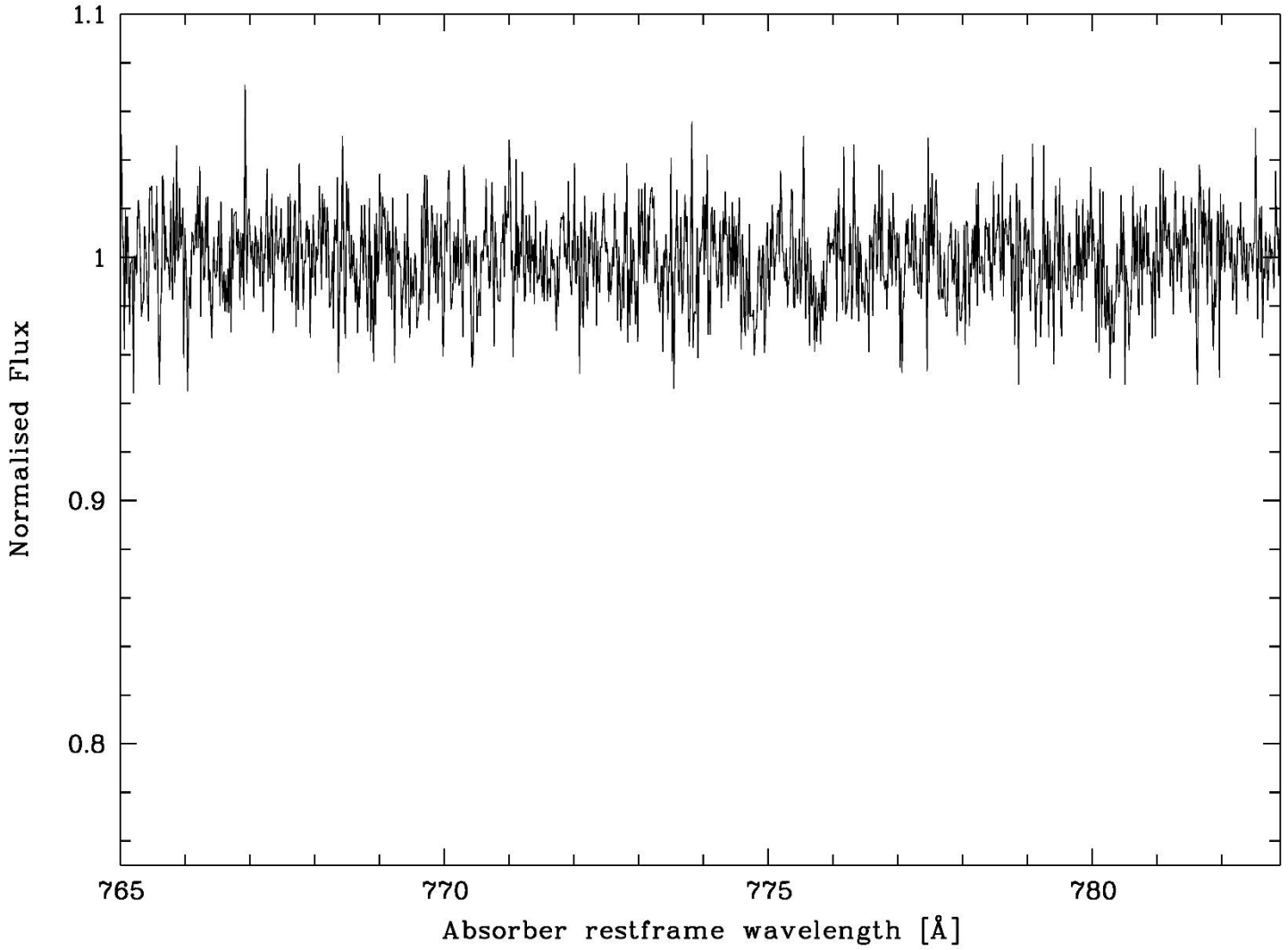
But wait (II). Bulk of NeVIII has lower column density.



Now what ?

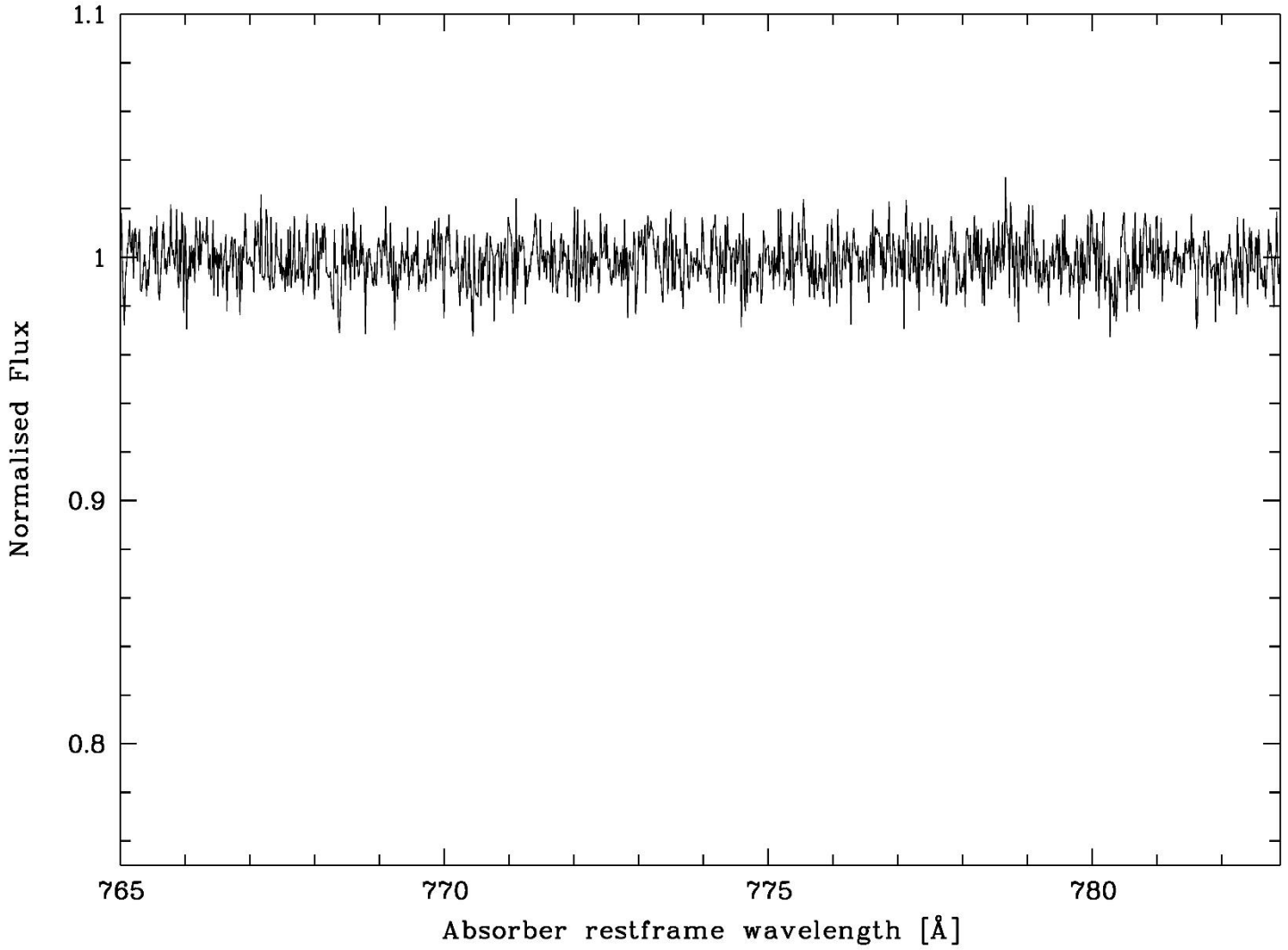

1.1
1
0.9
0.8
Normalised Flux
765
770
775
780
Absorber restframe wavelength [Å]
log N_{NeVIII} = 12.5

This is where the power of stacking comes to rescue.



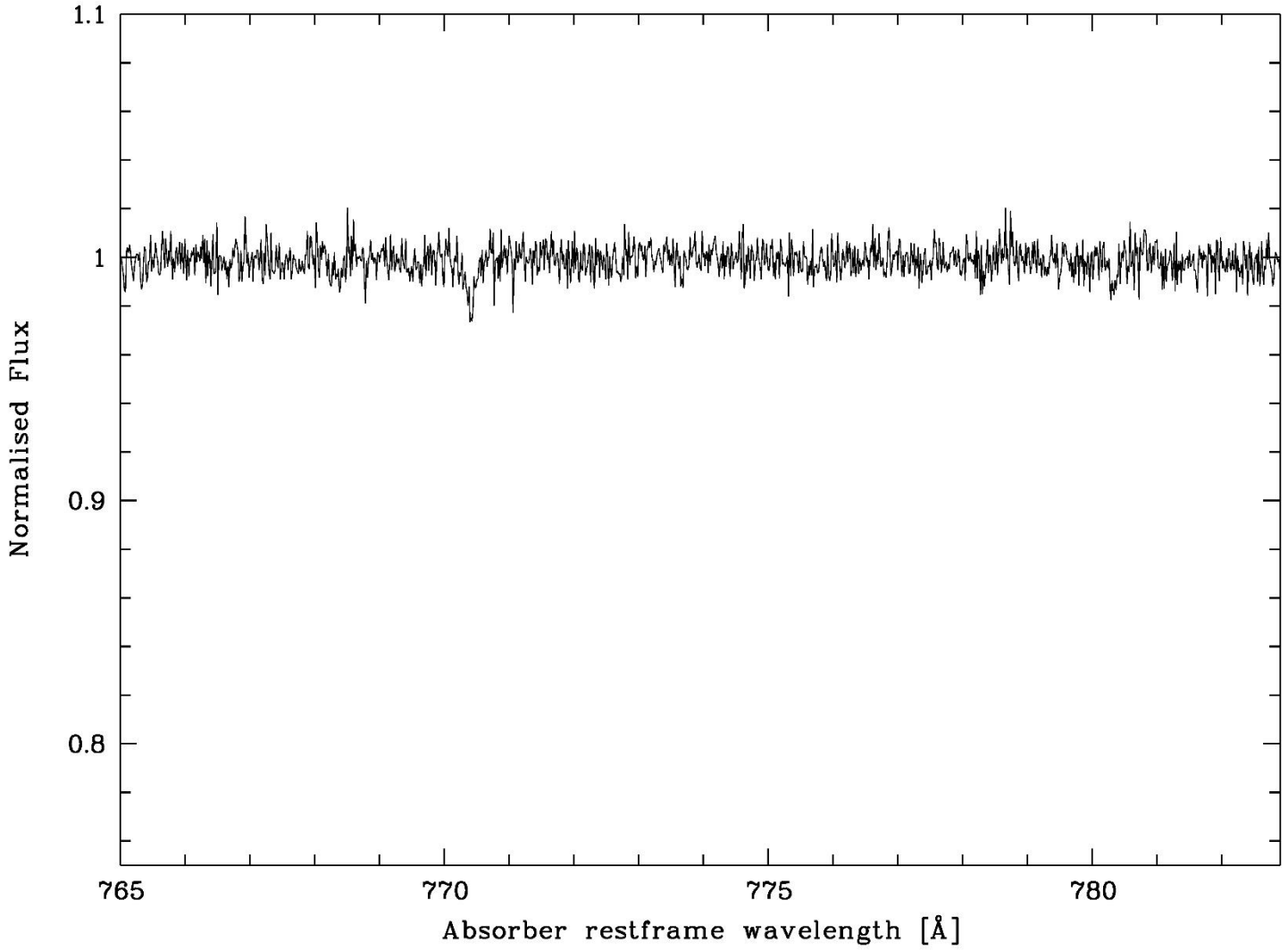
N = 3

This is where the power of stacking comes to rescue.



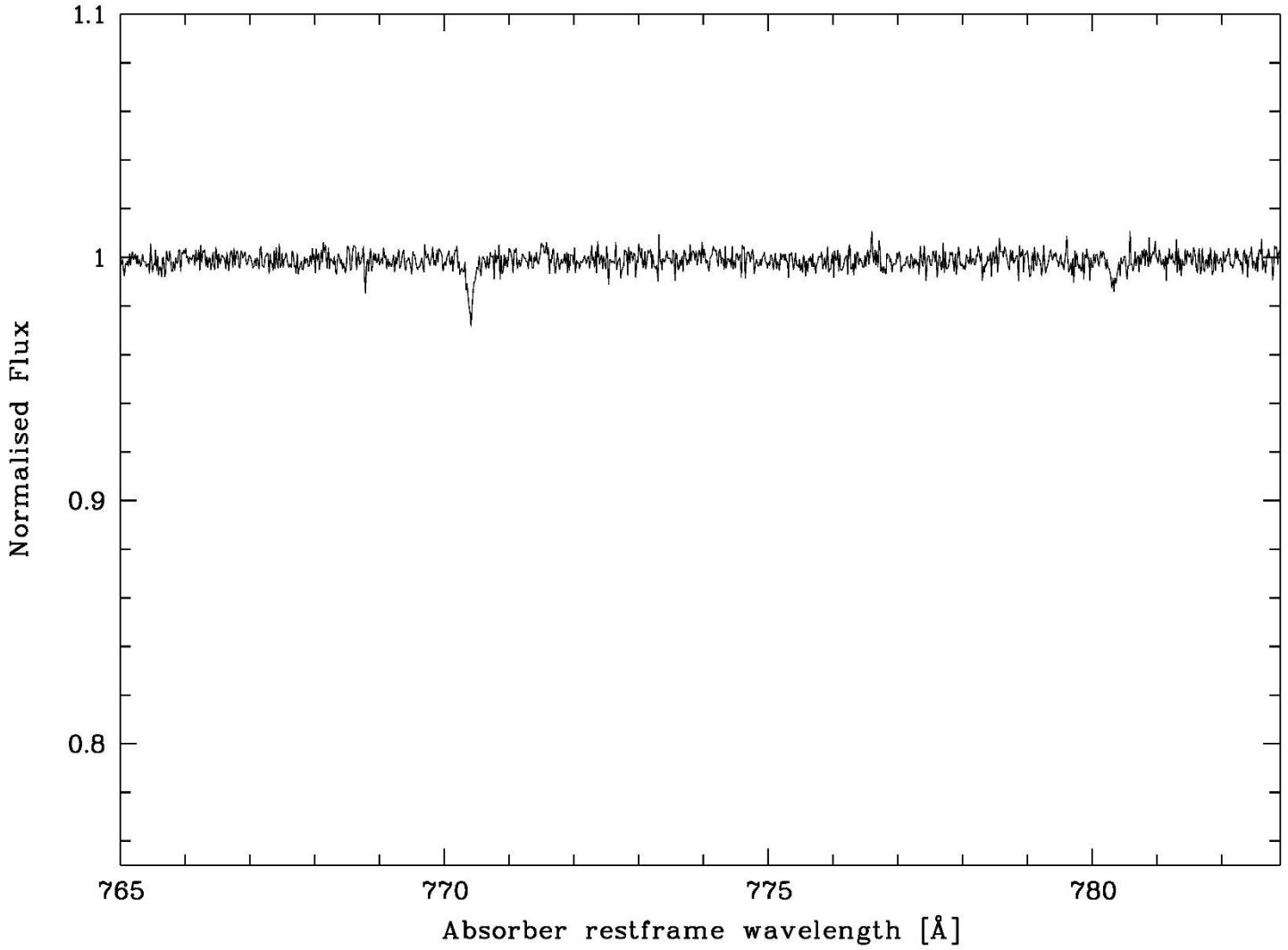
N = 10

This is where the power of stacking comes to rescue.



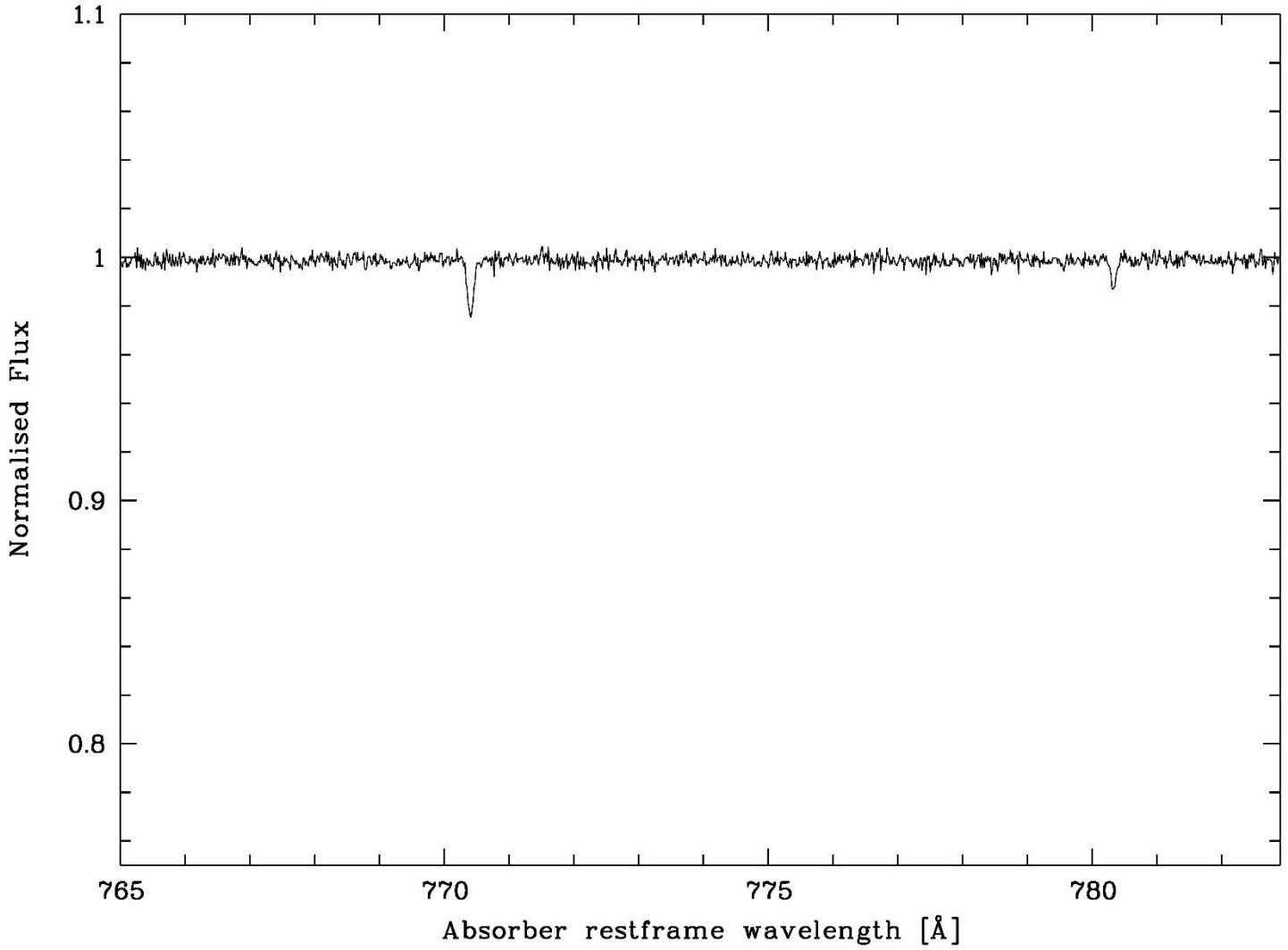
N = 30

This is where the power of stacking comes to rescue.



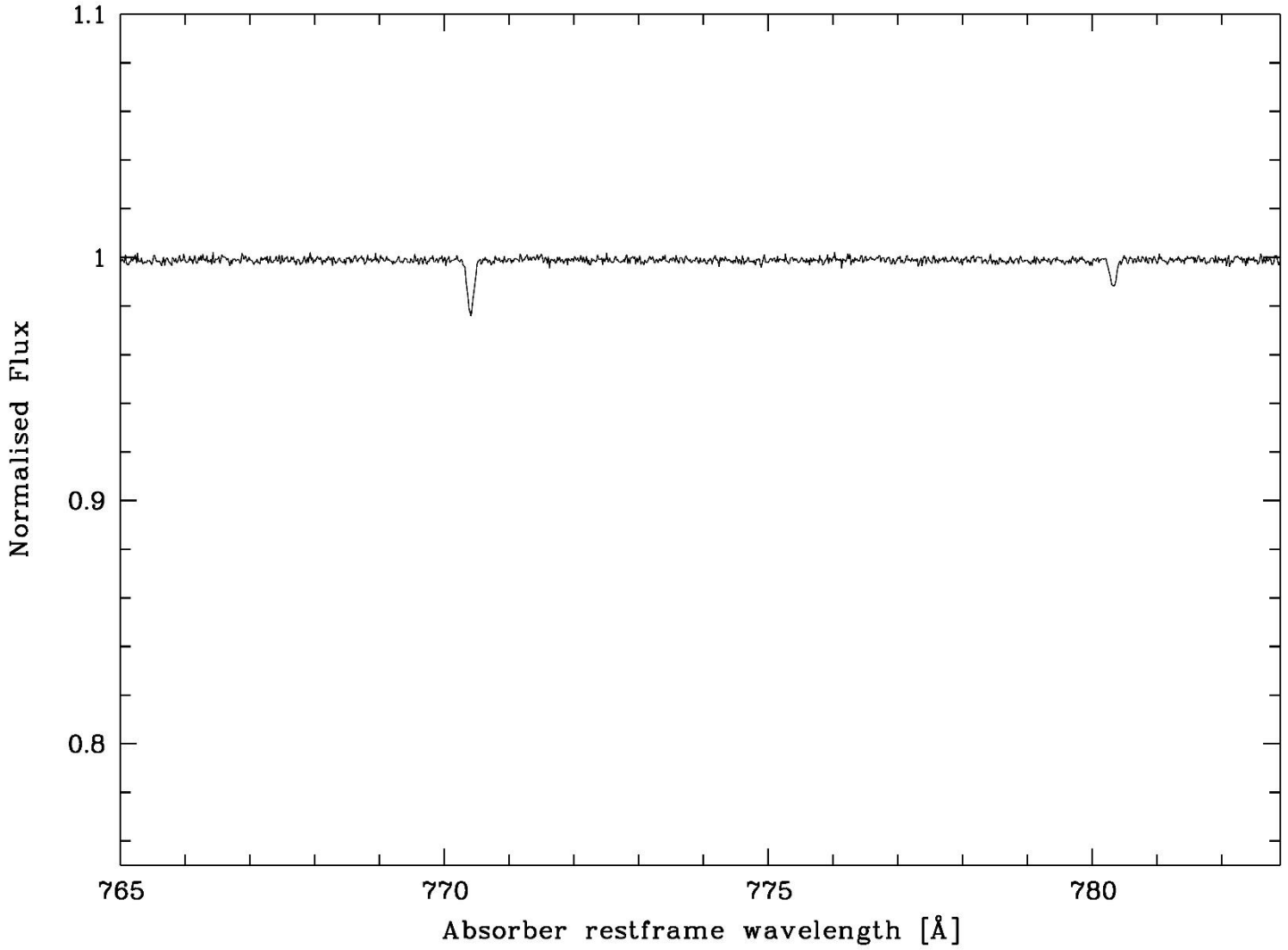
N = 100

This is where the power of stacking comes to rescue.



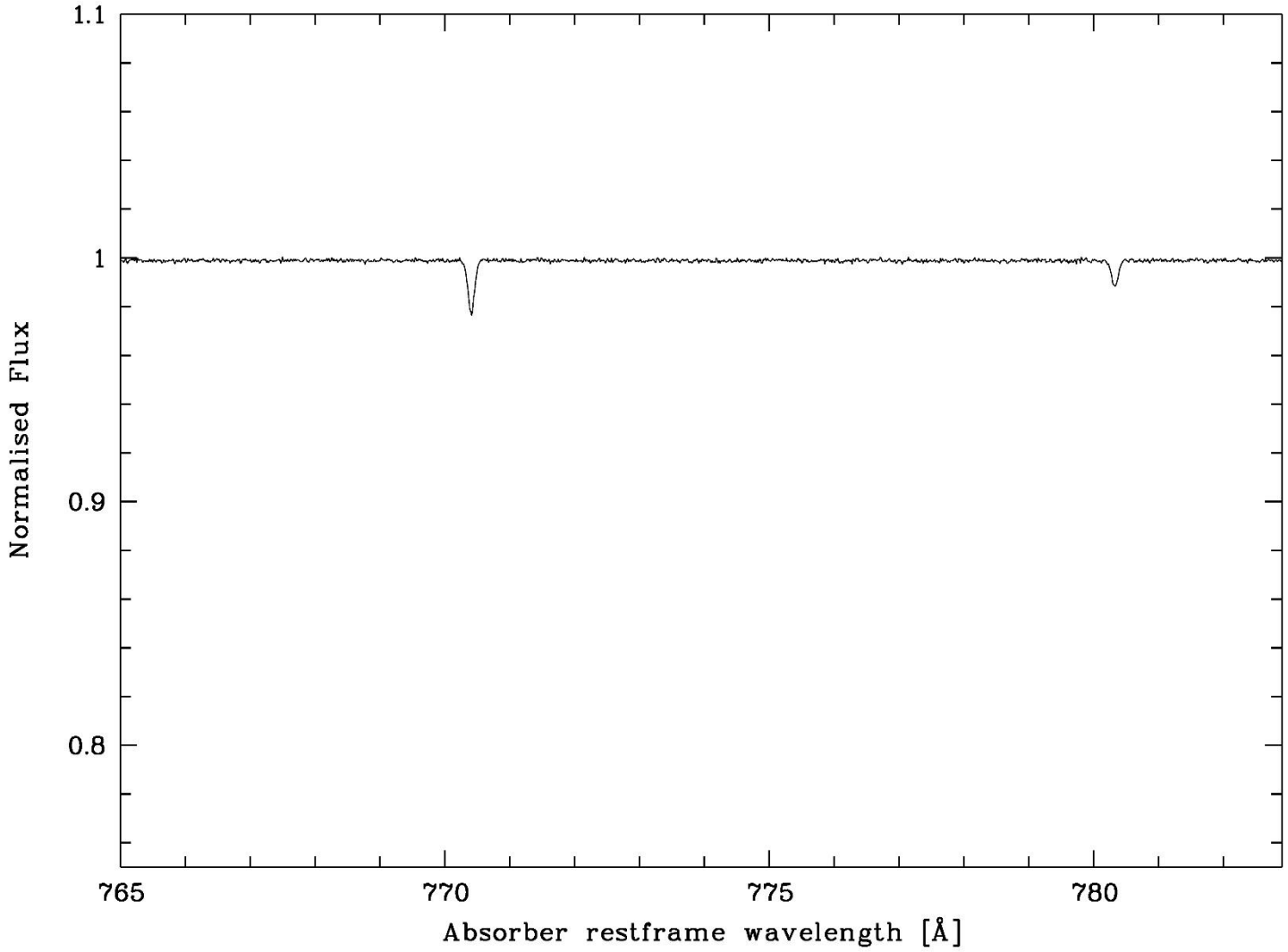
N = 300

This is where the power of stacking comes to rescue.



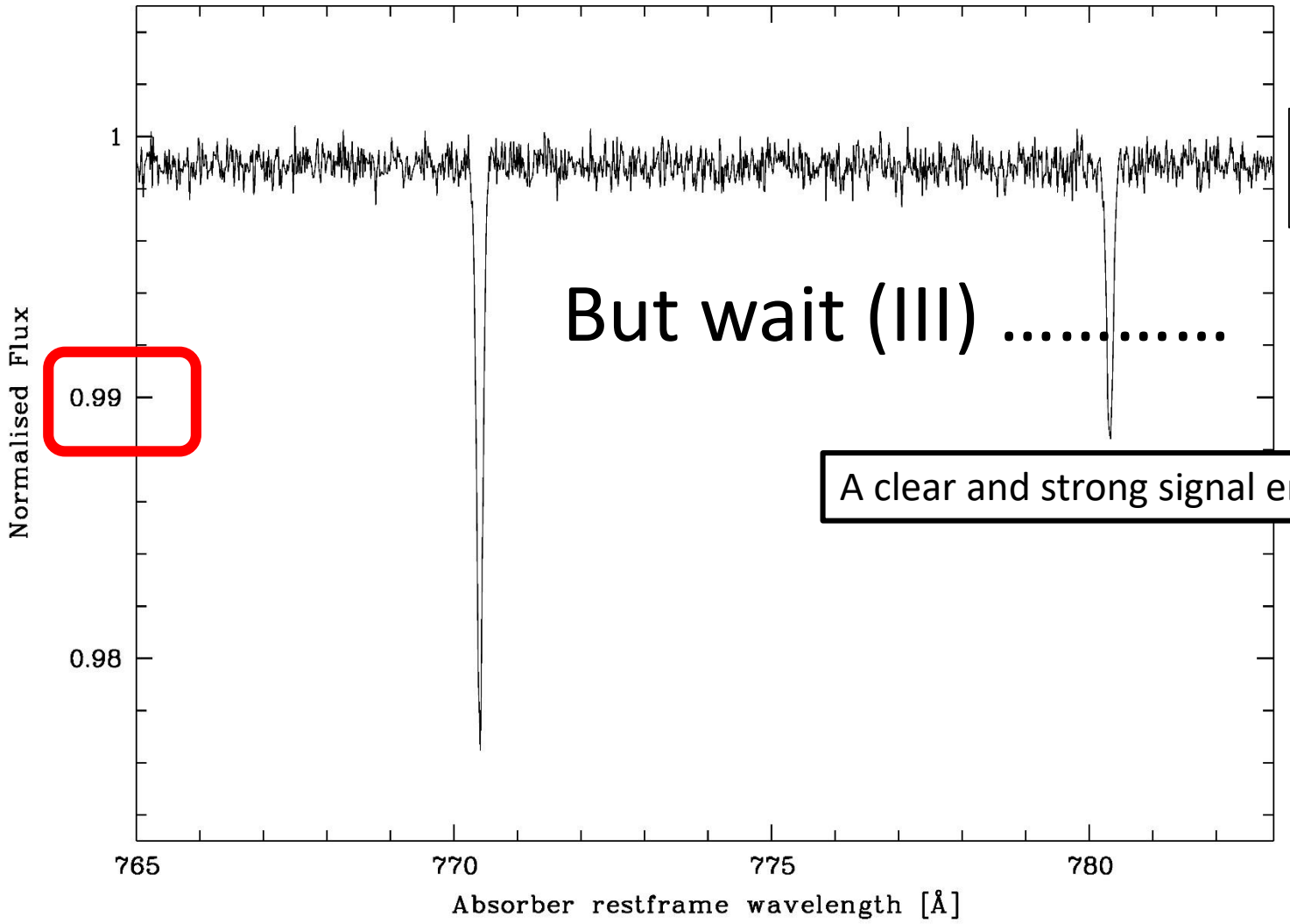
N = 1000

This is where the power of stacking comes to rescue.



N = 4000

We beat the noise !

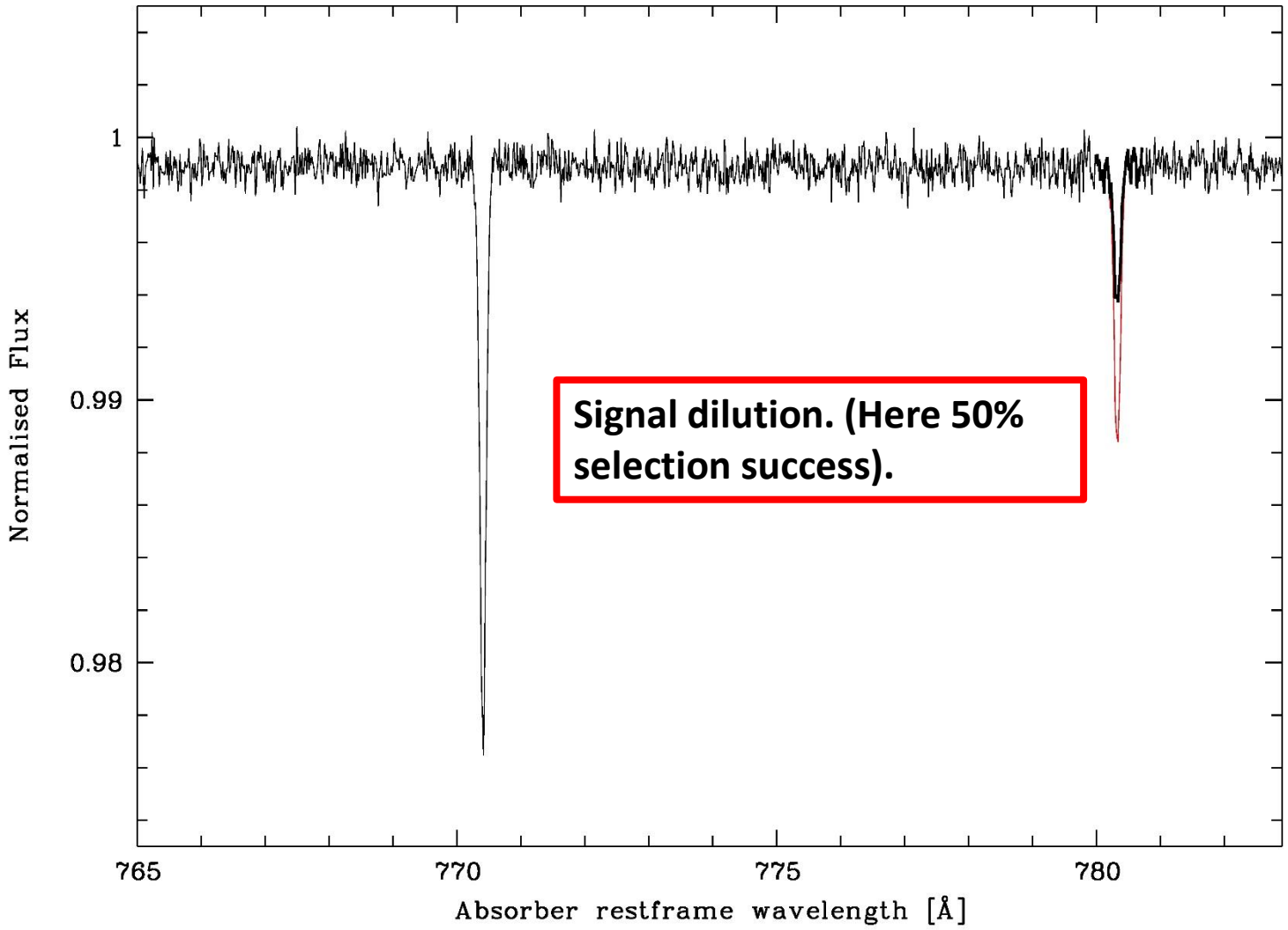


But wait (III) ……

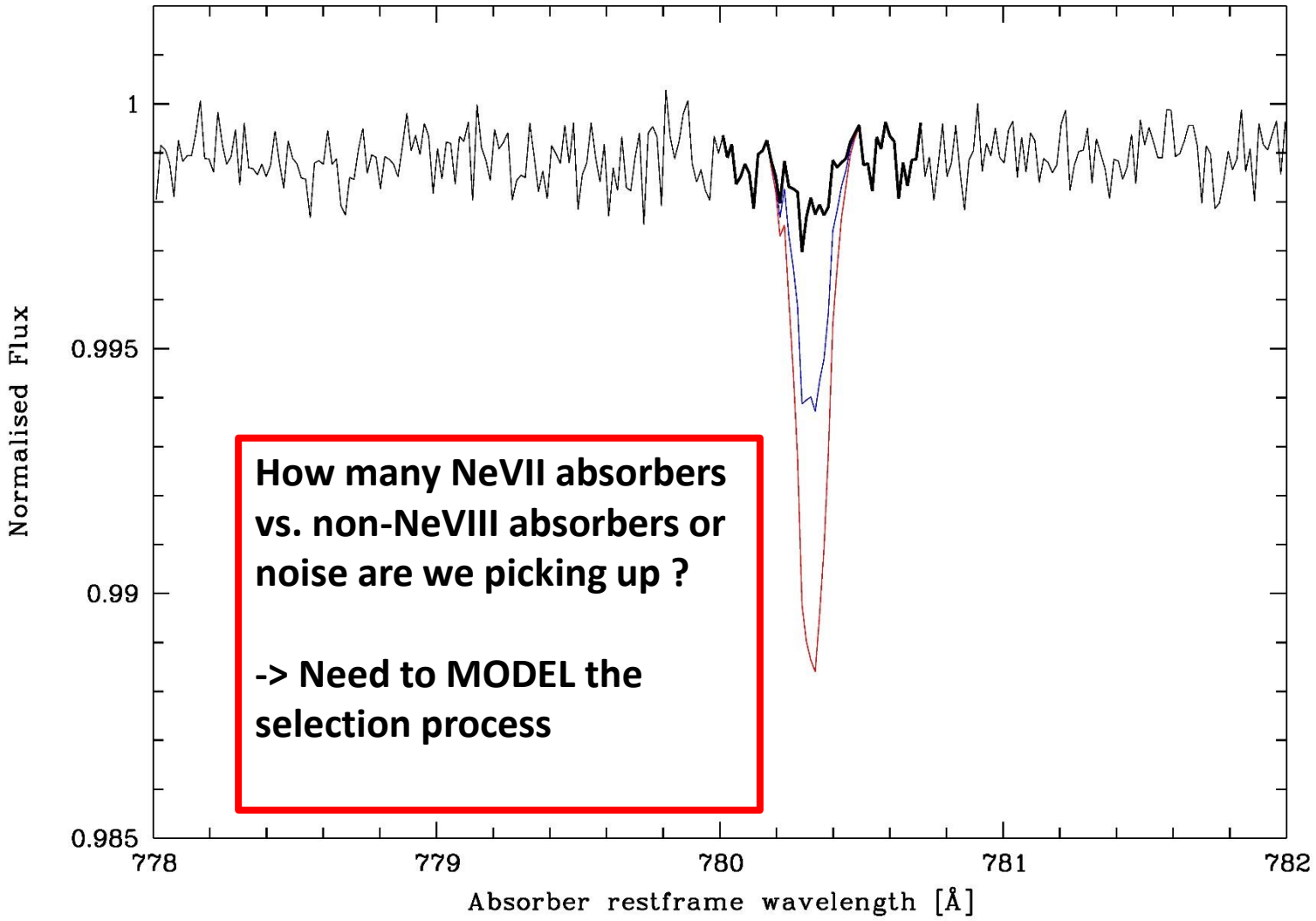
"Pseudo-continuum" not at flux of unity.

A clear and strong signal emerges.

Not all features are truly NeVIIIa. (That's the reason for the term 'agnostic'.)



We need to estimate the dilution. (That's where **all** the work is.)



We create mock spectra by modelling NeVIII and unrelated absorption plus noise, replicating the real data's flux distribution.

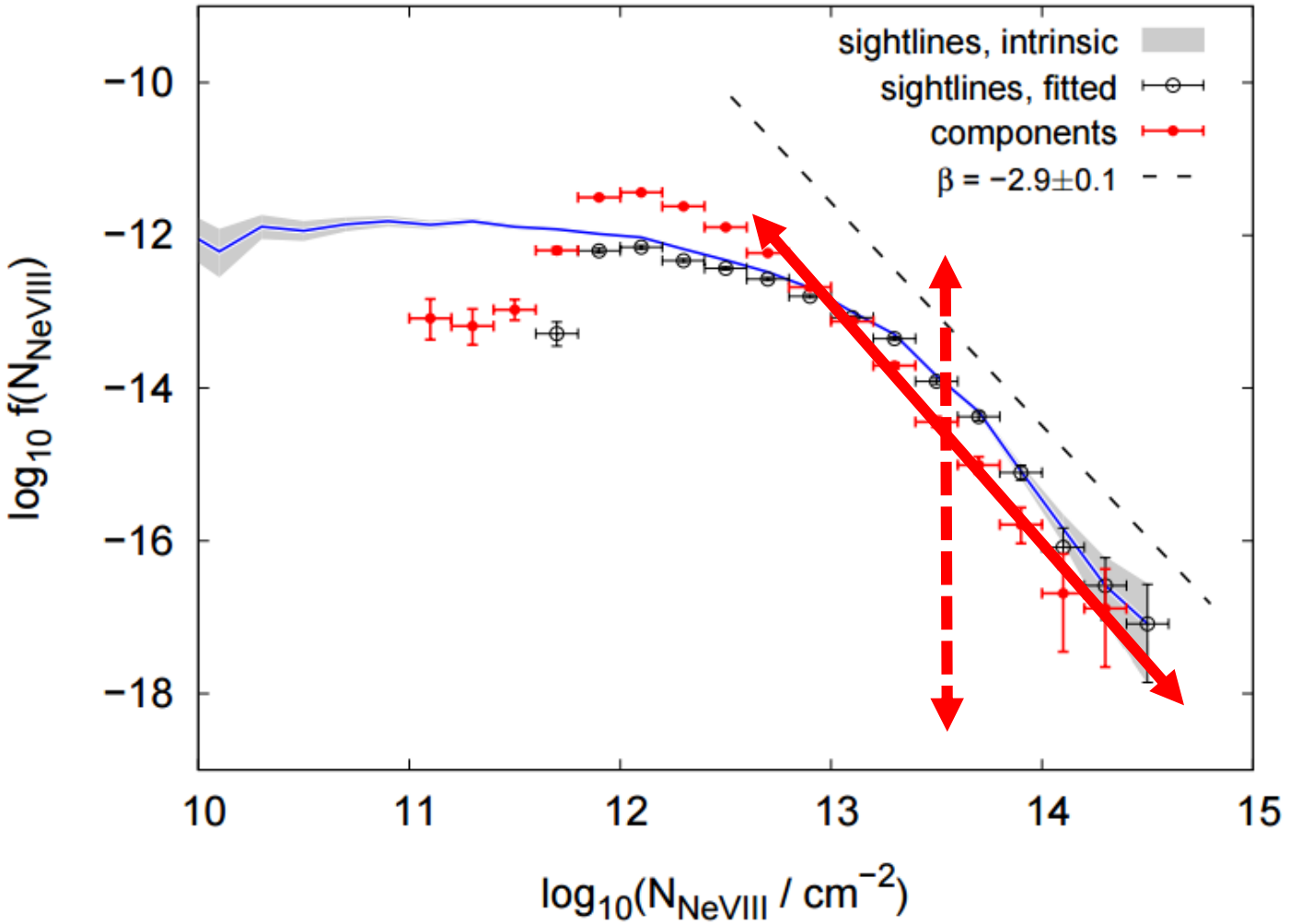
If you are REALLY interested in the somewhat tedious details, I am more than willing to talk your ear off……over a proper beverage !

0.0001

0.8 1 1.2

Transmitted Flux F

However, one detail is important : We model the distribution of column densities as unbroken power-law.



Tepper-Garcia 2013

We use a large coherently prepared low-z COS AGN sample.

An HST/COS Survey of the Low-Redshift IGM. I. Survey, Methodology, & Overall Results

Charles W. Danforth, (1), Brian A. Keeney (1), Evan M. Tilton (1), J. Michael Shull (1), Matthew Stevans (1, 2), Matthew M. Pieri (1, 3), John T. Stocke (1), Blair D. Savage (4), Kevin France (1), David Syphers (1), Britton D. Smith (1, 5), James C. Green (1), Cynthia Froning (1, 2), Steven V. Penton (1, 6), Steven N. Osterman (1) ((1) University of Colorado, Boulder, (2) University of Texas, Austin, (3) University of Portsmouth, (4) University of Wisconsin, Madison, (5) Royal Observatory, Edinburgh, UK, (6) Space Telescope Science Institute, Maryland)

(Submitted on 11 Feb 2014 (v1), last revised 10 Jul 2015 (this version, v2))

We use high-quality, medium-resolution {\it Hubble Space Telescope}/Cosmic Origins Spectrograph (HST/COS) observations of 82 UV-bright AGN at redshifts $z_{AGN} < 0.85$ to construct the largest survey of the low-redshift intergalactic medium (IGM) to date: 5343 individual extragalactic absorption lines in HI and 25 different metal-ion species grouped into 2610 distinct redshift systems at $z_{abs} < 0.75$ covering total redshift pathlengths $\Delta z_{HI} = 21.7$ and $\Delta z_{OVI} = 14.5$. Our semi-automated line-finding and measurement technique renders the catalog as objectively-defined as possible. The cumulative column-density distribution of HI systems can be parametrized $dN(>N)/dz = C_{14}(N/10^{14} cm^{-2})^{-(\beta-1)}$, with $C_{14} = 25 \pm 1$ and $\beta = 1.65 \pm 0.02$. This distribution is seen to evolve both in amplitude, $C_{14} \sim (1+z)^{2.0 \pm 0.1}$, and slope $\beta(z) = 1.73 - 0.26z$ for $z < 0.47$. We observe metal lines in 427 systems, and find that the fraction of IGM absorbers detected in metals is strongly dependent on N_{HI}. The distribution of OVI absorbers appear to evolve in the same sense as the Lya forest. We calculate contributions to Ω_b from different components of the low-z IGM and determine the Lya decrement as a function of redshift. IGM absorbers are analyzed via a two-point correlation function (TPCF) in velocity space. We find substantial clustering of \HI\ absorbers on scales of $\Delta v = 50 - 300$ km/s with no significant clustering at $\Delta v > 1000$ km/s. Splitting the sample into strong and weak absorbers, we see that most of the clustering occurs in strong, $N_{HI} > 10^{13.5} cm^{-2}$, metal-bearing IGM systems. The full catalog of absorption lines and fully-reduced spectra is available via MAST as a high-level science product at this http URL

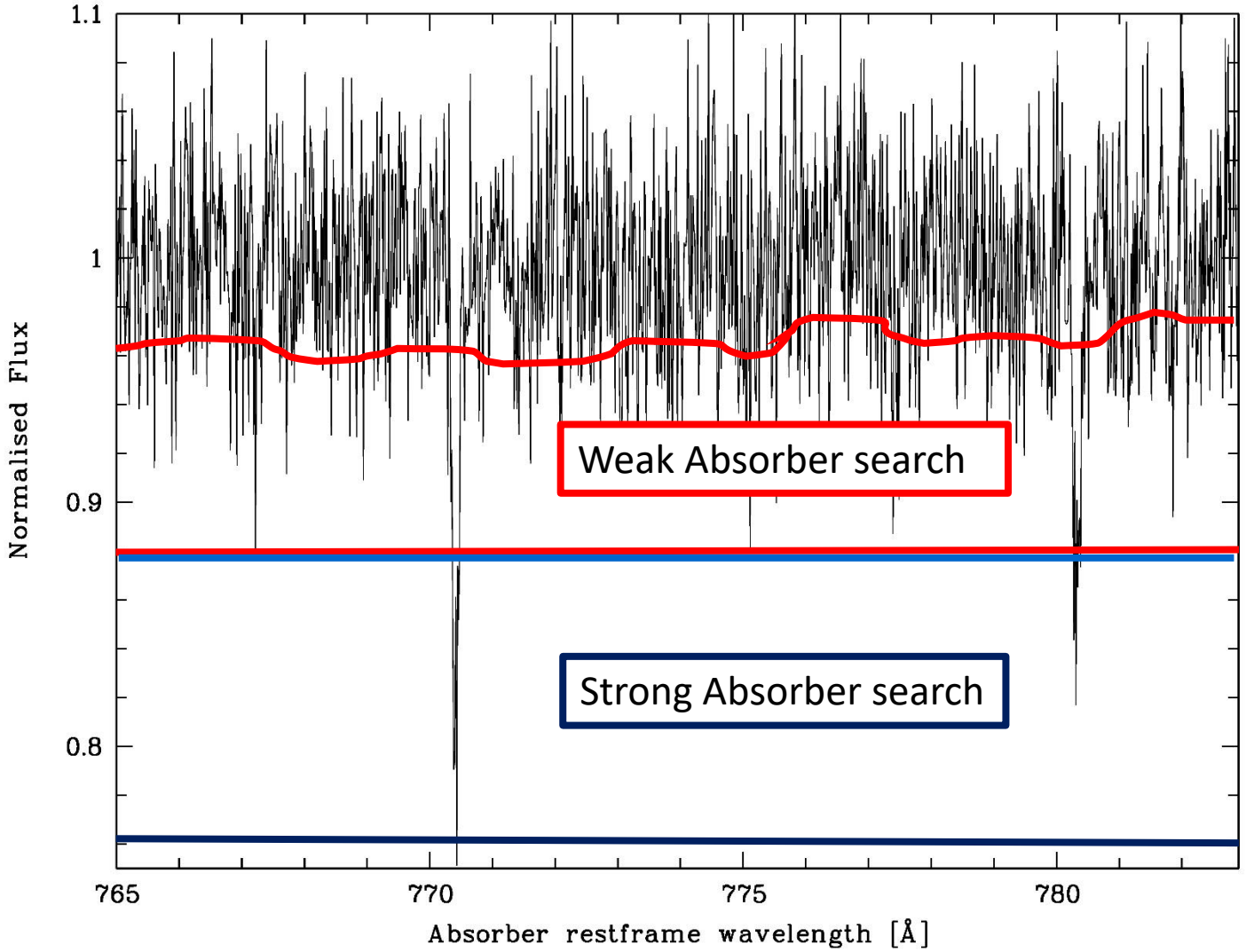
Comments: This is the heavily-revised version (circa July 2015) of the original paper and archive (circa Feb 2014). Resubmitted to ApJ. 26 pages in ApJ format, 16 figures, and 7 tables in one heck of a paper. Associated MAST high-level science product at this http URL

For our purposes : 26 sightlines (added a few higher-z objects), Δz (NeVIII) = 7.83

Observed frames : 1150 – 1750 Å

Altogether : > 20 000 pixels (rebinned)

We select pixels agnostically – only two criteria are needed.

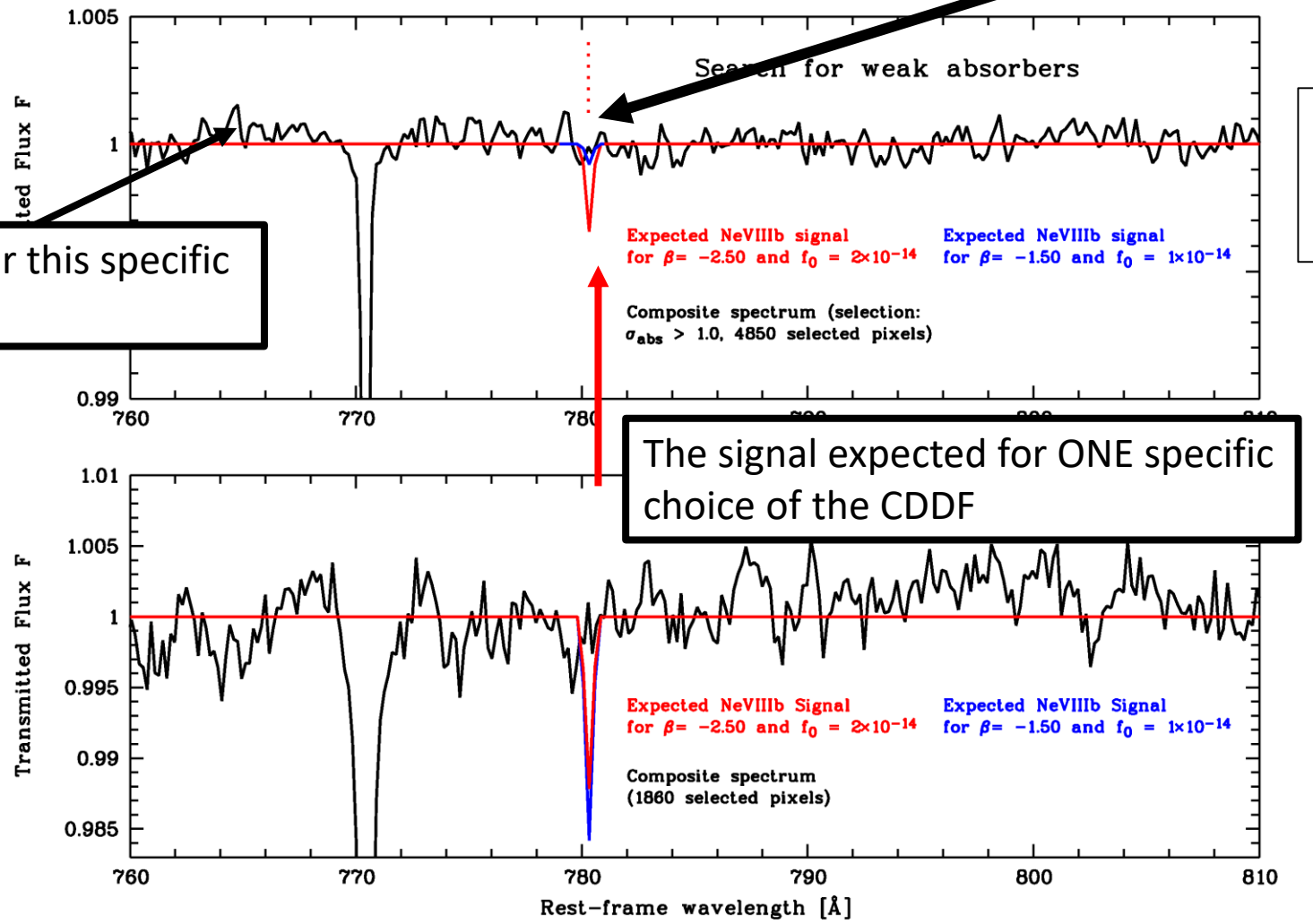


Significance limit : σ(abs) > limit

Low flux limit : f > f_{limit}

Then we stack……and…..

Then we stack……and….. come up with a non-detection !

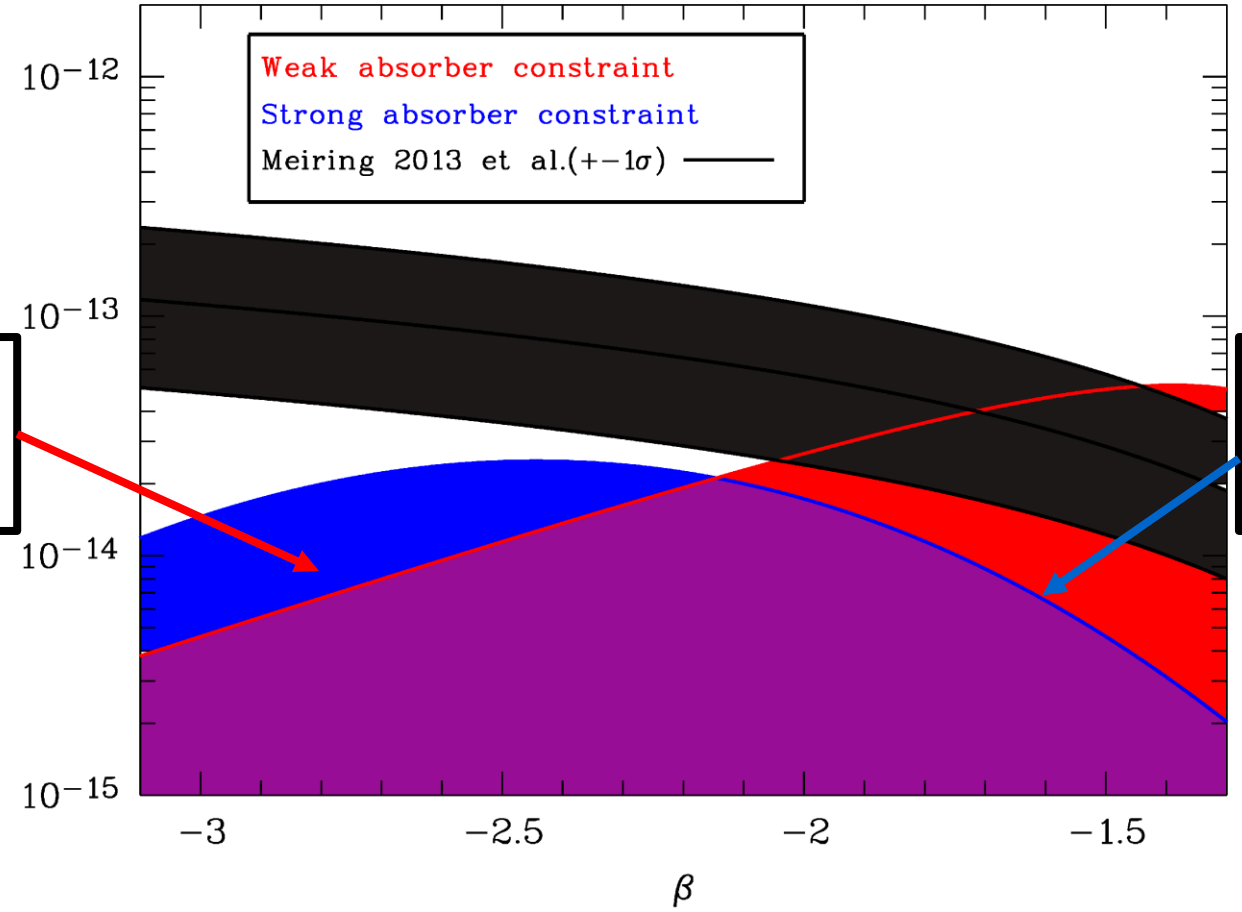


This is the composite for this specific choice of CDDF.

The signal expected for ONE specific choice of the CDDF

With such an exquisite S/N, this is a very meaningful non-detection.

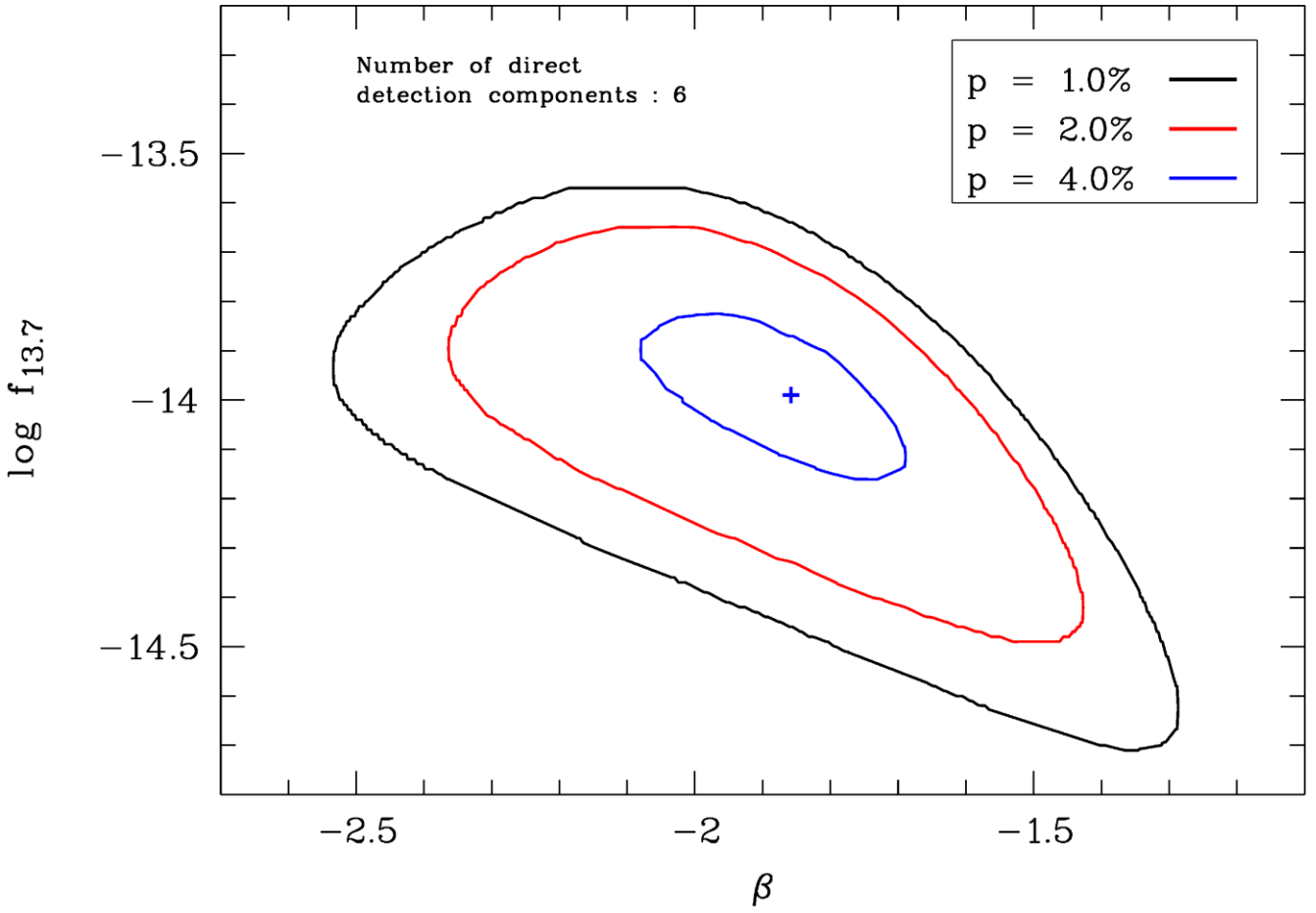
We can place the currently tightest limits on the NeVIII absorber population.



Steep slopes :
Beware of producing too many weak absorbers !

Shallow slopes :
Beware of producing too many strong absorbers !

Combining existing direct detections with our non-detection via agnostic stacking yields the CCDF with the highest likelihood.



This constitutes the **first MEASUREMENT** of the cosmological incidence rate of the NeVIII population !

log f_13.7 = -13.99(+0.20-0.23)
β= -1.86(+0.18-0.26)

Yields :
dn/dz (log N>13.7) = 1.38(+0.97-0.82)

The cosmic density for NeVIII we derive is lower than predicted by simulations. The estimated baryon density of the NeVIII-bearing gas constitutes 4% of the total baryonic mass.

- Integrating the CCDF yields the **cosmic density** :
  - Ω_{NeVIII} (12.3 < log N < 15.0) = 2.2(+1.6-1.2) x 10^{-8}
  - Compare to Rahmati et al. (EAGLE simulation) :
  - Ω_{NeVIII} (12.3 < log N < 15.0) ~ 6.5 x 10^{-8}

- Estimating the **baryonic mass density** depends on metallicity, ionization fraction, and relative metal abundance :
  - Ω_b = 1.8 x 10^{-3} x $\frac{0.13}{f(\frac{NeVIII}{Ne})}$ x ($10^{[Ne/H]}$)$^{-1}$ = 4% of Planck Collaboration's 2016 Ω_b

Summary

(i.e. the essentials in case your eyelids were too heavy or you were daydreaming about your favourite team's World Cup Glory)

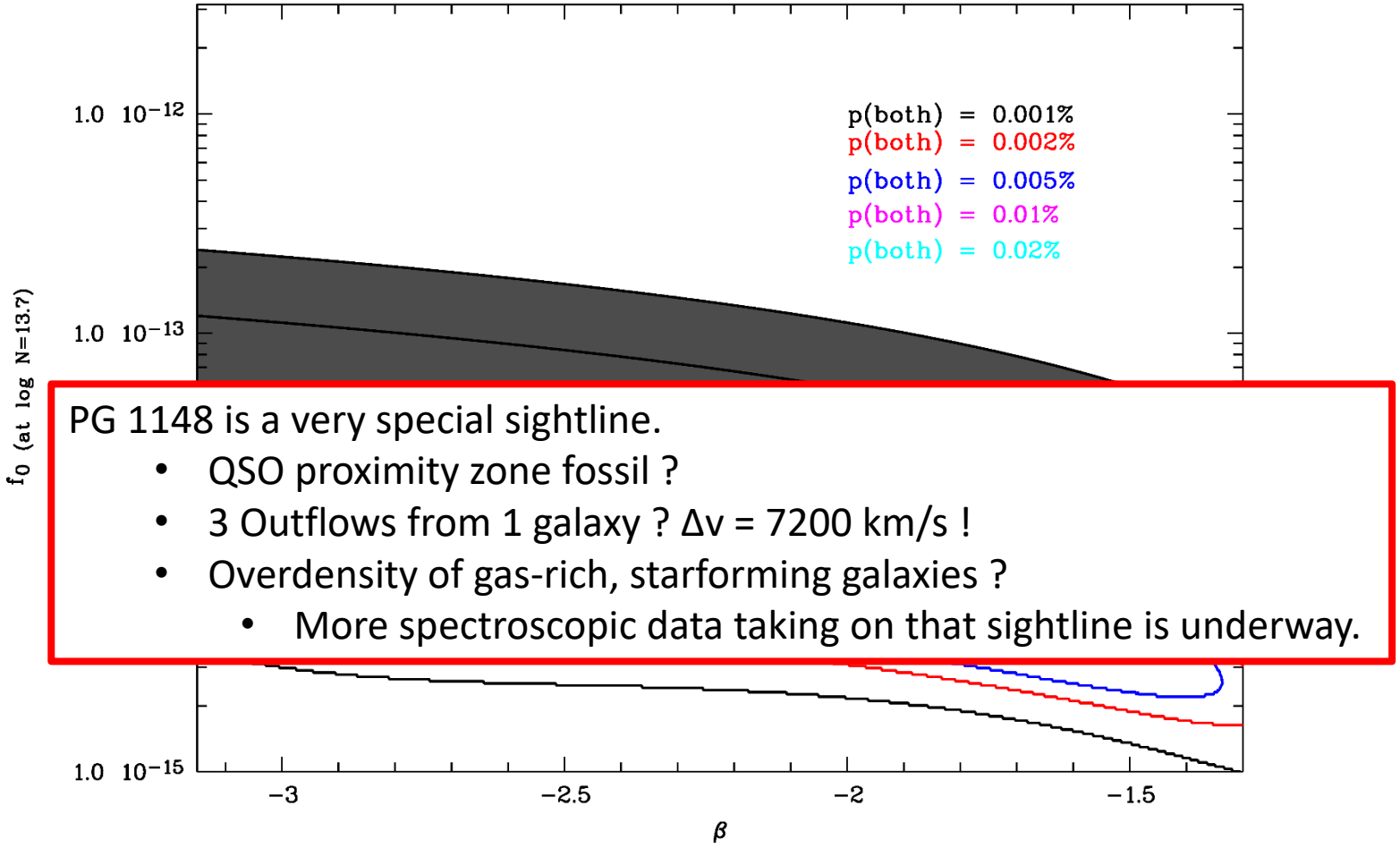
- **Agnostic Stacking** :
  - A method to **statistically** characterise widespread absorber populations with individually weak signals relinquishing the need to securely identify individual absorbers
  - Relies upon doublet nature of metal lines
  - Requires modelling of underlying population
  - Very **versatile** (have not elaborated on this aspect here)
    - Plans : Mg X (almost done), OVI (to complement existing surveys) ; NV (notoriously difficult), weak HI
    - see Pieri et al. 2014 for another application

- **NeVIII absorbers** at z~0.85 are **rare beasts.** (Even the weak ones.)
  - Meiring+ 2013 : PG1148 very unusual, interesting sightline
  - Combining direct detection statistics with our non-detection yields **best estimate** for CDDF -> cosmic density of NeVIII appears to be lower than predicted in current simulations
  - Estimate of cosmic baryon density of NeVIII-bearing-gas : 4% of Planck Collaboration's 2016 Ω_b

- See : **Frank et al., 2018, MNRAS*, 476, 1356*** for full details

Extra slides begin here – if needed

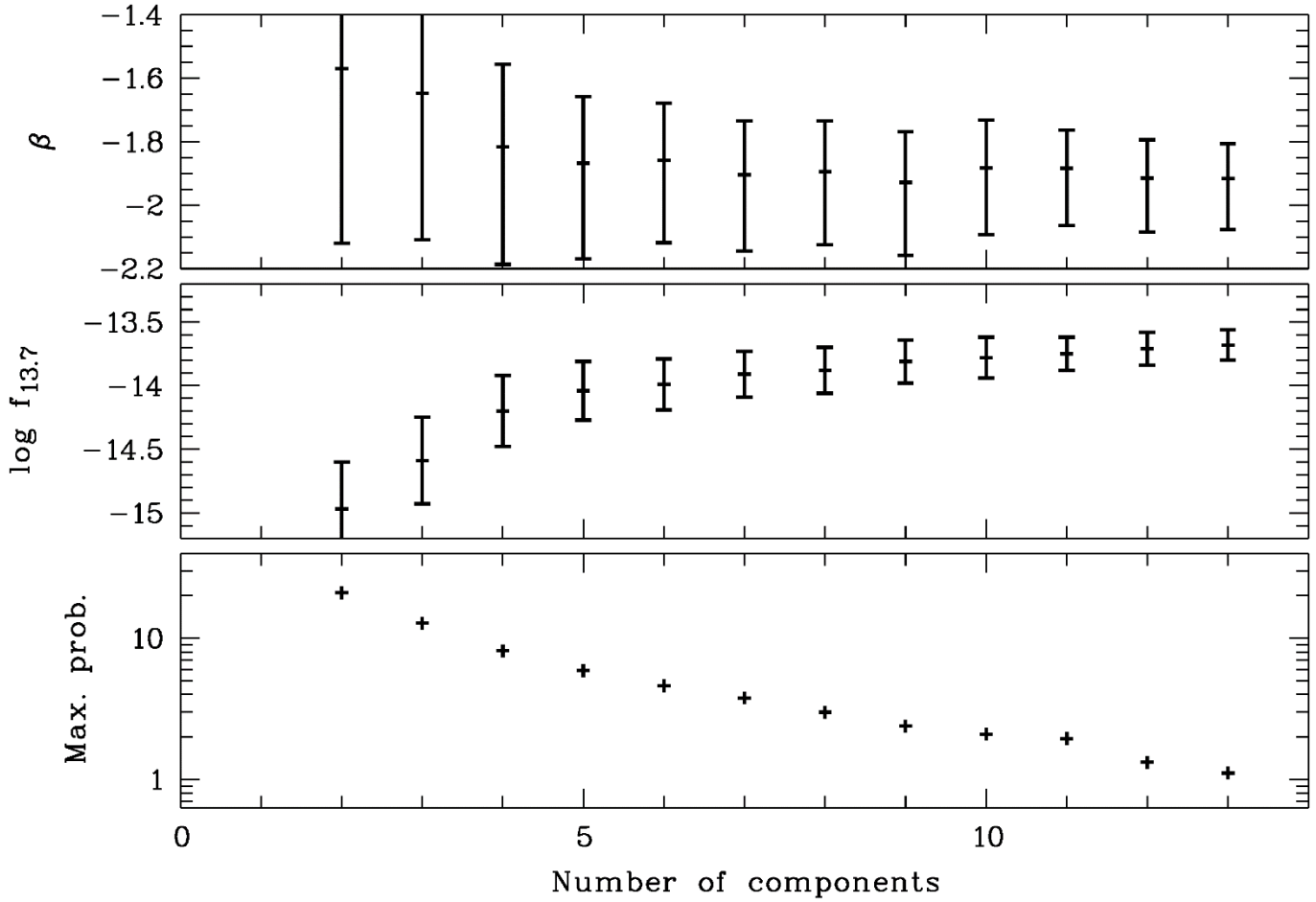
Revisiting PG1148 :
Can we have 3 absorbers in one sightline & still see nothing in the composite ? Yes, but……..



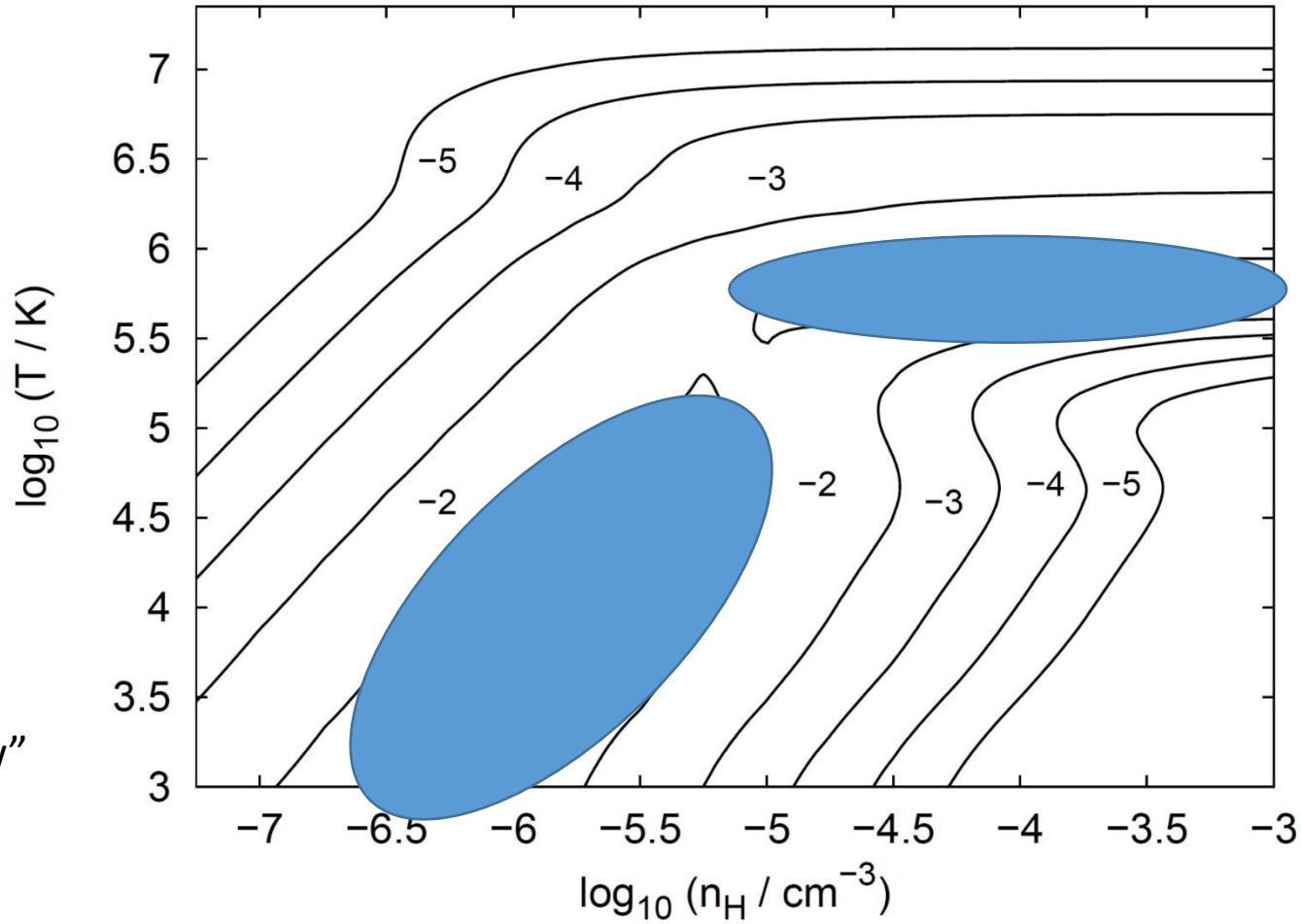
PG 1148 is a very special sightline.

- QSO proximity zone fossil ?
- 3 Outflows from 1 galaxy ? Δv = 7200 km/s !
- Overdensity of gas-rich, starforming galaxies ?
  - More spectroscopic data taking on that sightline is underway.

The slope of the CDDF is well constrained, regardless of the number of confirmed “components” in directly detected absorbers.



There are two paths to NeVIII.

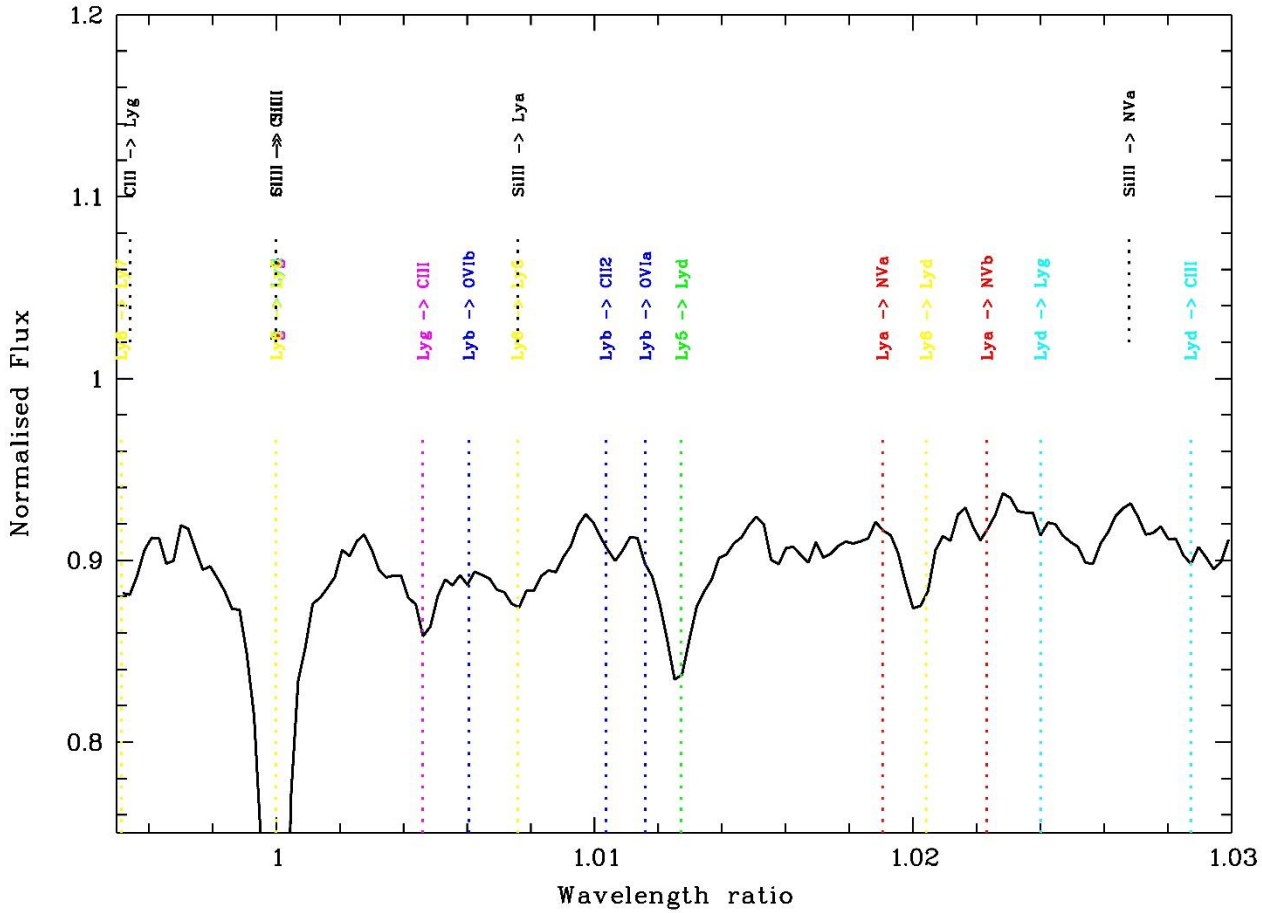


Collisionally ionised “high” density, $T>10^5$ K

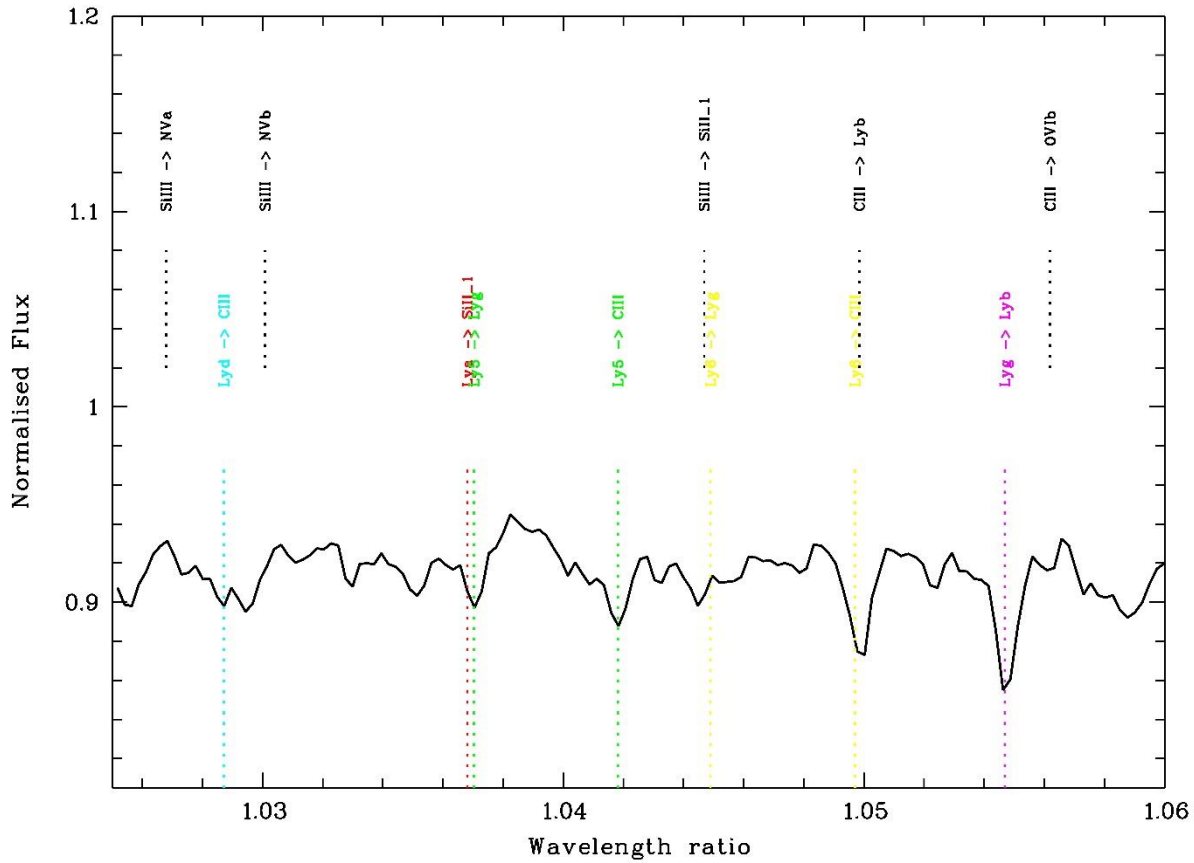
Photo-ionised “low” density, $T<10^5$ K

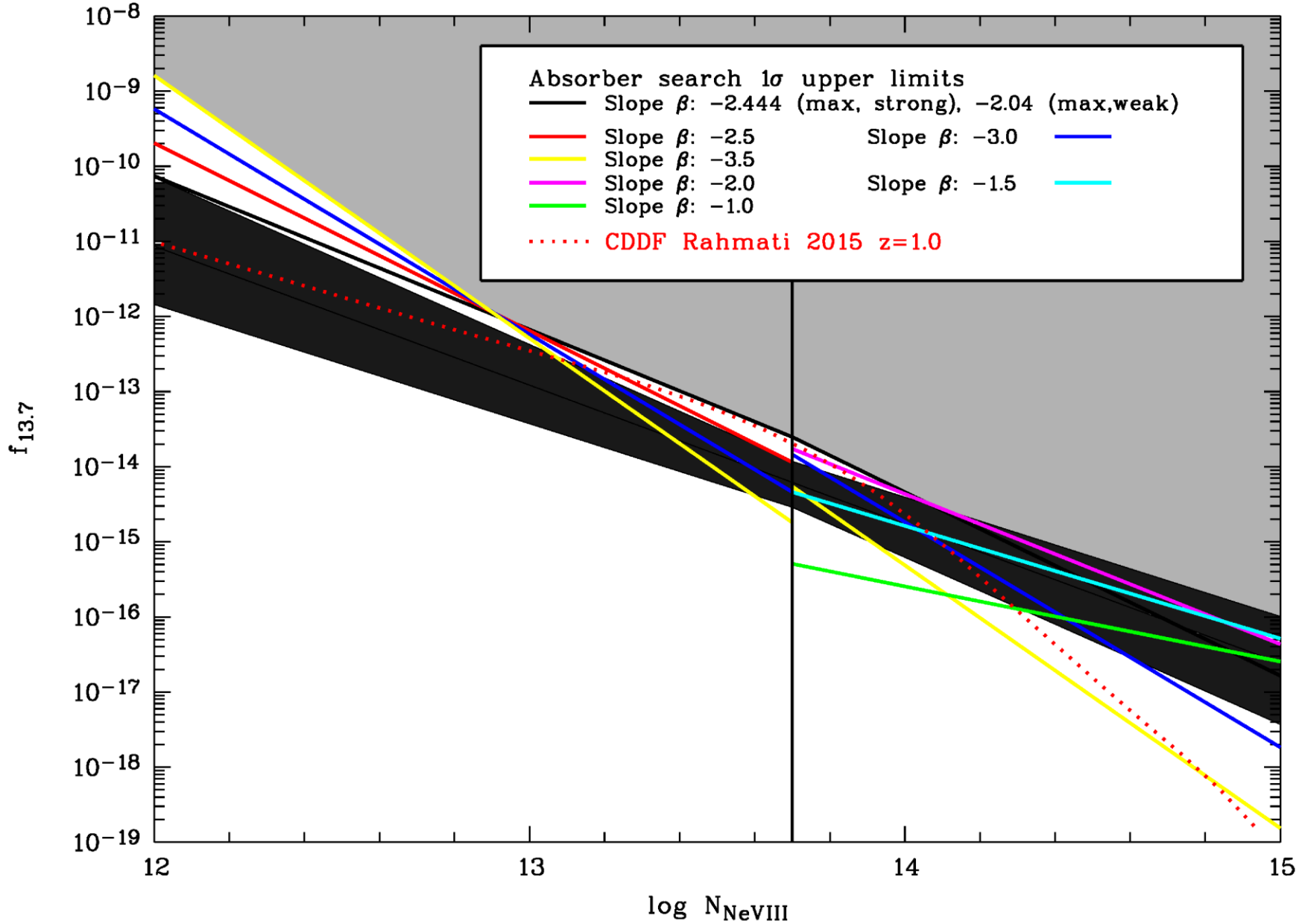
Tepper-Garcia 2013

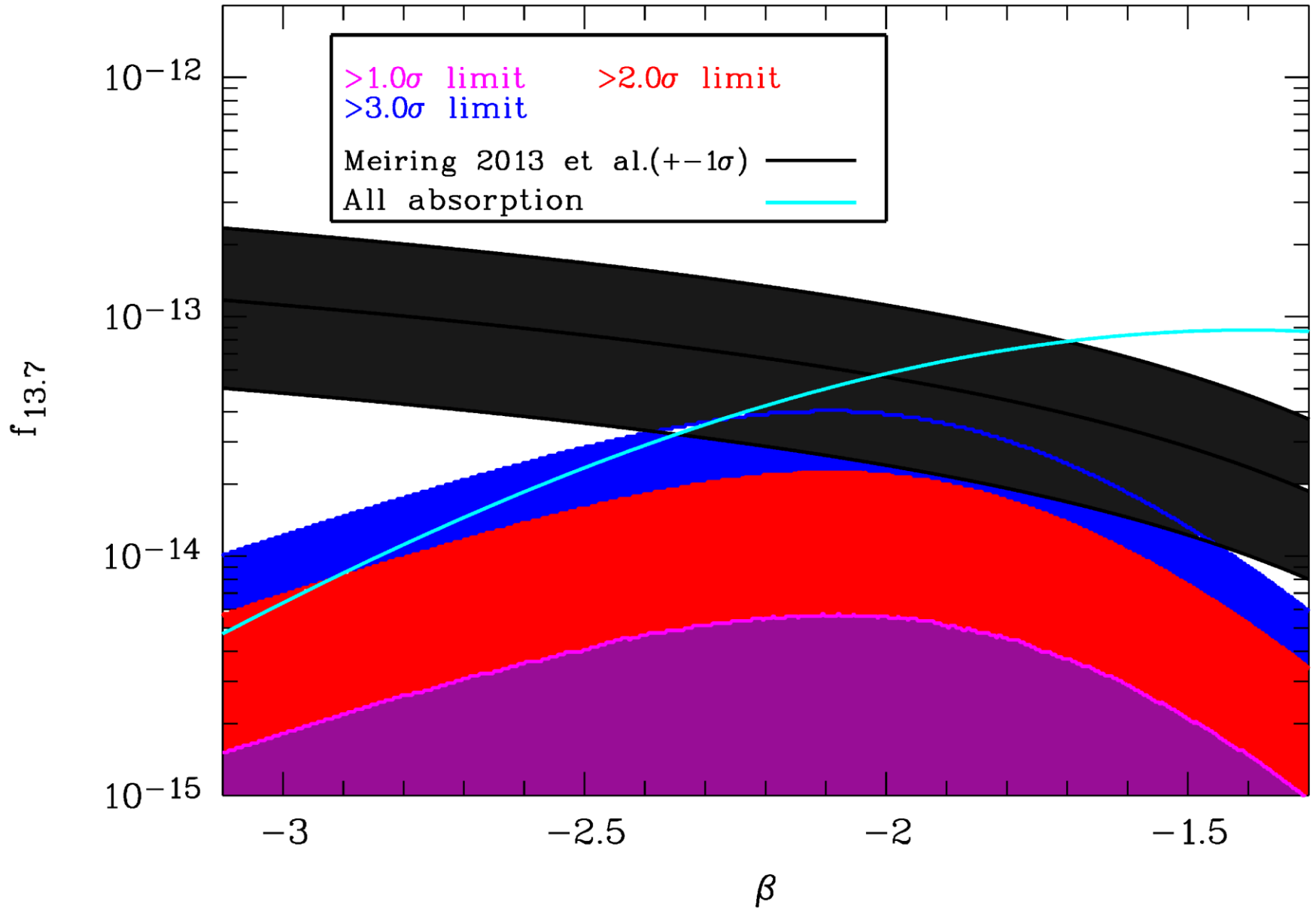
Testing the procedures for stronger and more abundant absorbers (I)



Testing the procedures for stronger and more abundant absorbers (II)




Absorber search 1σ upper limits
Slope β: −2.444 (max, strong), −2.04 (max,weak)
Slope β: −2.5
Slope β: −3.5
Slope β: −2.0
Slope β: −1.0
Slope β: −3.0
Slope β: −1.5
CDDF Rahmati 2015 z=1.0
f13.7
log NNeVIII
10−8
10−9
10−10
10−11
10−12
10−13
10−14
10−15
10−16
10−17
10−18
10−19
12
13
14
15


>1.0σ limit
>2.0σ limit
>3.0σ limit
Meiring 2013 et al.(+−1σ)
All absorption
10−12
10−13
10−14
10−15
f13.7
−3
−2.5
−2
−1.5
β

Data quality after rebinning