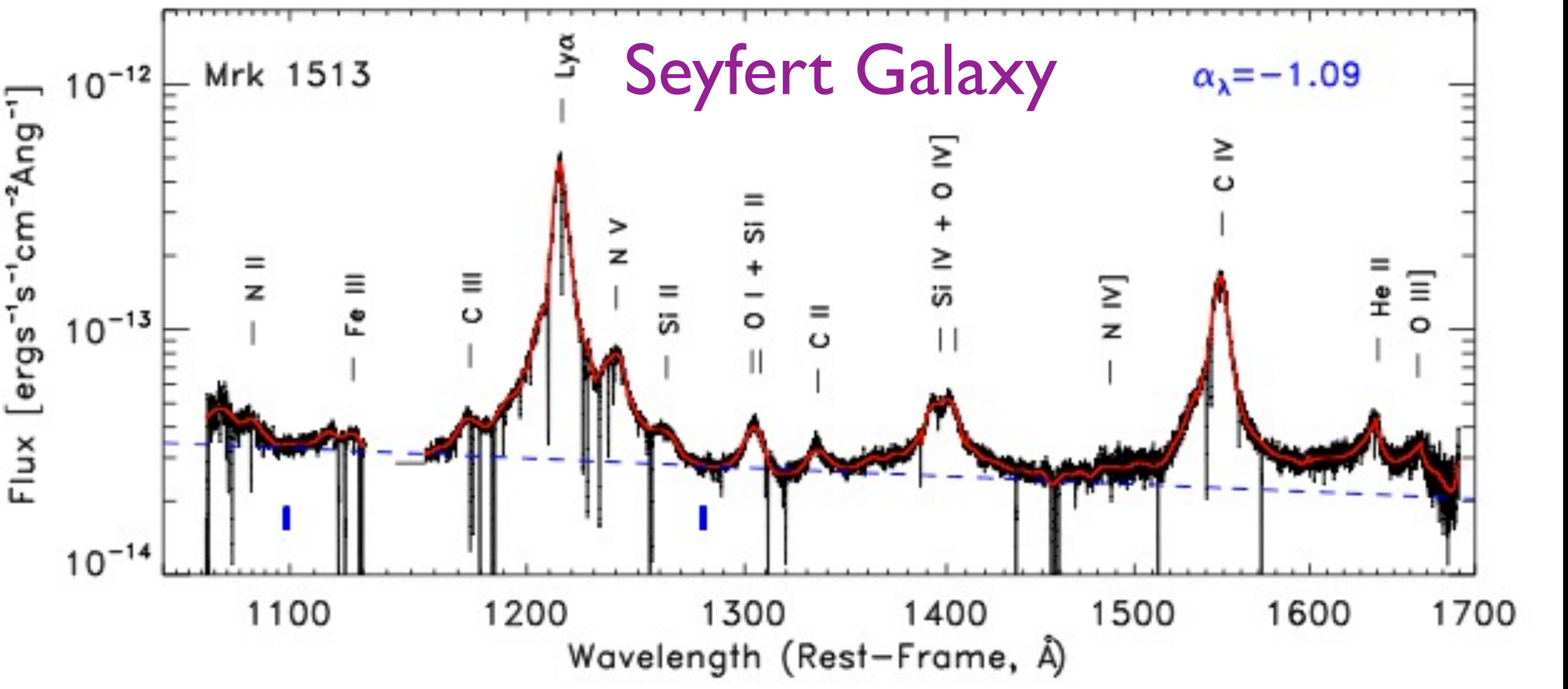
New Results from the Cosmic Origins Spectrograph

Michael Shull
(Univ of Colorado)

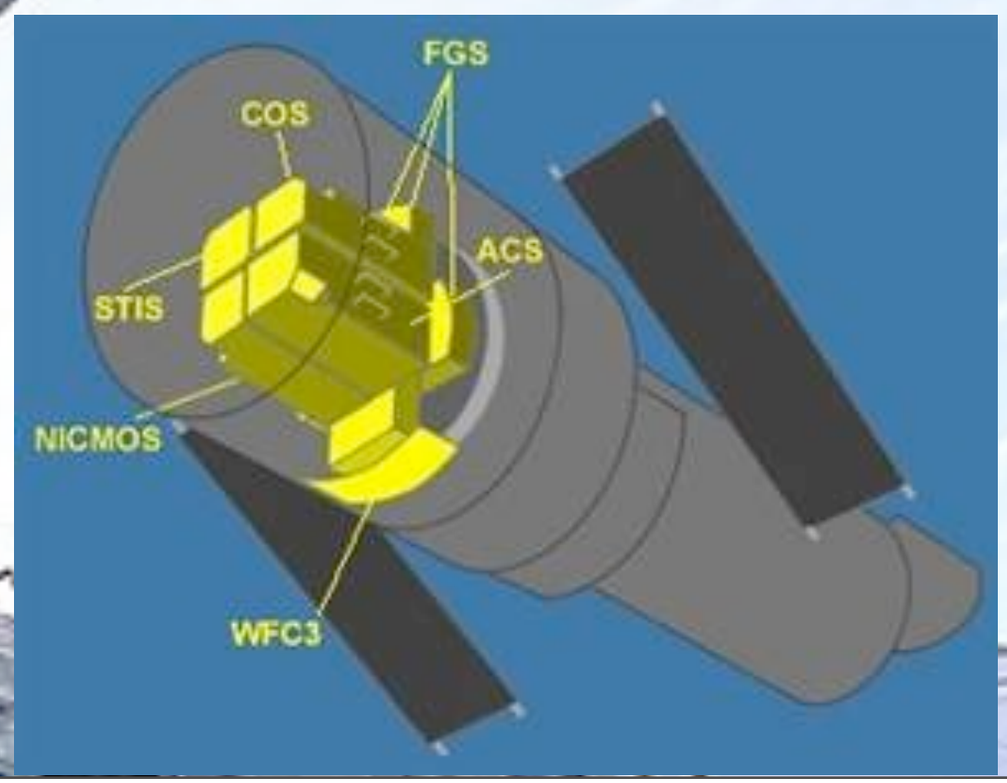
UC Berkeley - Nov 8, 2012
Astrophysics Colloquium




May 2009


Hubble
Servicing
May 2009
Two New
Instruments
WFC3 & COS

Installing the Cosmic Origins Spectrograph



Highlights of recent COS results:

(1) Low-redshift Intergalactic Medium (IGM)

"missing baryons"	Lyα and O VI
"warm-hot IGM"	Lyα, O VI, Ne VIII
"metal evolution"	C IV, Si IV, O VI

(2) QSO Composite Spectrum (lines, UV continua)

(3) He II epoch of reionization (z = 2.5-3.2)

Why do we care about the IGM?

- Probably contains 50 - 90% of baryons

- Source of gas for new star formation
(Low-metallicity infall to galaxies)

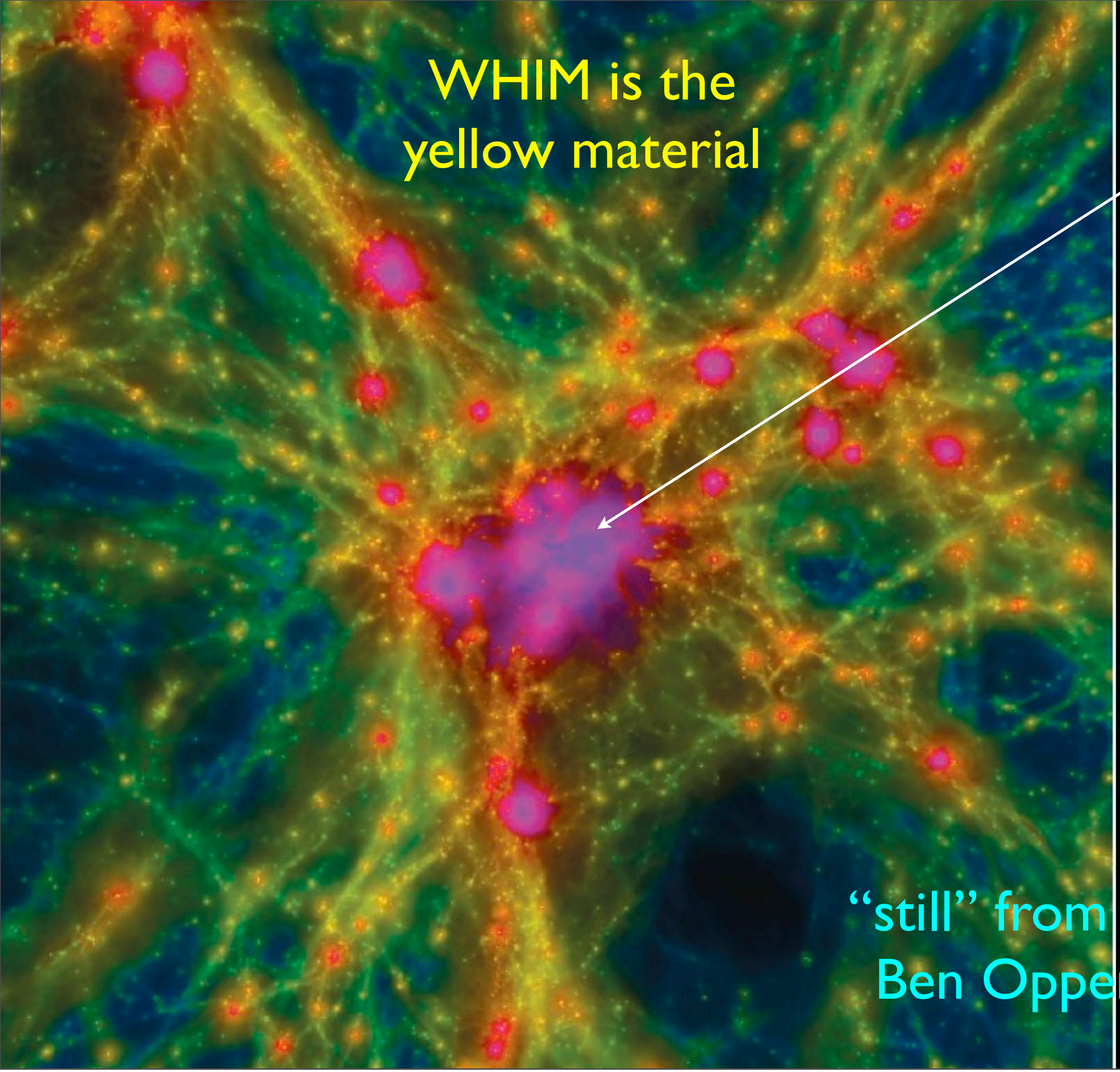
- Fossil record of "feedback" & reionization
(near-pristine matter in Cosmic Web)

Feedback from Galaxy Formation:

Ionizing Radiation

Kinetic Energy & Heat

Heavy Elements into CGM and IGM

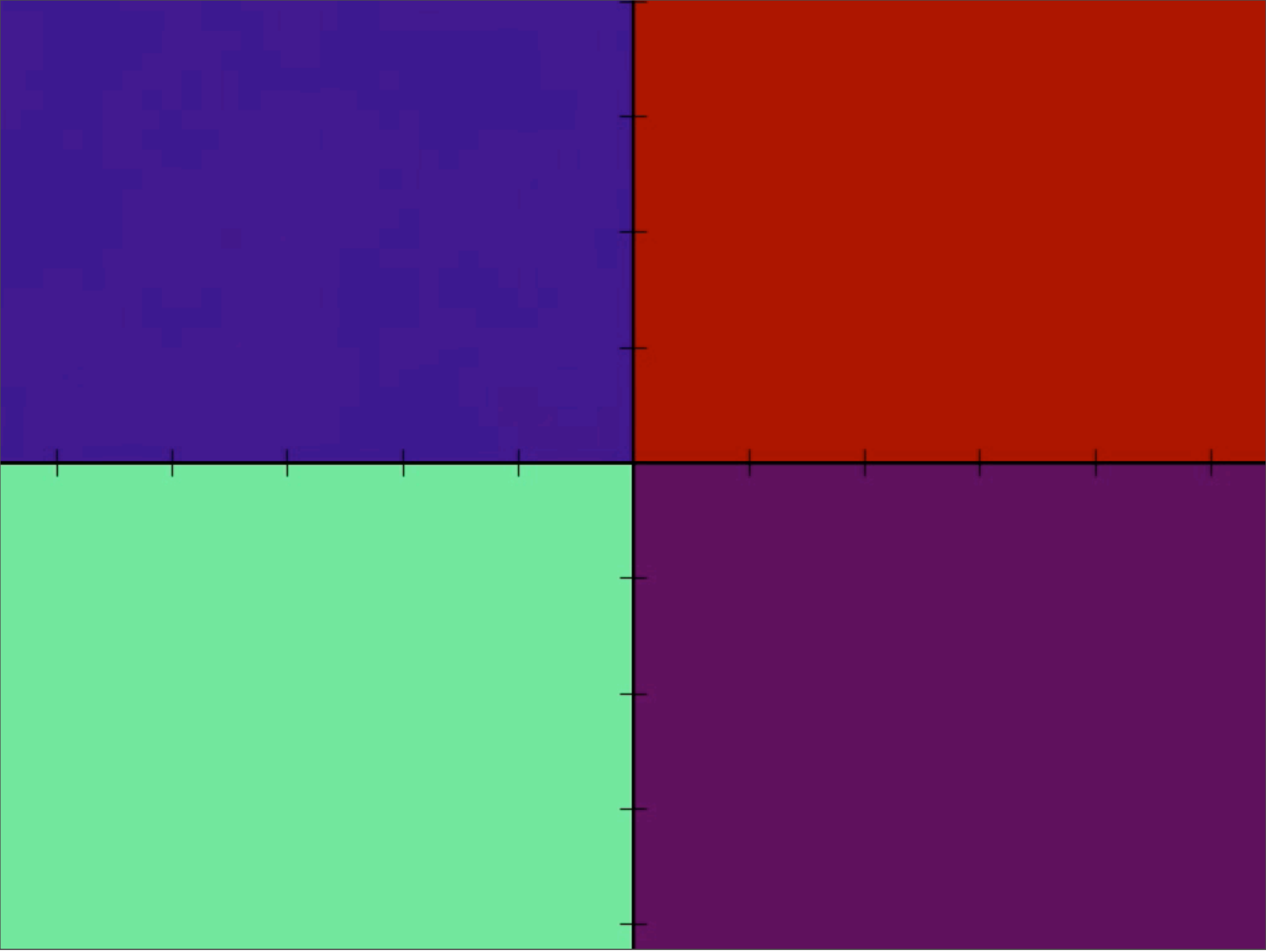


Regions of feedback

Metals injected unmixed

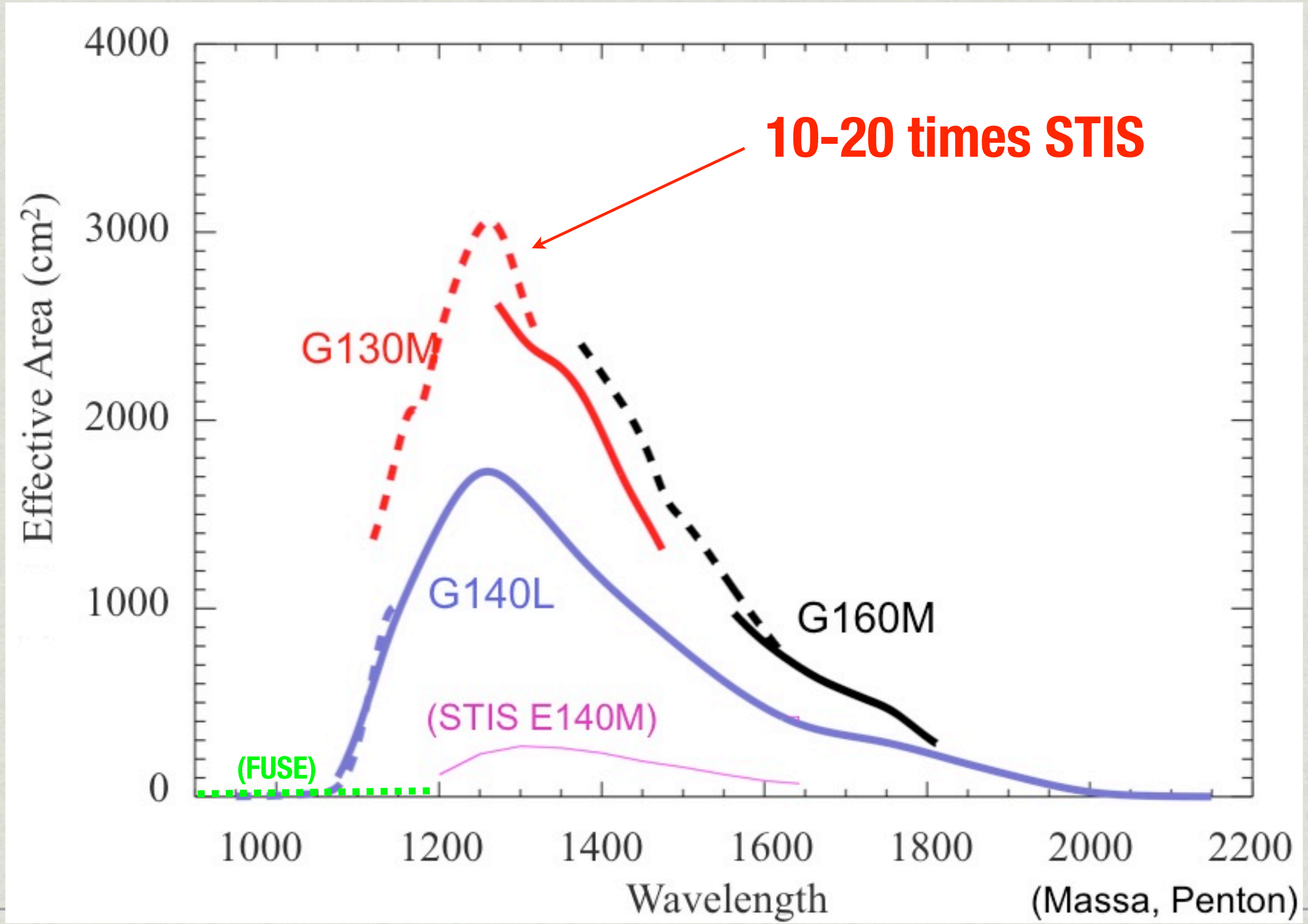
Possible overcooling

"still" from movie by Ben Oppenheimer



Saturday, November 10, 2012

COS Detector Performance



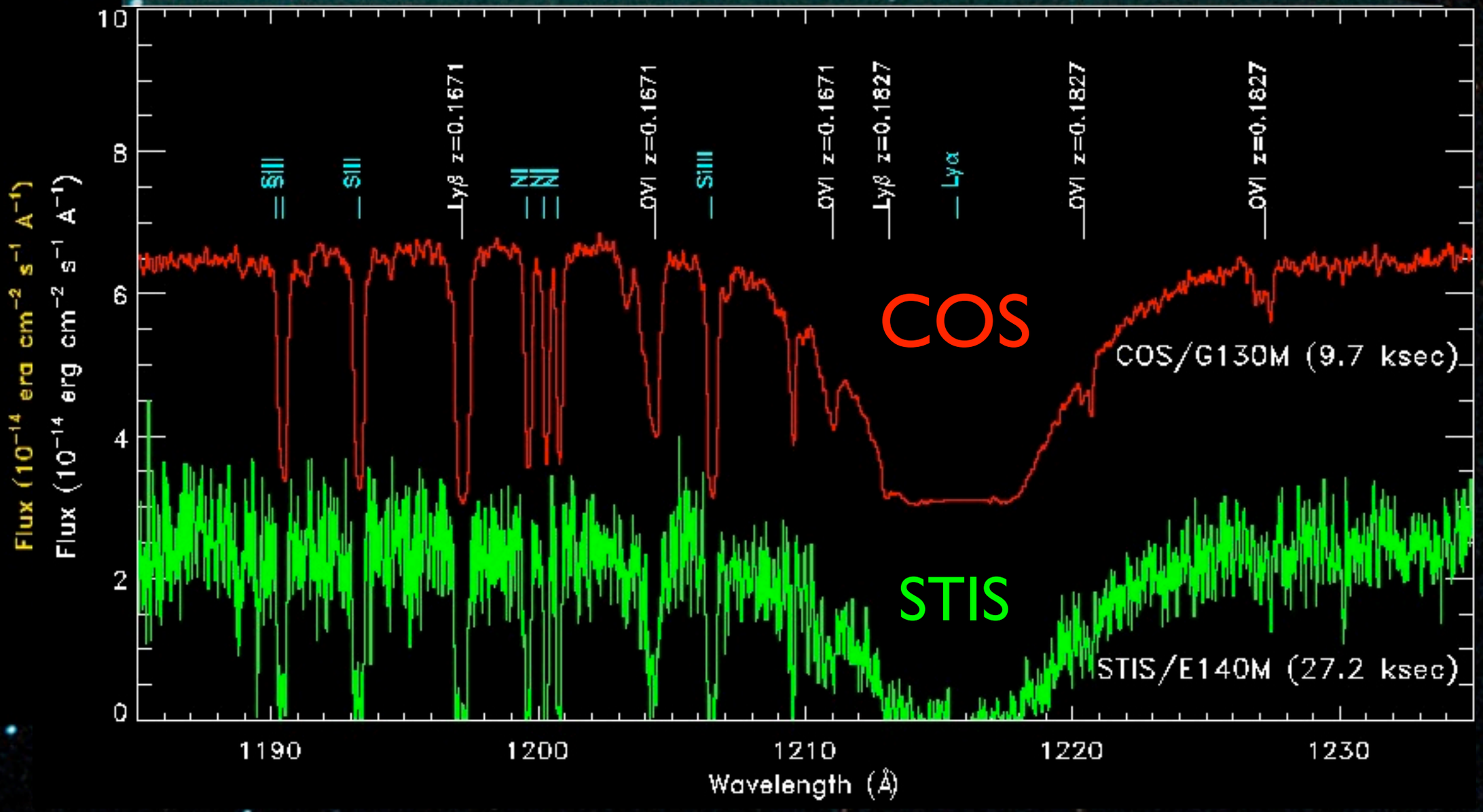
COS can get S/N = 50

PKS 0405-123

Gas absorption in Intergalactic Medium (IGM)

— ~~Oxygen~~ OVI

— ~~Hydrogen~~ LyB

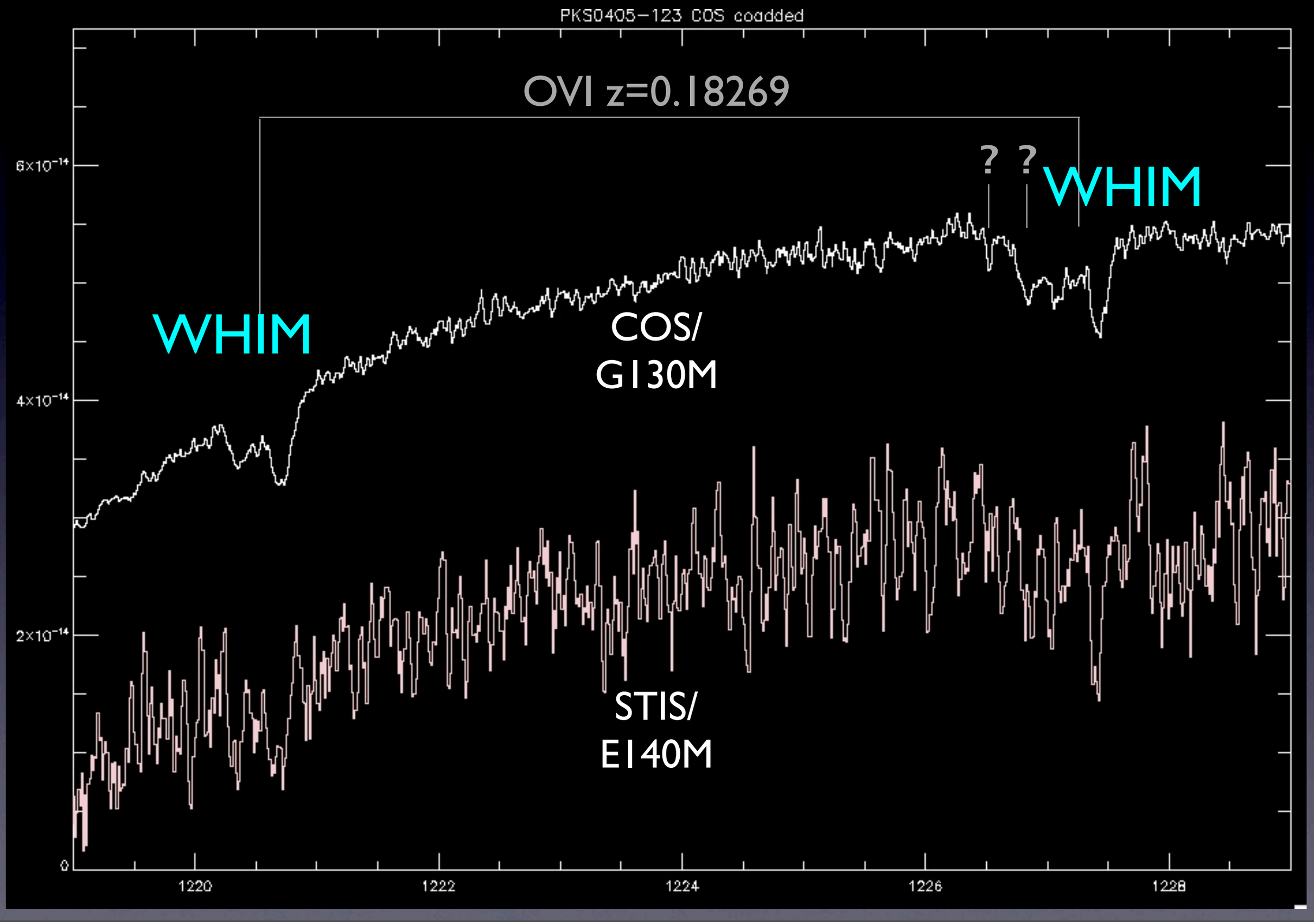


Wavelength (Ångstroms)

Hubble Space Telescope • COS

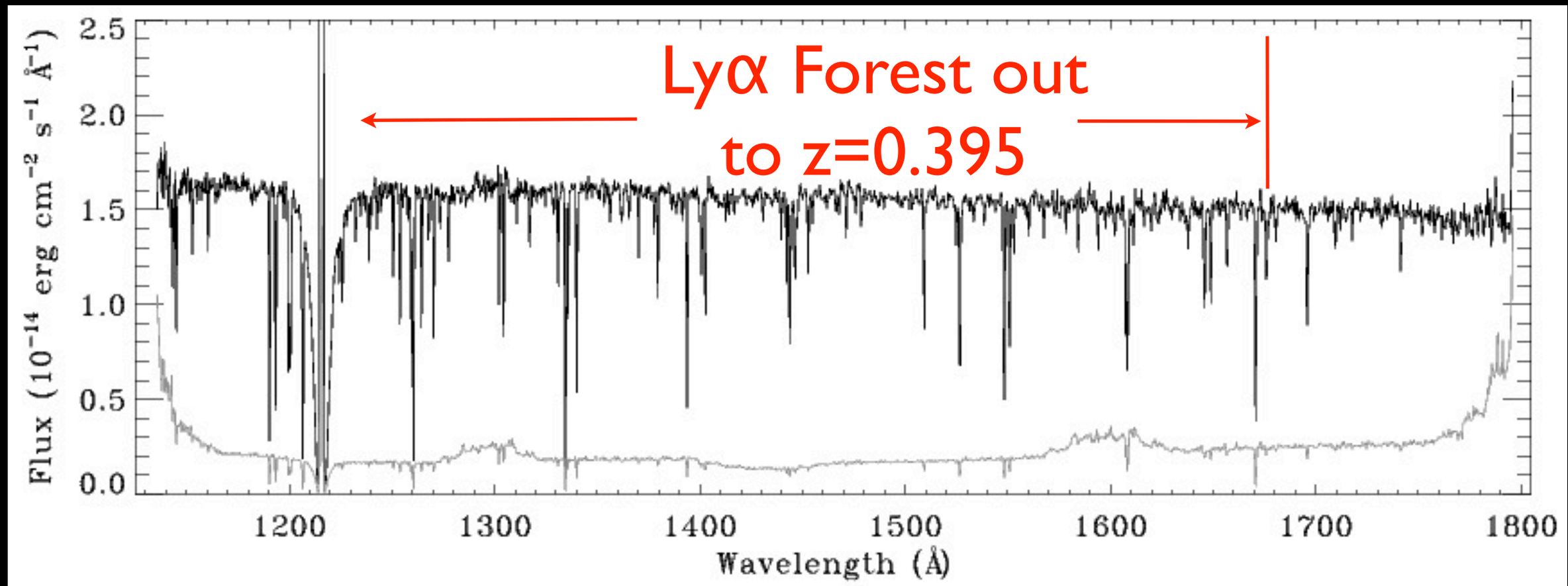
NASA, ESA, the Hubble SM4 ERO Team, and DSS
STScI-PRC09-25g

COS easily detects O VI at z > 0.10



BL Lac Redshifts from Lyα Forest

IES 1553+113 (3 orbits, COS/G130M+G160M)



- Featureless AGN continuum → unknown redshift
- 41 intervening Lyα absorbers along sight line (5 OVI abs)
- first direct redshift limit: $z_{AGN} \geq 0.395$ based on IGM systems

Gamma-ray blazar at z > 0.4 Danforth et al. 2010

Temperature
(Shock-Heating)

$V_{200} = Vs / 200$ km/s

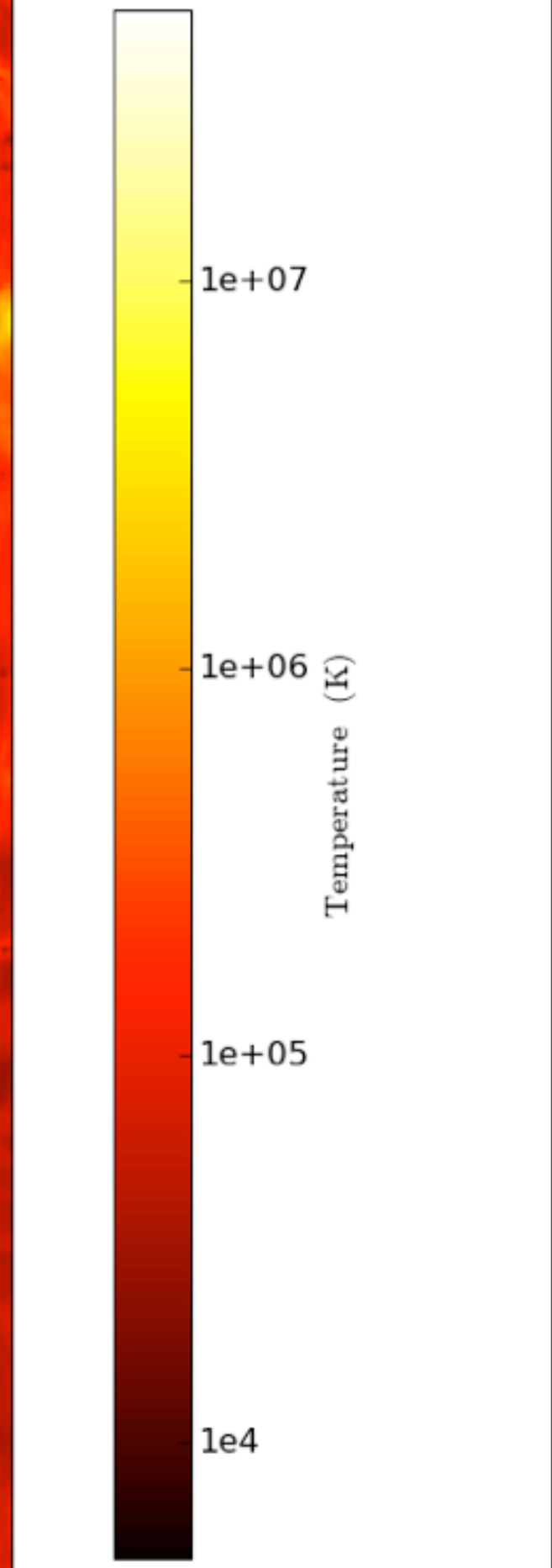
3 Mpc/h

Adiabatic Shocks:

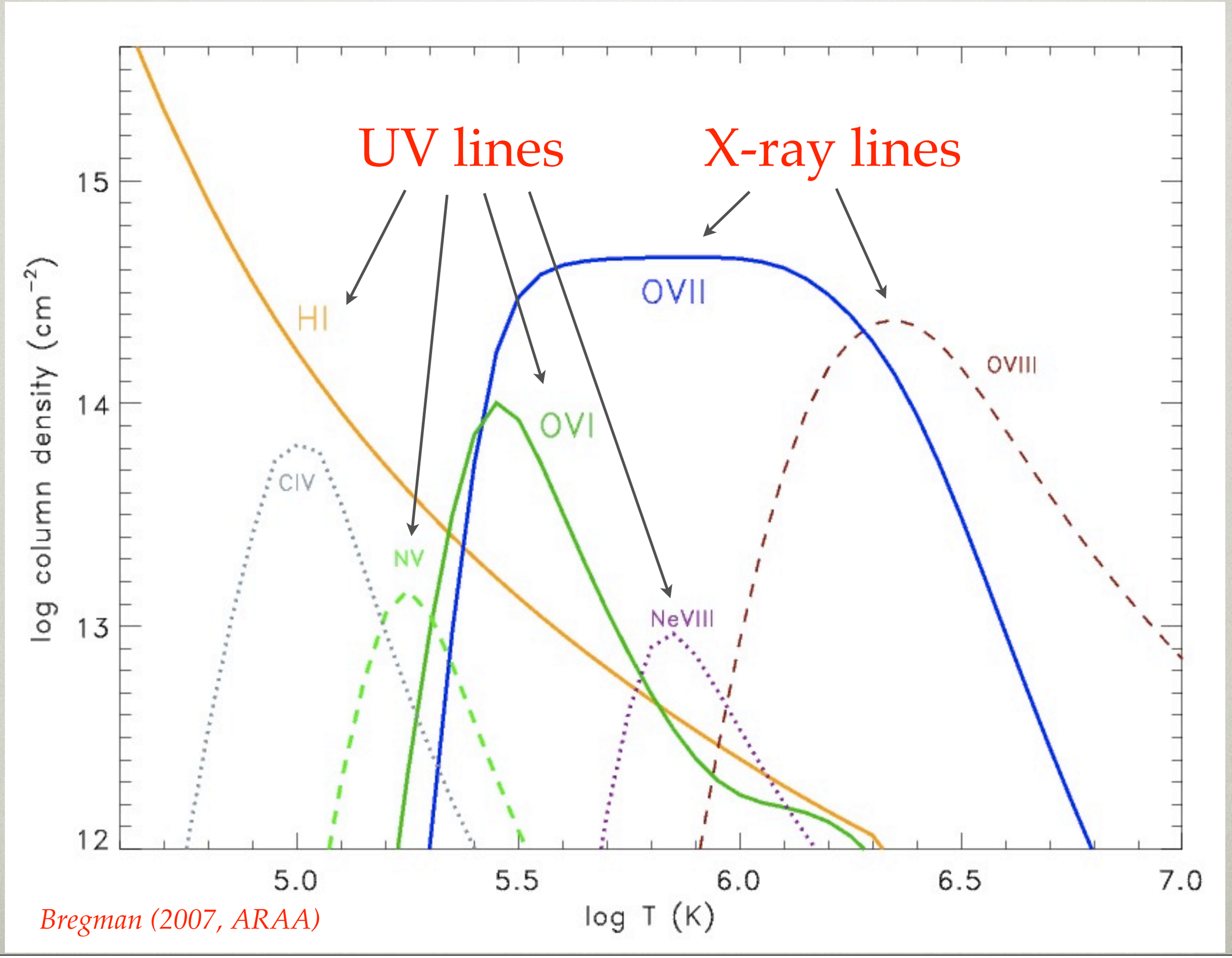
$T_s = (3\mu/16k)(V_s)^2$

$\approx (4 \times 10^5 \text{ K})(V_{200})^2$

$z = 0$

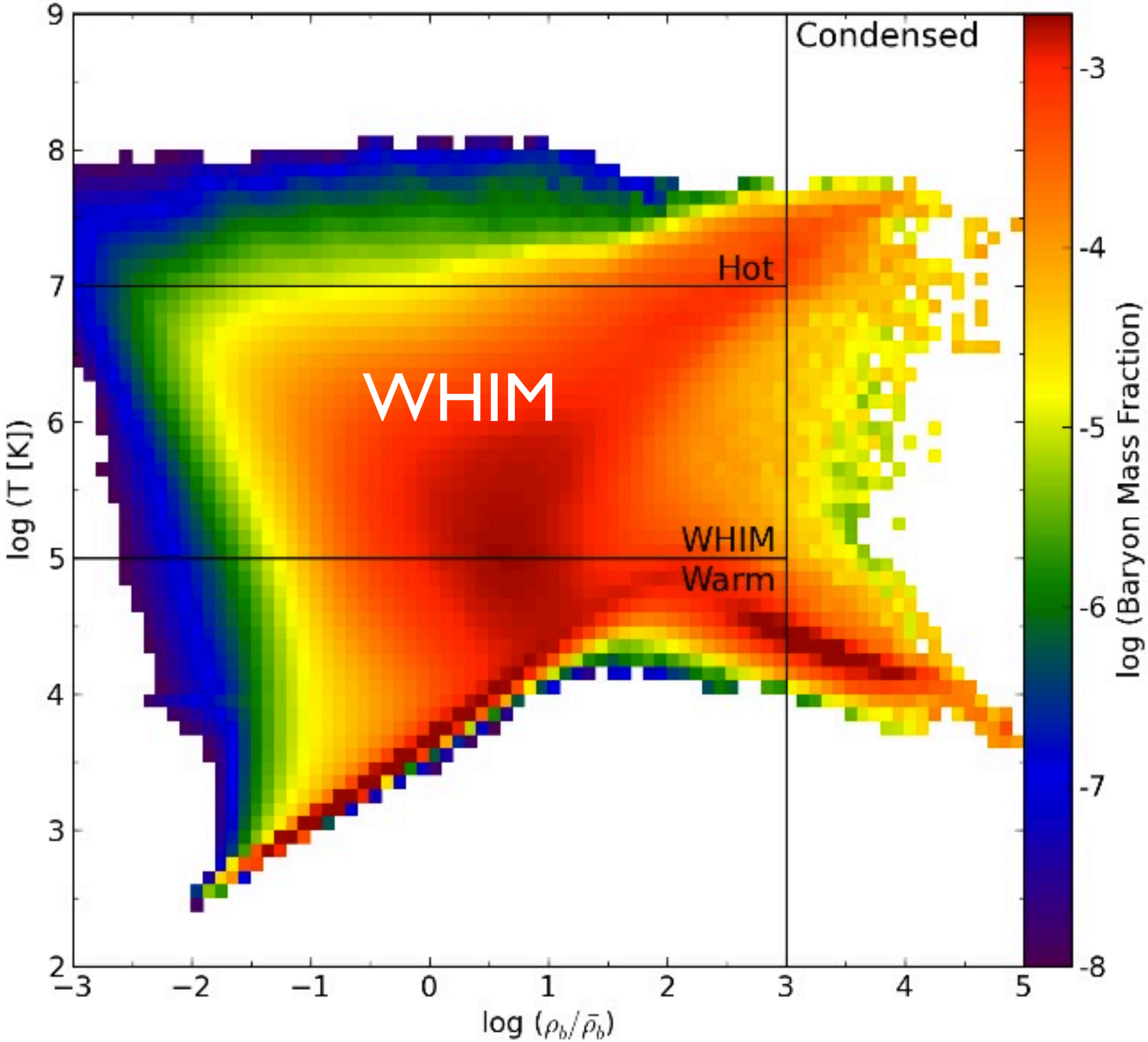


Warm-Hot Intergalactic Medium: T=10^5-10^7 K



Bregman (2007, ARAA)

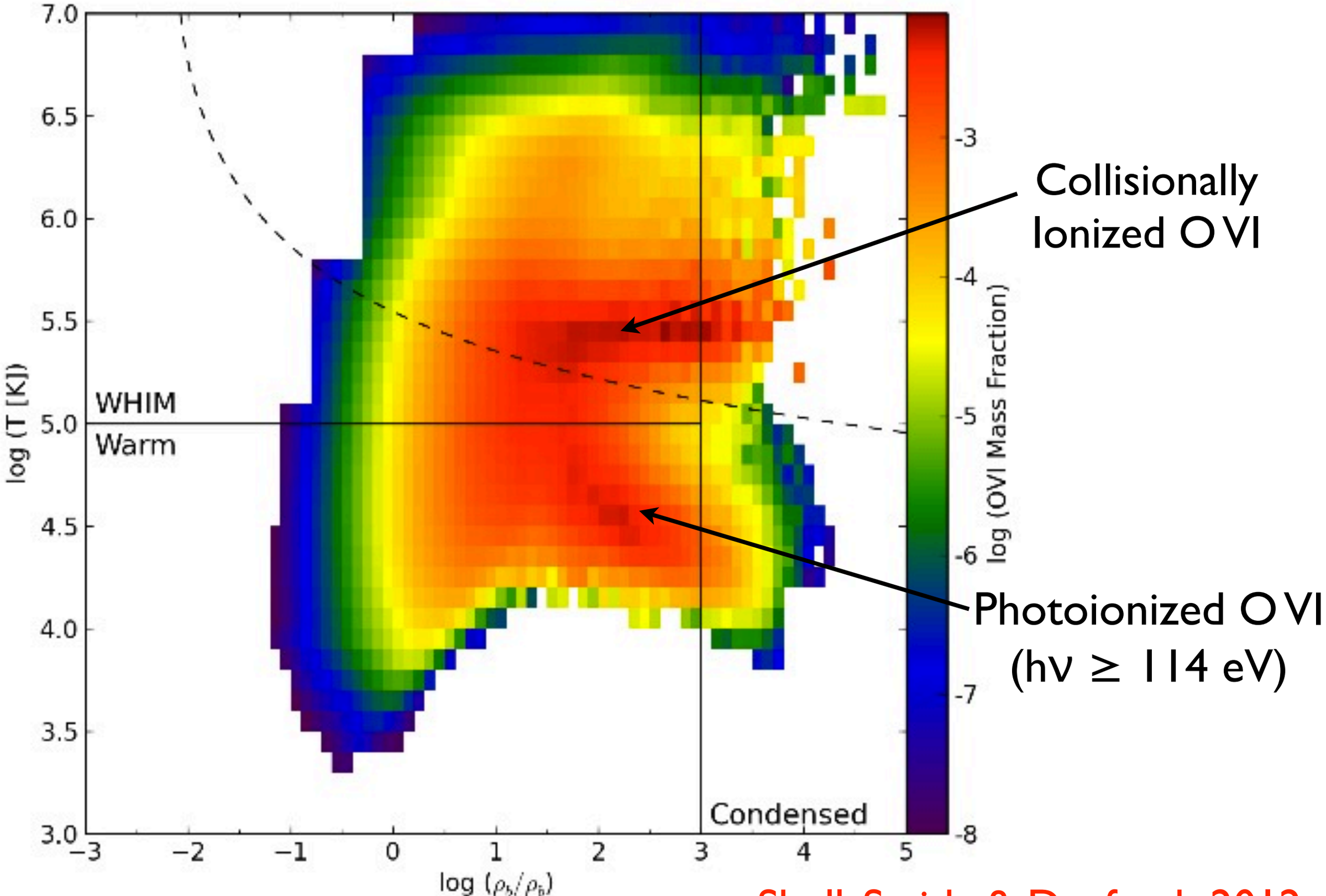
Baryon "phase plot" (Temperature - Density)



Simulations color-coded by baryon mass

Shull, Smith, & Danforth 2012

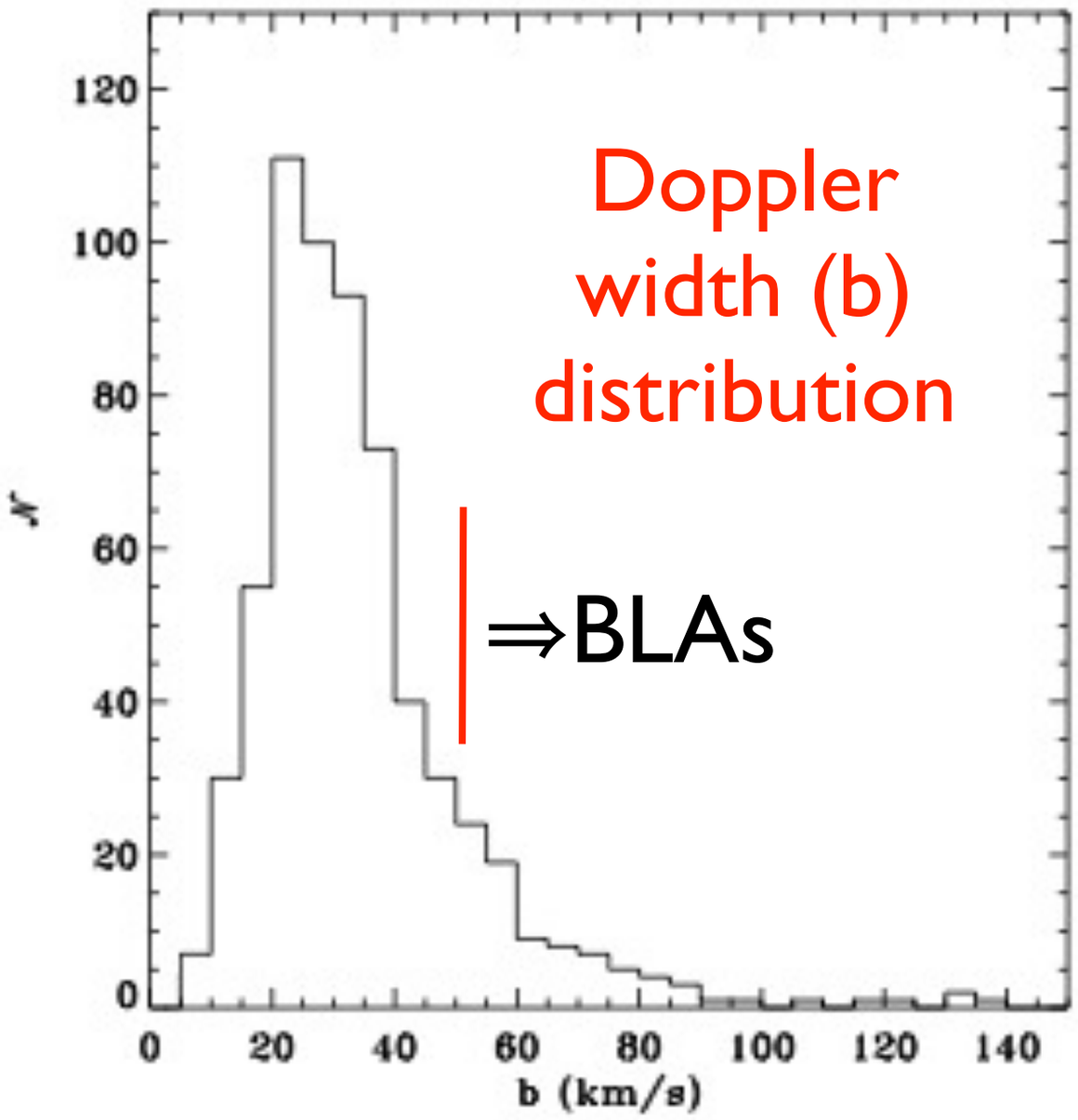
IGM/CGM phase diagram (O VI)

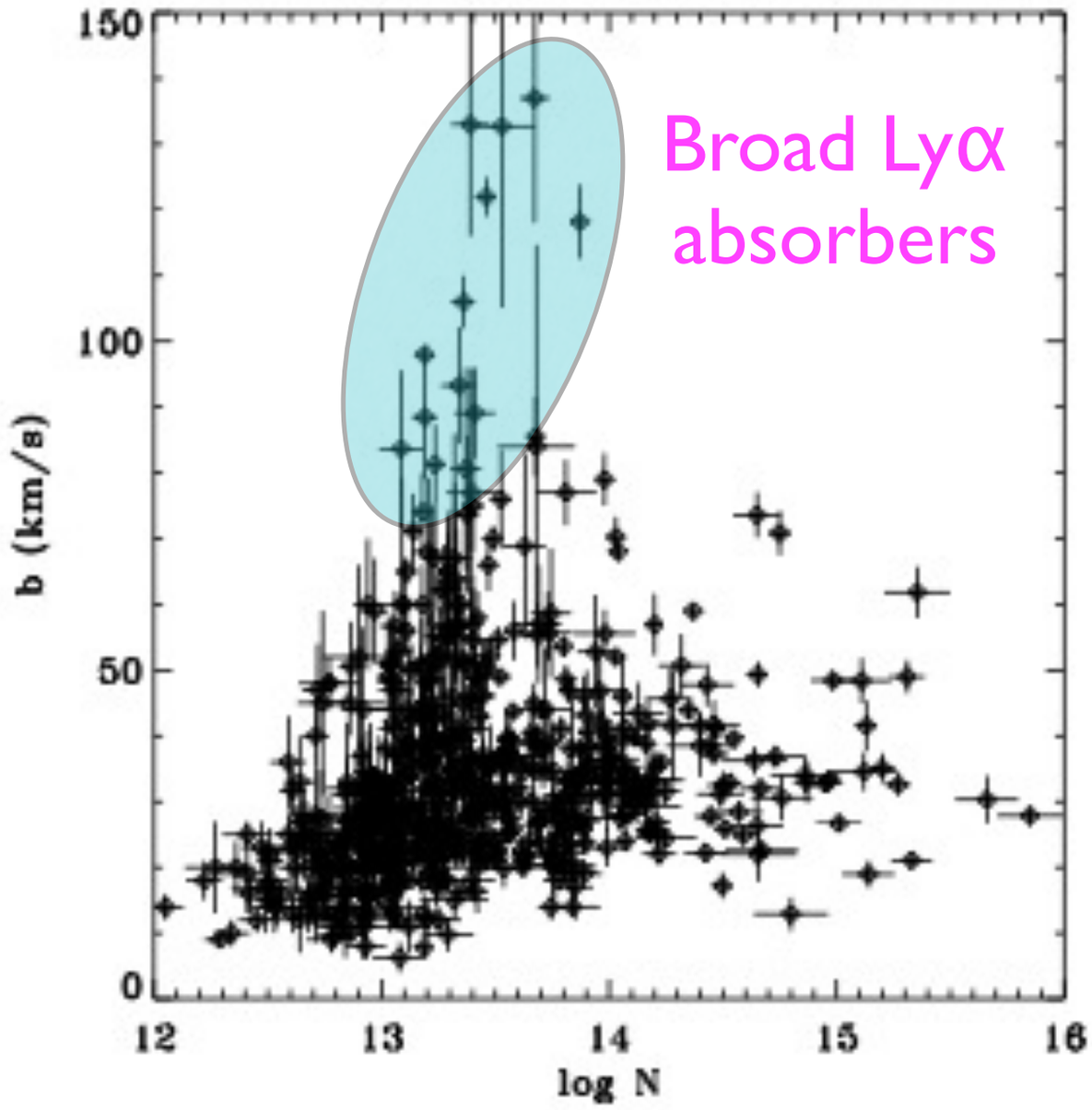


Shull, Smith, & Danforth 2012

H I (Lyα) Absorber Survey

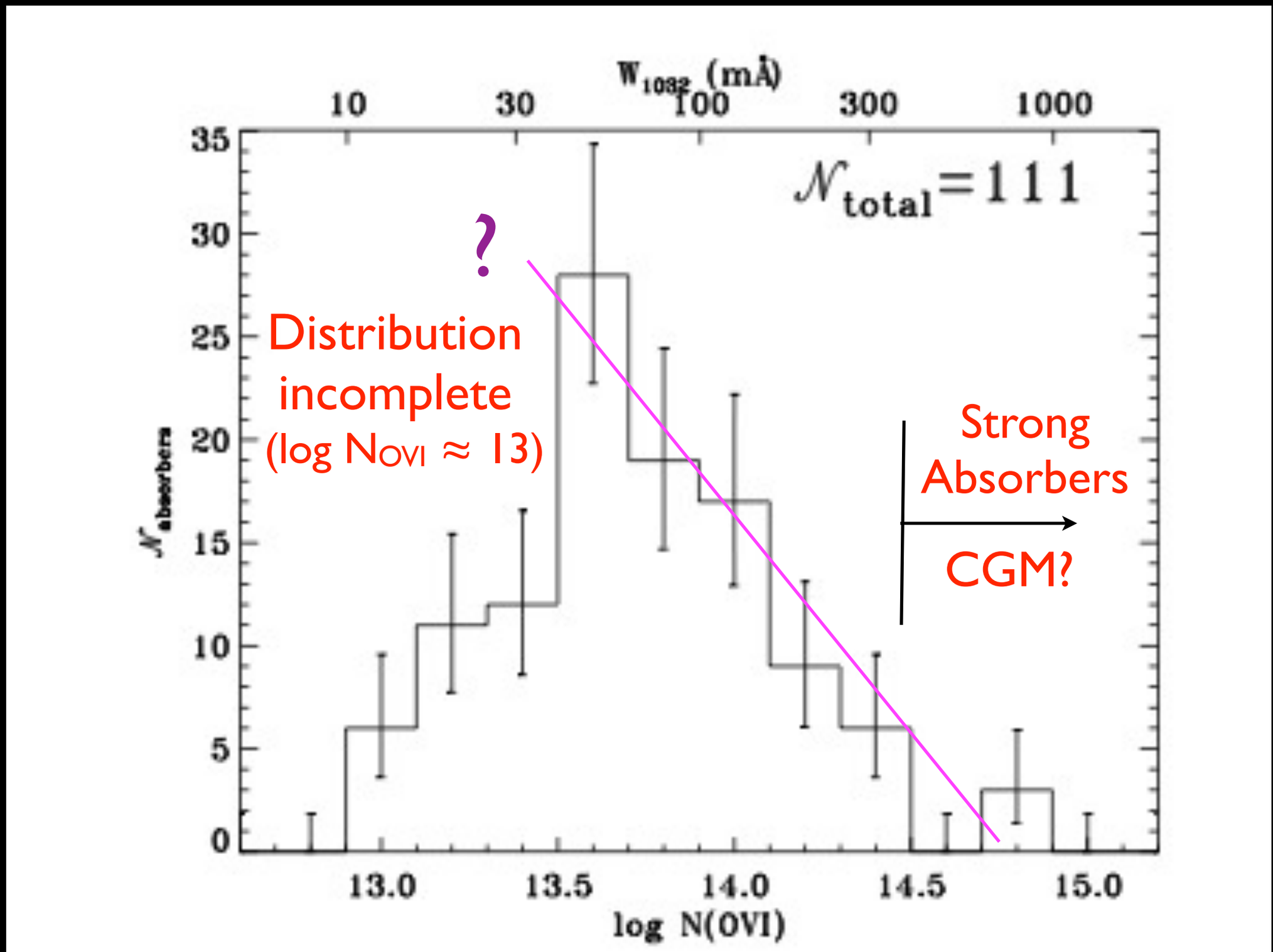
Tilton et al. 2012, ApJ





111 OVI absorbers over $(\Delta z)_{tot} = 6.1$

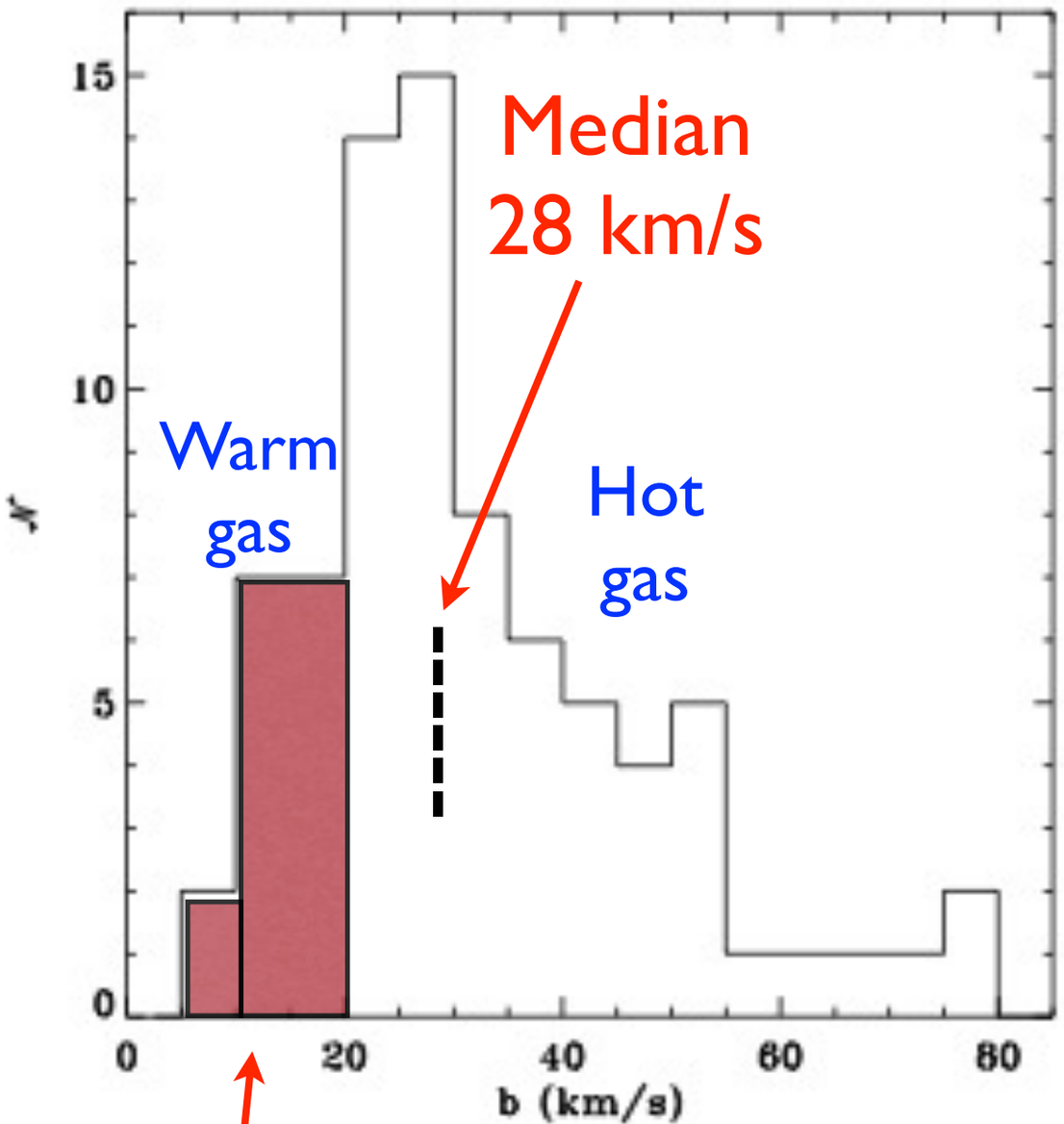
Tilton et al. 2012

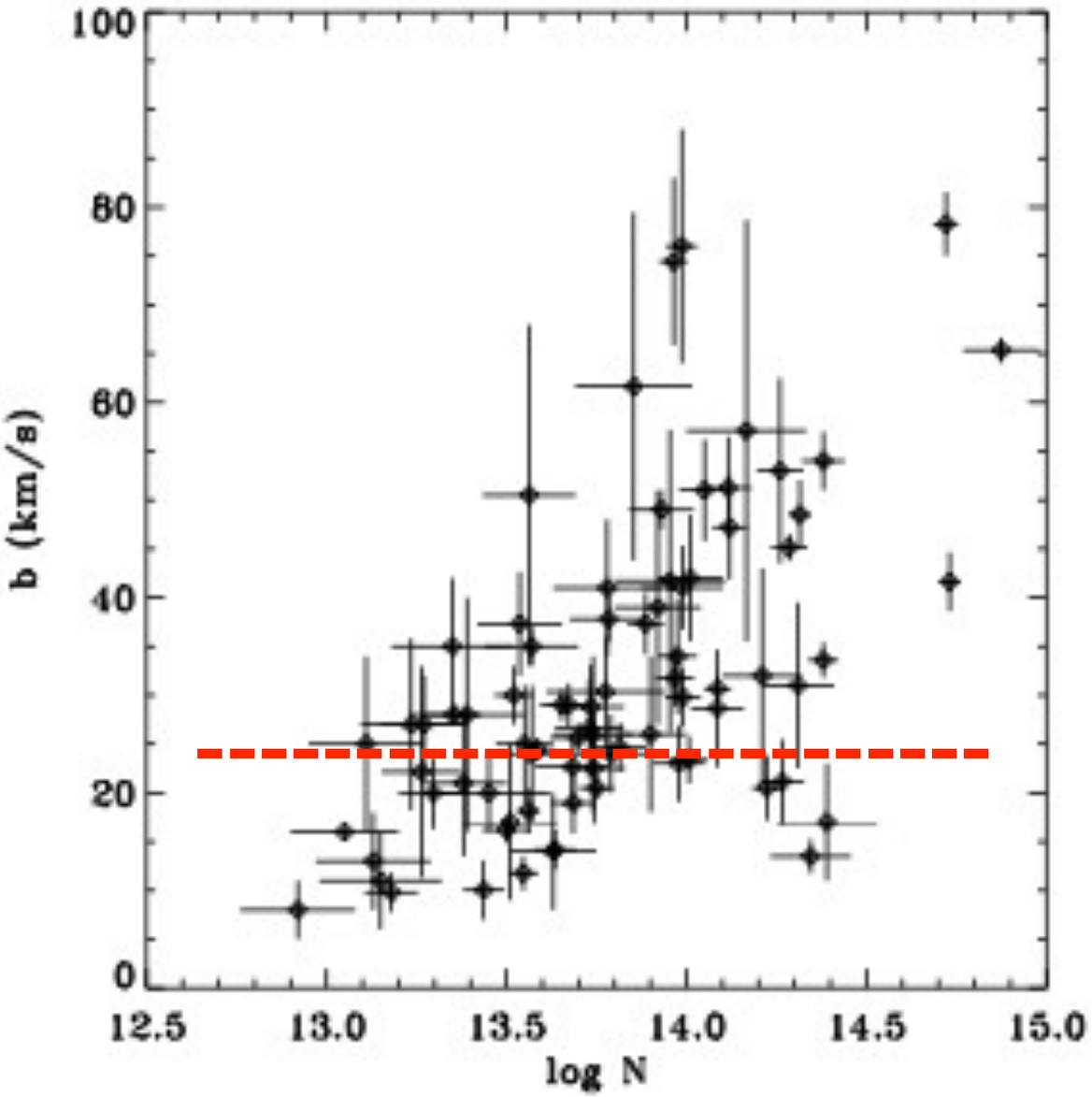


Doppler-width distribution (O VI)

$b_{th} = (2kT/m)^{1/2}$

Tilton et al. 2012



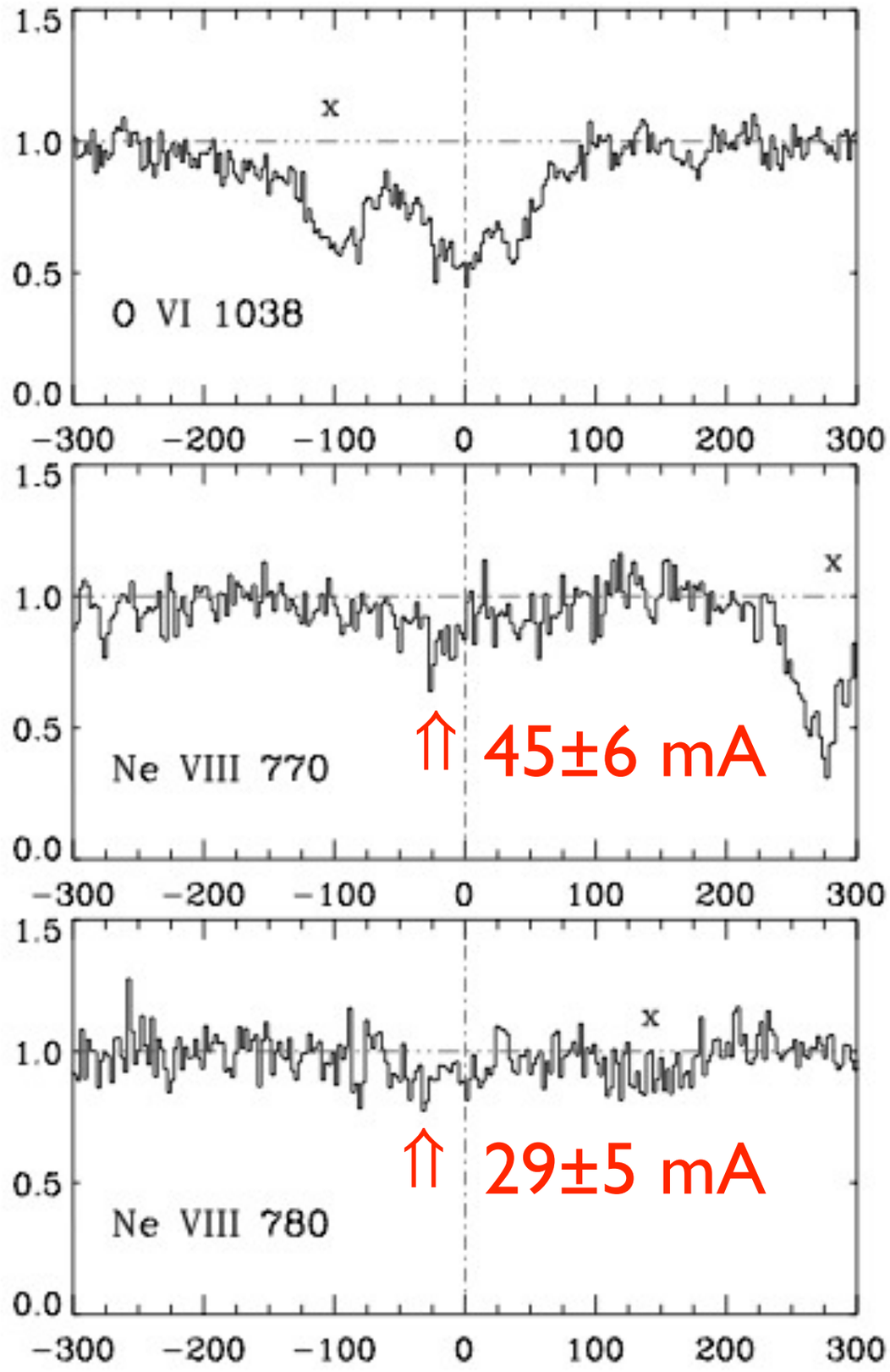


20% have
b < 20 km/s

$b_{OVI} = (17.2 \text{ km/s}) [T/3x10^5 \text{ K}]^{1/2}$

Ne VIII detected at z = 0.4951 (WHIM at 5×10^5 K)

Narayanan et al. 2011, ApJ



$\log N_{NeVIII} = 13.96 \pm 0.06$

$\log N_{OVI} = 14.47 \pm 0.02$

$[Ne/H] = -0.6 \pm 0.3$

$(Ne/O)_{sun} = 0.17$

Ne VIII and O VI doublets are (2s - 2p) transitions

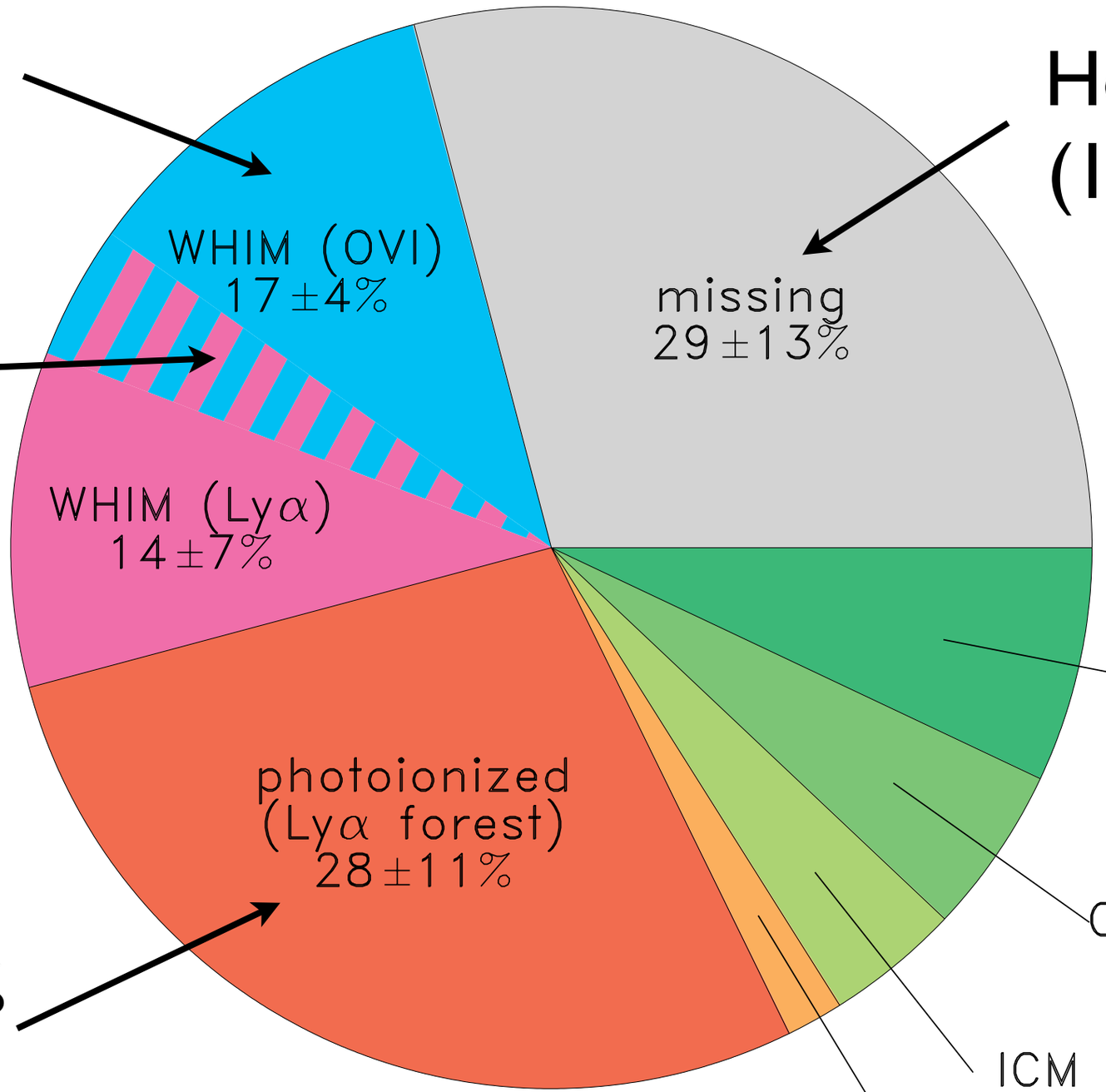
Current Status of Low-z Baryon Census

Shull, Smith, & Danforth 2012, ApJ

Subtracting off photoionized O VI

Double-counted Broad Lyα

Hotter Gas? (1-2 x10^6 K)



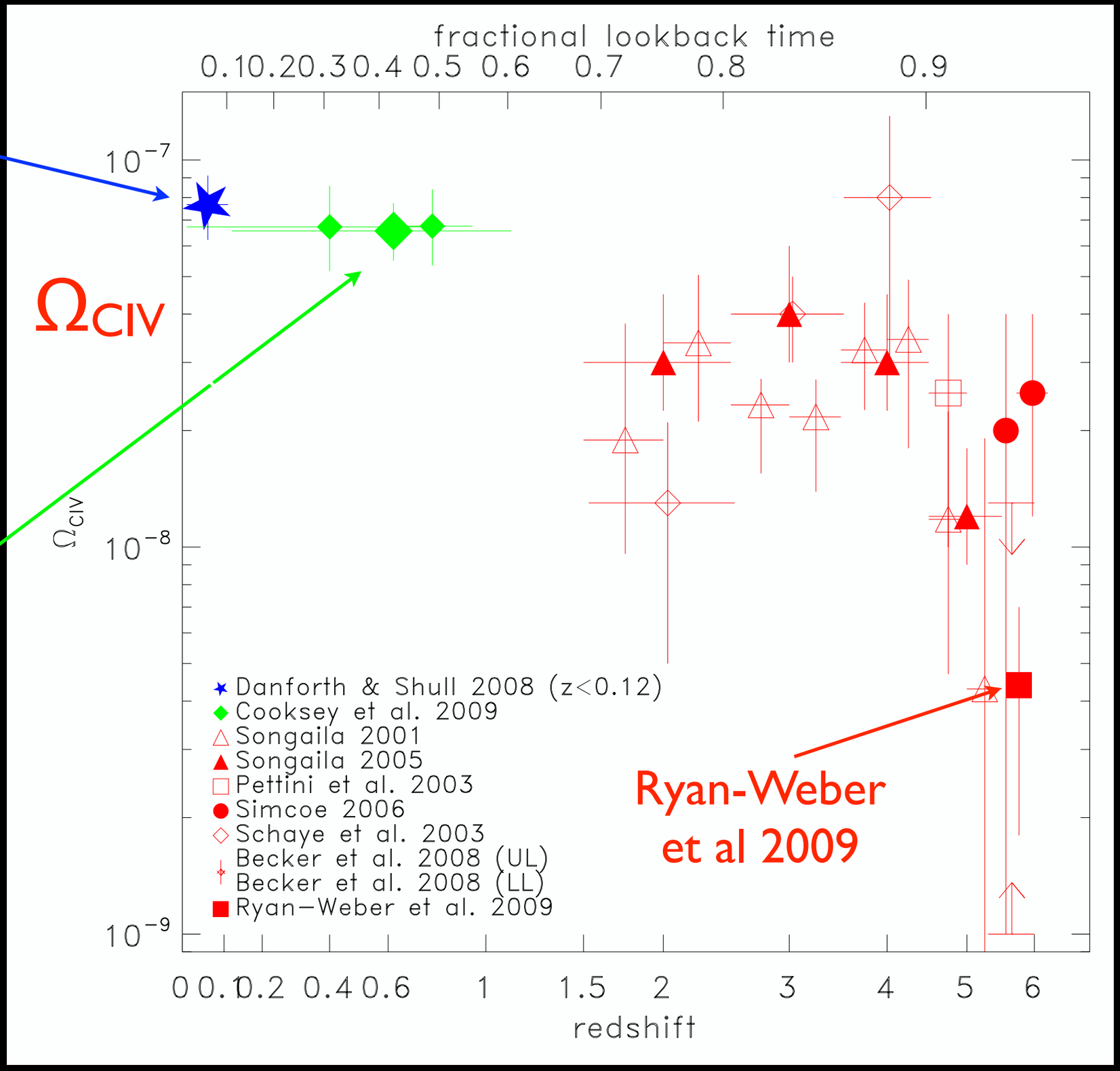
Could rise to 31% with low-N_{HI} absorbers

Metal Evolution in the IGM

STIS/E140M survey
(Shull & Danforth 2010)

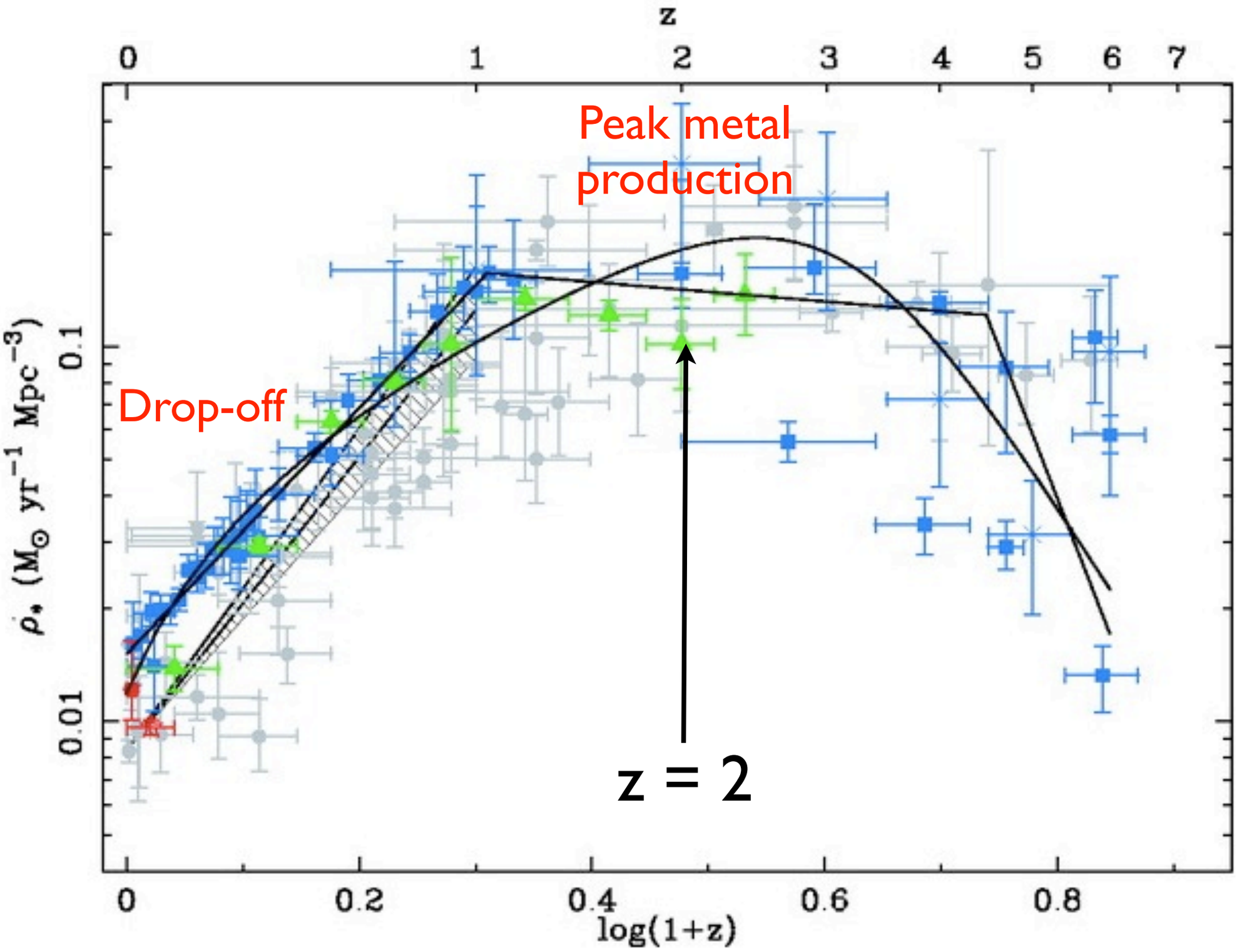
$\Omega_{CIV} \approx 8 \times 10^{-8}$

STIS/E230M survey
(Cooksey et al 2009)

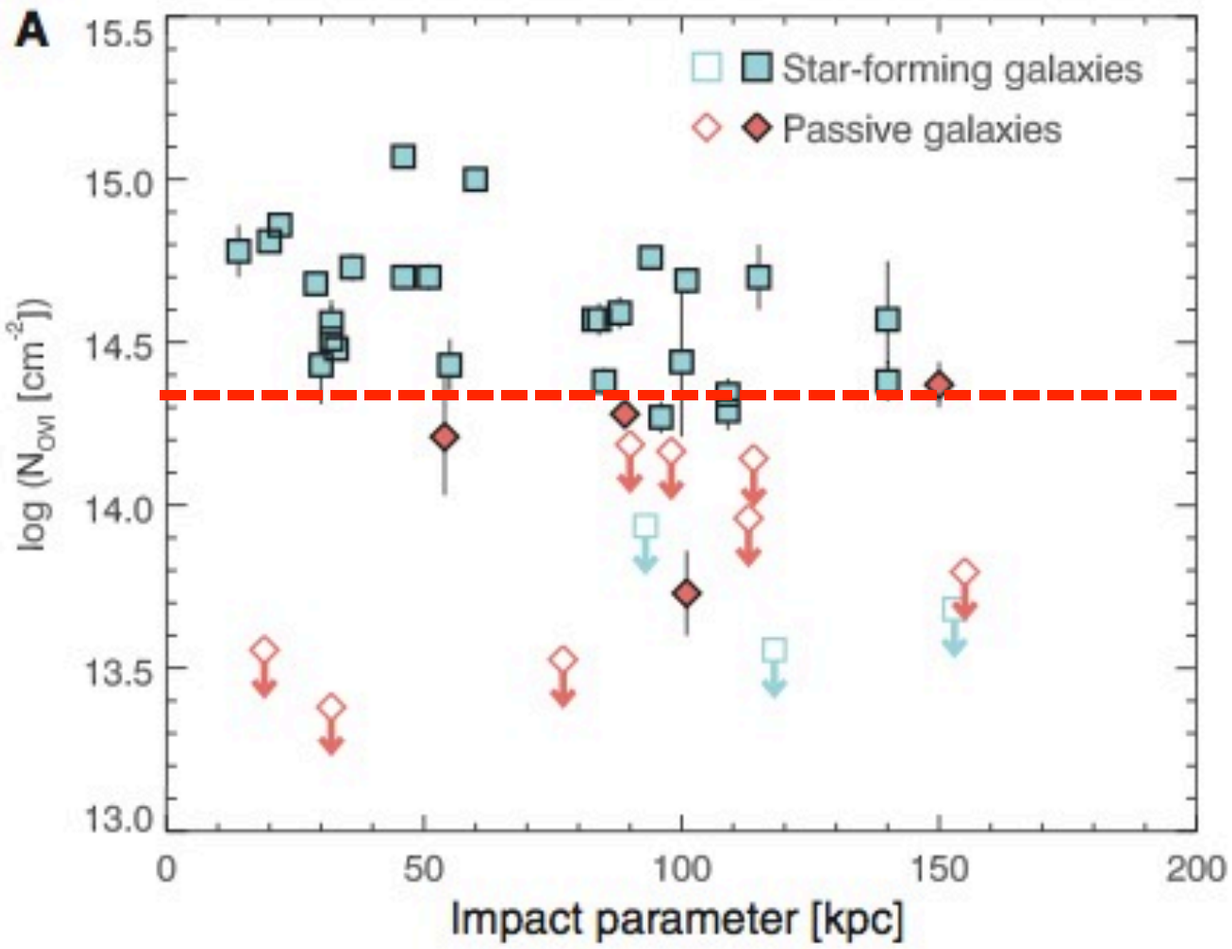


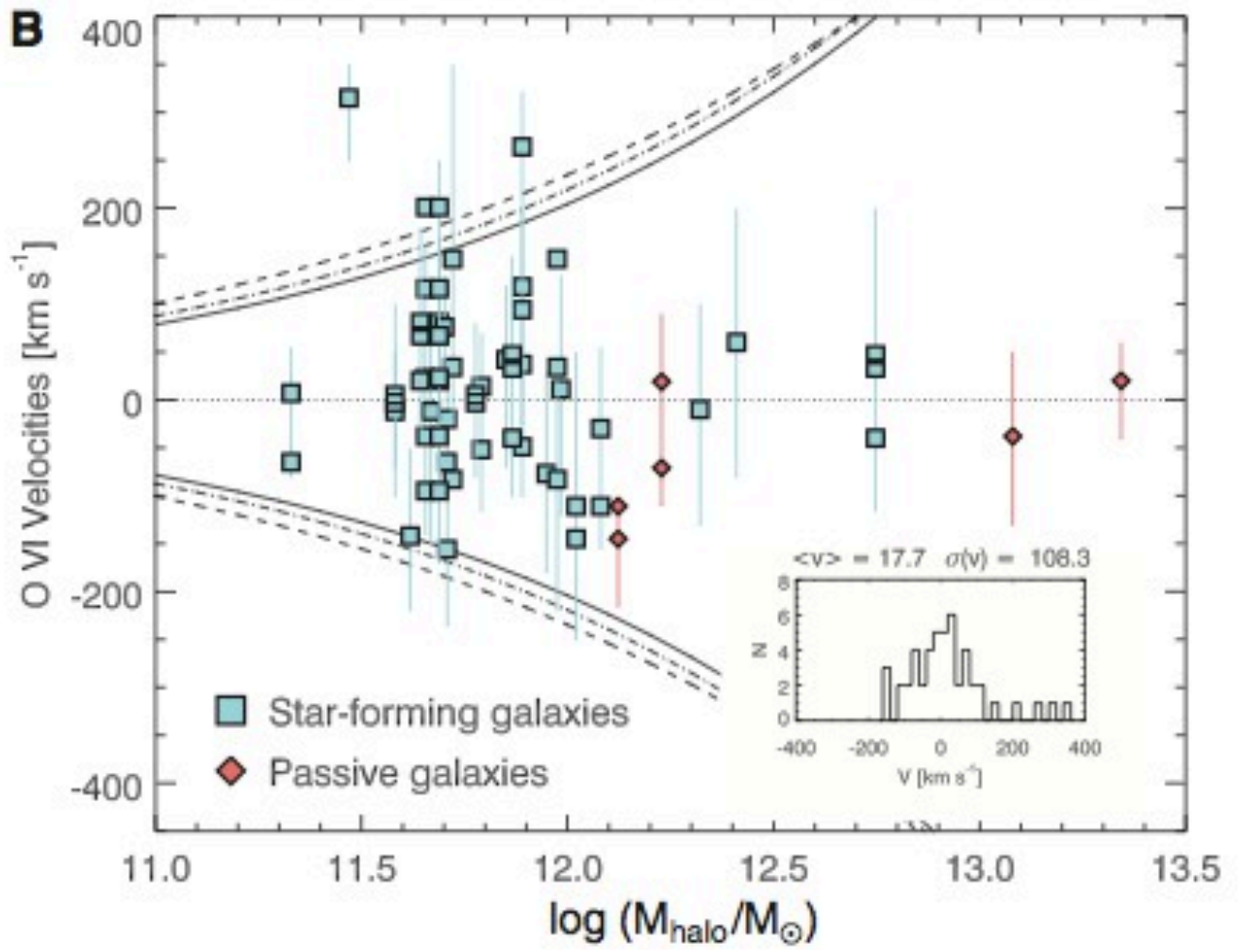
Star Formation Rate History

compiled by Hopkins et al. 2007



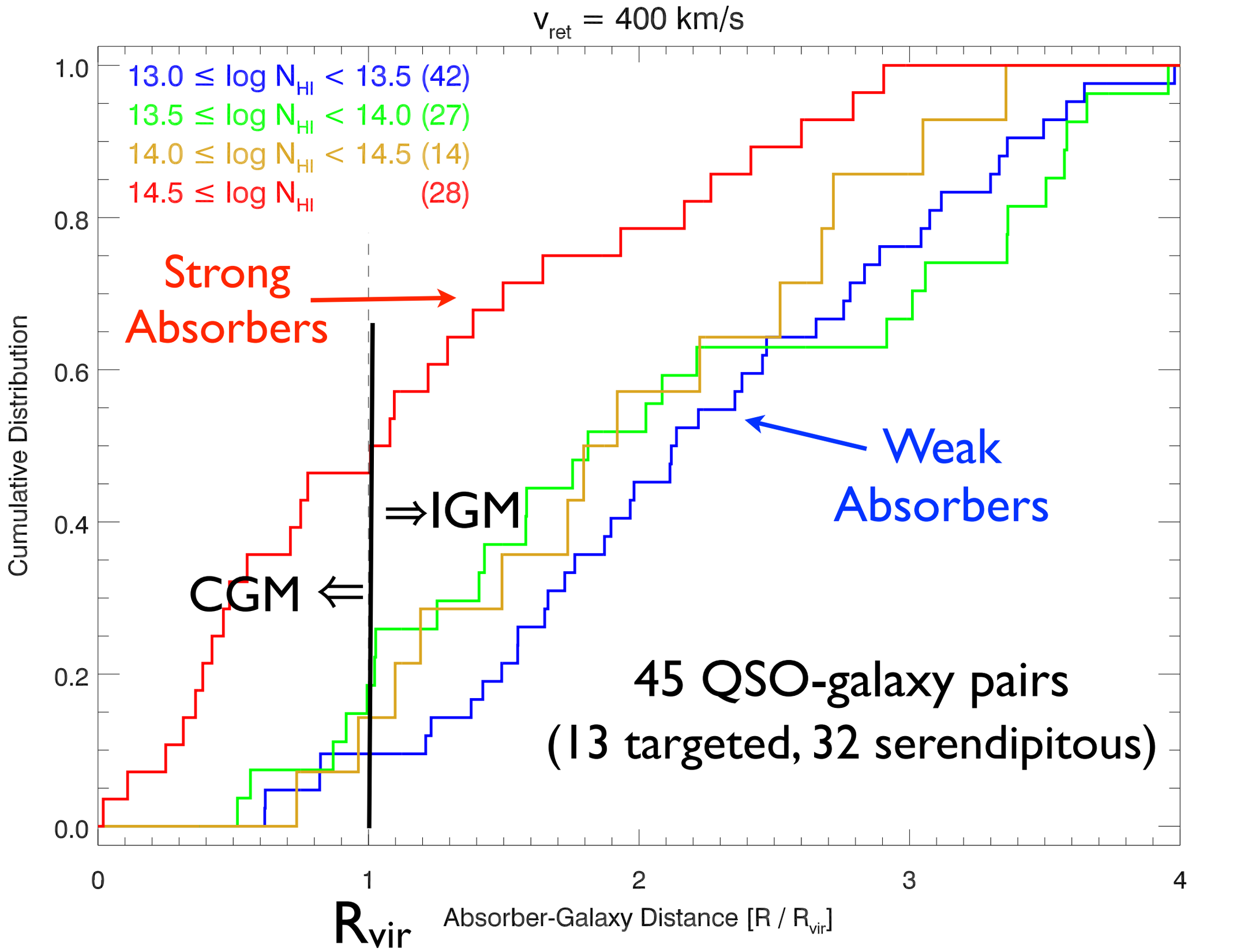
Tumlinson et al. (2011)
O VI probes of galactic halos and CGM





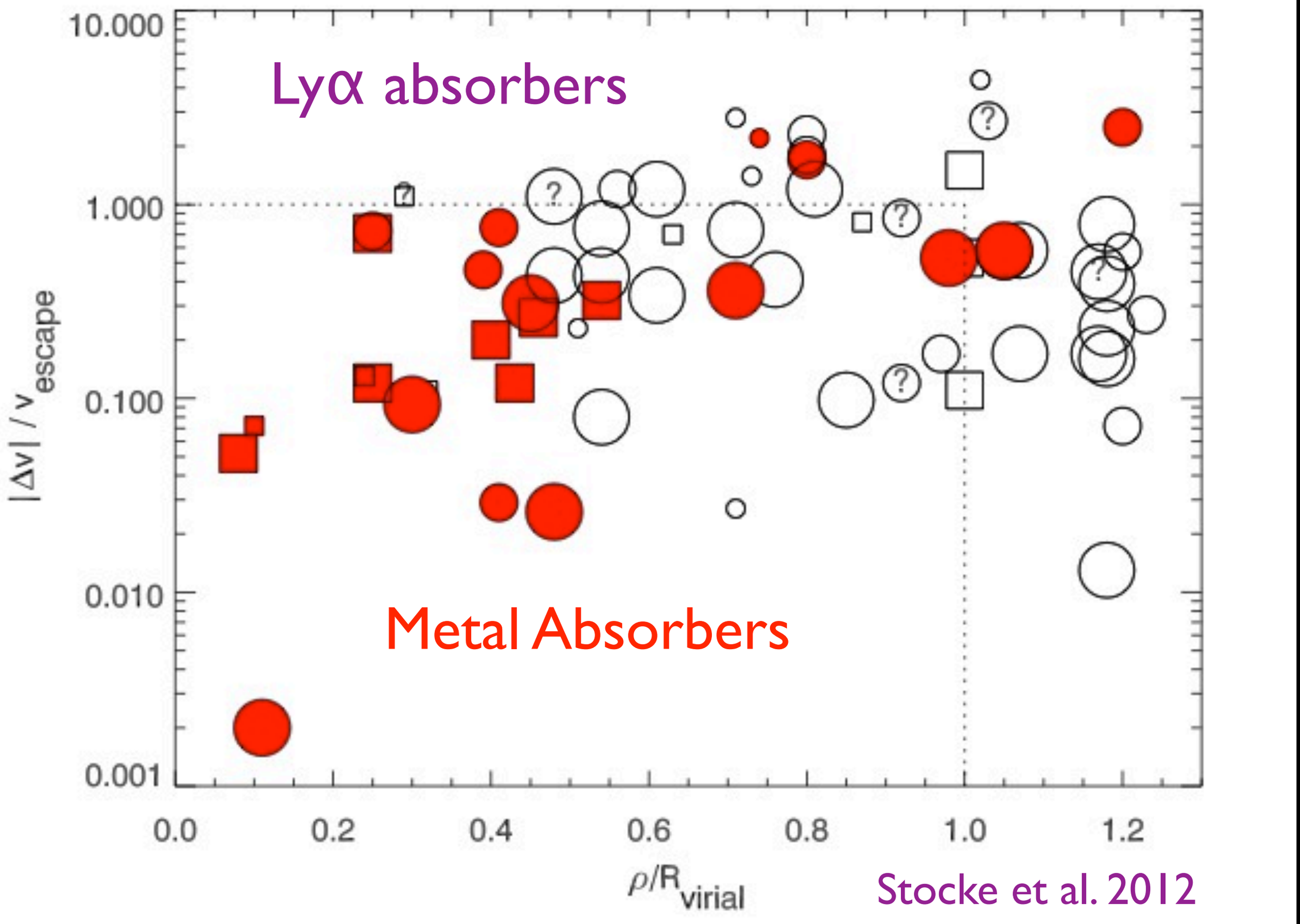
Strong O VI absorbers in CGM around star-forming galaxies

Cumulative Distribution of Lyα Absorbers



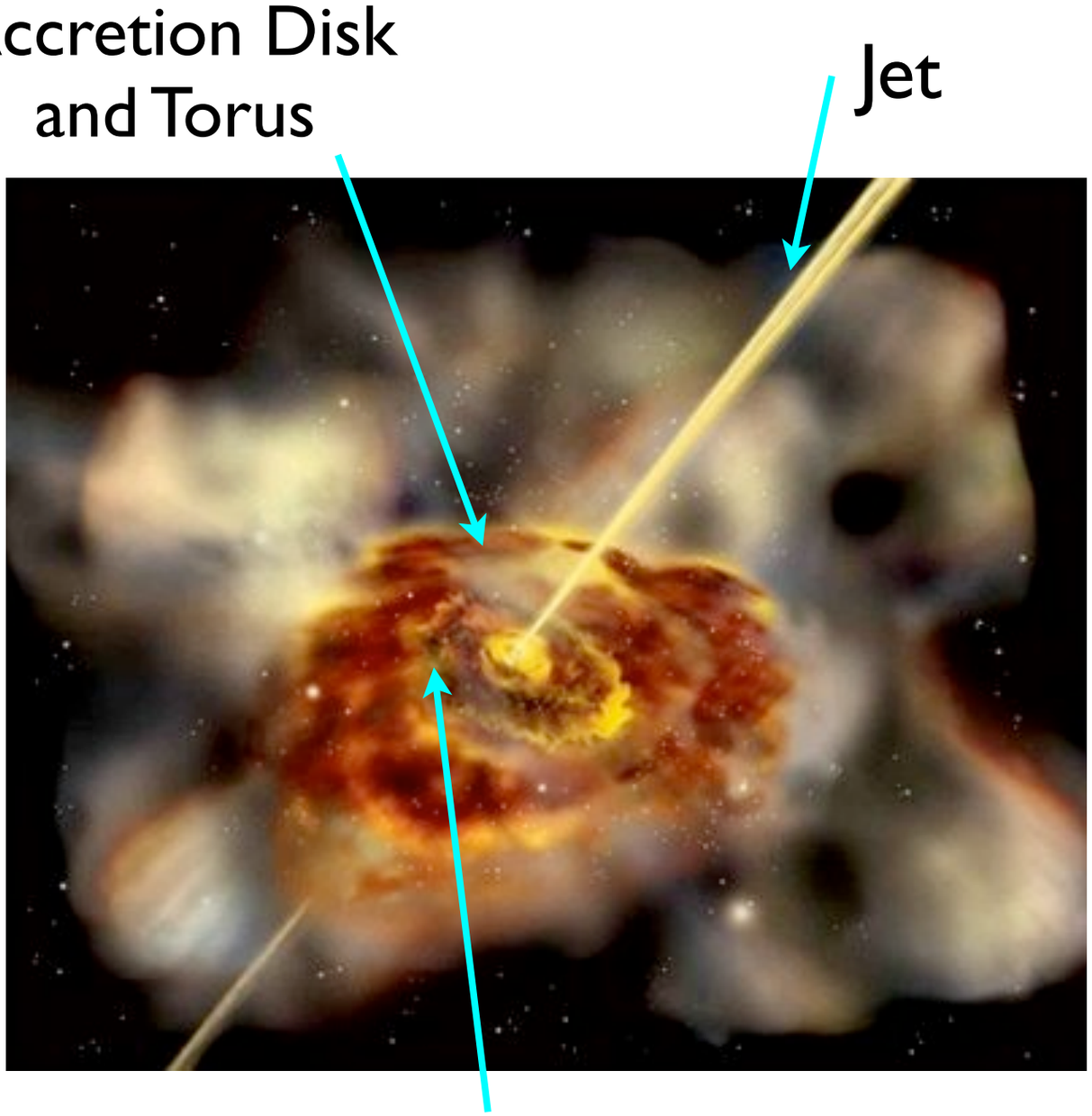
Stocke, Keeney, Danforth, Shull 2012

Use normalized ratios: (r/R_{vir}) and (v/v_{esc})



Stocke et al. 2012

Quasar UV Spectra



Active Galactic Nuclei (AGN)

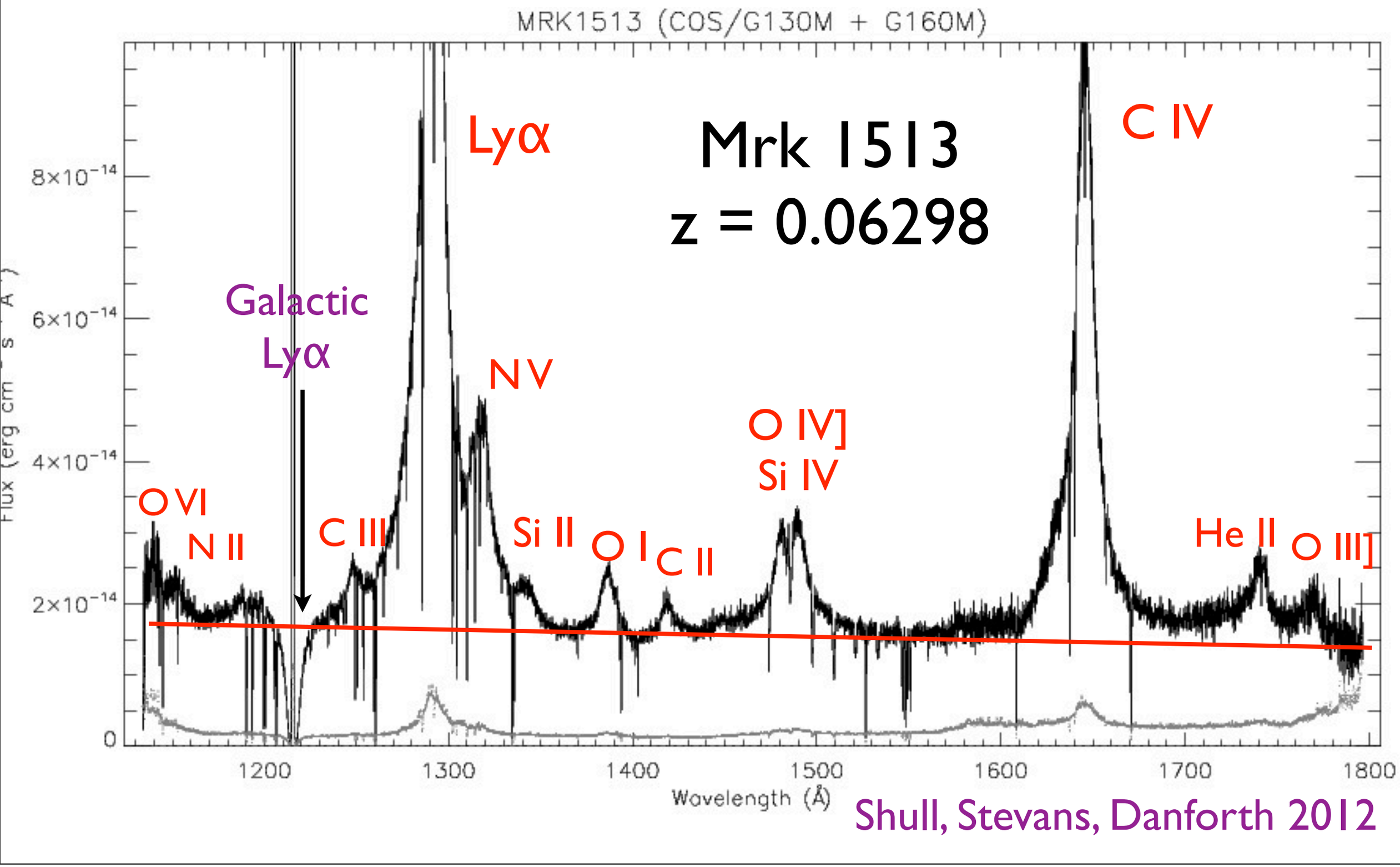
Their ionizing radiation probably dominates the ionization state of H, He, and heavy elements in the IGM

$h\nu \geq 13.6$ eV (H I)

$h\nu \geq 54.4$ eV (He II)

$h\nu \geq 114$ eV (O VI)

Quasar spectra from COS
UV continuum and broad emission lines



Shull, Stevans, Danforth 2012

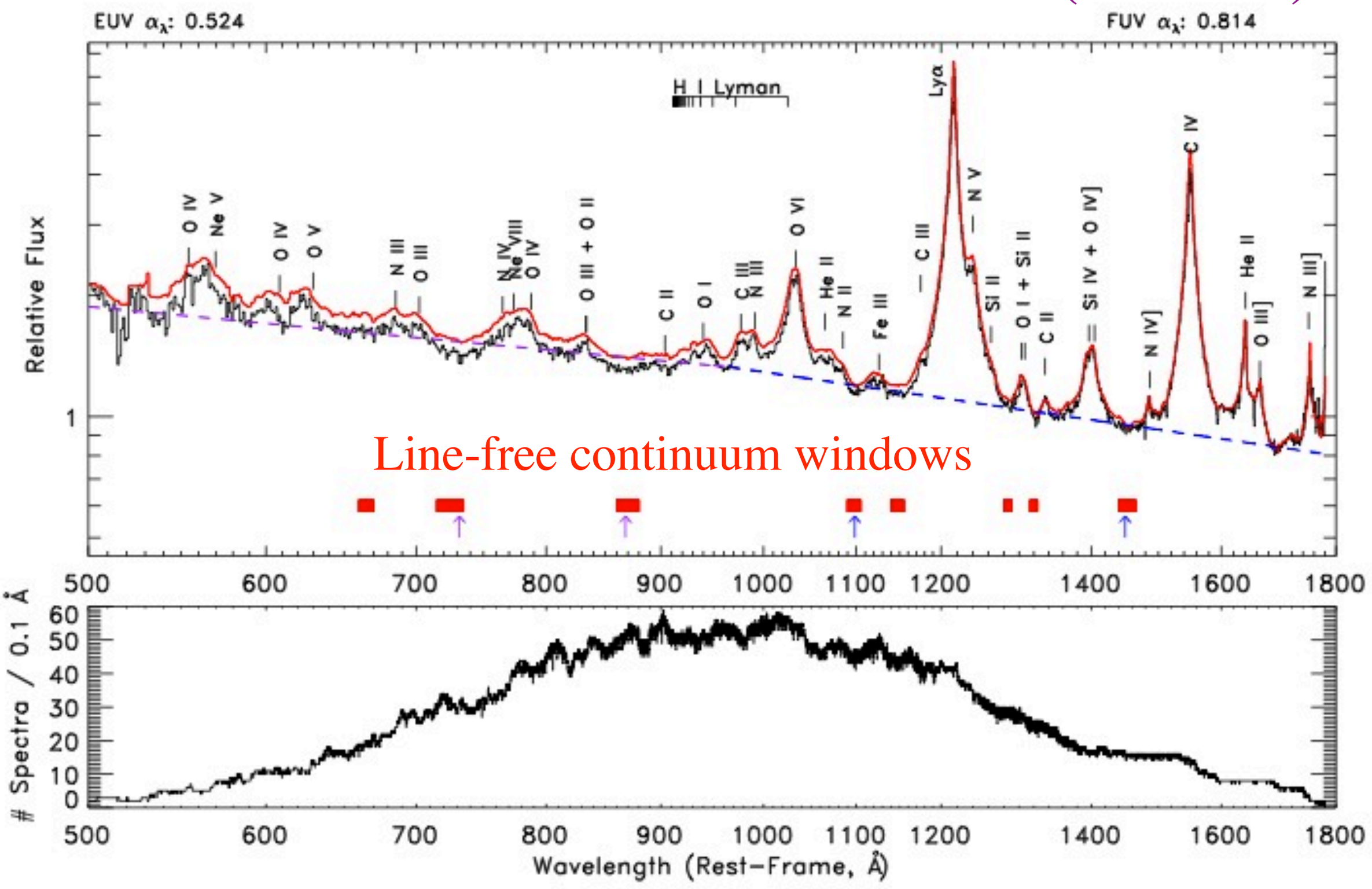
85 AGN co-added

Shull, Stevans & Danforth (2012)

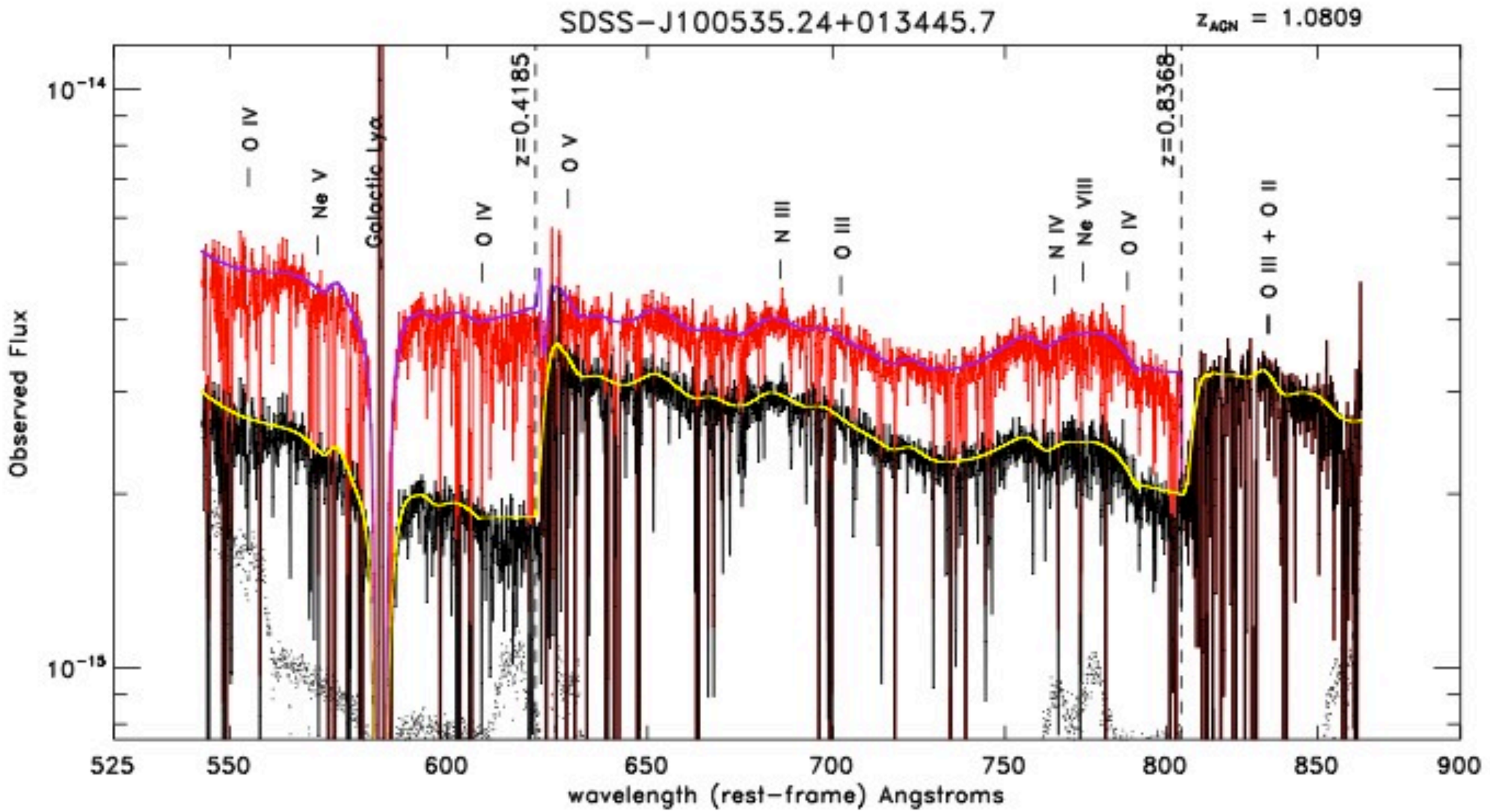
Stevans et al. in prep. (2013)

$F_\nu \propto \nu^{-1.48}$ (in EUV)

$F_\nu \propto \nu^{-1.19}$ (in FUV)

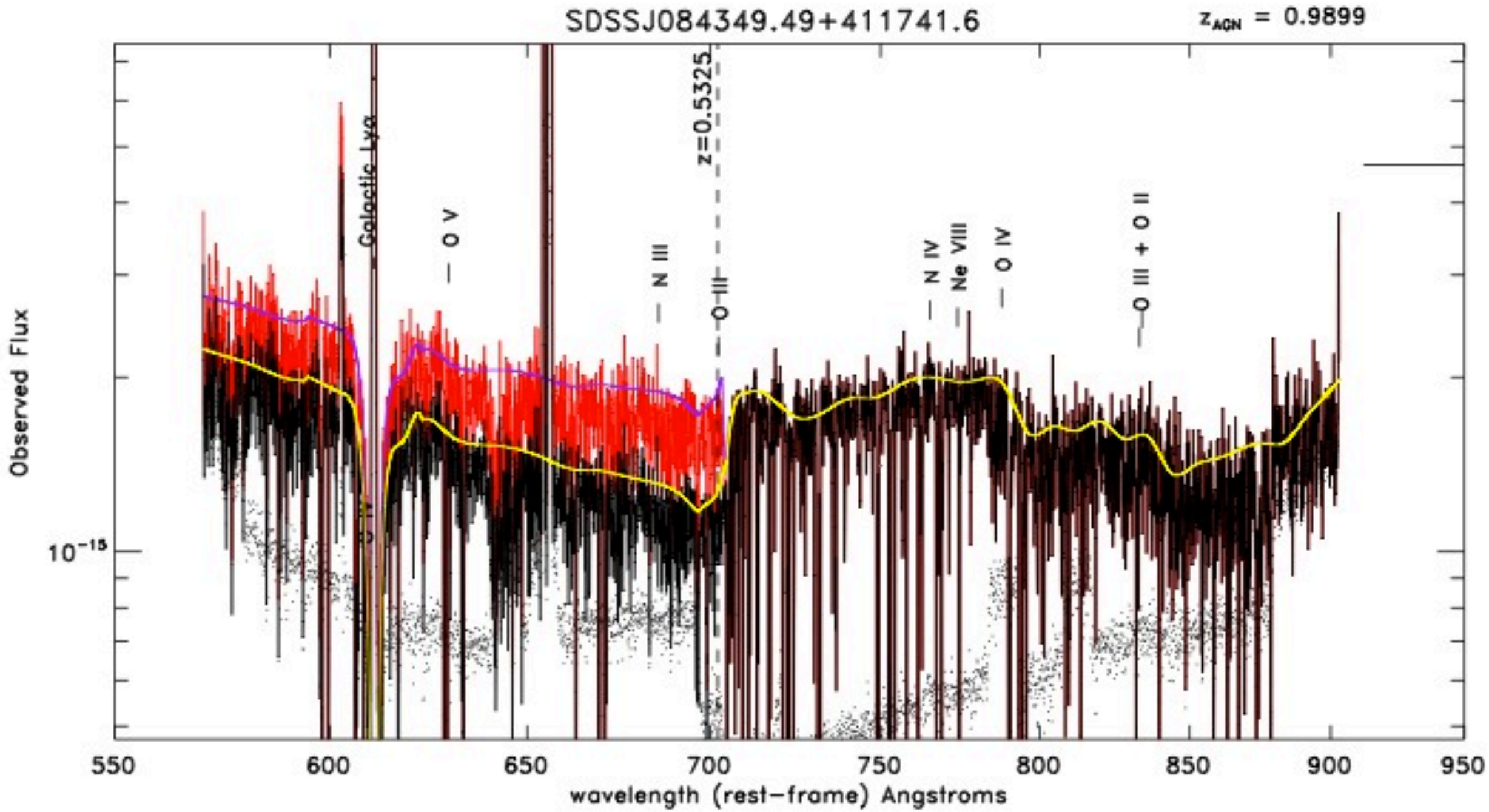


QSO (z = 1.081) plus two Lyman-limit systems (z_{LLS} = 0.4185) and (z_{LLS} = 0.8368)



Stevans et al., in prep

QSO (z = 0.9899) plus LLS (z_{LLS} = 0.5325)



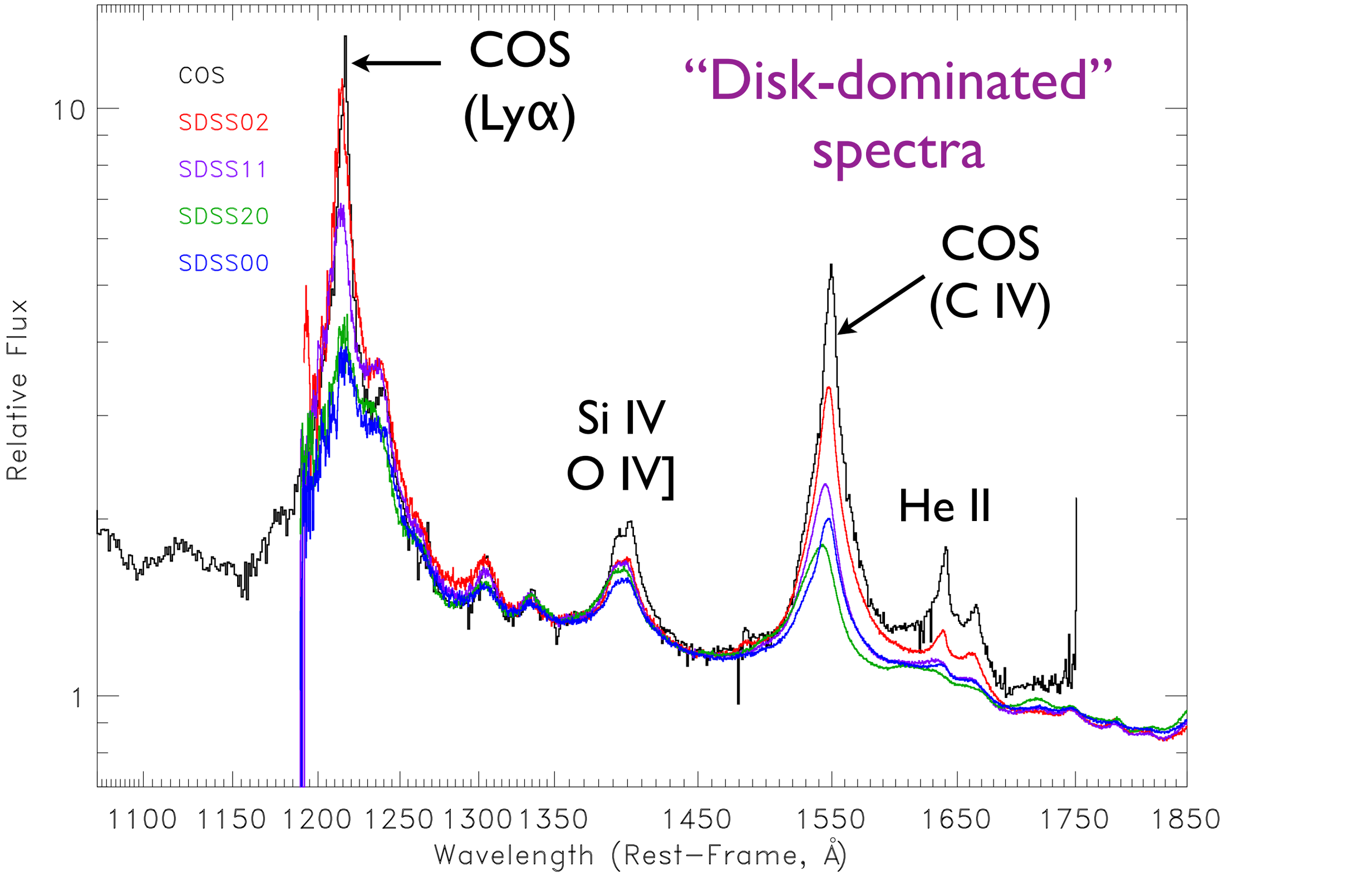
Stevans et al., in prep

COS composite

Shull, Stevans, Danforth (2012)

SDSS composites

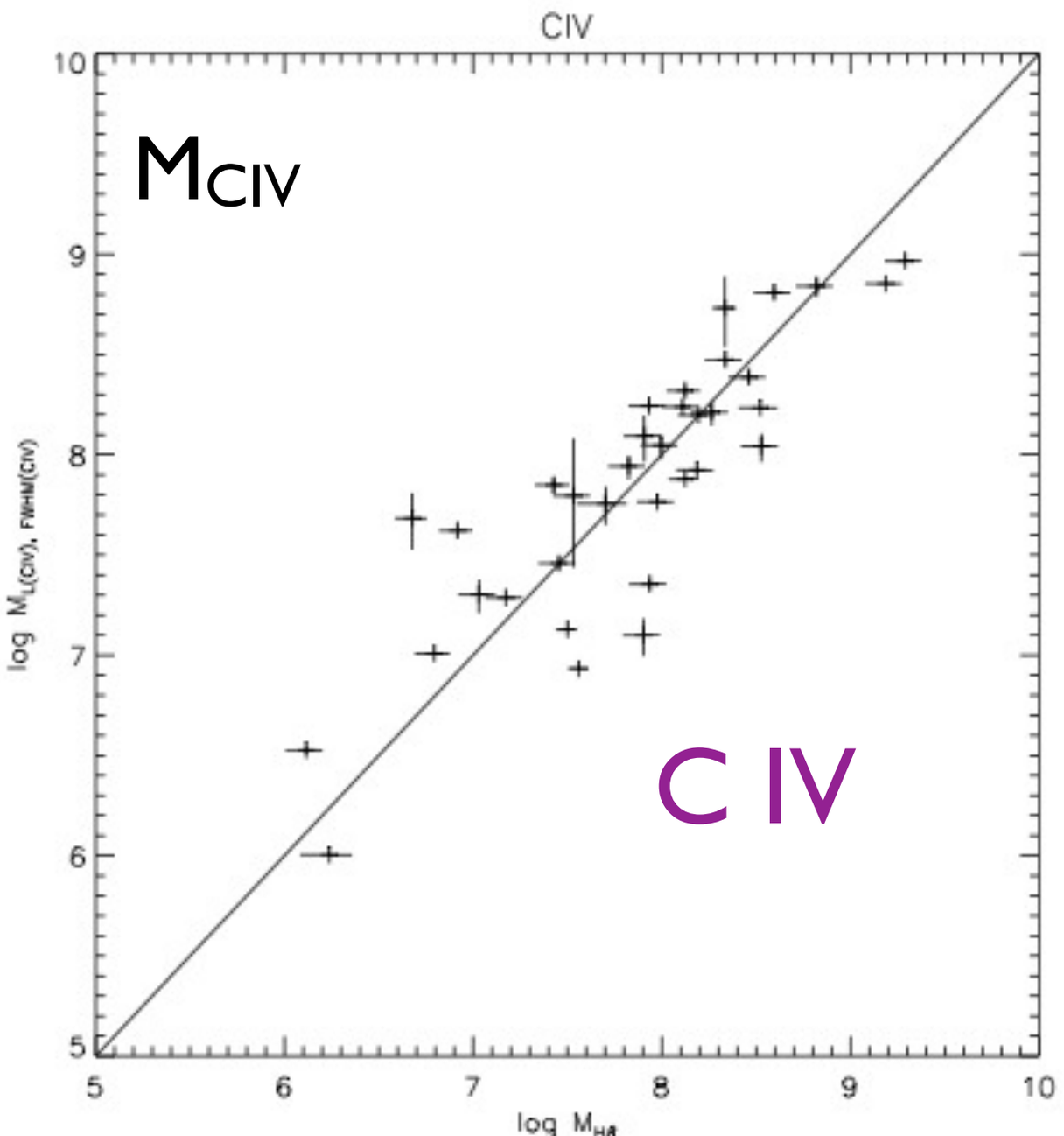
Richards et al. (2011)

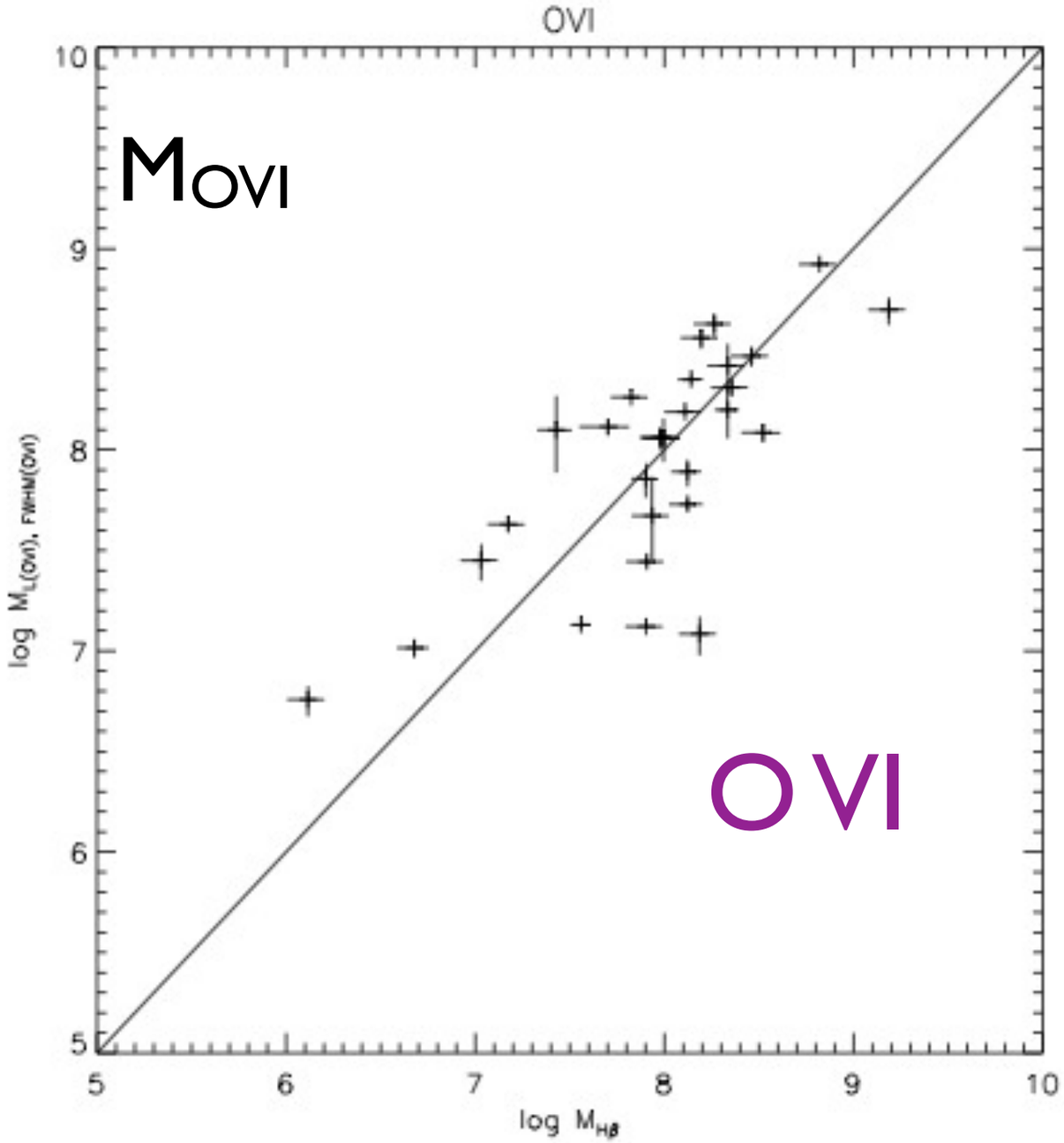


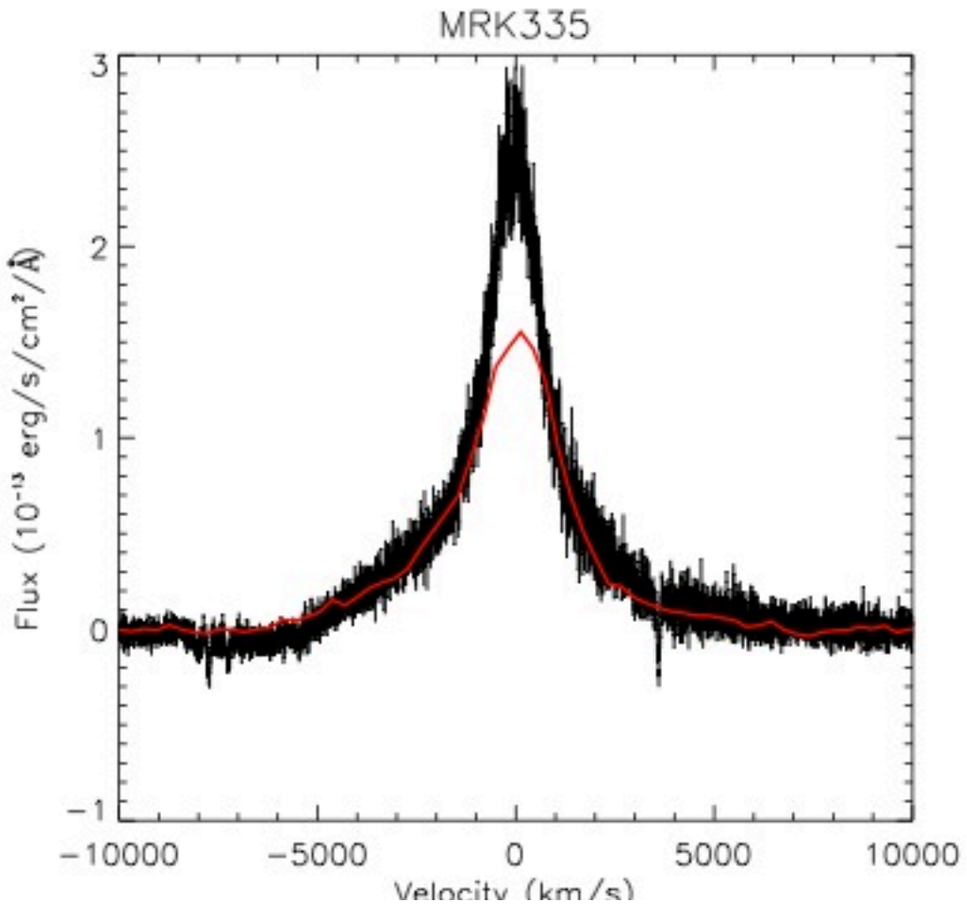
$$M_{\rm BH} = f\frac{R_{\rm BLR}(\Delta v)^2}{G},$$

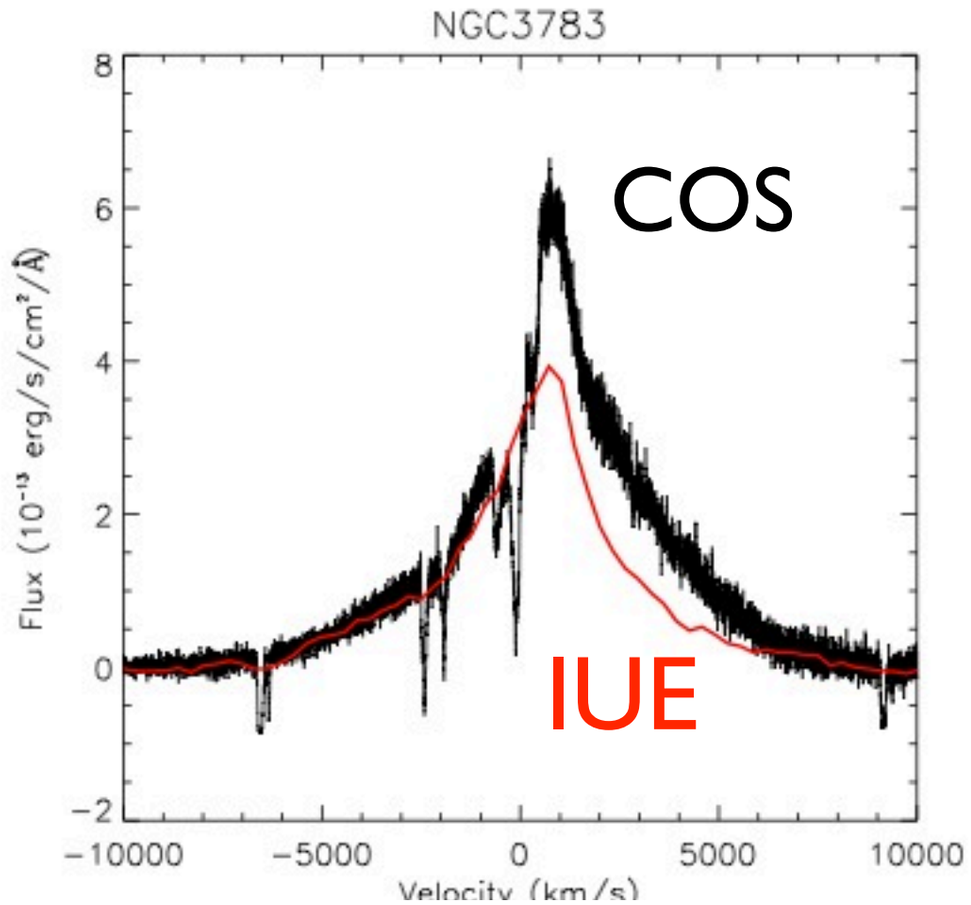
Black Hole Mass Calibrations
C IV λ1549 and O VI λ1035

Tilton, Shull, & Danforth 2013



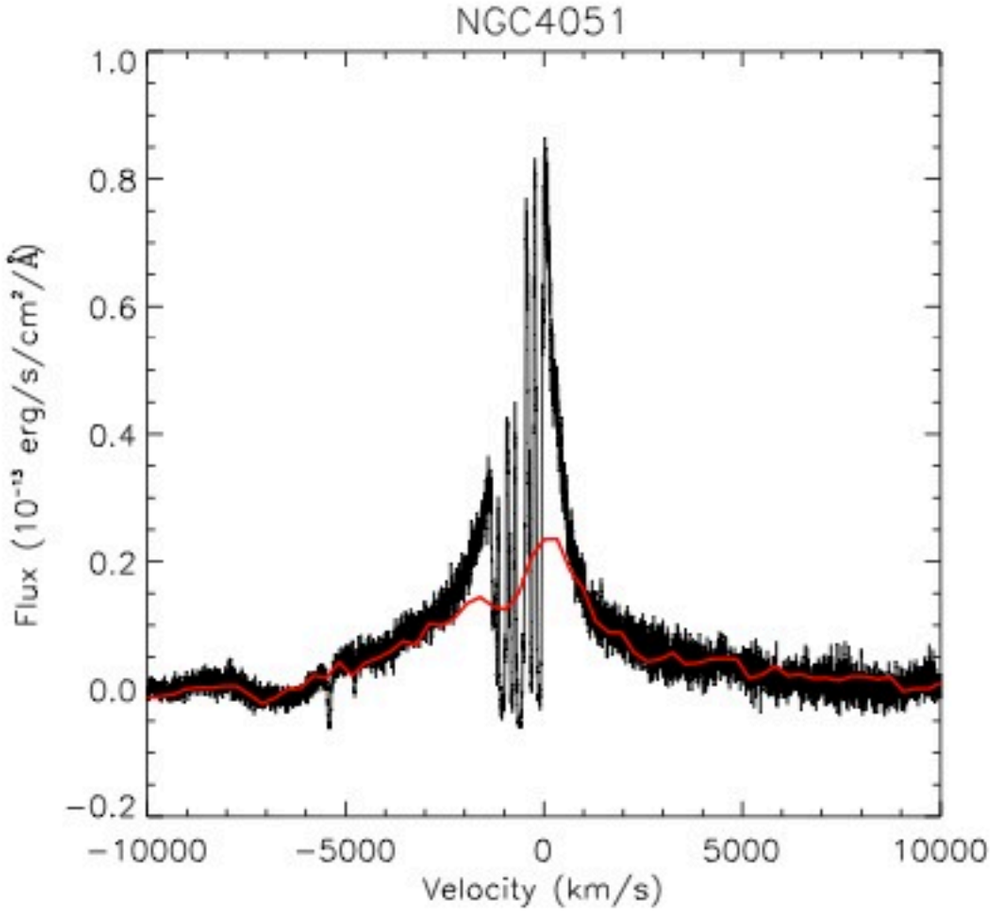


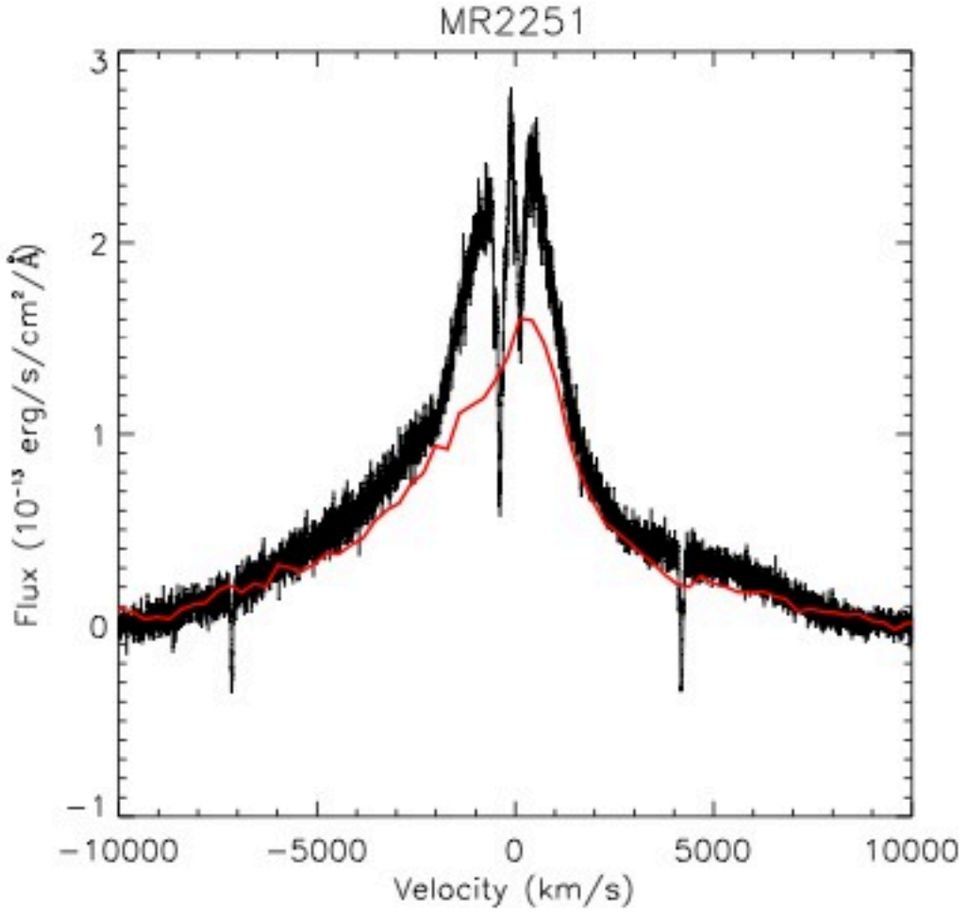




Tilton et al. 2013

C IV 1548, 1549



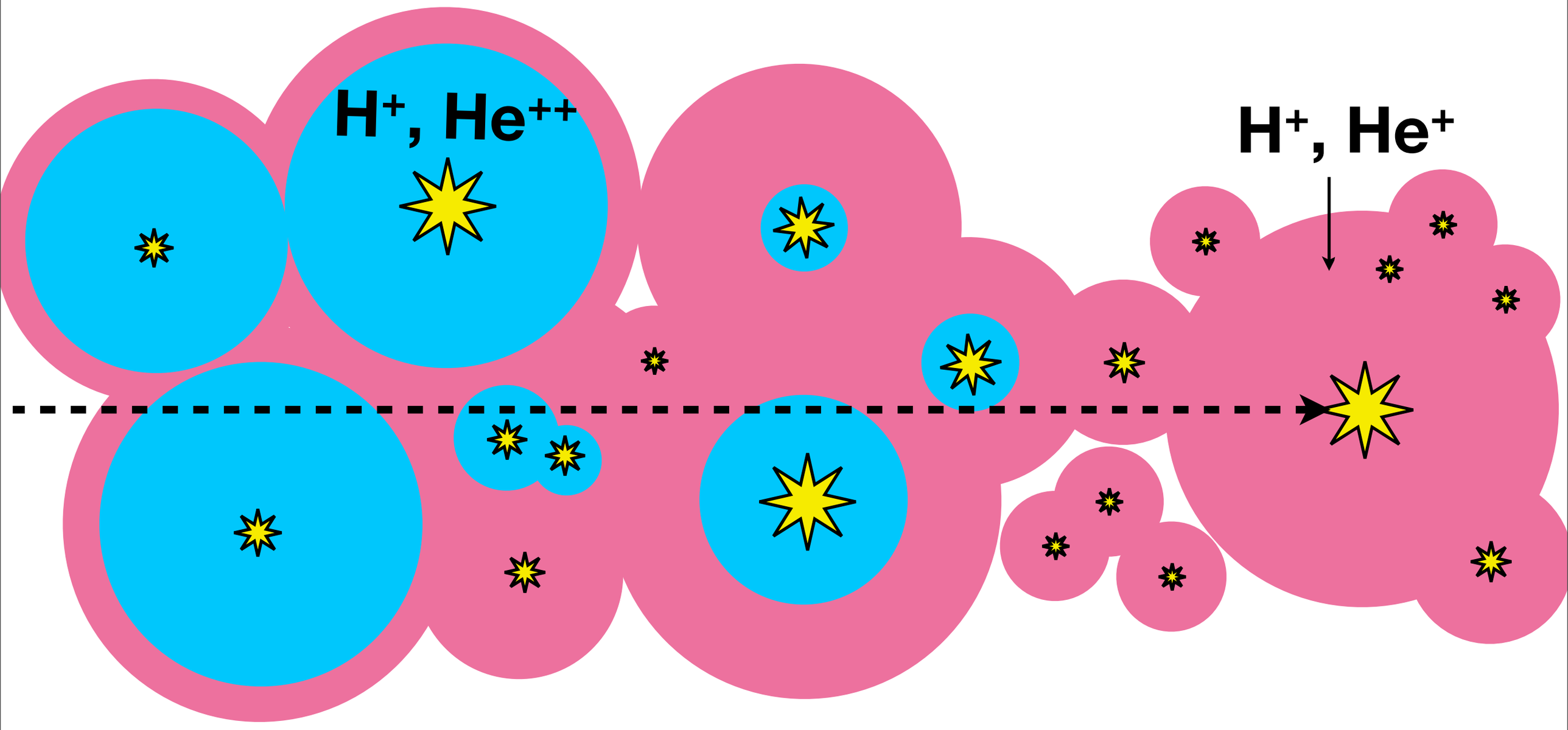


Low-redshift IGM
($z < 0.5$ and $t < 5$ Gyr)

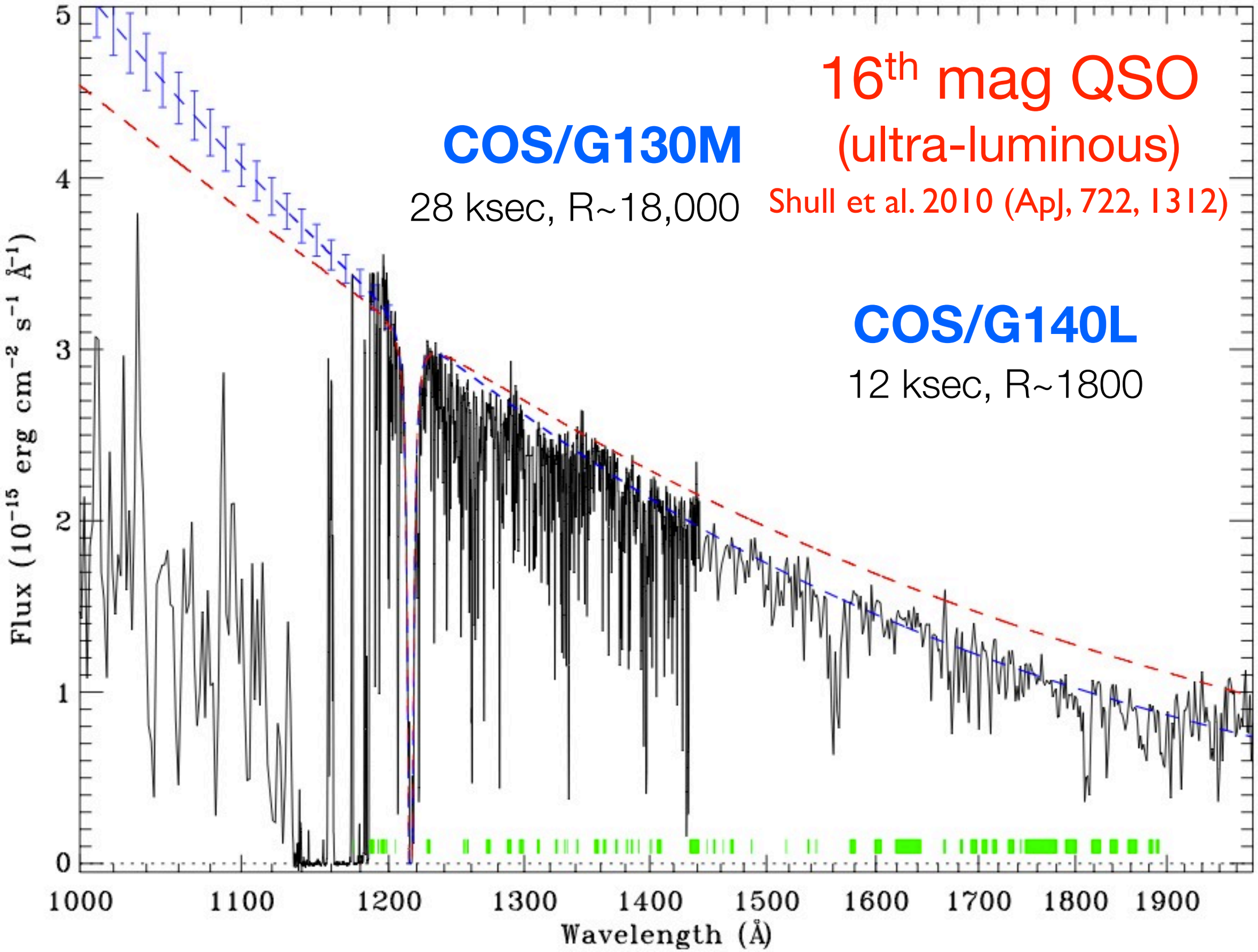
He II Reionization Epoch
$z \approx 2.7 - 3.2$

Hubble/COS spectra
explore the ionization era
of Helium (11 Gyr ago)

Helium Reionization: The Cartoon Picture

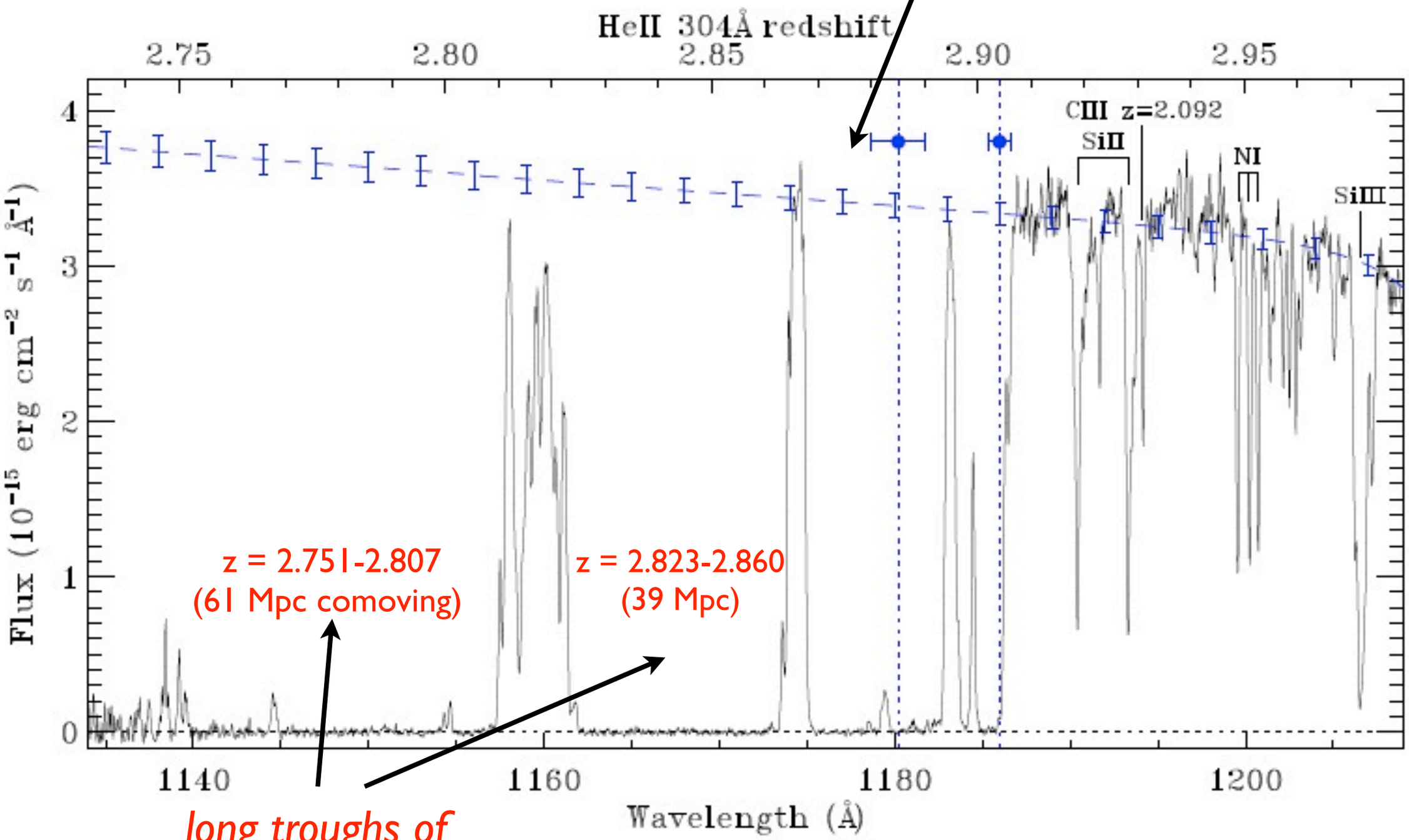


Unprecedented View of HE 2347-4342



Patchy He II Reionization (z ≈ 2.7-2.9)

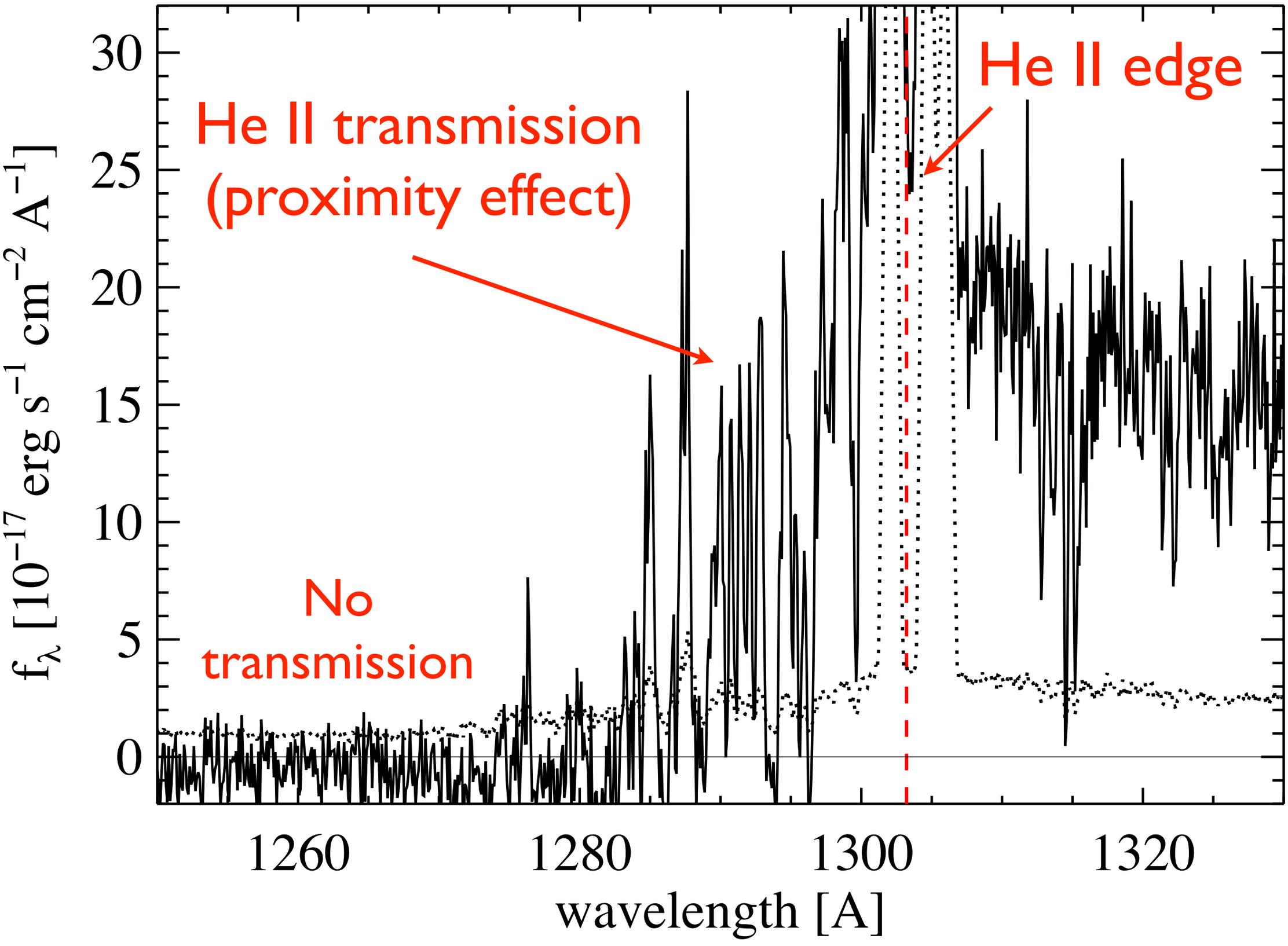
No QSO "proximity effect"



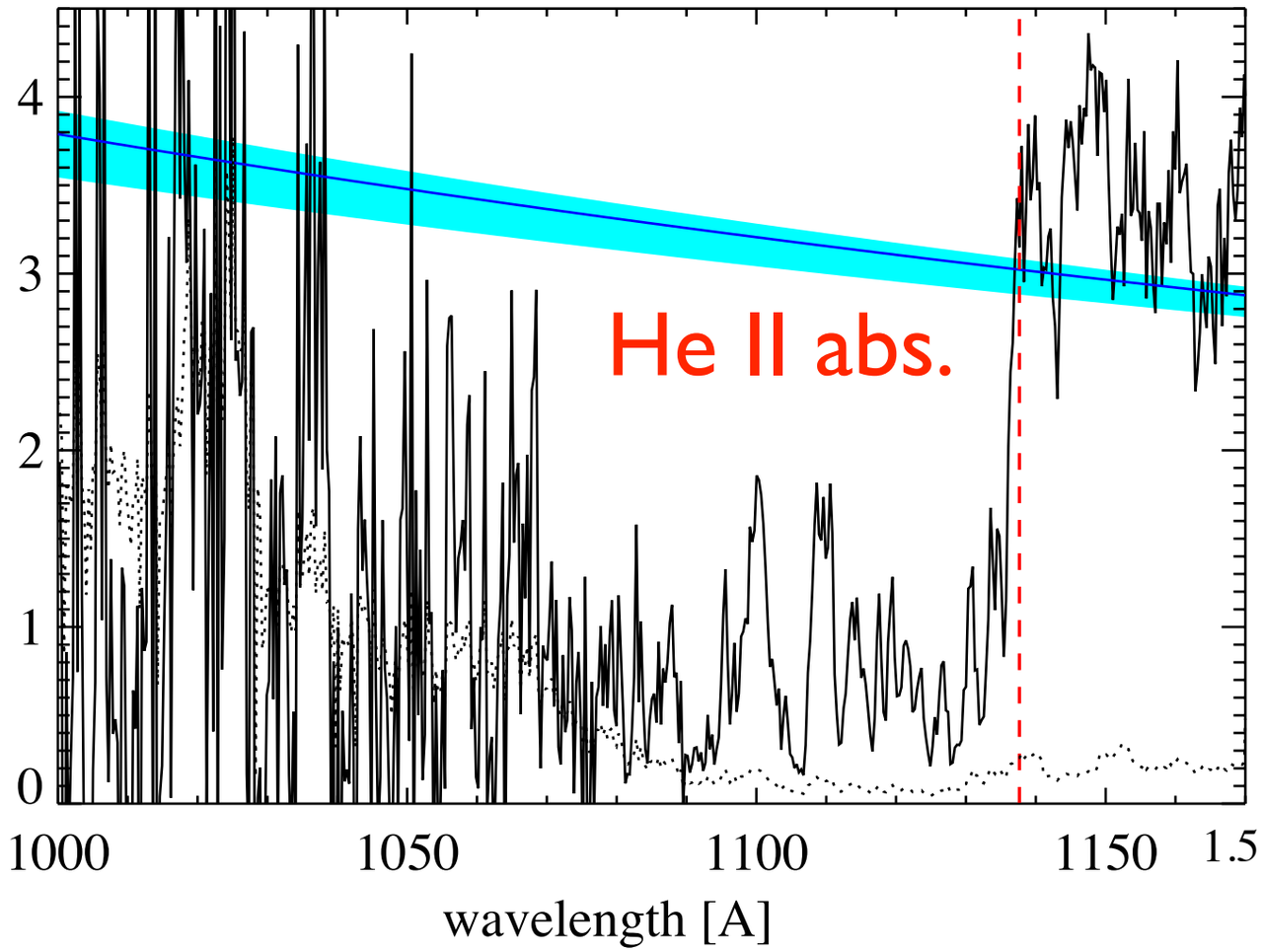
long troughs of strong He II absorption

New COS Data: Q0302-003 (z = 3.286)

Syphers & Shull 2013



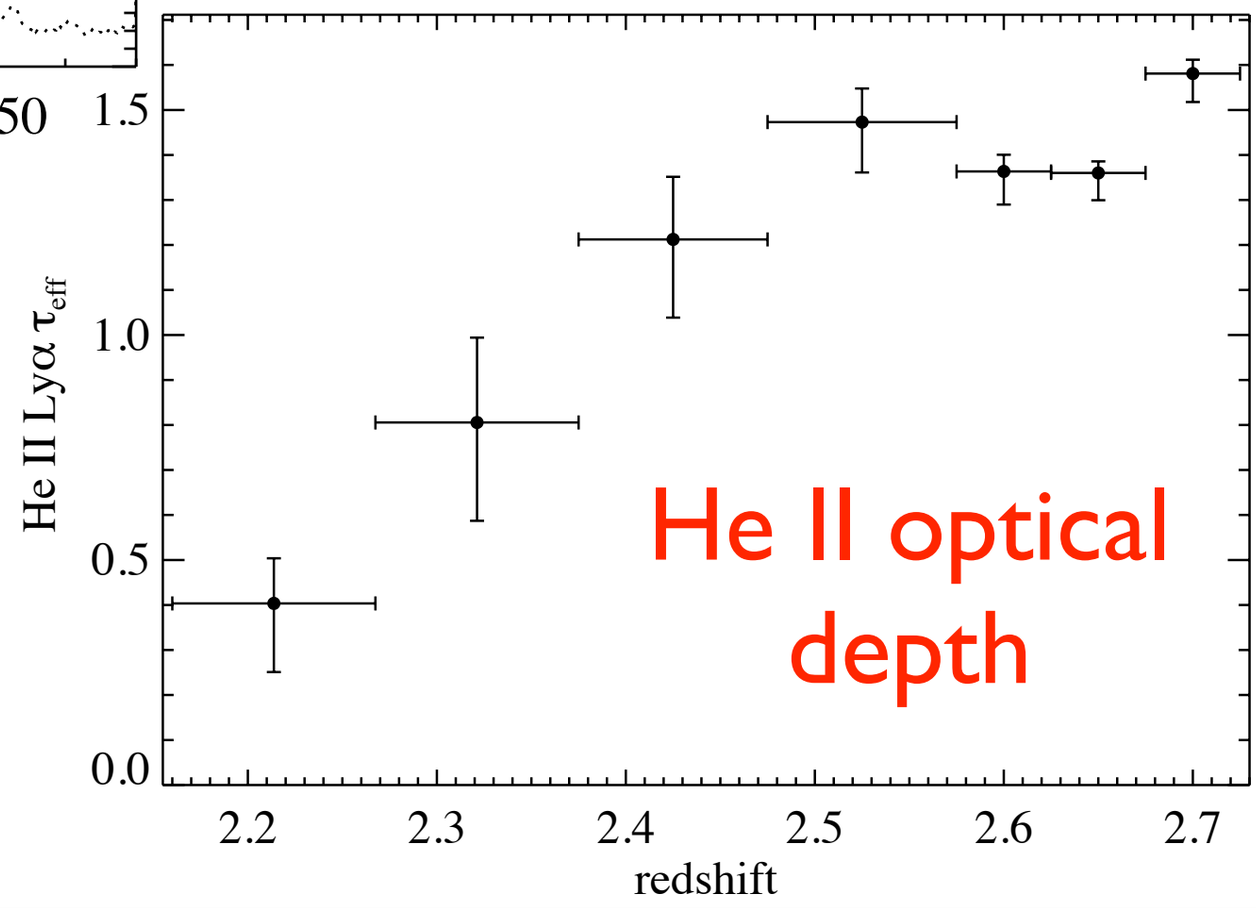
HS 1700+6416 (z = 2.733)



COS (G140L) spectrum

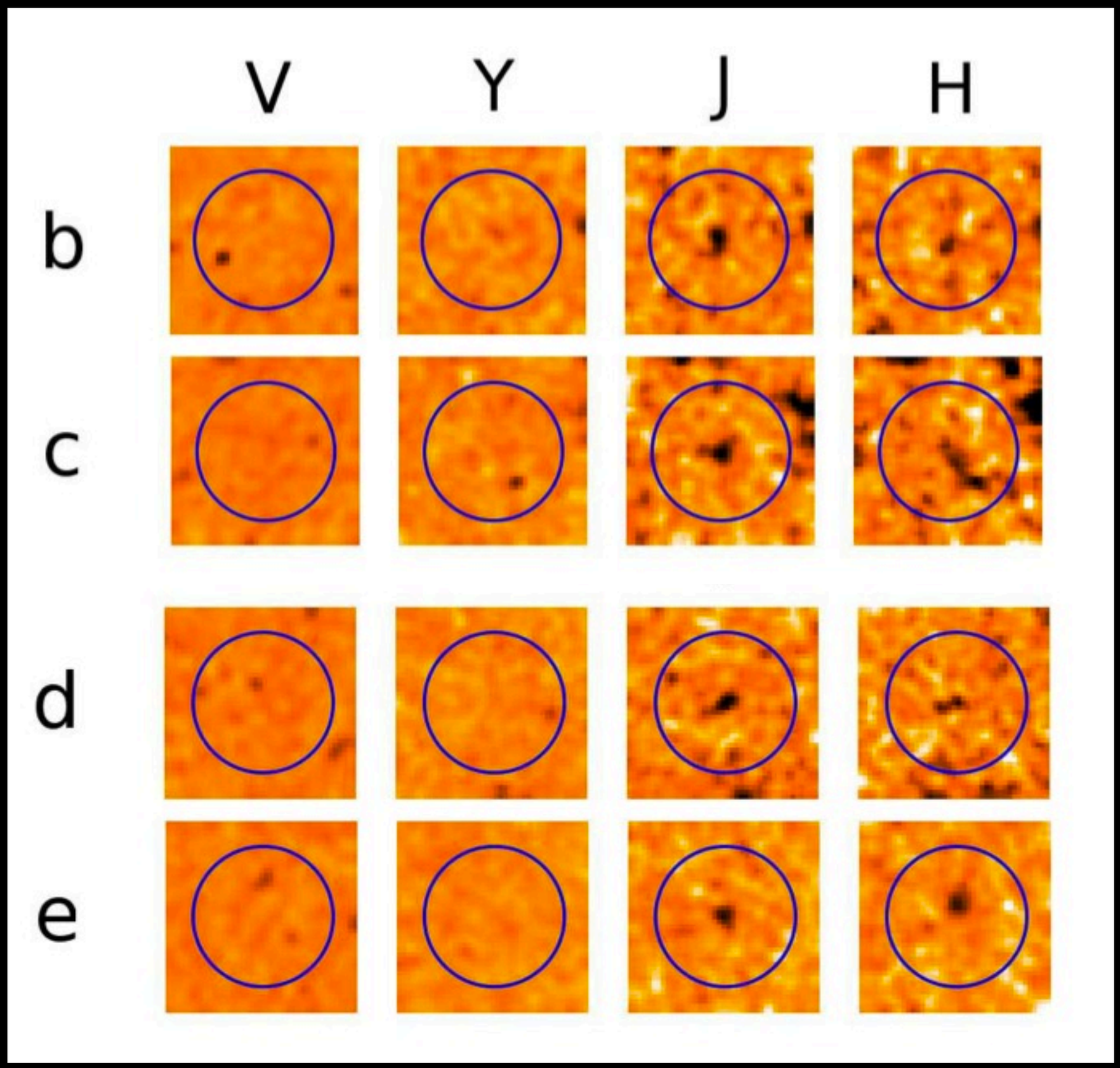
Syphers & Shull 2013

T_{eff} recovery (z < 2.5)



He II optical depth

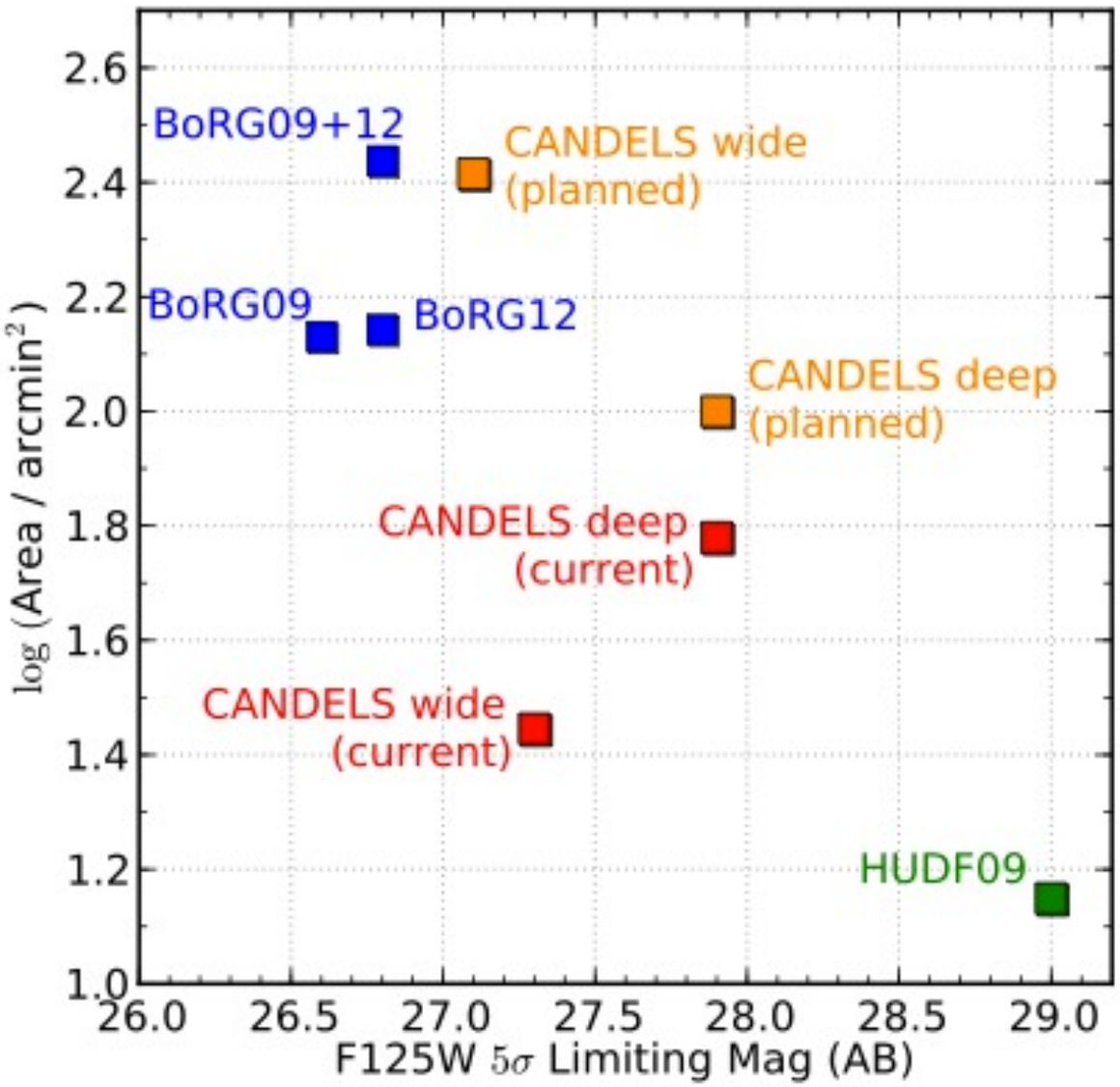
COS Parallels -- New Galaxies at Redshift z ≈ 8



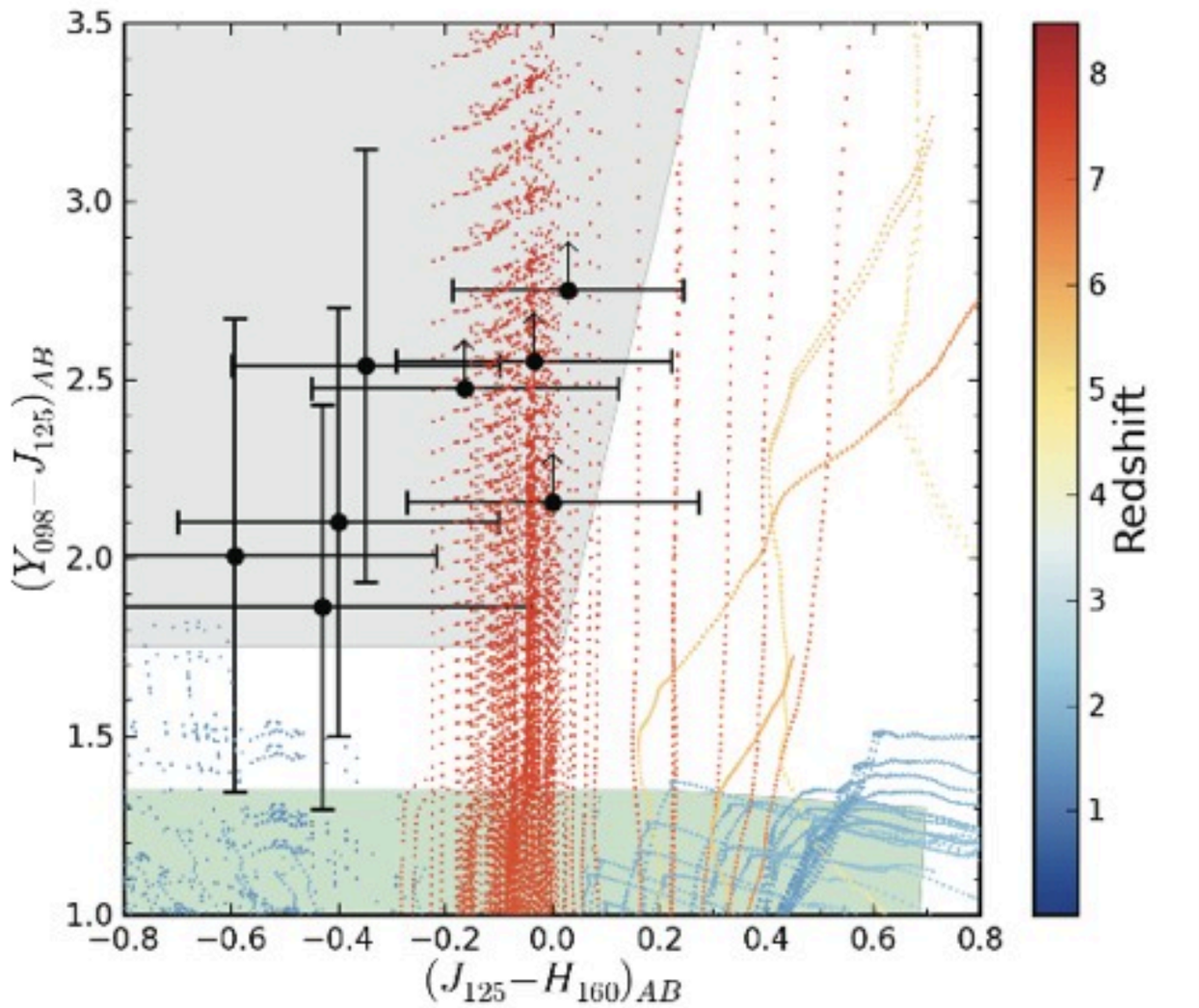
650 Myr after Big Bang

Trenti et al.2011, ApJL, 727, L39

Discovered by Hubble's New WFC-3 Camera (Infrared channel)

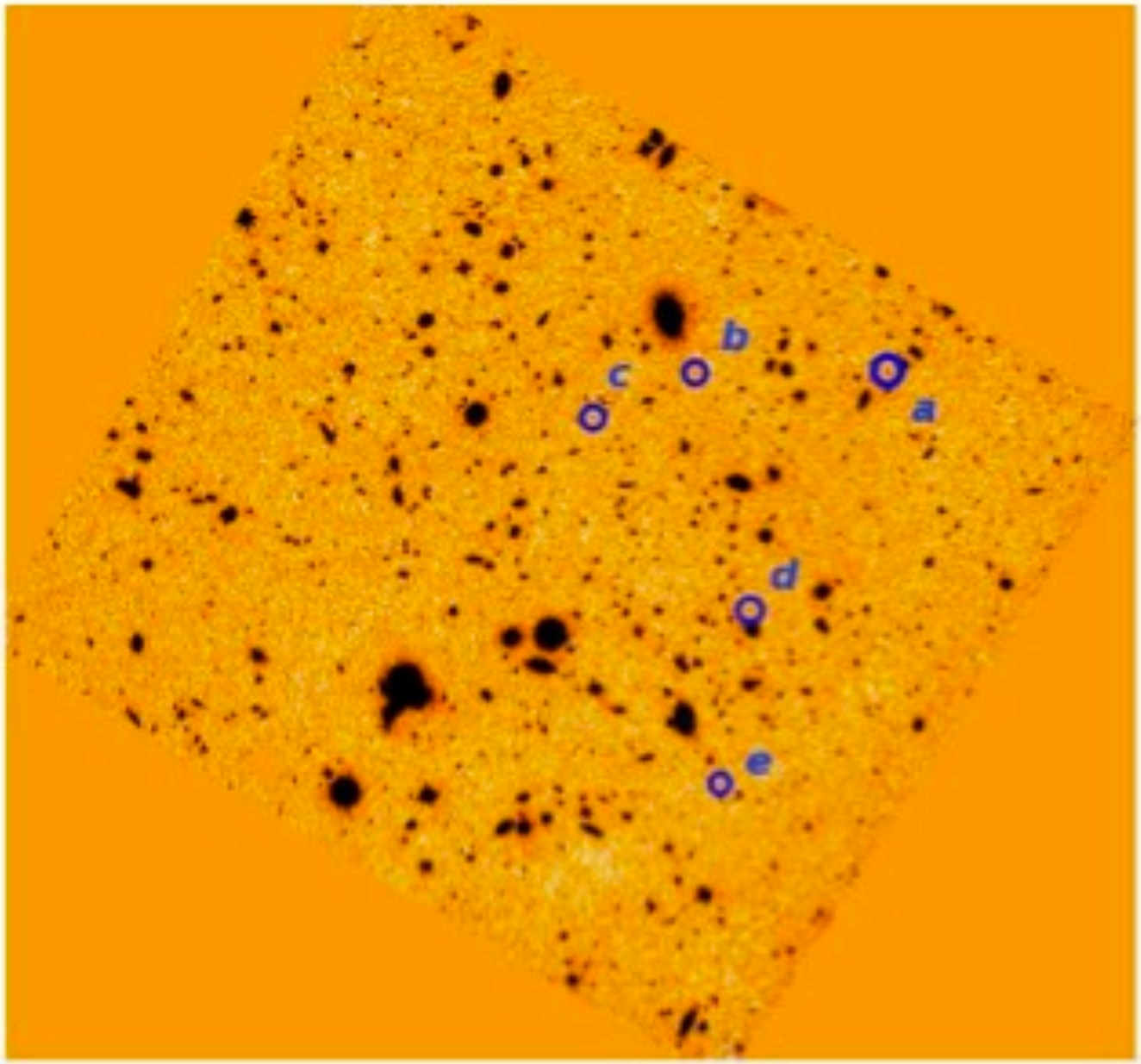


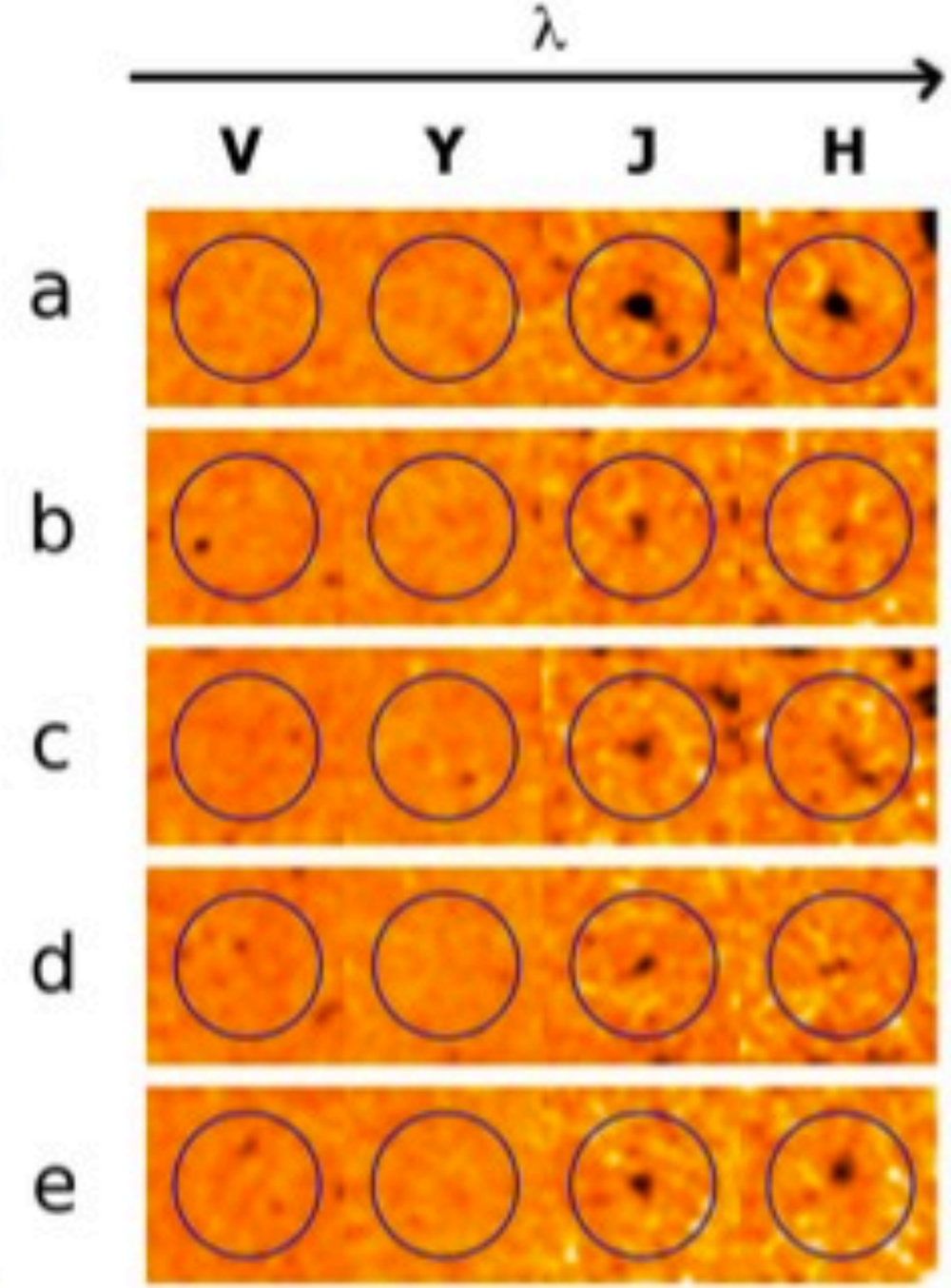
Lyman-break galaxy (dropout detections)



BoRG program has the widest coverage (280 arcmin^2) but to m_{AB} ~ 26.8 mag

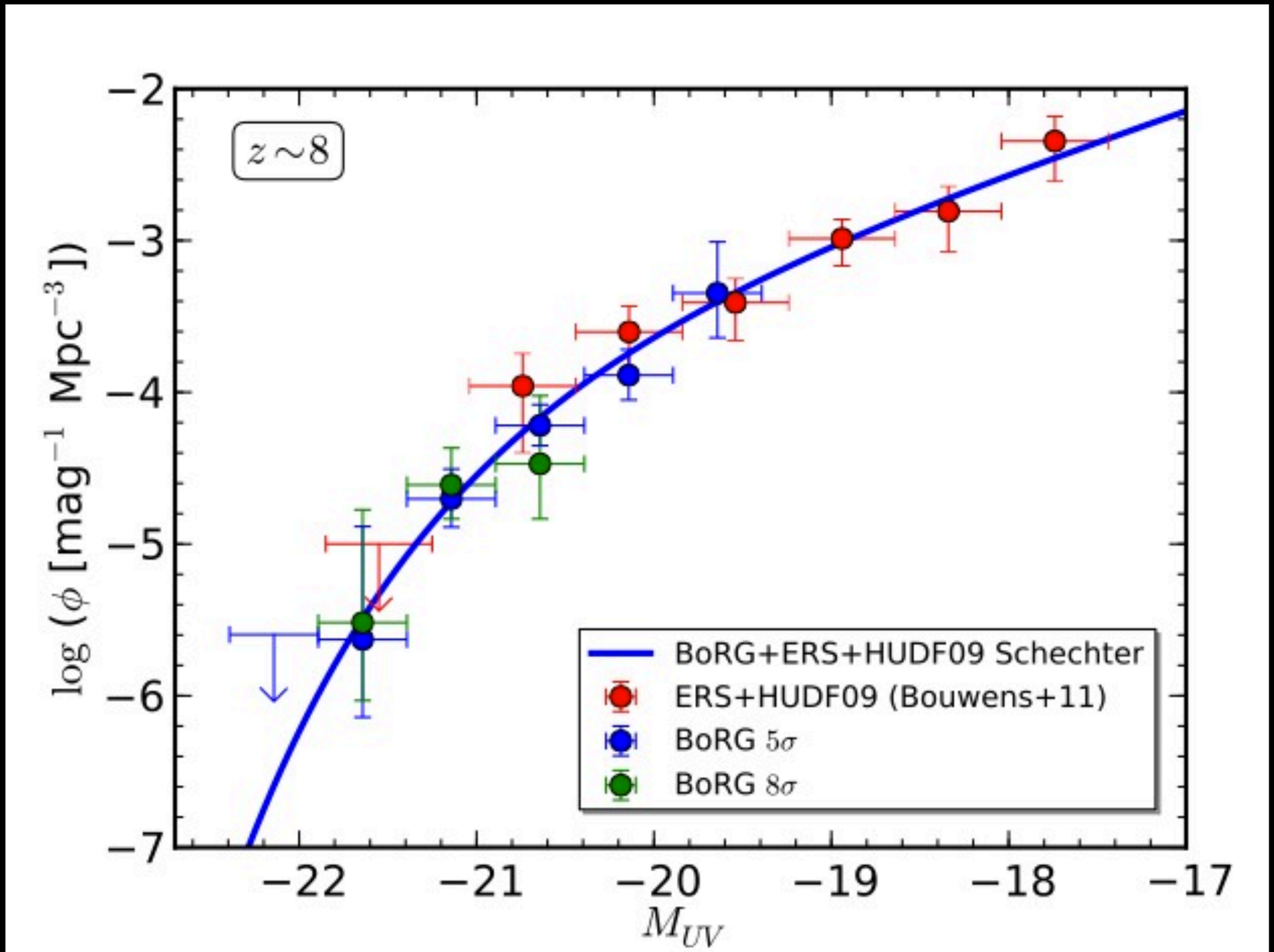
Proto-cluster of galaxies at z ≈ 8 (Trenti et al. 2012, ApJ)





Luminosity Function (z ~ 8)

Bradley et al. (2012)



Future with COS

IGM Baryon, Galaxy, Metallicity Surveys (to z ~ 0.5)

"Rest of the Baryons.... The Edge of Metals"

O VI (IGM & Halos) and Ne VIII (WHIM & CGM)

He II reionization-epoch studies (z ≈ 2.4 - 3.3)

Future UV spectroscopic surveys can use Lyα and metal lines to measure evolution of baryons, ionizing radiation, and heavy elements over the last 8 Gyr

Enjoy COS and Hubble (while they last)