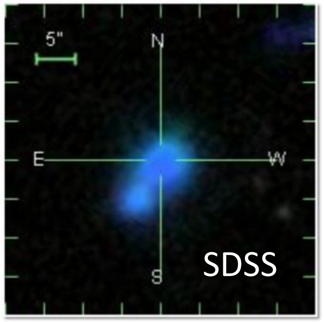
I Zw 18-NW as a Cosmological Probe of the Reionization Era



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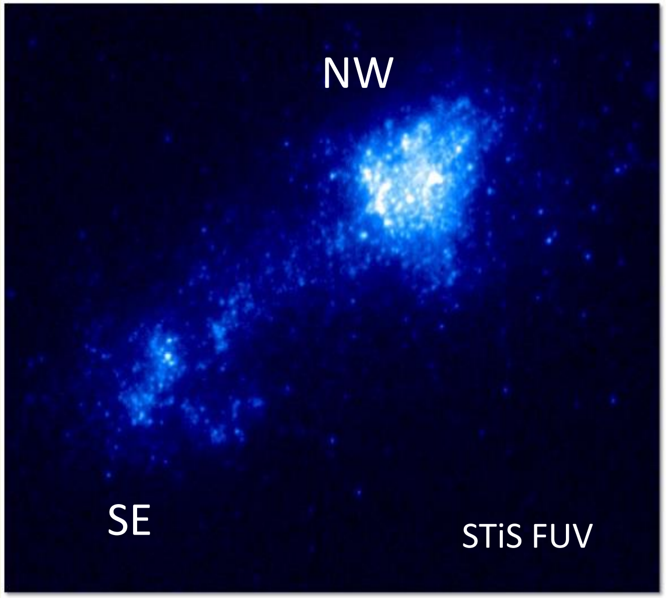

I Zw 18-NW Fast Facts

- $M_{1600,AB}$ = -14.4; Distance ~ 18 Mpc (Aloisi+07)
- Age of NW star cluster ~ 5 Myr (Tmax~40,000 K)
- $M_{BH} > 85\ M_{\odot}$ (Kaaret & Feng 2013)
- $M_{\star} \sim 5\times10^{5}\ M_{\odot}$; $M_{gas} \sim 1\times10^{8}\ M_{\odot}$; $M_{dyn} = 3\times10^{8}\ M_{\odot}$ (Lelli + 12)
- log $Z/Z_{\odot}$ (H II region); ~ -1.7; Z(H I region)~-2, with Z=0 pockets? (Lebouteiller, SH+13)

I Zw 18 is like the (so far) unseen dwarf galaxies that reionized the universe

LOWER-LUMINOSITY GALAXIES COULD REIONIZE THE UNIVERSE: VERY STEEP FAINT-END SLOPES TO THE *UV* LUMINOSITY FUNCTIONS AT $z \geqslant 5$–8 FROM THE HUDF09 WFC3/IR OBSERVATIONS*

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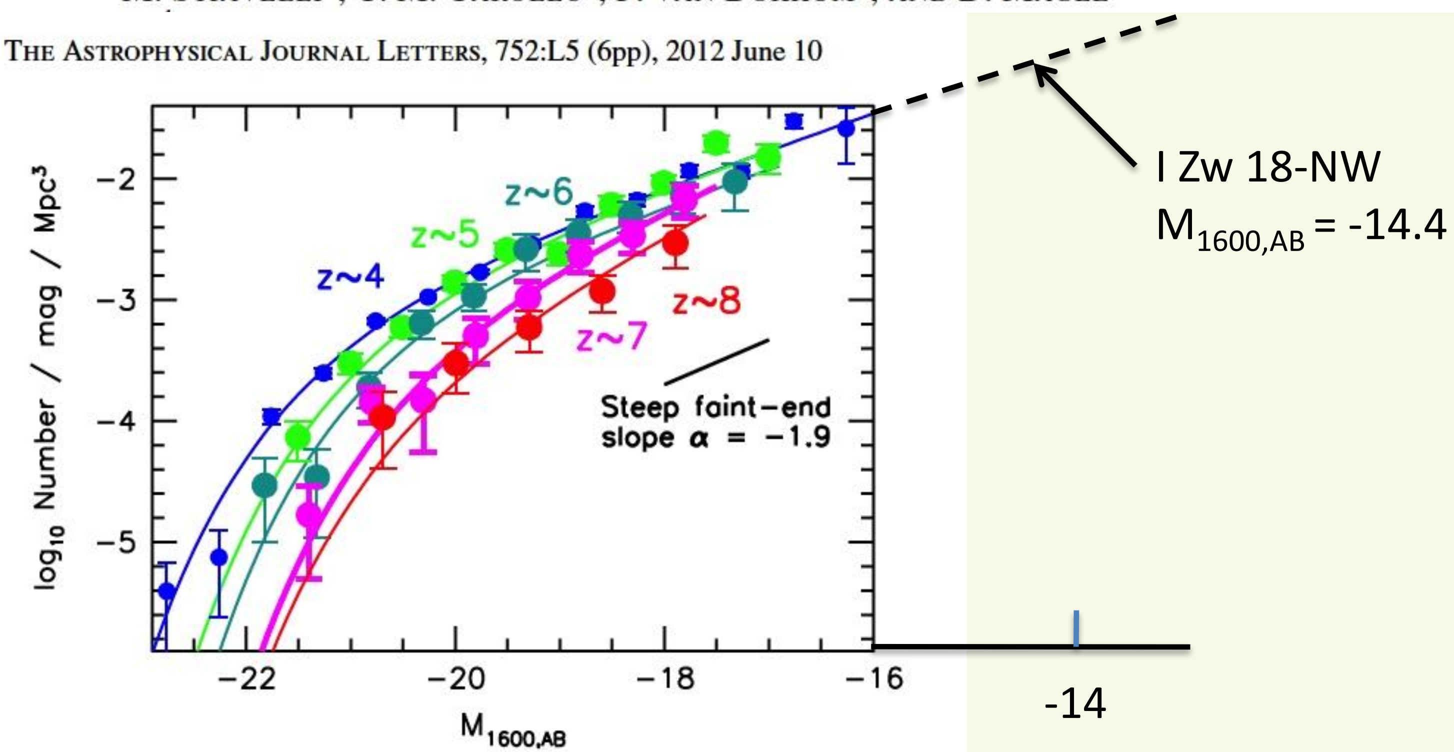
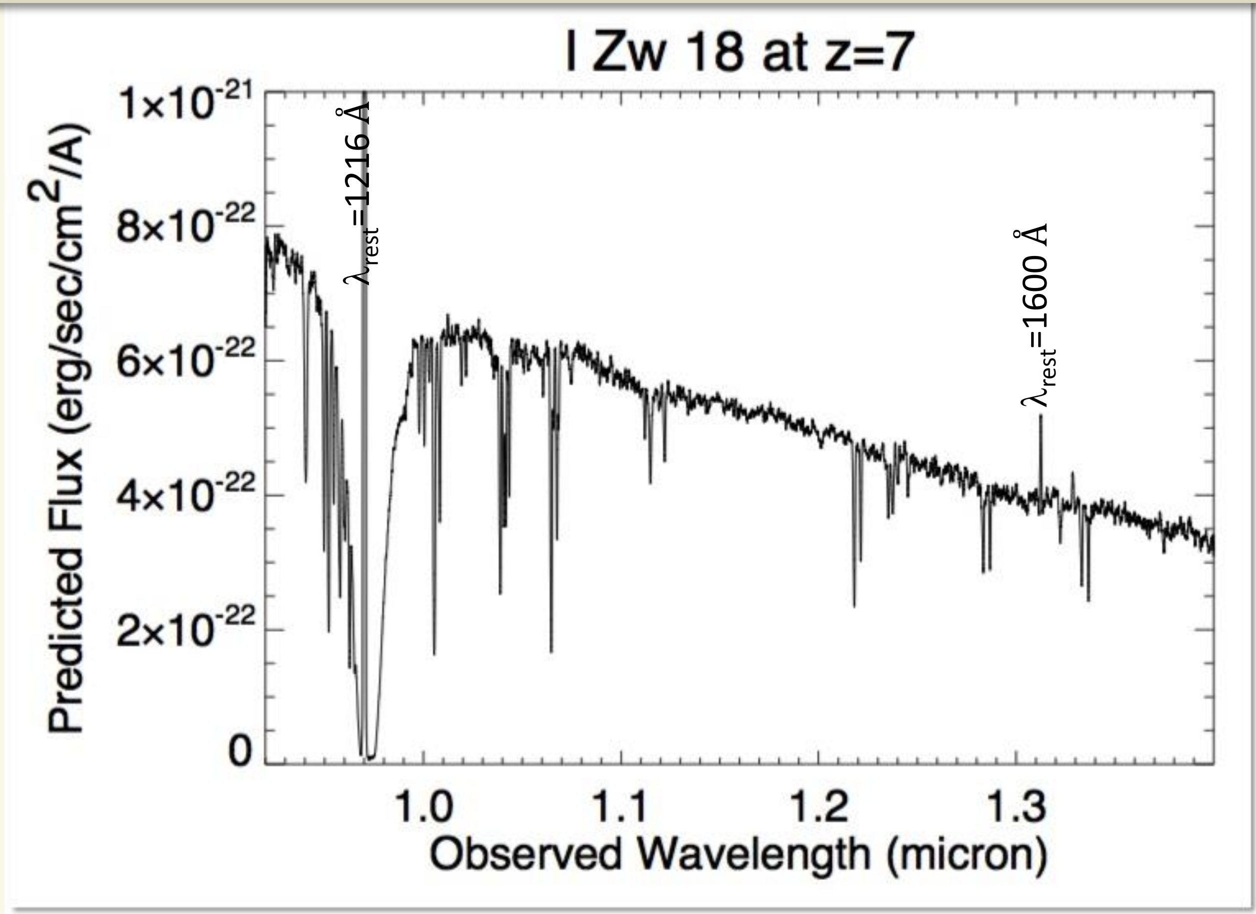
The Astrophysical Journal Letters, 752:L5 (6pp), 2012 June 10



I Zw 18-like dwarf galaxies at z~7 are too faint for detailed spectral analysis by JWST



1-day exposure

λ_{obs} (μ)	S/N
1.28	1.8
0.97	1.1
0.97 (10X)	11.1

I Zw 18 can help us understand primitive galaxies at high redshift and how reionization occurred

Very low-Z massive stars are born and evolve differently from higher-Z stars

Low-Z on the ZAMS are hotter (up to T_{eff} ~63,000 K for M_i=150 $M_\odot$, log Z=-1.7)

∴ expect harder radiation

Low-Z stars are smaller than $Z_\odot$ stars

∴ may be born rotating faster

Rotation-induced mixing is much more efficient at low Z (Maeder & Meynet 2012)

∴ expect N enhancement in rapidly rotating stars

∴ expect more stars undergoing chemically homogeneous evolution (CHE)

Stellar winds in very low-Z stars are weak to non-existent

∴ angular momentum is not lost to a stellar wind → progenitors of GRB's?

∴ **stellar mass is not significantly reduced by evolution**

→ **produce massive black holes**

Binary interactions are important in massive stars

~ 70% of all stars born as O stars are members of a binary system that will interact by Roche lobe overflow

~ 40% of all O stars will be affected during their main sequence life-time, impacting subsequent evolution

~ 33% of O stars are stripped of their envelope before they explode as hydrogen-deficient CC SNe (Types Ib, Ic and IIb)

~ 20-30% of all O stars will merge with a nearby companion

(Sana+13)

... especially low-Z binaries

- GW150914 is the result of a merger of 30 + 30 M_{sun} black-holes
- **I Zw 18 hosts a massive X-ray binary (M>85 $M_{\odot}$)** (Kaaret +2013)

I Zw 18-NW has an embedded ultra-luminous X-ray source

Kaaret+Feng 2013

X-Ray Spectral Fits

Model	χ^2/DoF	L_X (10^{40} erg s^{-1})	N_H (10^{21} cm^{-2})	kT/E_c (keV)	Γ
Power law	220.8/151	3.0	3.8 ± 0.5		2.01 ± 0.06
Diskbb	172.0/151	1.1	0.7 ± 0.3	1.05 ± 0.05	
Cutoff power law	156.7/150	1.2	1.4 ± 0.6	2.1 ± 0.6	0.80 ± 0.26
Diskbb+power law	157.3/150	1.3	1.4 ± 0.6	1.04 ± 0.07	2
Simpl * kerrbb	153.4/150	1.2	1.2 ± 0.4		2

Model	N_H (10^{21} cm^{-2})	Γ/kT	Fit/dof	F_X (10^{-15} ergs cm^{-2} s^{-1})	L_X (10^{39} ergs s^{-1})
POW	$1.44^{+0.38}_{-0.37}$	$2.01^{+0.14}_{-0.16}$	18.1/20*	72.1	1.6
RAY	$0.87^{+0.27}_{-0.24}$	$4.06^{+1.84}_{-1.19}$	23.0/20*	66.6	1.4

Thuan + 2004

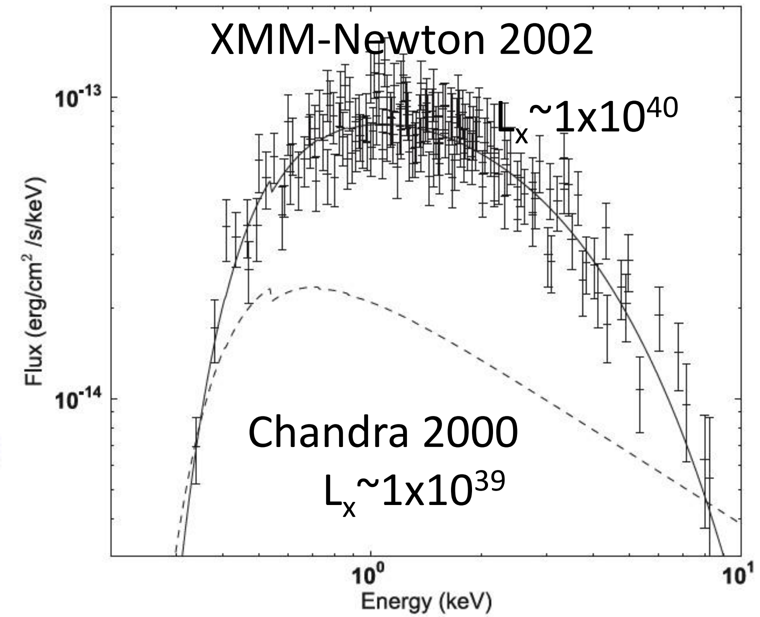
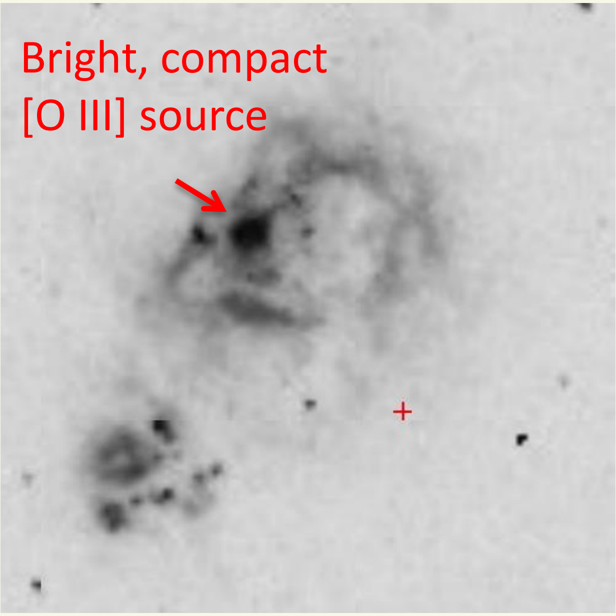


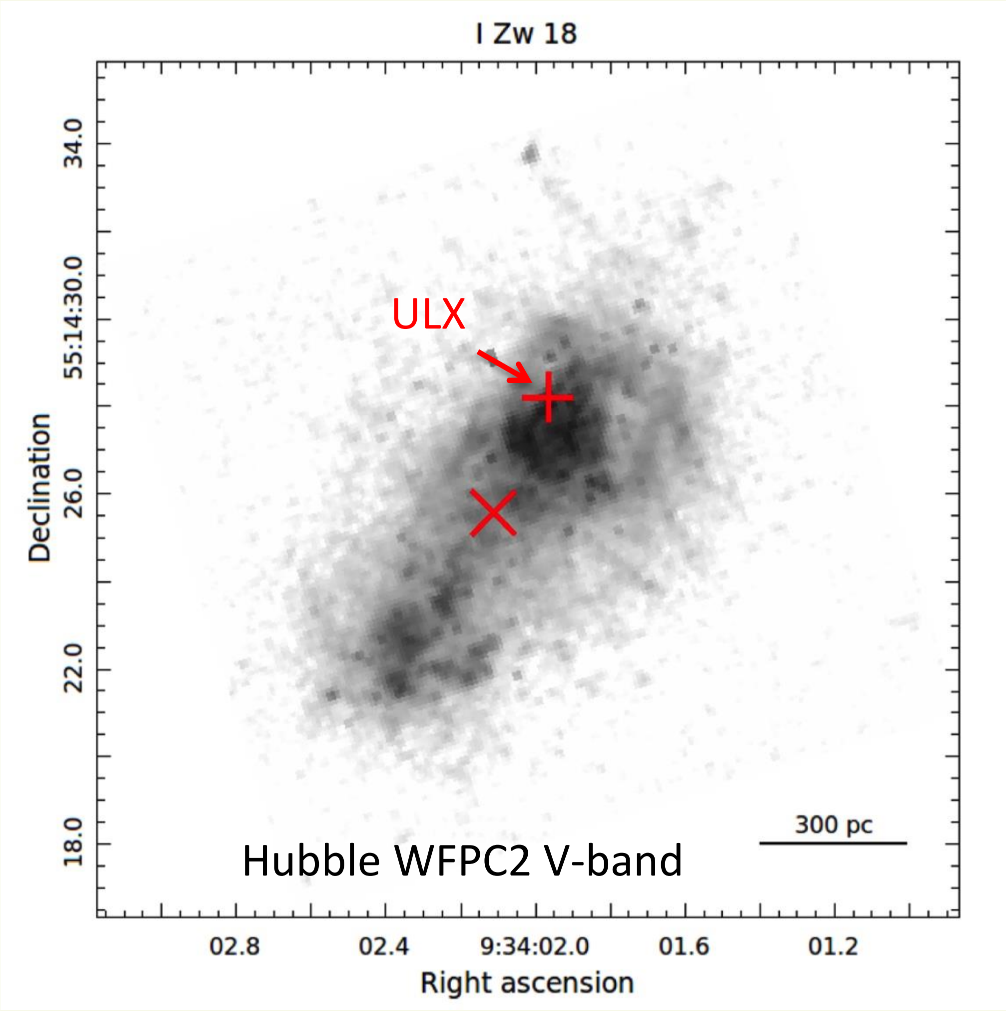
Figure 3. X-ray spectra of I Zw 18 at low and high flux levels. The points and the solid curve show the *XMM* observation fitted with the cutoff power law model. The dashed curve shows the power law model fitted to the *Chandra* data.

The ULX is a massive X-ray binary with an estimated BH mass, M_{BH}>85 $M_\odot$

The MXRB is in a bright, compact source Hα, He II 1640, 4686, and [O III] 5007



Hubble Legacy Archive
WFPC2 F5002N [O III]

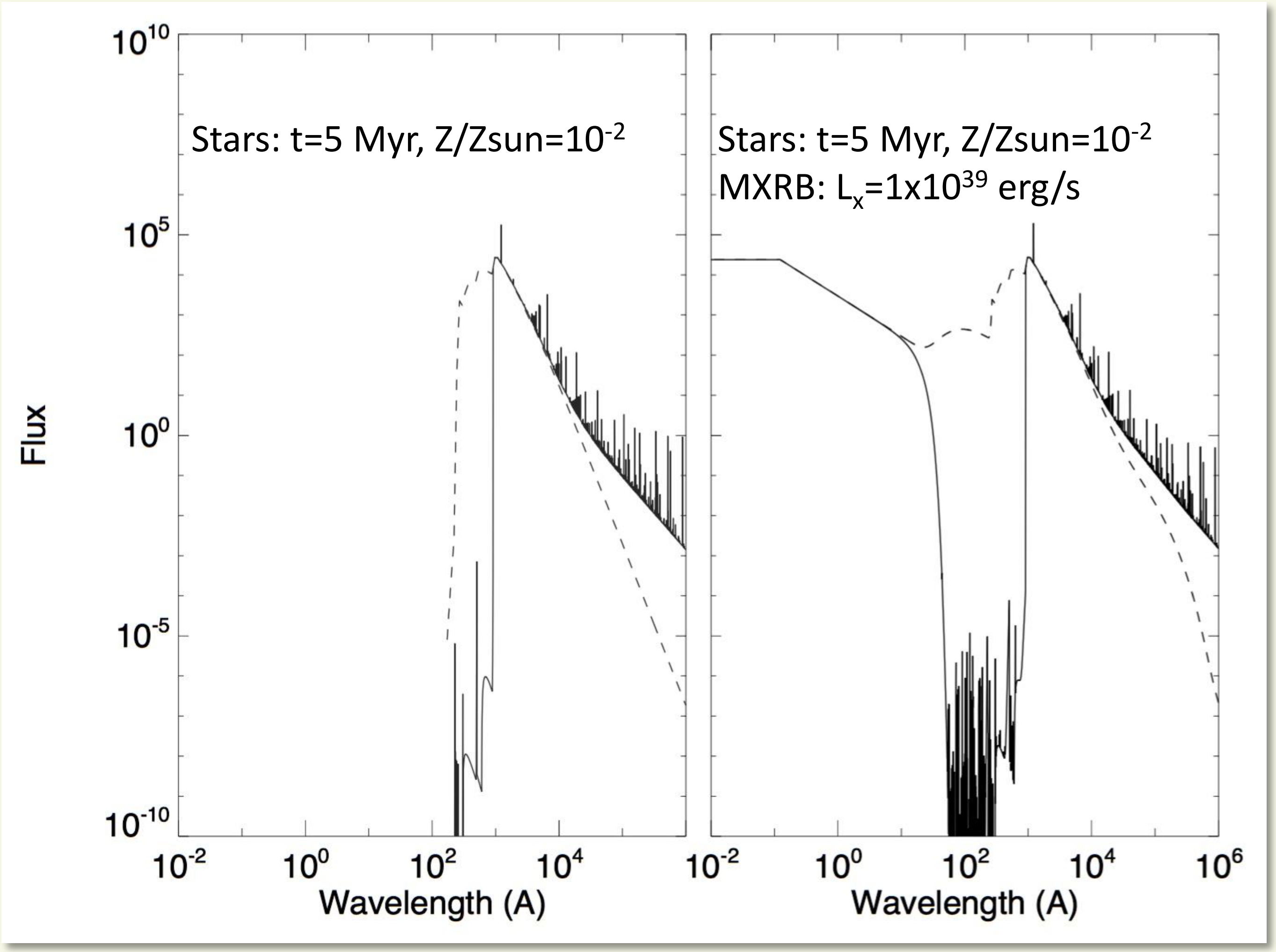


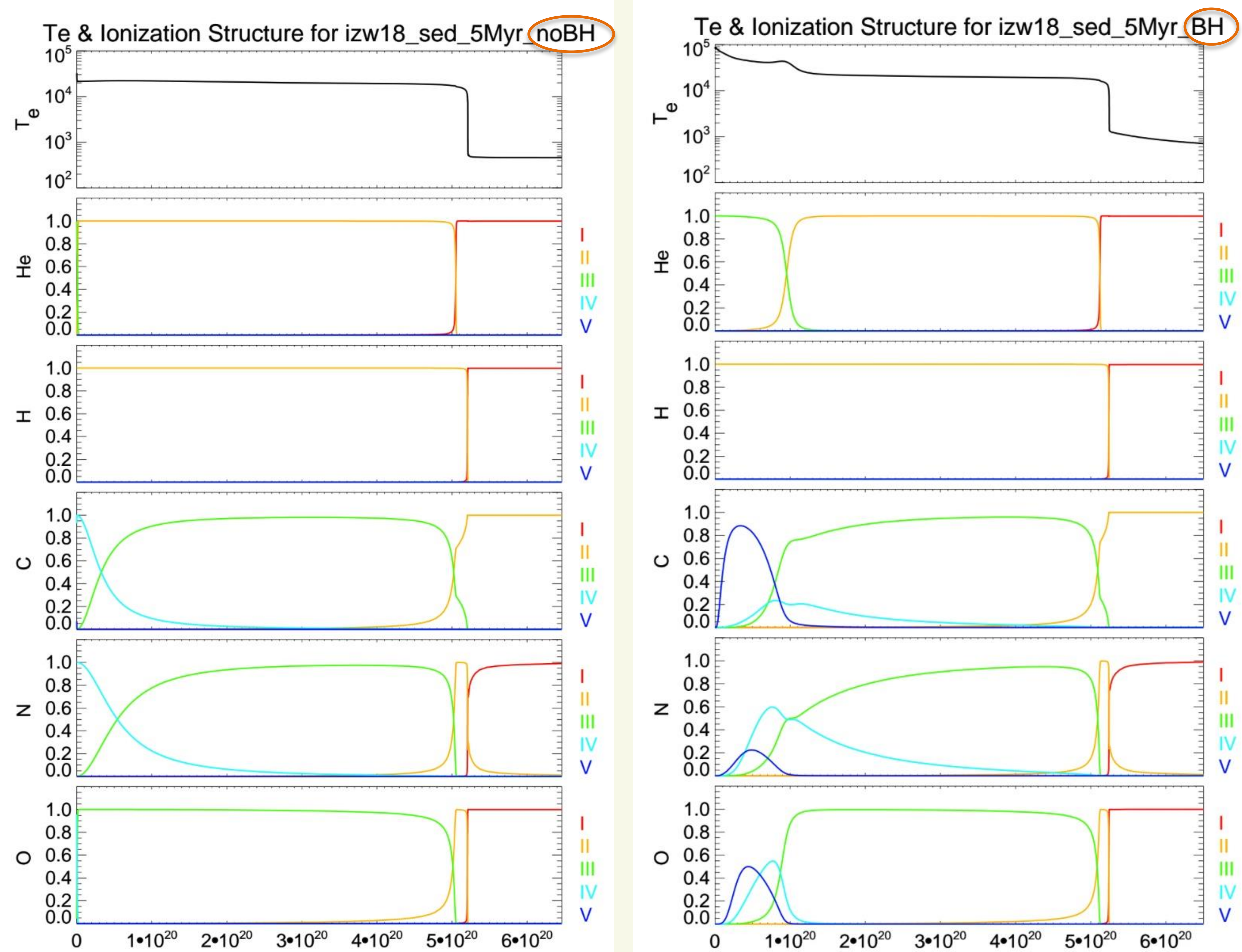
Hubble WFPC2 V-band

Kaaret & Feng 2013

Effect of BH on SED

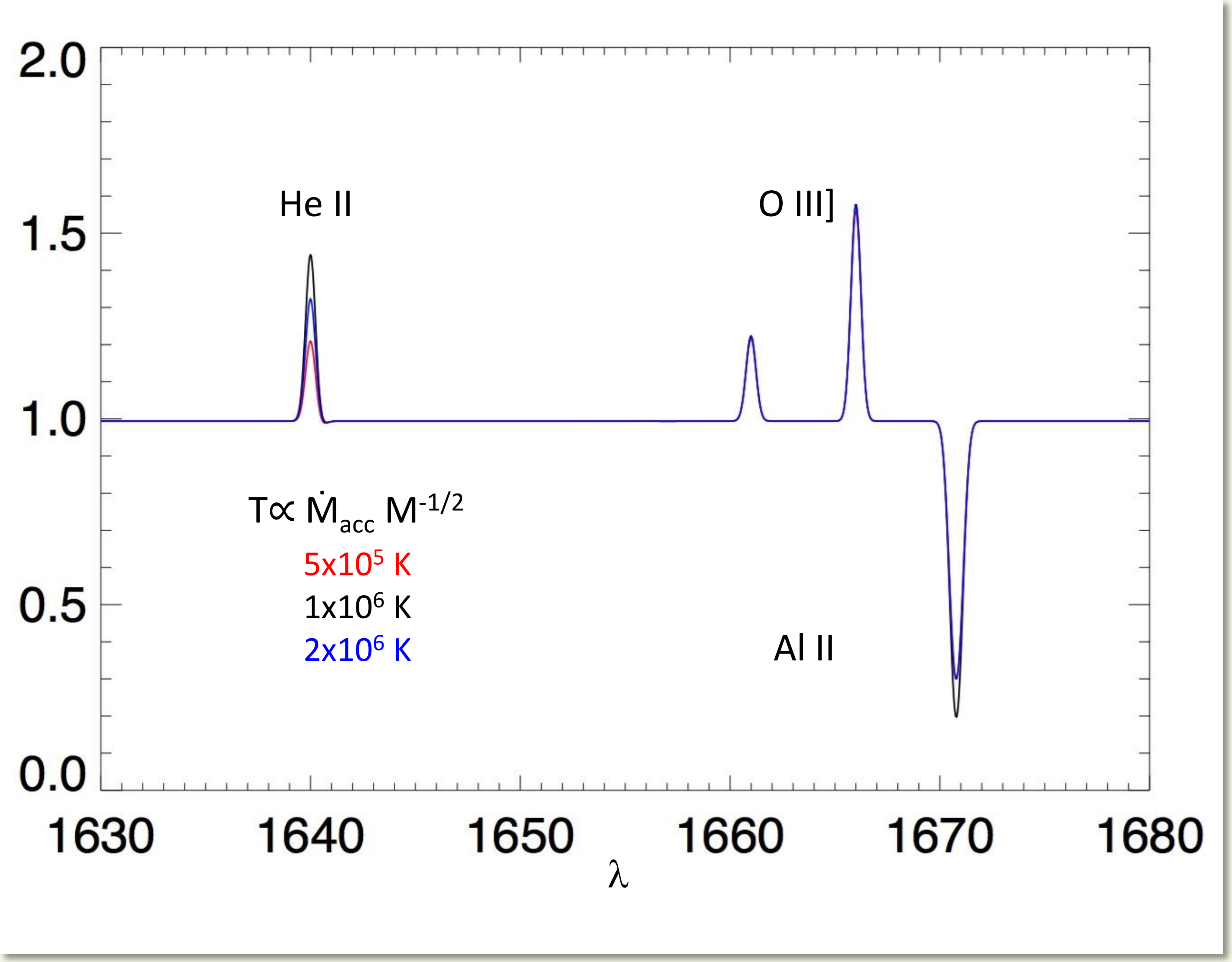
- - - SED incident at inner edge of CLOUDY model (1×10^{17} cm)
----- Transmitted SED



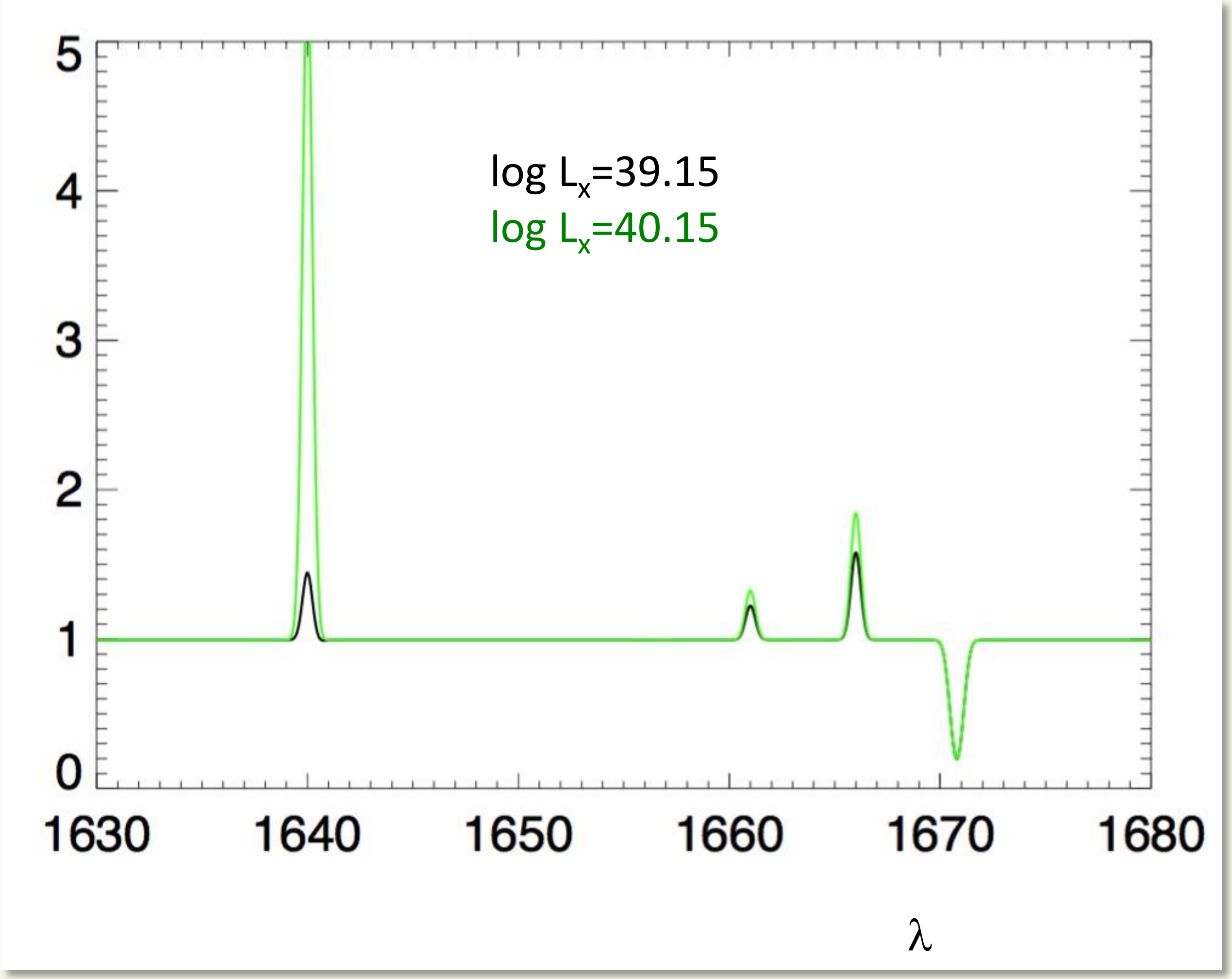


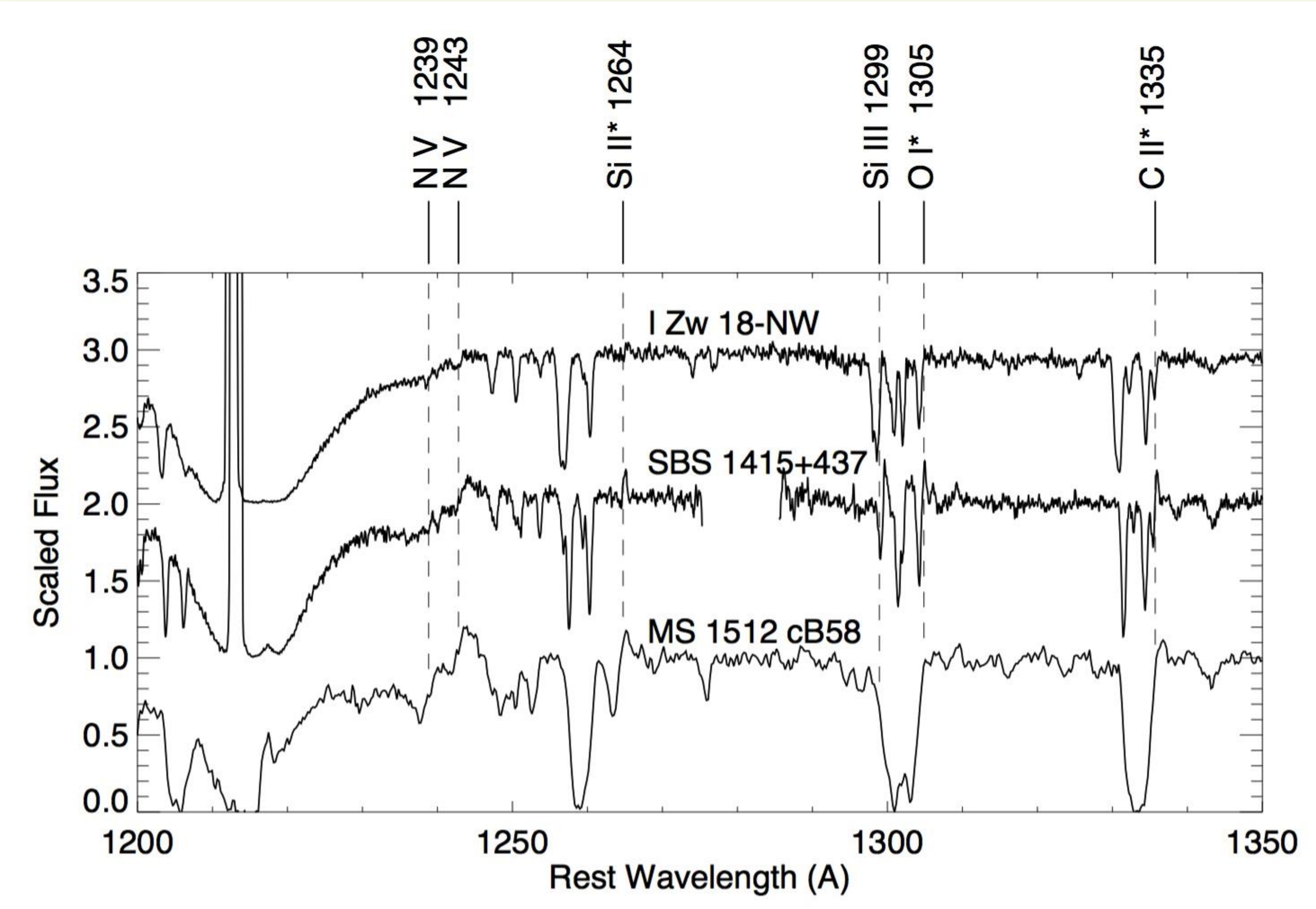
Te & Ionization Structure for izw18_sed_5Myr_noBH
Te & Ionization Structure for izw18_sed_5Myr_BH
T_e
10^5
10^4
10^3
10^2
He
H
C
N
O
1.0
0.8
0.6
0.4
0.2
0.0
I
II
III
IV
V
0
1•10^20
2•10^20
3•10^20
4•10^20
5•10^20
6•10^20

Effect of T_e on UV spectrum

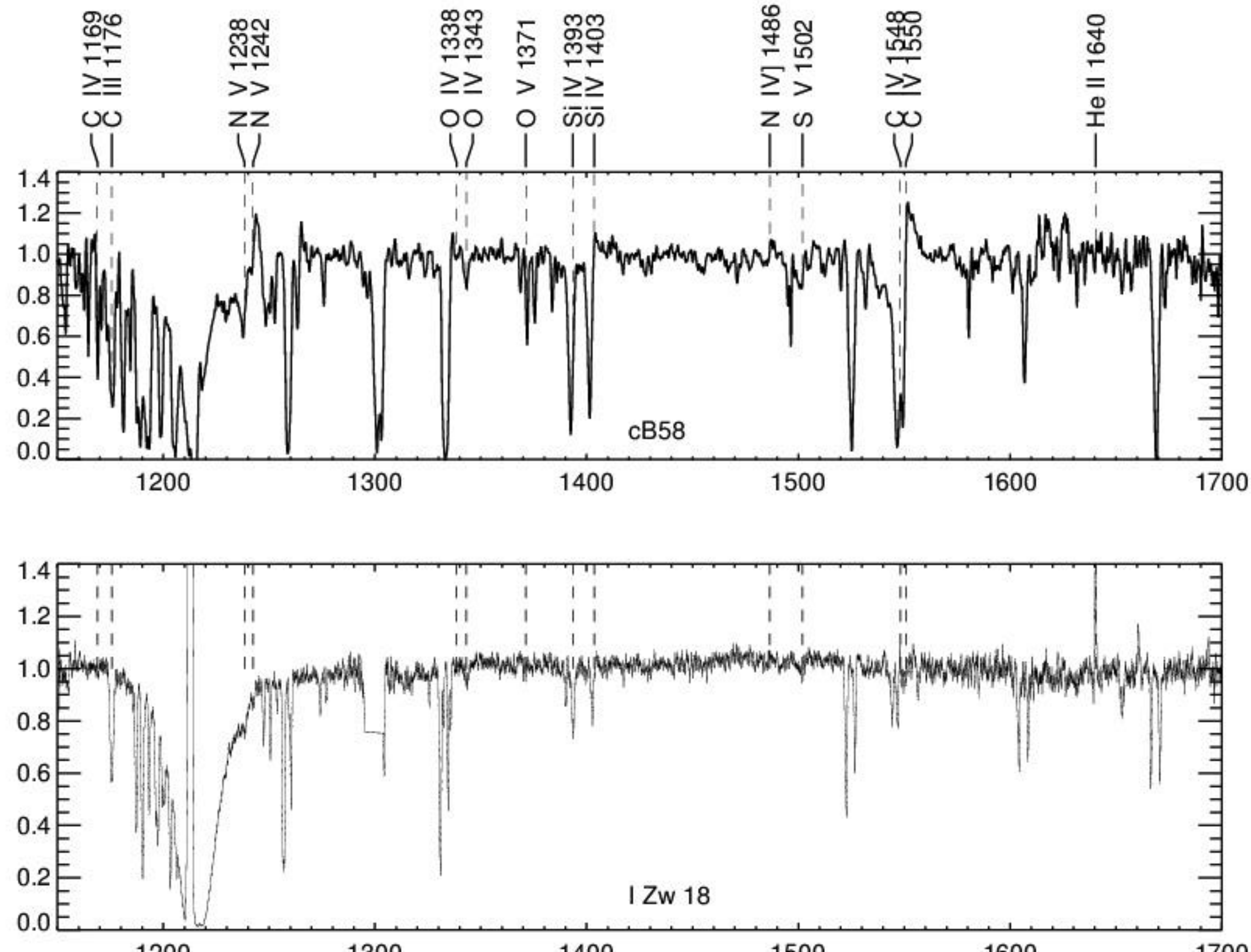


Effect of L_x on UV spectrum

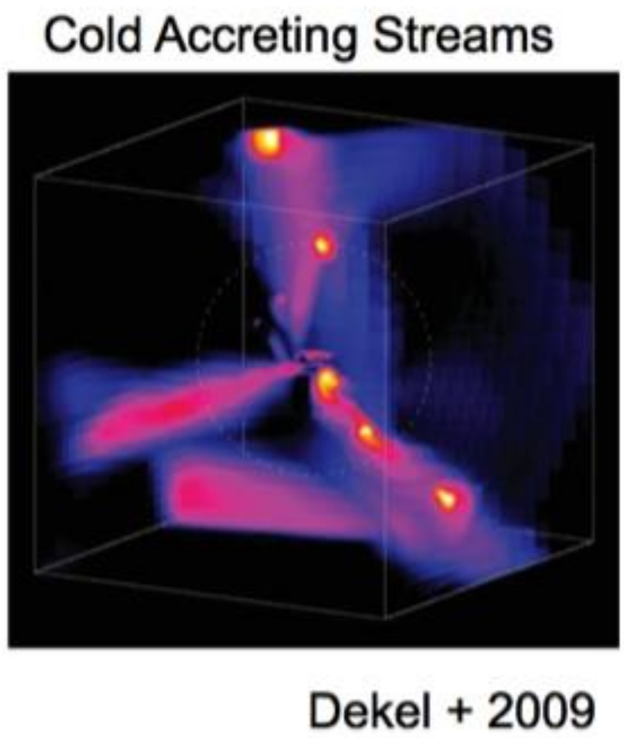


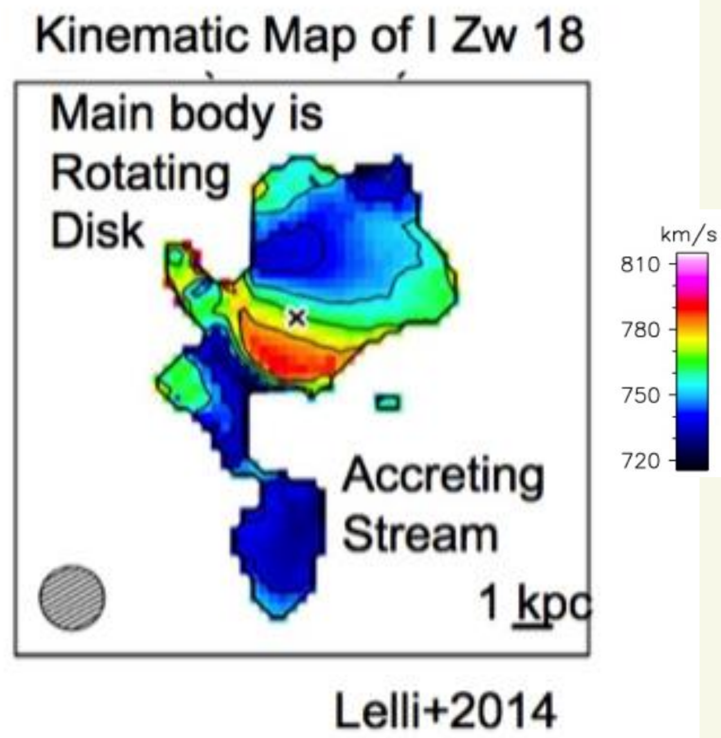


N V 1239
N V 1243
Si II* 1264
Si III 1299
O I* 1305
C II* 1335
I Zw 18-NW
SBS 1415+437
MS 1512 cB58
Scaled Flux
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1200
1250
1300
1350
Rest Wavelength (A)


C IV 1169
C III 1176
N V 1238
N V 1242
O IV 1338
O IV 1343
O V 1371
Si IV 1393
Si IV 1403
N IV] 1486
S V 1502
C IV 1548
C IV 1550
He II 1640
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
cB58
1200
1300
1400
1500
1600
1700
I Zw 18

Accretion of pristine stream onto I Zw 18-NW?





This southern stream “does not seem kinematically connected with the SE region of the main body of I Zw 18, as the gas velocity changes abruptly from 790 km s^{-1} to 720 km s^{-1}. .. At the junction between I Zw 18 and the stream, the HI line profiles are double peaked, suggesting that there are two distinct components, possibly well-separated in space but projected to the same location on the sky”. (Lelli+14)

He II emission is incongruous with the metal-line spectrum