Ionized winds driven away from black holes
(SPEX/PION exercise)
(Continued)

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Explore the PION absorption model

The model is:

$$\texttt{hot} \times \texttt{reds} \times \texttt{pion} \times (mbb + pow) \tag{1}$$

Plot and compare the model spectra with $\log \xi = 2.0$ (frozen) but different column densities ($N_{\rm H} = 10^{19}, 10^{20}, 10^{21}..., 10^{24}$ cm^{-2}); Summarize the trends of the absorption feature with increasing $N_{\rm H}$.

```
bash > cat 5-5-1.com
data inst_amo1 bhiw_amo1
plot device xs

dist 0.01158 z
comp reds
comp hot
comp pow
com mbb
log exe 5-2-2result

com pion
com rel 3:4 5,1,2
com rel 5 1,2

SPEX > log exe 5-5-1
SPEX > par 1 5 xil val 2
SPEX > par 1 5 xil s f
SPEX > par 1 5 nh val xxx
SPEX > cal
SPEX > pl ty model
SPEX > pl fill disp f
SPEX > pl ux ang
SPEX > pl uy ang
SPEX > pl x lin
SPEX > pl y lin
SPEX > pl
SPEX > pl adum xxx
```

From Fig. 1, we can see that:

1. The larger $N_{\rm H}$, the earlier the continuum decreases, which means, in small wavelength, the flux of the spectra which set large $N_{\rm H}$ for `pion` component is smaller than that set small $N_{\rm H}$ for `pion` component.

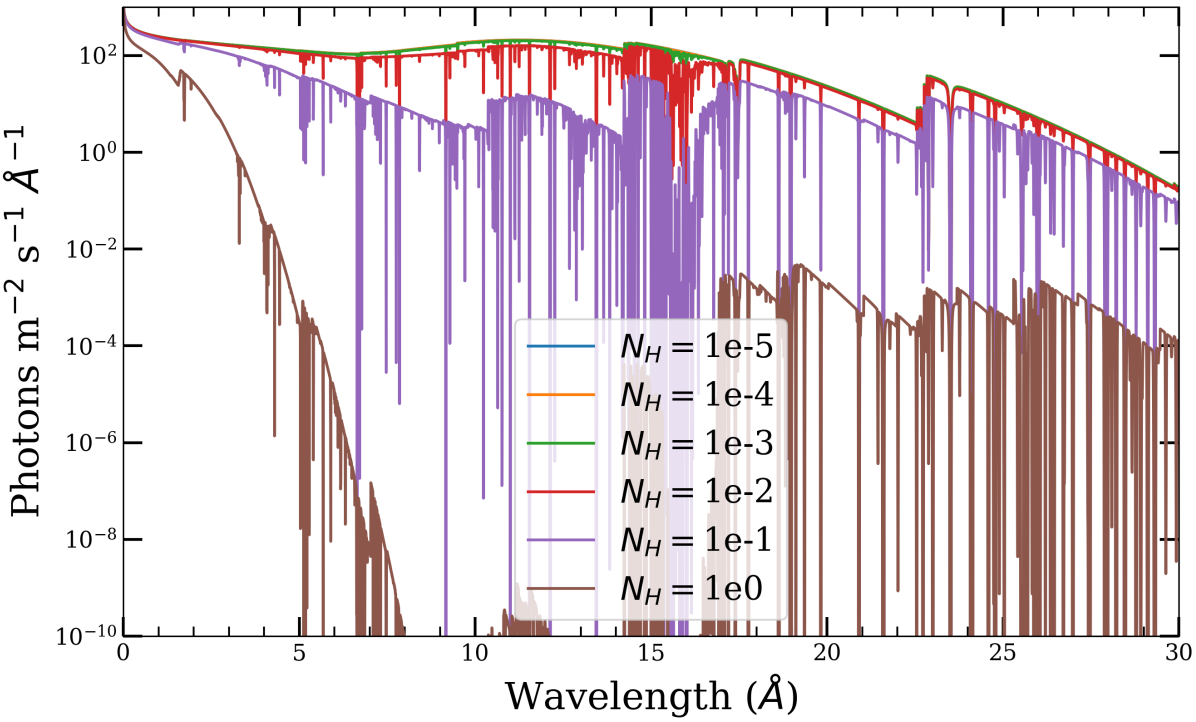


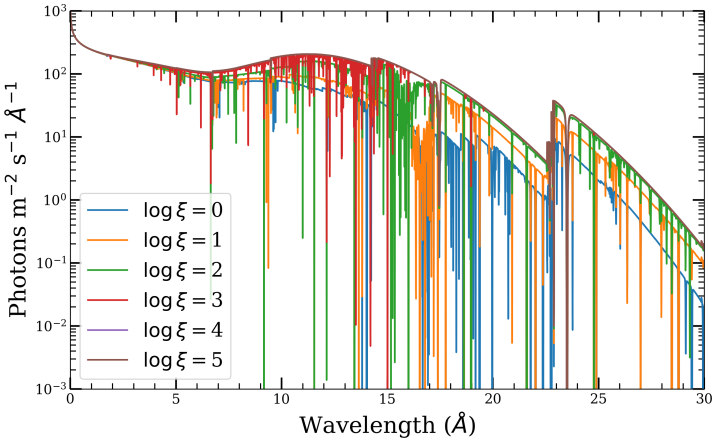
Figure 1: The wavelength-Flux figure.

2. When $N_{\rm H}$ is smaller than 10^{-3} m^{-2}, the continuum is almost the same but absorption lines become more with the increment of $N_{\rm H}$. When $N_{\rm H}$ is larger than 10^{-3} m^{-2}, the absorption is evident for the continuum.
3. The larger $N_{\rm H}$, the more absorption lines.

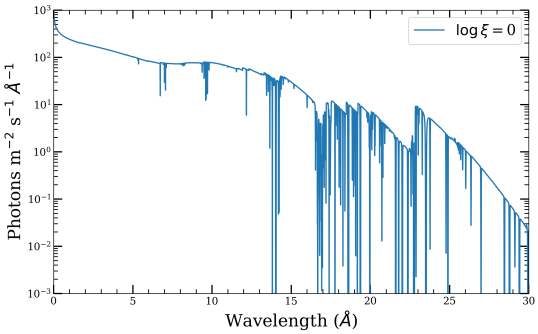
Plot and compare the model spectra with $N_{\rm H} = 10^{22}$ cm^{-2} (frozen) but different $\log\xi = 0, 1, 2, ..., 4, 5$, where ionization parameter ξ is in units of erg s^{-1} cm (i.e., 10^9 W m). Zoom into the wavelength region of $6.6 - 7.3$ Å. What are these lines? Summarize the trends of the absorption feature with increasing $\log\xi$ for global and zoom-in regions.

```
SPEX > log exe 5-5-1
SPEX > par 1 5 nh val 1e-2
SPEX > par 1 5 nh s f
SPEX > par 1 5 xil val xxx
SPEX > cal
SPEX > pl ty model
SPEX > pl fill disp f
SPEX > pl x lin
SPEX > pl y lin
SPEX > pl ux ang
SPEX > pl uy ang
SPEX > pl
SPEX > pl adum xxx
```

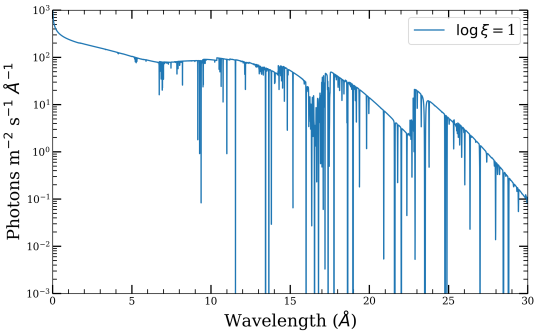
From Fig. 2 and Fig. 3, we can see that:
1. When $\log\xi < 4$, as $\log\xi$ increases, the flux of the continuum increases, which means that the



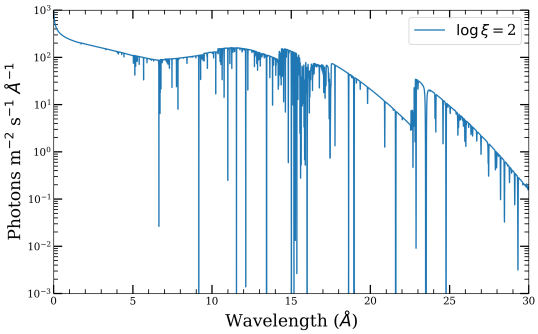
(a)



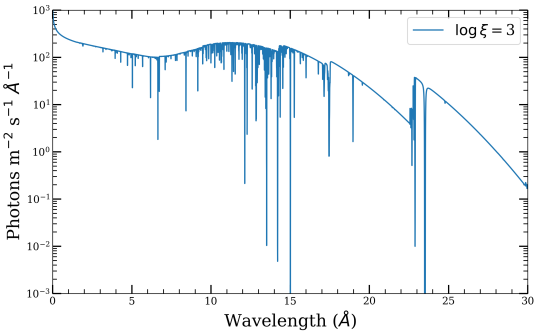
(b)



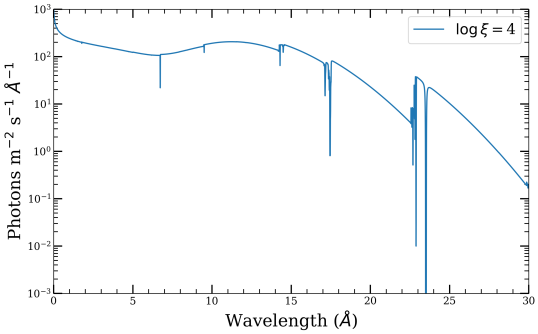
(c)



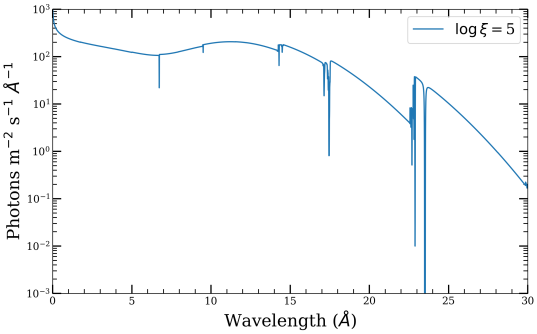
(d)



(e)

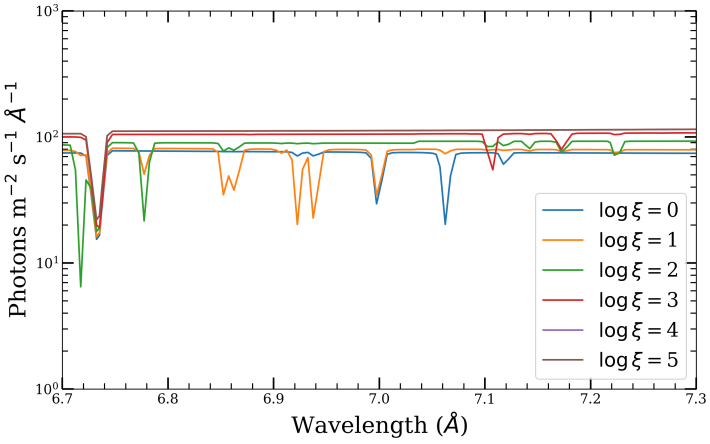


(f)

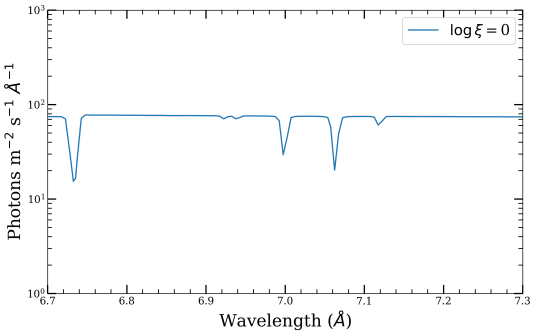


(g)

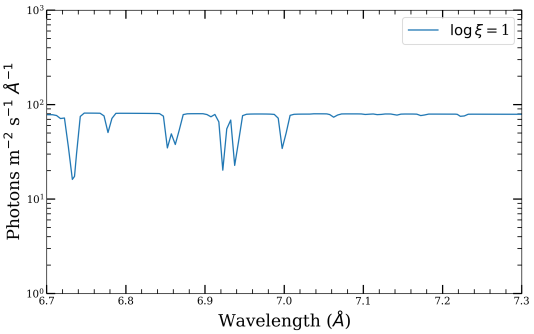
Figure 2: The Wavelength-Flux figure. The x-axis range is $0 - 30$ Å.



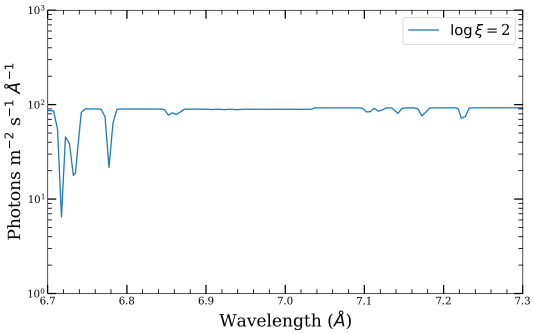
(a)



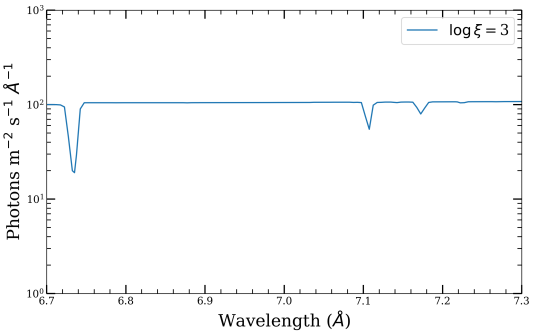
(b)



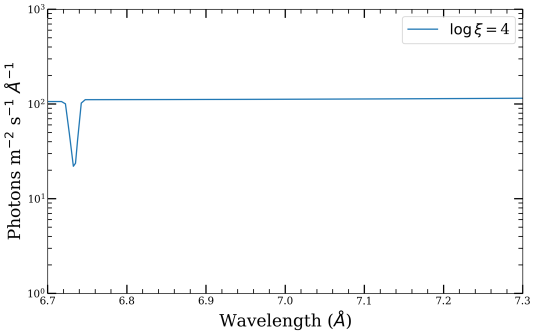
(c)



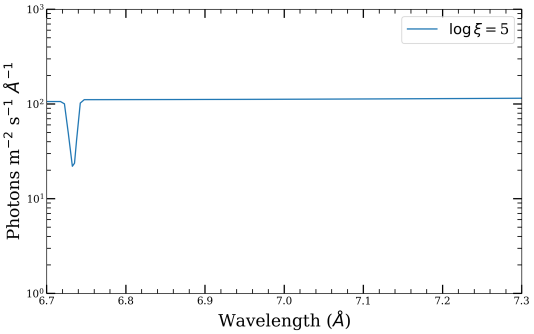
(d)



(e)



(f)



(g)

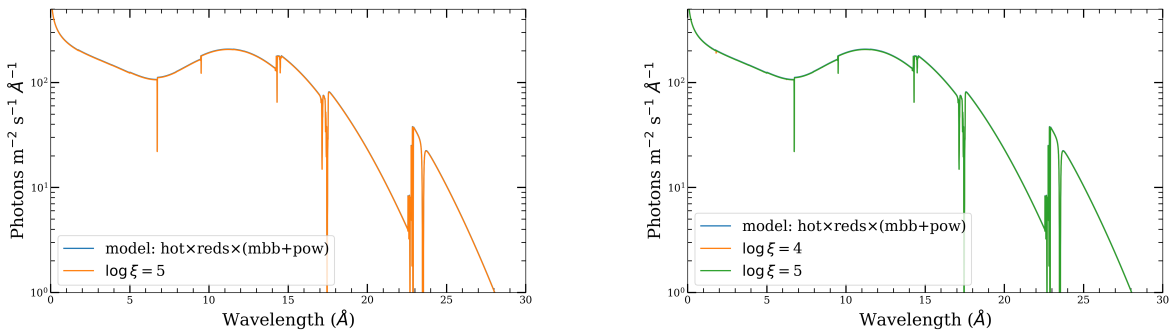
Figure 3: The Wavelength-Flux figure. The x-axis range is $6.6 - 7.3$ Å.

absorption of the continuum decreases. When $\log \xi \geq 4$, the spectra no longer change.

2. Different $\log \xi$ will lead to the absorption of different lines (see Fig. 1). When $\log \xi$ is large enough (> 4), it will hardly lead to absorption (see Fig. 4).

$\log \xi$	1	2	3	4	5	6	7
0	$6.72 - 6.74$	$6.98 - 7.0$	$7.04 - 7.08$				
Absolute	$6.64 - 6.66$	$6.9 - 6.92$	$6.96 - 7.0$				
Line	Ni XXVII	Co XXVI	Fe XXIV				
1	$6.72 - 6.74$	$6.76 - 6.78$	$6.84 - 6.86$	$6.86 - 6.88$	~ 6.92	$6.92 - 6.94$	$6.98 - 7.0$
Absolute	$6.64 - 6.66$	$6.68 - 6.7$	$6.76 - 6.78$	$6.78 - 6.8$	~ 6.84	$6.84 - 6.86$	$6.9 - 6.92$
Line	Ni XXVII	Fe XXV	Al XI	Fe XXIV	Al XI	Co XXV	Co XXVI
2	$6.7 - 6.72$	$6.72 - 6.74$	$6.76 - 6.78$				
Absolute	$6.62 - 6.64$	$6.64 - 6.66$	$6.68 - 6.7$				
Line	Al XII	Ni XXVII	Fe XXV				
3	$6.72 - 6.74$	$7.1 - 7.12$	$7.16 - 7.18$				
Absolute	$6.64 - 6.66$	$7.02 - 7.04$	$7.08 - 7.1$				
Line	Ni XXVII	Fe XXIV	Fe XXVI				
4	$6.72 - 6.74$						
Absolute	$6.64 - 6.66$						
Line	Ni XXVII						
5	$6.72 - 6.74$						
Absolute	$6.64 - 6.66$						
Line	Ni XXVII						

Table 1: The absorption lines in different $\log \xi$. The prediction of lines is from NIST.



(a) (b)

Figure 4: The wavelength-flux figure with different model components.

$\log \xi$	1	2	3	4	5	6	7
0	$6.72 - 6.74$	$7.06 - 7.08$	$7.14 - 7.16$	~ 7.2			
Initial	$6.64 - 6.66$	$6.98 - 7.0$	$7.06 - 7.08$	~ 7.12			
Line	Ni XXVII	Fe XXIV	Co XXVI	Mg XI			
1	$6.72 - 6.74$	$6.85 - 6.86$	$6.92 - 6.94$	~ 6.94	~ 7.0	$7.01 - 7.02$	$7.06 - 7.08$
Initial	$6.64 - 6.66$	$6.77 - 6.78$	$6.84 - 6.86$	~ 6.86	~ 6.92	$6.93 - 6.94$	$6.98 - 7.0$
Line	Ni XXVII	Al XI	Co XXV	Mn XXV	Co XXVI	Mn XXV	Ni XXVI
2	$6.72 - 6.74$	$6.79 - 6.80$	$6.85 - 6.86$	$7.25 - 7.26$			
Initial	$6.62 - 6.64$	$6.71 - 6.72$	$6.77 - 6.78$	$7.17 - 7.18$			
Line	Ni XXVII		Al XI	Fe XXVI			
3	$6.72 - 6.74$	$6.81 - 6.82$	$7.18 - 7.19$	$7.24 - 7.26$			
Initial	$6.64 - 6.66$	$6.73 - 6.74$	$7.1 - 7.11$	$7.16 - 7.18$			
Line	Ni XXVII	Mg XII	Mg XII	Fe XXIV			
4	$6.72 - 6.74$						
Initial	$6.64 - 6.66$						
Line	Ni XXVII						
5	$6.72 - 6.74$						
Initial	$6.64 - 6.66$						
Line	Ni XXVII						

Table 2: The absorption lines in different $\log \xi$. The model set the order of `pion`. The prediction of lines is from NIST.

Fit the spectrum with the model set up as Eq. 1

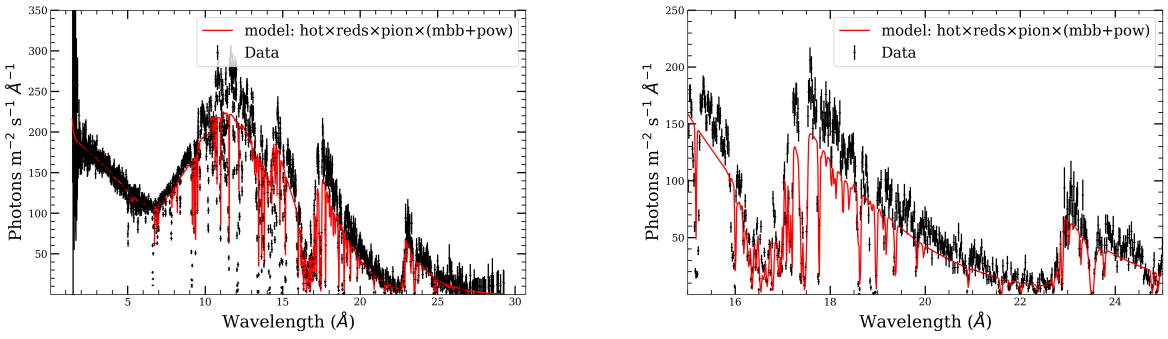
To reproduce the Fe UTA (Unresolved Transition Array) feature, I think `xil` in the `pion` component should be set to 1.

```
bash > cat 5-5-3.com
data inst_amo1 bhiw_amo1
plot device xs

dist 0.01158 z
comp reds
comp hot
comp pow
com mbb
log exe 5-2-2result

com pion
com rel 3:4 5,1,2
com rel 5 1,2
par 1 5 xil val 1
cal
pl ty data
pl ux ang
pl uy fang
pl
fit
pl

SPEX > log exe 5-5-3
```



(a) (b)

Figure 5: The wavelength-flux figure. (a): the x-axis range is $0 - 30$ Å. (b): the x-axis range zoom in $15 - 25$ Å.

Fit the spectrum with two PION components

The model is:

$$\texttt{hot} \times \texttt{reds} \times \texttt{pion1} \times \texttt{pion2} \times (mbb + pow) \tag{2}$$

Starting with a reasonable guess, fit the spectrum with the model set up as Eq. 2. Write a discussion section on the suitable order of the two pion components.

`xil` of another `pion` should not be set smaller than 1, because we do not need another Fe UTA feature. I set `xil` of `pion2` to be 3.

```
bash > cat 5-6-1.com
data inst_amo1 bhiw_amo1
plot device xs

dist 0.01158 z
comp reds
comp hot
comp pow
com mbb
com pion
log exe 5-5-3result

com pion
com rel 3:4 6,5,1,2
par 1 5 xil val 3
cal
pl ty data
pl ux ang
pl uy fang
pl
fit
pl

SPEX > log exe 5-6-1
```