



VIRGINIA TECH®

Solving Mysteries Using Cloudy

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dehghanian@vt.edu

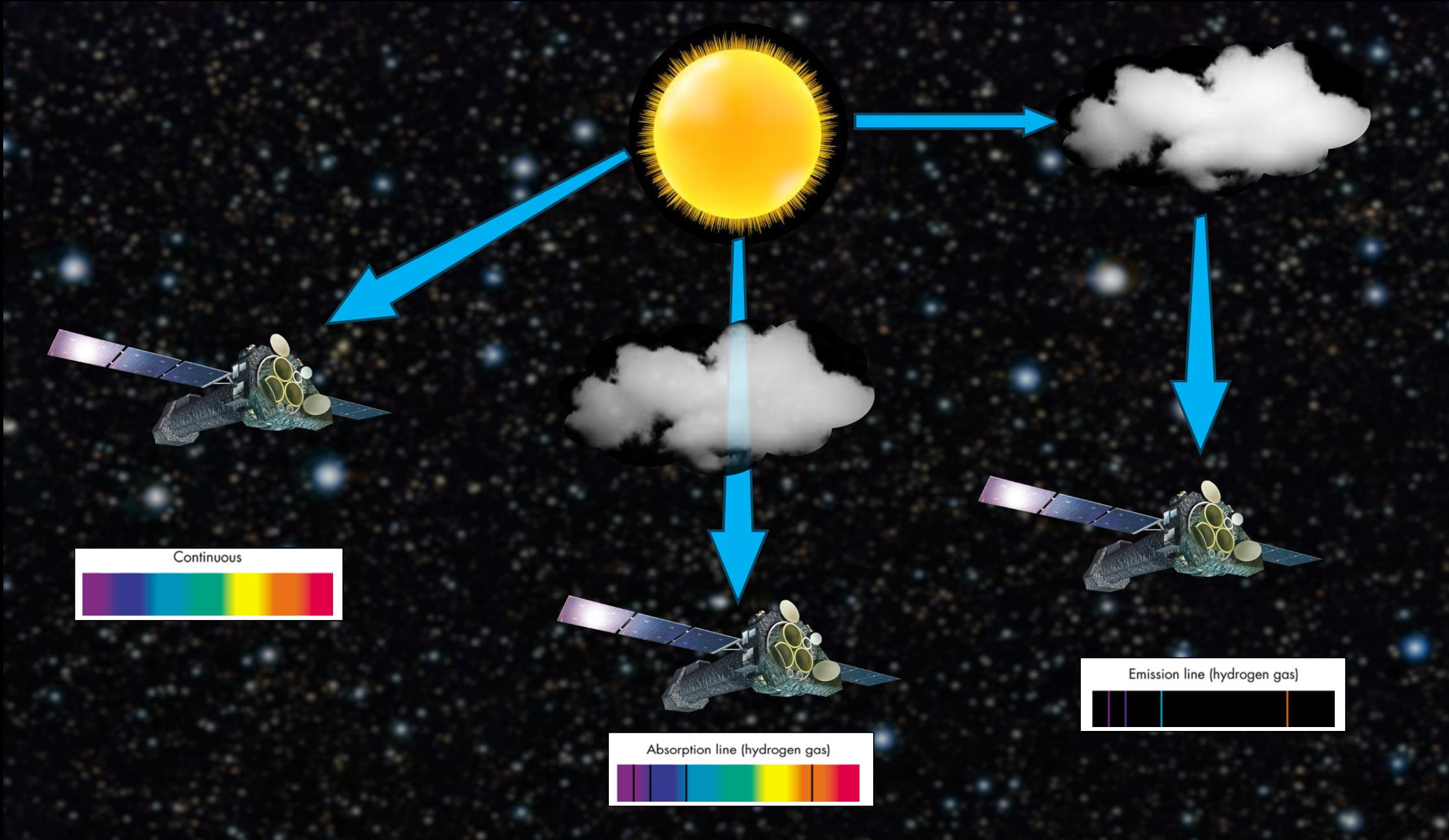
August 2024

Credit: ESA/Hubble, L. Calçada (ESO)

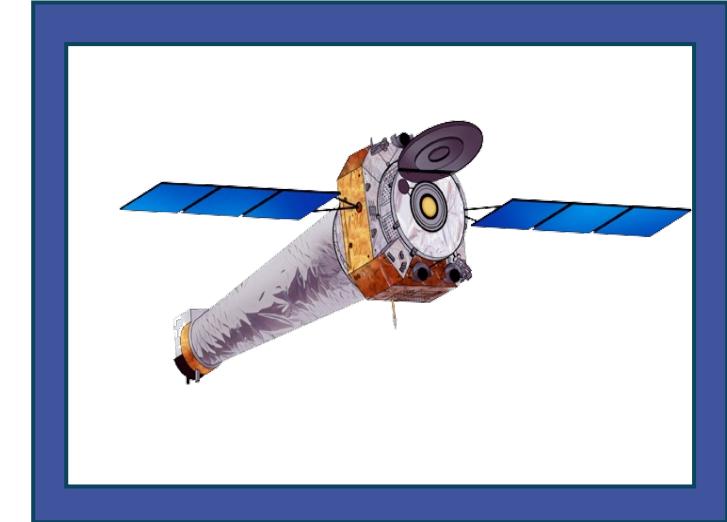
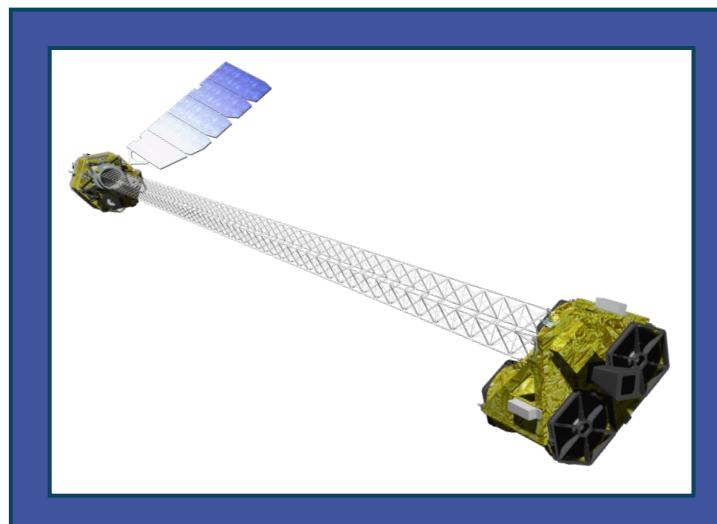
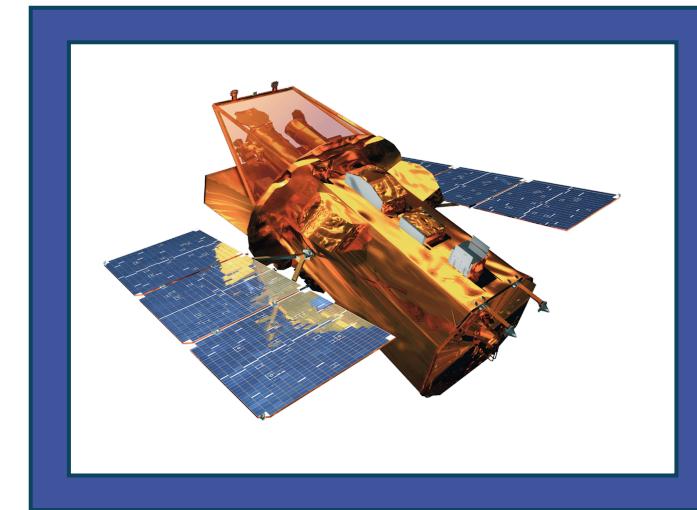


Some Background

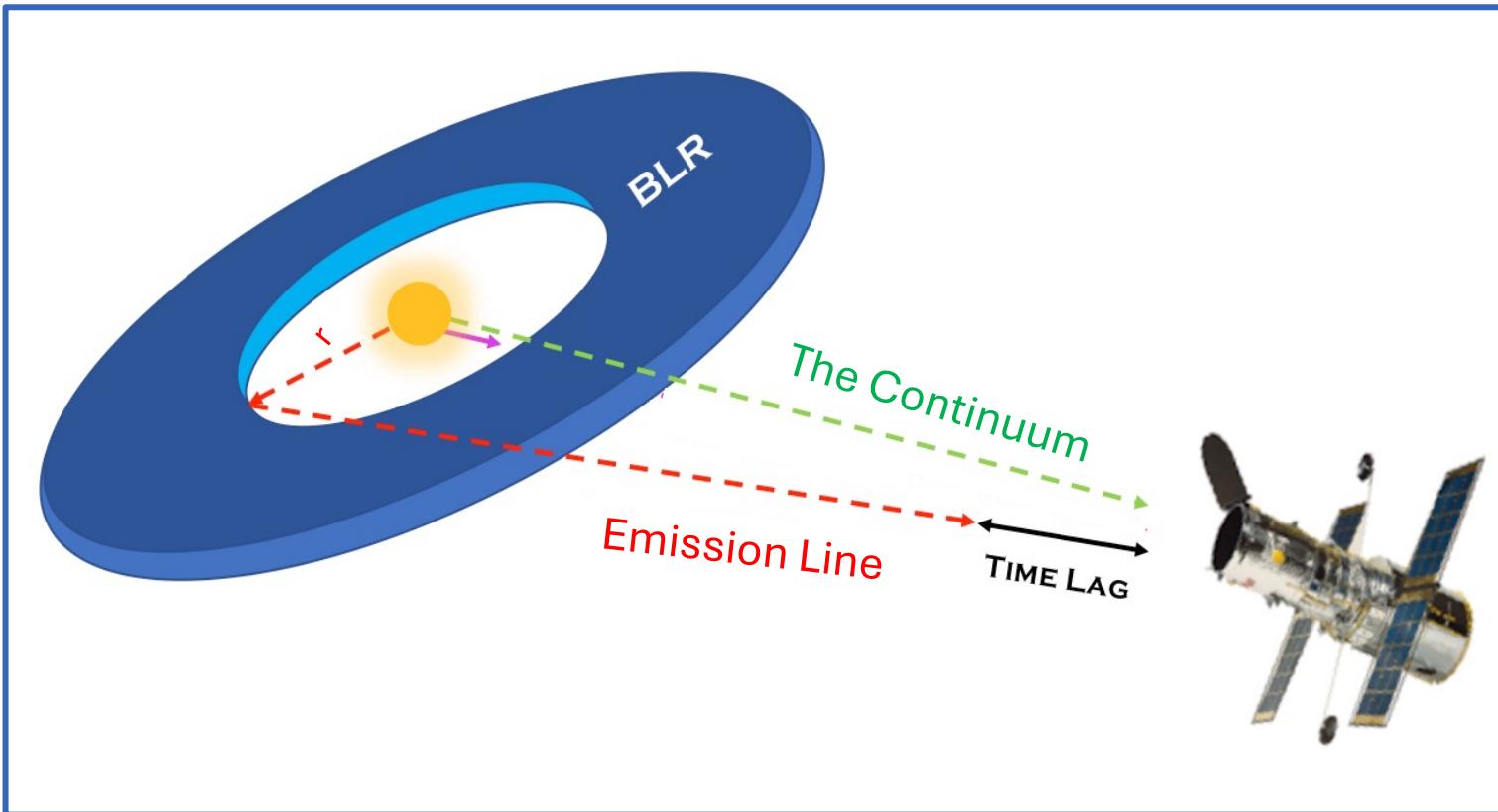




AGN S T O R M Project (2014)



Reverberation Mapping



Estimation of AGN's Mass

$$M = \frac{r v^2}{G}$$

Two parameters needed:

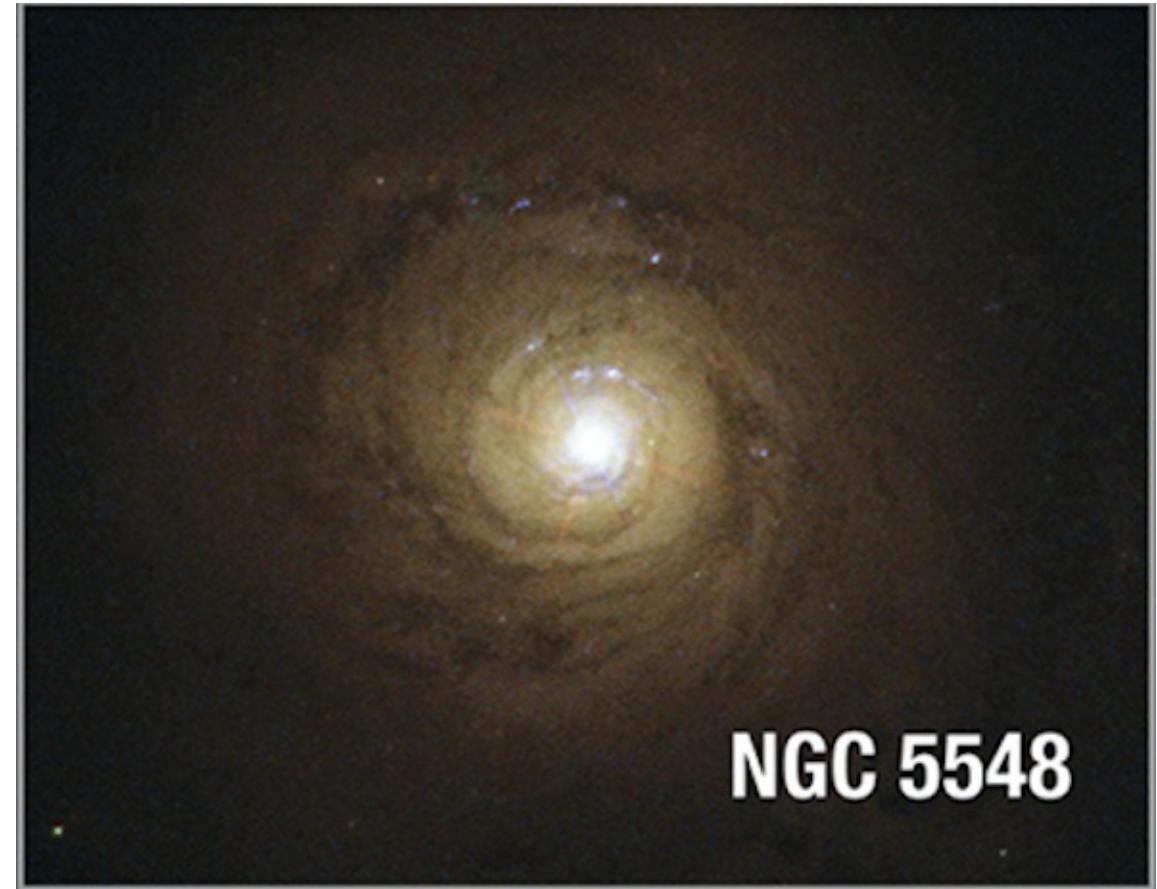
1-velocity → from Doppler line broadening!

2-distance → through
“Reverberation Mapping”

NGC 5548

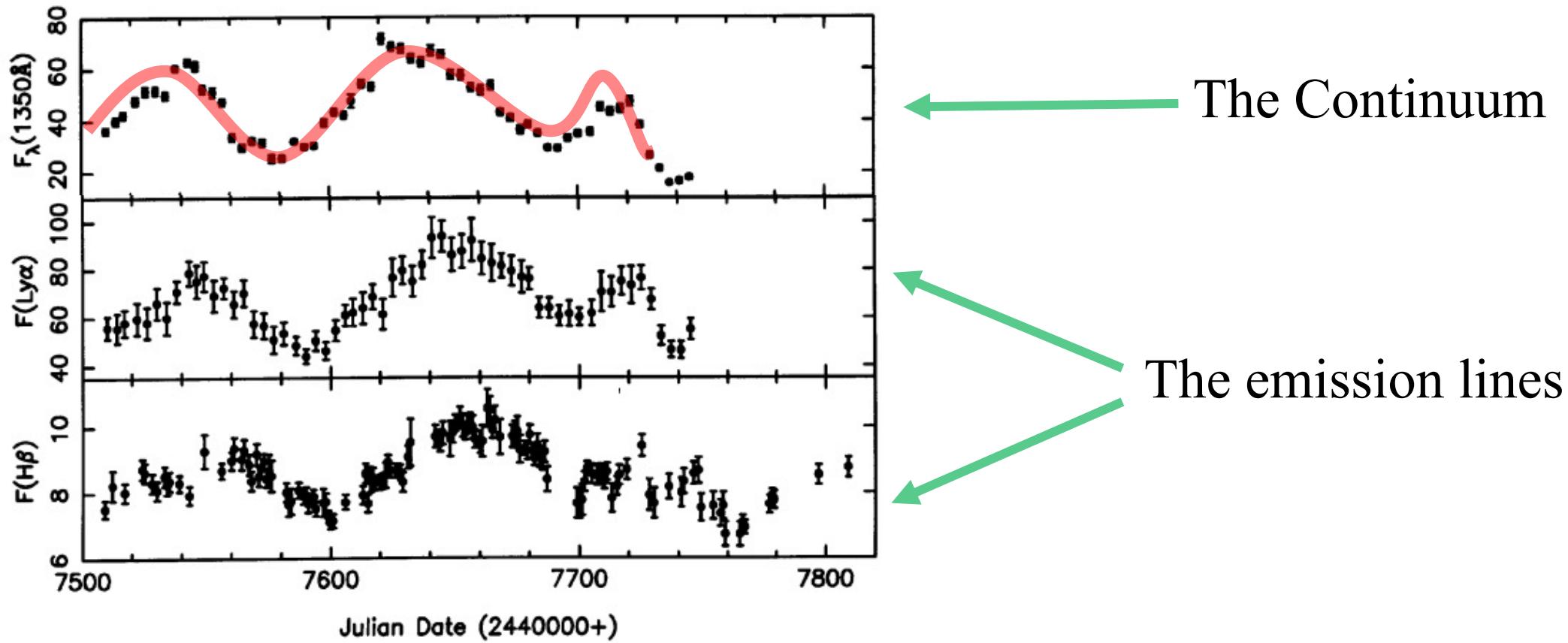
Distance: 245 million LY

Mass of BH: $7 \times 10^7 M_\odot$



What they expected to see:

Sample light curves for NGC 5548 from 1988-1989



Also:

- The dimensionful ionization parameter ξ is defined as:

$$\xi = \frac{L}{n_H R^2} [\text{erg cm s}^{-1}]$$

- The dimensionless ionization parameter U is defined as:

$$U = \frac{Q_H}{4\pi c n_H R^2}$$

Also:

- The dimensionful ionization parameter ξ is defined as:

$$\xi = \frac{L}{n_H R^2} [\text{erg cm s}^{-1}]$$

- The dimensionless ionization parameter U is defined as:

$$U = \frac{Q_H}{4\pi c n_H R^2}$$

$$\log \xi = \log U + \text{constant.}$$

Part I:

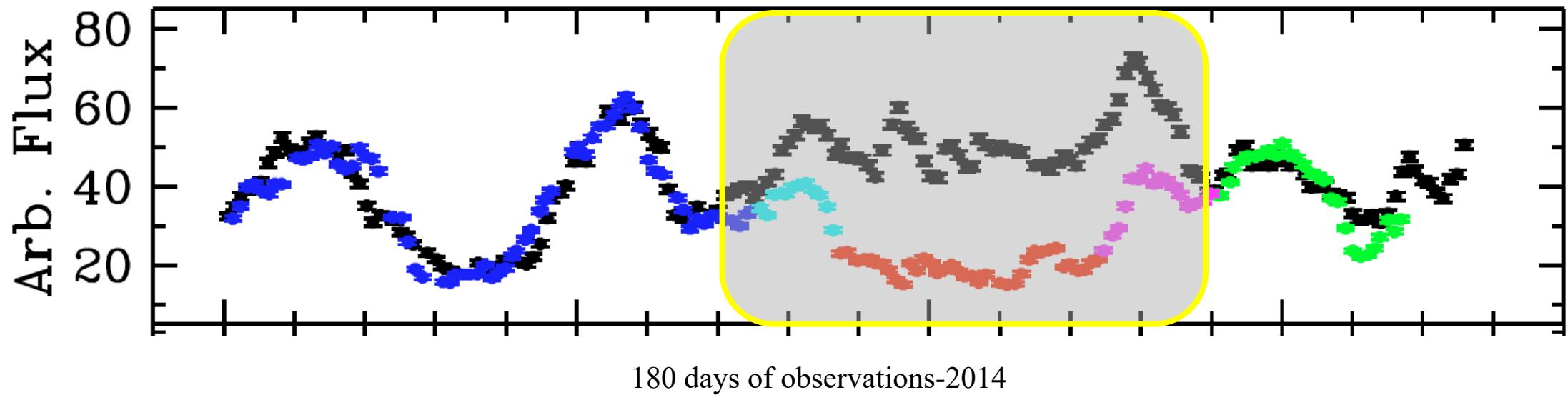
The Sad Story

2014-2017



Results from the campaign

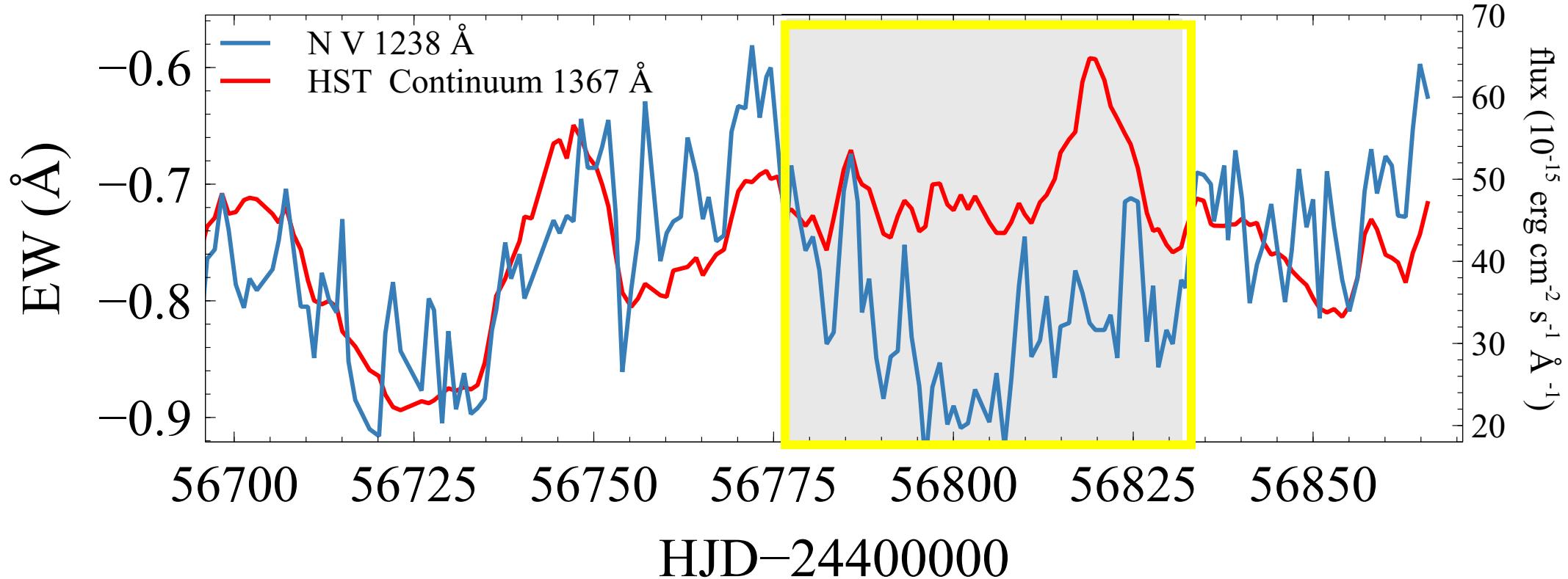
1- Emission Line Holiday (STORM)



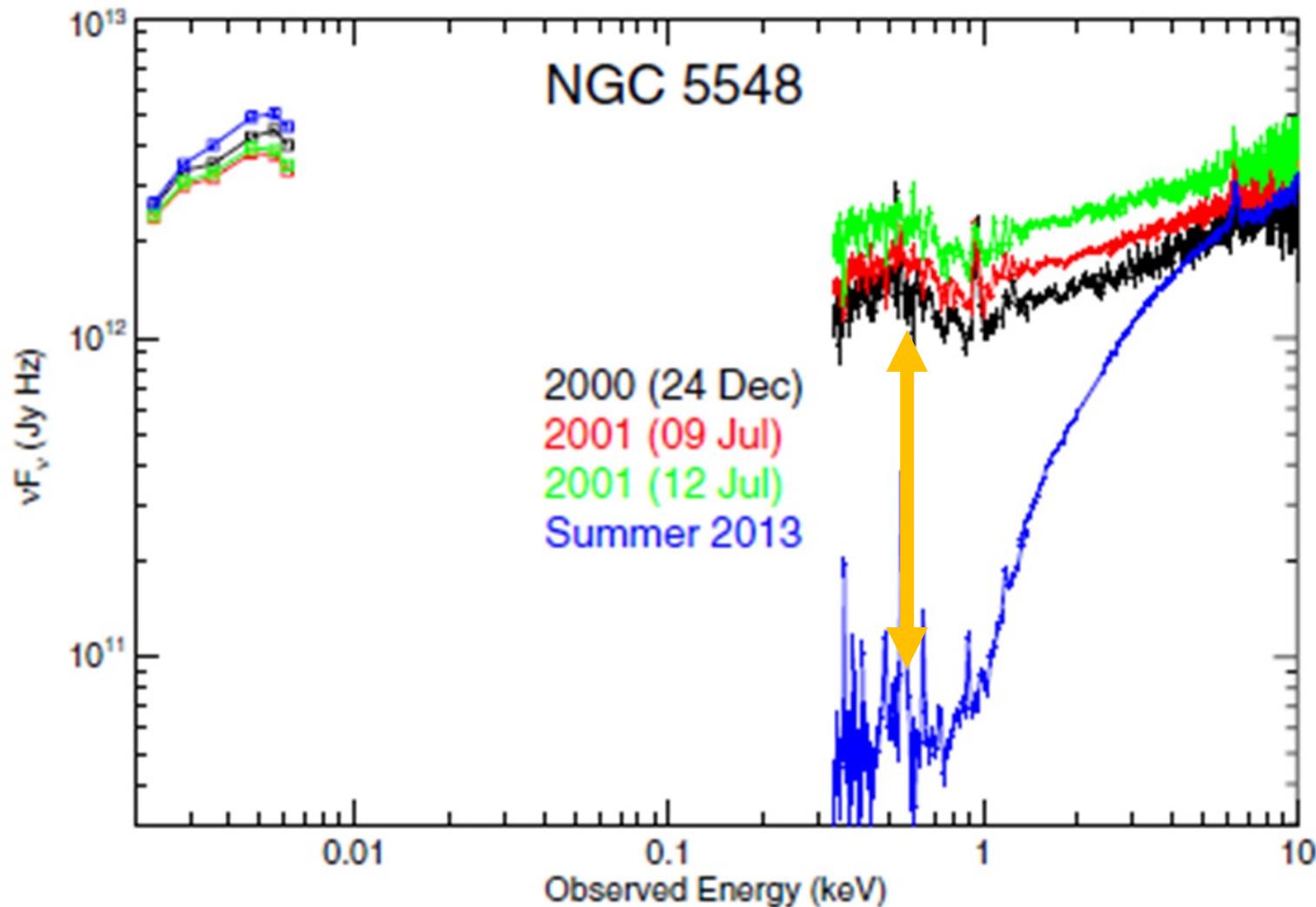
The Continuum

CIV Emission Line

2- Absorption Line Holiday (STORM)

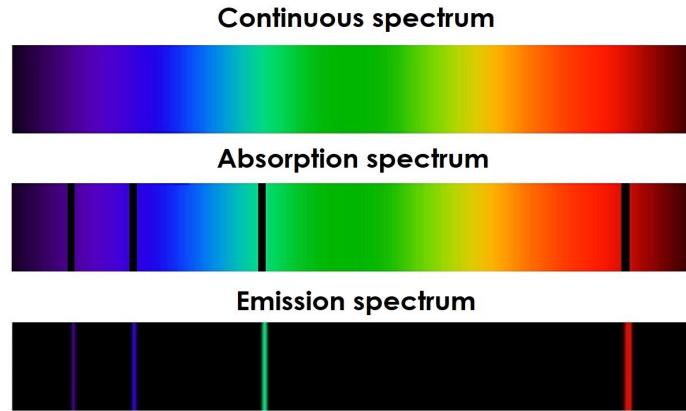


3- Heavy Absorption in X-ray (Anatomy)

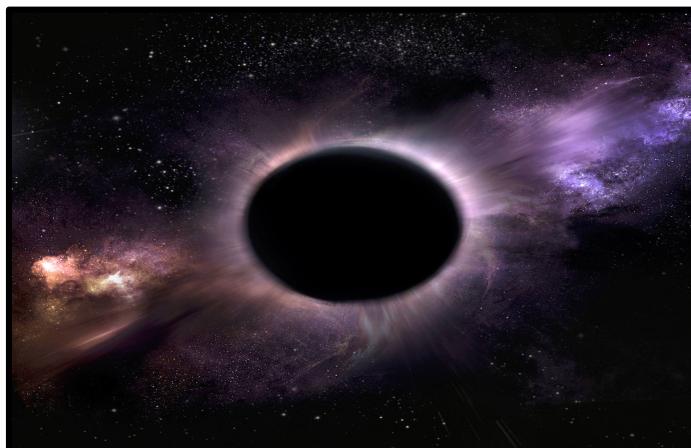




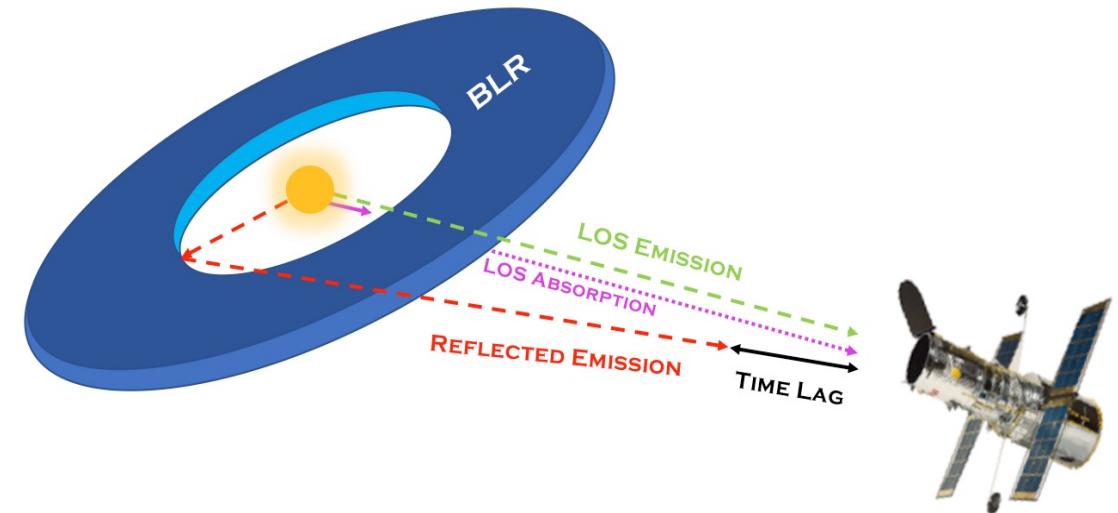
Why are these results so important?



RM method is the only direct way to measure the mass of black holes



The correlation between the continuum and the emission lines is the basic requirement for the RM method

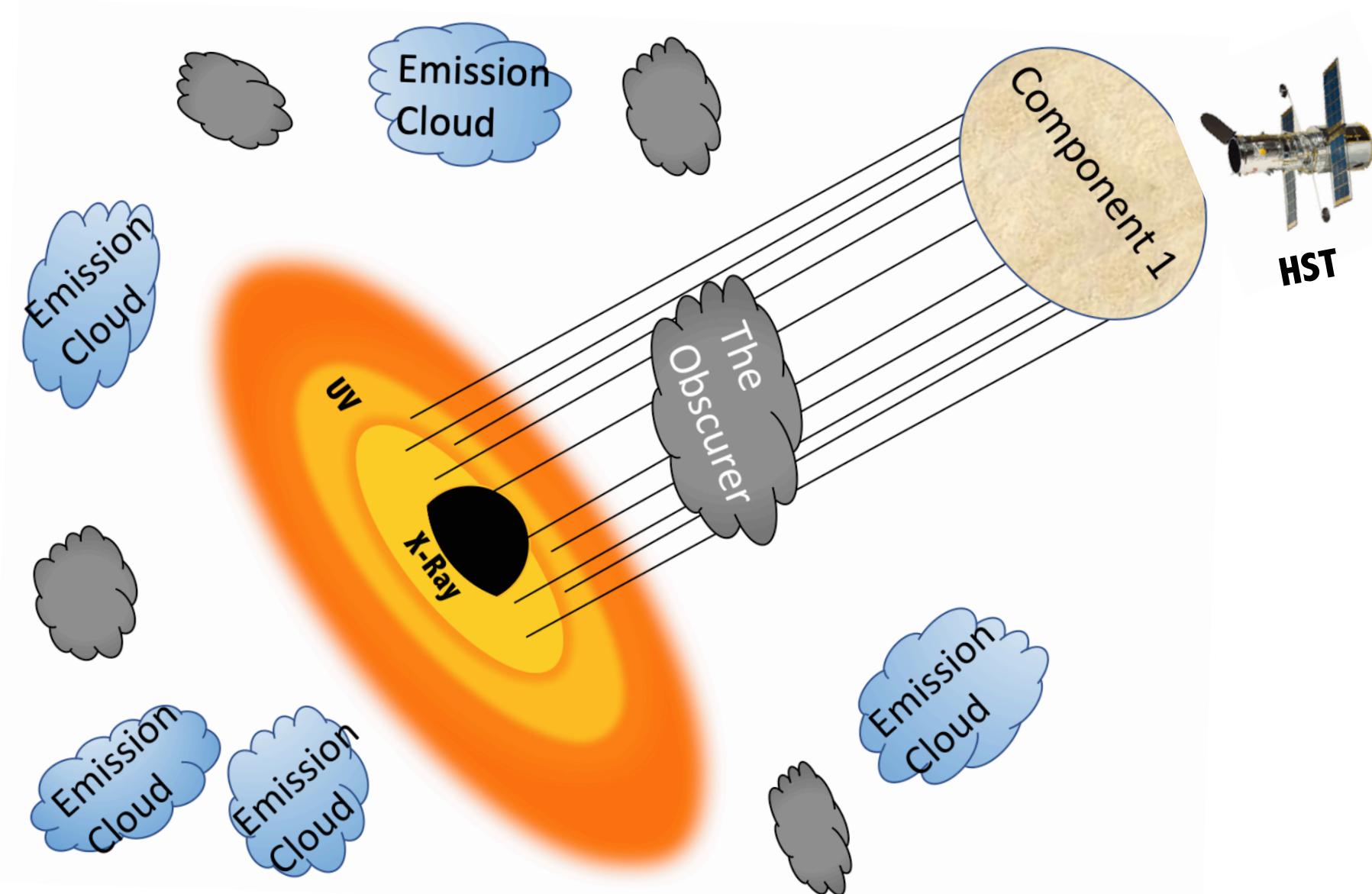


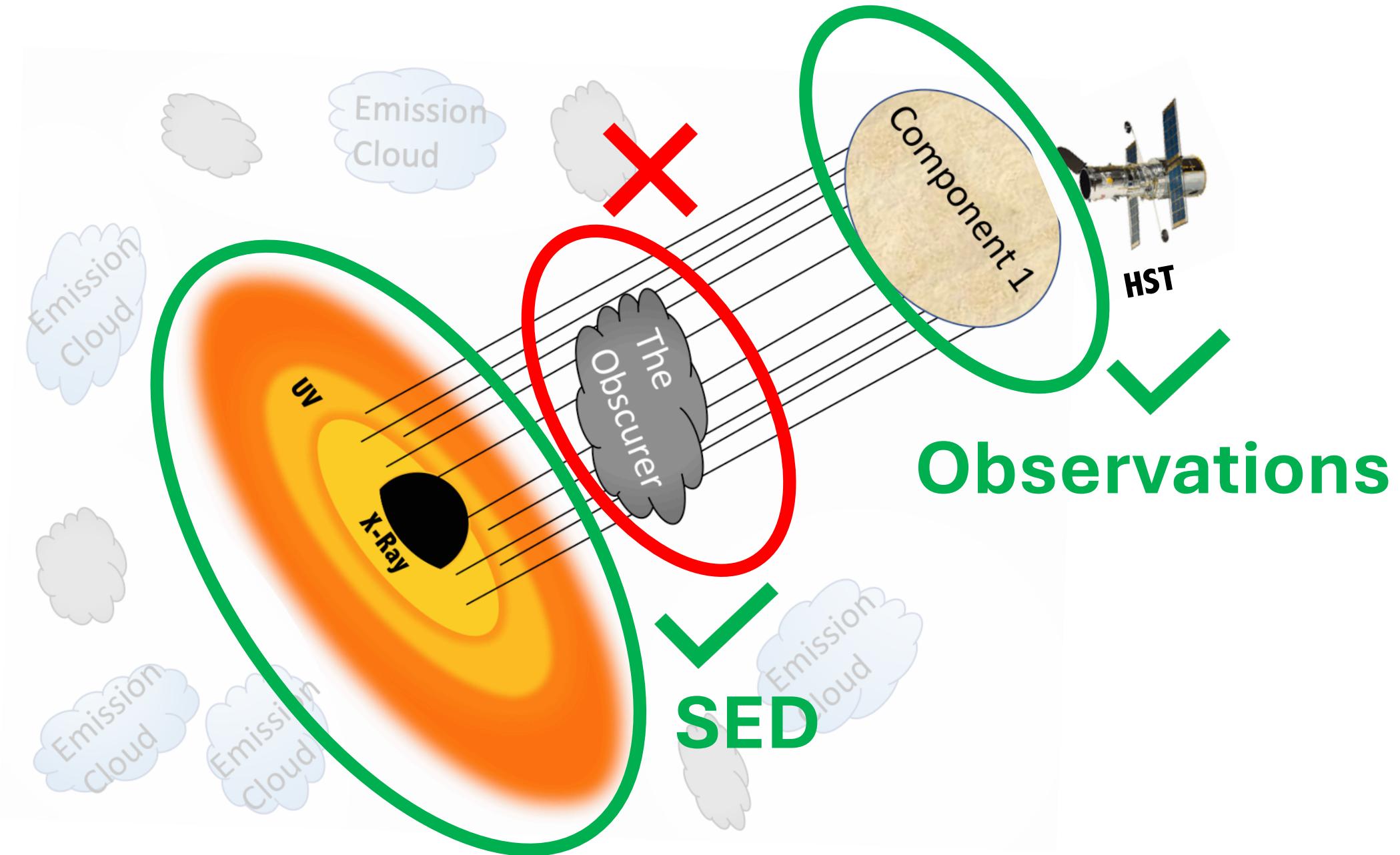
Mass of BH is what everybody wants to know. It controls the galaxy and it teaches us about the evolution of the galaxies.

Cloudy Team Into Action

2017-2019





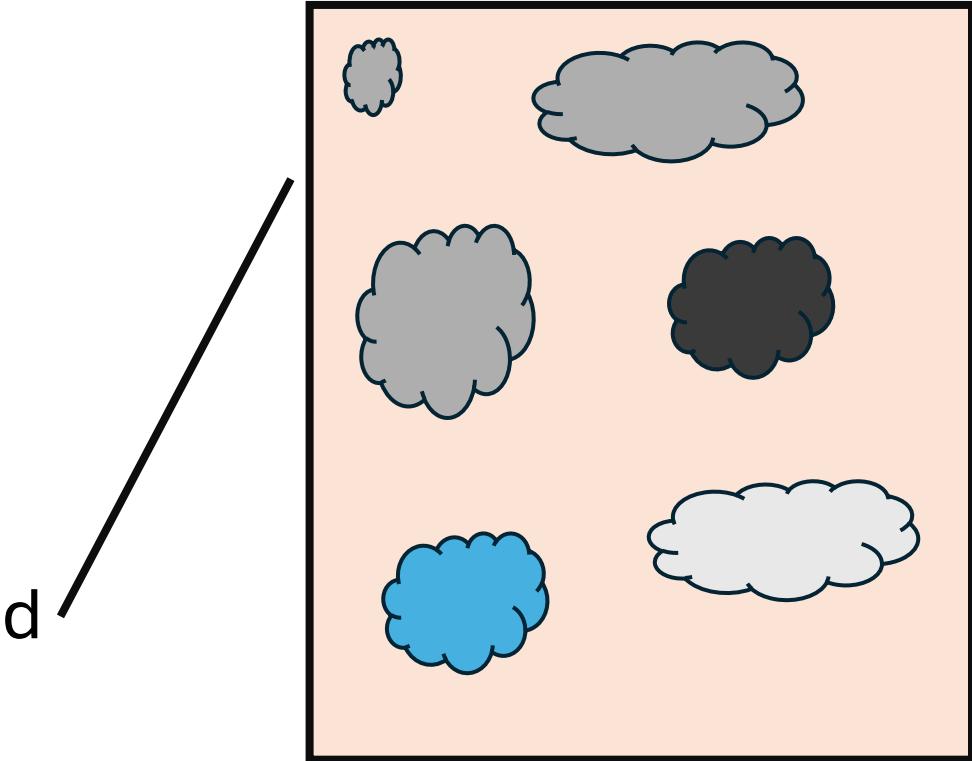


Cloudy:

1- Takes the SED produced by the AGN

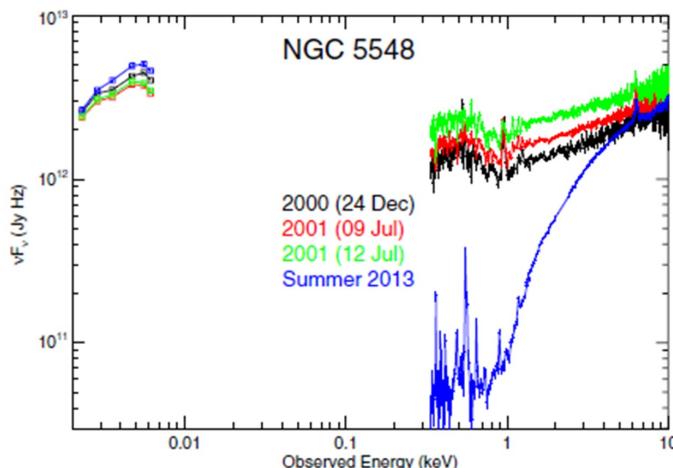
2- Passes this SED through the obscurer and predicts the transmitted SED

3-Passes the OBSCURED SED through the absorption component1 and predicts the spectrum observed by HST



AGN

Table SED "NGC5548.sed"
set save prefix "obs1"
hden 10
xi -1.2
stop column density 22.08
save continuum units kev ".con"
save transmitted continuum ".tran"



The Obscurer

```
Table Read "obs1.tran"  
nuF(nu) 3.023 0.2  
set save prefix "cf99"  
hden 4.72  
#stop zone 1  
stop column density 21.5  
save line list ".lin" "lines.dat" absolute no hash  
save continuum units kev ".cone"  
save continuum units angstrom ".cona"  
save species column densities ".dens" no hash last  
"H"  
"H+"  
"H2+"  
"C"  
"C+"  
"C+2"  
"C+3"  
"Si"  
"Si+""Si+2"  
"Si+3"  
"N"  
"N+"  
"N+2"  
"N+3"  
"N+4"  
"He"  
"He+"  
"He+2"  
"He[2]"  
end
```

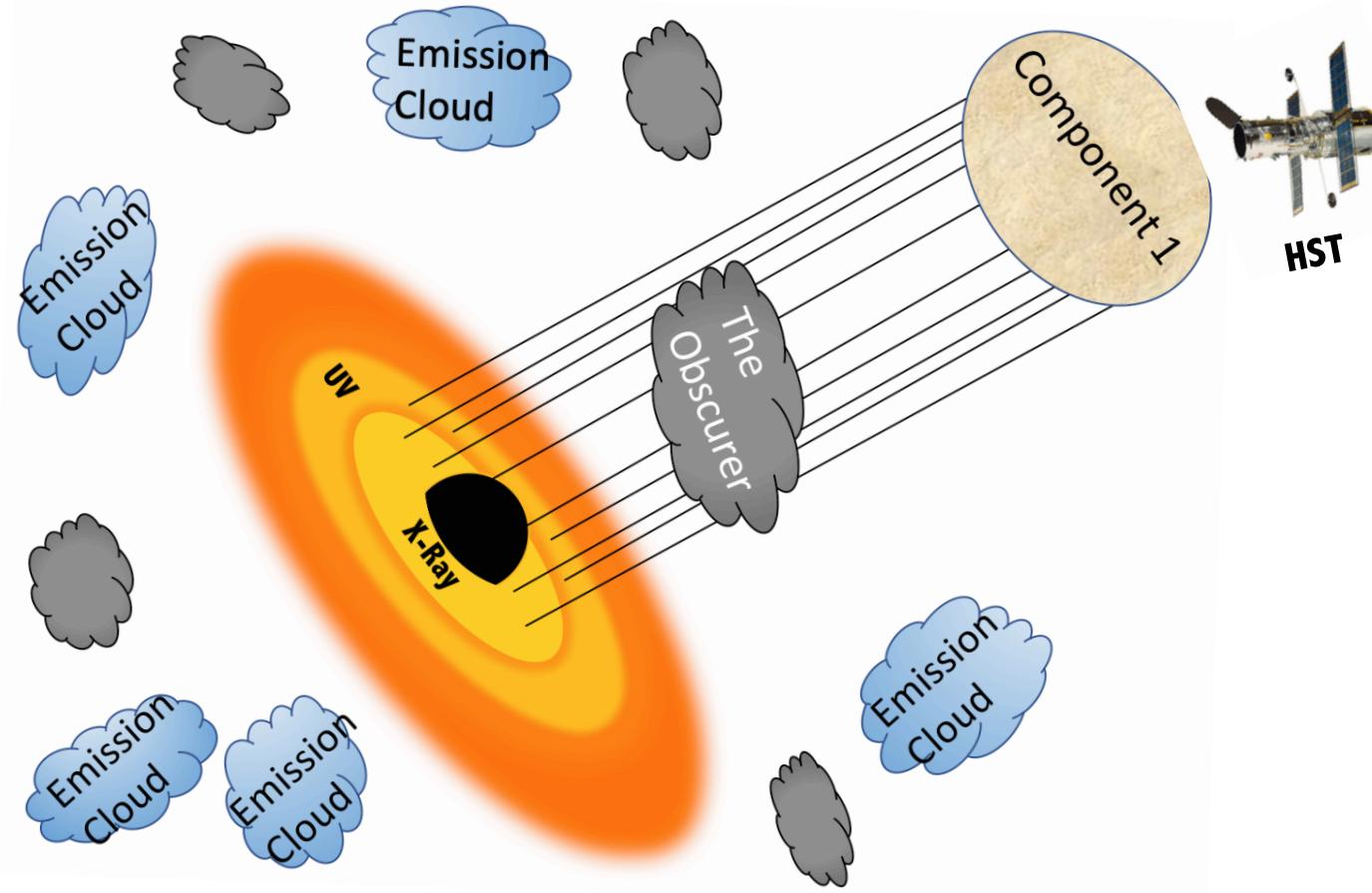
Part III:

The Happy Ending

2019-2020



The Absorption-Line Holiday

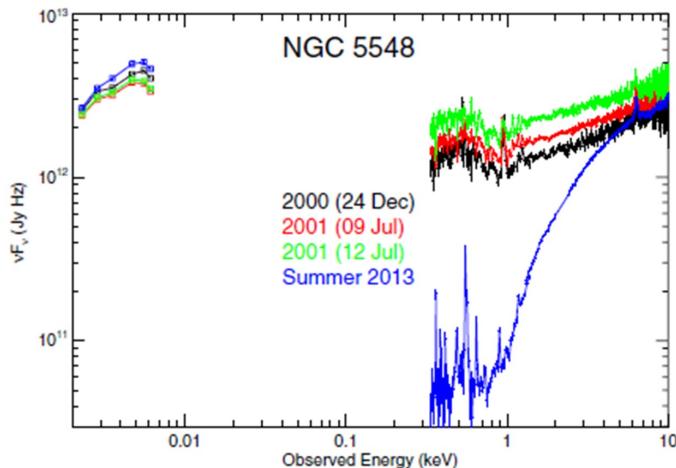


There are two possibilities

- 1- Holiday is a result of variable luminosity**

- 2- Holiday is a result of variable shape**

```
Table SED "NGC5548.sed"
set save prefix "obs1"
hden 10
xi -1.2
stop column density 22.08
save continuum units kev ".con"
save transmitted continuum ".tran"
```

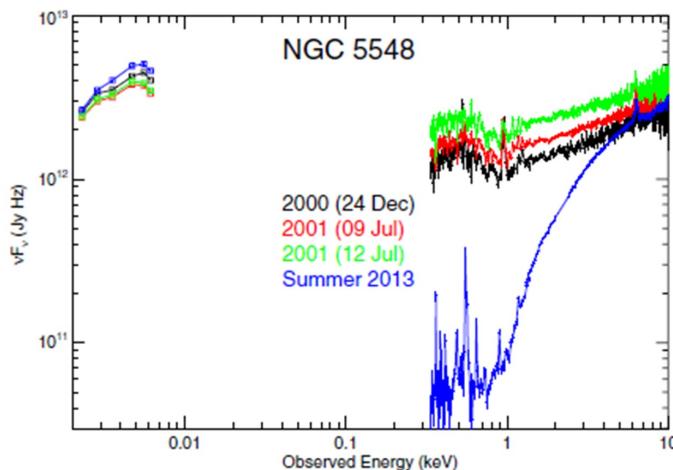


```
Table Read "obs1.tran"
nuF(nu) 3.023 0.2
set save prefix "cf99"
hden 4.72
#stop zone 1
stop column density 21.5
save line list ".lin" "lines.dat" absolute no hash
save continuum units kev ".cone"
save continuum units angstrom ".cona"
save species column densities ".dens" no hash last
"H"
"H+"
"H2+"
"C"
"C+"
"C+2"
"C+3"
"Si"
"Si+"
"Si+2"
"Si+3"
"N"
"N+"
"N+2"
"N+3"
"N+4"
"He"
"He+"
"He+2"
"He[2]"
end
```

There are two possibilities

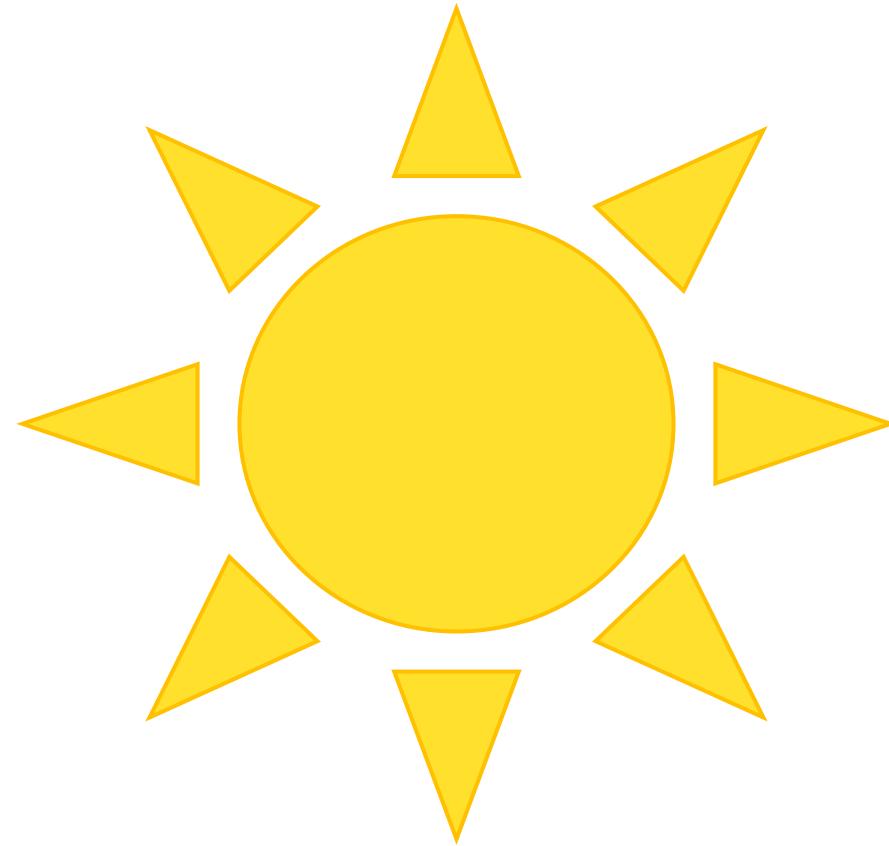
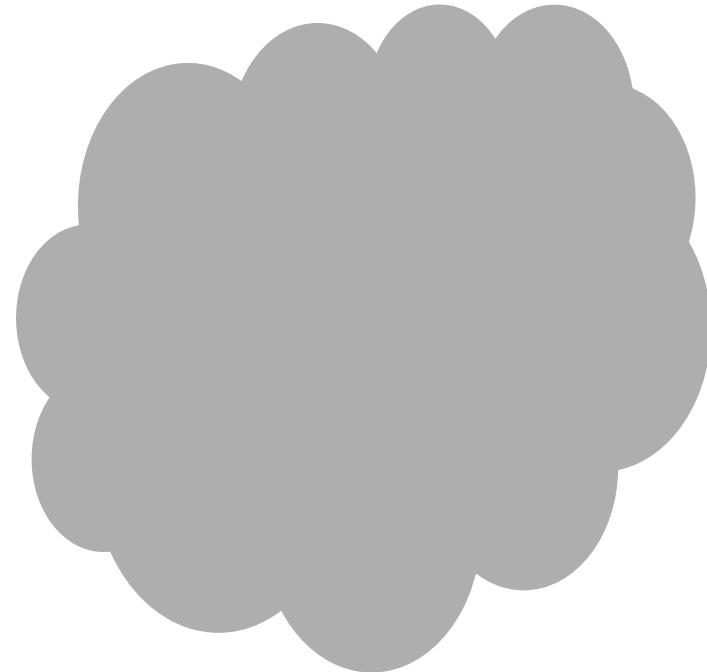
- 1- Holiday is a result of variable luminosity**
- 2- Holiday is a result of variable shape**

```
Table SED "NGC5548.sed"
set save prefix "obs1"
hden 10
xi -1.2
stop column density 22.08
save continuum units kev ".con"
save transmitted continuum ".tran"
```



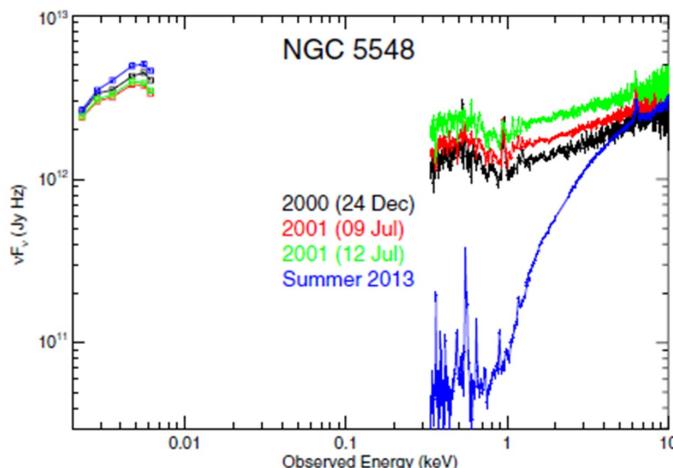
```
Table Read "obs1.tran"
nuF(nu) 3.023 0.2
set save prefix "cf99"
hden 4.72
#stop zone 1
stop column density 21.5
save line list ".lin" "lines.dat" absolute no hash
save continuum units kev ".cone"
save continuum units angstorn ".cona"
save species column densities ".dens" no hash last
"H"
"H+"
"H2+"
"C"
"C+"
"C+2"
"C+3"
"Si"
"Si+"
"Si+2"
"Si+3"
"N"
"N+"
"N+2"
"N+3"
"N+4"
"He"
"He+"
"He+2"
"He[2]"
end
```

Changes in the obscurer affects the shape of the SED



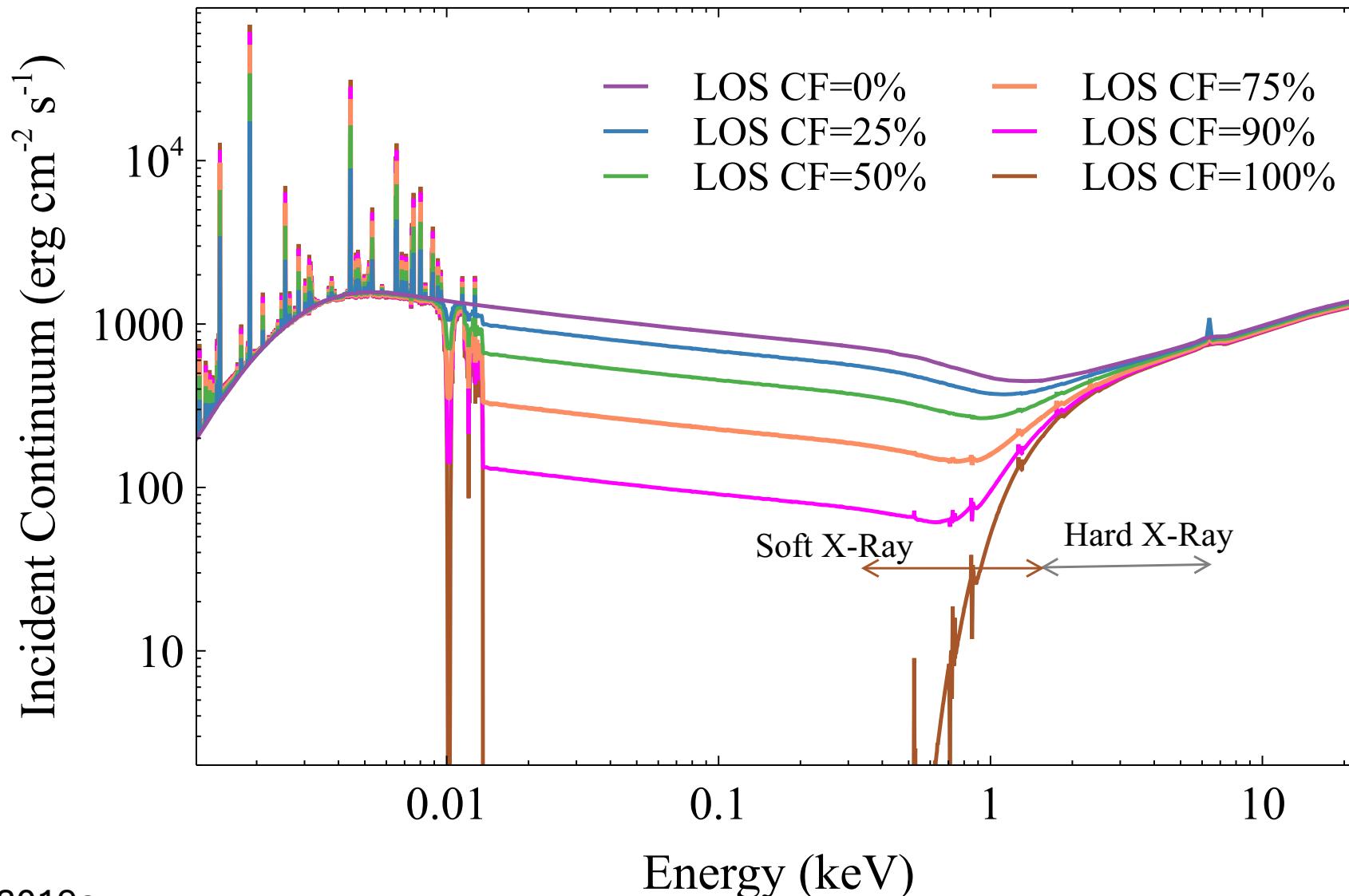
Line of Sight Covering Factor 100 %

```
Table SED "NGC5548.sed"
set save prefix "obs1"
hden 10
xi -1.2
stop column density 22.08
save continuum units kev ".con"
save transmitted continuum ".tran"
```

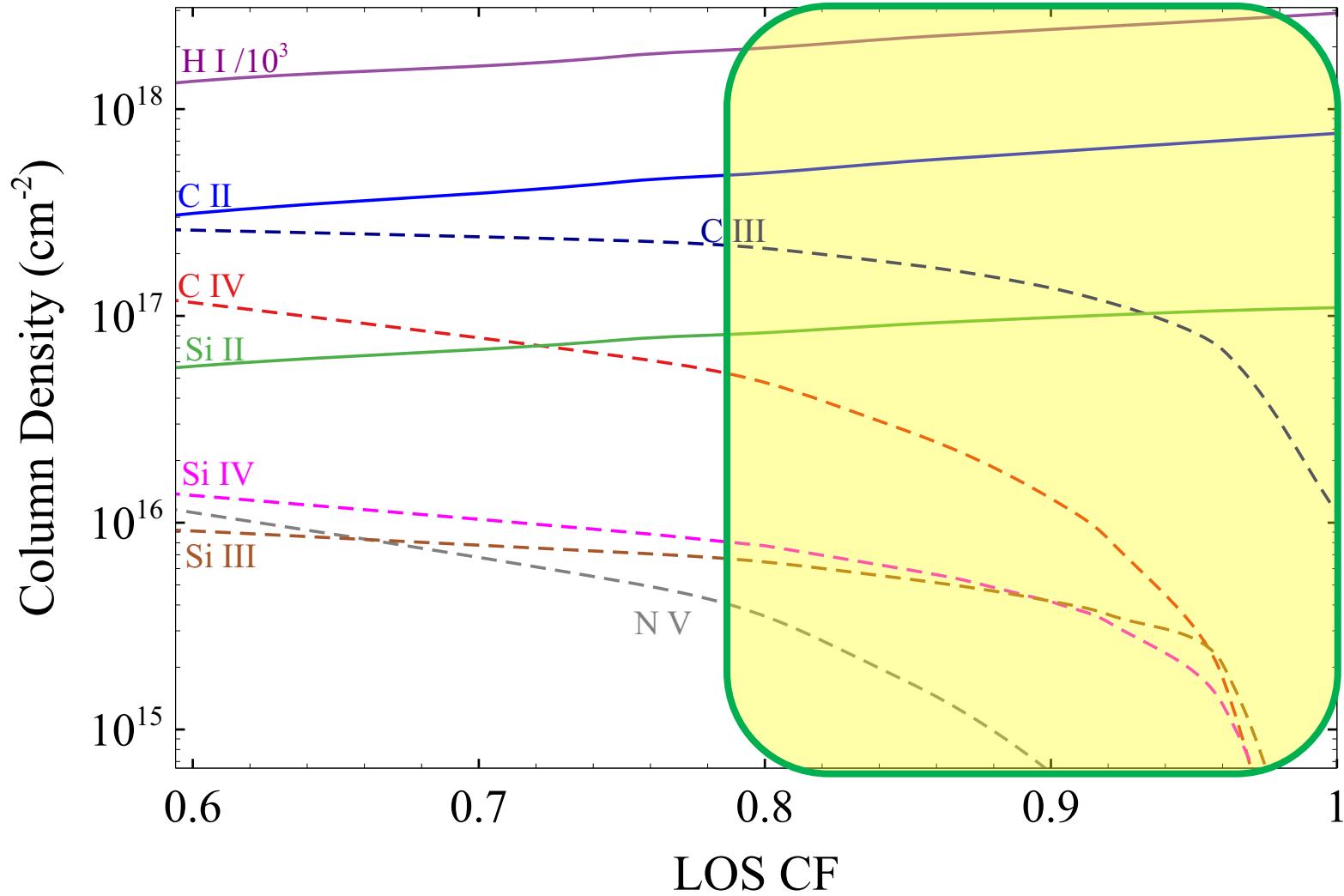


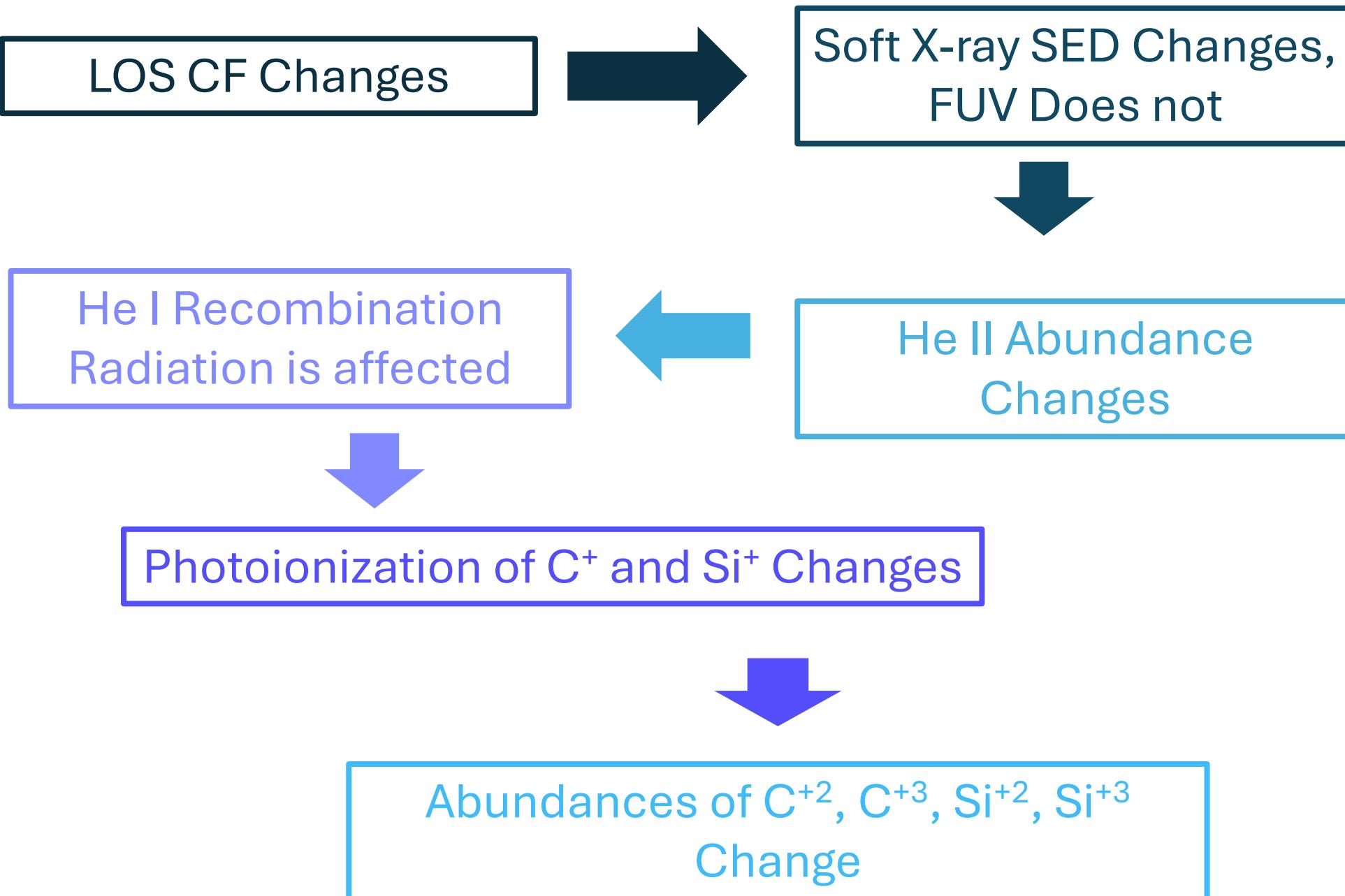
```
Table Read "obs1.tran"
#in next line we make the coverage by obs-comp1 80%
nuF(nu) 2.926 0.2
Table SED "NGC5548.sed"
#in next line we make the not-covered transmitted line 20%
nuF(nu) 2.340 0.2
set save prefix "cf80"
hden 4.72
#stop zone 1
stop column density 21.5
save line list ".lin" "lines.dat" absolute no hash
save continuum units kev ".cone"
save continuum units angstrom ".cona"
save species column densities ".dens" no hash last
"H"
"H+"
"H2+"
"C"
"C+"
"C+2"
"C+3"
"Si"
"Si+"
"Si+2"
"Si+3"
"N"
"N+"
"N+2"
"N+3"
"N+4"
"He"
"He+"
"He+2"
"He[2]"
end
```

The effects of variable covering factor on the shape of the SED

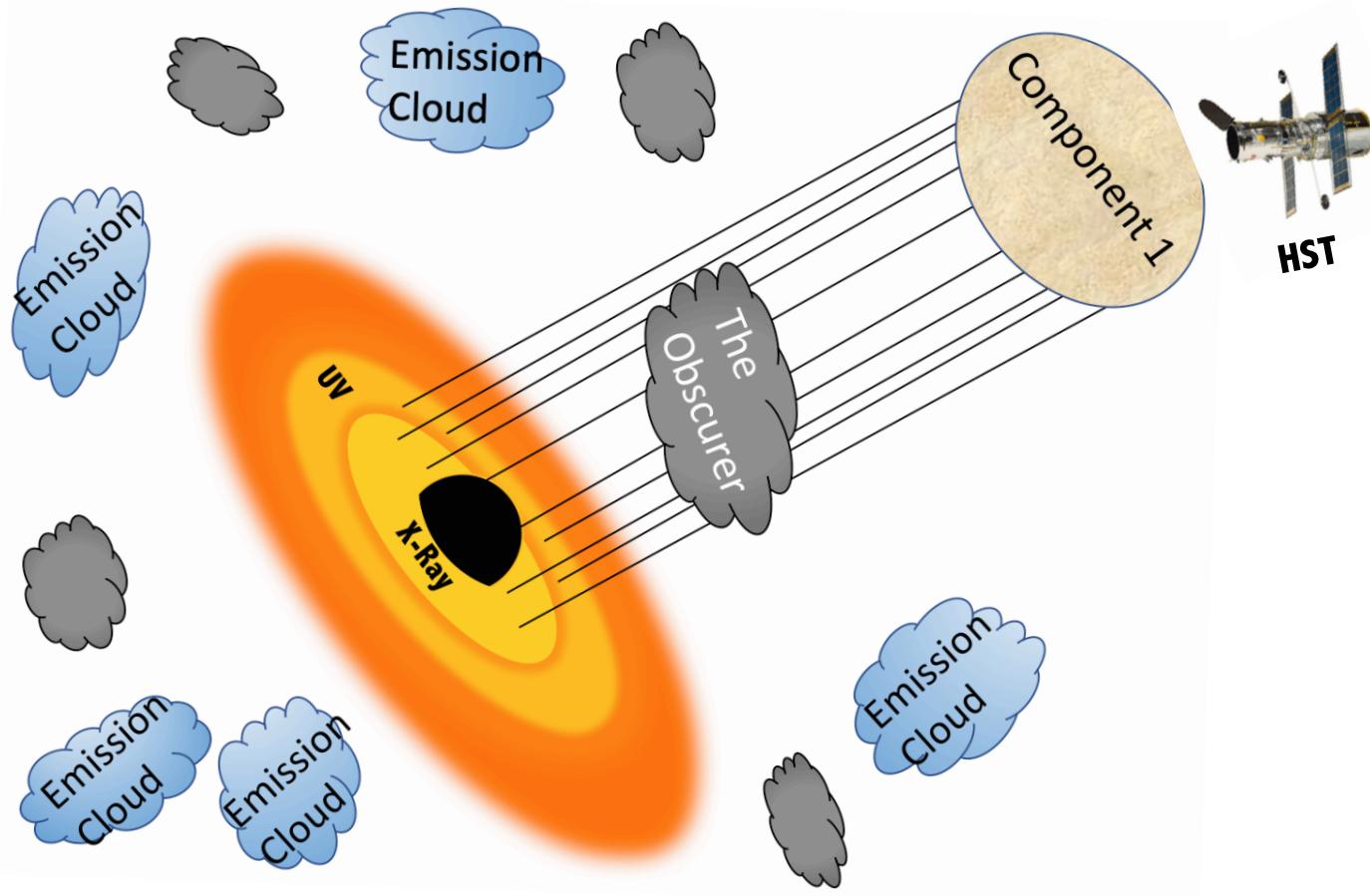


The effects of variable CF on the absorption lines





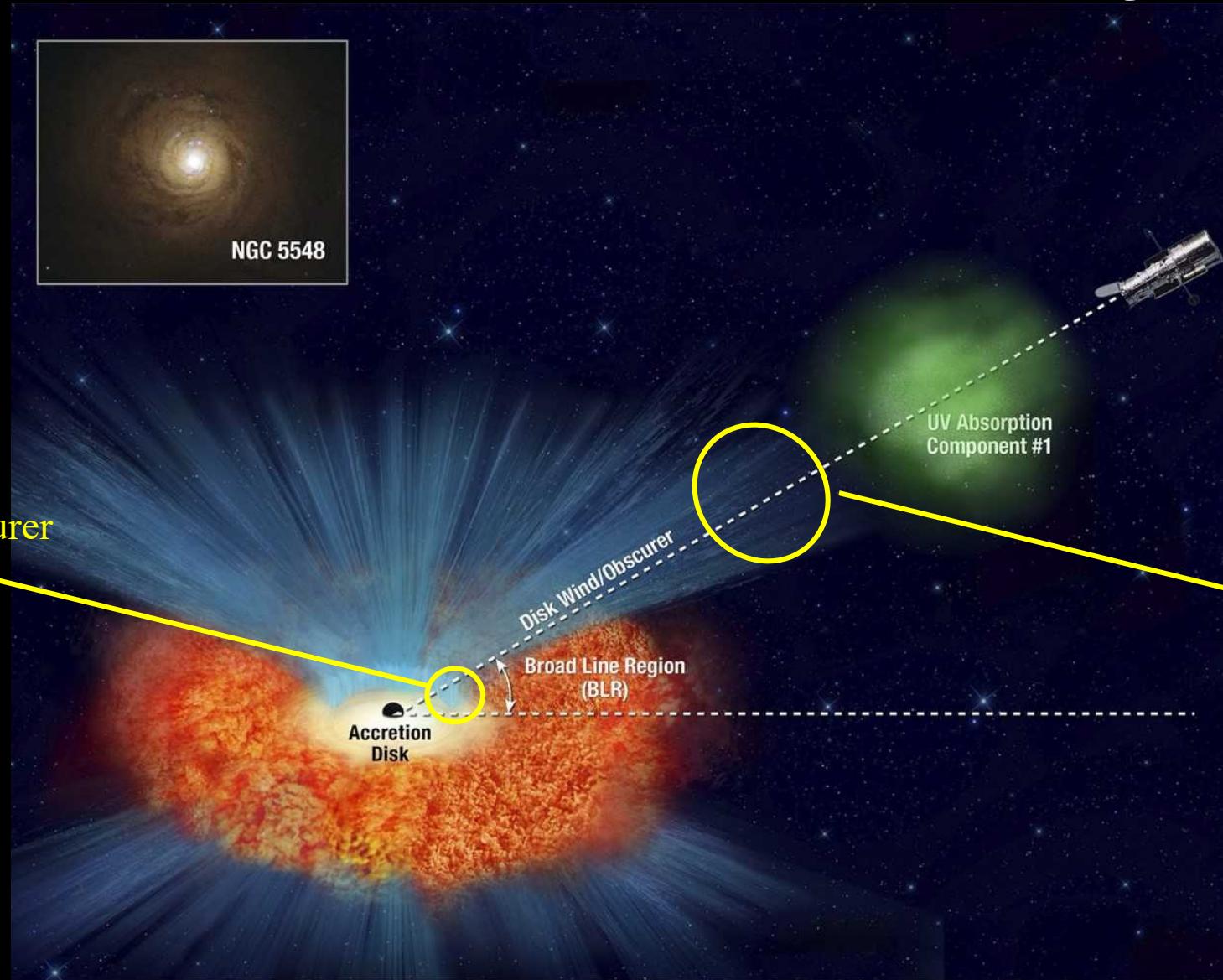
The Emission-Line Holiday



The Emission-Line Holiday

The equatorial obscurer

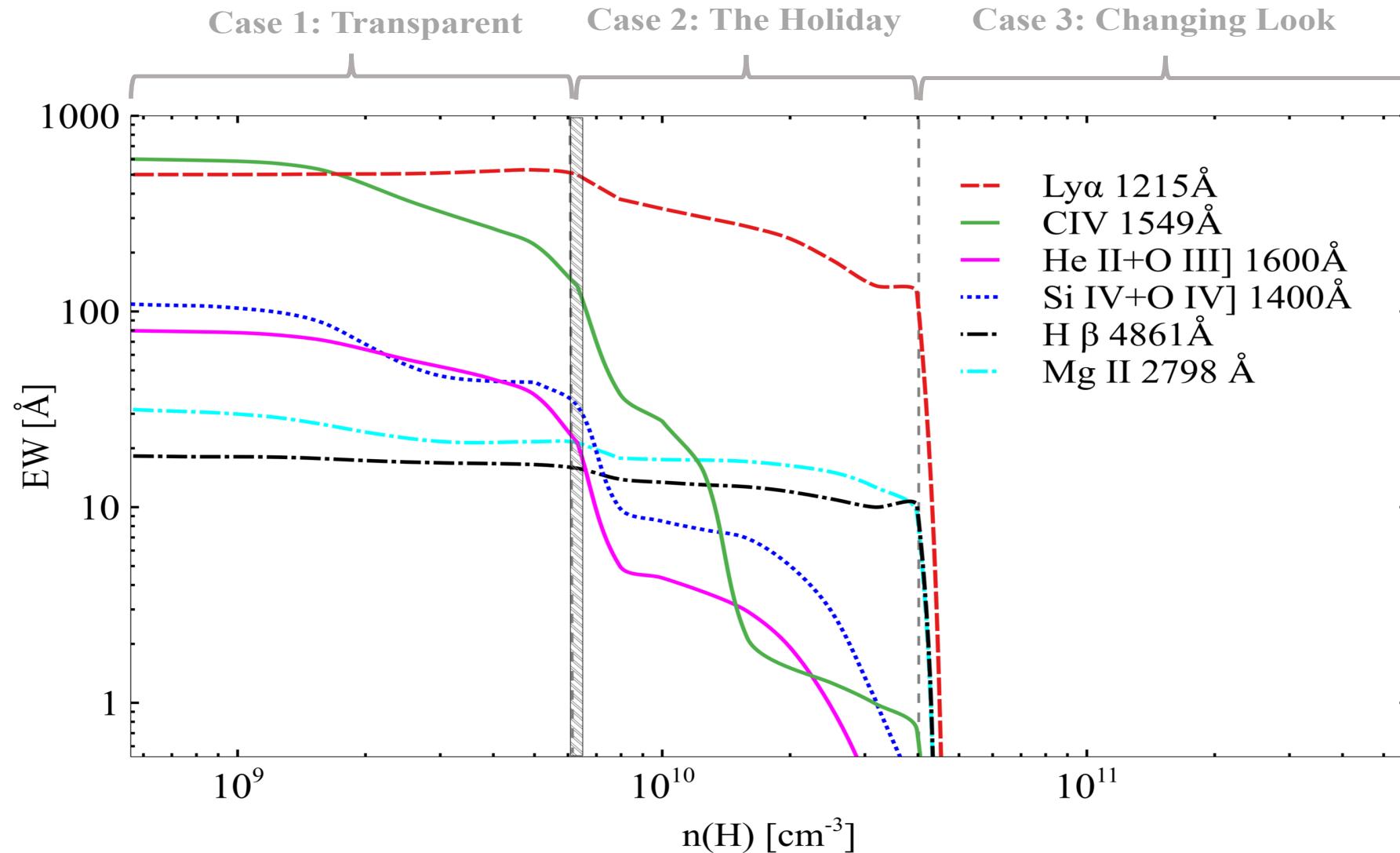
The LOS obscurer



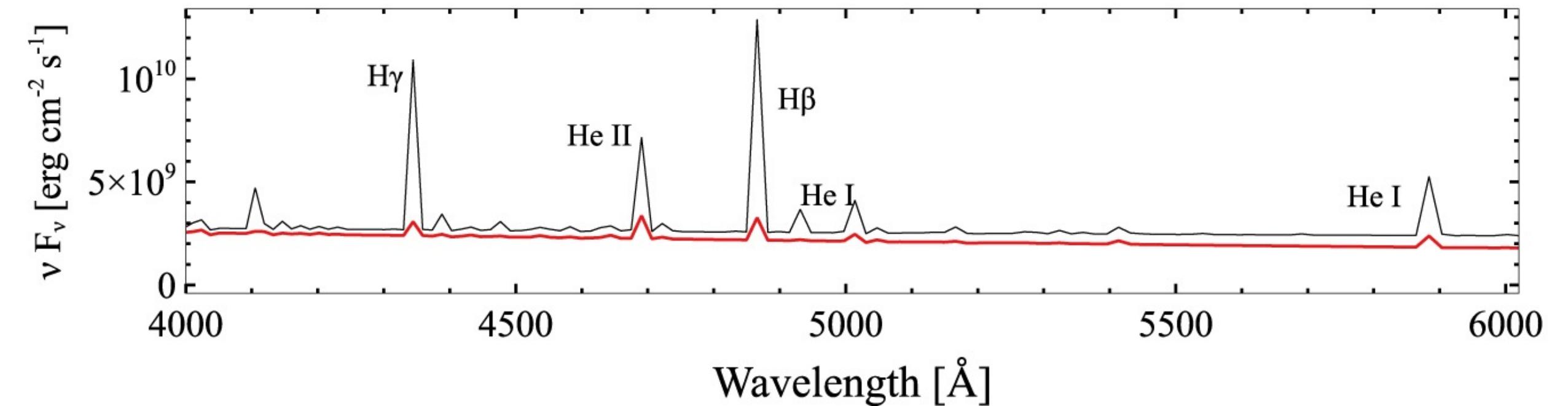
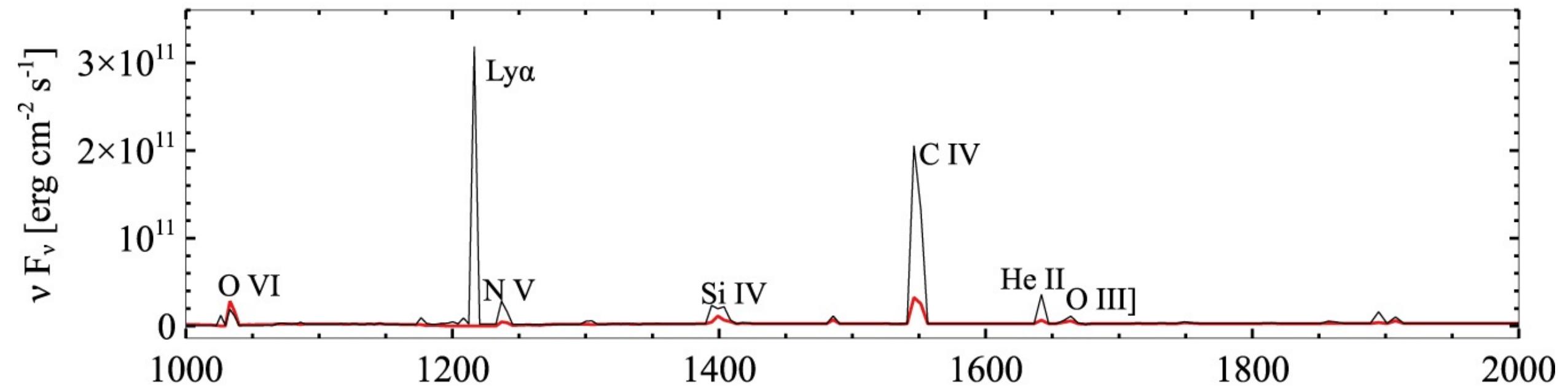
There are two possibilities

- 1- Holiday is a result of variable luminosity**
- 2- Holiday is a result of variable wind**

Changes in the BLR- considering the equatorial obscurer



— $n(H) = 10^9 \text{ cm}^{-3}$ — $n(H) = 10^{11} \text{ cm}^{-3}$

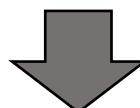


The disk wind mass loss rate increases



The extent of the LOS obscurer increases

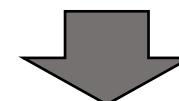
The density of the equatorial obscurer increases



Emission line holiday



Its LOS covering increases

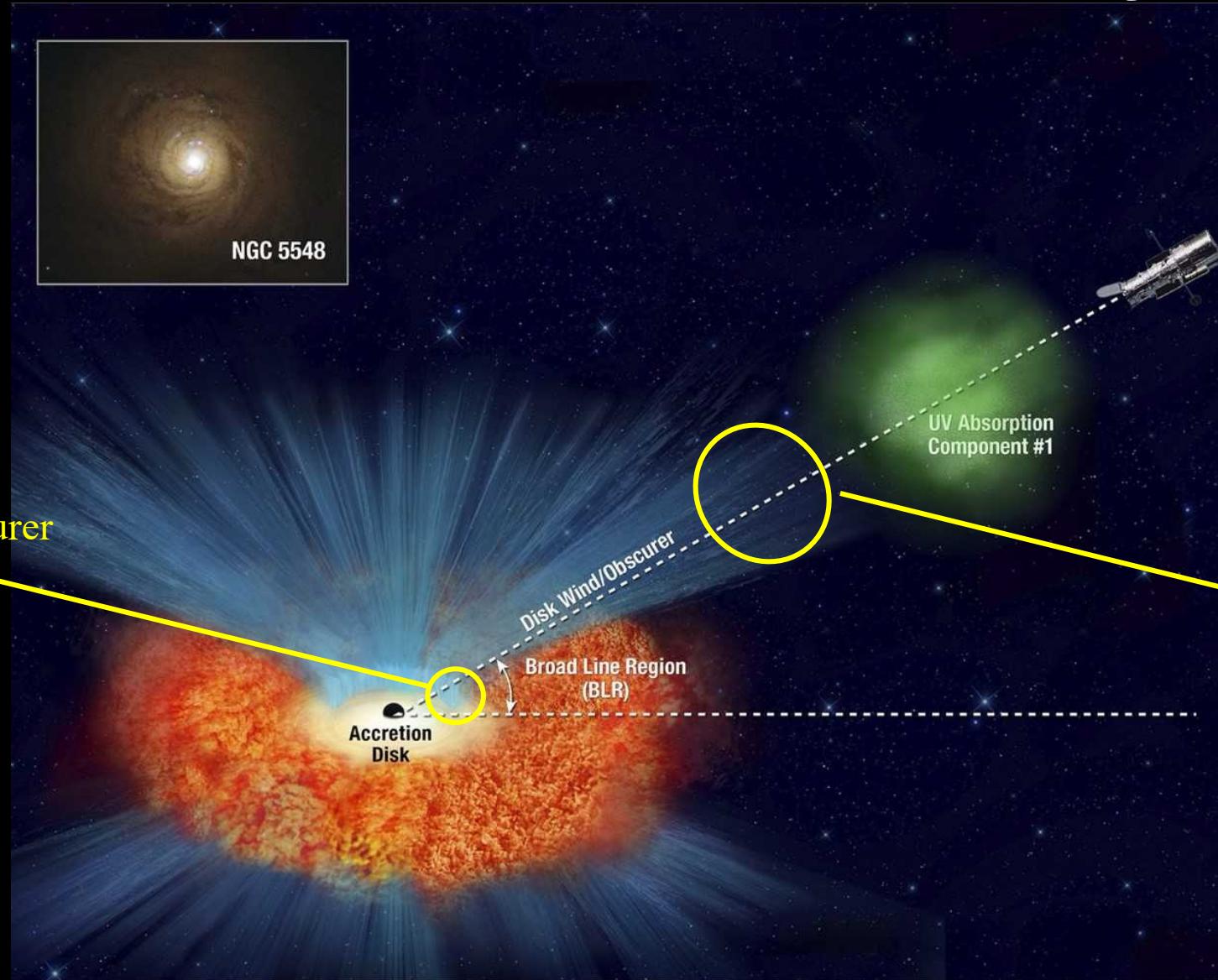


Absorption line holiday

The Emission-Line Holiday

The equatorial obscurer

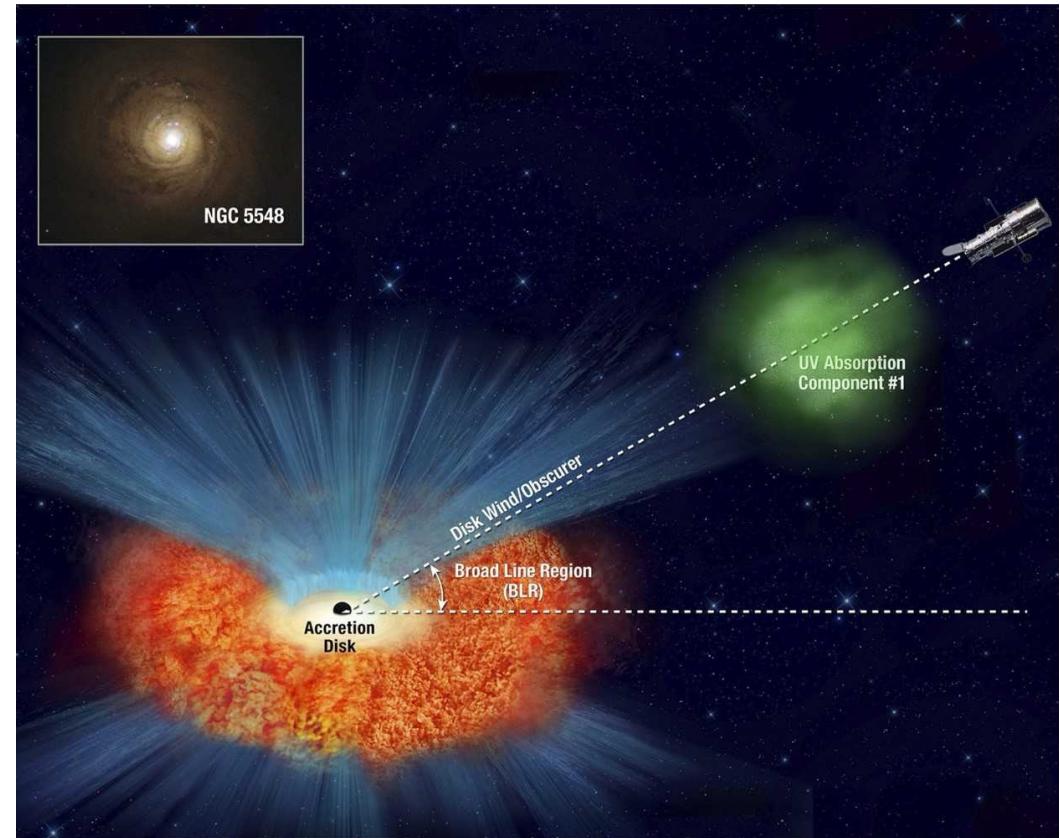
The LOS obscurer



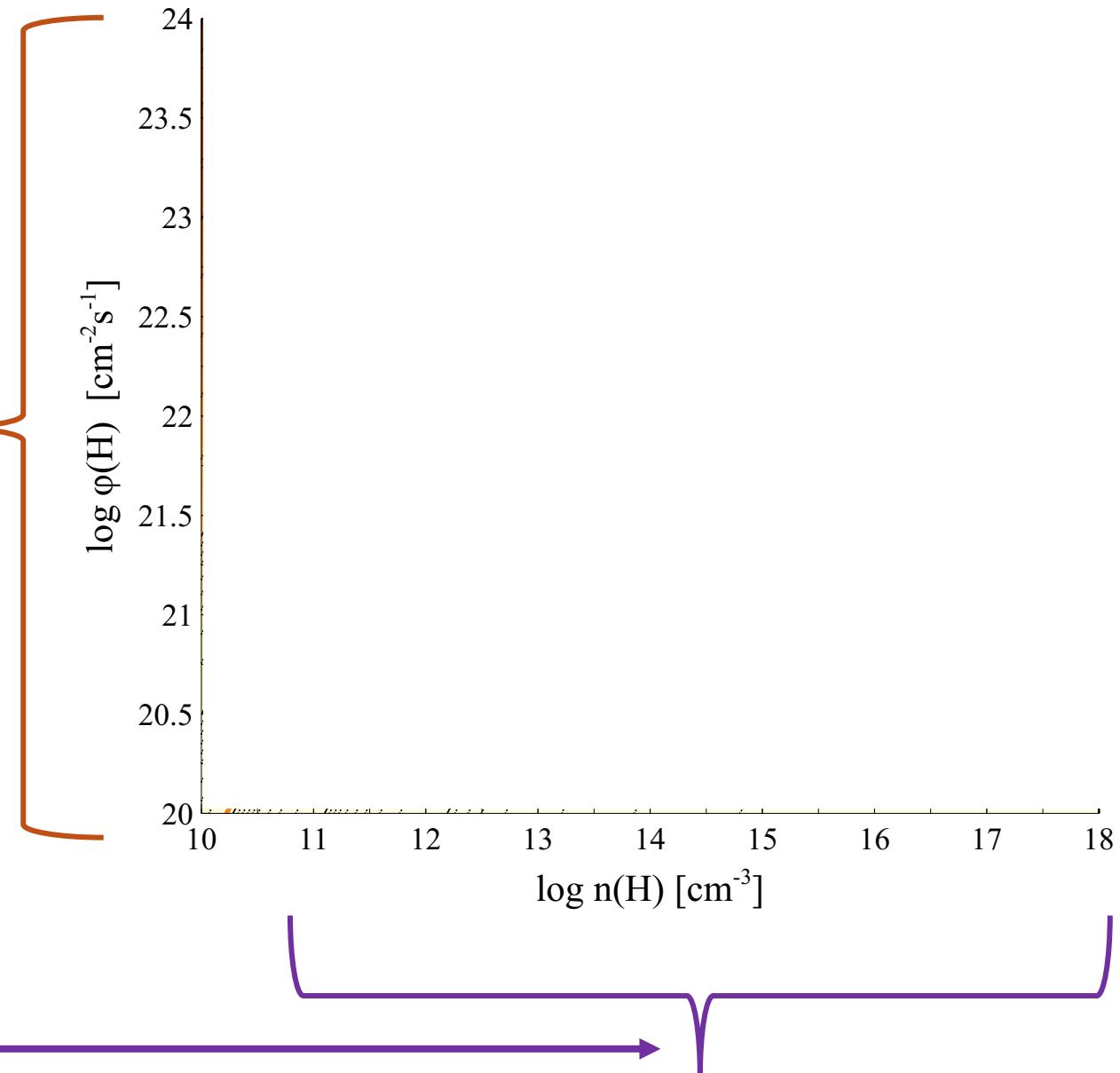
Part IV: Lets Go Beyond 2021



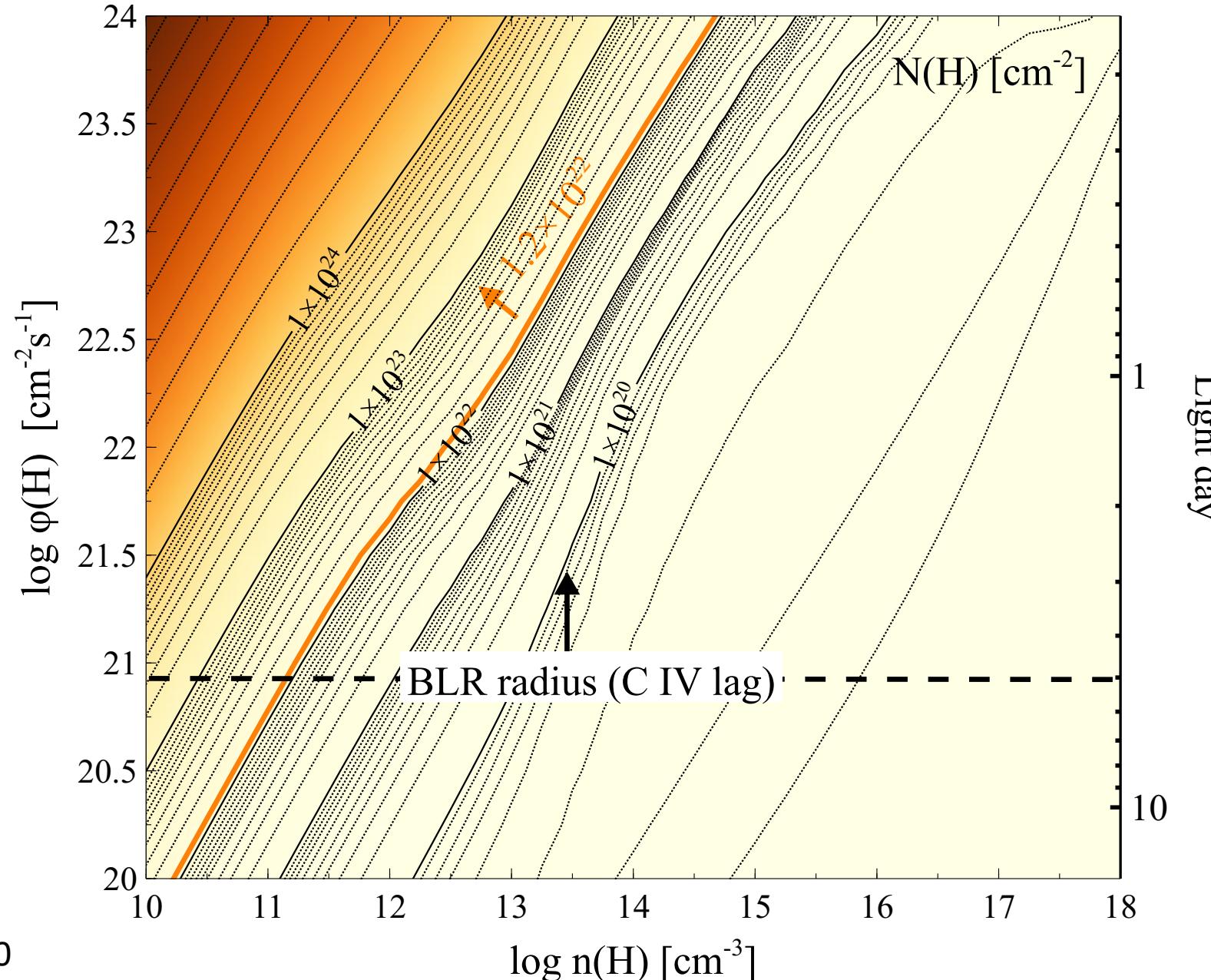
```
Table SED "NGC5548.sed"
set save prefix "L0C_case1"
hden 13 vary
grid 10 18 0.25
phi(H) 22 vary
grid 20 24 0.25|
```



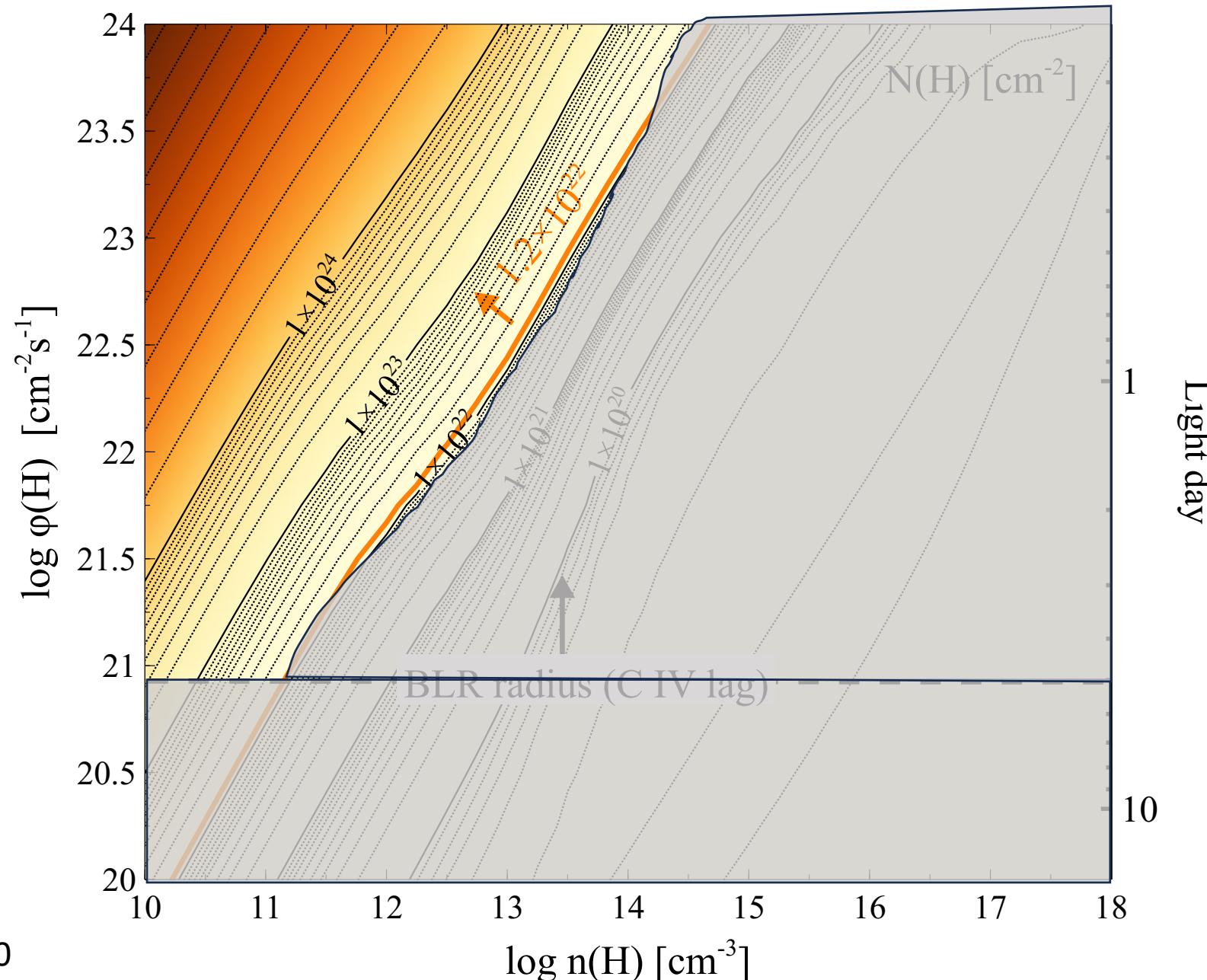
```
Table SED "NGC5548.sed"
set save prefix "LOC_case1"
hden 13 vary
grid 10 18 0.25
phi(H) 22 vary
grid 20 24 0.25
```



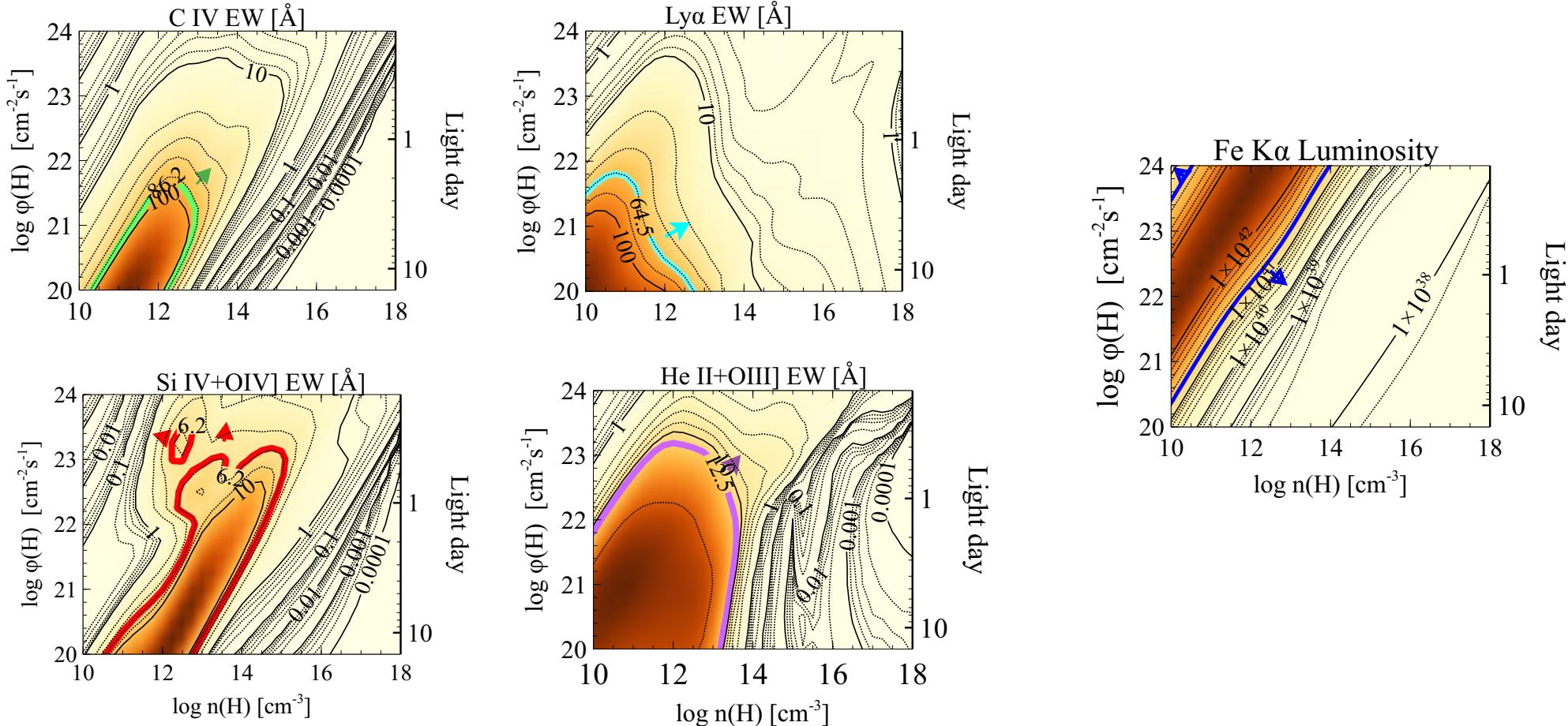
A Novel Approach to Trace the Disk Wind



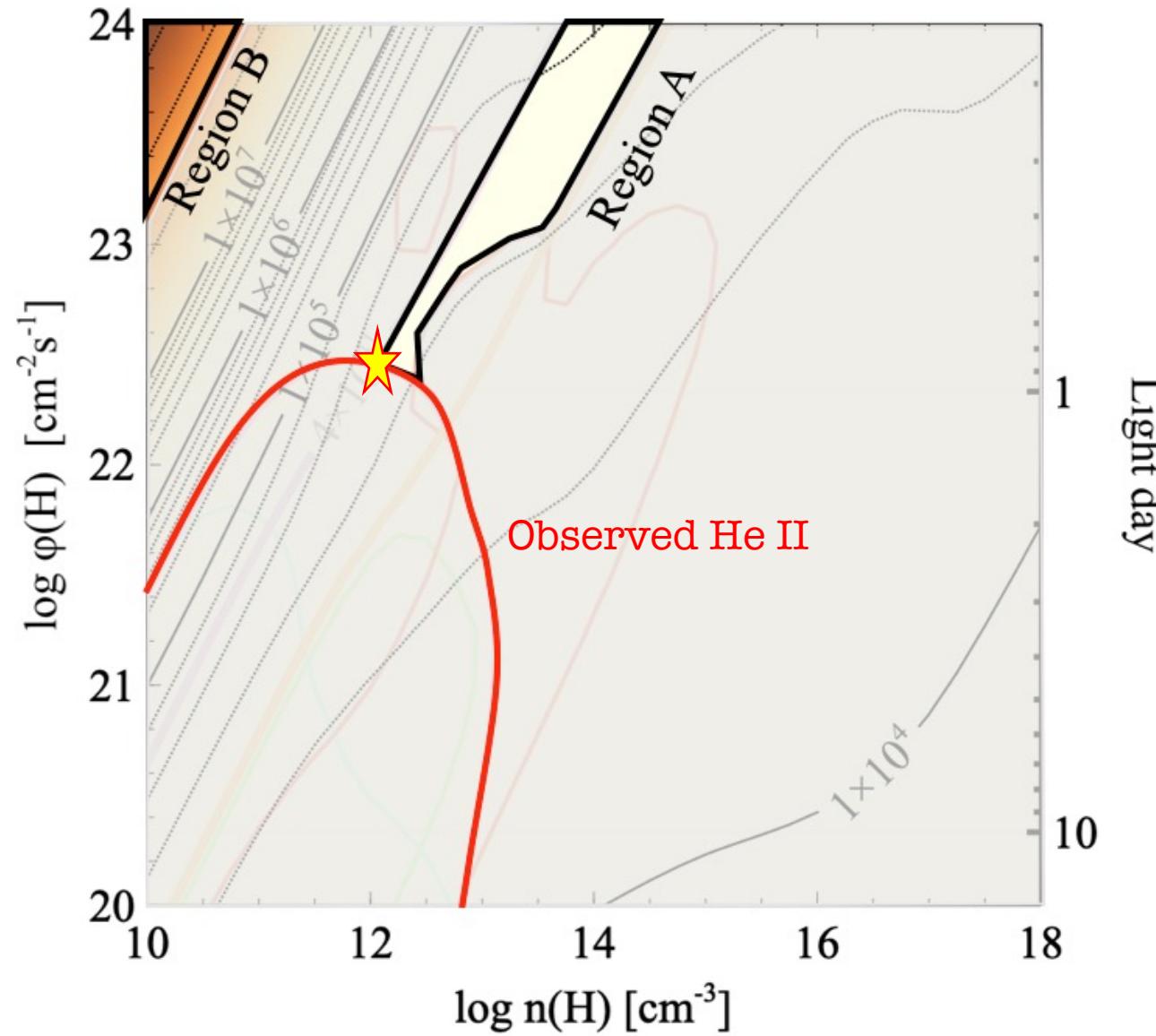
A Novel Approach to Trace the Disk Wind



Emission from the disk wind



Temperature [K]



$$n(H) = 12 \text{ cm}^{-3}$$

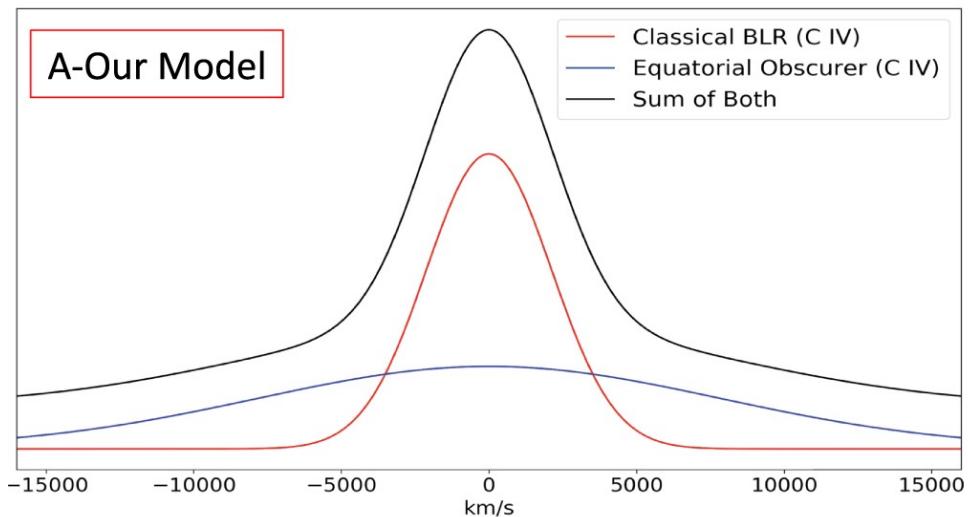
$$N(H) = 10^{23} \text{ cm}^{-2}$$

$$R = 1 \text{ Light Day}$$

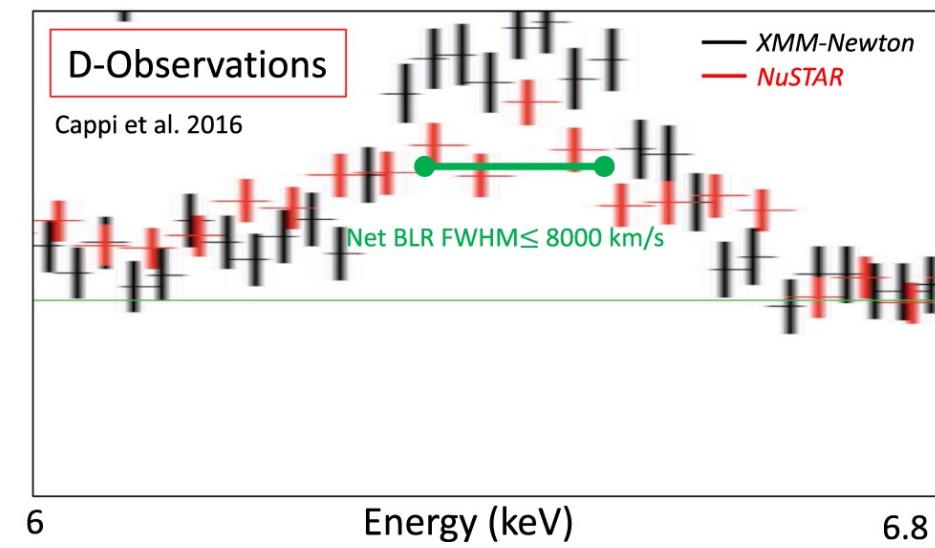
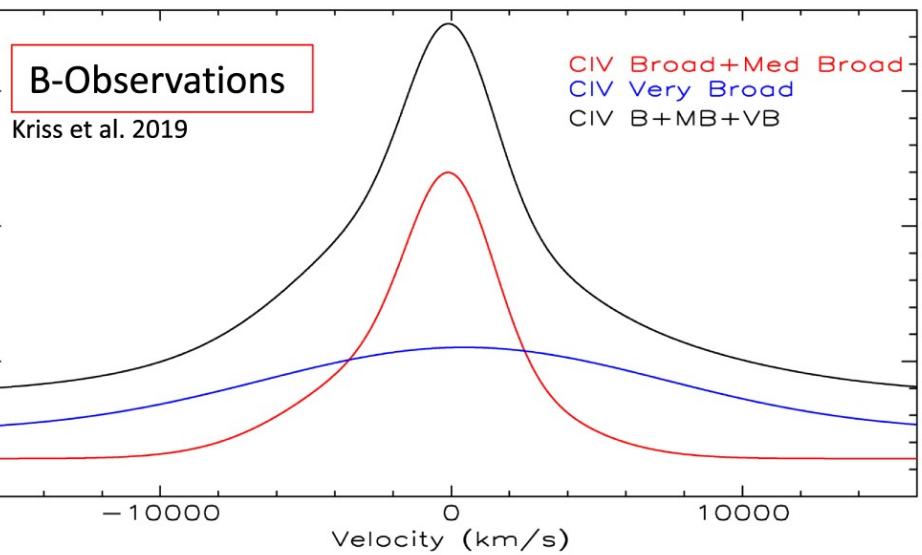
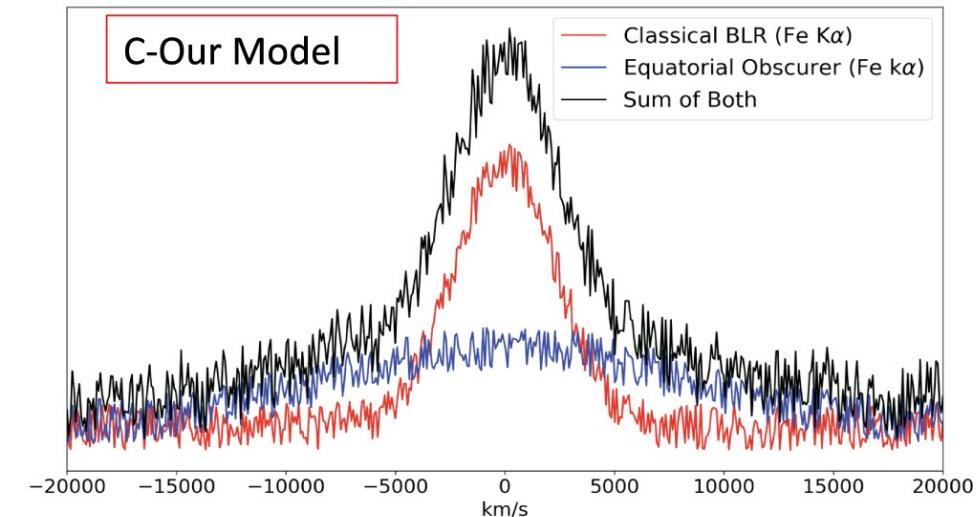
$$T = 5 \times 10^4 \text{ K}$$

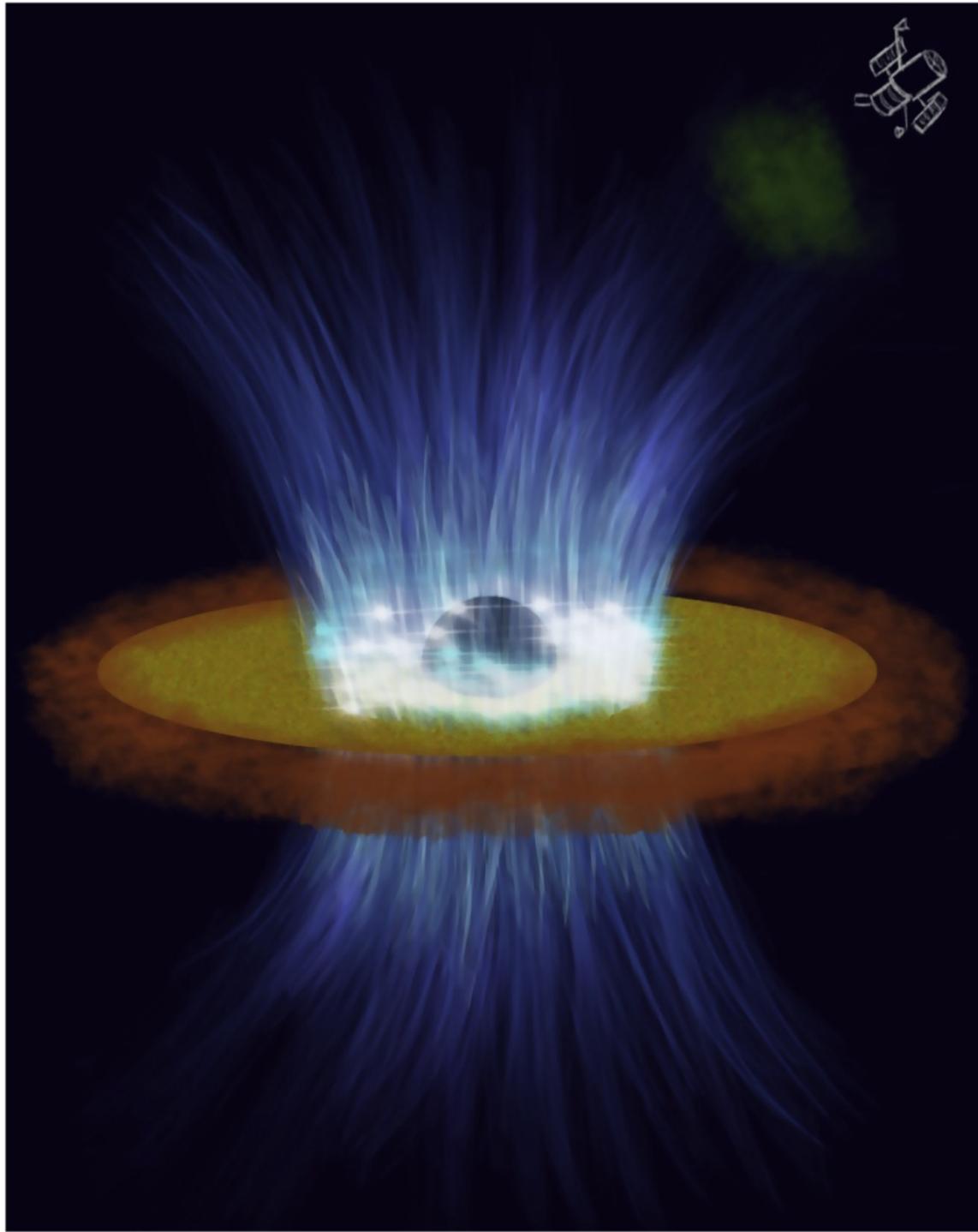
$$\xi = 1 \text{ erg cm s}^{-1}$$

C IV ($\text{EW}_{\text{wind}} = \text{EW}_{\text{BLR}} = 50\% \text{EW}_{\text{total}}$)

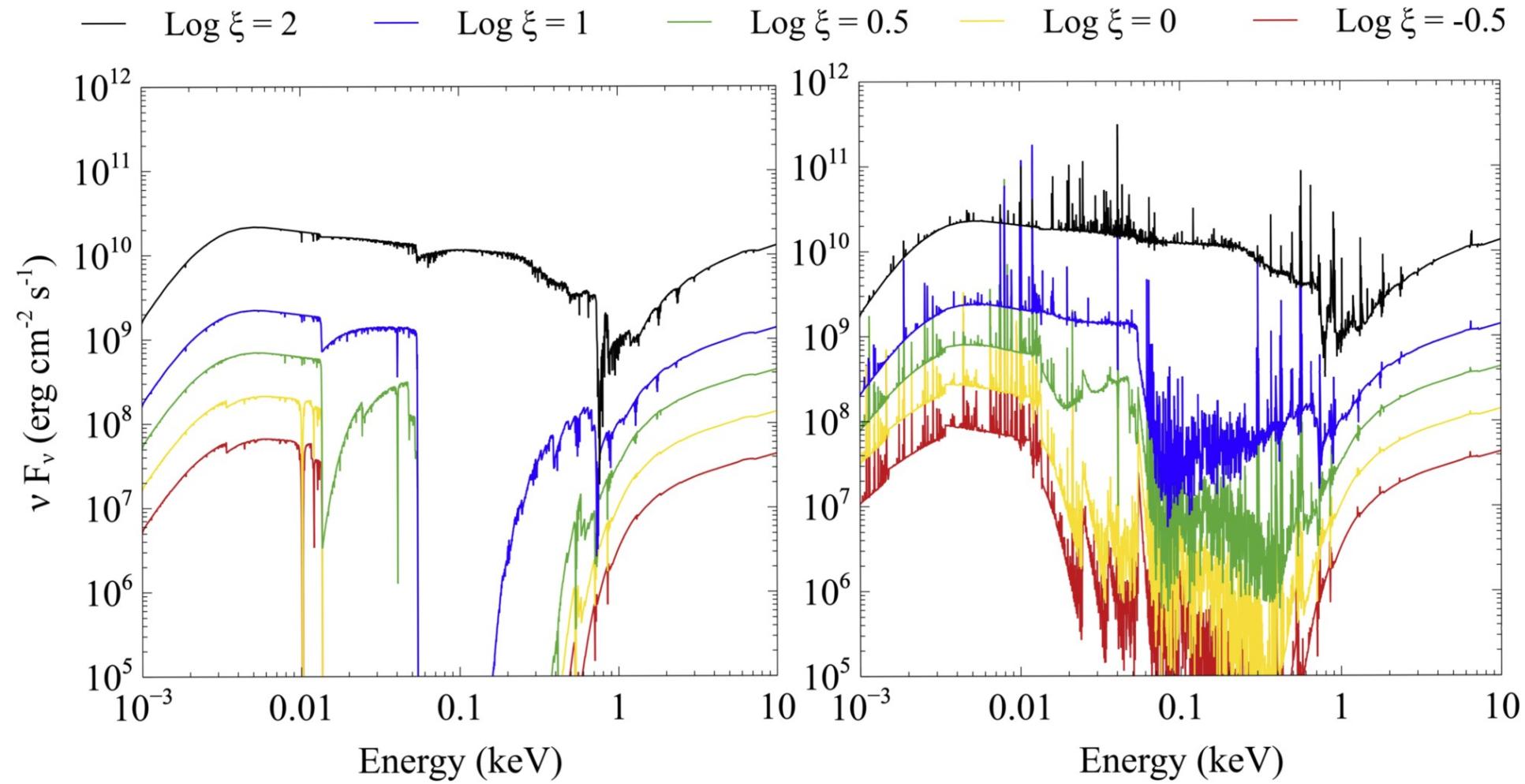


Fe K α ($\text{EW}_{\text{wind}} = \text{EW}_{\text{BLR}} = 50\% \text{EW}_{\text{total}}$)

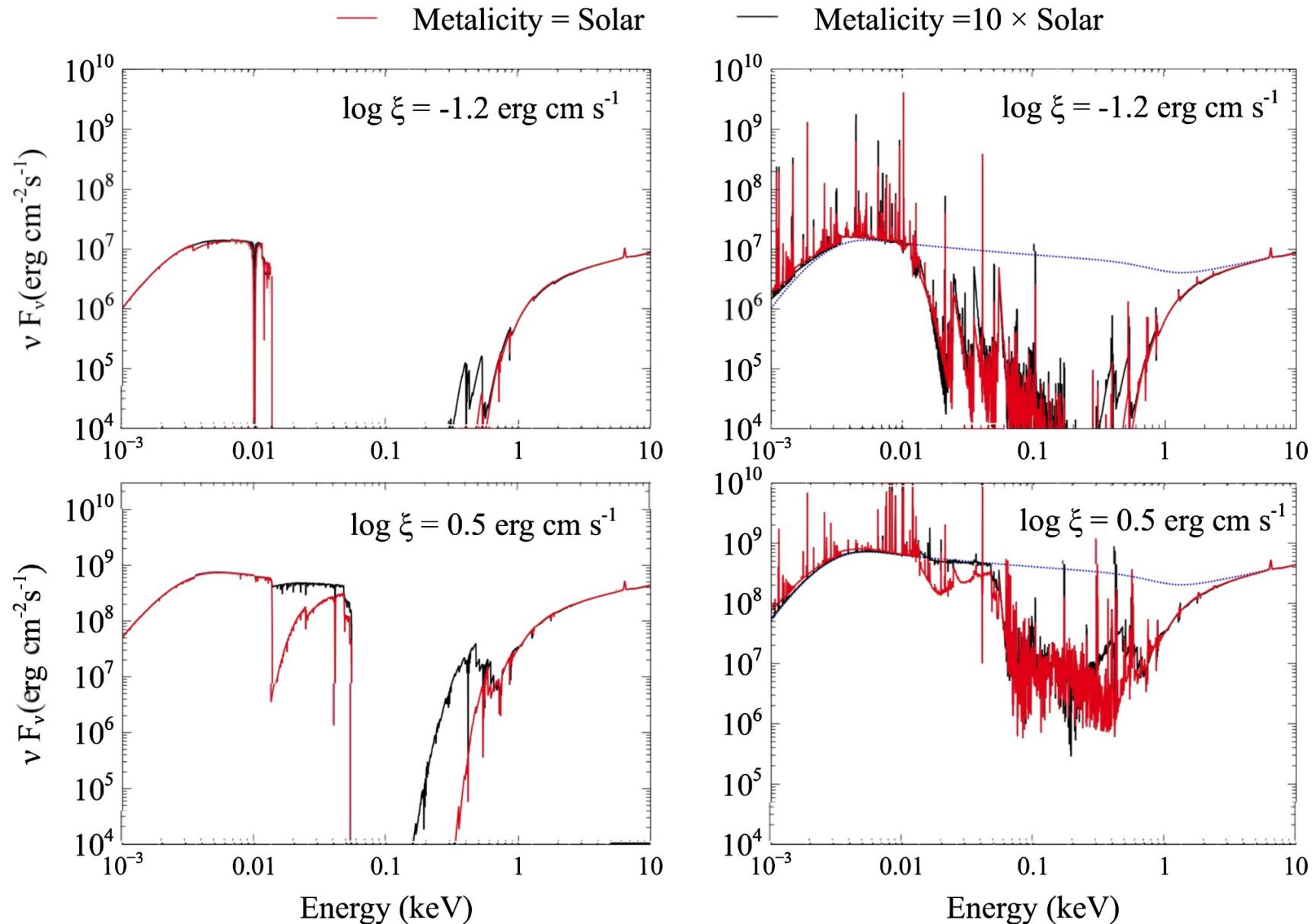




Atlas of UV and X-Ray Spectroscopic Signatures of the Disk Wind



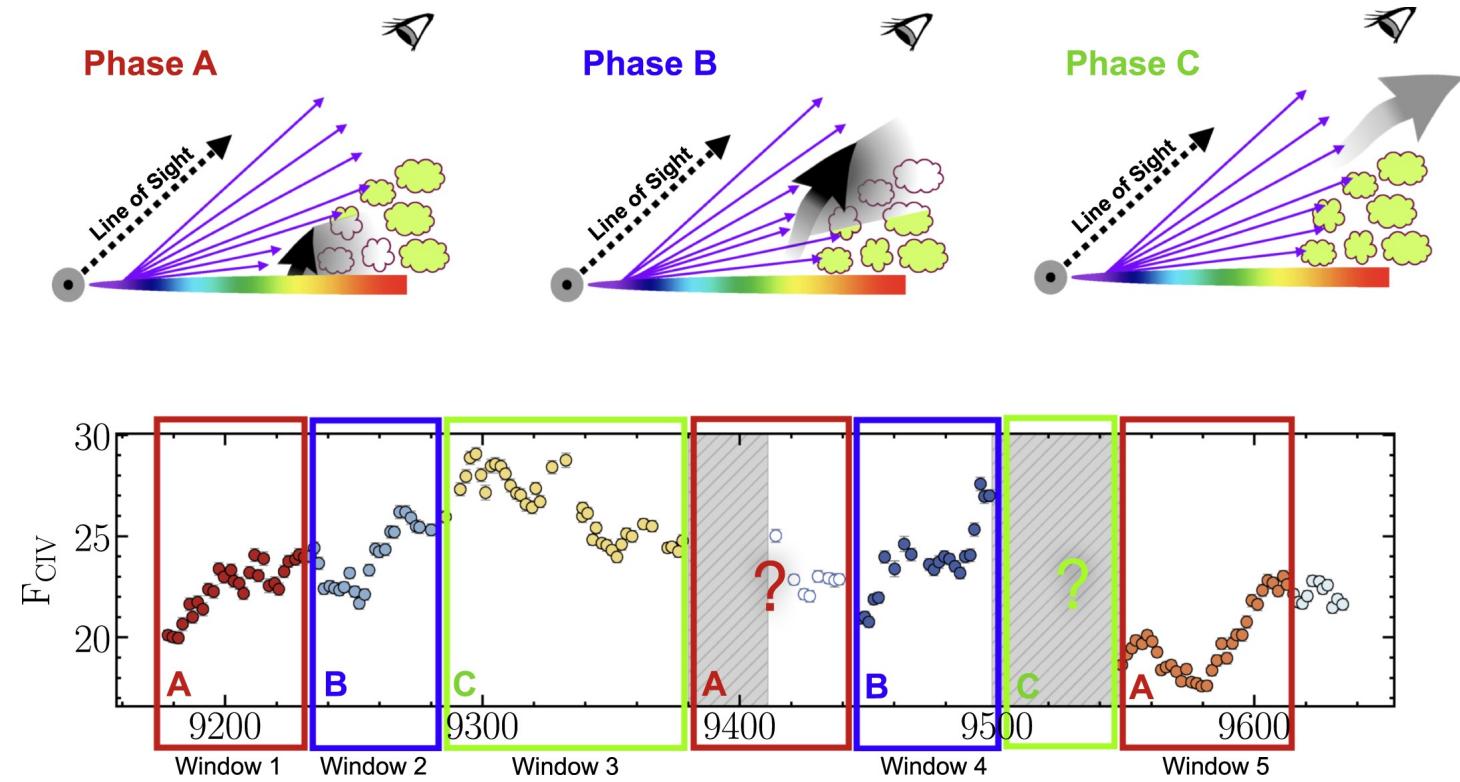
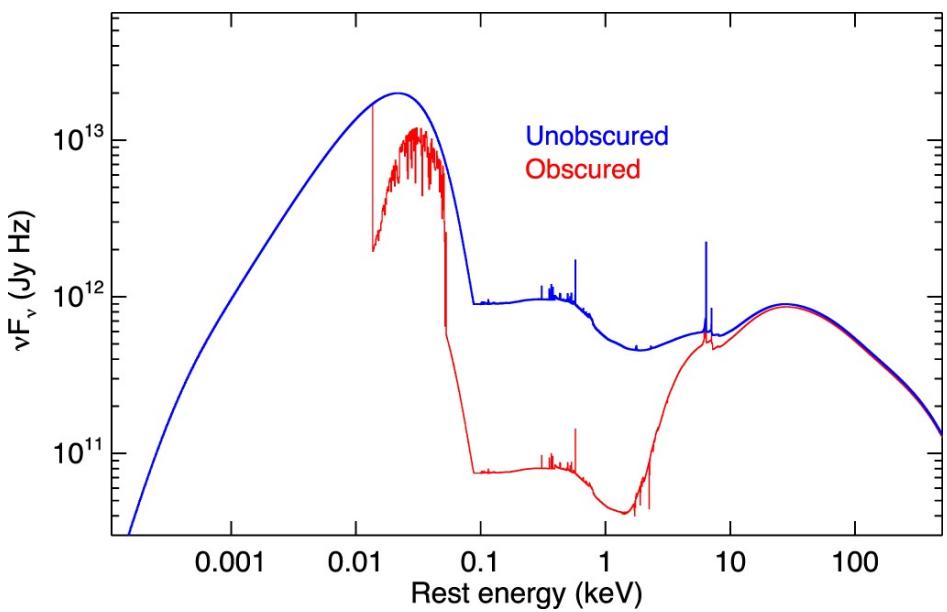
Atlas of UV and X-Ray Spectroscopic Signatures of the Disk Wind



**Future:
Not a unique
phenomenon**



AGN STORM2: Mrk 817



Thank You for Your Attention!

Any questions? Please ask.

