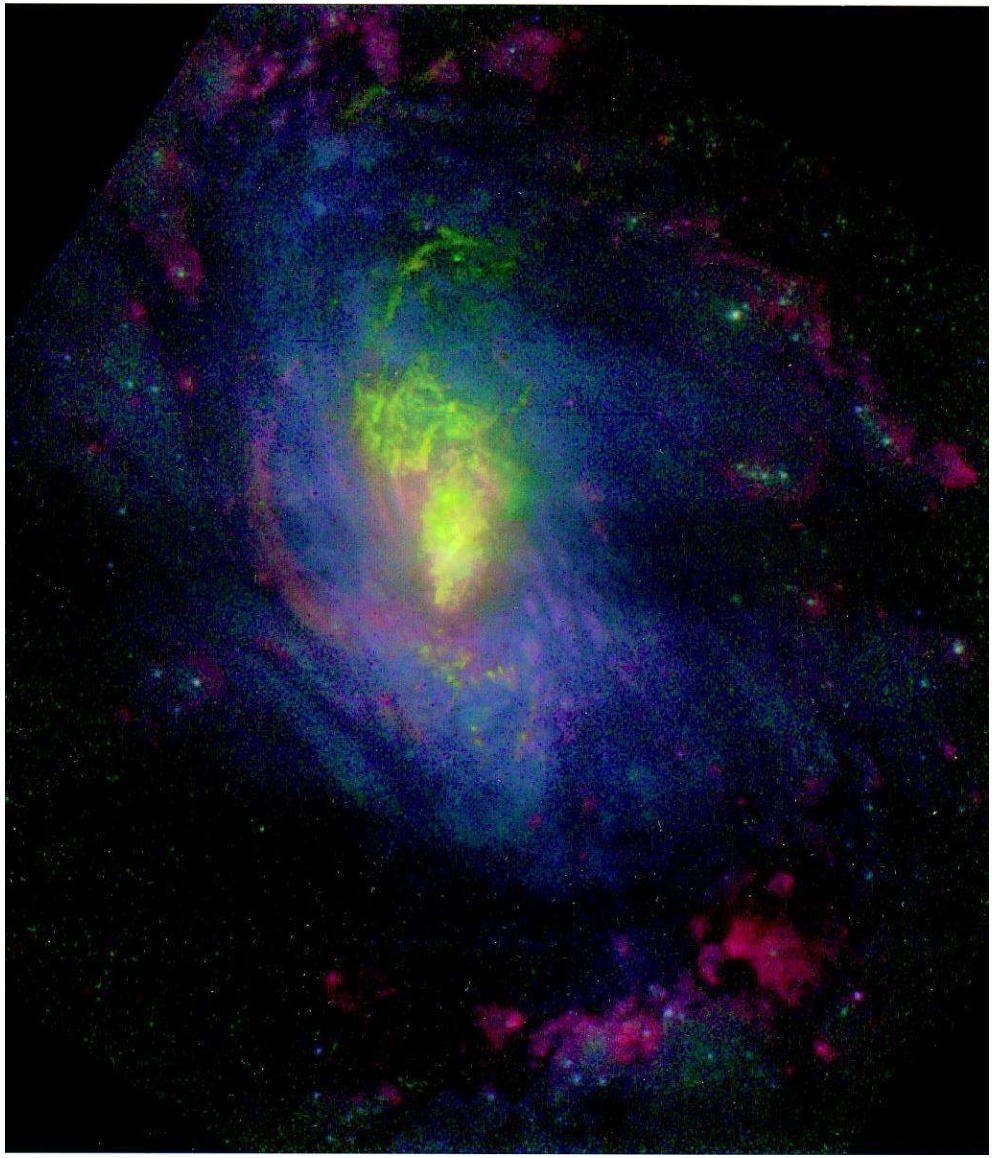
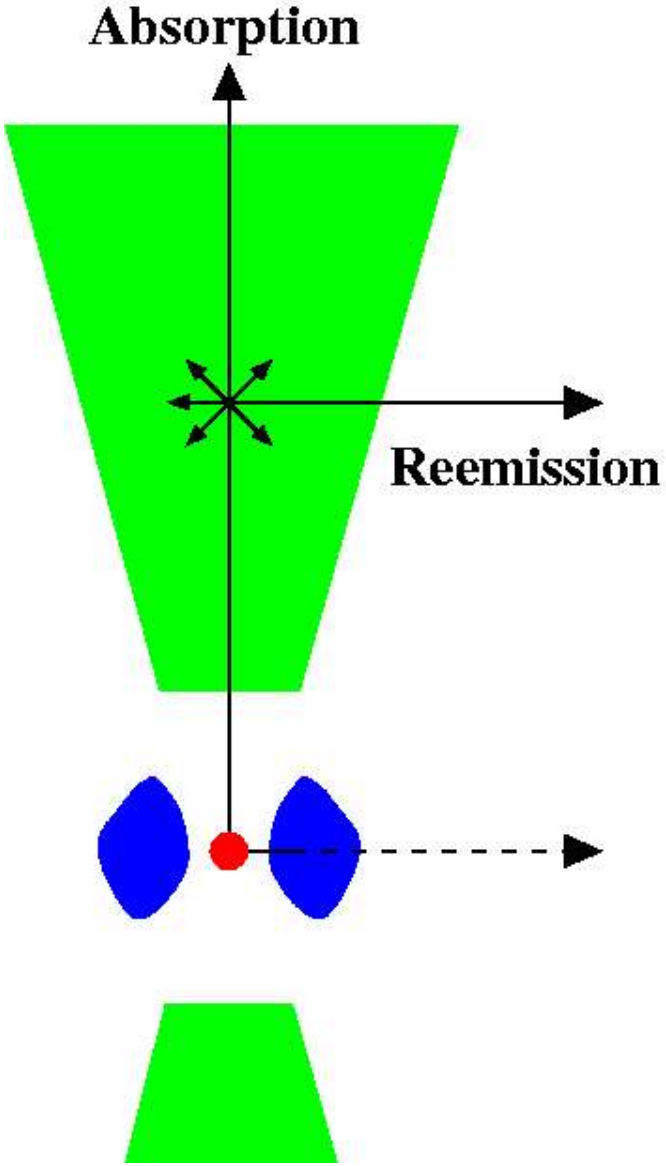
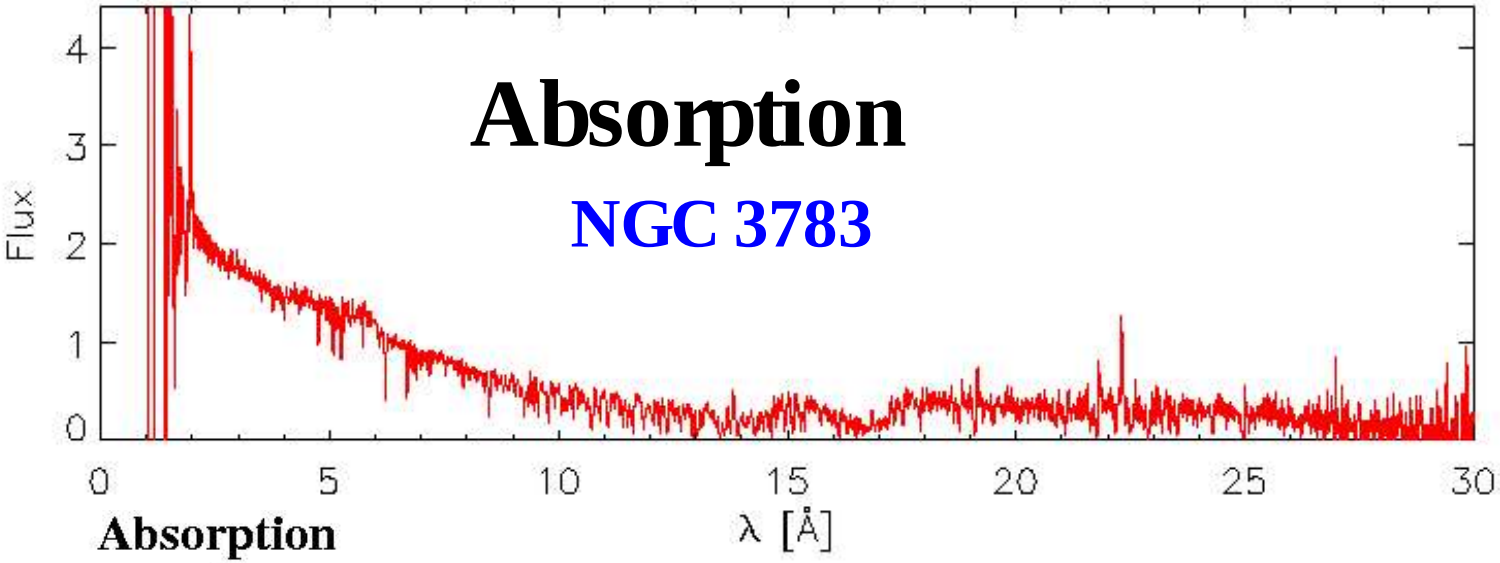
X-ray Absorption and Emission Features from Active Galactic Nuclei

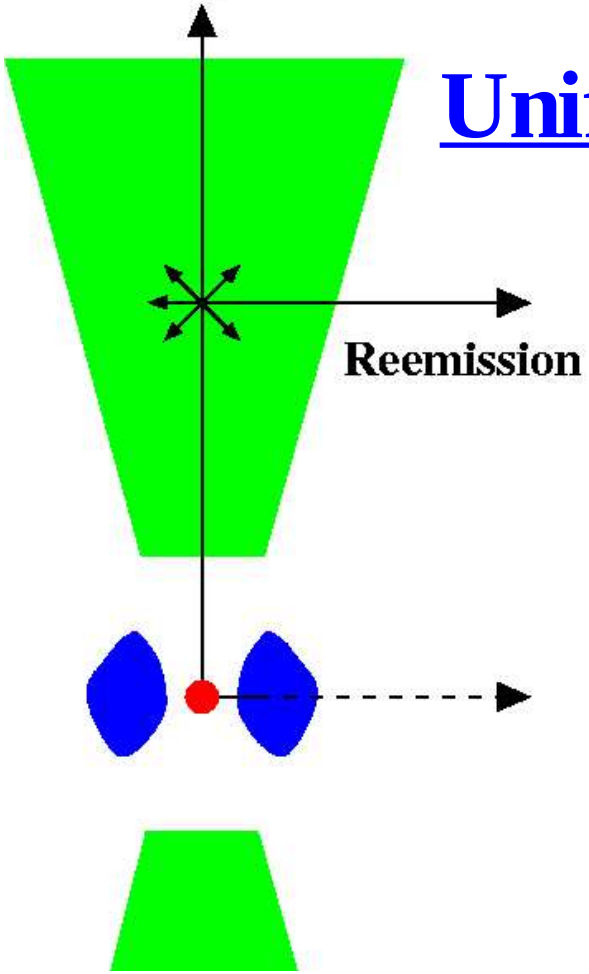
Ali Kinkhabwala, Masao Sako, Ehud Behar, Ming Feng Gu, Steve Kahn, Frits Paerels, John Peterson
Bert Brinkman, Jelle Kaastra, Rob van der Meer, Duane Liedahl

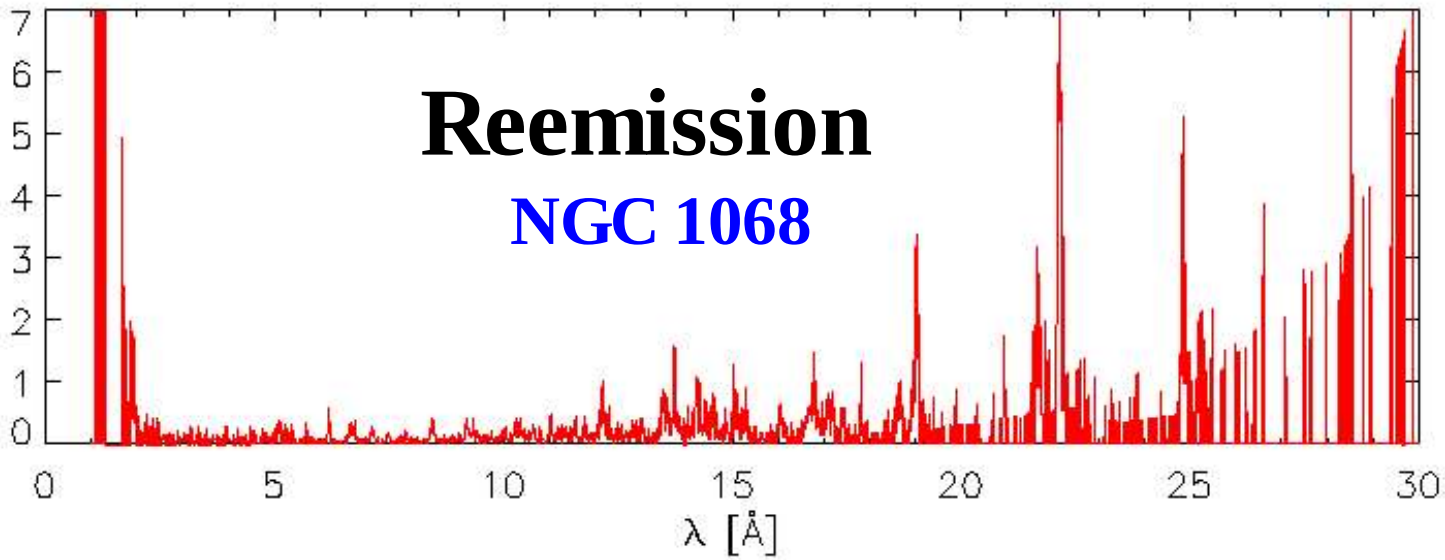






Unified Model of Active Galactic Nuclei



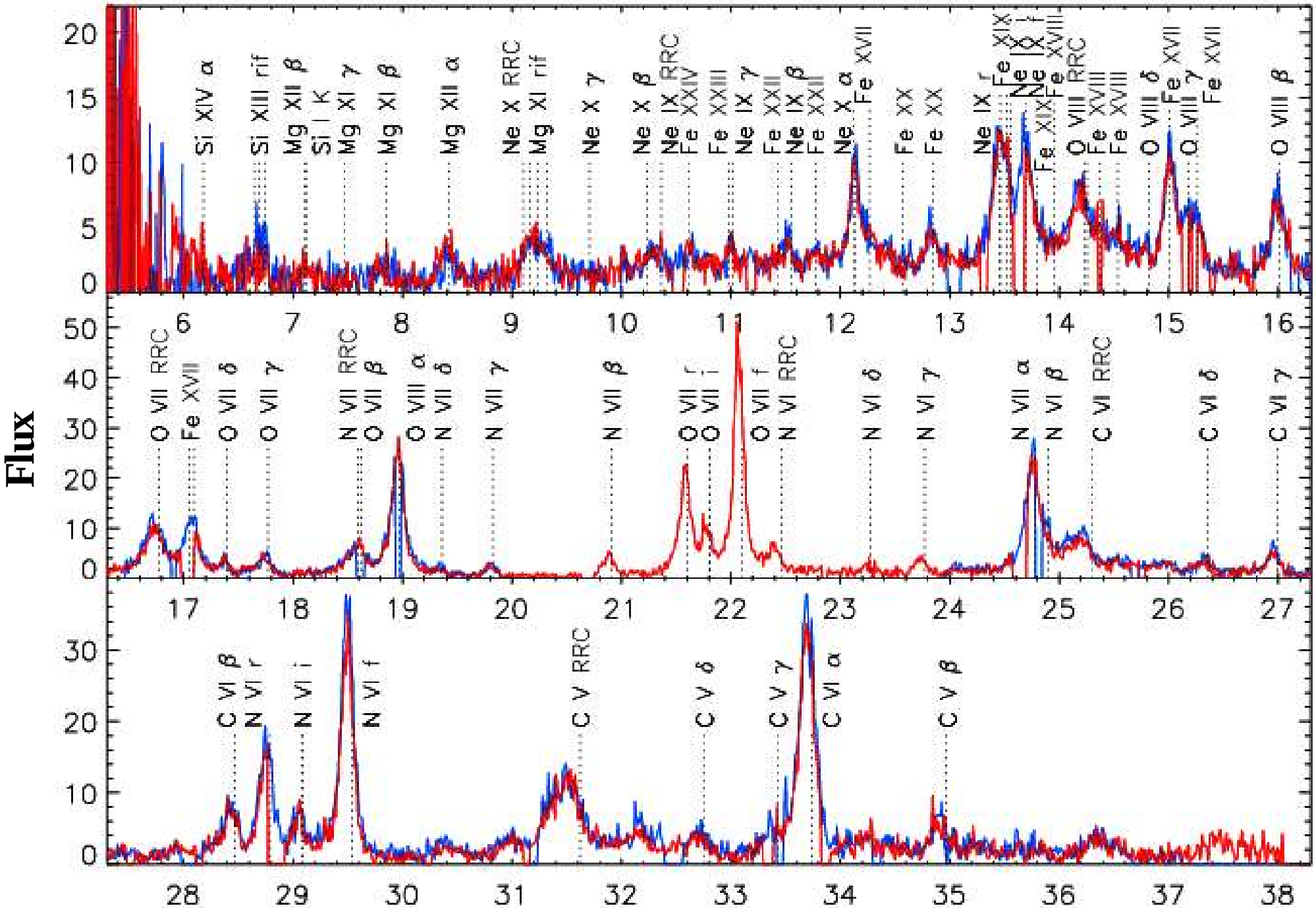


Outline

I. Reemission

II. Absorption

NGC 1068 (XMM)


Flux
Si XIV α
Si XIII rif
Mg XII β
Si I K
Mg XI γ
Mg XI β
Mg XII α
Ne X RRC
Mg XI rif
Ne X γ
Ne X β
Ne IX RRC
Fe XXIV
Fe XXIII
Ne IX γ
Fe XXII
Ne IX β
Fe XXII
Ne X α
Fe XVII
Fe XX
Fe XX
Ne IX r
Fe XIX
Ne IX i
Ne IX f
Fe XVIII
Fe XIX
O VIII RRC
Fe XVIII
Fe XVIII
O VIII δ
Fe XVII
O VIII γ
Fe XVII
O VIII β
O VII RRC
Fe XVII
O VII δ
O VII γ
N VII RRC
O VII β
O VIII α
N VII δ
N VII γ
N VII β
O VII r
O VII i
O VII f
N VI RRC
N VI δ
N VI γ
N VII α
N VI β
C VI RRC
C VI δ
C VI γ
C VI β
N VI r
N VI i
N VI f
C V RRC
C V δ
C V γ
C VI α
C V β

Ionic Rate Equation

$$n_{Z,z,i}(\vec{r},t), F(E,\vec{r},t), T(\vec{r},t), B.C.'s$$

$$\begin{aligned}
\frac{dn_{Z,z,i}}{dt} = & \sum_{k\geq 1}\sum_{j} n_{z-1,j} n_e^k C_{z-k,j}^{z,i} + \sum_{1\leq k\leq z}\sum_{j} n_{z-k,j}\left[\{nC\}_Q\right]_{z-k,j}^{z,i} \\
& - \sum_{1\leq k\leq z}\sum_{j} n_{z,i}\left[R+D+n_e C+\{nC\}_Q\right]_{z,i}^{z-k,j} \\
& - n_{z,i}\sum_{j}\left[R+n_e C+\{nC\}_Q+A\right]_{z,i}^{z,j} + \sum_{j} n_{z,j}\left[R+n_e C+\{nC\}_Q+A\right]_{z,j}^{z,i} \\
& - n_{z,i}\sum_{k\geq 1}\sum_{j} n_e^k C_{z,i}^{z+k,j} - n_{z,i}\sum_{k\geq 1}\sum_{j}\left[\{n\,C\}_Q\right]_{z,i}^{z+k,j} \\
& + \sum_{k\geq 1}\sum_{j} n_{z+k,j}\left[R+D+n_e C+\{nC\}_Q\right]_{z+k,j}^{z,i} \\
& + \sum_{q,q'} n_q\left[R+n_{eC}+\{nC\}_Q\right]_q^{q'+z,i} - \sum_{q,q'} n_{z,i}\left[\{nC\}_q\right]_{q+z,i}^{q'} + \sum_{q,q'} n_q\, W_q^{q'+z,i}
\end{aligned}$$

$$C_A^B(\vec{r},T(\vec{r},t)) = \int\left[\sigma^C\right]_A^B(E)\, v(E,t)\, f(E,T(\vec{r},t))\, dE$$

$$R_A^B(\vec{r},F(E,\vec{r},t)) = \int\left[\sigma^R\right]_A^B(E,\vec{r})\, F(E,\vec{r},t)\, dE$$

Simplifying Assumptions for Photoionized Plasma

1. All ions are in their ground state (X-ray transitions are fast)
2. Reemission occurs in optically thin medium
3. Collisional excitation/ionization negligible
4. Isotropic cone geometry
5. Global steady state
6. Ionization Rate = Recombination Rate (for neighboring charge states)
7. Relative ion ratios are constant throughout medium

For $i > g$:

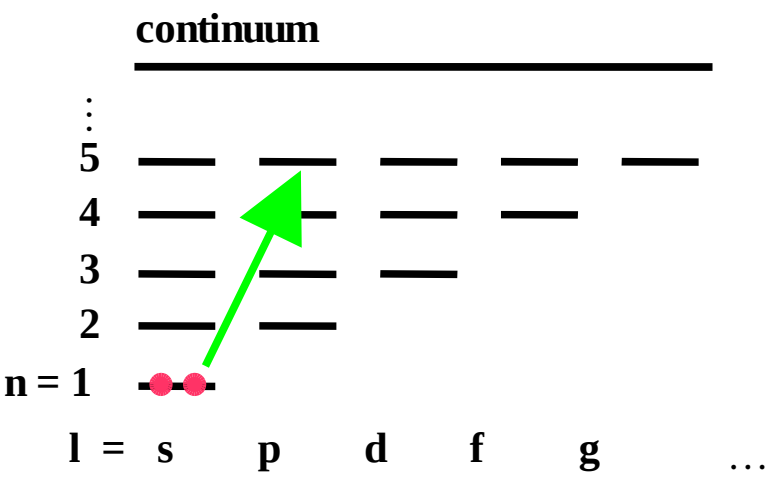
$$\boxed{\begin{aligned} & N_{z,i}\left(\sum_{j<i} A_{z,i}^{z,j} + \sum_{1\le k<z}\sum_{j} D_{z,i}^{z-k,j}\right) - \sum_{j>i} N_{z,j} A_{z,j}^{z,i} = C \\ & \frac{C_{z-1,g}^{z,i}}{C_{total}} \int n_{z,g}\left(\sum_{j} R_{z,g}^{z-1,j} + \sum_{j} R_{z,g}^{z,j} f_{z,j}^{D}\right) dVC \\ & + \int n_{z,g} R_{z,g}^{z,i} dV + \int n_{z+1,g} R_{z+1,g}^{z,i} dVC \end{aligned}}$$

$$\int n_{z,g} R_{z,g}^{z',j} dV = \frac{\Omega}{4\pi} G_z \int dE \left[\sigma^R\right]_{z,g}^{z',j}(E) L(E) \frac{1-e^{-\tau(E)}}{\tau(E)}$$

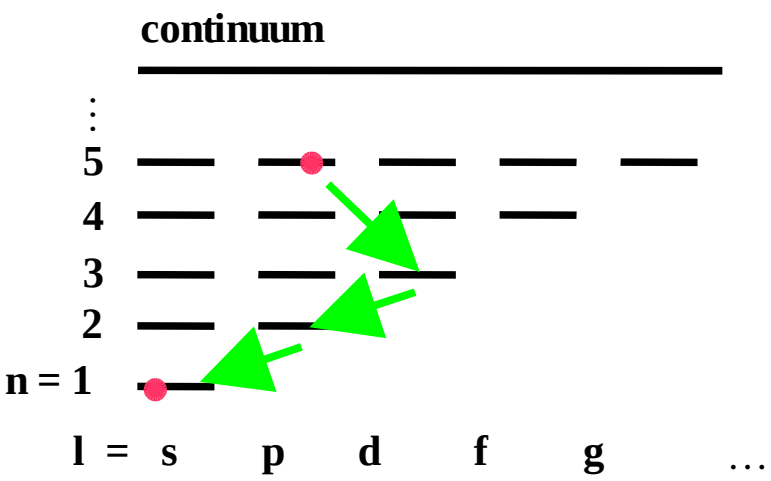
Photoionized Plasma

H- and He-like Ions

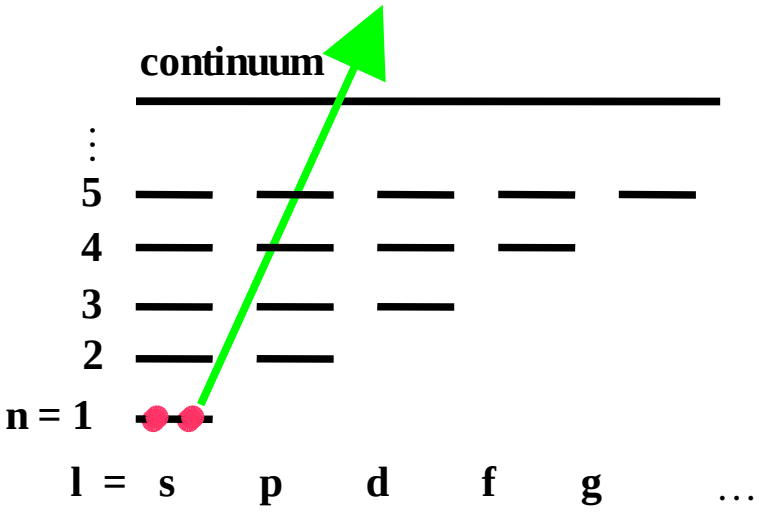
Photoexcitation



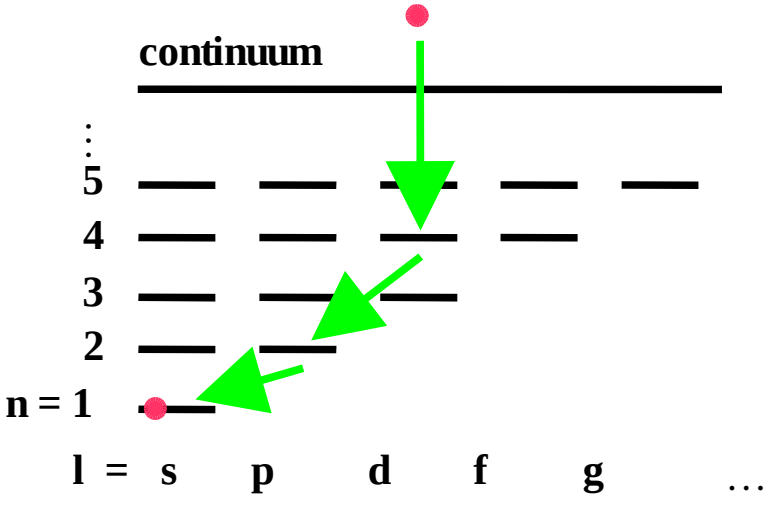
Radiative Decay

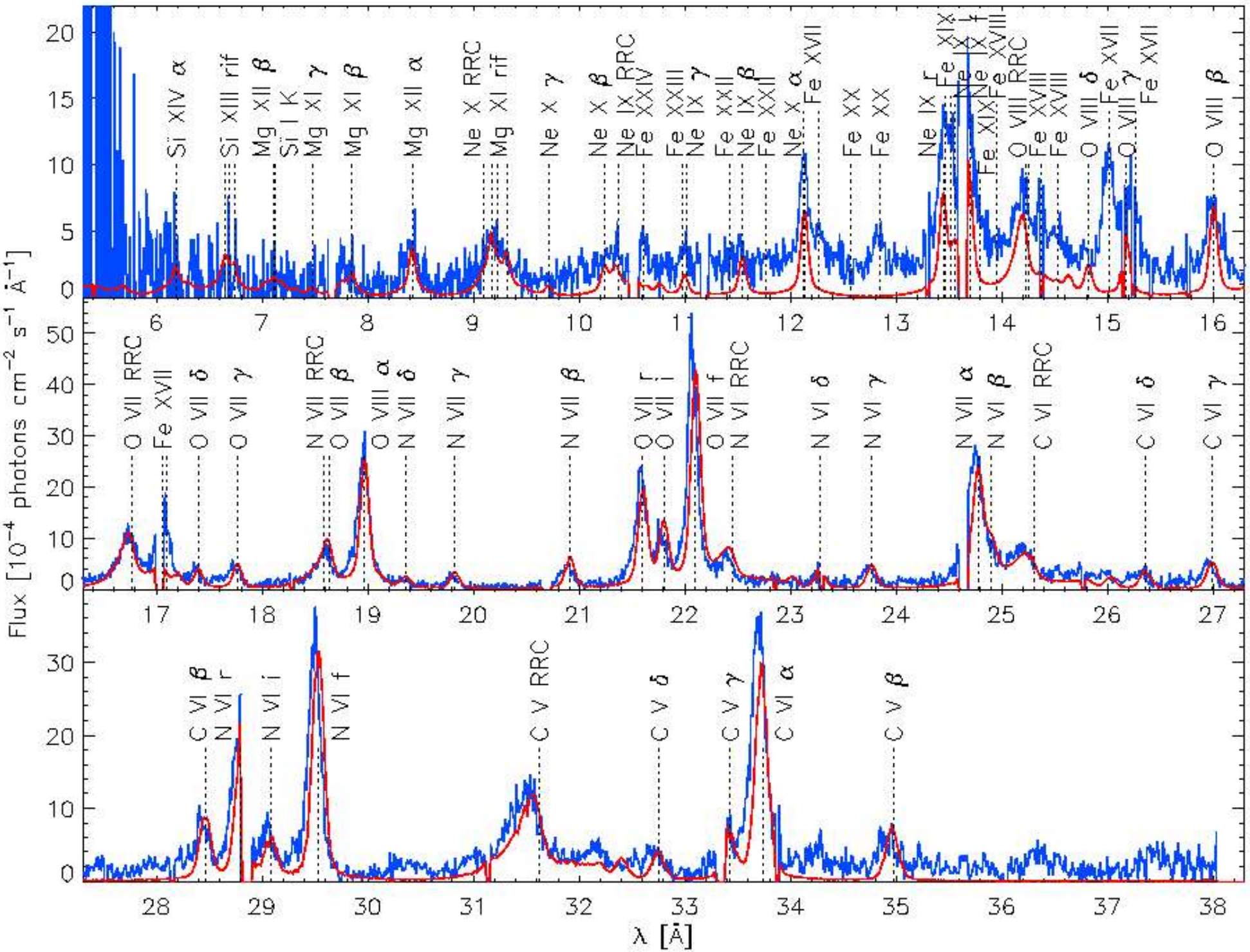


Photoionization



Recombination/ Radiative Cascade

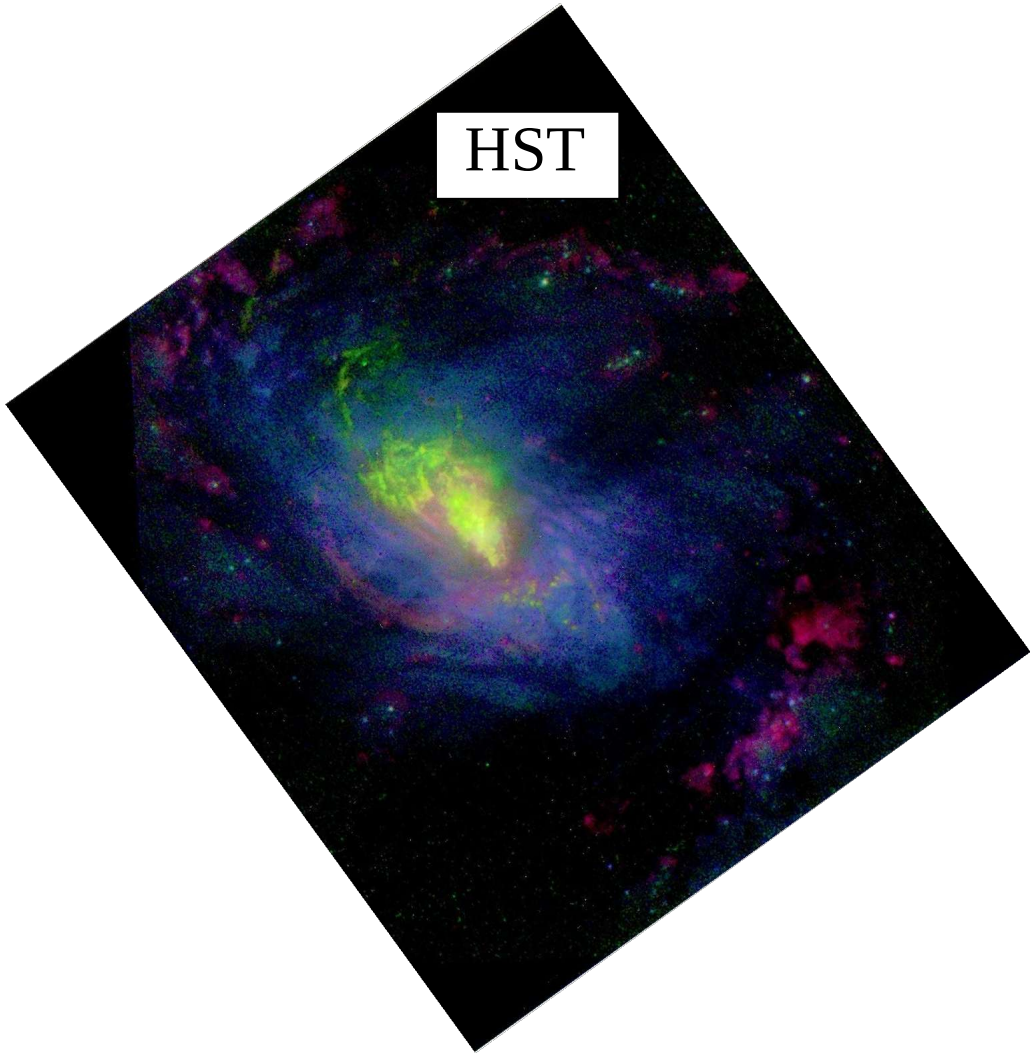




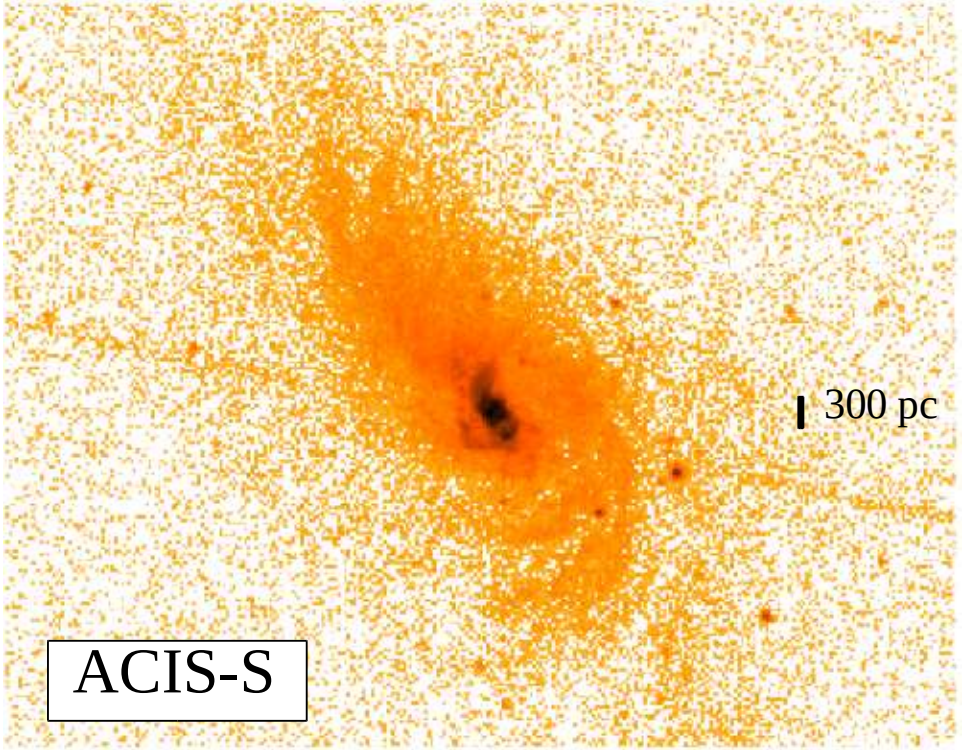
Flux [10^-4 photons cm^-2 s^-1 Å^-1]
λ [Å]
Si XIV α
Si XIII rif
Mg XII β
Si I K
Mg XI γ
Mg XI β
Mg XII α
Ne X RRC
Mg XI rif
Ne X γ
Ne X β
Ne IX RRC
Fe XXIV
Fe XXIII
Ne IX γ
Fe XXII
Ne IX β
Fe XXII
Ne X α
Fe XVII
Fe XX
Fe XX
Ne IX r
Fe XIX
Ne IX i
Ne IX f
Fe XIX
Fe XVIII
O VIII RRC
Fe XVIII
Fe XVIII
O VIII δ
Fe XVII
O VIII γ
Fe XVII
O VIII β
O VII RRC
Fe XVII
O VII δ
O VII γ
N VII RRC
O VII β
O VIII α
N VII δ
N VII γ
N VII β
O VII r
O VII i
O VII f
N VI RRC
N VI δ
N VI γ
N VII α
N VI β
C VI RRC
C VI δ
C VI γ
C VI β
N VI r
N VI i
N VI f
C V RRC
C V δ
C V γ
C VI α
C V β

Young et al. (2001)

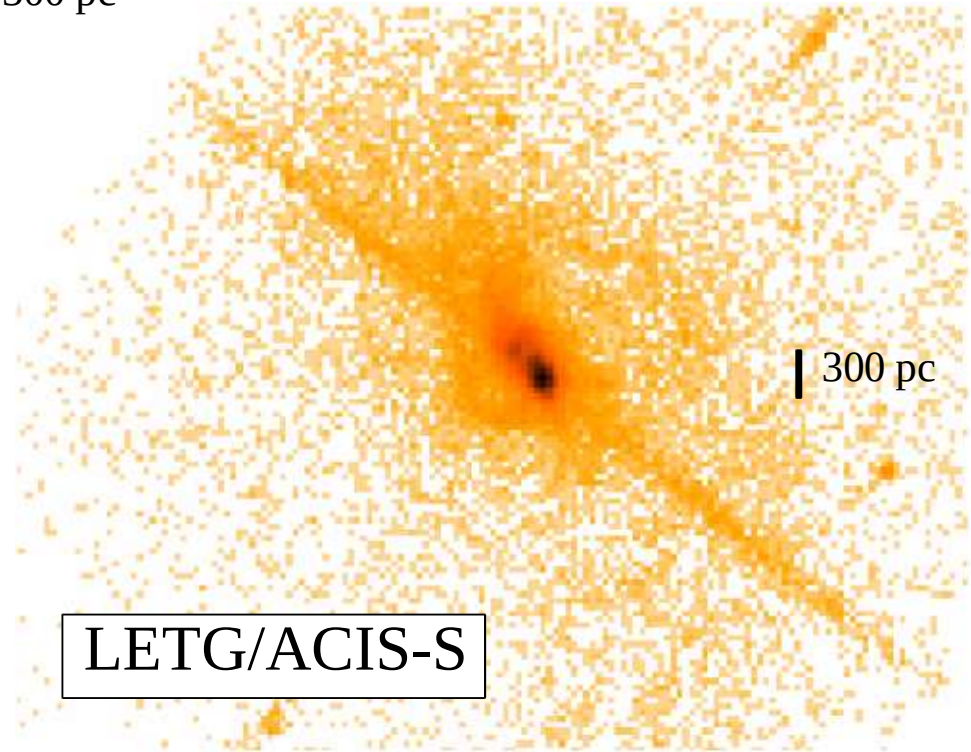
NGC 1068



Bruhweiler et al. (2001)

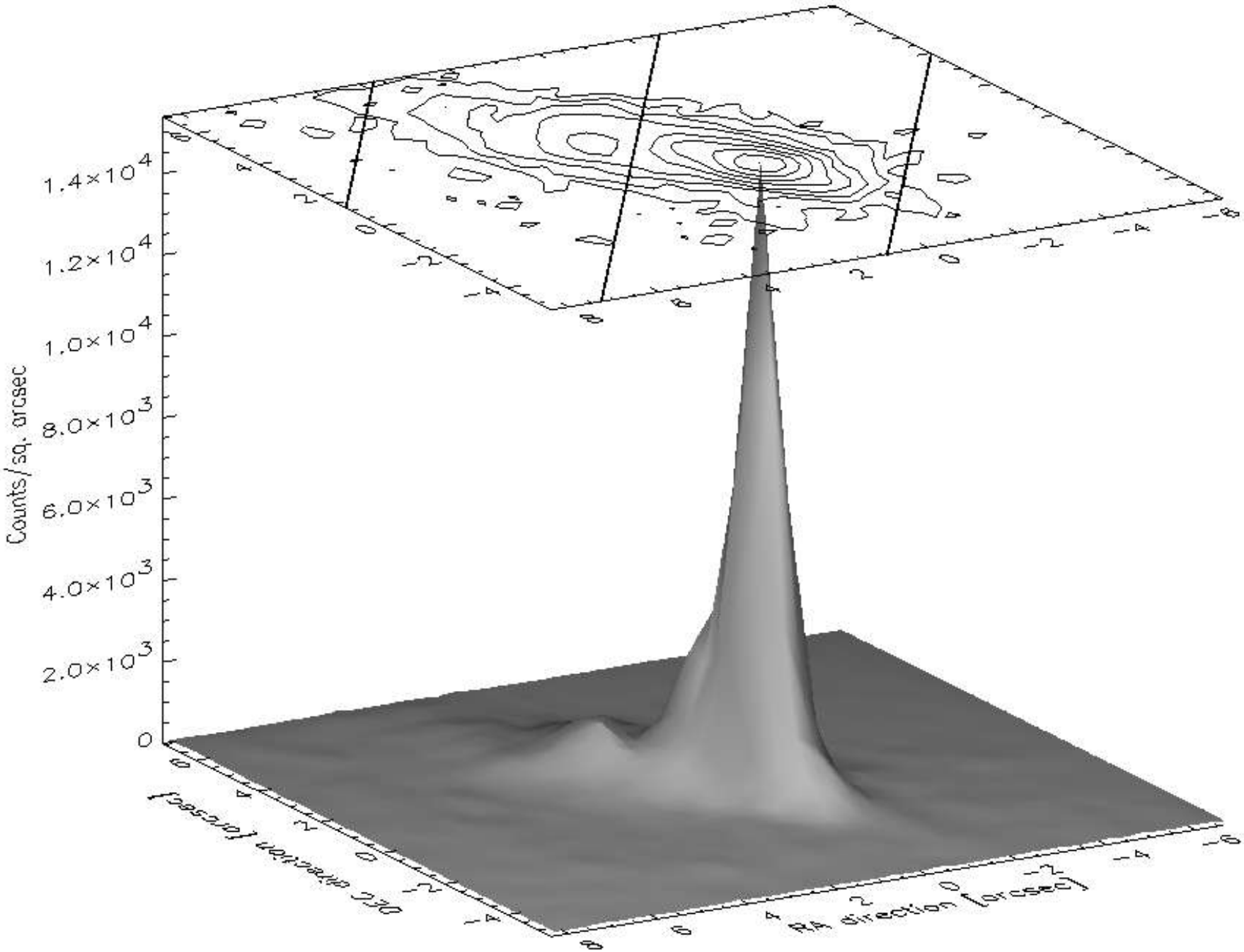


300 pc



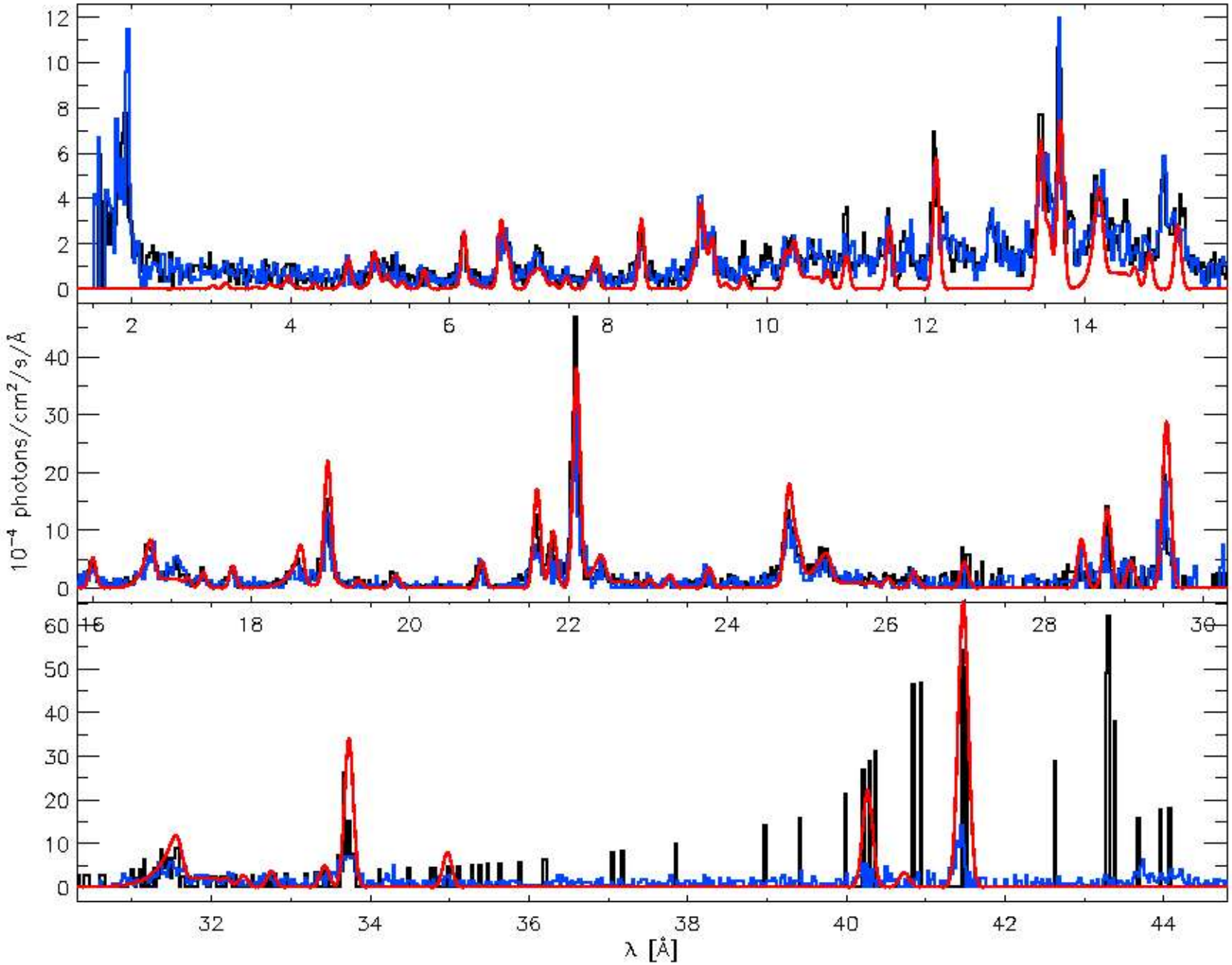
Brinkman et al. (2002)

Spatially-Resolved Spectroscopy



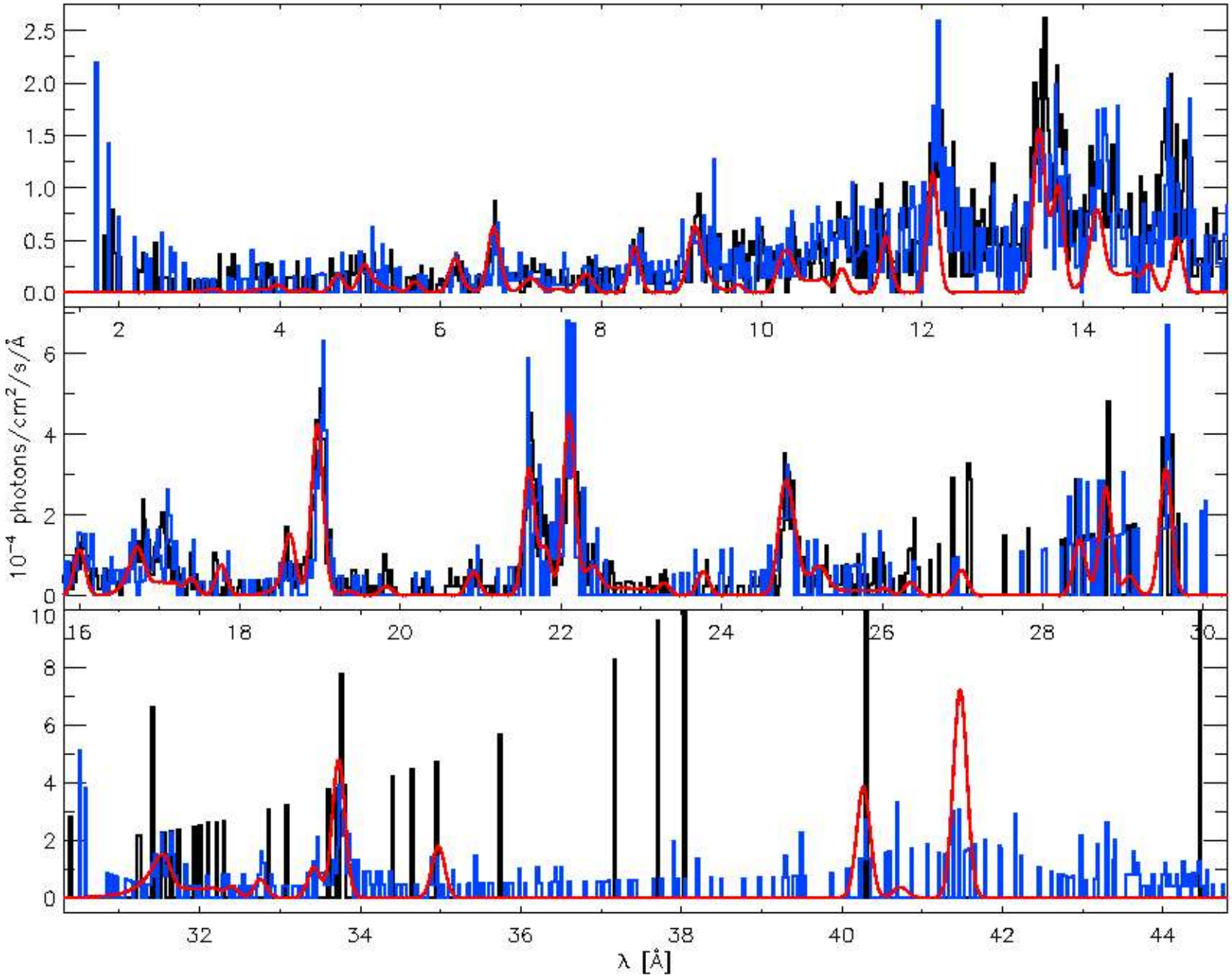
NGC 1068 (LETGS)

Primary



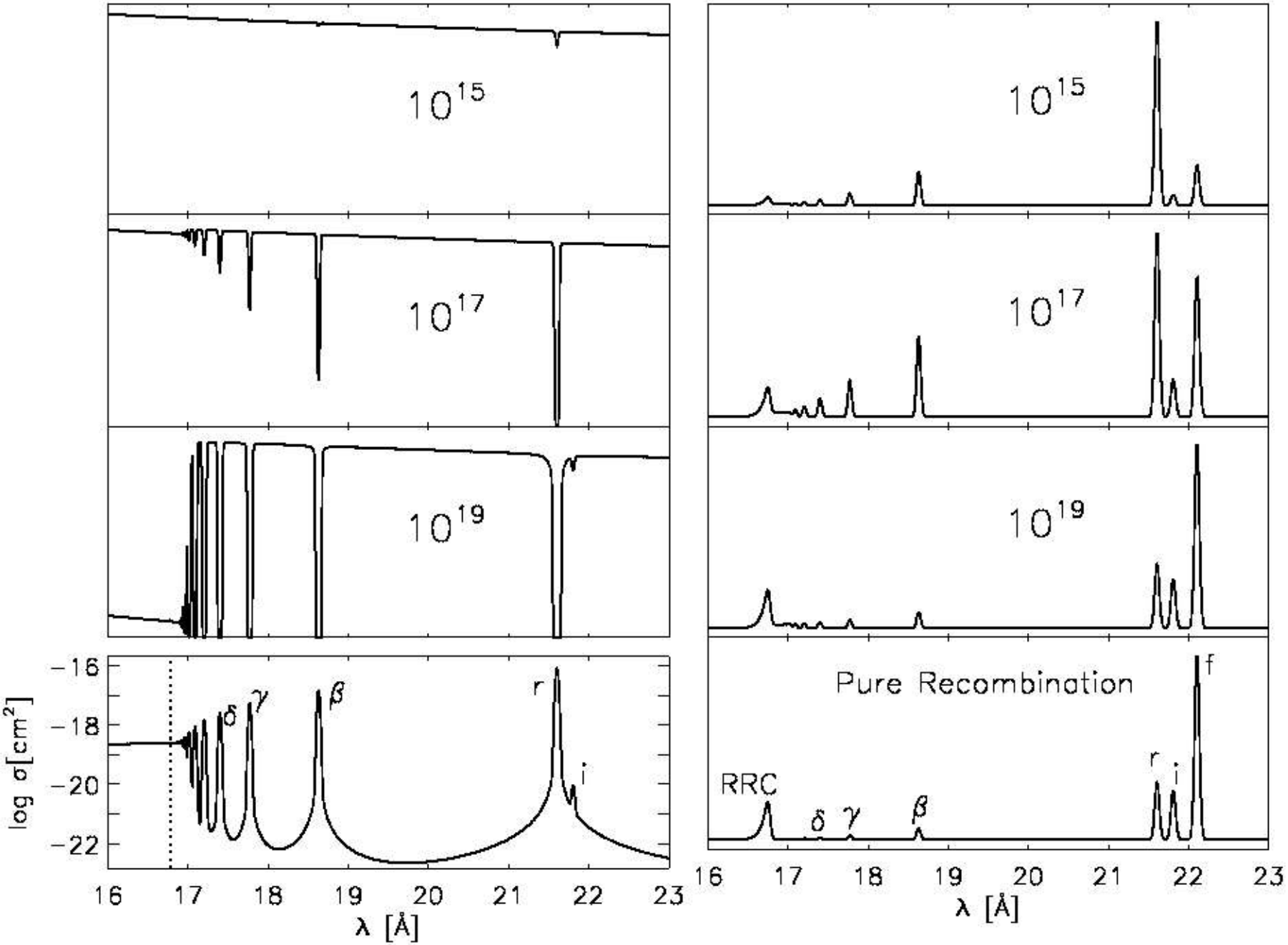
NGC 1068 (LETGS)

Secondary

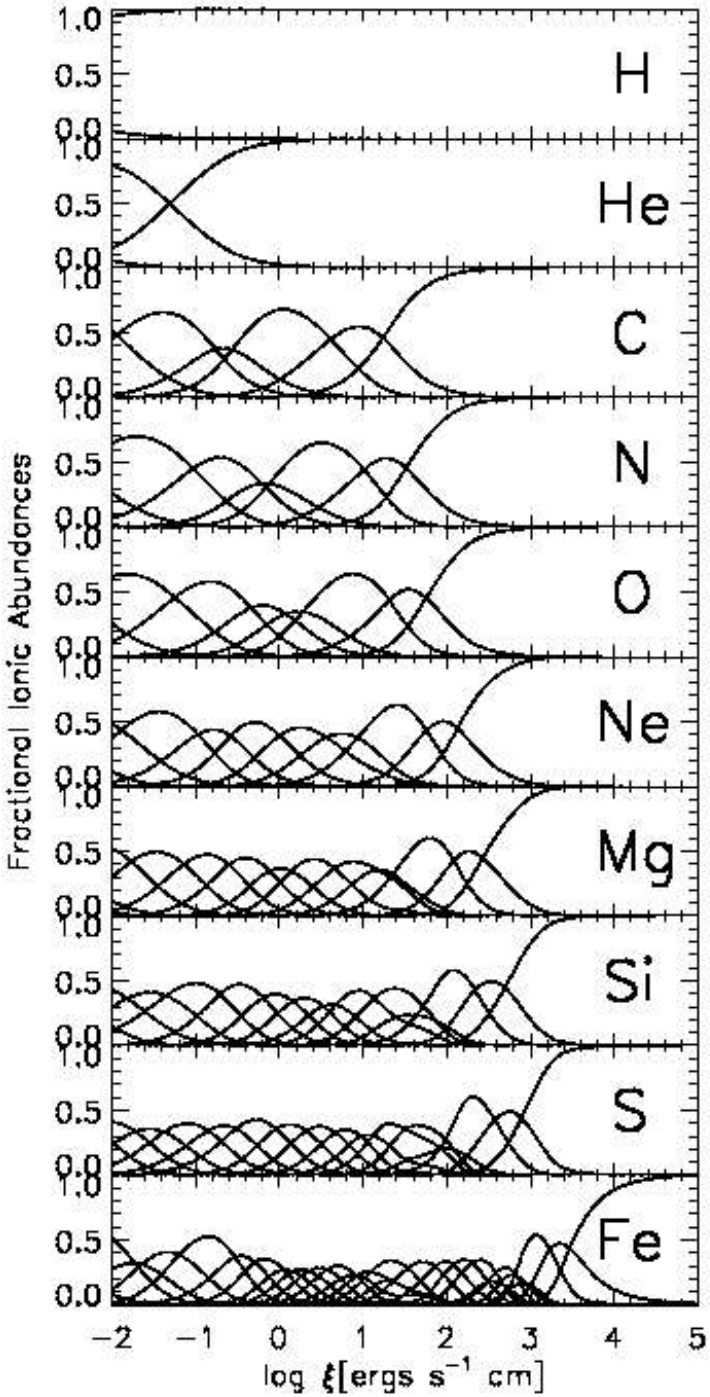


O VII: Column Density

Absorption **Reemission**



Ionic Distributions



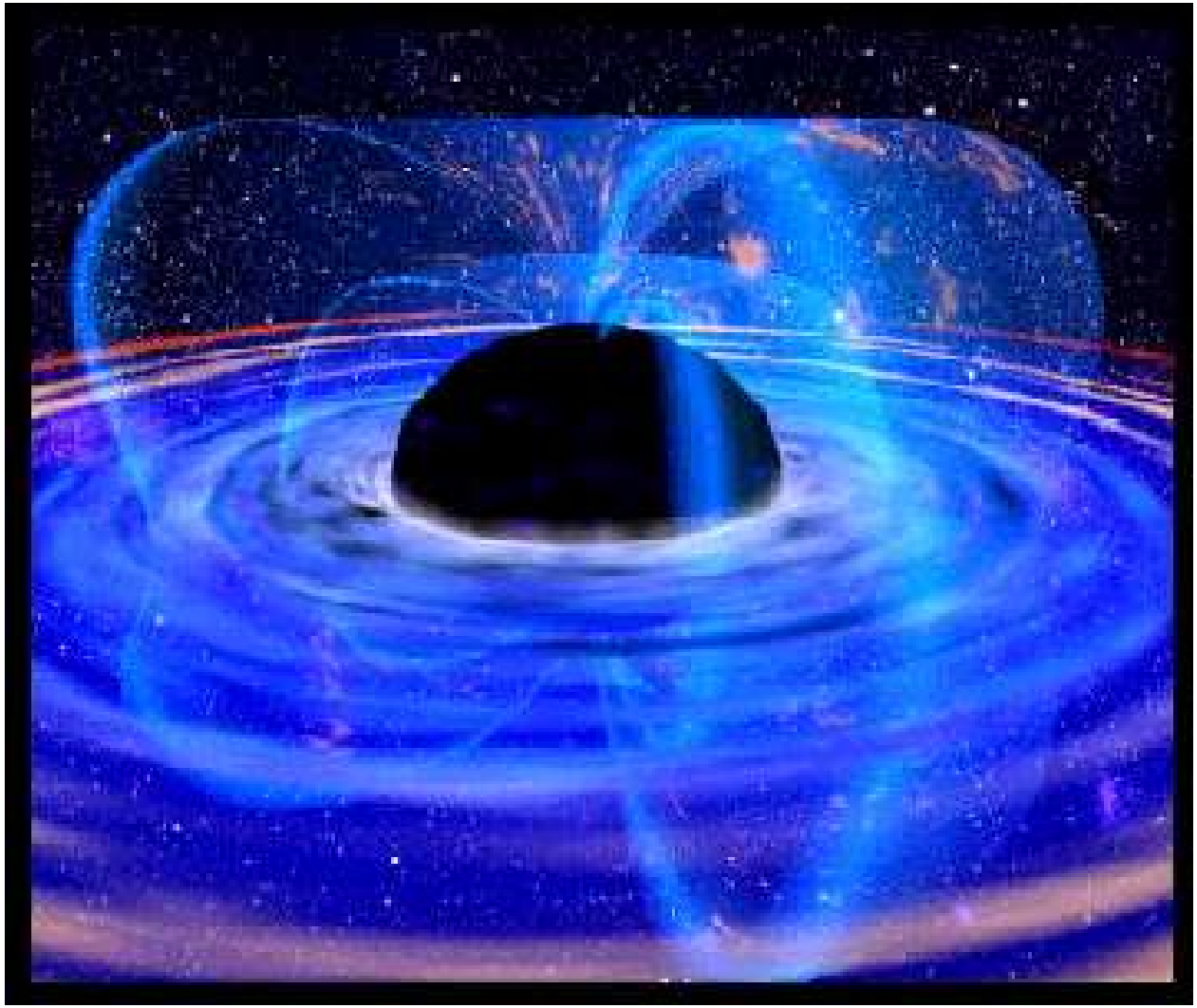
$$\xi = \frac{L}{nr^2}$$

Outline

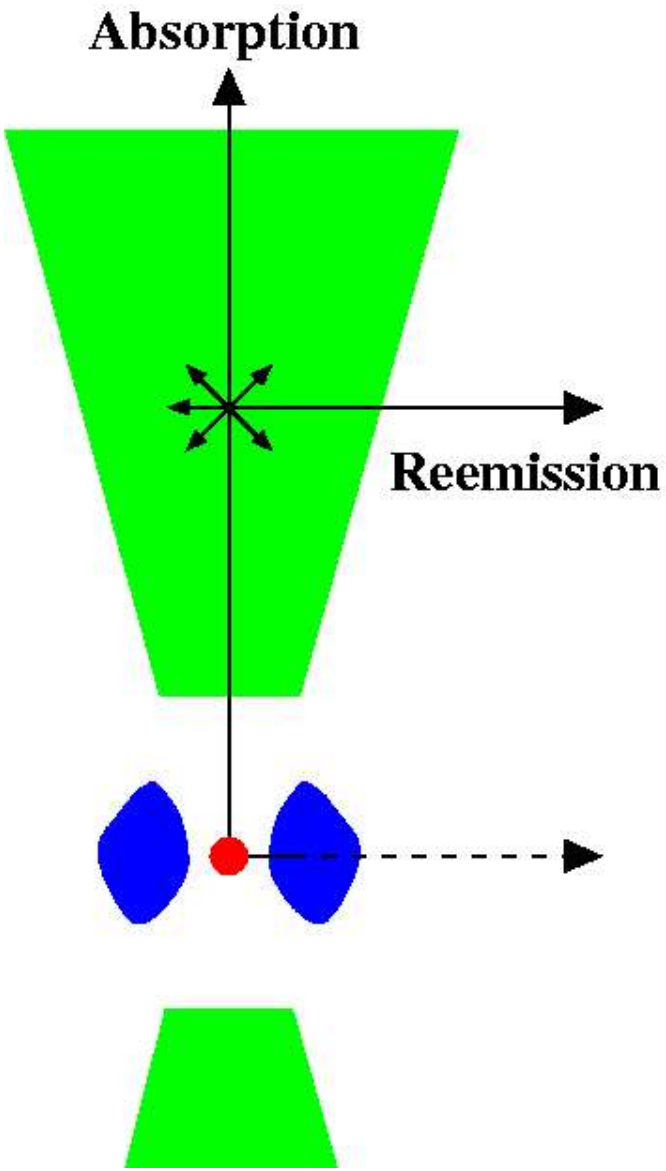
I. Reemission

II. Absorption

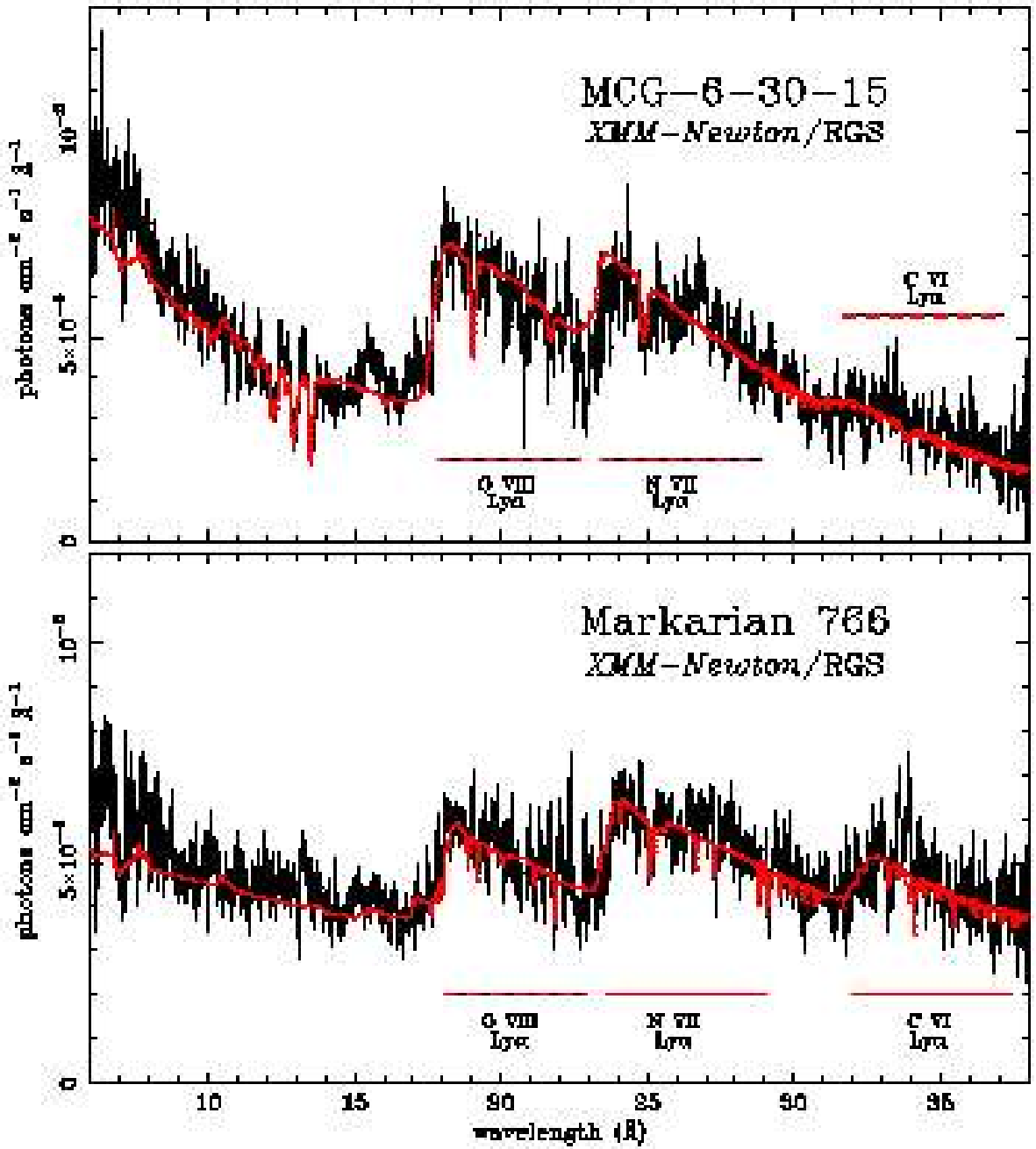
Relativistic Emission or Ionic Absorption?



vs.

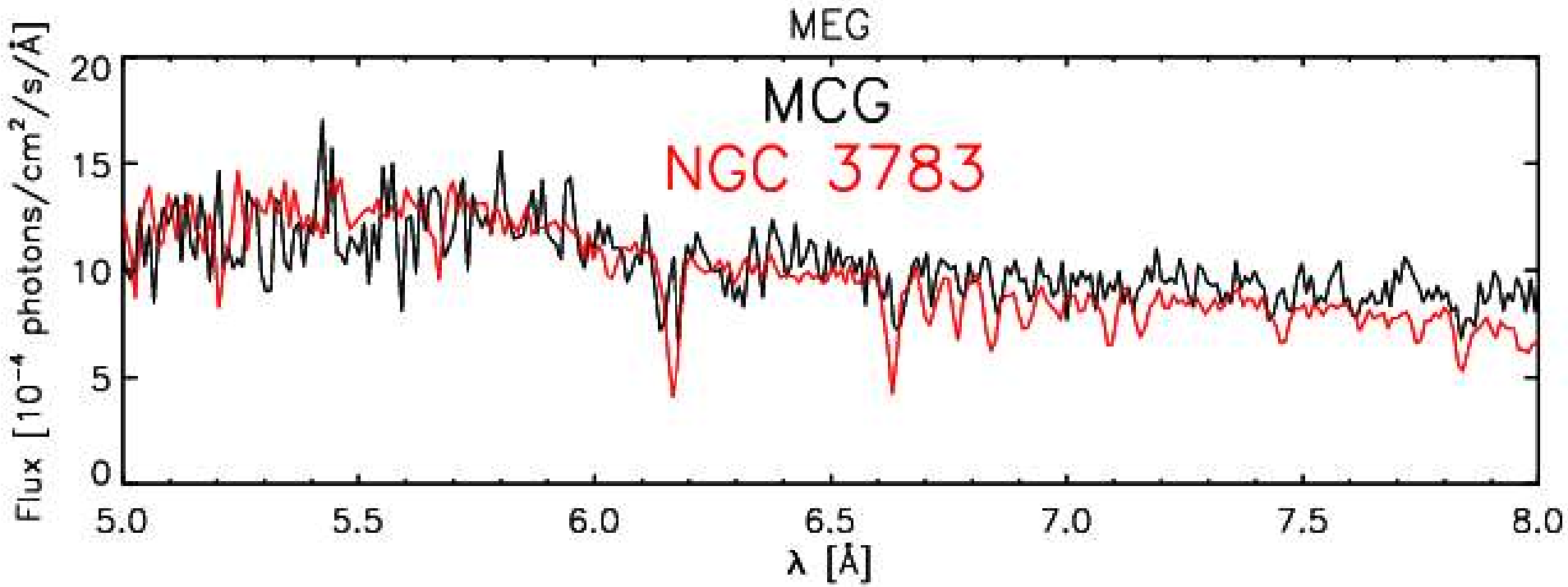


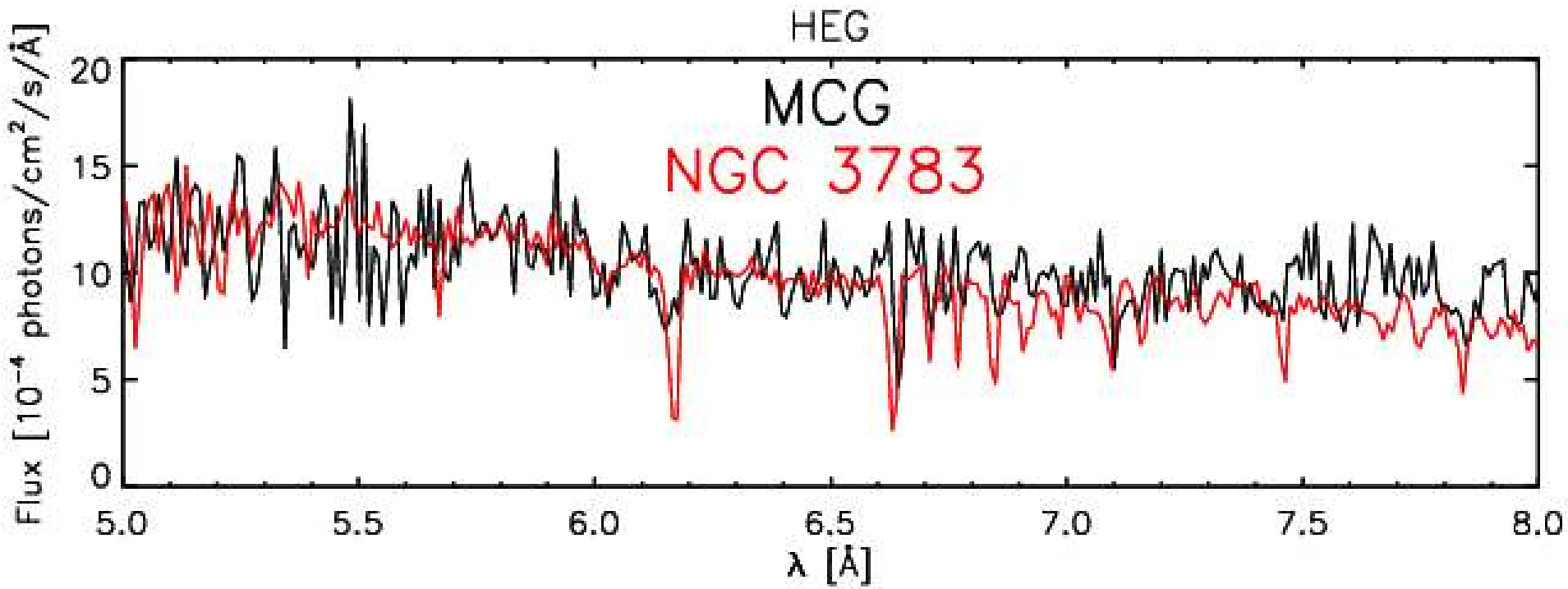
Relativistic line interpretation



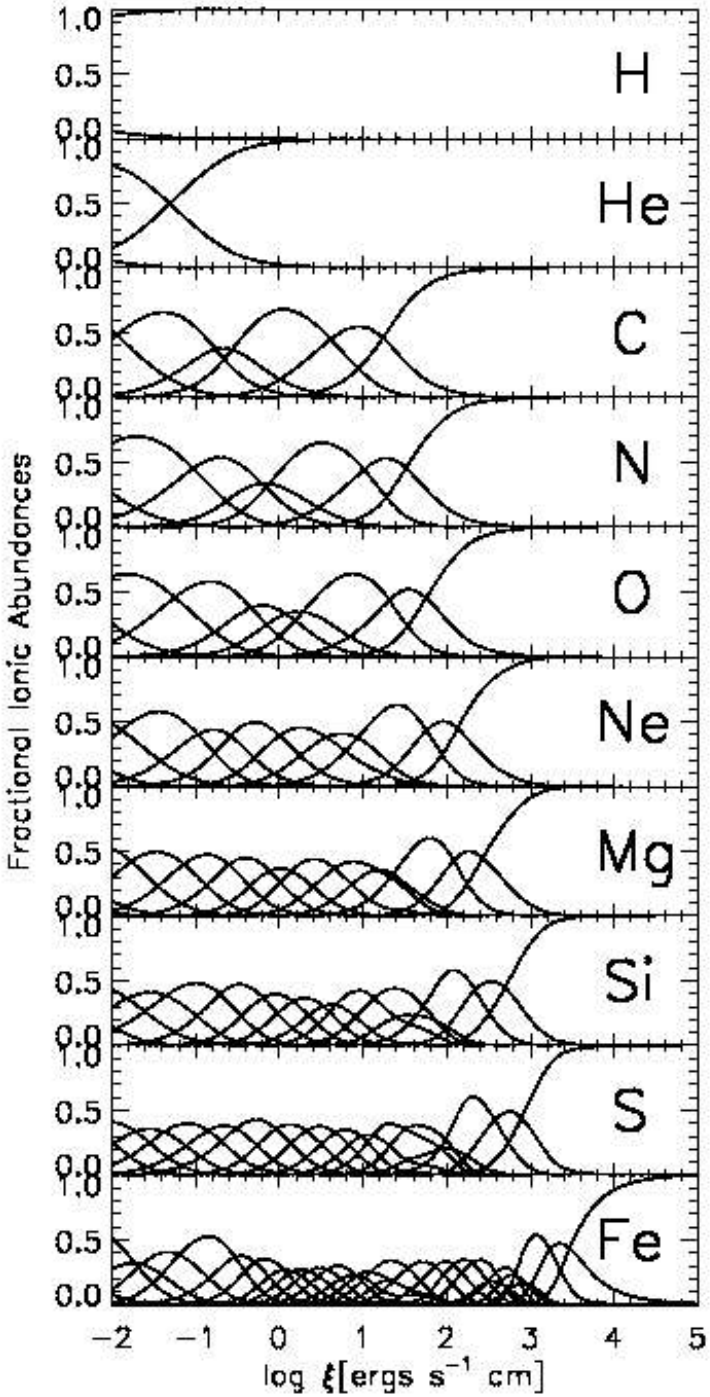
(Branduardi-Raymont et al. 2001)

Silicon


MEG
MCG
NGC 3783
Flux [10^{-4} photons/cm^2/s/Å]
λ [Å]
0
5
10
15
20
5.0
5.5
6.0
6.5
7.0
7.5
8.0

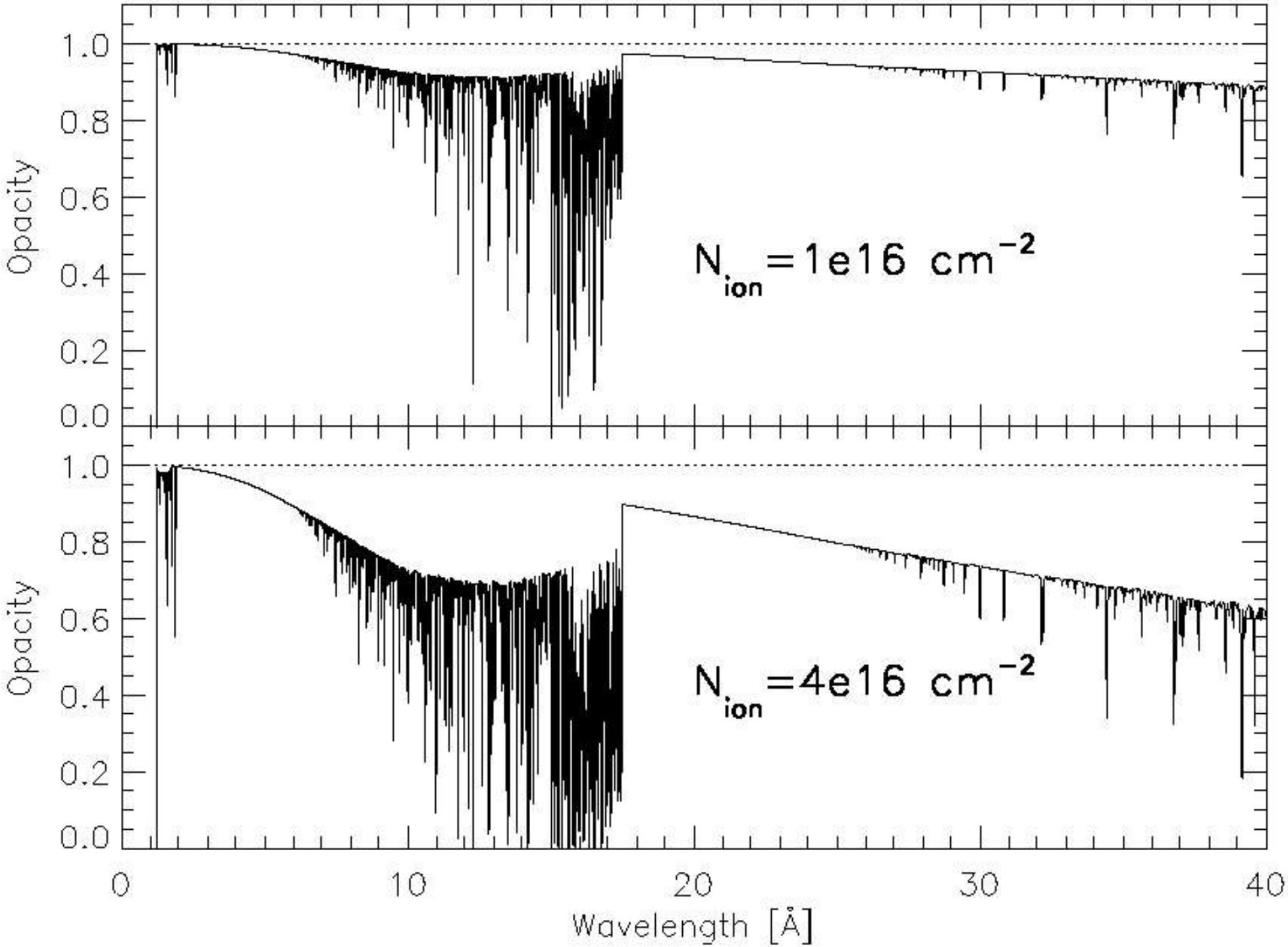

HEG
MCG
NGC 3783
Flux [10^{-4} photons/cm^2/s/Å]
λ [Å]
0
5
10
15
20
5.0
5.5
6.0
6.5
7.0
7.5
8.0

Ionic Distributions

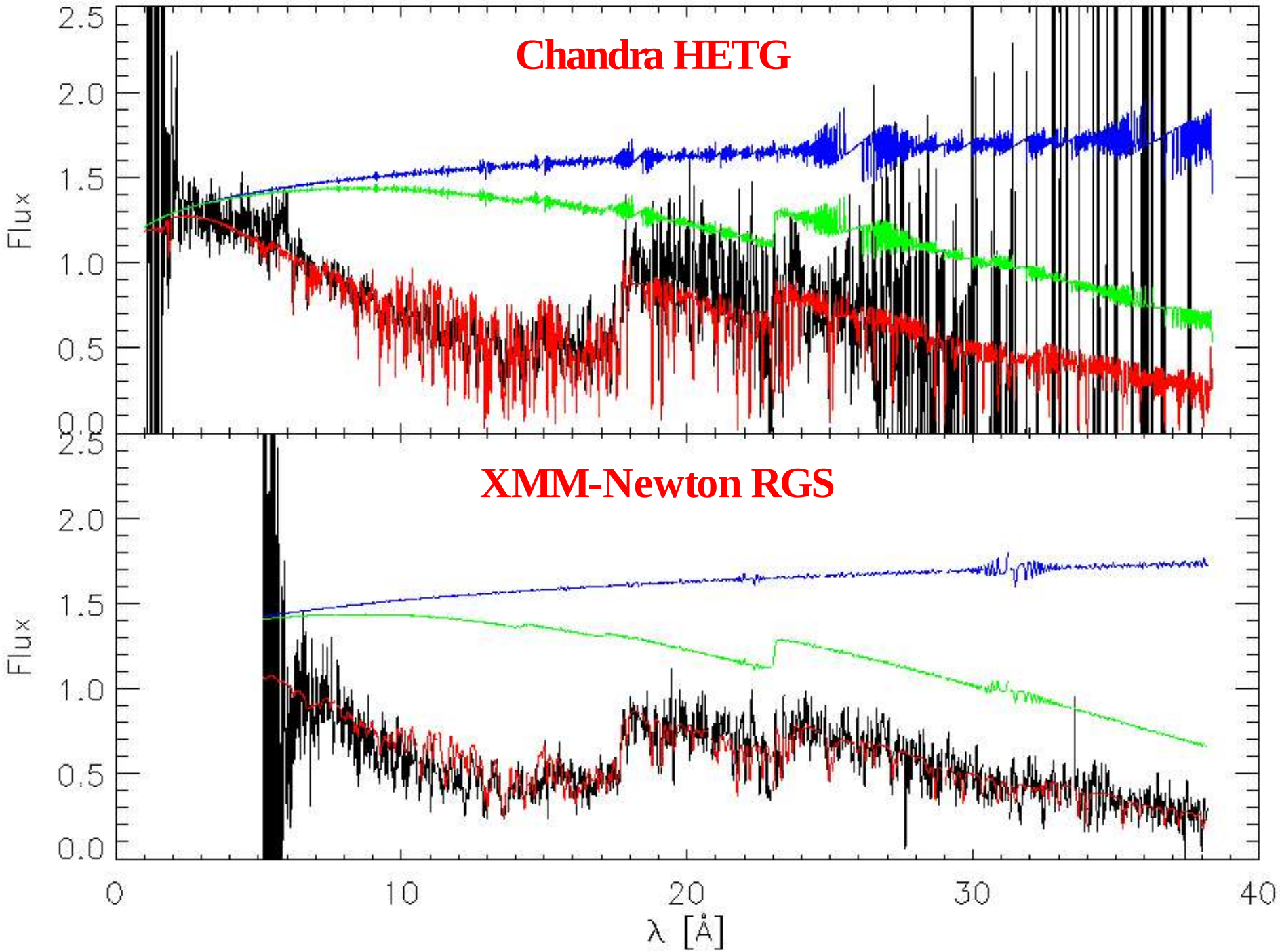


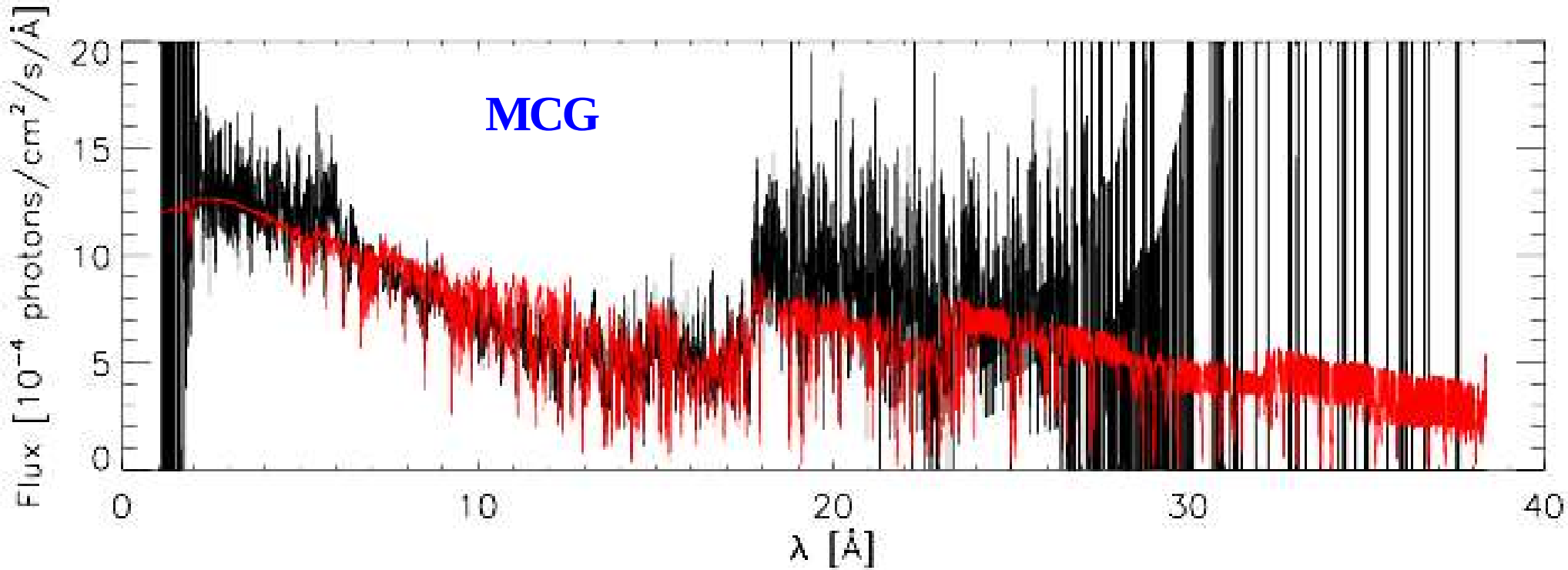
$$\xi = \frac{L}{nr^2}$$

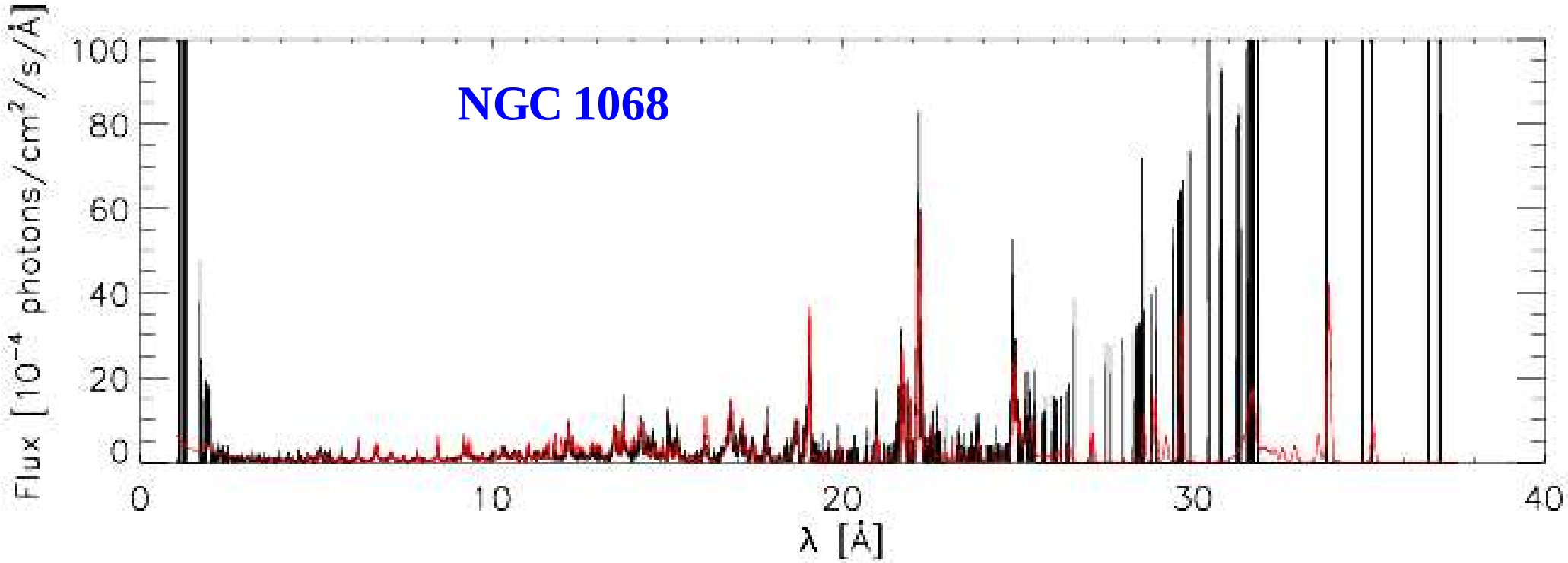
Iron Opacity



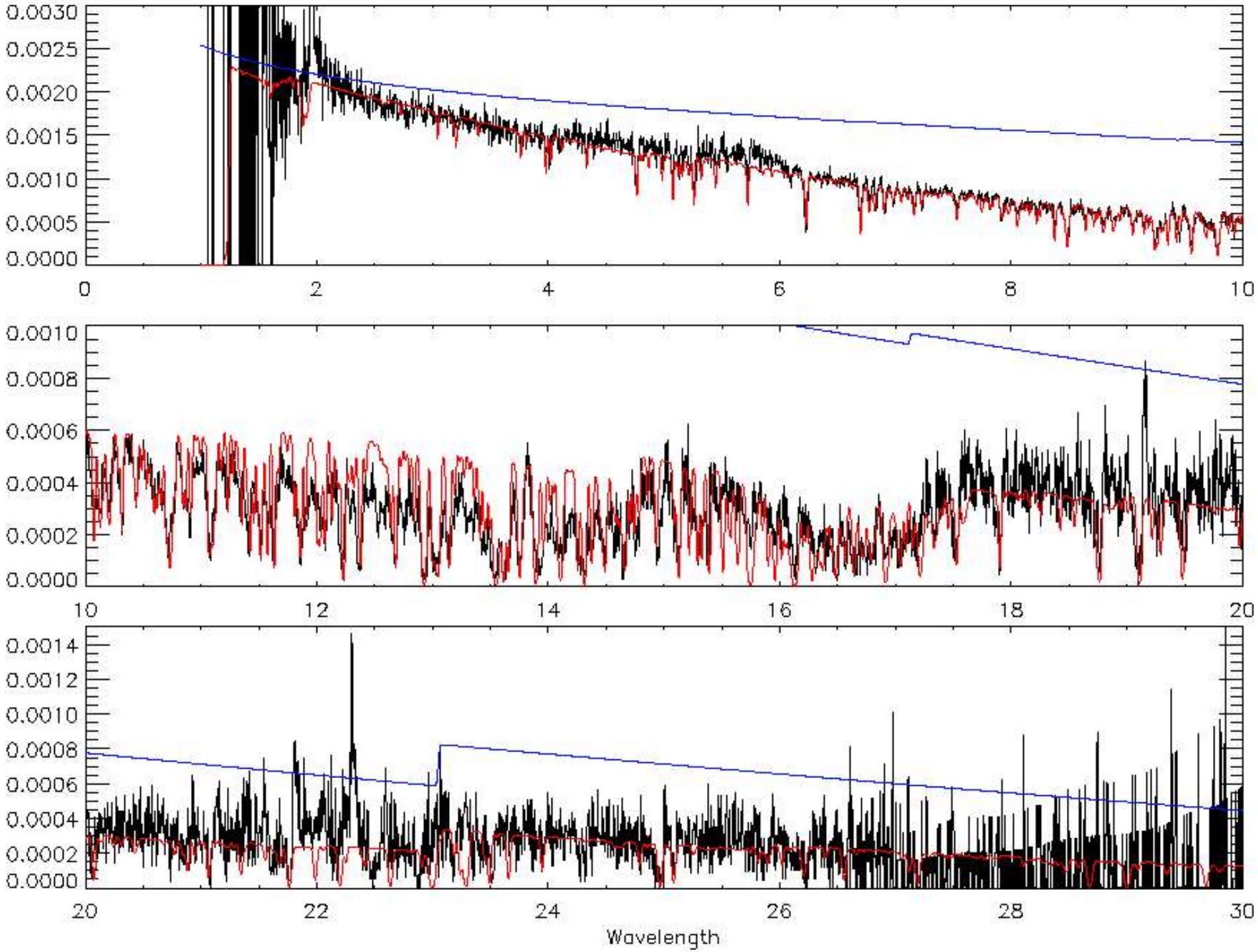
MCG: Pure Absorption



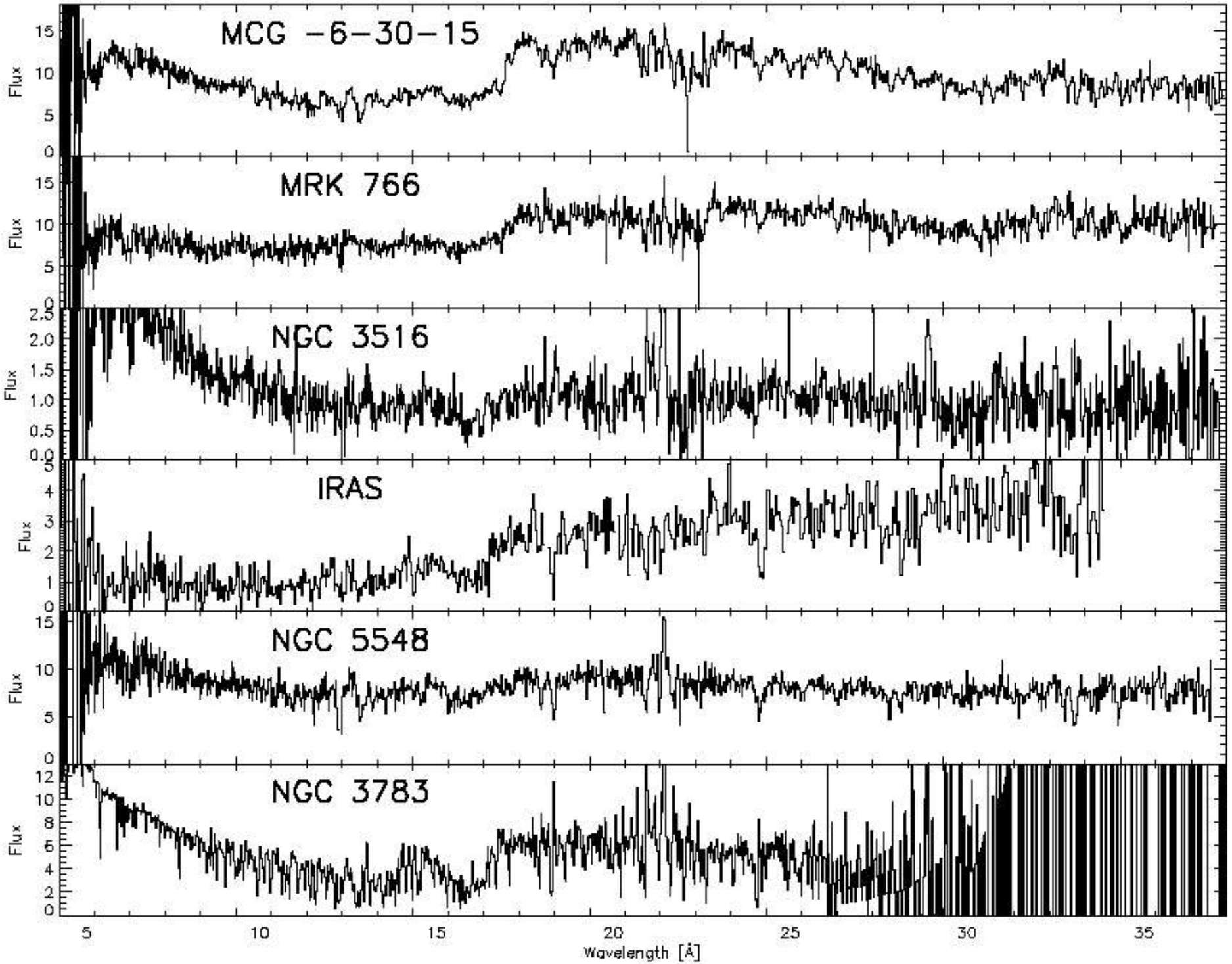

MCG
Flux [10^{-4} photons/cm^2/s/Å]
λ [Å]
0
5
10
15
20
0
10
20
30
40


NGC 1068
Flux [10^{-4} photons/cm^2/s/Å]
λ [Å]
0
20
40
60
80
100
0
10
20
30
40

NGC 3783


0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
0
2
4
6
8
10
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
10
12
14
16
18
20
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
20
22
24
26
28
30
Wavelength

Seyfert 1 Galaxies



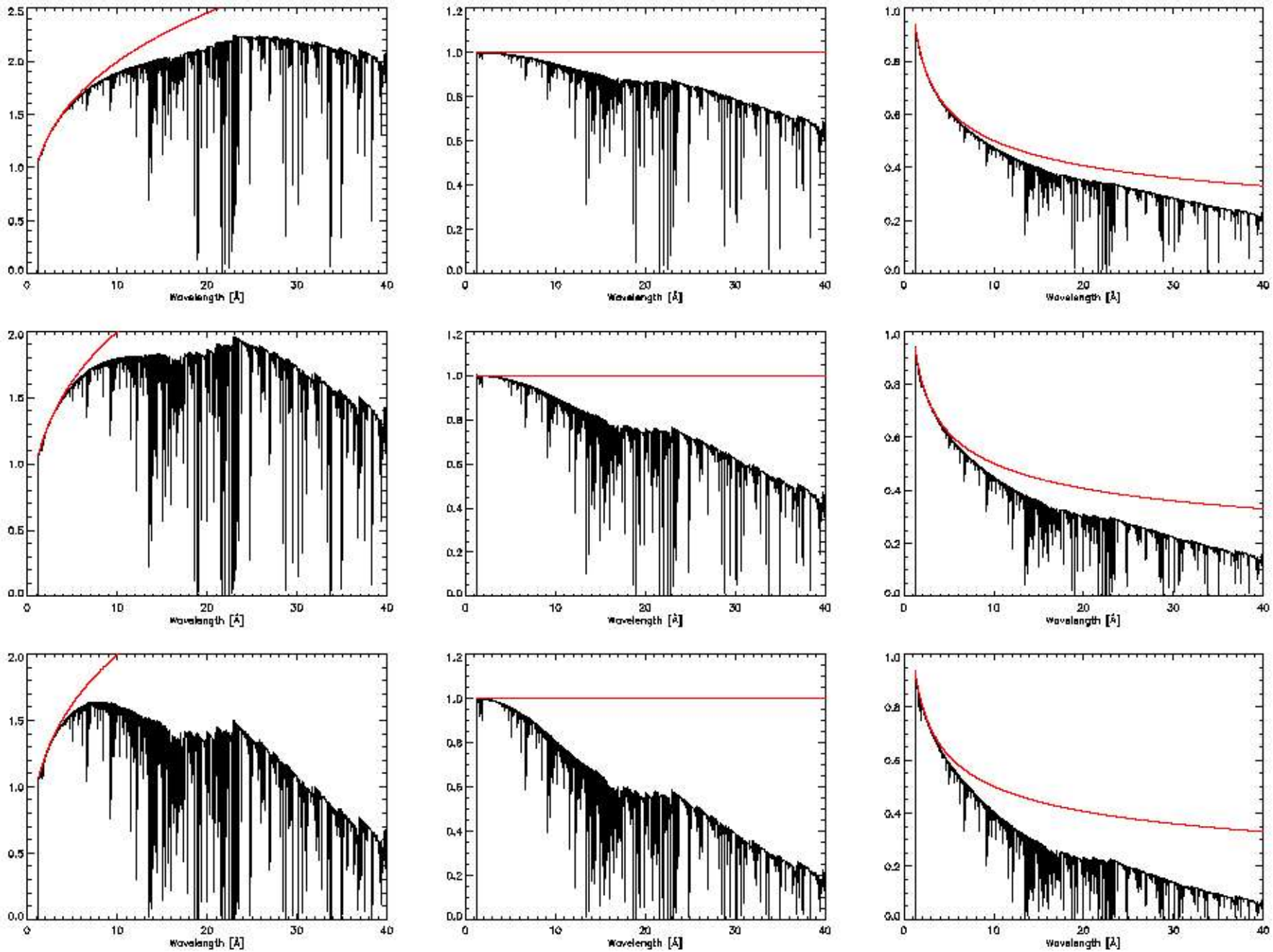
Flat ionization distribution: log = -3 to 5

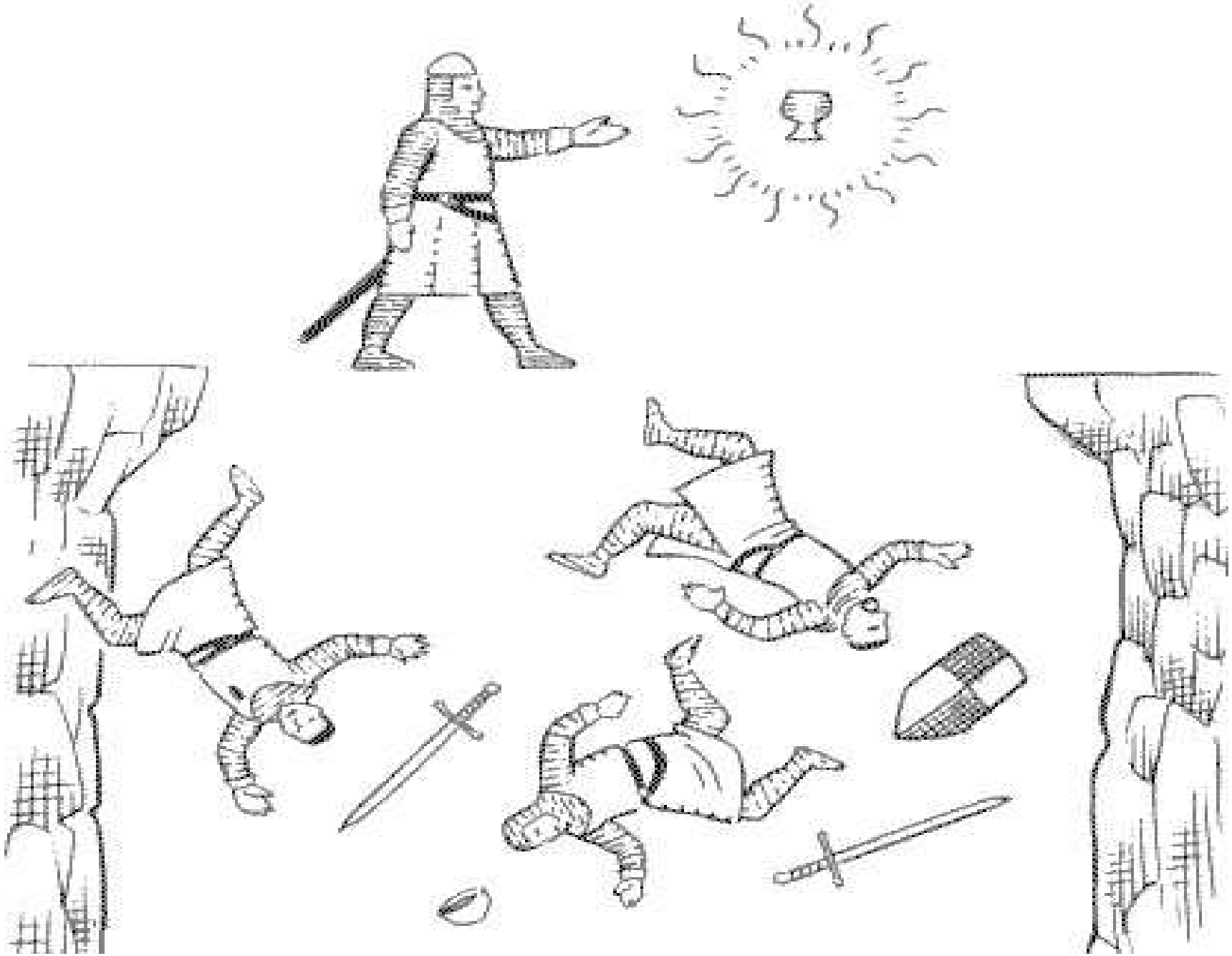
=2.3 =2.0 =1.7

N_H=1e21

N_H=2e21

N_H=4e21





XSPEC models:

PHOTOION, PHSI, PHXI, MIABS, SIABS, XIABS, ADDEXT, MULEXT, TAUEXT

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