Physics and phenomenology of Active Galactic Nuclei in X-rays and ultra-violet

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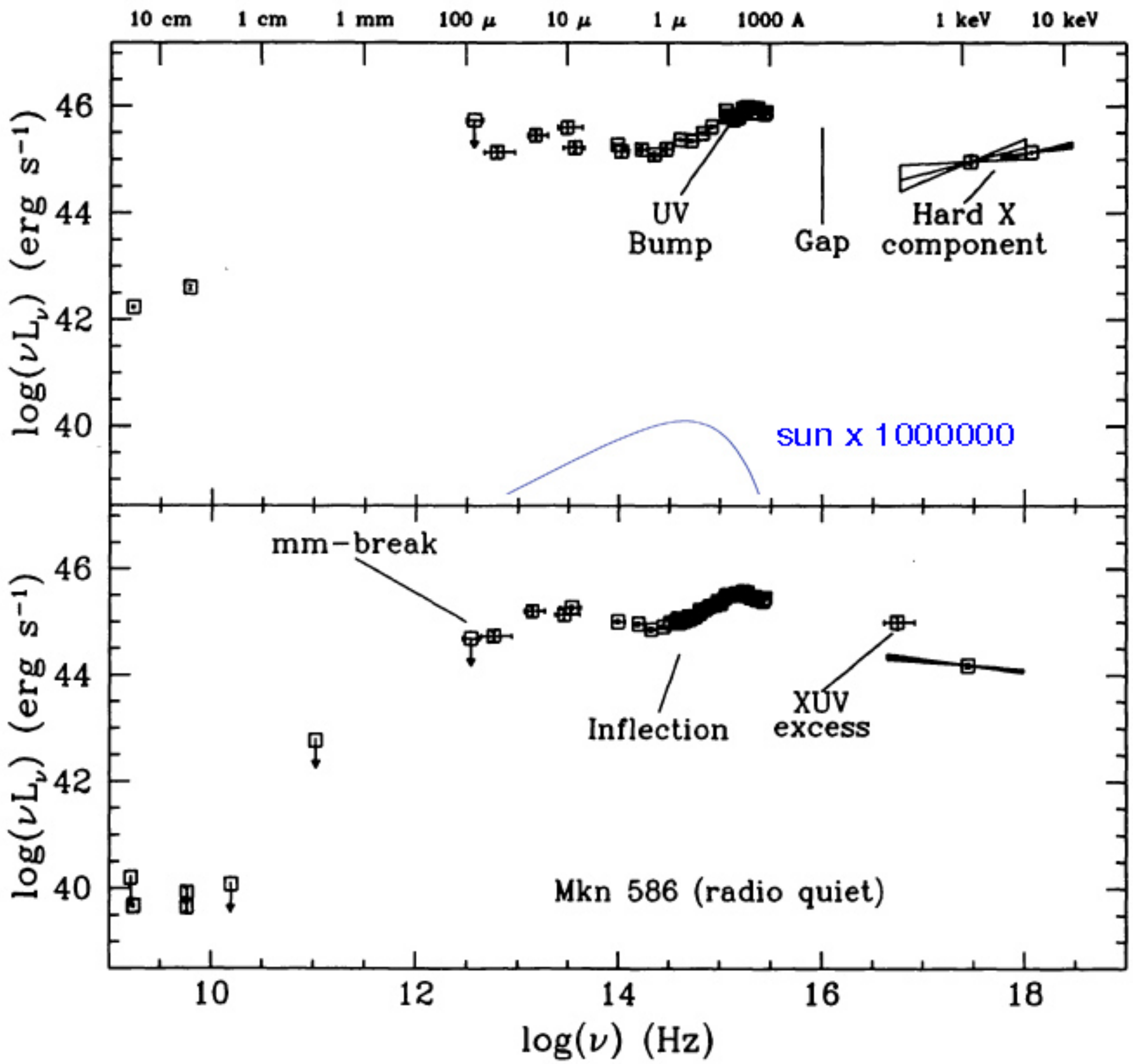
- Intro
- Classical spectra
- UV
- Warm absorbers

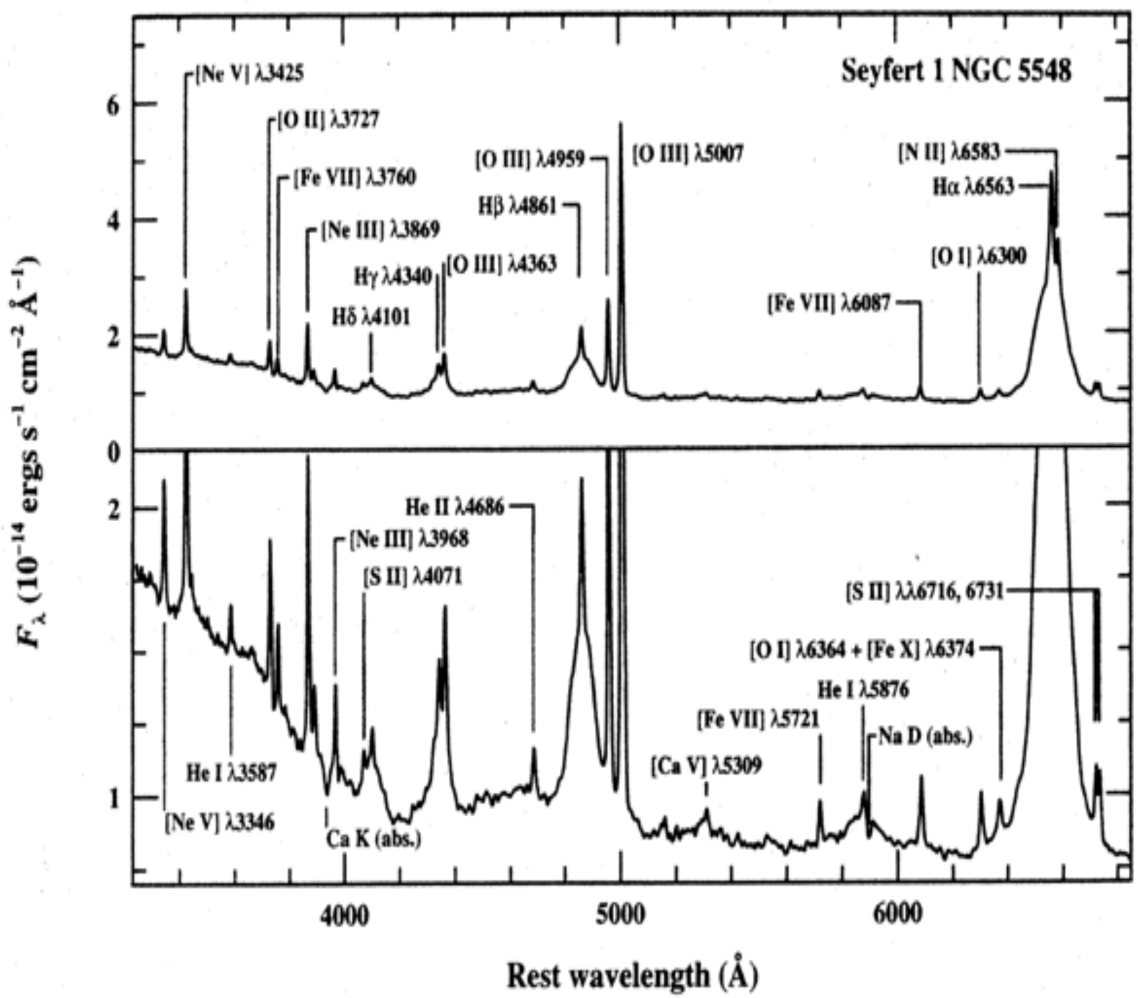
The broad-band spectrum of active galaxies

- ~flat over 6-8 decades
- Very different from stars
- Most are strong X-ray sources

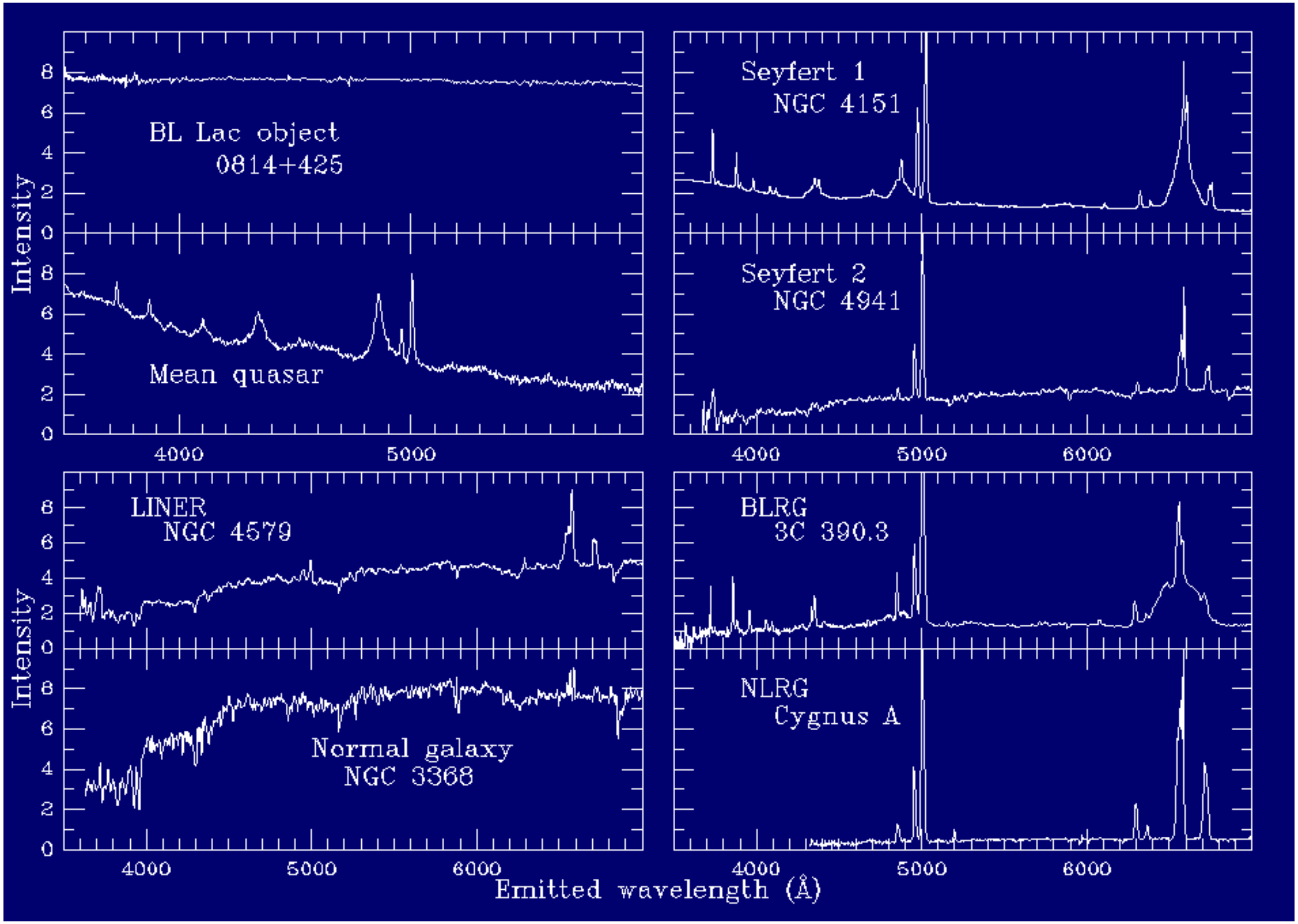


Active Galaxies can be classified by their optical spectra

- Emission lines divide into
  - Broad (v>1000 km/s) primarily permitted lines
  - Narrow (v<1000 km/s) includes forbidden lines
- Forbidden line strengths constrain broad line density, size
- A lot of gas is moving around; where is it going?



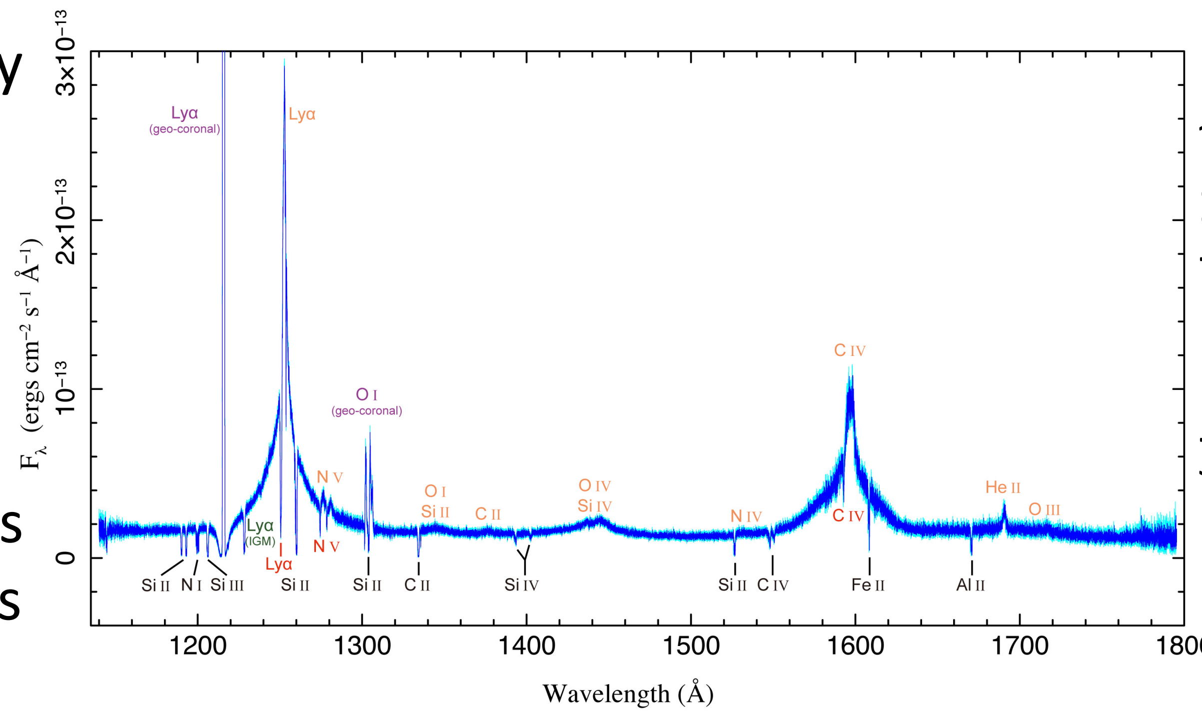
There is a range of line properties for different types of AGN



UV spectra are even more spectacular

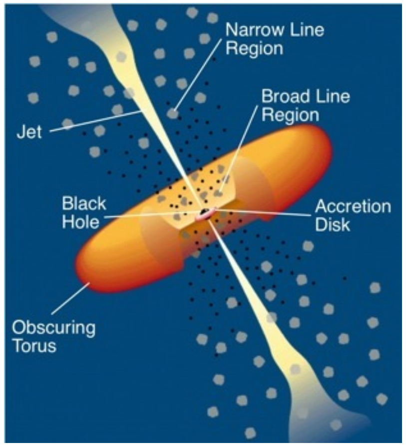
- Line profiles are very smooth
- Lines from diverse ionization stages have very similar profiles
- Warm absorber lines and foreground lines are narrow, superimposed on emission

HST/COS spectrum of Mkn 290

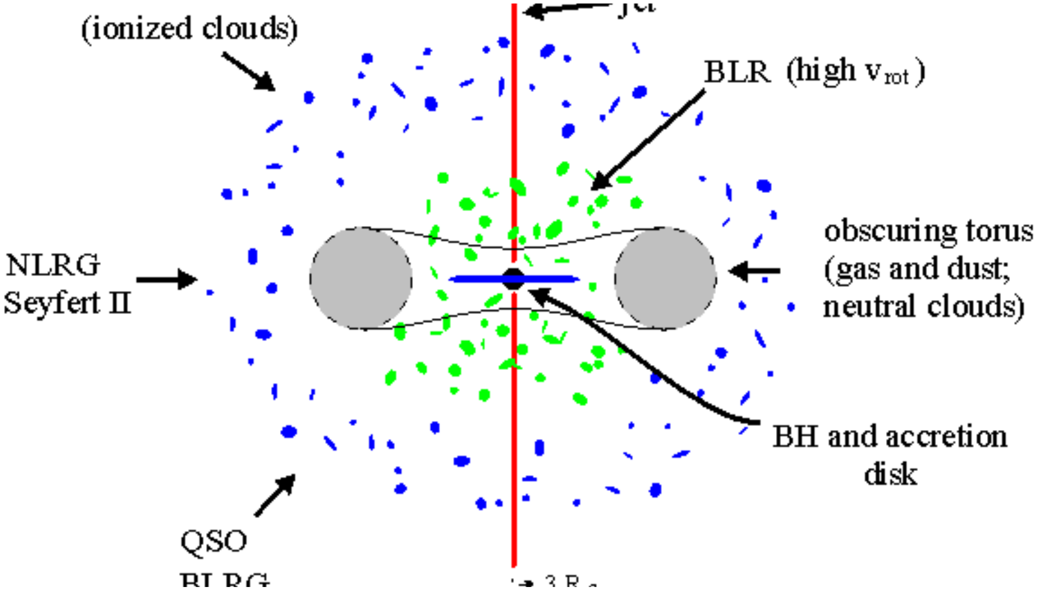


(Zhang et al. 2015)

Similarities in the line profiles lead to a very simple model



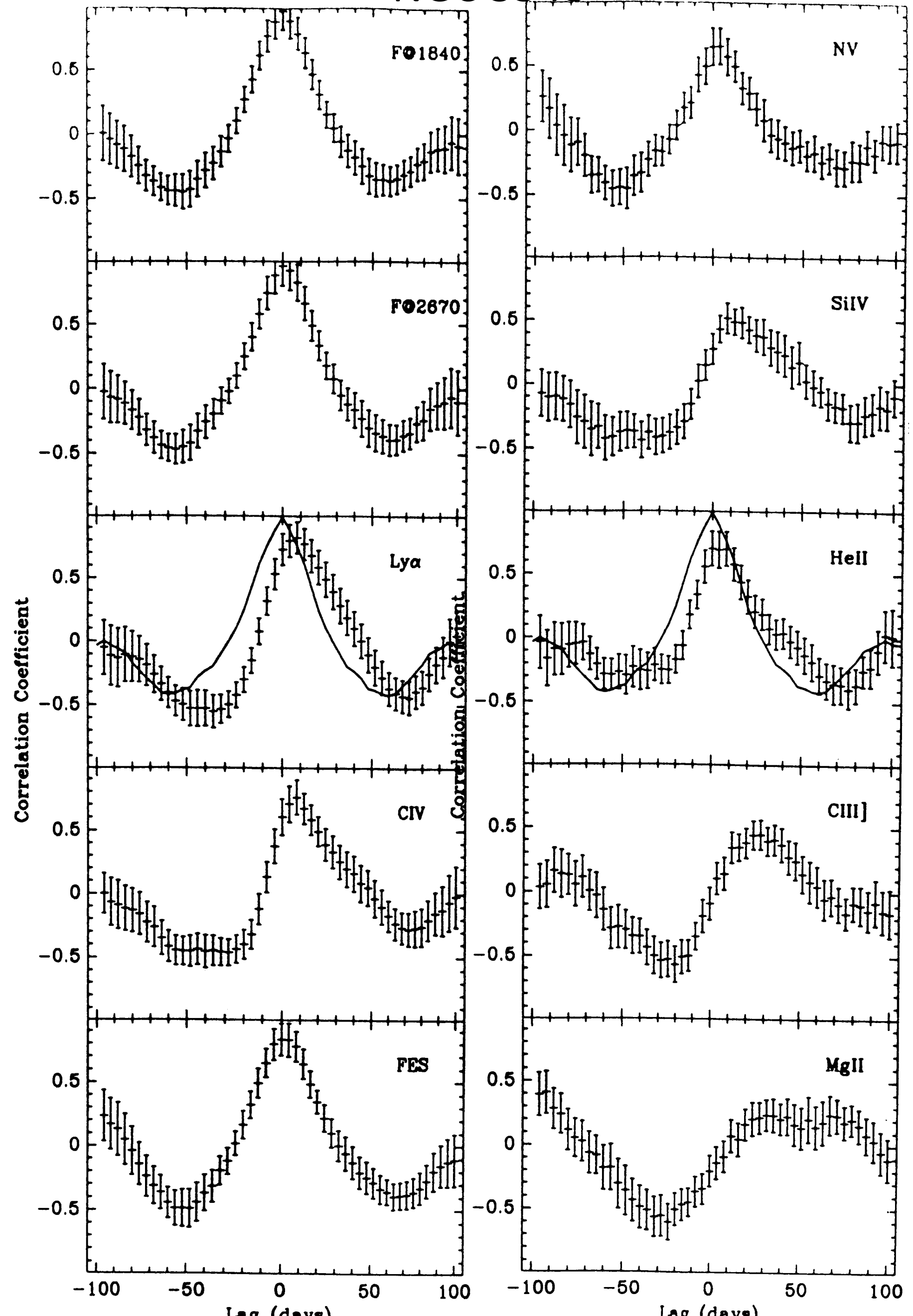
- Clouds radiate in all lines owing to ionization stratification within a cloud
- Very large numbers of small clouds are implied
- Small filling factor
- Clouds are ~spherically distributed around center
- Cloud velocities are ~isotropic



Cross correlation coefficients lines vs. uv continuum

- → Cross correlation coefficients are not the same for all lines
- shorter lags for high ionization lines
- smaller correlation for low ionization lines
- continuum shows no obvious wavelength dependence → disk?
- → and how can single population of clouds explain this?
- If there is a distribution of conditions, what determines it?
- Why is it apparently universal?

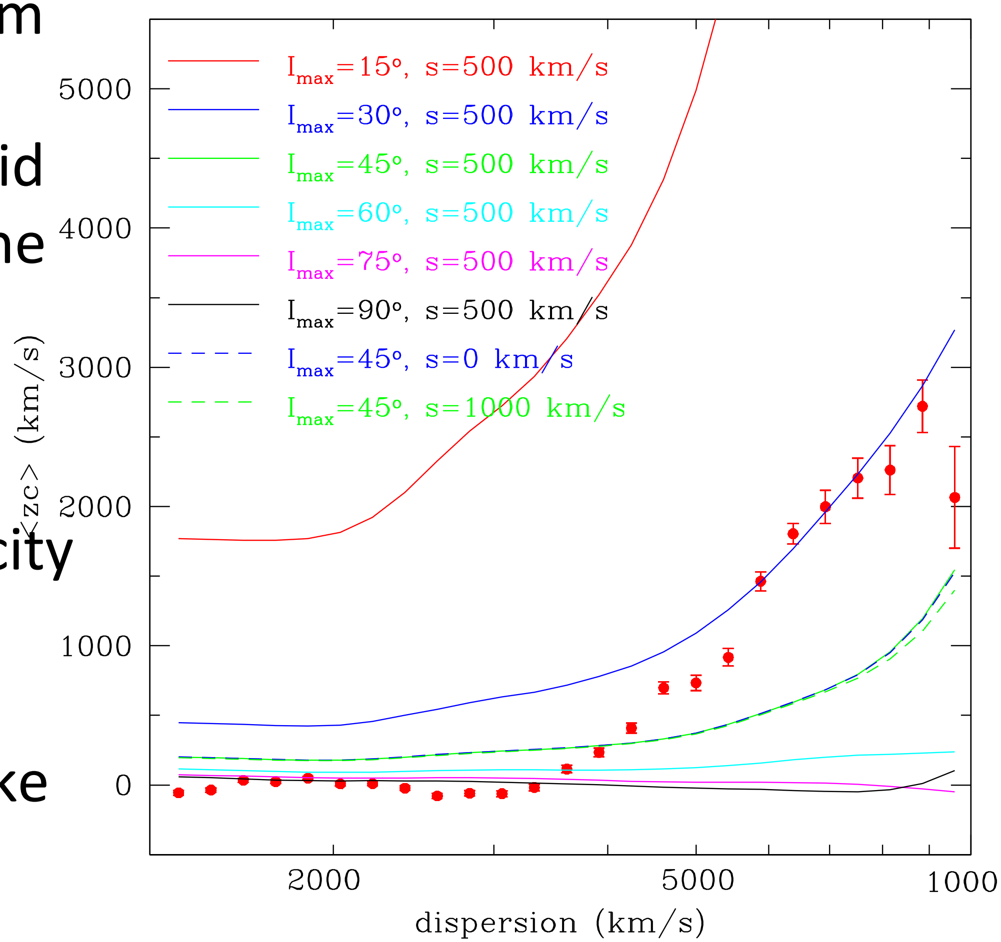
NGC 5548



Clavel et al. 1991

Broad lines contain information about cloud dynamics

- Broad line cloud speeds ~10^4 km s^{-1}
- special relativity → line centroid will be blueshifted relative to the galaxy
- line width is a measure of the isotropic velocity distribution
- → test models for the 3d velocity field
- Observed sloan sample (~10^5 objects) consistent with disk-like distribution
- Best fit requires keplerian disk
- Small net radial flow
- obscured when i<30°



Tremaine et al. (2012)

A solution? Disk Wind model

- Broad emission lines are formed by a wind; smooth flow
- Wind originates from accretion disk local UV radiation
- Dominant line formation mechanism is resonance scattering
- Broadening is predominantly from ordered outflow and rotation
- Innermost region is highly ionized by X-rays from center
- Launching radius is $R \sim 2GM/v^2 \sim 100\ R_G$

ACCRETION DISK WINDS FROM ACTIVE GALACTIC NUCLEI

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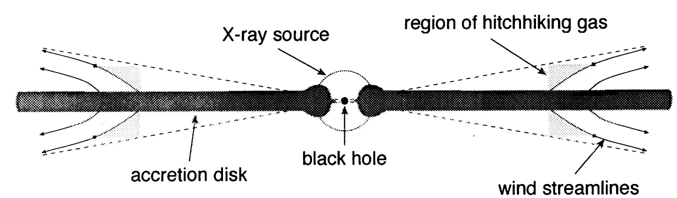
Received 1995 February 23; accepted 1995 April 13

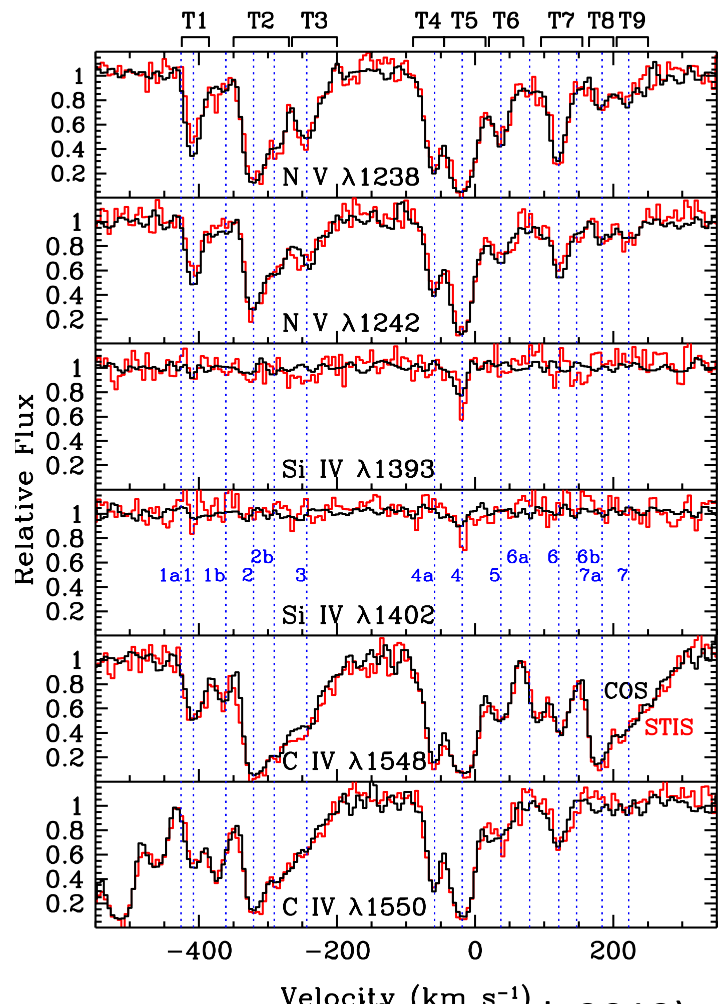


(Proga et al. 2000)

Warm absorber in UV produce narrow features superimposed on broad emission lines

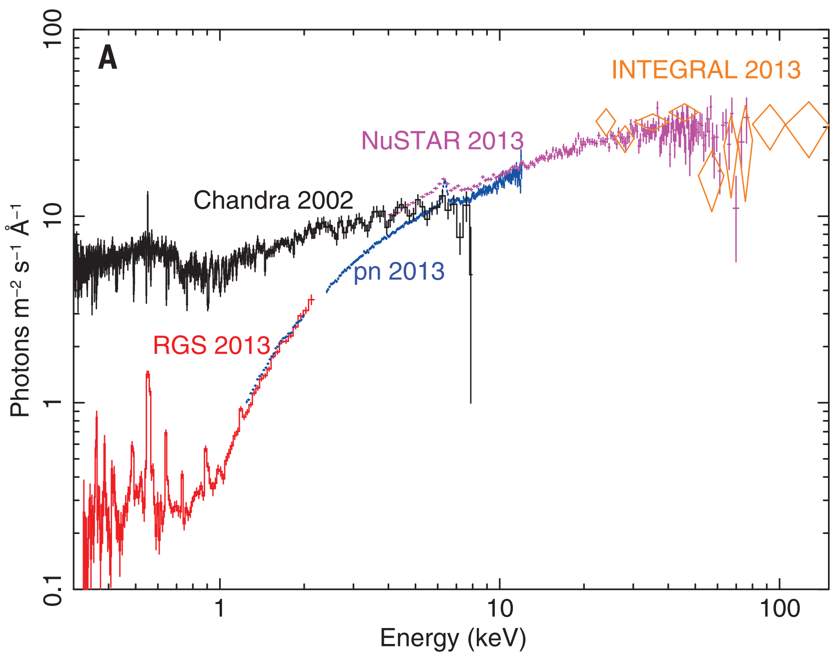
- UV Lines can be resolved using COS and STIS
- → FWHM~300 km s^{-1},
- v~500 – 1000 km s^{-1}
- Smaller than apparent X-ray widths
- Column can be estimated from doublet rations → Evidence for partial covering in some lines
- Approximate correspondence in velocity and ionization parameter with X-ray warm absorber components

Mrk 509

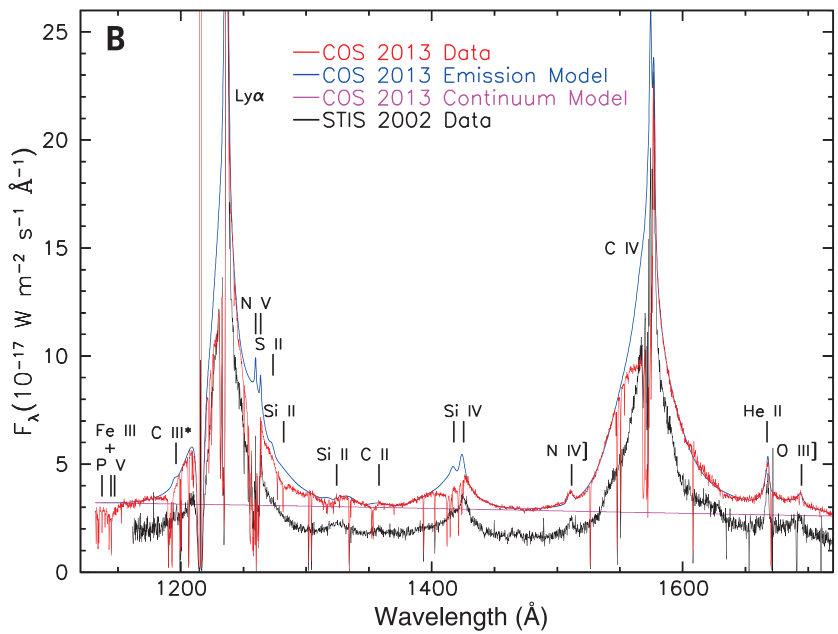


(Arav et al. 2012)

Warm absorbers can show strong variability



ngc 5548

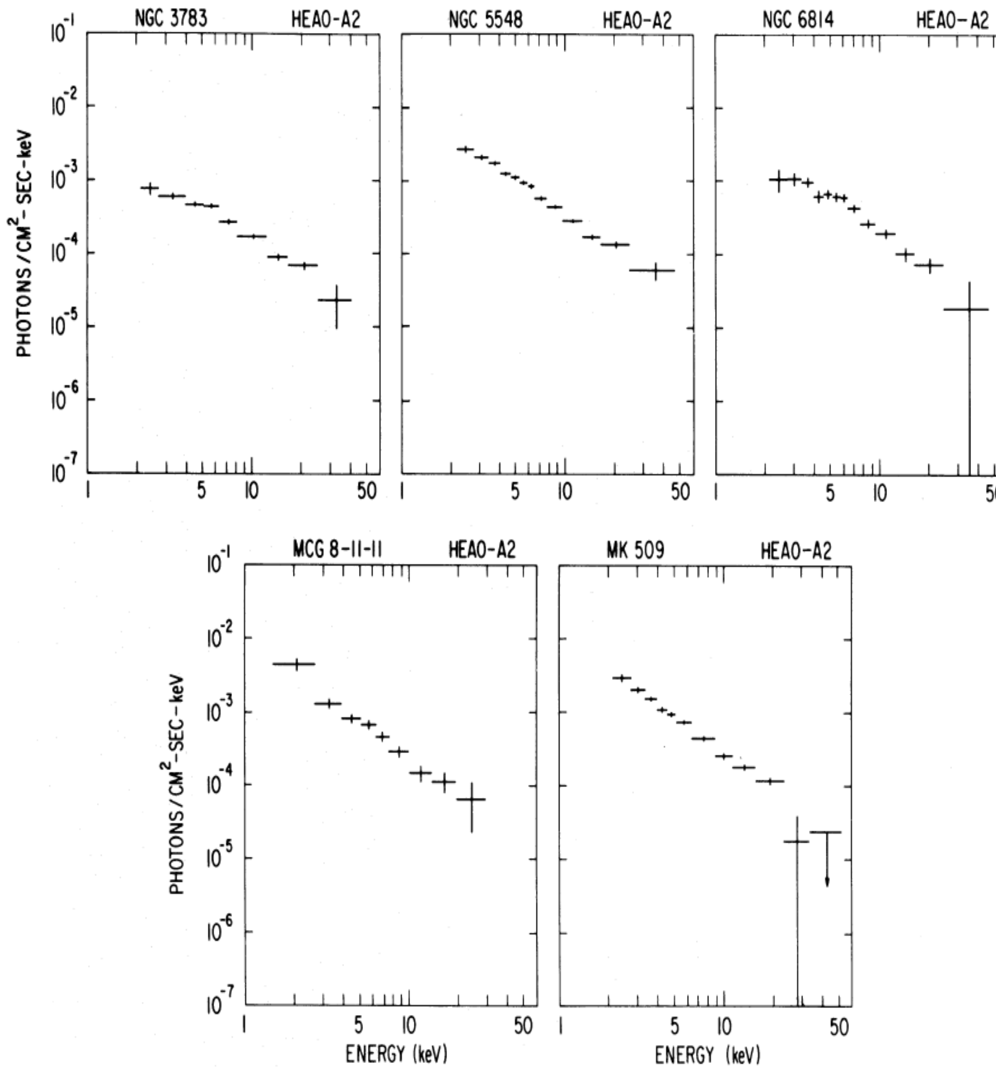


(Kaastra et al. 2014)

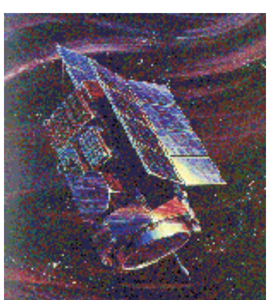
X-ray continuum spectra of AGN show a ~power law shape

- In the 2-10 keV band, remarkable uniformity of X-ray continuum spectra

HEAO-1 spectra

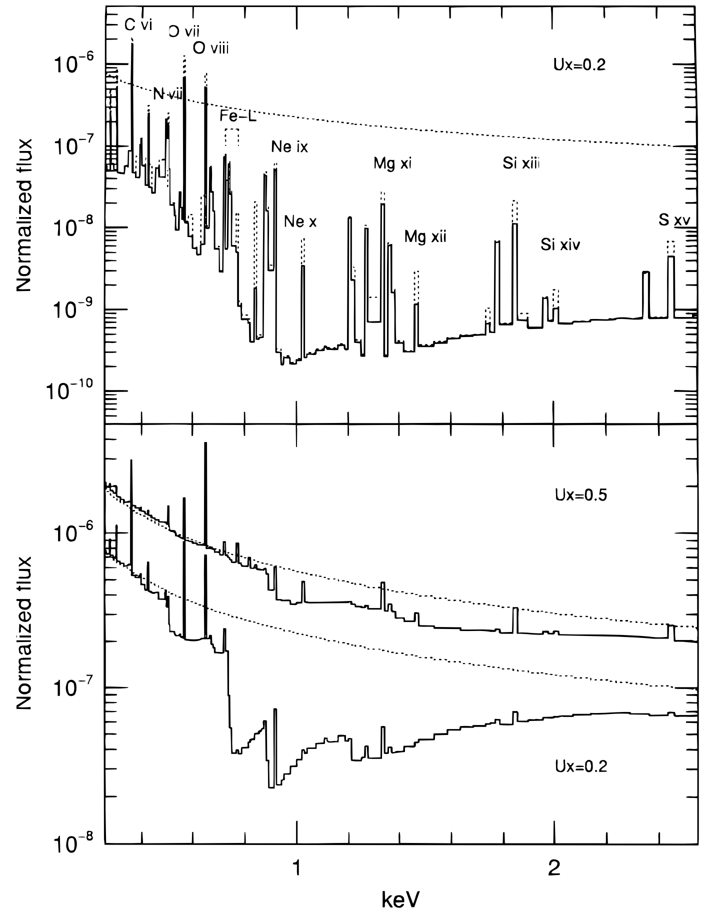


(Mushotzky et al., 1978)



Predicted AGN X-ray spectrum

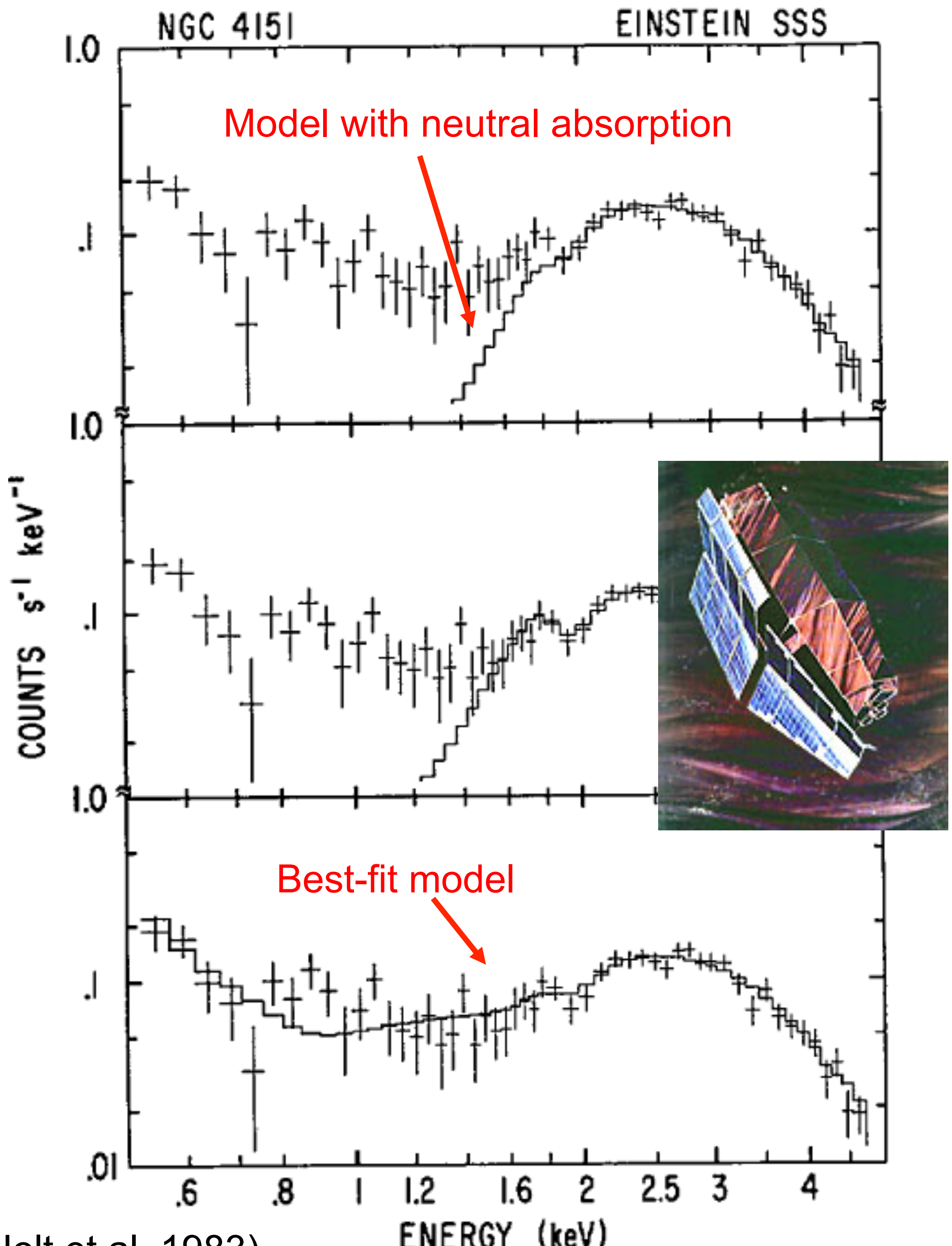
- Before Chandra and XMM it was assumed that X-ray gas would resemble broad line clouds
- X-rays would show emission lines due to extended spherical gas with with density less than broad line clouds



(Netzer 1996)

The first sensitive X-ray spectra of AGN showed something surprising

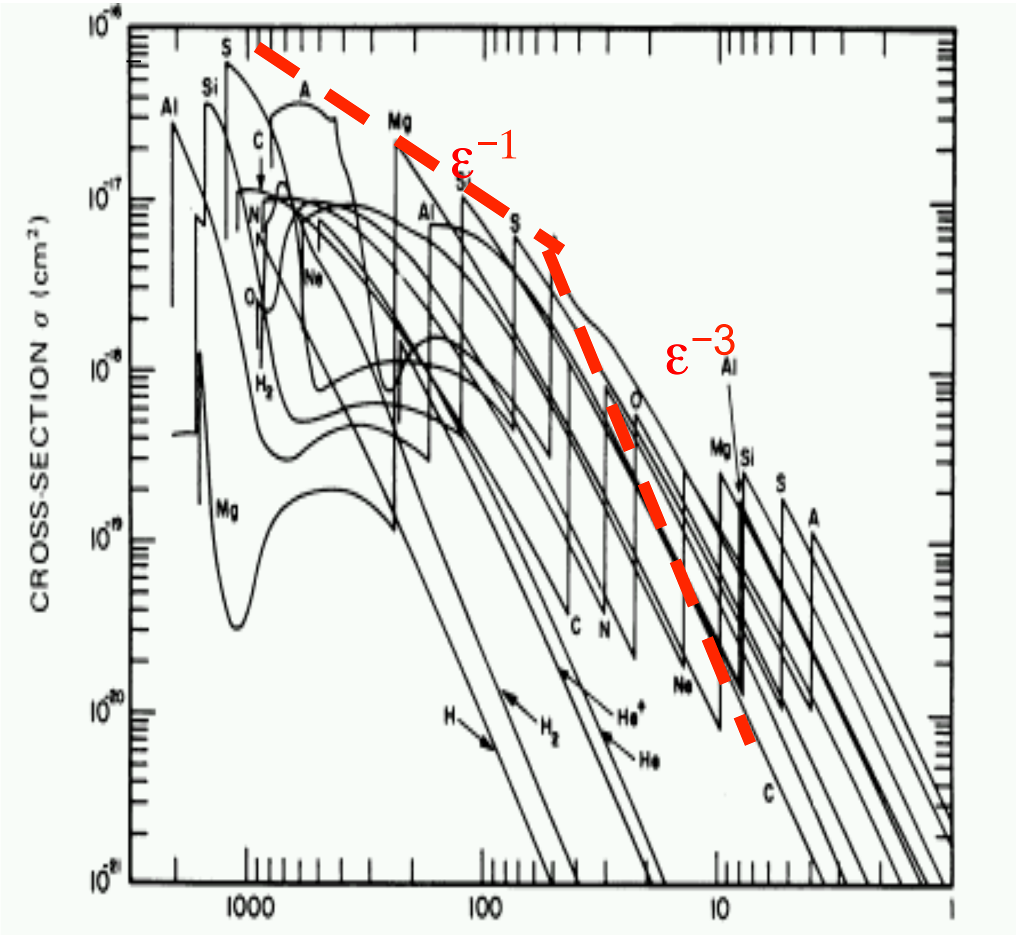
- Neutral absorption is observed in all X-ray sources
- In some AGN the low energy spectrum shows a more gradual decrease at low energies than predicted by neutral absorption
- This was interpreted as partial covering at first



(Holt et al. 1983)

The microphysics of low energy X-ray absorption: scaling behavior of photoionization cross sections

- Above threshold, the cross section decreases (crudely) as $\sim \varepsilon^{-3}$ ($\sim \lambda^{+3}$)
- The cross section at threshold scales approximately as $\sim Z^{-2}$
- The threshold energy scales approximately as Z^{2}
- ==> threshold cross section scales approximately as $\sim \varepsilon^{-1}$
- This is true if all elements have the same abundance

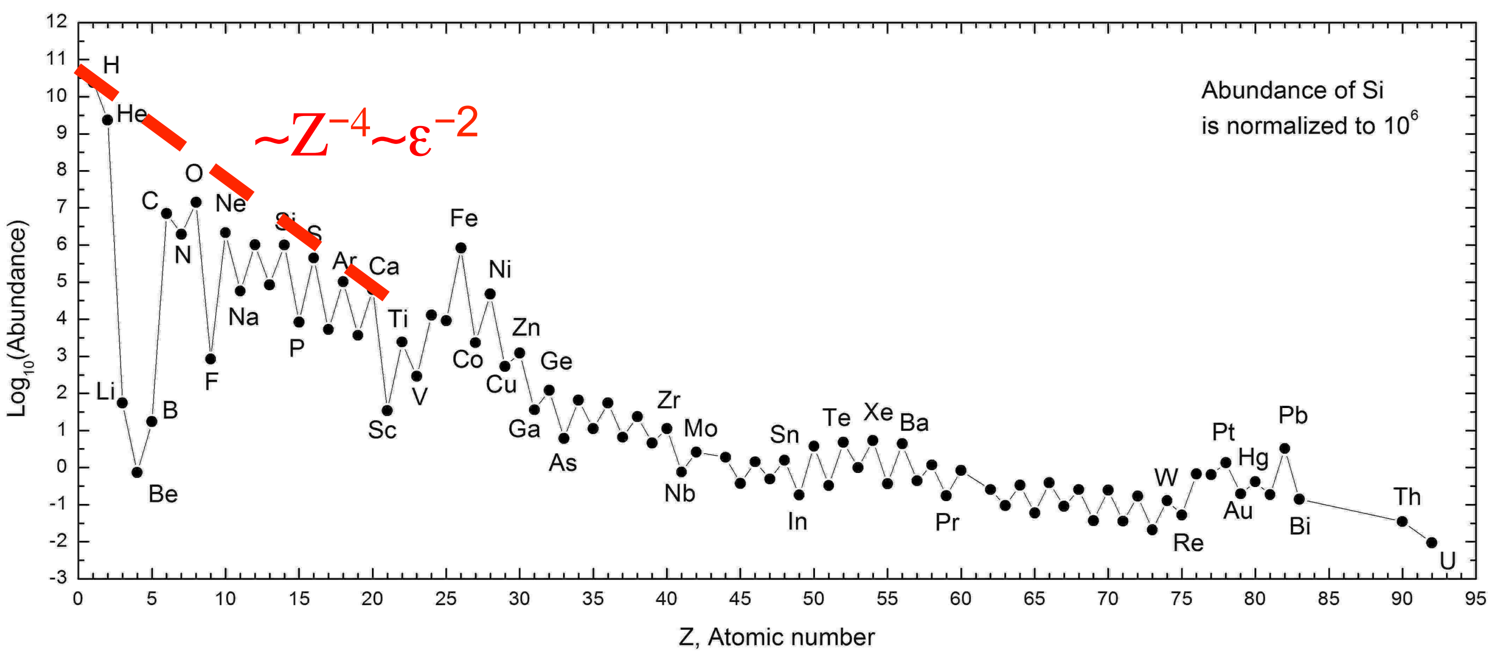


Wavelength (A)

(Zombeck)

The microphysics of low energy X-ray absorption: the effect of cosmic element abundances

- But the abundances of elements in astrophysics are determined by the big bang and stellar nucleosynthesis
- The abundances (of even-Z) elements decrease ~ Z^{-4}



The microphysics of low energy X-ray absorption: the effect of cosmic element abundances

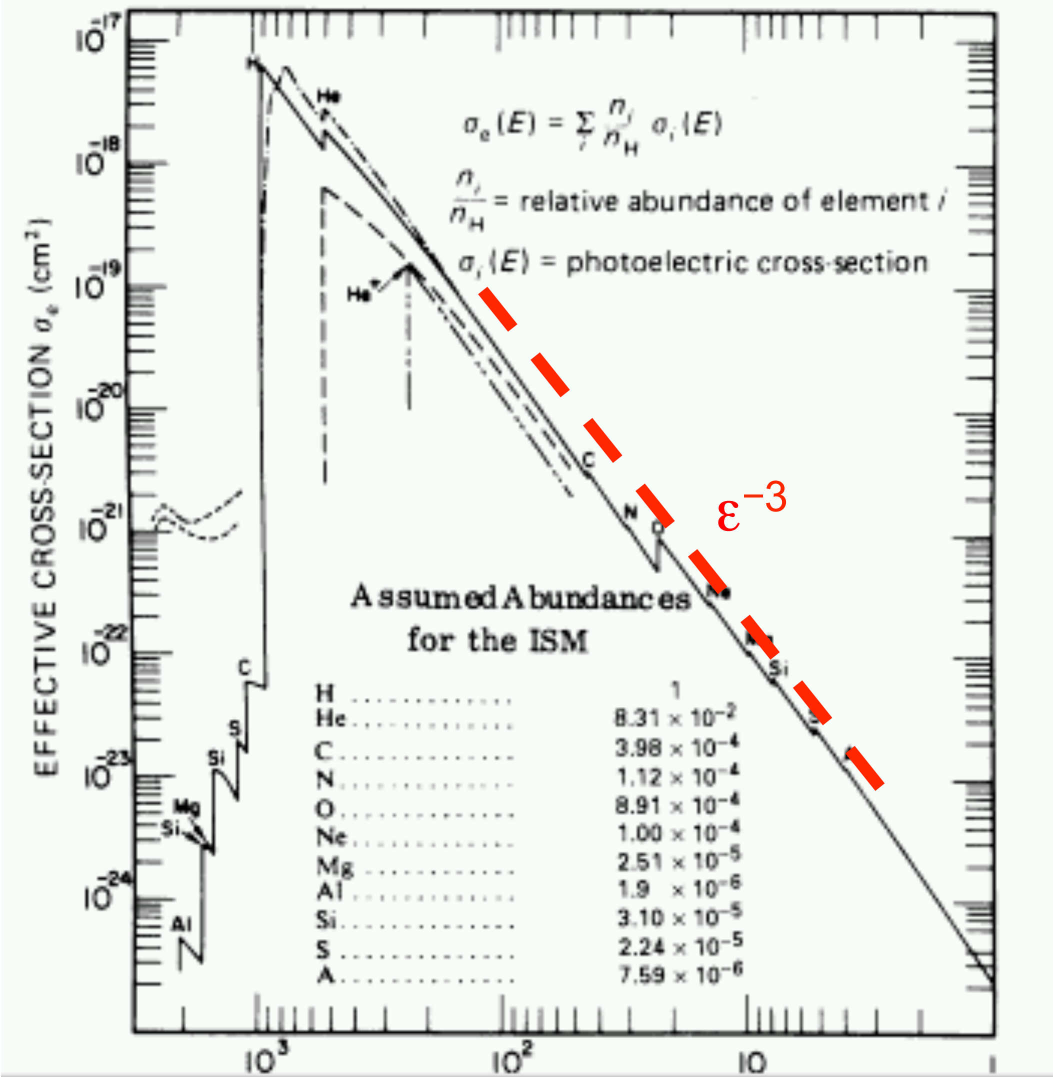
- Then the cross section per nucleus of the ensemble of elements in the interstellar medium is
  - $\sigma_{ensemble} \sim y_{abund}\sigma_{threshold}$

    $\sim Z^{-4}\, Z^{-2}$

    $\sim \varepsilon^{-3}$

==>contributions by Z>1 elements lie approximately on an extrapolation of the H cross section

- Leads to approximate ε^{-3} cross section for absorption by interstellar matter, from 13.6 eV --> 10 keV

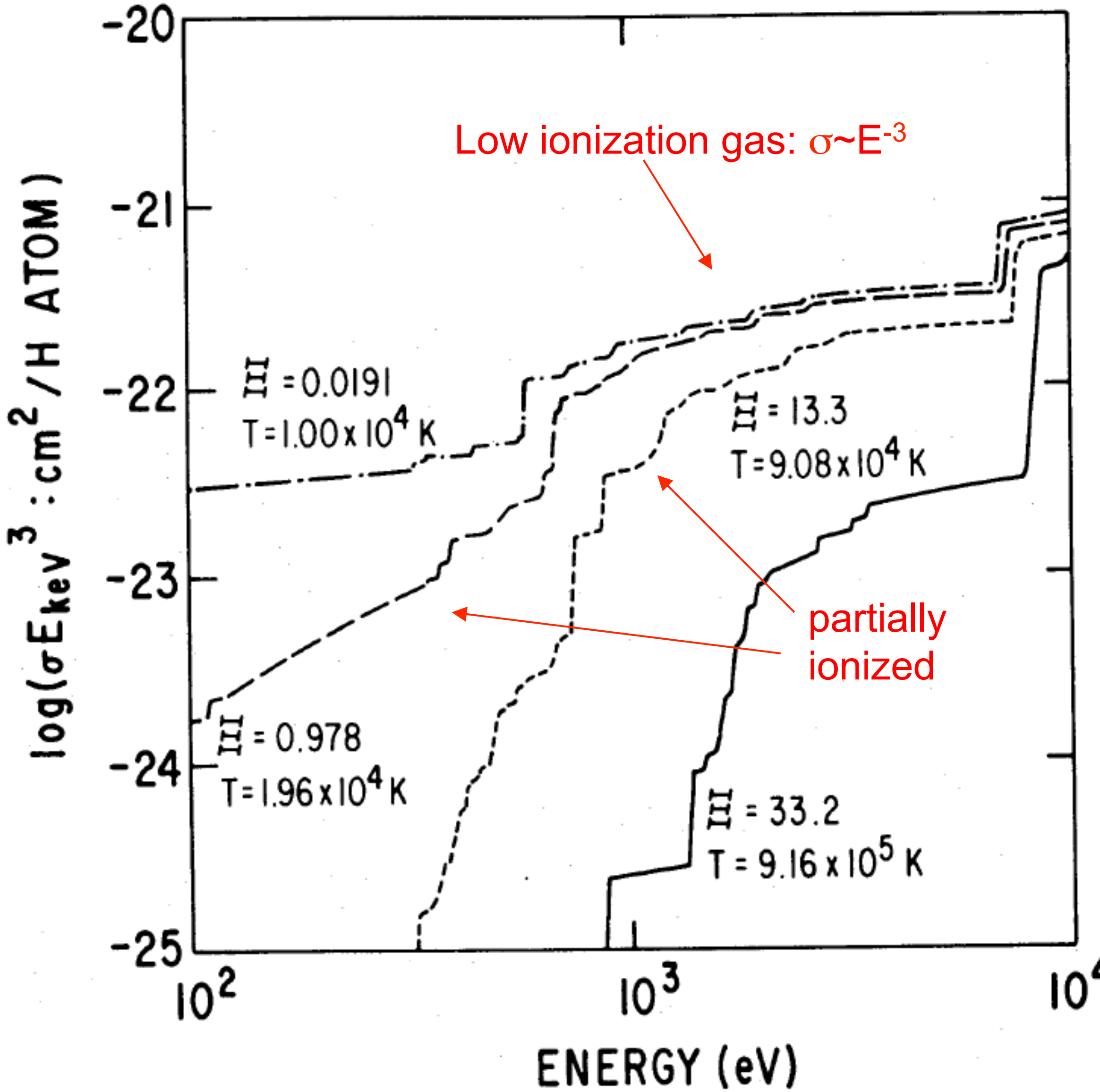


Wavelength (A)

(Morrison and McCammon; Zombeck)

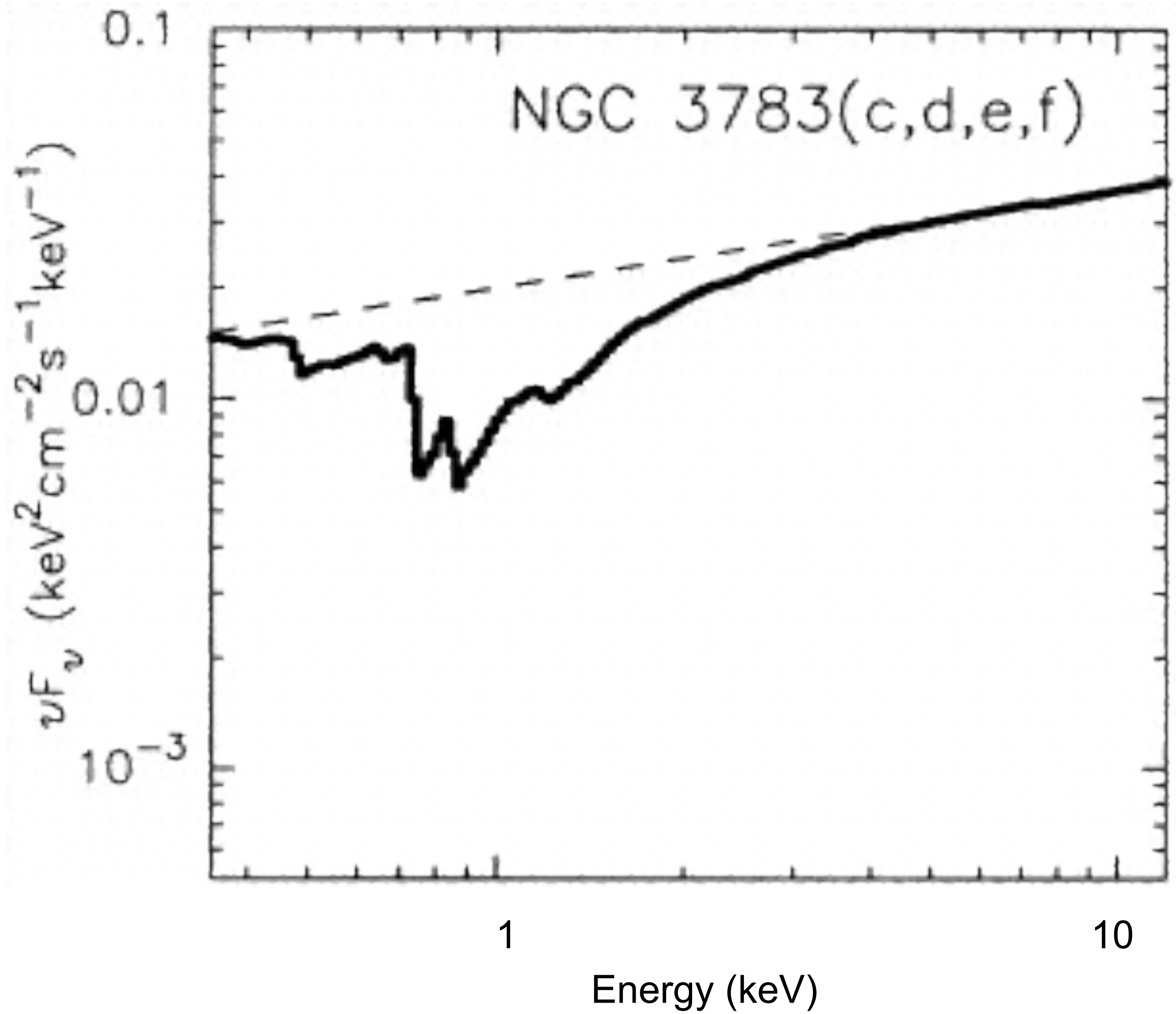
The explanation: gas is partially ionized

- Neutral gas absorbs X-rays primarily by photoionization of H, He at energies less than ~0.5 keV
- In ionized gas, the light elements are most easily ionized
- Heavy elements remain, and provide opacity at higher energies when the gas is partially ionized
- At the higheset ionization, only Fe remains

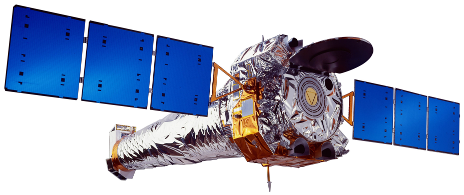


We now know that these ‘warm absorber’ spectra are common in Seyfert Galaxies

- ASCA found Warm absorber spectra in the majority of Seyfert galaxies bright enough to observe

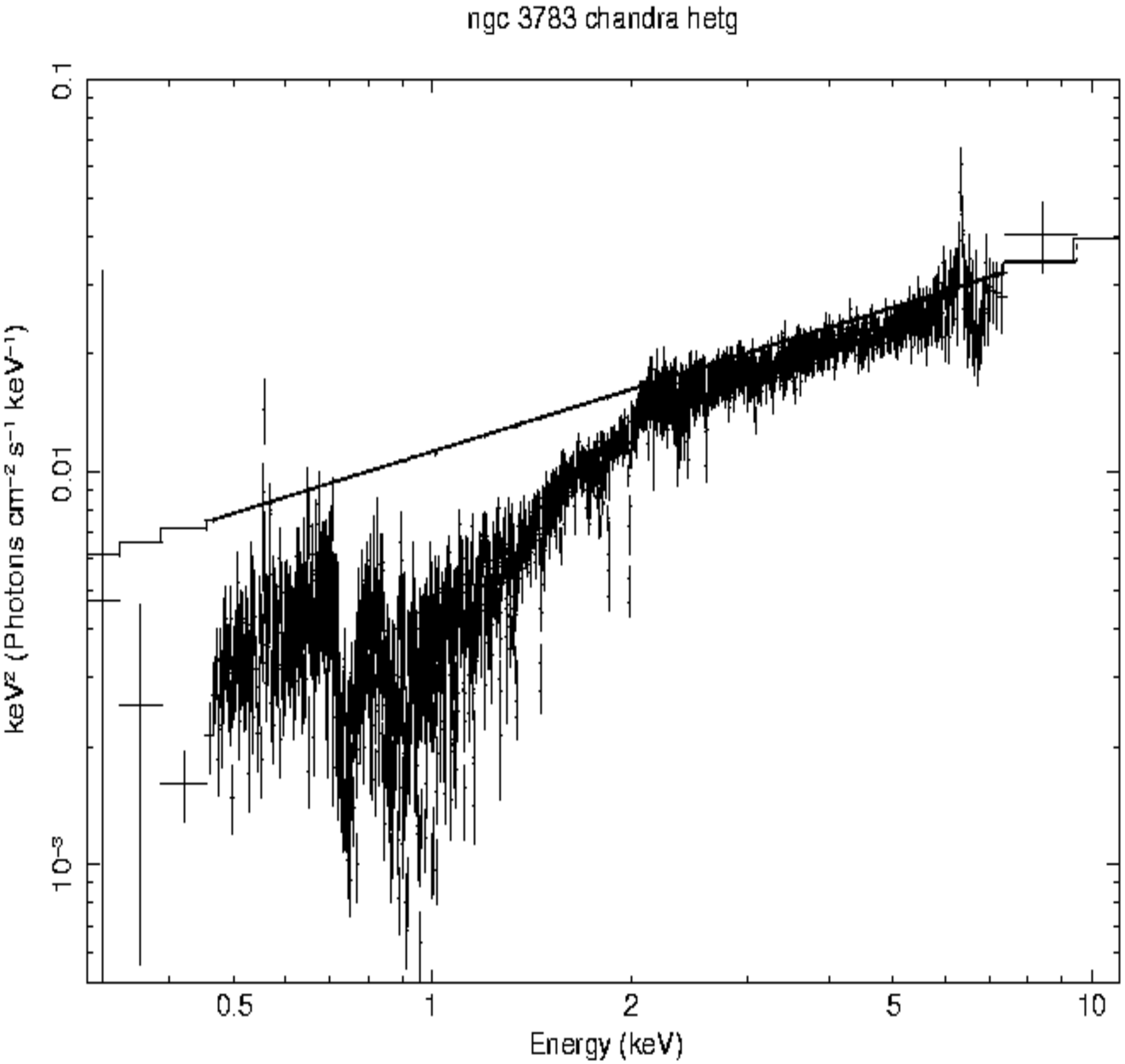


(George et al., 1996)



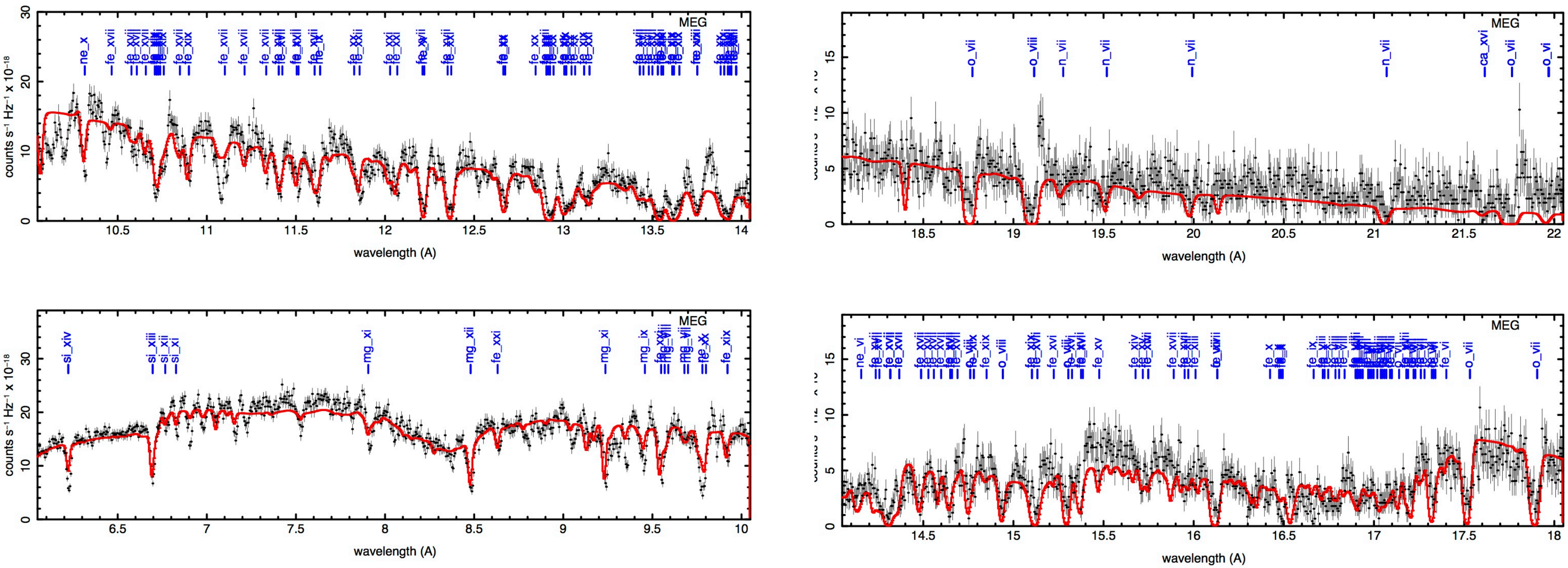
Observations with Chandra and XMM reveal more complexity

- Grating observations showed many narrow absorption features
- Broadened and blueshifted by ~1000 km s^{-1}
- Outflowing from the black hole
- This was a surprise



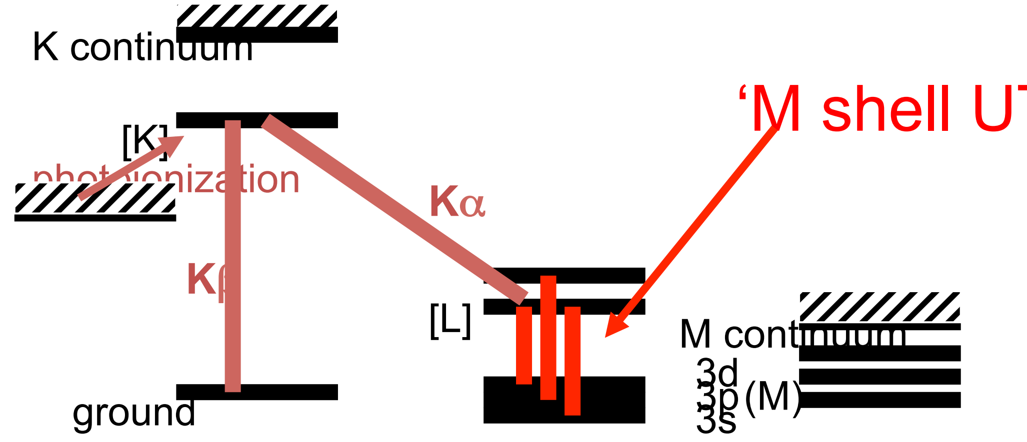
Spectrum shows absorption from a wide range of ions

NGC3783

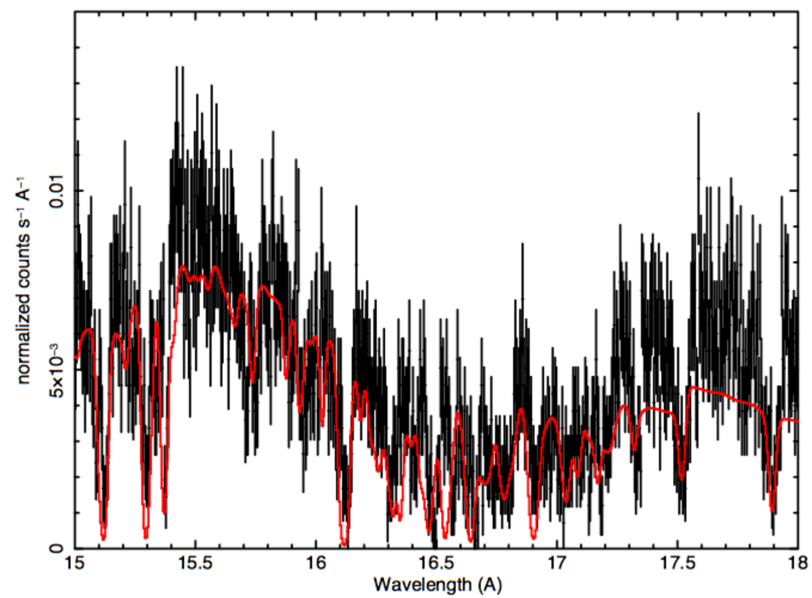


Iron m shell uta

- Comes from 2p-3s or 2p-3d radiative excitation in Fe II-XVI (Behar et al. 2002)
- $>10^2$ lines blend per ion
- Predominance of ~17A feature in NGC3783
- --> Fe < Fe X
- Crucial check on ionization balance of iron relative to other elements (eg. Si)

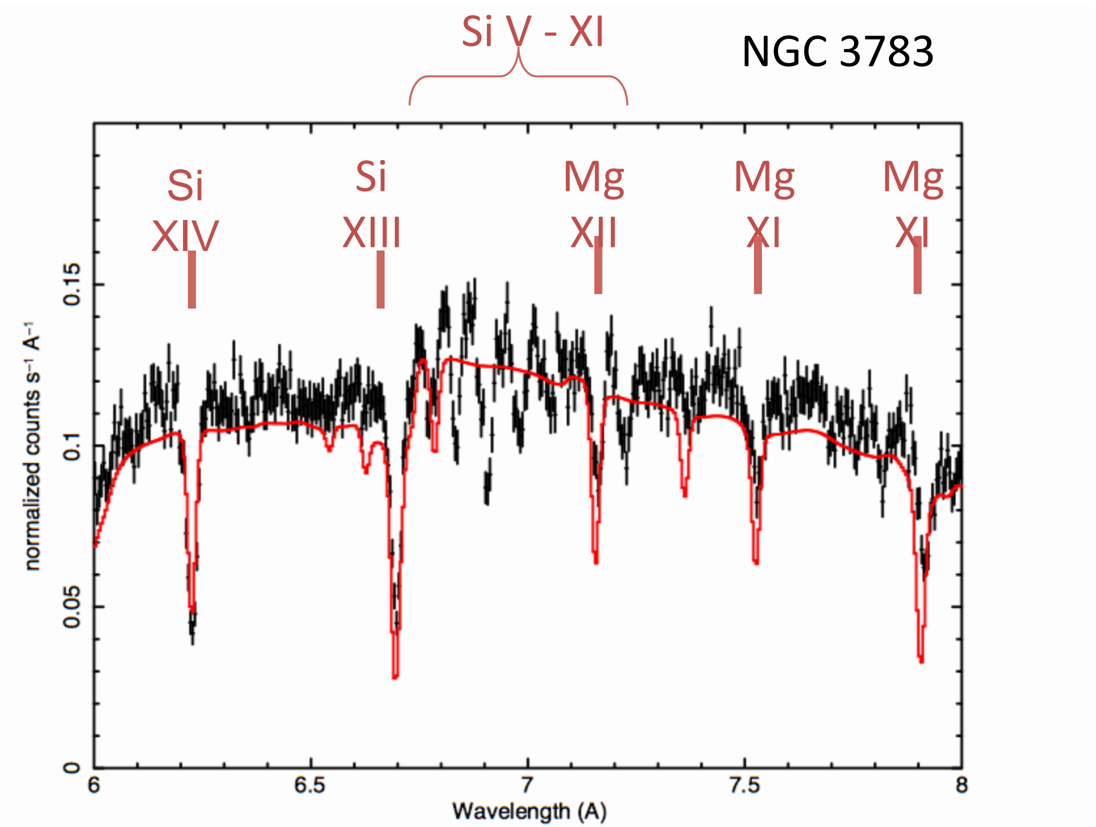


Fe XVIII - I

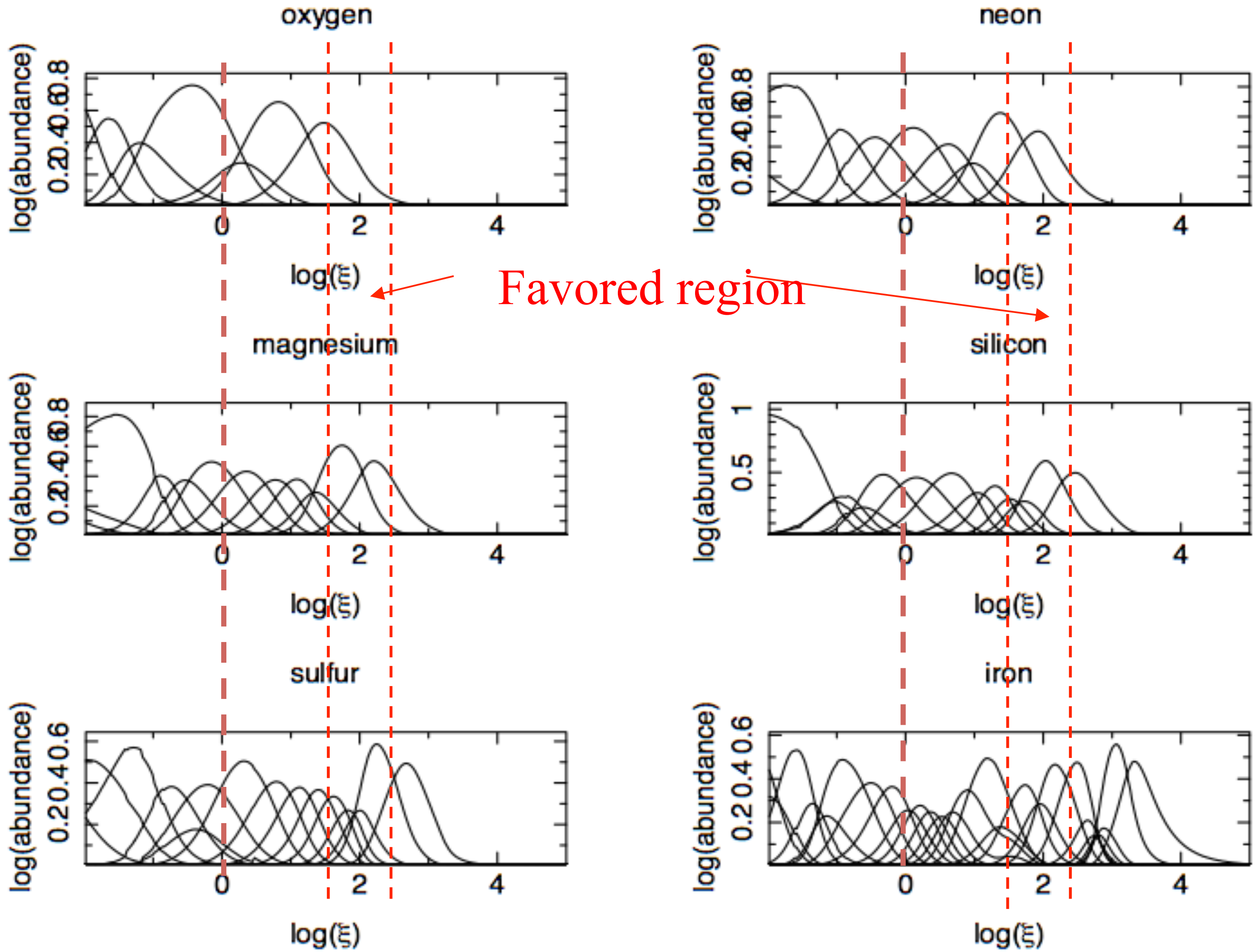


Si K lines show range of ionization states

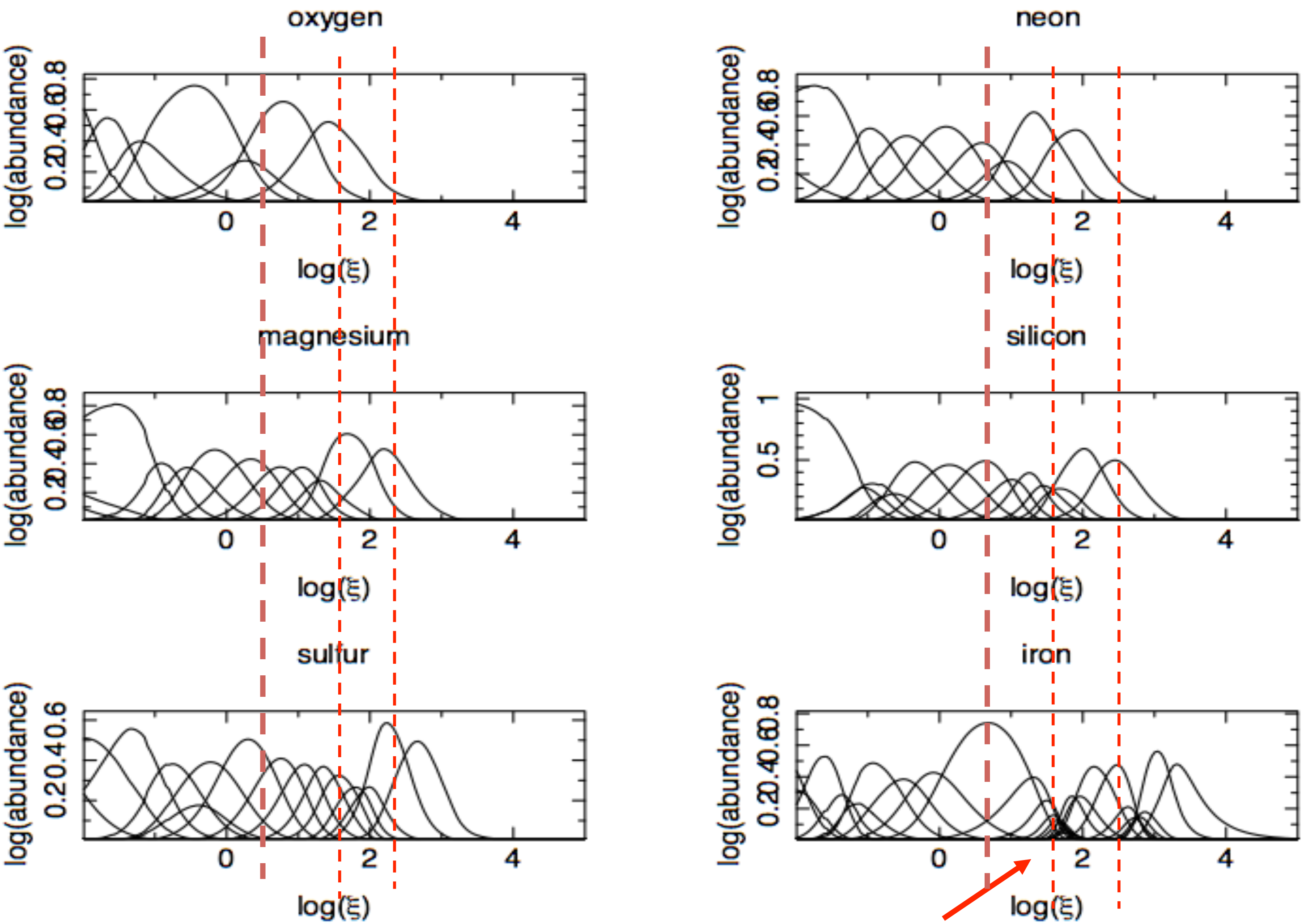
- Lines due to Si XIV and Si XIII indicate highly ionized gas
- Also see lines due to inner shell absorption from lower states of Si, indicates lower ionization material → down to Si V
- Constraining to ionization balance relative to Fe
- See Si VIII and above



There was an apparent discrepancy in the Si and Fe ionization states

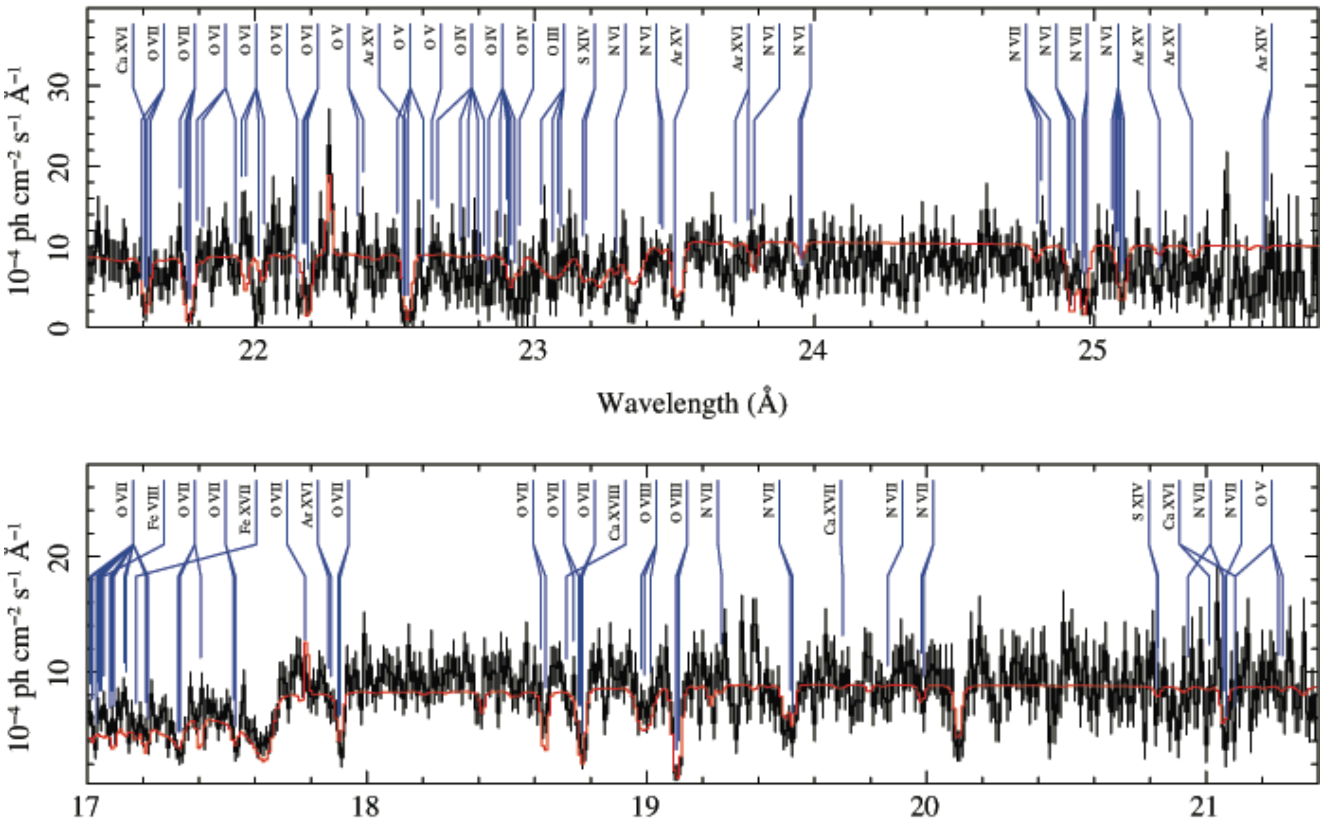


This led to a reexamination of the rates affecting ionization balance for iron (Badnell,2006)



M shell ions move to larger ionization parameter

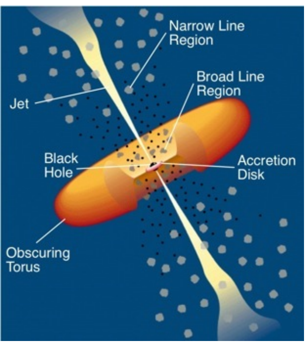
More evidence for gas at a wide range of ionization states

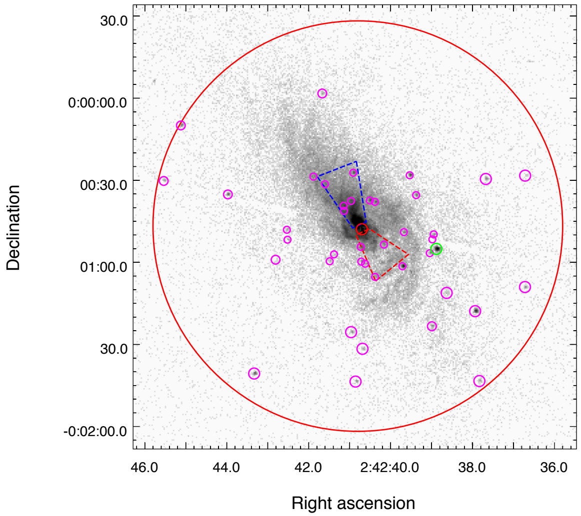


- Essentially all ion stages of oxygen are observed in HETG spectrum of Mcg-6-30-15

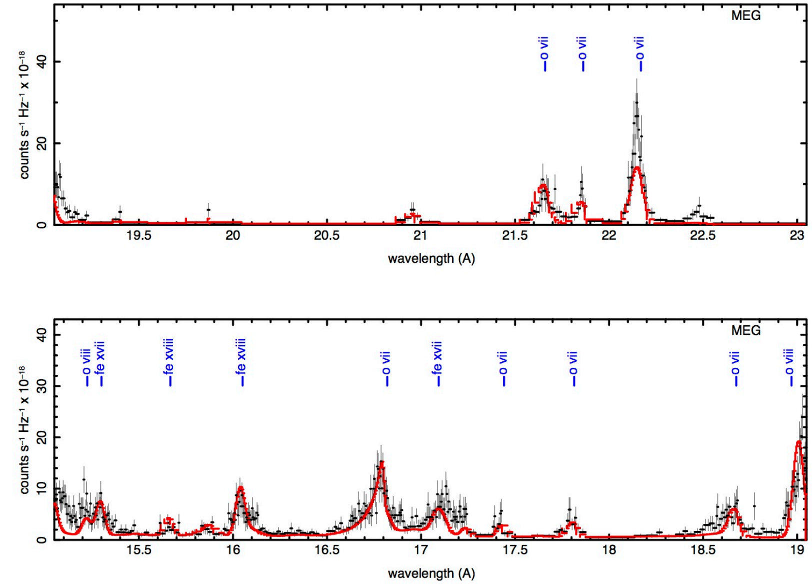
Seyfert 2 galaxies show emission, but there may be confusion

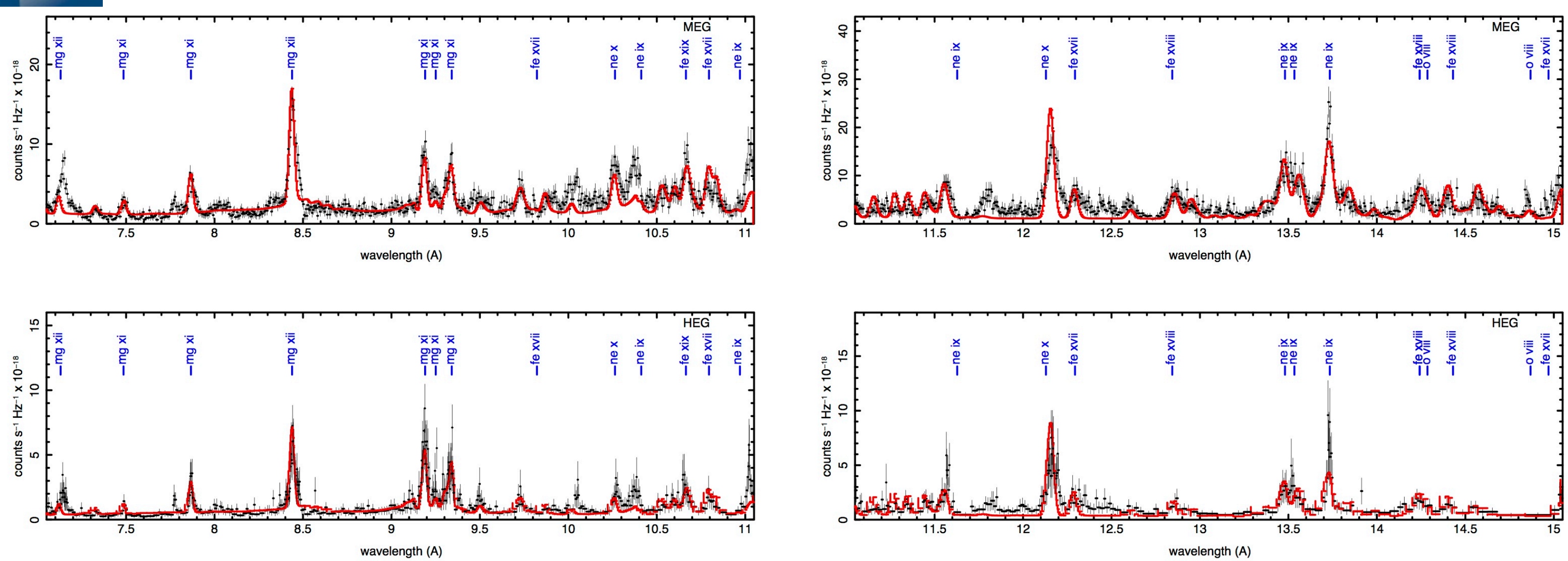
NGC1068





(Bauer et al. 2015)

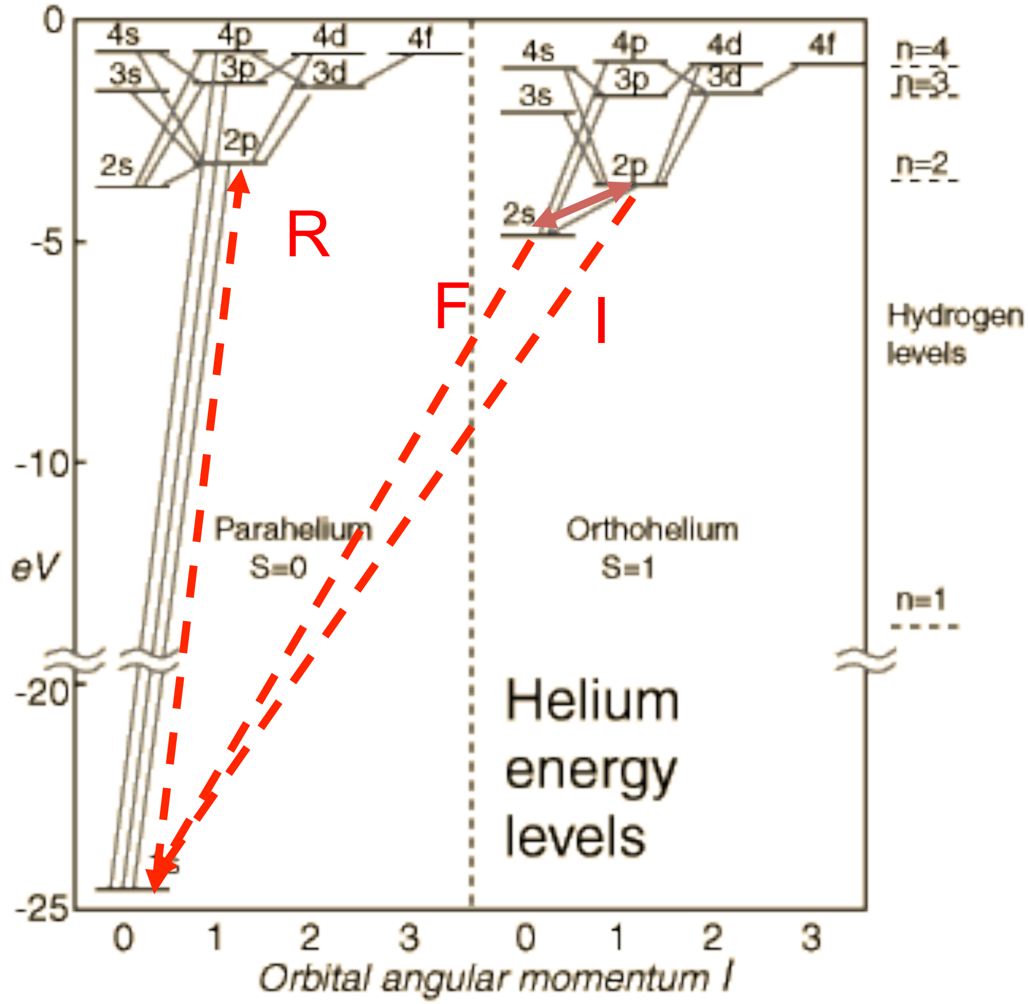




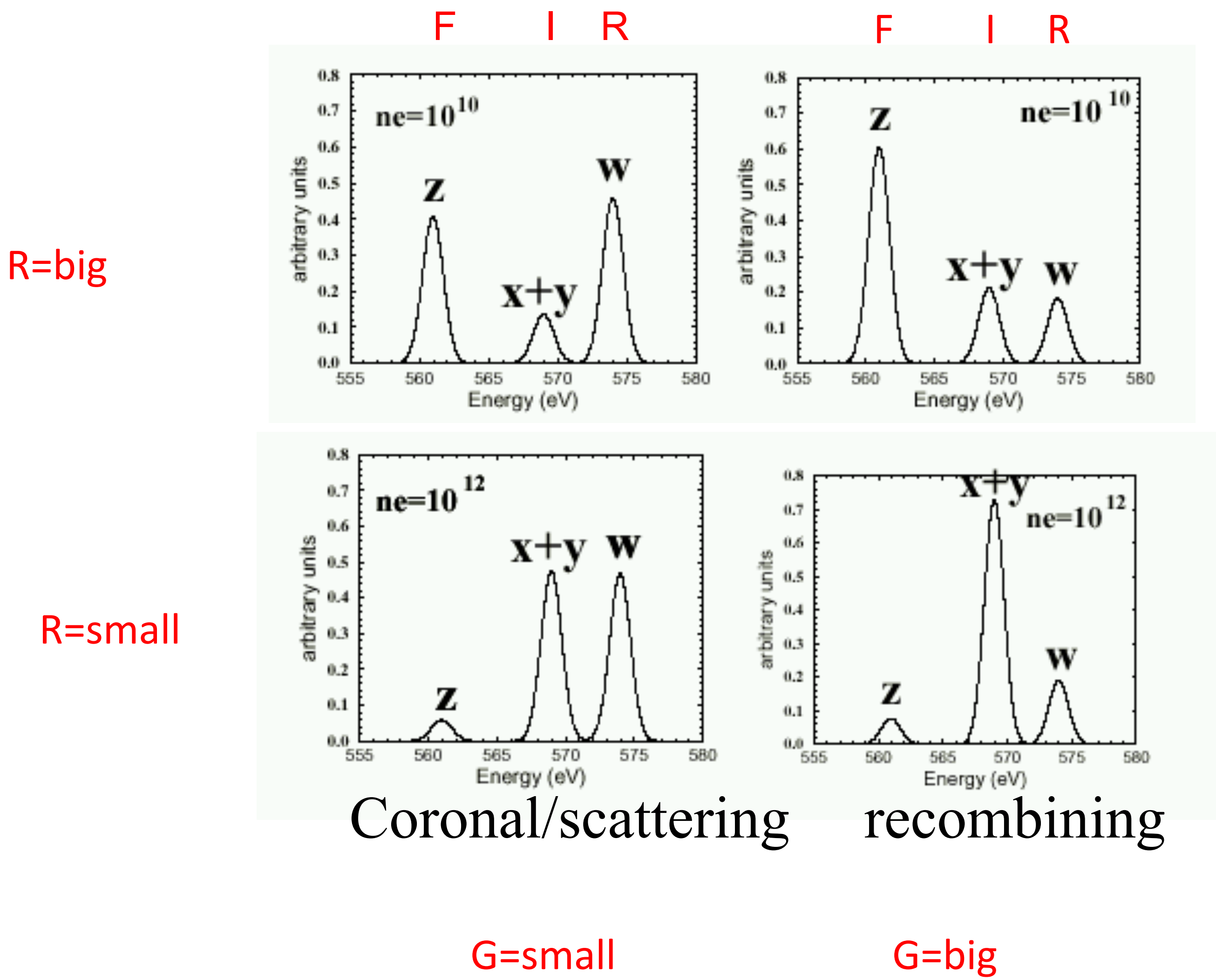
He-like lines diagnose conditions: density and temperature or excitation

g=(F+I)/R

r=F/I

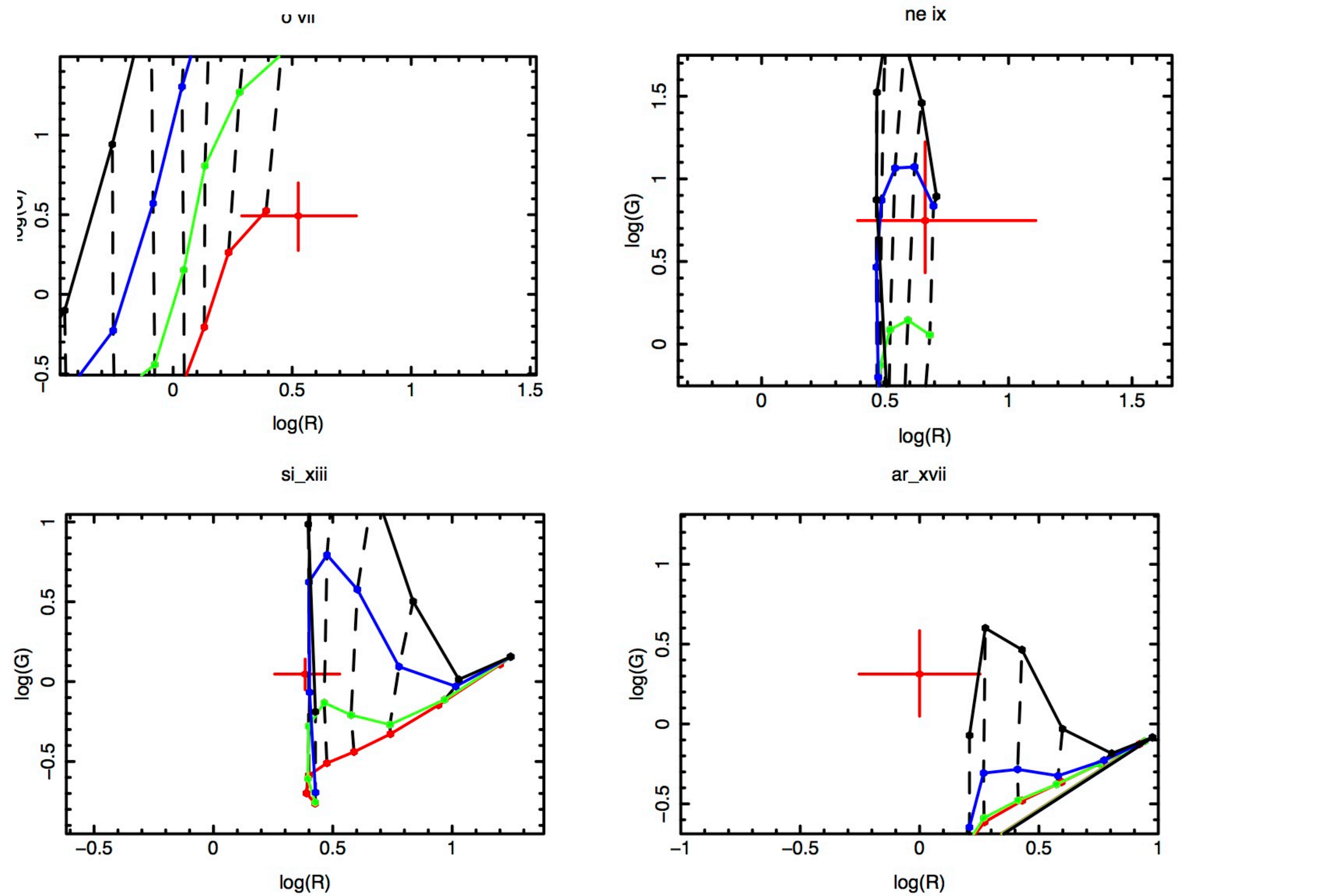


Density and temperature/excitation dependence of He-like lines



(Porquet and Dubau 1998)

Models produce different G ratios for different ions..

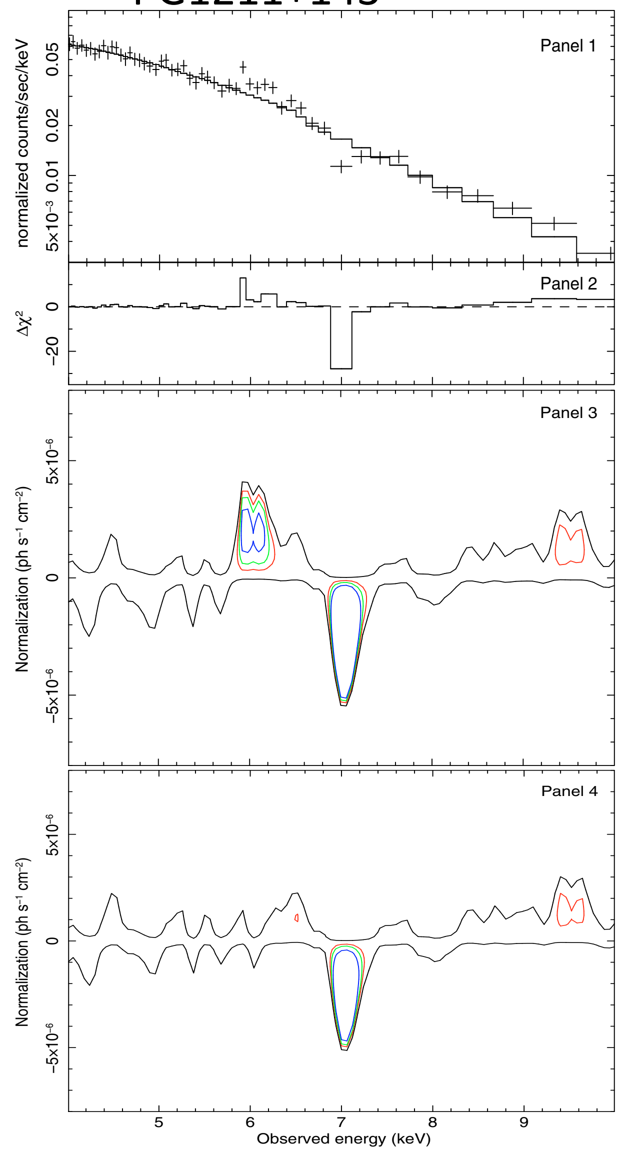


- Large G: O, Ne → primarily recombination emission
- small G: Mg, Si, Ar → radiative excitation emission
- Does not work quantitatively

Some agns show broad absorption at energies > 7 keV

- If due to Fe XXVI → evidence for outflows at ~0.1c → ultrafast outflows (UFOs)
- Features are variable in time
- Observed from ~ 1/3 of all warm absorber sources
- Implied mass loss rate is large

PG1211+143



(Tombesi et al. 2010)

Warm absorber questions

- General properties: $v \sim 10^8$ cm s^{-1}, $N \sim 10^{21}$ cm^{-2}
- Location is uncertain; virial flow $\rightarrow$ $R=2GM/v^2 \sim 0.01$ pc $M_6\, v_8^{\,2}$
- $M=\Omega\, R\, v\, N\, m_H=6 \times 10^{24}$ gm s^{-1} $R_{pc}\, v_8\, N_{21}\, \Omega/4\pi$
- Compare with $M_{accretion}= L/\eta c^2 \sim 1 \times 10^{24}\, L_{44}\, \eta_{0.1}$
- What is Ω? How can it be big and small at the same time?
- What is R? Where does warm absorber originate?
  - Virial R is near location of torus … evaporative flow?
- Emission vs absorption $\rightarrow$ correspondence but it's complicated by nlr
- Ufos? What's going on?
- Ionization distribution: continuous or not?
- Variability $\rightarrow$ size constraints

summary

- AGNs have been studied intensively for >50 years
- We still have diverse ideas about what is happening in emitting/absorbing gas
  - Broad line clouds = disk wind
  - But not widely accepted
  - Warm absorbers = evaporative flow associated with obscuring torus
  - But not widely accepted
- Ufos = ???
- What decides how much goes out vs. in?