THE MANY FACES OF X-RAY EMISSION LINES FROM ACTIVE GALACTIC NUCLEI

Ehud Behar,

Masao Sako, Ali Kinkhabwala, and Steven Kahn

Columbia University, New York, NY

Other Collaborators

Columbia University (New York):

Frits Paerels, Andy Rasmussen, Daniel Savin

SRON (The Netherlands)

Bert Brinkman, Jelle Kaastra, Katrien Steenbrugge

MSSL (UK)

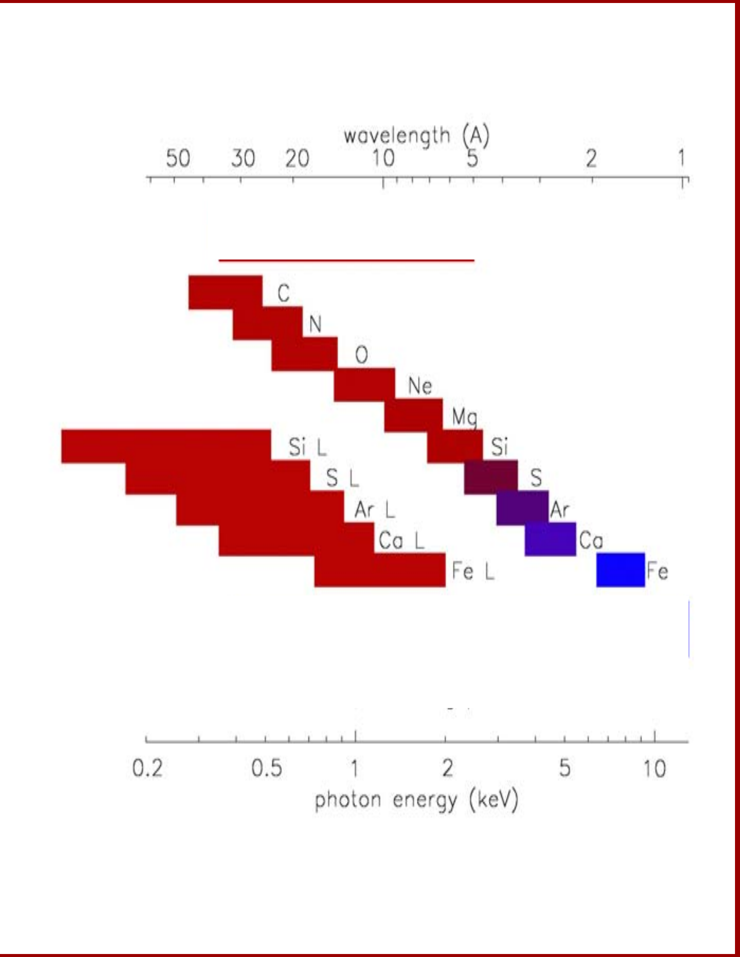
Alex Blustin, Graziella Branduardi-Raymont

Outline

- Very Brief Introduction
  - The Soft X-Ray Band
  - *Chandra* and *XMM-Newton*
  - Active Galactic Nuclei - AGN
- X-Ray Spectra of Type I AGN
  - Distinguishing Between Emission and Absorption
  - Narrow and Broad Emission Lines
  - Relativistically Broadened (Accretion Disk) Lines
  - Fluorescence Lines
- X-Ray Spectra of Type II AGN
  - Photoionized Plasmas vs. Collisional Plasmas, AGN vs. Starburst
  - Measuring temperatures with Radiative Recombination “Continuua”
  - Measuring Column Densities NOT Along The Line of Sight
  - Elemental Abundances
- Summary – On the Unification of AGN Sources

Features of the X-Ray Band: Highly Ionized Atoms

- The conventional (soft) x-ray band (1 to 100 Å or ~ 0.2 – 10 keV) comprises spectral lines from many K-shell and L-shell ions pertaining to all of the cosmically abundant elements from C to Ni.
- The x-ray band is uniquely compact. It includes several ions from each element and many lines from each ion.
- This wealth of lines and ions allows for elaborate and robust diagnostics of important plasma quantities such as temperatures, densities, column densities, ionization states, and elemental abundances.



A New Era in X-Ray Astrophysics: *Chandra* and *XMM-Newton*

- The *Chandra* Observatory (NASA):
  Launched July 23, 1999
  1 telescope
  2 CCD cameras
  2 transmission grating spectrometers
  (HETGS & LETGS)

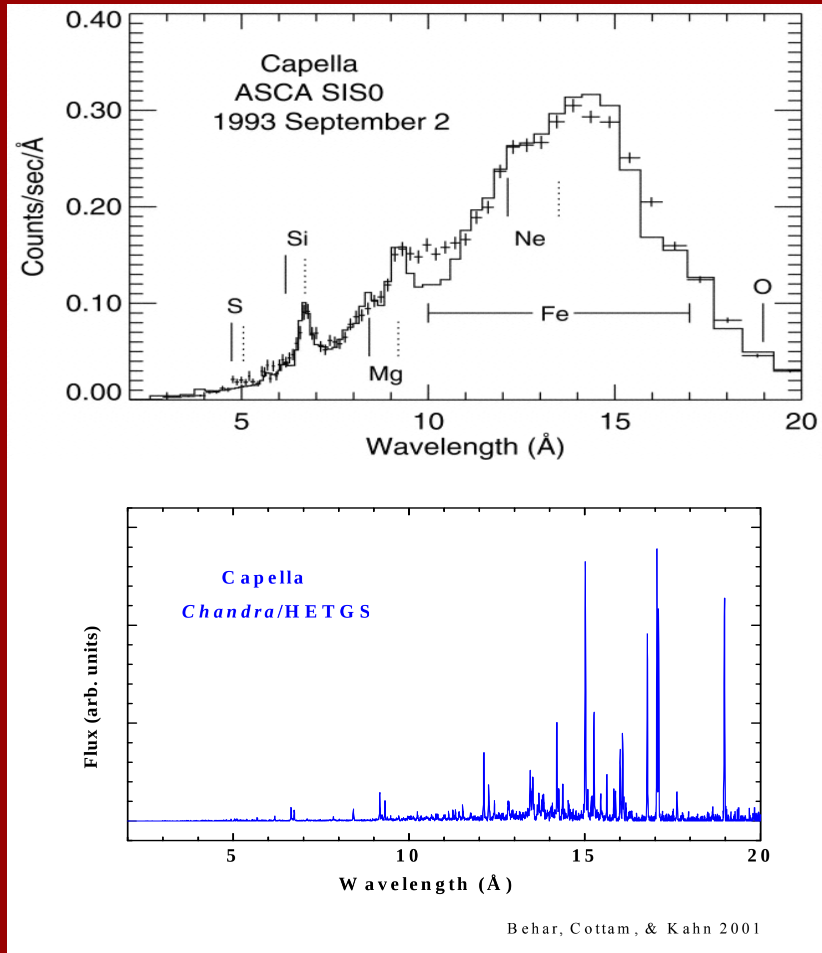
- *XMM-Newton* (ESA):
  Launched December 10, 1999
  3 telescopes
  2 reflection grating spectrometers (RGS)
  1 Optical/UV monitor

The Difference That High Spectral Resolution Makes

- ❖ Spectrum of the stellar binary Capella obtained with the CCDs on board *ASCA*

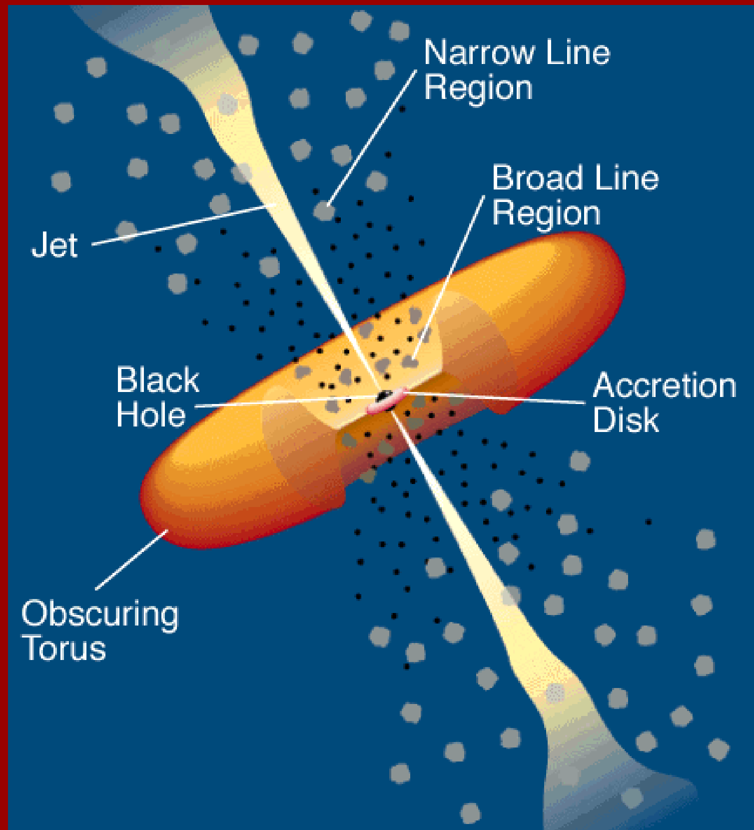
  (Brickhouse, Dupree, Edgar et al. 2000)

- ❖ Spectrum of Capella obtained with the high energy transmission gratings (HETGS) on board *Chandra*



Active Galactic Nuclei (AGN)

- ❖ The "Canonincal" Picture of AGN based on UV, optical, and radio observations:
  - Central Engine: Supermassive BH
  - Accretion through disk
  - High-velocity outflows (Brandt)
  - Dusty structure (torus):
    Gives rise to two "types" of AGN, depending on observer's position

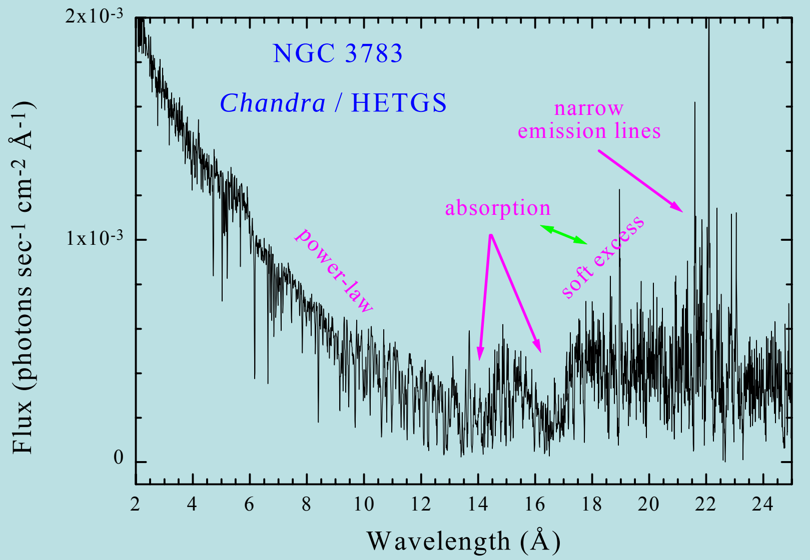


Cartoon by Urry and Padovani

Type-I AGN: Spectral Components

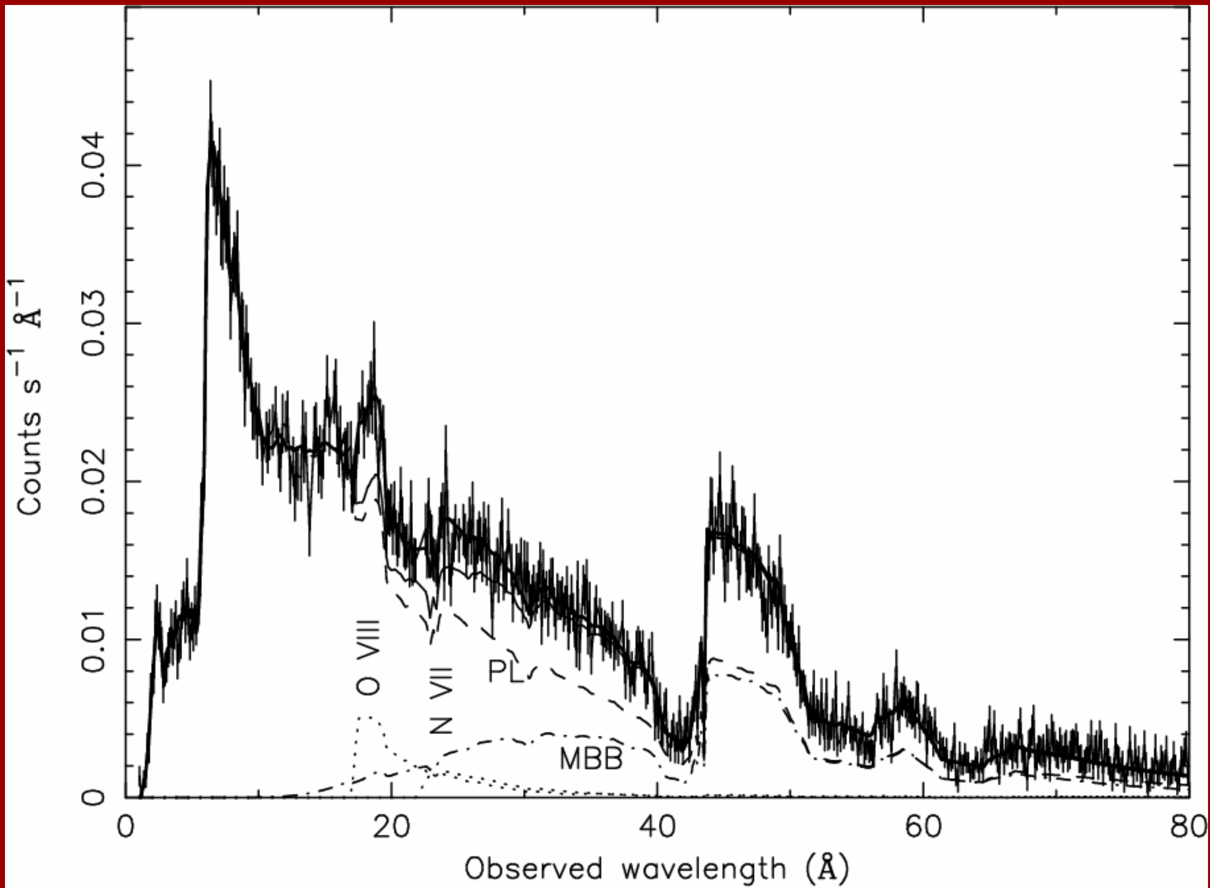
- X-ray spectral components (schematically):
  - High-energy **power-law** continuum
  - **Soft excess**
    (power-law, BB, modified BB)
  - **Absorption** lines and edges (?) superimposed by the **highly ionized outflow** along the line of sight (Kallman, Brandt)
  - Secondary, processed continuum and emission lines (reflection) by ionization cone
  - Fluorescence lines by (near) neutral species

- Distinguishing between the various components is not always straightforward



Data courtesy of Kaspi, Brandt, George, et al.

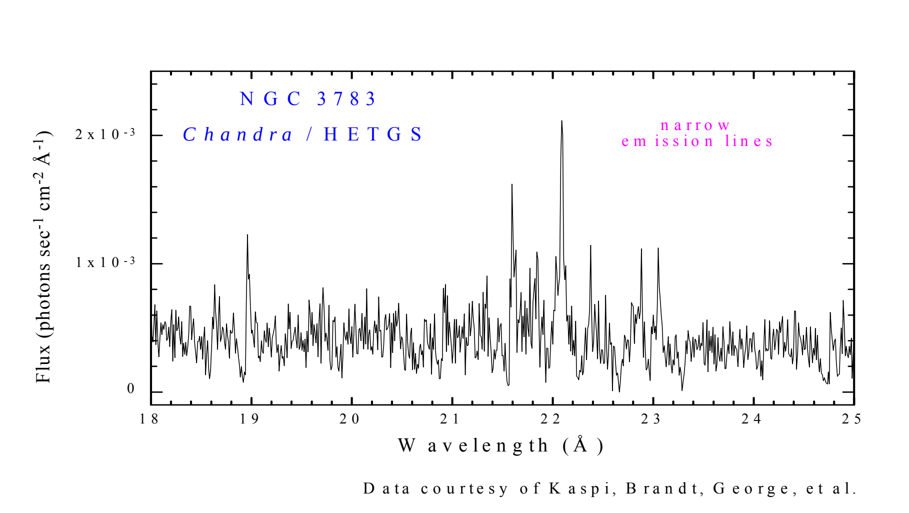
Type I AGN (cont.): Constructing the Continuum

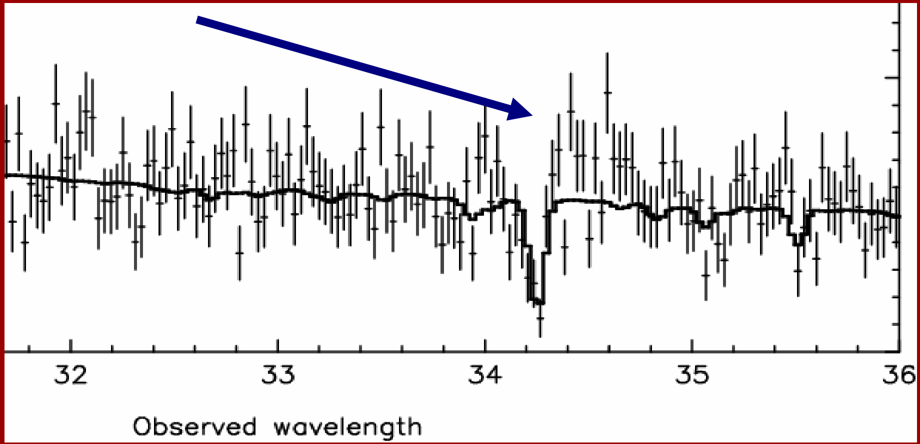


NGC 5548 / LETGS (Kaastra, Steenbrugge, Raassen, et al. 2002)

Type I AGN (cont.): Narrow and Broad Emission Lines

- Emission from ionization cone
  - Narrow lines:
    - $v_{out} \approx 0 - 200$ km/s
    - Unresolved $v_{turb} <\approx 300$ km/s
  - Broad lines (e.g., C^{5+} in NGC 5548):
    - $v_{out} \approx 0$ km/s
    - $v_{turb} = 10{,}000$ km/s $=$ BLR (C^{3+}, He^{+})

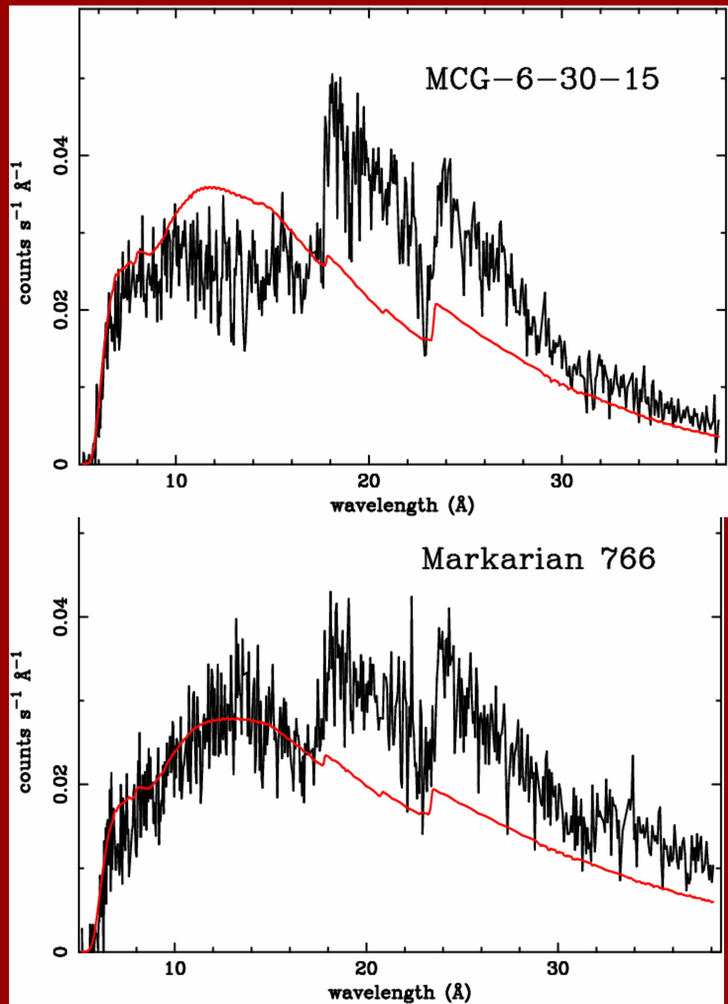




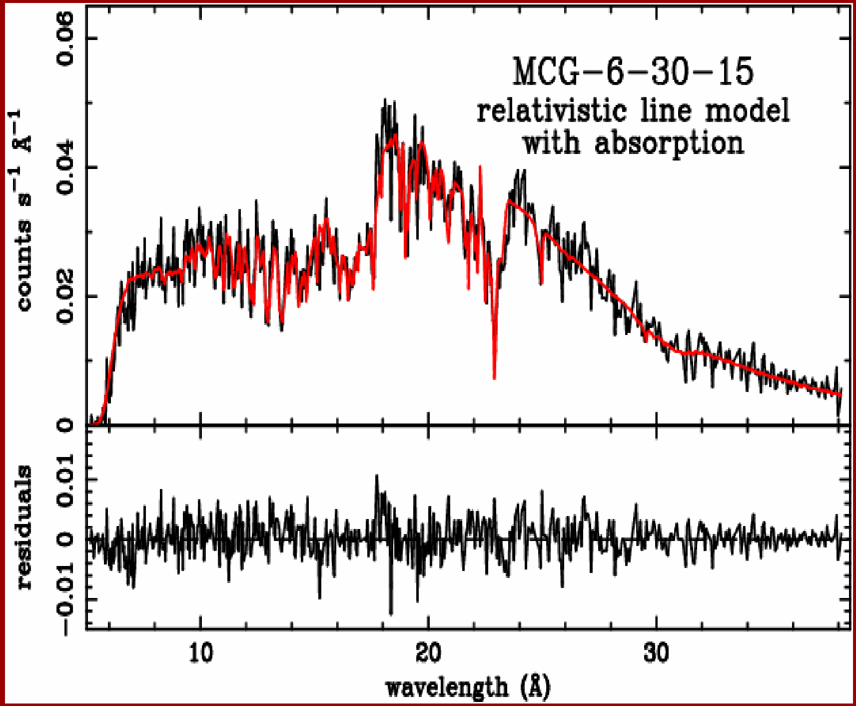
Type I AGN (cont.): Two Weird Looking Spectra

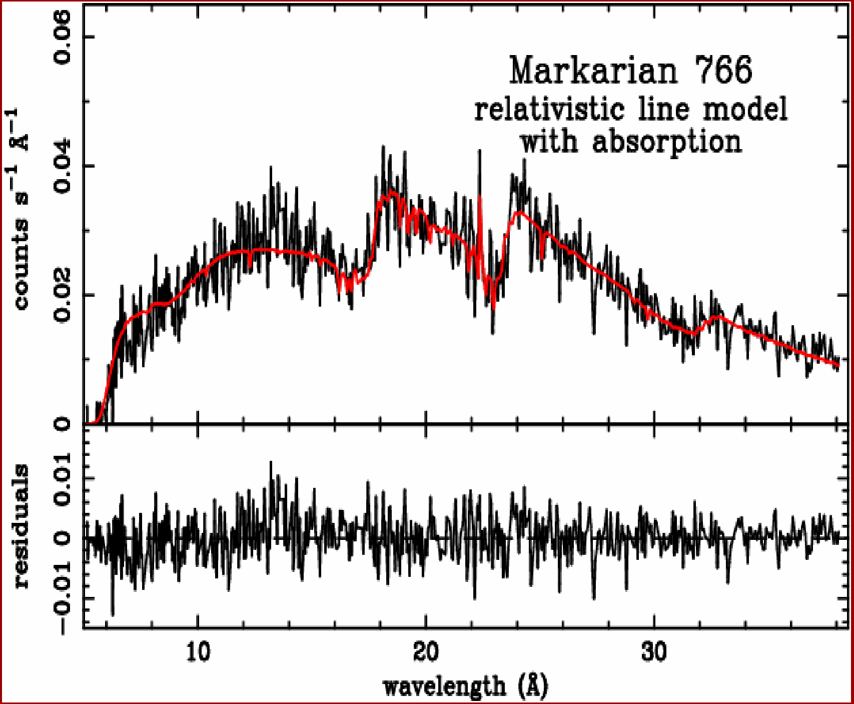
- RGS spectra of MCG-6-30-15 and Markarian 766
  (Branduardi-Raymont, Sako, Kahn, et al. 2001)

- Where does emission end and absorption begin?



Type I AGN (cont.): Relativistically Broadened Lines

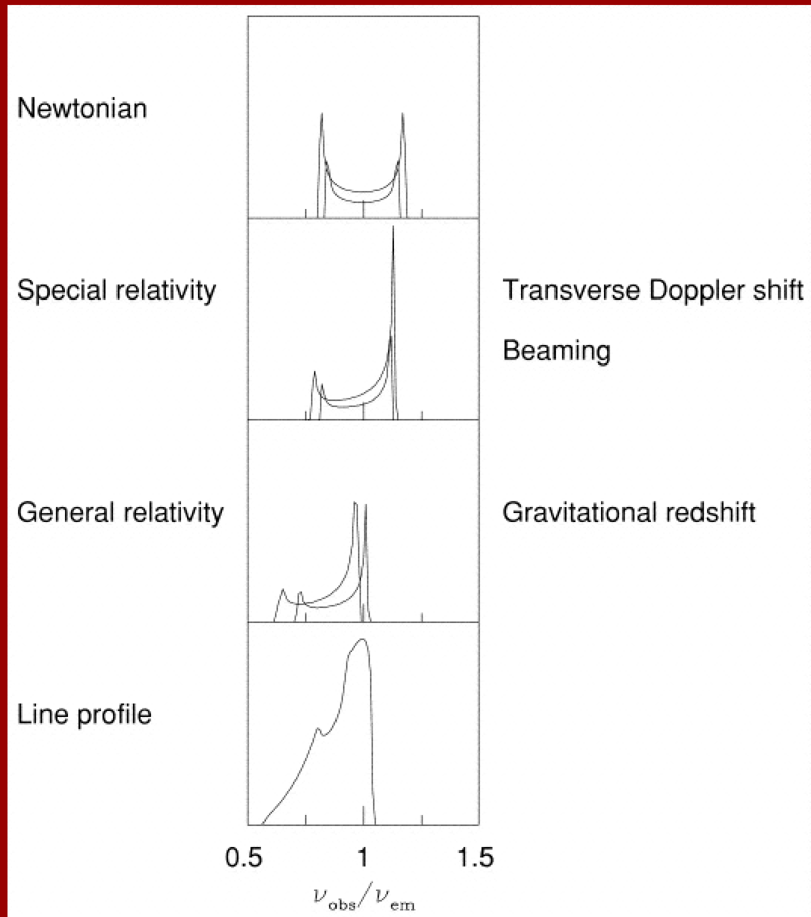




Branduardi-Raymont, Sako, Kahn et al. 2001

Spectral Lines Emitted Close to a Massive Black Hole

- ❖ Relativistically broadened lines
  - Have been observed before for the Fe-K fluorescence line
  - Provide accretion disk parameters:
    - ❖ Inclination angle
    - ❖ Emissivity profile
    - ❖ Inner most stable orbit



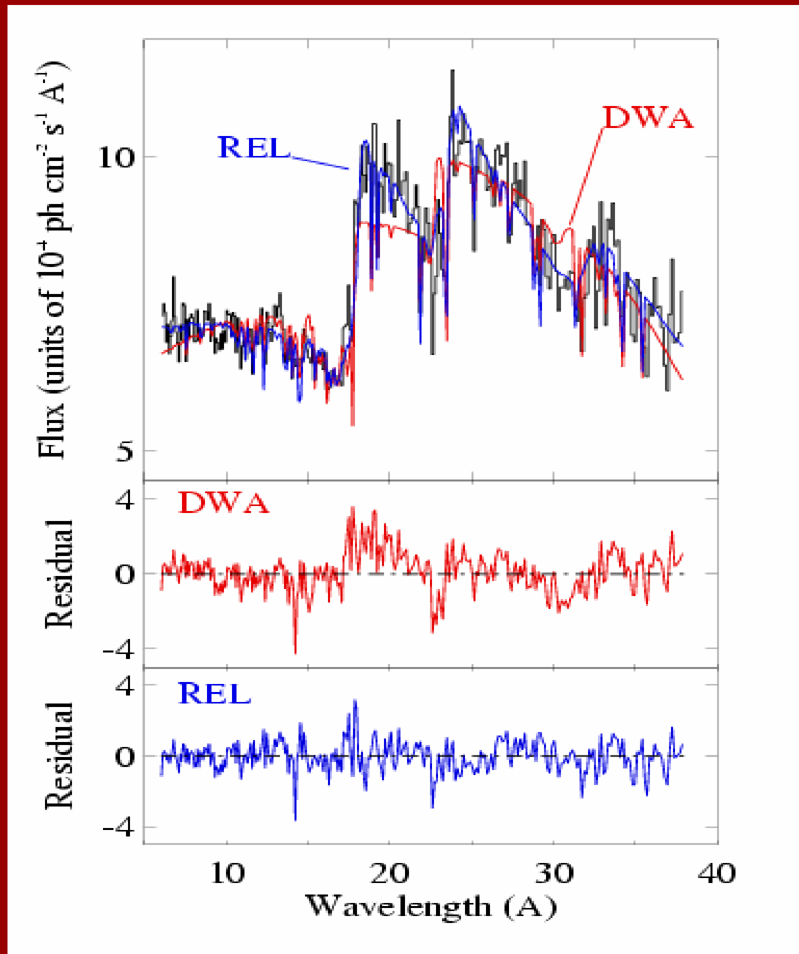
Fabian, Iwasawa, Reynolds, and Young, 2000

Type I AGN (cont.): Alternative Models Are Tested

- Comparison of relativistic line model (REL) with dusty warm absorber model (DWA) demonstrated on the RGS spectrum of Markarian 766

- Conclusions similar to those of Sako et al. (2002) that absorption alone can not explain the spectrum

- See also Kallman's talk earlier this morning

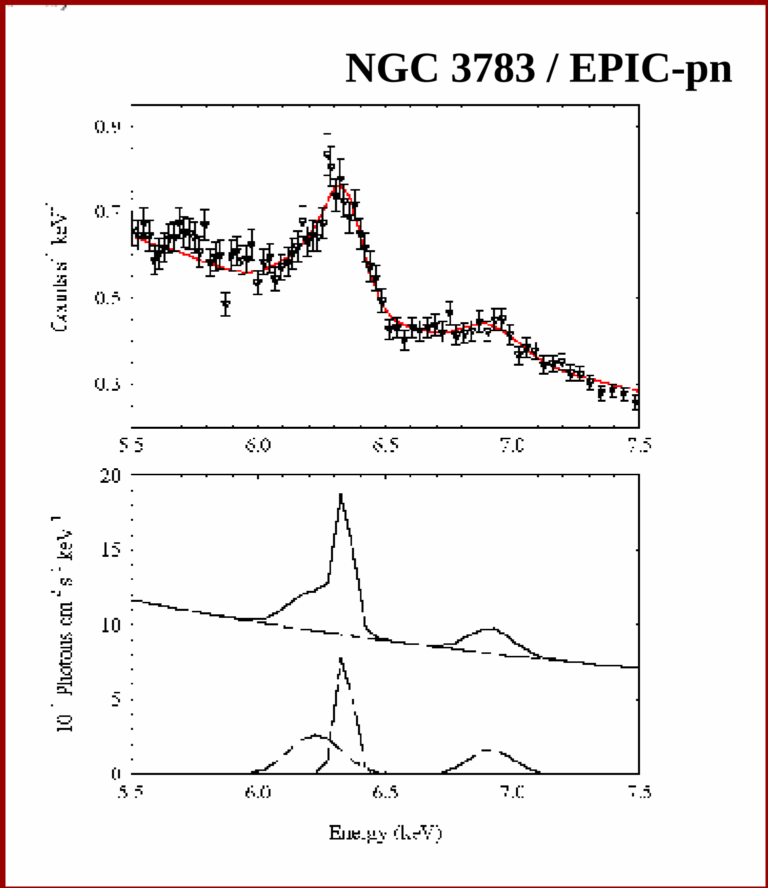


Mason et al. 2002

Type I AGN (cont.)
… and a combination thereof

- ❖ It is not uncommon to find in one source a combination of several components (narrow and broad) emitting the same line and overlapping in wavelength space

- ❖ The Fe-K fluorescence line: both narrow and broad (probably not relativistic)



Blustin, Branduardi-Raymont, Behar et al. 2002

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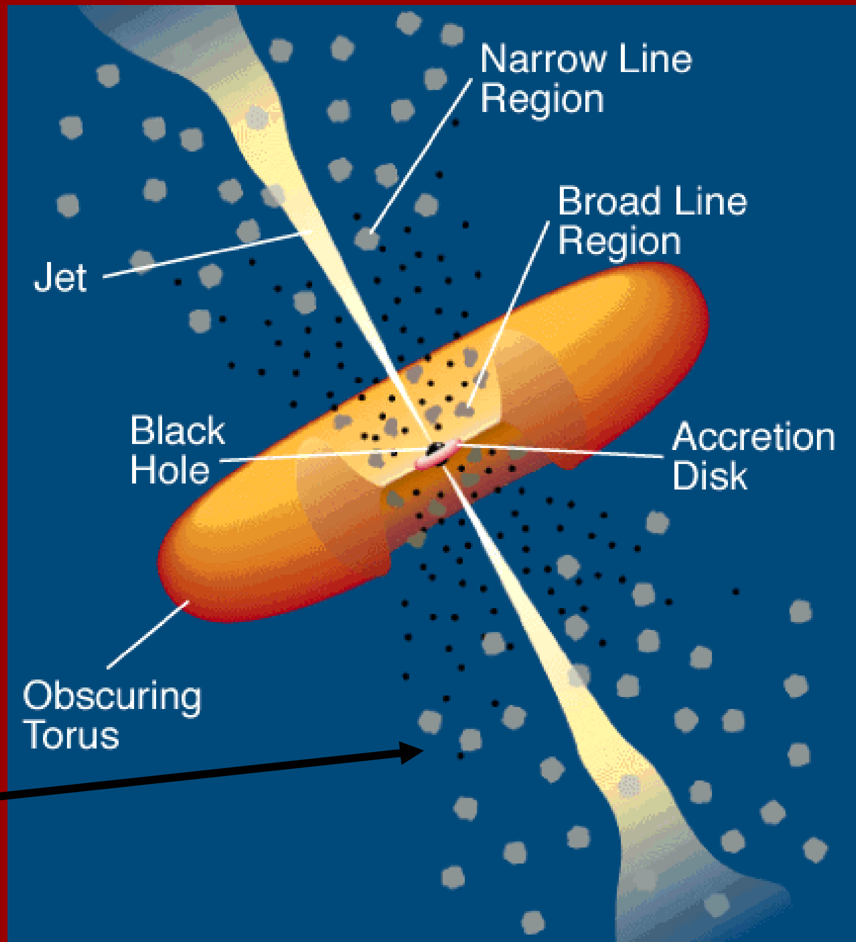
Type II AGN

❖ Same source (?), but different point of view:



observer

Differences Between Collisional and Photoionized (X-Ray) Plasmas

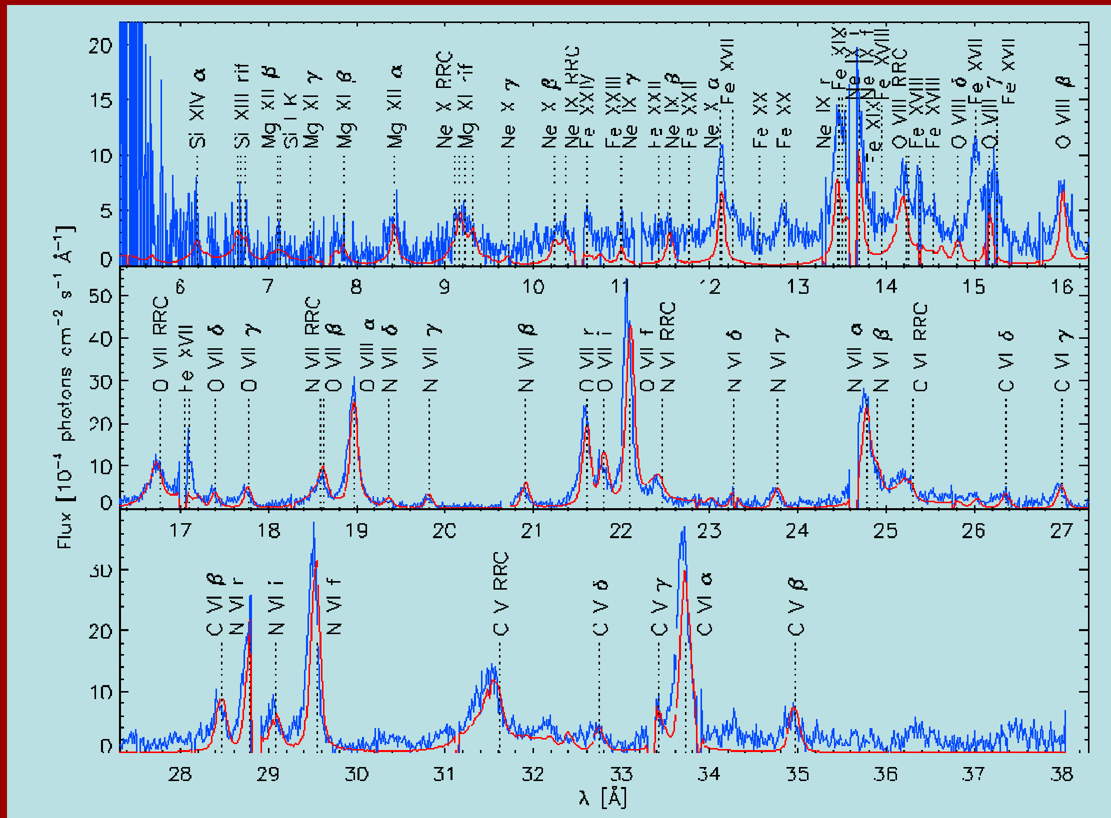
Collisional Plasma

- External energy source
(high temp. ~ keV)
- Electron impact ionization (T_e)
- Recombination:
DR ($\Delta n > 0$) and RR
- X-ray line production:
collisional excitation
and ensuing cascades
- Stellar coronae, SNRs, galaxies,
clusters, laboratory (generally)

Photoionized Plasma

- Only radiation field
(low temp. ~ eV)
- Photonization ($\xi = L / nr^2$)
- Recombination:
RR and DR ($\Delta n = 0$)
- X-ray line production:
recombination, cascades,
and photoexcitation
- X-ray binaries, AGN,
Z-pinch experiments

Type-II AGN (cont.): Discrete Emission

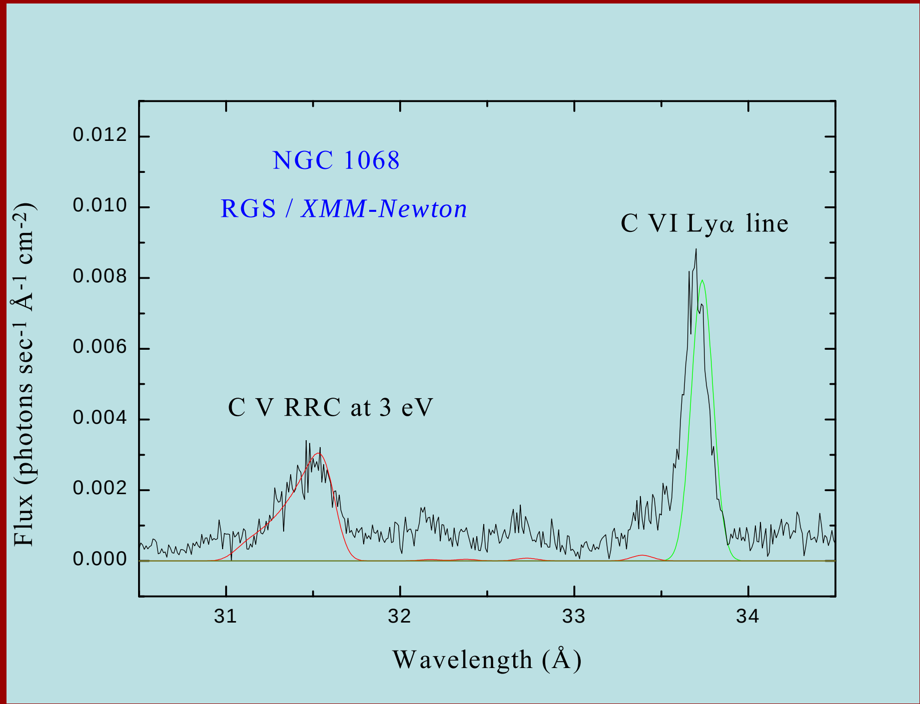


NGC 1068 / RGS

Kinkhabwala, Sako, Behar, et al. 2002

Type II AGN (cont.): The RRC

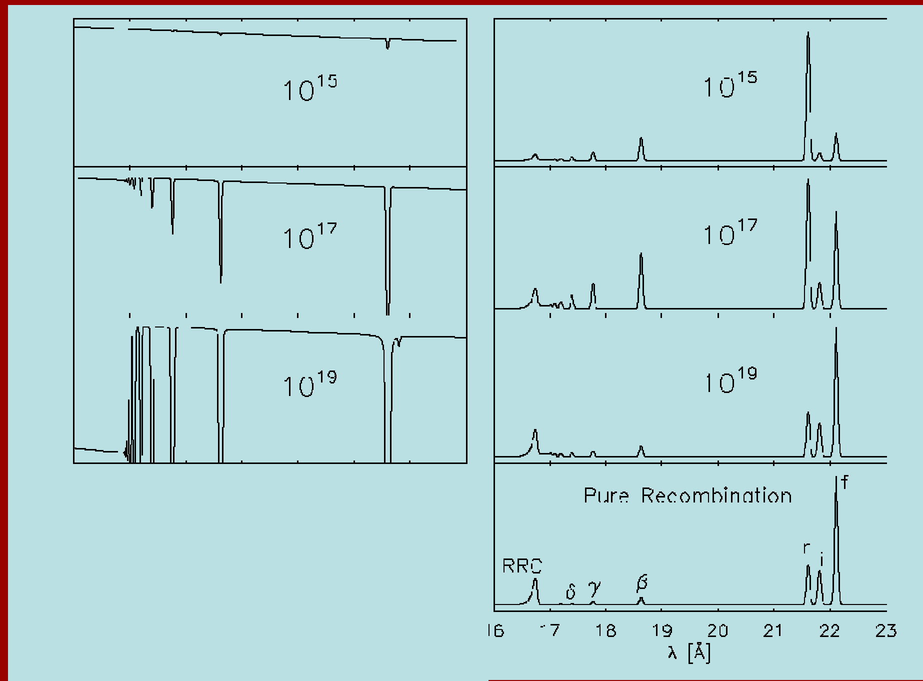
- Narrow Radiative Recombination Continuua (RRCs) resemble emission lines
- Their shape maps out directly the electron energy distribution (e.g., temperature)
- Indeed, temps. (kT_e) of a few eV are measured



Measuring Column Density *Perpendicular* to the Line of Sight

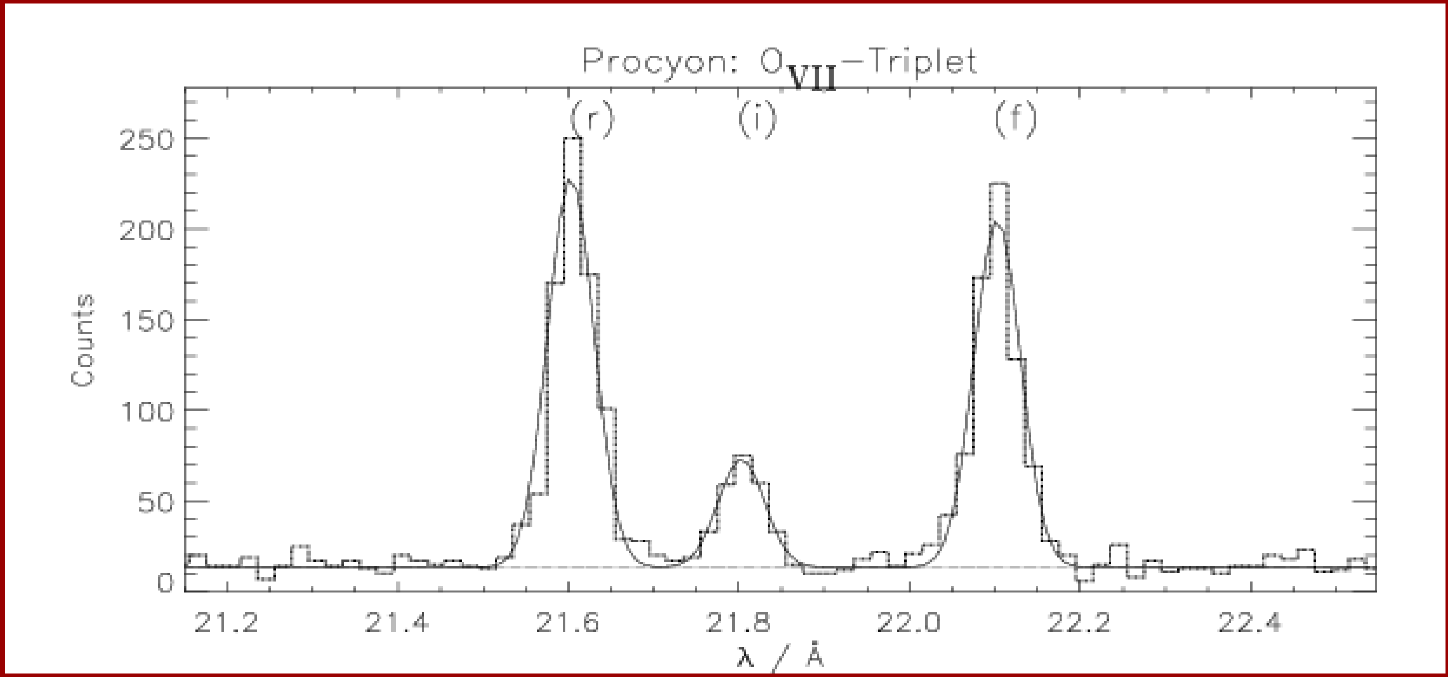
- Line ratios depend strongly on the balance between recombination and photoexcitation (PE), which, in turn, depends directly on the column density (& line width).
- When the resonance lines saturate, the PE contribution diminishes while recombination persists.
- The PE effect can be somewhat mimicked by hot collisional gas.
- This has caused confusion in the x-ray community in the context of the AGN-Starburst connection.
- Fortunately, the high-*n* lines remove this ambiguity.

Type I view **Type II view**



Kinkhabwala, Sako, Behar, et al. 2002

The He-Like Triplets



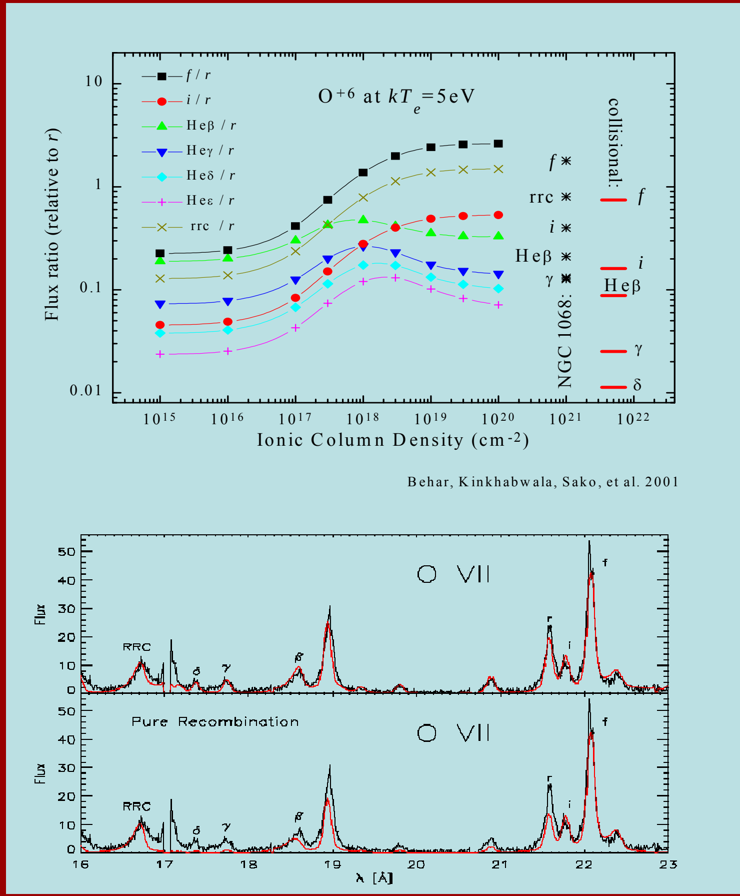
- ❖ In collisional plasmas, the resonance line is always the strongest.

Ness, Mewe, Schmitt et al. 2001

Type II AGN: Measuring Column Density (cont.)

- The high-*n* lines provide a clear distinction between AGN (PIP) and starburst (CIP).

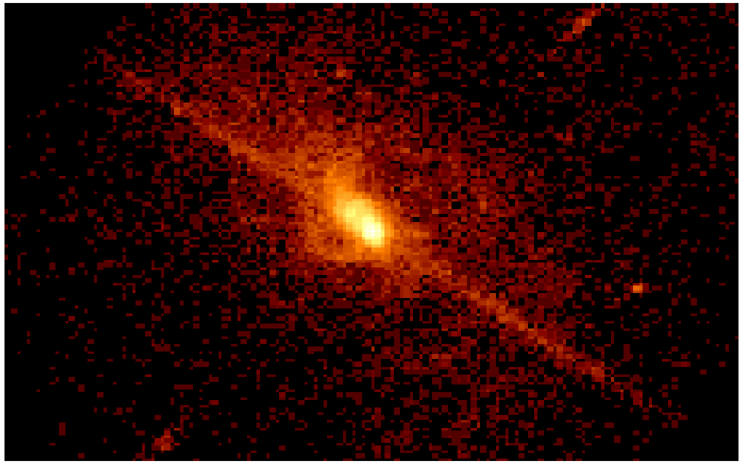
- The x-ray spectra of all type II AGN (e.g. NGC 1068) we have looked at so far can be explained by pure photoionization models (i.e., no starburst).

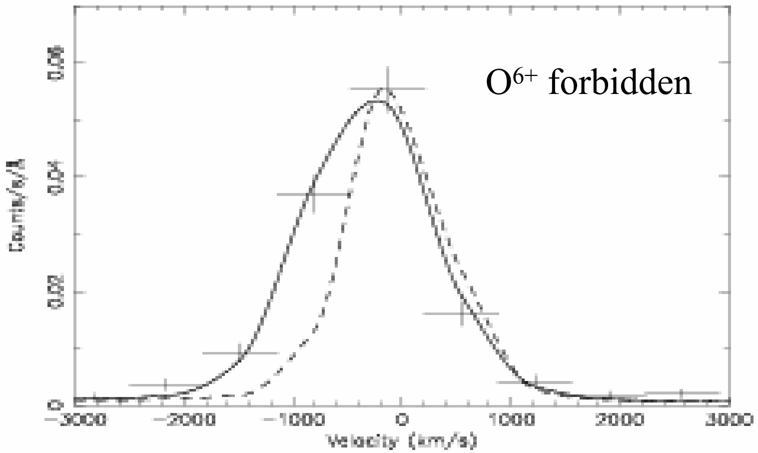


Kinkhabwala, Sako, Behar, et al. 2002

Type II AGN (cont.)
Measuring Velocity Widths

- *Chandra* (LETGS) just resolves the AGN in NGC 1068 and its line profiles
- 1.5 arcsec = 350 light yrs
- Spatial extent hampers percise velocity measurements (slitless spectroscopy!)
- Nonetheless, velocities can be constrained:
  v_{out} = -250 ± 20 km/sec
  v_{turb} = 320 ± 200 km/sec

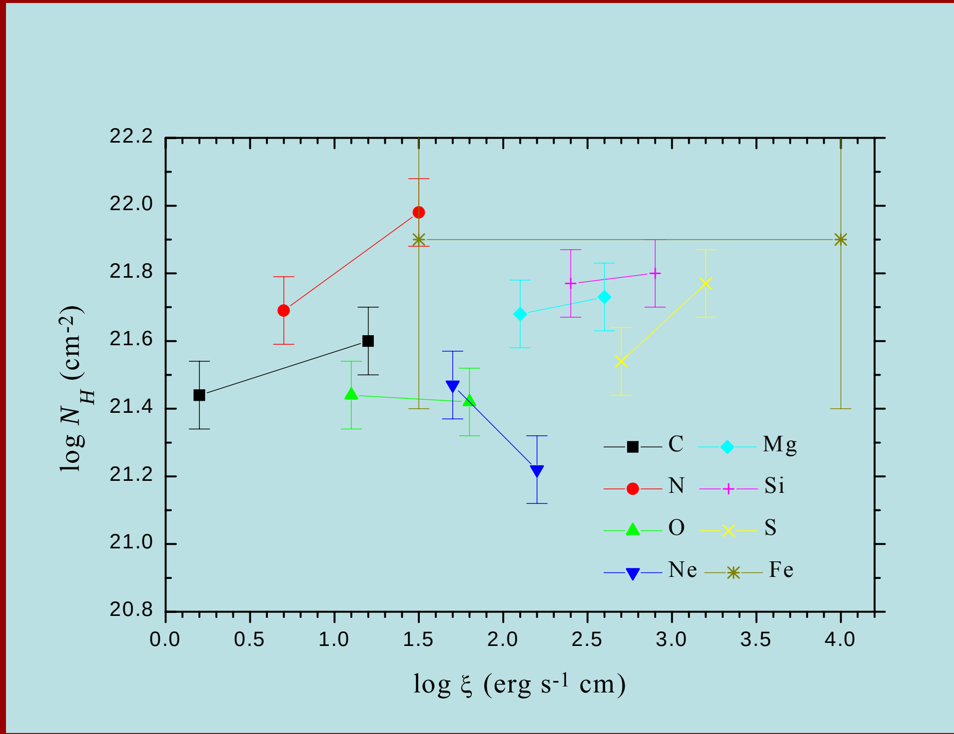




Type II AGN (cont.)
Measuring Elemental Abundances

- Vertical offsets in the N_H plot as a function of the ionization parameter ξ, as deduced from the measured *ionic* column densities N_i , reveal the *relative* elemental abundances:

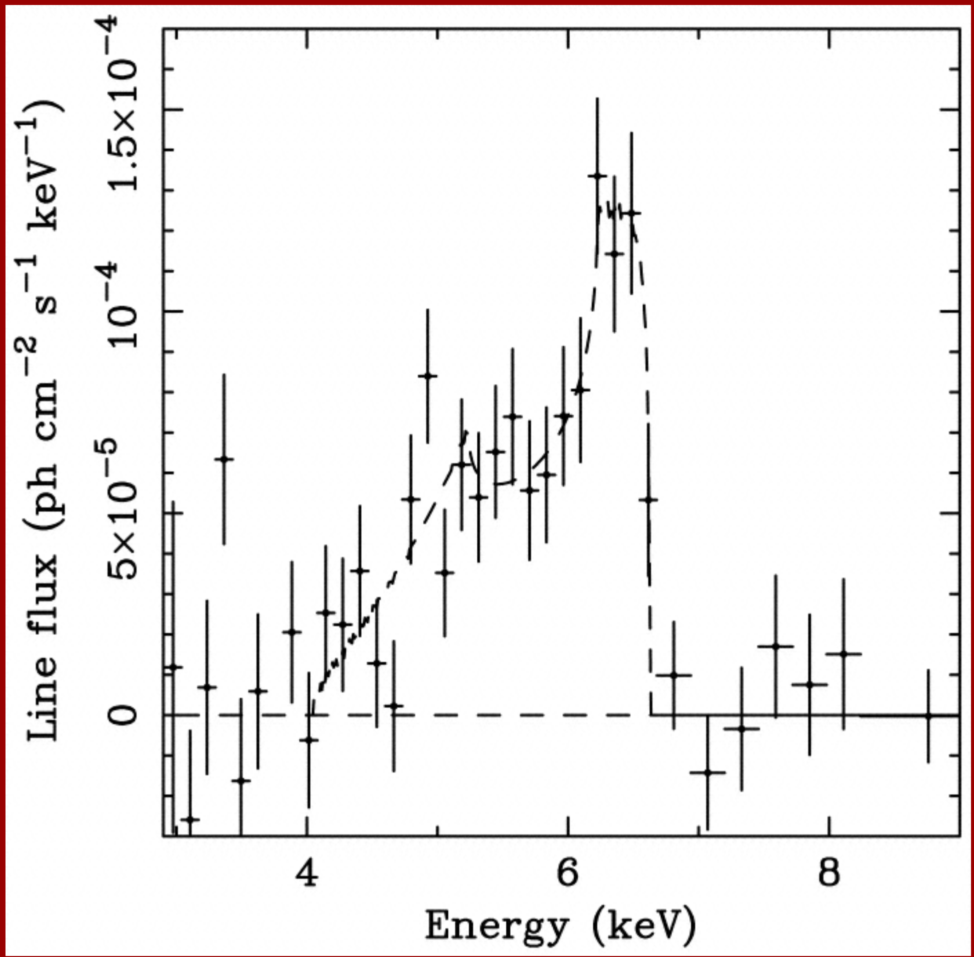
$$N_H = N_{i,z} \Big/ f_i(\xi_{\max}) A_Z$$



Summary: The X-Ray Type-I - Type-II AGN Connection

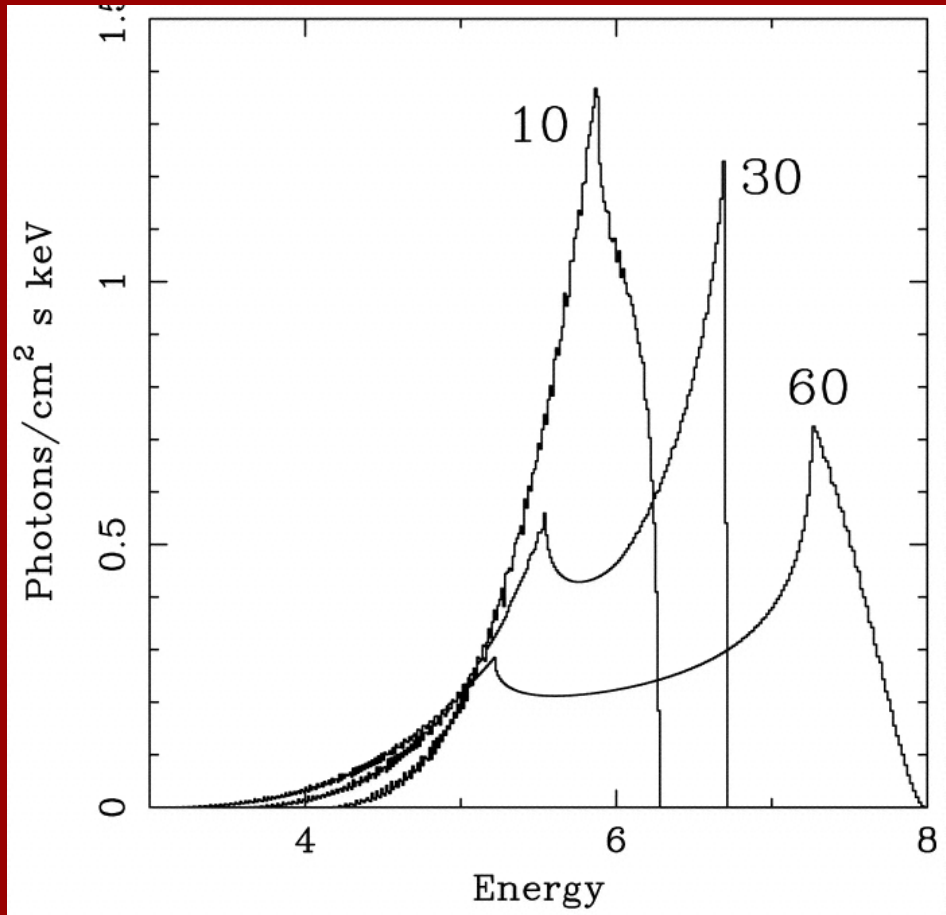
- The emitting/absorbing plasmas in both type I and type II AGN seem to feature similar characteristics and physical parameters:
  - Low photoionization temperatures (a few eV)
  - Outflow velocities (up to a few times 100 km/sec)
  - Turbulent (bulk) velocities (a few times 100 km/sec, but also 10,000 km/sec)
  - Column densities (N_H = a few times 10^{21} cm^{-2})
  - Solar elemental abundances (for the most part)
  - No significant x-ray emission by collisional plasma (i.e., no SB)
- Type I AGN are unique in providing a glimpse at the immediate BH environment
- All these reinforce the "canonical" unified picture of AGN in the x-rays
- A BIG question remains regarding the location (density) of the gas:
  - In type II AGN: observed to be extended up to a few 100 light yrs
  - In type I AGN: accurate timing measurements are required
- Connection to other wavebands is also established through broad and narrow emission lines (BLR and NLR) and also by inner-shell absorption

Fe-K line in the *ASCA* SIS spectrum of MCG -6-30-15



Tanaka et al. (1995)

GR lines: dependence of profile on inclination angle



Fabian et al. (2000)

Comparison of the Performance Characteristics of the *Chandra* and *XMM-Newton* Spectrometers