ACTIVE GALACTIC NUCLEI: The Splattering Blender

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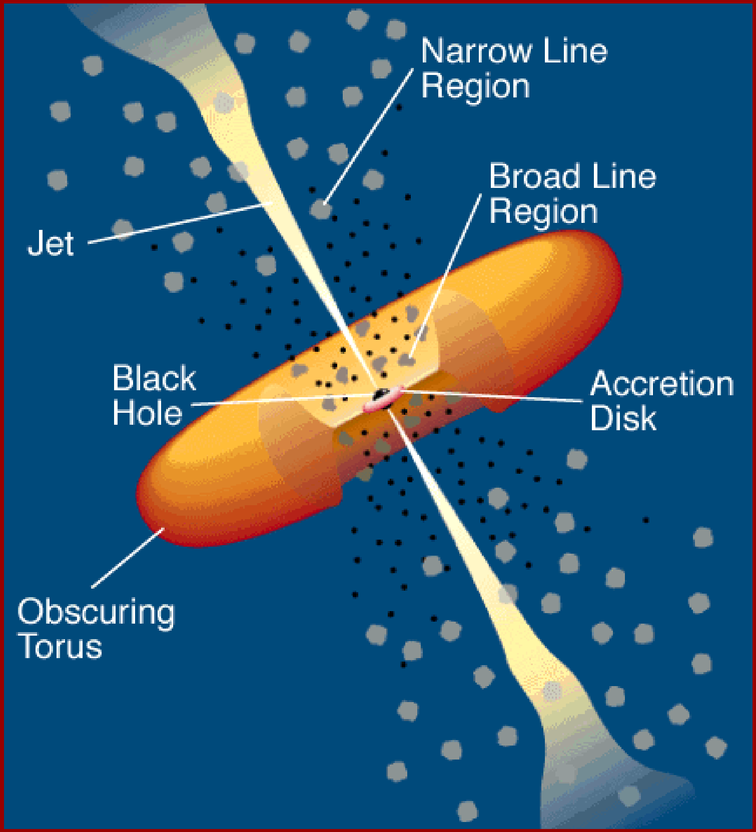
Outline

- Introduction
  - The Unified Picture of AGN
  - The X-Ray View of This Picture
  - Open Questions
- High Precision X-Ray Measurements
  - Grating Observations with *XMM-Newton* & *Chandra*
  - The Measurable Quantities
- Very Long RGS Observation of NGC 3783
  - Spectral Variability
  - Absorption & Emission by Oxygen
- Comparison with Other X-Ray & UV Observations
- Ultra-fast Quasar Outflows

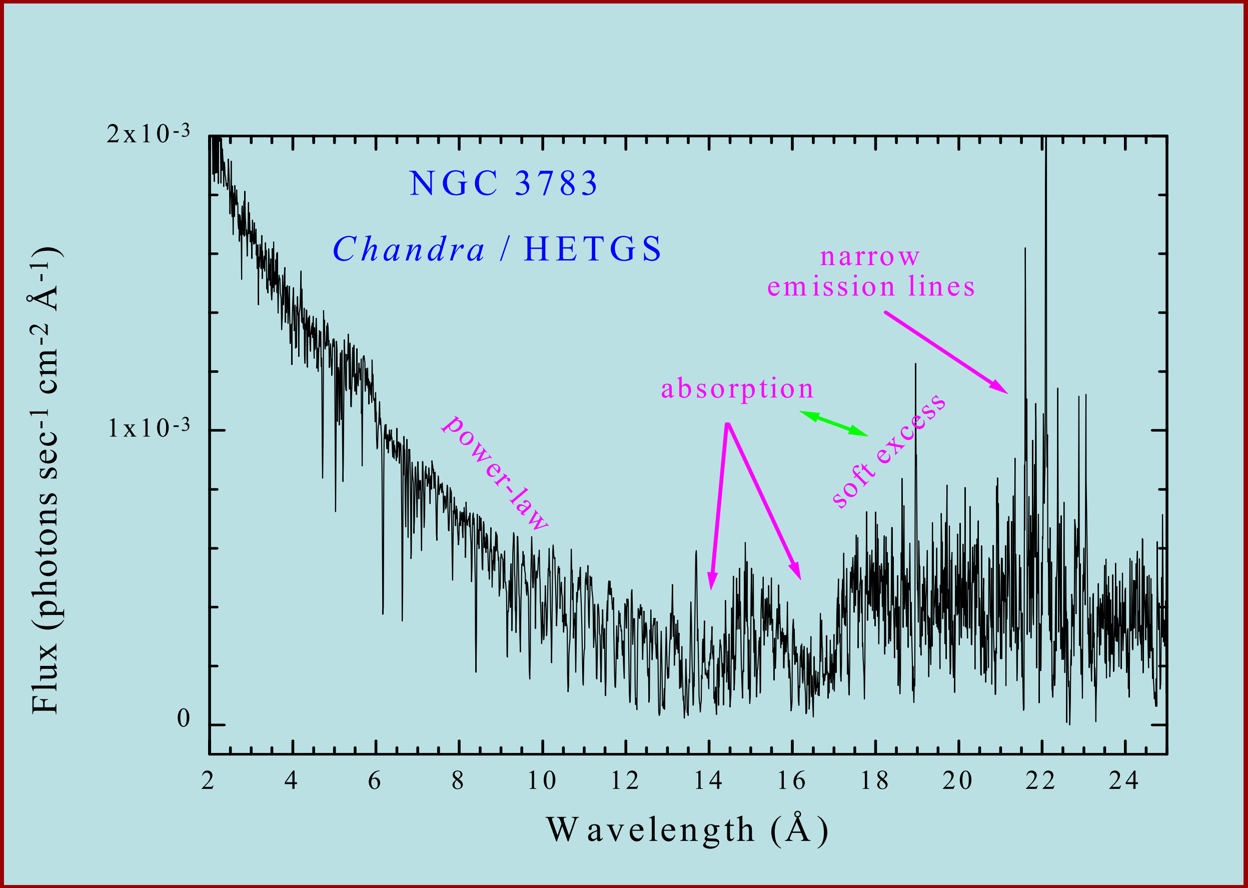
Active Galactic Nuclei (AGN)

- “Canonical” Picture of AGN based on UV, optical, and radio observations:
  - Central Engine: Supermassive BH
  - Accretion through disk
  - Dusty structure (torus)
- Giving rise to two “types” of AGN, depending on observer’s position (Antonucci & Miller 1985)

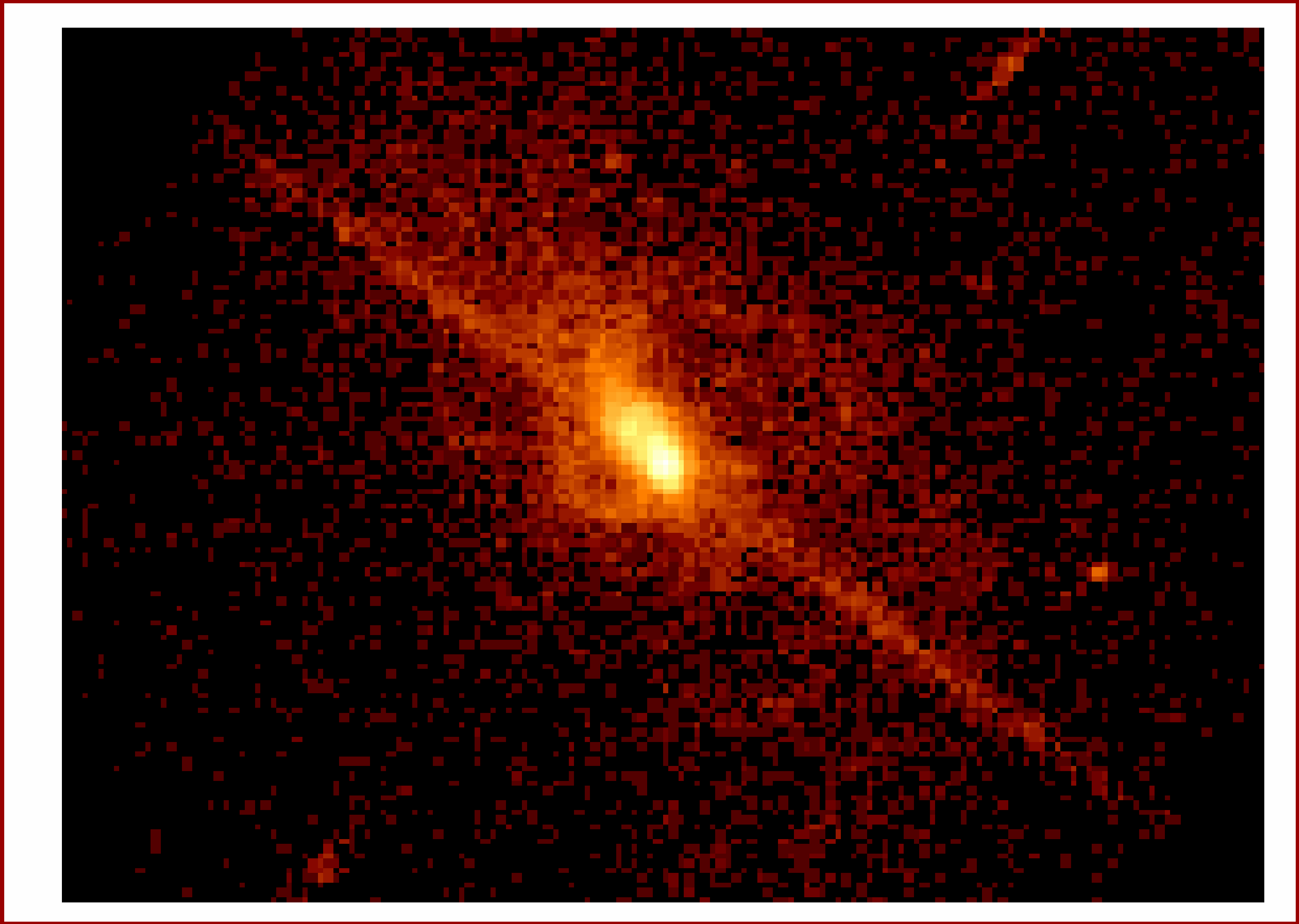


Cartoon by Urry and Padovani

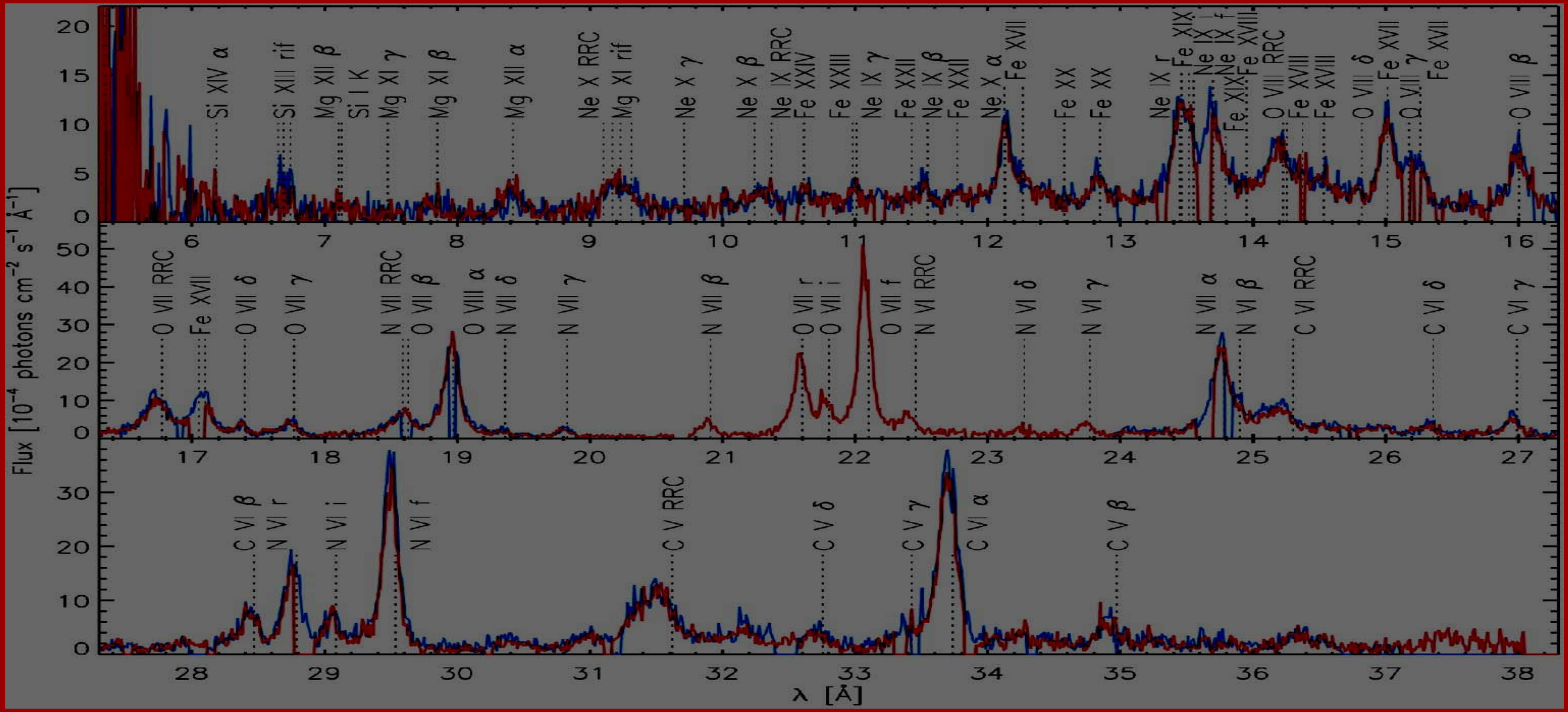
Type I AGN, The X-Ray Picture: Point Source Absorbed By Outflow



Type II AGN, The X-Ray Picture: Extended Emission



… Photoionized by the Central Source



=> At least qualitatively, so far,
the unified model holds in the X-ray regime

More Quantitatively: Open Questions Regarding The X-Ray Outflows

- WHERE is this X-ray absorbing gas located?
  - Is it the same extended gas that we see in type II's (as I would like to think)?
  - Or, is it next to the BLR (as suggested until recently by everybody)?
- WHAT is the GEOMETRY and PHYSICAL FORM of the X-ray absorber/emitter?
- Is the X-ray outflow SIGNIFICANT for the AGN system in terms of mass and energy, or is this "AGN weather"?
  (IS THIS A WORTHWHILE RESEARCH TOPIC?)
- Is the picture we get from the nearby Seyferts APPLICABLE also to high-luminosity quasars?

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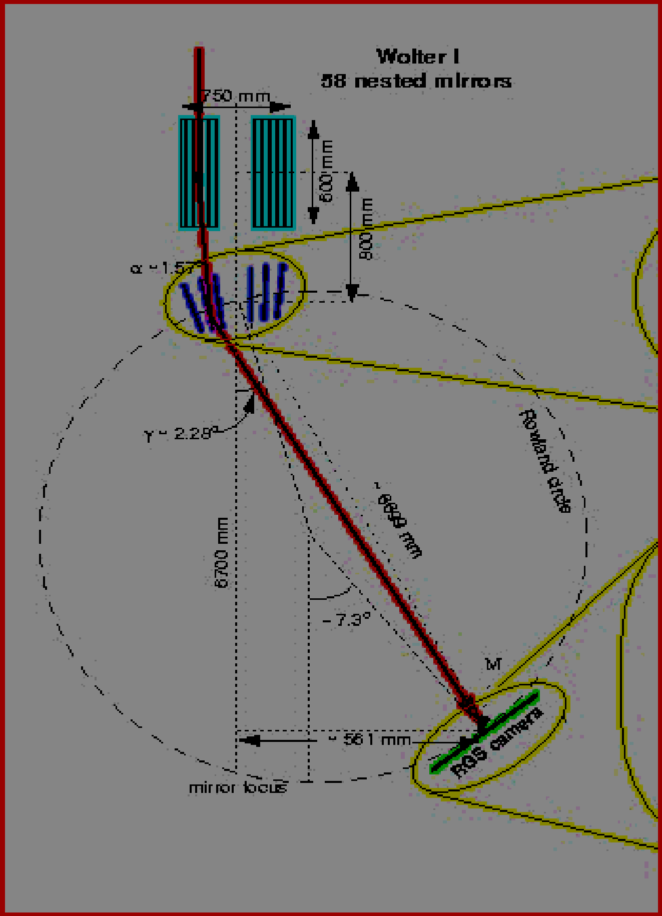
Golden Era of X-Ray Astrophysics: *Chandra* and *XMM-Newton*

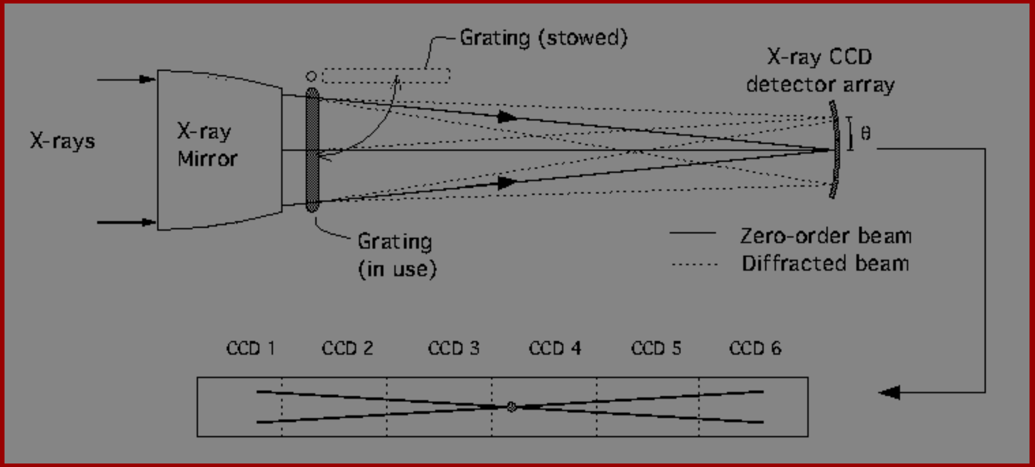
- **The *Chandra* Observatory**
  Launched by NASA July 23, 1999
  Payload:
  1 telescope, 2 CCD cameras,
  2 transmission grating spectrometers (HETGS & LETGS)

- ***XMM-Newton***
  Launched by ESA December 10, 1999
  Payload:
  3 telescopes, 3 CCD cameras,
  2 reflection grating spectrometers (RGS)

The Grating Spectrometers



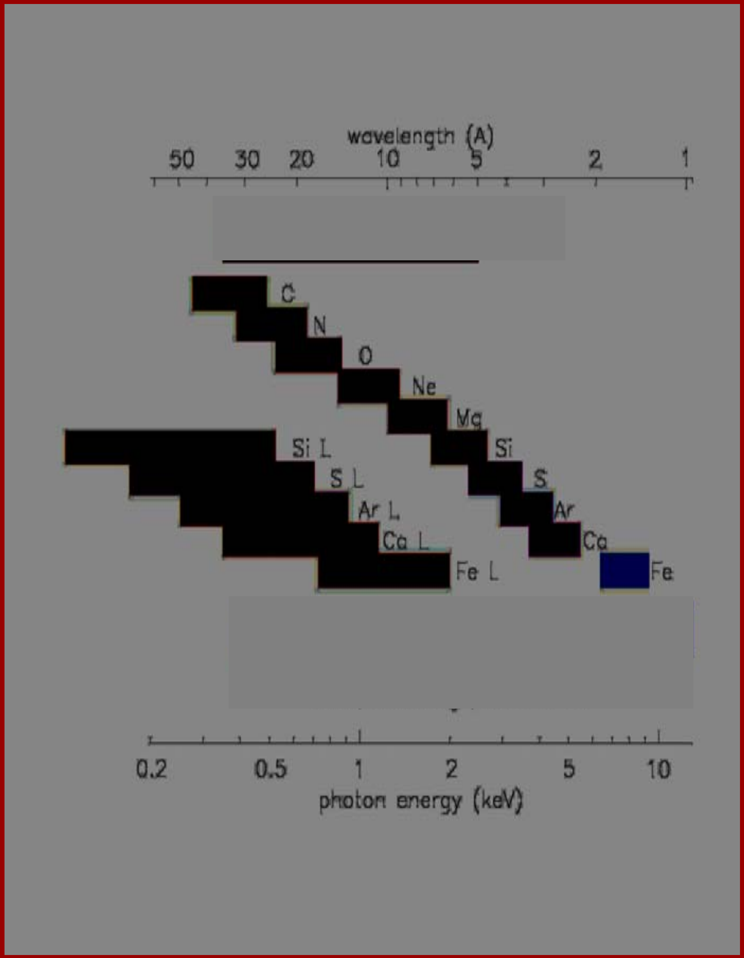
Reflection (*XMM-Newton*) and Transmission (*Chandra*)



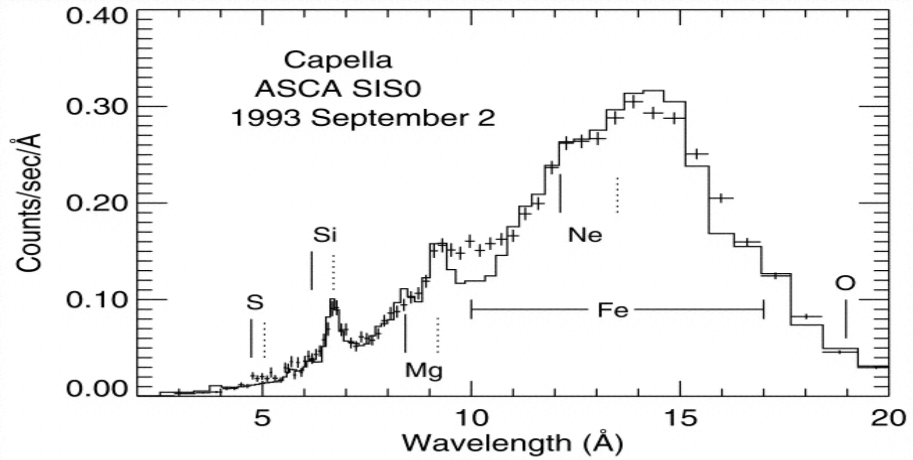
The X-Ray Band: Observing Highly-Ionized Atoms

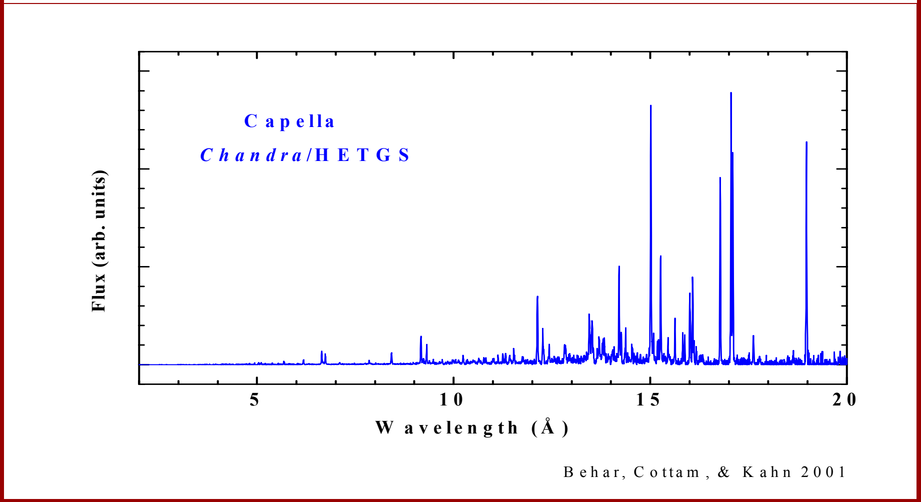
- Roughly 0.2 – 12 keV or 1 to 60 Å
- Extremely rich in spectral lines of many K-shell and L-shell ions
- ALL of the cosmically abundant ELEMENTS from C …, Fe, Ni, …
- Uniquely compact: SEVERAL IONS pertaining to each element (ALL IONS in absorption)
- ENTIRE SERIES of spectral lines

=> Elaborate and robust PLASMA DIAGNOSTICS over a wide range of temperatures, densities, column densities, ionization states, and elemental abundances.



The Difference High Spectral-Resolution Makes





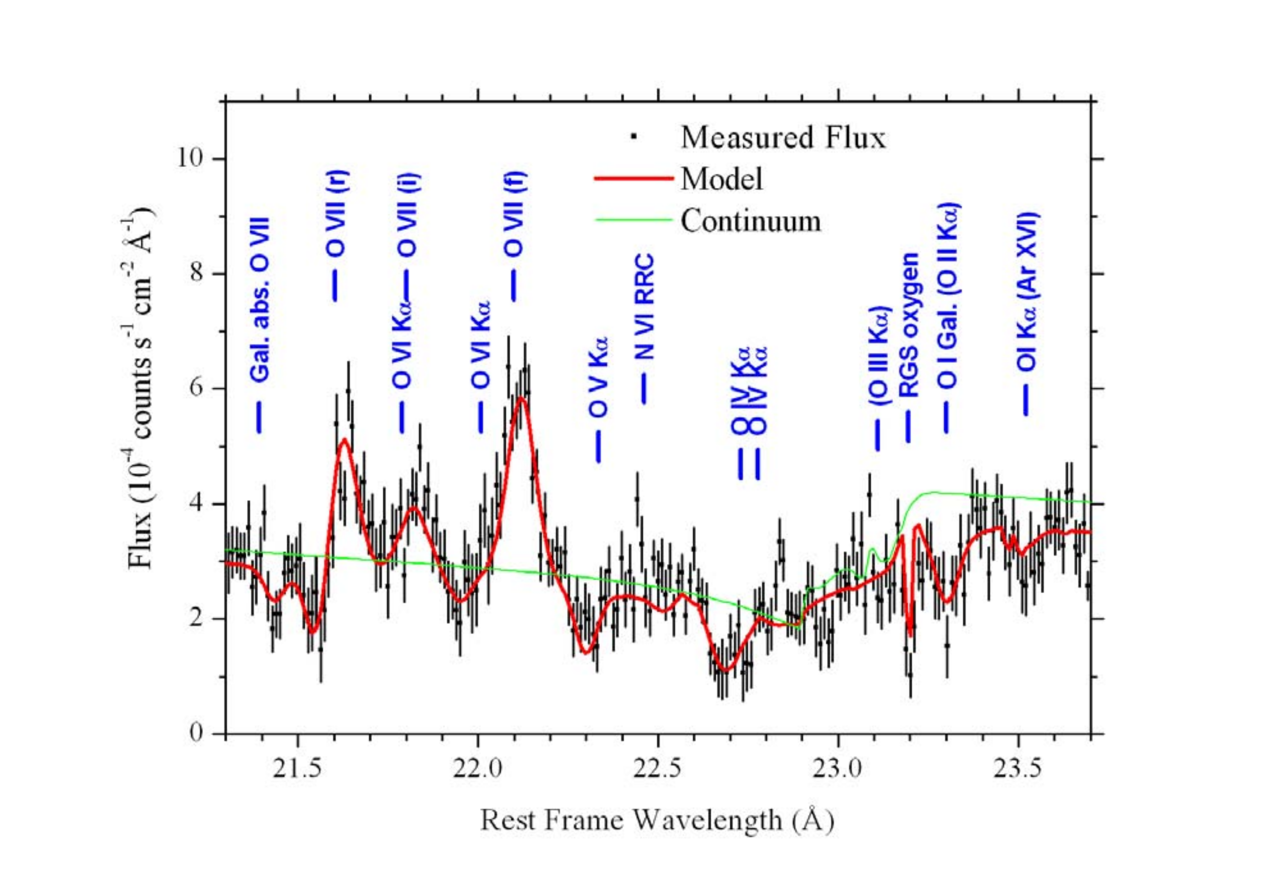
ASCA spectrum

Brickhouse, Dupree, Edgar et al. 2000

Measurements made Possible with Line-Resolved Spectroscopy

- line id's =>
  ionization state & chemical composition
- line centroids => outflow velocities
- line profiles => kinematic structure
- absorption equivalent widths & photoelectric edge depths => column densities
- emission line fluxes =>
  volume emission measure (& column densities)

Indeed, Spectrum is Rich with Absorption & Emission Lines



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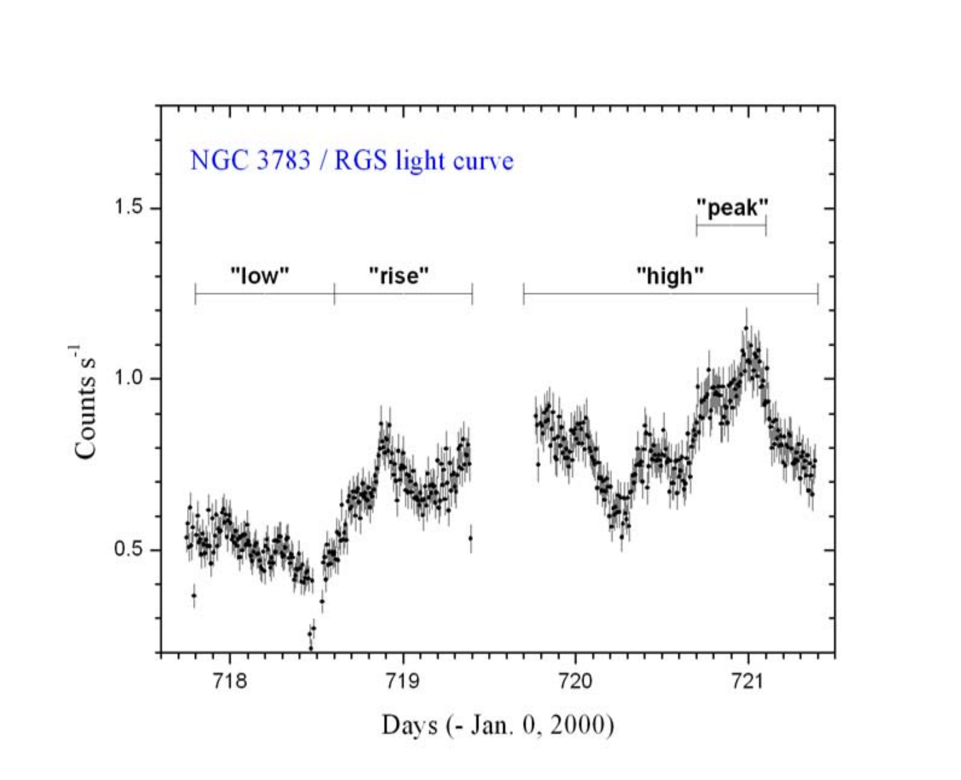
XMM-Newton & the RGS Stare Down NGC 3783

- *XMM-Newton* observed NGC 3783 for 280 ks as part of the RGS guaranteed time program during December 17-21, 2001
- The primary goal of the observation was to shed new light on the location, geometry, and form of perhaps the best warm absorber accessible for grating spectroscopy (Kaspi et al. 2000, 2001, 2002)
- The RGS detected more than 200,000 source photons producing the deepest yet exposure of an ionized absorber (along with the long HETGS observation)

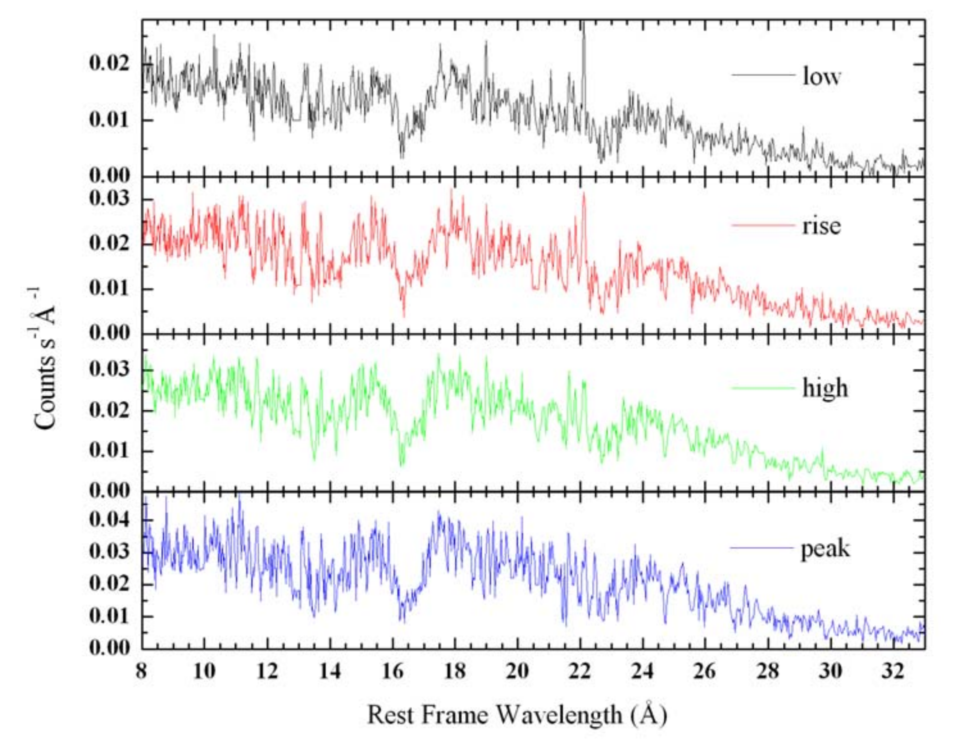
Variability, Definitely!
But, *Spectral* Variability?

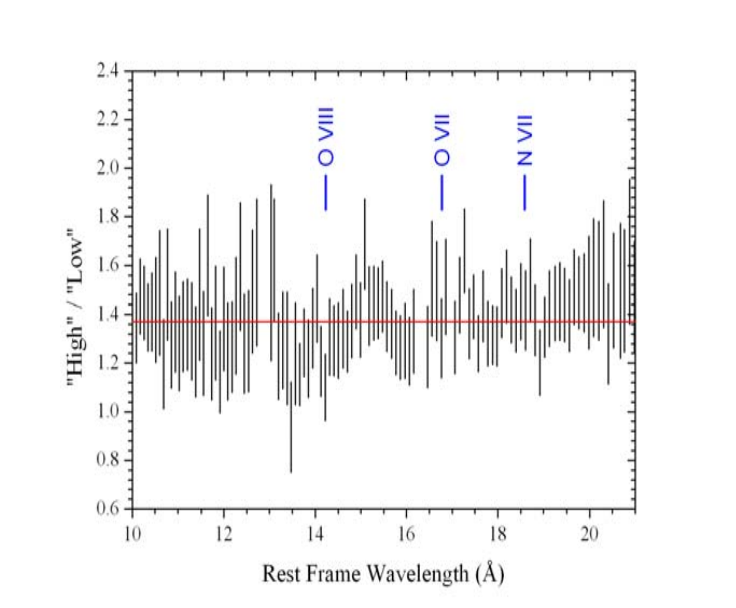


- Change in the absorber's ionization state lagging after the rise of the ionizing continuum, could potentially give us the absorber's position along the line of sight

$$\tau_{ion}^{-1} = \int \sigma^{PI}(E) F_E(E) dE = \int \sigma^{PI}(E) F_E^{obs}(E) \frac{d^2}{r^2} dE$$

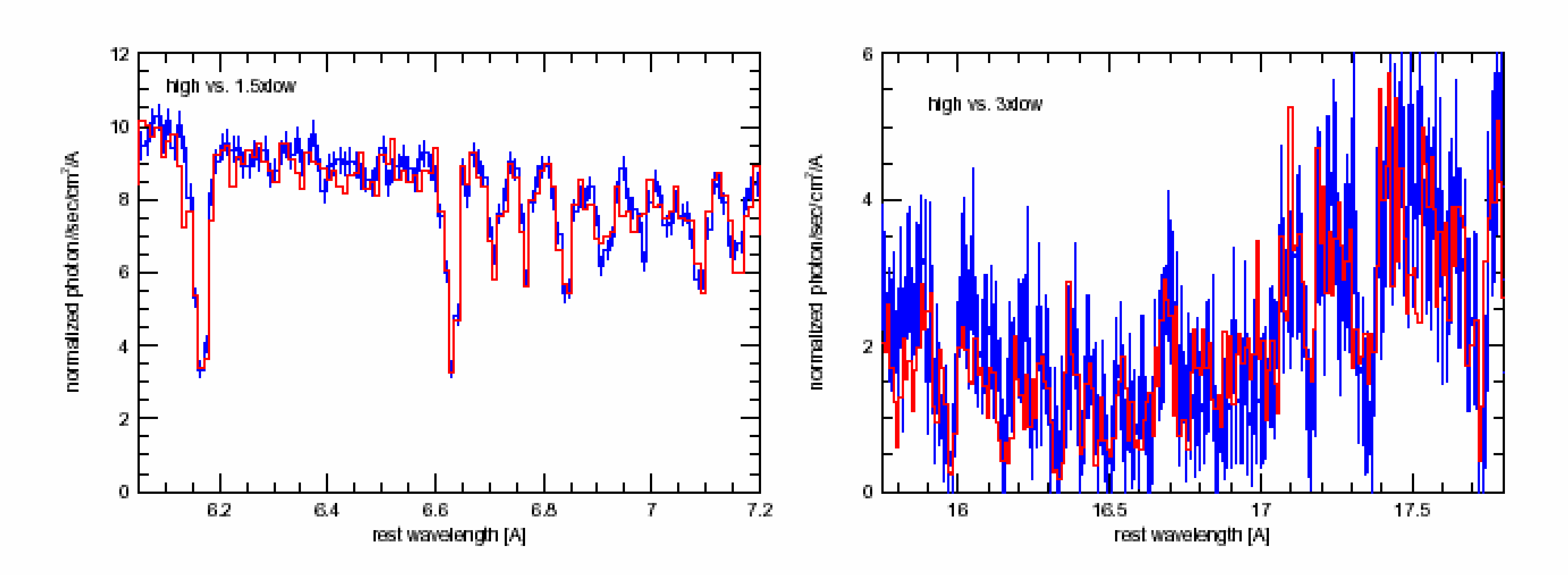
Apparently, No Spectral Variability Over ~ Day





$=> r_{OVII} \geq 0.5\ pc;\ r_{FeM} \geq 3\ pc\ (r_{BLR} \leq 0.003\ pc)$

Chandra/HETGS Finds No Spectral Variability Either



Netzer et al. (2003)

Relating Measured Quantities to Desired AGN Parameters

$$N_H \equiv \int_{r_{min}}^{r_{max}} n_H dr = \frac{n_H}{n_e}\frac{L}{\xi}\left(\frac{1}{r_{min}} - \frac{1}{r_{max}}\right) \quad \left(\equiv \frac{N_{ion}}{f_q A_{el}}\right)$$

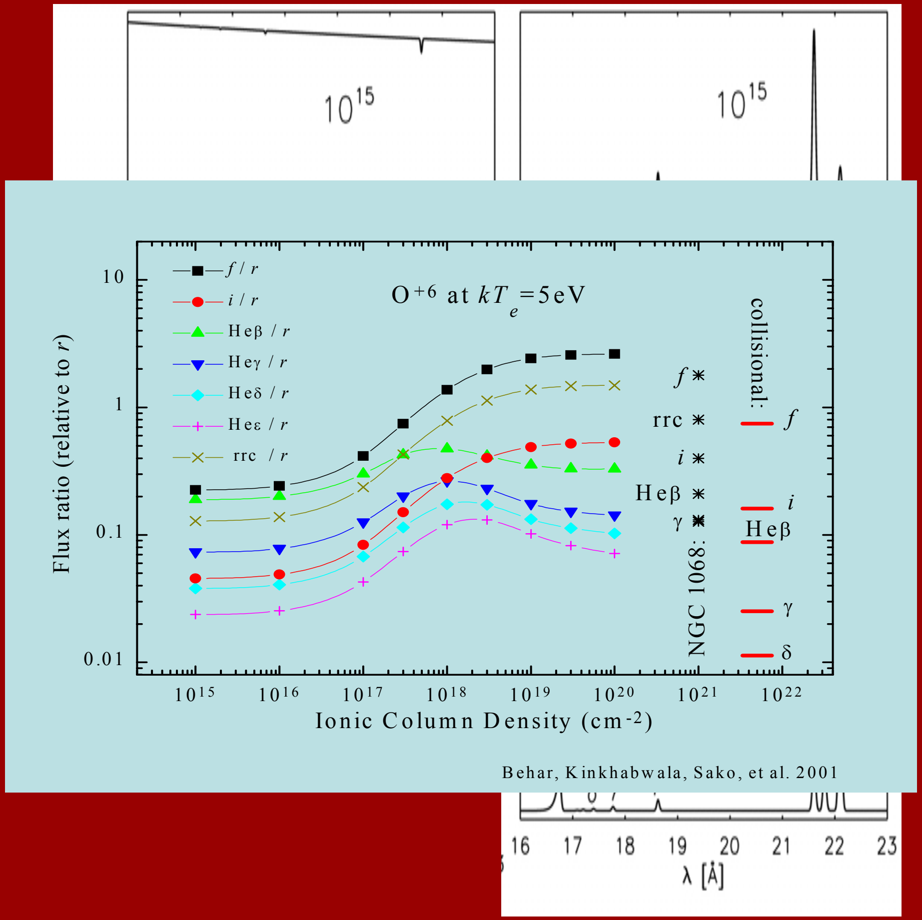
(where the ioniz. param. $\xi = \frac{L}{n_e r^2}$ is equivalent to T_e in hot plasma)

$$EM = \frac{n_H}{n_e}\langle n_e\rangle^2 V \quad \left(= \frac{4\pi d^2 F_{ji}}{f_q A_{el} P_{ji}} = \frac{EM_{ion}}{f_q A_{el}}\right)$$

- We measure N_H (via τ_{ji} , τ_∞), $\xi(q)$, L, & EM (F_{ji}), and know n_H/n_e , d, and P_{ji}
- Still, it is impossible to solve separately for r_{min} & r_{max} or for $\langle n_e \rangle$ & V

Reasons to Believe the X-Ray Absorber & Emitter are Connected

- Focusing on Oxygen-K …
- P Cygni profiles:
  λ_0^{em} = 300 ± 230 km/s ;
  λ_0^{ab} = - 600 ± 150 km/s
- Similar velocity widths:
  em.: 1220 ± 230 km/s ;
  ab.: 820 ± 280 km/s
- Similar ionization state:
  ξ = 30 erg s^{-1} cm
- Similar inferred ionic column densities (O VII):
  (1 ± 0.3) × 10^{18} cm^{-2}



Geometrical Scenarios

- Localized clouds (e.g., BLR):

$\Delta r \equiv r_{max} - r_{min} \ll r \Rightarrow V = \Delta r^3$

⇒ $EM = (n_H/n_e) n_e^2 \Delta r^3$

⇒ $N_H = (n_H/n_e)(L/\xi)(\Delta r / r^2)$

⇒ with $\xi \Rightarrow \Delta r, r, n_e$

⇒ BUT, we get $\Delta r \approx r \approx 10$ pc

⇒ … Cannot be

- Ionization Cones (e.g., type II AGN):

$dV = 2\Omega r^2 dr \,;\, r_{max} \gg r_{min}$

⇒ $EM = 2\Omega N_H (L/\xi$

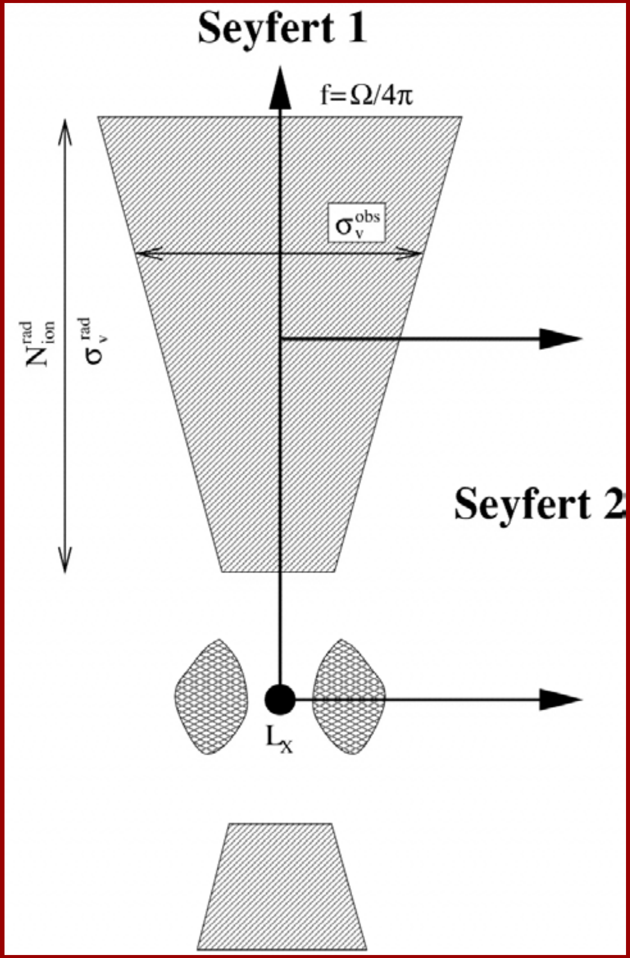
⇒ $N_H = (n_H/n_e)(L/\xi) r_{min}^{-1}$

⇒ with $\xi \Rightarrow \Omega, r_{min}, n_e$

⇒ $r_{min} = 10$ pc ;
$2\Omega / 4\pi = 10$-30 % (≈25 %) ;
$n_e \leq 600$ cm^{-3}

Ionization Cone Geometry

- Consistent with present observation
- Consistent with imaging and spectroscopic observations of Seyfert 2's
- Consistent with occurrence of absorbing outflows
- Therefore, reinforces AGN unified picture in the X-rays
- r_{max} not constrained, but EM and N_H per unit distance scale as r^{-2} (because $n \sim r^{-2}$)



Outflow Mass Estimates

$$M = \int_{r_{min}}^{r_{max}} n_H \mu m_H dV = \frac{n_H}{n_e} \int_{r_{min}}^{r_{max}} \frac{L}{\xi r^2} \mu m_H 2\Omega r^2 dr$$

$$\dot{M} = \frac{n_H}{n_e} \frac{L}{\xi r^2} \mu m_H 2\Omega r^2 v_{out} = \frac{n_H}{n_e} \frac{EM}{N_H} \mu m_H v_{out}$$

yields 2 - 6 x 10^{33} g yr^{-1}, to be compared with:

$$\frac{L_{bol}}{\dot{M}_{acc} c^2} = 5\% =>$$

0.4 x 10^{33} g yr^{-1}

If true, this is more than just "AGN weather".
It is the "splattering blender".

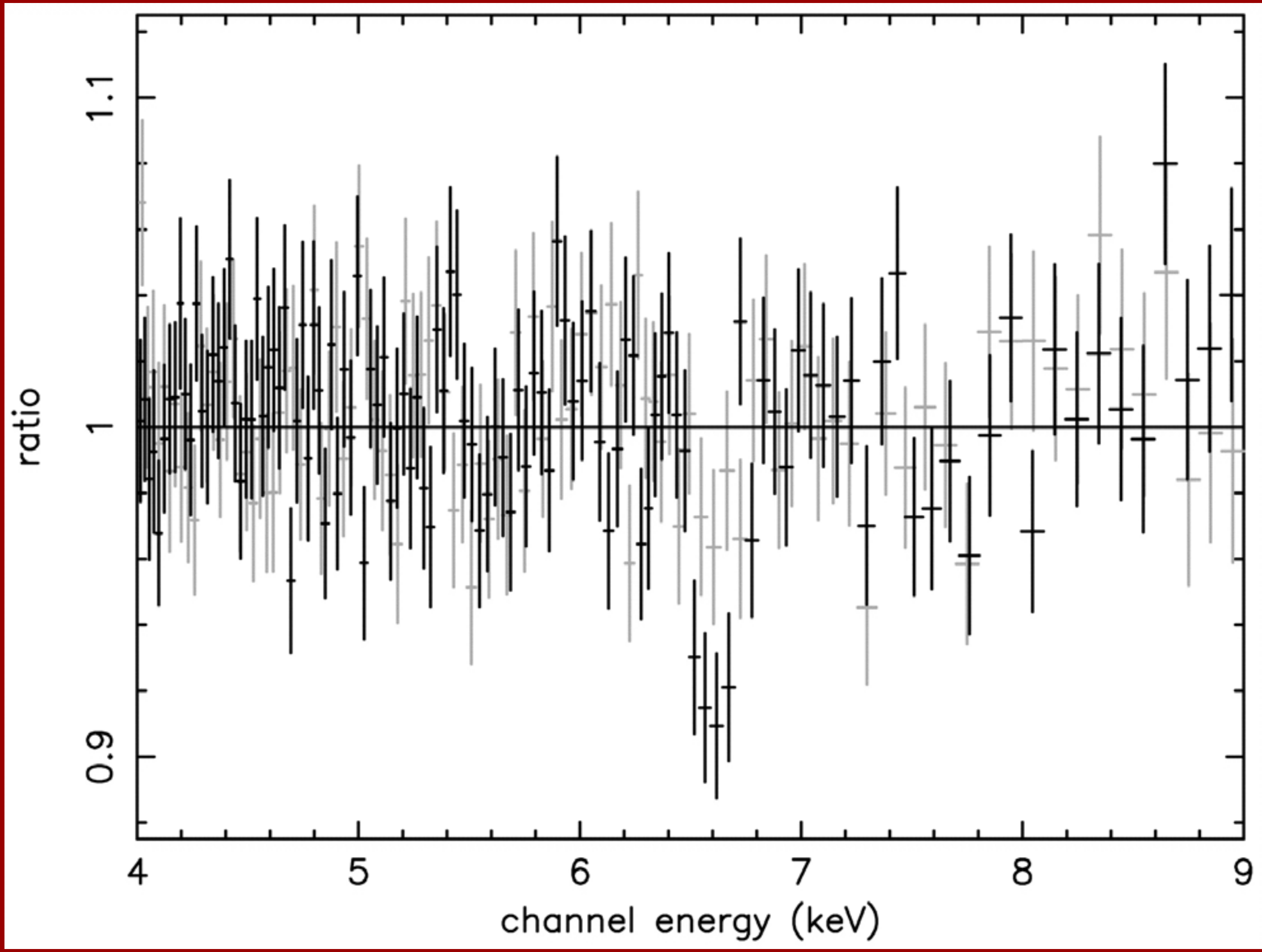
Does A Huge Mass Outflow Make Sense?

- In terms of energy, for the low-*L* AGN, radiation and accretion still dominate the energy budget (*v* << *c*):

$$\frac{L_{outflow}}{L_{bol}} = \frac{\frac{1}{2}\dot{M}_{out}}{5\%\dot{M}_{acc}}\left(\frac{v}{c}\right)^2 \cong 4\times 10^{-4}$$

- For high-luminosity quasars, outflow rate not clear
- Radiation Pressure? Needs to be Verified

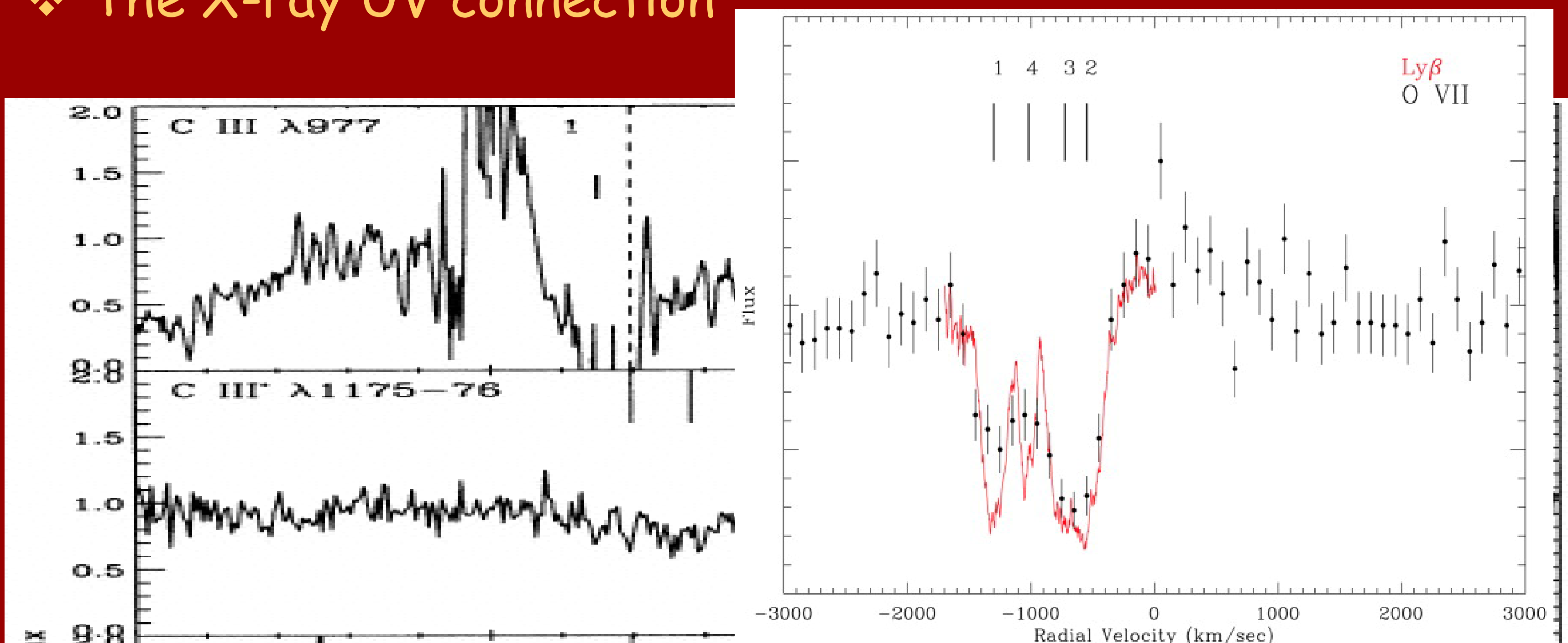
Fe-K CCD Spectrum Does Vary. Stratification?



Reeves et al. 2004

Comparison with Other Observations - NGC 3783 in the UV

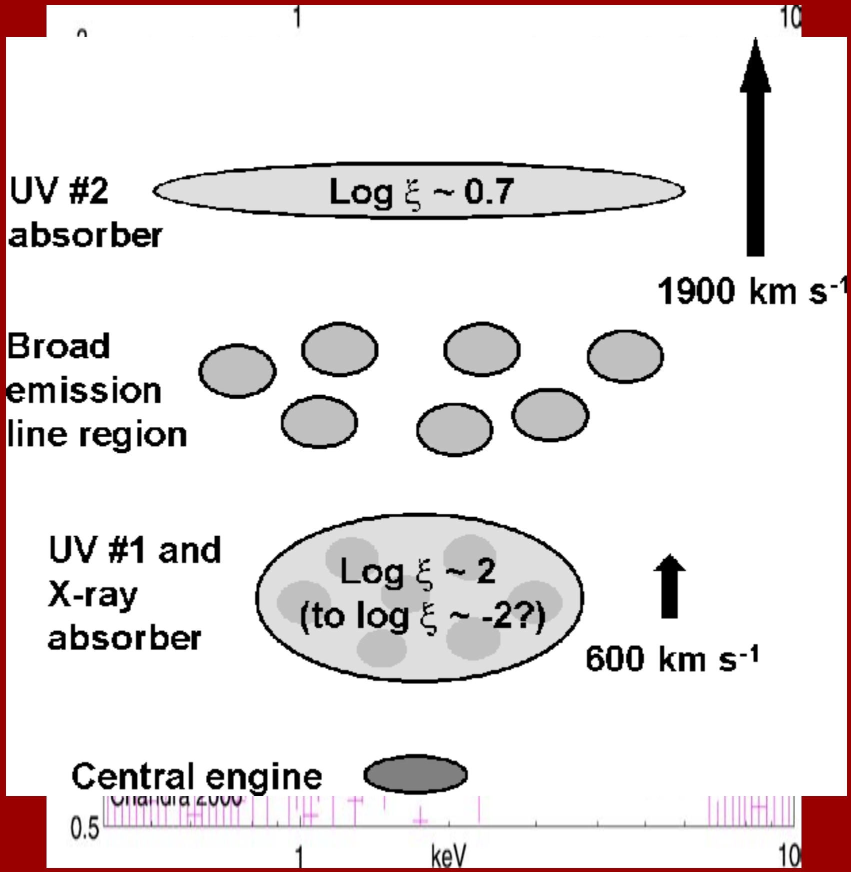
- Absorption from excited (2s2p) levels of C III at ~1175 Å => high density => low *r* (for given ξ)
  (Gabel et al. 2003 following Bromage et al. 1985)
- The X-ray UV connection



Gabel et al. 2003

Comparison with Other Sources

- NGC 3516, Netzer et al. 2002, recombination times from color analysis of long ASCA observation => 0.2 pc. (see also Reynolds & Fabian 1995 on MCG-6-30-15)
- NGC 7469, Blustin et al., Kriss et al., 2003, UV fitting => absorber behind BLR: sub-pc



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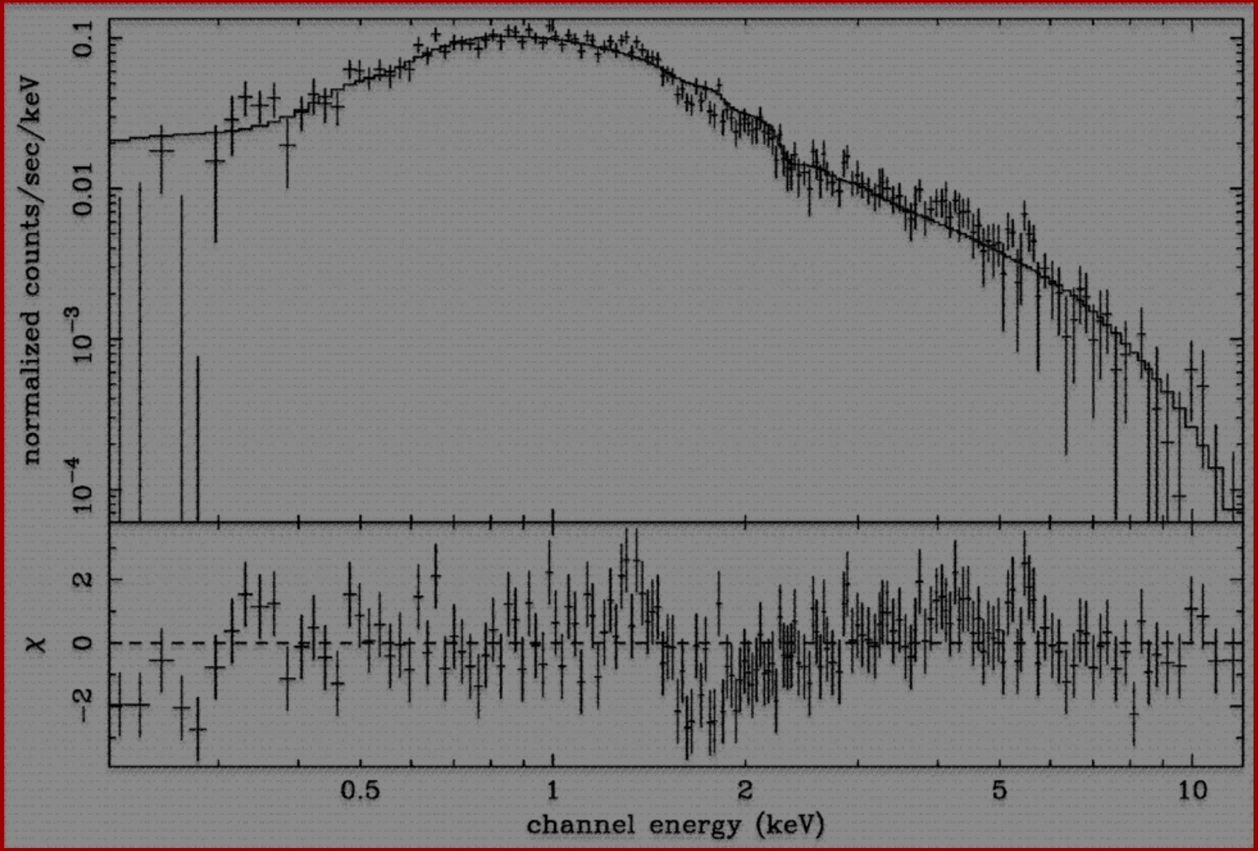
Ultra High Velocity Outflows in Bright Quasars



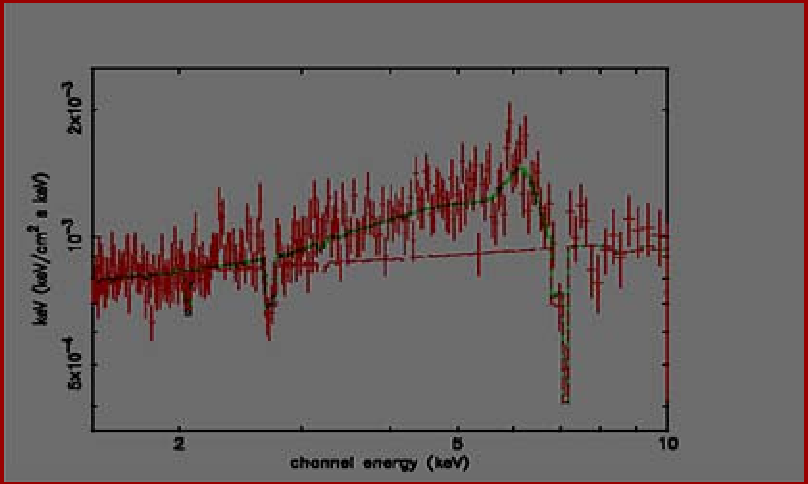
APM 08279+5255 (Hasinger, Schartel, & Komossa 2003)

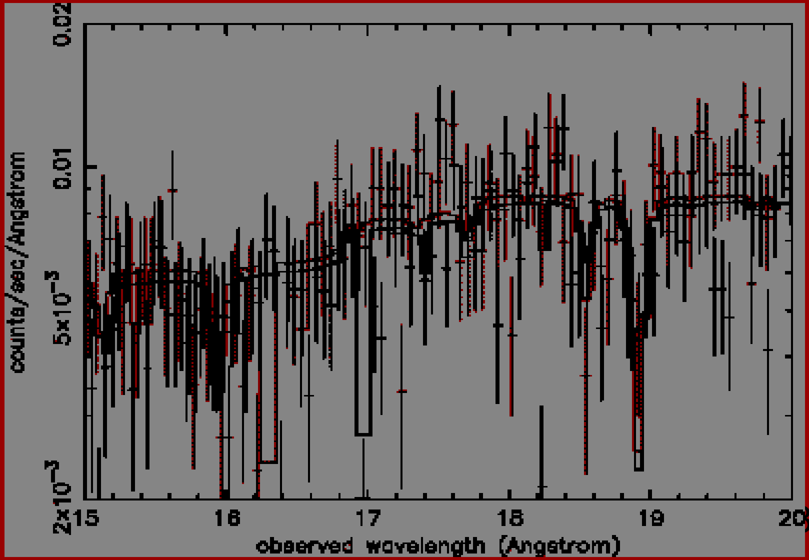
Sub-luminal Outflows

- Claimed in several high-luminosity quasars.
- High column densities (~ 10^{23} cm^{-2}) have been estimated.
- Ultra high velocities (0.1 - 0.4 c) measured - though line/edge identification is tricky.
- Recall, $M_{dot} \sim n_H v_{out} \sim (EM / N_H) \times v_{out}$, while EM is not well constrained in these sources, so mass outflow may still be less than in Seyferts. (?).
- Intense outflows could be associated with high L / L_{edd} (Pounds et al.)

PG 1211+143

- With *XMM-Newton* / EPIC and RGS
- Absorption lines of H- and He- like ions of Fe, S, Mg, Ne, O, N, and C at ~ 0.1 c
  - very different from the APM source
- The source of the wind has been postulated to come from an optically thick "photosphere" the size of ~100 R_S in high accretion rate (L/L_{Edd}) sources also producing the soft excess.



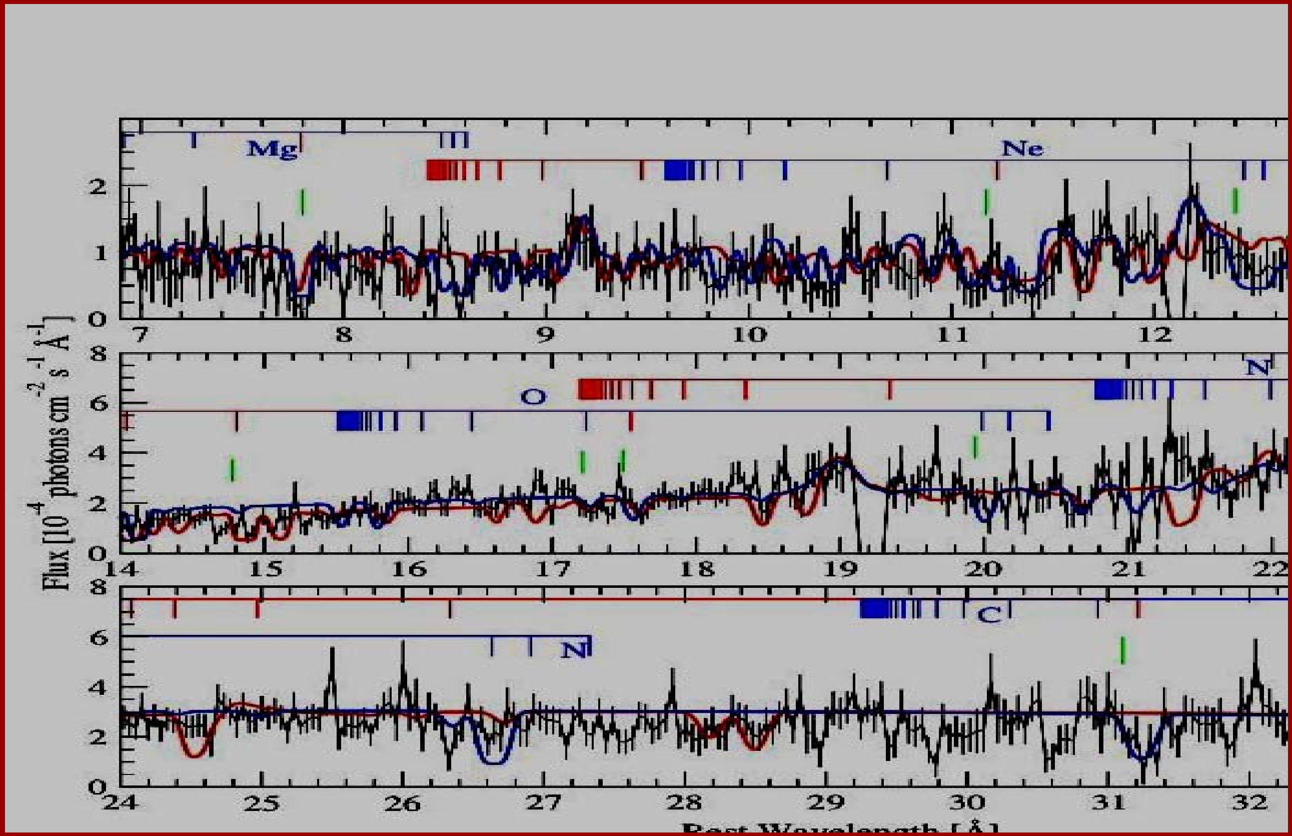


Pounds, et al. 2003

Ultra-High Velocity Outflows In High Luminosity Quasars - So Far

Source	V_{out} [c]	N_H [10^{23} cm^{-2}]	UV BAL (km/s)	L / L_{Edd}
APM 08279+5255	0.2 , 0.4	1 ± 0.5	Y (12.4K)	high
PG 1211+143	0.08 - 0.1	5	N	1.1
PG 1115+080	0.1 , 0.34	0.1 ± 0.05, 6.9	Y (?)	0.7
PG 0844+349	0.2- 0.26	4	N	0.3
PDS 456	0.16	5	N	1.0

Alternative Interpretation to PG 1211+143 with v = 3,000 km/s



Kaspi & Behar 2005

Conclusions:
The Splattering Blender Picture

- NGC 3783 ionization cone measurements:
  - Location: beyond 10 pc
  - Opening angle: $2\Omega / 4\pi \approx 10 - 30$ %
  - Mass outflow rate: a few M_o per year >> mass accretion rate
- Disclaimer: Measurement contingent upon the narrow-line X-ray emission and absorption originating from the same outflow
- Attractiveness of Results:
  Substantiation of the AGN unified model in the X-ray regime and consistent with occurrence of outflows in Seyferts
- Problem: Contrast with other X-ray and UV measurements
- Further applications:
  - Ultra-fast winds in Quasars
  - Important mechanism for metal enrichment of the IGM?

Collaborators on AGN Topics

- RGS Science Team:
  Andy Rasmussen, Ali Kinkhabwala (CU)
  Alex Blustin, Graziella Branduardi-Raymont (MSSL)
  Masao Sako, Steve Kahn (Stanford)
  Jelle Kaastra, Katrien Steenbrugge (SRON)
- HETGS Observation:
  Hagai Netzer, Shai Kaspi (TAU)
- High Velocity Outflows in Quasars:
  Shai Kaspi (Technion)