Strong Gravity Effects in the High Luminosity Quasar E1821+643

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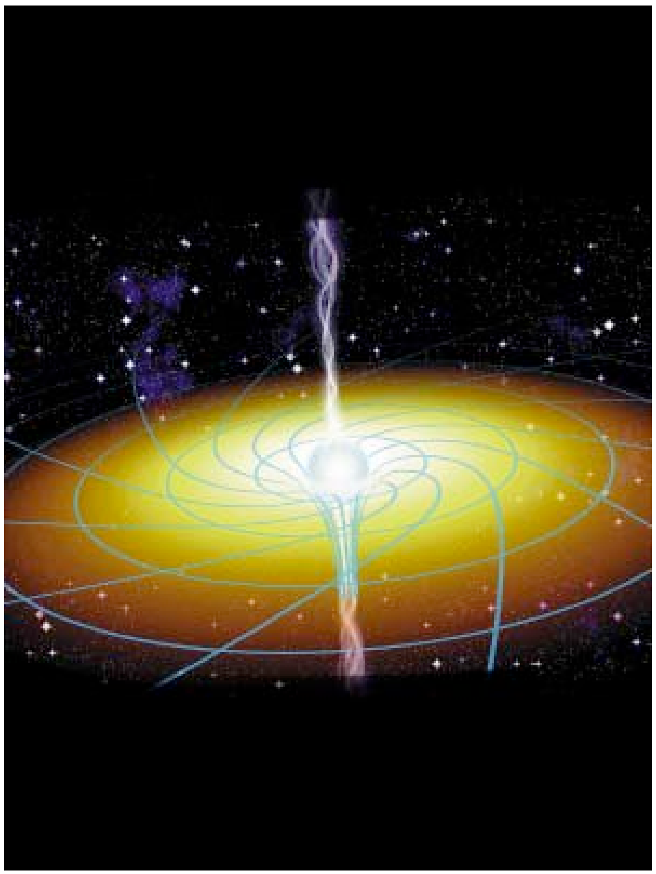
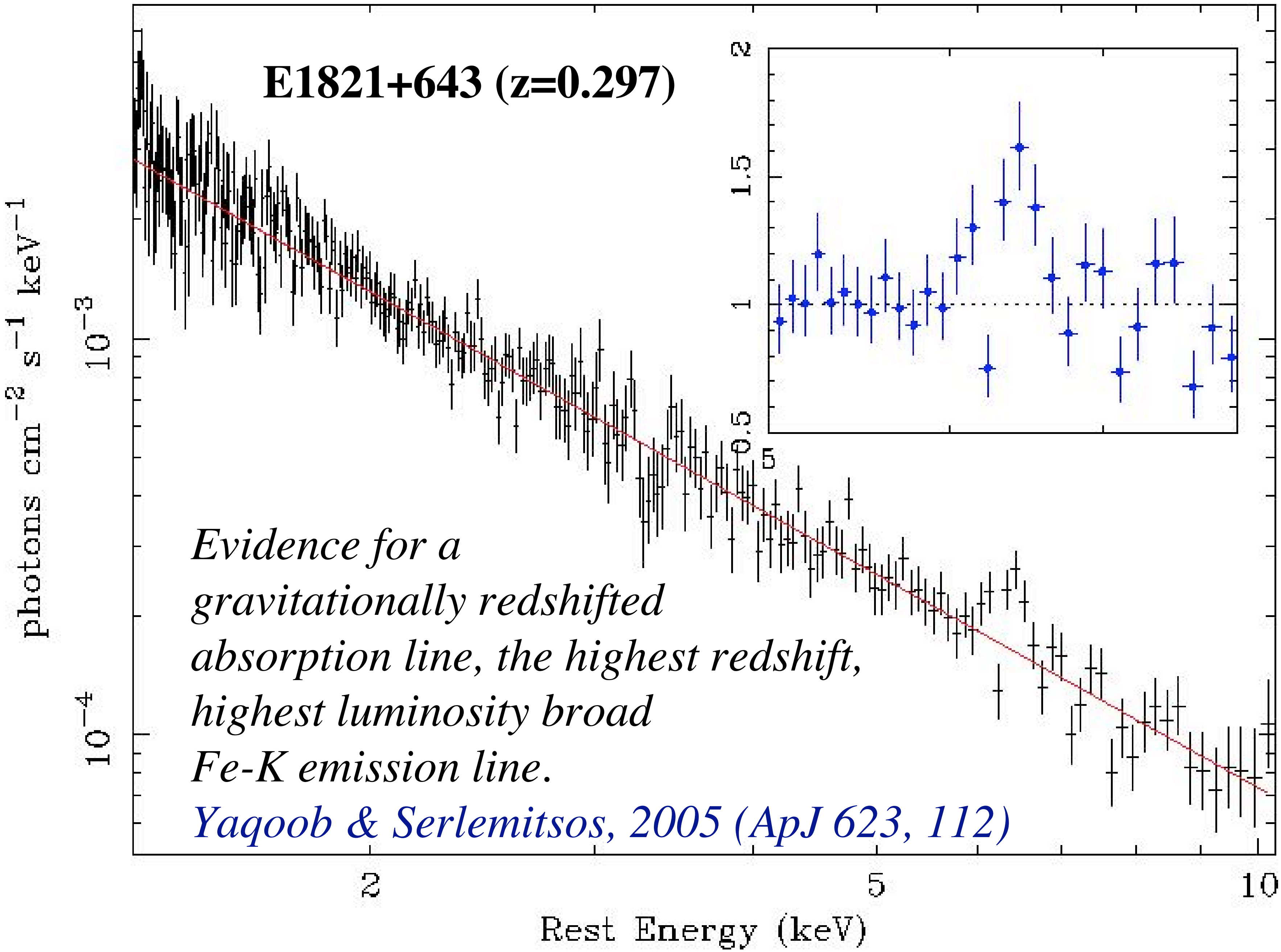


A narrow, redshifted absorption line (likely due to Fe XXV or Fe XXVI) super-imposed on the red wing of a broad Fe K line was discovered with the Chandra HETGS in the high luminosity RQ quasar E1821+643 (z=0.297). Although inflow (v/c ~ 0.07-0.11) and/or gravitational redshift can account for the absorption line (at ~6.2 keV in the quasar frame) we show that the an outflow with modest velocity (100s of km/s) located within ~6-10 gravitational radii of the putative central black hole cannot be ruled out. Redshifted absorption lines have since been found in a few other AGN. The discovery of a broad Fe K emission line in such a high-luminosity AGN brings into question the validity of the so-called "X-ray Baldwin effect".



E1821+643 (z=0.297)
photons cm^{-2} s^{-1} keV^{-1}
10^{-3}
10^{-4}
2
5
10
Rest Energy (keV)
2
1.5
1
0.5
5
Evidence for a gravitationally redshifted absorption line, the highest redshift, highest luminosity broad Fe-K emission line.
Yaqoob & Serlemitsos, 2005 (ApJ 623, 112)

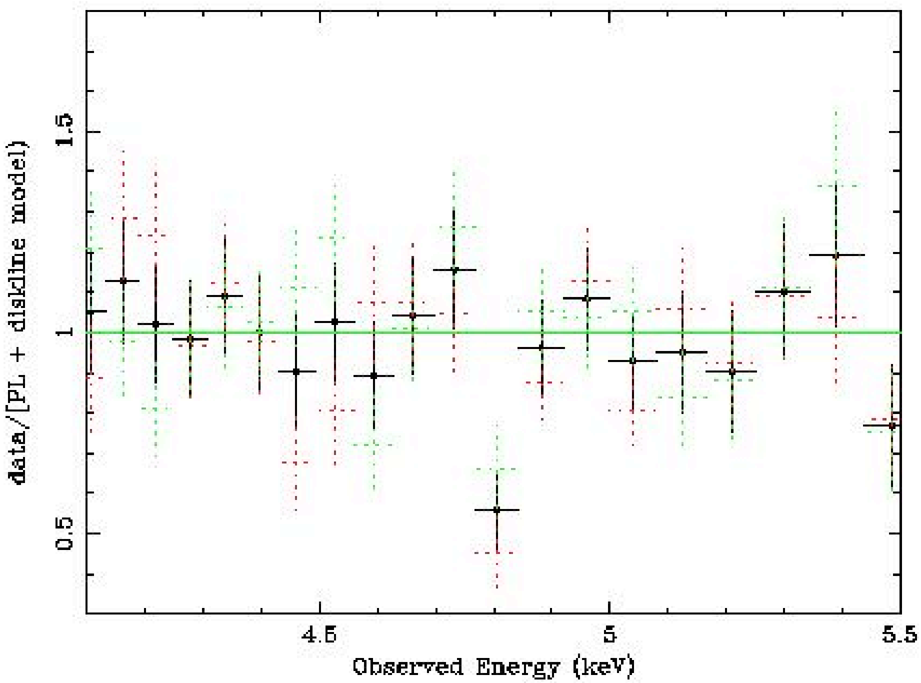
E 1821+643 : Fe–K Absoprtion Feature

Reality of the Absorption Feature

Absorption feature is present in BOTH plus and minus arms of the Chandra High Energy Grating (HEG).

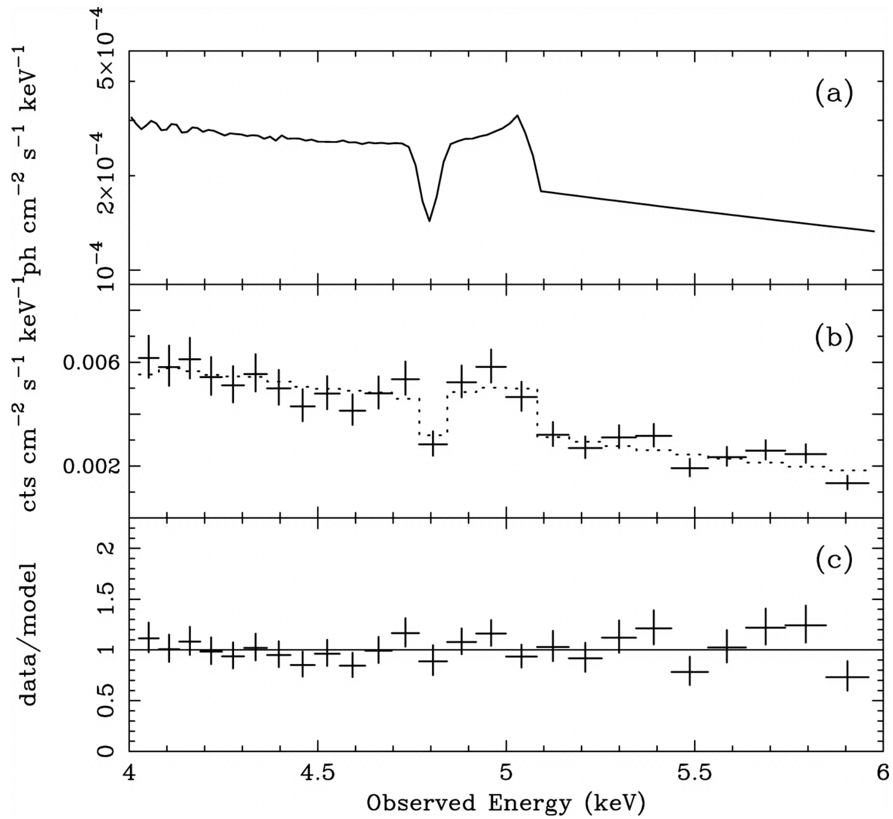
Black: Combined plus & minus orders

Red: –1 Order ***Green: +1 Order***

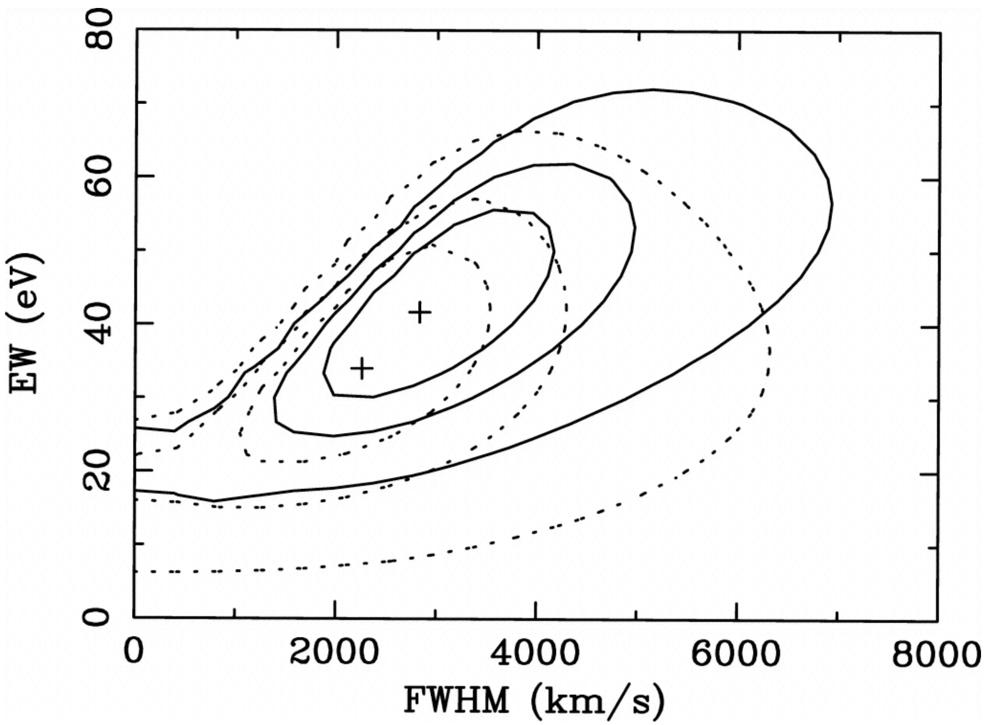


Significance of absorption line (from Monte Carlo simulations) is 2-3σ , depending on assumptions.

Disk Emission Line Plus Gaussian Absorption Line Fit.



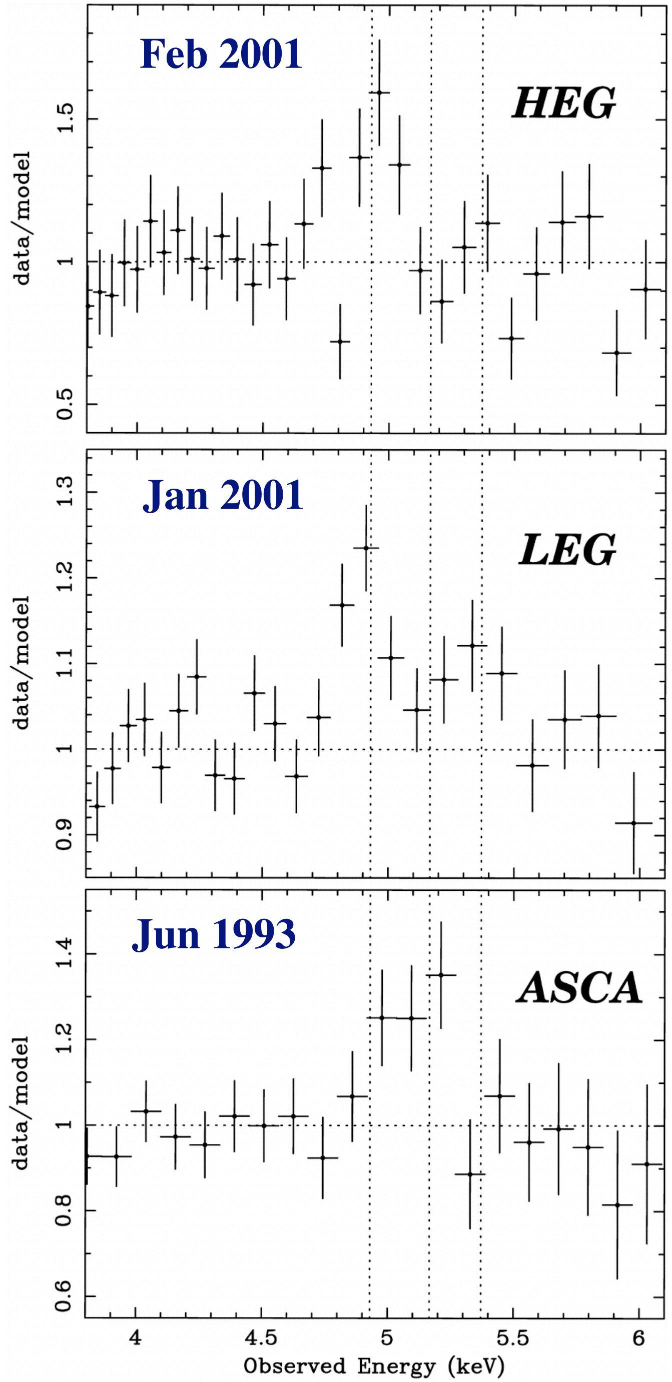
Absorption Line Parameters

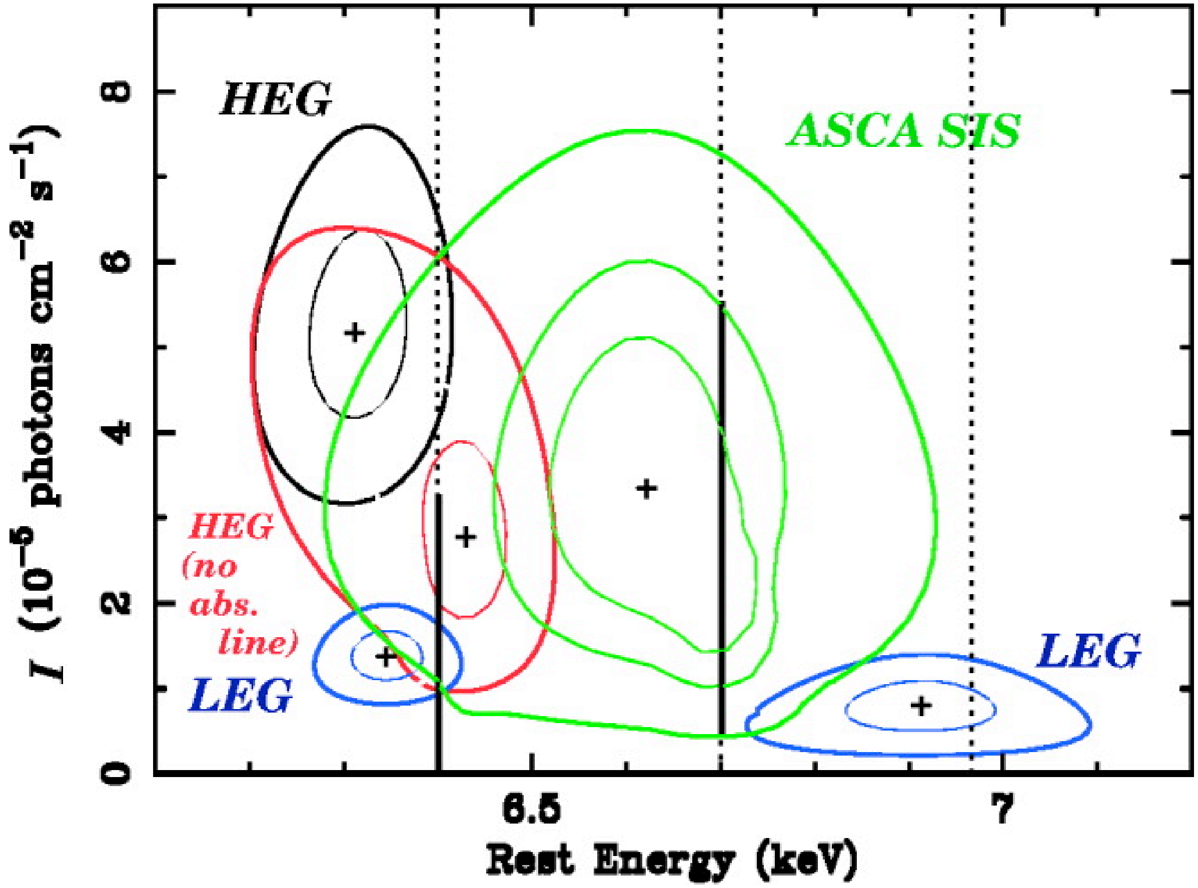


Relativistic Disk-Line Fits to *Chandra* HEG Data for E1821+643

Parameter	Value
C-statistic	1014.5
Degrees of freedom	966
Disk-line rest energy (keV)	$6.57^{+0.01}_{-0.01}$ (6.51–6.68)
Disk-line emissivity index, q	$2.69^{+0.19}_{-0.19}$ (2.36–3.08)
Outer disk radius, R_{out}	>930 (>18)
Disk inclination, θ_{obs} (deg)	$0.0^{+0.4}_{-0.0}$ (0–27)
Disk-line intensity (10^{-5} photons cm^{-2} s^{-1})	$7.0^{+1.9}_{-1.7}$ (3.6–10.2)
Disk-line EW (eV)	209^{+51}_{-57} (107–305)
Absorption line center energy (keV)	$6.220^{+0.018}_{-0.013}$
Absorption line Gaussian width, σ (keV)	$0.021^{+0.012}_{-0.008}$
Absorption line velocity width, FWHM (km s^{-1})	2385^{+1440}_{-950}
Absorption line EW (eV)	34^{+13}_{-13}
Power-law photon index, Γ	$1.84^{+0.03}_{-0.03}$
2–10 keV Observed flux (10^{-11} ergs cm^{-2} s^{-1})	1.2
2–10 keV Luminosity, quasar frame (10^{45} ergs s^{-1})	3.3

- **68%, 90%, 99% confidence contours. Absorption line modeled with a Gaussian. Solid: Emission line modeled with a Gaussian. Dotted: Emission line modeled with a relativistic disk line (see table).**
- **All spectral fitting parameters are in the quasar frame.**
- **Absorption line is only marginally resolved (i.e. unresolved by the HEG at 99% confidence).**
- **Redshift corresponds to effective velocities ~21000 km/s (Fe XXV) or 32000 km/s (Fe XXVI).**





- *Fe K emission line profile variability (non-contemporaneous observations).*
- *Contours are 68% and 99% (plus 90% for ASCA), obtained with Gaussian fits.*
- *Red contour is for HEG data without absorption line (consistent with Fang et al. 2002).*
- *Notice double-peaked (or lines from more than one ionization state) for LEG data. Black lines are for a double-Gaussian model applied to the ASCA data (see also Yamashita et al 1997).*

Redshifted Absorption Lines in other Quasars

- **PG1211+143 (Reeves et al. 2005): Chandra LEG data. Two absorption lines, V~ 0.23c and 0.35c (if Fe XXVI Lya, 0.20c & 0.32c Fe XXV). Line widths poorly constrained, upper limit 7800 km/s FWHM.**
- **Mkn 509 (Dadina et al. 2005): XMM-Newton EPIC data. V~ 0.21c (if Fe XXVI Lya, 0.18c if Fe XXV).**
- **Q0056-363 (Matt et al. 2005): XMM-Newton EPIC data. V~ 0.23c (if Fe XXVI Lya, 0.20c if Fe XXV).**
- ***Compare with V~ 0.11c (Fe XXVI) or ~ 0.07c (Fe XXV) for E1821+643.***
- ***In all cases, the EWs range from tens to ~100 eV.***
- **Curve of growth analysis for E1821+643 gives a lower limit on the optical depth at the center of the resonance line, and a lower limit on the column density of the ion responsible for the absorption. We get N>9 x 10^{16} cm^{-2} and $\tau > \tau_0$(1000/FWHM [km/s]) where τ_0 = 0.174 or 0.321 for Fe XXV or Fe XXVI respectively.**
- ***Column density and optical depth limits for PG 1211+143, Mkn 509, and Q0056-363 are similar to those obtained for E1821+643 because of the similar EWs and the fact that the absorption lines are not clearly resolved.***
- **Note: identification with lines other than from Fe creates a problem with predicted Fe lines (for "regular" abundances), which are not observed.**

Inflow or Outflow?

Could the absorption line in E1821+643 be due to gravitationally redshifted outflow?

Photoionized outflows with v ~ hundreds of km / s have been found to be common in type 1 AGN by Chandra gratings.

High velocity outflows found by XMM in two quasars:

PG 1211+143: v ~ 25,000 km / s; R ~ 260 Rg
PG 0804+349: v ~ 60,000 km / s; R ~25Rg

(Lower v ~ 3000 km/s claimed by Kaspi et al. 2005 for PG 1211+143).

Both outflows are optically thick.
Thick photosphere near BH in ~Eddington accretors may be common.

If absorption line in E1821+643 is gravitationally redshifted outflow (due to H–like Fe absorption) then

R ~ 9.7 Rg for v ~ 1000 km / s

R ~ 4.3 Rg for v ~ 25,000 km / s
R ~ 6.2 Rg for v ~ 60,000 km / s

Mass flow rate depends on the (unknown) filling factor.

Summary

- **Redshifted (1+z ~ 0.07-0.11c) absorption line, probably due to Fe XXV or Fe XXVI, found in the RQ high-luminosity (L[2-10 keV] ~ 3 x 10^{45} erg/s), high z (0.297) quasar E1821+643 from *Chandra* HETG data.**
- **We cannot distinguish between pure gravitationally redshifted outflow, gravitationally redshifted inflow, pure inflow, or a predominantly gravitational redshift.**
- **Similar redshifted absorption lines have been found in three other quasars (PG1211+143, Reeves et al. 2005; Mkn 509, Dadina et al. 2005; Q0056-363, Matt et al. 2005).**
- **If gravitational redshift dominates, the lines will be an important new probe of strong gravity. Interpreting the absorption line profiles will be free from the uncertainties in the 3-dimensional matter distribution, which plagues the interpretation of emission lines.**
- **Relativistic broad Fe K emission line found in E1821+643: the highest luminosity AGN/quasar so far to harbor a broad line. Along with the large EW Fe K emission line in Q0056-363 (Matt et al. 2005), the discovery of these emission lines means that the "X-ray Baldwin Effect" no longer exists (without further qualification).**

References

Dadina, M. et al. 2005, A&A, 442, 461.

Fang, T., et al. 2002, ApJ, 565, 86.

Kaspi, S., & Behar, E. 2005, astro-ph/0509562.

Mathur, S. et al., Weinberg, D. H., & Chen, X. 2003, ApJ, 582, 82.

Matt, G. et al. 2005, A&A, 435, 857.

Porquet, D., & Reeves, J. N. 2003, A&A, 408, 109.

Reeves, J. N. et al. 2005, astro-ph/0509280.

Yamashita, A., et al. 1997, ApJ, 486, 783.

Yaqoob, T. & Serlemitsos, P. 2005, ApJ, 623, 112.

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