PROBING UNIFICATION WITH HIGH-RESOLUTION SPECTROSCOPY OF

NGC 2110

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Fe Kα Lines and Reflection: AGN Geometry

- The Fe Kα line complex in general consists of a narrow line core, possibly accompanied by broadened emission
- What is the origin of the broad emission?
  - Relativistically blurred diskline?
  - Compton shoulder?
  - Broad line region?
  - Unmodeled absorption?
- If we can deconvolve the contributions from the two, we can probe AGN geometry
- Vital to treat direct+reflected continuum and absorption effects self-consistently
NGC 2110

Nearby \((z=0.0076, D_L=33 \text{ Mpc})\) NELG

- Historical subclass of Seyferts with narrow (<600 km/s) optical lines (Seyfert 2-like) but much stronger hard X-ray emission (Seyfert 1-like)
- Flat X-ray spectra may imply they dominate XRB at low energies (e.g. Iwasawa et al. 1997)
- **Transitional** between Seyfert 1 and Seyfert 2? (Lawrence & Elvis 1982)

**ASCA, BeppoSAX, etc. \(\Rightarrow 2\text{-}10 \text{ keV} X\)-ray spectrum is very flat \((\Gamma=1.4)\)**

- Accompanied by moderate absorption \((N_H=3\times10^{22} \text{ cm}^{-2})\)

**ASCA Fe K complex hard to interpret**

- Diskline, either oriented at intermediate angles to l.o.s. (Weaver & Reynolds 1998) or nearly face-on (Turner et al. 1998)
OBSERVATIONS AND RESULTS
NGC 2110 was observed with Chandra for a total of 250 ks and XMM-Newton for 60 ks. An initial analysis showed variability in flux only, and so the continuum spectra were analyzed jointly.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Date</th>
<th>Exposure (ks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HETGS</td>
<td>2001 Dec 19</td>
<td>35</td>
</tr>
<tr>
<td>HETGS</td>
<td>2001 Dec 20</td>
<td>80</td>
</tr>
<tr>
<td>HETGS</td>
<td>2001 Dec 22</td>
<td>35</td>
</tr>
<tr>
<td>HETGS</td>
<td>2003 Mar 05</td>
<td>100</td>
</tr>
<tr>
<td>EPIC/RGS</td>
<td>2003 Mar 05</td>
<td>60</td>
</tr>
</tbody>
</table>
Continuum Fitting

- Initial fit with single, moderately absorbed power law ($N_H=3\times10^{22}$ cm$^{-2}$, $\Gamma=1.4$)
- Soft excess seen below 2 keV
- Significant improvement in fit with the addition of a lightly absorbed ($N_H=7\times10^{20}$ cm$^{-2}$) power law ($\Gamma_{\text{soft}}=\Gamma_{\text{hard}}$)
- Still very flat photon index ($\Gamma=1.4$), but...
Continuum Fitting

- Insufficient opacity at Si K and Fe K edges
- Improvement in the fit with the additional edges
- Does this imply an extra absorber?
- Significant improvement with a 3x partially covered power law
- Photon index rises to $\Gamma = 1.74 \pm 0.05 \Rightarrow$ consistent with canonical values in Seyferts
- No evidence for ionized absorption in HETGS data

<table>
<thead>
<tr>
<th>Component</th>
<th>Column density ($\text{cm}^{-2}$)</th>
<th>Covering fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{H,1}$</td>
<td>$1.6 \times 10^{23}$</td>
<td>32%</td>
</tr>
<tr>
<td>$N_{H,2}$</td>
<td>$2.8 \times 10^{22}$</td>
<td>65%</td>
</tr>
<tr>
<td>$N_{H,3}$</td>
<td>$7.7 \times 10^{20}$</td>
<td>3%</td>
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Fluorescent Line Diagnostics

- Chandra HETGS best suited to probe narrow lines
- Neutral fluorescent Kα lines detected from Si, S, Ar, Ca, Fe
- Narrow Fe Kα and Si Kα line cores just resolved with HETGS

<table>
<thead>
<tr>
<th>Line</th>
<th>Energy (keV)</th>
<th>Width (km s(^{-1}))</th>
<th>Equivalent width (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe Kα</td>
<td>6.397±0.007</td>
<td>900±500</td>
<td>80±30</td>
</tr>
<tr>
<td>Si Kα</td>
<td>1.740±0.002</td>
<td>600±400</td>
<td>6±2</td>
</tr>
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</table>

- Distant, neutral fluorescing region
- No evidence for diskline
- Marginal (2.5σ) evidence for v. slight broadened base of Fe Kα
**Reflection**

- Self-consistent treatment of reflection (i.e., lines+pexrav continuum)
- No change in fit parameters
- Suzaku provides vital constraints on strength of reflection
- Stringent limit of $R<0.1$ (Reeves et al. 2006; Okajima et al. 2007)
- NGC 2110 is one of the few Seyferts with no evidence for disk reflection, nor complex absorption
CIRCUMNUCLEAR ENVIRONMENT
Multiwavelength Imaging

- Excellent spatial agreement between X-ray and [OIII] (Evans et al. 2006)
- Both clearly offset from radio, but extend along similar p.a.
- X-ray & [OIII] emission influenced by, but not directly associated with, radio jet?
- ACIS X-ray spectrum modeled by, e.g., two thermal plasma models ($kT_1=0.3$ keV; $kT_2=5$ keV)

Chandra (0.5-1.5 keV) / VLA / HST [OIII] overlay
Gratings Spectrum

- Evans et al. (2006) considered 3 mechanisms for producing the environment:
  - Shock-heating by the radio jet
  - Electron-scattered nuclear radiation
  - Photoionization by the AGN
- High-resolution grating spectroscopy can in principle distinguish between these models
- Tentative evidence for O VIII Ly α, as well as the O VIII RRC feature first reported by Guainazzi & Bianchi (2006)
- Photoionization and collisional ionization processes both important?
Recap

ASCA, BeppoSAX, etc. found

- Flat ($\Gamma = 1.4$) 2-10 keV spectrum
- Moderate absorption ($N_H = 3 \times 10^{22}$ cm$^{-2}$)
- Diskline emission, either face-on or at intermediate angles

Chandra, XMM-Newton (and Suzaku – Okajima et al. 2007)

- Compton-thin partial-coverer model
- Photon index 1.7-1.8
- No evidence for ionized absorption
- Marginally resolved (900±500 km s$^{-1}$) Fe Kα line core
- No evidence for disk reflection
- Multiwavelength imaging + HETGS evidence for (weak) ionized emission
  \[ \Rightarrow \] extended circumnuclear environment is photoionized or collisionally ionized?

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Consistent with an origin in a Compton-thin, distant (> 1pc) neutral absorber
Orientation consistent with edge-on view
Steepening of photon index using multiple partial-coverer model ⇒ NELGs do not have significantly flatter spectra w.r.t. Seyfert 1, 2?
No disk reflection, unlike other Compton-thin Seyferts observed with Suzaku (Reeves et al. 2006)
Vital to treat absorption and reflection effects in a self-consistent manner in order to evaluate AGN geometry
High spatial and spectral resolution, together with high effective area, are key to determining the spatial distribution and energetics (collisional vs. photoionization) of circumnuclear environments in AGN