Photoionised gas in Seyfert 1 Galaxies revealed through emission lines in high resolution spectra

Anna Lia Longinotti (MIT), Achille Nucita, Maria Santos-Lleo, Matteo Guainazzi (ESAC)
Well established evidence for Compton thick torus on parsec-scale:

IR interferometry in Sy 2 NGC 1068 (Jaffe et al. 04)

Several X-ray measurements of ubiquitous narrow Fe Kα line from Compton Reflection in type 1 AGN (Bianchi +07)
Obscured AGN at high resolution: average spectrum of a Seyfert 2

- CIELO catalogue of 69 obscured AGN (Guainazzi & Bianchi 07)
- Soft X-ray spectra dominated by transitions of H- and He-like O, Ne, C and high detection rate of narrow RRC of T~ few eV, photoionisation by the AGN continuum.
- Large EW due to no continuum
- Best studied case NGC1068, (Kinkhabwala+ 02) see Dan Evans’s talk

Spatial coincidence of HST O[III] and Chandra soft X-ray images of Seyfert 2s shows that soft-X-ray emission is mostly consistent with photoionisation in the extended NLR (Bianchi et al. 06)
Unobscured AGN at high resolution: average Seyfert 1?

- Direct view of the nuclear continuum
- In ~50% of sources, warm absorbers of numerous $N_H, \xi$
- Different flux levels (Sy2 are always soft X-ray obscured)

XMM-Newton pn data-to-model ratios of Seyfert 1: variety of soft X-ray shapes
Emission lines in Seyfert 1: the case for Mrk 335

<table>
<thead>
<tr>
<th>Date</th>
<th>Exp (ks)</th>
<th>$\Gamma_{\text{soft}}$</th>
<th>Flux_{\text{soft}} (10^{-12} \text{ cgs})</th>
<th>$\Gamma_{\text{hard}}$</th>
<th>Flux_{\text{hard}} (10^{-12} \text{ cgs})</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>22</td>
<td>2.84±0.03</td>
<td>1.9±0.1</td>
<td>1.02±0.07</td>
<td>3.3±0.8</td>
</tr>
<tr>
<td>2006</td>
<td>130</td>
<td>2.72±0.01</td>
<td>32±0.1</td>
<td>2.09±0.01</td>
<td>18±0.2</td>
</tr>
</tbody>
</table>

XMM high state: usual Seyf1 continuum with complex Iron K line (O’Neill et al. 2007)

Swift, XMM low state: flux drop, flattening of hard X-ray spectrum possibly due to gas partially covering the AGN (Grupe et al. 2007, 2008)
Mrk 335 RGS spectra

Data-to model (power law) ratios

2006 high state:
no warm absorber

2007: low state
Mrk 335 RGS spectra

Data-to model (power law) ratios

2006 high state:
no warm absorber

2007: low state
Analogy with Sy2?

Soft X-ray lines in Mrk 335 may be signature of photoionisation in the NLR as for Sy2: the nuclear continuum drops, the NLR becomes visible in the X-rays, agreement with Unification scheme...
Soft X-ray emission lines

Detected emission lines

<table>
<thead>
<tr>
<th>Transition</th>
<th>$\lambda$ (lab) (Å)</th>
<th>$\Delta C$</th>
<th>$\Delta C_{FWHM(FeVII)}$</th>
<th>Flux $^{18-24}$</th>
<th>$\phi$ m$^{-2}$ s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe XVII</td>
<td>17.073</td>
<td>0.06±0.04</td>
<td></td>
<td>0.06±0.04</td>
<td></td>
</tr>
<tr>
<td>O VII Heß</td>
<td>18.627</td>
<td>0.06±0.04</td>
<td></td>
<td>0.06±0.04</td>
<td></td>
</tr>
<tr>
<td>O VIII Lyα</td>
<td>18.969</td>
<td>0.27±0.05</td>
<td></td>
<td>0.27±0.05</td>
<td></td>
</tr>
<tr>
<td>O VII Heß (r)</td>
<td>21.600</td>
<td>0.17±0.08</td>
<td></td>
<td>0.17±0.08</td>
<td></td>
</tr>
<tr>
<td>O VII Heß (i)</td>
<td>23.890</td>
<td>0.31±0.09</td>
<td></td>
<td>0.31±0.09</td>
<td></td>
</tr>
<tr>
<td>O VII Heß (f)</td>
<td>22.101</td>
<td>0.16±0.07</td>
<td></td>
<td>0.16±0.07</td>
<td></td>
</tr>
<tr>
<td>NV II Lyα</td>
<td>23.481</td>
<td>0.18±0.05</td>
<td></td>
<td>0.18±0.05</td>
<td></td>
</tr>
<tr>
<td>CVI Lyß</td>
<td>28.446</td>
<td>0.20±0.07</td>
<td></td>
<td>0.20±0.07</td>
<td></td>
</tr>
<tr>
<td>CVI Lyν</td>
<td>33.736</td>
<td>0.24±0.07</td>
<td></td>
<td>0.24±0.07</td>
<td></td>
</tr>
</tbody>
</table>

Underlying power law $\Gamma \sim 2.7$

Average Seyfert 2 spectrum
Soft X-ray emission lines

Detected emission lines

<table>
<thead>
<tr>
<th>Transition</th>
<th>(\lambda) (lab) (Å)</th>
<th>Flux(^{\text{FWHM}}) ph m(^{-2}) s(^{-1})</th>
<th>(\Delta C)</th>
<th>Flux(^{\text{FWHM}}) ph m(^{-2}) s(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe XVII</td>
<td>17.073</td>
<td>&lt; 0.05</td>
<td>(\Delta C=1)</td>
<td>0.06±0.04</td>
</tr>
<tr>
<td>O VII He(\beta)</td>
<td>18.627</td>
<td>&lt; 0.03</td>
<td>(\Delta C=0)</td>
<td>0.06±0.04</td>
</tr>
<tr>
<td>O VIII Ly(\alpha)</td>
<td>18.969</td>
<td>0.20±0.04</td>
<td>(\Delta C=31)</td>
<td>0.27±0.05</td>
</tr>
<tr>
<td>O VII He (r)</td>
<td>21.600</td>
<td>0.10±0.06</td>
<td>(\Delta C=4)</td>
<td>0.17±0.08</td>
</tr>
<tr>
<td>O VII He (i)</td>
<td>21.790</td>
<td>0.26±0.08</td>
<td>(\Delta C=21)</td>
<td>0.31±0.09</td>
</tr>
<tr>
<td>O VII He (f)</td>
<td>22.101</td>
<td>0.17±0.07</td>
<td>(\Delta C=12)</td>
<td>0.16±0.07</td>
</tr>
<tr>
<td>NV VII Ly(\alpha)</td>
<td>24.781</td>
<td>0.13±0.05</td>
<td>(\Delta C=12)</td>
<td>0.18±0.05</td>
</tr>
<tr>
<td>CV I Ly(\beta)</td>
<td>28.446</td>
<td>0.13±0.06</td>
<td>(\Delta C=13)</td>
<td>0.20±0.07</td>
</tr>
<tr>
<td>CV I Ly(\alpha)</td>
<td>33.736</td>
<td>0.15±0.06</td>
<td>(\Delta C=8)</td>
<td>0.24±0.07</td>
</tr>
</tbody>
</table>

Underlying power law \(\Gamma \approx 2.7\)

Average Seyfert 2 spectrum
Line ratios in He-like O triplet and line fluxes for all detections

+ CLOUDY simulations

Parameters range:
Electron density = \(10^9-10^{11}\) cm\(^{-3}\)
Column Density= \(10^{20}-10^{22}\) cm\(^{-2}\)
\(\log U\) (ionisation par)= 0.4-0.8

\[U = \frac{Q(H)}{4\pi r^2 n(H)c}\]
\[Q(H) = k \int_{\nu_1}^{\nu_2} \frac{\pi F_{\nu}}{h\nu} d\nu\]

Gas distance within \(2 \times 10^{16-17}\) cm
Line ratio diagnostic and CLOUDY

Parameters range:

- Electron density: $10^9 - 10^{11}$ cm$^{-3}$
- Column Density: $10^{20} - 10^{22}$ cm$^{-2}$
- log U (ionisation parameter): 0.4-0.8

Density diagnostic: $R = \frac{f}{i}$
Temperature diagnostic: $G = \frac{(f + i)}{r}$

From FWHM H$\beta$ line and BH mass, location consistent with BLR clouds.

$$U = \frac{Q(H)}{4\pi r^2 n(H)c}$$

$$Q(H) = k \int_{\nu_1}^{\nu_2} \frac{\pi F}{\nu} d\nu$$

Gas distance within $2 \times 10^{16-17}$ cm.
X-ray emission lines in the BLR: other sources

- NGC 7213  see next talk by S. Bianchi
- Mkn 279 Costantini et al. 2007
- Akn 564 Smith et al. 2008
  and many more sources

- Mkn 841, two-phase warm absorber and emission lines
  Longinotti in prep.
- NGC 4051 Nucita et al. in prep.
High state: well established two-phase warm absorber (Krongold et al. 07, Steenbrugge et al. 09)

Low state: prominent emission lines (Pounds et al. 04)
Conclusions

- Photoionised gas in AGN may lie also within the optical Broad Line Region
- Geometry, relation to BLR clouds and other physical properties need to be explored, e.g. connection of X-ray clouds with warm absorbers (see NGC4051) and with accretion disc
- More and more and more high resolution data need to be analysed: so far only Mrk 335