The current state of disk wind observations in galactic Black Hole LMXBs through X-ray absorption lines

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Finding Extreme Relativistic Objects
10\textsuperscript{th} Edition

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The current context

- Accretion in Black Hole X-ray Binaries

- Low-Mass X-ray Binaries
  - Accretion through Roche-Lobe overflow → Accretion disk
The current context

- Accretion in Black Hole X-ray Binaries

- Low-Mass X-ray Binaries
  - Accretion through Roche-Lobe overflow $\rightarrow$ Accretion disk
  - Switch between two standard states
    - Hard State $\rightarrow$ Hard SED, jet in radio
      signature of (possibly) truncated accretion disk
    - Soft State $\rightarrow$ Soft SED, no jets, accretion disk extends close to the EH
The current context
- Accretion in Black Hole X-ray Binaries

- Low-Mass X-ray Binaries
  - Accretion through Roche-Lobe overflow → Accretion disk

Switch between two standard states

- Soft State
- Hard State

[1] Petrucci et al. 2019
The current context

- Winds detections in Black Hole X-ray Binaries

- First detections of blueshifted narrow absorption lines before 2000\(^2\)\(^3\)
  - material + low speed = not jet

- Many detections in the 2000s with the new generation of XRTs

\(^2\) Ueda et al. 1998
\(^3\) Kotani et al. 2000
The current context

- Winds detections in Black Hole X-ray Binaries

- First detections of blueshifted narrow absorption lines before 2000
  - material + low speed = not jet

- First global analysis by Ponti et al. in 2012
The current context

- Winds detections in Black Hole X-ray Binaries

- First detections of blueshifted narrow absorption lines before 2000 [2][3]
  - material + low speed = not jet
The current context

- Winds detections in Black Hole X-ray Binaries

- First detections of blueshifted narrow absorption lines before 2000 [2] [3]
  - material + low speed = not jet

- Winds → soft state
  → high inclination

[1] Ueda et al. 1998
The current context

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- Due time for a new analysis

Quick search results:

- "black hole" + "low mass X-ray Binary" year:2012-2022

Your search returned 533 results
Methodology

Main elements

To do a global analysis, we need:

- A sample of sources
    - 68 sources + 13 more

- Data from these objects
  - Let’s start with all XMM EPIC pn exposures → 140 exploitable spectra from 33 sources

- A Methodology

Methodology

- Line detection

- Methodology

- Data reduction
- Continuum & High-energy fit
- Blind Line Search
- Line fit
- Line significance assessment
Methodology

▪ Line detection

Example of output after step 2 (blind search) in 4U1630-47
Methodology

- Line detection

Follow-up of the previous exposure after step 3 (line fit)
Methodology

- Line detection

Follow-up of the previous exposure after step 3 (line fit)

Tested in a second blind search
Results

- Global HID behavior

Main HID for the sample with sources as color

- Almost all detections are in soft or in transitioning states
Results

- Global HID behavior

- Main HID for the sample with blueshift in km/s
Results

- Distributions

- There are 33 sources with XMM exposures, 15 of which have constraints on their inclination.

- Detections are considered significant above 0.99 confidence

<table>
<thead>
<tr>
<th></th>
<th>Number of sources with at least 1 detection</th>
<th>Number of individual significant detections</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Lines</td>
<td>10</td>
<td>46</td>
</tr>
<tr>
<td>FeXXV Kα</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>FeXXVI Kα</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>NiXXVII Kα</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>FeXXV Kβ</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>FeXXVI Kβ</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>FeXXVI Kγ</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
Results

- Distributions

☐ All significant line detections are for high-inclined objects
Results

- Distributions

- Repartition of the intrinsic line parameters
Results

Correlations

- Equivalent width – HR for all lines: "significant" correlation

![Correlation Plots]

**equivalent widths - Hardness Ratio for all absorption lines**

Pearson: $r = -0.405^{+0.078}_{-0.04}$, $p = 0.005^{+0.01}_{-0.03}$

Spearman: $r = -0.405^{+0.047}_{-0.089}$, $p = 0.005^{+0.014}_{-0.004}$

**blueshifts - Hardness Ratio for all absorption lines**

Pearson: $r = 0.319^{+0.193}_{-0.123}$, $p = 0.031^{+0.183}_{-0.023}$

Spearman: $r = 0.423^{+0.124}_{-0.162}$, $p = 0.003^{+0.013}_{-0.003}$
Results

- Correlations

Hints at multiple correlations in 4U for FeXXVI Kα
Results

- Correlations

Hints at multiple correlations in 4U for FeXXV Kα
Results
- Correlations

Opposing trends between Kα and Kβ lines
We can test other correlations from the analysis
  - Presence/absence of emission lines
  - Ratios between parameters of lines of the same complex
  - Differences between linked/unlinked line parameters

Caveats/improvements of the analysis itself
  - Use more physical models for tabulated objects
  - Probe at more exotic lines/parameter spaces
    (redshifted lines/search in strong emission features/...)

Add MOS exposures when available, and Chandra/Suzaku data

Compute stability curves and check the compatibility with physical models
Thanks for your attention !
Methodology

- Line detection

- Data reduction
  - data download, reduction and products (spectra) computation

- Continuum + High-Energy fits
  - simplistic models (absorbed pl +/diskbb) in [0.3-10]keV and [4-10]keV

- Blind search
  - 2d $\Delta \chi^2$ map from the addition of a narrow line with varying E and F

- Second fitting procedure to get the line parameters
  - Progressive addition of significant emission/absorption components

- Significance assessment of the lines with MC simulations
  - Fakeit ‘till you make it
Beside each final fit parameter/uncertainty and the flux in diverse bands computed from the continuum model, for all lines we store:

- The equivalent width/associated errors
- The blueshift/associated errors
- The line significance computed from the fakeit simulations (each line is considered significant above 99%)
- The ‘linked’ status of each line’s energy
Methodology

- Line detection

Second blind search from the results of the incremental fit
The current context

- Modeling and stability of absorption lines

The picture is much more complex now

- What about intermediate states?
  - Many observations but unclear global behavior

- Thermal and/or MHD driving\[5\][6] to launch the material?
  - $T_{\text{wind}} \ll T_{\text{acc}}$

- The spectral shape affects the thermal stability and $\xi$
  - Wind always here\[7\] but only detectable in the right conditions?

The wind thermal stability curves can be computed
- Very sensitive to the SED → requires broad band data that doesn’t exist

With a bit of physically motivated[8] extrapolation...[9]
The current context

- Modeling and stability of absorption lines
The current context

- Modeling and stability of absorption lines

Now to be compared with observations for objects with detections