Principal Component Analysis

Revealing AGN Spectral Variability

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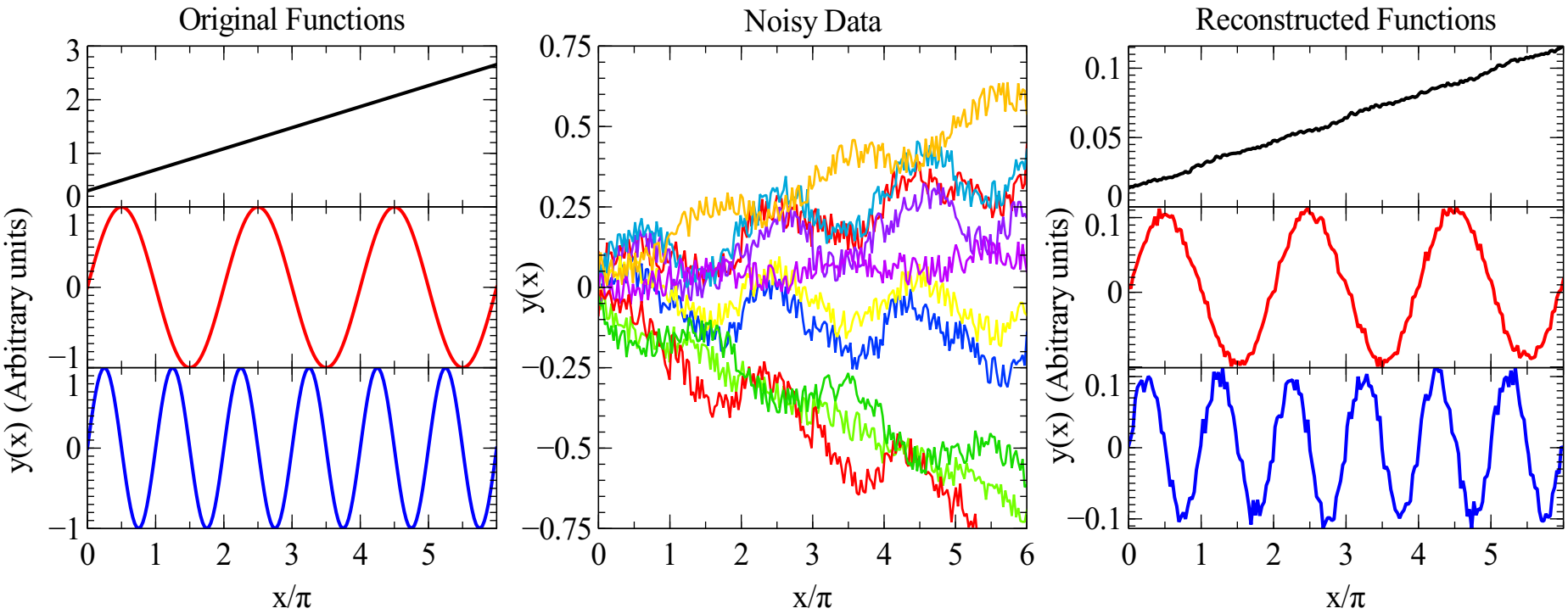
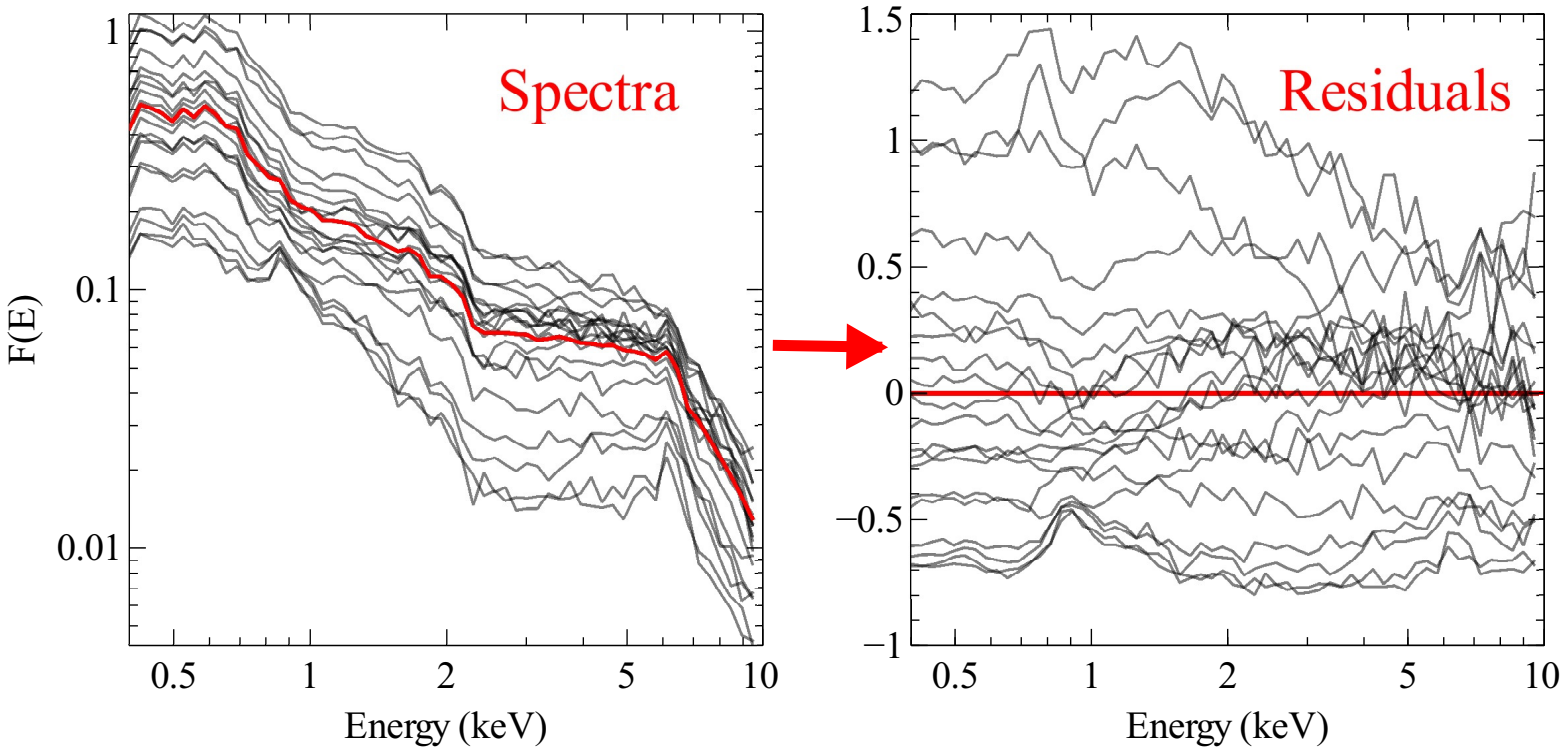
A simple example



- PCA isolates and returns the different components of a signal, removing some of the noise.
- When we apply this to AGN spectra, it retrieves the different variable spectral components, in a model-independent way, and we can match these to predictions from simulations.

Applying PCA to spectra



To apply this to spectra, we divide the dataset into 10 ks spectra, then calculate normalised residuals. These residual spectra are then fed into the code. This removes the effects of the effective area of the detector, and prevents bias from higher flux at low energies.

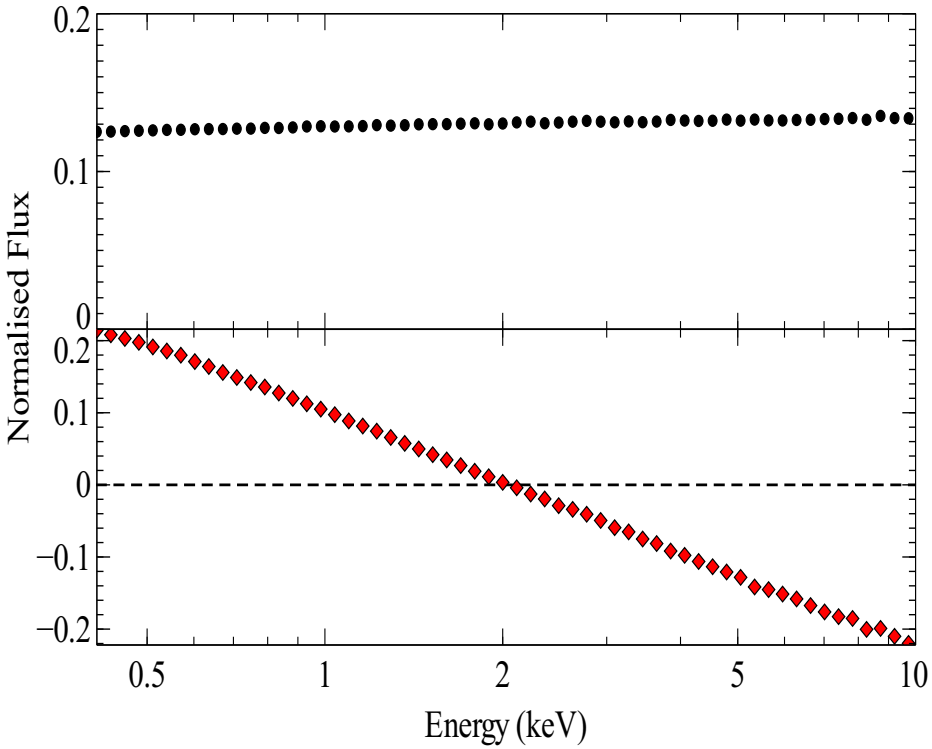
Predictions

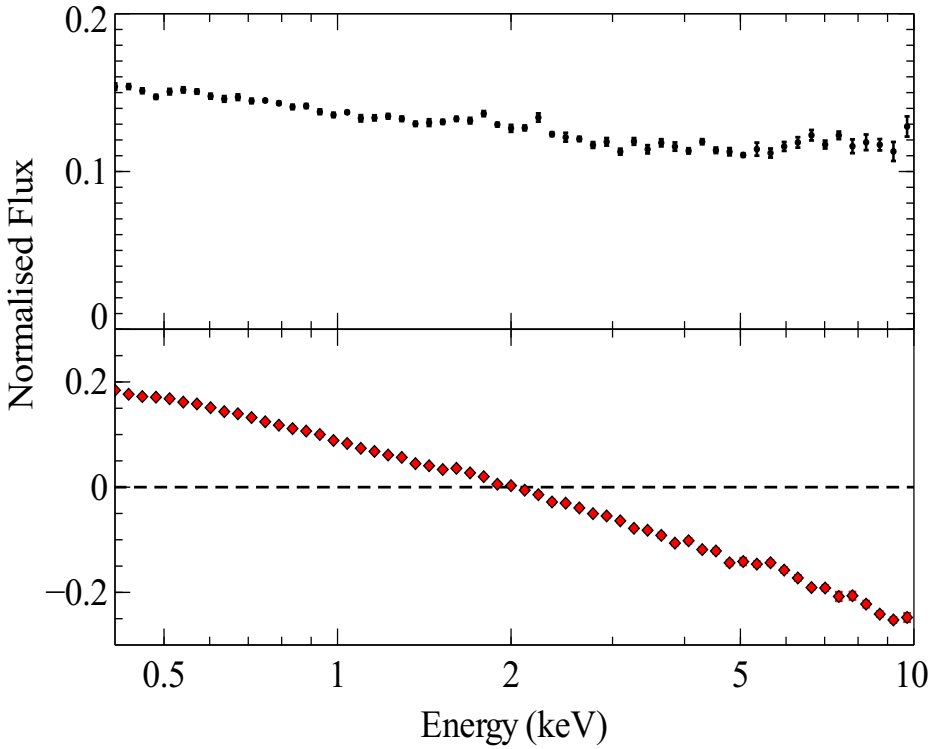
- We can generate unique predictions for the PCs returned from different spectral models, by simulating a set of fake spectra and allowing the model components to vary.
- These simulated components can then be compared with the components returned from real data, to identify the cause of spectral variability in a particular source.

Sample

- We have applied this method to a sample of ~ 30 bright, variable AGN from the XMM-Newton archive.
- The method is highly dependent on the total number of counts, so we need at least one complete orbit, preferably more. There are now many sources in the archive with this much time, however!
- We plan to extend this to other instruments, as well as looking at binaries. It is interesting to note that there is no reason data from multiple observatories could not be combined, if the instrumental response is properly accounted for.

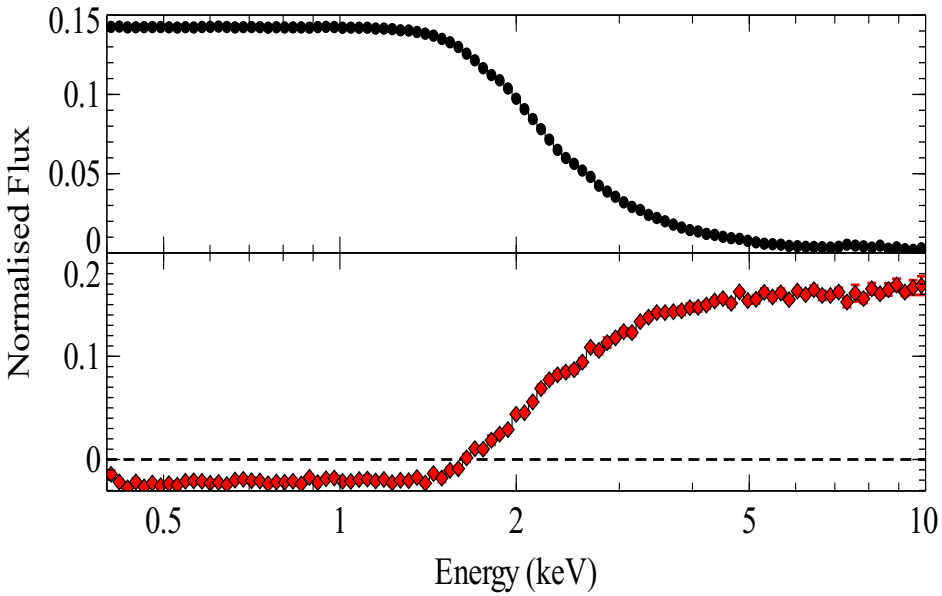
PCA of a powerlaw: 3C 273

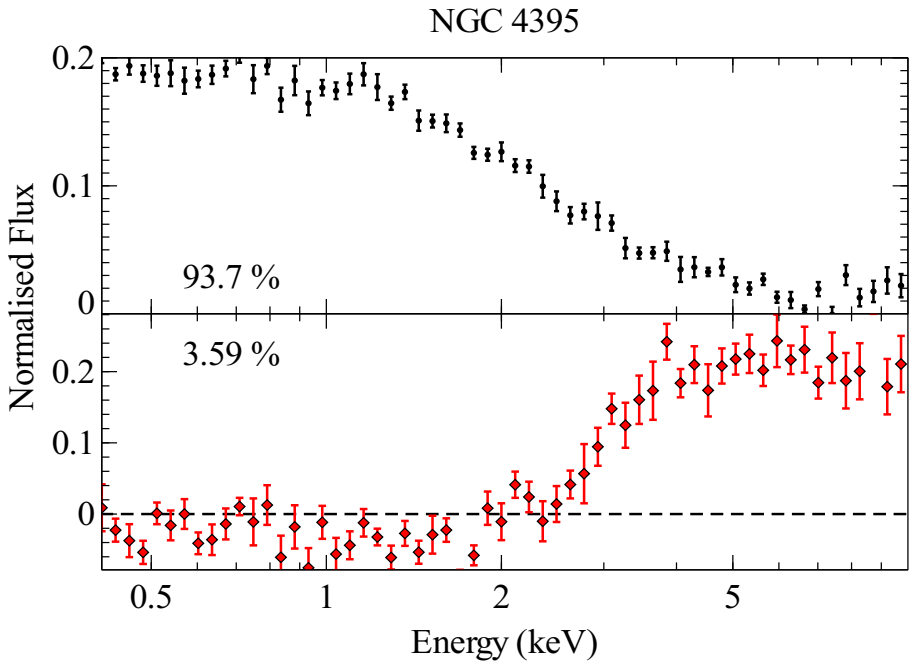




- Left Fig shows the PCs returned from PCA of a simulation of a powerlaw, varying in normalisation and photon index.
- Right Fig shows the same thing, but for real data from 3C 273.

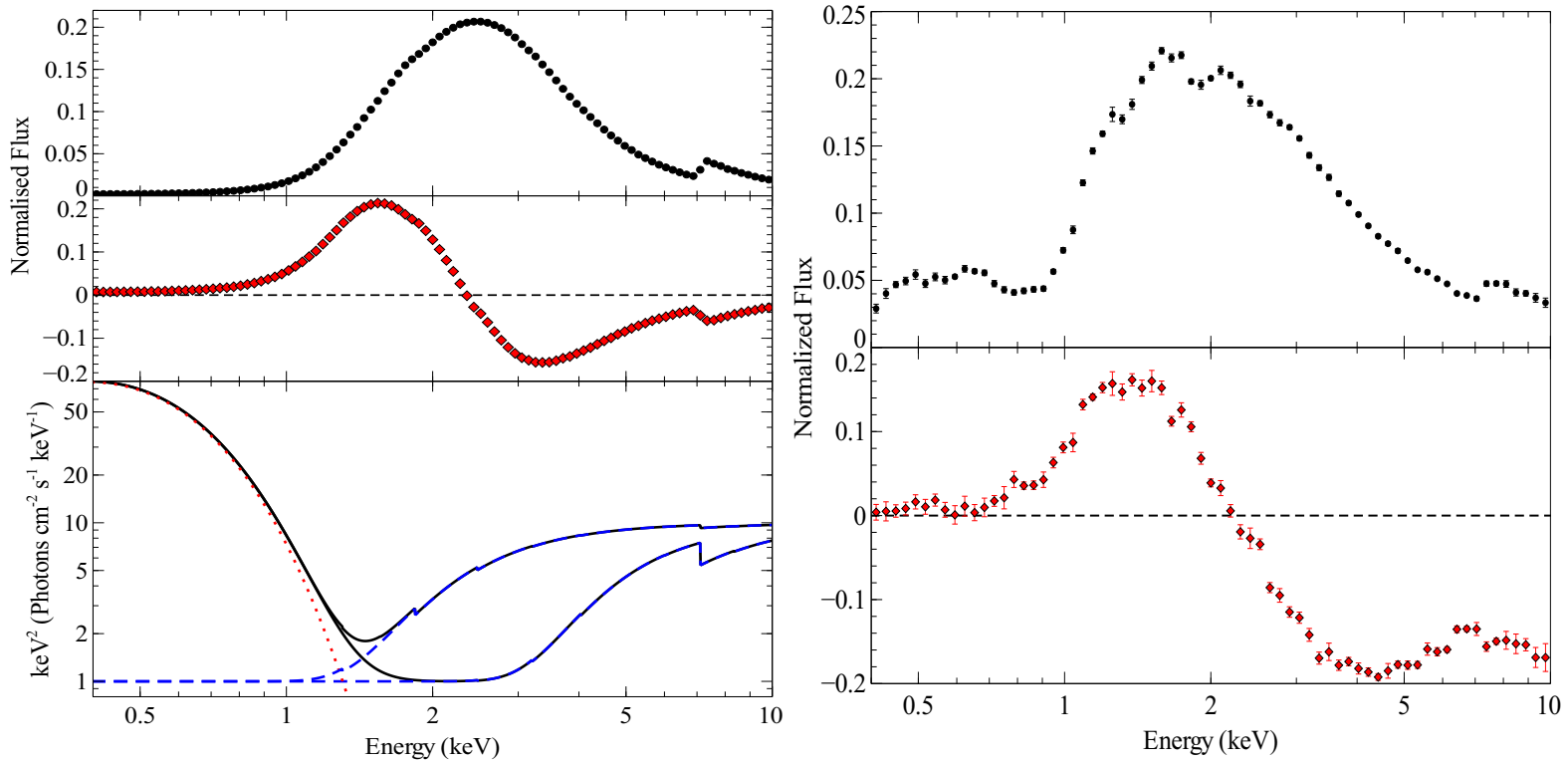
PCA of absorption I: NGC 4395





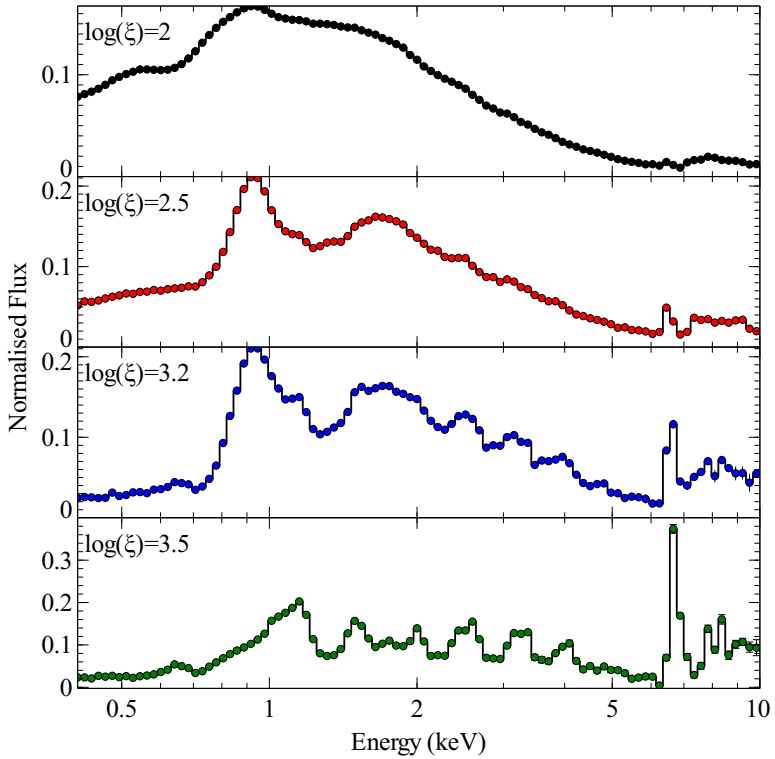
- Left Fig shows the PCs returned from PCA of a simulation of a partially-covered powerlaw, varying in covering fraction and continuum flux.
- Right Fig shows the same thing, but for real data from NGC 4395.

PCA of absorption II: NGC 1365



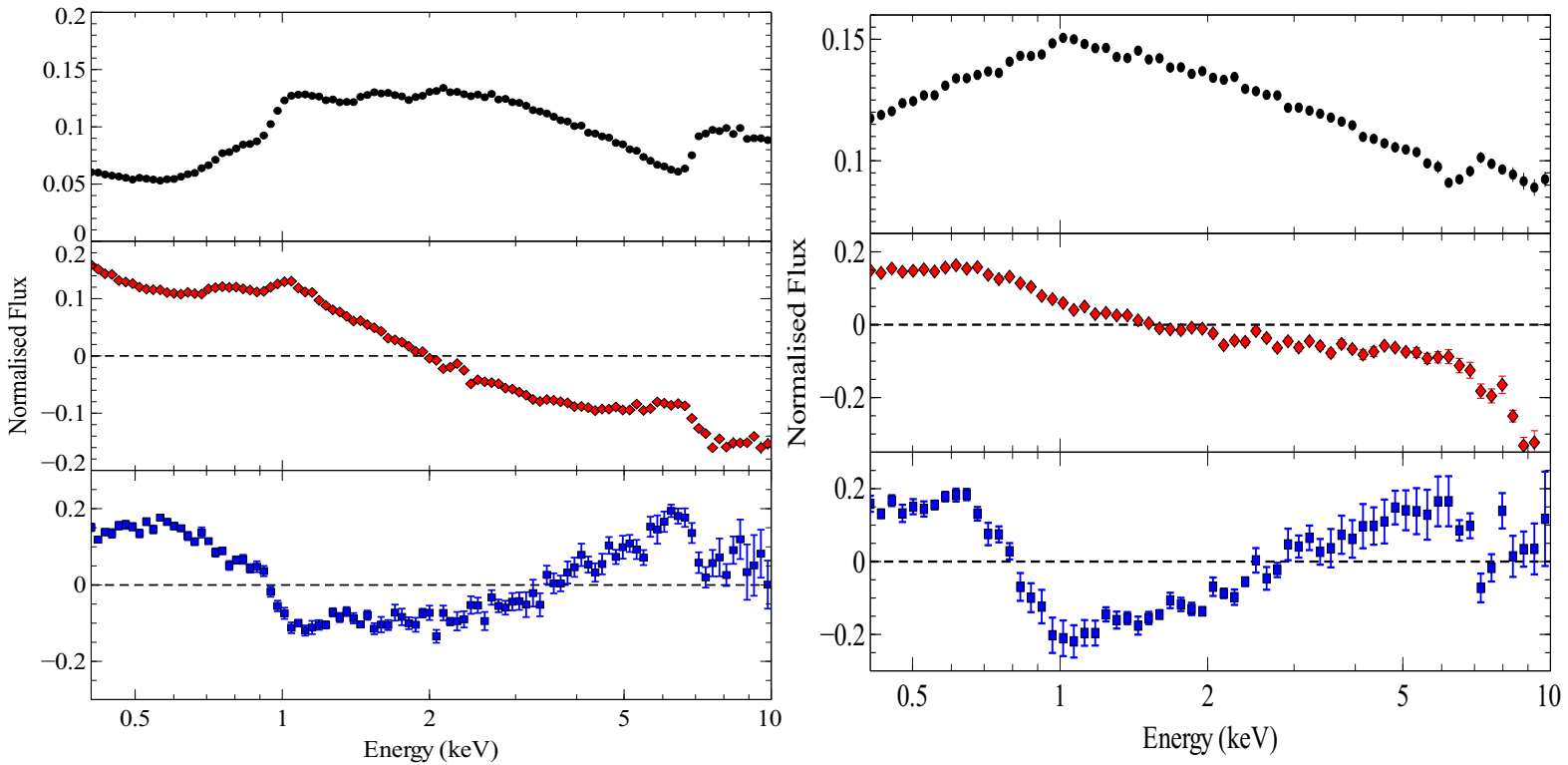
- Left Fig shows a simulation of varying column density, with a constant BB component at low energies.
- Right Fig shows the PCs from NGC 1365, where the low energy variability is damped out by diffuse gas around the AGN.

PCA of absorption III: Where are the warm absorbers?



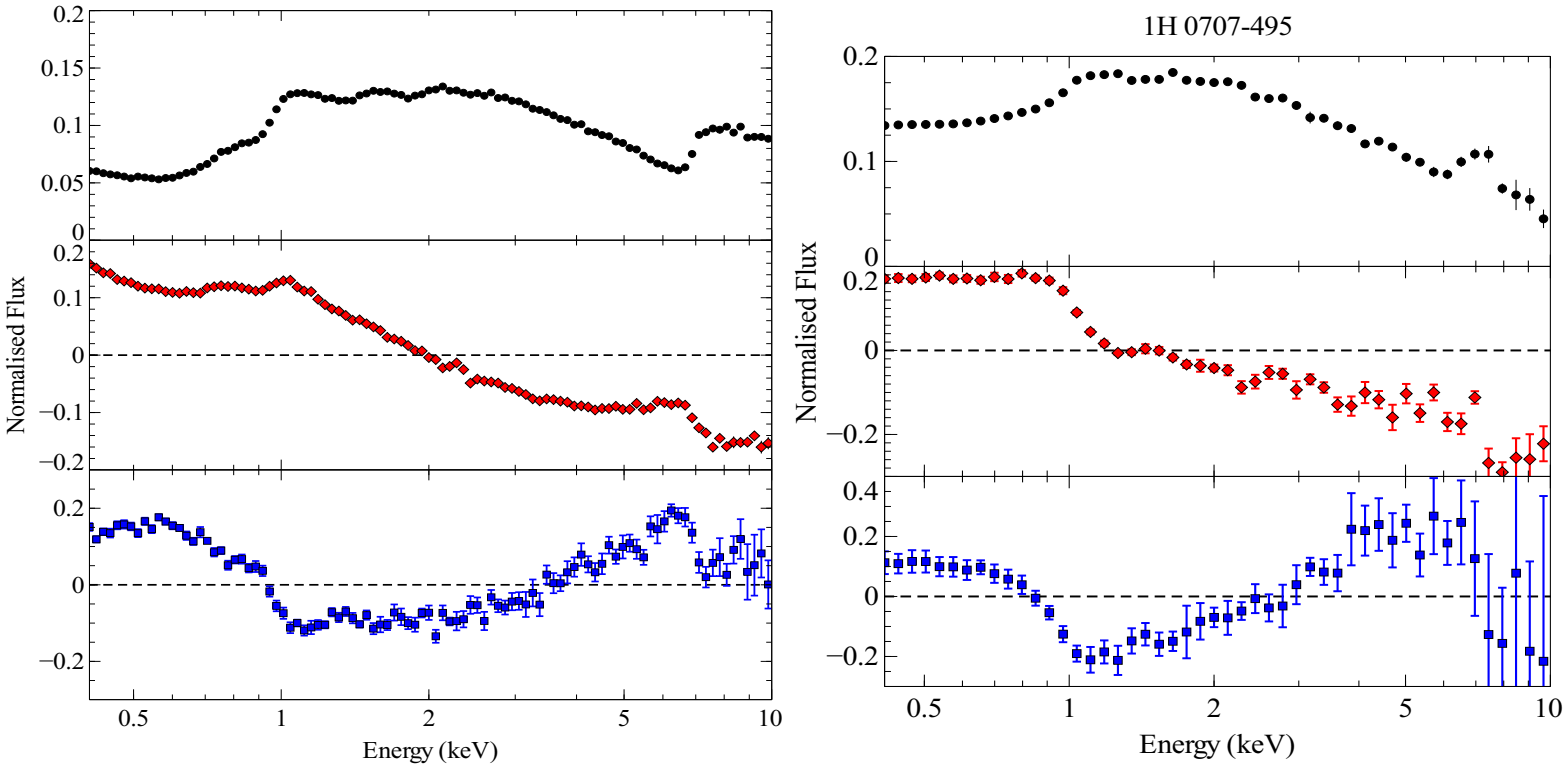
- Many of the AGN in our sample show unambiguous evidence of warm absorption, but we don't see any robust signatures of ionized absorption variability in our sample.
- Two explanations for this: 1) PCA is optimised for broad-band spectral variability, so narrow features get lost; 2) warm absorbers are generally less rapidly variable than either the intrinsic source spectrum or the absorption caused by BLR clouds etc.

PCA of reflection I



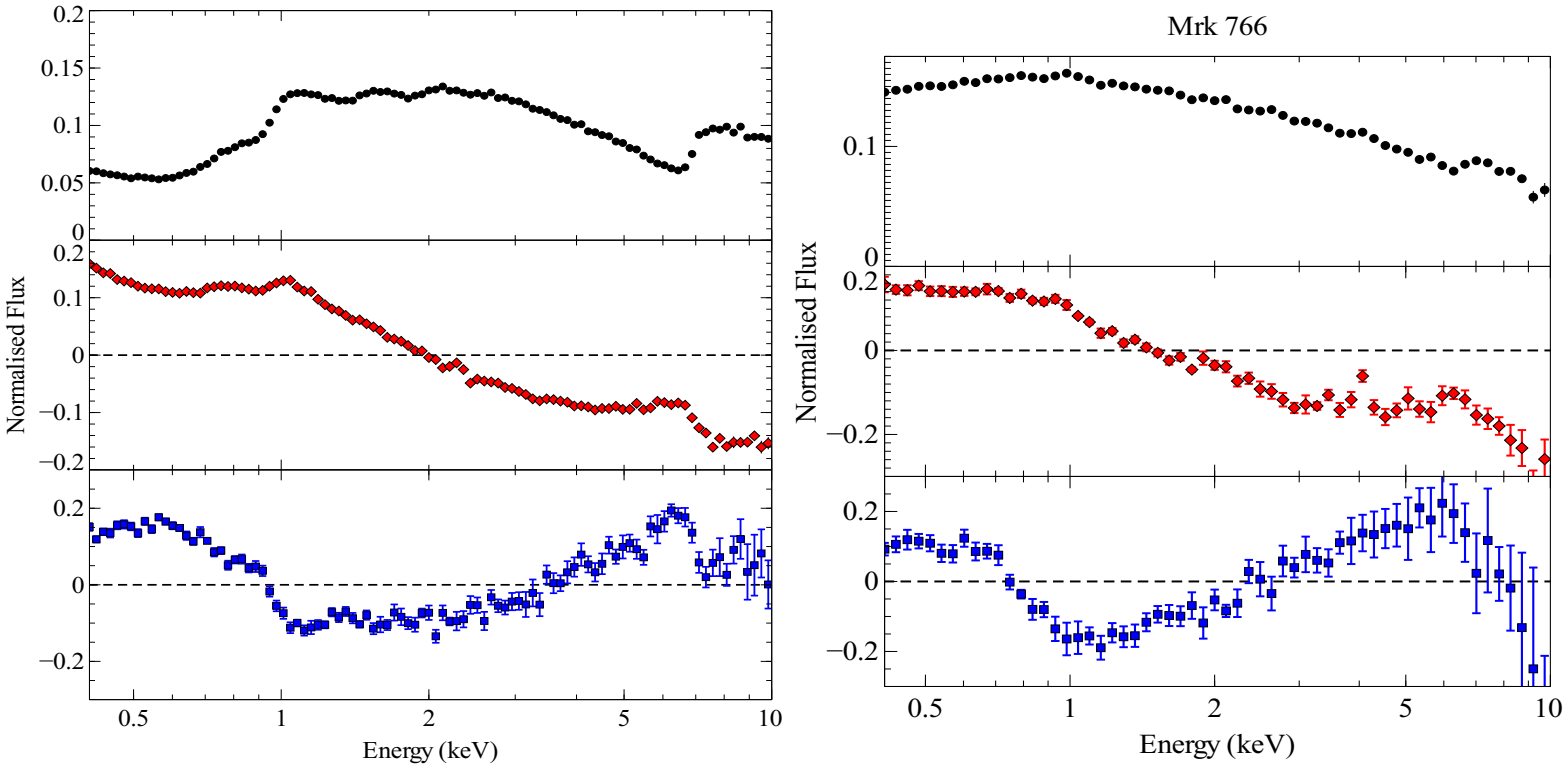
- Left Fig shows the PCs returned from PCA of a simulation of a powerlaw, varying in normalisation and photon index AND a blurred reflection component, which is less variable than the powerlaw.
- Right Fig (from Parker et al. 2014) shows the same thing, but for real data from MCG–6-30-15...

PCA of reflection II



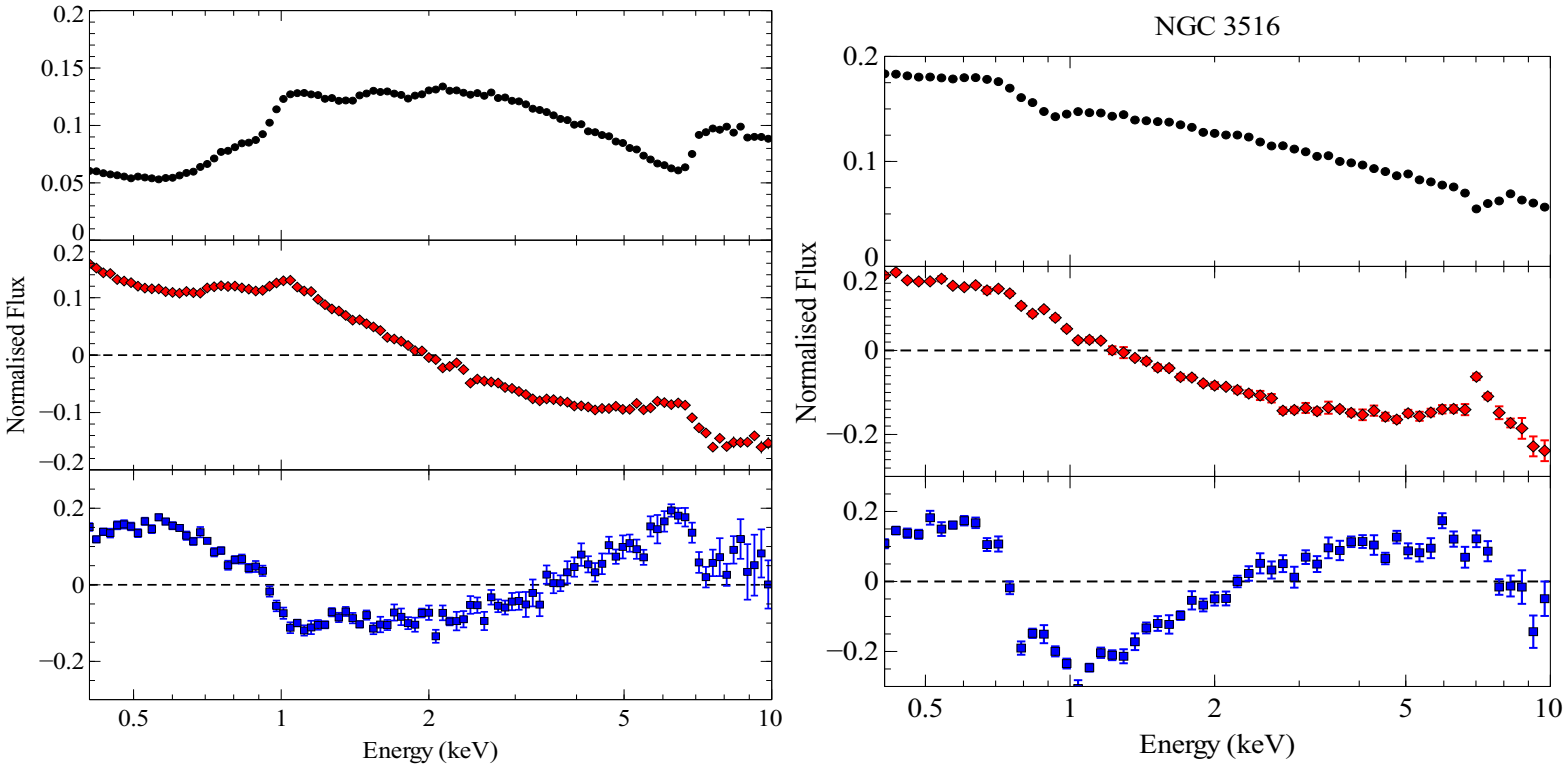
...and 1H 0707-495...

PCA of reflection III



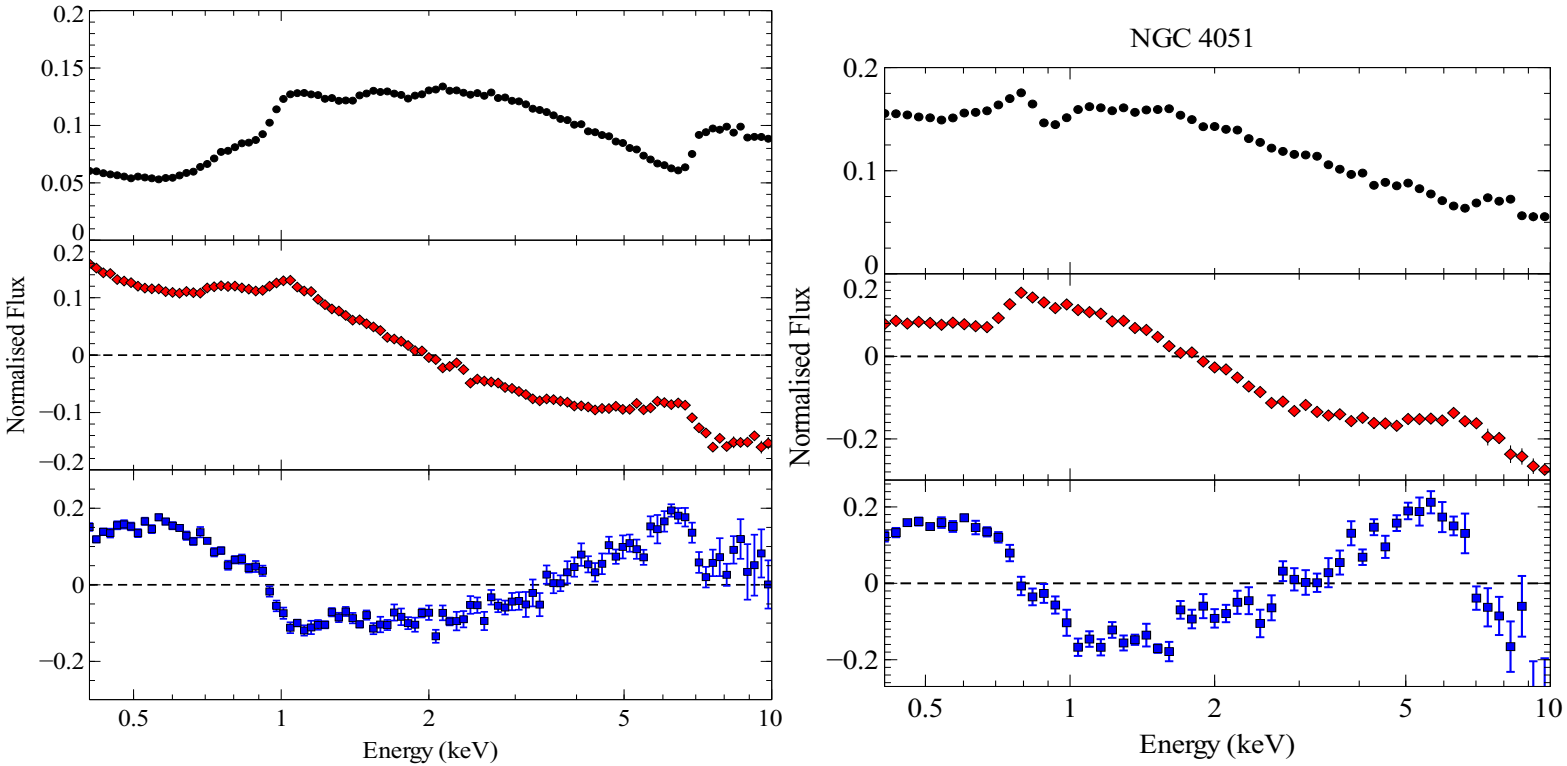
...and Mrk 766...

PCA of reflection IV



...and NGC 3516...

PCA of reflection V



...and NGC 4051!

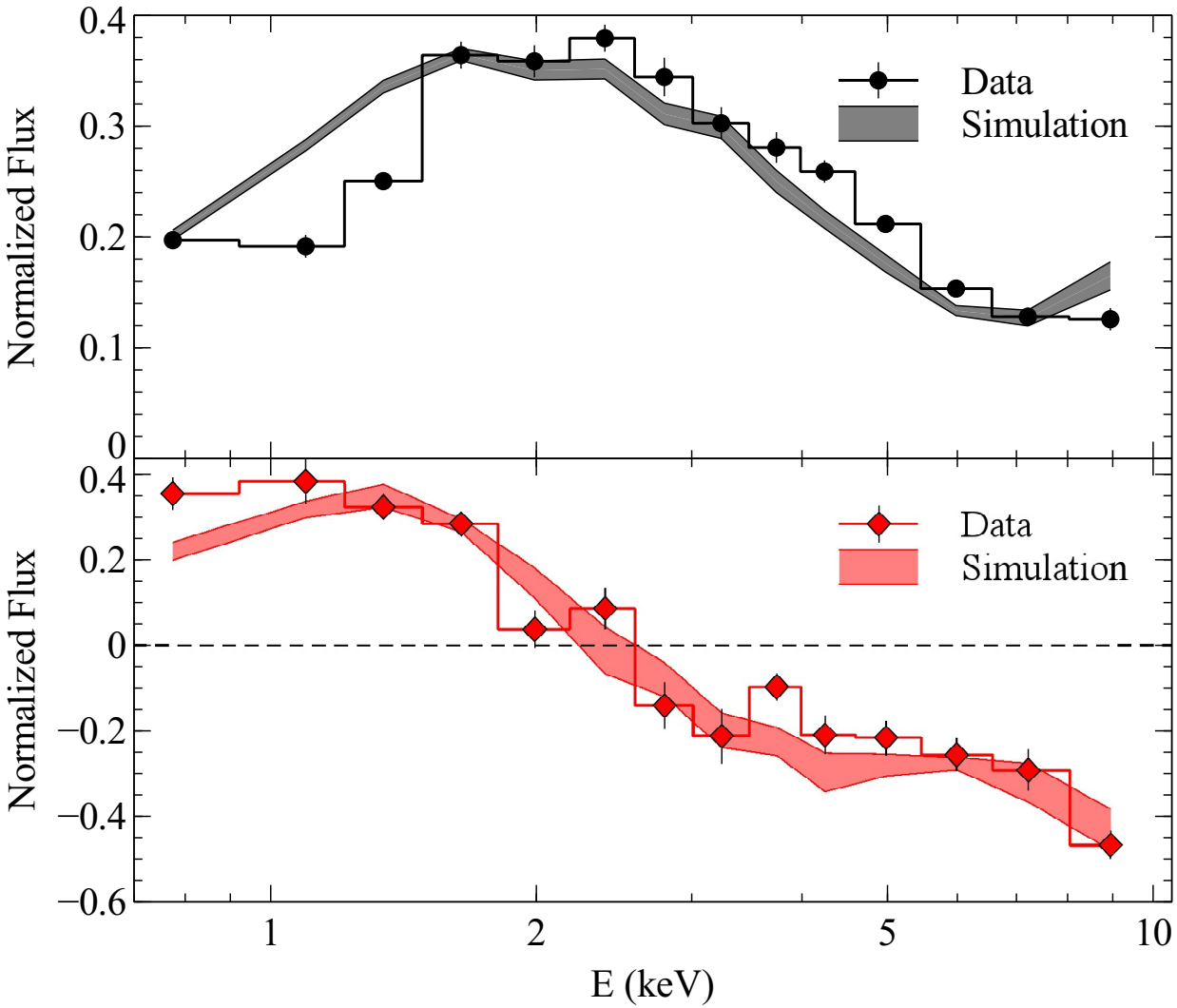
PCA of reflection

- All five of these sources are dominated by the same variability mechanism.
- The method shows, in a completely model independent way, that there has to be a spectral component responsible for both the soft excess and broad iron line in these sources.
- In all these sources (and several others) there is a strong pivoting term, which can be well modelled with changes in the photon index.
- In all cases, the soft excess and iron line is less variable than the continuum.

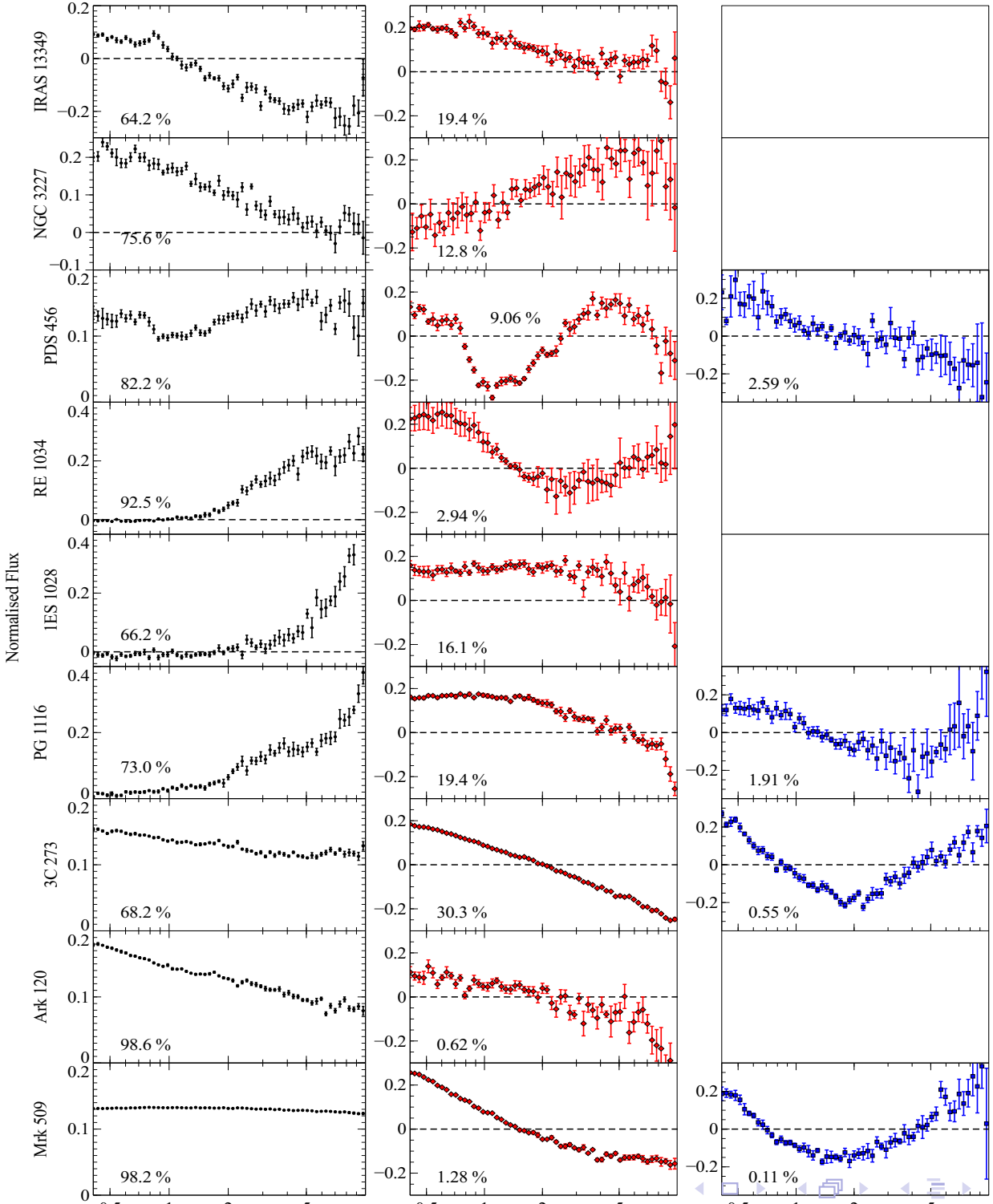
Conclusions

- PCA is a powerful tool for examining AGN variability. It returns completely unbiased, model-independent spectral components, and can be used to examine and quantify their variability.
- An analysis of a large sample of bright, variable AGN has revealed a large number of different variability patterns. These patterns can be matched to the predictions from simulations to unambiguously determine the nature of the variability in each source.

Mrk 335



Gallo et al., in prep.


Normalised Flux
IRAS 13349
64.2 %
19.4 %
NGC 3227
75.6 %
12.8 %
PDS 456
82.2 %
9.06 %
2.59 %
RE 1034
92.5 %
2.94 %
1ES 1028
66.2 %
16.1 %
PG 1116
73.0 %
19.4 %
1.91 %
3C 273
68.2 %
30.3 %
0.55 %
Ark 120
98.6 %
0.62 %
Mrk 509
98.2 %
1.28 %
0.11 %