A unified spectral variation model for Seyfert 1 Galaxies observed with NuSTAR and XMM/Suzaku

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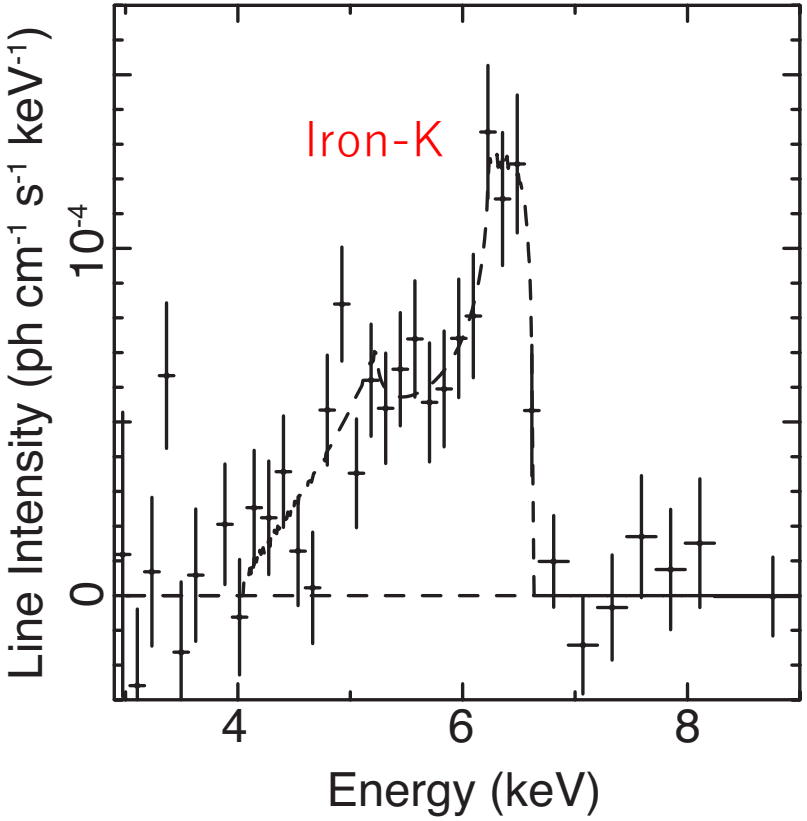
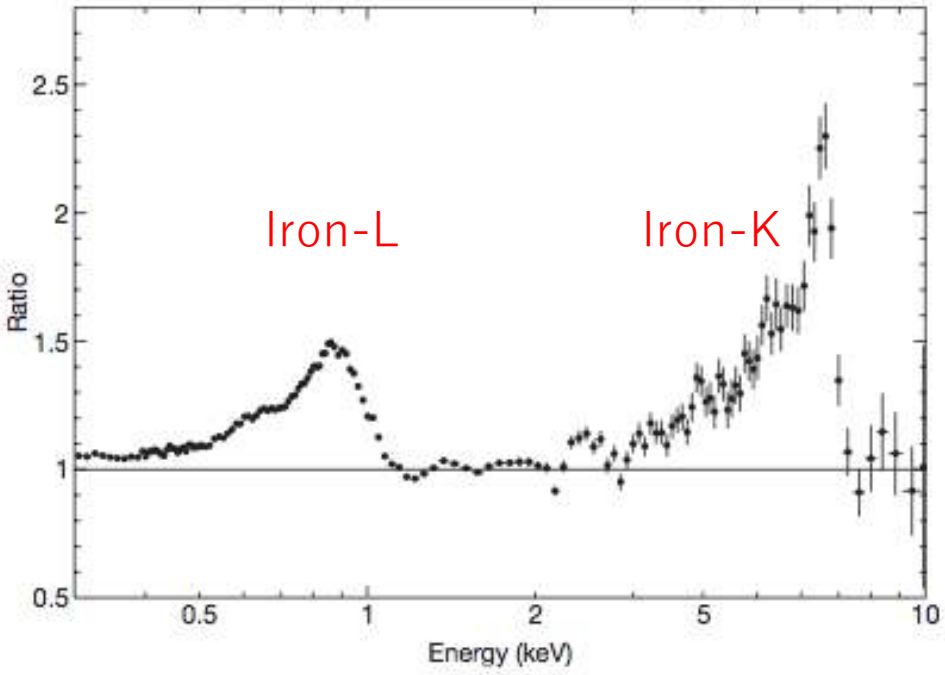
2. Variable Double Partial Covering Model
3. NuSTAR and XMM/Suzaku Simultaneous Observations
4. Data Analysis and Results
5. Summary

1. Introduction

Apparently broad Iron K- and L- emission line features in Seyfert galaxies

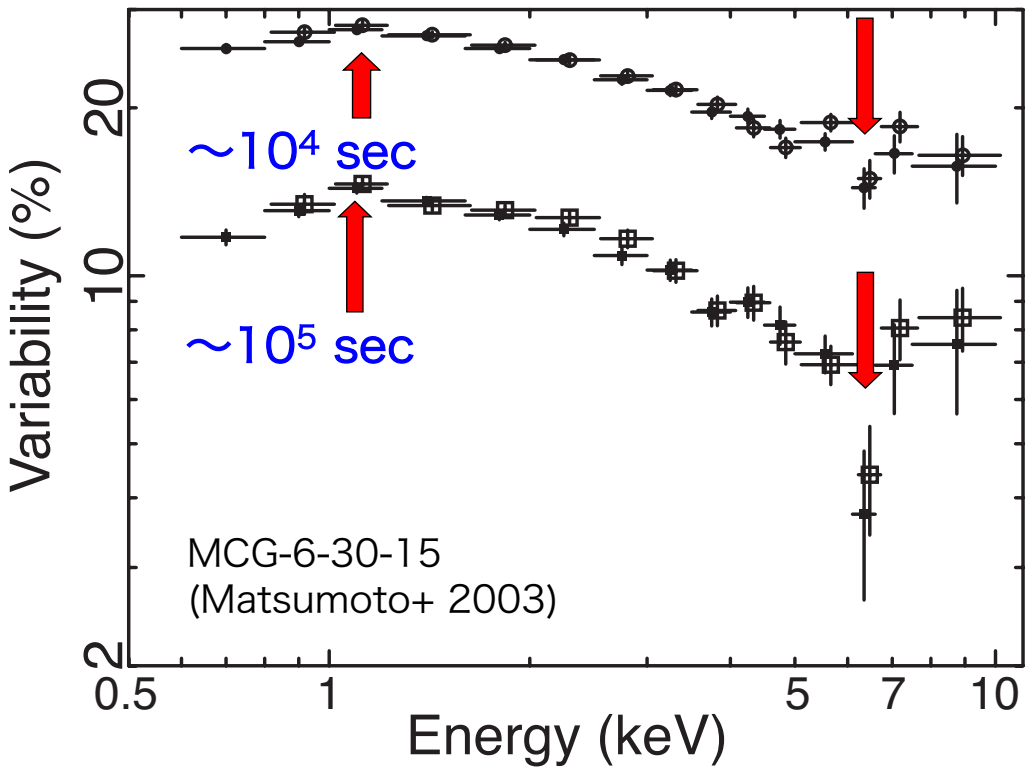


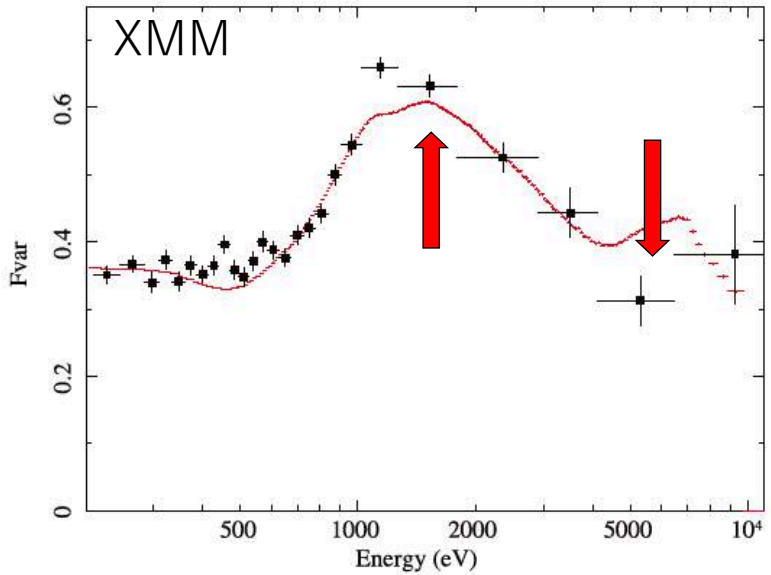
MCG-6-30-15 with ASCA (Tanaka+ 1995)

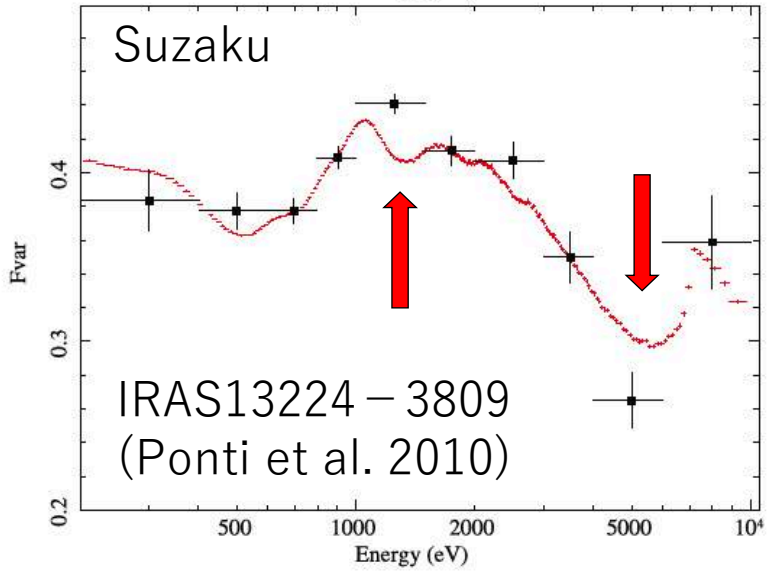


1H0707-495 with XMM (Fabian+ 2009)

Root Mean Square (RMS) spectra

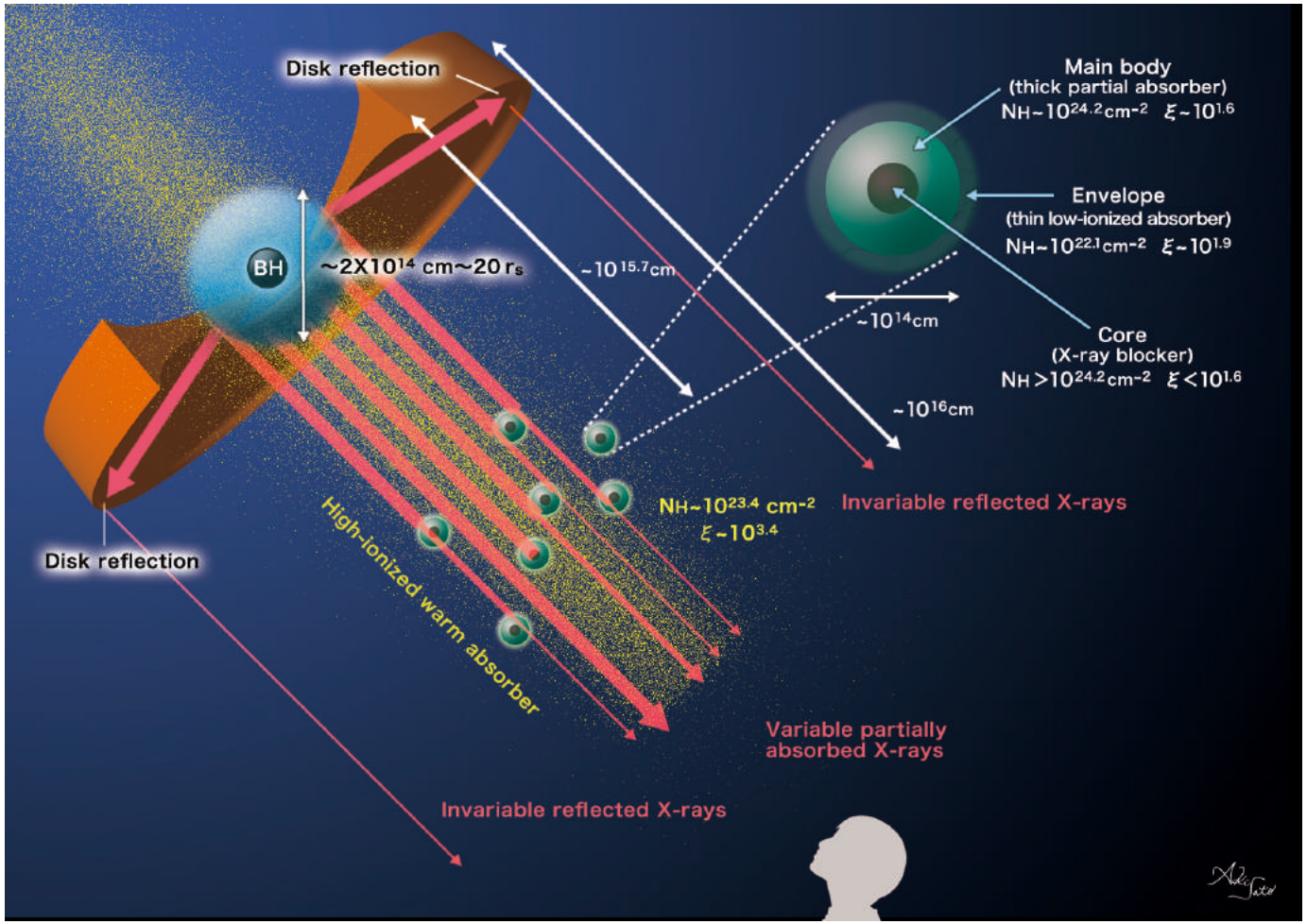






- Characteristic drop in the iron K-band and peak in the iron L-band

2. Variable Double Partial Covering Model



Miyakawa, Ebisawa and Inoue (2012)

Assume double layer partial covering clouds

Thick/cold core → iron K-edge

Thin/hot layer → iron L-edge

Most spectral variations below 10 keV at timescales less than day are due to change of the partial covering fraction

Mizumoto, Ebisawa and Sameshima (2014), Iso et al. (2016), Yamasaki et al. (2016), Mizumoto and Ebisawa (2017)

Variable Double Partial Covering Model

- Variation of the *partial covering fraction* explain most of the observed spectral variations below ~10 keV.

MCG-6-30-15 (Miyakawa, Ebisawa and Inoue 2012)

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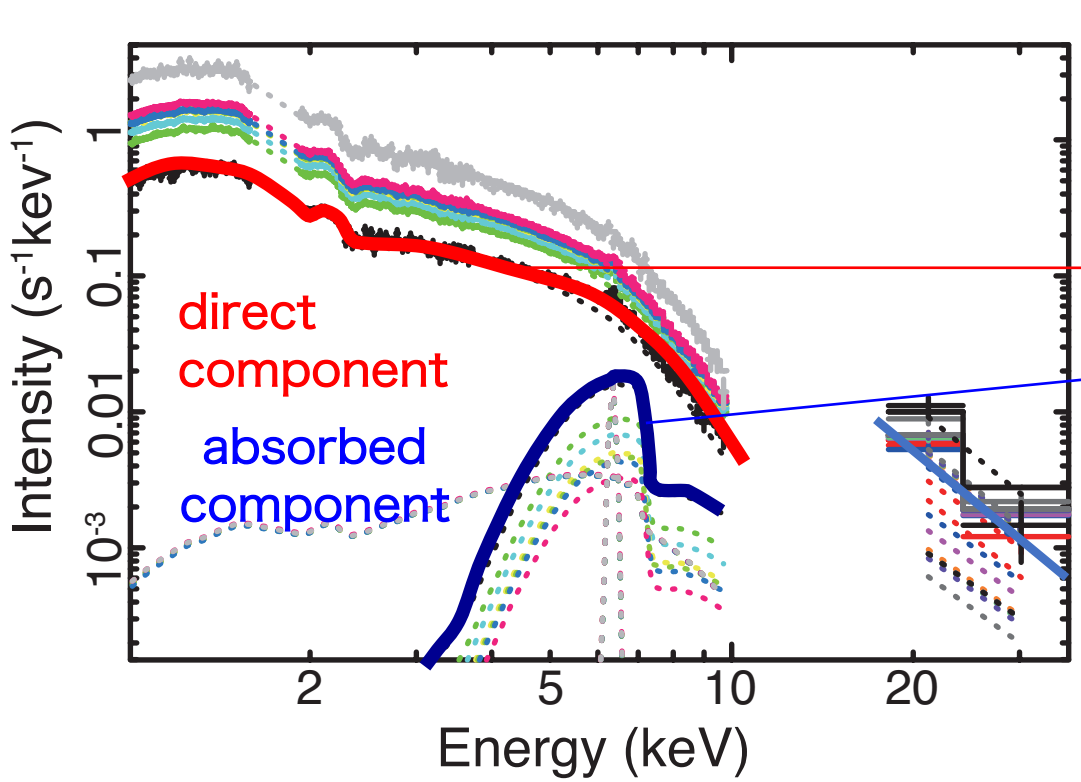

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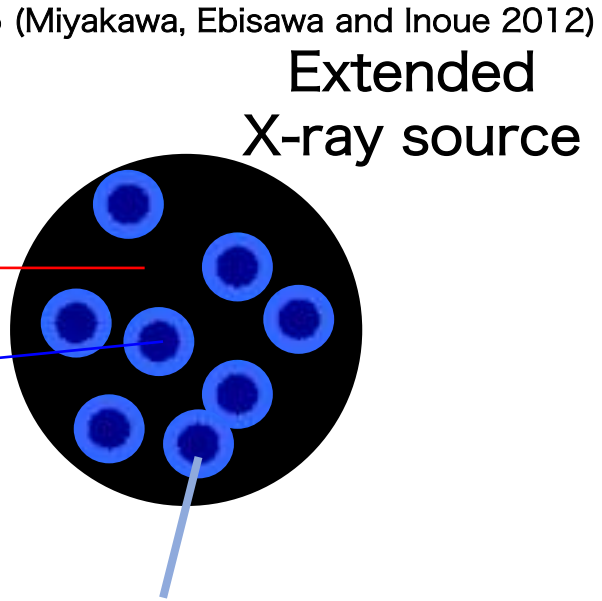

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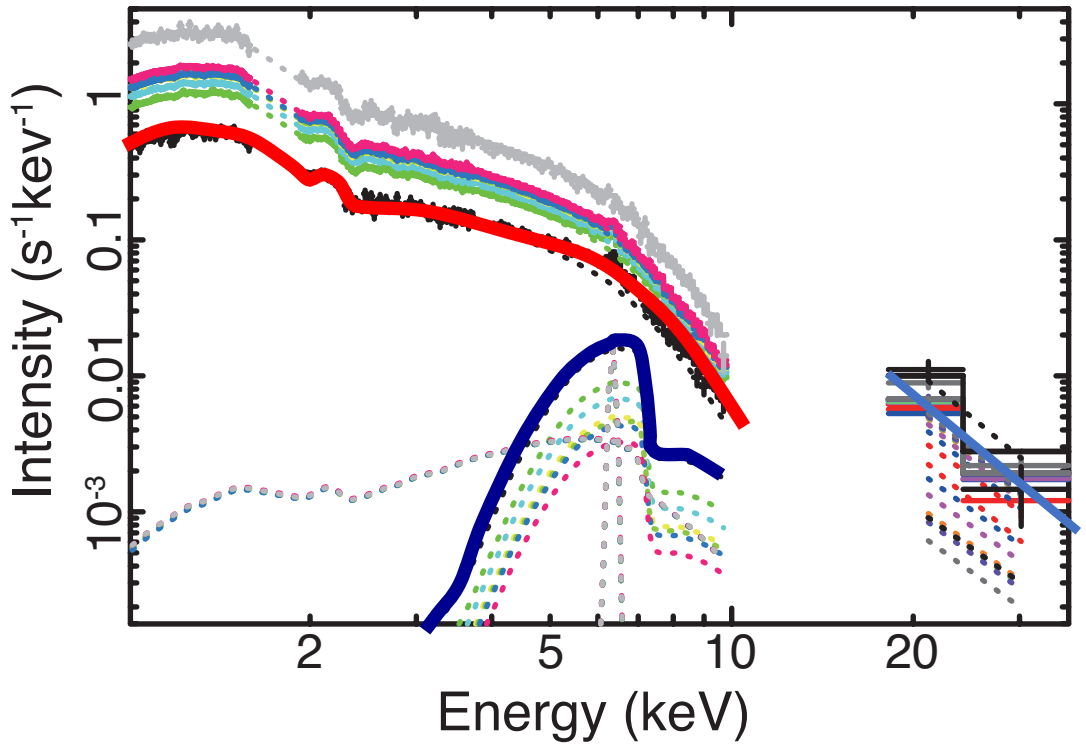

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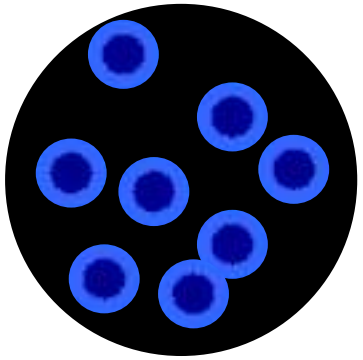

Covering fraction varies

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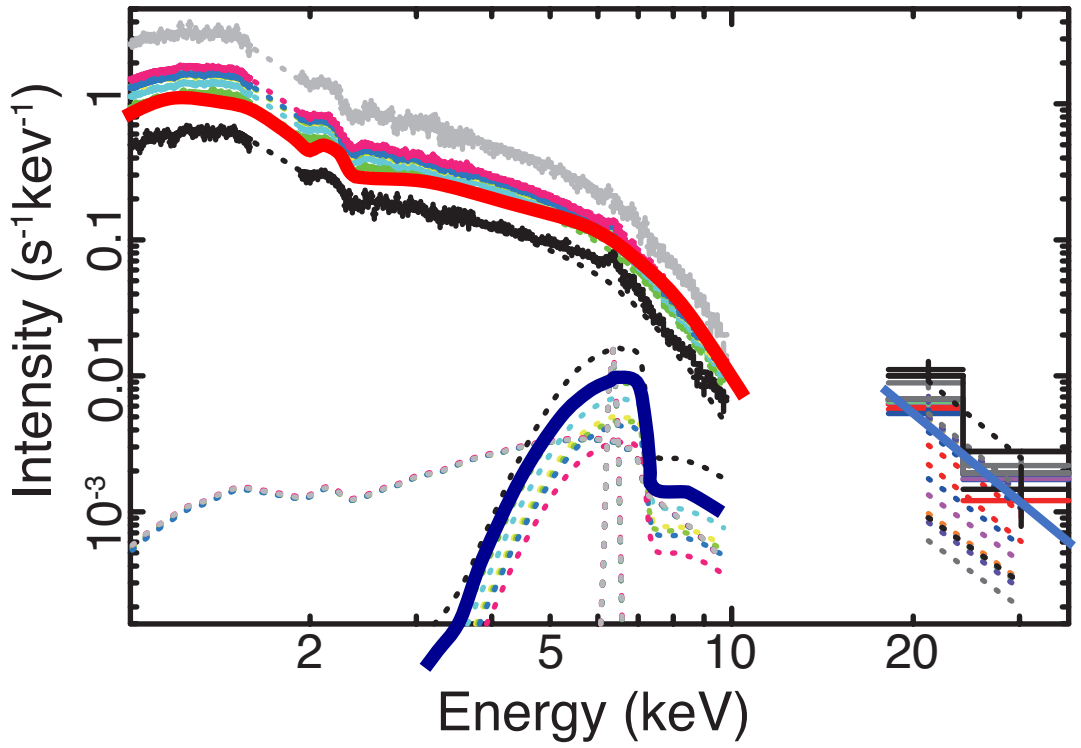

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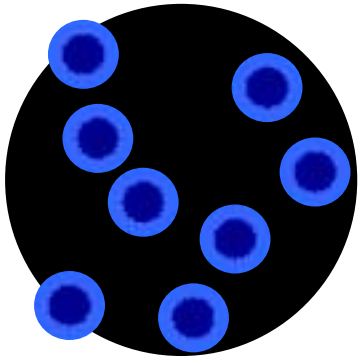

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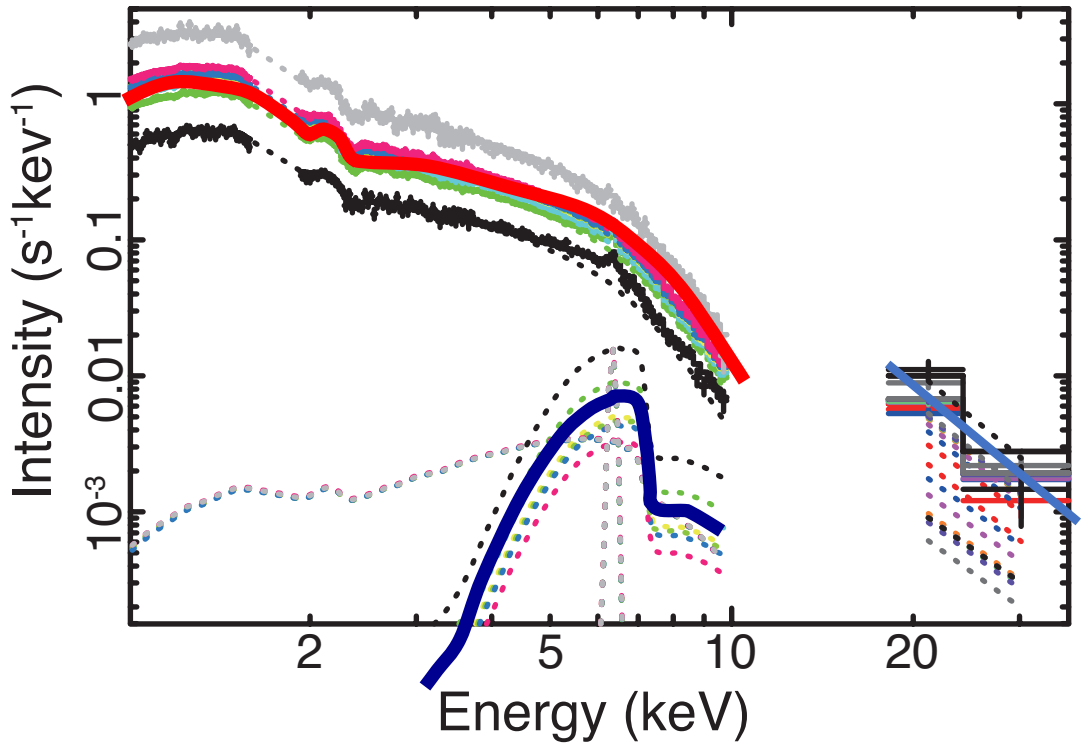

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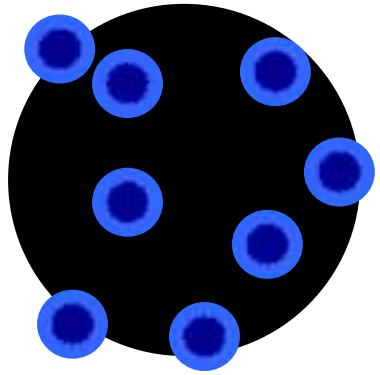

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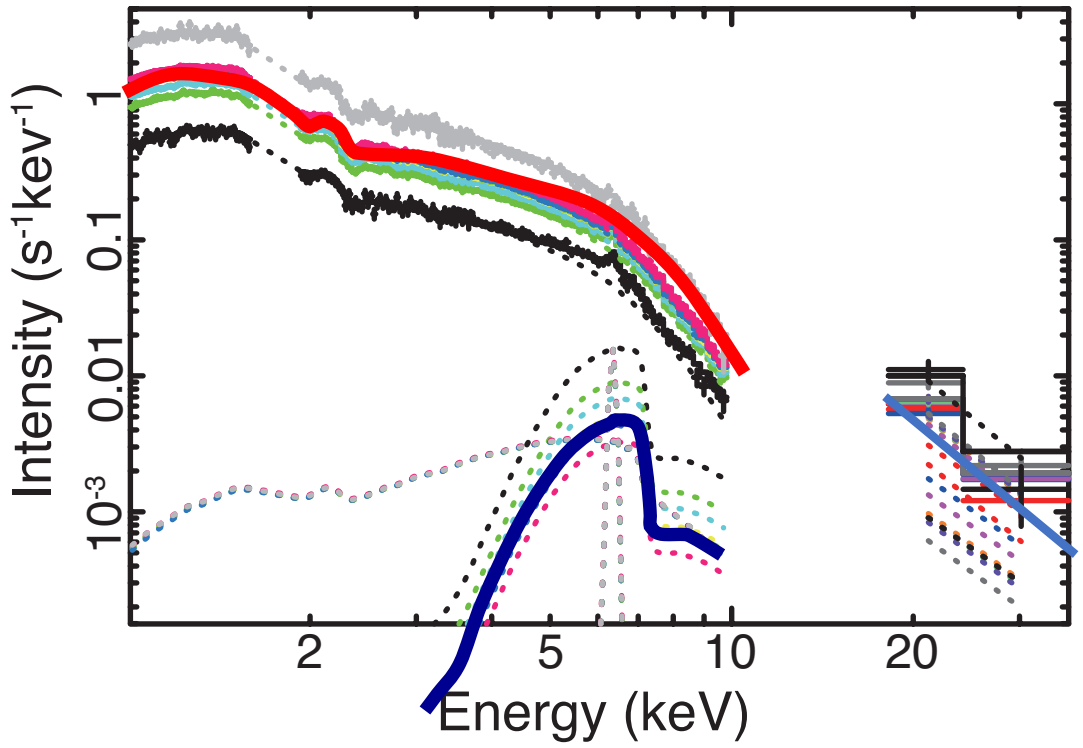

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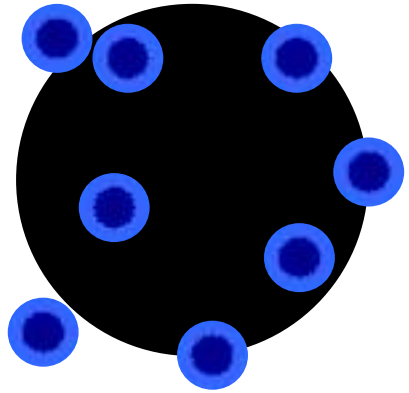

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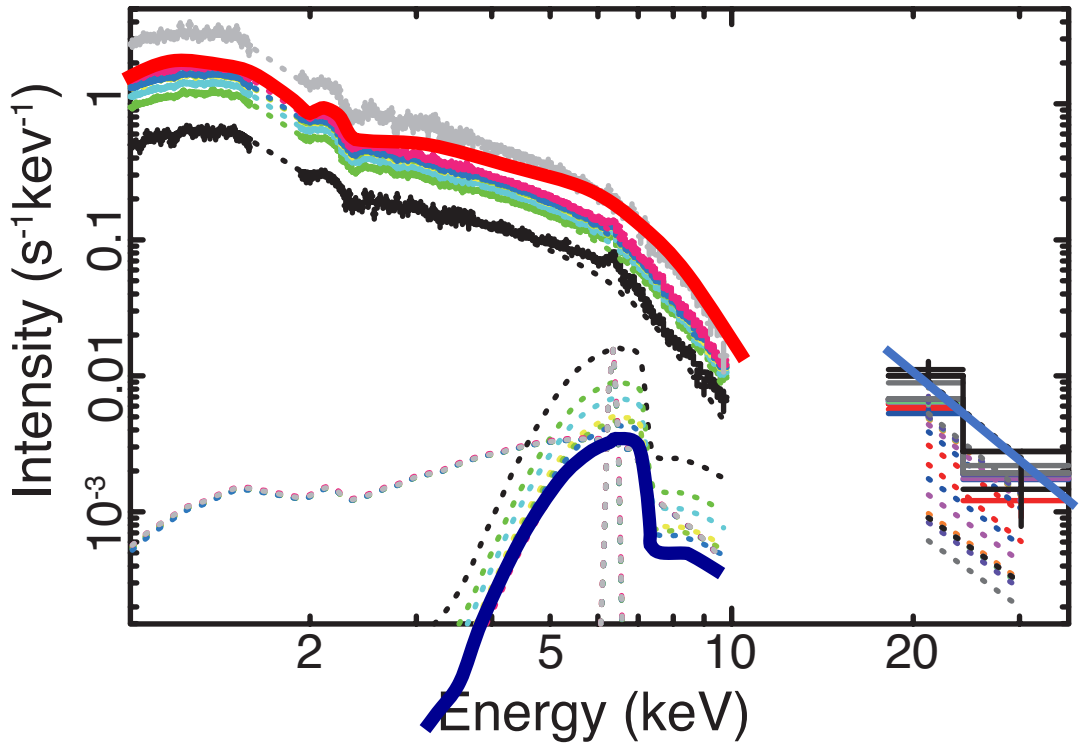

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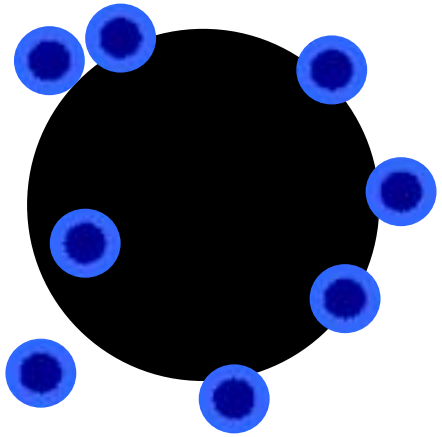

Covering fraction varies

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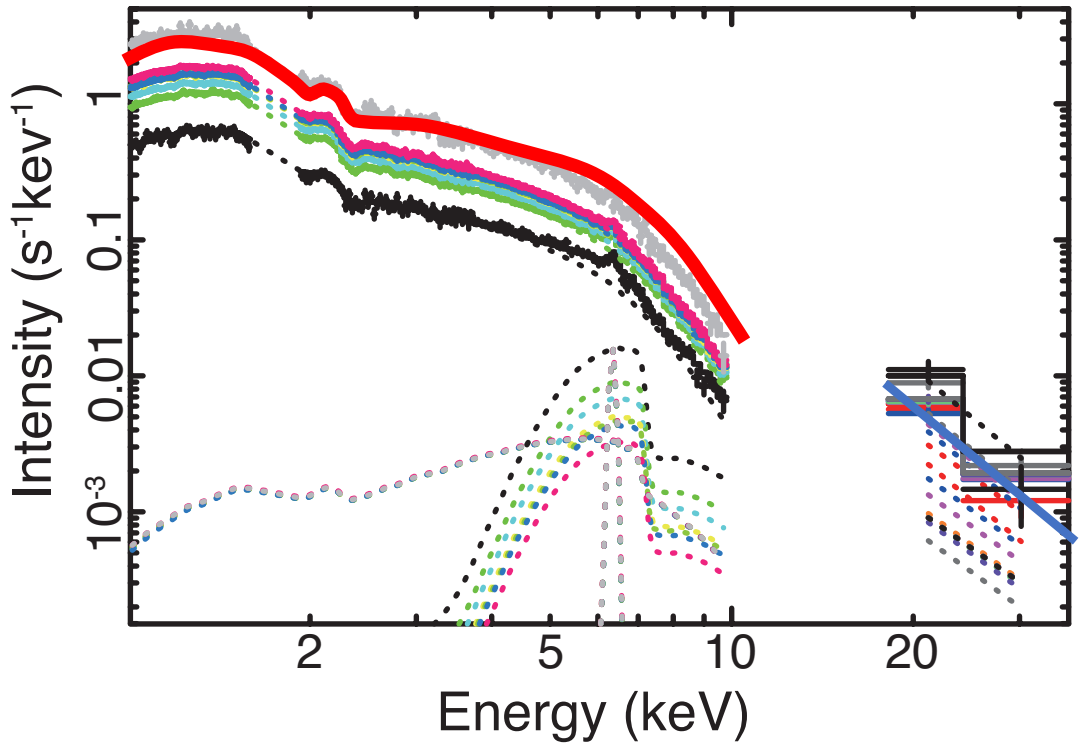

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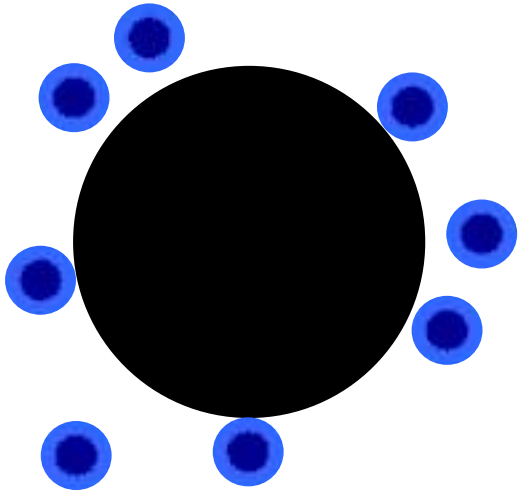
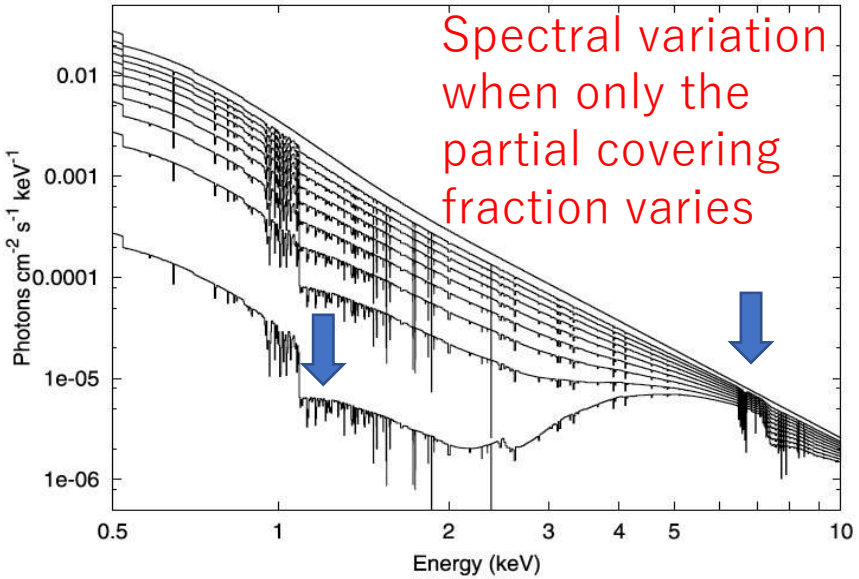


Covering fraction: Null

Spectral variation and the RMS spectra



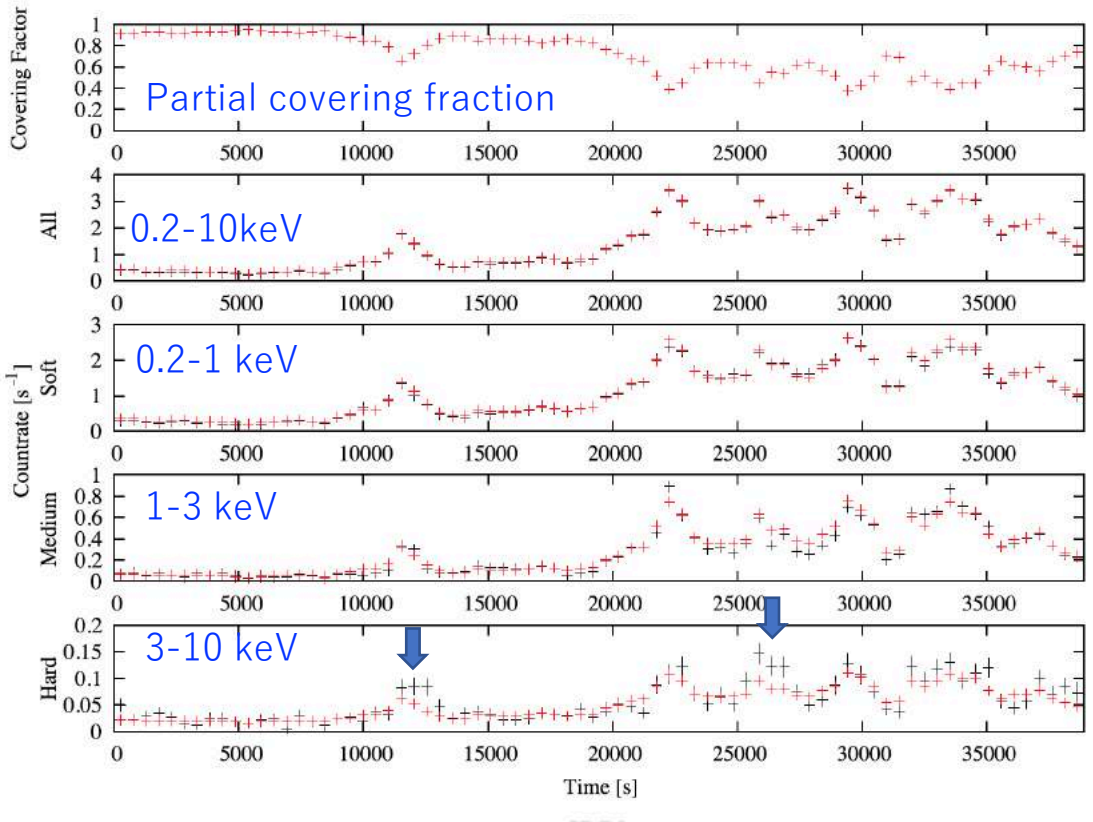
Yamasaki et al. (2016)

Energy (keV)

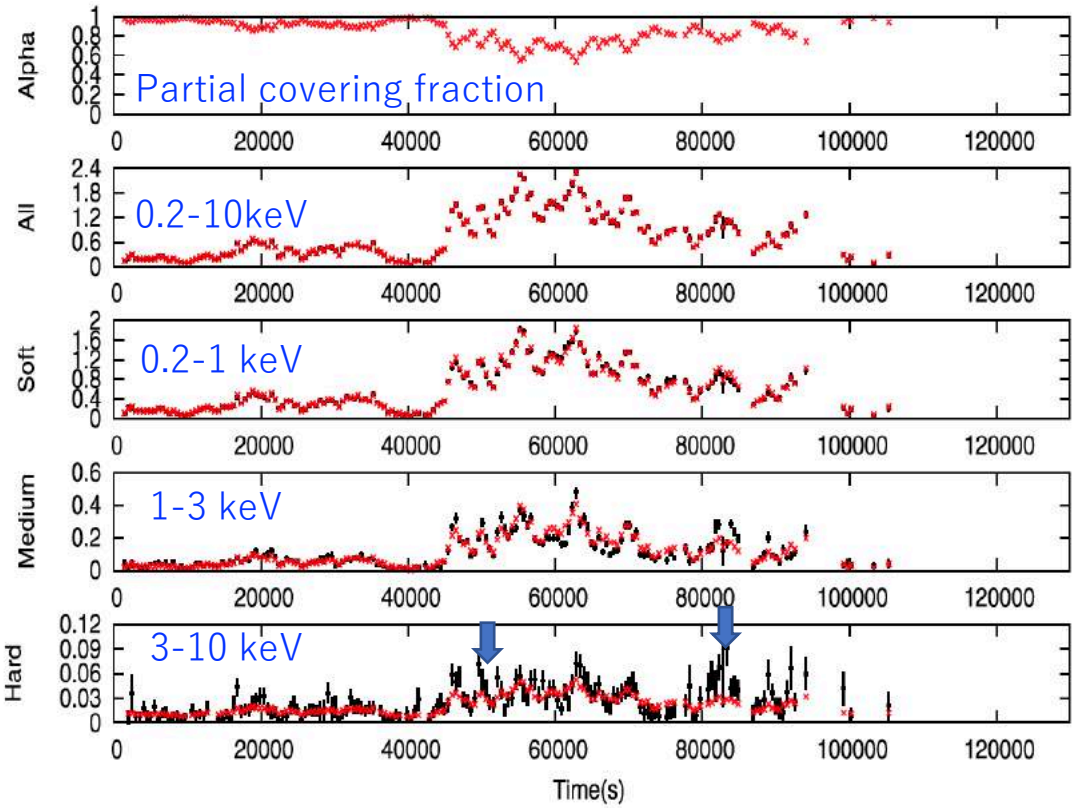
Light curves

Black: data
Red: model

1H0707-495 (MES 2014)



IRAS13224-2809 (Yamasaki et al. 2016)



Soft (0.2 – 1 keV) X-ray variation is described by only change of the partial covering fraction
Residuals in hard X-rays (3-10 keV) → Suggests presence of independent hard component

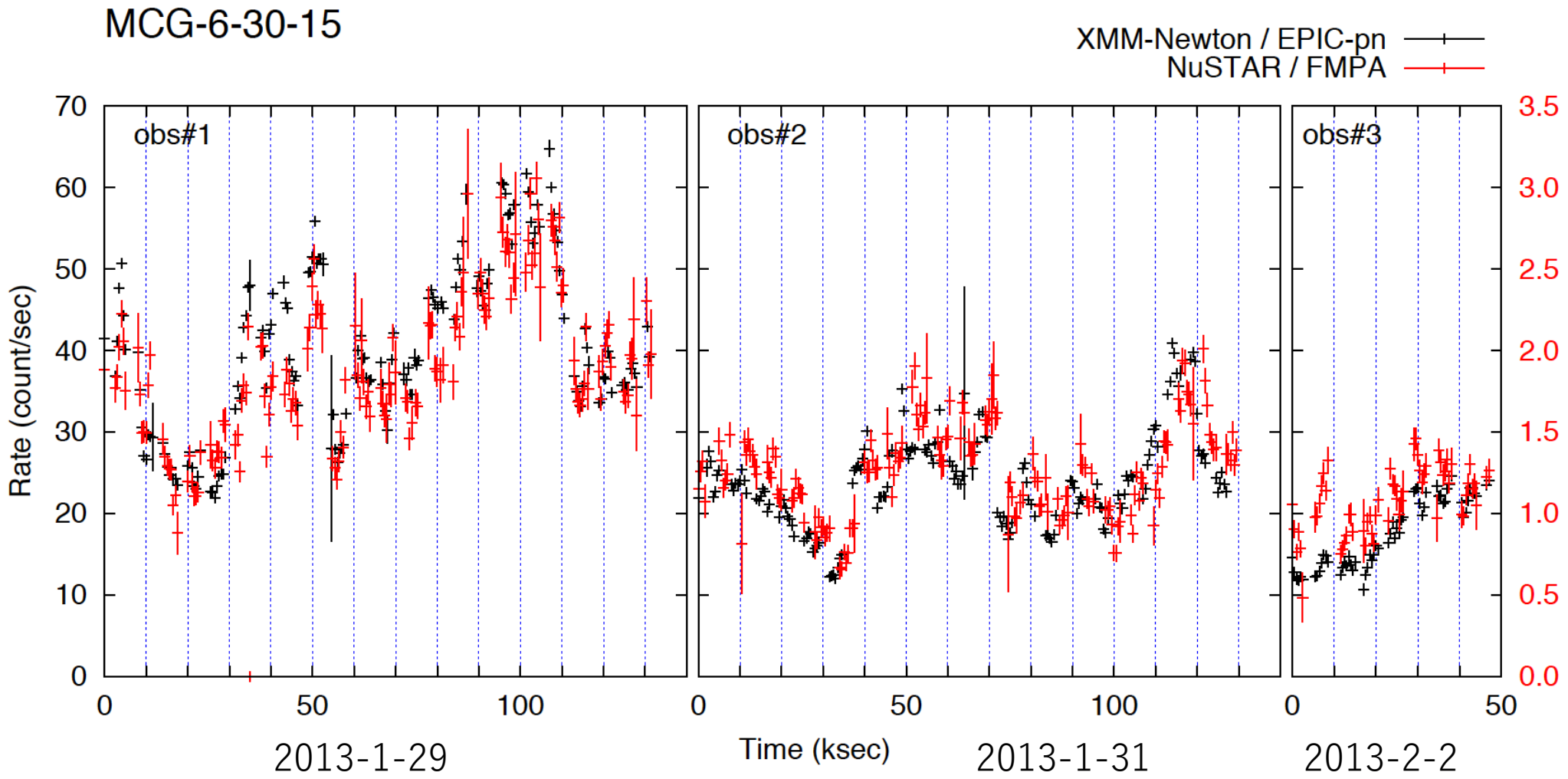
Summary of the Variable Double Partial Covering Model

- Variable Double Partial Covering model can explain most of the soft X-ray variation (<< 10 keV) at timescales less than ~day
  - Variation of the partial covering fraction of the double-layer clouds
- Presence of an independent hard X-ray component suggested

3. NuSTAR and XMM/Suzaku Simultaneous Observations

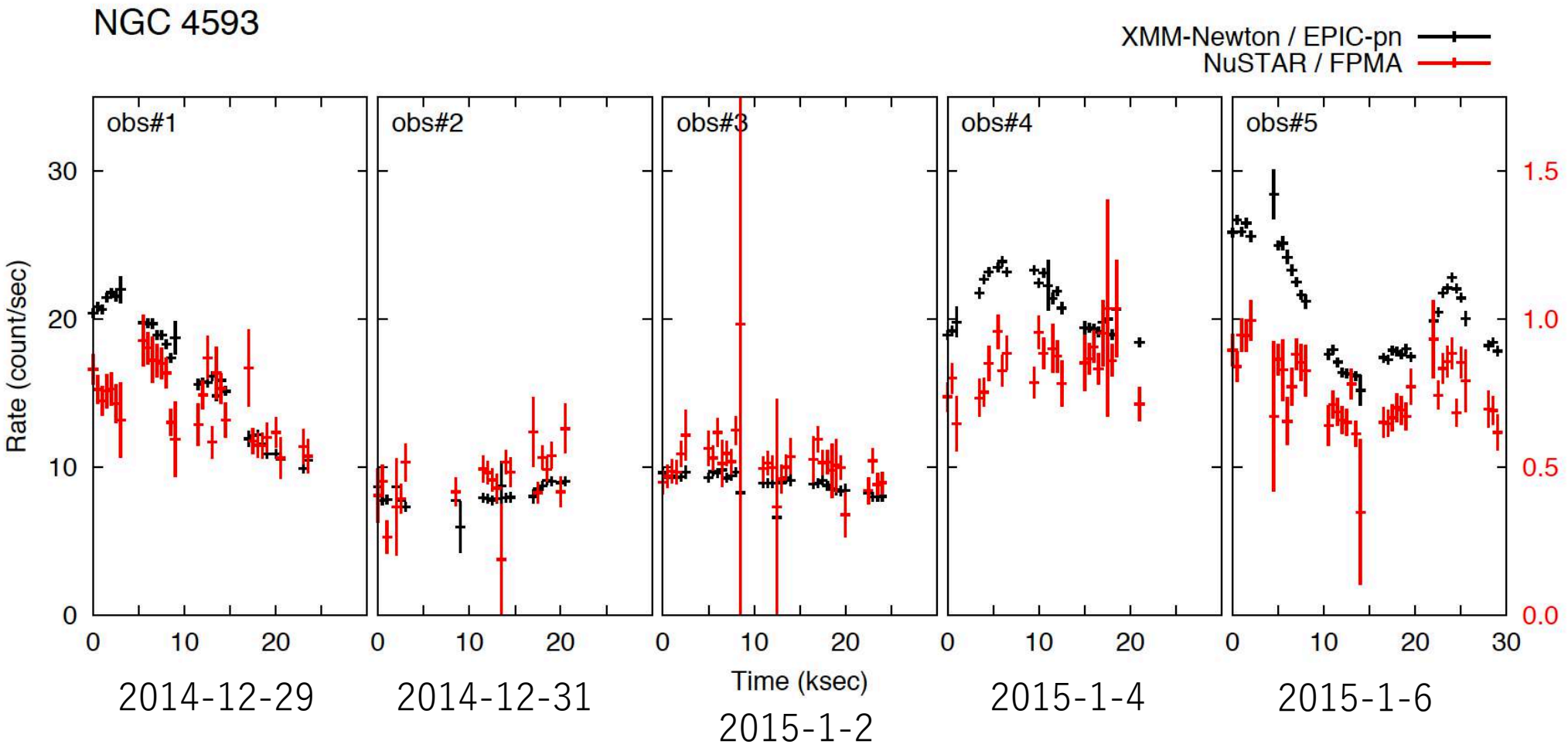
- We look into the NuSTAR and XMM/Suzaku archives for Seyfert galaxies with broad iron K-line/edge feature to study spectral variations in 0.2 – 78 keV
- We select only *exactly simultaneous* observations with NuSTAR and XMM/Suzaku
- We choose MCG-6-30-15, NGC 4593, NGC1365, Swift J2127.4+5654, MCG-5-23-16
- We divide data into discrete “observations”, separated by time-gaps longer than ~a day.
- In total, we have 5 sources, 16 observations.

Kusunoki et al. in preparation

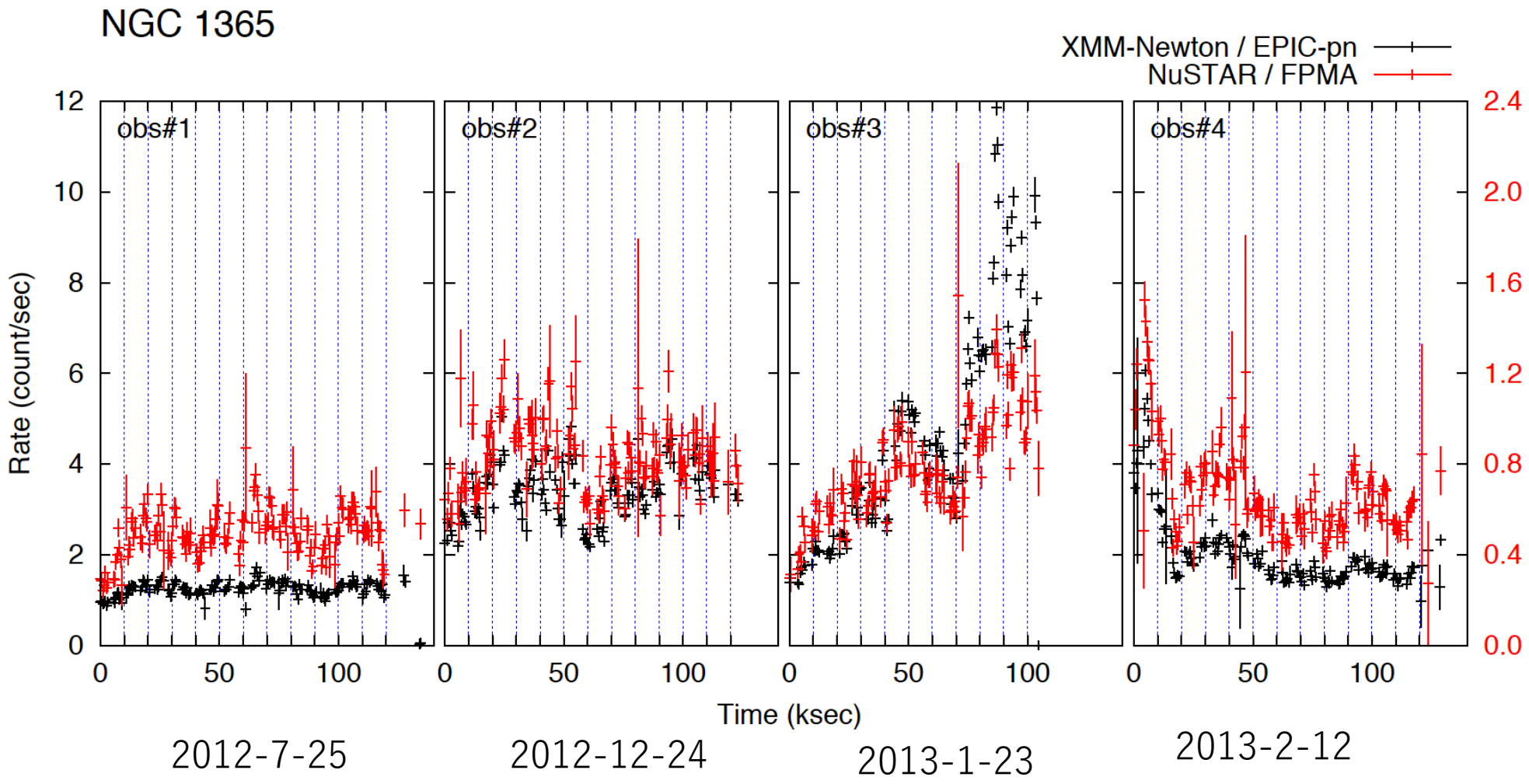


Vertical dotted lines indicate boundaries of time-slice spectra

3 observations

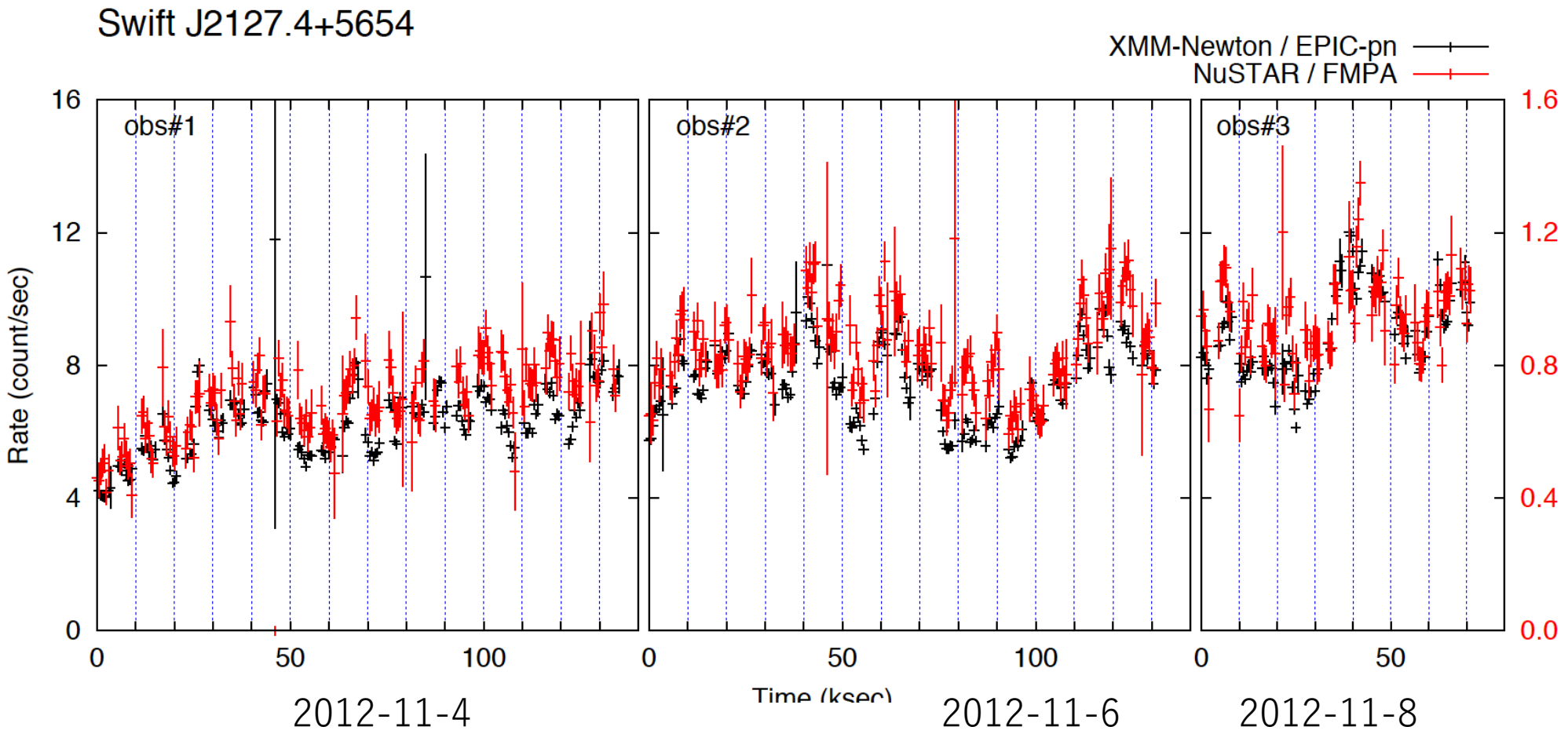


5 observations



Vertical dotted lines indicate boundaries of time-slice spectra

4 observations



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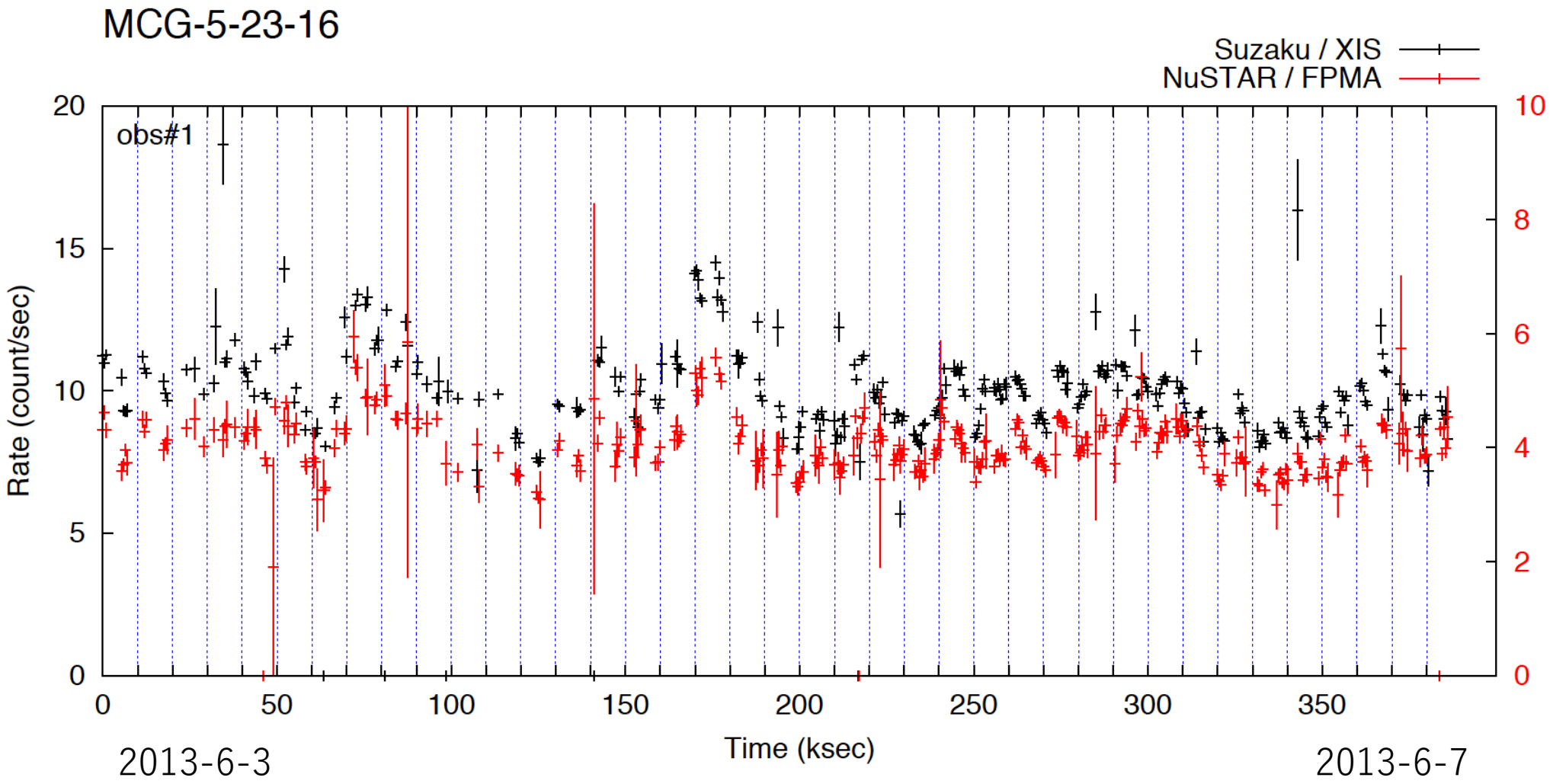


Vertical dotted lines indicate boundaries of time-slice spectra

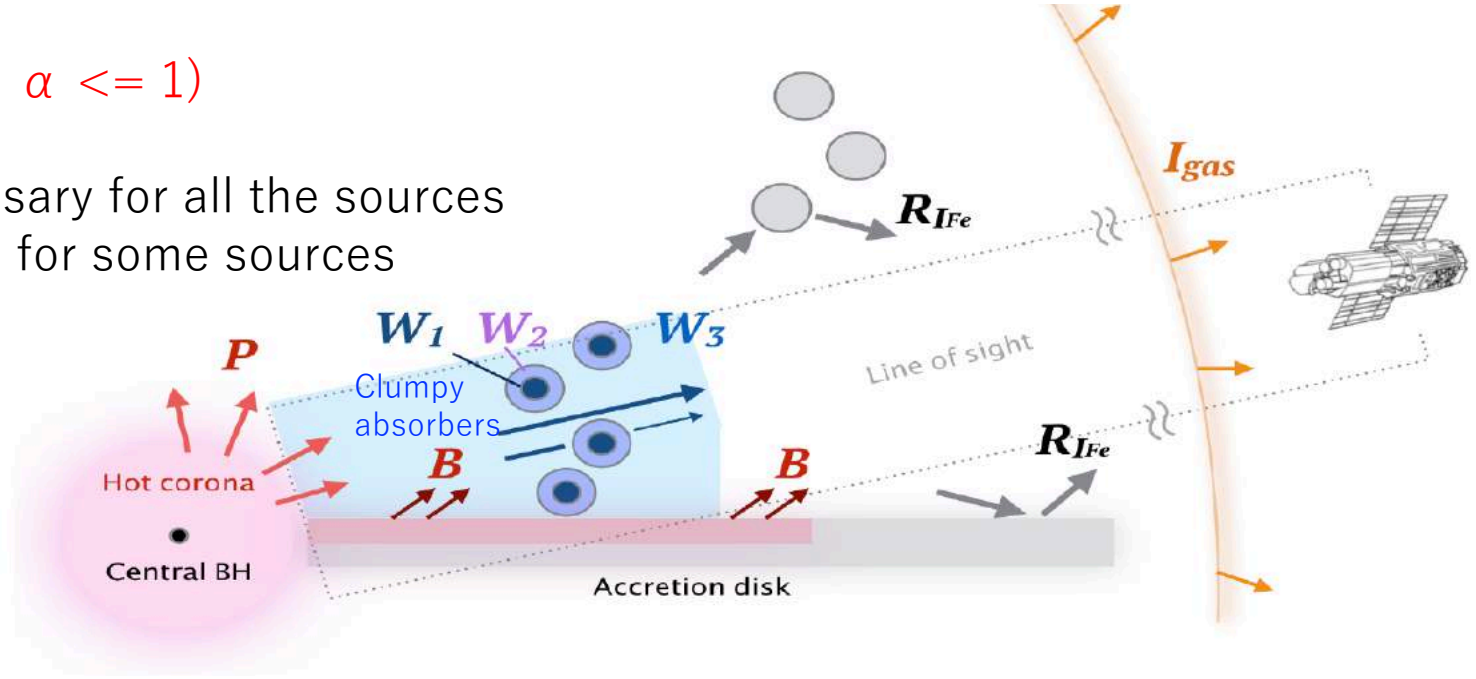
1 long observations (~380 ksec)

4. Data Analysis and Results

- The “standard” spectral model we adopted

$$F = \underline{A\ [\ (P+B)(1-\alpha+\alpha W_1)(1-\alpha+\alpha W_2)}\ W_3 \underline{+R_{I_{\rm Fe}}} + B + I_{\rm gas} + G]$$

- α – Partial covering fraction (0 <= α <= 1)
- P – Power-law component
- Underlined components are necessary for all the sources
- Other components are not needed for some sources



XSPEC model expression

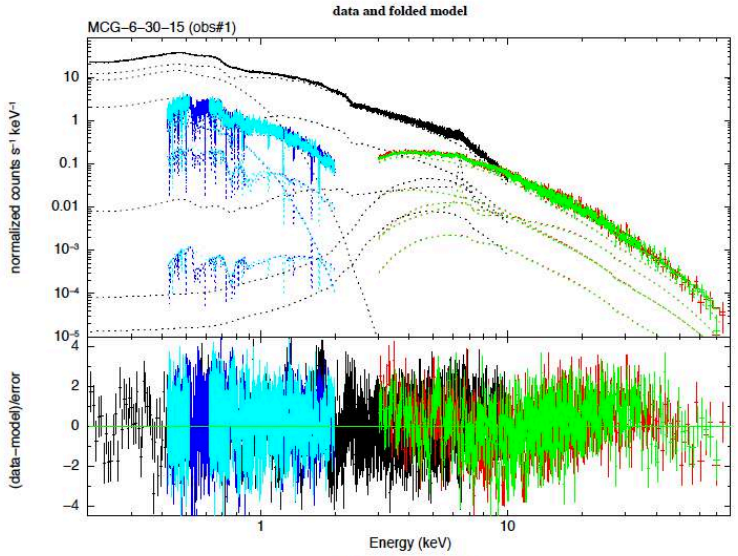
$$\underline{\texttt{phabs}*((\texttt{cutoffpl}+\texttt{diskbb})(\texttt{mtable}*\texttt{partcov})(\texttt{mtable}*\texttt{partcov})}*\texttt{mtable}$$
$$\underline{+\texttt{pexmon}}+\texttt{diskbb}+\texttt{mekal}+\texttt{gaussian})$$

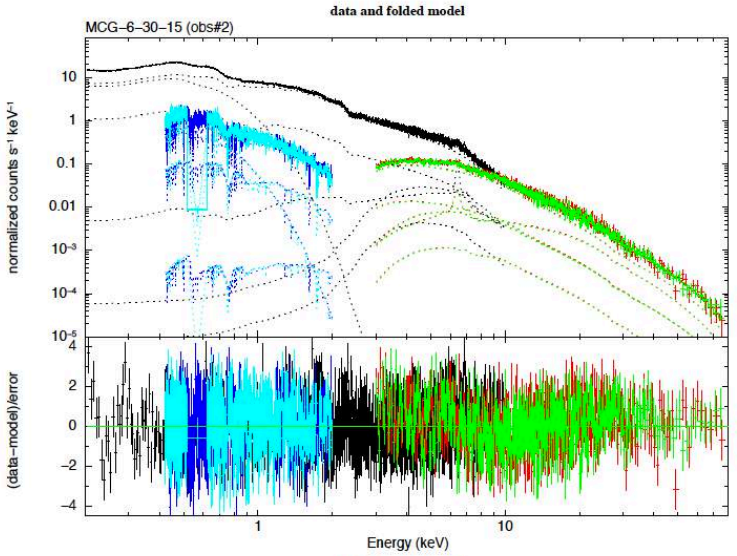
- Spectral model for individual sources

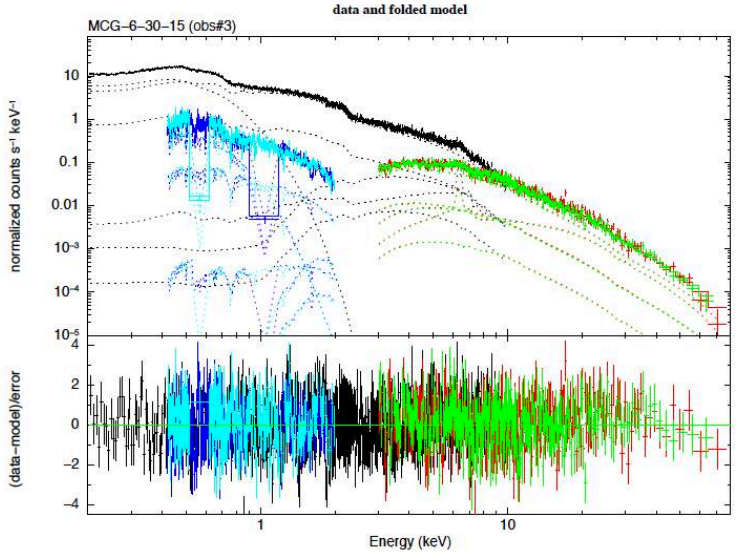
MCG-6–30–15	$F = A[P(1-\alpha+\alpha W_1)(1-\alpha+\alpha W_2)W_3 + R_{I_{\rm Fe}} + B + G]$
NGC 4593	$F = A[(P+B)(1-\alpha+\alpha W_1)(1-\alpha+\alpha W_2)W_3 + R_{I_{\rm Fe}}]$
NGC 1365	$F = A[P(1-\alpha+\alpha W_1)(1-\alpha+\alpha W_2)W_3 + R_{I_{\rm Fe}} + B + I_{\rm gas} + G]$
Swift J2127.4+5654	$F = A[P(1-\alpha+\alpha W_1)(1-\alpha+\alpha W_2) + R_{I_{\rm Fe}}]$
MCG-5–23–16	$F = A[P(1-\alpha+\alpha W_1)W_3 + R_{I_{\rm Fe}}]$

Minor model differences among sources

Time-average energy spectra(1)



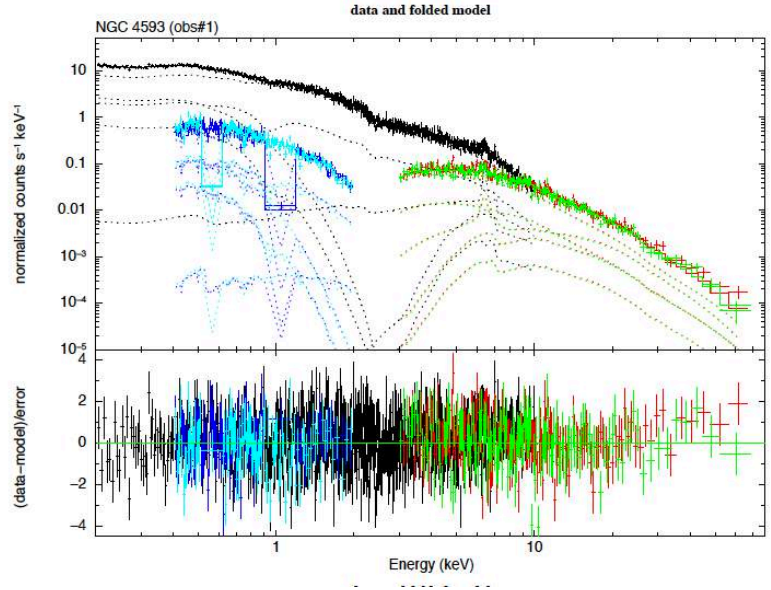


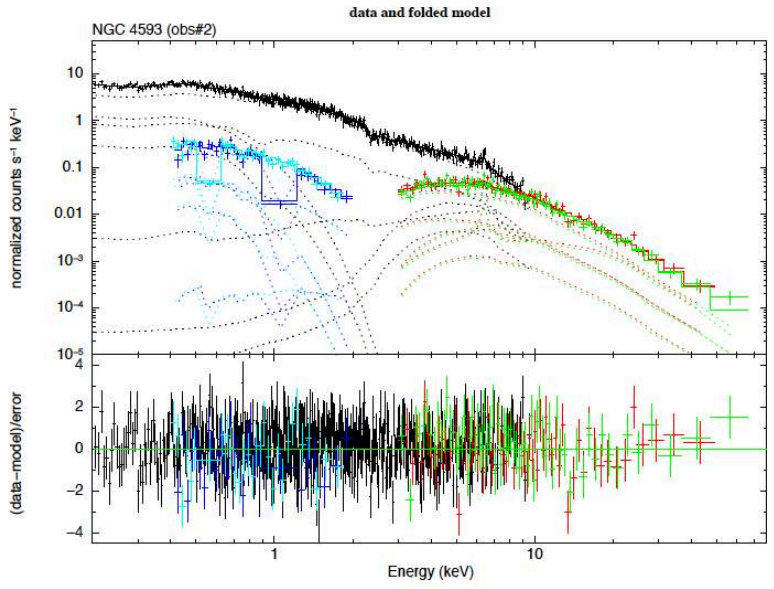


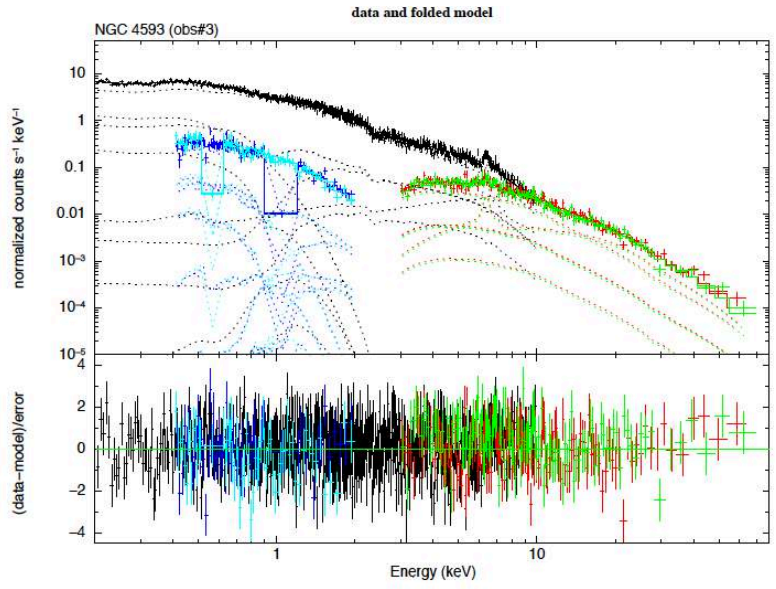
MCG-6-30-15
3 observations
XMM EPIC, RGS1 and 2
NuSTAR

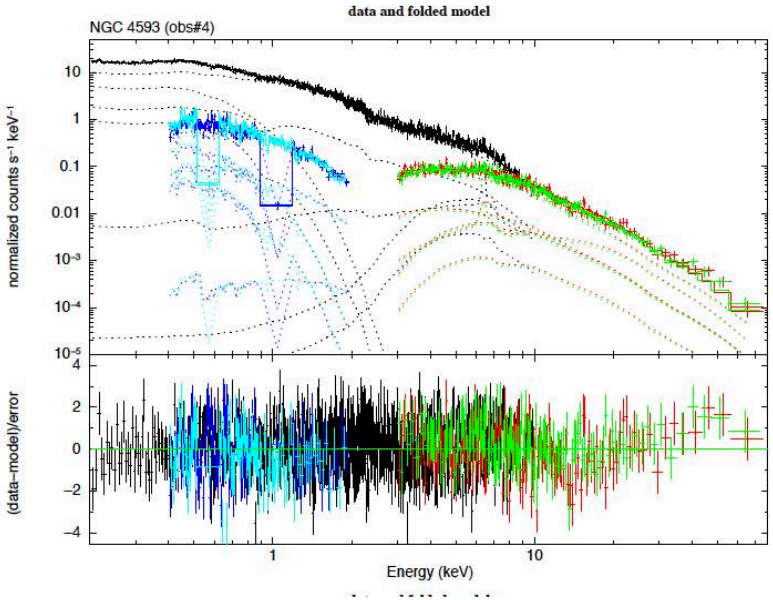
Spectral parameters are different between observations

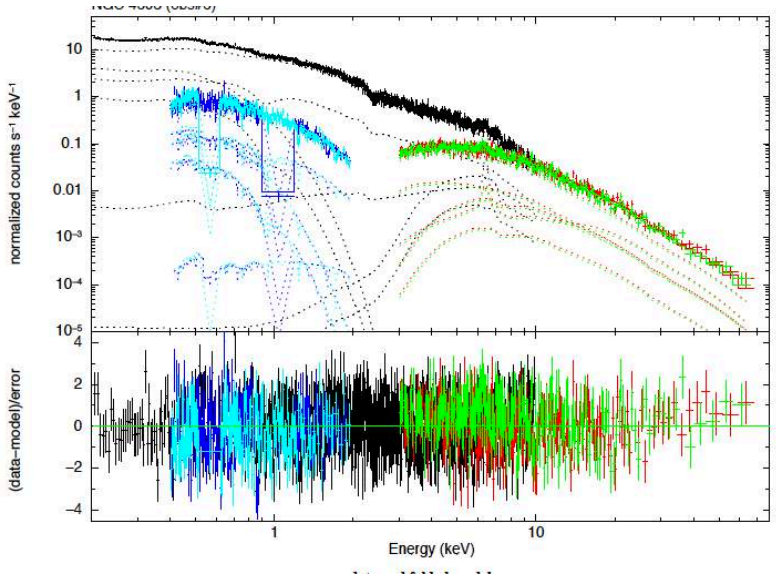
Time-average energy spectra(2)





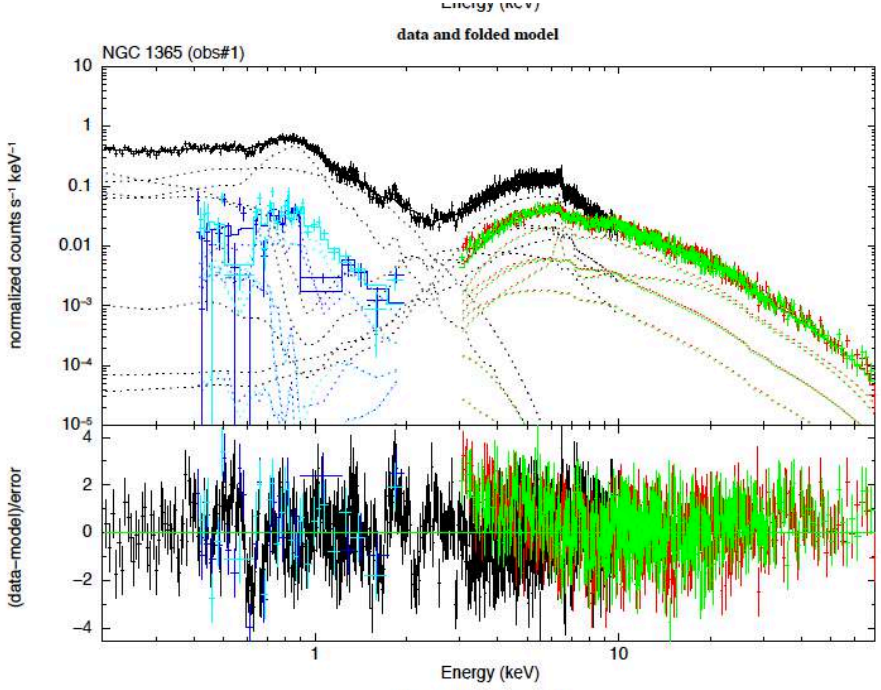


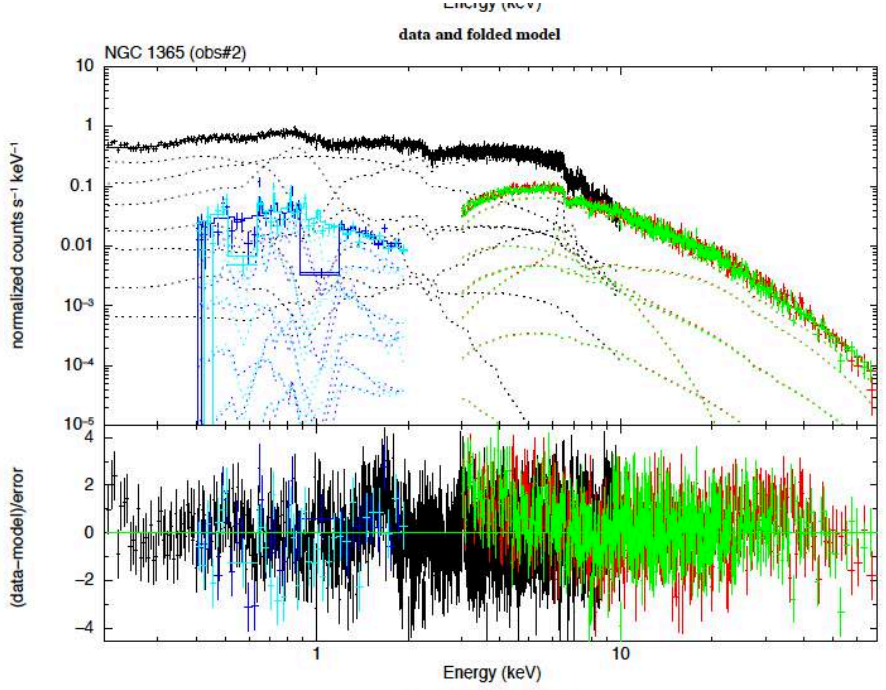


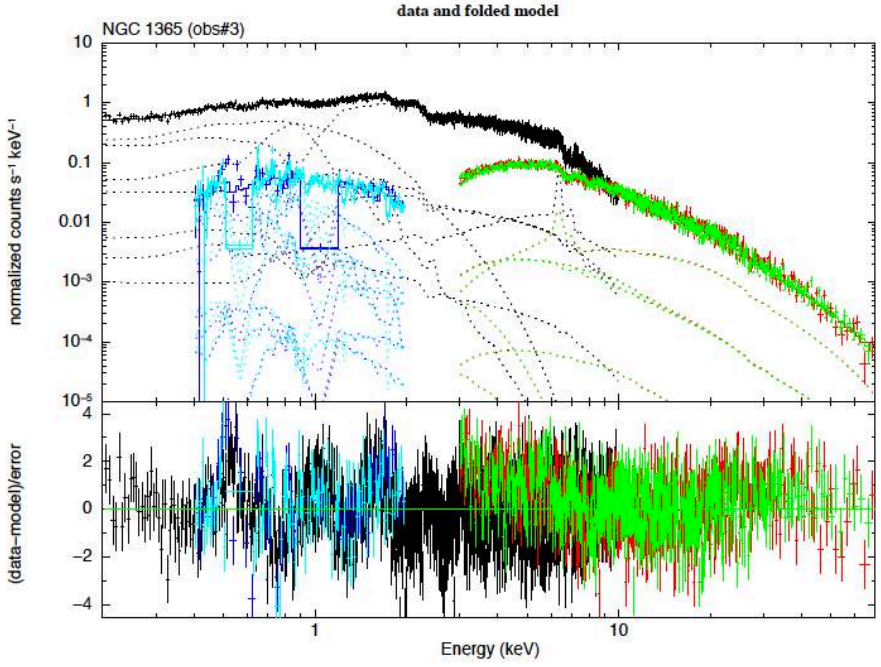


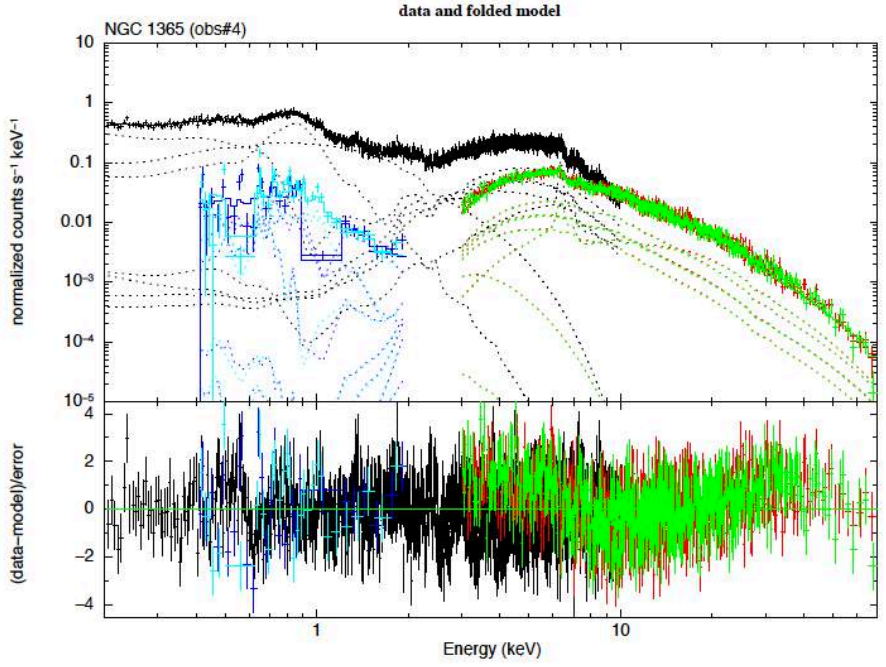
NGC4593
5 observations
XMM EPIC, RGS1 and 2
NuSTAR

Spectral parameters are different between observations







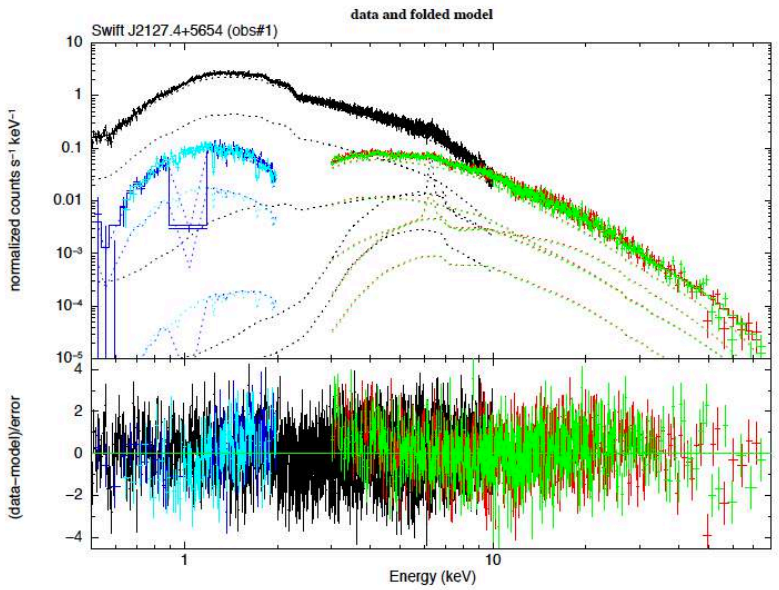


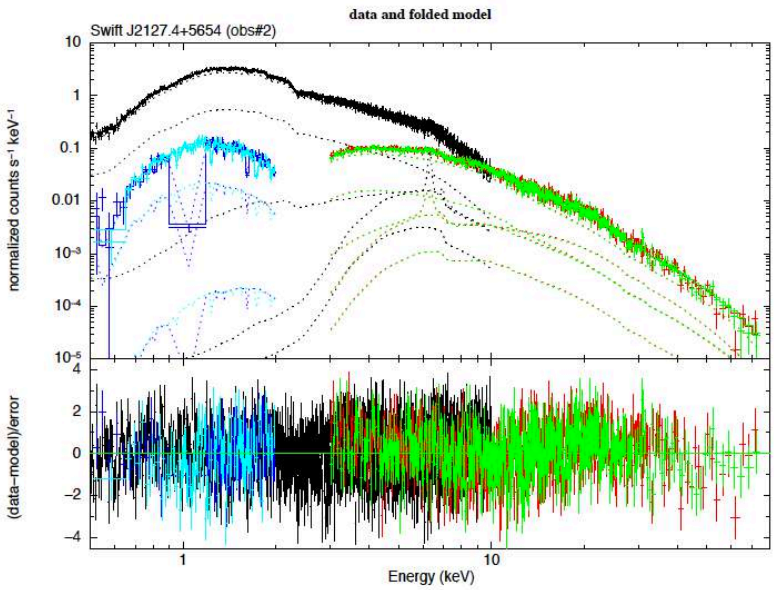
Time-average energy spectra(3)

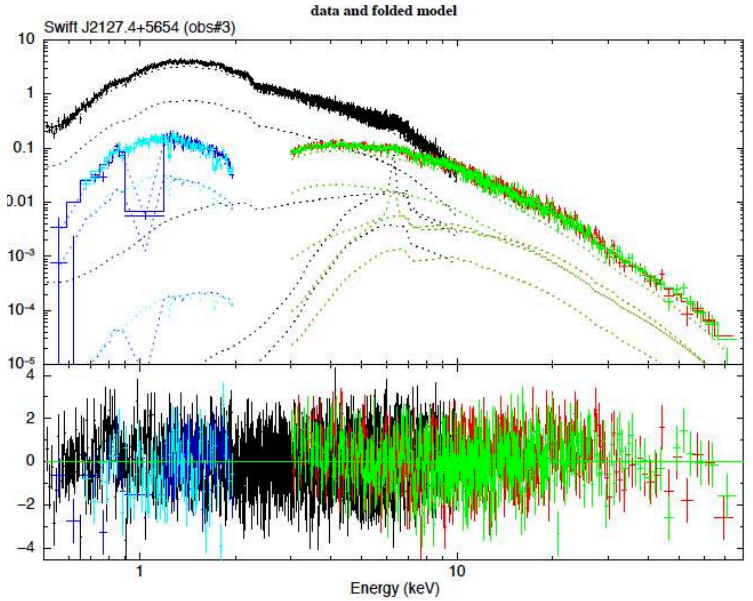
NGC1365
4 observations
XMM EPIC,
RGS1 and 2
NuSTAR

Spectral parameters are different between observations

Time-average energy spectra(4)



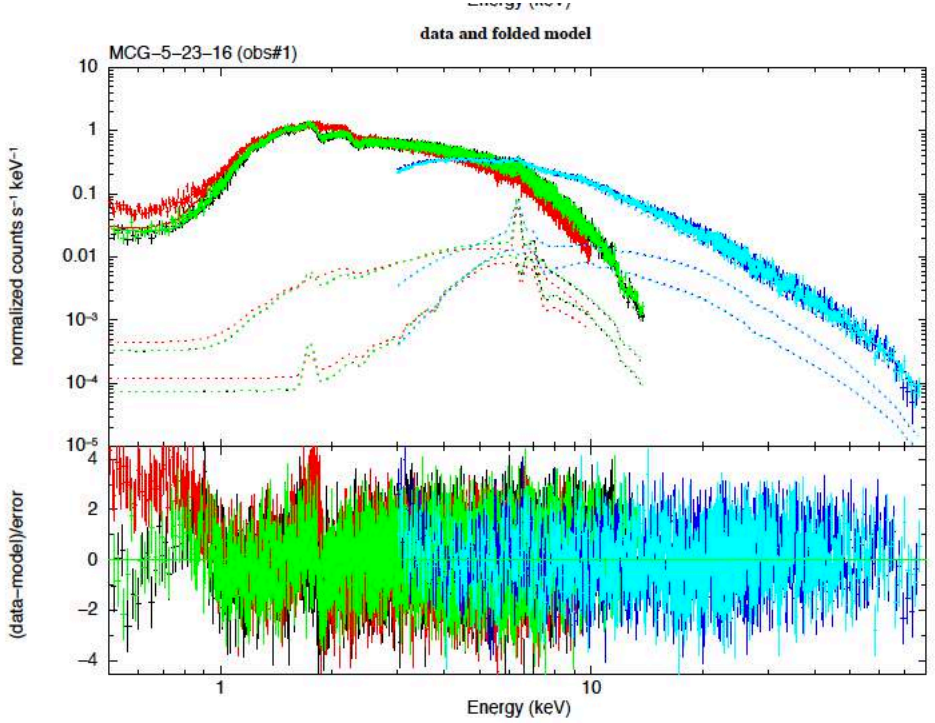




Swift J2127.4+5654
3 observations
XMM EPIC,
RGS1 and 2
NuSTAR

Spectral parameters are different between observations

Time-average energy spectra(5)



MCG-5-23-16
1 observation
Suzaku and
NuSTAR

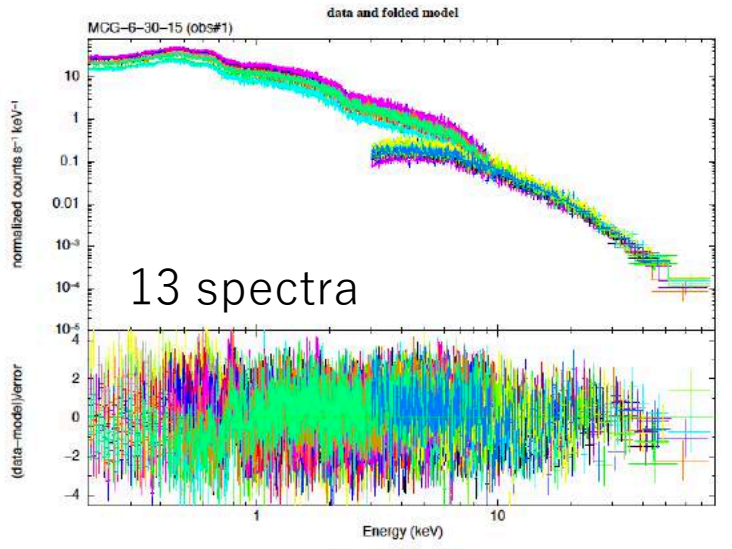
Time-average energy spectra summary

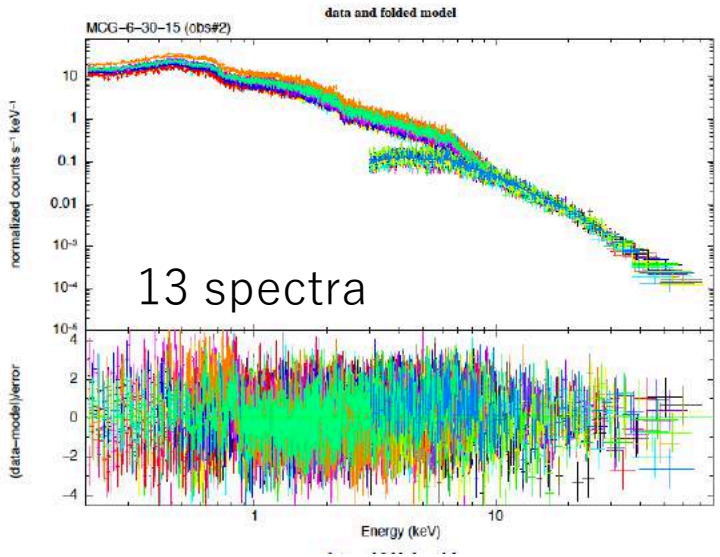
- The “standard” model is successful in 0.2-78 keV for all the five sources, with slight differences among sources
- For each source, luminosity/spectra are significantly variable at timescales of > day.

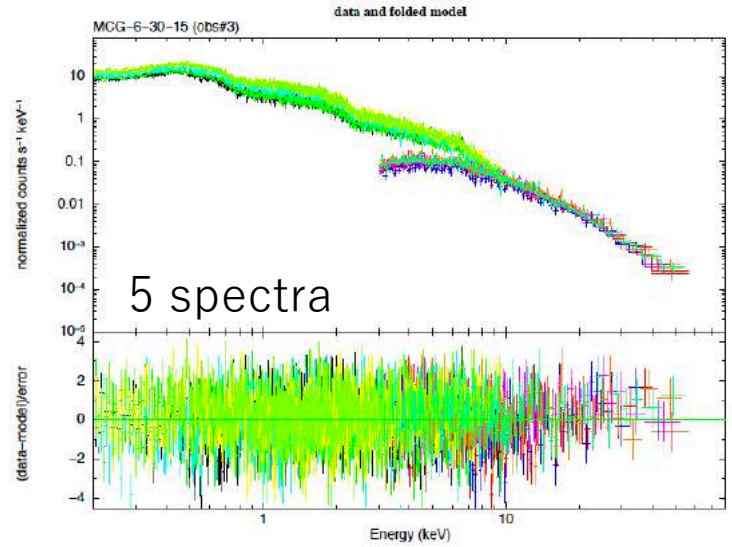
Spectral analysis within ~day

- Below timescales of ~day, we assume spectral variations are expressed with only two variable parameters:
  - Partial covering fraction, α
  - Normalization of the power-law component, N
  - Other spectral parameters are invariable.
- Try to explain the following :
  - Time-slice spectra
  - Intensity-slice spectra
  - RMS spectra
  - Light curves

Time-slice spectra (1)

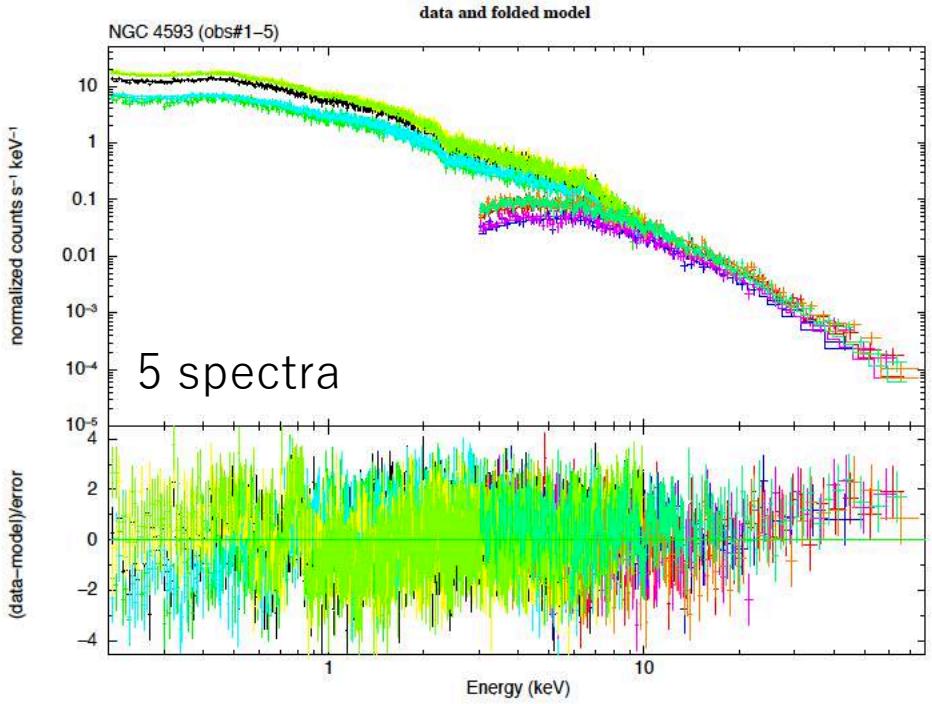






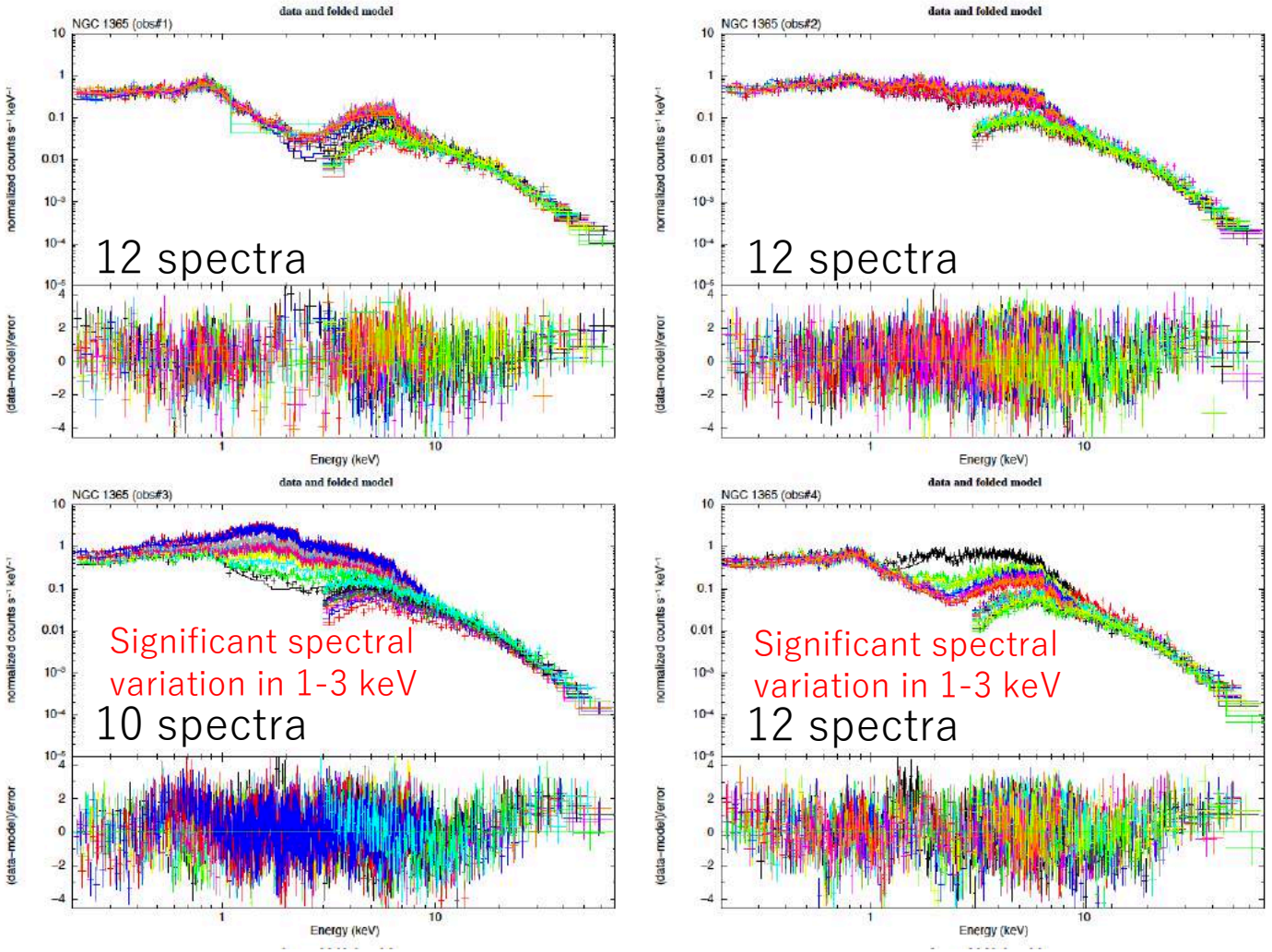
MCG-6-30-15
Each observation is divided into ~10 ksec segments, and all the time-slice spectra are fitted simultaneously only varying α and N

Time-slice spectra(2)



NGC4593
5 observation spectra are fitted simultaneously only varying α and N

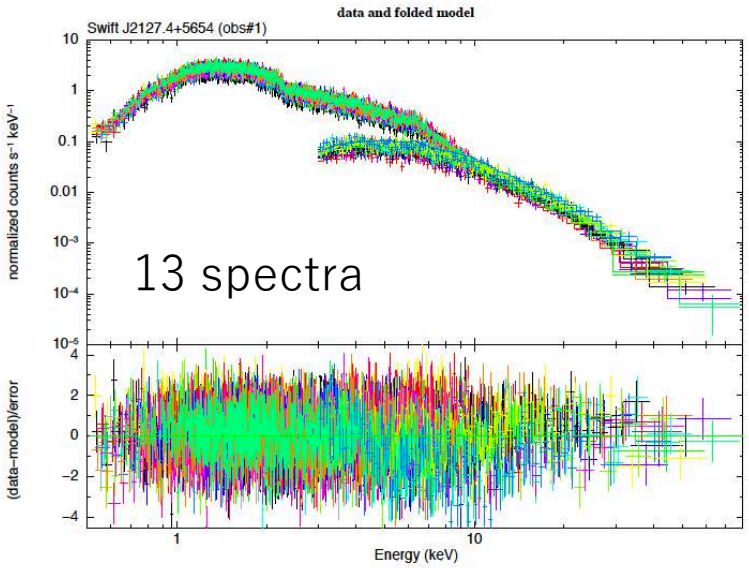
Time-slice spectra (3)

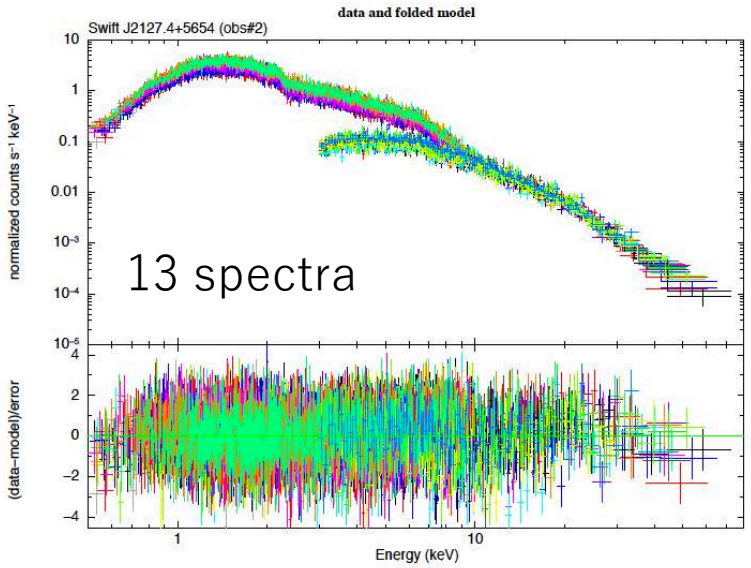


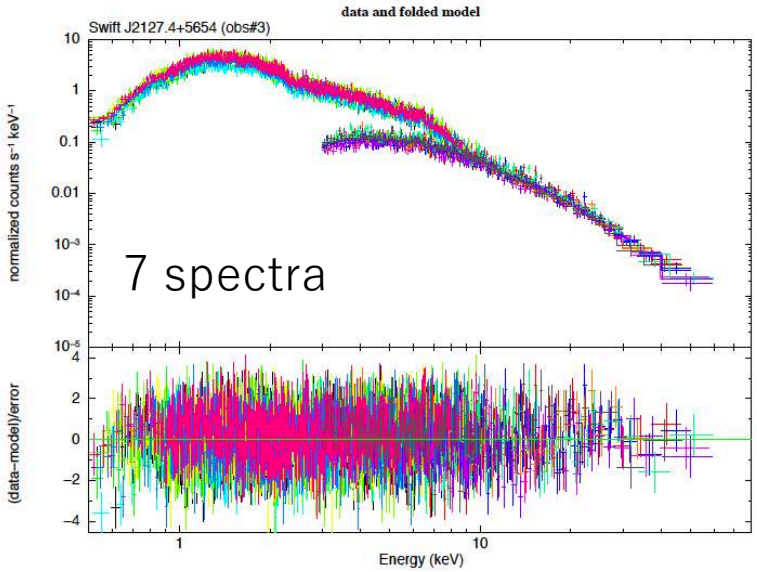
NGC1365

Each observation is divided into ~10 ksec segments, and all the time-slice spectra are fitted simultaneously only varying α and N

Time-slice spectra (4)



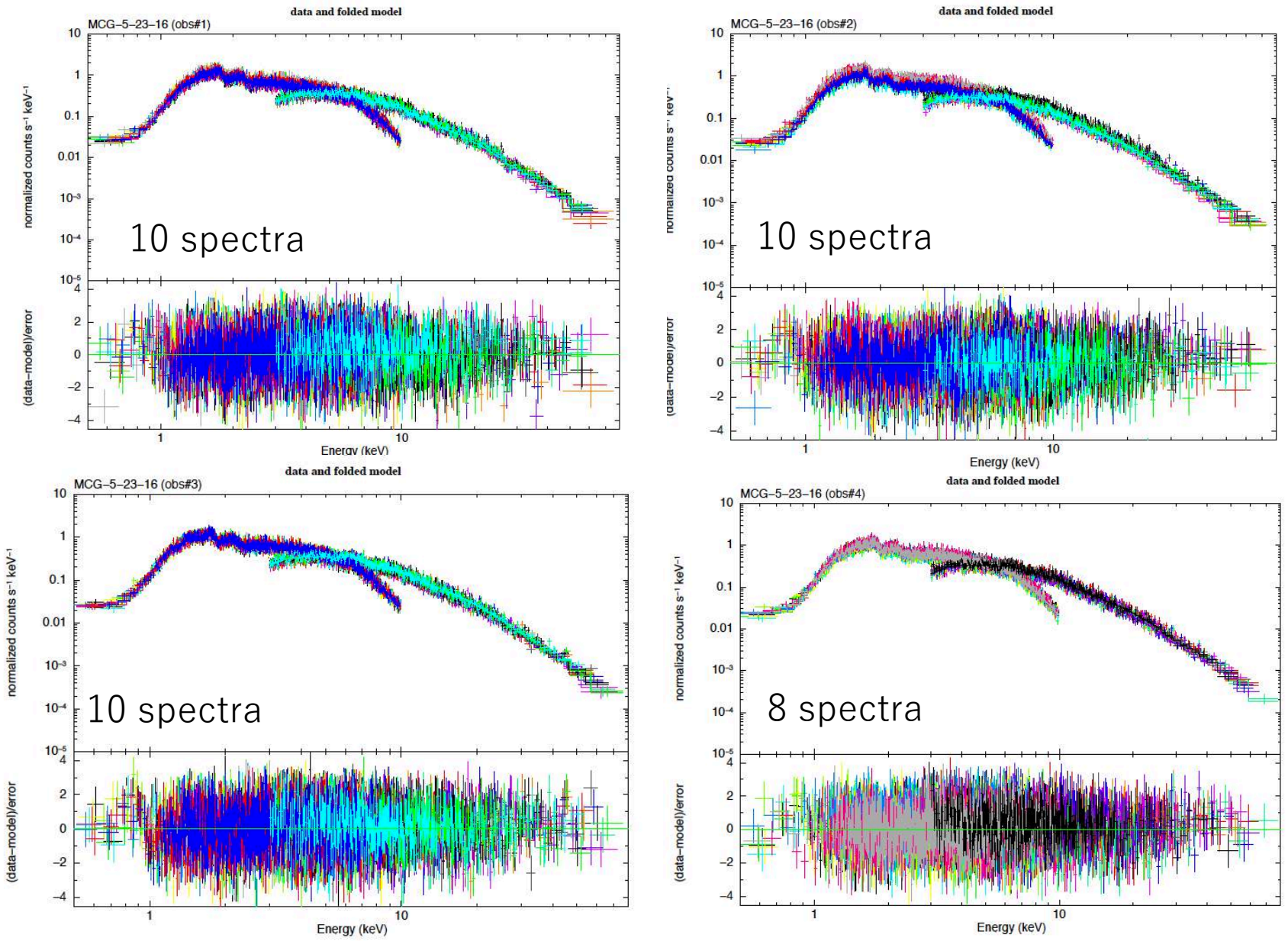




Swift J2127.4+5654

Each observation is divided into ~10 ksec segments,
and all the time-slice spectra are fitted simultaneously
only varying α and N

Time-slice spectra (5)



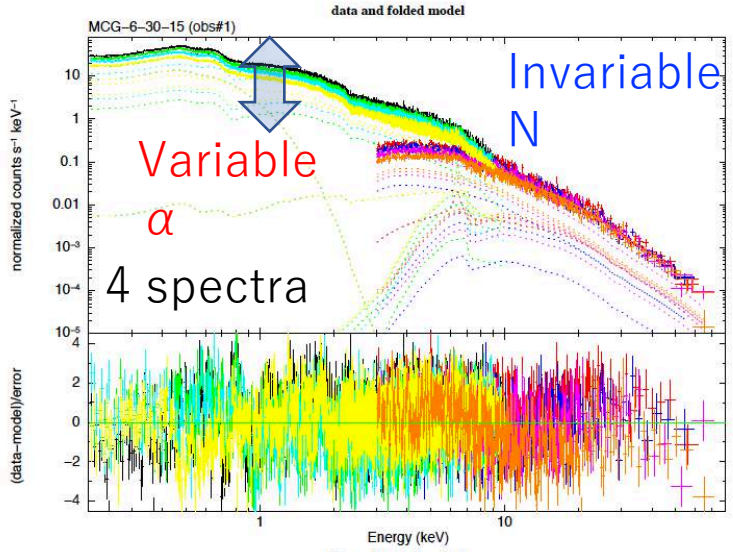
MCG-5-23-16
A single long observation (~380ksec)
is divided into 4 sub-observations.
Each sub-observation is divided every ~10 ksec

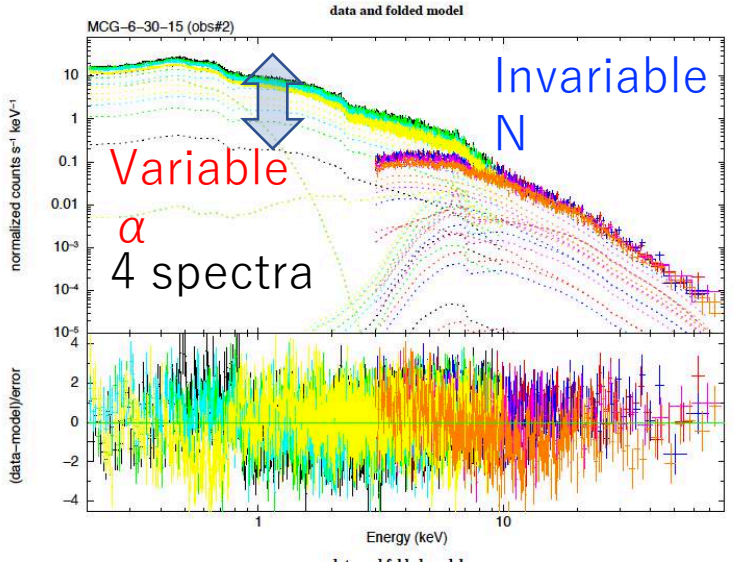
The time-slice spectra are fitted simultaneously only varying α and N

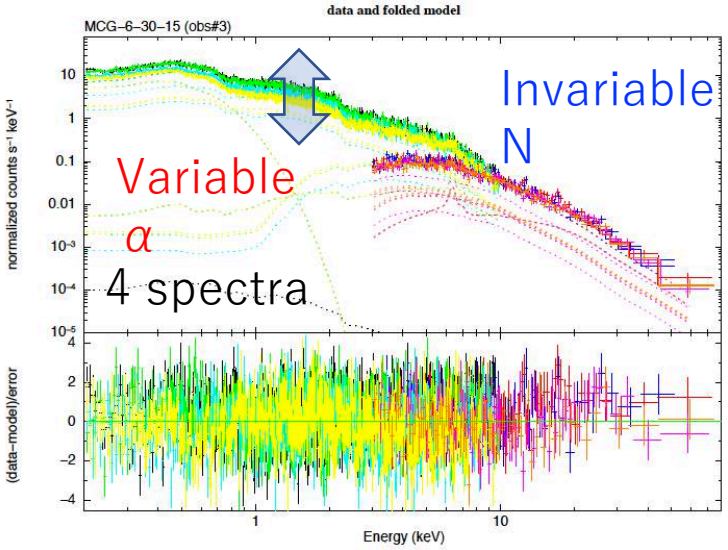
Time-slice spectra summary

- Spectra variation (0.2-78 keV) in timescales between 10 ksec and ~day is explained only by variations of the partial covering fraction α and the power-law normalization N

Intensity-slice spectra: based on <10 keV



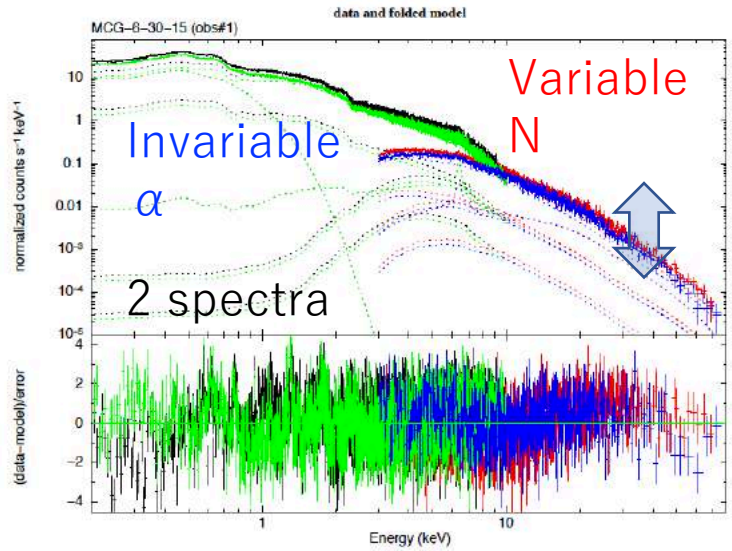


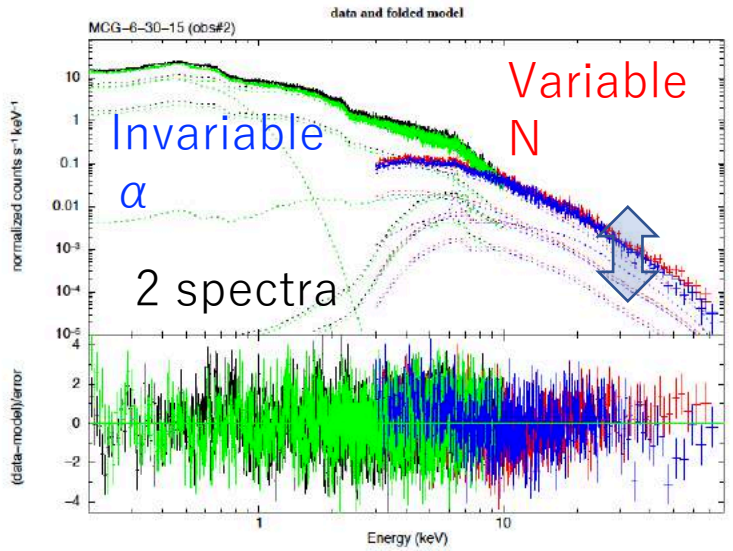


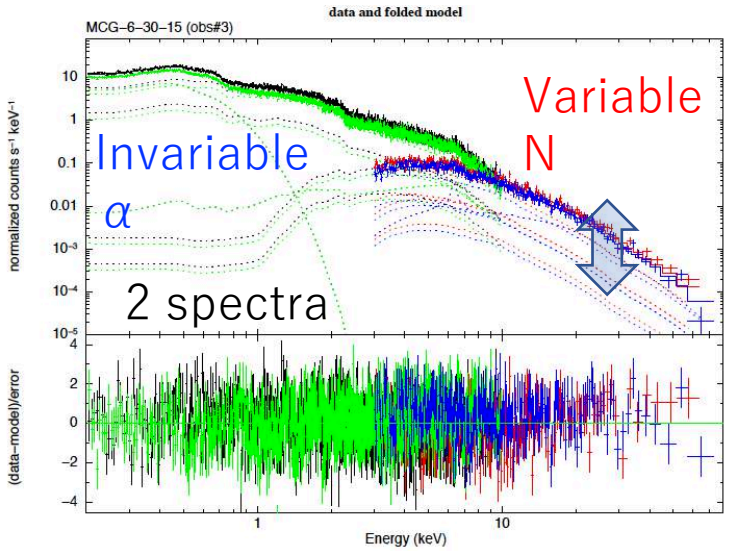
Similar results obtained for the other sources

MCG-6-30-15
Each observation is divided into 4 spectra based on the flux below 10 keV, and the four spectra are fitted simultaneously only varying α

Intensity-slice spectra: based on >10 keV







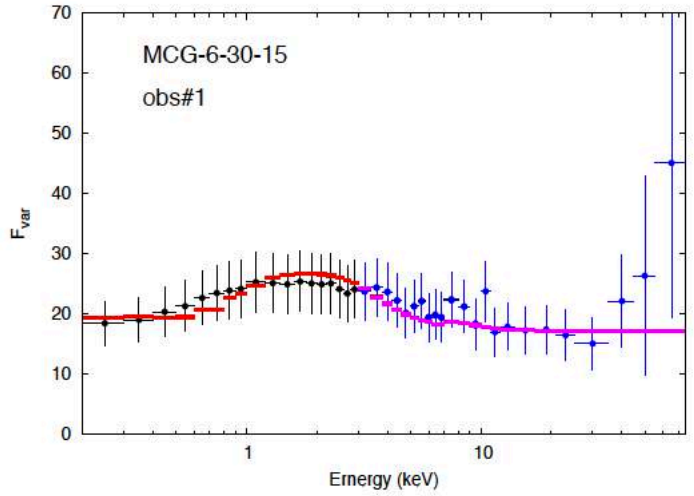
Similar results obtained for the other sources

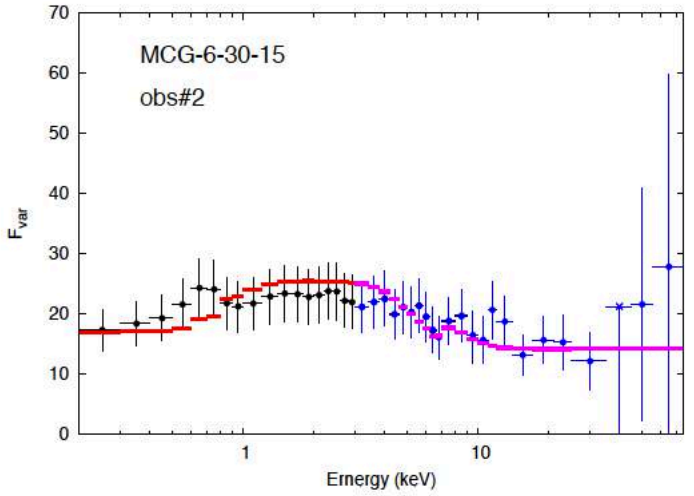
MCG-6-30-15
Each observation is divided into 2 spectra based on the flux above 10 keV, and the two spectra are fitted simultaneously only varying N

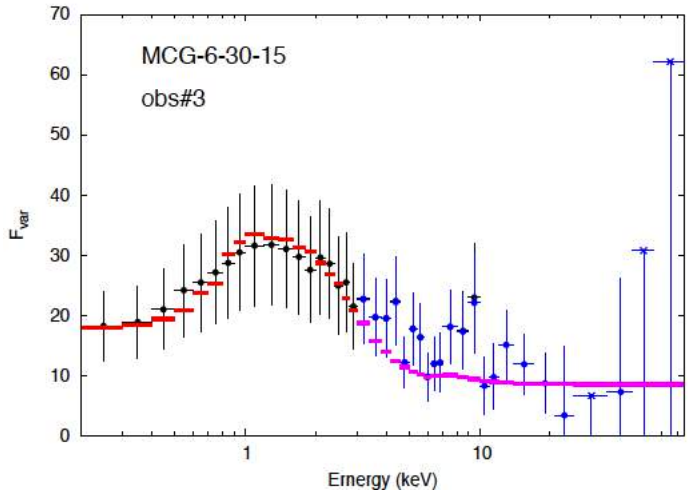
Intensity-slice spectra summary

- When spectra are sliced according to the flux < 10 keV, the 0.2-78 keV spectra are fitted with only variation of α
- When spectra are sliced according to the flux > 10 keV, the 0.2-78 keV spectra are fitted with only variation of N
- Spectral variations below ~10 keV and above ~10 keV are independent.
- *Variation of the partial covering fraction α and the power-law normalization N are independent*

RMS spectra(1)







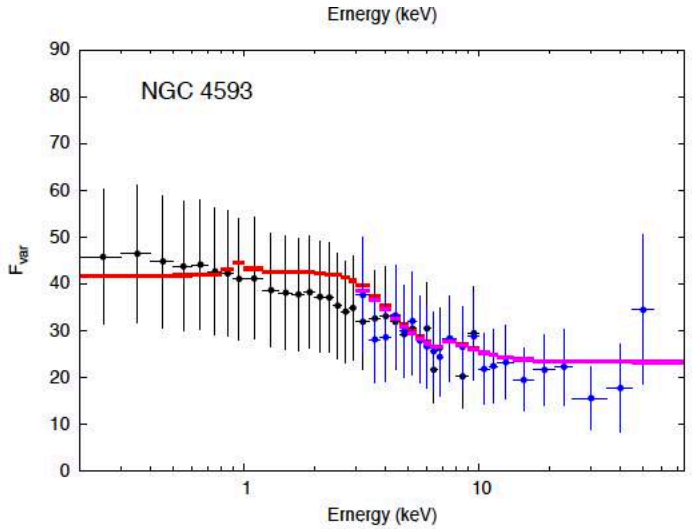
MCG-6-30-15

RMS spectra are calculated from the time-sliced spectra.

Model RMS spectra are calculated from the best-fit spectral models

Observed RMS spectra are explained only variations of α and N.

RMS spectra (2)



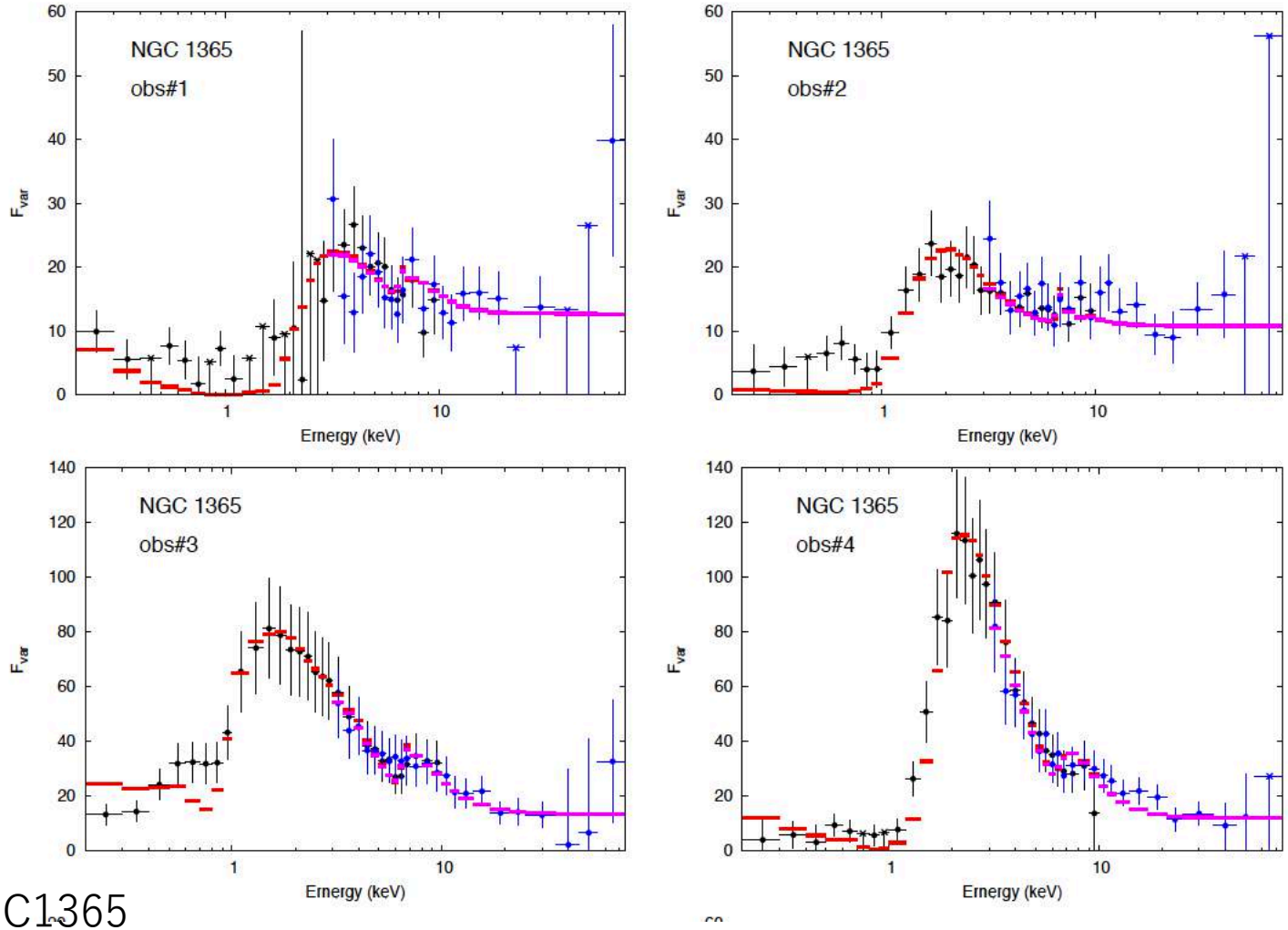
NGC4593

RMS spectra are calculated from the time-sliced spectra.

Model RMS spectra are calculated from the best-fit spectral models

Observed RMS spectra are explained only variations of α and N.

RMS spectra (3)



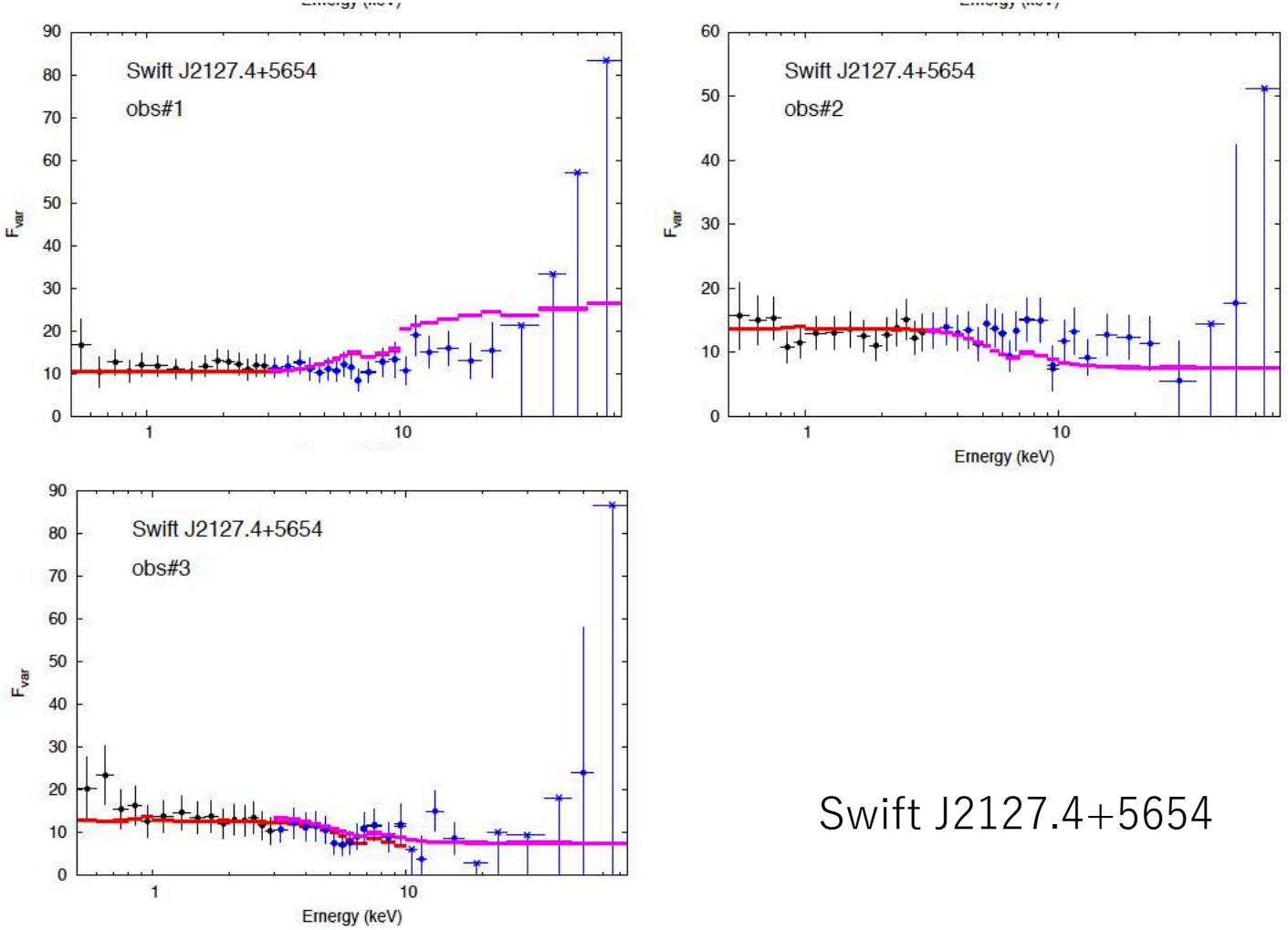
NGC1365

RMS spectra are calculated from the time-sliced spectra.

Model RMS spectra are calculated from the best-fit spectral models

Observed RMS spectra are explained only variations of α and N.

RMS spectra (4)



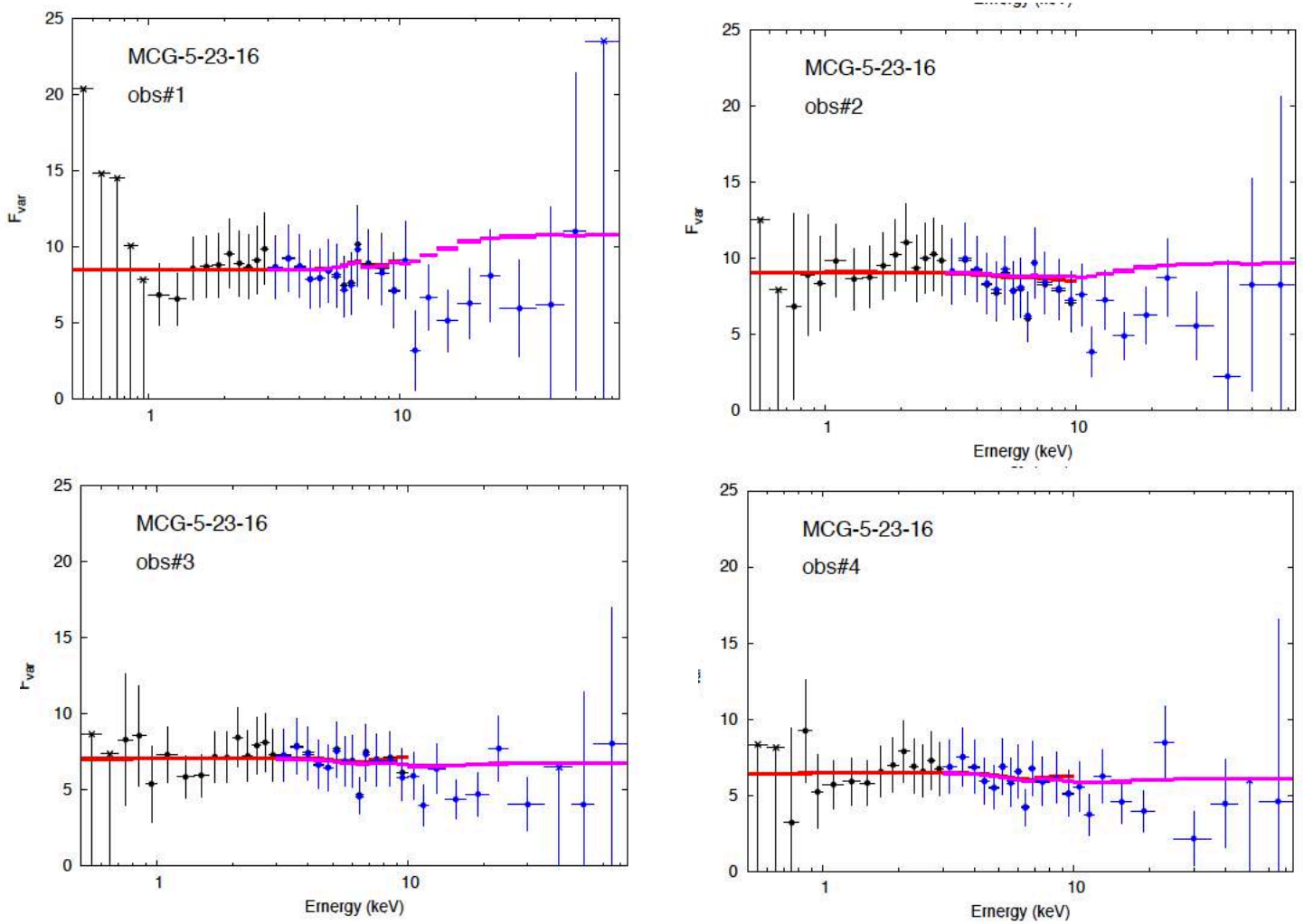
Swift J2127.4+5654

RMS spectra are calculated from the time-sliced spectra.

Model RMS spectra are calculated from the best-fit spectral models

Observed RMS spectra are explained only variations of α and N.

RMS spectra (5)



RMS spectra are calculated from the time-sliced spectra.

Model RMS spectra are calculated from the best-fit spectral models

Observed RMS spectra are explained only variations of α and N.

MCG-5-23-16

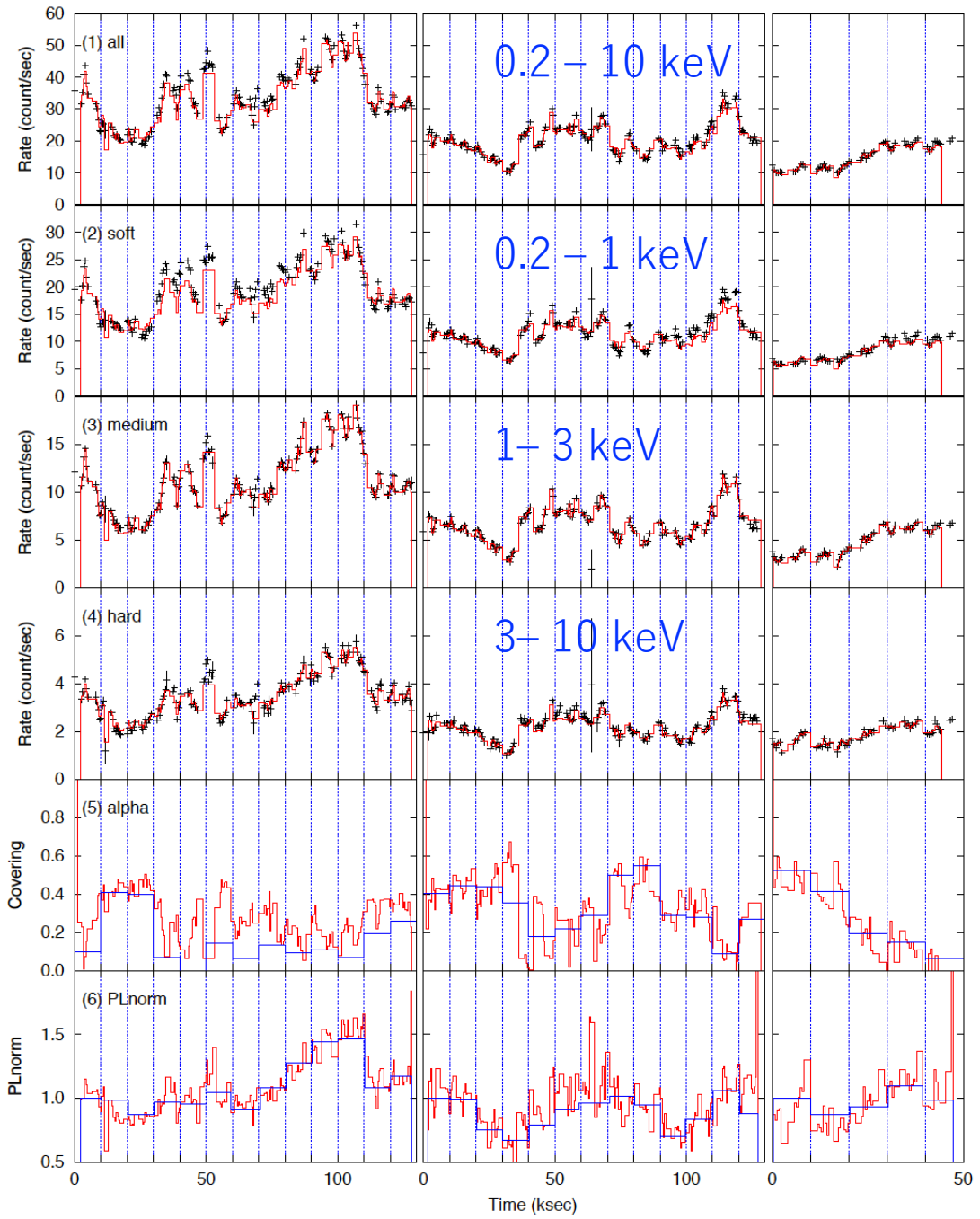
Light curves (1)

Light curve is made with 1ksec time-bin for different energy bands.

Model light-curve is made, where only α and N are varied to fit the light-curve.

Light-curve within ~day is explained only variation of α and N

MCG-6-30-15



Black: data
Red: model

Partial covering fraction α

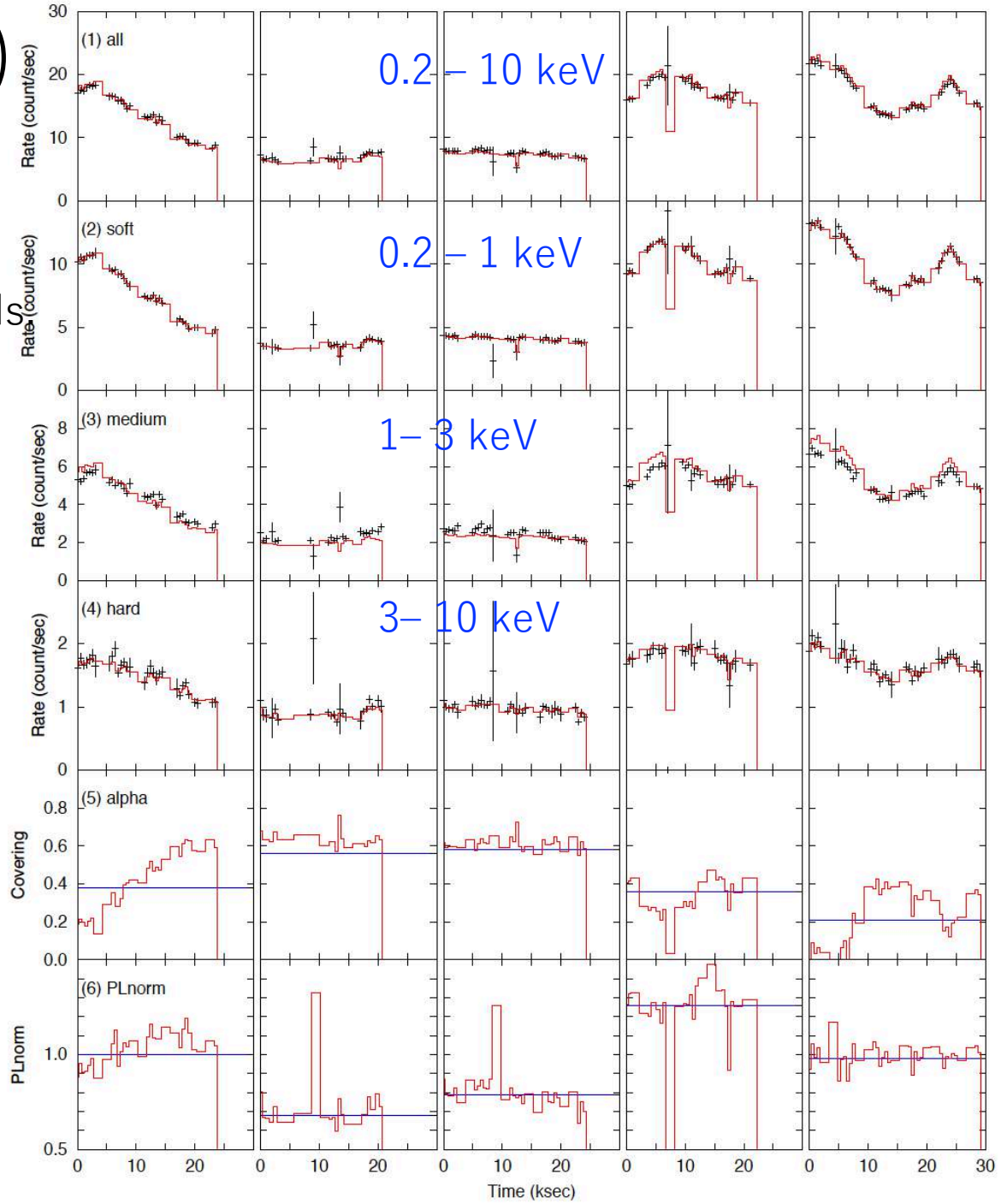
Power-law normalization N

Light curves(2)

Light curve is made with 1ksec time-bin for different energy bands.

Model light-curve is made, where only α and N are varied to fit the light-curve.

Light-curve within ~day is explained only variation of α and N



NGC4593

Black: data
Red: model

Partial covering fraction α

Power-law normalization N

Light curves(3)

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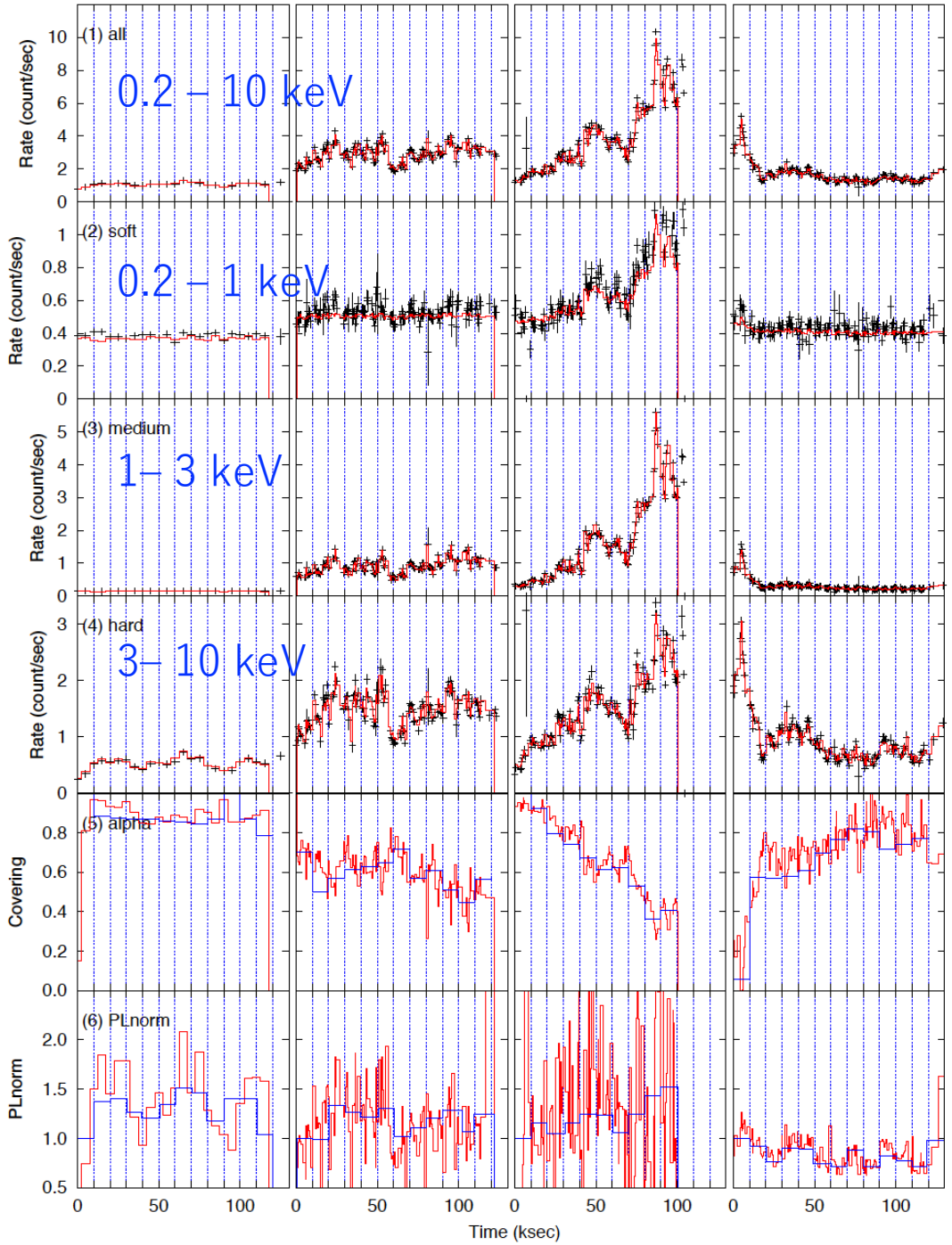
Model light-curve is made, where only α and N are varied to fit the light-curve.

Light-curve within ~day is explained only variation of α and N

NGC1365



Black: data
Red: model

Partial covering fraction α

Power-law normalization N

Light curves(4)

Light curve is made with 1ksec time-bin for different energy bands.

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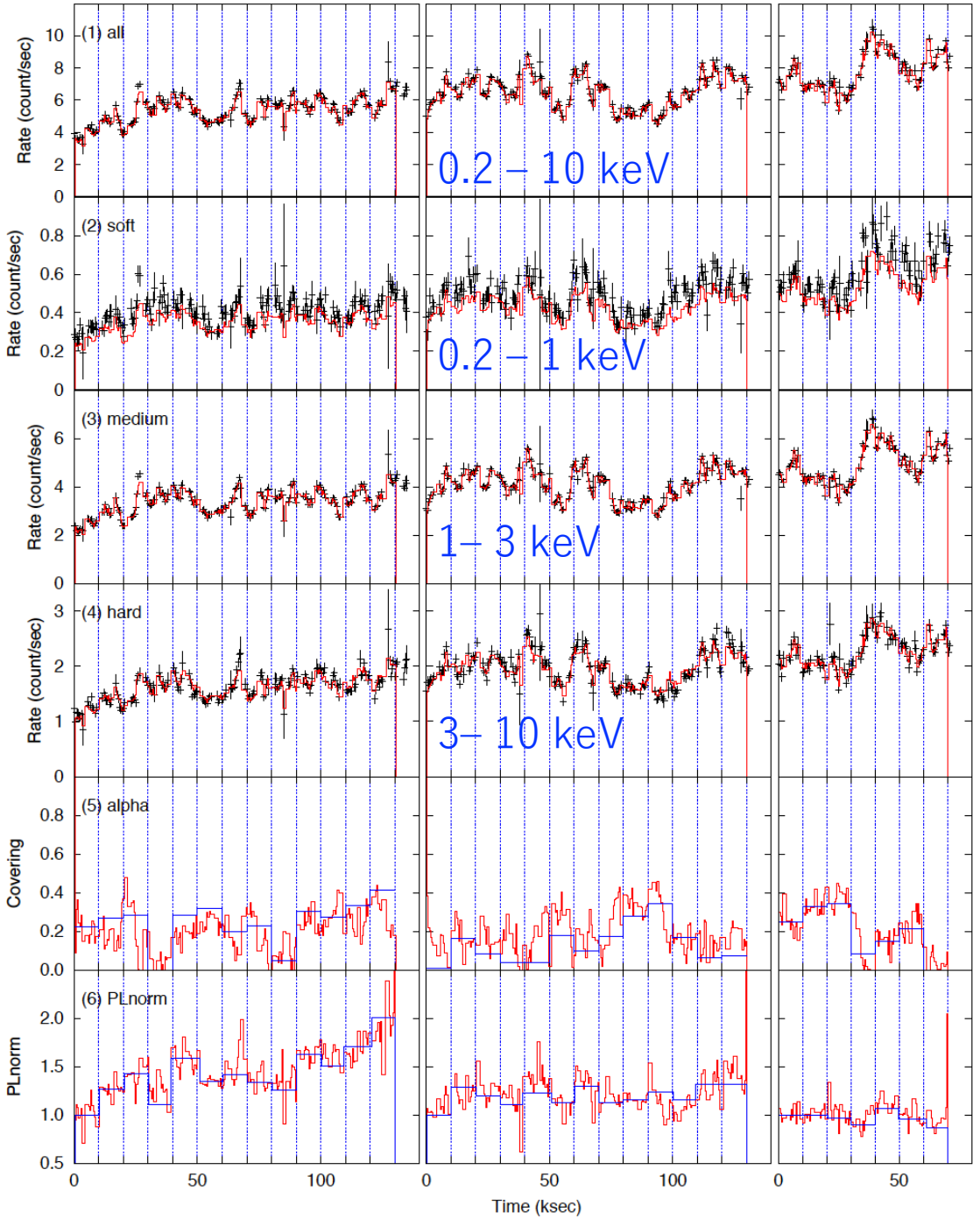
Light-curve within ~day is explained only variation of α and N

Swift J2127.4+5654



Black: data
Red: model

Partial covering fraction α

Power-law normalization N

Light curves(5)

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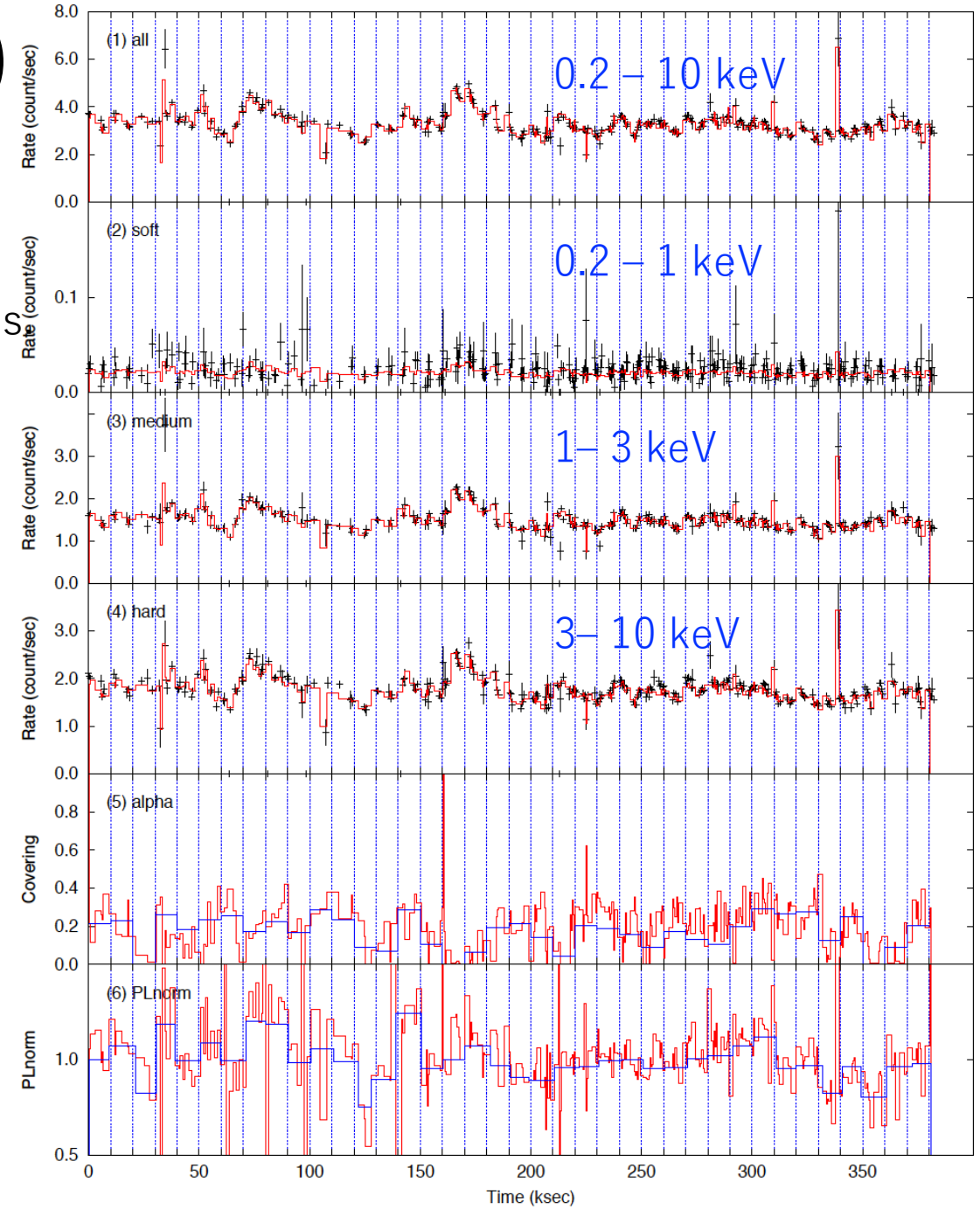
Light-curve within ~day is explained only variation of α and N



Black: data
Red: model

Partial covering fraction α

Power-law normalization N

MCG-5-23-16

5. Summary

- Variable double partial covering model is successful to explain energy spectra of Seyfert galaxies in 0.2-78 keV
  - Double-layer partial covering clouds in the line-of-sight
- Spectral variations below timescales of ~day are mostly explained by two independent parameters:
  1. Partial covering fraction
  2. Normalization of the power-law component

Next step:

- We are now trying to explain the characteristic energy dependent time-lag (reverberation) in the current framework. (Mizumoto in prep.)