Illuminating the Disk/Corona/Jet Connection in NLS1 Galaxies

Laura Brenneman (SAO)
The X-ray Universe: Rome
June 7, 2017

Illuminating the Disk/Corona/Jet Connection in NLS1 Galaxies

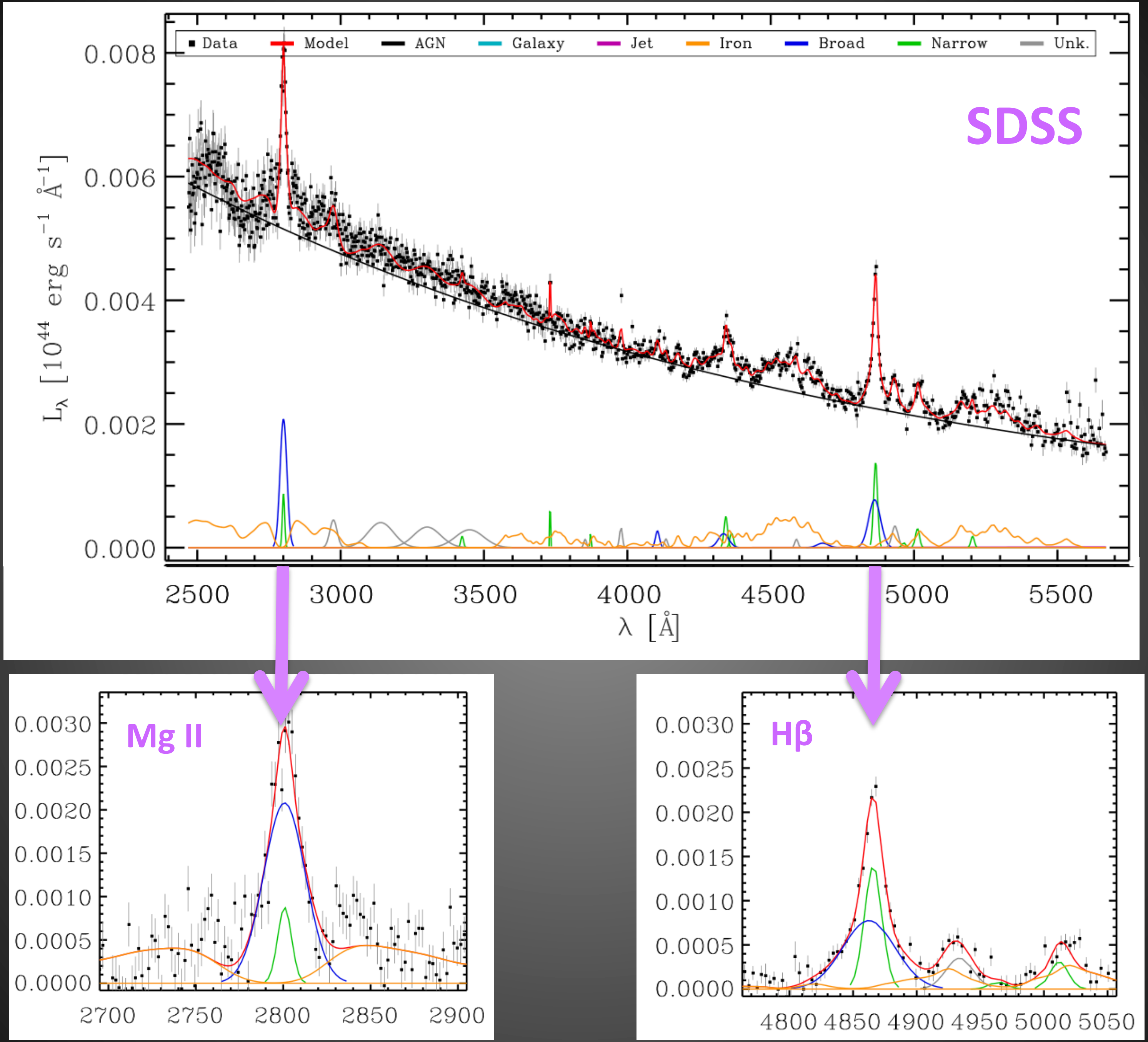
Collaborators: Michael Parker, Jon Miller, Sera Markoff, Chris Reynolds

What are Narrow Line Seyfert 1s?

- Identified by Osterbrock & Pogge (1985) as objects with small widths of the broad Balmer lines: Hβ FWHM < 2000 km/s.
- Weak [OIII]5007/Hβ emission (flux ratio < 3) and strong emission from Fe II complexes (e.g., Boroson & Green 1992).
- Strong soft X-ray excess < 2.5 keV.
- Physical drivers and correlations among emission-line and continuum properties not yet well understood.
- Historically thought that most NLS1s are objects with high accretion rates, close to or even super-Eddington, and low black hole masses; lie systematically below normal M-σ relation (Mathur & Grupe 2005).

What are Narrow Line Seyfert 1s?

- Identified by Osterbrock & Pogge (1985) as objects with small widths of the broad Balmer lines: Hβ FWHM < 2000 km/s.
- Weak [OIII]5007/Hβ emission (flux ratio < 3) and strong emission from Fe II complexes (e.g., Boroson & Green 1992).
- Strong soft X-ray excess < 2.5 keV.
- Physical drivers and correlations among emission-line and continuum properties not yet well understood.
- Historically thought that most NLS1s are objects with high accretion rates, close to or even super-Eddington, and low black hole masses; lie systematically below normal M-σ relation (Mathur & Grupe 2005).



Calderone+ (2014)

What are Narrow Line Seyfert 1s?

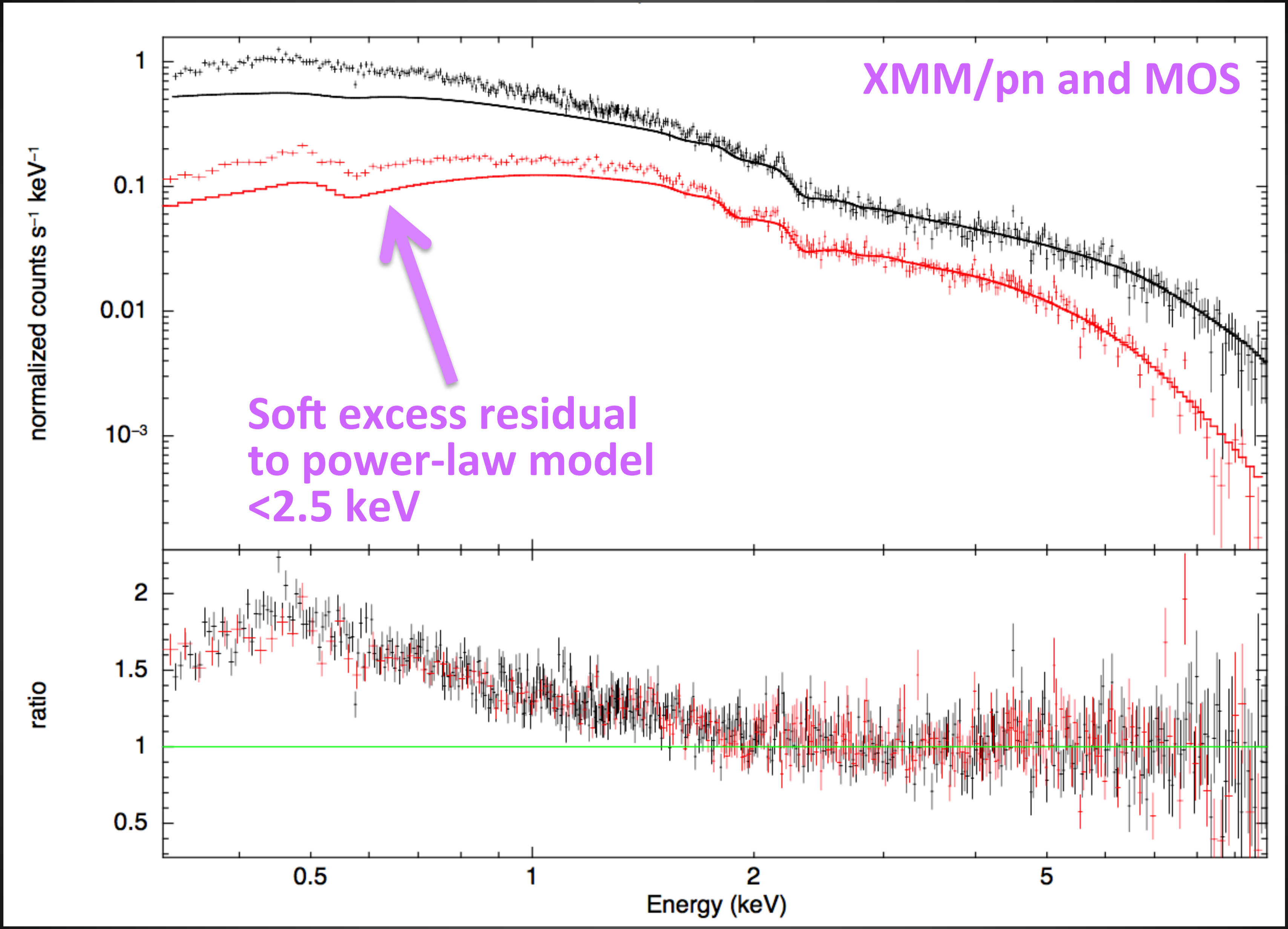
- Identified by Osterbrock & Pogge (1985) as objects with small widths of the broad Balmer lines: Hβ FWHM < 2000 km/s.

- Weak [OIII]5007/Hβ emission (flux ratio < 3) and strong emission from Fe II complexes (e.g., Boroson & Green 1992).

- Strong soft X-ray excess < 2.5 keV.

- Physical drivers and correlations among emission-line and continuum properties not yet well understood.

- Historically thought that most NLS1s are objects with high accretion rates, close to or even super-Eddington, and low black hole masses; lie systematically below normal M-σ relation (Mathur & Grupe 2005).



XMM/pn and MOS

Soft excess residual
to power-law model
<2.5 keV

Bhattacharyya+ (2014)

What are Narrow Line Seyfert 1s?

- Identified by Osterbrock & Pogge (1985) as objects with small widths of the broad Balmer lines: Hβ FWHM < 2000 km/s.

- Weak [OIII]5007/Hβ emission (flux ratio < 3) and strong emission from Fe II complexes (e.g., Boroson & Green 1992).

- Strong soft X-ray excess < 2.5 keV.

- Physical drivers and correlations among emission-line and continuum properties not yet well understood.

- Historically thought that most NLS1s are objects with high accretion rates, close to or even super-Eddington, and low black hole masses; lie systematically below normal M-σ relation (Mathur & Grupe 2005).

What are Narrow Line Seyfert 1s?

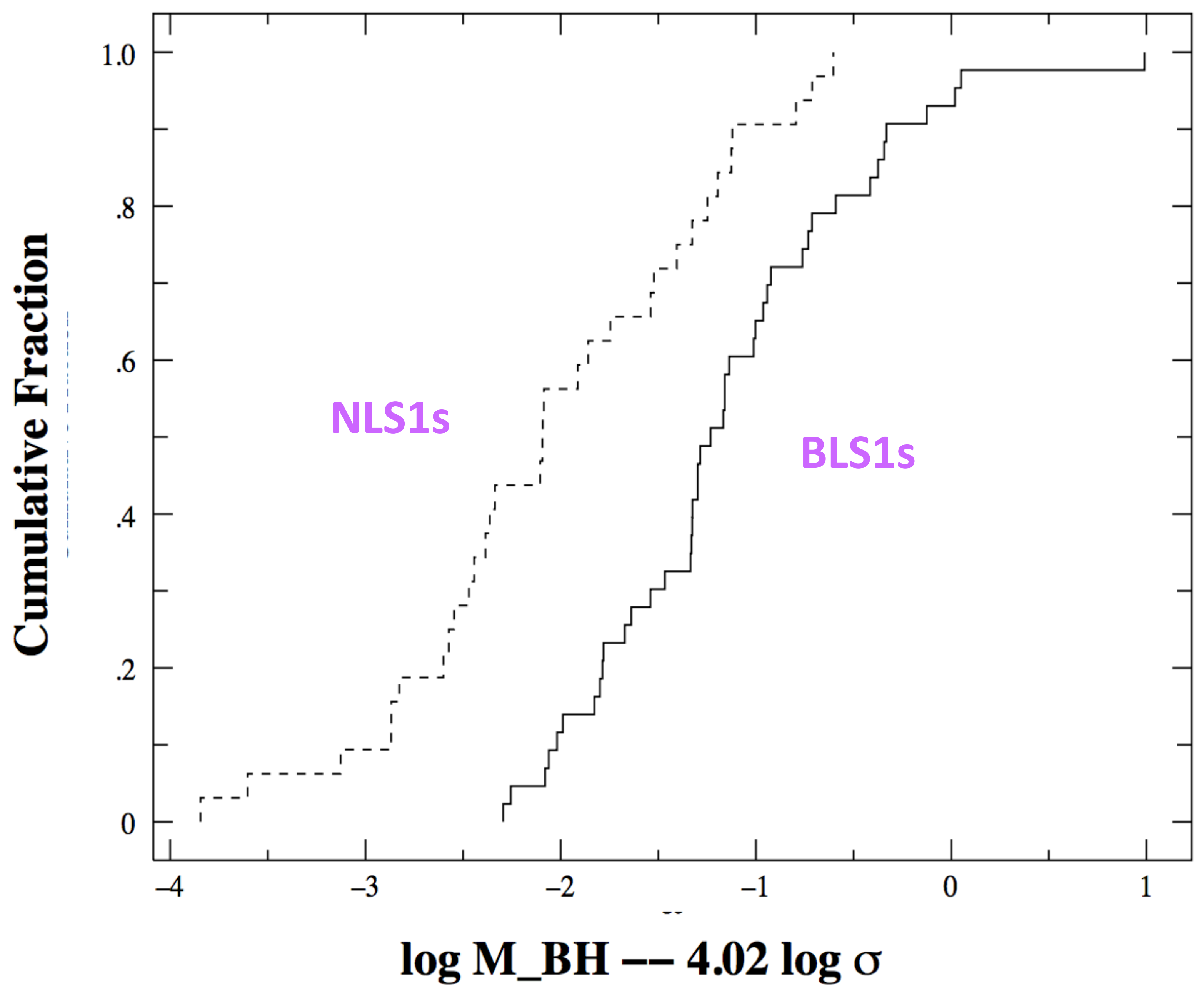
- Identified by Osterbrock & Pogge (1985) as objects with small widths of the broad Balmer lines: Hβ FWHM < 2000 km/s.

- Weak [OIII]5007/Hβ emission (flux ratio < 3) and strong emission from Fe II complexes (e.g., Boroson & Green 1992).

- Strong soft X-ray excess < 2.5 keV.

- Physical drivers and correlations among emission-line and continuum properties not yet well understood.

- Historically thought that most NLS1s are objects with high accretion rates, close to or even super-Eddington, and low black hole masses; lie systematically below normal M-σ relation (Mathur & Grupe 2005).



Mathur & Grupe (2005)

What about their jet properties?

- Little is known about their radio properties as a class, though most are radio-quiet; only ~25 radio-loud NLS1s identified to date.
- 7% of all NLS1s, vs. ~15% of general AGN population. Why??
- Now have *Fermi* γ-ray detections in 7 of these objects (Foschini+ 2015).
- Flat spectral indices and SEDs differ significantly from RQ NLS1 SEDs, indicate that these are likely sources with relativistic jets viewed close to face-on, more akin to FSRQs than the classic picture of RQ NLS1s (e.g., MCG-6, 1H0707).

What about their jet properties?

- Little is known about their radio properties as a class, though most are radio-quiet; only ~25 radio-loud NLS1s identified to date.

- 7% of all NLS1s, vs. ~15% of general AGN population. Why??

- Now have *Fermi* γ-ray detections in 7 of these objects (Foschini+ 2015).

- Flat spectral indices and SEDs differ significantly from RQ NLS1 SEDs, indicate that these are likely sources with relativistic jets viewed close to face-on, more akin to FSRQs than the classic picture of RQ NLS1s (e.g., MCG-6, 1H0707).

What about their jet properties?

- Little is known about their radio properties as a class, though most are radio-quiet; only ~25 radio-loud NLS1s identified to date.

- 7% of all NLS1s, vs. ~15% of general AGN population. Why??

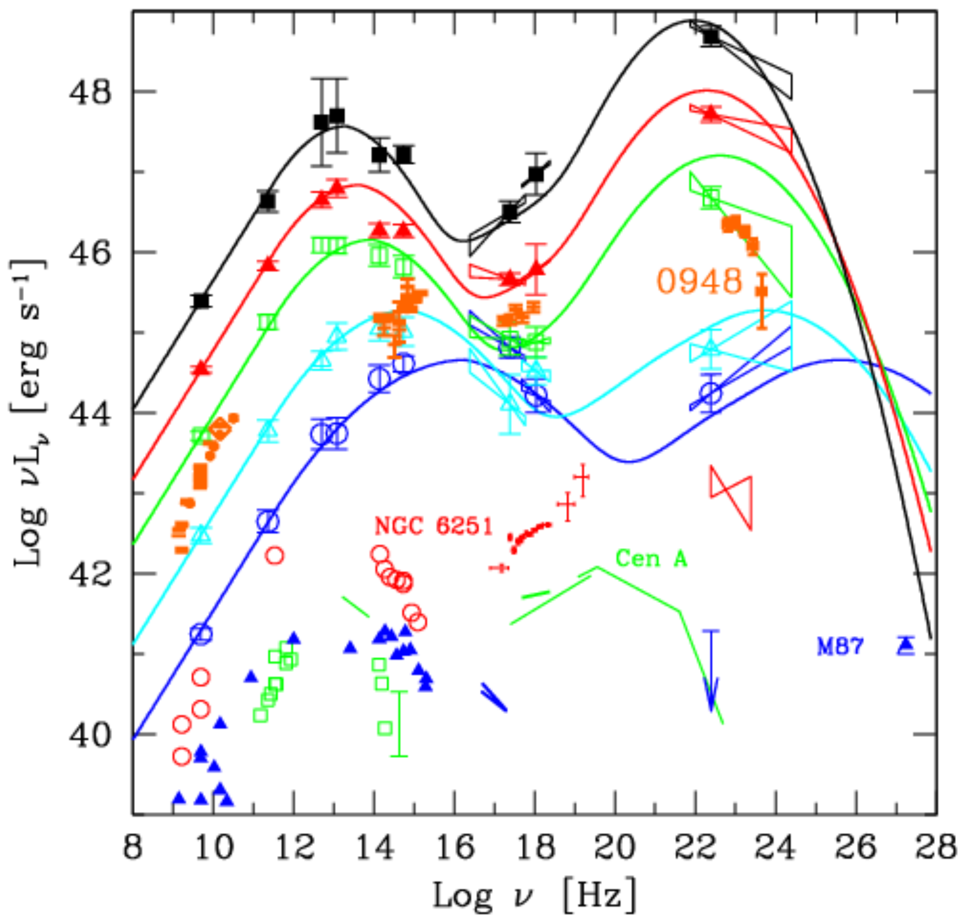
- Now have *Fermi* γ-ray detections in 7 of these objects (Foschini+ 2015).

- Flat spectral indices and SEDs differ significantly from RQ NLS1 SEDs, indicate that these are likely sources with relativistic jets viewed close to face-on, more akin to FSRQs than the classic picture of RQ NLS1s (e.g., MCG-6, 1H0707).

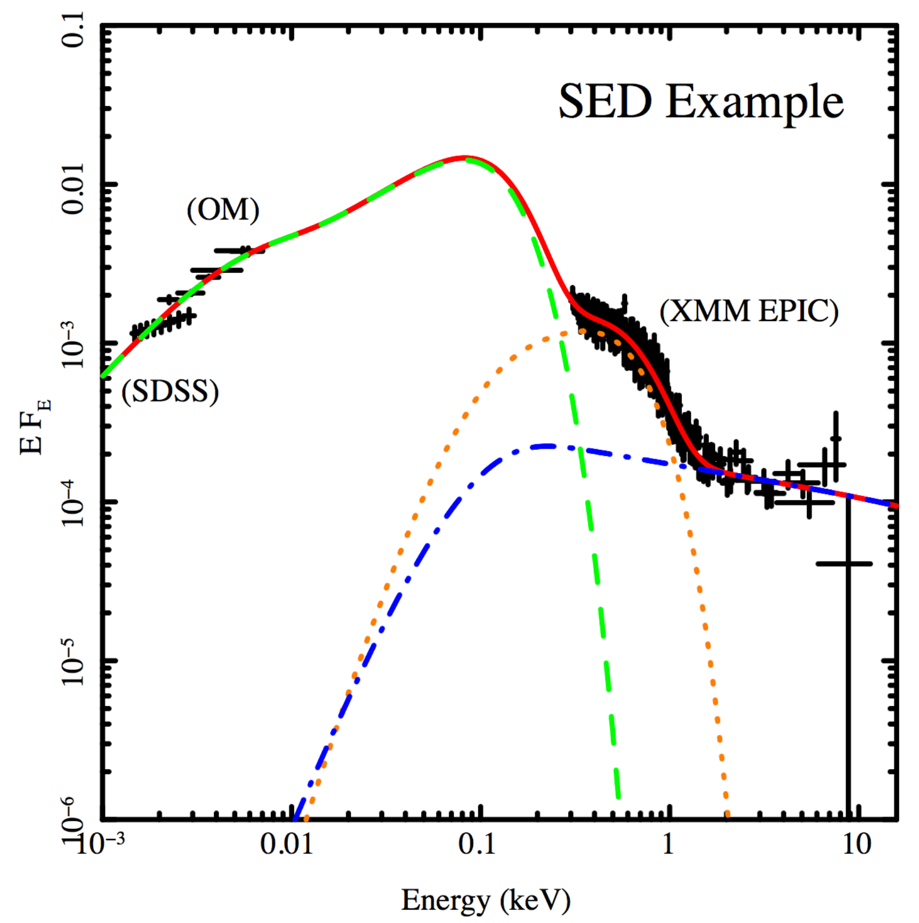
What about their jet properties?

- Little is known about their radio properties as a class, though most are radio-quiet; only ~25 radio-loud NLS1s identified to date.
- 7% of all NLS1s, vs. ~15% of general AGN population. Why??
- Now have *Fermi* γ-ray detections in 7 of these objects (Foschini+ 2015).
- Flat spectral indices and SEDs differ significantly from RQ NLS1 SEDs, indicate that these are likely sources with relativistic jets viewed close to face-on, more akin to FSRQs than the classic picture of RQ NLS1s (e.g., MCG-6, 1H0707).

Sun+ (2014)



Jin+ (2012)

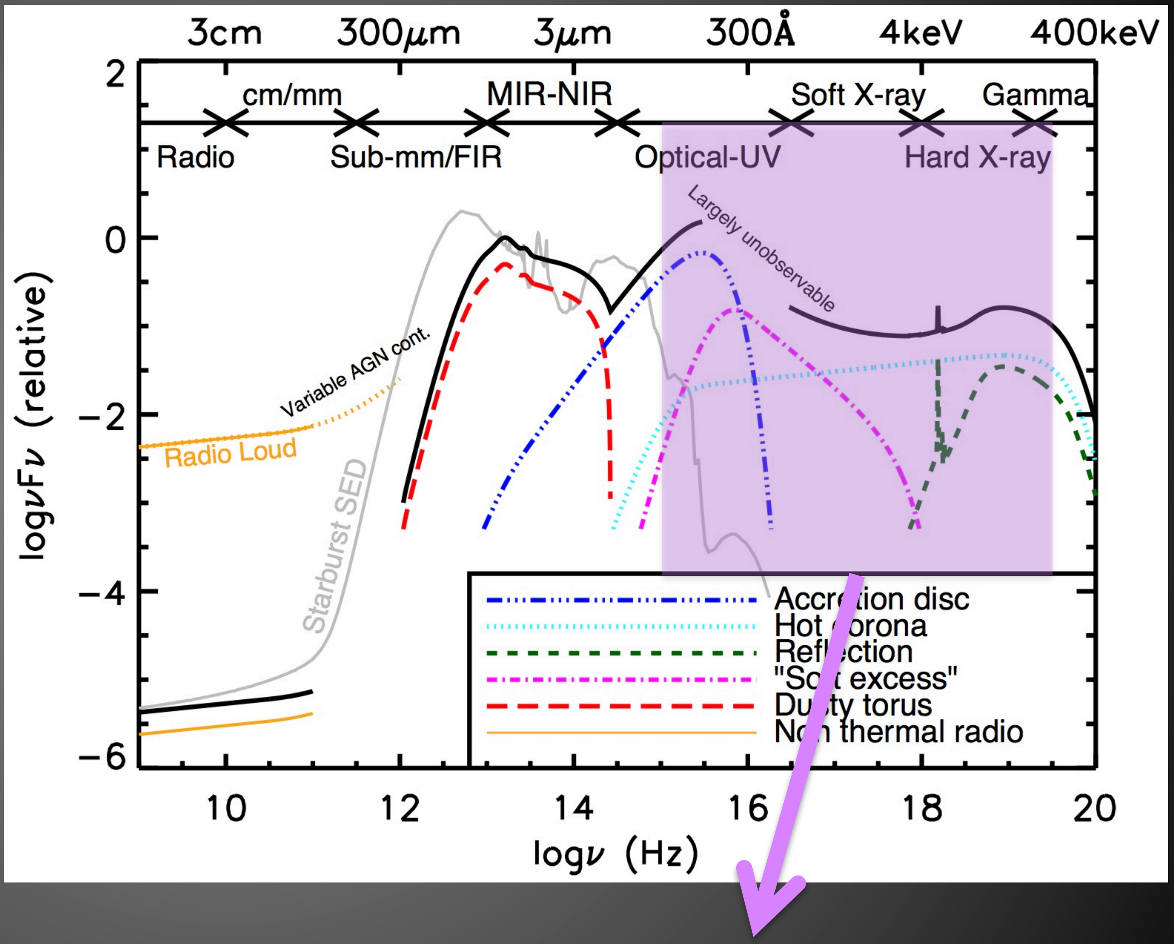


Radio- and γ-loud NLS1s tend to have spectra resembling larger-mass FSRQs, with higher hard-energy power from their jet emission.

Radio-quiet NLS1s characteristically show higher soft flux, weak hard X-ray emission consistent with their lack of jets and their relatively low black hole masses.

What about their jet properties?

- RL NLS1s now thought to be at high mass end of this class due to underestimation of black hole masses, overestimation of L_{bol} (Calderone+ 2014).
- This makes radio- and γ-loud NLS1s an important bridge population for studying disk/corona/jet physics.
- Broadband X-ray observations are critical: have all three spectral components contributing.



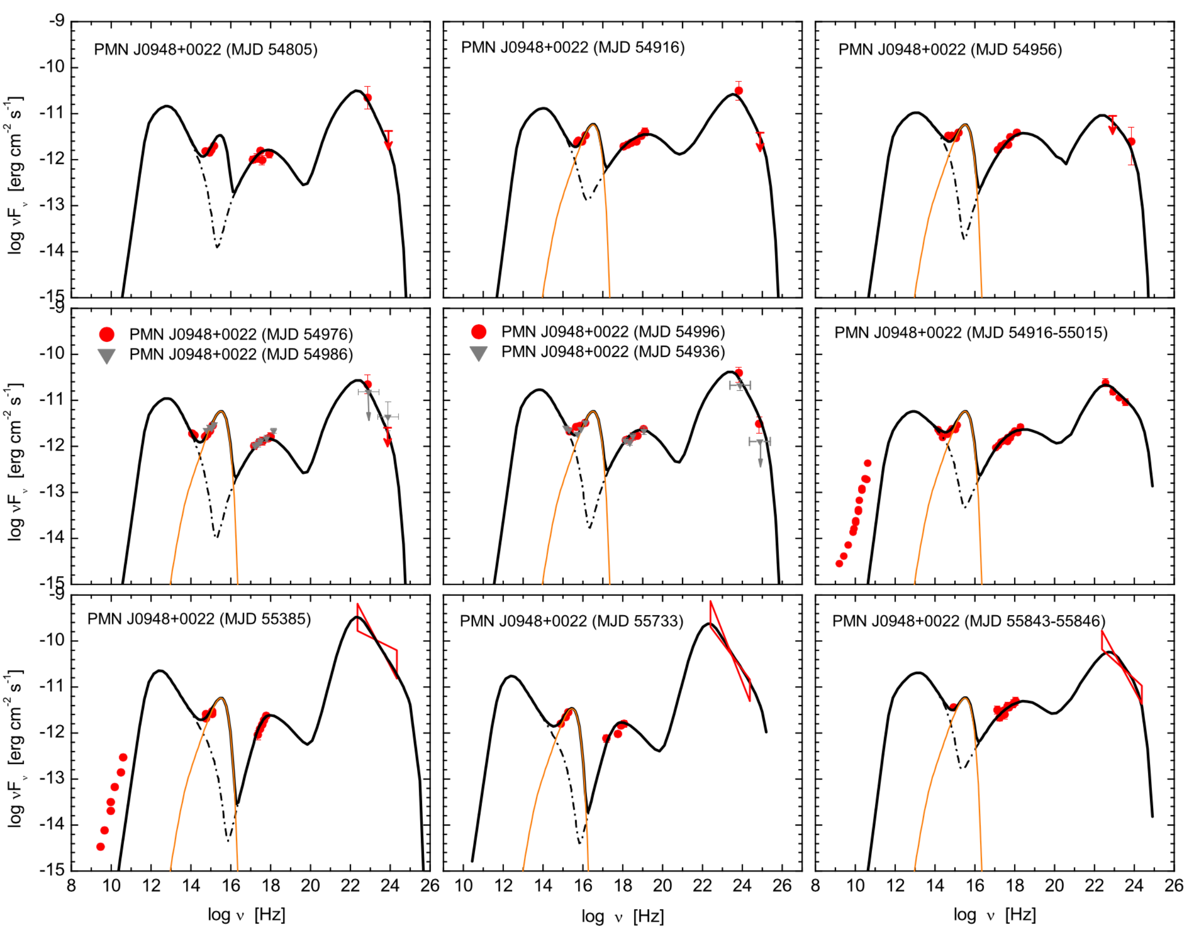
Energy range covered by *XMM* + *NuSTAR*

PMN J0948+0022

- First detected radio and γ-loud NLS1 (Abdo+ 2009).
- R_L > 1000 (Zhou+ 2003), z = 0.5851.
- Quoted black hole masses range from 4e7 M_{sun} from Hβ, 8.1e8 M_{sun} from Mg II (Zhou+ 2003), to 1.6e9 M_{sun} using Shakura-Sunyaev disk modeling (Calderone+ 2014).
- Kpc-scale jet at angle <22° from VLBI observations (Doi+ 2006).

PMN J0948+0022

- Multi-λ campaign from March - July 2009: flux decrease from optical to γ-ray bands followed by increased radio emission.
- Past flaring showed a different delay or no correlated variability (Foschini+ 2011, D'Ammando+ 2014).
- Radio-γ connection is complex in this object.

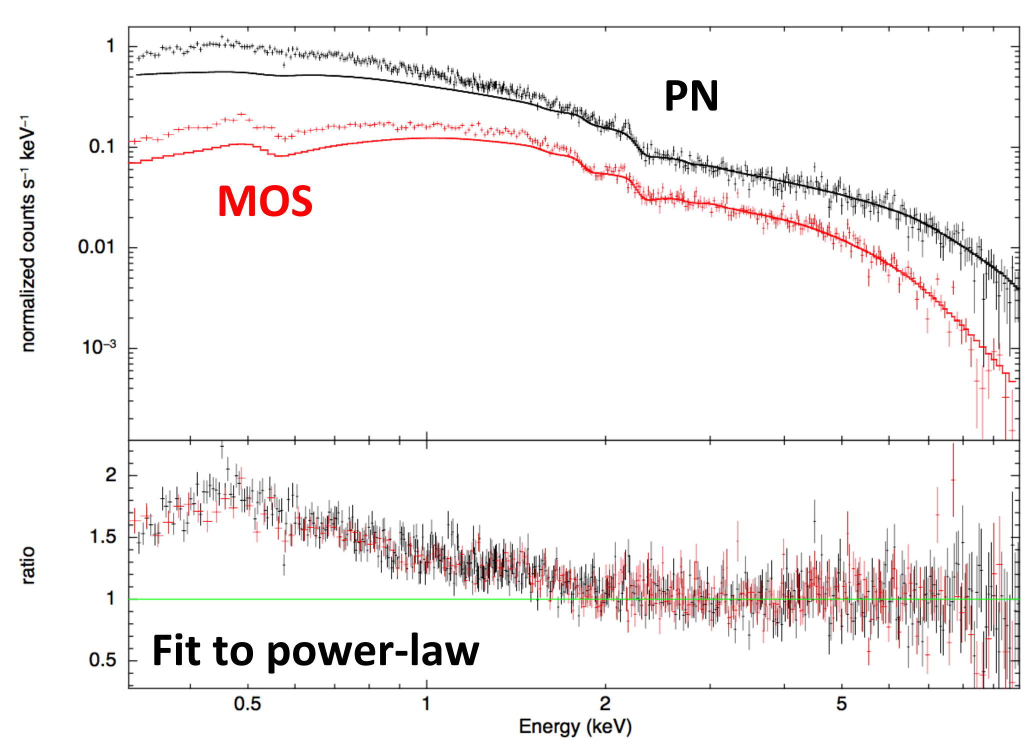


Sun + (2014)

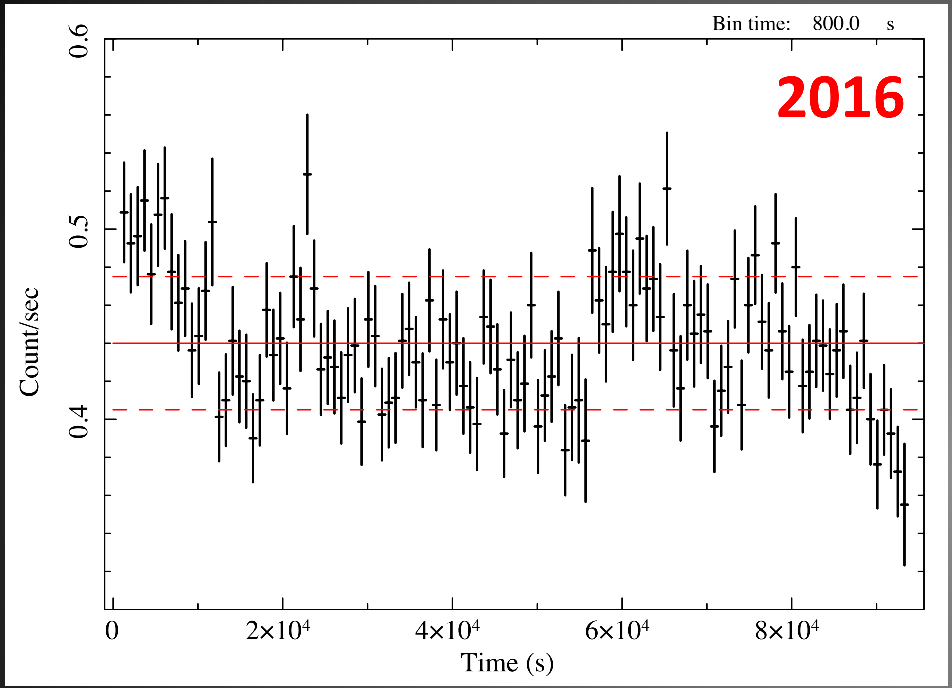
Sun+ (2014)

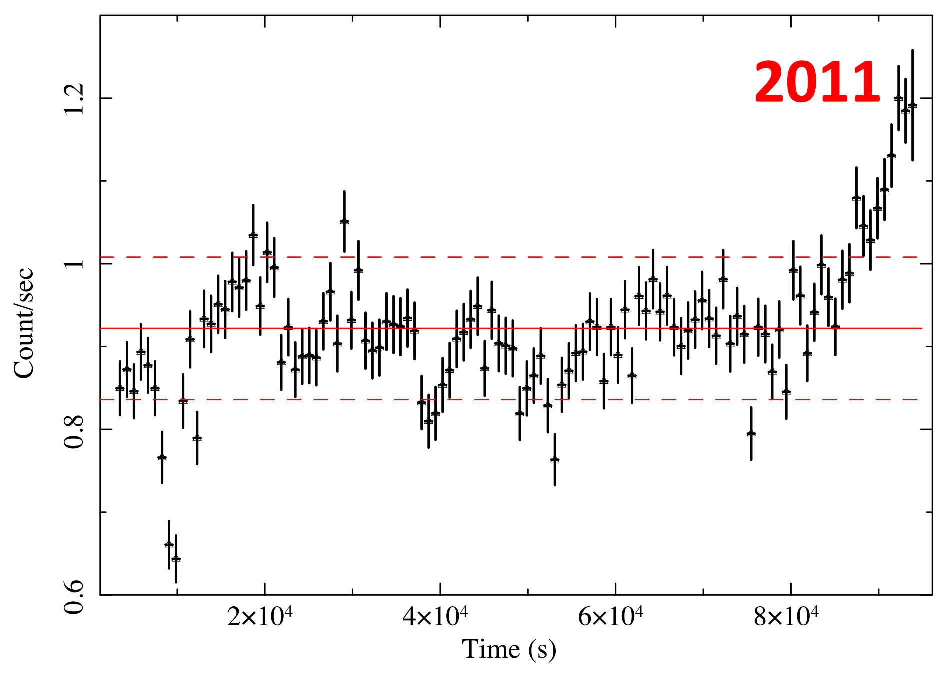
Previous X-ray Modeling

- *XMM* Observations in 2008 (25 ks) and 2011 (93 ks), as well as our 2016 *XMM* (93 ks) + *NuSTAR* (200 ks) campaign.
- Bhattacharyya+ (2014; B14) considered previous *XMM* data (MOS+pn) and attempted 4 different model fits: DISKBB+ZPO, COMPTT+ZPO, SWIND1+ZPO, KDBLUR (ZPO+REFLIONX). Similar fits done in D'Ammando+ (2014).
- COMPTT+ZPO model yielded best results; with addition of *NuSTAR*, *XMM*/OM, can we better constrain continuum and definitively rule out highly ionized, blurred reflection?



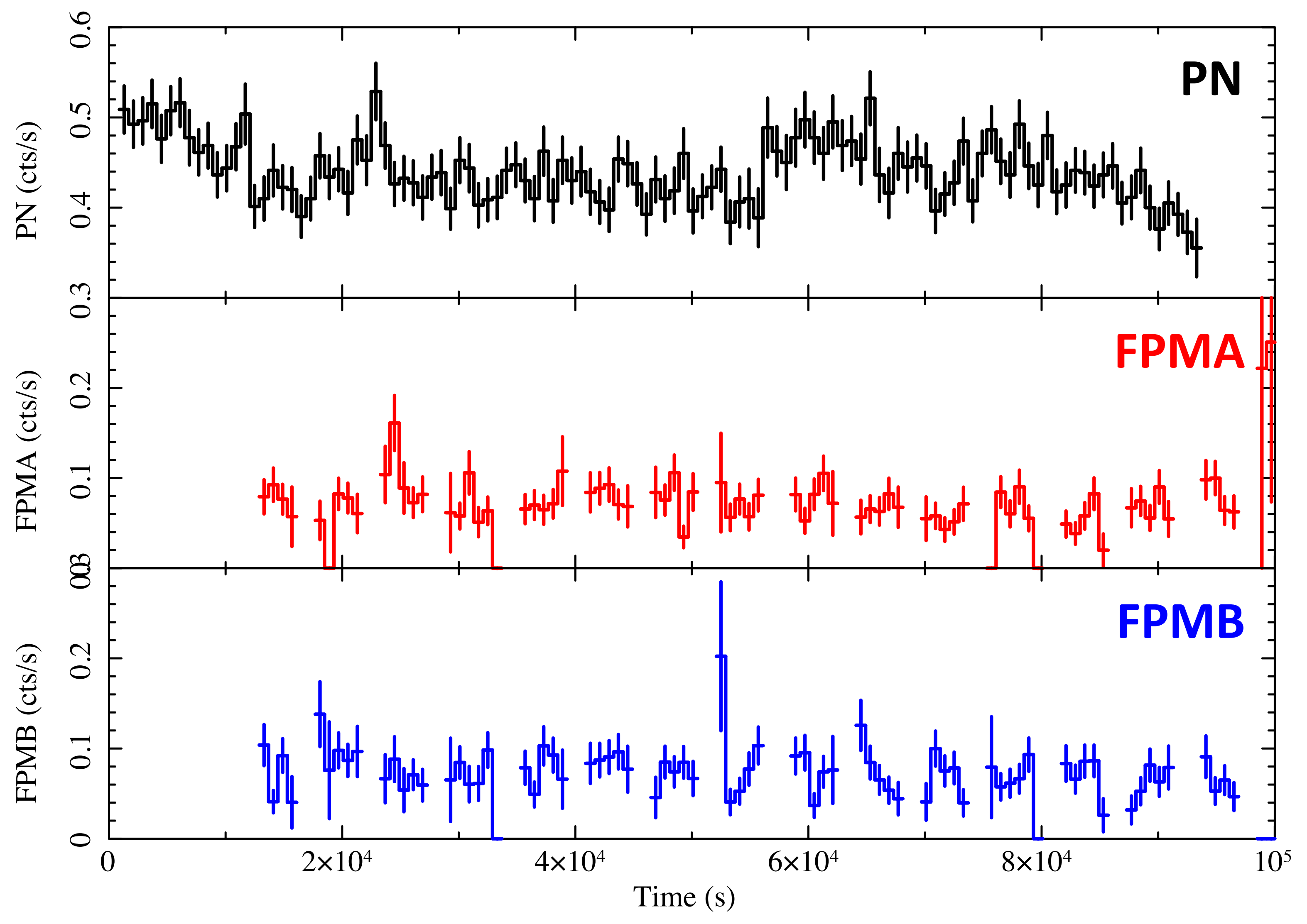
The 2016 *XMM+NuSTAR* Campaign



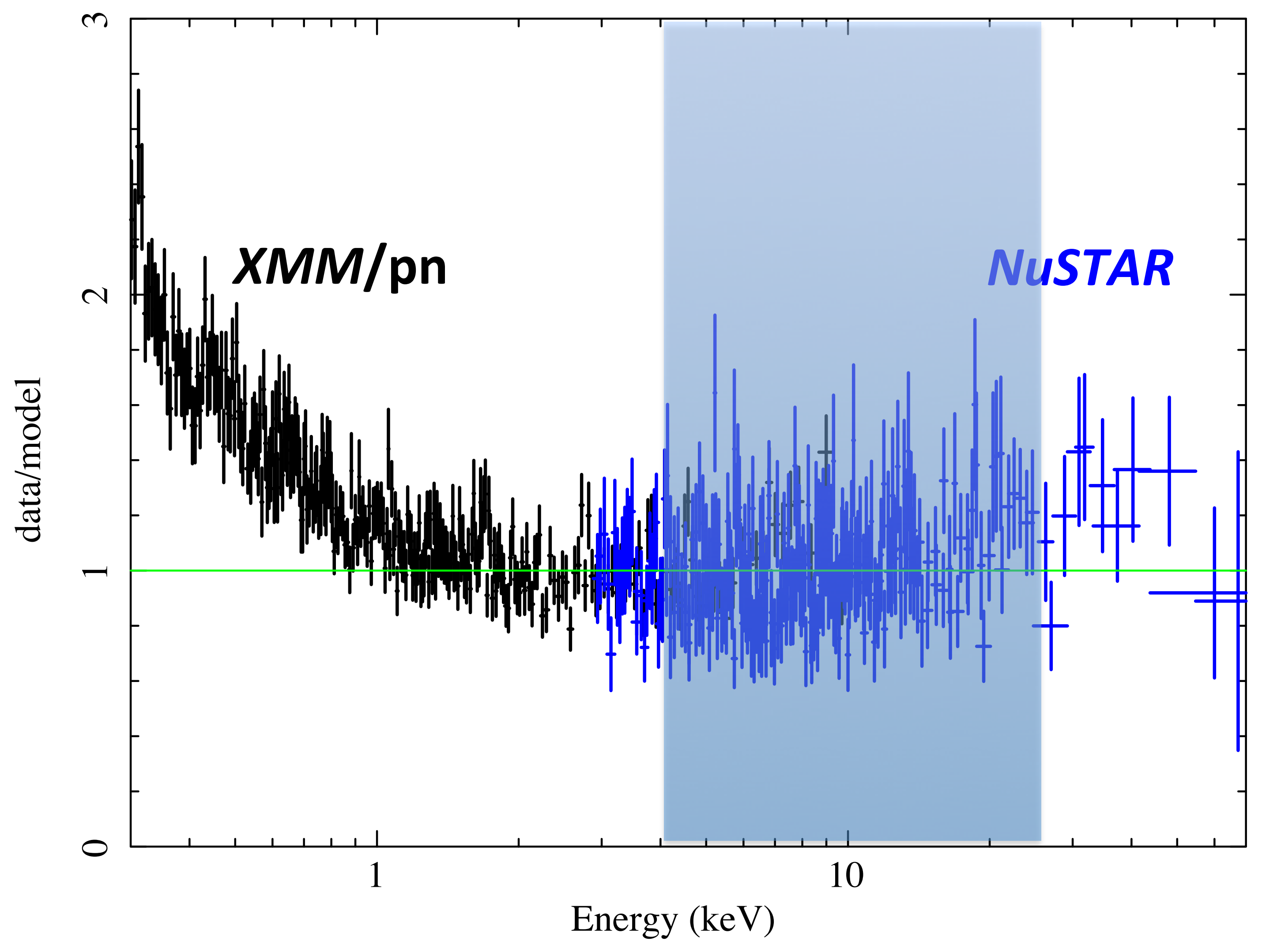


- EPIC-pn light curves show modest intra-observation variability (~1.5x), more significant changes (~2x) between epochs with 2011 being brighter.
- RMS variability increases with source flux (B14).
- 2011 data also show multiple sharp dips in the light curve, though no change in spectral shape seen during the largest one.

2016 Hardness Ratio Light Curves

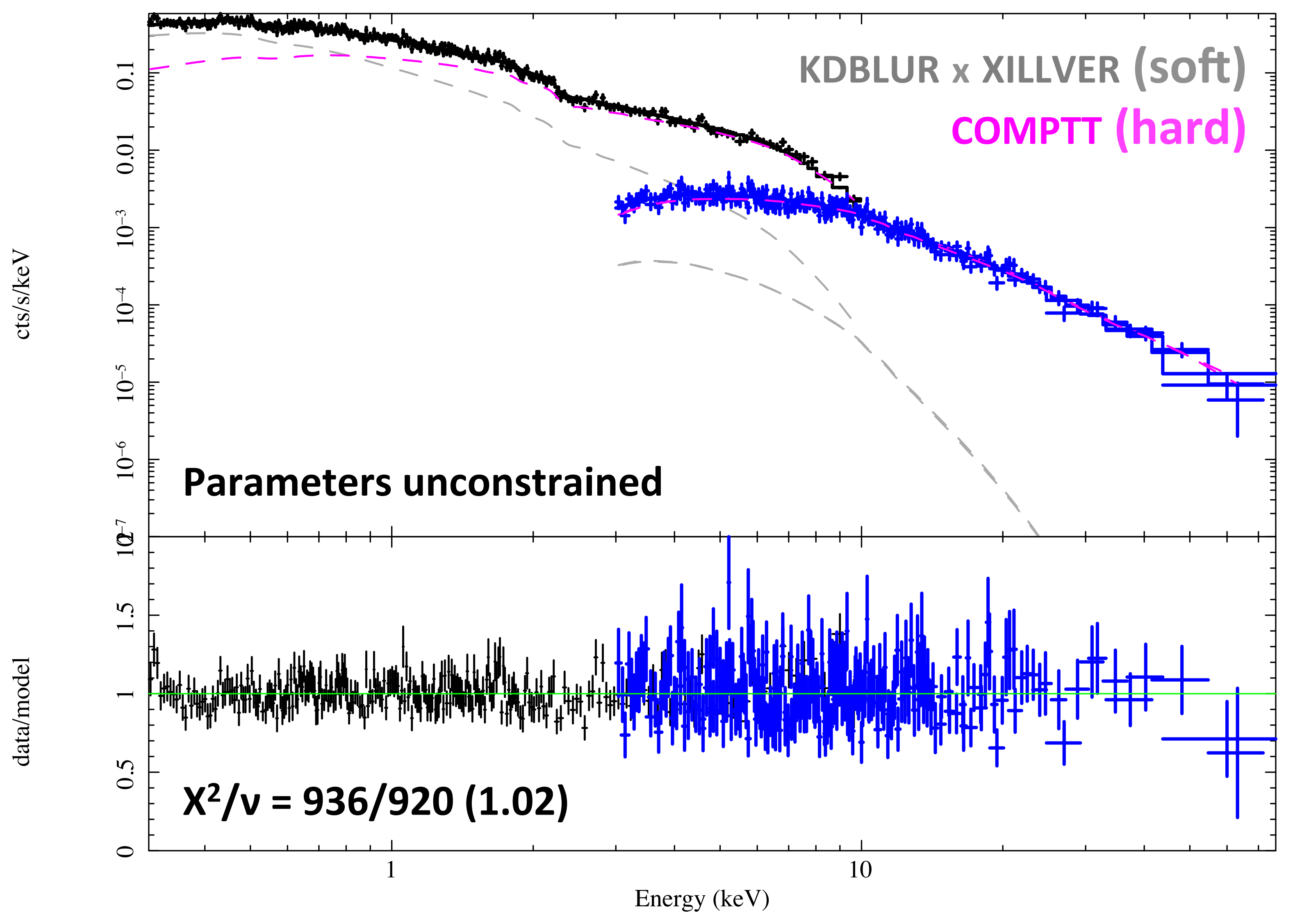


2016 Spectrum vs. Power-law



Obvious soft excess, hard X-ray curvature, but reflection isn't immediately apparent.

2016 *XMM*/pn + *NuSTAR:* reflection



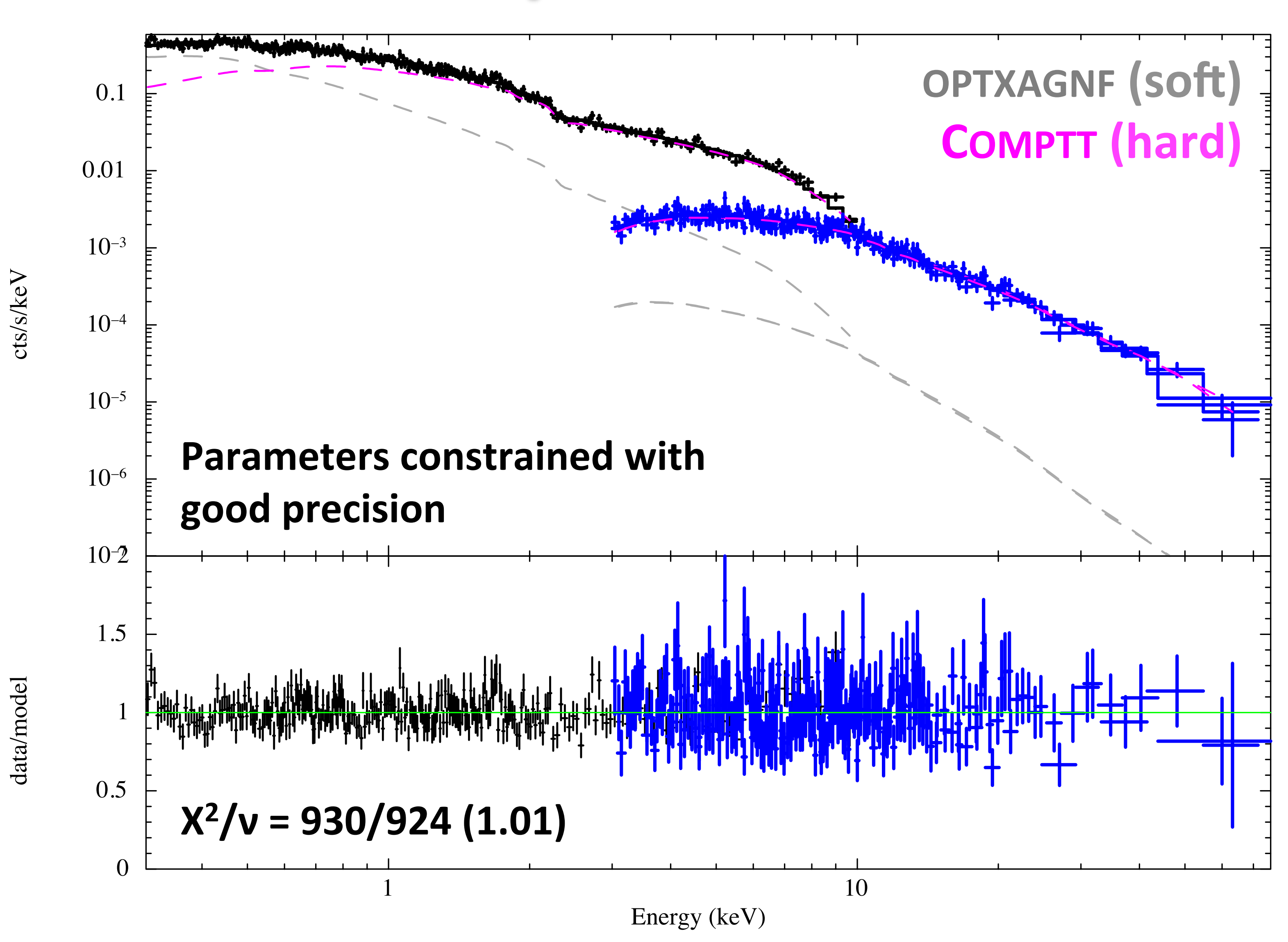
KDBLUR x XILLVER (soft)

COMPTT (hard)

Parameters unconstrained

X^2/ν = 936/920 (1.02)

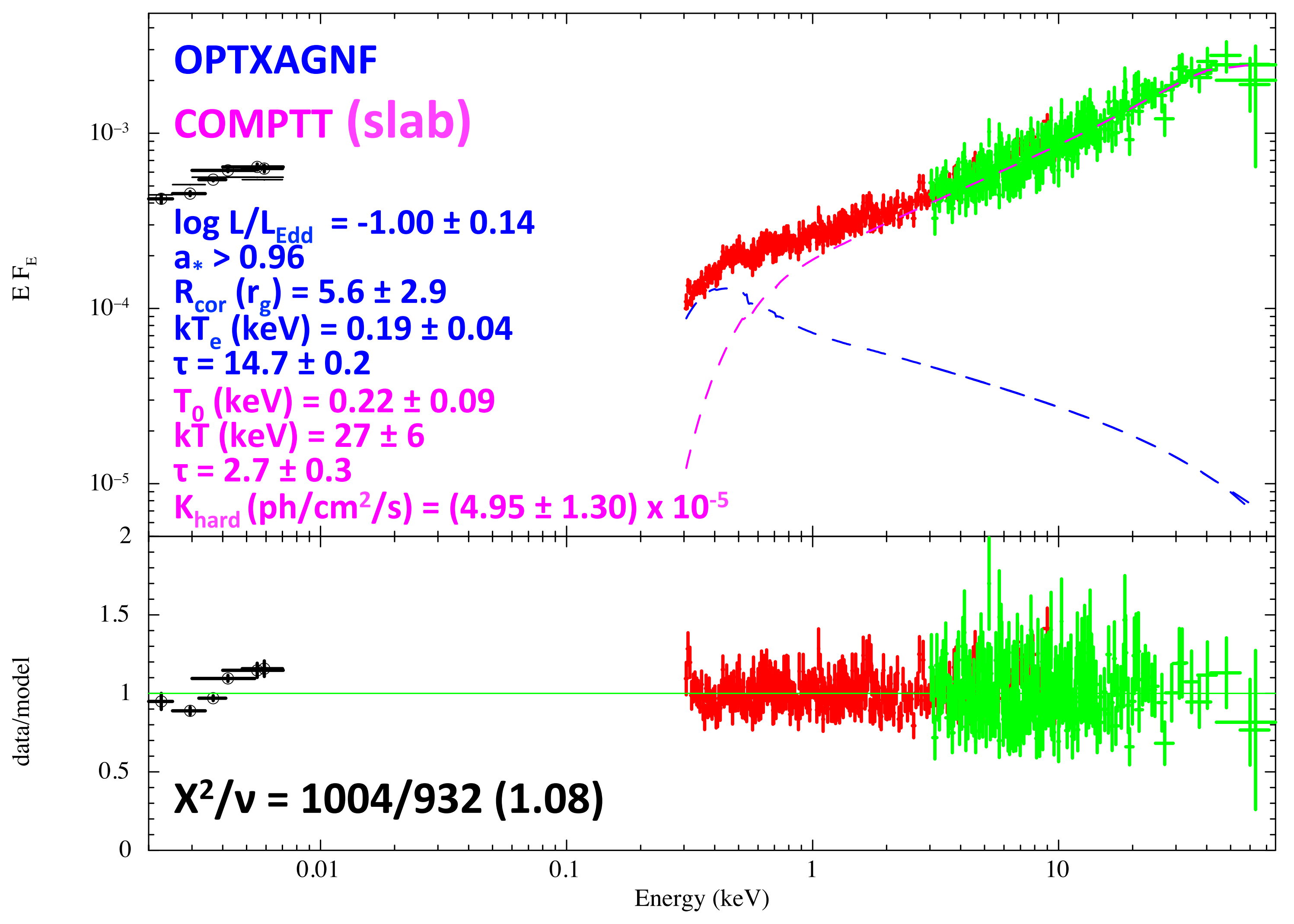
2016 *XMM*/pn + *NuSTAR:* soft Comptonization



Parameters constrained with good precision

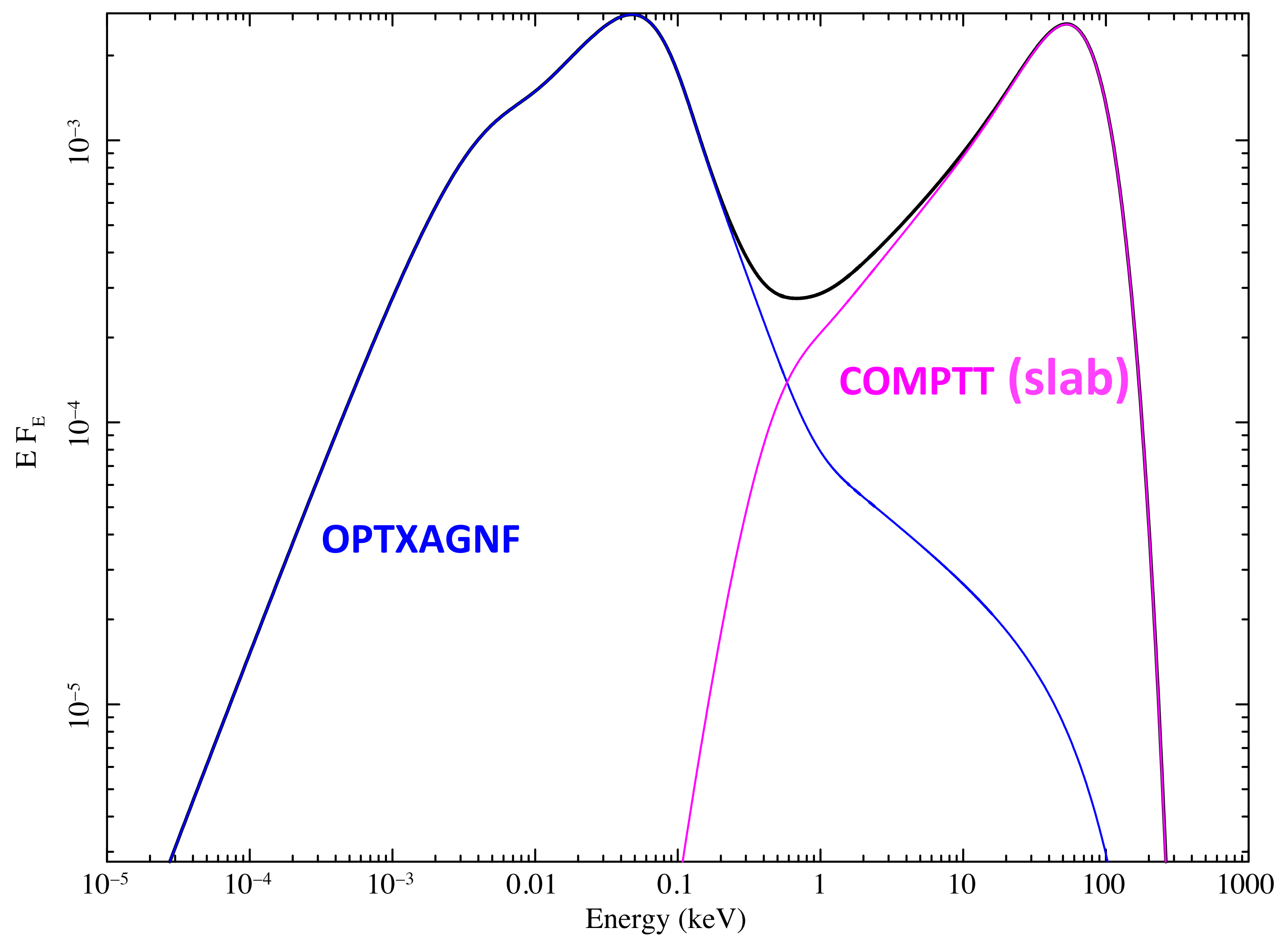
χ^2/ν = 930/924 (1.01)

Including the Optical Monitor Data



Reflection model must include an additional component of soft emission (e.g., DISKBB, ZBREMS); overall fit is much worse for OM: $\chi^2/\nu > 1.30$, parameters not well constrained.

Unabsorbed Optical – X-ray SED Model



Where is the Reflection?

- No significant evidence for reflection in PMN J0948+0022.
- Jet inclination angle <22° and no intrinsic absorption seen, so we should be getting a good view of the inner regions of this AGN.
- Considering that we measure $L/L_{edd} \sim 0.1$, we *should* expect to see inner disk reflection features in this source, but jet/corona emission is likely drowning it out if it's present.
- None of the RL NLS1s examined has definitive evidence for reflection (per A. Lohfink). In other RL AGN we see examples of reflection (e.g., 3C120, 4C74.26) with strong jets, but these are the exception to the norm, in which reflection signatures disappear as jet becomes more prominent (e.g., 3C273).
- Are we staring straight down the jet at all radio- and γ-loud NLS1s? Are we missing a population of inner disks misaligned with the jet axis?

Musings on Black Hole Spin

- Spin seems to be high in RQ NLS1s that have been observed so far based on reflection modeling (e.g., MCG-6, 1H0707).

- Our OPTXAGNF fitting of the soft excess prefers a rapid spin as well: $a_* > 0.96$; caveat in that no reflection available to check this.

- Was previously thought that NLS1s on average harbor less rapidly spinning black holes than Seyferts to account for the lower frequency of radio-loudness among NLS1 (Komossa+ 2006).

- Evidently not… hypothesis that NLS1s are an early evolutionary stage of higher-mass Seyferts is faulty due to mass underestimates in RL NLS1s, high spins measured in some RQ NLS1s.

- Role of spin in triggering jets thus remains unclear… accretion mode differences playing major role?? In need of more self-consistent jet modeling to address this.

Conclusions

- Best-fitting model for PMN J0948+0022 in 2016 has two Comptonizing components: cool one responsible for soft excess, warm one for corona/jet.
- Finding a relatively low coronal temperature relative to other broad- and narrow-line Sy 1 seen so far: kT ~ 27 keV is on low end of distribution (Fabian+ 2015), especially for its mass. Reinforces this object as a member of a bridge class between RQ NLS1s and higher mass RL AGN.
- Future work: full model incorporating 2011 *XMM* data as well, also any radio/γ data available for 2016. Exploring other non-thermal corona models, e.g., EQPAIR.
- New Markoff jet model forthcoming that folds RELXILL in with a jet continuum; ideally want a model that can self-consistently tie together multiple Comptonization zones, jet (forthcoming model by C. Done).