Cygnus X-1:

as viewed by every flying X-ray satellite

Michael A. Nowak (MIT-Kavli institute)
-with-
Manfred Hanke, Sarah Trowbridge, Sera Markoff,
Jörn Wilms, Katja Pottschmidt, Paolo Coppi,
Dipankar Maitra, John Davis, & Frank Tramper

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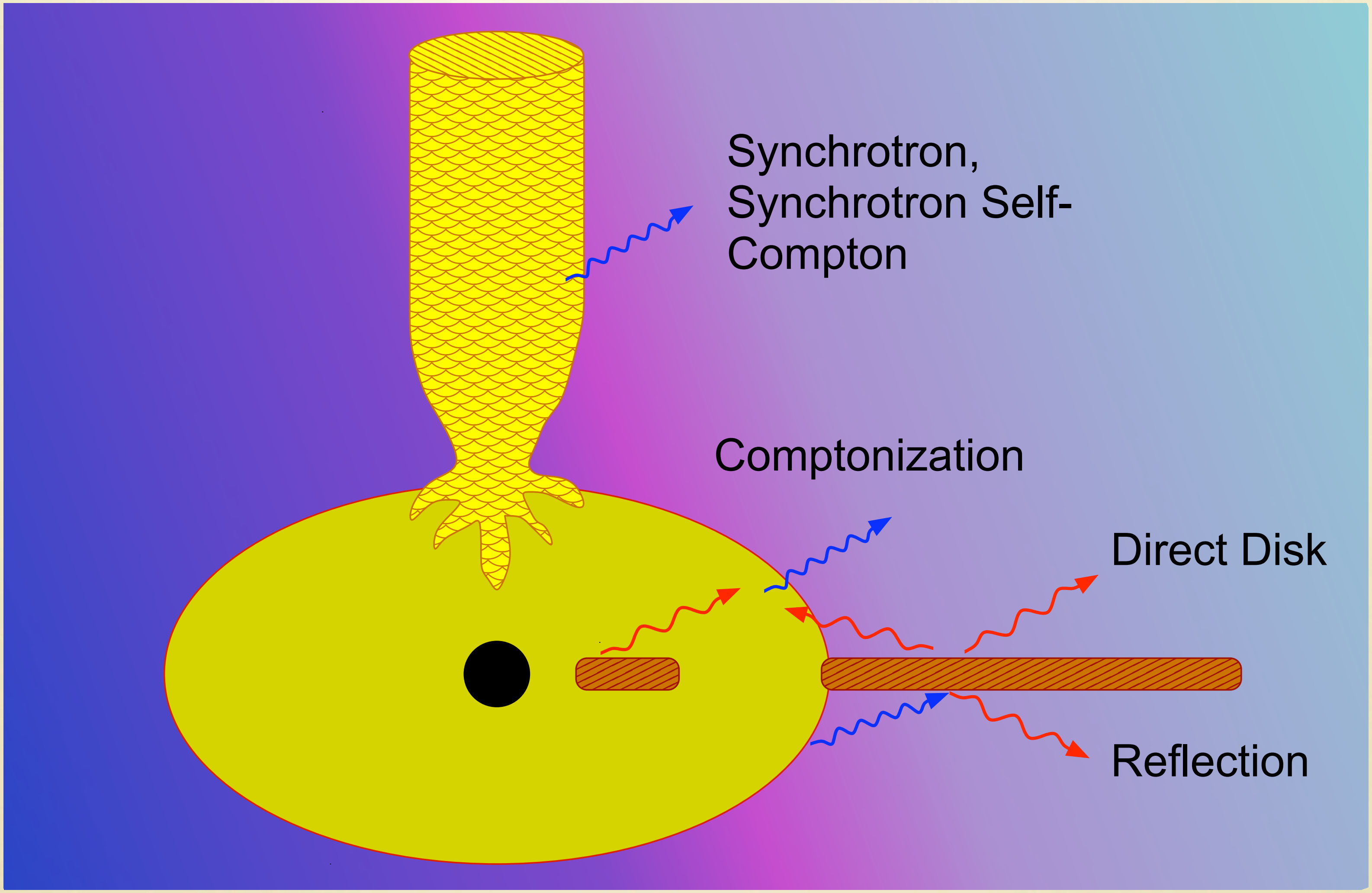
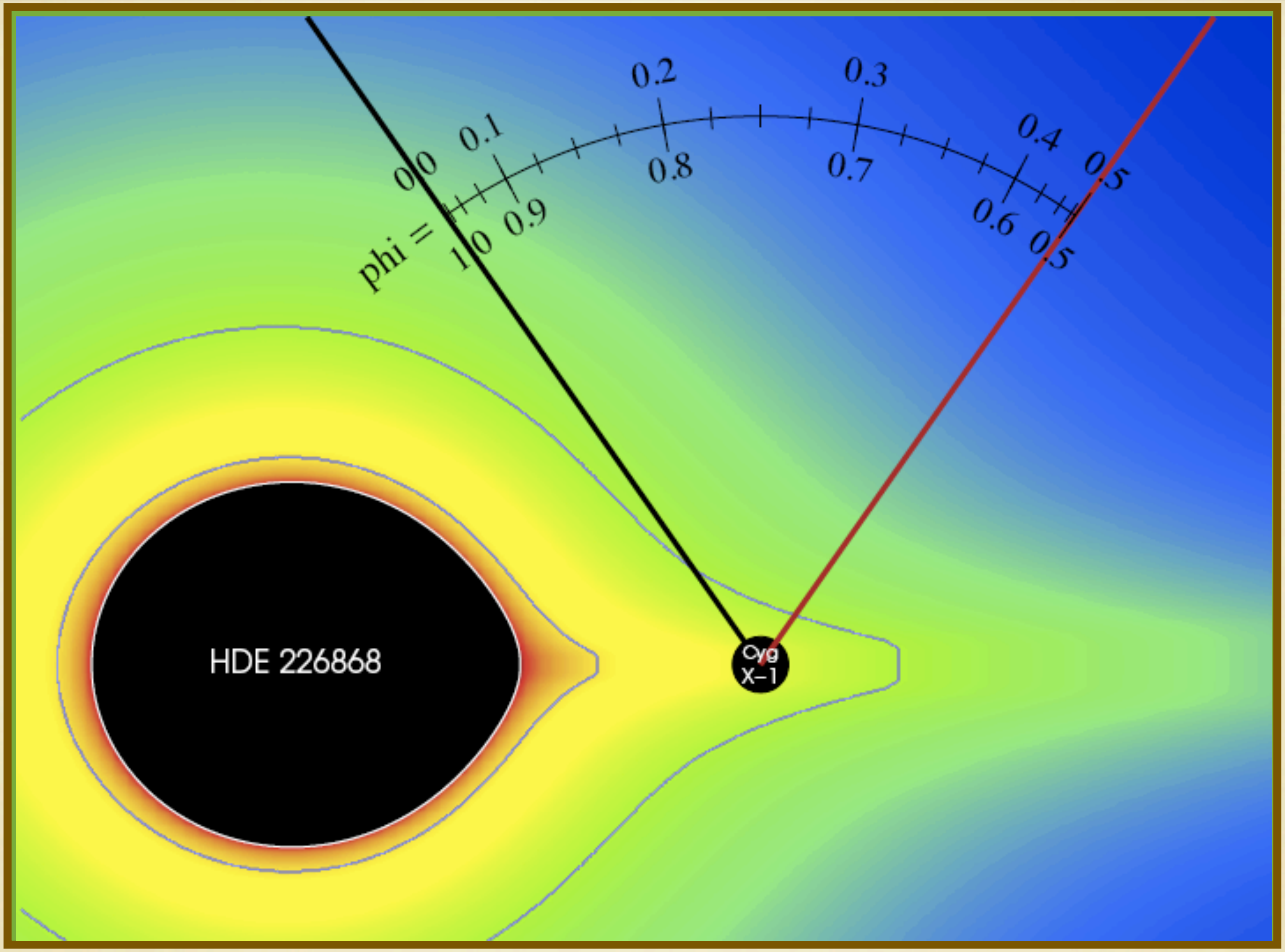
The Question:

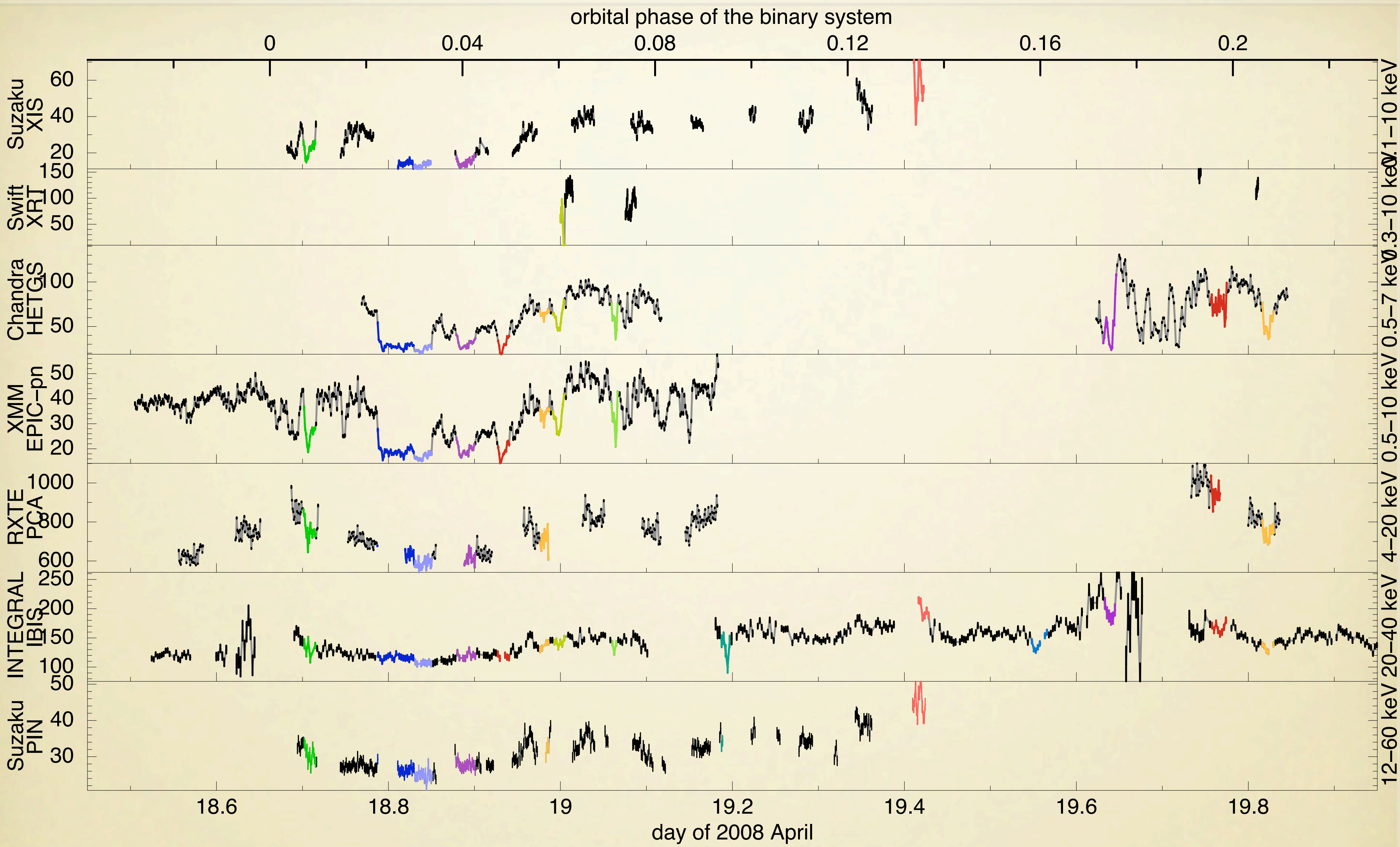


The Campaign:

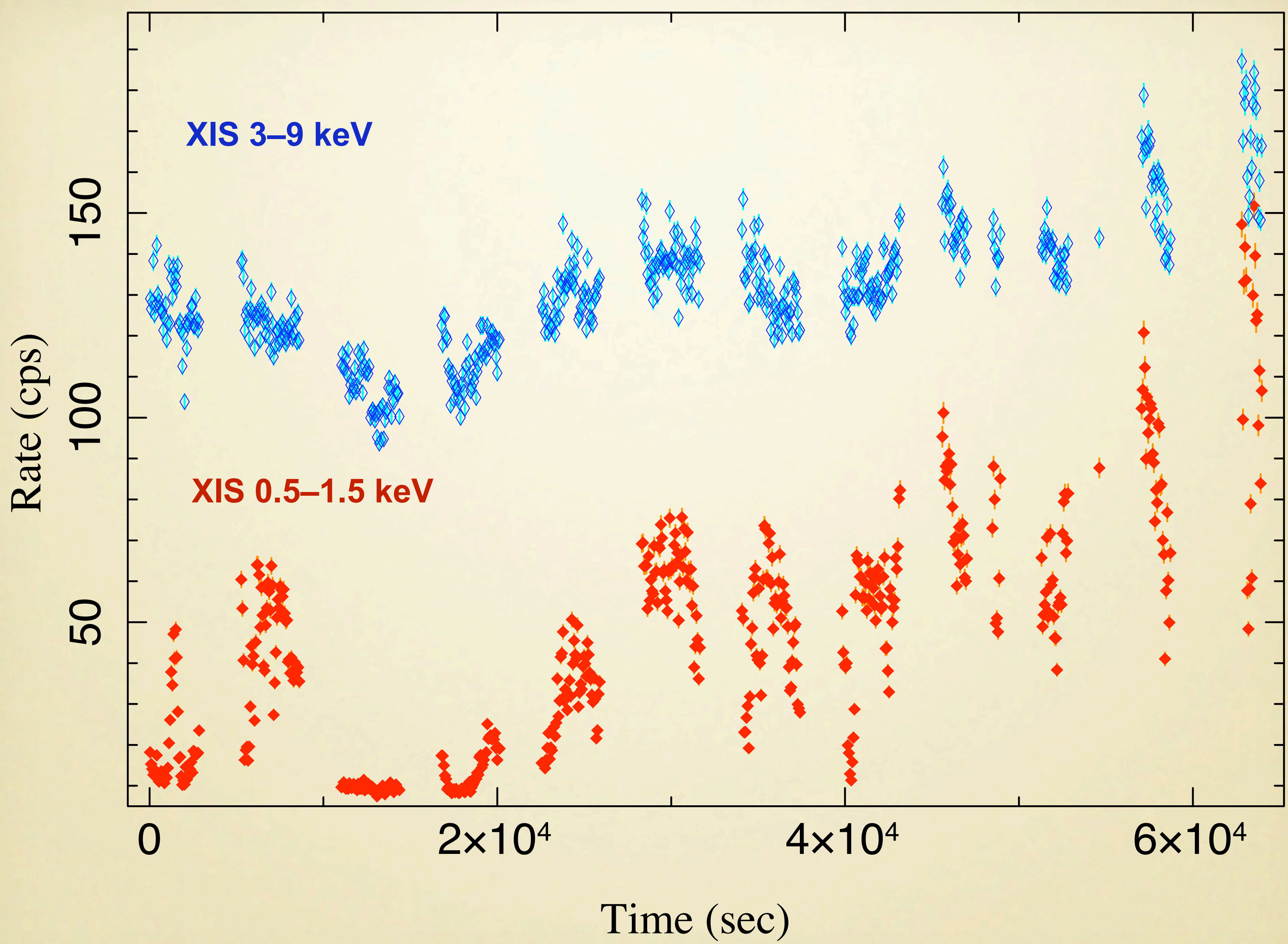
- April 19, 2008 - Orbital Phase 0, i.e., Viewing Through The Secondary Wind
- All Flying X-ray Satellites
  - Chandra, Xmm-Newton, RXTE, Suzaku, Swift, Integral
  - 0.5 - 500 KeV

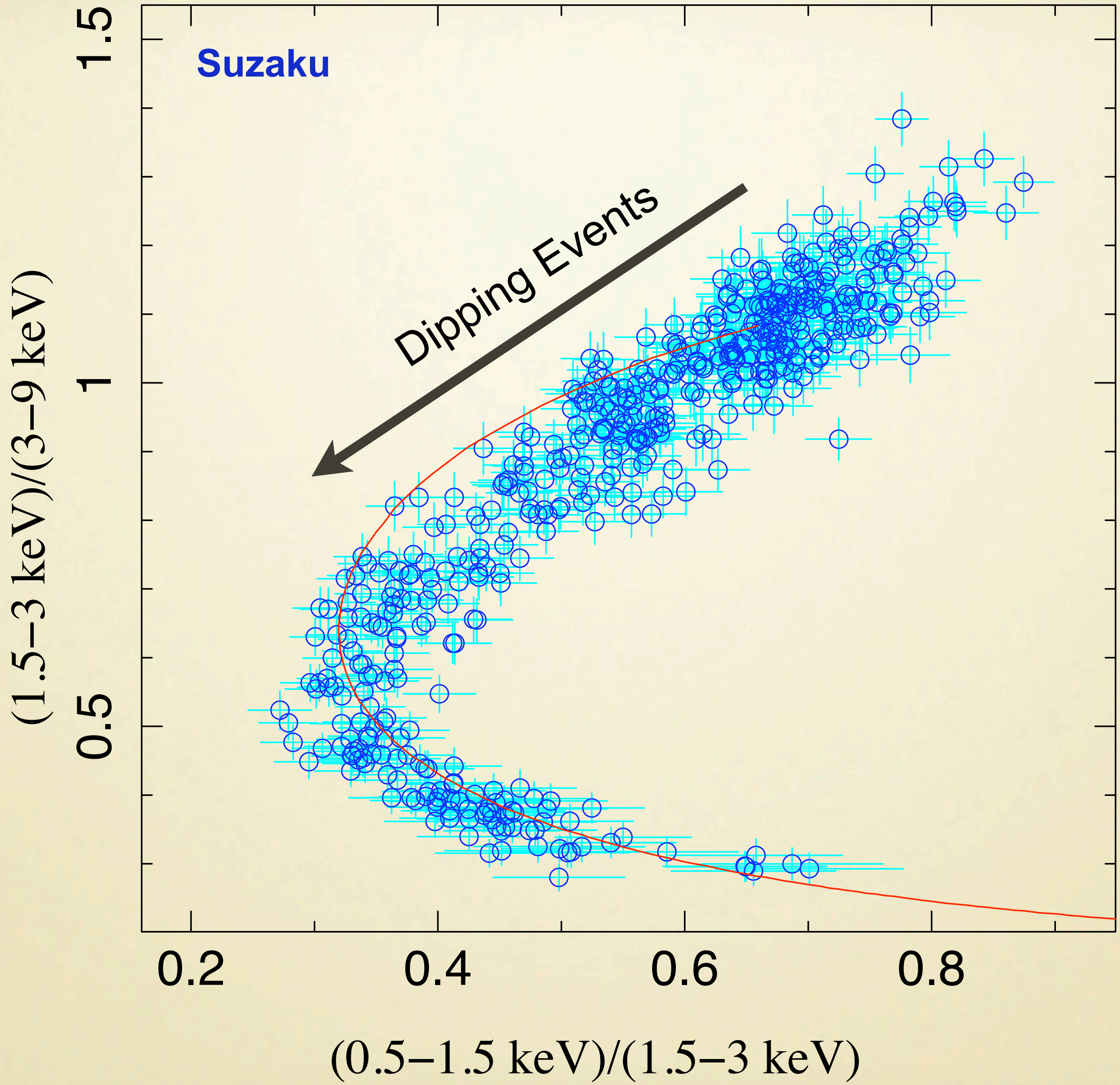


(Hanke et al. 2009, ApJ, 690, 330)



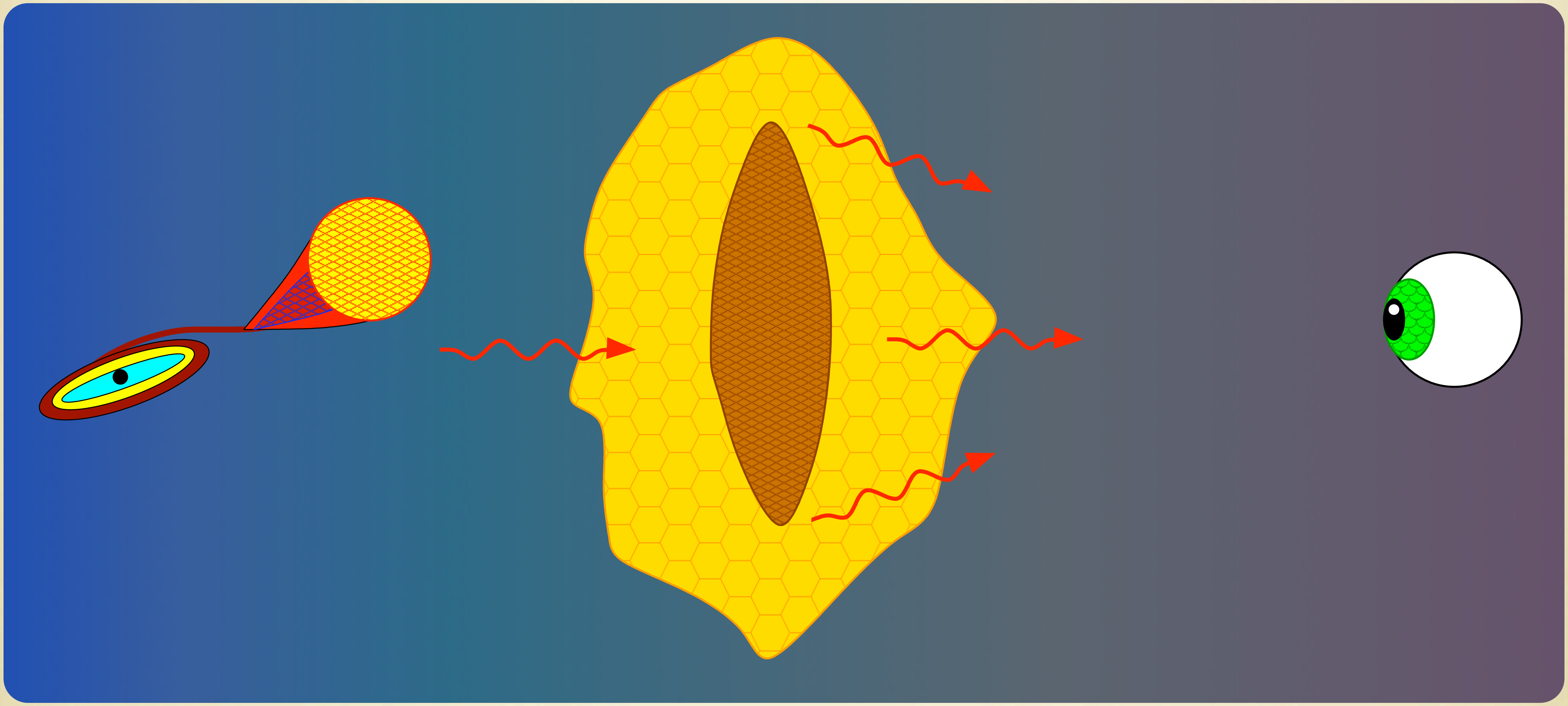
(Lightcurves Courtesy M. Hanke)


XIS 3–9 keV
XIS 0.5–1.5 keV
Rate (cps)
50
100
150
0
2×10⁴
4×10⁴
6×10⁴
Time (sec)



Suzaku
Dipping Events
1.5
1
0.5
0.2
0.4
0.6
0.8
(1.5−3 keV)/(3−9 keV)
(0.5−1.5 keV)/(1.5−3 keV)

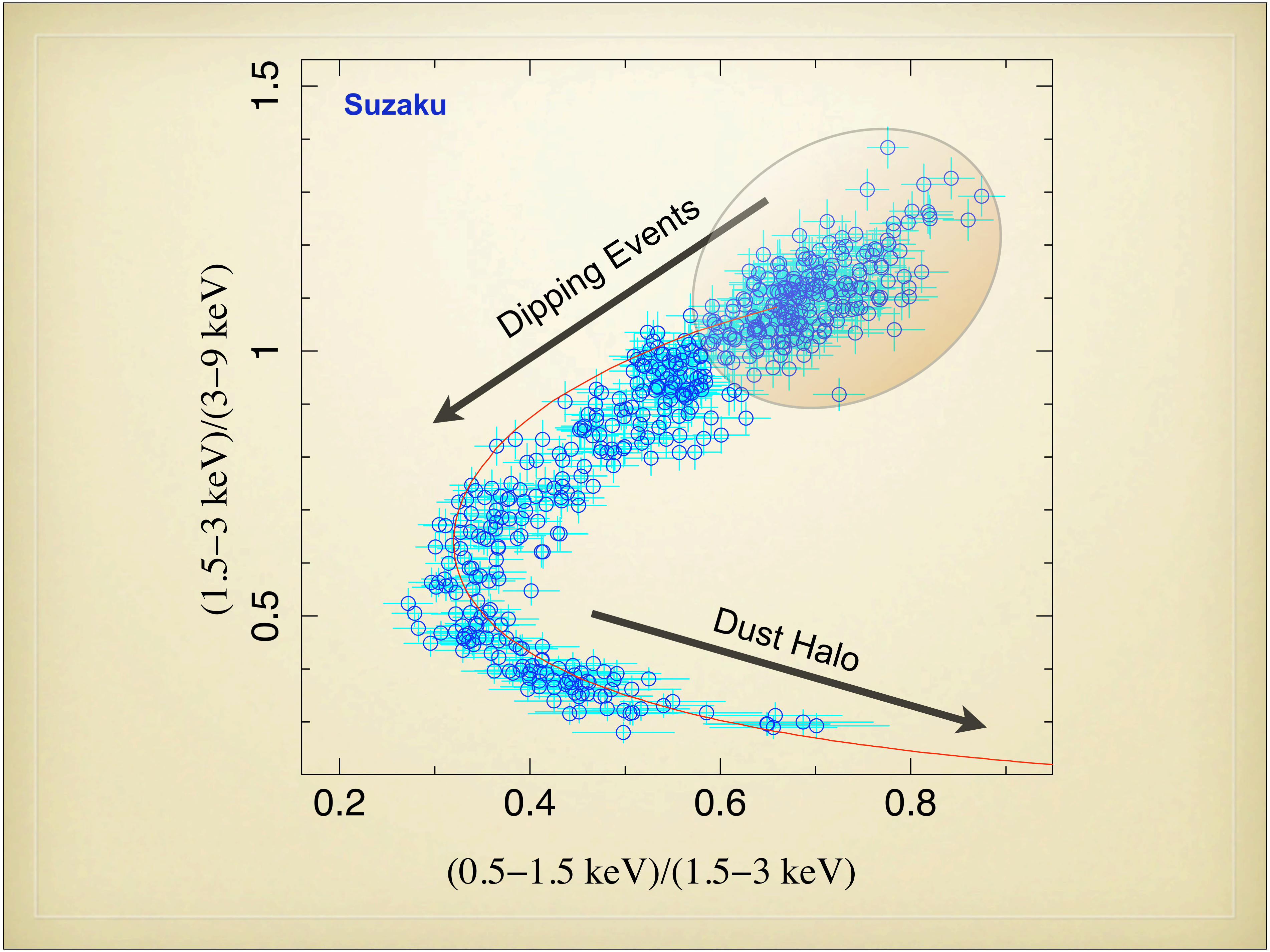
The Dust HAlo



Loss Term: Chandra, Swift, XMM-Newton

A "Wash": RXTE-PCA, Suzaku-XIS

Unimportant: Suzaku-HXD, RXTE-HEXTE, INTEGRAL

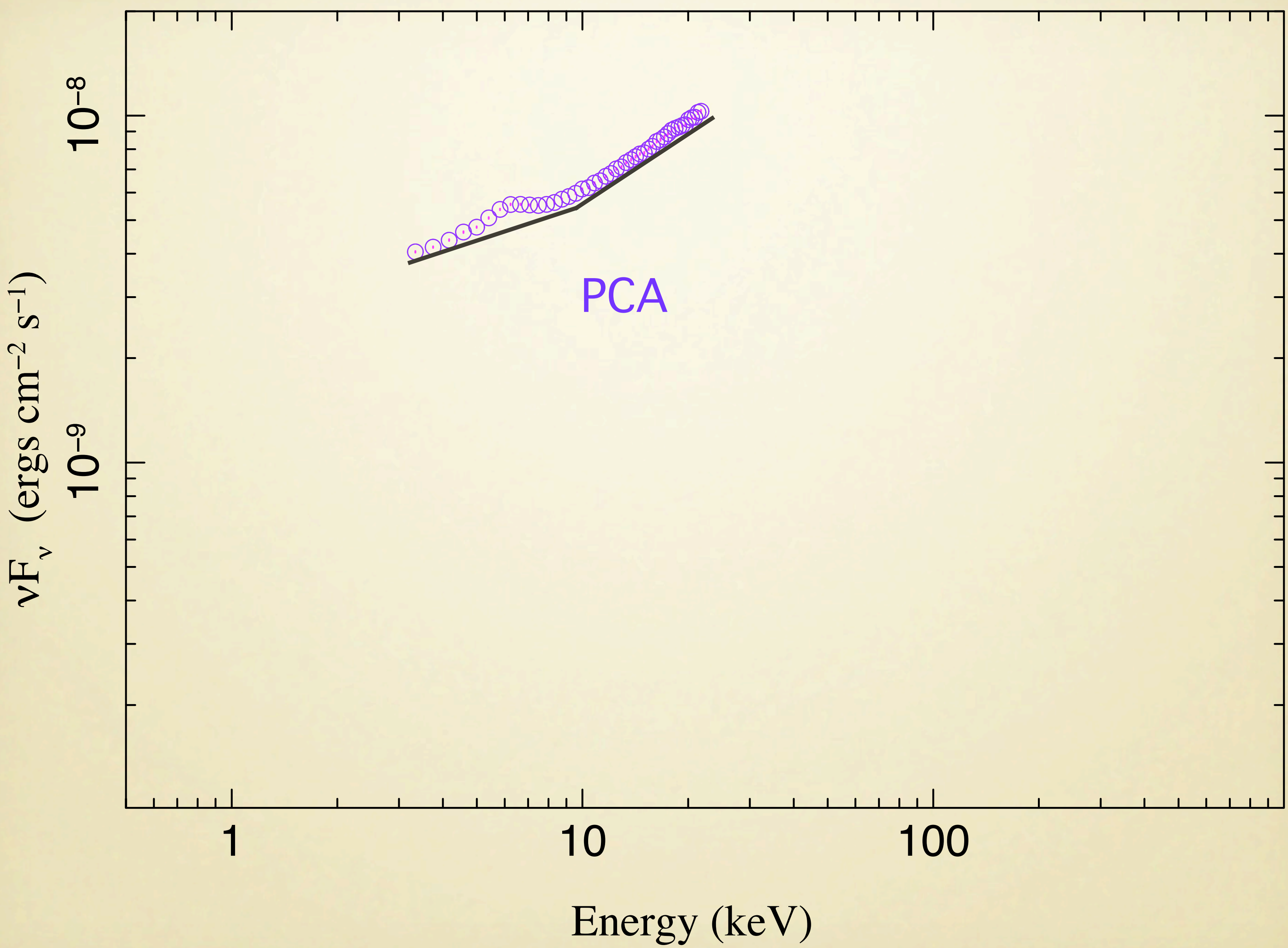


Suzaku
Dipping Events
Dust Halo
1.5
1
0.5
0.2
0.4
0.6
0.8
(1.5−3 keV)/(3−9 keV)
(0.5−1.5 keV)/(1.5−3 keV)

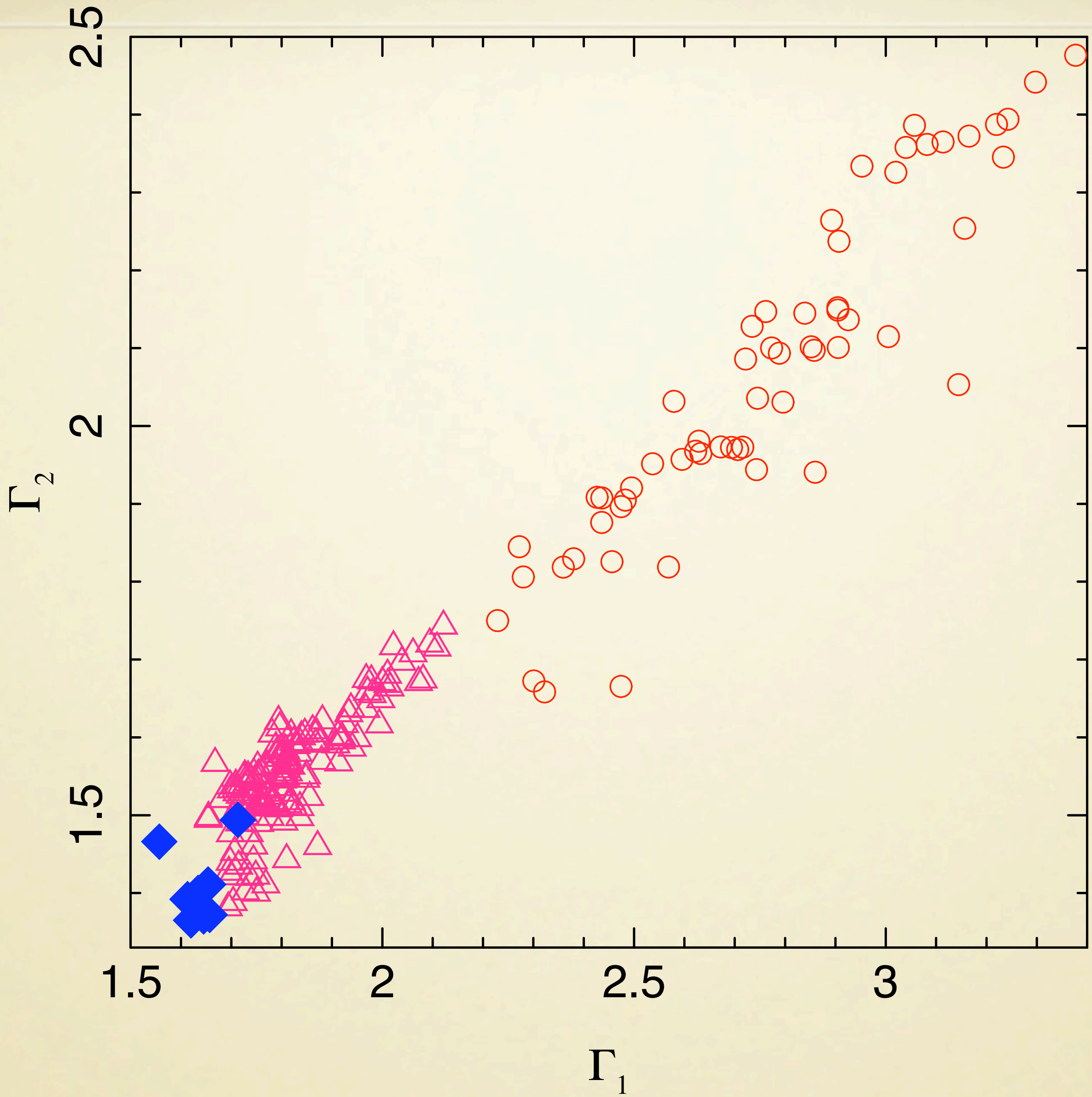
Properly "Unfolding" The Spectra

$$\boxed{\frac{C(h) - B(h)}{T \int R(E,h)A(E)\, dE}}$$

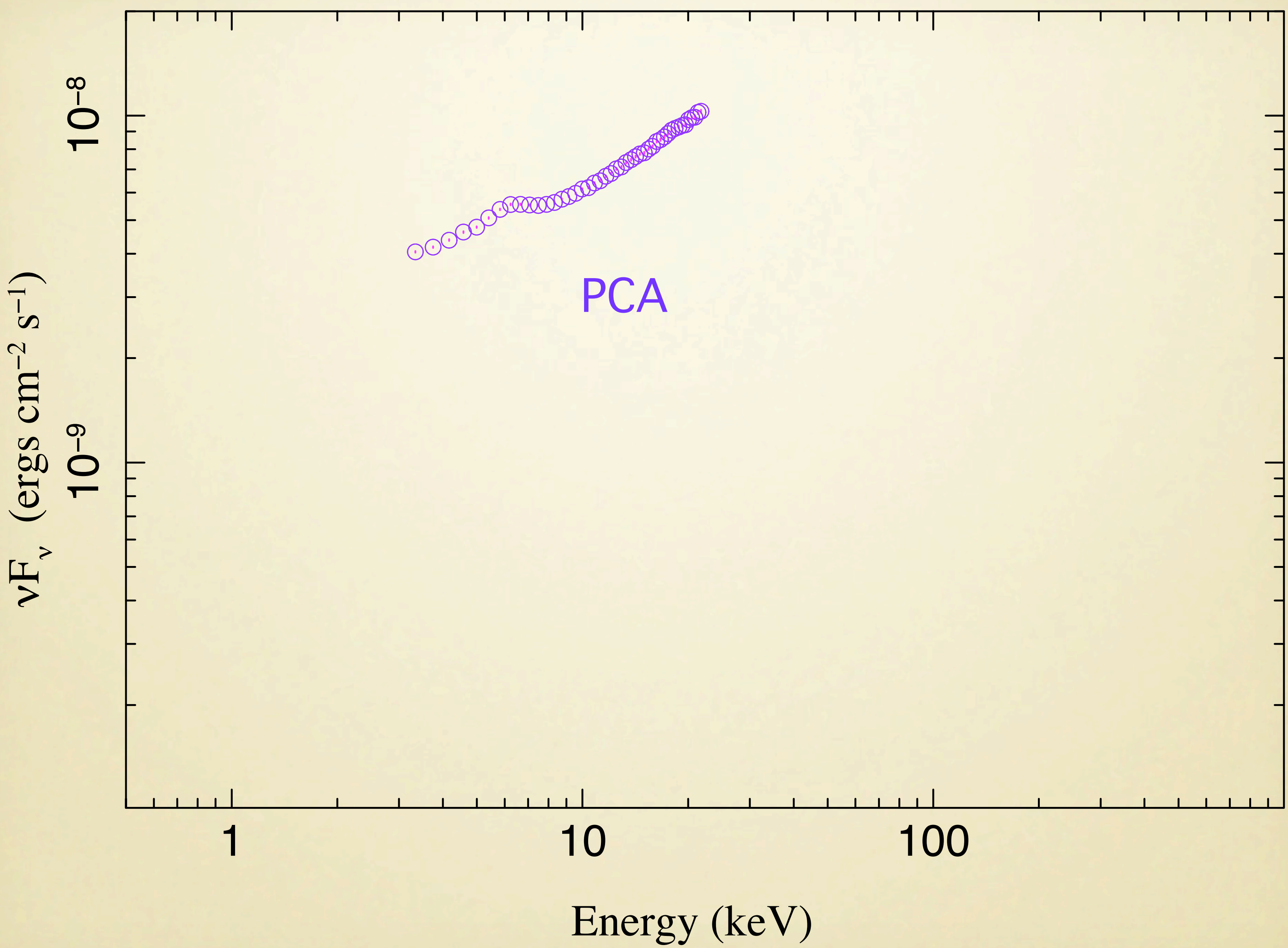
The Spectra are **Independent** of Assumed Model



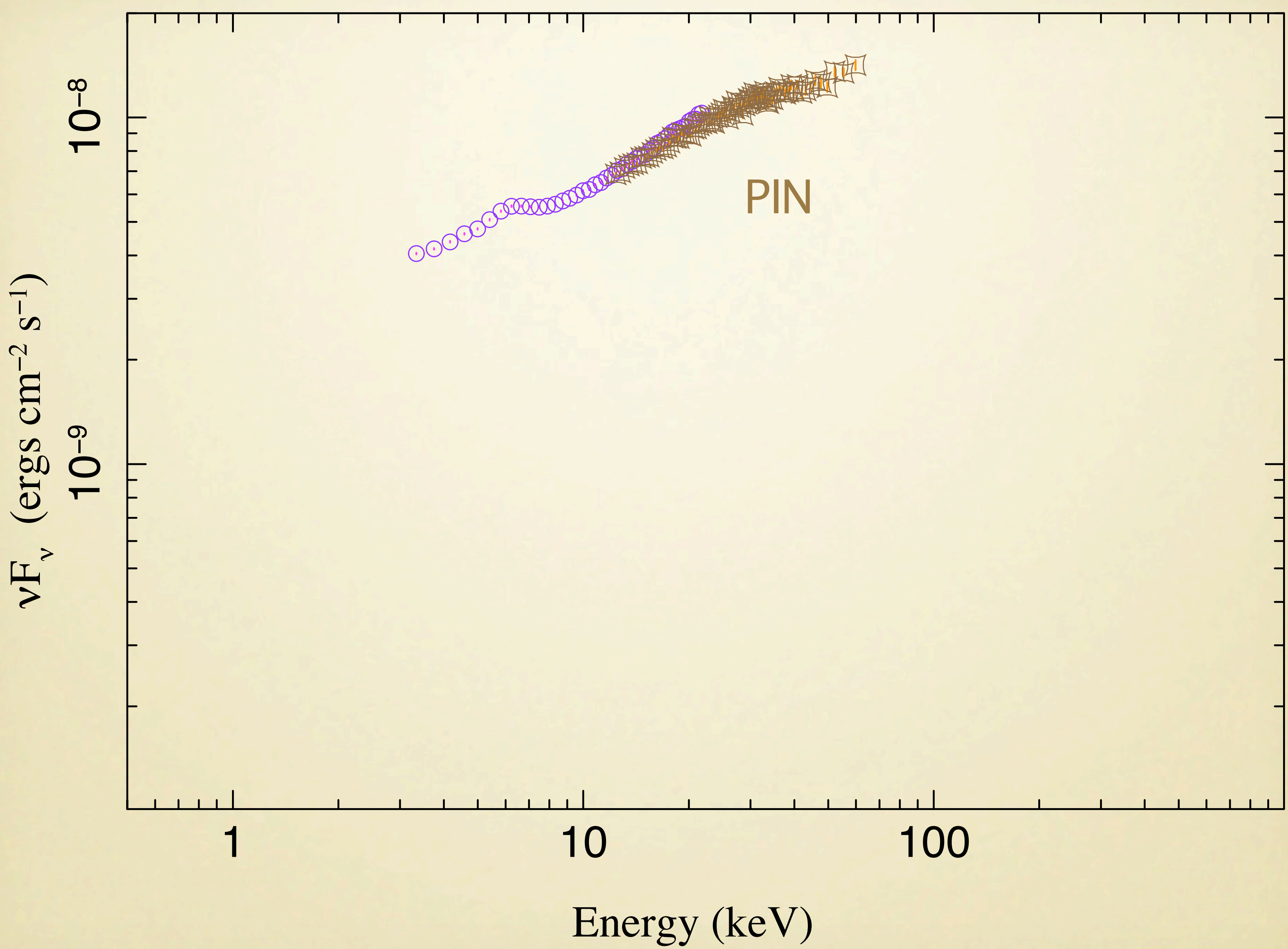
PCA
νFν (ergs cm⁻² s⁻¹)
10⁻⁸
10⁻⁹
1
10
100
Energy (keV)



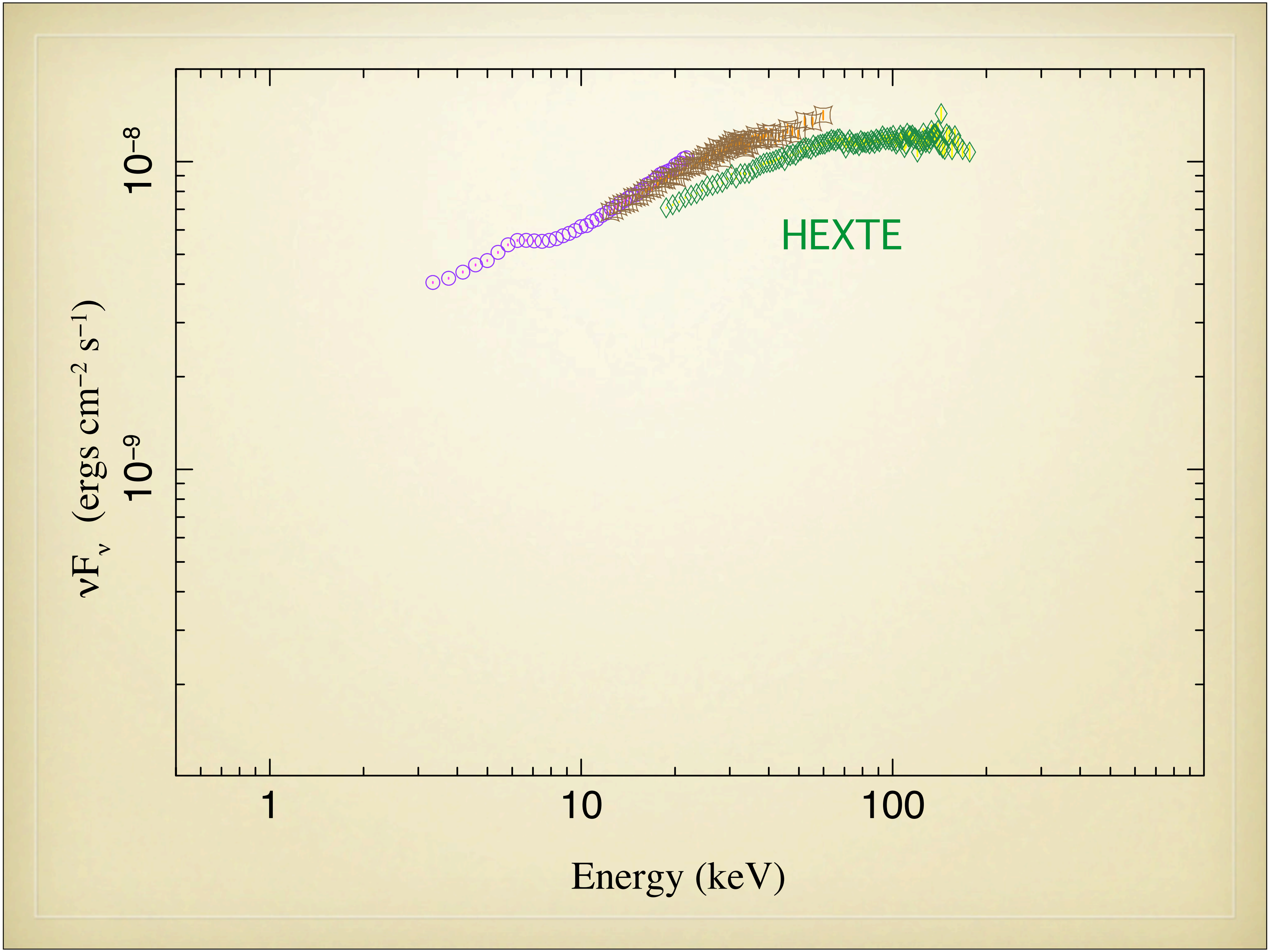
(Wilms et al. 2006, A&A, 447, 245)



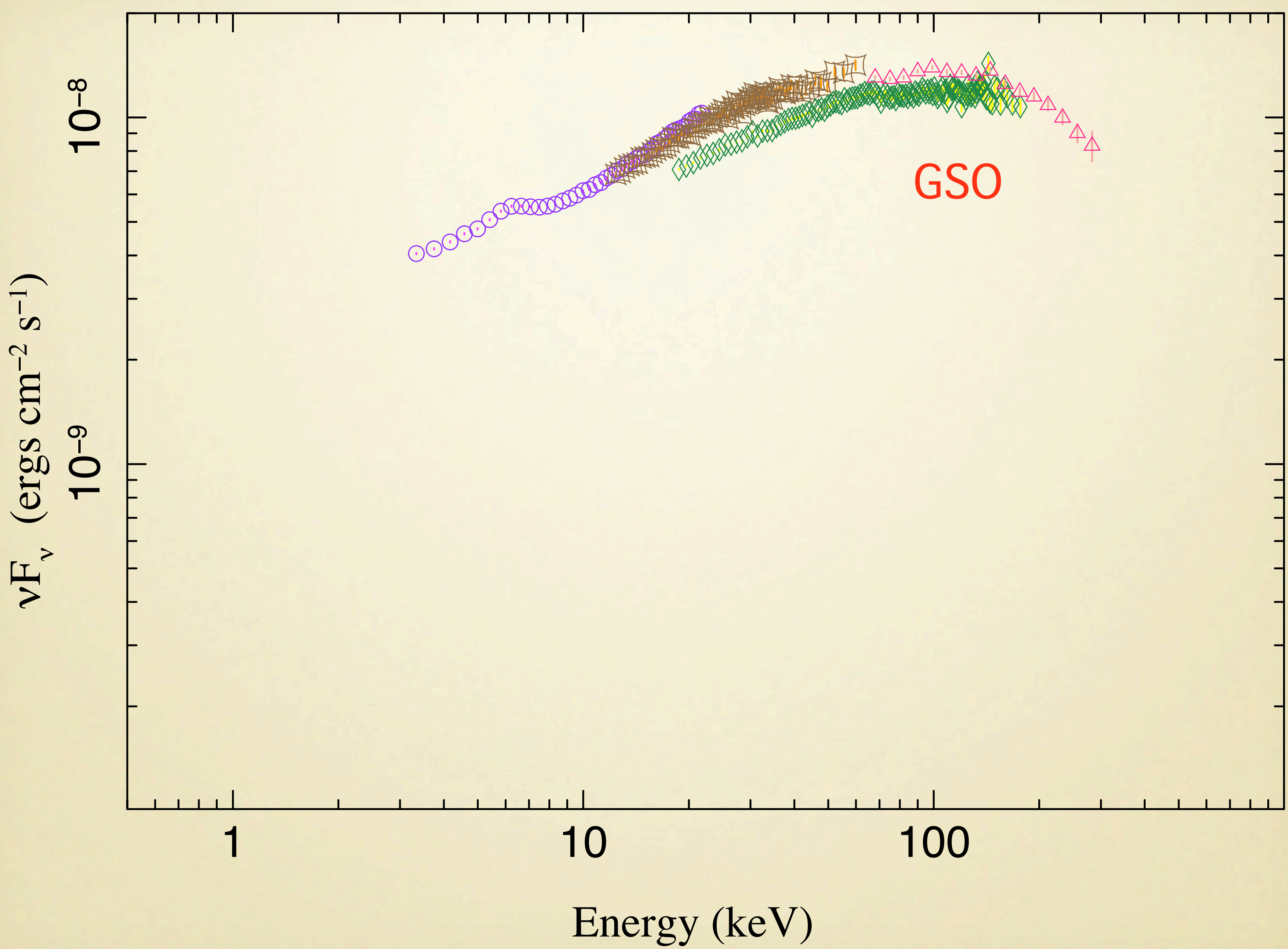
PCA
10^{-8}
10^{-9}
νF_ν (ergs cm^{-2} s^{-1})
1
10
100
Energy (keV)



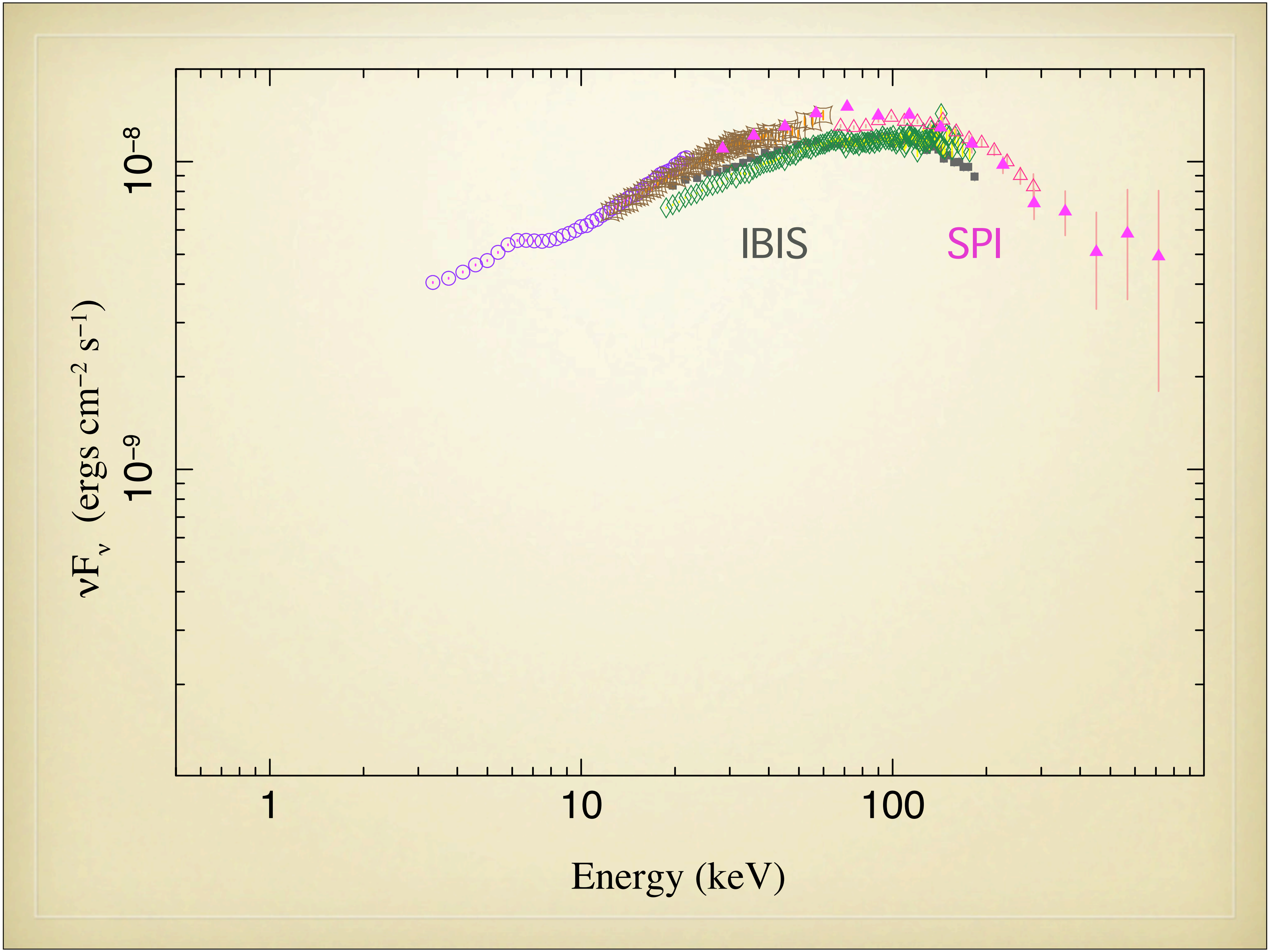
PIN
10^{-8}
10^{-9}
νF_ν (ergs cm^{-2} s^{-1})
1
10
100
Energy (keV)



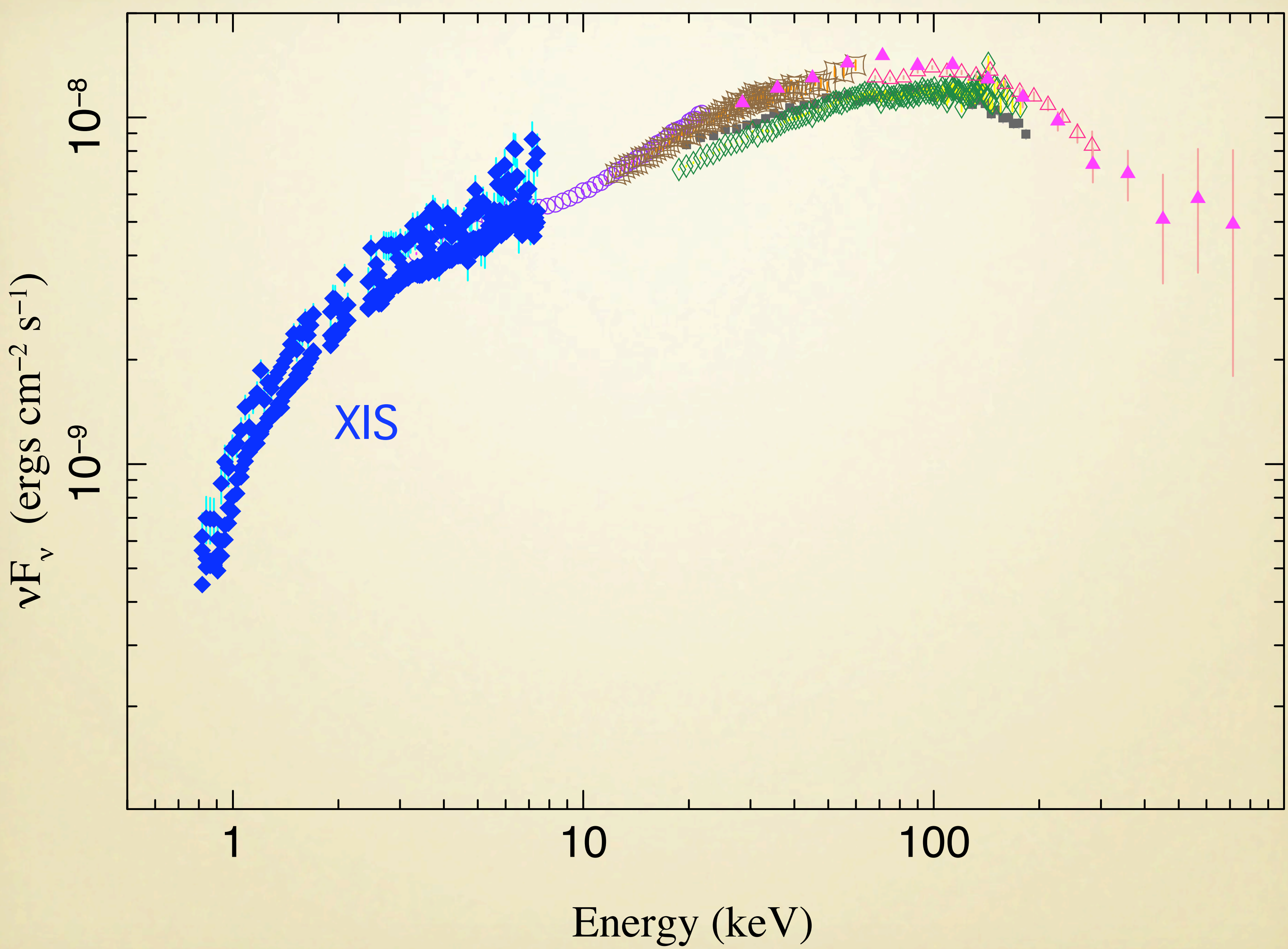
HEXTE
10^{-8}
10^{-9}
νF_ν (ergs cm^{-2} s^{-1})
1
10
100
Energy (keV)



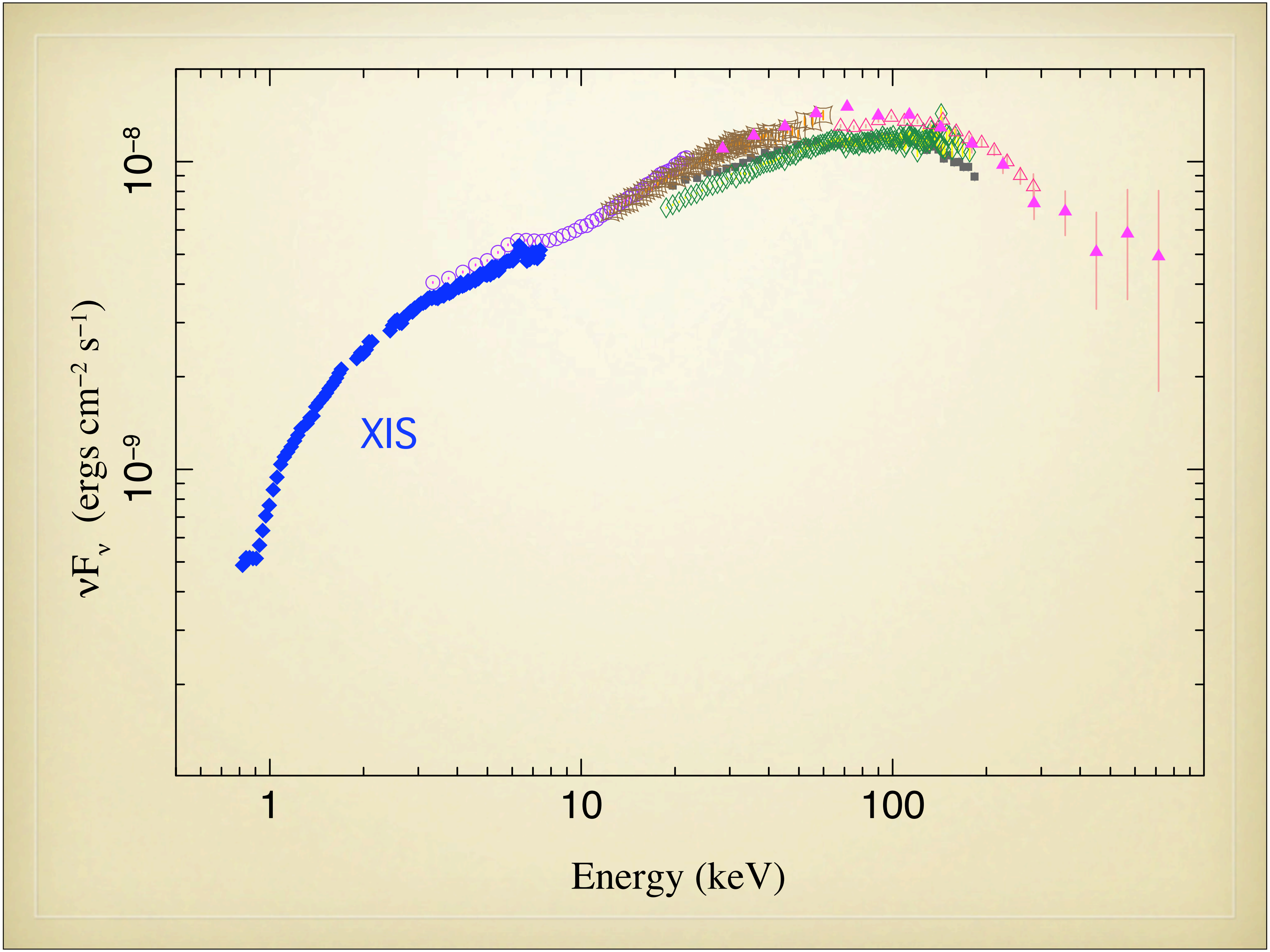
GSO
10^{-8}
10^{-9}
νF_ν (ergs cm^{-2} s^{-1})
1
10
100
Energy (keV)



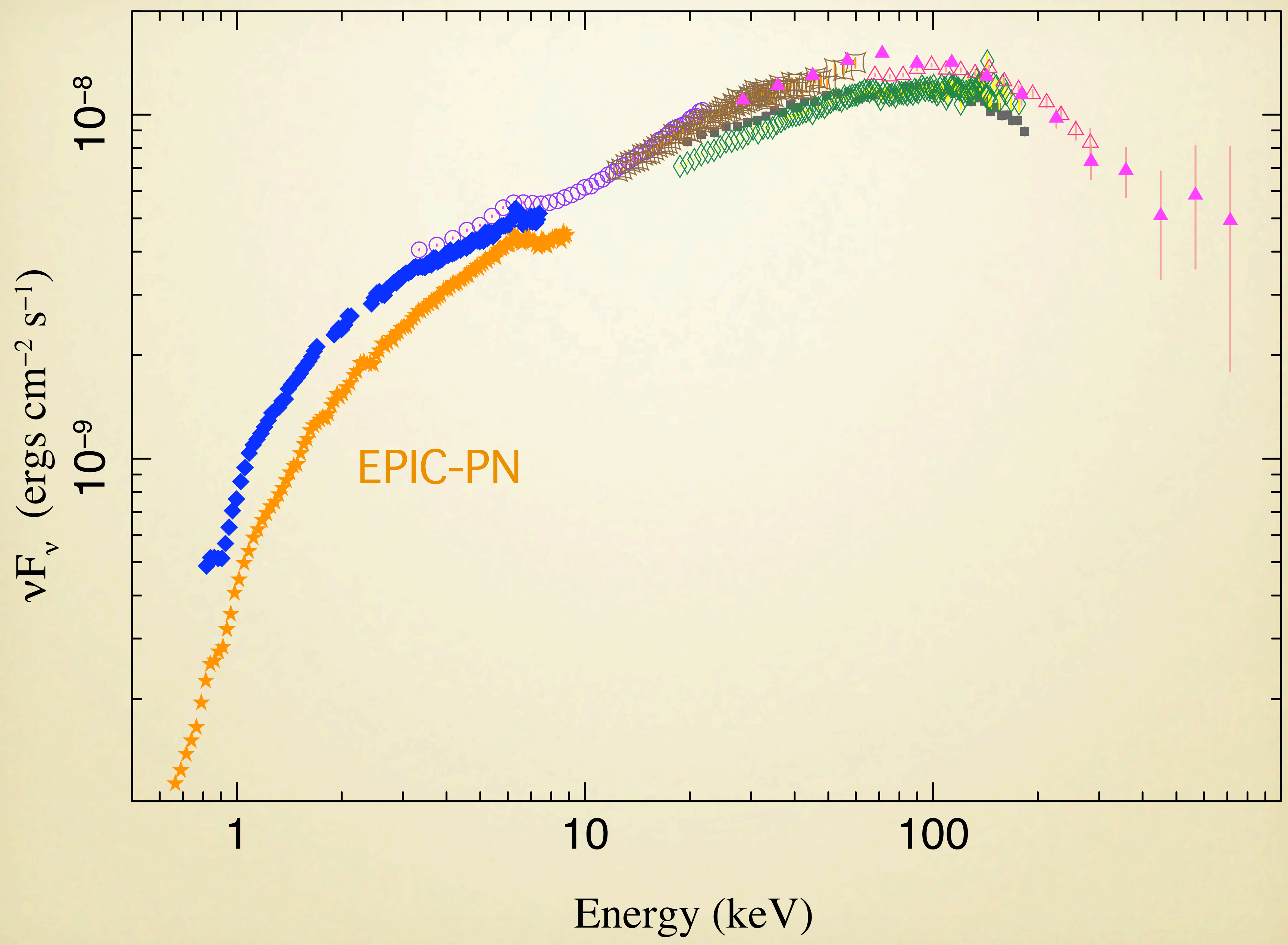
IBIS
SPI
10^{-8}
10^{-9}
νF_ν (ergs cm^{-2} s^{-1})
1
10
100
Energy (keV)



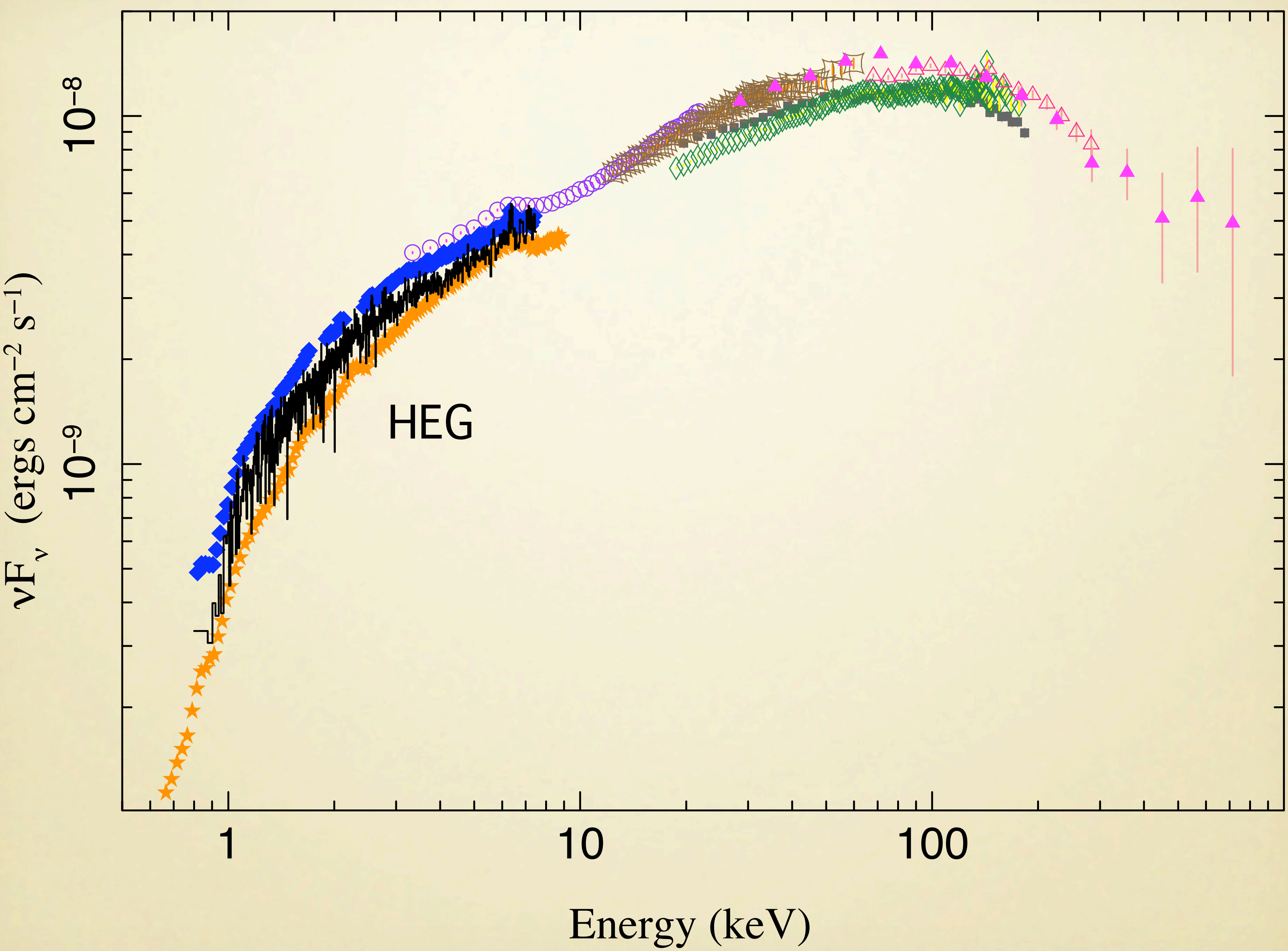
XIS
10−8
10−9
νFν (ergs cm−2 s−1)
1
10
100
Energy (keV)



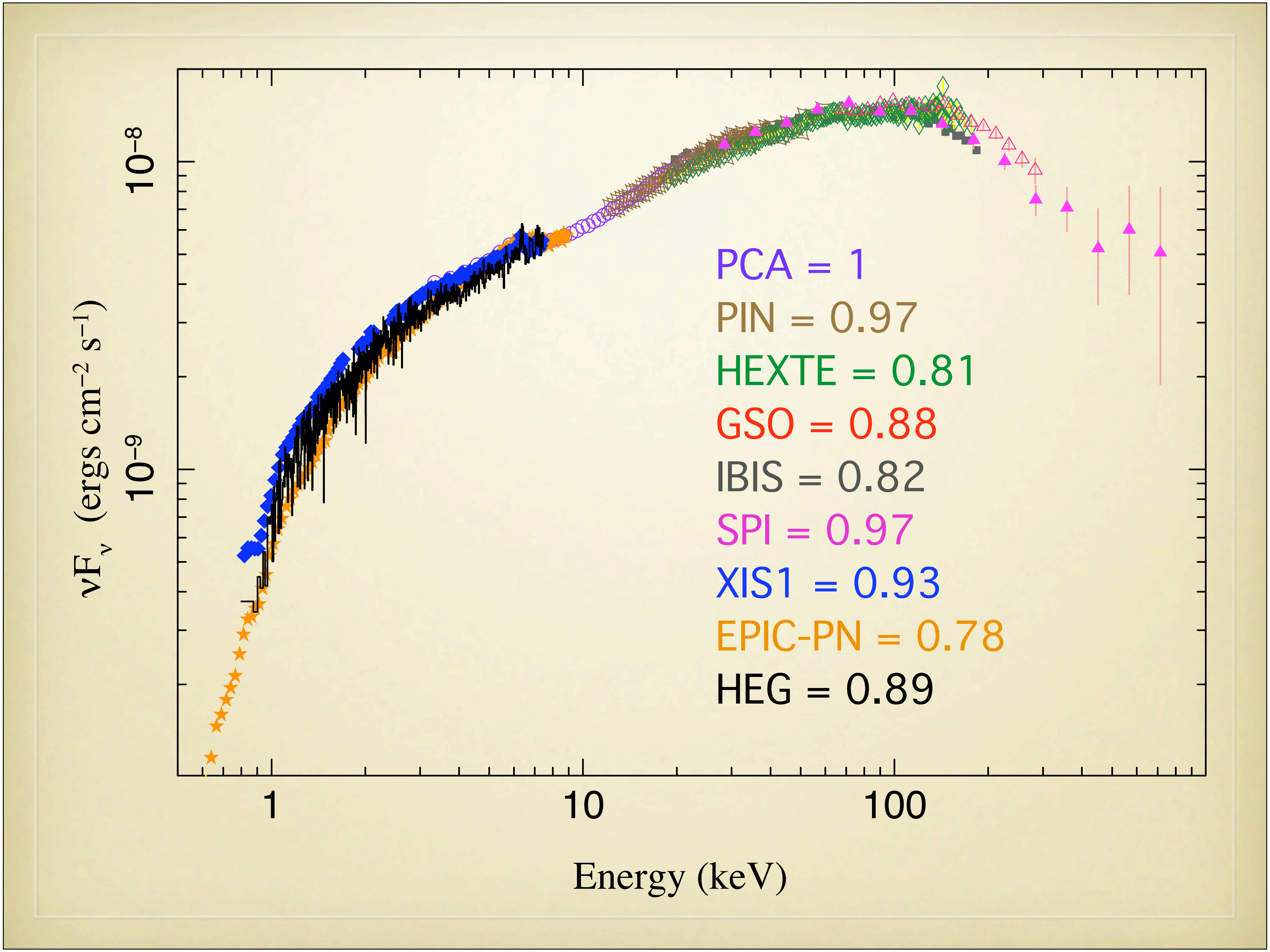
10^{-8}
10^{-9}
νF_ν (ergs cm^{-2} s^{-1})
XIS
1
10
100
Energy (keV)



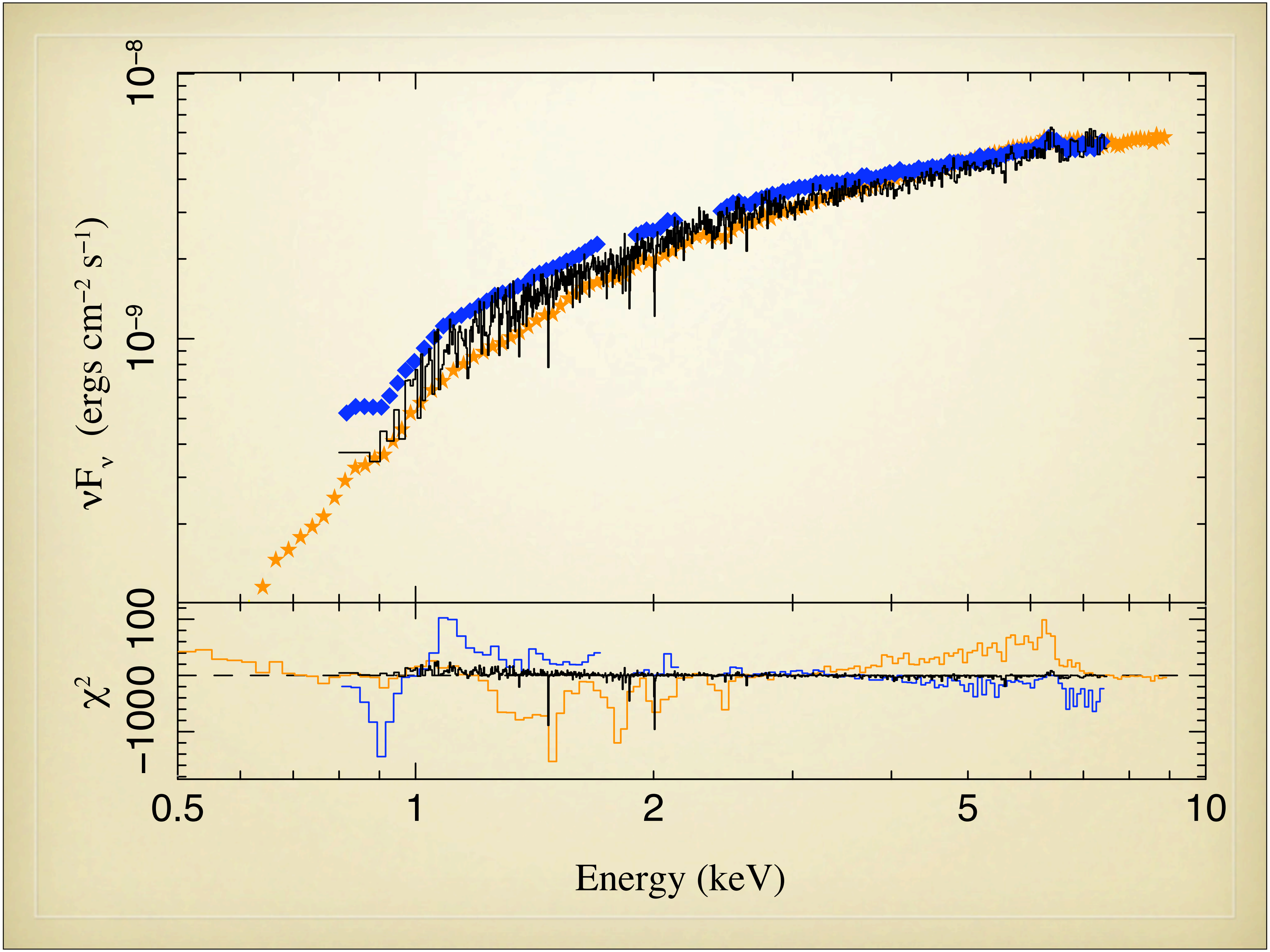
10^{-8}
10^{-9}
νF_ν (ergs cm^{-2} s^{-1})
EPIC-PN
1
10
100
Energy (keV)



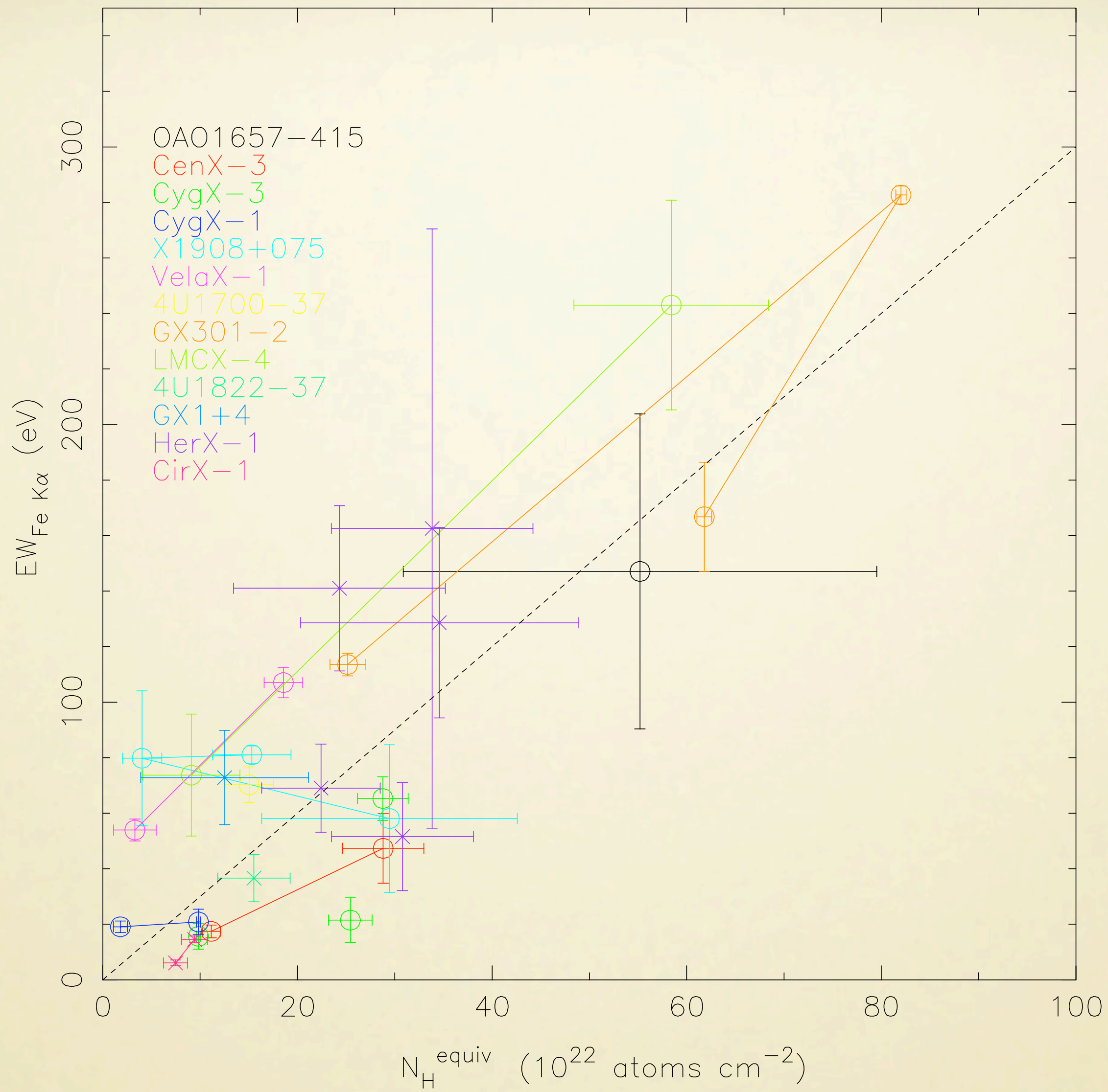
νF_ν (ergs cm^{-2} s^{-1})
10^{-8}
10^{-9}
HEG
1
10
100
Energy (keV)



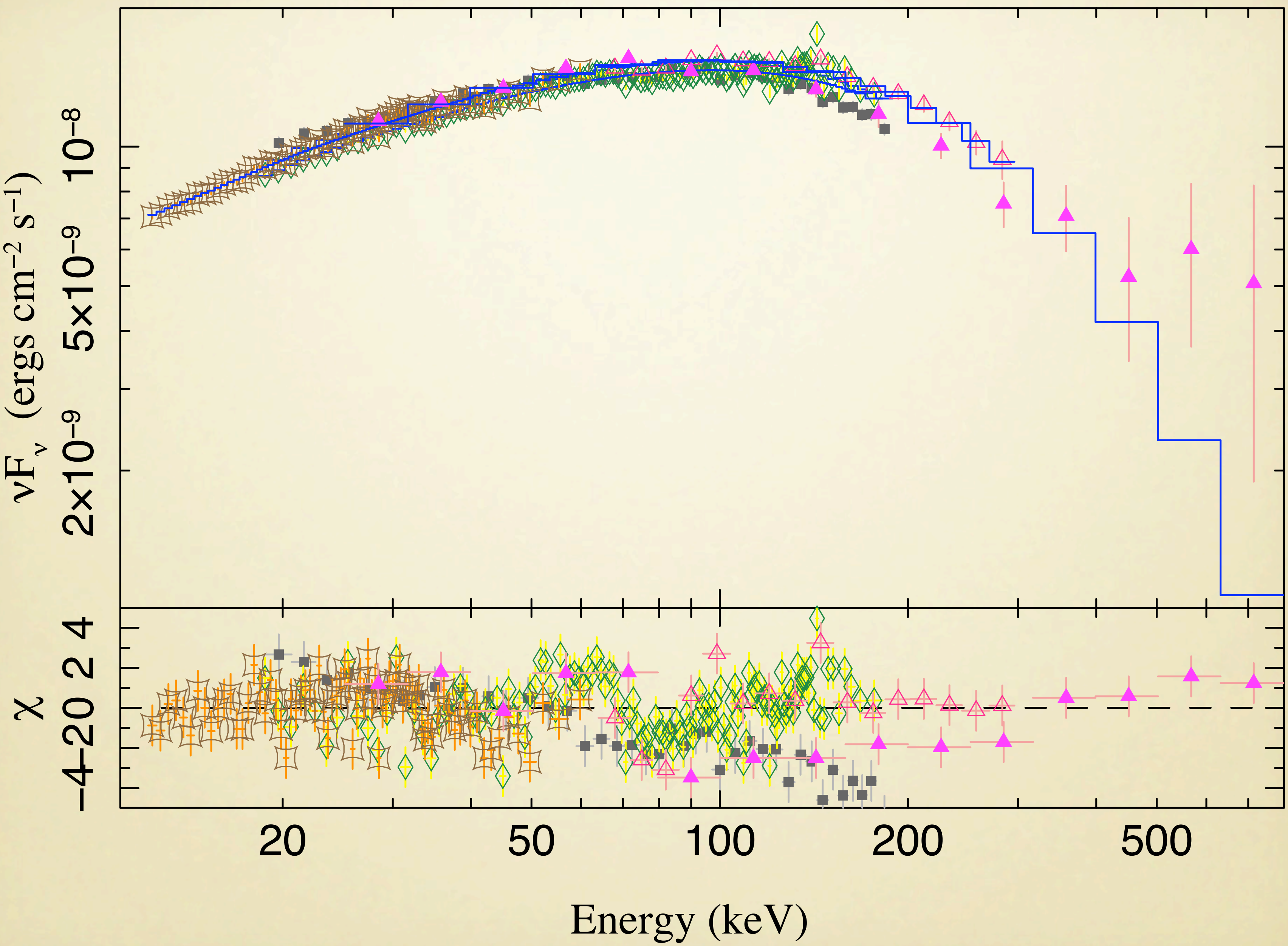
PCA = 1
PIN = 0.97
HEXTE = 0.81
GSO = 0.88
IBIS = 0.82
SPI = 0.97
XIS1 = 0.93
EPIC-PN = 0.78
HEG = 0.89
νF_ν (ergs cm^{-2} s^{-1})
10^{-8}
10^{-9}
1
10
100
Energy (keV)



10^{-8}
10^{-9}
νF_ν (ergs cm^{-2} s^{-1})
χ^2
100
0
−1000
0.5
1
2
5
10
Energy (keV)



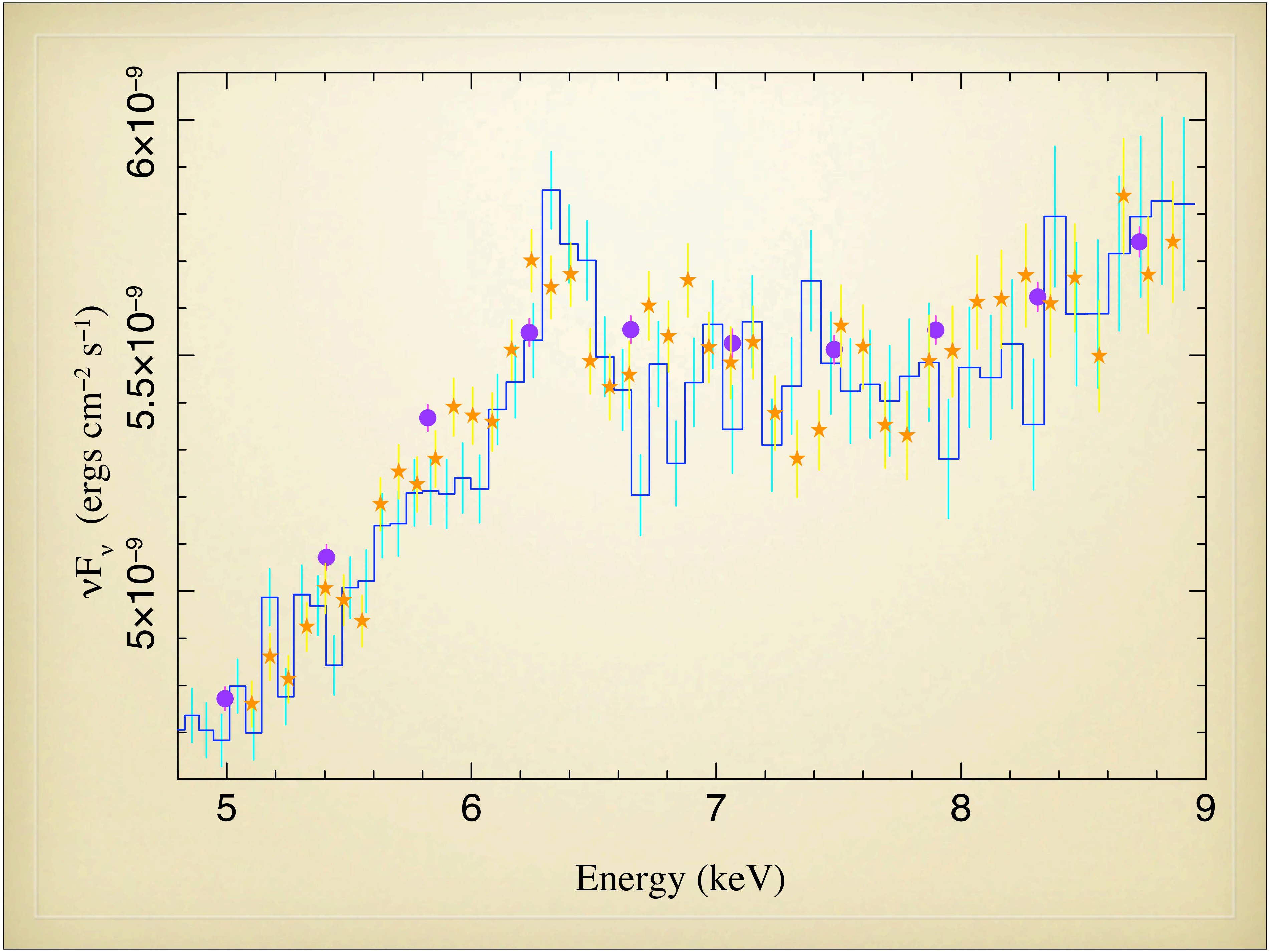
(Torrejon, Schulz, & Nowak 2010, ApJ, 715, 947)



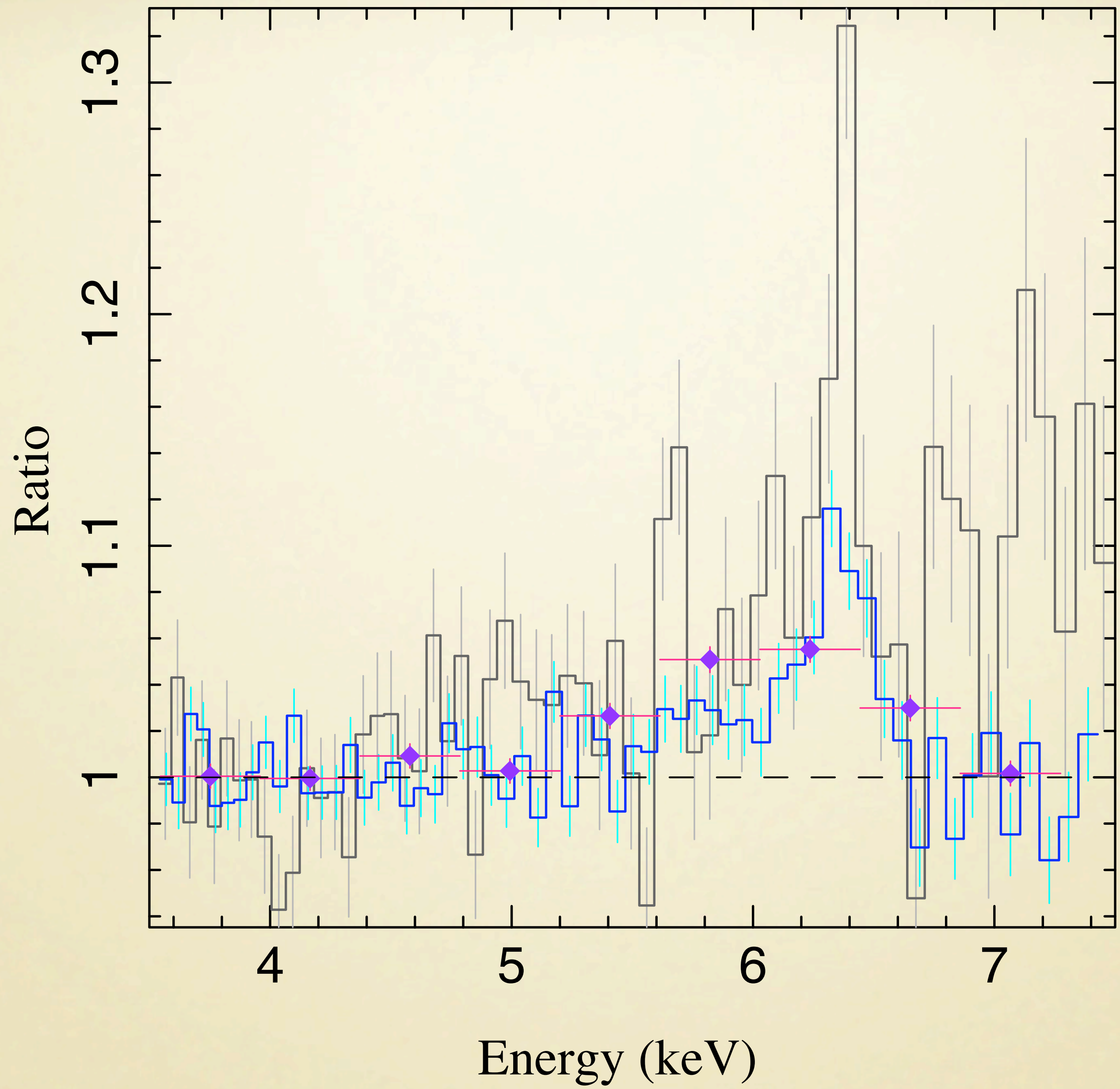
νF_ν (ergs cm⁻² s⁻¹)
10⁻⁸
5×10⁻⁹
2×10⁻⁹
χ
−4 −2 0 2 4
20
50
100
200
500
Energy (keV)

Hard Tails

- Observation Has an ~160 KeV Rollover
- "Characteristic" Corona Temperature?
- Cyg X-1 Ranges From 125-255 KeV
  - Generally, Harder = Higher, But A Great Deal Of Variation
- Well Measured BHC Cutoffs Range From ~50-300 KeV



νF_ν (ergs cm^{-2} s^{-1})
6×10⁻⁹
5.5×10⁻⁹
5×10⁻⁹
5
6
7
8
9
Energy (keV)

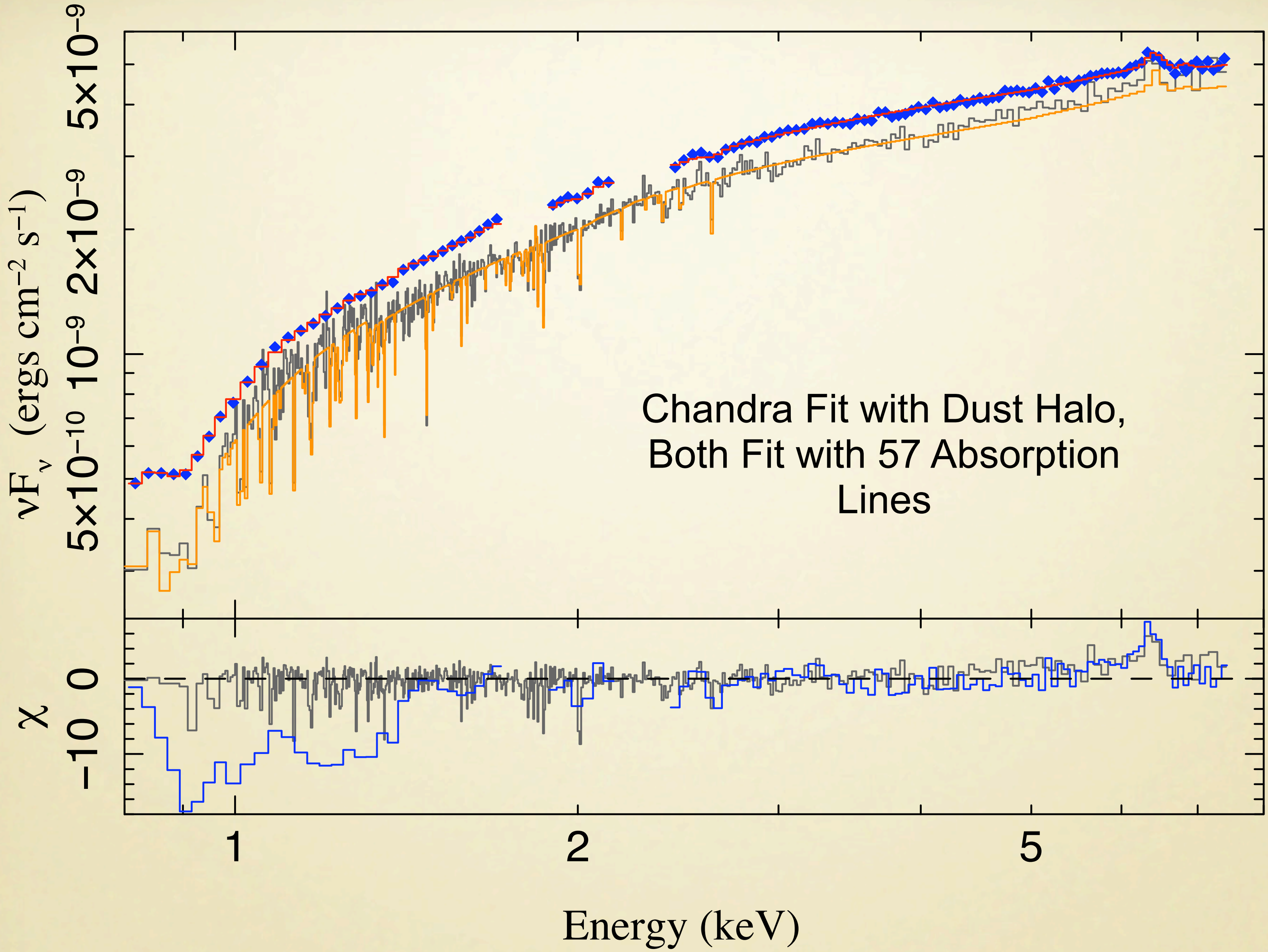

Ratio
1.3
1.2
1.1
1
4
5
6
7
Energy (keV)

Fitting Spectra:

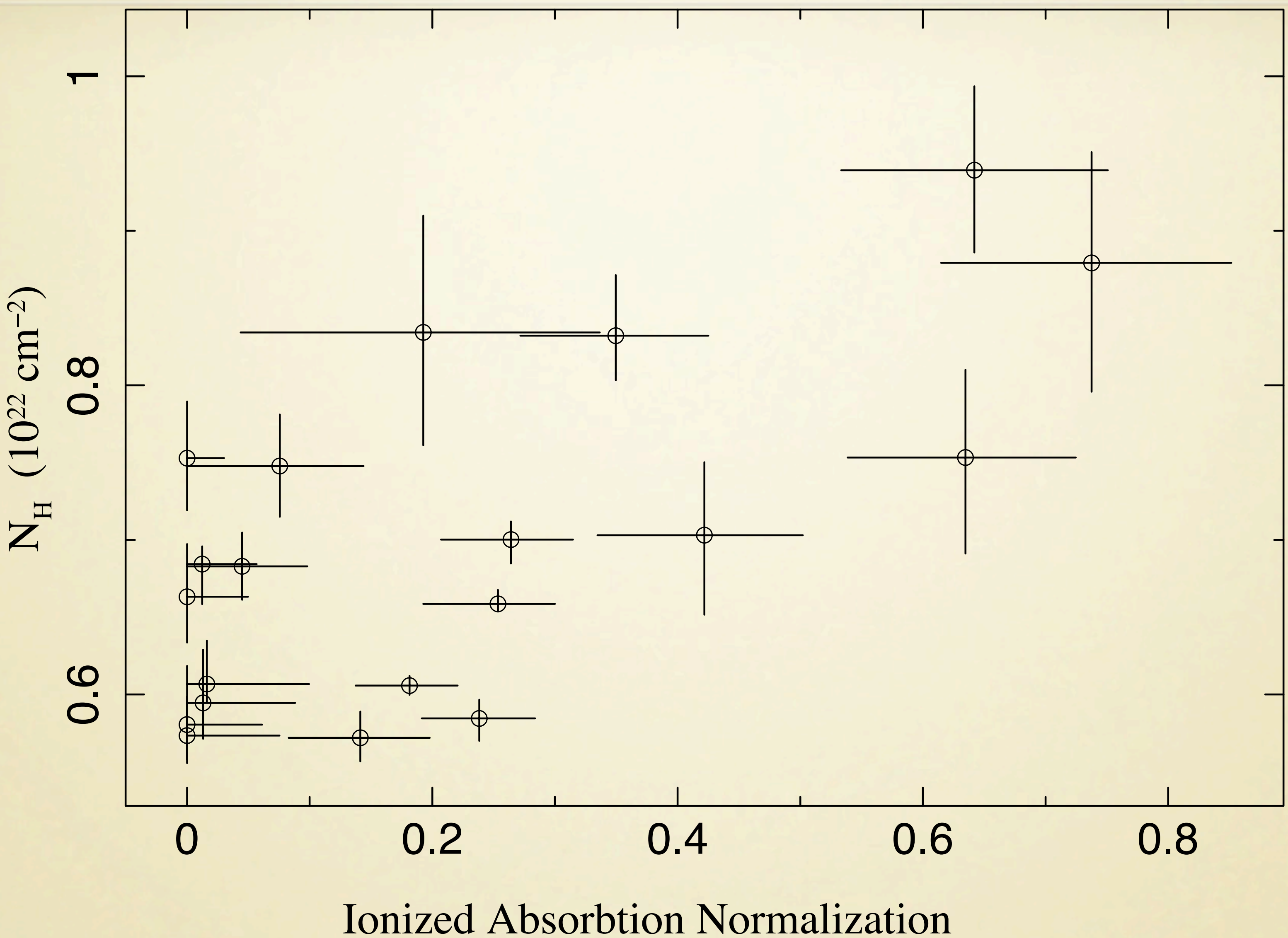
- Multiple RXTE/Suzaku Spectra, So We Restrict Ourselves To This Pair
- Use Chandra/Suzaku to Create Ionized Absorber Model
- Fit the 0.8-300 KeV Range With Four Spectral Models
    - Three Comptonization, One Jet
    - All Fit The Data Well

Side Note on Mechanics:

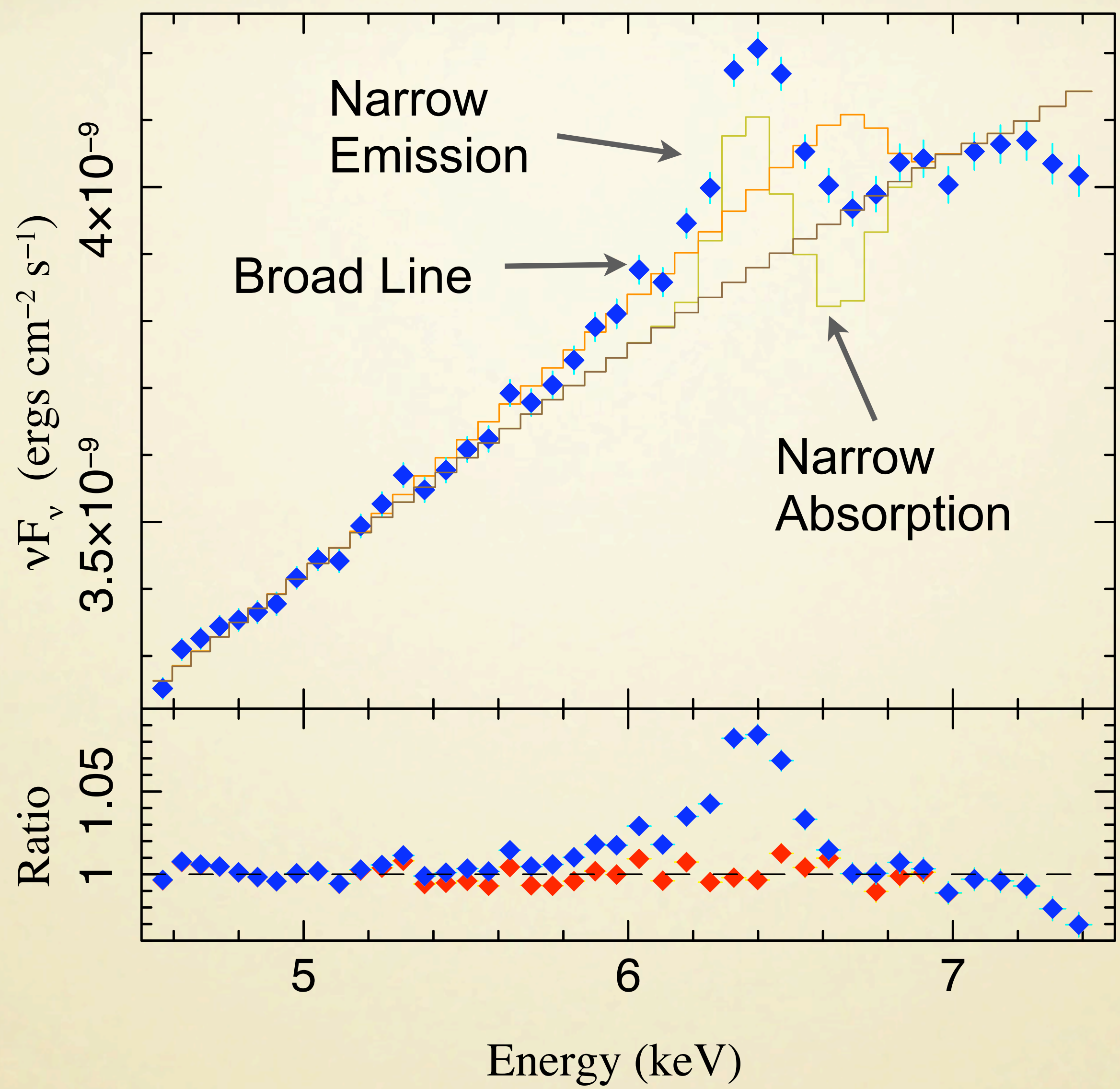
- Fitting Up to 11 Separate Spectra, With Very Expensive Models
- Interactive Spectral Interpretation System (ISIS) Speeds Up The Process
  - Cached Versions of Slow Models
  - Transparently Parallelized Fitting & Error Bar Searches
  - Factor of 40 Speed Up



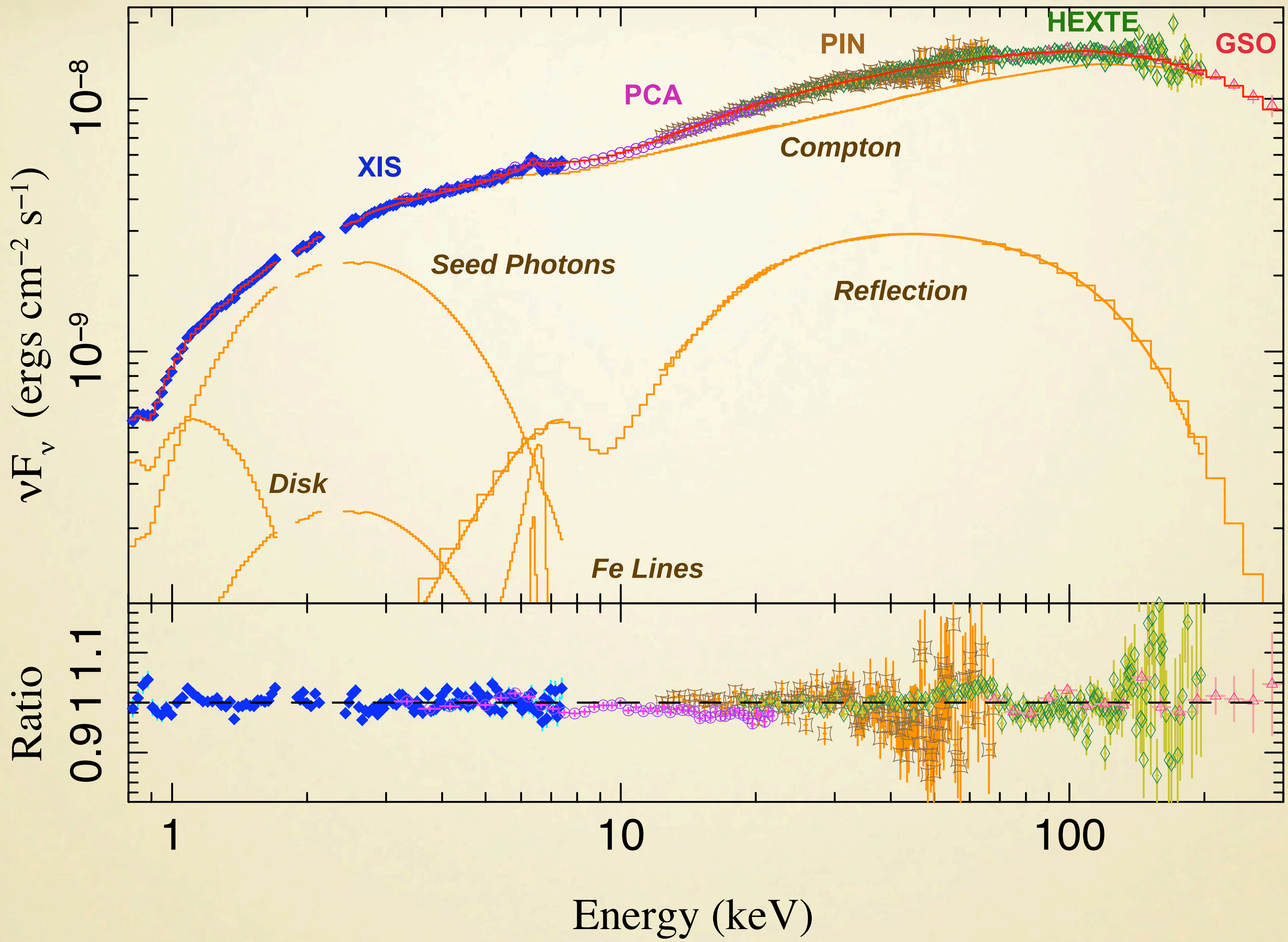
Chandra Fit with Dust Halo,
Both Fit with 57 Absorption
Lines
νF_ν (ergs cm⁻² s⁻¹)
χ
Energy (keV)



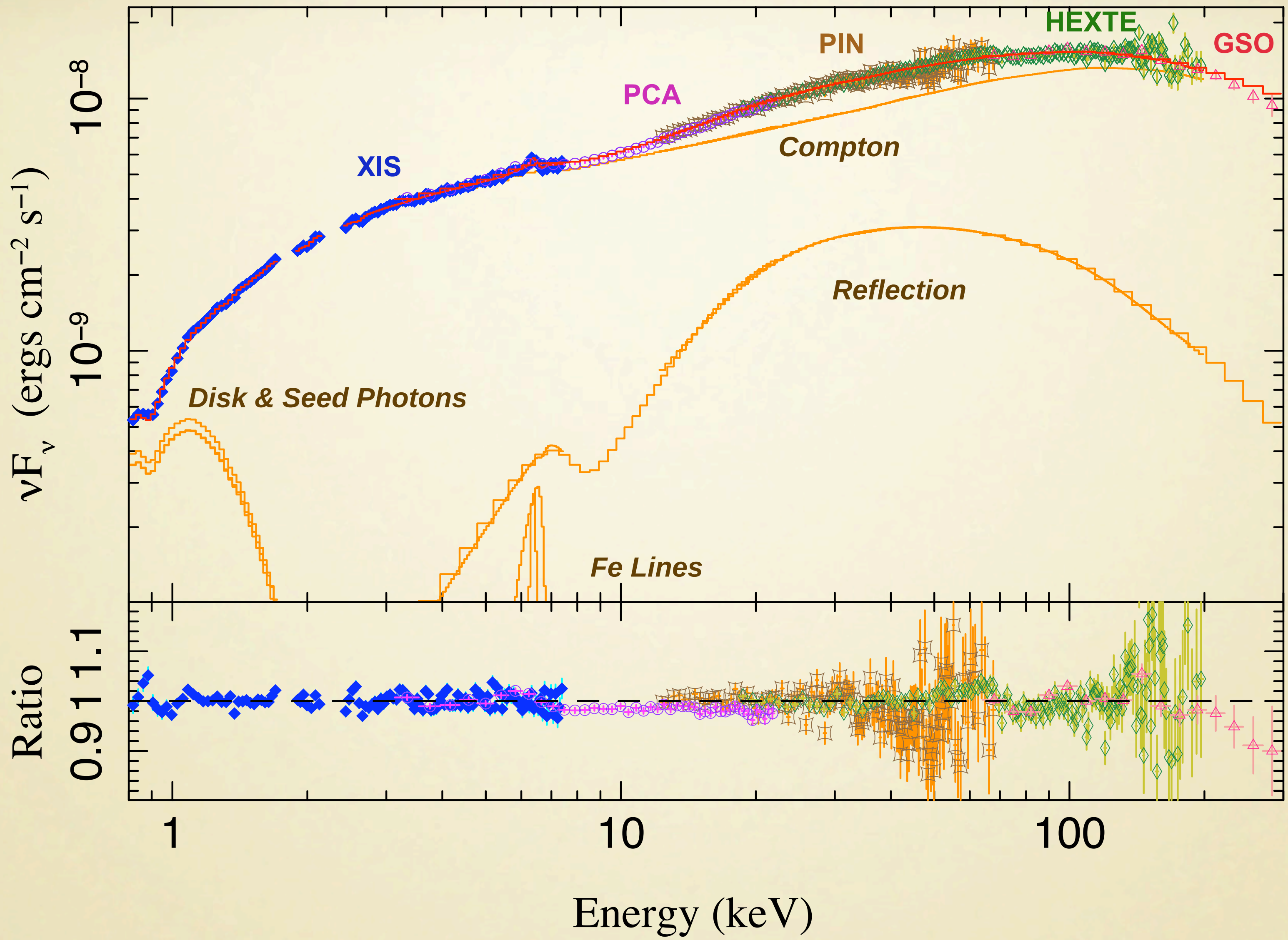
(Miller et al., In Preparation)



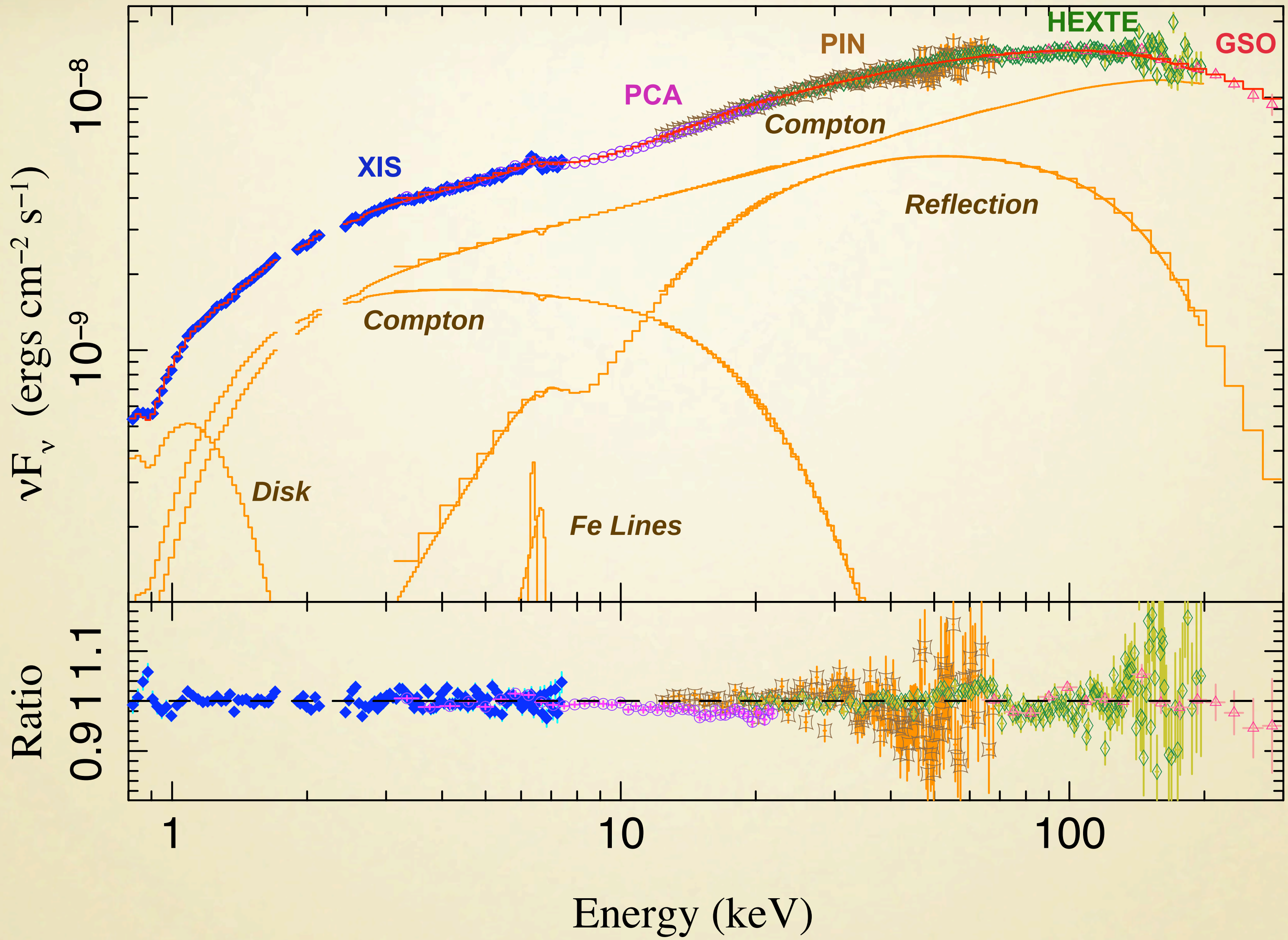
Narrow Emission
Broad Line
Narrow Absorption
νFν (ergs cm−2 s−1)
4×10−9
3.5×10−9
Ratio
1.05
1
5
6
7
Energy (keV)



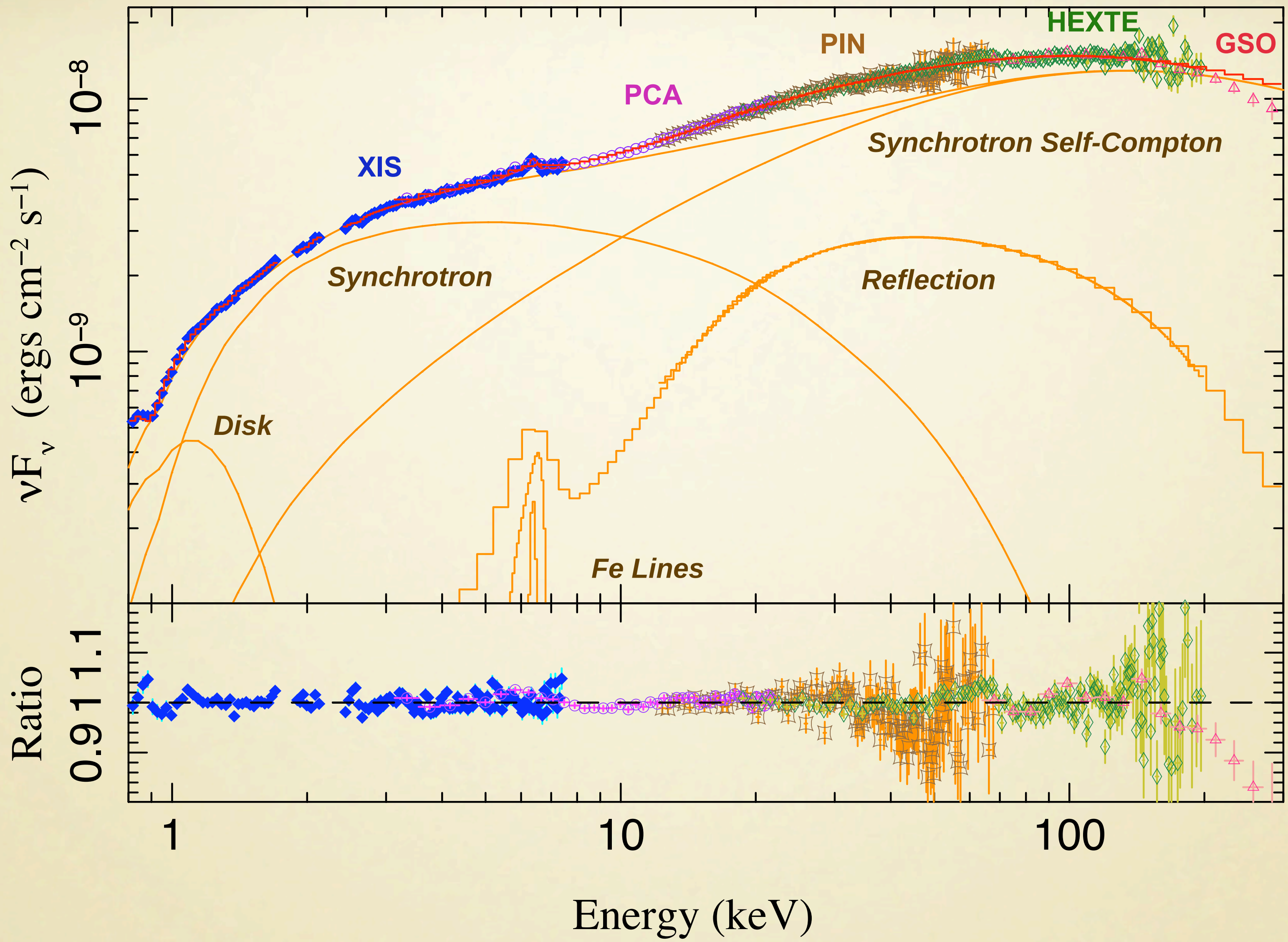
CASE 1: THERMAL CORONA, HIGH KT SEED PHOTONS



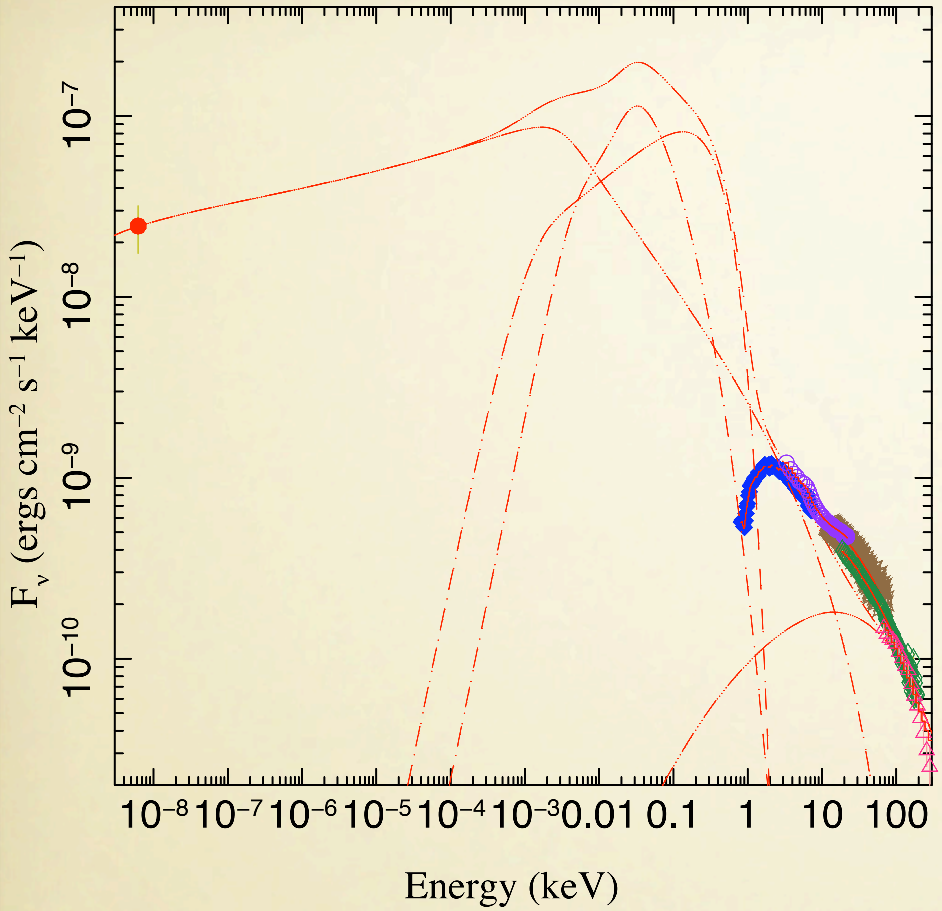
CASE 2: NON-THERMAL CORONA, LOW KT SEED PHOTONS



CASE 3: DOUBLE (PATCHY?) THERMAL CORONA, LOW KT SEED PHOTONS



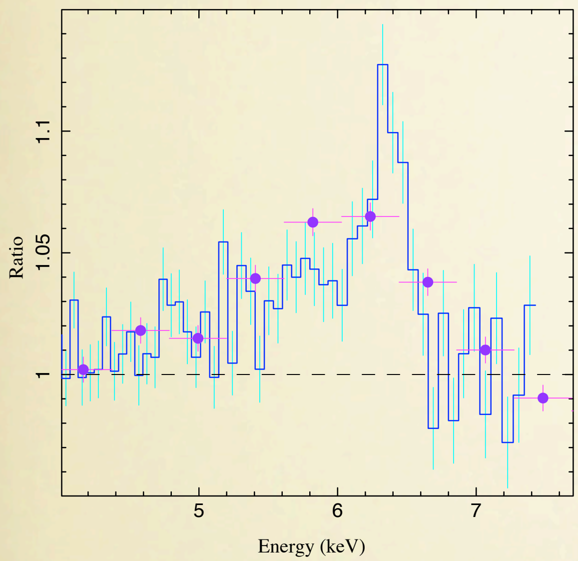
CASE 4: JET MODEL



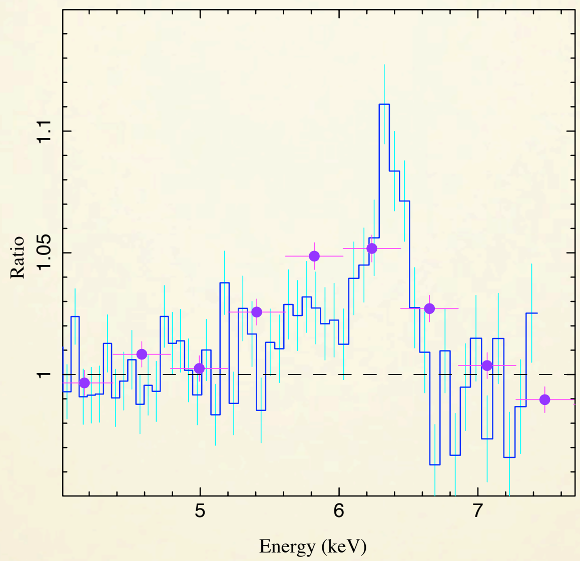
- Jets Also Fit The Radio Spectra
- But Do Not Yet Have Self-Consistent Pair Production & Cooling
- Models Are Under Development to Address This Issue

CASE 4: Jet Model

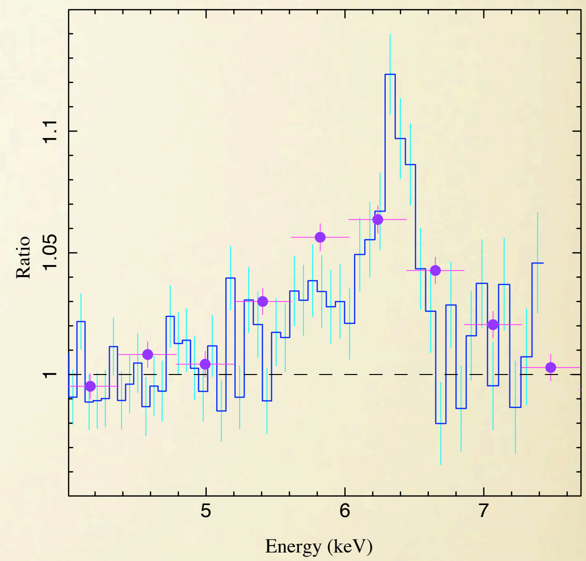
Thermal Corona | **Non-Thermal Corona** | **Jet Model**



$R_{in} \sim 6\ GM/c^2$



$R_{in} \sim 36\ GM/c^2$



$R_{in} \sim 29\ GM/c^2$

Equivalent Widths Span A Factor of Two

The Takeaway:

- Reasonably Good Consistency Among Satellite Spectra
- One **Must** Take Account of Both the Dust Halo & The Ionized Absorption
- A Variety of Models Fit The Data Equally Well
- **All** Agree That The Observed Spectral Break Is **More Than Just Reflection**
    - "Extra" Soft Component, **In Addition To Low KT Disk**

The Takeaway:

- There Is A Broadened Fe Line
- Parameters Are Continuum Dependent
  - But Always Relativistic