Probing Accretion and Circumnuclear Material in AGN

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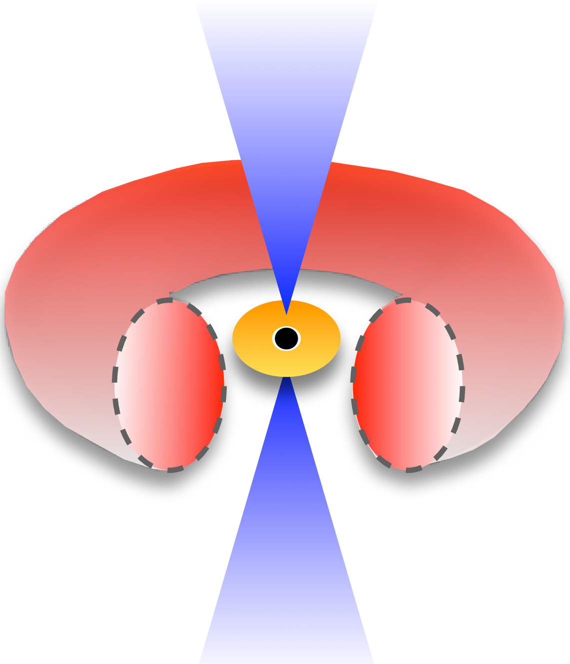
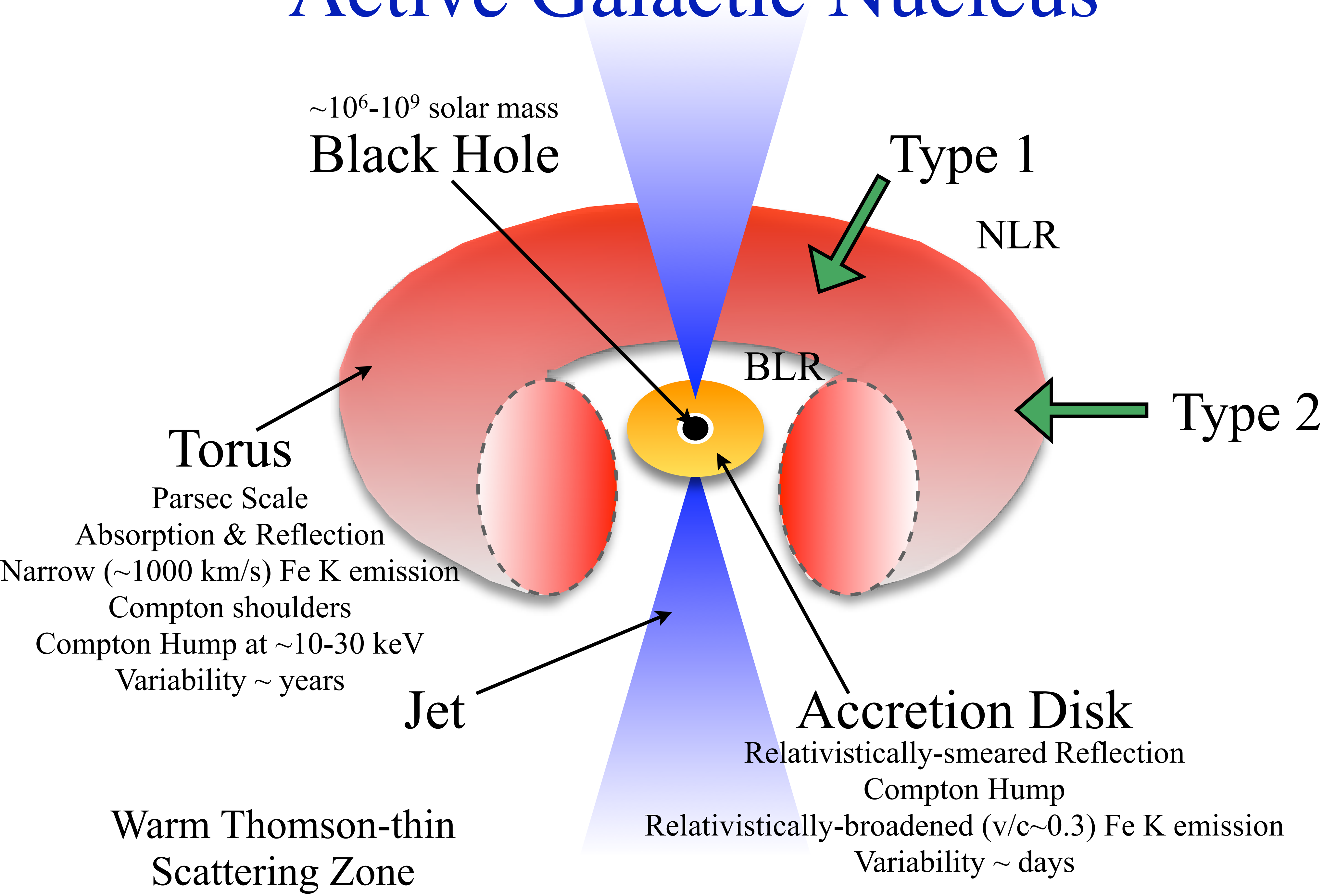
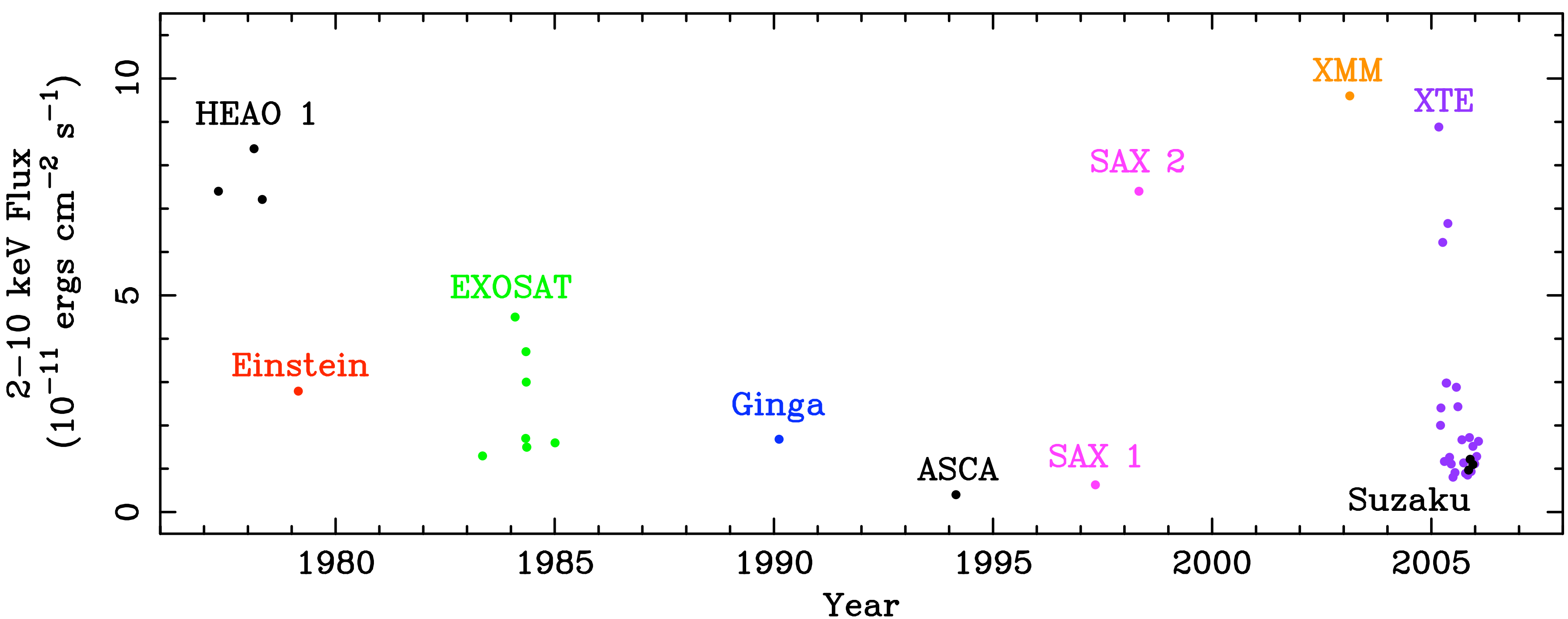


Active Galactic Nucleus



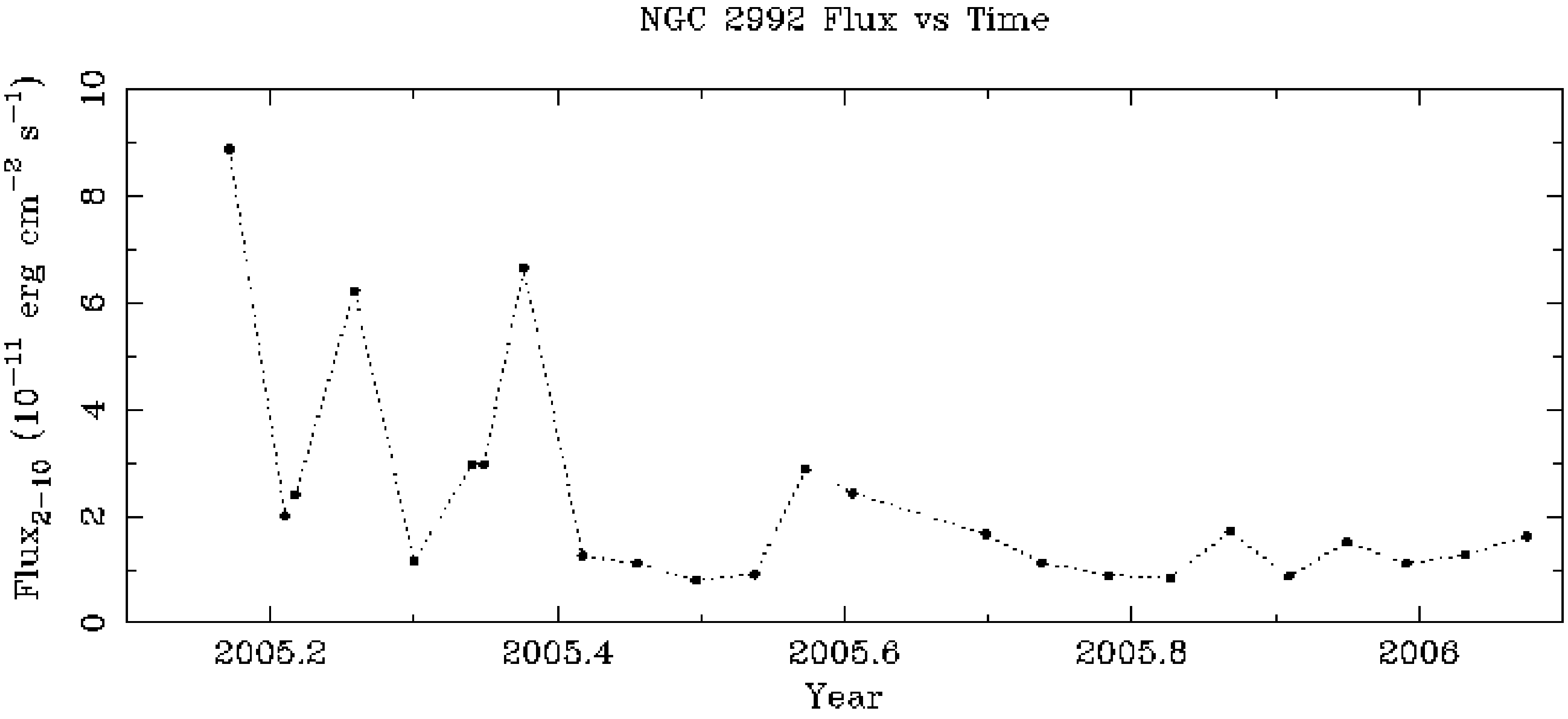
Seyfert Galaxy NGC 2992

- This relatively nearby (z = 0.00771) source was first detected by HEAO-1 in 1977 and has subsequently been observed by nearly every X-ray mission to date.
- The continuum flux varied by a factor of ~20 in past 30 years, accompanied by complex variability in the Fe Kα line complex.
  - The variability was believed to be a result of concluded quenching and revival of accretion (Gilli et al. 2000).
  - In the low state, the source exhibited properties of a type 2 AGN; however, in the high state it exhibited properties that are more consistent with a type 1 object.



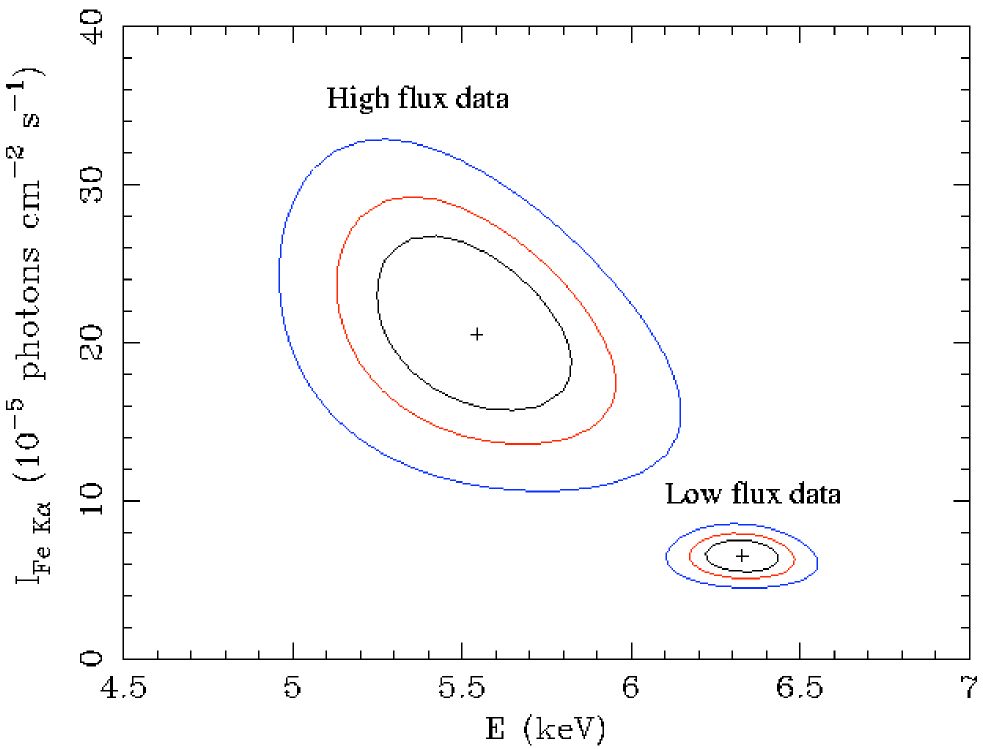
NGC 2992: *RXTE*

- NGC 2992 was monitored for 1 year with the RXTE PCA (March 2005 - January 2006).
- A total of 24 observations were obtained.
- The 2-10 keV continuum flux varied by a factor of ~10 on *short timescales* (on the order of days to weeks).
  - The measured continuum flux covered nearly the entire historical range, making it unlikely that the variation is due to the accretion mechanism switching on and off.



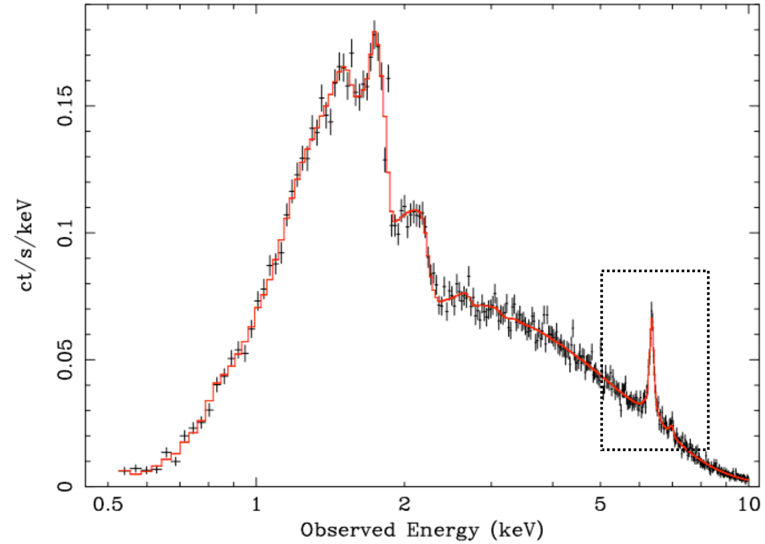
NGC 2992: *RXTE*

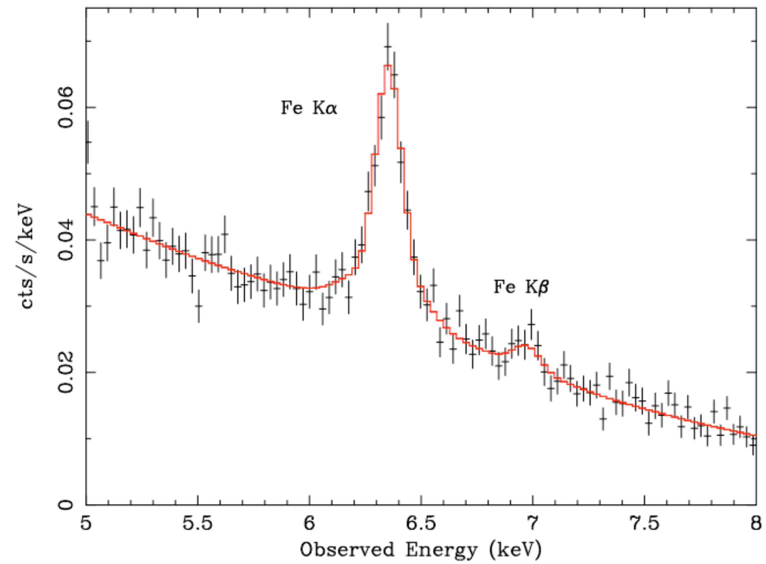
- Fe Kα line emission was detected in most of the 24 RXTE observations.
- However, the intensity of the Fe Kα line did not vary as dramatically as the continuum flux.
- During the **non-flaring** periods, the line peaked at ~6.4 keV.
- *But*, while the source was in the **high-flux** state, a highly red-shifted (~5.6 keV), broadened line dominated.
    - This may be evidence that the broad line is due to localized flaring in the inner accretion disk!



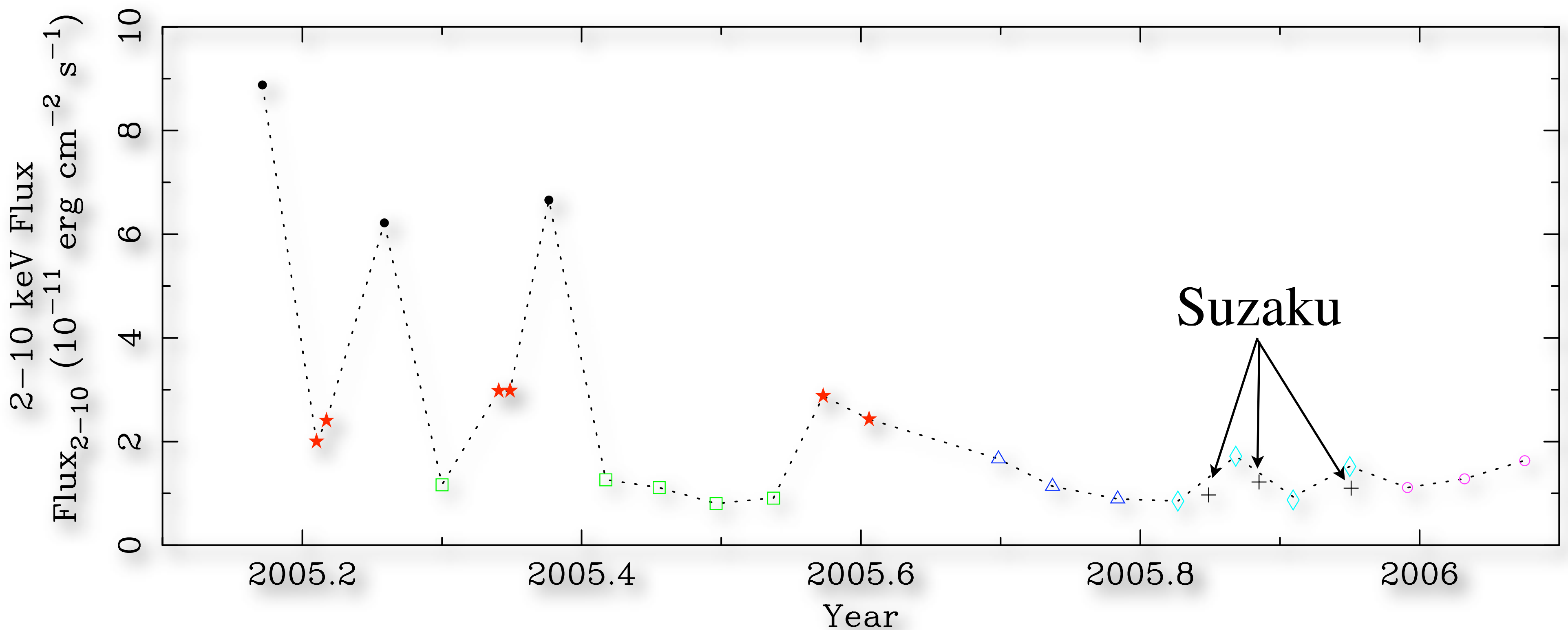
NGC 2992: *Suzaku*

- Three observations of NGC 2992 were made with the Suzaku XIS that were *quasi-simultaneous with the low-state RXTE observations* (November - December 2005).
- Suzaku detected both Fe Kα *and* Fe Kβ emission lines.
  - Kβ is much more sensitive to the ionization state than Kα and **we determined that the predominant ionization state of Fe in the distant matter is less than Fe VIII**.
  - **Both broad and narrow components of the Fe Kα emission line were detected**, implying that there is persistent line emission from both the accretion disk and from more distant matter (i.e. from the putative obscuring torus).





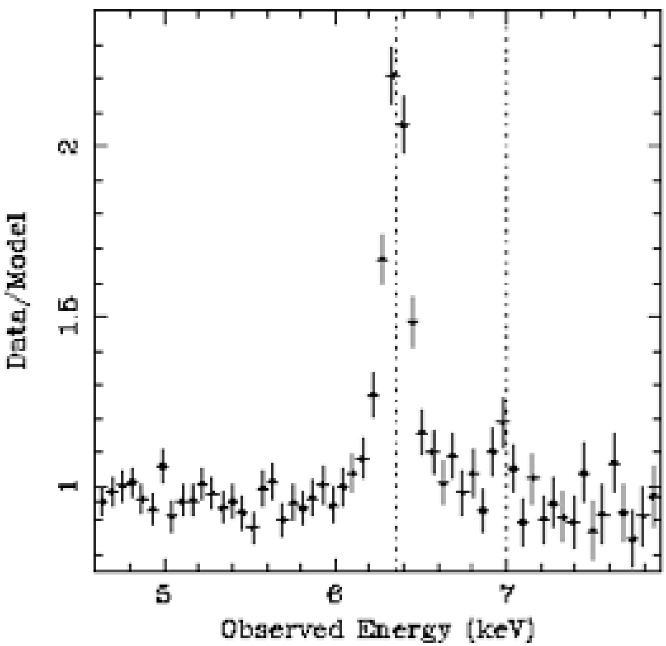
NGC 2992 Lightcurve: *RXTE & Suzaku*



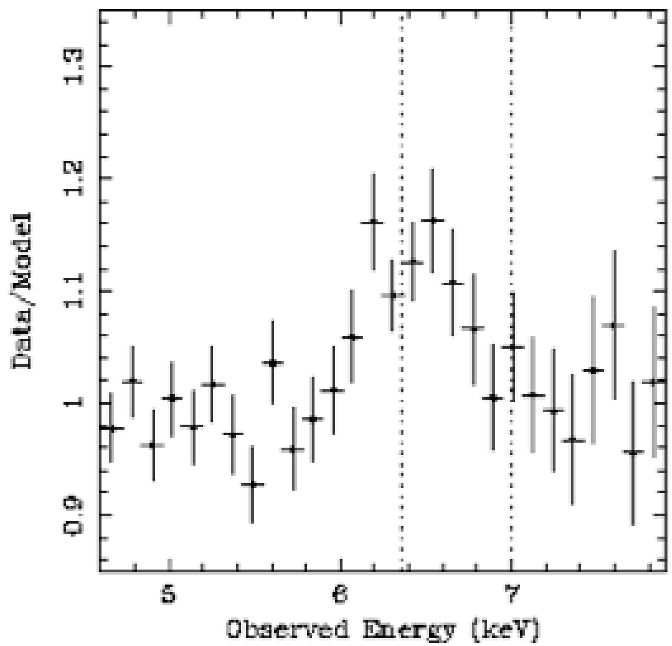
NGC 2992: *Suzaku*

- Modeling the narrow core of the Fe Kα emission revealed a broad base to the line complex.
- *The broad and narrow components of Fe Kα were decoupled* (with a confidence level of > 3σ) in this source *for the first time* with the XIS data.
- Decoupling the line is rarely possible with other sources.

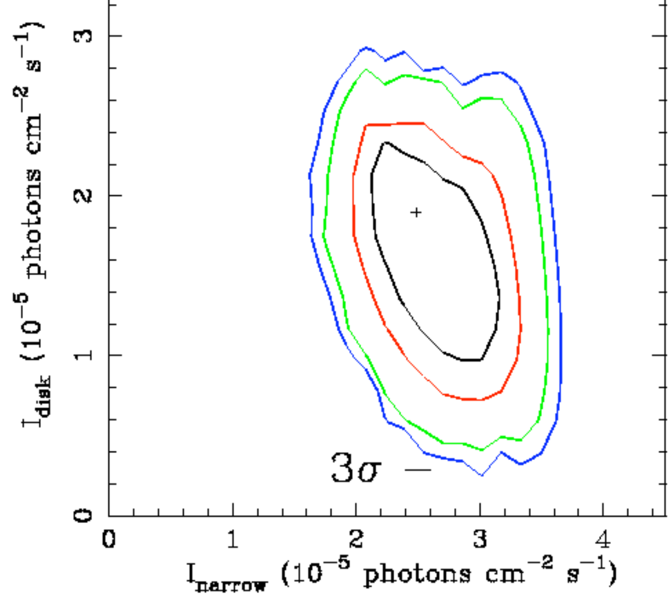
Narrow + Broad Fe Kα and Fe Kβ



Broad Fe Kα residual

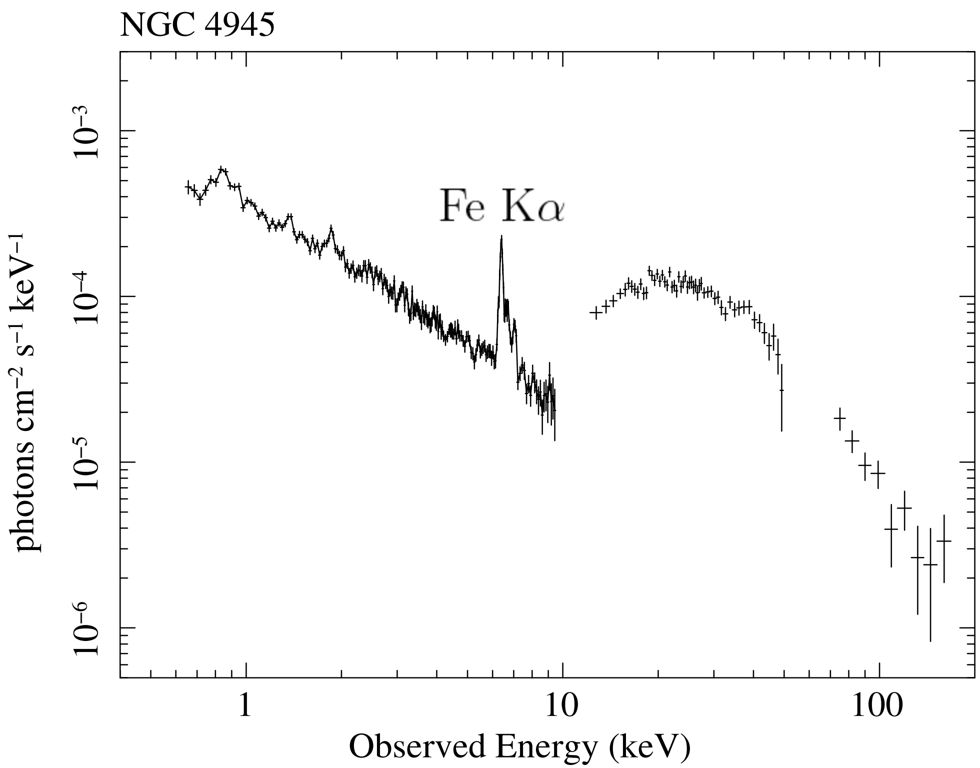


Confidence contours for the broad vs. narrow Fe Kα emission lines

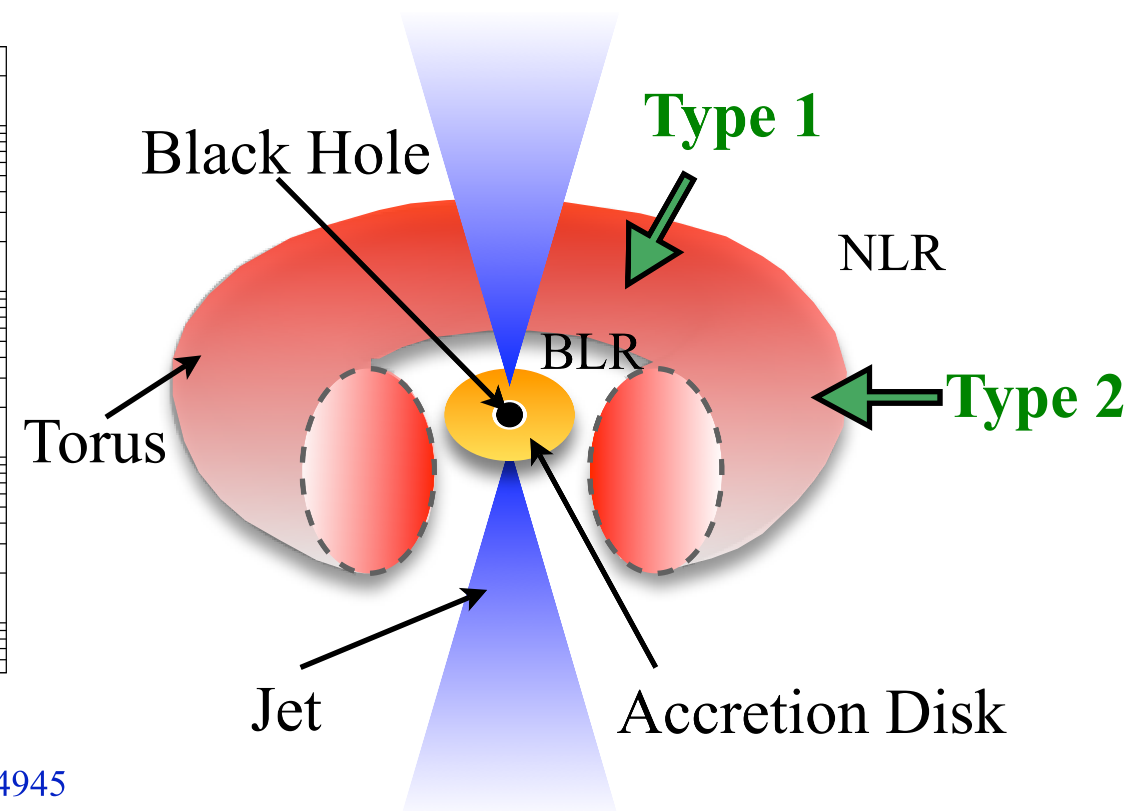


A New Toroidal Reprocessor Model

- The reprocessor (putative torus) absorbs and transmits and/or reflects high energy radiation from the source, affecting the observed spectra of:
  - **Type 2 AGN (Compton-thick *or* -thin)**: line of sight passes through reprocessor and signatures of transmission and scattering are present in the spectrum.
  - **Type 1 AGN**: observed spectrum may have Compton reflection signatures.
- Photoelectric absorption + Compton down-scattering produces the so-called "Compton hump" at ~10-30 keV and Compton shoulders on emission lines.

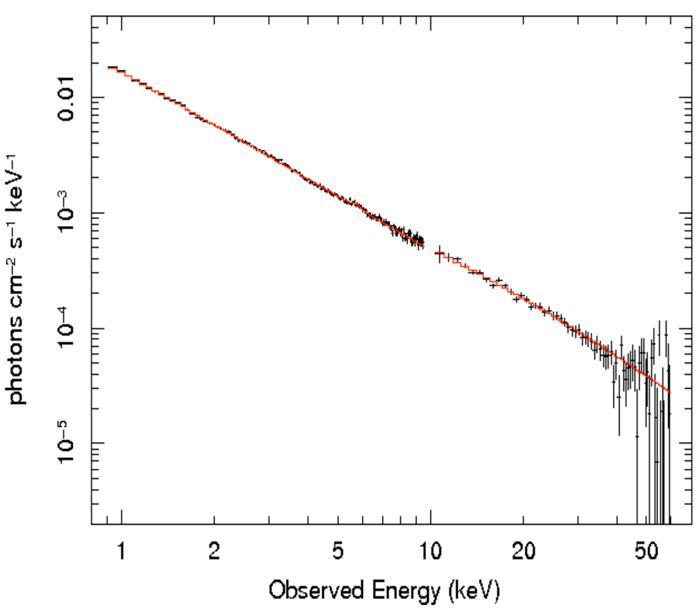


X-ray/γ-ray spectrum of Compton-thick, Type 2 AGN NGC 4945

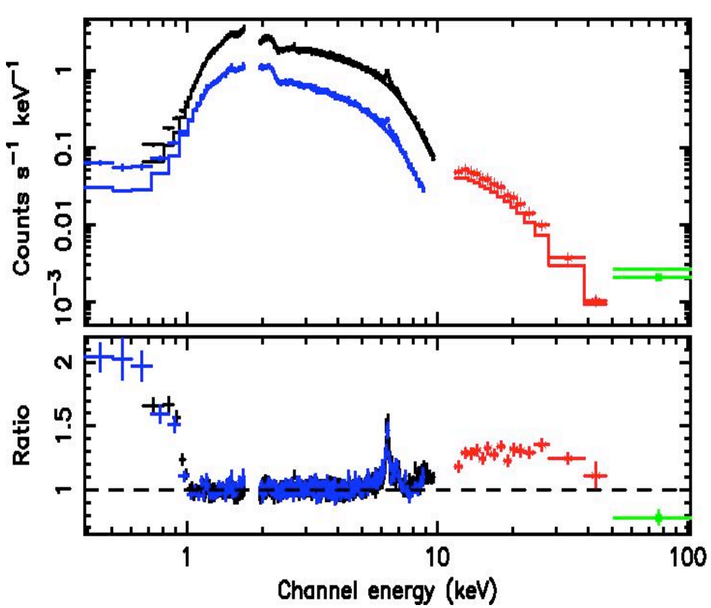


Why Do We Need This Model?

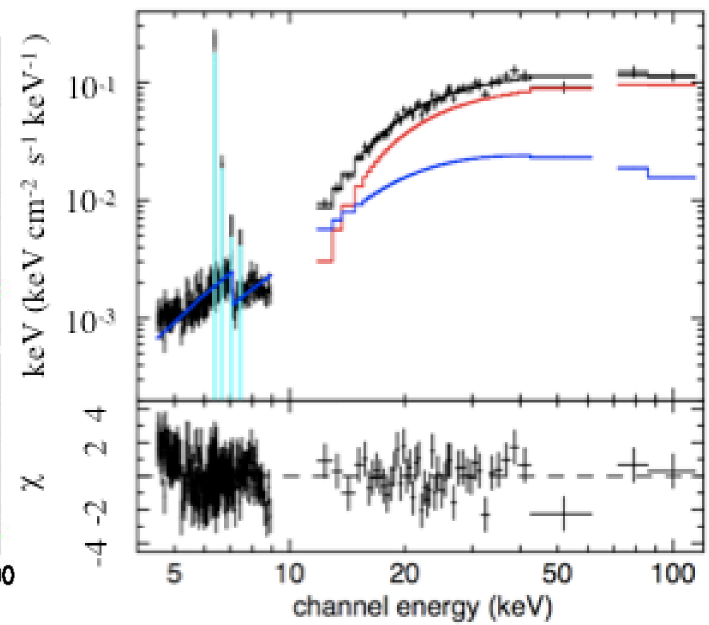
- Currently no generalized tool is available for *direct fitting* of an observed spectrum for AGNs with Compton-thick reprocessors with an *arbitrary input spectral shape.*
  - It is common practice to use disk reflection to model the reprocessor (wrong geometry, no emission lines, cannot constrain N_H).
  - In addition to fitting obscured (type 1.5-2) AGNs spectra, the model will allow us to derive upper limits on the column density and opening angle of a possible reprocessor (out of the line-of-sight) in type 1 AGNs.



Type 1 AGN
3C 273



Reeves *et al.* (2007)
Compton-Thin, Type 2 AGN
MCG -5-23-16

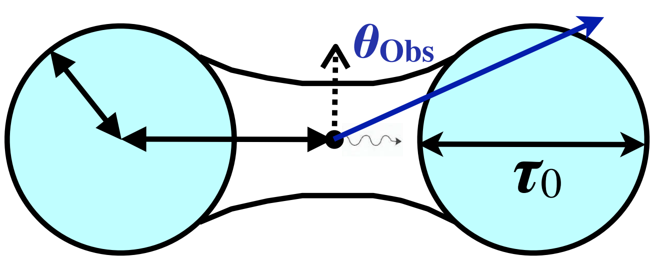


Itoh *et al.* (2007)
Compton-Thick, Type 2 AGN
NGC 4945

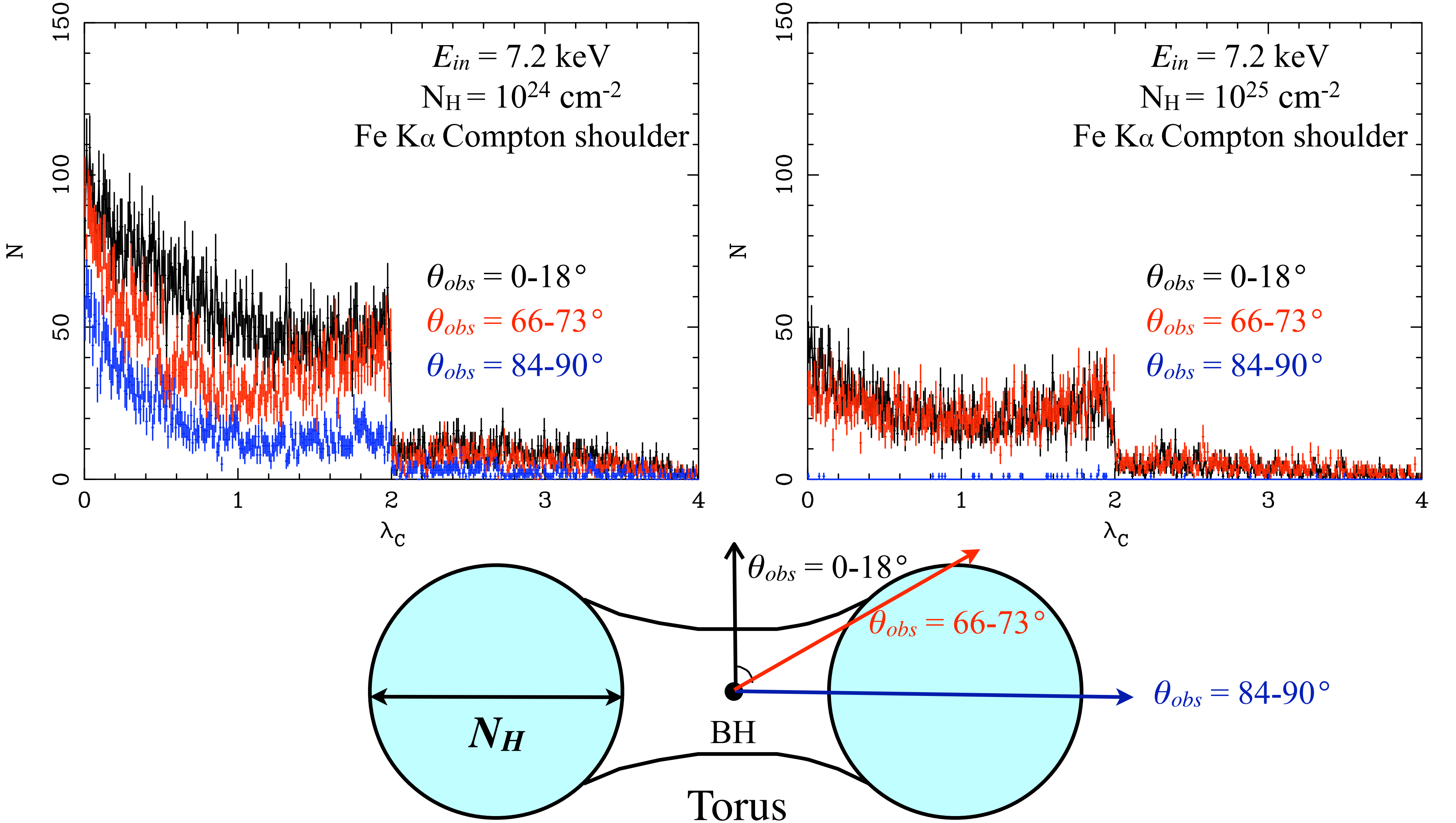
A New Model for Compton-Thick Reprocessors

- Previous reprocessor models assume a ***fixed*** input spectrum - this does not allow for direct fitting of the observed spectrum.
- Our model does not assume an input spectrum - our model will enable the user to determine the best-fit input parameters from the observed data (e.g. it may be used with any other model in XSPEC).
    - Employ grids of ***pre-calculated Green's functions*** (response to a mono-energetic input) instead of grids of pre-calculated spectra.
- The resolution in *both* the lines and continuum will be sufficient for use with observed data from both current and planned future missions.
    - The model will make use of recent work on atomic data in order to more accurately model the Fe Kα, Fe Kβ, and Ni Kα emission lines and their Compton shoulders.
- **Free parameters will include**: column density of the reprocessor, Fe abundance, inclination angle of the observer, torus opening angle, as well as an arbitrary number of input continuum parameters

This methodology will be applied to several geometries; the first set of models will be toroidal.



Sample Green's Functions: Fe Kα Compton Shoulder



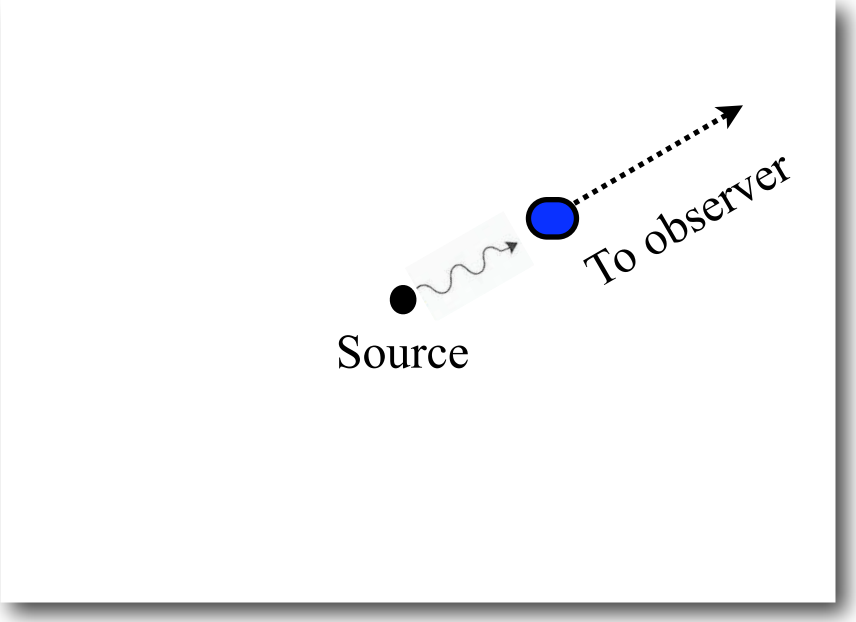
Summary

- Collectively, the X-ray data for NGC 2992 present a picture of both persistent Fe K line emission from the disk (broad base) and distant matter (narrow core) and short-term flaring emission (variable broad line) from the disk.
  - This type of complexity in the Fe K emission, as well as complexity in the continuum due to multiple reflection continua, is typical for many AGN.
  - The narrow Fe K line probes matter out of the line-of-sight and this material may be Compton-thick, even if the line-of-sight absorption is Compton-thin.
- We are creating an X-ray spectral model for Compton-thick toroidal reprocessors in AGNs (for arbitrary input spectra).
  - Initially we focus on a torus geometry, but we plan to extend this work to include other appropriate geometries (i.e., wedge, clumpy configurations).
  - Emission lines and reflection continuum are treated self-consistently.
  - The Green's function grids will allow the column density, Fe abundance, inclination angle and opening angle to be fitted, in addition to the arbitrary spectral input parameters.
  - It will allow us to fit observed spectra with energies out to ~200 keV.

Thank you!

Currently Used/Available Methods of Fitting

- **Absorption only** (ignore scattering)
- **cabs**: $(e^{-N_H*(\sigma_T + \sigma_{abs})})$
  - simple attenuation by a "blob" of material in the line of sight, reflected photons neglected



cabs: transmission only, no reflection from material out of the line-of-sight

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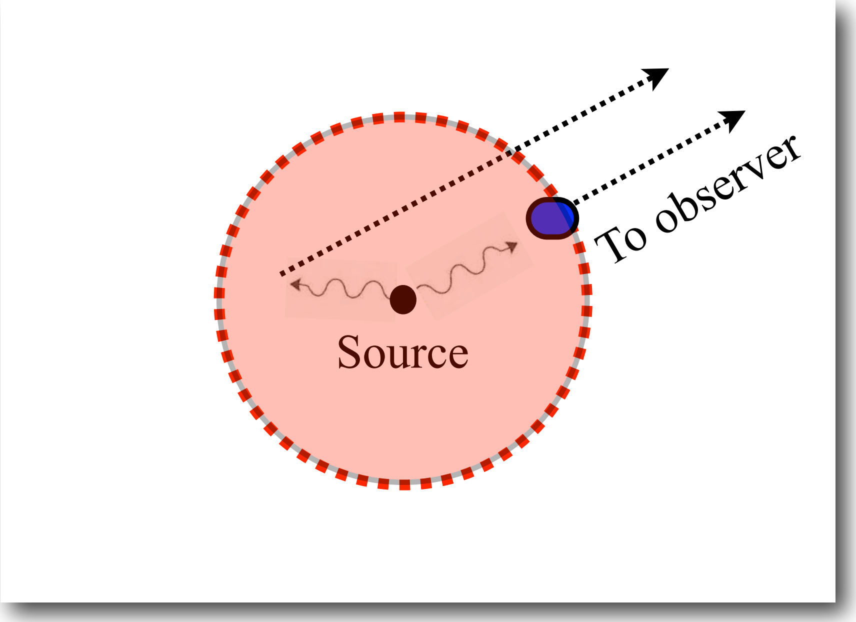
- **plcabs**: ($e^{-N_H*(1.2*\sigma_T+\sigma_{abs})}$)
  - X-ray transmission and reflection for a spherical distribution
  - power law with exponential cutoff
  - non-relativistic approximations, valid only to ~10-18 keV (rest frame), depending on N_H
  - Valid only for N_H up to 5×10^{24} cm^{-2}



cabs: transmission only, no reflection from material out of the line-of-sight

plcabs: spherical distribution, no line emission

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- **Disk reflection** (Pexrav)
  - wrong geometry, so derived parameters are not very useful
  - fixed input spectral form
  - no emission lines (must be put in ad hoc, as in cabs and plcabs)
  - reflection can't be related to line-of-sight N_H

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- **Custom-made tables**

Toroidal Reprocessor Models

- To create such a model, Monte Carlo methods must be employed. However, since spectral fitting is iterative and requires thousands of calculations (as model parameters are varied and the best fit is found), this is prohibitively slow.
- Generally solved by interpolating between pre-calculated grids of models
  - Only practical for 2-D grids (ie, only 2 model parameters may be free during fitting)
  - A reprocessed spectrum depends on the incident spectrum with unknown parameters, but the calculated spectrum assumes a fixed input spectral form
  - ***Currently no generalized tool is available for <u>direct fitting</u> of an observed spectrum for AGNs with Compton-thick reprocessors with an <u>arbitrary input spectral shape</u>.***

Currently Used/Available Methods of Fitting

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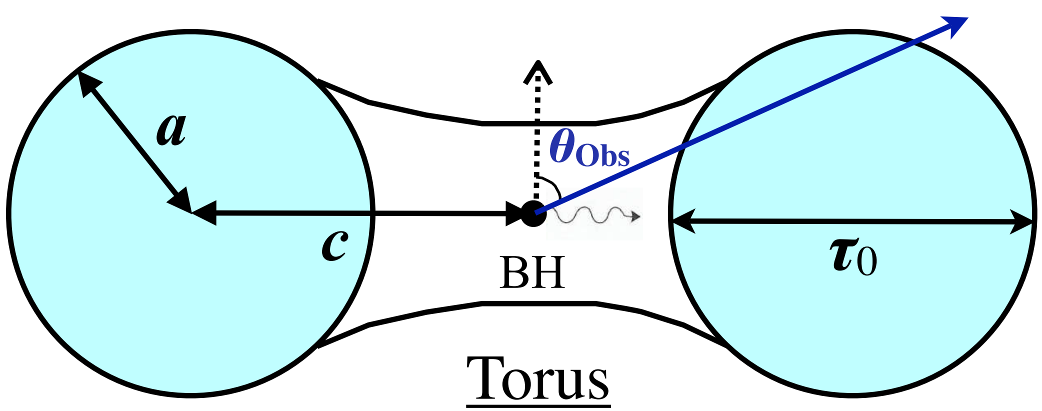
  - no emission lines (must be put in ad hoc, as in cabs and plcabs)
  - reflection can't be related to line-of-sight N_H
- **Custom-made tables**
  - restricted # of free parameters
  - input continuum shape is fixed
  - have not treated both the Fe K line and the continuum with sufficient detail

The Model

- Assumes a torus exists, is stable, has a uniform density, and is “cold”
  - Follows a distribution of injected photons as they are scattered and/or absorbed by the reprocessor
    - Escape function has up to 4 solutions for a given set of initial coordinates
    - Must account for re-entry into opposite side of torus
  - There are no hydrodynamic calculations
  - Does not account for winds blown off by the central source
  - Greens functions stored in Compton wavelengths bins (instead of energy bins)



Sample Green's Functions

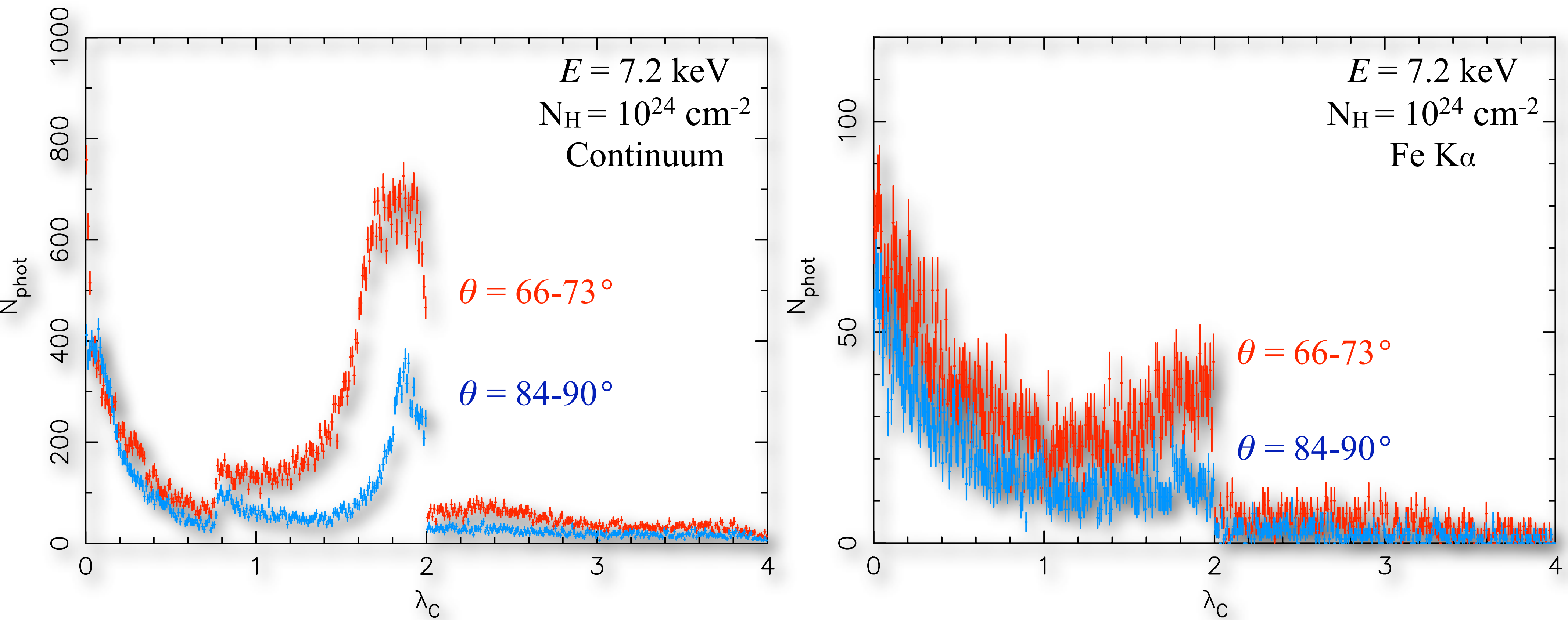


Table 1. NGC 2992 *RXTE* Observation Log

Obs	Start[a]		End[a]		Exposure[b]	Count Rate[c]
1	04/03/05	13:27:23	04/03/05	14:20:27	6368	10.590 ± 0.064
2	18/03/05	17:18:35	18/03/05	17:31:07	1504	2.287 ± 0.106
3	21/03/05	08:16:11	21/03/05	08:54:51	4640	2.730 ± 0.062
4	05/04/05	10:07:39	05/04/05	10:57:47	4928	7.467 ± 0.068
5	20/04/05	12:12:27	20/04/05	12:57:47	5440	1.326 ± 0.055
6	05/05/05	07:37:31	05/05/05	08:28:43	6144	3.646 ± 0.055
7	08/05/05	06:25:15	08/05/05	07:04:59	4576	3.673 ± 0.063
8	18/05/05	10:11:15	18/05/05	11:14:43	5216	8.084 ± 0.068
9	02/06/05	07:32:11	02/06/05	08:16:11	5280	1.555 ± 0.055
10	16/06/05	06:30:35	16/06/05	07:24:27	6464	1.350 ± 0.051
11	01/07/05	03:34:35	01/07/05	04:27:55	6400	0.802 ± 0.050
12	16/07/05	03:57:31	16/07/05	04:35:07	4512	1.203 ± 0.060
13	29/07/05	03:19:39	29/07/05	04:10:03	6048	3.402 ± 0.056
14	10/08/05	03:07:55	10/08/05	04:01:31	6432	2.841 ± 0.053
15	12/09/05	22:44:27	12/09/05	23:35:07	5600	1.882 ± 0.053
16	27/09/05	00:55:55	27/09/05	01:46:51	6112	1.322 ± 0.051
17	14/10/05	01:45:31	14/10/05	02:39:07	5600	0.886 ± 0.055
18	29/10/05	19:13:31	29/10/05	20:03:07	5632	1.013 ± 0.054
19	13/11/05	22:35:23	13/11/05	23:23:07	5728	1.970 ± 0.054
20	28/11/05	22:34:03	28/11/05	23:27:23	6400	1.687 ± 0.051
21	13/12/05	17:55:07	13/12/05	18:45:31	6048	1.827 ± 0.055
22	28/12/05	19:46:51	28/12/05	20:30:35	5248	1.278 ± 0.057
23	12/01/06	18:06:34	12/01/06	18:59:54	6400	0.850 ± 0.051
24	28/01/06	09:52:11	28/01/06	10:45:31	6368	1.882 ± 0.053

[a]Universal time

[b]Exposure time is given in seconds

[c]Count rate is given in counts s^{-1}

Table 1. NGC 2992 *Suzaku* Observation Log

Obs	Start[a] (UT)		End[a] (UT)		Count Rate[b] (ct/s/XIS)	Exposure Time[b] (s)
1	6/11/2005	14:16:51	7/11/2005	14:01:50	0.3888 ± 0.0027	34664.5
2	19/11/2005	21:42:59	20/11/2005	23:24:45	0.5096 ± 0.0032	31641.5
3	13/12/2005	10:15:37	14/12/2005	12:08:38	0.4408 ± 0.0026	41681.0

[a] Start and end times correspond to the time tags of the first and last photons respectively in the cleaned and filtered events files combined from XIS2 and XIS3. [b] Mean (0.5–10 keV) count rates and exposure times are for XIS2 and XIS3 *per XIS*.

NGC 2992: Suzaku

- Fe Kα and Fe Kb energies depend on ionization state of Fe in the emitter
- Can relate observed and theoretical energies by

  $E_{i,FeK\alpha}$ (observed) = A+BxE $_{i,FeK\alpha}$(true),

  $E_{i,FeK\beta}$ (observed) = A+BxE $_{i,FeK\beta}$ (true)

  – i: ionization state
  – A: offset in instrument energy scale
  – B: residual uncertainty in gain, possible Doppler or gravitational shifts