Long-term spectral evolution of the optical-X-ray synchrotron emission of PKS 2155-304

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Outline

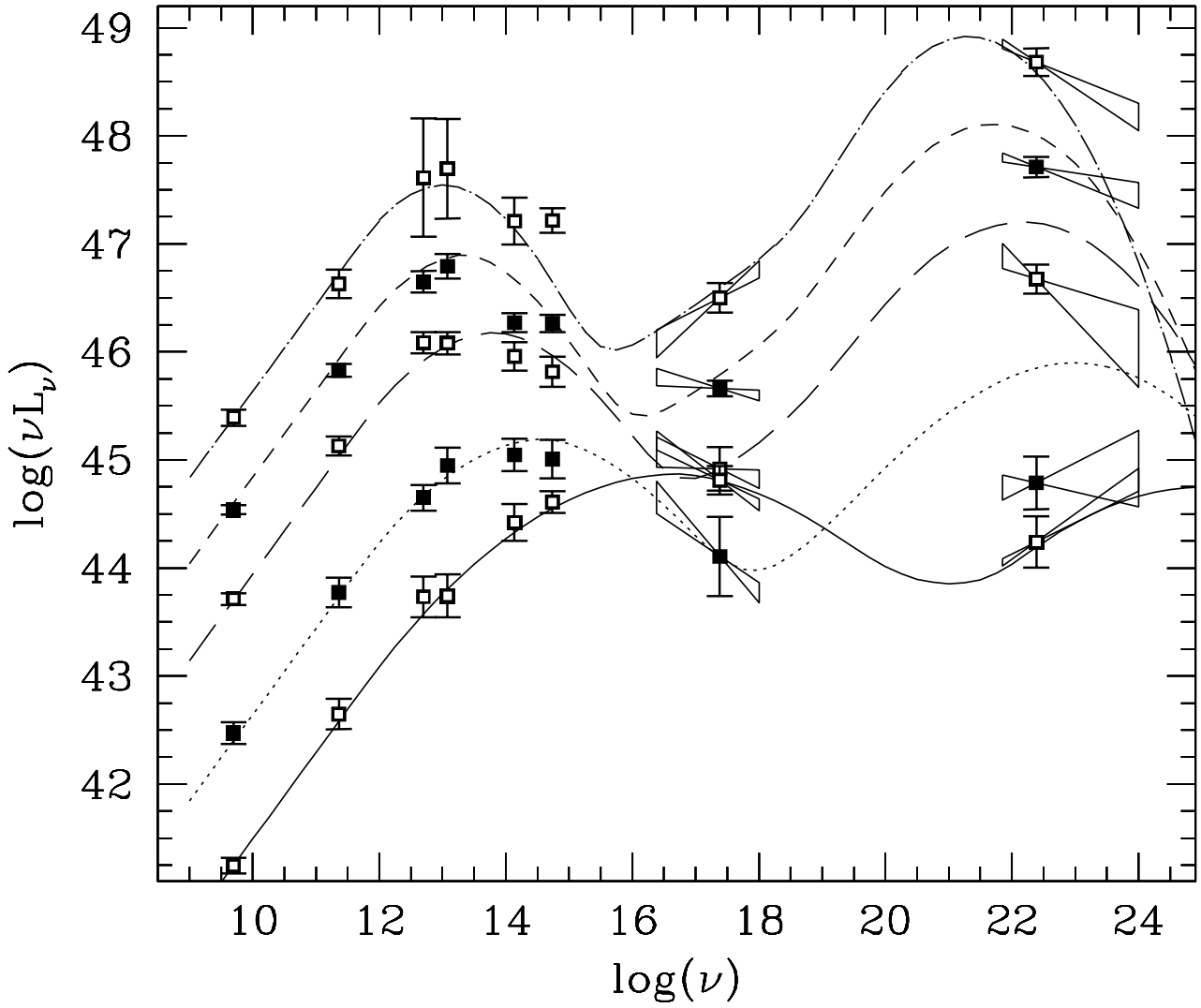
Introduction - Blazar

- What is blazar?
  - a subclass of active galactic nuclei (AGN).
  - relativistic jet closely alined with the line of sight.
  - strong variation at all bands.
  - broad non-thermal continuum from radio to TeV γ-ray with two peaks.
  - weak or no absorption/emission features.
  - high polarization.
- Why study blazar?
  - almost purely jet radiation: good for study radiation mechanism.
  - jet: a common phenomena in astrophysics and good place to study particle acceleration and energy transportation.
  - connection with blackhole: central engine, link with accretion disk and jet.

Introduction - Blazar

- How to classify blazars?
  - high frequency peaked blazar (HBL): peak at UV/soft X-ray bands.
  - low frequency peaked (LBL): peak at IR/optical bands.
  - flat spectral radio quasar (FSRQ).
  - the blazar sequence: HBL - LBL - FSRQ.
  - anticorrelation between radio flux and peak frequency.
- How blazars radiate?
  - two model families: leptonic and hadronic.
  - leptonic models: synchrontron + self-Compton (SSC), synchrotron + external Compton (EC)
  - synchrotron + self-absorption: radio, infrared, optical, UV, soft X-ray.
  - inverse Compton scattering: hard X-ray, γ-ray.

Introduction - Blazar



Introduction - Source and Observer

- PKS 2155-304
  - high frequency peaked blazar with TeV radiation detected.
  - one of the brightest source at X-ray band.
- *XMM-Newton* data for long term study
  - multi-wavelength: 6 optical-UV bands + X-ray EPIC-pn detector at 0.2-10 keV.
  - high X-ray energy resolution: good for spectral analysis.
  - large amount of data: 7 years, more than 10 observations, totally 900 ks.

Introduction - Source and Observer

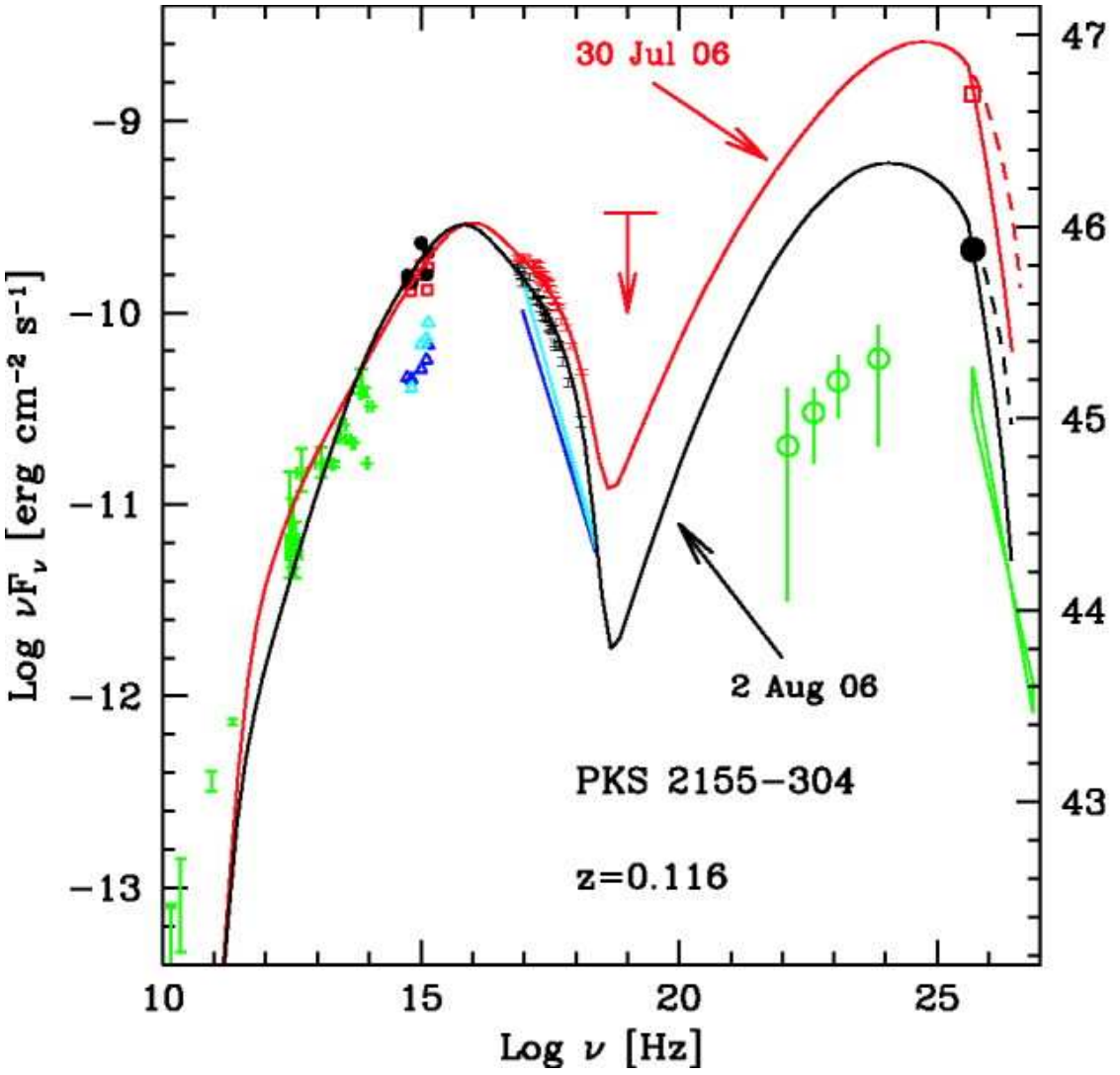


Figure: *Swift* observation of PKS 2155-304 in 2006 (Foschini et al., 2007)

Method

Table: Summary of Observation

Rev.[a]	Obs. No.	Exp. ID	Date (UTC)	Mode[b]	Bkg[c]	Pileup
0087	0124930101	087-1	2000-05-30 10:20:09 to 05-30 20:53:29	SW	Yes	Yes
	0124930201	087-2	2000-05-31 00:52:59 to 05-31 17:21:38	SW	Yes	Yes
0174	0080940101	174-1	2000-11-19 19:00:40 to 11-20 10:55:39	SW	No	Yes
	0080940301	174-2	2000-11-20 13:15:19 to 11-21 05:25:19	SW	Yes	Yes
0362	0124930301	362-1	2001-11-30 03:12:05 to 11-30 15:30:29	TI	No	No
		362-2	2001-11-30 15:54:06 to 12-01 04:17:30	SW	No	Yes
0450	0124930501	450-1	2002-05-24 11:18:09 to 05-24 20:08:10	SW	No	Yes
		450-2	2002-05-24 20:31:33 to 05-25 05:19:52	SW	No	Yes
		450-3	2002-05-25 05:43:16 to 05-25 14:01:35	SW	No	Yes
0545	0124930601	545-1	2002-11-29 23:32:52 to 11-30 15:20:17	SW	No	No
		545-2	2002-11-30 15:57:29 to 12-01 07:14:54	TI	Yes	No
0724	0158960101	724	2003-11-23 00:52:28 to 11-23 08:16:59	SW	No	No
0908	0158960901	908-1	2004-11-22 21:41:36 to 11-23 05:36:06	SW	No	No
	0158961001	908-2	2004-11-23 19:52:01 to 11-24 06:58:11	SW	No	No
0993	0158961101	993	2005-05-12 12:57:05 to 05-12 20:51:35	SW	Yes	Yes
1095	0158961301	1095	2005-11-30 20:40:02 to 12-01 13:19:33	SW	Yes	Yes
1171	0158961401	1171	2006-05-01 12:31:58 to 05-02 06:24:50	SW	No	No
1266	0411780101	1266-1	2006-11-07 00:31:25 to 11-07 08:50:03	SW	No	No
		1266-2	2006-11-07 08:52:19 to 11-07 18:35:53	SW	No	No
		1266-3	2006-11-07 18:38:36 to 11-08 04:24:57	SW	No	No

[a] Revolution number.
[b] Exposure mode: SW - small window mode; TI - timing mode.
[c] High background period.

Method

- X-ray spectral analysis
  - severe pileup and high background periods are carefully excluded.
  - background subtracted.
  - fit model: single powerlaw and broken powerlaw with photo-electric absorption.
  - energy range: 0.2-10 keV for SW mode and 0.5-10 keV for TI mode.
- Optical-UV photometry
  - automatically by OM pipeline script in SAS.
  - background subtracted but no extinction correction.

Method

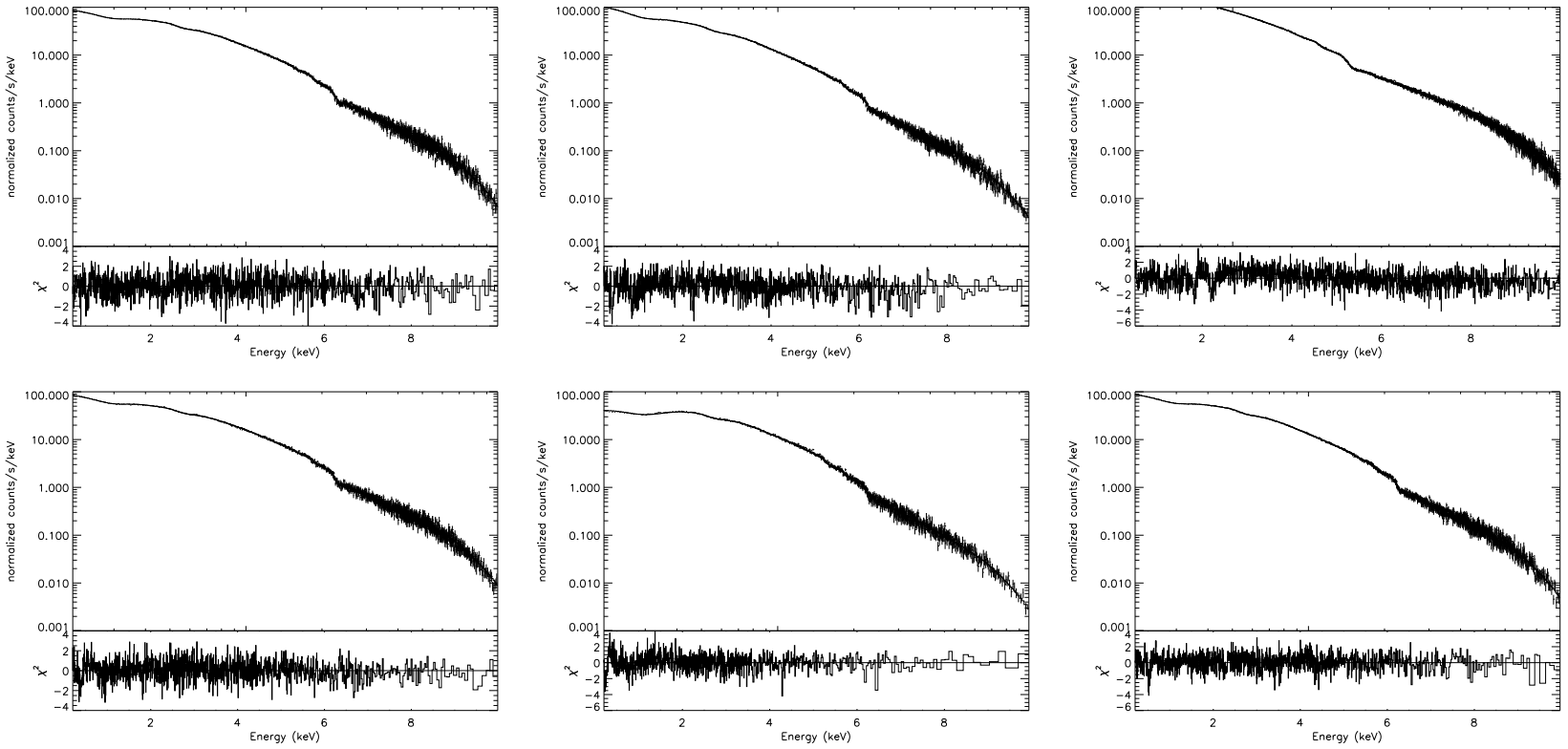


Figure: spectral fitting

Prelimenary Results

Table: Summary for Spectra Fitting

Obs. ID.	Model	Index 1	Index 2	Flux	Chi-squared
087-1	single	$2.554^{+0.003}_{-0.003}$	-	$4.213^{+0.025}_{-0.024}$	1596.3/1104
	broken	$2.501^{+0.006}_{-0.007}$	$2.650^{+0.012}_{-0.011}$	$3.867^{+0.038}_{-0.037}$	1117.9/1102
087-2	single	$2.513^{+0.002}_{-0.002}$	-	$4.521^{+0.019}_{-0.020}$	2150.5/1305
	broken	$2.474^{+0.005}_{-0.005}$	$2.610^{+0.011}_{-0.010}$	$4.182^{+0.032}_{-0.030}$	1526.1/1303
174-1	broken	$2.563^{+0.008}_{-0.008}$	$2.768^{+0.009}_{-0.008}$	$2.0791^{+0.021}_{-0.021}$	1231.2/1154
174-2	broken	$2.604^{+0.008}_{-0.008}$	$2.829^{+0.008}_{-0.008}$	$2.048^{+0.018}_{-0.017}$	1101.5/1063
362-1	broken	$2.573^{+0.005}_{-0.005}$	$2.812^{+0.003}_{-0.003}$	$6.252^{+0.017}_{-0.018}$	2112.0/1704
362-2	broken	$2.557^{+0.007}_{-0.007}$	$2.812^{+0.009}_{-0.009}$	$4.583^{+0.032}_{-0.032}$	1444.6/1219
450-1	single	$2.615^{+0.003}_{-0.003}$	-	$2.792^{+0.015}_{-0.015}$	1566.9/1166
	broken	$2.539^{+0.012}_{-0.012}$	$2.676^{+0.010}_{-0.008}$	$2.626^{+0.021}_{-0.021}$	1128.2/1164
450-2	single	$2.517^{+0.003}_{-0.003}$	-	$3.255^{+0.017}_{-0.017}$	1810.5/1219
	broken	$2.453^{+0.008}_{-0.009}$	$2.598^{+0.009}_{-0.010}$	$3.021^{+0.025}_{-0.024}$	1225.3/1217
450-3	single	$2.365^{+0.003}_{-0.003}$	-	$5.175^{+0.023}_{-0.023}$	2009.2/1480
	broken	$2.342^{+0.004}_{-0.004}$	$2.539^{+0.031}_{-0.025}$	$4.948^{+0.030}_{-0.029}$	1606.5/1478
545-1	broken	$2.496^{+0.009}_{-0.009}$	$2.822^{+0.007}_{-0.007}$	$1.558^{+0.009}_{-0.010}$	1697.2/1313
545-2	broken	$2.499^{+0.008}_{-0.008}$	$2.796^{+0.006}_{-0.006}$	$2.310^{+0.010}_{-0.010}$	1699.3/1563
724	single	$2.806^{+0.004}_{-0.004}$	-	$1.342^{+0.009}_{-0.009}$	1655.8/1029
	broken	$2.693^{+0.016}_{-0.019}$	$2.882^{+0.010}_{-0.010}$	$1.248^{+0.011}_{-0.012}$	1161.6/1027

Prelimenary Results

Table: Summary for Spectra Fitting (continued)

Obs. ID.	Model[a]	Index 1	Index 2	Flux[b]	Chi-squared[c]
908-1	broken	$2.637^{+0.017}_{-0.017}$	$3.000^{+0.012}_{-0.011}$	$1.222^{+0.014}_{-0.013}$	1014.6/884
908-2	broken	$2.554^{+0.012}_{-0.013}$	$2.890^{+0.008}_{-0.008}$	$1.884^{+0.014}_{-0.015}$	1464.4/1111
993	single	$2.586^{+0.004}_{-0.004}$	-	$3.645^{+0.029}_{-0.031}$	1121.4/892
	broken	$2.516^{+0.014}_{-0.016}$	$2.651^{+0.013}_{-0.012}$	$3.407^{+0.043}_{-0.043}$	917.2/890
1095	single	$2.649^{+0.002}_{-0.002}$	-	$3.670^{+0.017}_{-0.017}$	1647.4/1214
	broken	$2.599^{+0.007}_{-0.007}$	$2.700^{+0.007}_{-0.006}$	$3.482^{+0.025}_{-0.025}$	1295.0/1212
1171	single	$2.606^{+0.002}_{-0.002}$	-	$1.552^{+0.007}_{-0.007}$	1488.2/1291
	broken	$2.609^{+0.003}_{-0.003}$	$2.246^{+0.147}_{-0.172}$	$1.604^{+0.013}_{-0.014}$	1419.6/1289
1266-1	single	$2.533^{+0.003}_{-0.003}$	-	$2.258^{+0.011}_{-0.011}$	1484.4/1316
	broken	$2.513^{+0.008}_{-0.004}$	$2.544^{+0.005}_{-0.005}$	$2.232^{+0.014}_{-0.017}$	1459.8/1314
1266-2	single	$2.547^{+0.002}_{-0.002}$	-	$2.473^{+0.011}_{-0.011}$	1536.6/1418
	broken	$2.560^{+0.004}_{-0.004}$	$2.497^{+0.011}_{-0.012}$	$2.557^{+0.018}_{-0.018}$	1433.1/1416
1266-3	single	$2.538^{+0.003}_{-0.003}$	-	$2.653^{+0.013}_{-0.012}$	1666.2/1443
	broken	$2.551^{+0.003}_{-0.003}$	$2.461^{+0.014}_{-0.015}$	$2.735^{+0.019}_{-0.018}$	1559.7/1441

[a] Models: single - single powerlaw; broken - broken powerlaw.

[b] $10^{-11}\mathrm{ergs/cm^2/s}$.

[c] χ^2 / degree of freedom.

Prelimenary Results

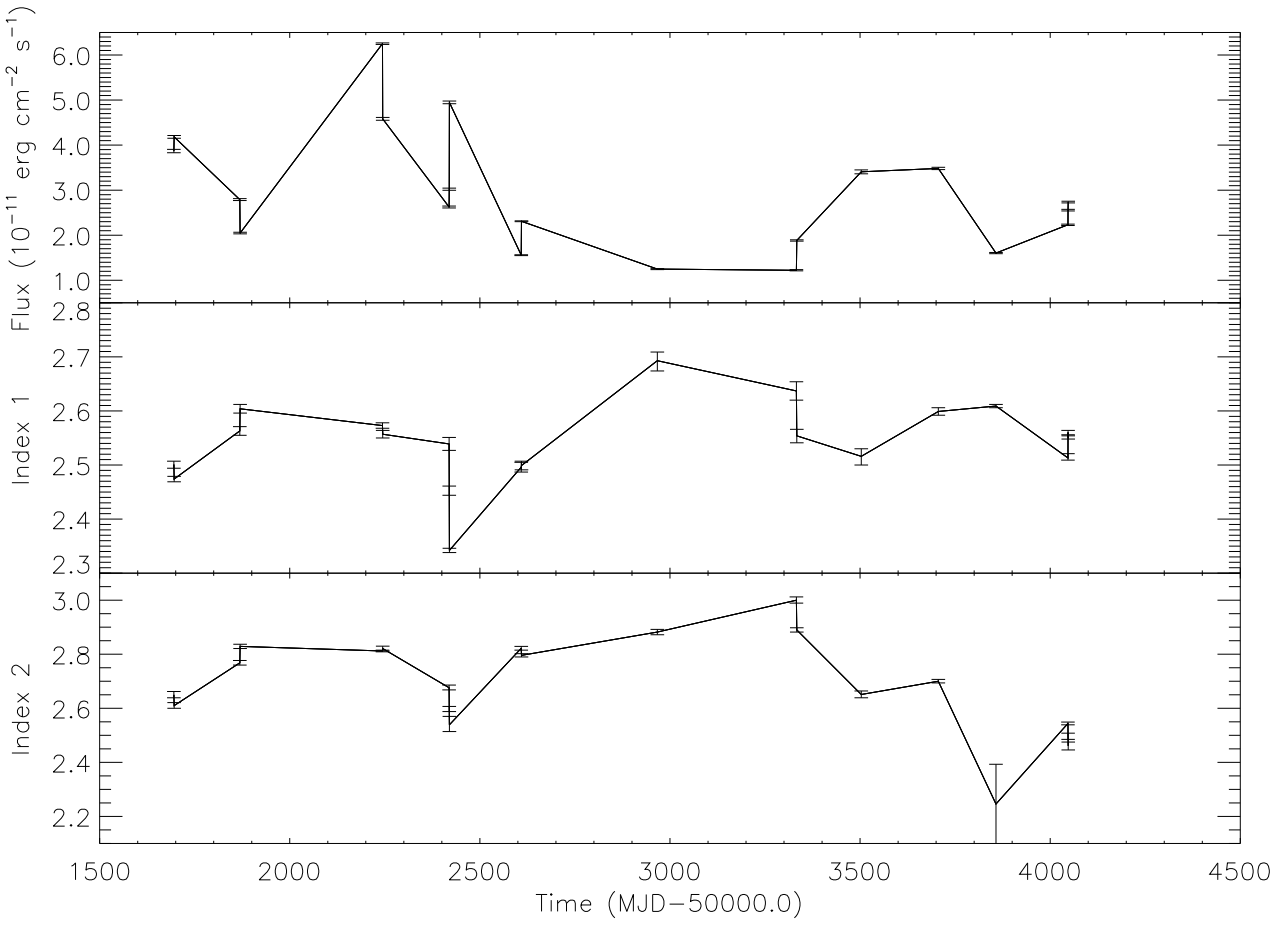


Figure: X-ray long term variation

Prelimenary Results

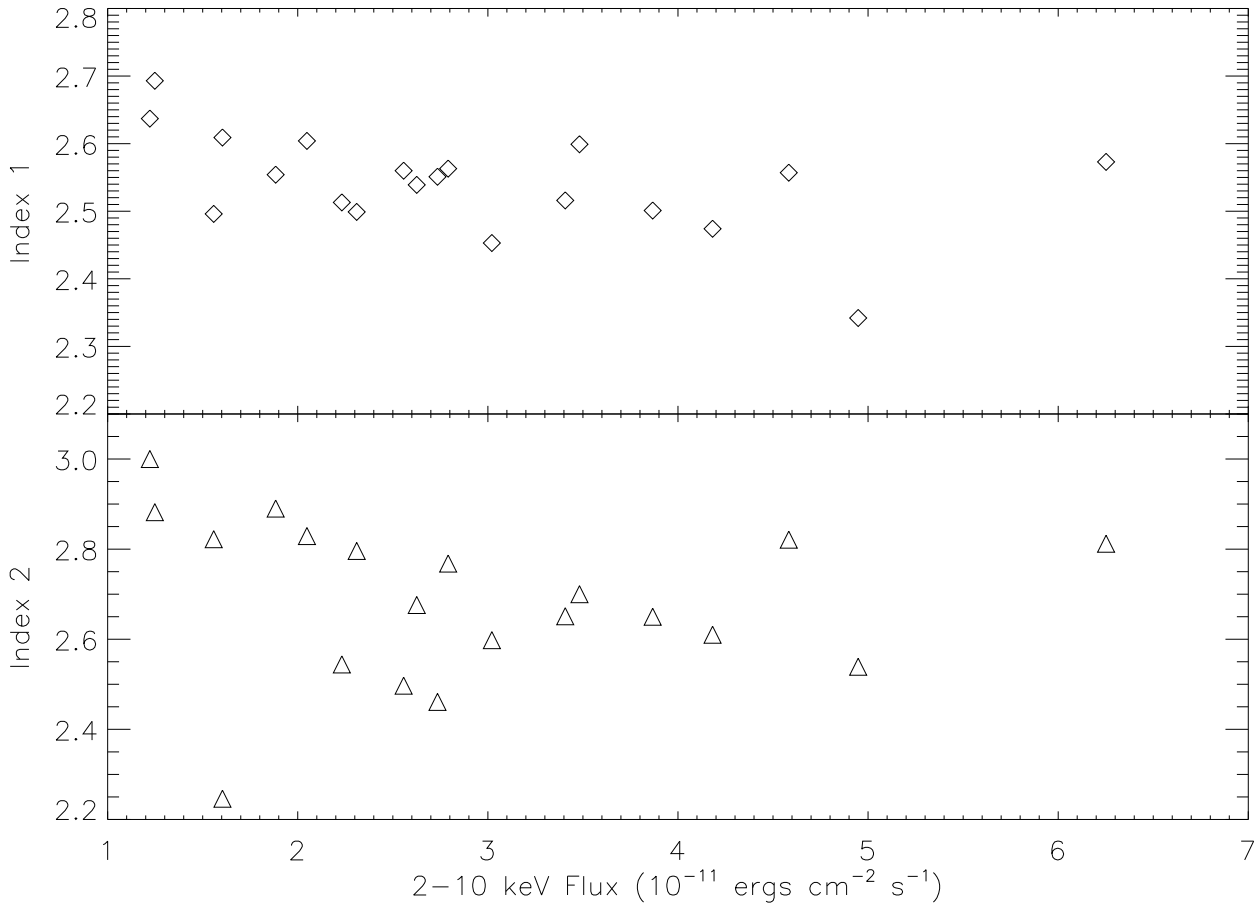


Figure: X-ray flux vs photon index

Prelimenary Results

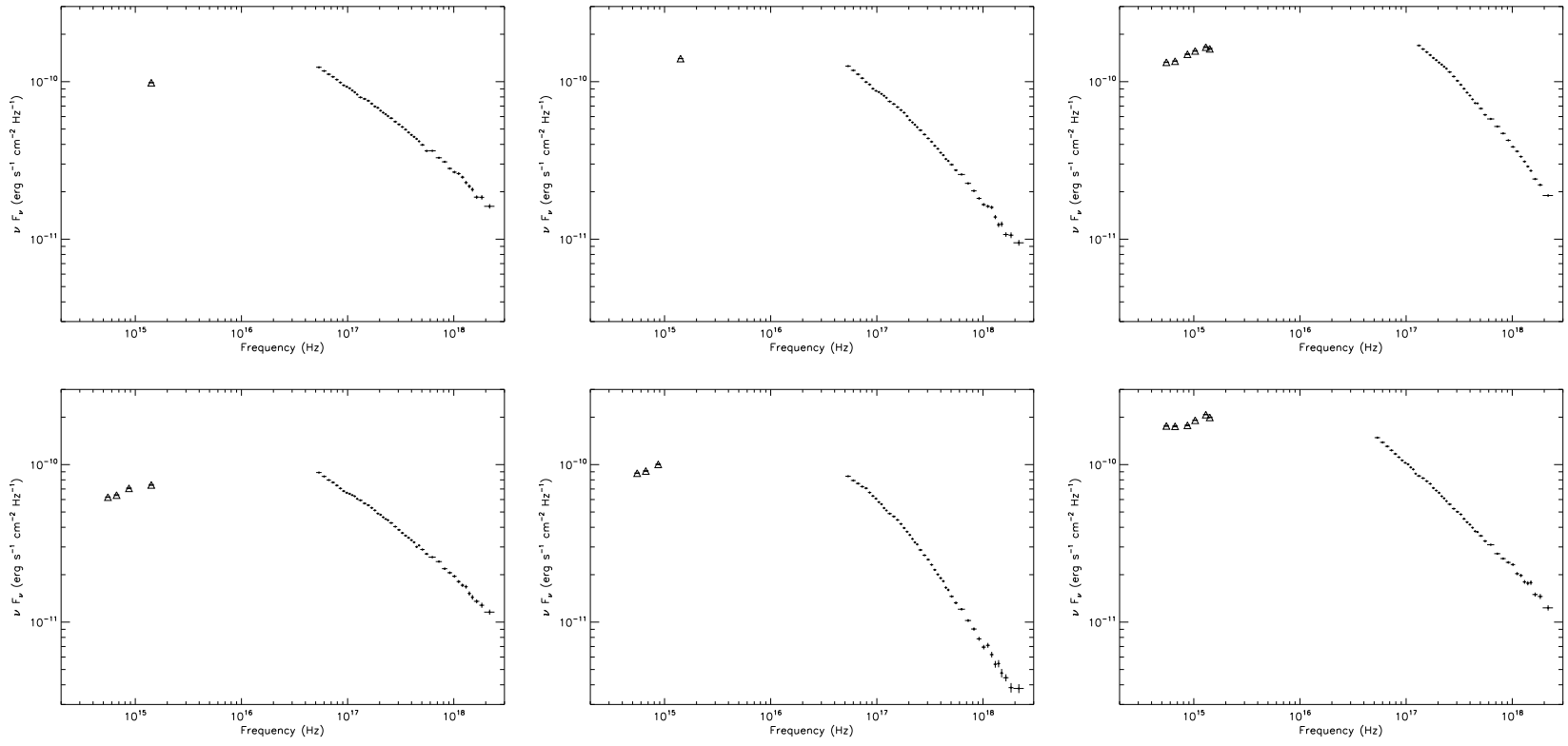


Figure: optical to X-ray SED

Prelimenary Results

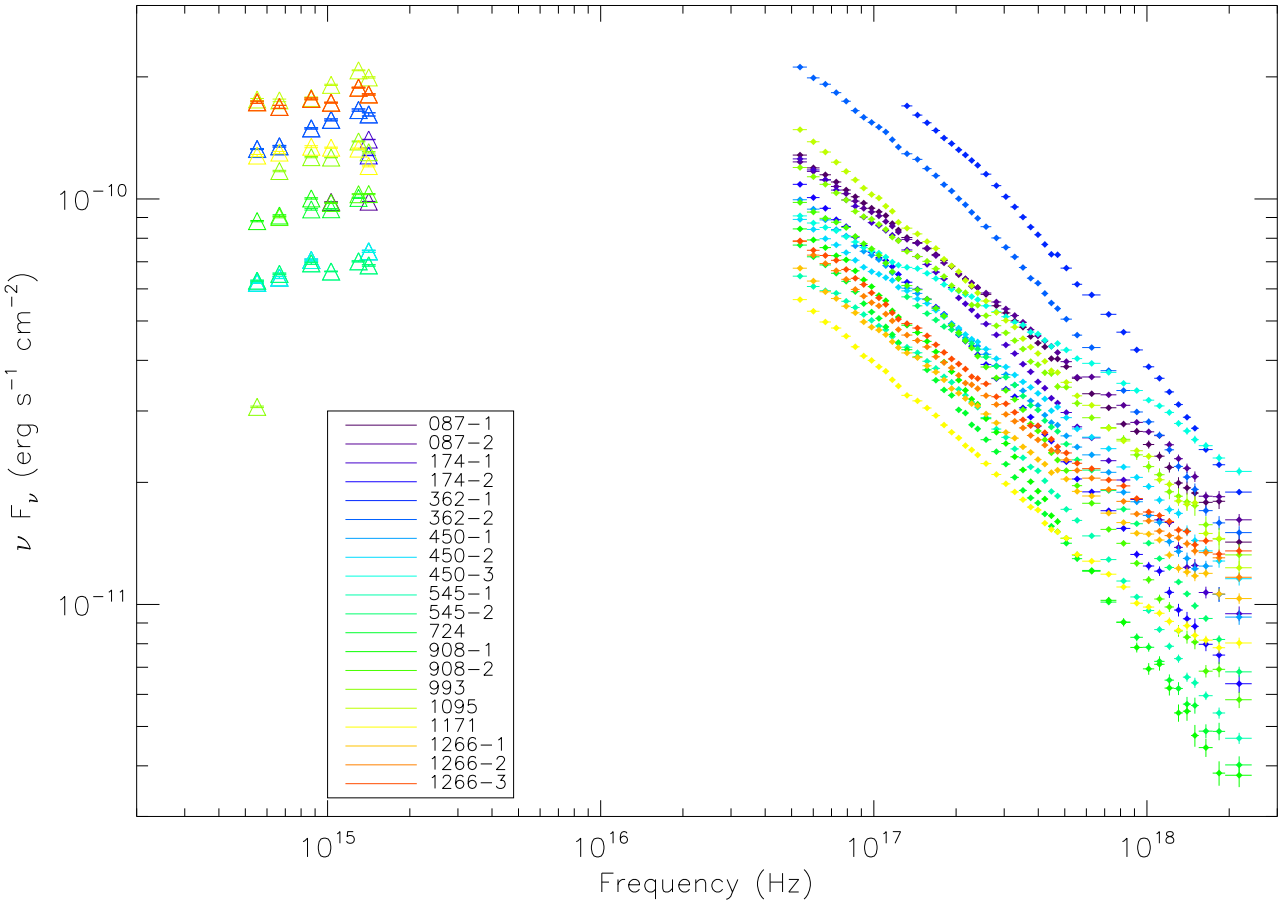


Figure: compare: all SEDs in one figure

Prelimenary Results

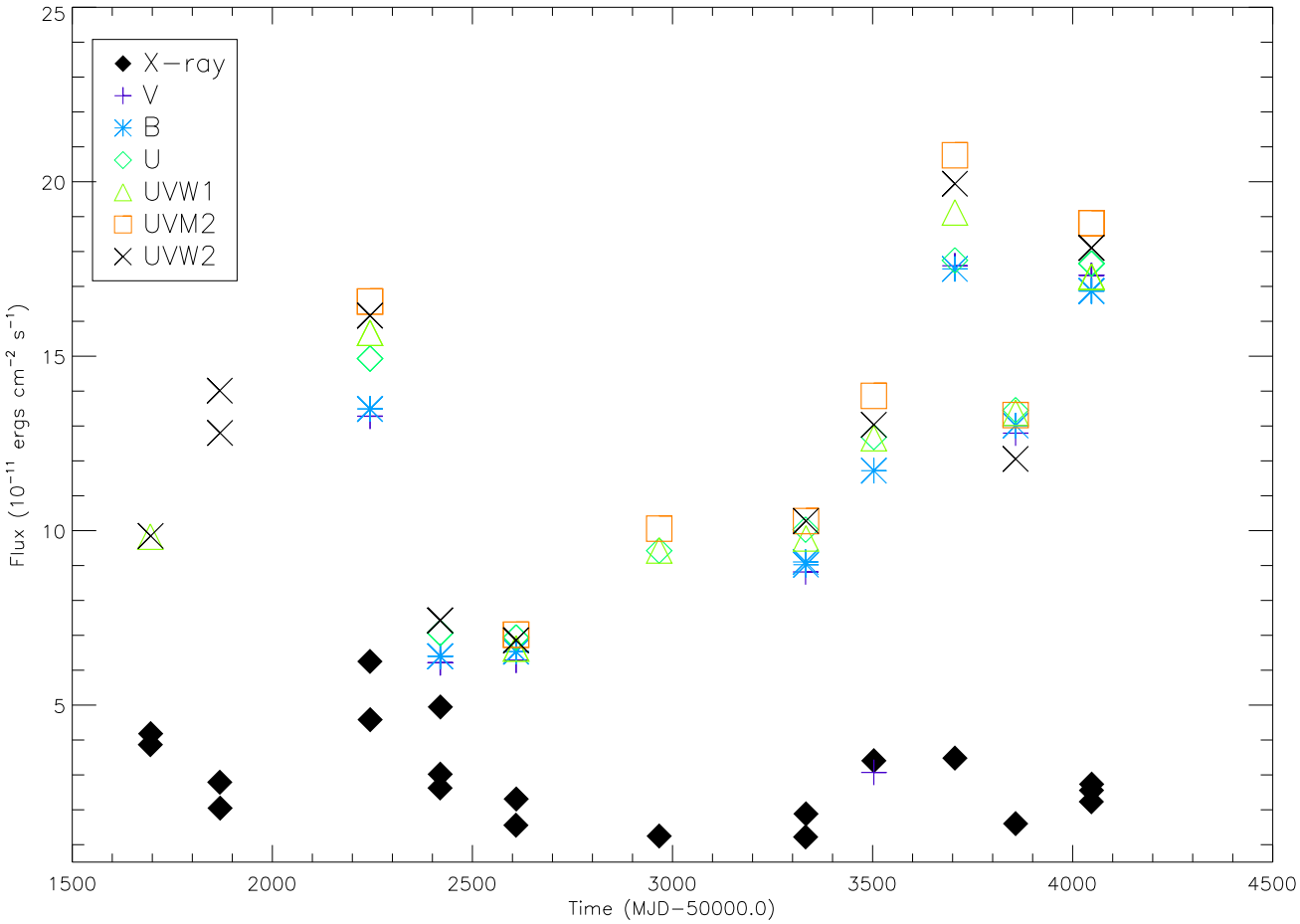


Figure: compare: multi-wavelength lightcurve

Question: IC component?

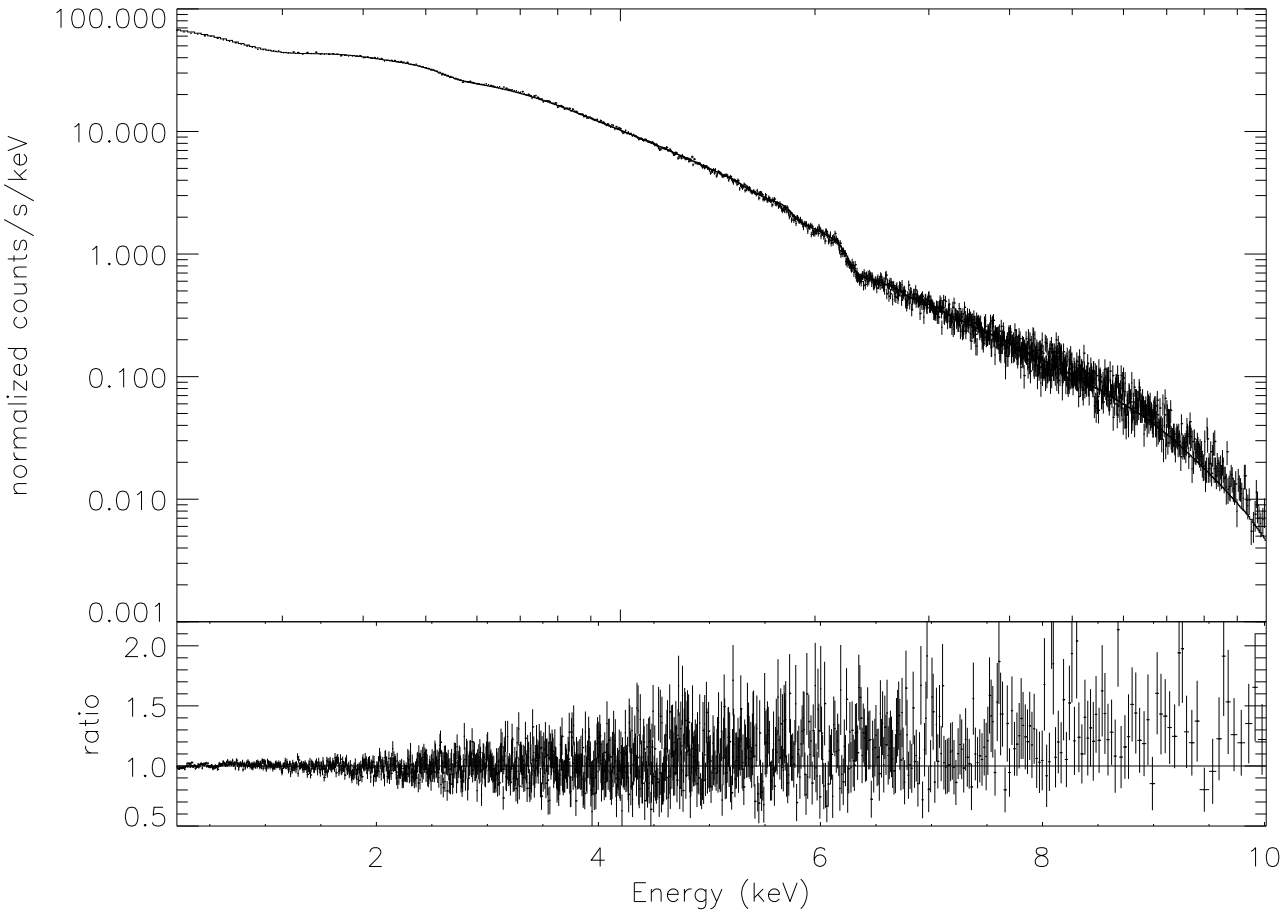


Figure: a strange hard excess in exp. 1171

Question: IC component?

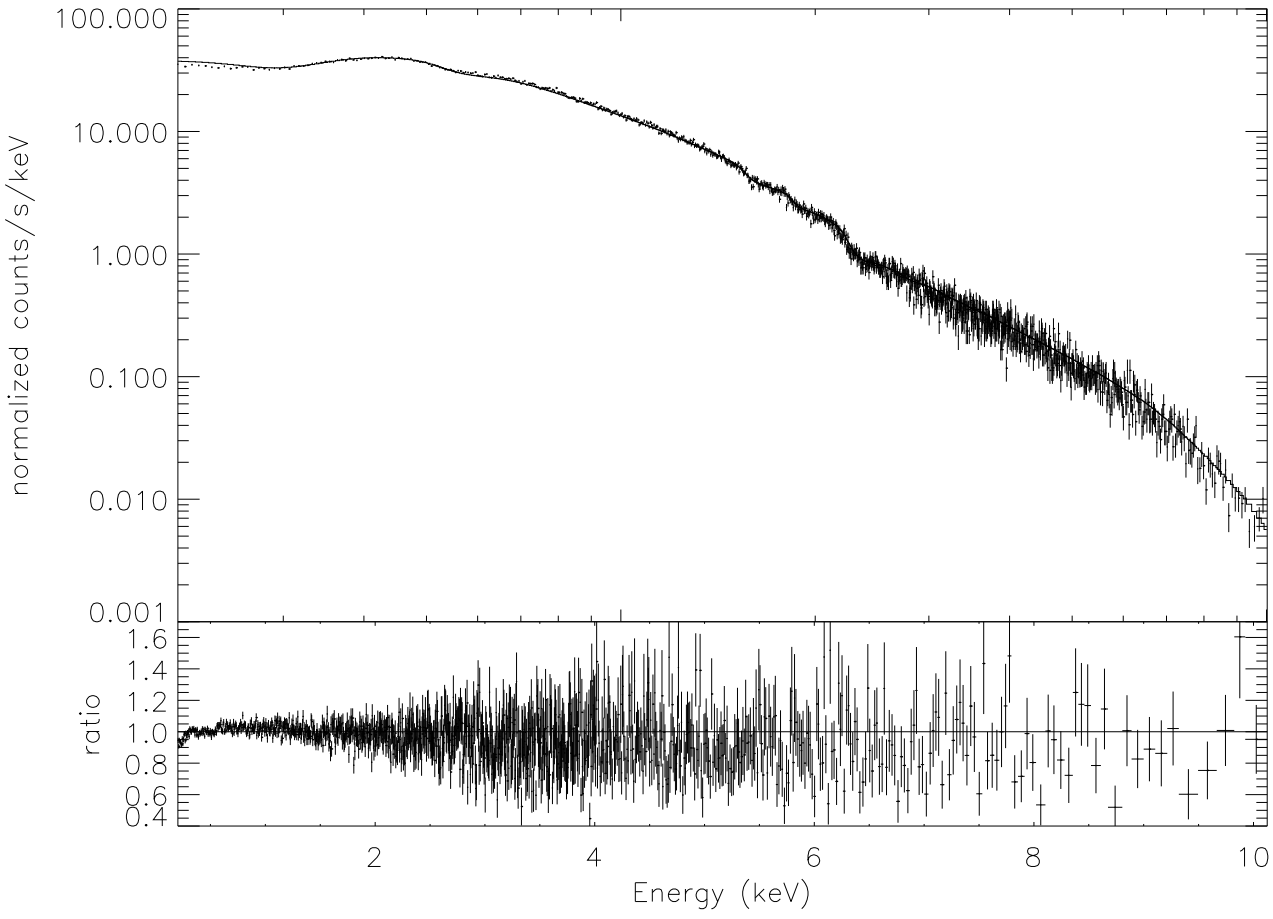


Figure: a common case from exp. 724 for comparison

Question: IC component?

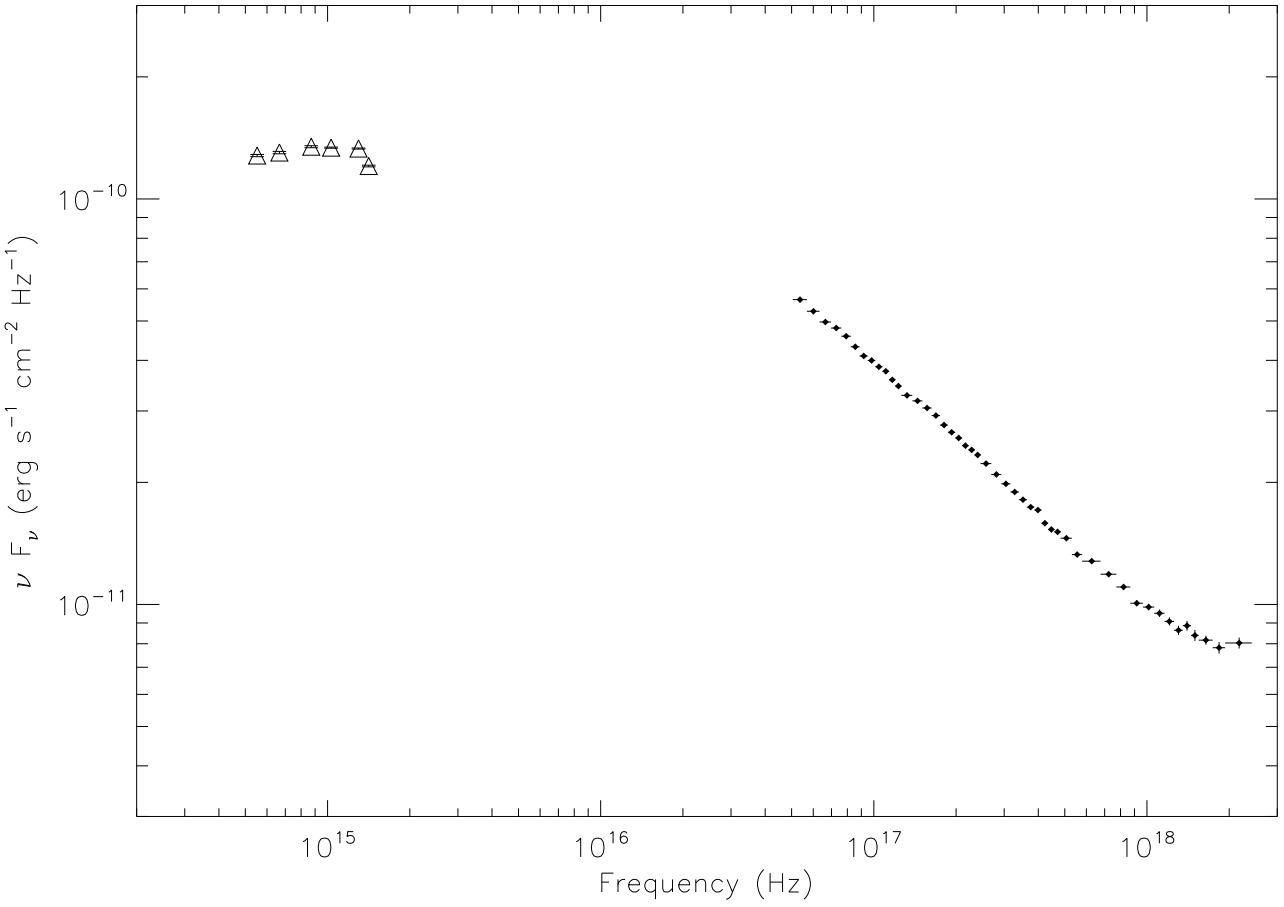


Figure: SED of exp. 1171

Question: IC component?

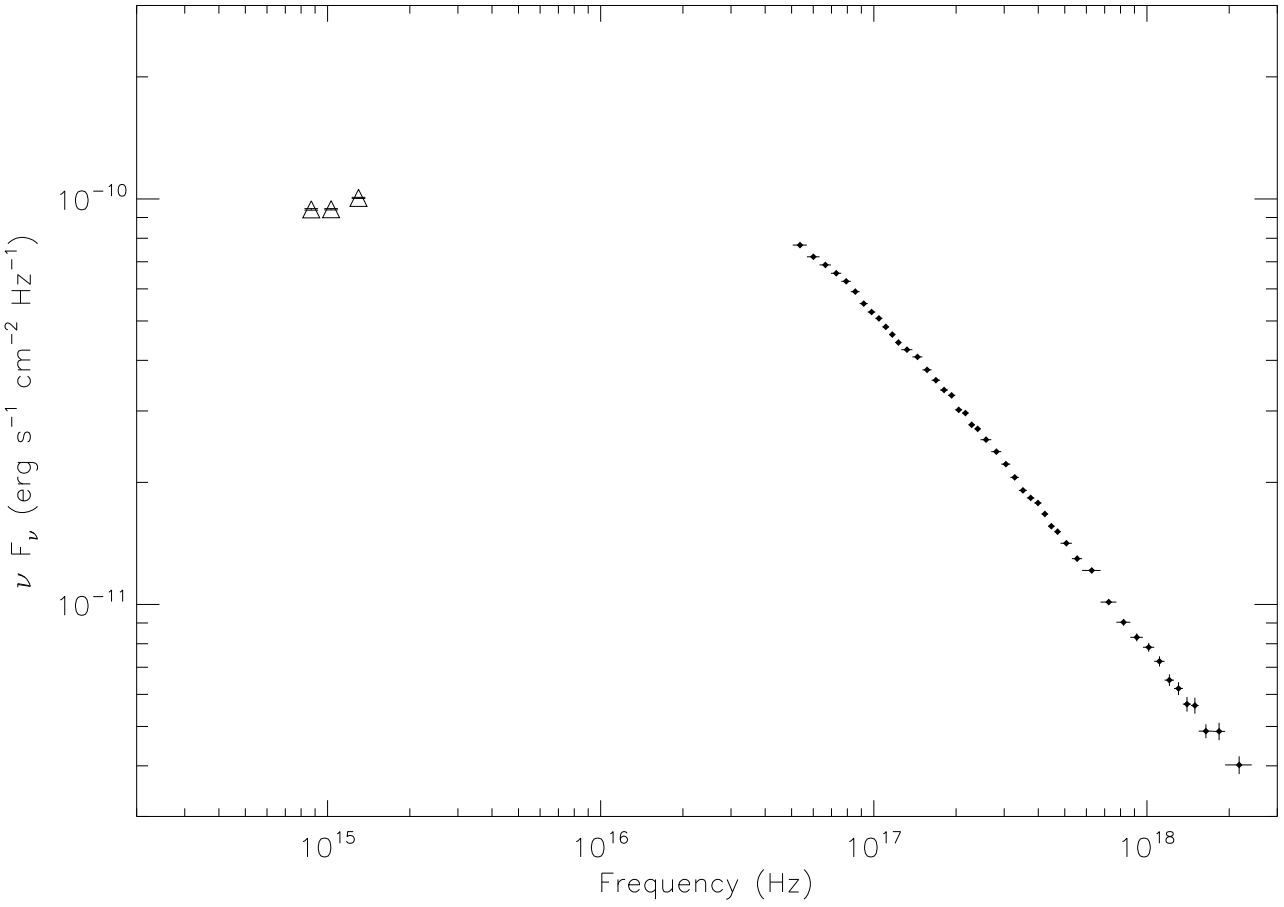


Figure: SED of exp. 724 for comparison

Question: IC component?

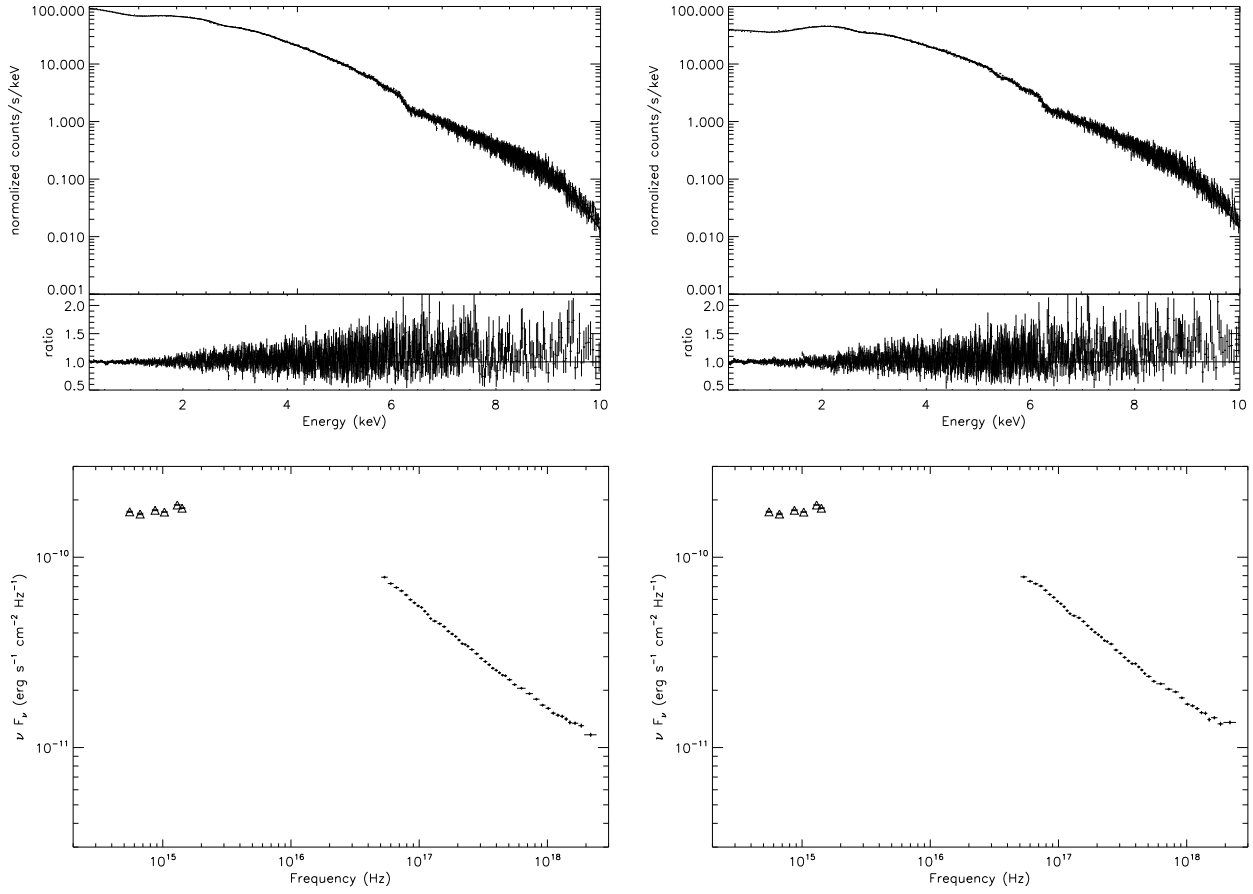


Figure: two other similar exposures: exp. 1266-2 (left) and exp. 1266-3 (right)

Discussion and Future Plan

- Spectra models
  - single powerlaw is not good for most cases while the broken powerlaw model gives generally good fitting.
  - it implies the synchrotron peak is commonly close to soft X-ray band.
  - nevertheless broken not so good for some observation: more complicated models may be required.
- Spectra variation
  - slight anti-correlation between flux and index: can be explained by different energy distribution of inject electrons and thus different energy distribution of emitting electrons.
- SED analysis
  - varies from case to case: change of physical parameters?
  - physical radiation models required to determine the parameters: what we are doing...
  - data from other experiments and other bands? radio, IR, hard X-ray, γ-ray, TeV...