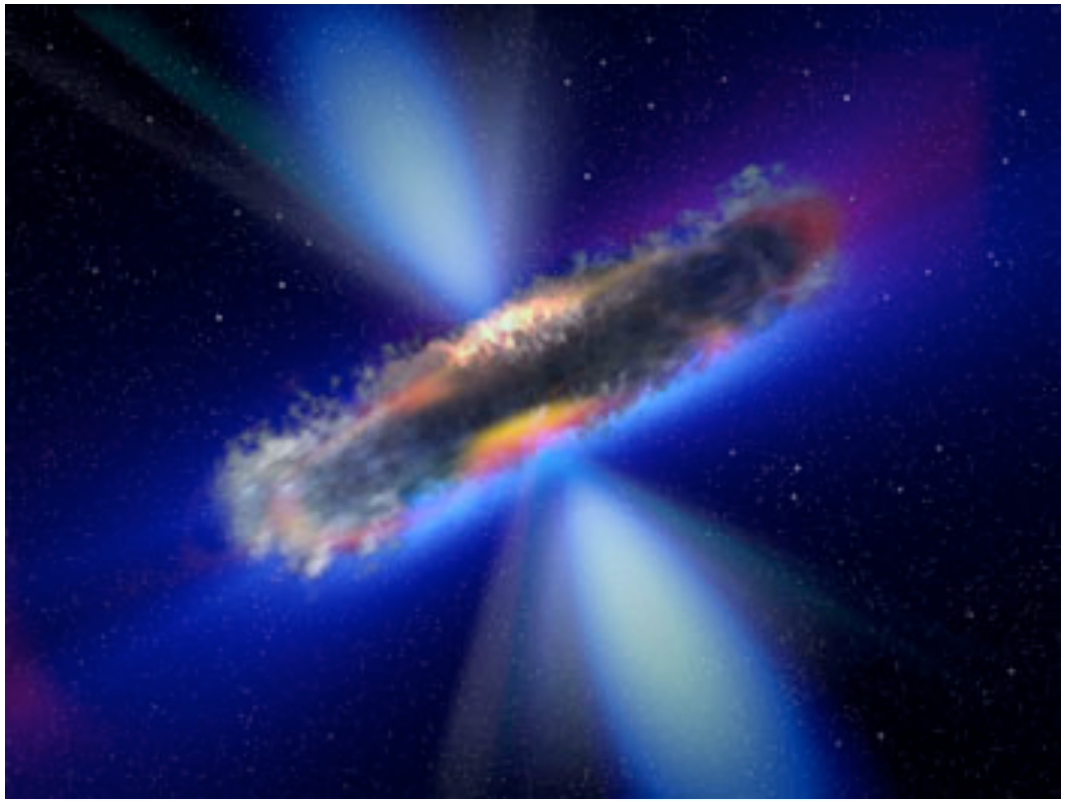
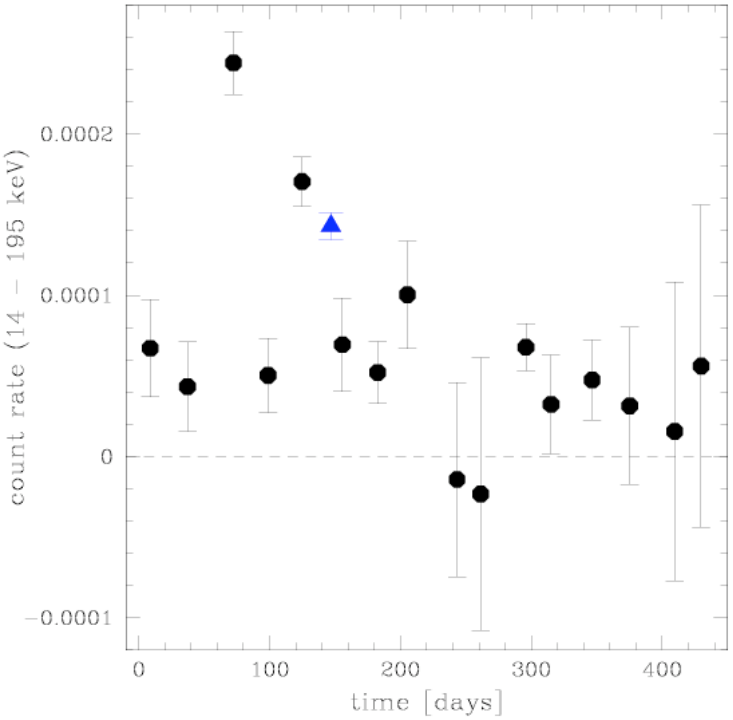
# Hard X-ray Variability of AGN



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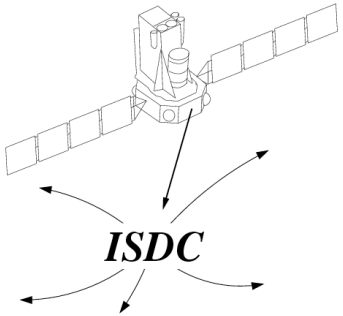




INTEGRAL Workshop Sardinia, October 19, 2007

# Overview

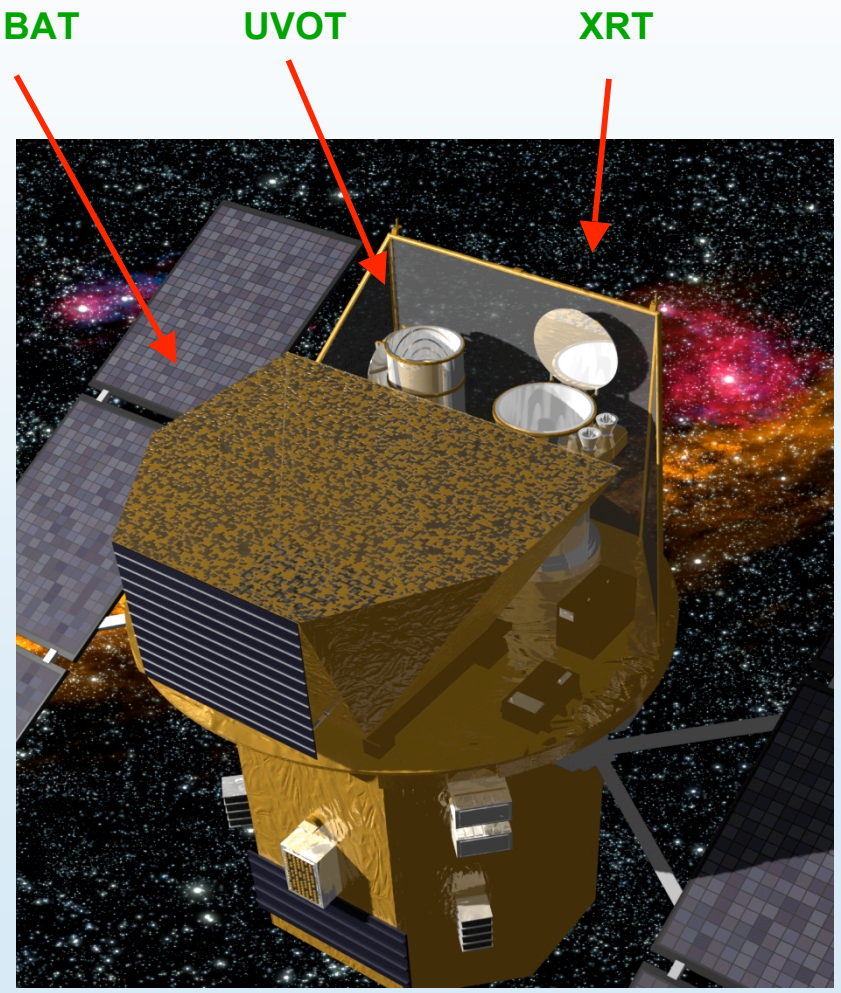
- Variability of AGN at hardest X-rays
- The Swift/BAT 9 month survey
- Swift/BAT detected AGN in the 9 month survey
- Scientific goals of variability analysis
- Variability analysis:
- Maximum Likelihood approach
- Structure Function
- Results
- Future work

# Swift Observatory

- Launched November 2004

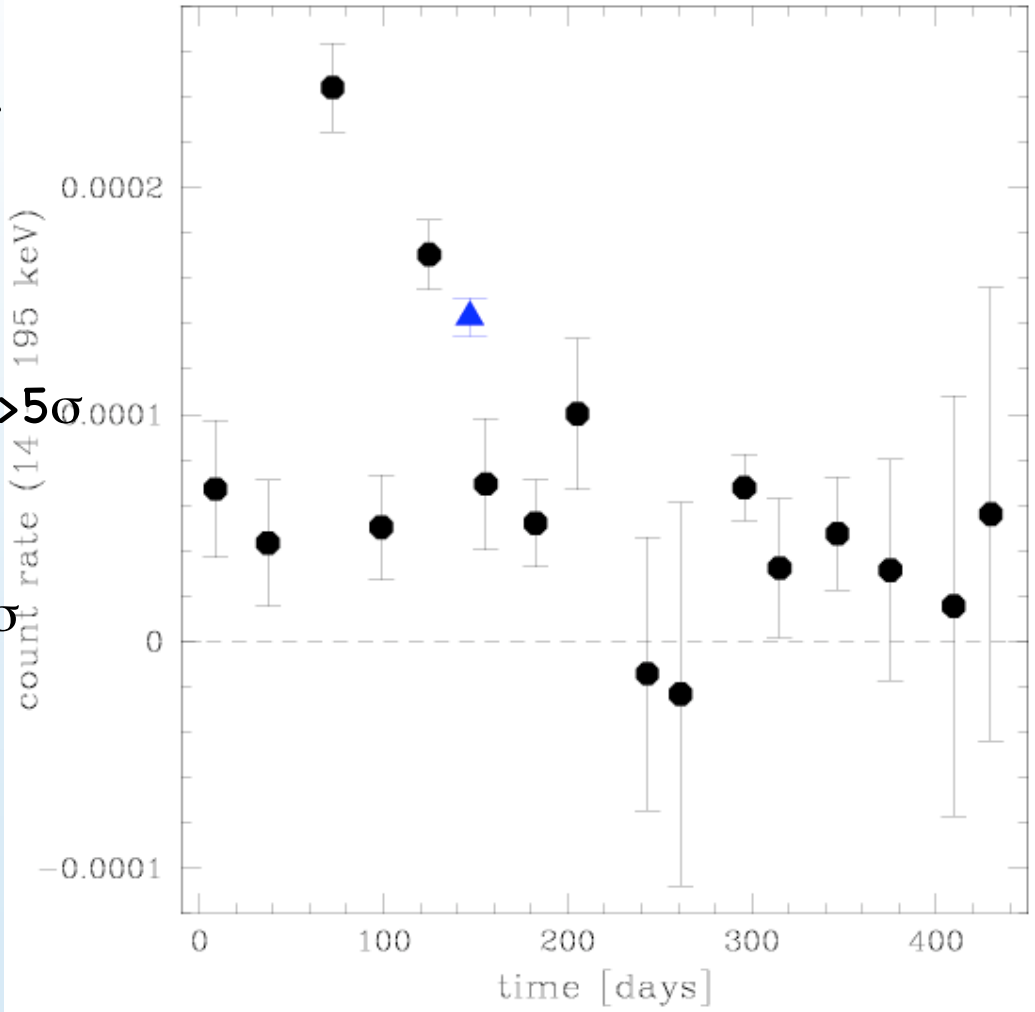
- Swift studies GRBs
- Random observation of the sky
- Swift/BAT: 15 -195 keV
- Large field of view: 2 sr

- Swift observatory paper:
  Gehrels et al. 2004, ApJ, 611, 1005



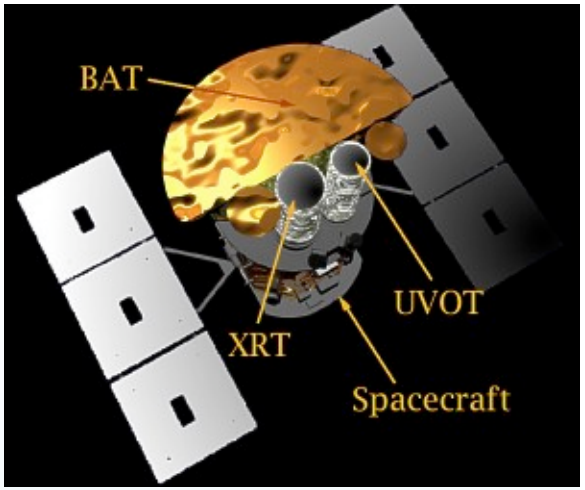
# Swift/BAT 9 month survey

- First 9 months of survey, starting December 2004
- Dwell-by-dwell (pointing) data
- 15 - 195 keV count rates
- 4 energy bands
- 408 sources with significance >5σ
- 160 AGN (w/o unid. sources)
- 44 AGN with significance >10σ




NGC 2992; Beckmann, Gehrels, Tueller (2007)

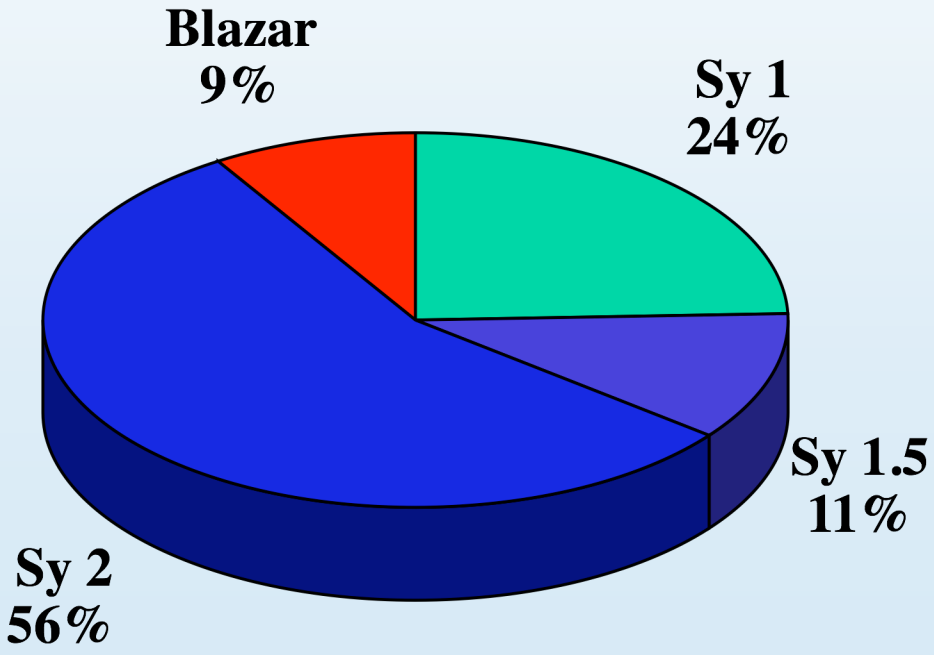
# Swift/BAT 9 month survey




- 44 AGN with significance >10σ
- 11 Seyfert 1
- 5 Seyfert 1.5
- 1 Seyfert 1.8 and 1 Seyfert 1.9
- 22 Seyfert 2
- 4 Blazars

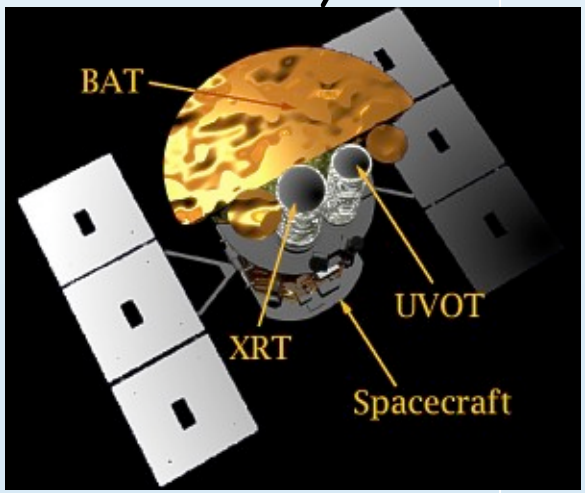
  (3C 273, 3C 454.3,

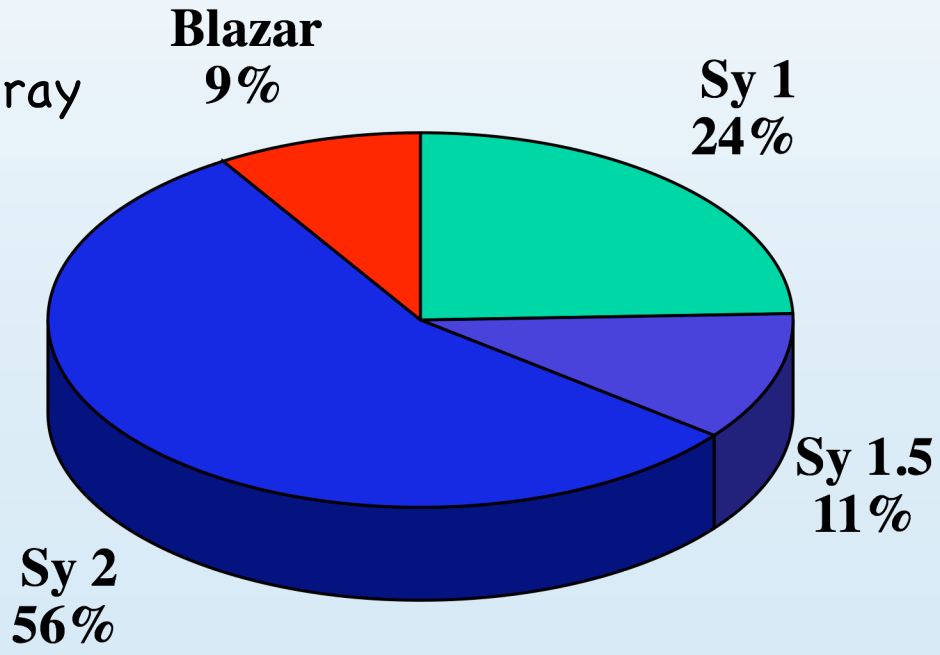
  4C +71.07, Mrk 421)



# Scientific goals

- Do AGN show variability above 15 keV ?
- On what time scales ?
- Does variability depend on source type ?
- Does variability depend on intrinsic absorption ?
- What processes drive the hard X-ray Variability?

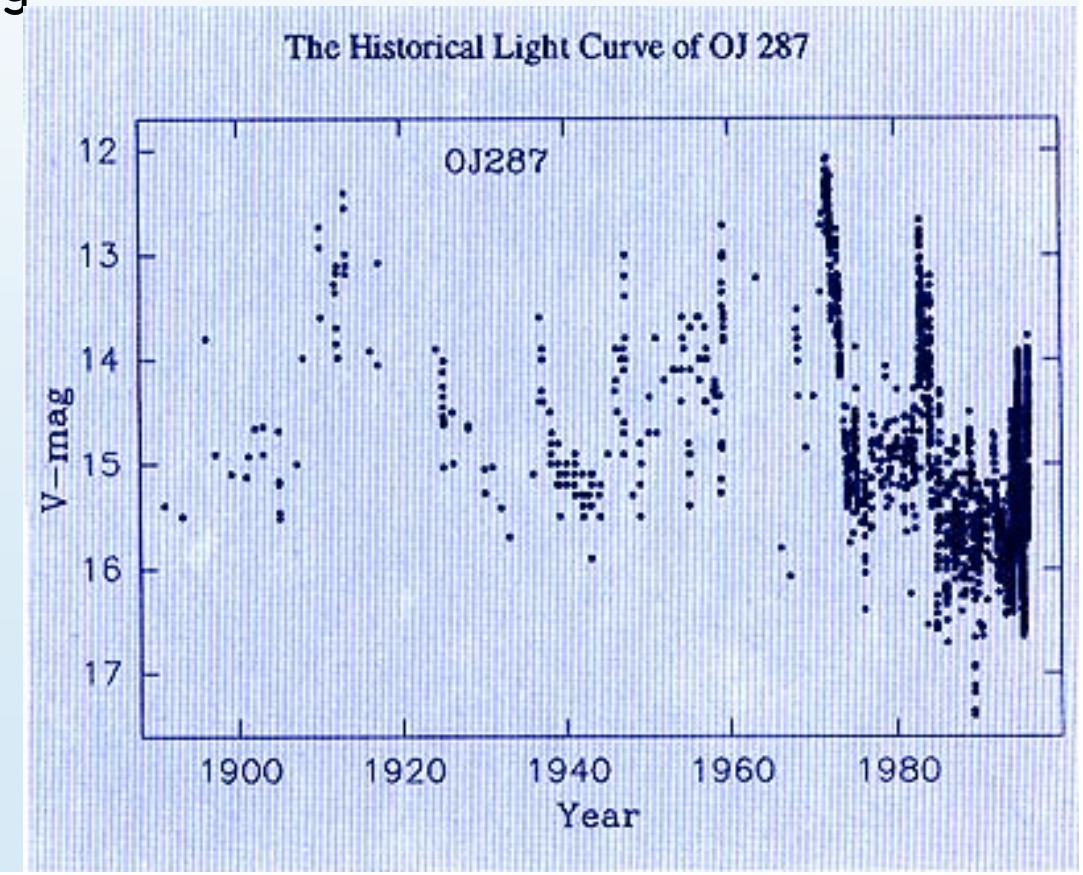


# Variability in AGN

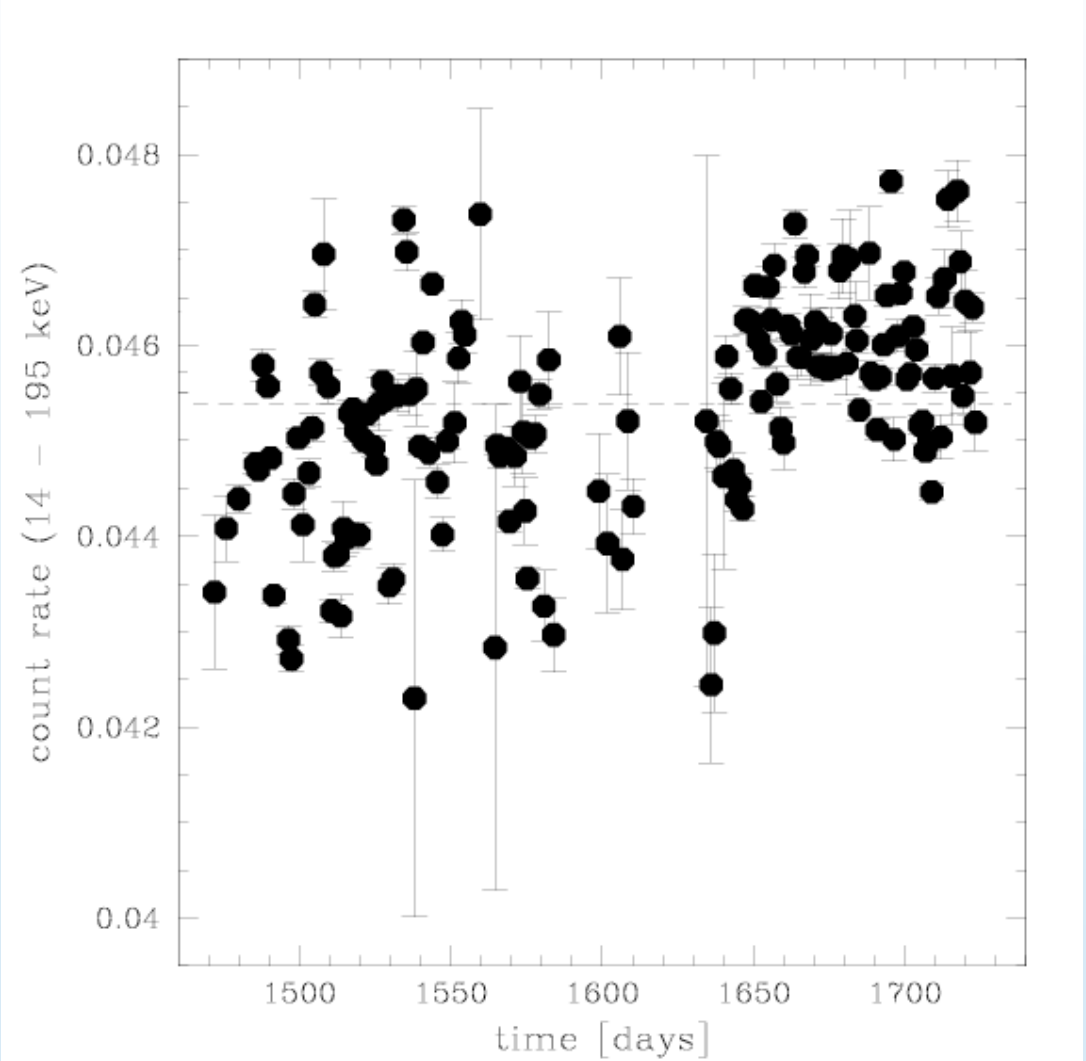
- AGN show variability on all time scales
- AGN do not show periodicity (except OJ 287 with 11 year cycle)
- We can though learn something from the strength of variability on different time scales

CGRO/BATSE did long term hard X-ray lightcurves but with lower sensitivity, thus less information on short time-scales



# Test Variability

- $\chi^2$ test - only for correct errors (systematic error?)




Crab lightcurve
from Swift/BAT
9 month survey

# Maximum likelihood estimator

- Variance has two components: noise and intrinsic variability $\sigma_Q$
- Assume that the intrinsic variability is constant
- For Gaussian statistics we can determine the probability density for obtaining the N measurements $(x_i, \sigma_i)$
- This can be solved in a simple least $\chi^2$ form (see Almaini et al. 2000, MNRAS, 315, 325, for details):

$$\sum_{i=1}^{N} \frac{(x_i - \bar{x})^2 - (\sigma_i^2 + \sigma_Q^2)}{(\sigma_i^2 + \sigma_Q^2)^2} = 0$$

- this becomes the excess variance for constant $\sigma_i$

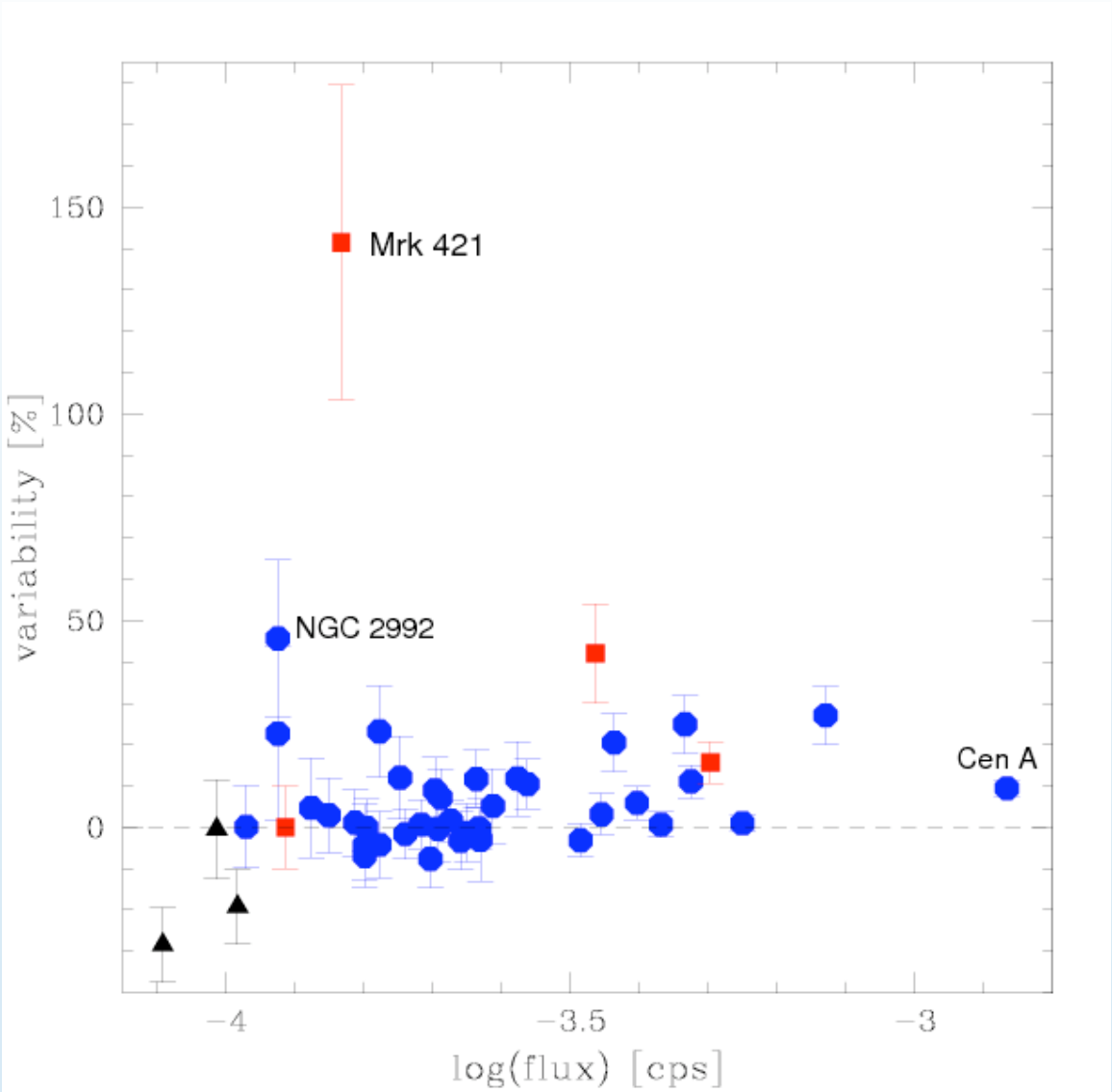
# Maximum likelihood estimator

- In order to estimate the systematics:
- Use the Crab lightcurve ($\sigma_Q = 1$ - $2$ %, depending on time scale)
- Use random positions in the sky to get the absolute offset ($f_o$)
- $\sigma_Q$ depends on time scale (too short - too much noise; too long - you lose information)
- We tried 1, 7, 20, 40 day time scale
- 20 day, random position: $\sigma_Q = 0.000036$ cps ($= f_o$)
- Small compared to Crab (0.045 cps) but close to faintest sources (0.0001 cps) and similar size as the $\sigma_Q$ of faint sources
- Variability estimator: $(\sigma_Q - f_o)/ f_X * 100\%$
- Errors through Monte Carlo simulation

$$\sum_{i=1}^{N} \frac{(x_i - \bar{x})^2 - (\sigma_i^2 + \sigma_Q^2)}{(\sigma_i^2 + \sigma_Q^2)^2} = 0$$

# Maximum likelihood estimator

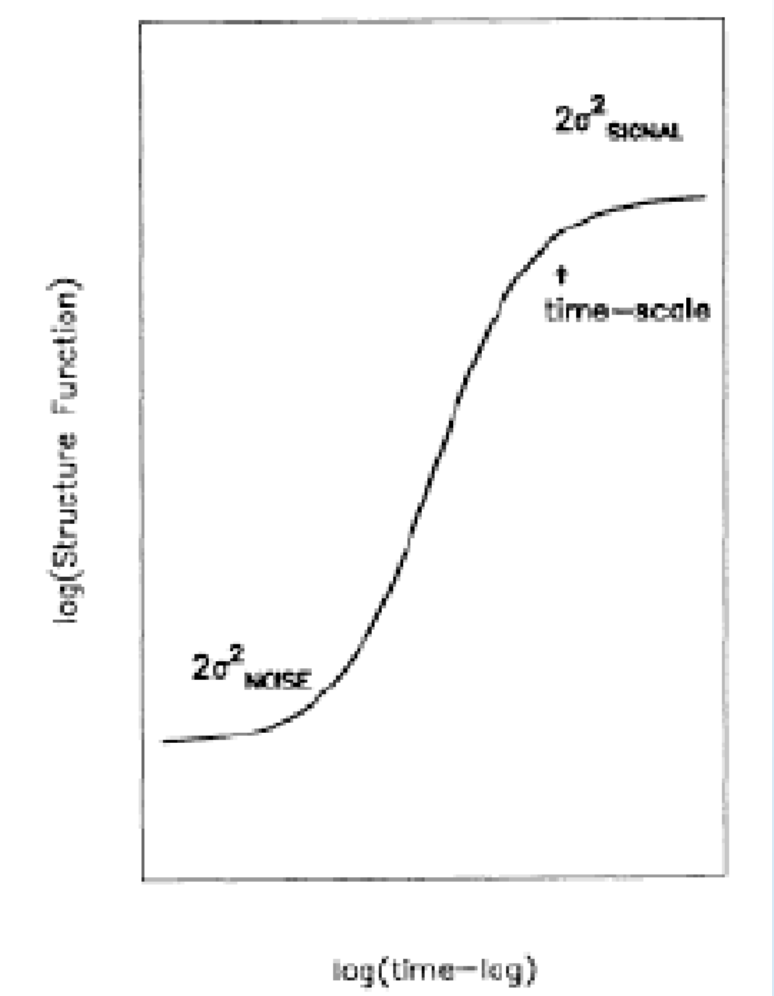
The variability is not a function of source flux




Blazars in red

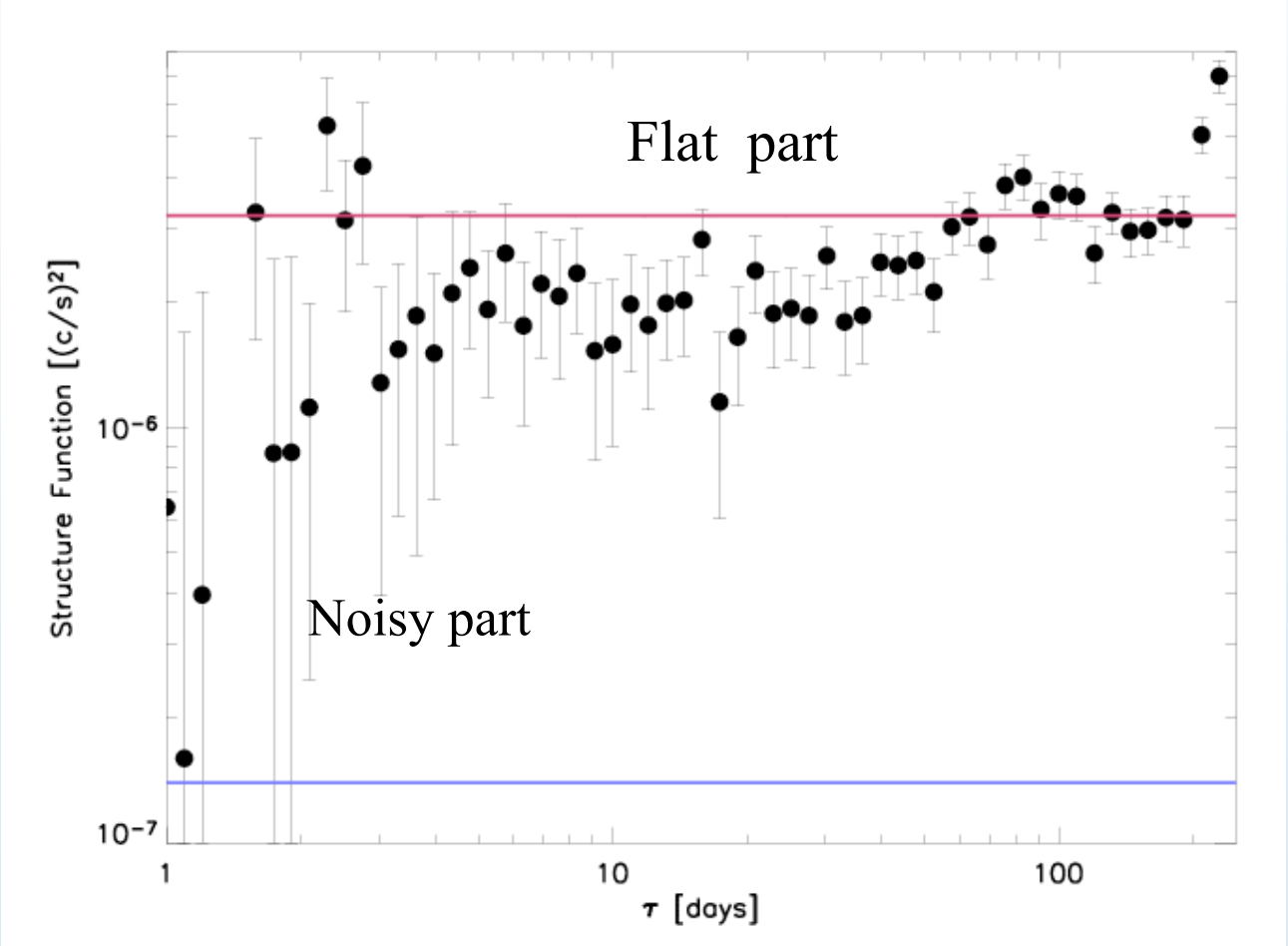
# Structure Function

Correlate each point of the lightcurve with the one at a given time difference $\tau$, sum up, and compare (see e.g. Paltani 1999, PASPC 159, 293; Simonetti et al. 1985, ApJ, 296, 46)



# Structure Function

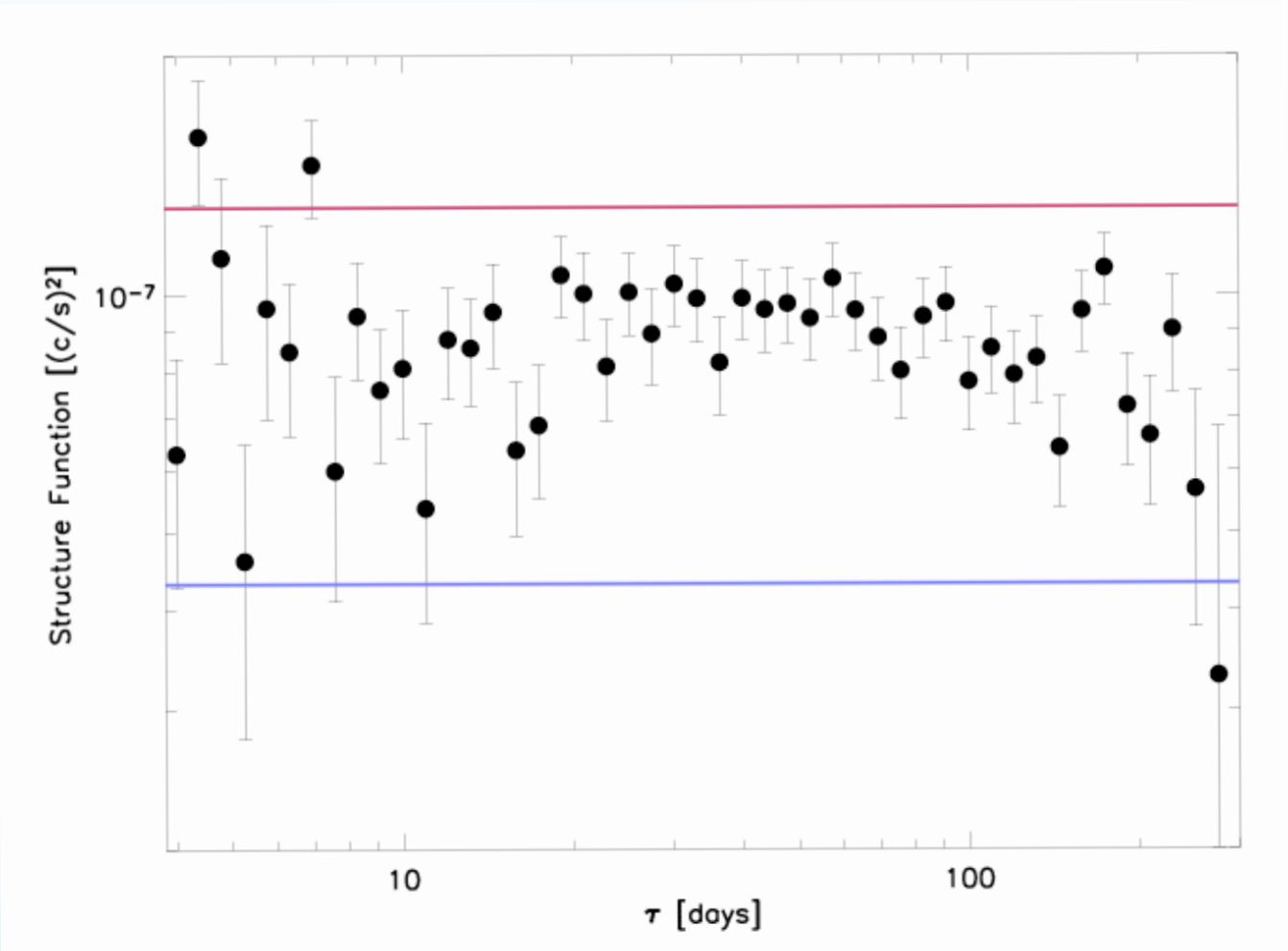
First test: How does the Structure Function look for a constant source?



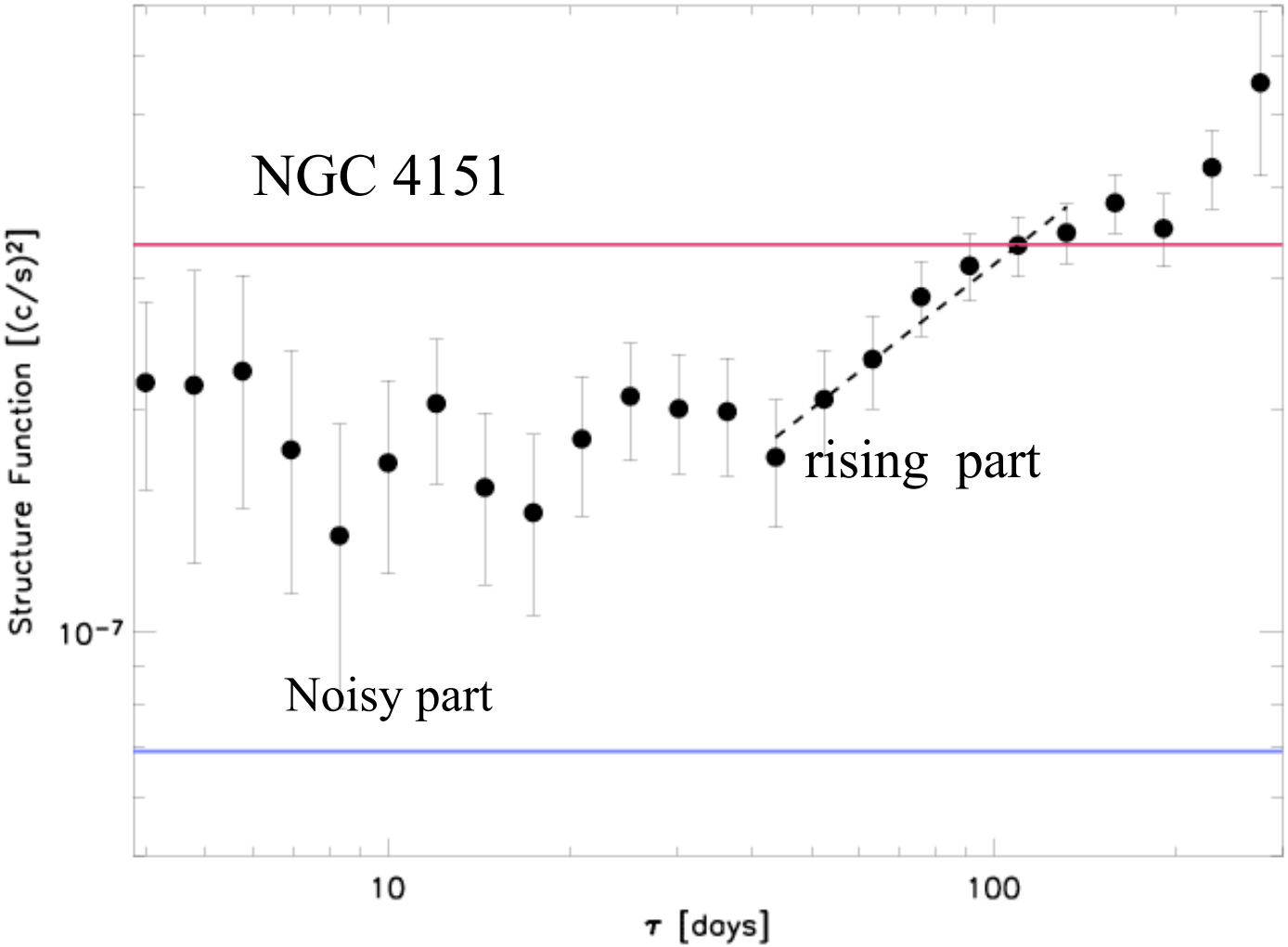
# Structure Function

Second test:

How does the Structure Function look for a random (= not existing) source?

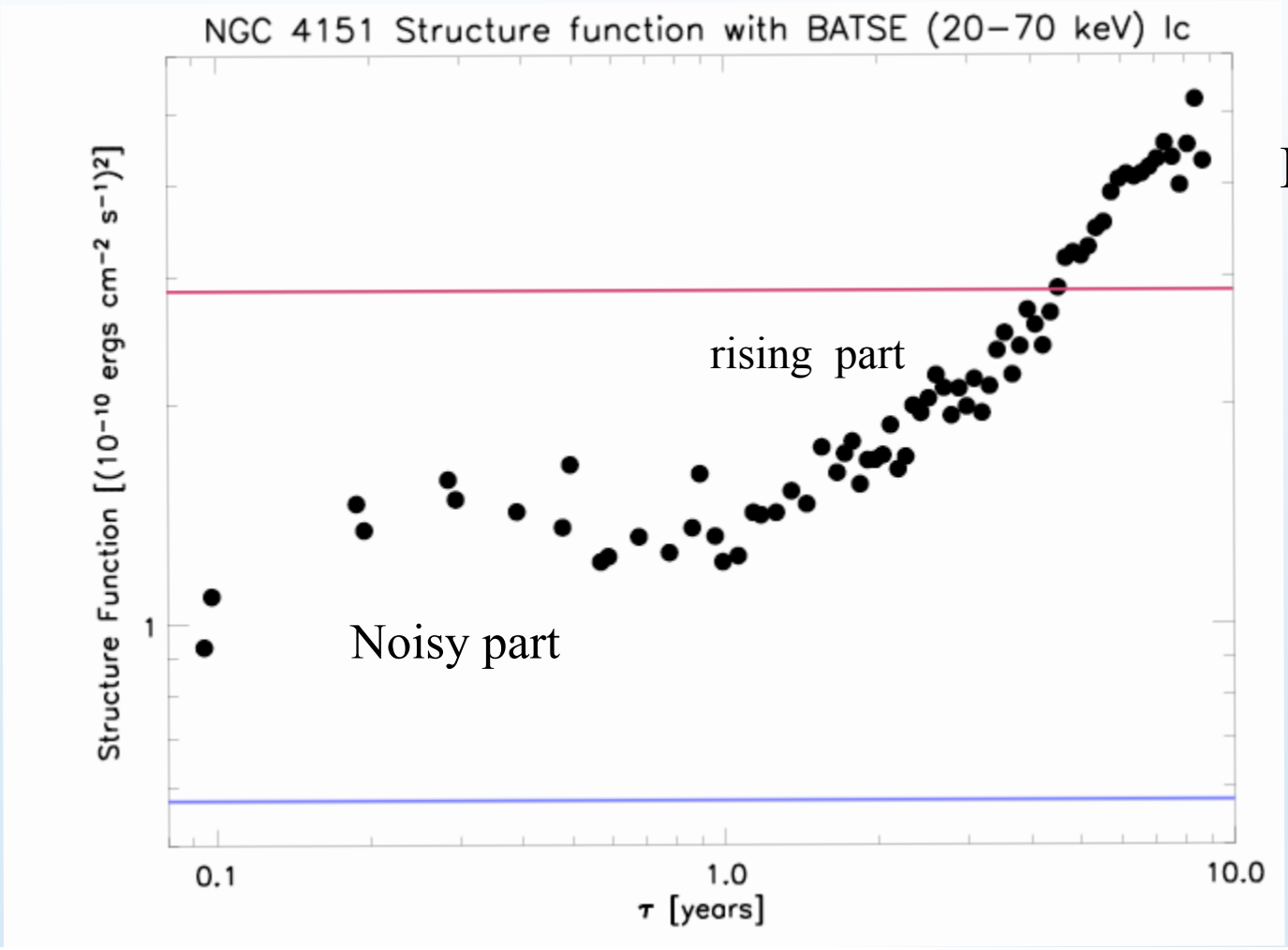


# Structure Function
## for a variable source



# Structure Function

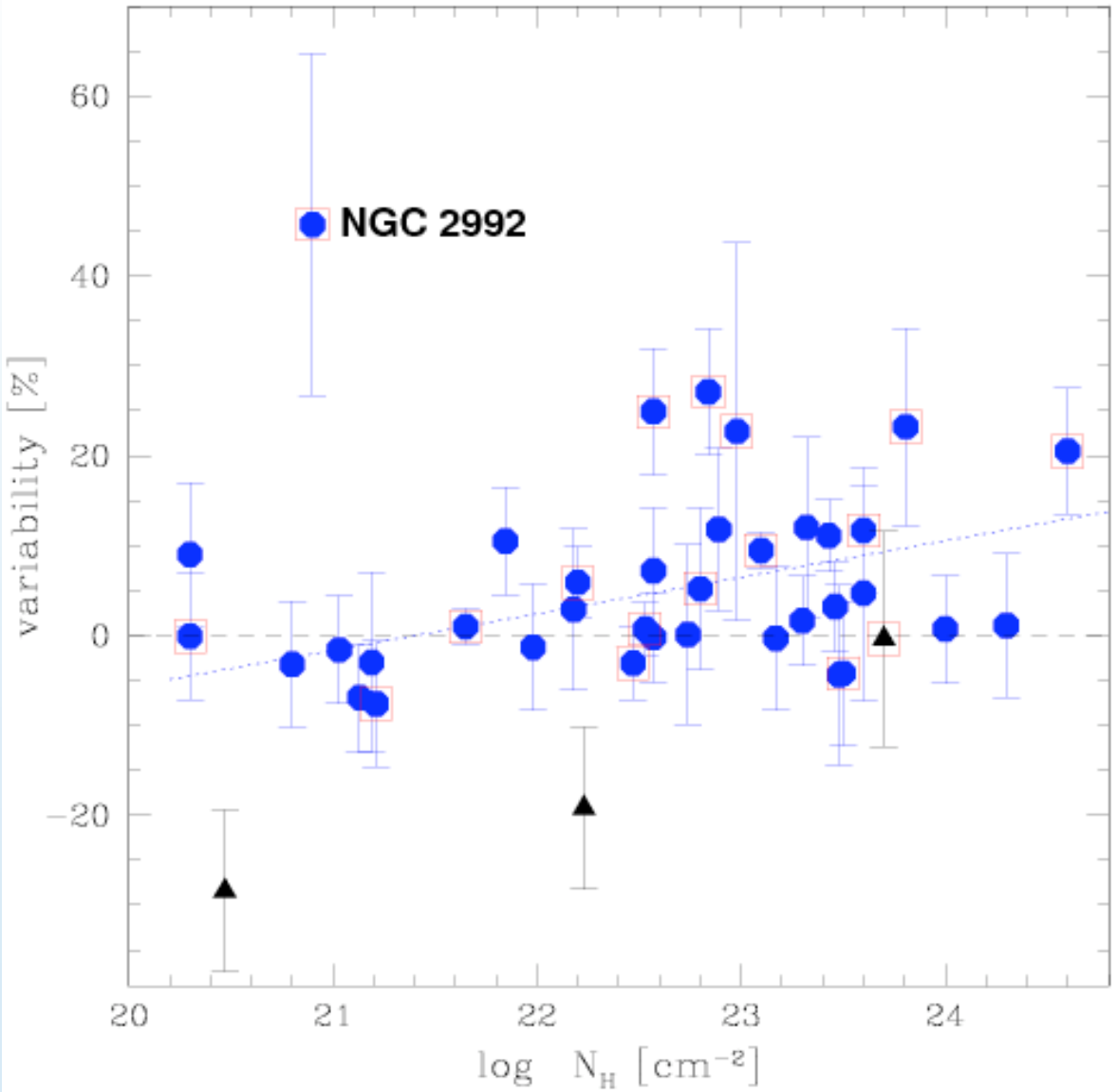
Compare structure function based on BAT with one based on CGRO/BATSE




Plateau ?

# Variability as a function of absorption?

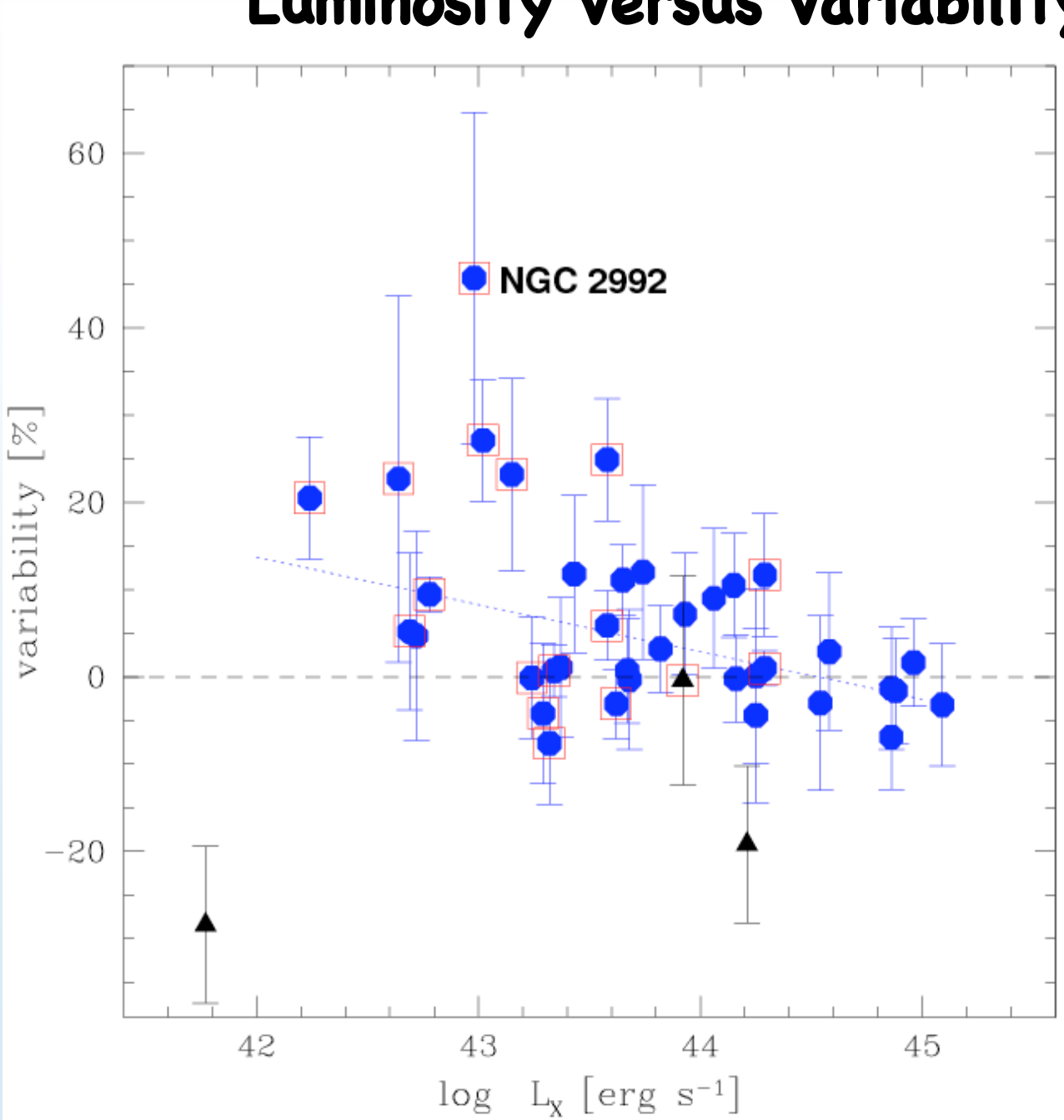
Variability seems to be a function of intrinsic absorption $N_H$




Blazars excluded

Red squares: variable according to SF

# Luminosity versus variability




Red squares: Variable according to SF analysis

# Results

- 44 Swift/BAT AGN
- 30% of Seyfert type AGN exhibit variability
- strong variability seen in blazars
- 15% show >20% variability in maximum likelihood estimator
- type 1 objects seem to be less variable than type 2
- probably a function of luminosity:
- variable objects are the ones with $Lx < 10^{44}$ erg $sec^{-1}$
- seen previously at soft X-rays, optical, UV
- Beckmann et al. 2007, A&A accepted, astro-ph/0709.2230

# Future work

- underlying physical process
- with long term lightcurves determine $\tau_{max}$
- can we learn something from the SF about the magnitude of variability?
- are absorbed/unabsorbed sources intrinsically different?
- use of INTEGRAL lightcurves to study shorter time scales