Spectral and Time Series Analyses of the Seyfert 1 AGN: Zw 229.015

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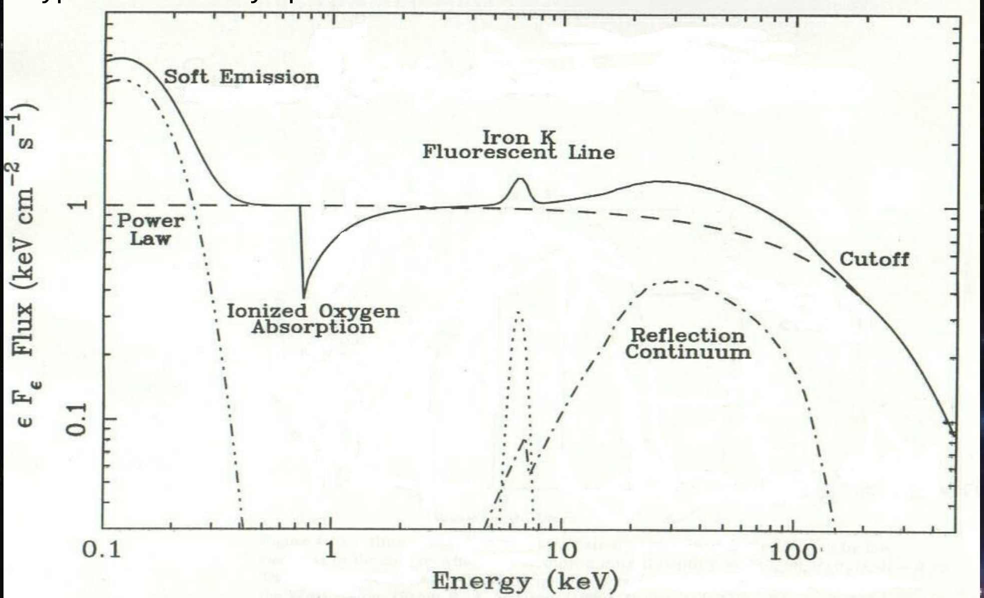
Outline

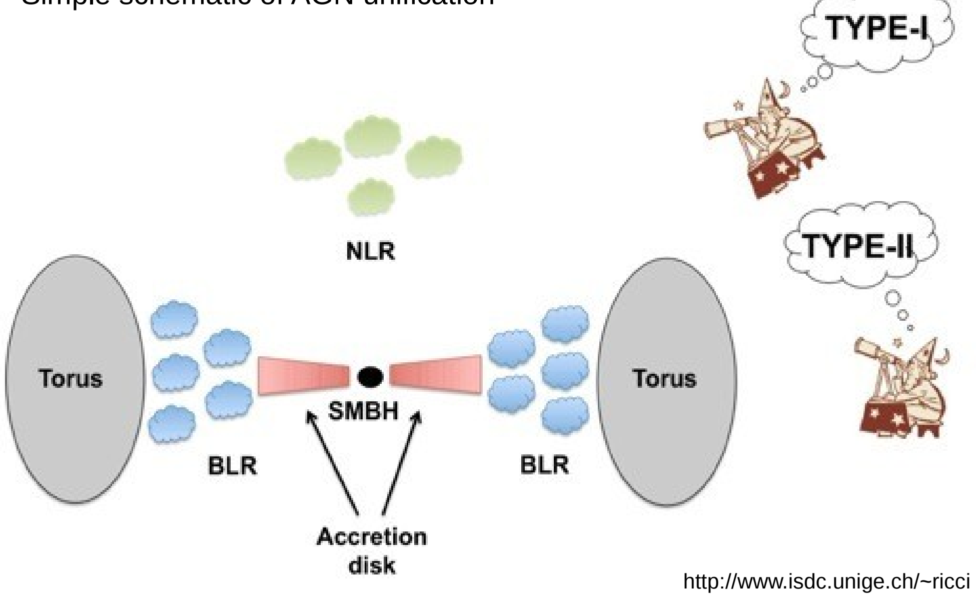
- Motivation & Brief Introduction
- Spectral Analysis
  - ✓ XMM-Newton EPIC data
- Timing Analysis
  - ✓ Cross-Correlation Function
  - ✓ Nonlinear Timing Analysis
- Conclusion & Summary

Introduction & Motivation

Typical AGN X-ray spectra



Simple schematic of AGN unification



- Zw 229.015 is a Seyfert 1 AGN at a redshift of 0.0275
- Its mass has been estimated to be about 10^7 solar masses by Barth et al. (2011)
- It was observed continuously by Kepler telescope from 2011 to 2014
- Our aim is to carry out simultaneous X-ray and optical analysis for the source
- This source has been well studied in the optical, thus X-ray analysis can further help in adequate modelling of such Seyfert 1 AGNs.

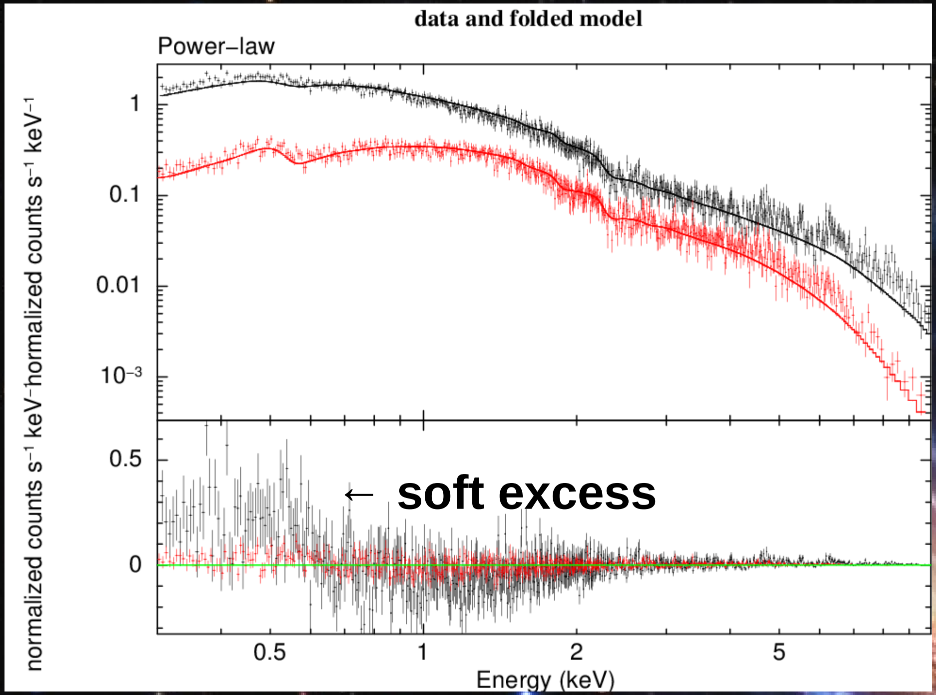
Spectral Analysis

- The data used in this analysis is the archival EPIC-PN and MOS data of the source obtained on June 5, 2011 on-board XMM-Newton.

- Data reduction followed standard procedure provided by the SAS software

- We fit the spectra in the range (0.3-10.0kev) with a simple powerlaw and observe the presence of some soft excess below 1.0kev (as shown below)

Plot of power-law spectral fit and its residue



Power-law fit parameters

Wabs nH (cm^{-2})	6.25 X 10^{20}
Photon index	2.04±0.006
X^2/d.o.f	2050/1410

Fitted Spectral Models

- Multi-colour Disc Blackbody Model [diskbb] (Mitsuda et al. 1984, Makishima et al. 1986)
- Smeared Absorption Wind Model [swind1] (Gierlinski & Done 2004)
- Thermal Componisation Model [compTT] (Titarchuk 1994)
- Relativistically Blurred Reflection Model [reflionx] (Ross & Fabian 2005)

Spectral plots for all four models

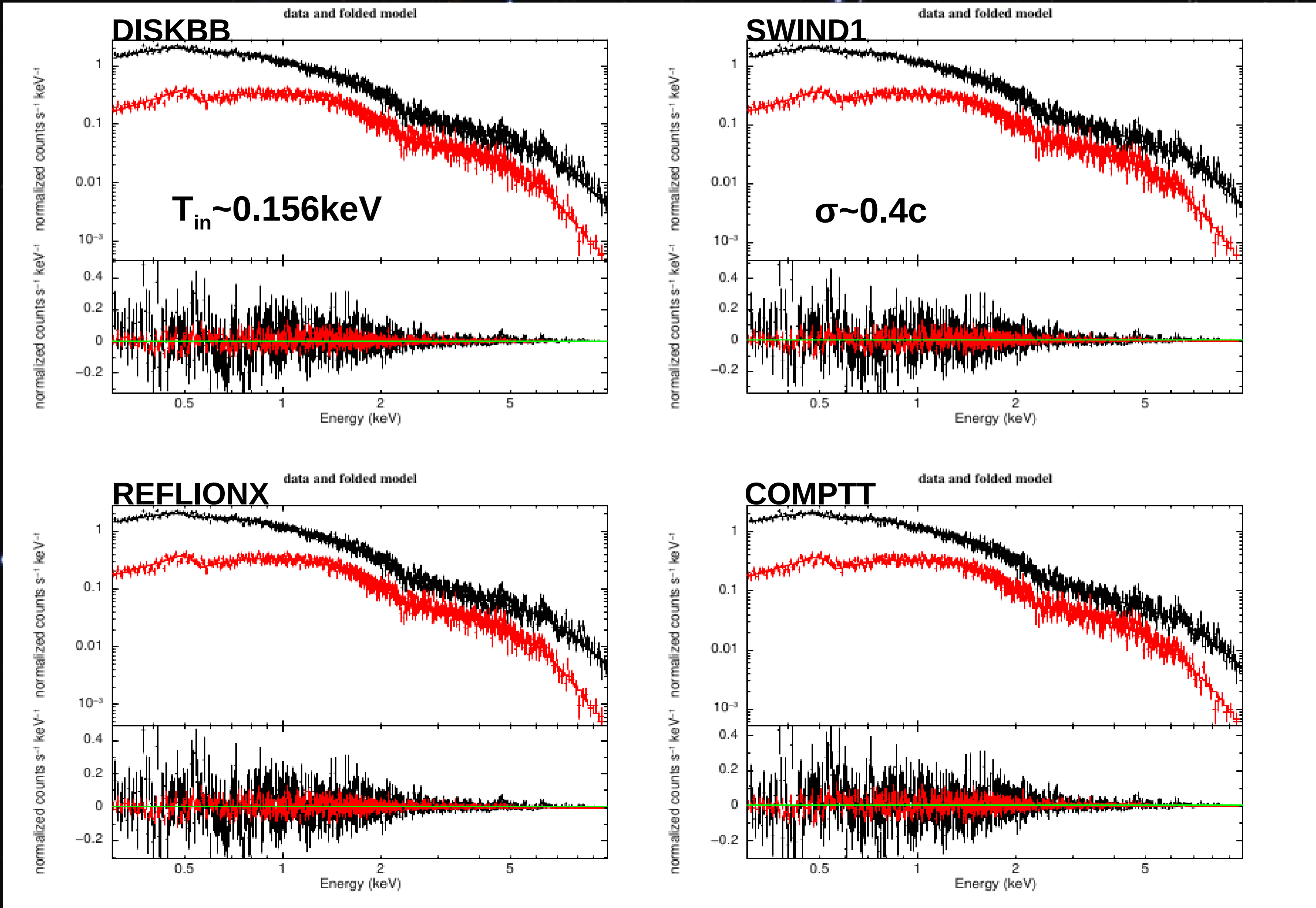
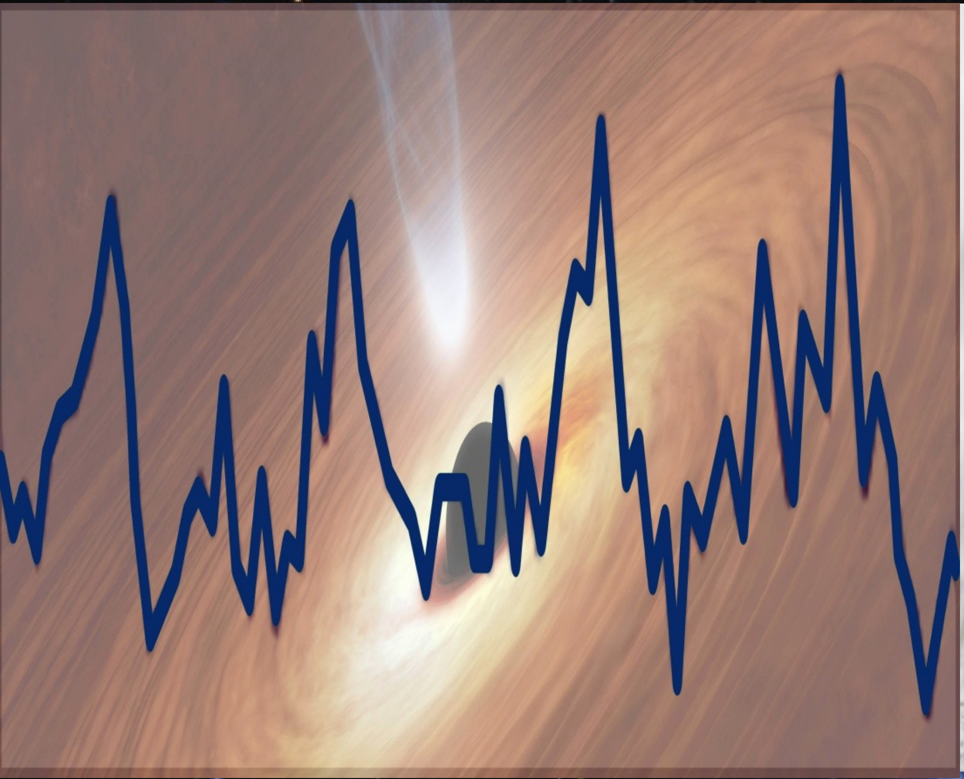


Table showing best-fit parameters

Model/Parameter & Best-fit values	
Model	constant*wabs*(diskbb+zpo)
Calibration factor (CF)	0.993 ± 0.008
T_{in} (keV)	0.156 ± 0.004
Photon index Γ	1.80 ± 0.013
χ^2/dof	1491/1408
Flux (erg cm^{-2} s^{-1})	6.655×10^{-12}
L (erg s^{-1})	1.14×10^{43}
Model	constant*wabs*(swind1*zpo)
Calibration factor (CF)	0.993 ± 0.008
Col. density ($\times 10^{22}$ cm^{-2})	13.80 ± 2.27
Log(ξ/erg cm s^{-1})	3.11 ± 0.07
σ (in units of v/c)	0.38 ± 0.04
Photon index Γ	1.96 ± 0.01
χ^2/dof	1439/1406
Flux (erg cm^{-2} s^{-1})	6.72×10^{-12}
L (erg s^{-1})	1.15×10^{43}
Model	constant*wabs*kdblur(atable{reflionx.mod}+zpo)
Calibration factor (CF)	0.991 ± 0.008
kdblur index	4.22 ± 1.45
$R_{in}(\frac{GM}{c^2})$	3.999 ± 0.491
Inclination(deg)	30
Photon index Γ	1.52 ± 0.082
Fe/Solar	0.469 ± 0.095
Reflionx Xi (erg cm s^{-1})	2308.32 ± 658.28
χ^2/dof	1436/1404
Flux (erg cm^{-2} s^{-1})	6.676×10^{-12}
L (erg s^{-1})	1.15×10^{43}
Model	constant*wabs*(comptt+zpo) *disc approximation*
Calibration factor (CF)	0.993 ± 0.008
T_0 (keV)	0.03
KT_e (keV)	0.632 ± 0.232
Optical depth τ_p	8.72 ± 1.63
Photon index Γ	1.52 ± 0.10
χ^2/dof	1435/1413
Flux (erg cm^{-2} s^{-1})	6.83×10^{-12}
L (erg s^{-1})	1.18×10^{43}

Timing Analysis

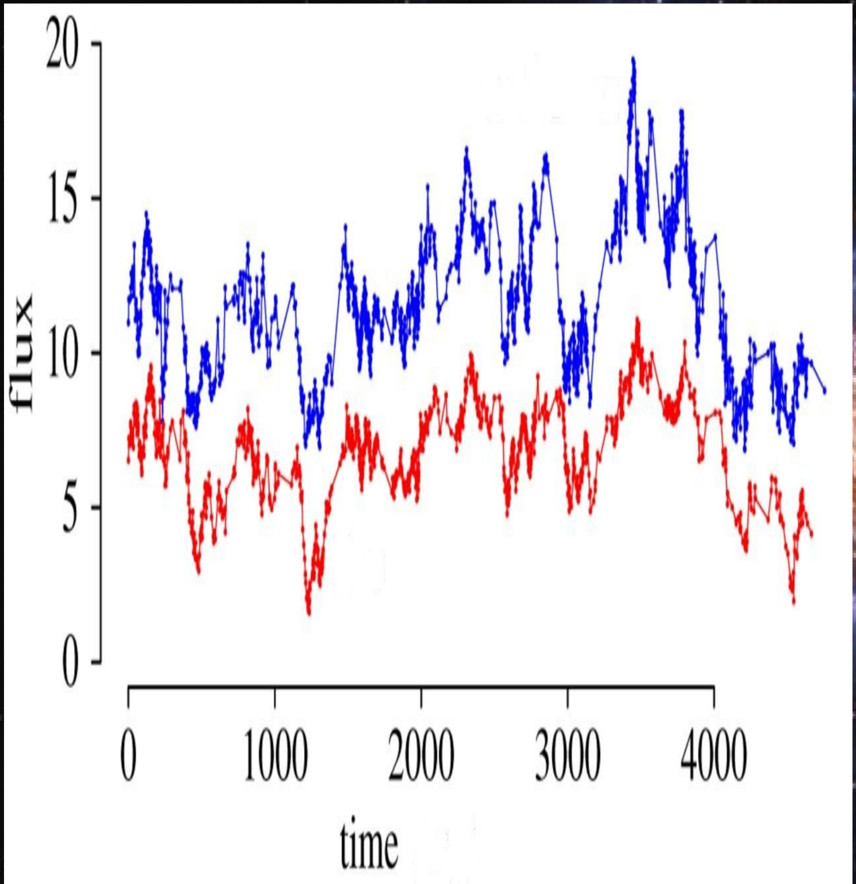


- ✓ Cross-Correlation Analysis
- ✓ Nonlinear Timing Analysis

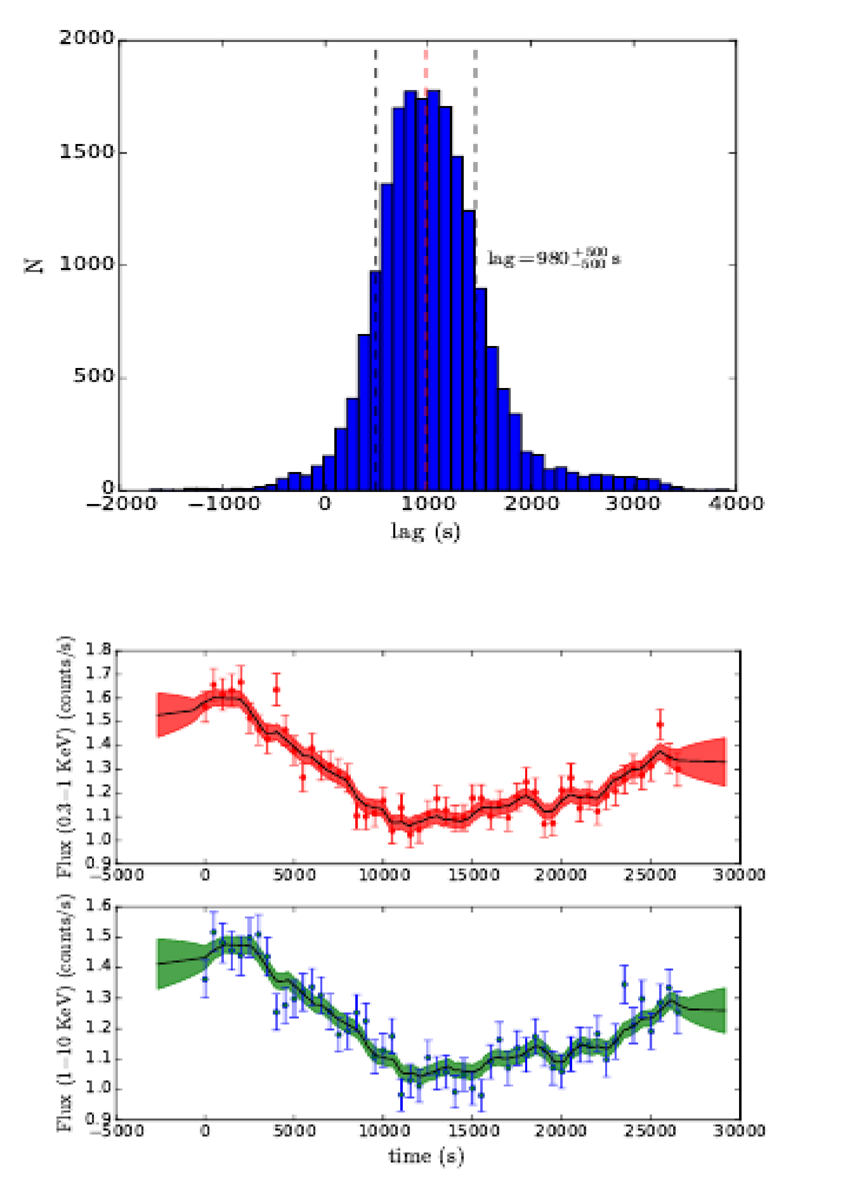
Cross-Correlation Analysis

Soft band: 0.3-1keV

Hard band: 1-10keV

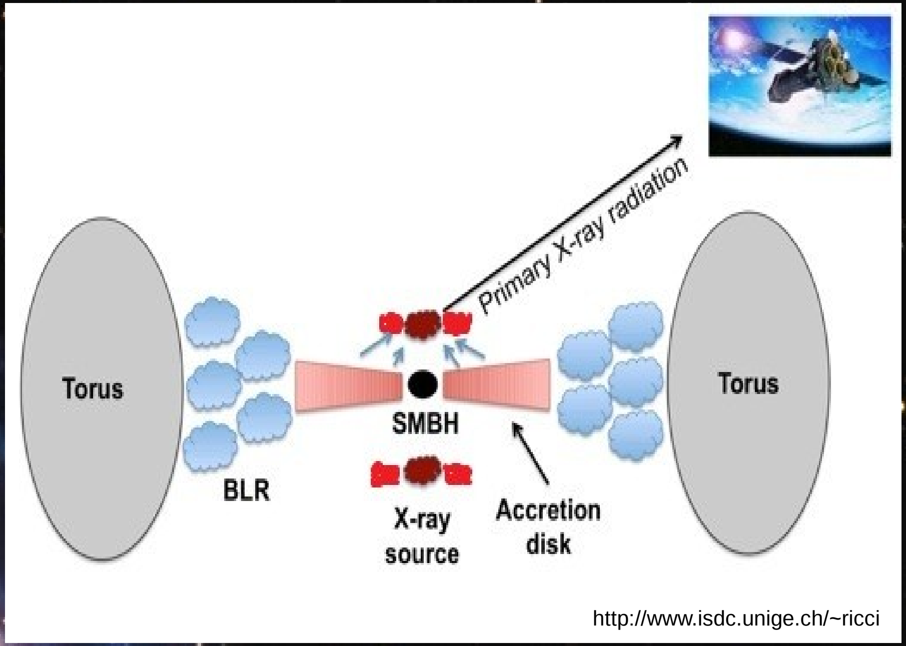


Time lag estimate using JAVELIN code



Estimation of corona size from time lag

• If T_{lag} ≈1000 s is the time it takes the soft photons from the cold corona to reach the hot corona where they are comptonised to higher energies, the separation d between the two coronae system can be roughly estimated to be:

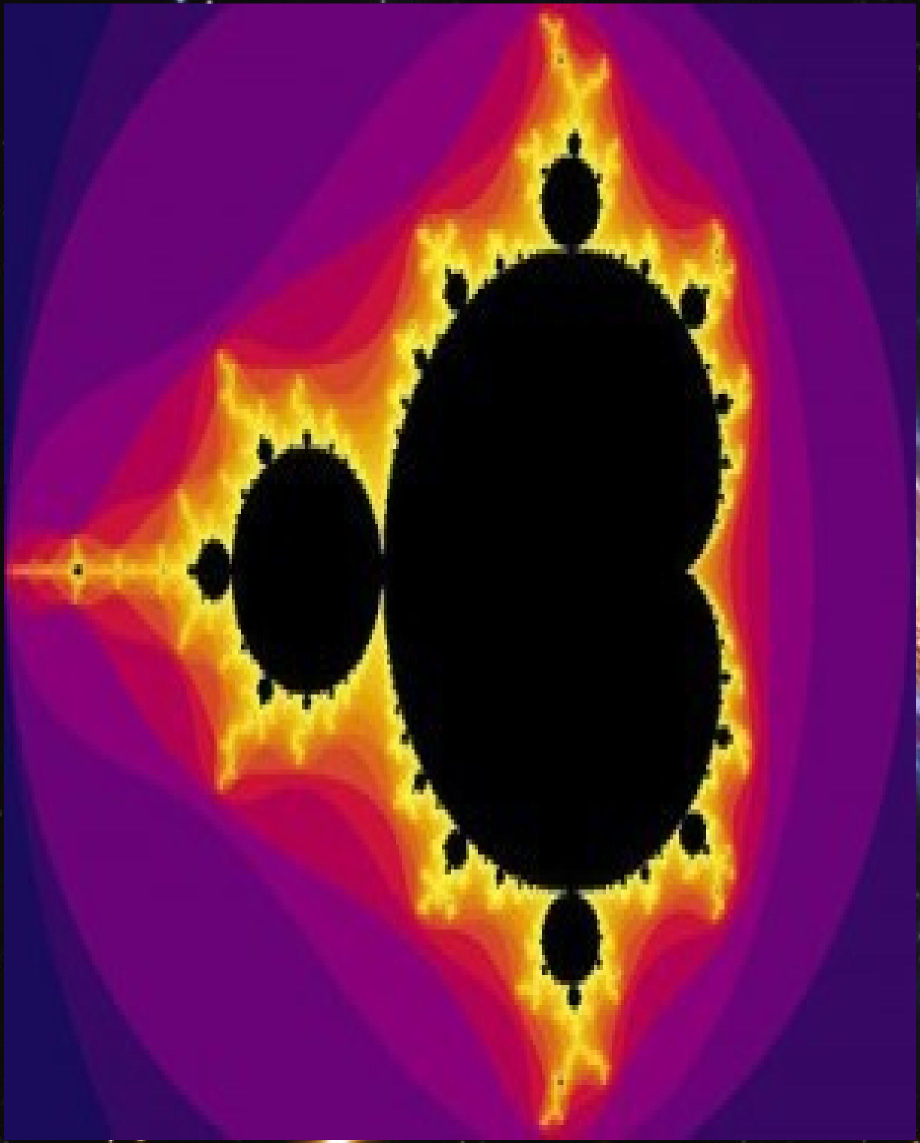


$$d = c \times T_{lag}$$
$$\approx 3 \times 10^{13}\ \mathrm{cm}$$
$$= 20R_g$$

• This indicates that the coronae system is very compact and outside this region, the disc emission will be dominated plausibly by Optical/UV photons.

Nonlinear Timing Analysis

A search for signatures of Chaos



- Vectors of dimension M are created from the time series $s(t_i)$ using a delay time τ such that:

$$x(t_i)=[s(t_i), s(t_i+\tau), s(t_i+2\tau),\ldots,s(t_i+(M-1)\tau)]$$

- The correlation integral is given by

$$C_M(R) = \frac{1}{N(N_c-1)} \sum_{i=1}^{N} \sum_{j\neq i\ j=1}^{N_c} H(R-|x_i-x_j|),$$

and the corresponding correlation dimension by

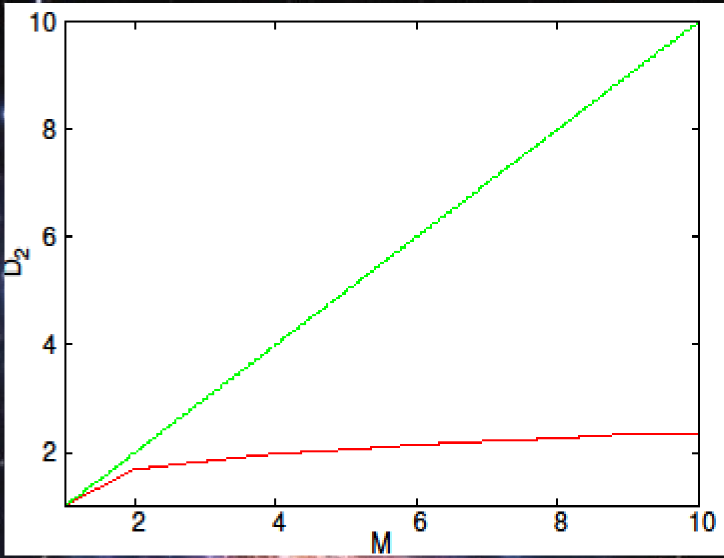
$$D_2 = \lim_{R\to 0}\left(\frac{d\log C_M(R)}{d\log R}\right).$$

- The plot of D_2 against M reveals the nonlinear dynamical properties of the system

Plots of D_2 as a function of M

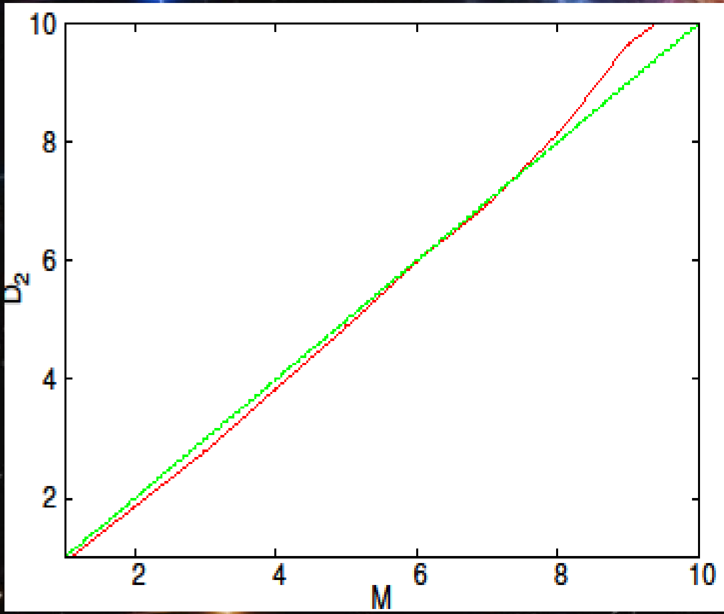
Unsaturated $D_2(M)$ implies stochasticity

Lorentz data

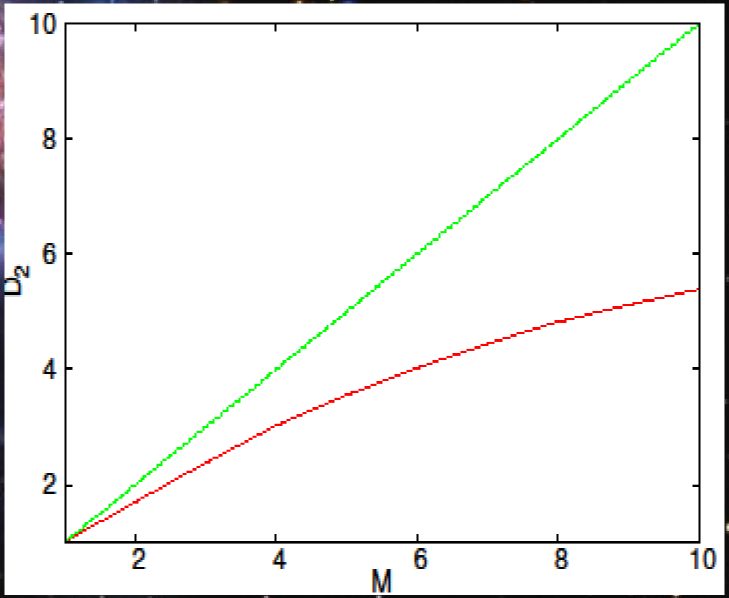


Saturated $D_2(M)$ implies fractal behaviour

XMM-Newton data



Kepler data



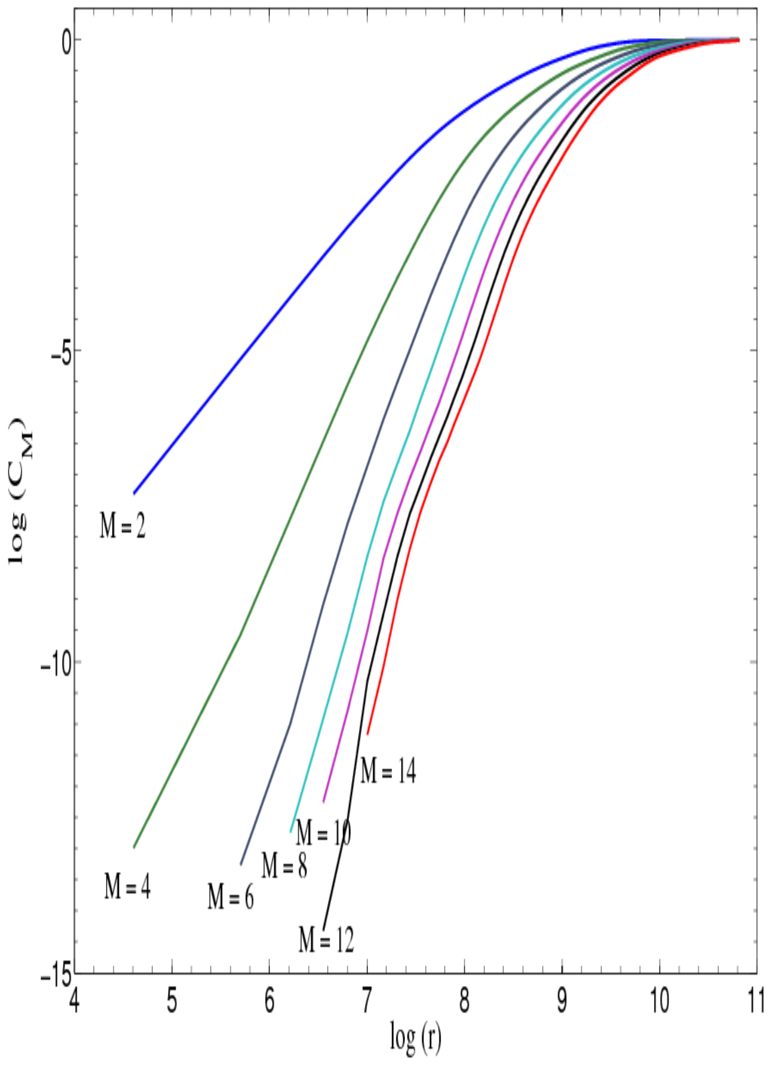
Conclusion & Summary

- The presence of weak soft excess emission has been observed below 1.0 kev
- The **thermal comptonization** and **relativistically blurred reflection** models give the most acceptable explanations to the possible origin of the soft excess as supported by cross correlation analysis of the lightcurves in two energy bands.
- From the observed positive lag between the soft and hard energy bands, we inferred that they are plausibly emitted from different regions extending only up to $20R_g$
- We have not found signatures of low dimensional chaos in both the optical and X-ray lightcurves of the source which may have important implications for the flow dynamics
- Multi wavelength studies of the spectral and timing properties of such sources by ASTROSAT and self-consistent MHD simulations will put further constraints on the above models


Thank you!!!

A search for signatures of Chaos

Typical plot of $\log(C_M)$ vs $\log(R)$



- We use XMM-Newton and Kepler lightcurves for the nonlinear time series analysis

- We apply the nonlinear time series analysis method involving the delay embedding technique (Grassberger & Procaccia 1983).

- Vectors of dimension M are created from the time series $s(t_i)$ using a delay time τ such that:

$$x(t_i)=[s(t_i), s(t_i+ \tau), s(t_i+ 2\tau),\ldots,s(t_i+(M-1)\tau)]$$

where M is the embedding dimension and τ is suitably chosen such that the vectors are not correlated