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MEMO

Date	24/03/2023	**Ref**	N/A
From	Matteo Guainazzi	**Visa**	N/A
To	Scientific Council of CAMK PAN		
Copy	N/A		

Subject: Review of the Ph.D. dissertation of Mrs. Saikruba Krishnan

I have read with great pleasure the Doctoral Thesis by Mrs. Saikruba Krishnan: "*Time-domain and Spectroscopic studies of Active Galactic Nuclei*". It is an original and interesting work, addressing important questions in modern extragalactic astrophysics.

The thesis is structured on two main projects, both related to the rigorous characterization and interpretation of photometric and spectroscopic variability in accreting super-massive black holes in galaxies: Active Galactic Nuclei (AGN). Variability is a defining characteristic of AGN. It holds the key to understanding a wide range of properties of their astrophysical systems: the accretion disk, the coupling between the disk and the X-ray emitting corona, the geometrical distribution and physical properties of gas and dust in the nuclear environment that could explain the simultaneous occurrence of out- (AGN feedback) and inflows (AGN feeding).

The first project is inspired by the Laplace's principle: "*The weight of evidence for an extraordinary claim must be proportioned to its strangeness*". It addresses the robustness – in terms of statistical significance and uniqueness of the astrophysical interpretation – of Quasi Periodic Oscillations (QPOs), recently claimed in a few AGN. If true, these detections would be crucial to inform our understanding of the innermost regions of the accretion flow, also because they would support scaling relations between AGN and stellar-mass accreting black holes. Available data quality for the latter systems is better by orders of magnitude than AGN over several parameter spaces. Mrs. Krishnan undertook a rigorous and systematic analysis of a representative sample of simulated light curves reflecting the typical noise spectrum observed in AGN optical as well as X-ray light curves. She convincingly shows that claims of QPOs in existing data are – regrettably – void without a proper definition of the null hypothesis probability tests, and without a complete simulation of all potential noise sources in the data. Furthermore, she derives empirical criteria that shall be followed to maximize the probability of true positive and minimize the probability of false positive detections. Her work is a bookcase example of rigorous treatment and uncompromising sharp interpretation of data. It also constitutes a fundamental reference for any scientists willing to undertaking this type of challenging analysis. Her study is particularly timely, due to the forthcoming high-cadence time surveys of the optical sky, which will shortly produce a true flood of good quality light curves. Mrs. Krishnan is aware if the observational context of her study, and appropriately extends it to consider effects related to the inevitably incomplete or irregular sampling of variable phenomena in real data. Finally, she determines the conditions required to detect period signals in putative super-massive black hole binary systems, an exciting field in view of possible multi-messenger observations offered by future space-borne gravitational wave observatories.

The second project deals with a specific variability event ("flare") discovered serendipitously during the X-ray survey carried out by the German experiment eROSITA. Mrs. Krishnan analysed the survey data, as well as data of follow-up pointed observations with XMM-Newton and NICER, to describe the full spectral evolution of a flare in an AGN from its onset to its fading. In her multi-instrument analysis, she shows a good command of the techniques to reduce and analyse X-ray data at moderate energy resolution. She carries out a throughout comparison of the data with state-of-the-art physically motivated models of the accretion disk and corona (and of their coupling). She concludes that changes in the accretion rate are likely to be the main driver of the observed photometric and spectroscopic evolution along the flare. She explains the discrepancy between the observed and the predicted viscous timescales in the disk in terms of a large disk aspect ratio (an explanation consistent with the spectral deconvolution). Even more importantly, Mrs. Krishnan put the X-ray results in the context of photometric and spectroscopic contemporaneous optical observations. As predicted, the fluxes in the optical and UV bands follow the evolution of X-rays during the flare. Optical spectroscopy also suggests changes consistent with a variable illumination of the Broad Line Region clouds, although the discrepant time evolution of different lines (most notably H_β versus HeII) remains puzzling. It could be followed up in the future through photoionization models.

In summary, I consider the doctoral thesis of Mrs. Saikruba Krishnan to be a valuable contribution and to meet the criteria prescribed by the law for a doctoral dissertation. Therefore, I request that this dissertation is admitted to a public defence.

I list hereafter a few comments, which I recommend Mrs. Krishnan to consider in preparing the final version of her thesis prior to the defence.

Faithfully,

Detailed comments

Sect. 1.6, Pag. 15:
The numerical factors preceding the formulae of the dynamical, thermal and viscous timescales do not seem to be consistent:

- The thermal timescale is defined as the orbital timescale multiplied by the inverse of the viscous parameter α. If the latter is expressed in units of 0.01, the numerical factor of formula (1.5) should differ from that of formula (1.4) by 100, as opposed to 16 as in the manuscript;
- Likewise, the viscous timescale is defined as the thermal timescale multiplied by the inverse of the square of the aspect ratio. Once this is included in formula (1.6) with no unit normalization, the numerical factor should not change, as opposed to a 10000 increase in the manuscript.

Table 2.1, Pag. 27:
The standard deviation of τ_2 is reported as 0.

Sect. 2.2.1, Pag. 27:
The definition of the "first" and "second peak" in unclear. The usage of the word "between" seems to imply a locus between two reference points, but only one is specified (the first negative-to-positive crossing, and the second positive-to-negative crossing, respectively)

Sect. 2.2.1, Pag. 28:
I would recommend showing a distribution of the limits on r_{corr}.

Sect. 2.2.2, Pag. 30:
The definition of the "second peak" is unclear here as well. Coupling this comment with that on Sect. 2.2.1 (Pag. 27) above, I would recommend adding a figure that shows the definition of the "first peak" and of the "second peak" for the case of a pure Lorentzian signal, analogous to Figure 2.2

Sect. 2.2.2, Pag. 30:
I would recommend mentioning the total number of false positives detected in the simulations shown in Figure 2.3.

Sect. 2.2.2, Pag. 31:
The statement: "*We present that … unbroken PL model.*" duplicates the previous sentence.

Sect. 2.2.2, Pag. 33:
I would recommend explaining why the recommended threshold on the correlation coefficient is "0.45-0.5", once it is demonstrated in this section that $r_{corr1,2}$ is <0.55 for all sampled frequencies.

Figure 2.5, Pag. 34:
The captions of the middle and bottom panels are inverted.

Figure 2.12, Pag. 45:
The caption for the central panel does not mention the whole range of gaps shown in the figure.

Sect. 2.4.1, Pag. 45:
The units for the $\nu_{\theta min}$ (lower, upper bounds) are missing.

Sect. 2.4.2, Pag. 47:
I would recommend that the manuscript would specify the standard deviation of the distribution of the randomly chosen points around the average sampling for the case of irregular sampling.

Sect. 2.4.3, Pag. 48:
The sentence: "*We find that … cent only at*" is cut.

Sect. 2.4.3, Pag. 48:
I would recommend including in the manuscript a figure showing the results of the tests described in this Section.

Sect. 2.5, Pag. 49:
There are two spelling mistakes in the following sentence: *"- `consistently … can produce `min*"

Sect. 3.2.1 – Pag. 61:
A minus sign is missing in the specification of the coordinates of LCRSB040659.9-385922.

Table 3.3 – Pag. 67:
The units of the normalizations are missing.

Sect. 3.3.1 – Pag. 67:
Models DISKBB and DISKPBB are mentioned without prior description.

Sect. 3.3.1 – Pag. 67:
I would recommend that the manuscript would explain more extensively why the best-fit parameters of the ionized disk reflection are "extreme". A maximally spinning black hole is commonly find in spectroscopic analysis of AGN, and one could expect on physical grounds a highly ionized disk.

Sect. 3.3.1 – Pag. 67:
The statement that `compTT` yields the best model for the soft excess is not justified considering Table 3.2, where the model using *thcomp* yields a significantly better χ^2.

Sect. 3.3.3 – Pag. 69:
The fact that the eROSITA spectra are well fit with simple steep power laws is unrelated to the spectral resolution of the instrument. As a matter of fact, the eROSITA CCDs have a slightly better energy resolution than the EPIC-pn on XMM-Newton.

Table 3.5 – Pag. 72:
The statistical uncertainties on the best-fit parameters are missing. Quoting them is particularly important, because statements on the time variability of the model parameters are made in the manuscript (cf. for instance Sect. 3.6.2, Pag. 78)

Sect. 3.4.1 and 3.4.2 – Pag. 73:
The reduced goodness-of-fit is significantly different between XMM1 & XMM2, and between the two models. Does the difference indicate that one of the two models is preferrable with respect to the other? Where do the models fail in reproducing the data in XMM1? Do the residuals suggest how the model could be further improved?

Table 3.6 – Pag. 75:
The statistical uncertainties on fluxes and widths are missing.

Sect. 3.5 – Pag. 76:
The manuscript should address why it is sensible to use a single epoch estimator of the black hole mass during an event when the UV flux changes significantly. Do the uncertainties on the black hole mass estimate consider the dynamical range of the UV flux?

Sect. 3.6.1 – Pag. 76:
I would recommend removing the galaxy contamination – being constant – from the ATLAS light curve to derive the variation of the AGN optical emission only.

Sect. 4.2 – Pag. 89:
The manuscript should explain why a decrease of the accretion rate and an increase in the truncation radius naturally decreases the temperature of the warm corona.