“Physical Conditions in the Broad-line Regions of Active Galaxies”
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Overall, this PhD thesis represents six published first-author papers focused on a narrow but important set of questions about the quasar broad-line region (BLR), some of its important observable properties, and their relationship to the underlying physical parameters. The papers start with a relatively simple question: can the distribution of the line ratio of Hbeta to optical Fe II be understood theoretical with a simple photoionization model? In general, the answer is yes, and builds in sophistication to include additional spectral properties. This is a good approach for a thesis, and in the end, with some caveats, the thesis has moved our understanding forward.

In this report, I will step through the chapters of the thesis and make critical and constructive comments, as well as recognizing the positive aspects of the work presented. I will finish with a set of general comments in the same spirit.

The introductory overview of chapter 1 shows a good command of the literature in general and the history of the subject, although there is a lot to sort through and those of us who were doing research on this topic during the 1990s might quibble here and there. There is also a good, clear statement about the primary BLR physics. The figures are generally well chosen. There are a few small mistakes that could be corrected, however. For example, the GRAVITY observations of NGC 3783 in Br Gamma are omitted, and the similarity of the FWHM of Hbeta and Fe II described by Boroson and Green (1992) is mischaracterized as the similarity of the equivalent widths. Also the early exponent in the R-L relation described by Kaspi et al. (2000) was 0.7, not 0.5, which required careful host galaxy subtraction of the low luminosity sources that was not done until years later.

On a philosophical point, it is odd that so many have regarded narrow-line Seyfert 1 galaxies (NLS1s) as special when they are merely one end of a continuous distribution. Experts in this subfield should probably stop doing that. Similarly, the population A and B classification repeats a traditional astronomical crime, arbitrarily separating objects in a continuous sequence into a false dichotomy with a poorly chosen nomenclature. This was already long clear when Sulentic and Marziani (2015) posed the question of their distinctness.

Paper 1: Modeling of the Quasar Main Sequence in the Optical Plane [Panda et. al. 2018, Astrophysical Journal, 866, 115

This first paper makes many simplifying assumptions that are almost certainly wrong, but are a very reasonable place to start. I actually like this approach very much despite it being objectively wrong, as this the BLR is complicated and trying to do everything right initially is a very challenging task. Many of the models employed are too simple, for instance, like the SED, but these are expanded in later papers. Still, we recover the conclusions of previous studies that in order to explain the largest R Fe II values, high density and high column density, as well as high metallicity, are likely required.

Probably my biggest criticism is the single-cloud assumption, which is clearly wrong. It is probably a valid approximation for the objects with the largest R Fe II values, which likely have large clouds dominating the emissivity and for which the Hbeta and Fe II time lags are similar (Hu et al. 2015). It is very probably not valid for objects with small R Fe II values. This is really an exercise in seeing if the models can match the largest values of R Fe II. On the other hand, this is fine place to start.

Something that feels lost in some of these papers is recognizing a saying we have in English: the map is not the territory. That is, the results of the models should not be automatically interpreted as the truth. This should be recognized throughout the thesis and is an intrinsic limitation of modeling. That’s ok.

Paper 2: CLOUDY view of the Warm Corona [Panda et al. 2019]

From my perspective, the main advancement in this paper is to expand the range of SED models and see their effects on the resulting optical spectra. The ultraviolet part of the work is less successful. I’ll comment later, but one shortcoming of the work focusing on R Fe II is that the reader does not see the entire output spectra from the models.

Paper 3. The Quasar Main Sequence Explained by the Combination of Eddington Ratio, Metallicity, and Orientation [Panda et. al. 2019, Astrophysical Journal, 882, 79

And Paper 4. Paper IV: Main trends of the quasar main sequence - effect of viewing angle [Panda et al. 2020, Contributions of the Astronomical Observatory Skalnat´e Pleso, 50, 1:293-308]

There is a fair amount of overlap between these papers and I’ll briefly comment on them together. We finally get some direct attention to orientation effects for a flattened BLR via the f factor. That’s good! We also start to get suggestions that we’ll be able to do cosmology based on this work. I’ll comment on that and a few other issues below.

There are some issues of parameter space to consider. In general models should be wide ranging and only restricted later.

Paper 5: The CaFe Project: Optical Fe II and Near-infrared Ca II Triplet Emission in Active Galaxies.I. Photoionization Modeling [Panda et. al. 2020, Astrophysical Journal, 902, 76]

Tough, but I like this approach in general.

And Paper 6: The CaFe Project: Optical Fe II and Near-Infrared Ca II triplet emission in active galaxies– simulated EWs, the co-dependence of cloud sizes and metal content [Panda 2021, Astronomy & Astrophysics

These two papers take an innovative and potentially important approach. The iron atom is complex and problematic in some ways. Maybe the Calcium triplet (CaT) would be better to use from a theoretical standpoint. The biggest drawback is that empirically CaT is hard to observe across a large range of redshifts. I'd suggest designing an observational project to observe CaT in a well selected sample of quasars would be a worthwhile project (e.g, with Xshooter).

Additionally, these papers also start to consider not just line ratios but equivalent widths, BLR covering factors, and other issues that are needed to bring the models into better comparison with reality. This goal is not quite accomplished. It is proposed that anisotropic continuum emission and/or a continuum seen through a filtering material affects a planar BLR, but this type of modeling is not quantitatively accomplished.

The appendices do an adequate job of explaining some relevant concepts of the thesis.

Let me consider several general issues about the thesis and its attack on the problem of EV1, the quasar main sequence, the the modeling of the BLR more generally. These comments are not necessarily strikes against the thesis, but indications of the scope of the projects and where future studies should likely be focused, or not.

There is a focus in these investigations on a very limited parameter space, which is ok. However, by comparing model output with other spectral lines observable in the optical and UV there are additional constraints to consider.

Additionally, there is a major spectral feature that is controversial in the literature and no accepted resolution: the strength of the NLR emission along the accretion rate/R Fe II trends. Different astronomers have claimed that the [O III] emission varies due to a changing SED, a changing opening angle, or a changing NLR density. This is in many ways a more interesting questions.

The BLR is not a single zone, as Panda acknowledges. Hbeta will be emitted from regions that will emit no Fe II. This is important. The BLR requires more complex models.

Also I have concerns about the most extreme Fe II emitters. In some ways they should be expected to require higher metallicity, and may not be expected to be typical objects that will be understood by the simplest models.

Based on the work of Rochais et al. (2017, MNRAS, 464, 553), I am skeptical that extreme Eddington Ratio objects will be particular good standard candles. Sources of scatter are still quite large and cannot be overcome by the proposed selection. The problem basically is that quasars with essentially identical spectra have quite different luminosities, and going to high accretion rates doesn't help very much.

These final comments may be considered suggestions for the direction of future work.

Summarizing, in my professional opinion the presented Thesis fulfills all the formal and customary requirements, and I recommend to proceed with the additional steps required to award Swayamtrupta Panda the PhD title.