Research History

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1. General education

For my general education in astrophysics i have worked on different problems making me familiar with different data types such as data cubes, spectroscopy and image data. For the specific case of the image data i have used the python implementation of the image reduction software Image Reduction and Analysis Facility (IRAF) to reduce images to for example produce color-magnitude plots of an ensemble of stars.

I have also worked with the Adaptive Mesh Refinement for self-gravitating magnetized fluid flows (RAMSES) code to run cosmological simulations to study the large scale structure of the Universe and the evolution of galaxies and the Robust Overdensity Calculation using K-Space Topologically Adaptive Refinement (ROCKSTAR) to identify and analyse dark matter halo in the simulations run using RAMSES. The work with RAMSES also included trying to use different physics to see how it affected the simulation, like using a dark matter only simulation compared to one that has hydrodynamics included.

2. Bachelor Project

For my bachelors project "Black hole mass measurements: On the measuring of the CIV emission line to estimate the black hole mass of distant quasars" i worked on a script in IDL that used the mass scaling relationship from found by M. Vestergaard and B. M. Peterson [5] to determine the black hole mass for 26 quasars over a redshift range from z=2.1 to z=2.3.

I worked with singe-epoch spectrum to obtain the continuum luminosity at 1450 Å and the Full Width at Half Maximum (FWHM) for the CIV line at 1549 Å, which were both needed for the scaling relationship. The continuum luminosity was determined by first fitting a power law to the continuum parts of the spectrum and then that model was used to obtain the flux density at 1450 Å, which was then lastly converted to a continuum luminosity. The continuum model was subtracted from the spectrum and the residual spectrum was used to model the CIV line and the nearby emission lines. The emission lines were modelled using multiple Gaussian functions. The figure on page 3 shows the different steps for this process. The FWHM was determined by two different methods, firstly by using the model and secondly by subtracting all the nearby emission lines from the spectrum and using the data profile for the CIV line. Care was taken with both methods to account for features such as noise spikes and absorption that affect the measurement of the FWHM.

I considered the pros and cons of the methods and plotted their FWHM and subsequently the determined mass against each other to see if they had a 1:1 relationship. The 1:1 relationship between the FWHM and black hole mass for the data profile and model was consistent to within one σ. With all the components for the mass scaling relationship i determined the mass and accompanying uncertainty. The black hole mass was plotted as a function of the redshift and continuum luminosity to test if there was a correlation present. I determined that within the redshift and luminosity range of the objects there were no clear correlation between the mass and these values. I plotted the FWHM as a function of the continuum luminosity as well to make sure there was not a false correlation between the mass and continuum luminosity. I compared the quasars to Seyferts analysed by B. M. Peterson et al. [3] and found that combined with the reverberation mapping masses from the Seyferts there did seem to be a strong positive correlation between the mass and continuum luminosity, but i had too few data points to conclude if this was an actual tendency for the objects or just a lack of data leading to a false inference. I also calculated the mass accretion rate and Eddington ratio for the quasars and found that the quasars i analysed were more accreting than the Seyferts, both in absolute and relative terms. I also compared the Eddington ratio for the quasars i analysed to a larger sample in by M. Vestergaard [4] and found them consistent within the relevant mass bin.

3. Master Thesis

I am currently working on my masters thesis titled "Reverberation mapping of nearby Seyfert galaxies for cosmology.". It was shown in 2014 how AGN in the local universe could be used as absolute distance standards by comparing the physical and angular scales of their dust tori (see "A dust-parallax distance of 19 megaparsecs to the supermassive black hole in NGC 4151" by S. F. Hönig et al. [2]). To get their physical scales, long-term, optical and near-infrared reverberation mapping must be performed. In the thesis I am working with the light curves of a dozen nearby AGN currently being monitored from Chile. I am then determining their delay times and physical sizes to use in cosmological measurements. The idea is to create a way to determine distances that is separate from the conventional "distance ladder", where each step has an associated uncertainty. I am using a combination of Bayesian statistics, Markov Chain Monte Carlo (MCMC) and Gaussian Processes (GP) to determine the X-ray driving function and the transfer function for the dusty torus and accretion disk of the AGN.

The transfer function is assumed to be a combination of a lognormal modified by a black body for the uniform temperature dusty torus and a lognormal modified by a power law for the accretion disk. This form of the transfer equation is more detailed than the top-hat transfer function usually used in reverberation mapping analysis and provides information about the physical parameters of the dusty torus and accretion disk. The driving function is defined as a Continous AutoRegressive process of the first order (CAR(1)) with a specific covariance function. This process can also be used to interpolate the light curves of the different observational bands. I am currently defining the driving function with a GP prior at the same times as the observations in the different bands using a latent variable implementation of GP's. I am then defining the transfer functions for all the bands and convolving them with the relevant parts of the GP, so i can compare them with the data of those bands. I am using a Bayesian approach so i write up priors for the transfer function parameters and GP hyperparameters and the likelihoods functions for the different bands and then i use a MCMC approach to generate samples from the posterior probability distribution. The specific sampler i use is a python implementation of a Hamiltonian Monte Carlo algorithm called the No-U-turn Sampler (NUTS) [1].

I am working on optimizing the sampler and debugging any problems related to convergence at the moment. Since each point defined for the GP prior is a variable i am working in a high dimensional parameter space, which is both computationally expensive and difficult to explore. I am also looking into reparameterizing the transfer equation so that the sampler has an easier time sampling. NUTS is affected by the scale of the parameters it samples, since it can only adapt its path length to one scale it can have problems with different scales and therefore have trouble sampling "funnels" in parameter space.

References

[1] M. D. Hoffman and A. Gelman. "The No-U-Turn Sampler: Adaptively Setting Path Lengths in Hamiltonian Monte Carlo". In: *Journal of Machine Learning Research* 15 (2014), pp. 1593–1623.

[2] S. F. Hönig et al. "A dust-parallax distance of 19 megaparsecs to the supermassive black hole in NGC 4151". In: *Nature* 515 (2014), pp. 528–530.

[3] B. M. Peterson et al. “Central Masses and Broad-Line Region Sizes of Active Galactic Nuclei. II. A Homogeneous Analysis of a Large Reverberation-Mapping Database”. In: *The Astrophysical Journal* 631 (2004), pp. 682–699.

[4] M. Vestergaard. “Early Growth and Efficient Accretion of Massive Black Holes at High Redshift”. In: *The Astrophysical Journal* 601 (2004), pp. 676–691.

[5] M. Vestergaard and B. M. Peterson. “Determining Central Black Hole Masses in Distant Active Galaxies and Quasars. II. Improved Optical and UV Scaling Relationships”. In: *The Astrophysical Journal* 641 (2006), pp. 689–709.

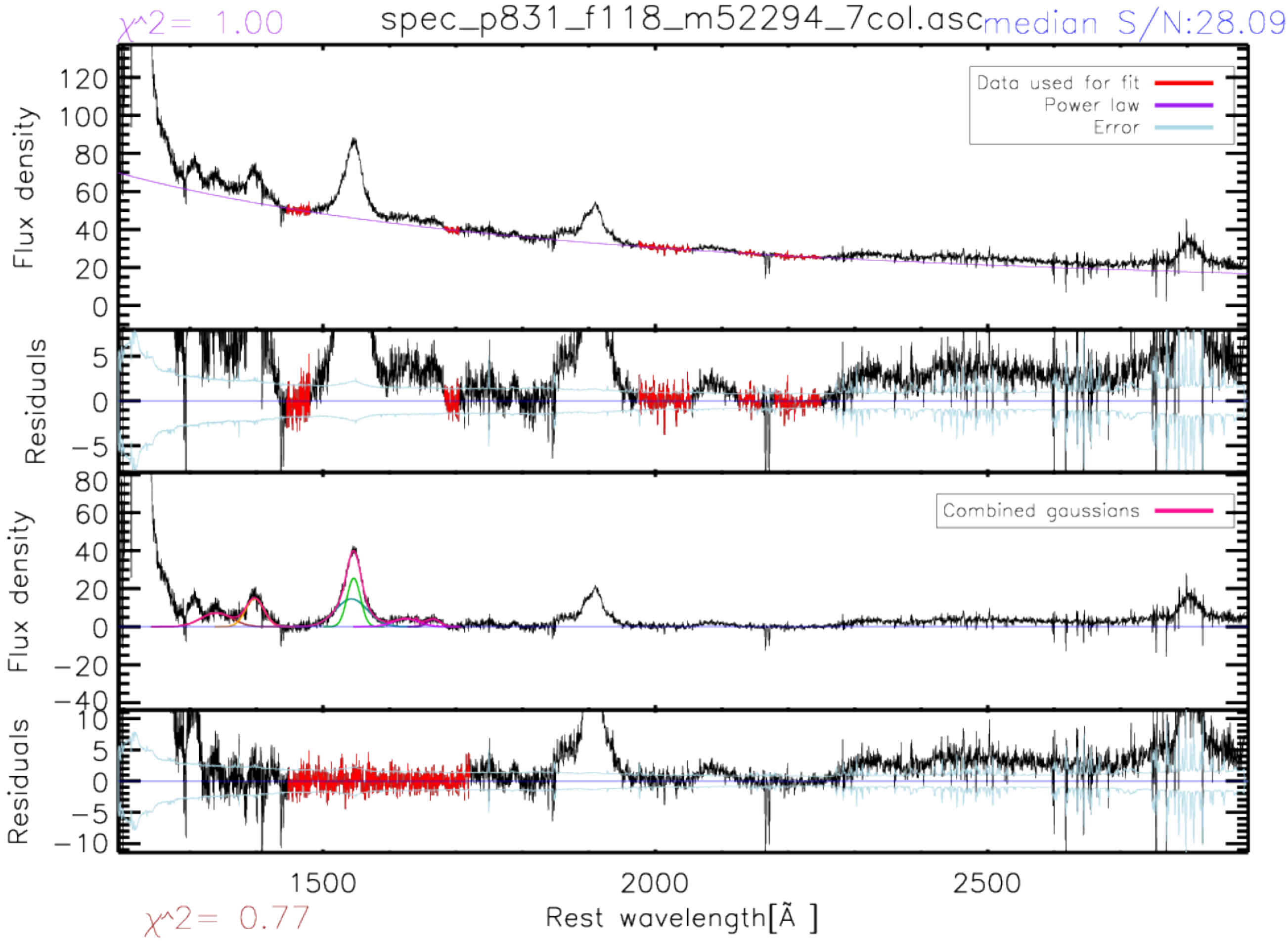

Figure 1: *A multi-panel plot of the different fits and their residuals used to determine a model of the CIV line. The rest wavelength is in angstrom and the Flux density is in $10^{-17} erg/s/cm^2/Å$. The median Signal to Noise of the data is shown in the upper right corner. From top to bottom we have (1) The power law fit made to the continuum part of the spectrum. The data used to fit a power law function is shown in red and the reduced χ^2 is shown above the plot (2) The residuals of the data when the modelled power law function is subtracted. A zero-reference line is provided for visual guidance. (3) Multiple Gaussian fits for the CIV emission line and other nearby line complexes are shown. The combined Gaussian functions is also shown with a single color. The data range fitted over is not shown in a different color, for the sake of readability. The reduced χ^2 for the Gaussian fits is shown in the bottom of the plot. (4) The residuals from subtracting the Gaussian functions. The area marked in red is the part of the spectrum used when the reduced χ^2 is calculated for the Gaussian functions.*