What made the quasar blush?

Emission mechanisms in optically red quasars

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Abstract

Quasars selected at radio frequencies have been shown to exhibit a much broader range of optical colours than the canonical blue colours of optically-selected quasars. This thesis sets out to explain this observation by the presence of optical non-thermal synchrotron emission, connected with the relativistic jet that powers the radio emission in these quasars.

In the first part of this thesis, we investigate the properties of synchrotron emission. This is firstly done from the perspective of observed optical synchrotron jets. The measured spectral indices of these jets show good evidence that the synchrotron spectrum is turning over at optical frequencies, indicating that the energy distribution of the emitting particles has a cutoff at some maximum energy. Secondly, we investigate analytic solutions for synchrotron emission from both ordered and tangled magnetic fields, and find that the emitted flux in the ordered field case exhibits a strong dependence on the viewing angle. This is compared with the expected dependence due to Doppler boosting caused by some bulk flow that would occur in a relativistic jet, and the implications for real jets are discussed.

The second part of the thesis is concerned with flat-spectrum radio quasars taken from the Parkes Half-Jansky Flat-spectrum Sample. We present an extensive data-set of optical and near-infrared photometry for > 100 objects, and fit theoretical models to these observations. We find that $\sim 40\%$ of the sources have power-law SEDs, while a similar number show evidence for two primary components: a blue power law and optical synchrotron emission. The blue power law is similar to the dominant component observed in the spectra of optically-selected QSOs. There is strong evidence that the synchrotron component has a turnover in the rest frame UV-optical region of the spectrum. In the remaining sources it is likely that the synchrotron peaks at longer wavelengths, while peaks at shorter wavelengths appear to be ruled out. The relative strengths of these two components show variations of more than four orders of magnitude. The sources with power law SEDs show evidence for an excess number of red power law slopes compared to optically-selected quasars.

Analysis of polarisation data, both optical (from the literature) and near-infrared (new observations), supports the presence of an optically red, highly polarised component, which is consistent with the fitted synchrotron component.

The properties of the BL Lacertæ objects in the sample are examined. It is found that, aside from having much lower emission line equivalent widths (by definition), the BL Lacs are indistinguishable from the other synchrotron-dominated sources in the sample. This suggests that the BL Lac phenomenon is caused primarily by a relative lack of emission line gas, rather than an excessively boosted synchrotron component.

Finally, observations of variability on timescales of hours in a source with no optical synchrotron emission demonstrates that the blue power law emission can exhibit short-timescale variations, a property which is often ascribed to synchrotron emission. This indicates that both components are important for modelling the optical emission from flat-spectrum radio quasars.

Declaration

This is to certify that:

① This thesis entitled "What made the quasar blush? Emission mechanisms in optically red quasars" comprises only my original work, except where indicated in the preface.

② Due acknowledgement has been made in the text to all other material used.

③ The thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

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Matthew Thomas Whiting

Preface

While most of the work presented herein is my own, there is some that is the result of collaborative work, or the result of the work of others. Any data that is used is cited accordingly in the text, and other specific details are listed here:

- Chapter 1 and a large part of Chapter 2 are reviews of the literature. References are quoted in the text.
- The derivation of the tangled-field synchrotron emission in Chapter 3 is taken mostly from Longair (1994). The ordered-field derivation, however, is my own work.
- The data set described in Chapter 4 is taken from Francis, Whiting, and Webster (2000). Paul Francis performed the bulk of the observations (although I did assist for nearly half the nights) and all the reduction. The discussion of the new systematic errors, while not in Francis et al. (2000), is presented in Whiting et al. (2001).
- Most of the modelling presented in Chapter 5 is also presented in Whiting et al. (2001). All the modelling is my own work.
- The optical polarisation data used in Chapter 6 comes from the literature, primarily Wills et al. (1992), and is cited accordingly in the text. Some of the near-infrared polarimetry was originally presented in Masci (1997), while the rest represents my new work.
- The analysis and its interpretation in Chapter 7 is my own work. Data used is cited accordingly in the text.
- The work in Chapter 8 is original and entirely my work.

Additionally, this research has made use of the NASA/IPAC Extragalactic Database (NED)[1] (which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration), as well as NASA's Astrophysics Data System Abstract and Article Services[2]. Some routines from Numerical Recipes (Press et al. 1997) were used in the analysis of the modelling.

[1]http://nedwww.ipac.caltech.edu/
[2]http://adswww.harvard.edu/

Acknowledgements

No undertaking of the magnitude of a Ph.D. thesis can be accomplished without help from many sources, and I have benefited over the past four years from the help and efforts of many people.

The first to be thanked must be Rachel Webster. She has been of immense help throughout the course of my studies, both in giving me direction when I needed it, and in being able to ask the questions that made me think about the deeper issues. That, surely, is the role of any good supervisor, and Rachel has excelled in that role.

Paul Francis, as well, deserves much praise. The compilation of the data set detailed in Chapter 4 is largely thanks to his hard work, in doing most of the observing and nearly all the reduction (which, when you have of the order of 1000 images, is a considerable effort!). I also thank Paul for his counsel and help throughout the Ph.D., particularly for his many comments during the development and analysis of the modelling.

I am most grateful to the University of Melbourne, for awarding me the Grimwade Scholarship. This scholarship has provided me with assistance in travelling to conferences and the like, and so has been invaluable in helping the progress of my research. I am also grateful for the hospitality shown me by Sr. Deirdre Rofe and the community of St. Mary's College, in my three enjoyable years as residential tutor there.

I have benefited from discussions and interactions with many people over the past four years, that have helped me develop my knowledge on the field of quasars and AGN, including Stefan Wagner, Matthew Baring, Ian McHardy, Dick Hunstead, and Patrick Leahy. Locally, Alicia Oshlack (my fellow Parkes partner-in-crime!), Matt O'Dowd and Frank Masci have all been invaluable. I also thank those who have helped with the observing that has formed part of this thesis, namely Paul Francis, Frank Masci, Michael

Drinkwater, Tori Ibbetson and Alicia Oshlack. The groovy title for this thesis is courtesy of Matt Tilling.

More generally, I thank all the members of the Melbourne Uni Astro group from the past four years, for their friendship, support and the many and assorted forms of cricket! This sentiment extends to my non-astro friends – I thank them all for their love, support, and their wonderful abilities to provide distractions from work!

Lastly, in the place of honour, I wish to thank my beloved family. Their love and support has been wonderful, particularly in this last year when things have been so hectic.

This thesis is dedicated to the memory of my beloved grandmother,
Mavis Simpson,
a loving soul who so dearly wanted to see the final version.
I hope she is reading it even now and is well pleased.

Contents

List of Figures

List of Tables