# The effects of dust grains in two dissimilar regions at opposite ends of the Milky Way

A thesis submitted to The University of Manchester for the degree of
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# Contents

# The University of Manchester

ABSTRACT OF THESIS submitted by Paul Ruffle
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I examine the detected effects of dust grains in two dissimilar regions at opposite ends of the Milky Way: firstly in explaining anomalous extinction values towards the Galactic bulge through observations of Planetary Nebulae (PNe); and secondly in explaining the apparent photon-dominated regions (PDRs) observed in metal-poor molecular clouds at the Galactic edge. Angular diameters, fluxes and extinction of compact PNe are derived from observations, providing evidence for steeper extinction towards the Bulge. I suggest that for the inner Galaxy the low-density warm ionized medium is the site of the anomalous extinction, and that low values of extinction can also be derived using dust models with a turnover radius of 0.08 microns. I then go on to examine the chemistry of Edge Clouds 1 and 2 (EC1 & EC2), molecular clouds with the largest galactocentric distances in the Milky Way. I present observations of both clouds and these are used to determine their physical characteristics. Chemical models are used to reproduce the abundances in EC2 and they indicate: heavy elements may be reduced by a factor of five relative to the solar neighbourhood; very low extinction due to a high gas to dust ratio; an enhanced cosmic ray ionisation rate; and a high UV field compared to local interstellar values. Observed high abundances of the radicals $C_2H$ and CN are typical of PDRs, but at the Galactic edge, metal abundances are expected to be much reduced. In addition, although EC2 does contain young stars, there is no evidence of the late-type stars which produce dust grains, thereby justifying the assumption of a high ratio of UV flux to grain surface area. Finally, I note that shocks from an old supernova remnant may be the source of the structure and dynamics observed in EC2.

# Declaration

I declare that no portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

# Copyright Statement

*The Galaxy, you know, is not simply a flat ovoid of any sort; nor is the periphery a closed curve. Actually, it is a double spiral, with at least eighty percent of the inhabited planets on the Main Arm. Terminus is the extreme outer end of the spiral arm, and we are at the other – since, what is the opposite end of a spiral?*

*Why, the center.*

Second Foundation, Isaac Asimov (1953)

*The stars, like dust, encircle me*

*In the living mists of light;*

*And all of space I seem to see*

*In one vast burst of sight.*

The Stars Like Dust, Isaac Asimov (1955)

*(Black) is like the silence of the body after death, the close of life.*

Wassily Kandinsky (1911)

*Why do you write to me 'God should punish the English'? I have no close connection to either one or the other. I see only with deep regret that God punishes so many of His children for their numerous stupidities, for which only He Himself can be held responsible; in my opinion, only His nonexistence could excuse Him.*

Albert Einstein (1915)

# Dedication

To Philip. I wish I had known you better.

# Acknowledgements

First and foremost, I would like to thank my supervisor, Tom Millar, for his help, support and advice during my time at Manchester. I also extend my gratitude to Albert Zijlstra, for steering me through my sojourn of Planetary Nebulae. To my mentor, Malcolm Gray, goes my appreciation for explaining the 'gobstopper' dust model and patiently listening (over several pints in *The Bull's Head*) to my tales of woe in my first year. I thank Gary Fuller for many tips and explanations on radio astronomy, and David Howe for being a thoroughly decent chap (and an ex-Open University student). To Helen Roberts goes my appreciation for helping me to run our chemical kinetic models, to Christian Henkel my gratitude for his LVG calculations, and to Don Lubowich my thanks for all that ARO 12m telescope time.

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Data reduction was carried out using the packages SPECX (JCMT), CLASS, GREG, MOPSIC (GILDAS) and MIDAS (ESO). PNe images were restored using IRAF as distributed by the National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract to the National Science Foundation of the United States. Graphs, plots and diagrams were generated by the above data reduction packages or by OpenOffice, Excel or GnuPlot. Adobe Illustrator and Photoshop were used for post processing of PostScript and bitmap files respectively. Computing was provided by: a Compaq XP1000 Tru64 Unix workstation; an Intel system running SuSE Linux 9; and an Apple G5 iMac running OS X Tiger. Microsoft Windows was NOT used at any time! This thesis was typeset with LaTeX and TeXShop on my iMac.

# The Author

Paul Ruffle started his first career in the late sixties, working as a graphic artist in design studios and advertising agencies in London. In the mid eighties he got involved with computers and the subsequent desktop publishing (DTP) revolution. This in turn led to working for a large multinational corporation producing multilingual publications and CD-ROM based multimedia. He also ran his own company, Geodesy Ltd, providing production consultancy services and building internet web sites.

Despite his creative abilities, Paul always had a strong interest in science, and physics and astronomy in particular. When he was a young boy his father took him to the London Planetarium and bought him a planisphere – a simple set of plastic disks that showed the positions of the stars at any time or place. In the intervening years he lost the little device, but not a fascination with the stars.

So in 1989 he started studying, in his free time, for a physics degree with the Open University, and obtained his BSc (Hons) in Natural Science in 2002. Towards the end of his studies he became increasingly interested in astrophysics and at the same time discovered that doing a PhD as a mature student was not entirely ‘pie in the sky’. In early 2002 he contacted a number of research groups in the UK and was subsequently offered a PPARC funded full time research studentship at UMIST (now The University of Manchester).

Paul is a founder member of FUSION – The Open University Physics Society and edits their Newsletter and Web site. He served on the committee of NEXUS – the student section of the Institute of Physics, and redesigned the NEXUS web site. He is also a fellow of the Royal Astronomical Society and an associate member of the Institute of Physics.

In the course of two careers he has travelled extensively. He reads science (fact and fiction), philosophy, biography and art history. Other activities include gardening, painting, photography a little sailing, and learning to ride a horse!

# Supporting Publications

**Molecular Line Observations of Edge Cloud 2**

T. J. Millar, D. A. Lubowich, H. Roberts, P. M. E. Ruffle, C. Henkel, G. Brammer and J. Pasachoff. In preparation, 2006.

**Metal-poor molecular gas beyond the optical disk of the Galaxy**

P. M. E. Ruffle, T. J. Millar, H. Roberts, C. Henkel and D. A. Lubowich. In *Astrochemistry Throughout the Universe: Recent Successes and Current Challenges, IAU Symposium 231, 29 August - 2 September, 2005 in Asilomar, California, USA. Cambridge University Press*, 2005.

**Metal-poor Molecular Gas in Edge Cloud 2 (EC2)**

P. M. E. Ruffle, T. J. Millar, H. Roberts, D. A. Lubowich, C. Henkel and G. Brammer. In *The dense interstellar medium in galaxies, Proceedings of the 4th Cologne-Bonn-Zermatt Symposium, Zermatt, Switzerland, 22-26 September 2003. Springer proceedings in physics*, Vol. 91, 2004.

**Angular diameters, fluxes and extinction of compact planetary nebulae: further evidence for steeper extinction towards the bulge**

P. M. E. Ruffle, A. A. Zijlstra, J. R. Walsh, M. D. Gray, K. Gesicki, D. Minniti and F. Comeron. *MNRAS*, 353, 796-812, September 2004.

**Angular diameters, fluxes and extinction of compact planetary nebulae: further evidence for steeper extinction towards the bulge**

A. A. Zijlstra, P. M. E. Ruffle and K. Gesicki. In *Asymmetric Planetary Nebulae III, eds. M. Meixner, J. Kastner and N. Soker, ASP Conference Series*, 313, 40-41, 2004.

**The Composition at the Outer Edge of the Galaxy**

D. A. Lubowich, G. Brammer, H. Roberts, T. J. Millar, C. Henkel, J. Pasachoff and P. M. E. Ruffle. In *Elemental Abundances in Old Stars and Damped Lyman-Systems, 25th meeting of the IAU, Joint Discussion 15, 22 July 2003, Sydney, Australia*, 2003.

Figure 1: (a) The author at the European Southern Observatory (ESO), La Silla, Chile. (b) the ESO NTT 3.5m, (c) the Max-Planck-Institut für Radioastronomie (MPIfR) Effelsberg 100m, (d) the Arizona Radio Observatory (ARO) 12m, (e) the Institut de Radio Astronomie Millimétrique (IRAM) 30m, (f) the James Clerk Maxwell (JCMT) 15m and (g) the Onsala Space Observatory (OSO) 20m telescopes.