A spectral-timing approach to the study of AGN outflows

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Bibliography

Alston, W. N., Markevičiūtė, J., Kara, E., Fabian, A. C., & Middleton, M. 2014, MNRAS, 445, L16

Alston, W. N., Vaughan, S., & Uttley, P. 2013a, MNRAS, 435, 1511

Alston, W. N., Vaughan, S., & Uttley, P. 2013b, MNRAS, 429, 75

Antonucci, R. 1993, ARA&A, 31, 473

Antonucci, R. R. J., & Miller, J. S. 1985, ApJ, 297, 621

Aoki, K., Iwata, I., Ohta, K., et al. 2006, ApJ, 651, 84

Arav, N. 1996, ApJ, 465, 617

Arav, N., Kaastra, J., Kriss, G. A., et al. 2005, ApJ, 620, 665

Arav, N., Korista, K. T., Barlow, T. A., & Begelman. 1995, Nature, 376, 576

Arav, N., Moe, M., Costantini, E., et al. 2008, ApJ, 681, 954

Arav, N., Gabel, J. R., Korista, K. T., et al. 2007, ApJ, 658, 829

Arav, N., Edmonds, D., Borguet, B., et al. 2012, A&A, 544, A33

Arav, N., Chamberlain, C., Kriss, G. A., et al. 2015, A&A, 577, A37

Arévalo, P., & Uttley, P. 2006, MNRAS, 367, 801

Arévalo, P., Uttley, P., Lira, P., et al. 2009, MNRAS, 397, 2004

Barcons, X., Nandra, K., Barret, D., et al. 2015, Journal of Physics: Conference Series, 610, 012008

Barvainis, R. 1987, ApJ, 320, 537

Behar, E., Rasmussen, A. P., Blustin, A. J., et al. 2003, ApJ, 598, 232

Behar, E., Sako, M., & Kahn, S. M. 2001, ApJ, 563, 497

Bennert, N., Jungwiert, B., Komossa, S., Haas, M., & Chini, R. 2006, A&A, 459, 55

Blandford, R. D., & McKee, C. F. 1982, ApJ, 255, 419

Blustin, A. J., Page, M. J., Fuerst, S. V., Branduardi-Raymont, G., & Ashton, C. E. 2005, A&A, 431, 111

Bottorff, M. C., Korista, K. T., & Shlosman, I. 2000, ApJ, 537, 134
Breedt, E., McHardy, I. M., Arévalo, P., et al. 2010, MNRAS, 403, 605
Cameron, D. T., McHardy, I., Dwelly, T., et al. 2012, MNRAS, 422, 902
Cappi, M., Done, C., Behar, E., et al. 2013, ArXiv e-prints, arXiv:1306.2330 [astro-ph.HE], ads
Chartas, G., Brandt, W. N., & Gallagher, S. C. 2003, ApJ, 595, 85
Collinson, J. S., Ward, M. J., Landt, H., et al. 2017, MNRAS, 465, 358
Costantini, E. 2010, Space Sci. Rev., 157, 265
Costantini, E., Gallo, L. C., Brandt, W. N., Fabian, A. C., & Boller, T. 2007a, MNRAS, 378, 873
Costantini, E., Kaastra, J. S., Arav, N., et al. 2007b, A&A, 461, 121
Costantini, E., Kriss, G., Kaastra, J. S., et al. 2016, A&A, 595, A106
Crenshaw, D. M., & Kraemer, S. B. 2007, ApJ, 659, 250
Crenshaw, D. M., & Kraemer, S. B. 2012, ApJ, 753, 75
Crenshaw, D. M., Kraemer, S. B., Boggess, A., et al. 1999, ApJ, 516, 750
Crenshaw, D. M., Kraemer, S. B., & George, I. M. 2003a, ARA&A, 41, 117
Crenshaw, D. M., Kraemer, S. B., Gabel, J. R., et al. 2003b, ApJ, 594, 116
Crummy, J., Fabian, A. C., Gallo, L., & Ross, R. R. 2006, MNRAS, 365, 1067
De Marco, B., Ponti, G., Cappi, M., et al. 2013, MNRAS, 431, 2441
De Rosa, G., Peterson, B. M., Ely, J., et al. 2015, ApJ, 806, 128
de Vaucouleurs, G., de Vaucouleurs, A., Corwin, Jr., H. G., et al. 1991, Third Reference Catalogue of Bright Galaxies. Volume I: Explanations and references. Volume II: Data for galaxies between 0^h and 12^h. Volume III: Data for galaxies between 12^h and 24^h.
den Herder, J. W., Brinkman, A. C., Kahn, S. M., et al. 2001, A&A, 365, L7
Denney, K. D., Watson, L. C., Peterson, B. M., et al. 2009, ApJ, 702, 1353
Di Gesu, L., Costantini, E., Arav, N., et al. 2013, A&A, 556, A94
Di Matteo, T., Springel, V., & Hernquist, L. 2005, Nature, 433, 604
Done, C. 2010, ArXiv e-prints, arXiv:1008.2287 [astro-ph.HE], ads
Done, C., Davis, S. W., Jin, C., Blaes, O., & Ward, M. 2012, MNRAS, 420, 1848
Dovciak, M., Matt, G., Bianchi, S., et al. 2013, ArXiv e-prints, arXiv:1306.2331 [astro-ph.HE], ads
Dumont, A.-M., Abrassart, A., & Collin, S. 2000, A&A, 357, 823
Ebrero, J., Kaastra, J. S., Kriss, G. A., de Vries, C. P., & Costantini, E. 2013, MNRAS, 435, 3028
Ebrero, J., Kriss, G. A., Kaastra, J. S., et al. 2011, A&A, 534, A40
Elvis, M., Wilkes, B. J., & Lockman, F. J. 1989, AJ, 97, 777
Fabian, A. C. 1979, Proceedings of the Royal Society of London Series A, 366, 449
Fabian, A. C. 2012, ARA&A, 50, 455
Fabian, A. C., Alston, W. N., Cackett, E. M., et al. 2017, Astronomische Nachrichten, 338, 269

Fabian, A. C., Zoghbi, A., Ross, R. R., et al. 2009, Nature, 459, 540

Ferland, G. J., Porter, R. L., van Hoof, P. A. M., et al. 2013, Rev. Mexicana Astron. Astrofis., 49, 137

Ferland, G. J., Chatzikos, M., Guzmán, F., et al. 2017, Rev. Mexicana Astron. Astrofis., 53, 385

Ferrarese, L., & Merritt, D. 2000, ApJ, 539, L9

Fiore, F., Elvis, M., Mathur, S., Wilkes, B. J., & McDowell, J. C. 1993, ApJ, 415, 129

Foltz, C. B., Weymann, R. J., Morris, S. L., & Turnshek, D. A. 1987, ApJ, 317, 450

Gabel, J. R., Kraemer, S. B., Crenshaw, D. M., et al. 2005, ApJ, 631, 741

Gallo, L. C., Boller, T., Brandt, W. N., Fabian, A. C., & Vaughan, S. 2004, A&A, 417, 29

Gaskell, C. M. 1988, ApJ, 325, 114

Gaskell, C. M., & Klimek, E. S. 2003, Astronomical and Astrophysical Transactions, 22, 661

Gebhardt, K., Bender, R., Bower, G., et al. 2000, ApJ, 539, L13

George, I. M., & Fabian, A. C. 1991, MNRAS, 249, 352

George, I. M., Turner, T. J., Netzer, H., et al. 1998, ApJS, 114, 73

Gierliński, M., & Done, C. 2004, MNRAS, 349, L7

Gierliński, M., Middleton, M., Ward, M., & Done, C. 2008, Nature, 455, 369

Goad, M. R., Korista, K. T., De Rosa, G., et al. 2016, ApJ, 824, 11

González-Martín, O., & Vaughan, S. 2012, A&A, 544, A80

Green, J. C., Froning, C. S., Osterman, S., et al. 2012, ApJ, 744, 60

Greenstein, J. L., & Schmidt, M. 1964, ApJ, 140, 1

Grier, C. J., Peterson, B. M., Pogge, R. W., et al. 2012, ApJ, 755, 60

Grier, C. J., Peterson, B. M., Horne, K., et al. 2013, ApJ, 764, 47

Haardt, F., & Maraschi, L. 1993, ApJ, 413, 507

Hall, P. B. 2007, AJ, 133, 1271

Halpern, J. P. 1984, ApJ, 281, 90

Hardcastle, M. J., Evans, D. A., & Croston, J. H. 2007, MNRAS, 376, 1849

Häring, N., & Rix, H.-W. 2004, ApJ, 604, L89

Hitomi Collaboration. 2016, Nature, 535, 117

Hutchings, J. B., Crenshaw, D. M., Kraemer, S. B., et al. 2002, AJ, 124, 2543

Kaastra, J. S. 2017a, Astronomische Nachrichten, 338, 146

Kaastra, J. S. 2017b, A&A, 605, A51

Kaastra, J. S., & Bleeker, J. A. M. 2016, A&A, 587, A151

Kaastra, J. S., Mewe, R., Liedahl, D. A., Komossa, S., & Brinkman, A. C. 2000, A&A, 354, L83

Kaastra, J. S., Mewe, R., & Nieuwenhuijzen, H. 1996, in UV and X-ray Spectroscopy of Astrophysical and Laboratory Plasmas, ed. K. Yamashita & T. Watanabe, 411

Kaastra, J. S., Raassen, A. J. J., Mewe, R., et al. 2004, A&A, 428, 57

Kaastra, J. S., Detmers, R. G., Mehdipour, M., et al. 2012, A&A, 539, A117

Kaastra, J. S., Kriss, G. A., Cappi, M., et al. 2014a, Science, 345, 64

Kaastra, J. S., Terashima, Y., Kallman, T., et al. 2014b, ArXiv e-prints, arXiv:1412.1171 [astro-ph.HE], ads

Kalberla, P. M. W., Burton, W. B., Hartmann, D., et al. 2005, A&A, 440, 775

Kallman, T., & Bautista, M. 2001, ApJS, 133, 221

Kara, E., Alston, W. N., Fabian, A. C., et al. 2016, MNRAS, 462, 511

Kara, E., Fabian, A. C., Cackett, E. M., et al. 2013, MNRAS, 434, 1129

Kaspi, S., Brandt, W. N., Netzer, H., et al. 2000, ApJ, 535, L17

Kaspi, S., Netzer, H., Chelouche, D., et al. 2004, ApJ, 611, 68

Kaspi, S., Brandt, W. N., George, I. M., et al. 2002, ApJ, 574, 643

King, A., & Pounds, K. 2015, ARA&A, 53, 115

Korista, K. T., Voit, G. M., Morris, S. L., & Weymann, R. J. 1993, ApJS, 88, 357

Kormendy, J., & Ho, L. C. 2013, ARA&A, 51, 511

Kotov, O., Churazov, E., & Gilfanov, M. 2001, MNRAS, 327, 799

Kraemer, S. B., Tombesi, F., & Bottorff, M. 2017, in American Astronomical Society Meeting Abstracts, Vol. 229, American Astronomical Society Meeting Abstracts, 250.57

Kraemer, S. B., Crenshaw, D. M., Gabel, J. R., et al. 2006, ApJS, 167, 161

Kriss, G. A., Krolik, J. H., Otani, C., et al. 1996, ApJ, 467, 629

Kriss, G. A., Scott, J. E., Alexander, T., et al. 2002, in Bulletin of the American Astronomical Society, Vol. 35, American Astronomical Society Meeting Abstracts, 571

Krolik, J. H., Horne, K., Kallman, T. R., et al. 1991, ApJ, 371, 541

Krolik, J. H., & Kriss, G. A. 1995, ApJ, 447, 512

Krolik, J. H., & Kriss, G. A. 2001, ApJ, 561, 684

Krongold, Y., Nicastro, F., Elvis, M., et al. 2007, ApJ, 659, 1022

Laha, S., Guainazzi, M., Dewangan, G. C., Chakravorty, S., & Kembhavi, A. K. 2014, MNRAS, 441, 2613

Laor, A., Jannuzi, B. T., Green, R. F., & Boroson, T. A. 1997, ApJ, 489, 656

Lawrence, A., Watson, M. G., Pounds, K. A., & Elvis, M. 1987, Nature, 325, 694

Lightman, A. P., & White, T. R. 1988, ApJ, 335, 57

Lodders, K., Palme, H., & Gail, H.-P. 2009, Landolt Börnstein, 44

Longinotti, A. L., Krongold, Y., Kriss, G. A., et al. 2013, ApJ, 766, 104

Lyubarskii, Y. E. 1997, MNRAS, 292, 679

Mao, J., Kaastra, J. S., Mehdipour, M., et al. 2017, A&A, 607, A100

Mathews, W. G., & Ferland, G. J. 1987, ApJ, 323, 456

Mathur, S., Gupta, A., Page, K., et al. 2017, ApJ, 846, 55

McHardy, I. M. 1989, in ESA Special Publication, Vol. 296, Two Topics in X-Ray Astronomy, Volume 1: X Ray Binaries. Volume 2: AGN and the X Ray Background, ed. J. Hunt & B. Battrick

McHardy, I. M., Koerding, E., Knigge, C., Uttley, P., & Fender, R. P. 2006, Nature, 444, 730

McHardy, I. M., Papadakis, I. E., Uttley, P., Page, M. J., & Mason, K. O. 2004, MNRAS, 348, 783

McHardy, I. M., Cameron, D. T., Dwelly, T., et al. 2014, MNRAS, 444, 1469

McKernan, B., Yaqoob, T., & Reynolds, C. S. 2007, MNRAS, 379, 1359

Mehdipour, M., Branduardi-Raymont, G., & Page, M. J. 2010, A&A, 514, A100

Murray, N., & Chiang, J. 1995, ApJ, 454, L105

Mushotzky, R. F., Done, C., & Pounds, K. A. 1993, ARA&A, 31, 717

Nandra, K., & Pounds, K. A. 1992, Nature, 359, 215

Nandra, K., Pounds, K. A., & Stewart, G. C. 1990, MNRAS, 242, 660

Nandra, K., Barret, D., Barcons, X., et al. 2013, ArXiv e-prints, arXiv:1306.2307 [astro-ph.HE], ads

Netzer, H. 1996, ApJ, 473, 781

Netzer, H. 2015, ARA&A, 53, 365

Nicastro, F., Fiore, F., Perola, G. C., & Elvis, M. 1999, ApJ, 512, 184

Otani, C., Kii, T., Reynolds, C. S., et al. 1996, PASJ, 48, 211

Padovani, P., Alexander, D. M., Assef, R. J., et al. 2017, A&A Rev., 25, 2

Pancoast, A., Brewer, B. J., Treu, T., LAMP2008 Collaboration, & LAMP2011 Collaboration. 2013, in American Astronomical Society Meeting Abstracts, Vol. 221, American Astronomical Society Meeting Abstracts #221, 309.08

Peterson, B. M. 2014, Space Sci. Rev., 183, 253

Peterson, B. M., & Bentz, M. C. 2006, New A Rev., 50, 796

Peterson, B. M., Denney, K. D., De Rosa, G., et al. 2013, ApJ, 779, 109

Pounds, K. A., & King, A. R. 2013, MNRAS, 433, 1369

Pounds, K. A., & Vaughan, S. 2011, MNRAS, 413, 1251

Press, W. H. 1978, Comments on Astrophysics, 7, 103

Press, W. H., Teukolsky, S. A., Vetterling, W. T., & Flannery, B. P. 1992, Numerical recipes in FORTRAN. The art of scientific computing

Press, W. H., Teukolsky, S. A., Vetterling, W. T., & Flannery, B. P. 2007, Numerical Recipes 3rd Edition: The Art of Scientific Computing, 3rd edn. (New York, NY, USA: Cambridge University Press)

Proga, D. 2007, in Astronomical Society of the Pacific Conference Series, Vol. 373, The Central Engine of Active Galactic Nuclei, ed. L. C. Ho & J.-W. Wang, 267

Proga, D., Stone, J. M., & Kallman, T. R. 2000, ApJ, 543, 686

Rees, M. J. 1984, ARA&A, 22, 471

Rees, M. J. 1987, MNRAS, 228, 47P

Reeves, J. N., Nandra, K., George, I. M., et al. 2004, ApJ, 602, 648

Reynolds, C. S. 1997, MNRAS, 286, 513

Reynolds, C. S., Fabian, A. C., Nandra, K., et al. 1995, MNRAS, 277, 901

Romero, G. E., Boettcher, M., Markoff, S., & Tavecchio, F. 2017, Space Sci. Rev.,

207, 5
Salpeter, E. E. 1964, ApJ, 140, 796
Sanfrutos, M., Miniutti, G., Krongold, Y., Agís-González, B., & Longinotti, A. L. 2016, MNRAS, 457, 510
Shakura, N. I., & Sunyaev, R. A. 1973, A&A, 24, 337
Silva, C. V., Uttley, P., & Costantini, E. 2016, A&A, 596, A79
Smith, R. K., Abraham, M. H., Allured, R., et al. 2016, in Proc. SPIE, Vol. 9905, Space Telescopes and Instrumentation 2016: Ultraviolet to Gamma Ray, 99054M
Springob, C. M., Haynes, M. P., Giovanelli, R., & Kent, B. R. 2005, ApJS, 160, 149
Steenbrugge, K. C., Fenovčík, M., Kaastra, J. S., Costantini, E., & Verbunt, F. 2009, A&A, 496, 107
Steenbrugge, K. C., Kaastra, J. S., de Vries, C. P., & Edelson, R. 2003, A&A, 402, 477
Steenbrugge, K. C., Kaastra, J. S., Crenshaw, D. M., et al. 2005, A&A, 434, 569
Stern, J., Behar, E., Laor, A., Baskin, A., & Holczer, T. 2014, MNRAS, 445, 3011
Suganuma, M., Yoshii, Y., Kobayashi, Y., et al. 2006, ApJ, 639, 46
Terrell, J. 1964, Science, 145, 918
Tombesi, F., Cappi, M., Reeves, J. N., & Braito, V. 2012, MNRAS, 422, L1
Tombesi, F., Cappi, M., Reeves, J. N., et al. 2010, A&A, 521, A57
Turner, T. J., Nandra, K., George, I. M., Fabian, A. C., & Pounds, K. A. 1993, ApJ, 419, 127
Turnshek, D. A. 1998, in Structure et Evolution du Milieu Inter-Galactique Revele par Raies D'Absorption dans le Spectre des Quasars, 13th Colloque d'Astrophysique de l'Institut d'Astrophysique de Paris, ed. P. Petitjean & S. Charlot, 263
Ulrich, M.-H., Maraschi, L., & Urry, C. M. 1997, ARA&A, 35, 445
Urry, C. M., & Padovani, P. 1995, PASP, 107, 803
Uttley, P., Cackett, E. M., Fabian, A. C., Kara, E., & Wilkins, D. R. 2014, A&A Rev., 22, 72
Uttley, P., & McHardy, I. M. 2001, MNRAS, 323, L26
Uttley, P., McHardy, I. M., & Papadakis, I. E. 2002, MNRAS, 332, 231
Uttley, P., McHardy, I. M., Papadakis, I. E., Cagnoni, I., & Fruscione, A. 1999, Nuclear Physics B Proceedings Supplements, 69, 490
Uttley, P., McHardy, I. M., & Vaughan, S. 2005, MNRAS, 359, 345
Vaughan, B. A., & Nowak, M. A. 1997, ApJ, 474, L43
Vaughan, S., Edelson, R., Warwick, R. S., Malkan, M. A., & Goad, M. R. 2001, MNRAS, 327, 673
Vaughan, S., & Uttley, P. 2005, MNRAS, 362, 235
Vaughan, S., & Uttley, P. 2006, Advances in Space Research, 38, 1405
Vaughan, S., Uttley, P., Pounds, K. A., Nandra, K., & Strohmayer, T. E. 2011a, MNRAS, 413, 2489
Vaughan, S., Uttley, P., Pounds, K. A., Nandra, K., & Strohmayer, T. E. 2011b,

MNRAS, 413, 2489
Wakker, B. P., Lockman, F. J., & Brown, J. M. 2011, ApJ, 728, 159
Weymann, R. J., Morris, S. L., Foltz, C. B., & Hewett, P. C. 1991, ApJ, 373, 23
Wilkins, D. R., Gallo, L. C., Silva, C. V., et al. 2017, MNRAS, 471, 4436
Willingale, R., Starling, R. L. C., Beardmore, A. P., Tanvir, N. R., & O'Brien, P. T. 2013, MNRAS, 431, 394
Yaqoob, T., Warwick, R. S., & Pounds, K. A. 1989, MNRAS, 236, 153
Zel'dovich, Y. B., & Novikov, I. D. 1964, Soviet Physics Doklady, 9, 246
Zoghbi, A., Fabian, A. C., Reynolds, C. S., & Cackett, E. M. 2012, MNRAS, 422, 129
Zoghbi, A., Fabian, A. C., Uttley, P., et al. 2010, MNRAS, 401, 2419
Zoghbi, A., Uttley, P., & Fabian, A. C. 2011, MNRAS, 412, 59

Contribution from co-authors

The bibliographic information for the chapters contained in this thesis is presented below. The relative importance of the co-authors is indicated by the order of the author list.

Chapter 2: Timing the warm absorber in NGC 4051
Silva, C.V., Uttley, P., & Costantini, E., 2016, A&A, 596, A79.

Chapter 3: Constraining the physical properties of the UV ionized absorber in NGC 5548 with time-dependent photoionization modeling
Silva, C.V., Kriss, G.A., Costantini, E., Uttley, P., et al.
To be submitted to Astronomy and Astrophysics

Chapter 4: The variability of the warm absorber in I Zwicky 1 as seen by XMM-Newton
Silva, C.V., Costantini, E., Giustini, M., Kriss, G.A., Brandt, W.N., Gallo, L.C., Wilkins, D.R.
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Publications

First-author articles

1. **Silva, C.V.**, Uttley, P., & Costantini, E., 2016.
   A&A, 596, A79. (**Chapter 2**)
   Timing the warm absorber in NGC 4051

2. **Silva, C.V.**, Costantini, E., Giustini, M., Kriss, G.A., Brandt, W.N., Gallo, L.C., Wilkins, D.R.
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   The short and long-term variability of the warm absorber in I ZW 1

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   Constraining the physical properties of the UV ionized absorber in NGC 5548 with time-dependent photoionization modeling

Co-authored articles

1. Markoff, S., Nowak, M.A., Gallo, E., Hynes, R., Wilms, J., Plotkin, R.M., Maitra, D., **Silva, C.V.**, Drappeu, S., 2015.
   The Astrophysical Journal Letters, 812, Issue 2, L25.
   As Above, So Below: Exploiting Mass Scaling in Black Hole Accretion to Break Degeneracies in Spectral Interpretation

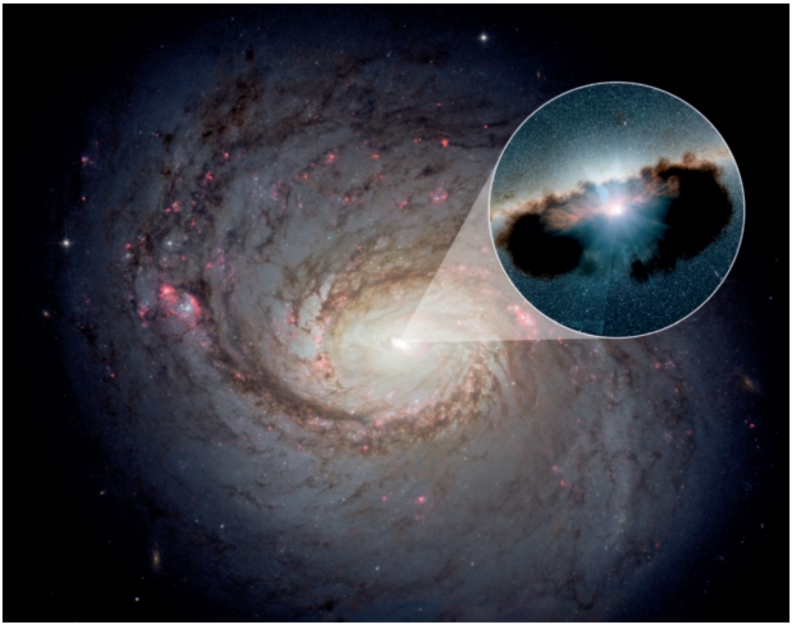
2. Wilkins, D. R.; Gallo, L.C.; **Silva, C.V.**; Costantini, E.; Brandt, W. N.; Kriss, G.A., 2017.
   Monthly Notices of the Royal Astronomical Society, Volume 471, Issue 4, p.4436-4451.
   Revealing structure and evolution within the corona of the Seyfert galaxy I Zw 1

Nederlandse Samenvatting

Het universum is structureel georganiseerd, van de kleinste tot de grootste schalen. Sterren, stellaire restanten, gas, stof/gruis, en donkere materie zijn middels de zwaartekracht aan elkaar gebonden in grotere systemen, genaamd sterrenstelsels. Volgens de meest recente waarnemingen bevat het waarneembare universum op zijn minst enkele biljoenen sterrenstelsels. Deze vormen samen weer grotere structuren, i.e. sterrenstelsel clusters, die vervolgens superclusters kunnen vormen. Men vermoedt dat er in het centrum van ieder sterrenstelsel een superzwaar zwart gat (hierna SMBH) bevindt. Sommige sterrenstelsels vertonen tekenen van activiteit in de kern, gerelateerd aan de accretie van materiaal op de SMBH. De centrale gebieden van sterrenstelsels, waar deze fenomenen plaatsvinden, worden actieve sterrenstelsels (hierna AGN) genoemd, en zijn extreem heldere bronnen.

De krachtige en aanhoudende emissie van AGNs reikt over het gehele elektromagnetisch spectrum. De materie die in een spiraalbeweging invalt, vormt een accretieschijf die thermische straling uitzendt in de vorm van optisch en UV licht. Krachtige non-thermische röntgenstraling wordt geproduceerd in een hete corona met lage dichtheid, gelegen in de binnenste delen van de kern. Accretie op de SMBH gaat ook gepaard met uitstromen. Deze uitstromen, in de vorm van sterk gecollimeerde straalstromen of een minder gecollimeerde wind van geïoniseerd gas, kan krachtig genoeg zijn om het gastheer-stelsel of zelfs het medium tussen clusters te beïnvloeden. De overdracht van stralings- of kinetische energie naar het sterrenstelsel in de vorm van uitstromen wordt 'AGN feedback' genoemd.

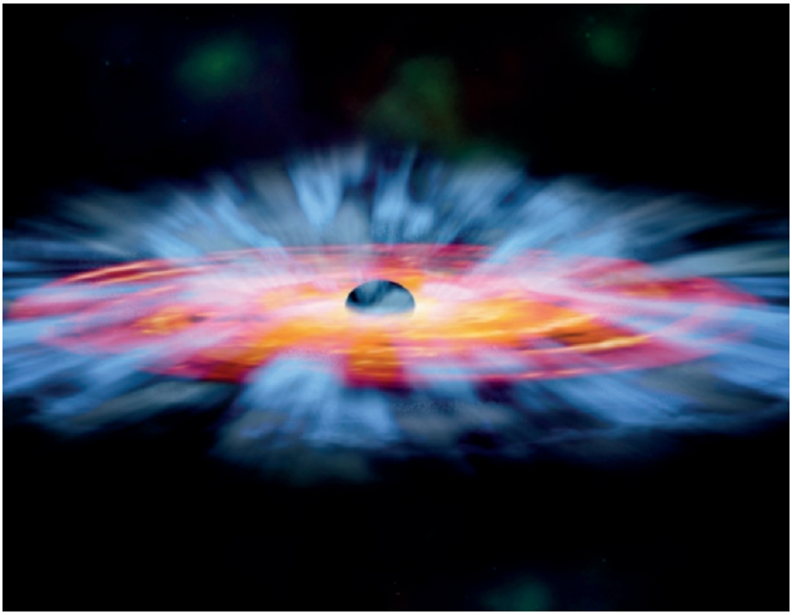
AGN feedback wordt vaak aangehaald als de waarschijnlijke verklaring voor de waargenomen connectie tussen de SMBH en zijn gastheer-stelsel. Observaties tonen aan dat de massa van het zwarte gat correleert met de snelheidsverdeling van de sterren in de centrale bobbel (i.e. de 'bulge') van het sterrenstelsel en de massa deze bobbel. Dit suggereert dat de groei en co-evolutie van de SMBH en het sterrenstelsel op een bepaalde wijze gereguleerd worden door de AGN. Om te achterhalen of de uitstromen verantwoordelijk zijn voor deze relatie is het eerst noodzakelijk om de overdracht van energie van de uitstromen naar het omgevende medium te kwantificeren. Hierdoor is het karakteriseren van de fysische eigenschappen van de uitstromen en hun bijdrage aan AGN feedback van cruciaal belang voor het begrijpen van de formatie en evolutie van de grootschalige structuren.



Figuur A: Close-up van het sterrenstelsel NGC 1068, genomen met de Hubble Space Telescope van de NASA. De inzet toont een illustratieve zoom-in op de centrale AGN. Origineel van NASA/JPL-Caltech.

Dit proefschrift richt zich op de studie van geïoniseerde uitstromen in de vorm van een zwak gecollimeerde wind. Deze uitstromen worden gedetecteerd middels de blauw verschoven absorptie lijnen in de UV en röntgen spectra van nabijgelegen Seyfert-sterrenstelsels. De hier gepresenteerde onderzoeken zijn gericht op het blootleggen van de fysieke eigenschappen van het gas door gebruik te maken van technieken gericht op de tijdvariaties in de energiespectra, i.e. 'spectrale-timing' analysetechnieken. Uit de analyse van de spectra is het mogelijk om sommige karakteristieken van het gas af te leiden, zoals de ionisatietoestand, de kolomdichtheid en de snelheid van de uitstroom. Het bepalen van de afstand van het gas tot de centrale bron is daarentegen niet eenduidig en is echter van fundamenteel belang voor het vaststellen van de bijdrage van deze uitstromen aan AGN feedback. De ionisatieparameter is dusdanig gedefinieerd dat de radiële afstand van het gas samenhangt met de dichtheid van het gas. Hierdoor leidt een afschatting van de dichtheid van het gas tot een schatting van de radiële afstand van het gas tot de centrale bron. Het gas, welke gefotoioniseerd wordt door de centrale bron, is onderworpen aan de intrinsieke variaties van het ioniserende continuüm. Zodoende reageert het gas op veranderingen in de invallende flux en wordt meer geïoniseerd wanneer de flux toeneemt en recombineert gedurende perioden van afnemende flux. De responstijd van het gas op de variaties in het continuüm is omgekeerd evenredig met de dichtheid. Het in detail registreren van de variabiliteit van de bron en de reactie van het gas op deze veranderingen levert derhalve een schatting van de dichtheid van het gas en daarmee een afstand van het gas tot de centrale bron. In dit proefschrift worden nieuwe technieken ontwikkeld om het absorberende gas te bestuderen, door gebruik te maken van de combinatie van de spectrale en temporale eigenschappen van het gas. Deze methoden bieden bruikbare hulpmiddelen voor het, in de toekomst, inperken van de fysische parameters van het geïoniseerde gas welke UV- en röntgenstralen absorbeert. Dit maakt het mogelijk om een completere schatting te maken van de rol van deze uitstromen in AGN feedback. De onderzoeken waarin we deze methoden toepassen en de implicaties van de daaruit volgende resultaten, worden hieronder kort beschreven.

In hoofdstuk 2 wordt een nieuwe methode ontwikkeld om het tijdsafhankelijke gedrag van de uitstroom, in reactie op de variabiliteit van het continuüm, te beoordelen. De respons van het gas op veranderingen in de ioniserende flux van de bron wordt berekend door het combineren van spectrale-timing analysetechnieken met een tijdsafhankelijk foto-ionisatiemodel. Vervolgens worden, voor het eerst, de effecten van de absorptie door foto-ionisatie op de röntgen-tijdvertragingen van AGNs voorspeld. Het signatuur van de uitstroom in de spectra van de tijdvertraging versus de Fourier-frequentie van een AGN is geassocieerd met de responstijd van het gas op de variaties in de flux van de ioniserende bron als gevolg van de foto-ionisatie en radiatieve recombinatie. Dit resulteert in een tijdsvertraging tussen de variaties in de lage-energie-röntgenstraling, welke beïnvloed wordt door de talrijke absorptiekenmerken, en de band van de hoge-energie-röntgenstraling waar de variaties in de continuüm domineren. Het toepassen van deze nieuwe methode op de uitgebreide waarnemingen, gemaakt met de XMM-Newton, van NGC 4051, toont aan dat het absorberende gas van deze bron in staat is een vertraging in de lage energie emissie te produceren (tot 100 seconden) bij lage Fourier-frequenties. De gevolgen van de bijdrage van het absorberende gas op de tijdsvertragingen in de röntgenstraling van de AGN zijn tweedelig. Ten eerste, het incorporeren van dit effect in het modelleren van de vertragingen maken het mogelijk om de verscheidene fysische processen meer accurate te ontrafelen, aangezien de bijdrage van het absorberende gas de andere processen te niet doet of zelfs overheerst over de andere processen die op vergelijkbare tijdschalen plaatsvinden. Ten tweede, dit onderzoek onthult de potentie van de spectrale-timing analysetechnieken om de uitstromen in het algemeen te karakteriseren. Met name in het geval van toekomstige missies, zoals Athena, waarbij deze methoden routinematig toegepast kunnen worden voor het in groot detail in kaart brengen van de uitstromen van AGN.



Figuur B: Artistieke impressie van AGN-uitstromen. Origineel van NASA en M.Weiss (Chandra X-ray Center).

In hoofdstuk 3 wordt het tijdsafhankelijke foto-ionisatiemodel, ontwikkeld voor de studie van het absorberende gas in hoofdstuk 2, uitgebreid en toegepast op de studie van het absorberende gas in de UV-band. Het model levert de tijdsafhankelijke kolomdichtheden van de ionen op, aangezien deze reageren op de variaties in het continuüm. In de optisch dunne limiet, zijn de kolomdichtheden van de ionen recht evenredig met de gemeten equivalente breedtes van de absorptietroggen. Vanwege deze lineariteit is het mogelijk om de voorspelde ionenconcentraties als een functie van tijd direct te vergelijken met de lichtcurven van de equivalente breedtes van de verschillende ionen. Het tijdsafhankelijk gedrag van het gas wordt zodoende berekend voor een reeks van gasdichtheden en ionisatietoestanden. Door het vergelijken van deze voorspellingen met de waargenomen data, is het mogelijk om tegelijkertijd de dichtheid en de ionisatieparameter van ieder gascomponent te schatten. De validiteit van deze innovatieve methode wordt hier gedemonstreerd door de toepassing ervan op de uitstekende data van NGC 5548, verkregen met de Cosmic Origins Spectrograph op HST gedurende een uitgebreide waarnemingscampagne. Door de tijdafhankelijke modellen te fitten aan de lichtkrommen van de equivalente breedtes, zijn zowel de dichtheid- als de ionisatieparameters van twee van de zes componenten van de UV-uitstroom in NGC 5548 ingeperkt. De inperkingen op de dichtheid kunnen vervolgens worden gebruikt om de locatie van deze componenten van de uitstroom te schatten. Deze interessante resultaten benadrukken de potentie van de tijdafhankelijke foto-ionisatiemodellen bij het verklaren van de variabiliteit van het absorberende gas en tonen aan dat het gebruik van deze modellen een veelvermogende methode is om de fysische parameters van de uitstromen bloot te leggen.

Ten slotte, in hoofdstuk 4, worden nieuwe waarnemingen van röntgenstraling, gemaakt met XMM-Newton van de Seyfert 1 sterrenstelsel I Zwicky 1 (I ZW 1) geanalyseerd. De geïoniseerde uitstroom in deze bron lijkt variabel te zijn op lange tijdschalen, echter vertoont de variabiliteit geen correlatie met de ioniserende bron, zoals verwacht zou worden volgens klassieke foto-ionisatiemodellen. Uitgebreid onderzoek van de spectrale- en temporale eigenschappen van het lage-energie-röntgenstralingsabsorptiespectrum suggereert een scenario waarbij delen met verschillende dichtheden, ontwikkeld in een niet-homogene uitstroom, over de jaren langs het gezichtsveld van de waarnemer bewegen. Dit verklaart de langetermijnveranderingen in de ionisatie van het gas en de afwezigheid van een correlatie met de ioniserende emissie. De resultaten van dit onderzoek onderbouwen de behoefte aan theoretische modellen die in staat zijn om het complexe gedrag van het absorberende gas te reproduceren, zoals de waargenomen variabiliteit in de uitstroom in I ZW 1.

Summary

The Universe is structurally organized, from the smallest to the largest scales. Stars, stellar remnants, gas, dust, and dark matter, are gravitationally bound in large systems called galaxies. According to the most recent observations, the observable Universe contains, at least, a couple of trillions of galaxies. These form larger structures, galaxy clusters, which may be organized in superclusters. It is thought that a supermassive black hole (SMBH) resides in the center of each galaxy. Some galaxies show signs of nuclear activity related to accretion of material onto the SMBH. The central regions of the galaxies associated with this phenomenon are called Active Galactic Nuclei (AGN).

AGN are extremely bright. The powerful and persistent emission of AGN spans the whole electromagnetic spectrum. While spiralling inwards, the accreting material forms an accretion disk which emits thermal radiation in the optical and the UV. Strong X-ray emission is powered by a hot and tenuous medium, the 'corona', situated in the inner most regions of the nucleus. Accretion onto a SMBH is also associated with outflow events. AGN outflows, either in the form of highly collimated jets or less collimated winds of ionized gas, can be powerful enough to impact the host galaxy, or even the intra-cluster medium. The transfer of radiative or kinetic energy to the galaxy and its surroundings in the form of outflows is termed 'AGN feedback'.

AGN feedback is often evoked as the likely explanation for the observed connection between the SMBH and its host. Observations show the mass of the black hole to correlate with the velocity dispersion of stars in the bulge, and with the galaxy bulge mass, which suggests the growth and co-evolution of the SMBH and the galaxy to be somehow regulated by the AGN. To decide whether the outflows are responsible for this relationship, it is first necessary to quantify the energy transferred by the outflowing material onto the surrounding medium. Hence, characterizing the physical properties of the outflows and their contribution to AGN feedback is of crucial importance to the understanding of large-scale structure formation and evolution.

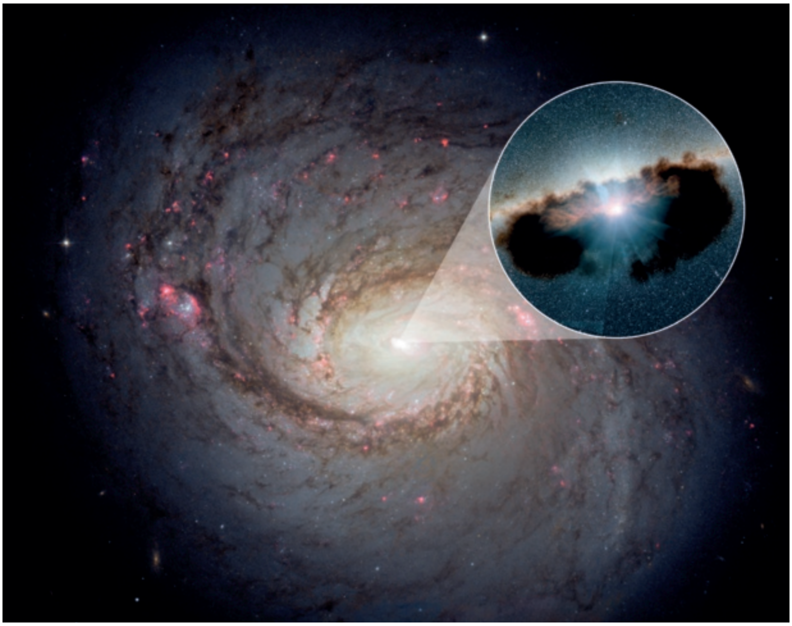


Figure A: NASA's Hubble Space Telescope close-up of the galaxy NGC 1068. The zoomed-in inset shows an illustration of the central AGN. Credits: NASA/JPL-Caltech.

This thesis focuses on the study of ionized outflows in the form of 'winds'. These outflows are detected by the imprint of blueshifted absorption features in the UV and X-ray spectra of nearby Seyfert galaxies. The studies here presented are aimed at uncovering the physical properties of the gas through the use of spectral-timing analysis techniques. From the analysis of the spectra it is possible to infer some of the characteristics of the gas, such as its ionization state, column density, and outflow velocity. Determining the distance of the gas from the central source however is not trivial, yet it is vital information for assessing the contribution of these outflows to AGN feedback. Through the definition of the ionization parameter, the radial distance is tied to the density of the gas, thus estimating the density of the gas results in an estimate of its distance to the central source. The gas, photoionized by the central source, is subjected to the intrinsic variations of the ionizing continuum. Accordingly, the gas reacts to the changes in the incident flux, becoming more ionized when the flux increases and recombining during periods of decreasing flux. The response time of the gas to the continuum variations is inversely proportional to the density. Monitoring the variability of the source and the response of the gas to these changes in detail thus yields an estimate of the density, and hence the distance of the gas from the central source. In this thesis, novel techniques are developed to study the absorbing gas by taking into account its combined spectral and temporal properties.

These methods offer useful tools for future constraints on the physical parameters of the ionized UV and X-ray absorbers, allowing for a more complete assessment of the role of these outflows in AGN feedback. The studies where we apply these methods and the implications of their results, are briefly described below.

In Chapter 2, a new method is developed aimed at assessing the time-dependent behaviour of the outflow, responding to the continuum variability. Combining spectral-timing analysis with a time-dependent photoionization model, the response of the gas to changes in the ionizing flux of the source is computed. Then, and for the first time, the effects of photoionized absorption on the X-ray time lags of AGN are predicted. The signature of the outflow in the lag-frequency spectra of AGN is associated with the response time of the gas to variations in the flux of the ionizing source, due to photoionization and radiative recombination. This results in a time delay between the variations in the soft X-rays, which are affected by numerous absorption features, and the hard X-ray band where the continuum variations dominate. Applying this novel method to the extensive XMM-*Newton* observations of NGC 4051, it is shown that the warm absorber in this source is capable of producing a soft lag (up to 100 s) at low Fourier frequencies. The consequences of the contribution of the absorbing gas to the X-ray time lags of AGN are two fold. Firstly, including this effect in the modelling of the lags will allow the different physical processes at play to be disentangled more accurately, since the contribution of the absorber may wash out or even dominate over other processes which may occur on similar timescales. Secondly, this study reveals the potential of spectral-timing analysis to characterize the outflows at large, particularly when future missions, such as Athena, become available, allowing these methods to be routinely used for mapping AGN outflows in great detail.

In Chapter 3, the time-dependent photoionization model developed for the study of the X-ray absorbing gas in Chapter 2 is expanded and applied to the study of the ionized absorbers in the UV band. The model yields the time-dependent ionic column densities as these respond to the variations in the illuminating continuum. In the optically thin limit, the ionic column densities are directly proportional to the measured equivalent widths of the absorption troughs. Due to this linearity, it is possible to directly compare the predicted ion concentrations as a function of time to the equivalent width light curves of the different ions. The time-dependent behaviour of the gas is thus computed for a range of gas densities and ionization states. When comparing these predictions to the real data, it is possible to estimate, simultaneously, the density and ionization parameter of each gas component. The validity of this innovative method is here demonstrated through its application to the exquisite data of NGC 5548, obtained with the Cosmic Origins Spectrograph on HST during an extensive monitoring campaign. By fitting the time-dependent models to the equivalent width light curves, both the density and ionization parameters of two out of the six compo-

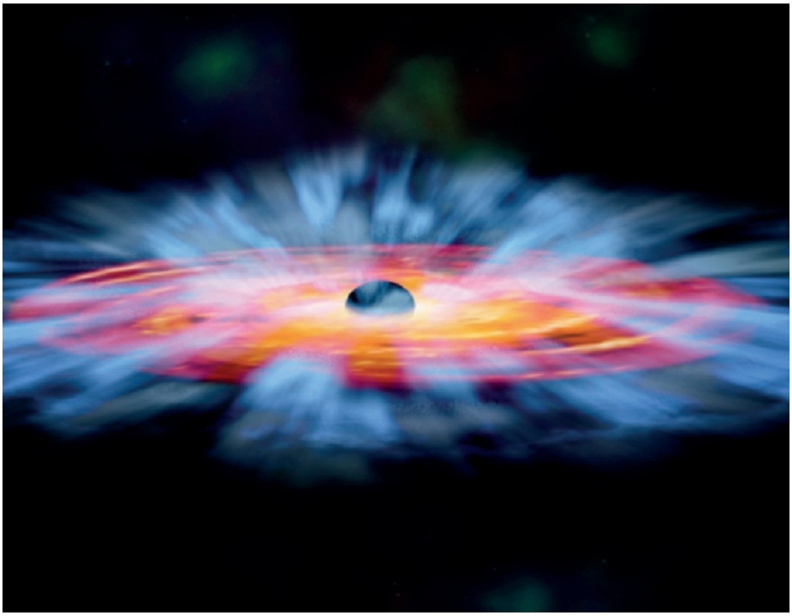


Figure B: Artist impression of AGN outflows. Credit: NASA and M. Weiss (Chandra X-ray Center).

nents of the UV outflow in NGC 5548 are constrained. The constraints on the density can then be used to estimate the location of these components of the outflow. These exciting results highlight the potential of time-dependent photoionization models in explaining the variability of the absorbing gas, as well as demonstrating this technique as a powerful method to uncover the physical parameters of the outflows.

Lastly, in Chapter 4, new X-ray observations taken with XMM-*Newton* of the Seyfert 1 galaxy I Zwicky 1 (I ZW 1) are analysed. The ionized outflow in this source appears to be variable on long timescales, yet its variability does not show a correlation with the ionizing source, as would be expected from classical photoionization models. Extensive modeling of the rich soft X-ray absorption spectrum through time-averaged spectral fitting, flux resolved spectroscopy, and time-resolved spectroscopy suggests a scenario where different clumps of different densities, developed in a non-homogenous outflow, cross the observer's line-of-sight over the years. This explains the long term changes in the ionization of the gas and the apparent absence of a correlation with the ionizing luminosity. The results of this study substantiate the need for theoretical models capable of reproducing more complex behaviour of the absorbing gas, such as the observed variability in the outflow in I ZW 1.

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Thank you,
Cátia

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