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Chapter 5

The big picture

In Chapter 4 and in Appendix A, C and D various approaches have been made to the understanding of the physical situation at the very center of the elliptical galaxy NGC 1052. This chapter summarizes the distinct results derived and puts them together into a consistent model of the pc–scale structure of the source. The model is kept as simple as possible in order to describe the observations on the one hand and not to introduce unnecessary and complicating components. It is based on the standard model for AGN (see Section 1.2.2 and 1.2.3), considering only the components accessible by radio interferometry (e.g., the BLR and NLR can be observed in optical astronomy but are not obviously needed from VLBI observations). It is assumed that the twin jet originates at the center of NGC 1052 in the vicinity of a supermassive black hole, which is surrounded by an accretion disk. The dimensions of the accretion disk are assumed to be negligible, compared to the resolved scales, i.e. its diameter is $\ll$1 pc.

The main result of this thesis is the fact that another component, a central absorber, is unavoidably needed for a correct model of the source. The dominance of this absorber is spatially bounded to the central parsec around the black hole and corresponds to the obscuring torus in the standard model (the geometrical, toroidal structure is not *a–priori* given; however, the term "obscuring torus" is used synonymously for "geometrically thick absorber", since it has become fairly common in usual terminology). Evidence for the presence of an obscuring torus surrounding the pc–scale twin jet of NGC 1052 comes from the following approaches:

- **Spectral index mapping:** Between 5 and 43 GHz the spectral index α diverges at both jet-cores. At high frequencies values of 2.5, the theoretical maximal spectral index in the case of synchrotron self-absorption, are approached but not exceeded. Between 5 and 8.4 GHz however, α reaches values larger than 4 on both sides of the emission gap. Although it is in principle possible to lower the values of α on the eastern side by choosing a different alignment, the effect of free-free absorption on the western side is indisputable.

- **Component spectra:** The model-fitting of the source with circular Gaussian components yielded component spectra with spectral indices larger than 4. The absorbed model components are the innermost ones of the 8.4 GHz model, representing the jet-cores of the eastern and the western jet respectively. Only a very conservative estimate of the (undetected) component flux density at 5 GHz can explain the spectrum of the core on the eastern side without the contribution of free-free absorption. On the western side this effect is again indisputable.

- **The brightness temperature distribution:** Along the eastern jet the distribution of brightness temperatures for the model-fit components can be explained well with an external absorber model. A cutoff in the distribution of T_b appears frequency-independent in all four models at a distance of about 3 mas east of the core. Inside this radius (corresponding to about 0.3 pc) the brightness temperatures of all model components fall substantially below the extrapolation from the outer part of the jet. They appear to be seen through a layer of free-free absorbing material with a column density of $\sim 6 \cdot 10^{22}\,\mathrm{cm}^{-2}$.

- **The absence of polarization above 5 GHz:** Although the total intensity from the core of the eastern jet is comparably strong at 5 and 8.4 GHz, the linear polarized emission detected at 5 GHz from this region has no counterpart at 8.4 GHz. One possible explanation for this behavior is that strong Faraday depolarization makes the intrinsically present linear polarization at 8.4 GHz from this (more central) jet-region undetectable.

- **The core shift analysis:** NGC 1052 is one of only a small number of extragalactic radio jets in which absolute core shifts with frequency can be measured. This is due to the symmetry of the twin jet, which constrains the absolute position of the central engine. Within the uncertainties of the latter, various scenarios agree on the necessity of free-free absorption to explain the measured core shifts. In the most plausible case the core shifts in both jets are caused by free-free absorption, with the western side being much stronger affected.

- **The X-ray spectrum of the nucleus:** The spectrum of the compact, nuclear X-ray emission implies an absorbing column density comparable to the values suggested by the brightness temperature analysis (see Appendix D). Attempts to avoid the absorbed component in the modeling of the measured spectrum do not lead to satisfactory results.

All of these various aspects of data analysis from observations of NGC 1052 are consistent with a model of a very dense absorber surrounding the central engine. This absorber seems to have a rather sharp edge since it starts to dominate the radiation from the eastern pc–scale jet within a few tens of milliarcseconds. It covers the inner 0.3 pc of the eastern jet and at least the same scale on the western side. A more detailed modeling of the absorber is difficult but might be possible with additional data from future observations. The combination of simultaneously performed multi-frequency VLBI and X-ray observations is capable of yielding estimates for the absolute density and the density gradients of the absorber. For the latter, the absolute position of the central engine needs to be determined more precisely from multi-epoch VLBI observations at the highest frequencies.

A sketch of this model is shown in Figure 5.1. The geometry of the absorber cannot be determined finally from the present data, but is not in contradiction to the standard model, which assumes a toroidal structure. Since the two jets seem to be oriented fairly close to the plane of the sky, it is difficult to distinguish a torus from a radially symmetric absorber. The most universally valid geometrical structure in concordance with the observational data presented in this thesis is an ellipsoid with a short axis of ~0.3 pc. The edge of

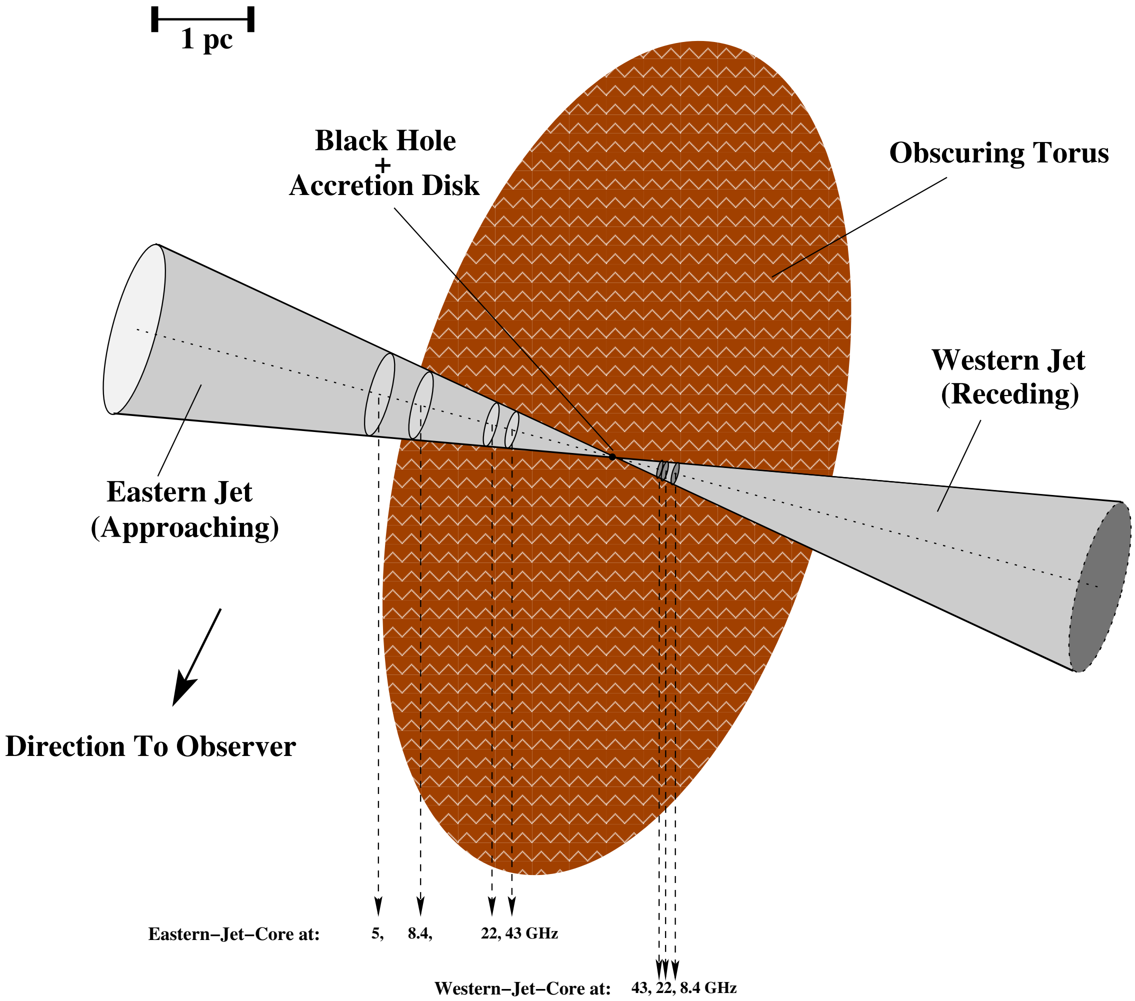

Figure 5.1: Model of the central parsecs in NGC 1052

the absorber may represent the surface of ionization from a central source, for example the accretion disk. Therefore, temperatures larger than 10^4 K are expected within the absorber, ensuring the presence of ionized, free-free absorbing material.

Bibliography

Barth, A. J., Filippenko, A. V., & Moran, E. C. 1999, Astrophys. J., 515, L61

Becklin, E. E., Tokunaga, A. T., & Wynn-Williams, C. G. 1982, Astrophys. J., 263, 624

Blandford, R. D. & Königl, A. 1979, Astrophys. J., 232, 34

Blumenthal, G. R. & Gould, R. J. 1970, Reviews of Modern Physics, 42, 237

Braatz, J. A., Wilson, A. S., & Henkel, C. 1996, Astrophys. J. Suppl., 106, 51

Brown, R. L. 1987, in Spectroscopy of Astrophysical Plasmas, 35–58

California Institute of Technology. 1991, BAAS, 23, 991

Claussen, M. J., Diamond, P. J., Braatz, J. A., Wilson, A. S., & Henkel, C. 1998, Astrophys. J., 500, L129

Condon, J. J., Condon, M. A., Gisler, G., & Puschell, J. J. 1982, Astrophys. J., 252, 102

Daly, R. A. & Marscher, A. P. 1988, Astrophys. J., 334, 539

de Vries, W. H., Barthel, P. D., & O'Dea, C. P. 1997, Astron. & Astrophys., 321, 105

Eckart, A. & Genzel, R. 1996, Nature, 383, 415

Falcke, H. & Biermann, P. L. 1995, Astron. & Astrophys., 293, 665

Falcke, H., Wilson, A. S., & Simpson, C. 1998, Astrophys. J., 502, 199

Fomalont, E. 1981, Newsletter. NRAO No. 3, p. 3, 1981, 3, 3

Forbes, D. A., Georgakakis, A. E., & Brodie, J. P. 2001, Monthly Not. Roy. Astron. Soc., 325, 1431

Fosbury, R. A. E., Mebold, U., Goss, W. M., & Dopita, M. A. 1978, Monthly Not. Roy. Astron. Soc., 183, 549

Gómez, J. L., Marscher, A. P., Alberdi, A., Jorstad, S. G., & García-Miró, C. 2000, Science, 289, 2317

Gabel, J. R., Bruhweiler, F. C., Crenshaw, D. M., Kraemer, S. B., & Miskey, C. L. 2000, Astrophys. J., 532, 883

Gallagher, J. S. 1986, Publ. Astron. Soc. Pacific, 98, 81

Georganopoulos, M. & Marscher, A. P. 1996, in ASP Conf. Ser. 100: Energy Transport in Radio Galaxies and Quasars, 67

Guainazzi, M. & Antonelli, L. A. 1999, Monthly Not. Roy. Astron. Soc., 304, L15

Guainazzi, M., Oosterbroek, T., Antonelli, L. A., & Matt, G. 2000, Astron. & Astrophys., 364, L80

Harris, D. E., Carilli, C. L., & Perley, R. A. 1994, Nature, 367, 713

Harris, D. E. & Krawczynski, H. 2002, Astrophys. J., 565, 244

Heeschen, D. S. 1970, Astron. J., 75, 523

Heeschen, D. S. & Puschell, J. J. 1983, Astrophys. J., 267, L11

Ho, L. C., Filippenko, A. V., & Sargent, W. L. 1995, Astrophys. J. Suppl., 98, 477

Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1997, Astrophys. J. Suppl., 112, 315

Högbom, J. A. 1983, in Indirect Imaging. Measurement and Processing for Indirect Imaging. Proceedings of an International Symposium held in Sydney, Australia, August 30-September 2, 1983. Editor, J.A. Roberts; Publisher, Cambridge, England, New York, USA, Cambridge University Press, 1984, 247

Johnston, K. J., Fey, A. L., Zacharias, N., Russell, J. L., Ma, C., de Vegt, C., Reynolds, J. E., Jauncey, D. L., Archinal, B. A., Carter, M. S., Corbin, T. E., Eubanks, T. M., Florkowski, D. R., Hall, D. M., McCarthy, D. D., McCulloch, P. M., King, E. A., Nicolson, G., & Shaffer, D. B. 1995, Astron. J., 110, 880

Jones, D. L., Tingay, S. J., Murphy, D. W., Meier, D. L., Jauncey, D. L., Reynolds, J. E., Tzioumis, A. K., Preston, R. A., McCulloch, P. M., Costa, M. E., Kemball, A. J., Nicolson, G. D., Quick, J. F. H., King, E. A., Lovell, J. E. J., Clay, R. W., Ferris, R. H., Gough, R. G., Sinclair, M. W., Ellingsen, S. P., Edwards, P. G., Jones, P. A., van Ommen, T. D., Harbison, P., & Migenes, V. 1996, Astrophys. J., 466, L63

Jones, D. L., Wehrle, A. E., Meier, D. L., & Piner, B. G. 2000, Astrophys. J., 534, 165

Jones, D. L., Wrobel, J. M., & Shaffer, D. B. 1984, Astrophys. J., 276, 480

Kameno, S., Sawada-Satoh, S., Inoue, M., Shen, Z., & Wajima, K. 2001, Publ. Astron. Soc. Japan, 53, 169

Kellermann, K. I., Vermeulen, R. C., Cohen, M. H., & Zensus, J. A. 1999, in American Astronomical Society Meeting, Vol. 194, #20.02

Kellermann, K. I., Vermeulen, R. C., Zensus, J. A., & Cohen, M. H. 1998, Astron. J., 115, 1295

Kemball, A. J., Diamond, P. J., & Cotton, W. D. 1995, Astron. &. Astrophys. Suppl., 110, 383

Knapp, G. R., Faber, S. M., & Gallagher, J. S. 1978, Astron. J., 83, 139

Krichbaum, T. P., Alef, W., Witzel, A., Zensus, J. A., Booth, R. S., Greve, A., & Rogers, A. E. E. 1998, Astron. & Astrophys., 329, 873

Krolik, J. H. 1999, Active galactic nuclei : from the central black hole to the galactic environment (Princeton, NJ, USA : Princeton University Press, 1999.)

Leppänen, K. J., Zensus, J. A., & Diamond, P. J. 1995, Astron. J., 110, 2479

Levinson, A., Laor, A., & Vermeulen, R. C. 1995, Astrophys. J., 448, 589+

Lobanov, A. P. 1998, Astron. & Astrophys., 330, 79

Marr, J. M., Taylor, G. B., & Crawford, F. 2000, in Astrophysical Phenomena Revealed by Space VLBI, Proceedings of the VSOP Symposium, held at the Institute of Space and astronautical Science, Sagamihara, Kanagawa, Japan, January 19 - 21, 2000, Eds.: H. Hirabayashi, P.G. Edwards, and D.W. Murphy, Sagamihara, Kanagawa, Japan: Institute of Space and astronautical Science, 2000, 91

Mayall, N. U. 1939, Lick Observatory Bulletin, 497, 33

McDowell, J. C. 1994, in Einstein Obs. Unscreened IPC Data Archive

Mirabel, I. F. & Rodríguez, L. F. 1999, Annu. Rev. Astron. Astrophys., 37, 409

Miyoshi, M., Moran, J., Herrnstein, J., Greenhill, L., Nakai, N., Diamond, P., & Inoue, M. 1995, Nature, 373, 127

Napier, P. J. 1994, in IAU Symp. 158: Very High Angular Resolution Imaging, Vol. 158, 117

Omar, A., Anantharamaiah, K. R., Rupen, M., & Rigby, J. 2002, Astron. & Astrophys., 381, L29

Pearson, T. J., Shepherd, M. C., Taylor, G. B., & Myers, S. T. 1994, in American Astronomical Society Meeting, Vol. 185, #08.08

Peterson, B. M. 1997, An introduction to active galactic nuclei (Cambridge, UK, New York, USA: Cambridge University Press)

Pogge, R. W., Maoz, D., Ho, L. C., & Eracleous, M. 2000, Astrophys. J., 532, 323

Ros, E. 1997, Astrometría diferencial de precisión con VLBI en el triángulo de Draco (y estudios de SN 1993J) (València, Spain: Servicio de Publicaciones, Universitat de València), 35

Rybicki, G. B. & Lightman, A. P. 1979, Radiative Processes in Astrophysics (New York, USA: Wiley-Interscience)

Schwartz, D. A., Marshall, H. L., Lovell, J. E. J., Piner, B. G., Tingay, S. J., Birkinshaw, M., Chartas, G., Elvis, M., Feigelson, E. D., Ghosh, K. K., Harris, D. E., Hirabayashi, H., Hooper, E. J., Jauncey, D. L., Lanzetta, K. M., Mathur, S., Preston, R. A., Tucker, W. H., Virani, S., Wilkes, B., & Worrall, D. M. 2000, Astrophys. J., 540, L69

Smith, D. A., Wilson, A. S., Arnaud, K. A., Terashima, Y., & Young, A. J. 2002, Astrophys. J., 565, 195

Thompson, A. R., Moran, J. M., & Swenson, G. W. 1986, Interferometry and synthesis in radio astronomy (New York, Wiley-Interscience)

Tingay, S. J. & Murphy, D. W. 2001, Astrophys. J., 546, 210

Van Gorkom, J. H., Knapp, G. R., Raimond, E., Faber, S. M., & Gallagher, J. S. 1986, Astron. J., 91, 791

Vermeulen, R. C., Readhead, A. C. S., & Backer, D. C. 1994, Astrophys. J., 430, L41

Vermeulen, R. C., Ros, E., Kellermann, K. I., Cohen, M. H., & Zensus, J. A. 2002, in prep.

Wagner, S. J. & Witzel, A. 1995, Annu. Rev. Astron. Astrophys., 33, 163

Weaver, K. A., Wilson, A. S., Henkel, C., & Braatz, J. A. 1999, Astrophys. J., 520, 130

Wells, D. C., Greisen, E. W., & Harten, R. H. 1981, Astron. &. Astrophys. Suppl., 44, 363

Wilson, A. S. & Yang, Y. 2002, Astrophys. J., 568, 133

Wilson, A. S., Young, A. J., & Shopbell, P. L. 2000, Astrophys. J., 544, L27

Wrobel, J. M. 1984, Astrophys. J., 284, 531

Young, A. J., Wilson, A. S., Terashima, Y., Arnaud, K. A., & Smith, D. A. 2002, Astrophys. J., 564, 176

Yusef-Zadeh, F., Melia, F., & Wardle, M. 2000, Science, 287, 85

Zensus, J. A. 1997, Annu. Rev. Astron. Astrophys., 35, 607

Zensus, J. A., Ros, E., Kellermann, K. I., Cohen, M. H., Vermeulen, R. C., & Kadler, M. 2002, in press (Astron. J., issue August 2002)