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Stochastic Modeling of Multiwavelength Variability of the Classical BL Lac Object OJ 287 on Timescales Ranging from Decades to Hours

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Abstract

© 2018. The American Astronomical Society. All rights reserved.. We present the results of our power spectral density analysis for the BL Lac object OJ 287, utilizing the Fermi-LAT survey at high-energy γ-rays, Swift-XRT in X-rays, several ground-based telescopes and the Kepler satellite in the optical, and radio telescopes at GHz frequencies. The light curves are modeled in terms of continuous-time autoregressive moving average (CARMA) processes. Owing to the inclusion of the Kepler data, we were able to construct for the first time the optical variability power spectrum of a blazar without any gaps across ~6 dex in temporal frequencies. Our analysis reveals that the radio power spectra are of a colored-noise type on timescales ranging from tens of years down to months, with no evidence for breaks or other spectral features. The overall optical power spectrum is also consistent with a colored noise on the variability timescales ranging from 117 years down to hours, with no hints of any quasi-periodic oscillations. The X-ray power spectrum resembles the radio and optical power spectra on the analogous timescales ranging from tens of years down to months. Finally, the γ-ray power spectrum is noticeably different from the radio, optical, and X-ray power spectra of the source: we have detected a characteristic relaxation timescale in the Fermi-LAT data, corresponding to ~150 days, such that on timescales longer than this, the power spectrum is consistent with uncorrelated (white) noise, while on shorter variability timescales there is correlated (colored) noise.

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Keywords

acceleration of particles, BL Lacertae objects: individual (OJ 287), galaxies: active, magnetic fields, radiation mechanisms: non-thermal

References

[1] Abdalla H., Abramowski A., Aharonian F. et al 2017 A&A 598 A39
[2] Abdo A. A., Ackermann M., Ajello M. et al 2009 ApJS 183 46
[3] Abdo A. A., Ackermann M., Ajello M. et al 2010 ApJ 715 429
[4] Abdollahi S., Ackermann M., Ajello M. et al 2017 ApJ 846 34
[5] Acero F., Ackermann M., Ajello M. et al 2015 ApJS 218 23
[6] Acero F., Ackermann M., Ajello M. et al 2016 ApJS 223 26
[7] Ackermann M., Anantua R., Asano K. et al 2016 ApJL 824 L20
[8] Aharonian F., Akhperjanian A. G., Bazer-Bachi A. R. et al 2007 ApJL 664 L71
[9] Aleksić J., Antonelli L. A., Antoranz P. et al 2011 ApJL 730 L8
[10] Aller H. D., Aller M. F. and Hughes P. A. 1985 ApJ 298 296
[11] Atwood W. B., Abdo A. A., Ackermann M. et al 2009 ApJ 697 1071
[12] Begelman M. C., Blandford R. D. and Rees M. J. 1984 RvMP 56 255
[13] Bevington P. R. and Robinson D. K. 2003 Data Reduction and Error Analysis for the Physical Sciences 3rd ed. (Boston, MA: McGraw-Hill)
[14] Bhatta G., Zola S., Stawarz Ł. et al 2016 ApJ 832 47
[15] Böttcher M., Reimer A., Sweeney K. and Prakash A. 2013 ApJ 768 54
[16] Burnham K. P. and Anderson D. R. 2004 Physics of Active Galaxies, Vol. 54 ed G. V. Bicknell, M. A. Dopita and P. J. Quinn (New York: Springer) 91
[17] de Young D. S. 2002 The Physics of Extragalactic Radio Sources (Chicago, IL: Univ. Chicago Press)
[18] Deeming T. J. 1975 Ap&SS 36 137
[19] Edelson R., Mushotzky R., Vaughan S. et al 2013 ApJ 766 16
[20] Edelson R. A. and Krolik J. H. 1988 ApJ 333 646
[21] Emmanoulopoulos D., McHardy I. M. and Papadakis I. E. 2013 MNRAS 433 907
[22] Falomo R., Pian E. and Treves A. 2014 A&ARv 22 73
[23] Finke J. D. and Becker P. A. 2015 ApJ 809 85
[24] Fiorucci M. and Tosti G. 1996 A&AS 116 403
[25] Foschini L., Ghisellini G., Tavecchio F., Bonnoli G. and Stamerra A. 2011 A&A 530 A77
[26] Gehrels N., Chincarini G., Giommi P. et al 2004 ApJ 611 1005
[27] Gelman A. and Rubin D. B. 1992 StaSc 7 457
[28] Ghisellini G., Celotti A., Fossati G., Maraschi L. and Comastri A. 1998 MNRAS 301 451
[29] Glass I. S. 1999 Handbook of Infrared Astronomy ed R. Ellis et al (Cambridge: Cambridge Univ. Press) 63
[30] Goyal A., Stawarz Ł., Ostrowski M. et al 2017 ApJ 837 127
[31] Howell S. B., Sobeck C., Haas M. et al 2014 PASP 126 398
[32] Hudec R., Bašta M., Pihajoki P. and Valtonen M. 2013 A&A 559 A20
[33] Hurvich C. M. and Tsai C. L. 1989 Biometrika 76 297
[34] Isobe N., Sato R., Ueda Y. et al 2015 ApJ 798 27
[35] Kastendieck M. A., Ashley M. C. B. and Horns D. 2011 A&A 531 A123
[36] Kataoka J., Takahashi T., Wagner S. J. et al 2001 ApJ 560 659
[37] Kelly B. C., Bechtold J. and Siemiginowska A. 2009 ApJ 698 895
[38] Kelly B. C., Becker A. C., Sobolewska M., Siemiginowska A. and Uttley P. 2014 ApJ 788 33
[39] Kelly B. C., Sobolewska M. and Siemiginowska A. 2011 ApJ 730 52
[40] Kushwaha P., Chandra S., Misra R. et al 2016 ApJL 822 L13
[41] Liodakis I., Pavlidou V., Hovatta T. et al 2017 MNRAS 467 4565
[42] Lister M. L., Aller M. F., Aller H. D. et al 2016 AJ 152 12
[43] Lomb N. R. 1976 Ap&SS 39 447
[44] Massaro E., Giommi P., Perri M. et al 2003 A&A 399 33
[45] McHardy I. M., Koerding E., Knigge C., Uttley P. and Fender R. P. 2006 Natur 444 730

[46] Meier D. L. 2012 Black Hole Astrophysics: The Engine Paradigm (Berlin: Springer)
[47] Nilsson K., Takalo L. O., Lehto H. J. and Sillanpää A. 2010 A&A 516 A60
[48] O'Brien S. 2017 arXiv:1708.02160
[49] O'Riordan M., Pe'er A. and McKinney J. C. 2017 ApJ 843 81
[50] Qian B. and Tao J. 2003 PASP 115 490
[51] Rani B., Lott B., Krichbaum T. P., Fuhrmann L. and Zensus J. A. 2013 A&A 557 A71
[52] Revalski M., Nowak D., Wiita P. J., Wehrle A. E. and Unwin S. C. 2014 ApJ 785 60
[53] Richards J. L., Max-Moerbeck W., Pavlidou V. et al 2011 ApJS 194 29
[54] Saito S., Stawarz Ł., Tanaka Y. T. et al 2013 ApJL 766 L11
[55] Sandrinelli A., Covino S., Dotti M. and Treves A. 2016 AJ 151 54
[56] Scargle J. D. 1982 ApJ 263 835
[57] Seta H., Isobe N., Tashiro M. S. et al 2009 PASJ 61 1011
[58] Sillanpaa A., Takalo L. O., Pursimo T. et al 1996 A&A 305 L17
[59] Sobolewska M. A., Siemiginowska A., Kelly B. C. and Nalewajko K. 2014 ApJ 786 143
[60] Takalo L. O. 1994 VA 38 77
[61] Takalo L. O., Sillanpaeae A. and Nilsson K. 1994 A&AS 107 497
[62] Timmer J. and Koenig M. 1995 A&A 300 707
[63] Ulrich M.-H., Maraschi L. and Urry C. M. 1997 ARA&A 35 445
[64] Urry C. M. and Padovani P. 1995 PASP 107 803
[65] Uttley P., McHardy I. M. and Papadakis I. E. 2002 MNRAS 332 231
[66] Valtaoja E., Teräsranta H., Tornikoski M. et al 2000 ApJ 531 744
[67] Valtonen M. and Sillanpää A. 2011 AcPol 51 76
[68] Valtonen M. J., Zola S., Ciprini S. et al 2016 ApJL 819 L37
[69] VanderPlas J. T. 2018 ApJS 236 16
[70] Vaughan S., Uttley P., Markowitz A. G. et al 2016 MNRAS 461 3145
[71] Villforth C., Nilsson K., Heidt J. et al 2010 MNRAS 402 2087
[72] Wagner S. J. and Witzel A. 1995 ARA&A 33 163
[73] Wills B. J., Wills D. and Breger M. 2011 ApJS 194 19
[74] Wills B. J., Wills D., Breger M., Antonucci R. R. J. and Barvainis R. 1992 ApJ 398 454
[75] Zola S., Valtonen M., Bhatta G. et al 2016 Galax 4 41