New Frontiers in Black Hole Astrophysics
Proceedings IAU Symposium No. 324, 2016
Andreja Gomboc, ed.

doi:10.1017/S1743921317001648

The Extremes of AGN Variability

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Abstract. We present results from our ongoing monitoring programs aimed at identifying and understanding Active Galactic Nuclei (AGN) in extreme flux and spectral states. Observations of AGN in extreme states can reveal the nature of the inner accretion flow, the physics of matter under strong gravity, and they provide insight on the properties of ionized absorbers and outflows launched near supermassive black holes (SMBHs). We present new results from our long-term monitoring of IC 3599, WPVS007, and Mrk 335, multi-wavelength follow-ups of the newly identified changing-look AGN HE 1136–2304, and UV–X-ray follow-ups of the binary SMBH candidate OJ 287 after its 2015 optical maximum, now in a new optical-X-ray–high-state.

Keywords. Black holes, galaxies, blazars, accretion, jets

1. Introduction: AGN in extreme flux and spectral states

The intrinsic X-ray spectra of radio-quiet AGN consist of two main components. (1) Thermal quasi-black-body emission from the accretion disk, contributing to soft X-rays, and (2) a hard X-ray spectral component likely arising from coronal emission above the accretion disk, and due to inverse Compton scattering of disk photons off a population of relativistic particles. The observed spectra are modified by the effects of absorption, reflection and re-emission (see Turner & Miller 2009 and Fabian 2016 for recent reviews). Ionized absorbing material near the SMBH imprints absorption edges and absorption lines on the observed spectra. Matter seen in reflection or emission from the inner accretion disk will inevitable be subject to relativistic effects, including blurring due to the high gaseous velocities, relativistic Doppler beaming, and gravitational redshift, producing characteristic emission-line profiles with blue horns and broad red wings. Further, if the corona is located very close above the inner disk, the effect of relativistic lightbending is strong, causing a strongly reflection-dominated spectrum. These effects therefore provide us with valuable diagnostics of the extreme physics near SMBHs. Spectral signatures are most pronounced in extreme states, especially low flux states. Therefore, we are carrying out programs to identify AGN in extreme flux and spectral states.

Based on our long-term AGN monitoring program with the satellite *Swift* (Gehrels *et al.* 2004), we have followed-up or newly identified some of the most highly variable AGN known today. When these undergo exceptional flaring activity, or go into deep low-states, we then trigger deep follow-up observations including with XMM-Newton and NuSTAR, and at other wavebands.

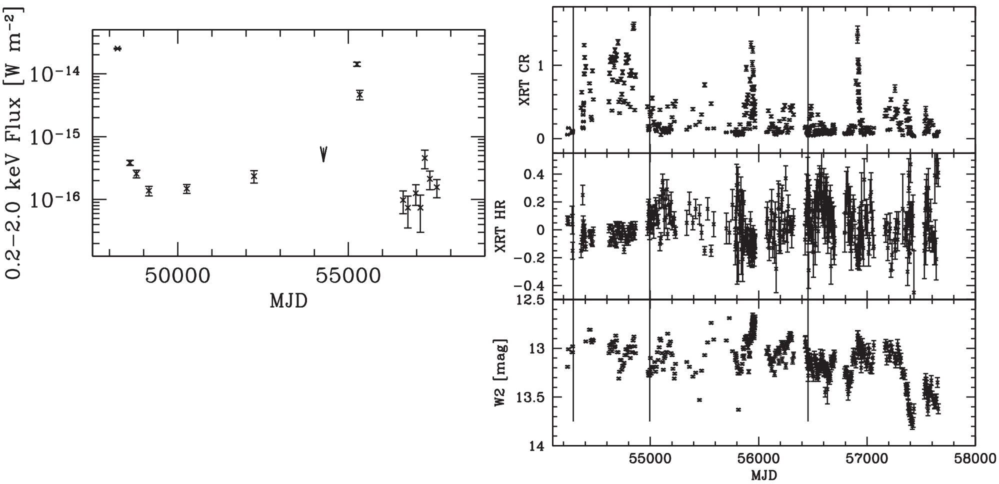

Figure 1. *Left:* Long-term X-ray lightcurve of **IC 3599** with two giant (factors ~ 100) outbursts. Our most recent *Swift* monitoring has shown that the X-rays continue to remain faint, while the UV is brighter again. *Right:* *Swift* lightcurve of **Mrk 335** (upper panel: X-ray telescope (XRT) countrate, middle panel: hardness ratio, lower panel: UVOT W2 magnitude). While historically X-ray bright, most recently, Mrk 335 has mostly remained in a low X-ray flux state, with occasional flaring.

2. IC 3599

IC 3599 is unique among AGN in its high-amplitude X-ray transience, accompanied by variable emission lines, first seen in 1990. The discovery of a second such (factor $\sim$100) outburst 20 yrs after the first (Komossa *et al.* 2014, Grupe *et al.* 2015), has ruled out an outburst scenario of a single stellar tidal disruption event (TDE) flaring only once. Variants of repeat TDEs in binary SMBH systems do not match observations well or require further testing. An accretion disk instability is well consistent with the data (Grupe *et al.* 2015). If confirmed, this is the first case where such a disk instability has been identified among accreting SMBHs. In 2015 IC3599 reached a third high-state in optical-UV emission, possibly indicating the onset of a third outburst. So far, however, the X-rays have remained faint (Fig. 1), implying that either the UV emission varies independent of the X-rays, or the UV predates the X-ray rise by months-years. Multiple flaring is not expected in scenarios, where both pairs of a binary star are tidally disrupted, producing only two peaks (Mandel & Levin 2015), but is well consistent with the scenario of a disk instability.

3. WPVS007

WPVS007 underwent a unique, giant-amplitude drop in its X-ray emission (factor 400) first detected with ROSAT, not seen in any other AGN. It has remained X-ray faint ever since the 1990s, except occasional rapid flaring. Results from years of multi-wavelength monitoring (e.g., Grupe *et al.* 2013, Komossa *et al.* 2014) along with HST UV spectroscopy (Leighly *et al.* 2015), suggest a rare viewing geometry into the central engine, with our line of sight grazing a clumpy molecular torus and the winds launched from its edge (Leighly *et al.* 2015). Its 2016 lightcurve is overall consistent with a steady decrease in extinction, while X-rays remain undetected.

https://doi.org/10.1017/S1743921317001648 Published online by Cambridge University Press

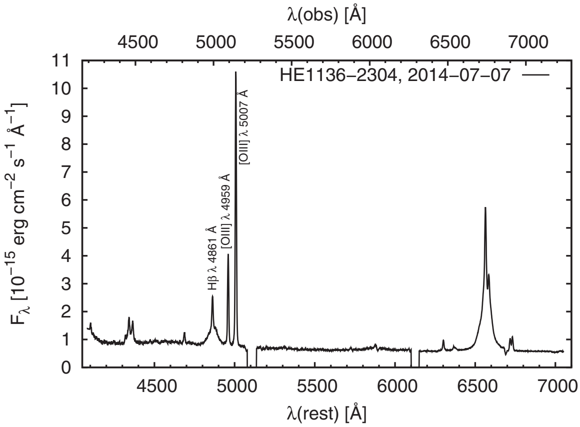

Figure 2. SALT optical spectrum of HE 1136-2304 from 2014, revealing its Seyfert-type change. In 1993, the broad Hα line was barely detected. Lines labelled are Hβ, [OIII]4363 and [OIII]5007.

4. Mrk 335

The NLS1 galaxy Mrk 335 is among the X-ray brightest, most variable AGN known; with pronounced episodes of X-ray flaring, and deep, long-lasting X-ray low-states rich in spectral features (e.g., Grupe *et al.* 2012; our Fig. 1). The broad-band X-ray spectrum is consistent with blurred reflection from an accretion disk around a nearly maximum spinning black hole ($a > 0.9$; Parker *et al.* 2014, Gallo *et al.* 2015, Wilkins *et al.* 2015), or alternatively with an extreme partially covering absorber, with $\log N = 23.3$ at low-state. While the nature of the lamppost illuminating the disk remains unknown, the base of a jet has been considered as a candidate (Gallo *et al.* 2015). Knowing accretion conditions of nearby, low-power radio sources provides us with an independent path to understanding the question, why only ∼10% of all AGN are radio-loud. Dedicated X-ray follow-ups including with Suzaku, NuSTAR, and XMM-Newton have been triggered in a deep low-state in 2013, a bright flare state in 2014, and most recently with XMM-Newton and HST in a deep UV low-state in 2015. The latter observation shows broad, fast (-5000 km s^{-1}) UV absorption in Lyα, C IV, and possibly O VI.

5. HE 1136–2304

The Seyfert galaxy HE 1136-2304 was detected in an X-ray flare state in the XMM-Newton slew survey, subsequently confirmed with *Swift* after increasing in X-ray flux by a factor ∼ 30. Follow-up observations with NuSTAR, XMM-Newton, and SALT (South Africa Large Telescope), quasi-simultaneous within 3 days, have identified HE 1136-2304 as one of the rare "changing-look" AGN (Parker *et al.* 2016), dramatically changing its optical Seyfert type, from almost type 2 in 1993 to a Seyfert 1.5 with strong Balmer emission lines in 2014 (Fig. 2). The observations are consistent with an intrinsic change in accretion rate.

6. The binary SMBH candidate OJ 287

Galaxy mergers and the binary black holes at their centers offer unique views on galaxy formation and evolution, and on black hole demographics and growth across cosmic times. Coalescing supermassive binaries are the strongest sources of gravitational waves in the universe. An intense search for wide and close systems in all stages of their evolution

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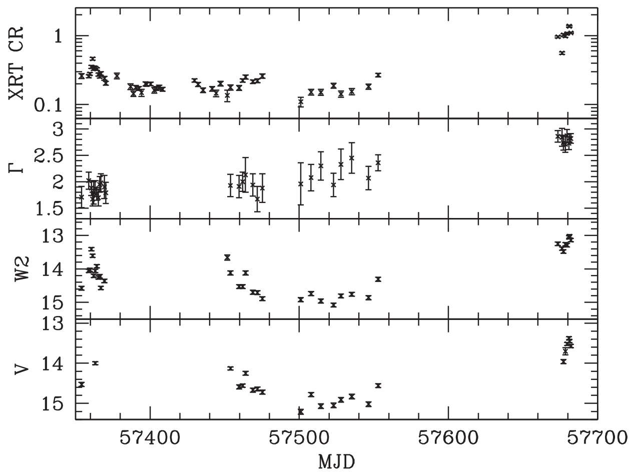

Figure 3. X-ray, UV, and optical lightcurve of OJ 287 taken with *Swift*, between December 2015 and October 2016.

is currently ongoing (review by Komossa & Zensus 2016). OJ 287 is one of the best candidates for hosting a sub-parsec binary SMBH, with quasi-periodic optical maxima every ∼12 years. Reports of a high optical peak flux in December 2015 (ATel 8372), along with a suggestion that this may correspond to the next decadal peak of OJ 287, which would then imply strong orbital precession of the secondary SMBH (Valtonen *et al.* 2016), has triggered many follow-up projects. Multi-frequency flux density monitoring with the 100m Effelsberg radio telescope started in December 2015 (Komossa *et al.* 2015). OJ 287 was also observed with *Swift*, first in triggered mode following the optical rise to a maximum in December 2015 (ATel 8401), more recently by us in order to follow the long-term X-ray evolution along with other wavebands (Fig. 3). In X-rays, the highest recent state was detected on October 12, 2016; more than two times brighter than the December 5 high-state, accompanied by bright UV emission, and by a significant softening of the X-ray spectrum ($\Gamma_x = 2.9 \pm 0.1$). Ongoing monitoring of OJ 287, and extremely high-resolution Event Horizon Telescope imaging, provide us with a unique chance of testing the binary SMBH scenario, and understanding one of the most massive blazars known.

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