240. Extreme nuclear transients

THE EXISTENCE of supermassive black holes (SMBH) is implicit in various scientific areas being impacted by Gaia: most notably in its survey of active galactic nuclei (AGN, essay 82), and the subset of compact dual AGN providing quantitative evidence for galaxy mergers (essay 163), in the detection of hypervelocity stars, which result from the disruption of a binary star system passing close to a black hole (essays 22 and 166), and in the detection of tidal disruption events (TDE), which result from the tidal disruption of a star as it passes close to a supermassive black hole (essay 206).

With the development of powerful optical transient surveys, a number of particularly luminous short-period transients have recently been discovered. They display a range of properties (such as variability timescale, light-curve trends, spectral index, and infrared flux), making it difficult to attribute them to a single physical mechanism. As well as tidal disruption events (TDE), there are sources classified as 'ambiguous nuclear transients' (ANT) and, most recently, the class of very high-luminosity 'extreme nuclear transients' (ENT).

In the latter category are ZTF20abrbeie/AT2021lwx (Subrayan et al., 2023, Wiseman et al., 2023), and two recent Gaia science alerts discoveries: Gaia16aaw (AT2016dbs) and Gaia18cdj (AT2018fbb), reported by Hinkle et al. (2025). Indeed, Gaia18cdj is notable as *'the most energetic single transient yet found'*. IFL Science described it as *'twenty-five times more powerful than the most energetic supernova ever observed…, and the biggest explosion event since the Big Bang'*. These extreme nuclear transients are the subject of this essay.

ACCRETION ONTO a galaxy's central supermassive black hole powers many of the most luminous events known. At redshifts $z \sim 1$, roughly 10% are actively accreting mass, and observed as AGN (e.g. Zou et al., 2024). AGN light curves commonly show stochastic variability on a range of timescales from minutes to years (e.g. Ulrich et al., 1997, MacLeod et al., 2012), with some showing long-term photometric trends often accompanied by dramatic spectral changes. Rarely, some also exhibit large coherent flares (Graham et al., 2017).

Optical transient surveys, including ASAS-SN and ZTF, have also revealed several classes of flares coincident with the nuclei of their host galaxies. These include tidal disruption events (TDE); rapid turn-on AGN (Wyrzykowski et al., 2017, Trakhtenbrot et al., 2019), and 'ambiguous nuclear transients' (ANT). The latter cannot easily be classified as either AGN flares or TDEs, with examples including ASASSN-18el (Trakhtenbrot et al., 2019), ASASSN-18jd (Neustadt et al., 2020), and ASASSN-20hx (Hinkle et al., 2022).

These various accretion-powered transients nevertheless share several key observational properties, including bright ultraviolet emission, strong emission lines, and often X-ray emission. And the smooth flares of nuclear transients over timescales of several months are distinct from the stochastic variability typical of AGN (Frederick et al., 2021, van Velzen et al., 2021).

TIDAL DISRUPTION EVENTS result from the disruption of a star as it passes close to a supermassive black hole (e.g. Rees, 1988, Evans & Kochanek, 1989, van Velzen et al., 2011, Gezari, 2021). Typically, the host galaxies of TDEs do not coincide with a strong AGN, although this is considered to be largely due to selection effects. More recently, an increasing number of TDE candidates have been discovered in host galaxies exhibiting weak AGN-type activity (Onori et al., 2022, Wevers et al., 2022, Hoogendam et al., 2024).

Most are considered to be consistent with the disruption of main-sequence stars of mass $0.5-2\,M_{\odot}$ (Ryu et al., 2020). Nevertheless, enhanced N/C ratios suggest a population resulting from more massive stars (Kochanek, 2016, Mockler et al., 2022, Miller et al., 2023).

AS OF SEPTEMBER 2024, the Gaia Science Alerts data base listed 25 919 alerts (Hodgkin et al., 2021). Of these, 7 141 were assigned to 23 classes, with 25 inferred to be tidal disruption events.

I say more about the phenomenon, their discovery history, the insights that are being gained from them, and details of Gaia's two brightest (15–18 mag) TDE discoveries, Gaia19bvo and Gaia19eks, in essay 206.

FROM THE Gaia alerts transient stream, Hinkle et al. (2025) leveraged its 10-year all-sky survey to select a sample of flare events with three major characteristics: large amplitudes (>1 mag), smooth light curves (less than 10% excess variability about the long-term flare evolution), and long timescales (>1 yr). Their search yielded two transients, Gaia16aaw (AT2016dbs) and Gaia18cdj (AT2018fbb) which, combined with the 'extraordinary accretion event' ZTF20abrbeie/AT2021lwx (Subrayan et al., 2023, Wiseman et al., 2023), resulted in a sample of three events which they referred to as 'extreme nuclear transients' (ENT). Their detailed properties, derived by Hinkle et al. (2025), are worth outlining.

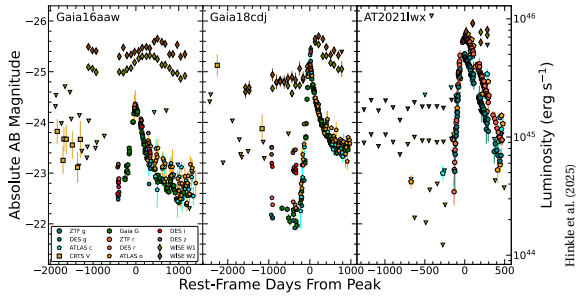
FIRSTLY, BOTH Gaia events are located within 0.8 kpc of their host-galaxy centres, confirming their nuclear transient nature (AT2021lwx has no detected host galaxy prior to the flare, so its offset is unknown). All three flares are smooth, luminous, and long-lived, with a rise of order 100 d to peak luminosity, and a slow decline of order 150 d to half their peak luminosity.

Pre- and post-flare: Somewhat reminiscent of extreme versions of ANTs, the ENTs detected prior to the flare show tentative signs of pre-flare variability, suggesting weak AGN activity within their host galaxies. After the ultraviolet/optical emission peaks, they show an infrared excess, suggesting transient heating of circumnuclear dust and re-emission at longer wavelengths.

Host galaxies: Optical and near-infrared follow-up spectra indicate that the events are at relatively high redshift, $z \approx 1$. From stellar population synthesis models, Hinkle et al. (2025) estimated that the host galaxies of Gaia16aaw and Gaia18cdj have masses $\sim 9 \times 10^{10} M_\odot$, and high star-formation rates $75 - 110 M_\odot\ \mathrm{yr}^{-1}$.

Black hole mass: Typical galaxy–SMBH scaling relations (McConnell & Ma, 2013) imply SMBH masses of $10^{8.4} M_\odot$ for Gaia16aaw and Gaia18cdj, and a similar upper limit for AT2021lwx. These are more massive than the majority of known nuclear transient hosts, and the host-galaxy masses are within the top few percent of stellar masses at $z = 1$ (when the Universe was half its current age), suggesting that the inferred SMBH masses are similarly extreme at such redshifts. In contrast, the high star-formation rates underlying Gaia16aaw and Gaia18cdj are only moderately exceptional at $z = 1$ when the star formation rate in the Universe was a factor 6 higher than today (Madau & Dickinson, 2014).

Luminosity and spectra: Their extremely high peak luminosities ($2-7 \times 10^{38}\ \mathrm{J\ s}^{-1}$) are 1000 times higher than core-collapse supernovae (SNe), 100 times higher than typical Type Ia supernovae, and 30 times higher than the extreme H-poor superluminous supernovae (SLSNe-I). The spectral energy distributions are well-fit by a blackbody model, consistent with super-Eddington accretion expected for TDEs (Evans & Kochanek, 1989).



Light-curve duration: Their light-curve decay timescales are significantly longer than most transients. The rest-frame durations for the flares to fade by half are around 171 d for Gaia16aaw, 155 d for Gaia18cdj, and 210 d for AT2021lwx. They stand out in the parameter space of peak absolute magnitude versus characteristic timescale as being particularly luminous and long-lived.

Radiated energy: Their total radiated energies are particularly high, ranging between $2 - 5 \times 10^{45}$ J, and corresponding to accreted masses $0.3 - 1.4 M_\odot$ (assuming a typical 10% accretion efficiency). These are much higher than typical TDEs and ANTs, being more than twice as energetic as the next most energetic known flares, PS1-10adi (Kankare et al., 2017) and ASASSN-15lh (Dong et al., 2016, Leloudas et al., 2016), and up to an order of magnitude higher in the cases of Gaia18cdj and AT2021lwx. Indeed, Gaia18cdj is *'the most energetic single transient discovered to date'*.

Space density: Compared to other known transient classes, such extreme nuclear transients are extremely rare, with a space density $\sim 10^{-3}\ \mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$.

Physical origin: Hinkle et al. (2025) argue that their high peak luminosities, long flare timescales, immense radiated energies, and implied accreted masses are consistent with the tidal disruption of an *intermediate-mass* ($\sim 3 - 10 M_\odot$) star by a massive ($> 10^8 M_\odot$) supermassive black hole. With the flare timescale scaling as $M_{BH}^{0.5}$, the high implied masses of the SMBHs naturally provide long-duration flares consistent with the ENT timescales. As roughly half the stellar mass in a tidal disruption event leaves the system (rather than falling back onto the black hole), the total radiated energies provide a lower limit on the stellar masses of around $3 M_\odot$.

More detailed models of the accretion processes, fallback rates, and energetics of these highly luminous flares are given by Fancher et al. (2025).

FOR THE FUTURE, these Gaia discoveries point to the probable detection of extreme nuclear transients at even higher redshifts, $z \sim 4 - 6$, for example with the Vera Rubin–LSST and Roman Space Telescope surveys. These even more extreme populations would provide further insights into the high-mass end of the supermassive black hole mass distribution.