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A New Population of Highly Energetic Nuclear Transients

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Abstract. We have identified a new population of luminous, optical, narrow-lined transients (FWHM ∼1000 km s^{-1}) coincident with the nuclear region of Seyfert galaxies. According to extensive spectrophotometric follow-ups of the main event (PS1-10adi), we could exclude both normal active galactic nucleus activity and changing-look quasars as the origin. The integrated energy output and spectral evolution over a time-scale of several years point to two possible paths of origin: a tidal disruption of a star by a supermassive black hole, or an extremely energetic supernova occurring within the Seyfert galaxy's narrow-line (or broad-line) region. The former model would require invoking a specific variant of a tidal disruption, while the latter would require an extremely efficient conversion of kinetic energy via shock interaction between the supernova ejecta and the dense ambient medium.

Keywords. Galaxies: Seyfert, supernovæ: general, accretion, black hole physics

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1. Introduction

Large-scale all-sky surveys have facilitated discoveries of luminous transients beyond the local universe. Kankare *et al.* (2017) presented a population of highly energetic, narrow-lined transients within a redshift range $z = 0.1$–0.4, with nuclear locations in Seyfert galaxies. The main event, PS1-10adi, was discovered by the Panoramic Survey Telescope and Rapid Response System 1 (Chambers *et al.* 2016) on 2010 August 15, coincident with SDSS J204244.74+153032.1 at $z = 0.203$ (Valenti *et al.* 2010). In addition, Kankare *et al.* (2017) reported preliminary data for PS1-13jw observed in SDSS J084453.56+425744.8, plus three candidate transient events found in the Catalina Sky Survey Data Release 2, in SDSS J233454.07+145712.8, SDSS J094806.55+031801.9 and SDSS J094608.49+351222.4. Independent discoveries of the latter two events were reported by Graham *et al.* (2017a,b). Furthermore, Drake *et al.* (2011) reported a similar event, CSS100217:102913+404220, in SDSS J102912.56+404219.7, suggesting that it is a supernova in the accretion disk of its host galaxy. The transient PS16dtm in SDSS J015804.75-005221.9, also recently reported, is likely to be part of this population as well; Blanchard *et al.* (2017) and Jiang *et al.* (2017) proposed that it is a tidal disruption flare. We note, too, that Moriya *et al.* (2017) have associated these events with interactions between a cyclic accretion disk wind and clouds in broad-line regions. This talk summarised the interpretation of the nature of PS1-10adi (Kankare *et al.* 2017), and showed how a spherical interaction model can describe the event.

2. Overview

PS1-10adi, and the population of similar transients, displays a very slow and smooth light-curve evolution which is uncommon for active galactic nuclei (AGNs). At the same time the total radiated energy of PS1-10adi is extremely high ($\sim 10^{52}$ erg), which is unique even for hydrogen-poor superluminous supernovæ (SNe). Furthermore, PS1-10adi displays a prominent, narrow hydrogen emission-line component (FWHM $\sim$ 900 km s^{-1}).

These events do not appear to be consistent with normal AGN activity. As Kankare *et al.* (2017) note, the smooth light-curve evolution of PS1-10adi is inconsistent with the stochastic variability of AGNs. At maximum brightness PS1-10adi was $\sim$10 times more luminous than its (quiescent) host galaxy; such variability is not commonly seen in narrow-line Seyfert galaxies. A small fraction of AGNs shows a larger-amplitude 'changing-look quasar' variability (MacLeod *et al.* 2012, 2016); however, the evolving narrow spectral lines of PS1-10adi are inconsistent with an AGN. This is due to the fact that the increased AGN luminosity is accompanied by increased emission from the AGN broad-line region (FWHM of a few thousands of km s^{-1}) near the black hole, whereas the more distant narrow-line region (FWHM <1000 km s^{-1}) remains unchanged. That is opposite to what is observed in PS1-10adi. Furthermore, the spectral energy distribution of PS1-10adi is also inconsistent with those of AGNs.

A supermassive black hole can tear apart a star that passes by (Rees 1988), a phenomenon known as a tidal disruption event (TDE). However, several aspects of PS1-10adi are inconsistent with those of known optical TDE candidates, as discussed by Kankare *et al.* (2017). The light-curves of PS1-10adi decline more slowly than expected – and observed – for TDE candidates, and the blackbody temperatures of PS1-10adi are lower and evolve faster than expected for TDEs (Gezari *et al.* 2012). Furthermore, the narrow spectral lines of PS1-10adi are not seen in TDEs; the optical TDE candidates are either rather featureless, or show broad emission lines (FWHM of several thousands of km s^{-1}; Arcavi *et al.* 2014).

Recent large-scale sky surveys have revealed a population of so-called superluminous SNe (Quimby *et al.* 2011). Most of those events are hydrogen poor, and in this case their energy source is commonly attributed to be a spin-down of a highly magnetic, millisecond neutron star (magnetar) created in the SN explosion (e.g., Inserra *et al.* 2013). However, for our data of PS1-10adi to be explained by a magnetar, it would require properties that are extreme, such as persistent sub-millisecond spin rates. In addition, the magnetar model does not provide a natural explanation for the narrow spectral lines of PS1-10adi. Similarly, radioactive decay of ^{56}Ni does not explain the observed evolution of PS1-10adi.

On the other hand, shock interaction between expanding ejecta and an ambient medium is an efficient method for converting kinetic energy into radiation. It offers a natural explanation for the high energies, the smooth light-curve evolution and the narrow-line spectral features of PS1-10adi-like events. The talk explored such a parameter space numerically, basing it on a thin-shell interaction model (Moriya *et al.* 2013) and assuming full conversion of shock energy into radiation. The scattering of the radiation through the ambient medium was taken into account (Sunyaev & Titarchuk 1980), but allowed for a moving inner boundary instead of a stationary one. For a dense and isotropic shell ($\rho \propto r^0$) the required parameters are $M_{\rm ejecta} \sim 20\ M_\odot$. During 1000 days following the explosion the forward shock has swept up $M_{\rm shell} \gtrsim 70\ M_\odot$ (Fig. 1). The model assumes $n_{\rm e} = 1.48 \times 10^8$ cm^{-3}. Lowering the ejecta mass would lead to a light-curve that declined too rapidly, while a lower density of the ambient medium would lead to a lower shell mass but very high shock velocities. The appearance of a red shoulder in the Balmer lines is consistent with $M_{\rm ejecta} < M_{\rm shell}$ for the shock to slow down to a velocity of $\sim$3000 km s^{-1} at +201 d. The shock velocities from our model are within a factor of $\sim$2 at the corresponding epoch. However, since the appearance of the red shoulder in the Balmer lines suggests an inherently asymmetrically expanding system, the inferred model parameters from a symmetrical model are uncertain.

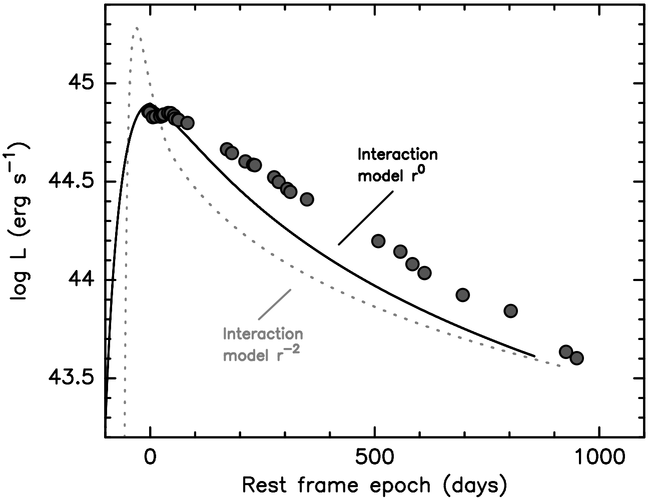

Figure 1. Modelling the bolometric light-curve of PS1-10adi based on a black-body formula but including an estimated UV excess component (see Kankare *et al.* 2017). A spherical interaction model for expanding material and an ambient medium shell (solid curve) is able to match the observations quite well; the discrepancies are probably caused by underlying asymmetries. However, assuming a density profile of r^{-2} (dotted curve) results in a worse match to the data.

Kankare *et al.* (2017) discussed several mechanisms that can contribute to a large mass of the ambient medium for a massive SN progenitor in the central regions of Seyfert galaxies. (1) The mergers of massive stars in dense stellar clusters can give rise to a very massive ambient medium and result in ultra-bright SNe (Portegies Zwart & van den Heuvel 2007), as suggested in the context of SN 2006gy. (2) A dense and photoionising environment can provide suitable conditions for the formation of a standing bow shock that can accumulate mass lost from a massive star efficiently into a standing shell (Mackey *et al.* 2014), as observed for Betelgeuse. (3) The narrow-line regions of Seyfert galaxies have an interstellar-medium density $n_e \gtrsim 10^6$ cm^{-3} (Netzer 1990), which is similar to that yielded for the circumstellar medium of normal Type IIn SNe.

Another possible explanation for the nature of PS1-10adi-like transients is that they are TDEs. Very different mechanisms of producing TDE radiation energy are proposed in the literature, e.g.: (1) the dissipation of energy in shocks, as streams of material from the star slowly circularise and merge in stream–stream collisions or with the material in the accretion disk (e.g., Piran *et al.* 2015, Shiokawa*et al.* 2015); (2) wind from the accretion disk driven by super-Eddington radiation (e.g., Strubbe & Quataert 2009); (3) reprocessing of the accretion energy by a static or expanding shell of (at least initially) bound stellar material (e.g., Metzger & Stone 2016). Yet another possible explanation for the nature of these objects is that they are TDEs if TDEs have a very specific mechanism in general. Metzger & Stone proposed a TDE model where a large fraction of the stripped stellar material is ejected in an outflow powered by the central accretion. If this expanding material collides and sweeps up ambient material in the broad-line region of the host Seyfert galaxy, it could potentially result in a PS1-10adi-like display, qualitatively similar to Type IIn SNe.

3. Summary

The properties of PS1-10adi-like transients are consistent with a stellar origin, and seem likely to arise from interacting systems, either from highly energetic SN explosions in the dense nuclear region of Seyfert galaxies or from tidal disruption events (but

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with specific constraints). Such events are 100–1000 times more energetic than normal SNe, and supersede even the hydrogen-poor superluminous SNe by a factor of 10. These transients will therefore provide exceptional possibilities for probing the universe at cosmological distances during the next generation of sky surveys with facilities like the Large Synoptic Survey Telescope. Now is the time to study them locally to understand their physical nature and explosion sites.

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