An unusually brilliant transient in the galaxy M85

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Historically, variable and transient sources have both surprised astronomers and provided new views of the heavens. Here we report the discovery of an optical transient in the outskirts of the lenticular galaxy Messier 85 in the Virgo cluster. With a peak absolute R magnitude of −12, this event is distinctly brighter than novae, but fainter than type Ia supernovae (which are expected in a population of old stars in lenticular galaxies). Archival images of the field do not show a luminous star at that position with an upper limit of 25, 30, 60 and 75 mag. Furthermore, we find no evidence for young stars (supergiants, clusters and H II regions). An analysis of Spitzer Space Telescope data we derive a pre-explosion limiting magnitude of F475W = 4.3.

On 8 January 2006 UT we initiated an optical photometric campaign with the automated Palomar 60-inch telescope (see Fig. 2 and Supplementary Table). The light curve, with its plateau of 70 days, is unlike that of a type Ia supernova. The plateau duration is also too short for an outburst from a luminous blue variable (LBV, such as η Carina). We began a programme of spectroscopic observations with the Palomar Hale and Keck I telescopes (Fig. 3). The Palomar spectrum obtained on 8 January 2006 UT did not contain any strong emission feature; the spectrum could be adequately described by a blackbody spectrum with effective temperature of approximately $T_{\text{eff}} = 4,600$ K. Likewise, the 3 February 2006 UT Keck spectrum was also featureless but unfortunately did not cover Hz. The 23 magnitude of ~19.3 projected 2.3 kpc from the centre of the lenticular (Hubble type S0) galaxy Messier 85 (M85; also known as NGC 4382) a member of the Virgo cluster of galaxies; see Fig. 1. We believe (see below) that the transient lies within M85 and thus we name the source the M85 Optical Transient 2006-1 (OT2006-1). Fortuitously, this field was observed by the Hubble Space Telescope three years earlier. From the archival Hubble Space Telescope data we derive a pre-explosion limiting magnitude of F475W = 4.3.

Figure 1 | Optical images of the field around M85 OT2006-1 obtained at two epochs. Data were obtained with the Low-Resolution Imager and Spectrograph (LRIS)10 at Keck (a) on 3 February 2006, and the Advanced Camera for Surveys aboard the Hubble Space Telescope (b, with a F475W filter; c, with a F850LP filter) on 1 February 2003. The event is located about 30' from the centre of M85 at $\alpha = 12 \text{ h } 25 \text{ min } 23.82 \text{ s}$ and $\delta = 18 \text{ h } 56.2'$. (J2000). After registering the Keck image to the Hubble Space Telescope image (the root mean square of the transformation was 40 mas) we were able to establish the following limits for a precursor object (progenitor star): 26.8 mag in the F475W filter (exposure 750 s) and 24.7 mag in the F850LP filter (exposure time 1,150 s). These limits exclude an LBV2 (origin for which $M_V = \text{mag$). Furthermore, we find no evidence for young stars (supergiants, clusters and H II regions). An analysis of Spitzer Space Telescope Infrared Array Camera data obtained on 21 December 2004 resulted in $\Delta$ upper limits of 25, 30, 60 and 75 mJy at 3.6, 4.5, 5.8 and 8.0 μm, respectively. The Lick Observatory Supernova Search observed M85 two hundred and twenty times from 2000 to 2006. We found no transient at the position of M85 OT2006-1 to (roughly R-band) magnitudes ranging from 20 to 21. No X-ray emission was detected in a Chandra X-ray Observatory observation12 obtained in June 2002 with a flux upper limit of $2.7 \times 10^{-4}$ counts s$^{-1}$ in the 0.3–10 keV band. Circles indicate the position of the transient in b and c.

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and 24 February 2006 UT Keck spectra showed a similar continuum but a number of emission lines were readily detected (Fig. 3). These latter spectra were the deepest, so it is likely that the lines were seen as a result of better sensitivity.

We associate the strongest lines at wavelengths $\lambda \approx 6,587 \, \text{Å} \text{and} \lambda \approx 4,874 \, \text{Å}$ with H$\alpha$ and H$\beta$, respectively. Assuming this identification is correct, the mean heliocentric (peak) velocity of the pair is $880 \pm 130 \, \text{km} \, \text{s}^{-1}$. We were unable to conclusively identify the remaining lines but do note that the spectra of many hypergiants contain a number of unidentified emission lines. The systemic velocity of M85 is $729 \pm 2 \, \text{km} \, \text{s}^{-1}$ and the velocity dispersion in the vicinity of the optical transient is $200 \, \text{km} \, \text{s}^{-1}$. The peak velocity of the Balmer lines is thus consistent with M85 OT2006-1 being located in M85. So if M85 is the host galaxy (for which we adopt a distance of 15 Mpc, the standard distance to M85 OT2006-1 being located in M85. So if M85 is the host galaxy of M85 OT2006-1 is $-12 \, \text{mag}$. This peak flux is ten times brighter than the brightest nova but (at least) ten times less luminous than type Ia supernovae (the sort expected in a lenticular galaxy). The narrow linewidth of the Hz line, $\sim 350 \pm 140 \, \text{km} \, \text{s}^{-1}$ (see Fig. 3), argues independently against an origin of either a nova or a supernova (including type II).

The Galactic foreground extinction towards M85 is negligible, $A_R = 0.08$ (ref. 7). The source intrinsic attenuation can be derived by comparing the observed ratio of the emission lines fluxes of H$\alpha$ ($3.2 \pm 0.2 \times 10^{-16} \, \text{erg} \, \text{s}^{-1} \, \text{cm}^{-2}$) and H$\beta$ ($0.9 \pm 0.1 \times 10^{-16} \, \text{erg} \, \text{s}^{-1} \, \text{cm}^{-2}$) and the theoretical value of 3.05 (case B recombination, low-density limit, $T = 5,000 \, \text{K}$). We estimate $E(B-V) = 0.14 \pm 0.17$, which corresponds to an R-band extinction of $0.40 \pm 0.08 \, \text{mag}$. This is too low to explain the unusual colour and temperature of M85 OT2006-1 with a strongly absorbed nova, supernova or LBV.

We searched archival data from the Hubble Space Telescope, the Spitzer Space Telescope and the Chandra X-ray Observatory in an attempt to constrain the progenitor. There is no evidence for a bright progenitor, and nor do we see tracers of massive star progenitors (see Fig. 1). This finding (and the shorter duration) rule out that M85 OT2006-1 is an LBV because LBVs are among the brightest stars, $M_V \sim -8$. We note that M85 is a galaxy composed of old stars with a possible trace of a spiral arm. We conclude that the M85 OT2006-1 probably arises from a population of stars with masses of a few times the mass of the Sun ($M_\odot$) or less.

We now turn to the physical parameters of M85 OT2006-1. The bolometric luminosity flux (as traced by $4\pi d^2f_V$, where $f_V$ is the spectral flux density at frequency $V$) of M85 OT2006-1 peaks at $4,874 \, \text{Å}$ or absorption features are seen in the (native) DBSP spectrum. Specifically we placed a limit of $6 \times 10^{-16} \, \text{erg} \, \text{s}^{-1} \, \text{cm}^{-2}$ for an emission line in the vicinity of Hz. In the LRIS red channel spectrum the brightest emission feature is at $\lambda = 6,587 \, \text{Å}$ (flux of $(3.2 \pm 0.2) \times 10^{-16} \, \text{erg} \, \text{s}^{-1} \, \text{cm}^{-2}$), which we identify with redshifted Hz. The velocity of the line centre is $1,020 \pm 150 \, \text{km} \, \text{s}^{-1}$, the full-width at half-maximum (FWHM) of the Hz line, after accounting for the instrumental FWHM, is $350 \pm 140 \, \text{km} \, \text{s}^{-1}$. In addition, we detect the following emission lines (central wavelengths, fluxes in units of $10^{-16} \, \text{erg} \, \text{s}^{-1} \, \text{cm}^{-2}$ and typical uncertainties of $1 \%$): H$\alpha$ $(4,115 \, \text{Å}, 0.3 \pm 0.1, 6,428 \, \text{Å} (0.9 \pm 0.1), 6,527 \, \text{Å} (1.5 \pm 0.4, 8,079 \, \text{Å} (0.8 \pm 0.1)$ and 8,106 A (0.7 ± 0.1). Further LRIS spectra were obtained on 3 and 23 February 2006 UT (not shown here). The 3 February 2006 LRIS spectrum did not include the Hz wavelength. For this spectrum, using a sliding 10 Å window, we were able to set a 3$\sigma$ upper limit of $6 \times 10^{-18} \, \text{erg} \, \text{s}^{-2} \, \text{cm}^{-1}$ in the vicinity of H$\beta$. 

**Figure 3 | Optical spectra of M85 OT2006-1.** Data were obtained within the Double Beam Spectrograph (DBSP) at the Palomar Hale 200-inch telescope (grey line, 1,800 s integration, 2006 January 8.53 UT and Keck/LRIS (blue line, 3,000 s, 2006 February 24.59 UT). Neither strong emission nor absorption features are seen in the (native) DBSP spectrum. Specifically we placed a limit of $6 \times 10^{-16} \, \text{erg} \, \text{s}^{-1} \, \text{cm}^{-2}$ for an emission line in the vicinity of Hz. In the LRIS red channel spectrum the brightest emission feature is at $\lambda = 6,587 \, \text{Å}$ (flux of $(3.2 \pm 0.2) \times 10^{-16} \, \text{erg} \, \text{s}^{-1} \, \text{cm}^{-2}$), which we identify with redshifted Hz. The velocity of the line centre is $1,020 \pm 150 \, \text{km} \, \text{s}^{-1}$ (see inset). On the blue side, the strongest feature is at $\lambda = 4,875 \, \text{Å}$ corresponding to redshifted Hz. I (flux of $(0.9 \pm 0.1) \times 10^{-16} \, \text{erg} \, \text{s}^{-1} \, \text{cm}^{-2}$), the equivalent widths are $10 \pm 1 \, \text{Å}$ (Hz) and $5 \pm 1 \, \text{Å} (H\beta)$. The full-width at half-maximum (FWHM) of the Hz line, after accounting for the instrumental FWHM, is $350 \pm 140 \, \text{km} \, \text{s}^{-1}$. In addition, we detect the following emission lines (central wavelengths, fluxes in units of $10^{-16} \, \text{erg} \, \text{s}^{-1} \, \text{cm}^{-2}$ and typical uncertainties of $1 \%$): H$\alpha$ $(4,115 \, \text{Å}, 0.3 \pm 0.1, 6,428 \, \text{Å} (0.9 \pm 0.1), 6,527 \, \text{Å} (1.5 \pm 0.4, 8,079 \, \text{Å} (0.8 \pm 0.1)$ and 8,106 A (0.7 ± 0.1). Further LRIS spectra were obtained on 3 and 23 February 2006 UT (not shown here). The 3 February 2006 LRIS spectrum did not include the Hz wavelength. For this spectrum, using a sliding 10 Å window, we were able to set a 3$\sigma$ upper limit of $6 \times 10^{-18} \, \text{erg} \, \text{s}^{-2} \, \text{cm}^{-1}$ in the vicinity of H$\beta$. 

**Figure 2 | Temporal evolution of M85 OT2006-1.** a. Observed light curve corrected for Galactic foreground extinction of $A_V = 0.08$ (ref. 7). Data for the plots are given in the Supplementary Table and come from the following sources (bands given in parentheses): Palomar 60-inch (P60; gRz), the Large Format Camera (LFC) on the Palomar Hale 200-inch (P200; zRI), the Widefield Infrared Camera (WIRCAM) on the Palomar Hale 200-inch telescope (P200; zRI), the Widefield Infrared Camera (WIRCAM) on the Keck-I 10-m telescope (gRI), Person’s Auxiliary Nasmyth Infrared Camera (PANIC) on the Magellan 6.5-m Baade telescope (VJK), the Near Infrared Echelle Spectrograph (NIRSPEC) on the Keck-II 10-m telescope (JHK) and the Wide Field Infrared Camera (WFPCAM) on the 3.8-m United Kingdom Infrared Telescope (UKIRT; JHK). Error bars are 1σ. JD, Julian day.
**Figure 4 | Phase space of cosmic explosive (supernovae) and eruptive (novae and LBVs) transients.** The vertical axis is the peak brightness in the R band and the horizontal axis is the duration of the event (τ). Events are represented by circles with the colour at peak magnitude coded as indicated in the key. M85 OT2006-1 and the M31 RV (red variable; ref. 1) (1σ error bars) clearly stand out in this figure in the following respects: they (1) are brighter than novae but (2) are less luminous than most supernovae (especially of type Ia, indicated with a 2σ brightness band) and (3) are distinctly red in colour when compared to subluminous core collapse supernovae (such as SN 1987A). Finally, the two events, unlike LBVs and core collapse supernovae, do not arise in star-forming regions. For any reasonable progenitor mass, both events exhibit hyper-Eddington peak luminosities, similar to the sources V838 Mon 

\[ \frac{L_{\text{peak}}}{R_{\text{peak}}} \approx 2 \times 10^{40} \text{ erg s}^{-1} \]

Over the first two months the total radiated energy is about \( E_{\text{rad}} \approx 6 \times 10^{46} \text{ erg} \). The inferred blackbody radius (in AU) of the object is substantial:

\[ R = \left( \frac{L_{\text{peak}}}{4\pi\sigma_{p}T_{\text{eff}}^{4}} \right)^{1/2} \approx 17 \left( \frac{T_{\text{eff}}}{4,600 \text{ K}} \right)^{-2} \]

where \( \sigma_{p} \) is the Stefan–Boltzmann constant.

The closest analogue to M85 OT2006-1 is M31 RV, a bright event (serendipitously) found in the bulge of Messier 31 and still lacking a satisfactory explanation. The extraordinary brilliance of M85 OT2006-1 (Fig. 4) makes it doubly mysterious. The Galactic transient V838 Monocerotis (ref. 9, while considerably less luminous (Fig. 4), exhibits similar plateau light curves and redward evolution of the broadband spectrum.

The distinctive physical parameters (relative to novae and supernovae; see Fig. 4) and the potential connection to a fundamental stellar process (merger)\(^{10} \) may warrant coining a name. We suggest the simple name ‘luminous red nova’, in which the adjectives highlight the principal characteristics of M85 OT2006-1. Statistics (especially including the nature of the host galaxies) and follow-up studies should help astronomers to unravel the origin of these enigmatic transients and also the physics of hyper-Eddington sources.

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**Supplementary Information** is linked to the online version of the paper at www.nature.com/nature.

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