Superluminous Supernovae: Current Status of Research

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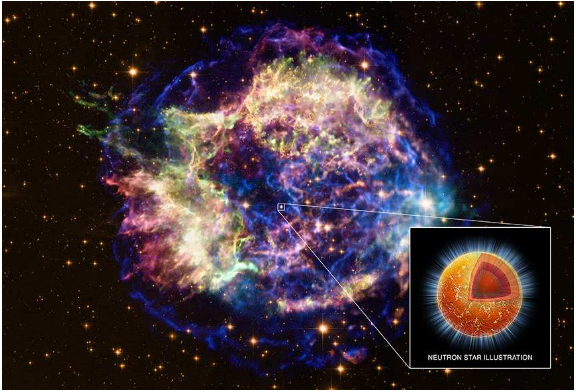
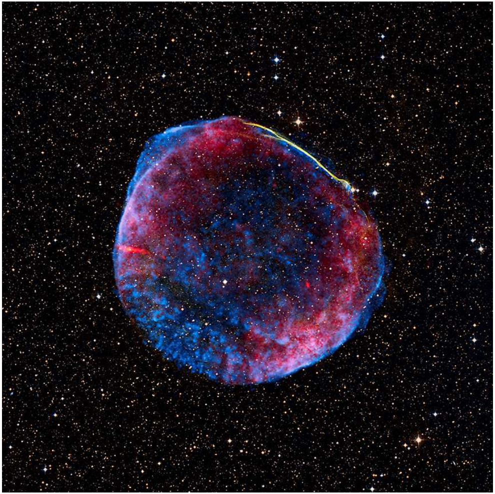
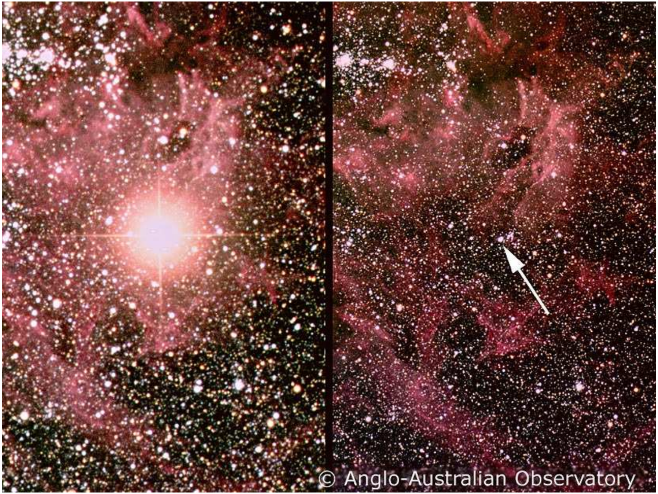
Supernova Remnant (SNR) Cas A, Chandra X-ray observatory



SNR 1006



SN1987A – the last of the nearest supernovae



Right panel: a blue supergiant as presupernova

Important numbers

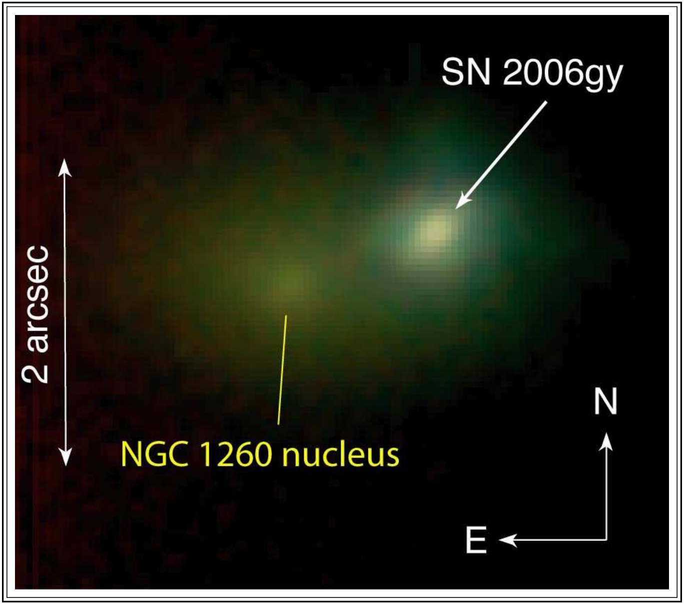
What we do know about ordinary SNe and SNRs:

Kinetic energy of ejecta

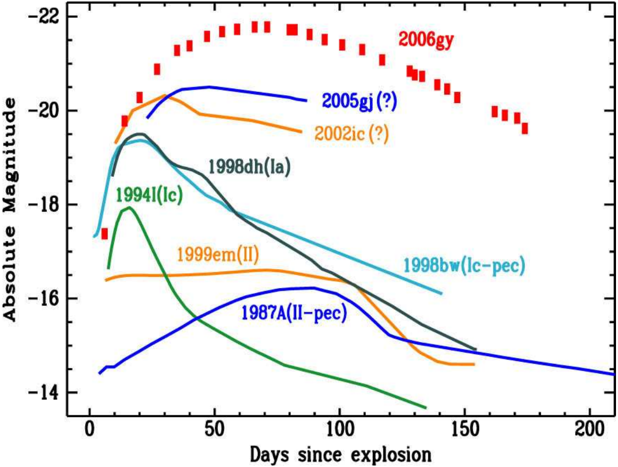
$\sim 10^{51}$ ergs = 1 foe = 1 **Bethe**

First year light $\sim$ 0.01 Bethe

SN 2006gy and the nucleous of its host galaxy



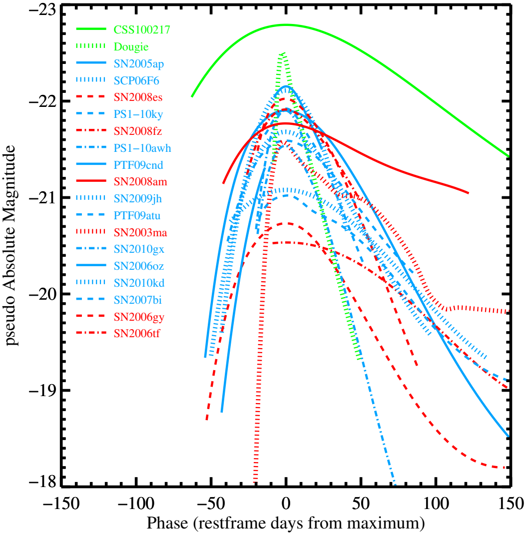
It used to be the Most Luminous SN in 2006, but not now



Now we have many SN events which are more luminous.

Wide range of super-luminous SNe

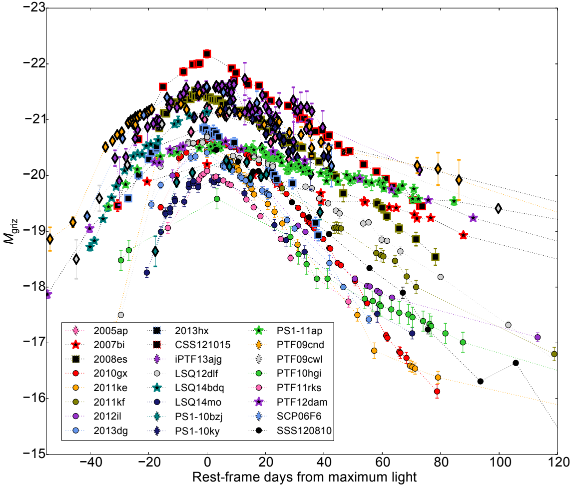
R.Quimby et al. 2013



Hydrogen-poor super-luminous supernovae

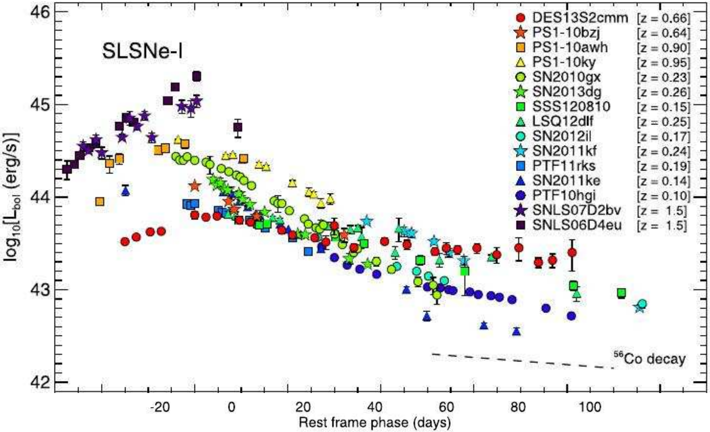
M.Nicholl et al. 2015

griz pseudobolometric light curves

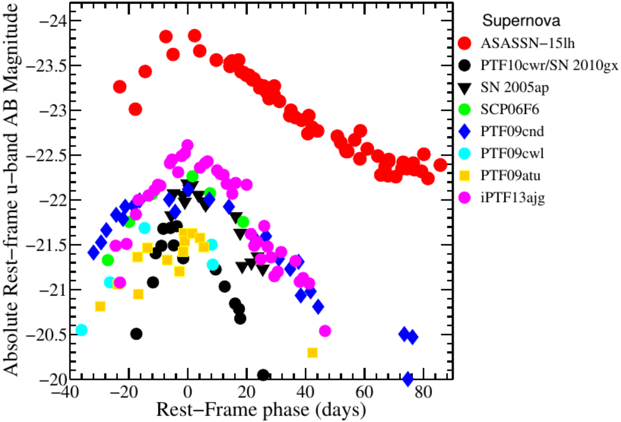


Another set and other units, SLSN-I

A.Papadopoulos et al. 2015

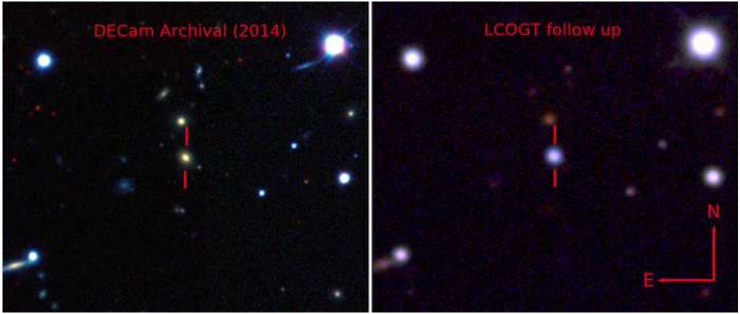


Hard case ASASSN-15lh: absolute u-band and other SLSNe



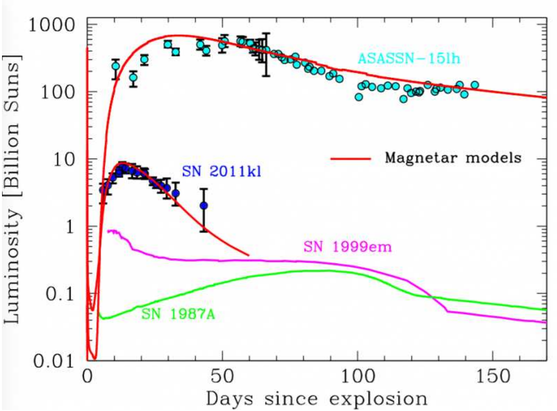
ASASSN-15lh was discovered by the All-Sky Automated Survey for SuperNovae (ASAS-SN) on 2015 June 14 at a redshift of $z = 0.2326$. Its light curve peaked at $V \sim 17$ mag implying an absolute magnitude of $M = -23.5$ mag, more than twice as luminous as any known supernova (Dong et al. 2016).

Host galaxy of ASASSN15lh



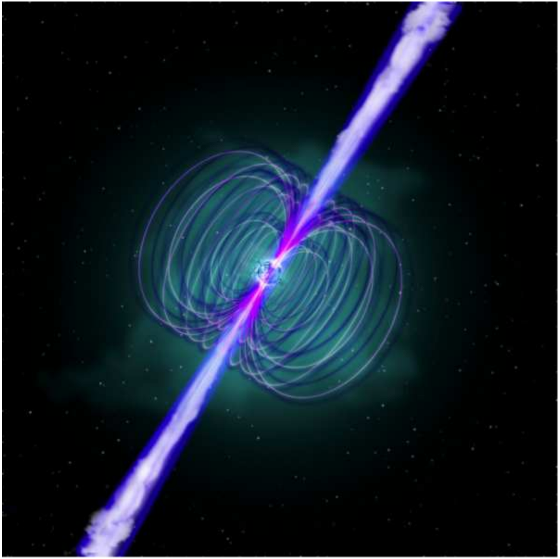
The yellow-orange host galaxy (left) before the supernova, and afterwards (right) when the ASASSN-15lh supernova's blue light outshines its host galaxy (Credit: The Dark Energy Survey / Benjamin Shappee of the Carnegie Institution for Science / ASAS-SN team)

Magnetar pumping in SNe



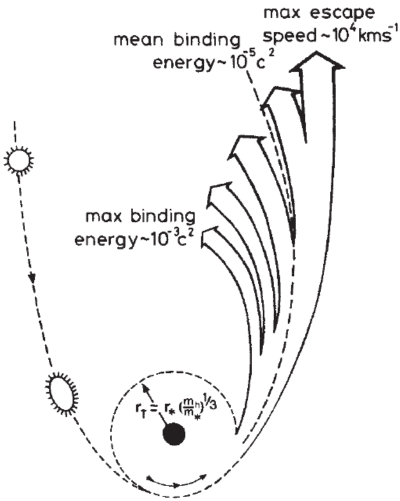
Light curves of ASASSN-15lh and SN 2011kl compared with normal supernovae SN 1999em and SN 1987A. (Credit: M.Bersten et al.)

Magnetar cartoon

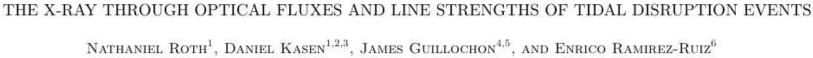


Artist impression of a magnetar boosting a super-luminous supernova and gamma-ray burst. (Credit: Kavli IPMU)

1st paper on **TDE** M.Rees, Nature 1988



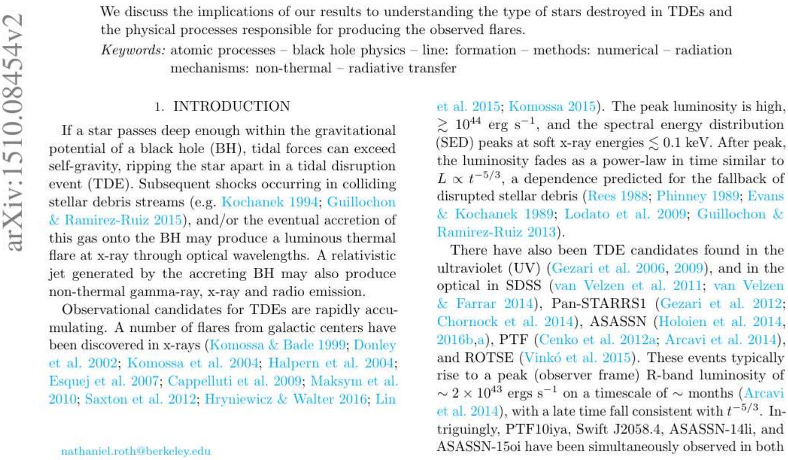
Problems with **TDE** Roth, Kasen 2016



THE X-RAY THROUGH OPTICAL FLUXES AND LINE STRENGTHS OF TIDAL DISRUPTION EVENTS

Nathaniel Roth[1], Daniel Kasen[1,2,3], James Guillochon[4,5], and Enrico Ramirez-Ruiz[6]

Problems with **TDE**. Roth, Kasen 2016



arXiv:1510.08454v2

We discuss the implications of our results to understanding the type of stars destroyed in TDEs and the physical processes responsible for producing the observed flares.

Keywords: atomic processes – black hole physics – line: formation – methods: numerical – radiation mechanisms: non-thermal – radiative transfer

1. INTRODUCTION

If a star passes deep enough within the gravitational potential of a black hole (BH), tidal forces can exceed self-gravity, ripping the star apart in a tidal disruption event (TDE). Subsequent shocks occurring in colliding stellar debris streams (e.g. Kochanek 1994; Guillochon & Ramirez-Ruiz 2015), and/or the eventual accretion of this gas onto the BH may produce a luminous thermal flare at x-ray through optical wavelengths. A relativistic jet generated by the accreting BH may also produce non-thermal gamma-ray, x-ray and radio emission.

Observational candidates for TDEs are rapidly accumulating. A number of flares from galactic centers have been discovered in x-rays (Komossa & Bade 1999; Donley et al. 2002; Komossa et al. 2004; Halpern et al. 2004; Esquej et al. 2007; Cappelluti et al. 2009; Maksym et al. 2010; Saxton et al. 2012; Hryniewicz & Walter 2016; Lin et al. 2015; Komossa 2015). The peak luminosity is high, $\gtrsim 10^{44}$ erg s^{-1}, and the spectral energy distribution (SED) peaks at soft x-ray energies $\lesssim 0.1$ keV. After peak, the luminosity fades as a power-law in time similar to $L \propto t^{-5/3}$, a dependence predicted for the fallback of disrupted stellar debris (Rees 1988; Phinney 1989; Evans & Kochanek 1989; Lodato et al. 2009; Guillochon & Ramirez-Ruiz 2013).

There have also been TDE candidates found in the ultraviolet (UV) (Gezari et al. 2006, 2009), and in the optical in SDSS (van Velzen et al. 2011; van Velzen & Farrar 2014), Pan-STARRS1 (Gezari et al. 2012; Chornock et al. 2014), ASASSN (Holoien et al. 2014, 2016b,a), PTF (Cenko et al. 2012a; Arcavi et al. 2014), and ROTSE (Vinkó et al. 2015). These events typically rise to a peak (observer frame) R-band luminosity of $\sim 2 \times 10^{43}$ ergs s^{-1} on a timescale of $\sim$ months (Arcavi et al. 2014), with a late time fall consistent with $t^{-5/3}$. Intriguingly, PTF10iya, Swift J2058.4, ASASSN-14li, and ASASSN-15oi have been simultaneously observed in both

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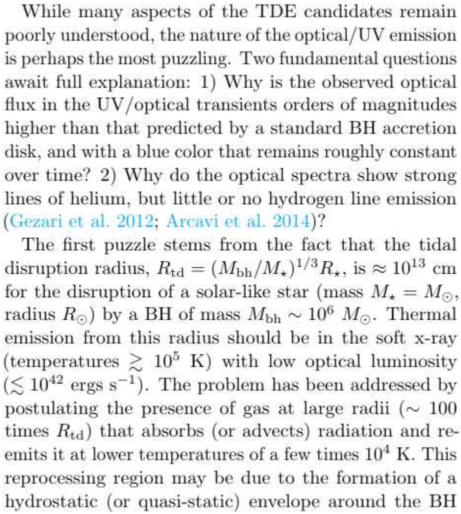
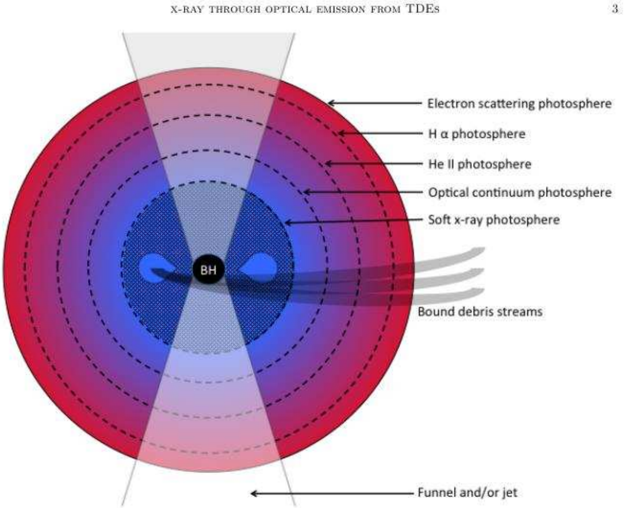
Problems with **TDE**. Roth, Kasen 2016



While many aspects of the TDE candidates remain poorly understood, the nature of the optical/UV emission is perhaps the most puzzling. Two fundamental questions await full explanation: 1) Why is the observed optical flux in the UV/optical transients orders of magnitudes higher than that predicted by a standard BH accretion disk, and with a blue color that remains roughly constant over time? 2) Why do the optical spectra show strong lines of helium, but little or no hydrogen line emission (Gezari et al. 2012; Arcavi et al. 2014)?

The first puzzle stems from the fact that the tidal disruption radius, $R_{\rm td} = (M_{\rm bh}/M_\star)^{1/3} R_\star$, is $\approx 10^{13}$ cm for the disruption of a solar-like star (mass $M_\star = M_\odot$, radius $R_\odot$) by a BH of mass $M_{\rm bh} \sim 10^6\ M_\odot$. Thermal emission from this radius should be in the soft x-ray (temperatures $\gtrsim 10^5$ K) with low optical luminosity ($\lesssim 10^{42}$ ergs $\rm s^{-1}$). The problem has been addressed by postulating the presence of gas at large radii (~ 100 times $R_{\rm td}$) that absorbs (or advects) radiation and re-emits it at lower temperatures of a few times 10^4 K. This reprocessing region may be due to the formation of a hydrostatic (or quasi-static) envelope around the BH

Envelope for **TDE**. Roth, Kasen 2016



Paper on **TDE** to appear in Nature Astronomy

The Superluminous Transient ASASSN-15lh as a Tidal Disruption Event from a Kerr Black Hole

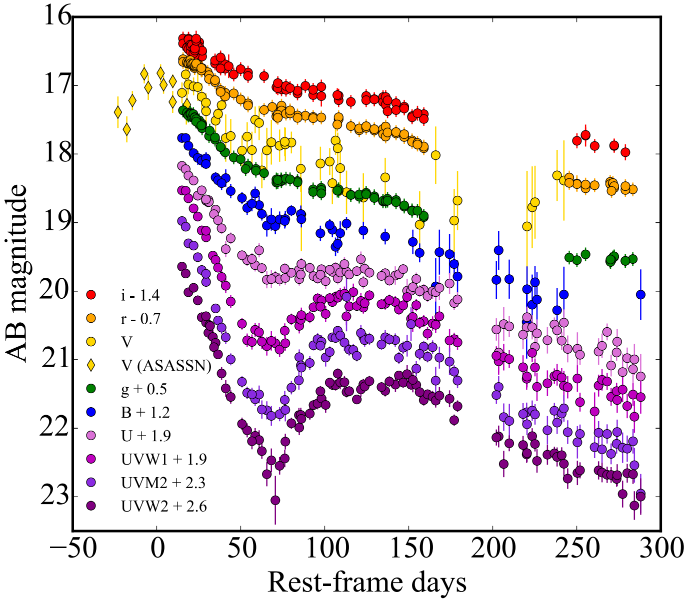
G. Leloudas[1,2], M. Fraser[3], N. C. Stone[4], S. van Velzen[5], P. G. Jonker[6,7], I. Arcavi[8,9], C. Fremling[10],

and others.
arXiv:1609.02927

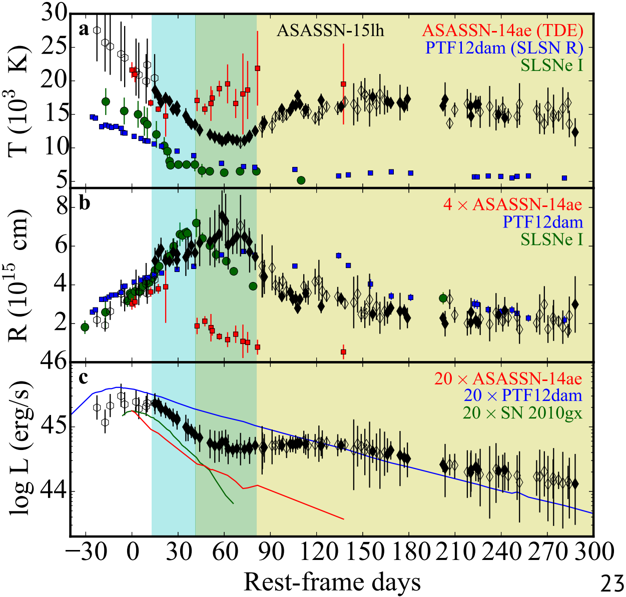
Arguments in favour of TDE vs SLSN

When a star passes within the tidal radius of a supermassive black hole, it will be torn apart. For a star with the mass of the Sun and a non-spinning black hole with a mass $< 10^8 M_\odot$, the tidal radius lies outside the black hole event horizon and the disruption results in a luminous flare. Observations over a period of 10 months show that the transient re-brightened significantly in the UV and that the spectrum went through three different spectroscopic phases without ever becoming nebular. The observations are more consistent with a tidal disruption event **(TDE)** than a super-luminous supernova because of the temperature evolution, the presence of highly ionised CNO gas at the line of sight and the improved localisation of the transient at the nucleus of a passive galaxy, where the presence of massive stars is highly unlikely. While the supermassive black hole has a mass $> 10^8 M_\odot$, a solar-mass star could be disrupted outside the event horizon if the black hole were spinning rapidly. The rapid spin and high black hole mass can explain the high luminosity of this event.

The light curve evolution of ASASSN-15lh in the rest frame



The evolution of the temperature, radius and luminosity of ASASSN- 15lh, compared to TDEs and SLSNe.



Thank you!