HMXBs as progenitors to core-collapse supernovae

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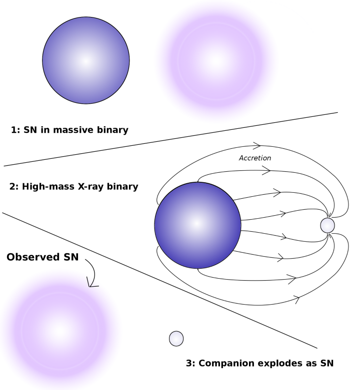
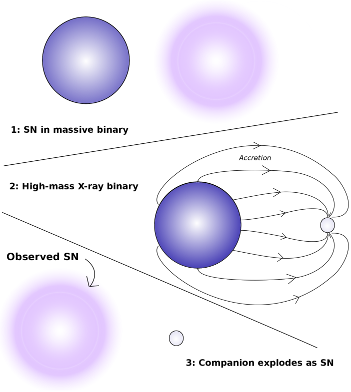
Background: HMXBs as progenitors to core-collapse supernovae

- Core-collapse SN types Ib, Ic and IIb are characterized by a lack of hydrogen in their spectrum.
  - This lack is attributed to the progenitor star having lost its outer layer prior to the explosion.
  - Also known as Stripped-Envelope Core-Collapse Supernovae
- Two main mechanisms for stripping the envelope:
  - Outer layer lost through stellar winds (giant Wolf-Rayet progenitor).
  - Binary interaction resulting in mass-transfer between companions (close binary systems).
- Relatively few direct observations of progenitors for these types of SNe.
- Relative importance of the two progenitor mechanisms still unclear.



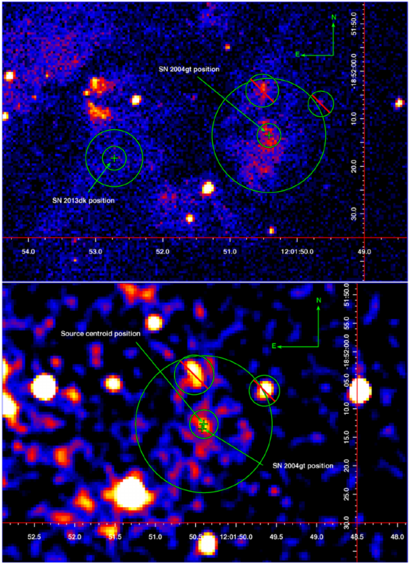
Background: HMXBs as progenitors to core-collapse supernovae

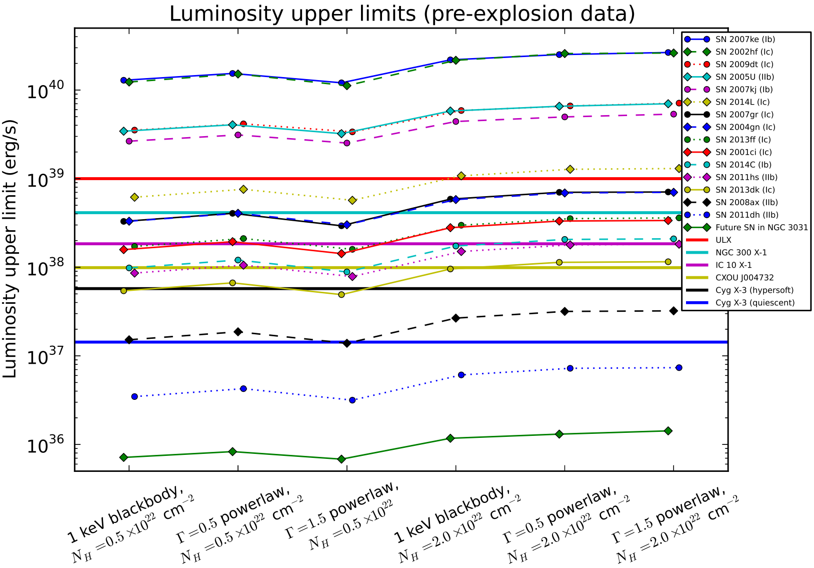
- A High-mass X-ray binary (HMXB) is a potential progenitor system for a stripped-envelope core-collapse SN.
  - → The possibility of X-ray bright progenitors.
- We carried out a systematic search for such progenitor systems (results published: Heikkilä T., Tsygankov S., Mattila S, Eldridge J.J., Fraser M., Poutanen J., 2016, MNRAS, 457, 1107)
- We searched the Asiago Supernova Catalog for SN types Ib, Ic and IIb, discovered after 1980 and within 100 Mpc.
- We searched the SN positions for any available pre-explosion X-ray data from the *Chandra X-ray observatory* archives.
  - 18 SNe were found to have pre-explosion data available.
  - 2 SN positions had an X-ray source that might potentially be associated with a progenitor system.
  - Upper limits of X-ray luminosity were established for 14 positions.



The pre-explosion sources at the positions of SN 2009jf and SN 2004gt

- SN 2009jf: Voss et al. (2011) noted the coincidence of the type Ib SN 2009jf with the position of the ultraluminous X-ray source (ULX) CXOU J230453.0+121959.
  - They suggest the possibility that the ULX may be a HMXB progenitor for the SN, though chance alignment is also possible.
  - This SN also had a post-explosion observation taken ∼30 days after explosion; Increase in ULX luminosity consistent with SN.
- SN 2004gt: SN located in a complex diffuse emission area. Source becomes more apparent when photons with energy below 1.5 keV are excluded from the *Chandra* observation.
  - Source is CXOU J120150.4185212 (from Zezas et al. 2006).




Luminosity upper limits (pre-explosion data)
Luminosity upper limit (erg/s)
10^{40}
10^{39}
10^{38}
10^{37}
10^{36}
1 keV blackbody, $N_H = 0.5 \times 10^{22}$ cm^{-2}
$\Gamma = 0.5$ powerlaw, $N_H = 0.5 \times 10^{22}$ cm^{-2}
$\Gamma = 1.5$ powerlaw, $N_H = 0.5 \times 10^{22}$
1 keV blackbody, $N_H = 2.0 \times 10^{22}$ cm^{-2}
$\Gamma = 0.5$ powerlaw, $N_H = 2.0 \times 10^{22}$ cm^{-2}
$\Gamma = 1.5$ powerlaw, $N_H = 2.0 \times 10^{22}$ cm^{-2}
SN 2007ke (Ib)
SN 2002hf (Ic)
SN 2009dt (Ic)
SN 2005U (IIb)
SN 2007kj (Ib)
SN 2014L (Ic)
SN 2007gr (Ic)
SN 2004gn (Ic)
SN 2013ff (Ic)
SN 2001ci (Ic)
SN 2014C (Ib)
SN 2011hs (IIb)
SN 2013dk (Ic)
SN 2008ax (IIb)
SN 2011dh (IIb)
Future SN in NGC 3031
ULX
NGC 300 X-1
IC 10 X-1
CXOU J004732
Cyg X-3 (hypersoft)
Cyg X-3 (quiescent)

The Continuing Search for X-ray bright progenitors

- Because most newly discovered transients are often unclassified, we search all new transients.
  - Automated search for any pre-discovery X-ray sources for any newly discovered transients available in public archives.
  - Two sources of transient listings: Bright Supernova webpage (BSN), Transient Name Server (TNS).
  - Search expanded to cover data from *XMM-Newton* as well as *Chandra*.
- Program automatically produces listing and preview X-ray images of the positions of any transients where pre-discovery X-ray data is available.
  - Most promising candidates selected for closer manual inspection (determine nature of the transient and X-ray source, what is known about them etc).
  - Follow-ups: If a transient/source combination looks interesting, we attempt to classify the transient (NOT), or see if it's possible to determine variability in the X-ray source (Swift).
- Running since 3.4.2017.
- Fully working, but new features are being added, improvements made etc.

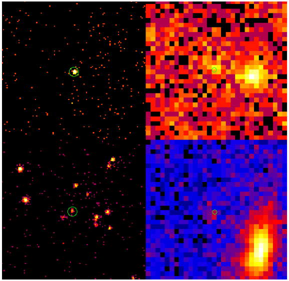


Figure : Clockwise from top-left: AT 2016drm (*Chandra*), ASASSN-15ut (*XMM*), AT 2017aht (*XMM*), Nova M31 2017-01a? (*Chandra*). Circle marks transient optical position (5" diameter).

The Continuing Search for X-ray bright progenitors

- Download BSN, TNS transient lists
- Read masterfile (database of previous searches and their results; complete list of all transients known to the program)
- Generate a searchlist by comparing the RA and Dec of the input transients with those on the masterlist to determine if they are new.
  - We also add previously known targets if they have not been searched for 30 days (subject to revision) to avoid missing previously proprietary data
  - All previously unknown targets will in return be added to the masterlist at the conclusion of the search
- Search the positions of all transients on the searchlist from both *Chandra* and *XMM-Newton* archives for any data where the target is in the FOV.
- If (previously unknown pre-discovery) data is found, the transient is added to a list of new targets, to be reported at the end of the search.
  - For each such target, the observation with the *longest* exposure time is downloaded, and used to produce a preview-image for the report.
- After all new positions have been searched, update masterlist and compose report of all transients with new pre-discovery data with preview images.

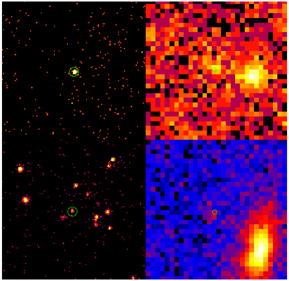
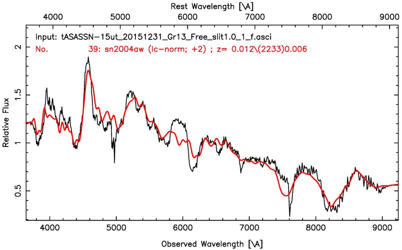
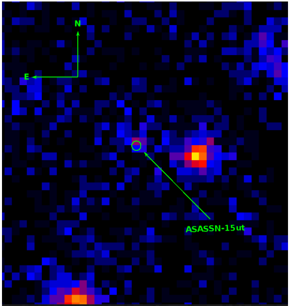


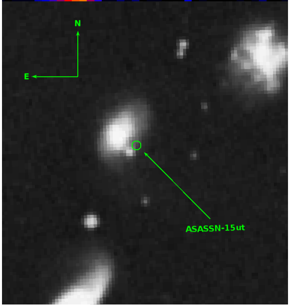
Figure : Clockwise from top-left: AT 2016drm (*Chandra*), ASASSN-15ut (*XMM*), AT 2017aht (*XMM*), Nova M31 2017-01a? (*Chandra*). Circle marks transient optical position (5" diameter).

ASASSN-15ut

- Discovered on 30.12.2015 in the galaxy NGC 88 at the distance of 44.8 Mpc (Kiyota et al.2015)
- Initially classified as Ia subtype Ia-91T (Firth et al.2016), however we find type Ic classification is more likely given that the SN is too faint to be type Ia given distance to the host galaxy.
- 48 ks *XMM* observation from 2002: Position aligns with known but unclassified X-ray source 2XMM J002121.3-483827.







Above: Black: ASASSN-15ut spectrum (from PESSTO) (H. Kuncarayakti). Red: SNID comparison spectrum for SN type Ic. Top right: ASASSN-15ut position, pre-explosion Chandra*. Bottom right: ASASSN-15ut position (DSS).*

AT 2017ddr

- Unclassified transient discovered on 5.4.2017 (Pan-STARRS1, Chambers et al.2017)
- 10 ks *Chandra* observation from 2010: transient aligns with known ULX CXOU J103522.2-2445135, also known as ESO 501-23 X-1 at the distance of 7.01 Mpc (Somers et al. 2013)
- Somers et al. compare the ULX position to HST-image of the position, find several optical sources in the area covered by the source.
- One of the optical sources could contain a high-mass stellar companion to a black hole, powering the ULX.
- However, the ULX might be an AGN as well.

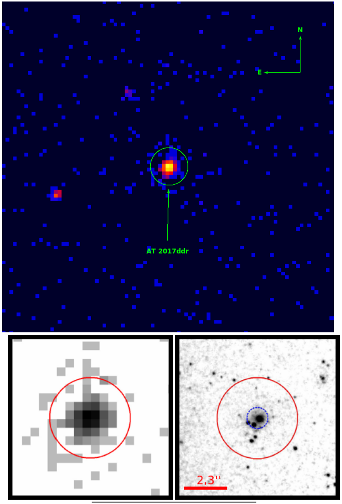
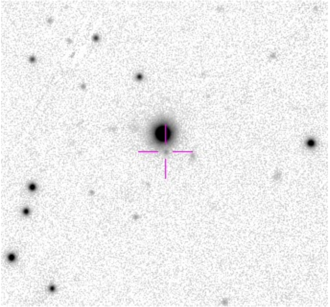
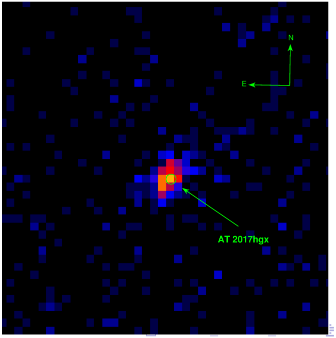


Figure : Top: AT2017ddr pre-explosion position with *Chandra*. Bottom: *Chandra* and *HST* images of the same region (from Somers et al. 2013).

AT 2017hgx (PS17esp)

- Unclassified transient discovered on 8.10.2017 (Pan-STARRS1, Chambers et al.2017)
- 43 ks *XMM* observation from 2001: transient aligns with unclassified X-ray source 1WGA J0020.3+8142 (also 3XMM J002022.5+814233).
- Archival flux measurement: 1.3×10^{-13} erg/s/cm^2
- SWIFT-followup: We obtained a 3ks observation post-transient to see any change in source characteristics (result: No detection, upper limit indicates no substantial increase in source X-ray flux).
- (Attempted transient classification with NOT failed due to bad seeing and problematic position of the transient, see image).





Top right: AT2017hgx position (PAN STARRS1)
Bottom right: AT2017hgx position (XMM)

Summary

- The progenitors of stripped-envelope core-collapse supernovae have lost their outer layer prior to the supernova-explosion, either through stellar winds or through binary interaction.
- A high-mass X-ray binary is a system that can strip this layer and therefore such systems can be hosts to the progenitors of this type of supernovae.
- We carried out a search for pre-explosion X-ray sources at the positions of such SNe and note the presence of two such sources. We also measured upper limits for pre-explosion non-detections of such sources where possible.
- Our ongoing monitoring program aims to detect pre-discovery X-ray sources for any new transients as they are reported.
- Several promising cases have been identified so far.
- Overall, however, they are most likely quite rare.