X-rays from SN 2012ca: A Type Ia-CSM supernova explosion in a dense medium

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INTRODUCTION

- ◆As a supernova (SN) shock propagates through the ambient medium, it heats it up to temperatures greater than millions of degrees, producing X-ray emission.
- ◆The X-ray emission acts as a probe of the circumstellar medium (CSM), providing a clue to the SN progenitor.
- ◆Prior to this work (Bochenek et al. 2018), X-ray emission from any Type Ia SNe had never been detected (Hughes et al. 2007, Margutti et al. 2014)
- ❑ **Type Ia-CSM SNe** have the spectrum of a Type Ia SN, with a superimposed narrow hydrogen line.
- ❑ Narrow H lines are presumed to originate in the CSM presumably formed by the companion star.

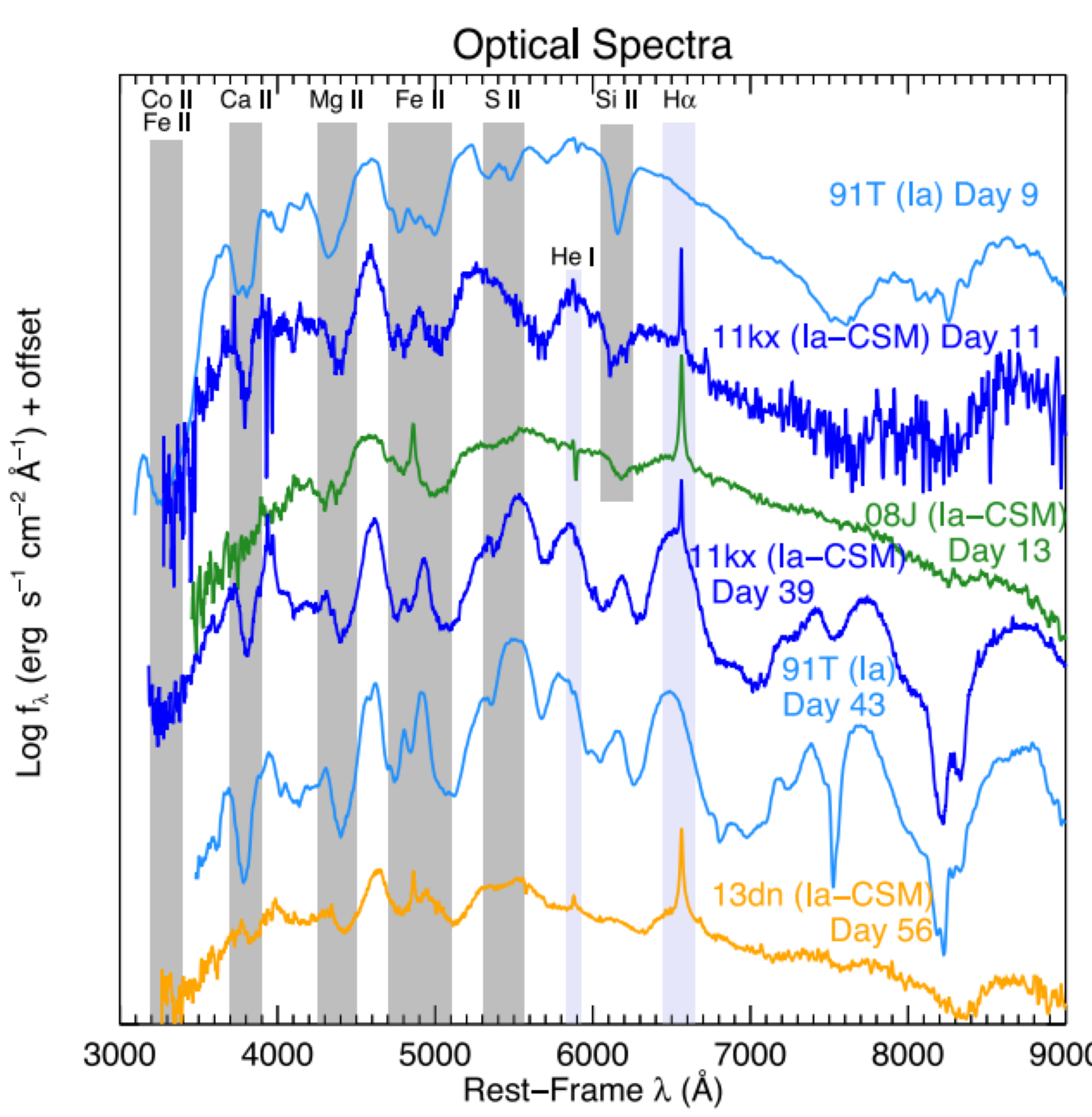

Figure 1 – **Early time optical spectra of Type Ia and Type Ia-CSM supernovae.** Reproduced from Fox et al. (2015).

- ❑ Balmer decrements ($I_{H\alpha}/I_{H\beta}$) > 5-10 in Ia-CSM SNe suggest high density CSM ($n_e > 10^8$ cm^{-3}), if due to collisional de-excitation (Silverman et al. 2013)
- ❑ Inserra et al. (2016) argue that SN 2012ca was likely a core-collapse explosion due to the required high efficiency of converting kinetic energy to luminosity.
- ❑ Fox et al. (2015) - lack of broad C, O and Mg lines in the spectrum, and presence of broad iron lines, suggest SN 2012ca is likely thermonuclear supernova.

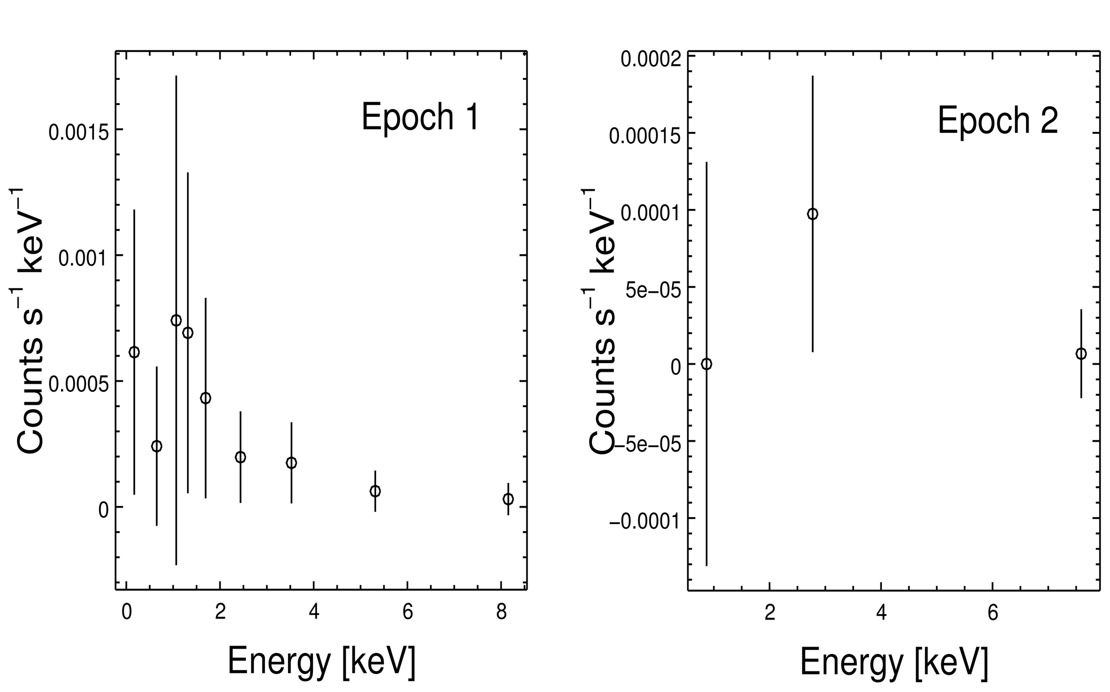

Figure 2 – **X-ray Spectra of SN 2012ca.** Left: Epoch 1. Right: Epoch 2. Grouped by four counts per bin. Note: Unbinned spectra were used in the analysis.

OVERVIEW

X-ray emission is one of the signposts of circumstellar interaction in supernovae (SNe), but till recently had been observed only in core-collapse SNe. The absence of X-ray emission from Type Ia SNe has been interpreted as a sign of a very low density CSM. Here we report late-time X-ray detections of SN 2012ca in Chandra data. The presence of hydrogen in the initial spectrum led to a classification of Type Ia-CSM, ***ostensibly making it the first SN Ia detected with X-rays.*** Our analysis of the X-ray data favors an asymmetric medium, with a high-density component which supplies the X-ray emission. The data suggest a number density > 10^8 cm^{-3} in the higher density medium, consistent with the large observed Balmer decrement if it arises from collisional excitation. Although high, it may be consistent with densities suggested for Type IIn or superluminous SNe. If SN 2012ca is a thermonuclear SN, the large CSM density could imply clumps in the wind, or a dense torus or disc, consistent with the single-degenerate channel. A core-degenerate channel, involving a white dwarf merging with the degenerate core of an asymptotic giant branch star shortly before explosion, leading to a common envelope around the SN, is also possible

Based on Bochenek et al. (2018).

OBSERVATIONS & DATA ANALYSIS

Instrument	Obs Date	Days After Outburst	Exposure (ks)	Count Rate (10^{-3} s^{-1})	N_H (10^{22} cm^{-2})	kT (keV)	0.5-7 keV Flux (10^{-14} ergs cm^{-2} s^{-1})
Chandra ACIS	2013-09-17	554	20	1.4 ± 0.29	6.0 ± 3.5	2.6 ± 1.8	$7.6^{+381}_{-5.1}$
Chandra ACIS	2014-03-27	745	20	$0.29^{+0.26}_{-0.16}$	5.2 ± 2.5	1.2 ± 0.5	$3.7^{+104}_{-3.0}$

◆Each observation was fit 7000 times using the *vmekal* thermal model, coupled to the *tbabs* absorption model. Figure 3 shows all models that could fit the data.

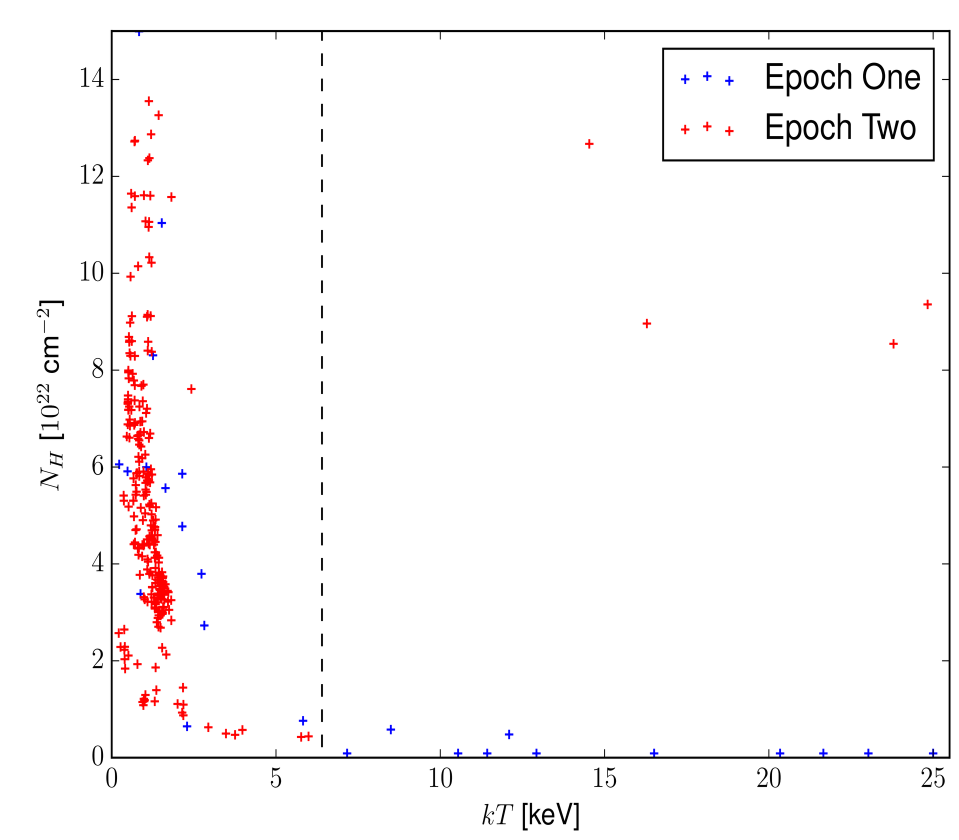

Figure 3 - **Acceptable X-ray spectral fit values** for column density (N_H) and temperature (kT). X-ray Luminosity suggests minimum density and N_H. Points to the right of dashed line are excluded because they suggest a low N_H at epoch 1 that increases by epoch 2. Best fit parameters were then obtained.

REFERENCES

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2) Bochenek et al., 2018, MNRAS, 473, 336
3) Dwarkadas et al., 2014, MNRAS, 440, 1917
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5) Hughes et al., 2007, ApJ, 670, 1260
6) Inserra et al., 2016, MNRAS, 459, 2721
7) Margutti et al., 2014, ApJ, 790, 52
8) Silverman et al., 2013, ApJ, 207, 3S
9) Soker et al., 2017, arXiv:1710.10791
10) Wang et al., 2004, ApJL, 604, L53

DISCUSSION

Symmetric 1-component medium:

- ➢ Simplest scenario
- ➢ Cooling time > expansion time - nonradiative shock:
  $L_X = n_e^2 \Lambda V$ (n_e =electron density, Λ=cooling function)
- ➢ Epoch 1: $n_e = 3.46^{+16.9}_{-1.44} \times 10^6$ cm^{-3}
- ➢ Epoch 2: $n_e = 1.22^{+5.03}_{-0.74} \times 10^6$ cm^{-3}

However, unlikely:

- ➢ Proton temperature from shock velocity and assumed composition ~ 20 keV
- ➢ Electron temperature from X-ray emission: 2.6 keV
- ➢ However, Coulomb equilibration time for this density < 10d - proton and electron temperatures should be equal!

More Likely, Asymmetric 2-component medium:

- ➢ The measured shock velocity (~3200 km s^{-1}) arises from shock propagating through the lower density component.
- ➢ The X-ray emission arises from shock propagating in a higher density (`*hd*') component (clumps, disk, CE).
- ➢ Cooling time < flow time in *hd* component: shock in *hd* component is radiative
- ➢ $L_X = 0.5\,(\alpha \times 4\pi r^2)\rho v_{shock}^3$
- ➢ Epoch 1: $n_e^{hd} = 1.16^{+1181}_{-1.06} \times 10^8\ \alpha^{-1}$ cm^{-3}
- ➢ Epoch 2: $n_e^{hd} = 1.85^{+336}_{-1.70} \times 10^8\ \alpha^{-1}$ cm^{-3}

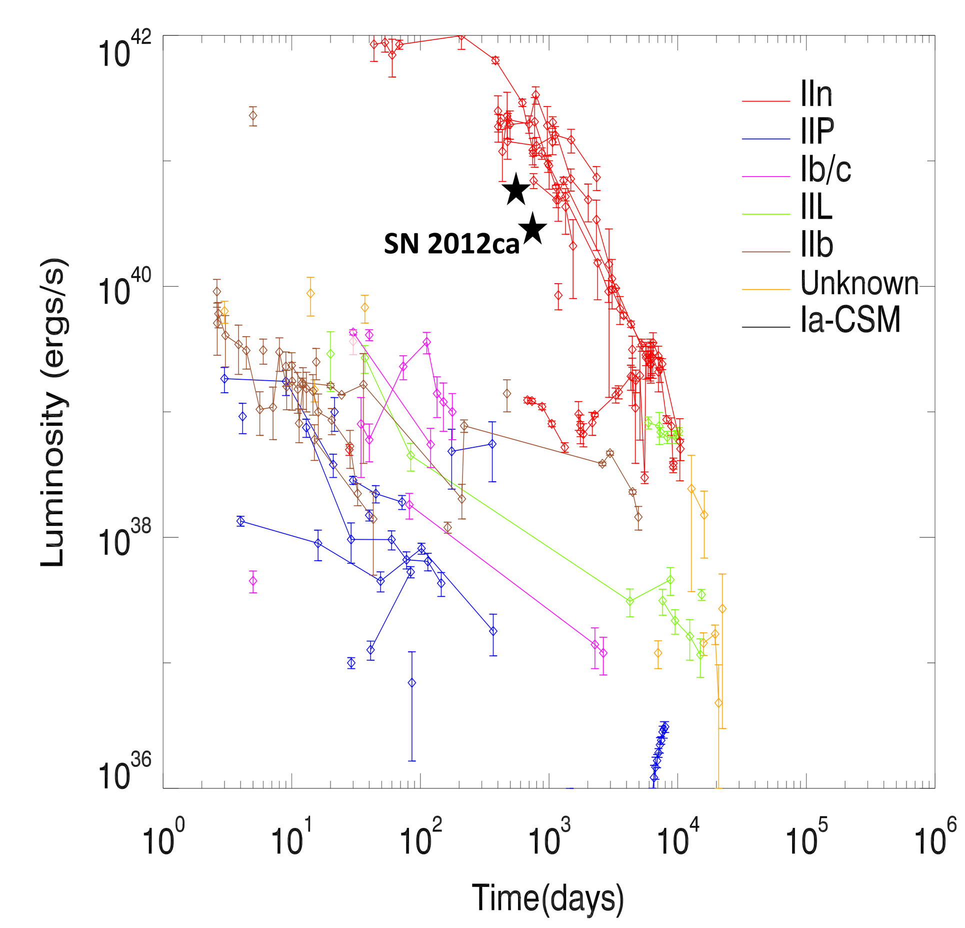

Figure 4 - **The X-ray light curves of most X-ray SNe**, grouped by type. Adapted from Dwarkadas et al. (2014). Stars represent X-ray luminosity of SN 2012ca.

- ➢ Our inferred densities are in line with other Ia-CSMs: 2005gj (Aldering et al. 2006), 2002ic (Wang et al. 2004) also have ambient densities > 10^8 cm^{-3} .
- ➢ If the CSM arises from a stellar wind: $\dot{M} > 3 \times 10^{-4} \frac{v_w}{10\ km/s}$ $M_\odot$ yr^{-1}, 6 orders of magnitude higher than limits around Type-Ia SNe (Margutti et al. 2014). 2-component medium requires even higher mass-loss.
- ➢ Our data require an extreme explanation in either the double or single degenerate scenario.
- ➢ Core-degenerate scenario can explain a dense, massive, asymmetric CSM (Soker et al. 2017).
- ➢ We cannot distinguish between the thermonuclear and core-collapse scenarios.
- ➢ Future X-ray (and radio) observations of Type Ia-CSM SNe could help to answer these questions.

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