Late-time X-ray observations Core-Collapse Supernovae

Constraints on emission from compact objects and CSM interaction

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Introduction

Late-time X-ray observations of core-collapse supernovae (SNe) offer unique insights into the formation of compact objects and the interaction with the circumstellar material (CSM). This work focuses on constraining the emission from compact objects and the overall late-time X-ray emission. At epochs years to decades after the explosions, we expect reduced CSM interaction and lower ejecta absorption, allowing the X-ray emission from the compact objects to become more prominent.

Sample

Our sample consists of ~100 SN, with a total of ~400 observations, that are:

- core-collapse supernova within 60 Mpc (omitting type IIn and other known strongly interacting SNe, as these are expected to produce strong X-ray emission due to CSM interaction)
- observed by an X-ray telescope (Chandra or XMM) later than 2 or 20 yrs after the explosion for stripped and type II respectively. The earlier time for stripped type is due to the lower ejecta absorption.

The sample of unique SNe is illustrated in **Fig. 1**

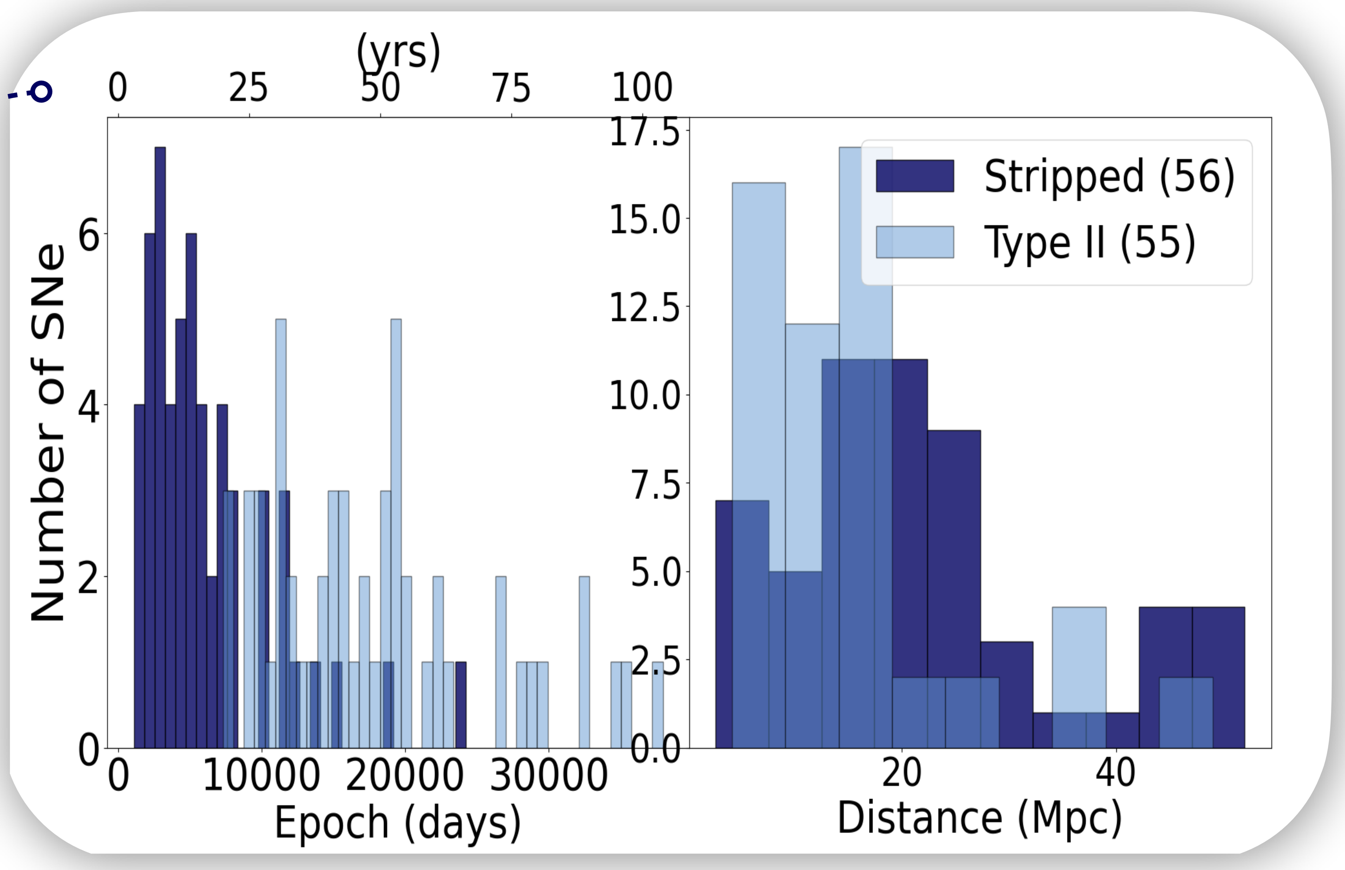

Fig. 1 The supernova sample: stripped (IIb, Ib & Ic) and type II

Methods

We fit the spectra of all detected SNe and calculate 3σ upper limits for the non-detected ones. We use a thermal component to account for the CSM interaction (`mekal` in XSPEC) and an absorbed power law with Γ=2 to account for the emission associated with the compact object (emerging pulsar wind nebulae are most likely to be detectable). The absorption by the asymmetric, metal-rich ejecta is modelled using the results [1] of 3D neutrino-driven supernova explosion models [2].

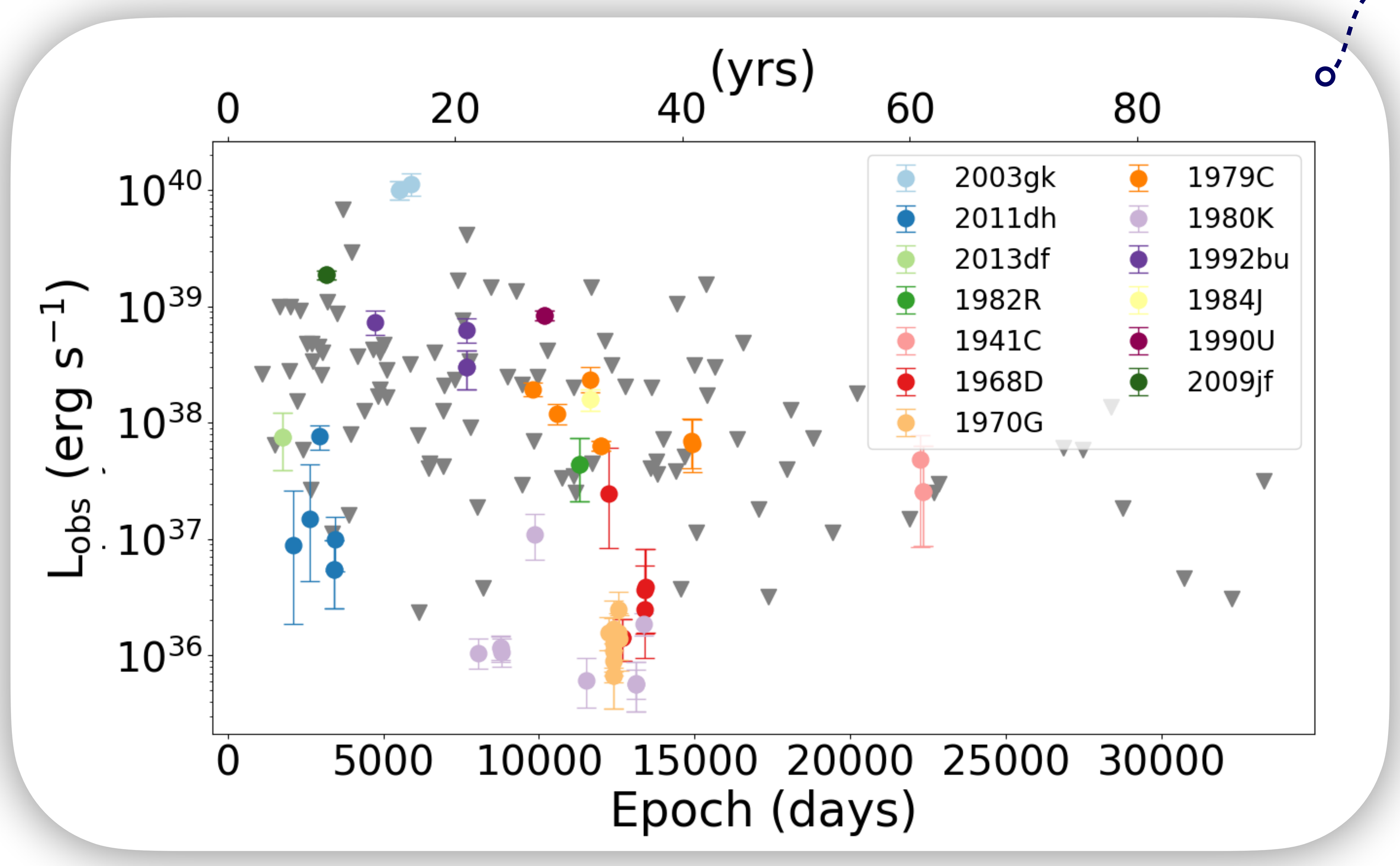

Fig. 2 Observed 2-10 keV luminosities and upper limits. Only the most constraining limit is shown for SNe with multiple observations. Coloured markers are detected SNe, and gray triangles are 3σ upper limits.

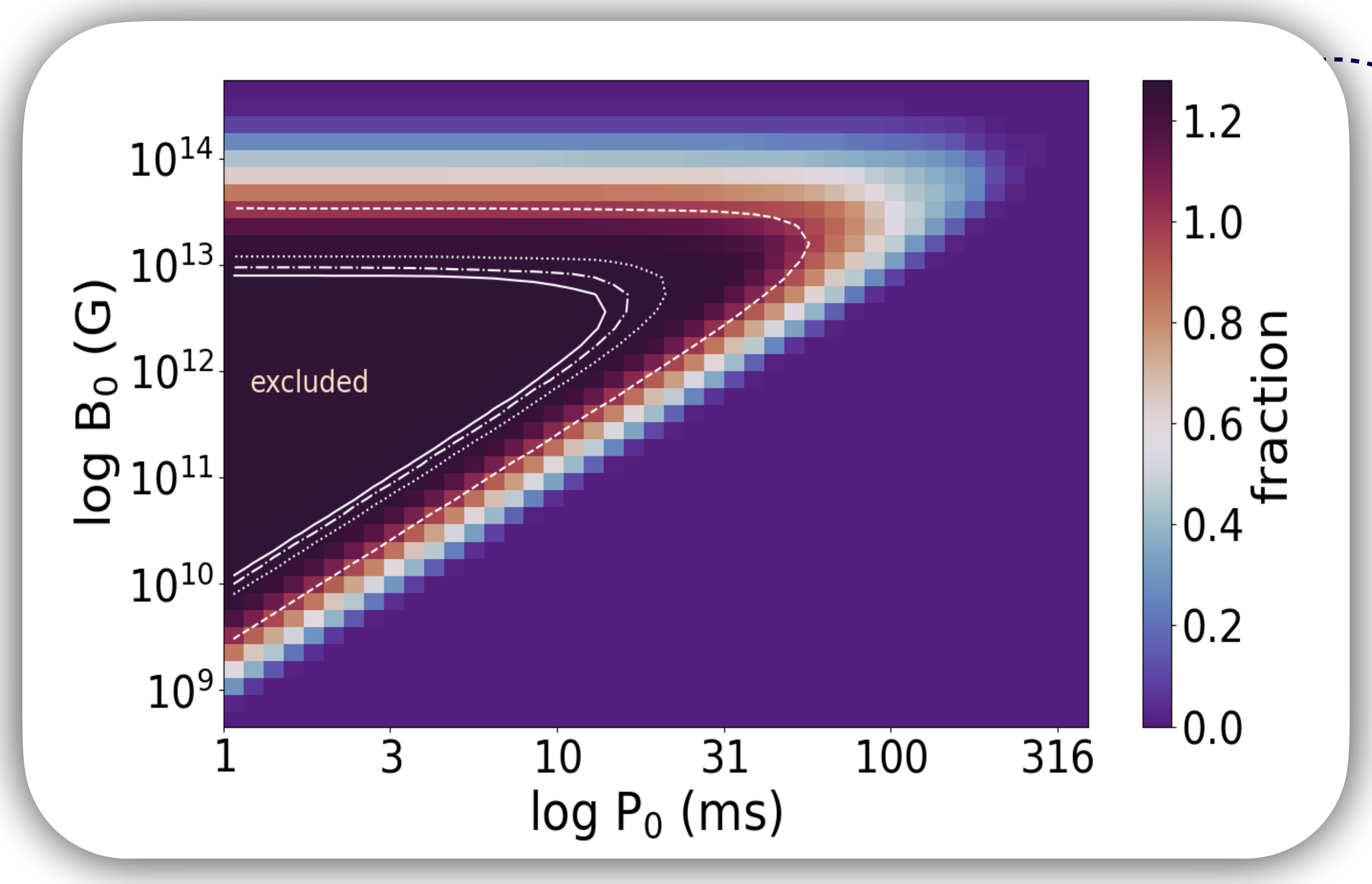

Fig. 4 Constraints on pulsar birth properties: spin period and magnetic field. Colour gradient is based on X-ray luminosities from a favourable viewing angle through the ejecta and demonstrates the fraction of the sample excluded at each point in the parameter space. Each line (dashed, dotted, dotted-dashed & solid) represents the contour at 0.5 for different lines of sight with increasing levels of ejecta absorption.

Supernova luminosities

We find that ~**10% of the SNe are detected** from **~5 yrs** after the explosion and up to **~60 yrs**, and with roughly an even ratio of detected stripped type and type II SNe.

Compact object luminosities

Given that SN explosions are asymmetric, different lines of sight correspond to various degrees of ejecta absorption. We provide results assuming different degrees of absorption. Approximately **5% of the sample shows emission that can be attributed to compact objects** in the case of a favourable viewing angle with negligible ejecta absorption.

We also see the effects of decreasing ejecta absorption over time, as the difference between the luminosities assuming negligible and median ejecta absorption is decreasing with time.

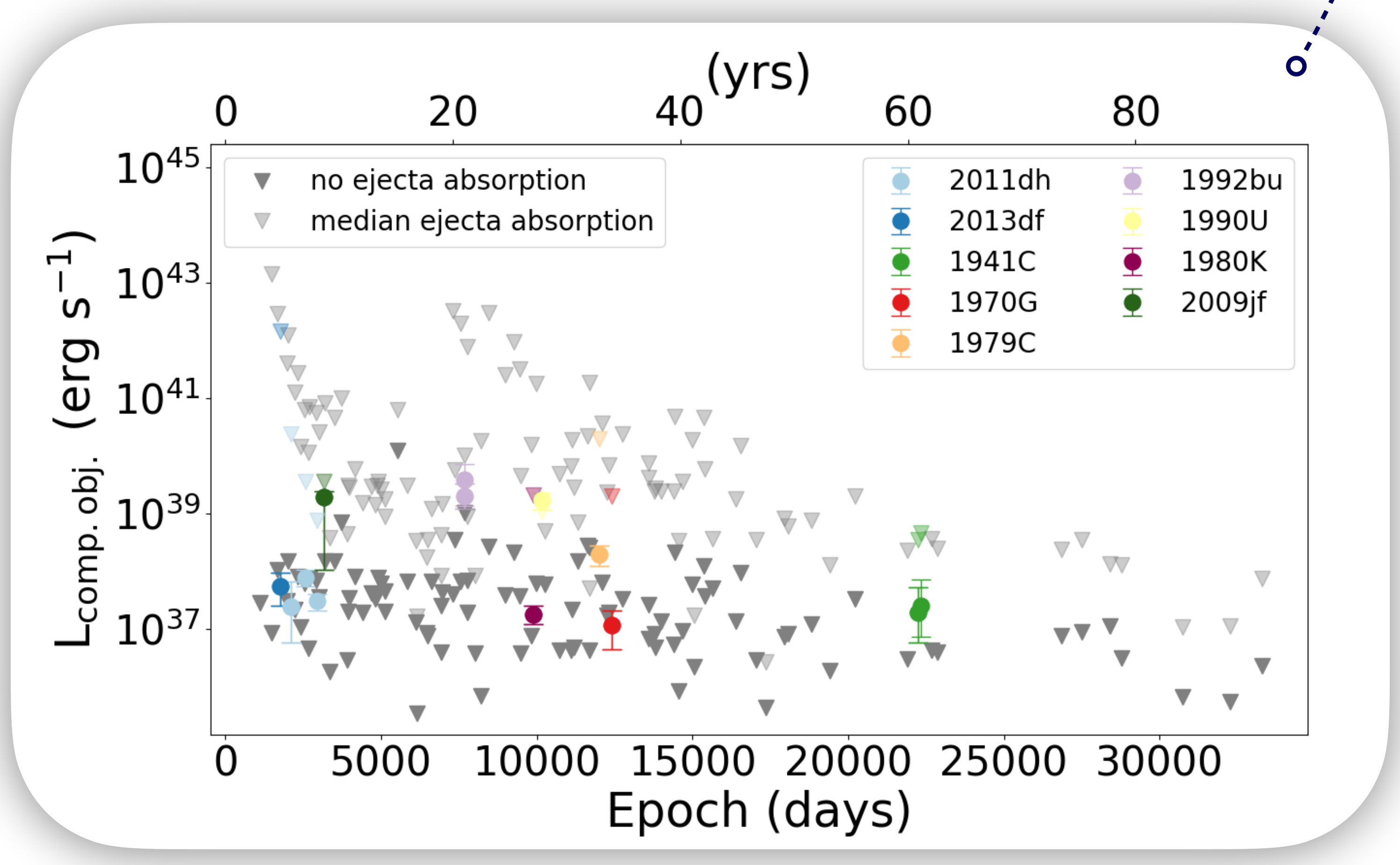

Fig. 3 X-ray luminosities over the power-law component, in the interval 2-10 keV, here attributed to the compact object. Coloured markers show SNe that can be fitted with a model including a power law, while gray triangles illustrate 3σ upper limits. Results for two different lines of sight, corresponding to negligible and median ejecta absorption, are illustrated by darker and opaque markers, respectively.

Constraints on pulsar properties

We constrain pulsar birth properties assuming all compact objects in our sample have pulsar wind nebulae powered by pulsar spin-down, modelled as rotating magnetic dipoles in vacuum. Furthermore, adopting a $10^{-19.6}\dot{E}^{0.45}$ fraction of the spin-down power to be emitted as X-ray emission in 2-10 keV [3].

Future work

Here we present the initial results from Chandra and XMM data. We are currently analysing results from SWIFT and NuSTAR and will soon also obtain more information on compact object properties and late-time CSM interaction.

References

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