Characterizing Mass-Loss Rates of Type II Supernova Progenitors with Late-Time Radio Observations

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Introduction

Nearly all massive stars die in core-collapse supernovae (SNe). In the centuries before its death, a massive star **ejects mass** into its immediate environment via stellar winds [1], filling the region with circumstellar matter (CSM). After the star explodes, the resulting **SN ejecta interacts with the CSM** as it travels outward, producing **radio emission** which can be observed for years to decades after the explosion.

We examine the late-time SN-CSM interaction of 307 Type II SNe to probe the CSM at **larger physical scales than ever before** and to **characterize the mass-loss histories** of the progenitor stars.

Methods

Observations: We made VLA observations of 307 SNe II in the X band (10 GHz) at low angular resolution (7.2” beam) and followed up on 25 detections in the C (6 GHz), X, and Ku (15 GHz) bands at high angular resolution (0.33”, 0.20”, 0.13”, respectively).

SN evaluation: We evaluated the likelihood that each detected source was a true SN detection using its radio light curve(s) (Fig. 1) and optical data (Fig. 2). We classify 9 sources as true SN detections.

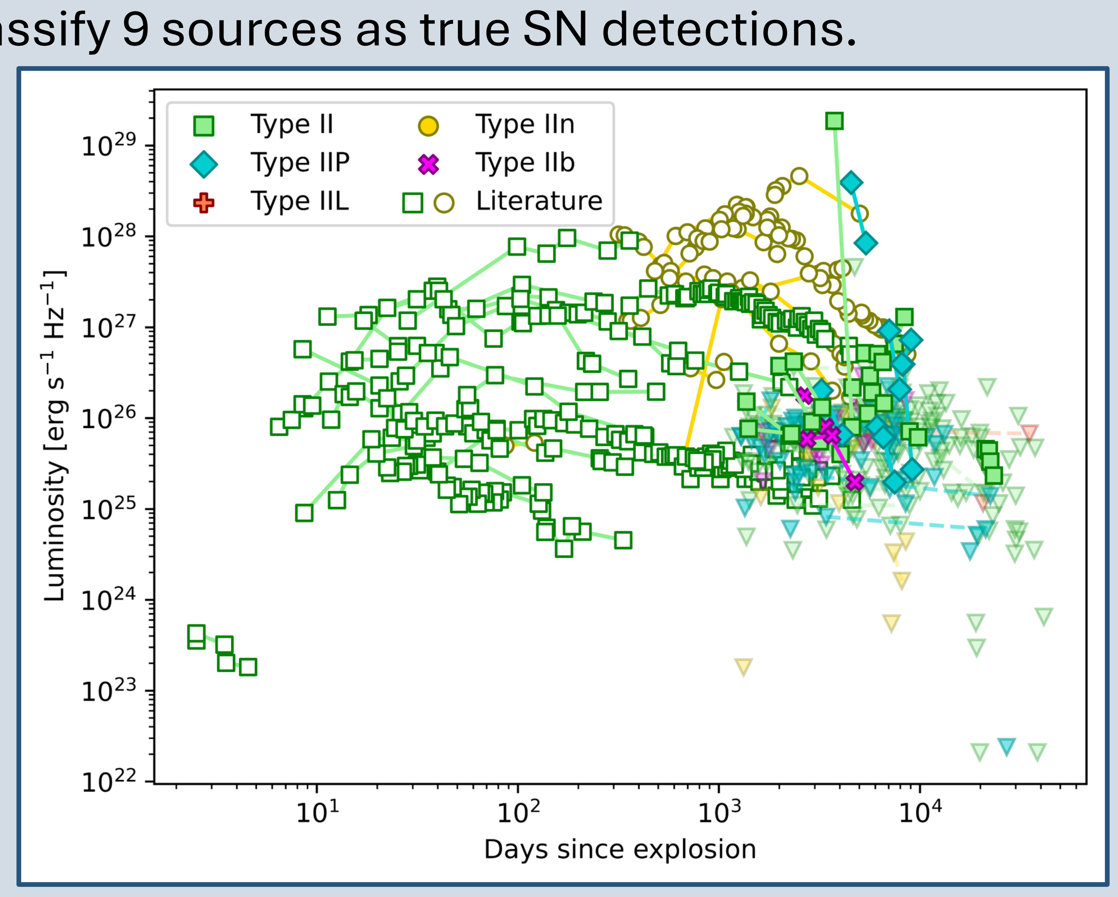

Figure 1. Light curves for different Type II SNe subtypes. Triangles represent 3σ limits for subtypes of the respective colors, derived from nondetections.

Conclusions

New constraints: Following our nondetections, we find no evidence of ubiquitous radio emission for SNe II at large timescales. We thus place late-time upper limits on the peak radio emission of Type II events. Our detections provide constraints on mass-loss rates and CSM densities consistent with previous studies of Type II events. Such detections may indicate CSM overdensities and unsteady pre-explosion mass-loss.

Future work: Our results provide a reference for further work on SN II progenitor mass loss. Future studies on Type IIb and II-P SNe should aim to observe sources across a range of phases from early- to late-time, searching for detections in the gap between upper and lower peak limits. Research specifically on II-P sources may attempt to probe even later phases than presented in our work.

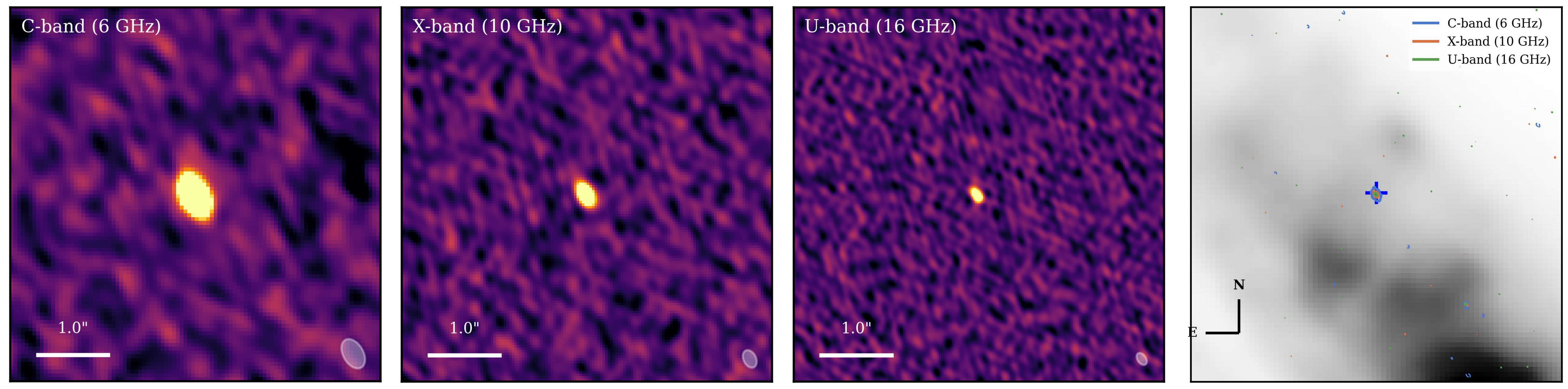

Figure 2. Radio observations (top row and left column) of SN2017gkk in the C, X, and Ku bands at high angular resolution. We use these observations to plot radio contours at the source’s position in an optical image of its host galaxy (lower right) and compare that position to the source’s known optical coordinates, marked by a blue ‘+’.

Results

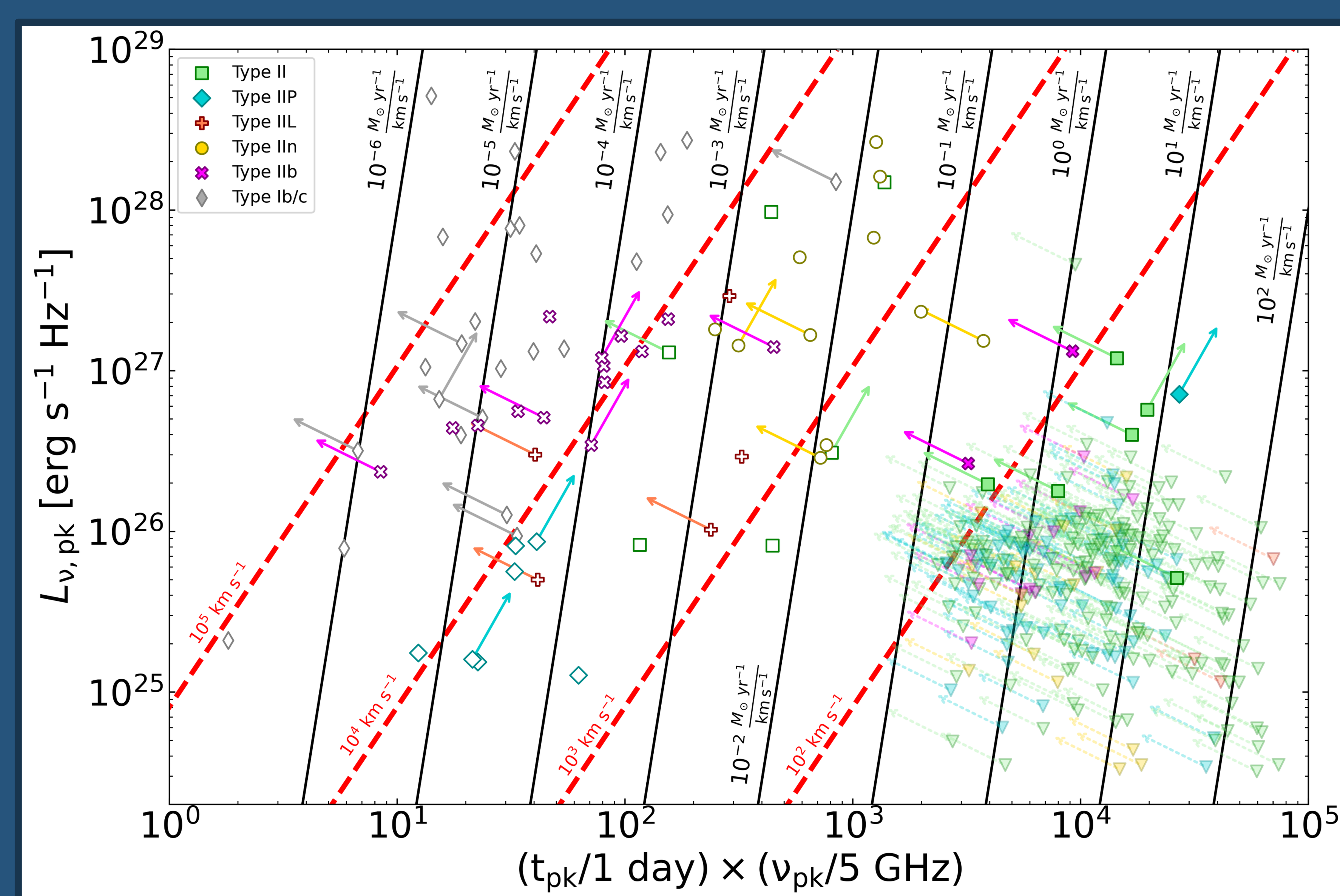

Figure 3. Sources plotted by subtype on a Chevalier diagram. Color-filled points indicate sources studied in this work; white-filled points are data from Sfaradi et al. (2025) [3]. Our peak frequencies and peak fluxes are derived from SED modeling. Arrows indicate whether a point is a limit, based on whether we observe a clear peak in the SED. Upper-limit arrows point left and lower-limit arrows point right. Triangles represent 3σ limits derived from nondetections. Red dashed lines correspond to SN shock velocities, and solid black lines correspond to progenitor mass-loss rates parametrized as $\dot{M}/v_w$, where v_w is the pre-explosion stellar wind velocity of the progenitor star.

We probe the CSM at the largest-ever physical scales to impose new, late-time constraints on the radio emission of Type II supernovae.

Upper limits from nondetections: The fact that the majority of our observed sources were undetected indicates that most Type II SNe no longer have luminous CSM interaction at radii of ~10^{17}–10^{18} cm. Detections in this late-time regime may therefore indicate CSM overdensities and, in turn, unsteady pre-explosion mass loss. We see a cluster of upper limits on the peak luminosities of Type II SNe between ~10^{25} and 10^{27} erg s^{-1} Hz^{-1}.

Constraints on Types IIb and II-P: We add upper limits on the peak frequency-time of SNe IIb with the detections of two sources and the nondetections of several more. These help close unconstrained early-time lower limits on the peaks established by other work [3]. With our nondetections of II-P sources we also place upper limits on the peak luminosities of these SNe. However, with our one late-time SN II-P detection showing a greater luminosity than previous early-time detections [3], we see that this specific source has not yet reached its peak.

References

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