Massive Stars Near and Far
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Constraining massive star mass loss through supernova radio properties

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Abstract. Supernova properties in radio strongly depend on their circumstellar environment and they are an important probe to investigate the mass loss of supernova progenitors. Recently, core-collapse supernova observations in radio have been assembled and the rise time and peak luminosity distribution of core-collapse supernovae in radio has been obtained. In this talk, we will discuss the constraints on the mass-loss prescriptions of red supergiants obtained from the assembled radio properties of Type II supernovae. We take a couple of mass-loss prescriptions for red supergiants, calculate the rise time and peak luminosity distribution based on them, and compare the results with the observed distribution. We found that the widely spread radio rise time and peak luminosity distribution of Type II supernovae can only be explained by mass-loss prescriptions having strong dependence on the luminosity. Red supergiant mass-loss prescriptions should have steep luminosity dependence in the supernova progenitor range.

Keywords. circumstellar matter, stars: mass-loss, supergiants, supernovae: general

1. Introduction

Mass loss is a major uncertainty in massive star evolution. Massive stars keep losing their mass from birth to death. Massive stars that are about to explode as supernovae (SNe) are surrounded by the circumstellar matter (CSM) that is formed by their mass loss throughout their lives (Dwarkadas 2005. The subsequent supernova (SN) explosions occur within the CSM.

After a SN explosion, a forward shock travels through the CSM formed by its progenitor. Electrons are accelerated at the forward shock, resulting in synchrotron emission. The synchrotron emission makes SNe bright in radio (Weiler et al. 2002). The rise time and peak luminosity of SNe in radio are determined by the synchrotron emission and absorption processes. The major absorption processes are synchrotron self-absorption at the forward shock when the CSM density is low and free-free absorpbtion at the unshocked CSM when the CSM density is high. Thus, the rise time and peak luminosity of SNe in radio strongly depend on the CSM density and we can estimate it based on the SN radio properties. Because the CSM density is determined by mass-loss rates of the SN progenitors, we can constrain the mass-loss prescriptions of massive stars through SN radio observations (e.g., Chevalier et al. 2006). In this talk, we focus on mass loss of red supergiants (RSGs) that are progenitors of Type II SNe. We refer to Moriya (2021) for full details.

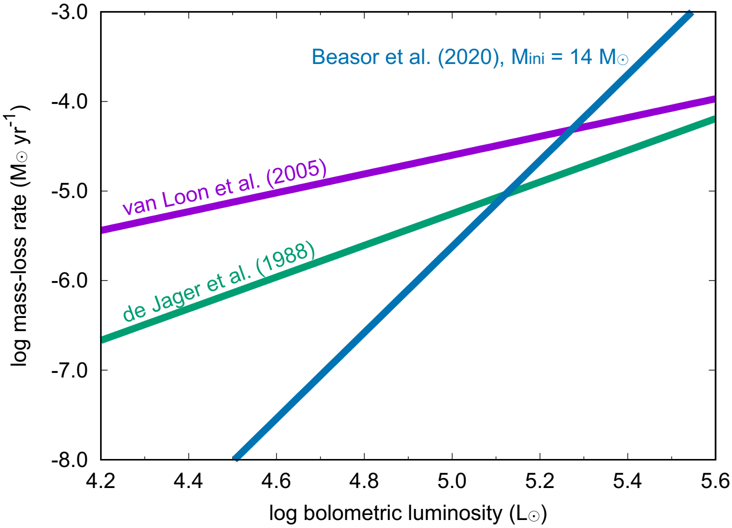

Figure 1. Representative RSG mass-loss prescriptions.

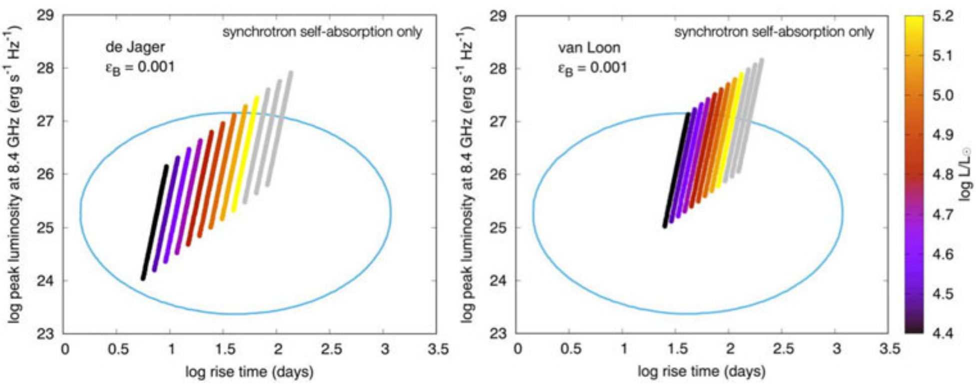

Figure 2. Rise time and peak luminosity distribution of Type II SNe and their comparison to the theoretical expectation from the de Jager prescription (left) and van Loon prescription (right).

2. RSG mass-loss prescriptions

Mass-loss mechanisms of RSGs are not well understood. Many different RSG mass-loss prescriptions have been used in stellar evolution calculations. Fig. 1 shows some examples of RSG mass-loss prescriptions. The RSG mass-loss rates by de Jager et al. (1988) and van Loon et al. (2005) have been often adopted. Recently, Beasor et al. (2020) proposed a RSG mass-loss prescription that depends on the initial mass ($M_{\rm ini}$). In Fig. 1, we show the case of $M_{\rm ini} = 14\ M_{\odot}$. Based on the three RSG mass-loss prescriptions, we estimate the expected rise time and peak luminosity distribution of Type II SNe in radio and compare it with the observed distribution provided by Bietenholz et al. (2021).

3. Comparison

Fig. 2 compares the expected rise time and peak luminosity distribution from the de Jager and van Loon rates. Each line shows the expected rise time and peak luminosity

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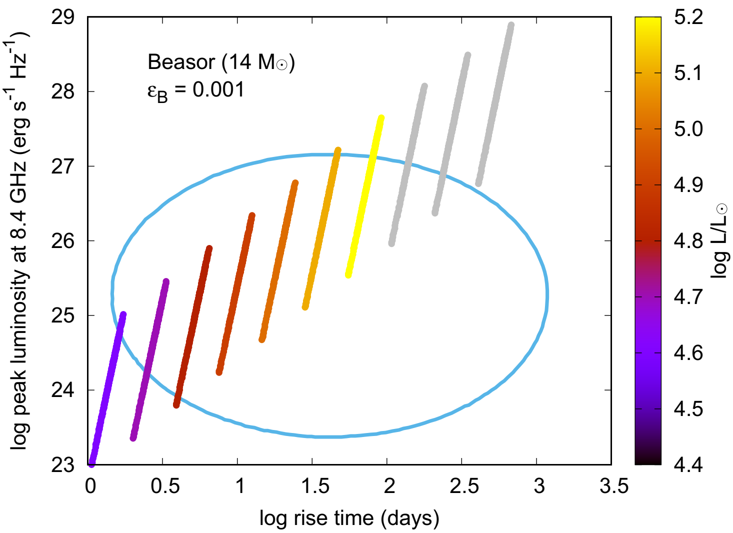

Figure 3. Same as Fig. 2, but for the Beasor mass-loss prescription with $M_{\rm ini} = 14\ M_{\odot}$.

range for the given progenitor luminosity. The gray lines are for $\log L/L_{\odot} = 5.3, 5.4$, and 5.5, which may not be the luminosity range of RSG SN progenitors (Smartt 2015). The blue oblate shows the observed rise time and peak luminosity distribution of Type II SNe from Bietenholz et al. (2021). We can find that the de Jager rate can better explain the diverse rise time and peak luminosity distribution in radio light curves observed in Type II SNe compared to the van Loon rate. Especially, the de Jager rate can cover the lowest luminosity range. This is because the de Jager mass-loss rate has the steeper dependence on the luminosity and thus it can cover from low to high mass-loss rate within the Type II SN progenitor luminosity range. Fig. 3 shows the case of the Beasor rate. Because of the very steep luminosity dependence of the Beasor rate, it also can cover the entire rise time and peak luminosity range in radio observed in Type II SNe.

4. Conclusions

The widely-spread distribution in the rise time and peak luminosity in radio observed in Type II SNe indicates that mass-loss rates of RSG SN progenitors have steep dependence on their luminosity. This fact prefers RSG mass-loss prescriptions by de Jager et al. (1988) and Beasor et al. (2020). While RSG SN progenitors may often have mass-loss enhancement shortly before their explosion (Yaron et al. 2017; Förster et al. 2018), the radio observations in Type II SNe are mostly sensitive to the mass loss before such mass-loss enhancement. A similar study has been conducted for massive helium star SN progenitors by Moriya & Yoon (2022).

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Discussion

SOMEONE: Is it possible to classify SNe only with radio properites?

MORIYA: We can probably distinguish Type IIn SNe from others because of their large radio luminosity. Other SN types are difficult to distinguish just by radio observations.

HOSSEINZADEH: Now that I think about it, SN 2021yja does have all the constraints you need. There was a radio detection that is not published yet.

MORIYA: Very nice! We may be able to get a constraint on the progenitor mass loss and get some information on the progenitor.

SMARTT: Very good - go for it! Think the missing link in the combination of progenitor + very early detection and follow-up + radio + nebular spectra has been having consistent, very early detections, but that now is looking routine with ATLAS+ZTF combinations (and others). There's an opportunity to do this more consistently I think. Requires a lot of effort, there is significant observing resources to coordinate.

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