SN 2012au: 13 Years of Broad-band Radio Emission from the Golden Supernova

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Introduction

In the months following initial detection of SN2012au, optical observations revealed it to be an extraordinary event (Milisavljevic+18). Compared to other Type Ib supernovae, it was very energetic ($E_K \sim 10^{52}$erg), expanding very rapidly, and the late-time spectra bear clear similarities with GRB supernovae. While early radio observations of the object seemed to be very typical for an interacting supernova, late time radio observations - that we present here - revealed a set of highly unusual spectral energy distributions (SEDs) that appeared completely unrelated to the initial radio emission.

Early-Time Radio Observations

Kamble 2014 reported radio observations from the first several months post-explosion of SN 2012au. We re-analyzed the dataset, following a more rigorous treatment of the shock dynamics - numerically integrating the momentum balance equation to compute shock radius and velocity over time. We found that the early-time synchrotron emission is well described by shock interaction with a broken power law CSM - transitioning from $\rho \sim r^{1.84}$ to $\rho \sim r^{1.92}$, roughly consistent with the wind density result of Kamble 2014. In Figure 1 below, we show our fits to the early data, as well as the extrapolation out to later times.

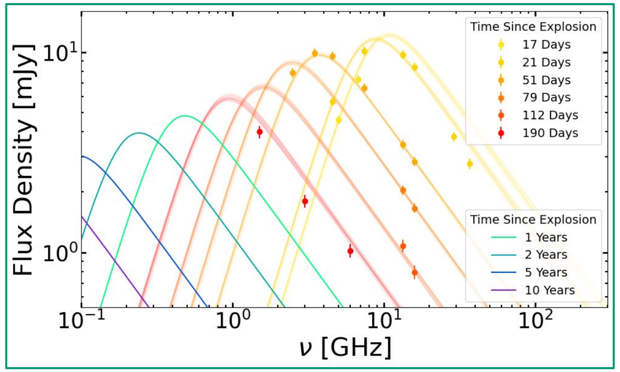

Figure 1

Deviation at Late Times

Six years after SN 2012au was first detected, optical observations revealed spectra that were unusual among nebular spectra of SNe in their oxygen features. The spectra implied a strong source of ionization.These features, along with a lack of H Balmer lines led Milisavljevic+18 to favor a pulsar wind nebula as the source of ionization. We followed up this observation with the VLA, confirming that the object was once again producing bright radio emission. We continued monitoring SN 2012au with multiwavelength VLA observations for another 5 years. As seen in Figure 2, the **late-time emission completely deviates from the extrapolation of the early data** in Figure 1.

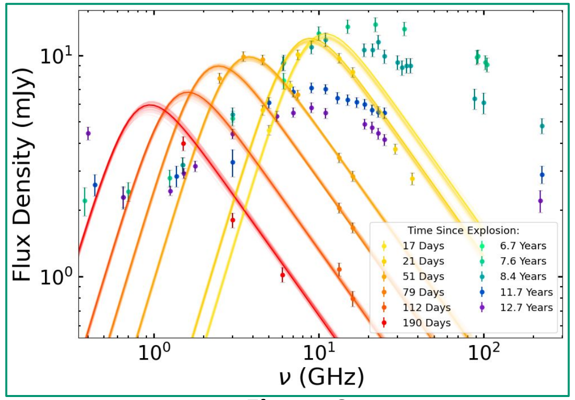

Figure 2

In addition to being inconsistent with the initial inferred shock, the late-time radio emission from SN 2012au exhibits other notably unusual features. (i) As frequency decreases, the spectral index flattens and may even invert. (ii) The spectral peak is unusually broad. (iii) The optically thin spectral index is very flat; corresponding to p = 1.6, compared to the typical assumed value of p = 3. A simple equipartition analysis of this emission, assuming the observed peaks are the result of synchrotron self-absorption, points to small shock radii ($\sim 10^{16}$ cm), low shock velocities (~300 km/s) and high densities ($n_e \sim 10^6$ cm^{-3}).

Two Component Model

A flattening spectral index at low frequencies has been observed before in another supernova: SN 1986J. Combining spectral analysis with VLBI, Bientenholz and Bartel concluded that the emission consists of two distinct components: a central component, peaking at higher frequencies and an extended component, dimming as it cascades to lower frequencies. We apply this two component approach to SN 2012au, modeling the low frequency component as an optically thin power law and the high frequency component as a broken power law, with a potential cooling break.The resulting fit in shown in Figure 3. The low frequency component can be well explained by the initial observed shock propagating through a slightly denser medium, but the higher frequency component has a few possible explanations, outlined below.

Potential Models

Our analysis of the high frequency component reveals that it must: (i) have high densities, (ii) low emitting volume, (iii) low shock velocity and, (iv) be hidden at early times. Any model must account for all of these properties.

Thin CSM Slice: A small cross section of the CSM may be much denser than the region the initial shock propagated through, similar to SN 2014C. This would decelerate it to low shock velocity, keep the emitting volume small, and hide the early emission with free-free absorption. We find that it is possible to construct such a CSM; however, it requires a very small filling fraction (f<0.005) and a lower value of ϵ_B in the inner CSM than the region where late time interaction is occurring.

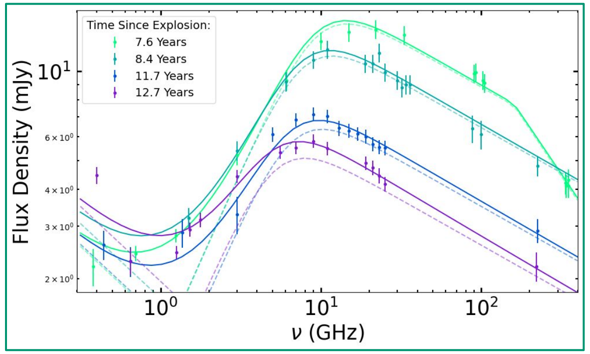

Figure 3

Small CSM Clump: This late emission may come from a dense clump of mass in the CSM, separated from the explosion center. In this case, emission would be hidden at early times because the shock had not reached the clump yet. The total volume of the clump may be fairly small and the shock may have been significantly decelerated by the time it reaches the clump. We find that a clump of radius $\sim 10^{15}$ cm and density of $n_e \sim 10^{6\text{-}8}$ cm^{-3} could reproduce the observed emission; however, it is difficult to physically motivate such an overdensity.

Pulsar Wind Nebula: The emission may be the emergence of the youngest ever observed pulsar wind nebula (PWN). The PWN would be the result of pulsar interactions with the innermost layer of ejecta - explaining the low shock velocities, small emitting volume, and high densities. It would also naturally be free-free absorbed by the surrounding ejecta and CSM at early times and become visible as the ejecta spread out. We are currently working on modeling the expected emission from a young PWN, which will be the final piece of analysis before publication of all these results.