Identifying the Remnants of Neutron Star Mergers

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What’s left after two neutron stars merge?
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hypermassive neutron star

“magnetar”
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hypermassive neutron star

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short GRB
What’s left after two neutron stars merge?

- Hypermassive neutron star
- “Magnetar”
- Short GRB

How long is this stage?
Long-lived magnetars in short GRBs: Extended emission

Perley et al. 2009
Long-lived magnetars in short GRBs: Extended emission

Perley et al. 2009
Long-lived magnetars in short GRBs: X-ray plateaus

Rowlinson et al. 2013
Long-lived magnetars in short GRBs: X-ray plateaus

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Rowlinson et al. 2013
Magnetar spin-down energy powers a radio transient?

“magnetar”

Nakar & Piran 2011; Metzger & Bower 2013
Magnetar spin-down energy powers a radio transient?

Energy $\sim 10^{52}$ erg

“magnetar”

Nakar & Piran 2011; Metzger & Bower 2013
Magnetar spin-down energy powers a radio transient?

Energy $\sim 10^{52}$ erg
Deceleration time $\propto E$, $n$, $v$

Nakar & Piran 2011; Metzger & Bower 2013
Model light curves for varying densities

$E \approx 10^{52}$
$v = 0.8c$
Model light curves for varying densities

$E \sim 10^{52}$

$v = 0.8c$

Rest-frame Time after Merger (yr) vs. $\nu L_\nu$ (erg s$^{-1}$)

Density labels: 1 cm$^{-3}$, 0.1 cm$^{-3}$, 0.01 cm$^{-3}$, 10$^{-3}$ cm$^{-3}$, 10$^{-4}$ cm$^{-3}$
Model light curves: 
Density is a key parameter

$E \approx 10^{52}$
$v = 0.8c$
### Model light curves:

**Density is a key parameter**

- **E~10^{52}**
- **v=0.8c**

<table>
<thead>
<tr>
<th>Density (cm⁻³)</th>
<th>Rest-frame Time after Merger (yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10⁻¹</td>
</tr>
<tr>
<td>0.1</td>
<td>10⁰</td>
</tr>
<tr>
<td>0.01</td>
<td>10¹</td>
</tr>
<tr>
<td>10⁻³</td>
<td>10²</td>
</tr>
<tr>
<td>10⁻⁴</td>
<td>10³</td>
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</table>
Existing radio observations of short GRBs are too early.
Radio observations as a test of the magnetar model

9 events with previous “signature” of a magnetar
Radio observations as a test of the magnetar model

9 events with previous “signature” of a magnetar

5.8 GHz, VLA
What constraints can the upper limits place on the magnetar model?

Fong et al., in prep
What constraints can the upper limits place on the magnetar model?

![Graph showing the 5.8 GHz flux density vs. rest-frame time after burst for different densities of 1 cm$^{-3}$, 0.1 cm$^{-3}$, 0.01 cm$^{-3}$, and 10$^{-3}$ cm$^{-3}$, with GRB 130603B labeled.](Fong et al., in prep)
What constraints can the upper limits place on the magnetar model?

Afterglow density constraints from Fong et al. 2015

Fong et al., in prep
What constraints can the upper limits place on the magnetar model?

GRB 130603B

$n < 0.08 \text{ cm}^{-3}$

Afterglow density constraints from Fong et al. 2015

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![Graph showing the 5.8 GHz flux density over rest-frame time after burst for GRB 080905A.](image)
What constraints can the upper limits place on the magnetar model?
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![Graph showing afterglow density constraints from Fong et al. 2015](image_url)
What constraints can the upper limits place on the magnetar model?

Afterglow density constraints from Fong et al. 2015

Fong et al., in prep
<table>
<thead>
<tr>
<th>GRB</th>
<th>$n &lt; \text{cm}^{-3}$</th>
<th>Rest-frame Time After Burst (yr)</th>
<th>5.8 GHz Flux Density ($\mu$Jy)</th>
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</thead>
<tbody>
<tr>
<td>050724A</td>
<td>$\leq 0.50$</td>
<td>$10^{-1}$ - $10^2$</td>
<td>$10^{-1}$ - $10^2$</td>
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<tr>
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<tr>
<td>070724A</td>
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<td>101219A</td>
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<td>130603B</td>
<td>$\leq 0.08$</td>
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<td>$10^{-1}$ - $10^2$</td>
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</tbody>
</table>
What constraints can the upper limits place on the magnetar model?

\begin{figure}
\centering
\includegraphics[width=\textwidth]{plot.png}
\caption{The figure shows \( \nu L_\nu \) (erg s\(^{-1}\)) as a function of rest-frame time after merger (yr).}
\end{figure}

\begin{equation}
\nu L_\nu (\text{erg s}^{-1})
\end{equation}

Fong et al., in prep
What constraints can the upper limits place on the magnetar model?

\begin{equation}
L_i (\text{erg s}^{-1})
\end{equation}

\begin{align*}
&1 \text{ cm}^{-3} \\
&0.1 \text{ cm}^{-3} \\
&0.01 \text{ cm}^{-3} \\
&10^{-3} \text{ cm}^{-3} \\
&10^{-4} \text{ cm}^{-3}
\end{align*}

\begin{axis}
\end{axis}

\text{Rest-frame Time after Merger (yr)}
What constraints can the upper limits place on the magnetar model?

Fong et al., in prep
What constraints can the upper limits place on the magnetar model?

Fong et al., in prep
Summary & Future Directions

+ Ruled out long-lived magnetars for densities greater than 0.01-0.1 cm\(^{-3}\)
+ Explore additional parameters (energy, velocity)
+ Consider future observations