Transient Events from Neutron Star Mergers

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Transient Astronomical Events

Transient astronomical events include all astronomical phenomenon that last for a short period of time: the Big Bang, gamma-ray bursts (GRBs), supernovae, X-ray transients (bursters), microlensing, AGN flares, etc.

In this talk I focus on transient events produced by neutron star mergers.

Merger of Neutron Stars

Merger of two neutron stars, or a neutron star and a stellar-mass black hole, is expected to happen with a rate ~1000 times lower than that of supernovae (Narayan et al. 1991, Phinney 1991, van den Heuvel & Lorimer 1996, Bloom et al. 1998).

The merger rate is about 100 per Myr per Milky-Way-Equivalent Galaxy (Abadie 2010).

Merger of Neutron Stars

The merger has been thought to be responsible for short-duration gamma-ray bursts.

The merger has been thought to be one of the most important sources of gravitational waves.

Merger of Neutron Stars

Merger of two neutron stars, or a neutron star and a stellar-mass black hole, ejects some neutron-rich material. Radioactive decay of the neutron-rich matter provides the energy source for the EM radiation from the merger.

Mini-Supernovae from Neutron Star Mergers

Mergers of neutron stars (NS+NS) or a neutron star and a stellar mass black hole (NS+BH) are expected to produce flares with major radiation in UV-Optical bands, with duration around a day, peak luminosity comparable to that of type Ia supernovae (Li & Paczynski 1998).

One-Zone Model for the Mini-Supernova

A NS+NS or NS+BH merger ejects an envelope of neutron-rich matter, most of which radioactive. The expanding envelope is spherical, has constant mass and uniform mass density. The surface radius R increases at fixed sub-relativistic velocity V.

Evolution of the Expanding Envelope

The temperature inside the expanding sphere varies because of:

- *Adiabatic expansion;*
- *Heat generation by radioactive decays;*
- *Radiative heat losses from the surface.*

The Heat Generation Rate

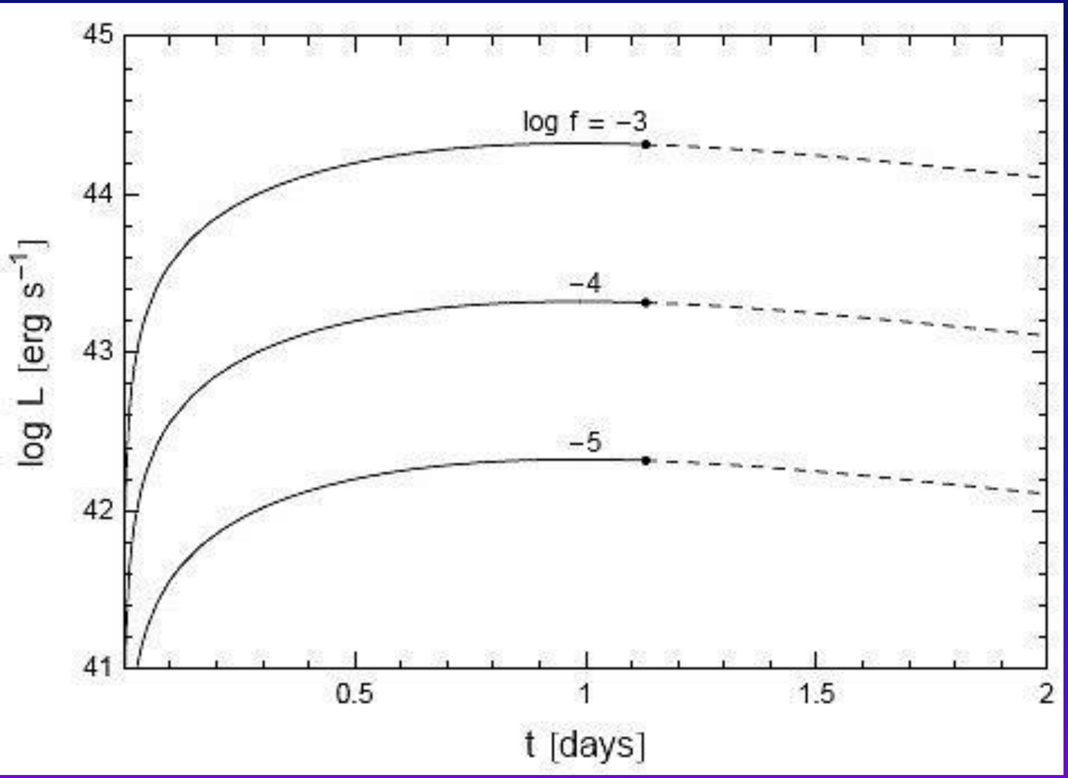
The radioactive decay of an element isotope:

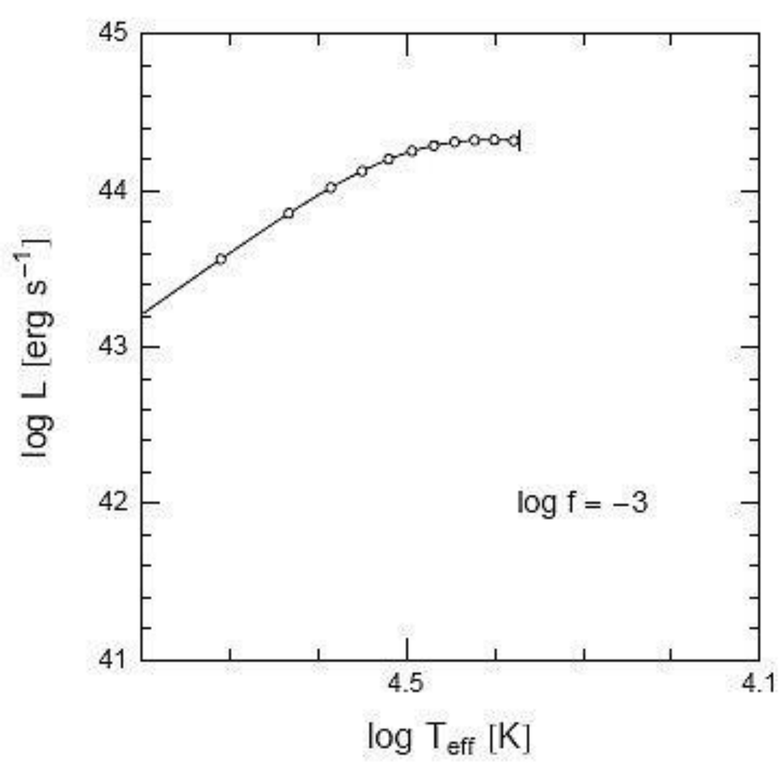
$$\epsilon = \frac{f c^2}{t_{\rm rad}} \exp\left(-t/t_{\rm rad}\right).$$

The envelope contains many decaying element isotopes, the total heat generation is the sum of that of individuals. Nuclear life times are distributed roughly uniformly in log intervals in time, thus

$$\epsilon = \frac{f c^2}{t},$$

The Lightcurve and Temperature Evolution





The Characteristic Parameters

The peak luminosity:

$$L_{\rm m} \approx 0.88\beta^{1/2}L_0 = 2.1 \times 10^{44}\ {\rm erg\ s^{-1}}\ \left(\frac{f}{0.001}\right)\left(\frac{M}{0.01M_\odot}\right)^{1/2}\left(\frac{3V}{c}\right)^{1/2}\left(\frac{\kappa}{\kappa_{\rm e}}\right)^{-1/2}.$$

The effective temperature at peak luminosity:

$$T_{\rm eff,m} \approx 0.79\beta^{-1/8}T_1 = 2.5 \times 10^4{\rm K}\ \left(\frac{f}{0.001}\right)^{1/4}\left(\frac{M}{0.01M_\odot}\right)^{-1/8}\left(\frac{3V}{c}\right)^{-1/8}\left(\frac{\kappa}{\kappa_{\rm e}}\right)^{-3/8}.$$

The Characteristic Parameters

The time at the peak luminosity:

$$t_{\rm m} \approx 1.5\beta^{1/2}t_{\rm c} = 0.98\ {\rm day}\ \left(\frac{M}{0.01M_\odot}\right)^{1/2}\left(\frac{3V}{c}\right)^{-1/2}\left(\frac{\kappa}{\kappa_{\rm e}}\right)^{1/2}.$$

The time duration:

$$\Delta t \approx 3.4\beta^{1/2}t_{\rm c} = 2.2\ {\rm day}\ \left(\frac{M}{0.01M_\odot}\right)^{1/2}\left(\frac{3V}{c}\right)^{-1/2}\left(\frac{\kappa}{\kappa_{\rm e}}\right)^{1/2}.$$

The transient event produced by a NS+NS or NS+BH merger has a peak luminosity in the bright supernova range. However, the duration of the luminous phase is only of a few days, much shorter than that of a supernova.

The merger model is sometimes called as a *mini-supernova*.

Summary

- Although neutron star mergers and black hole-neutron star mergers must happen in the Universe and the properties of the resultant transients are predicted, they have never been detected yet.
- Detection of the mergers will be very important for understanding the merger process, general relativity effects, gravitational wave physics, and short GRBs.