Magnetar fitting routine

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June 5, 2017

1 Overview

This is a matlab routine to fit bolometric supernova light curves with magnetar central engine model (with spin-down expression from Kasen & Bildsten 2010) following the Arnett 1982 formalism, with modification of kinetic energy treatment as described in Inserra, Smartt, Jerkstrand et al 2013 (also the paper reference for this code).

If you use this code for a publication please acknowledge this with a link to the website
https://star.pst.qub.ac.uk/webdav/public/ajerkstrand/Codes/Genericarnett/.

2 Background

Arnett 1982 derived an analytic framework to model (bolometric) supernova light curves. Between 1982 and 2006 this framework was largely ignored (averaging 3 citations per year), but around 2006/2007 a dramatic increase in usage occurred as new surveys were bringing in samples of data that needed rapid and rough modelling.This has been widely used to model normal radioactivity-powered SNe.

In the Arnett 1982 formalism, the light curve depends only on the power source and on the effective diffusion time scale

$$\tau_m(\kappa, M_{ej}, E_k) = \frac{1.05}{\sqrt{13.7c}} \kappa^{1/2} M_{ej}^{3/4} E_k^{-1/4} \ s \tag{1}$$

for constant density. Thus, for an assumed power source and an assumed κ, a SN can be fit for the M_{ej}^3/E_k.

2.1 Extension to generic power sources

In the Arnett framework some assumptions of the SN structure is made. However, there is no fundamental requirement that the energy source has to be radioactivity. The final expression constains the power function $P(t)$ of the energy source, but this could basically be anything.

The first paper realizing this and extending the formalism to other power sources was Chatzopoulos 2012, who considered magnetar power source, and circumstellar interaction power source (there is also an initial attempt in Chatzopoulos et al 2011 but that equation is typoed).

Our paper in 2013 was the second one to apply an Arnett formalism generalized beyond radioactivity. Here we also considered two other important aspect of the problem

- The dynamic effect of the magnetar, needed to get estimates of ejecta masses
- Attachment of an envelope and calculation of time-dependent photospheric velocity

2.1.1 Dynamic effects of magnetar

The difference between the 56Ni/56Co case (as described in Arnett 1982) and the magnetar case is that energy input by the magnetar can be so large that acceleration of the ejecta must be taken into account (radioactive decay energy is always too small for this). Thus, it is not possible to just replace the radioactive power source with the magnetar power source; one must consider the dynamic changes by the magnetar too.

Because the formalism still requires a time-constant kinetic energy, some kind of optimal time-average between the initial kinetic energy (cretaed by the explosion) and the final energy (with acceleration by the magnetar) must be used. We found this optimal value to be $1/2(E_{init} + E_{final})$ by calibrating the solutions to the radiation hydrodynamic models of Kasen & Bildsten.

3 Usage

3.1 Step 1

Create a data input file with the following format (see also provided file test.txt):

- First 2 lines : comments.
- Column 1: Observer-frame epoch relative to peak (days)
- Column 2: Logarithm of SN rest-frame bolometric luminosity ($\log_{10}(L_{bol}$ (erg/s)))
- Column 3: 1-sigma error on $\log_{10}(L_{bol})$

Any upper limits should be listed at the end of the file, and controlled by parameter "skip" below (=number of upper limits).

3.2 Step 2

Copy and paste the section "if (obj == 'test')" to create an entry for your object, replacing 'test' with your data file name, and changing the various variables to the new data set (shiftmin, shiftmax, skip, redshift, E_51, Mej_mag, B14_mag, Pms_mag, savename). These are explained in the code.

3.3 Step 3

Set the physical fit variables κ, α, dotrap, κ_{pp}. These are explained in the code.

3.4 Step 4

Set the grid parameters f_{low}, f_{high}, N_{Mej}, N_{B14}, N_{Pms}, N_{shift}, t_{end}. These are explained in the code.

3.5 Step 5

Run the code. Observed velocities and temperatures need to be added into Figs 2 and 3.

There is in general a need to run a few times iteratively, to take the dynamic coupling into account. After each run, get Emag and Erad (from just typing their names in the command window), and update the line E_51 = 1 + 0.5*(Emag - Erad). When convergence is reached, the SN has kinetic energy of 1 B (assumed), plus half the final energy added by the magnetar, as we found to be the optimal treatment with respect to hydrodynamic solutions.