Metallicity Dependence of Gamma-Ray Burst Progenitors

Robert G. Izzard, Enrico Ramirez-Ruiz & Christopher A. Tout

Institute of Astronomy, University of Cambridge, United Kingdom

Summary: Core collapse of a massive star to give a relativistic fireball jet is a widely disscused scenario for gamma-ray burst production. However, the nature of the stellar progenitor remains unclear - the jet may not be able to break through the envelope of a large or slowly rotating star. Break-out is aided if the progenitor originates in a low metallicity environment, when stars are smaller in radius, lose less mass and consequently have more massive cores. Both effects favour GRB formation. Population synthesis calculations are carried out using a Monte Carlo approach which allows us to explore what effect initial mass, metallicity and membership in a binary system have on GRB production.

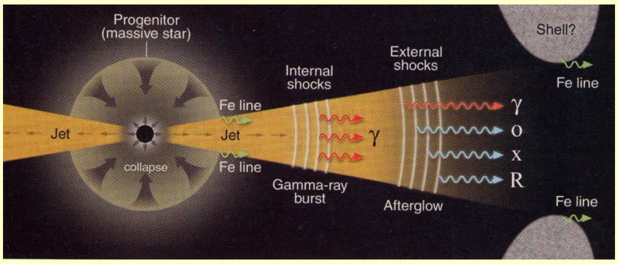

Figure 1: *Schematic of a GRB from a massive stellar progenitor: a relativistic jet which undergoes internal shocks produces a burst of gamma-rays and an external shock (afterglow) through iteraction with the external medium which leads successively to gamma-rays, X-rays, optical and radio. Fe lines may arise from X-ray illumination of a pre-ejected shell (e.g. a supernova remanant) or from continued X-ray irradiation of the outer stellar envelope.*

II. The role of metallicity: Metallicity Z influences the stellar evolution of massive stars mainly through bound-free and line opacities in the outer layers of massive stars owing to their influence on stellar wind mass loss rates. Low metallicity keeps the radius of the star smaller and reduces mass loss. The lower the metallicity, the higher the stellar mass for Wolf-Rayet star formation, This increases the mass of the heaviest CO core and favours black hole formation after a supernova and so GRBs. From stellar models with a variety of initial masses and metallicities for single and binary stars we find that the Ib/c supernova rate from stars with core masses above $6-8\,\mathrm{M}_\odot$, thought to be the GRB progenitors, significantly increases with decreasing metallicity, so GRBs are more likely to form in low Z populations (Fig. 3).

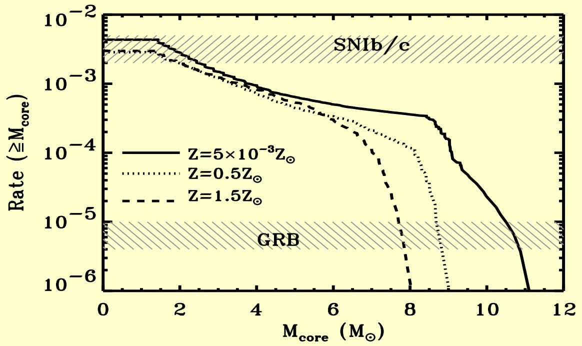

Figure 3: *SN Ib/c (GRB progenitor?) rate above a given core mass as a function of metallicity for stars in binaries. The minimum core mass for GRB production is thought to be about* $6-8\,\mathrm{M}_\odot$, *the region where the dependence of the rate on* Z *can vary by several orders of magnitude. Dashed regions show observed rates, which, for GRBs, will also depend on beaming solid angle.*

I. What are gamma-ray bursts? GRBs are sudden, intense flashes of gamma-rays which, for a few seconds, light up an otherwise dark gamma-ray sky. They are detected about once a day, and outshine every other gamma-ray source in the sky, including the sun. Major advances have been made in the last few years, including the discovery of slowly fading X-ray, optical and radio afterglows of GRBs, the identification of host galaxies at cosmological distances and the establishment of evidence that many of them are associated with star forming regions and possibly supernovae. The leading model for GRBs involves a relativistic fireball, with the gamma-rays produced by synchrotron or inverse Compton radiation from accelerated electrons in optically thin shocks. The ultimate energy source of the fireball is thought to be the gravitational energy release associated with the temporary mass accretion on to a black hole after the collapse of a massive star in a supernova (Fig. 1).

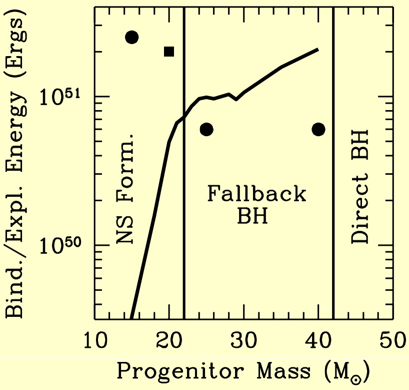

Figure 2: *Binding energy (solid line) of all but the inner* $3\,\mathrm{M}_\odot$ *core of the star and explosion energy (dots) vs. progenitor mass. If the explosion energy is less than the binding energy, the compact remnant exceeds* $3\,\mathrm{M}_\odot$ *and collapses to form a black hole. The explosion energy drops and the binding energy rises with increasing progenitor mass/core mass. Supernova 1987A is shown by the square.*

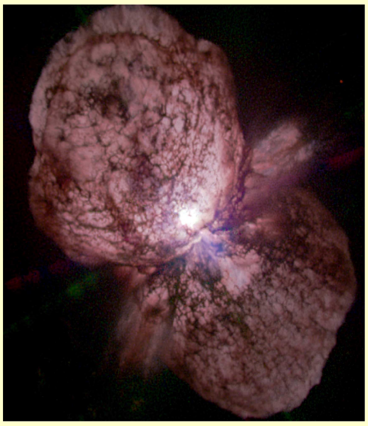

Figure 4: *This colour composite HST image shows* η *Carinae, a prime candidate for a GRB. It is thought to have a mass of about* $100\,\mathrm{M}_\odot$ *and may be part of a duplicitous star system.*

References:
Fig 2 : Fryer, Woosley and Hartmann 1999, ApJ, 526, 177
Fig 3 : Izzard, Ramirez-Ruiz & Tout, 2001 (in preparation)
Fig 4 : http://antwrp.gsfc.nasa.gov/apod/ap000813.html
MacFadyen A. I., Woosley S. E., 1999, ApJ, 524, 262
Paczyński B., 1998, ApJ, 494, L45
Hurley, Pols & Tout 2000, MNRAS 315, 543
Hurley, Tout & Pols 2001, MNRAS (in press)