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Bursting Stars:

Two particular types of explosive events stand out in high-energy astrophysics. One of these, so far detected from within our galaxy, is the sudden release of powerful bursts of X-rays from neutron stars. The second one is known to occur in distant galaxies and defined principally by the γ-rays that are put out. The X-ray and γ-ray bursts are among the most interesting dynamical phenomena in astronomy as they teach us about stellar evolution and large scale structure, as well as fundamental physics.

Although the X-ray and γ-ray bursts share an explosive identity, they differ in important ways. X-ray bursts barely damage the underlying star. Thus the stars not only survive the event in this case, but also repeat it. In contrast, γ-ray bursts completely destroy the underlying object in a spectacular display of cosmic fireworks not seen in other physical contents.

X-ray Bursts:

X-ray bursts were discovered independently by several groups in 1975. Of the ~ 200 X-ray binaries known, about 100 are low-mass systems, over half of which are accreting neutron stars. Most of these neutron stars are known to produce X-ray bursts. The mean quiescent source luminosity of these objects is $L_0 \sim (0.3-2) \times 10^{37}$ erg s^{-1}, which is roughly $\frac{1}{10}$ of the Eddington limit. When an X-ray burst goes off, it typically has a rise time $\lesssim 1s$, lasts 3-1000 s, and recurs on a timescale of $\sim (10^3 - 10^6)$ s. The bursts have luminosities $L_b \sim 10^{39}$ erg s^{-1} and total energies $E_b \sim 10^{39} - 10^{40}$ erg. Note that L_b is near or above L_{edd}.

Of the X-ray burst sources, ~ 35 exhibit photospheric expansion, which is consistent with the view that neutron star's atmosphere is blown away when the luminosity exceeds L_{edd}. The primary evidence for the thermonuclear interpretation of X-ray bursts comes from a comparison between the time-integrated quiescent and burst fluxes: $\frac{L_b}{L_o} \sim 20-300$.

The thermonuclear flash model has been very successful in reproducing the basic features of the X-ray burst phenomenon, which include the short rise time, the recurrence timescales, the luminosities, the energies released, the spectral softening as the burst decays, and the $\frac{L_b}{L_o}$ ratio.

X-ray bursts are caused by the unstable burning of freshly accreted H/He on the surface of the neutron star, which is accumulated over a period of a few hours to form a layer that is ~10m thick. As the accretion continues, the nuclear fuel is compressed and heated hydrostatically. Therefore both the density and temperature of the accreted layer increases (the highest increase occuring at the bothom) until the Hydrogen starts burning into Helium. This first happens in a thin shell via the pp-chain as temperature is initially low. At high temperatures H burns into He via the CNO-cycle, and He can in turn burn to C via the triple-α reaction.

Explosions eventually occur because these processes are thermally unstable. As the temperature increases, the rate of collisions between the various nuclear species also increase, which enhance the reaction rate. By releasing more energy, this further raises the temperature thereby initiating a runaway process. These situations will lead to various combinations of H and He "flashes" that are observed as X-ray bursts. The burst spectrum is essentially a blackbody. Under the assumption that the emitting surface is spherical, one derives a photospheric radius that is smaller than the neutron star radius. This suggests that only a portion of the neutron star surface burns and radiates at any given time during the event. The neutron star's magnetic field may play an important role in this respect.

It has been long thought that a strong magnetic field stabilizes the nuclear burning by funneling H and He onto the polar caps where enhanced temperature causes the nuclear fuel to burn more rapidly, and hence avoiding the pileup of the matter that will produce a thermonuclear explosion. Recend discoveries show that the flash still occurs but at the magnetic poles of of the neutron star, which then propagates around the star. A very important question arises that how the nuclear burning actually propagates across the stellar surface. This is a subject of considerable interest in computational astrophysics, where these processes are modeled with high resolution grids and state-of-the-art nuclear reaction network and equation of state.

As an aside, we note that in X-ray bursts the flame propagates within 1cm of the surface, and hence is easily observable. This is very different, for example, from the case of type Ia supernova where burning takes place deep inside the star, which makes it impossible to see the process from the outside. Also, a typical neutron star rotates at few hundred revolutions per second. This provides hundreds of snapshots available per burst, which allows us to view all points on the neutron star's surface.