letters to nature

Do superheavy elements imply the existence of black holes?

THE discovery[1] of the superheavy elements 116, 124, and 126 raises the question of where these elements are likely to have been formed. The majority of the post-iron-peak nuclei are thought to have been produced in conditions of explosive nucleosynthesis (the r-process), particularly in conventional supernova explosions. The ability of the r-process to produce superheavy elements is, however, very uncertain[2]. The conditions necessary for superheavy element synthesis (β-decays occurring sufficiently slow that the $n\gamma \rightleftharpoons \gamma n$ equilibrium is not disturbed) are difficult to realise in astrophysical situations. The n-process (J. B. Blake and D. N. Schramm, unpublished) requires less extreme conditions (the β decays are important) and may occur more often. The majority of the elements normally attributed to the r-process may have been synthesised in this way. Neutron-induced fission causes both processes to terminate at nuclei with high proton numbers, Z, but the n-process may allow it to reach the higher Z value.

We note that superheavy elements, such as those discovered and others much less stable in our environment, must exist in the outer layers of a neutron star[3]. Moreover, ideal conditions for the production of superheavy nuclei (high neutron flux and rapid β decays) are found in the disruption of a neutron star. The β decay rate is then fast compared with the expansion time scale (ref. 4 and J. M. Lattimer and D. N. Schramm, unpublished). We envisage such disruption being possible in either of two ways, both of which involve a black hole. Lattimer and Schramm (unpublished) and Lattimer *et al.*[4] have considered the tidal disruption of a neutron star from a close encounter with a black hole. Most of the disrupted star is swallowed by the hole, but some of the processed stellar material is assumed to escape.

Perhaps a more likely situation in which a neutron star is disrupted occurs when it accretes sufficient material that its mass exceeds the maximum mass for stable neutron stars. It has no alternative other than to collapse to form a black hole, and it again seems plausible that some of the outer layers are thrown off as it does so. The binary X-ray sources such as Her X-1 and Cen X-3 provide evidence that accreting neutron stars do exist.

The accretion process is enhanced if such binary systems tend to evolve towards coalescence, as is expected. One product of such evolution could be the giant stars envisaged by Thorne and Zytkow[5], in which accretion on to a neutron star core is a major power source for the whole star. Assuming that the neutron star cannot accept material at a rate much above that consistent with the Eddington limiting luminosity ($\sim 10^{38}$ erg s^{-1}), then $\sim 10^8$ yr are required before the collapse takes place. The resultant explosion could observationally closely resemble that of a more conventional supernova.

We thus argue that the most likely site for the production of superheavy elements is in the surface layers of a neutron star. The most plausible means by which these layers can be returned to the interstellar medium involve the intervention, or formation, of a black hole. We should, however, mention that in certain supernova models involving a hard equation of state, it is conceivable that the central regions collapse to neutron star densities, form superheavy elements, and then bounce. This may disrupt the original star entirely, leaving no remnant at all.

J. E. PRINGLE
D. S. P. DEARBORN
A. C. FABIAN

Institute of Astronomy,
Madingley Road,
Cambridge CB3 0HA, UK

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Do superheavies come from neutron stars?

THE recent report of discovery of superheavy elements[1] (with nuclear charges near the predicted values for shell closure, $Z = 114$ and $Z = 126$), in surprisingly large quantities in terrestrial material, raises the question of the astrophysical sources for such nuclei. The very lightest nuclei may have been created in the first hours of the big bang, but significant amounts of elements beyond helium could not have been formed in these conditions. The heavier elements must have been formed in stars, and those as massive as uranium were probably formed by intense neutron bombardment immediately before or accompanying supernova explosions[2]. It seems unlikely, however, that superheavy nuclei could have been formed in this way, since attempts to reach the 'stability islands' by successive neutron captures must proceed by nuclei with very short lifetimes. This would almost certainly be the case for the island about $Z = 126$, if not for that at $Z = 114$. I would suggest that neutron stars might be a source for such superheavy nuclei.

Before theories of nucleosynthesis had reached their present state, Mayer and Teller considered evaporation from a fluid 'polyneutron' as a source of heavy elements[3], and came to the conclusion that nuclei with atomic masses of several hundred might be formed. With some qualification, such a polyneutron may be identified with a neutron star. We now know that the surface of a neutron star will very quickly be cooled below the crystalline melting point by neutrino emission processes[4], but it will be fluid for a short time after the collapse of a supernova core. Densities considerably higher than equilibrium values of perhaps $\rho \sim 10^{11}$ g cm^{-3} might be reached at the surface during oscillations following collapse. Evaporation of superheavies from the surface of such a newly formed neutron star would thus be virtually simultaneous with formation of heavy elements by neutron capture in the supernova explosion itself. Fission and β decay of the initial droplets of nuclear matter would be expected to yield some of the relatively stable elements about $Z = 114$, 126 and perhaps 164.

Another possibility is the disruption of a neutron star by tidal interaction with a black hole[5]. Matter can be ejected to infinity in such an encounter, and this matter might include