Astronomy

Supernovae and the distance scale

from Sidney van den Bergh

IN SPITE of fifty years of observational effort, the Hubble constant, which measures the size (and somewhat less directly the age) of the Universe, remains poorly determined. That is so because galaxies are extremely distant and so the 'standard candles' within them are exceedingly faint. The most luminous known standard candles are supernovae of type I (SNI) at maximum light. On page 337 of this issue, W.D. Arnett, D. Branch and J.C. Wheeler suggest that it may be possible to calibrate the maximum luminosity of SNI directly from nuclear physics. This approach bypasses the traditional and error-prone 'distance ladder' technique for the determination of the extra-galactic distance scale.

It is now generally believed that the precursors of SNI are mass-accreting carbon/oxygen white dwarfs in close binary systems. The C-O nuclear fuel in these objects will ignite if mass transfer from a binary companion pushes the total mass of the white dwarf above about 1.4 solar masses (the Chandrasekhar limit). Nuclear incineration of C-O to radioactive ^{56}Ni in an exploding white dwarf will produce 1.4×10^{51} erg per solar mass. Most of this energy ends up as kinetic energy of matter ejected during the supernova explosion.

The optical luminosity of SNI is believed to result from the trapping and thermalization of the γ rays and positrons emitted by the decay of ^{56}Ni through ^{56}Co to ^{56}Fe. Detailed hydrodynamical calculations have indicated that a C-O white dwarf that is pushed over the Chandrasekhar limit will produce 0.4 - 1.4 solar masses of ^{56}Ni. Based on these calculations and other evidence, the best estimate of Arnett *et al.* is that a SNI will produce 0.6 solar masses of ^{56}Ni and that the decay of one solar mass of ^{56}Ni would produce a maximum supernova luminosity of $(2.2 \pm 0.2) \times 10^{43}$ erg s^{-1}. They then deduce, from knowledge of supernova spectra, that the decay of 0.6 solar masses of ^{56}Ni will produce a supernova with a maximum blue magnitude, M_B(max), of -19.5, with limits of -20.4 and -19.1, corresponding to 1.4 and 0.4 solar masses of ^{56}Ni.

For SNI that have been observed to occur in elliptical and lenticular galaxies (which are generally dust-free) with redshifts larger than 3,000 km s^{-1} (for which random motions of individual galaxies can be neglected), Arnett *et al.* find that $M_B(\max) = -18.4 + 5 \log (H/100)$. Substitution of their calculated value of M_B(max) into this relation yields $H = 59$ km s^{-1} Mpc^{-1}, with upper and lower limits of 73 and 39 km s^{-1} Mpc^{-1}.

This result places Arnett *et al.* firmly on the side of those who find that the Hubble constant is small enough to accommodate the age of the Universe derived from evolutionary age models of globular cluster stars — about 1.8×10^{10} years. Those who favour larger values of the Hubble constant and smaller ages of the Universe will, no doubt, bring forward four arguments. First, incineration of a carbon/oxygen white dwarf might, in fact, produce less than 0.4 solar masses of nickel. Second, calculation of the maximum optical luminosity of SNI involves rather complex radiative transfer calculations in a supernova shell in which physical conditions are not yet perfectly understood. Third, more photoelectric observations of supernovae are required to support the assumption that all SNI have the same luminosity at maximum light. And, fourth, it is not yet entirely certain that SNI at maximum light are well represented by spherical black bodies with a temperature of 20,000 K.

As long as such uncertainties remain, the search will continue for additional calibration techniques for the extra-galactic distance scale. New urgency has been given to this search by the recent work of A.R. Walker (*Mon. Not. R. astr. Soc.* **212**, 343; 1985) which suggests that the calibration of the Cepheid distance scale may be in error by as much as 0.2 - 0.3 mag. Promising new methods for the calibration of the extra-galactic distance scale, which have not yet been fully exploited, involve observation of the light curves of distant novae (two of which have recently been discovered in the Virgo cluster galaxy M87) and comparison of the luminosity functions of distant globular systems with those of M31 and the Galaxy. Such determinations are now possible by detecting the maxima of the luminosity functions for the distant globular cluster systems surrounding NGC3379 and M87. The ultimate solution to the distance-scale problem may have to await the Space Telescope. □

Sidney van der Bergh is at the Dominion Astrophysical Observatory, Victoria, British Columbia V8X 4M6, Canada.

Palaeontology

Scottish window on terrestrial life in the Lower Carboniferous

from Andrew R. Milner

ONE of the areas of the world that has the greatest potential for filling some of the gaps in our knowledge of the land fauna before the middle stage of the Upper Carboniferous — the Westphalian (316–296 Myr) — is the Scottish Midland Valley around and between Edinburgh and Glasgow. This area is covered by sequences of freshwater, estuarine and marine beds and there are many coal-mines and surface workings cutting through the appropriate horizons. Over the last decade, the palaeontological community has benefited greatly from sustained prospecting in that area by Mr Stanley Wood. Amongst other new sites, he has revealed an early Upper Carboniferous lake-bed assemblage of aquatic amphibians and fishes at Cowdenbeath[1,2]; an early Upper Carboniferous coastal assemblage of fishes and crustaceans at Bearsden[3]; and, as reported on page 355 of this issue, the first Lower Carboniferous assemblage of terrestrial amphibians, arthropods and plants at East Kirkton[4].

The origin and early diversification of terrestrial animal life is a vast palaeontological and evolutionary jigsaw of which we still have only a handful of pieces. The first certain terrestrial arthropods — from the Rhynie Chert and the Old Red Sandstone — are of Lower Devonian age (410 - 400 Myr), whilst the earliest known amphibians are Upper Devonian (around 360 Myr) and already show few relictual fish-like characteristics. To cover the intervening time span, some half-dozen localities have produced only fragments of information about terrestrial arthropods, although the recently reported Middle Devonian locality at Gilboa, New York State[5] shows great promise. The record has until now been little better for the early Carboniferous and it is not until the Westphalian that palaeobiologists can study comprehensive assemblages of myriapods, arachnids, insects, molluscs and vertebrates. Many groups of terrestrial animals make their first appearance as fossils in the Upper Carboniferous, in particular the winged insects and reptiles, but their very structural diversity at this time speaks for a long previous history. By the time we can see what is happening on land, many of the most interesting events have already taken place.

This, then is the significance of the East Kirkton assemblage, which is quite unlike any previously described association of Lower Carboniferous/Mississippian animals. It seems to be in a spherulite-bearing freshwater limestone laid down in shallow pools associated with hot springs[6]. No fish or benthic invertebrates are present, suggesting that the pools were generally uninhabitable. To my knowledge, only two Palaeozoic sites, both younger, show environmental similarity