Feathers, filaments and theropod dinosaurs

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One of the hottest debates in palaeontology is whether birds evolved from dinosaurs. A study of two exceptionally well-preserved specimens of a theropod dinosaur from China — complete with skin, internal organs and eggs — provides new clues to the origin of feathers.

Ever since John Ostrom resuscitated the idea in the 1970s, palaeontologists have been piling up the evidence in favour of theropod dinosaurs as the ancestors of birds. Recently, the gap between theropods and birds has been narrowed even further. Important avian characters, such as the furcula (wishbone), have been discovered in theropods thought to be close to birds[1]. And typical theropod characteristics, such as an enlarged claw on digit two of the foot, have been found in early birds[2]. The final, clinching fact would be the discovery of evidence of feathers — a defining feature of birds — in theropods.

Cue *Sinosauropteryx prima*, the so-called 'feathered' dinosaur from China (Fig. 1). Reports of this sensational discovery first appeared[3] in late 1996. Although few scientists have yet seen the fossil material, some are already incorporating *Sinosauropteryx* into models for the origin of feathers and bird flight[4]. Still others argue[5] that the 'feathers' are merely an artefact of preservation. On page 147 of this issue[6], Chen, Dong and Zhen present the first detailed description of *Sinosauropteryx*, and show that the integument (skin) bore discrete filamentous structures. But are they feathers?

Figure 1 **Reconstruction of *Sinosauropteryx* by Michael W. Skrepnick. Three exceptionally well-preserved specimens of this dinosaur have been recovered from the Early Cretaceous Yixian Formation of China. Two of these are described by Chen *et al.*[6], who show that *Sinosauropteryx* bore discrete structures that could have been 'proto-feathers'.**

Chen *et al.* describe two almost complete, near-adult individuals, with evidence of soft tissues including the integument, the eyes and possibly some internal organs[7]. They are, without doubt, the best-preserved dinosaur remains yet found. These, along with a third specimen, were recovered by Chinese farmers in Liaoning Province, China (P. J. Currie, personal communication). They were found in beds of the Yixian Formation, part of a thick sequence of lake sediments intercalated with volcanic deposits. During the past six years, these sediments have yielded many superbly preserved fossils. The result is an almost complete Early Cretaceous (145–97.5 million years ago) continental biota, composed of plants, insects, fish, lizards, turtles, pterosaurs, dinosaurs, mammals and numerous birds[8] — the latter often preserved with their plumage intact[9].

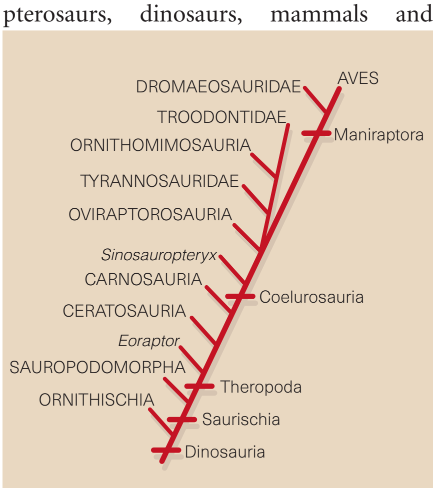

Figure 2 **The relationships of *Sinosauropteryx* to other dinosaurs. *Sinosauropteryx* is not as closely related to birds as many other theropods, yet it is the first non-avian theropod that seems to show evidence of feather-like structures. (Modified from ref. 10.)**

In life, *Sinosauropteryx* was about the size of a large chicken and distinguished by its deep, narrow body, remarkably long tail and rather short, stout forelimbs (Fig. 1). Like its close relative *Compsognathus*, from the Late Jurassic of Europe (163–145 million years ago), *Sinosauropteryx* has a very specialized hand. Its massive first digit bears a large claw that might have served as a killing tool. Last meals provide further evidence of an active, predatory lifestyle — a lizard in the gut region of one individual[6] and a tiny mammal in the third specimen (P. J. Currie, personal communication). The body of the larger individual described by Chen *et al.* also contains another surprise — two small, oval structures which, judging by their shape, size and position, are almost certainly eggs. This is the first reasonably convincing record of this type of association for any dinosaur and, if correctly identified, provides incontrovertible evidence that this individual was female. Moreover, the relatively small size of the eggs and the possibility of paired oviducts[6] suggest that, unlike modern birds (which have a single oviduct and, in general, smaller clutches of relatively large eggs), theropods had a more reptile-like reproductive system with two oviducts that produced larger numbers of relatively small eggs.

The most striking features of the fossils are the well-preserved remains of the integument, which forms a dark halo above the skull, neck, back, hips and both sides of the tail. Small patches of integument also occur on the skull, and are associated with the forelimbs, rib-cage and legs. The halo is composed of many coarse, sinuous filaments, which are possibly hollow and up to 40 mm long[6]. The filaments seem to be discrete structures and, although often matted and tangled, are not encased in skin or remnants of the decaying dermis, as some have suggested[5]. Branching of the filaments — a construction that is also typical of feathers — has been reported[6,10], but the topography of this branching is not yet clear.

This brings us to the critical question: are these structures some kind of 'proto-feather'? Chen *et al.*[6] and others[4,10] clearly favour this idea. They draw comparisons with the plumules of modern birds, which are relatively simple structures without barbules or hooklets. But any argument for homology between the feathers of birds and the integumentary structures of *Sinosauropteryx* needs to be supported by more than general similarities in structure and position. High-resolution microscopy and biogeochemical tests might provide some answers, but they will not solve all of the problems. Moreover, if *Sinosauropteryx* bears proto-feathers, we might expect similar (or perhaps even more feather-like) structures to have been present on at least some of the theropods that are more closely related to birds than is *Sinosauropteryx* (Fig. 2). Exceptionally well-preserved remains of the integument are now known for two of these dinosaurs — the ornithomimosaur *Pelecanimimus*[11], and a small, unnamed maniraptoran theropod from Brazil[12]. In both cases, however, there is no evidence of the filamentous structures found in *Sinosauropteryx*.

So, it seems that we still do not have absolute proof that some dinosaurs were feathered. Or do we? The Liaoning deposits have yielded three examples of another putative dino-bird intermediate, *Protarchaeopteryx*. According to a preliminary report by Ji and Ji[13], these individuals have well-preserved evidence of true feathers. While we wait for further details of these Chinese fossils, we might consider the irony of the present situation — nothing for hundreds of years and then, suddenly, a whole flock of evidence. □

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Cosmology

An unprincipled Universe?

Peter Coles

One of the central tenets of cosmological orthodoxy is the Cosmological Principle, which states that, in a broad-brush sense, the Universe is the same in every place and in every direction. This assumption has enabled cosmologists to obtain relatively simple solutions of Einstein's General Theory of Relativity that describe the dynamical behaviour of the Universe as a whole. These solutions, called the Friedmann models[1], form the basis of the Big Bang theory. But is the Cosmological Principle true? Not according to Sylos-Labini *et al.*[2], who argue, controversially, that the Universe is not uniform at all, but has a never-ending hierarchical structure in which galaxies group together in clusters which, in turn, group together in superclusters, and so on.

These claims are completely at odds with the Cosmological Principle and therefore with the Friedmann models and the entire Big Bang theory. The central thrust of the work of Sylos-Labini *et al.* is that the statistical methods used by cosmologists to analyse galaxy clustering data are inappropriate because they assume the property of large-scale homogeneity at the outset. If one does not wish to assume this then one must use different methods.

What they do is to assume that the Universe is better described in terms of a fractal set characterized by a fractal dimension D. In a fractal set, the mean number of neighbours of a given galaxy within a volume of radius R is proportional to R^D. If galaxies are distributed uniformly then $D = 3$, as the number of neighbours simply depends on the volume of

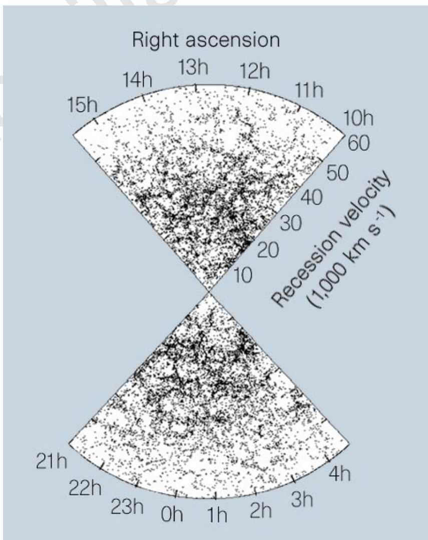

Figure 1 **The big picture — the Las Campanas redshift survey, each dot marking a galaxy with a well-determined redshift. The survey maps the Universe out to recession velocities of 60,000 km s^{-1}, corresponding to distances of a few hundred million parsecs. Although no fractal structure on the largest scales is apparent (there are no clear voids or concentrations on the same scale as the whole map), one statistical analysis[2] finds a fractal dimension of two in this and other surveys, for all scales — conflicting with a basic principle of cosmology.**

the sphere and the average number-density of galaxies. A value of $D < 3$ indicates that the galaxies do not fill space in a homogeneous fashion: $D = 1$, for example, would indicate that galaxies were distributed in roughly linear structures (filaments). Sylos-Labini *et al.* argue that $D = 2$, which suggests a roughly planar (sheet-like) distribution of galaxies.

Most cosmologists would accept that the distribution of galaxies on relatively small scales, up to perhaps a few tens of megaparsecs (Mpc), can indeed be described in terms of a fractal model. This small-scale clustering is expected to be dominated by purely gravitational physics, and gravity has no particular length scale associated with it. But standard theory requires that the fractal dimension should approach the homogeneous value $D = 3$ on large enough scales. According to standard models of cosmological structure formation, this transition should occur on scales of a few hundred Mpc.

The main source of the controversy is that most available three-dimensional maps of galaxy positions are not large enough to encompass the expected transition to homogeneity. Distances must be inferred from redshifts (see box), and it is difficult to construct these maps from redshift surveys, which require spectroscopic studies of large numbers of galaxies.

Sylos-Labini *et al.* have analysed a number of redshift surveys, including the largest so far available, the Las Campanas redshift survey[3]. They find $D = 2$ for all the data they look at, and argue that there is no transition to homogeneity for scales up to 4,000 Mpc, way beyond the expected turnover. If this were true, it would indeed be bad news for the orthodox among us.

Their results are, however, at variance with the visual appearance of the Las Campanas survey, for example, which certainly seems to display large-scale homogeneity (Fig. 1). Objections to these claims have been lodged by Luigi Guzzo[4], for instance, who has criticized their handling of the data and has presented independent results that appear to be consistent with a transition to homogeneity. It is also true that Sylos-Labini *et al.* have done their cause no good by basing some conclusions on a heterogeneous compilation of redshifts called the LEDA database[5], which is not a controlled sample and so is completely unsuitable for this kind of study. Finally, it seems clear that they have substantially overestimated the effective depth of the catalogues they are using. But although their claims remain controversial, the consistency of the results obtained by Sylos-Labini *et al.* is impressive enough to raise doubts about the standard picture.

Mainstream cosmologists are not yet so worried as to abandon the Cosmological Principle. Most are probably quite happy to admit that there is no overwhelming direct evidence in favour of global uniformity from current three-dimensional galaxy catalogues, which are in any case relatively shallow. But this does not mean there is no