So why are these compact, high-redshift galaxies such a theoretical conundrum? Elliptical galaxies have long been seen as the end-point of galaxy formation: when a star-forming spiral or irregularly-shaped galaxy, full of young blue stars, has its star formation quenched by some astrophysical-feedback process, it quickly ages to become a 'red and dead' elliptical. As the overall star-formation rate of the Universe winds down with time, it seems natural to find an increasing number of these galaxy fossils full of old red stars. But such red galaxies are found to be more massive than any star-forming galaxy, so something extra is needed to provide the mass.

The consensus has been that elliptical galaxies have also assembled through mergers of smaller galaxies, a process naturally expected in current galaxy-formation theories[8]. The most massive ellipticals would be the result of major mergers of smaller ellipticals — with these progenitors having been of roughly equal mass. Elliptical galaxies are observed to follow tight scaling relationships between size, mass and velocity, which one might think would be seriously disturbed by mergers. However, computer simulations show that mergers simply 'move' the galaxies along the relationships without making them significantly less tight[9].

But this picture breaks down when size evolution is taken into account: if you merge enough elliptical galaxies at high redshift to account for the size change, you also make many more high-mass galaxies than are observed in the nearby Universe. An alternative is that if mergers are predominantly minor — those in which a low-mass object merges into one of much larger mass — size growth can be achieved without a substantial increase in mass[10]. However, low-mass galaxies generally contain a lot of young stars, so this seems inconsistent with the observed old stellar populations of the high-redshift compact galaxies and their nearby descendants.

This 'lack of fit' with the standard picture of elliptical-galaxy formation has driven a search for ways other than mergers by which the size of these galaxies could have blown up. For example, feedback processes such as an energy injection from a supernova[11] or quasar[12] could achieve that by expelling gas from the galaxy slowly (or rapidly), making the galaxy's gravitational potential well shallower and moving stars into larger orbits. But these processes require a level of star or quasar activity that has not been observed. A more exotic explanation could involve the yet unknown nature of dark matter.

Any successful explanation of the size evolution must solve what I call the synchronization problem, which in my view is the most fundamental. The size–mass scaling relationship is tight in the nearby Universe, and possibly also at high redshift. It is just the normalization of this relationship that evolves. There are no massive compact elliptical galaxies today. Therefore, the high-redshift (early-epoch) compact galaxies must be growing in size with time (Fig. 1). But, at the same time, the Universe is making new elliptical galaxies, and somehow both the growing and the newly formed galaxies fall within the same tight size–mass relationship at all epochs. Their evolution is 'synchronized' through some process that is either a coincidence or an important new piece of astrophysics.

A lot hinges on the interpretation of van Dokkum and colleagues' single velocity-dispersion measurement[4] of 1255–0. As large telescopes acquire new multi-object, near-infrared spectrographs, we can expect to see many hundreds of such velocity-dispersion measurements in the next few years. We can also expect to see improved measurements of the structural and environmental properties of these compact galaxies, which will help us to figure out how bad the problems we have in explaining these objects really are. It remains to be seen whether we need conventional or novel explanations for their astounding growth into the most massive elliptical galaxies we see today. ■

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1. Abraham, R. G. *et al. Astrophys. J.* **669,** 184–201 (2007).
2. Cimatti, A. *et al. Nature* **430,** 184–187 (2004).
3. van Dokkum, P. G. *et al. Astrophys. J.* **638,** L59–L62 (2006).
4. van Dokkum, P. G., Kriek, M. & Franx, M. *Nature* **460,** 717–719 (2009).
5. Trujillo, I. *et al. Astrophys. J.* **692,** L118–L122 (2009).
6. Kriek, M. *et al. Astrophys. J.* **700,** 221–231 (2009).
7. Cenarro, A. J. & Trujillo, I. *Astrophys. J.* **696,** L43–L47 (2009).
8. De Lucia, G., Springel, V., White, S. D. M., Croton, D. & Kauffmann, G. *Mon. Not. R. Astron. Soc.* **366,** 499–509 (2006).
9. Boylan-Kolchin, M., Ma, C.-P. & Quataert, E. *Mon. Not. R. Astron. Soc.* **369,** 1081–1089 (2006).
10. Bezanson, R. *et al. Astrophys. J.* **697,** 1290–1298 (2009).
11. Damjanov, I. *et al. Astrophys. J.* **695,** 101–115 (2009).
12. Fan, L., Lapi, A., De Zotti, G. & Danese, L. *Astrophys. J.* **689,** L101–L104 (2008).

ARCHAEOLOGY

The earliest musical tradition

Daniel S. Adler

Music is a ubiquitous element in our daily lives, and was probably just as important to our early ancestors. Fragments of ancient flutes reveal that music was well established in Europe by about 40,000 years ago.

The Palaeolithic caves of the Swabian Jura in southwestern Germany have been a source of valuable and often provocative archaeological discoveries for many decades. In particular, finds of figurative art from the early Aurignacian — the earliest Upper Palaeolithic archaeological culture associated with modern humans in Europe — suggest that these hunter–gatherers had the knowledge, expertise, incentive and time to craft sophisticated objects for use in ritual activities. These activities probably served to affirm group affiliation, signal social identity and mark important social events or rites of passage. Conard *et al.*[1] (page 737 of this issue) now reveal that the Aurignacian inhabitants of the Swabian Jura had also mastered the art of music. Their detailed report highlights the discovery of a largely complete flute (Fig. 1) and two small flute fragments in the oldest Aurignacian layer at Hohle Fels Cave.

Conard recently reported[2] the discovery of a female figurine carved from mammoth ivory in an Aurignacian layer at Hohle Fels dated to at least 35,000 years ago (based on the newly calibrated radiocarbon timescale). At present, this is the earliest such find in the world. Additional examples of figurative art — of mammoths, horses, bison, cave lions, waterfowl and half-human, half-animal 'therianthropes' — have also been found in Aurignacian layers at Hohle Fels and other sites in the Swabian Jura. These finds suggest that the region was inhabited by a population of *Homo sapiens sapiens* that had mastered, among other things, the manipulation of mammoth ivory into three-dimensional, naturalistic forms for purposes not directly related to daily economic needs. Just as we continue to do today, these

H. JENSEN/UNIV. TÜBINGEN

Figure 1 | Sounds old. Conard *et al.*[1] have discovered the oldest known flute, at Hohle Fels Cave in Germany. The flute is made from bird bone, and dates from the early Aurignacian, 40,000 years ago.

hunter–gatherers produced symbolic objects that embodied complex beliefs shared by a larger community of individuals.

The newly discovered flutes[1] suggest that music accompanied both daily and ritual activities. The most complete specimen, measuring 21.8 centimetres in length and with a diameter of 0.8 centimetres (Fig. 1), was produced from the radius (lower forelimb) of a griffon vulture. This flute retains five finger holes — although there may have been more — and the proximal end of the radius has been modified to serve as a mouthpiece. The two smaller fragments, made of ivory, are clearly derived from at least one other flute. There is little doubt that these implements are flutes, and given that they were recovered from secure, meticulously excavated and documented contexts within the cave, their archaeological association, stratigraphic provenance and age are not in question.

The oldest Aurignacian layer from which the three flute fragments were recovered dates to approximately 40,000 years ago and directly overlies the final Neanderthal layer. This date is believed to mark the initial expansion of modern human populations into the Swabian Jura, probably via the Danube Corridor[3]. although these are currently the earliest flutes known, it is reasonable to expect that even earlier examples were produced within and outside the region: the instruments from Hohle Fels are too 'evolved' in terms of design and manufacture to represent the first flutes. The makers and players of the Aurignacian flutes were thus not novices, but had considerable musical knowledge and experience that may have resulted from some form of transgenerational communication. Moreover, the earliest musical instruments, such as drums and rattles, were probably made of perishable materials — perhaps wood and hide — that are not routinely preserved in the archaeological record. Even so, these flutes from southwestern Germany are of immense importance, as they document a mature musical tradition that was firmly in place thousands of years earlier than previously thought.

The discoveries reported by Conard and colleagues[1] answer several crucial questions about the context and antiquity of early music in the Upper Palaeolithic. But precisely how and why music became such a ubiquitous — and economically profitable — aspect of virtually every modern human society is unclear. Unlike the origins of language, which have long been the subject of intense research, the evolutionary significance of music has only recently been seriously investigated. Specifically, researchers seek to understand whether the human faculty for music is subject to natural selection. If so, when and under what circumstances did it evolve, and how might it have affected the reproductive fitness of individuals and groups that expressed musical behaviours?

Several general theories have been proposed to explain the evolution of music. For example, music is thought to have aided group cooperation, social cohesion and group synchrony, and coalition signalling[4–6]. It may also have played a part in mate selection, conflict reduction or vocal grooming[4]. Music could even have acted as a mnemonic device for long-term information exchange. But efforts to develop testable evolutionary hypotheses of music have been largely unsuccessful, and it is widely accepted that, if music is an evolutionary adaptation, then it probably had a complex origin that might be related to pre-existing cognitive and auditory adaptations in humans. Comparative research on the musical capacities of non-human animals[7] will allow us to develop a better understanding of which aspects of a general musical faculty, if any, are unique to humans.

The discovery of the flutes[1] from Hohle Fels make it clear that, by the early Aurignacian period roughly 40,000 years ago, our modern human predecessors in the Swabian Jura (and probably elsewhere) had thoroughly integrated music into their everyday lives — most probably as a critical element in rituals, but also as a means of fostering a sense of shared identity and common purpose. Music almost certainly helped to build and maintain group cohesion and social networks, by creating shared norms of musical aesthetics and storytelling, and through the strong emotions that music can elicit. Although we will never know precisely what music these Palaeolithic flautists played, or under what conditions they played it, Conard and colleagues' extraordinary finds[1] are clear proof that our ongoing obsession with music and musicians is of considerable antiquity. ■

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1. Conard, N. J., Malina, M. & Münzel, S. C. *Nature* **460,** 737–740 (2009).
2. Conard, N. J. *Nature* **459,** 248–252 (2009).
3. Conard, N. J. & Bolus, M. *J. Hum. Evol.* **44,** 331–371 (2003).
4. Huron, D. *Ann. NY Acad. Sci.* **930,** 43–61 (2001).
5. Hauser, M. & McDermott, J. *Nature Neurosci.* **6,** 663–668 (2003).
6. Wiltermuth, S. S. & Heath, C. *Psychol. Sci.* **20,** 1–5 (2009).
7. Hagen, E. H. & Bryant, G. A. *Hum. Nature* **14,** 21–51 (2003).

STRUCTURAL BIOLOGY

Aerial view of the HIV genome

Hashim M. Al-Hashimi

A bird's-eye view of the higher-order structure of HIV-1's entire RNA genome reveals new motifs in surprising places. Structural biologists can now zoom in on these regions to explore their functions further.

The genome of RNA viruses, such as the human immunodeficiency virus (HIV; Fig. 1), folds to form higher-order structures with stems and loops that contain motifs directing various steps of viral replication. Structural biologists usually 'cut out' these motifs and zoom in to determine their three-dimensional structures in an attempt to further understand their function. On page 711 of this issue, however, Watts *et al.*[1] zoom out and provide an 'aerial view' of the secondary structure of the entire HIV-1 genome. Using an innovative technique, they identify functional RNA motifs in surprising regions and define principles that govern the organization of the structure of the HIV-1 genome.

The methods commonly used to obtain detailed atomic-resolution images of biomolecules — nuclear magnetic resonance (NMR) spectroscopy and X-ray crystallography — have limitations that preclude analysis of the structure of entire RNA genomes. Both techniques rely on measuring the interactions between light and matter. In NMR spectroscopy, a solution containing the RNA of interest is immersed in a magnetic field and radiofrequencies are used to excite signals from its individual nuclei. As the size of the RNA under analysis increases, the signals become weaker and more congested, limiting structure determination of RNAs that are hundreds of nucleotides long.

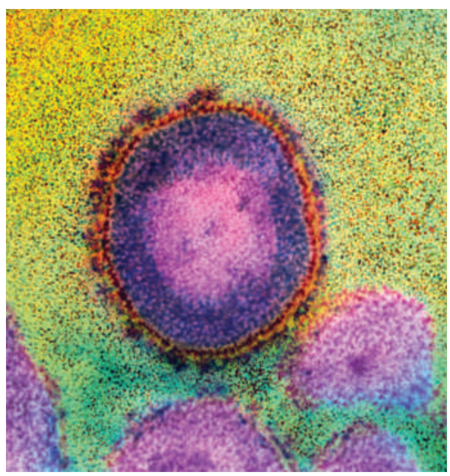
NIBSC/SPL

Figure 1 | HIV. Transmission electron micrograph of a section through HIV. The virus is surrounded by an outer coat (red), and the RNA genome is enclosed in an inner protein core (pink).

X-ray crystallography measures the diffraction of X-rays when they strike crystals