PALAEOANTHROPOLOGY

On the origin of our species

Gaps in the fossil record have limited our understanding of how *Homo sapiens* evolved. The discovery in Morocco of the earliest known *H. sapiens* fossils might revise our ideas about human evolution in Africa. SEE LETTERS P.289 & P.293

CHRIS STRINGER & JULIA GALWAY-WITHAM

Modern *Homo sapiens* share certain skeletal features that can also be recognized in fossil remains. These include a high, rounded braincase (the part of the skull that surrounds the brain), a small face tucked beneath it, and small, separated brow ridges (bone ridges above the eye socket). Our understanding of episodes in human evolution is mainly based on fossils and the available DNA. However, gaps in our knowledge remain about when and where *H. sapiens* evolved from ancestral humans within the genus *Homo*. On page 289, Hublin *et al.*[1] report the earliest known *H. sapiens* fossils, and present an analysis of the size and shape of these remains. Accompanying dating evidence is provided by Richter *et al.*[2] on page 293. The fossils, excavated with associated stone tools, provide crucial information about early steps in the evolution of *H. sapiens*.

Fossil remains indicate that early modern *H. sapiens* were present in Africa from about 200,000 years ago[3], and these individuals had an anatomy similar to that of humans today. However, DNA analyses of living people and fossils[4] suggest that our lineage diverged from that of our close relatives, the Eurasian Neanderthals and Denisovans, more than 500,000 years ago — considerably earlier than the first recognizable early modern *H. sapiens*. This could imply that earlier members of the *H. sapiens* lineage existed that had features pre-dating the emergence of the full suite of modern skeletal traits, and that instead had a preponderance of archaic (primitive), rather than modern, features. Until now, it has been difficult to identify such fossils.

Human fossils[5] (Fig. 1) were recovered from Jebel Irhoud, Morocco, in northwest Africa, in 1961 and 1962, alongside stone tools described as 'Mousterian', a name given to artefacts associated with Neanderthal sites. Given the popular view at the time that modern humans had evolved from Neanderthal ancestors (a now falsified idea), these fossils were called African Neanderthals. They were estimated to be about 40,000 years old[6]. Size and shape analyses of the fossils in the 1970s[7] indicated that one skull had a facial structure that was quite distinct from that of Neanderthals and more closely resembled that of *H. sapiens*. However, because it was thought to be a comparatively young fossil, it was not considered as a potential ancestor of later *H. sapiens*[7].

A child's jaw was found at the site in 1968, and analysis of the teeth indicated a modern-looking growth pattern[8]. This was significant because modern humans mature more slowly and over a longer period than was the case for archaic humans such as *Homo erectus* and Neanderthals. Furthermore, this specimen was dated to approximately 160,000 years ago[8,9]. Because more-modern-looking human fossils had been found in East African sites of similar age[10], the view persisted that the Jebel Irhoud fossils were marginal in their location in Africa and peripheral to the origins of *H. sapiens*.

Figure 1 | Skull-shape differences. Structural differences in ancient skulls can illuminate evolutionary steps. Replica casts of the original skulls are shown. **a**, A skull found in Sima de los Huesos, Spain, that is around 430,000 years old[12] is thought to represent an early form of Neanderthal. The Sima cranium exhibits some traits observed in more-recent Neanderthals, such as the characteristic Neanderthal brow-ridge shape, but also retains some more ancestral features not seen in later Neanderthals, such as a broader face and smaller average brain size. **b**, An approximately 60,000–40,000-year-old skull[16] from La Ferrassie, France, is an example of a late Neanderthal. **c**, Hublin *et al.*[1] and Richter *et al.*[2] report approximately 350,000–280,000-year-old fossils from Jebel Irhoud in Morocco that could represent an early stage in *Homo sapiens* evolution. The facial shape of a Jebel Irhoud fossil previously discovered at the site[5] shows similarities to the structure of more-modern humans, such as the presence of delicate cheekbones. However, the shape of the braincase (the section of the skull enclosing the brain) is archaic in form, and has an elongated shape that is less globular than the structure of more-modern *H. sapiens*. **d**, An approximately 20,000-year-old *H. sapiens* fossil[16] from Abri Pataud, France, has a globular braincase. Scale bar, 5 cm.

Figure 2 | Jebel Irhoud, Morocco. A view of the site studied by Hublin *et al.*[1] and Richter *et al.*[2]. When the site was occupied by early humans, it would have been a cave, but the covering rock and much sediment were removed by work at the site in the 1960s.

The Jebel Irhoud excavations (Fig. 2) reported by Hublin *et al.* and Richter *et al.* have uncovered additional stone tools and human fossils, including a partial skull and a lower jaw. Analysis of these findings, along with fossils recovered during the 1960s, has allowed at least five individuals to be identified. These fossils accumulated in a layer dated to about 350,000 to 280,000 years old by the authors, who tested flint artefacts and a human tooth. Thanks to improvements in dating techniques, particularly in luminescence dating, this layer, from which all the specimens had been excavated, is now revealed to be approximately twice as old as previously thought.

The tools the authors discovered are assigned to the Middle Stone Age (about 300,000–40,000 years ago), and were found with fauna showing evidence of human modification and charcoal, perhaps indicating controlled use of fire. Similar Middle Stone Age artefacts have been described in southern and eastern African sites, although those artefacts are consistently younger than the ones from Jebel Irhoud. Given the secure dates for the fossils and tools, the Jebel Irhoud site represents the earliest known association of *H. sapiens* and artefacts from the Middle Stone Age. The Sahara Desert in northern Africa is inhospitable today, but faunal evidence and modelling of ancient climates suggest that there were times when it could have been crossed[11], possibly enabling humans and their technologies to migrate across the continent. Alternatively, Middle Stone Age technologies might have arisen independently in multiple locations in Africa.

Hublin *et al*. used a shape-analysis statistical technique to compare the excavated fossils with those of ancient human relatives dated to between 1.8 million and 150,000 years ago, modern *H. sapiens* fossils from the past 130,000 years and Neanderthals. Facially, Neanderthals and most of the other fossil humans were clearly distinguishable from the Jebel Irhoud specimens, which were most similar to modern *H. sapiens*. The lower-jaw fossil from Jebel Irhoud also showed the greatest shape similarity to the jaw of modern *H. sapiens*, although it is much larger. The Jebel Irhoud material showed some structural variation, however, particularly in brow-ridge size, which is possibly related to within-species sex differences.

The Jebel Irhoud braincases retained some archaic features, such as an elongated shape and low height when compared with the braincases of *H. sapiens* fossils from within the past 130,000 years. Their external braincase shape was intermediate between that of archaic and more-modern-looking fossils, but was most similar to the late archaic *H. sapiens* skull from Laetoli in Tanzania[10] and the early modern *H. sapiens* skulls from Qafzeh in Israel[10]. Their internal braincase shape was distinctive. Perhaps it represents a structure near the beginning of the trajectory that led to the evolution of the globular brain shape characteristic of *H. sapiens* during the past 130,000 years[1].

We agree with Hublin and colleagues that the Jebel Irhoud fossils now represent the best-dated evidence of an early 'pre-modern' phase in *H. sapiens* evolution. These specimens probably constitute an early representative of the *H. sapiens* lineage that could illuminate the evolution of our species in a way equivalent to how the early Neanderthal Sima de los Huesos fossils[12] from Atapuerca in Spain have provided insight into the development of Neanderthals.

The authors suggest that the Jebel Irhoud fossils could aid our understanding of *H. sapiens* evolution across the whole of Africa. The facial shape of two skulls looks like a larger version of that found in *H. sapiens* today, and Hublin and colleagues make comparisons with the approximately 260,000-year-old Florisbad fossil from South Africa[10], often assigned to early *H. sapiens*. However, it seems increasingly probable that the delicate face of modern humans is inherited from non-*sapiens* ancestors in our family tree[10]. If so, such similarities between the Irhoud and Florisbad fossils could be parallel retentions of primitive ancestral features, rather than indications of kinship across Africa. We currently lack data about human connections around and across the Sahara at this time, and it is not known how isolated the Jebel Irhoud population would have been. Moreover, similarities between the Jebel Irhoud material and fossils[13,14] from Zuttiyeh and Tabun in Israel are a reminder that corridors on the African periphery 300,000 years ago might have periodically linked northern Africa and western Asia.

Hublin and colleagues suggest that clear-cut boundaries in *H. sapiens* evolution, such as the descriptions of fossils as 'archaic' or 'anatomically modern', are likely to fade as the fossil record improves. They are probably right, although their evidence adds to the picture of an extended temporal overlap of archaic and more-modern-looking forms across the continent that includes the dating of the primitive species *Homo naledi* in South Africa to about 300,000 years ago, as reported[15] last month. Perhaps additional dating studies will clarify the extent of the overlap and the processes that might have led to the evolution of modern humans. The authors propose that the globular brain shape of present-day humans could have evolved comparatively recently, making this a potential defining characteristic of human modernity. Given the likelihood that both brain size and shape evolved independently and in parallel along the Neanderthal and *H. sapiens* lineages over a period of at least 400,000 years, this might also imply that cognitive differences could have developed between the two species during that time. ■

Chris Stringer *and* **Julia Galway-Witham** *are in the Department of Earth Sciences, Natural History Museum, London SW7 5BD, UK.*
e-mail: c.stringer@nhm.ac.uk

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OPTICAL PHYSICS

One ring to multiplex them all

High-speed communication systems that use optical fibres often require hundreds of lasers. An approach that replaces these lasers with a single, ring-shaped optical device offers many technical advantages. See Letter p.274

VICTOR TORRES-COMPANY

Optical-fibre communication systems form the backbone of the Internet. Current systems rely on a technology called wavelength-division multiplexing to transmit digital information at high speeds. On the transmitter side, this technology combines (multiplexes) many optical channels into a single optical fibre. Each channel uses a laser of a different frequency, and hundreds of lasers are typically needed to occupy the bandwidth available in a fibre-optic link. On page 274, Marin-Palomo *et al.*[1] demonstrate that all of these lasers can be replaced by a single light source known as a microresonator frequency comb — a development that could lead to extremely fast data transmission.

A microresonator frequency comb is an optical device that allows light of many optical frequencies to be generated in a micrometre-scale platform (Fig. 1). Tobias Kippenberg, one of the current paper's co-authors, helped to pioneer this technology about a decade ago[2]. The device essentially consists of a light source, called a pump laser, and a microresonator — a set-up also known as an optical cavity, which is used to trap light at certain 'resonance' frequencies. The frequency of the pump laser is closely tuned to a particular resonance of the cavity, and for microscale low-loss cavities, the light is highly confined. The authors made their cavity from a nonlinear material, which allowed the photons from the pump laser to be converted into photons of different frequencies[2].

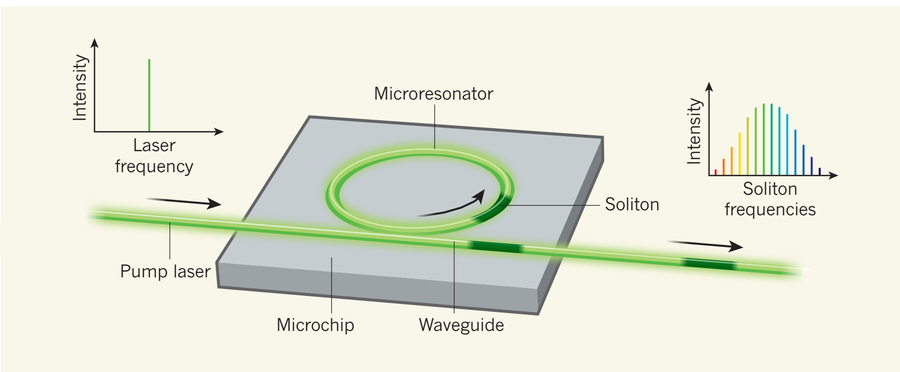

Figure 1 | Optical-fibre communications using a single laser. Marin-Palomo *et al.*[1] report a light source for simplifying data transmission through an optical fibre. Their device consists of a microchip containing a ring-shaped optical system called a microresonator and a waveguide — a structure that directs the propagation of light. The microresonator confines light at certain frequencies known as resonances. By tuning the frequency of a 'pump' laser to one of these resonances, the authors show that a sequence of short optical pulses called solitons can be produced. The optical spectrum of these solitons is a set of evenly spaced frequency lines, each of which can be used for an individual optical channel carrying an independent data stream. The authors control the number of channels by precisely engineering the dimensions of the microresonator, enabling them to generate more than 90 frequency lines from a single device. The quality of these signals is sufficiently high to achieve a data-transmission speed of more than 50 terabits per second (1 terabit is 10^{12} bits). The black arrows indicate the direction of light propagation.

Under the right conditions, the new optical frequencies are phase-locked. This means that at certain times there is constructive interference between all the frequencies (the crests and troughs of the light waves reinforce each other), leading to a substantial build-up of optical power inside the cavity. The resulting waveform consists of a sequence of pulses known as dissipative Kerr solitons. The formation of these solitons in an optical cavity requires a fine balance between the properties of the cavity and the pulses themselves[3].

Although Marin-Palomo *et al.* are not the first to observe dissipative Kerr solitons in optical cavities[4], they are the first to use these light sources for optical communications. The authors manufactured their optical cavity using advanced microlithographic techniques. The cavity consists of a microresonator arranged in a ring-like structure (with a radius of 240 micrometres) that is made of silicon nitride, a widely used thermal insulator in the electronics industry. The authors carefully engineered the cavity's geometry to enable the generation of more than 90 optical frequencies from a single pump laser. These frequencies entirely cover two of the bands used for optical-fibre communications (the C- and L-bands), corresponding to a bandwidth of approximately 10 terahertz (1 THz is 10^{12} Hz). The authors can control the frequency spacing between the channels with a precision of approximately 200 kHz — a feature that, besides its uses in optical-fibre communications, offers prospects for molecular spectroscopy[5].

Marin-Palomo and collaborators report a series of impressive system-level demonstrations, whereby the individual channels are multiplexed to yield a data-transmission rate of more than 50 terabits per second. The current transmission-speed record[6] is 2,150 terabits per second, but involves a special type of optical fibre and a different kind of laser frequency comb. The key aspect of the authors' microresonator comb is that it achieves an astonishing performance in a microscale platform. With recent developments in 3D photonic integrated circuits[7], one can start to dream about combining all of the necessary optoelectronic components of a comb-based wavelength-division-multiplexing system, as required for practical applications.

One concern when generating many frequency components from a single laser is the amount of power that can be obtained per channel. A fundamental drawback with

CORRECTION

The News & Views article 'Palaeoanthropology: On the origin of our species' by Chris Stringer and Julia Galway-Witham (*Nature* **546,** 212–214; 2017) stated that at least five individuals were identified from human fossils uncovered in excavations reported by Hublin *et al.* (*Nature* **546,** 289–292; 2017) and Richter *et al.* (Nature **546,** 293–296; 2017). However, fossil samples uncovered during previous excavations were also used to identify the individuals. The text of the News & Views article has been amended online.