concentration during exposure. Our spatial resolution of 120 nm is superior to that achieved by conventional rapid-laser prototyping and by conventional TPA fabrication[1–8] (smaller voxels can be formed, but it is difficult for isolated voxels to appear in the same scanning electron micrograph; in an actual fabrication, the spatial resolution may be better than 120 nm).

As an example of subdiffraction-limit fabrication, we produced a micro-oscillator, which must be the smallest functional micromechanical system produced (note that the microspring shown in Fig. 2a, b has a spiral diameter of only 300 nm). To operate such a minute spring, we converted it into an oscillator by fixing one end to an anchor attached to a glass substrate and polymerizing a bead (diameter, 3 μm) at the other end. We used laser-trapping force[11,12] to capture the bead, pulled the spring (Fig. 2b), and then released it from its displacement (Fig. 2c, inset) to set the vibration in motion (see movie in supplementary information).

An 820-nm, 19-mW laser offered a trapping force of about 3 piconewtons, which is equivalent to a $20g$ acceleration of the bead, where g is the acceleration due to gravity. However, because of the large specific surface of the oscillator, viscosity heavily damped the oscillation. We assume that the damping force is proportional to the velocity of the bead movement, $f_{\mathrm{vis}} = 6\pi\eta rv$ (Stokes' law), where η (1.084×10^{-3} pascals per second at 25 °C) is the liquid viscosity and v is the bead velocity. The spring damping oscillation can be expressed as $md^2x/dt^2 = -kx - 6\pi\eta r(dx/dt)$, where m (1.6×10^{-14} kg) is the bead mass and k is the spring constant to be determined. Figure 2c shows the bead displacement during spring restoration against time, from which the spring constant was deduced to be 8.2 nN m^{-1}. Such soft springs are directly applicable to the investigation of the mechanical properties of micro-objects.

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Supplementary information is available on *Nature*'s website (http://www.nature.com).

Sex determination

Viviparous lizard selects sex of embryos

No one suspected that temperature-dependent sex determination (TSD)[1–3], whereby the sex of embryos depends on the temperature at which they develop, might occur in viviparous (live-bearing) reptiles, because thermoregulation in the mother results in relatively stable, raised gestation temperatures. But here we show that developing embryos of the actively thermoregulating viviparous skink *Eulamprus tympanum* are subject to TSD, offering the mother the chance to select the sex of her offspring and a mechanism to help to balance sex ratios in wild populations.

Sex determination is the programmed cascade of events through which an undifferentiated gonad develops into a testis or an ovary. In vertebrates, sex is determined either by a genotypic mechanism at the time of fertilization, which depends only on genetic factors, or by environmental factors that act after fertilization. Species that are subject to TSD provide an example of the latter mechanism and usually lack heteromorphic sex chromosomes. Reptiles rely on either temperature or genetic factors to influence the sex of their offspring[4].

E. tympanum is a medium-sized scincid lizard found in high-elevation habitats in southeastern Australia, with a litter size of one to five young[5]. As no species within *Eulamprus* has detectable heteromorphic sex chromosomes, we investigated whether *E. tympanum* might be subject to TSD. We maintained mothers at different laboratory temperatures and used palpation of the hemipenes[6] and histology of neonatal gonads[7,8] to establish sex. To our surprise, we discovered that gestation temperature has a highly significant effect on sex ($P < 0.001$), with warmer temperatures giving rise to male offspring (Fig. 1).

Active thermoregulation by pregnant viviparous lizards distinguishes the thermal environment of development from that in oviparous species. A combination of active thermoregulation and TSD provides the female lizard with the opportunity to select the sex of her offspring. In the laboratory, all females provided with unlimited conditions for thermoregulation maintained body temperatures of 32 °C and produced exclusively male offspring. Equal sex ratios resulted from natural gestation in two field seasons.

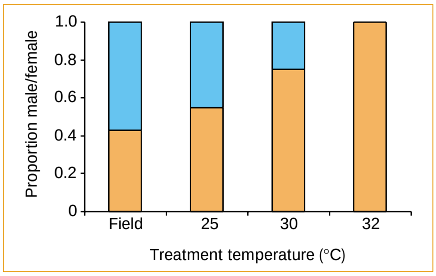

Figure 1 Influence of gestation temperature on the sex ratio of offspring of the viviparous lizard *Eulamprus tympanum*. Females maintained at 32 °C ($n = 21$) for the duration of pregnancy gave birth to exclusively male offspring ($n = 55$); those maintained at 30 °C ($n = 20$) gave birth to predominantly male offspring ($n = 58$; 75% were male); those maintained at 25 °C ($n = 11$) gave birth to offspring of both sexes ($n = 20$; 55% were male); those undergoing most of their gestation in the field ($n = 24$) also produced a mix of sexes ($n = 58$; 43% were male). Orange portions of bars represent male offspring; blue portions represent female offspring.

We do not understand the mechanism by which females select body temperature to give equal sex ratios in the field; the implication is that thermoregulatory conditions may be restricted. Alternatively, other factors, such as unbalanced adult sex ratios, may result in mothers selectively thermoregulating to produce offspring that help to balance the population sex ratio. A viviparous skink from Tasmania adjusts the sex ratio of its offspring according to the operational sex ratio of the adult population[9]; presumably, TSD provides the mechanism for selection of neonatal gender by the mothers. Our population of *E. tympanum* has an adult sex ratio that is not significantly different from unity[10] in the field, where they produce an equal sex ratio of neonates; however, our laboratory population was all female and produced all sons when given the opportunity to thermoregulate.

TSD may explain the fact that *E. tympanum*, like many other viviparous taxa, is restricted to alpine regions. The warmer temperatures further down the slopes would encourage production of exclusively male offspring and lead to the eventual extinction of those populations. A combination of alpine distribution and TSD is likely to be a problem in the event of rapid climate change or global warming, as these species may not be able to evolve rapidly enough to compensate[11]. For alpine species, there can be no retreat to cooler climates, so a rise in environmental temperature would result in increased production of males. Models predict a temperature rise of 4 °C by 2100 (ref. 12), which could seriously alter the sex ratio and lead to extinction of species such as *E. tympanum*.

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Ancient chronology

Astronomical orientation of the pyramids

Spence speculates that Egypt's pyramid builders found true north by using a plumb line: when the stars Kochab and Mizar were seen on the same vertical, one was facing north[1]. As evidence in support of this hypothesis, she points to the proposed interstar-line precession past the north celestial pole at a rate of 27′ per century (cy). We argue that a mathematical error affects this result, which when corrected points more strongly to a different pair of stars. This suggests that the conventional ancient chronology, instead of being compressed, may actually have to be expanded slightly.

The elementary error here is that the interstar-line drift of 27′ cy^{-1} occurs at an altitude of 30° (Giza's latitude), but to apply this drift to ground orientation, one must divide by cosine 30°. So, on the ground, 31′ cy^{-1} is the actual misorientation rate. Thus, the actual drift rate is significantly greater than Spence's empirical rate of orientation change of the pyramids themselves (the slope of line ***a*** in Fig. 4 of ref. 1).

When the pyramids were built, only two stars brighter than fifth magnitude lay anywhere near the pole: Thuban (3.65 mag, 1.5° distant) and the irregularly variable star 10 Draconis (4.5–5.0 mag). In 2627 BC, the pole was equidistant (1°) from each star, so the pole was the obtuse apex of a squat isosceles triangle formed between itself and the two stars. When both stars were at the same altitude, north was the direction bisecting them. (For more than a millennium after 2627 BC, there was no star brighter than 10 Draconis nearer to the celestial pole.)

Among several mechanical methods, north could have been determined in the dark by sighting the two horizontal stars simultaneously against a pointed post, the pyramidal top of an obelisk, or any similar object; when the observer can eclipse both stars simultaneously on opposite sides of the peak, the line from the observer to the peak points northwards. This simultaneous-eclipse method does not require the post or obelisk to be illuminated, making it simpler than Spence's plumb-line method; there is no easy way to see a plumb line at night while retaining the observer's night-vision acuity.

Although 10 Draconis is barely visible under modern industrial skies, it is recorded in all four large preclassical naked-eye star catalogues: Hipparchos, 128 BC; Ulugh Beg, AD 1437; Tycho, AD 1601; and Hevelius, AD 1661. Spence's Kochab and Mizar are indeed brighter than Thuban, but the eye-precision she assumes implies that the Kochab–Mizar line will confusingly pass into detectable and uncentred non-verticality in a matter of a few (perhaps ten) seconds. (Spence's suggestions of 5-year or 1–2-year precision for dating the pyramids imply a surveying precision of about 1′.) So Spence's method, although possible, would require agile quickness. In contrast, the midpoint between Thuban and 10 Draconis gives a ground orientation within 1′ of true north for over 5 minutes on either side of its transit. The very slow motion of these stars (and the small size of any potential orientation error from their use) is due to their close proximity to the celestial pole.

The precision of raw, naked-eye stellar observations can be significantly better than 3′, but we justify the utility of our two stars by reference to the scrupulous naked-eye catalogues of Tycho and Hevelius[2,3]. Tycho's raw data survive for both stars[4], eight observations in all: r.m.s. errors are 2′ for Thuban and 3′ for 10 Draconis. In Hevelius' catalogue, the equatorial coordinates of Thuban and 10 Draconis (his Draco stars 8 and 32) have great-circle errors of 1′ and 0′, respectively. Thus, the dimness of 10 Draconis was in itself no barrier to accurate measurement of its position in pre-industrial times, and such precision could easily be replicated for an azimuth observation, even using simple instruments, by positioning the observer's eye at a large enough distance from the eclipsing post.

In 2627 BC, the misorientation associated with our obvious and straightforward method was null but precessionally increasing at 27.4′ cy^{-1} in azimuth, which matches Spence's 28′ cy^{-1} empirical rate much more closely than her Mizar–Kochab method (31′ cy^{-1}). This implies dates of 2638 BC for Khufu's pyramid and 2607 BC for Khafre's. (Error estimates could be 2–10 years, depending on assumptions regarding the builders' craftmanship.) These dates are a few decades outside the conventional ranges Spence cites[5]. But our implied date for the ascension of Khufu (2640 BC) is twice as near to a conventional boundary as Spence's 2480 BC (Table 1 in ref. 1). Back-disparity makes more sense than Spence's very forward dates, when current orthodoxy is based on king lists that are "seldom complete"[1].

It seems odd that either method would have been used before the time when it was correct. Because the best pyramid orientations occur for the two greatest pyramids, this could simply indicate that engineering science peaked at the time of Khufu–Khafre. Thuban passed within 0.1° of the pole in 2800 BC, a chance event that may have stimulated the historical flowering of celestially based surveying, which was unquestionably used for the pyramids built soon after that at Giza. A stellar explanation of the Giza pyramids' location (in latitude) has already been proposed[6].

Latitude (but not orientation) could be found in a single night near the time of the winter solstice anywhere close to 2600 BC by bisecting Thuban's circumpolar semicircle, because this star was within 10° of the equinoctial colure for centuries after 2700 BC. Because 10 Draconis was within 10° of the solstitial colure for three decades either side of 2613 BC, on the same or any neighbouring night, orientation might also have been found by bisecting the circumpolar arc of 10 Draconis. Although twilight would have cut the arc to slightly less than 180°, this still would have been adequate for the purpose. By coincidence, both orientation methods that depended on 10 Draconis were most accurate at virtually the same time: 2627 BC for the Spence interstar method applied to Thuban and 10 Draconis, and 2613 BC for the 10 Draconis arc method.

Before Spence's proposal[1], a possible connection was suggested[7] between precession and the pyramids' misorientation, but the horizon-based observations proposed would be too prone to difficulties with high refraction, uneven topography, dip and atmospheric extinction to be practical. So, despite a few disagreements, we welcome Spence's creativity in pointing out the possibilities of orienting the pyramids by observing northern stars higher in the sky and near to the meridian, which doubly minimizes corruption by refraction.

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Spence replies — Rawlins and Pickering have correctly identified an error: I should indeed have divided the calculated figures for the distance of the line between β Ursae Minoris and ζ Ursae Majoris from the pole