several occasions as well. For instance, the unadorned wings of the most famous species in the genus, *D. melanogaster*, derive from a distant spotted ancestor.

Prud'homme *et al.* took advantage of this chequered history to study the genetic basis for convergence. To validate their approach, they examined two spotted species that derive from the same spotted ancestor and whose spots would therefore be expected to share the same genetic basis. Their previous work with one of these species, *D. biarmipes*, identified mutations in a part of the regulatory region of the *yellow* gene (called the spot element) as responsible for one origin of the wing spot[4]. This gene encodes an enzyme involved in pigment synthesis[5], and mutations affecting its expression have contributed to the evolution of certain pigmentation patterns in other fruitfly species[6]. During wing development in *D. biarmipes* and *D. elegans*, the *yellow* gene is expressed specifically in a region that prefigures the black spot of the adult wing, implying that there is probably a similar underlying genetic basis for the spots in these species.

So much for similarity by common descent; what about convergent similarity? The repeated spot losses and gains turn out to have a surprisingly similar genetic basis. In two independent cases of spot loss, represented by *D. gunungcola* and *D. mimetica*, different sets of mutations in the spot element of the *yellow* regulatory region abolish expression of *yellow* specifically in the spot region of the wing. The spot element comprises just a few hundred of the roughly 180 million base pairs of the fruitfly genome, making this a 'similar' genetic basis by any reasonable criterion.

Even more striking is the case of *D. tristis*, a species that underwent an independent, convergent acquisition of the wing spot. Here, the spot regulatory element does not harbour the mutations responsible for spot production in this species. Instead, Prud'homme *et al.* discovered a different regulatory element that activates *yellow* expression in the spot region of the wing. The convergently similar wing spots of *D. biarmipes* and *D. tristis* are therefore the product of mutations in the same gene, but involve co-option of different regulatory elements.

These results hint at generalities in the genetic basis for anatomical evolution. The spot gains and losses all result from mutations that affect the expression of the gene, reinforcing the notion that such regulatory mutations constitute a major component of the genetic basis for anatomical evolution[7,8]. The fact that the resulting anatomy is so similar conveys a more subtle and interesting message. The developing wings of fruitflies are patterned by signalling molecules that activate the expression of transcription factors. These proteins in turn activate the spatially restricted expression of genes such as *yellow*, which encode proteins that convert the pattern into anatomical structures. The spatial scaffold for producing a spot

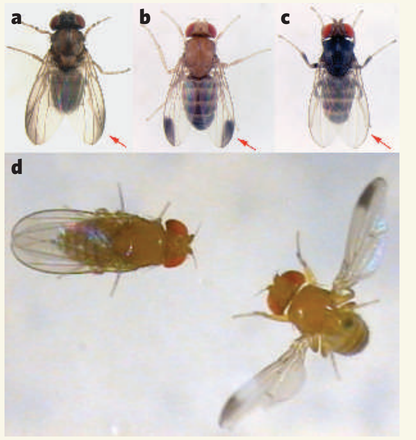

Figure 1 | Spots on flies. a–c, The wing spots on male flies of the *Drosophila* genus. *Drosophila tristis* (**a**) and *D. elegans* (**b**) have wing spots that have arisen during convergent evolution. *Drosophila gunungcola* (**c**) instead evolved from a spotted ancestor. **d,** Males wave their wings to display the spots during elaborate courtship dances. (Photographs courtesy of B. Prud'homme and S. Carroll.)

is therefore present even in species lacking spots[9]. If, through random mutation, a gene acquires a new binding site for a transcription factor in its regulatory region[10], its expression is likely to change in ways that reflect the existing spatial scaffold.

This explains similarities in the size, shape and position of independently evolved spots. But why was *yellow* involved each time, given that many fruitfly genes affect pigmentation? The authors argue that a gene already expressed in the wing (such as *yellow*) is much more likely to be recruited to produce a new wing pattern through a small number of mutations. This is because it already possesses regulatory elements that interact with some of the transcription factors required to produce the new pattern.

Of course, none of this explains why mutations that generate or erase spots become established within fruitfly populations. The reason for that seems to be sex. Male fruitflies woo potential mates using elaborate courtship dances that involve a good deal of wing waggling (Fig. 1d). Accordingly, shifts in mate-choice preferences among females could drive rapid changes in wing patterns[11,12]. Perhaps because it is already expressed in wings, *yellow* has repeatedly provided genetic variation that produces anatomical differences, making it central to the diversification of fruitfly coloration. ■

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ASTRONOMY

Trouble at first light

Piero Madau

The question of how much light the first stars produced is fundamental to models of the Universe's development. But observations have so far failed to agree: is the answer a lot, or not very much at all?

On page 1018 of this issue, Aharonian *et al.*[1] report the detection of copious high-energy γ-ray emission from two 'blazars' — a class of active galaxy — around 2 billion light years from Earth. This observation indicates that such radiation can travel largely unimpeded through the cosmos, and implies that the infrared glow of the first stars in the Universe and their remnants is fainter than previous measurements had led us to believe. If true, that could influence our ideas of how and when the first structures in the Universe evolved.

The formation of structure in the Universe is believed to proceed hierarchically, with smaller galaxies merging, through the action of gravity, to build more massive ones. But the timing and sequence of the events through which the very first galaxies and stars formed remain largely unknown. According to current theories, the first dwarf galaxies hosted metal-free stars over a hundred times more massive than the Sun. These stars shone intensely for only a few million years and then either blew themselves apart in gigantic supernova explosions, or collapsed to form the first massive black holes.

Astronomers have long been rummaging through the Universe for tell-tale signs of these dramatic beginnings. When the first stars ignited, they emitted large numbers of photons at ultraviolet wavelengths. These photons 'reionized' the surrounding atomic hydrogen gas that had formed as the Universe cooled. Just last month, astronomers using NASA's Wilkinson Microwave Anisotropy Probe (WMAP) reported the latest detection of photons produced soon after the Big Bang. Their data show that these 'cosmic microwave background' photons became polarized (tending to oscillate in only one direction perpendicular to their line of travel) by scattering on free electrons in the early Universe. The level of polarization allows the era of reionization to be pinpointed to some 400 million years after the Big Bang, when the Universe was just 3% of its present age[2].

So how much of the background light that we see comes from the first stars? As the Universe aged and expanded, part of the ultraviolet radiation emitted by these stars was absorbed again by re-formed atomic hydrogen. Lower-energy ultraviolet light escaped this fate, but was stretched to longer, redder wavelengths. Therefore, although the early stellar populations were twinkling so long ago that current telescopes cannot detect them, their combined energy output is recorded in diffuse light that reaches Earth in the near-infrared region of the electromagnetic spectrum, at wavelengths of a few micrometres. Resolving this infrared glow is, however, a daunting task, because many other celestial sources — among them older stars in closer galaxies, active galactic nuclei known as quasars, and the bright foreground sources in the Milky Way and the Solar System — emit radiation at similar wavelengths.

Nevertheless, several groups have claimed to have found the footprints of baby galaxies at near-infrared wavelengths, using data from NASA's Cosmic Background Explorer (COBE)[3–5] and Spitzer Space Telescope[6], and Japan's Infrared Telescope in Space (IRTS)[7]. Their evidence comes in two forms. First, there is an excess signal above the combined emission of normal foreground galaxies that would require energetic events to have occurred in the early Universe. Second, the very uneven distribution of the radiation could arise from the spatial clustering properties of primordial stellar systems.

But rather than helping to decipher the epoch of cosmic first light, such observations have in fact created another puzzle. Simply stated, the dawn of galaxies seems to be too brilliant: the excess signal outshines the cumulative emission from all galaxies between Earth and the extremely distant first stars. If primordial sources are to account for all of this infrared radiation, current models of star formation in the young Universe look distinctly shaky. Too many massive stars ending their brief lives in a giant thermonuclear explosion would, for instance, eject large amounts of heavy elements such as carbon and oxygen into space, polluting the cosmos very early on and altering for ever the composition of the raw material available for second-generation stars. But if the first-generation stars were to collapse to massive black holes instead, gas accretion onto such black holes would produce large amounts of X-rays. Both variants seem to be in conflict with current observations[8–10].

Figure 1 | Eyes to the light. The four HESS telescopes in the veldt of central Namibia.

Enter Aharonian and colleagues[1], and their measurements of teraelectronvolt (TeV) γ-ray photons from blazars. These photons, which carry 10^{12} times more energy than visible light, interact with near-infrared photons through the quantum-mechanical process of electron–positron pair creation. Through this process, most of the TeV photons are absorbed long before they reach Earth. The observed level of γ-ray attenuation can, therefore, be used to estimate indirectly the energy density of infrared starlight present in intergalactic space.

The authors' observations were made with the High Energy Stereoscopic System, HESS, inaugurated in Namibia in 2004 and operated by a collaboration of scientists from nine countries. HESS uses four large telescopes (Fig. 1) arranged at the corners of a 120-metre square to detect the faint flashes, lasting only a few billionths of a second, of blue 'Cherenkov' light emitted when a high-energy γ-ray hits the atmosphere. Up to four images are combined to determine the direction of the γ-ray and the energy it deposits in the atmosphere.

Since June 2004, HESS has accumulated more than 80 hours of observations on two blazars. The γ-rays emitted by these most distant known sources have energies between 0.2 and 3 TeV; infrared radiation at wavelengths longer than 1 micrometre absorbs γ-ray photons of energy greater than 0.7 TeV. So, if such γ-rays were propagating through a dense sea of infrared photons, as implied by previous measurements[3–7], the spectra of the two blazars recorded by HESS would reveal evidence of strong, energy-dependent attenuation. But Aharonian *et al.*[1] show that intergalactic space is more transparent to γ-rays than would be expected if an infrared background excess existed. Remarkably, the attenuation in the HESS images seems consistent merely with the integrated infrared output from resolved foreground galaxies, together with the total extragalactic light produced by second-generation stars according to recent theoretical calculations[11].

What is the cause of the discrepancy between the HESS data and previous results? Aharonian and colleagues point out that their interpretation of the HESS results relies on the assumption that the intrinsic γ-ray spectra of the two active galaxies are not at odds with current models of blazar behaviour. Further high-energy observations of blazars at different cosmological distances should settle this issue. But it seems unlikely that they will be able to supply the fine-tuning required to make the HESS data consistent with the previously reported excess of infrared background light.

The distribution of this excess infrared component over different wavelengths is almost identical to that of sunlight reflected from local interplanetary dust clouds[12]. It is therefore conceivable that not all of the foreground emission has been subtracted from the diffuse-sky maps, and the excess may not be extragalactic after all. On the other hand, the fluctuations detected in highly sensitive images taken with the Infrared Array Camera onboard Spitzer[6] do not change between observations performed six months apart, and changes would be expected if their origin was zodiacal light within the Solar System.

Whatever the final resolution of the mystery concerning the signature of the first stars, the HESS findings[1] will stir much debate among cosmologists. They are likely to spark further attempts to glimpse the crucial early stages of the galaxy formation process. ■

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