increasing fitness (the function being selected for — drug resistance in this instance). This argument assumes that mutations that have been selected because they increase fitness in one sequence context will also tend to do so when swapped into another sequence context. The modularity need not be perfect to give sexual selection a distinct advantage.

Sexual PCR requires sequences that are related enough to swap information. The degree of relatedness can be quite modest: using a polymerase that works at low temperature (and had to be replenished in each replication cycle), Stemmer created recombinants between genes whose segments of uninterrupted identity were only 4.1 bases long on average[4]. Still, recombination in a population of random sequences would be restricted to subfamilies of similar sequences — families that would be vanishingly small in the initial stages of *in vitro* evolution. If, moreover, the sequences are short, as in random peptide libraries, there may not be enough modularity for sex to be an advantage anyway. So I think the most plausible field of application of the new technique is just the type of project reported here[5]: selection of a new function in an evolving population of related, gene-sized molecules. □

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GALAXY FORMATION

Dust in the distance

R. D. Joseph

THE formation and early evolution of galaxies is one of the fundamental unsolved problems of astrophysics. Theories flourish almost unchecked by observational constraints, because objects seen at early times are very distant and therefore faint. So detecting any property of a galaxy at high redshift is an achievement and is likely to provide a new insight into some aspect of galaxy formation and evolution. One such measurement is reported by Dunlop *et al.* on page 347 of this issue[1]. They have detected a signature of dust in the radiogalaxy 4C41.17 — at a redshift of 3.8, the most distant galaxy known.

One of the difficulties besetting researchers in this area is just to find and identify galaxies at cosmological distances. Here, powerful radiogalaxies come into their own, since by virtue of their large intrinsic luminosities they can be detected at great distances. Nearby examples of such radiogalaxies always turn out to be elliptical galaxies, and so high-redshift radiogalaxies might well be the progenitors of present-day ellipticals. A number of astronomers have even argued that this or that radiogalaxy was a 'primaeval galaxy', that is, a galaxy in which the first generation of star formation is taking place[2,3]. On the other hand, there seems to be considerable diversity of properties among the dozen or so high-redshift radiogalaxies studied[4] — partly, no doubt, because the high-radioluminosity phase is brief compared with the evolutionary timescale for massive stars.

Dunlop *et al.* chose to study 4C41.17. At a redshift of 3.8 this is the most distant object yet discovered that has optical properties apparently dominated by light from stars (quasars at greater redshifts are known). Using the James Clerk Maxwell Telescope on Mauna Kea, they successfully detected radiation emitted by 4C41.17 at a wavelength of 800 micrometres. They argue convincingly that this is thermal radiation emitted by dust at a temperature of about 50 K, and they show that this implies a dust mass in the galaxy of about 300 million solar masses. By fitting a typical 'infrared galaxy' spectrum to these data (in the rest frame) they infer an infrared luminosity of at least 5×10^{13} times that of the Sun. This is a prodigious luminosity, rivalling those of the most luminous quasars. Dunlop *et al.* have apparently identified the second-most luminous infrared galaxy known.

The IRAS galaxy F10214+4724, at a redshift of 2.3, retains its title as the most luminous galaxy known[5], and it is interesting to compare the properties of the two. The radiogalaxy 4C41.17 is a factor of six less luminous and has a third the mass of dust. Measurements of carbon monoxide emission permit determination of the mass of molecular dust in the IRAS galaxy, and imply a gas-to-dust ratio of 400. If one assumes this ratio is applicable to 4C41.17, this gives a mass of molecular gas for the radiogalaxy about a factor of three less than that of F10214+4724. Thus in its infrared luminosity, dust content and inferred gas content, 4C41.17 seems to be less extreme and remarkable than F10214+4724 only by factors of about 3 to 5.

What is the energy source responsible for the extraordinary luminosities of these two galaxies? The two likely processes are either a burst of star formation or an active galactic nucleus (AGN). There is obviously an AGN in the centre of 4C41.17, but it is certainly not clear that this is the main source of the high-energy photons which are absorbed by the dust and re-radiated in the far-infrared (100–200 μm). Because of the large dust opacity in the centres of virtually all infrared-bright galaxies, it is difficult or impossible to be certain that one can view deep enough to see the highly broadened emission lines associated with an active nucleus if they were present. My own opinion, based on the apparently huge mass of molecular gas in both these objects, is that there is very likely to be a massive burst of star formation going on and that is probably the source of the infrared luminosities. If rapid star formation does cause most of the far-infrared luminosity in either of these galaxies, a star formation rate of 10^3 to 10^5 solar masses per year is required. This is enough to build a large galaxy in 10^7 to 10^9 years.

Are these objects, then, examples of the elusive primaeval galaxies, the Holy Grail of observational cosmology? I would suggest not, for there must already have been one generation of massive stars that have evolved off the main sequence and produced the heavy elements which make up the large masses of dust observed. On the other hand, the masses of molecular gas inferred to be present are a significant fraction of the stellar mass of a giant elliptical galaxy, so what we may be seeing in both cases is a late stage in the formation of a galaxy.

One of the limitations in using high-redshift radiogalaxies to investigate galaxy properties at early times has been that so few had been identified among the vast numbers of radiogalaxies known. Recently, however, it has emerged that selecting those radiogalaxies with an extremely steep radio spectrum is a good way to identify distant galaxies. With a much larger sample of high-redshift radiogalaxies, and the new generation of large telescopes and powerful infrared instruments, their study looks set to become an industry with considerable potential for providing information about the earliest phases of galaxy development. □

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