NATURE

100 YEARS AGO

... owing to the kindness of Dr. Hampson, we have been furnished with about 750 cubic centimetres of liquid air, and, on allowing all but 10 cubic centimetres to evaporate away slowly, and collecting the gas from that small residue in a gas-holder, we obtained, after removal of oxygen with metallic copper and nitrogen with a mixture of pure lime and magnesium dust, followed by exposure to electric sparks in presence of oxygen and caustic soda, 26.2 cubic centimetres of a gas, showing the argon spectrum feebly, and, in addition, a spectrum which has, we believe, not been seen before. ... it may be concluded that the atmosphere contains a hitherto undiscovered gas with a characteristic spectrum, heavier than argon, and less volatile than nitrogen, oxygen, and argon; the ratio of its specific heats would lead to the inference that it is monatomic, and therefore an element. If this conclusion turns out to be well substantiated, we propose to call it "krypton", or "concealed." Its symbol would then be Kr.

From *Nature* 9 June 1898.

50 YEARS AGO

The practice of the whalers is to try to catch the largest whales – the gunner who does this gains in reputation; but any whale is better than none, since the factory ships have to be filled with oil. Since the average length of the whales killed is decreasing, it must be concluded that either the larger whales are becoming more difficult to catch or that they have been pretty well killed off. The former assumption cannot stand, for against powerful modern catchers the bolting whale stands no chance. It must take frequent breaths while travelling at speed, remaining practically at the surface all the time, and so can be easily followed and run down. With regard to the latter assumption, the remarks made to me after the last Antarctic season by a very experienced whaler are pertinent. He told me that blue whales were not what they used to be, and that the enormous animals of past years were either extremely scarce or non-existent. ... The inevitable conclusion is that the larger animals have been killed off, and that the survivors do not live long enough to attain the great size of former years.

From *Nature* 12 June 1948.

Observational cosmology

Through a glass brightly

Andrew Blain

The record for the most distant object in the Universe is broken regularly, but the record for the object with the largest apparent luminosity has been much more durable, resting[1] with IRASF10214+4724 since 1991. But a new champion has emerged — as described by Irwin *et al.*[2] in a forthcoming paper, APM08279+5255 appears to be ten times more luminous.

F10214 was identified during a survey to measure the redshifts of galaxies detected using the IRAS satellite. IRAS was sensitive to the far-infrared thermal emission from grains of interstellar dust in the Milky Way and other galaxies. The dust is heated to between 20 and 100 K by the visible and ultraviolet light emitted by stars or active galactic nuclei (AGN), and re-radiates this energy in the far-infrared waveband. So the presence of dust decreases the visible and ultraviolet luminosity of a galaxy or AGN, and increases its infrared luminosity.

The most luminous IRAS galaxies mostly have redshifts of up to about 0.1, but F10214 was found to have the much larger redshift of 2.3. Sources with large redshifts are at great distances — the light observed from objects at redshifts 0.1 and 2.3 was emitted when the Universe was 85% and 17% of its present age, respectively. To be detectable at such a large distance, F10214 had to be about 100 times more luminous than its low-redshift counterparts, and so appeared to have a luminosity of approximately $3 \times 10^{14}\ L_{\odot}$ (a solar luminosity, $L_{\odot}$, is 3.9×10^{26} W). Taken at face value, this would be a very remarkable object. The excitement was tempered slightly when F10214 was found to be magnified by a factor of about 40 by the gravitational lensing[3] effect of a foreground galaxy[4]. Its true luminosity is only comparable to that of the most powerful low-redshift IRAS galaxies. Nevertheless, it provided a valuable case study as the first distant galaxy found to emit most of its energy in the far-infrared waveband, fitting in well with models of galaxy formation which predict large quantities of dust in early objects.

If F10214 surprised its observers, then APM08279 must have been a rude shock for Irwin *et al.*[2]. It was discovered during spectrographic observations made to measure the exact velocities of cool carbon-rich stars orbiting in the halo of the Milky Way[5]. APM08279, first thought to be a star, was recognized as a distant quasar, at a redshift of 3.87, because of the characteristic redshifted emission and absorption lines in its spectrum.

As bright as a star in the halo of our Galaxy, but at the outer edge of the observable Universe, APM08279 appears to be remarkably luminous. Its relative brightness in the APM and IRAS catalogues indicates that more than half of its power is emitted in the mid-infrared waveband, and its inferred luminosity is about $5 \times 10^{15}\ L_{\odot}$. On average, one IRAS source with the same apparent magnitude was detected per two square degrees of the sky — the area of about ten full Moons. No more than one in 10^4, and maybe as few as one in 10^6 of these sources, is expected to have a redshift greater than three[6], and so fewer than two sources like APM08279 would be expected in the whole sky.

But APM08279 is almost certainly gravitationally lensed by a foreground galaxy. Absorption lines in its spectrum show that our line of sight to the quasar intersects three

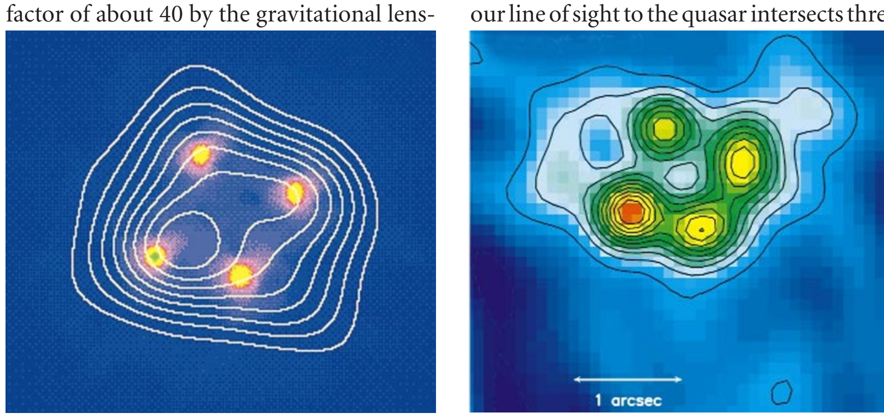

Figure 1 **The Cloverleaf. This quasar has been gravitationally lensed, by an intervening galaxy, into four separate images. As with the newly discovered ultra-luminous object APM08279+5255, the gravitational lensing makes the Cloverleaf seem much brighter than it really is. The optical emission** (left) **from the centre of the object heats surrounding dust, which re-radiates the energy in the sub-millimetre band** (right).

potential lensing galaxies. Furthermore, its optical image appears to be slightly elongated[2]. This can be explained if the source is a pair of almost equally bright lensed images with a separation of 0.33 arcsec, blurred into one by the atmosphere — exactly as expected for a strongly magnified quasar. When a correction is applied for the estimated lensing magnification, the source becomes fainter, and so less unusual.

The higher 0.1-arcsec spatial resolution of the Hubble Space Telescope should confirm or refute the lensing hypothesis. Another quasar, H1413+117 — 'the Cloverleaf', is lensed by an elliptical galaxy into four images of comparable brightness[7] (Fig. 1). The Cloverleaf is also a bright IRAS source, and has been observed in detail over a wide range of wavelengths. It is to be hoped that observations of comparable quality for APM08279, which is brighter than the Cloverleaf, will be available soon.

The identification of APM08279 is more strong evidence that luminous dusty galaxies and quasars exist in the distant Universe. Many more such sources should still be lurking unconfirmed in the IRAS catalogue[2]. In fact, it is quite plausible that IRAS sources as dusty and luminous as APM08279, but with more heavily obscured spectra similar to that of F10214, lie in the surveyed field[2], but were not observed because they are missing from the optically selected APM catalogue. Accounting for this class of source would increase the numbers of high-redshift, high-luminosity galaxies even further.

The existence of sources such as APM08279 is consistent with the results of the first direct systematic survey that is sensitive to very distant dusty galaxies and quasars[8]. This survey was carried out in the submillimetre waveband, to detect the redshifted radiation from distant dusty star-forming galaxies and quasars. Submillimetre-selected sources are almost all located at high redshifts, at which gravitational lensing is most likely to occur. It is difficult to build the sensitive instruments required for submillimetre surveys[9], but they are now becoming available[10], and the planned all-sky survey by ESA's Planck Surveyor satellite will be of particular interest. Planck Surveyor will not only map the cosmic microwave background radiation with unprecedented precision, but will also detect a large number of extremely distant and luminous gravitationally lensed galaxies and quasars[11]. The identification of APM08279 is an excellent omen for this systematic survey of the distant Universe. □

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Thermodynamics

Liquid landscape

Austen Angell

Supercooled liquids — that is, liquids at temperatures below their normal freezing point — can undergo a subtle transition to a microscopically fixed, yet amorphous state: a glass. The temperature of this transition depends on how quickly the liquid is cooled, so it has seemed more natural to describe the process in terms of kinetics, rather than some immutable thermodynamics. But on page 554 of this issue[1] Sastry, Debenedetti and Stillinger show how changes in the dynamic properties of glass-forming liquids[2,3] can be related to changes in the nature of the system's underlying energy landscape.

'Landscape paradigms' are used to describe the qualitative behaviour of complex systems[4]. In such systems there are many metastable states, and many possible transitions between the different states. The system's state is represented by a point which moves on or above a surface, according to rules decided by the problem under consideration. The types of system described by the landscape model range from economics and evolution, through neural networks, spin glasses and proteins, to molecular clusters and viscous liquids. For each problem, the height of the surface may correspond to a different parameter — 'fitness' is to be maximized for an evolving species, for example; and some energy is to be minimized for a system of molecules. For the latter, the landscape topology controls the kinetics[5], and the average energy of the minima visited at temperature T reflects the thermodynamics.

For viscous liquids and glasses, the system point depends on how a collection of N particles are arranged, because the system's energy is determined by the exact positions of all the particles. The energy landscape is a surface with $3N+1$ dimensions, and impossible to conceptualize properly. Nevertheless, a two-dimensional representation (Fig. 1a) is useful, and can illustrate the distinctions between liquid, crystal and glass.

In equilibrium, the liquid moves between minima in a region of energy determined by the temperature. When the temperature is increased, the system will spend most of its time 'higher up' on the energy landscape, gaining access to more possible states. This is in accordance with the principle that fixed-volume systems in equilibrium should minimize their free energy (the Helmholtz free energy $A = E - TS$, where E is the internal energy and S is the entropy). S is large when the number of states that the system can visit is large. The relation is that inscribed on Boltzmann's tomb, $S = k_B \ln W$ where W is the number of possible states (here, energy minima on the landscape; vibrational states equilibrate far more quickly, and so can be treated separately).

Perfect crystals occupy just one deep minimum, and melt in order to lower their free energy by gaining access to all the minima of the landscape — for melting at fixed volume, the entropy change TdS just balances the internal energy change dE. Glass-formers are liquids that fail to find their way back to the crystal minimum on cooling, and hence wander down among the myriad minima of the landscape as they supercool ('down'

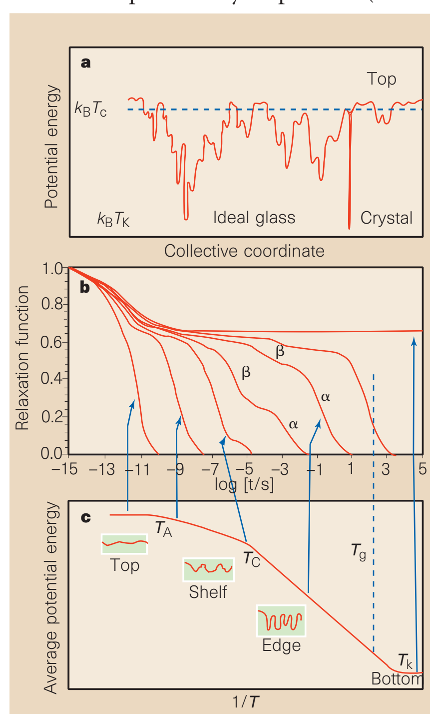

Figure 1 **Three angles on glass.** a, **In the energy-landscape depiction, the internal energy of a system depends on the configuration of all its particles (here simplified to one dimension).** b, **The relaxation function shows the approach to equilibrium over time.** c, **The average energy of the energy-landscape slice sampled at different temperatures, with an indication (in boxes) of the form of the minima in each energy range.**