sense that combining the responses to many antigens might be needed to achieve strong, sustainable and strain-independent protection. This is leading to renewed interest in whole-parasite approaches, so the time is ripe for Mueller and colleagues' report[1].

Mueller *et al.* have constructed the first *Plasmodium* parasite that cannot develop in the host's liver. For this, they knocked out the recently identified *UIS3* gene in *P. berghei* in rodent erythrocytes — the erythrocytic stages being the only ones that can be genetically manipulated. The gene is not essential during the parasite life cycle until the sporozoite reaches the liver. There, the mutant sporozoite penetrates hepatocytes normally, but fails to develop further. Inside cultured hepatocytes, most knockout parasites are rapidly eliminated at an early stage, unlike irradiated parasites, which persist for days[8]. However, mice immunized by injection of at least 30,000 knockout sporozoites in various 'prime–boost' regimens were protected against wild-type sporozoites injected one month after the last immunization. Follow-up of these mice will reveal whether this protection can last even longer.

This proof-of-principle study raises the question of whether genetically modified *P. falciparum* sporozoites could be used as a vaccine for humans. They would seem to offer at least once crucial advantage over irradiated sporozoites. Defined genetic mutations should generate safer and more reliably attenuated parasites, provided that they are constructed by a replacement ('double crossover') strategy, to avoid the possible genetic reversion associated with an insertion ('single crossover') approach.

On the practical side, the traditional view holds that a live sporozoite vaccine is unrealistic because of the technical and logistical problems associated with the production, storage and administration of parasite forms that can only be generated in mosquitoes. However, some have argued[9] that these difficulties may not be insurmountable, and that sporozoites collected from the salivary glands of laboratory-reared mosquitoes could be purified, freeze-stored in a way that does not affect their invasive capacity[10], and later injected beneath the host's skin. A vaccine dose of 10^4–10^5 sporozoites (equivalent to a thousand bites) has been proposed in the context of irradiated sporozoites[9], although this number seems rather low, even assuming that syringe- and mosquito-injected sporozoites are equally infective, which remains to be seen. Perhaps some genetically impaired liver-stage parasites will turn out to be better protectors than irradiated ones, and require fewer sporozoites to induce protection. Parasites blocked at different times in their differentiation might express distinct sets of antigens that result in distinct protection efficiencies.

Ultimately, assuming that the technical hurdles of producing a live sporozoite vaccine for mass immunization can be overcome, concerns about the safety of injecting humans with parasites that have been grown in human erythrocytes and mosquito cells will remain. There is the risk that other, unidentified pathogens might be delivered with the vaccine. It might be possible in the near future to produce infectious sporozoites from erythrocytic stages without needing mosquitoes[11]. But human erythrocytes would still be required for parasite multiplication.

Nonetheless, on the long road towards a live attenuated malaria vaccine, Mueller and colleagues' study[1] offers an encouraging step forwards, and may usher in an era of 'reverse vaccinology'. The production of other weakened parasites by reverse genetics might serve as new probes of host immune responses, and studies of the genes expressed in the modified parasites might hold the key to new sets of protective antigens. Thus, in addition to being candidates for live vaccines, attenuated parasites might aid the development of more potent subunit vaccines. ■

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Planetary science

Construction-site inspection

Alycia J. Weinberger

How do you build a planetary system? Astronomers are tackling the question by peering back in time at the gas and dust surrounding stars younger than our Sun.

A laboratory experiment in planetary formation would take perhaps a hundred million years to complete. Luckily, nature has been kind in providing some local analogues of the early nebula that formed our Solar System. These flattened structures of gas and dust around other stars are called circumstellar disks, and to look at disks ranging from a million years old up to the age of the Sun is to look at the planetary construction process. The challenge for astronomers is to make measurements in enough detail to allow comparisons with a Solar System whose present form we know well. Three papers[1–3], one in this issue, now provide new examples of how astronomers are facing up to that challenge.

The best-studied young disk is around the star Beta Pictoris, known in shorthand as β Pic, and fresh images by Telesco *et al.*[1] (page 133; Fig. 1) show a planet-building history marked by destructive collisions. Measurements by Okamoto *et al.*[2] of the composition of this collisional debris show that it was heated in a manner reminiscent of the heating undergone by samples of Solar System dust. As telescopes get bigger and detectors improve, observers are teasing more and more detail out of this disk, but β Pic will remain just one example of nature at work. New techniques that combine the light of large telescopes are making it possible to study numerous, more distant disks with the same level of detail as applied for decades to β Pic. The first such observations, reported by van Boekel *et al.*[3], allow measurement of the chemical variation with location within disks.

The detailed structure and composition of disks can only be determined once they have been discovered from their heat radiation. Dust in orbit around the stars absorbs their light, heats up and, like a city pavement on a summer's evening, radiates that energy back. One of the first of these disks to be

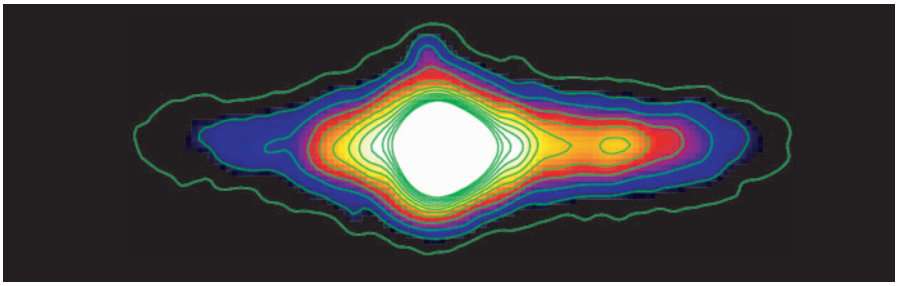
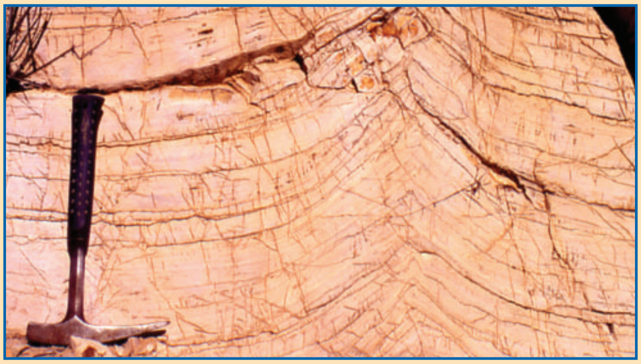


Figure 1 **The β Pic disk, imaged in the mid-infrared at 11.7 μm by Telesco *et al.*[1], shows a clump of hot dust far from the star. See also their Fig. 1 on page 133.**

Palaeoclimate

Ripples of stormy weather



According to the ‘snowball Earth’ hypothesis, our planet was almost entirely covered by ice at least twice in the Neoproterozoic era, between about 710 and 635 million years ago. This deep-freeze climate would have destroyed most of the budding life that existed before the ensuing Cambrian explosion of organisms.

But far from becoming a more hospitable place when the ‘snowball’ finally thawed after the second episode of glaciation, the Earth was swept by winds close to hurricane strength, according to Philip Allen and Paul Hoffman writing elsewhere in this issue (*Nature* **433,** 123–127; 2005). The sustained storms whipped up surface waves in the oceans that moulded the sediments in shallower ocean margins into giant sand ripples, much like their smaller cousins found on beaches today.

The ancient ripples are preserved in sedimentary rocks around the world, and have crest-to-crest distances of several metres. In comparison, the ripples seen in shallow water today typically measure less than 20 cm in wavelength. The picture shows a characteristic giant wave ripple from Namibia that was created during the rise in sea level after the glaciation 635 million years ago. The hammer handle is 33 cm long.

The steepness and height of the ripples are evidence for winds of at least 72 km per hour over long stretches of sea. The structures must therefore have formed along coasts that were exposed to the swell from the open ocean. But what would be considered a one-off extreme storm today must have been characteristic for the climate of the time, otherwise the waves would not have had time to imprint their signature in the sediments.

Allen and Hoffman estimate that the giant ripples formed at depths of 200–400 m, far deeper than the extent of oscillations from surface waves in today’s more benign climate. This gives a hint of the profound effect the stormy climate must have had on upper-ocean turbulence and currents.

Such violent mixing could have resulted from the contrast between cold continental ice cover and the warmer, increasingly uncovered tropical oceans as the ice sheets retreated. The difference in temperature and consequently air pressure could have produced the inferred prevalence of storms, the giant ripples bearing witness to the power unleashed by a changing climate.

Heike Langenberg

discovered is that around β Pic[4], a star that has about twice the mass of the Sun and is ‘only’ 60 light years away. The disk is fortuitously aligned so that we see it directly through its plane, and for 20 years astronomers have observed it at every available wavelength and with every available technique[5–7].

Telesco *et al.*[1] have measured the spatial distribution of the hot dust around β Pic with a new camera on one of the world’s largest telescopes, Gemini South in Chile. The temperature of the dust they image is similar to that of dust found in the inner Solar System as far out as the orbit of Mars; but, thanks to the eight times greater luminosity of β Pic, the dust is seen to extend over a region the size of our entire Solar System.

The perplexing question raised by these observations is why one side of the disk is much hotter than the other. Telesco *et al.*[1] suggest that a giant collision has recently released very small particles into the disk that are being heated by the star. Such particles would be likely to disperse rapidly, so their confinement to one part of the disk means that we must be observing the disk at a special time in its history, within a century of the collision between two large, perhaps even Pluto-sized, planets. A large impact is the leading theory for the creation of our own Moon[8]. In any case, it seems likely that planets lurk around this star, although they remain undetectable with today’s planet-hunting techniques.

Using the similarly sized Subaru telescope on Hawaii, Okamoto *et al.*[2] demonstrate that the innermost region of the β Pic disk, 20 times closer to the star than the warm clump of dust imaged by Telesco *et al.*, has a high fraction of crystalline silicate grains. Glassy silicates must be heated to a temperature of 1,000 K to anneal into crystals[9], and this temperature is reached only quite close to the star. Yet asteroids and comets in our Solar System provide a puzzling comparison: although formed far from the Sun, they too contain crystals[10]. Either crystals that formed in the small, hot region close to the Sun were distributed throughout our disk, or they formed *in situ* as a result of local heating mechanisms such as shocks[11,12]. Such shocks could arise as the self-gravity of disk gas and dust causes clumps and spiral arms to come and go.

The difference in the distribution of crystals in the β Pic disk and in the Solar System should reflect a difference in their histories. β Pic is about 15 million years old; but although it is a youngster compared with the 4.5-billion-year-old Sun, both disks are wispy remnants of their original proto-planetary nebulae, and shocks no longer operate in them. So observations of still younger disks will be required if we are to have the chance of revealing the heating mechanisms at work.

As there are no stars closer to us that are younger than β Pic, astronomers must turn to clever optical techniques to study younger disks in comparable detail. Infrared interferometry combines the light from two widely spaced telescopes to make them function as one large one. Using two units of the Very Large Telescope in Chile, each the size of Gemini or Subaru but separated by 100 m, van Boekel *et al.*[3] have probed the composition of three disks that lie two to four times farther away than β Pic at even higher spatial resolution than was used for the studies of β Pic itself. They show that disks only 10% of the age of β Pic, but very similar to it in mass, have a high degree of crystallinity. Furthermore, the inner part of the disks — the part lying about one to two times the distance from the Earth to the Sun — can be almost entirely crystalline; and, unlike β Pic, even the outer parts contain a large mass in crystals.

With these results[3], modellers of radial transport of dust and *in situ* shocks finally have data to match their theories to. They must grapple with the rapidity and efficiency with which dust is heated and coagulated in disks. Right now, alas, no theory is ruled out, but we can expect more physical models to result. Meanwhile, the hunt is on for more examples of planetary construction sites to study. ■

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