tributed by bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions, the main forms of dissolved carbon in the oceans, and so changes in alkalinity affect the ocean's capacity to absorb CO_2. Unless chloride levels fell or the concentration of major cations rose proportionally with increased sulfate concentration, seawater alkalinity should have decreased, with important consequences for the carbon cycle. It will be interesting to establish whether any changes in ocean alkalinity occurred during the past 3 Ma, because atmospheric PCO_2 levels are quite sensitive to changes in both the magnitude and vertical distribution of alkalinity in the oceans.

Turchyn and Schrag's conclusion that sea-level change is a major driver of marine SO_4^{2-} chemistry further emphasizes the importance of sea-level change to the operation of the continental margin "biogeochemical reactor." Sea-level change also affected carbon sequestration through the frequent glacial-interglacial climate cycles of the past few 100,000 years, including the Last Glacial Maximum (*4*). It appears that the loss of the continental-margin sink for major nutrients such as phosphorous may have caused a glacial-interglacial redistribution of carbon sequestration between the margin and the deep sea. Thus, the work by Turchyn and Schrag not only demonstrates that the marine sulfur cycle has been more dynamic over the last few million years than we thought, but it further focuses our effort toward understanding the importance of the continental margins in affecting climate change on Earth over all time scales. The next step will be to try and better understand what the interesting implications of the changes in elemental cycling at the continental margins have been.

References

1. A. V. Turchyn, D. P. Schrag, *Science* **303**, 2004 (2004).
2. R. S. Ganeshram *et al.*, *Geochim. Cosmochim. Acta* **67**, 2599 (2003).
3. A. Paytan *et al.Science* **282**, 1459 (1998).
4. P. Bertrand *et al.*, *Mar. Geol.* **130**, 1 (1996).

ASTRONOMY

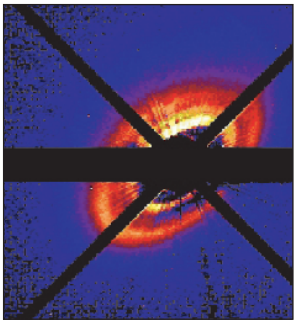
Nearby Planetary Disks

David Mouillet

Understanding the complex process of planetary system formation around a star is one of the major challenges of astronomy today. The conditions required for our own solar system to come into existence, with its stable arrangement of planets and moons, might seem quite unlikely. Study of our solar system alone, however, does not reveal how frequently planetary systems may form around other stars, and which fraction may end up with stable planets likely to support liquid water, possibly favoring the development of life.

During the past decade, the detection of planets around more than 100 bright stars similar to the Sun has clearly demonstrated that planet formation is not an unimportant process. These observations have revived a number of unsolved questions about the size, orbits, and statistics of the discovered planets (*1*, *2*). Another approach is to directly study young systems—circumstellar disks that still contain the material likely to form planets. By sampling systems from a number of evolutionary stages, stellar types, and environments, researchers can draw a comprehensive picture of planetary formation under various conditions. Yet, the detection and imaging of these very faint planetary disks have been successful for only a handful of cases since the discovery of the disk around β Pictoris in the mid-1980s (*3*). On page 1990 of this issue, Kalas *et al.* (*4*) report an interesting image that shows a circumstellar dust disk around AU Microscopii (AU Mic), a sister star to β Pictoris. The young age of the host star and its nearness to us make it very favorable for detailed investigation. Of special interest is the fact that discovery of its very low mass complements previous findings of disks that have only been imaged around more massive stars.

What do we know about the circumstellar disks that harbor planet formation? During the early youth of a star, the infalling material is structured within an accretion disk that is massive, viscous, and opaque, containing more gas than dust. A number of such disks have been detected and/or resolved (*5*). However, the opacity mainly reveals the shape of the disk envelope, or the overall mass content, at far-infrared or millimeter wavelengths. Within a few million years, most of the gas has been either accreted or blown out, while some of the dust has accreted to form larger bodies, up to planetesimals or even planets. At this stage, the small dust grains are no longer protected by the presence of gas that would otherwise reduce their relative velocities and shield the grains from stellar radiation: They are very rapidly destroyed through strong collisions and/or radiation pressure. Consequently, these so-called debris disks are very faint and are difficult to image. The observed disk in visible and near-infrared images consists of short-lived reflecting dust grains produced by collisions among planetesimals (*6*). Such images, possibly with high angular resolution (resolving distances typical of our own solar system's extension around nearby stars), reveal the content and the distribution of this underlying population of planetesimals. Moreover, the distribution of grain sizes, their composition, and asymmetrical structures in the disk tell us about the physical conditions and the dynamics within such active disks (see the figure). This is the basic information needed to understand the physics of the disks when planets are forming or have just been formed.



Young solar system. Debris disk around the 5-million-year-old star HD 141569, located at 100 parsecs (*8*).

During this stage, the influence of the star is crucial in determining the evolution time scale of the disk and the processes that destroy the dust grains. In particular, the impact of the stellar radiation pressure dramatically depends on the star spectrum, and ultimately, on the stellar mass. The disk discovered by Kalas *et al.* surrounds a much less massive star (0.5 solar mass) than those in the previously known systems. The proximity of the star (10 parsecs) will also make it possible to resolve very small structures in the disk, and to investigate its properties close to the star. Such properties are very favorable to further investigations with higher accuracy and will provide an interesting point of comparison for our current models in the case of low-mass stars (which are far more numerous than high-mass stars).

Those questions motivate a number of complementary developments. At long wavelengths (sensitive to the intrinsic emission of the cold circumstellar matter), the Spitzer Space Telescope (operating since 2003 and capable of spatial resolution) will discover much fainter dust disks, thanks to its considerably improved sensitivity (*7*). Later, the ground-based large array of 64 antenna (ALMA, the Atacama Large Millimeter Array) will probe this cold dust and gas with high angular resolution at millimeter and submillimeter wavelengths. In the visible and near-infrared, coronography and adaptive optics on large ground-based telescopes are now leading to improved high contrast and high–angu-

The author is at the Laboratoire d'Astrophysique de l'Observatoire Midi-Pyrenees, 57 av Azereix. BP826, Tarbes 65008, France. E-mail: mouillet@bagn.obs-mip.fr

lar resolution capability. The next generation of such instruments will eventually lead to the direct detection of less and less massive planets.

During the 1980s, exozodiacal dust disks were found around a variety of stars. In the 1990s, the presence of planets around stars was found to be relatively common. A consistent strategy is now in place to understand and characterize the formation and evolution of these planetary systems. Eventually, we should be able to investigate nearby individual cases, and ultimately, terrestrial planets.

References
1. M. Mayor, D. Queloz, *Nature* **378**, 355 (1995).
2. S. Udry, M. Mayor, N. C. Santos, *Astron. Astrophys.* **407**, 369 (2003).
3. B. A. Smith, R. J. Terrile, *Science* **226**, 1421 (1984).
4. P. Kalas, M. C. Liu, B. C. Matthews, *Science* **303**, 1990 (2004); published online 26 February 2004 (10.1126/science.1093420).
5. S. V. W. Beckwith, in *The Origin of Stars and Planetary Systems*, C. J. Lada, N. D. Kylafis, Eds. (NATO ASI Ser. C, Kluwer, Dordrecht, Netherlands, 1999), p. 579.
6. A.-M. Lagrange, D. E. Backman, P. Artymowicz, in *Protostars and Planets IV*, V. Mannings, A. P. Boss, S. S. Russell, Eds. (Univ. of Arizona Press, Tucson, AZ, 2000), p. 639.
7. N. J. H. Evans *et al.*, *Proc. Astron. Soc. Pac.* **115**, 965 (2003).
8. D. Mouillet *et al.*, *Astron. Astrophys.* **372**, 61 (2001).

NEUROSCIENCE

Genetic Control of Cortical Convolutions

Pasko Rakic

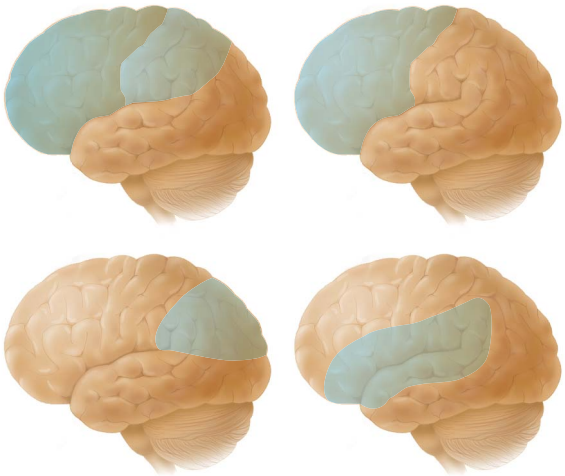
The cerebral cortex is composed of a sheet of neurons that during evolution has increased by three orders of magnitude in surface area. In humans, the cerebral cortex has assumed a highly convoluted (gyrencephalic) shape. A remarkable aspect of cortical development is that none of the constituent neurons, even in the large primate cerebrum, are generated within the cortex itself. Rather, cortical neurons originate in the proliferative ventricular and subventricular zones lining the cerebral cavity and then migrate to their proper laminar and areal positions (*1*). In all mammals, but particularly in the gyrencephalic primate cerebrum, this migration to appropriate positions critically depends on the transient scaffolding formed by shafts of elongated radial glial cells that span the fetal cerebral wall (*2*).

Elucidation of the cellular and molecular events underlying cortical development has come primarily from investigating the smooth (lysencephalic) mouse cerebrum, which is amenable to experimental approaches including the induction of genetic mutations (*3*–*6*). In contrast, spontaneous mutations in humans are nature's unique experiments that enable deciphering of developmental mechanisms, such as the formation of cortical convolutions, that cannot be studied in lysencephalic rodents. On page 2033 of this issue, Piao *et al.* (*7*) provide a state-of-the-art genetic analysis of a human disorder called bilateral frontoparietal polymicrogyria. Patients with this syndrome have an enlarged number of smaller convolutions in the cerebral cortex associated with profound cognitive abnormalities. The authors report that abnormal development in the same cortical location in these patients is caused by eight separate mutations in the human *GPR56* gene encoding an orphan G protein–coupled receptor. This finding implicates G protein–coupled receptor signaling in the development of specific areas of the human cerebral cortex.

Bilateral frontoparietal polymicrogyria is an autosomal recessive syndrome that has been mapped to a locus on chromosome 16q12-21 (*8*). In the new study, Piao *et al.* convincingly show that in each of 12 pedigrees the *GPR56* mutations segregate with polymicrogyria, and only affected patients carry homozygous *GPR56* mutations. They diagnosed the disease according to characteristic cranial magnetic resonance imaging and clinical manifestations. No mutations were observed in the *GPR56* gene in 260 control chromosomes. In addition, the authors demonstrated that the mouse *Gpr56* gene preferentially affects neuronal progenitors in the embryonic mouse proliferative zones. This indicates that the regional patterning of the cerebral cortex occurs at early stages of development, during production and migration of neurons, rather than later in response to abnormal axonal inputs.

The type of polymicrogyria studied by Piao *et al.* arises bilaterally in the sensory and association motor cortical areas of the frontal and parietal cerebral lobes. There are other types of bilateral polymicrogyria that selectively affect different cortical areas (see the figure). This suggests that mutations in specific genes affect cell proliferation only in the regions of the embryonic ventricular zone subjacent to these cortical areas. This, in turn, indicates that the proliferative zone consists of a heterogeneous population of progenitor cells that form a "protomap" (*2*) rather than a uniform sheet of totally equipotent stem cells. Because different regions of the ventricular zone have become separate targets for mutation in congenital malformations, one can speculate that a random mutation during human evolution could be the underlying cause of regional cortical enlargement (*2*).

The other intriguing feature of polymicrogyria is that the affected cortex, although thinner than normal, forms a larger number of convolutions with a net increase in cortical surface. It is instructive that during evolution, cerebral convolutions are formed concomitantly with an increase in cortical surface due to the addition of radial units (minicolumns), but without a comparable increase in cortical thickness (*2*). Why does an increase in the number of neurons result in surface expansion, rather than in a thicker cortex or amorphous cell mass? According to the radial unit model of cortical evolution (*2*), the cortical surface



Types of polymicrogyria syndromes. In the congenital malformation bilateral frontoparietal polymicrogyria, affected individuals have an enlarged number of smaller convolutions in the cerebral cortex that are associated with profound cognitive abnormalities. There are several region-specific types of bilateral symmetric polymicrogyria that are caused by mutations in different genes and can be distinguished by where they are localized in the human cerebral cortex (blue shading). This family of syndromes includes (clockwise from top left) bilateral frontal polymicrogyria, bilateral frontoparietal polymicrogyria described in the Piao *et al.* study (*7*), bilateral parieto-occipital polymicrogyria, and bilateral perisylvian polymicrogyria.

CREDIT: KATHARINE SUTLIFF AND PRESTON HUEY/*SCIENCE*

The author is in the Department of Neurobiology, Yale University School of Medicine, New Haven, CT 06520, USA. E-mail: pasko.rakic@yale.edu