The nascent field of sociogenomics is predicated on two of the most significant ideas in biology to emerge from the latter half of the 20th century. First, many aspects of social life, including social behavior, have a biological basis and are thus influenced to some extent by genes and the forces of evolution (*13*). Second, the functions of many genes are highly conserved between invertebrates and vertebrates even for complex traits (*15*), so that much can be learned from strategically chosen models. Appropriately, social insects and developmental biology, the subjects of Abouheif and Wray's (*10*) paper, contributed profoundly to these hard-won insights.

Paradoxically, elucidation of the molecular biology of insect sociality is now possible because of a plethora of information about a nonsocial insect, *Drosophila*, as well as powerful new genomics techniques. This endeavor draws on rich traditions of research on social insects from the perspectives of evolutionary biology, ecology, ethology, neurobiology, and development, as the study by Abouheif and Wray (*10*) so nicely illustrates. The sequencing of the honey bee genome will provide a foundation for comparative analysis and facilitate gene identification in other social insect species. It will boost sociogenomics enormously and further enhance the value of social insects as models in diverse fields of biology.

By now, you're probably muttering that the only topic for which social insects have not been promoted in this article is world peace. In fact, I don't have to, because *The New York Times* (*19*) already did! In their news story entitled "A lesson in détente from the insect world" they discuss Giraud *et al.*'s (*20*) remarkable work on the Argentine ant *Linepithema humile*. This creature, normally a highly territorial species in its native habitat in South America, has in some parts of Europe become quite tolerant of individuals from other nests, forming a loose confederation that extends at least 6000 km and consists of millions of nests comprising billions of workers. Behavioral and genetic analyses suggest that here is a case where it might actually pay a society to fight less often with its neighbors. Politicians, but more importantly molecular biologists, would do well to "Go to the ant…" —and its cousins—and "consider her ways" (*21*). There is much to learn.

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PERSPECTIVES: APPLIED PHYSICS

Squeezing X-ray Photons

Till H. Metzger

Almost 150 years ago, Maxwell formulated the equations that govern electromagnetic wave propagation. The equations predict that in materials in which the index of refraction changes in a stepwise fashion, a discrete set of modes should be observed. The polarization, shape, and amplitude of these modes or "guided waves" can be controlled through the design of the waveguide.

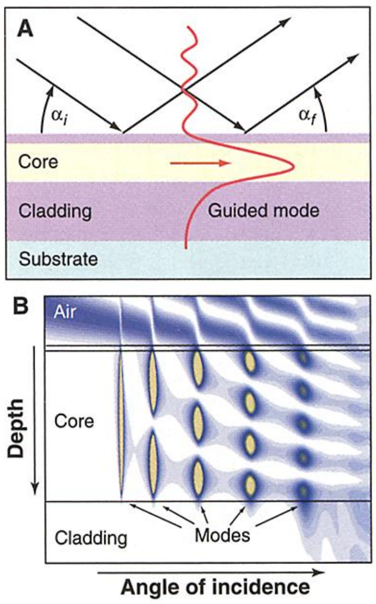
Guided waves have found many uses, from efficient radiation sources to communication technology, but x-rays have proven difficult to control. On page 230 of this issue, Pfeiffer *et al.* (*1*) report an important advance toward using guided waves to create coherent hard x-ray beams with small spot sizes. These beams will help to decipher the structure and dynamics of nanometer-scale objects.

The art of guiding waves has been developed at different times for different parts of the electromagnetic spectrum. Cavity resonators of microwaves and radar were known long before the invention of lasers and optical fibers. Hard x-rays are the last frontier, requiring interfaces perfect enough to support mode propagation and guiding of 0.1-nm radiation.

Such precision seemed impossible to achieve until Spiller and Segmüller demonstrated that x-rays can propagate in suitable planar thin-film structures (*2*). More recently, Feng *et al.* introduced the concept of resonant beam couplers (see the first figure) (*3*). These structures enable efficient coupling of x-rays into planar waveguides. A thinned surface cladding is used, thereby avoiding coupling of the beam through the front end. The latter would inevitably lead to large losses, because the diameters of available x-ray beams are orders of magnitude larger than the guiding layer.

The resonant beam coupler principle has boosted research into x-ray waveguides, leading to new devices that could produce x-ray beams with submicrometer diameters (*4*, *5*). New applications included diffraction with nanometer-sized beams (*6*) and phase contrast projection microscopy (*7*) (see the second figure). But all these efforts were limited to planar thin-film structures in which the beam is confined to one dimension. The most interesting applications require a two-dimensionally confined beam.

Pfeiffer *et al.* (*1*) now report the first proof of principle that resonant beam coupling can be realized in two dimensions. They show that x-ray reso-



Resonant beam coupling. (A) In thin-film sandwich x-ray waveguide, resonant modes can be excited at certain grazing angles α_i in the waveguide channel (yellow) by coupling a parallel beam through the cap layer. The resonantly enhanced beam propagates parallel to the surface and exits at the edge of the structure. **(B)** Electrical field intensity as a function of incidence angle. A discrete set of modes (resonances) is observed in the waveguide, with the number of nodes and antinodes characteristic for the resonant wave propagation.

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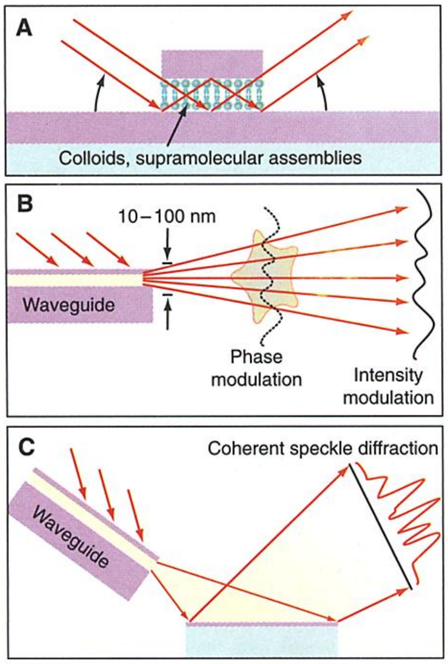

Waveguide applications. (A) Diffraction or spectroscopy of matter incorporated in the waveguide enhances the signal-to-noise ratio through resonance effects. **(B)** Waveguides can also serve as a point source of coherent x-rays. The intrinsic divergence can be used for coherent imaging or photon correlation spectroscopy in a projection setup, in which the information of a nanometer-sized object near the fiber tip is carried to a detector positioned in the far field. **(C)** In contrast to x-ray fiber optics, the beam is coherent; that is, the waveguide acts as a filter for the coherent fraction of the incoming beam, making it useful for photon correlation spectroscopy or coherent scattering.

nances can be excited in two-dimensional (2D) channel structures and clarify the corresponding coupling mechanism.

Many technological improvements will be required before their device can be used as an efficient x-ray point source. However, the reported ~2×10^4 photons per second out of a 33 nm by 68 nm opening is already impressive, representing a 70-fold improvement (gain) over a hypothetical pair of slits of the same dimensions under identical instrumental settings.

Given the rapid gain increases in planar waveguides in recent years, similar improvements in 2D waveguides through optimization of the fabrication process are likely. Relative to other focusing techniques, the 2D x-ray waveguide reported by Pfeiffer *et al.* offers unique opportunities for creating coherent hard x-ray beams with spot sizes below 100 nm.

Such beams could probe the structure and the dynamics of individual colloids, nanocrystals, supramolecular assemblies, or organelles in the cell. While structural information can be deduced from imaging or diffraction of the nanobeam, photon correlation spectroscopy may be used to study dynamics, even in the same experimental setup. In the latter case, the waveguide would replace the pinhole currently used in x-ray photon correlation experiments.

As an important step toward these goals, Pfeiffer *et al.* have performed an impressive demonstration of the basic resonance effect, which occurs when one shines a parallel synchrotron beam onto a suitably designed nanostructure. Almost any nanostructure can be analyzed by a diffraction experiment—but not every nanostructure can change the propagation of the beam.

Pfeiffer *et al.* have shown that the interaction of the beam with carefully designed interfaces goes beyond the well-known examples of other beam-shaping devices such as Fresnel zone plates, compound refraction lenses, and planar x-ray multilayers. Their work suggests that the combination of lithographic nanostructures and x-rays may have more surprises in store.

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PERSPECTIVES: PALEOCLIMATE

Earth's Long-Term Memory

Hugo Beltrami

For climate predictions from general circulation models to be interpreted with confidence, a robust record of past climatic changes is required. Without such a record, natural variability of the climate system cannot be separated from the possible changes induced by human activity. Resolving this issue is essential for addressing future climate change.

Two different approaches are widely used to reconstruct Northern Hemisphere climatic change during the last 500 to 1000 years. Both show a warming in the 20th century, but for earlier centuries they observe different patterns of climate change. Do these disagreements reflect only differences in the spatial distribution of sites, or are they due to intrinsic limitations of the methods?

The first method uses large data sets of various temperature proxies, such as tree rings and oxygen isotopes in ice cores, to construct a model of past temperature change (*1*). The second relies on geothermal data from boreholes worldwide to model ground temperature changes and the energy balance at Earth's continental surface (*2–4*).

Comparison of these multiproxy and geothermal paleoclimatic models is difficult because of differences in the spatial distribution of data. But preliminary comparison (*5*) yields some important differences. In particular, they disagree over the existence of a cold period between 1500 and 1800 A.D. Such a cold spell is documented in all geothermal models but does not appear as a strong signal in the multiproxy reconstructions (*1*).

To understand these discrepancies, we must first understand how surface temperatures are reconstructed in the borehole method and why direct comparison with multiproxy data is not possible.

If we assume that Earth's upper crust is in thermal equilibrium, then the temperature distribution in the upper few kilometers will be determined by the long-term (>1000 years) surface temperature and the internal heat flow (considered constant for time scales less than 10^6 years). Under the conditions of constant surface temperature and internal heat flow and homogeneous thermal properties of the underground rocks, the temperature increases linearly with depth. In most cases, the subsurface is not homogeneous, but thermal properties can be measured in rock samples and standard corrections applied.

The situation changes if Earth's surface warms (or cools). In this case, a quantity of heat will be gained (or lost) by the ground. These changes in the energy balance at the surface will propagate and be recorded underground as perturbations to the equilibrium thermal regime.

Typically, perturbations penetrate about 20 m in a year, 150 m in 100 years, and 500 m in a millennium, depending on the thermal properties of the subsurface rocks. Hence, recent energy balance changes at the surface remain recorded in the shallow subsurface. Analysis of these underground anomalies provides the basis of the borehole method. The temperature anomalies observed in the Northern Hemisphere (see the figure) show that the spatial variability of the surface energy balance is large.

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