has partly shifted to confirming or refuting the new solar abundances of references *1–3*. Despite the more sophisticated modeling of the atmosphere and spectrum, could it be that the revised values are in fact underestimated and the real abundances closer to the old ones? Recently, independent analyses based on different 3D solar atmosphere models have appeared, which tend to find intermediate values (*12–15*). Unfortunately, these latest studies have been restricted to only oxygen and without considering the molecular transitions; hence, it remains to be shown that all available abundance indicators will yield consistent results. Reassuringly, the particular choice of 3D model turns out to be relatively unimportant. Instead, the main differences come from subtleties in the computations of the solar spectrum, especially how possible blending lines from other elements and collisional cross sections for the nonequilibrium spectral line calculations are treated, and how the strengths of the spectral lines are measured. However, the jury is still out on whether these alternative choices are preferable to those in the original 3D-based analyses that sparked the whole solar modeling problem. If true, these intermediate oxygen abundance results would alleviate but not remove the discrepancy with helioseismology. Another explanation working in concert would then still be required, presumably related to refinements in the solar interior modeling or opacity calculations.

Perhaps an amicable resolution to the solar modeling problem is possible after all through compromises by both the solar atmosphere and interior camps. Regardless of how the final blame is apportioned, studies of the Sun as well as other stars will then be on a much firmer footing. With stars as widely used cosmic probes, this will directly translate to a better understanding of the universe as a whole.

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10.1126/science.1148787

ECOLOGY

Bugs' Bugs

Evaluation of the chemical relationship between a beetle and its microbial associates shows that microbial ecology can lead to potential drugs.

May R. Berenbaum[1] and Thomas Eisner[2]

Although scientific progress leads to constant reevaluation and revision of concepts and ideas, one observation that has remained robust in the face of accumulating evidence across the centuries is that there are a lot of insects in the world. In 1758, in his profoundly influential book *Systema Naturae*, Carolus Linnaeus (*1*) described all animal species known at the time; of the 4203 species of animals he named, 2102—more than half—were insects. Linnaeus also provided a flexible binomial framework for naming and classifying organisms; species descriptions of all kinds have accumulated apace, but since Linnaeus began this effort they have accumulated fastest for insects. Between 1758 and 1800, close to 60,000 insect species were described; from 1800 to 1850, about 360,000 additional species were identified. Today, about 950,000 species of insects have been described.

A robust corollary of the observation that there are a lot of insects in the world is that the greatest proportion of all insect species belongs to the order Coleoptera—more than one-third of all known species are beetles. Today, more than 300,000 species of beetles have been described. Erwin and Scott (*2*), in a 1-year study of only 19 individuals of a single tree species (*Luehea seemannii*) in Panama, found more than 950 species of beetles, many of them new discoveries (that count did not even include weevils, the largest family of beetles). How many beetles remain undescribed is anyone's guess, but some experts estimate that it is between 5 and 8 million species.

Focused on only a single (but well-known) species of beetle, *Dendroctonus frontalis*, Scott *et al*. on page 63 of this issue (*3*) dramatically illustrate that, as numerous as they may be, beetles may represent just the tip of the biodiversity iceberg. A single beetle species itself can house an entire community of associated species. *D. frontalis* infests pine trees but is dependent on two symbiotic fungi—*Entomocorticum* sp. A, and to a lesser extent, *Ceratocystiopsis ranaculosus*—which both grow in the vascular system of the tree and provide food for the beetle larvae. Another fungus, *Ophiostoma minus*, can be a symbiont that assists the beetle in overcoming the defenses of the host tree, but it can also inhibit growth of the principal

Medicinal sources? Microbes (by the thousands) associated with insects remain to be discovered and tested for chemicals. Shown is a *Camponotus* ant infested with a *Cordyceps* fungus, which is related to the beetle-killing fungus that produces cyclosporin, the well-known immune-suppressive drug. The pharmacological properties of the ant-infesting fungus have yet to be investigated.

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Entomocorticum fungal food source. The beetle deals with the aggressive fungus by harboring yet another species—an actinomycete bacterium—that secretes antibiotics to kill *O. minus*.

This coleopteran complexity eluded detection until now, even though *D. frontalis*, first described 140 years ago (*4*), is a widespread pest and arguably the most economically important pest of southern pine plantations in the United States. And it is by no means unique in harboring a complex microcosm of interacting species. *Acromyrmex* leaf-cutting ants associate with two very specialized symbiotic basidiomycete fungi that grow in underground gardens as food. At the same time, these ants maintain actinomycete *Pseudonocardia* bacteria on their cuticle to manufacture antibiotics that inhibit the growth of an unwelcome associate—*Escovopsis*, a parasitic fungus that attacks the food-source fungal garden (*5*). As Scott *et al*. suggest, in view of the enormous selection pressure that pathogens can exert, protective associations with antibiotic-producing bacteria may be a ubiquitous feature of insect-fungus partnerships. Given that more than 300,000 species of beetles are currently known, the number of partnerships, fungal associates, and bacterial symbionts yet to be elucidated is daunting.

According to May (*6*), the reasons for cataloging biodiversity are the "same reasons that compel us to reach out toward understanding the origins and eventual fate of the universe, or the structure of the elementary particles that it is built from." May also reminds us that Earth's biodiversity is declining at an unprecedented rate, due in large part to anthropogenic changes in land use, climate, soil, and water and air quality. How many beetles, with their communities of associates, will have ceased to exist before Scott *et al*. and other investigators can work out the details of their interrelationships is anyone's guess. According to the Red List of Threatened Species provided by the International Union for Conservation of Nature (*7*)—an authoritative accounting of rare, threatened, and endangered species—fewer than 800 of the 950,000 or so species of insects that have been described (~0.1%) have been evaluated as to their status. Moreover, of the insect species that have been evaluated, almost three-fourths are threatened. The powerful antibiotic chemistry exploited by the southern pine beetle that allows it to go about its business attacking trees is just one example of a more tangible benefit of examining terrestrial interactions than simply gaining insights into the cosmos.

There is no limit to what remains to be discovered in that interactive zone between macroorganism and microbe, where so many biological mutualisms and antagonisms play out. Microbes blanket the planet, and in their infinite variety they must be involved in infinite interactions. Deciphering these could lead to a vast increase in ecological knowledge, as well as to the isolation of natural products of unforeseen function. The latter possibility, clearly envisioned by Scott *et al*., is one that we take to be of particular importance. Chemical prospecting—the search for chemicals of use from nature, including medicinals—has been relegated to low priority by industry nowadays, in the belief that nature has already been exhaustively screened for such compounds. Scott *et al*. provide proof that such belief is unjustified, that the microbial world has been all but thoroughly explored (see the figure). Sure enough, microbes have been screened for some types of biotic and antibiotic action, but the bulk of their chemical capabilities remain to be uncovered. As demonstrated by Scott *et al*., even the least wanted among species can be the source of useful leads. A concerted effort to look into the more subtle aspects of microbial chemistry is therefore very much in order. The fact is that we don't even know the microbes themselves that inhabit our planet, let alone the molecules they need to secure their survival. Microbial ecology is still very much a part of the great frontier.

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10.1126/science.1164873

ATMOSPHERIC SCIENCE

From Ocean to Stratosphere

Rising tropical sea surface temperatures alter atmospheric dynamics at heights of 16 kilometers or more.

Rudolf Deckert and Martin Dameris

The increasing burden of greenhouse gases from human activities, such as carbon dioxide, is warming the troposphere (the lowest part of Earth's atmosphere), whereas in the stratosphere (above the troposphere and extending from ~16 to 50 km), higher greenhouse gas concentrations cause a net radiative cooling that may delay ozone hole recovery in the Antarctic. But the picture is even more complex. Recent studies have shed light on how mass exchange between troposphere and stratosphere may be affected by tropical sea surface temperatures (SSTs) that are rising as a result of global warming.

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The mass exchange between troposphere and stratosphere—the Brewer-Dobson circulation—is characterized by persistent upwelling of air in the tropics from the troposphere into the stratosphere. The air then downwells in the extratropics, mixing stratospheric air back into the troposphere, with a turnaround time of a few years (*1*). Some observational data indicate that the troposphere-stratosphere mass exchange is accelerating (*2*). Most numerical studies with coupled chemistry-climate models support this finding and relate it to the anthropogenic climate signal (*3*), but it is uncertain which mechanism communicates the anthropogenic climate signal to the mass exchange.

This mechanism needs to be pinpointed because the troposphere-stratosphere mass exchange affects the chemical composition and climate of Earth's atmosphere. The tropical upwelling branch of the Brewer-Dobson circulation lowers temperatures and ozone concentrations, especially in the lower stratosphere. The low temperatures in turn freeze-dry the upwelling tropospheric air. Furthermore, the upwelling controls the lifetime of anthropogenic ozone-depleting substances with sinks in the stratosphere. In the extratropical stratosphere, downwelling causes adiabatic warming and ozone accumulation until

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