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Radiation budget is called to account

Ahilleas N Maurellis

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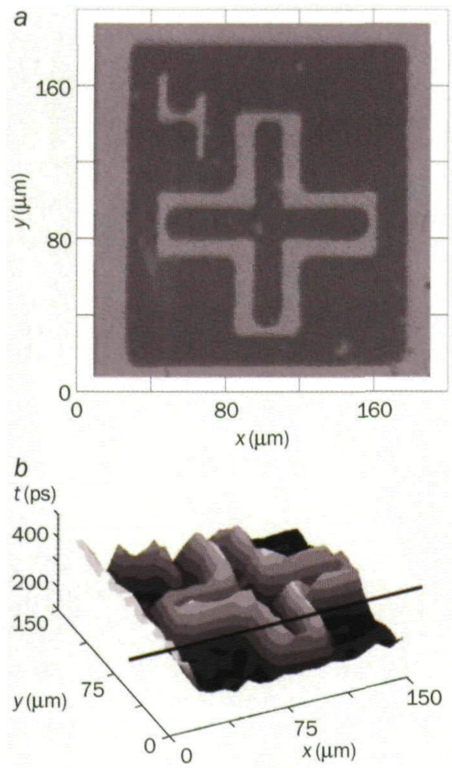
sorbing the positrons and re-emitting them at energies close to 1 electron volt.

The antiparticles are then passed through a "pre-bunching" section where they emerge in a beam almost 20 μm in diameter, with each pulse lasting 2 nanoseconds (A Zecca *et al.* 1995 *Europhys. Lett.* **29** 617). These pulses then go through a stage of brightness enhancement, followed by a final buncher that reduces the duration of the pulse to 200 picoseconds and its diameter to 2 μm. Each part of the instrument is connected by suitable "electron" optics, while the optics in the positron column is designed to focus the antiparticles onto the sample over a wide range of energies (500–20 000 eV) and without deteriorating the time structure of the bunches. This ability to vary the bunch energy allows the positrons to be implanted at different depths. In other words, the scanning positron microscope offers a totally non-destructive method of profiling a sample in three dimensions.

Let us return to the enhancement of the beam brightness, which is related to the intensity of the beam per unit area. The Munich group has developed a sophisticated way of increasing the brightness of the beam based on a technique first suggested in 1980 by Allen Mills of Bell Labs in New Jersey. Kögel and co-workers implant the positrons in a single crystal of tungsten, which re-emits them with an astonishing brightness gain of 3×10^5. Since the brightness and intensity of positron sources are many orders of magnitude smaller than their electron counterparts, this stage is probably the most important part of the microscope. Indeed, it means that the beam can be focused down to a small spot size with almost no intensity loss.

The Munich team examined a test chip where a platinum pattern was deposited onto a silicon-oxide substrate using both electron and positron microscopes (see figure). The



(a) The surface of a silicon wafer patterned with a platinum layer (dark), as viewed in an electron microscope. (*b*) The same wafer imaged in three dimensions by a scanning positron microscope.

positron microscope provided additional information about the electron momentum that cannot be extracted using an electron microscope or any other analysis technique. The researchers also demonstrated that positrons can reveal defective regions on a scratched gallium-arsenide crystal that are invisible in optical and electron images.

The time for industry to begin using positron techniques is approaching, as testified by Paul Coleman of the University of Bath during the latest workshop on low-energy positrons held in Santa Fe in the US this summer. However, three conditions must first be met. First, the size of the beam spot needs to be reduced. Second, the measurement time must be made shorter. And third, the machines and procedures need to be standardized for industrial use.

The greatest achievement of the Munich group has been to reduce the spot size down to 2 μm, compared with standard beams that can be up to several millimetres wide.

Meanwhile, the measurement time depends on the intensity of the high-energy positron source. In the Munich instrument, the sodium-22 source limited the measurement time to 800 seconds per pixel. This clearly hinders the applicability of the machine to industrial work. Kögel and co-workers are now planning to use positrons generated at a nuclear reactor. While this technique could reduce the measurement time by a factor of 100–1000, it is not practical for widespread use in industry.

A different approach looks more promising. Some 20 years ago, Kelvin Lynn and Barry McKee, then both at Brookhaven National Laboratory, proposed a so-called field-enhanced moderator, which could produce 100 times more positrons than existing moderators using the same radioactive source. It is possible that such an innovation will appear in the near future, in which case small radioactive sources could do the job in an industrial lab.

Some 10 years ago the lifetime technique was considered the most powerful of all the positron-annihilation techniques. Since then, however, background-reduction techniques have enforced the Doppler-broadening method, which can now tell us about the atoms surrounding the defect. The next generation of microscopes will possibly combine different detection methods to yield a wider set of information within the same measurement time. It is clearly an exciting time for positrons.

Radiation budget is called to account

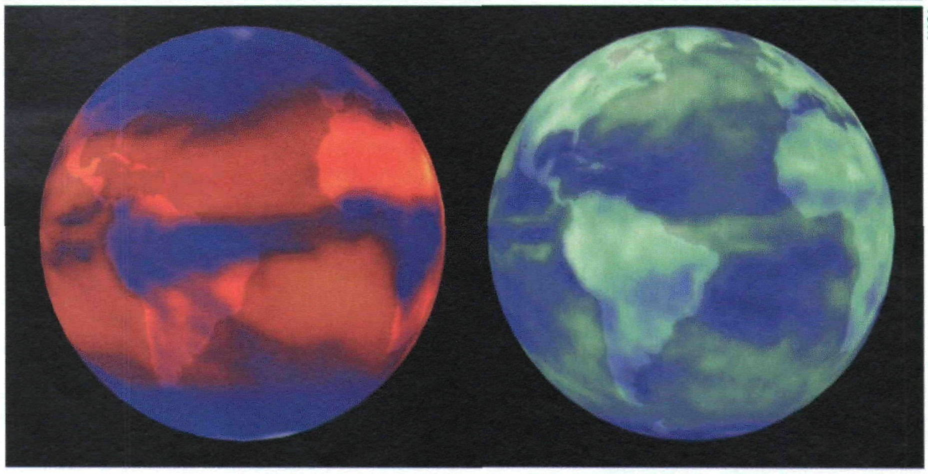
From Ahilleas N Maurellis in the Space Research Organization Netherlands, Utrecht, the Netherlands

Earlier this year a group of some 70 scientists spent an intense week in the foothills of the Rocky Mountains in Colorado reviewing the current understanding of the radiation budget of the atmosphere. The meeting, the latest in the series of Chapman Conferences organized by the American Geophysical Union, focused on the so-called anomalous absorption of solar radiation in the atmosphere (see agu.org/meetings/cc01fprog.html).

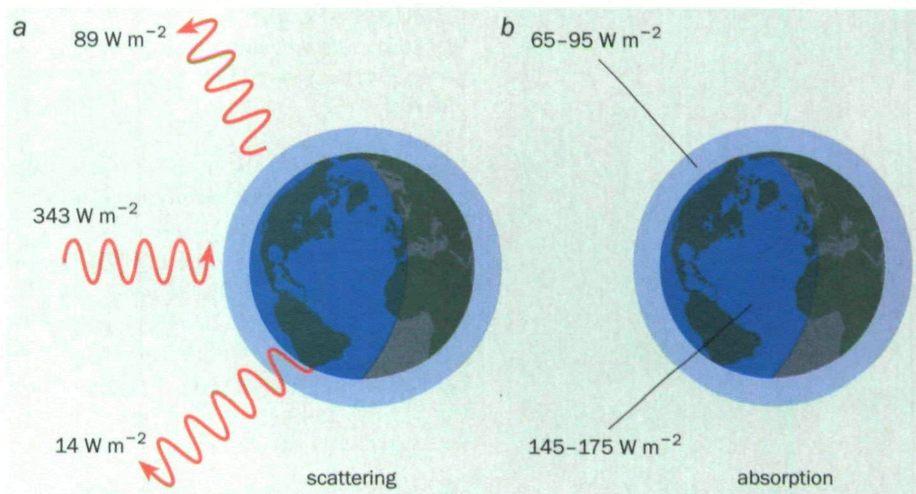
Evidence gathered over the past 20 years has increasingly shown that the absorption of solar radiation predicted by models is significantly less than the absorption measured experimentally. Current models predict that, on a global average, the atmosphere absorbs about 65 $W m^{-2}$, whereas observations from the top of the atmosphere and the Earth's surface show that the actual absorption is 95 $W m^{-2}$. This mismatch of some 30 $W m^{-2}$ corresponds to about 10% of the globally averaged incoming solar radiation, suggesting that some extra anomalous absorption needs to be added to the models.

The implications for climate modelling, and the evaporation and condensation of water on a global scale, are enormous, according to Jeff Kiehl, Anthony Slingo and others at the meeting. The reason is that the most significant absorber of radiation in the atmosphere, water vapour, heats up the atmosphere far more than other greenhouse gases like carbon dioxide. Although missing spectroscopic information on water vapour could still provide some additional absorption in atmospheric models, the Chapman Conference showed that there were more important modelling and observational issues to be dealt with first (see Maurellis in *Physics World* February p22).

Field observations consist of upward and downward radiation fluxes, which are measured at a number of altitudes. Satellites measure the fluxes at the top of the atmosphere, while aircraft evaluate the flux somewhere in the middle (usually about 7–10 km above ground, the working altitudes of most aeroplanes and of clouds). Other flux measurements are made at or near the ground.



Satellite instruments measure the thermal radiation (left) emitted into space from the Earth's surface and atmosphere together with the sunlight (right) reflected by the ocean, land, clouds and aerosols.



(*a*) It is well known that the Earth receives a global average of 343 W m^{-2} of radiation from the Sun each year. Equally well known are the amounts that are scattered back into space (89 W m^{-2}) and by the atmosphere (14 W m^{-2}). (*b*) Models and observations disagree about the amount of radiation absorbed and re-radiated by the Earth and the atmosphere.

Radiation modellers must first take an inventory of all the known absorbers, scatterers and emitters of radiation in the atmosphere. They also need to accumulate data on the vertical distributions of the relevant gases and particulates, as well as their spectroscopic signatures. This information is then combined in models that calculate the fluxes at the altitudes where the field measurements are made.

Two candidates for anomalous absorption have been identified so far: clouds and aerosols – atmospheric particles some 0.01–10 μm in size that vary widely in shape, orientation and origin. It has been known for some time that the radiation absorbed by individual clouds can differ considerably from the predictions of models. At the meeting, William O'Hirok showed that the energy contribution of clouds to the radiation budget is –4 to 2 W m^{-2} at visible wavelengths and 17 to 28 W m^{-2} in the near infrared. The amount of absorption depends, in particular, on the water-vapour content and the height of the cloud. However, Albert Arking pointed out that once the average of many global measurements is made, the measurements and models of the clouds tend to agree.

But the situation is different for aerosols. The energy contribution to the Earth–atmosphere system due to aerosols (also known as the radiative forcing) is still quite uncertain, even in situations where the sky is completely cloud free. This is partly because the huge range of aerosol properties is still a long way from being fully understood. The implication is that even clear-sky absorption is not completely understood and this may be partly due to problems with understanding measurements of diffusely scattered, as opposed to direct, sunlight.

As Chuck Long pointed out, previous field observations may have had errors that could account for almost one-third of the anomalous absorption. In general, the instruments that measure incoming and reflected radiation, known as pyranometers and pyrgeometers, are difficult to calibrate in the laboratory and may function differently when operated in the field. For example, the domes that cover these devices are prone to heating, which, according to Si-Chee Tsay and Stephen Schwartz, may bias the measurements by as much as 5–25 W m^{-2}. Satellite instruments are even harder to maintain at a known calibration.

The radiation-modelling problems are somewhat different, largely due to the huge difficulties in describing a system as complex as the Earth's atmosphere. The effects of hundreds of millions of molecular absorption lines need to be incorporated into the computer codes via parametrization schemes, which usually focus only on the short-wave region of the spectrum (i.e. wavelengths less than about 5 μm). Such schemes interpolate over the range of possible solutions to the differential equations involved, and are essential in order to reduce computation times.

An unfortunate by-product of generating optimized parametrization schemes is that small, but significant, portions of the spectrum may be overlooked. For example, Kou-Nan Liou and others explained that up to one-third of the anomalous absorption might be accounted for by considering longer wavelengths and reducing parametrization errors. The field of atmospheric modelling also encompasses many different codes, each with slightly different inclusions and omissions, making it difficult to compare like with like.

But there is still a possibility that our knowledge of the radiation physics of the atmosphere is somewhat incomplete. In addition to the unaccounted water-vapour lines, Veronica Vaida indicated that effects due to the water-vapour dimer (a transitional collisional state induced by the close proximity of two water-vapour molecules) may explain some of the missing absorption in models. However, Susan Solomon, William Conant and Robert Portman showed that dimer effects in the visible part of the spectrum were small.

In addition, Herch Nussenzveig demonstrated that sharply peaked structures in the aerosol scattering cross-sections, known as Mie resonances, could also account for the mismatch between theory and observations. Meanwhile, Jose Vanderlei Martins and others explained that the contribution of aerosols, in particular black soot, is very likely to have been seriously underestimated and could explain much more of the remaining anomaly.

Perhaps most importantly, the Chapman meeting showed that the 10% anomaly is closer to 2% in the clear-sky case – although it is still comparable to the radiative forcing due to greenhouse gases. In one way or another, physicists have been pursuing this problem for more than a 100 years, since Samuel Langley showed in a paper for the US War Department that the atmosphere's ability to selectively absorb solar energy heats the Earth more than expected. For reasons more apposite than war, we should not consider the radiation budget fully balanced – at least not just yet.

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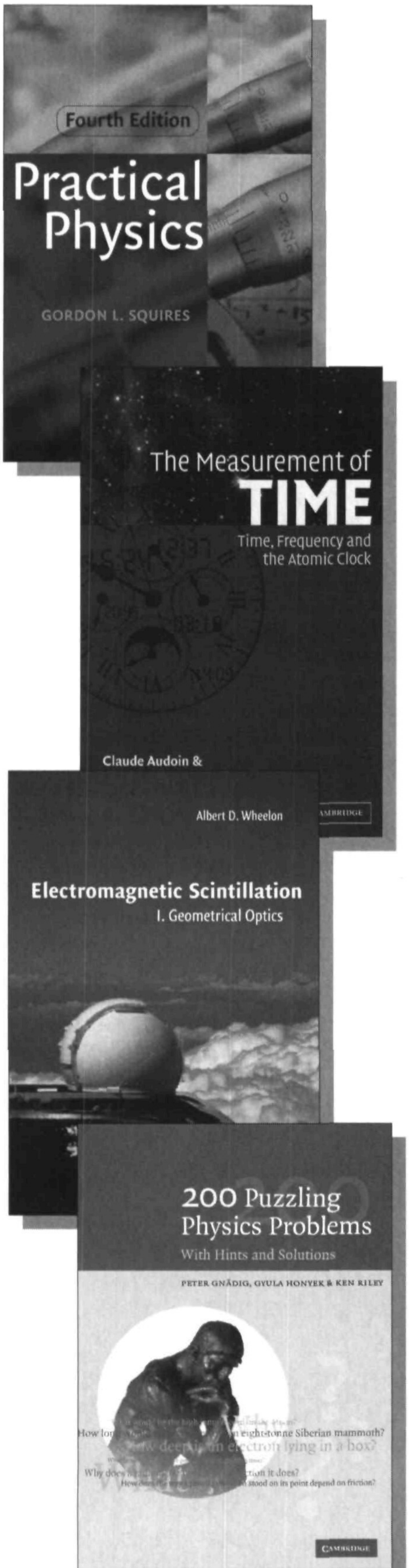

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