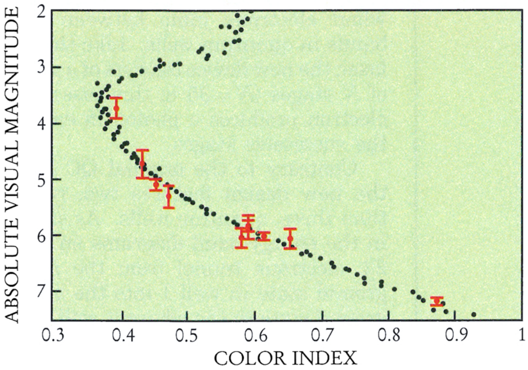

FIGURE 2. HERTZSPRUNG-RUSSELL DIAGRAM of four very metal-poor globular clusters in the Galactic halo. The absolute magnitude at which the distribution turns right, off the main sequence, measures how old these isochronous clusters are. The cluster stars (black points) are too far away for Hipparcos parallax measurements, but the absolute magnitude scale has been adjusted to bring their main sequence branch into line with nearer subdwarfs of the same metal content (red points), whose distances were measured by Hipparcos. (Adapted from ref. 1.)

quence at a well-defined point, above and to the left of which there are no more stars remaining on the main sequence. The turnoff for such an isochronous population, as shown in figure 2, leads onto a much narrower path than the broad red-giant branch seen in figure 1. Figure 2 is the H-R diagram for four very old globular clusters, presumably all being roughly the same age. The low-mass stars remaining on the main sequence are in the realm of the "subdwarfs."

Recalibrating the subdwarfs

The absolute visual magnitude at the turning point tells us, with the aid of astrophysical models, the age of the isochronous population. The older the population, the farther down the main sequence (toward the lightest, slowest-burning stars) is the turnoff. But these age determinations depend sensitively on how well the absolute magnitudes are calibrated.

Living well outside the Galactic disk, in the halo, the globular clusters are all too far away for direct Hipparcos distance determinations. So Reid took Hipparcos distance determinations for 15 nearer halo subdwarfs with the same low metal content as the oldest globular cluster stars and used them to recalibrate the absolute visual magnitude scale of the subdwarf main sequence in the globular-cluster Hertzsprung–Russell diagram.

The stars showing red error bars in figure 2 are the nearby calibrating Hipparcos subdwarfs. Because all the stars in a given globular cluster are at essentially the same distance from us, and the magnitude scale is logarithmic, one recalibrates the globular cluster H-R distribution simply by shifting it up or down the absolute magnitude axis until one gets the best fit with the calibrating Hipparcos subdwarfs. The assumption, of course, is that halo subdwarfs of a given low metal content will lie precisely on the same main sequence, irrespective of whether or not they are in the globular clusters.

Reid concludes that the four oldest, metal-poorest globular clusters in his study are in fact 15% farther away than was believed before Hipparcos. That corresponds to a 30% increase in intrinsic luminosity and consequently a decreased age estimate of 11–13 billion years.

The Hubble constant

Reid's recalibration also bears directly on estimates of the Hubble constant and the age of the universe. If distant, highly redshifted galaxies are farther away than previously thought, H_0 becomes correspondingly smaller and thus the cosmological models yield greater ages for the universe. The cosmological distance scale depends, at its base, on estimates of the intrinsic luminosities of "standard candles" nearer home.

Among the most important local distance indicators are variable stars such as Cepheids and RR Lyraes. Reid's result pushes the RR Lyraes in the globular clusters farther away, implying that all RR Lyraes are intrinsically brighter and more distant than previously thought. Michael Feast (University of Capetown) and Robin Catchpole (Royal Greenwich Observatory) reach much the same conclusion about Cepheid variables.[2] Using Hipparcos parallax measurements of some 200 Cepheids, they argue that estimates of H_0, most of which rest heavily on Cepheid variable observations, must now be reduced by about 10%. That would bring the age of the universe up to about 10–13 billion years, further easing the conflict with the globular cluster ages.

Not everyone agrees. John Fernley (International Ultraviolet Explorer Observatory, Madrid) and coworkers have used Hipparcos measurements of the "proper motions" of 144 relatively nearby RR Lyrae stars to determine their distances by what is called statistical parallax.[4] Only RR Lyrae itself, the archetype of the class, is close enough for trigonometric parallax. For the others, one measures angular velocities across the celestial sphere and determines the mean distance of the sample by assuming that the Doppler radial velocities of these halo stars are statistically equal to their transverse velocity components. Fernley and company conclude that the pre-Hipparcos calibration of the RR Lyrae absolute magnitude needs no revision. In particular, they disagree with the Feast–Catchpole assertion that the assumed distance to the Large Magellanic Cloud, an important rung on the cosmological distance ladder, needs to be increased.

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References

1. I. N. Reid, Astron. J. **114**, 161 (1997).
2. M. Feast, R. Catchpole, Mon. Not. R. Astron. Soc. **286**, L1 (1997).
3. J. C. Mermilliod *et al.*, in *Proc. Venice '97 Hipparcos Symposium*, M. Perryman, P. Bernaca, eds., ESA publication SP-402, in press.
4. J. Fernley *et al.*, in *Proc. Venice '97 Hipparcos Symposium*, in press.

Infrared Laser Illustrates Another Way to Achieve Gain

Thanks to an innovative design, researchers have made an infrared semiconductor laser whose wavelength can be electrically tuned.

The standard way to build a laser is to produce a population inversion between an upper and a lower energy level. But laser gain is proportional not only to the population difference between two states but also to the oscillator strength, which depends on both the energy difference between the upper and lower states and the probability of a transition between them. By focusing on these often-overlooked factors, a group at Bell Laboratories, Lucent Technologies, has made a semiconductor infrared laser with a unique property: It is electrically tunable over a 6% range.[1]

Like the quantum cascade (QC) laser developed at Bell Labs by the same team, (see PHYSICS TODAY, July 1994, page 20) the new laser emits photons when electrons jump between subbands in quantum wells. Like the QC laser, the new device consists of a series of N stages ($N = 35$ in this case): An electron produces a photon in each of the successive stages.

Contrary to the original QC laser, the new design features two, rather than three, quantum wells. As shown in the energy-band diagrams on page 23, electrons tunnel from the $m = 1$ ground state in well 1 into the $m = 1'$ ground state in the adjacent well (well 2), emitting a photon in the process. Because of the thin barrier on the far side of well 2, electrons tunnel rapidly out and keep the second well empty. By contrast, a thick injection barrier on the right of well 1 helps keep the electron density constant there.

As the diagrams show, the electric field bias progressively changes the shapes of the quantum wells. At high enough fields (diagram c), the floors of the wells are slanted. Thus, the electron population in well 1 is squeezed into a smaller region closer to well 2, enhancing the probability of a transition between them. Through the linear Stark effect, the electric field also increases the energy difference between the two levels. Both factors boost the oscillator strength until the gain equals the optical losses.

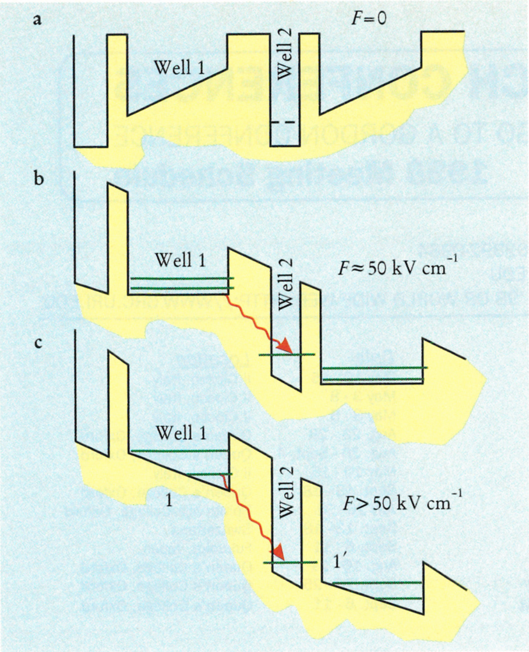
With this design, Jérôme Faist and his Bell Labs colleagues demonstrated continuous-wave lasing at a wavelength of 6.56 μm with a threshold current of just under 0.8 A and a power output of about 40 mW at a temperature of 60 K. The current density is about equal to the best result so far with any QC laser.

Tunability

The tunability of these lasers comes from the variation in energy-level differences caused by the Stark effect: Applying a stronger bias voltage should cause the laser to emit a photon with a shorter wavelength. But once you increase the bias voltage enough to achieve lasing, the voltage is pinned at this threshold value, and the laser wavelength is also fixed.

The Bell Labs group still found a way to tune this laser, explained Federico Capasso, the group's leader. The trick is to add an adjustable parameter. His team broke the electrical contact into two parts and fed a different current density through each contact. By varying the current densities—while keeping the total gain equal to the losses—the researchers can shift the laser wavelength, tuning it from about 6.2 μm to about 6.6 μm.

The Bell Labs team can also adjust the operating temperature to change the wavelength of QC lasers, albeit by



ENERGY LEVELS in one stage of the quantum cascade laser for different values of electric field F. No photons are emitted (**a**) until the field is high enough (**b**) for electrons to go from the bottom level ($m = 1$) in well 1 to the bottom level ($m = 1'$) in well 2. Lasing occurs at stronger fields (**c**), when the potential in well 1 moves electrons closer to well 2. The barriers keep well 1 at a constant population level and well 2 empty. (Adapted from ref. 1)

a smaller percentage range. The researchers recently demonstrated this temperature tuning with a QC laser of the original design to which they had added distributed feedback to get single-mode lasing with 60 mW of power at 300 K.[2] In other work,[3] the same group made the active regions out of superlattices to produce a high-power pulsed QC laser at 8 μm.

Another type of QC laser is being designed to operate at shorter wavelengths, below 5 μm. In these shorter-wavelength QC lasers—developed by researchers at the University of Houston working with colleagues at Sandia National Laboratory and the Naval Research Laboratory—the electron transition occurs between the valence and conduction band rather than within the same subband.[4] Lasers of this design have operated at powers of nearly 500 mW, but so far they emit from both ends of the laser. Other researchers are also developing multiple quantum-well lasers in this observationally important region of the infrared.

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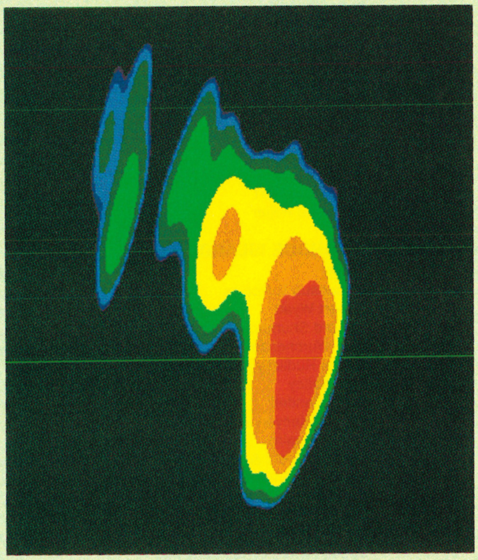
References

1. J. Faist, F. Capasso, C. Sirtori, D. L. Sivco, A. L. Hutchinson, A. Y. Cho, Nature **387**, 777 (1997).
2. J. Faist, C. Gmachi, F. Capasso, C. Sirtori, D. L. Sivco, J. N. Baillargeon, A. Y. Cho, Appl. Phys. Lett. **70**, 2670 (1997).
3. G. Scamarcio, F. Capasso, C. Sirtori, J. Faist, A. L. Hutchinson, D. L. Sivco, A. Y. Cho, Science **276**, 773 (1997).
4. C.-H. Lin, R. Q. Yang, D. Zhang, S. J. Murry, S. S. Pei, A. A. Allerman, S. R. Kurtz, Electron. Lett. **33**, 598 (1997).

Radio Telescope in Space Maps Quasar Jet

What's remarkable about this radio image of quasar 1156+295 (shown in false-color form) is how it was obtained—using a radio telescope in space.



Radio waves are so long that high angular resolution can be achieved only with big telescopes—the bigger the better. Since the 1960s, radio astronomers have used interferometry to synthesize large apertures by combining signals from widely separated telescopes. Naturally, the largest aperture obtainable on the ground is Earth's diameter of 13 000 km.

Now, this terrestrial barrier has been breached by HALCA, a radio astronomy satellite launched by Japan's Institute of Space and Astronautical Science. In its elliptical orbit, HALCA ranges as far as 21 000 km from Earth's center, so that when it observes in conjunction with a ground-based telescope—in this case, the Very Long Baseline Array—a maximum baseline of 33 000 km is achieved, yielding a resolution of 0.3 milliarcseconds at an operating frequency of 5 GHz. That's enough to see things the size of 10 light-years at the quasar's distance of 6.5×10^9 light-years—a threefold improvement over ground-based arrays operating at the same frequency.

With its finer detail, this HALCA image (made at 1.6 GHz with 1 milliarcsec resolution) shows a jet of supersonic plasma shooting out from the heart of the quasar, which can be seen from the ground only at much higher frequencies. Moreover, because of the steeply falling energy dependence of its electron distribution, a jet like this one is much more prominent at low frequencies. The HALCA images, therefore, reveal smaller structures that are invisible in ground-based observations.

The achievement of the HALCA team lies not just in putting an 8-meter radio telescope on board a spacecraft. To obtain interference fringes, the team has succeeded in time-tagging the wavefronts arriving at the various telescopes with an accuracy of about 1 μs. For a rapidly moving space-based instrument whose precise frequency standard and high-data-rate recorders are actually on the ground, this is a remarkable technical accomplishment.

Still in its in-orbit checkout phase, HALCA (which stands for Highly Advanced Laboratory for Communications and Astronomy, and is meant to sound like *haruka*, the Japanese word for "distant") will embark on a full program of astronomical observations once calibrations are complete and regular, routine operations can be maintained.

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