soon to discover, "such appears *not* to be the case."

In examining aspects of the wrist, shoulder, pelvis, and thigh bone in these two species, McHenry came to the following conclusion: "Except in relatively minor details, the postcranium in the first bipeds, *A. afarensis* and *A. africanus*, are very similar to one another and unlike any living hominoid [apes and humans]." McHenry had expected to see differences between the two species, some degree of change in a human direction between *afarensis* and *africanus*, for example. Instead he saw stability, stability of an identifiable *Australopithecus* locomotor adaptation, which was distinct from the modern human adaptation.

For many years McHenry had interpreted the presence of certain primitive aspects of the locomotor skeleton of *africanus* as the result of an absent or weak selection pressure on them, a view he called the "baggage hypothesis." But having done the comparison with *afarensis* and seen the continuity of so many such characters, McHenry believes that this explanation is "much less likely." In other words, these primitive characters might well be an integral part of a specific australopithecine bipedal adaptation.

For instance, the most striking feature of the early *Australopithecus* skeleton is the curved hand and foot bones, which, says McHenry, must imply significant tree-climbing in the daily lives of these creatures. This is not to say that these early hominids shuffled along in a stooping, simian gait when they walked on the ground. Rather, suggests McHenry, *Australopithecus* bipedality involved "different firing patterns of the muscles, different movement of the hip joint, and so on. They were nuances on the striding gait, that's all."

For McHenry, the most significant aspect of these studies is that they add emphasis to the notion of mosaic evolution, a dissociation between evolutionary change in different parts of the body. Upright walking preceded dental changes, which in turn preceded significant enlargement of the brain. The evolution of hominids did not, apparently, involve a large feedback loop that tied these three human characters together as one. "Our reconstruction of the lifeways of these early hominids must take this fact into account," McHenry urges. ■

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ADDITIONAL READING

C. O. Lovejoy, "The origin of man," *Science* **211**, 341 (1981).
A. R. E. Sinclair, M. D. Leakey, M. Norton-Griffiths, "Migration and hominid bipedalism," *Nature (London)* **324**, 307 (1986).
W. Leutenegger, "Origin of hominid bipedalism," *ibid.* **325**, 305 (1987).
H. M. McHenry, "The first bipeds," *J. Hum. Evol.* **15**, 177 (1986).

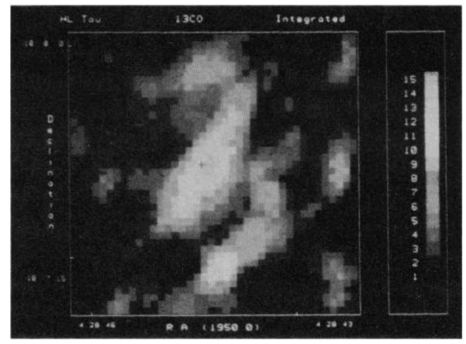
Glimpses of Solar Systems in the Making

New observations at both visible and radio wavelengths are allowing theorists to test their ideas of how planetary systems come to be

BEFORE the flight of the Infrared Astronomy Satellite (IRAS) in 1983, astronomers' understanding of planetary formation could have been described, with only slight exaggeration, as a huge edifice of theory balanced on a single data point of fact: our own solar system. Since then, however, researchers have been able to expand their empirical base considerably. The all-sky infrared survey conducted by IRAS turned up some two dozen nearby stars that showed "infrared excesses," interpreted as heat from extended disks of gas and dust surrounding each star. Since these were exactly the kind of disks that observers had expected to find around stars that were forming planets, the IRAS discoveries have been followed up by a flurry of ground-based observations. Among the fruits of that effort are three new results presented in Pasadena, California, at the January meeting of the American Astronomical Society.

■ β *Pictoris.* Although β Pictoris is an inconspicuous object to the naked eye—at a distance of 53 light-years it is only the second brightest star in the dim southern constellation of Pictor, the painter's easel—it is actually an A5 star, several times brighter and more massive than the sun. It appears to be less than 1 billion years old, allowing for considerable uncertainty, and is thus quite young by stellar standards.

In April 1984, after IRAS had identified β Pictoris as having an infrared excess, Bradford A. Smith of the University of Arizona and Richard J. Terrile of the Jet Propulsion Laboratory managed to obtain an image of the source. They verified that β Pictoris is indeed surrounded by a disk: the structure appears edge-on from our vantage point and extends at least 400 astronomical units to either side of the central star. (One astronomical unit is about 150 million kilometers, the distance from the earth to the sun. For comparison, Pluto is 40 astronomical units from the sun.) On the other hand, Smith and Terrile's image covered only one wavelength band, centered around 0.89 micrometer at the far red end of the visible spectrum. They were therefore unable to say much about the size and composition of the particles in the disk. Now, however, two

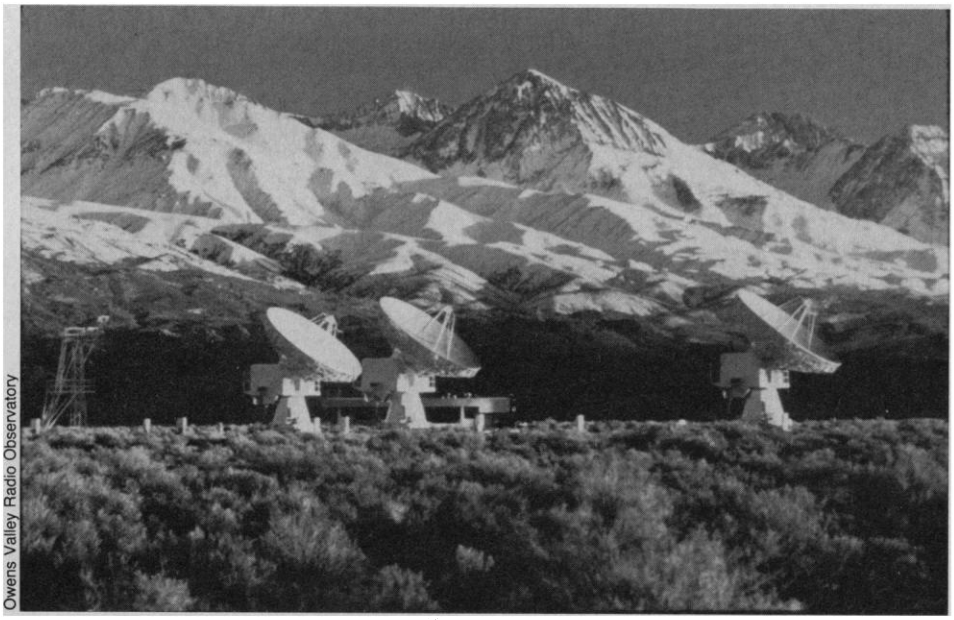


The disk around HL Tauri. *As shown in this map of carbon monoxide around the star, the disk extends roughly 1000 astronomical units outward from HL Tauri and is nearly edge-on to Earth. Steven Beckwith and Anneila Sargent have found that the disk rotates according to Kepler's laws of planetary motion.*

independent groups have rectified that problem. Benjamin Zuckerman of the University of California, Los Angeles, and his colleagues* have imaged the disk in three wavelength bands, centered at 0.45, 0.55, and 0.9 micrometer. Francesco Parsce and Christopher Burrows of the European Space Agency, currently on assignment to the Space Telescope Science Institute in Baltimore, have imaged the disk in four wavelength bands covering the same range.

On the most important fact the two groups are in agreement: within the admittedly large errors (about 20%), the reflectivity of the disk material is independent of wavelength. If anything, it is slightly tilted toward the red. This immediately suggests that the light from β Pictoris is being reflected from particles that are considerably larger than 1 micrometer. If the particles were much smaller than that, their size would be less than the wavelength of visible light and they would scatter much more strongly at the shorter wavelengths. (This size effect, which was first analyzed by Lord Rayleigh in the 19th century, arises from the wave nature of light and has nothing to do with what the particles are made of; in Earth's

* Jonathan Gradie and Joan Hayashi, University of Hawaii; Harland Epps, University of California, Los Angeles; Robert Howell, University of Wyoming.


Owens Valley Radio Observatory

The Owens Valley millimeter-wave interferometer. *Operated by the California Institute of Technology, the recently constructed interferometer consists of three movable radio telescopes, each 10.4 meters in diameter. At their widest separation they have the resolution of a single dish 100 meters across.*

atmosphere, for example, the scattering of sunlight from air molecules is what makes the sky blue.)

At the same time, as Zuckerman points out, the IRAS measurements *do* show a strong falloff at longer wavelengths. If one assumes that the visible and infrared emissions are coming from the same particles—which is by no means certain—then the data are consistent with an average particle size of roughly 4 micrometers. Such particles would be similar to those seen in the comas of comets within our own solar system, says Zuckerman. However, he estimates that the total mass of particles in the disk is about that of Jupiter, or about 1000 times the mass of the comets that are known to orbit on the outskirts of our solar system.

Alternatively, as Burrows suggests, the data may be revealing compositional differences in the disk. For example, the emissions seen in visible light may come from icy particles that reflect the starlight, whereas the emissions seen by IRAS may arise from dark, rocky grains that absorb the light and then reradiate the energy in the infrared.

In any case, the β Pictoris particles are far larger than typical interstellar dust grains, which average about 0.1 micrometer across. This may mean that the particles are dust grains that have somehow agglomerated into larger chunks. Or they may be fragments of material produced by collisions of larger bodies in the β Pictoris system. Either way, the disk material is clearly being processed in some fashion. One key question is just what kind of processing has gone on in the regions of the disk right around β Pictoris. The star is already old enough to have formed planets there, if a planetary system is going to form at all. But for now, at least, direct observation of those planets is still beyond the resolving power of ground-based telescopes.

■ *HL Tauri.* Lying just north of the Hyades cluster in the constellation of Taurus, the bull, this star appears to be considerably younger than β Pictoris. Indeed, it is still embedded in the Taurus Dark Cloud, the molecular cloud that gave it birth. Moreover, previous observations of its circumstellar disk show submicrometer-sized grains, more in line with interstellar grain sizes.

In the most recent observations, however, Steven Beckwith of Cornell University and Anneila I. Sargent of the California Institute of Technology have bypassed the solid material in the disk and have gone after an even more important component: the gas. Using Caltech's Owens Valley millimeter-wave interferometer, they have mapped the emissions from carbon monoxide in the disk, which serves as a tracer for the much more abundant (but harder to see) hydrogen gas. More precisely, they have mapped the emissions from molecules containing the carbon-13 isotope; the molecules containing carbon-12 are so abundant that the disk is essentially opaque at their emission wavelength and information is lost.

First, their observations have verified that the material around HL Tauri does indeed form a disk, which had not been completely certain before. The system is like β Pictoris in that the disk lies nearly edge-on to Earth. But it is also considerably larger: about 1000 astronomical units in radius.

Second, Beckwith and Sargent have found that the gas molecules revolve around the star in Keplerian orbits. Doppler shifts in the carbon monoxide emissions show that the gas on one side of HL Tauri is moving toward Earth, while the gas on the other side is moving away. Moreover, the gas lying closer to the star is moving faster than the gas lying farther out. Of course, this is exactly what one would expect in a protoplanetary disk. But as Beckwith points out, it is gratifying to confirm that prediction nonetheless.

And finally, Beckwith and Sargent have obtained an accurate estimate of the total mass of the disk: about one tenth the mass of the sun, or some ten times the mass of all the planets in our own solar system put together. "It's huge," says Beckwith, "a factor of 50 more than the previous lower limits." On the other hand, he says, this is also what one would expect: the current thinking is that a nascent solar system will generally start out with quite a bit more mass in the protoplanetary nebula than eventually winds up in the planets themselves. "So the new observation raises the mass into just the right range for the theories," he says.

■ *T Tauri.* Zuckerman, his UCLA student David A. Weintraub, and Caltech's Colin R. Masson have used the Owens Valley interferometer at carbon monoxide wavelengths to identify two concentrations of gas about 500 to 600 astronomical units out from the star T Tauri, which lies quite close to HL Tauri in the same molecular cloud complex. Each gas blob is approximately the mass of Jupiter, and each appears to orbit T Tauri roughly in the plane of the sky.

T Tauri is already famous as the prototype for a whole class of newborn, low-mass stars: the "T-Tauri" stars. It is also known to be a highly complex double-star system containing one member that shines more or less in the clear and a companion about 100 astronomical units away that is so shrouded in dust that it can be observed only in the infrared. On the other hand, such complexity may actually mean that T Tauri is more typical than our own sun, since some 80% of the stars in the galaxy are also members of multiple-star systems. Thus the importance of the T Tauri gas blobs: "It's one of the fundamental questions about planetary formation," says Zuckerman. "Can planets form in binary systems? And if so, are their orbits stable?" These new observations may help provide an answer. ■

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ADDITIONAL READING

B. A. Smith and R. J. Terrile, "A circumstellar disk around β Pictoris," *Science* **226**, 1421 (1984).