PERSPECTIVES: ASTRONOMY

Dusty Disks and Planet Mania

Paul Kalas

One of the great astronomical discoveries of the 1980s was that there exist stars, some like our sun, surrounded by circumstellar disks that are replenished by larger, unseen parent bodies such as asteroids and comets (*1*). Thus, a decade before Mayor and Queloz proved that the star 51 Pegasi is accompanied by an object with a mass comparable to that of Jupiter (*2*), astronomers had dusty evidence that small, solid objects had formed and continue to generate dust around other stars. Unfortunately, the space telescope that provided these results, the Infrared Astronomical Satellite, did not have sufficient resolution to directly map the spatial distribution of the circumstellar dust.

These same dusty disks appeared in science headlines again in April because several were spatially resolved by a new generation of ground-based instruments (*3*). These cameras are sensitive to thermal radiation with wavelengths between 10 μm and 1 mm. An advantage of observing in this range is that it is easier to detect objects next to optically bright stars.

A compelling case is HR 4796, a star that Jura discovered in 1991 to have thermal emission from warm, circumstellar dust (*4*). Observers using optical and near-infrared cameras tried to image the postulated dust disk (*5*), but the disk was too close to the bright central star. Now, using cameras sensitive to 20-μm wavelength radiation, two observing teams have mapped emission from a dust disk that stands out clearly as a peanutlike shape 3 arc seconds across (*6, 7*). At the distance to HR 4796, this corresponds to a diameter of 200 astronomical units (AU), and the waist in the middle is due to a central cavity in the dust disk. But one of the most interesting aspects of this disk is that a companion star lies just 500 AU or more away. This is good news because half of all stars belong to multiple systems, and HR 4796 demonstrates that solid objects can orbit stably even when another star is located relatively nearby.

In this case, the news headlines announced "Scientists Find Evidence of Planets in Formation," a claim borrowed directly from the astronomers' press releases (*8, 9*). Unfortunately, the new data provide only weak support for this enticing conclusion. First, the astronomers argue that HR 4796 is about the right age to form planets and, therefore, planet formation explains the dust disk with its central cavity. Would you agree with a doctor who takes your photograph and concludes that you have cancer because you are about the right age to have cancer? (Well, you might ask for more tests, but the direct evidence is lacking.) Second, our knowledge of planet formation applies to solar-type stars, not necessarily to more massive and more luminous A-type stars such as HR 4796.

P. KALAS

Dust at dusk. The zodiacal dust cloud, Comet C/1995 O1 (Hale-Bopp), Taurus, and the Pleiades from Calar Alto, Spain. The zodiacal light is due to a disk of dust around the sun that is replenished by the debris of objects such as Hale-Bopp.

Finally, consider the following discrepancy: Holland *et al.*, using a camera sensitive to wavelengths near 1 mm, reported in the same week several ground-breaking maps of dust around Vega, Fomalhaut, and Beta Pictoris (*10*). The advantage of maps in this wavelength regime is that the dust emission is directly related to the dust mass. Fomalhaut's dust disk shows a central hole, much like that around HR 4796. Vega's dust disk, though, has a "blob" of enhanced dust emission at about 70 AU, but with no obvious hole in the center. The dust map of Beta Pictoris has a prominent blob 600 AU from the star, slightly above the disk plane. Holland *et al.* speculate that the blobs represent local concentrations of dust due to the gravitational influence of unseen planets. Thus, for HR 4796 and Fomalhaut, planets create central cavities in the dust distribution, whereas for Vega and Beta Pictoris, planets produce local concentrations.

Could the apparent discrepancy result from "planet mania," a bias among astronomers in which every cavity and blob, even a wiggle, in circumstellar dust disks is taken as evidence for extrasolar planets? Which dust-planet relation does theory favor?

Theory supports both interpretations. One can show that gravitational perturbations from a planetary object will eventually create a cavity in a dust disk (*11*). But does Earth create a dust cavity in our own zodiacal dust cloud (see figure)? Actually, observations, which are well modeled by Dermott, show that Earth creates a wake of dust as it moves through its orbit (*12*). This dust wake looks like a large blob following Earth, but with a diameter roughly 1000 times greater.

At present, therefore, we cannot uniquely identify the cause of the dust blobs and dust cavities near these four stars. Planet-mass objects are just one of the physically possible ideas. The astronomers state this clearly in their journal articles, guarding against the planet mania label. For the unconvinced optimists, one should know that all four stars are more massive than the sun and each will have a total lifetime of about 1 billion years. Thus, life as evolved as it is on Earth will never have time to develop on the hypothetical planets.

One can better argue that at least smaller objects, such as comets and asteroids, are responsible for replenishing the short-lived dust. The inclinations of the dust disks to the line of sight approximate the inclinations of unseen parent objects. If a Jupiter-mass planet is ever indirectly found around one of these stars, then knowledge of the system's inclination will help constrain the planet's orbit and mass.

The new dust maps also convincingly give the total mass of dust around these stars, which to first approximation decreases linearly as a function of age. On a heuristic note, the decrease in dust mass inversely proportional to age does not compare well against the early evolution of our solar system. The cratering histories of the moon, Mercury, and Mars give a rough idea of how much debris existed around the sun. We find that the cratering rate decreased as age^{-3} for the first billion years after planet formation and then tapered to age^{-1} after that. The difference in debris time scales may demonstrate that other

The author is at the Max-Planck Institute for Astronomy, Koenigstuhl 17, D-69117 Heidelberg, Germany. E-mail: kalas@mpia-hd.mpg.de

planetesimal systems form and evolve quite differently than our solar system.

In the most recent extrasolar planet "discovery," Terebey and her collaborators purport to actually image a candidate planet with the Hubble Space Telescope (*13*). The key to interpreting the faint point of light they observe as a planet is knowing the distance—if it is very far away, then it could be a background star. Terebey's group finds this distance by claiming that the planet is physically associated with a stellar system of known distance, as evidenced by a streak of dust-scattered light connecting the two.

Their interpretation is bold because anyone who has photographed the sky in regions that are rich in star formation finds all sorts of filaments and arcs of dust that are produced for a variety of reasons, none associated with planets. Background stars can peek out from behind the dust, but Terebey's group claims only a 2% chance of seeing a background star in their field. Nevertheless, a background star remains as a viable alternate interpretation.

Even if the object lies at the distance claimed, it is also possible that the candidate planet is a star whose light is dimmed by foreground dust. One fascinating case in point is the companion to the binary star HK Tauri. At the June meeting of the American Astronomical Society, Stapelfeldt and Koresko revealed that what was previously considered a star is actually a tiny reflection nebulosity created by a young star that itself is completely hidden by foreground dust (*14*).

A more critical problem with the planet interpretation is that the streak of dust connecting the candidate planet to the stellar system coincides with a ridge of dense gas along the edge of a stellar outflow cavity mapped by Hogerheijde (*15*). Therefore, it seems more likely that the arc is created by a well-known stellar phenomenon rather than the slight gravitational influence of an ejected Jupiter. The latter point has been tested by Mac Low, Bate, and Burkert (*16*), who find that a Jupiter-mass planet cannot produce a trail of material as large as the one observed. In summary, a key piece of evidence required to support the planet interpretation—its spatial association with the young binary stars to the northwest—is lost.

The Terebey group plans to obtain a spectrum of the object, which should pin down its physical nature. Astronomers will certainly be finding new extrasolar planets in the near future, but in this case the existing evidence suggests that planet mania has struck once again.

References and Notes

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PERSPECTIVES: THE GLOBAL CARBON CYCLE

In Balance, with a Little Help from the Plants

Pieter P. Tans and James W. C. White

Our industrial civilization needs energy and lots of it. The major source of that energy has been coal, oil, and natural gas. What has happened so far to the carbon dioxide emitted into the atmosphere as a result? About half remained airborne, contributing to the concern about man-made climate change, but where did the rest go?

It is overwhelmingly clear from the geologic record of trace gas concentrations preserved in ice and firn that the atmospheric concentration of CO_2 is much higher now than during the past hundreds of thousands of years (*1*). Its rise has been especially steep during the latter half of the 20th century. These facts continue to surprise some people who point out that the annual rate of CO_2 emission from fossil fuel burning is less than one-tenth that of natural processes such as global photosynthesis or the exchange of CO_2 between the atmosphere and the oceans. Furthermore, the oceans contain 50 times more carbon than the atmosphere. How could there possibly be a problem?

There are three reservoirs of carbon in constant exchange with each other: the atmosphere, the oceans, and the terrestrial biosphere, consisting of plants and soils. The oceanic and terrestrial reservoirs are in near equilibrium or near steady state with the atmosphere, with enormous fluxes of carbon moving to and from the atmosphere, in each case nearly canceling each other. However, it is the small noncanceling ("net") portion that causes atmospheric CO_2 to increase or decrease. For decades, the emissions from fossil fuel burning have been substantially larger than either the net exchange with the oceans or the net difference between photosynthesis and respiration.

Exchange with the really large geological reservoirs, such as limestone, is so slow that for thousands of years the carbon added to the atmosphere will stay confined to the three "mobile" reservoirs mentioned above. Neglecting the biosphere, we can calculate that, once steady state has been restored after 1000 years or so, 85% of today's emissions will have been added to the oceans and 15% to the atmosphere. Worse, the atmospheric portion will increase with continuing emissions. Thus, we are either committing our Earth "permanently" to enhanced greenhouse forcing or ourselves to never-ending global management of carbon stocks.

Early estimates of huge losses of carbon from plants and soils due to biomass burning and deforestation (*2*) have recently given way to the idea of a terrestrial biosphere nearly balanced (globally) with respect to carbon. From a climate management point of view, this is good news. Apparently, we are getting an assist from plants. This change in thinking was forced most strongly by atmospheric data. There are now seven independent lines of evidence.

First, carbon-cycle modelers have always had difficulty accommodating high terrestrial emissions in their model oceans calibrated with ^{14}C and tritium from nuclear tests and with chlorofluorocarbons (*3*). The smaller than expected north-south gradient of atmospheric CO_2, combined with data on the partial pressure of CO_2 in

P. P. Tans is at the Climate Monitoring and Diagnostics Laboratory, National Oceanic and Atmospheric Administration, Boulder, CO 80303, USA. E-mail: ptans@cmdl.noaa.gov. J. W. C. White is at the Institute of Arctic and Alpine Research and the Department of Geology, University of Colorado, Boulder, CO 80309, USA.