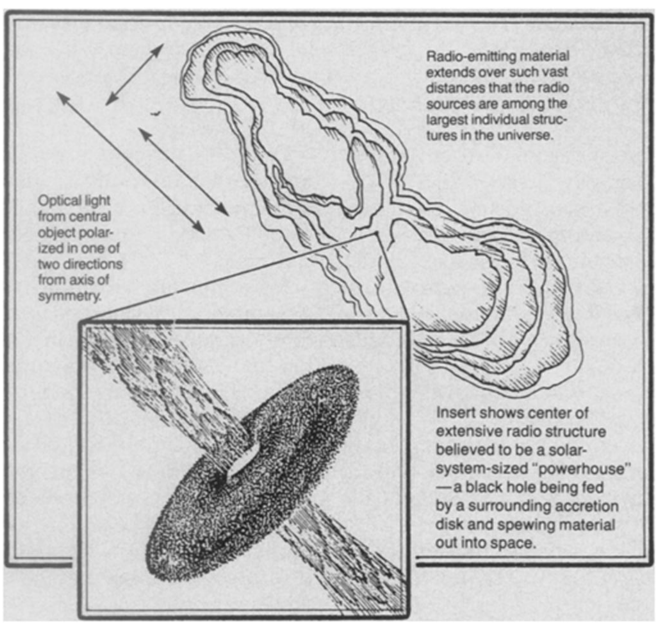
Swallow Transsonically and Stay Fat

Fat lasts; thin fades for accretion disks according to new supercomputer calculations

By DIETRICK E. THOMSEN

You can't be too rich or too thin in Beverly Hills, so they say. And a lot of the world takes its style cues from that town. However, there is at least one place in the universe where thin is ephemeral and fat means stability and durability. That is in accretion disks, the disks of matter that astrophysicists suppose surround such things as black holes and maybe other condensed objects like white dwarf stars. These disks could provide a lot of energy, and so structures of this kind — a condensed object surrounded by an accretion disk — could supply the energy for such things as quasars, active galaxies and similar high powered astronomical phenomena.

The prescription for fatness is one of the things confirmed by a recent supercomputer calculation of the conditions under which accretion disks can exist performed by John F. Hawley and Larry Smarr of the University of Illinois at Urbana — Champaign and James R. Wilson of the Lawrence Livermore Laboratory in Livermore, Calif. At the same time as theoretical belief in accretion disks was thus being strengthened, Joseph Miller of the University of California's Lick Observatory and Robert Antonucci of the National Radio Astronomy Observatory were doing observations that they now say give the strongest evidence yet that disks are actually there.



UC Santa Cruz

Disks are supposed to form because of the strong gravitational field of a black hole. The forces it exerts draw matter from the surroundings, from a companion star if the black hole has one. If this matter came straight on, it would fall down the black hole and disappear from the known universe. However, it ought to come with a certain amount of angular momentum, that is, rotary motion. If it comes off a rotating or orbiting star, it will certainly carry some of the rotary motion with it. Aside from such an obvious case, it is a truism among astrophysicists that nearly all the matter in the universe participates in a rotary motion of some kind.

So nature throws the black hole a curve, so to speak. Matter that comes on with angular momentum is likely to go into orbit. If the situation were Newtonian, it all would go into orbit. Some matter would be captured into elliptical orbits; some might take hyperbolic or parabolic paths as nonperiodic comets do around the sun.

The black hole case, however, has to be calculated by Einsteinian general relativity. Here some of the material, even though it has angular momentum, will go directly down the hole because there is a minimum angular momentum below which it will not go into orbit. The stuff that does go into orbit will generally form a disk in the equatorial plane of the rotating black hole. (These solutions are for rotating black holes.) How much goes directly down the hole; how much stays in the disk? Is the disk stable? Does viscosity in the disk dissipate the angular momentum and lower it enough that after a short time everything vanishes down the hole? Or can the disk recoup its losses by continuous recruitment from the outside?

Smarr says that previous theoretical models were not realistic enough to give good answers to these questions. Derived by mathematical analysis, they were forced to adopt too many simplifying assumptions and ignore too many details. Before supercomputers were available, he says, nobody had really been able to put down the equations and calculate.

Mathematical analysis is a very powerful technique when it works. It involves manipulating equations by the techniques of disciplines such as algebra and calculus. If an analytic solution can be found, it will be very general. It will provide answers to a whole lot of related particular problems. But often an equation is such that analysis is powerless to solve it, or the solution involves a monumental amount of work. Recourse is then had to numerical solutions, calculating out with numbers, usually for a specific problem or problems.

Computers are very good at numerical solutions. As computers have improved, the variety of problems susceptible to numerical solutions has increased tremendously. This one required one of the biggest and fastest supercomputers. It was done on the Cray I computer at the Max Planck Institute in Garching near Munich, and took 30 hours of its time.

Analysis usually works with continuous or nearly continuous equations. The equations are functions. That is, they relate the value of one quantity to the value of one or more other quantities. It could be, for example, the pressure of gas in the accretion disk related to location in the disk. Given the equation one can calculate the pressure at any point. Then one can calculate the pressure at a nearby point, and the nearby point can be infinitesimally close to the first one. This imperceptible shading of point into point, value into value is characteristic of continuous equations and illustrates their power as calculational tools.

The computer does not deal with continuous equations, however. For the numerical solution, they have to be converted into finite difference equations. Instead of being valued at points infinitesimally close together, the equations are valued at a series of points a set (finite) distance apart. The computer does its number crunching — and there is a tremendous amount of number crunching to do — with the differences between these set points. As the calculations deal with quantities that vary over space, the technique is equivalent to casting a net over the space occupied by the accretion disk. Usually in this kind of procedure all the equations are valued at the same points, but in this one some equations are valued on the lines of the net, some in the middle of the spaces. This innovation yields a better solution, the researchers say.

Smarr says he spent the last three summers in Munich doing the computation. There is a Cray I at Livermore, and it did some of the work, but problems of secrecy made its use impractical. If Hawley, for example, had wanted to go to Livermore to do the work, he would have had to get a "Q" clearance. This is a difficult and tedious proceeding. Munich is one of the few places in the world where a supercomputer is available in a nonsecret laboratory. The experience has prompted Smarr to start working with the National Science Foundation to obtain funds for a few supercomputer centers to be available to university researchers without the necessity of security clearance.

The completed calculation shows some surprises compared to previous theoretical models. One of the longstanding questions was whether the disks ought to be thin or thick in the polar direction. This calculation shows that, if thin disks form, they are likely to be transient; fat disks will persist.

The inner edge of the disk can be closer to the black hole. Its location depends on where the centrifugal force generated by the angular momentum of the gas just balances the inward gravitational pull. This turns out to be only about half as far from the black hole as previously thought. The inward flow of the gas is transsonic, so at this inward edge a shock forms. The shock sends waves back through the disk, and the consequent heating and gas pressure puff the disk into a fat doughnut. The disk could stay flat only if it had an (unlikely) method of radiating the heat away very fast.

The shock also generates a hydrodynamic instability called a Rayleigh-Taylor instability, which permits hot bubbles and fingers to form in the gas. These have a tendency to shoot out along cones centered on the rotation axis of the black hole. This makes an interesting connection to observation, as many quasars and active galaxies have associated with them teardrop-shaped lobes of radio-emitting material that could have been shot out in this fashion. With all this going on, Smarr says, very little of the material actually

Three stages in the development of an accretion disk imaged in false color by computer graphics. The black hole is the dot in the center.

Hawley and Smarr

Here, bubbles and fingers of hot matter generated by a Rayleigh-Taylor instability have formed.

Here, the bubbles and fingers extend themselves. Eventually the matter in them will shoot outward along the dark red cones.

gets to fall down the black hole — about one percent.

Over about the same few years Miller and Antonucci, who started out as a graduate student at the University of California at Santa Cruz campus, where the Lick Observatory is headquartered, have been measuring the polarization in the light from quasars. Quasars appear in the telescope as points of light. Detail cannot be distinguished, so evidence of structure must be indirect.

Light from the centers of quasars ought to be generated unpolarized, that is, vibrating in random directions. Yet Miller and Antonucci found some quasars with significant polarization parallel to and some with polarization perpendicular to the direction of the axis of the radio-emitting lobes.

Light that is unpolarized can be polarized by being reflected. Where the polarization is parallel to the axis, the amount of polarization is fairly small. This leads to the conclusion that the polarized light has been reflected off a thin (and probably transient) accretion disk, while at the same time a lot of unpolarized light is coming to us directly. In the case of parallel polarization the proportion of polarized light is quite high. This would indicate that the light had come out past a fat and relatively darker accretion disk and been reflected toward us by matter that happened to be in the neighborhood. Miller and Antonucci conclude: "Our findings give new support for the accretion disk picture." □

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New Hope for Binge Eaters: Advances in the Understanding and Treatment of Bulimia — Harrison G. Pope Jr. and James I. Hudson. Explains bulimia, the syndrome of compulsive binge eating followed by purging, and answers the questions of those who suffer from the disorder. Offers a detailed description of new studies in which bulimia has been linked to depression and bulimia sufferers have been treated successfully with anti-depressant drugs. Har-Row, 1984, 239 p., $14.95.