

because the energy and momentum of electrons can be conserved in optical interactions, thus permitting amplification to occur, and its bandgap energy can be adjusted to correspond to the region of photon energies for which the loss of optical fibers is a minimum.

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THOMAS REPLIES: Tom Pearsall is right about our SOA error, and we're grateful to him. Based on the responses I've received, many teachers and lecturers have also read the article with "great interest," and have been passing on the (now corrected) optical communications information to their students.

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Insect Flight Simulation Resembles Navier-Stokes

We read with interest the article on the most recent accomplishments in insect hovering research (PHYSICS TODAY, December 2000, page 22). We would like to draw attention to work published a decade earlier,^{1,2} which seems to have been missed by the author, that expressly resorted to the same two-dimensional simplifications to investigate and explain the essence of insect flight.

Over a decade ago, the complexities of insect flight so apparent in the seminal paper by Christopher Soms and Marvin Luttges³ inspired us to design an experimental apparatus. It allowed us to study 2D vortex shedding and thrust generation by an airfoil undergoing translation and pitching that resembled insect wing motions during hovering flight.¹ Almost concurrently with the experimental work, we realized that the hovering jet generated by the physical model was amenable to computational Navier-Stokes simulations.² The numerical simulations gave good agreement with measured results.

References

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Black Hole Candidates Weigh In

The article "Chandra X-ray Observatory Examines a New Kind of Black Hole" (PHYSICS TODAY, November 2000, page 19) introduces the topic of mass determination for astrophysical black hole candidates (BHC).

Several existing methods for "weighing" a BHC are detailed in current astrophysics literature. If the BHC is in a binary system, it is sometimes possible to estimate its "mass function," a lower limit on its mass, through optical photometry and spectroscopy. A more difficult challenge arises when the object is not part of a binary system and gravitational effects cannot be exploited. Andrew Ptak and Richard Griffiths¹ made x-ray flux estimates for a prominent pointlike source in the galaxy M82, arguing that the flux comes from a discrete, compact object.

Assuming the source in M82 is radiating at a substantial fraction of the Eddington limit, Ptak and Griffiths estimated a lower mass limit of about 500 solar masses. But this approach provided only a crude estimate, and uncertainties could span three orders of magnitude.

More precise estimates of BHC masses are presented by Edward Colbert and Richard Mushotsky,² who studied spectra from nearby galaxies with a Comptonization model.^{3,4} In this model, the low-energy blackbody x-ray photons are assumed to come directly from the thin accretion disk, whereas the hard photons that form the power-law tail of the spectrum come from upscattering by the energetic electrons rushing toward the black hole. This is analogous to shock acceleration of particles. To determine mass, the idea is to extract the blackbody component from the emergent spectrum whose shape is modified by Compton scattering off hot electrons.³ The intensity of the blackbody radiation depends on the emission area of

the accretion disk. Depending on the color temperature, typically $kT = 0.2 - 1.2$ keV, the effective radius of this area can be 5 to 15 Schwarzschild radii.

The next problem is to determine a ratio of color to effective temperature, the so-called color factor. This characterizes the deviation between the emergent spectrum and a pure blackbody. For the pure blackbody case, the luminosity per unit area is a product of the fourth power of the temperature and the Stefan-Boltzmann constant. Equating the observed, integrated luminosity to this expression yields a different temperature from that inferred from the blackbody spectral fit. This phenomenon is well known in solar and stellar astrophysics. For example, the Sun has an effective temperature of 5500 K, but its spectrum is not described by a 5500-K blackbody. Physically, this difference results from scattering effects in the solar atmosphere, through which we view the substrata to about an optical depth of one.

For BHCs in our Galaxy, the appropriate color factor can be determined theoretically by invoking assumptions about the accretion disk, or empirically by using a source with a known black hole mass and distance. One must then assume that the color factor inferred is approximately invariant. Our group calibrated the color factor using a source, GRO J1655 - 40, with known mass, distance, and orbital inclination.⁴ The color factor thus obtained was approximately 2.6. The inferred spectral parameters then allow a distance-to-mass determination. For sources in our Galaxy, distances are often crudely determined, but in external galaxies they are generally more precise.

Thus, finally we may determine the only remaining unknown—the black hole mass. This method was applied to a number of galactic sources.^{3,4} Comparison of our results with those obtained by other methods suggests an accuracy of better than 30%.

One of us (Titarchuk) applied this technique to nearby Galaxy spectra obtained by Colbert and Mushotsky² and found BHC masses of about 120, 600, and 10^4 in spiral galaxies M33, NGC 1313, and NGC 5408, respectively. These results provide compelling evidence that "middleweight" black holes may exist near the centers of three spiral galaxies.