

above. One exciting possibility is that Archean ophiolites may hold clues to the nature of an early subsurface biosphere at ancient mid-ocean ridges, at the time of the earliest known life on Earth (13).

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14. Lavas: Basaltic pillow lavas, Mid-Atlantic Ridge, about 3 m wide; photo taken from submersible Alvin. Sheeted dike complex: exposed on a steep cliff, Hess Deep Rift, eastern Pacific Ocean, about 6 m wide; mosaic of digital images from Argo II ROV, about 6 m wide. Plutonic complex: interlayered gabbroic and ultramafic plutonic rocks from the Smartville Ophiolite Complex, California, about 1 m across. Residual mantle tectonites: depleted upper mantle peridotite from Bay of Islands Ophiolite Complex, Canada, about 4 m across.

PERSPECTIVES: ASTRONOMY

How to Find a Stellar Black Hole

Joseph F. Dolan

Black holes are now widely accepted as the cause of many phenomena in astrophysics, from supermassive black holes at the centers of galaxies to stellar-mass-sized black holes in x-ray binaries (1). Black holes are the simplest objects physics can think of to explain the behavior of these systems. There remains the theoretical possibility, however, that these objects may be more exotic than black holes. Recent observations have come tantalizingly close to ruling out more exotic objects in x-ray binaries, providing the best evidence yet that stellar-mass-sized black holes must exist.

In compact stars, the inward force of gravity acting on the star's outer layers is balanced by the pressure generated by the Pauli exclusion principle acting on its electrons (in white dwarfs) or nucleons (in neutron stars). The star is in equilibrium when its total energy, E (the sum of the positive energy associated with the pressure generated by the Pauli exclusion principle and the negative gravitational energy), is at a minimum. Chandrasekhar first showed (2) that compact stars have a maximum mass, M_{max} , beyond which they are not stable. If the mass is more than about 1.5 times the mass of the sun, M_{sun} , then E can be decreased without being bound by decreasing the star's radius and increasing its (negative) gravitational energy. No equilibrium radius exists, and general relativity predicts gravitational collapse to a point singularity—a black hole.

The black hole is not visible to the outside world, however. Schwarzschild found (3) that according to general relativity, no signal can reach the region of space-time

outside the Schwarzschild radius

$$R(S) = 2GM/c^2 \sim 3 M/M_{\text{sun}} \text{ km} \quad (1)$$

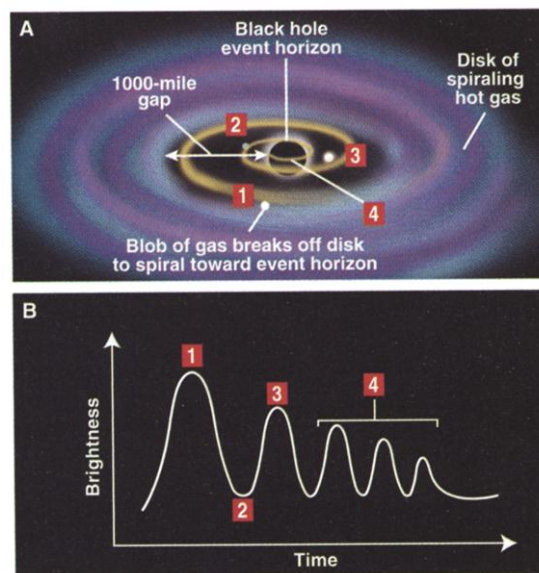
from the region inside, where M is the mass of the black hole, c is the speed of light, and G is the gravitational constant. (The time coordinate also goes to zero at this distance.) The boundary between the

minimum mass above M_{max} ; for example, $M > 6 M_{\text{sun}}$ for Cyg XR-1 (4). This ruled out a white dwarf or neutron star but still allowed more unusual objects, such as a Q star (5). Two recent studies now report what are likely to be signatures of an event horizon, and thus of a black hole, in such x-ray binary systems.

Garcia *et al.* (6) used the Chandra satellite to monitor the x-ray luminosity of six candidate black-hole transients in quiescence. (Transient x-ray sources exhibit episodes of outburst lasting several weeks separated by long periods of extremely low luminosity, a behavior connected to episodic mass transfer from a companion star.) Quiescent black-hole transients were 1/100th as luminous in x-rays as quiescent neutron-star transients with similar orbital periods. The authors attribute the effect to the fact that most of the radiation generated locally in the quiescent accretion disk disappears across the event horizon of the black hole.

This method for detecting an event horizon requires knowledge of the local luminosity that the system produces in the accretion disk. Garcia *et al.* use an advection-dominated accretion flow (ADAF) model of the disk to calculate its local luminosity. It has been suggested (7) that adiabatic inflow-outflow solutions (ADIOS) may instead be operating in transients during quiescence. In this case, most of the energy generated by accretion would be carried away from the central object by mass outflow above and below the plane of the disk. The low luminosity observed would not be directly related to the existence of an event horizon, or possibly even a black hole. Theoretical work still needs to be done on the nature of the accretion in black-hole transients (8).

Another approach to detecting the event horizon of a black hole was proposed by Stoeger in 1980 (9). He proposed that individual flare patches—



Dying pulse trains. (A) A luminous clump of material detaching from the inner edge of the accretion disk spirals into the event horizon and disappears. (B) Photometric signature of the clump's emission.

two regions is called the event horizon. Every black hole will have an event horizon, so the naked point singularity is forever shielded from our view. But because any object with an event horizon must be a black hole, detection of such a horizon would prove the existence of a black hole.

Observations of Cyg XR-1 and other x-ray binary systems have shown that the x-ray source is a compact object with a

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clumps of material whose radiative characteristics stand out above the mean flux of the system—would appear to emit pulsed radiation because of the aberration of light away from the direction of Earth when they orbit on the far side of the black hole (see the figure). The separation between pulses should decrease as the material spirals into the event horizon. The peak intensity of the pulses should also decrease as the material approaches the event horizon because of the Doppler effect in the gravitational potential well of the black hole. The last visible pulse should thus be the weakest. In contrast, if the accreting object had a solid surface, as in a neutron star, the last pulse would be the largest as the material impacted the surface.

Dolan (10, 11) has analyzed high-speed photometer (HSP) data from Cyg XR-1 obtained with the Hubble Space Telescope (HST) (12). He detected two series of pulses in the ultraviolet (UV) that bear the characteristics of a dying

pulse train and thus the signature of an event horizon. The statistical confidence level is not high enough, however, to prove that the pulses are not stochastic variations in the flux (13). Further observational studies of Cyg XR-1 in the x-ray and UV are needed to confirm the presence of dying pulse trains.

Other theories of gravity that are also consistent with the three classical tests of general relativity (14–16) do not predict the existence of black holes and event horizons, which may provide a fourth test of general relativity. In these theories, collapsed objects that are not point singularities can exist, but only radiation directed nearly radially outward can escape from their surface. If the impact of accreting material occurs on a part of their surface not visible from Earth, no radiation would reach us. If the orbital topography near compact objects in these competing theories cannot produce a way to reproduce these observations, the detection of event horizons may be another successful test of the validity of general relativity.

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PERSPECTIVES: DEVELOPMENT

Legs, Eyes, or Wings—Selectors and Signals Make the Difference

Markus Affolter and Richard Mann

People naturally like to compare individuals. Biologists, too, are especially keen to do this and have spent decades cataloging the differences between organisms that display interesting variations in their basic body plans. For the many cases in which such body plan differences are inherited, variations have been traced to specific genes, first in the fruit fly *Drosophila melanogaster* and later in vertebrates. Most of these genes encode evolutionarily conserved transcription factors that control the development of morphogenetic fields, discrete sets of cells that give rise to specific structures in the adult. Such genes are generally referred to as “selectors” because they select distinct developmental pathways that ultimately give rise to structures such as eyes, antennae, legs, or wings in the fly (1). Although these selector genes are known to encode transcription factors, exactly how they orchestrate the development of morphogenetic fields remains something of a

mystery. The study by Guss *et al.* (2) on page 1164 of this issue, provides us with a more detailed understanding of how selector genes might work.

To build a leg or a wing, cells need to know not only which structure they are making, but also where they are located within that structure. A large body of beautiful work has given us an understanding of how a cell knows where it is. Specifically, the generation of positional information within morphogenetic fields is controlled by a small, evolutionarily conserved set of intercellular signaling pathways. In *Drosophila*, these include the epidermal growth factor, Decapentaplegic (Dpp), Wingless, Hedgehog, and Notch signaling pathways. Importantly, for each of these pathways, one of the last steps is the activation of a pathway-specific transcription factor (the signaling effector). Not surprisingly, these same pathways are used repeatedly during development to provide positional information to most, if not all, of the structures in developing animals. Thus, to generate a leg or a wing, the selector transcription factors must somehow interpret the positional information laid down by these signaling pathways (see the figure). How do signaling path-

ways and selector proteins interact with each other in vivo? Is specificity generated during transcription or at a later, post-transcriptional step? And what are the exact contributions of signaling pathways and selector proteins to the final structure?

There are two models to explain how selector transcription factors interpret positional information laid down by signaling pathways. The first model suggests that the target genes of selector proteins and the target genes of signaling cascades are largely distinct. According to this model, the products of the two sets of target genes would interact with each other to provide a cell with both its positional address and its identity. An alternative view posits that signaling pathways and selector proteins share many of the same target genes. According to this model, signaling effector proteins and selector transcription factors would interact with the regulatory DNA sequences (enhancers) that control the expression of these target genes. Several pieces of evidence support the second model. For example, in *Drosophila* a target gene enhancer activated by the Labial (Lab) selector protein also requires input from the Dpp signaling pathway (3, 4). Similarly, a target gene enhancer that is activated in the developing heart is coregulated by the selector protein Tinman (Tin) and the Dpp pathway (5).

The study by Guss *et al.* (2), together with previous work from this group (6), extends these ideas to the fly wing. They show that Scalloped, the DNA binding component of the selector protein complex

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