"web" of baryons. Theorists predict that the missing baryons in these filaments have high temperatures (10^5 to 10^7 K) but low densities, making them particularly difficult to detect (*4*).

At these temperatures, oxygen exists with one, two, or three bound electrons (OVIII, OVII, and OVI, respectively). It is the most abundant element that is not fully ionized under these conditions. OVI has strong absorption lines in the ultraviolet, whereas OVII and OVIII absorb and emit at x-ray energies. Recently, researchers have found the first observational evidence for the "missing" baryons by detecting these absorption and emission lines with four different space-based telescopes.

X-ray and far-ultraviolet absorption lines from oxygen can be detected against some extremely bright active galactic nuclei with the Chandra observatory, Far Ultraviolet Spectroscopic Explorer (FUSE), Hubble Space Telescope (HST), and the XMM-Newton telescope. The strongest absorption lines are not redshifted and hence originate near our Milky Way Galaxy (*5*, *6*). Nicastro *et al.* (*7*) argue that absorption does not occur in our galaxy but in a dilute gas that fills, and may extend beyond, our Local Group of galaxies. This interpretation agrees with theoretical expectations. Several other groups of galaxies are known to contain hot gas from their diffuse x-ray emission.

At redshifts beyond the Local Group, absorption lines from the same oxygen species are seen in the spectra of a few active galactic nuclei. Fang *et al.* (*8*) and Mathur *et al.* (*9*) have detected absorption by intervening OVII and OVIII gas, providing evidence for the hot gas predicted by theory. In the far ultraviolet, Savage *et al.* (*10*) have detected OVI along several sightlines, demonstrating that gas at 10^5 to 10^6 K is plentiful.

In a different approach, we (*11*) have detected hot x-ray–emitting gas with a shadowing technique. Hot diffuse baryons produce a faint x-ray glow around the sky, but other sources of diffuse x-ray emission, such as the Milky Way, must be excluded. This is accomplished by using the cold gas in another galaxy, which absorbs the background diffuse x-rays, leading to a shadow in the background emission that we observe.

The detection of hot diffuse baryons (*7–11*) is a major step in our understanding of the present state of the universe. However, the important quantitative work still lies before us. The most rapid progress is likely to come from efforts to study OVI absorption with FUSE and HST in the next few years. OVI emission will be studied by NASA with a Small Explorer named "Spectroscopy and Photometry of the Intergalactic Medium's Diffuse Radiation," scheduled for launch in 2005.

At x-ray energies, additional efforts are planned to detect absorption and emission from the cosmic web with Chandra and XMM-Newton. These studies are limited to a few of the most favorable targets owing to sensitivity limitations. Such limitations will be overcome by the Generation-X telescope planned by NASA.

Collectively, these observations will determine the mass of baryons in the cosmic web along with their spatial structure and temperature distribution. These data are fundamental to understanding the formation and evolution of the structures in our universe.

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PERSPECTIVES: ASTRONOMY

Microquasar Fireworks

Michael P. Rupen

Over the past decade, astronomers have discovered several transient, highly relativistic jet sources associated with stellar-mass black hole binary systems in our galaxy (*1*). These are called microquasars, by analogy to the much more powerful relativistic jets found in radio galaxies at moderate distances, and to quasars at the edge of the known Universe.

In radio galaxies and quasars, the jets are powered by accretion onto massive black holes. They are surprisingly efficient at transporting the resulting energy out to large distances, often well beyond the edge of the host galaxy (*2*, *3*). There the jet may collide with the intergalactic medium, releasing its bulk kinetic energy in a terminal shock, from which the material flows back to inflate huge radio lobes (see the figure).

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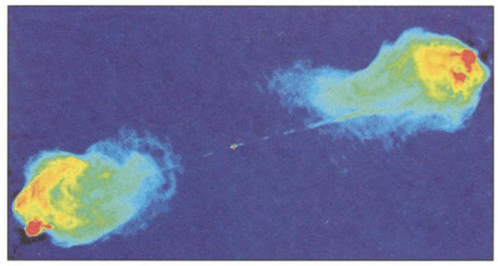

The radio galaxy Cygnus A. A narrow, highly collimated jet links the central core to the outer lobes. The lobes extend to ~195,000 light years from the center—double the optical radius of the host galaxy. The very bright "hot spots" at the ends of the jets are thought to be the areas where the jet hits the surrounding intergalactic medium; the resulting shock produces high-energy particles and fields, and the splashback creates the huge radio lobes. In most microquasars, the inner part of the jet is seen but the interaction region is missing. Original data from (*8*).

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The jets in microquasars seem very similar in terms of speed, power source, and collimation. One would therefore expect similar fireworks when they hit the interstellar medium. A few unusually steady and long-lived sources (*4*) show signs of such collisions, but most microquasars do not; in fact, there is little evidence that these short-lived jets interact at all with their surroundings. This is not too disturbing for any individual source: Some jets remain collimated but fade as they move out, and others may expand and get lost in the background. But some microquasars must surely interact with the interstellar medium at some point. On page 196 of this issue, Corbel *et al.* (*5*) report evidence that they do.

Like most other microquasars, XTE J1550-564 was discovered when it underwent a strong x-ray flare. Such flares are usually interpreted as the result of runaway accretion in a black hole binary star system. Observations with very long baseline interferometry (*6*) resolved the associated radio emission into three emission "blobs" roughly oriented along an east-west line. The system thus bore the hallmarks of a typical microquasar radio jet.

Transient microquasars' jets usually move out with roughly constant velocity and rapidly fade below detectability. But XTE

The author is at the National Radio Astronomy Observatory, Socorro, NM 87081, USA. E-mail: mrupen@aoc.nrao.edu

J1550-564 is different in several intriguing ways. First, the eastern component, although fading, remains detectable more than 3 years after the initial explosion. The radio emission is synchrotron, produced by relativistic particles spiraling around strong magnetic fields, which together exert an enormous pressure. The mere fact that we still see this emission after such a long time requires some way of confining those particles and fields.

Second, this same eastern component has decelerated considerably, with the velocity declining by at least a factor of 2 between 2000 and 2002. The most obvious explanation is that it is slowing down as it plows through the circumstellar or interstellar medium. The resulting ram pressure may in fact be holding the relativistic particles together. But ram pressure at relativistic speeds is exceptionally strong. The gradual deceleration of this component, without substantial brightening, implies either that it is much heavier than minimum energy arguments would suggest, or that the surrounding medium is exceedingly tenuous.

The western component is very different. At first, it simply faded below detectability in the usual fashion; but it has recently reappeared as a strong radio and x-ray source about 2 light years from the black hole. This source is aligned with the original radio jets, pointing back toward the parent system. It looks very much like the hot spots and lobes of giant radio galaxies.

These observations suggest that we are at last seeing direct evidence of a transient microquasar jet crashing into the surrounding material. If we can measure the density of that material through optical lines or other tracers, then the evolution of this source may allow us to measure the basic physical properties of a jet, such as its total mass and momentum.

Both jet components have been detected with radio and x-ray telescopes. Similar radio emissions have been seen many times in the past, but this is the first time that x-ray emission has been seen in a microquasar so far from the central object. If this emission is synchrotron, like the radio emission, then the required particle energies are enormous, in the tera–electron volt range. Alternatively, the x-rays may result from inverse Compton emission, in which photons from some background field (such as the cosmic microwave background) gain energy from collisions with relativistic particles. Both processes have been observed in extragalactic jets (*7*). It is not clear which dominates here, because the current optical/infrared data are not sensitive enough to determine whether a single synchrotron power law connects the radio emission to the x-ray emission.

These observations leave a number of puzzles. Why do the jets become visible again a couple of light years from the parent system? Does this observation imply an evacuated cavity, and if so, how did it form? Perhaps the supernova explosion that made the black hole also carved out a vacuum for the jets, or the jets themselves inflated a bubble. More generally, why do we see so few decelerating jets and so few terminal shocks? And given that at least a few microquasars do dump their energy at large distances from the binary system, how effective are these jets in stirring up the interstellar medium?

We have known about the jets and lobes of radio galaxies for decades, but those are very long-lived, and we effectively see only a single snapshot of their structure. By contrast, microquasars are ephemeral: The initial explosion that gives rise to the jets may last a few days, and the jets themselves quickly escape their parent system. The observations of Corbel *et al.* (*5*) illustrate the final stages of this rapid evolution, as the jets crash into the interstellar medium, expiring in a blaze of glory only a few years after their birth.

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PERSPECTIVES: PARASITOLOGY

A Requiem for Chloroquine

I. M. Hastings, P. G. Bray, S. A. Ward

Chloroquine (CQ) has historically been the mainstay of malaria treatment, particularly in the worst affected regions of sub-Saharan Africa. The recent development of widespread CQ resistance in *Plasmodium falciparum*, the most dangerous of the four malaria parasite species, has contributed significantly to escalating mortality rates in Africa (*1*) and to the resurgence of malaria as an immediate public health priority (*2*). Several pressing scientific questions have emerged within the context of this humanitarian disaster: What is the molecular basis for CQ resistance, and how has this influenced the dynamics of resistance? Why did CQ remain effective for 20 years, yet its immediate replacement sulfadoxine-pyrimethamine (SP) last less than 5 years? Has the widespread deployment of CQ jeopardized the use of other drugs targeting the same parasite biochemical pathways? As reported on page 210 of this issue, Sidhu *et al.* (*3*) have obtained data relevant to all three questions by creatively exploiting the *pfcrt* gene, which encodes a putative transporter protein in the digestive vacuole membrane of the malaria parasite. They replaced the endogenous *pfcrt* gene in a CQ-sensitive strain of *P. falciparum* with a *pfcrt* gene from each of three CQ-resistant strains. All such replacement strains ("constructs") showed CQ resistance in vitro, demonstrating that *pfcrt* mutations are sufficient, within their selected genetic background, to encode resistance. Reduced levels of *pfcrt* gene expression in the constructs also showed that up-regulation of *pfcrt* is not required for resistance. Next, the authors investigated cross-resistance between CQ and other antimalarial drugs.

Previous work from this and other groups has implicated eight or nine different *pfcrt* mutations in the development of CQ resistance (*4*). The sequential accumulation of these mutations plausibly explains the observed genetics and epidemiology of CQ resistance (see the figure). So why did CQ last so much longer than SP as a frontline antimalarial? First, four sequential mutations in the *dhfr* gene—which encodes dihydrofolate reductase, an enzyme essential for parasite folate metabolism and targeted by the drug pyrimethamine—appear sufficient for SP resistance (*5*). These four mutations accumulate much faster than the nine required for CQ resistance. Second, CQ persists at therapeutically useful concentrations for a much shorter period than SP, leading to lower selection pressures for resistance (*6*). Third, CQ resistance may involve genes other than *pfcrt*, such that sexual recombination during the malaria life cycle breaks down genetic combinations, slowing resistance (*7, 8*). The putative involvement of other genes remains controversial. Sidhu *et al.* show that *pfcrt* alone

The authors are at the Liverpool School of Tropical Medicine, Pembroke Place, Liverpool L3 5QA, UK. E-mail: hastings@liverpool.ac.uk; p.g.bray@ liverpool.ac.uk, saward@liverpool.ac.uk