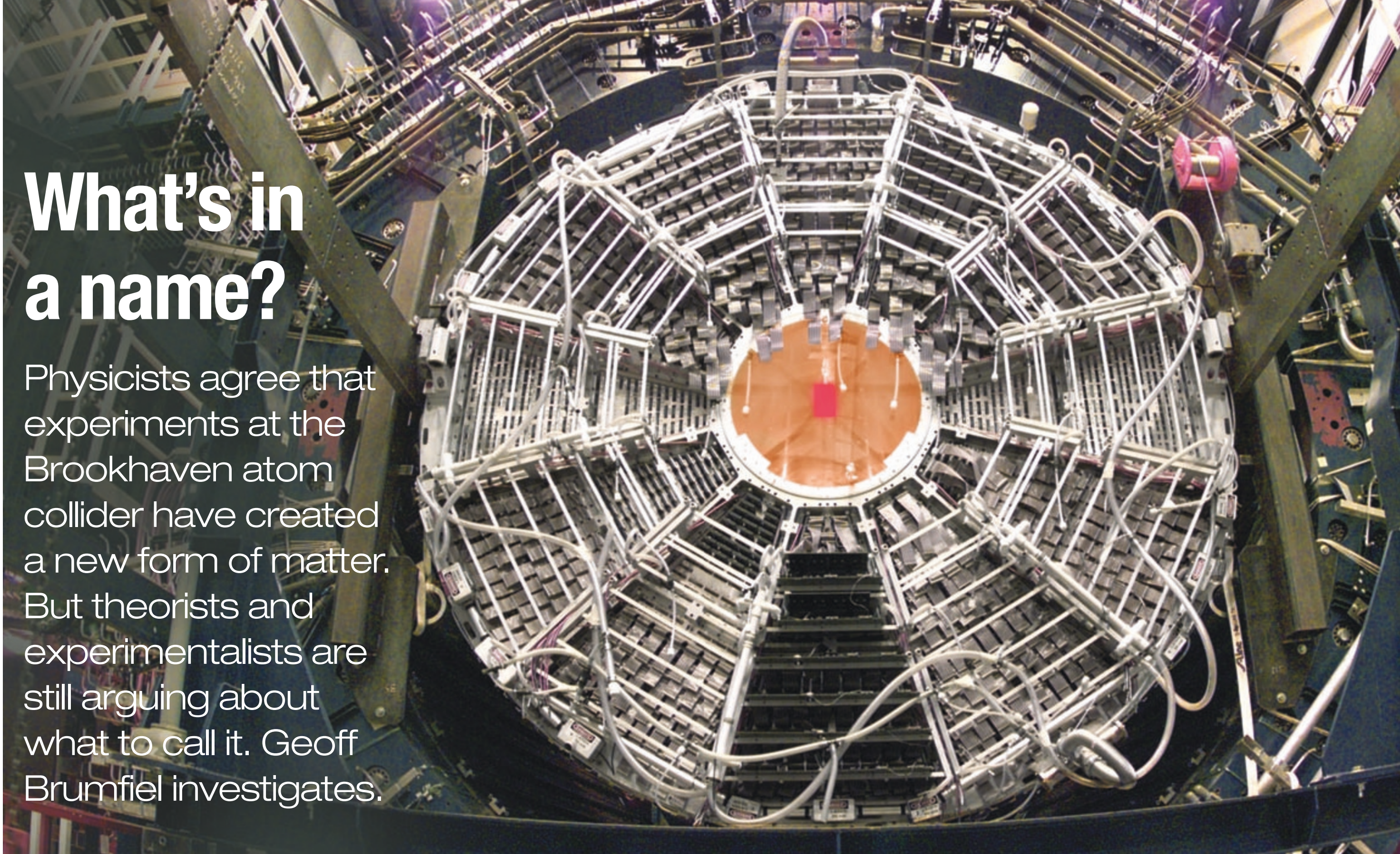

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What's in a name?

Physicists agree that experiments at the Brookhaven atom collider have created a new form of matter. But theorists and experimentalists are still arguing about what to call it. Geoff Brumfiel investigates.

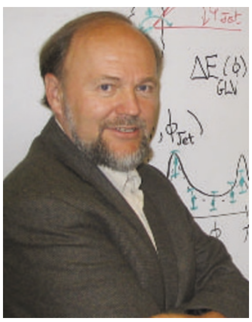
Just over a year ago, a rare event took place at Brookhaven National Laboratory on Long Island, New York. It didn't happen in the lab's massive atom smasher, but in a packed seminar room. Here experimentalists and theorists collided in a very public manner at a special colloquium held to announce "exciting new results".

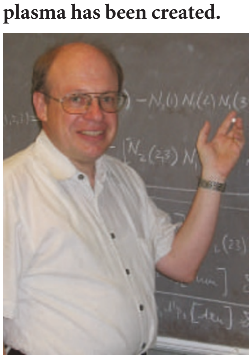
Since June 2000, Brookhaven's particle accelerator, the Relativistic Heavy Ion Collider (RHIC), has smashed atoms together in a bid to make an extremely hot state of matter with a name only a physicist could love: the quark–gluon plasma. For decades, theorists have been creating detailed models of this plasma, which was thought to exist in the early Universe, and RHIC was built in an attempt to confirm or refute these calculations.

A year after the machine was switched on, the four detectors that make up RHIC saw signs of the new plasma state. Subsequent experiments re-examined those hints and generated a lot more data. So expectations among the physicists, politicians and journalists were high at the colloquium in June 2003. Were the experimental groups ready to announce the discovery of the quark–gluon plasma?

The announcement never came. Instead, researchers presented a series of long lectures on the physics happening inside the collider. Detail by aching detail, members of the four detector teams laid out the case that RHIC had produced a very hot, dense form of matter that had never been seen before.

The reporters and dignitaries scratched their heads as they left the lecture hall. They had heard enough physics in two hours to give many of them a low-grade migraine, but they were no closer to knowing whether RHIC had created the strange state of matter it was built to discover.





Theorists Miklos Gyulassy (above) and Ulrich Heinz believe that a quark–gluon plasma has been created.

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Then came the press briefing. Top experimentalists and leading theorists gathered in another packed room to try to explain in simpler terms what the experiment had achieved. William Zajc, an experimentalist from Columbia University, New York, who represented RHIC's PHENIX detector, said that there might be a quark–gluon plasma in the machine. But he added: "I think we would like to rule out any more ordinary explanations first." Then Miklos Gyulassy, a Columbia theorist, gave everyone the answer they had been waiting for. "It is a quark–gluon plasma," he declared. "Period."

In the year since this meeting, a fully fledged feud has erupted between experimentalists and theorists over whether RHIC has indeed created a quark–gluon plasma (often shortened to QGP). The two camps are still working together — the nature of the experiments means that they have to — but they are also locked in an intense and very public debate that both sides agree is unprecedented in the field. The result has been confusion among journalists, government supporters of the work, and interested members of the public.

This summer has brought an uneasy truce. The 1,000-plus physicists and engineers associated with RHIC's detectors reached a collective decision in June to wait for more results before making an announcement. "There was surprising accord," says Mark Baker, acting spokesman for the PHOBOS detector. For their part, the theorists remain unapologetic. The findings pass the "toughest and most critical test", says Gyulassy. "Within our current models, there is no other state that can exist," adds Xin-Nian Wang, who heads the nuclear-theory programme at Lawrence Berkeley National Laboratory in California.

Cosmic goo

The QGP is the name assigned to what experimentalists and theorists alike believe was the earliest form of matter in the Universe. Just a millisecond after the Big Bang, the story goes, the Universe was little more than a hot, gooey mass of quarks — the sub-subatomic particles that make up protons and neutrons, among other things — and gluons, the particles that glue the quarks together. Physicists hope that studying the plasma in the lab will bring them closer to understanding the early Universe.

But to study a QGP, physicists first have to make one. This is no mean feat because in today's Universe, quarks are firmly bound in

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Experimentalists at RHIC want more data before naming the new form of matter they have generated.

groups of two or three. To pull them apart you have to smash large atoms together at high speeds, a task that requires an enormous amount of energy. Enter RHIC. It uses several accelerators to push gold atoms up to energies of 100 billion electron volts inside a 4-kilometre ring and then smash them together at six different collision points.

Each head-on collision creates a fireball 300 million times hotter than the surface of the Sun. It's at that moment that physicists believe a QGP might briefly be created. Detectors at four of the collision points record the shower of subatomic particles released from the gold atoms, and computers extrapolate what happened during the impact.

The experimentalists are like accident investigators who have a series of time-lapse photos from a head-on vehicle collision, and must reconstruct what the thousands of working parts inside the two cars looked like the instant their front bumpers touched. Except that, rather than having examples of the actual cars to work with, all they have are sketches from automotive experts of what they think the cars look like.

The biggest problem for the detector teams is that there is no single 'sketch' or model for a QGP, says Baker. At different points in the collision process, different theories must be used to explain how the gold atoms are behaving. Sometimes some of the theories agree with the data, but sometimes they don't. "Until the whole theory everywhere is understood, I'm not ready to sign off on a QGP discovery," Baker says.

But Ulrich Heinz, a theorist at Ohio State University in Columbus, says that sort of expectation is unrealistic. Converting colliding atoms into a QGP requires a phase transition — like water boiling into steam — and so it is not surprising that different theories are needed to explain the different phases. "We'll always have to live with the fact that these quark–gluon plasmas are very dynamical beasts," he says.

> "It's as if Columbus hit land and came back unexcited about it."
> — Miklos Gyulassy

Further confusion stems from the fact that RHIC has changed the scientists' understanding of the QGP itself. For example, most theorists believed that a QGP would behave like a gas, but RHIC's data suggest that it flows more like a liquid. "It's not what people had predicted," says Nick Samios, a former director of Brookhaven.

The complexity of the experiments lies at the heart of the debate between the two communities. Unlike colliders that smash together individual protons and antiprotons, the gold collisions in RHIC bring some 400 neutrons and protons together at once. Trying to capture what happens as these all fleetingly turn into mush is a challenge both for the detectors and for the subsequent painstaking analysis. Each collision yields billions of data points, which are used to extrapolate a set of properties that only partially resemble a QGP — and whose behaviour is far harder to predict than that of a single particle. Zajc sums up the situation succinctly: "There's no smoking gun."

Such complexities are not confined to RHIC's experiments. In 2000, researchers at the Super Proton Synchrotron at CERN, the European Laboratory for Particle Physics near Geneva in Switzerland, announced that they had tantalizing hints of a QGP. They stopped short of claiming a QGP discovery, choosing instead the term 'quark–gluon matter'. But journalists were less discriminating, and many used the two terms interchangeably. "Many people here felt that they stole the thunder from RHIC," says Baker. RHIC researchers lashed out at CERN, calling the claims unfounded. So, Baker says, the RHIC team feels even more pressure to make careful and conclusive measurements.

Split decision

Another reason why the experimentalists are reluctant to rush into claiming a discovery may be that they won't face any competition until the next accelerator at CERN comes online in 2007, says Samios. Until then there is no pressure to make a big announcement. "It's more psychology than physics," he says.

By contrast, the theorists who have devoted decades to calculating features of the QGP are impatient to declare victory. "To me it's as if Columbus hit land and came back unexcited about it," says Gyulassy. Heinz adds that it is now important to move away from discovery measurements and to begin characterizing the plasma's behaviour. "We need to start exploring the details of this new kind of matter," says Heinz.

What the public would make of another discovery announcement is unclear. Attendees at the annual Quark Matter conference held in Oakland, California, in January were confronted with two seemingly contradictory positions. Experimentalists offered reams of collision data without dubbing the phenomenon a QGP, whereas some theorists, including Gyulassy, announced the discovery of a QGP in their talks. When *The New York Times* ran a story titled "Tests suggest scientists have found Big Bang goo", officials at the Department of Energy, which oversees RHIC, reportedly hit the roof because they had not been consulted before such a major announcement.

Behind the scenes the two camps are still talking, and at a quieter lab meeting in June took the first steps towards a reconciliation. Wang believes that the meeting helped experimentalists focus more on the 'big picture', which may speed a conclusion to the debate.

For now, it seems that both sides are trapped in a stalemate. Zajc hesitates to give a precise date for when, or even if, a QGP discovery will be announced at RHIC. "We're still collecting evidence, and I think we're making good progress," he says. But the theorists say that the days of QGP are already here. "The evidence is overwhelmingly clear," Gyulassy says. "It's time we gave it a name." ■

Geoff Brumfiel is *Nature*'s Washington physical sciences correspondent.