surements. As for 4U 0142+61, he adds, more detailed observations at other wavelengths are needed to determine how seriously it affects the accretion model.

NASA's Marsden agrees. "Only if the accretion model is strongly and unequivocally ruled out will new models be widely accepted," he says.

Meanwhile, some surprising recent evidence suggests that the two types of mystery objects may be different creatures altogether. Bryan Gaensler of the Massachusetts Institute of Technology in Cambridge studied SGRs and AXPs associated with supernova remnants. From the ages and distances of the supernova remnants and the displacement of the neutron stars from the remnants' centers, he calculated that AXPs are rushing away from the remnants at speeds on the order of 500 kilometers per second. That is not unexpected, as neutron stars are believed to be born with high "kick velocities" from the supernova explosions that create them. What is surprising, though, is that SGRs appear to be moving four times as fast.

That velocity difference poses a tough choice, Kouveliotou says. If astronomers have matched the neutron stars with the right supernova remnants, then it's hard to see how SGRs and AXPs could be related and yet travel at such different velocities. Conversely, if they are related, then for at least one of the two types of objects, "the apparent association with supernova remnants must be bogus," says Kouveliotou.

Van Kerkwijk admits that the supernova link could be stronger: Although most SGRs and AXPs seem to be related to supernova remnants, only for two of the six known AXPs and two of the four known SGRs is the evidence clear-cut. For a third SGR, the neutron star is so far away from the supernova remnant that it must be moving at 2900 kilometers per second if the two objects are indeed related. Kevin Hurely of the University of California, Berkeley, hopes to check that figure by using Chandra to measure the displacement of the x-ray source across the sky.

In the end, the links, if any, between AXPs and SGRs will come from that familiar wellspring: more data. Unfortunately, even the most sensitive orbiting observatory or ground-based telescope can't detect the superstrong magnetic fields that would prove or disprove the magnetar model. But they might reveal whether AXPs draw power from accretion, or whether any of them is consorting with one of Paczyński's white-dwarf mergers. If the observations rule out such alternatives, magnetars will look better and better to astrophysicists.

And if the magnetar model prevails? One consequence, Duncan says, is that magnetars might not be as rare as they seem. From their theoretical life-span and the known number of SGRs and AXPs, it's straightforward to calculate that a new magnetar should be born in the Milky Way galaxy about every 1000 years. Ten million "dead" magnetars might well be zooming through interstellar space at this moment, Duncan says—black beasts camouflaged by cosmic night.

—GOVERT SCHILLING

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NEWS

Tatars' Saucy Project Takes on the World

A dark horse called Dulkyn aims to put the Republic of Tatarstan in the race to detect gravitational waves

KAZAN—On the edge of this city on the Volga River, in a cavernous underground hall off limits to most visitors, stand two rows of what look like massive tombs. The structures—12 pale yellow cabins, boxy and featureless—belong to the State Institute of Applied Optics. Eleven of them house some of the most advanced optical equipment in the world: laser setups for carving diffraction gratings and holographic plates, onetime components of a Soviet missile defense shield then in development.

Each cabin rests on a separate foundation to reduce the effects of seismic vibrations; inside, temperatures are kept precisely at 19 degrees Celsius. Such a sanctuary is necessary for reliably cutting tiny diffraction patterns—and essential to an experiment in the lone cabin that isn't part of the production complex. Here, in a room within a room, a novel project aims to do something never done before: use lasers to detect the pull of the moon on Earth's gravitational field. The Kazan team members call their experiment, which they hope to undertake this fall, "the lunar test." Some experts, however, call it lunacy.

"A few crazy ideas turn out to be genius. This one is just crazy," says Moscow State University physicist Vladimir Braginsky, the dean of Russian gravitational-wave researchers (see sidebar). He disparages the Kazan group's chances of achieving its ultimate goal, which is to modify a laser setup to detect ripples in the fabric of space-time—specifically, low-frequency gravitational waves emanating from the outer-space objects known as binary pulsars.

But even if the experiment fails, many others say it's worth supporting. The laser system could serve as a gyroscope that would "give a good measure of Earth's rotation," says Karsten Danzmann, one of the architects of GEO-600, a British-German gravitational-wave detector. "It's a very courageous idea," adds Philippe Tourrenc of Pierre and Marie Curie University in Paris, a founding father of the French-Italian VIRGO detector and one of the few westerners who has had a firsthand look at the Kazan setup.

For 4 decades, physicists pursuing this goal have built ever bigger and more elaborate experimental facilities with growing confidence that they are on the verge of plucking a relativistic gravitational signal

Roaring mouse? Feisty Tatarstan is gambling on scientific glory.

Light show. Dulkyn has assembled the key components of its pentagonal laser system.

from a sea of earthly noise. The stakes are high. The first group to measure gravitational waves from any source will blaze a trail into uncharted astrophysics and will almost certainly bag a Nobel Prize. Major efforts now under way include VIRGO, a laser interferometer being built near Pisa; TAMA, a Japanese interferometer nearly finished outside Tokyo; and the GEO-600 interferometer near Hannover, Germany. Grandest of all is the $365 million Laser Interferometer Gravitational-Wave Observatory (LIGO), a U.S.-led effort to use laser beams to detect high-frequency gravitational waves from supernovas (*Science*, 21 April, p. 420). Russia's two leading gravitational-wave teams—Braginsky's group and another led by Alexander Sergeev at the Institute of Applied Physics in Nizhny Novgorod—have signed on to LIGO.

By contrast, the Kazan group's puny $1 million tabletop experiment, dubbed "Dulkyn," is a definite dark horse. Dulkyn is a "heroic effort on a low budget," says Danzmann, who predicts that noise will doom Dulkyn's gravitational-wave quest. Most others say they know too little of Dulkyn to prognosticate. For better or worse, that will soon change: The Kazan group has been invited to present the concept in Perth, Australia, in July 2001, at the annual Edoardo Amaldi Conference, the main meeting of the world's gravitational-wave researchers. Ending Dulkyn's decade of isolation could lead to collaborations and financing—or, if critics like Braginsky are right, send it right back into obscurity.

Like the optics institute that houses it, Dulkyn is a child of the Soviet military-industrial complex. Its roots date to the early 1980s, when military scientists launched an effort to develop a new kind of radar to scan the ionosphere for incoming missiles. The results, if any, remain secret. But as a spin-off of the project, Zufar Murzakhanov and theoretician Alexander Balakin of Kazan State University (KSU) proposed a scheme in 1989 for probing Earth's gravitational field and possibly exploiting gravitational waves as a navigation tool. Just months after the Soviet Council of Ministers approved the project and planned to allot it a generous 5 million rubles in funding—roughly the same sum in U.S. dollars at the time—the Soviet Union dissolved, dragging with it into the abyss most funding for defense research.

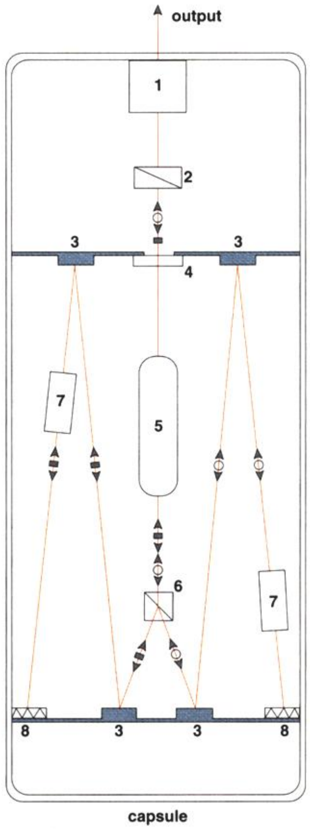
Deprived of military support, Murzakhanov and Balakin opted in on the civilian hunt for gravitational waves. That itself was not a first for Kazan, a city with a rich history in the sciences. In the early 1960s, Alexei Petrov—known today for a theorem in his name defining three types of Einsteinian curved spaces—had founded KSU's department of relativity theory and gravitation and had planned to build a gravitational-wave detector. But the project was abandoned after Petrov moved to Kiev in 1965.

Reviving gravitational-wave research in Kazan meant finding a new source of funding. Shunned by Moscow, Murzakhanov and Balakin appealed to the president of the Republic of Tatarstan, a semi-autonomous region within the Russian Federation. Murzakhanov remembers how he was grilled by Tatarstan cabinet members: "The first pointed question was, 'What will this project give to society?' I told them the point is to investigate our universe and gather knowledge. They looked at us like we had psychiatric problems."

Still, the upstart project appealed to top officials eager to put Tatarstan on the map. The independent-minded republic—which last year embarked on a program to replace the Cyrillic alphabet with Latin script, and where most public buildings fly Tatarstan's green, white, and red striped flag, rather than the Russian flag—was filled with a defiant civic pride, and it had oil revenue to throw at a long shot that would win international acclaim if it succeeded.

Murzakhanov and Balakin assembled a team and, along with Rinat Daishev and Alexander Skochilov, created the Gravitational Wave Research Center Dulkyn, after the Tatar word for "wave." They struck upon a system that, they claim, should be able to overcome the key hurdle of all gravitational detectors—measuring minuscule signals in a thicket of noise—by accumulating the signal over time. Dulkyn has no chance of sensing the fleeting bursts of high-frequency gravitational waves that LIGO is designed to detect. Rather, the Kazan group is hoping to feel low-frequency gravitational waves kicked up by space-time–warping binary pulsars. These vibrations are the quarry of LISA, a European–U.S. interferometer array planned for launch later this decade (*Science*, 10 December 1999, p. 2060). Composed of three satellites in a triangular formation 5 million kilometers apart, LISA will orbit far above any ground-based noise, such as low-frequency thermal fluctuations, that would tend to mask the signal.

Dulkyn, if it is completed, will substitute patience for LISA's sublime isolation. In the experiment, one laser beam will traverse a 5-meter-long perimeter of a pentagonal array of mirrors. A second beam, of a different polarization, will be diverted from this path by diffraction gratings and run a longer route. Gravitational waves will shift, ever so slightly, both the wave phase and the resonant frequency of these beams as they are generated by the laser, says Balakin. In the beam traveling the perimeter route, the equal distances between the five mirrors will serve to damp the gravitational-wave–induced shifts, like ironing out



Practical payoff? Kazan's innovative gravimeter, a spin-off of the gravitational-wave project, may hold promise for monitoring oil reserves.

CREDITS: DULKYN

Keeping the Beat in a Noisy World

MOSCOW—Vladimir Braginsky and his team do their best work in a Stalin-era bomb shelter. In the basement of the towering main building of Moscow State University, in a room once stocked with provisions for professors to ride out a nuclear war, the physicist and his research group have built the world's steadiest pendulum.

Braginsky and his device are at the vanguard of an effort to tune in to gravitational waves from space. A decade ago, Russia's most prominent gravitational-wave researcher realized that only a multinational effort—and massive amounts of cash—would overcome the technical hurdles that prevent scientists from perceiving these ripples in space-time. So he cast his lot with the massive U.S.–led Laser Interferometer Gravitational-Wave Observatory (LIGO), which aims to measure such perturbations by reflecting laser beams back and forth along two 4-kilometer tunnels. The sharp-witted Moscow State professor is everything that his colleagues building a detector in Kazan (see main text) are not: a well-known player who's embraced by the scientific community.

Braginsky's forte is ferreting out sources of noise that obscure gravitational-wave signals. His main contribution to LIGO has been to attack the perturbations affecting the mirrors that bounce the laser beams along their way. The mirrors, freely suspended in the tunnel, will wiggle ever so slightly when jostled by a gravitational wave—a motion that will cause the laser light to change phase by about a trillionth of its wavelength. (The wavelength of light is about half a micrometer, or 1/80 the width of a human hair.) To make such subtle shifts detectable, Braginsky must tackle everything from thermal vibrations to quantum fluctuations.

"We're living in a hot, noisy world," he says. One source of noise is the Brownian motion of the mirror's molecules. There are two ways to damp it: bring temperatures as near to absolute zero as possible, or weaken the connection between the mirror and the outside world. Braginsky has done the latter with his model system, in which a 2-kilogram weight, the pendulum bob, serves as a surrogate for a mirror. He has discovered that fashioning the bob—and the fiber it hangs from—out of extremely pure silica reduces Brownian fluctuations caused by friction of the bob's movement. (LIGO's mirrors are made from fused silica.) The best raw material, he found, comes from a Russian factory that once supplied silica fiber to the military for use in the Soviet equivalents of Tomahawk and cruise missiles.

Damping Brownian motion also means setting up a "mismatching impedance." In simple terms, Braginsky says, that means hooking up the pendulum "to a very heavy wall"—in this case, the bomb shelter's bulwark, a 1.6-meter-thick, 10,000-ton slab of concrete running the length of the building. Braginsky's team has diminished the friction in the pendulum's oscillations so effectively that, if left unchecked at room temperature, it would swing unassisted for 5.4 years—a world record. The LIGO team wants Braginsky to extend that so-called relaxation time to an even century.

Braginsky himself has little time to relax, as his quest for near-perfection takes him down increasingly arcane byways of physics. A couple of years ago, he discovered that electrical fields induce transient quantum states on the surface of the bob that affect its motion. Reducing this noise "is terra incognita," Braginsky says. "Nobody has done anything like this before." But he clearly relishes this latest challenge.

–R.S.

wrinkles in a shirt. But in the internal route, where the beam travels farther between mirrors after being diffracted, the phase shifts will persist and intensify until, after days or weeks, Balakin argues, they will be discernible after subtracting the effects of noise seen in both beams.

The approach "is extremely elegant in the finest traditions of experimental physics," says physicist Ed Langham, a former director of satellite operations for the Canadian Space Agency who, under the auspices of the Canadian Executive Service Organization, spent 2 weeks in Kazan in 1999 helping Dulkyn draft a business plan.

Before embarking on the gravitational-wave experiment, however, the Kazan team will undertake its lunar test. Conceived by Skochilov, the test languished during a 2-year funding drought following the August 1998 ruble crash, but it revived a few months ago when Dulkyn received a cash injection from the local government following a visit to the facility by Russian Vice Premier Ilya Klebanov. The team will use the money to put the finishing touches on a modified laser system designed to detect shifts in wave phase in the generation frequency of a laser beam, induced by 12-hour lunar tides.

Success would by no means guarantee that Dulkyn can detect relativistic gravitational waves from binary pulsars, which would be far more subtle. But it would confirm the principles of Dulkyn, says Daishev, and give the team confidence to undertake the relativistic experiment. And even if Dulkyn never detects a single gravitational wave, the work could yield practical payoffs, such as gyroscopes or gravimeters for use in oil exploration and geophysical studies.

Assuming the project does clear its lunar hurdle, the Kazan scientists plan to raise about $350,000 to complete their pentagonal laser system. They hope to install the instrument in a facility to be built underground on the Volga, 60 kilometers south of Kazan. If all goes well, Dulkyn's first crack at detecting gravitational waves could come in 2003, soon after LIGO is operating fully.

Tatar pride. The members of the Dulkyn team, led by Zufar Murakhanov (front center), hope that this summer's Amaldi conference is their ticket into the gravitational-wave community.

CREDIT: DULKYN

Could the Tatar David possibly beat the American Goliath? "Only a few people will bet that gravitational waves are first detected by Dulkyn, but this is not an argument against the project," says Winfried Zimdahl, a physicist at the University of Konstanz in Germany who visited Dulkyn last year with two colleagues and wrote a letter supporting it to the Tatarstan Academy's president. Other experts are more skeptical. "It's a pity, but there seems to be some law that says [a gravitational-wave detector] has to be big," says physicist James Hough of the University of Glasgow. Still, Zimdahl sees no harm in helping out an unconventional project that challenges the establishment. "After all," he adds in a playful nod to another underdog, "David is by far the more charming character!"

–RICHARD STONE