

The Great Soviet-American Extragalactic Investigation

The cosmos yields ever so slightly

When looking toward the ends of the universe for answers to cosmic questions, little earthly problems like finding out what time it is, making a long-distance phone call, or deciphering an operating manual can mean the difference between success or failure. That's what a trio of Caltech radio astronomers discovered when they took part in the first Russian-American joint investigation of extragalactic objects last fall.

The Caltech people participating in the investigation were Marshall Cohen, professor of radio astronomy; and Kenneth Kellerman and Barry Clark (PhD's at Caltech in 1963 and 1964), currently at the National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia. The other members of the team from the U.S. included David Jauncey of Cornell, and John Payne from NRAO.

The experiment consisted of making simultaneous observations at two widely separated telescopes—NRAO in West Virginia and at the Crimean Astrophysical Observatory on the Black Sea in the USSR. The technique used has been called "very long baseline interferometry" (VLB). It gives angular resolution 1,000 times better than that obtainable with the largest optical telescope. Cohen, Clark, and Kellerman, with Jauncey, developed the VLB technique only three years ago.

In the Russian-American investigation, the 140-foot radio dish in West Virginia and the 72-foot dish in the Crimea were used like a pair of eyes, 6,000 miles apart in a straight line through part of the earth. When focused on the same object at the same time, the two radio "eyes" eliminate much of the fuzziness of standard radio telescope observations and, in some cases, give the actual size of the object. The system was designed to resolve a radio object as small as a beach ball a quarter million miles away.

Long baseline interferometry is made possible by atomic oscillators used to synchronize the observations. The atomic oscillator, which must be stable to within one part in a hundred billion, is attached to the radio dish and drives a clock. The clocks on the two dishes must be synchronized to within a few millionths of a second.

The purpose of these studies is to learn something about the mechanics of explosions that seem to be associated

with such objects as quasars, and to find out something about their structure. The best way to do this is to look at the objects, which apparently are born small and expand with age, when they were very young.

Astronomers hope these kinds of observations, continued over a period of several years, will reveal changes in the configurations of the objects. Such information would help them develop a model and then an explanation of the exploding source.

But a technique that had worked well in an earlier joint investigation between the U.S. and Sweden ran into trouble in the Soviet Union because of a succession of ordinarily minor problems that mushroomed to critical proportions.

Kellerman and an engineer, John Payne, were scheduled to go to Russia three weeks before the start of the observations to set up and test the VLB equipment. Three Russian astronomers were to come to Green Bank to work with Cohen, Clark, and Jauncey on the American end of the base line.

The problems started almost from the moment Kellerman landed in Russia. He describes it this way:

"On September 10 I arrived in Moscow with my wife and was met at Sheremetevo Airport by Leonid Matveyenko of the Soviet Academy of Science. After retrieving our luggage, Matveyenko told the customs man 'Akademy Nauk,' and we passed through customs without any inspection or formality. We later found much use for the phrase 'Akademy Nauk,' which indicated that we were guests of the Academy of Science and would open any and all doors from looking at the crown jewels to getting last-minute reservations on a Russian airplane.

"Our equipment was scheduled to arrive September 15, and Matveyenko was dispatched to the airport to collect it. He returned that evening and reported he needed the 'baggage ticket.' I tried to explain that you don't get a baggage ticket with freight and that in any case I was already in Moscow when the shipment left the United States, and I could not possibly have any of the papers prepared when the shipment left. This appeared to cause some concern among the Russians.



The 72-foot dish at the Crimean Astrophysical Observatory on the Black Sea—the eastern end of the 6,000-mile interferometer base line.

“The following day we obtained a letter from the Academy of Science to the cargo and customs people saying that it was OK for me to collect our equipment. Matveyenko and I drove to the airport in a car and were followed by a truck which was to carry everything back to Moscow. Following about an hour of being sent from one office to another and several heated discussions, we were led to a shed that contained the equipment (or as all Russians insisted on calling it, the ‘aperture’). Matveyenko appeared to be a little surprised at the size and weight of our ‘aperture,’ which consisted of three large wooden crates plus 25 boxes of magnetic tapes weighing a total of 3,000 pounds.

“It had been pointed out to us that the boxes were too big fit in the cargo door of an Aeroflot airplane to be flown to the Crimea. I argued that since they had come from London by Aeroflot they must fit. But my reasoning proved incorrect since the planes flying from Moscow to the Crimea have smaller doors than those flying from Moscow to London.

“There then followed a big discussion (Russians seem to like big discussions) as to whether the ‘aperture’ should be shipped by truck or railroad. To complicate the situation, it was necessary to send the rubidium clock and VLB control unit first to Leningrad to synchronize the clock with the German Loran (long-range navigation)

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station, while the tape recorder, front ends, and 25 cartons of magnetic tape were to go directly to the Crimea. It was finally decided to send the shipment to the Crimea by train and the one to Leningrad by truck.

“That evening the whole VLB party—John Payne, Matveyenko, Leonid Kogan (a Russian engineer assigned to the project), my wife, and I flew to Leningrad aboard an Aeroflot TU 104 jet. We also carried in the airplane our atomic clock that we hoped to set with the aid of Loran, which we were told was easy to receive in Leningrad. On our arrival, we were met by a delegation from the Pulkova Observatory where we planned to set up our Loran equipment.

“Lacking a proper Loran antenna, we strung a wire across the floor and promptly received what appeared to be the Loran transmission from Sylt, Germany. Only the Sylt station was supposed to transmit with a 79.6-millisecond period, and the signal we were receiving had an apparent period of 80.0 milliseconds.

“After wasting two days and convincing ourselves that everything was working properly, and rejecting the unlikely possibility that Loran had changed its period without announcement, the light finally dawned—we were not receiving Loran at all but an unadvertised Russian copy. The real Loran appeared to be buried in interference from the most powerful transmitter in the USSR, located only a few miles away, which broadcast entertainment to Soviet ships all over the world.

“It was rumored that at various odd hours of the night on certain days of the week the interfering station would temporarily stop broadcasting, but this never materialized, and it was becoming clear that we were getting nowhere fast.

The discussion degenerated into the difference between electrical + and physical + and electrons and holes.

Imagine a Russian trying to get on a flight from Miami to New York with a strange, ticking box, and having only a voltmeter and pliers for luggage.

“We had previously explored the possibility of flying a running clock into the USSR, but our Russian colleagues in Moscow indicated that this would be ‘impossible.’ But in Leningrad they were more optimistic and thought that it might be arranged. On September 21, I telephoned Bert Hansson, one of our collaborators on previous VLB experiments in Sweden, to see if he could arrange to synchronize their clock in Stockholm and send it to Leningrad. But I was told that (1) it was a weekend, and there was no one around to prepare a proper box; (2) they had no batteries, and it was not possible to buy batteries on the weekend; and (3) Sweden had just experienced a major storm which blew down an antenna at their observatory and had damaged the director’s yacht. Nevertheless, Bert promised to ‘see what he could do.’

“Meanwhile, the first observations were only about a week away, and we hadn’t even been to the Crimea site yet. So John decided to go alone to the Crimea to set up the VLB equipment, install the front ends, and check out the TWX machine that was supposed to be installed. I stayed behind in Leningrad to struggle with the Loran receiver and await the clock from Sweden.

“Having no success with the Loran receiver and not hearing from Sweden, I found things looking a bit grim, but on the night of September 24 we went anyway to the Leningrad airport to meet the Aeroflot flight from Stockholm. To our pleasant surprise, there was a heavy wooden box addressed to me, strapped in a first-class seat with a safety belt. Of course, the customs man wanted to see what was inside. We handed him some official looking papers of explanation and opened the box. He took a quick look, saw a few glowing lights, looked with astonish-

ment at the clock ticking loudly, and said OK. We quickly left before he could change his mind.

"We synchronized the NRAO clock to the Swedish clock, attached the Russian batteries in case of power failure, and left it to run at Pulkova. We had the nickel-cadmium batteries supplied with the Swedish clock recharged and set off for the airport to fly to the Crimea. We also carried two 6-volt car batteries and an inverter to supply 230 volts. This combination gave us a battery capacity that was good for about 25 hours—more than enough (so we thought) for a two-and-a-half-hour plane trip. The whole load weighed about 200 pounds, and it took some explaining to get it on the airplane.

"The flight was uneventful, and upon arriving in Simferopol, the capital of the Crimea, we were met by Dr. Ivan Moiseyev, director of the radio astronomy station in the Crimea, and set off on a two-and-a-half-hour winding drive through the mountains to Yalta. (This was the first of ten such trips I was to make.)

"In Yalta we were greeted by John with the news that (1) the TWX machine could not be connected because the lines were not good enough; (2) the 50 ohm, 10 dB loss cable they promised us was 72 ohms and had 20 dB loss, which meant we could not get enough signal from the control building to the antenna; (3) he could not receive the Loran timing signals from Turkey.

"But the real blow came when the box was opened: The clock had stopped on the airplane halfway between Leningrad and Simferopol. The batteries had lasted only about an hour.

"This was the low point of the expedition. We had no time synchronization, not enough local oscillator signal to the telescope focus, no way to communicate with Green Bank by TWX, and the first observations were only five days away.

"Someone had to carry the Swedish clock back to Leningrad and synchronize it with the NRAO clock that was still running (we hoped) at the Pulkova Observatory. Only in the USSR, you do not just go to the airport and buy a ticket for Leningrad, particularly if you happen to be carrying an atomic clock (size about 4 x 2 x 1 feet, weight 150 pounds) with you. To make matters a bit worse, it was the end of the tourist season, and the planes leaving the Crimea were booked solid.

"Since there was so little time remaining, John and I decided the only way to get enough local oscillator signal to the mixer was to move the VLB equipment from the control room to the telescope. It took some courage to announce this decision because the control room was on

the second floor of the building and it had taken the better part of a day to get the two heavy VLB racks installed. But our Russian friends took it in good spirit, and in order not to damage the equipment insisted on repacking everything in crates. Getting the crates down the stairs was a formidable task, but not nearly as difficult as trying to get them up to the operating room of the telescope structure, which was about 15 feet above the ground and accessible only via a narrow staircase. For this task a crane was summoned from the Crimean Astrophysical Observatory about 100 miles away, and the VLB equipment was ceremoniously hoisted into place in front of 15 to 20 spectators.

"The following morning I departed by car with Kogan and our rubidium clock to catch a 9 a.m. flight to Leningrad. The plan was to arrive in Leningrad about noon, set the clock and recharge the batteries, and return on an evening flight to the Crimea. When we arrived at the airport, we found that the plane was full, and we would have to wait until 5 p.m. before leaving.

"Just before plane time, the local chief at the airport, a rather formidable looking Russian lady, wanted to know what was in our box, and why it couldn't go in the baggage compartment, and also where our personal luggage was. We tried to explain, carefully avoiding the use of the term 'atomic clock,' and had some difficulty in convincing her that we had no personal luggage because we were coming back in a few hours! Imagine a Russian trying to get on a flight from Miami to New York carrying a strange looking box (ticking, of course) with wires and batteries, and having only a voltmeter, a pair of pliers, and a large screwdriver for luggage; and you get the picture.

"When we arrived in Leningrad at 8 p.m., it was cold

During flight we took turns running to the rear every 15 minutes to check batteries. To look inconspicuous, I pretended I was going to the toilet.

I finally got worried enough about it at six o'clock to wake John Payne and ask him where the manuals on the thing were.

"At the end of the three-centimeter run we were planning to break out some vodka to toast the Russians at about 140030 UTC, but we never made it because they broke out the cognac at 140020. It was quite a party."



and raining (it's always cold and raining in Leningrad), and there was no car to take us to the observatory. After getting a good soaking in the rain, we finally hailed a taxi and got to Pulkova. We resynchronized the clock, charged the batteries, and were ready to return to the Crimea. Unfortunately, since it was the end of the tourist season, not very many people were flying to the Crimea this particular Saturday night, and so to save some rubles, Aeroflot had cancelled our return flight.

"The next morning we made it to the airport, only to find that there was a mistake on our ticket and that actually the plane would leave at 11 o'clock, not 10 o'clock. Just to be safe I suggested that since we had to wait an hour we should plug the clock in and not drain the batteries. Upon opening the box to get the power cord, we found that the clock had stopped again!

"It was easy enough to cancel our flight, but a major problem to book a new flight. In Russia you can't buy airplane tickets at the airport, only at your hotel or at the Aeroflot ticket office in Leningrad. However, we were not staying at a hotel. To further complicate the situation, it was Sunday. And in Russia no one works on Sunday, including the airline office. Nevertheless, I told Kogan to go into Leningrad and get us a ticket for an afternoon flight while I went back to the observatory to 'reorganize' the clock and batteries. (I was beginning to have blind faith in my Russian colleagues' ability to overcome all bureaucratic obstacles.)

"It was becoming increasingly clear that we were doing something wrong with the batteries. Someone suggested that maybe they were being charged backward, and perhaps the Russian definition of + and - was not the American or Swedish definition. The discussion then degenerated into the difference between 'electrical' + and 'physical' + and electrons and holes, etc., which was clearly all nonsense.

"We later realized that our problem was that each night the line voltage, which was nominally 230 volts, would drop to about 190 volts and slowly discharge the NiCd batteries that were attached to run the clock in case of power failure. Since NiCd batteries were sealed, there was no way to measure the state of charge until the terminal voltage began to drop. This occurred only as the batteries were nearly discharged.

"Kogan telephoned that he had managed to get us two plane tickets for a 4 o'clock flight. Following another big send-off and round of handshakes and good wishes, we departed once again for Leningrad airport.

"This time we didn't take any chances on the batteries running out. During the three-hour flight Kogan and I took turns running to the rear of the plane every 15 minutes to check the batteries with our voltmeter. In order not to look too conspicuous, I pretended each time to be going to the toilet. But after a few sessions we realized that this was even more suspicious looking.

"Toward the end of the plane ride, the NiCd batteries



To celebrate the experiment's success the Russians had a cake—appropriately, showing the object being observed to be a red star—made up in Yalta.

began to fail, and we switched over to the auto battery we were carrying. We made it to the Crimea and managed to transfer everything to the car without mishap. Halfway to the observatory we had to go over to the battery that was running the car. With this we made it to the observatory and got the clock attached to the 230 (more or less) volt line.

“The first observations were planned just as a test for the main run two weeks later. The plan was to run a few tapes on 3C 273 and 3C 454.3, the two strongest sources at 3 cm. The run on 3C 454.3, unfortunately, came about 3 a.m. local time in the Crimea. So when it was finished, John and I looked about for a ride back to our hotel and some badly needed sleep. We found our Russian colleagues upstairs breaking open the vodka and cognac. After completing 2 percent of the scheduled observing, they decided it was clearly time for a celebration. Following two hours of eating, drinking, and declarations of Soviet-American friendship and cooperation, we were finally taken to our hotel.

Late the next morning we were met by Moiseyev and had a leisurely lunch, after which he told us ‘Oh, by the way, a telegram arrived this morning.’ It was from Barry Clark. The frequency had been set wrong at Green Bank, and he wanted to repeat the run on 3C 273 in about two hours. We made a quick trip out to the observatory, arriving with about an hour to spare and managed to run the tapes on time.

“The plan was to immediately return the tapes to NRAO for processing before the next run two weeks later. This might be considered wishful thinking, but it had all been carefully arranged in advance. Immediately following the second 3C 273 run, the tapes were quickly packed up and driven to Yalta, where a Russian astronomer was waiting to leave for Moscow. He would deliver the tapes to the foreign office of the Soviet Academy of Sciences where they would be collected by a driver from the U.S. Embassy, who would bring them to the U.S. Scientific Attache, who would then give them to a returning American geologist who was flying to Washington that afternoon. Having been alerted by our telegram, Barry would be at the Washington airport to collect the tapes when they arrived. It seemed like a ‘sure-fire’ scheme, and we could relax until the next run.”

But the problems had just begun. Here’s how Clark tells of his part in the odyssey:

“It so happens I never did get the telegram that told me about this whole arrangement. I was just sitting around Green Bank for some days wondering where the heck the tapes were. Then finally this guy in Washington rang up and said he had a couple of tapes there. One of our people went to Washington and picked the things up.

“We spent three or four days trying to process the tapes, but we were unable to make the interferometer work. Well, it was strongly suggested that something was wrong somewhere.

“Many, many things can go wrong in an experiment like this, but one of the more likely possibilities was that something had happened to the clock on the way to the Crimea. So it was decided that I should go over there with a little crystal clock, which wasn’t really that good but could furnish an order of magnitude check on things.

“When I arrived at the observatory in the Crimea, we found the time on the clock I had brought was dramatically different from the clock that Ken had brought down from Leningrad. Luckily, the interference cleared up for a few hours, and we were able to pick up the signal of the Loran station in Turkey. That signal confirmed that the clock brought from Leningrad was correct, and that something had happened to the crystal clock.

“Communication was still one of our biggest problems. Before the main experiment we never had a phone conversation in which somebody who knew what was happening was on both ends of the phone.

“The usual thing was to ring up the operator and say, ‘I wish to talk to this number in the U.S. I would like to book this call for tonight at eight o’clock.’ At eight o’clock

We really attacked the communications problem. We sent a telegram, booked a phone call, and tried to send a TWX all at the same time.

the phone would ring, and the operator would say, 'It is impossible to reach the U.S. at this time. We'll let you know when we can make contact.' And then, at some random time in the next three or four days, the phone would ring in Green Bank, and the phone would ring in the Crimea, and the operator would say, 'America, speak!'

"We had such trouble that our Russian friends finally called up the National Minister for Communications of the Soviet Union and said we had to be able to contact Green Bank by telephone. Thereafter, we had reasonable luck using the telephone. By this I mean we could place a telephone call and have it go through in three or four hours.

"We set up for the first of the main observing sessions at six centimeters wavelength. This was scheduled to be a two-day observing session. Since we got no results from the previous test experiments, we were also going to send a few more tapes very quickly back to Green Bank for further processing. Kellerman was going to Moscow with the tapes to take them directly to the American Embassy to get them shipped off as fast as possible.

"At about five o'clock of the morning Ken was to leave for Moscow with the tapes, I was sitting there staring at the equipment and worrying about things as usual. It finally occurred to me that there was one switch on a piece of fancy commercial equipment that didn't seem to be in the right position. It was confusingly labeled 'switch.' I had, indeed all of us had, looked at the thing and worked through the symbolism and concluded that was a reasonable way to have the thing set. But I finally

got worried enough about it at six o'clock to wake up John Payne and ask him where the manuals on the thing were. I looked it up and indeed the switch was in the wrong position.

"This meant frequencies were in error, probably on the order of a kilocycle, which was totally disastrous unless it could be measured. And there was no equipment around capable of measuring it to the necessary precision. By that time I concluded the observations on the tapes were useless.

"My first concern was that we should extend the observing period. To do that we had to let the people in Green Bank know, since it doesn't do much good to observe on only one end of the base line. So we really attacked the communication problem on that. We sent a telegram, booked a phone call, and tried to send a TWX all at the same time. We intercepted Kellerman at nine in the morning. He came back, picked up a couple of good tapes, and went back to the airport. On arriving in Moscow, he also sent a telegram to Green Bank. We finally reached Green Bank by telephone and then ran through the six-centimeter observations again. We were able to get the tapes back to Green Bank, have them processed, and find out the interferometer was working before we started our observations in the three-centimeter series. This made us a great deal happier."

There is one thing about experiments in long baseline interferometry. They end on time. And no one had to tell the Russians when to start the celebration.

Clark says, "On that equipment you know when things are going to happen. At the end of the three-centimeter run we were planning to break out some vodka to toast the Russians about 140030 UTC, but we never made it because they broke out the cognac at 140020. It was quite a party."

Meanwhile, back in Green Bank, the crew of astronomers just turned off the switches and went to bed, too exhausted to think about celebrating.

Although the sensitivity at three centimeters was not as high as expected, and no major breakthroughs were made in the six-centimeter observations, the astronomers were satisfied that the investigation had contributed to the body of data that will help scientists to understand the nature of extragalactic objects.

The investigation also revealed something on earth that may prove far more significant than the results of the observations of universe—that genuine scientific cooperation between the Soviet Union and the United States is possible.