search & discovery

Gravity waves attract theories and experiments

The recent announcement in the popular press that an Israeli group had found gravitational waves coming from a pulsar is just the tip of the gravitational iceberg. Since Joseph Weber's report in 1969 that he had observed gravitational waves at 1661 Hz, more and more experimenters have been preparing their own experiments to observe the waves. And theorists have been busy trying to explain what sort of source will produce gravitational waves.

Theory. Recently Charles Misner[1] (University of Maryland) proposed in *Physical Review Letters* that the source Weber observed could be putting out gravitational synchrotron radiation, in narrow angles and at high frequencies.

By observing the signals over a six-month period and finding that the signals varied with sidereal time, Weber had concluded that the source of gravitational waves is at the center of the galaxy. If the source is a quadrupole source radiating isotropically, this would require that 1000 solar masses/year be radiated away from the center of the galaxy, Weber reported.

Subsequently Dennis Sciama, Martin Rees (Cambridge) and George Field (Berkeley) considered what events would signal mass loss from the center of the galaxy, such as changes in the orbits of stars and movement of hydrogen away from the center. They obtained various limits on how much mass could be lost by the center of the galaxy and obtained as an upper limit 1 solar masses/year if the loss has been going on for 10^8 years. Thus their estimate was inconsistent with Weber's estimate of 1000 solar masses/year.

Misner's way out of this inconsistency was to change the angular distribution of the source. He says the radiation all goes out in the plane of the galaxy and notes that the earth is sitting right on the plane of the galaxy to within 1 part in 1000. You could then get by with a source that only radiates into 1/1000th of the whole sphere available to it and reduce the Weber estimate of mass loss to one solar mass/year in the same bandwidth assumed by Weber (several hundred Hertz).

Misner assumes that the gravitational synchrotron radiation is produced by a large, strongly rotating black hole. He points out that only a black hole would give a gravitational potential well deep enough to accelerate masses to the relativistic velocities that gravitational synchrotron radiation would require. And a rotating black hole could act preferentially in its equatorial plane. Another reason Misner thinks that the source is a strongly rotating black hole in the center of the galaxy is (following some ideas of James Bardeen and of D. Lynden-Bell) that it's natural to think the matter that fell in came from a population of rotating matter like the kind we see nearby; so the black hole would have angular momentum, probably very close to the maximum possible. Hence the gravitational field of the source contains built into it, essentially in the plane of the galaxy, the angular momentum of the black hole.

By assuming gravitational synchrotron radiation, not only does Misner overcome the power difficulty with a quadrupole source, but also the low-frequency difficulty, he says. For a

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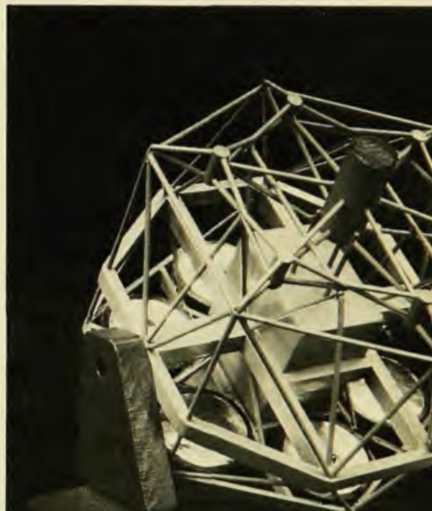
Multimirror infrared telescope planned

The University of Arizona and the Smithsonian Astrophysical Observatory are collaborating to build a large optical-infrared multimirror telescope. The telescope will have a light-collecting area equal to that of a conventional 176-inch telescope, but will consist of six 72-inch telescopes mounted on a common framework in a hexagonal array around a common axis with their images combined on this axis through two plane-mirror reflections. The six-barreled tube structure will be supported in an altitude–azimuth geometry and will be located at SAO's Mt. Hopkins station (elevation 8500 ft), 40 miles south of Tucson, Arizona.

In the center of the telescope array will be a 40-inch telescope that will serve both as a guide telescope and as a collimator that will produce (with auxiliary cube-corner reflectors) twelve parallel segments of a laser beam. The beam will run along the periphery of the optical path of each of the six subsystems, a pair of beams for every subsystem. Positional information derived from the laser beams will be fed back to piezoelectric actuators on the six secondary mirrors that will control the tilt and focal positions so as to maintain the superposition and focus of the six images. This will pro-



Model of multimirror telescope to be built by University of Arizona and Smithsonian Astrophysical Observatory. The six 72-inch telescopes will have a light-collecting area equal to a conventional 176-inch telescope.

duce an envelope of a point-source image not more than 0.7 arcsec in diameter. According to N. P. Carleton, of SAO, 1-2 arcsec is usually considered good seeing for an optical telescope, and weather conditions permit seeing better than 0.7 arcsec only about 10% of the time.

The advantages of this kind of telescope, according to Carleton, lie essentially in eliminating the need for a huge monolithic primary mirror that might weigh as much as 30 tons. This single large piece, in addition to being expensive, sets the high scale of weight and size for the rest of the installation. The problems and costs involved in conventional telescope construction are such that the Soviet 236-inch will probably be the largest that anyone will ever attempt, Carleton says. The multimirror design offers very large potential savings in cost, and the designers hope that it will show the way toward constructing a much larger telescope of similar design. Also, the same principles should prove useful in solving the problems of launch, control and assembly of a large space telescope, Carleton says.

"In thinking about such a structure as this," Carleton told us, "one must remember that the stiffness-to-density ratio of metals is at least as good as that of glass or quartz." Also, a metal structure can be made to have much less excess weight than even a quartz one; it is only in thermal expansion that metals are inferior to glasses. Hence, a structure like the multimirror telescope can be made to be extremely light and rigid, giving a very firm base from which the fine positioning of optics may be done by the control system. The six primary mirrors will be of light fused-quartz construction and will therefore be easy to support.

The telescope was designed with far-infrared photometric observation in mind, and therefore has minimum-size secondary mirrors, so that one sees as little as possible of thermally emitting surfaces when one looks through the telescope. Also, in order to permit rapidly alternating observations of an infrared source and of the sky beside it, so that the sky emission may be subtracted from the observations, the six secondary mirrors may be caused to wobble in unison, so that the field of view jumps back and forth between two positions that are many seconds of arc apart. According to Frank Low of the University of Arizona, this is the only large telescope that has been designed with these considerations in mind for far-infrared photometry. Another possibility that will be investigated is the usefulness of bringing the six images into coherent registration at wavelengths of 10-20 microns. No large ground-based telescope can produce images anywhere near its diffraction limit in visible light because of atmospheric distortion of the wavefronts. It is not known at present how much the longer wavelengths are influenced by the atomosphere. If this influence proves sufficiently small, then diffraction-limited observations with this telescope would permit spatial resolution of 0.5 to 1.0 arcsec in the far infrared, a several-fold increase over that presently realized, according to Low.

The telescope will have a high-quality field that is 5 arcminutes in diameter. This is smaller than that of most optical telescopes, but a wider field can be provided by more complicated relay optics. Much of the telescope's use, however is expected to be in the spectroscopy of individual objects, with instruments such as the echelle spectrometer, the Fourier-transform spectrometer and the Fabry-Perot interferometer. To accomodate instruments that do not readily swing on the back of the telescope, the combined beam may be relayed out to a focus at the end of the altitude axis, where an instrument may ride around on the azimuth table, with constant gravitational loading.

The telescope is presently in the detailed-design stage and is expected to be completed in less than three years. Those involved in the design and execution of the project include Fred L. Whipple, Director of SAO, Aden B. Meinel, Director of the Optical Sciences Center at Arizona, R. J. Weymann, Director of the Steward Observatory at Arizona and Michael Reed of the University of Arizona. —SMH

Gravity waves

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reasonable mass estimate of the black hole, say 10^8 solar masses, quadrupole radiation would come out at 1 cycle/hour. Then Weber would be seeing a harmonic of order 10^6. High-frequency harmonics are characteristic of synchrotron modes of radiation, Misner points out.

In a companion paper, Misner, R. A. Breuer, D. R. Brill, P. L. Chrzanowski, H. G. Hughes III and C. M. Pereira (University of Maryland)[2] discuss a model for producing gravitational synchrotron radiation, in which some superaccelerator accelerates masses to energies of 1000 GeV/nucleon and aims them at exactly the right point so that instead of scattering off the nearby hole, they go into unstable orbits, in which they circle around many times. Although the model is totally artificial, Misner says, it enables one to start learning how to handle this kind of radiation at high frequencies and narrow beams. This artificial model gives a frequency spectrum wider than Weber's rough extrapolations had assumed; with the spectrum from this model, the mass-loss estimate becomes ten solar masses/year.

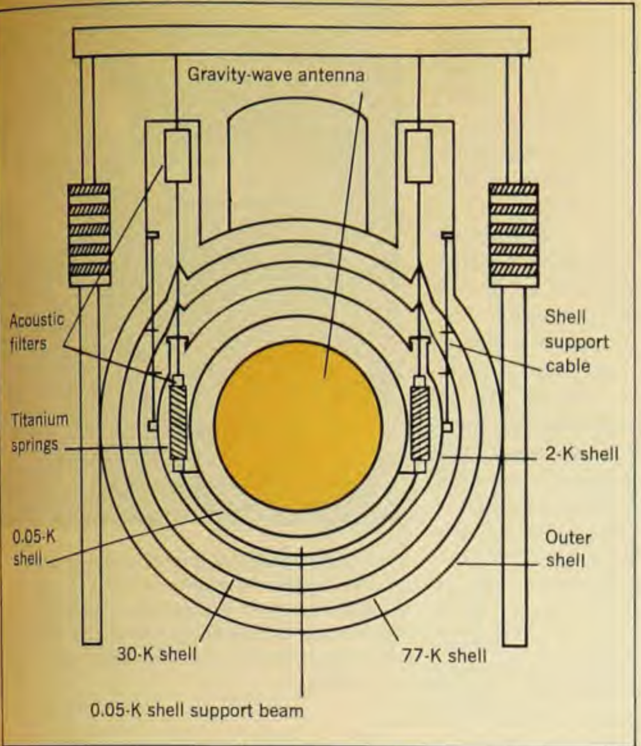
At a general relativity meeting held in Berkeley on 4 February, Remo Ruffini (Princeton) criticized the model of Misner and his collaborators. The Misner argument was essentially based on the analysis of unbounded circular orbits, quite uninteresting from an astrophysical point of view, while the ultrarelativistic conditions necessary to have a synchrotron effect are not fulfilled in the case of more realistic bounded orbits, either in the Schwarzschild or Kerr analysis, Ruffini said.

Ruffini also criticized the Misner analysis because it was not done for gravitational radiation (spin 2), but only in the case of the asymptotic behavior (large multipoles) for scalar radiation (spin 0).

Ruffini, together with Marc Davis (Princeton), Jayme Tiomno (Institute for Advanced Study) and Frank Zerilli (University of North Carolina), have done a detailed fully relativistic analysis[3] for electromagnetic (spin 1) and gravitational (spin 2) radiation. Moreover, they analyzed the details of the spectrum in the low-multipole region. Ruffini said that in this more complicated but more realistic analysis they conclude there is a strong defocusing effect. They found that while in all the three cases under extreme relativistic circumstances an enhancement of the highest multipoles is present, the three spectra differ radically at low multipoles. In the case of gravitational radiation, the low multipole contributions are essential. These two criticisms, Ruffini says, raise very serious questions about the effectiveness of the gravitational synchrotron radiation mechanism in concentrating energy into a plane.

The analysis of the asymptotic regime (high multipoles) of the spectrum of gravitational radiation emitted in ultrarelativistic orbits is currently being treated in work by Breuer, Ruffini, Tiomno and C. V. Vishveshwara (NYU). This work will throw new light, Ruffini said, on the effectiveness of beaming in these very idealized relativistic orbits.

One of the main points of this recent work has been to focus attention on the very different polarization properties of gravitational radiation. Ruffini and his collaborators have analyzed the problem of a particle falling radially into a black hole, while the case of a particle in a circular orbit has been analyzed by them and by D. Chitre and Richard Price (University of Utah). In



Gravity-wave detector suspension system being built at Louisiana State University. Antenna is 3 feet in diameter, 10 feet long and weighs about 12000 pounds. It will be suspended on a superconducting magnet (not shown).

both cases a very strong characteristic polarization pattern has been found.

Using the qualitatively different tensor spectrum to extrapolate the Weber observations increases the energy requirements by a factor of about six, as compared to the scalar spectrum, Misner says.

In a third companion paper, Tony Tyson (Bell Labs) and David Douglass[4] (University of Rochester) say that Weber's data are inconsistent with 100% polarized radiation in the direction of the galactic center; the source could appear to be in the direction of the galactic center but in reality be somewhere else in the sky and be highly polarized. They say that the maximum limit on the polarization of a source at the galactic center is between 30 and 40%. (Earlier, Ruffini and John Wheeler[5] of Princeton had given the response of a Weber-type antenna directed East–West to sources of randomly polarized radiation coming from the center of the galaxy.)

Misner believes it will be complicated to find a synchrotron radiation source that will not give nearly 100% polarization, but he believes there are possibilities.

In a new calculation now in process, Chrzanowski is calculating the radiation emitted when a particle falls into a black hole without sufficient angular momentum to maintain itself in a circular orbit. Misner believes there is a fair chance it would emit substantial energy in the synchrotron modes.

Weber. The real need at this point is for more observations. In the Israeli experiment, which was reported in *Newsweek* and elsewhere, Dror Sadeh and Meir Meidav (Tel Aviv University) and Ari Ben-Menahem (Weizmann Institute), use the earth itself as the gravity-wave detector. A seismometer detects the surface acceleration of the earth. Its output is Fourier analyzed and one looks for the characteristic frequency of a pulsar.

Such an experiment had earlier been performed by Weber and Reginald Clemens. Another such experiment had been done by Frank Press and Ralph Wiggins (MIT), using a large-aperture seismic array that was built to detect nuclear explosions. Weber had used a single seismometer. Both experiments were negative. Now Weber plans to look for pulsars by putting a seismometer on the moon during the Apollo 17 mission in December.

Weber's experiment is now automated and is continuing to show coincidences between the cylinders at Argonne and at Maryland. He is concentrating his efforts right now on improving the time resolution by a factor of ten, with renewed inspiration following his recent marriage to astronomer Virginia Trimble.

Weber is working on cryogenic gravity-wave detectors at both locations. He has now cooled a bar to 4 K and observed its noise.

Last year Weber reported his first results with the disk detector (which he ran in its radial mode at 1661 Hz). He found that the radiation is pure tensor. He is now instrumenting the disk to measure polarization directly.

The disk detector will also help to further determine the bandwidth. In an earlier experiment Weber used a cylinder at 1580 Hz, a cylinder at 1661 Hz and a third cylinder at 1661 Hz, two of them being at Maryland and one at Argonne. He found that the counting rate for the 1580-Hz device in coincidence with one of the 1661-Hz devices was the same as for the two 1661-Hz detectors in coincidence. Thus the bandwidth is at least 80 Hz wide. With the disk operating in its quadrupole mode its frequency will be 1000 Hz. It will be operating in coincidence with one at Argonne and should get a much better handle on the bandwidth.

Other experiments. At Bell Labs and Rochester, Tyson and Douglass are planning to operate two cylinders in coincidence within the year. They will run simultaneously at 710 Hz, which is the first longitudinal mode, 2070 Hz, the third longitudinal mode, and 3200 Hz, the fifth longitudinal mode.

At Louisiana State University and at Stanford University, William Hamilton and William Fairbank will be running two cylinders, which will be suspended on a superconducting magnet; they will eventually be cooled to the millidegree region. The superconducting instrumentation will also be sensitive to the third and fifth harmonics of the bar; the fundamental is 800 Hz.

At the Joint Institute for Laboratory Astrophysics, Judah Levine is using a laser interferometer to measure strains in the earth's crust (PHYSICS TODAY, June 1971, page 19); he has been looking for gravitational waves from the Crab pulsar and will soon look for waves from some of the other lower-frequency pulsars.

At Moscow State University Vladimir Braginski has two cylinders operating, which are similar to Weber's, have the same frequency, but use a capacitive pick-off system. Braginski eventually plans to make an array of nine antennas all across Soviet Siberia; if his time resolution is good enough he will be able to measure pulse velocity.

In the United Kingdom there are three groups. At the University of Bristol, Peter Aplin is building an antenna which consists of two pieces with a piezoelectric transducer sandwiched into the middle; the device is expected to have very good timing, so that one might hope to map out the behavior of the metric on a millisecond to millisecond basis. Ronald Drever at the University of Glasgow is operating a Bristol-type detector and building three more. And at the University of Reading, Douglas Allen is building a Bristol-type antenna.

In Italy, at ESRIN in Frascati, K. Maischberger, Bruno Bertotti and G. Fiocco are now operating a Weber-type detector at 1661 Hz; Weber hopes to join in a coincidence experiment with them. At the University of Rome Edoardo Amaldi, Guido Pizzella and Giorgio Careri are planning a third cylinder like the ones to be at LSU and Stanford, thus allowing the possibility of measuring the speed of the waves picked up at all three locations.

In Germany, Hans Billing (Max Planck Institute in Munich) is constructing a duplicate of Weber's experiment. He is planning to do a coincidence experiment with Frascati and Weber. —GBL

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First experiments set for CEA colliding beams

The Cambridge Electron Accelerator, which has been developed into an electron-positron colliding-beam device, is now producing electron and positron beams at 2 GeV and with peak currents of about 15 mA and is preparing for its first high-energy experiments. To produce a collision between a positron beam and a stationary electron with the same center-of-mass energy, one would need a positron beam energy of 16 000 GeV.

The development of the device has been the primary activity of the laboratory since July 1970. The electron-positron collisions will be used to investigate electromagnetic processes and the production of strongly interacting particles by one- and two-photon processes.

CEA is now the highest energy electron-positron colliding-beam device in the world. In later experiments, each beam will have its energy increased from 2 to 3.5 GeV. The next highest energy operating device of a similar nature is located at Frascati, Italy, where beams of 1.3 GeV are available. Three other storage rings currently under construction in the same energy range as the CEA are SPEAR at SLAC with 2.5 GeV in each beam, DESY (Deutsches Elektronen Synchrotron) in Hamburg with 3.5 GeV in each beam and Novosibirsk in the Soviet Union with about 3 GeV in each beam.

The most important of the recent modifications to the accelerator, which began operations in 1962, is a 150-foot long stretch of vacuum chamber into which the two counter-rotating beams are switched for storage and collision. The chamber, known as the bypass section, contains a special arrangement of focusing quadrupole magnets, called a low-beta insert, which focuses the beams to a cross-sectional diameter of about 0.004 inches, one-tenth of the beam diameter in the ring. Without these special focusing sections, head-on electron-positron collisions would be so rare an experimenter might have to wait several weeks for one. The sections were first proposed by K. W. Robinson and G.-A. Voss of the CEA.

An extremely high particle density is necessary for a useful number of collisions. To provide this, beams are built up by injecting a succession of pulses of electrons and positrons at lower energy from a linear accelerator and then storing the beams after they have reached full energy for an hour or so while they collide. CEA researchers had to produce a vacuum of about 10^{-12} atmospheres to permit such long storage times.

New magnets also had to be developed for a damping system to control radiation anti-damping and others to keep beam instability from growing out of control during the storage period.

Like previous colliding-beam systems, the CEA development has been plagued by the effects of beam instabilities and beam-beam interactions. At this time the positron beam that can be annihilated routinely is limited to a peak value of about 15 mA by coherent synchrotron oscillations, and the electron beam that can be safely injected in the presence of positrons is limited to about the same value by beam-beam interaction. Several ways of increasing both limits are being developed.

The electron-positron collisions that will be produced by the machine will provide a way to test the fundamental laws of quantum electrodynamics, and since all energetically permitted particle-antiparticle pairs that are coupled to the electromagnetic field will be produced, there is a chance to observe new particles with the machine.

In the one-photon process, which will be studied at the CEA, a colliding electron-positron pair results in the annihilation of both to one virtual photon, which then produces a particle-antiparticle pair.

CEA 2-GeV colliding-beam device is now producing peak currents of about 15 mA. Bypass is in front and synchrotron in rear. Technician stands at the interaction region, which is now surrounded by detection apparatus.

The field of "two-photon physics," in which two virtual photons collide and produce a variety of reactions, will also be studied with the CEA. In this type of collision, the electron and positron each emit virtual photons, which then collide and produce particle-antiparticle pairs while the original electron and positron keep traveling with reduced energy.

The first experiment on the CEA, which will be carried out by a joint CEA-Harvard group, concentrates on the study of electromagnetic one- and two-photon processes and on the measurement of the cross sections for hadron production. A second experiment being prepared by a group of physicists from CEA, MIT, Southeastern Massachusetts University and Northeastern University will use a magnetic field around the interaction region for a detailed analysis of the collision products.

Van de Graaff voltage raised to 14.4 MV

Many nuclear physicists working with big tandem Van de Graaffs would like to raise the energy of their accelerators by buying new acceleration tubes from High Voltage Engineering Corp. In tests with its own MP-0 (Emperor) tandem Van de Graaff, High Voltage reported that voltages as high as 14.4 MV were achieved, which the company says is the highest dc voltage ever applied to an acceleration tube. In the past, tandems only ran at 10–11 MV on terminal; beyond this value the tubes would fail. With the new tubes, a conventional tandem would be able to run at 28–30 MeV. □