Josephson Detectors Make Astronomical Observations

Since the discovery of the Josephson effect, astronomers have been intrigued with the possibility of using junctions of two superconductors connected by a weak link to detect millimeter and submillimeter radiation from astronomical objects. Now Bruce T. Ulrich of the University of Texas has reported (at the American Astronomical Society meeting in New York last December) the first astronomical observations with a Josephson junction; he has observed the sun, moon and Venus. His group and other groups (at the University of California at Berkeley and at the State University of New York at Stony Brook) are testing several different ways of using Josephson-type junctions in hopes of improving sensitivity.

Astronomers have found surprises every time a new spectral region or lower intensity level opened up; the new detectors will undoubtedly do likewise. Frank Low's pioneering bolometric observations have already shown that some of the nuclei of Seyfert and infrared galaxies radiate strongly in the millimeter and submillimeter region; the optically brightest quasar, 3C273, radiates the major fraction of its total energy in the submillimeter and infrared—perhaps new observations will show a link between such objects. Because the 3-K blackbody radiation peaks around 1 mm, one may obtain more convincing evidence for the "big bang."

The Josephson junction is an optimal astronomical detector for wavelengths between 100 micrometers and 3 millimeters and perhaps longer wavelengths; in this range the device offers high sensitivity, subnanosecond response times and insensitivity to near-infrared and visible radiation, Ulrich told us. With conventional bolometric detectors in the short millimeter and submillimeter region, one must filter out visible and near infrared.

In most astronomical objects the visible and near infrared contain much more energy than the far infrared. The sun, for example, radiates a million times more energy at wavelengths shorter than 100 microns than it does at longer wavelengths. Even the 300-K room-temperature background radiation contains a thousand times more energy at these shorter wavelengths. Generally it is extremely difficult to construct filters that are sufficiently opaque at short wavelengths but transparent at longer. With Josephson junctions such filters are unnecessary.

The ultrarapid response of the detector makes it promising for high-speed astronomy, for example in observing rapidly pulsating radio sources and other objects. Ulrich is now trying to detect the Crab pulsar at 1 mm. Observation at this wavelength would be roughly half way, on a logarithmic scale, between 1-meter radio observations and 2-micrometer near-infrared measurements.

Ulrich noted that because the ac Josephson effect is inherently a coherent quantum effect, one might be able to build a sensitive coherent or superheterodyne detector or parametric amplifier for the 1-mm and submillimeter wavelength region. One might even be able to construct a voltage-tunable far-infrared and millimeter-

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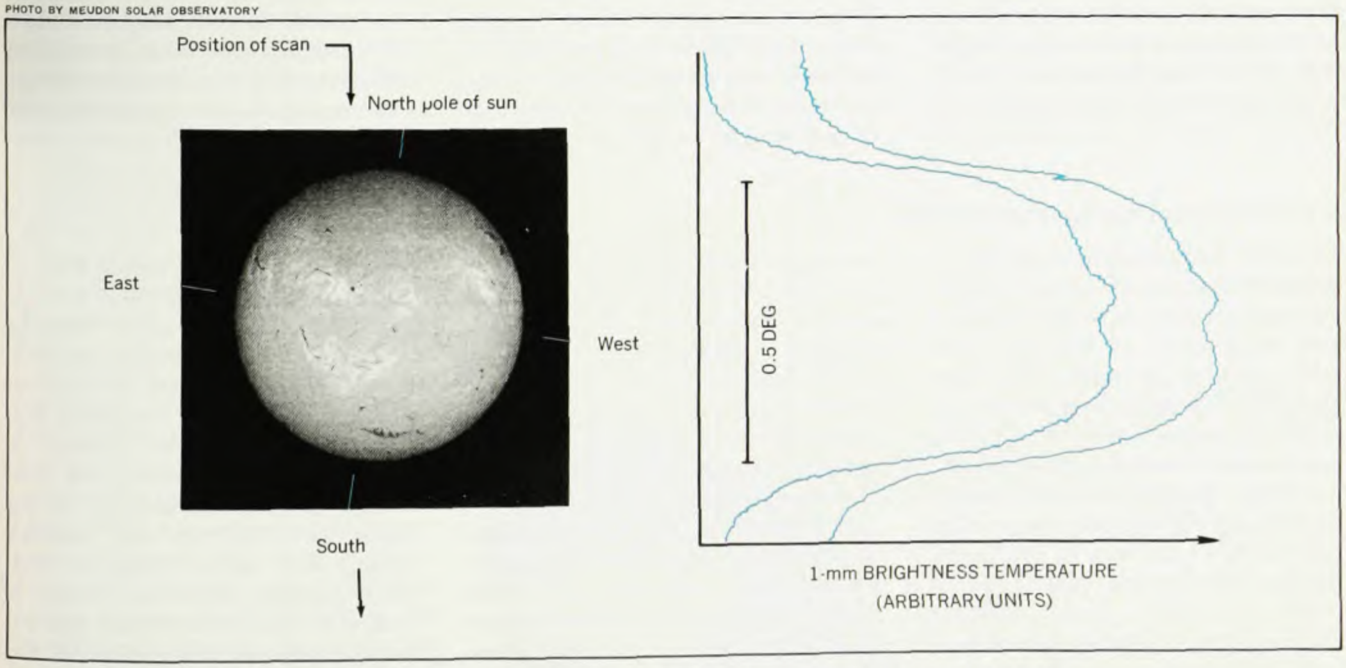

JOSEPHSON-JUNCTION SCAN of the sun at 1-mm wavelength using the 107-inch McDonald Observatory reflector. Note appearance at 1 mm of enhanced emission from a sunspot and also from an active region visible in the H_α photograph of the sun. The two north–south scans, taken 7 minutes apart in time, as part of a complete 1-mm map of the sun, show reproducibility of observations. Recorder time constant was 0.3 sec and scan rate 0.25 deg per minute of time.

wavelength spectrometer to observe interstellar molecules. In the superheterodyne mode, the junction operates as both a local oscillator and mixer. Through the ac Josephson effect a voltage V impressed across the junction generates an ac current through the junction at a frequency of $2eV/h$ (e is electron charge and h is Planck's constant). The incident radiation mixes with the ac current through the junction and the resulting intermediate frequency can be amplified as in a conventional superheterodyne receiver.

Texas observations. In the present Texas detector a point-contact Josephson junction is current biased to an operating point above zero voltage, and the changes in the I–V characteristic caused by incident radiation as a function of position on the astronomical source are detected as voltage changes.

Ulrich has been making astronomical observations with his detector for more than a year. By using a new stabilization technique Ulrich told us he is able to reproduce junction characteristics for periods of weeks.

To study the sun, the image of the sun is scanned across the detector and the output recorded. Telescope resolution for the 1.0–1.5-mm band is about 2 arc minutes (full width at half maximum). Telescope optics are protected from overheating by placing a black polyethylene filter over the end of the telescope tube to exclude radiation shorter than 10 microns. On 17 June 1969 Ulrich found that the 1-mm emission from the sun showed 10% peaks in emission above the solar effective temperature of 6000 K during times of moderate solar activity (see figure). The peak in emission coincides in position with a sunspot visible in the Hα photographs. Ulrich did not find the 5% fluctuations in millimeter brightness temperature over time scales of one minute reported previously by other observers.

The existing Texas detector, called "SLED" (Superconducting Link Electromagnetic Detector) has a current sensitivity, or noise equivalent power referred to the junction, of better than 10^{-14} watt/Hz$^{1/2}$ at 1 mm, Ulrich told us. The sensitivities for the best bolometers, also referred to a position at the detector, are a few time 10^{-14} watts/Hz$^{1/2}$. The ultimate sensitivity of this point-contact detector is not limited by fluctuations of the photon background flux to the same extent as the bolometer, Ulrich said; unlike the bolometer the junction is not sensitive to background photons at short wavelength.

At Berkeley Raymond Chiao and his students are building a new kind of Josephson-type detector, which he discussed at the Chicago APS meeting. In principle it should be capable of detecting individual microwave photons, just as a photomultiplier does in the visible region, Chiao told us. Theoretically the Josephson junction would act as a photodiode with a quantum efficiency of unity . Bolometers, for example, have a quantum efficiency of 1 part in a million at 1 cm. Even the maser, because it detects both phase and intensity has an inherent noise that the superconducting detector would not have, as it only detects intensity.

The Berkeley group uses a Dayem bridge (developed by Aly Dayem and Philip Anderson of Bell Labs), which consists of a thin film of tin split in two by a scratch; a very thin bridge connects the two parts (it must be less than the coherence length—about 4 microns). Then the Berkeley group deposits normal metal on top of the superconductor; the proximity effect weakens the bridge, which makes the critical current comparable to the photon current and thereby increases the sensitivity. Chiao says that the new detector gives much more reproducible results than the point-contact junction and should have a sensitivity about 20 times higher.

The next step will be to put the detector into a strip-line resonator, a microwave cavity that has a very low impedance. By putting the bridge into the skin of the cavity where the radiation-induced current is a maximum, one can detect the rms current caused by the presence of a photon. Chiao feels the cavity will improve sensitivity by another factor of 20. Eventually he and Charles H. Townes expect to use the detector with the Hat Creek (20-foot) radio telescope.

At Stony Brook Hong-Yee Chiu, Y. H. Kao and Jose Warman have built a niobium powder Josephson junction; oxidized niobium acts as the insulating part of the junction. Their junction also has a sensitivity at the junction of about 10^{-14} watts/Hz$^{1/2}$. This spring they will start preliminary measurements on the sun employing a homemade radio telescope. —GBL

A Visit with Paul McDaniel of the AEC

The AEC Division of Research has an annual budget of $400 million (including capital items), of which about 3/4 goes for physics and the rest to the other physical sciences. That sum makes the division the largest supporter of physics research in the US. To find out how funds are allocated and what the major directions of AEC-funded research are, we spent the day at AEC headquarters with Paul W. McDaniel, director of the division, deputy director Daniel R. Miller, senior associate director Arthur E. Ruark (now retired), Walter E. Hughes (assistant director for administration) and the five assistant program directors.

The AEC is an independent agency headed by the five commissioners, who are appointed by the President for five-year terms. The assistant general manager for research and development is Spofford G. English, who is in charge of five divisions: Division of Research (which covers all the physical sciences), Division of Biology and Medicine, Division of Isotopes Development, Division of Peaceful Nuclear Explosives and Division of Nuclear Education and Training. Physics is also supported by other parts of the AEC such as the Reactor Physics Branch of the Division of Reactor Development and Technology.

The Division of Research employs about 68 persons, 25 of them scientists, who initiate and terminate programs but do not do research of their own; it is their job to decide what research to support and how much to pay for it. About half of the funds the division is responsible for are high-energy physics (defined as 1 GeV or higher); the group is headed by William A. Wallenmeyer. George A. Kolstad handles medium and low-energy physics. Donald K. Stevens heads the Metallurgy and Materials group, over half of which is solid-state physics. Replacing Amasa S. Bishop as head of Controlled Thermonuclear Research is Roy Gould of Cal Tech. Alexander van Dyken is in charge of the chemistry program, about half of which is for nuclear chemistry; another large part is chemical physics.

What directions? "How do you