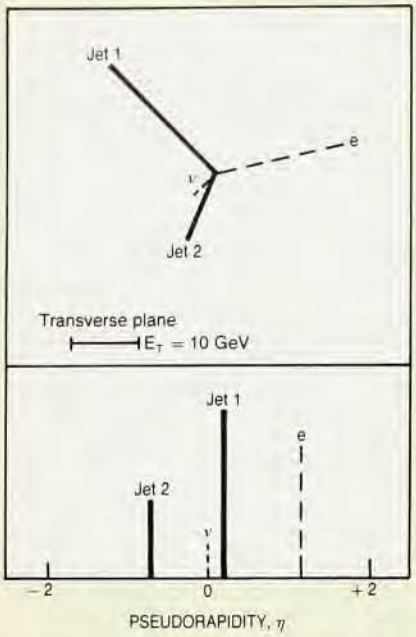

One of the six top candidate events. Top sketch gives transverse momentum of electron, neutrino, jets 1 and 2 in a plane perpendicular to the beam direction. Plot below gives pseudorapidity (a measure of the angle with respect to the $\bar{p}$ beam) of electron, neutrino, jets 1 and 2. Total invariant mass of electron, neutrino, jets 1 and 2 is 76 ± 7 GeV/c^2 and total invariant mass of electron, neutrino and jet 2 is 48 ± 7 GeV/c^2.

simplification appears to pay off, he said, but it's a "novel technique that people aren't comfortable with." For the next generation of hadron colliders, such as the Superconducting Super Collider, with 20 TeV/beam instead of the 270 GeV/beam available last year with the CERN collider, Cline feels such jet analysis will be needed to discover new particles.

Assuming the top quark mass is indeed between 30 and 50 GeV, one can estimate the number of events expected; this number, three, is to be compared to the 6 ± 2.4 events the UA1 group has reported.

Anomalous events. Last fall both the UA1 and UA2 groups reported that among the Z^0 events, there were some in which the Z^0 decays into a single photon and a lepton pair, a decay considered highly unlikely. The new anomalous events reported this spring and summer by the UA1 and UA2 groups don't all appear to be the same phenomenon. At the Washington APS meeting, Jean Marc Gaillard (Orsay) described[1] the UA2 anomalies. The group found three or possibly four events that looked like a W decaying into an electron, a neutrino and extremely energetic jets. Gaillard said there are also preliminary indications of excess events in the mass distributions around 150 GeV.

At the same APS meeting, Rubbia quoted Valentine Telegdi (ETHZ): "Yesterday's sensation is today's calibration and tomorrow's background." He said that UA1 found five events in which a missing transverse energy larger than 40 GeV is associated with a narrow jet. Thus the anomalous events reported[2] by UA1, known as "monojets," could be characterized, Rubbia said, "as a very energetic photon or jet on one side, and essentially nothing on the other side—50, 70 or 80 GeV just disappears."

Rubbia described another anomaly at the APS meeting: when $Z^0 \rightarrow e^+e^-$ or $\mu^+\mu^-$, the UA1 group finds that an unexpectedly large number of such decays are associated with two or more jets. "The Standard Model doesn't permit that," he said.

Rubbia feels the anomalies are analogous to the discovery of strange particles, "We're talking about new physical processes! No one mass value shows up. It's too new. Now we'll try to pinpoint it."

Next month, after its 14-month shutdown, the CERN $p\bar{p}$ collider starts operating again and will run for several months. CERN hopes to raise the energy from 270 to 320 GeV/beam and increase the luminosity. Both UA1 and UA2 will be operating with improved detectors, hoping to gain further information on the top quark and the anomalies, and to search for the Higgs boson. —GBL

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IRAS exposes a remarkable infrared galaxy

The visible image of Arp220 was just interesting enough to warrant its inclusion in Halton Arp's 1966 *Atlas of Peculiar Galaxies*. But only now are we beginning to see how very peculiar this galaxy really is. While it ranks behind about 10 000 other known galaxies in visible brightness, the recent Infrared Astronomy Satellite (IRAS) survey has shown Arp220 to be one of the ten brightest extragalactic infrared sources in the sky. Almost 99% of its total energy output is in the infrared. From the red shift of its visible line spectrum one deduces a distance of about 100Mpc (300 million light years). At this distance its observed infrared brightness implies a total luminosity of 2×10^{12} times that of the Sun. This astonishing luminosity, a hundred times that of normal galaxies like our own, is exceeded only by the most luminous quasars. Quasars, however, emit strongly at visible and shorter wavelengths.

The 57-cm IRAS infrared telescope was launched into orbit in January 1983 (see PHYSICS TODAY, May, page 17). If the uniqueness of Arp220 had been appreciated before IRAS ran out of its superfluid-helium coolant 10 months later, one might telemetrically have ordered a special detailed scan of this unprepossessing 14th (visible) magnitude galaxy near Arcturus in the summer night sky. But in fact Arp220 did not come to special attention until last January, after IRAS had ceased to function, when Thomas Soifer (Caltech) of the IRAS team was taking a closer look at the data base of the 500 brightest far-infrared point sources found in the IRAS extragalactic survey. He was astonished to discover that one of the very brightest of these corresponded to the very faint optically identified galaxy Arp220.

Soifer and his colleagues now believe that ARP220 is not really unique among the infrared sources discovered by IRAS. They have come to regard it as the closest, and therefore the prototypical example, of a new class of extremely luminous galaxies characterized by the puzzling fact that they radiate overwhelmingly in the infrared. The other observed galaxies of this class, they believe, are so much further away that they are not clearly discernible in the definitive Palomar optical sky survey.

These more distant cousins of Arp220 may well be found among the nine "blank-field sources" identified[1] last September by James Houck (Cornell), Soifer and their IRAS colleagues. Among the bright, presumably extragalactic, infrared sources discovered in the IRAS all-sky survey, Houck and company found nine for which the Palomar Observatory Sky Survey catalog showed no corresponding visible galaxy—just a blank field or a very faint image in the patch of sky delineated by the error bars of the IRAS-measured position of the infrared source. The Palomar catalog, the deepest and most comprehensive optical survey of the northern sky, is reliable for sources brighter than magnitude 18.5.

At the June meeting of the American Astronomical Society in Baltimore, Soifer[2] pointed out that if Arp220 were ten times further away than it is—the distance of the prototypical quasar 3C273—it would still look bright to IRAS. But its optical magnitude would fall below the Palomar survey limit. Thus, but for the grace of proximity, Arp220 might have ended up among Houck's blank-field sources.

Arp220 is 80 times more luminous at 60 microns in the infrared than in the blue (440 nm). This extraordinary ratio is uniquely high among the IRAS sources for which the Palomar survey shows optically discernible galaxies. But it is quite consistent with the blank-field sources, for which the IRAS intensities and the sensitivity limits of the Palomar survey imply *lower* limits for the 60-micron/blue flux ratio ranging from 12 to 50. This "suggests that Arp220 may well be the prototype of a class of galaxies previously referred to as 'unidentified' [or blank-field] infrared sources," Soifer told the Baltimore meeting. It seems clear that the infrared luminosity of Arp220 is thermal radiation from dust that absorbs and reradiates the shorter-wavelength primary output of the galactic powerhouse. But whether this primary source is a quasar-like nucleus shrouded in dust or an extraordinary population of newborn massive stars still enveloped in their natal dust remains unresolved.

One other possible relative of Arp220 is Markarian231, far and away the most luminous of the known Seyfert galaxies. Ten years ago, Frank Low and George Rieke (University of Arizona) discovered that Mrk231 was a very bright shorter-wavelength infrared source. With a much higher effective blackbody temperature than Arp220, Mrk231 is much brighter at the near-infrared wavelengths accessible to ground-based observation. But even at 60 microns, Mrk231 has a very high ir/blue ratio—about 30. This pecular Seyfert galaxy is the only known celestial object, aside from Arp220 and the most luminous quasars, with a luminosity in excess of 10^{12} $L_{\odot}$

The optical image of Arp220 appears to have two oval nuclei, each about 15 arcseconds across, just touching one another, with more tenuous material arcing outward to total width of roughly 50″—corresponding to a fairly typical galactic diameter of about 70 000 light years. The peculiarity that warranted inclusion in Arp's catalog is the narrow ridge of reduced brightness between the two bright nuclei. Whether this ridge represents a real absence of material—perhaps suggestive of two galaxies in collision—or a lane of obscuring dust is not clear.

Although the 30″ spatial resolution of the rather cursory IRAS survey mode is insufficient to resolve the infrared source in Arp220, the center of the source can be much better localized. The intense infrared output appears to emanate from the optically depleted central ridge. This is also the location of the surprisingly strong and highly localized radio source discovered in Arp220 by Linda Dressel (now at Rice) and James Condon at the National Radio Astronomy Observatory in 1978.

Arp220 has a number of other idiosyncrasies. It turns out to be a quite exceptionally bright hydroxyl maser source. A radio examination at Arecebo by Felix Mirabel two years ago uncovered a somewhat perplexing contradiction: The radio spectrum of Arp220 showed very broad atomic-hydrogen absorption lines, indicating an abundance of unusually turbulent atomic hydrogen gas. But the hydrogen *emission* lines one might consequently expect were nowhere to be seen.

Apparent self-contradiction also manifests itself in the optical spectrum of Arp220. Even before the IRAS data raised the question of the nature of the galaxy's prodigious infrared source, its bright radio source posed much the same question. Last year Timothy Heckman (University of Maryland) and his colleagues[3] undertook a spectroscopic study at optical wavelengths of thirty galaxies, including Arp220, that harbor unusually bright radio sources. They were seeking to distinguish between two alternative explanations for these intense, localized radio sources: the Seyfert and "starburst" models. The Seyfert model imagines the existence of a Seyfert-type galactic nucleus—essentially a mini-quasar—imbedded in the much larger spiral galaxy. On the other hand, the radio source might be manifesting a localized region of hyperactive (starburst) star formation. These are essentially the same alternatives suggested for Arp220 by the IRAS infrared data.

Of the 30 galaxies in the Heckman spectroscopic survey, Arp220 was the only one that defied classification in terms of these competing models. Its broad "forbidden" OIII (doubly-ionized atomic oxygen) emission line is strongly suggestive of a Seyfert nucleus. A prominent hydrogen-beta absorption line in the optical spectrum of Arp220, on the other hand, presents conflicting evidence. It implies the presence of many very young stars, lending support to the starburst model.

The IRAS telescope examined the infrared sky in broad wavelength bands at 12, 25, 60 and 100 microns. In its survey mode, IRAS spent about one second looking at each resolution element (roughly one arcsec square) of the sky. [Specially ordered detailed scan modes such as the one that discovered the dust ring around Vega (PHYSICS TODAY, May, page 17) can achieve much finer resolution.] With 30″ resolution, most galaxies are indistinguishable in the infrared from point sources. Availing themselves of the Palomar optical catalog, the IRAS team found that by staying well away from the region of the Milky Way they could quite reliably distinguish bright galaxies from stellar sources by requiring that the infrared flux be higher at 60 microns than at the shorter infrared wavelengths.

The infrared spectrum of Arp220 peaks at 100 microns. Fitting the infrared spectrum from 25 μm to 100

The infrared sky, as seen (in galactic coordinates) by the IRAS all-sky survey. The black stripes are the only regions not scanned by the IRAS orbiting telescope. More than 250 000 point sources are shown, heavily concentrated near the galactic equator, the plane of the Milky Way, with our galactic center at the origin. False colors indicate source temperatures: Blue is warmest, red coolest. The blue point sources near the equator are mostly dust-shrouded stars. The yellow–purple regions above the center (in the constellation Ophiochus) and at the far right just below the equator (in Orion) are regions of intense star formation in our Galaxy. The Small and Large Magellanic Clouds, two nearby galaxies, are the two white blobs below center right. More distant galaxies, including Arp220, appear as yellow–green point sources distributed across the sky.

μm to a blackbody curve—"admittedly too simple-minded," Soifer told us—gives an effective blackbody temperature of 62 K. The IRAS team concludes that this infrared output is thermal radiation from one or more clouds of solid dust particles perhaps a tenth of a micron in size, in radiative equilibrium with the visible and ultraviolet source(s) they obscure. The total luminosity of these primary sources, $2\times10^{12}L_{\odot}$, is an order of magnitude higher than that of any other known galaxy (except for quasars and Mrk231), and almost 99% of it comes to us by way of this thermal reradiation in the infrared. Knowing the interstellar dust of our own galaxy, one presumes that the dust consists primarily of graphite and silicates.

In the months since Houck's identification of the nine IRAS blank-field sources, there have been two efforts to take a closer optical look. Using highly sensitive charge-coupled-device detectors, Houck and coworkers at the Palomar 5-meter telescope and Mark Aaronson's University of Arizona group at the 4-meter Cerro Tololo telescope in Chile have looked for optical images corresponding to the blank-field infrared sources. Of the six sources accessible in the night sky during these months, five have indeed yielded faint images of very distant galaxies. (The sixth turns out to be a local interstellar source.) Two or three of these faint images appear to have compound structures somewhat like Arp220, suggesting that they may be interacting galaxies.

Interacting galaxies. At the Baltimore meeting, Carol Lonsdale (JPL) reported the results of her study of the IRAS data on a selection of galaxies whose morphological appearance in Arp's *Atlas* suggests that they are merging or otherwise interacting galaxies in close proximity. She concludes that such galaxies are strongly overrepresented among the bright infrared sources discovered by IRAS. "Much of the strong infrared emission of the galaxies is likely to be caused by bursts of massive star formation triggered by the interactions," Lonsdale reported. "The most advanced mergers," she told the meeting, had the highest ratios of infrared to blue emission.

When galaxies come into close proximity with one another, their mutual gravitational perturbation is thought to induce shock waves in the interstellar gas and dust, accelerating the rate of star formation. Very young stars are seen primarily by the thermal reradiation from their obscuring dust clouds, which they have not yet had time to dispel. This starburst picture provides an appealing scenario for Arp220, except for the troubling detail that none of Lonsdale's interacting galaxies come close to Arp220 in total luminosity. The highest luminosity found among them is a few times $10^{11}L_{\odot}$. If quasars are indeed the only sources that can put out more that $10^{12}L_{\odot}$, one must consider the possibility that a dust cloud at the center of Arp220—and perhaps the blank-field sources and Mrk231 as well—is hiding an embedded quasar.

Mrk231, like Arp220, has a peculiar morphological appearance, suggestive of a "disturbed" galaxy, although neither is a clear case of interacting galaxies. Low, who is a member of the IRAS team, suggests that Mrk231 may be a later evolutionary stage of the Arp220 class, with a hotter appearance because more of the dust has been dissipated. His suggested scenario is something of a merger between the Seyfert and starburst models: "It appears that collisions between galaxies trigger the infrared-galaxy phenomenon, with runaway formation of massive stars in the nucleus producing active nuclei and quasar-like properties. This suggests that superluminous ir galaxies evolve into quasars, while their less luminous kin produce the far more numerous Seyfert galaxies, all with massive black holes at their centers."

The next generation orbiting infrared telescope should provide much more detailed spectroscopic information to help resolve the puzzle of Soifer's "remarkable infrared galaxy." IRAS was intended as a survey instrument to take a quick first look around the entire infrared sky, unobstructed by our atmosphere. This task it has accomplished with remarkable success. But the spectral resolution of the IRAS survey was rather crude, providing a $\Delta\lambda/\lambda$ wavelength resolution no better than 30%. Its proposed successor, called SIRTF, is planned to be an observatory-class instrument, with a spectroscopic resolution of about 10^{-3}. The acronym SIRTF originally stood for Shuttle Infrared Telescope Facility. A shuttle-based telescope, however, would have a mission lifetime of only a few weeks. The remarkable and somewhat unexpected longevity of IRAS has emboldened the community to revise the SIRTF plan. The acronym now stands for Space Infrared Telescope Facility—a free-flying, satellite-based instrument with a useful lifetime of several years. Resupplied with coolant by a shuttle, the telescope could live for five years or even longer. A free-flying telescope also has the virtue of avoiding the infrared-bright exhaust gases that would trouble it in a shuttle environment.

SIRTF would have an aperture diameter only about 50% larger than IRAS. But its spatial resolution would be diffraction limited over its entire wavelength regime. The IRAS telescope was diffraction limited only at 60 and 100 microns. With newer detector technology and more deliberate scanning modes, SIRTF would have an effective sensitivity more than a thousand times that of IRAS, exploited for improved spectroscopic resolution as well as greater imaging sensitivity and resolution.

When the National Academy of Sciences Astronomy Survey Committee, headed by George Field (see PHYSICS TODAY, April 1982, page 46), recommended the construction of SIRTF, the presumption was that it would operate aboard a space shuttle. The free-flying SIRTF satellite now strongly favored by the infrared astronomers would, however, cost about half again as much as a shuttle-based instrument—perhaps $500 million. At a special session of the Baltimore meeting, NASA scientist Jeffrey Rosendahl told the astronomers that the short-term fiscal prospects for SIRTF were dim. With AXAF, the Advanced X-ray Astronomy Facility scheduled to begin construction in 1987, there is unlikely to be enough NASA money for the anticipated SIRTF startup in 1989, he told them. The Field Committee had given AXAF the highest priority among all proposed new major projects. But in setting its priorities among *new* proposals, Soifer points out, the Committee was treating the shuttle-based SIRTF as a project to which NASA was already committed.

"SIRTF is so important that we should make every effort to get it underway in 1989," argues NASA chief scientist Frank McDonald. In July the NASA Office of Space Science and Applications was in fact in the process of selecting the instruments that would fly aboard SIRTF. —BMS

Note added in proof. Another superluminous ir galaxy, NGC6240, looking very much like Arp220, has just been unearthed from among the IRAS data. Thus within the IRAS survey domain of about 100 Mpc we now know of three galaxies (including Mrk231) emitting at $10^{12}L_{\odot}$, with no quasars of comparable luminosity. There appears to be a population hierarchy suggestive of a continuum—with Seyfert galaxies rather common, superluminous ir galaxies more rare, and quasars rarer still.

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