The Center of Our Galaxy

Of all the remarkable objects discovered in our galaxy during the past few decades only one can unequivocally be called unique. Thirty thousand light-years away, hidden from our eyesight in the constellation of Sagittarius, is the nucleus of our galaxy, the hub around which the whole Milky Way revolves.

The environment of a star situated near the galactic center is strikingly different from the neighborhood of our own solar system. Consider, for example, what the sky would look like to a hypothetical astronomer situated one parsec away from the nucleus. (This is approximately the distance between the Sun and its nearest neighbor star.) The brightest single object visible would be a brilliant red star, with an apparent magnitude of about −10, some 100 times brighter than Venus appears to us at its brightest. In most directions our astronomer would see many more bright stars than he would see if he were on Earth, and the total light from them would exceed full moonlight. The majority of the stars would be to one side of him, in the direction of the nucleus of the Galaxy, in a giant cluster increasing in brightness to its center. From this center would emanate radio waves 10,000 times more intense than any signals detected by radio astronomers on Earth. All around the astronomer would be pink and green clouds of ionized gas illuminated by hot blue stars. As they orbit the nucleus of the Galaxy, many of the stars would change their apparent positions in the sky far more rapidly than do the Sun’s neighbors, so that in the astronomer’s lifetime the visual appearance of the sky would change significantly. Dra-

1. A parsec is the unit of distance commonly used by astronomers; it is equal to 3.26 light years. — Ed.

Figure 1. The central one-degree of our Galaxy as seen at 2.2 μm (top) and by visible light (bottom). Because photographic techniques cannot be used at 2.2 μm wavelengths, the upper picture was made by scanning a telescope fitted with an infrared detector across the sky. (Illustration courtesy of E. Becklin and G. Neugebauer, Caltech)


97/MERCURY/September-October 1979
matic events such as novae and supernovae would be much more common than in the solar vicinity.

Magnificent though the nighttime view would be, any astronomer with an interest in the universe on a larger scale than his immediate surroundings would have a hard time if he lived so close to the galactic center. Interstellar space in that vicinity contains a far higher concentration of dust grains than does the solar neighborhood, and the light from stars more than a few parsecs away would be very severely reddened. In some directions the interstellar clouds would be so thick as to block his view entirely. The twin problems of interstellar extinction and a bright night sky make it doubtful if he could see any external galaxies at all. Radio and infrared astronomers would also find observations difficult because of the high levels of background radiation at these wavelengths.

One of the remarkable features about this description of the center of the Galaxy is that it is based entirely on observations at nonvisual wavelengths. Between us and the center of the Galaxy lie vast clouds of interstellar gas and dust which absorb and scatter any light that passes through them. These clouds are so opaque that all but about one part in 10 billion of the light emitted in our direction from the center of the Galaxy is absorbed or scattered by dust grains. What is left of this light is far too faint and diffuse to be studied by even the largest telescopes on Earth. Fortunately for us, however, the central region of the Galaxy is a powerful source of many kinds of radiation besides visible light, and some of this invisible radiation, in particular the infrared and radio radiation, is able to reach the Earth without being greatly affected by the intervening dust clouds. Almost everything that we know about the center of the Galaxy, therefore, is based on evidence obtained with radio and infrared telescopes, mainly during the last five to ten years. What is the evidence, and how do astronomers piece it together to obtain the sort of picture which we have been describing?

The penetrating power of infrared radiation is well illustrated by Figure 1, which shows part of the constellation of Sagittarius as seen by visible light (bottom) and 2.2 micrometer (\(\mu m\)) infrared radiation (top)\(^2\). Because the distant stars are hidden by dust clouds, the visible picture is dominated by stars comparatively near

---

2. A micrometer or micron equals one millionth of a meter. – Ed.
Figure 3. The Kuiper Airborne Observatory, a Lockheed C-141 aircraft operated by NASA, containing a 90cm telescope. This observatory has been used extensively to study the infrared emission from the galactic center.

the Sun. Some of these nearby stars also show up as bright spots in the infrared picture, but the most important feature in the top figure is the broad band of radiation lying along the direction of the Milky Way. The hundreds of millions of stars whose radiation combines to form this band lie within 100 parsecs of the nucleus of our galaxy. The concentration of stars, and hence the brightness of the 2.2 \( \mu \)m radiation, becomes stronger and stronger the closer one approaches the brightest point on the picture. This point is the nucleus of our galaxy.

The infrared maps shown in Figure 2 show the central region of the Galaxy in much more detail at two different wavelengths, namely 2.2 \( \mu \)m and 10 \( \mu \)m. At both wavelengths we see a cluster of objects about a parsec across surrounding the nucleus. With one or two exceptions, however, the objects seen at the two wavelengths are not the same. The nature of these objects can be determined, at least to a limited extent, by examining their infrared spectra. In this way it has been found that many of the objects in Figure 2a are late-type giant stars,\(^3\) while the object IRS7 is an M-type supergiant. The discovery of this particular star near the galactic center is particularly important, because M supergiants cannot live for very long; its existence therefore suggests that new stars could have been forming in the galactic center at least until comparatively recently.

Infrared spectroscopy, in particular of hydrogen at the 2.2 \( \mu \)m wavelength and of ionized neon gas at the 12.8 \( \mu \)m wavelength, shows that the central parsec is also full of clouds of ionized gas, a result which was also deduced from observations made at centimeter radio wavelengths. These clouds are about the same size and luminosity as many of the compact HII (or ionized hydrogen) regions found in the spiral areas of our galaxy. Their existence indicates that there must be strong sources of ultraviolet radiation nearby to ionize the gas. A plausible origin for the radiation is a number of blue-hot O or B-type stars. These stars are capable of producing a substantial portion of the total luminosity being radiated from the central parsec of the Galaxy, but because most of this power is radiated at ultraviolet wavelengths these stars would not show up directly on the infrared maps in Figure 2. More exotic sources of ultraviolet ionization such as supermassive objects cannot be ruled out, however. The individual HII regions manifest themselves as the bright objects seen at 10 \( \mu \)m in Figure 2b.

Although dust grains comprise only a minute fraction of the mass of the galactic center region, they have an enormous influence on the way that we perceive it. The reason for this is that dust grains are extremely efficient at absorbing short-wavelength energy, such as light or ultraviolet radiation, and re-emitting it as infrared. Most of the light given out from stars near the center of the Galaxy is absorbed within a few parsecs and re-emitted at infrared wavelengths between 20 and 200 microns. Although radiation at these wavelengths can pass through the darkest region of the Galaxy with little hindrance, it is prevented from reaching the surface of the Earth by water vapor in our atmosphere. To detect this radiation we must therefore use infrared telescopes carried aloft either under stratospheric balloons, or in aircraft such as NASA’s Gerard P. Kuiper Airborne Observatory (Figure 3), a converted C-141 aircraft carrying a 90-cm telescope. Measurements made using this flying observatory indicate that total luminosity of the central 1-parsec diameter cluster is probably in the range equivalent to three to ten million Suns.

The presence of gas, dust, young O and B stars and the M supergiant star all suggest that new stars may be forming in the vicinity of the galactic center. At the moment, however, we do not know exactly where. In general, one of the most reliable indicators of potential star formation in our galaxy is the presence of dense concentrations of gases in the form of molecules. Although hydrogen is always the major constituent of such clouds, they are best detected by using a millimeter-wave radio telescope tuned to the wavelength of the charac-

3. Late-type giant stars have relatively cool surfaces and thus emit more infrared radiation. — Ed.
teristic emission of carbon monoxide molecules at 2.6 \( \mu \)m. Surveys of the central regions of our galaxy made in this way indicate that there are indeed dense dark clouds of gas and dust near the nucleus, but there do not appear to be any such clouds associated with the 1-parsec diameter cluster itself. If there are young stars in the central cluster it is possible that they have drifted there from outside. Alternatively, the way stars form in the center of the Galaxy could be different from the way they form elsewhere in the Milky Way.

We also know that stars die in the vicinity of the galactic center. Although we have yet to witness an actual supernova explosion in this region, astronomers see remnants of these occurrences as areas of bright synchrotron radio emission caused by fast moving electrons spiraling around magnetic field lines in the spaces between the stars. A particularly strong region of such emission lies about 5 parsecs to the east of the nucleus.

Of all the objects in the central 1-parsec of the Galaxy, one stands out from the others in a way which makes astronomers fairly certain that it is the actual nucleus of the Galaxy. The source designated number 16 in Figure 2a does not have the characteristic spectral features of an M-type giant star, but is too bright to be a dwarf star. This fact, together with its infrared colors and the suggestion in Figure 2a that it is not a point source (as a single star would be) but extended, indicate that it probably comprises a dense cluster of stars. The number of stars in the cluster is unknown, but is probably between a hundred and a million, depending on how bright each individual star is. The concentration of stars here is much greater than anywhere else in the Galaxy that we know about.

Within the cluster number 16 is the most mysterious object in the galactic center region, a source of strong radio emission less than 10 A.U.\(^4\) in diameter. Radio sources as intense and as small as this are almost unknown within our galaxy, and for this reason — rather than any adequate understanding of how it works — astronomers believe that this radio source marks the very nucleus of our galaxy. One idea that theoretical astronomers are considering is that the radio source is associated with a black hole in the center of the cluster.

number 16. Stars and gas in the cluster would occasionally be “caught” by this black hole, and, during their fall into it, give off energy in some form or other.\(^5\) It is difficult to test this hypothesis directly, since the black hole itself has a diameter of less than 0.1 A.U., much too small for us to detect. Some indication that such an object might exist comes from recent infrared studies of the motion of ionized neon gas within the central parsec. The motion of this gas is much more complicated than the simple rotation around the nucleus that astronomers had expected to see, but there are indications that within the cluster number 16 there are objects with a total mass about 4 million times the mass of our Sun. A considerable part of this mass must be in the form of the stars comprising the cluster, but the possibility that some of it lies within a massive black hole is being taken seriously enough by some astronomers for them to be making detailed calculations of how such a black hole would react with the gas and the stars which surround it. One of the problems is that the black hole in this model must not generate any more power than the 10 million Sun’s worth of infrared energy that is actually observed to come from the central 1-parsec diameter region.

How does the nucleus of our galaxy compare with those of other galaxies? This question is hard to answer because the nuclear regions of other galaxies are all much farther away, and therefore cannot be seen in such fine detail as ours can. On the other hand, in studying other galaxies we often have the advantage that we have an unhindered direct view of them, so we can study their light as well as radio and infrared emission. One phenomenon that can be directly compared, however, is the total amount of infrared power being emitted from the central few hundred parsecs of different galaxies. If we do this we find very large differences between galaxies, even among spiral galaxies which otherwise resemble each other. For example, the total power being emitted from the central 300 parsecs of our galaxy is about 1 billion times the luminosity of our Sun, that from the Andromeda galaxy (M31) is less than 200 million times our Sun’s brightness, while that from NGC253 is as bright as 30 billion Suns. A few galaxies, called Seyfert galaxies, are much more luminous than this, emitting up to 4 trillion times the Sun’s energy. With such a wide range of power among galaxies it is hard to know whether our galaxy is “typical” or even if there is such a “typical” galactic nucleus. For example, one point of view has it that galactic nuclei spend parts of their lives as very luminous Seyfert galaxies, parts as nuclei with intermediate luminosity like our own, and parts as undistinguished nuclei like M31. The clue to understanding the present nucleus of the Milky Way is therefore likely to come from studies of other galaxies as it is from further observations of our own, studies which are continuing at the present time.

For further reading


Wanted: Photographs of Old A.S.P. Activities and Members

As part of the celebration of its 90th anniversary, the Astronomical Society of the Pacific would like to put together a historical file on the Society’s early members and activities.

We would be most grateful if anyone with photographs, newspaper clippings, etc. could send a copy to the Society. If we receive any interesting material, we will try to reproduce some of it in future issues of Mercury.

Please send materials or suggestions to:

Andrew Fraknoi
Executive Officer
The Astronomical Society of the Pacific
1290 24th Avenue
San Francisco, CA 94122

---

4. 10 A.U. would be about 1.5 billion kilometers or 930 million miles. — Ed.

5. For more about massive black holes and active galactic nuclei, see the article by William Kaufmann in the Sept/Oct 1978 issue of Mercury. — Ed.