On 14 January 1966, NASA Administrator James Webb (1906-1992) wrote a letter to the prominent Harvard physicist, Professor Norman F. Ramsey Jr. (1915-2011), asking him to establish an advisory group that would:

Review the resources at our NASA field centers, and such other institutions as would be appropriate, against the requirements of the next generation of space projects and advise NASA on a number of key problems, such as:

(1) How can we organize these major projects so that the most competent scientists and engineers can participate?

(2) How can academic personnel participate and at the same time continue in strong academic roles?

(3) What mechanism should be used to determine the scientific investigations which should be conducted?

(4) How does a scientist continue his career development during the six to eight years it requires to develop an ABL [Automated Biological Laboratory] or a large astronomical facility?

(5) Should we change the orientation of some of our NASA Centers?

(6) What steps should be taken in scientific staffing, both inside and outside NASA, over the next few years to assure that we have the proper people at the proper places to do the job?

(7) How can we obtain the competent scientists to take the key roles in these major projects?  

Ramsey assembled his advisory group, and they worked through the spring and summer on their report, which they delivered to the Administrator on 15 August 1966. Their first recommendation was that the NASA Administrator appoint a General Advisory Committee to bring to bear “maximum competence” on “the formulation and execution of long-term programs of NASA.”

This recommendation, and many of the others in the report, were not what NASA was looking for, and so the Administrator turned to the National Academy.
of Sciences to find answers for at least some of the questions posed to Ramsey. The result of the extended deliberations between the Academy and the university community was the formation of USRA.3

At about the time that James Webb approached the president of the National Academy of Sciences with questions on how best to involve university students and faculty in NASA’s research programs, a graduate student at Caltech discovered the location of the center of the Milky Way Galaxy. The student was Eric Becklin, and his thesis advisor was Professor Gerry Neugebauer (1932-2014), who was one of the pioneers of infrared astronomy.

Becklin and Neugebauer had used an infrared photometer with the 24-inch telescope on Mt. Wilson to scan the small region of the sky in the Sagittarius constellation that was thought to be the dynamical center of the rotating Milky Way Galaxy. Becklin later told the story of his discovery:

"Back then, people weren’t even sure where the center was. There was some vague understanding. There was a radio source called “Sagittarius A,” a very strong radio source, but there was even debate whether that was really the center or not.

There is so much dust between us and the galactic center, it is completely opaque. You do not see the stars in the galactic center. The most powerful telescopes cannot see it.

Infrared radiation gets through the dust, because its wavelengths are longer...

It was in August of 1966. I was up at Mt. Wilson. It was a beautiful night on the small 24-inch telescope. And, as we were looking with the infrared detector, we were seeing more and more stars.

This is the signal in the infrared, and each star gives you more signal, and we were building up, as we were getting closer to the center, more and more stars. And we were actually seeing through the dust, for the first time, and then came to a peak, and then back down again, and I knew, immediately, that that was the center of our Milky Way, and that I was the first person to actually see the stars in the very core of our galaxy.4"

The photons recorded by Becklin had a wavelength of 2.2 microns (µ), also written 2.2 micrometers (µm), which is $2.2 \times 10^{-6}$ meters. This wavelength is in the “near infrared” part of the electromagnetic spectrum, i.e., near to the visible range, which runs from about 0.38 microns (violet light) to 0.75 microns (red light). The “mid infrared” part of the electromagnetic spectrum corresponds to photons with longer wavelengths, and the “far infrared”
with still longer wavelengths. The accompanying table shows the infrared spectral regions, wavelength ranges, temperatures of the sources of the radiation, and what can be seen in the three ranges.

Earth’s atmosphere absorbs photons in much of the infrared wavelengths. As shown in the accompanying figure, however, the atmosphere is partially transparent to the wavelength that Becklin used at the Mt. Wilson Observatory, i.e., at 2.2 microns.

Near infrared radiation coming from a distant source in the universe is not affected by intervening dust. As can be seen from an all-sky mosaic of the Milky Way shown below, this is not true of the visible light, which is blocked by dust.

Eric Becklin had located the center of our galaxy, and he and Neugebauer at Caltech, as well as other researchers elsewhere, began to map the central region of the Galaxy in wavelengths that corresponded to atmospheric “windows,” e.g., 2.2 microns and 10 microns. In 1975, Becklin and Neugebauer published a paper in which they used an infrared photometer with the 200 inch Hale telescope at the Palomar Observatory. In the article, they showed maps of the central 1 minute of arc of the Milky Way Galaxy with resolutions of a few seconds of arc. In this central 1 minute of arc, they identified 19 sources of infrared radiation at 2.2 microns and 9 sources at 10 microns.
Becklin and his colleagues were beginning to see the structures at the center of the Milky Way Galaxy, but they knew that to determine the nature of the sources of radiation they would need to make high-resolution observations at longer infrared wavelengths. Unfortunately, the Earth’s atmosphere is mostly opaque at these wavelengths. The solution to this problem was to make observations from the Earth’s stratosphere, above 99% of the atmospheric water vapor, which causes the blockage of far infrared radiation. By 1975, NASA had developed a means of doing that with the Gerard P. Kuiper Airborne Observatory (KAO).

The KAO was a modified Lockheed C-141 military cargo plane, outfitted with a 36-inch reflecting telescope in the front part of the plane. A retractable door above the telescope was closed for landings and take offs and opened only when the plane reached the desired altitude for observation, normally between 41,000 and 45,000 ft.

Becklin and his colleagues at Caltech soon were able to schedule flights on the KAO, and in 1975 they viewed the Galactic center at a resolution of about 1 minute (60 seconds) of arc. The Caltech team measured the flux of infrared radiation in three wavelength bands simultaneously, 30, 50, and 100-microns, from a single field of view. From this data they mapped the far infrared surface brightness and the color temperature.

An all-sky mosaic of the Milky Way recorded from Earth-based observatories over several months of 2008 and 2009. (Courtesy of the European Southern Observatory (ESO), Serge Brunier and Frederick Tapissier.) The image is oriented so that the plane of the Milky Way is horizontal, and the bulge of the Galactic Center is in the center.
in a small region at the galactic center. They concluded their data provided:

**Very strong support for the idea that the far-infrared radiation is thermal emission from dust.** In particular, the wavelength dependence of the source size is a natural result of a temperature gradient in the dust that is produced by heating by a centrally concentrated energy source.8

By 1982, Becklin had moved to the University of Hawaii. He was the lead author on a paper that reported on KAO flights conducted in 1979. Becklin and his colleagues made measurements of the central 4 arc minutes of the Galaxy at 30, 50, and 100-microns. They found that the 30-micron radiation peaks strongly at the center of the Galaxy, while the 50 and 100-micron radiation patterns form lobes on either side of the 30-micron peak. At the galactic center, there is a local minimum in the 100-micron surface brightness. Assuming that in this part of the far infrared spectrum, the source of the radiation is dust, they concluded that the dust density decreases inward over the central 10 light years or so of the Galaxy. In this central region, they found that the total luminosity of the sources heating the dust, which radiates the far-infrared emission, is between ten million and thirty million times the luminosity of the Sun.9

If the stars in the central region of the Galaxy were all like the Sun, there must be 10 to 30 million of them in a volume that is perhaps 10 light years across. For comparison, the Sun’s nearest neighbor is about 4 light years away. Based on the data shown in the accompanying figure, Becklin and his colleagues concluded that the galactic center is located in a central cavity, about 5 light years in radius, within a larger ring of dust and gas.10

This conclusion was confirmed by experiments conducted by a group of researchers from Cornell University on KAO flights in 1995.11 They found a “minispiral” structure surrounded by a circumnuclear ring of dust and gas at the center of the Galaxy. The lobes of 50 and 100-micron radiation found by Becklin and his colleagues correspond to concentrations of radiating dust in the line of sight from either end of the ring, seen somewhat “edge on.”

The 1995 flights by the Cornell group were among the last for the KAO, which was decommissioned in October of that year. NASA discontinued the KAO flights to save money that would be used for the development of the successor to the KAO, the Stratospheric Observatory for Infrared Astronomy (SOFIA).

In April of 1996, NASA issued a request for proposals in a competitive solicitation for (1) the provision of an airplane that could be modified to become SOFIA; (2) the modification of the airplane; and (3) the management of science for the observatory once it was operational. USRA persuaded Eric Becklin, now at UCLA, to be the science leader for SOFIA. The USRA Project Manager was Tom Bonner, who had earlier worked for NASA at the Langley Research Center and had experience in the modification of aircraft.

The USRA-led team, with partners United Airlines and Chrysler Technologies Airborne Systems (CTAS), won the NASA competition. United Airlines provided a Boeing
747 SP and CTAS, which was purchased by L3 Communications, conducted the extensive modification of the aircraft at its plant in Waco, Texas. SOFIA would house a 2.5-meter telescope that was provided by the German Aerospace Center (DLR). After several years of development and testing, the SOFIA observatory was operational in 2010.

While SOFIA was under development, Becklin continued his research on the center of the Galaxy. With colleagues at UCLA, in particular Professor Andrea Ghez, Becklin conducted observations of the central stellar cluster of the Galaxy at 2.2 microns using the 10-meter W. M. Keck telescope near the summit of Mauna Kea in Hawaii.

Ghez had developed methods for minimizing distortions of infrared images that result from turbulence in the atmosphere. With these techniques and the large aperture of the Keck telescope, the UCLA team tracked the motions of a group of stars orbiting what had been called Sgr A* (pronounced Sagittarius A star), which is at the dynamical center of the Galaxy.

The orbits around Sgr A* of some of the stars tracked by the UCLA Galactic Center Group are shown in the accompanying figure. The orbital period for SO-2, for example, has been measured to be 16.17 years. Given an estimate of the semi-major axis of the orbit, one can use the measured orbital period and Kepler’s laws to determine the attracting mass at Sgr A*.

In 1998, Becklin and the UCLA Galactic Center Group reported that the motions of the stars around Sgr A* indicated the stars were orbiting a mass of about 2.6 million solar masses. The luminosity at 2 microns in the small region around Sgr A* was only about 40 times the luminosity of the Sun at the corresponding wavelength band. The UCLA group concluded that, “given the high mass-to-light ratio observed, the central mass concentration is certainly composed primarily of dark matter.”

The group considered and ruled out several other possibilities and concluded that the Milky Way Galaxy harbors a black hole with a mass of $2.6 \times 10^6$ solar masses. Subsequent measurements of the motions of the stars around Sgr A* have yielded a value for the mass of the Milky Way’s black hole of more than $4 \times 10^6$ solar masses.

In 1995, Ted Dunham of NASA’s Ames Research Center was asked what SOFIA could do that the KAO couldn’t:

**SOFIA’s mirror is 3 times bigger than the KAO’s, so its area is 9 times bigger. This means that it collects 9 times as much light as the KAO does. In addition, because the mirror is bigger its angular resolution is better because of diffraction, an effect related to the wave nature of light. The big problem**
in infrared astronomy is the very bright background from thermal emission from the telescope and atmosphere. The better resolution of the telescope means that if you are looking at a point source, like a star, you have to look at 9 times less background sky area than with the KAO. When you combine the larger collecting area and the smaller background area, it turns out that it takes 81 times less observing time to do the same observation with SOFIA than with the KAO! An observation that would take half a KAO flight can be done with SOFIA in 2 or 3 minutes!

Of course, a lot of observations will be made that take an hour from SOFIA. These are totally impossible from the KAO–they would take 10-15 whole flights! Another way of looking at this is that you can do in one SOFIA flight what we now do with the KAO in a whole flight year!

The kinds of things that people will do with SOFIA that can’t be done with the KAO will be in looking at star forming regions in more detail, looking at how stars form in other galaxies (that’s right on the edge of the KAO’s capability), better understanding of what is going on in the center of the galaxy, looking at the planets in our solar system in more detail and at some wavelengths where they are undetectable with the KAO, and a bunch of other things that I forgot and haven’t even thought of yet. It will be a very interesting time when SOFIA starts flying.14

Few people were more pleased and excited when SOFIA started flying than Dr. Eric Becklin.

Soon after the award of the contract for SOFIA, USRA issued calls for proposals for instruments that would be attached to the telescope. One of the instruments that won the competition was the Faint Object Infrared Camera for the SOFIA Telescope (FORCAST) from Cornell University, with Professor Terry Herter as the Principal Investigator. FORCAST can record infrared radiation from 5 to 40 microns.
On flights in June of 2011, SOFIA/FORCAST observed the Circumnuclear Ring at the Galactic center.

To some degree these early flights confirmed and provided more detail to the Cornell observations of the galactic center via the KAO. The Circumnuclear Ring was found to have a radius of about 4.5 light years and to be inclined by 67 degrees from the plane perpendicular to the line of sight to Sgr A*. The density of the ring was found to be about 10,000 particles per cm$^3$, with density clumps of 5 to 9 times the background that are typically half a light year in length along the inner edge of the ring.\textsuperscript{15}

The lead author for the paper that reported the observations of the Galactic Circumnuclear Ring was Ryan Lau, a graduate student of Terry Herter at Cornell University. Lau obtained his Ph.D. in 2014, and his thesis title was “Probing the Extreme Environment of the Galactic Center with Observations from SOFIA/FORCAST.”

Soon after defending his dissertation, Lau published an article in which he and his colleagues used SOFIA/FORCAST observations to answer a question about the source of dust in galaxies.\textsuperscript{16} It’s generally been thought that dust is created in supernova explosions, where there is a contact surface between the driver gas and dust coming out of the supernova and the ambient gas of the surrounding interstellar medium. A shock wave proceeds from the contact surface into the ambient gas and dust, but another shock wave proceeds from the contact surface back into the driver gas and dust. The question was whether this reverse shock wave would destroy most of the dust grains that had been produced by the supernova explosion. As noted by Lau and his colleagues:

Recent studies have argued that [supernovae] may be net destroyers of dust in present-day galaxies ... but net producers of dust in the earliest-forming galaxies in the universe ... However, no direct observational evidence currently exists of the quantities of SN-condensed dust surviving the passage of the reverse shock through the ejecta.\textsuperscript{17}

Lau and his colleagues provided the missing evidence by using SOFIA/FORCAST to study the dust in the remnant of an old core-collapse supernova near the center of the Galaxy. They estimated that something like 7% to 20% of the dust produced by this 10,000-year-old supernova survived the reverse shock and was delivered to the interstellar medium.
In the Acknowledgements section of his thesis, Ryan Lau addressed a remark to Eric Becklin, who had discovered the location of the Galactic center almost 50 years before.

*I was very honored to have worked with you on our Galactic center observations of the Circumnuclear Ring—thank you for all the support and guidance.*

Almost 50 years after James Webb asked, “how can academic personnel participate [in major NASA efforts] and at the same time continue in strong academic roles,” USRA provided a case-in-point answer by managing the science for US participation in SOFIA in a way that allowed Terry Herter to develop FORCAST and focus on science and the training of graduate students such as Ryan Lau. Surely, James Webb would have approved.


6 Arc seconds - A great circle in the sky contains 360 degrees. Each degree contains 60 minutes of arc, and each arc minute contains 60 seconds of arc. A second of arc, therefore, is a very tiny length in the sky, but it corresponds to almost 10 light years of distance when viewing the center of the galaxy. The standard abbreviation for an arc minute is ' ', and the abbreviation for an arc second is “”.

7 Color temperature - To determine the color temperature, one measures the energy flux of a source at two different wavelengths. The color temperature is the temperature of the source if it were a black body that radiated energy corresponding to the energy flux in the two wavelengths that were measured. Becklin and his colleagues used the wavelengths of 50 and 100 microns to determine the color temperature, and they found temperatures up to about 100 Kelvins in the central region of the galaxy.


14 Communication from Ted Dunham


17 Ibid., p. 413.

18 Lau, R. (2014) Probing the extreme environment of the galactic center with SOFIA/FORCAST. A Dissertation Presented to the Faculty of the Graduate School of Cornell University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy., p. viii.