The Discovery of Cosmic Radio Noise

Natural radio emission from our Galaxy was detected accidentally in 1932 by Karl Guthe Jansky, a physicist working as a radio engineer for Bell Telephone Laboratories. Why didn't "real" astronomers of the time pursue radio astronomy and make this discovery first? In part, because they knew too much. They knew that stars are nearly blackbody radiators at visible wavelengths. The spectral brightness $B_\nu$ at frequency $\nu$ of an ideal blackbody radiator is given by Planck's Law

$$B_\nu(T) = \frac{2\nu^3}{c^2} \frac{1}{\exp\left(\frac{\nu}{kT}\right) - 1},$$

where

$B_\nu$ is the power emitted per unit area per unit bandwidth per steradian of solid angle by a black body,

$h \approx 6.63 \times 10^{-27}$ erg s = $6.63 \times 10^{-34}$ Joule s = Planck's constant,

$\nu$ = frequency in cycles per second, or hertz (so Hz = s$^{-1}$),

$k \approx 1.38 \times 10^{-16}$ erg K$^{-1}$ = $1.38 \times 10^{-23}$ Joule K$^{-1}$ = Boltzmann's constant,

$c \approx 3.00 \times 10^{10}$ cm s$^{-1}$ = $3.00 \times 10^8$ m s$^{-1}$ = the speed of light, and

$T$ is the absolute temperature (K) of the black body.

In the low-frequency radio limit, the dimensionless quantity $\nu/(kT) \ll 1$ for most astronomical sources. For example, the photosphere (the visible surface) of the Sun has temperature $T \approx 5800$ K. At $\nu = 1$ GHz, which was near the high-frequency limit of radio technology in 1932,

$$\frac{\nu}{kT} \approx \frac{6.63 \times 10^{-27} \text{ erg s} \times 10^9 \text{ Hz}}{1.38 \times 10^{-16} \text{ erg K}^{-1} \times 5800 \text{ K}} \approx 8 \times 10^{-6}$$

Replacing the exponential term in Planck's equation by its Taylor-series approximation

$$\exp\left(\frac{\nu}{kT}\right) - 1 \approx 1 + \frac{\nu}{kT} + ... - 1 \approx \frac{\nu}{kT}$$

yields the simple Rayleigh-Jeans approximation

$$B_\nu(T) \approx \frac{2\nu^3}{c^2} \frac{kT}{\nu} = \frac{2kT\nu^2}{c^2} = \frac{2kT}{\lambda^2}$$

to the blackbody spectrum at low frequencies or long wavelengths. The radio flux from a star, which subtends a very small solid angle, would be undetectably low. This argument is
more-or-less correct; in fact, even the most sensitive modern radio telescopes could not detect the 1 GHz blackbody emission from the photosphere of a star like the Sun at the distance $d \approx 1$ pc of the nearest star.

Example: What is the flux density $S_\nu$ at $\nu = 1$ GHz of a $T = 5800$ K blackbody the size of the Sun (radius $R_\odot \approx 7 \times 10^{10}$ cm) at the distance of the nearest star, about 1 parsec ($d \approx 3 \times 10^{18}$ cm)?

The flux density $S_\nu$ of a source is defined as the power per unit area received in a unit bandwidth ($\Delta \nu = 1$ Hz) at frequency $\nu$ (so the mks units of $S_\nu$ are $\text{W} \text{m}^{-2} \text{Hz}^{-1}$). The flux density received from a compact source having brightness $B_\nu$ and subtending a solid angle $\Omega \ll 1$ sr is simply

$$S_\nu = B_\nu \Omega$$

$$B_\nu = \frac{2kT\nu^2}{c^2}$$

$$B_\nu \approx \frac{2 \times 1.38 \times 10^{-16} \text{erg K}^{-1} \times 5800 \text{ K} \times (10^9 \text{ Hz})^2}{(3.00 \times 10^{10} \text{ cm s}^{-1})^2}$$

Since Hz = s$^{-1}$ and sr is dimensionless,

$$B_\nu \approx 1.78 \times 10^{-15} \text{ erg cm}^{-2} \text{ sr}^{-1}$$

$$\Omega = \frac{\pi R_\odot^2}{d^2} \approx \frac{\pi (7 \times 10^{10} \text{ cm})^2}{(3 \times 10^{18} \text{ cm})^2} \approx 1.71 \times 10^{-15} \text{ sr}$$

$$S_\nu \approx 3.0 \times 10^{-30} \text{ erg cm}^{-2}$$

$$S_\nu \approx 3.0 \times 10^{-33} \text{ J m}^{-2} \approx 3.0 \times 10^{-33} \text{ W m}^{-2} \text{ Hz}^{-1}$$

The flux densities of astronomical sources are so small in mks units that radio astronomers normally express flux densities in Jy (for Jansky) defined as $10^{-26} \text{ W m}^{-2} \text{ Hz}^{-1}$, or mJy ($10^{-3}$ Jy), or $\mu$Jy ($10^{-6}$ Jy). Thus
This is too faint even for modern radio telescopes, which can detect continuum sources as faint as $S \sim 100 \, \mu$Jy.

In the 1920s, Bell Telephone offered transatlantic telephone service based on "shortwave" ($\lambda \sim 15 \, \text{m}$) radio transmissions. Natural radio static caused serious interference with these transmissions, so Bell asked their young electrical engineer Karl Jansky to determine its origin. Jansky built the antenna shown below to monitor radio static at 20.5 MHz. It produced a fan beam near the horizon and could be rotated in azimuth (the angle measured from north to east along the horizon). Jansky discovered that most of the static is caused by numerous tropical thunderstorms. In addition he found a steady "hiss" whose strength rose and fell almost daily, with a period of 23 hours and 56 minutes. He recognized that this is length of the sidereal day (the time it takes the Earth to rotate once in the reference frame of the fixed stars), deduced that the hiss originated outside the solar system, and identified the direction of the Galactic center as the source of the strongest emission. He published his results in the paper "Electrical Disturbances of Apparently Extraterrestrial Origin" (Jansky, K. J. 1933, Proc. IRE, 21, 1387).
Karl Jansky pointing out the region of the Galactic plane emitting the strong cosmic noise.

**Image credit**

Jansky's discovery appeared on the front page of the New York Times, but Bell Telephone had no practical interest in the cosmic component of radio static and reassigned Karl Jansky to other projects. Jansky himself believed that the cosmic noise was thermal emission because it produced a steady hiss in headphones that sounded like the hiss produced by vacuum-tube amplifiers. Skeptical astronomers couldn't understand how such strong (equivalent to the emission from a $T \sim 2 \times 10^5$ K blackbody covering most of the inner Galaxy) radio noise was produced and ignored it.

The only person who took a serious interest in Jansky's discovery was the amateur radio operator and professional radio engineer Grote Reber. He later wrote:

"My interest in radio astronomy began after reading the orginal articles by Karl Jansky. For some years previous I had been an ardent radio amateur and considerable of a DX [long-distance communication] addict, holding the call sign W9GFZ. After contacting over sixty countries and making WAC [Worked All Continents, an amateur-radio award], there did not appear to be any more worlds to conquer."

Radio astronomy became his obsession. He devoted years of his life to building the world's first radio antenna having a parabolic reflector at his own expense in his back yard in Wheaton, IL and mapping the Galaxy with it.
Grote Reber's backyard radio telescope in Wheaton, IL. The parabolic reflector is about 10 m in diameter. His original telescope was dismantled and reassembled near the NRAO visitors science center in Green Bank, WV. Image credit

Since Reber also expected $B_\nu \propto \nu^2$, the low-frequency spectrum of a black body, he started observing at $\nu = 3300$ MHz, the highest technically feasible frequency in 1937. When he failed to see anything, he concluded that the radio spectrum of the Galaxy was not Planckian. Next he tried 910 MHz, still with no luck, but "since I am a rather stubborn Dutchman, this had the effect of whetting my appetite for more." In 1938 he finally succeeded in detecting and mapping (with about $10^\circ$ angular resolution) the Galaxy at 160 MHz, thereby confirming Jansky's discovery and demonstrating that the radio emission has a distinctly nonthermal spectrum. He observed only at night because automotive ignition interference in Wheaton, IL was too strong during the day, recording radiometer meter readings by hand once per minute. His results were published in the Astrophysical Journal (Reber, G. 1940, ApJ, 91, 621).
Then World War II intervened, hindering astronomical research but stimulating enormous progress in radio and radar technology. The same engineers and physicists who developed and used this technology during the war led the rapid scientific development of radio astronomy immediately afterward.

If you are interested in learning more about the early history of radio astronomy, read the NRAO web pages on this subject.