RADIO INTERFEROMETRY

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Reference: Carroll, Bradley W. & Ostlie, Dale A. (2007), *An Introduction to Modern Astrophysics*, 2nd Edition; Pearson Education - Chapter 6, Problems 6.12 - 6.14.

The angular resolution of a single radio telescope isn't particularly good. Using the Rayleigh criterion for resolution, a telescope of diameter D observing at wavelength λ can resolve objects separated by an angle θ given by

$$\theta = 1.22\frac{\lambda}{D} \tag{1}$$

For example, if a telescope with $D = 25$ m observes at the 21 cm line of hydrogen, the resolution is

$$\begin{aligned}
\theta &= 1.22\frac{0.21}{25} && (2)\\
&= 0.010248 \text{ rad} && (3)\\
&= 0.587^{\circ} && (4)
\end{aligned}$$

The resolution can be greatly improved by using *interferometry*. The idea behind interferometry is similar to that of the diffraction grating. Suppose we have two telescopes separated by a baseline distance d, and both telescopes are observing an object that makes an angle θ with the normal to the ground. The radio waves travelling to one telescope will go a distance $L = d\sin\theta$ further than those to the other telescope. If $L = \left(n - \frac{1}{2}\right)\lambda$ the signal at one telescope is exactly out of phase with the signal at the other. Since λ is known (it's the wavelength at which we're doing the observing), we can adjust the angle θ of the telescopes until the combined signal vanishes.

The angle by which the telescopes must be changed to move from one minimum (or maximum) to the next is found from

$$\begin{aligned}
\sin\theta &= \frac{L}{d} && (5)\\
\cos\theta\,\Delta\theta &= \frac{\Delta L}{d} && (6)\\
&= \frac{1}{d}\left[\left(n+1-\frac{1}{2}\right)\lambda-\left(n-\frac{1}{2}\right)\lambda\right] && (7)\\
&= \frac{\lambda}{d} && (8)\\
\Delta\theta &= \frac{\lambda}{d\cos\theta} && (9)
\end{aligned}$$

If the two telescopes are separated by the diameter of the Earth, then for $\lambda = 21$ cm and observations near $\theta = 0$ we have

$$\begin{aligned}
\Delta\theta &= \frac{0.21\text{ m}}{1.2742\times10^{7}\text{ m}} && (10)\\
&= 1.65\times10^{-8}\text{ rad} && (11)\\
&= 0.0034'' && (12)
\end{aligned}$$

Thus the resolution is about a million times better than for a single telescope on its own.

Several arrays of radio telescopes have been built. The Very Large Array (VLA) in New Mexico consists of 27 dishes, each 25 m in diameter, spread over a circle 27 km in diameter. Along with the increased resolution, the VLA has a total collection area of $27\times\pi\times(12.5)^2 = 13253\text{ m}^2$ which is equivalent to a single dish of diameter 130 m.

Another large array is situated at the Atacama Large Millimeter Array (ALMA) in Chile. It consists of 50 12 m diameter antennas with an additional 16 smaller dishes, and was completed in 2013. The 50 main dishes provide $\binom{50}{2} = 1225$ distinct baselines for pairs of telescopes.

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