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

$$\sin\theta = \frac{L}{d} \tag{5}$$

$$\cos\theta\,\Delta\theta = \frac{\Delta L}{d} \tag{6}$$

$$= \frac{1}{d}\left[\left(n+1-\frac{1}{2}\right)\lambda-\left(n-\frac{1}{2}\right)\lambda\right] \tag{7}$$

$$= \frac{\lambda}{d} \tag{8}$$

$$\Delta\theta = \frac{\lambda}{d\cos\theta} \tag{9}$$

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

$$\Delta\theta = \frac{0.21\text{ m}}{1.2742\times 10^{7}\text{ m}} \tag{10}$$

$$= 1.65\times 10^{-8}\text{ rad} \tag{11}$$

$$= 0.0034'' \tag{12}$$

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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