

RADIO INTERFEROMETRY

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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

$$\theta = 1.22 \frac{\lambda}{D} \quad (1)$$

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

$$\theta = 1.22 \frac{0.21}{25} \quad (2)$$

$$= 0.010248 \text{ rad} \quad (3)$$

$$= 0.587^\circ \quad (4)$$

This is about the apparent size of the moon.

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 $L = (n - \frac{1}{2}) \lambda$ 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

$$\sin \theta = \frac{L}{d} \quad (5)$$

$$\cos \theta \Delta \theta = \frac{\Delta L}{d} \quad (6)$$

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

$$= \frac{\lambda}{d} \quad (8)$$

$$\Delta \theta = \frac{\lambda}{d \cos \theta} \quad (9)$$

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

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

$$= 1.65 \times 10^{-8} \text{ rad} \quad (11)$$

$$= 0.0034'' \quad (12)$$

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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