

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

$$(0.1) \quad \theta = 1.22 \frac{\lambda}{D}$$

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

$$(0.2) \quad \theta = 1.22 \frac{0.21}{25}$$

$$(0.3) \quad = 0.010248 \text{ rad}$$

$$(0.4) \quad = 0.587^\circ$$

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

$$(0.5) \quad \sin \theta = \frac{L}{d}$$

$$(0.6) \quad \cos \theta \Delta \theta = \frac{\Delta L}{d}$$

$$(0.7) \quad = \frac{1}{d} \left[\left(n + 1 - \frac{1}{2} \right) \lambda - \left(n - \frac{1}{2} \right) \lambda \right]$$

$$(0.8) \quad = \frac{\lambda}{d}$$

$$(0.9) \quad \Delta \theta = \frac{\lambda}{d \cos \theta}$$

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

$$(0.10) \quad \Delta \theta = \frac{0.21 \text{ m}}{1.2742 \times 10^7 \text{ m}}$$

$$(0.11) \quad = 1.65 \times 10^{-8} \text{ rad}$$

$$(0.12) \quad = 0.0034''$$

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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