An Introduction to Radio Astronomy

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"A universe of radio sounds to which mankind had been deaf since time immemorial now suddenly burst forth in full chorus..."

– John D. Kraus, 1981
of Jansky's discovery of cosmic radio waves in 1932
Cosmic Search, iss.12, vol. 3, no. 4, p.8

Useful Equations

- Wavelength and frequency: $\lambda = c/f$
- Angular resolution (radians): $\theta \approx \lambda/D$
- Linear size from angular size: $L = D_{\text{distance}} \cdot \tan\theta$
- Minimum detectable flux density (Jy):

$$\Delta S = (1 \times 10^{-23}) \frac{2k_B T_{\text{sys}}}{A_{\text{eff}}\sqrt{\Delta\nu\tau}}$$

- Effective collecting area: $A_{\text{eff}} = \eta\pi D^2/4$
- Spectral index: $S_\nu \propto \nu^\alpha$
- Interferometer maximum baseline: $\theta \sim \lambda/B_{\text{max}}$

1 How Big, How Sharp, and How Sensitive?

In this question, we will explore in a somewhat rudimentary way how telescope design affects angular resolution and sensitivity. Let us consider three fictional radio telescopes A, B, and C, with the following parameters observing at a wavelength of $\lambda = 5$ cm.

Category	**A**	**B**	**C**
Diameter (D)	100 m	50 m	10 m
Aperture Efficiency (η)	64 %	68 %	61 %
System Temperature (T_{sys})	45 K	40 K	50 K

Table 1: Parameters for three fictional radio telescopes observing at $\lambda = 5$ cm.

1a: Calculate the observing frequency corresponding to a 5 cm wavelength of light.

1b: Calculate the angular resolution θ for each telescope in arcminutes.

1c: Calculate the effective collecting area for each telescope.

1d: Calculate the minimum detectable flux density ΔS for each telescope assuming a bandwidth of 100 MHz and an integration time of 1 second.

1e: Select the most appropriate telescope (A, B, or C) for each of the following observing scenarios:

1) Detecting extremely faint extragalactic radio sources at 6 GHz
2) Mapping the structure of a nearby bright supernova remnant around a degree or so in size
3) Observing bright, compact radio sources like pulsars or masers
4) Conducting a shallow sky survey to locate moderately bright sources over a large area

2 Question 2: Large Single Dish vs Array of Small Dishes

Arrays of small telescopes can mimic the performance of a single large dish via interferometry.

2a: Explain qualitatively why an array of many small dishes can achieve higher angular resolution than a single large dish.

Consider telescope A (100 m single-dish). We might try to improve on it using 10 identical dishes in an interferometric array (array D).

2b: To match the total collecting area of telescope A, how many C dishes would you need?

2c: To match the angular resolution of telescope A, what would the distance between the two furthest C dishes in a linear array need to be?

2d: Consider arranging 10 C dishes in a Y-shaped configuration (Figure 1). One telescope is at the center, and three telescopes lie along each of three equally-spaced arms at distances of 100 m, 300 m, and 700 m from the center. Using this layout, answer the following:

1) Identify the minimum baseline and calculate the maximum angular resolution (smallest beam) of the array.
2) Identify the maximum baseline and calculate the minimum angular resolution (largest beam) of the array.
3) Calculate the total collecting area of the array, assuming each C dish has effective area A_{C}.
4) Estimate the minimum detectable flux density ΔS_{D} for the array, assuming $\Delta S \propto 1/\sqrt{N}$ where N is the number of dishes, and using the value for a single C dish calculated in Q1d.

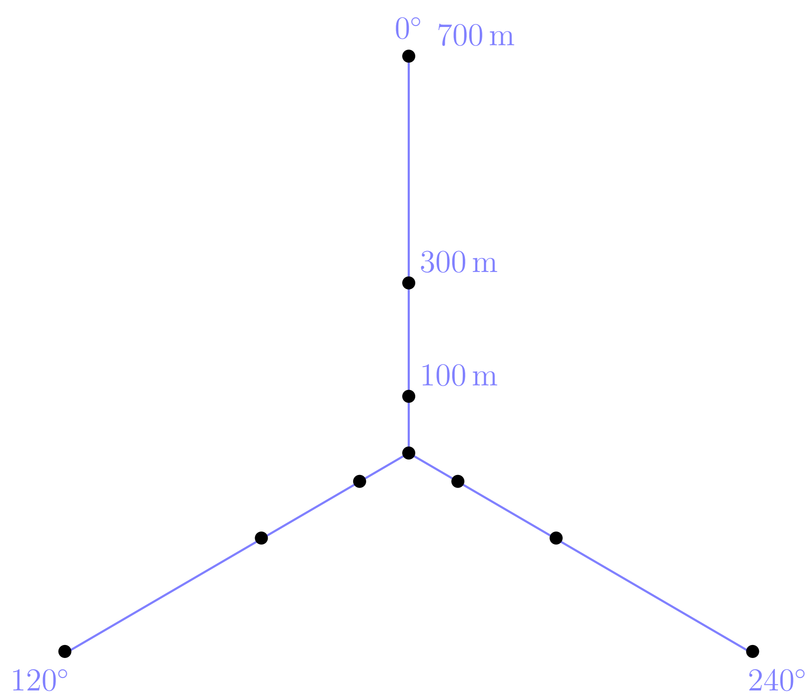

Figure 1: Y-shaped array D of 10 C dishes. One dish is at the center, and three equally spaced dishes lie along each arm.

3 Question 3: Spectral Index and Radio Colours

The spectral index α describes how flux density varies with frequency:

$$S_\nu \propto \nu^\alpha$$

3a: Calculate the flux ratio $S_5/S_{1.4}$ for $\alpha = -0.1$ and $\alpha = -0.7$.

3b: Identify which sources are "flat" ($\alpha \sim 0$) or "steep" ($\alpha \sim -0.7$) in the radio.

3c: Observations at multiple frequencies can reveal changes in the source's structure. Explain qualitatively why the measured flux might appear different when observed with a telescope whose beam size remains constant at different frequencies.

3d: Suppose your telescope has an angular resolution of 3 arcmin at 1.4 GHz. Estimate the angular resolution at 5 GHz. How does this improved resolution help in studying the source?

3e: Imagine you have flux measurements of the source at several frequencies. How could you use them to determine the dominant emission mechanism and physical properties?