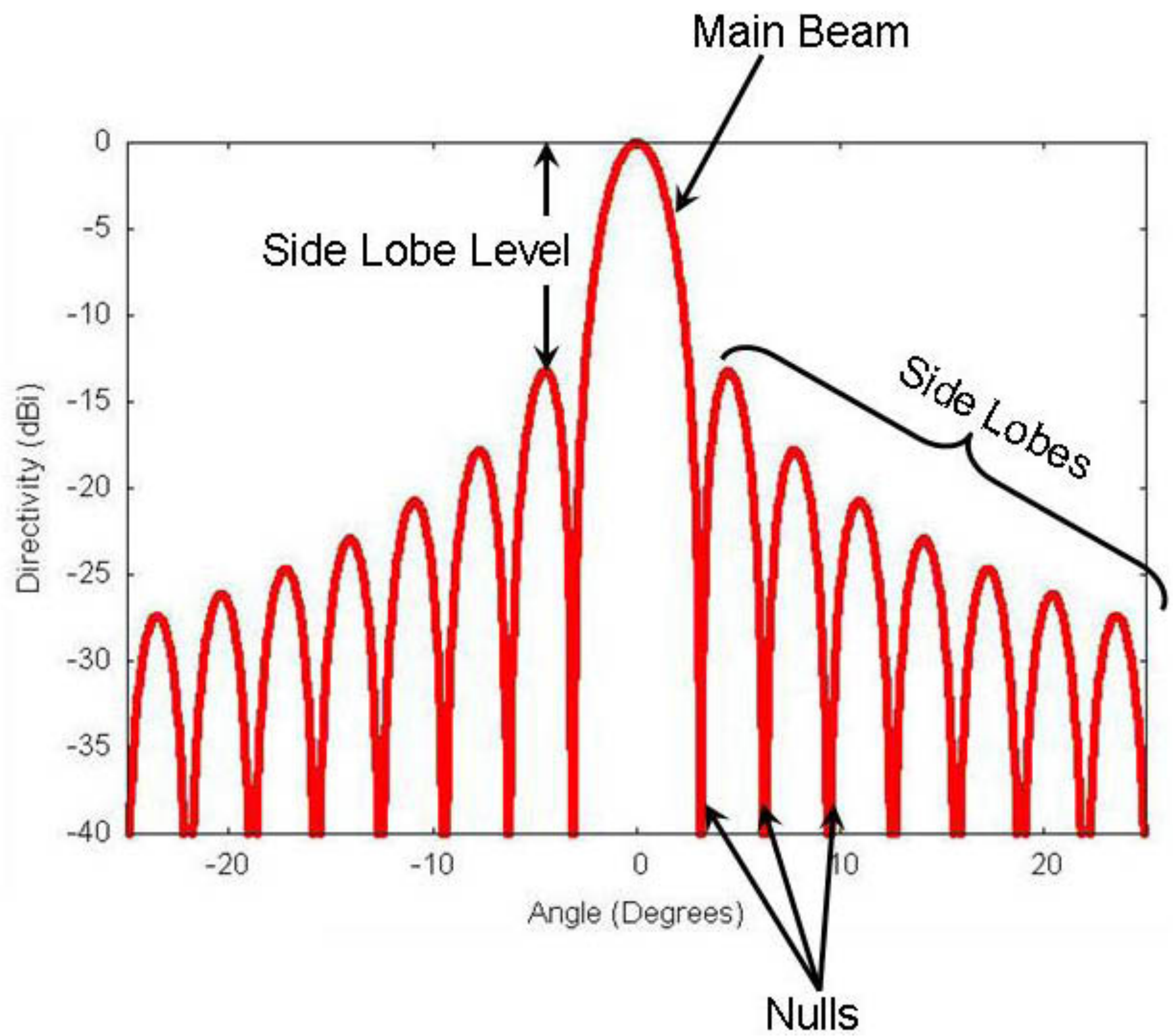
Single-Dish Radio Astronomy

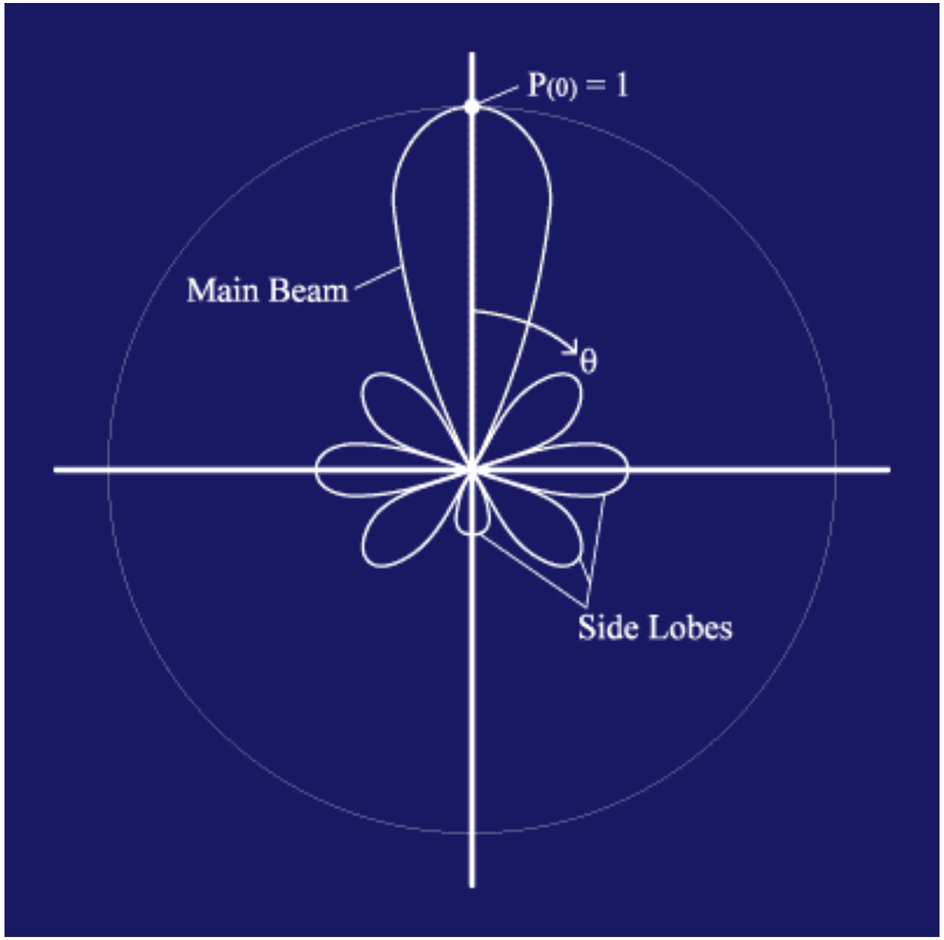
- Beam
- Sensitivity
- Beam dilution
- Total power measurements
- Sky subtraction
- Receivers

Beam Pattern

- The beam pattern for a circular aperture can be shown to be the Airy function (J_1 Bessel function)



- This pattern has sidelobes in addition to the main beam
- Can approximate the main beam by a Gaussian



Antenna Temperature

- We can use either flux density, f_ν in Jy, or antenna temperature, T_A in K, to measure the amount of signal detected by a radio telescope

$$I_\nu = \frac{2kT_A\nu^2}{c^2} = \frac{2kT_A}{\lambda^2} \qquad f_\nu = I_\nu \Omega_B$$

where Ω_B is the solid angle of the beam

- Note S_ν is often used for f_ν by radio astronomers

Effective Area

- Depending on various factors the full telescope area will not perfectly detect all the radiation
- Can define an effective area

$$A_{eff} = \eta A_{geom}$$

where η is the aperture efficiency

- And

$$\Omega_B \approx \frac{\lambda^2}{D^2} \approx \frac{\lambda^2}{A_{eff}} \qquad f_\nu = \frac{2kT_A}{\lambda^2}\Omega_B = \frac{2kT_A}{A_{eff}}$$

Sensitivity

- The sensitivity of a radio telescope can be characterised in a number of ways
- Forward gain is the increase in antenna temperature of the telescope for a 1 Jy source (K/Jy) given by

$$Gain = \frac{T_A}{f_\nu} = \frac{A_{eff}}{2k}$$

- System noise temperature, T_{sys}, is the noise generated by the antenna and receiver system (K)
- System equivalent flux density, *SEFD*, is the flux equivalent of the system temperature

$$SEFD = \frac{T_{Sys}}{Gain} = \frac{2kT_{Sys}}{A_{eff}}$$

Noise level

- The noise level from sampling considerations is now either

$$\Delta T = \frac{T_{Sys}}{\sqrt{\Delta \nu \cdot \tau}}$$

or

$$\Delta f_{\nu} = \frac{SEFD}{\sqrt{\Delta \nu \cdot \tau}} = \frac{2kT_{Sys}}{A_{eff}\sqrt{\Delta \nu \cdot \tau}}$$

where *Δν* is the bandwidth (Hz) and τ is the integration time of the observation (s)

Detection

- For a Gaussian noise distribution the typical threshold for detection is usual considered to be when the signal is three times the noise level

$$\frac{Signal}{Noise} = \frac{S}{N} = \frac{T_{Source}}{\Delta T} > 3 \quad \text{or} \quad \frac{S}{N} = \frac{f_{\nu}}{\Delta f_{\nu}} > 3$$

- This is referred to as a 3σ detection

Beam dilution

- Consider a source with uniform brightness temperature $T_B(source)$ over a angular size θ_{Source} with a beam of size θ_{Beam}
- If $\theta_{Source} > \theta_{Beam}$ then $T_A = T_B$
- But if $\theta_{Source} < \theta_{Beam}$ i.e. a point source, then

$$T_A = \left(\frac{\theta_{Source}}{\theta_{Beam}} \right)^2 T_B < T_B$$

Flux density or Intensity

- Keep in mind whether you are dealing with a flux density or intensity variable and which is most appropriate
- Flux density f_ν (Jy) is good for point or compact sources
- T_A or flux density per beam (Jy/beam) are measures of intensity and good for very extended sources

Nyquist Sampling

- In order to fully sample structure in a map made with a beam size θ_{Beam} the map must be sampled at least every $\theta_{Beam}/2$
- Similarly for fully sampling a spectral line with width Δv_l the spectral channels must be smaller than $\Delta v_l/2$

Sky subtraction

- The atmosphere is usually brighter than the astronomical target, $T_B(sky) \sim 3$ K, so need to correct for the sky using either:
- Position-switching – observe On-source and then move telescope to a blank Off-source region with the spectrum given by ratio

$$\frac{On - Off}{Off}$$

- Need to use for continuum observations
- Or frequency-switching – switch the frequency of the observations by a small amount between a Signal and Reference frequency with the spectrum given by

$$\frac{\text{Sig} - \text{Ref}}{\text{Ref}}$$

- Can use for spectral line observations

Receivers

- The telescope is responsible for collecting radio power from the sky and providing it to the receiver
- The receiver then converts this to an electrical signal that can be used by conventional electronics

- e.g., suppose we want to observe a water maser at 22 – 23 GHz
- Front-end receiver will amplify the incoming signal and mix it with a reference radio signal (the local oscillator signal at [perhaps] 20 GHz)
- This gives an amplified signal where the interesting bit is in frequencies 2 – 3 GHz

- Interesting bit is in 2 – 3 GHz, so apply a filter to cut out signal below 2 GHz and above 3 GHz (removes noise)
- Now pass to the back-end system with amplifies this intermediate frequency (IF) signal
- Next pass to a spectrometer that breaks the signal up into (say) 10^4 channels, each 0.1 MHz wide

- Finally pass the signal from each channel to an integrator to add up the signals that come in over a few seconds
- Write the results out to a computer that will allow observer to average a lot more later

Summary

- For observations with a single dish radio telescope need to consider:
  – Observing setup - sampling
  – Sensitivity – can you detect your source
  – Sky subtraction – which technique
  – Contamination – strong sources in sidelobes