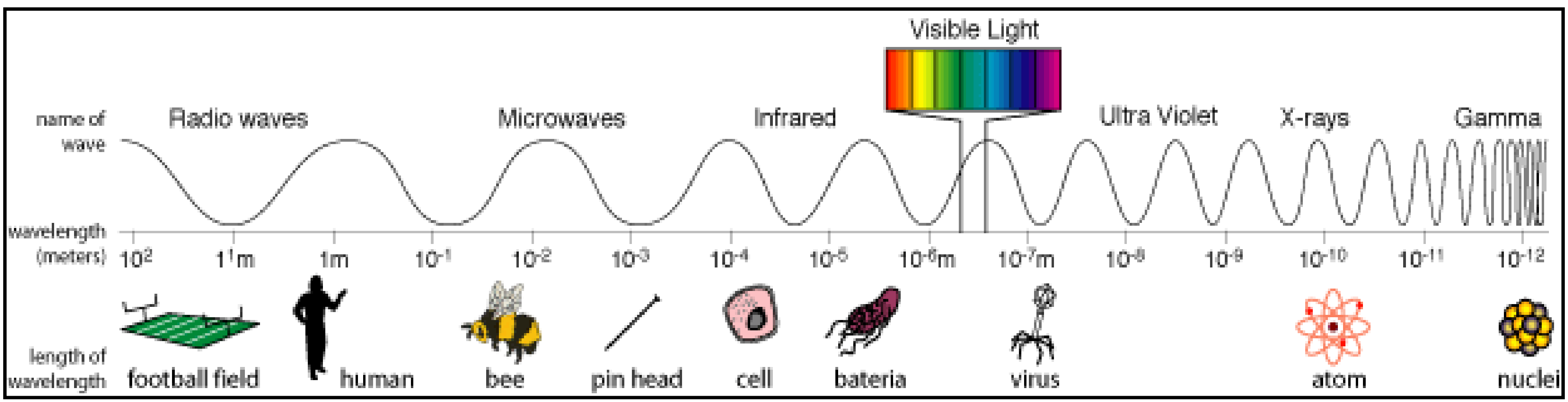
Introduction to Radio Astronomy

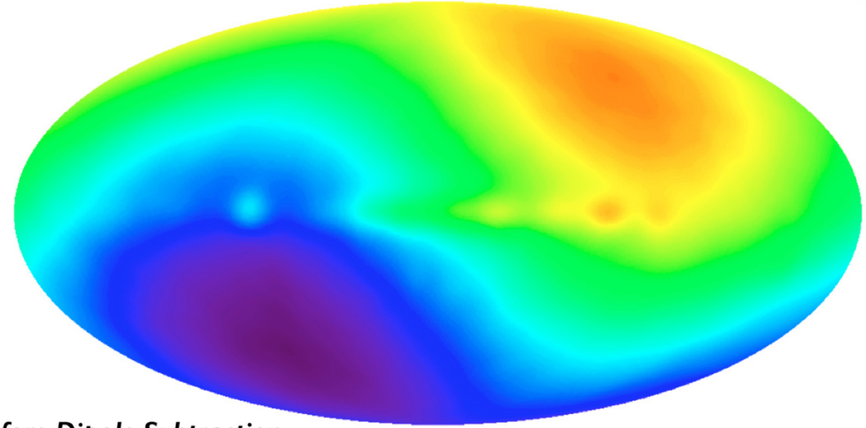
- Sources of radio emission
- Temperature: Blackbody radiation in radio astronomy
- Radio telescope characteristics
- Why radio astronomy is different from optical astronomy

Sources of Radio Emission

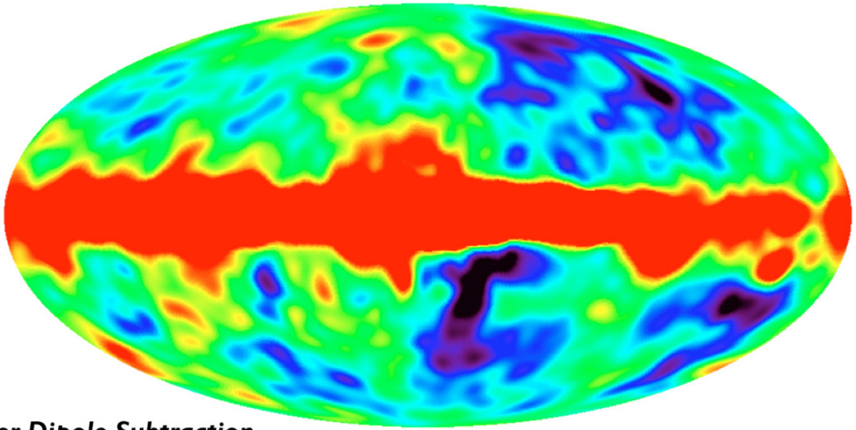
- Blackbody (thermal)
- Continuum sources (non-thermal)
- Spectral line sources



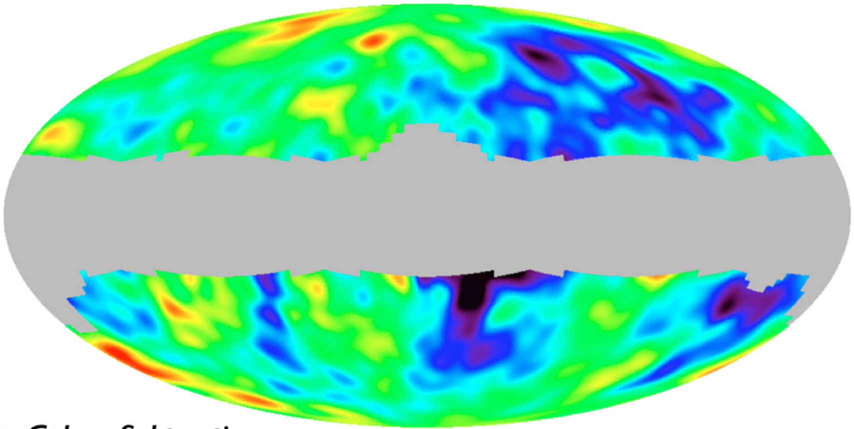
DMR 53 GHz Maps



Before Dipole Subtraction



After Dipole Subtraction

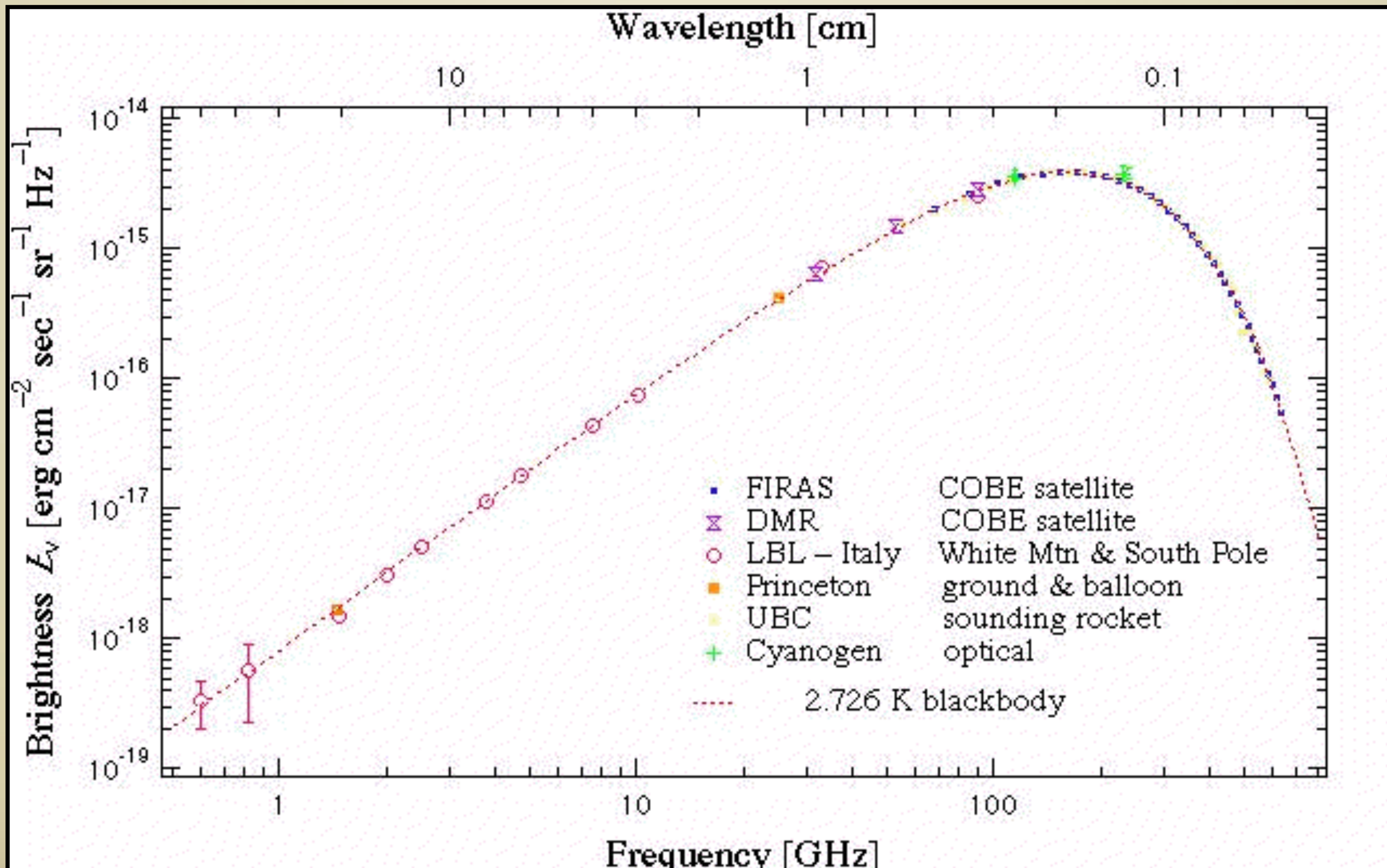


After Galaxy Subtraction

Blackbody Sources:

The cosmic microwave background, the planets, etc

- Obs in cm requires low temperature: $\lambda_m T = 0.2898$ cm K
- Flux = const × ν^{α} × T $\lambda_m T = 0.2898$ cm K
- For thermal sources α is ~2 (flatter for less opaque sources)

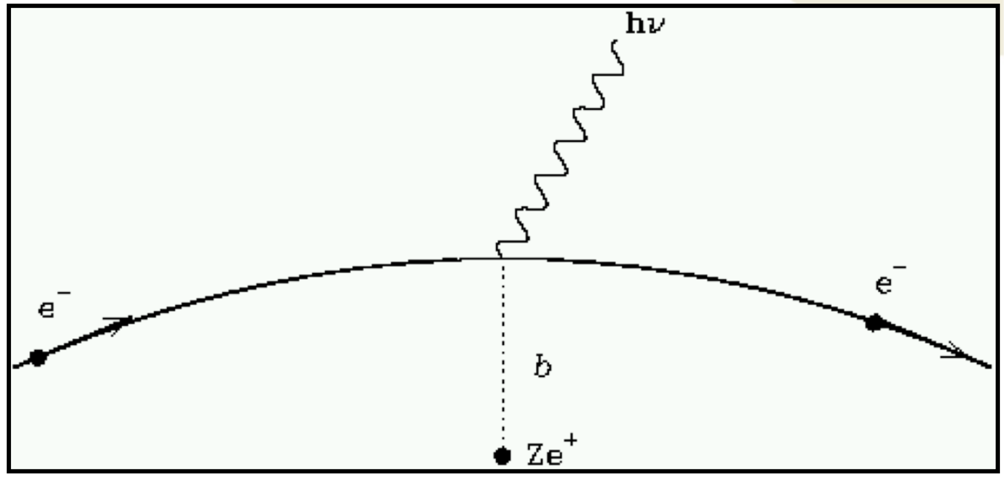


Continuum (non-thermal) Emission:

Emission at all radio wavelengths

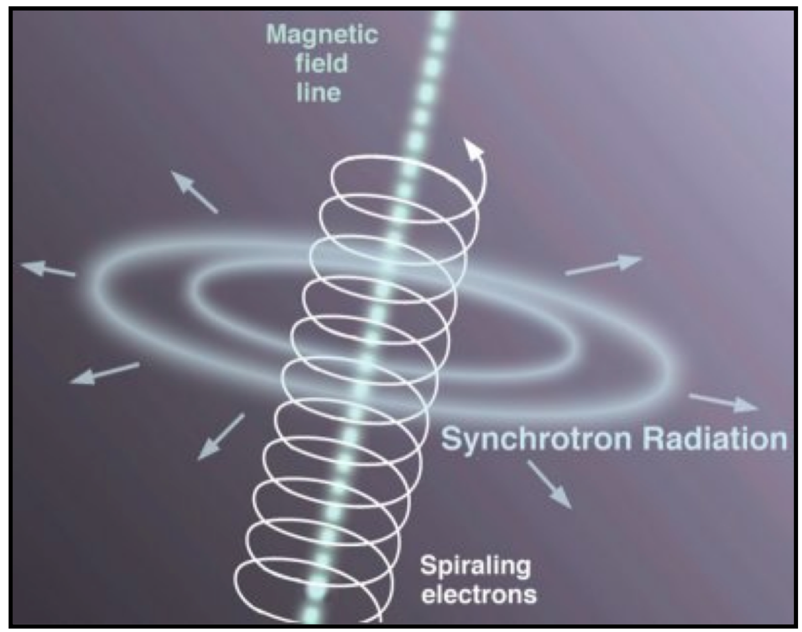
Bremsstralung (free-free):

Electron is accelerated as it passes a charged particle thereby emitting a photon

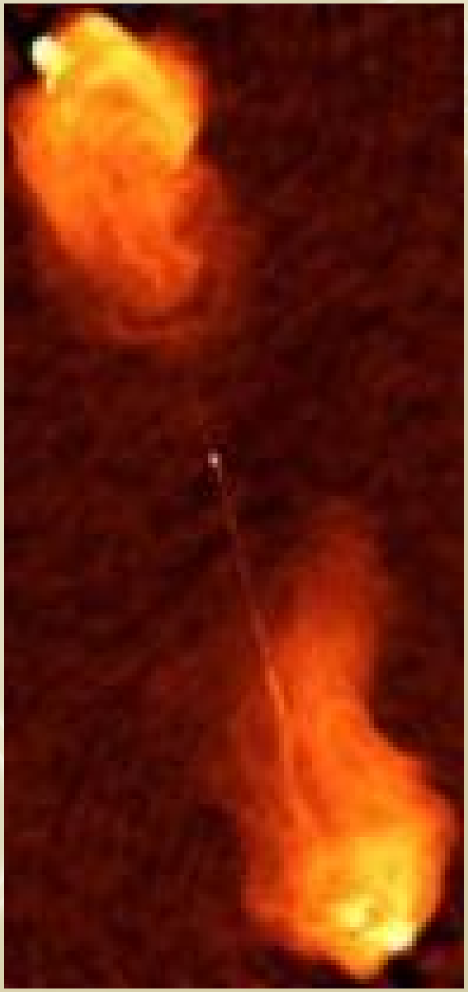


Synchrotron:

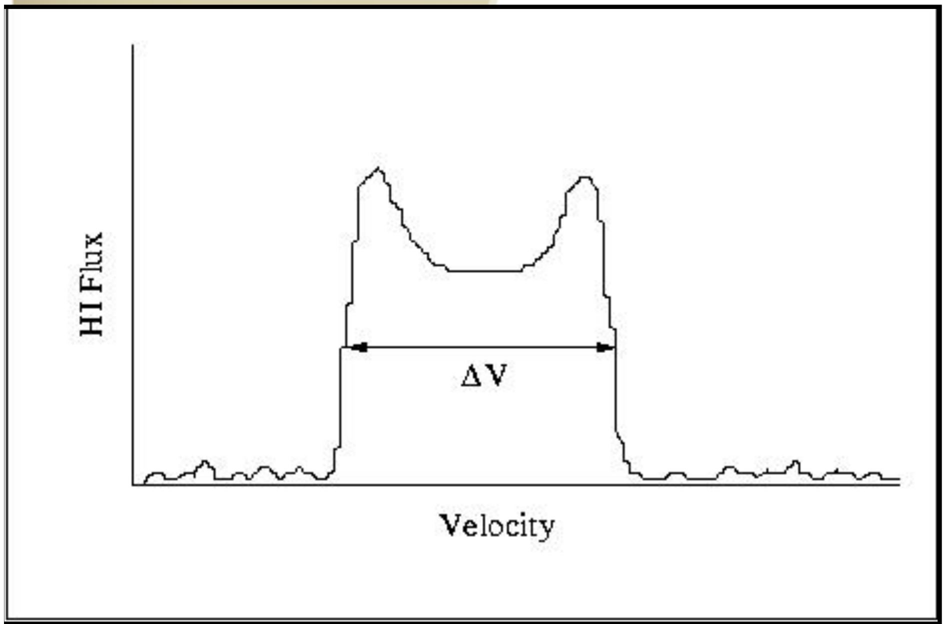
A charged particle moving in a magnetic field experiences acceleration and emits a photon

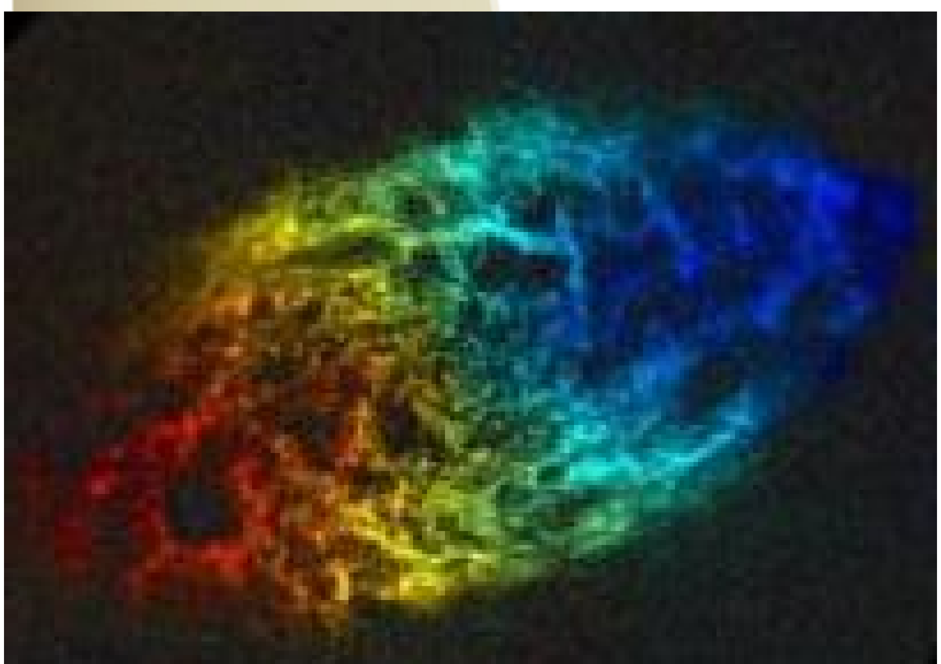


Sources of Continuum Emission



21cm Line of Neutral Hydrogen, cont.





- HI spectral line from galaxy
- Shifted by expansion of universe (“recession velocity”)
- Broadened by rotation

Radio Telescope Characteristics
sensitivity

- **Sensitivity is a measure of the relationship between the signal and the noise**
- **Signal:** the power detected by the telescope
- **Noise:** mostly thermal from electronics but also ground radiation entering feedhorn and the cosmic microwave background. Poisson noise is ALWAYS important. Interference is also a HUGE problem (radar, GPS, etc.)

Radio Telescope Characteristics
semantics

- **Preferred unit of flux density:** (requires calibration) is Jansky:

  $1Jy = 10^{-26}$ W m^{-2} Hz^{-1}

- **Brightness:** Flux density per unit solid angle. Brightness of sources are often given in temperature units

What's the deal with Temperature?

$$B_\nu(T) = \frac{2\,h\nu_0^3}{c^3}\frac{1}{\exp\left(\frac{h\nu}{k\,T}\right)-1} \;=\; \frac{2k\nu^2}{c^2}\,T$$

Rayleigh-Jeans Approximation, where "T" is Brightness Temperatur

Units are Watts m^{-2} Hz^{-1} radian^{-2}

$$S_\nu = \int B_\nu\,\mathrm{d}\Omega$$

$$S_\nu = 2.65\ T_B\ \theta^2/\lambda^2$$

Jy, arc minutes and cm are the units.

If the telescope system has a noise uncertainty ΔS_ν

There is a limit on T_B or ΔT_B

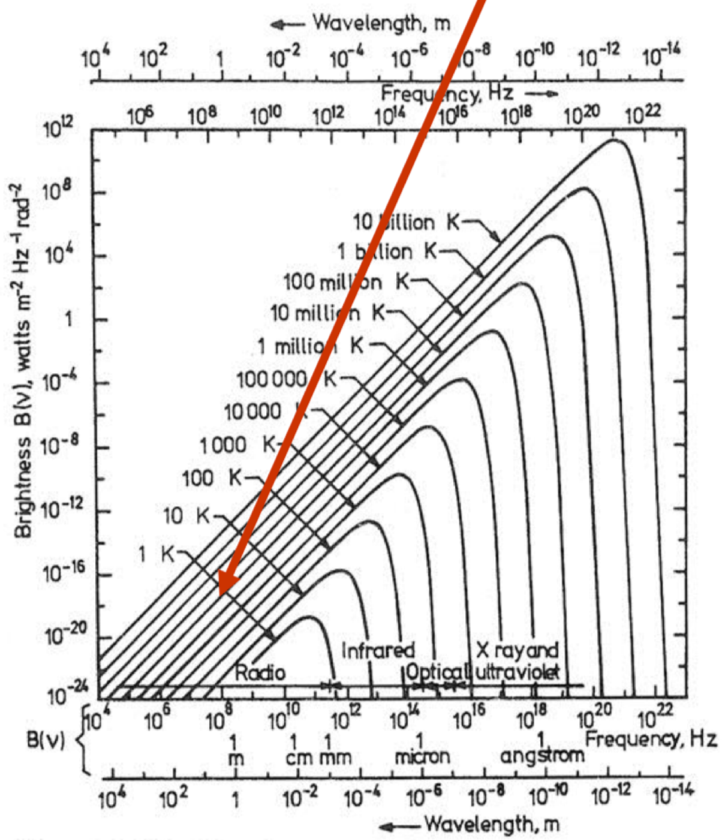


Fig. 1.6. The Planck spectrum for black bodies of different temperatures

Radio Telescope Characteristics
Temperatures

In radio astronomy power is often measured in temperature - the equivalent temperature of a blackbody producing the same power

- **System temperature**: temperature of blackbody producing same power as telescope + instrumentation without a source
- **Brightness temperature:** Flux density per unit solid angle of a source measured in units of equivalent blackbody temperature
- **Antenna temperature:** The flux density transferred to the receiver by the antenna. Some of the incoming power is lost, represented by the aperture efficiency

Radio Telescope Characteristics
polarization

- H I sources are un-polarized
- Synchrotron sources are often polarized – ***E***-field in plane of electron’s acceleration
- Noise sources (man-made interference) are often polarized
- Each receiver can respond to one polarization – one component of linear or one handedness of circular polarization
- Usually there are multiple receivers to observe both polarization components simultaneously

Parameterization of Polarization

- Linear E_x and E_y with phase difference ϕ
- Stokes' parameters:

  $I = E_x^2 + E_y^2$

  $Q = E_x^2 - E_y^2$

  $U = 2E_xE_y\cos\phi$

  $V = 2E_xE_y\sin\phi$
- Unpolarized source: $E_x = E_y$ and $\phi = 0$
- Un-polarized $Q = 0$, $V = 0$, and $I = U$;
- Stokes' I = total flux (sum of x and y polarizations)

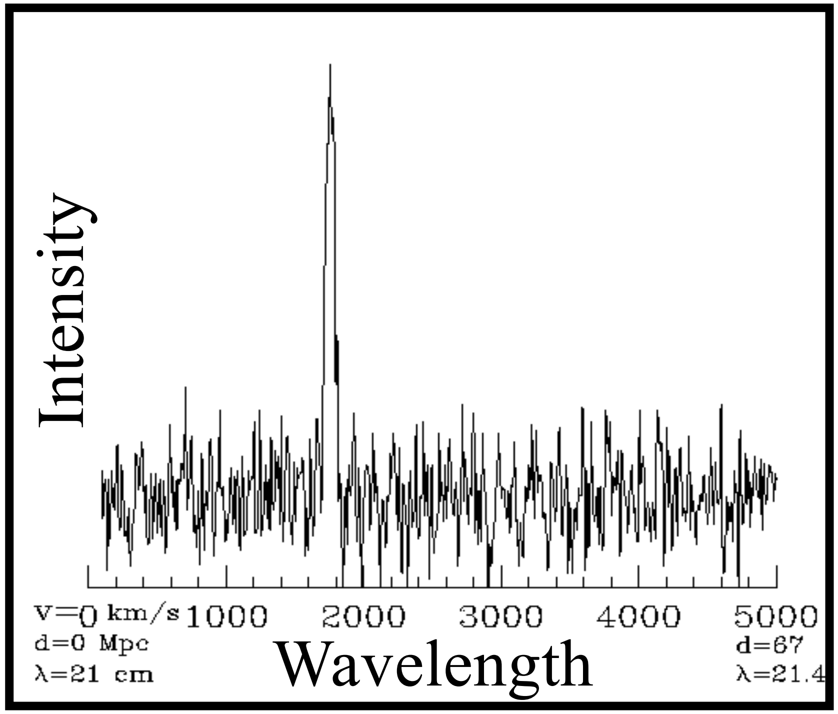
Radiometer Equation

$$T_{rms} = \alpha T_{sys} / \sqrt{\Delta \nu t}$$

- T_{rms} = rms noise in observation
- $\alpha \sim (2)^{1/2}$ because half of the time is spent off the source

  off-source = position switch

  off-frequency = frequency switch
- T_{sys} = System temperature
- $\Delta\nu$ = bandwidth, i.e., frequency range observed
- t = integration time



Radio vs Optical Astronomy

- Primary difference is, well, wavelength

$$\lambda_{radio}/\lambda_{optical} \sim 10^5\text{-}10^6$$
$$\lambda_{21cm}/\lambda_{5500Å} = 3.8\text{x}10^5$$

- This ratio of wavelengths also effects the resolution. The 305m Arecibo telescope is equivalent to a .8mm optical telescope!:

$$\vartheta = \lambda/D$$
$$D_{21cm}/\ D_{5500\ Å} = \lambda_{21cm}/\lambda_{5500Å}$$

Radio vs Optical Astronomy

- This difference in resolution means radio telescopes are diffraction limited
- The resolution is a function of aperture (telescope size) not seeing
- Resolution given by:

$$\vartheta = 1.22(\lambda/D)$$

$$\vartheta_{21\text{ cm, Arecibo}} \sim 2.9'$$

- Radio telescope arrays allow for high res. observations not possible with a single dish