Name: Radio Astronomy 423

Midterm Exam #1

_________________________ March 3, 2021

1. Short answer questions:

a) What is the usual data product output from a correlator like the correlator for the VLA or the LWA?

b) Briefly describe one effect that limits the field-of-view that we can obtain with an interferometer.

c) Draw lines below to match up the physical properties below through a Fourier Transform:

	FT	
Voltage Time Series		Antenna power pattern
Antenna Aperture		Visibility
Sky Brightness		Power Spectrum

d) Explain what the SEFD is for an antenna and which is more desirable, a low number or a high number for the SEFD?

2. Data rates. For the full Long Wavelength Array we plan to record up to 32 MHz of bandwidth from 50 stations. To help deal with RFI we will use 8 bit samples. (a) What is the total data rate in GB/sec coming into the correlator from all 50 stations? (b) If we want a temporal resolution of 10 milliseconds, what is the maximum number of independent channels across the full 32 MHz bandwidth? (c) If our longest baseline is 1000 km and we are observing at a frequency of 80 MHz, what is the expected angular resolution in arcseconds from the full LWA?

3. **Flux density**. At the point of closest approach, Pluto is 38.5 AU from the Earth. Suppose we measure an angular size of 0.108 arcseconds and a flux density of 12 mJy at a wavelength of 1.3 mm. (a) What is the radius of Pluto in kilometers? (b) What is the temperature of the surface in degrees Kelvin?

4. Noise. (a) List at least three factors that contribute to the system temperature of an entire radio telescope system. (b) What is the fundamental (quantum) noise limit (in K) for a coherent receiver working at a frequency of 300 GHz? (c) Explain why interferometry works so well in the radio, but not in the optical, X-ray, or gamma-rays?

5. Antenna Gain. (a) Calculate the SEFD for a 100 m antenna assuming an aperture efficiency of 60% and a system temperature of 30 K. (b) If we pointed at a 1 mJy source for 100 seconds with 100 MHz bandwidth, what would be the rms noise (in mJy)? (c) If we pointed instead at a 100 Jy source for 100 seconds with 100 MHz bandwidth would the noise be less, the same, or more?

6. Receivers. (a) Sketch a typical heterodyne receiver and label all its parts. (b) Describe what is happening at each stage of the receiver (use at least one sentence for each part you listed in (a). (c) What practical arrangement of components is used to minimize the receiver temperature, T_r?

Constants and astronomical quantities:

Speed of light	$c = 3 \times 10^{10}$ cm s^{-1}
Planck's constant	$h = 6.626 \times 10^{-27}$ erg s
Gravitational constant	$G = 6.67 \times 10^{-11}$ N m^{2}kg^{-2}
Stefan-Boltzmann's constant	$\sigma = 5.67 \times 10^{-8}$W m^{-2} K^{-4}
Boltzmann's constant	$k = 1.38 \times 10^{-16}$ erg K^{-1}
Mass of the Sun	1 $M_{\odot} = 1.99 \times 10^{30}$ kg
Surface temperature of the Sun	$T_{\odot} = 5800$ K
Mass of a hydrogen atom	1 $M_H = 1.67 \times 10^{-27}$ kg
Astronomical unit	1 AU = 1.496×10^{11} m
Parsec	1 pc = 3.26 ly = 3.086×10^{16} m = 206,265 AU
1 Jy	10^{-23} erg s^{-1} cm^{-2} Hz^{-1}
Conversion Kelvin (K) to Celsius (C)	T[K]=T[C]+273
Conversion Celsius (C) to Fahrenheit (F)	T[F]=$\frac{9}{5}$T[C]+32
1 radian	206,265 arcseconds

Useful equations:

$\lambda\nu = c$ and $E = h\nu$ for photons

$\lambda_{max} = \frac{0.29cmK}{T}$ Wien's Law and $F = \sigma T^4$ Stefan - Boltzmann Law

$B_\nu = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/kT}-1}$ Planck Function

$T_b = \frac{\lambda^2 S_\nu}{2k\Omega}$ Brightness Temperature

$K.E. = 3/2kT$ (per particle) and $V = \sqrt{(3kT/m)}$ (average velocity of particle)

$\theta = 1.02\lambda/D$ (in radians)

$V = \frac{\lambda_{\rm obs}-\lambda_0}{\lambda_0}c$ doppler velocity

$S = \frac{W}{4\pi d^2 \Delta\nu}$ Flux and power and $W = kT\Delta\nu$

$A_e = G\lambda^2/4\pi$ where G=1.5 for a Hertz dipole

$A_e = \lambda^2/\Omega_a$ for all antennas

$\Delta S = \frac{SEFD}{\sqrt{\Delta\nu\tau}}$ where SEFD = Tsys/GAIN

$GAIN = \frac{\eta_A A}{2k}$ antenna gain

$d = D/\alpha$ distance equation for small angles and a known Diameter