UNIVERSITY OF PRETORIA

PHY 300

FINAL OBSERVATIONAL ASTRONOMY EXAMINATION

1 JUNE 2015

Marks: 100 total
Time: 3 hours (12h – 15h)

Part I: Radio (40 points)
Part II: Optical (60 points)

Please write Part I in one 8-page examination booklet.
Please write Part II in a separate 8-page examination booklet.
Use additional booklets as needed.

PART I: RADIO ASTRONOMY
[40 points total]

Answer 3 questions

1. [10 points]

a) Draw a block diagram of a Heterodyne receiver for use in **R**adio Astronomy. Describe the function of each component as well as the principle of heterodyne mixing. (*4 points*)

b) Describe all the sources of noise that contribute to the total system temperature, T, and use a statistical argument to derive the radiometer formula for the rms noise temperature : (*4 points*)

$$\sigma_{\mathrm{T}} \approx \frac{T_{\mathrm{sys}}}{\sqrt{\Delta\nu_{\mathrm{RF}}\tau}}$$

Where τ is the integration time, and $\Delta\nu_{\mathrm{RF}}$ is the receiver bandwidth.

c) The MeerKAT L-band receivers will benefit from an engineering innovation enabling digitisation, directly at the radio frequency, thereby omitting the mixer component. How will this improve their sensitivity? (*1 point*)

d) In a simple receiver a 30 dB (i.e. gain 1000) amplifier with a noise temperature of 4K is followed by a mixer with a noise temperature of

1000K. What is the percentage contribution of the mixer to the noise temperature of the total system? (*1 point*)

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2. [10 points]

a) Describe, with the aid of a diagram, the emission mechanism which gives rise to:
1) the 21 cm hydrogen line and
2) the 2.6 mm rotational line of carbon monoxide. (*4 points*)

b) Discuss the important uses and complementariness of these lines in radio astronomy, both Galactic and Extragalactic. (*4 points*)

c) How do observations of HI in galaxies indicate the presence of dark matter? (*2 points*)

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3. [10 points]

a) Describe Michelson's stellar interferometer and how it was used to measure the diameters of stars. Hence, extrapolate to today's radio VLBI systems and detail their major system components. (*5 points*)

b) The ALMA array in Chile has a maximum baseline of 15 km. What is its highest angular resolution at a wavelength of 3mm? (*2 points*)

c) In early VLBI of extragalactic sources, great excitement was generated by measurements indicating that some extragalactic radio sources showed apparent expansion velocities, between separated components, which were greater than the speed of light (*superluminal velocities*). Describe these observations and show, with the aid of a diagram, how they were reconciled with the constancy of 'c'. (*3 points*)

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4. **[10 points]**

Describe ***either***,

the discovery, origin and subsequent studies of pulsating radio sources, Pulsars. (*10 points*)

or

Write notes on the Square Kilometer Array, SKA, its precursors, its antennae and its scientific objectives and potential. (*10 points*)

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PART II: OPTICAL ASTRONOMY
[60 points total]

5. Stellar Brightnesses and Magnitudes [20 points]

You are standing outside at night when you see a 'shooting star.' The shooting star is caused by a small rocky meteor burning up in the Earth's atmosphere as it enters and is slowed down by atmospheric friction.

You measure the total brightness (summed along the path) to be first magnitude. It lasts for 3 seconds at that brightness, and then is finished.

a. How many watts are given off by the meteor? You can assume that the flare is at 50 km high in the atmosphere, directly above you. And assume that the spectrum of the flare is identical to that of the Sun. (That is, the burning rock burns with the spectrum of a black body at 6000 K.) You will need to use the luminosity and magnitude of the Sun for this. (10 points)

b. How large was the meteor (i.e., chunk of rock) itself, in grams? You can assume that 100% of the impactor's incoming kinetic energy is converted to thermal energy at 6000K. You can also assume that the impactor came from infinity (that is, with a velocity equal to that of Earth's escape velocity). (10 points)

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6. Diffraction Limits [10 points]

An eagle's eye opening ('iris') is roughly the same size as a human's, about 8 mm in diameter. However, the eagle's retina is of higher resolution than our our own -- that is, its retina has a greater number of "pixels per millimeter" than our do, because the eagle's eye reaches the diffraction limit, while ours don't.

a. Discuss briefly (one or two sentences) the concept of the 'diffraction limit' as it applies to this case. (5 points)

b. An eagle is flying overhead and sees a mouse. The mouse is 10 cm long. How high can the eagle be to be able to resolve the mouse directly below it (that is, to have the mouse be > 1 "pixel" in the eagle's eye)? Assume a wavelength of 500 nm. (3 points)

c. How close must the eagle fly if it wants to resolve the mouse's eyes? You can assume they are of diameter 2 mm. (2 points)

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7. Celestial Distances [5 points]

The picture below is from the flyby of comet Hyukatake past the Earth in March 1996. Among other things, it shows **mountains**, **stars**, the **comet**, and a nearby **galaxy** (Andromeda, the closest to us).

The mountains are roughly 1 km away. List the rough distances to the other listed objects. Order-of-magnitude is fine; use appropriate units. (5 points)

CHOOSE EITHER #8 OR #9 – YOU NEED NOT ANSWER BOTH

8. Stellar Power and Flux [15 points]

Spacecraft require power to operate their instruments throughout the solar system. At Earth, many spacecraft are solar powered. A typical satellite in Earth orbit may have a surface area of 2 m^2 of solar cells. These are about 20% efficient in converting the Sun's flux into power.

a. How many watts do they generate, when pointed directly at the Sun? (5 points)

b. At Pluto (distance 33 AU), how many watts would be generated by the same solar panels, illuminated by the Sun? (5 points)

c. Someone might ask you, "But can't you just power a spacecraft from the stars?" What power (in watts) is generated by the same solar cells, powered by the stars? (5 points)

Assume that most of the flux is dominated by the 1000 closest stars, and that each of these has a spectrum like that of the Sun. Although their distances vary, assume a typical stellar distance of 30 ly.

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9. Motion of Satellites [15 points]

You are searching for new satellites of Uranus. Assume a telescope of diameter 3 meters, focal length 10 meters, and CCD with pixel size 10 um x 10 um.

You think there may be some new satellites orbiting at a distance of around 30 Uranus radii (that is, $a = 30\ R_U$).

a. For a moon at this orbit, what is its speed, in km/sec? (5 points)

b. What is the speed of this moon, in pixels/hour? Assume that the motion is projected in a straight line along one axis of the CCD (e.g., the motion is not radial to or from the observer).

(5 points)

c. Your initial images are looking promising, but have a very low SNR of 1 in 5 minutes. Your detector is very good (low dark-current and bias), so the main source of noise is Poisson noise. You would like to increase your exposure to get to SNR of 5. How long an exposure does this require? (5 points)

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10. Evolution of the Telescope [10 points]

Describe briefly the significant differences between these telescopes pictured below. A table or list is fine. Be sure to consider the optics, focal length, the construction, the mount, various aberrations, imagers used, and so forth.

Be specific: "higher-quality images" is not sufficient!

(10 points)


CELESTRON

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Equations

Angular size	$\theta = d/R$	
Parallax half-angle	$\theta = 1\,\text{AU}/R$	Stellar distance R
Flux	F = E / A	
Flux from a point source	$F = L/4\pi R^2$	
Received radiation	E = F * A	
	E = F * A * (1-a)	Albedo a
Energy of a photon	$E = h\nu$	
Wavelength	$v = \nu\lambda$	
Snell's law	$n_1 \sin\theta_1 = n_2 \sin\theta_2$	
Reflection	$\theta_{inc} = \theta_{refl}$	
Lens equation	$1/f = 1/d_i + 1/d_o$	
Compound lens	$1/f' = 1/f_1 + 1/f_2 - d/(f_1 f_2)$	
Focal ratio	$f/ = f/D$	
Magnification at eyepiece	$M = f_t/f_e$	
Image scale	$1/f$	Units of radians per distance
Black body emitted surface flux	$F = \sigma T^4$	
Wien's Law	$\lambda_{peak} \sim 1/T$	
Magnitudes	$F_2 = 2.5^{\Delta m} F_1$	
	$\Delta M = -2.5 \log_{10}(F_1/F_2)$	
Hour Angle	HA = ST - RA	Sidereal Time, Right Ascension
Elevation (or Altitude) Angle	θ = 90 - lat + dec	
Poisson Noise	Uncertainty (*i.e., noise*) $= \sqrt{N}$	$N = \#$ of counted photons
Signal:Noise Ratio for Poisson-dominated signal	$SNR = N/\sqrt{N}$	
Data Numbers	$DN = ((N * QE) + I_{dark} + B)/G$	Bias B, Gain G
Orbital Velocity	$v = \sqrt{GM/R}$	Orbital distance R
Escape Velocity	$v = \sqrt{2GM/R}$	