Exercise session - 'Astronomy'

31.03.2017

1 Deep Space Observation

The faintest galaxies observed by the Hubble Space Telescope have apparent magnitudes around 30. Suppose these galaxies are ≈ 3 Gpc away. Assuming every star in these galaxies emits about the same amount of light as the Sun (a false assumption, but let's make it just the same), how many stars would these galaxies contain?
Hint: The number of stars in each galaxy will be equal to amount by which the galaxy is intrinsically brighter than the Sun — e.g. a galaxy with 10 Sun-like stars has a brightness 10 times that of the Sun.

2 Astrophotography

The Moon (angular diameter $\alpha = 31'$) shall be photographed with a telescope whose objective has a diameter of $D = 20$ cm and a focal length of $f = 150$ cm.

a) What is the expected size of the Moon in the focal plane of the objective?

b) What is the angular resolution of this telescope in the optical spectrum?
The Apollo 11 crew landed on the Moon on July 20, 1969. After approximately 21 hours and 30 minutes they left its surface again while having performed a 'Moon walk' of about 250 metres in that time.
Given the distance to the Moon of about $d_M = 385000$ km, what is the distance on the Moon's surface you can resolve with your telescope?
Are you able to locate the human imprints on the Moon by the Apollo 11 mission?
What diameter should an optical telescope have to resolve this landing site?
Congratulations, you found a very reasonable argument against conspiracy theories about faking the Moon landing!

c) You want to take a photography of the Moon now and you bought a very expensive but really fancy CCD camera with a size of 4499×3599 pixels, each of them of size $6\ \mu\text{m} \times 6\ \mu\text{m}$. You place your camera in the focal plane of the telescope. Roughly estimate how many pixels of the camera will receive a signal and find the fraction of the CCD array covered by the Moon's image.

3 Resolution of Telescopes in Different Bands of Electromagnetic Waves

1. *Mirror telescopes in the optic and infrared band:*

   a) What must be the size of a mirror telescope's main mirror if we want to resolve a proto-planetary disk of diameter 1000 AU around a star being 140 pc away from the Earth with at least 10 independent points in infrared light of wavelength $\lambda = 2.1$ µm?

   b) What size must such a mirror have if we want to resolve a planet at 1 AU around its star which is itself 50 pc apart from the Earth in the optical band?

2. *Infrared interferometry:*
   What is the distance two telescopes should have to resolve a dust torus around an active galactic nucleus using wavelengths of $\lambda = 10$ µm? The dust torus has an inner diameter of 1 pc and the active galactic nucleus is located at a distance of 14 Mpc from the Earth.

3. *Comparison to Radioastronomy:*

   a) Redo your calculations in 1.) and 2.) in the case of wavelengths $\lambda_H =$ 21 cm (emission line of atomic hydrogen due to quantum mechanical interactions between the electron and the nucleus) and $\lambda_{\mathrm{CO}} = 1.3$ mm (rotational transition in CO)!

   b) Are those diameters realizable with single radiotelescopes or do we need interferometry? Recall that the largest radiotelescope has a diameter of about 300 meters.

4 Astronomy with Spectral Lines

Having listened to my little summary of spectral lines and their broadening, consider the following tasks:

1. For ammonia (NH_3) at $T = 20$ K and hydrogen (H_2) at $T = 1000$ K find the velocity spread Δv of a spectral line.

2. Spectral resolutions are often stated as $A = \frac{\lambda}{\Delta\lambda}$. In the optical and infrared bands resolutions can vary between $A = 300, 5000, 10^5$ which correspond to poor, medium and high resolutions. Can we resolve the thermal broadening of any line of the molecules above with modern spectrometers?

3. Now you want to explore an exoplanet to find life there. Your idea is to record the spectrum of the exoplanet's atmosphere while the star's light shines through it.

From the human standpoint, oxygen is a necessary ingredient for the evolution of complex biochemical life. Moreover, the average temperature of the planet should be such that liquid water can exist on the surface which means approximately $T = 300$ K. You know of one particular characteristic spectral line of oxygen in the optical spectrum. Can you resolve the width of the spectral line with modern spectroscopes?