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Astro 8060 HW 2

1. $H\beta$, $v_r = 5000\,km/s$, J, H, K bands, redshift?

$\lambda_{H\beta_{rest}} = 4861\,Å \rightarrow \pm 5000\,km/s$ in Doppler

$\pm$ cosmo. redshift too

$1+z = (1+z_{cosmo})(1+z_{Doppler}) \Rightarrow z_{cosmo} = \frac{1+z}{1+z_{Dopp}} - 1$

Filter	λ_{eff} (μm)	FWHM (μm)	λ_{min} (μm)	λ_{max} (μm)
J	1.22	0.213	1.007	1.433
H	1.63	0.307	1.323	1.937
K	2.19	0.390	1.800	2.580

$1+z = \frac{\lambda_{obs}}{\lambda_{emit}} \Rightarrow z_{cosmo} = \frac{\lambda_{obs}/\lambda_{emit}}{1+z_{Dopp}} - 1$

$1+z_{Dopp} = \sqrt{\frac{1+\beta}{1-\beta}}$, $\beta = \frac{v_r}{c}$

$z_{cosmo} = \frac{\lambda_{obs}/\lambda_{emit}}{\sqrt{(1+v_r/c)/(1-v_r/c)}} - 1$

$\lambda_{em\,H} = 0.4861\,\mu m$ $\quad c = 3\times10^5\,km/s$

λ_{obs} = band ranges

$z_{cosmo} = \frac{1.007/0.4861}{\sqrt{(1+5000/3\times10^5)(1-5000/3\times10^5)}} - 1 = 1.07$

$z_{cosmo} = \frac{1.433/0.4861}{\sqrt{(1+5000/3\times10^5)(1-5000/3\times10^5)}} - 1 = 1.94$

$z_{cosmo} = \frac{1.323/0.4861}{\sqrt{(1+5000/3\times10^5)(1-5000/3\times10^5)}} - 1 = 1.72$

$z_{cosmo} = \frac{1.937/0.4861}{\sqrt{(1+5000/3\times10^5)(1-5000/3\times10^5)}} - 1 = 2.98$

$z_{cosmo} = \frac{1.800/0.4861}{\sqrt{(1+5000/3\times10^5)(1-5000/3\times10^5)}} - 1 = 2.70$

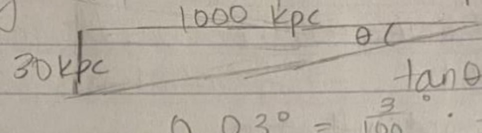
$z_{cosmo} = \frac{2.580/0.4861}{\sqrt{(1+5000/3\times10^5)(1-5000/3\times10^5)}} - 1 = 4.30$

For J $\rightarrow$ $1.07 < z < 1.94$

For H $\rightarrow$ $1.72 < z < 2.98$

For K $\rightarrow$ $2.70 < z < 4.30$

2. galaxy 1 Mpc away, d = 30 kpc, size on sky?



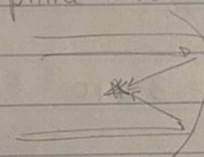
$\tan\theta = \frac{30\,kpc}{1000\,kpc} = 0.03 \approx \theta$

$0.03° = \frac{3}{100}° \cdot \frac{60'}{1°} \cdot \frac{60''}{1'} = 108''$

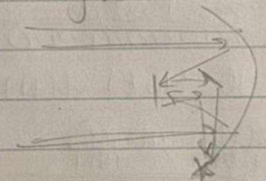
$\boxed{0.03° = 1.8' = 1'48'' = 108''}$

3. d = 8m, optical, f/3 prime focus, f/12 Nasmyth focus, seeing 0.5 arcsec FWHM, Nyquist sample, physical size in microns of ccd pixel? prime focus? Nasmyth focus? field of view in each case w/ 2048^2 pixels?

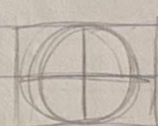
prime focus



Nasmyth focus



Nyquist



$f/3 \rightarrow R = 3 = \frac{f}{D} = \frac{f}{8m} \Rightarrow f = 24m$

$f/12 \rightarrow R = 12 = \frac{f}{D} = \frac{f}{8m} \Rightarrow f = 96m$

$S = \frac{206265}{f}$ [arcsec / mm] $\quad S = \frac{206265}{24m \cdot \frac{1000mm}{m}} = 8.59\ \frac{arcsec}{mm}$

$S = \frac{206265}{96m \cdot \frac{1000mm}{m}} = 2.14\ \frac{arcsec}{mm}$

$p = \frac{0.5''}{2} = 0.25''$ (Nyquist)

$\frac{0.25''}{8.59''/mm} = 0.029\ mm = 29\ \mu m$

$\frac{0.25''}{2.14''/mm} = 0.116\ mm = 116\ \mu m$

$FOV = p \cdot N_{pix} = 0.25'' \cdot 2048 = 512'' = 8'32''$

prime → 29 μm
Nasmyth → 116 μm
FoV → 8'32''

4. $B = 9.5$, $\frac{erg}{s\,cm^2\,Å}$? $\frac{ph}{s\,cm^2\,Å}$? Jy?

$f_\nu(Jy) = F_{vega,0}\, 10^{-0.4m}$

$F_{\nu,0,B} = 4440\ Jy$

$f_\nu(Jy) = 4440\ Jy\ 10^{-0.4(9.5)} = \boxed{0.703\ Jy}$

$0.703\ Jy \cdot \frac{10^{-26}\ W/m^2 Hz}{1\ Jy} \cdot \frac{10^7\ erg/s}{1W} \cdot \frac{1m^2}{100\,cm^2} = 7.03\times10^{-24}\ \frac{erg}{s\,cm^2\,Hz}$

$\frac{\partial\nu}{\partial\lambda} = -\frac{c}{\lambda^2}$ $\quad \lambda_{eff\,B} = 0.44\ \mu m = 4400\ Å$

$\frac{\partial\nu}{\partial\lambda} = \frac{-3\times10^{18}\ Å/s}{(4400Å)^2} = -1.54\times10^{11}\ Hz/Å$

$f_\lambda = f_\nu \frac{\partial\nu}{\partial\lambda} = 7.03\times10^{-24}\ \frac{erg}{s\,cm^2\,Hz} \cdot 1.54\times10^{11}\ \frac{Hz}{Å}$

$= \boxed{1.08\times10^{-12}\ \frac{erg}{s\,cm^2\,Å}}$

$1\ ph = \frac{hc}{\lambda} = \frac{6.624\times10^{-27}\ erg\cdot s \cdot 3\times10^{18}\ Å/s}{4400\ Å} = 4.51\times10^{-12}\ erg$

$1.08\times10^{-12}\ \frac{erg}{s\,cm^2\,Å} \cdot \frac{ph}{4.51\times10^{-12}\ erg} = \boxed{0.2411\ \frac{ph}{s\,cm^2\,Å}}$

5. $m_{AB} = 20$, $\lambda = 5500Å$, Johnson V? $\frac{ph}{s\,cm^2\,Å}$?

$f_\nu(Jy) = 3631\ Jy\ 10^{-0.4 m_{AB}} = 3631\ Jy\ 10^{-0.4(20)}$

$f_\nu = 3.63\times10^{-5}\ Jy$

$3.63\times10^{-5}\ Jy \cdot \frac{10^{-26}\ W/m^2 Hz}{1\ Jy} \cdot \frac{10^7\ erg/s}{1W} \cdot \frac{1m^2}{100\,cm^2} = 3.63\times10^{-28}\ \frac{erg}{s\,cm^2\,Hz}$

$1\ ph = \frac{hc}{\lambda} = \frac{6.624\times10^{-27}\ erg\,s \cdot 3\times10^{18}\ Å/s}{5500\ Å} = 3.61\times10^{-12}\ erg$

$3.63\times10^{-28}\ \frac{erg}{s\,cm^2\,Hz} \cdot \frac{ph}{3.61\times10^{-12}\ erg} = 1.00\times10^{-16}\ \frac{ph}{s\,cm^2\,Hz}$

$\frac{\partial\nu}{\partial\lambda} = -\frac{c}{\lambda^2} = \frac{-3\times10^{18}\ Å/s}{(5500\ Å)^2} = -9.91\times10^{10}\ \frac{Hz}{Å}$

$1.00\times10^{-16}\ \frac{ph}{s\,cm^2\,Hz} \cdot \frac{9.91\times10^{10}\ Hz}{Å} = \boxed{9.96\times10^{-6}\ \frac{ph}{s\,cm^2\,Å}}$

$f_\nu(Jy) = F_{vega,0}\ 10^{-0.4m}$

$3.63\times10^{-5}\ Jy = 3540\ Jy \cdot 10^{-0.4m} \Rightarrow m = \boxed{19.97 = V}$

6. $A \rightarrow \frac{1 MJy}{sr}$ @ 5500 Å, $\frac{erg}{s\,cm^2\,Hz\,arcsec^2}$? $\frac{erg}{s\,cm^2\,Å\,arcsec^2}$?
$\frac{mag}{arcsec^2}$? $\frac{ph}{s\,cm^2\,Å\,arcsec^2}$?

$$\frac{1\,MJy}{sr} \cdot \frac{10^6\,Jy}{1\,MJy} \cdot \frac{10^{-26}\,W/m^2\,Hz}{1\,Jy} \cdot \frac{10^7\,erg/s}{1\,W} \cdot \frac{1\,m^2}{100^2\,cm^2} = 1 \times 10^{-17} \frac{erg}{s\,cm^2\,Hz\,Sr}$$

$$1\,Sr \cdot \frac{1\,rad^2}{1\,Sr} \cdot \frac{180^2\,deg^2}{\pi^2\,rad^2} \cdot \frac{60'^2}{1^2\,deg^2} \cdot \frac{60''^2}{1'^2} = 4.25 \times 10^{10}\,''^2/Sr$$

$$1 \times 10^{-17} \frac{erg}{s\,cm^2\,Hz\,Sr} \cdot \frac{1\,Sr}{4.25 \times 10^{10}\,''^2} = \boxed{2.35 \times 10^{-28} \frac{erg}{s\,cm^2\,Hz\,arcsec^2}}$$

$$1\,ph = \frac{hc}{\lambda} = \frac{6.624 \times 10^{-27}\,erg \cdot s \cdot 3 \times 10^{18}\,Å/s}{5500\,Å} = 3.61 \times 10^{-12}\,erg$$

$$\frac{\partial\nu}{\partial\lambda} = -\frac{c}{\lambda^2} = \frac{-3 \times 10^{18}\,Å/s}{5500^2\,Å^2} = 9.91 \times 10^{10}\,\frac{Hz}{Å}$$

$$2.35 \times 10^{-28} \frac{erg}{s\,cm^2\,Hz\,arcsec^2} \cdot \frac{9.91 \times 10^{10}\,Hz}{Å} = \boxed{2.33 \times 10^{-17} \frac{erg}{s\,cm^2\,Å\,arcsec^2}}$$

$$2.33 \times 10^{-17} \frac{erg}{s\,cm^2\,Å\,arcsec^2} \cdot \frac{ph}{3.61 \times 10^{-12}\,erg} = \boxed{6.45 \times 10^{-6} \frac{ph}{s\,cm^2\,Å\,arcsec^2}}$$

$$f_\nu(Jy) = 3631\,Jy\,10^{-0.4 m_{AB}}$$

$$10^6\,Jy = 3631\,Jy\,10^{-0.4 m_{AB}} \Rightarrow m_{AB} = -6.099$$

$$\frac{1\,MJy}{Sr} \cdot \frac{-6.099\,mag}{1\,MJy} \cdot \frac{Sr}{4.25 \times 10^{10}\,arcsec^2} = \boxed{-1.43 \times 10^{-10} \frac{mag}{arcsec^2}}$$

Q7.

Charged Coupled Devices, commonly called CCDs, are detectors used in lots of astronomy research and data collection. They have the ability to take images in the optical, which is the electromagnetic band in which humans can see. CCDs are made of a few main components: a metal, an oxide, and a semiconductor. Because of this, some CCDs are called MOS (metal-oxide-semiconductor) capacitors. CCDs can be n-type (negative) or p-type (positive), which corresponds to whether there is an excess or deficit of electrons in the dopant (element) within the semiconductor. Figure 1 shows a general diagram of what a MOS capacitor or CCD may look like.

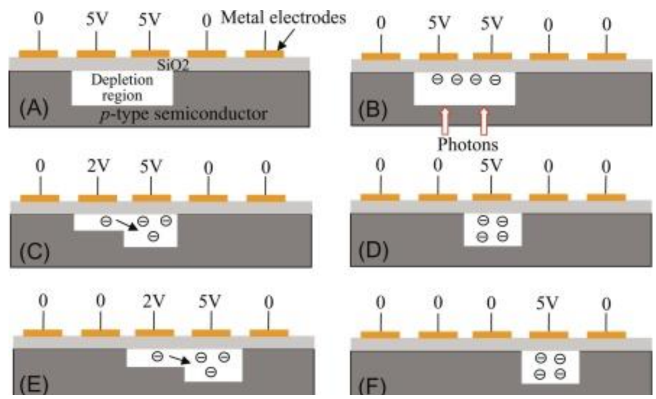


Figure 1. A general diagram of a metal-oxide-semiconductor capacitor with potential wells.

When the detector is exposed to light, the incident photons coming from the target of the observation release electrons in the metal of the MOS capacitor via the photoelectric effect. Each pixel can accept incident photons. These electrons travel across a gap until they reach the potential wells of the MOS capacitor; in there, they cannot escape without a change in voltage in the surrounding pixels. Because of this, many people draw the analogy that each pixel of a CCD is similar to an "electron bucket". The electrons stay in the collection region until they are moved away to be read out. Each "bucket" can only hold so many electrons. For that reason, it is important that people using CCDs are not overexposing the detector; if a potential well overfills, the information about the initial amount of electrons coming in is lost, and the resulting data is not as informative or reliable. The exposure time and the amount of incoming light should be inversely related.

Once the CCD is done reading in light, the information is pulled from the detector. One column at a time, with what is called a parallel register, the detector adjusts the voltage within the surrounding area of the potential wells in order to move the electrons from their "buckets". Then for each column, using a serial register, the "buckets" are emptied and the CCD reads the amount of electrons in each pixel in the form of voltage.

This voltage is sent to an amplifier next. The amplifier amplifies the voltage and sends it to an analog-to-digital converter, also known as an ADC. The ADC has a set number of electrons, called a gain, that create one ADU (analog digital unit). The gain of a CCD is an intrinsic characteristic of that specific CCD and can be adjustment in manufacturing. Once the ADC has converted the voltage coming in to a digital number coming out, this number is sent down the line and stored in the computer's memory. This is the result that a researcher would see when they view the data of an exposed CCD.

Links used (outside of class notes):

https://en.wikipedia.org/wiki/Charge-coupled_device

https://www.techtarget.com/searchstorage/definition/charge-coupled-device

https://www.eesemi.com/ccd.htm