1. $m_2 - m_1 = -2.5 \log\left(\frac{F_2}{F_1}\right)$

3% error in flux $\Rightarrow$ $F_2/F_1 = 1.03$ or $= 0.97$

$m_2 - m_1 = -2.5 \log(1.03) = -0.032$

$m_2 - m_1 = -2.5 \log(0.97) = 0.033$

$\Rightarrow$ 3% error in magnitude

2. source A w/ surface brightness 1 MJy / sr at 5500 Å

V filter, CCD cam on 2.3m telescope

QE = 1.0 → FWHM of V band ~880 Å (google)

$R = N_{tot} \cdot \Delta\lambda \cdot A \cdot f_\lambda$ → use I_λ from HW2

6.46×10^{-6} ph s^{-1} cm^{-2} $Å^{-1}$ $arcsec^{-2}$

$A = \pi \left(1.15 m \cdot \frac{100 cm}{1 m}\right)^2$

$= 41547.563 \ cm^2$

$R = (1) \cdot (880 \cancel{Å}) \cdot (41547.563 \ \cancel{cm^2})$
$\cdot (6.46 \times 10^{-6} \ ph \ s^{-1} \ \cancel{cm^{-2}} \ \cancel{Å^{-1}} \ arcsec^{-2})$

$= 236.1895 \ ph \ s^{-1} \ arcsec^{-2}$

3. galaxy $d = 10$ Mpc

monochromatic luminosity 10^{38} erg s^{-1} $Å^{-1}$ (optical)

2.3m telescope V filter

$QE = 0.5$

observe at $X = 2$

→ monochromatic luminosity – luminosity per wavelength or frequency unit

→ assuming luminosity isotropic (?)

$$R = (QE \cdot N_{atmos}) \cdot \underset{\substack{\downarrow \\ 880\,Å}}{\Delta\lambda} \cdot \underset{\substack{\downarrow \\ (115\,cm)^2\pi}}{A} \cdot f_\lambda$$

$$N_{atmos} = \left(2.5^{2 \cdot 0.2}\right)^{-1} = 0.693$$

$$f_\lambda = \frac{10^{38}\ erg\ s^{-1}\ Å^{-1}}{4\pi(10\,Mpc \cdot 10^{6}\,pc \cdot Mpc^{-1})^2} = 8.842 \times 10^{-15}\ erg\ s^{-1}\ cm^{-2}\ Å^{-1}$$

$$E_{ph} = \frac{hc}{\lambda} = \frac{6.626 \times 10^{-27}\ erg \cdot \cancel{s} \cdot 3\times10^{18}\ \cancel{Å}/\cancel{s}}{5500\ \cancel{Å}} = 3.613 \times 10^{-12}\ erg\ ph^{-1}$$

$$f_\lambda = \frac{8.842\times10^{-15}\ \cancel{erg}\ s^{-1} cm^{-2}\ Å^{-1}}{3.613\times10^{-12}\ \cancel{erg}\ ph^{-1}} = 2.447 \times 10^{-3}\ ph\ s^{-1}\ cm^{-2}\ Å^{-1}$$

$$R = (0.5 \cdot 0.693)(880\ \cancel{Å})(115\ \cancel{cm})^2\pi\,(2.447\times10^{-3}\ ph\ s^{-1}\ \cancel{cm^{-2}}\ \cancel{Å^{-1}})$$

$$= 31009\ ph\ s^{-1}$$

4. $R_S = 0.2\ ph\ s^{-1}$, $R_B = 0.5\ ph\ s^{-1}\ pix^{-1}$, $R_D = 10\ e^-\ hr^{-1}\ pix^{-1}$

$N_R^2 = 5\ e^-/pix$

PSF $\sim$ 4 pix $\rightarrow N_{pix}$

$$R_D = \frac{10 e^-}{hr} \cdot \frac{1 hr}{3600 s} = \frac{1}{360}\ e^-\ s^{-1}$$

$$\frac{S}{N} = \frac{0.2t}{\sqrt{0.2t + 4(0.5t + t/360 + 5)}}$$

$\Rightarrow$ using desmos, $t \approx 552786.825\ s$ for $S/N = 100$

$$552786.825\ s \cdot \frac{1\ min}{60\ s} = 9213 \text{ 1-min exposures}$$

5. WIRO: $N_R^2 = 4.5\, e^-/pix$ $\quad R_D = 0$

prime focus imager 2.3m $f/2.1$ telescope 13.5 μm pixels

observations taken at airmass $X = 1$

detector QE = 0.9, other QE = 0.7

for S/N = 100, t = ? → assume 1.1" seeing

22 mag star, V filter

full moon μ_V = 20 mag arcsec^{-2}; new μ_V = 22 mag arcsec^{-2}

googled V band zero point

$$f_\nu = (3597.28\,\text{Jy})\,10^{-0.4(22)} = 5.701\times10^{-6}\ \text{Jy}$$

$$= (5.701\times10^{-6}\,\text{Jy})(10^{-26}\,\text{W m}^{-2}\,\text{Hz}^{-1}\,\text{Jy}^{-1}) = 5.701\times10^{-32}\ \text{W m}^{-2}\,\text{Hz}^{-1}$$

$$= 5.701\times10^{-32}\,\text{W m}^{-2}\,\text{Hz}^{-1}\cdot 10^{7}\,\text{erg s}^{-1}\,\text{W}^{-1}\cdot 10^{-4}\,\text{cm}^{-2}\,\text{m}^{2} =$$
$$5.701\times10^{-29}\ \text{erg s}^{-1}\,\text{cm}^{-2}\,\text{Hz}^{-1}$$

$$\nu f_\nu = \lambda f_\lambda \Rightarrow f_\lambda = \frac{c}{\lambda^2} f_\nu = \frac{3\times10^{18}\,\text{Å/s}}{(5300\,\text{Å})^2}\, 5.701\times10^{-29}\,\text{erg s}^{-1}\,\text{cm}^{-2}\,\text{Hz}^{-1}$$

$$f_\lambda = 5.654\times10^{-18}\ \text{erg s}^{-1}\,\text{cm}^{-2}\,\text{Å}^{-1}$$

$$E_{ph} = \frac{hc}{\lambda} = \frac{6.624\times10^{-27}\,\text{erg}\cdot\text{s}\cdot 3\times10^{18}\,\text{Å/s}}{5500\,\text{Å}} = 3.613\times10^{-12}\ \text{erg}$$

$$f_\lambda = \frac{5.654\times10^{-18}\,\text{erg s}^{-1}\,\text{cm}^{-2}\,\text{Å}^{-1}}{3.613\times10^{-12}\,\text{erg ph}^{-1}} = 1.565\times10^{-6}\ \text{ph s}^{-1}\,\text{cm}^{-2}\,\text{Å}^{-1}$$

$$R_S = QE\cdot N_{atmos}\cdot \Delta\lambda\cdot A\cdot f_\lambda$$

$$= 0.9(2.5^{0.2})^{-1} \cdot 880\,\mathring{A} \cdot \pi(115\,cm)^2 \cdot 1.565\times10^{-6}\ ph\ s^{-1}\,cm^{-2}\,\mathring{A}^{-1}$$

$$= 42.872\ ph\ s^{-1}$$

for full moon $\mu_V = 20$ mag arcsec^{-2}

$$f_\nu = (3597.28)\,10^{-0.4(20)} = 3.597\times10^{-5}\ Jy\ arcsec^{-2}$$

$$= 3.597\times10^{-5}\ Jy\ arcsec^{-2} \cdot 10^{-26}\ W\,m^{-2}\,Hz^{-1}\,Jy^{-1} = 3.597\times10^{-31}\ W\,m^{-2}\,Hz^{-1}\,arcsec^{-2}$$

$$= 3.597\times10^{-31}\ W\,m^{-2}\,Hz^{-1}\,arcsec^{-2} \cdot 10^{7}\ erg\ s^{-1}\,W^{-1} \cdot 10^{-4}\ cm^{-2}\,m^{2} = 3.597\times10^{-28}\ \frac{erg\ s^{-1}\,cm^{-2}}{Hz^{-1}\ arcsec^{-2}}$$

$$\nu f_\nu = \lambda f_\lambda \Rightarrow f_\lambda = \frac{c}{\lambda^2} f_\nu = \frac{3\times10^{18}\,\mathring{A}/s}{(5500\,\mathring{A})^2} \cdot 3.597\times10^{-28}\ erg\ s^{-1}\,cm^{-2}\,Hz^{-1}\,arcsec^{-2}$$

$$f_\lambda = \frac{3.568\times10^{-20}\ erg\ s^{-1}\,cm^{-2}\,\mathring{A}^{-1}\,arcsec^{-2}}{3.613\times10^{-12}\ erg\ ph^{-1}} = 9.874\times10^{-6}\ \frac{ph\ s^{-1}\,cm^{-2}\,\mathring{A}^{-1}}{arcsec^{-2}}$$

$$R_B = QE \cdot N_{atmos} \cdot \Delta\lambda \cdot A \cdot f_\lambda$$

$$= 0.7(2.5^{0.2})^{-1} \cdot 880\,\mathring{A} \cdot \pi(115\,cm)^2 \cdot 9.874\times10^{-6}\ ph\ s^{-1}\,cm^{-2}\,\mathring{A}^{-1}\,arcsec^{-2}$$

$$= 210.392\ ph\ s^{-1}\,arcsec^{-2}$$

$\Rightarrow$ for new moon,

$$R_B = 0.7(2.5^{0.2})^{-1} \cdot 880\,\mathring{A} \cdot \pi(115\,cm)^2 \cdot 1.565\times10^{-6}\ ph\ s^{-1}\,cm^{-2}\,\mathring{A}^{-1}\,arcsec^{-2}$$

$$= 33.345\ ph\ s^{-1}\,arcsec^{-2}$$

platescale:

$$F = R \cdot D = 2.1 \cdot 2.3\,m = 4.83\,m \cdot \frac{10^6\,\mu m}{1\,m} = 4.83 \times 10^6\,\mu m$$

$$s = \frac{206265}{F} = \frac{206265}{4.83 \times 10^6\,\mu m} = 0.0427\ \text{arcsec}/\mu m$$

one pixel subtends:

$$\text{pix} = 13.5\,\mu m \cdot 0.0427\ \text{arcsec}/\mu m = 0.577\ \text{arcsec}$$

$$\text{FWHM} \sim \frac{1.1''}{0.577''} = 1.9\ \text{pix} \Rightarrow N_{pix} = 4\ \text{pix}$$

pixel subtends:

$$(0.577'')^2 = 0.332\ \text{arcsec}^2$$

$\Rightarrow$ full moon $R_B = 210.392\ \text{ph}\,s^{-1}\,\text{arcsec}^{-2} \cdot 0.332\ \text{arcsec}^2\,\text{pix}^{-1}$
$= 69.928\ \text{ph}\,s^{-1}\,\text{pix}^{-1}$

new moon $R_B = 33.345\ \text{ph}\,s^{-1}\,\text{arcsec}^{-2} \cdot 0.332\ \text{arcsec}^2\ \text{pix}^{-1}$
$= 11.083\ \text{ph}\,s^{-1}\,\text{pix}^{-1}$

full moon:

$$\frac{S}{N} = \frac{42.872\ \text{ph}\,s^{-1}\,t}{\sqrt{(42.872\,t) + 4(69.928\,t + 0 + 4.5)}} \Rightarrow t \sim 29.78\ \text{min}$$

new moon :

$$\frac{S}{N} = \frac{42.872 \text{ ph s}^{-1}\, t}{\sqrt{(42.872\, t) + 4(11.083t + 0 + 4.5)}} \Rightarrow t \sim 8.44 \text{ min}$$

full moon exposure takes a lot longer than the new moon one which makes sense as the full moon is much brighter than our object

$\Rightarrow$ we are background limited ... ?

(in the notes the background limited case doesn't include N_R^2)

6. KECK : imager $QE = 0.8$ used for obj with
$S/N = 50$ in $t = 10$ min in narrowband filter of $50\,\text{Å}$

WIRO : $t = ?$ to get $S/N = 50$ with $QE = 0.95$
in broadband V filter

assume source limited case :

$$\frac{S}{N} = \frac{R_s t}{\sqrt{R_s t}} = \sqrt{R_s t}$$

KECK : $50 = \sqrt{R_s \cdot 600\,s}$

$$50^2 = R_s \cdot 600\,s$$

$$R_s = \frac{2500\ ph}{600\,s} = 4.167\ ph\,s^{-1}$$

$$R_s = QE \cdot \Delta\lambda \cdot A \cdot f_\lambda$$

$$f_\lambda = \frac{4.167\ ph\,s^{-1}}{0.8\,(50\,\text{Å})\,\pi(500\,cm)^2} = 1.326 \times 10^{-7}\ ph\,s^{-1}\,cm^{-2}\,\text{Å}^{-1}$$

↳ assuming I can just use the same flux

WIRO :

$$R_s = QE \cdot \Delta\lambda \cdot A \cdot f_\lambda$$

$$= 0.95\,(880\,\text{Å})\,\pi(115\,cm)^2\,(1.326 \times 10^{-7}\ ph\,s^{-1}\,cm^{-2}\,\text{Å}^{-1})$$

$$= 4.607\ ph\,s^{-1}$$

$$50 = \sqrt{4.607\,t} \Rightarrow t \sim 9.04\ min$$