Worksheet 4 Solutions

1. **How skinny?** In this class we make frequent use of the "Skinny Angle Theorem," which states $\sin\theta \approx \theta$. How large can θ be for this approximation to be good to 1%, i.e. $(\sin\theta - \theta)/\sin\theta < 0.01$? Express your answer in radians, in degrees, and in arcseconds. Can you think of an astronomical measurement of an angle for which the Skinny Angle Theorem is a poor approximation?

   Using a tool like Desmos (Mathematica seems to struggle with solving this equation), we find:

$$\left|\frac{\sin\theta - \theta}{\sin\theta}\right| < 0.01 \implies -0.244 < \theta < 0.244 \tag{1}$$

   We are interested in positive angles, so we focus on $0 < \theta < 0.244$. This is in radians, so converting units:

$$\theta < 0.244\,\text{rad} \tag{2}$$

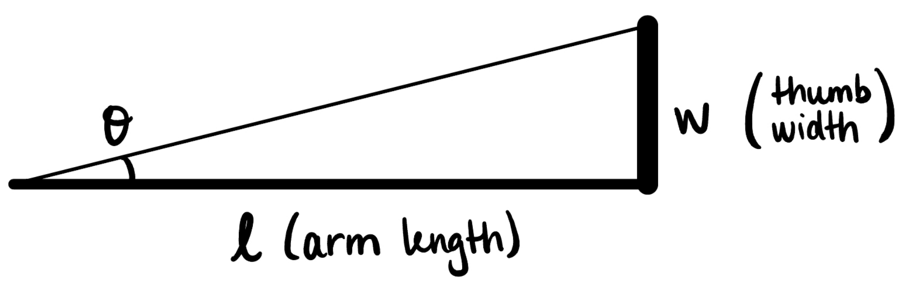
$$= 0.244\,\text{rad}\left(\frac{360^\circ}{2\pi\,\text{rad}}\right) \approx 14.0^\circ \tag{3}$$

$$= 14.0^\circ\left(\frac{60 \times 60\,\text{arcsec}}{1^\circ}\right) \approx \boxed{50300\,\text{arcsec}} \tag{4}$$

   This means that the Skinny Angle Theorem applies in basically all astronomical situations.

2. **The Rule of Thumb** states that your thumb at arm's length subtends a degree.

   (a) Verify this rule by measuring various arms and thumbs with the tape measures provided. How precise are your thumb angle measurements? Is there a better finger to use?

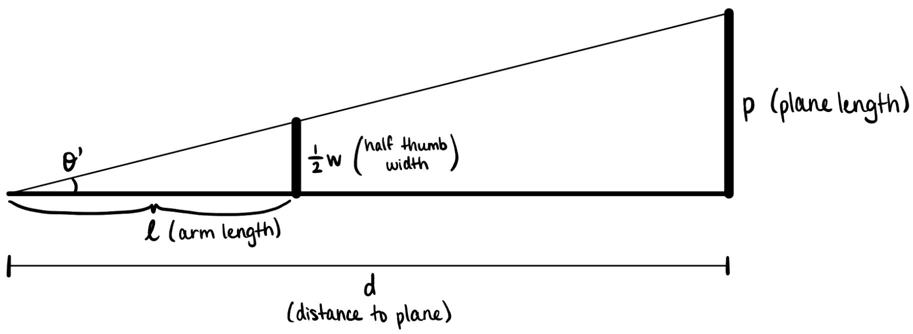


   Let's say your arm length is $\ell = 65\,\text{cm}$ and your thumb width is $w = 1.8\,\text{cm}$ (everyone's measurements will be a bit different, and you can also average your group's measurements). Then, using the Skinny Angle Theorem, the angle subtended by your thumb at arm's length is:

$$\theta = \frac{w}{\ell} = \frac{1.8\,\text{cm}}{65\,\text{cm}} \approx 0.0277\,\text{rad}\left(\frac{360^\circ}{2\pi\,\text{rad}}\right) \approx \boxed{1.6^\circ} \tag{5}$$

   Some people find a value closer to 1° using a smaller finger like their pinky. If you wanted to think about precision: How similar are your angles calculated for each member of your group? How much do the largest/smallest angles vary from the angle calculated using the average of each measurement? Accuracy, on the other hand, asks how close your result is to the "correct" answer of 1°.

(b) You spot a large airliner in the sky that subtends half of your thumb's width at arm's length. How high up, in feet, is it flying? Work with your group members to come up with good order-of-magnitude estimates for various dimensions.

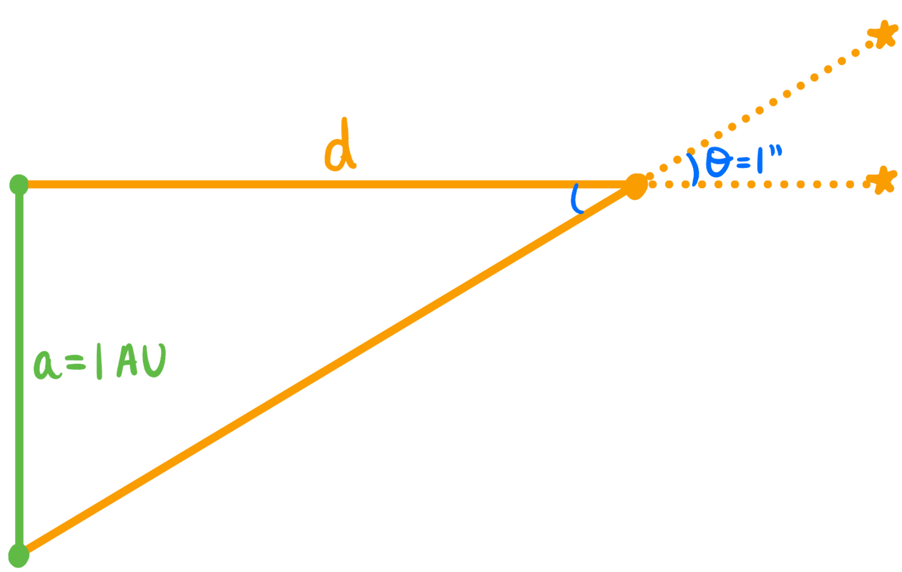


Let's estimate that the length of the airliner is $p = 100\,\text{m} = 10^4\,\text{cm}$. Applying the Skinny Angle Theorem:

$$\theta' = \frac{\frac{1}{2}w}{\ell} = \frac{p}{d} \implies \frac{1}{2}wd = p\ell \implies d = \frac{2p\ell}{w} = \frac{2(10^4\text{cm})(65\,\text{cm})}{1.8\,\text{cm}} \approx 7.2\times10^5\,\text{cm} = \boxed{7.2\,\text{km}} \quad (6)$$

3. **What is a parsec?** One commonly used tool used to measure the distance to a star is "trigonometric parallax." This works by measuring the angular distance a star appears to move with respect to a background field of much more distant stars as the Earth moves one quarter of an orbit, i.e. as the Earth translates a distance $a = 1$ AU. The movement being purely perpendicular to the line of sight ("sideways") is a good approximation since 1 AU $\ll$ 1 pc.

(a) There are 60 arcminutes in a degree and 60 arcseconds in an arcminute. What is the distance, measured in cm and light years, of a star that moves by 1 arcsecond when the Earth moves by 1 AU? This is a "parsec" (Get it? A **par**allax of 1 arc**sec**!).



Using the Skinny Angle Theorem:

$$d = \frac{a}{\theta\,[\mathrm{rad}]} \tag{7}$$

We need to convert arcseconds to radians:

$$1'' = (1'')\frac{1'}{60''}\frac{1^\circ}{60'}\frac{\pi\,\mathrm{rad}}{180^\circ} \approx \frac{1}{206265}\,\mathrm{rad} \tag{8}$$

$$\theta = 1'' \implies \theta\,[\mathrm{rad}] = \frac{1}{206265} \tag{9}$$

We also need to convert AU to cm and ly:

$$a = 1\,\mathrm{AU} \approx 1.5 \times 10^{13}\,\mathrm{cm} \tag{10}$$

$$1\,\mathrm{ly} \approx 9.5 \times 10^{17}\,\mathrm{cm} \tag{11}$$

Then:

$$d = 206265(1\,\mathrm{AU}) = 206265(1.5 \times 10^{13}\,\mathrm{cm}) \approx \boxed{3.1 \times 10^{18}\,\mathrm{cm}} \tag{12}$$

$$= (3.1 \times 10^{18}\,\mathrm{cm})\frac{1\,\mathrm{ly}}{9.5 \times 10^{17}\,\mathrm{cm}} \approx \boxed{3.3\,\mathrm{ly}} \tag{13}$$

$$\equiv 1\,\mathrm{pc} \tag{14}$$

(b) Give a general formula relating the distance, d, measured in parsecs, to the angle, θ, measured in arcseconds.

If we use the approach from part (a) but do not convert the units of arcseconds and AU, we see:

$$1\,\mathrm{pc} = \frac{1\,\mathrm{AU}}{1''} \implies d\,[\mathrm{pc}] = \frac{a\,[\mathrm{AU}]}{\theta\,['']} \tag{15}$$

(c) How many AU are in a parsec? Is our assumption that 1 AU $\ll$ 1 pc valid?

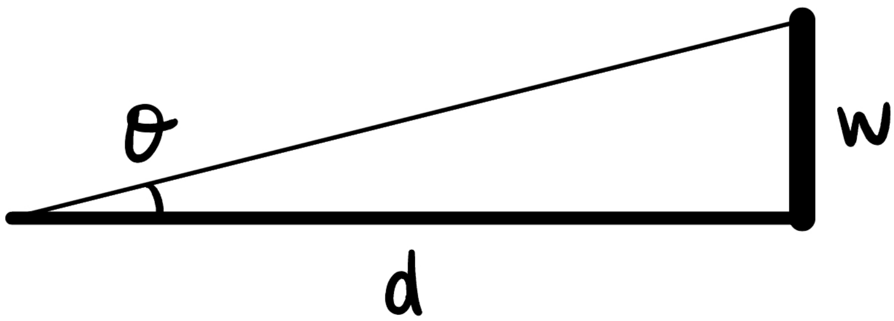
In part (a), eqn. 12, we saw that $1\,\mathrm{pc} = 206265\,\mathrm{AU}$, so the assumption that $1\,\mathrm{AU} \ll 1\,\mathrm{pc}$ is valid.

(d) The *Gaia* mission is a satellite-based survey to measure parallaxes for roughly 10^9 sources in the Galaxy, with a astrometric precision of about 10 μas (micro-arcseconds), for apparent magnitudes down to about $m_d = 14$. What maximum distance does this correspond to?

Assume Gaia measures parallax angles over a translational distance of $a = 1\,\mathrm{AU}$. The maximum distance d_{max} corresponds to the minimum parallax angle that Gaia can measure, $\theta_{min} = 10\,\mu\mathrm{as} = (10^{-5})''$. Applying our result from part (b):

$$d_{max}\,[\mathrm{pc}] = \frac{a\,[\mathrm{AU}]}{\theta_{min}\,['']} = \frac{1}{10^{-5}} = 10^5 \implies d_{max} = \boxed{10^5\,\mathrm{pc}} \tag{16}$$

(e) Let's get a sense of scale for *Gaia*'s precision. How far away from your thumb would you need to be for it's width to subtend an angle of 10 μas? What is an object that has this angular size when viewed from the opposite side of this classroom? Use the Orders of Magnitude page on Wikipedia to find things to compare these distances and sizes to.



We know:

$$d = \frac{w}{\theta\,[\text{rad}]} \tag{17}$$

From problem 2b, the width of a thumb is $w_{thumb} = 1.8\,\text{cm}$. Assume that the length of the classroom is $d_{class} = 10\,\text{m} = 10^3\,\text{cm}$.

For the first part of this question, we are given $\theta = 10\,\mu\text{as}$ and $w = w_{thumb}$, and we want to find d. From eqn. 8 in part (a), the conversion between arcseconds and radians is $1'' = \frac{1}{206265}$ rad, so:

$$\theta = 10\mu\text{as} = (10^{-5})'' = \frac{10^{-5}}{206265}\,\text{rad} \tag{18}$$

Then, using eqn. 17:

$$d = \frac{1.8\,\text{cm}}{\frac{10^{-5}}{206265}} = 1.8(10^5)(206265)\,\text{cm} \approx 3.7 \times 10^{10}\,\text{cm} \tag{19}$$

This is close to the distance to the moon, 3.8×10^{10} cm.

For the second part of the question, we are given $\theta = 10\,\mu\text{as} = \frac{10^{-5}}{206265}$ rad and $d = d_{class}$, and we want to find w. Using eqn. 17:

$$w = 10^3\,\text{cm}\left(\frac{10^{-5}}{206265}\right) \approx \boxed{4.8 \times 10^{-8}\,\text{cm}} \tag{20}$$

X-rays have wavelengths of $\sim 0.01 - 10\,\text{nm}$, so our calculated width of $4.8 \times 10^{-8}\,\text{cm} = 0.48\,\text{nm}$ is in the X-ray wavelength range.

4. **Distance modulus**: Consider the flux, F_{10}, of an astronomical object with bolometric luminosity, L, located at a distance $d = 10$ pc from the Earth.

(a) Compare F_{10} to the flux, F_d, of that same object measured at an arbitrary distance, d.

In general, the flux from an object with luminosity L at a distance d is $F = \frac{L}{4\pi d^2}$, so:

$$\frac{F_{10}}{F_d} = \frac{\frac{L}{4\pi(10\,\text{pc})^2}}{\frac{L}{4\pi d^2}} = \left(\frac{d}{10\,\text{pc}}\right)^2 \tag{21}$$

(b) Relate the flux ratio to the magnitude difference, $m_d - m_{10}$, where m_{10} is the *absolute magnitude* of the object, and m_d is the *apparent magnitude*.

From the definition of magnitude:

$$\frac{F_{10}}{F_d} = 10^{0.4(m_d - m_{10})} \tag{22}$$

(c) Express $\Delta m = m_d - m_{10}$ as a function of distance (we're no longer interested in fluxes). This is known as the "distance modulus" of the object, which is a proxy measurement for distance commonly used by astronomers.

Substituting the result from part (a):

$$\left(\frac{d}{10\,\mathrm{pc}}\right)^2 = 10^{\Delta m} \tag{23}$$

Taking the log of both sides:

$$2\log\left(\frac{d}{10\,\mathrm{pc}}\right) = 0.4\Delta m \tag{24}$$

$$\Delta m = \frac{2}{0.4}\log\left(\frac{d}{10\,\mathrm{pc}}\right) = 5\left(\log\left(\frac{d}{1\,\mathrm{pc}}\right) - \log 10\right) = 5\log\left(\frac{d}{1\,\mathrm{pc}}\right) - 5 \tag{25}$$

Here $d/(1\,\mathrm{pc})$ indicates that the distance is measured in units of parsecs.

(d) To what distances, d, do distance moduli of $\Delta m = \{0, 1, 5, 10\}$ correspond?

Re-arranging the result from part (c), eqn. 24:

$$\log\left(\frac{d}{10\,\mathrm{pc}}\right) = 0.2\Delta m \tag{26}$$

$$\frac{d}{10\,\mathrm{pc}} = 10^{0.2\Delta m} \tag{27}$$

$$d = (10\,\mathrm{pc})10^{0.2\Delta m} \tag{28}$$

Plugging in the given Δm values, we get $d = \boxed{\{10, 15.8, 100, 1000\}\,\mathrm{pc}}$.

5. **The distance to a neighbor's place**: α Centauri A (α Cen A) is a star with a luminosity $L_\star = 1.5L_\odot$ and an apparent magnitude of $m_{d,A} = -0.3$. The Sun has an absolute magnitude, $m_{10,\odot} = 4.8$.

(a) What is the distance, in parsecs, to α Cen A?

Using the result from part (d):

$$d = (10\,\mathrm{pc})10^{0.2(m_{d,A} - m_{10,A})} \tag{29}$$

We have a value for $m_{d,A}$, but we need $m_{10,A}$. From the definition of magnitude:

$$10^{0.4(m_{10,A} - m_{10,\odot})} = \frac{F_{10,\odot}}{F_{10,A}} = \frac{\frac{L_\odot}{4\pi(10\,\mathrm{pc})^2}}{\frac{L_A}{4\pi(10\,\mathrm{pc})^2}} = \frac{L_\odot}{L_A} \tag{30}$$

$$0.4(m_{10,A} - m_{10,\odot}) = \log\frac{L_\odot}{L_A} \tag{31}$$

$$m_{10,A} = m_{10,\odot} + 2.5\log\frac{L_\odot}{L_A} \tag{32}$$

Plugging this into eqn. 29:

$$d = (10\,\mathrm{pc})10^{0.2\left(m_{d,A} - m_{10,\odot} - 2.5\log\frac{L_\odot}{L_A}\right)} = (10\,\mathrm{pc})10^{0.2\left(-0.3 - 4.8 - 2.5\log\frac{L_\odot}{1.5L_\odot}\right)} \approx \boxed{1.2\,\mathrm{pc}} \tag{33}$$

(b) What is α Cen A's distance modulus?

By definition:

$$\Delta m = m_{d,A} - m_{10,A} \tag{34}$$

Plugging in eqn. 32:

$$\Delta m = m_{d,A} - m_{10,\odot} - 2.5 \log \frac{L_\odot}{L_A} = -0.3 - 4.8 - 2.5 \log \frac{L_\odot}{1.5 L_\odot} \approx \boxed{-4.7} \tag{35}$$

(c) What is the absolute magnitude of α Cen A?

Because we previously solved symbolically, we can refer to eqn. 32:

$$m_{10,A} = m_{10,\odot} + 2.5 \log \frac{L_\odot}{L_A} = 4.8 + 2.5 \log \frac{L_\odot}{1.5 L_\odot} \approx \boxed{4.4} \tag{36}$$

(d) α Cen A is part of a triple system, along with α Cen B and Proxima Cen. α Cen B has an apparent magnitude of $m_{d,B} = 1.3$. What is its luminosity compared to the Sun?

From the definition of magnitude:

$$10^{0.4(m_{d,A} - m_{d,B})} = \frac{F_{d,B}}{F_{d,A}} = \frac{\frac{L_B}{4\pi d^2}}{\frac{L_A}{4\pi d^2}} = \frac{L_B}{L_A} \tag{37}$$

$$L_B = L_A 10^{0.4(m_{d,A} - m_{d,B})} = 1.5 L_\odot 10^{0.4(-0.3-1.3)} \approx \boxed{0.34\, L_\odot} \tag{38}$$

(e) Proxima Cen has an apparent magintude of $m_{d,P} = 11$. What is its luminosity compared to the Sun?

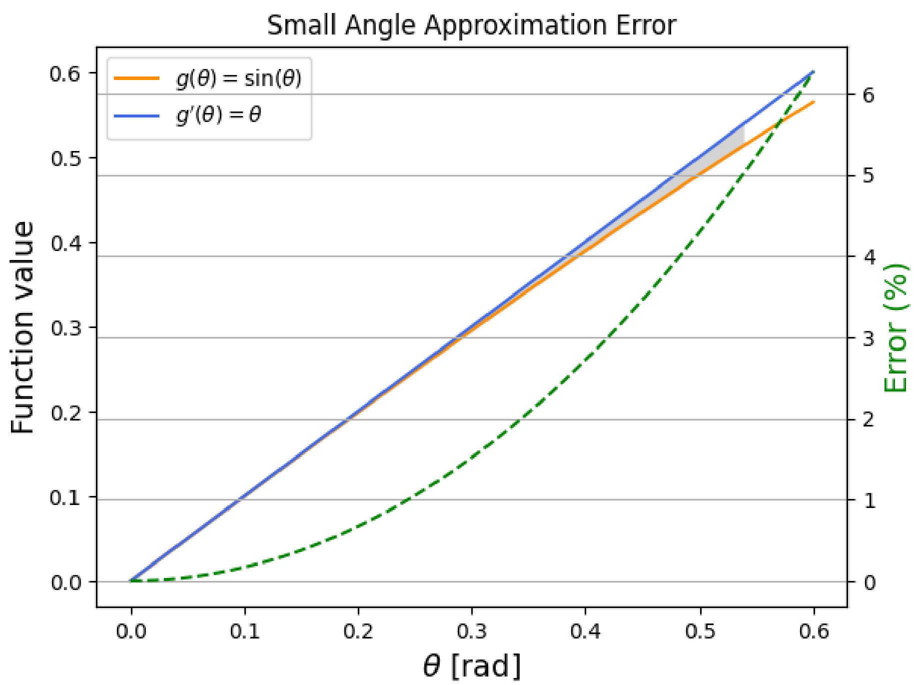
As in part (d):

$$L_P = L_A 10^{0.4(m_{d,A} - m_{d,P})} = 1.5 L_\odot 10^{0.4(-0.3-11)} \approx \boxed{4.5 \times 10^{-5}\, L_\odot} \tag{39}$$

Homework Questions:

1. **Coding Practice:** Use Python to create a figure comparing $g(\theta) = \sin\theta$ to the small-angle approximation of $g'(\theta) = \theta$. For what range of θ does $g'(\theta) = g(\theta)$ to within 5%? Describe your methodology and thinking in your blog post, and of course include your figure.

   This question is asking us to evaluate how large θ can be for the small angle approximation to be good to 5%, i.e. $\left|\frac{(\sin\theta - \theta)}{\sin\theta}\right| < 0.05$.



We are only interested in positive angles, so we focus approximately on $\boxed{0 < \theta < 0.54 \text{ radians}}$.

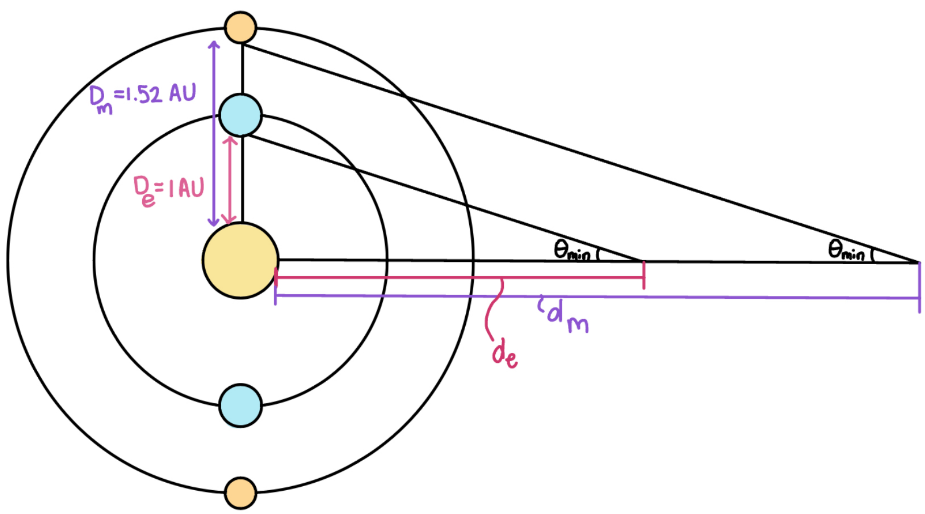
```python
import numpy as np
import matplotlib.pyplot as plt

# Define simple functions
def g(theta):
    return np.sin(theta)
def gprime(theta):
    return theta

# Define a range of theta values (play around with this)
theta_values = np.linspace(1e-6, 0.6, 200)

# Calculate the function values
g_values = g(theta_values)
gprime_values = gprime(theta_values)

# Calculate the percentage error between g(theta) and g'(theta)
error_values = np.abs((g_values - gprime_values) / g_values) * 100

# Find the range of theta where g'(theta) = g(theta) to within 5%
condition = error_values <= 5  # 5% error threshold
within_5_percent = theta_values[condition]
percent_range = (within_5_percent.min(), within_5_percent.max())

# Plot functions and error curve
fig, ax1 = plt.subplots()
ax1.plot(theta_values, g_values, label='$g(\\theta) = \\sin(\\theta)$',color='darkorange')
ax1.plot(theta_values, gprime_values, label="$g'(\\theta) = \\theta$",color='royalblue')
ax1.fill_between(theta_values, g_values, gprime_values, where=error_values <= 5, color='lightgray')
ax1.set_xlabel('$\\theta$ [rad]',fontsize=14)
ax1.set_ylabel('Function value',fontsize=14)
ax1.set_title('Small Angle Approximation Error')
```

```python
ax1.legend()
ax2 = ax1.twinx()
ax2.plot(theta_values, error_values, linestyle='--', color='green', label='Error
    between $g(\\theta)$ and $g\'(\\theta)$')
ax2.set_ylabel('Error (%)', color='green',fontsize=14)  # Labeling error axis with
    percentage
ax2.tick_params(axis='y', labelcolor='black')
print("Range of theta where error is within 5%:", percent_range)
plt.grid(True)
plt.show()
```

2. Compare the maximum measurable distance if you conduct a parallax survey from Mars with the same limiting parallax angle, θ_{min}, as an identical survey conducted from the Earth.

   Let d_e be the maximum distance we can measure in the Earth based survey and d_m be the maximum distance we can measure in the Mars based survey. Each survey has the same limiting parallax angle θ_{min} but differ in baseline distance: $D_e = 1$ AU and $D_m \approx 1.5$ AU. We can compare d_m to d_e:

$$\frac{d_m}{d_e} = \frac{\frac{D_m}{\theta_{min}}}{\frac{D_e}{\theta_{min}}} = \frac{D_m}{D_e} = \boxed{1.5} \tag{40}$$



   Since the baseline of Mars's orbit ($D_m \approx 1.5$ AU) is larger than that of Earth's orbit ($D_e = 1$ AU), a Mars based survey will be able to measure a 1.5× farther distance for the same limiting parallax angle.

3. In addition to the α Cen triple system, there's another nearby red dwarf called Barnard's Star at a distance of 1.8 pc from the Sun.

   (a) Use the three stars in the α Cen system plus Barnard's Star and the Sun to estimate the number density of stars in the Galaxy, $n_\star$, under the assumption that the Galaxy contains a uniform density of stars.

   There are $N_* = 5$ stars are within a radius of $R = 1.8$ pc. Assuming that the Galaxy contains a uniform density of stars, the number density within a sphere of radius 1.8 pc will be a good overall estimate for the Galaxy.

$$n_* = \frac{N_*}{V} = \frac{5}{\left(\frac{4\pi(1.8)^3}{3}\right)} \approx \boxed{2 \times 10^{-1}\ \text{pc}^{-3}} \tag{41}$$

(b) If you conduct a parallax survey with a precision of 0.001 arcseconds, how many stars will you measure distances to?

The precision of a parallax survey determines the limiting parallax angle, or the smallest parallax angle that can be accurately measured by the survey. Recall that 1 parsec is defined as the distance when a baseline of 1 AU subtends a parallax angle of 1 arcsecond. Let $a = 1$ AU be the baseline distance, $\theta_{min} = 0.001$ as and maximum distance d (in pc) be:

$$d_{max} = \frac{a}{\theta_{min}} = \frac{1 \text{ AU}}{0.001 \text{ as}} = 10^3 \text{ pc} \tag{42}$$

To determine how many stars we can measure distances to within a sphere of radius d, we can use the equation from part (a):

$$N_* = n_* V = 2.04 \times 10^{-1} \cdot \frac{4\pi(1000)^3}{3} \approx \boxed{9 \times 10^8 \text{ stars}} \tag{43}$$

(c) What will be the apparent magnitude of the faintest Sun-like stars you will observe ($m_{10,\odot} = 4.8$)?

Let $m_{d_{max},\odot}$ be the apparent magnitude of the faintest Sun-like stars we can observe at a maximum distance $d_{max} = 1 \times 10^3$ pc. We can use the distance modulus equation:

$$m_{d_{max},\odot} - m_{10,\odot} = 5 \log d_{max} - 5 \tag{44}$$

Plugging in, we get:

$$\boxed{m_{d_{max},\odot} \approx 15} \tag{45}$$

4. SN 1604, also known as Kepler's Supernova, is a Type Ia supernova that occurred in our galaxy in the year 1604. At its peak brightness it reached an apparent magnitude of $m_d = -2.5$ and was visible to the naked eye during the day! Type Ia supernovae are useful because they all have about the same absolute magnitude, m_{10}, when they reach maximum brightness.

(a) Look up the typical value of the absolute magnitude of a type Ia supernova, and use this to give an estimate for the distance to SN 1604, measured in parsecs.

At its brightest, a typical Type Ia supernova (SN Ia) reaches an absolute visual magnitude of -19.5. In #4c of the worksheet we derived an expression for the distance modulus, where $\Delta m = m_d - m_{10}$:

$$\Delta m = 5 \log d - 5 \tag{46}$$

Solving for distance in #4d we arrived at:

$$d = 10 \text{ pc} \cdot 10^{\frac{\Delta m}{5}} \tag{47}$$

Plugging in $m_d = -2.5$ and $m_{10,SN} = m_{10} = -19.5$ we get:

$$\boxed{d \approx 2.5 \times 10^4 \text{ pc}} \tag{48}$$

(b) What is the parallax of SN 1604?

Parallax is inversely proportional to the distance to the object. Since the Type Ia supernovae is so far away, the parallax is essentially zero:

$$p = \frac{1AU}{2.5 \times 10^4 \text{ pc}} \approx \boxed{4 \times 10^{-5} \text{ arcseconds}} \quad (49)$$

(c) What is the peak luminosity of SN 1604 compared to the luminosity of the Sun?

The difference in absolute magnitude is related to the luminosity ratio:

$$m_{10,SN} - m_{10,\odot} = -2.5 \log_{10} \left(\frac{L_{SN}}{L_\odot} \right) \quad (50)$$

This becomes:

$$\frac{L_{SN}}{L_\odot} = 10^{0.4(m_{10,\odot} - m_{10,SN})} \quad (51)$$

Plugging in $m_{10,\odot} = 4.83$ and $m_{10,SN} = -19.5$, we get:

$$\boxed{\frac{L_{SN}}{L_\odot} = 5.4 \times 10^9} \quad (52)$$

(d) At what distance would the apparent magnitude of a type Ia supernova exceed that of the full Moon, which has $m_d = -11$?

$$\Delta m = 5 \log d - 5$$

Substituting in the apparent magnitude of the moon, $m_d = -11$, and the absolute magnitude of a Type Ia supernova, $m_{10} = -19.5$, we get:

$$\boxed{d \approx 500 \text{ pc}}$$

Within 500 pc, the apparent magnitude of a Type Ia supernova would exceed the apparent magnitude of the full Moon.

(e) If the human eye has a limiting magnitude of 7, estimate the limiting magnitude of the Keck telescope, which has a aperture diameter of 10 meters. Then, estimate the maximum distance to which the Keck telescope can observe a Type Ia supernova.

Let $m_{eye} = 7$, $D_{eye} = 4$ mm, $D_{Keck} = 1 \times 10^4$ mm and m_{Keck} is unknown. We have the following relationship between F_{eye} and F_{Keck}:

$$\frac{F_{eye}}{F_{Keck}} = 10^{0.4(m_{Keck} - m_{eye})} \quad (53)$$

Solving for m_{Keck}:

$$m_{Keck} = m_{eye} + \frac{5}{2} \log_{10} \left(\frac{F_{eye}}{F_{Keck}} \right) \quad (54)$$

The amount of light gathered by a telescope is proportional to its collecting area: $\frac{\pi D^2}{4}$. The brightness of a star for telescope 1 compared with that star's brightness for telescope 2 is then equal to: D_1^2/D_2^2. For this case:

$$\frac{D_{Keck}^2}{D_{eye}^2} = 6.25 \times 10^4 \quad (55)$$

Let F_{eye} corresponds to the limiting magnitude of the naked eye. Since the Keck telescope has 6.25×10^4 times more collecting area, a star with a flux of $F_{eye}/6.25 \times 10^4$ will appear just as bright to Keck as F_{eye} did to our unaided eyes. Thus, the faintest source Keck can see has a flux of $F_{Keck} = F_{eye}/(6.25 \times 10^4)$ or:

$$\frac{F_{eye}}{F_{Keck}} = 6.25 \times 10^4 \tag{56}$$

Plugging this into equation 13:

$$\boxed{m_{Keck} \approx 19} \tag{57}$$

For the next part, we are asking at what distance would the apparent magnitude of a Type Ia supernova be equal to the limiting magnitude for the Keck telescope. Using Equation 12 we have:

$$d = 10 \text{ pc} \cdot 10^{(m_{Keck} - m_{10})/5} \approx \boxed{5 \times 10^8 \text{ pc}} \tag{58}$$

(f) How might type Ia supernovae be useful for measuring the distances to objects outside of the Milky Way Galaxy?

When we observe type Ia supernovae, we can measure its apparent magnitude and since they all have about the same absolute magnitude, m_{10}, when they reach maximum brightness we can then use the distance modulus to calculate the distance to the supernova. Type Ia supernovae are used as so-called standard candles to measure the distance to their host galaxies. Type Ia supernovae can be used to measure distances from about 1 Mpc to over 1000 Mpc and serves as the next rung in the distance ladder after parallax.