

PHYS 1040: Solution

Assignment #3, Spring 2008

1: I have to get away!

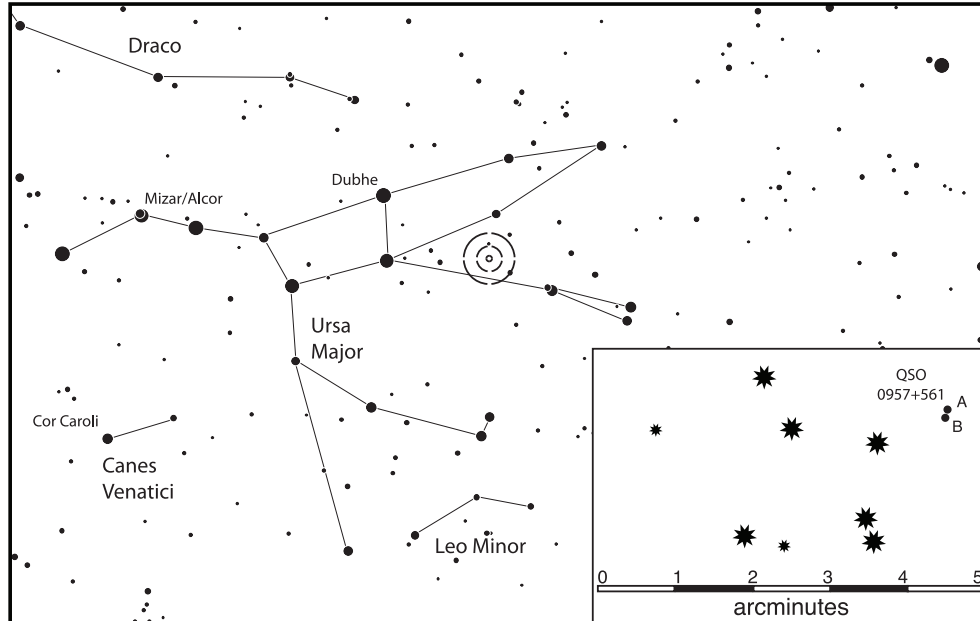
In astronomy, *escape velocity* is the speed you must attain in order to escape the gravitational pull of a massive object. The more massive the object, the higher the escape velocity. For Earth, the escape velocity is about 11 km/s. For the Sun, the escape velocity is about 618 km/s. For an object like a *black hole*, the escape velocity is the speed of light, $v = 3.0 \times 10^8$ m/s.

In Hollywood movies, escape velocity is the speed you must attain to escape pursuers. In the greatest movie of all time, *The Empire Strikes Back*, the *Millennium Falcon* must jump to lightspeed to escape Imperial Star Destroyers. In this case, the escape velocity is also the speed of light. :-)

2: Quasar, Quasar, So Far Away!

The most obvious indication that the quasars are extremely far away is their large redshifts. Using current cosmological models, the large redshift tells us that the recessional velocity of the quasars is so large they must be a large fraction of the distance to the edge of the observable Universe. Astronomers say “they are deep in the Hubble flow.”

If one is unwilling to accept that redshifts are great indicators of distance (for instance, because you are a traditional astronomer from the late 1800s, or you just don't believe anything Shane tells you on principle), the distance to the quasars is also implied by gravitational lensing. Many quasars (for example, the classic *Double Quasar* QSO 0957+561 in Ursa Major¹, shown below) lie behind massive galaxies, which divide the quasar light into multiple images. For the quasar to be lensed, it must lie at a distance much greater than the distance to the galaxy.



¹This quasar can be seen in 20" amateur telescopes from dark sky sites.

3: Radio wavelengths!

The Larson Radio Telescope is the premiere instrument for radio astronomy along the Wasatch Front (when it gets built! Until then, the Weber State University Radio Telescope is it).

To determine the wavelength of radio light, we remember that all light travels at the speed of light, so if I know the frequency f , then the wavelength λ can be found from the speed of light c :

$$c \simeq \lambda \cdot f \quad \rightarrow \quad \lambda = \frac{c}{f} .$$

The values we need to use are:

$$\begin{aligned} c &= 3.0 \times 10^8 \text{ m/s} && \text{speed of light} \\ f &= 1.5 \times 10^9 \text{ Hz} && \text{frequency of radio light} \end{aligned}$$

Putting this all together:

$$\lambda = \frac{3.0 \times 10^8 \text{ m/s}}{1.5 \times 10^9 \text{ Hz}} = 0.2\text{m}$$

Note that radio light has long wavelengths, on sizes you can see with your eye! This is why radio antennae (like the one on your car) are the size they are – they are close in size to the wavelength of the radio light they are trying to receive.

4: My science officer is a Blockhead!

Clearly the science officer aboard the *USS Intrepid* is a blockhead! Mr. Block probably should go back to Weber State University and take an astronomy class!

Tidal forces are the force an object experiences because the strength of a gravitational field (such as that being produced by a black hole) changes with distance. If you approach the black hole too closely, the field will pull more strongly on your feet than your head (if you jump in feet first) and you will be spaghettified. Far from the black hole, there are still tidal forces, but the gravitational force is weak enough that the intermolecular forces that keep your body and your starship stuck together are strong enough to keep you from being torn apart.

5: Bright, Dim, Bright, Dim, Bright, Dim...

The *Cepheid period luminosity relationship* discovered by Henrietta Swan Leavitt notes that the timescale over which the light from a Cepheid variable changes (the *period*) is directly related to the intrinsic brightness of the star (the *luminosity*).

In astronomy this is extremely useful. It means if I can measure the period of a star's brightness variations (easily done with a simple Timex watch, commonly carried by many students), you instantly have a way to determine what it's intrinsic brightness is. Measuring intrinsic brightness (often called *absolute magnitude*) in astronomy is notoriously difficult, because it depends on how far away a star is. From Earth, you observe the *apparent magnitude*, but if you know the absolute magnitude (found using the period-luminosity relationship), you can work out the true distance to the star.

6: The Observer's Perspective

The brightness of objects decreases with distance, and increases with proximity. This is a fundamental result from basic astrophysics, and one which most of you have direct experience with. Consider a flashlight. If you hold the flashlight up to your eyeball, it appears to be extremely bright (don't do this – you'll probably see some spots for sometime afterward if you do this). If you have your friend walk half a kilometer down the road with the flashlight, it will look much dimmer. The *observed brightness* of an object depends on how far away the object is.

Now consider if you have two flashlights (and two very tolerant friends, who are willing to do astronomy experiments with you). Supposed your two friends carry the flashlights half a kilometer down the road. Both flashlights appear to be dimmer than when they are close to your eyeball, but they are still *the same brightness*. One friend is easier to bribe with cookies than the other, and walks an additional distance down the road so

they are one kilometer away. Now one flashlight is dimmer than the other — clearly it is *farther away*. Or is it? Maybe it is just *dimmer* because its battery is starting to die!

So how do we know if it is just far away or if it is dimmer? To distinguish between the two cases, astronomers invented the concept of *absolute brightness*. Absolute brightness is the brightness an object (like a star or a flashlight) would have *IF* it could be placed at a known distance. Objects of the same brightness look the same when held at the same distance. More importantly, objects of different brightness look different when held at the same distance. Determining the absolute brightness of stars in astronomy is a long standing problem, and many creative methods have been discovered (most notably the Cepheid relationship discovered by Henrietta Swan Leavitt).