1 Lecture 2 and 3: Number Review/The Celestial Sphere

- Finish chapter 1 in the textbook
- Appendices 1,2
- Exercises: Do all Review and Discussion and all Conceptual Self-Test; Problems 1), 2), 3)

1.1 Number review

There will not be much math in this course, but we will need to use numbers to discuss distances scales, time, and angular measurements on the sky. Please do not fret if you have a math phobia! You will not be required to apply complicated formula or learn advanced math. What we want you to gain is a sense of scale which will allow you to make estimates without calculating anything at all.

- Scientific Notation
  - in astronomy we deal with vast scales, from the size of the atom to the size of the Universe
  - not useful to write numbers like $1,000,000,000$
  - instead, we see that we can just multiply by 10 many times, so the above number can be written as $10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$ – this still isn't too helpful, we can do better – exponents
  - the exponent tells us to multiply the base number as many times as the exponent says
  - example: 10^2 means multiply the base number, in this case 10, twice. So $10^2 = 10 \times 10 = 100$. In our previous example, we had 10 multiplied nine times, we can write the same thing as 10^9
  - 10^1 means just the number 10
  - now, consider $10^3 \times 10^5$, what do we do? Well the first part tells us to multiply 10 three times and the second one says multiply 10 five times. The multiplication sign between the two tells us to multiply the two numbers and so we have 10 multiplies eight times or $10^3 \times 10^5 = 10^8$
  - when we multiply two numbers of the same base with exponents, we just add the exponents
  - so, $10^{10} \times 10^{13} = 10^{10+13} = 10^{23}$ – it's that simple!
  - now, what happens if we have really small numbers, like $1/1,000$ or $1/10,000,000$ – we can use exponents again

  - we know that we add exponents when we multiply, so consider $10^3 \times 10^{-2}$. Adding the exponents we get $10^3 \times 10^{-2} = 10^{3-2} = 10^1 = 10$. But we know that $10^3 = 1,000$ and so 10^{-2} must equal $1/100$ – we divided by 100.
  - in other words, if we see a negative exponent, it is the same time as dividing by the base that many times
  - as an example, we see that $10^{10} \times 10^{-4} = 10^6$
  - also notice that $10^1 \times 10^{-1} = 10/10 = 10^0 = 1$ – any base (other than 0) to the exponent 0 is equal to 1 because we are just dividing the base by itself
  - as an example of scientific notation, instead of say that the speed of light is $300,000$ km/s we could say 3×10^5 km/s
  - Scientific notation will be useful in our astronomy course when we need to convert between units of length

- Stop, think, and question
  - when you need to convert between scales in this course (eg. light years to kilometres), don't blindly convert and move on – think about the answer
  - if you are asked to estimate the mass of a basketball and you come up with 10^{24} kg, you need to stop and look for your mistake (unless you happen to believe basketballs are the same size as the earth!)
  - thinking about the answer is more important than applying the mechanics to achieve it

- The power of estimation
  - in this course we will often need to estimate quantities based on some already known property
  - the technique involved is applicable to everyday life, not just PHYS 1901 or science courses – you will get a chance to practice these methods in this course
  - crude estimates can be obtained by following the exponents with multiples of 10
  - here is an example that illustrates the method: Suppose I asked you, "How many city police officers are there in Ottawa?" You might be tempted to look up the number, but you can make a quick estimate. First, always think in powers of 10 and determine the underlying quantity that sets the scale for the problem – in this case, it is the population of Ottawa – which is about 1 million people or 10^6 people. Now, we ask, how many people per police officer are there in Ottawa? Clearly 1 officer for every person is far too many. How about 10 people per officer? – still too many. How about a 10^2 people per officer? – that's better, but it seems a touch too large. How about 10^3 people per officer? – that sounds much better, and 10^4 people per officer sounds too few. So let's go with 10^3 people per officer. Given that Ottawa has 10^6 people, this means that there are (10^6 people/10^3 people per officer = 10^3 officers) – the actual number is about 1200

  - see if you can estimate the number of public school teachers in Ottawa
  - notice that in the example we did not worry about any factors 2 or 5 or any other complicated consideration – all we followed were the powers of 10
  - when estimating a quantity, determine the power of 10 that seems reasonable for intermediate quantities that you understand – if you have trouble at this step, it just means that you need to learn more about the problem
  - these techniques will come in handy in this course
  - please carefully read Appendices 1 and 2 of your textbook

1.2 The celestial sphere

- obvious view – everything goes around the earth
- ancient peoples saw patterns in the stars and made stories about them – the constellations
- the constellation are formed from distant stars that appear "projected" on to the night sky – the stars in any given constellation are at a variety of distances from us
- PROJECTION DIAGRAM
- we now know that it is the earth that moves – both around its own axis each day and around the sun in our orbit each year
- it can be helpful to retain the view that the earth is the centre of a celestial sphere – for the remainder of this class, we will take this point of view
- CELESTIAL SPHERE DIAGRAM
- imagine a powerful light source in the middle of the earth that project the lines of longitude and latitude on to the celestial
- celestial latitude – declination
- celestial longitude – right ascension
- observers can see half the celestial sphere
- points on the sky can be labelled by the celestial co-ord system
- declination $(-90°, 90°)$
- right ascension (0hr, 24hr) – we will see why right ascension is measured in hours rather than degrees shortly
- background stars appear fixed to the celestial sphere, rotate across the sky each day with the celestial sphere

- Question: How long does it take for the celestial sphere to rotate completely around? In other words, how long will it take a given star to go from its highest point in the sky and back again?
- might think that answers is 24 hours, but we need to think about this more...
- before we can answer this question, think about the sun in its orbit
- ORBIT DIAGRAM
- explains the seasons – angle of incidence key, not distance
- apparent motion of the sun over the year on the celestial sphere
- earth spins like a top with a wobble – precession, caused by gravitational effects from the moon and the sun ($26,000$ year period)
- ECLIPTIC DIAGRAM
- the sun takes one year to move around the ecliptic plane
- the constellations that the sun move through called the zodiac
- can now answer our question on how long a star takes to go around
  - sun takes one year to move around the ecliptic
  - mean solar time based on sun's highest point in the sky
  - 356 day in one year – sun moves $0.98°$ per day along the ecliptic
  - earth rotates about $1°$ in 4 mins
  - must subtract this from the 24 hour day to account for the sun's motion
  - time taken for the star to go around: 23 hours 56 minutes – called the *sidereal* day
  - ORBIT DIAGRAM DEPICTING DAILY ORBIT MOVEMENT
- same this happens with the moon – sidereal moon
- DIAGRAM OF SIDEREAL MONTH
- moon passes into the earth's shadow – lunar eclipse (reason why we know the earth is round)
- earth passes into the moon's shadow –solar eclipse (moon and sun almost the same angular size)
- ECLIPSE DIAGRAM
- MOON INCLINED ORBIT DIAGRAM

- moon's orbit inclined to the ecliptic by about 5°
- only when nodes line up with the sun can there be an eclipse
- SHOW ANIMATIONS

1.3 Angles and measurement

- Ancient Greeks, Eratosthenes, determine the earth size
- circumference of a circle $2\pi R$, 360°
- ALEXANDRIA-SYENE DIAGRAM
- $$\frac{7.2^\circ}{360^\circ} = \frac{\text{distance between cities}}{\text{Earth's circumference}}$$
- more generally
- parallax – angle subtended
- PARALLAX DIAGRAM
- $$\frac{\text{angle subtended}}{360^\circ} = \frac{\text{baseline}}{2\pi \times \text{distance}}$$
- can use these ideas to determine the size of the moon and distance to the moon
- Aristarchos recognized that the the earth's shadow from a lunar eclipse is about three times the diameter of moon – earth three times bigger than the moon
- LUNAR ECLIPSE DIAGRAM
- Alexandria-Syene measurement gives the size of the earth – measuring the angular size of the moon with this information and Aristarchos's relative size measurement gives the earth moon distance – Ancient Greeks new the distance to the moon!
- knowing the distance to the moon in principle implies the ability to calculate the earth-sun distance – in practice, not possible to get an accurate determination with the unaided eye
- EARTH-SUN DISTANCE DIAGRAM