Massachusetts Institute of Technology
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12.409 Observing Stars and Planets, Spring 2002

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Can We Observe *x* Tonight?

This is an important question to be able to answer, this being an observing subject and all. The answer to this question is "yes" only if the answer to the following 4 questions is "yes":

1.Is the weather cooperating?

2.Is *x* bright enough, given our observing equipment?

3.Is the sky dark enough?

4.Is *x* high enough above our horizon?

This handout addresses the answering of questions 2, 3, and 4, and explains how to use information published in the *Astronomical Almanac* to decide whether to go for a specific object at any given time.

As for question 1, that's a *different* class... (12.310)

Contents

1 Brightness Scale

The *magnitude* system refers to the numeric scale used by astronomers to quantify object brightness. Its rather baroque character can be traced to its origins over 2000 years ago, when the Greek scholar Hipparchus first began visually classifying stars into six brightness categories, with the brightest stars called "stars of the first magnitude", slightly fainter ones "stars of the second magnitude", and so on. When 19th century astronomers sat down to come up with some sort of mathematical expression corresponding to Hipparchus' original six magnitudes, it was discovered that the brightness of some of the stars he'd assigned magnitude 1 were actually too bright to be so classed based on the rest of his system; these brightest stars now carry magnitudes of 0 and *-1*.

Oops.

But, let's press on, shall we?

Call the *intensity* of light source n I_n, measured in $\frac{energy}{area \cdot time}$. The difference in magnitude between objects with respective intensities I_1 and I_2 is then defined as

$$\Delta m = m_2 - m_1 \equiv -2.5 \log_{10} \frac{I_2}{I_1} \quad (1)$$

This definition can be rearranged to show the admittedly non-intuitive relationship between the objects' intensities in terms of magnitudes:

$$-0.4\Delta m = \log \frac{I_2}{I_1} \;;\; 10^{-0.4\Delta m} = \frac{I_2}{I_1} \;;\; I_2 = I_1 \cdot 10^{-0.4\Delta m} \quad (2)$$

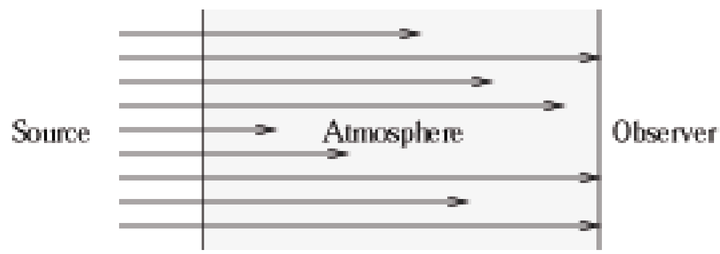
Happily, for most of our purposes here in the seminar we won't need to mess around with Equation 1 up there; a few tabulated values should prove sufficient:

Δm	**I_2/I_1**
0	1.0
1	≈2.5
2	≈6.3
2.5	10
3	≈16
4	≈40
5	100

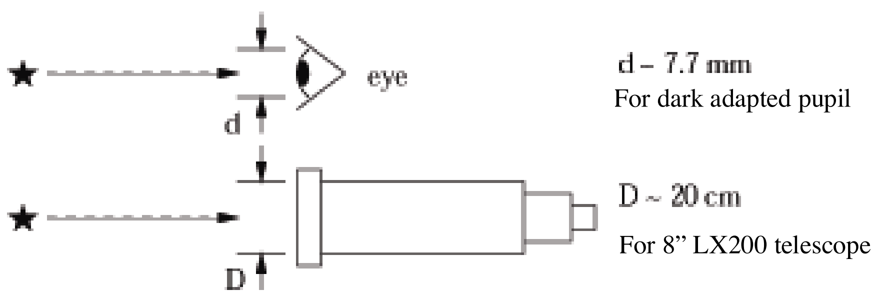
Object	**Magnitude**
Sun	-26.8
Full Moon	-13.6
Venus (at brightest)	-4.4
Jupiter	-2
Sirius (α Cma)	-1.4
Vega (α Lyr)	0.0
Uranus	+6 (naked eye limit)
quasar	+13
faintest object detected (Earth-based) (≈ glow of cigar on Moon seen from Earth)	+29

1.1 Effects on apparent brightness

1. *Extinction*: Loss of light as it passes through the atmosphere. Normal extinction on a clear night is about 0.2 mag. at the zenith and increases quickly as you start looking at lower altitudes.



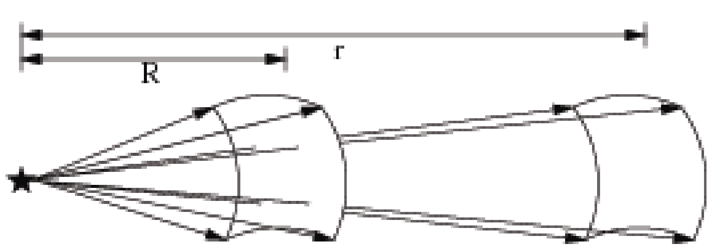
2. *Telescope:* How much does it help us? It collects an amount of light proportional to the AREA of the objective mirror, as shown in Figure 2.



How many magnitudes fainter should we be able to see (theoretically) with the LX200, under IDEAL conditions (clean and otherwise perfect optics, ...)?

$$\frac{I_2}{I_1} = \frac{A_{telescope}}{A_{eye}} \tag{3}$$

3. Effect of *distance* on apparent brightness is known as the "inverse square law." The changing brightness of Mars is due mostly due to its changing distance as it orbits the Sun. This also contributes to changes in brightness of Venus (along with phase, the amount of the disk that we see illuminated by the Sun).



$$I_r = I_R \frac{R^2}{r^2}$$

Here's how the change, in magnitudes, depends on distance --- if an object with distance *R* away from an observer appears to be magnitude *M,* then from a different distance *r* the same object would appear to be magnitude *m* according to

$$\begin{aligned} m - M &= \Delta m \\ &= -2.5\log\frac{I(r)}{I(R)} \\ &= -2.5\log\left(\frac{I(R)\cdot R^2/r^2}{I(R)}\right) \\ &= -2.5\log\left(\frac{R^2}{r^2}\right) \\ &= -5\log\frac{R}{r} \end{aligned} \tag{4}$$

This last form of the equation is commonly known as the distance modulus.

2 Coordinate Systems

2.1 Terrestrial coordinates

latitude (ϕ): + north / - south of the equator (range: $-90° < \phi < 90°$)

longitude (λ): +east / - west of the Prime Meridian at Greenwich, UK where:
$\lambda = 0^\circ\ 00'\ 00'' = 0^h\ 00^m\ 00^s$ (range: $-180° < \lambda < 180°$ although sometimes you might see $0 < \lambda < 360°$).

[the ' and " are ARC MINUTES and ARC SECONDS.]
[the h, m and s are HOURS, MINUTES and SECONDS OF TIME.]

This sign convention is known as “east longitude”, the currently-adopted standard for usage in astronomy. (Watch out when using older references though, which may have used the opposite sign convention, “west longitude”). The rest of this handout assumes use of east longitude.

Examples of notation and useful coordinates:

- MIT Campus:
  $\phi = +42^\circ\ 21'\ 38'' = +42^\circ.3606$
  $\lambda = -71^\circ\ 05'\ 36'' = -71^\circ.0933 = -4^h.73956 = -4^h\ 44^m\ 22^s.4$
  for the LX200 which uses only positive longtitude in degrees:
  $\lambda = 288^\circ\ 54'\ 24'' = 288^\circ.9067$

- Wallace Observatory, in Westford, MA:
  $\phi = +42^{o}\ 36'.6 = +42^{o}.610$
  $\lambda = -71^{o}\ 29'.1 = -71^{o}.485 = -4^{h}.7657 = -4^{h}\ 45^{m}\ 56^{s}$
  for the LX200 which uses only positive longtitude in degrees:
  $\lambda = 288°\ 30'\ 54'' = 288°.515$

2.2 Celestial coordinates

declination ("Dec", δ): + north / - south of the *celestial equator*

right ascension ("RA", α):+ east of *vernal equinox ("First Point of Aries")*

Note that the celestial equator and vernal equinox are not fixed with respect to the stars over long time periods (by virtue of a *slow* phenomenon called *precession of the equinoxes)* so celestial coordinates are referenced to the equator and equinox at some particular date and time, such as year 2000.0 or 1950.0. In general, the RA and Dec of an object at a specific date and time *t* may also be given in "apparent coordinates", which are referenced to the *true* equinox at that same particular date and time *t*. Apparent coordinates are given for aiming properly-aligned telescopes with accurate and precise setting circles, while 2000 or 1950 coordinates are used for plotting objects on star atlases for use in star-hopping.

Sample notation: the bright star Vega (α Lyr), referenced to "equator and equinox of 1986.5":

$\mathrm{Dec}_{1986.5} = \delta_{1986.5} = +38^{o}\ 46'\ 14''$

$\mathrm{RA}_{1986.5} = \alpha_{1986.5} = 18\text{h}\ 36\text{m}\ 28.9\text{s}$

Note that for RA, 24h = 360^{o} , so 1h of RA = 15^{o} .
This is the basis of converting time to degrees and vice-versa:

$18\text{h}\ 36\text{m}\ 28.9\text{s} \rightarrow 18.60803\text{h} \times 15\ \text{deg/hr} = 279.1204^{o} \rightarrow 279^{o}\ 07'\ 13''$

and clarifies the otherwise weird-looking expression

$$\mathbf{cos}(18\text{h}\ 36\text{m}\ 28.9\text{s}) = 0.1585$$

2.3 Observer-based coordinates

altitude (Alt): measured "due up" from horizon ≡ 0^o

azimuth (Az): measured East from "North point" ≡ 0^o. Note that this creates a *left-handed* coordinate system!

hour angle (HA): lines of constant hour angle are identical to those of constant right ascension, but HA values are measured eastward and westward from the *observer's meridian* ≡ 00h 00m 00s. HA's are conventionally specified in the range –12h to +12h: objects which have yet to transit your meridian have a negative HA, while objects already past transit have a positive HA.

3 Time Scales

3.1 Solar times

Solar times are based on the period of the rotation of the Earth with respect to the Sun.

UT = Universal Time: mean solar time at Prime Meridian at Greenwich ($\lambda = 0^o\ 00'\ 00''$ = 0h 00m 00). This is by convention the time scale used when documenting astronomical observations.

ZT = Zone Time: (e.g. EST, EDT) mean solar time at the *reference longitude* for whatever time zone you happen to be in. The reference longitude for the eastern time zone is $\lambda_{EST} = -75^o$ (it passes roughly through Philadelphia), so

$$UT = EST - (-75^o/(15^o\ /hour)) = EST + 5\ hours$$

LMT = Local Mean Time: mean solar time at *your* particular longitude λ_{Obs}. Tables in the Astronomical Almanac for sunrise/set, moonrise/set, and the various flavors of twilight are given in LMT.

Relations:

$$UT = ZT - \lambda_{zone}\ ;\ UT - LMT - \lambda_{obs} \tag{5}$$

3.2 Sidereal times

Sidereal times are based on the interval between successive meridian passages of the vernal equinox (a point in space defined as a point on the meridian of Greenwich at the time of the vernal equinox – the change from winter to spring in the northern hemisphere).

GST = Greenwich Sidereal Time: "HA of vernal equinox for observer at Greenwich"; corresponds to the RA of the objects transiting the meridian for an observer at Greenwich.

LST = Local Sidereal Time: "HA of vernal equinox for local observer"; corresponds to the RA of the objects transiting the meridian for an observer's particular longitude.

Relations for sidereal timescales:

$$LST = GST + \lambda_{obs}\ ;\ \Delta sidereal\ time = 1.0027379 \times \Delta solar\ time$$
$$\text{where } 1.0027379 = \frac{sidereal\ days\ in\ year}{solar\ days\ in\ year} = \frac{366.25}{365.25} \tag{6}$$

Another way to look at this relates sidereal time to observer based coordinates and celestial coordinates above:

$$LST = RA + HA \tag{7}$$

Note that a sidereal clock runs *faster* than a solar clock by 1 day/year, which is about 4 minutes/day.

A table mapping 0h UT each day to its corresponding GST is given in the *Astronomical Almanac*, Section B, "Universal and Sidereal Times".

4 Sun/Moon Rise/Set tables

In Section A of the *Astronomical Almanac*, you'll find tables which can be used to quickly determine times of

- sunrise and sunset
- moonrise and moon set
- civil twilight (morning & evening)
- nautical twilight (beginning & ending)
- astronomical twilight (beginning & ending)

We can call the state when the sky is as dark as it's going to get "astronomical darkness", so "ending astronomical twilight" becomes "beginning astronomical darkness", and "beginning astronomical twilight" becomes
"ending astronomical darkness".

For our purposes, and for now, we'll stop here. In this day and age, it is unusual for an astronomer (amateur or professional) to determine the hour angle, altitude, or azimuth for a target object longhand. Usually, observers use software like *Voyager III*, or online ephemerides for moving targets (the planets and asteroids), to determine when and whether an object is observable at a given time. However, it can be done with a bit of spherical trig and some time…

5 Other useful items in the Astronomical Almanac

You may not use the use the Astronomical Almanac to calculate the sunset time, or the altitude of an object but you might find some other useful purposes for it. For example, Section F contains information regarding the configuration of the satellites of the planets which would help you identify which moons of Jupiter (or another planet) you are seeing. Also located right at the beginning are dates for the various phases of the moons, dates for any lunar and solar eclipses for the year, and other astronomical planetary pheonomena.