

# Planning Observations

## Observational Astronomy

### Introduction

For a professional astronomer, proper planning for an observing run is absolutely critical. Simply whipping together a list of targets is not sufficient to insure the collection of the intended data. This holds true especially for ground based telescopes, because they are restricted in what they can see by Earth's curvature and rotation. The brightness of the object will be an issue when observing with a CCD camera because it will need to collect enough photons of the target object to obtain the desired signal-to-noise ratio. This forces a calculation of the necessary exposure time for each object, which is based on the object's magnitude, the moon's brightness, the overall brightness of the sky, certain characteristics of the CCD, and the desired signal-to-noise ratio.

## 1 Selecting Objects

### 1.1 Target List

The first part of planning an observing run is to know what celestial objects would provide the desired data, and what their properties (coordinates, magnitude, apparent size<sup>1</sup>) are. For the purposes of this lab, the list of targets is already chosen and is given in Table 1 in Section 1.3.

### 1.2 Coordinates

Finding the objects in the night sky depends on knowing their coordinates, and in this exercise the equatorial coordinate system will be used. This system of coordinates uses an imaginary sphere in space, around Earth, called the *Celestial Sphere*. The coordinates used on this sphere are right ascension (the azimuthal angle,  $\phi$ , in spherical coordinates), and declination (the polar coordinate,  $\theta$ , in spherical coordinates). Declination (dec) is a latitudinal coordinate, meaning that it measures the angle of a star above or below the *Celestial*

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<sup>1</sup>Apparent size is used for all these objects because they are all galaxies, nebulae, etc. Thus, they are all larger in the sky than stars (point sources).

*Equator*, which is Earth's equator projected onto the celestial sphere<sup>2</sup>, and is measured in degrees. The dec angle will be  $0^\circ$  at the equator,  $+90^\circ$  at the north pole, and  $-90^\circ$  at the south pole. Right ascension (RA) is a longitudinal coordinate, so it measures the angle of a star east of some reference point, that being the vernal equinox point, which is the point on the celestial sphere representing the sun's position during the vernal equinox<sup>3</sup>. Right ascension is measured in hours of arc, so it will be somewhere between 0 and 24 hours of arc for an object's position. A positive value of RA means the angle is measured East from the vernal equinox point. Also note that it is a simple matter to convert between hours of arc and degrees. There are  $360^\circ$  in a complete circle, and also 24 hours in a circle, so the units are easy to convert back and forth.

### 1.3 Target Characteristics

The basic characteristics for the target objects need to be cataloged to correctly calculate signal-to-noise ratios and exposure times. Astronomers no longer need to worry about keeping volumes of data tables around to get this information from as there are many resources online from which to obtain it. A convenient, searchable archive with lots of useful information is kept at <http://www.seds.org/~spider/ngc/ngc.cgi?1>. The Enter your Catalog Number field at the bottom of the page, will accept values for various catalogs, but the NGC numbers are all provided for you in Table 1 so use those. Just type the NGC number (either just the number, or 'NGC' then the number). It will bring up a page with an image of the object, and a table of information about it. From the table you will need to obtain the following information: Right Ascension, Declination, Apparent Brightness (which is another way of saying 'apparent magnitude'), and Apparent Size (in parsecs). As per the exercise sheet, you will need to determine these values for all the objects in Table 1.

Table 1: List of target objects to be observed.

1	Andromeda Galaxy (M31)
2	Ring Nebula (M57)
3	Blue Snowball (NGC 7662)
4	NGC 869
5	NGC 884
6	Ptolemy's Cluster (M7)
7	Open Cluster M47
8	Orion Nebula (M42)
9	Globular Cluster M15

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<sup>2</sup>This will lead to  $0^\circ$  declination being at a different angle than the plane of the solar system due to the tilt of Earth's axis, and thus of the equator. There are other coordinate systems that get used, such as Ecliptic Coordinates and Galactic Coordinates.

<sup>3</sup>The vernal equinox is the point at which the lengths of day and night are equal for the first time during the year, usually occurring around March 20

## 1.4 Sidereal Time vs. Solar Time

When trying to determine when an object will be visible during the year, it is important to understand the concept of sidereal time, as opposed to solar time. Solar time is the system that uses the sun as a reference point. One solar day is the time taken for the sun to come back around to the same position in the sky after one rotation of Earth about its axis. Sidereal time uses the stars as references. The time necessary for a star to return to the same position in the sky as it was the day before is defined as one sidereal day, which is 4 minutes shorter than a solar day (you need to write out why this is on the exercise sheet). Because of how the coordinate system is set up for sidereal time, an observer will know the local sidereal time at the current location by noting the right ascension of an object that is directly overhead.

## 1.5 Target Visibility: Declination Angle

You need to determine the visibility of the objects listed on the exercise sheet. To determine the visibility of a given object, you will need to know the local sidereal time during the intended observation. The first thing to do, though, is to see if what you want to view is at a declination that will be visible at all. Since declination doesn't change nightly like RA, you can just compare the latitude of the observer with the declination of the object. If the declination is more than  $90^\circ$  north or south from the latitude, then it will never get above the horizon for you to see it. If the source is at a proper declination, you must then determine if the RA allows it to be in your local sky on the night and time of the intended viewing.

## 1.6 Target Visibility: Right Ascension

This is more difficult, and can be done in numerous ways. The most basic way to see if the target object will be up in the sky is to figure out the local sidereal time during the intended observation, then compare it with the RA of the target. The sidereal time would be tedious to calculate by hand, which is why there are many handy web-based calculators to do it for you. One such calculator is at <http://www.csgnetwork.com/siderealjuliantimecalc.html>. You will need to enter the date, time<sup>4</sup>, latitude, and longitude<sup>5</sup> of the observations into the respective fields, then click **calculate**. This will convert the values to local sidereal time, which is what you will need. Since the local sidereal time is equivalent to the RA of the observer's meridian<sup>6</sup>, the difference in the RA values between sidereal time and the target will indicate how close the target is to crossing the observer's meridian. If the object is within 6 hours east or west of the observer's meridian, then it will theoretically be visible.

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<sup>4</sup>The time you will need to input is in UT (Universal Time), which is local time as measured from Greenwich, England. For the eastern time zone in the U.S., the local time is offset by -5 hours from Greenwich. For daylight savings, the offset is -4 hours.

<sup>5</sup>Values for longitude are positive for east and negative for west.

<sup>6</sup>A meridian is defined as a circle of constant longitude that covers  $360^\circ$  of latitude. The observer's meridian is the meridian that intersects the observer's zenith. Basically, it's the imaginary north-south circle around Earth that passes directly over your head in the sky.

Once you have determined which targets are within the declination range for viewing at Troy's latitude, you will use this procedure to see which ones will be visible on the chosen observation date.

## 2 Calculating Exposure Times

One of the more important pieces of information an astronomer will need for an observing run is the exposure time for each object being observed. The key is to get images of as many objects as possible while maximizing the data (thus, maximizing the signal-to-noise ratio) collected from each one. This can be extremely limiting when the targets are all dim. You will now go through the process of calculating exposure times for the objects on your target list.

As you learned in previous labs dealing with the CCD camera, the signal-to-noise ratio for an image you want to take depends partly on the relative brightness of the object being observed and the exposure time of the image. Recall the equation for the signal-to-noise ratio:

$$\frac{S}{N} = \frac{N_{star}}{\sqrt{N_{star} + n_{pix}(N_{sky} + N_{dark} + N_{read}^2)}} \quad (1)$$

- $N_{star}$  = rate of electrons produced in CCD from source object
- $n_{pix}$  = number of CCD pixels gathering light from the object
- $N_{sky}$  = rate of electrons produced in CCD from sky background
- $N_{dark}$  = rate of electrons produced in CCD by dark current
- $N_{read}$  = number of electrons produced from read noise in CCD

### 2.1 $N_{star}$

You will need to calculate  $N_{star}$  for each object, which is the rate of electrons that the object will produce on the CCD per second (which will be found by getting the number of photons received by the telescope and multiplying by the quantum efficiency of the CCD). The relationship used is the following:

$$N_{star} = \frac{S_0 \cdot A \cdot \Delta\lambda}{2.5^V} \cdot QE \cdot (1 - \epsilon) \quad (2)$$

- $S_0$  =  $5.5 \times 10^7$  photons per second
- $A$  = Aperture (diameter of the mirror in meters)
- $\Delta\lambda$  = Bandwidth in nm (500 nm if there is no wavelength filter)
- $V$  = Apparent magnitude of the object
- $QE$  = Quantum efficiency of the CCD
- $\epsilon$  = Optical efficiency

## 2.2 $N_{sky}$

The value for  $N_{sky}$  can be calculated in exactly the same manner as  $N_{star}$  in section 2.1. You will need to use the sky brightness (16 magnitudes), the pixel dimensions (in arcsec/pixel), and the total number of pixels to determine the apparent magnitude of the sky that is contributing noise.

## 2.3 $n_{pix}$

To determine the effective number of pixels that are collecting light from the object, there is a basic relation that you can use:

$$n_{pix} = 1.5 \cdot [S/\theta]^2 \quad (3)$$

Where  $\theta$  is the individual pixel size in arcsec, and S is a measure of the apparent size of the target object. Apparent size refers to the amount of the sky an object occupies due to its large size. The apparent size will be in arcsec.

## 2.4 Signal-to-Noise Ratio

The total number of electrons produced by the object during the course of the exposure is  $N_{star} \cdot t$ , which alters equation 1 so it can be solved for t, the integration (exposure) time:

$$\frac{S}{N} = \frac{N_{star}t}{\sqrt{N_{star}t + n_{pix}(N_{sky}t + N_{dark}t + N_{read}^2)}} \quad (4)$$

Which can be solved for t to give:

$$t = \frac{-B + (B^2 - 4AC)^{\frac{1}{2}}}{2A} \quad (5)$$

$$A = N_{star}^2 \quad (6)$$

$$B = -\left(\frac{S}{N}\right)^2 (N_{star} + n_{pix}(N_{sky} + N_{dark})) \quad (7)$$

$$C = -\left(\frac{S}{N}\right)^2 (n_{pix}N_{read}^2) \quad (8)$$

From the CCD Characteristics lab, necessary values for the CCD camera are<sup>7</sup>:

$$N_{dark} = 0.5 \text{ electrons/pixel/second}$$

$$N_{read} = 12 \text{ electrons/pixel}$$

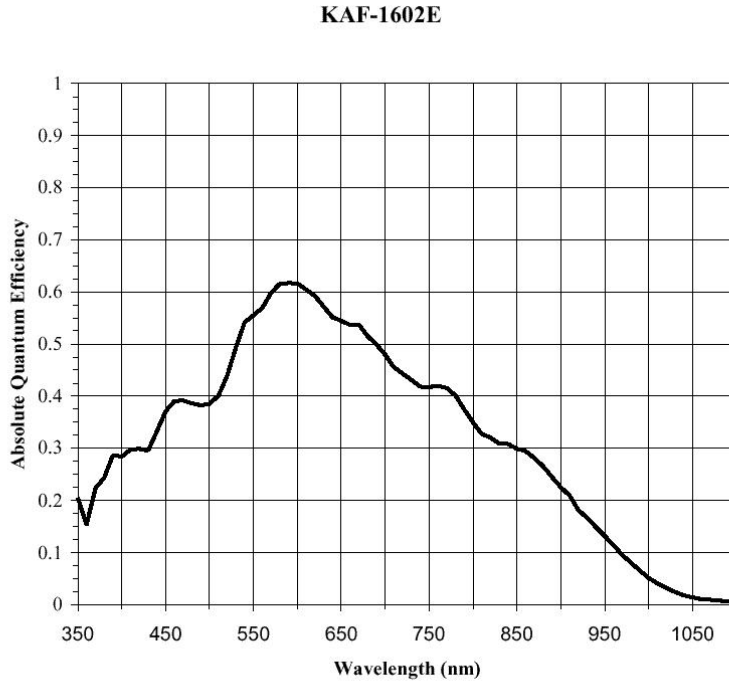


Figure 1: This is the quantum efficiency curve for the KAF-1602E CCD chip, which our ST-8E camera uses.

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<sup>7</sup>Notice that the read noise,  $N_{read}$ , does not depend on time.