The Messier Marathon

Astronomy 142 — Project Manual

Spring 2024

1 Introduction

The first interesting catalog of non-stellar objects that do not belong to the Solar system was that compiled by Charles Messier in the late eighteenth century. In the era of Messier's activity, solar-system astronomy seemed the most exciting frontier, exemplified by Herschel's (1781) discovery of Uranus and the realization that the orbital anomalies of the new planet could be explained most easily by another planet, or planets, further away. Within this rubric was the study of minor solar system bodies, which in those days meant comets, as asteroids were not discovered until 1801. Messier was a hunter of comets. In his hunt, he and his assistant Pierre Méchain also discovered many fuzzy, extended objects that could be mistaken for comets at a glance, but which seemed not to move with respect to the fixed stars. Messier published this list (1781) as a warning to fellow comet-hunters. Originally containing 103 objects[1], the catalog expanded slightly during the 20th century as astronomers, notably Camille Flammarion and Helen Sawyer Hogg, re-read additional notes and descriptions of observations kept by Messier and Méchain. There are now officially 110 Messier objects. The catalog includes most of the brightest examples of stellar clusters, gaseous nebulae, and galaxies visible from the northern hemisphere. Very influential in its day, the M catalog spawned many more collections of extended celestial objects, starting with the *General Catalogue of Nebulae and Clusters of Stars* (GC; 1864), the *New General Catalogue* (NGC; 1888), and its appendices the *Index Catalogues* (IC; 1896, 1905), compiled by John Herschel and John Dreyer, from observations by William, Caroline and John Herschel. Professional and amateur astronomers alike remain fascinated by the wide variety of astrophysical processes which can be studied in detail in the Messier objects.

The Messier catalog has two features that many find particularly interesting. First, there are two brief intervals each year in which every object in the catalog could in principle be observed between sunset and sunrise. Second, the number of objects is sufficiently small that a good observer can point a telescope at each object during the course of one clear dark night, but sufficiently large to make it a challenge. This observing program — all, or at least nearly all, the M objects in a single night — is called the Messier Marathon. The Marathon is very popular among amateur astronomers. The longer of the two Messier-catalog visibility windows lies in the last couple of weeks of March and the first couple of weeks of April, and thus falls within the prime ASTR 142 observing season. In this experiment, we will run the Messier Marathon, recording CCD images of the M objects, or at least their centers.[2]

[1]Some of the objects were known to be non-stellar and non-planetary for a long time before Messier. For example, of the first 45 catalog objects he published, the last four are naked-eye nebulosities known to the ancients, which Messier added for completeness: the middle "star" of Orion's sword (M42 and M43), the Beehive Cluster in Cancer (M44) and the Pleiades in Taurus (M45). The Andromeda Nebula (M31), also visible to the naked eye, was known at least 800 years before Messier's time. Several other M objects were discovered within the generation or two before Messier: for instance, the Great Hercules Cluster (M13), which is barely visible to the naked eye under perfect conditions, was described by Halley, and the Crab Nebula (M1) by Bevis, early in the 1700s. But Messier was the first to collect these scattered observations, add many other examples systematically, and publish the results, so his work had more impact than that of his predecessors.

[2]Serious amateur astronomers usually consider the use of computer-controlled telescopes to be against the rules of the Messier Marathon. Beware of thinking that completion of this project entitles you to stand in the august company of those who have done it with Dobsonians pointed by hand; they will consider you a cheater. On the other hand, most of them do not record images of the targets while they are running the Marathon, and you will.

2 Experimental procedure

2.1 Planning your Messier Marathon

There are 110 objects in the catalog and less than 12 hours of darkness in which to observe them, so each object needs to be acquired and imaged in less than six and a half minutes. Thus no one succeeds at the Messier Marathon without carefully planning the sequence of observations. It is not possible to simply go through the list in right-ascension or catalog-number order. Instead, you need to take account of the times at which objects set and rise, noting the constraints imposed by the southernmost objects that are not above the horizon for very long, and use the flexibility of the long observing windows for the northernmost objects.

During the past few weeks of *Learn Your Way Around The Sky* lessons in recitation, you have learned everything you need to know to calculate the rising and setting times of each object and the Sun, to the required, better-than-a-few-minutes accuracy. First, there is the relation between zenith angle ZA and hour angle HA, in terms of an object's declination δ and the observer's latitude λ:

$$ZA = \cos^{-1}\left(\cos HA \cos\delta\cos\lambda + \sin\delta\sin\lambda\right) \tag{1}$$

which you derived in Recitation 5. Then there is local sidereal time, ST, which depends upon the observer's longitude L, time t (in UT) since the Vernal equinox (at t_1), longitude L_1 at which it was noon at the Vernal equinox, and Earth's orbital parameters, including the sidereal rotation period $P_\oplus$, the length of the day, the semimajor axis length a, eccentricity ε, and ecliptic obliquity Ψ. In Recitations 4, 6, and 8, you derived the components of sidereal time, which expressed in sidereal days is

$$ST = (t - t_1)\left(\frac{1}{P_\oplus} - \frac{1}{\text{day}}\right) + \frac{1}{2\pi}\left[L - L_1 + \Delta\theta_\varepsilon(t) + \Delta\theta_0(t)\right] + \text{mod}\left(\frac{t - t_1}{\text{day}}, 1\right) \tag{2}$$

where by $\text{mod}(x, 1)$ we mean the part of x in excess of the largest integer smaller than x, or in this case time of day on a 24-hour clock, with the integer number of previous days subtracted off, and where

$$\Delta\theta_\varepsilon(t) = \frac{\Delta\omega_0}{\omega}\sin\omega(t - t_0) \qquad\qquad \Delta\theta_0(t) = \frac{1 - \cos\psi}{2}\sin 2\omega(t - t_1) \tag{3}$$

Here ω is the angular frequency of the mean Sun, $\Delta\omega_0$ is the difference in Solar angular frequency between perihelion and aphelion, t_0 is the time of perihelion, and ψ is the obliquity of the ecliptic. Finally, there is the celestial position of the Sun, for which you obtained the declination in Recitation 9, and for which the right ascension is only slightly different from sidereal time:

$$\alpha_\odot = \text{mod}\left(2\pi(t - t_1)\left(\frac{1}{P_\oplus} - \frac{1}{\text{day}}\right) + \Delta\theta_\varepsilon(t) + \Delta\theta_0(t), 2\pi\right)$$
$$\delta_\odot = -\psi\cos\left[\omega(t - t_2) - \Delta\theta_\varepsilon(t) - \Delta\theta_0(t)\right]$$

Here the results would be in radians, t_2 is the time of the last winter equinox, and $(\text{mod } x, 2\pi)$ again means that the largest integer multiple of 2π is subtracted off, that can still leave a positive result.

"All" that needed to be done, then, to obtain the rising and setting times of each Messier object and the Sun for any arbitrary night of the year, is to solve for the times t on that night which satisfy

$$\cos ZA_{\text{max}} = \cos\left(ST(t, L) - \alpha\right)\cos\delta\cos\lambda + \sin\delta\sin\lambda \tag{4}$$

for each target's α and δ. Then take the rising and setting times and arrange the order of observation, such that the average pace of the observations — say, one every five or six minutes — can accommodate observation of each object after it rises and before it sets. In Figure 1, the results of such a calculation are rearranged into one practical realization of the Messier Marathon.

Fortunately, you will not have to go to this much trouble. The popularity of Messier Marathons among amateur astronomers has led to the presence online of several Messier Marathon planners

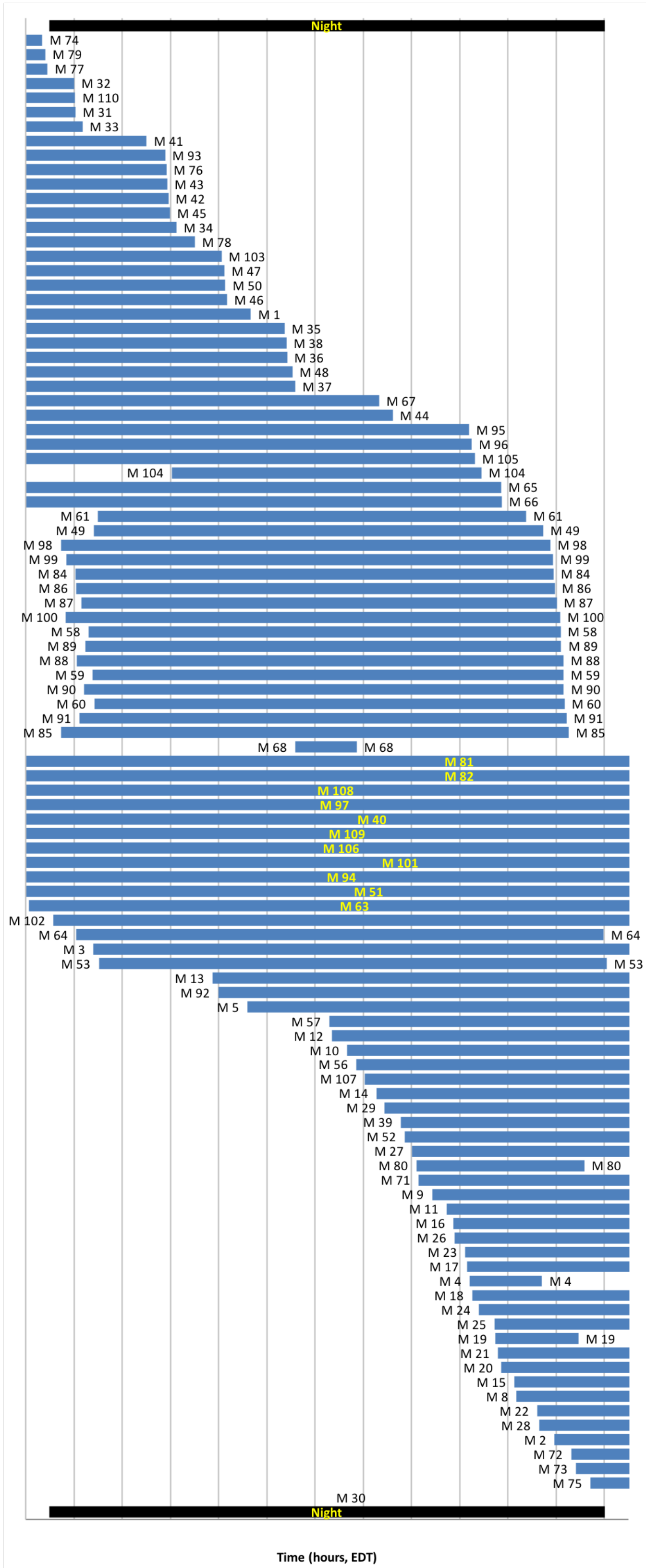

Figure 1: Rising and setting times for the Messier objects, organized in a sequence to aid in determining the order of observations during the Messier Marathon.

which can be customized for any observing date: just google "Messier Marathon planner." But you do know how to do the calculations which these planners do, and you could do them if you wanted to. We will not ask for them in this project, because they involve the use of numerical root-finding routines which are not easily implemented.

With all this in mind, here is the pre-observing procedure to be followed:

1. As you will see, there is very little down time for anyone on the observing team during the course of this project. There are three tasks that must be performed constantly through the night, and we presume that team members will rotate periodically so that everybody gets to enjoy each different task.

2. Download the Messier catalog, available as either .txt or .csv file on the course website.

3. Calculate the amount of time each object is above the effective horizon, $2HA(ZA_{\max})$. Identify the objects which never get above the horizon and should therefore be left out of the observing list. Identify circumpolar objects and prepare to keep them handy: you must always be observing something, and these may serve if you would otherwise have to wait for an object to rise. *(Please remember: The telescope at Mees cannot be slewed to a position below the North Star! Just because an object is circumpolar does NOT mean that you can observe it at any point during the night.)*

4. Look up or calculate the times of sunset and sunrise, and the length of the night, for your observing night.

5. Refine your observing list by identifying the objects which rise too late or set too soon. Determine your time budget: the number of seconds available for each object on the average. By consulting online Messier Marathon plans and Figure 1, determine the order in which the list should be observed. Make a spreadsheet list of targets and times at which you should begin observing each target.

   Hint: Note the position of M68 in Figure 1. Consider how this, and other objects with very narrow windows of observability, constrain the schedule.

6. Plan to take at least 2 minutes of imaging data per object with the L filter. The imaging should be in the form of a short exposure (20–30 sec) followed by centering if necessary, and either a longer exposure or a series of short ones. For faint objects (e.g. most galaxies) in a dark sky, it would be best to take one long exposure; for bright objects (e.g. M42) or bright sky conditions (twilight or moonlight) it works better to take a stack of short exposures and average them afterwards.

7. Learn enough about the Messier objects to know which are unlikely to have their interesting parts fit in the 15.4 arcminute wide camera field. Flag these objects on your observing plan spreadsheet. For these targets, you will only be able to record images of the center with the camera.

8. Present your list, with calculations and order appropriate for the observing night, to Prof. Douglass for review. No group gets to observe without presenting a blow-by-blow plan in advance.

9. Unlike the observing projects in ASTR 111, this one takes all night. Therefore, you will be required to sleep at the Gannett House after your observations are done and before returning to campus. Plan accordingly by packing for an overnight stay at the observatory, and remember the all-important requirement of packing sufficient food. (Unfortunately, Mees is beyond the range of pizza delivery; the nearest restaurants and grocery stores in Naples, and the nearest restaurants on your way home that are likely to be open are in Victor.) Familiarize yourself with the rules of the observatory sleeping quarters at the Gannett House.

10. Bring your notebooks, and you would do well to also bring your personal laptop or tablet computer. Paper copies of the in-person observing checklist will also prove useful, though these will also be accessible to you online at Mees.

11. Arrive **at least 45 minutes before sunset**. The telescope and camera must be ready to go, and all team members must be at their stations, before the sun goes down.

2.2 Observations

Two team members should be stationed at two specific jobs: telescope and CCD camera operator and scribe:

- The Scribe orders the observations, enforces the schedule, and maintains a spreadsheet in which they record the correspondence between file name and object being observed, exposure times, etc. The scribe is also in charge of quality control: making sure that the images are not saturated, and making sure that the target is centered properly, etc.; calculates the necessary offsets to center the targets.

- The telescope and camera operator moves the telescope to acquire the targets; offsets the telescope at the request of the scribe, in the process of centering targets, using `TCSGalil Telescope > Movement > Offset`; and looks for opportunities to sync the telescope coordinates whenever a star happens to be centered in the camera, thus to keep the pointing sharp.

Rotate the team members among the jobs at least once an hour. Here is the recipe that should be followed:

1. Start the telescope and initialize its pointing by following Steps 1–14 (skip #11) in Section I of the Mees Observatory remote-observing checklist. This leaves you with `TCSGalil`, `Firefox`, and `TheSkyX` running on the TCS computer.

2. Start the CCD camera by following steps 15–16 in Section I of the remote-observing checklist. The camera should now be ready to observe.

3. Once the sky is dark enough, open the dust cover (step #11), initialize the telescope's pointing (step #17), and focus the telescope (step #18). The telescope should now be ready to observe.

   Notable differences from ordinary observations:

   (a) You will not have time to change the file name prefix for every object. Rely on a generic prefix and the serial numbers, and the spreadsheet maintained by the scribe, to keep your targets and data sorted.

   (b) No time, or need, to autoguide.

   (c) Because you will be using only one filter, but changing targets and exposure times so frequently, it will be more convenient to take data with TheSkyX's `Camera > Take Photo` tools instead of the usual `Camera > Take Series`.

4. Begin the Marathon. The scribe is in command, enforces the following of the plan, and maintains the spreadsheet of file names and targets. Illustrations of the routine:

   Scribe Move to M*xx*.

   Telescope We're there.

   Scribe Looks like a galaxy nucleus in the 20 second image, please move us 5 minutes west and 3 minutes north.

   Telescope Done. Two-minute exposure in progress. By the way, the 20 second image was number 147 and the current one is 148.

   Scribe Duly noted. Get ready for M*yy* next.

Telescope Image 148 done and ready for next.

5. Occasionally:

   Telescope 20-second image number 230 already beautiful, brightest stars barely on scale. Can we do 16 20-second images?

   Scribe No time for that; make it 9 20-second images.

   Telescope Oh, all right. 230 through 239 in progress.

6. The non-routine: Whenever an object is not clearly seen in the camera quickly point to a nearby bright star, center it in the camera, and update the TCS telescope position, then point back to the target. You will have to learn how to do this in no more than a couple of minutes.

7. **When all this is done**, or when the Sun comes up — whichever is first, shut down the telescope by following the steps in Section II of the remote-observing checklist.

8. Go to the Gannett House and get some sleep. You may not return to campus until at least the driver(s) sleeping for at least four (4) hours. This safety rule will be strictly enforced.

3 Data reduction

Now we calibrate your Messier Marathon images. Since the images differ only in target and integration time, this task benefits greatly from CCDStack's automation. Make sure your team divides the data-reduction workload equitably among the members.

Set aside a few hours for your team to meet in the POA or on Zoom and remotely log into your team's account on the workstation in B&L. Find the directory on this computer's desktop in which the Master Dark and Bias frames are kept. Then:

1. Start CCDStack, using the icon in the Windows taskbar.

2. Open all your Messier Marathon images using either `File > Open...` or `File > Open Selected...` and navigating to your working directory. This will present you with the full stack of these images, which you can page through and examine with the tools on the left side of the window.

3. Calibrate the images *en masse*. Choosing `Process > Calibrate` evokes the `Calibration Manager` dialog. Using the two tabs and three buttons, specify the master dark frame and bias frame appropriate to CCD temperature ($-20°$C) and binning (1×1). Then click `Apply to All`.

4. Next, remove hot pixels: those with (permanently) high and variable dark current that does not subtract out in calibration. Choose `Process > Data Reject > Procedures`. In the resulting dialog choose `reject hot pixels` from the dropdown menu, specify a `strength` of 30, check `clear before apply`, then click `Apply to All`. Then choose `interpolate rejected pixels` from the dropdown menu, and again click `Apply to All`.

5. Then cold pixels: also with permanent dark-current problems, if not completely dead. Repeat Step 6, substituting `cold` for `hot` in the first dialog.

6. Choose `File > Save > All`. In the `File Name` box of the resulting dialog, enter a suffix indicating the degree of processing the images have had, e.g. `Cal`. Then click `Save`.

7. You are now done with the entire stack; choose `File > Remove all images - Clear`.

8. Now, using the scribe's spreadsheet of observations, identify all multiple images of given objects, such as those described in step 5 of Section 2.2.

   (a) Use `File > Open...` to open the first set.

(b) Align all of these images so that the stars are in precisely the same places. Choose `Stack > Register`, which brings up the `Registration` dialog.

(c) On the `Star Snap` tab, click `remove all reference stars`, then `select/remove reference stars`. Double-click to select 6–8 stars which do not have any particularly close neighbors, are not close to the edge of the image, do not include extremely bright looking stars, and are spread uniformly around the cluster. Page through the stack of images to see how close to being in alignment they already are. Drag any misaligned ones into closer alignment. Then click `Align All` to shift the frames into rough alignment.

(d) Switch to the `Apply` tab, choose `Nearest Neighbor` from the dropdown box, and click `Apply to All` to shift the frames very accurately into alignment. Page through the images to make sure it worked. It should now be difficult to tell when you page from one image to the next.

(e) Choose `Stack > Normalize > Control > Both`. In response to the subsequent instructions, drag a rectangle well off of the object's center to represent `background`, and click `OK`. Then drag a rectangle encompassing the brightest part of the target to represent the `highlights`, again clicking `OK`.

(f) This registered, normalized stack of images can be corrected for cosmic-ray hits and satellite trails. Choose `Stack > Data Reject > Procedures`. In the resulting dialog pick `Poisson sigma reject` from the dropdown box, specify a `sigma multiplier` of 2.2 (sigma) and an `iteration limit` of 8, and click `Apply to All`. Then select `interpolate rejected pixels` from the dropdown menu, and again click `Apply to All`.

(g) Choose `File > Save > All`. In the `File name` box of the resulting dialog, enter a suffix indicating the degree of processing the images have had, e.g. `RegNormFix`. Then click `Save`.

(h) Average the stack of images using `Stack > Combine > Mean`. Save this image as well (`File > Save > This`), using the first file name in the stack as a suffix, and Mean as a prefix.

(i) Choose `File > Remove all images - Clear`.

Repeat this for each multiple observation.

9. Using `File > Open Selected...`, open all of the calibrated images (`Cal` suffix).

10. Page through the images and remove from the stack (`Ctrl-R`) all of the images which went into an average: those with suffix `CalRegNormFix`.

11. Using `File > Open Selected...` again, open all of the averages of the multiple images (`Mean` prefix.

12. Now comes the time consuming part. You now have as many as 110 images in the stack: your best try on each of the Messier objects you observed. Go through them one by one, and make each look as good as possible by use of the Adjust Display tools. By "good," we should mean that the image stretch (`Gamma` and `DDP` parameters) is adjusted to show all details of the object from brightest to dimmest, that `Maximum` is chosen not to saturate too much of an image's brightest parts, and that `Background` is chosen so that the image is black at levels below the dimmest detected part of the object: thus blotting out any sky background, but none of the stars brighter than that.

13. When you are done beautifying the images, save them all in scaled form: `File > Save > All`, with JPEG as the `Save as Type`. Leave copies of all images in the working directory you created on the observing computer.

4 Analysis

As your main result, you have digital images of the vast majority of the Messier objects.

1. Make a master table of final images and object descriptions, with the objects listed in the order you actually observed them. Include in the descriptions a classification of each object made in accordance with its appearance. For each galaxy, this should include your estimate of the Hubble type as is consistent with the image you took.

2. Make an additional cross-reference table in which the objects are sorted according to their classification: open cluster, globular cluster, planetary nebula, H II region/reflection nebula, supernova remnant, elliptical galaxy, spiral galaxy. Comment on the ranges of brightness and angular size observed under each of these classes.

3. Pay particular attention to the identification and classification of three objects: M40, M73, and M102.

5 Lab reports

Each student must write their own report, in which they explain the purpose, methods, and outcomes of the observations, and your complete set of images, object descriptions, and cross references. We offer a sample lab report on the class website, to give an idea of the length and level of detail expected.