THE MESSIER CATALOG (CCD IMAGING)

SYNOPSIS: You have the opportunity to use the SBO telescopes to do electronic imaging of celestial objects from the Messier catalog using a CCD camera.

EQUIPMENT: Sommers-Bausch Observatory telescopes, CCD camera, and image processing software, a planisphere (rotating star wheel) or other star chart.

NOTE: This is an advanced lab exercise that may be possible only if a sufficient number of clear nights are available. Students who pursue this exercise should be willing and prepared to spend additional time and effort in order to process their work.

Part I. The Messier Catalog

During the years from 1758 to 1782 Charles Messier, a French astronomer (b. 1730 d. 1817), compiled a list of approximately 100 diffuse objects that were difficult to distinguish from comets through the telescopes of the day. Discovering comets was the way to make a name for yourself in astronomy in the 18th century, so Messier's aim was to catalog objects that were often mistaken for comets such that they would not be bothered with again. Ironically these are perhaps the most interesting objects in the night sky and are well worth looking at!

The Messier Catalog soon became well-known as a collection of the most beautiful objects in the night sky, including a supernova remnant, diffuse and planetary nebulae, open and globular star clusters, and spiral and elliptical galaxies. It was one of the first major milestones in the history of the discovery of deep sky objects, as it was the first comprehensive and reliable list of its kind. The study of these objects by astronomers has, and continues to, lead to important discoveries such as the life cycles of stars, the reality of galaxies as separate "island universes" and the age of the universe. Many of the beautiful pictures taken by the Hubble Space Telescope are of Messier objects. Today's versions of the catalog usually also include additional of objects observed by Messier and his collegial friend, Pierre Mechain, but were not included in his original list.

Objects in the Messier catalog are given a number preceded by the letter "M" (for Messier, of course!) For example, the Andromeda Galaxy is the 31st object in the Messier catalog and is hence also known as "M31." The table below lists all the Messier objects in order. The object type, angular size (in arcminutes) and common name are listed, as well as the constellation in which the object resides. Interestingly, for some of the catalog entries it has been difficult to determine which object Messier originally saw, as his notes were sloppy! Thus the identity of some objects are still under debate. For example, there is some question as to the identity of M102. Some believe it is an accidental re-labeling of M101 while others believe it to be the galaxy NGC 5866 (**NGC**, the "new general catalog," is another catalog of non-stellar objects). M104 through M110 are objects that were believed to have been originally seen by Messier but for some reason not cataloged. They were later added to the Messier catalog by Mechain and other astronomers.

Object	Object Type	Angular Size (')	Distance (kly)	Constellation	Common Name
M1	Supernova Remnant	6	6.3	Taurus	Crab Nebula
M2	Globular Cluster	13	36.2	Aquarius	
M3	Globular Cluster	16	30.6	Canes Venatici	
M4	Globular Cluster	26	6.8	Scorpius	
M5	Globular Cluster	17	22.8	Serpens Caput	
M6	Open Cluster	15	2	Scorpius	Butterfly Cluster
M7	Open Cluster	80	1	Scorpius	Ptolemy's Cluster
M8	Diffuse Nebula	60	6.5	Sagittarius	Lagoon Nebula
M9	Globular Cluster	9	26.4	Ophiuchus	
M10	Globular Cluster	15	13.4	Ophiuchus	
M11	Open Cluster	14	6	Scutum	Wild Duck Cluster
M12	Globular Cluster	15	17.6	Ophiuchus	
M13	Globular Cluster	17	22.2	Hercules	Hercules Cluster
M14	Globular Cluster	12	27.4	Ophiuchus	
M15	Globular Cluster	12	32.6	Pegasus	
M16	Open Cluster	7	7	Serpens Cauda	Eagle Nebula
M17	Diffuse Nebula	11	5	Sagittarius	Omega Nebula
M18	Open Cluster	9	6	Sagittarius	
M19	Globular Cluster	13	27.1	Ophiuchus	
M20	Diffuse Nebula	28	2.2	Sagittarius	Triffid Nebula
M21	Open Cluster	13	4.25	Sagittarius	
M22	Globular Cluster	24	10.1	Sagittarius	
M23	Open Cluster	27	4.5	Sagittarius	
M24	Open Cluster	5	10	Sagittarius	
M25	Open Cluster	40	2	Sagittarius	
M26	Open Cluster	15	5	Scutum	
M27	Planetary Nebula	8	1.25	Vulpecula	Dumbbell Nebula
M28	Globular Cluster	11	17.9	Sagittarius	
M29	Open Cluster	7	7.2	Cygnus	
M30	Globular Cluster	11	24.8	Capricornus	
M31	Spiral Galaxy	178	2200	Andromeda	Andromeda Galaxy
M32	Elliptical Galaxy	8	2200	Andromeda	
M33	Spiral Galaxy	73	2300	Triangulum	
M34	Open Cluster	35	1.4	Perseus	
M35	Open Cluster	28	2.8	Gemini	
M36	Open Cluster	12	4.1	Auriga	
M37	Open Cluster	24	4.6	Auriga	
M38	Open Cluster	21	4.2	Auriga	
M39	Open Cluster	32	0.825	Cygnus	
M40	Double Star	1	0.3	Ursa Major	Winnecke 4
M41	Open Cluster	38	2.4	Canis Major	
M42	Diffuse Nebula	85	1.6	Orion	Orion Nebula
M43	Diffuse Nebula	20	1.6	Orion	
M44	Open Cluster	95	0.5	Cancer	Praesepe
M45	Open Cluster	110	0.4	Taurus	Pleiades
M46	Open Cluster	27	5.4	Puppis	
M47	Open Cluster	30	1.6	Puppis	
M48	Open Cluster	54	1.5	Hydra	
M49	Elliptical Galaxy	9	60,000	Virgo	
M50	Open Cluster	16	3	Monoceros	
M51	Spiral Galaxy	11	37,000	Canes Venatici	Whirlpool Galaxy
M52	Open Cluster	13	7	Cassiopeia	
M53	Globular Cluster	13	56.4	Coma Berenices	
M54	Globular Cluster	9	82.8	Sagittarius	
M55	Globular Cluster	19	16.6	Sagittarius	

Object	Object Type	Angular Size (’)	Distance (kly)	Constellation	Common Name
M56	Globular Cluster	7	31.6	Lyra	
M57	Planetary Nebula	2	4.1	Lyra	Ring Nebula
M58	Spiral Galaxy	6	60,000	Virgo	
M59	Elliptical Galaxy	5	60,000	Virgo	
M60	Elliptical Galaxy	7	60,000	Virgo	
M61	Spiral Galaxy	6	60,000	Virgo	
M62	Globular Cluster	14	21.5	Ophiuchus	
M63	Spiral Galaxy	10	37,000	Canes Venatici	Sunflower Galaxy
M64	Spiral Galaxy	9	12,000	Coma Berenices	Blackeye Galaxy
M65	Spiral Galaxy	8	35,000	Leo	
M66	Spiral Galaxy	8	35,000	Leo	
M67	Open Cluster	30	2.25	Cancer	
M68	Globular Cluster	12	32.3	Hydra	
M69	Globular Cluster	7	25.4	Sagittarius	
M70	Globular Cluster	8	28.0	Sagittarius	
M71	Globular Cluster	7	11.7	Sagitta	
M72	Globular Cluster	6	52.8	Aquarius	
M73	Open Cluster	3	?	Aquarius	
M74	Spiral Galaxy	10	35,000	Pisces	
M75	Globular Cluster	6	57.7	Sagittarius	
M76	Planetary Nebula	3	3.4	Perseus	
M77	Spiral Galaxy	7	60,000	Cetus	
M78	Diffuse Nebula	8	1.6	Orion	
M79	Globular Cluster	9	39.8	Lepus	
M80	Globular Cluster	9	27.4	Scorpius	
M81	Spiral Galaxy	21	11,000	Ursa Major	Bode's Galaxy
M82	Irregular Galaxy	9	11,000	Ursa Major	
M83	Spiral Galaxy	11	10,000	Hydra	
M84	Elliptical Galaxy	5	60,000	Virgo	
M85	Spiral Galaxy	7	60,000	Coma Berenices	
M86	Elliptical Galaxy	8	60,000	Virgo	
M87	Elliptical Galaxy	7	60,000	Virgo	Virgo A
M88	Spiral Galaxy	7	60,000	Coma Berenices	
M89	Elliptical Galaxy	4	60,000	Virgo	
M90	Spiral Galaxy	10	60,000	Virgo	
M91	Spiral Galaxy	6	60,000	Coma Berenices	
M92	Globular Cluster	11	26.1	Hercules	
M93	Open Cluster	22	4.5	Puppis	
M94	Spiral Galaxy	7	14,500	Canes Venatici	
M95	Spiral Galaxy	5	38,000	Leo	
M96	Spiral Galaxy	6	38,000	Leo	
M97	Planetary Nebula	4	2.6	Ursa Major	Owl Nebula
M98	Spiral Galaxy	10	60,000	Coma Berenices	
M99	Spiral Galaxy	6	60,000	Coma Berenices	
M100	Spiral Galaxy	7	60,000	Coma Berenices	
M101	Spiral Galaxy	22	24,000	Ursa Major	Pinwheel Galaxy
M102	Spiral Galaxy	5	40,000	Draco	
M103	Open Cluster	6	8	Cassopeia	
M104	Spiral Galaxy	9	50,000	Virgo	Sombrero Galaxy
M105	Spiral Galaxy	2	38,000	Leo	
M106	Spiral Galaxy	19	25,000	Canes Venatici	
M107	Globular Cluster	10	19.6	Ophiuchus	
M108	Spiral Galaxy	8	45,000	Ursa Major	
M109	Spiral Galaxy	7	55,000	Ursa Major	
M110	Elliptical Galaxy	17	2200	Andromeda	

I.1 Read through the Messier catalog. Which objects are the farthest away? Is this what you'd expect for the types of objects that are included?

I.2 Which types of object are the most nearby? Why don't we (or, more specifically, why didn't Messier) see these types of objects at greater distances?

Part II. The CCD Camera

Rather than use conventional photography, you will use a special type of electronic camera, known as a CCD. In the last 15 years, the **CCD** ("charge-coupled device") camera has revolutionized the way astronomers do astronomy. Rather than preparing photographic plates or film using specialized sensitizing techniques and then exposing for many hours to "capture" the sky, observatories now use these electronic detectors to reconstruct an image of the sky in the form of computer bytes and data arrays.

The advantages of using a CCD camera instead of conventional photographic film are numerous:

- **Sensitivity** - An astronomical CCD detector is 20 to 60 times more sensitive to light than film - allowing exposures to be made in seconds or minutes rather than hours.
- **Linearity** - Twice the amount of light produces twice the signal value in a CCD, while the behavior of photographic film is much more complex; it is therefore much easier to analyze the results in a quantitative manner.
- **Dynamic range** - The CCD detector can accommodate a far larger range of intensity than film; useful information on both bright and dim objects can be obtained simultaneously in the same field and at the same time.
- **Threshold** - While photography requires a certain minimum of light before anything at all is recorded, CCDs respond to any level of light reaching the detector.
- **Digital processing** - Photography is a form of "analog" data, exhibiting a continuous range of gray-scale brightness that does not lend itself well to quantitative analysis. Further, development of film takes time and noxious chemicals, so you are unable to see your results (or worse, mistakes) until well after the fact. CCDs produce "digital" data: the image is acquired directly by a computer and the information is in the form of an array of digital values, ready for immediate analysis and processing.

However, photography still offers some advantages over electronic imaging:

- **Size** - The largest CCD detectors currently available are about the same size as an exposed square of 35mm film; most are much smaller. This means that film can photograph much larger regions of the sky, producing "panoramas" while CCDs usually concentrate on "close-up" shots.
- **Resolution** - The size of an individual CCD picture element, or "pixel", determines the smallest feature that can be resolved. Photographic grain sizes are much smaller than current-technology pixel sizes, so that photographs contain more spatial detail.

You will use the CCD camera on the 8-inch telescope that is mounted piggyback on the 18-inch telescope; this permits the small ST-6 detector to see a larger patch of the sky, thus it is useful for deep-sky imaging. Even though the 8-inch telescope has less light-gathering capability than the 18-inch, the sensitivity of the CCD detector allows you to get a much brighter image than what you can see with your eye through the 18-inch. The field of view of the CCD on the 8-inch is similar to that of the 16 or 18-inch with a 55mm eyepiece. This allows you to find your object with the 16 or 18-inch before taking a picture with the CCD.

II.1 How many times more light does the 18-inch telescope collect compared to the 8-inch?

Of prime importance is the field of view of the CCD camera. How much of the sky can it see? To determine this you must know two things: the plate scale and the size of the detector. The plate scale is a measure of the angular extent each pixel sees, which depends on the size of the pixels and the telescope to which the CCD camera is attached.

II.2 For the ST-6 CCD camera on the 8-inch f/6.3 telescope the plate scale is 3.8 arcseconds per pixel. The ST-6 camera is a 375 x 242 pixel array (meaning it has 375 pixels in each East-West row and 242 pixels in each North-South column). What is the field of view of the ST-6 camera when it is on the 8-inch?

III. Observations

The goal of this lab is to get pictures of at least three Messier objects. Depending on the size of the class, your instructor will gather you into groups of 2 to 4 students. Once in a group, follow the following steps for each object. Note: It is *essential* that you keep good records on each exposure and include all pertinent background information regarding equipment, technique, and exposure with each image or photograph. Don't make the same mistakes that Messier made! It's very frustrating to create a beautiful image but not know what it is or how it was acquired. Fill in *all* the information in the table on the next page.

III.1 Before you can look at an object you must first make sure that it is currently visible in the night sky. Use the planisphere on the South wall of the observing deck (or your own if you have one) to determine what constellations are currently visible. Also make sure the constellation is visible to the 16 and 18-inch telescopes. For example, constellations just now on the eastern horizon will not be visible (although they may be in a few hours.) Also, the roof makes it difficult to see objects to the North. Look at the Messier catalog and find objects within the constellations that you think are visible. Want help finding objects that look interesting? There are several books at the observatory that have pictures of many of the Messier objects. The display wall near the entrance of SBO may also help. And of course your instructor will have his or her favorites.

III.2 Will your object be too big to look at? Some of the Messier objects are very large and they may not fit in the field of view of the CCD camera. The Messier catalog in this lab lists the largest angular size for each object *in arcminutes* (1 arcminute = 60 arcseconds). Make sure your object will fit in the field of view of the CCD camera. If it doesn't you may want to choose another object.

III.3 Once you have an object you'd like to observe, ask the instructor or the assistant to move the 16-inch telescope to your object. This will confirm that your object is indeed visible to and accessible by the telescopes. If not, return to step III.1 and start over. Look at the object through the main eyepiece and confirm that it is there. It may be very faint and hard to see. Allow your eye a few minutes to let your eye adjust and use the "averted vision" technique to help you see it. Hopefully this will later give you an appreciation for the power of the CCD camera!

III.4 Now go to the 18-inch telescope and ask your instructor or assistant to move the telescope to your object. Guide the telescope so that your object is near the center of the field of view as seen through the 18-inch eyepiece. Ask your instructor to take a 30-second exposure. The picture will shortly appear on the screen. Ask the instructor to save the image to disk. *Be sure to record the filename of your object. Otherwise you will be unable to later determine which file is yours!*

III.5 Repeat steps III.1 through III.4 for at least two more objects. If time permits you may do more if you like.

Catalog Number	Object Type	Object Name (if any)	Constellation	Weather (e.g. clear, hazy, etc.)	Image Filename

IV. Image Analysis

Your instructor will return to you printed copies of you images. These are yours to keep so don't write on them! But before you take them home and hang them on your wall there's some science to be done with them. A property of an object that is of fundamental interest is its actual physical size.

IV.1 Determine the largest angular size of three objects you observed. Do this by measuring the width of your image to determining the scale of the image in arcminutes/cm (remember that you already know the field of view from II.2). Now measure your object along is longest length, and use the image scale to determine its largest angular size. How do these compare to the values given in the Messier catalog? Why might there be some discrepancy?

IV.2 Use the small angle approximation relationship (as discussed in other labs as well as a section in the introductory section of the manual) to determine the actual physical size of your three objects. The distances to each object are also listed in the Messier catalog in units of kilo-light years (kly). Give your answers in appropriate units (light years, Astronomical Units, etc.) e.g., centimeters are not suitable for galaxies!

V. Fame and Fortune

The Observatory conducts a contest for the “Astrophoto of the Month”, which may be either a CCD image taken at Sommers-Bausch, or a standard photograph of a celestial object. If you think your finished work is of sufficient quality to have it exhibited for others to see, consult the contest rules on the observatory’s website (located at *http://cosmos.colorado.edu/sbo/gallery/contest.html*) and make an entry or two! Besides notoriety, you’ll also receive a (very) modest reward if you win!