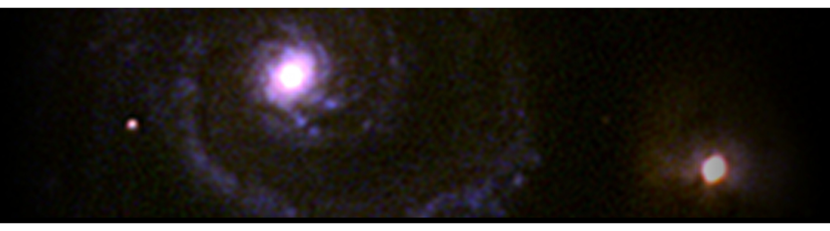
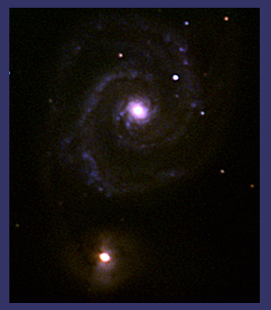


Color Imaging of Celestial Objects

M51 – *The Whirlpool Galaxy*



The aptly-named *Whirlpool Galaxy* was the first galaxy that we decided to capture. Its size was perfect for the dimensions of the camera, and most importantly, its colorfully-distinct, interesting features make M51 a wonderfully photogenic target. A mere 23 million light-years away, M51 is among our closest spiral galaxies.

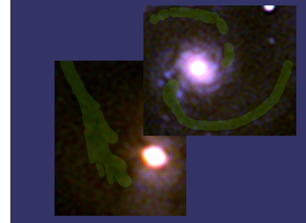
Companion

M51's most distinct feature is its companion galaxy, NGC519. Even with an amateur telescope, one can distinguish it from M51. Its distinctly red-orange tint and amorphous structure indicates a stellar population consisting mostly of old, long-living stars.

Spiral Arms

The bluish-gray color of the spiral arms of many such galaxies comes from the illumination of hot, young stars, which give off a lot of blue light and ultraviolet radiation. These stars form in *H II Regions*, which are dense clouds of hydrogen, ionized by the radiant energy of such newborn stars. With larger telescopes, a red tint caused by the ionized hydrogen can be seen in these regions, and is commonly emphasized.

Dust Lanes



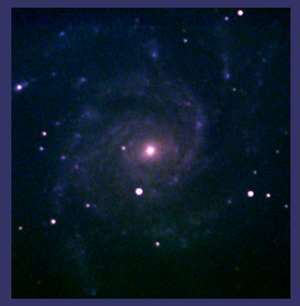
These bands of darkness are caused by immense clouds of interstellar "dust" which consists of cool gas, molecules and small particles. Given their dark nature, it's easy for them to go unnoticed; they can only be seen by blocking the light behind them. Thus, they are most visible near M51's nucleus and a region of its companion galaxy.

The Messier Catalog

You'll notice that each of the objects we decided to photograph have a name which starts with an "M". Objects with such names are known as *Messier objects*, named after an 18th century French astronomer, Charles Messier, a man who had an affinity for comets. At the time, astronomical equipment was still quite limited by today's standards, and it was easy to mistake nebulous shapes in the sky for comets, so Messier made a catalog of all non-comet nebulae that he encountered and shared in the world, primarily to assist other comet aficionados.

Messier's catalog includes 103 of the largest and most visible nebulous objects that can be seen from the Northern Hemisphere. Today, they are popular targets for amateur astronomers. We deliberately chose our targets from this catalog, knowing that they would be our best shot at capturing details that would otherwise be very difficult to see.

M101 – *The Pinwheel Galaxy*

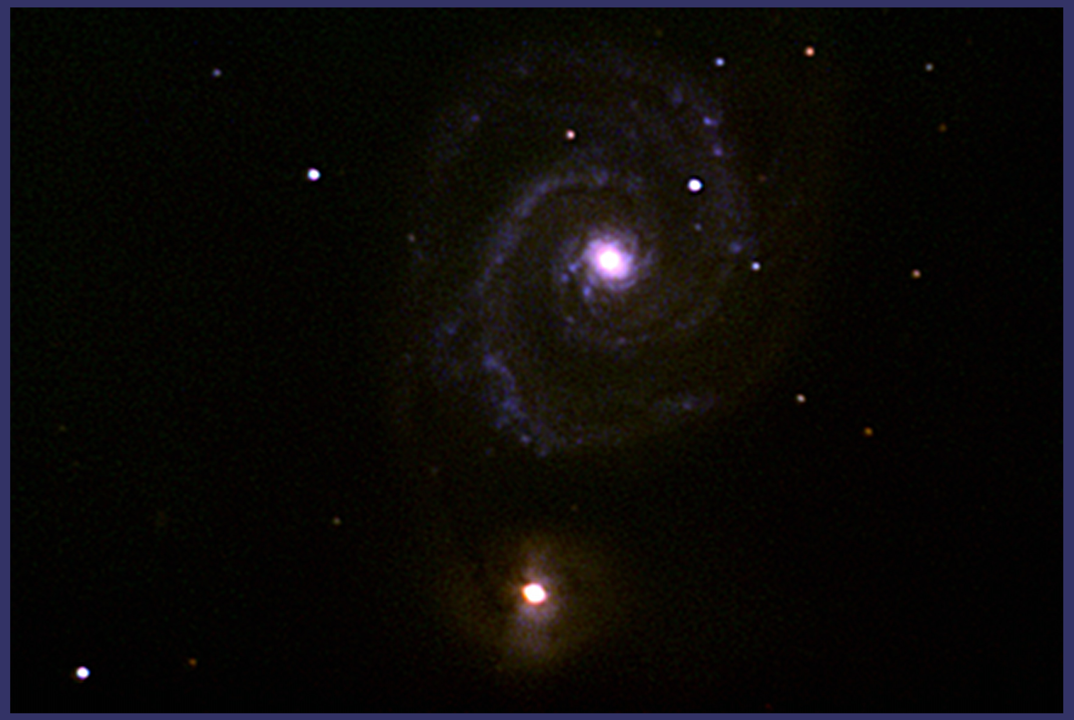


M101 is very similar to M51 in that they are both about 23 million light-years away and both spiral galaxies. M101, however, is visually larger, but also dimmer; therefore, it was significantly more difficult to capture, since it required a greater number of exposures, and couldn't fit fully in our camera's field of view.

Caveats

When photographing dim phenomena like M101, you need to take many long exposures (30 seconds or greater) to capture enough detail. Unfortunately, the Earth rotates, which means that the objects in the sky appear to move. To compensate for this, many modern telescopes of a certain quality will attempt to "track" the target object while it moves across the sky. Of course, these devices aren't perfect, and it's not uncommon for your target to drift out of view after several exposures.

Since M101 was significantly larger than any other objects we shot, many of the exposures were lacking a region of M101. The final image has been left un-cropped, and you can see where certain color filters missed entire regions (a few stars at the bottom appear very green, and the top of the image is noticeably dimmer). The moral of this story? Never turn your back on your telescope!



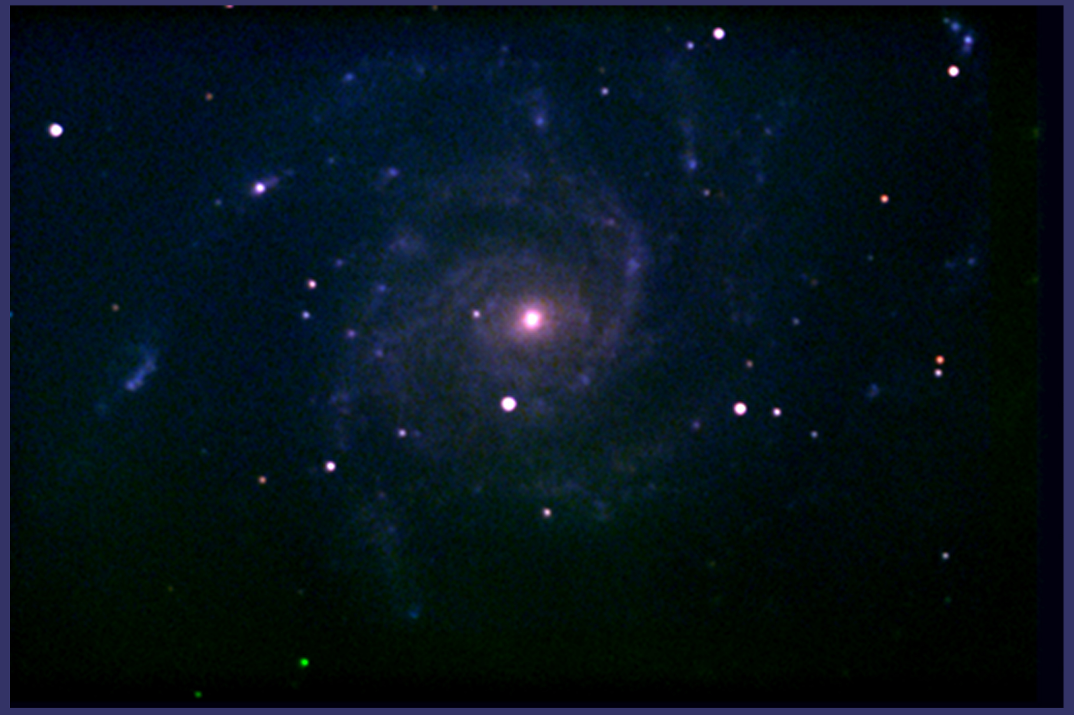
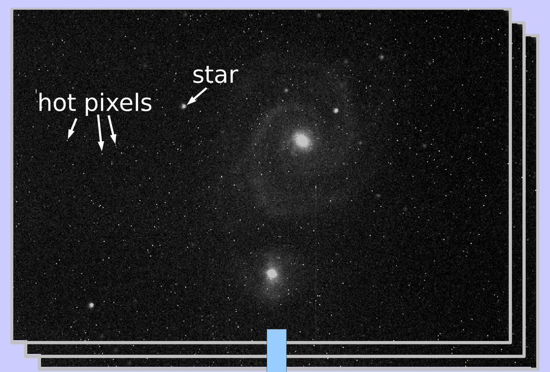
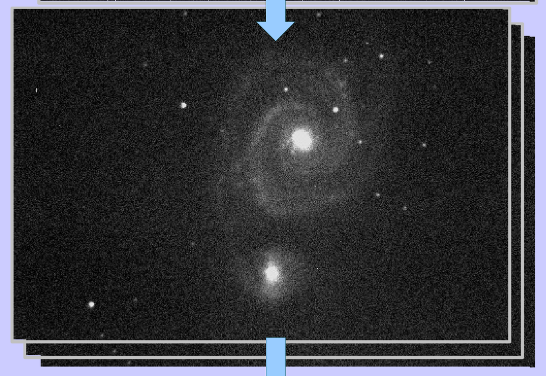
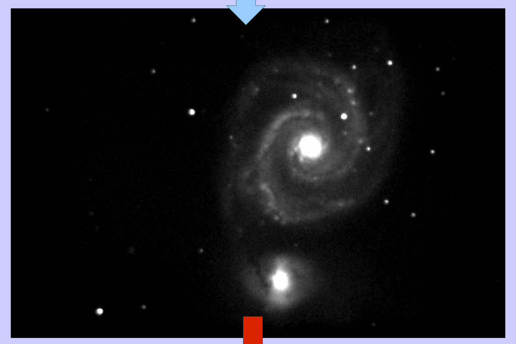
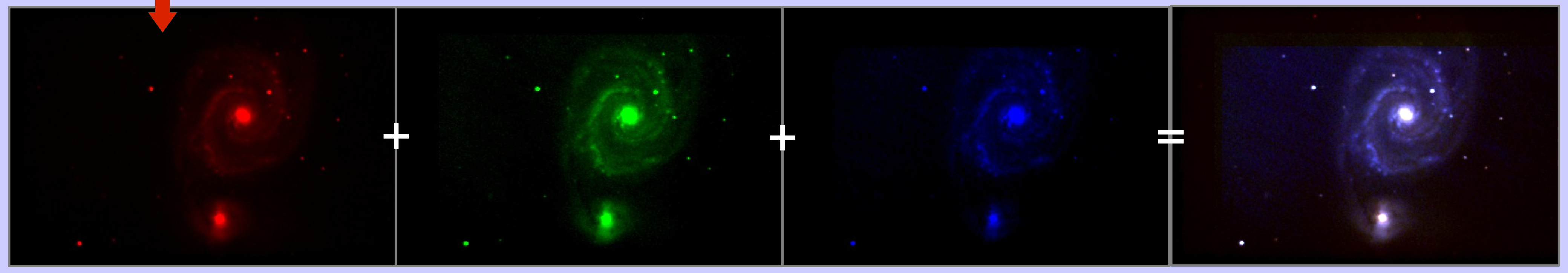


Image Processing









The Images first taken using the CCD camera yield a series of raw images that need processing. There are a number of problems with these images - random noise, 'hot pixels', dust on the mirror, and even satellites or cosmic rays can distort the images and make it difficult to see anything useful. Through a number of different techniques we can eliminate most of the noise and render some final high quality images. The first image on the left is an example of a raw image taken of M51. Take notice of the large amount of one pixel wide white dots that cover the image; these are not stars. The image is covered in 'hot pixels', which are false readings given by the CCD chip. Typically many of these raw images are taken (we took 30-60) in each of three different color bands: red, green, and blue.

To remove 'hot pixels' we first take a series of images with identical exposure time to the astronomical images we are going to take, but with the camera shutter closed. These are called 'dark-frame' images, and are taken simply to expose hot pixels. Taking the median of the series of these images will yield a dark frame image with an average value for all hot pixels, which is then subtracted from each 'raw' image. As you can see on the left, the result is a much cleaner image showing no random dots covering the image. However, there remains a problem, these images still have a lot of background noise, and as the example on the right shows, often times other problems can occur with individual images – in this case, a satellite passing through the field of view.

The next step in the process is to 'stack' images to try and weed out background noise and improve the signal of the actual object we are taking an image of. It also removes any random artifacts as we see on the example in the right. First the images in each band (red, green, blue) are shifted to align properly, and then stacked on top of each other and averaged to form a final stacked image. This image has the lowest noise and should be the clearest and best result from our raw data.

Finally, the stacked processed images formed from the raw data in each of our color bands are assigned color values and added together to get the final color image. This can be tricky since boosting any one of the three color values too much can lead to a false color image.

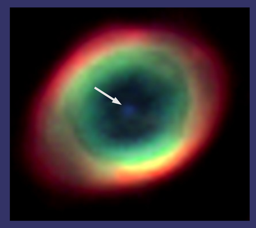
Planetary Nebulae

Confusingly named, *planetary nebulae* have little to do with planets, and much to do with stars; specifically, certain stars that are nearing the end of their relatively peaceful life cycle. As such a star reaches a certain size, it sheds its outer layers of gas due to an increase of internal pressure. These gases become ionized from energy being radiated from the remaining star, and emit colorful light depending on the type of gas and its degree of ionization. The result is a stunning display, typically spherical or elliptical in form. With a basic telescope or even binoculars, the largest and closest to our solar system are easily seen as gray, amorphous blobs, but only with long-exposure photography can their true majesty be revealed.

M57 – *The Ring Nebula*

The *Ring Nebula* is perhaps one of the most famous planetary nebulae in our galaxy (at least from the perspective of our solar system), due to its beautiful color bands and distinct appearance. Unfortunately, it's considerably smaller than the other three features we shot, so the finer details aren't as prominent. However, we chose M57 because of it's colorful reputation; we wanted to make sure that we'd capture some detail with each color filter, and for that it was a wise decision.

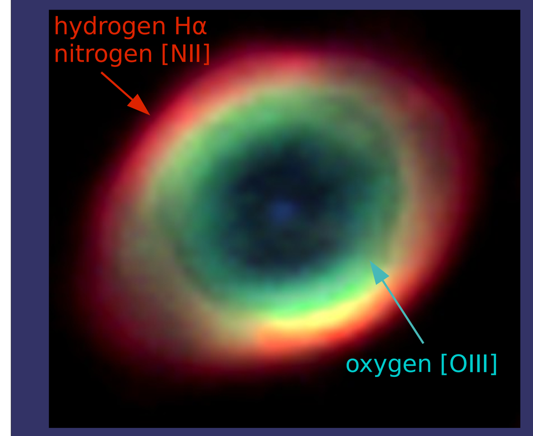
Central Star

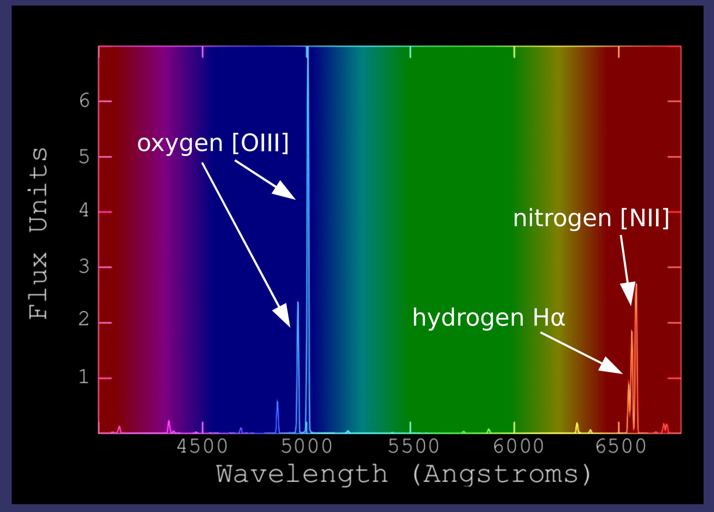


The beautiful colors of the Ring Nebula come from the layers of ionized gas which have been shed by a dying star known as a *white dwarf*. These types of stars are very dim in comparison to most other stars, but the star responsible for M57 can clearly be seen in our final image.

Color Rings

What gives the Ring Nebula its name are its beautiful bands of color. The outer red ring is primarily composed of ionized red and "hot" hydrogen – electrons orbit hydrogen atoms at a high energy state, and while moving to a lower state, release energy in the form of light with a very particular red wavelength. The remaining green-blue interior is primarily composed ionized oxygen. The spectroscopy graph below shows these distinct emissions (colors are approximate).





O'Dell, C. R.; Henney, W. J.; Sabbadin, F.
Tangential Motions and Spectroscopy Within NGC 6720, the Ring Nebula
The Astronomical Journal, Volume 137, Issue 4, pp. 3815-3825 (2009)

M27 – *The Dumbbell Nebula*

Of all nearby planetary nebulae, the Dumbbell Nebula is the biggest and brightest. It is so bright, that the luminosity of the nebula alone is 100 times that of our Sun's. On a dark night, it can be seen with ordinary binoculars. It's no wonder, then, why M27 was the first planetary nebula added to the Messier catalog. In fact, M27 was the first planetary nebula of any kind to be discovered. Like the *Ring Nebula*, the red clouds seen mostly on the edge of the nebula come from hydrogen, while the blue gas comes from ionized oxygen.

Central Star

Like M57, the Dumbbell's central star is also clearly visible in our exposure – much more so, even. In fact, for such a star (a white dwarf), it is unusually bright. With a radius of about 1/20th of our Sun's, and weighing about half as much, it is the largest known white dwarf observed by astronomers to date, which explains the nebula's sheer brightness.

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2010