Magnification vs. Resolution

Can you see the flag on the Moon?

About the Activity

Answering questions from your visitors regarding how much detail the telescope can resolve, such as “Can you see the flag on the Moon?”

Topics Covered

- How much detail can we see with our eyes?
- How much detail with backyard telescopes?
- How much detail with Hubble or Keck telescopes?
- Understand that the difference between magnification and resolution
- Basics to consider when purchasing a telescope

Materials Needed

- Moon Images Cards
- Star Mask Template
- Black construction paper (see Preparation below for how to make these)
- Flashlight
- Scissors
- Pins and nails of various thickness
- Adhesive tape

Participants

- Adults, teens, families with children 5 years and up.
- If using with a school/youth group, age 7 and older.
- From one person to fifteen participants

Location and Timing

These activities are perfect for use at a star party, with youth groups, or in the classroom. For exploring "Can you see the flag on the Moon?" you will want a dark environment, preferably outside.

- Can you see the flag on the Moon? (2 Presentation Options):
  3 - 5 minutes
- Magnification vs. Resolution - Moon Images: 5 minutes

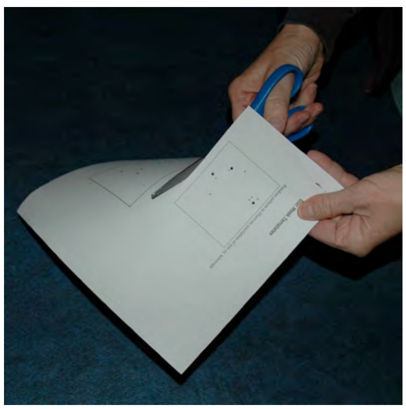
Additional astronomy activities can be found here: http://nightsky.jpl.nasa.gov

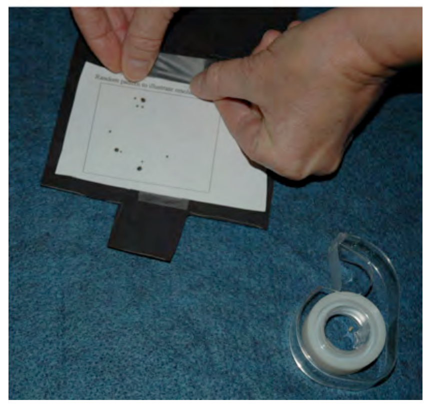
Preparation

To make your star mask(s):

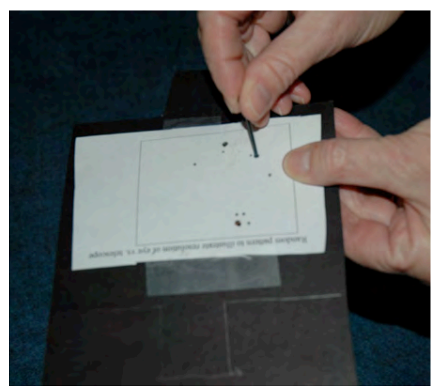
a) Place your flashlight on the black construction paper and draw a square that will cover the front of your flashlight, allowing for a tab (see photo >).

b) Cut out the Star Mask Template pattern and lay it on the square. Tape the template to the construction paper.





c) Use the nail to punch the larger holes and the straight pin to poke the small holes. (see photo >)



d) Remove the template.

e) Tape the star mask over the front of your flashlight.

Detailed Activity Descriptions

Can you see the flag on the Moon?

<table>
<tr><th>Leader's Role</th><th>Participants</th></tr>
<tr><td colspan="2">Key message for your visitors to take home:
Observing instruments, including your eye, have limited resolution.</td></tr>
<tr><td colspan="2">Materials: Flashlight with star mask, telescope</td></tr>
<tr><td>PRESENTATION OPTION # 1
<u>To Do:</u>
Stand at least 20 feet (6 meters or about 6 – 7 paces) away from your visitors. Shine the flashlight covered with the star mask toward your visitors.
<u>To Say</u>:
How many stars do you see?

<u>To Do:</u>
Move forward toward your visitors with the flashlight until you are about five feet (1.5 meters) away from them.
<u>To Say</u>:
Now how many stars do you see?

Just like your eyes have a limit to how much detail they can resolve at a particular distance, telescopes do too.
At the distance of the Moon, the smallest feature your eye alone can resolve is about 60 miles (100 km) across.</td><td>Can you see the flag/footprints on the Moon?

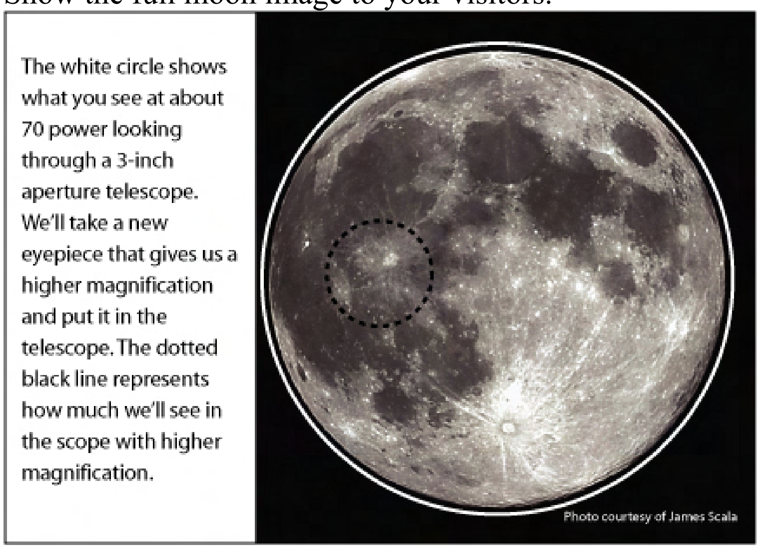
Say number.

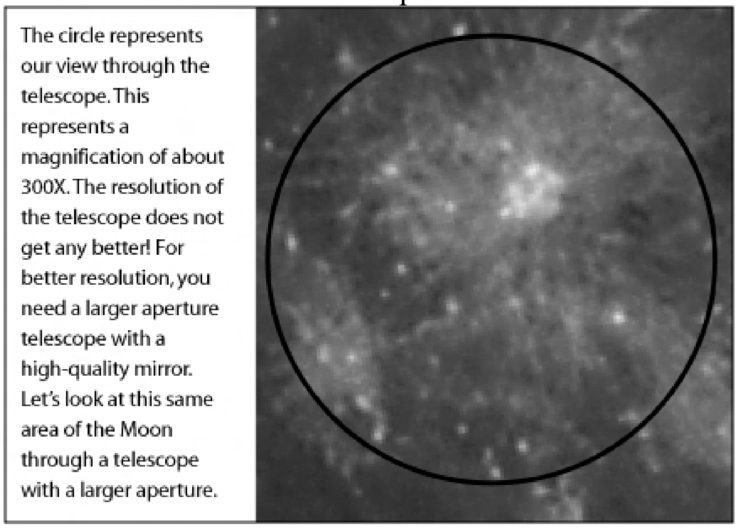
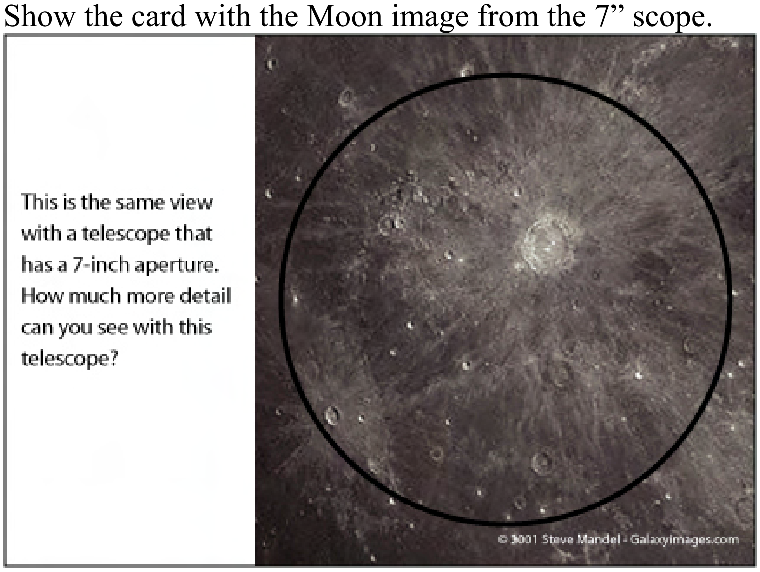
Say larger number.</td></tr>
</table>

<u>To Say</u>: Backyard telescopes can generally do about 30 – 60 times better than your eyes. Under the best of conditions, like dark skies and steady air, we might even do better than that. This scope can generally get about 60 times better resolution, so at the distance of the Moon, the smallest feature this telescope could resolve would be how big?	About a mile.
Right 1 mile. How big is a flag? About 3' x 5'	Smaller than that.
Can we see the flag on the Moon with this telescope?	No.
The Hubble can see about 1,200 times more detail than our eyes. At the distance of the Moon, that's about the length of a football field.	Can the Hubble telescope see the flag?
Would the Hubble be able to see the flag? We would need a telescope with 60,000 times better resolution than our eyes to see something as small as a flag on the Moon! That would have to be a telescope out in space with a diameter of over 450 feet! (one and a half football fields or the height of a 45 story building). But take a look through the scope and tell me what you can see!	No.
Presentation Tip: See the discussion under "Background Information" about adaptive optics on the Keck telescope on Mauna Kea in Hawaii.	

Leader’s Role	Participants’ Roles (Anticipated)
Key message for your visitors to take home: Observing instruments, including your eye, have limited resolution.	
Materials: Flashlight with star mask, telescope.	
PRESENTATION OPTION # 2 *To Do:* Place the flashlight with star mask about 50-60 feet away (about 3 to 4 car lengths or about 15 – 20 paces) on a table or chair. Turn on the flashlight. Set up a telescope to point at the flashlight. *To Say:* See that light over there? It represents a field of stars. How many stars do you see?	Say number.
Let’s see if the telescope can allow you to distinguish more stars.	
To Do: Have each visitor view flashlight through telescope. *To Say:* How many stars do you see now?	Say larger number.
These telescopes have much better resolution than our eyes do – about 60 times better. You can see with the telescope from 60 feet away the same that you’d see with your eye from one foot away.	
Look at the Moon. At the distance of the Moon, the smallest feature your eye alone can resolve is about 60 miles (100 km) across. Since this scope can generally get about 60 times better resolution than your eye, at the distance of the Moon, the smallest feature this telescope could resolve would be how big?	A mile.
Right 1 mile. So can we see a 3-foot by 5-foot flag on the Moon with this telescope?	No.
To Do: If the Moon is visible, re-position your telescope on the Moon. Have each visitor view the Moon through the telescope. *To Say:* Tell me what you CAN see.	

MAGNIFICATION vs. RESOLUTION

Leader's Role	**Participants' Roles (Anticipated)**
Key message for your visitors to take home: Magnification is determined by the eyepiece used, not by the size of the telescope. Resolution – or how much detail you can see – depends primarily on the aperture of the telescope (assuming the equal quality of the primary lens or mirror). Higher magnification might make it easier for your eye to perceive the detail the telescope is capable of giving you, but the telescope cannot collect any more detail (in other words, get better resolution) with higher magnifications.	
Materials: Moon image cards or "MoonMagnify.ppt" PowerPoint Optional (you supply): paper towel tubes.	
<u>*To Do :*</u> Show the full moon image to your visitors.  *(Optional*) Have your visitors look through a paper towel tube to simulate looking through a telescope. <u>*To Say*</u>*:* The white circle around the Moon shows what you see at a magnification of about 70 times looking through a 3-inch aperture telescope. What are we looking at? Do you think we'll see a lot more detail if we magnify this? We'll take a new eyepiece that gives us higher magnification and put it in the telescope. The dotted black line represents how much we'll see in the scope with under higher magnification. Let's see what that looks like.	The Moon! Yes.

Leader's Role	**Participants' Roles (Anticipated)**
<u>To Do:</u> Show the card with the close-up of the moon in the 3" scope.  *<u>To Say:</u>* The circle represents our view through the telescope. This represents a magnification of about 300X. How do you like this? The resolution of the telescope does not get any better. For better resolution, you need a larger aperture telescope with a high-quality lens or mirror. Let's look at this same area of the Moon through a telescope with a larger aperture and a high-quality lens.	It's OK. Pretty fuzzy.
<u>To Do:</u> Show the card with the Moon image from the 7" scope.  *<u>To Say</u>:* This is the same view with a telescope that has a 7" aperture. How much more detail can you see with this one?	A lot!

<table>
<tr><th>Leader’s Role</th><th>Participants’ Roles (Anticipated)</th></tr>
<tr><td><u>To Say</u>:
Although other telescope characteristics, like magnification, are sometimes referred to as the telescope’s “power”, the “power” of the telescope is not how much the image is magnified. It is primarily the size of the primary lens or mirror - how big around the telescope is.

So when you go to buy a telescope, pay more attention to the diameter, or aperture, of the telescope and the quality of the mirror or lens, not the claimed magnification. Larger diameter telescopes collect more light from the object you are viewing. The diameter, or aperture, of the telescope is one of the primary factors that determines how bright the image is and how much detail you will see when you use an eyepiece to magnify the view.</td><td></td></tr>
<tr><td><u>Presentation Tip:</u>
Here is additional information to help your visitors understand:

As you increase magnification, the amount of sky you are looking at generally gets smaller* - you are looking at a smaller amount of the object you are viewing. The amount of light the telescope is gathering does not change. The resolution of the telescope does not change. The eyepiece allows you to pick how much of that area of sky you want to view. Higher magnification might make it easier for your eye to perceive the detail the telescope is capable of giving you, but the telescope cannot collect any more detail (in other words, get better resolution) with higher magnifications.

*Different eyepieces with the same focal length or magnification can have different fields of view. For example, after looking at the moon through a low-magnification eyepiece that allows you to see the entire disk of the moon, it is possible to switch eyepieces to one with both a higher magnification and a larger field of view, enabling you to still see the whole moon, but at higher magnification. The field of view decreases as the magnification increases only if the two (low- and high-magnification) eyepieces are the same type.</td><td></td></tr>
</table>

Background Information

Hold your index finger at arm's length against the sky. That's about 1 degree of sky. Close one eye. What can you cover with your finger – in this room? Outside the window? What's the farthest thing you can cover up?

A circle has 360 degrees. Each degree can be divided further into 60 minutes of arc. These are called arc minutes, abbreviated "arcmin".

A 20/20 eye has a resolution of about 1 arcmin. An arcmin is the apparent thickness of an unfolded small paper clip about 8 feet away. Close one eye – what does one arcmin cover – in this room? Outside?

1. As you increase magnification (by using different eyepieces), the amount of sky you are looking at will generally get smaller - you are looking a smaller amount of the object you are viewing. The amount of light the telescope is gathering does not change. The resolution of the telescope does not change. The area of sky the scope is collecting light from doesn't change. The eyepiece allows you to pick how much of that area of sky you want to view. It's very much like taking a photo and zooming in on a small area of that photo. Higher magnification might make it easier for your eye to perceive the detail the telescope is capable of giving you, but the telescope cannot collect any more detail (in other words, get better resolution) with higher magnifications.

2. NASA telescopes for the most part have a fixed field of view. You can "magnify" the images obtained from such telescopes by enlarging them, but you will not get any better resolution.

Resolution of the telescope

Each arc minute ("arcmin") can be divided further into 60 arc seconds, abbreviated "arcsec".

Our (amateur) telescopes generally have a lower resolution limit of one arcsec. That's about the apparent thickness of an unfolded paperclip about 160 yards away – (about one and a half times the length of a football field). The Hubble Space Telescope has a best resolution of about 0.05 arcsecs. That's about the apparent thickness of the unfolded paper clip almost 2 miles away.

(Chandra has a resolution of 0.5 arcsecs and Spitzer about 4 arcsecs.)

See the chart "**Smallest Resolvable Features**" below. This shows the smallest resolvable feature of various objects visible in telescopes.

On the same page is a list of the stars with the largest angular diameters. Since the stars for the most part are less than 1/1000 of an arcsec across, the stars are not resolvable as disks in our telescopes since they subtend angles much smaller than one arcsec. They are bright enough to see but not big enough to resolve into a disk, like you can with a planet.

So, when your visitors look through the telescope at stars, the stars are actually going to appear smaller than when they look at them naked eye.

Our eye's smallest resolution is generally one arcmin. So the stars are going to appear to our eyes to be at least one arcmin in size. The telescope's smallest resolution is one arcsec, so the stars in the scope will appear much smaller than one arcmin, but no smaller than one arcsec. Think of a grid of pixels on a CCD chip. If we apply the pixel analogy to our eye and the telescope, our eye's "pixel" is one arcmin across and a telescope's "pixel" is one arcsec across. See the examples and discussion below under "**Why don't the stars look bigger in the scope?"**

The Keck Observatory, Adaptive Optics, & Resolution

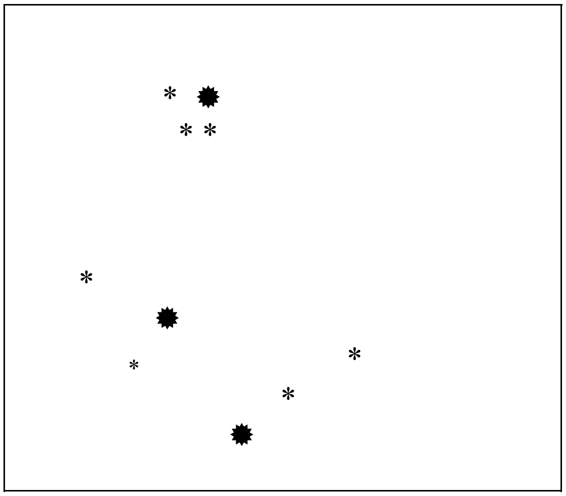
This is from Laura Kraft, Public Information and Outreach Officer, W. M. Keck Observatory, California Association for Research in Astronomy:

> *We cannot see in optical bands (visible light) with adaptive optics. I explain the reason below in Note 1.*
>
> *Our highest possible resolution is actually with the Keck Interferometer (see Note 2). I only mention it because we get .005 arcsecond resolution at 2.2. microns with the Interferometer (wow!), the effective resolution of the distance between Keck I and Keck II, which is the equivalent of an 85-meter telescope. The interferometer only works in near- and mid-infrared wavelengths (up to 10 microns).*
>
> *Here is my best summary:*
>
> *BEST RESOLUTION/Optical/AO-OFF/FOV*
> *Limited to the seeing of Mauna Kea. Generally averages at 0.4-0.6 arcseconds. Largest field of view possible with an instrument is 16.7 arcminutes by 5 arcminutes (DEIMOS).*
>
> *BEST RESOLUTION/Near Infrared/AO-OFF/FOV*
> *Best ever seen is 0.15 arcseconds at 2.2 microns. A number affected by seeing. FOV varies, but the wide-field camera on the best instrument for Keck AO (NIRC2) is 40x40 arcsecs.*
>
> *BEST RESOLUTION/Near Infrared/AO-ON/FOV*
> *0.045 arcseconds at 2.2 microns. Wide field camera is 40x40 arcsecs.*
>
> *Here are the notes:*
>
> *1: Visible light is taken from the focused light and used to guide the*

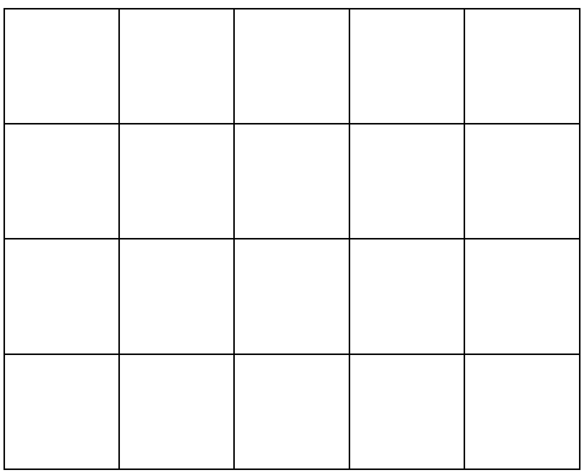
wavefront sensor, which tells the computer what the atmosphere is doing, and then the computer knows how to correct for the longer infrared light. To use adaptive optics with visible light, (on the Keck system) you would need to feed a shorter-than-optical wavelength of light into the wavefront sensing camera so that the system could correct for visible light. In other words, to split a wavelength shorter than the one you are working with to have it guide your camera. So Keck can only look at wavelengths longer than optical with adaptive optics.

2: Interferometers use synthesis imaging to construct an image from measurements of the object's Fourier transform function. (http://mathworld.wolfram.com/FourierTransform.html).

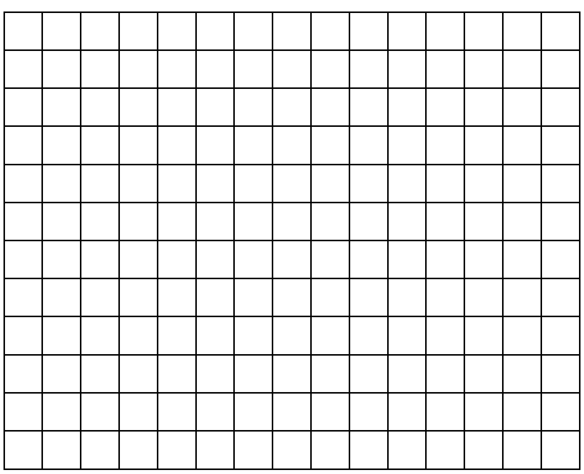
Why don’t the stars look bigger in the scope?



The top square on the left shows simulated sizes and locations of stars in a small area of the sky
(not to scale)

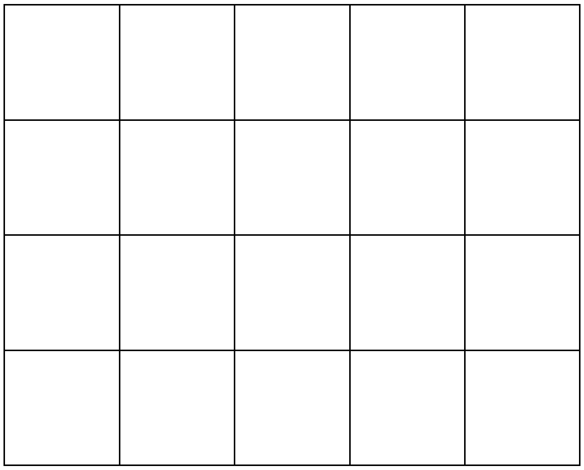


The middle grid on the left represents your eye as a CCD chip. Overlay this grid on the star field above and color in each square where there are no stars. The white squares will represent the light your eye will see.
See example next page.
How big will the stars look with your eye? Will you be able to distinguish all the individual stars?

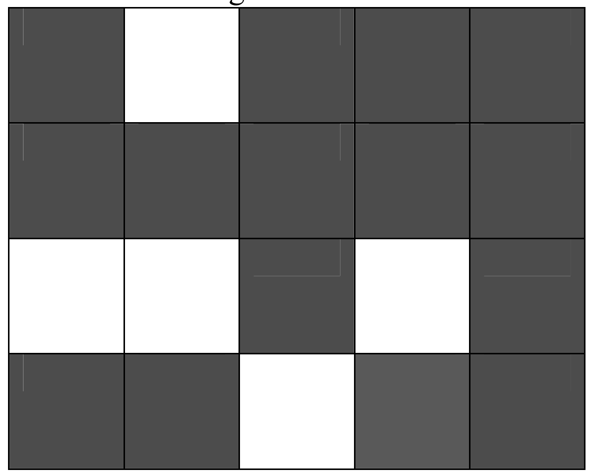


The bottom grid on the left represents the telescope’s view as a CCD chip (not to scale!). Telescopes have a much better resolution that the eye. Overlay this grid on the star field above and fill in each square where there are no stars. The white squares will represent the light you will see in the telescope.
See example next page.
How big will the stars look in the telescope?

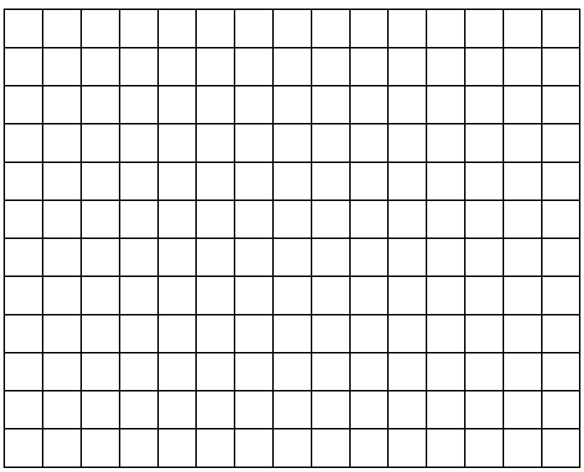
Using the “Example Star Field” below…

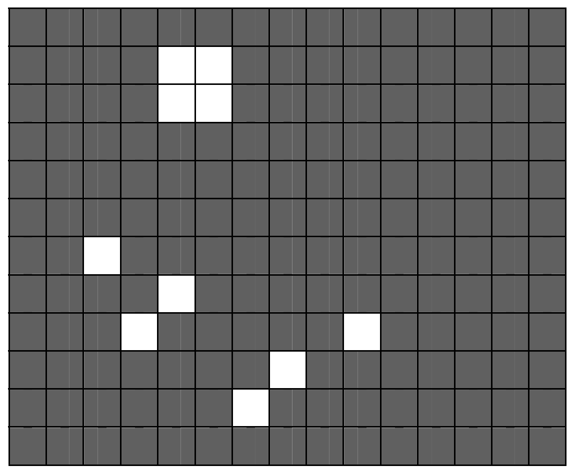


… the filled in grids would look like these.



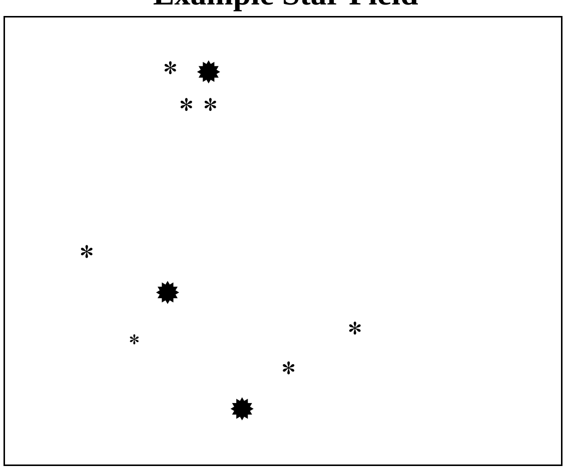
With your eye, you’d see 5 “big” stars.





With a telescope, you’d see all 10 stars and they would look smaller in the field of view.

Example Star Field



Smallest Resolvable Features

Object	**Distance from Earth**	**Size of 1 arcmin at distance of Object**	**Size of 1 arcsec at distance of Object**	**Hubble 0.05 arcsec**
Moon	240,000 miles	60 miles	1 mile	1/20th of a mile or about the length of a football field
Jupiter	Close approach about 425 million miles	125,000 miles (Jupiter's diameter is 88,000 miles!)	2,000 miles	100 miles
Trifid Nebula (M20)	5,200 light years	1.5 lt yrs	0.03 lt yr	9 billion miles (about twice the distance across the Solar System)
Hercules Cluster (M13)	25,000 ly	7 light years	1/10 ly	30 billion miles
Whirlpool Galaxy (M51)	37 million ly	10,000 lt yrs	150 lt yrs	7 lt yrs

1 light year is almost 6 trillion miles

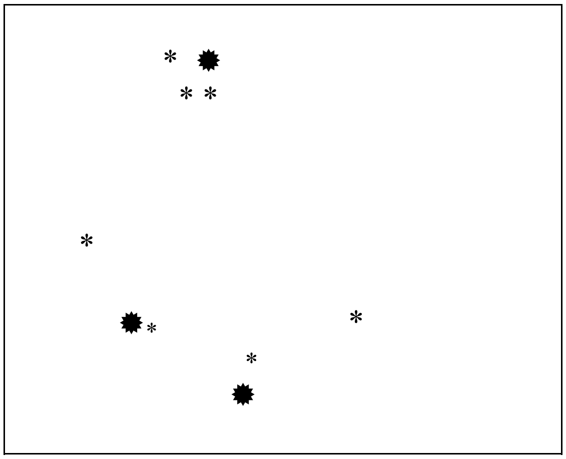
At the distance of the Moon, one arcmin is about 60 miles, 1 arcsec is about a mile – the smallest crater we can see in the scope would be about 1 mile across – so can we see the flag on the Moon? No.

Size of the stars: For the most part, the angular sizes of stars are less than 1/1000th of an arcsec. Here are some with the **largest** angular diameters.

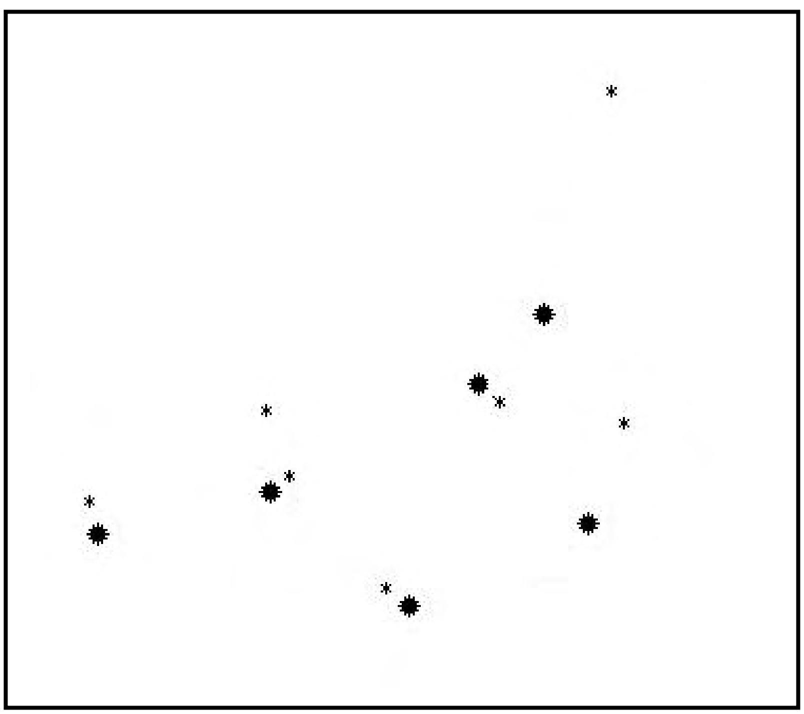
	Type	Distance (LY)	Diameter(arcsec)	Solar diameters
Betelgeuse	M1Ib	425	0.054	734.4
Antares	M1Ib	520	0.041	682.2
Proxima Centauri	dM5	4.2	0.007	1.0
Polaris	F7 Ib	430	0.00328	45

Star Mask Templates

Random pattern to illustrate resolution of eye vs. telescope



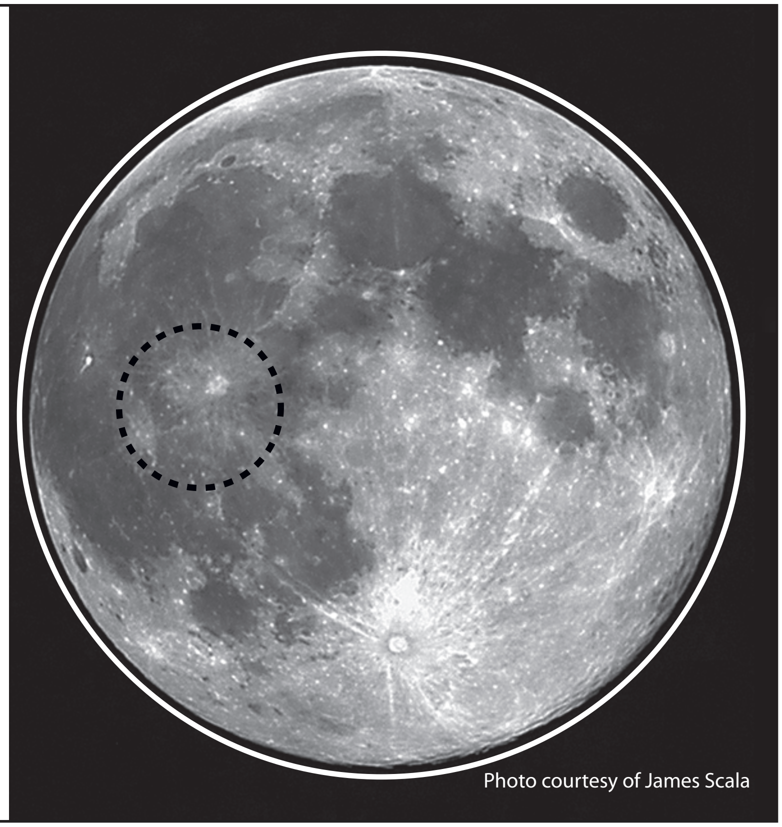
Simulates Pleiades



For instructions on making and using Star Masks, see the section "What do I need to prepare?" (on the previous page)

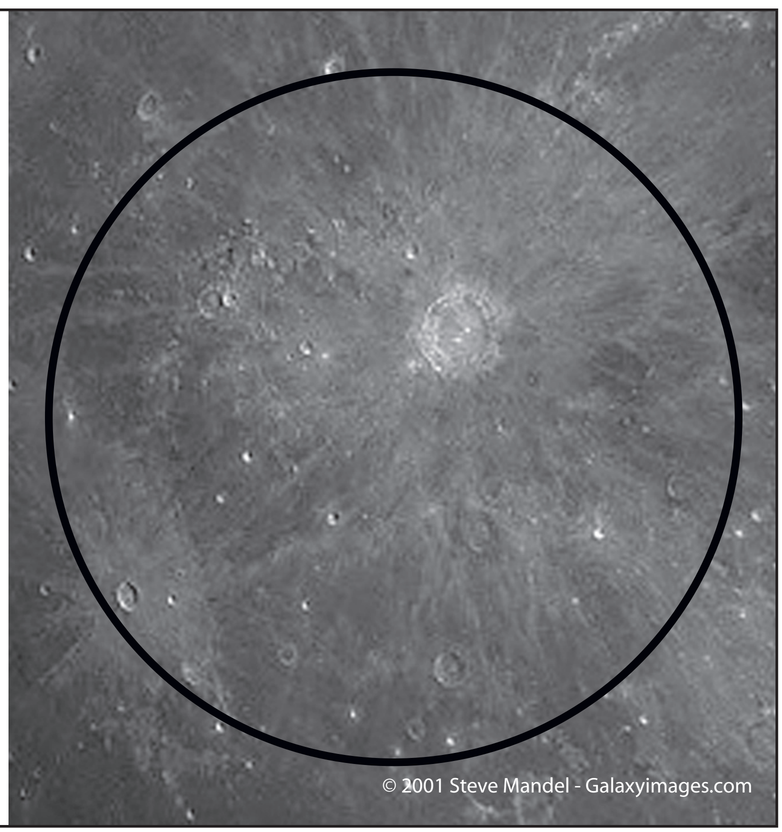
Moon Magnify: Sheet A

The white circle shows what you see at about 70 power looking through a 3-inch aperture telescope. We'll take a new eyepiece that gives us a higher magnification and put it in the telescope. The dotted black line represents how much we'll see in the scope with higher magnification.



Front #1

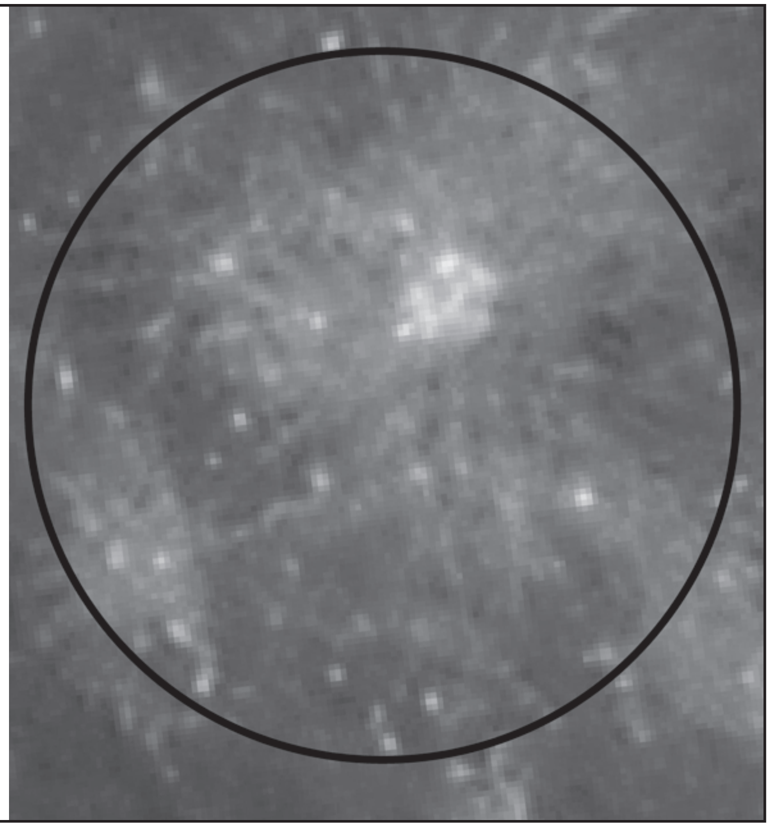
This is the same view with a telescope that has a 7-inch aperture. How much more detail can you see with this telescope?



Front #2

Moon Magnify: Sheet B

The circle represents our view through the telescope. This represents a magnification of about 300X. The resolution of the telescope does not get any better! For better resolution, you need a larger aperture telescope with a high-quality mirror. Let's look at this same area of the Moon through a telescope with a larger aperture.



Back #1

Although other telescope characteristics, like magnification, are sometimes referred to as the telescope's "power", the "power" of the telescope is not how much the image is magnified. It is primarily the size of the primary lens or mirror – how big around the telescope is.

So when you go to buy a telescope, pay more attention to the diameter, or aperture, of the telescope and the quality of the mirror or lens, not the claimed magnification. Larger diameter telescopes collect more light from the object you are viewing. The diameter, or aperture, of the telescope is one of the primary factors that determines how bright the image is and how much detail you will see when you use an eyepiece to magnify the view.

Back #2