How Did the Moon Get Inside My Telescope?

Barry Spletzer
Somehow, telescopes fool our eyes and cameras by squeezing light year sized objects into an 1-1/4 inch eyepiece and then making it look much bigger.
The Principle is Amazingly Simple

This is the what - without the why
The telescope must give our eyes what they ‘expect’ to see.
Only the few light rays entering the eye are used.
A point light source becomes a point on the retina - in the right place
All that is needed is that small bundle of light rays emanating from a point.

It's the ultimate optical illusion, our eyes cannot tell the difference.
These Two Very Different Arrangements Are Equivalent
An object forms a point-by-point image on the retina.

So many points will image an object.
This way, We can make a replica of an object

Even a tiny replica will work

How do we make the replica?
A Replica is a point-by-point reconstruction that is close to us

The replica is called an image
How do we do this?

.....first, the preliminaries
The Simplest Optical System
The Pinhole

Builds a point-by-point image on a plane by admitting very little light
Big pinholes are bright but blurry
The pinhole gives a clear dim picture or a bright fuzzy one.
For very bright objects, pinholes do a good job.
Optics tries to provide the best of both worlds

Fill the pinhole with glass to better control the light
Classic simple optical systems

Parallel light (starlight) is focused by a properly shaped mirror or lens
They must be the Proper Shape to 0.004 hairbreadth

Piece by piece, build up the parabolic shape

A lens can be spherical (easier) due to more design factors
Equally important, skew rays focus, too but not precisely.

There is no shape to focus both.
A lens/mirror is a big pinhole...except:

• It has a focal length
• Sharpness varies with angle
The blur grows quickly away from the center.

It also grows with increasing diameter.
But they focus light to the 'right' spots

Just like a pinhole
The center beam goes straight through
These Points Make an Image

The illusion (image) is complete
Telescope Terminology

Aperture \((D)\) - Mirror/lens diameter

Focal length \((L)\) - mirror-to-image distance

f-number or f-ratio \((f)\) - \(f = \frac{L}{D}\)

We identify scopes by \(D\) and \(f\)
SO FAR: A (very slightly) concave mirror or a lens makes an image

How does this make things look bigger?
Angular Size - The key to magnification

\[ \alpha = \frac{D_{\text{Sun}}}{L_{\text{Sun}}} = \frac{D_{\text{Moon}}}{L_{\text{Moon}}} = 0.0093 \]
The Sun is 400 Times the size of the Moon

But they look the same size
Closer and Smaller Can Look the Same

\[ \alpha = \frac{2160 \text{ mi}}{231,821 \text{ mi}} = \frac{0.11 \text{ mm}}{12 \text{ mm}} = 0.0093 \]

1/2 inch (12 mm)

0.004" (0.111 mm)
Much Closer and Sorta Smaller
Looks Bigger

231,821 mi

\[
\alpha_1 = \frac{2160 \text{ mi}}{231821 \text{ mi}}
\]

\[
\alpha_2 = \frac{2 \text{ mm}}{12 \text{ mm}}
\]

\[
\text{Mag} = \frac{\alpha_2}{\alpha_1} = 18 \times
\]

1/2 inch (12 mm)

0.08" (2 mm)
The Telescope and Angular Size

The angle is preserved (though inverted) through reflection or refraction.
Viewed from the mirror or lens (one focal length away)...

The angular size of the object and image are precisely equal

Regardless of the system
A magnifying glass will not focus the Sun to a point, but an image...

A small, very bright, upside down image
Remember...the ratio of angular size is the magnification.

Viewed from one focal length, the magnification is 1.0. From 1/2 focal length, it's 2.0 etc.

For a focal length of $L$, the image viewed from a distance $d$ is magnified by $L/d$.

It's how many times closer you are.
Closer is Bigger, but....
Our Close Vision Is limited

At 10 inches or more it’s OK

In close, we can’t bend the light enough and it gets blurry
What’s a Magnifier Anyway?
It lets us get closer than 10 inches

Magnification is defined by how much closer we can get
With just the primary mirror we are stuck with low magnification

6-inch f-3.0 it’s 1.8 x
10-inch f-4.5 it’s 4.5x
17.5 inch f-4.5 it’s 8x
A magnifying glass that straightens out the light
We’ve turned parallel light into parallel light

What an accomplishment
Remember Magnification

Magnification = \frac{L}{d}

Mirror Focal Length \( (L) \)
Eyepiece Focal Length \( (d) \)
It magnifies the angle...

...and thus the size
The eyepiece has a tough job

Fast primary mirror = 2 degrees FOV using
  \( f \)-number and diameter

Low end eyepiece = 40 degree FOV using
  refractive index, dispersion, face curvature, spacing, surface shaping
Rainbows aren’t always pretty

Prism

Simple Lens

Achromat
...but the hype

Wide Stellar Swaths

Aberrations

Spacewalk

Tack Sharp Images

Multicoated

Field Curvature

Long eye relief

Computer designed
Unending:
Variety,
Claims,
Expense
$25-$500
Eyepiece Cross Sections

Huygenian
Ramsden
Kellner
Plossl
Abbe
König

Erfle 5-Element
Erfle 6-Element
Nagler Type 1

Lots of glass costs money
There are advantages to fancy eyepieces

Wider field - more light bending
Sharper edge images - precise refraction
Better color - Multiple corrections
Sometimes brighter images - coatings
Field of View Varies Widely

- 40 mm König - 29x
- 56 mm Plossl - 20x
- 30 mm Plossl - 38x
- 13 mm Nagler - 88x
- 13 mm Plossl - 88x
- 8 mm Nagler - 140x
- 8 mm Plossl - 140x
Eyepiece FOV/True FOV = Magnification
Put It All Together
Remember the View From the Mirror

The Field stop/Focal length is the maximum field of view
Magnification is Cheap

• Short focal length (high X) eyepieces are cheaper (smaller, less glass)
• Barlows are simple lenses

But magnification isn't everything (or Tasco would be the best)
Magnification - Good and Bad

• Bigger
• Closer
• Dimmer
• Fuzzier
Barlow magic

A concave lens bends light out effectively lengthening the focus...

...and increasing magnification
More Light Combats Dimming

Constant surface brightness means $\text{Mag} = 4D$ (inches)

Bigger $D$ reduces fuzziness

More Light Is Expensive
For planets, brightness is not a big concern.

For deep sky, it is THE concern.
First Time Buying Advice

• What do you want to do?
  • Small scope for planets
  • Big scope for galaxies
• Check out the public TAAS events
• Spend on optics, not gadgets
  • Avoid fancy computerized scopes
• Don’t buy magnification
• TAAS members are a great resource
• With a TAAS membership there are loaner scopes from 3” to 13”
The Image Gives Us What We Expect
The Primary Makes the Image

But we can't see it well
Focal Length determines Image Size
The Eyepiece Finishes the System

True FOV

Field Stop

Apparent FOV
Eyepieces Are Complex and Varied

- Huygenian
- Ramsden
- Kellner
- Plossl
- Abbe
- König

- Erfle 5-Element
- Erfle 6-Element
- Nagler Type 1
A Primary Purpose is to Gather Light

1/4"

D
Bigger Is Not Always Better
Other Scope Types

- **Corrector plate**
- **Curved secondary**

**Schmidt-Cassegrain**
- Spherical primary
- Aspheric secondary
- Weird corrector

**Maksutov**
- All Spherical

**Meniscus**
Galileo’s Telescope

- Gives an upright image
- Doesn’t even use a “magnifying glass”
The Rules Apply