Physics Part 3
OPTICS

Into to Telescopes
Version for
CSUEB (8” Celestron)

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Telescope

Celestron C-8

Aperture 8”= 203 mm
Focal Ratio: f/10
Focal Length: 2030 mm

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Outline

A. Light Gathering Power and Magnitudes

B. Magnification

C. Resolution

D. References

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A. LGP

1. Magnitude Scale
2. Limiting Magnitude
3. Star Counts

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1. Magnitudes and Brightness

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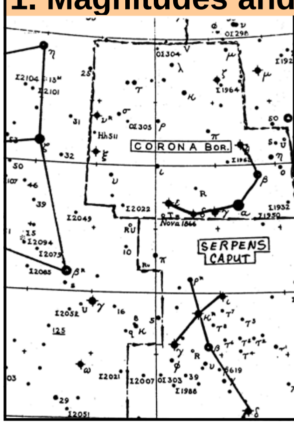
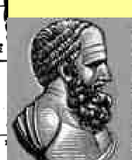
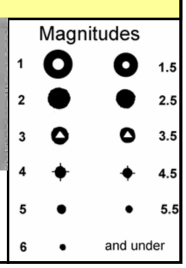


1. Magnitude Scale:
Hipparchus of Rhodes (160-127 B.C) assigns “magnitudes” to stars to represent brightness. The eye can see down to 6th magnitude





1b Herschel Extends the Table

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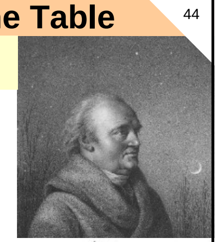
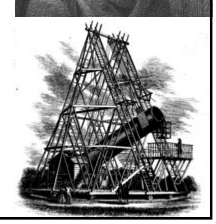
William Herschel (1738-1822) extended the scale in both directions

TABLE SC-VI Apparent Magnitudes of Various Objects

Object Name	Apparent Magnitude m	
Sun	-26.8	
Moon	-12.6	
Venus	-4.4	
Vega	+0.04	
Polaris	+2.	
Uranus	+6.	Visual Limit
Pluto	+15.	
Kitt Peak Limit	+24.5	
Space Tel. Limit	+28.	





1c Herschel-Pogson Relation

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Herschel's measurements suggested a 1st magnitude star is 100x more luminous that a 6th magnitude one. Norman Pogson (1854) showed that this is because the eye's response to light is logarithmic rather than linear.

$$\Delta m = -2.5 \text{Log}(r)$$

TABLE SC-V Magnitude Difference vs. Luminosity Ratio

Perceived Magnitude Difference=Δm	Actual Luminosity Ratio=r
2.5	10 times
5	100 times
7.5	10^3 times
10	10^4 times
12.5	10^5 times
15	10^6 times
17.5	10^7 times
20	10^8 times
22.5	10^9 times

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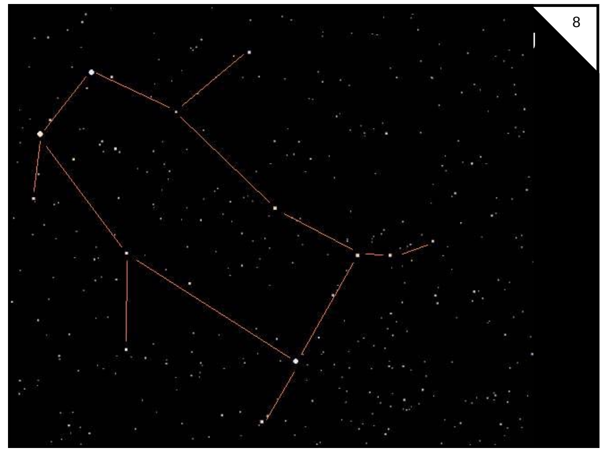

2a Light Gathering Power

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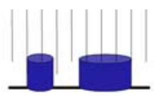
- Aperture=diameter of objective mirror (8 inch)
- Light Gathering Power (aka Light Amplification) is proportional to area of mirror



$$\text{LGP} = \left(\frac{\text{Aperture objective}}{\text{Aperture eye}}\right)^2$$

$$= \left(\frac{203\,mm}{6\,mm}\right)^2 = 1145$$

2b Limiting Magnitude

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- Telescope LGP in magnitudes:

$$\Delta m = 2.5 Log(1145) = +7.6$$

- Limiting magnitude of naked eye is +6, hence looking through scope we can see +13.6
- However, At SCU, limiting magnitude due to streetlights is perhaps +3.5, hence looking through scope we can see only up to +11

3a Number of Stars by Magnitude

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Magnitude Class	Range Included	Number by Magnitude	Cumulative Total
-1	-1.50 to -0.51	2	2
0	-0.50 to +0.49	7	9
+1	+0.50 to +1.49	13	22
+2	+1.50 to +2.49	71	93
+3	+2.50 to +3.49	192	285
+4	+3.50 to +4.49	625	910
+5	+4.50 to +5.49	1,963	2,873
+6	+5.50 to +6.49	5,606	8,479
+7	+6.50 to +7.49	15,565	24,044
+8	+7.50 to +8.49	21,225	45,269

•There are only about 15 bright (first magnitude and brighter) stars
•There are only about 8000 stars visible to naked eye
•There are much more stars with higher magnitude!

3b Number of Stars by Magnitude

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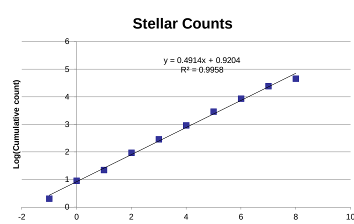

By extrapolating to magnitude +11, we might be able to see up to a million stars in our galaxy on an average night at Hayward

Note, the galaxy has perhaps 100 billion stars.

B. Magnifying Power

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1. Telescope Design
2. Magnification Power
3. Minimum Magnification

1. Basic Telescope Design

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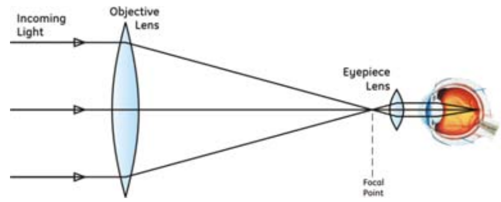
a. Refractor Telescope (objective is a lens)

Focal Length of Objective is big

Focal Length of eyepiece is small



1b Newtonian Reflecting Telescope

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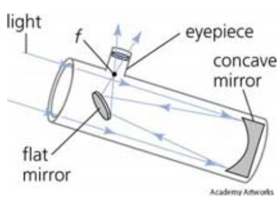
- Objective is a mirror
- Focal length is approximately the length of tube
- Light is directed out the side for the eyepiece



1c Schmidt Cassegrain Reflecting Telescope

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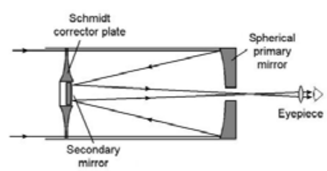
- Cassegrain focus uses “folded optics” so the focal length is more than twice the length of tube
- Light path goes through hole in primary mirror
- Schmidt design has corrector plate in front



2. Magnification Power

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The overall magnification of the angular size is given by the ratio of the focal lengths

$$Power = -\frac{F_{objective}}{F_{eyepiece}}$$

For our scope (F_o=80 inch=2032 mm), with a 26 mm eyepiece, the power would be:

$$Power = -\frac{2032\,mm}{26\,mm} = 78\times$$

3a. Too Much Magnification?

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- Extended objects (planets, nebulae, galaxies) when magnified more will appear fainter

Low Power High Power

3b. Too Much Magnification?

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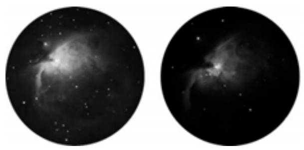
- Too much magnification and you won't see it at all!
- Its about surface brightness! Your eye can't see below a certain amount.



Low Power High Power

3c. Surface Brightness

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- "S" Units: magnitudes per square arcseconds. For object of total magnitude "m" over angular area "A" (in square arcseconds):

$$S = m + 2.5Log(A)$$

- S=22 is an ideal sky
- S=19 in suburbia
- S=18 if full moon is up
- S=17 in urban area

- Dumbbell Nebula has S=18.4, so if moon is up, probably can't see it, no matter how big of aperture you have! Can never see it in an urban area!

3d. Exit Pupil, minimum magnification

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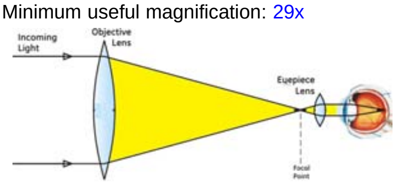
- Lower power is better for faint diffuse objects, BUT If the outgoing beam of light is bigger than aperture of eye (7 mm maximum), the light is wasted!
- Maximum useful eyepiece for our scope: $F_e = (7\,mm)\dfrac{F_o}{A_o} = 70\,mm$
- Minimum useful magnification: 29x



C. Resolution

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1. Acuity of Eye
2. Airy Diffraction
3. Limiting Resolution

1. Airy Diffraction

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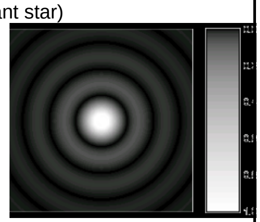
- Light through a circular aperture will diffract.
- Light from a point like object (distant star) will appear as a "blob" with rings.
- Size of blob: $\theta = 1.22\dfrac{\lambda}{A}$
  "A" is aperture,
  λ is wavelength
  θ in radians (multiply by 206,265 to convert to arcseconds)



- For our telescope (A=203 mm), for 500nm light the blob is 0.6". (Limiting Optical Resolution of scope is listed as 0.68").

2. Limiting Resolution

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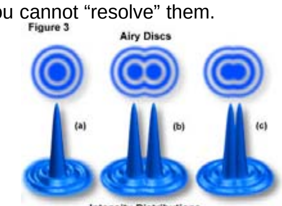
- If two stars are closer than the limiting resolution, the "blobs" will overlap and you cannot "resolve" them.
- Observing close double stars tests the quality of your optics.



- The maximum useful magnification is when the eye starts seeing these blobs, i.e. the diffraction disk is magnified to 2'=120". For our telescope, this is about at 120"/0.6"=200×, so an eyepiece smaller than 10 mm will start to show fuzzballs.

3 Acuity of the Eye

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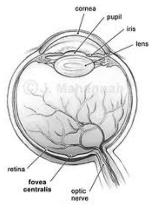
- Assuming aperture of 6.5 mm smallest detail eye can possibly resolve due to diffraction limit would be 20".
- **Acuity of Eye**: Fovea of eye has best resolution (this is what you are using to read), but spacing of "cone" receptors limits us to 1'=60"
- Hence Saturn (20") must be magnified at least 3x for eye to resolve it into a disk.
- Example: with magnification power of 100x, the smallest detail we can "see" with eye looking through scope is only 0.01'=0.6"
- Note, sky turbulence limits us to about 1", so above 60× we may see the star "dance" around.



D. References

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Notes

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