



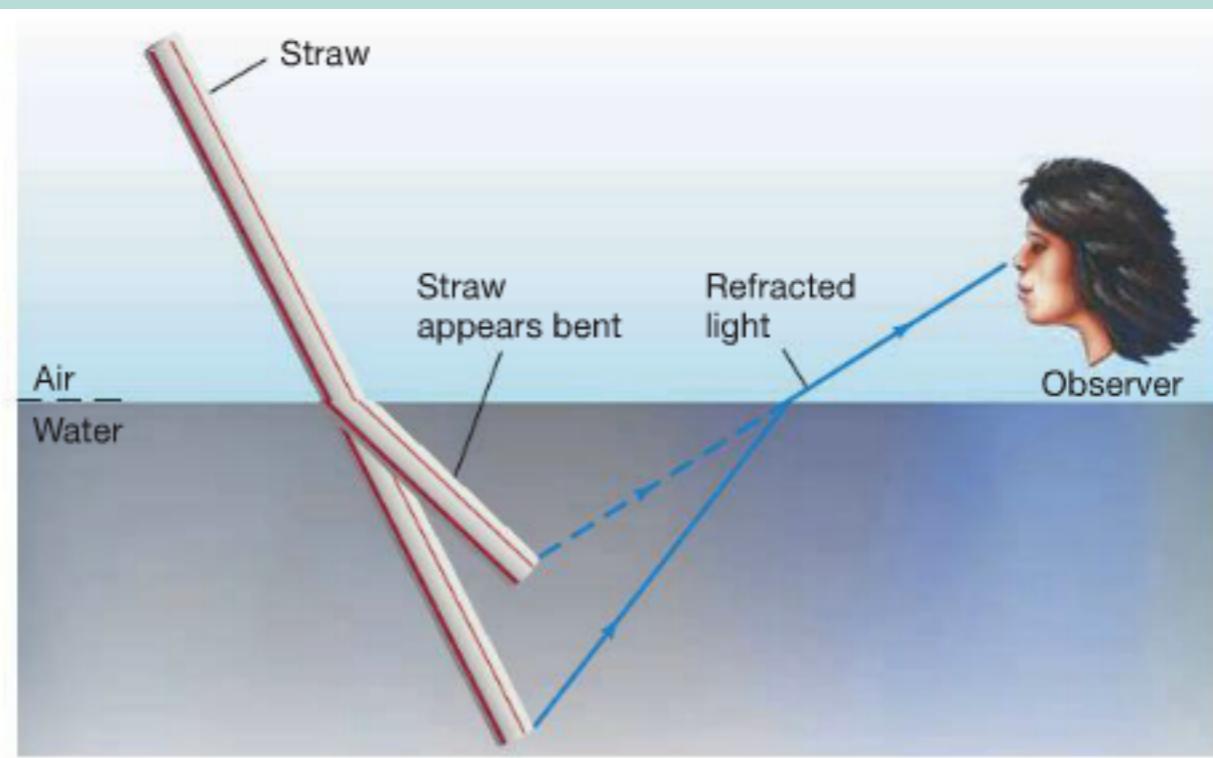
## Lecture 5: Telescopes

with your host:

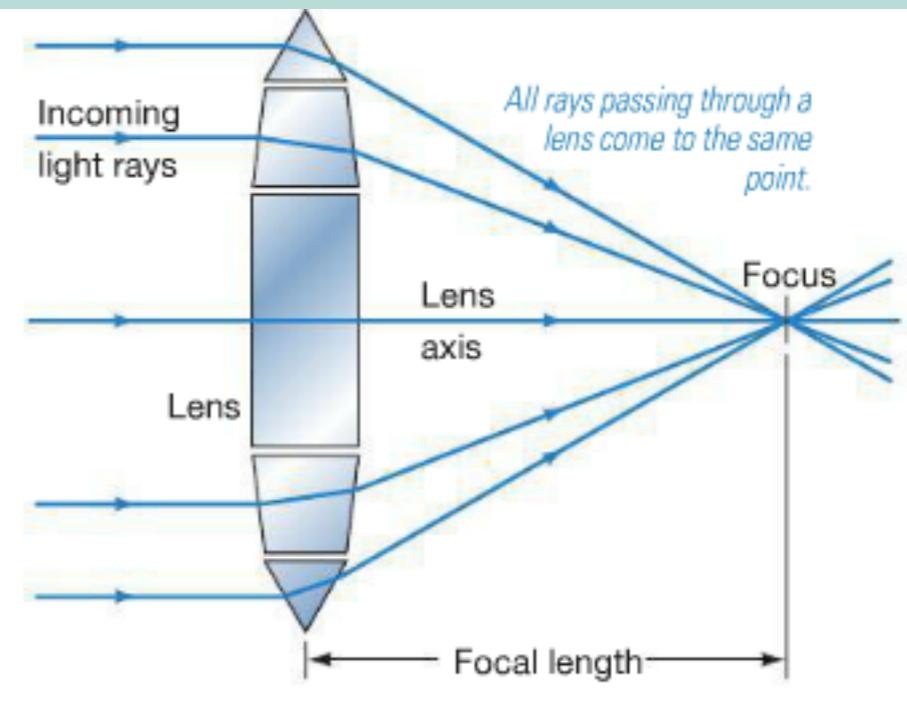
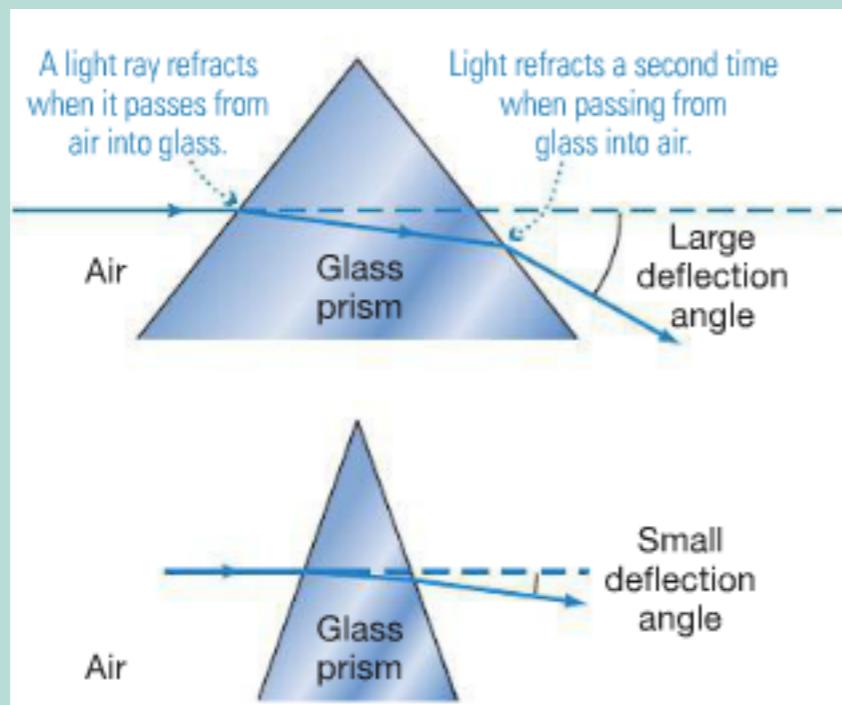


Coop

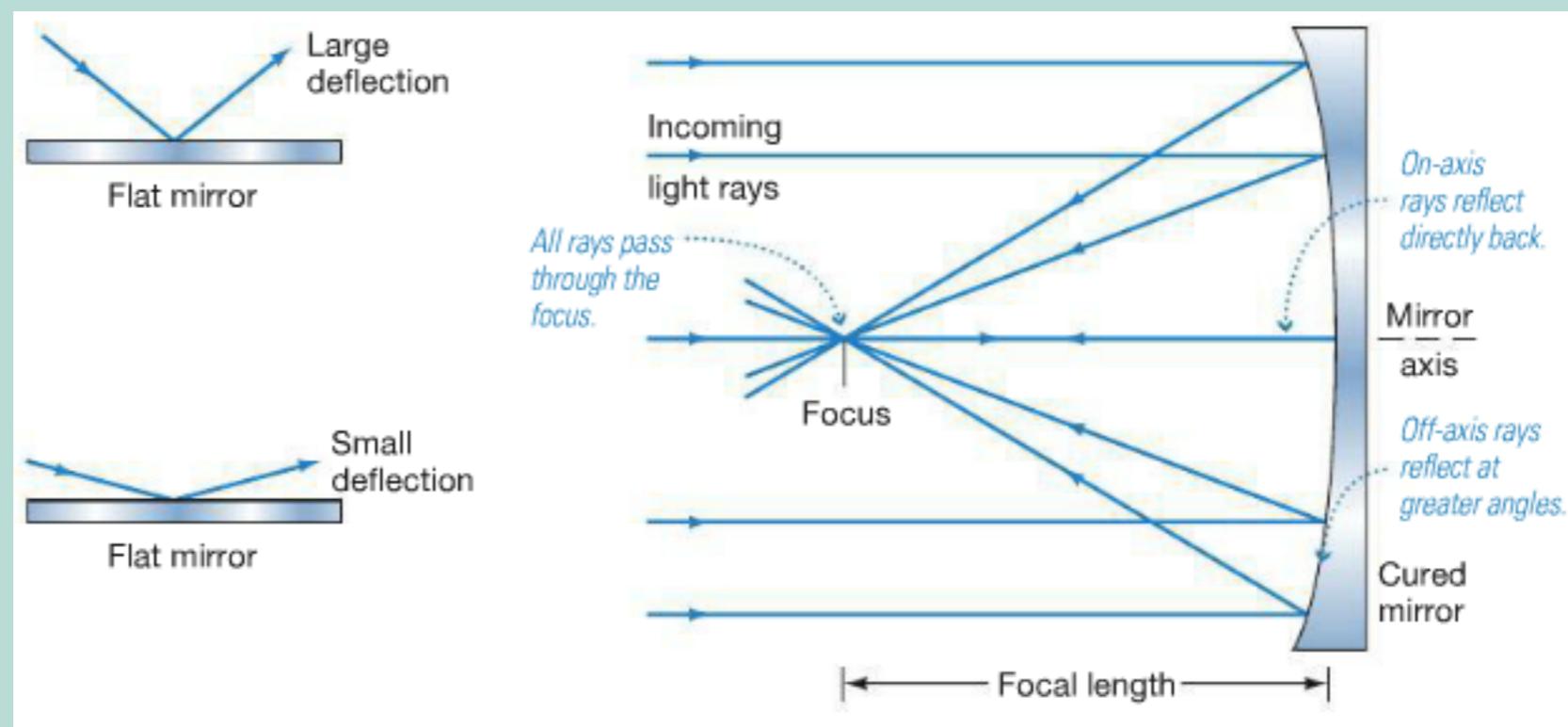
# Refraction



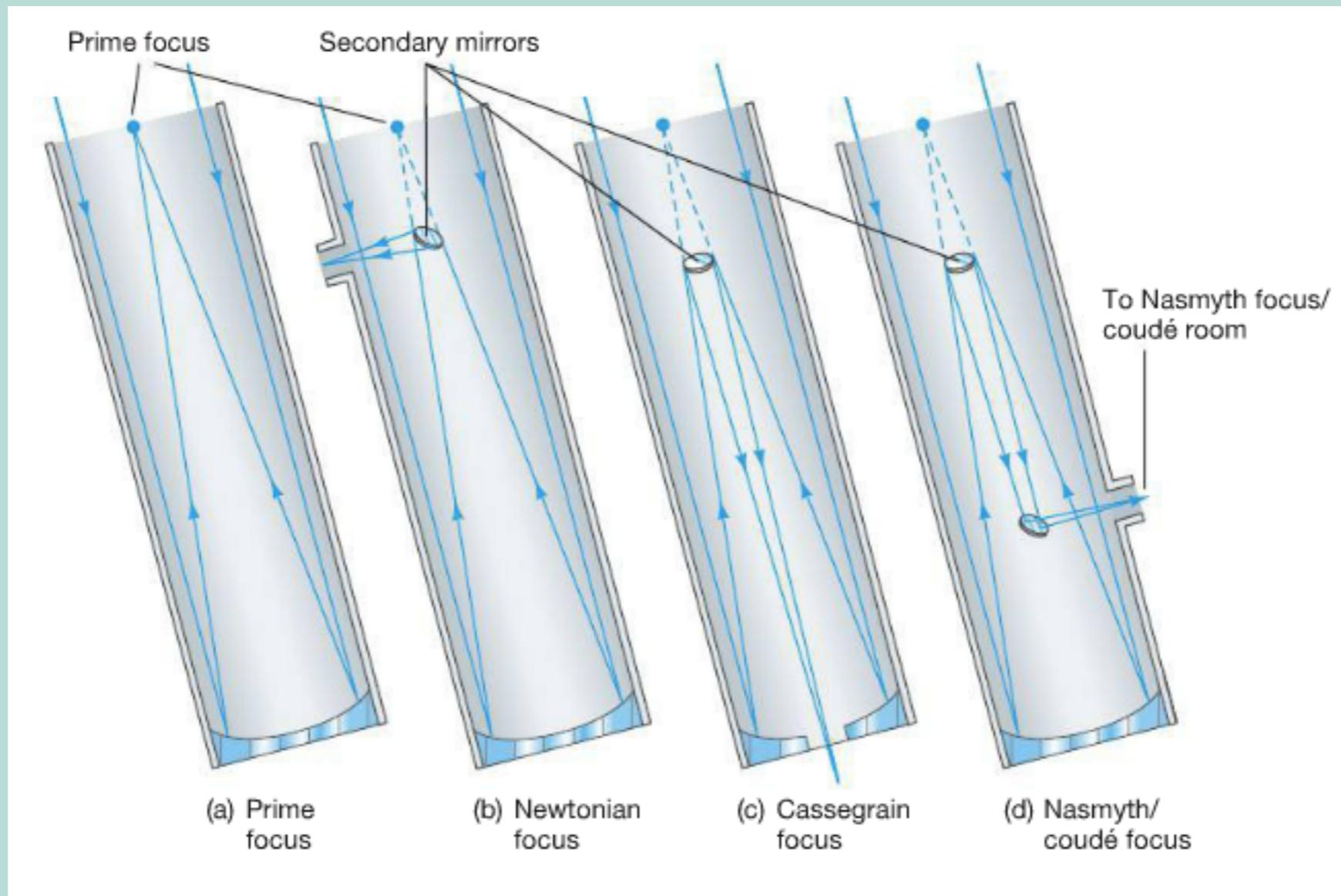
# Lenses



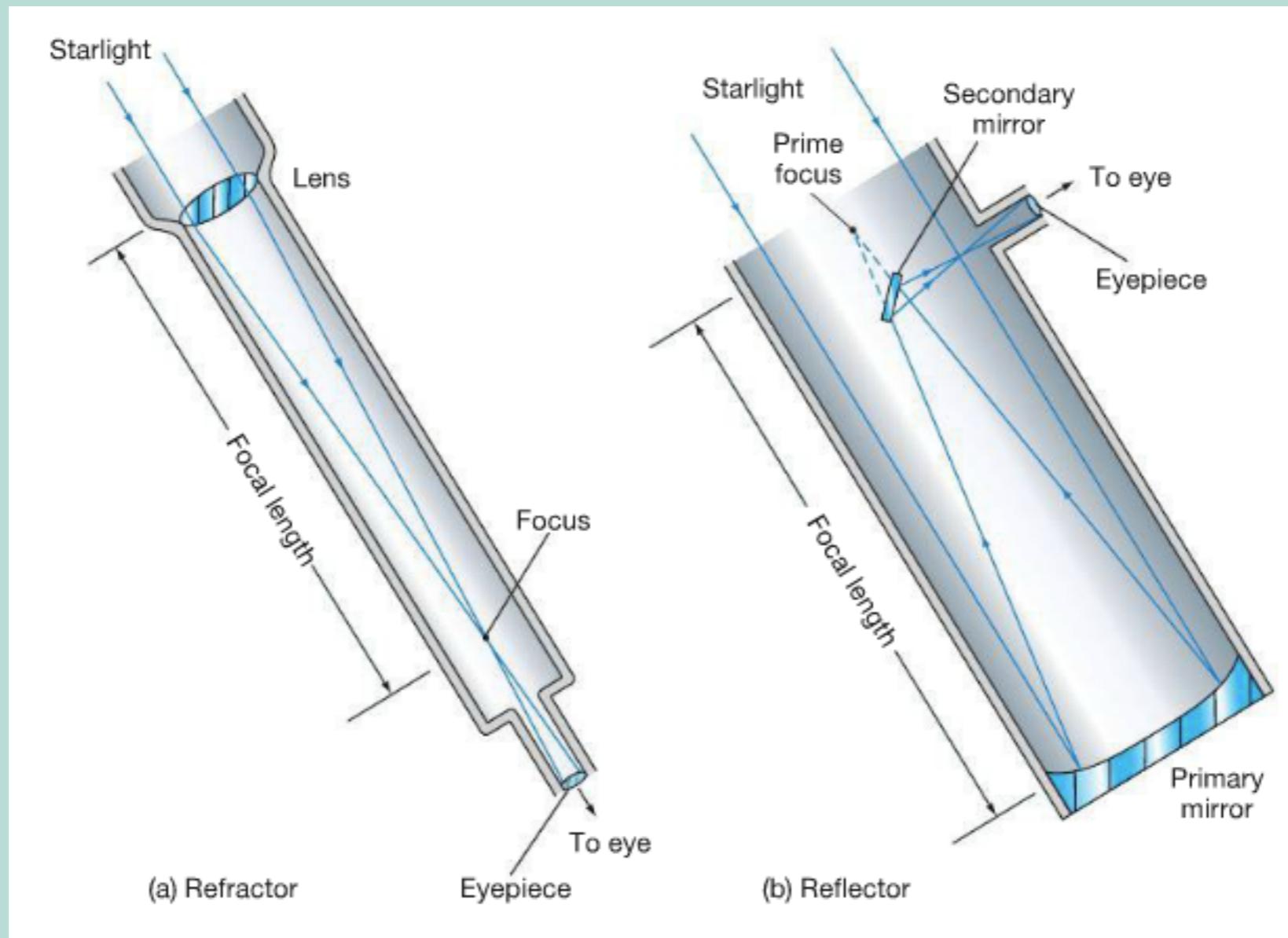
# Reflection



# Different Reflecting Telescopes



# Refraction vs Reflection Telescopes



# Refraction vs Reflection Telescopes

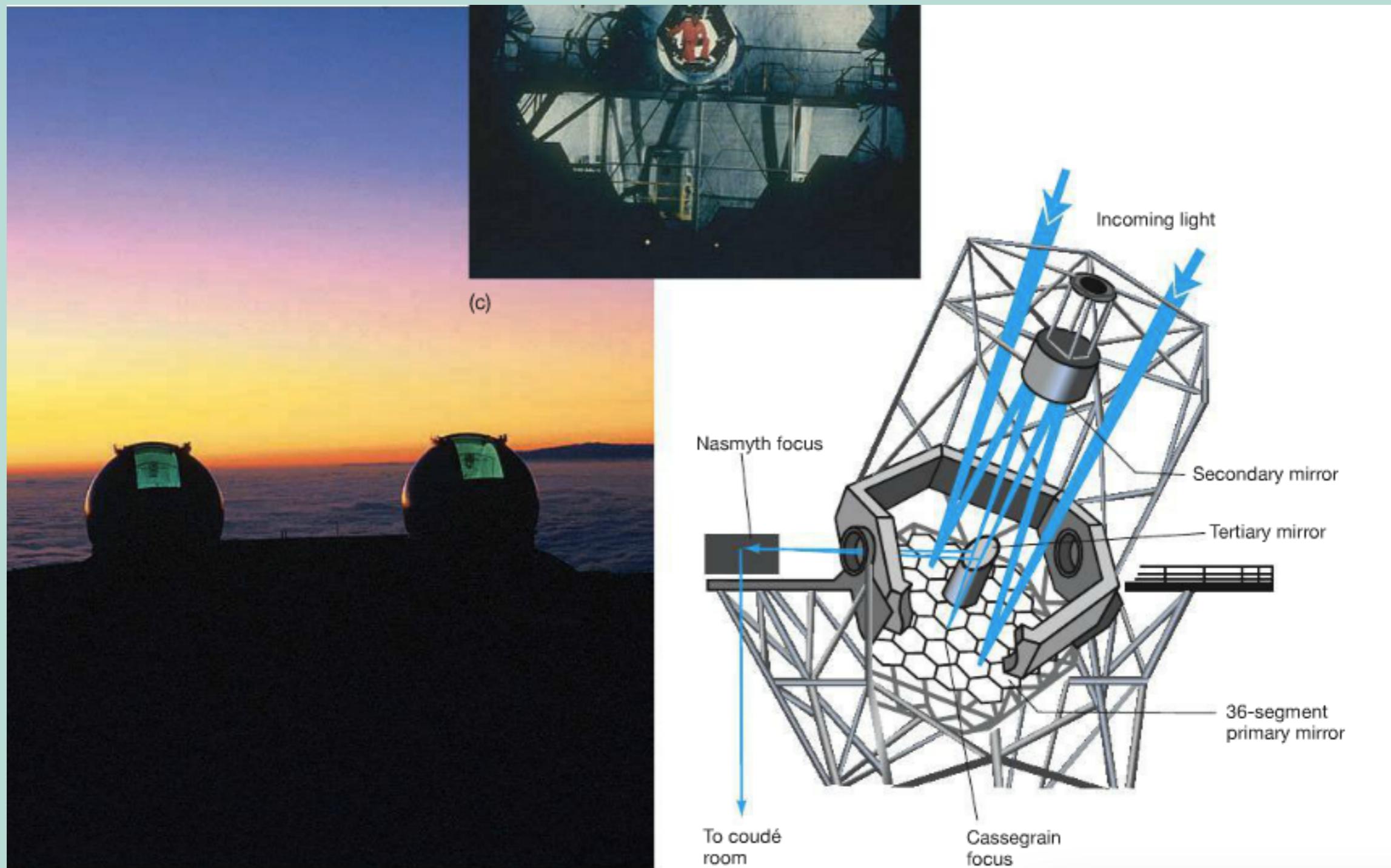
- Chromatic Aberration
- Absorption
- Support
- Double the Surfaces

# Telescopes are Light Buckets



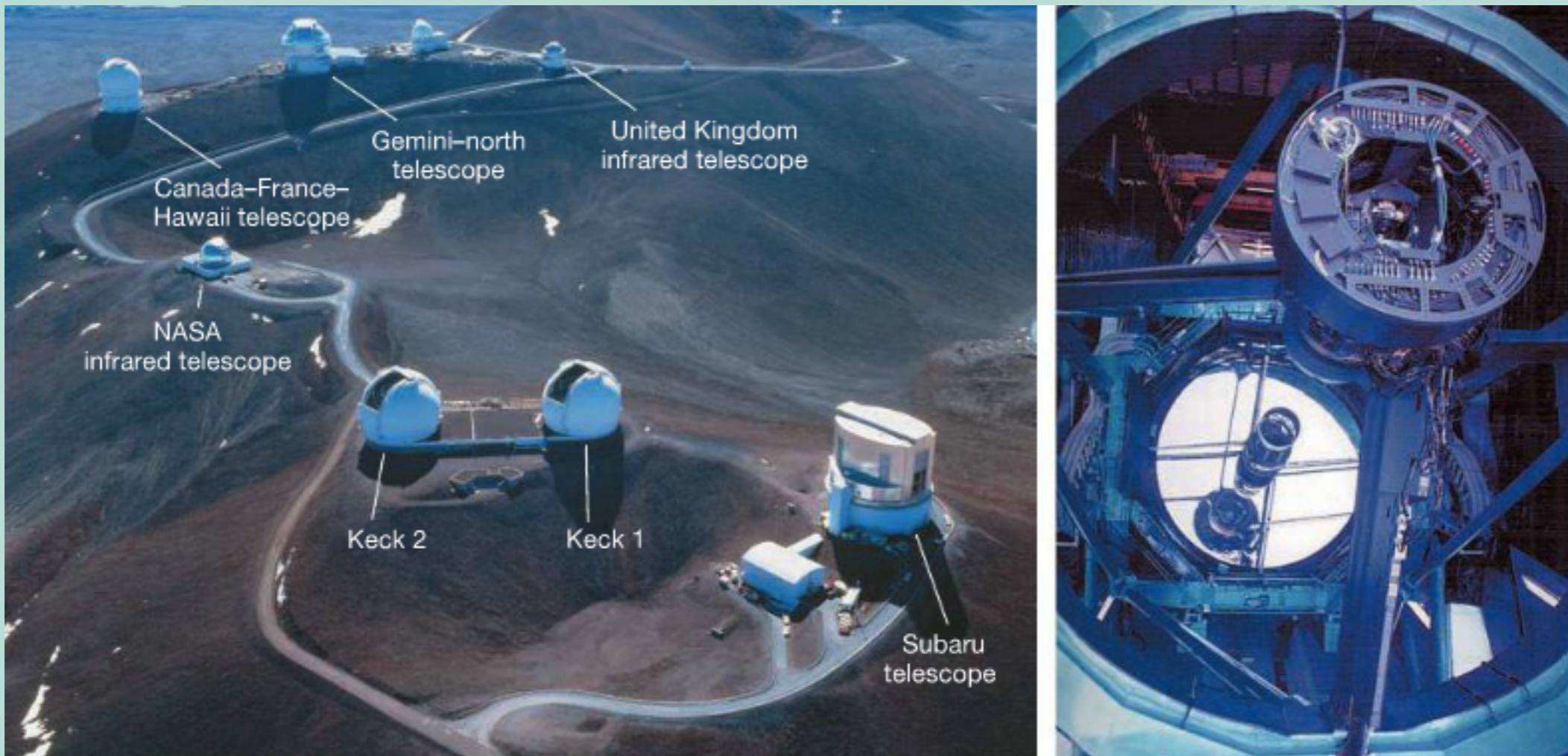
- Gathering area goes like length squared

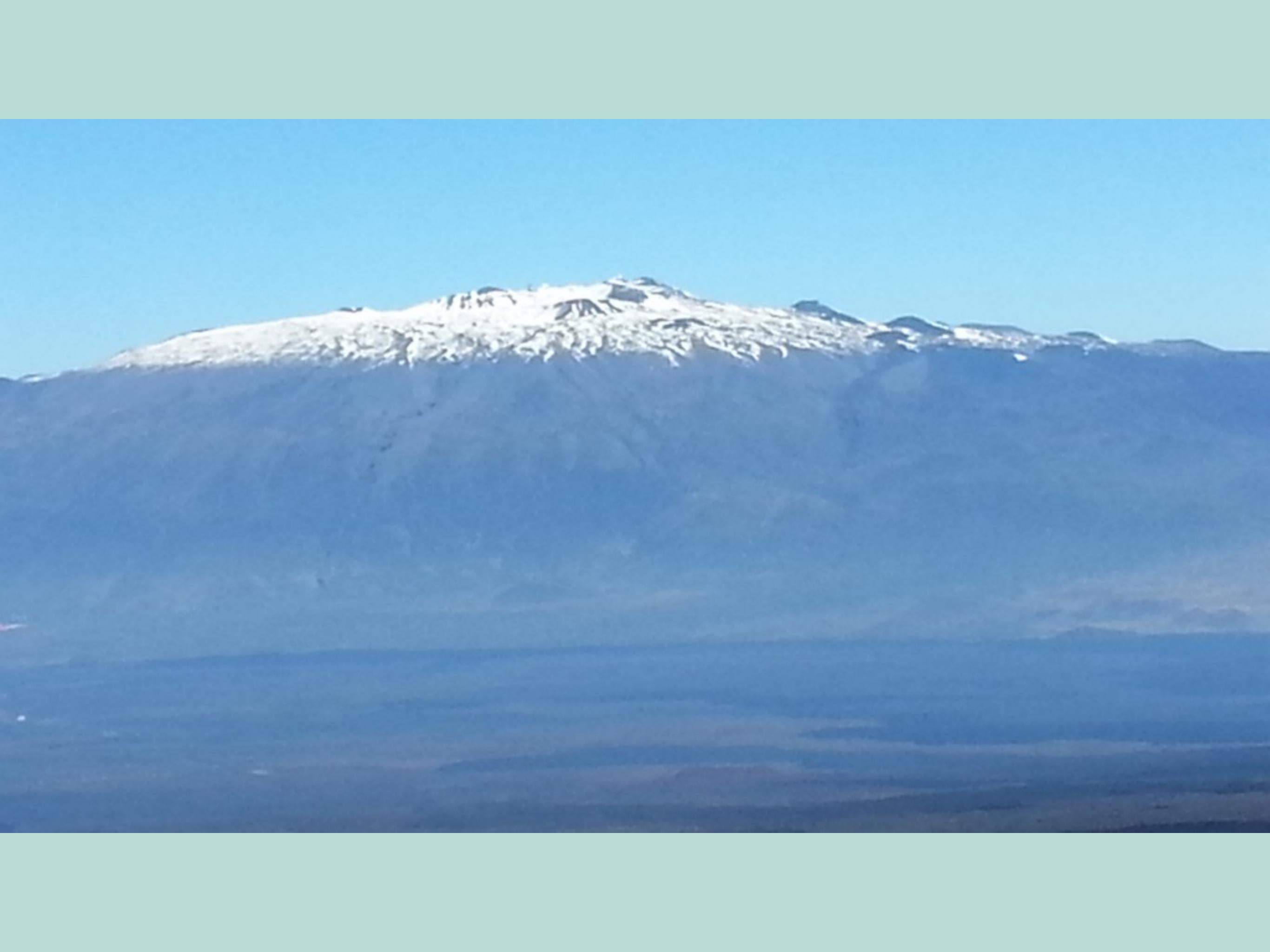
# Keck I and II



36 hexagonal mirrors for a total of 10 meters

# Mauna Kea



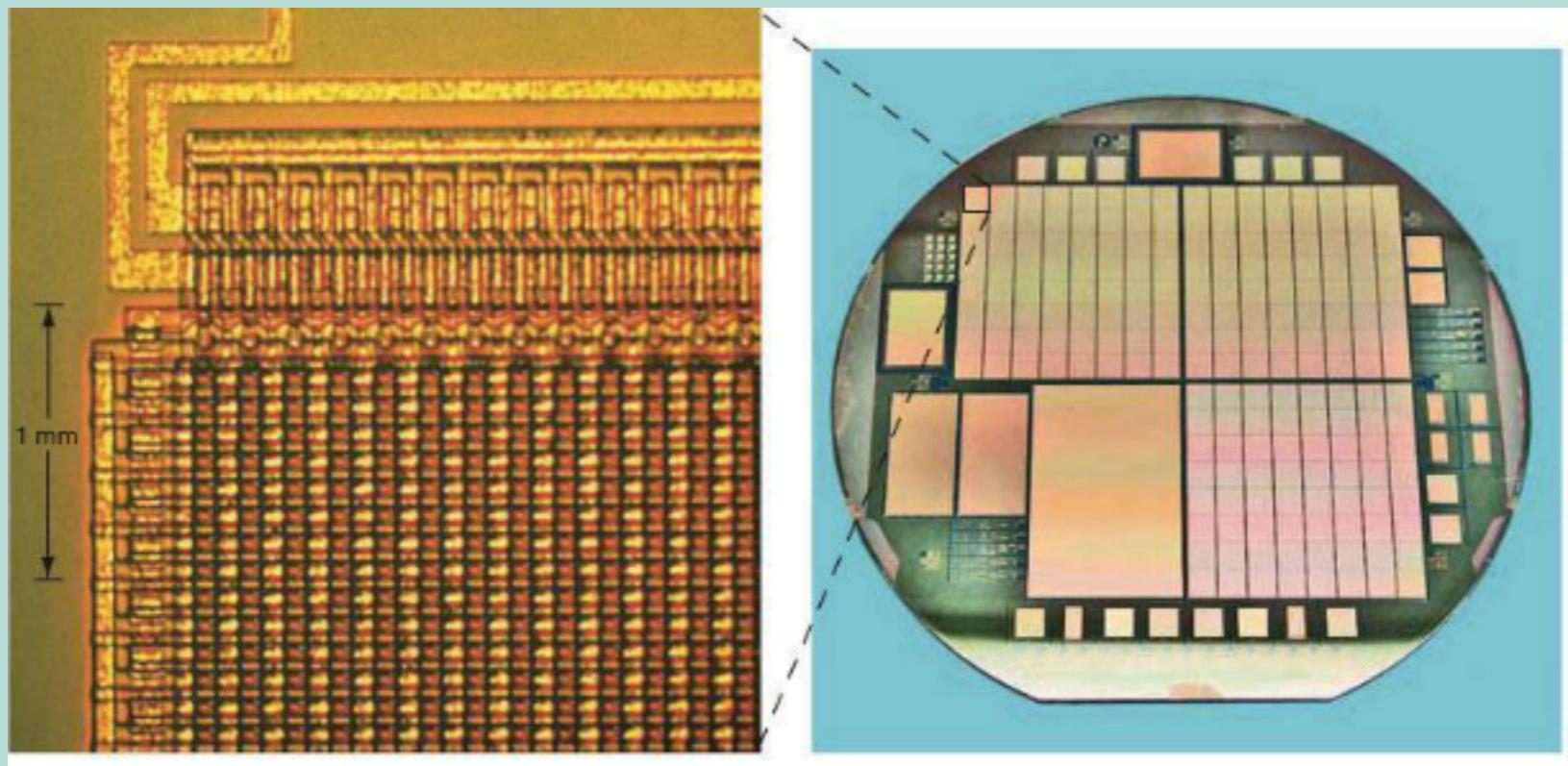


# Atacama, VLT



- Atacama Desert (northern chile)
- 4, 8.2m mirrors (16m equivalent)
- can resolve .001" (2 meters on the moon)

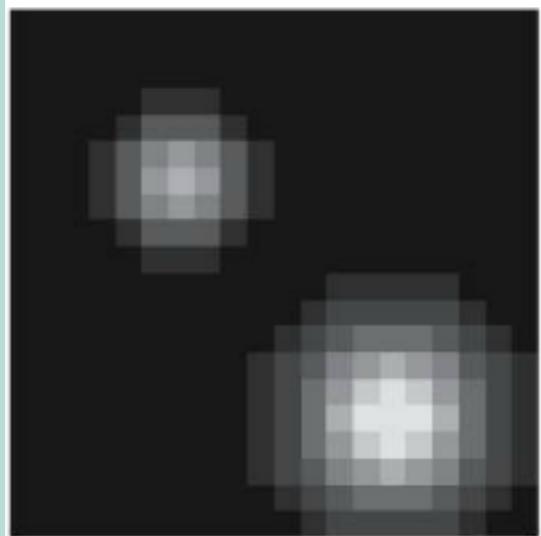
# CCD (Charge Coupled Device) Chip



..I told you science was all a lie

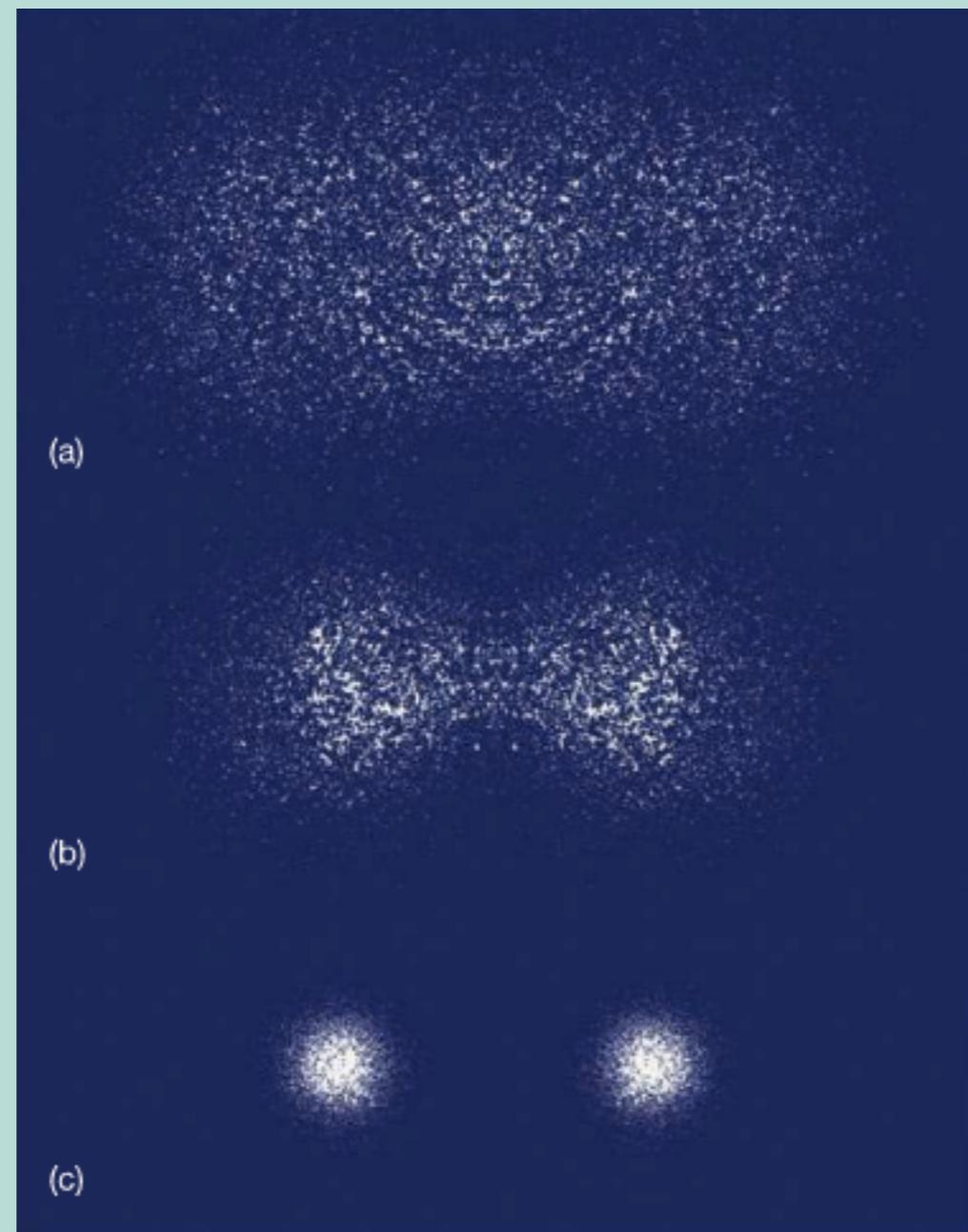
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	3	3	3	1	0	0	0	0	0	0	0	0
0	0	0	1	3	5	6	5	3	1	0	0	0	0	0	0	0
0	0	0	1	3	6	7	6	3	1	0	0	0	0	0	0	0
0	0	0	1	3	5	6	5	3	1	0	0	0	0	0	0	0
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0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	1	2	2	2	2	2	1
0	0	0	0	0	0	0	0	0	0	1	2	3	4	4	4	3
0	0	0	0	0	0	0	0	0	1	2	3	5	6	7	6	5
0	0	0	0	0	0	0	0	0	1	2	4	6	8	9	8	6
0	0	0	0	0	0	0	0	0	1	2	4	7	9	9	7	4
0	0	0	0	0	0	0	0	0	1	2	4	6	8	9	8	6
0	0	0	0	0	0	0	0	0	1	2	3	5	6	7	6	5
0	0	0	0	0	0	0	0	0	1	2	3	4	4	4	3	2
0	0	0	0	0	0	0	0	0	1	2	2	2	2	2	1	0

(c)



# Diffraction Limitation

$$\text{angular resolution (arcsec)} = 0.25 \frac{\text{wavelength } (\mu\text{m})}{\text{diameter } (\text{m})}$$



# Resolution



10'



1'

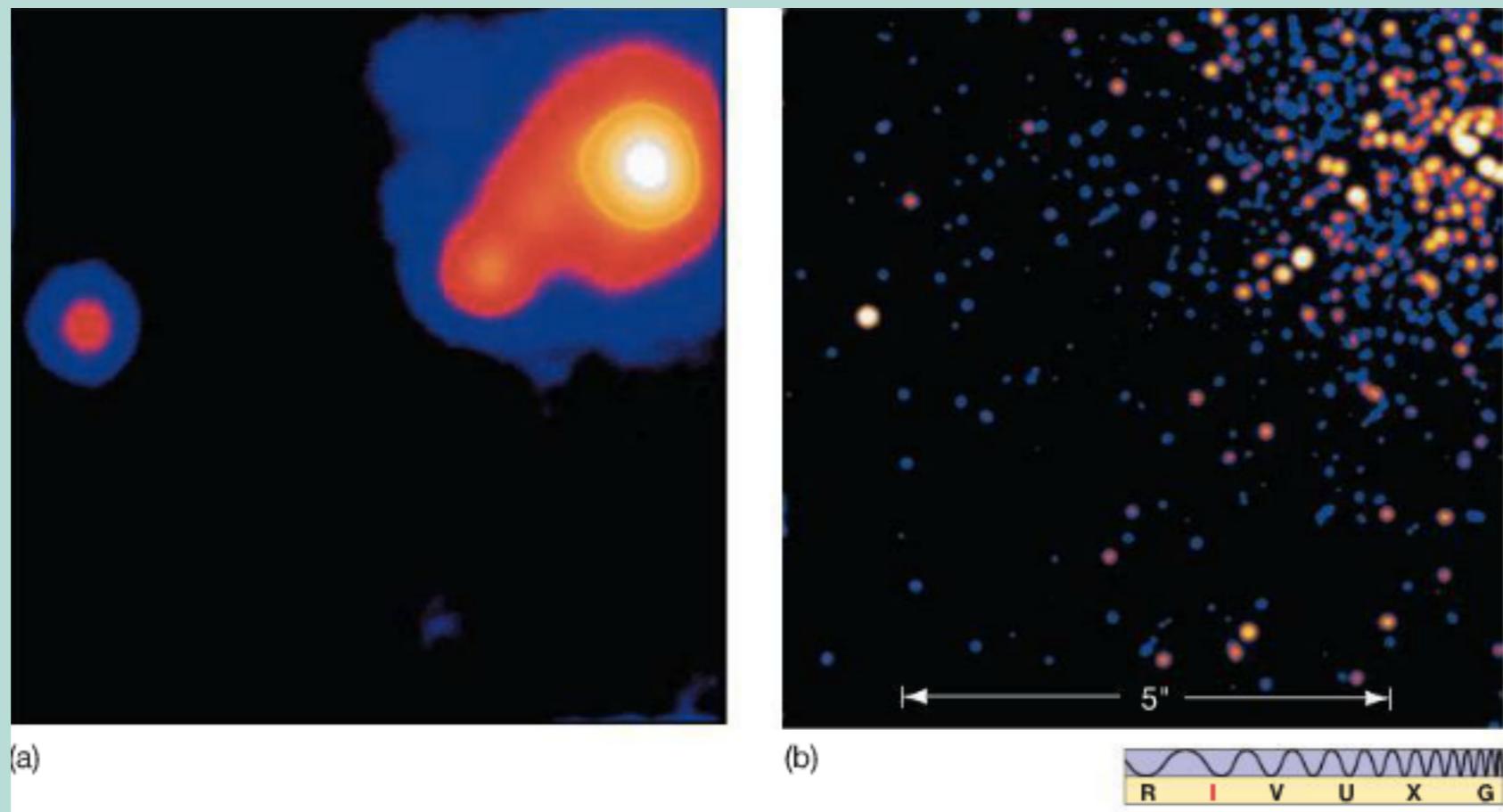


5''

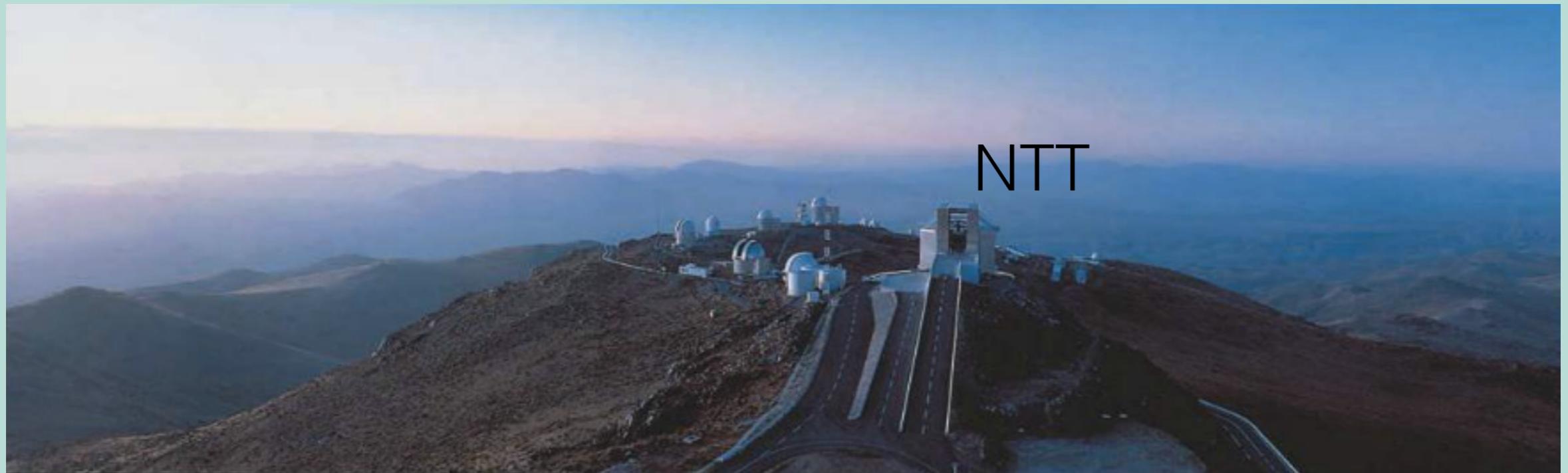


1''

# Active Optics



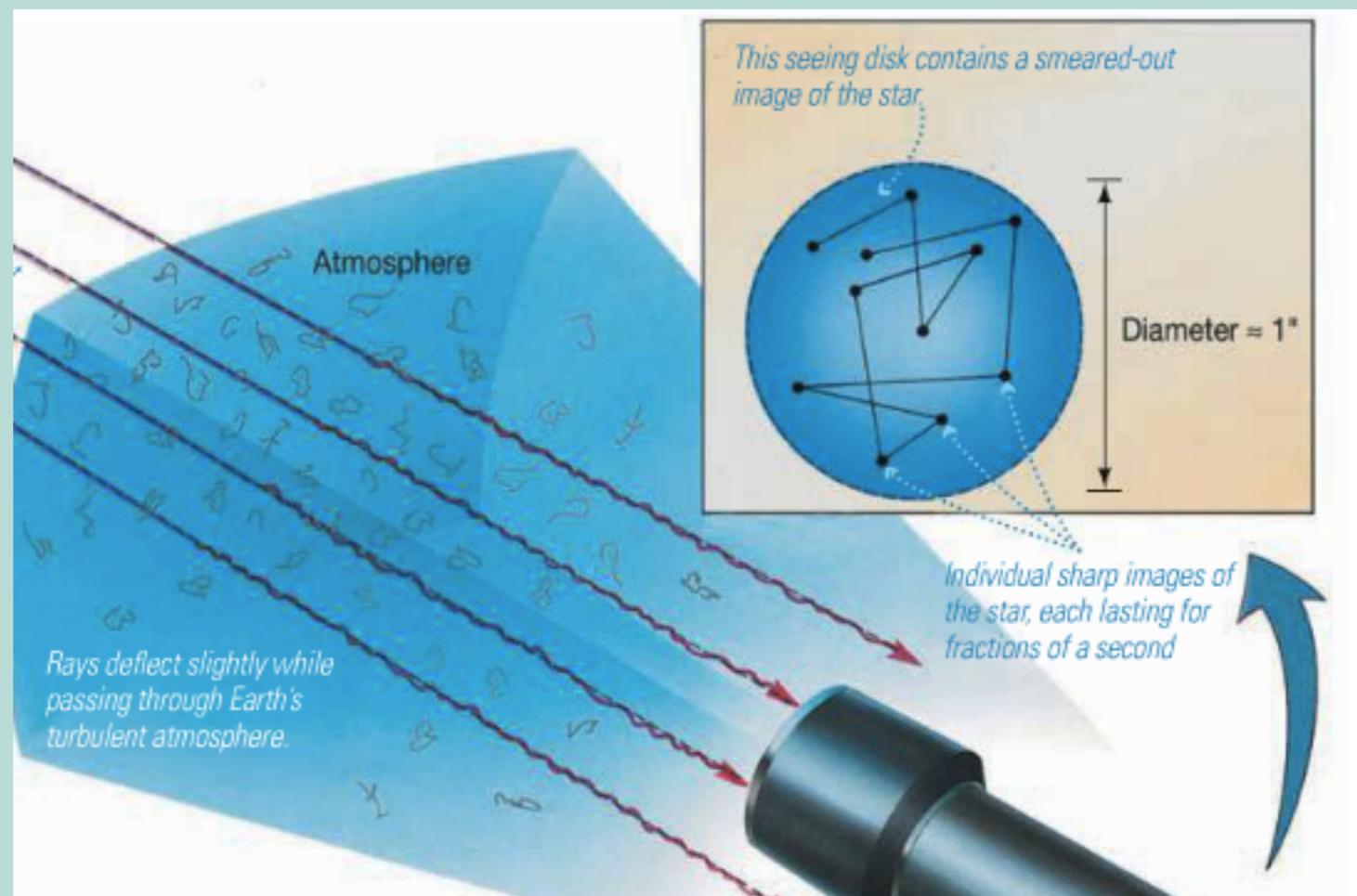
# European Southern Observatory



NTT

La Silla, Chile

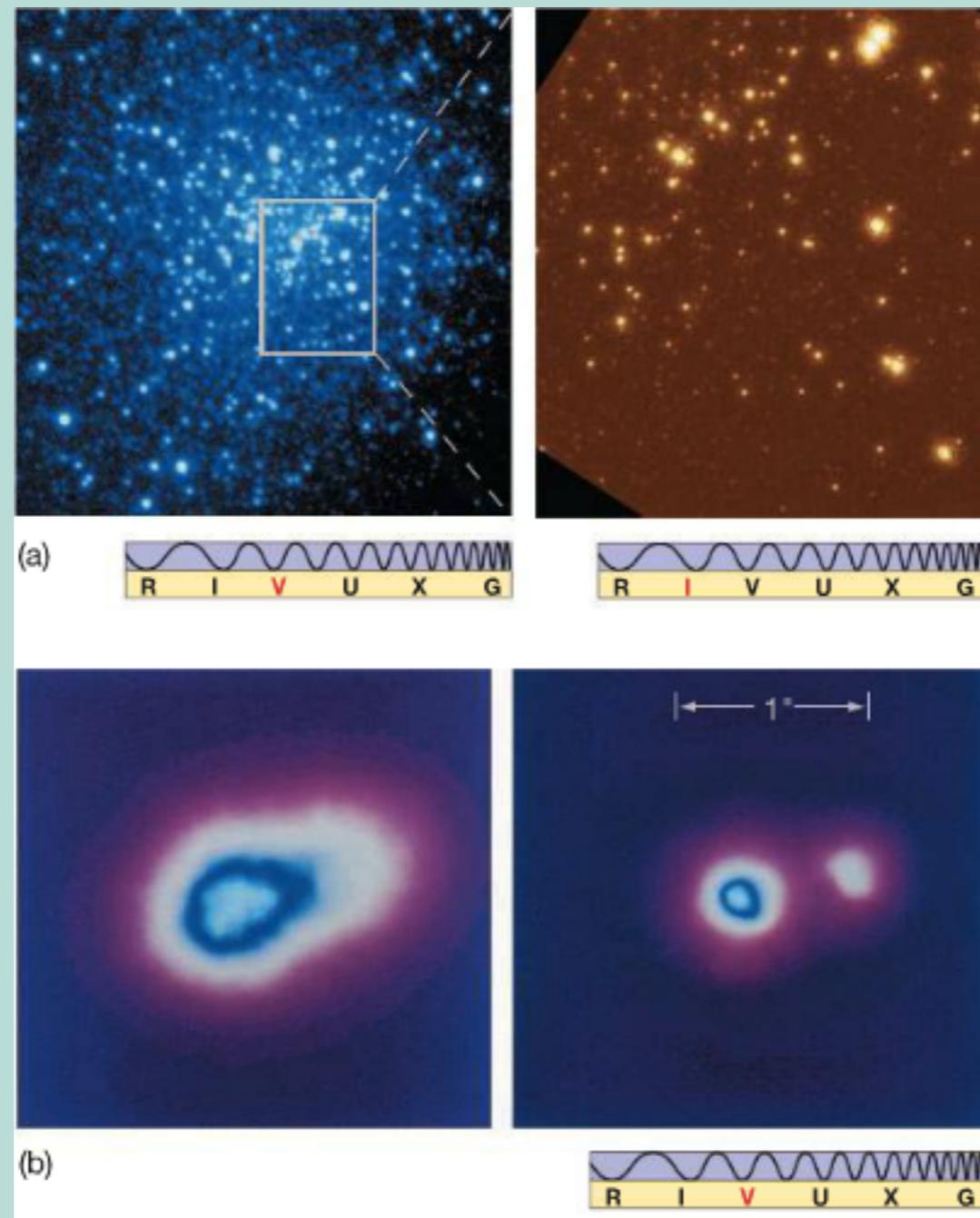
# 'seeing' stars



# Adaptive Optics



# Adaptive Optics



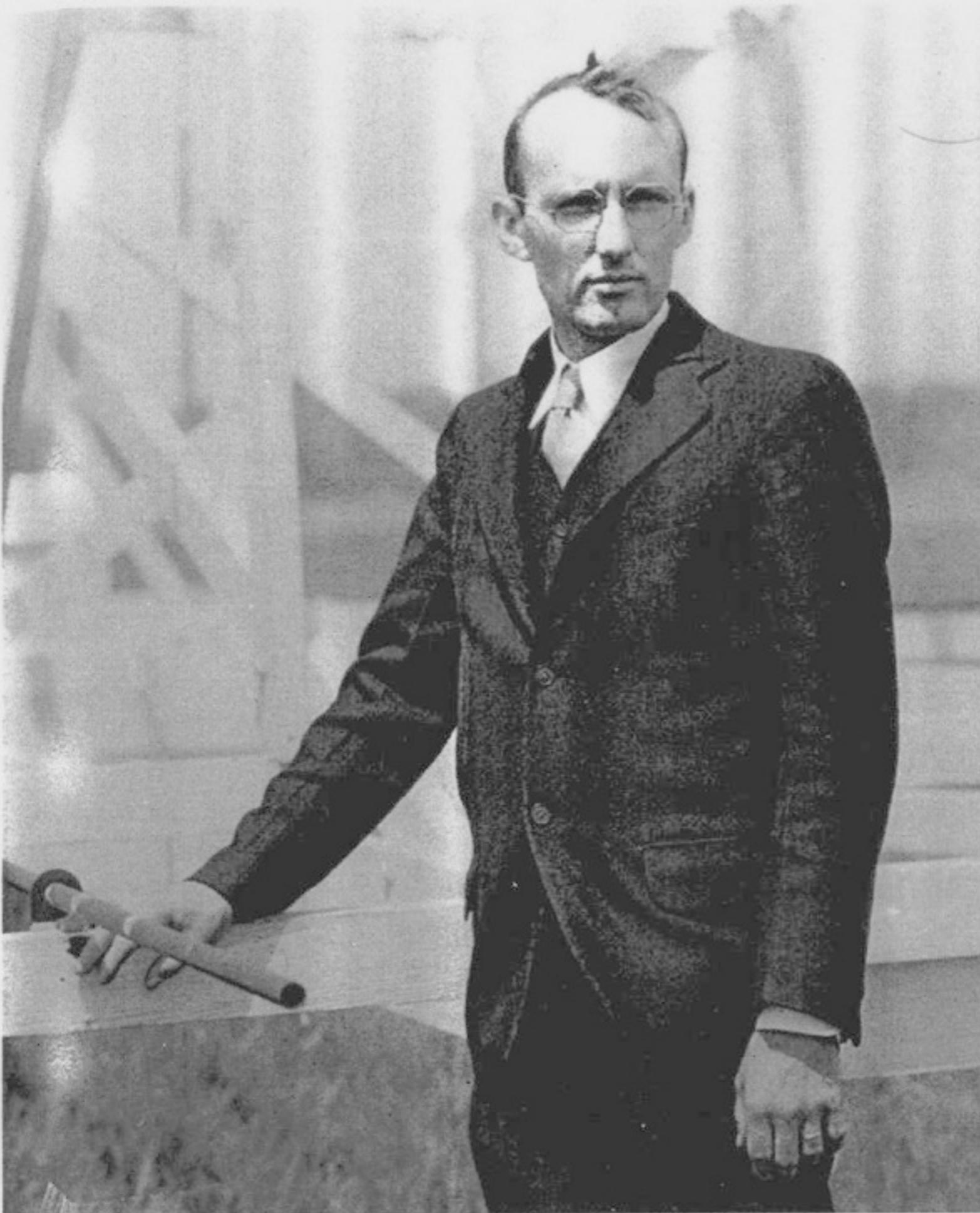


FIG. 1—Karl Guthe Jansky, about 1933.

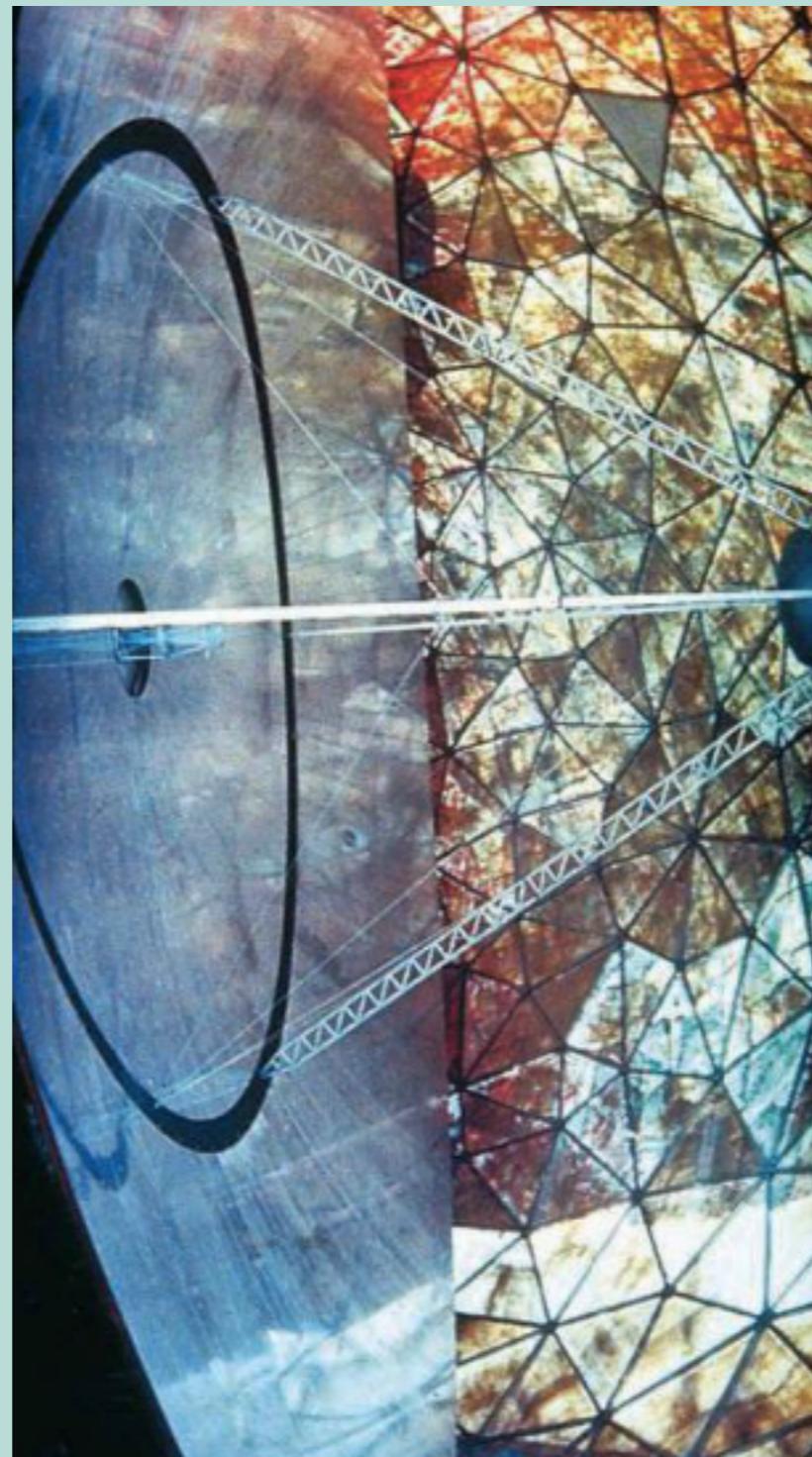
# National Radio Astronomy Observatory



Greenback, WV

Steerable!

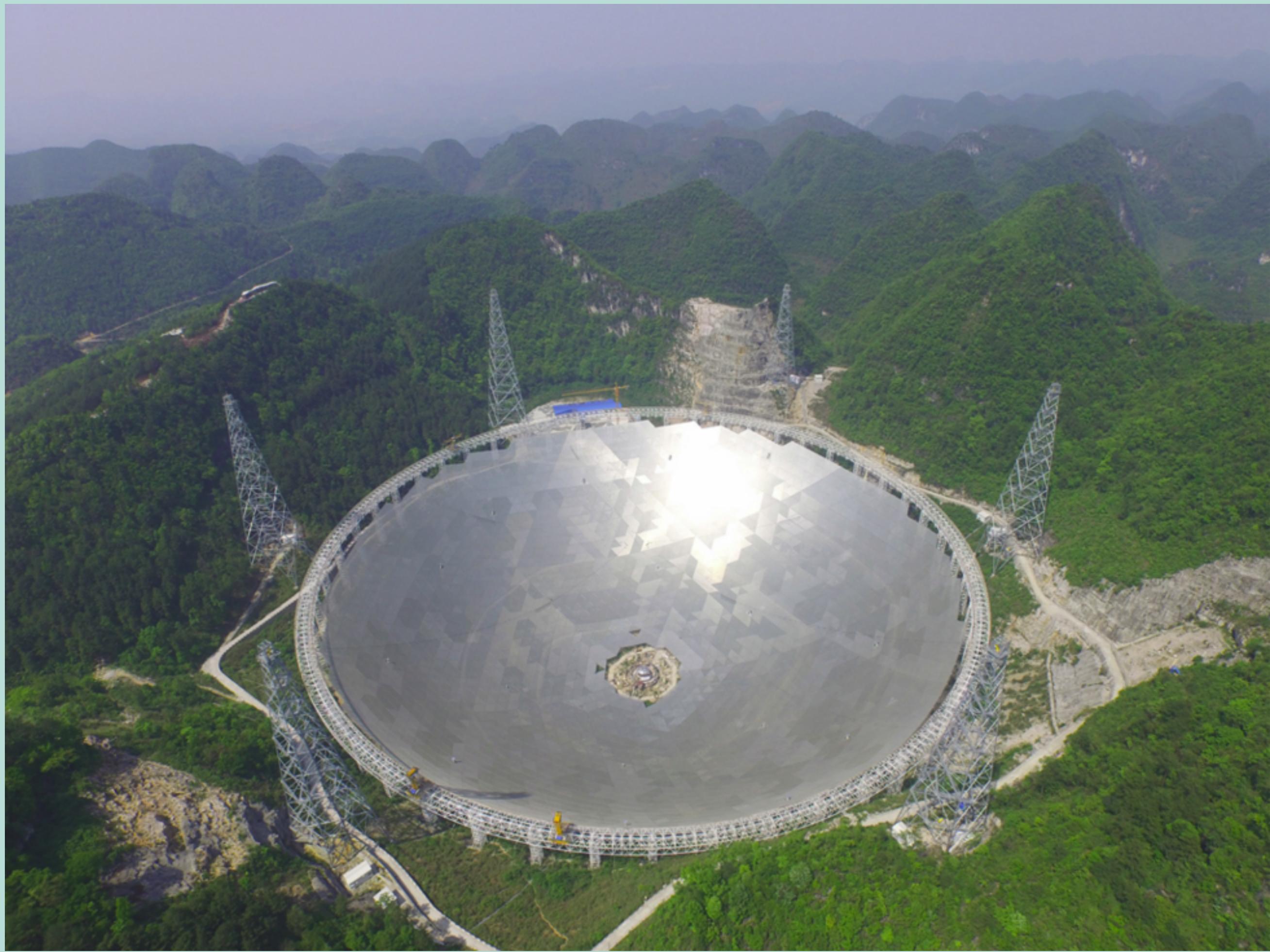
# Haystack Observatory

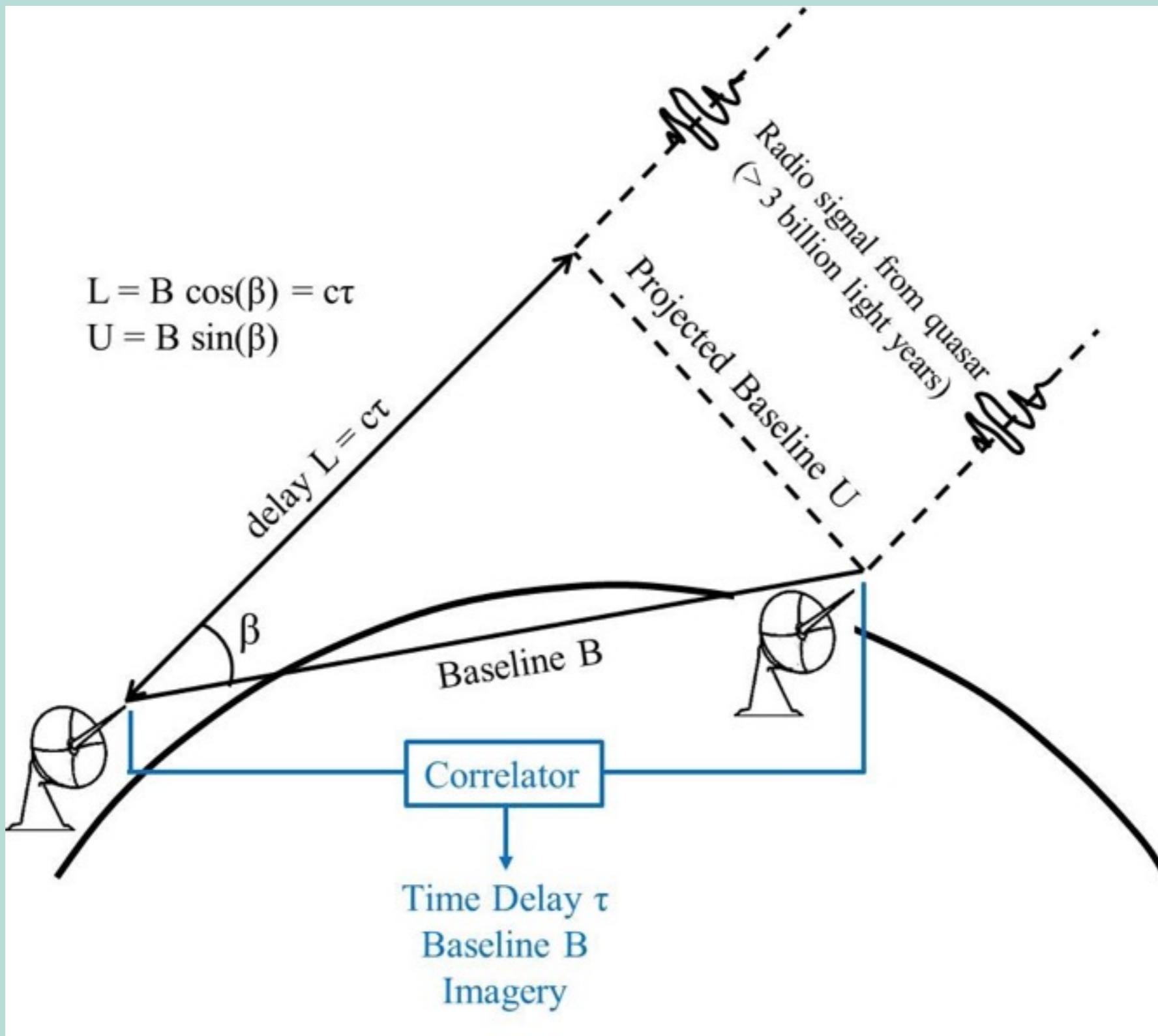




NEBOC  
HAYSTACK OBSERVATORY







# ALMA (Atacama Large Millimeter Array)

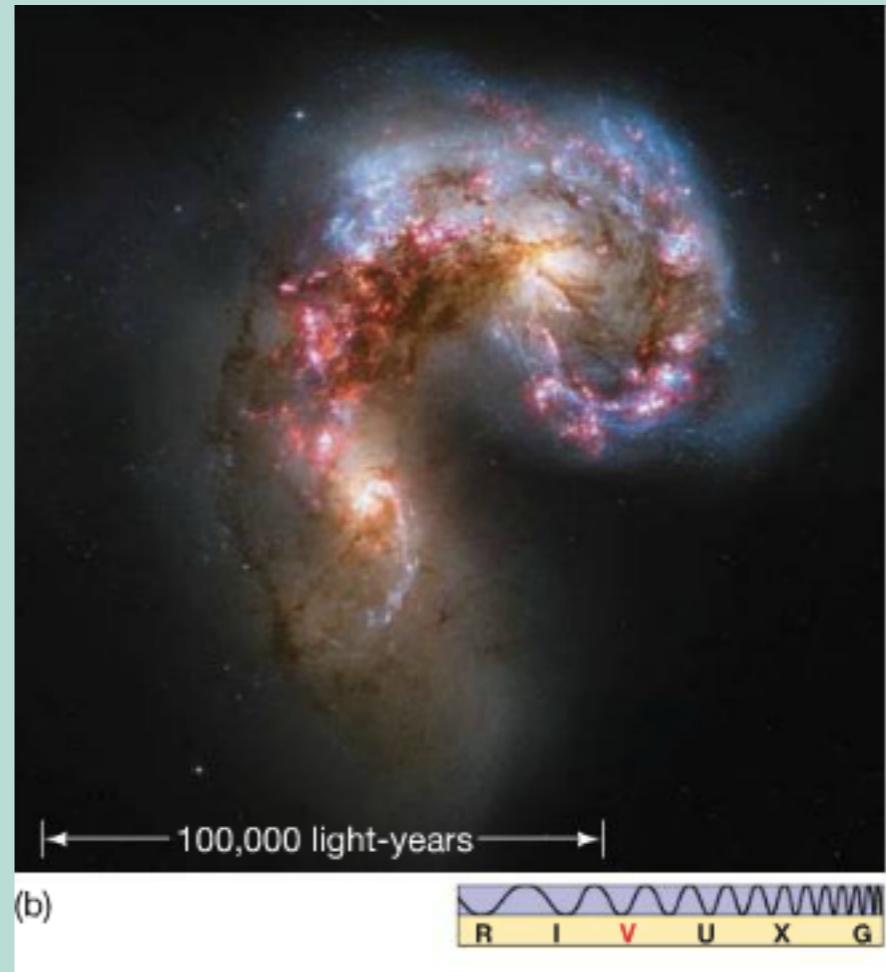
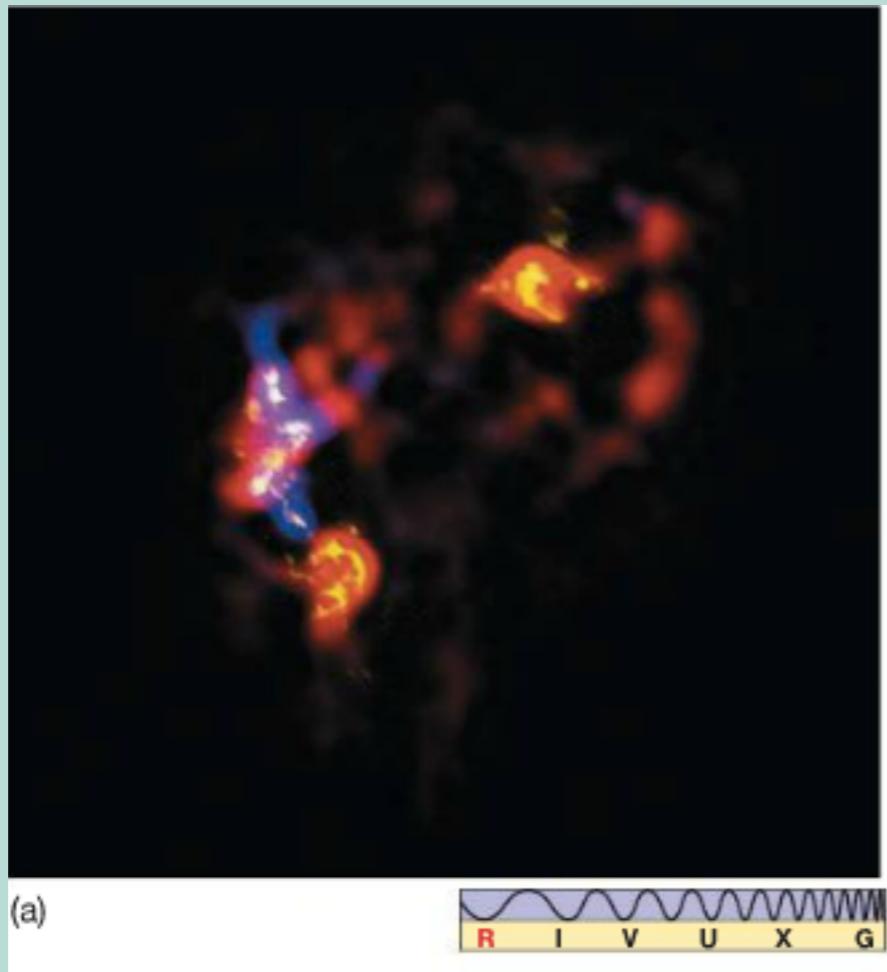


# Very Large Array

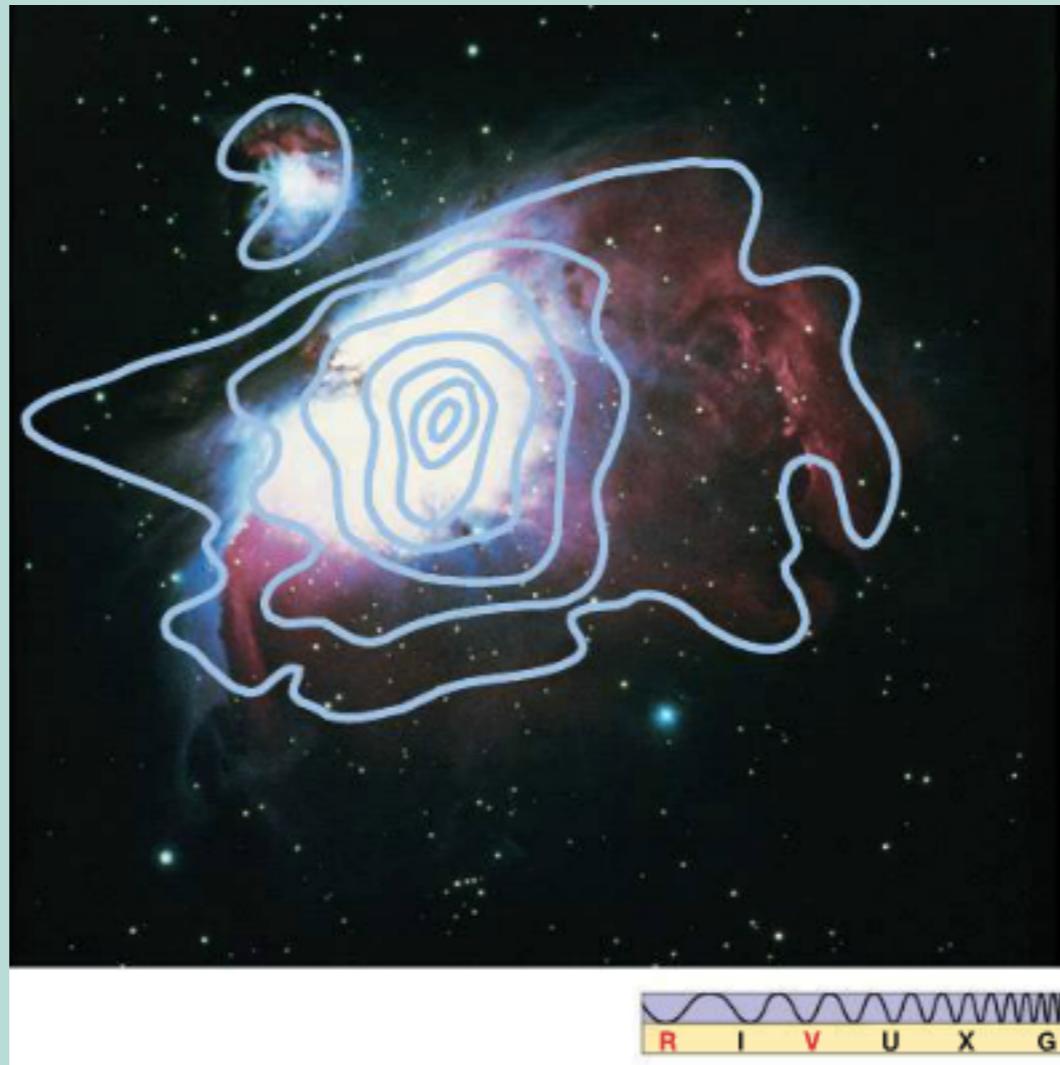


New Mexico

# Galaxies Colliding (radio & visible)

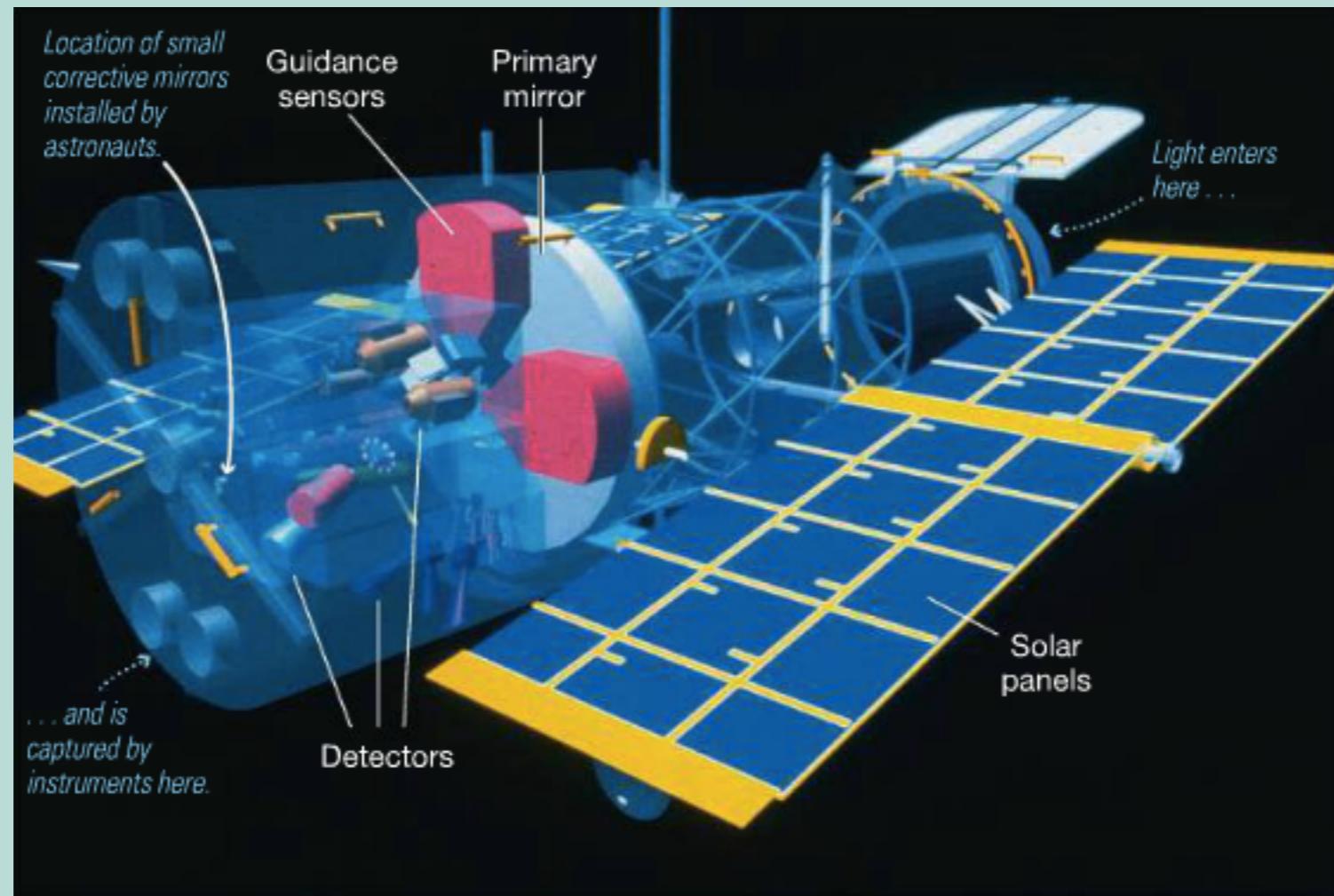


# Radio Astronomy is Complementary!

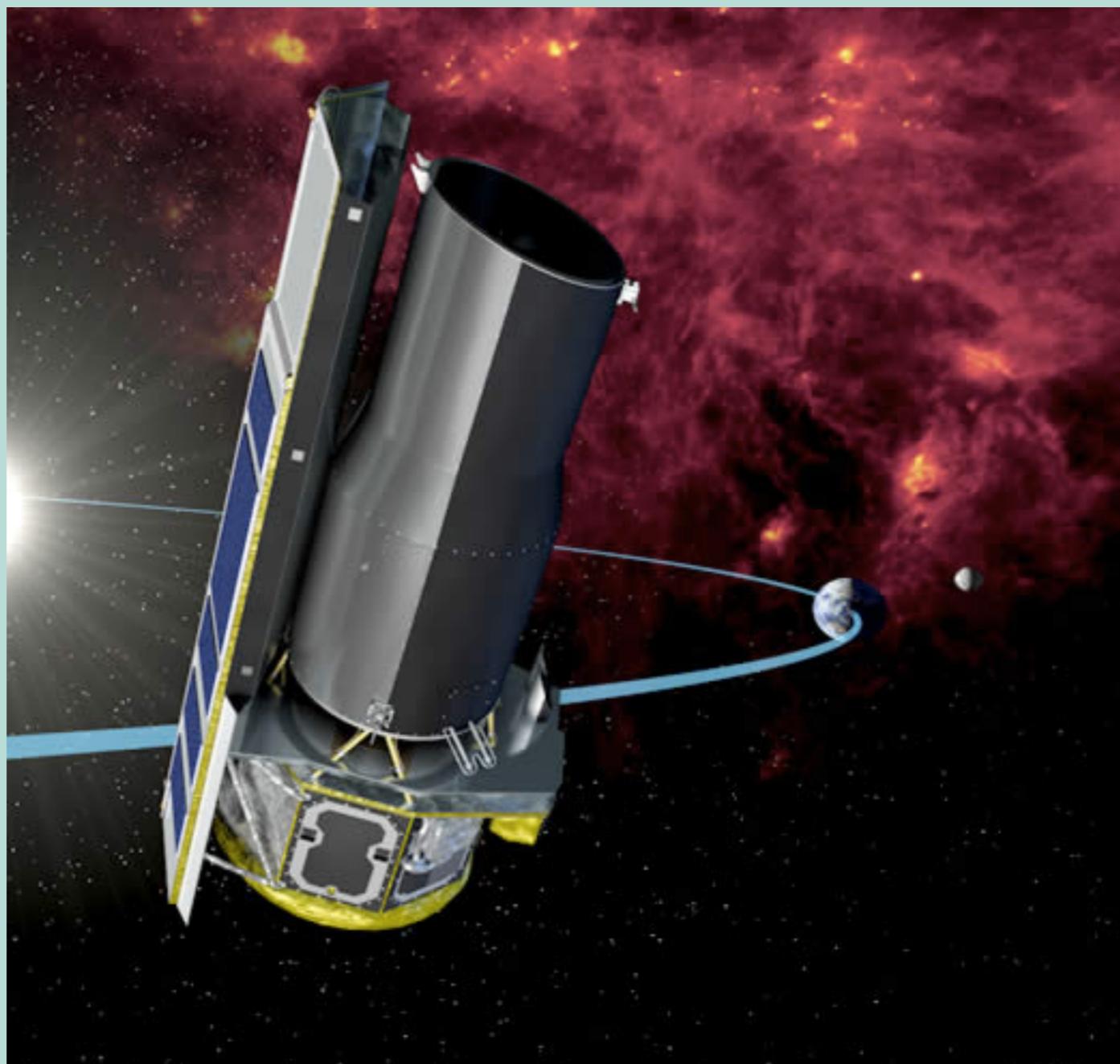


# Good IR = Space!

## Hubble Space Telescope



# Spitzer Space Telescope



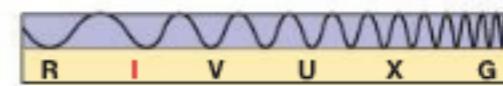
# Infrared Reveals Structure



(a)



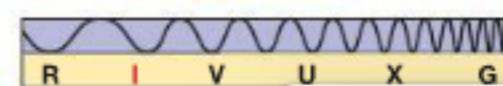
(b)



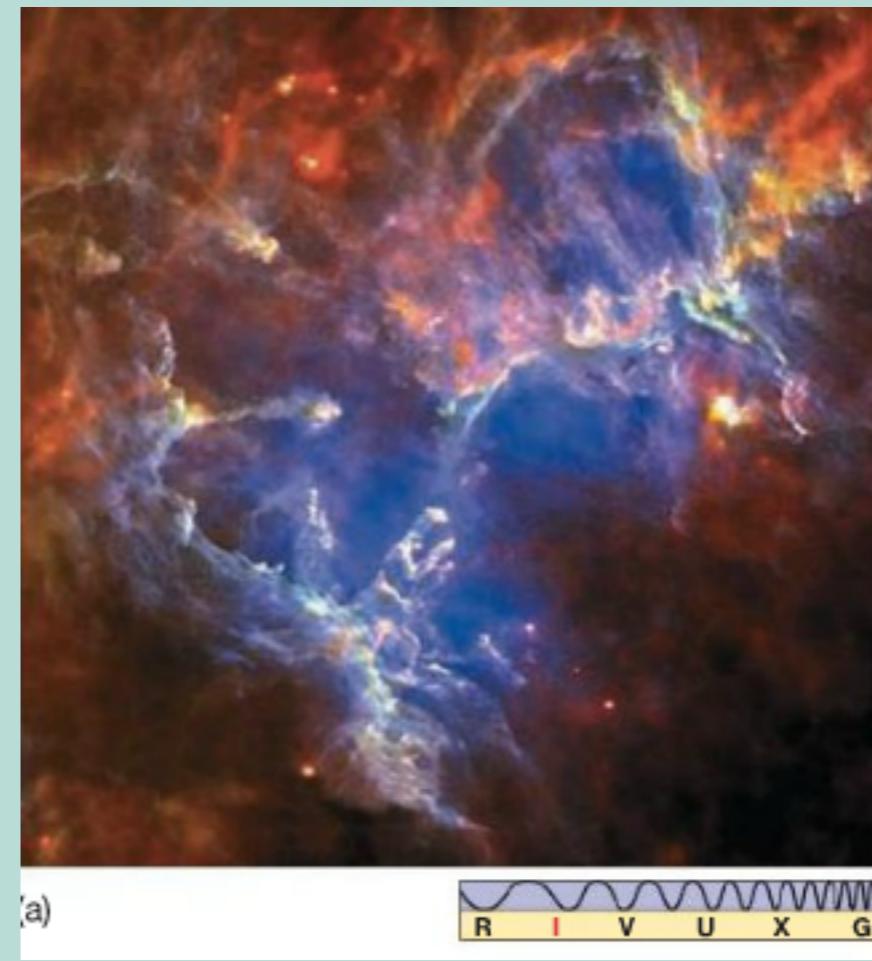
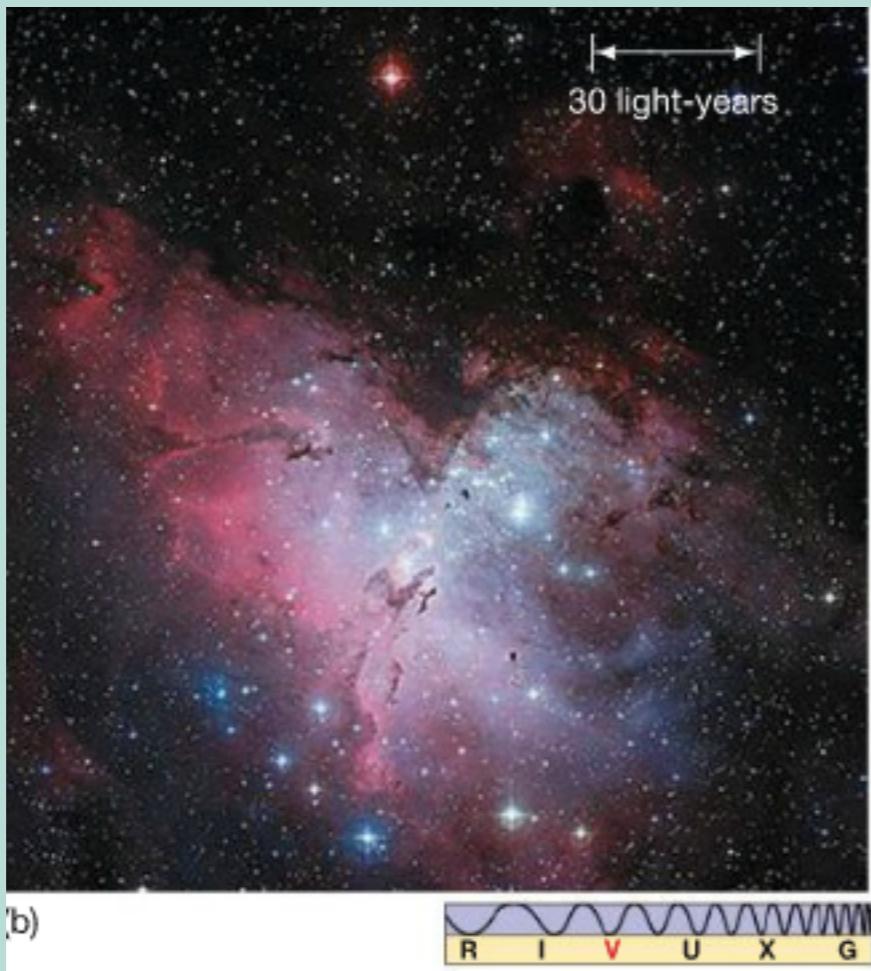
(c)



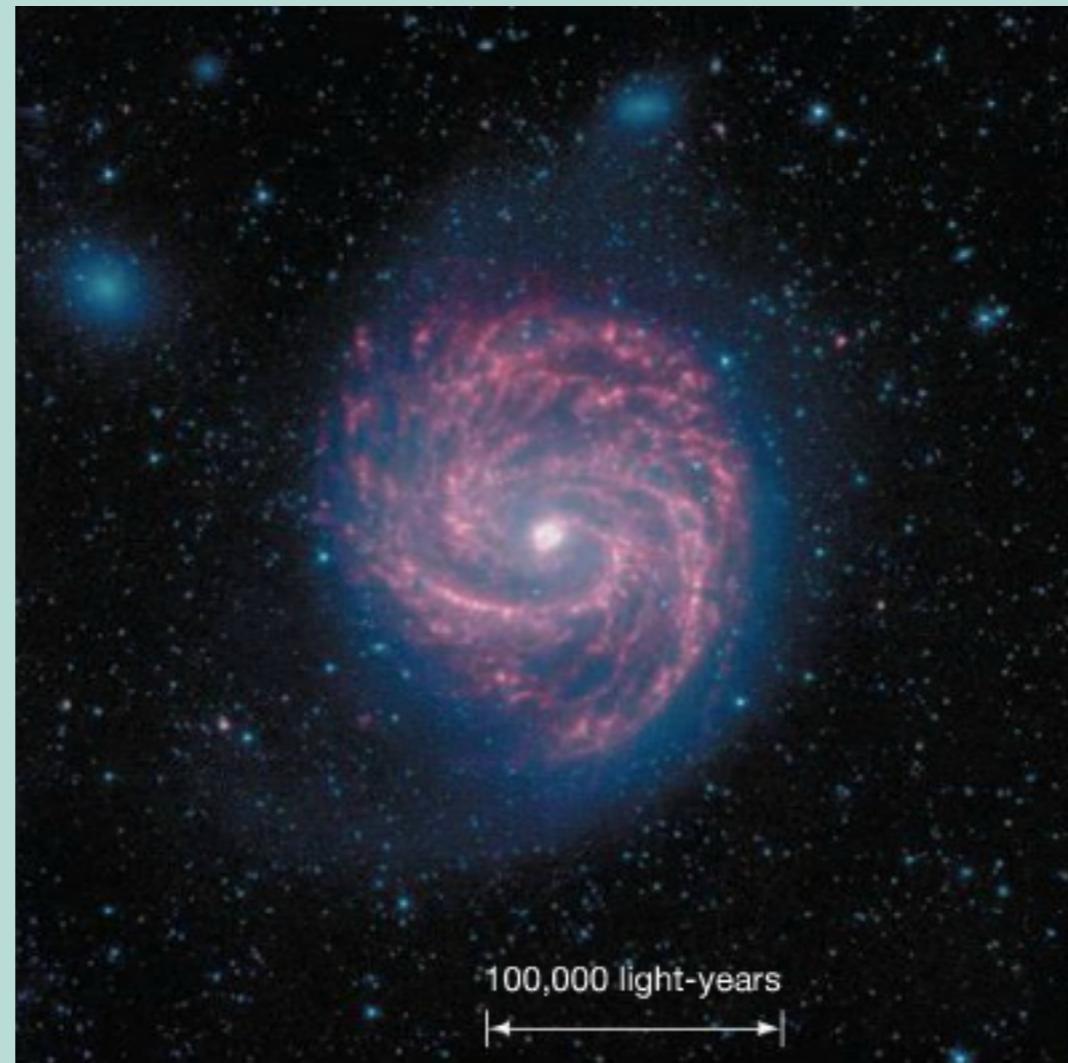
(d)



# Infrared Reveals Structure



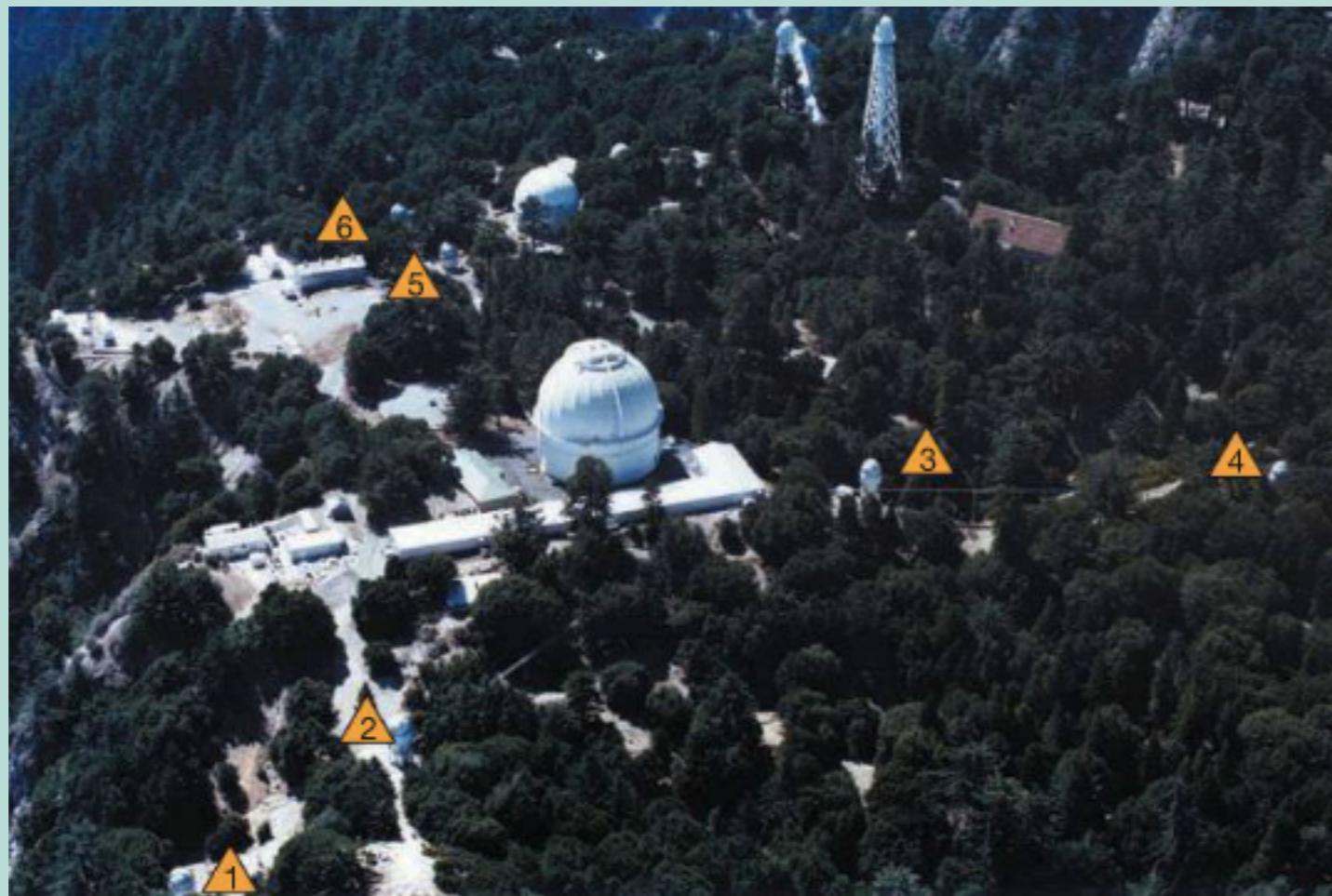
# Spitzer in the IR



# Spitzer in the IR

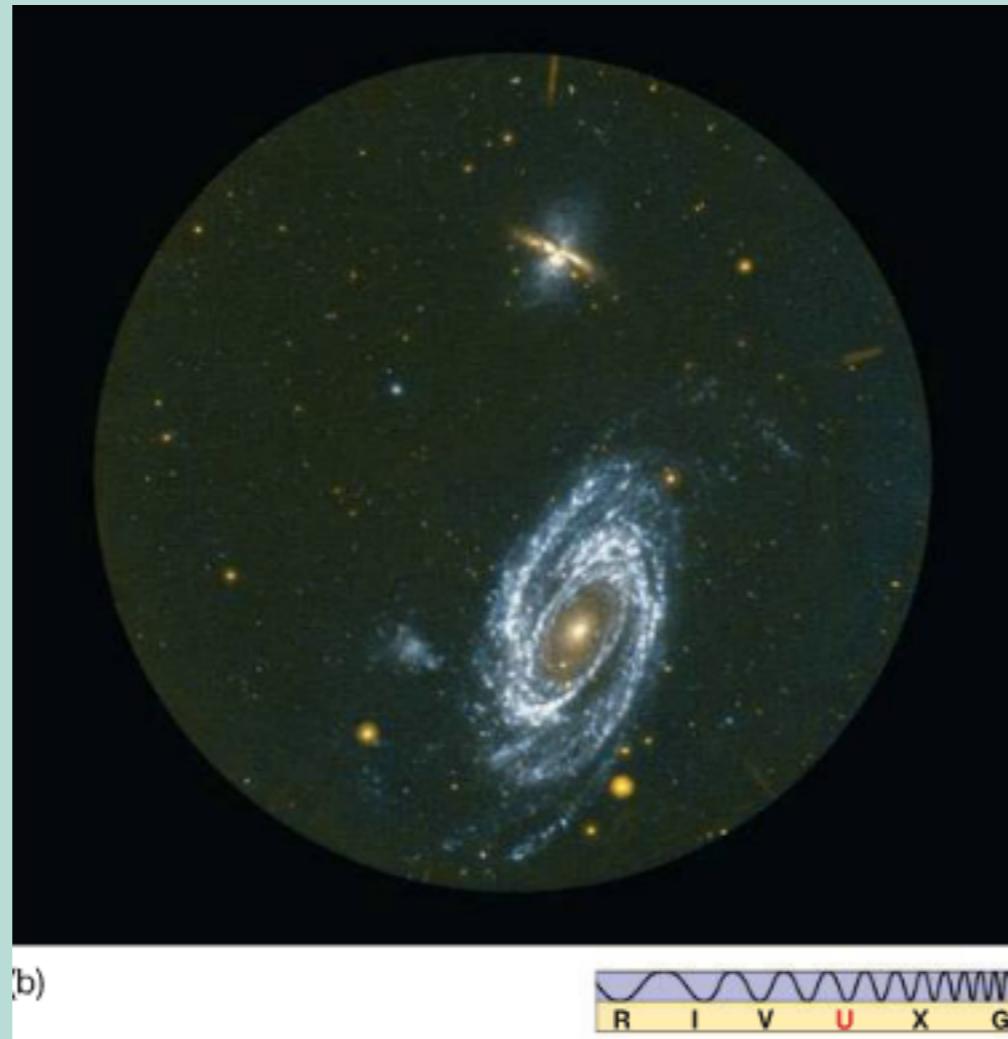


# Chara



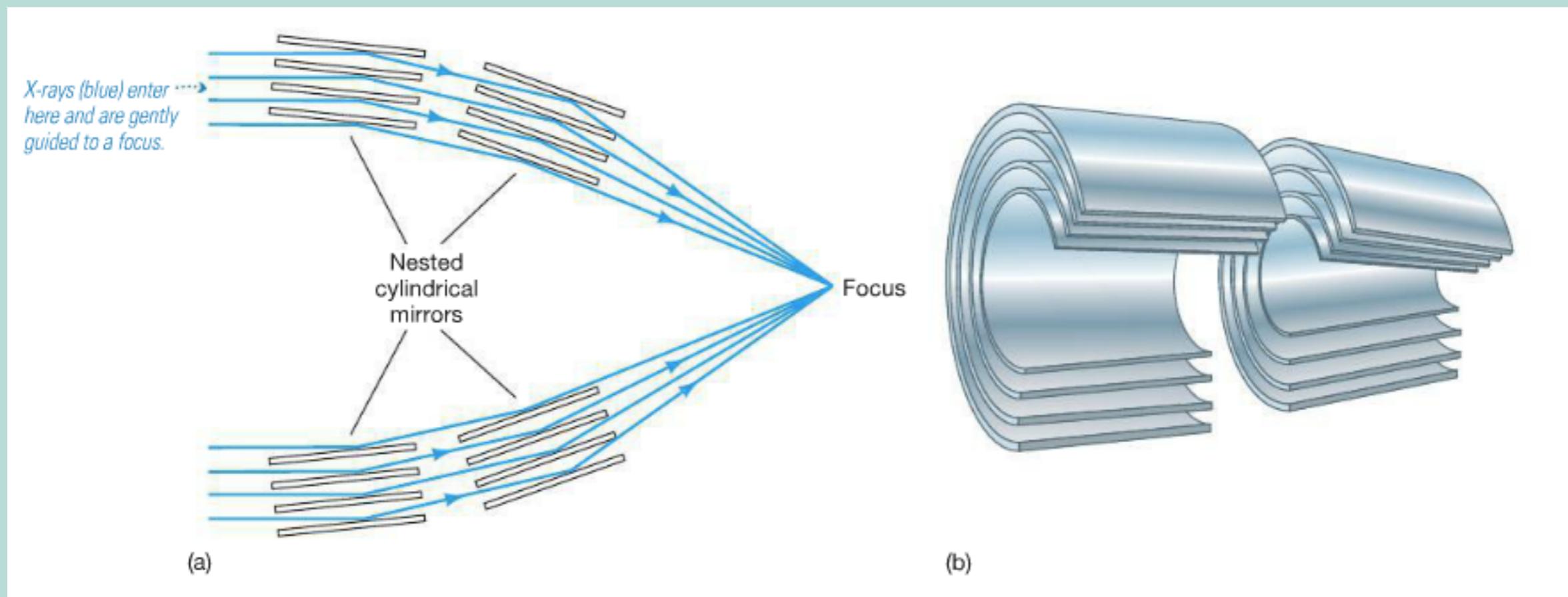
- Mt. Wilson CA

# Ultraviolet

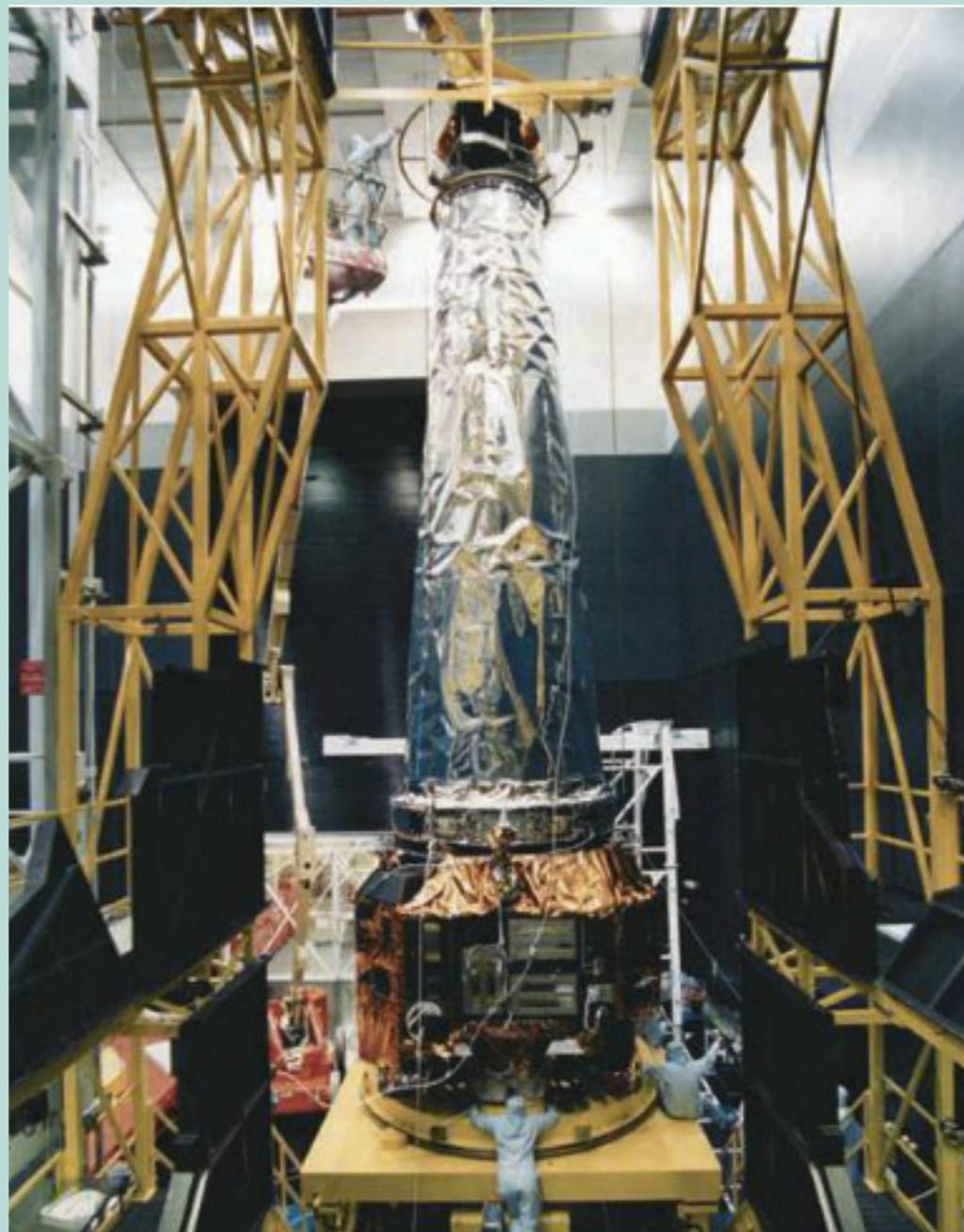


International Ultraviolet Explorer

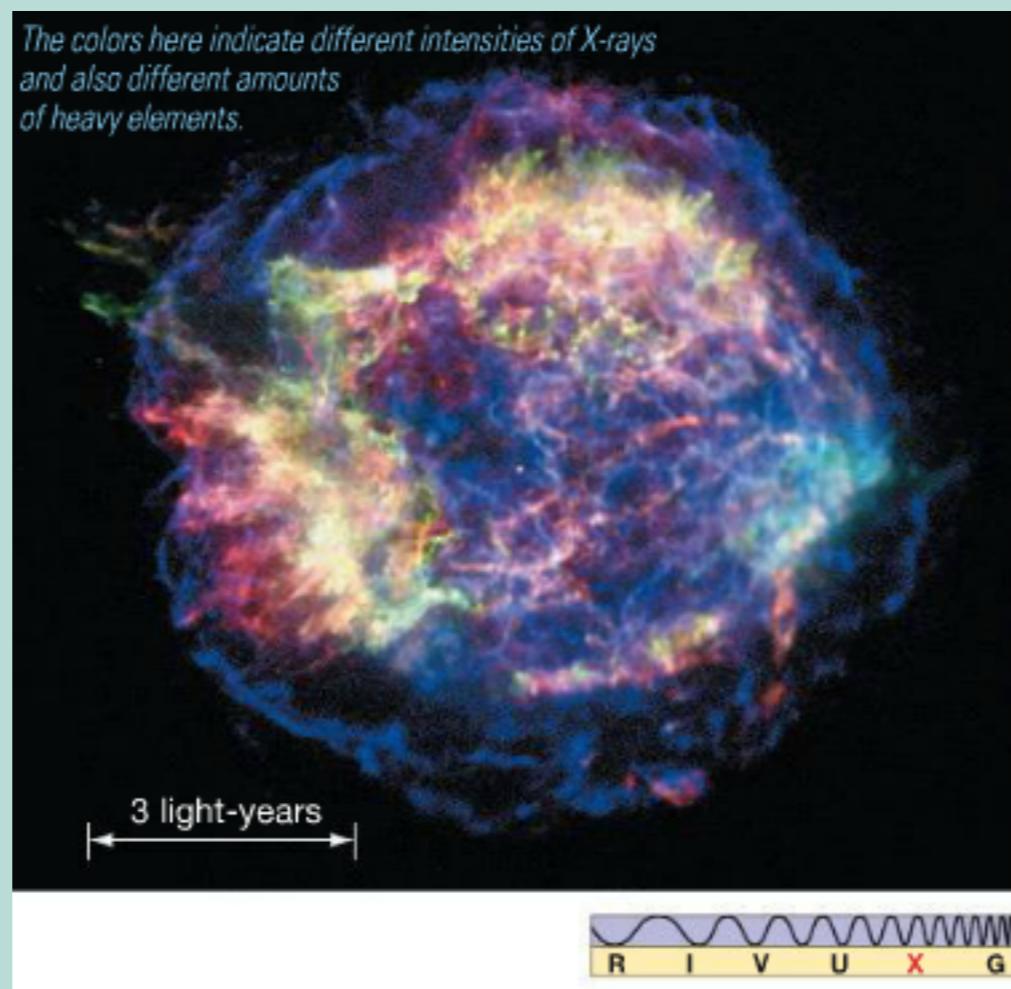
# X-Ray Mirrors



# Chandra



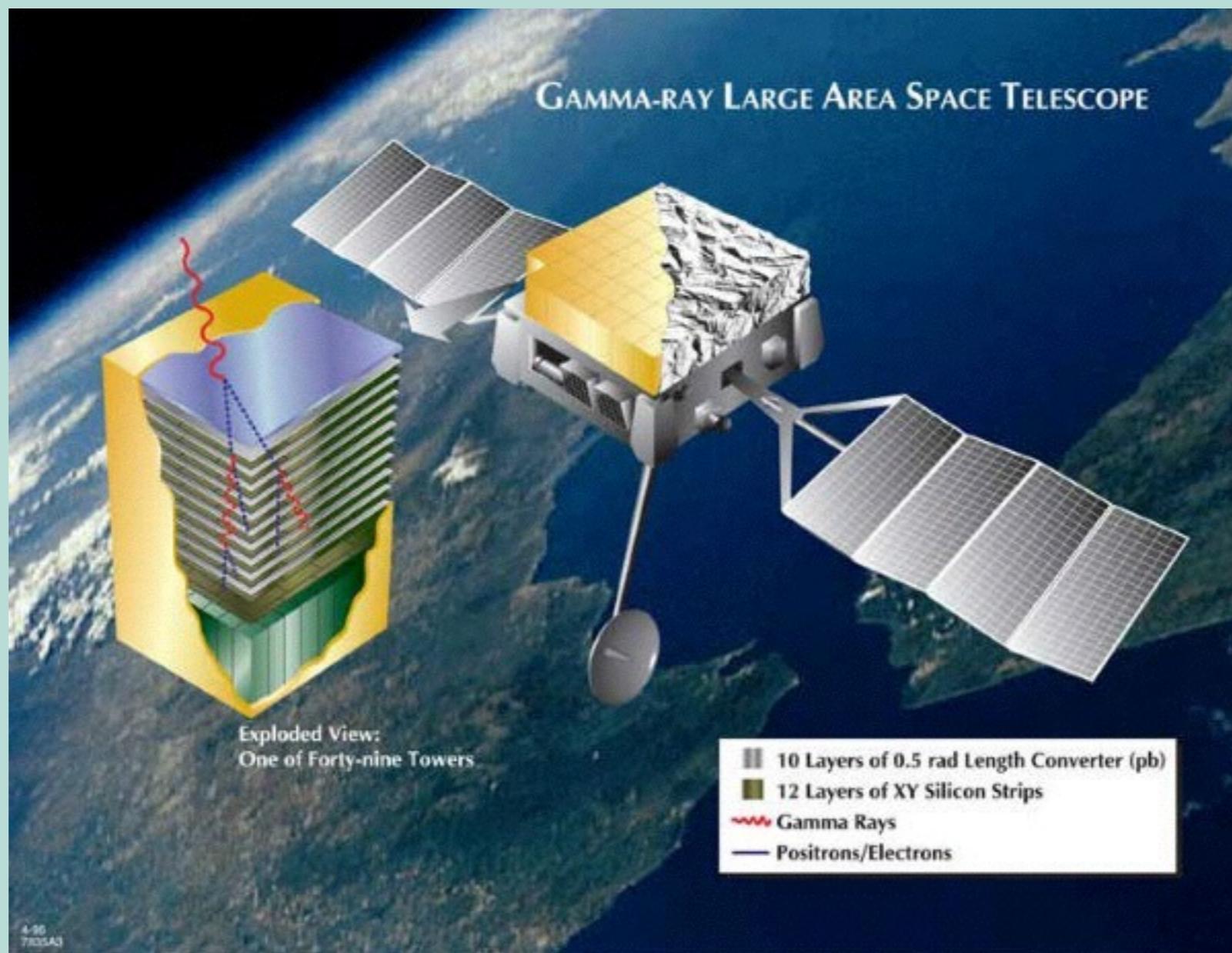
# False Color X-Ray image (supernova)



# Hubble Spitzer Chandra: Crab Nebula

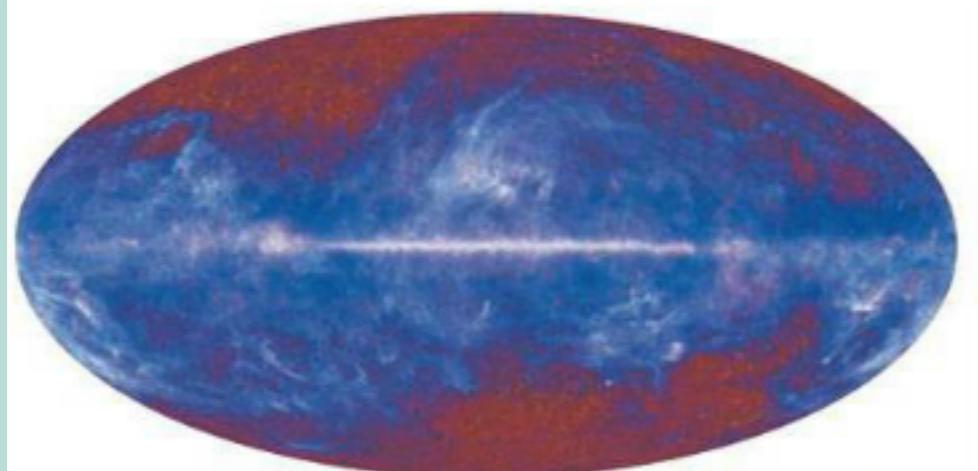


# Fermi



# Gamma Ray Image

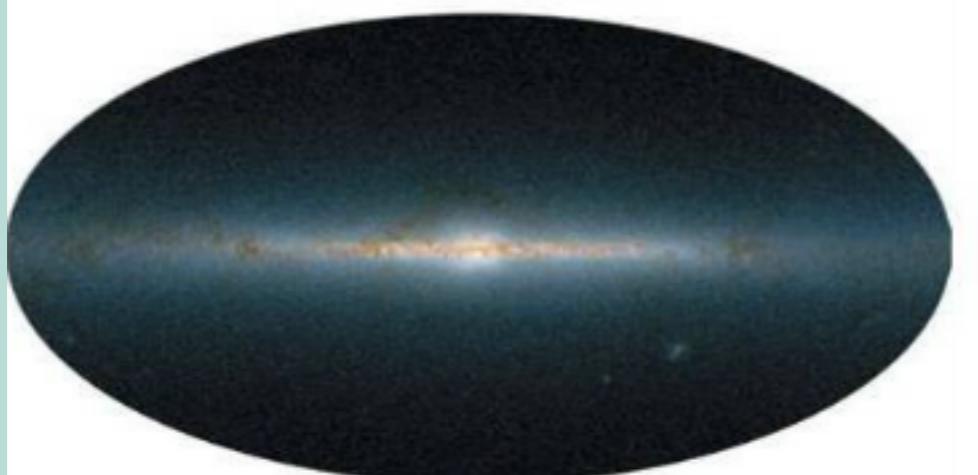




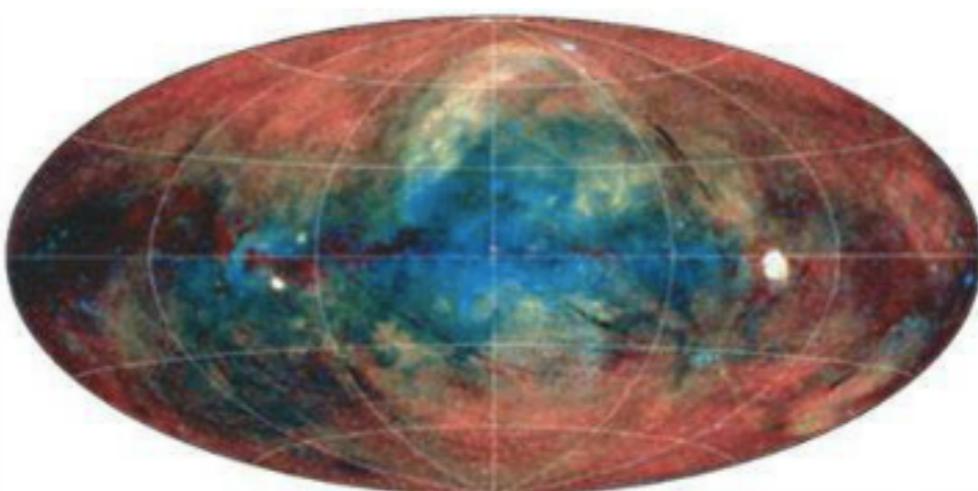
(a)



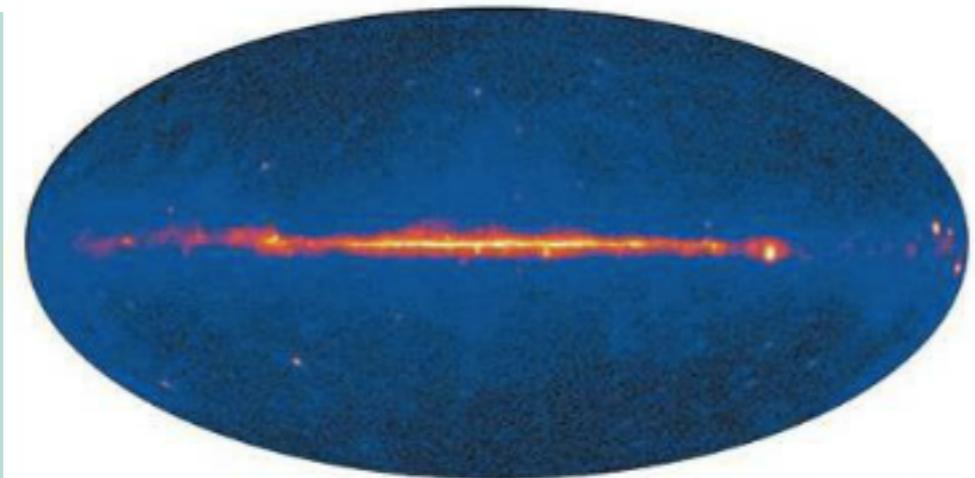
(c)



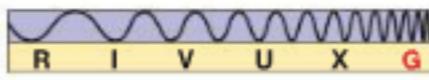
(b)



(d)

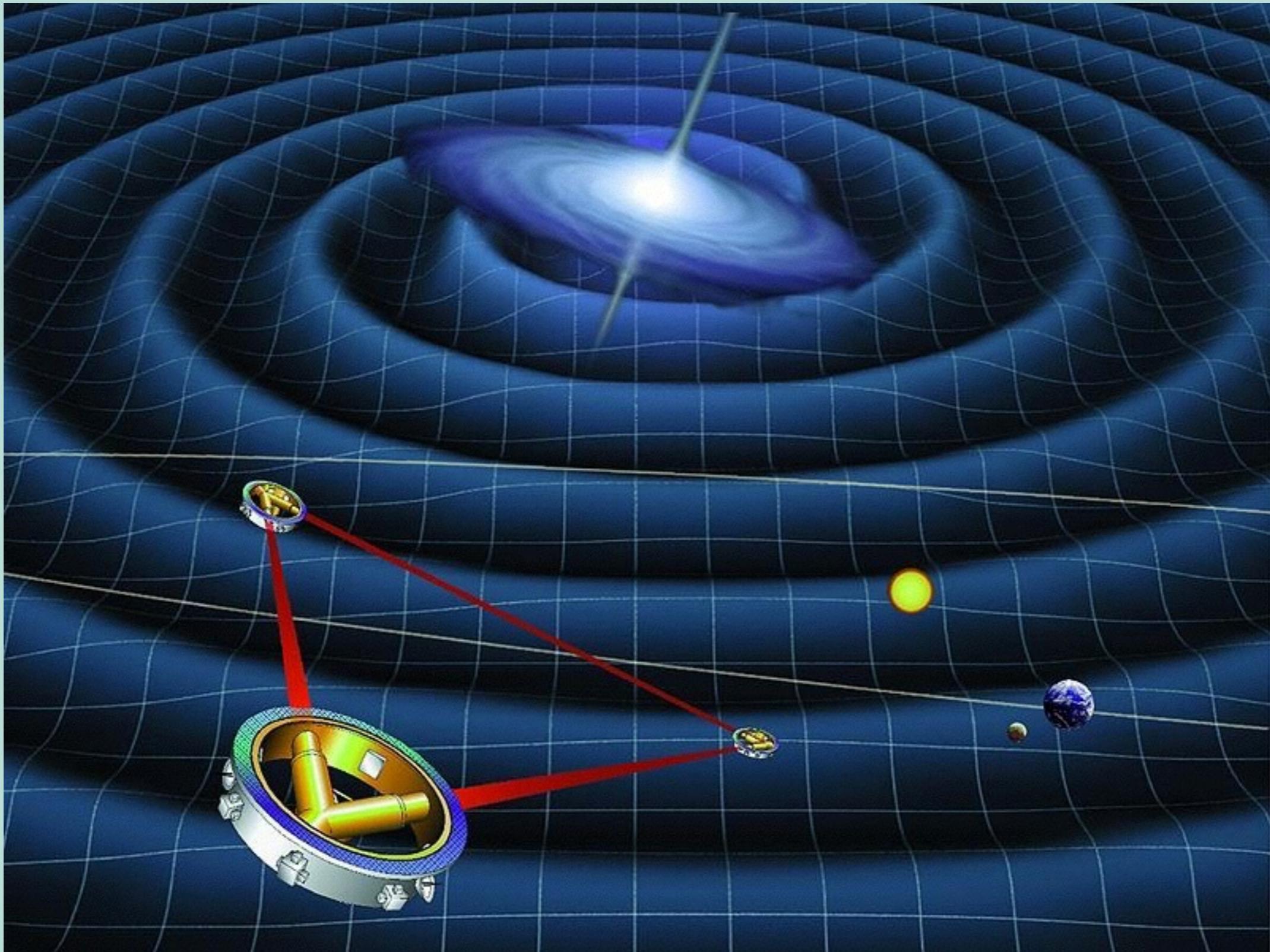


(e)





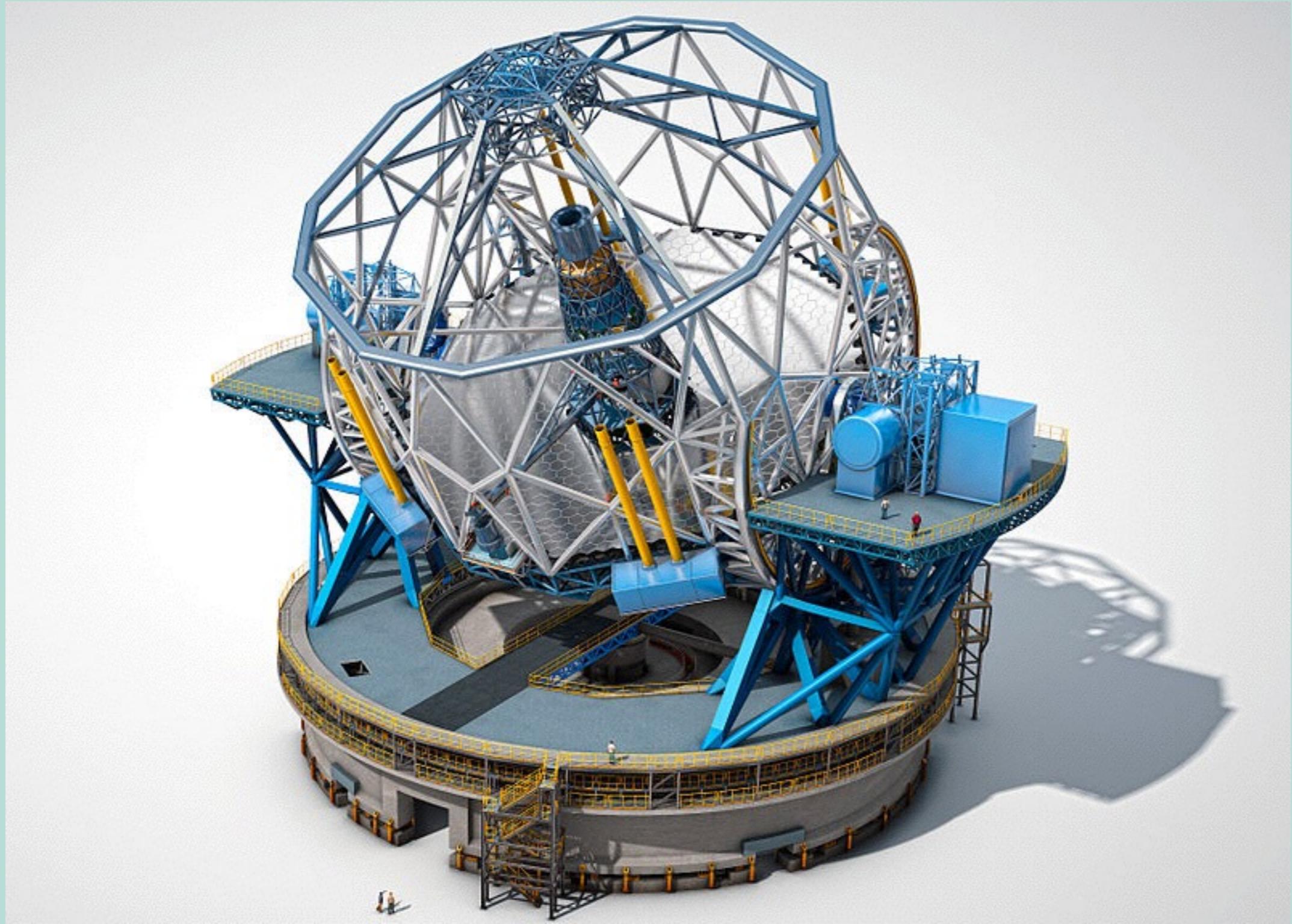
# LISA (Laser Interferometer Space Antenna)



# JWST (James Webb Space Telescope)



# European Extremely Large Telescope



40 meter diameter, 6 laser adaptive optics