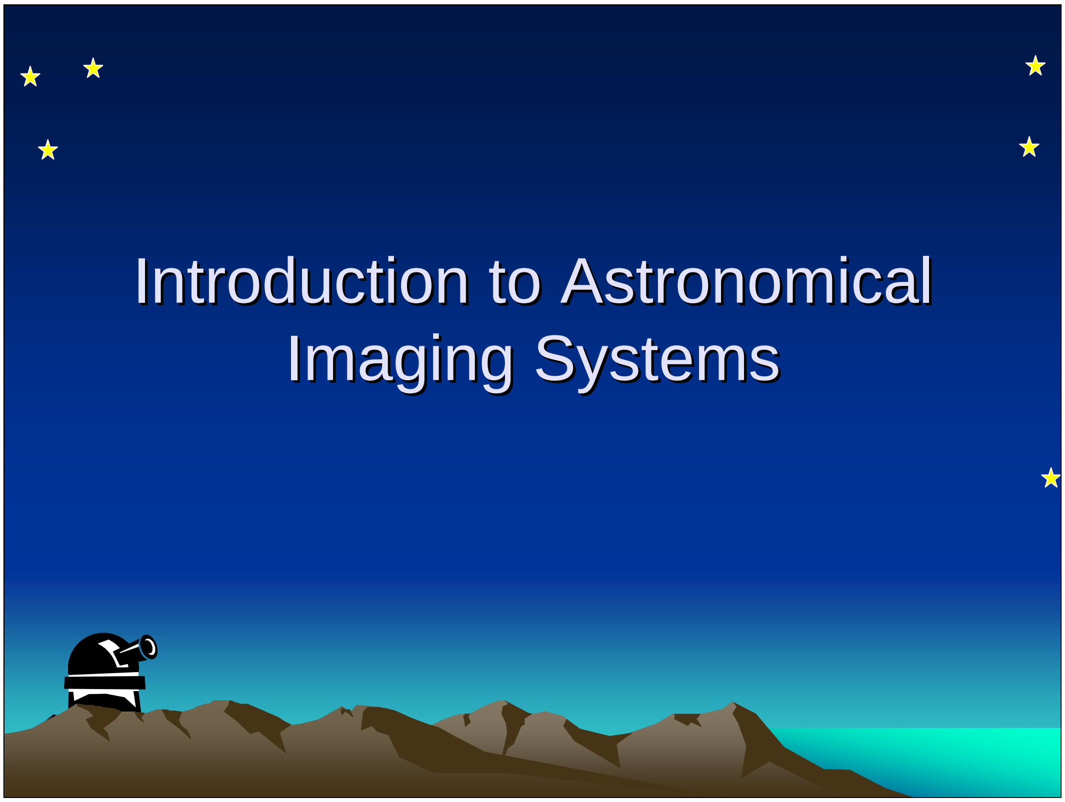

Introduction to Astronomical
Imaging Systems

Goal of Imaging Systems

- Create an "image" of a scene that may be measured to calculate some parameter (some "quantitative information) about the scene
- Examples:
  - Diagnostic X ray
  - Digital Photograph
  - "CAT" Scan (computed tomography)
  - "MRI" (magnetic resonance imaging)

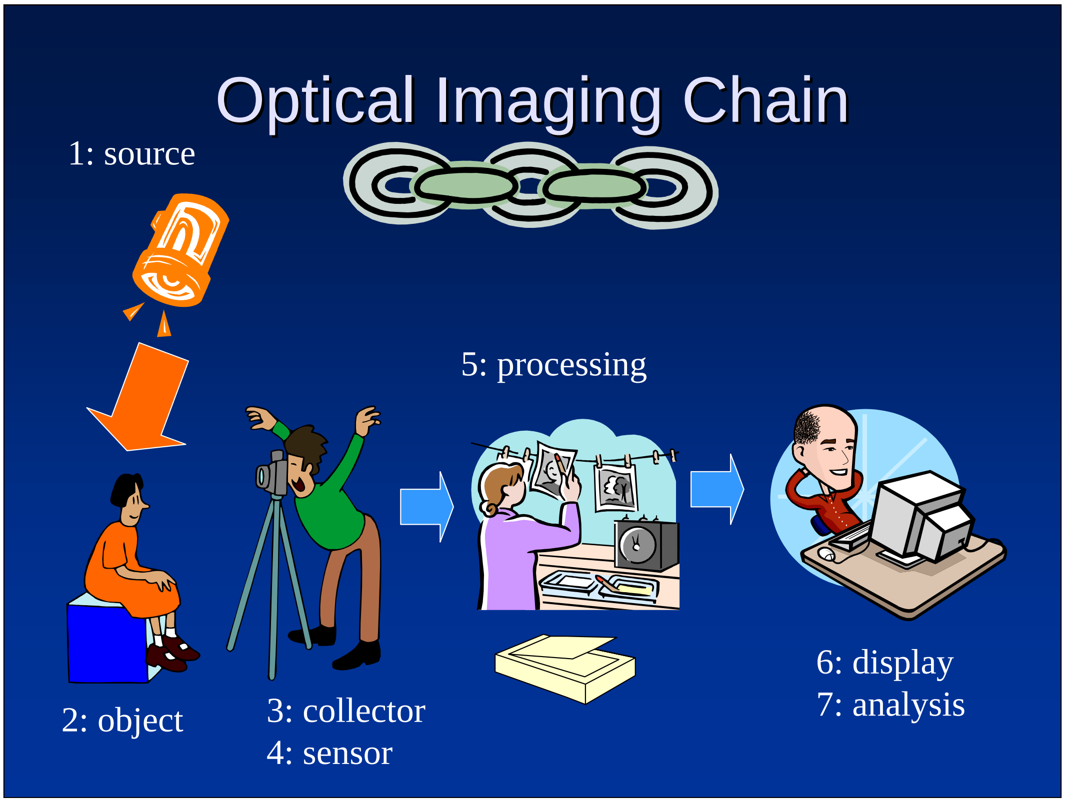
Imaging "Chain"
"Stages" of Imaging Systems

One Possible Classification:

1. Object
2. Source

(often one and the same!)

3. Collector (lens and/or mirror)
4. Sensor
5. Image Processing (computer or eye-brain)
6. Display
7. Analysis

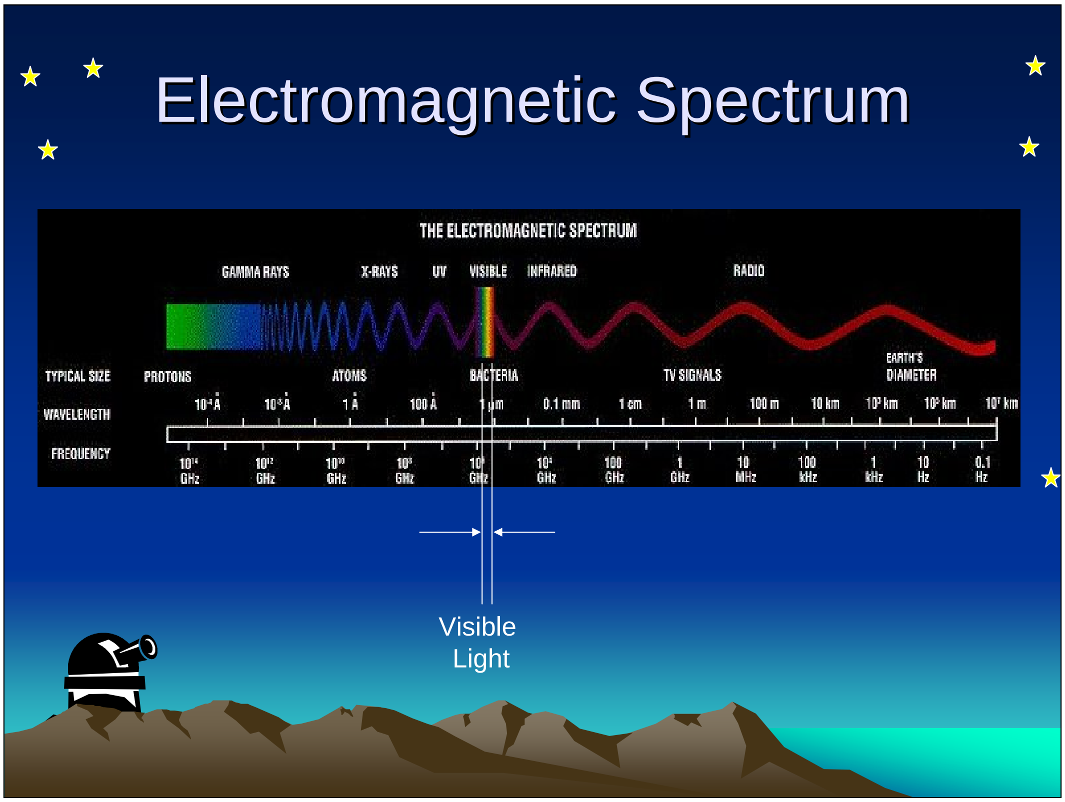

Optical Imaging Chain
1: source
5: processing
2: object
3: collector
4: sensor
6: display
7: analysis

Issues in Astronomical Imaging

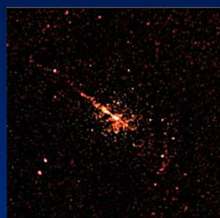
- (Differences between astronomical and "normal" imaging)
  - – Distances between objects and Earth
  - – Intrinsic "brightness" of object
    - generally very faint $\Rightarrow$ large image collectors
  - – Type of energy emitted/absorbed/reflected by the object
    - wavelength regions
  - – Motion of object
    - Intrinsic or Apparent

When you think of a clear, dark night sky, what do you visualize?

- Human visual system (HVS) is fine-tuned to focus, detect, and process *(i.e.,* to create an "image" of) the particular wavelengths where the Sun emits most of its energy
  - evolutionary outcome: we see "best" in the dominant available band of wavelengths
- As a result, when we look at the night sky, what we see is dominated by starlight (like the sun)
  - We think of *stars and planets* when we think of astronomy

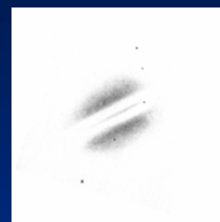

Electromagnetic Spectrum
THE ELECTROMAGNETIC SPECTRUM
GAMMA RAYS
X-RAYS
UV
VISIBLE
INFRARED
RADIO
TYPICAL SIZE
PROTONS
ATOMS
BACTERIA
TV SIGNALS
EARTH'S DIAMETER
WAVELENGTH
10^{-4} Å
10^{-2} Å
1 Å
100 Å
1 μm
0.1 mm
1 cm
1 m
100 m
10 km
10^3 km
10^5 km
10^7 km
FREQUENCY
10^{14} GHz
10^{12} GHz
10^{10} GHz
10^8 GHz
10^6 GHz
10^4 GHz
100 GHz
1 GHz
10 MHz
100 kHz
1 kHz
10 Hz
0.1 Hz
Visible Light

Information at Different Wavelengths – Centaurus A



X Rays (Chandra)

Ultraviolet (GALEX)

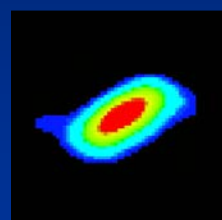


Visible Light
Sketch by John Herschel

Visible Light
(Anglo-Australian Obs.)

Near Infrared
(2MASS)

Mid Infrared
(Spitzer Space Telescope)



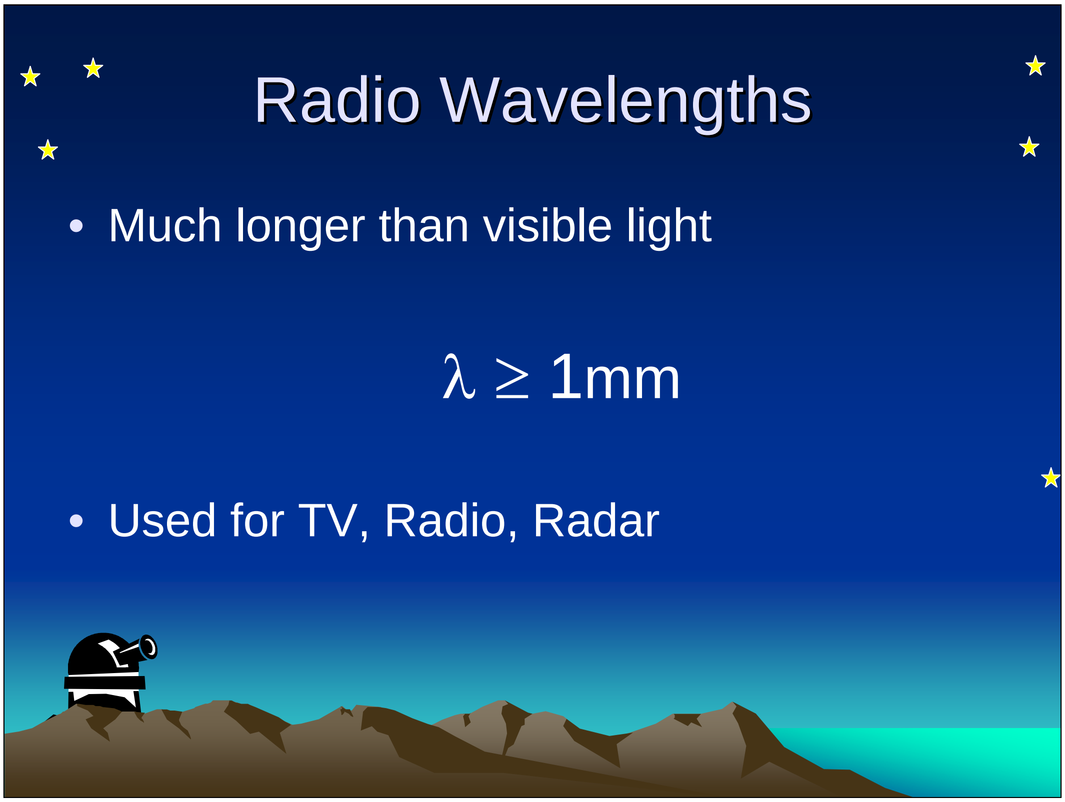
Far IR (IRAS)

Radio (VLA)

← Decreasing Wavelength λ

Systems/Sensors for Different λ

- Radio Waves: Radio Telescope
- Infrared Light: Telescope w/ IR Camera
- Visible Light: Optical Telescope
- Ultraviolet Light: Space-based Telescope
- X Rays: Space-based X-Ray Telescope



Radio Wavelengths
• Much longer than visible light
λ ≥ 1mm
• Used for TV, Radio, Radar

Radio Telescope

100m at Green Bank, WV

Image courtesy of NRAO/AUI

305m at Arecibo, Puerto Rico

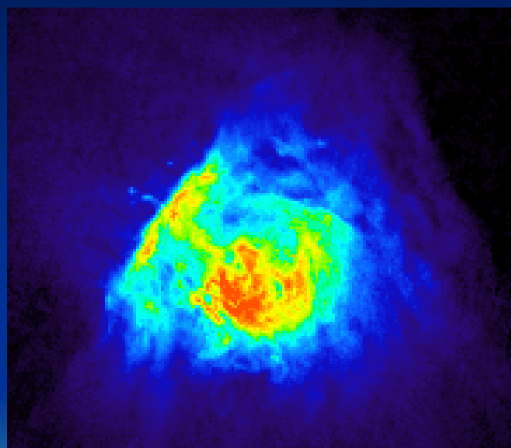
http://www.naic.edu/about/ao/telefact.htm

Radio Telescopes

- Diameter of "collector" is very large

  (10s – 100s of meters)
- Large Diameter Necessary to Obtain "Angular Resolution"
  – Ability to distinguish two sources that are close together (separated by a small angle)

Radio vs. Visible, Orion Nebula



$\lambda \approx 207$ mm $\approx 207{,}000{,}000$ nm

NCSA Astronomy Digital Image Library

700 nm $\geq \lambda \geq 400$ nm

Imaging Instruments Used for Previous Photos of Orion Nebula

Radio Telescope Array

4.2m

Optical Telescope

Image courtesy of NRAO/AUI

Very Large Array = VLA

Image courtesy of NRAO/AUI

- 27 telescopes
- 25m diameter
- transportable on rails
- separations up to 36 km (22 miles)

Infrared Wavelengths (IR)

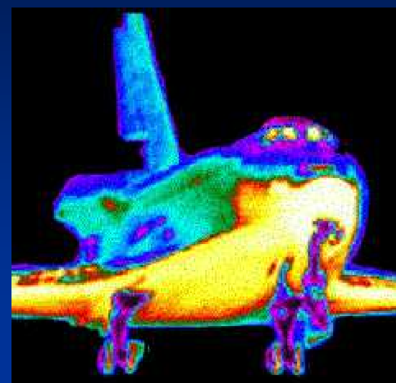
- Wavelengths λ are longer than for visible light

$$25\mu m \geq \lambda \geq 1\mu m$$

- This light is absorbed by water vapor in atmosphere

"Thermal Infrared" Astronomy

- Conveys information about temperature
  - i.e., images show "heat"



Courtesy of Inframetrics

Infrared Astronomy

- Because “thermal” infrared light is generated by heat, detector must be cooled to a lower temperature to measure the light
  - Uncooled detector is analogous to camera that also has an internal light source
    - camera itself generates a measurable signal
- Cooling detector is a BIG issue in infrared astronomy

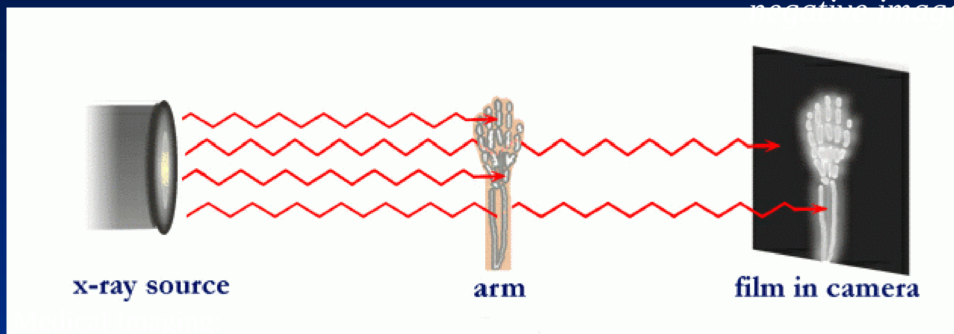
X-Ray Wavelengths

- Much shorter than visible light

$$0.1\text{nm} \geq \lambda$$

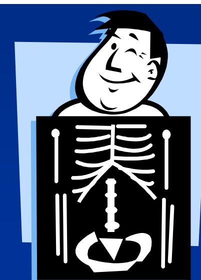
- X-Ray Telescope creates image of distribution of X rays in object

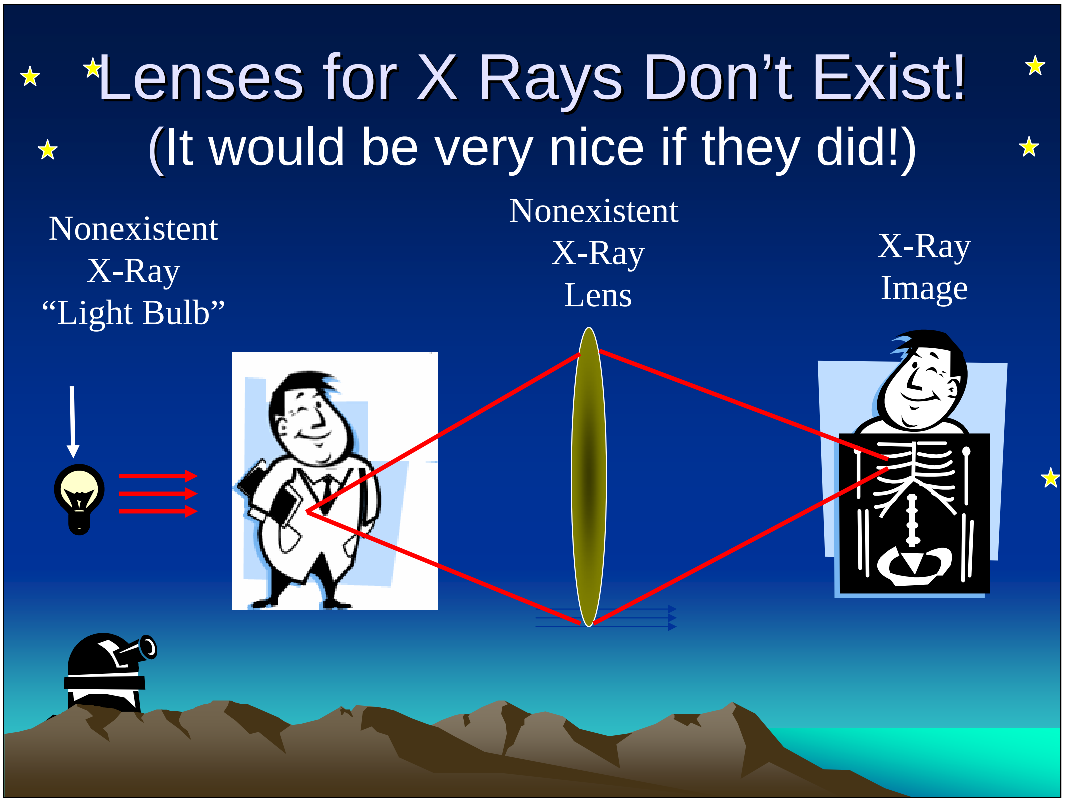
Medical X-Ray Imaging



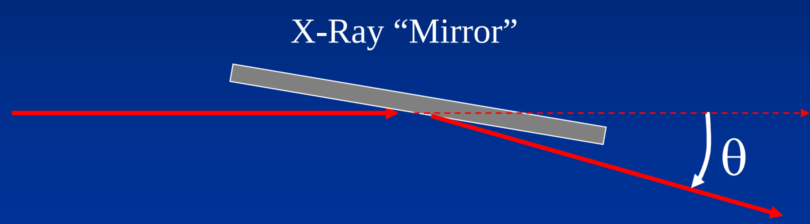
1. X Rays from source are absorbed (or scattered) by dense structures in object (e.g., bones). Much less so by muscles, ligaments, cartilage, etc.
2. Most X Rays pass through object to “expose” X-ray sensor (film or electronic)
3. After development/processing, produces *shadowgram* of dense structures

   (X Rays pass “straight through” object without “bending”)

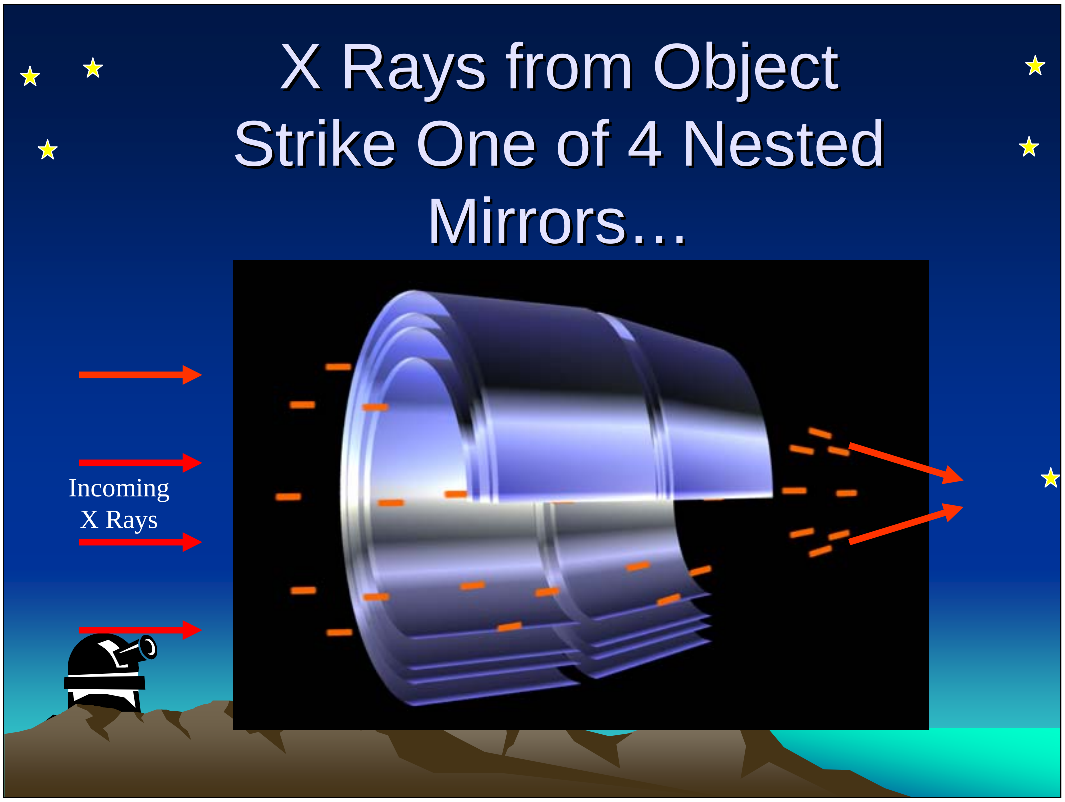



Lenses for X Rays Don’t Exist!
(It would be very nice if they did!)
Nonexistent
X-Ray
“Light Bulb”
Nonexistent
X-Ray
Lens
X-Ray
Image

X Rays CAN Be Reflected at Small Angles (*Grazing Incidence*)



X Ray at “Grazing Incidence
is “Deviated” by Angle θ
(which is SMALL!)


X Rays from Object Strike One of 4 Nested Mirrors…
Incoming
X Rays

Summary

- Need Imaging Systems that Can “See” the Entire Spectrum of Wavelengths (“Colors”)
  – Different Information is Conveyed at Different Wavelengths
    - X Rays and Gamma Rays
    - Ultraviolet (UV) Light
    - Visible Light
    - Infrared Light
    - Radio Waves
- The Different Systems Have VERY Different Requirements