Reading: Chapter 6, Sect. 6.4; Chapter 14 + assignment posted on Astro 150 Canvas
Homework: questions on special reading - submit before recitations on Wednesday
Exam 1: Wednesday, September 16 in recitation: review materials posted soon on Canvas

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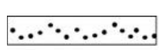
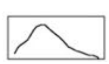
Last time: **The Telescope (and where to put it)**

- ultimate goal - every photon. The telescope as light bucket.
- size matters - bigger = more photons and better resolution
- different configurations for different purposes

Today: **What to do with those photons**

- instrumentation - squeezing info out of all photons
- getting around (or above) the atmosphere is critical
- astronomy from space provides access to all wavelengths

What do we do with the image?

- Look at it (with an eyepiece)!
- **Imaging** 
  - brightness as a function of position
- **Photometry** 
  - accurate measurement of brightness
- **Spectroscopy** 
  - brightness as a function of wavelength

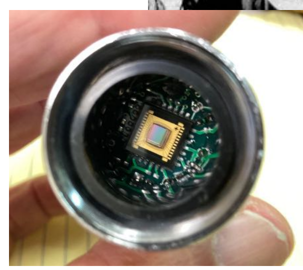
Imaging

accurate measure of brightness as a function of position

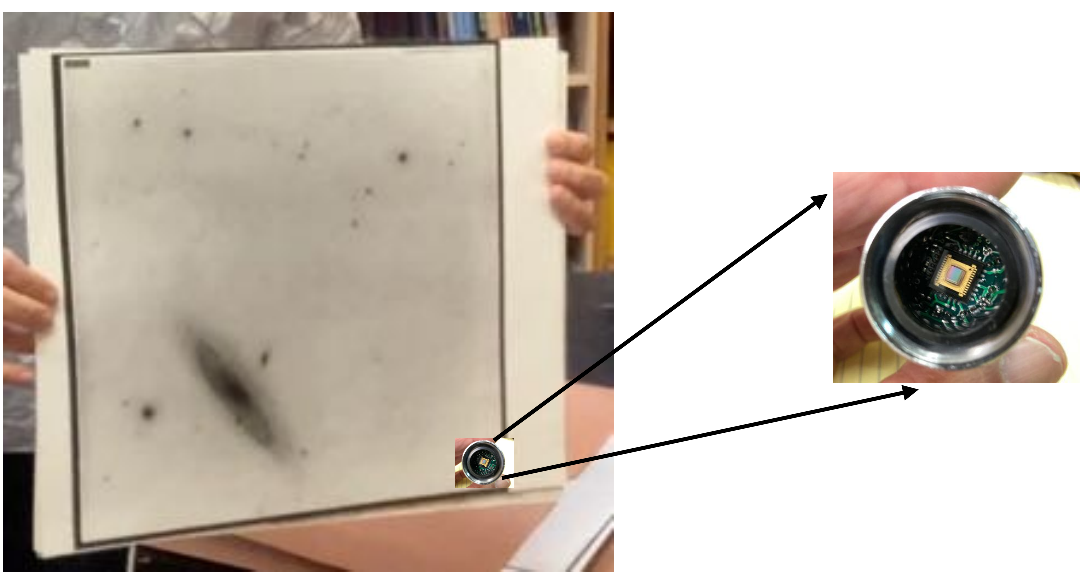
- Photographic Plate (so... 20th century...)
  - covers large areas
  - permanent image (> 100 years!)
  - but:
    - very inefficient (<< 10%)
    - small "dynamic range"
    - "nonlinear" sensitivity - they get tired! Photographic Plate (so... 20th century...)

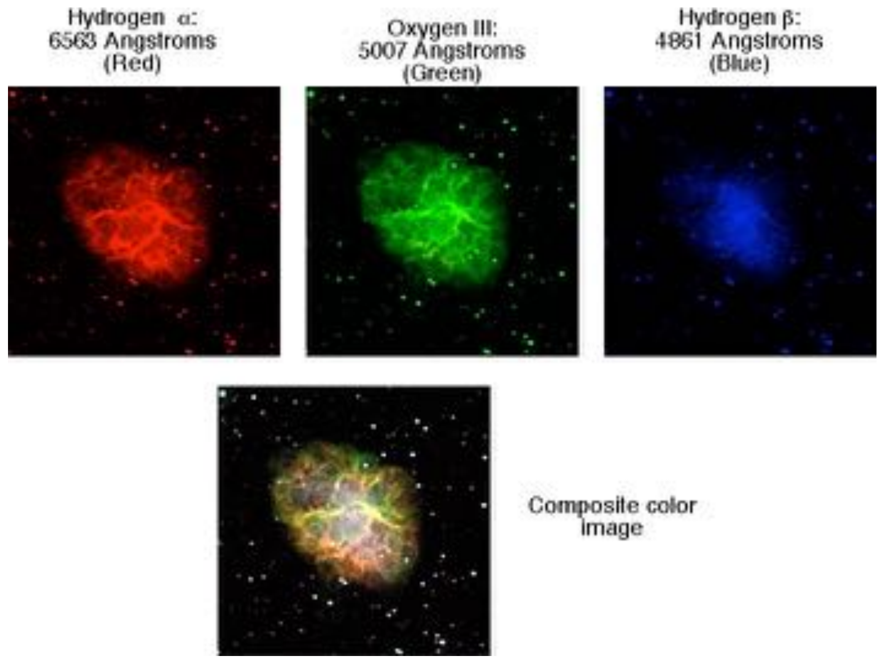
Edwin Hubble at the Palomar Schmidt

- **Charge Coupled Devices (CCDs)**
  - array of tiny photodetectors on a single chip
  - read out directly into computer
  - efficiency approaches 100 %
  - large dynamic range
  - linear sensitivity
  - but:
    - small area of sky coverage
    - need lots of devices - lots of memory and computer horsepower



Palomar Plate vs. consumer CCD

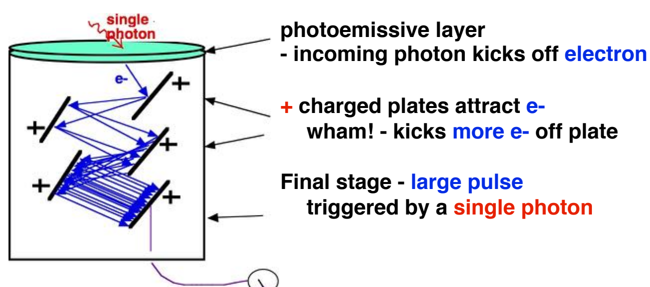




Photometry

accurate measure of brightness (as a function of time, color, . . .)

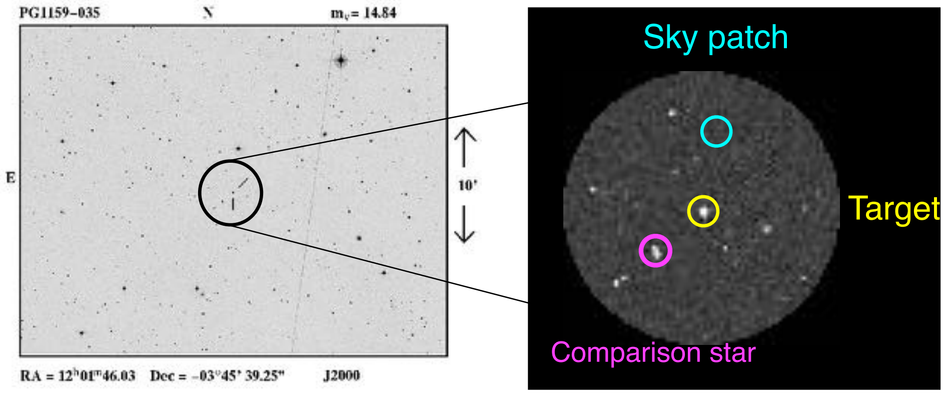
- Photomultiplier (old school...)
  - electronic tube to amplify weak signals
  - COUNTS PHOTONS! -



  - precise, fast, but inefficient (<30%)
- **CCDs**

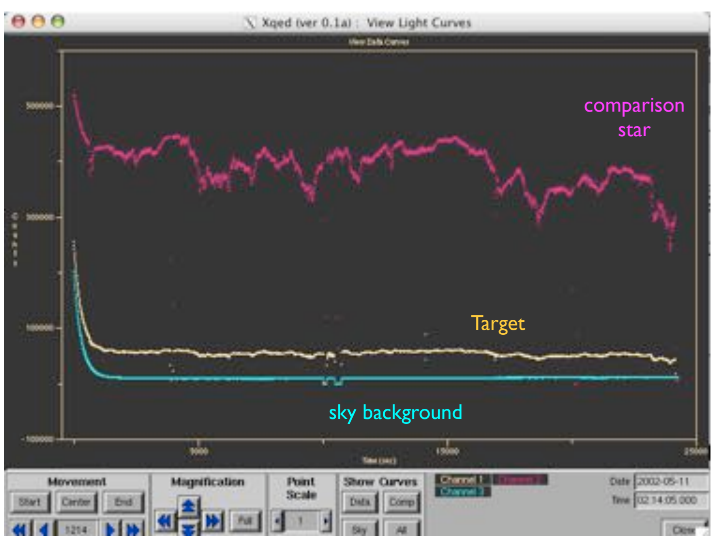
Aperture photometry

(multiple PMTs or 1 CCD)

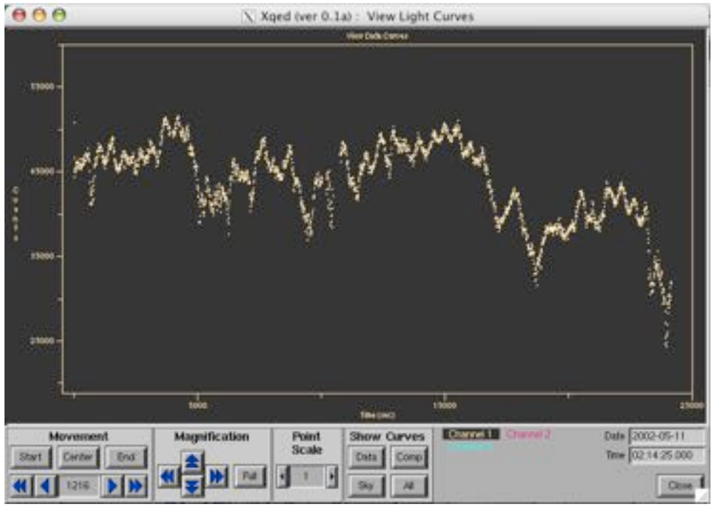


CCD Frame
(10 s duty cycle!)

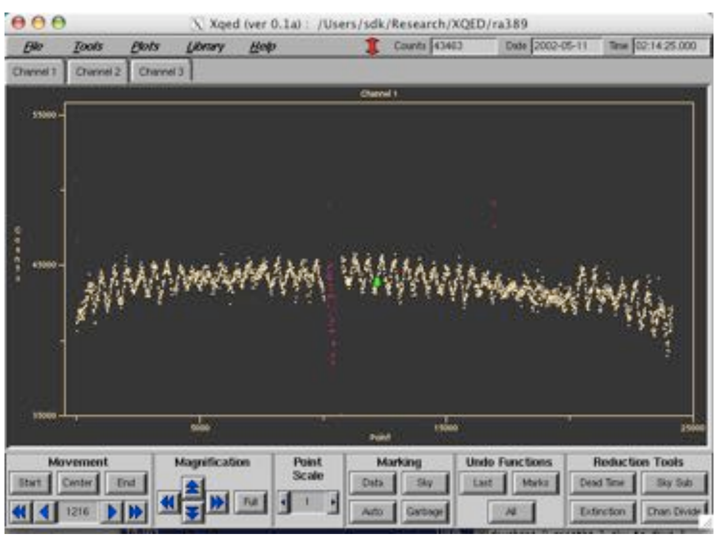
the raw data - 3 channel photometry



sky background subtracted from target

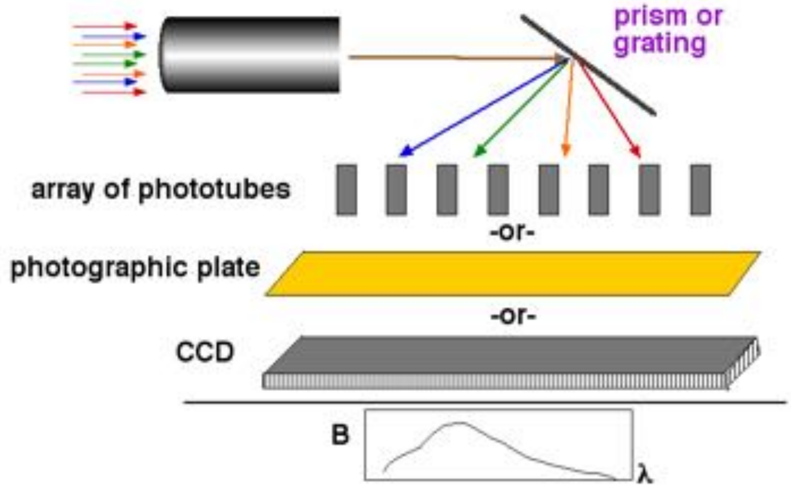


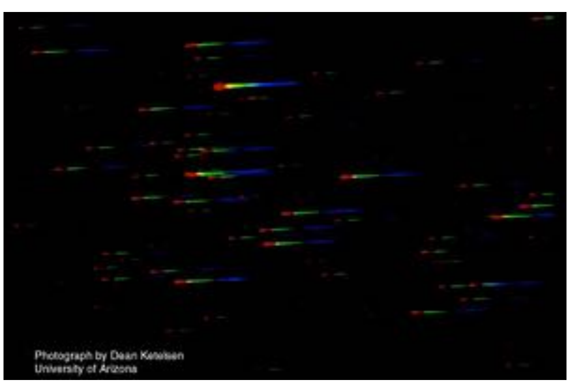
target divided by comparison

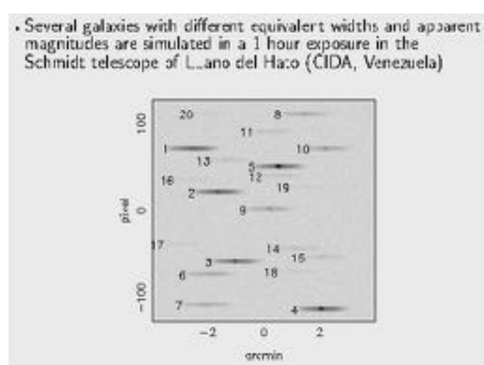


Spectroscopy

measurement of brightness as a function of wavelength







Telescope Performance

- **Optical Accuracy**
  - required surface accuracy to a fraction of a wavelength
  - optical telescope - 1/10,000,000 inch
  - radio telescope - 1mm
- **Mechanical Accuracy**
  - pointing (and hold) to resolution limit (i.e. << 1 arc second for optical telescopes)
- **Environment**
  - minimize light pollution
  - stable atmosphere ('good seeing')
  - go up, up up!
    - aircraft
    - balloons / sounding rockets
    - space

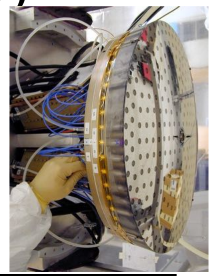
Atmospheric Seeing (scintillation)

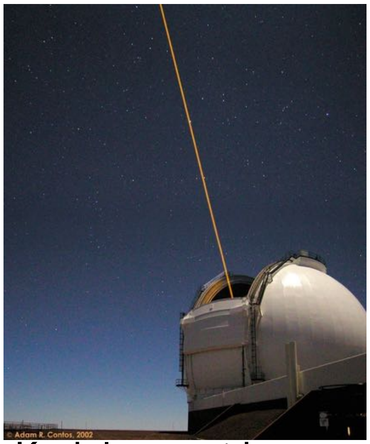
Ground vs. Space

- **<u>Ground-based</u>**
  - **Advantages**
    - relatively inexpensive per unit aperture
    - unlimited size of optics and instruments
    - “easy” access for upgrades / repairs / novel uses
  - **Disadvantages**
    - limited coverage of electromagnetic spectrum
    - atmospheric “seeing” - blurring by atmosphere
    - useful at most half the time: weather, sunlight, moonlight
- **<u>Space-based</u>**
  - **Advantages**
    - access to the entire electromagnetic spectrum
    - free from atmospheric distortion
    - continuous observation without interruption from Sun, Moon, weather
  - **Disadvantages**
    - extremely expensive to develop, deploy, and operate
    - limited lifetime, expensive or impossible to upgrade or repair
    - limited aperture and data delivery rate

Adaptive Optics (AO)

- remove blurring effects of atmosphere
- sense changing atmosphere & compensate by 'reverse blurring' image with deformable mirror
- technique developed by ISU Alum Robert Fugate





Keck laser guide star

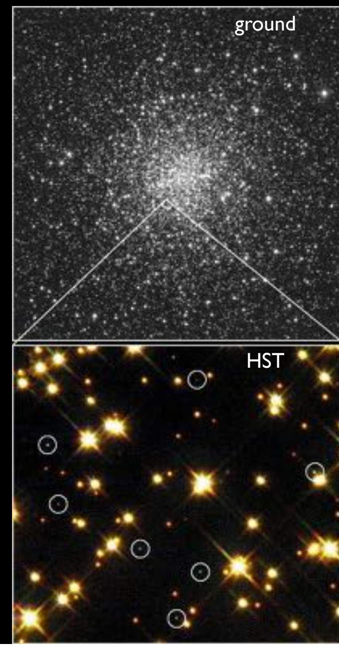
VLT

Astronomy from Space

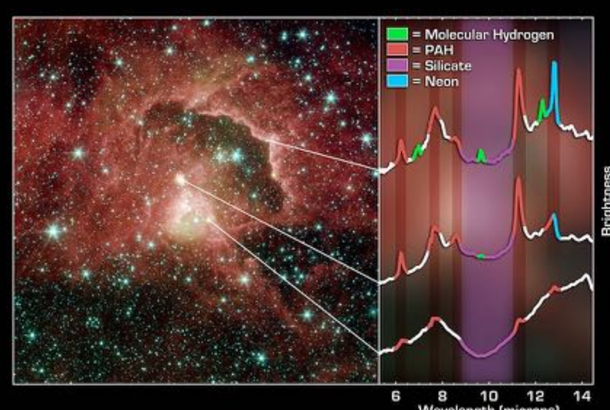
- **The Hubble Space Telescope**: 1990 - 2020+**?**
    - 2.4 meter diameter reflector
  - UV - Optical - IR sensitivity
  - astronaut serviceable (4 servicing missions)
    - on-orbit repair / replacement of parts
    - installation of upgraded instruments
  - current instruments
    - **ACS**: Advanced Camera for Surveys
    - **NICMOS**: Near IR Camera / Multi Object Spectrograph
    - **COS**: Cosmic Origins Spectrograph
    - **WFC3:** Wide Field Camera, v.3

- **Other Active Space Telescopes**
  - Spitzer Space Telescope (Infrared) (2003 - 2009/19)
  - Chandra X-Ray Telescope (X-ray) (1999 - 2020+)
  - Fermi : Gamma Ray Telescope (2008 - 2020+)

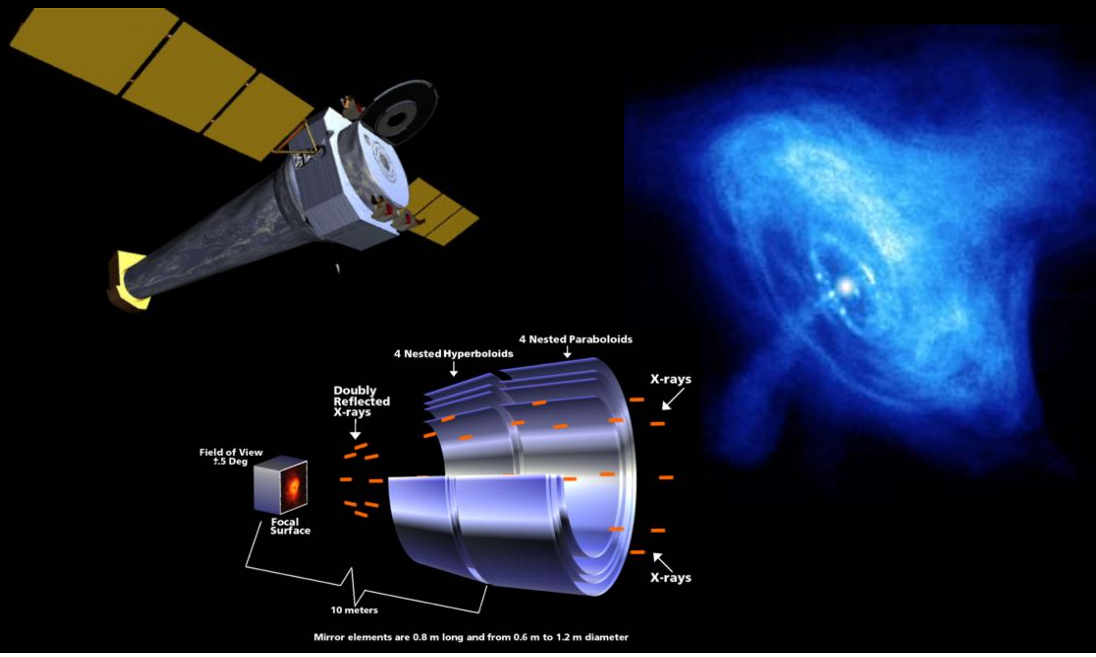
The Hubble Space Telescope



The Spitzer Space Telescope (IR)



The Chandra Space Telescope (X-ray)

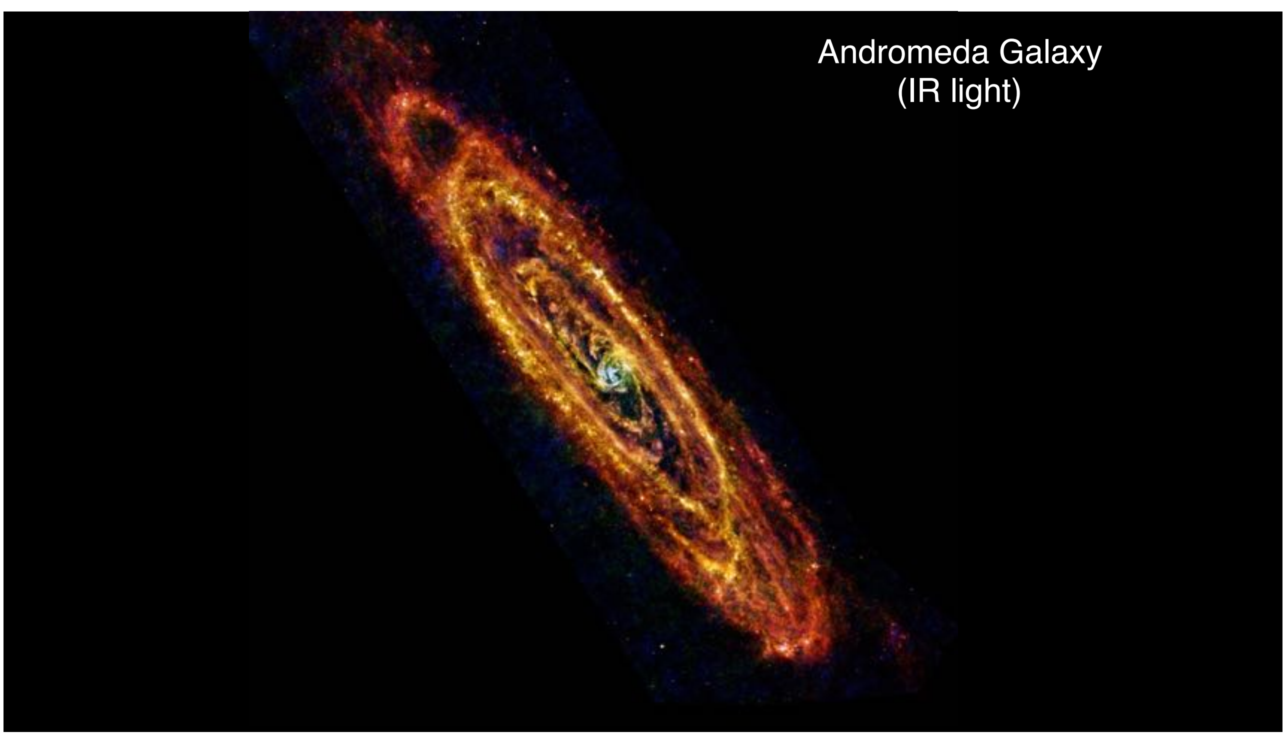


infrared optical X-ray

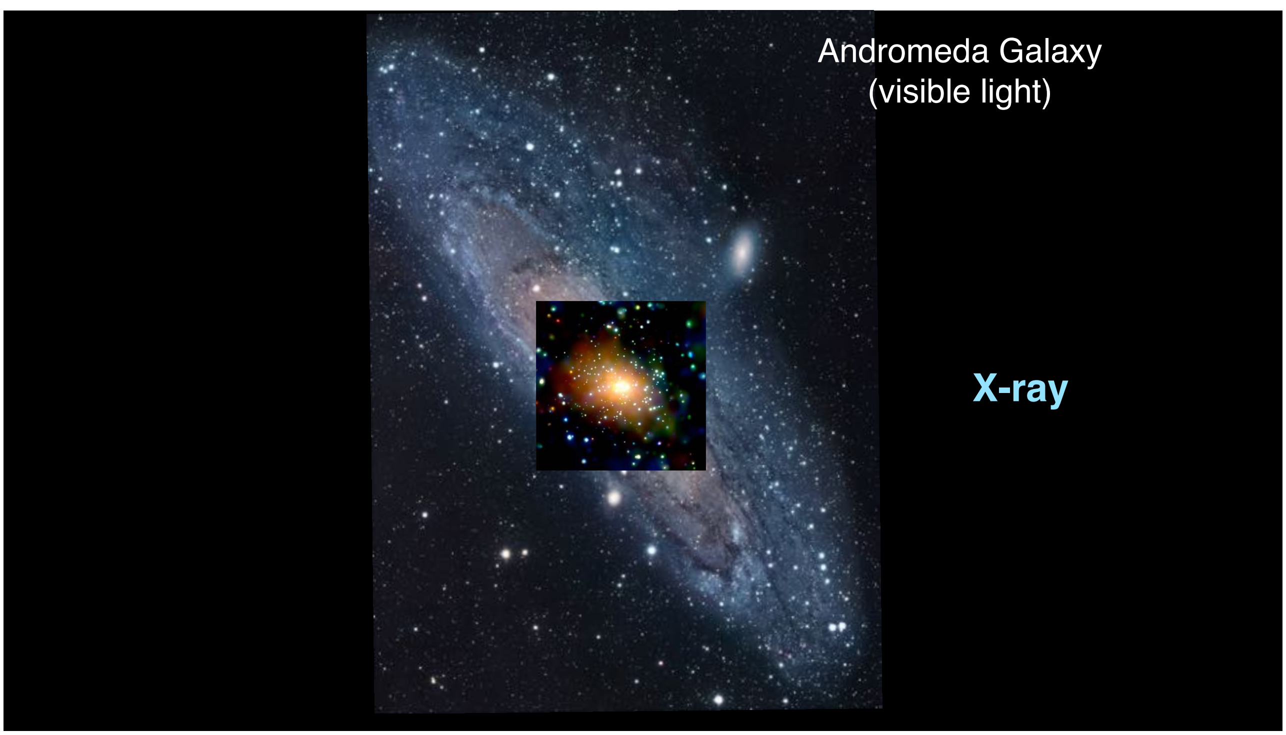
Spiral Galaxy M101 Spitzer Space Telescope • Hubble Space Telescope • Chandra X-Ray Observatory

NASA / JPL-Caltech / ESA / CXC / STScI ssc2009-03b


Andromeda Galaxy
(visible light)


Andromeda Galaxy
(IR light)


Andromeda Galaxy
(ultraviolet light)


Andromeda Galaxy
(visible light)
X-ray

Next up - James Webb Space Telescope
scheduled launch: October 31, 2021

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