## ASTR 1040: Stars & Galaxies


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*Lecture 5 Tues 28 Jan 2020*
*zeus.colorado.edu/astr1040-toomre*

## *Topics for Today*

- What our atmosphere does to "light"
- Magic of "adaptive optics"
- Radio telescopes: many dishes make a big one (interferometry or "aperture synthesis")
- Telescopes in space -- and why
- Next: Our *Nearest Star the Sun* in overview

- *Finish reading Chap 14 (Our Star) in detail*
- *Thursday class meets in Fiske Planetarium*
- *Observatory Night #1 this Thur Jan 30 by signup*

## *Problems in Looking Through Our Atmosphere*

- Many wavelengths are **absorbed** (just don't make it through to surface)
- Turbulence in atmosphere distorts light:
  - stars appear to "twinkle"
  - angular resolution is degraded
- Man-made light is reflected by air particles, yielding bright night sky
  - this is *light pollution*

## *Light Pollution*

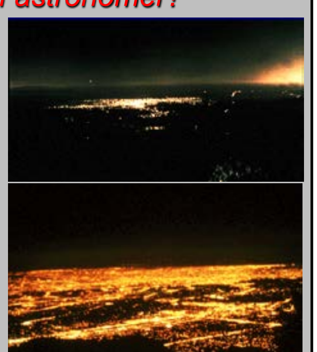
*90% of Earth's population cannot see the Milky Way*

## *How many light bulbs does it take to screw up an astronomer?*

*An immediately curable pollution: simply turn the lights off!*

*Stop "uplight", glare: wastes billions of $$ in energy, use "low-pressure Na-Hg"*

*Several famous observatories are now useless…*



LA Basin View from Mt. Wilson Observatory, 1908 and 1998

## *Quest for Good Weather and Seeing*

- *Mauna Kea, Big Island of Hawaii, 14,000' elevation, middle of the Pacific*
- *Dry, high, dark and isolated. Best on the planet?*

## Telescope Sites

- *The best sites are high, dark and isolated.*
- *Even in the best places, atmospheric angular resolution is typically 0.3-0.5 arcsec at visible wavelengths*

Kitt Peak, Arizona

Paranal, Chile

Canary Islands

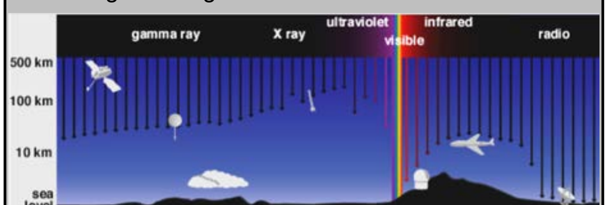
Mauna Kea, Hawaii

## Reading Clicker Q  B

- *Which wavelength regions CAN be studied with ground-based telescopes?*
- A. All light with wavelengths longer than ultraviolet
- B. Radio, visible, and very limited portions of infrared and ultraviolet
- C. All light with wavelengths shorter than infrared
- D. Infrared, visible, and ultraviolet

## Atmospheric Absorption of "Light"

- Earth's atmosphere absorbs most types of light
  (not entirely bad, or we would be dead!)
- Only *visible, radio, and some IR and UV* light get through to the ground

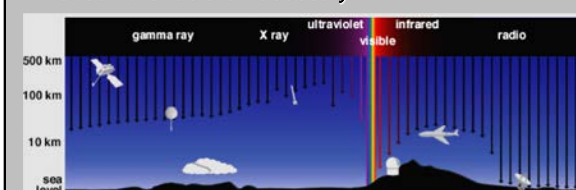



*To observe other wavelengths, must put telescopes in space!*

## UV, X-rays and Gamma-rays

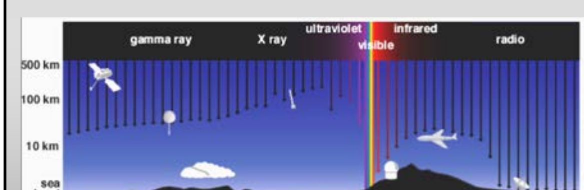
- *These all have enough energy to ionize electrons out of atoms or break apart molecules*

  → Heavily absorbed by the atmosphere
- *Space or high altitude (balloon, rocket) observatories are necessary*

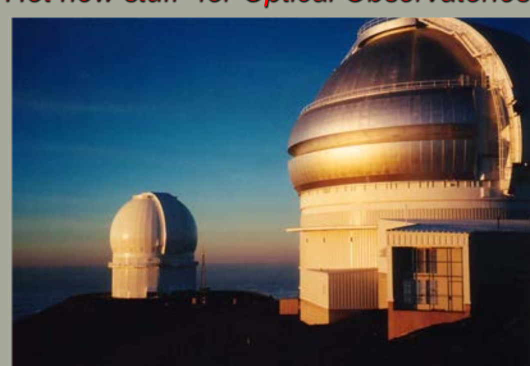



## Why bother with "other light"?

- *… Many very hot objects shine brightest in such UV, X-ray and gamma-ray photons*
- *… And cool star-forming regions are brightest in IR*

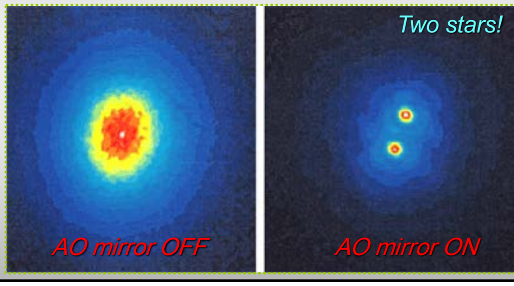



## "Hot new stuff" for Optical Observatories



## Adaptive Optics (AO) – "de-twinkle" stars

- Wavefronts of star light are deformed by atmosphere
- Can distort shape of mirror (very fast) to correct for distortions by atmosphere – *hot new technology*

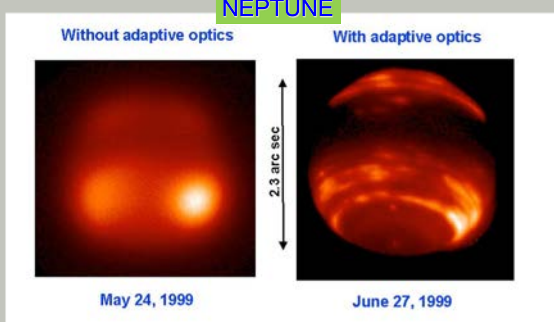



## Adaptive Optics to the Rescue!

- Use a laser to create an artificial star and correct for the distortion caused by Earth's atmosphere
  - If you bounce the incoming light off a warped mirror (of exactly the right shape) the light comes off corrected
- It's like reversing the effect of a funhouse mirror

## Adaptive Optics benefits

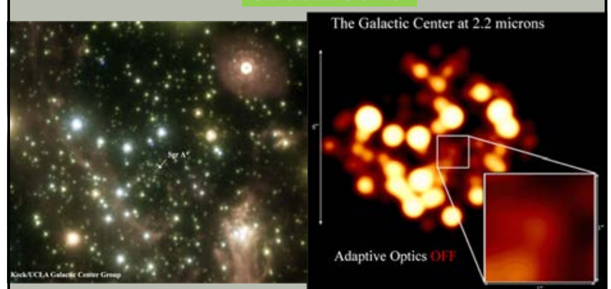
NEPTUNE




Images from the Keck Observatory

## Adaptive Optics wizardry

Galactic Center




## Clicker Q - galaxy B

- *In observing a distant galaxy, the H alpha spectral line of hydrogen (usually in the visible) is now in the IR portion of the spectrum. What can you conclude?*
- *A. Galaxy is made purely of hydrogen*
- *B. Galaxy is moving away from us*
- *C. Galaxy is moving towards us*
- *D. Galaxy has very weak gravity*

## So what gets through our atmosphere?

- *RADIO WAVES: most get through*
  - *Thus radio telescopes are built on the ground*
- *Weather is not an issue*
  - *Radio waves come right through the clouds*
- *But poorer angular resolution*
  - *Why?*
    - *VERY long wavelengths!*

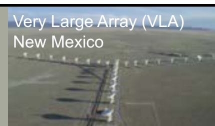

## Green Bank Telescope (100+m)

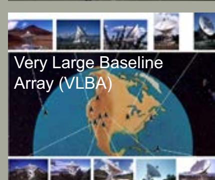
## Radio Telescopes – Biggest Single Dish

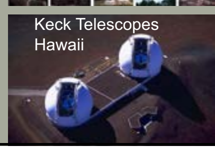
305 m Arecibo PR

## Interferometry

- Join multiple telescopes together to simulate one large telescope.
- Very Large Array (VLA) in New Mexico has 27 dishes (each 25 m) across in a 40 km valley
- Very Large Baseline Array (VLBA) is an array of ten telescopes around the hemisphere
  - Resolutions as small as 0.001 arcseconds for radio light
- The twin Keck telescopes can also be an infrared interferometer.

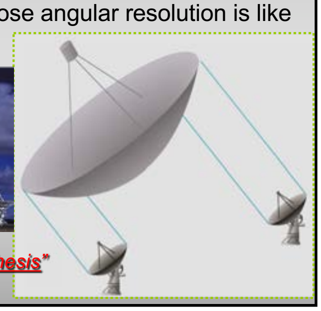


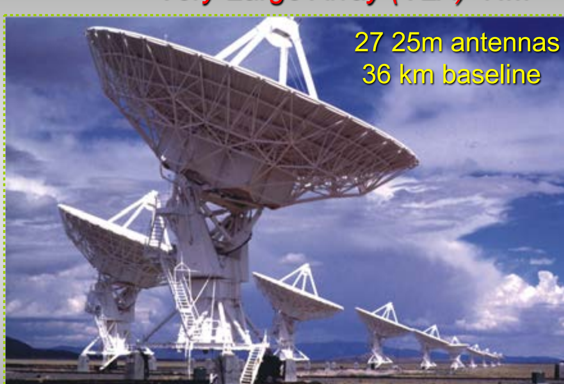

## Radio Interferometry – many small look big!

- Two (or more) radio dishes observe the same object
- Signals from each “interfere” with each other
- Can construct image whose angular resolution is like that from a huge dish!

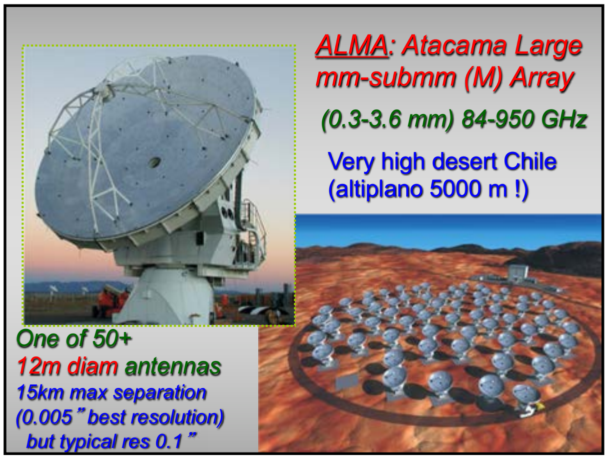


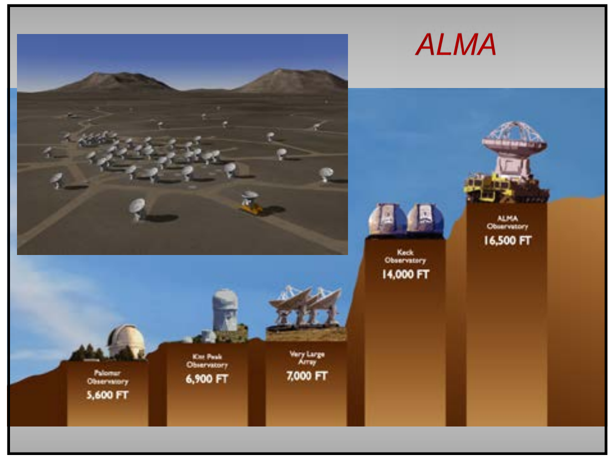
VLA – “Large Aperture Synthesis”

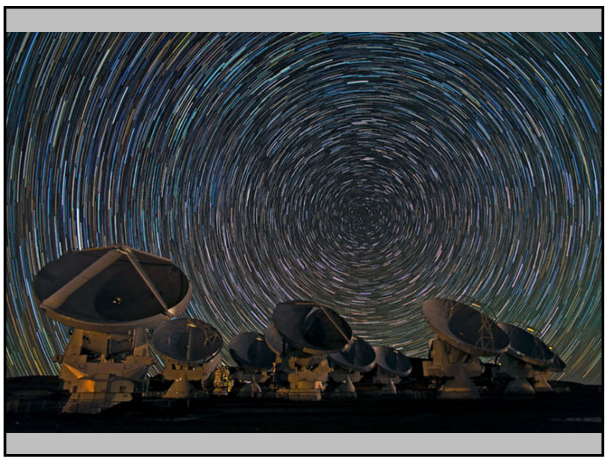
## Very Large Array (VLA) NM

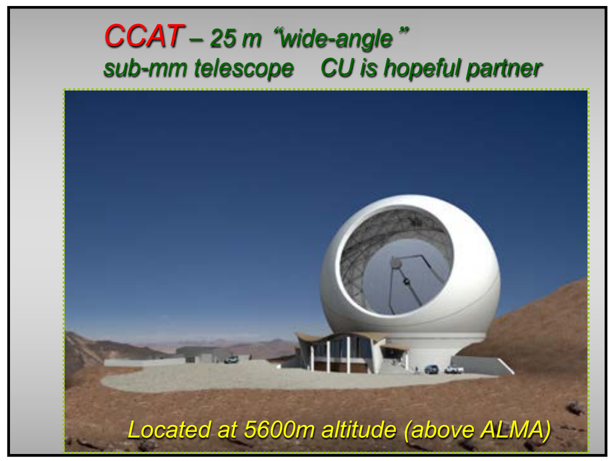


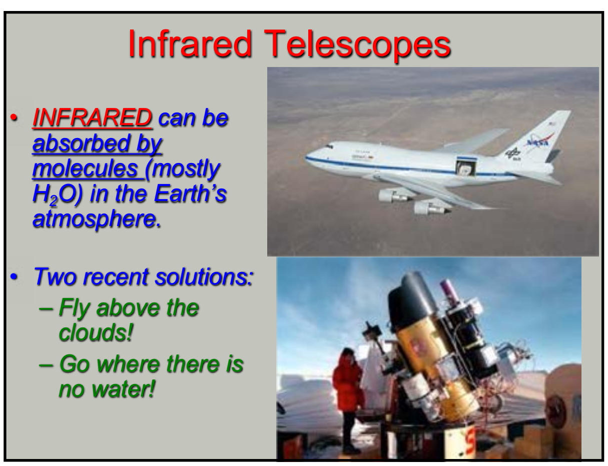

## VLBA in Owens Valley CA


ALMA: Atacama Large mm-submm (M) Array
(0.3-3.6 mm) 84-950 GHz
Very high desert Chile (altiplano 5000 m !)
One of 50+
12m diam antennas
15km max separation
(0.005" best resolution)
but typical res 0.1"


ALMA
Palomar Observatory 5,600 FT
Kitt Peak Observatory 6,900 FT
Very Large Array 7,000 FT
Keck Observatory 14,000 FT
ALMA Observatory 16,500 FT




CCAT – 25 m "wide-angle"
sub-mm telescope CU is hopeful partner
Located at 5600m altitude (above ALMA)


Infrared Telescopes
• INFRARED can be absorbed by molecules (mostly H2O) in the Earth's atmosphere.
• Two recent solutions:
– Fly above the clouds!
– Go where there is no water!

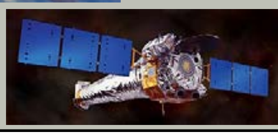

For other wavelengths we have to get above the atmosphere
• UV, X-rays, Gamma Rays
• Methods: balloons, rockets, Space Shuttle, satellites

## NASA's Great Observatories

Compton Gamma Ray Observatory

Spitzer Space Telescope
Infrared

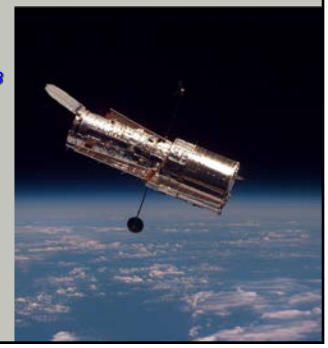
Hubble Space Telescope
UV/Visible



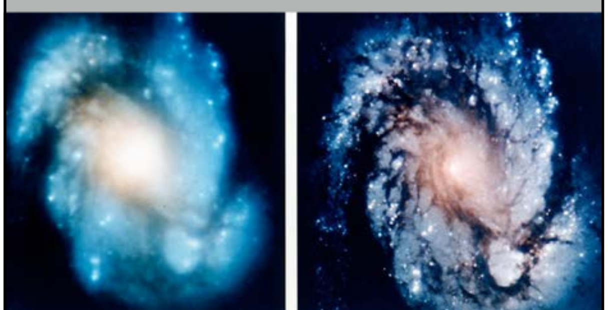
Chandra X-Ray Observatory

## Hubble Space Telescope: NASA's most famous observatory

- Launched in 1990
  - Error in mirror made blurry images
- Corrective optics installed in 1993 (Ball Aerospace here in Boulder)
- Small (only 2.5 meters) but diffraction-limited
- Low orbit accessible by Shuttle, refurbishing missions mean long lifetime (1990 to 2014+)
- $5 billion over 20 years = 10-100 times more costly than ground-based telescope



## Very sharp images from Hubble … and much more



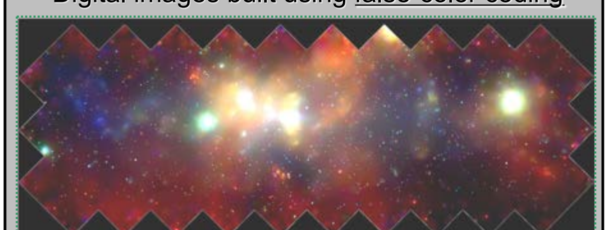
## How do you point a space telescope in orbit ?

1. Squirt from jets to change direction (hydrazine)
2. Torque by electric currents in big coils while flying through Earth's magnetic field
3. Torque by electric motors spinning up or down "reaction wheels"

ANGULAR MOMENTUM DEMONSTRATION

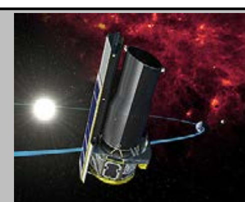
## "Nonvisible" Light – X-ray, UV, IR, Radio

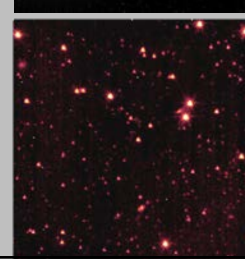
- Most light is invisible to human eye
- Special detectors can record such light
- Digital images built using false-color coding



Chandra X-ray image of center of our Milky Way Galaxy

## SPITZER Infrared Telescope

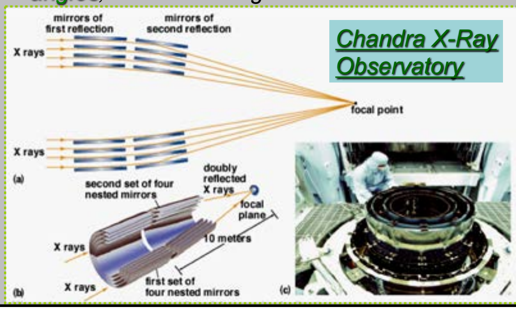




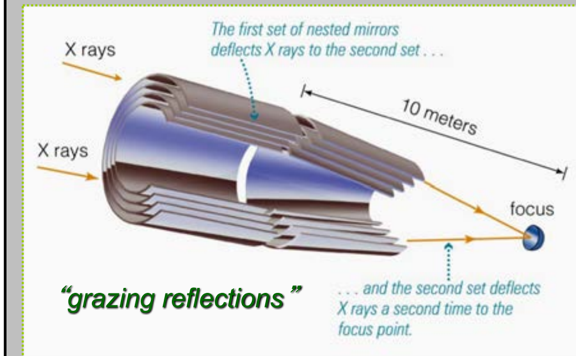
- Launched August 2003
- Trails behind Earth to get away from Earth's thermal spectrum
- 0.85m aperture , T ~ 5.5 K
- Cooled with liquid helium, had 2-5 years worth, now used up (warmer phase)

## X-Ray Telescopes – do it their own way!

- *X-ray photons can pass right through a mirror*
- *Such photons can only be* ***reflected at shallow angles****, like "skimming stones" off water surface*

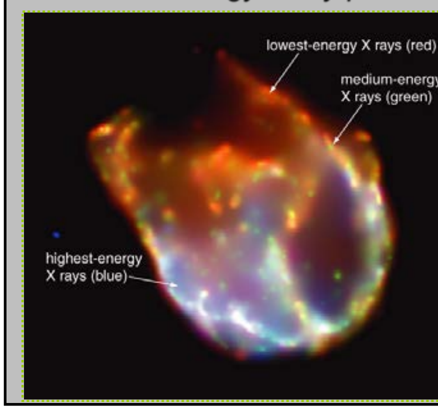



## Bigger view of Chandra's X-ray Imaging




## Chandra X-ray Observatory (at $L_2$ Lagrangian)

## Multi-energy X-ray picture




*Chandra: Supernova Remnant SNR: N132D*

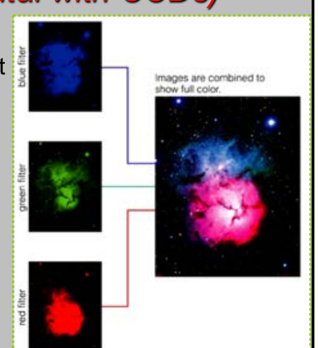
## Instruments in the Focal Plane

*How astronomers use light collected by a telescope:*

1. ***Imaging***
   - use camera to take pictures (images)
   - photometry: measure amount and color (with filters) of light from object
2. ***Spectroscopy***
   - use spectrograph to separate light in detail into its different wavelengths (colors)
3. ***Timing***
   - measure how amount of light changes with time (sometimes in a fraction of a second)

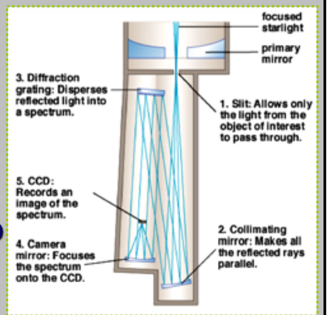
## Imaging (Digital with CCDs)

- *Filters* are placed in front of camera to allow only certain colors to be imaged
- Single color images are superimposed to form "true color" images.

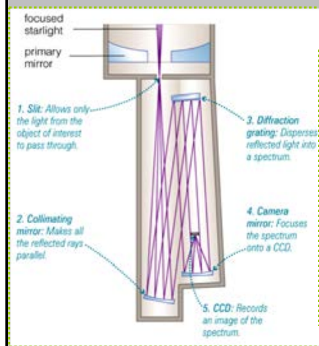


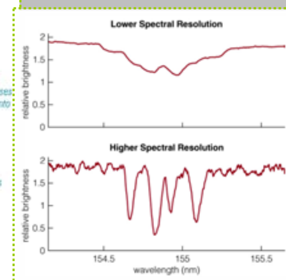
## *Spectroscopy – analyzing the light*

- Spectrograph reflects light off a ***grating***: finely ruled, smooth surface
- Light (by interference) disperses into colors
- This ***spectrum*** is recorded by digital CCD detector

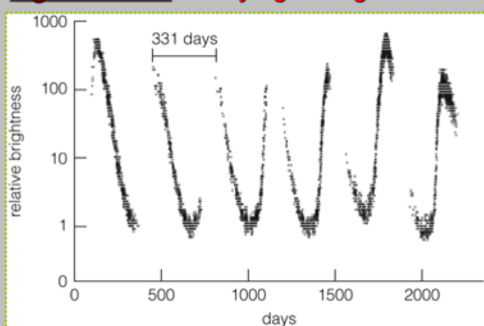



## *Spectral resolution is vital but also "costly in photons"*




## *Light curves: Studying changes with time*




*Variable star MIRA: period ~331 days*