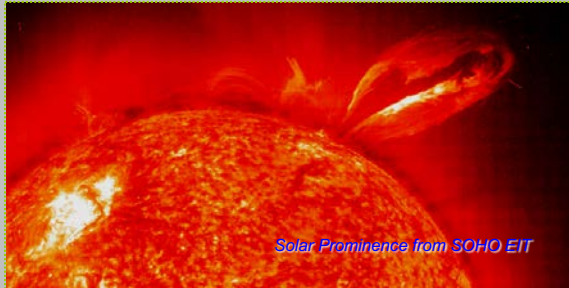


ASTR 1040: Stars & Galaxies



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Lecture 6 Thur 2 Feb 2017
zeus.colorado.edu/astr1040-toomre

Topics for Today and Tues

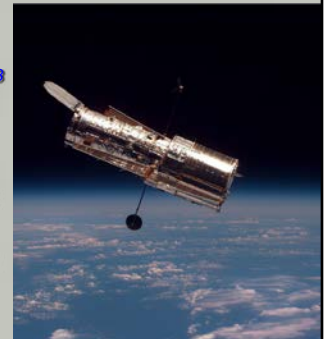
- Some further comments about telescopes
- Start with how Sun is put together
- Why is a star spherical, and does not collapse? (Gravitational equilibration)
- Why does it shine, and must it shine? What is the energy source? (Fusion of H to He)
- Complete detail read Chap 14 (Our Star)
- Read S4.1, S4.2 (quarks, leptons, ..)
- New Homework #3 (The Sun) passed out
- Observatory # 2 on Thur Feb 9, signup

The largest optical telescopes are designed to have

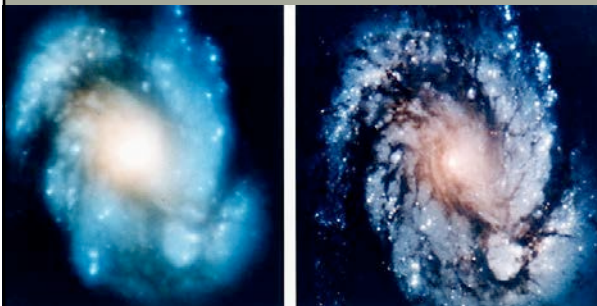
- A. high magnification, large collecting area, and high angular resolution
- B. high magnification, large collecting area, and low angular resolution
- C. low magnification, large collecting area, and low angular resolution
- D. large collecting area and high angular resolution - the magnification is of secondary importance
- E. large collecting area and low angular resolution - the magnification is of secondary importance
- (here "high angular resolution" = small angle)

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 meant long lifetime (1990 to 2018+)
- \$5 billion over 20 years = 10-100 times more costly than ground-based telescope

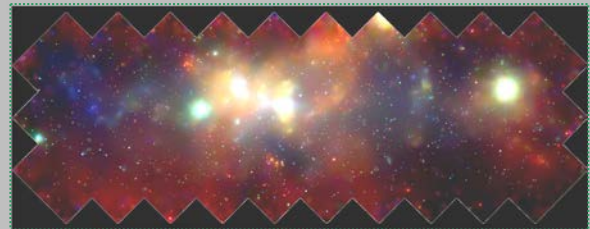


Very sharp images from Hubble ... and much more



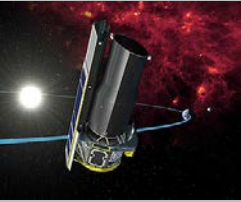
"Nonvisible" Light – X-ray, UV, IR, Radio

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

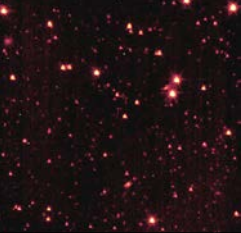


Chandra X-ray image of center of our Milky Way Galaxy

SPITZER Infrared Telescope

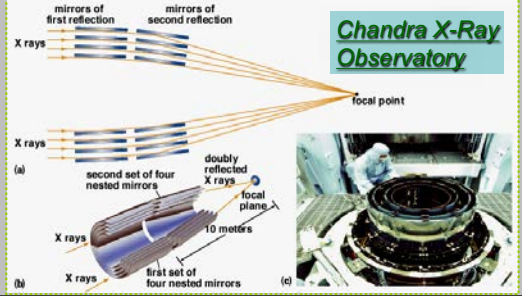


- Launched August 2003
- **Trails behind Earth to get away from Earth's thermal spectrum**
- **0.85m aperture , T ~ 5.5 K**
- Cooled with liquid helium, had 2-5 years worth, now used up (warmer phase)



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



Chandra X-Ray Observatory

mirrors of first reflection mirrors of second reflection

X rays

focal point

(a) X rays

(b) X rays

(c) X rays

second set of four nested mirrors

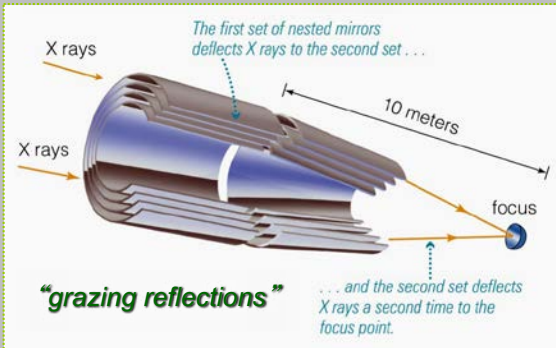
doubly reflected X rays

focal plane

10 meters

first set of four nested mirrors

Bigger view of Chandra's X-ray Imaging



X rays

X rays

The first set of nested mirrors deflects X rays to the second set . . .

10 meters

focus

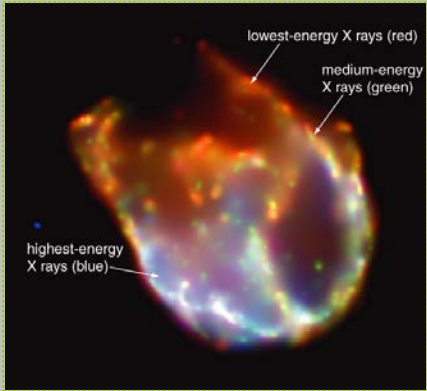
“grazing reflections”

. . . and the second set deflects X rays a second time to the focus point.

Chandra X-ray Observatory (at L₂ Lagrangian)



Multi-energy X-ray picture



lowest-energy X rays (red)

medium-energy X rays (green)

highest-energy X rays (blue)

Chandra: Supernova Remnant SNR: N132D

Clicker

What does the technique of interferometry allow?

- ... to make astronomical observations without interference from light pollution
- ... the same telescope to make images with both radio waves and visible light
- ... to determine the chemical composition of stars
- ... multiple telescopes to obtain the angular resolution better than the individual telescopes
- ... multiple telescopes to obtain a total light-collecting area larger than the individual telescope

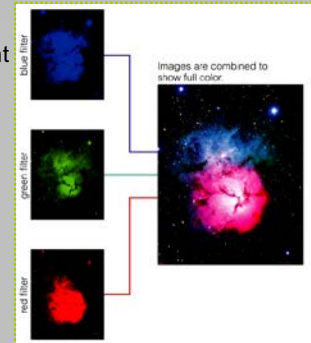
Instruments in the Focal Plane

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)

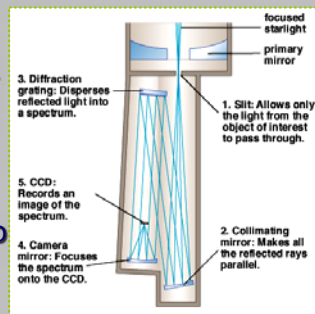
Imaging (Digital with CCDs)

- **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

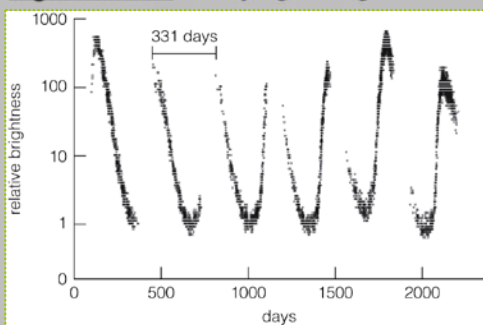


Spectral resolution is vital but also “costly in photons”

The diagram shows a spectrograph with five numbered steps: 1. Slit allows light from the object of interest to pass through. 2. Collimating mirror makes reflected rays parallel. 3. Diffraction grating disperses reflected light into a spectrum. 4. Camera mirror focuses the spectrum onto a CCD. 5. CCD records an image of the spectrum.

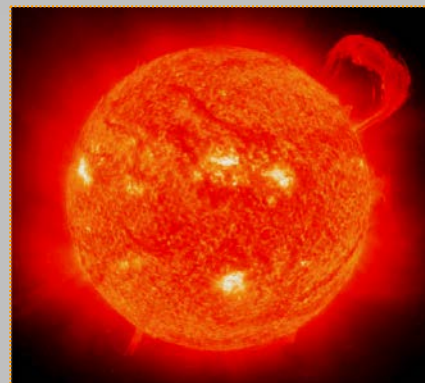
Below the diagram are two graphs of relative brightness vs. wavelength (nm). The top graph, labeled "Lower Spectral Resolution", shows a broad, smooth curve with a single wide peak. The bottom graph, labeled "Higher Spectral Resolution", shows a much narrower peak with many smaller, distinct sub-peaks, indicating that more photons are needed to achieve this level of detail.

Light curves: Studying changes with time



Variable star MIRA: period ~331 days

Next to Our Nearest Star Chap 14



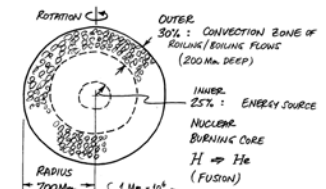
Big Qs about the Sun (and any star)

- Why is a star **ROUND** ?
- What keeps a star from **collapsing inward** ?
- What keeps it **shining** ?
- Why does it **rotate** and have **varying magnetic fields** ?

OVERVIEW of the Sun

Sun is round, rotates, burns H to He

THE SUN: OUR LOCAL NEIGHBORHOOD STAR
A PROTOTYPICAL STAR



ROTATION ω

OUTER: 30% : CONVECTION ZONE OF ROLLING/BOILING FLOWS (200 Mm DEEP)

INNER: 25% : ENERGY SOURCE NUCLEAR BURNING CORE H + He (FUSION)

RADIUS 700 Mm $\left\{ \begin{array}{l} \frac{1}{109} \text{ Mm} = 10^6 \\ \text{EARTH RADIUS} = 6.4 \text{ Mm} \end{array} \right.$

RADIUS (R_{\odot}) = 700,000 Km $\left\{ \begin{array}{l} \approx \frac{1}{109} \text{ EARTH RADIUS} \\ \approx \frac{1}{227} \text{ EARTH-SUN DIST.} \end{array} \right.$

MASS (M_{\odot}) = $2 \times 10^{30} \text{ Kg} \approx 300,000 \text{ EARTH MASS}$

COMPOSITION (WHAT IS SUN MADE OF):

(ALL GAS)	"X"	73 %	HYDROGEN (BY MASS)
	"Y"	25 %	HELIUM
	"Z"	2 %	ALL OTHER ELEMENTS "METALS"

Sun is a big ball of "plasma"

- Hydrogen and helium are **ionized** by the high temperature throughout most of star
- Such electrically-conducting **GAS** is called a **PLASMA**
- Movement of plasma has currents flowing, builds **magnetic fields and electric fields**



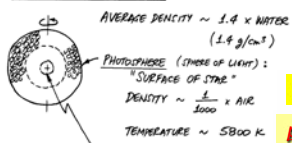
SUN IN PROFILE

Vast range in temperature and density

chromosphere

corona

THE SUN IN PROFILE



SURFACE

photosphere

NUCLEAR BURNING CORE:
CENTRAL DENSITY $\sim 160 \times \text{WATER}$
TEMPERATURE $\sim 16 \text{ MILLION K}$

CORE

OUTSIDE PHOTOSPHERE:

CHROMOSPHERE (SPHERE OF COLOR)
HOT UPPER ATMOSPHERE ($10^4 - 10^5 \text{ K}$)
PRODUCE SOME EMISSION (BROAD) LINES

CORONA

VERY HOT (2 MILLION K),
VERY LOW DENSITY
GRADUALLY EJECTS INTO SOLAR WIND
STREAMING AWAY FROM SUN

ATMOSPHERE

Big System View of Sun

core
radiative zone
convection zone
photosphere
chromosphere
corona
solar wind

