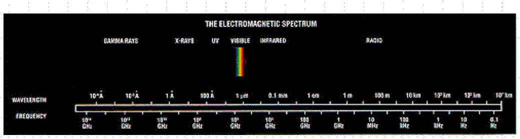
Telescopes

Our Window on the Sky

What Does a Telescope Do?

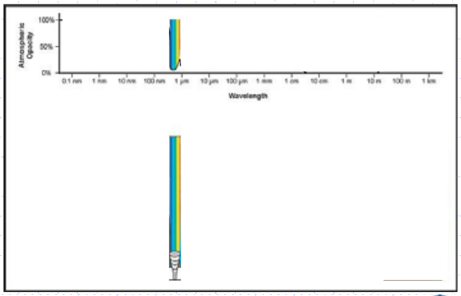
- Gathers and amplifies light
  - Bigger aperture is better
  - Aperture = LGP
  - Aperture = Resolution
- Magnifies the image
  - Magnification is the least useful characteristic of a telescope
  - For optical telescopes, magnification can be changed by changing the eyepiece

EM Spectrum

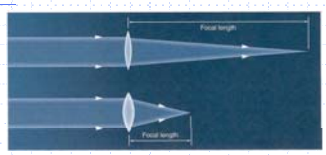


- Every region of the EM spectrum is astronomically useful
- Some regions are easier to use than others

Atmospheric Windows

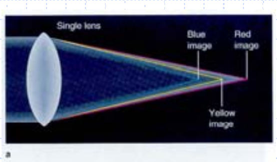


Optics



- Elements that bring collimated light to focus:
  - Lenses
  - mirrors

Optics: Chromatic Aberration

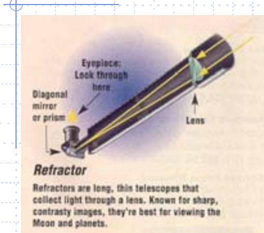


A lens design which resolved the problem of chromatic aberration for refractor telescopes was discovered in 1733 by Hall but kept secret until it was uncovered and used commercially in 1759 by John Dolland and his son.

Optics

Divergent sources produce collimated light at a sufficiently far distance

Telescope Designs

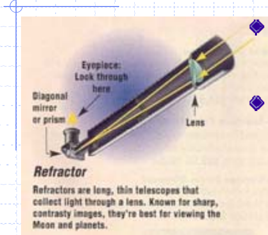


Courtesy Orion Telescopes and Binoculars

A Dutch eyeglass maker, Hans Lippershey, is given credit for the invention of the telescope in 1608.

Galileo was the first to use the telescope to look at the stars and other objects in the sky and systematically record his observations.

Telescope Designs



Courtesy Orion Telescopes and Binoculars

- Advantages
  - High contrast images
  - Entire 1° objective used
- Disadvantages
  - Length of OTA = focal length
  - Large apertures very expensive
    - (highest cost per cm)
  - Suffers from chromatic aberration

Telescope Designs

Courtesy Orion Telescopes and Binoculars

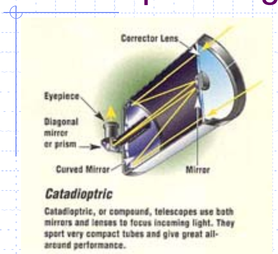
Newton designed a reflecting telescope in 1668. (In 1672 he invented a reflecting microscope, and some years later he invented the sextant which was rediscovered by J. Hadley in 1731.)

Telescope Designs

Courtesy Orion Telescopes and Binoculars

- Advantages
  - Lowest cost per cm of aperture
  - Does not suffer from chromatic aberration
- Disadvantages
  - May suffer from spherical aberration
  - 2° mirror obstruction lowers contrast
  - Eyepiece inconveniently positioned for viewing zenith
  - OTA length = Focal length

Telescope Designs

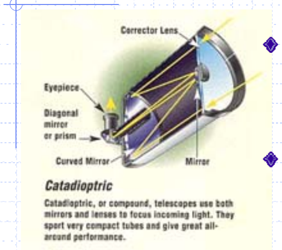


Courtesy Orion Telescopes and Binoculars

Variations of the Newtonian reflector in which the light was reflected back through a hole in the primary mirror were invented by James Gregory in 1663 and by Cassegrain in 1672.

A third type of "Cassegrain" telescope, which uses a spherical mirror and a correcting lens, was invented in 1930 by Bernhard Schmidt.

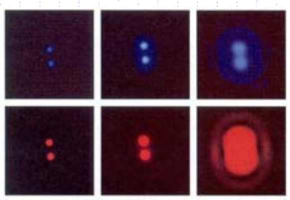
Telescope Designs



Courtesy Orion Telescopes and Binoculars

- Advantages
  - Folded light path gives long focal length in small tube
  - Visual back in convenient location
- Disadvantages
  - 2° mirror obstruction lowers contrast
  - Cost is higher than Newtonian but lower than equivalently sized refractor

Optics



Magnification:

$$Power = \frac{F_{\text{telescope}}}{F_{\text{eyepiece}}}$$

Dawes Limit:

$$R = 2.5 \times 10^5 \frac{\lambda}{D}$$

R in arcsec
λ in m
D in m

Resolution

NGC 253 (Sculptor), 10 Mly

A Few Observatories

Astronomy in a variety of regions of the electromagnetic radiation spectrum

Yerkes 1-m Refractor

The Yerkes 1-m refractor (University of Chicago) remains the largest aperture refractor in the world.

Finished in 1897. The OTA is 63' long.

Gemini 8.1-m

Two telescopes:
- Mauna Kea (North)
- Cerro Pachón (South)

Provides complete and unobstructed coverage of both the northern and southern skies

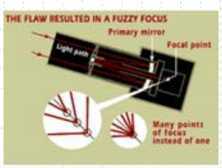
Hubble Space Telescope

NASA

- 2.4-m observatory orbiting 600 kilometers (375 miles) above Earth
- Works around the clock.
- Designed in the 1970s and launched in 1990. Serviced in orbit during 3 STS missions.
- Every day, 3 to 5 gigabytes of data archived
- Original mission to study cosmic expansion. Has met mission goal and far more.

Hubble Space Telescope

NASA



Adapted from Hubblesite.org

High Energy Observatories

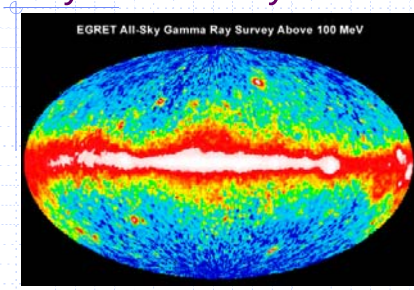
Compton Gamma Ray Observatory

Launched April 1991 aboard STS-37

De-orbited in June, 2000

The observatory was named in honor of Dr. Arthur Holly Compton, who won the Nobel prize in physics for work on scattering of high-energy photons by electrons.

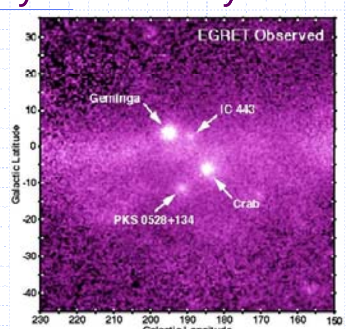
Compton Gamma Ray Observatory



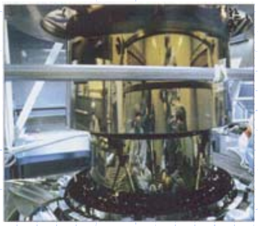
Geminga Pulsar

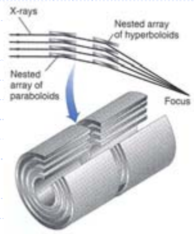
Crab Pulsar

Compton Gamma Ray Observatory

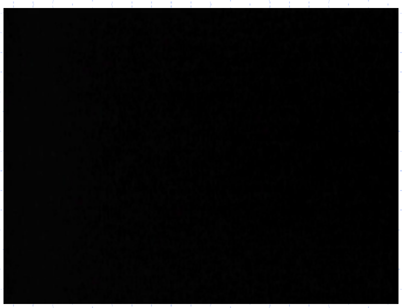


Chandra X-Ray Telescope

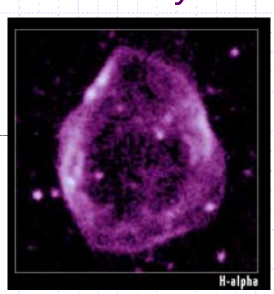




Chandra X-Ray Observatory

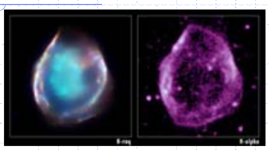


Chandra X-Ray Observatory



(NASA/CXC/Rutgers/J. Hughes et al.)

Chandra X-Ray Observatory



Chandra X-ray Observatory image of the SNR DEM L71 reveals a hot inner cloud (aqua) of glowing Fe and Si surrounded by an outer blast wave. Data from the Chandra observations show that the central 10^7 °C cloud is the remains of a supernova explosion that destroyed a white dwarf star.

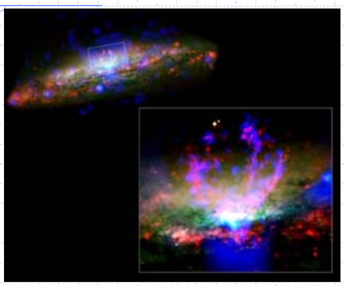
Chandra X-Ray Observatory

DEM L71 presents a perfect example of the double-shock structure which develops when a star explodes and ejects matter at high speeds into the surrounding ISM. The expanding ejecta drive a shock wave that races ahead of the ejecta into the interstellar gas, bright outer rim. The pressure behind this shock wave drives an inward-moving shock wave that heats the ejecta, seen as the aqua cloud.

The computed ejected mass was found to be comparable to the mass of the Sun. This and the X-ray spectrum, which exhibits a high concentration of iron atoms relative to oxygen and silicon, convincingly show that the ejecta are the remains of an exploded white dwarf star.

The size and temperature of the remnant indicate that it is several thousand years old.

Chandra X-Ray Observatory



NASA/CXC/U.North Carolina/G.Cecil

NGC 3079 (UMa)

X-ray image has been combined with Hubble's optical image. Towering filaments consisting of warm (about 10,000°C) and hot (about ten million °C) gas blend to create the bright horseshoe-shaped feature near the center.

Chandra X-Ray Observatory

The correlation of the warm and hot filaments suggests that they were both formed as a superwind of gas -- rushing out from the central regions of the galaxy -- carved a cavity in the cool gas of the galactic disk. The superwind stripped fragments of gas off the walls of the cavity, stretched them into long filaments, and heated them. The full extent of the superwind shows up as a fainter conical cloud of X-ray emission surrounding the filaments.

The superwind originates in the center of the galaxy either from activity generated by a central supermassive black hole or by a burst of supernova activity. Superwinds are thought to play a key role in the evolution of galaxies by regulating the formation of new stars, and by dispersing heavy elements to the outer parts of the galaxy and beyond. Chandra data indicate that astronomers may be seriously under-estimating the mass lost in superwinds and therefore their influence within and around the host galaxy.

Low Energy Observatories

IRAS

Infrared Astronomy Satellite
Infrared Space Observatory

Infrared Astronomy

Infrared observations reveal cool states of matter.

(left) Howard McCallon, (right) NASA/2MASS/IPAC

Jodrell Bank Radio Telescope

© Jonathan Blair / CORBIS

Dedicated in 1957 on the Cheshire Plain, the 76-m Jodrell Bank Radio Telescope (Lovelle Telescope) remains among the world's largest fully steerable radio telescopes.

It is the flagship of the Jodrell Bank Observatory (Dept of Physics and Astronomy, University of Manchester). Astronomers here also use X-ray, optical, infrared and mm-wave instruments across the globe and in space to make complementary observations.

Green Bank Radio Telescope

NRAO, NSF

The 100–m Robert C. Byrd Green Bank Telescope is the largest single-dish fully steerable radio telescope. It began operation in 2000 in Green Bank, West Virginia and can point anywhere in the sky to a precision better than 1/1000 degree.

The main dish is so large that it could house a football game.

Arecibo

The Arecibo Radio Telescope is the largest single-dish telescope in the world.

The "dish" is 305 m (1000 feet) in diameter, 167 feet deep, and covers an area of about twenty acres. The surface is made of almost 40,000 perforated 3x6 foot aluminum panels, supported by a network of steel cables strung across the underlying karst sinkhole. It is a spherical reflector.

Suspended 450 feet above the reflector is the 900 ton platform containing the radio receivers.

VLA

NRAO/AUI/NSF

Dedicated in 1980. The VLA consists of 27 25-m radio telescopes electronically (interferometrically) combined to give an effective aperture of 36 km (22 mi) with the LGP of a 130-m dish.

VLBA

VLBA antenna at Owen's Valley, CA

The Very Long Baseline Array (VLBA) is a system of 10 radio telescopes controlled remotely from the VLA Operations Center. The antennas are spread across the United States from St. Croix in the Virgin Islands to Mauna Kea, Hawaii, making it the world's largest dedicated, full-time astronomical instrument

Paranal VLT Observatory

ESO

The Paranal Observatory is comprised of four 8.2-m telescopes, working separately or at a combined interfer-ometric focus with an effective aperture of 300-m.

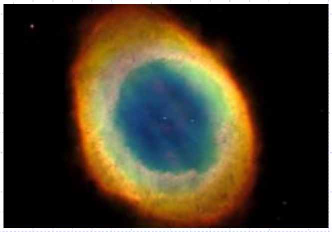
Applications

Trapezium in M42

J. Bally, D. Devine, & R. Sutherland, D. Johnson (CITA), HST, NASA

New star systems are forming in huge globs of gas and dust known as Proplyds. Looking closely also reveals that gas and dust surrounding some of the dimmer stars appears to form structures that point away from the brighter stars.

Ring Nebula in Visible Light



Hubble Heritage Team (STScI / AURA), NASA

The view of planetary nebula M57 from Earth is looking straight into what is actually a barrel-shaped cloud of gas blown off by a white dwarf central star.

Eagle Nebula in Serpens

Jean-Charles Cuillandre (CFHT), Hawaiian Starlight, CFHT

Bright blue stars are still forming in the dark pillars of the Eagle Nebula, M16.

M16 is about 7000 light-years distant and spans about 20 light years. It can be seen with binoculars toward the constellation of Serpens.

Eagle Nebula in Serpens

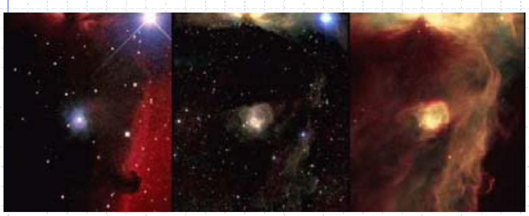
Made in NIR with the ESO's 8.2-meter Antu telescope, this wide-field image makes the pillars seem more transparent, as the longer wavelengths partially penetrate the obscuring dust. Observing in the NIR allows astronomers to look inside the finger-shaped lumps of material dubbed evaporating gaseous globules (EGGs).

Eagle Nebula in Serpens

Comparing the two views reveals that nearly a dozen of the EGGs do indeed have stars embedded near their tips.

Jean-Charles Cuillandre (CFHT), Hawaiian Starlight, CFHT

A Famous Nebula in IR

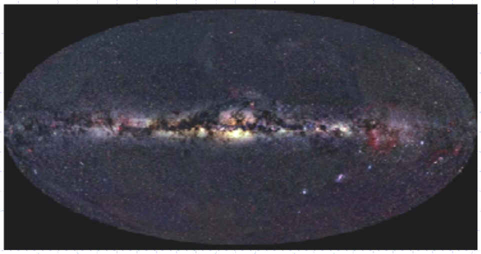


Visible NIR (2MASS) MIR (ISO)

Visible (Howard McCallon), near-infrared (2MASS), and mid-infrared (ISO) view of the Horsehead Nebula.

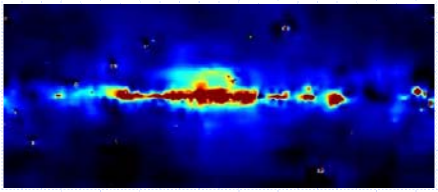
Leaving Local Space...

The Milky Way in Visible Light

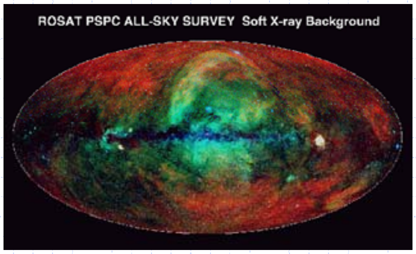


Axel Mellinger, 1999

The Milky Way in Gamma Ray

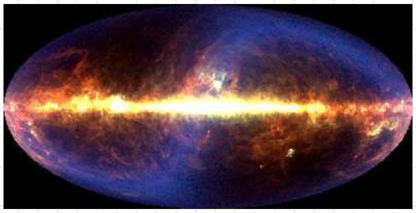


The Milky Way in X-Ray



B.Aschenbach & M.J.Freyberg, MPE Report 272

The Milky Way in IR

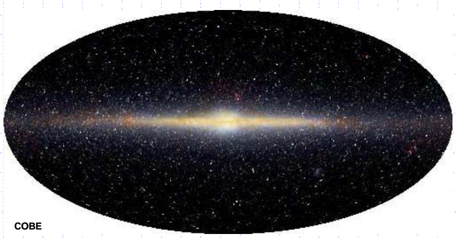


Michael Hauser (Space Telescope Science Institute), the COBE/DIRBE Science Team, and NASA

Emission due to warm dust

The Milky Way in IR

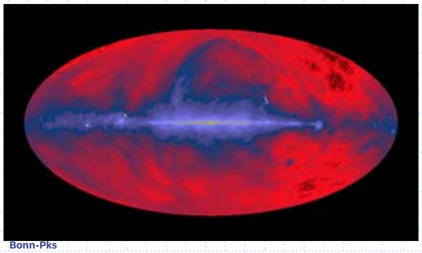
The Milky Way in the FIR



COBE

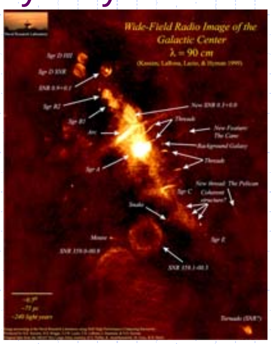
This image is almost in the microwave (240 μm)

The Milky Way in Radio

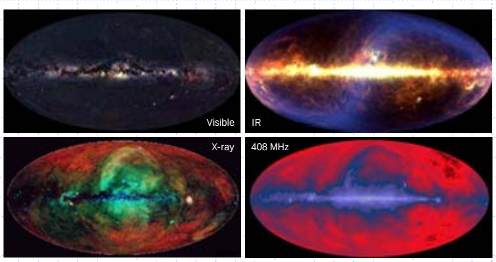


Bonn-Pks

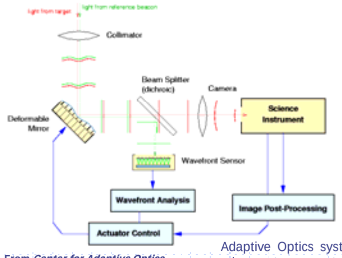
The Milky Way in Radio



Quick Visual Review



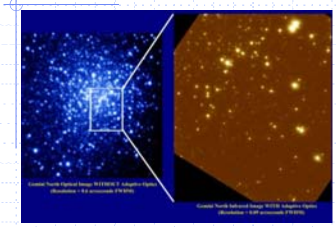
Adaptive Optics



From *Center for Adaptive Optics*

Adaptive Optics systems use deformable mirrors to correct for the effects of atmospheric distortions to starlight, resulting in significantly sharper images.

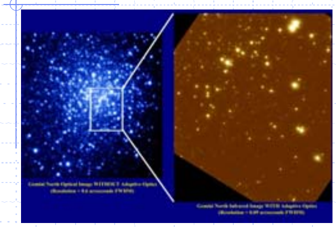
Adaptive Optics



These images are of the central region of globular cluster NGC 6934, 50,000 ly distant. Observations of globular clusters tell us how the first generation of stars in our Galaxy formed some 12 to 15 billion years ago and how they have evolved ever since.

Gemini Observatory, US National Science Foundation, and University of Hawaii Institute for Astronomy

Adaptive Optics



The resolution of the image on the right is comparable to resolving the separation between two automobile headlights at 2000 miles!

The optical picture on the left is sharp and clear because of the good atmospheric conditions on Mauna Kea and the excellent optical quality of the Gemini telescope. Yet NGC 6934 contains so many stars that even the thin atmosphere above Mauna Kea blurs the starlight enough that the stars overlap and can no longer be studied individually.