Astro 358/Spring 2006

(48915)

Galaxies and the Universe

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Figures for Lecture 20+21 : Tu Apr 04 + Th Apr 6

Lecture 20

- Collecting area and angular resolution of a telescope

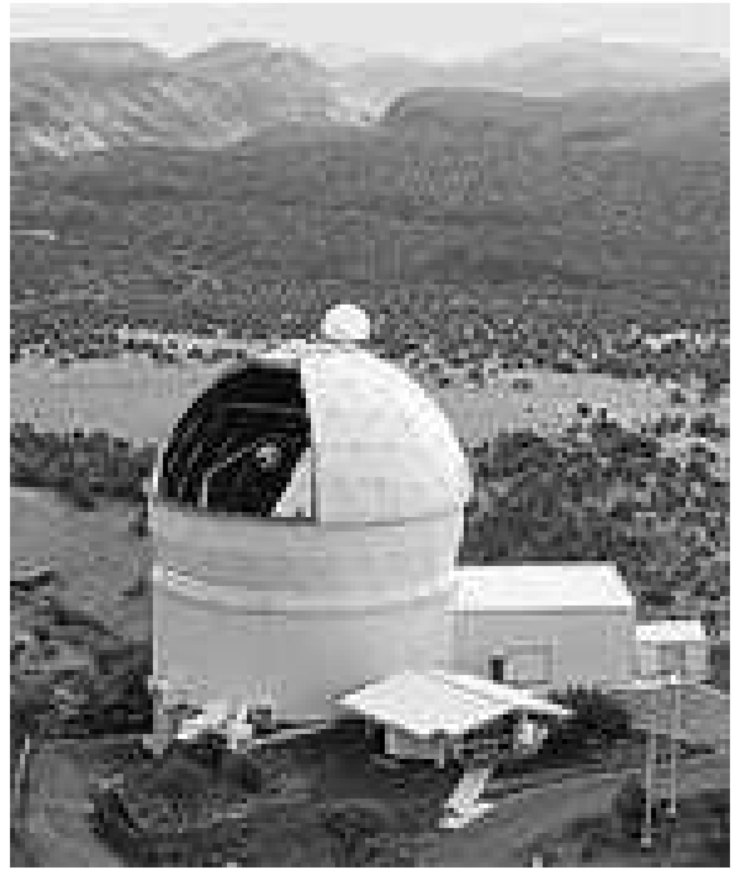
- Space-based telescopes

- Multi-wavelength (from gamma-ray to radio) observations to map ‘visible’ components (stars, gas, dust) of galaxies

Collecting area and angular resolution of a telescope

Largest Optical and Infrared Telescopes

Keck 10-m telescope at 5000 feet on Mauna Kea in Hawaii



9.2m Hobby Eberly Telescope of UT Austin at the Mac Donald Observatory

Largest Optical and Infrared Telescopes

Concrete base, 40 ft diameter, that supports the 9.2m Hobby Eberly Telescope

Largest Ground-Based Telescopes

10-m SALT telescope in South Africa
UT is a partner in the SALT consortium.
Inaugurated in 2005

Next Generation Largest Ground-Based Telescopes

Giant Magellan Telescope GMT

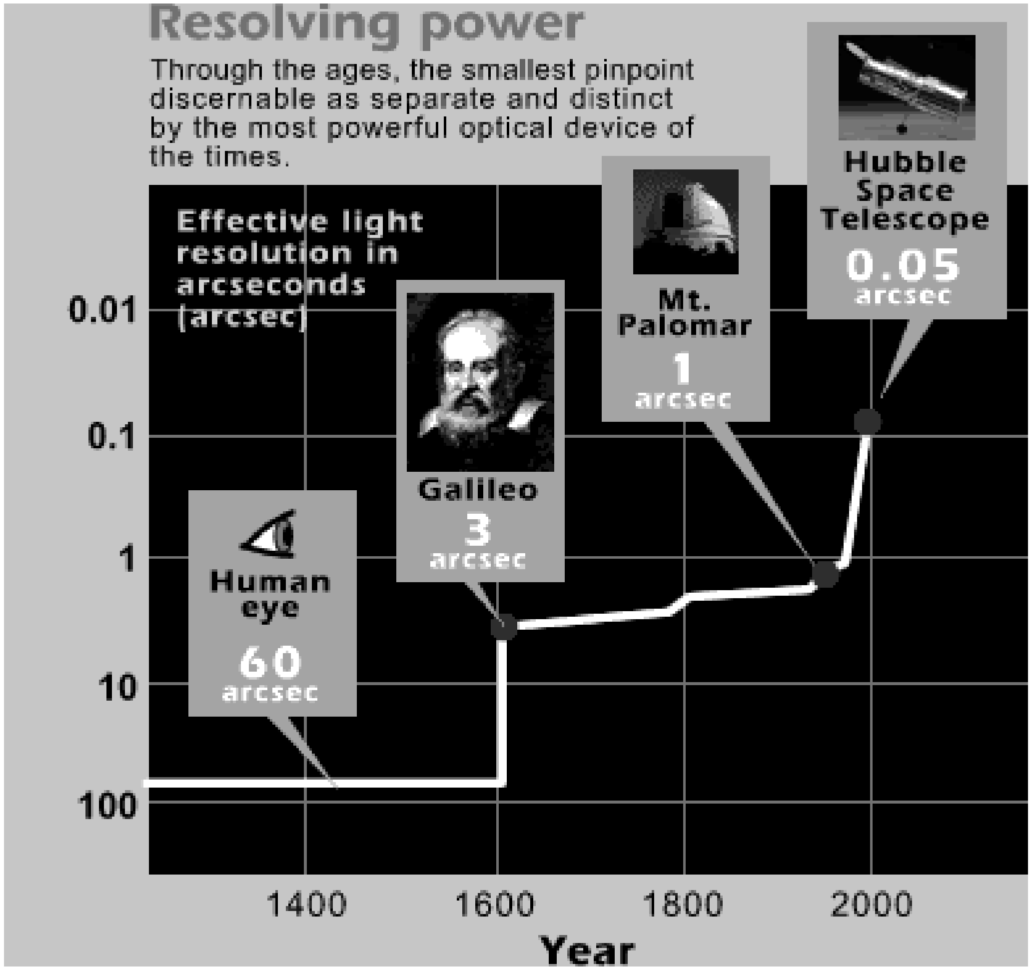
- 7 mirrors of size 8.4 m
(equiv to aperture of diameter 22 m)

- Location = Northern Chile
- First light in 2016

GMT partners include
- Arizona
- **UT Austin**
- Carnegie Observatories
- Harvard
- MIT
- Michigan

Casting of first mirror completed 27 Oct 2005!

Angular Resolution of Telescopes



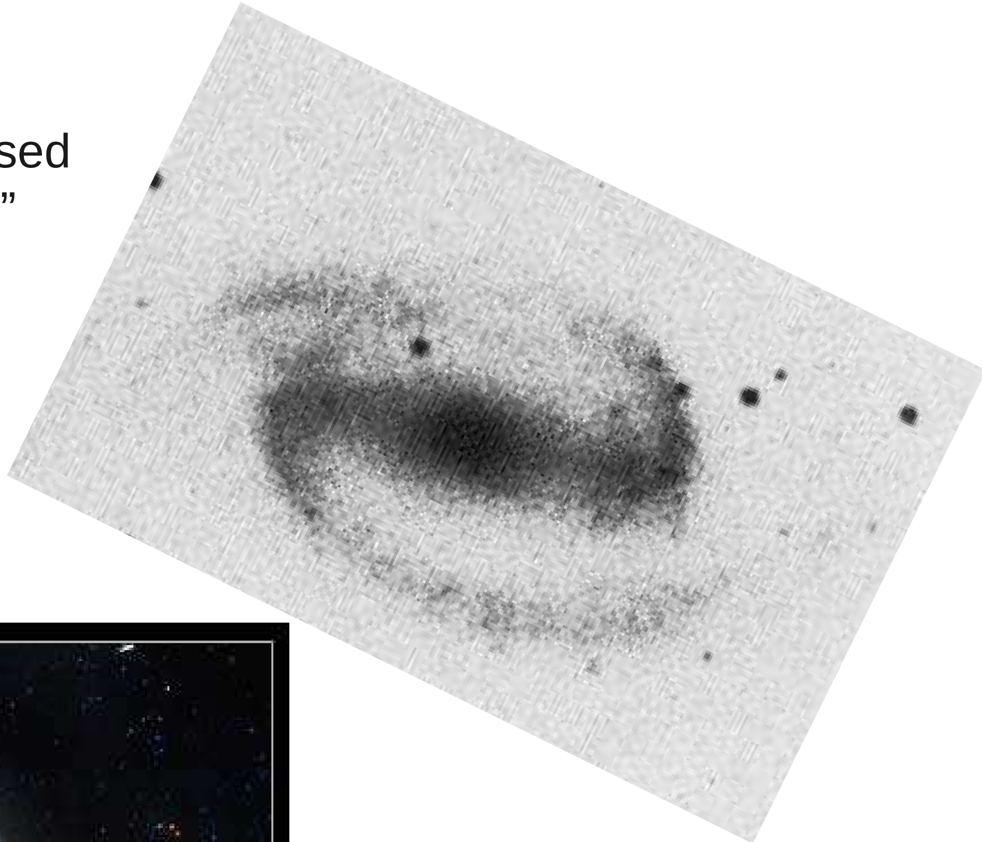
- Angular resolution of ground-based telescopes is limited by the "seeing" of the Earth's atmosphere, i.e, by turbulence

- Ground-based optical seeing >= 0.5"

- Hubble Space Telecope has an angular resolution ~ 0.05" at optical wavelengths !

Angular resolution of Telescopes

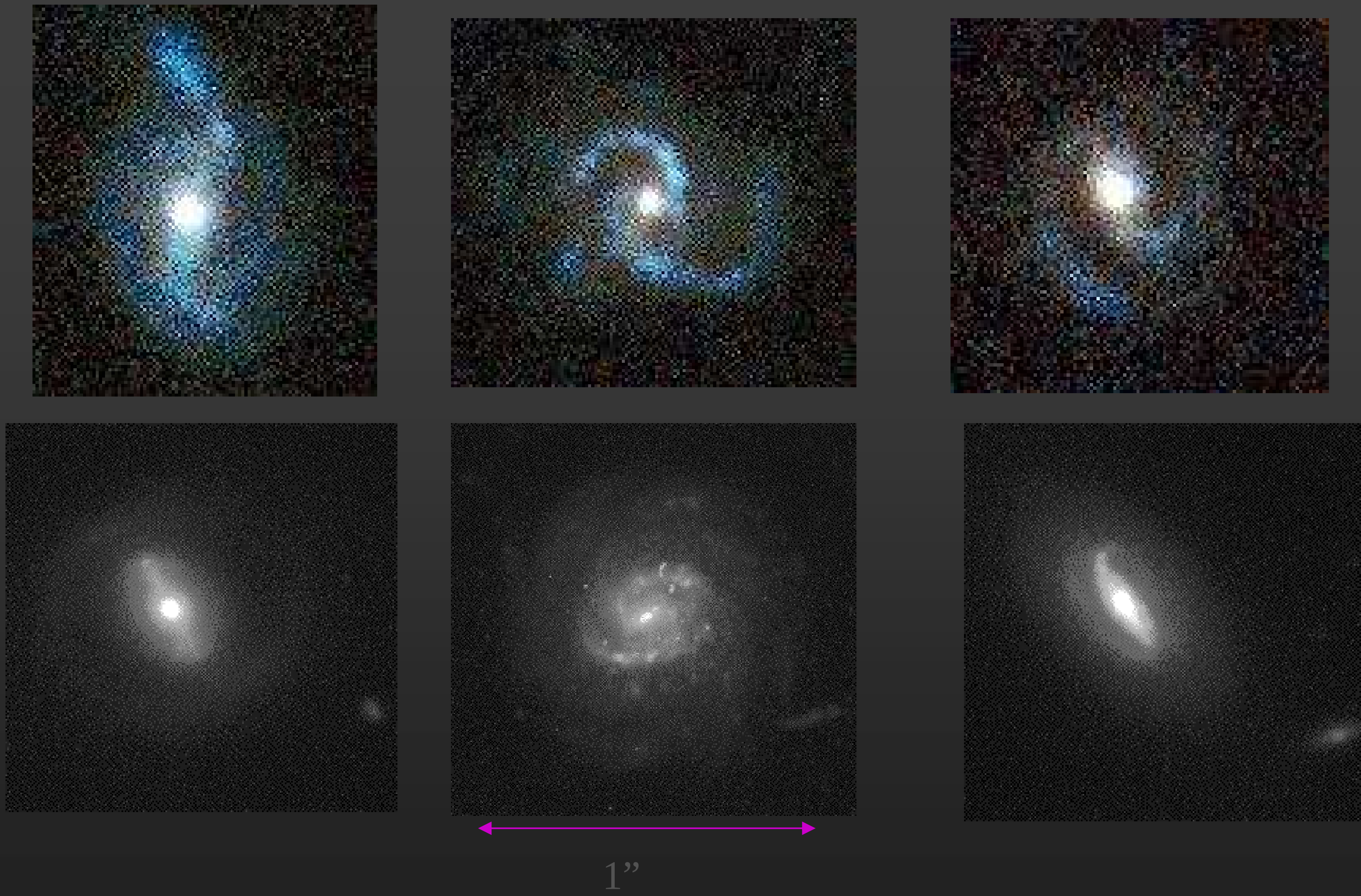
NGC 1300 : ground-based
image with seeing ~ 2”



NGC 1300 HST
image with
seeing ~ 0.05”

Angular resolution of Telescopes

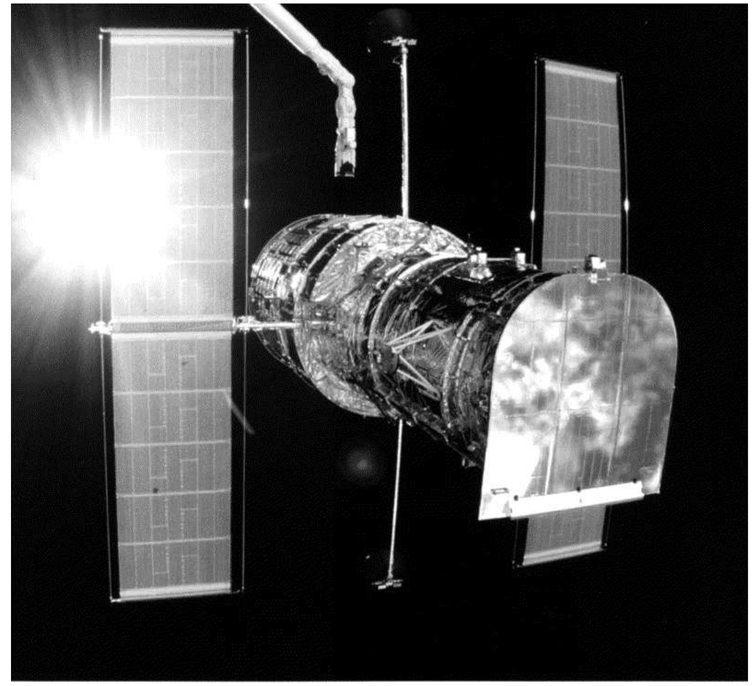
HST images of spiral galaxy pair: seeing ~ 0.05”



HST images with angular resolution of 0.08” resolve the structure (bars, spirals disks, bulges) of distant galaxies (at lookback times of 4.5 to 8 Gyr) and whose size is a mere 1” on the sky ! Ground-based images would blur the entire galaxy into one seeing element! (Images from GEMS survey)

Space-based telescopes

Why do we put telescopes in space?



---Advantages of putting a telescope in space ?

à No blurring by Earths's atmosphere: images have high angular resolution.

à No absorption by Earth's atmosphere of Gamma-ray, X-ray, UV, some IR, submm

à Avoid infrared background (glare) emission from Earth's atmosphere and sky : can see faint IR sources

-- Disadvantages of space-based telescopes?

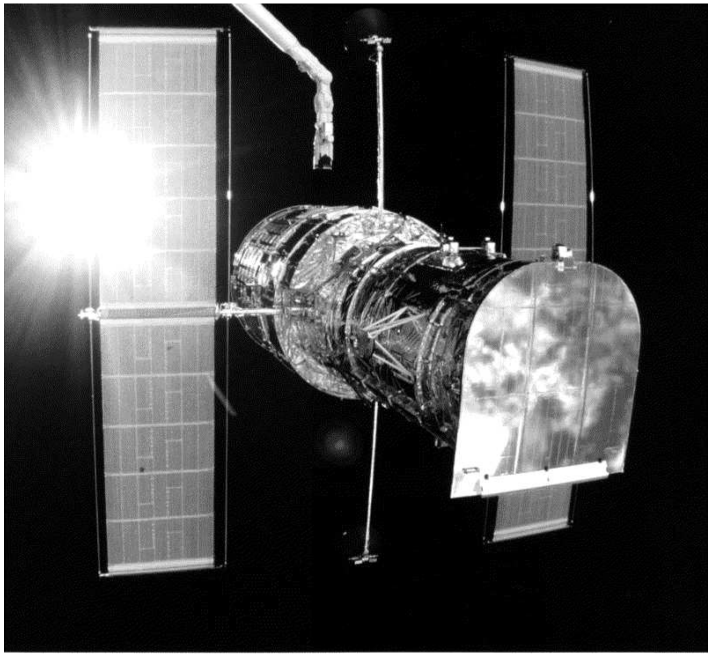
à Cannot have large collecting area (else unstable and would need high power)

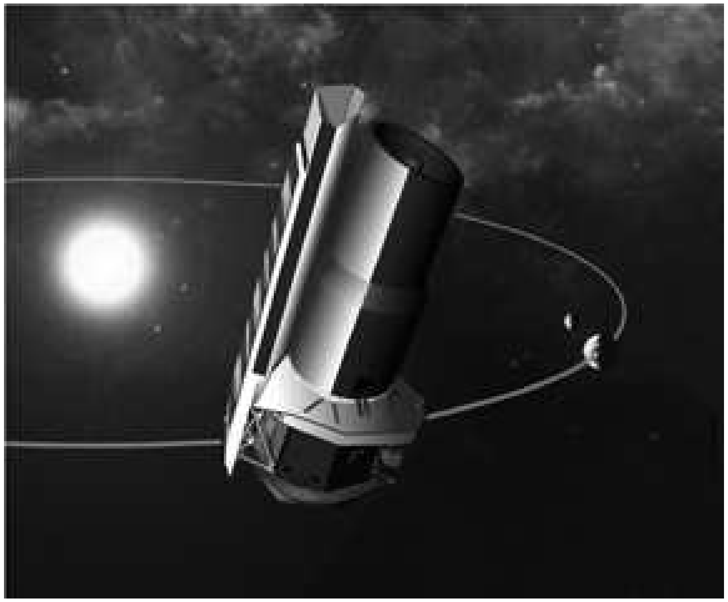
à Costly to repair and upgrade : servicing missions by astronauts

à Re-entry for larger telescopes can be dangerous (e.g., CGRO was 17 tons!)

NASA's Four Great Observatories

Hubble Space Telescope
(2.5 m; 1990)
Takes UV, optical and
near-infrared images
that are 10 times sharper
than from the ground



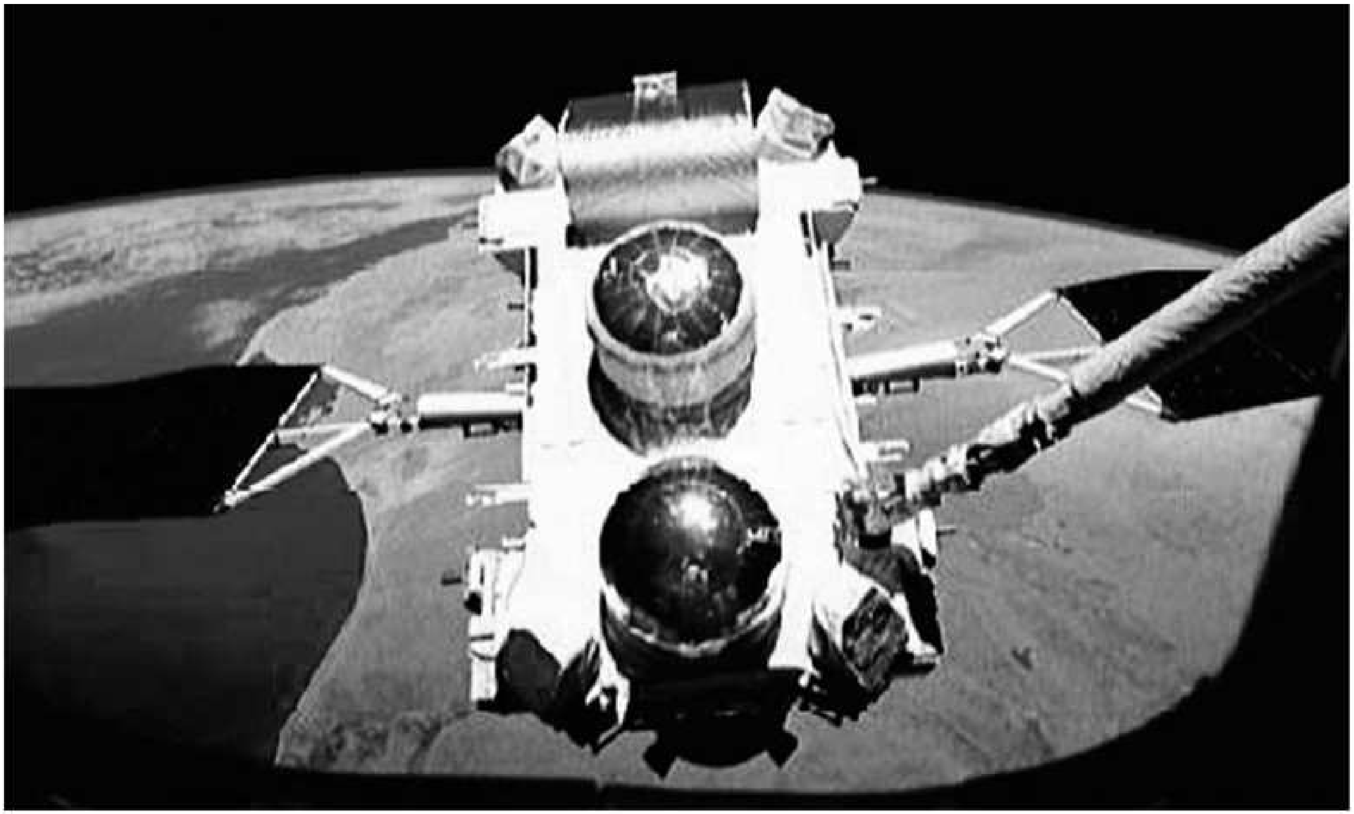


Chandra X-ray Observatory (CXO; 1999)
Largest satellite launched by Columbia

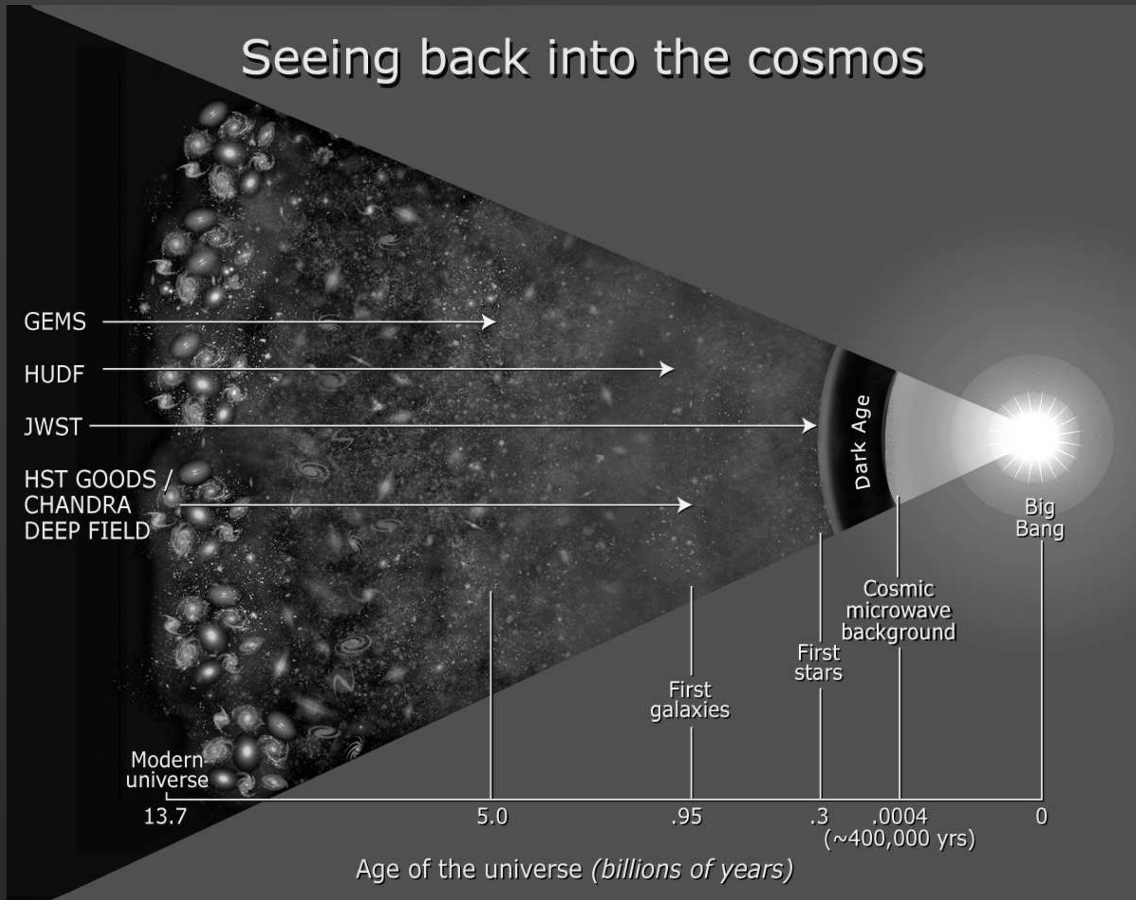
Spitzer Infrared
Space Telescope
(0.85m; 2003)

Largest infrared
satellite launched
into space

NASA's Four Great Observatories



- Compton Gamma- Ray Observatory (not active)
- 1991 to 2000; deployed at 17 tons from Space Shuttle



13.7 0.8 0.3 0 Age of Universe (Billions of Years)

The present-day Universe is 13.7 Gyr old and mature galaxies lare fully in place

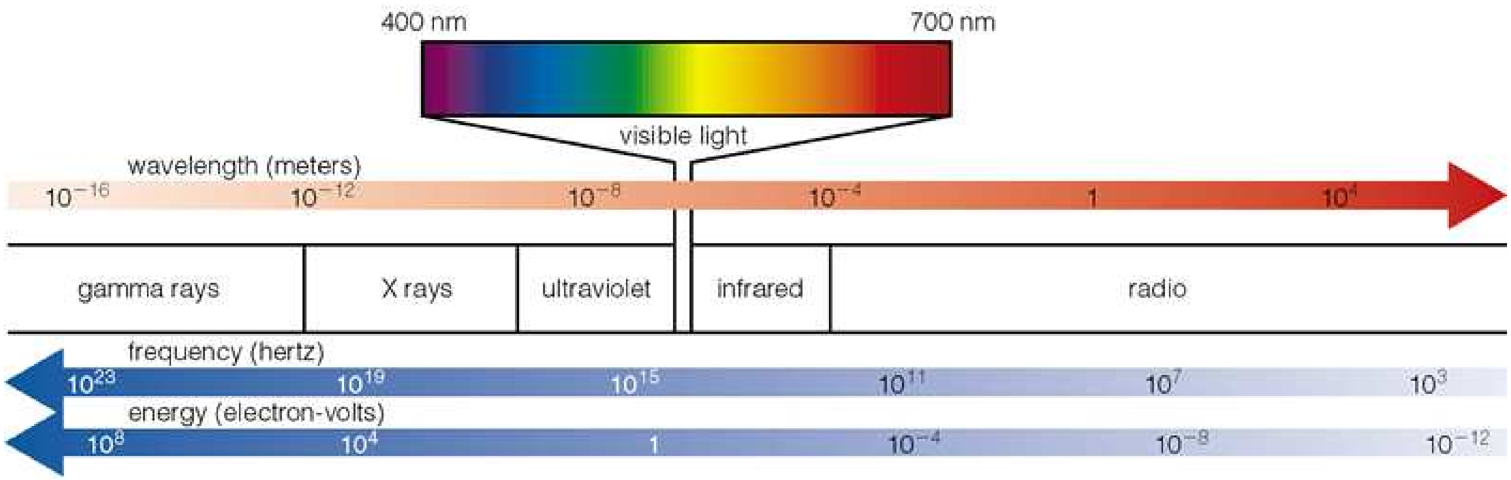
HST allows us to see epochs when the Universe was 0.8 Gyr old, 5% of its present age…a toddler

JWST will allows us to see epochs when the Universe was 0.3 Gyr old, and detect clusters of the very first stars

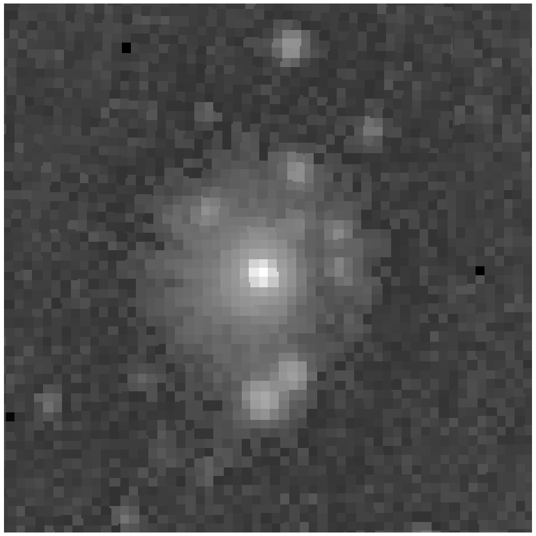
Multi-wavelength (from gamma-ray to radio) observations to map 'visible' components (stars, gas, dust) of galaxies

Observations of a galaxy at different wavelengths trace different visible components

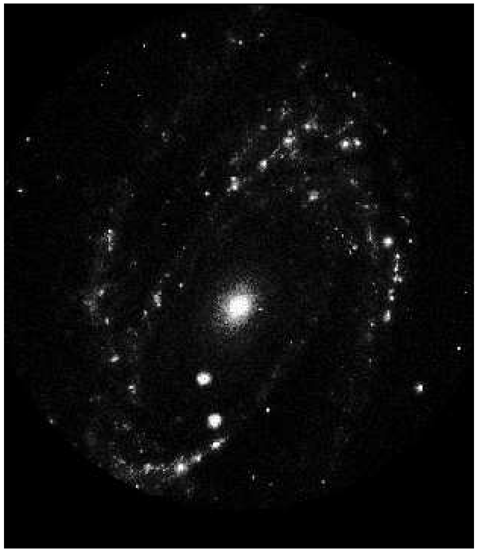
- cold and hot stars (i.e stars of different mass, age, metallicity)
- cold (few K) warm (100 K) , hot (10^7 K) gas
- dust



Multi-Wavelength view of M81



X-ray/ROSAT

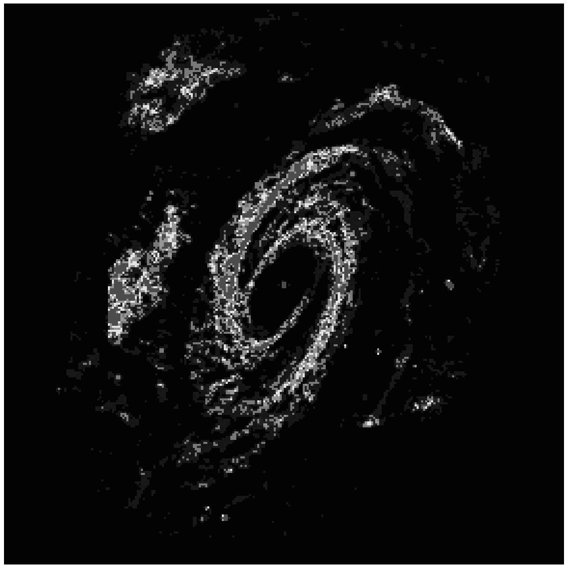


Ultraviolet/ASTR0-1

Visible light

Near infrared/Spitzer

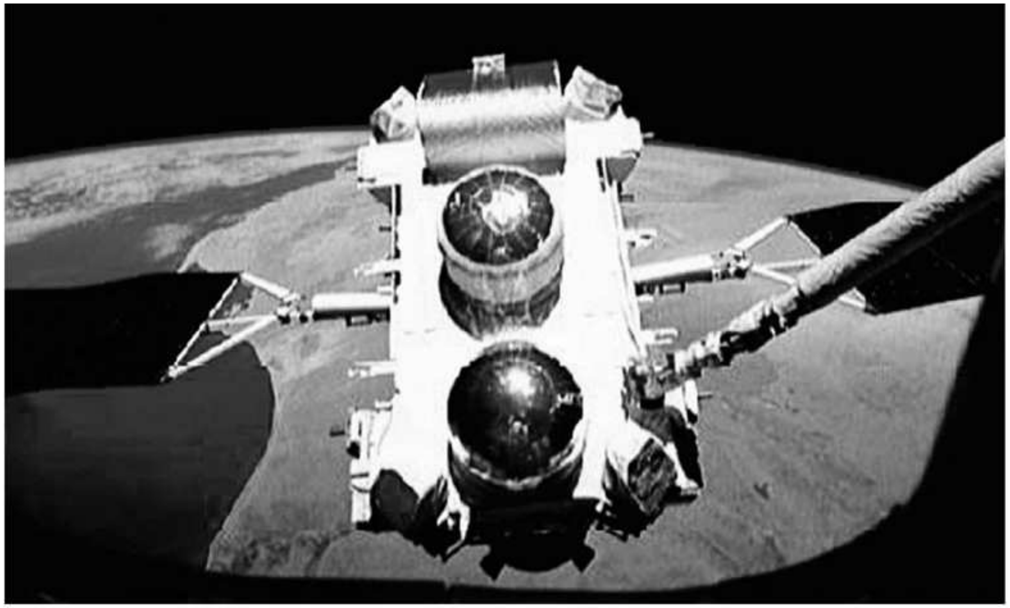
Far-infrared/Spitzer



Radio 21cm/VLA

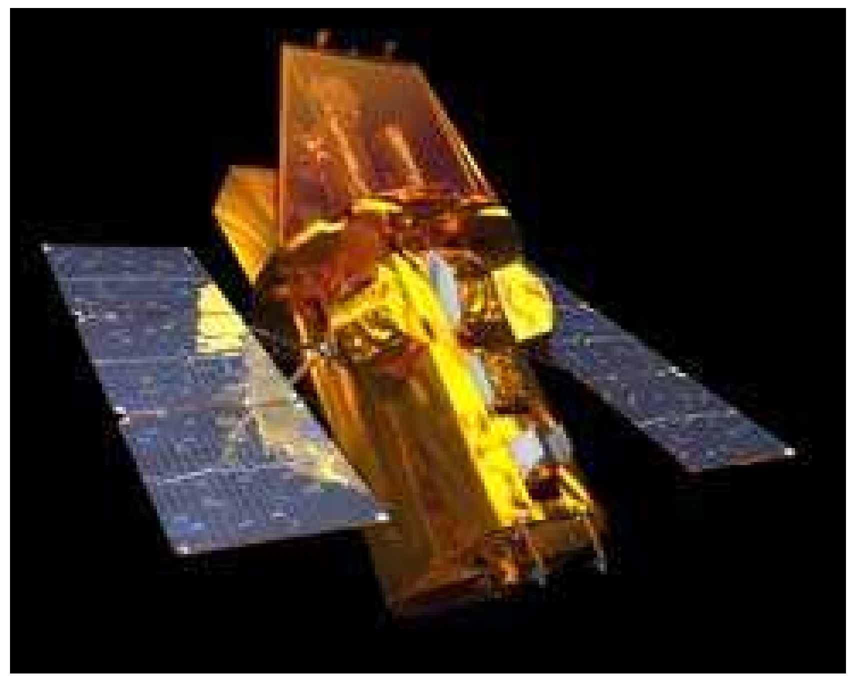
Imaging the Universe at Gamma-Ray and X-ray Wavelengths

Gamma-Ray Observatories



- Compton Gamma- Ray Observatory

- 1991 to 2000; deployed at 17 tons from Space Shuttle; 17 tons!



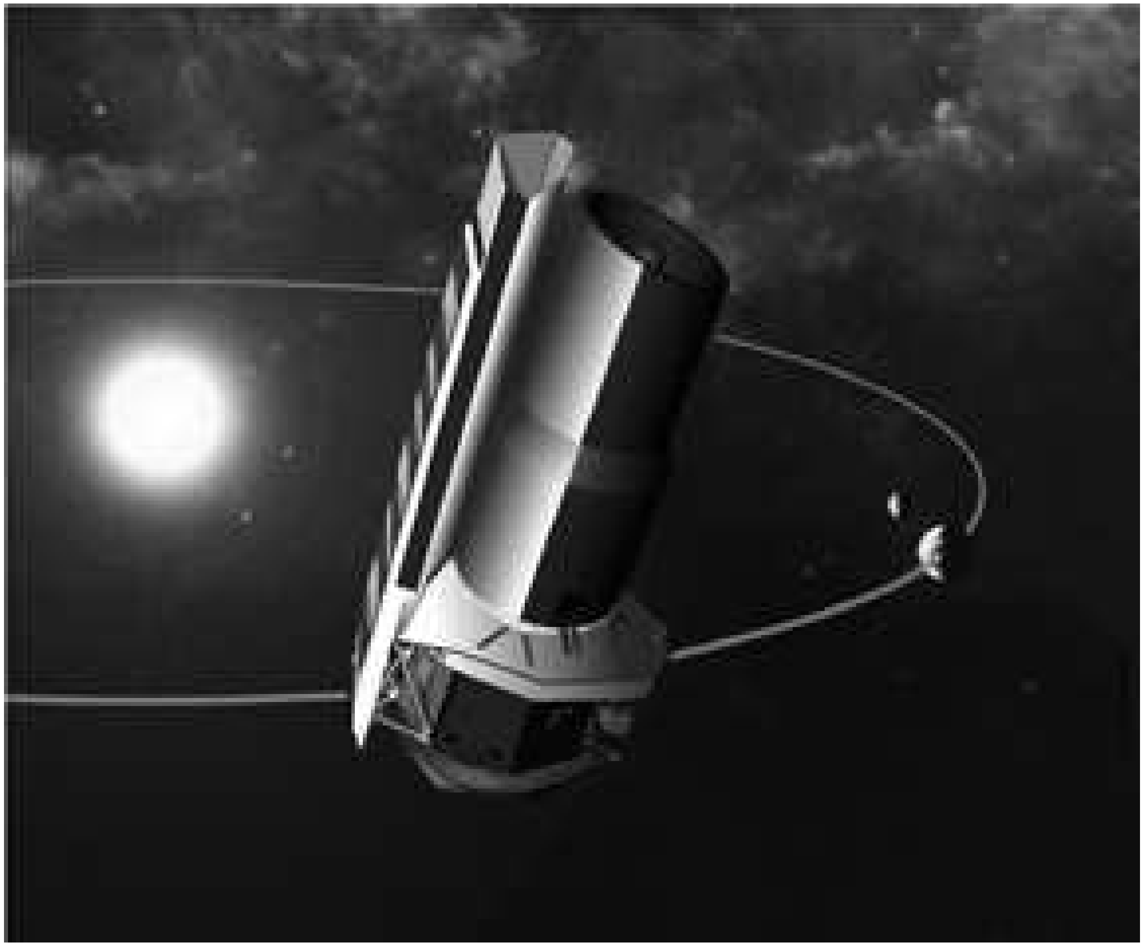
- NASA's Swift Gamma Ray Burst Explorer launched Nov 2004

- Dec 2004 : reported the brightest flash of light ever detected from beyond the solar system: more energy than the sun emits every 150,000 years!!!

à Gamma Ray Burst from a distant neutron star

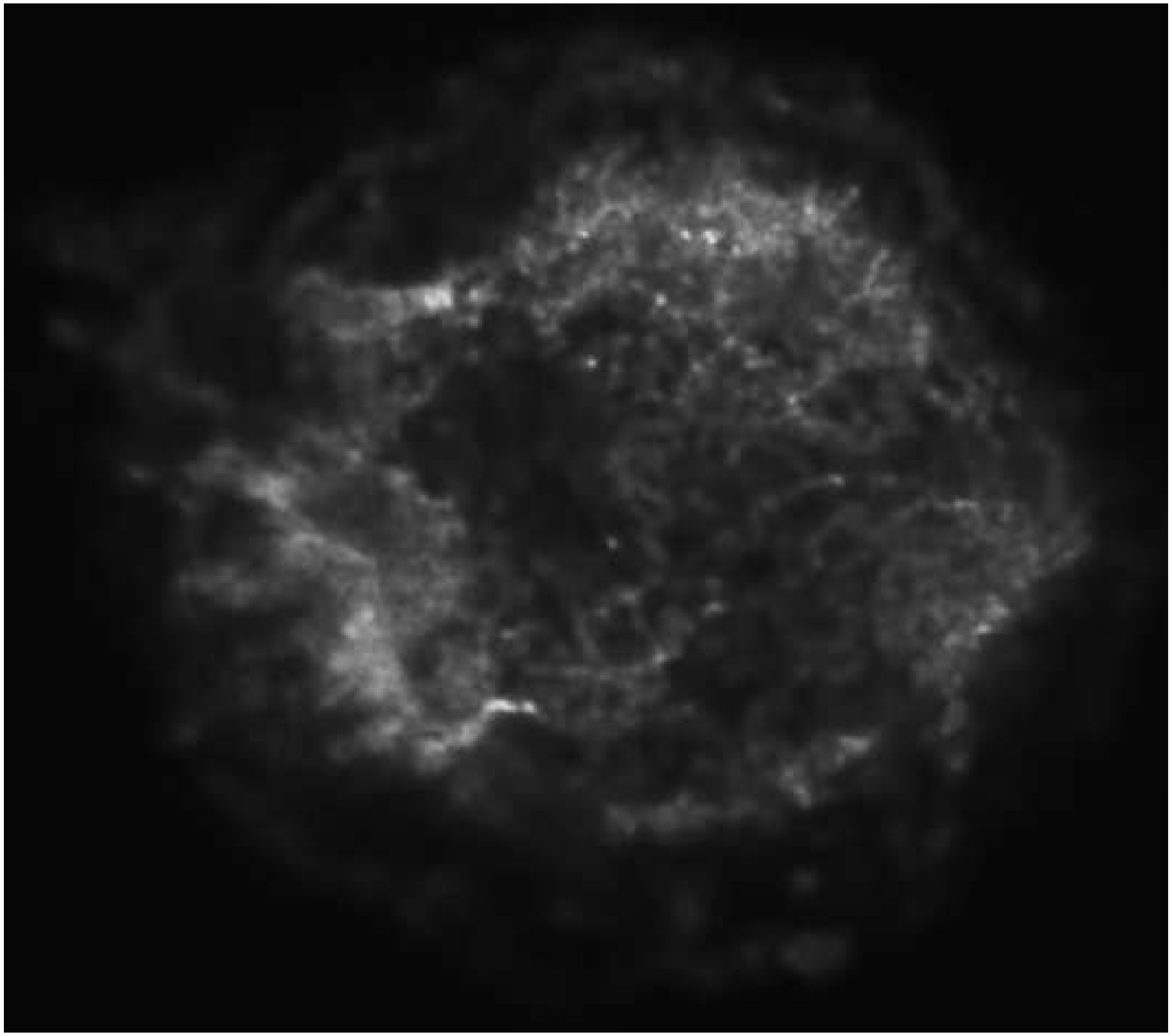
X-Ray Observatories

Early X-ray observatories: Einstein (1978-1980), ROSAT (1991-1999)



- Chandra X-Ray Observatory. Launched by NASA in1999
- Larger field of view, sensitivity,resolution than predecessors

X-Ray Wavelengths

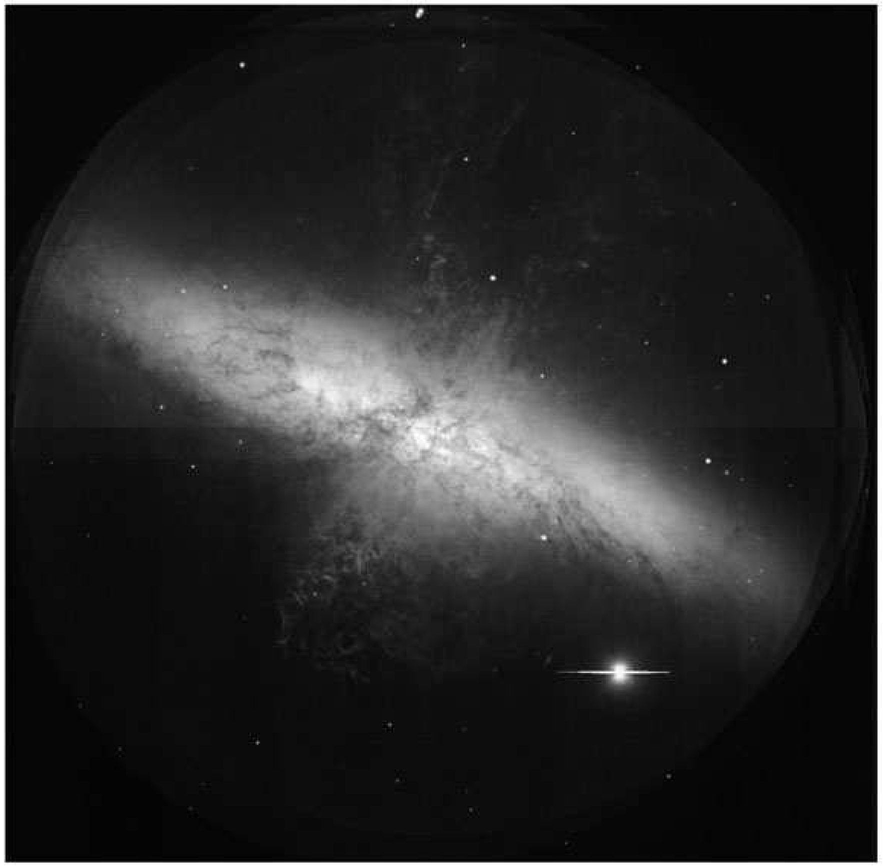


Supernova Remnant
Cassiopeia A

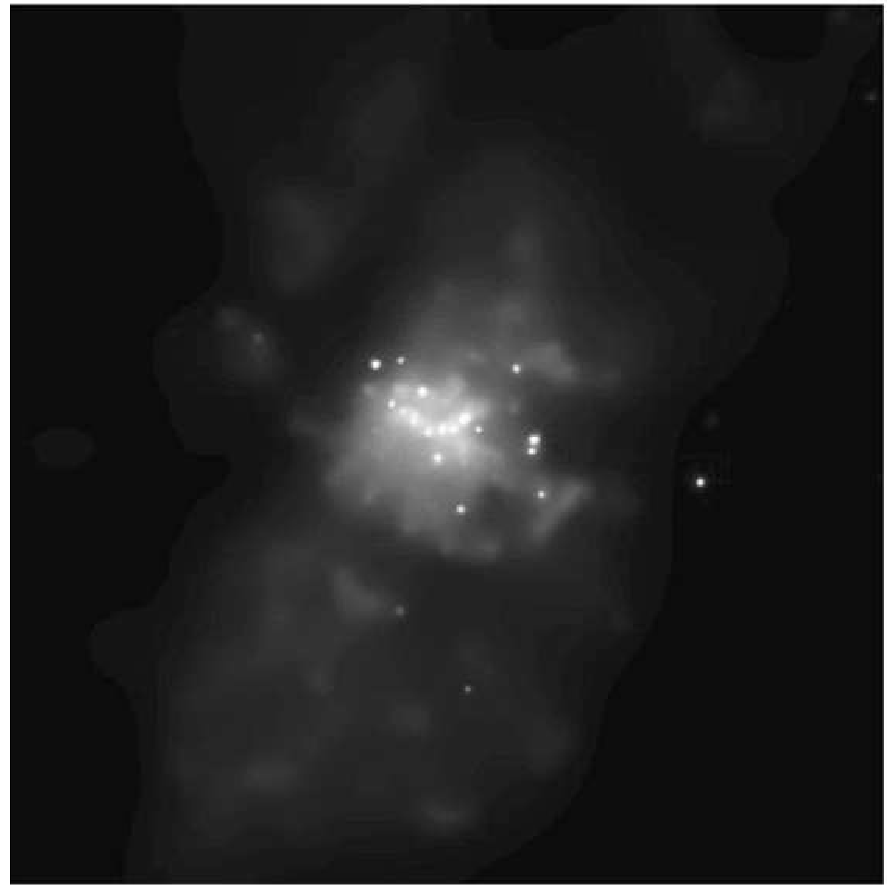
X-ray shows a hot bubble of 10^7 K gas that is heated by shocks from the supernova remnnant

X-Ray Wavelengths

Starburst Galaxy M82: central starburst driving an outflow



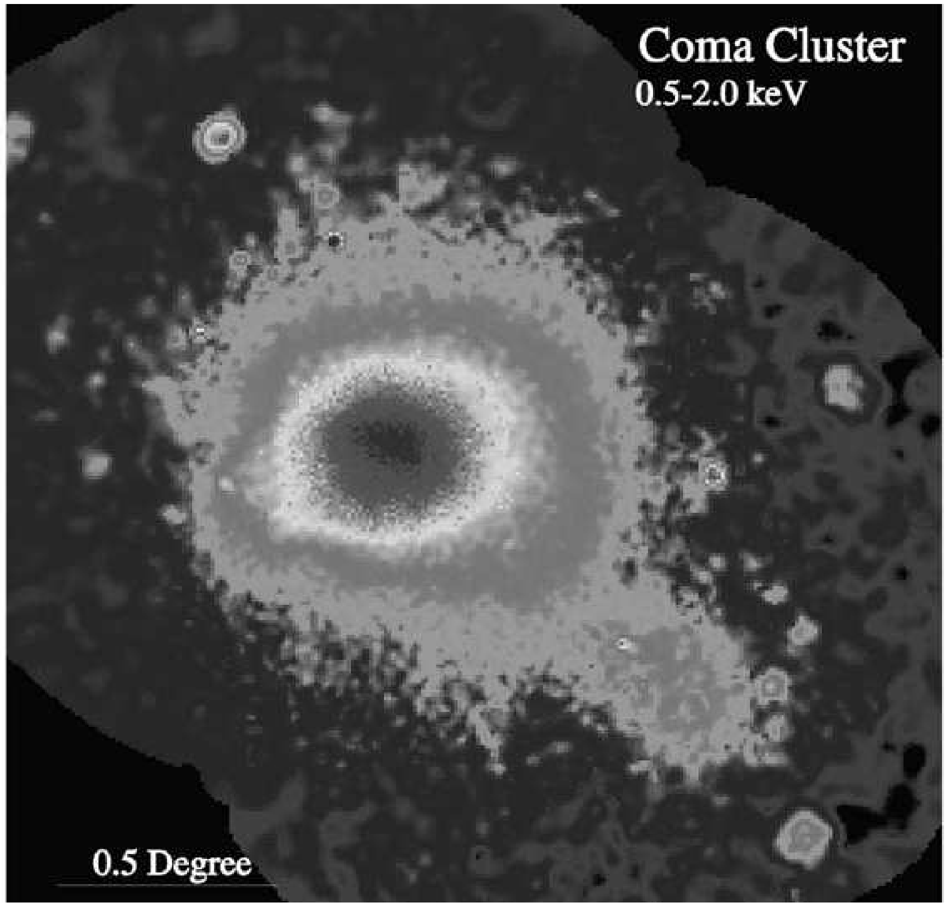
Visible light



X-ray

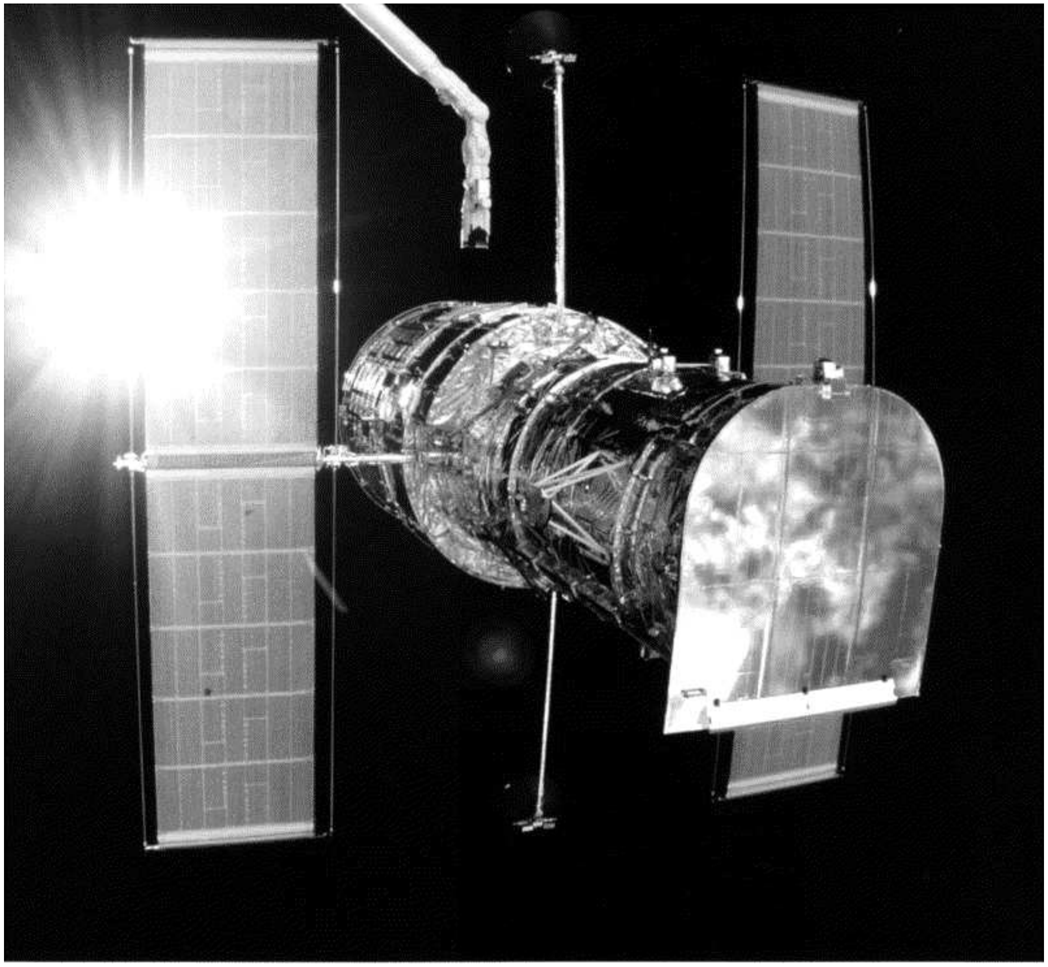
X-Ray Wavelengths

X-ray observations reveal hot (10^7 to 10^8 K) gas between galaxies in a cluster



Imaging the Universe at Optical Wavelengths

Hubble Space Telescope (HST)



HST observes at UV, optical and near-IR wavelengths

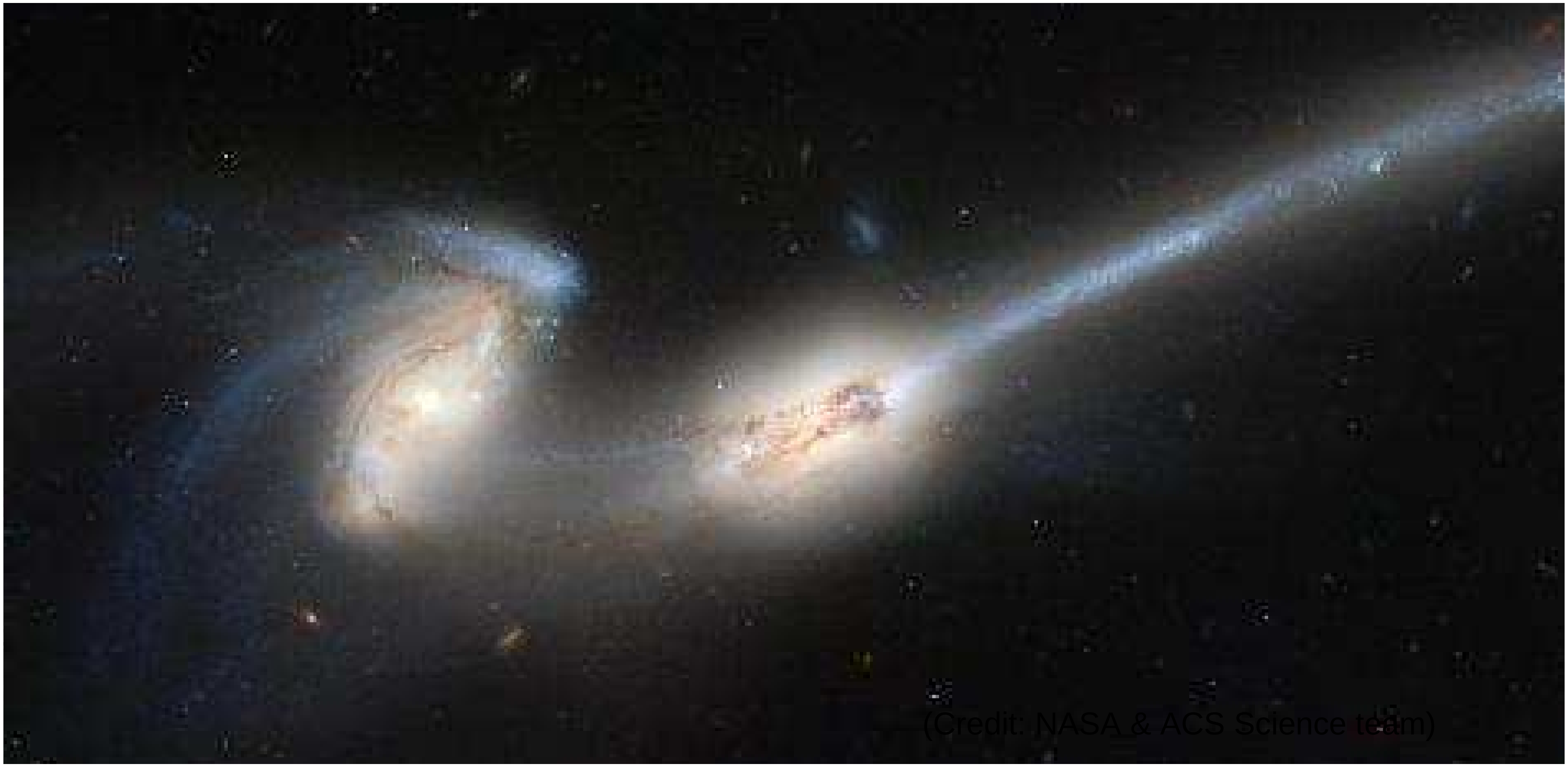
Latest optical camera on board is called the Advanced Camera for Surveys (ACS)

- Launched in 1990
- Mirror diameter= 2.5-m
- Orbits 600 km above Earth
- Powered by solar batteries

Images from the ACS camera aboard Hubble Space Telescope

ACS image shows the dust lanes (shocks) on the two edges of the bar. These shocks show how the bar transports gas from the outer disk of a spiral galaxy down to the center, where the gas fuels huge episodes of star formation and maybe even black holes

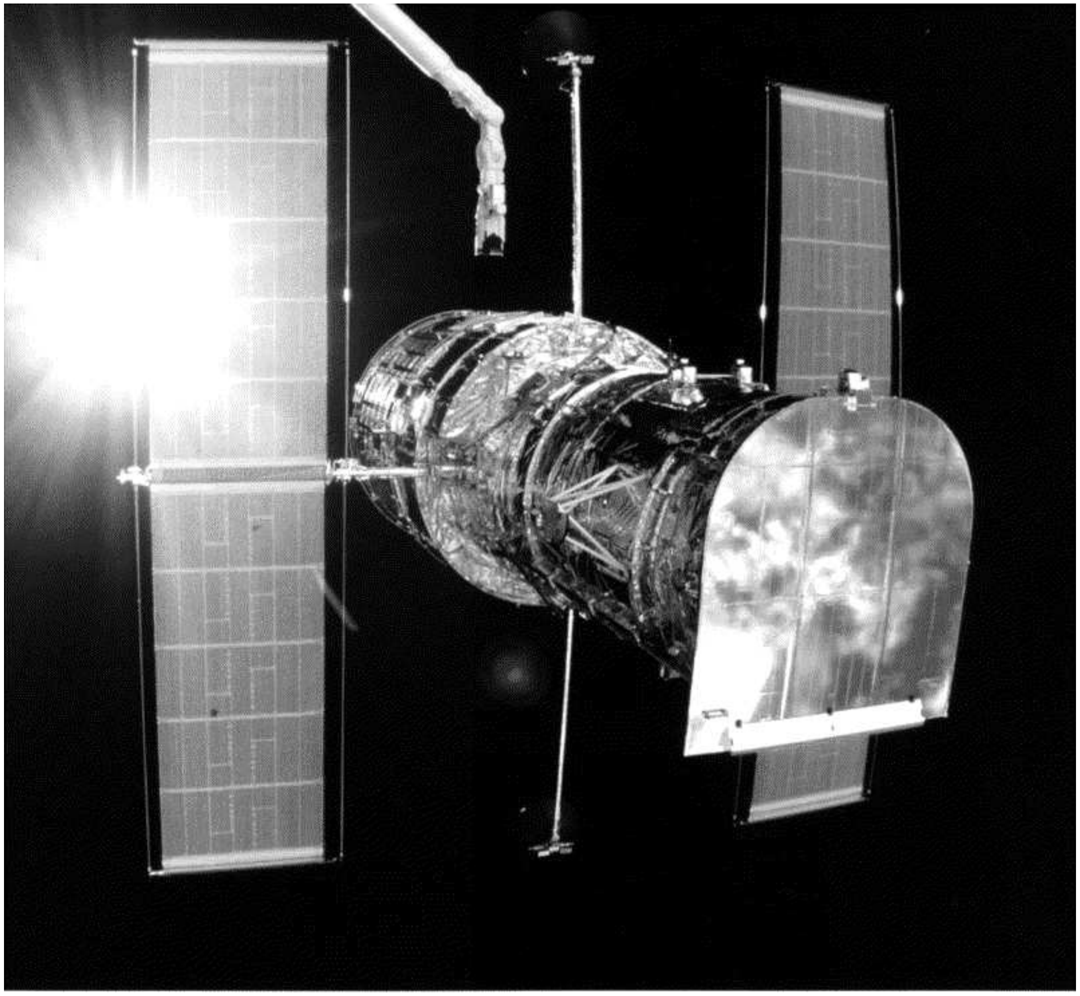
Images from the ACS camera aboard Hubble Space Telescope



ACS image shows details of a collision between 2 spiral galaxies, 100,000 light years apart

***The Fate of the Hubble Space Telescope ***

Hubble Space Telescope (HST)



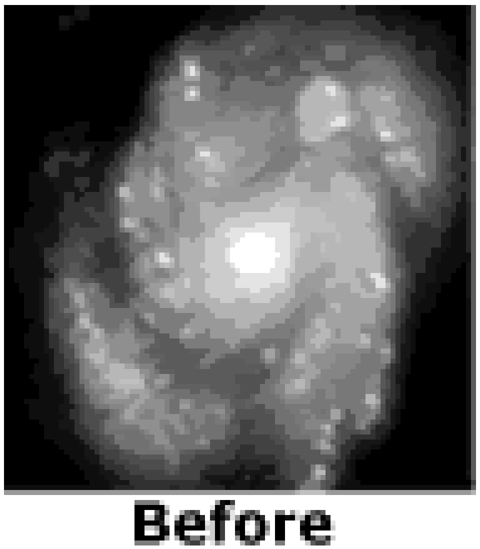
- Launched in 1990
- Mirror diameter= 2.5-m
- Orbits 600 km above Earth
- Powered by solar batteries
- Instruments on board :
  uv, optical, infrared

à No blurring by Earths's atmosphere à high spatial resolution.

à Can observe UV photons without absorption by E's atmosphere

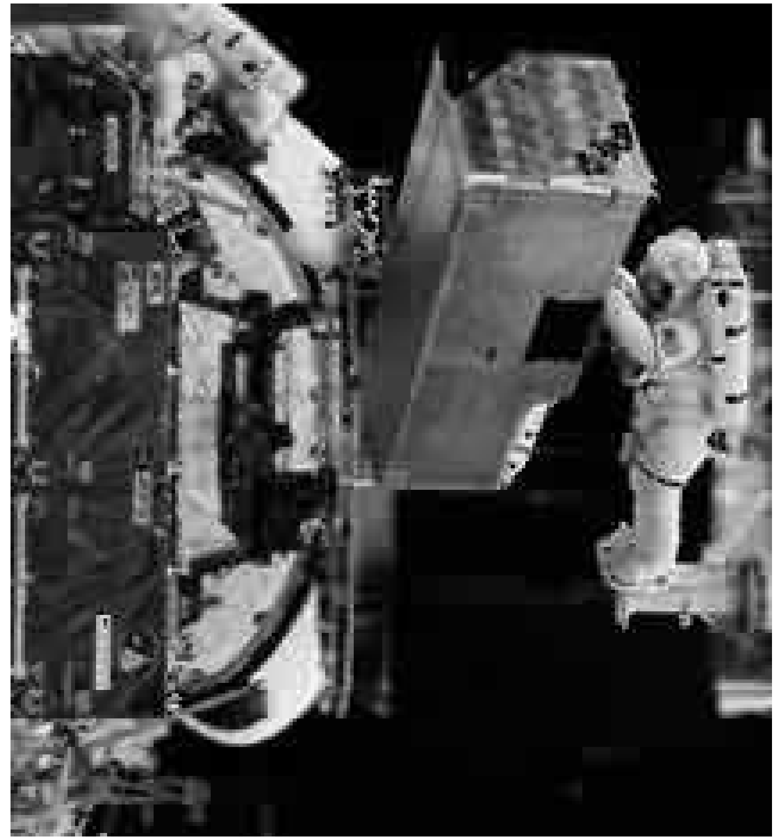
à Can observe infrared emission without high background (glare) from sky

SM1 : Restoring HST’s Vision



Before COSTAR

After COSTAR



Hubble’s mirror was incorrectly shaped à could not focus light à fuzzy images!!
Servicing mission 1 (SM1) via shuttle Endeavor installed a correction optics system called COSTAR (developed by STScI) to correct HST’s vision!

SM2: Adding NICMOS and STIS aboard HST

HST latched to dock of Discovery

Patching up insulation material of HST

Servicing mission (SM2) in Feb 1997 via shuttle Discovery:
Astronauts install Infrared and ultraviolet instruments called NICMOS and STIS

SM3: Installing new gyroscopes and ACS aboard HST

Servicing Mission 3 (SM3) split into two parts.

à SM3A in Dec 1999 via shuttle Discovery replace all 6 gyroscopes on HST

à SM3B in Mar 2002 via shuttle Columbia : replace solar panels, install powerful ACS

The astronauts for SM3B

Advanced Camera for Surveys (ACS)

10 times more powerful than previous camera:

Much **larger field of view and sharper** images

SM4 and the Future of HST

Last shuttle servicing Mission (SM4) to HST was scheduled in 2004 with the following goals:

à Replace gyroscopes and solar batteries of HS... without these HST drifts or dies by 2008

à Install 2 instruments already built to push frontiers of knowledge

Wide Field Camera 3 (WFC3) : Dark energy & the Fate of the Universe
Most masssive galaxies

Cosmic Origins Spectrographs (COS) : First light in the Universe

On Feb 1/2003 after a mission to conduct lab experiments in space,Columbia shuttle exploded on Feb 1 2003, killing 7 astronauts, during re-entry of Earth
à SM4 postponed

If shuttles return to flight this May 2006, SM4 is first priority

Imaging the Universe at Infrared Wavelengths

Infrared Wavelengths

Movie: From optical to IR view of M81 (Courtesy: NASA/Spitzer)

à Near-IR at 1 to 3 micron: penetrate the dust and shows **old stars**

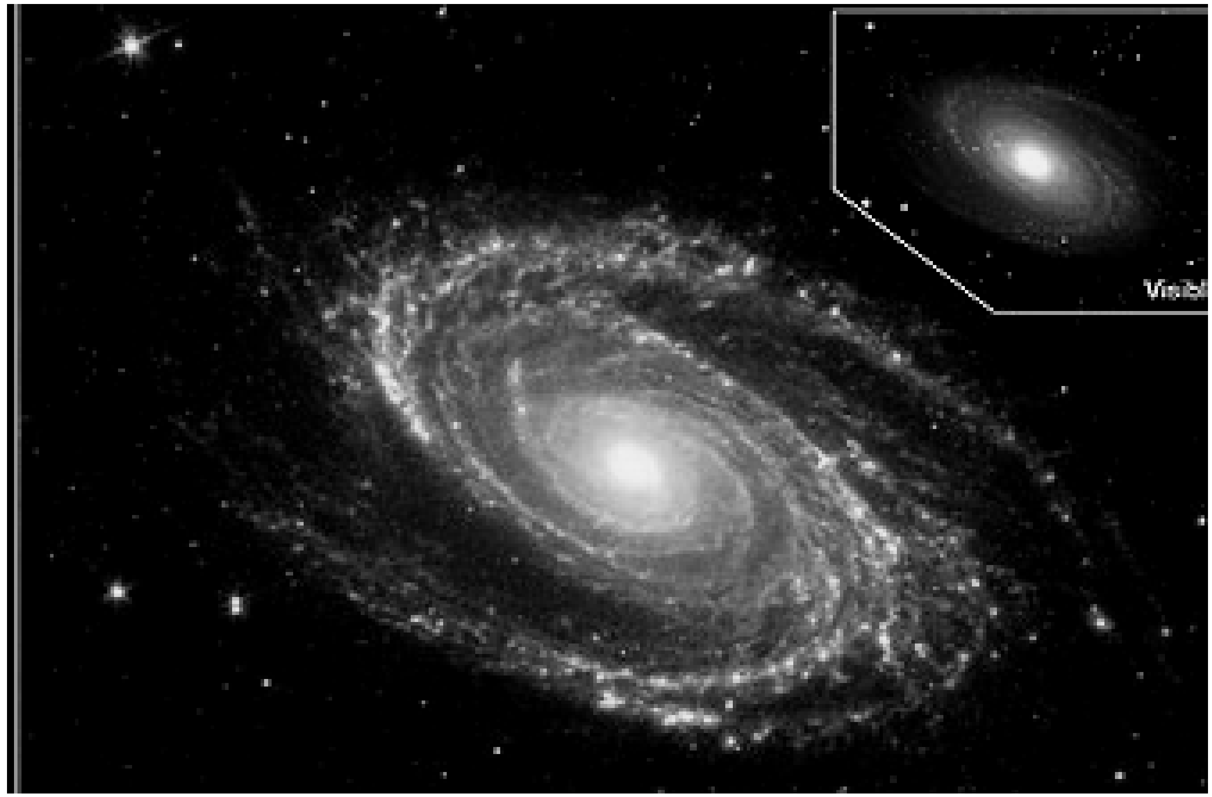
à Mid and far-IR from 10 to 100 micron shows **hot dust and gas forming young stars**

Infrared Wavelengths

M81 galaxy

(Courtesy: NASA/Spitzer)

Underlying low mass stars



Infrared composite made from 3.6, 8.0, 24 micron images

Regions with hot dust and gas heated by young stars

Infrared Wavelengths

Movie : From visual to infrared look at dark globule in IC 1386
(Courtesy:NASA/Spitzr)

- Visual image shows one star + dark patch of dust in globule head
- Near-IR 3.6 mu image penetrates the dust to show 2nd star and cavity in globule head
- Mid IR 8 and 24 mu images trace hot dust+ gas filaments made when winds from massive stars compress gas à Thick dusty discs around young stars = precursor of planetary systems

Radio Wavelengths (mm to m)

VLA operating at cm wavelengths

Very Large Array (VLA) : 27 radio antennas, each 25-m , arranged in a Y-shaped array

Data from the antennas is combined electronically to give the resolution of an antenna 36, 000 m across

Located in Plains of San Agustin fifty miles west of Socorro, New Mexico

Radio: 21 cm emission line from atomic hydrogen

Maps of the emission line at 21 cm (radio wavelengths) trace atomic hydrogen.
à reveal tidal tails at large radii, and unravels the interaction history
à reveal atomic gas in outer parts of disks galaxies: may form stars if compressed

The visible light image shows
- a relatively undisturbed disk
- a 20,000 pc tail to the left
- NO disturbance to the right

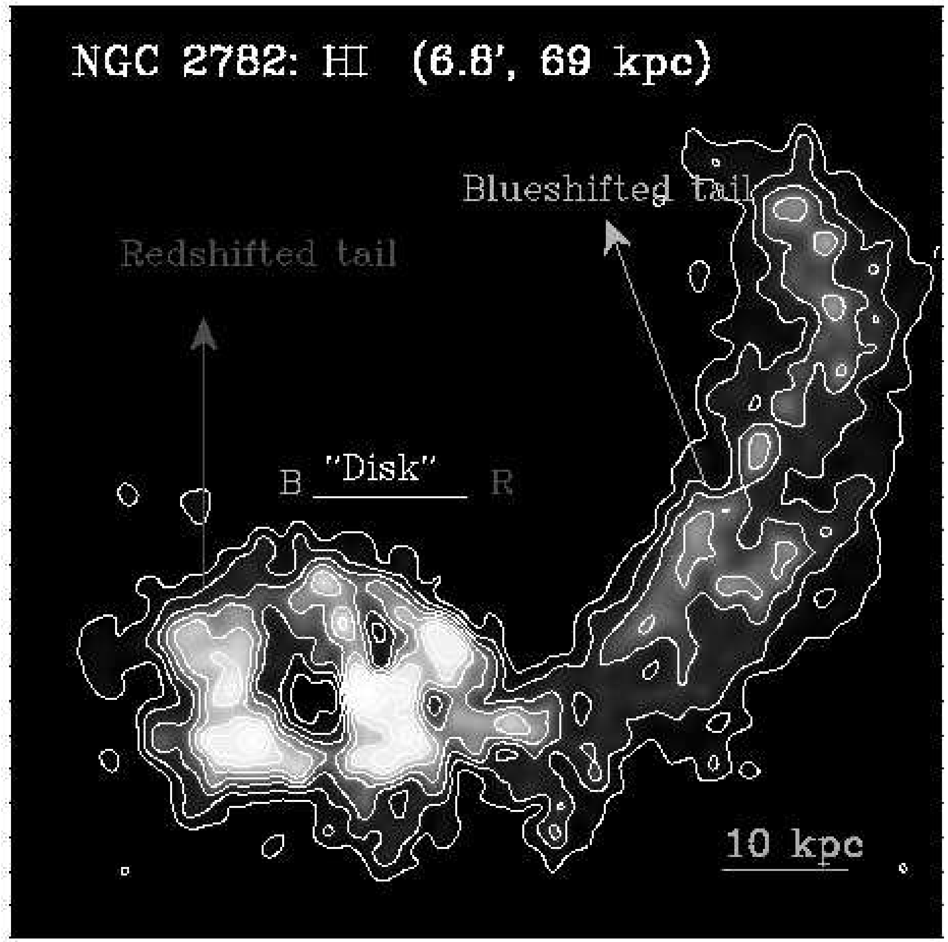
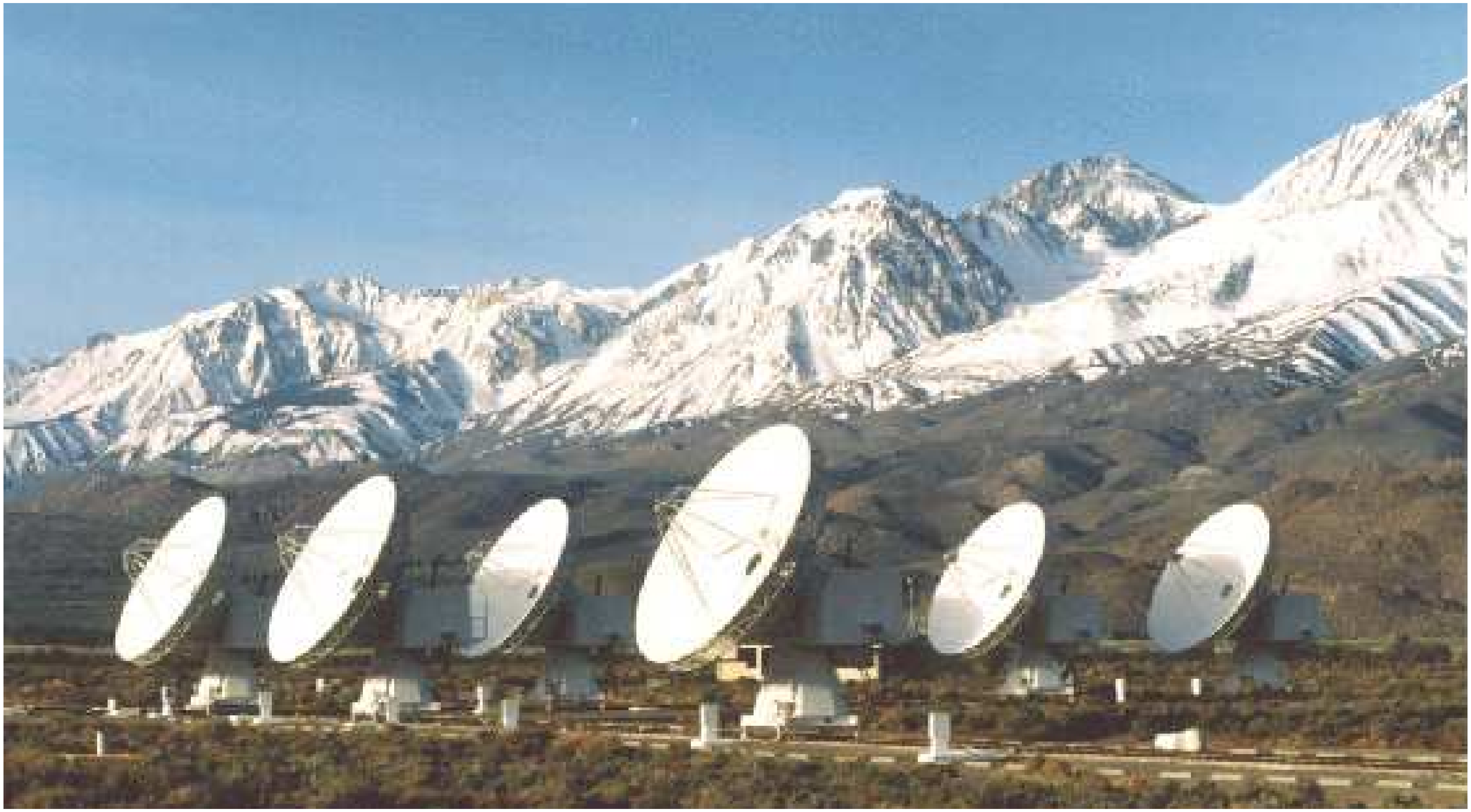


Image at 21 cm (atomic H) shows the disk and a HUGE 50,000 pc tail to the right

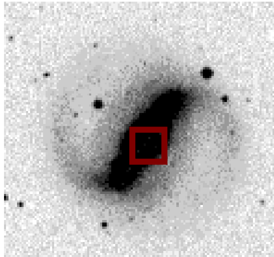
OVRO operating at mm   wavelengths



Caltech's Owens Valley Radio Observatory (OVRO) has a mm array made of 8 radio telescopes, each 10.2 meters in size,

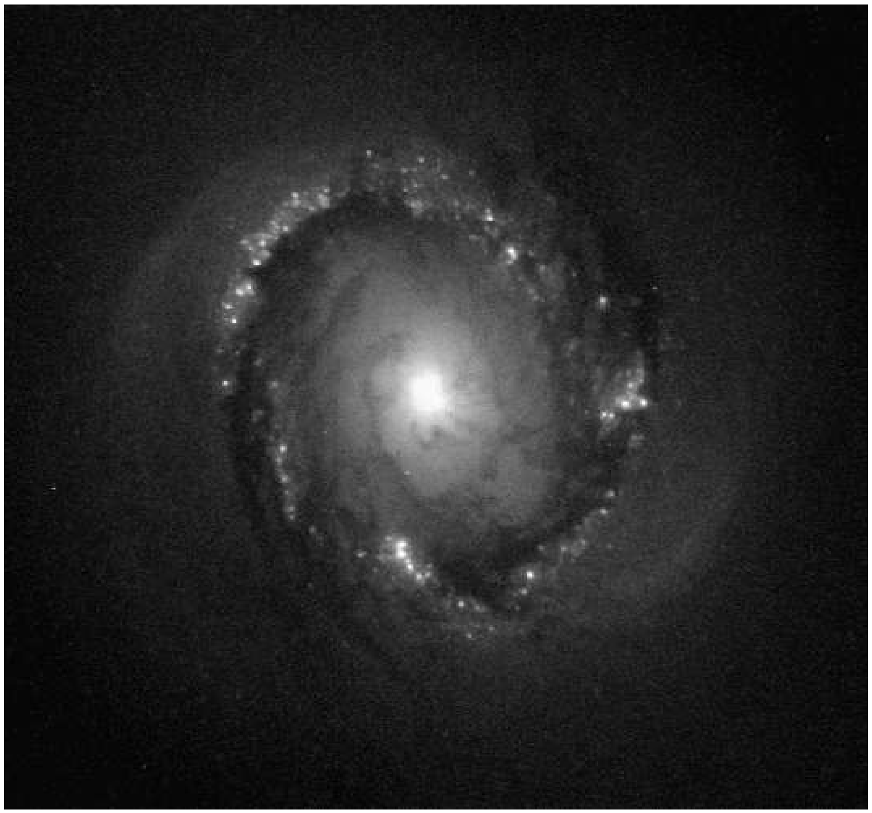
Located on east side of the Sierra Nevadas in California, ~250 miles north of Los Angeles.

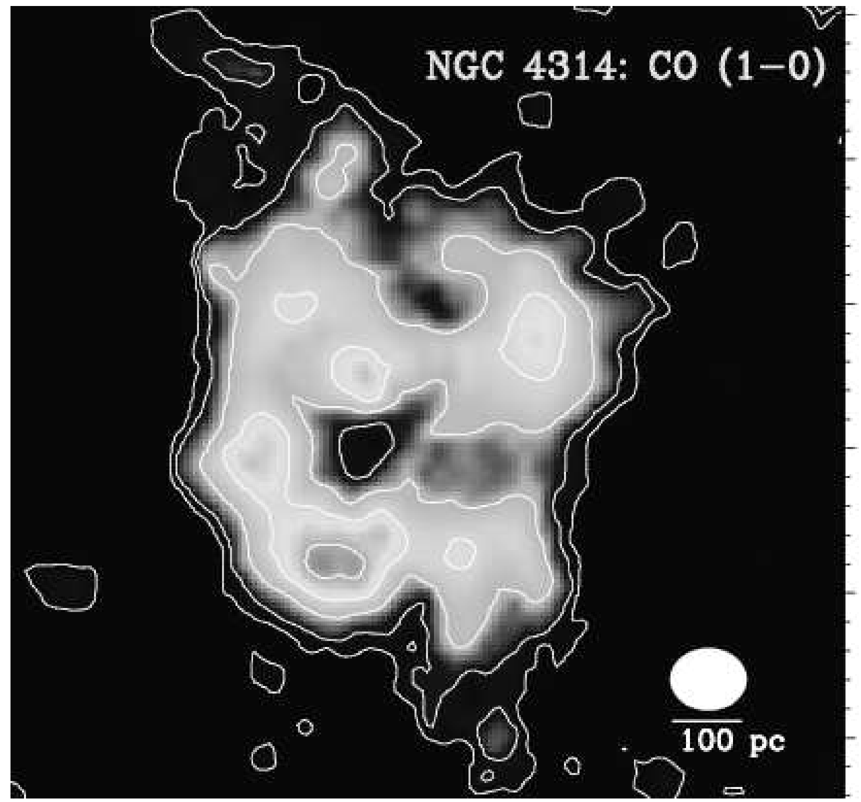
At radio λ : observe 24 hrs a day. Only shut down in the summer when humidity is high….



Radio (mm) Wavlengths

Radio observation at 3 mm trace molecular hydrogen. When the latter reaches high enough densities, gravity makes it collapse into new stars



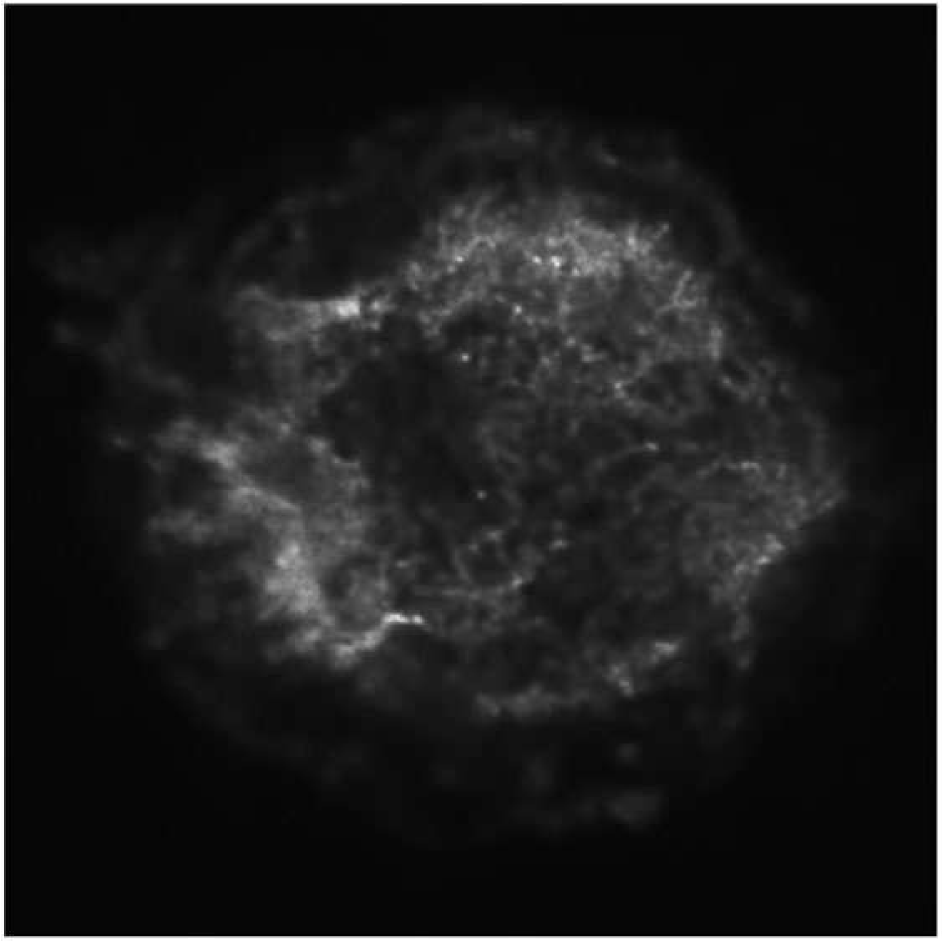


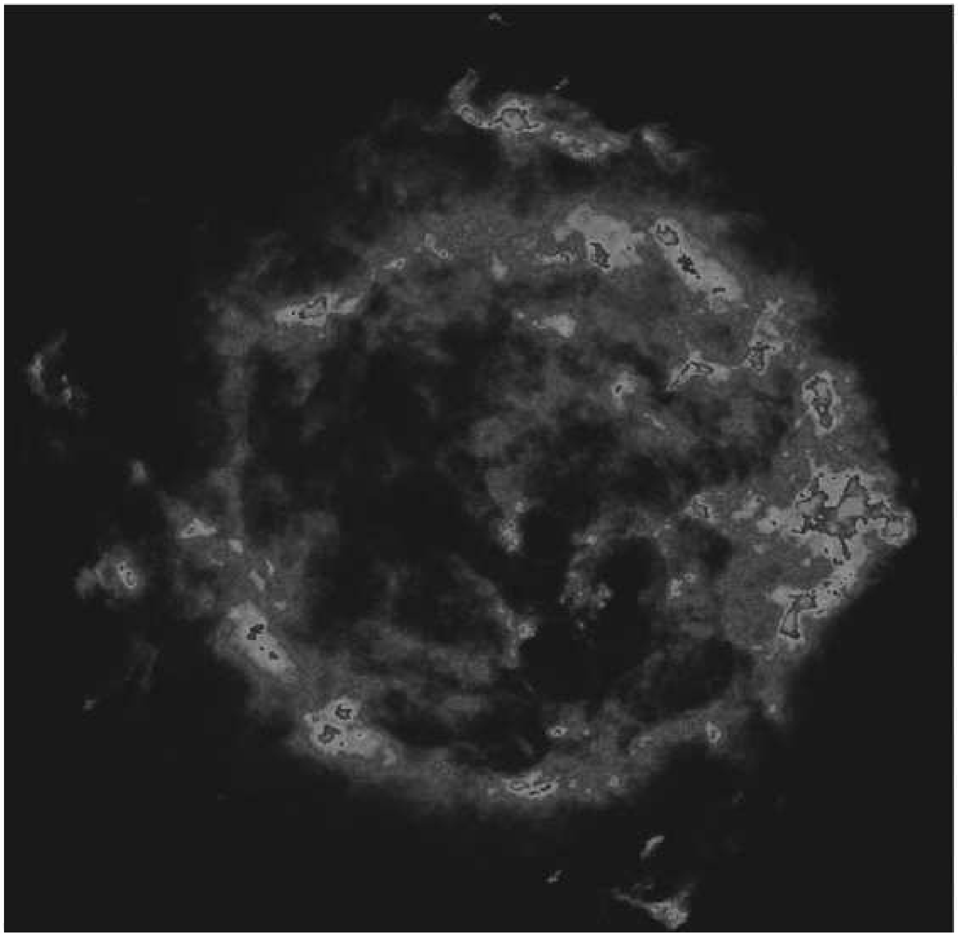
UV and visible images from HST show a speactacular ring of young stars, a few millon yrs old. Courtesy: Benedict/ NASA)

Radio observation at 3 mm trace molecular hydrogen from which the stars are forming. (Jogee et al . 2004)

Radio continuum at 20 cm

Supernova Remnant Cassiopeia A :





X-ray shows a hot bubble of 10^7 K gas that is heated by shocks from the supernova remnnant

Radio continuum 20 cm map traces thermal free-free emission + non-thermal synchroton radiation. See class notes