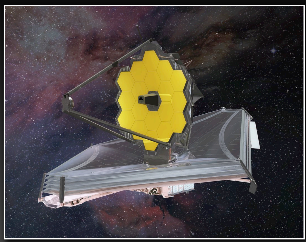
Telescopes

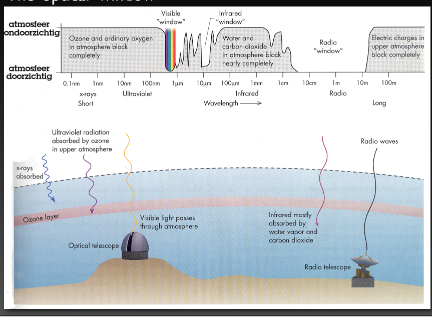



Koupelis : chapter 5
OpenStax : chapter 6

1

Atmospheric windows

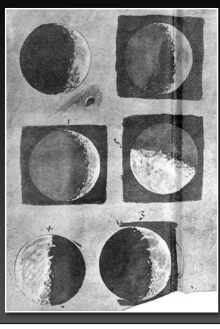
The ‘optical’ window



2

Optical telescope

Galileo Galilei’s telescope

3

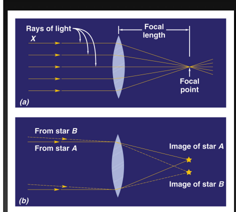
The telescope

- provides a strong magnification
- collects many photons
- produces sharp images

4

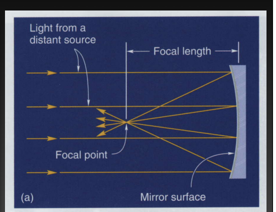
Optical telescope

Refractor



lens bends and focuses the light

Reflector



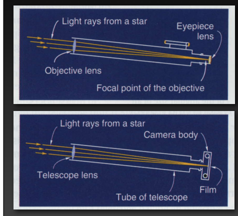
mirror reflects and focuses the light

5

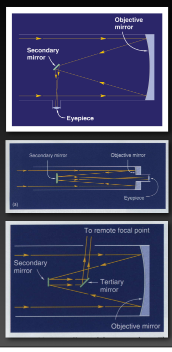
6

Optical telescopes

Refractor



Reflector



7

The magnification of a telescope

$$\text{Magnification} = \frac{\text{focal length of lens/mirror}}{\text{focal length of eye-piece}}$$

$$M = \frac{f_{lens/mirror}}{f_{eye\text{-}piece}}$$

Gratama-telescope of Blaauw Observatory :

f_{mirror} = 3200 mm

$f_{eye\text{-}piece}$ = 13 mm

$$M = \frac{3200}{13} = 246$$

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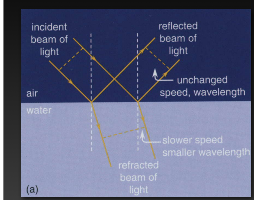
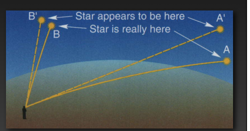
The refraction of light





A light beam changes direction at the surface of 2 media.

The change of direction depends on the angle of incidence

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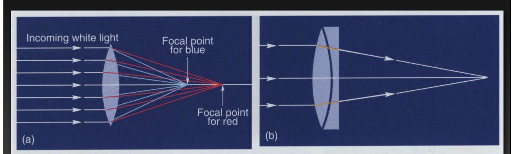
Chromatic aberration

the amount of refraction depends on the wavelength



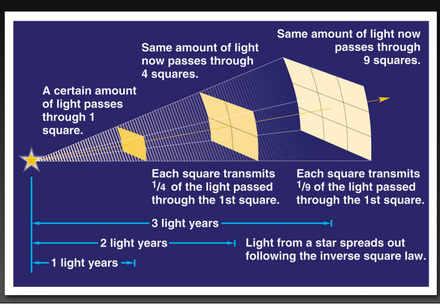
Blue light is refracted more strongly than red light.

A second or third lens can reduce the aberration but it can not eliminate it.

Chromatic aberration does not happen for reflection!

10

The "$\frac{1}{R^2}$ - law"



11

The larger the diameter of the lens/mirror, the more light (photons) will be collected.

Eye's pupil in the dark : ~8 mm diameter

Largest telescopes : ~8 m diameter

Question:
how much more light is collected by a large telescope?

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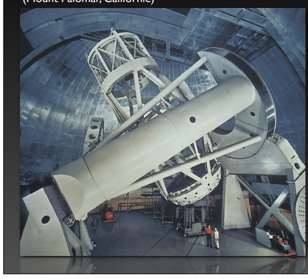
Bigger *is* better

5-meter Hale Telescope
200" reflector telescope
(Mount Palomar, Californie)



Yerkes Observatory
40" refractor telescoop
1897 - 1909

13

The bigger the diameter of the lens/mirror, the sharper the image:

A larger telescope can make sharper images:

$$\text{Diffraction limit [arcsec]} \approx 2.1\times10^5 \, \frac{\lambda\,[\text{m}]}{D\,[\text{m}]}$$

λ — wavelength; D — diameter

This is known as the 'angular resolution' of a telescoop.

Example : λ = 500 [nm] = 5×10^{-7} [m]
D = 10 [cm] = 0.1 [m]

$$\text{Angular resolution} = 2.1\times10^5 \, \frac{5\times10^{-7}}{0.1} = 1.1 \text{ [arcsec]}$$

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'seeing' : the atmospheric limit

The diffraction limit of a telescope is rarely reached!
turbulence in the atmosphere smears the image…

The *seeing* limits the angular resolution to ~1 arc-second.

Solutions:
- observe from space
- use 'adaptive optics'

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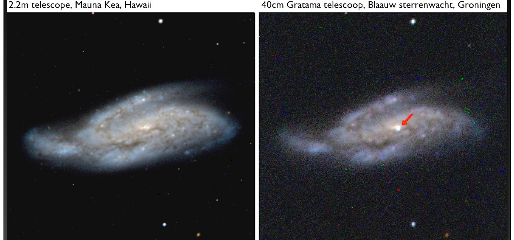
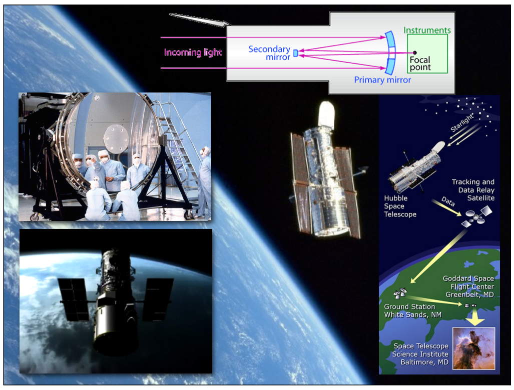
'seeing' : the atmospheric limit

Supernova in NGC 4088

24 maart 1996
University of Hawaii
2.2m telescope, Mauna Kea, Hawaii

15 maart 2009
University of Groningen
40cm Gratama telescoop, Blaauw sterrenwacht, Groningen




Incoming light
Secondary mirror
Instruments
Focal point
Primary mirror
Starlight
Tracking and Data Relay Satellite
Hubble Space Telescope
Data
Goddard Space Flight Center Greenbelt, MD
Ground Station White Sands, NM
Space Telescope Science Institute Baltimore, MD

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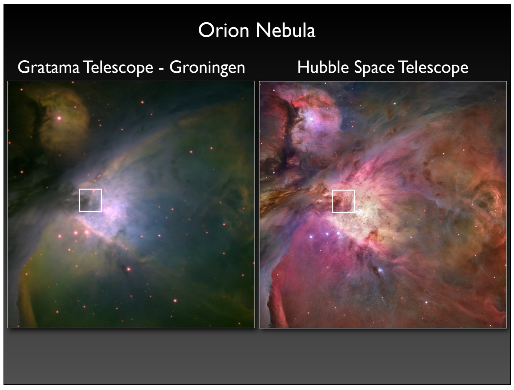
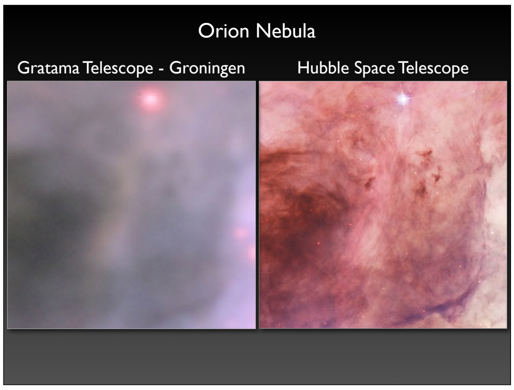

Orion Nebula
Gratama Telescope - Groningen
Hubble Space Telescope

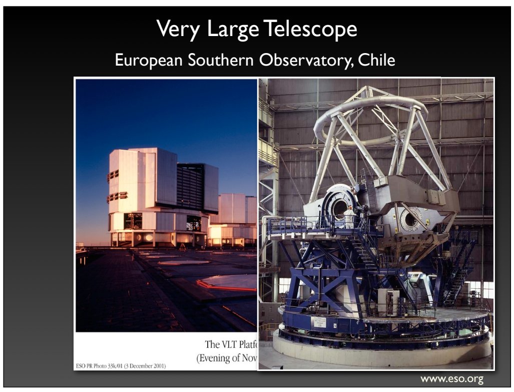
17


Orion Nebula
Gratama Telescope - Groningen
Hubble Space Telescope

18


Very Large Telescope
European Southern Observatory, Chile
The VLT Platform at Paranal
(Evening of November 25, 2001)
www.eso.org

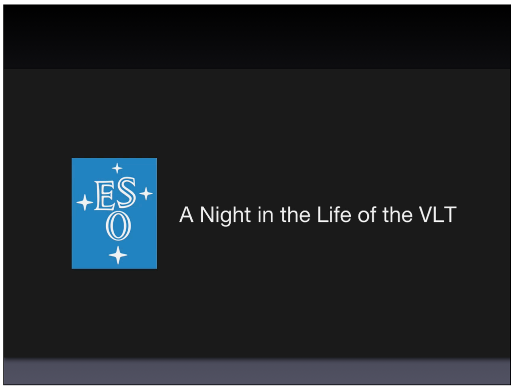
19


Very Large Telescope
European Southern Observatory, Chile
www.eso.org

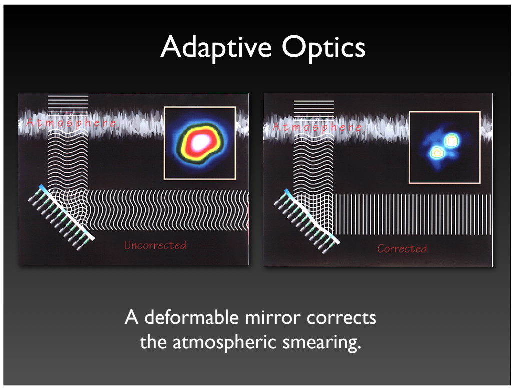
20


movie: Quantum of Solace

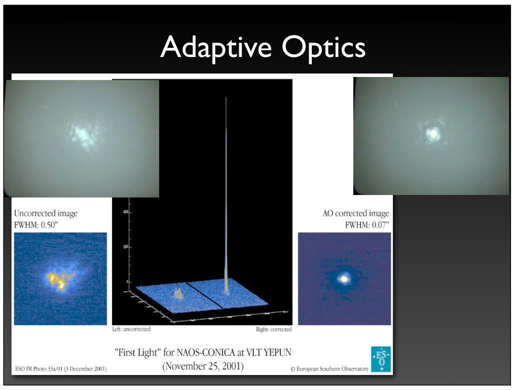
21


ESO
A Night in the Life of the VLT

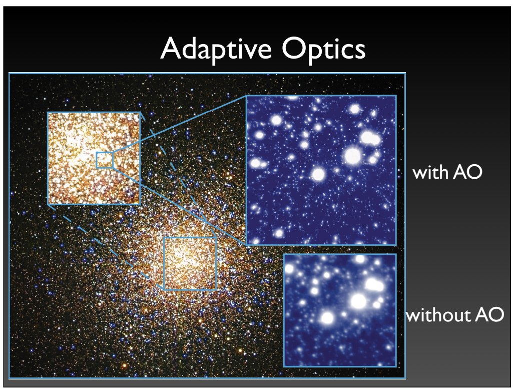
22


Adaptive Optics
Uncorrected
Corrected
A deformable mirror corrects
the atmospheric smearing.

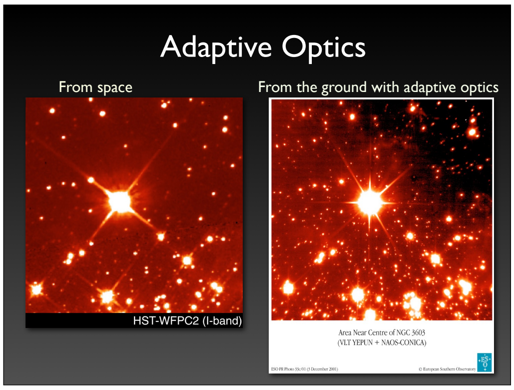
23


Adaptive Optics
Uncorrected image
FWHM: 0.50"
AO corrected image
FWHM: 0.07"
"First Light" for NAOS-CONICA at VLT YEPUN
(November 25, 2001)

24


Adaptive Optics
with AO
without AO

25


Adaptive Optics
From space
From the ground with adaptive optics
HST-WFPC2 (I-band)
Area Near Centre of NGC 3603
(VLT YEPUN + NAOS-CONICA)

26


the earth at night…

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view from the Blaauw Observatory…

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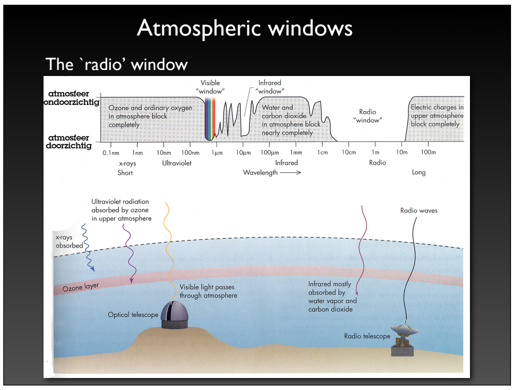
Atmospheric windows
The `radio' window
Visible "window"
Infrared "window"
atmosfeer ondoorzichtig
atmosfeer doorzichtig
Ozone and ordinary oxygen in atmosphere block completely
Water and carbon dioxide in atmosphere block nearly completely
Radio "window"
Electric charges in upper atmosphere block completely
0.1nm
1nm
10nm
100nm
1µm
10µm
100µm
1mm
1cm
10cm
1m
10m
100m
x-rays
Ultraviolet
Infrared
Radio
Short
Wavelength
Long
Ultraviolet radiation absorbed by ozone in upper atmosphere
x-rays absorbed
Radio waves
Ozone layer
Visible light passes through atmosphere
Optical telescope
Infrared mostly absorbed by water vapor and carbon dioxide
Radio telescope

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Dwingeloo telescope, Netherlands
25m diameter

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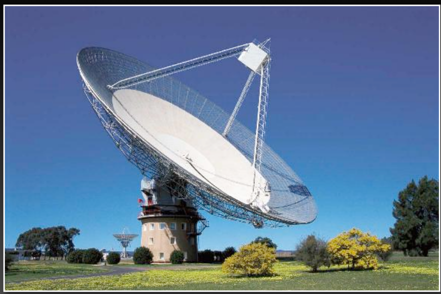
Parkes telescope, Australie



64m diameter movie : “The Dish”

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Green Bank Telescope, USA

100m diameter largest steerable radio telescope

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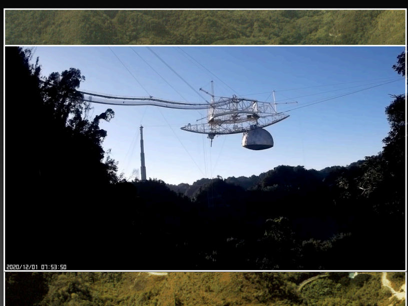
Arecibo, Puerto Rico

300m diameter movie : “Goldeneye”

33

Arecibo, Puerto Rico



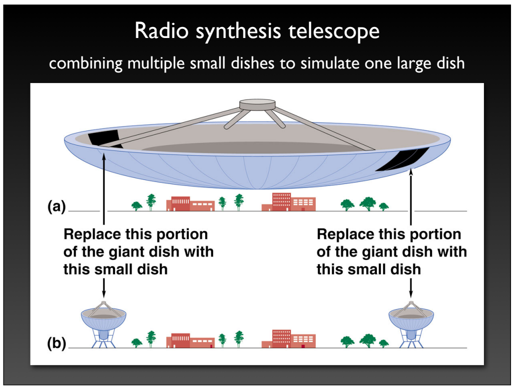
300m diameter movie : “Goldeneye”

34

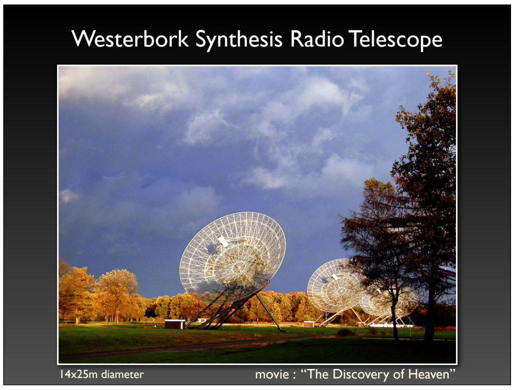
FAST, China

500m diameter largest dish in the world

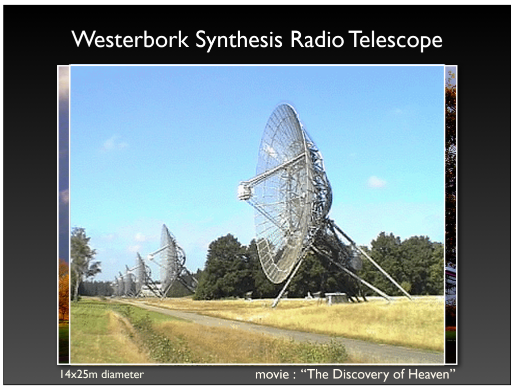
35


Radio synthesis telescope
combining multiple small dishes to simulate one large dish
(a)
Replace this portion of the giant dish with this small dish
Replace this portion of the giant dish with this small dish
(b)

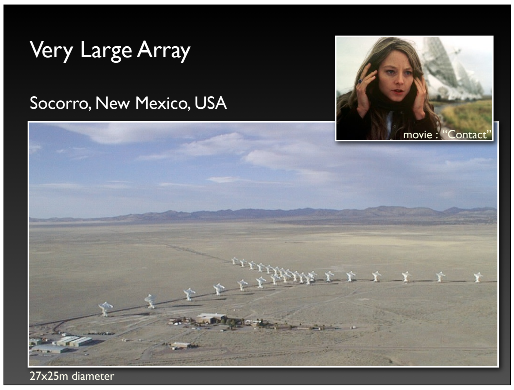
36


Westerbork Synthesis Radio Telescope
14x25m diameter
movie : "The Discovery of Heaven"

37


Westerbork Synthesis Radio Telescope
14x25m diameter
movie : "The Discovery of Heaven"

38


Very Large Array
Socorro, New Mexico, USA
movie : "Contact"
27x25m diameter

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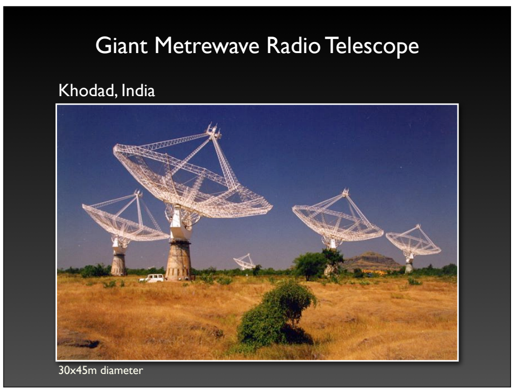
Giant Metrewave Radio Telescope
Khodad, India
30x45m diameter

40

Atacama Large Millimeter Array

www.almaobservatory.org

http://www.eso.org/public/unitedkingdom/videos/archive/category/alma/

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LOFAR: Low Frequency Array

- 26.000 antennas
- superfast internet connection
- together simulate one large telescope
- pointed by computer

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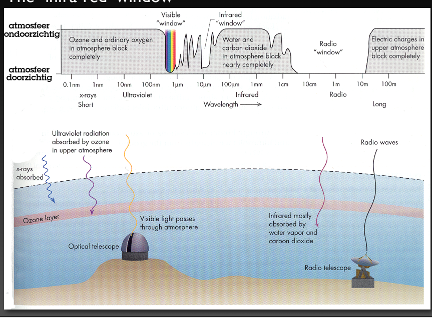
Atmospheric windows

The `infra-red' window



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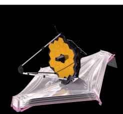
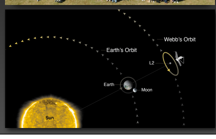
Infra-Red

James Webb Space Telescope





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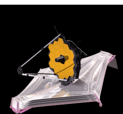
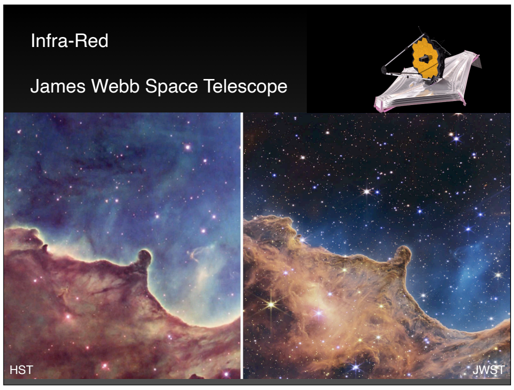
Infra-Red

James Webb Space Telescope



45


Infra-Red
James Webb Space Telescope
HST
JWST

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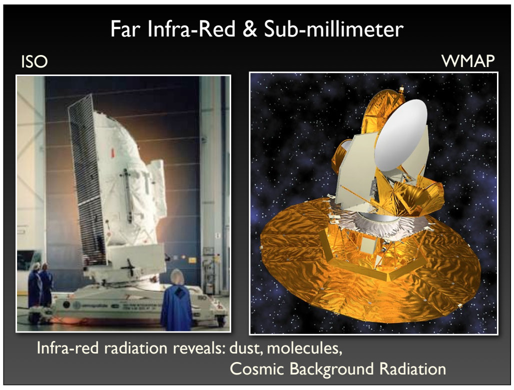
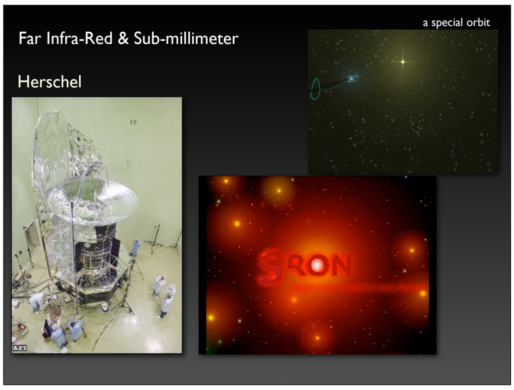
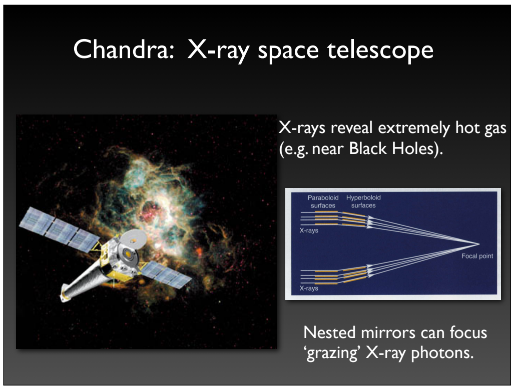

Far Infra-Red & Sub-millimeter
ISO
WMAP
Infra-red radiation reveals: dust, molecules,
Cosmic Background Radiation

47


Far Infra-Red & Sub-millimeter
Herschel
a special orbit

48


Chandra: X-ray space telescope
X-rays reveal extremely hot gas
(e.g. near Black Holes).
Paraboloid surfaces
Hyperboloid surfaces
X-rays
Focal point
X-rays
Nested mirrors can focus
'grazing' X-ray photons.

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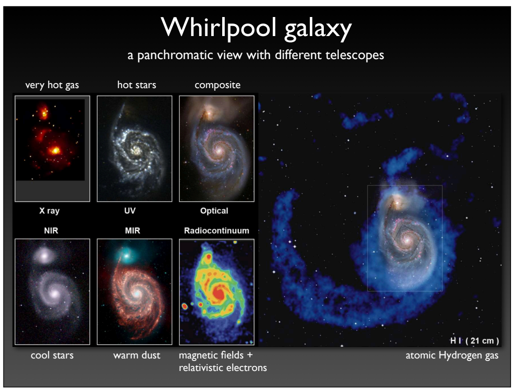
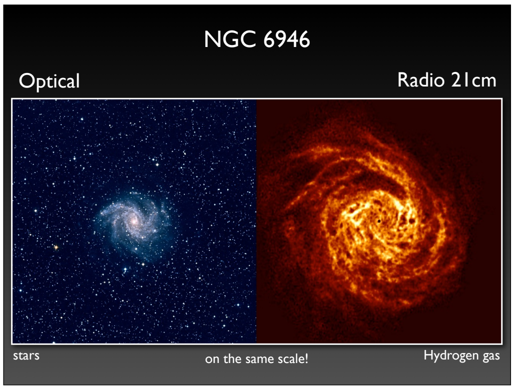

Whirlpool galaxy
a panchromatic view with different telescopes
very hot gas
hot stars
composite
X ray
UV
Optical
NIR
MIR
Radiocontinuum
cool stars
warm dust
magnetic fields +
relativistic electrons
H I (21 cm)
atomic Hydrogen gas

50


NGC 6946
Optical
Radio 21cm
stars
on the same scale!
Hydrogen gas

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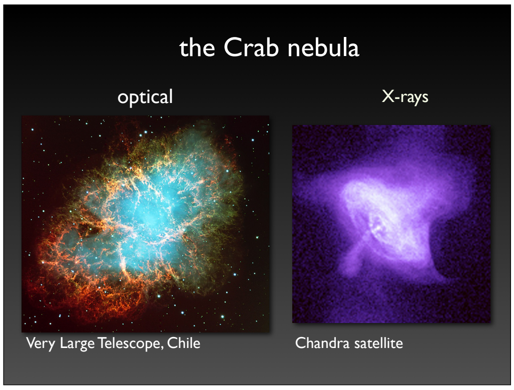
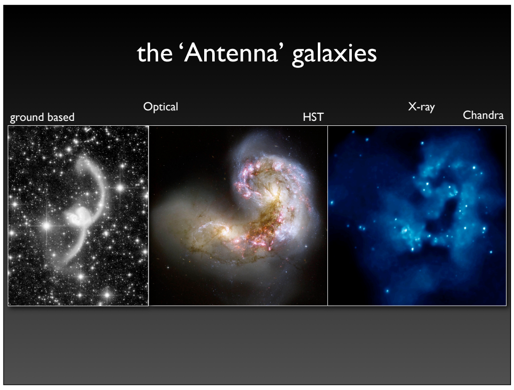

the Crab nebula
optical
X-rays
Very Large Telescope, Chile
Chandra satellite

52


the 'Antenna' galaxies
ground based
Optical
HST
X-ray
Chandra

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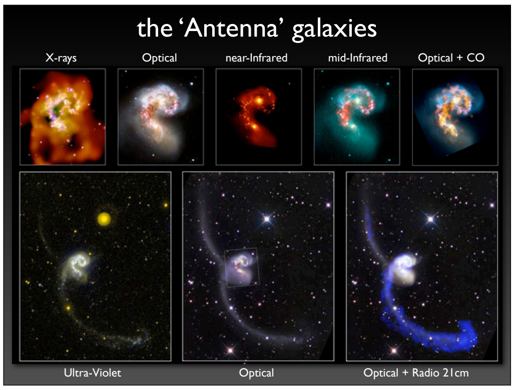
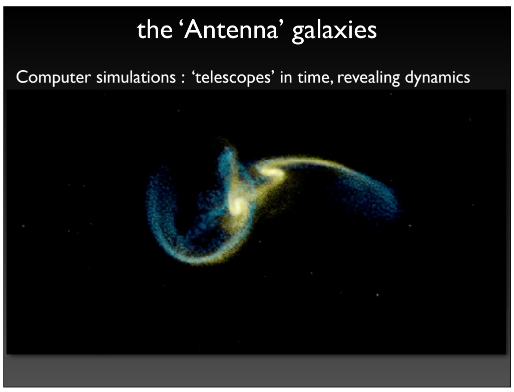

the 'Antenna' galaxies
X-rays
Optical
near-Infrared
mid-Infrared
Optical + CO
Ultra-Violet
Optical
Optical + Radio 21cm

54


the 'Antenna' galaxies
Computer simulations : 'telescopes' in time, revealing dynamics

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upcoming facilities
Square Kilometre Array
South Africa / Australia
European
Extremely Large Telescope
Chile

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