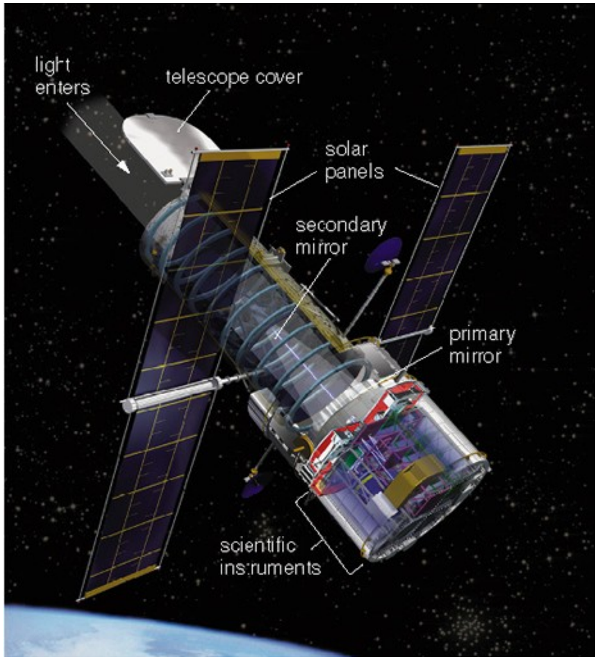
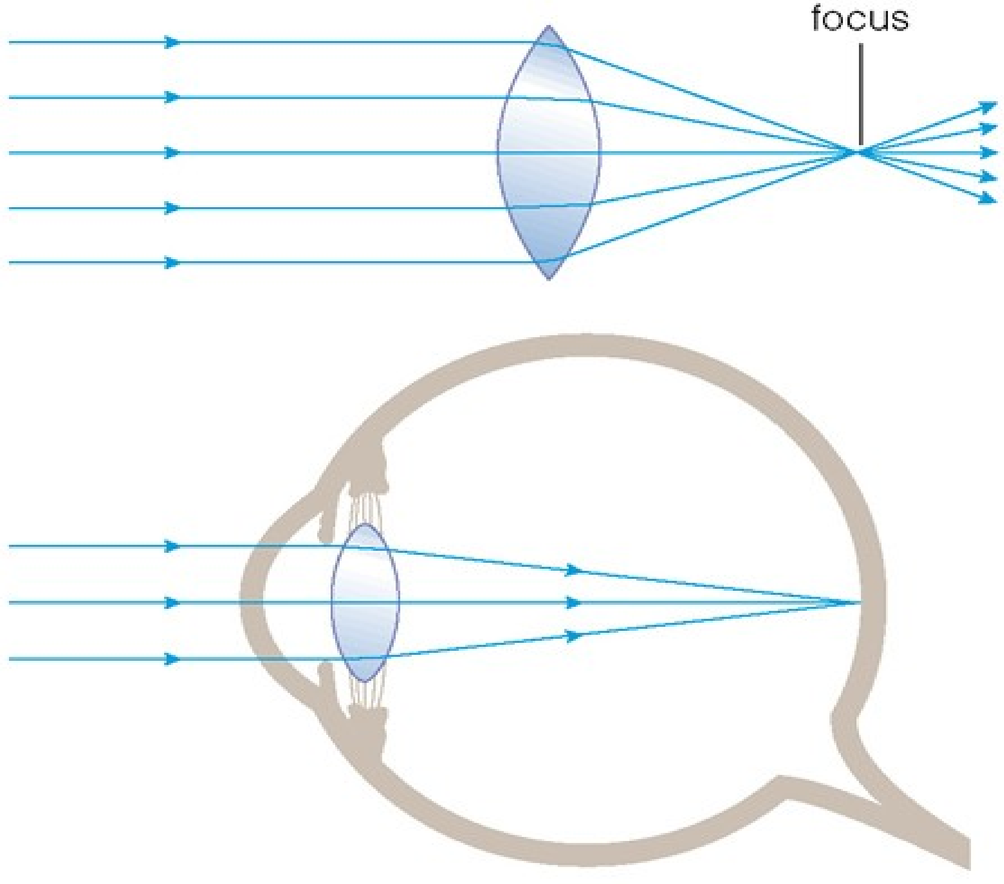
Pre-telescope era ----- 'pre-history' in astronomy

Telescope era (1609-   ):



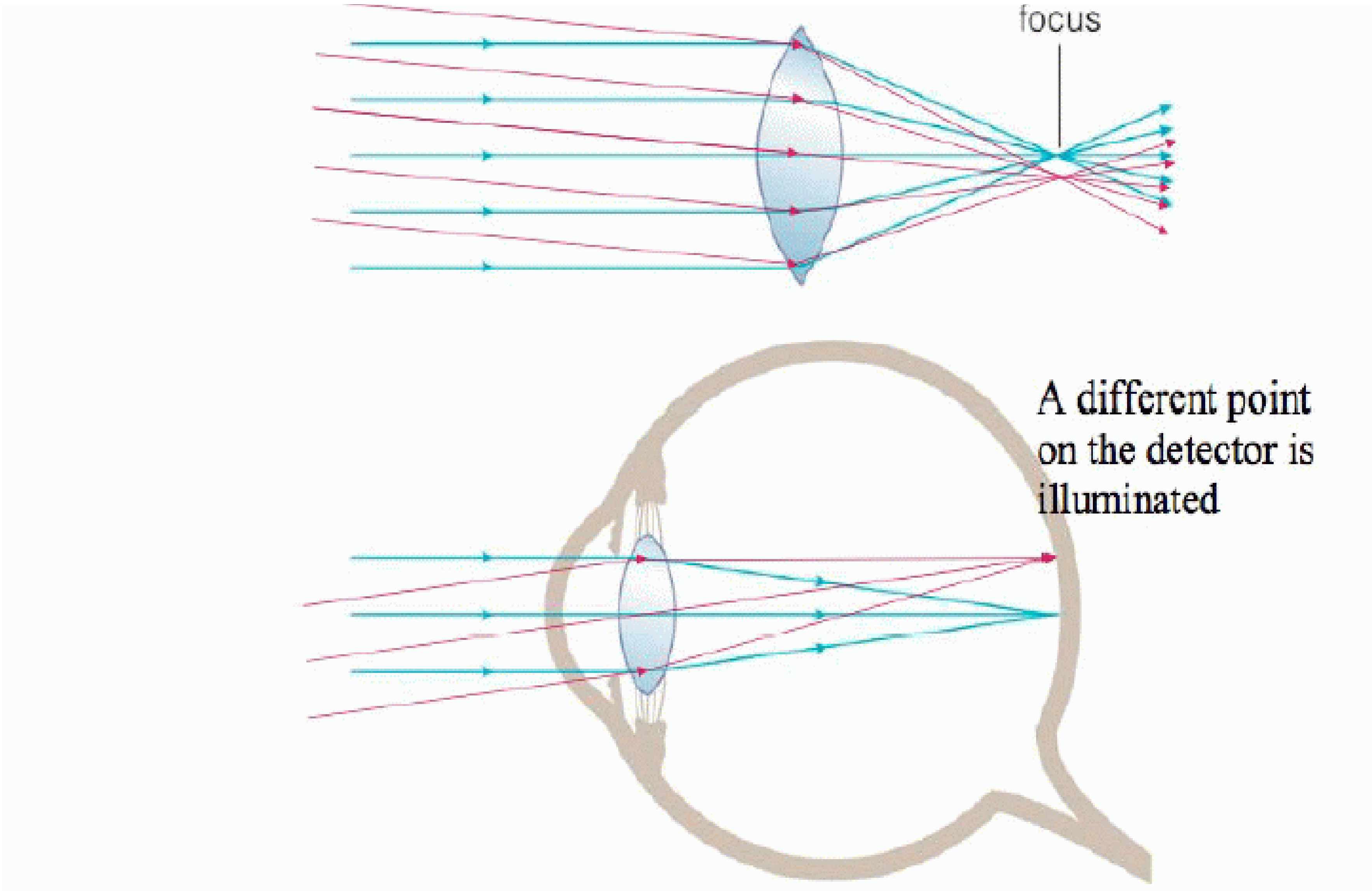
Lense:

parallel lights are bent by the lense to a single point

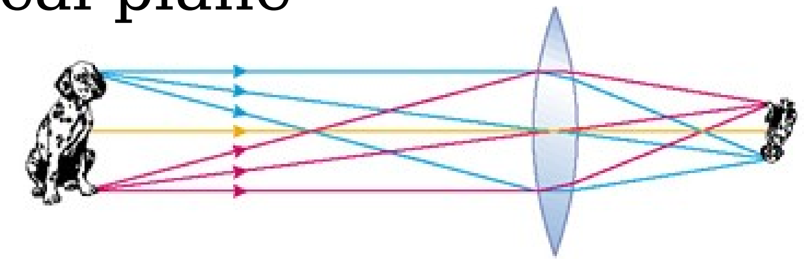


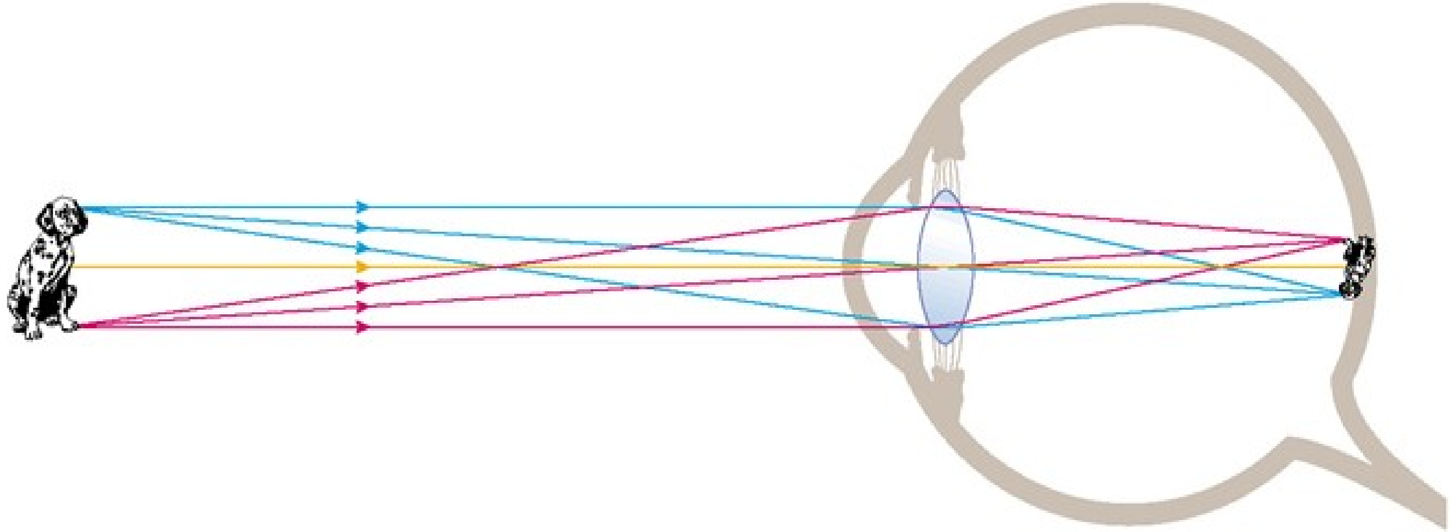
Lense:

lights from different directions are bent by the lense to different points

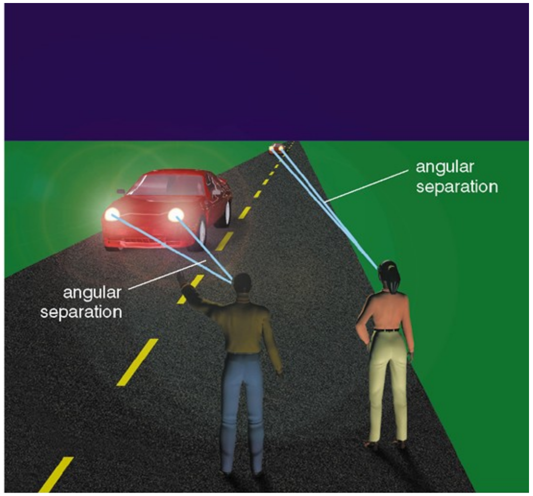


Lense:
an image forms at the focal plane





human eyes operate at optical wavelength,
pupil size ~ 0.6 cm
with an angular resolution of ~ 20 arcseconds



pre-telescope precision;
a lion @ 10km away ~ 100 arcseconds

A **telescope** is a light collecting and focusing device.

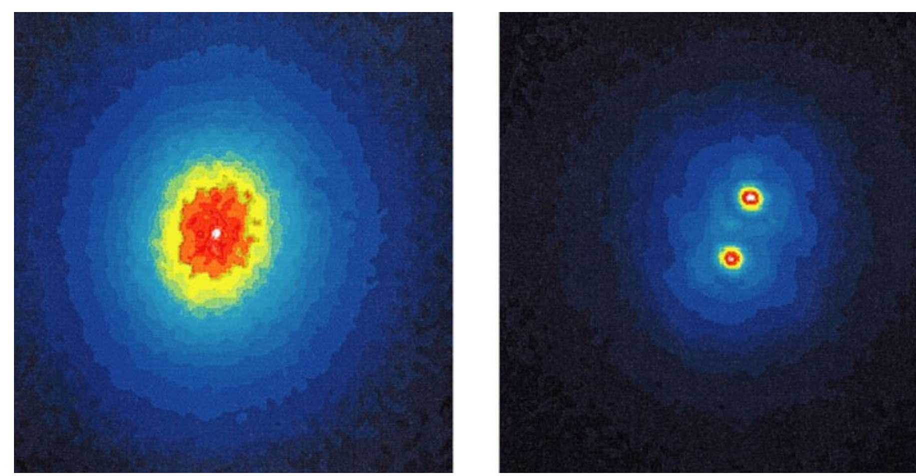
1) collecting power

number of photons collected goes as d^2

2) size determines angular resolution

larger size: better resolution

(diffraction rings: photons are waves)



Diffraction limit (best angular resolution) of various telescopes:

		d(cm)	~ l (cm)	1.22 l/d (")
Very Large Array	radio	3.6×10^6	20	1.3"
(SIRTF	infrared	85	5×10^{-3}	15"
Keck	optical	1000	5×10^{-5}	0.01"
(Hubble	optical	240		0.05")
(human eye	optical	0.6		20")
(55mm camera	optical	5.5		2.5" << 20")
Chandra	X-ray	10	1×10^{-7}	0.002"

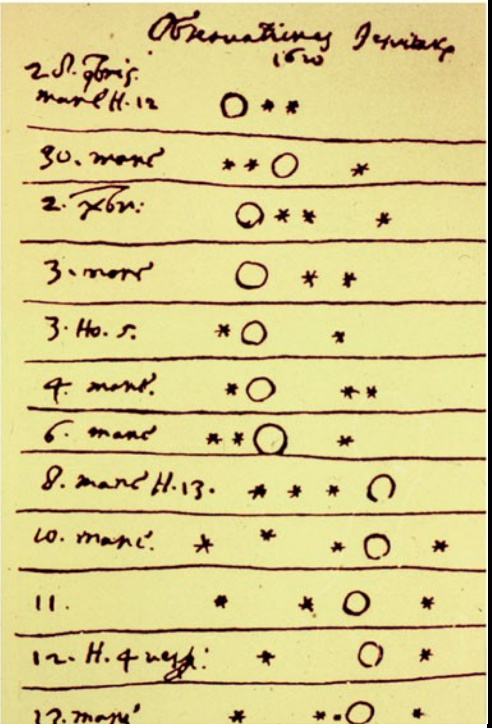
1 arcsecond = 1/60 arcminute = 1/3600 degree

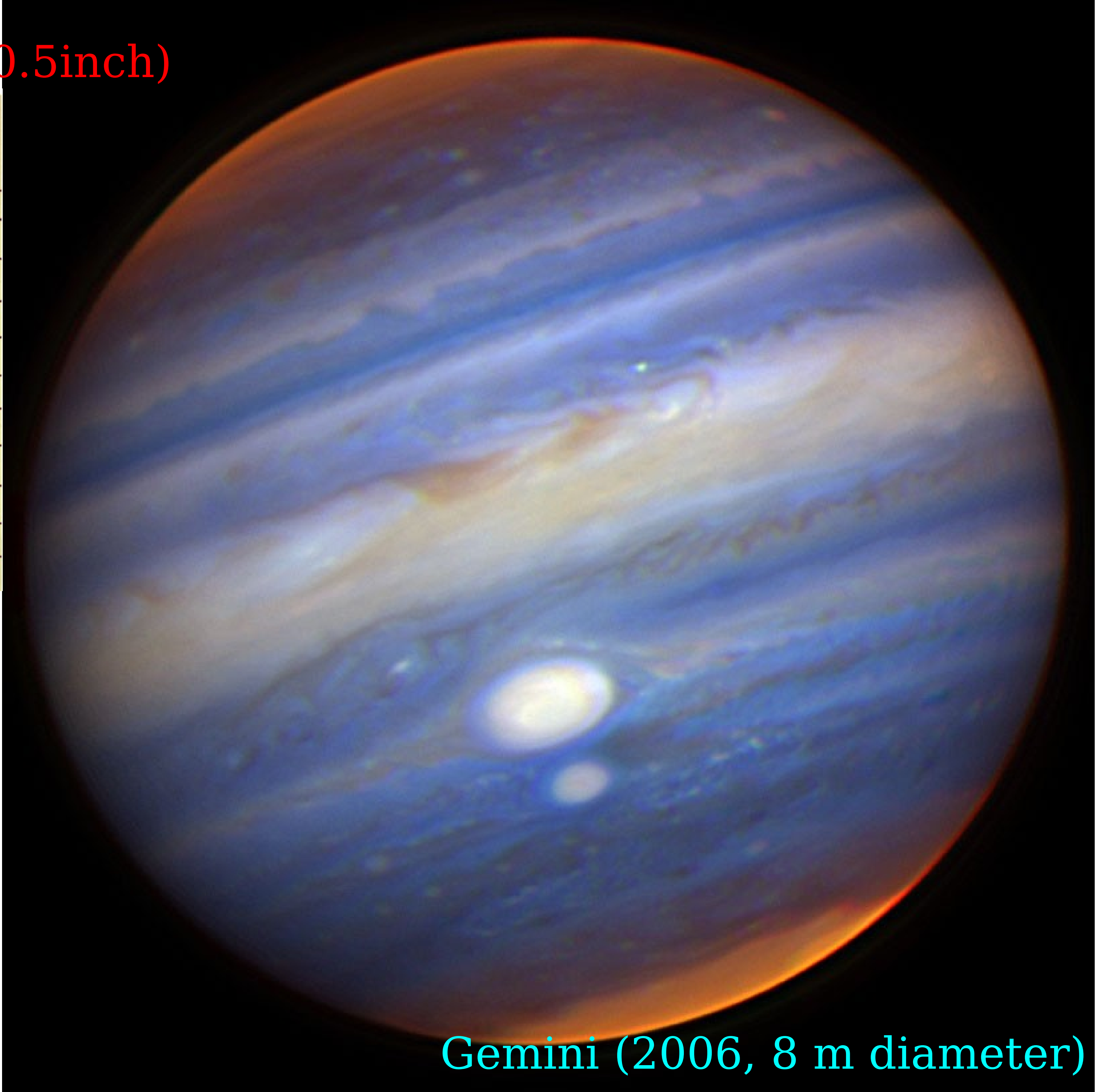
(1 deg = width of index finger if arm stretched out)

a lion @ 10km away: ~ 100" *(if pupil is 10 times smaller...)*
a movie screen @ the Moon: ~ 0.01"
a galaxy @ the end of the observable universe: ~ 0.5" *(but also very dim)*
size (event-horizon) of the Galactic centre black-hole: ~ 0.000002"

Gemini (North) telescope:
Mauna Kea, Hawaii
8 metre diameter

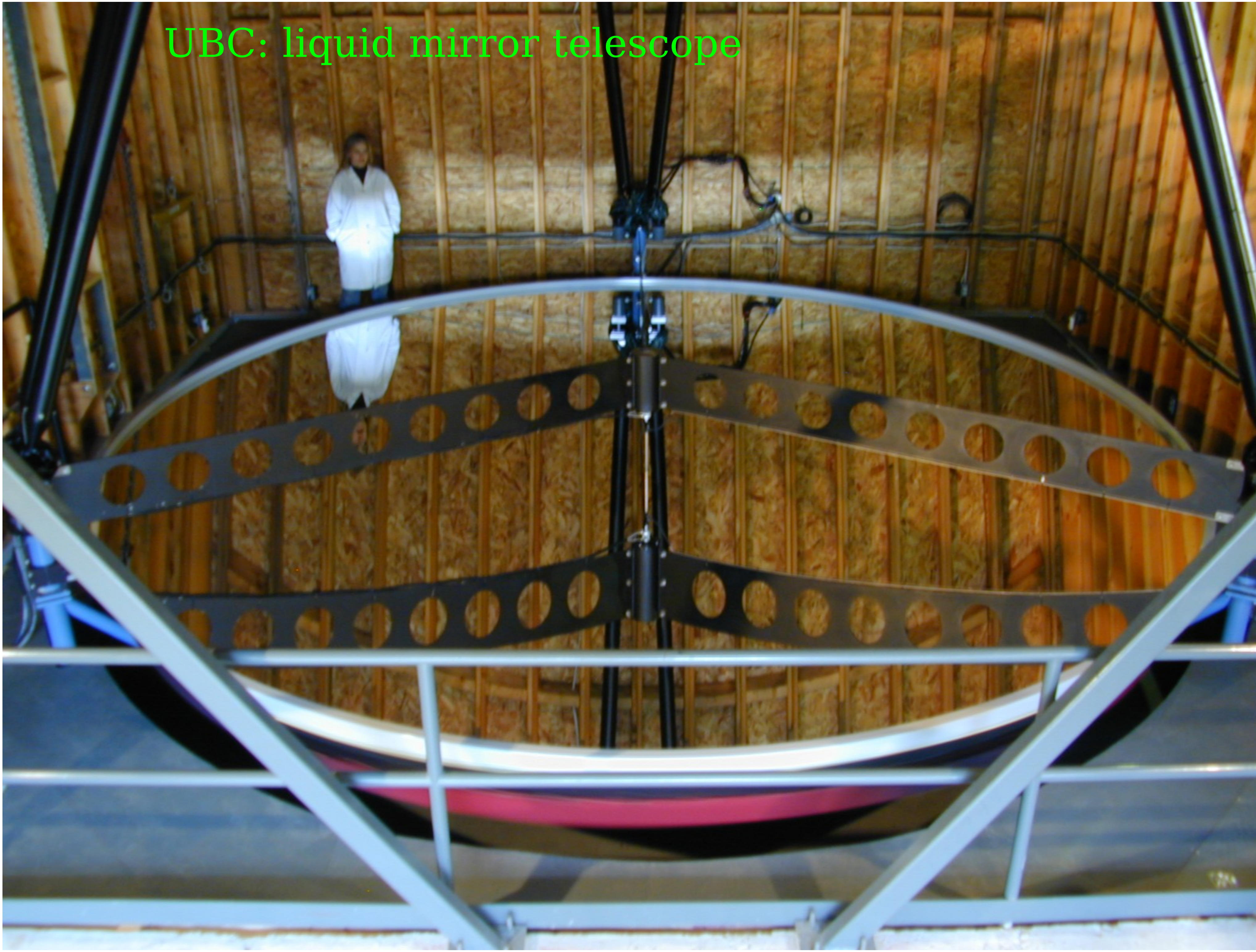
Galileo (1610, 0.5inch)





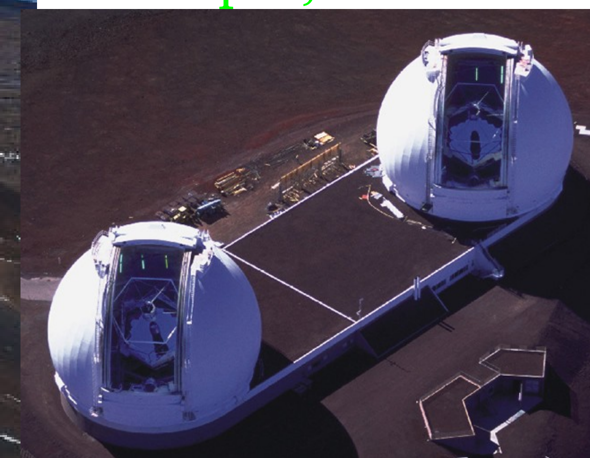
Gemini (2006, 8 m diameter)

UBC: liquid mirror telescope



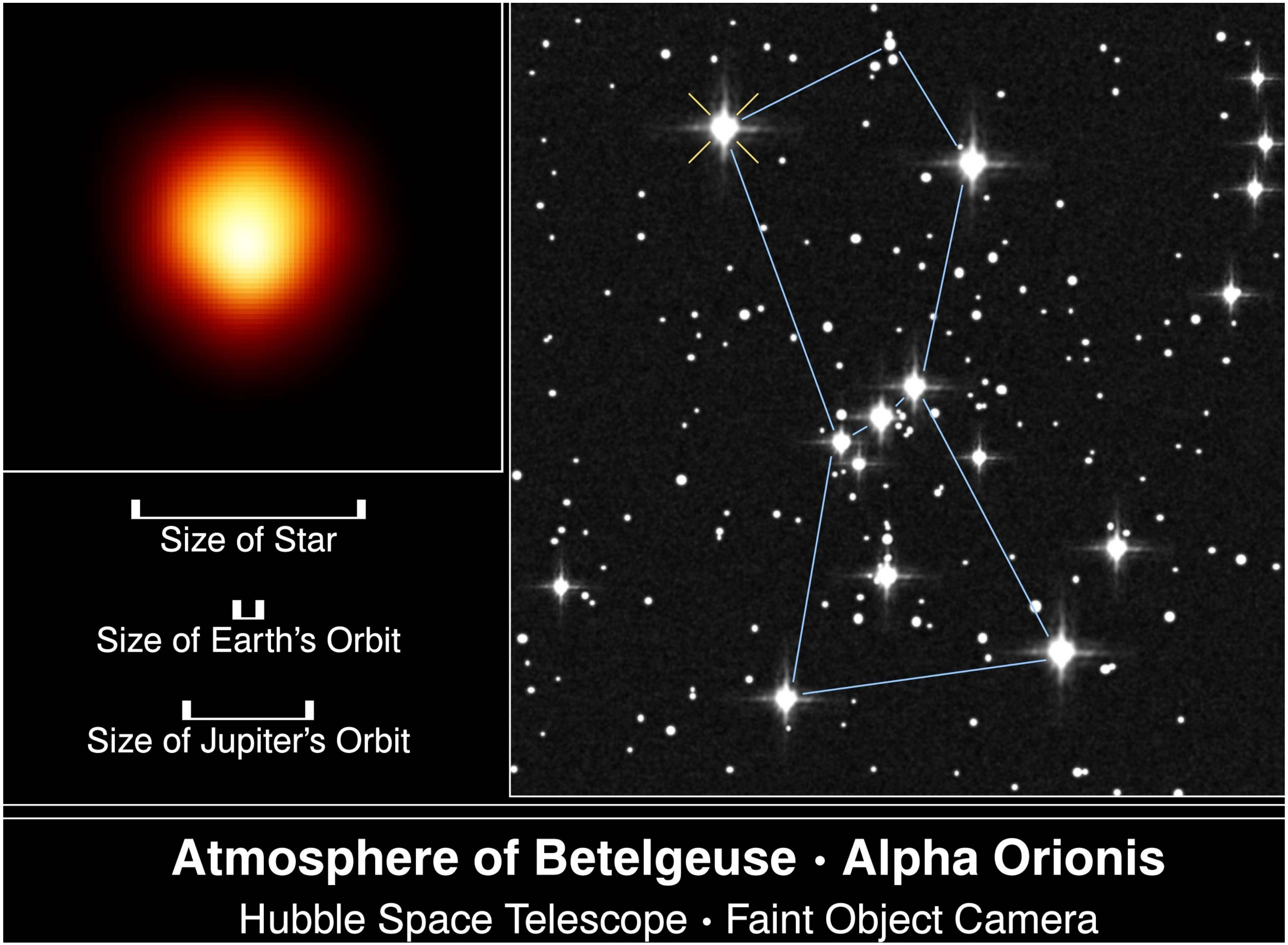
(optical & infrared)

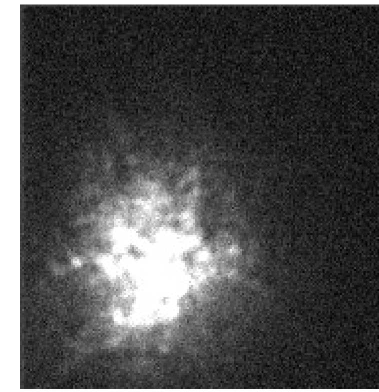
Keck (foundation) telescopes, 10meter



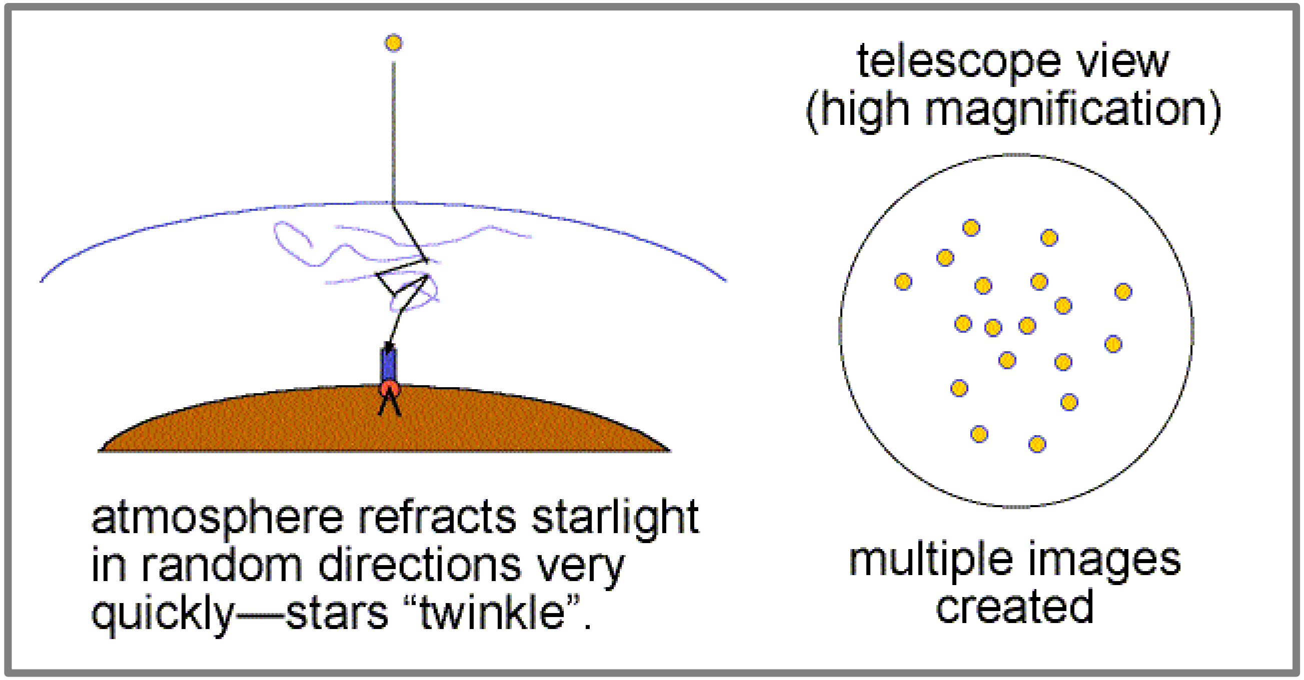
Las Campanas, Chile (Magellans, ~ 2500m)

Betelgeuse


Size of Star
Size of Earth's Orbit
Size of Jupiter's Orbit
Atmosphere of Betelgeuse • Alpha Orionis
Hubble Space Telescope • Faint Object Camera



Why do stars twinkle?



while planets don't....

--- why Gemini (8m) is not as good as Hubble (2.4m)

1) atmosphere is turbulent nearer the ground (∼ 10km thick)

the troposphere

2) lights from a star (point source) is scattered around to look like a fuzz ball

"seeing" ∼ radius of the fuzz

4) large telescopes are not built on beaches, but high atop mountains, or in high deserts, to minimize "seeing"

median seeing:

Richmond Hill, Toronto: 1.7"

Mauna Kea, Hawaii (4.2km): 0.65"

Paranal, Chile (2.4km): 0.64"

Dome C, Antarctica(4km) 0.2"

5) going to space removes all atmospheric seeing

Keck 10 meter telescope on Hawaii(4.2km): 0.65"

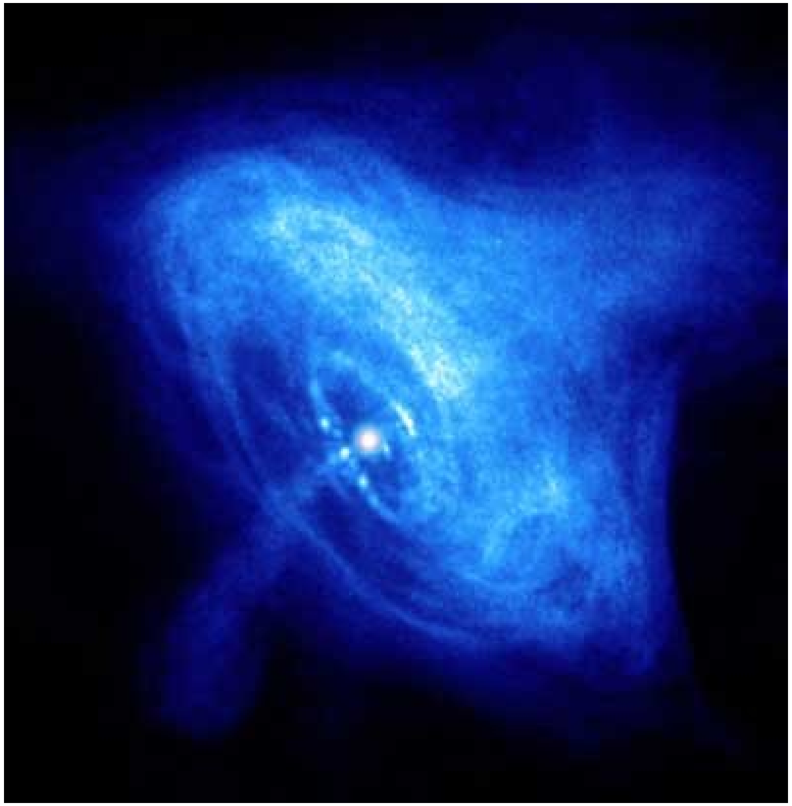
Hubble 2.4 meter telescope(600km): 0.05" (diffraction-limit)

can also be beaten by a new technique: adaptive optics

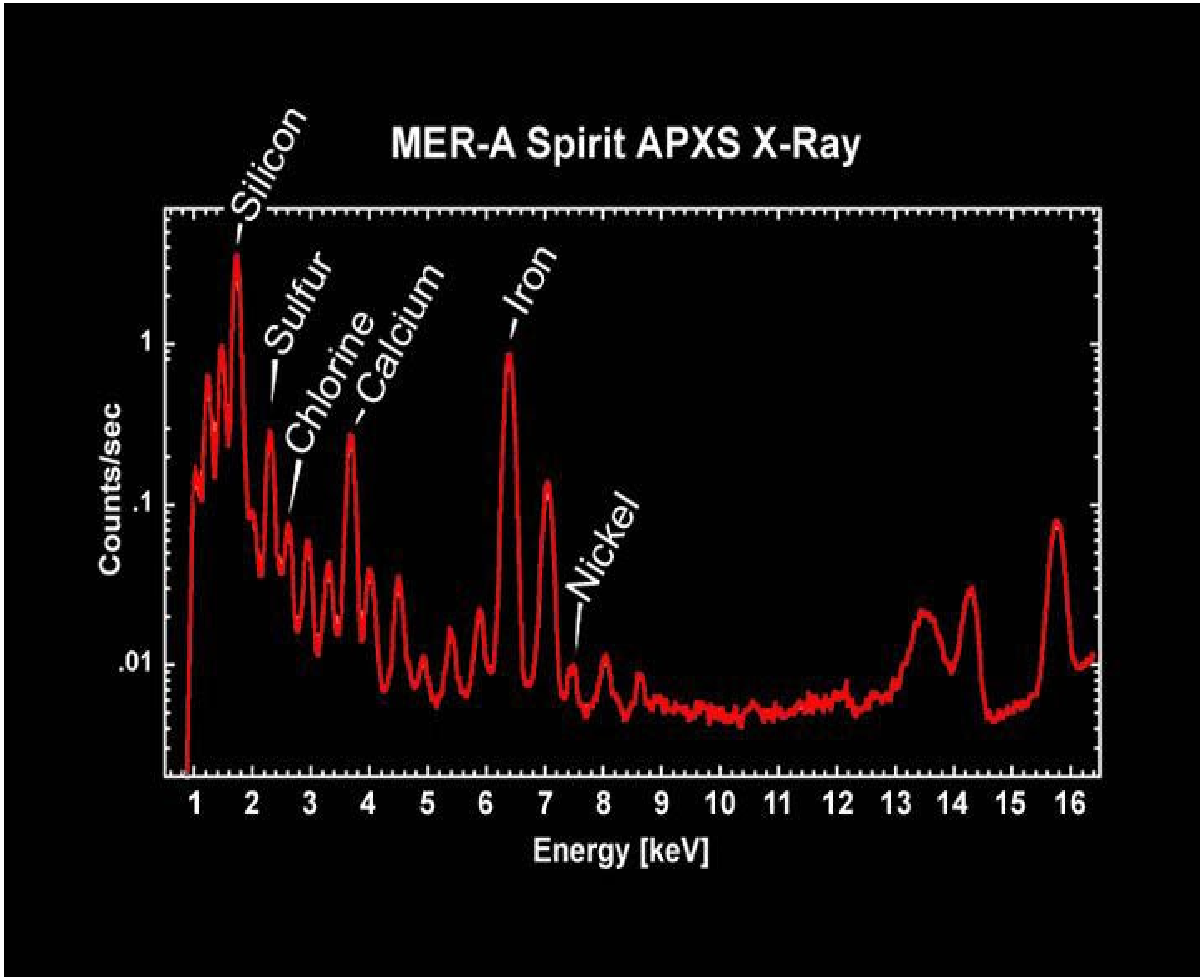
How do astronomers observe using a telescope?

Two basic modes of observations:

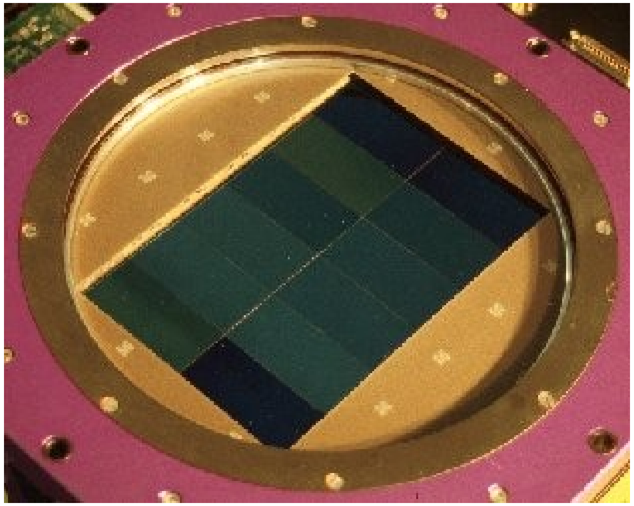
Spectroscopy: measure the spectrum of light from one direction, obtain chemical composition, temperature, velocity…. (like a prism)



Imaging: take pictures



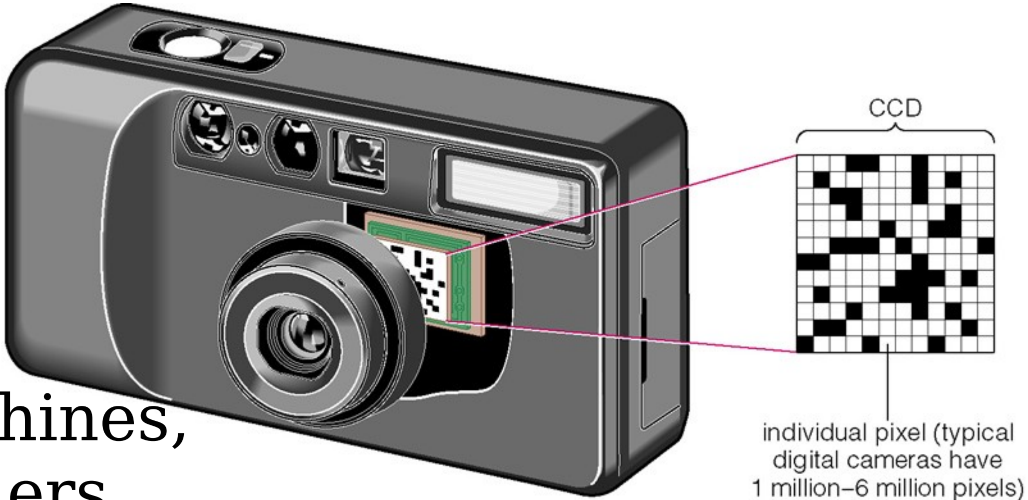
Light received (focused) by the telescope is recorded on a CCD (charge-coupled-device)



Canada-Hawaii-France Telescope
100 million pixel CCD

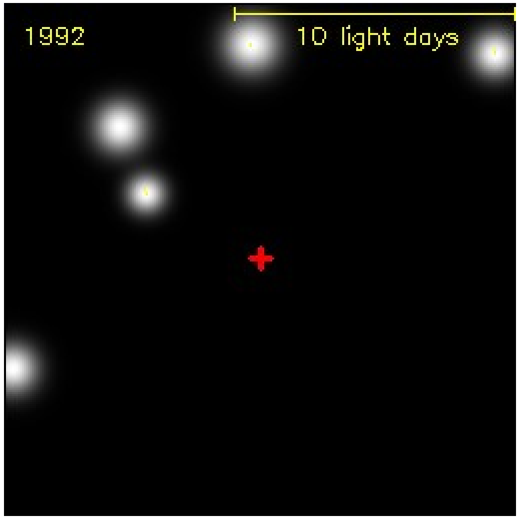
photon --> electrons --> charge level

CCD was first applied in astronomy to substitute photographic plates *(reusable, fast, accurate)*



Also in digital cameras,
fax machines, copy machines,
scanners, bar-code readers...

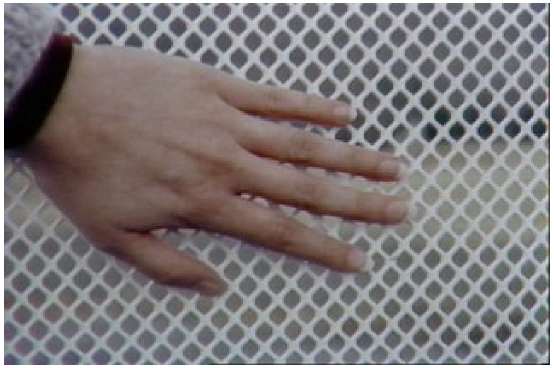
Motion of stars near the Galactic centre – there is a black-hole ~ 3 million solar masses



This is obtained using an infrared telescope, because visible (optical) light is thoroughly absorbed by the intervening dust

An infrared telescope need to be cooled down to a low temperature, otherwise it glows glaringly…

Radio Telescopes



1) radio can penetrate the atmosphere

2) your cell-phone is a 'radio telescope'

3) radio telescopes are much cheaper to build

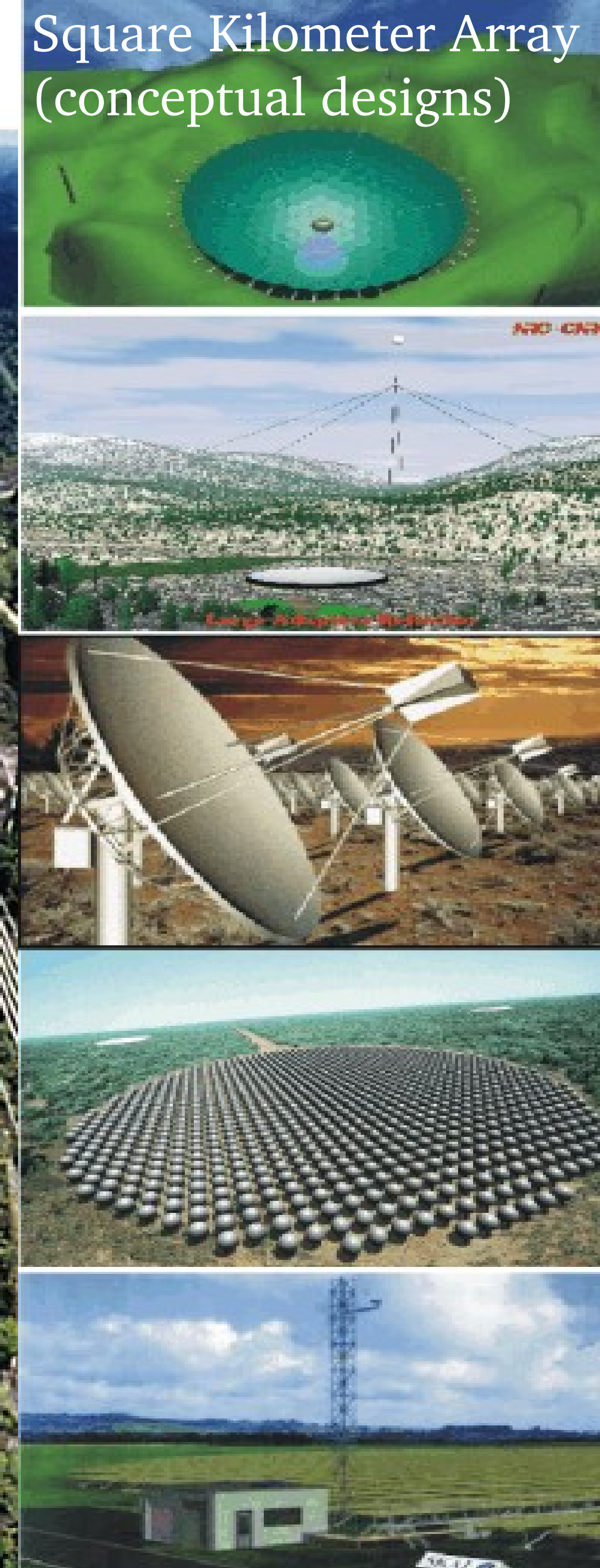
(radio photons have longer wavelengths)

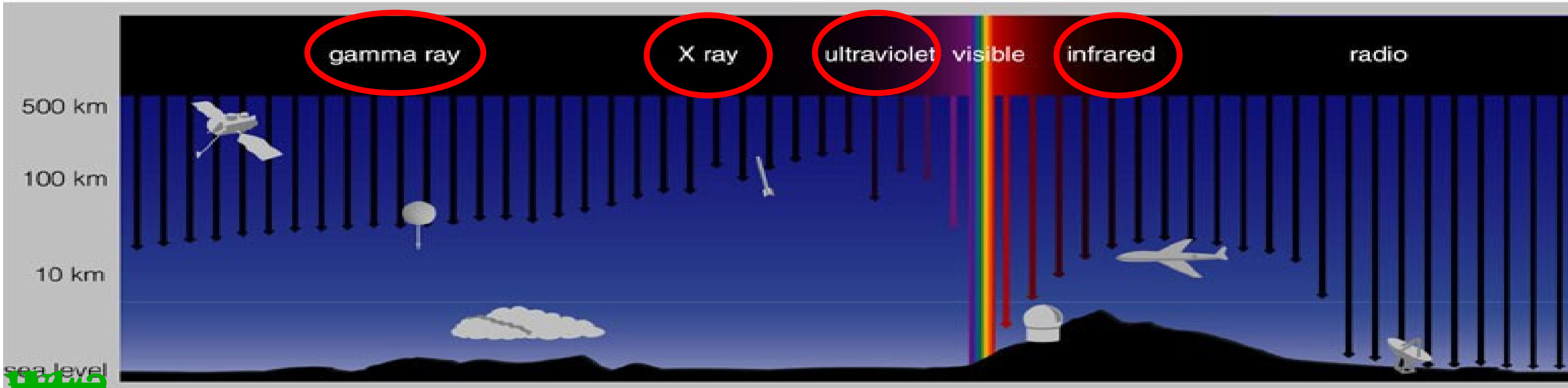
4) radio telescopes do not suffer from 'seeing',
but ones needs to collect a LOT of photons
(radio photons have lower energies, diffraction limit)
so they need to be much larger than optical ones

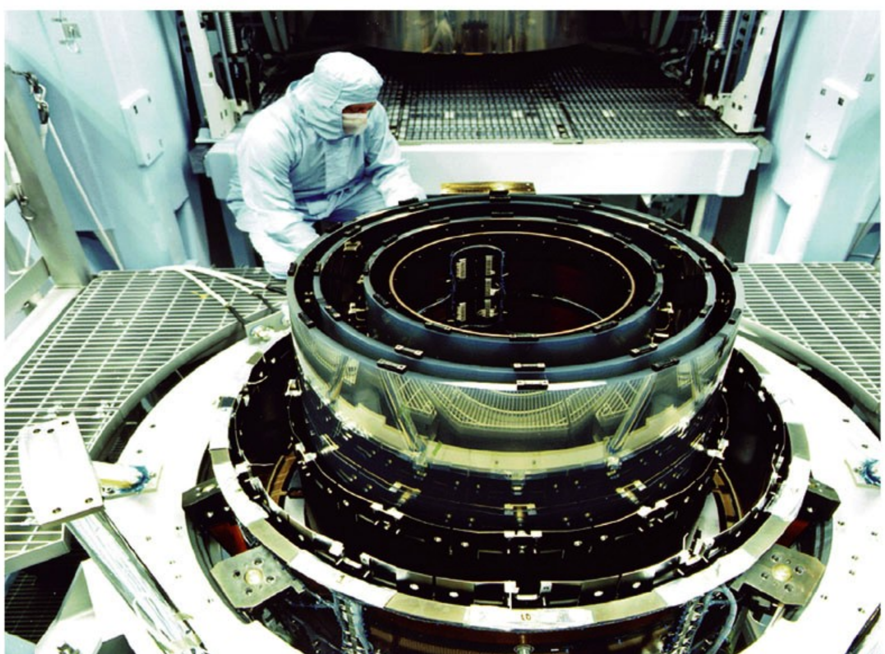
5) it's easier to build many small telescopes than a single large one, observe '*en masse*' (interferometry)

VLBA (very-large-baseline-array): use the ~ whole earth

Radio Telescopes: present & future

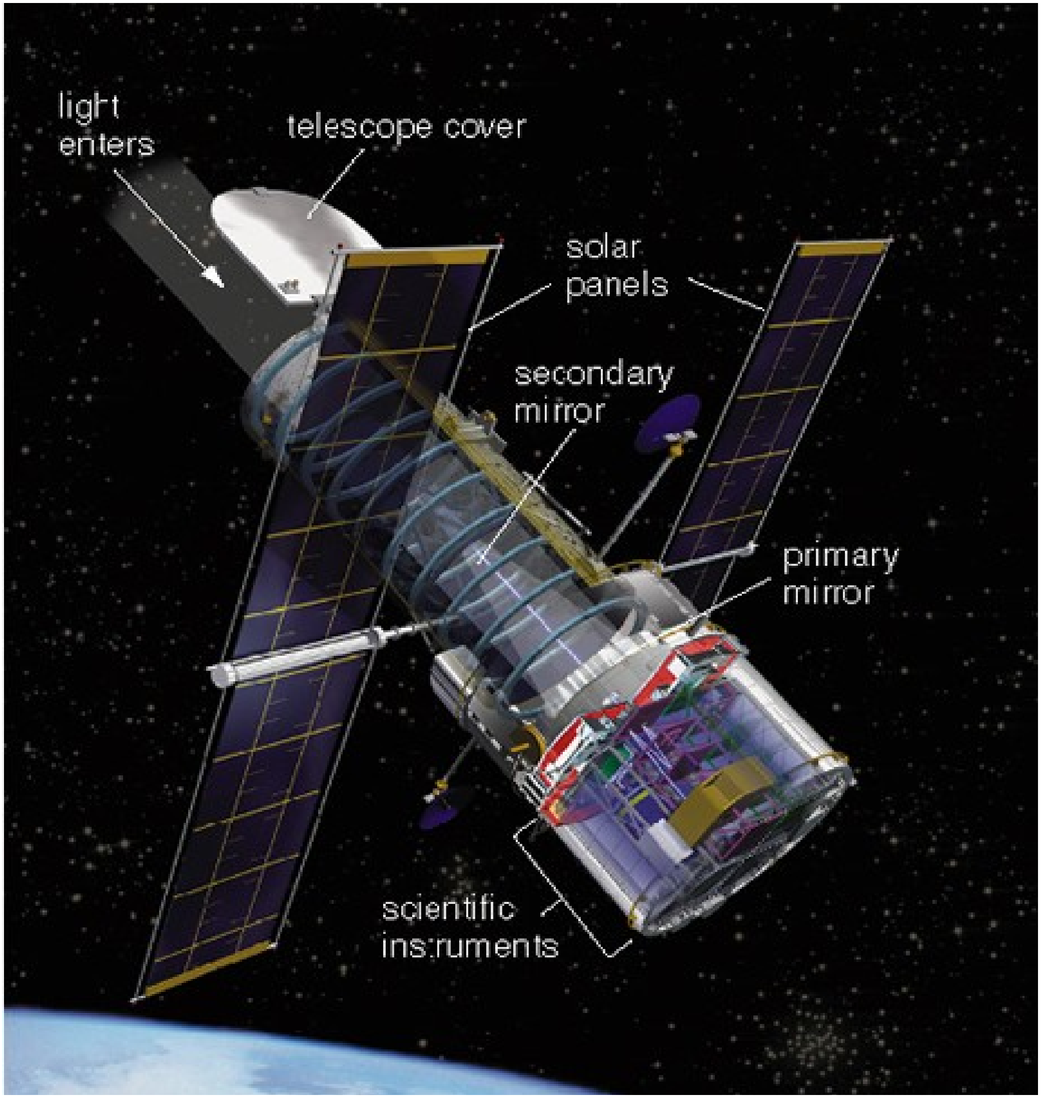






Chandra satellite (Gamma-ray)

SOFIA(Infrared)



The Hubble Space Telescope

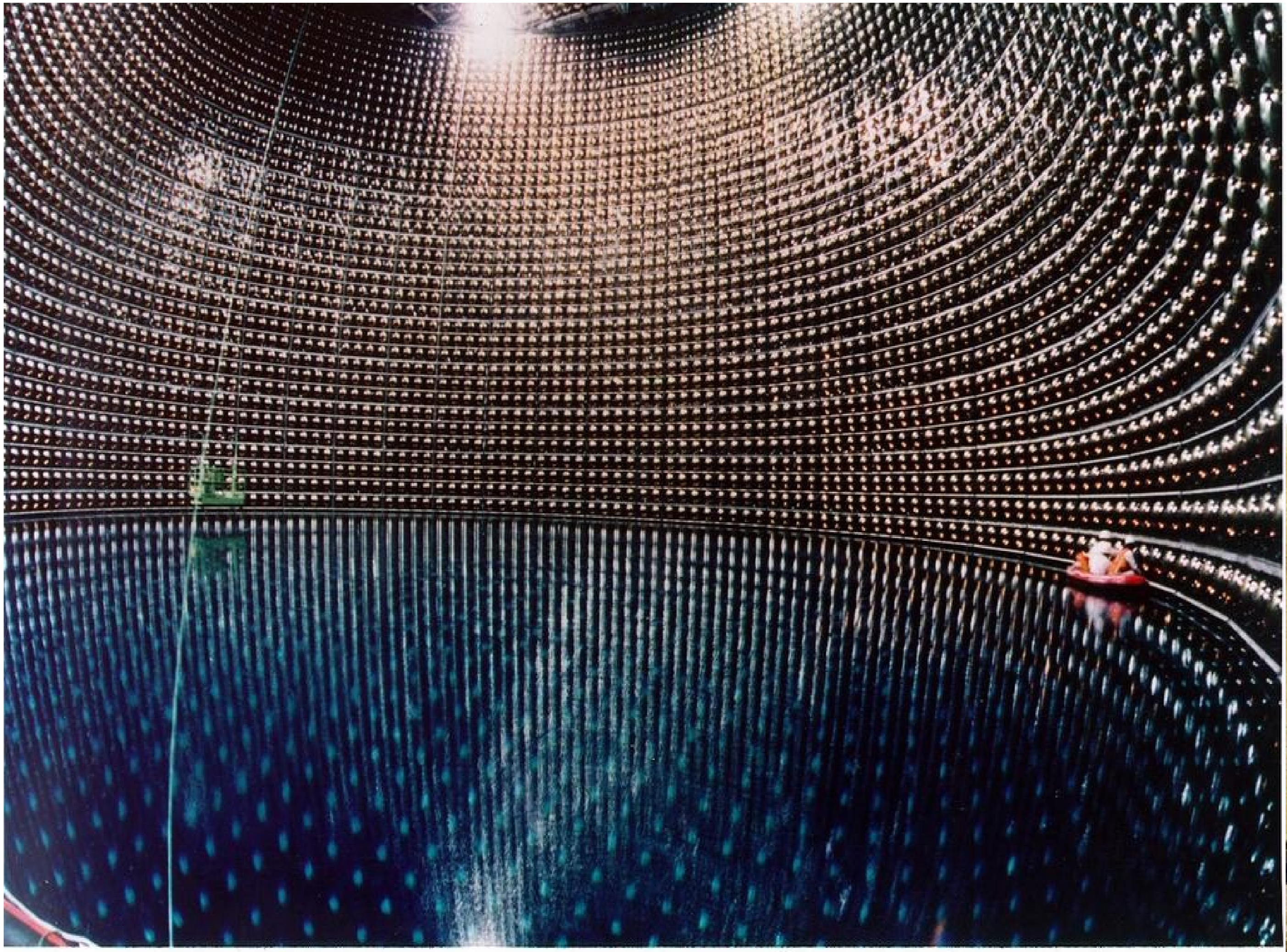
1) avoid atmospheric distortion

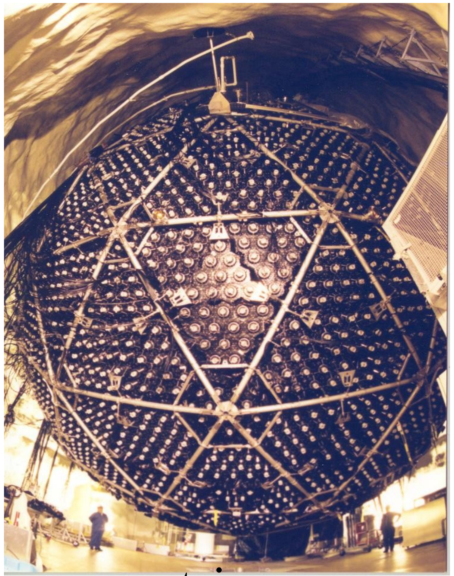
2) can observe in ultraviolet

3) expensive, difficult to service
each service mission
~ 1 Billion dollars

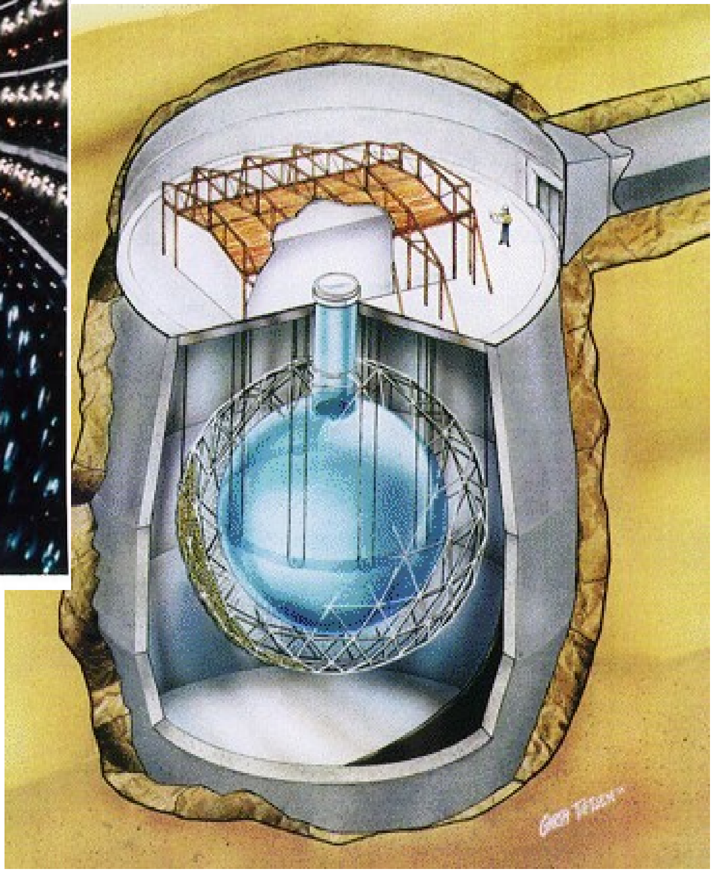
Dream Site

More exotic telescopes:
e.g. neutrino telescopes



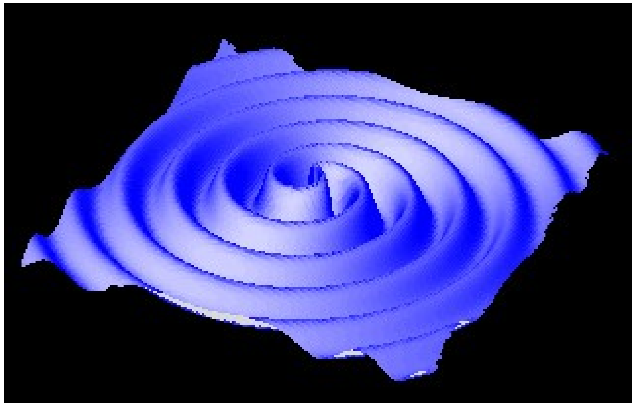


Sudbury neutrino observatory (Canada)



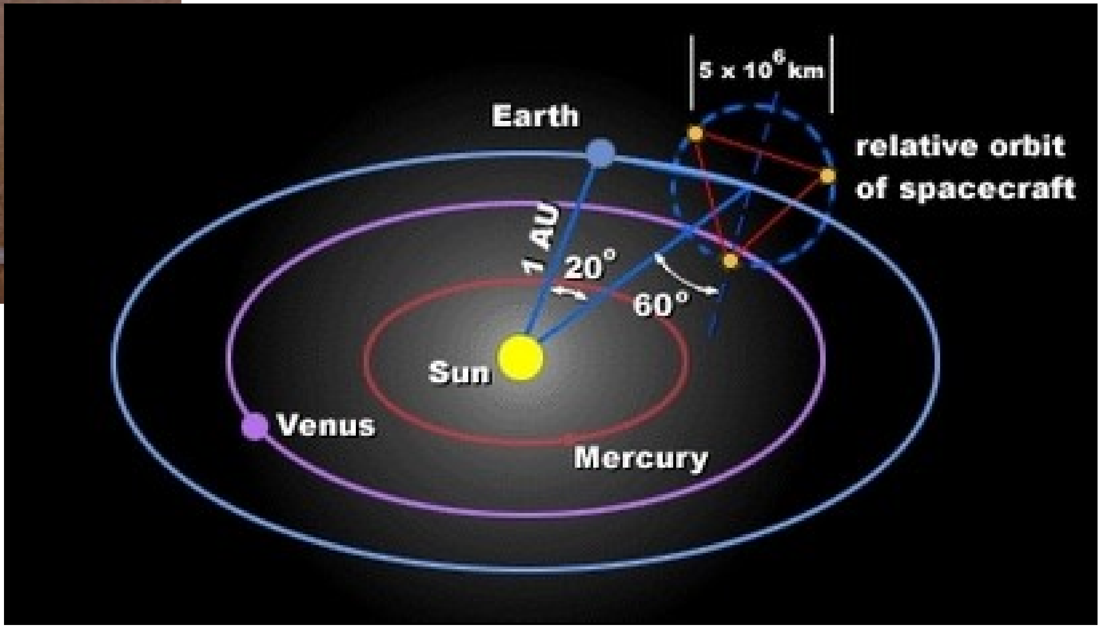
Super-Kamiokande (Japan)

Gravitational-Wave telescopes



--- mergers (NS-NS, NS-BH, WD-BH, BH-BH....)
--- gravitational waves from early universe

Laser Interferometer
Gravitational-wave observatory (LIGO)
40km arm length
Hanford, Washington State



Space version (LISA)

Even using stars as our telescopes....

MILLISECOND PULSAR TIMING ARRAY – 2001