THE UNIVERSE
YOURS TO DISCOVER

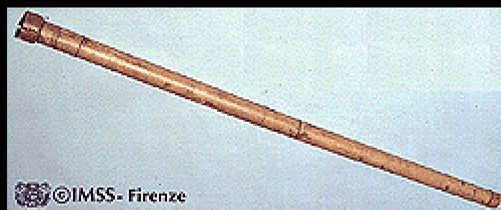
INTERNATIONAL YEAR OF
ASTRONOMY
2009

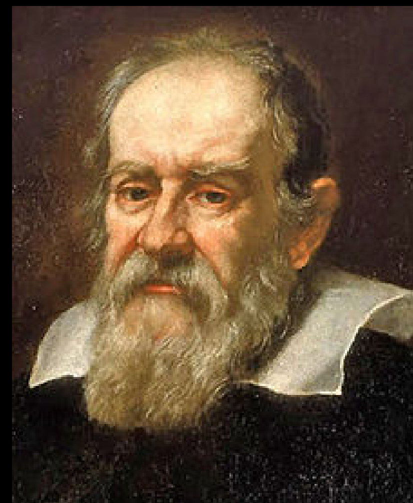
Telescopes Now

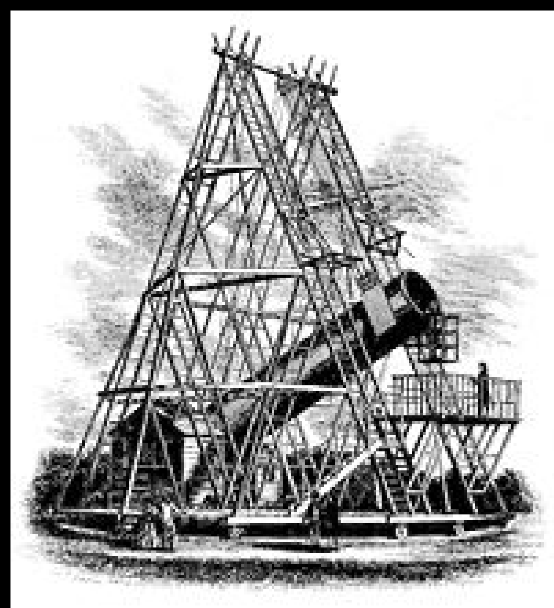
- When Galileo sought to introduce the telescope to the study of the heavens in 1609, he had to master the material and mechanical techniques needed for making and improving his instruments, to train himself as an effective observer, to argue for support from the Senate in Venice or the Medici Family in Florence, to get his results published, noticed and accepted, and to use them to advance his position and authority in a developing and contentious field.
- What practical, political, technical, financial and organisational challenges face telescope builders today?

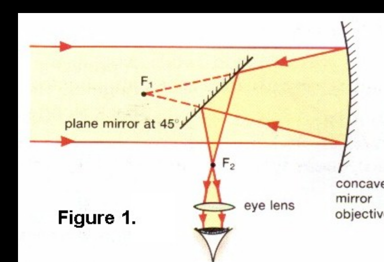
Scheme of Lecture

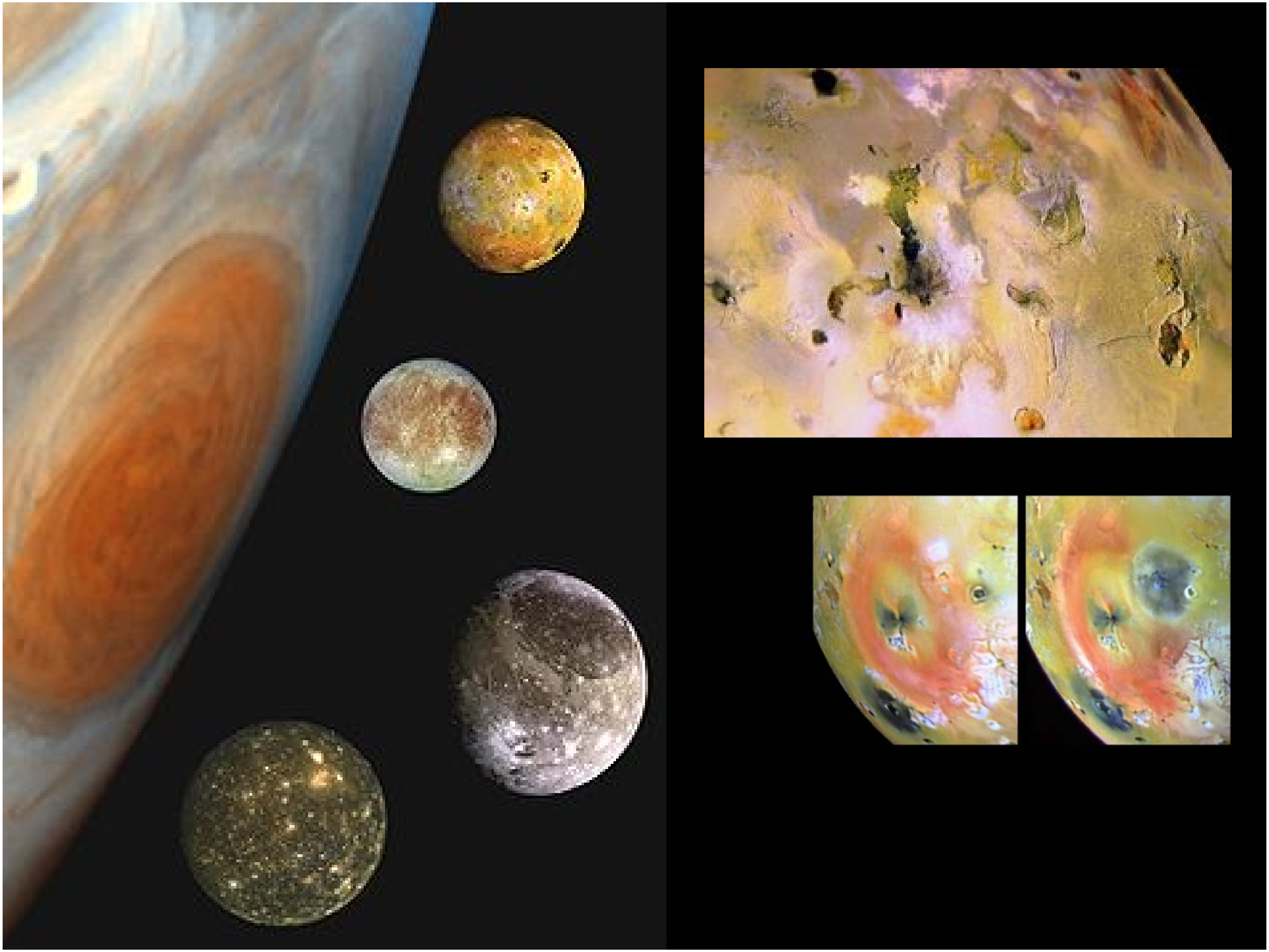
- UC London: my accidental move to astronomy
- Space telescopes and instrumentation
- Rocket-borne telescopes
- European TD-1A satellite
- Balloon-borne telescopes
- International Ultraviolet Explorer satellite
- Anglo-Australian Telescope instrumentation
- Image Photon Counting System
- Hubble Space Telescope and Image Photon Detector
- IPCS observing: “Flying Circus”
- Palomar
- Kitt Peak
- Anglo-Australian Observatory
- European Southern Observatory
- “Became” an astronomer at Palomar
- Generated new branch of observational cosmology
- La Palma Observatory: INT; JKT; CATC; William Herschel Telescope
- WHT outside budget and to be cancelled
- Saw how WHT could be built for half the price
- Proposed to SRC; led study; WHT approved
- Director Royal Greenwich Observatory
- Built UK Observatory; and built WHT to budget
- Director RGO and Royal Observatory Edinburgh
- On to Gemini Telescopes

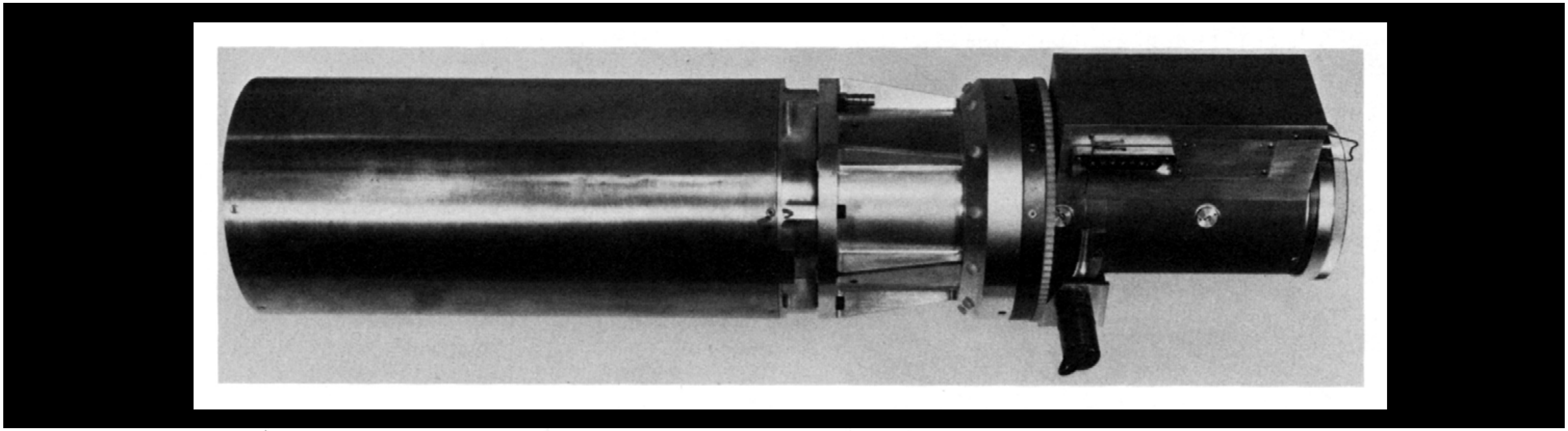

©IMSS- Firenze

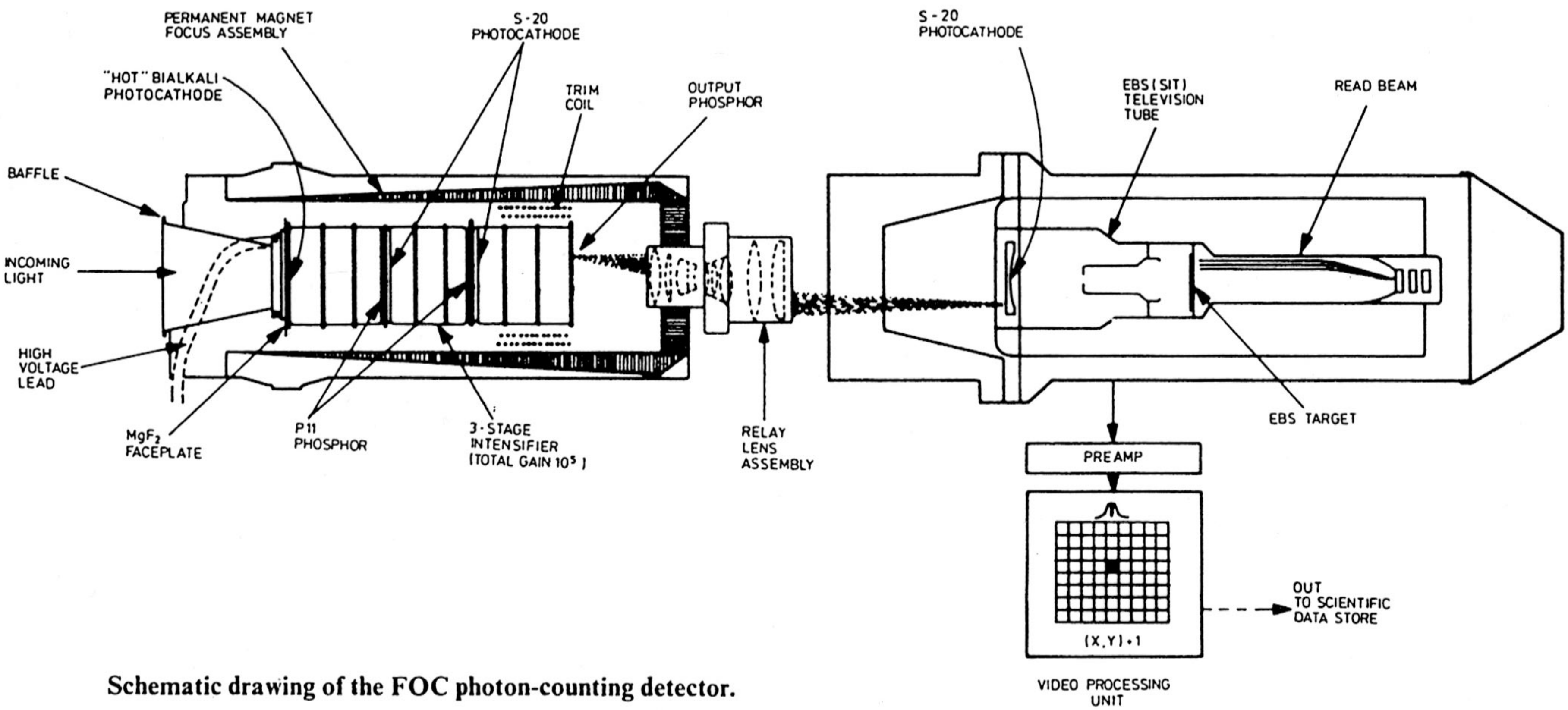




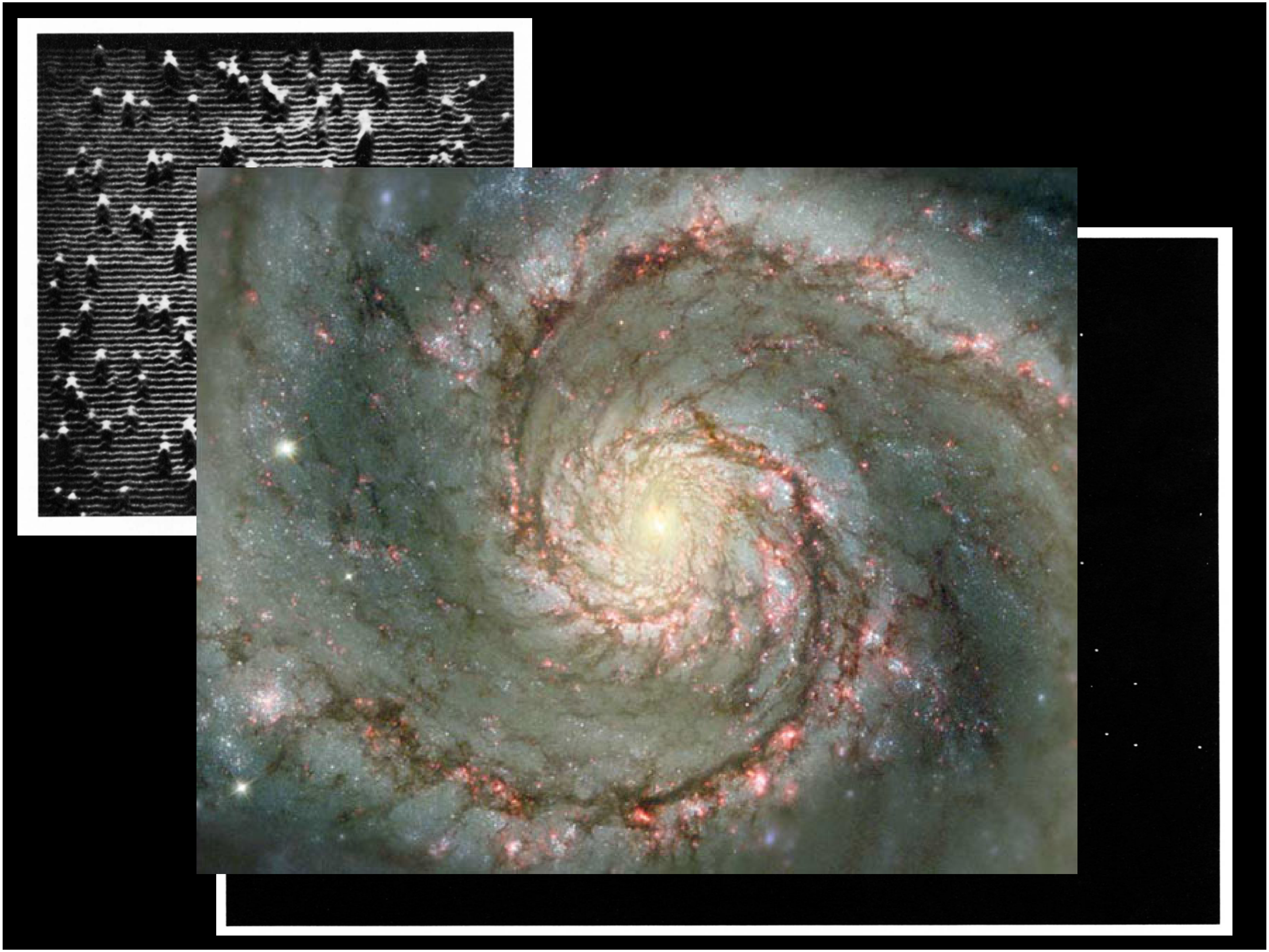

F1
plane mirror at 45°
F2
eye lens
concave
mirror
objective
Figure 1.

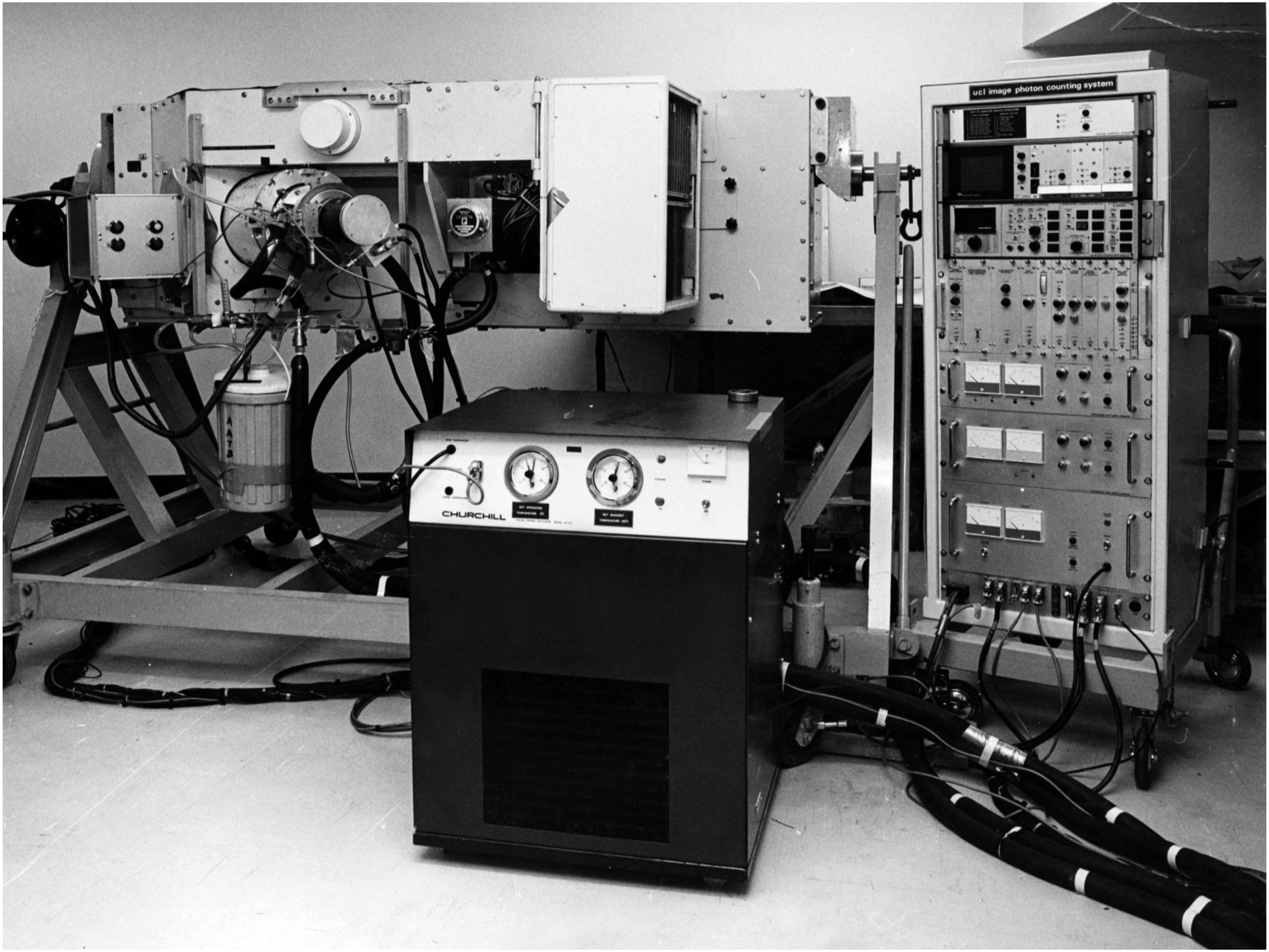






Schematic drawing of the FOC photon-counting detector.



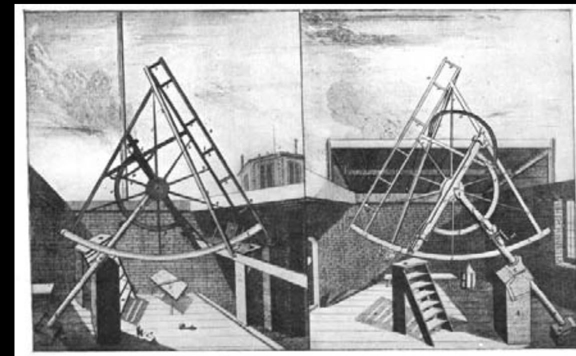

ucl image photon counting system
CHURCHILL


THE WILLIAM HERSCHEL TELESCOPE

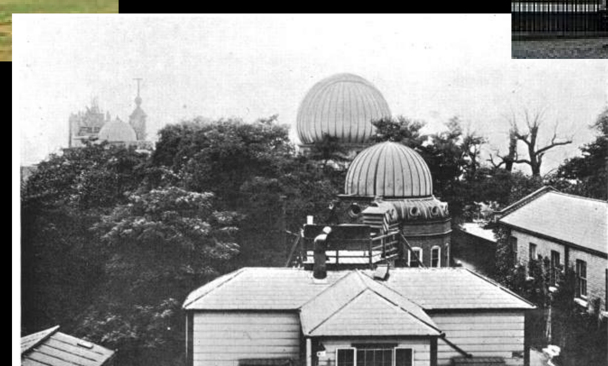


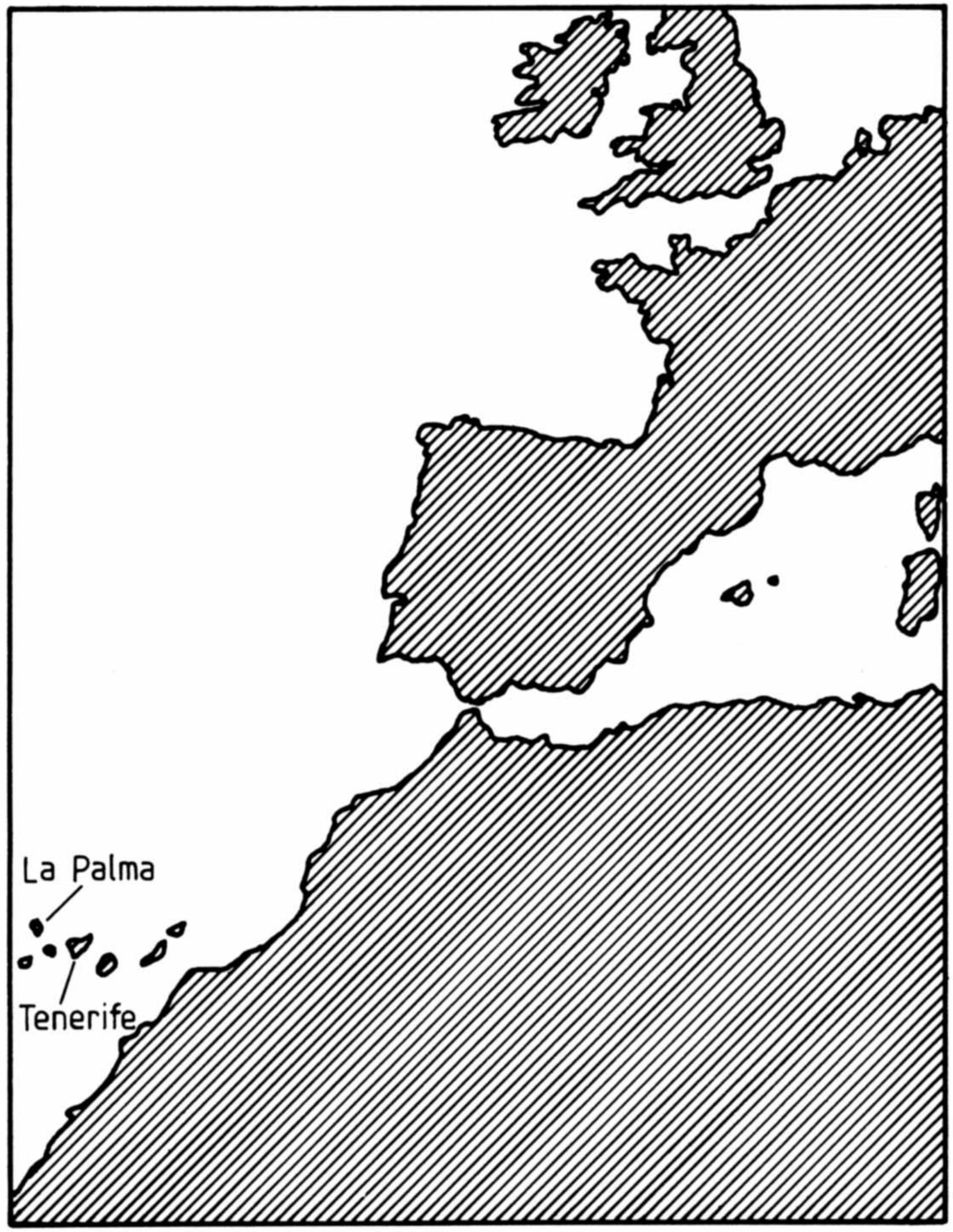
All ~~day~~ long, a tough gang of astrophysicists would monopolize the telescope and intimidate the other researchers.

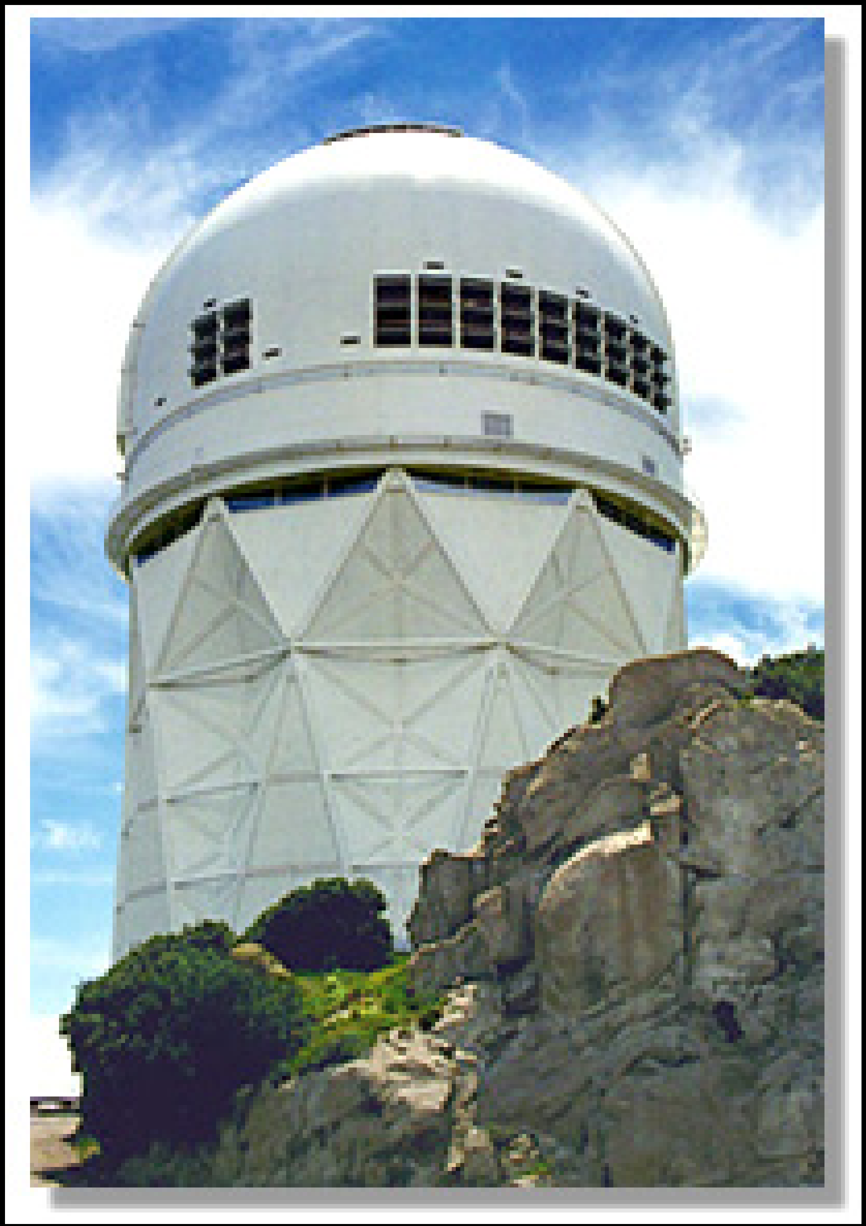
THE 'CAMERA STELLATA' IN FLAMSTEED'S TIME.
(*From an engraving in the 'Historia Cœlestis.'*)

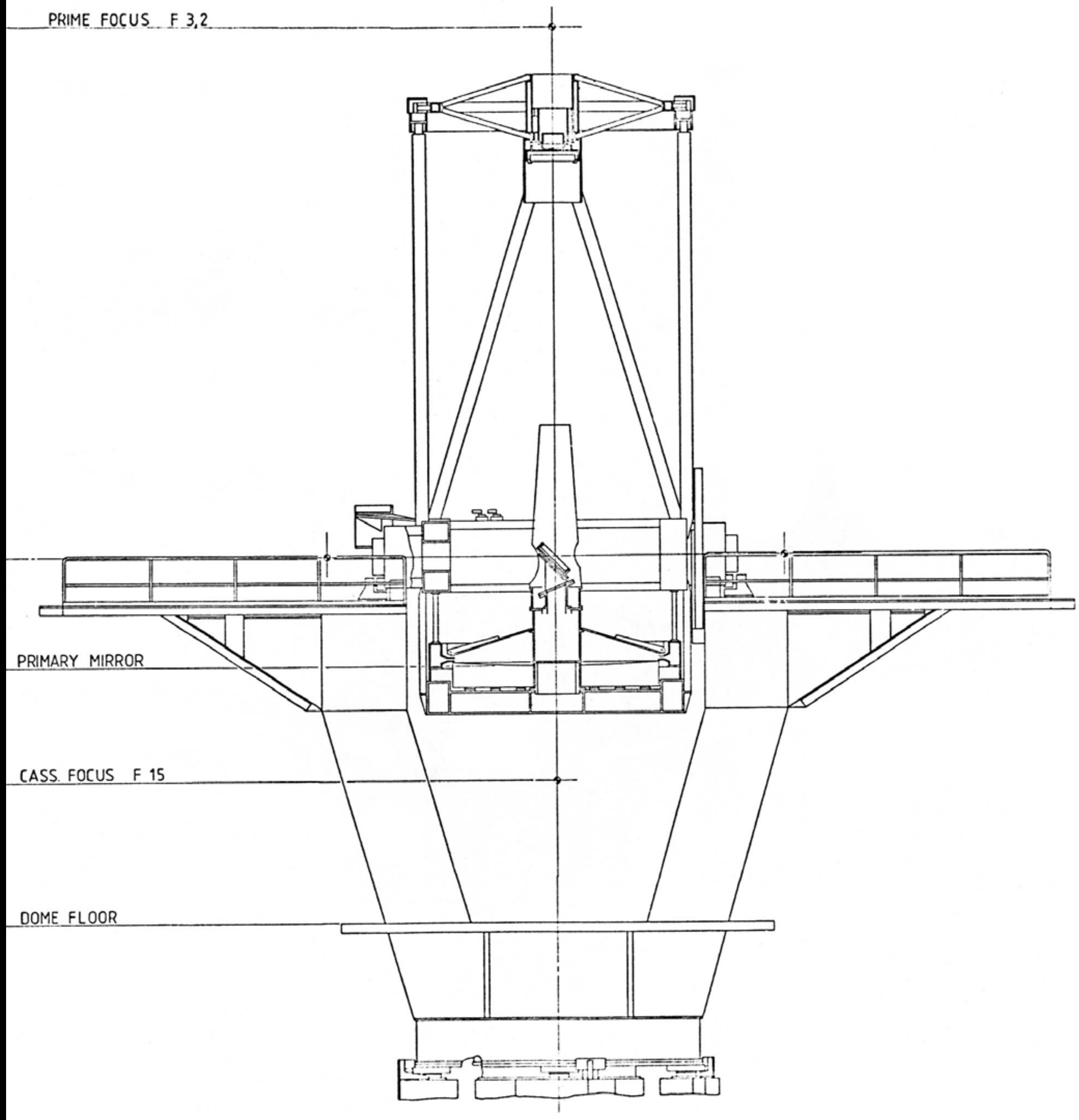


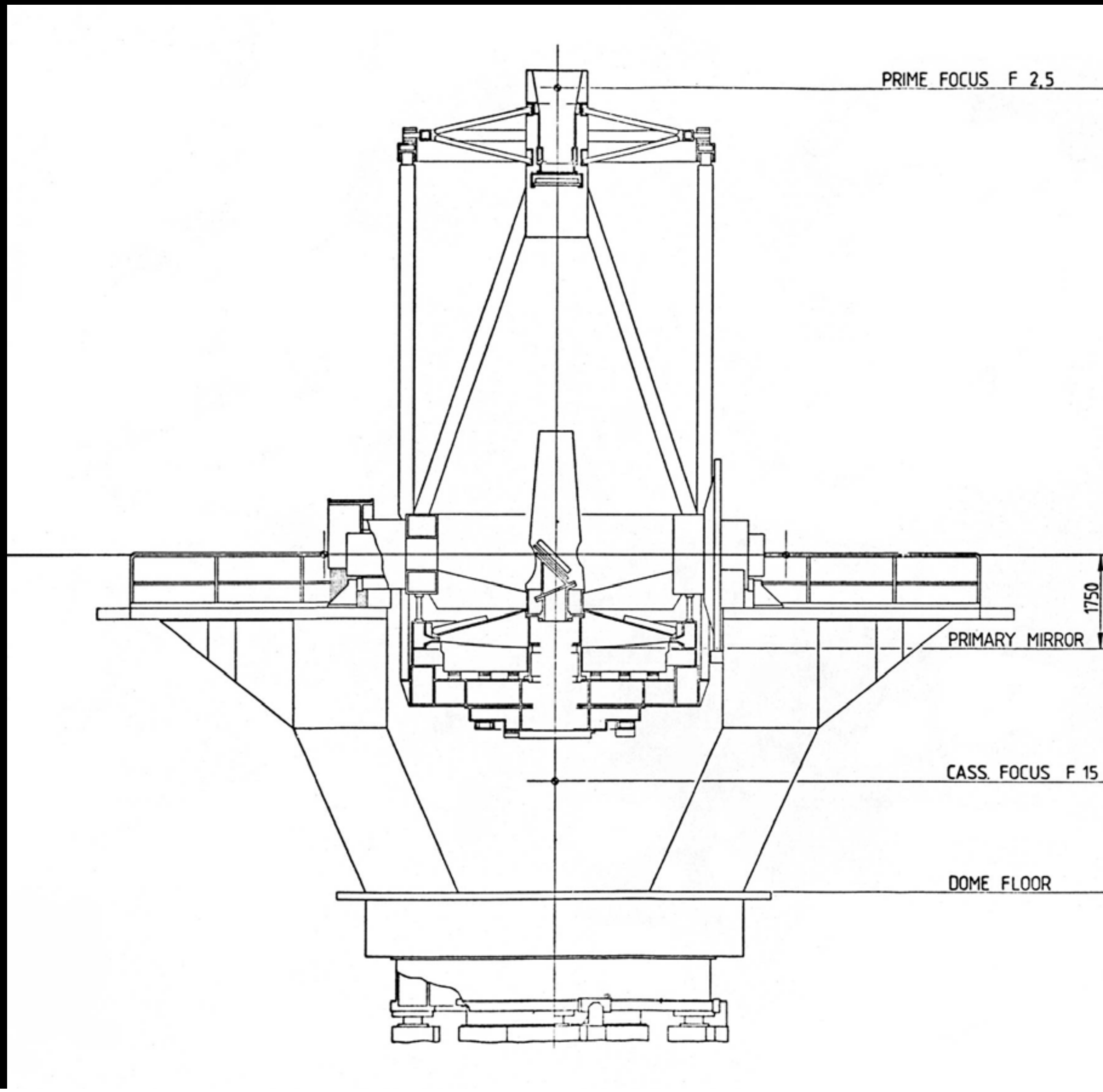
FLAMSTEED'S SEXTANT.
(*From an engraving in the 'Historia Cœlestis.'*)



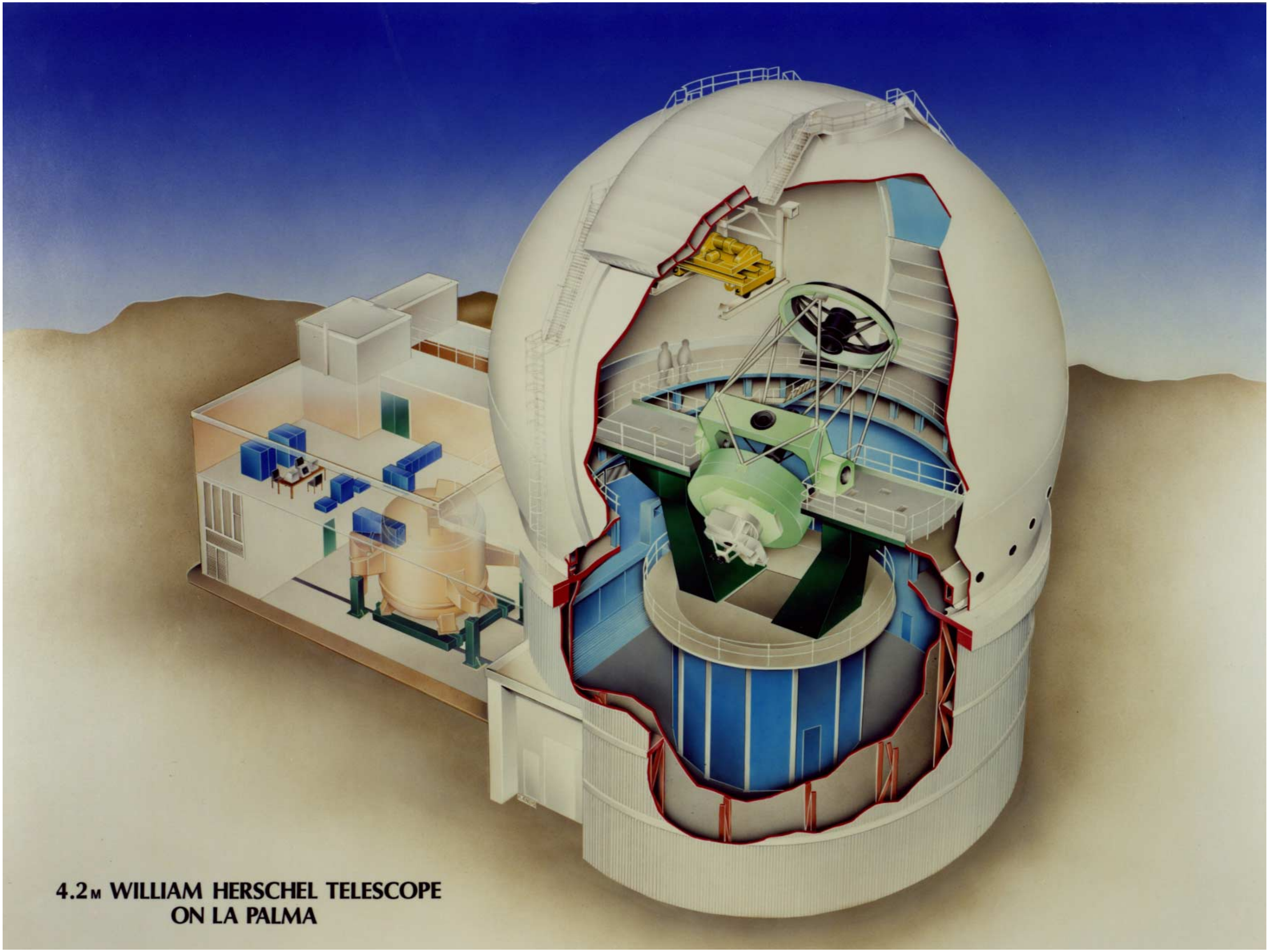


La Palma
Tenerife

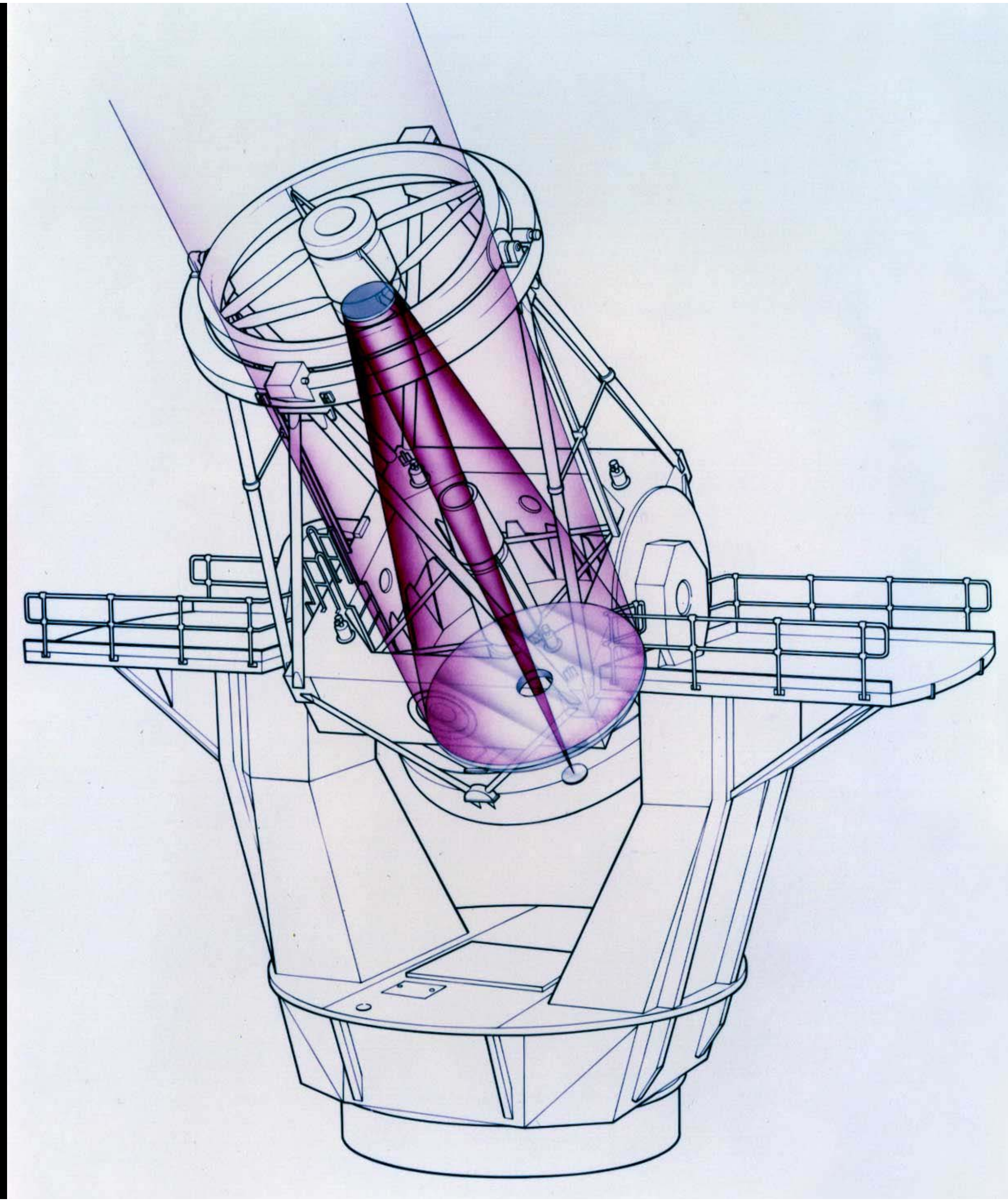


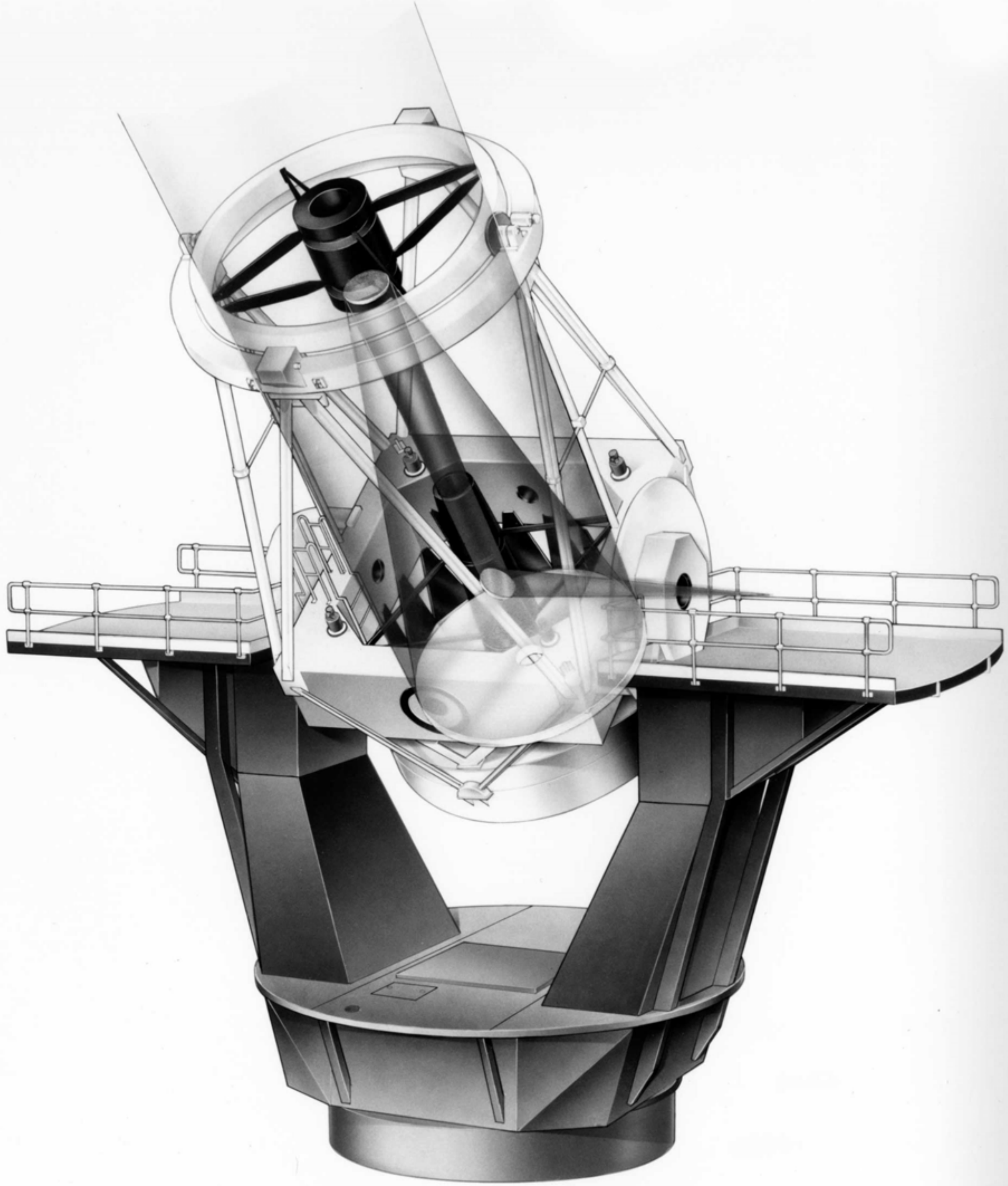

PRIME FOCUS F 3,2
PRIMARY MIRROR
CASS. FOCUS F 15
DOME FLOOR



PRIME FOCUS F 2,5
1750
PRIMARY MIRROR
CASS. FOCUS F 15
DOME FLOOR


4.2M WILLIAM HERSCHEL TELESCOPE
ON LA PALMA





Autofib-2: Robotic fibre-positioner to place up to 150 fibres at positions in the prime-focus field accurate to $\pm 10\mu m$.

Prime-focus assembly: includes a field corrector over 40 arcmin, atmospheric-dispersion corrector, filter wheel, and CCD acquisition and guide unit. For *prime-focus deep imaging camera or Autofib-2.*

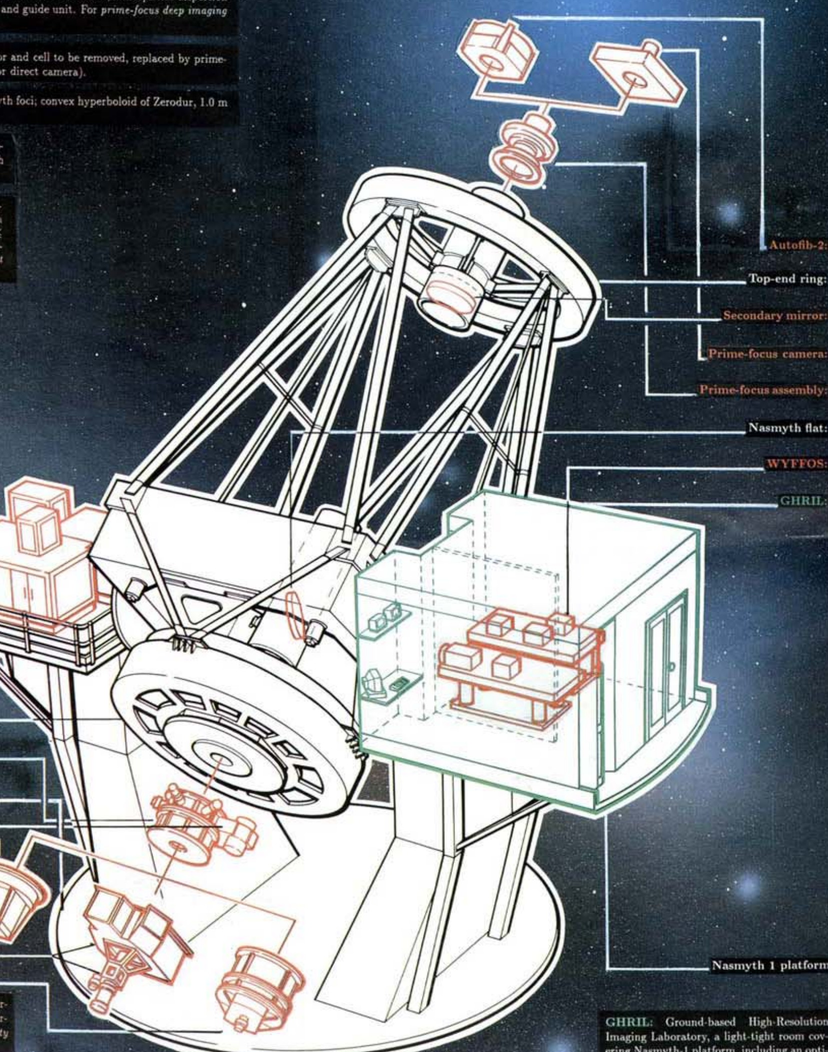
Top-end ring: rotates for secondary mirror and cell to be removed, replaced by prime-focus corrector and instrument (Autofib-2 or direct camera).

Secondary mirror: for Cassegrain/Nasmyth foci; convex hyperboloid of Zerodur, 1.0 m diameter.

Nasmyth flat: Cervit, 0.6×0.4 m, introduced into beam at 45° to select Nasmyth focus 1 or 2.

UES: Utrecht Echelle Spectrograph for high-resolution spectroscopy over the wavelength range 3000 – 11,000 Å, with $40,000 \leq R \leq 105,000$. For *stellar physics, planetary nebulae, quasar absorption lines, primordial element abundance measurements.*

Prime-focus camera: CCD camera which (with CCD mosaic) can image over the 40-min diameter field. For *deepest direct imaging, faint galaxies and clusters.*



TAURUS-2: Wide-field Fabry-Perot interferometer obtaining spectra over field of 9 arcmin with $2000 \leq R \leq 100,000$ for *velocity fields of extended objects.*

ISIS: Intermediate-dispersion double spectrograph, field-of-view 4×0.9 arcmin, the two arms optimized for red and blue, $2000 \leq R \leq 10,000$, wavelength range 3000 – 11,000 Å, for *general-purpose polarimetry and spectrophotometry, extended and stellar objects.*

LDSS-2: Low-Dispersion Survey Spectrograph, field-of-view 11.5 arcmin in diameter, wavelength range 3700 – 7500 Å, uses multi-aperture plates produced for each sky field required together with grism dispersing elements giving $R \sim 1000$ to produce simultaneous spectra of up to 200 objects. For *star-cluster systems, faint galaxy clusters.*

Primary mirror and mirror cell: Cervit, 4.2-m diameter f/2.5 concave paraboloid mirror, mounted on an axial flotation system of 64 roll-diaphragm seals with independently-controlled gas pressure, together with axial radial-support system plus defining links.

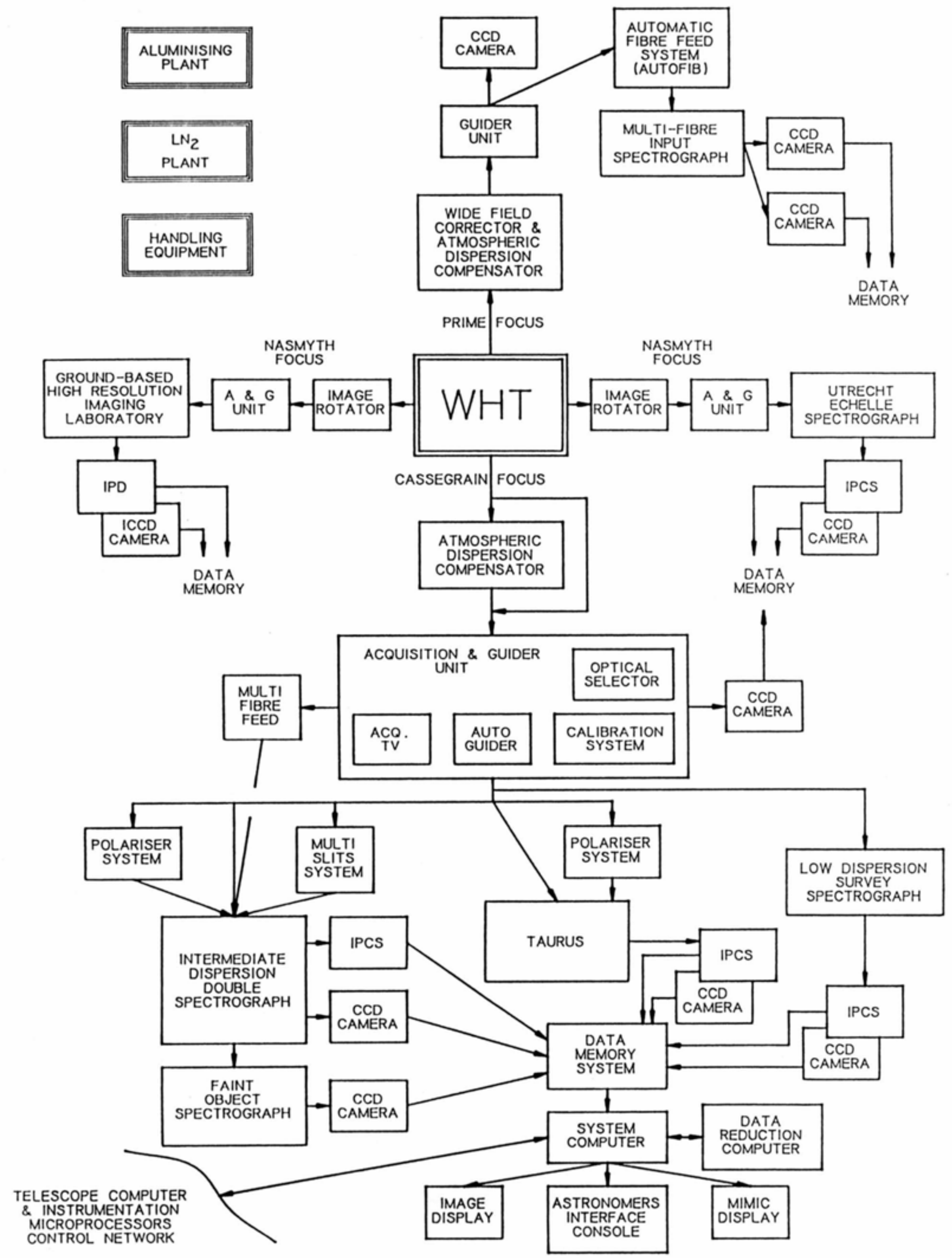
Acquisition and Guider Unit: Mounted on primary-mirror cell turntable (to 'stabilize' image orientation by de-rotation, necessary for an altitude-azimuth-mount telescope), filter slides, field mirror in/out to select either the auxiliary port camera or ISIS/FOS, LDSS, TAURUS-2.

Hitchiker: Direct CCD camera, 6×4 arcmin field, 7 arcmin off-axis, used to obtain deep images of random fields during long ISIS/FOS exposures on particular objects.

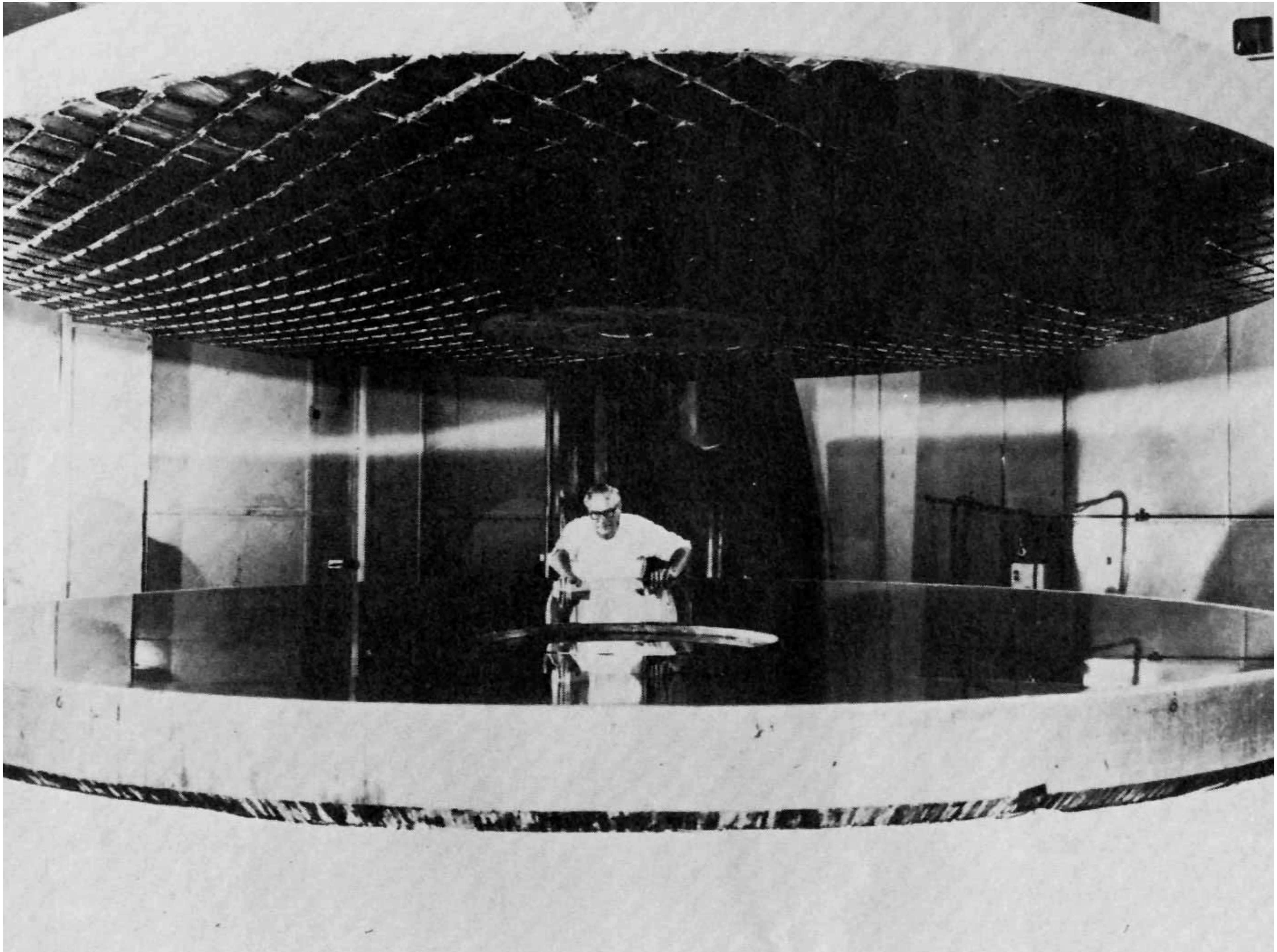
GHRIL: Ground-based High-Resolution Imaging Laboratory, a light-tight room covering Nasmyth-1 platform, including an optical bench on which imaging experiments can be conducted and a workstation from which the telescope can be controlled.

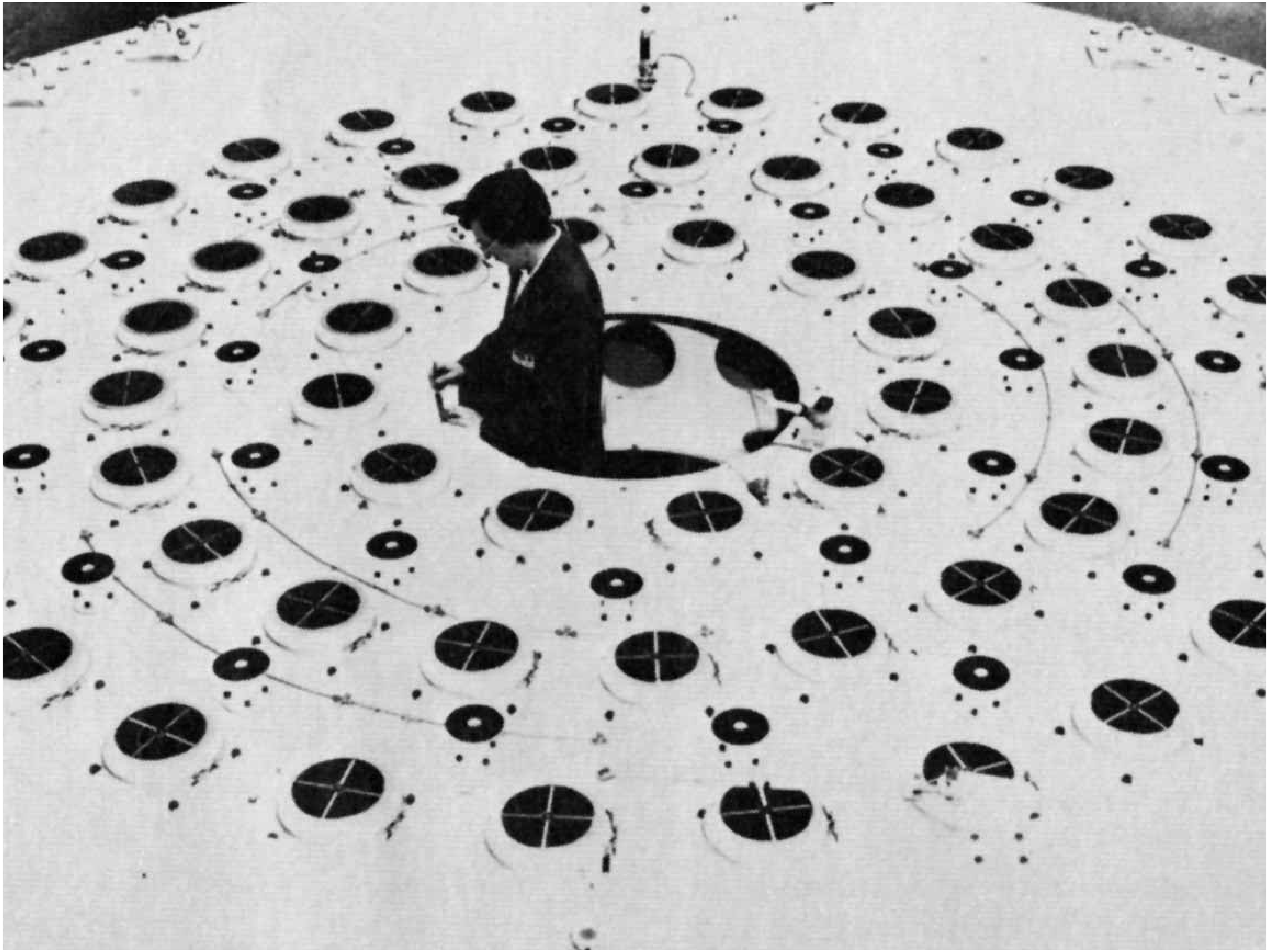
FOS-2: Faint-object spectrograph, field-of-view 4×2 arcmin, wavelength range 3500 -10000 Å, $300 \leq R \leq 500$, for *spectrophotometry of faint/distant objects.*

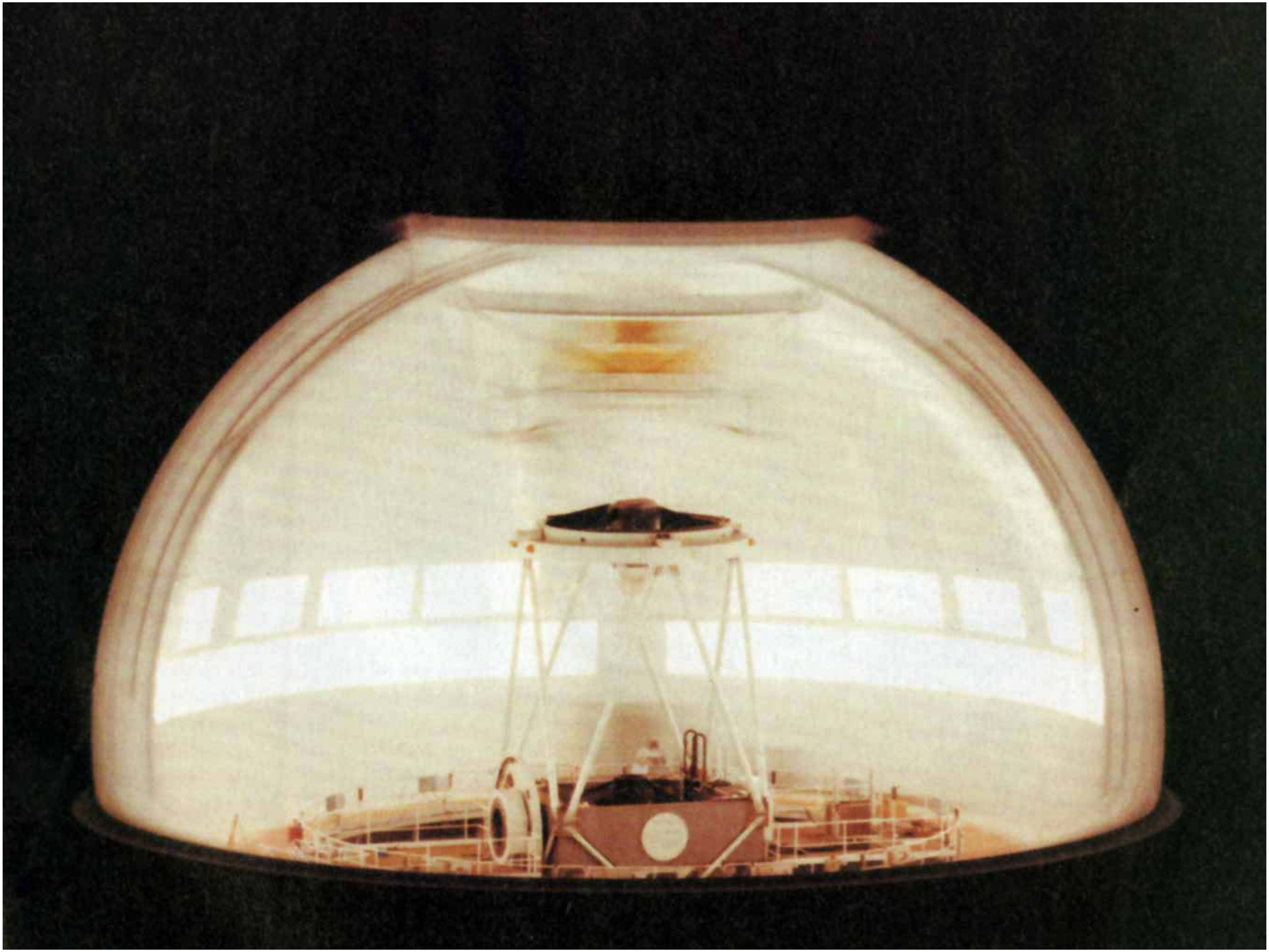
WYFFOS: Wide-Field Fibre-Optic spectrograph optimized for input from the 150 optical fibres of Autofib-2 at the WHT prime focus; wavelength range 3500 – 11,000 Å, $R \sim 3000$, for *general-purpose multi-object spectroscopy, star clusters, gas in galaxies, nearby galaxy clusters.*

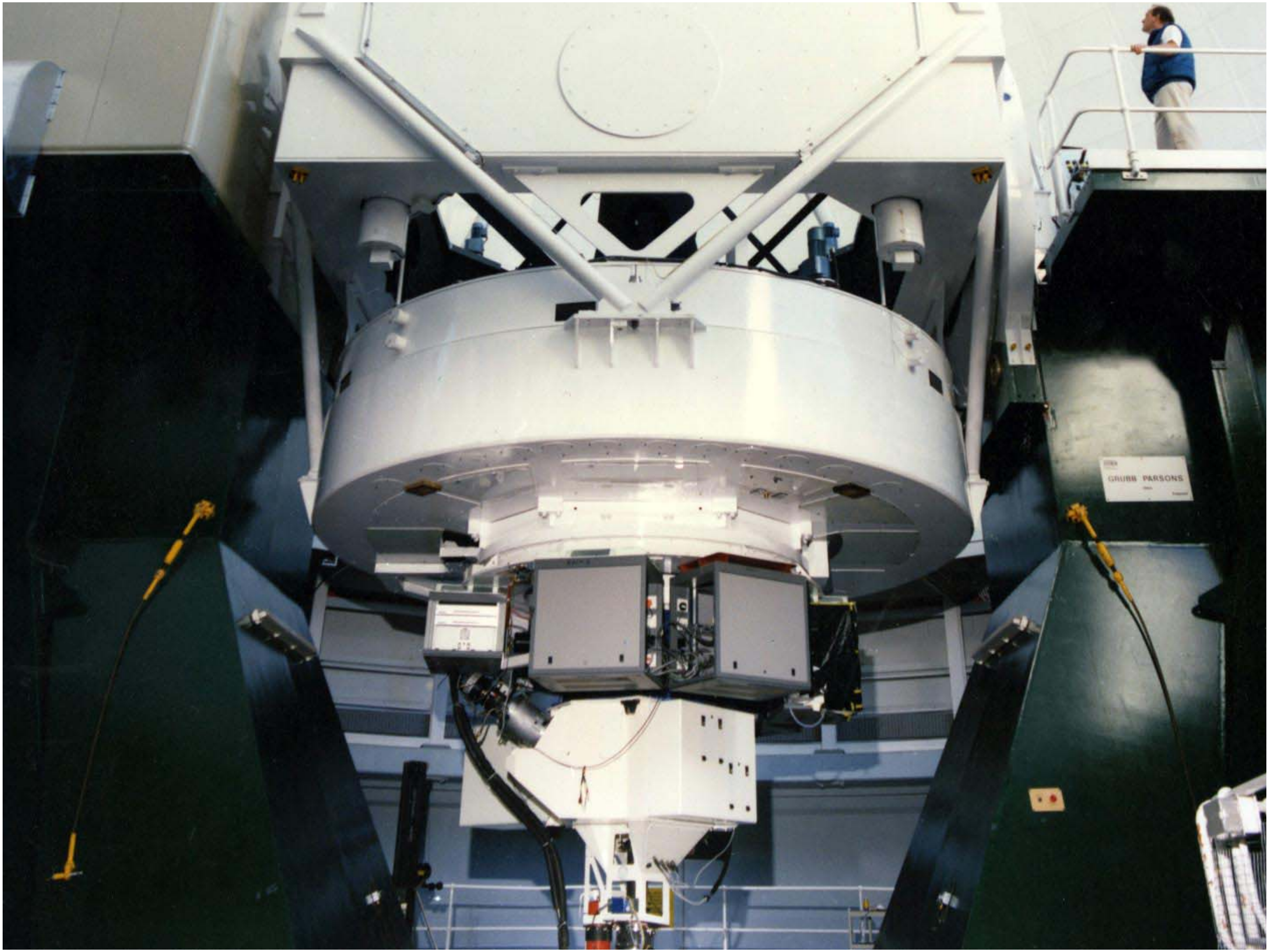


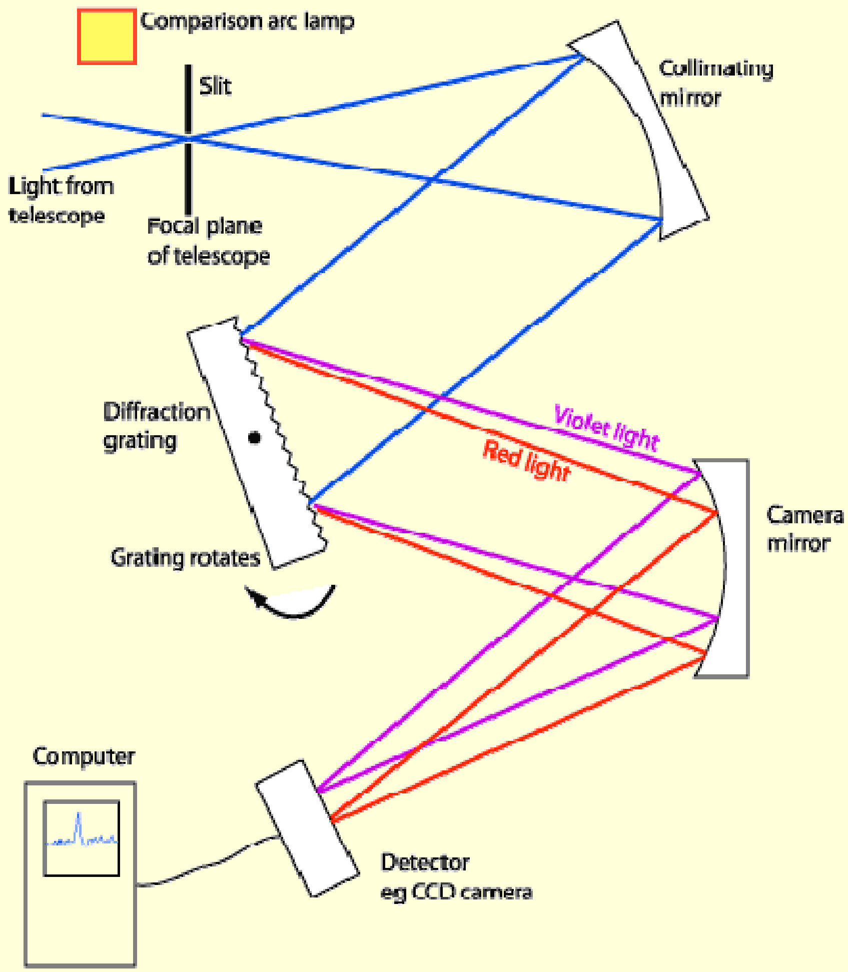
ALUMINISING PLANT
LN2 PLANT
HANDLING EQUIPMENT
CCD CAMERA
AUTOMATIC FIBRE FEED SYSTEM (AUTOFIB)
GUIDER UNIT
MULTI-FIBRE INPUT SPECTROGRAPH
CCD CAMERA
CCD CAMERA
WIDE FIELD CORRECTOR & ATMOSPHERIC DISPERSION COMPENSATOR
DATA MEMORY
PRIME FOCUS
NASMYTH FOCUS
NASMYTH FOCUS
GROUND-BASED HIGH RESOLUTION IMAGING LABORATORY
A & G UNIT
IMAGE ROTATOR
WHT
IMAGE ROTATOR
A & G UNIT
UTRECHT ECHELLE SPECTROGRAPH
IPD
ICCD CAMERA
DATA MEMORY
CASSEGRAIN FOCUS
IPCS
CCD CAMERA
DATA MEMORY
ATMOSPHERIC DISPERSION COMPENSATOR
ACQUISITION & GUIDER UNIT
OPTICAL SELECTOR
MULTI FIBRE FEED
ACQ. TV
AUTO GUIDER
CALIBRATION SYSTEM
CCD CAMERA
POLARISER SYSTEM
MULTI SLITS SYSTEM
POLARISER SYSTEM
LOW DISPERSION SURVEY SPECTROGRAPH
TAURUS
INTERMEDIATE DISPERSION DOUBLE SPECTROGRAPH
IPCS
IPCS
CCD CAMERA
CCD CAMERA
IPCS
DATA MEMORY SYSTEM
CCD CAMERA
FAINT OBJECT SPECTROGRAPH
CCD CAMERA
SYSTEM COMPUTER
DATA REDUCTION COMPUTER
TELESCOPE COMPUTER & INSTRUMENTATION MICROPROCESSORS CONTROL NETWORK
IMAGE DISPLAY
ASTRONOMERS INTERFACE CONSOLE
MIMIC DISPLAY



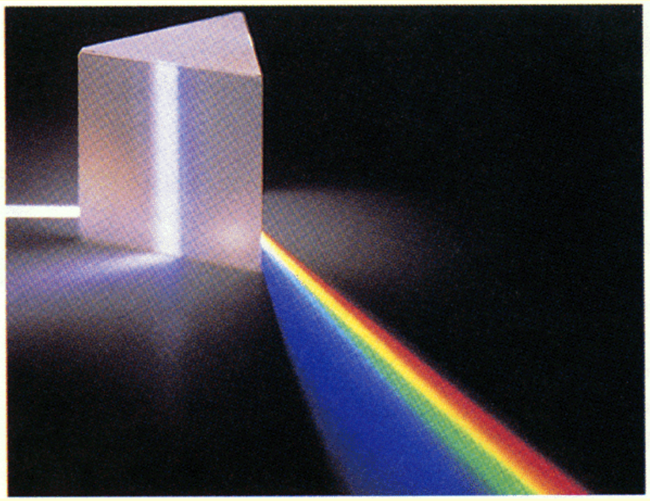


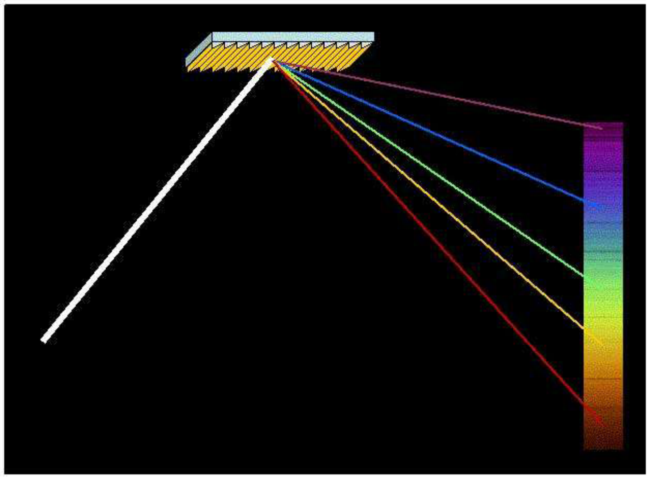


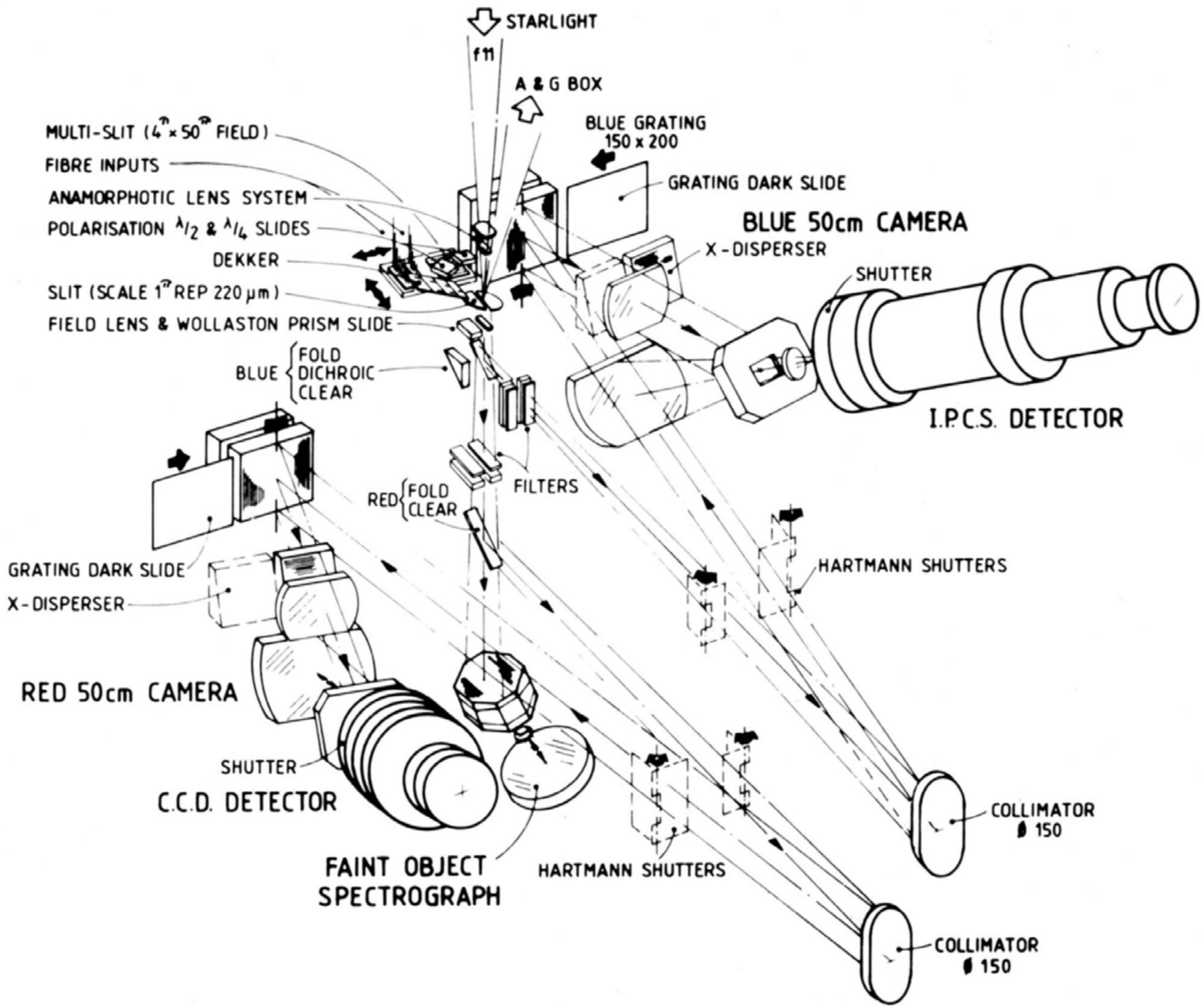

GRUBB PARSONS



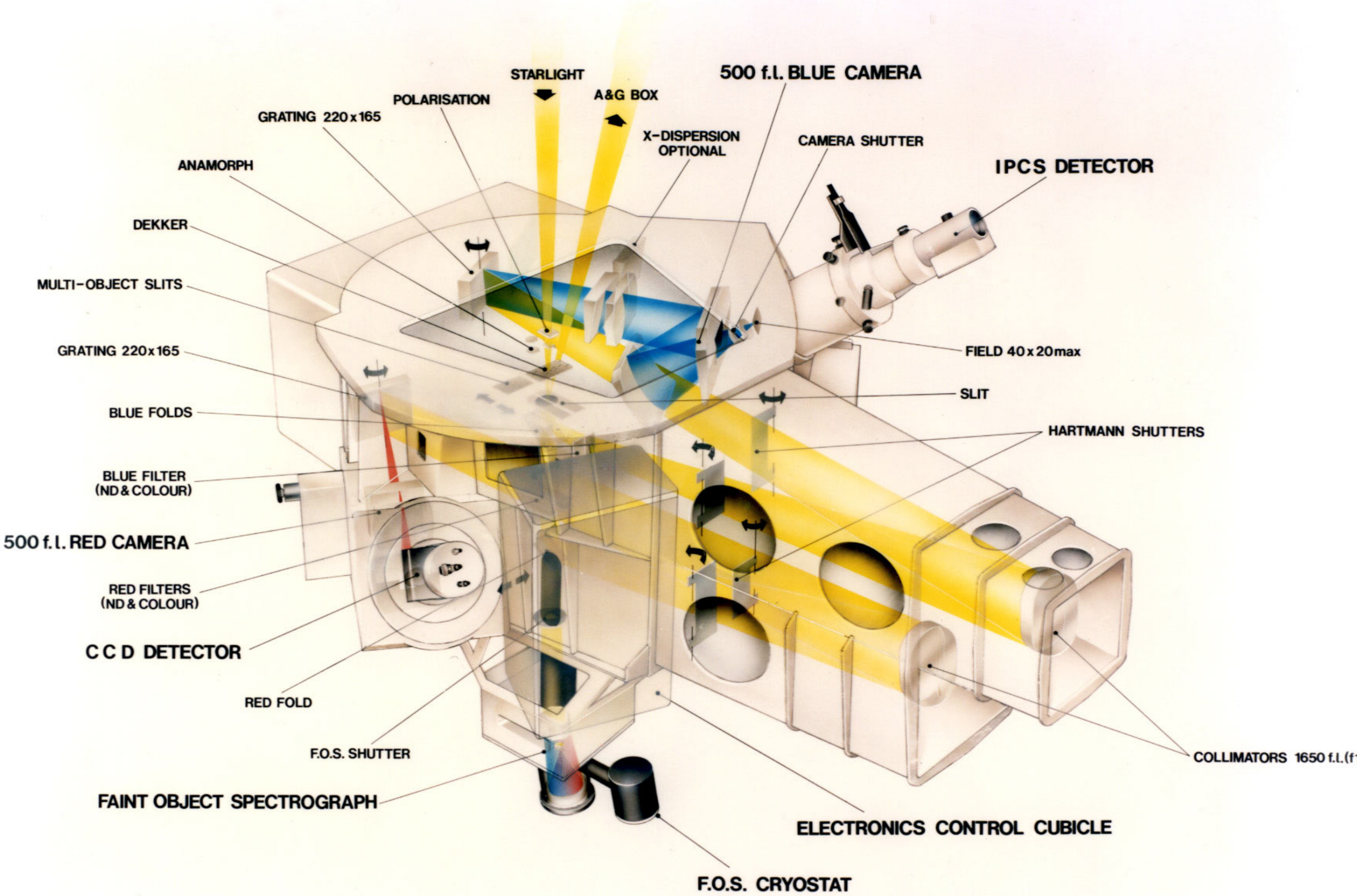
A Schematic Diagram of a Slit Spectrograph





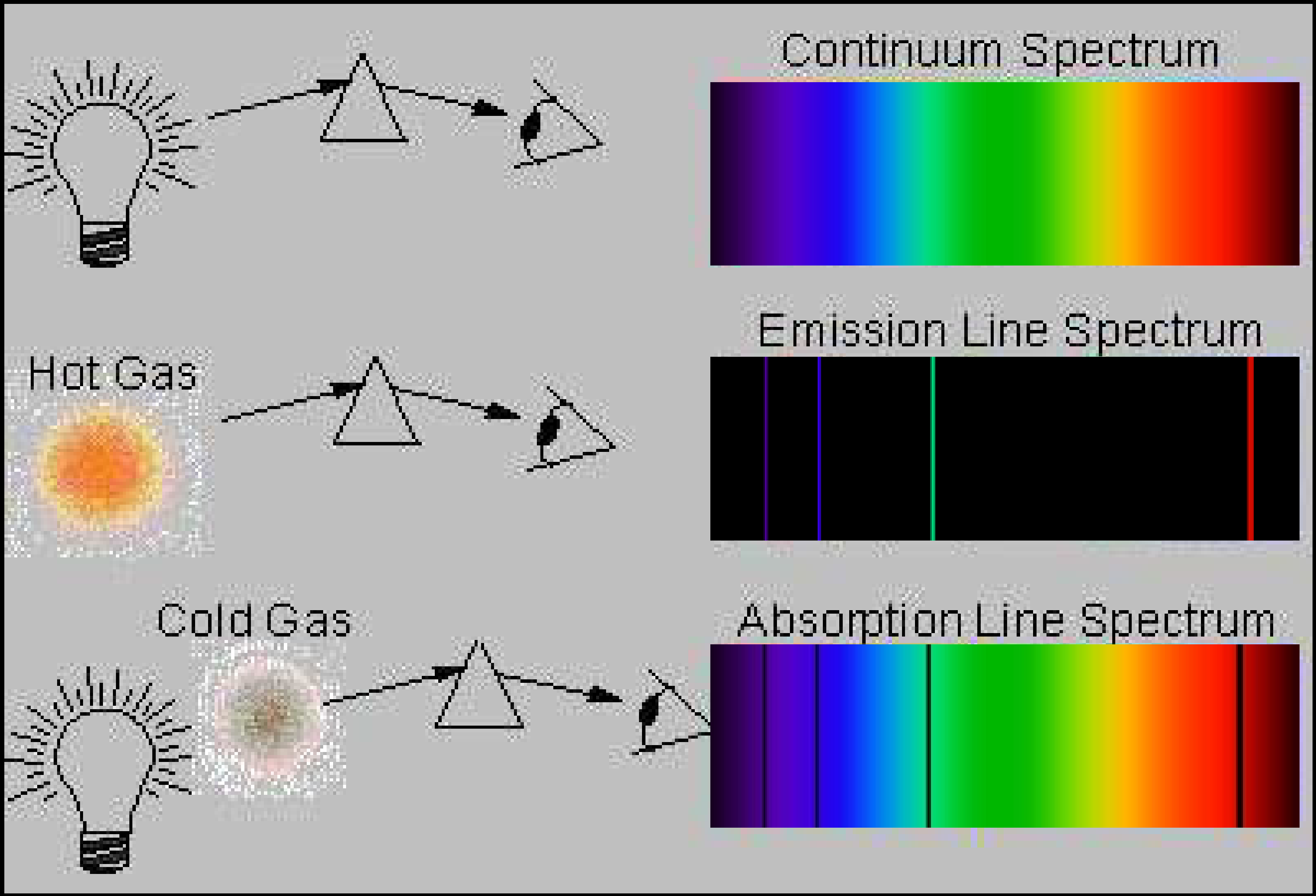


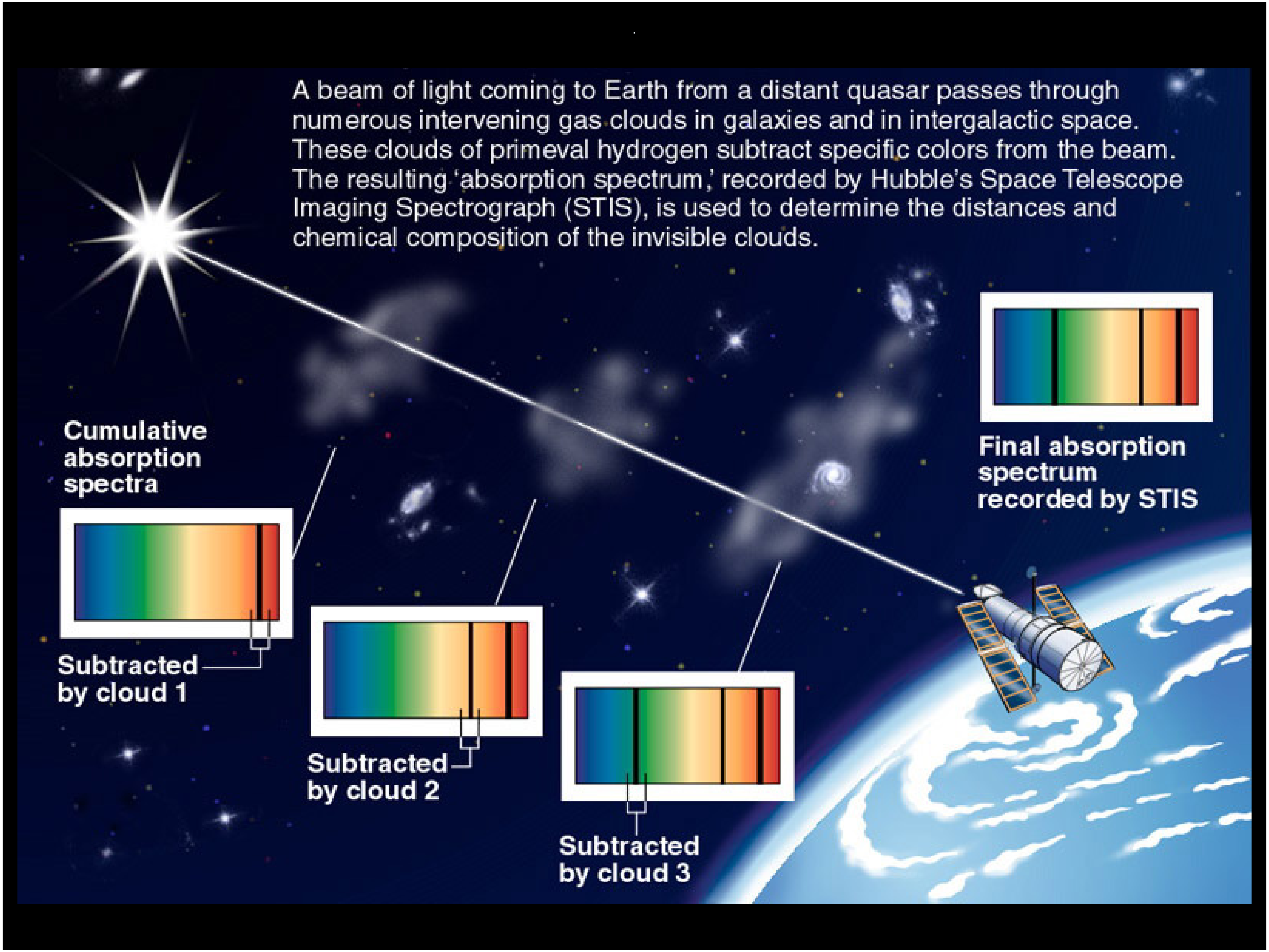
STARLIGHT
f11
A & G BOX
MULTI-SLIT (4" x 50" FIELD)
FIBRE INPUTS
ANAMORPHOTIC LENS SYSTEM
POLARISATION λ/2 & λ/4 SLIDES
DEKKER
SLIT (SCALE 1" REP 220 μm)
FIELD LENS & WOLLASTON PRISM SLIDE
BLUE {FOLD DICHROIC CLEAR
FILTERS
RED {FOLD CLEAR
BLUE GRATING 150 x 200
GRATING DARK SLIDE
BLUE 50cm CAMERA
X-DISPERSER
SHUTTER
I.P.C.S. DETECTOR
HARTMANN SHUTTERS
COLLIMATOR ∅ 150
GRATING DARK SLIDE
X-DISPERSER
RED 50cm CAMERA
SHUTTER
C.C.D. DETECTOR
FAINT OBJECT SPECTROGRAPH
HARTMANN SHUTTERS
COLLIMATOR ∅ 150



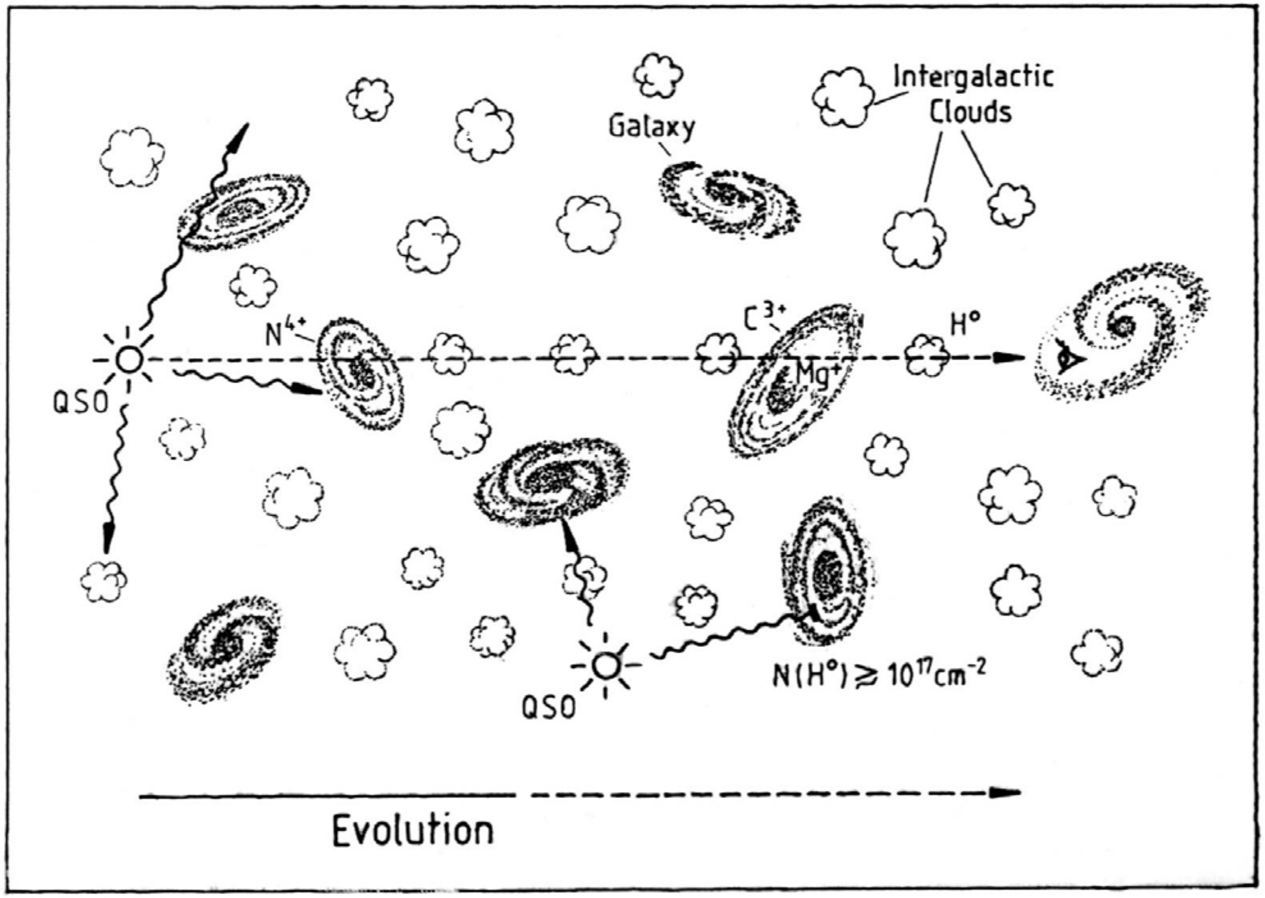
'ISIS' SPECTROGRAPH

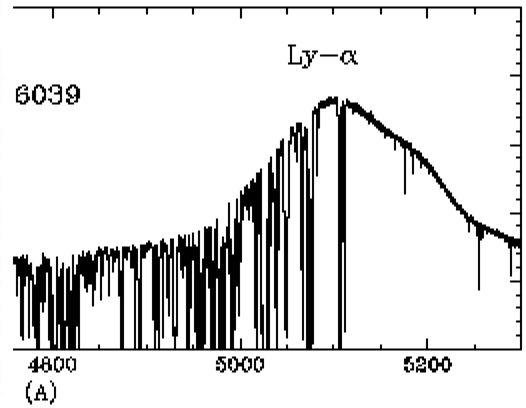
4.2M W.H.T CASSEGRAIN INSTRUMENT

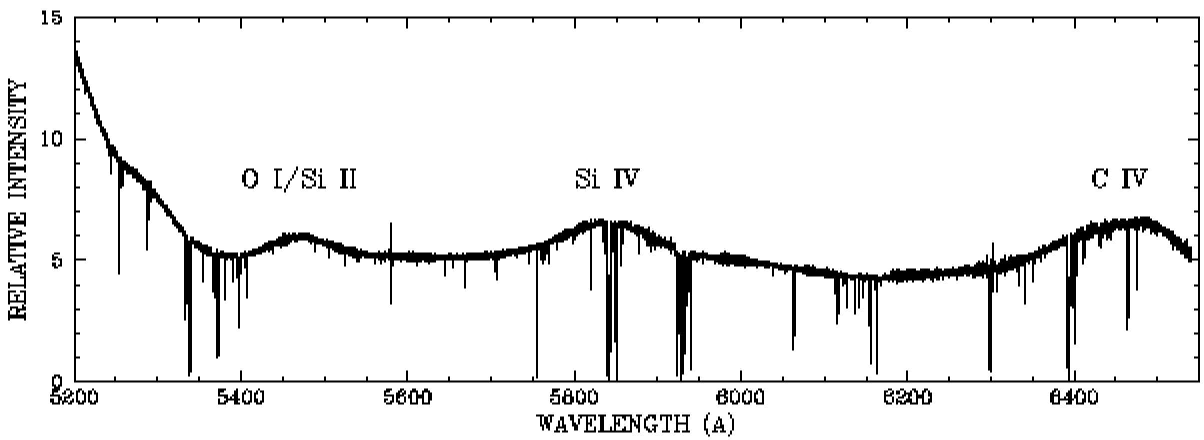

Continuum Spectrum
Emission Line Spectrum
Hot Gas
Cold Gas
Absorption Line Spectrum

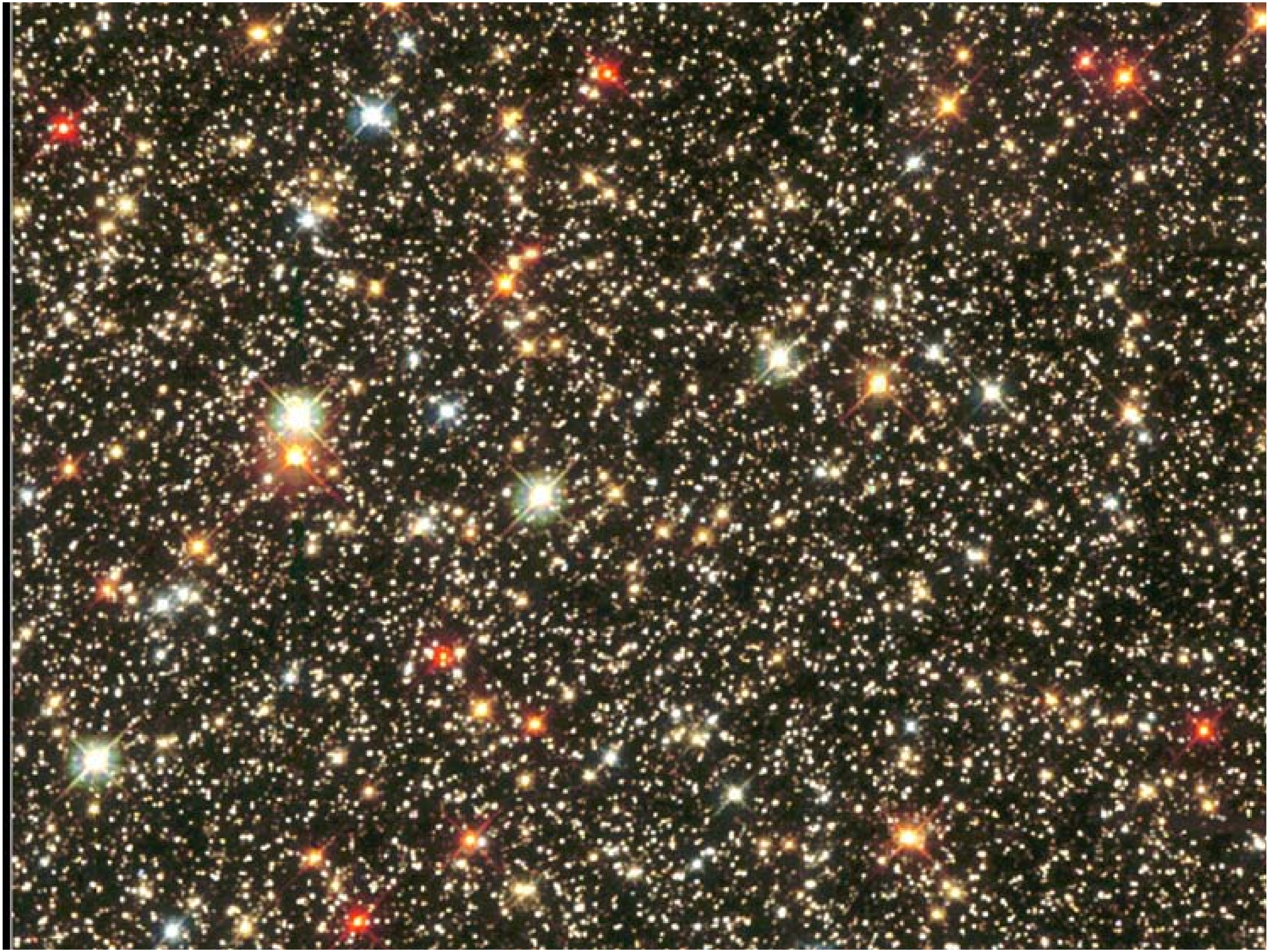


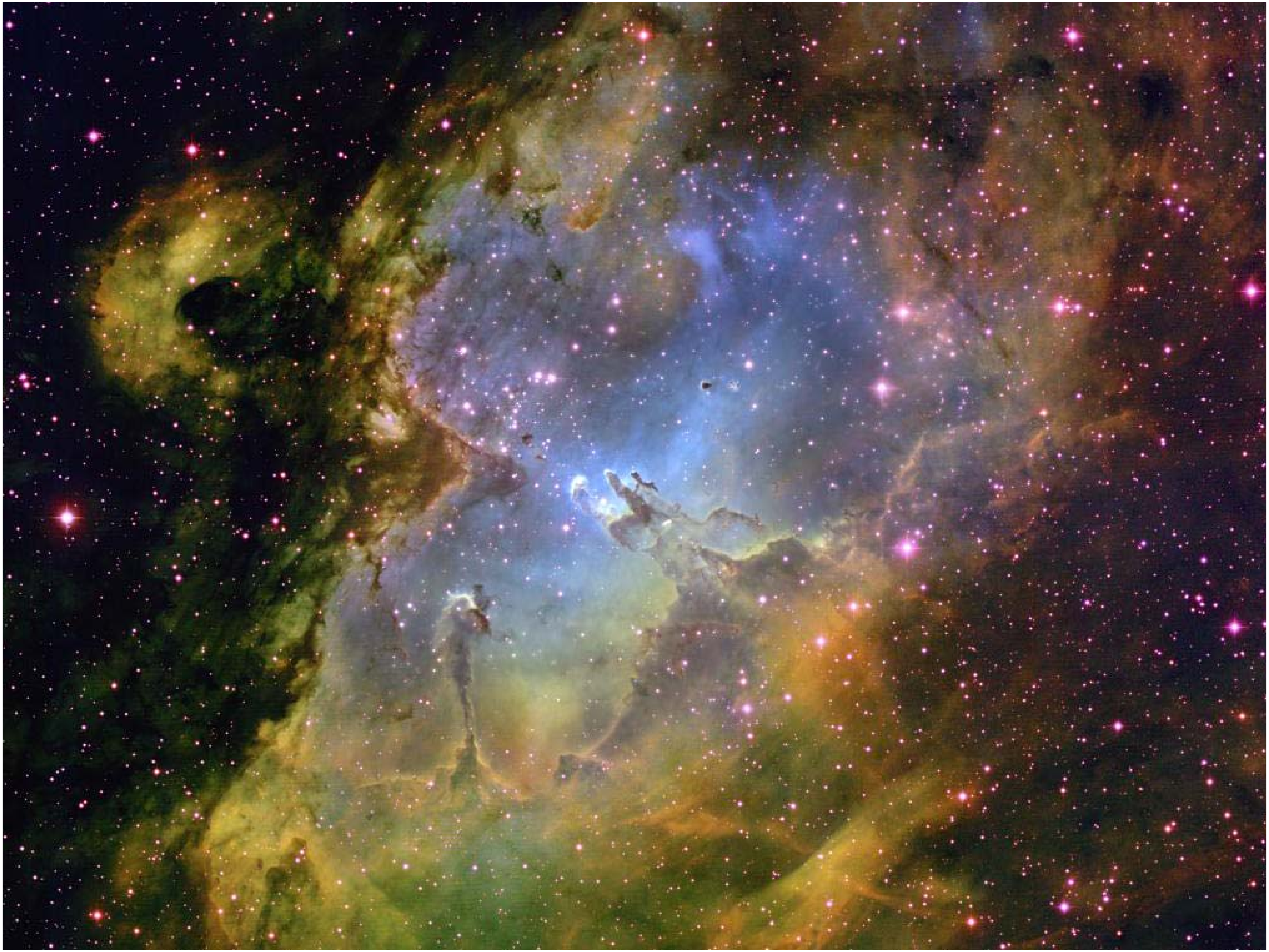
A beam of light coming to Earth from a distant quasar passes through numerous intervening gas clouds in galaxies and in intergalactic space. These clouds of primeval hydrogen subtract specific colors from the beam. The resulting 'absorption spectrum,' recorded by Hubble's Space Telescope Imaging Spectrograph (STIS), is used to determine the distances and chemical composition of the invisible clouds.
Cumulative absorption spectra
Subtracted by cloud 1
Subtracted by cloud 2
Subtracted by cloud 3
Final absorption spectrum recorded by STIS

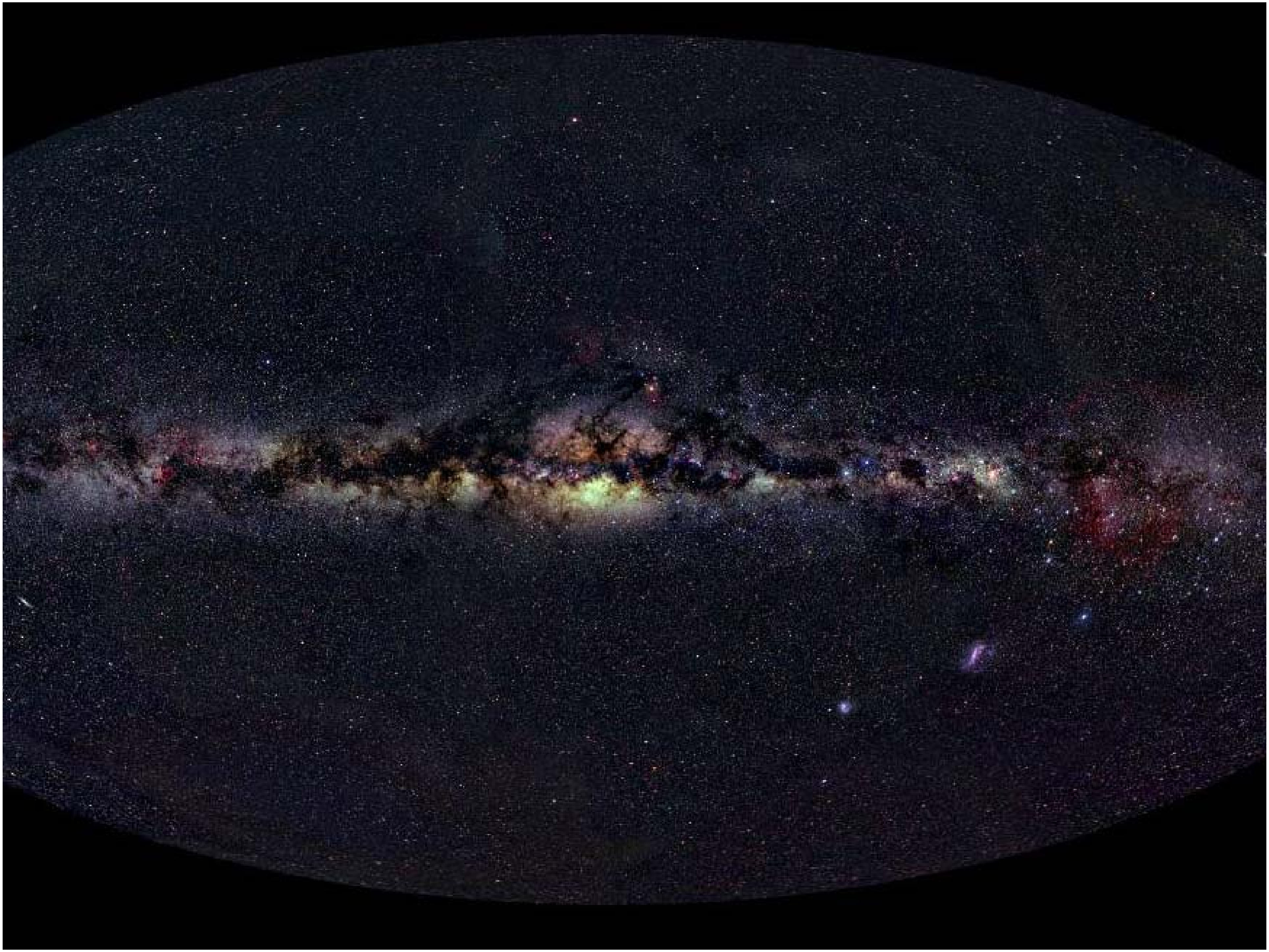

Intergalactic
Clouds
Galaxy
N^{4+}
C^{3+}
H^{o}
Mg^{+}
QSO
QSO
$N(H^{o}) \gtrsim 10^{17} cm^{-2}$
Evolution

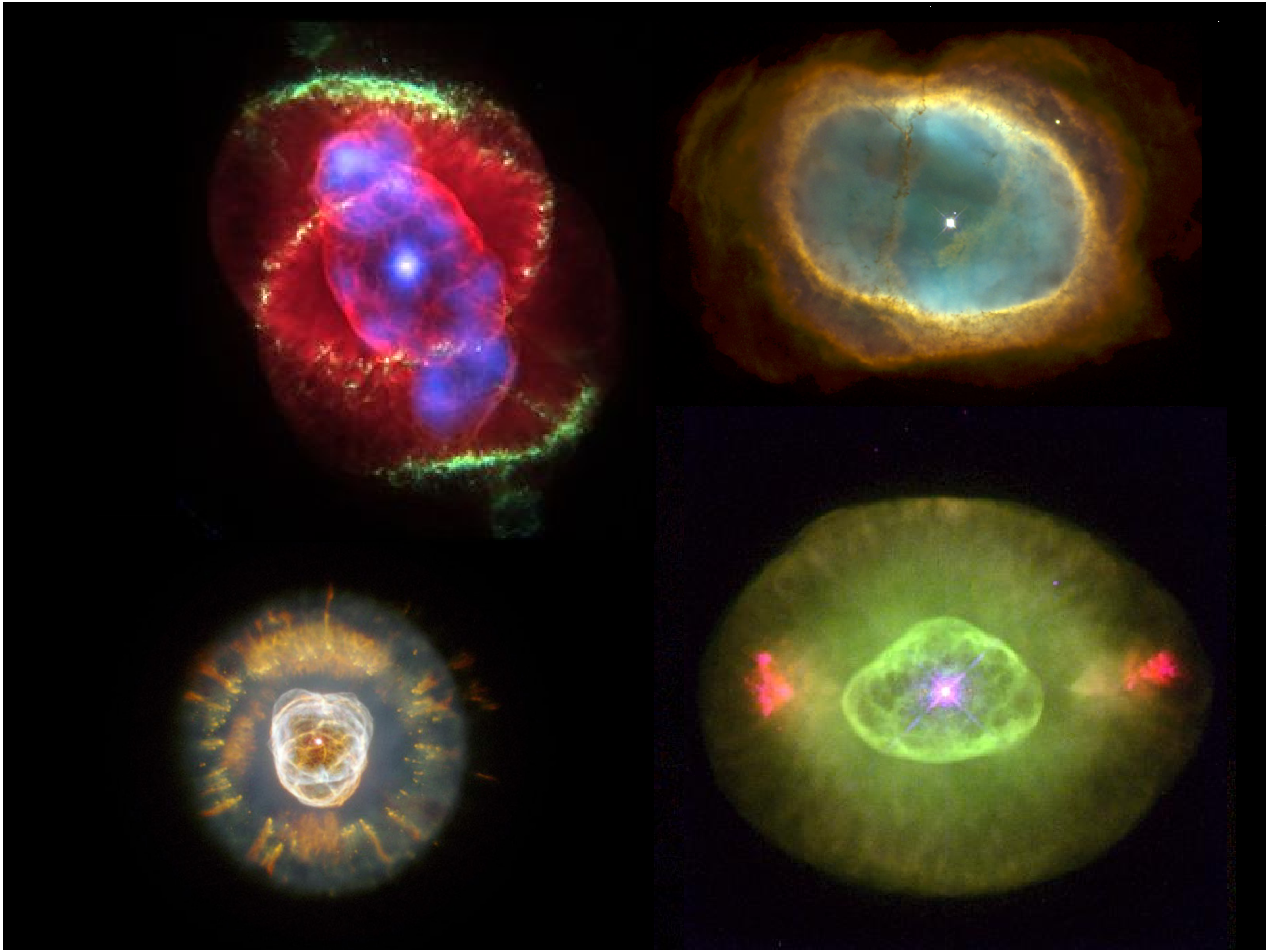

6039
Ly−α
4800
5000
5200
(A)

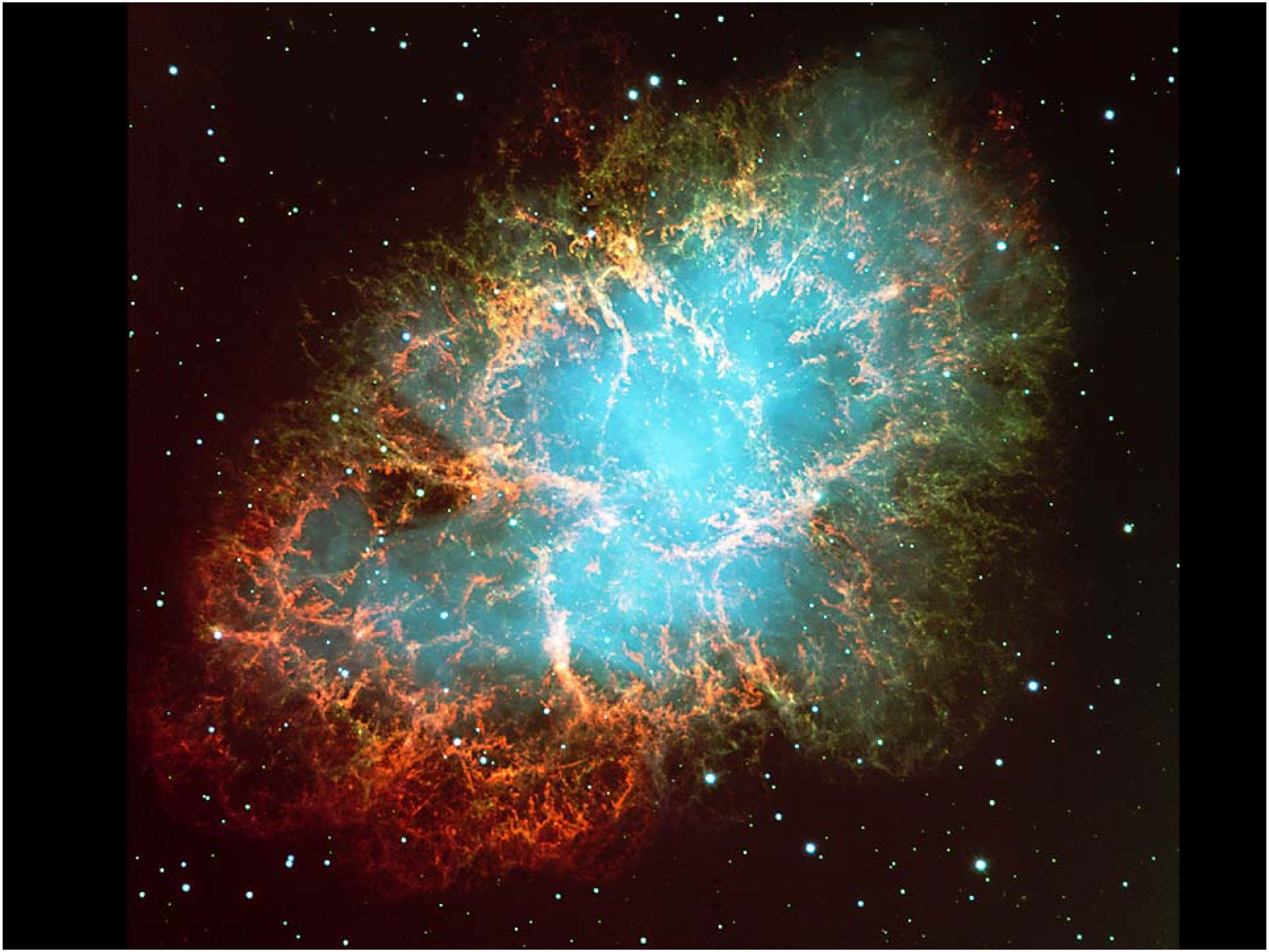

15
10
5
0
RELATIVE INTENSITY
O I/Si II
Si IV
C IV
5200
5400
5600
5800
6000
6200
6400
WAVELENGTH (A)

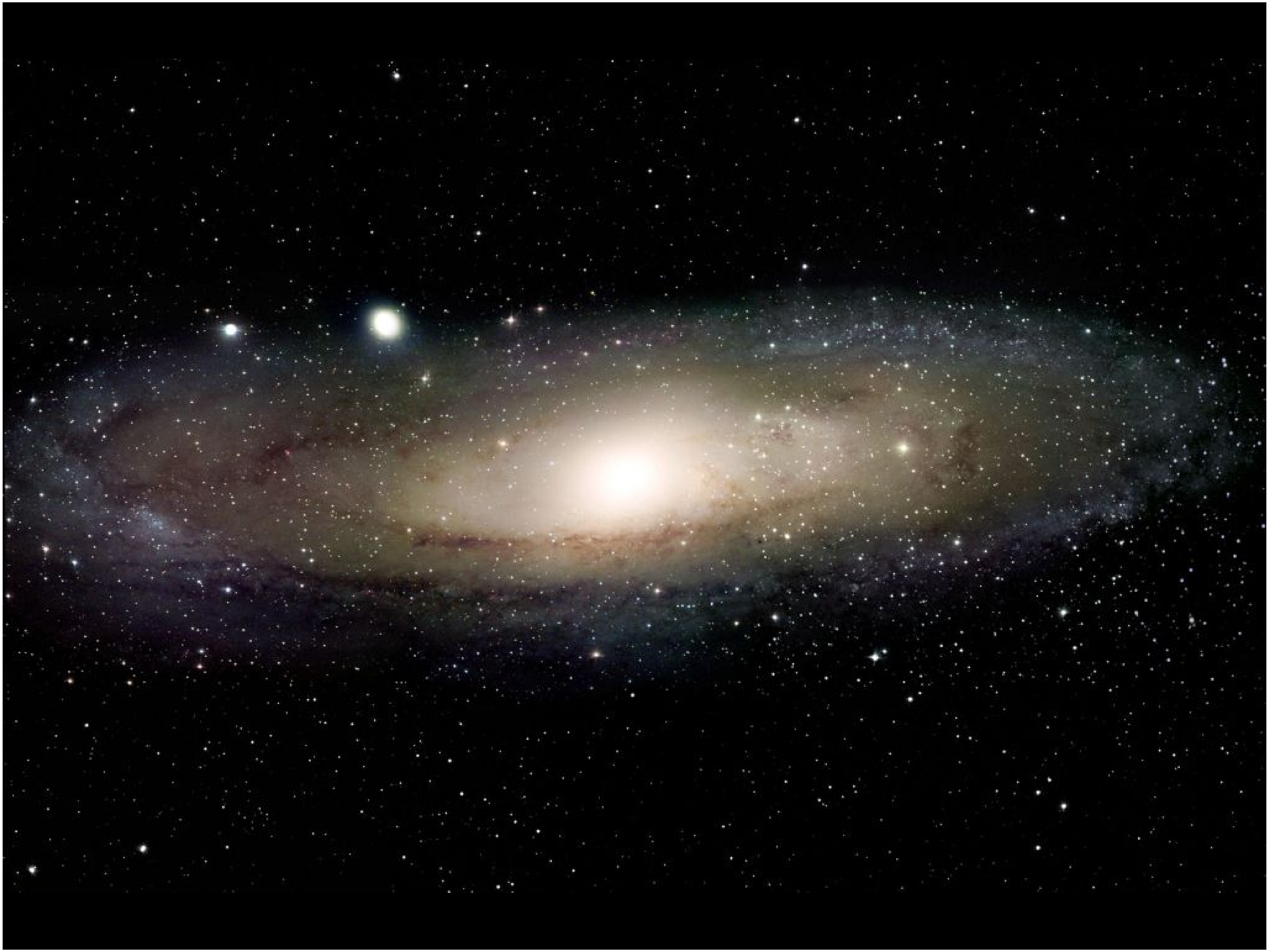


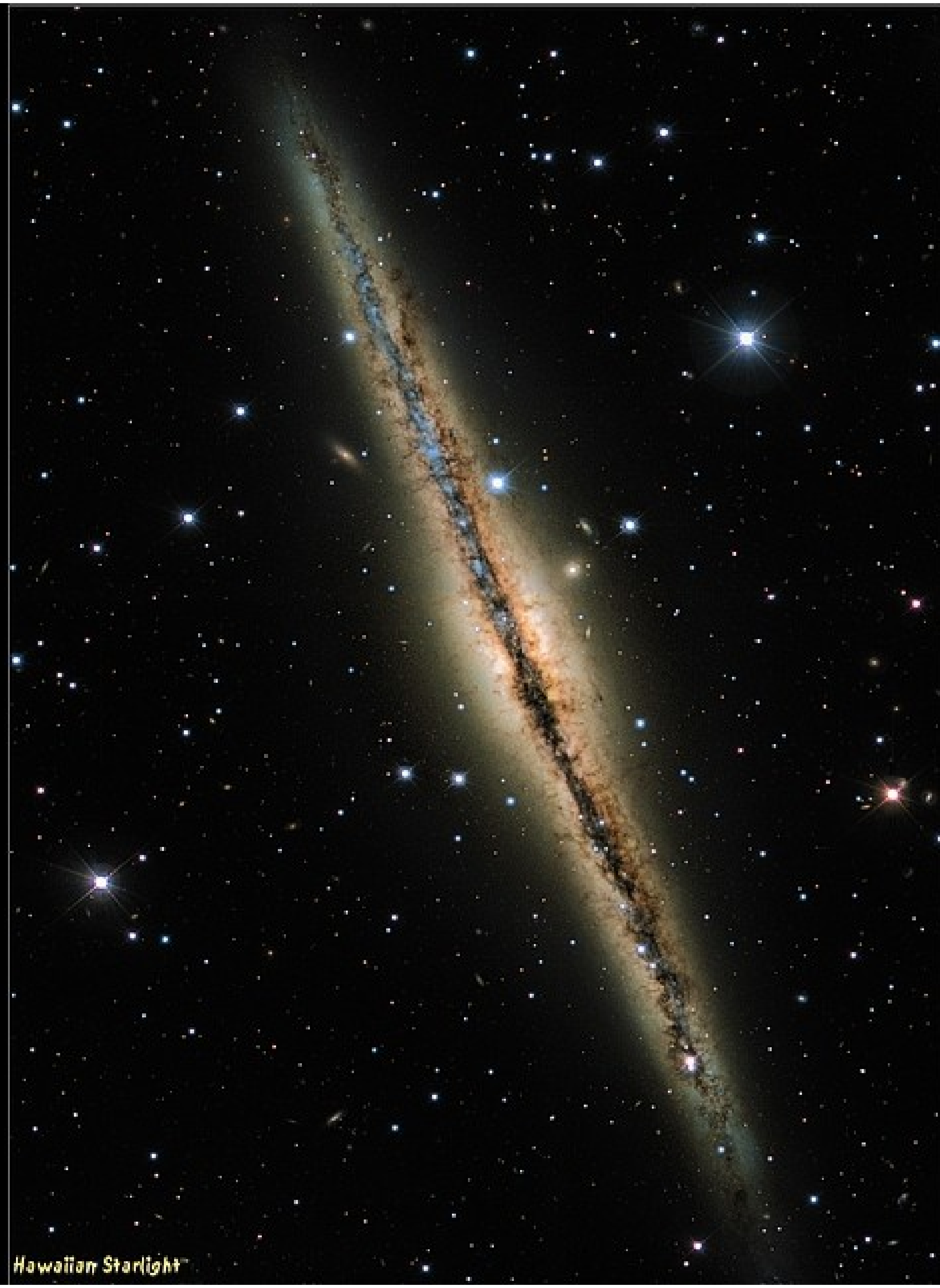


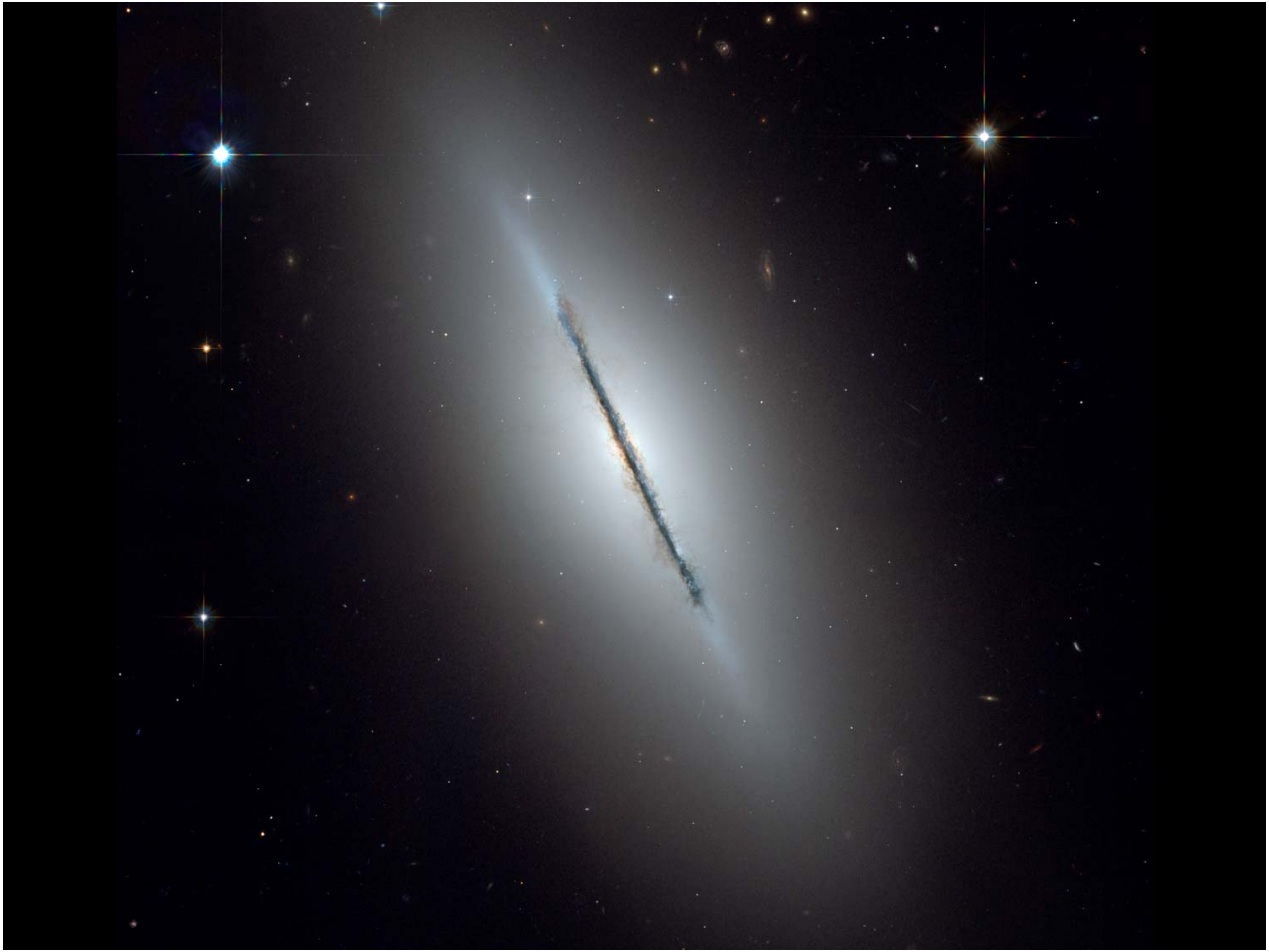


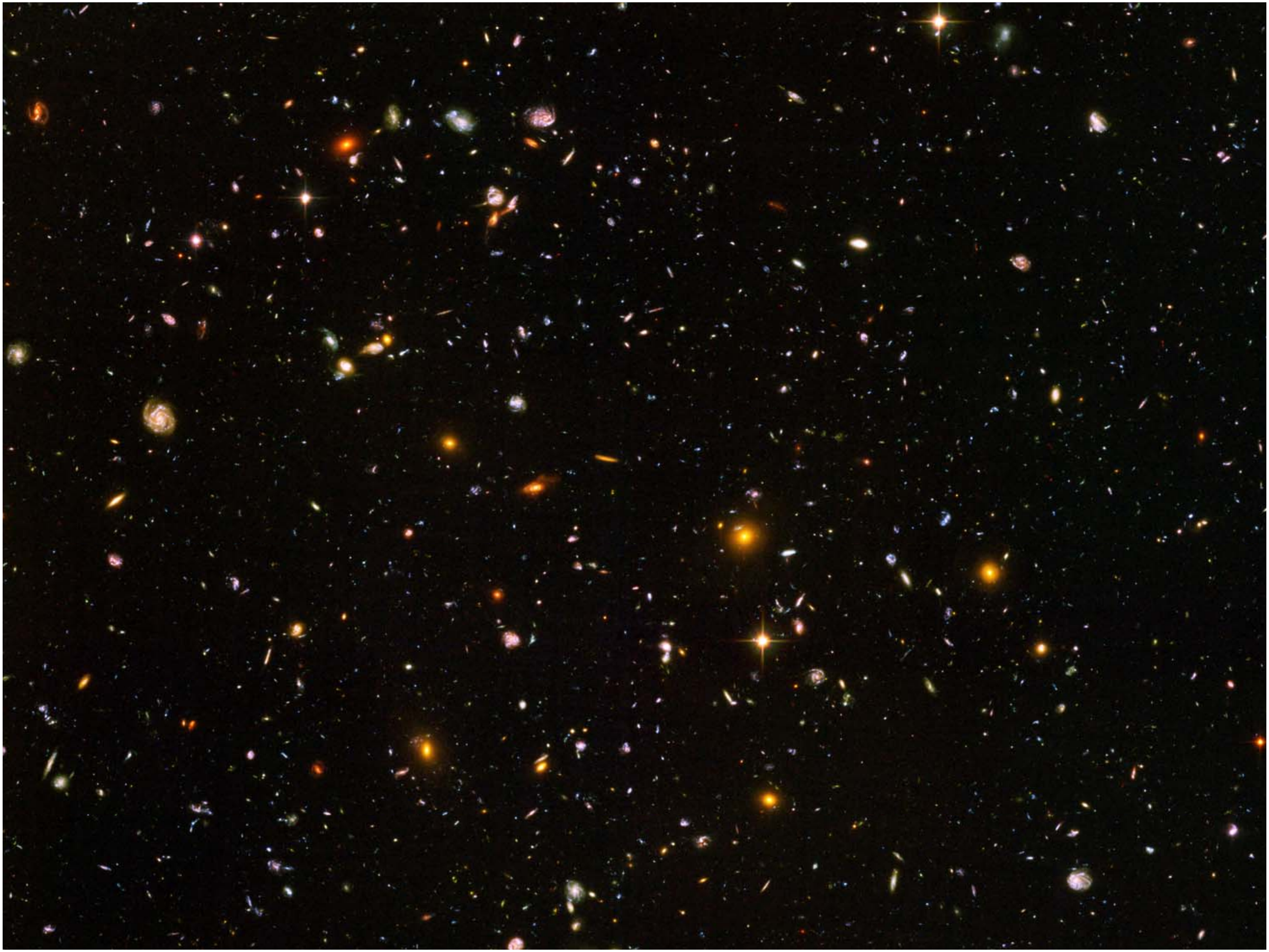


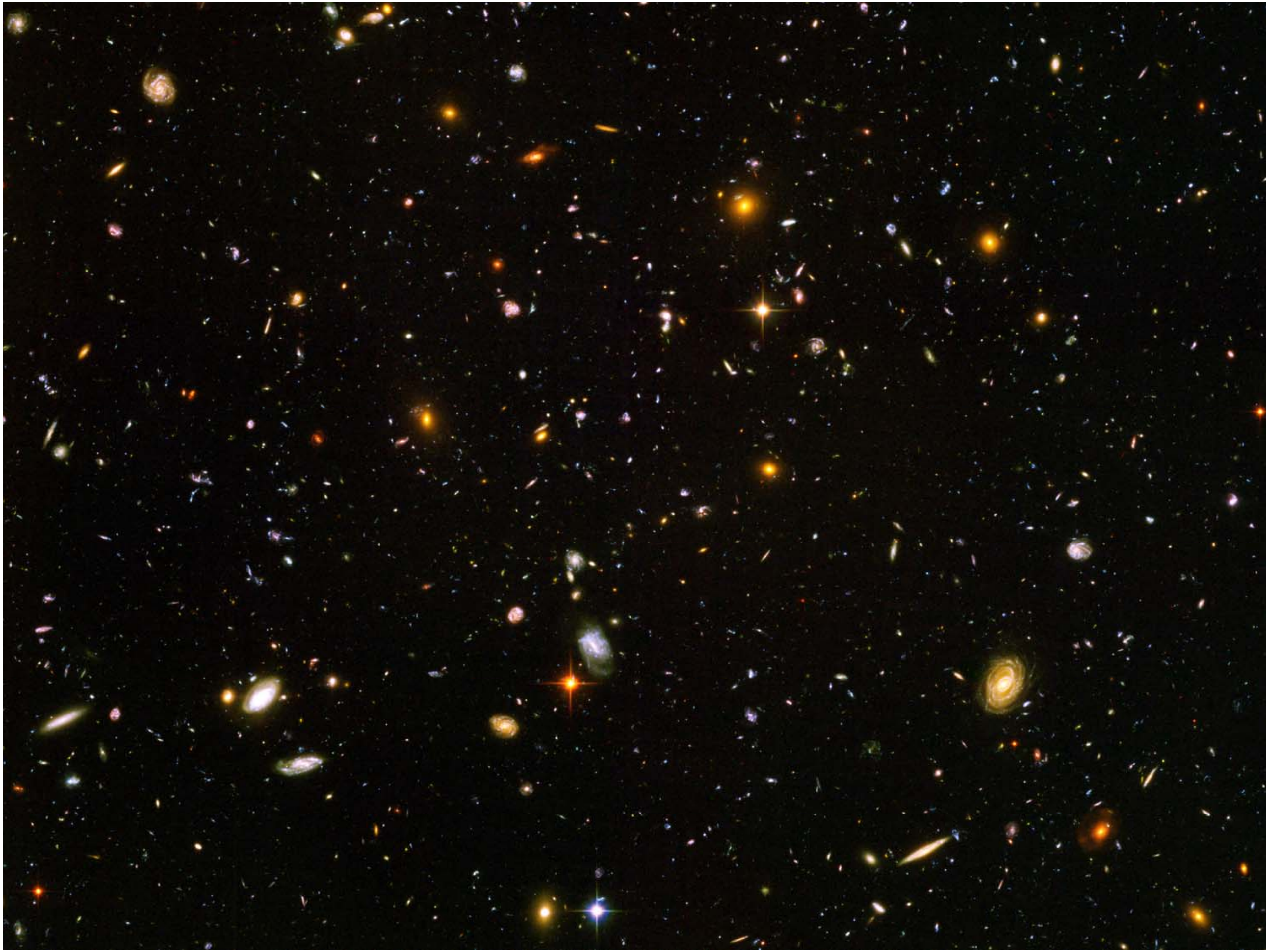


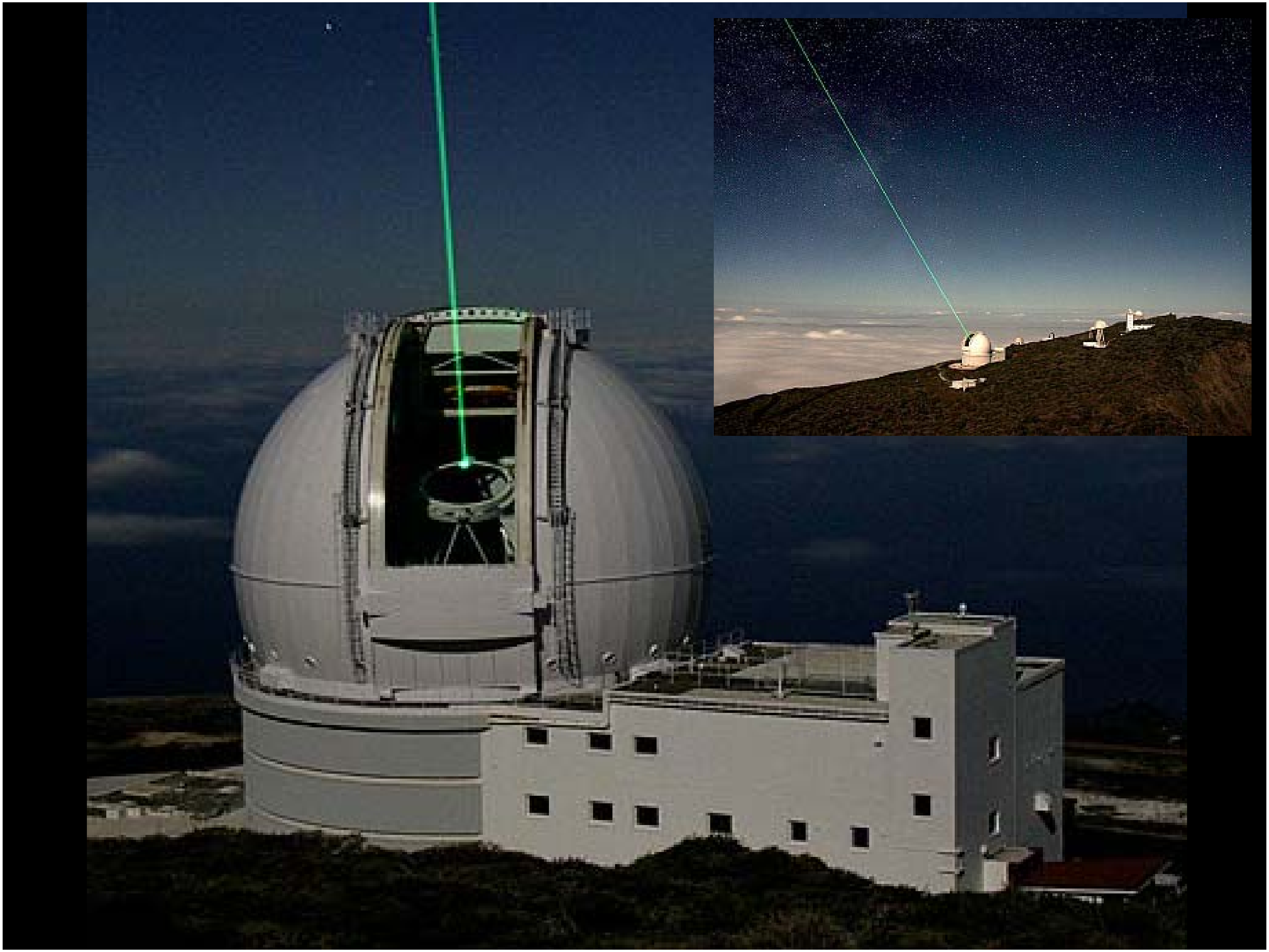


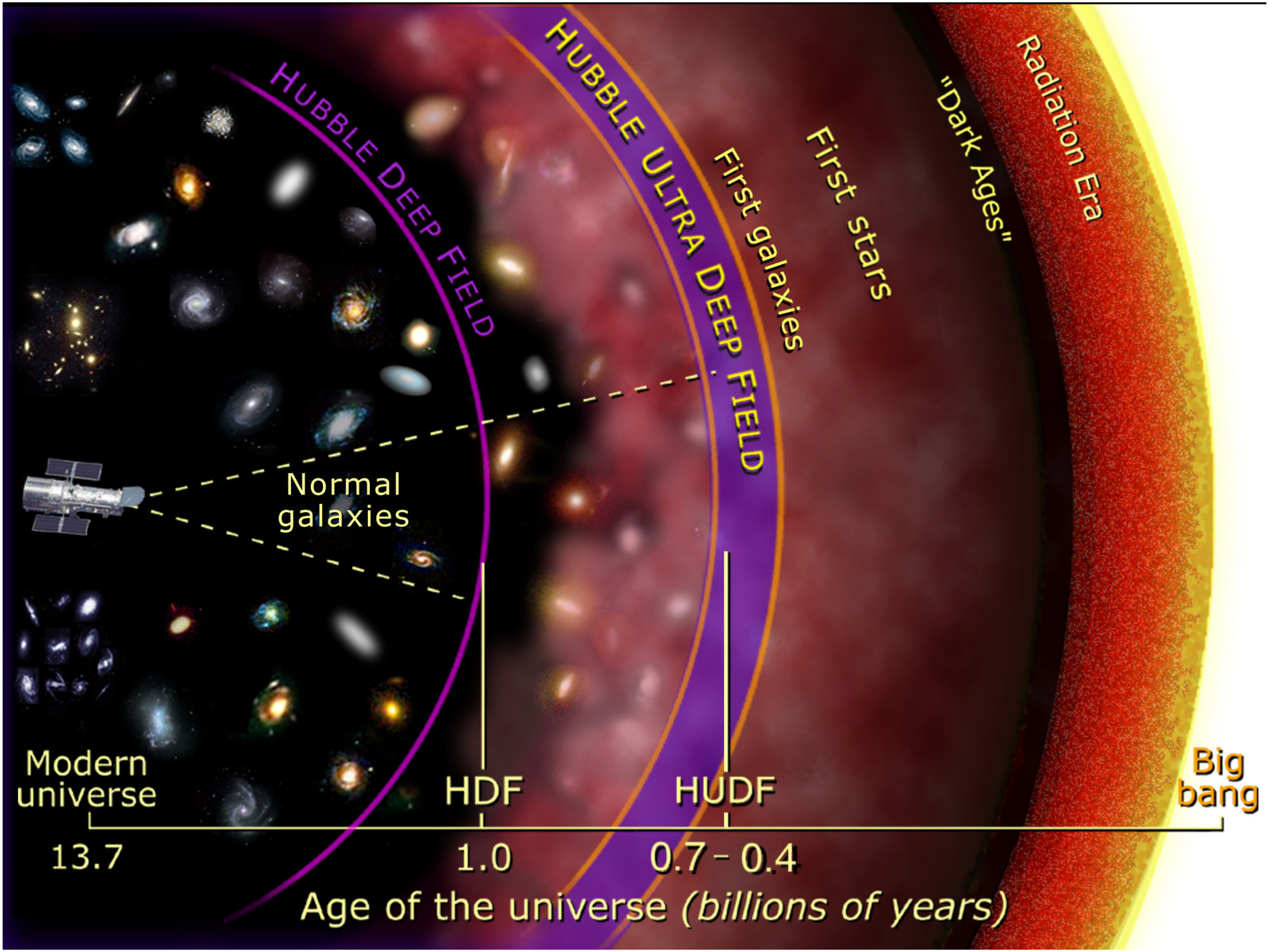

Hawaiian Starlight

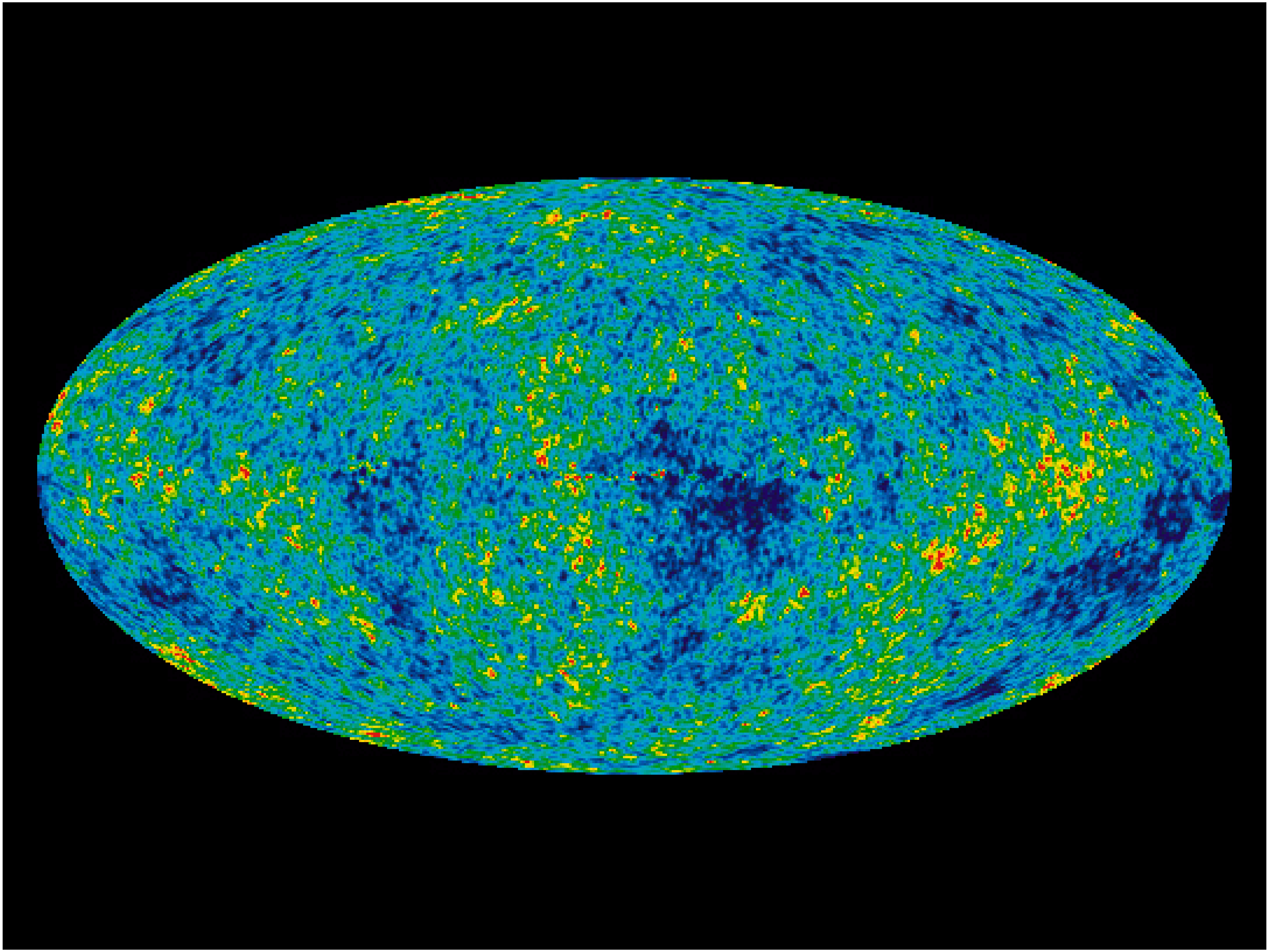









HUBBLE DEEP FIELD
HUBBLE ULTRA DEEP FIELD
First galaxies
First stars
"Dark Ages"
Radiation Era
Normal galaxies
Modern universe
HDF
HUDF
Big bang
13.7
1.0
0.7 – 0.4
Age of the universe (billions of years)

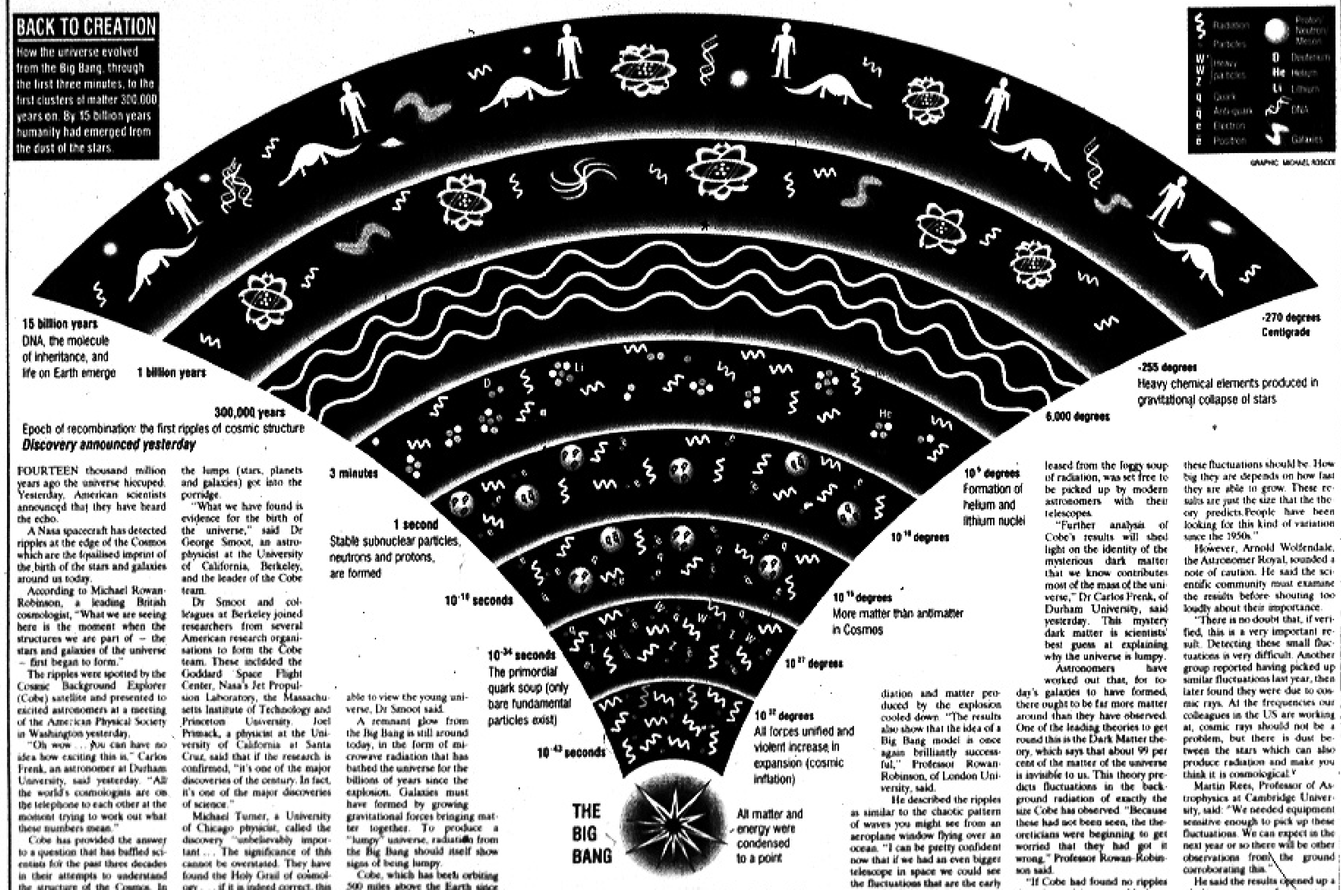


THE INDEPENDENT

No 1,722 FRIDAY 24 APRIL 1992 *** Published in London 40p

A Nasa spacecraft has detected echoes of the galaxies' birth fourteen thousand million years ago. The discovery about the formation of the stars after the Big Bang has been hailed by excited scientists as the Holy Grail of cosmology. **Susan Watts** and **Tom Wilkie** report

How the universe began



FOURTEEN thousand million years ago the universe hiccuped. Yesterday, American scientists announced that they have heard the echo.

A Nasa spacecraft has detected ripples at the edge of the Cosmos which are the fossilised imprint of the birth of the stars and galaxies around us today.

According to Michael Rowan-Robinson, a leading British cosmologist, "What we are seeing here is the moment when the structures we are part of — the stars and galaxies of the universe — first began to form."

The ripples were spotted by the Cosmic Background Explorer (Cobe) satellite and presented to excited astronomers at a meeting of the American Physical Society in Washington yesterday.

"Oh wow ... you can have no idea how exciting this is," Carlos Frenk, an astronomer at Durham University, said yesterday. "All the world's cosmologists are on the telephone to each other at the moment trying to work out what these numbers mean."

Cobe has provided the answer to a question that has baffled scientists for the past three decades in their attempts to understand the structure of the Cosmos. In the 1960s two American researchers found definitive evidence that a Big Bang had started the whole thing off about 15 billion years ago. But the Big Bang would have spread matter like thin gruel evenly throughout the universe. The problem was to work out how the lumps (stars, planets and galaxies) got into the porridge.

"What we have found is evidence for the birth of the universe," said Dr George Smoot, an astrophysicist at the University of California, Berkeley, and the leader of the Cobe team.

Dr Smoot and colleagues at Berkeley joined researchers from several American research organisations to form the Cobe team. These included the Goddard Space Flight Center, Nasa's Jet Propulsion Laboratory, the Massachusetts Institute of Technology and Princeton University. Joel Primack, a physicist at the University of California at Santa Cruz, said that if the research is confirmed, "it's one of the major discoveries of the century. In fact, it's one of the major discoveries of science."

Michael Turner, a University of Chicago physicist, called the discovery "unbelievably important ... The significance of this cannot be overstated. They have found the Holy Grail of cosmology ... if it is indeed correct, this certainly would have to be considered for a Nobel Prize."

Since the ripples were created almost 15 billion years ago, their radiation has been travelling toward Earth at the speed of light. By detecting the radiation, Cobe is "a wonderful time machine" able to view the young universe, Dr Smoot said.

A remnant glow from the Big Bang is still around today, in the form of microwave radiation that has bathed the universe for the billions of years since the explosion. Galaxies must have formed by growing gravitational forces bringing matter together. To produce a "lumpy" universe, radiation from the Big Bang should itself show signs of being lumpy.

Cobe, which has been orbiting 500 miles above the Earth, since the end of 1989, has instruments on board that are sensitive to this extremely old radiation. The ripples Cobe has found are the first hard evidence of the long-sought lumpiness in the radiation.

Cobe detected almost imperceptible variations in the temperature of the radiation, which measures 270C below zero. Those variations — only about thirty-millionths of a degree — represent slight differences in the density of matter at the edge of the universe, ripples of wispy clouds surrounded by slightly less dense matter, the scientists said yesterday. The smallest ripples the satellite picked up stretch across 500 million light years of space.

Cobe has taken a snapshot of the universe just 300,000 years after Big Bang itself — at a point in time when the foggy fireball of radiation and matter produced by the explosion cooled down. "The results also show that the idea of a Big Bang model is once again brilliantly successful," Professor Rowan-Robinson, of London University, said.

He described the ripples as similar to the chaotic pattern of waves you might see from an aeroplane window flying over an ocean. "I can be pretty confident now that if we had an even bigger telescope in space we could see the fluctuations that are the early signs of individual galaxies themselves. It's just a matter of technology now," he added.

The point in time of Cobe's snapshot is known as "the epoch of recombination". At this point, the early galaxies began to form and light from these galaxies, released from the foggy soup of radiation, was set free to be picked up by modern astronomers with their telescopes.

"Further analysis of Cobe's results will shed light on the identity of the mysterious dark matter that we know contributes most of the mass of the universe," Dr Carlos Frenk, of Durham University, said yesterday. This mystery dark matter is scientists' best guess at explaining why the universe is lumpy.

Astronomers have worked out that, for today's galaxies to have formed, there ought to be far more matter around than they have observed. One of the leading theories to get round this is the Dark Matter theory, which says that about 99 per cent of the matter of the universe is invisible to us. This theory predicts fluctuations in the background radiation of exactly the size Cobe has observed. "Because these had not been seen, the theoreticians were beginning to get worried that they had got it wrong," Professor Rowan-Robinson said.

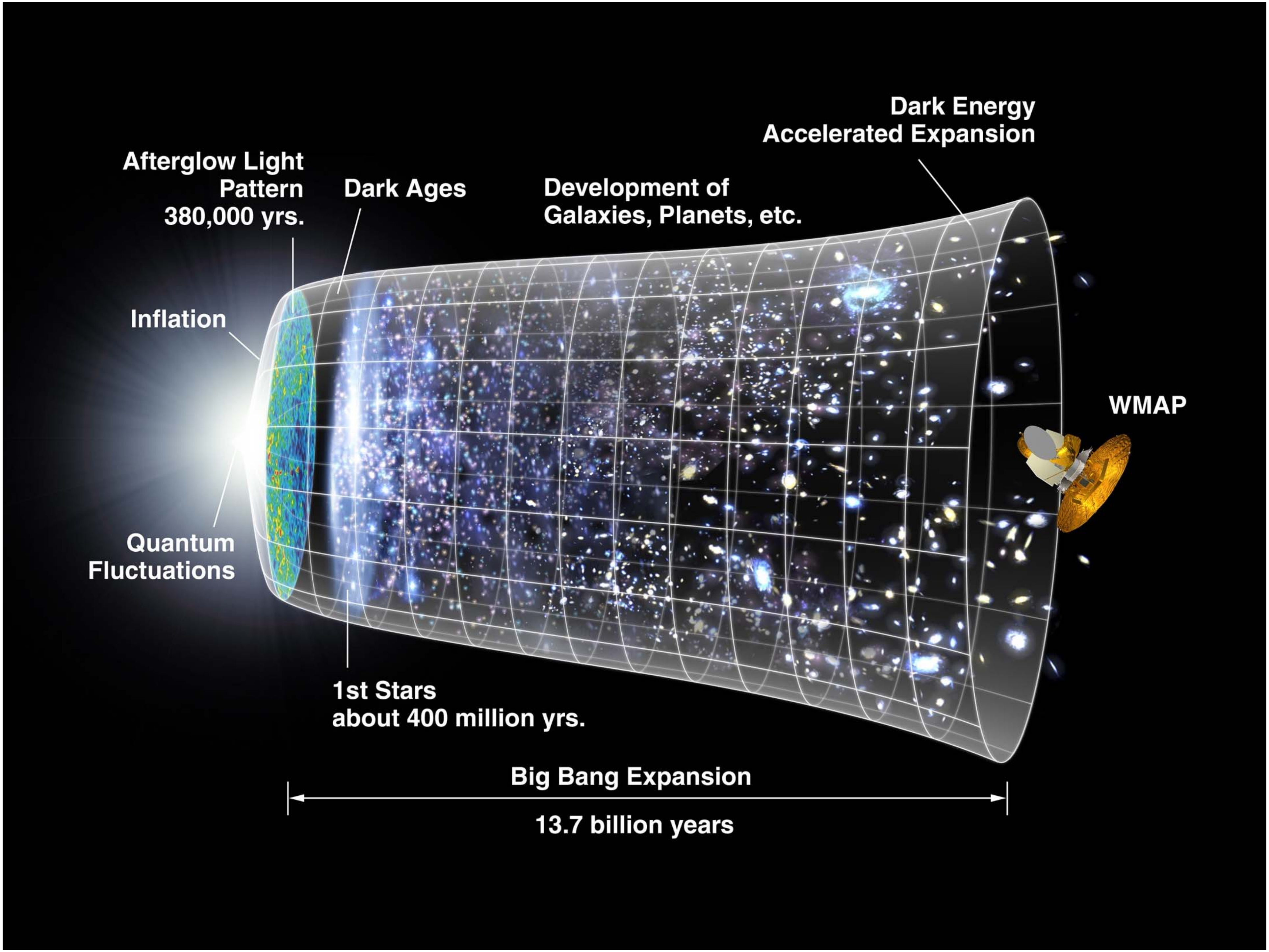
"If Cobe had found no ripples the theoreticians would have been in disarray; their best shot at understanding how galaxies were formed would have been disproved," he added. "The cold dark matter theory is a very beautiful one which makes very exact predictions about what the size of these fluctuations should be. How big they are depends on how fast they are able to grow. These results are just the size that the theory predicts. People have been looking for this kind of variation since the 1950s."

However, Arnold Wolfendale, the Astronomer Royal, sounded a note of caution. He said the scientific community must examine the results before shouting too loudly about their importance.

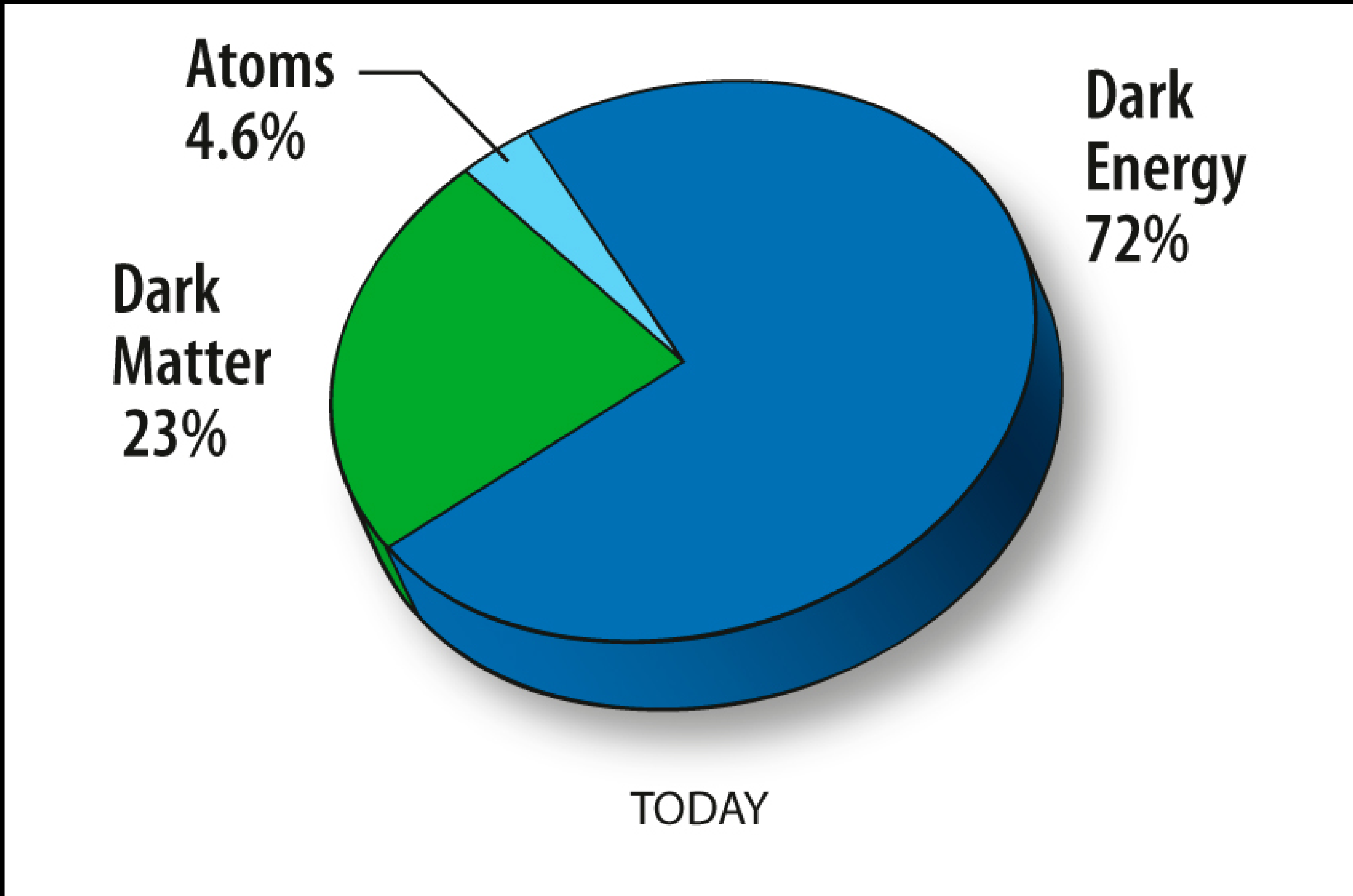
"There is no doubt that, if verified, this is a very important result. Detecting these small fluctuations is very difficult. Another group reported having picked up similar fluctuations last year, then later found they were due to cosmic rays. At the frequencies our colleagues in the US are working at, cosmic rays should not be a problem, but there is dust between the stars which can also produce radiation and make you think it is cosmological."

Martin Rees, Professor of Astrophysics at Cambridge University, said: "We needed equipment sensitive enough to pick up these fluctuations. We can expect in the next year or so there will be other observations from the ground corroborating this."

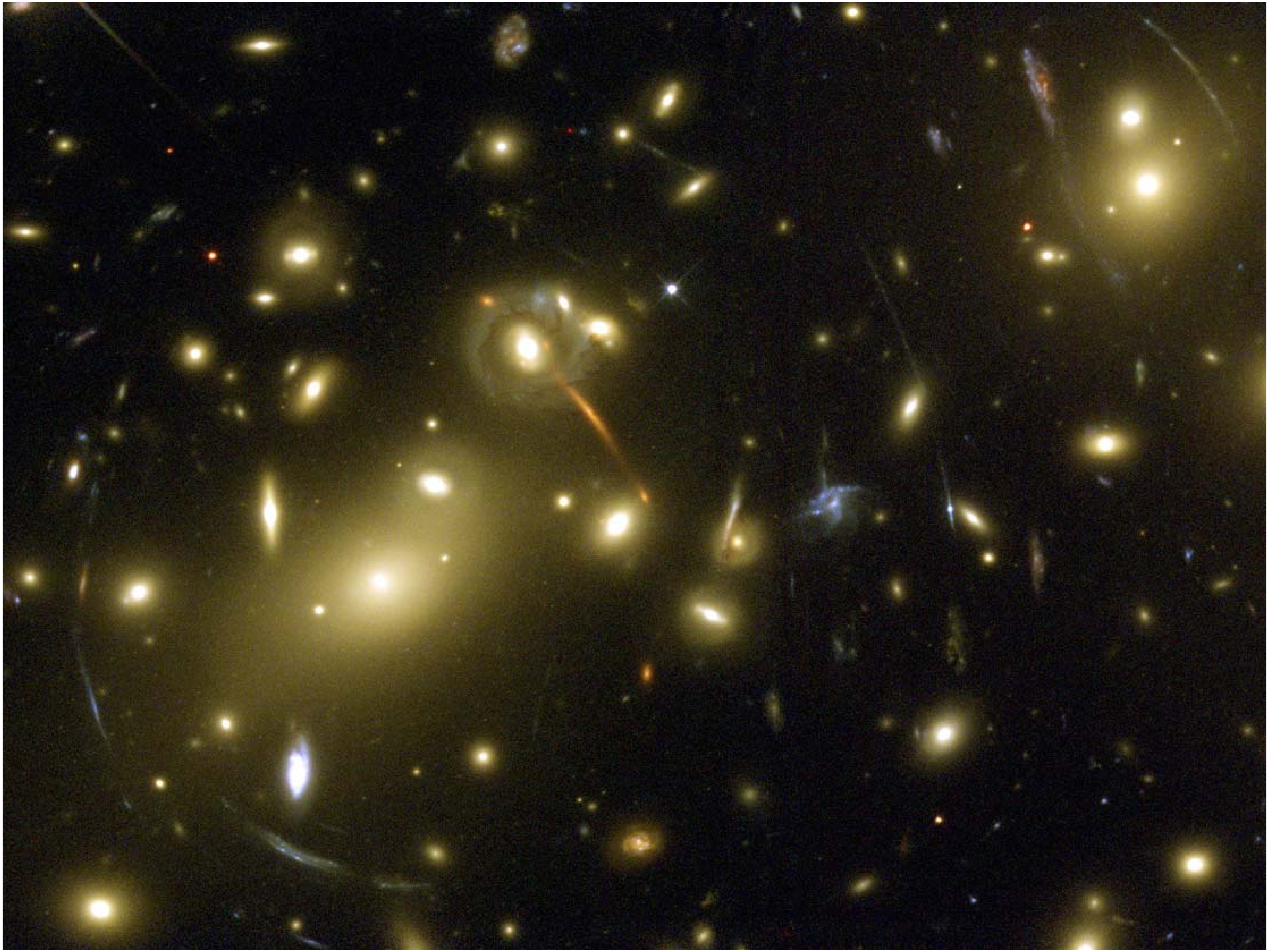
He said the results opened up a whole new area of astronomy. "Now we have seen them we can start analysing them. We can learn a lot about the history of the universe — what happened when. We might find, for example, that there was a second foggy era after the original fog lifted."

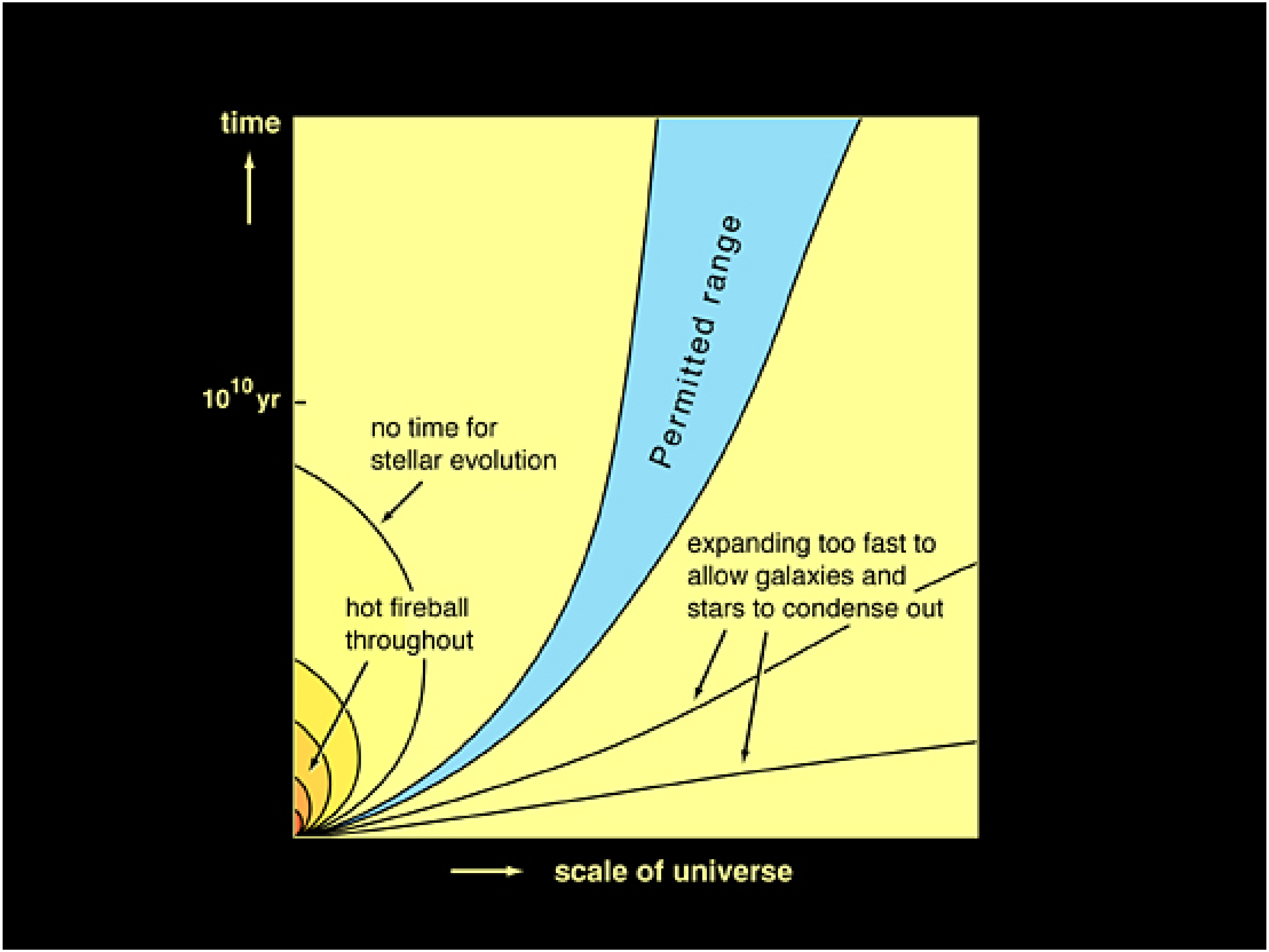


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
380,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

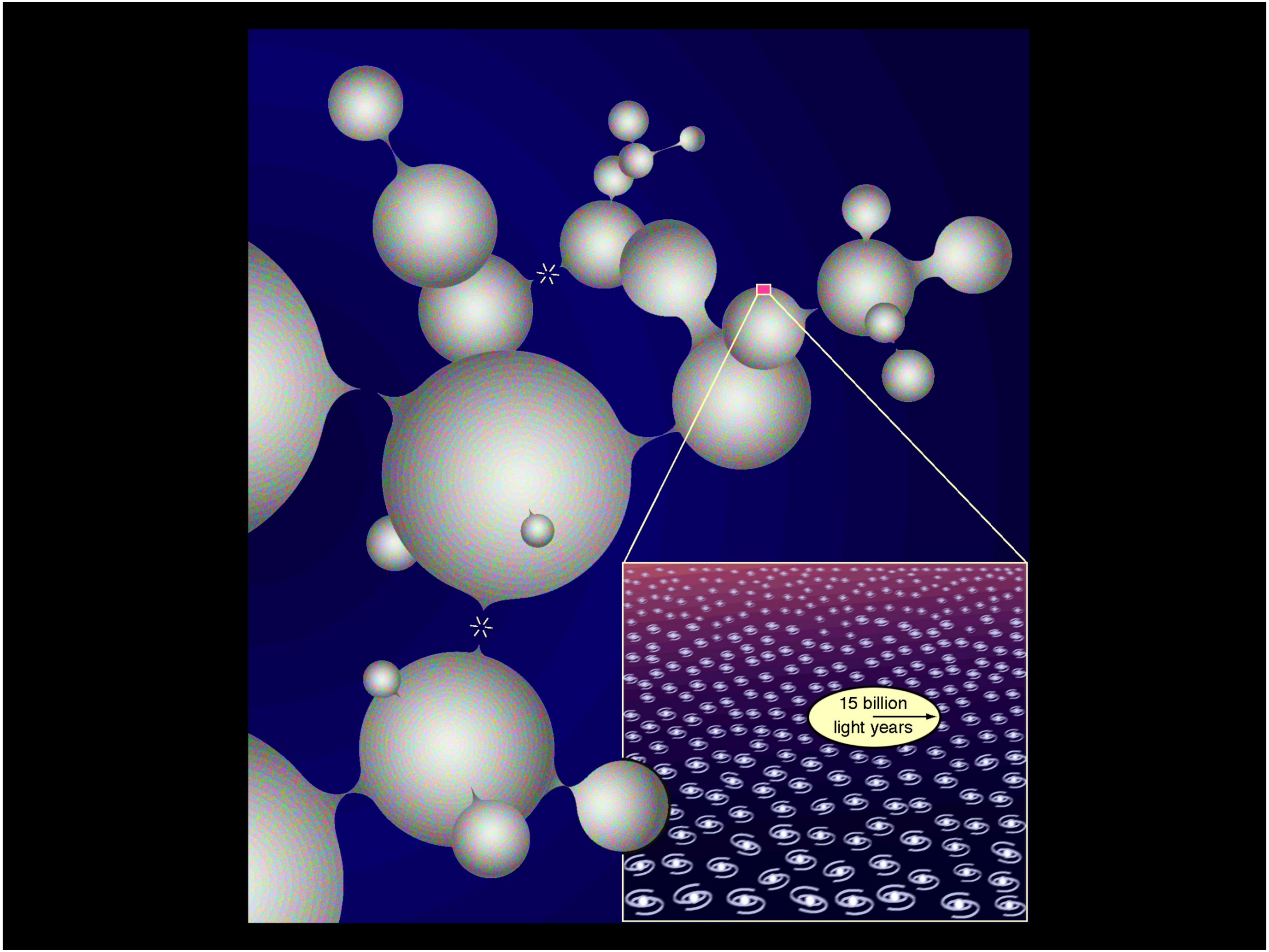


13.7 BILLION YEARS





time
10^{10} yr
no time for
stellar evolution
Permitted range
hot fireball
throughout
expanding too fast to
allow galaxies and
stars to condense out
scale of universe


15 billion
light years