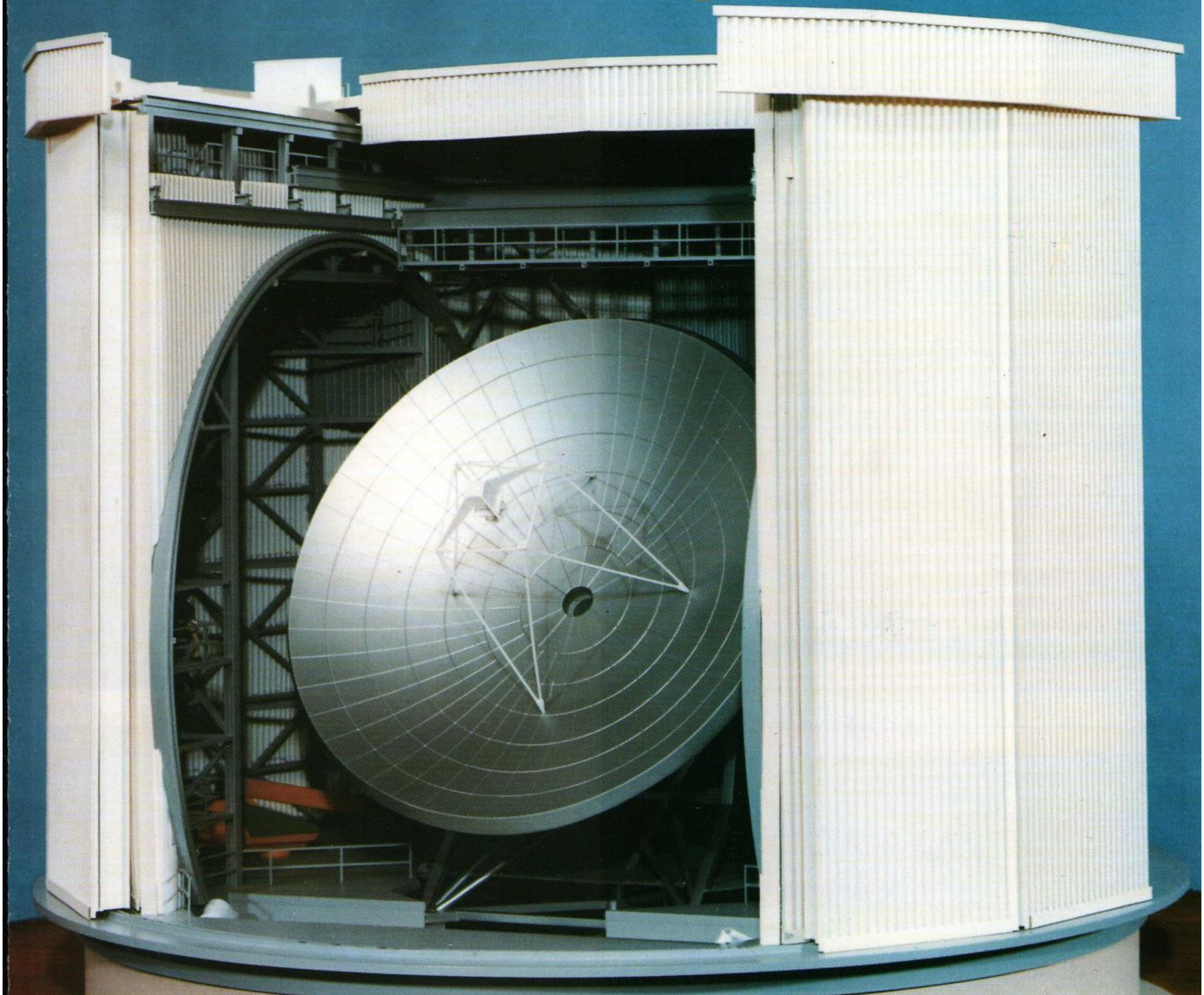
James Clerk Maxwell Telescope



The James Clerk Maxwell Telescope will be the largest telescope in the world for observations in the submillimetre region of the spectrum. It is being built jointly by the United Kingdom and the Netherlands with funds provided in the ratio of 4:1 by the Science and Engineering Research Council (SERC) and the Nederlandse Organisatie voor Zuiver-Wetenschappelijk Onderzoek (ZWO). By arrangement with the University of Hawaii it is being installed at the Mauna Kea Observatory on the island of Hawaii.

JAMES CLERK MAXWELL
(1831–1879)

The Science

The last of the wavebands still to be opened up for astronomical exploration by ground-based telescopes are the millimetre and submillimetre regions of the spectrum.

A few examples of the types of study which will become possible with the James Clerk Maxwell Telescope are as follows:—

- It is now known that stars form in dense regions of interstellar gas which are opaque to optical radiation. However, at infrared and millimetre wavelengths these regions are transparent and it is possible to investigate the detailed processes going on inside them by observations in these wavebands. There are many different ways in which millimetre and submillimetre observations can help elucidate the properties of these regions. The regions are cool and very rich in molecular gases. The radiation emitted in the form of molecular lines is one of the most important tracers of the physical properties of these regions. The densities and temperatures of the clouds can be determined as well as the motions in the gases. In this way, it is hoped that much better understanding can be gained of the processes by which stars form. This is one of the key problems of modern astronomy.

- Because of the richness of the molecular line spectra of these regions, it is possible to map out in detail the distribution of different chemical species within molecular clouds. This is one of the most interesting fields for the relatively new discipline of interstellar chemistry. The densities found in interstellar clouds are much lower than those found in terrestrial laboratories and consequently many rare molecular species can survive in the interstellar gas.

Right: The Orion nebula is the closest region of active star formation to the Earth. (Photograph by David Malin using the Anglo-Australian Telescope.)

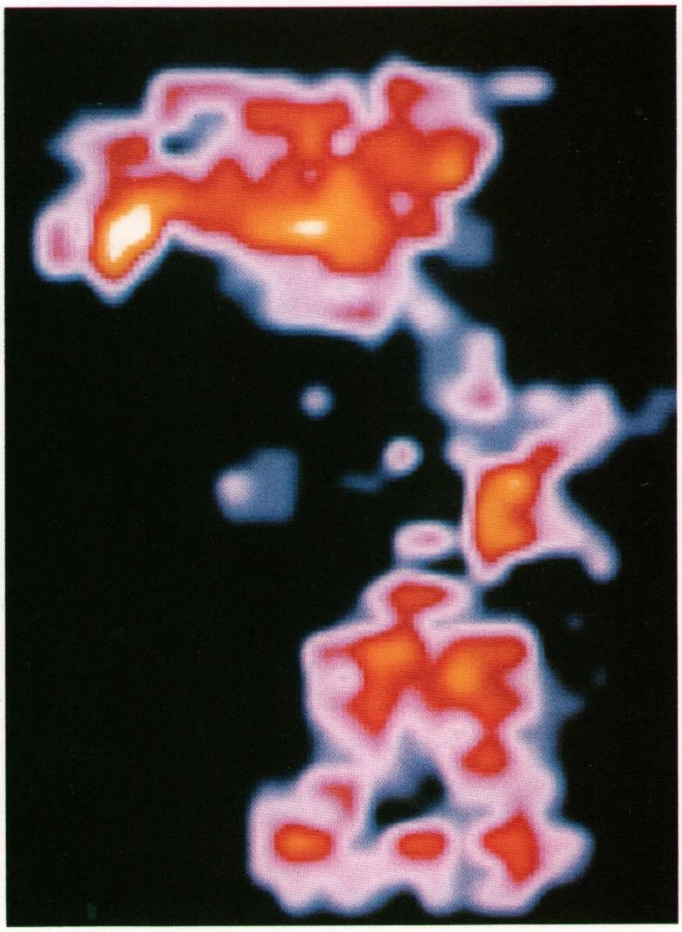
- The use of molecular line radiation as a tracer of the abundances of different chemical species in different locations within galaxies is an ideal method of studying the chemical evolution of the material out of which the stars in galaxies are formed. It will be particularly helpful in understanding whether or not nucleosynthesis (the production of heavier elements from lighter ones) has occurred uniformly throughout galaxies, whether or not infall of matter from other galaxies or intergalactic space is important and how the regions around stars are enriched by the products of stellar nucleosynthesis.

- The continuum radiation emitted by the cool dust clouds in which stars form is detectable at submillimetre wavelengths. These regions need to be studied with high angular resolution to identify the regions where the youngest stars and their precursors, the protostars, are forming.

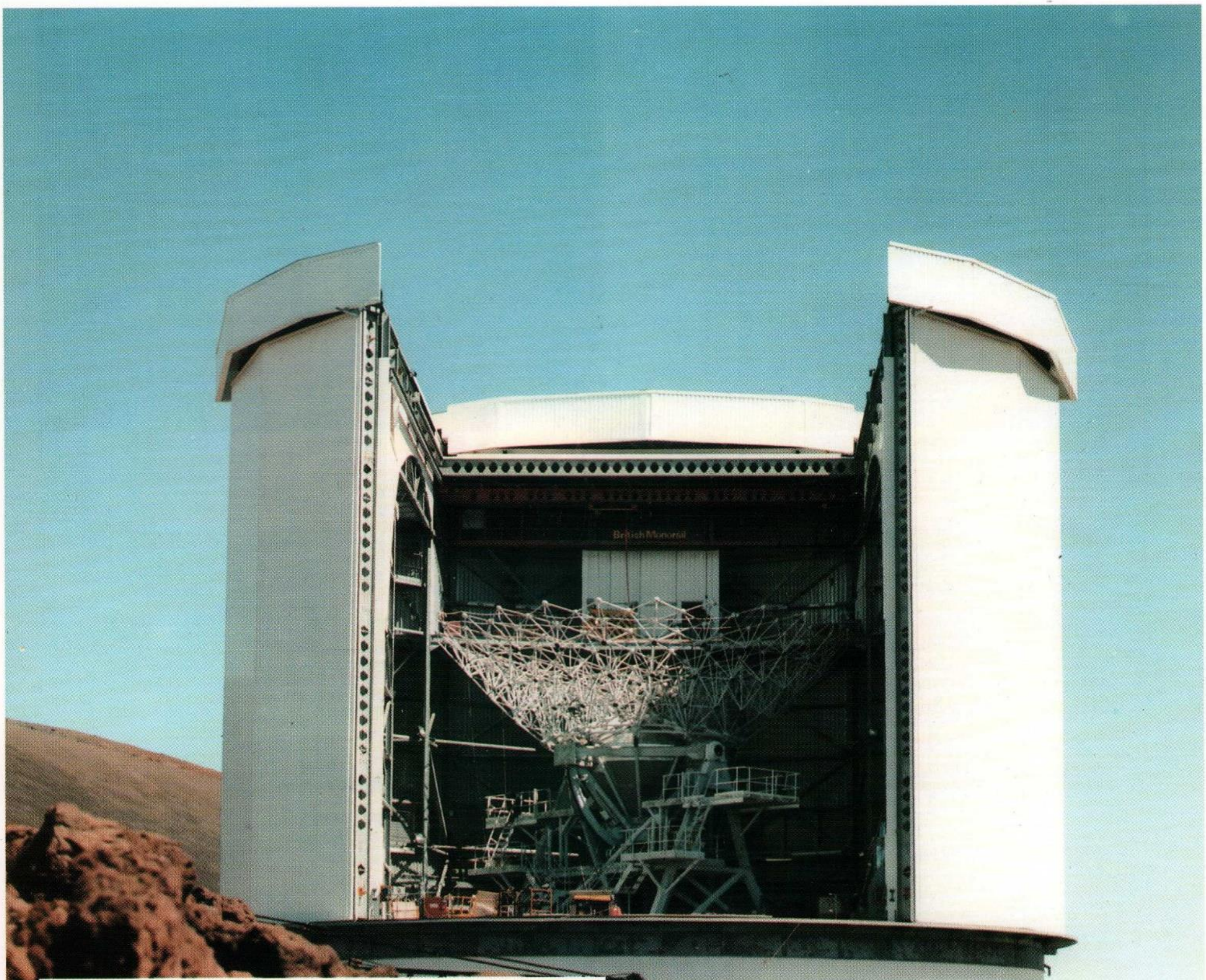
- The nuclei of active galaxies like quasars are strong sources in the submillimetre waveband and the determination of their spectra and time variability is very important for understanding the total energy demand of the active nuclei and also the physical conditions in the most extreme conditions within such nuclei.

- Many sensitive tests are possible involving fluctuations in the microwave background radiation. This radiation permeates the whole of space and is the cool relic of the hot early phases of the Universe. There are many reasons why there should be small ripples in this radiation related to the origin and evolution of galaxies and some of these effects can be studied uniquely in the submillimetre waveband.

Right: The distribution of molecular hydrogen in the vicinity of the region of star formation in the gaseous nebula Messier 17. (Observations made with the UK Infrared Telescope.)



The Telescope



The completed telescope structures, in the enclosure, during construction in 1985.

The telescope is of the classical Cassegrain type with a 15 metres diameter paraboloidal primary reflector and a 75 centimetres hyperboloidal secondary reflector. The primary surface is produced by supporting 276 lightweight aluminium panels on a mild steel space frame designed to deform uniformly as the elevation angle changes, in order to maintain a paraboloidal shape.

To operate efficiently at submillimetre wavelengths, ie, in the range 0.3–1.0 mm, the telescope must retain its paraboloidal shape to a very high accuracy. The formal specification calls for a surface accuracy of 50 microns (0.05 mm) (rms) under all operating conditions, guaranteeing efficient operation down to 0.8 mm wavelength. However, successful development of the surface panels, in particular, suggests that the accuracy will be close to 30 microns corresponding to efficient operation down to 0.5 mm wavelength.

To match the high resolution (10 arcseconds at 0.8 mm) associated with its diameter and accuracy, the pointing accuracy is specified to be 5 arcseconds absolutely and 2 arcseconds relatively.

The reflector system is supported on an altazimuth mount. Movements in elevation and azimuth are made using direct current torque motors acting through frictional contact.

The secondary mirror is adjustable in three mutually perpendicular directions and can be vibrated in the plane perpendicular to the 'optical' axis to allow background subtraction by on- and off-source measurements.

When completed in 1986, the telescope will be the world's largest telescope capable of observing efficiently at submillimetre wavelengths. There are, however, telescopes with similar formal specifications with respect to size and accuracy being built on the same timescale. The most notable of these are the three dishes for the IRAM interferometer which is under construction on the Plateau de Bure near Grenoble at an altitude of 2,500 metres.

The largest dishes at present able to operate efficiently in the submillimetre waveband are those of the California Institute of Technology which form a three dish interferometer in Owens Valley, California. A fourth dish of the same design and of 10.4 metres diameter is being built on Mauna Kea some 150 metres away from the James Clerk Maxwell Telescope.

Inset right: Section of a surface panel, showing one of the remotely controlled adjusters.

The Receivers

Sophisticated solid state detectors, often cooled to the temperature of boiling liquid helium (4.2 K), form the basis of many submillimetre receiving systems. Using heterodyne techniques in accurately made mixers, signals of a few hundred gigahertz (GHz) (1 gigahertz = 1,000,000,000 cycles per second) are reduced to frequencies which then can be amplified, filtered and analysed to produce line spectra corresponding to transitions in the many molecules found in space.

Other detectors, using bolometric techniques, receive energy over a continuous spectrum of frequencies covering the full range of the telescope. Separation into sub-divisions of the spectrum is achieved by filters on the input side of the system.

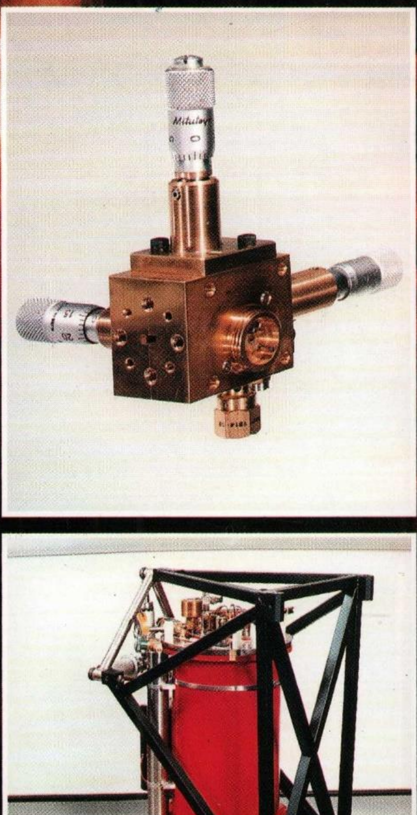
The initial set of receivers will consist of:

- a continuum receiver with a set of filters, including filters for 150, 225, 345, 470 and 690 GHz.
- two heterodyne line receivers based on cooled Schottky diode detectors to operate at 230/270 GHz and 345 GHz.
- a line receiver based on a cooled indium antimonide detector to operate at 490 GHz.

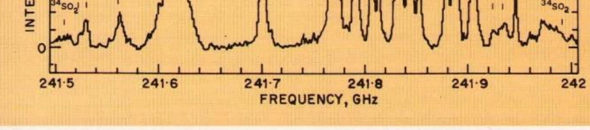
Top left: High frequency doubler for microwave receiver, made at the Rutherford Appleton Laboratory.

Bottom left: Continuum receiver for the frequency range 115 to 800 GHz, constructed at the Royal Observatory, Edinburgh.

Main picture: Colour coded view of the Orion nebula from the IRAS survey, showing molecular clouds which will be objects of interest for the James Clerk Maxwell Telescope.



Part of line spectra obtained using a heterodyne receiver at the Owens Valley Observatory of the California Institute of Technology. (Ref: Sutton, E. C., Blake, G. A., Masson, C. R., Phillips, T. G., Astrophysical Journal)



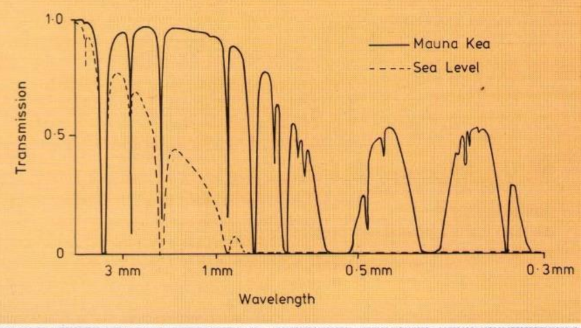
The Site

At submillimetre wavelengths, water vapour in the atmosphere attenuates strongly the radiation from astronomical objects. For this reason, the telescope needs to be at a high site to be above as much of the water vapour as possible.

Isolated high mountains on islands are particularly good sites because the absence of large land masses reduces convection which would lift water vapour to higher altitudes. The volcanic mountain of Mauna Kea, at an altitude of 4,200 metres, on the island of Hawaii, is the best site in the world where there is an established observatory. This observatory, which is operated by the University of Hawaii, already has six telescopes in operation. These include some of the finest optical and infrared telescopes in the world. The United Kingdom Infrared Telescope (UKIRT), which is operated by the Royal Observatory, Edinburgh, at 3.8 metres diameter is the world's largest infrared telescope.

Aerial view of Mauna Kea Observatory, (Courtesy of the Institute for Astronomy, Honolulu).

Atmospheric transmission at millimetre and submillimetre wavelengths.



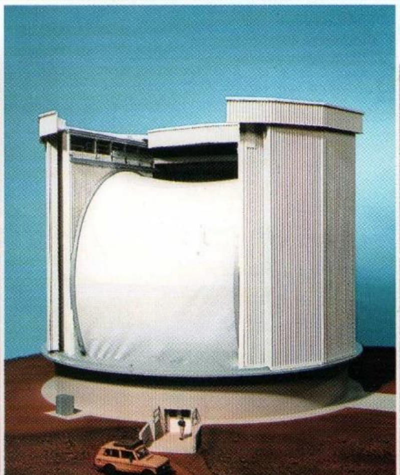
The Enclosure

The enclosure with the roof shutters and doors closed, September 1985.

The environmental conditions on Mauna Kea can be harsh. Winds in excess of 150 km/h are experienced and the air temperature varies between + 10°C and − 5°C. Significant falls of snow can occur but the biggest problem is ice which can form horizontally to a thickness of more than 30 centimetres.

To protect the telescope and allow the surface accuracy to be maintained it is contained in an enclosure which rotates with it. The viewing aperture is, unusually, covered with a membrane of woven polytetrafluoroethylene which will allow operation up to 70 km/h wind speed. For higher wind speeds, the doors and roof shutters will be closed to provide protection up to 200 km/h. The membrane material not only has a transparency of greater than 90% over the operational waveband but also protects the surface of the telescope by transmitting no more than 20% of the incident solar radiation. The building, which weighs some 450 tonnes and is 22.3 metres high and 28 metres diameter, can be rotated in ten minutes.

Inset: Model showing the enclosure with the membrane in position.



The Organisation

RUTHERFORD APPLETON LABORATORY, OXFORDSHIRE

Overall responsibility for management of the project during the construction phase. Design of the enclosure and antenna including development and manufacture of the surface panels.

Development of high frequency mixers for the receiver systems.

ROYAL OBSERVATORY, EDINBURGH

Responsible for development and construction of the first continuum receiver with Queen Mary College. Responsible for operation of the facility after it has been commissioned.

MRAO, UNIVERSITY OF CAMBRIDGE

Responsible for detailed guidance on the scientific aspects of the project. Partnership with Rutherford Appleton Laboratory in the design of the antenna. Development of the microprocessor system for control and monitoring, together with the software for data analysis. Construction of the first (230 GHz) heterodyne receiver.

NFRA, DWINGELOO THE NETHERLANDS

Responsible for receiver development and the construction of the 345 GHz line receiver with the University of Utrecht. Thermal analysis of complete facility.

QUEEN MARY COLLEGE, LONDON

Responsible for the electromagnetic analysis of the antenna and for receiver development including the detector for the 490 GHz receiver and filters for the continuum receiver.

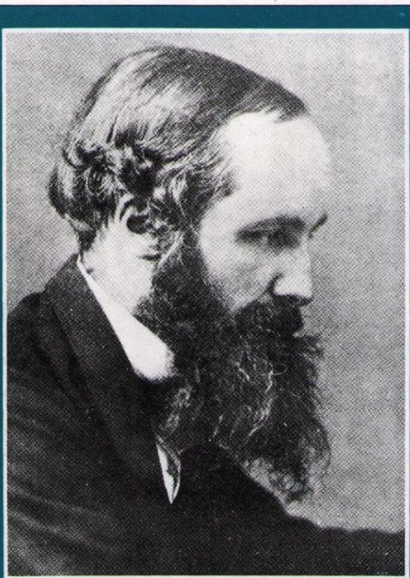
UNIVERSITY OF UTRECHT

Responsible for the design, development and construction of the secondary mirror system. Developed the acousto-optic spectrometer for the 345 GHz receiver.

OTHER PARTICIPANTS:

University of Kent—receiver correlator and detector development
Laboratory for Space Research Groningen—receiver development

James Clerk Maxwell



As the father of electromagnetism, whose equations have described the foundations of astronomy, it is appropriate that James Clerk Maxwell should be honoured by associating his name with the world's largest submillimetre wave telescope.

Maxwell was born in Edinburgh in 1831 and was educated at that University. He later became the first Cavendish Professor of Physics at the University of Cambridge. His contributions to physics spanned essentially the whole of the discipline but his key contributions lay in the theory of electromagnetism and in the kinetic theory of gases. In the latter field he discovered the velocity distribution of atoms and molecules in gas, known as the Maxwell Velocity Distribution.

Of greater relevance to astronomy, he discovered the laws of electromagnetism through a brilliant piece of mathematical physics. In making these discoveries he showed that light is a form of electromagnetic radiation.

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