

THE WEBERSAT CAMERA:
AN INEXPENSIVE EARTH IMAGING SYSTEM

by Stephen Jackson & Jeffrey Raetzke

Abstract:

WEBERSAT, a 27 pound LEO satellite launched by the Ariane 40 on January 21, 1990 into a 500 mile polar orbit, carries several payload experiments that were developed as a learning experience for engineering students at Weber State University. The experiments include a modified color CCD camera and video flash digitizer.

Operational command and control of the spacecraft and its payloads is performed by students in the College of Applied Science & Technology, from a ground station located on the WSU campus. Here, the students and their advisors monitor on-board systems, plan & execute experiments, and observe test results.

This paper describes the satellite's on-board camera system and will discuss video experiment results to date.

INTRODUCTION

Background

WeberSat is a small, yet sophisticated satellite now available for experimental and educational use by interested groups and individuals. It is one of four "MicroSats" developed by the Radio Amateur Satellite Corporation (AMSAT), in cooperation with the Center for Aerospace Technology (CAST) at Weber State University. WeberSat was launched from Kourou, French Guiana aboard ESA's Ariane 40 vehicle on January 21, 1990. It is WSU's second major satellite project, and involves undergraduate students, faculty, and industry advisors from many disciplines.

The 27 pound, 9" x 9" x 12.5" satellite is in a 500 mile, sun-synchronous, polar orbit with a period of 100.7 minutes.

Four to six passes per day are visible from the ground station at WSU.

Like the other MicroSats, WeberSat is an amateur radio satellite capable of store-and-forward message handling, and uses the amateur packet (AX.25) protocol for all data transmissions. WeberSat differs from its three cousins in that it contains a number of experiments in an extra "attic" module. (FIGURE 1.)

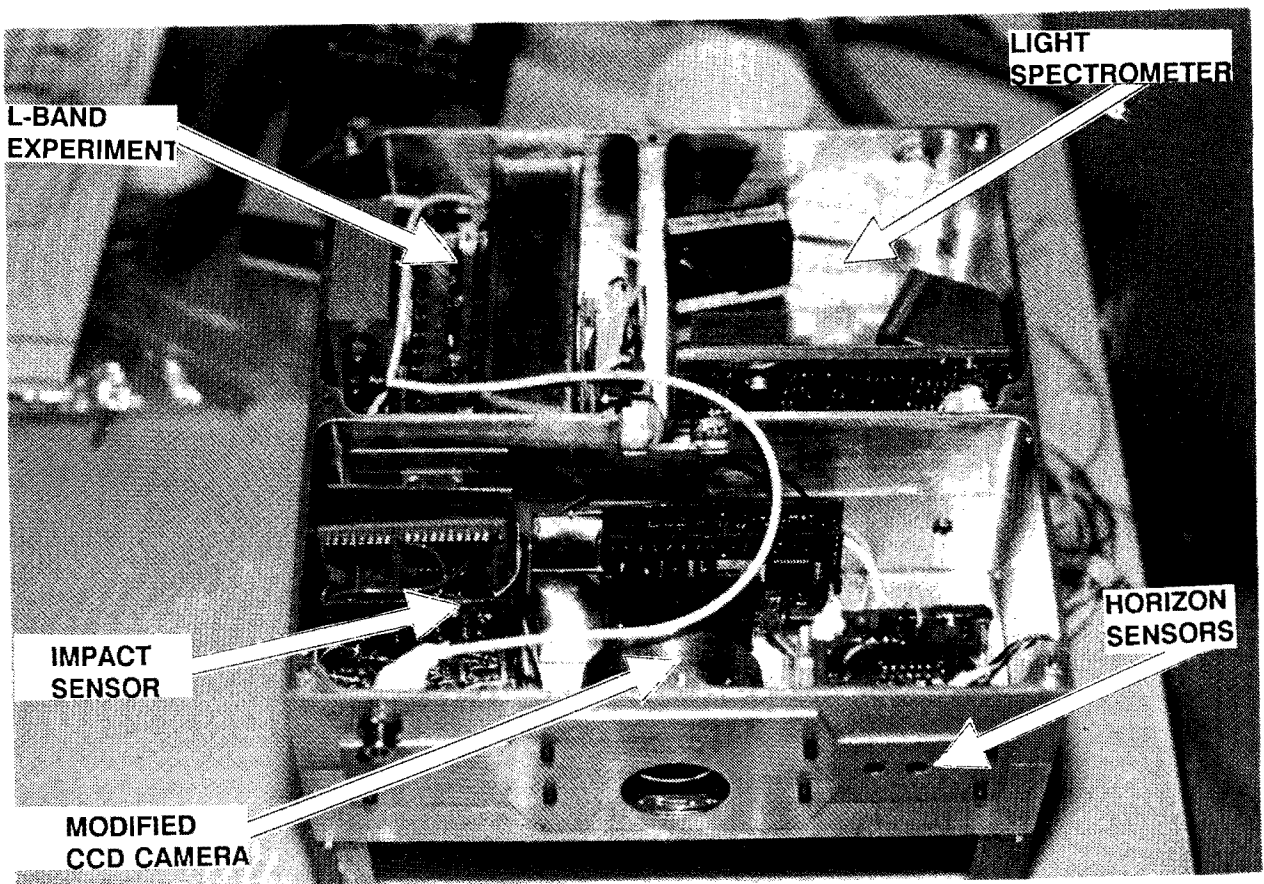


Figure 1
THE WEBERSAT ATTIC MODULE

As shown in FIGURE 2, the satellite has six sections vertically stacked, which communicate through an on board local area network. The top two modules form the "attic" which contains various experiments, including:

- Micro Meteor Impact Sensor
- L-Band Video Uplink Receiver
- Horizon Sensor
- CCD Color Camera
- CCD Light Spectrometer
- Video Flash Digitizer.

Scope

The major topics that will be discussed in this paper are: the mission of the camera, the camera specifications, results to date, difficulties in shooting quality pictures, and the steps taken to overcome some of these problems.

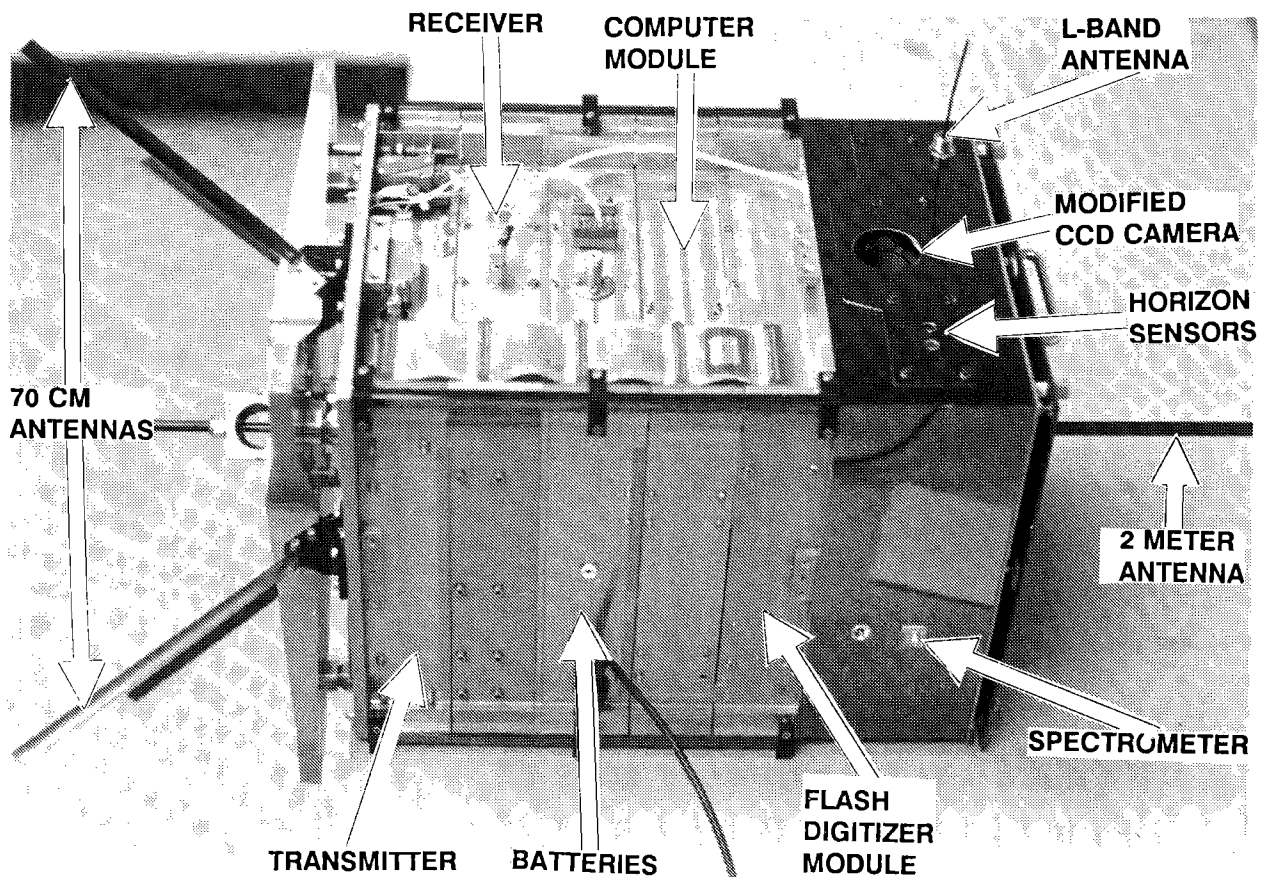


Figure 2
WeberSat's Modular Construction

Camera Mission Overview

The mission of the camera system is to provide images of the earth, moon, sun, and stars with a modified, off the shelf, low cost, Charged Coupled Device (CCD) camera. This serves as a platform for various experiments and projects which provide Engineering Technology students with the opportunity to plan, execute and analyze images from space, giving a real world dimension to their other assignments.

CCD Color Camera

WeberSat's CCD color camera (FIGURE 3) is a modified Canon CI-10 with a 25 mm lens and automatic iris. It has 780 x 490 pixel resolution, and from its 500 mile orbit can see an area of 170 x 135 miles when it is looking straight down. The following changes were made to the basic design in order to make the camera space worthy:

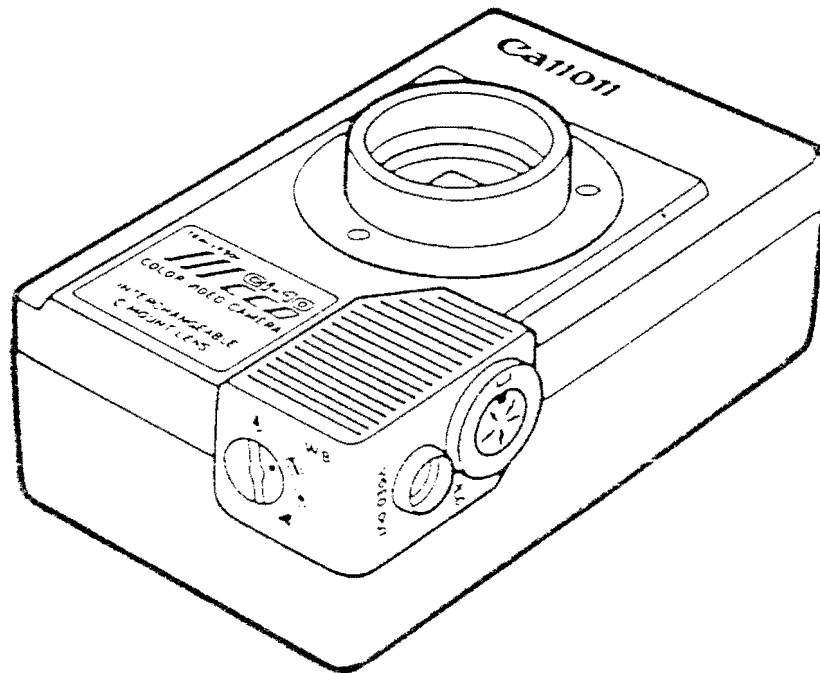


Figure 3
WeberSat's unmodified CCD Camera

- 1) Replaced iris range control potentiometer with a programmable potentiometer to accommodate widely varying brightness levels.
- 2) Added a 10.7 MHz digitization clock, phase-locked with the 3.579545 MHz color reference.
- 3) Replaced focusing mechanism with a fixed focus support.
- 4) Replaced aluminum electrolytic capacitors with solid tantalum capacitors.

Camera output signals, composite video, red, green, blue, and the 10.7 MHz digitization clock are fed to the flash digitizer, where they are processed for storage in the spacecraft computer RAM.

Camera control commands are stored and executed via the on board computer. The command information includes desired shoot time, horizon sensor or array illumination constraints, and iris settle-in delay. The on board software also controls the iris potentiometer setting, and the time-out delay for the horizon search. Uploaded command information can be routinely varied for each picture as desired. However, actual software changes are more complex due to the extensive simulations required to ensure safe operation.

On power-up, the camera draws a surge current of three amperes. This quickly drops off to the nominal value of 360mA at 10 volts. As this is normally the power budget for the entire spacecraft, the camera remains on only as long as necessary to complete the programmed photo sequence. This is insured by software and firmware safeguards.

Method of Image Acquisition

WSU's student ground crew is responsible for planning & executing takes, and analyzing the picture data. The process of taking a picture basically consists of determining the target, setting the appropriate sensor constraints so that the satellite CPU knows when it has acquired the target, and setting the maximum iris size & settling time. The step-by-step process evolved as follows:

- 1) The operator must determine the time that the satellite will be over the target area and the appropriate iris setting for the target. This data is entered into a command called "Take". The iris constraint controls a feedback resistor in the automatic iris control circuit (FIGURE 4) which sets the maximum opening of the iris.

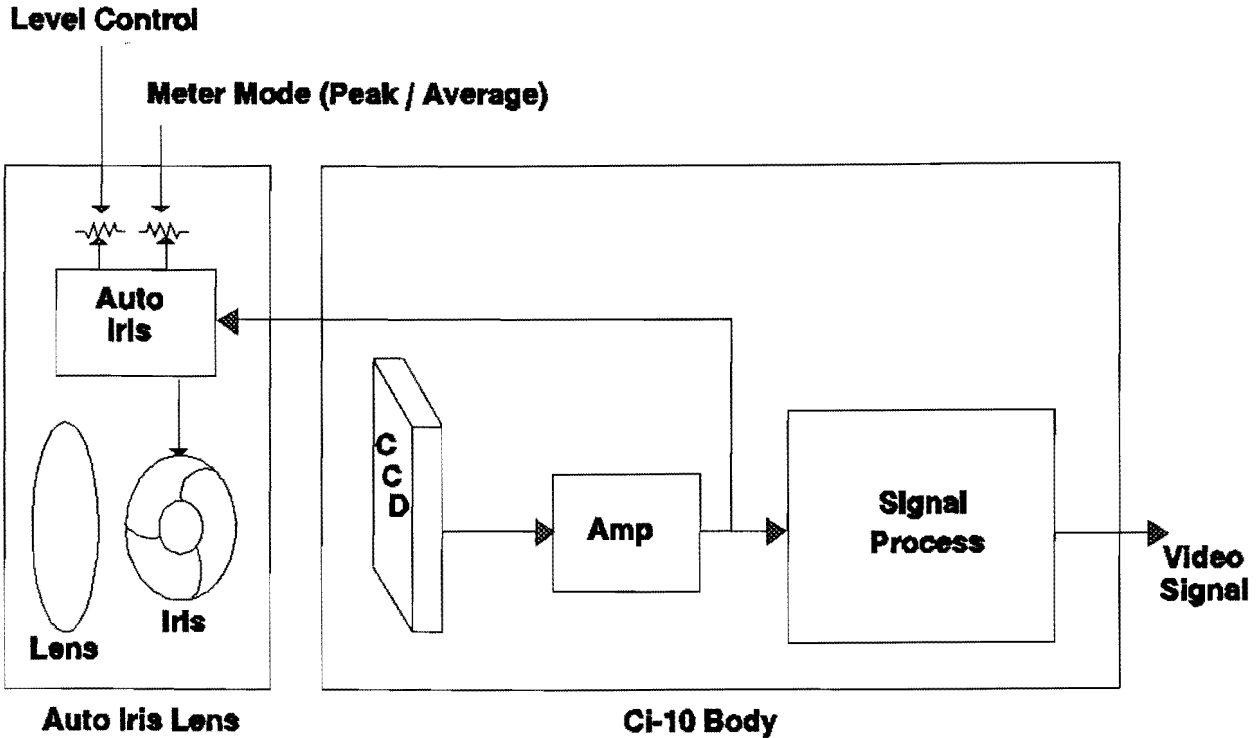


Figure 4: The Auto Iris Circuit

- 2) The operator must set up sensor parameters so the satellite knows when the camera is pointing at the desired object, such as the earth, sun, or deep space. There are two systems that can be set to accomplish this task: The horizon sensor which is composed of two photodiodes aimed through holes in the wall of the attic module, and the system of solar array current sensors which can be used to determine pointing angle from varying degrees of facet illumination.
- 3) The time out constraint, set by a separate command, is a safety value that forces the picture to be taken even though the photo parameters have not been met. This feature insures that the camera control algorithm will not cause the satellite's microprocessor to lock up, or the software to crash. The time-out delay is normally set at ten to fifteen minutes.

Development of the Image Acquisition Method

The current method of taking pictures is the result of months of observation, and has evolved from a shotgun approach to a more precise method. The first photo software went aboard the

satellite on February 22, 1990 and the first pictures were taken shortly thereafter. The first method used was to set the iris to a prelaunch value and shoot all twelve pictures using only horizon sensors to locate the targets. The photos were later analyzed with hope that the camera was pointing down for some of the shots.

This method was soon abandoned, as more was learned about the rotation rate of the spacecraft and its attitude variation with latitude. However, this approach still did produce some interesting pictures.

Due to the interaction of the passive attitude control magnets with Earth's magnetic field, it is known that the Z-axis of the spacecraft is parallel to the surface over the magnetic equator. After careful observation of Whole Orbit Data, it was found that the attitude changes sharply within +/- 30 degrees magnetic, producing pointing angles adverse to earth imaging beyond this range of latitudes.

The present method of imaging therefore concentrates efforts in this equatorial band where the probability of favorable attitude is greatest. In addition, solar array current value constraints are also used to determine the orientation of the satellite, as the horizon sensor data alone is sometimes "noisy". Most importantly, operators have now bracketed the proper iris settings which seem to provide the best earth images. These changes have resulted in roughly a 40% success rate as opposed to around 1% for the old system.

Problems & Fixes

Many of the early photos from the WeberSat camera were over or under exposed, seemingly regardless of the automatic iris control. Numerous attempts at manually commanding the iris size, and searching for possible software problems yielded no clues. A careful analysis of the on-orbit conditions proved helpful:

With 1.41×10^5 lux of Solar illumination at earth's orbital radius, and an average earth albedo of .39, the normal illumination seen by WeberSat when observing the earth is 5.5×10^4 lux.

The camera has a standard sensitivity of 200 lux at an aperture diameter of F/2.8, or 8.9mm. This means that an aperture of roughly F/46.5 or .538mm diameter is required for earth observation. This is a rather small aperture for a camera iris system originally intended for general industrial applications where standard steps range from F/2 to F/22.

The problem seemed clear: The auto-iris control couldn't accommodate the small aperture needed. A time delay feature was added to the next version of the software, allowing the camera to take pictures as the iris opened from full closure which the iris was known to do on power-up. This partial fix improved results, and permitted a number of excellent shots to be taken during the summer of 1990. However, results were not easily duplicated even with the same delay and nominal iris settings.

System characteristics remembered from ground tests, and considerable experimentation with delay values finally yielded another idea: The auto-iris was indeed working, but required much more time to step down to the aperture called for, it being so narrow.

By increasing the settling delay time by a factor of 100, and using what has been found to be nominal iris size values, repeatable, high quality earth images are now being produced.

More Questions

Several long-term observations have raised additional questions about WeberSat and its camera system. In particular, it has been noted over the past year and a half that the vast majority of valid photo attempts have occurred between the months of March and October.

This has generated some speculation that seasonal variations in either sun angle, spacecraft attitude, or both may adversely affect the probability of receiving valid photos during the winter months.

Additional observation will be required to firmly establish the existence and possible cause(s) of this anomaly.

Experiments

Among the WeberSat payloads, the CCD color camera has been the primary focus since launch, and several experiments have been performed. These experiments include: Taking pictures by moon light & during solar eclipses, testing various iris settings, and using the variety of sensors to help aim the camera as previously discussed. Imaging of the sun, moon and stars has been accomplished.

Applications

Low cost imaging systems combined with small satellite technology will allow various institutions to explore space applications that may not be practical with higher cost systems now available. The development of these low cost systems will allow more experimentation with space-based imaging, and make new commercial applications more cost effective.

Considerable potential exists for similar imaging systems in the areas of attitude sensing (sun, earth, moon, & star sensors) and remote inspection.

Results

WeberSat's camera system has provided interesting data, and a few surprises. The CCD camera has successfully imaged meteorological features of the earth, land masses and a number of astronomical objects.

One of the best earth pictures (Appendix 1, Figure 1) was taken April 14, 1991 over the Andaman sea. It shows clouds and a coast line of Sumatra.

The moon picture (Appendix 1, Figure 2) was taken March 21, 1991 as part of an experiment to image the earth by moon light. The image of the moon was unexpected because of the difficulty in detecting the relatively low reflected light level with the coarse sensors with which WeberSat is equipped.

The sun picture (Appendix 1, Figure 3) caused some concern that the extreme brightness could cause damage to the CCD array in the camera, but after careful analysis it was determined that there was no evidence of any degradation in the camera performance.

The horizon picture (Appendix 1, Figure 4) surprised the ground station team not because it is the best horizon picture to date but because there are also three stars or planets visible in the image. Star pictures were considered unlikely because it was thought that stars like reflected moon light would not be bright enough for the CCD to pick up with a fixed integration time of less than 1/60 second. The three dots on the lower right hand corner were first thought to be single event upsets (SEU)s. After closer examination, it was found that they were several pixels wide, meaning that they are not SEUs and are more likely to be stars or planets.

Several attempts were recently made to photograph the earth and Sun during a solar eclipse. Due to incorrect pointing angles, this experiment was unsuccessful. Valuable whole-orbit data was collected during the event, however.

The pictures mentioned are only a small sample of the very best photos to date. Pictures are taken on a continuing basis, and better images are being produced as techniques become more refined.

Conclusion

In conclusion, the WeberSat CCD camera demonstrates that a low cost camera can be used in space applications with only minor modification, and that excellent results can be achieved with such a system.

ACKNOWLEDGMENT

The design, development and launching of the WeberSat and other small satellites work at Weber State University is funded through a grant from the State of Utah Department of Community and Economic Development Centers of Excellence program. The authors would like to acknowledge the continuing technical support of Chris Williams, Bob Argyle and all the student, faculty and industry volunteers.

BIBLIOGRAPHY

"CCD Cameras: Digital Astrophotography is Here." by Michael Chibnik; Astronomy, October 1990, Vol. 18, P 66-74.

"MicroSat Eclipse Variation With Season" by Franklin Antonio; AMSAT-NA Technical Notes, 1990-FA-01.

The Space Shuttle Closed Circuit Television System" by Larry A. Freedman; IEEE pub. 0547-3578/81/0000-0023, 1981. Courtesy of B. Embrey, NASA/JSC.

Weather Satellite Users' Handbook, by Dr. Ralph E. Taggart [chp. 1, P 4; ARRL pub. 1990].

"WeberSat Operations and Experiment Results" by C. Bonsall, S. Jackson, J. Raetzke, et al.; Proceedings, 1990 AIAA/USU Small Satellite Conference."

Webersat Users' Manual, by Charles Bonsall et al.; Weber State University, Center for AeroSpace Technology, Ogden, Utah 84408, 1991.

APPENDIX 1:

IMAGES FROM WEBERSAT

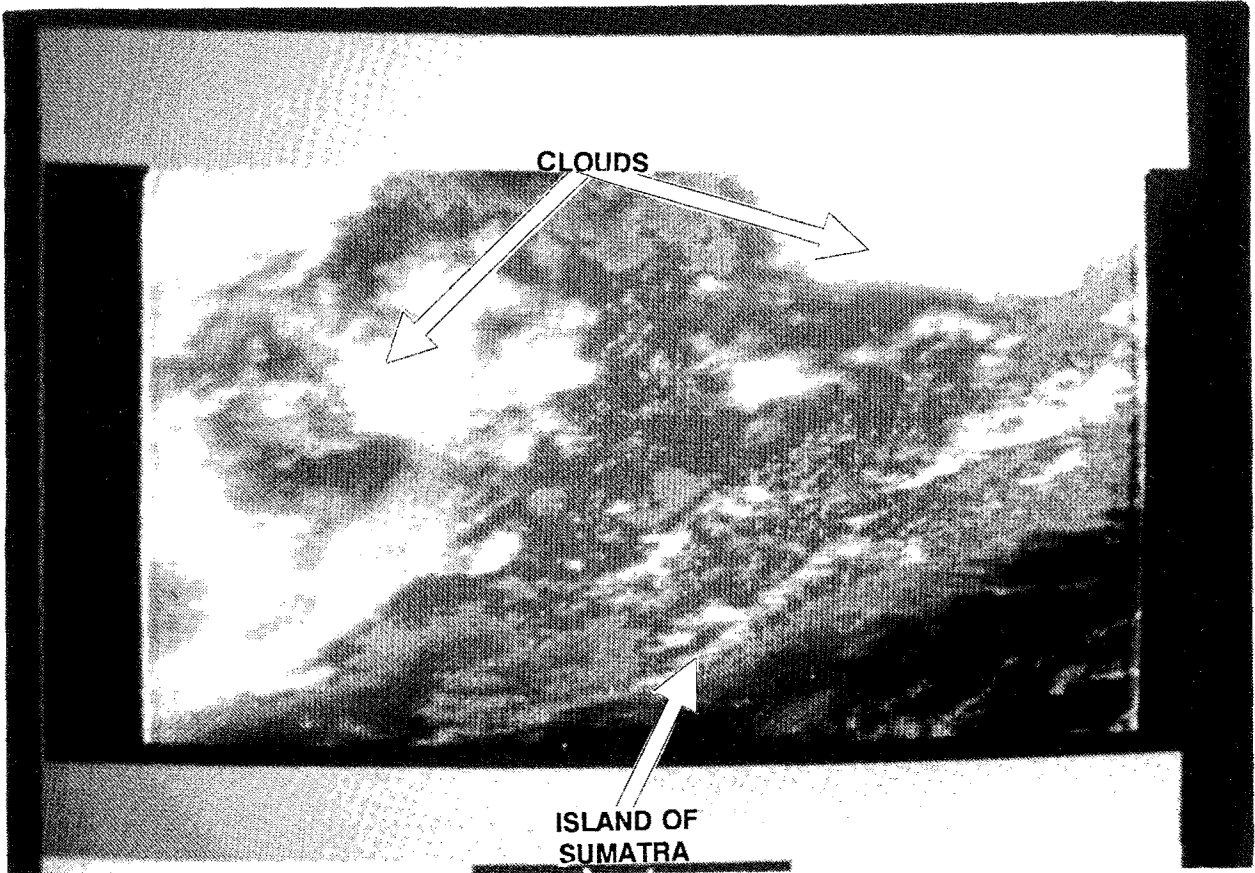


FIGURE 1
THE ANDAMAN SEA PICTURE
TAKEN APRIL 14, 1991

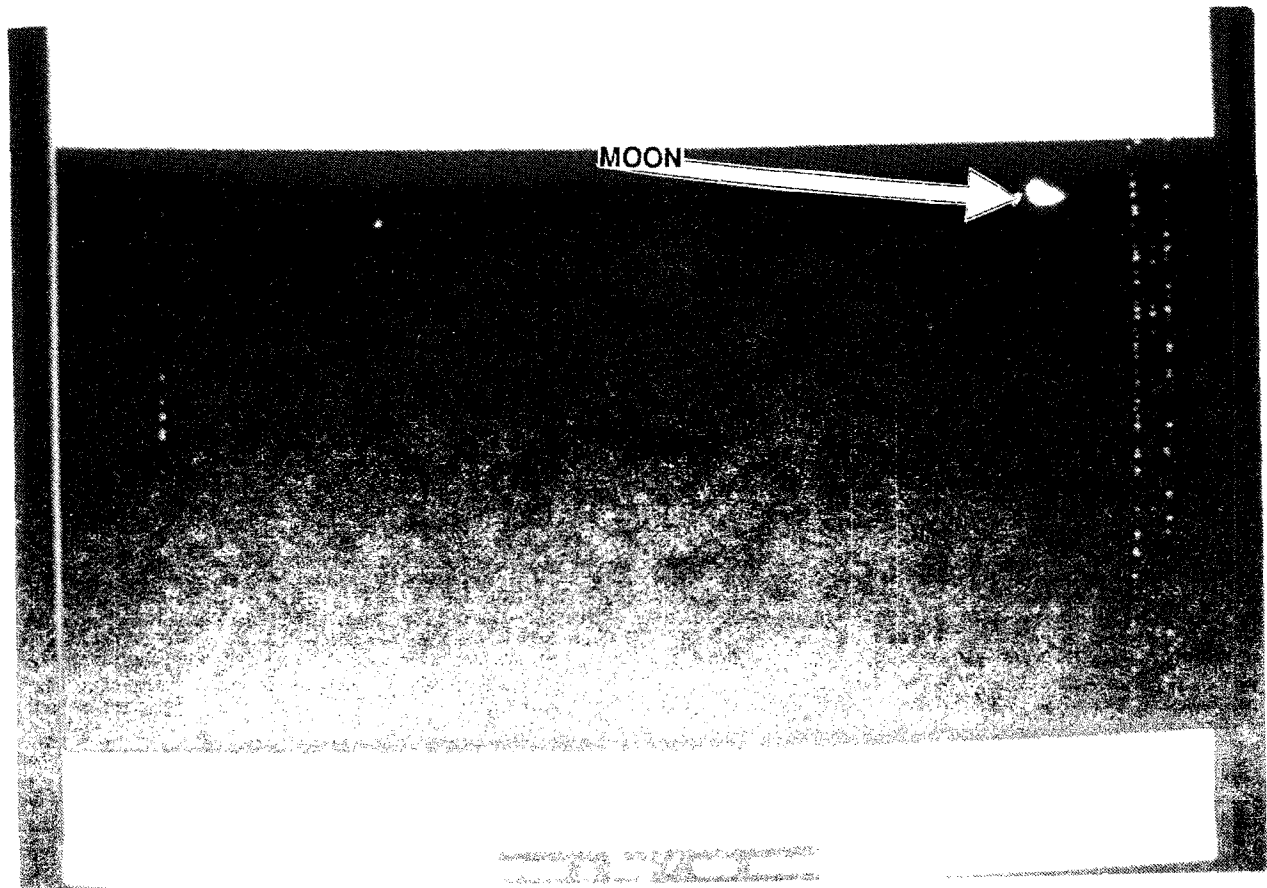


FIGURE 2
THE MOON PICTURE
TAKEN MARCH 21, 1991

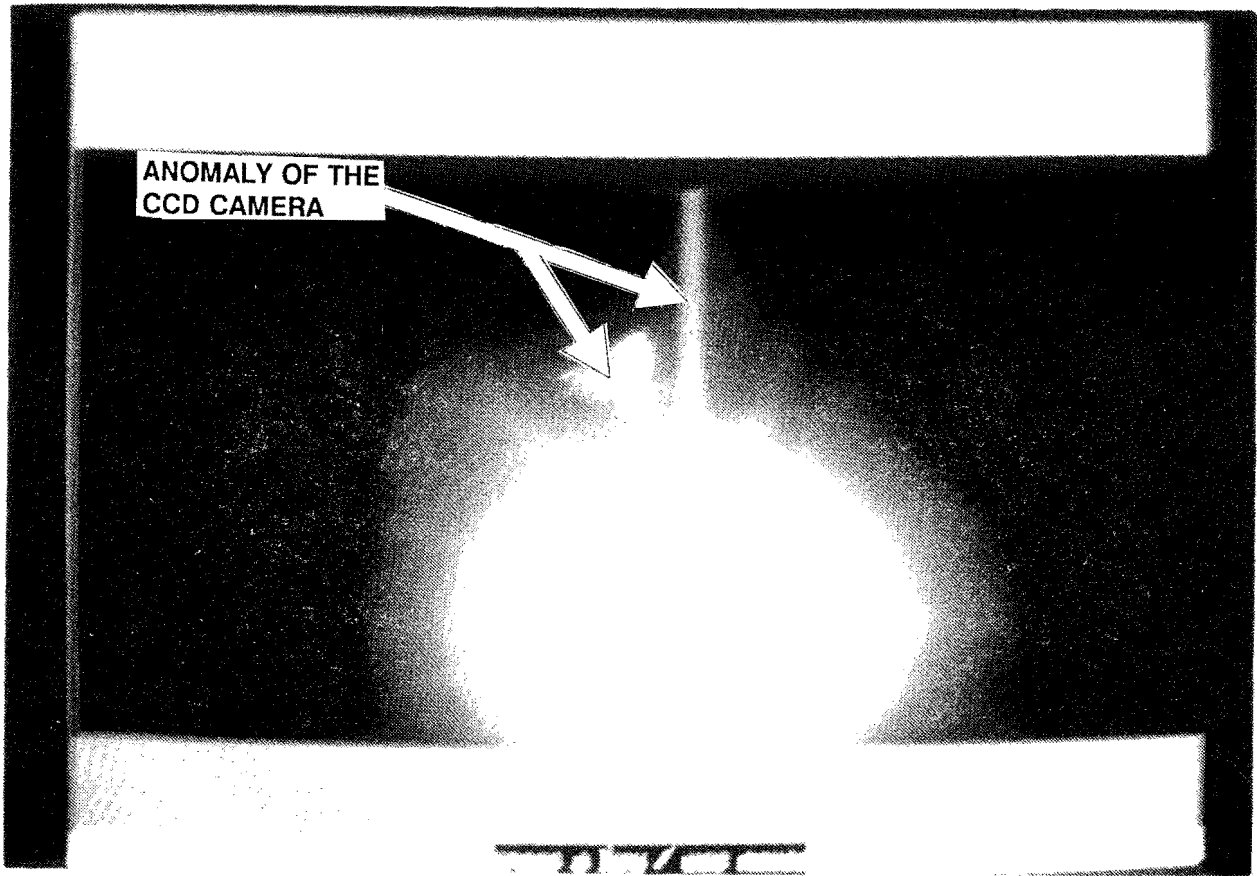


FIGURE 3
THE SUN PICTURE
TAKEN JULY 1990

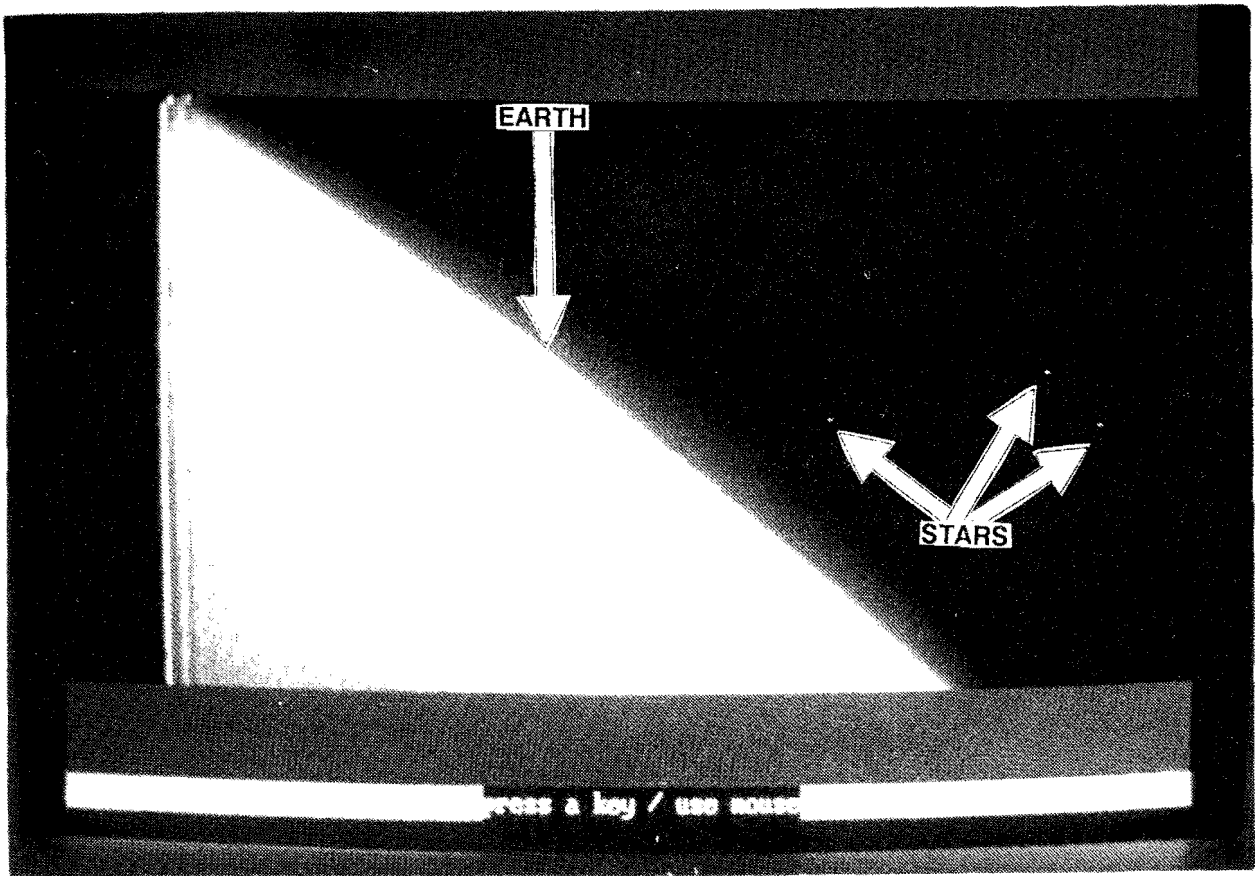


FIGURE 4
THE EARTH'S HORIZON WITH STARS
TAKEN JULY 2, 1991