Naval Research Laboratory
Washington, DC 20375-5000

NRL Report 9207

The Spartan 1 Mission

R. G. CRUDDACE AND G. G. FRITZ
E.O. Hulburt Center for Space Research

D. J. SHREWSBERRY
NASA Goddard Space Flight Center

D. C. BRANDENSTEIN, J. O. CREIGHTON, G. GUTSCHEWSKI,
S. W. LUCID, S. R. NAGEL, AND J. M. FABIAN
NASA Johnson Space Center

D. ZIMMERMAN
NASA Kennedy Space Center

E. E. FENIMORE
Los Alamos National Laboratory

C. GROSS
McDonnell Douglas Corporation

July 11, 1989

Approved for public release; distribution unlimited.

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b RESTRICTIVE MARKINGS

2a SECURITY CLASSIFICATION AUTHORITY

2b DECLASSIFICATION / DOWNGRADING SCHEDULE

3 DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release; distribution unlimited.

4 PERFORMING ORGANIZATION REPORT NUMBER(S)
NRL Report 9207

5 MONITORING ORGANIZATION REPORT NUMBER(S)

6a NAME OF PERFORMING ORGANIZATION
Naval Research Laboratory

6b OFFICE SYMBOL (If applicable)
4120

7a NAME OF MONITORING ORGANIZATION

6c ADDRESS (City, State, and ZIP Code)
Washington, DC 20375-5000

7b ADDRESS (City, State, and ZIP Code)

8a NAME OF FUNDING / SPONSORING ORGANIZATION
(See page ii)

8b OFFICE SYMBOL (If applicable)

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c ADDRESS (City, State, and ZIP Code)
Washington, DC 20546

10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO
			DN480-104

11 TITLE (Include Security Classification)
The Spartan 1 Mission

12 PERSONAL AUTHOR(S)
(See page ii)

13a TYPE OF REPORT
Final

13b TIME COVERED
FROM 1980 TO 1985

14 DATE OF REPORT (Year, Month, Day)
1989 July 11

15 PAGE COUNT
18

16 SUPPLEMENTARY NOTATION

17 COSATI CODES

FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Space science
X-ray astronomy
Spartan program
Space shuttle

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This report documents the first Spartan mission. The Spartan program, an outgrowth of a joint Naval Research Laboratory (NRL)/National Aeronautics and Space Administration (NASA)-Goddard Space Flight Center (GSFC) development effort, was instituted by NASA for launching autonomous, recoverable payloads from the space shuttle. These payloads have a precise pointing system and are intended to support a wide range of space-science observations and experiments.

The first Spartan, carrying an NRL X-ray astronomy instrument, was launched by the orbiter Discovery (STS 51G) on June 20, 1985 and recovered successfully 45 h later, on June 22. During this period, Spartan 1 conducted a preprogrammed series of observations of two X-ray sources—the Perseus cluster of galaxies and the center of our galaxy. The mission was successful from both an engineering and a scientific viewpoint. Only one problem was encountered--the attitude control system (ACS) shut down earlier than planned because of high-attitude control-system gas consumption. A preplanned emergency mode then placed Spartan 1 into a stable, safe condition and allowed a safe recovery.

(Continues)

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a NAME OF RESPONSIBLE INDIVIDUAL
Raymond G. Cruddace

22b TELEPHONE (Include Area Code)
202-767-2344

22c OFFICE SYMBOL
4129

DD Form 1473, JUN 86 Previous editions are obsolete SECURITY CLASSIFICATION OF THIS PAGE

8a. NAME OF FUNDING/SPONSORING ORGANIZATION

Office of Space Science and Applications
National Aeronautics and Space Administration

12. PERSONAL AUTHOR(S)

Cruddace, R.G., Fritz, G.G., Shrewsberry, D.J., Brandenstein, D.C., Creighton, J.O., Gutschewski, G., Lucid, S.W., Nagel, S.R., Fabian, J.M.*, Zimmerman, D., Fenimore, E.E., and Gross, C.†

*Now with ANSER, Arlington, Virginia
†Now at Tel Aviv University

19. ABSTRACT (Continued)

This report describes the events of the mission and presents X-ray maps of the two observed sources, which have been produced from the flight data.

CONTENTS

Frontispiece — Spartan 1

THE SPARTAN 1 MISSION

INTRODUCTION

Spartan is a program introduced by the National Aeronautics and Space Administration (NASA) to facilitate scientific research using the space shuttle. Inspired by the sounding-rocket program, Spartan employs autonomous payloads, each equipped with a precise pointing system and deployed by the shuttle orbiter in Earth orbit. After performing a preprogrammed series of measurements, which for most missions are astronomical observations, the Spartan payload is retrieved by the orbiter after 2 days and returned to Earth.

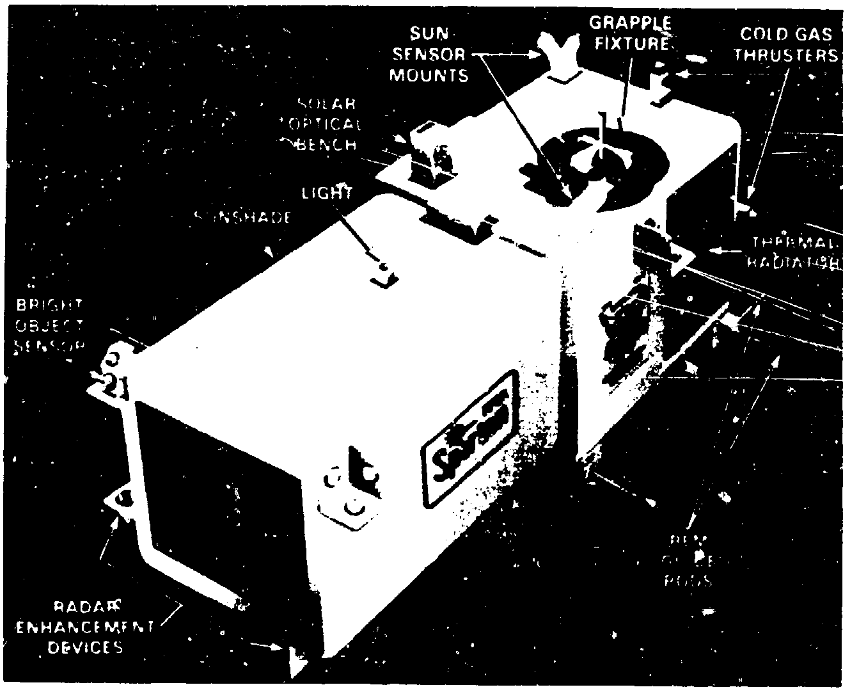
The development of the Spartan concept started in 1976 in a collaborative effort by the Naval Research Laboratory (NRL) and the Goddard Space Flight Center (GSFC). The results of early studies are described in Refs. 1 through 3. Development of the first flight payload (Spartan 1) started in 1980 and accelerated in 1982, when Spartan 1 was placed on the flight manifest for the August 1984 launch of STS 41F. The complete Spartan team was then assembled consisting of persons from GSFC, NRL, the Johnson Space Center (JSC), and the Kennedy Space Center (KSC). GSFC was responsible for payload development and testing, and NRL executed a similar scientific-instrument function, performing X-ray astronomical observations. The Perseus cluster of galaxies and the center of our own galaxy were selected for study. JSC and KSC assumed responsibility for integrating Spartan 1 into the orbiter and for developing the techniques needed to deploy and retrieve the payload in orbit. A shuttle malfunction postponed the Spartan 1 flight for 10 months, and it finally flew in June 1985 on STS 51G, on board the orbiter Discovery. In this report, we describe Spartan 1, its flight, and some of the scientific results.

THE SPARTAN 1 PAYLOAD

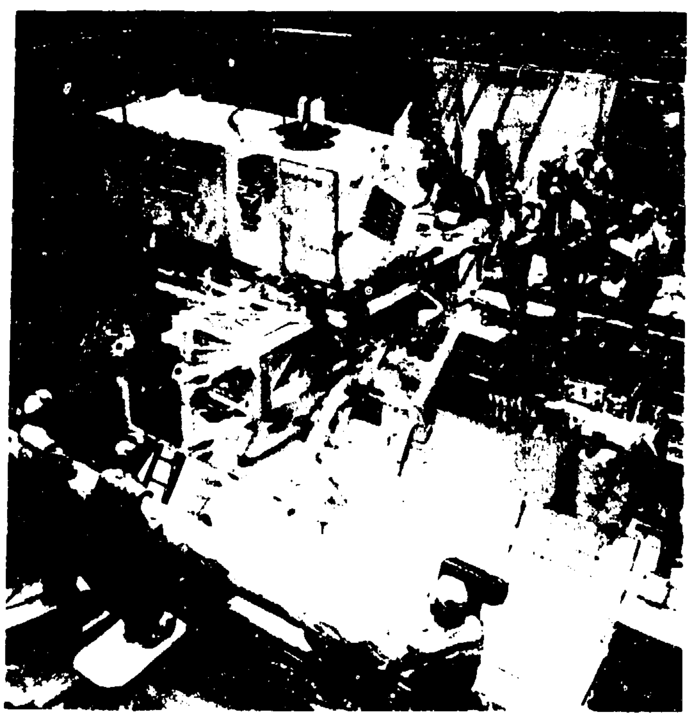
Figure 1(a) shows the major features of Spartan 1. The long rectangular sunshade was designed to shield the X-ray detectors, a startracker, and two aspect cameras from direct sunlight during daylight observations. The principal payload subsystems are in the rectangular body behind the sunshade. Figure 1(b) shows the payload mounted on the support structure in the orbiter bay. The photograph was taken during the installation operation in the Orbiter Processing Facility at KSC.

Figure 2(a) shows the payload during final assembly at KSC. The lower section contains the payload functional control system (PFCS), the attitude control system (ACS) and three 28 V silver-zinc batteries (one a reserve) with a total capacity of 700 A.h. Scientific instruments consisting of two large, finely collimated, X-ray proportional counters, are being lowered into the upper section. These detectors are sensitive to X-rays in the 1 to 15 keV band, have an aperture with a collecting area of 1320 cm^2, and are collimated to view a slit on the sky 5-arcmin wide (full width, half maximum (FWHM)) and 3° long (FWHM). Figure 2(b) shows the detectors—two 35-mm cameras and a startracker—mounted on a flat rectangular structure, the "optical bench."

Manuscript approved February 21, 1989.

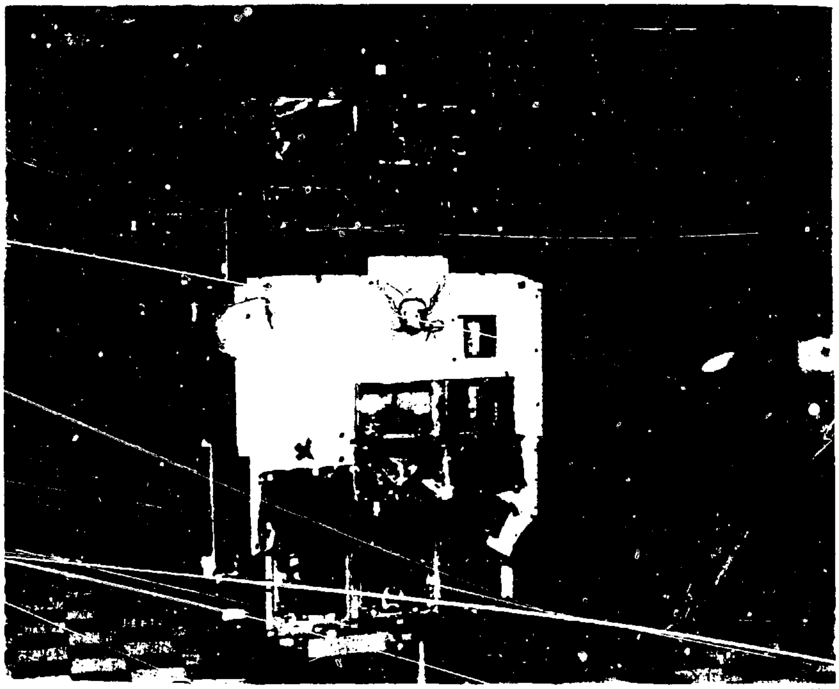


(a)

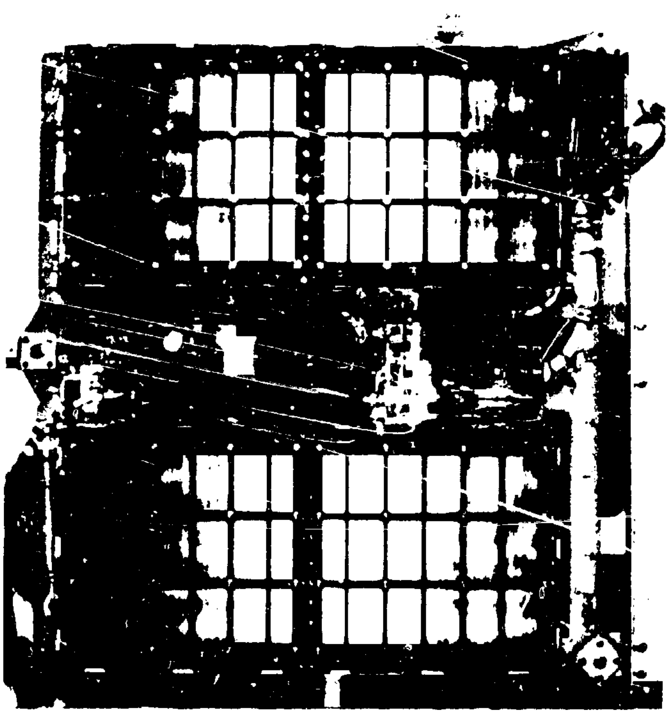


(b)

Fig. 1 — (a) The Spartan 1 payload; (b) Spartan 1 installed on its support structure in the Orbiter Processing Facility at the Kennedy Space Center



(a)



(b)

Fig. 2 — (a) The Spartan 1 payload being assembled at the Kennedy Space Center. The X-ray detectors are being lowered into the payload; (b) Front view of the apertures of the two finely-collimated X-ray detectors. Visible in between are the covered apertures of the startracker and two 35-mm aspect cameras

Several important external characteristics of Spartan 1 are evident in Fig. 1—the grapple fixture, which is engaged by the arm of the shuttle remote manipulator system (RMS); the structure remote engage mechanism (REM), which mates with the support bridge in the orbiter; various ACS gas thrusters and solar attitude sensors; reflectors to enhance ground tracking by radar; and the thermal surfaces. These surfaces include a multilayer insulation blanket painted white on the outside and thermal radiator surfaces of aluminized Teflon to reject heat from the payload electronics. Spartan 1 is 126 by 42 by 48 in., and it weighs 2222 lb.

The basic PFCS functions are timing, power switching, data encoding, and data storage. The internal clock, which starts at deployment, is used to time payload shutdown in free flight after the conclusion of the observations. Ten modes are selected by the power switching system—one for free flight configuration, one for minimum reserve shutdown (MRS) mode, and the rest for preflight and in-orbit checks. The MRS mode, designed for an emergency, is entered when either the battery voltage or ACS gas pressure falls below preset threshold values. This was, in fact, activated during the mission. The data encoding system is a sounding rocket, pulse-code modulated (PCM) unit, operating at 12500 bits/s. The PCM encoder is programmed to accept a combination of analog and digital signals, the latter including event counts and parallel- and serial-digital data. The encoded data are stored by a Bell and Howell MARS 1400 tape recorder, with a capacity of 10^{10} bits.

For attitude control, the ACS uses gas jets supplied with argon regulated to 60 psia. The pneumatic system stores argon at 3000 psia in two 1615 in^3 tanks identical to those employed by the astronaut manned-maneuvering unit (MMU). The jets, with thrust of 0.2 lbf-ft, respond to commands formulated by using one of three inputs:

- computer-generated steering signals and the outputs of a three-axis, rate-integrating gyroscope assembly,
- star-tracker output, or
- output of the solar attitude sensors.

The startracker is located between the two X-ray detectors and is aligned with the detector-view axis. The principal solar-attitude sensors have a view axis orthogonal to the star-tracker axis (Fig. 1). The complete astronomical observing sequence is stored in a microcomputer capable of storing 1000 commands, which takes control of the payload during free flight. It controls the pointing maneuvers and several functions in the scientific instrument including high-voltage turn-on, aspect-camera operation, and calibration of the X-ray detectors.

THE SPARTAN 1 MISSION

Spartan 1's scientific goal was to study the structure of the Perseus cluster and the galactic center by obtaining detailed X-ray emission maps. These surveys were made by sweeping the slit field of view of the detectors in many directions across each source. For the Perseus cluster, each scan was 86.0 arcmin long, and the scan rate was 16.2 arcmin per minute. A computer constructed each image postflight by using techniques familiar in medical X-ray tomography. The free-flight operations of Spartan 1 were optimized under numerous technical constraints to maximize this X-ray observing time. One such constraint was the prior deployment of three communications satellites—MORELOS, ARABSAT, and TELSTAR—so that Spartan 1 operations did not begin until mission-elapsed time (MET) $5^d\ 1^h\ 35^m$.

All signals to Spartan 1 were sent by a crew member on the aft flight-deck (AFD) who used a hand-held unit resembling a pocket calculator. Binary-coded signals were transmitted along a single, twisted-wire-pair cable leading from the AFD to the orbiter. Table 1 summarizes the four basic instructions sent to the payload in preparation for undocking and deployment. During the self check, Spartan 1 powered itself up and internally conducted a series of PFCS, ACS, battery, and scientific instrument checks. These checks were all positive, whereupon Spartan 1 informed the crew member by means of the APC that it was ready for flight.

Table 1 — Preparation of Spartan 1 for Free Flight

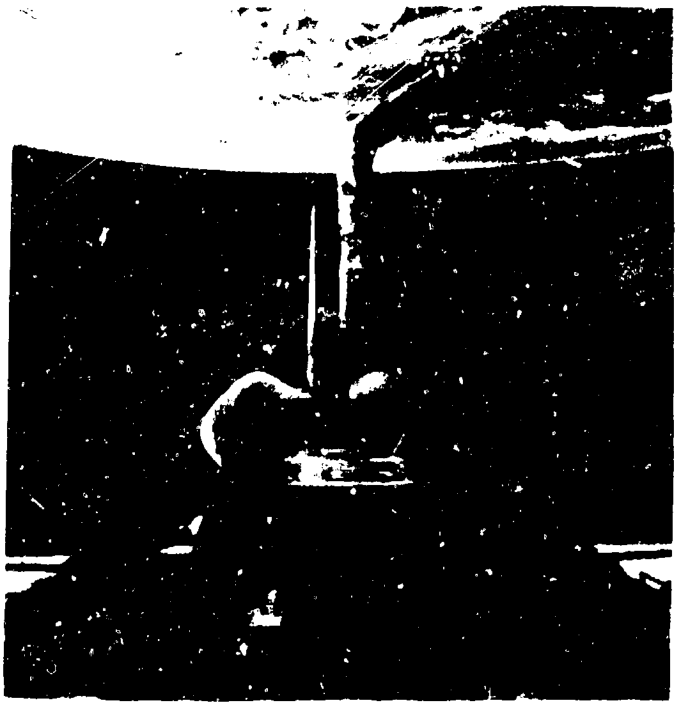
Time before	Function
$2^h\ 54^m$	Turn on ACS computer and gyro heaters
$2^h\ 39^m$	Send "program select" code to register changes in launch day and deployment time
$1^h\ 55^m$	Start self check
$1^h\ 24^m$	Place payload in standby mode: power to ACS computer and gyros heaters only

At this point, the crew unlatched Spartan 1 from its support structure and grappled it by use of the RMS (Fig. 3(a)). The RMS then extracted the payload and held it over the orbiter bay as depicted in Fig. 3(b). This was designed to align the startracker within 2° of the star Vega and to point the "solar optical bench" (Fig. 1) at the sun. Spartan 1 was released 3 min after sunrise at MET $3^d\ 4^h\ 29^m$, or precisely $16^h\ 2^m\ 1^s$ UT on June 20, 1985 (Fig. 3(c)). The release initiated an immediate power-up of the payload followed 30 s later by enabling of the ACS gas system. After 2.5 min, Spartan 1 performed a pirouette maneuver, a rotation of 45° clockwise, then counterclockwise about an axis through the grapple fixture. The pirouette lasted 90 s. It informed the crew that the ACS was performing correctly and that Spartan 1 could continue its mission. Discovery then performed two burns (1 and 2 ft/s), to effect a safe separation from the payload.

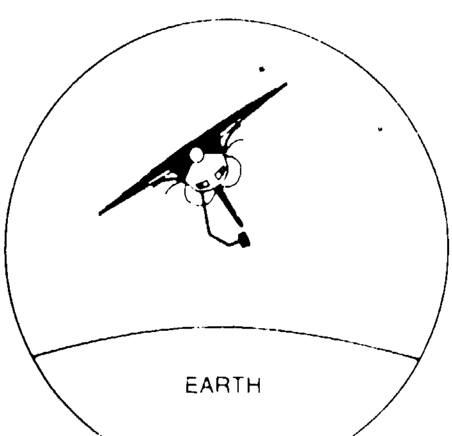
Spartan 1 now entered a critical phase of its flight, namely acquisition by the ACS of an inertial reference frame. This had to be delayed a full orbit, however, to avoid confusing the solar attitude sensors with reflections from the orbiter bay. Table 2 summarizes the steps taken in the acquisition procedure.

Table 2 — Spartan 1 Attitude Acquisition

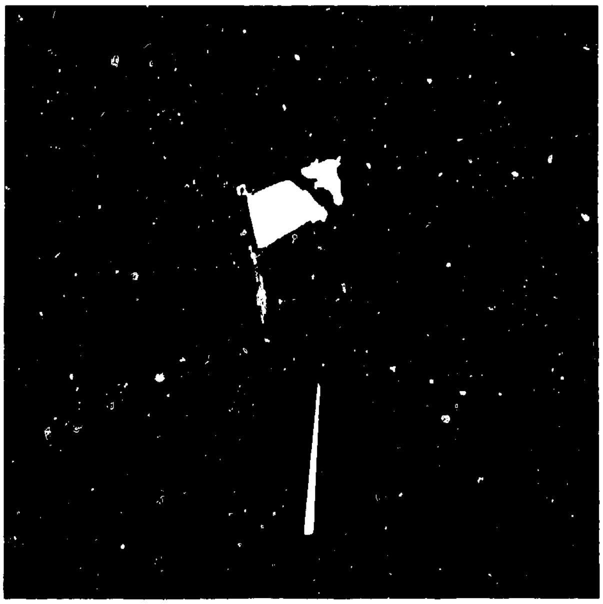
Time after deployment	Function
$1^h\ 59^m$	Solar-optical bench locks onto the sun
$2^h\ 36^m$	Night pass: startracker locks onto Vega: gyro update in two axes
$2^h\ 54^m$	Maneuver 23°.8 to Deneb
$2^h\ 55^m$	Startracker locks onto Deneb: update third gyro axis



(a)



(b)



(c)

Fig. 3 — (a) Undocking of Spartan 1 during the STS 51G mission; (b) Orientation of Discovery and position of Spartan 1 at deployment. (c) Spartan 1 after release by the orbiter RMS (visible at right)

With this critical phase completed, Spartan 1 embarked on a preprogrammed, 23-h program of X-ray observations. This program repeated the same pattern each orbit—one scan of the Perseus cluster, one of the galactic center, and a repeat of the last three steps of Table 2—using the stars Altair and Deneb to update the ACS gyro reference. The only change from orbit to orbit was the direction of scanning each X-ray source.

Meanwhile, Discovery slowly drifted away from Spartan 1 (Fig. 4(a)), reaching a maximum separation of 92 nmi at about MET 4^d 5^h, or 16 orbits (~ 24 h) after deployment. The payload was tracked by C-band radar from the ground allowing the JSC mission control team to accurately compute both its Earth-centered position vector and the Discovery-Spartan state vector to plan the rendezvous maneuvers. Table 3 chronicles the orbiter reaction control system (RCS) burns and tracking activities (Fig. 4(a)), which brought Discovery from a range of 92 nmi to the final rendezvous stages at a range of a few miles.

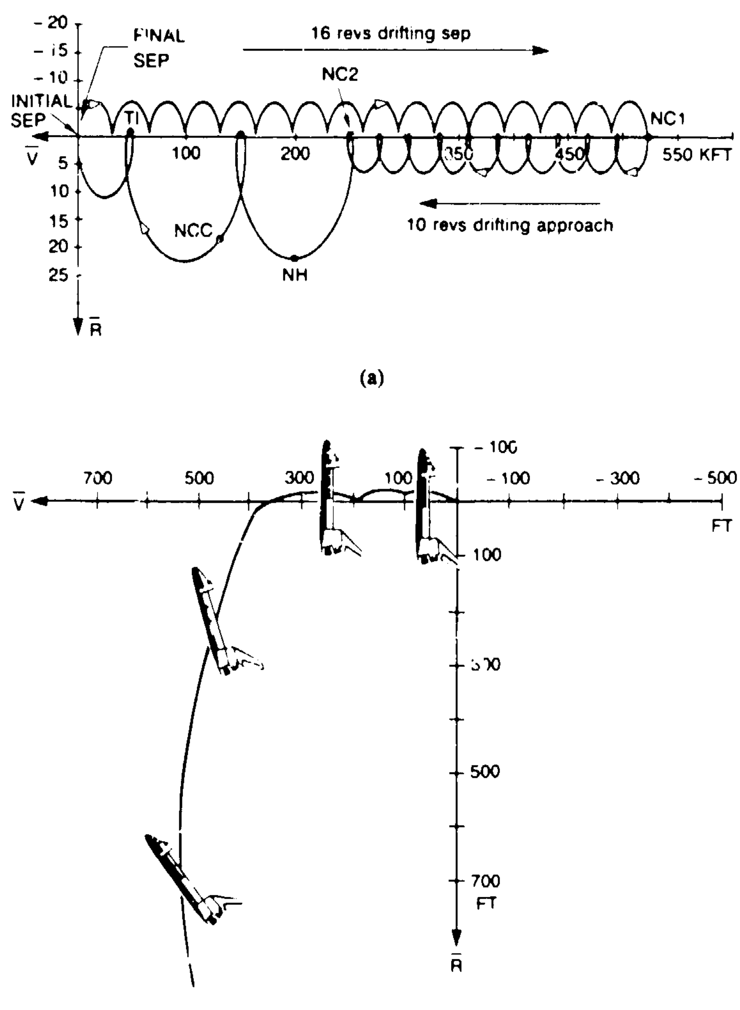


Fig. 4 — (a) The motion of Discovery with respect to Spartan 1. $\bar{V}$ is the direction of orbital motion, and $\bar{R}$ is the vector toward Earth. (The orbiter's NC1, NC2, NCC, and TI burns are described in the text.) (b) The approach of Discovery to Spartan 1 during the final rendezvous phase. As in (a), Spartan 1 is always at the origin.

Table 3—Rendezvous of Discovery with Spartan 1

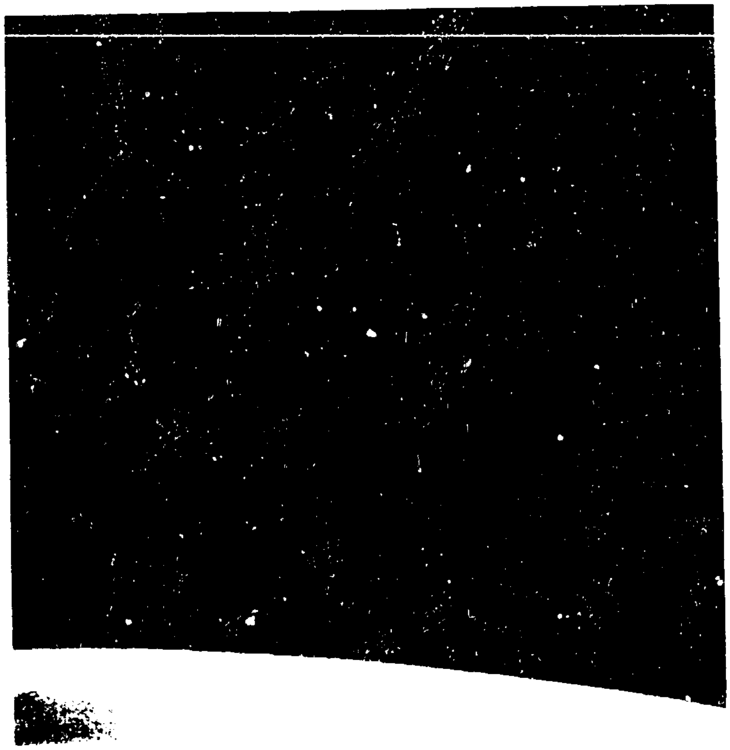
Mission-elapsed time (MET)	Activity	Purpose
$4^d\ 5^h\ 21^m$	NC - 1 burn: 5.1 ft/s: range 92 nmi	Initiate slow approach to Spartan 1
$4^d\ 20^h\ 41^m$	NC - 2 burn: range 35 nmi	Accelerate approach
$4^d\ 21^h\ 09^m$	Spartan 1 acquisition by the Crew Optical Alignment System (COAS)	Tracking and data input to orbiter computers
$4^d\ 21^h\ 59^m$	Spartan 1 acquisition by orbiter K-band radar: range 20 nmi	Tracking and data input to orbiter computers
$4^d\ 22^h\ 47^m$	NCC burn: 1.25 ft/s	Correct out-of-plane velocity difference between Discovery and Spartan 1
$4^d\ 23^h\ 45^m$	TI burn range: 8 nmi	Set up final rendezvous trajectory

After the TI burn, Discovery entered the critical phase of the rendezvous under manual control by the mission commander, who relied primarily on visual sighting of Spartan 1. Figure 4(b) illustrates Discovery's attitude and trajectory in this phase. On approaching the payload, the crew reported that Spartan 1 was in a stable attitude but had an incorrect orientation. Figure 5(a) shows the view of Spartan 1 from the AFD at this time, indicating that the payload had shut itself down prematurely and entered the MRS mode. Postflight analysis revealed that this occurred $17^h\ 32^m$ after deployment because of a low-pressure signal from the ACS gas-supply system. The data revealed unexpected noise in the ACS rate-gyro signal, which had caused excessive gas-valve action during maneuvering. The problem was corrected before the second mission.

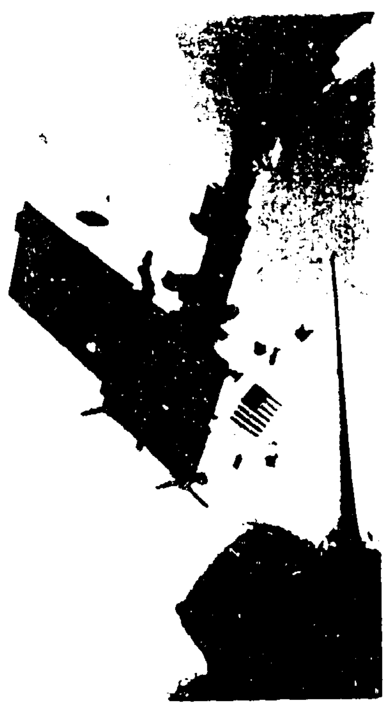
Regrappling of Spartan 1 by use of the RMS was achieved successfully by the crew in a difficult and unrehearsed operation in which the RMS worked at the limit of its reach. The operator could not see the grapple fixture directly but relied instead on the RMS wrist television monitor. This option was selected to avoid a crew-intensive fly-around maneuver, which had yet to be tried in a shuttle mission. The regrappling occurred as scheduled at $13^h 31^m 55^s$ UT on June 22, 1985, 45.5 h after deployment. Figure 5(b) shows Spartan 1 being returned to the orbiter bay.

THE SCIENTIFIC RESULTS

When MRS occurred, $17^h\ 32^m$ after deployment, Spartan 1 had completed 10 scans of the Perseus cluster and 8 scans of the galactic center. In both sets of observations, enough information was obtained to permit excellent X-ray maps to be constructed of the two sources. The results are displayed in Fig. 6.



(a)



(b)

Fig. 5 - (a) Orientation of Spartan 1 at rendezvous. This orientation was unexpected because there was a premature payload shutdown late in its mission; (b) Spartan after recovery, on the end of the RMS.

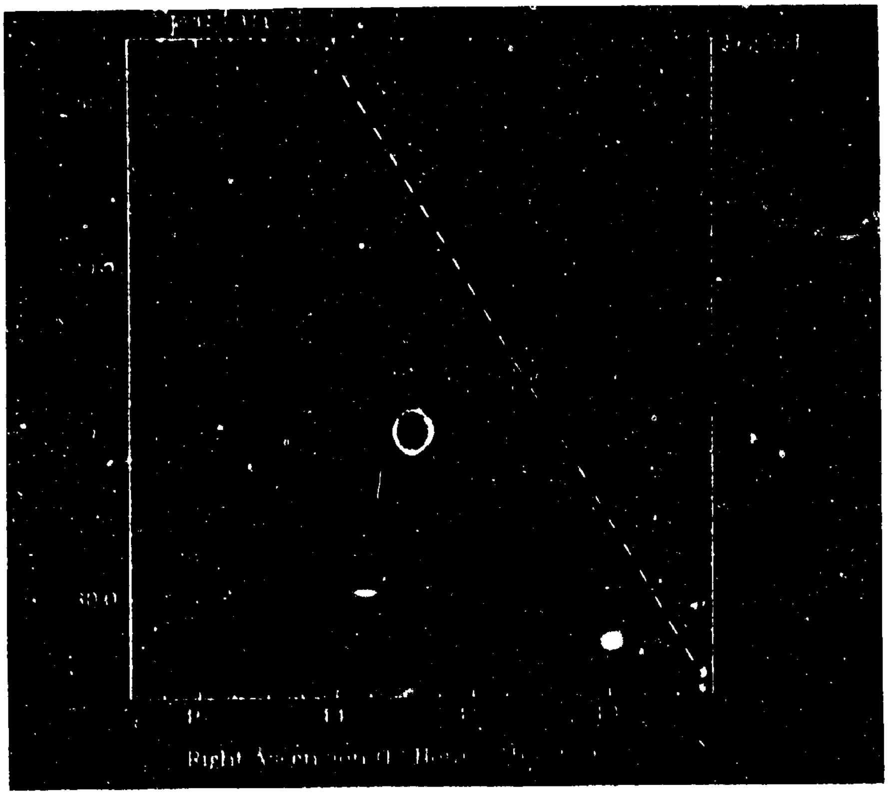


Fig. 6 — (a) Diffuse X-ray emission from hot gas (~ 10^8 K) in the Perseus cluster of galaxies. Cluster galaxies, which have fuzzy images, may be identified throughout the field but are more numerous near the center. The contours are loci of constant surface brightness, which change by a factor 2.25 between adjacent contours; (b) X-ray sources at the galactic center discovered by Spartan 1. The dashed ellipse delineates an area of weak diffuse emission. The contours within the ellipse are produced by a number of weak X-ray sources surrounding the nucleus of the galaxy. The straight dashed line is the plane of the galaxy.

The contours of X-ray surface brightness shown in Fig. 6(a) have been superposed on an optical picture of the sky taken from the Palomar sky survey. Numerous galaxies, which can be distinguished from stars by their fuzzy appearance and the absence of diffraction spikes, are evident to the eye, and careful inspection has revealed thousands of galaxies in this cluster in Perseus, known to astronomers as Abell 426. As is the case in most clusters of galaxies in the universe, the gravitational well of the cluster is filled with a very hot gas ($\sim 10^8$ K), which is revealed predominantly by its X-ray emission. It is of great interest to astrophysicists to study the spatial distribution of this emission, for three reasons:

- to elucidate the origins of the gas, for it is not yet clear what proportion has been shed or stripped from galaxies, and what proportion is the remnant of the primordial gas from which galaxies formed,

- the gas distribution responds to the shape of the potential well, so that the X-ray contours yield information about the distribution of mass in the cluster. For example, the contours in Fig. 6(a) reveal a slight elongation in a roughly EW direction. This may relate to a prominent chain of galaxies in the Perseus cluster running WSW from the center, and

- astrophysicists continue to puzzle over the mass required to create the potential well, because it exceeds by a large margin the mass we can account for as galaxies and gas. Some invisible ("dark") matter of unknown origin pervades the cluster. Measurements of the radial density and temperature gradients in the hot gas allow the distribution of this dark matter to be measured.

The special feature of the Spartan 1 instrument has been its ability to measure the density and temperature of the intracluster gas out to large radii, in the case of Perseus to more than 40 arcmin (Fig. 6(a)). Earlier imaging observations have been unable to reach so far from the cluster center or to measure radial temperature profiles.

The Spartan 1 map of the galactic center (Figure 6(b)) examines a very small region within only 100 pc of the "galactic nucleus." The density of stars increases very rapidly as the nucleus is approached. The nucleus is thought to be the site of a compact object, a black hole, having a mass of between 10^3 and 10^6 solar masses. The spectral characteristics of the northern-most source (1E1743.1-2843) and the three relatively bright sources to the south suggest that they may be members of familiar classes of X-ray sources. A1742-294 and SP1742.2-2959 probably belong to the class of burst or "quasi-periodic oscillator" (QPO) sources, whereas 1E1743.1-2843 and 1E1740.7-2942 reveal harder X-ray spectra and more absorption intrinsic to the source; they are suspected of being binary X-ray pulsars.

The region to the south of 1E1743.1-2843, the patch of emission roughly at the center of the dashed ellipse, is of special interest for it contains the galactic nucleus. This region comprises a number of faint sources that could not be resolved fully by Spartan 1. However, it is clear from comparing the Spartan 1 results with the observations made by the Einstein Observatory in 1979 that these sources are variable. The region may comprise many faint sources that are continually brightening and dimming. Of particular significance is one source that may be the nucleus itself, and it is clear that this source has faded significantly between 1979 and 1985.

In addition to the sources described, Spartan 1 detected weak diffuse emission from a disk-shaped region lying within the dashed ellipse shown in Fig. 6(b). Its dimensions are approximately

80 × 180 pc. Although we know from the Spartan 1 data that the spectrum of this emission is similar to that of the discrete sources, its origin has yet to be determined.

CONCLUSIONS

The principal conclusion to be drawn from the Spartan 1 mission is that exciting scientific research on a modest scale may be performed effectively and economically using the space shuttle. The prerequisites are a minimum of paperwork and superfluous management, and a close working relationship among the shuttle crew, the engineers, and the scientists. Enthusiasm and professional skill were 90% of the success of Spartan 1.

The homework has been done in not just the Spartan program but also in complementary programs such as the Getaway Special (GAS) canisters and the Hitchhiker/SPOC attached payload systems. It remains to capitalize on this investment, for there is no shortage of scientific instruments waiting to be flown.

ACKNOWLEDGMENTS

We acknowledge the consistent and solid support throughout the Spartan 1 program of the Office of Space Science and Applications at NASA Headquarters and the efforts of many engineers at GSFC, KSC, JSC, and NRL, who worked together to make Spartan 1 so successful.

REFERENCES

1. R.G. Cruddace, G.G. Fritz, and S. Shulman, "SPEAR: Small Payload Ejection and Recovery for the Space Shuttle," *Astronautics and Aeronautics*, p. 42, Jan. 1977.

2. D.J. Olney, and R.G. Cruddace, "Free-flying Shuttle Payloads, an Extrapolation of Sounding Rocketry into the Shuttle Era," AIAA Paper No. 79-0485, 1979.

3. R.G. Cruddace, G.G. Fritz, and D.J. Shrewsberry, "Space Research and Spartan," AIAA Paper No. 85-0502, 1985.