A Brief Introduction to the Jet Propulsion Laboratory

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The organization that I work for is the Jet Propulsion Laboratory (JPL). It is one of the major research centers of the National Astronautic and Space Administration (NASA), and is mainly responsible for unmanned deep space explorations. JPL's spacecrafts have explored eight of the nine planets of the Solar System (including Earth). In the following, I will briefly describe JPL's history and some major discoveries we made in deep space exploration.

JPL was founded on October 31, 1936. On that day, Prof. Theodore Von Karman of the California Institute of Technology led a team of students conducted a rocket propulsion experiment along the bank of Arroyo Seco in the city of Pasadena, California. From then on, JPL continued to grow and has become a research center of more than 5000 people (Figure 1). In fact, the "Father of Chinese Rocket Science", Dr. Tsien Weichang, also had worked at JPL. He joined Prof. Von Karman's research team and made a lot of contributions to the science of jet propulsion.

Figure 1: Ariel View of JPL

From 1936 to the 1960s, JPL's main focus was rocket and jet propulsion research. Starting in the 60s, JPL began the development of unmanned spacecraft. The early objective of such developments was to collect data from the Moon to support human Lunar landing projects. Later on, the scope of unmanned missions was expanded to include the exploration of other planets. The first series of such missions was the Mariner program. There were 10 missions in the Mariner program in total. The targets were Venus, Mars, and Mercury. Due to the lack of experience, the failure rate of the Mariner spacecrafts was rather high. Out of the ten missions, only five were successful. Even so, those successful missions sent back many valuable images to the human race for the first time. These images showed us the landscape of Mercury, which looked very similar to the Moon (Figure 2), the cloud top of Venus (Figure 3), and the most detailed images of Mars at that time (Figure 4).

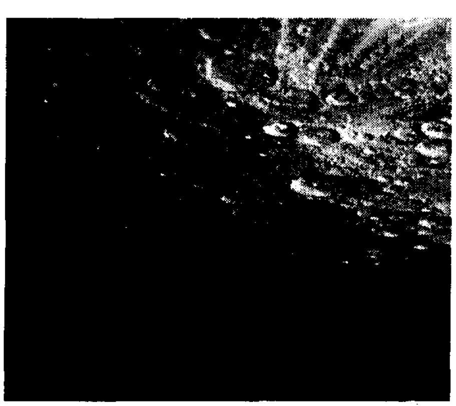


Figure 2: Surface of Mercury
(Taken by Mariner 10)

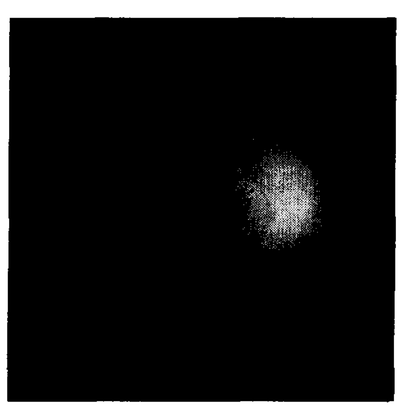


Figure 3: Cloud Top of Venus
(Taken by Mariner 10)

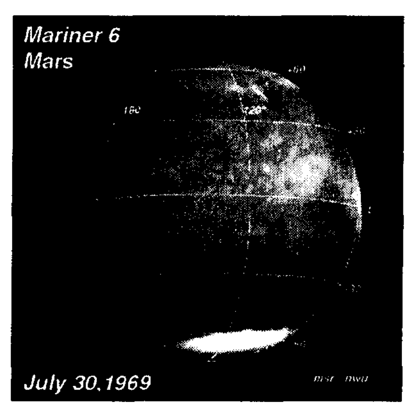


Figure 4: Distant View of Mars
(Taken by Mariner 6)

In the 70s, the JPL-developed Viking I and Viking II spacecrafts landed on Mars. That was the first time in the history that a man-made object landed on another planet (Figure 5). The Viking spacecrafts continued to operate on the surface of Mars for 12 years, and proved that there was no sign of life around the landing sites. By the end of the 70s, JPL launched Voyager I and Voyager II spacecrafts. The destinations were Jupiter and Saturn. These two spacecrafts has met with unsurpassed success. Among a long series of discoveries, they revealed that Jupiter actually had a very thin ring (Figure 6). The mysterious Great Red Spot on Jupiter that puzzled the astronomers for more than three hundred years was actually a gigantic vortex (Figure 7). Jupiter's satellites had active volcanoes (i.e., Io, see Figure 8) and water ocean under ice crust (i.e. Europa). The rings of Saturn were actually composed by hundreds of thin rings (Figure 9). Due to their success, the Congress of United States approved funding to extend the mission of Voyager 2 to visit Uranus and Neptune. Subsequently, Voyager 2 discovered two new rings on Uranus (Figure 10), the mysterious geological formation on Uranus' satellite Miranda (Figure 11), the Great Dark Spot (Figure 12) and rings (Figure 13) on Neptune, and the traces of methane dusts that were ejected by ice volcanoes on Neptune's satellite Triton. The Voyager spacecrafts are still operating and may discover the boundary of the Solar System for us within the next decade.

Figure 5: Surface of Mars (Viking 1)

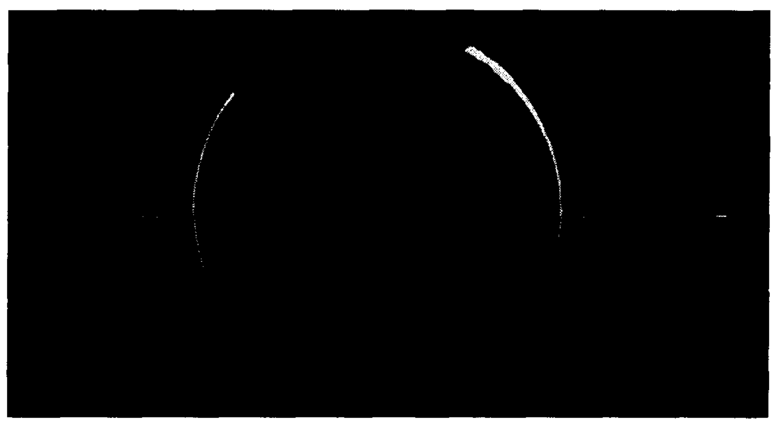


Figure 6: Jupiter's Ring

Figure 7: Jupiter's Red Spot

Figure 8: Active Volcano on Io

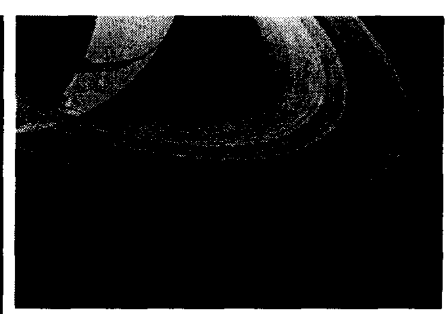


Figure 9: Saturn's Ring

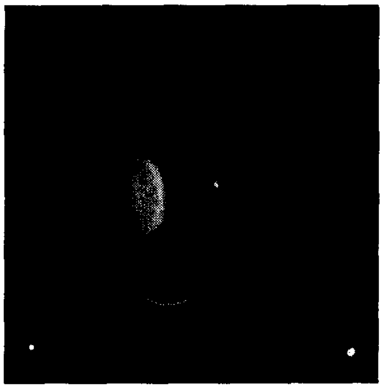


Figure 10: Uranus' Ring

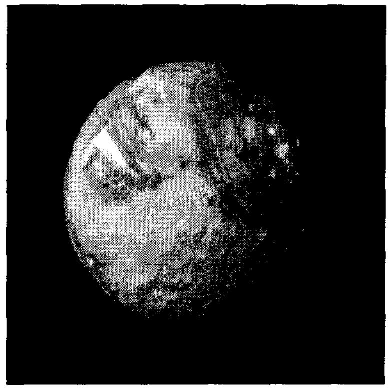


Figure 11: Geological Formation of Miranda

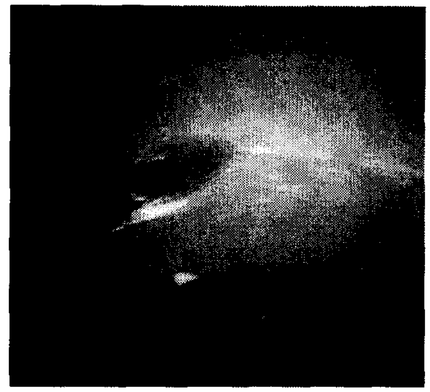


Figure 12: The Great Dark Spot

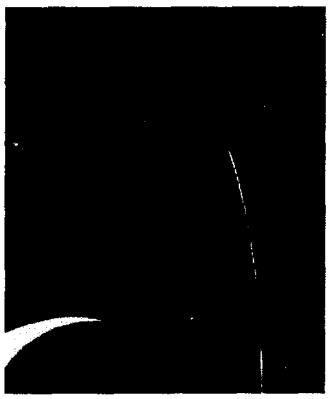


Figure 13: Neptune's Ring

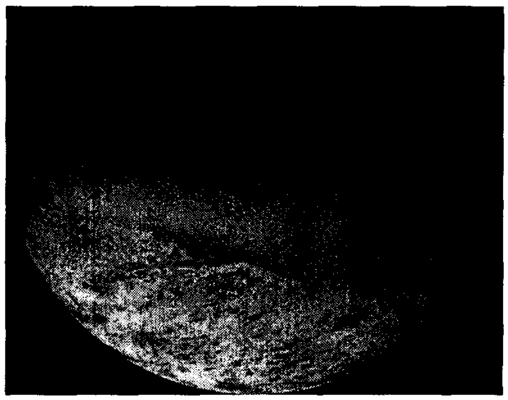


Figure 14: Traces of Methane Dust from Triton's Ice Volcanoes

Except the Vikings, all the spacecrafts mentioned above had fly-by missions. In the late 80s and 90s, JPL began to focus on obiter and landing missions. The most important missions included the Magellan, which used radar to penetrated the thick clouds on Venus and took pictures of its surface (Figure 15), and the Galileo that dropped a probe into Jupiter's atmosphere and orbited around it for more than five years. On its way to Jupiter, Galileo also took some close-up images of the asteroid Ida and discovered that it has its own tiny satellite (Figure 16). Another spacecraft, the Cassini, has been launched but not yet arrived at its destination. The Cassini will orbit around Saturn in the year 2004 and drop a probe into the atmosphere of its largest satellite Titan.

In addition to planetary exploration, JPL also had other types of missions. Examples include the Ulysses that observed the north and south poles of the Sun, the DS1 that took close-up pictures of the comet Borrelly (Figure 17), and the Stardust that will collect samples from the tail of the comet Wild-2. The Stardus will arrive at the Wild-2 in January 2004 and will bring back the sample to Earth by January 2006.

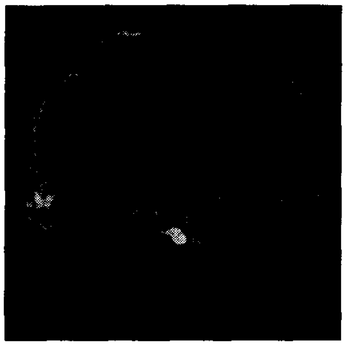


Figure 15: Magellan's Radar Mapping of Venus' Surface

Figure 16: Asteroid Ida and its Satellite

Figure 17: Comet Borrelly (Taken by DS1)

Starting in the 90s, many scientists were interested in Mars again. NASA has assigned many Mars missions to JPL. The mission that aroused most of the public interests was the Mars Pathfinder and especially the Mars Rover that it carried. It was especially exciting to see the Mars Rover roamed around the surface of Mars and examined the rocks and soils (Figure 18).

Figure 18: The Landing Site of Mars Pathfinder

Unfortunately, JPL does not have too much luck on Mars. First of all, the Mars Observer that was launched in 1992 disappeared during the Mars orbit insertion. Later on, JPL built another spacecraft, the Mars Global Surveyor, to replace the Mars Observer. Then, there were two back-to-back failures of the Mars Climate Observer and the Mars Polar Lander in 1999. These two failures shook JPL. On the other hand, the people at JPL were very capable. They quickly learnt the lessons and then moved on to develop new missions. The Mars Odyssey was launched in 2001 and other Mars missions will be launched in 2003, 2005, and 2009. From the pictures that were sent back from Mars Global Surveyor, there are evidences that liquid water still exist on some steep terrain on Mars. Hence, many scientists suspect that there might be some primitive forms of life in those areas on Mars. Therefore, Mars exploration will likely to continue for a long time in the foreseeable future.

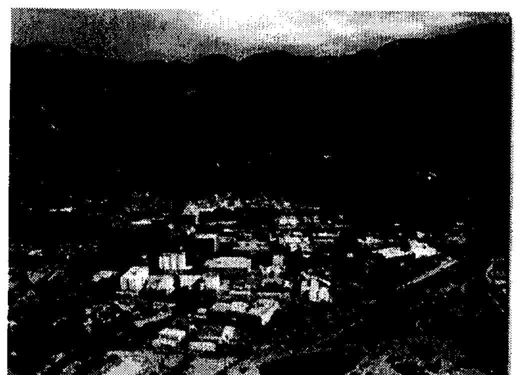
Many people asked me why we have to spend so much money to explore space. I have multiple answers to this question. First, human race has curiosity. This curiosity is the impetus for social and cultural advancements. In the meantime, this universe is also mysterious. Space exploration can satisfy our curiosity about the universe. Second, the more we learn about this universe, the more we know about ourselves. People in the Medieval time thought that Earth was the center of the universe. Now, we know that Earth is only a fragile planet. Moreover, by knowing the hostile environments of the other planets, we will take better care of this only planet that can support life and intelligence in the Solar System. Third, every object including planets, satellites, asteroids, and comets in the Solar System is actually a huge science laboratory. Whenever we observe some unexpected phenomena on these bodies, that is the opportunity for us to verify our scientific theories. Last and probably the most practical reason is that many technologies developed by space exploration can improve our daily life. The best example is the development of the integrated circuit, which is the driving force of the information technology nowadays, was actually stimulated by the need to reduce the weight of spacecraft. The cost of space exploration may seem enormous. However, comparing with military spending, this cost is trivial. Therefore, space exploration is one of the best investments that mankind has ever made. And I am glad that I have opportunity to participate in such meaningful endeavor.

附錄:噴射推進實驗室 (Jet Propulsion Laboratory)簡介

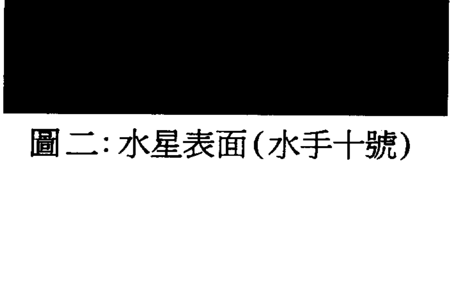
周乃標(Savio Chau, Ph.D., Group Supervisor/Principal Engineer, Jet Propulsion Laboratory)

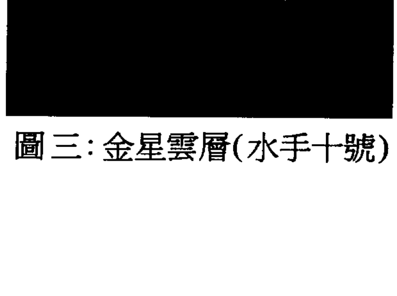
我在美國工作的機構是噴射推進實驗室 (Jet Propulsion Laboratory, 簡稱 JPL)，是美國太空總署(National Astronautic and Space Adminstration, 簡稱 NASA) 轄下的重點研究中心之一，專門負責無人太空船在深太空的探險，我們所建造的太空船，已探測過太陽系九大行星中的八個行星（連地球在內），以下我會將JPL 的歷史和在太空探索中的幾個重要發現作出簡介。

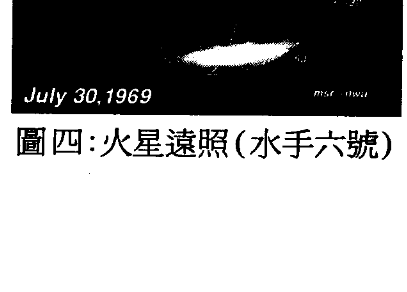
JPL 創始於1936 年10 月31日。當日加州理工學院(California Institute of Technology) 的馮加文(Von Karman) 教授率領一群學生在巴沙迪那(Pasadena)市山邊一條稱爲亞來若(Arroyo Seco)的小溪旁進行火箭推進實驗，從此JPL 就一直發展至現今有五千多人的研究中心（圖一）。說起來 **JPL** 和中國火箭之父錢學森博士頗有淵源，他後來也加入了馮加文教授的火箭推進研究小組，爲火箭升空高度的理論作出重大貢獻。


圖一：噴射推進實驗室全貌

由1936 年至1960 年期間，JPL 的主要任務是火箭推進研究，六零年代以後，**JPL** 開始無人太空船的建造，初期的任務是爲月球登陸計劃用無人太空船搜集資料，之後轉爲向其他行星探測，最先的是水手號太空船系列(Mariner series)，共有十艘太空船，目標是金星、火星、和水星。那時由於經驗不足，失敗比率頗高，十次任務中只有五次成功，但雖然如此，這些太空船爲人類首先送回這些行星的眞貌，使人認識到水星的表面和月球極相似（圖二）、金星雲層的形狀（圖三）、以及到那時爲止最詳盡的火星表面圖片（圖四）。


圖二: 水星表面(水手十號)

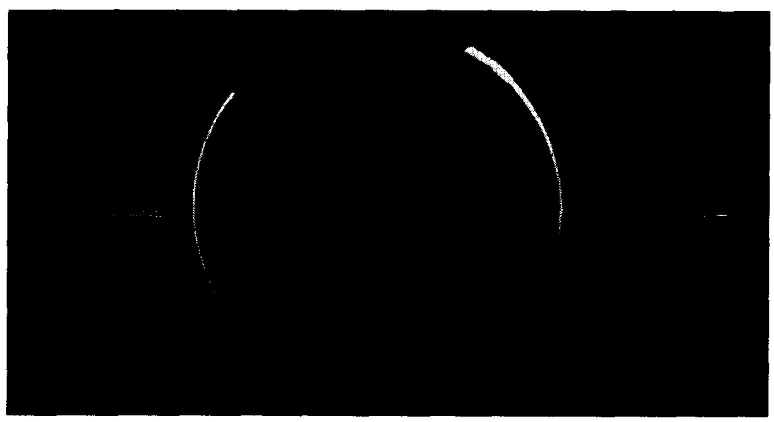

圖三: 金星雲層(水手十號)



圖四:火星遠照(水手六號)

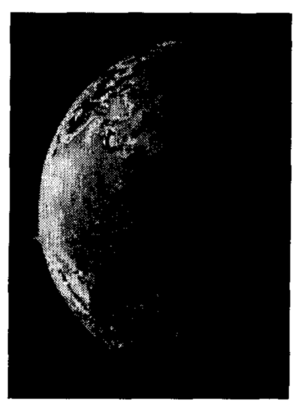
七零年代中，JPL 建造和發射的維京一號和二號 (Viking 1, Viking 2)，相繼登陸火星，這是人類有史以來第一次降落其他行星（圖五），維京太空船在火星表面持續操作長達十二年，並證明在著陸範圍內無生物跡象。七零年代末，JPL 又發射航海者一號和二號 (Voyager 1, Voyager 2)，目標是木星和土星，這兩艘太空船獲得空前成功，陸續發現了原來木星也有稀薄的光環（圖六）、困惑天文學家三百多年的木星大紅斑原來是一個大氣流旋渦（圖七）、木星的衛星也有活火山（衛星伊奧 Io, 圖八）甚至埋在冰層下的海洋（衛星歐羅巴 Europa）、土星的光環原來由千百個的小光環構成等等（圖九），由於這些發現，美國國會撥款將航海者二號的任務延長，再往前探測天王星及海王星，在天王星發現了兩個新光環（圖十）及其衛星米蘭特(Miranda)的古怪地形（圖十一），又發現海王星也有一個大黑斑（圖十二）和光環（圖十三）及其衛星泰勒坦(Triton)上有噴出固體沼氣塵埃的冰火山（圖十四），現今航海者一號和二號還操作良好，可能在未來十數年內爲人類找出太陽系的邊沿。

圖五: 火星表面(維京一號)

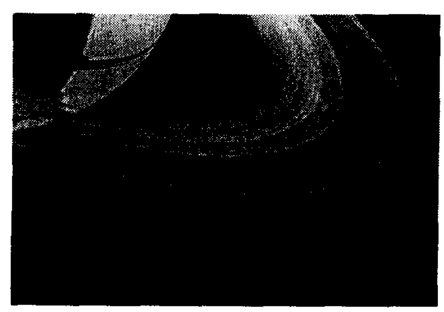


圖六: 木星光環(航海者一號)

圖七: 木星大紅斑(航海者一號)



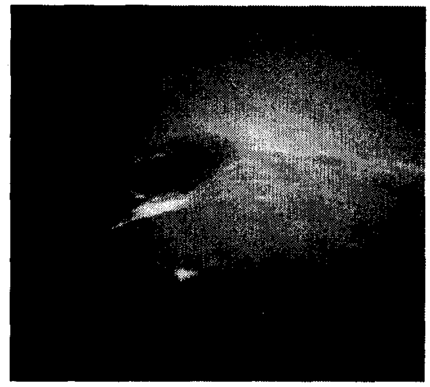
圖八: 木星衛星伊奧(Io)之活火山



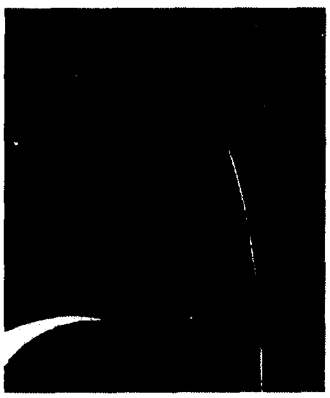
圖九: 土星光環

圖十: 天王星光環

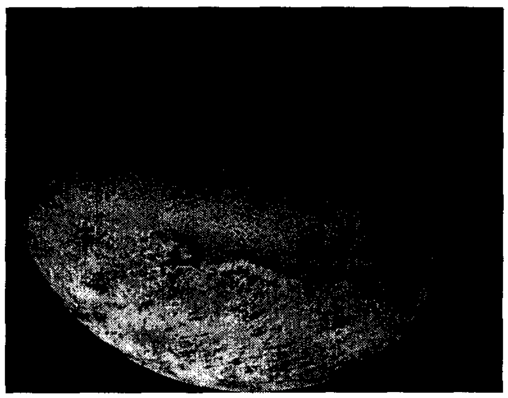
圖十一: 天王星衛星
米蘭特的奇怪地形



圖十二: 海王星大黑班



圖十三: 海王星光環



圖十四: 海王星衛星泰勒坦上
冰火山噴發過的痕跡

上述各太空船除了維京一號和二號，主要任務都是掠過觀察(fly-by)，到了八零年代後期及九零代，**JPL** 開始對各行星進行多項環繞觀察(orbiting) 和降落任務 (landing)，其中最重要的幾項計劃包括有麥哲倫號 **(Magellan)** 用雷達穿透金星厚厚的雲層而攝得地面情況（圖十五），還有加俐略(Galileo) 號對木星進行長達五、六年的環繞觀察及向木星的大氣層投入探測器，在往木星途中，加俐略號還攝得小行星愛達(Ida) 的近距離照片及發現原來該小行星也有自己的衛星（圖十六），已發射但還未抵達目的地的有環繞土星的卡先里(Cassini) 號，將會於2004 年底飛抵土星及向它的最大衛星泰妲(Titan) 投入探測器。

除行星外，JPL 還發射過尤里斯(Ulysses) 號觀察太陽的南北兩極，在彗星探測方面，有DS1 號的對波里利(Borrelly) 彗星的近距離觀察（圖十七），及星塵(Stardust) 號太空船取回懷特(Wild-2)彗星尾巴的樣本的

計劃，星塵號太空船將於2004年1月抵達懷特彗星及在2006年1月將彗星尾巴樣本帶返地球。

圖十五: 麥哲倫號用雷達拍得的金星表面

圖十六: 加俐略號拍得小行星愛達及其衛星

圖十七: DS1號拍得波里利彗星表面

九零年代開始，科學家重新燃起對火星探險的興趣，所以美國太空總署也交付JPL多項火星探險的任務，其中最能引起公衆注意的就是探路者(Mars Pathfinder)太空船，尤其是所攜帶的小型巡遊車(Mars Rover)，在火星表面走來走去測試火星地質，頗爲矚目（圖十八），

圖十八: 探路者降落在火星表面

可惜JPL在火星的運氣並不太好，首先是火星觀察號(Mars Observer)太空船在1992年在進入火星軌道時無故失蹤，事後JPL另造一艘火星環球偵察號(Mars Global Surveyer)代替。然後就是在九八年的兩艘太空船：火星氣象號 (Mars Climate Observer) 及火星極地探險號(Mars Polar Lander)的相繼失敗，那次失敗對JPL的士氣打擊不少，然而JPL的工作人員畢竟都是精英，事後馬上進行檢討，很快又重新全力投入新的探險計劃，在2001年發射了火星歷程號(Mars Odyssey)，還會分別在2003年、2005年及2009年，發射火星探險太空船，由於火星環球偵察號(Mars Global Surveyer)太空船拍得的照片顯示火星的懸崖還有活水的跡象，因此不少科學家相信火星上可能有低等微生物的希望，所以在未來一段日子裏，火星探險的計劃還會方興未艾。

有不少朋友曾經問我爲甚麼人類要花這麼多資源去從事太空探險，這問題的答案是多方面的，首先，人類是好奇的，這種好奇心是社

會進步的動力，而這個宇宙充滿神秘，對太空進行探險，可滿足人類對宇宙的好奇心，第二，當人類對宇宙的認識愈多，就愈能了解自己的實況，中古時代人們以爲地球是宇宙的中心，現在才知道地球只是一顆脆弱的小行星，加上看到了其他星体上的惡劣環境，就使我們愈加珍惜這唯一可讓人類生存的地球，第三，太陽系中的每個星体實際上都是一個龐大的科學實驗場，當每次我們觀察到這些星体上有出乎意料之外的自然現象時，就是驗證我們科學理論的最好機會，最後也是最實際的，就是從太空探險中發展出來的科技，往往給我們日常生活帶來很多方便，最佳例子就是今日世界推動資訊科技的聚積電路，是當初太空總署爲減輕太空船重量的研究所促成的，太空探險的經費看以龐大，但若與人類在軍事上的花費比起來，簡直是微不足道，因此太空探險應該是人類最理想的投資之一，而我也很慶幸有機會從事如此有意義的工作。