DRAFT

To Pluto from a First-Class Postage Stamp [working title]

The first mission to Pluto is presently under development at NASA's Jet Propulsion Laboratory. Inspired by a nagging 29-- cent postage stamp, the mission concept began with a chance conversation between two engineers.

by

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GETTING STARTED

It really began in 1900, when Konstantin Tsiolkovsky in Russia published the first scientific paper describing how a multi-stage rocket could achieve the 9 km/see velocity needed to place an object in orbit around the Earth. This came at a time when the "mile-a-minute" (= 60 mph, or 0.027 km/see) barrier had yet to be broken by an automobile, so many scientists considered Tsiolkovsky's "breakthrough" to be merely science fiction.

Mr. Tsiolkovsky didn't think of going to Pluto. Young Clyde Tombaugh, who grew up on farms in Illinois and Kansas, was hired in 1929 at the observatory started by world-renowned astronomer Percival Lowell to search for "Planet-X." In February 1930, Mr. Tombaugh found what we now call Pluto. Our Sun's ninth planet had been postulated to account for apparent irregularities in the motions of Uranus and Neptune.

During 1991, with *Voyager 2's* Neptune encounter two years behind us, the U.S. Postal Service issued ten stamps commemorating the success of planetary exploration. On a stamp for each of the first eight planets and the Moon appeared an illustration of the celestial body with one of the spacecraft which visited it. [Picture of stamp] The stamp for Pluto simply announced, "NOT YET EXPLORED," as if to taunt engineers and scientists at Pasadena's Jet Propulsion Laboratory (JPL) , where the stamp were unveiled in a first-day-of-issue ceremony on October 1.

In order to beat Pluto's collapsing atmosphere and a hemisphere falling into shadow for the next century, we are designing what may be the fastest object ever launched from Earth. What follows is our story, still unfolding, which we hope will culminate with a dual flyby of Pluto around 2006 [Rendering of s/c at Pluto-Charon]. A few dozen people are leading the effort today from organizations scattered around the United States. We have many enthusiastic supporters, ranging from NASA Administrator Dan Goldin to schoolteachers, reporters, students, friends and colleagues. And we have a few detractors who question the speed of our pace, our ability to meet stringent cost targets, the value of visiting Pluto, or who just wish they were in our shoes.

WE ARE NOT THE FIRST

The idea of a fast flyby to Pluto is not new. Stacy Weinstein collaborated with JPL's Ross Jones in 1989 on an idea for a 5-6 year direct trip with a 39 kg microspacecraft. Mostly due to timing (not too many people paid attention to microspacecraft back then) , the idea received little attention.

1990 brought with it a new Pluto flyby idea. A design effort coordinated by Bob Farquhar (then at NASA headquarters) called for a 350 kg spacecraft with 45 kg of science payload to be launched off a low cost Delta II. While much lighter than other planetary spacecraft, the high energy needed to get to Pluto directly could not be supplied by the Delta II; thus, the trajectory took us by Earth and Jupiter for gravity assists before finally making it to Pluto in 13.6 years with launch opportunities in 2001 - 2003.

1991 brought yet another Pluto flyby concept: the Mariner Mark II (MMII - a version is now being built for *Cassini*). Weighing over 2000 kg without propellant and costing over $1 billion, this Pluto flyby was to have a daughter probe to see both sides of Pluto, a large science payload, and had a flight time of 16 years launched off a Titan IV/Centaur onto the same trajectory as the previous 350-kg spacecraft would have used. With its sister mission, the Neptune Orbiter, the two new MMII missions would go into production just after the MMIIs were being launched for *Cassini* and the since-canceled Comet Rendezvous and Asteroid Flyby. Many felt strongly that mass, flight time, and cost for an initial Pluto flyby were headed in the wrong direction. Stacy didn't enjoy the thought of trying to support a mission which wouldn't get to Pluto until 2017.

By the end of fiscal year 1991, any hope of a fast Pluto flyby looked pretty bleak.

At about this time, Rob Staehle was working for Bob Easter on ways to make JPL more efficient and cost effective. With a lot of great ideas on paper, Rob feared that they would stay on paper unless given a test. What better way to test the concepts than with a mission? On October 1, 1991, that mission was born. Rob stopped by friend Stacy's office with the Pluto stamp. Rob jokingly asked what we were doing about this travesty of "Pluto - Not Yet Explored." Stacy scoffed at Rob's idea of the possibility of doing an orbiter explaining that Pluto's small mass wouldn't even start to slow the spacecraft down.

Undaunted, Rob suggested a microspacecraft with staged solid rocket motors. Stacy was still doubtful, especially since "no one ever pays attention to microspacecraft around here." At that point, Rob recounted a meeting where he was shown a 300 gram attitude control camera which would fit in the palm of a hand was shown to him. Incredulous, Stacy took a look at Rob's orbiter, and in a week and a half announced that a 35 kg orbiter could be placed into orbit around Pluto, but that the flight time would be 18 years and there was a concern with keeping the solid rocket motors warm that long. However, 18 years for an orbiter didn't look so bad next to a 16 year flyby.

We then started mustering support from around the JPL community. Rob started with the chief scientist, Moustafa Chahine, who liked the idea and gave us his support, encouraging John Beckman and Charles Elachi to fund a small proposal. We also needed science support, and the first two people Stacy went to were Bob Brown and Rich Terrile, both members of the NASA-chartered Outer Planets Science Working Group (OPSWG). While Bob was very busy with the *Cassini* mission, he was instrumental in helping us get early backing. Rich has a wonderful way of making science understandable to the non-scientist and has a great gift for speaking, especially when impassioned, which has proven invaluable in many forums. He was equally incensed at the long flight times and high costs of the MMII Neptune and Pluto concepts. After serving on the *Voyager* imaging team, he was itching to go back to the outer planets as well as help try to change the culture of the lab.

We set a very stringent mass goal of 35 kg on the -spacecraft; of that, 5 kg and 3 watts were for science. HOPPY Price came up with our first spacecraft configuration: [Line drawing of early Pluto s/c] the subsystems were "pasted" on the back of the antenna without a supporting bus! With Hoppy working on *Cassini* we then recruited Chris Salvo to develop the spacecraft system design issues. Rob also brought people on-board who normally would not be brought on so soon in the design phase; these people have proved invaluable as well: Doug Abraham for Launch Approval, John Schlue and Mike Taylor from Product Assurance, Hershal Fitzhugh and Roy Appleby from Test and Launch Operations, Dick Caputo for scheduling, John Carraway from mission operations, Paul Henry from instrument development, Walt Boyd for accounting, Mike Zydowicz from Systems Safety, Jim Wilson and Dave Seidel from Public Affairs, and Peggy Easter and Stu Imai for Procurement.

We had a number of hurdles to jump: 1) our peers were not used to seeing very small spacecraft and tended to laugh at our attempt, 2) we had to garner OPSWG support for a quick trip to Pluto in which the MMII instrument payload which they'd been tempted with would have to be greatly scaled back, and 3) proving that we could control costs. Luckily, senior lab management and NASA headquarters were beginning to look for less expensive missions with more focused science results. Part of the money for the MMII Neptune/Pluto studies was parceled over to two Pluto mission developments: the "Pluto 350" mission (reborn from the 1990 design), [Line drawing Pluto 350 s/c] and the "Pluto Fast Flyby," so named because it could get to Pluto in less than half the time of the other designs; the orbiter concept had been dropped. [Line drawing of PFF s/c] The Pluto arena was leading to a showdown between the two concepts. Life cycle costs at first glance were a wash; the trade was between flight time and breadth of science. The debate went on through the April 1992 OPSWG Mid-term Review. While headquarters was leaning toward the fast flyby concept, they could not sign up to it without OPSWG -endorsement.

Three weeks earlier, Dan Goldin had taken over as NASA Administrator. His encouraging philosophies -- to design better, faster, cheaper missions -- coupled with the idea of empowering employees to make their own decisions (and be held accountable for the risk) were right in line with the Pluto Fast Flyby thinking. In May, Rob had the fortune of being invited to attend a ceremony at the Motion Picture Academy of Arts and Sciences, in which Dan Goldin was to return Steven Spielberg's Oscar to the Academy from the statuette's sojourn aboard the Space Shuttle. Determination seized Rob, who in turn seized the opportunity to speak to Mr. Goldin about our mission development. When Rob told him that we wanted to launch in 1998, Mr. Goldin asked why we couldn't launch sooner. Rob handed Mr. Goldin the team's half inch-thick (doubled-sided) mid-term report containing the mission details which Mr. Goldin promised to read that night. Mr. Goldin was soon asking Wes Huntress at NASA headquarters how his Pluto mission was doing.

In the meantime, Alan Stern of the Southwest Research Institute and Rich had slowly begun to convince the OPSWG that there were small instruments out there which could fit into the Pluto mission needs. After negotiations in July 1992 in which the engineers and scientists worked side-by-side, a set of top priority objectives were established. Once it was proven to OPSWG's satisfaction that the Pluto Fast Flyby could accommodate these key objectives, the Pluto 350 concept was dropped and the Pluto Fast Flyby mission development continued full steam.

WHY PLUTO?

As the last first mission to a planet in our Solar System, the Pluto mission holds phenomenal potential for discovery. If -there is one lesson to be learned from the previous first planetary missions, it's that you can expect to be surprised.

What little we already do know about this planet is fascinating.

With a diameter of about 2300 km Pluto is the smallest known planet. It's inclined and eccentric orbit of the Sun carries it between 30 and 50 times farther from the Sun than the Earth and gives Pluto wide seasonal variations. Only a small portion of Plutois 248 year orbit has been sampled since its discovery. These properties, the smallest, farthest, coldest, most difficult planet to explore, make Pluto the Mt. Everest of planetary exploration.

Pluto has a thin atmosphere and a relatively large moon, Charon, orbiting at a distance of about 20,000 km. Methane is a constituent of the surface and atmosphere; except for recent detections of nitrogen and carbon monoxide, little else is known about the other components. *Voyager* results suggest that Neptune’s moon Triton is a near twin of Pluto in size and albedo. Triton has a complex geology [Picture of Triton], active surface eruptions, polar ice caps, seasonal surface frost changes and limb hazes. Only a spacecraft encounter can provide this kind of information. Pluto is now just past perihelion, its closest approach to the Sun. As it moves outward it is cooling and its atmosphere is condensing. It is essential that Pluto be explored before the 2020's when its atmosphere will be frozen onto its surface for the next two centuries.

The onset of a deep southern-hemisphere winter is also plunging more and more of Pluto and Charon into long-term shadow where they cannot be imaged mapped with Pluto and Charon tipped 118 degrees. For about half of their 248 year orbits their north polar region point toward the Sun leaving the opposite pole in shadow for decades. In 2005 less than 10% of Pluto will be in seasonal shadow. However, by 2015 that percentage will increase -to 20%. By the 20301s, the polar orientation to the Sun will cause almost the maximum possible fraction of Pluto and Charon to be hidden in a decades-long shadow. This shadowing will not be significantly reversed until the 2060's. The last time humans had an opportunity to study Pluto near perihelion a young George Washington was vandalizing cherry tress.

CHALLENGING THE NORMS: BUILDING MISSION AND SPACECRAFT

"Studies need not apply," Rob admonished assembled industry representatives seeking Pluto-related contract opportunities at a November 1992 industry briefing. We asked aerospace engineers and marketers to tell us about real hardware they could build to help our little spacecraft lose even more weight. We were not interested in a lot of "what-if" analyses purporting to show that if we did this, that and the next thing, look what a terrific result you could have. . .on paper. In an industry swamped with "studies" Rob banned the word "study," insisting that if we used the word, it would imply that our end product would be a nice report that would wind up alongside other reports of so many worthy but unflown missions clogging people's offices.

We have each worked on a lot of studies, and they have their place for sifting through ideas by learning the merits, obstacles, and feasibility of a variety of alternatives. But don't we already know enough to go to Pluto? Isn't visiting the last known, unexplored planet in our Solar System a sufficiently compelling objective? Let's get on with it!

Well, it's never quite that simple.

Moving from our original concept in January of a 35 kg probe carrying a camera and a radio, in April 1992 we arrived at a slightly more robust, and realistic, 100 kg mass. We did not -propose to actually fly this spacecraft, as without redundant subsystems, it lacked the reliability needed for a seven year mission. If almost any part in the radio transmitter failed, for example, we would never hear from it again. Multiply that by tens of thousands of parts, even with a pedigree of high reliability, and the chance of even one of the two spacecraft completing its mission appeared to be roughly 60%. No human endeavor is ever 100% sure, but with a few hundred million dollars of taxpayers money at stake, a 40% probability of complete failure seemed more like gambling.

After a great deal of hard work by many experts at JPL and elsewhere contributing free overtime, we arrived at our so-called "1992 Baseline" mission, with a spacecraft concept weighing 164 kg. Working alongside our design engineers, Caltech students completed a full-size mockup, and we shipped our first "hardware" August 21 to the World Space Congress in Washington, DC [Picture of mockup w/Zitola].

With the mockup seen by thousands at NASA's exhibit, an end-to-end plan for how we would build, test, launch, operate, and get the scientific results back from our mission, and a modestly detailed estimate showing that we could develop the mission for under $400 million, we proudly presented our results to OPSWG members and our NASA sponsors. After adding redundant subsystems and assuring we could meet broader scientific objectives set by Alan Stern's OPSWG, our spacecraft mass had grown to 164 kg, with a still comparatively swift flight time of about eight years.

Having converted many critics along the way, we expected praise during the September close of the Government's 1992 fiscal year. Our sponsors, Carl Pilcher and Wes Huntress, of NASA's Solar System Exploration Division, indeed seemed pleased. We had accomplished what many said could not possibly be accomplished in the brief period since getting the green light in January, and we 'had done the job for thousands of dollars less than we had promised.

So we were shocked to learn that Dan Goldin, Wes Huntress' boss's boss, was furious. "What happened to 100 kg?" Mr. Goldin hadn't read the fine print.. the part about reliability and more limited scientific objectives. "The Bureaucrats have spoiled your beautiful dream!"

So, we were told by our sponsors, in so many words, "No, don't proceed with your plan to finalize your design, solicit a scientific team, or build and launch your mission to Pluto."

"GO ON A DIET!"

Our instructions were instead to go on a diet. We joked that our 164 kg spacecraft mass was about the combined weight of two fat engineers. We set ourselves a goal of 110 kg, or about the weight of two slim engineers, a man and a woman.

Part of our diet involves curbing a voracious appetite for making every possible measurement one can think of at Pluto. Unfortunately, scientific instruments are usually expensive, massive, power hungry and put further requirements on the spacecraft. However, the data they gather is the reason to go to Pluto ! A crucial agreement we have with the OPSWG is the three primary science goals for this mission: 1) imaging the geology of Pluto and Charon, 2) mapping their surface composition, and 3) characterizing Pluto's atmosphere. We are designing the spacecraft around just these primary goals. It turns out that once you have instruments to meet these goals you can also do much more. The challenge is to design these instruments so they fit into a small volume, consume very little power and are inexpensive. Rich spends much of his time finding ways to get the most from a very small (relative to past outer planet "missions) allocation of resources. Among the "new ways of doing things," we are economizing on the payload by sharing components.

We hope to combine several instruments into one by sharing the common components like the telescope optics. When we started, the idea of having payload weigh under 10 kilograms was met with skepticism and resistance. Now, after studying miniature instruments which have already been built, we are confident we can do the job and return more data from Pluto than Voyager did at Triton.

It's one thing to be told to lose weight; it's another to be given the proper resources to attack the problem! With the Advanced Technology Insertion (ATI) process we have $5M to shop for lightweight components and subsystems. Of course, the money isn't enough to buy the ready-to-fly part; but, it does allow ' some important advancements. First, we surveyed industry, Federal labs and academia for Pluto-applicable hardware. This survey provided the information needed to solicit focused "Request for Proposals" (RFPs). Successful bidders are now building critical items such as antenna, electronics, operations software and propulsion components which are lighter, smaller quicker, and/or use less power than has ever flown on a planetary mission. These are to serve as proofs-of-concept. While not flight qualified, these components cost a fraction of flight cost and give us time to learn what will work and what won't for our unique mission. In many cases, our ATI funding is insufficient to cover each proposed design and proof-of-concept effort, so participants are augmenting their Pluto money with internal research accounts to achieve their goals. ATI results are not paper studies but actual products we will test.

We set aside a small pot of ATI money for student-led projects. The same rules apply: the products must be tangible, not paper studies. A number of university proposals have been considered and are being funded; one even holds potential for "commercial benefits if it works. We are committed to involving students in mission development and later in mission operations.

TAKING RISK

Our design at the end of Fiscal 1992 was indeed conservative, as Mr. Goldin noted. With a lot of innovation from people at JPL, industry, universities, and other government laboratories, we can now see our way down to about 120 kg, *if* work starting now pans out. With luck, we may pick up other gains to reach our goal.

There will be a lot of newer technology in our lighter design. And "newer" typically means "unproven," implying greater risk. This seems to be exactly what Mr. Goldin is imploring us, and funding us, to do. Many within our industry feel that much of the industry has become too risk-averse, and perhaps too comfortable with minor upgrades of yesterday's technology. The United States didn't put people on the Moon with "comfortable" or risk-averse technology. Nor did the Soviets and Americans launch the first planetary probes in this manner. So if the United States and NASA are not going to put the vanguard of technology into the first mission to Pluto, where are we going to put it? What *will* we use to lead ourselves into the next millennium?

So if our entire science activity can be accomplished with instruments which together weigh a fraction of today's spaceborne interplanetary television cameras, and if all the data we collect at Pluto is stored in a memory weighing less than many of today's computer keyboards, and if our high-gain antenna to send signals five light-hours back to Earth weighs about the same as the telephone on our desks, perhaps we will have helped push technological achievement. And perhaps we will plant the seeds for the next generation of robotic space exploration, whose designers of 7 kg Mars rovers and 25 kg asteroid explorers will 'wonder why we did not consider 100 kg to be the height of extravagance. Indeed, such plans are on the horizon, and we must work knowing that if we are successful, our achievement will soon be eclipsed.

THE NEXT STEPS

If we succeed, our design at the end of this year will lead to "breadboard" hardware and software in 1994. By this we mean we will create the spacecraft and ground equipment in effect on a small number of workbenches in laboratories. The first mission equipment we build, following from that built in our current ATI phase, often won't look much like a spacecraft, but it will demonstrate that we can perform the necessary functions at the level of components (like a radio receiver), and subsystems (such as propulsion) . Testing will verify critical electronic and mechanical functions of sensors, thrusters, valves, computers, electronic memory, and so on. Computer software written on ordinary personal computers, will verify our scheme to send commands to the spacecraft, and to govern interactions between different parts of the spacecraft and ground equipment. This early software will be used and upgraded to test as we build, and will evolve into the computer commands to be launched onboard the spacecraft.

Our next step, planned for 1995, is "brassboard" equipment. This hardware and software is to be close in form, fit, and function to what we plan to fly, but will lack the reliability and thoroughness needed for the actual mission. Breadboard level testing is expected to reveal flaws in our design and show better ways we can implement complex functions, such as routing data from the camera to the memory. These lessons will be incorporated into brassboard equipment, which will look similar to what we plan to fly, but will generally be heavier. Because "breadboard hardware is the least expensive, and brassboard equipment much less expensive than flight equipment, problems found and solved at these stages are much easier to fix than after we have a larger team working with expensive, flight-quality parts.

If we avoid many pitfalls, inspire enough supporters, and garner the needed political support to proceed, we are hopeful of a "new start" in Fiscal 1996, where the Pluto mission would be funded as an individual line item in the Federal budget. (Funding up to this stage comes from the so-called Advanced Studies budget.) There is a great deal of competition among worthy projects of all kinds for limited funds. However, we believe that we owe the nation something more than the images and knowledge of the last planet. Many of us on the Pluto team grew up during the high visibility of the Apollo era space program. A time when the nation put great value on the role NASA played in feeding high technology into the private sector. This perception inspired many young people to pursue careers in the sciences and is directly responsible for our participation in the Pluto mission. Now we would like to return the favor by giving some of the old NASA excitement back to the nation. We do this by mandating that the newest technologies will be used, by challenging ourselves to build small, inexpensive but sophisticated spacecraft, and by reaching out to communicate our pursuit to the young.

When we do begin building our flight equipment, the progressive design-build-test cycles of the ATI, breadboard and brassboard phases are expected to drive out nearly all of the major kinds of problems we are expecting. Of course it is the problems we are not expecting that most worry us, so the flight equipment will be no piece of cake. But we are carrying healthy cost and schedule reserve to deal with the unexpected problems we all know will be there.

If we are not forthcoming with every cost-saving innovation in both what we do and the way in which we do it, there will in all probability be no mission. We have been given a strict cost cap of $400 million (in 1992 dollars) for development of the spacecraft, instruments, and ground system, from new start through 30 days after launch. If at any time it appears that we cannot meet our objectives within this budget, we can expect our project to be canceled. We are preparing for a firm cap on mission operations costs as well.

In today's climate, we cannot afford to be slow. Time is money. And the willingness of taxpayers to support this mission of exploration and inspiration is a privilege which can be revoked at any time. Add to this the standard of excellence for planetary missions which have preceded us, and we have a very big challenge ahead.

We can use all the encouragement we can get, and we appreciate your support.

Acknowledgements

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Further Reading

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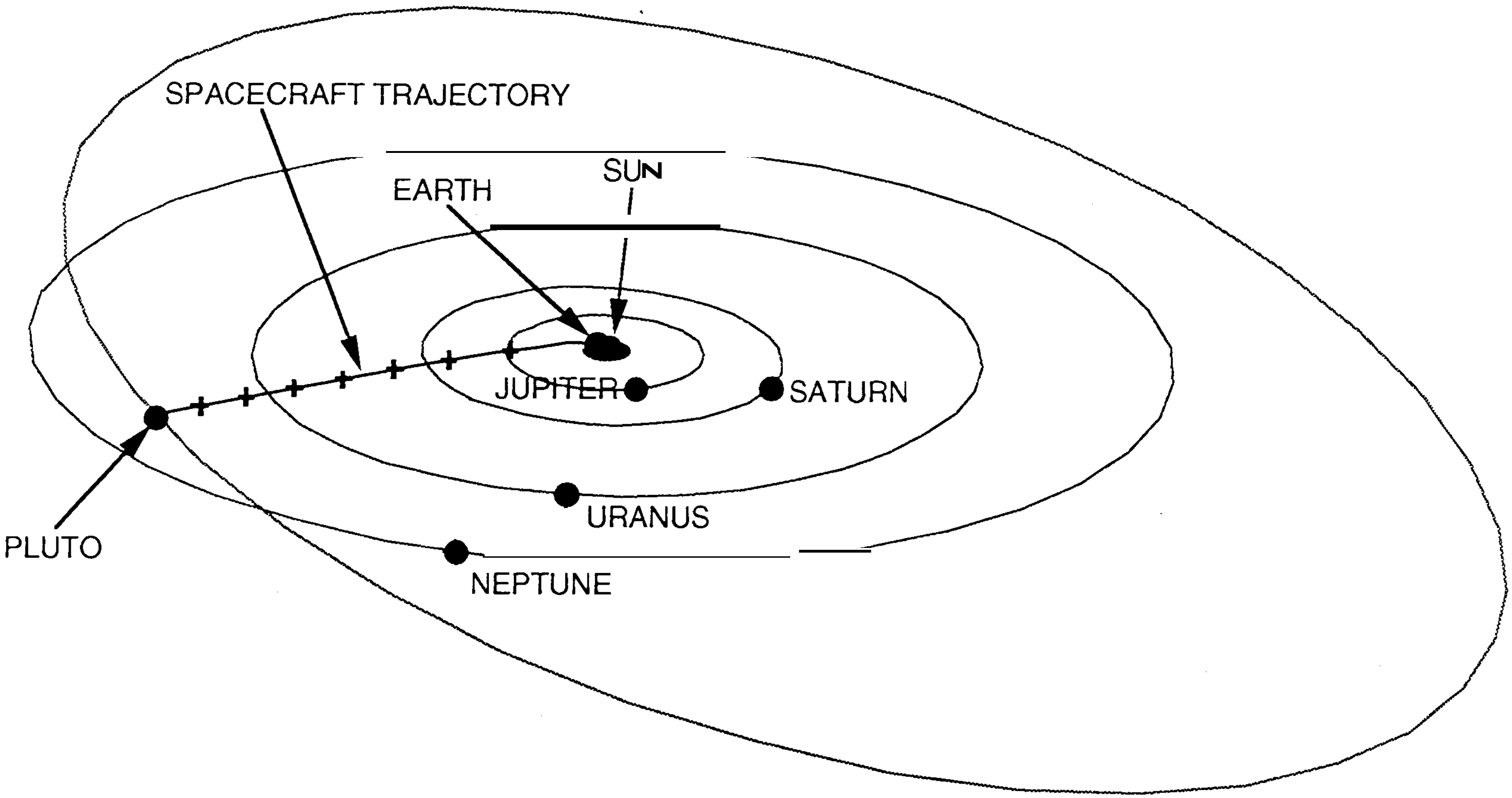
The Authors

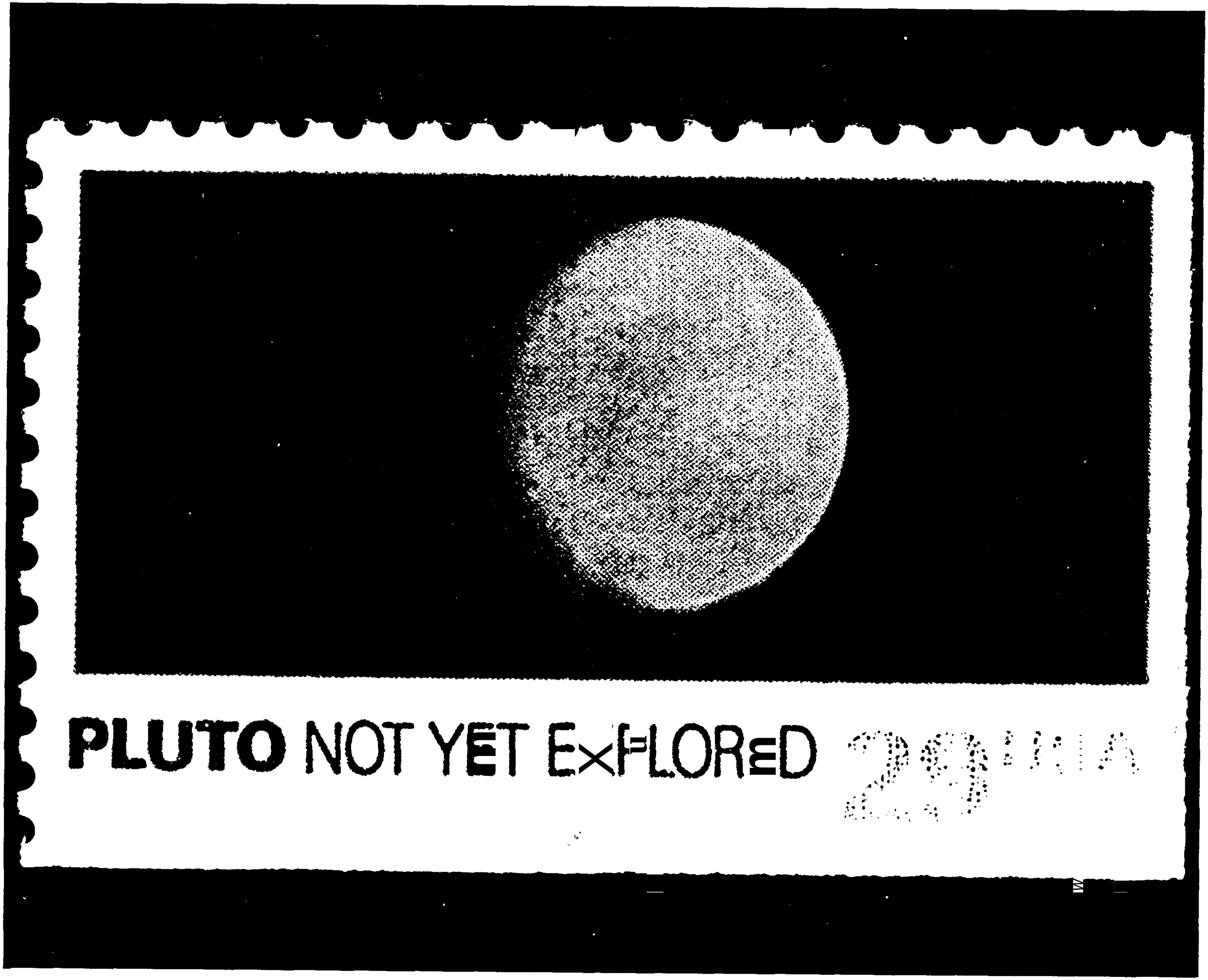
Rob Staehle is Manager of the Pluto Fast Flyby Preproject at JPL . His experiment, "Bacteria Aboard Skylab, " was flown when he was in high school and college. From Purdue University and engineering training at NASA's Marshall Space Flight Center, he joined JPL's Voyager Project to help plan photopolarimeter observations at Jupiter. He has since worked on numerous advanced mission ideas including lunar bases and human Mars exploration. He spent 7 years as an engineer and manager in the Space Station *Freedom* program. Rob is also President of the World Space Foundation, which sponsors solar sail and asteroid research, and a search for planets beyond Pluto. He enjoys hiking, photography, and travel.

Dr. Rich Terrile is an astronomer in the Earth Space Science Division at the Jet Propulsion Laboratory. He graduated from the State University of New York at Stony Brook with a B.S. in both Physics and Astronomy in 1972. In 1973 he received an M.S. and in 1978 a Ph.D. in Planetary Science from the California Institute of Technology. He was Group Supervisor for the Planetary Astronomy Group at JPL, a member of the Voyager Imaging Science Team and is currently developing instrumentation for the direct detection of extra-solar planetary systems. Dr. Terrile is the discoverer of several moons of Saturn, Uranus and Neptune and together with Bradford A. Smith of the University of Arizona, he took the first pictures of another solar system around the nearby star Beta Pictoris. He is a private pilot, has interests in photography, cinematography and special effects, and was the technical advisor on two major motion pictures. He also studies and performs improv comedy and designs instrumentation for use in neuro-surgery.

Stacy Weinstein is in the Advanced Projects Group of JPL's Mission Design Section. On the Pluto Fast Flyby Team, she is responsible for the trajectory, navigation, and launch vehicle as well as student projects. One of the youngsters inspired by the Space Age, she was the only 7th grader in Peoria, Illinois to have pictures of Mars taken by the *Viking* lander a year earlier. After graduating with a Bachelorts in Aerospace Engineering from MIT in 1987, she started at JPL on the Cassini Mission Design Team. She has since been involved with JPL's Pluto efforts as well as a variety of advanced concepts, including Discovery Workshop proposals for the Mars Polar Pathfinder and the Mars Operational Environmental Satellite (MOES). Stacy enjoys music (rock/alternative) , sailing, golf and writing.



Pluto Fast Flyby


PLUTO NOT YET EXPLORED
29

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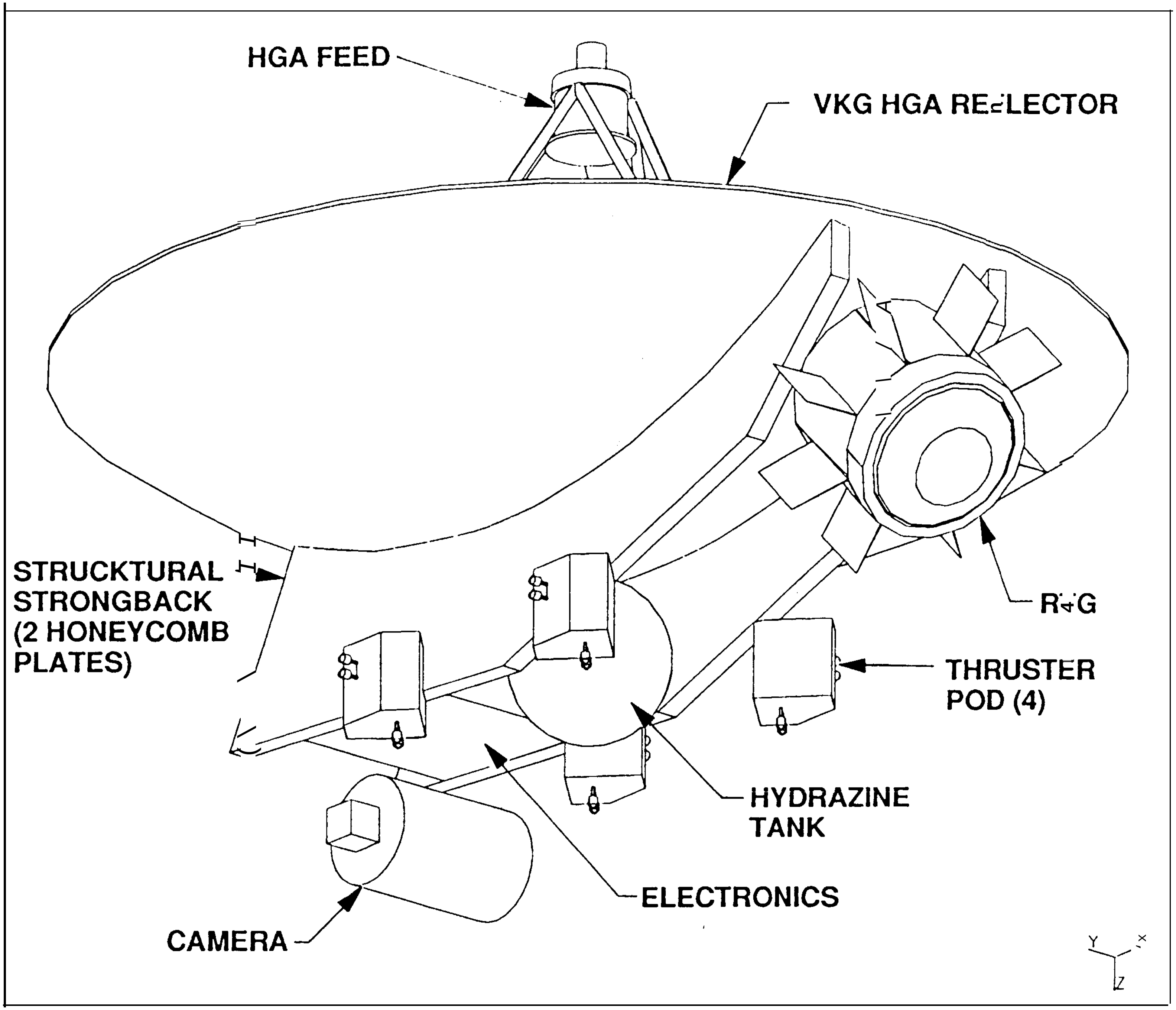
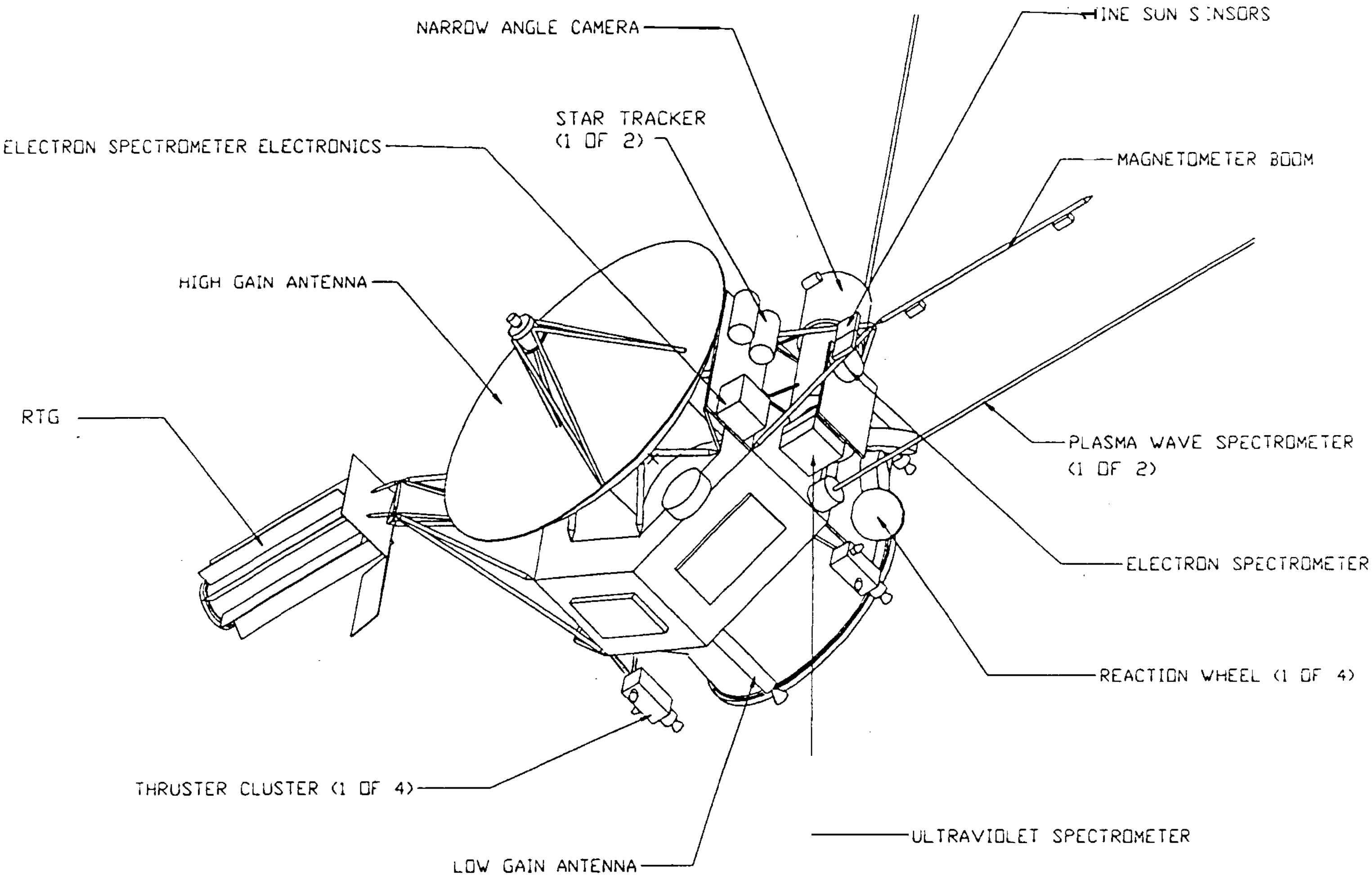


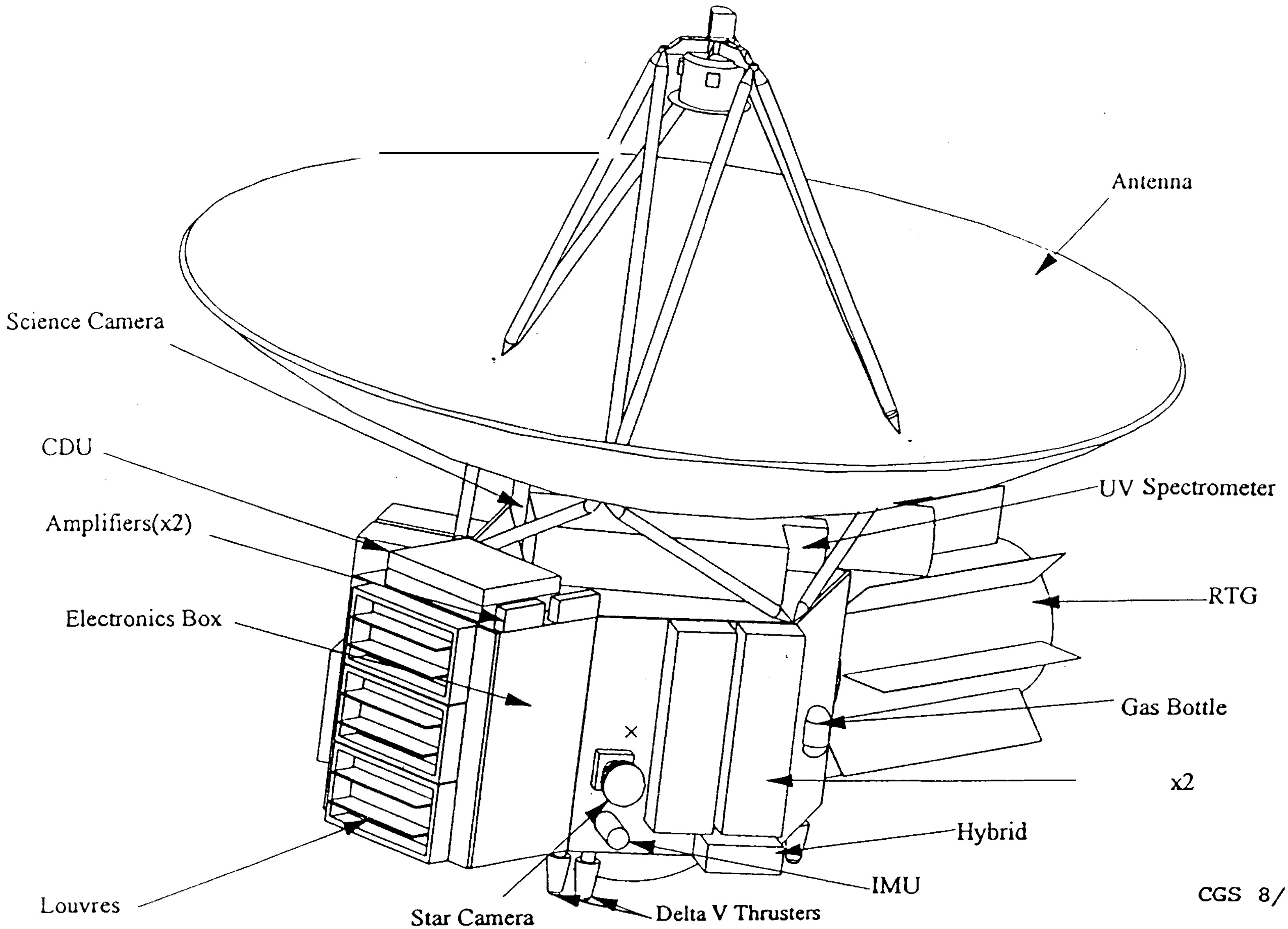
SPACECRAFT CRUISE / ENCOUNTER CONFIGURATION



JPL

P UTO EXPLORATION WI H VERY SMAL SPACECRAFT

SPACECRAFT CRUISE/ENCOUN ER CONFIGURATION (+Z ISOMETRIC VIEW)



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Picture of Triton (Voyager)