Voyager – The Right Staff

Introduction
During the "golden decade" of interplanetary space exploration (1970-1980) many „firsts" never thought to be possible before occurred. All those history making projects were launched from Cape Canaveral in Florida on US Titan-Centaur "heavy duty" launch vehicle configurations:

Helios-1	10 Dec 1974 - 16 Mar 1986	Closest approach to the Sun 0.3 AU, first major US/German cooperation. Data reception over 10 years, covering one complete solar-cycle*).
Viking-1 Orbiter (VO1) Lander (VL1)	28 Aug 1975 - Aug. 1980 End of 1982	Mapping of Mars, robotic landers for soft landing, panoramic close-up, high-resolution images transmission and soil sample analysis.
Viking-2 Orbiter (VO2) Lander (VL2)	09 Sep 1975 - End of July 1978 12 Apr 1980	Coordinated mission with Viking-1 to retrieve and secure maximum science return possible. 16.000 Mars images from the VL2 camera were transmitted to Earth.
Helios-2	15 Jan 1976 – 07 Jan 1981	Closest approach to the Sun 0.29 AU, still unmatched. Last data reception: 6 March 1980
Voyager-1	05 Sep 1977	Fast trajectory to outer planets Jupiter and Saturn, delivering the first high resolution image of the great red spot and detecting the first extraterrestrial volcano on Jupiter's moon Io, cruising on to Saturn and its moon Titan. The Saturn encounter moved Voyager-1 out of the ecliptic plane terminating its prime mission, but enabling Voyager-1 to speed on to leave the heliosphere on 25th August 2012 as the first man-made object.[1] Status 14th April 2016: [2] Distance from Earth: 20,069,769,629 km RTLT (round-trip-light-time): 37hrs 11min 31sec-
Voyager-2	20 Aug 1977	Coordinated mission with Voyager-1, "grand tour" to outer planets continued in the ecliptic to Uranus and Neptune. Status 14th April 2016:[2] Distance from Earth: 16,582,620,200 km RTLT (round-trip-light-time): 30hrs 43min 47sec
		***) Note:** Helios-1, its original planned mission duration being only 18 months, could be operated in extended mission mode until 16. March 1986. This unexpected long duration of more than 10 years for Helios-1 and the excellent functioning of the scientific instruments enabled the scientists to collect field- and particle data covering an entire solar cycle of 11 years and further enhance and correlate their measurements with the two Voyager spacecraft (Voyager-1 launch on 15th Sept 1977, Voyager-2 launched earlier on 20th Aug 1977) having similar field- and particle instrumentation, thus covering the whole space environment between 0.3 AU and beyond the Earth orbit (< 1AU).

As can be seen from the table above all projects have fulfilled their missions over and above all expectations and have been long retired except the two Voyagers which are still sending unprecedented data back to Earth. The achievements of the two interplanetary Voyager probes are plentiful and well documented (e.g., Wikipedia).

The Voyager missions were originally meant to last four years, and took the probes initially to Jupiter, then Saturn. As a bonus since everything was working well, Voyager 2 also went to Uranus and finally Neptune. Voyager -1 spun off after the Saturn/Titan encounter to continue its journey "out of the ecliptic" and eventually became the first "man-made" object to leave the heliosphere. Don Gurnett, principal investigator for the Voyager Plasma Wave Experiment, from the University of Iowa said: 'When you hear this recording, please recognize that this is an historic event. It's the first time that we've ever made a recording of sounds in interstellar space. It took us 10 seconds to realize we were in interstellar space'. [1]

Scientists hope to learn more about this "heliosheath" region - the outermost layer of the heliosphere where the solar wind is slowed by the pressure of interstellar medium - during the time Voyager 2 is traveling through until it also exits into interstellar space.
Against all expectations both Voyagers vintage electronics and thrusters are still, mostly, working in the intense -253C cold of outer space. What's more, their sensors are still sending data. That said, by 2025 almost all the instruments sending scientific information will be turned off as the probes' tiny plutonium-238 power sources dwindle (see table below).

The on-board camera on each Voyager, for instance, was deactivated to save power 25 years ago. This was after Voyager -1 took a now-iconic "family portrait" of the solar system from almost 4bn miles out. It captured Neptune, Uranus, Saturn, Jupiter, Venus, Earth (the Earth seen, in the late astrophysicist Carl Sagan's phrase, as a "pale blue dot") and the Sun, by then just a tiny point of light. By ~2030 the craft will stop communicating with the Earth, although in perfect mechanical condition, probably for eternity.
The two interstellar ambassadors also carry a gold-plated disc each containing multicultural greetings, songs and photos, just in case one of the probes bumps into an intelligent species on its journey through the universe.

The following table summarizes the planned powering-down [3] of the two Voyagers probes, but still maintaining communications capability. Ed B. Massey, previous project manager for the Voyager interstellar mission said: "That signal, produced by a 20 watt radio transmitter, is so faint that the amount of power reaching our antennas is 20 billion times smaller than the power of a digital watch battery" [7]. This also is one of the great achievements of this mission - to be able to receive Voyager-1 with a 20W transmitter output power over 20,000,000,000 miles away from Earth. This was only possible with the gradual expansion of the powerful NASA/JPL Deep Space Network (DSN) and the application of highly sophisticated antenna arraying techniques. The ground station personnel around the world performed a tremendous job not mentioned and appreciated often enough.

	VOYAGER 1	VOYAGER 2
Power Off Plasma (PLS) Subsystem.	2007	
PLS Heater	2007	
Power Off Planetary Radio Astronomy Experiment (PRA)	2008	2008
Power off Ultra Violet Spectrometer (UVS)	2016	1998
Termination of Data Tape Recorder (DTR) operations	~2018	2007
Termination of gyro operations	~2017	2016
Initiate instrument power shutdown	~2020	~2020
Can no longer power any single instrument	No earlier than 2025	No earlier than 2025

Canberra DSN station complex
Main antenna with 70 m dish diameter [NASA]

Sept. 12, 2013: Suzanne Dodd speaks at Voyager 1 press conference (image: space.com)

The Operations Team

Being in extreme "extended mission mode" the Voyager controllers have been moved out of JPL's main complex in Pasadena to an annex located a couple of miles away on West Woodbury Road in Altadena. It is quieter there and out of the focus of the media people always looking for high suspense, excitement and new breakthroughs.

To determine that Voyager-1 had left the solar system, the team had to listen and analyze recordings made by Voyager's 8-track tape recorder (interstellar space sounds different than the outer reaches of the solar system).

"It's like flying an Apple-II computer" said Suzanne Dodd [4], Voyager's current interstellar project manager. Dodd wanted to get Voyager to speed that up a bit and Larry Zottarelli was her guy. Larry, known as the last original Voyager engineer will retire in 2016 at age of 80 Zottarelli has been on the Voyager-1 mission since the day it was launched on September 5, 1977. He worked on Voyager's flight data systems, which uses only 64 kilobytes of memory (0.000064 gigabytes) featuring long-since retired computer languages. The result can be listened to by clicking the "Voyager interstellar sound" link above.

"We often have questions about how something works," Dodd said. "People who work on the project now don't know why something was built a certain way -- and with Voyager in its 38th year, it's hard to find the documentation that goes with it."

Virtually every document about Voyager was printed or written down on paper. Each time the Voyager team moved locations, some of the papers would be lost during the packing process.

Dodd has a secretary whose full-time job is scanning reams of paper about Voyager into a document cloud system to make the manuals easily searchable. But engineers don't always write stuff down. Some Voyager engineers have passed away, taking the spacecraft's secrets with them.

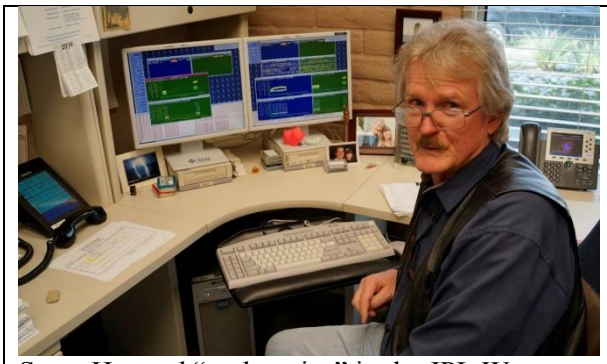
For example, the Voyager team realized last decade that part of the spacecraft's flight software was going to turn off in 2010. Dodd called as many retired engineers on the Voyager team as she could, but no one remembered why that routine was programmed into Voyager.

Dodd and her team guessed that no one dreamed the mission would last as long as it has, and the team wanted to ensure that there was enough power for some of Voyager's other routines. She opted to override that command and keep Voyager running – only Zottarelli could do that.

However, with Zottarelli retiring, the challenge was to bring someone on who knows older programming languages and isn't 80 years old.

"Finding people who can do that are few and far between," Dodd said.
Though NASA found a younger engineer who was brought on to work with Zottarelli and eventually replace him, Dodd said it's an impossible task.
"No one will replace him," Dodd said. [4]

Back to the Voyager "off-campus location" on West Woodbury Road: on a chilly March morning in 2015, Steve Howard [5], beyond retirement age, unlocks the door to his office at 5 am to begin his shift in the JPL Annex, Building 600, Altadena. Two computer screens are squeezed on to his corner desk along with family photos, a tissue box and the multichannel voice intercom connecting him in real-time with all DSN antenna sites around the world (Goldstone, Madrid, Canberra) . Howard is a ground/mission controller sending commands to the Voyagers billions of miles away from Earth through the DSN while competing for precious antenna usage time with the other ongoing, more prominent interplanetary JPL/NASA missions, always keeping in mind that the response time (RTLT) to his commands is over 30 hrs.
Steve Howard is alternating with Enrique Medina [6], also around retirement age – "we take turns and one of us is always on call. The team is connected all the time by their smartphones. We will hear, that way, which engineering channel is out of tolerance and then we will connect from home with secure IDs and special codes, troubleshoot, determine and sometimes fix it from home. Or in some cases, one of us will drive in. That usually happens four to five times a month.



Steve Howard "at the reins" in the JPL West Woodbury office, Altadena ("off campus") [8]

Original Voyager-1,2 control rooms (late 1970's) at JPL Pasadena [NASA] ▶

On a typical day, when the California sun is up, the others would arrive. Without looking up they recognize each other by their approach. When jingling, it is Tom Weeks [6], attitude control engineer (ACE), who once came to L.A. to be Rockstar; he carries his keys in a thick bunch and his hair still as proud as a Heavy metal guitarist. The quiet voice, that's Larry Zottarelli [6], the programmer and "computer whisperer", understanding his machines like no one better does. Regina Wong, responsible for science instrument data was already involved in the construction of the probes in the 1970's, Sun Matsumoto, risk control and Suzy, Jeff, Glenda and Roger might drop in as required also unmistakable by their steps.

Steve Howard - the Space Cowboy, sometimes comes to serve in cowboy hat and boots - loves cowboy songs glorifying the hard farm work. He compares the work on the ranch with the work on the probes in space: "all alone way out there and frequently leading to mend the fence" [6].

Medina would flip through the flight schedule printed on paper: times, instructions, codes. Usually this would all be on a screen as a file. But Roger Ludwig – the sequence planner –stubbornly prints on paper where the sequences look like a surrealistic poem and clean-cut. "We need to mark our computers to make sure the janitors don't unplug them accidentally because they look like surplus. Here, some "modern era equipment" Medina says, Ultra 2 machines which Howard has mended many times, almost 20 years old.

"Why did Voyager-1 survive that long out there, in the depths of the universe, where it is so murky that the sensors must search for the sun in the dark, where it is so cold that the temperature sensors fail, where everything, which is not triple covered with Teflon, Mylar and Kapton is frozen and only the wind from extinct stars whistles along the booms - why did Voyager-1 survive?
Medina continues: "sometimes people are away, but we love Voyager so much that though it's not part of our employment we'll come in and do it anyway. Attitude control is my assigned sub-system, but if the propulsion or the power needs attention, we all do multiple jobs," he adds. "I've been working on Voyager since the Uranus encounter in 1986, and I will retire when Voyager retires in 2025. My wife doesn't like that idea at all, as we already have a retirement place by the beach back in Mexico." [5]

Engineers are not given to emotion, but the romance of this incredible voyage of discovery has, by their own account, kept the ageing mission team together. Even latecomers, who were at school when Voyager was launched, have been working on the same mission for 30 years and more. "I'm in my mid-50s and treat the craft like my ageing parents," says Suzanne Dodd, who was 16 at launch, joined as a graduate student and whose card now proclaims surely one of the cooler job titles in science: Project manager, Voyager Interstellar Mission. [4]
"You treat them with a certain amount of reverence; you know they're stately spacecraft, venerable senior citizens, and you want to do everything possible for them to have a healthy lifetime," she says. "You need to help them a bit because things have failed and you want to be careful other things don't. Most of the engineers here have dedicated their career to this project. They have turned down opportunities for promotions and other things because they like Voyager so much they want to stay with it."

Medina's devotion to the Voyager is clear to see. "This has been part of my life for so long, and they pay us to do it, so how can you stop doing something you love? I even talk about the spacecraft like it's a person, especially if it's my sub-system." [5]
Steve Howard feels the same. "I just love to think of everything, all those 65,000 parts on each craft, working up there," he says. "Oh man, it really is something. Every time we come in here, it's just a gift. And you know that one day it could stop."[5]

SpaceOps News had the chance to get some more insights into the inner workings of Voyager operations in an e-mail discussion with Suzanne Dodd.

SpaceOps News: How many consoles or workstations do you currently have available at the West Woodbury Road complex and how big is the operations team (on-line and off-line personnel). Is the team also supported by dedicated personnel at JPL?

Suzanne Dodd: The operations team is a total of 12 people, 9 of which are engineers. 10 of the people are dedicated to Voyager and we have several others who are part time. We have 6 workstations in our mission support area and another 6 workstations used for the science data processing.

SpaceOps News: How is the coordination and the data exchange with the still active experimenters being maintained?

Suzanne Dodd: We process the science data return daily and package it up into weekly segments that the science teams then retrieve.

SpaceOps News: Could you try to explain the secret how you were able to adapt the operational needs of the Voyager missions from high activity phases through a reduced extended mission over so many years – how have you been able to come up with just the right number of people having the required know-how and an unexpected dedication never heard of before, reaching even beyond retirement age?

Suzanne Dodd: Due to the long round trip light times and reduced staffing levels from the planetary mission, the Voyager Interstellar Mission (VIM) uses repetitive activities that are stored on board to do most of the calibration and science gather activities. These activities are stored in what's called the baseline sequence which repeats itself over and over. We then have overlay sequences to due special activities like playbacks. Our engineers are responsible for multiple systems, for example sequencing and telecom or power and attitude control. No one on the project has only one job. Everyone is committed to flying voyager as long as possible and will help out where ever needed.

For the most part, Voyager is the very reality of space – slow, patient science, humdrum perhaps, but real. It's only a 20-minute drive from Altadena to Hollywood, where brilliant fake versions of space exploration are confected. But Voyager, starring real people who keep tissues and family photos on their desks and real buildings rather than set designers' glamorous fantasies, just happens to be the only real interstellar mission there will probably be in the lifetime of anyone alive today. It is surely one of the most amazing things in human history. [5] … and can't be appreciated highly enough!

Voyager spacecraft flight model exhibited at JPL (gold-plated record in front of the main body) [8]

References

[1] A blue dot in a cosmic ocean: Radio signal from NASA's Voyager travels outside our solar system is seen from Earth for the first time Associated Press 16 Sept 2013 (MailOnline)
[2] Voyager the interstellar mission (http://voyager.jpl.nasa.gov/)
[4] NASA's last original Voyager engineer is retiring (@David GoldmanCNN, 27 Oct 2015)

[5] 40 Years and counting: the team behind Voyager's space odyssey (Jonathan Margolis @ObsMagazine 15 March 2015)
[6] Die All-Wissenden, Roland Schulz, SZ Magazin, Heft 24/2014
[7] Voyager 1 Now most distant human-made object in space, NASA Press Release February 13, 1998 http://voyager.jpl.nasa.gov/news/pressrelease2.html
[8] Images by Noah Rabinowitz (www.wired.com/2014/10!voyager-mission)