Air and Space this Week

Item of the Week

STARDUST

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"And now the purple dusk of twilight time
Steals across the meadows of my heart
High up in the sky the little stars climb…."

No, I'm not channeling the ghost of Hoagy Carmichael; well, maybe a little bit. But the subject of this Item is not the loss of one's life love, but rather an intrepid spacecraft that used a rather-interesting technology to return material outgassed from a comet to Earth for study.

WHY WAS SAMPLING A COMET IMPORTANT?

Planetologists try to work out the history of the Solar System and the bodies within it. We learn a lot from examining the Earth in detail, but the Earth is a dynamic place, constantly modifying its surface through a variety of processes, so there is less chance to see what the Earth was like long ago. Comets come to us from the outermost part of the Solar System, where they have been essentially in "cold storage" for eons. There is a good likelihood that their chemistry reflects the chemistry from which the Earth and other planets formed. Meteorites are important, too, but they lack the volatile components, the snow in the "snowbank model," of comets. Therefore, acquiring a sample of cometary material, both rock and ice component, became a science priority for NASA.

But how could a robotic spacecraft acquire a representative sample and return it to Earth without damage?

NASA planners went to work. Approaching a comet nucleus was well within NASA's existing expertise. But acquiring a sample without adversely affecting it was not. There were two possible tactics to use. The first would be to land on a comet, gather some of its surface material, lift off from the comet, and return the sample to Earth. Comets have very little gravity, so getting the spacecraft to a desired spot and land there could be difficult.

The other tactic would entail flying a spacecraft into its tail, the material coming off a comet when it gets close enough to the Sun for the ices that bind it together to melt/evaporate. While both tactics ran the risk of spacecraft damage from impacting material coming off the comet, this approach made for simpler spacecraft maneuvering. However, a way to snag material in the comet's tail would have to be developed. NASA chose the second tactic, and planned a mission they would come to call "Stardust."

COMET WILD 2

The ideal comet would not be too large or too small. A large comet would likely be shedding more material and that would be a greater risk to the spacecraft; a small comet might have too little material in its tail to get a good sample. Further, spacecraft operational constraints require sampling occur close enough to Earth for a spacecraft to be able to reach it easily. But a comet that has been routinely coming that close for an extended period would likely have lost a lot of the material NASA was seeking to collect. NASA looked for comets that now get close enough at some part of their orbit to be in range, but having an orbit that got them that close now only came about "recently." A recent orbit-altering gravitational encounter between an outer planet and a comet that hitherto had spent most of its time very far from the Sun would make an ideal target.

One comet in particular, 81P/Wild 2, was just such a comet. The "81P" in its name means it was the 81^{st} "periodic" comet known, one with a well-defined orbit and observations lasting a number of orbital periods. When discovered, Wild (pronounced "Vilt") was in an orbit that had a period of 43 years and kept the comet no closer to the Sun than Jupiter. However, back-calculating its pre-discovery position from its now-observed orbital elements showed that it passed near Jupiter in 1974, four years before it was discovered by Paul Wild. Out in the cold most of its life, it was within reach of NASA, and still unaltered enough for NASA's needs!

81P/Wild is much too small for gravity to have forced it into a spherical shape. Its sort-of potato shaped, 5.5 x 4.0 x 3.3 km. It still has a lot of volatiles, as evidenced by its low bulk density, only 0.6 g/cm2 (water's density is 1.0 g/cm3). Its total mass is on the order of 10^{10} metric tons.

AEROGEL

Let's imagine a simple approach to capturing high-speed-but-delicate material coming off a comet. What if we could get a giant pillow to cushion the impact of comet bits and keep them from bouncing off? OK, that sounds more cartoonish than realistic, but it's the basic approach the NASA mission planners took. A big pillow is ridiculous, of course, but could there possibly be a way to softly catch comet material and keep ahold of it, all without damage?

Answer: Yes (as only NASA can)!

A strange substance called "silica aerogel" had been discovered over a century ago. It had some amazing physical properties. Think what smoke would be like if you could turn it instantly into a solid. It would have very low density, yet be an excellent thermal insulator. Just the kind of stuff NASA needed to insulate the large tanks of very, very cold liquids used to fuel large rockets. But aerogel had a fatally-serious drawback – it was incredibly fragile. So other, heavier and less-handy insulation systems had to be used "back in the day."

A Kennedy Space Center mechanical engineer named James Fesmire found a way in 1992 to make a more flexible, hence less fragile, version of aerogel, that he could use to insulate the cryogenic fuel systems he had to deal with. But he needed help in making it. KSC awarded a

Small Business Innovation Research contract to an outfit called Aspen Systems Inc. to work up a flexible aerogel suitable for NASA use. A lot of research and experimentation went into the aerogel technology, and Aspen soon knew it had a product that was not only useful to NASA, but had other commercial applications as well.

NASA engineers thought that aerogel might make a good trap for the high-speed, low-mass particles that come off a warming cometary surface. They conducted a number of tests, and found at that they were right.

STARDUST'S MISSION(S)

NASA had a good target for acquiring unchanged material from the outermost Solar system, and they now had the technology that could capture it. They then perfected the spacefaring capability to send a spacecraft to collect a comet sample, put it in a re-entry capsule, and send it safely through the atmosphere to the hands of Earth-bound scientists. They put it all together and built the *Stardust* spacecraft.

Stardust was launched on **February 7**, 1999, ***twenty-five years ago this week***. It carried a collector of dust-sized objects with doors that allowed some of them to be in use while others were not. The spacecraft opened some of the doors a year after launch, in order to sample the interplanetary medium away from a planet. The spacecraft flew by Earth on January 15, 2001, for a gravitational assist. It collected another interplanetary dust sample in late 2002.

The orbit planners had to come up with a plan that would get *Stardust* to Wild's tail when the comet was maximally active, while including the necessary gravity assist from Earth. Their orbits of the Sun they planned serendipitously allowed for a fly-by of a small asteroid, 5535 Annefrank, named for the doomed diarist. Annefrank is quite small, and the fly-by geometry was unfavorable for pictures, but the encounter was a good rehearsal for the spacecraft operations that would be required at Wild.

January 2, 2004, was the big day. *Stardust* flew into the tail of Wild, opened the remaining doors on its particle collector, and made other measurements of the comet as it flew by. It would take another two years and two weeks for Stardust to fly by Earth and jettison the sample capsule. It was recovered successfully, and was found to contain a lot of comet and interplanetary particles. More on them later.

But wait, there's more (work for the busy Stardust spacecraft)! But first …

DEEP IMPACT

Impact cratering is an important process affecting planetary surfaces. The population of craters on a surface give important clues as to its age, even if only in a relative sense. Imagine if you don't have enough sense to come in from the (light) rain; the number of wet spots on your shirt will be a reflection of how long you were out, even if that number can't reveal how long in minutes you were out (unless you know the rate of raindrop impacts). If you put on a hat after you had been out a while, the fact that it had fewer wet spots per unit area than your shirt would reveal to all that you put on you hat later. The same idea holds true for cratering on a planet/moon/asteroid; if their surface has parts that are younger, they will have fewer craters. And if you can get a piece of that surface and date it radiometrically, you can calibrate the impact rate over time (one of the primary objectives of study of the Apollo returned samples).

How various factors affect the size of craters is important, too. So understanding the mechanics of impact crater formation under different conditions can be as important as the distribution of craters on a surface.

Meteor Crater in Arizona, other impact scars around the world, computer simulations, and high-speed impact scale modeling together have all been used in this effort. And a specific NASA mission was conducted to examine the process up-close and in real time. It was called *Deep Impact*, a Discovery-class mission comprising two parts, a copper "cannonball" and its carrier, which also had a good imaging system. The idea was to fly Deep Impact at a target, release the cannonball, and use the imager to watch the impact take place, then image the resulting crater. The imager would be able to see a wide range of wavelengths; copper was selected as the impactor material because its spectral signature could be relatively-easily subtracted from the resulting image data.

The target selected for this harsh treatment was a comet named 9P/Tempel 1. *Deep Impact* was launched on January 12, 2005, just over a year after Stardust collected its samples from Wild 2, and before those samples had been returned to Earth. Comets, at least when close enough to the Sun, have active surfaces, so scientists were curious to see the resulting crater caused by *Deep Impact* right after it formed, but also see it again later, in order to see how the crater might have changed as Tempel 1 adjusted itself after being hit. Tempel 1 was struck, and the resulting plume and crater were imaged, on July 4, 2005 no less. What great fireworks for Independence Day that year!

The problem was that the *Deep Impact* spacecraft had moved on.

NASA has a long and rich tradition of getting the most out of its successful missions. *Deep Impact*, succeeded at Tempel 1, but it was only a fly-by there. However, NASA trajectory planners are wizards, and there was another comet within range of *Deep Impact* for it to examine, even if it didn't have another cannonball to fire. The comet was called 103P/Hartley 2, and the spacecraft was renamed *EPOXI*, the *Extrasolar Planet Observation and Deep Impact EXtended Investigation.* EPOXI successfully returned valuable data from its flyby of 103P/Hartley 2 on November 4, 2010. Hartley 2 turned out to be a rather odd body; it's shaped like a peanut and its two lobes have different physical properties. It's likely that Hartley 2 is two, conjoined small asteroids now traveling together.

STARDUST/NExT

NASA planners weren't done with *Stardust* quite yet. In spite of its successful capture and return to Earth of cometary material from Wild 2, there was more work for it to do. The trajectory folks used its pass by Earth to drop off its samples to boost it to a trajectory that would allow it to examine Tempel 1 well after it was struck by *Deep Impact*'s cannonball, an opportunity not in *Stardust*'s initial mission plan. The spacecraft was renamed *NExT*, (*New Exploration of Tempel 1*). *NExT* acquired imaging data before and during its fly-by of Tempel 1, which happened on February 15, 2011.

Getting initially-unplanned "two-fers" out of these to spacecraft really increased the "bang for the buck" scientific return of both.

As only NASA can!

STARDUST RESULTS

One of the biggest surprises of the Stardust mission came during the fly-by. Seventy-two high-resolution pictures were obtained during the closest approach. Scientists had expected to see a lumpy, cratered body. Instead, the images revealed Wild 2 to have deep holes, some with vertical or even over-hanging sides, not like impact craters at all!

Over 200 scientists were involved in the analysis of the material returned from comet Wild 2. They were expecting the rocky dust to be "pre-solar grains," material that condensed in the outer part of the proto-solar nebula, much like the dust envelope astronomers see around stars in their formation process. A goodly number of particles had the expected chemistry, but… Surprise, surprise! The chemistry of many of the returned particles showed that had suffered pretty-intense heating, and some bore the signature of water being present during that process. Those particles had formed much closer to the (proto) Sun than previously supposed!

But wait, there's more! Detailed analysis of the material returned by Stardust took a long time, and in 2009, scientists detected the presence of glycine in some of the particles. Glycine is an amino acid, one of the components of terrestrial biology. In this case, glycine formed in Space and that process could have delivered at least one amino acid to Earth rather than having it formed here.

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