News Feature: Mission to 2014 UN271 using OITS

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Comets are often the least "loyal" but sometimes the most spectacular members of the Solar System family. Their orbits often make them nearly interstellar objects. An unusually large one on a very eccentric orbit is therefore of special interest to i4is. Astronomical investigators recently discovered the largest comet yet known - it is the size of a respectable minor planet. Here John Davies reports on this intriguing object and the initial work on a possible mission to intercept it by Adam Hibberd of the i4is Project Lyra team. Adam's more detailed and recent work on this challenge, *2014 UN_{271} Spacecraft Missions*, is elsewhere in this issue. Many of the ideas here are Adam's - but please attribute any blunders to John. This article appeared as a Principium preprint for i4is members, announced in their 8 July Newsletter.

The Comet

C/2014 UN_{271} appears to be a very large Oort cloud comet. It was discovered by Pedro Bernardinelli and Gary Bernstein from archival images. Such a "throwback" discovery is not unusual. Much useful information is effectively buried in systematic astronomical observations and comet hunting detective work is not necessarily conducted by observational astronomers - either professional (as in the interstellar object 1I/'Oumuamua by Pan-STARRS team of the Institute for Astronomy at the University of Hawaii) or amateur (as in the interstellar object 2I/Borisov by Gennadiy Borisov). This new discovery has an orbit which shows it to be from the Oort cloud, the roughly spherical space surrounding the Solar System where many long period comets have their aphelion. Bernardinelli-Bernstein (named after its discoverers) has an orbital period in millions of years and a predicted aphelion so far out in the Oort cloud that it will be subject to perturbation by gravitational influences from beyond the Solar System. In fact its eccentricity is so close to one that it is very loosely bound to the Solar System and an unexpected perturbation might cause it to leave the solar system - though only after a few million years heading out again! BB will reach perihelion in 2031, coming no closer than Saturn which is 10 astronomical units away, ie 10 times further from the Sun than we are. All this is interesting from an astronomical point of view but not unusual.

What is unusual about BB is its size. Typically comets range up to a few tens of km in diameter - though they produce a coma which is much larger when warmed by the Sun. BB is at least 100 km across and may be 200 km. Dr Colin Snodgrass, at the University of Edinburgh and a member of the ESA Comet Interceptor team, has said “With a reasonable degree of certainty, it’s the biggest comet that we’ve ever seen”.

A comet exploration pioneer
ESA image of Philae lander
Credit:ESA/ATG medialab

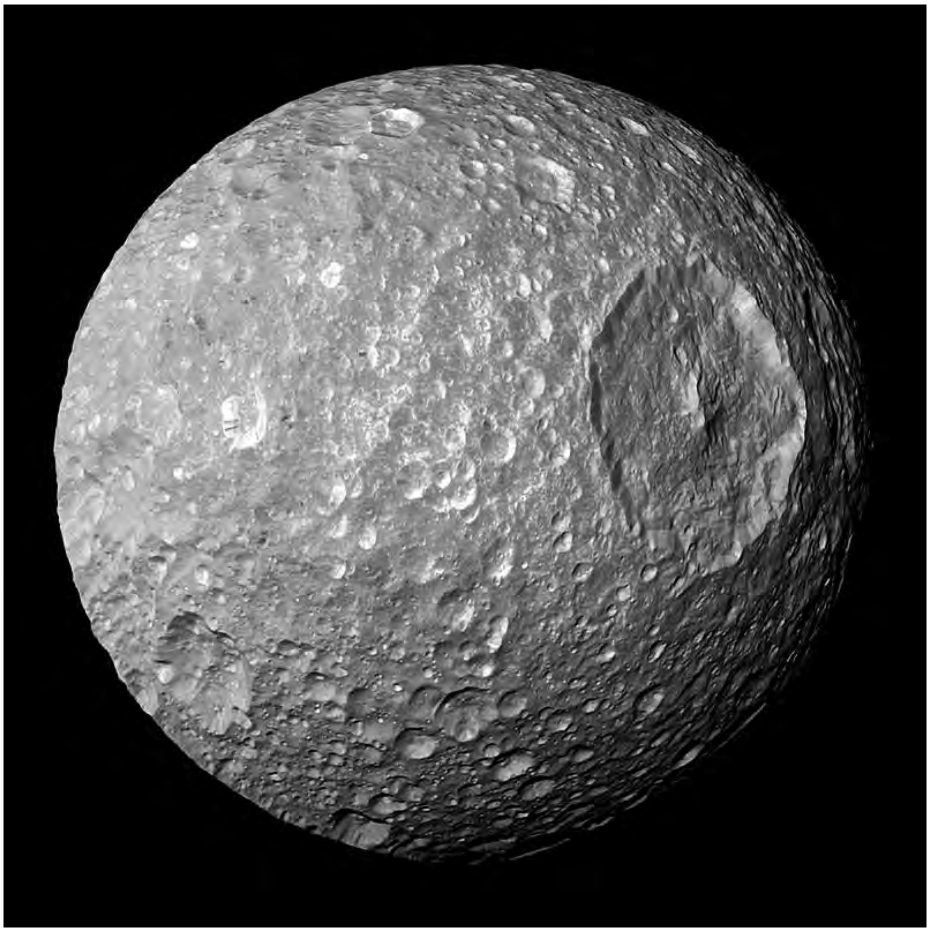
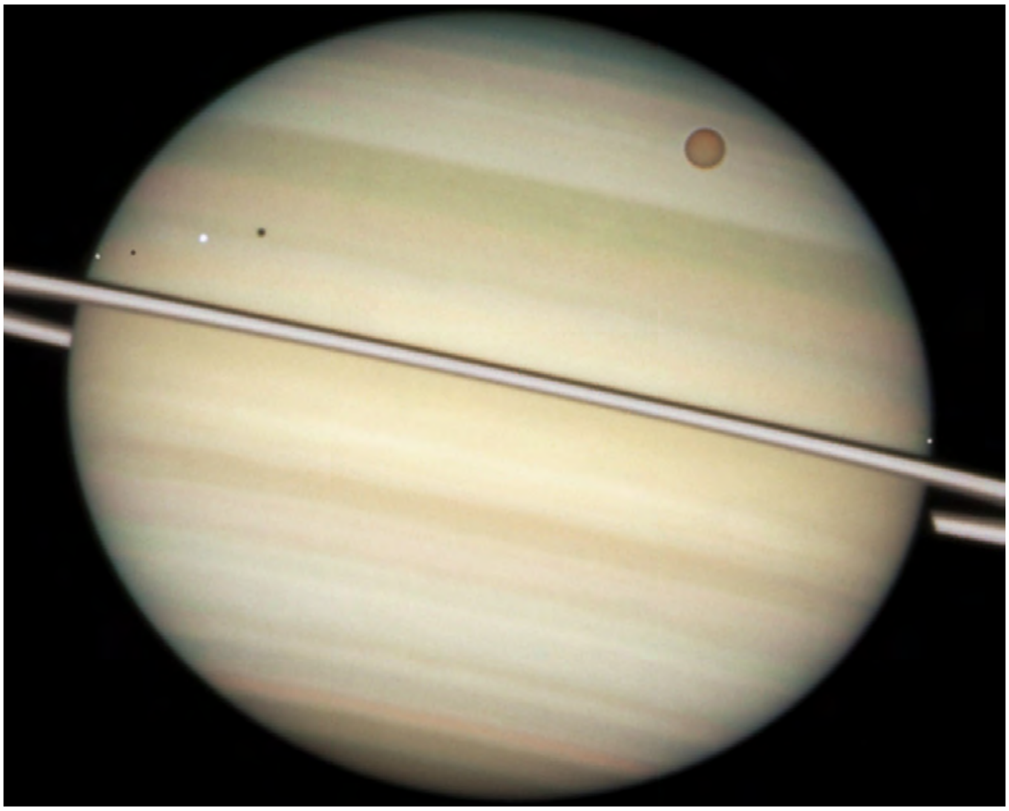


Image of Saturn's moon Mimas - from NASA spacecraft Cassini. Mimas is 396 km in diameter and its giant crater Herschel is 130 km across - giving an idea of the resolution which might be obtained by a probe to BB which is around 100-200 km in diameter.

Credit: NASA

A Mission

So should there be a mission to BB, presumably close to its perihelion at 10 AU? Telescopes cannot match orbiting probes even at Mars, about half an AU away at its closest, so in crude terms the argument for a probe is strong provided the results are desirable enough and the i4is Project Lyra team is already studying the possibility. Two contrasting images from Saturn, at the same 10 AU distance, suggest the case for a probe. Images are only part of the science to be gathered, of course, but they make the point.



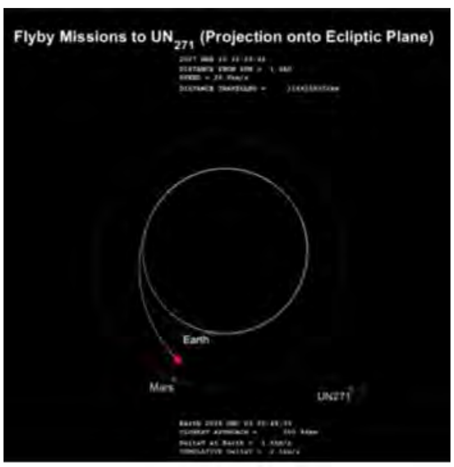
Contrasting with the Cassini image of Mimas here is what the Hubble telescope sees from its low Earth orbit. The image captures four moons of Saturn, 10 AU out from the Sun, which is as close as BB will be at perihelion. The ESA caption says "The giant orange moon Titan - larger than the planet Mercury - can be seen at upper right. The white icy moons that are much closer to Saturn, hence much closer to the ring plane in this view, are, from left to right: Enceladus, Dione, and Mimas." and "Hubble can see details as small as 300 kilometres across on Saturn." sci.esa.int/web/hubble/-/44464-quadruple-saturn-moon-transit-snapped-by-hubble

Credit: ESA/Hubble

Here is an early mission suggestion from Adam Hibberd, using his Optimum Interplanetary Trajectory Software (OITS) [1] and a combination of NOMAD and MIDACO-Solver [2]. This initial mission profile is -

Number	Encounter	Date	Sun Distance (AU)	Arrival Velocity (kms^{-1})	Departure Velocity (kms^{-1})	ΔV (kms^{-1})	Cumulative /W (kms^{-1})	Periapsis (km)
1	EARTH	2025 DEC 25	0.984	0.000	0.118	0.118	0.118	N/A
2	DSM @1.0AU	2026 JUN 03	1	29.670	29.679	0.543	0.661	N/A
3	EARTH	2026 DEC 03	0.986	0.443	5.727	1.392	2.053	200.8
4	MARS	2027 APR 18	1.656	10.279	10.279	0.000	2.053	206.1
5	EARTH	2028 OCT 03	1	8.816	12.119	2.269	4.322	200
6	2014 UN271	2033 AUG 06	11.952	12.658	12.658	0.000	4.322	N/A

After Earth departure with a velocity change (ΔV) 0.188 km/second (ie 188 metres per second - a modest 420 miles per hour) the probe to BB would execute a deep space manoeuvre (DSM) with ΔV 0.543 km/sec, a bigger push, to bring it back to Earth for a slingshot manoeuvre, rocket assisted by 1.392 km/sec. Mars would provide a "free" slingshot, no rocket assisted ΔV, to bring the probe back to Earth for a final slingshot manoeuvre, rocket assisted by 2.269 km/sec. Leaving on Christmas Day 2025 would enable a flyby of BB on 6 August 2033 at 12.658 km/sec. Adam has produced an animation of this proposal.



Animation of mission candidate using Mars gravitational assist - drive.google.com/file/d/1hMg1a848PblvBle0N08ie3d-BAdt-Olg/view

The apparent close proximity of C/2014 UN_{271} to Mars and its slow apparent motion is simply because this is a 2D projection onto the ecliptic. UN_{271} will cross the ecliptic almost vertically and probe would flyby as this happens.

The probe could clearly perform useful observations from well before to well after the encounter but it's worth noting that at 12.658 km/sec a distance of a 100 km diameter would take 100/12.658 = 7.9 seconds so much would need to be done in a relatively short time. The probe could, of course, release an impactor and, even without further rocketry, a 1 kg impactor would yield 160,000 kjoules[3] or about the equivalent of about 38 grams of TNT. The possible effect on a 100 km "dirty snowball" is clearly a "matter for further study".

Other considerations include the possibility of a rendezvous with BB, which would allow much more detailed investigation - more about that below. For a flyby, the best arrival time of the probe is when BB intersects the ecliptic around August 6th 2033 as in the mission profile above. By definition all of Earth's velocity is in the ecliptic plane and since the probe would be launched from Earth, to make optimal use of this velocity which it has been given by Earth, its trajectory would 'prefer' also to be in the ecliptic. Any deviation from that plane along its interplanetary trajectory would require an extra ΔV component out of the ecliptic, which would use up more fuel - and, of course, the "tyranny" of Tsiolkovsky's equation reminds us that all fuel to be used later has to be accelerated by fuel used earlier - except where you can steal momentum from a handy object which can spare it, such as Earth or Mars in our example. Thus Adam is finding that nearly all the good flyby trajectories arrive at BB around 2033 August 6th.

[1] See - *How to reach Interstellar Visitors, Optimum Interplanetary Trajectory Software* - in Principium Issue 27 November 2019.

[2] NOMAD - A blackbox optimization software (www.gerad.ca/nomad/) to get the general solution followed by MIDACO-Solver (Mixed Integer Distributed Ant Colony Optimization www.midaco-solver.com).

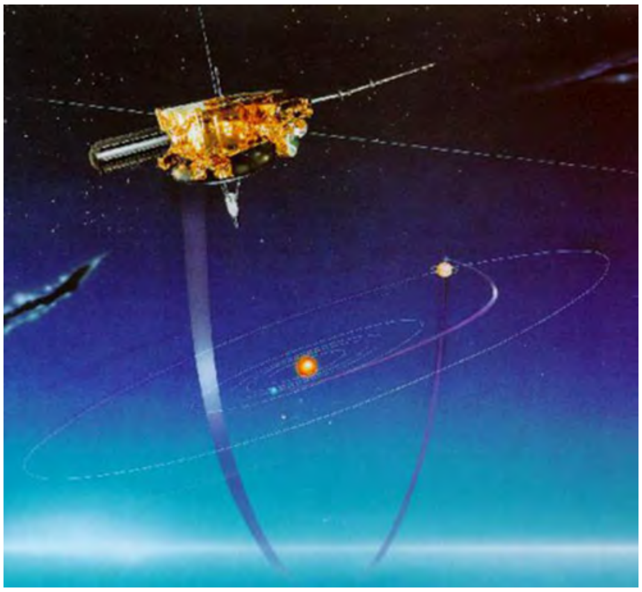
[3] Kinetic energy = $1/2mv^2$ =$0.5*1*12,658^2$ = 160,224,964 = 160,225 kjoules.

Is a rendezvous practical?

If our probe could rendezvous with BB the science rewards would be considerable! The opportunities for investigation can be imagined by the example of the Rosetta mission [1] to the comet 67P/Churyumov-Gerasimenko. The approach, orbit and subsequent landing of the subprobe Philae will not be forgotten by those who followed it in 2014.

For a rendezvous with BB the probe must apply ΔV on arrival to match its velocity with BB. Unfortunately when BB intersects the ecliptic the arriving probe velocity will be almost 90 degrees to that of BB meaning a massive change in its velocity. This is because the inclination of BB's orbit is over 90 degrees to the ecliptic. In other words it's flying through the ecliptic almost perpendicular to the plane of rotation of the Solar System. Thus for a rendezvous, the probe should aim to arrive at BB long after it has passed through the ecliptic so that the relative velocity of the probe and BB is at a much lower angle, allowing a much easier rendezvous manoeuvre. Although a gravity assist can also be used to divert a probe out of the ecliptic [2] the rendezvous challenge remains much more daunting than a flyby mission.

A rendezvous is also much more complex in terms of instrumentation, possibly including a lander like Philae, as well as a major challenge in terms of additional ΔV - even if Tsiolkovsky can be dodged using gravitational assistance!



Example of an out-of-ecliptic mission, visualisation of the unique orbit of the ESA Ulysses probe.

Credit ESA www.esa.int/Science_Exploration/Space_Science/Ulysses_overview

What next?

The team are looking at a range of potential missions and in much more detail than the above initial calculation and, of course, the science implications of such a mission. One unknown factor is the prevalence of such very large comets which, like the ISO 1I/'Oumuamua, cannot be confidently predicted from a single instance. Comet impacts are major concern for Earth defence and the existence of comets of this size, and possibly larger, makes the case for investigation even stronger, if only to inform future detection and countermeasures.

[1] www.esa.int/Enabling_Support/Operations/Rosetta

[2] Note the examples of the NASA Voyager 1 (35 degrees out of the ecliptic) and ESA Ulysses (80 degrees). See - T Franc, The Gravitational Assist, WDS 2011 - Proceedings of Contributed Papers, www.mff.cuni.cz/veda/konference/wds/proc/pdf11/WDS11_309_f12_Franc.pdf