NEW HORIZONS:

FROM RESEARCH PAPER TO PLUTO

EXAMINING THE ROLE OF ACADEMIC PUBLISHING IN LAUNCHING AND LEARNING FROM DEEP SPACE MISSIONS

MENDELEY

Contents

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Cover art by Claudia Stocker. Cover layout by Jonathan Beyer.
Written by Paul Tavner, Educational Resources Manager, Mendeley.
Special thanks to Shruti Desai, William Gunn, Sarah Hoey, Judith Kamalski and Ricardo Vidal.

Foreword

"NASA's New Horizons probe will fly by Pluto at 14km/s, using instruments to examine its atmosphere and surface and then transmit this information back 3 billion miles by X band for us to interpret and view.

This would have been the subject of science fiction when I was at school, but is now science fact. I feel proud and honoured for such a momentous scientific mission to be completed within my lifetime.

With imagination and determination, it is humbling to see what we are capable of."

- Stephen Hawking[1]
April 2015

When asked to consider space exploration, the first image brought to mind is often the astronaut. The intrepid explorers, donning their distinctive space suits and strapping in for a rocket ride to outer space.

If asked to think a little wider, we may visualize the mission controllers. Often just a disembodied voice - "Houston" - or, at a push, a room of tense-looking men and women sitting at acronymed consoles.

But the truth is that space exploration is a wide pyramid. It takes a team of thousands to send something into space - from mathematicians calculating trajectories to coders programming software.

Perhaps the most important group of all is the academics. The men and women who dedicate their lives to the pursuit and application of knowledge. It is this group who establish what is science fact and what remains confined to science fiction. For now, at least.

This report is therefore dedicated to the academics, who work to make our dreams of space travel into reality. We hope it sheds some light on the work they do and the sheer amount of effort that goes in to turning the topics of research papers into missions of space exploration.

- Jessica L. Reeves
Head of User Engagement, Mendeley

The Path to Pluto

The term "citizen science" was yet to be coined in late nineteenth century America, but it provides an apt description of the steps involved in the discovery and naming of Pluto.

Astronomers had long held strong suspicions of the existence of another body outside the orbit of Neptune. American astronomer and businessman Percival Lowell observed discrepancies in the orbits of both Neptune and Uranus that he attributed to the gravitational influence of an undiscovered planet, which he labeled "Planet X."

> **Ever since celestial mechanics in the skillful hands of Leverrier and Adams led to the world-amazed discovery of Neptune, a belief has existed begotten of that success that still other planets lay beyond, only waiting to be found.**
>
> -Percival Lowell[2]
> 1915

Serious investigations were made into the theory, with many researchers scouring the skies for proof of the elusive body. A number of claims were put forward, but without conclusive evidence. Lowell died in 1916 and progress stalled.

In 1930, however, a young researcher, working at Lowell's observatory in Flagstaff, Arizona, made a momentous discovery. Clyde William Tombaugh had never attended college - his chances ruined by a hailstorm that destroyed the crops on the family's Kansas farm - but had taught himself astronomy, and began building his own telescopes. The drawings he produced from his observations were enough to secure him a position at the observatory. He was assigned the task of pursuing the search for Planet X by observatory director Vesto Melvin Slipher. He was just 22.

Tombaugh painstakingly examined photographic images taken by the Observatory, using a "blink comparator" to rapidly compare two plates for traces of moving objects. He searched for almost a year, before, on 18 February 1930, his systematic analysis revealed a suitable candidate. By comparing plates from January 23 and 29, and checking against another from January 21, he was convinced that Lowell had been vindicated. After further investigation the discovery of a new planet was officially announced on 13 March to worldwide acclaim.

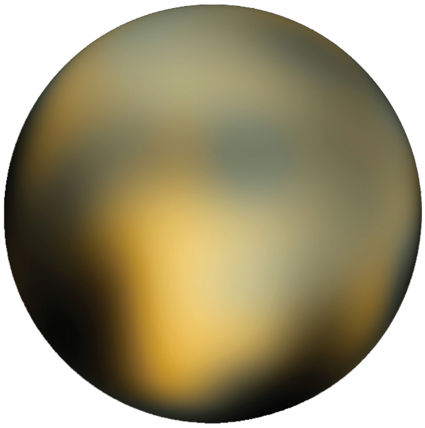
> **Doctor Slipher, I have found your Planet X.**
>
> -Clyde Tombaugh[3]
> February 1930

As discoverers, responsibility for naming the new planet fell to the staff of Lowell. Suggestions were received from around the world, but it was the name "Pluto" which received unanimous support at the observatory.

Suggested by an eleven-year-old English schoolgirl, Venetia Burney, the name seemed to meet a number of criteria. It followed the convention of naming planets after gods from classical mythology. Its namesake was ruler of the permanently benighted underworld, an appropriate comparison for the icy planet lurking in near total darkness at the edge of the solar system. It also incorporated the letters "P" and "L" - regarded by the Lowell staff as fitting tribute to their founder. The name was officially announced on 1 May 1930.

As the 20th century progressed, the Planet X theory was gradually dismissed. Closer examinations of Pluto revealed that it could not possibly influence the orbits of Neptune and Uranus. Better observations allowed more precise estimates of Pluto's mass to be produced - and revealed the planet to be much smaller than first believed. Although initially thought to be larger than Mercury, observation of Pluto's largest moon - Charon - in 1978 allowed a precise estimate to be made, putting Pluto's mass at 1/500th that of Earth.

Improvements in technology were also making it easier to discover new celestial objects and allowing smaller bodies to be detected. Many of these new objects were found to be close to the size of Pluto - and in some cases were believed to exceed it. Pluto resisted calls to reclassify it for some time, but following an International Astronomical Union resolution in 2006 Pluto found itself downgraded from planet status. Although the decision is not unanimously accepted, Pluto is now usually referred to as a "dwarf planet."[4]



**Pluto by the Hubble Space Telescope.
From a series taken 2002 - 2003.
Photo credit: NASA**

We now know that the space beyond Neptune's orbit is filled with a multitude of objects. The "Kuiper Belt" resembles the asteroid belt between Mars and Jupiter, but on a much greater scale. Instead of rocky asteroids, the most common bodies are made of frozen materials dating back to the earliest days of the solar system.

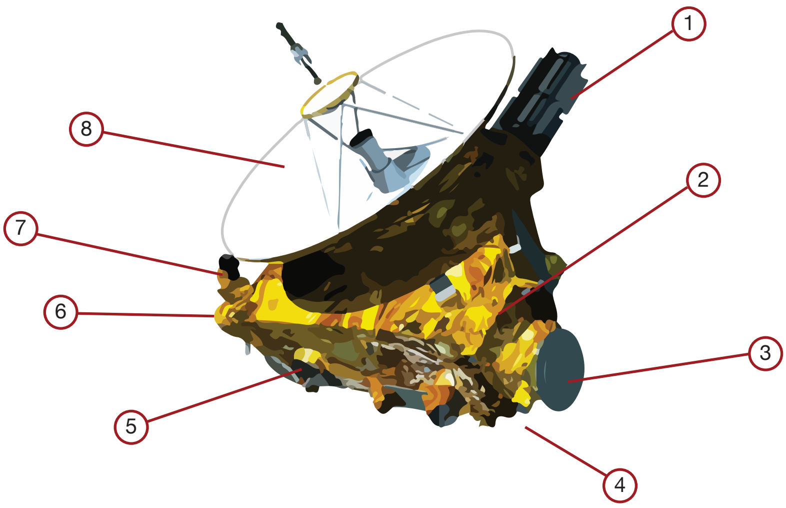
Pluto is the largest currently known object in the Kuiper Belt, but it has been hypothesized that certain moons of Neptune and Saturn[5] also had origins inside the belt.

New Horizons

The New Horizons mission received approval in November 2001[6]. Its objective was to send a spacecraft to Pluto - the only unexplored planet (still recognized as a planet at that time) in the solar system. Previous missions intended to reach Pluto - including *Pluto Fast Flyby* and *Pluto Kuiper Express* - had been cancelled, but after a thorough new profile selection process, NASA committed to launching *New Horizons* as part of its New Frontiers program.

Due to the distances involved - New Horizons would have to cover nearly three billion miles to reach its objective - the craft was designed to have as little mass as possible, but would be launched using the huge Atlas V expendable launch system. This guaranteed the greatest possible velocity for the craft.

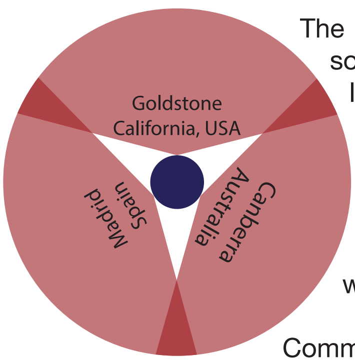
When the mission launched on 19 January 2006, the probe left Earth on a solar system escape trajectory travelling at nearly 37,000 mph. It crossed the Moon's orbit just eight hours and thirty-five minutes after lift-off, and reached that of Mars only 78 days later. The probe gained a gravity boost from the gas giant Jupiter to accelerate past 51,000 mph, but would still have over eight years to travel to its objective. New Horizons is expected to make its closest approach of Pluto and its moons on July 14, 2015[6]



1. **Radioisotope Thermoelectric Generator (RTG)**
   Provides electrical power produced using the decay of plutonium-238 fuel.
2. **Alice**
   A sensitive ultraviolet imaging spectrometer used to study atmospheric composition and structure.
3. **Ralph**
   Imaging apparatus used to photograph and map surface details during the encounter.
4. **Venetia Burney Student Dust Counter (SDC)**
   Designed by students at the University of Colorado at Boulder. Measures concentration of dust particles.
5. **Long Range Reconnaissance Imager (LORRI)**
   Camera and telescope apparatus used to take photos of target at longer ranges.
6. **Solar Wind Around Pluto (SWAP)**
   Instrument used to measure solar wind activity in the vicinity of Pluto. Also measures atmospheric escape.
7. **Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI)**
   Directional energetic particle spectrometer. Used to study energetic particles in Pluto's atmosphere.
8. **Radio Science Experiment (REX)**
   Performs radio science experiments on Pluto's atmosphere once the probe is occluded from Earth.[7]

Phoning Home

Communicating with a probe three billion miles from Earth poses a number of challenges for the New Horizons team. Luckily, they can rely on NASA's Deep Space Network (DSN), operated by the Jet Propulsion Laboratory in California.



The DSN is a network of highly sophisticated antenna arrays, located in three sites around the globe. These sites, distributed at roughly 120-degree intervals around Earth, ensure constant contact can be maintained with objects in deep space.

Communications received from New Horizons are sent from DSN to mission control and used to check the probe's progress. Scientific data is then relayed on to the Science Operations Center for processing.

It's possible to track which of three DSN sites is currently in contact with New Horizons via DSN *Now*[8]:
http://eyes.nasa.gov/dsn/dsn.html

Race against time

Pluto takes nearly 248 years to perform a complete orbit. Since 1988, it has been moving further away from the Sun, meaning that it receives less light and less heat. Observers feared that this would result in Pluto's atmosphere "freezing out" - where the reduction in temperature causes particles to drop out of their gaseous state. These particles then fall to the planet surface - thinning the overall atmosphere and making analysis more difficult.

Recent observations have suggested that this is not necessarily the case[9,10], but reaching Pluto quickly still ensures that more of the dwarf planet's surface will be exposed to sunlight - making it easier to resolve details not visible in areas covered by darkness.

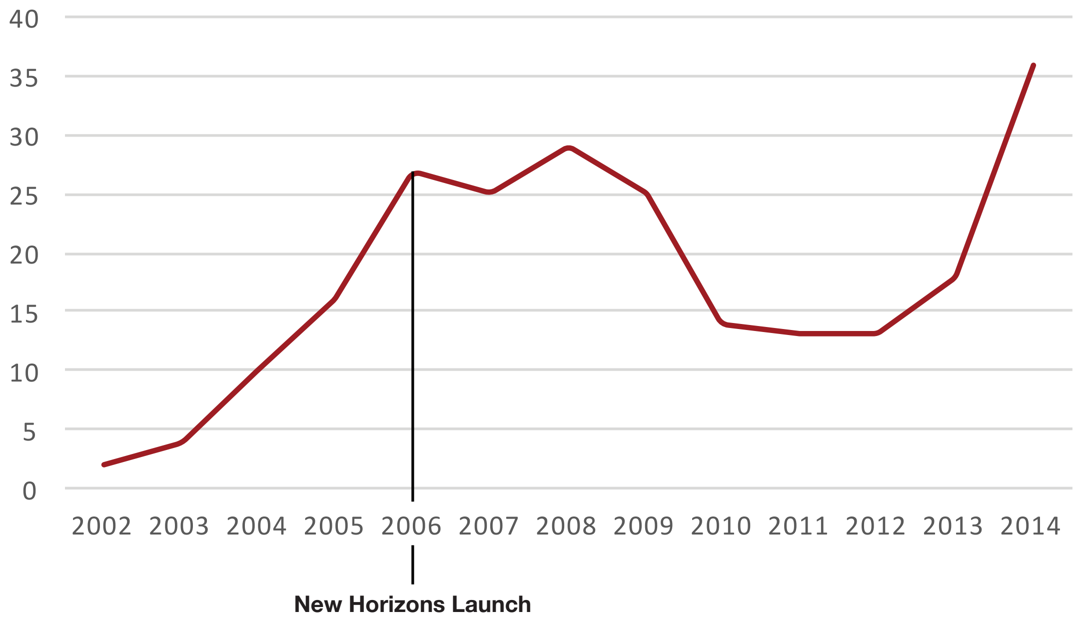
Measuring Scientific Output

Scientific output around deep space missions can be visualized using data from sources such as Scopus. Since these missions are designed to provide observers with detailed information about their targets, it stands to reason that we would expect to see output peaking after an objective has been met, but it's also interesting to look at how anticipation for results manifests throughout the course of a mission.

Of course, no mission would be possible without a huge scientific effort. Even before receiving approval, thousands of hours of research will have gone into assessing a mission's viability. All components of a craft owe a huge debt to the investigation of energy specialists and materials scientists - before even considering the advanced payload that each craft carries (see page 3 for details of the equipment on New Horizons).

Once a mission receives approval and preparations for launch begin in earnest, however, scientists begin to look forward to the data they will receive from the mission and to the questions they will be able to answer as a result.

Number of Scopus Articles mentioning New Horizons per year 2002-2014



The dataset used to plot this graph was generated in Scopus using a set of papers that were found to reference 'New Horizons' and 'Pluto' in either the title, keywords or abstract.

This produced a set of 242 documents. All items were then reviewed for relevance and inappropriate papers were excluded - leaving 241 as of July 2015.

This dataset is used throughout this report and can be easily reproduced via Scopus for verification purposes.

Examining output around the New Horizons mission reveals some interesting features. Following mission approval in 2001[6], the first explicit mention of the mission in Scopus is a conference paper from 2002[11] (see page 5 for more information about Yanping Guo). At this point the launch vehicle and subsequent velocity of the probe were unknown, so the abstract speculated that the encounter might possibly not take place until 2016.

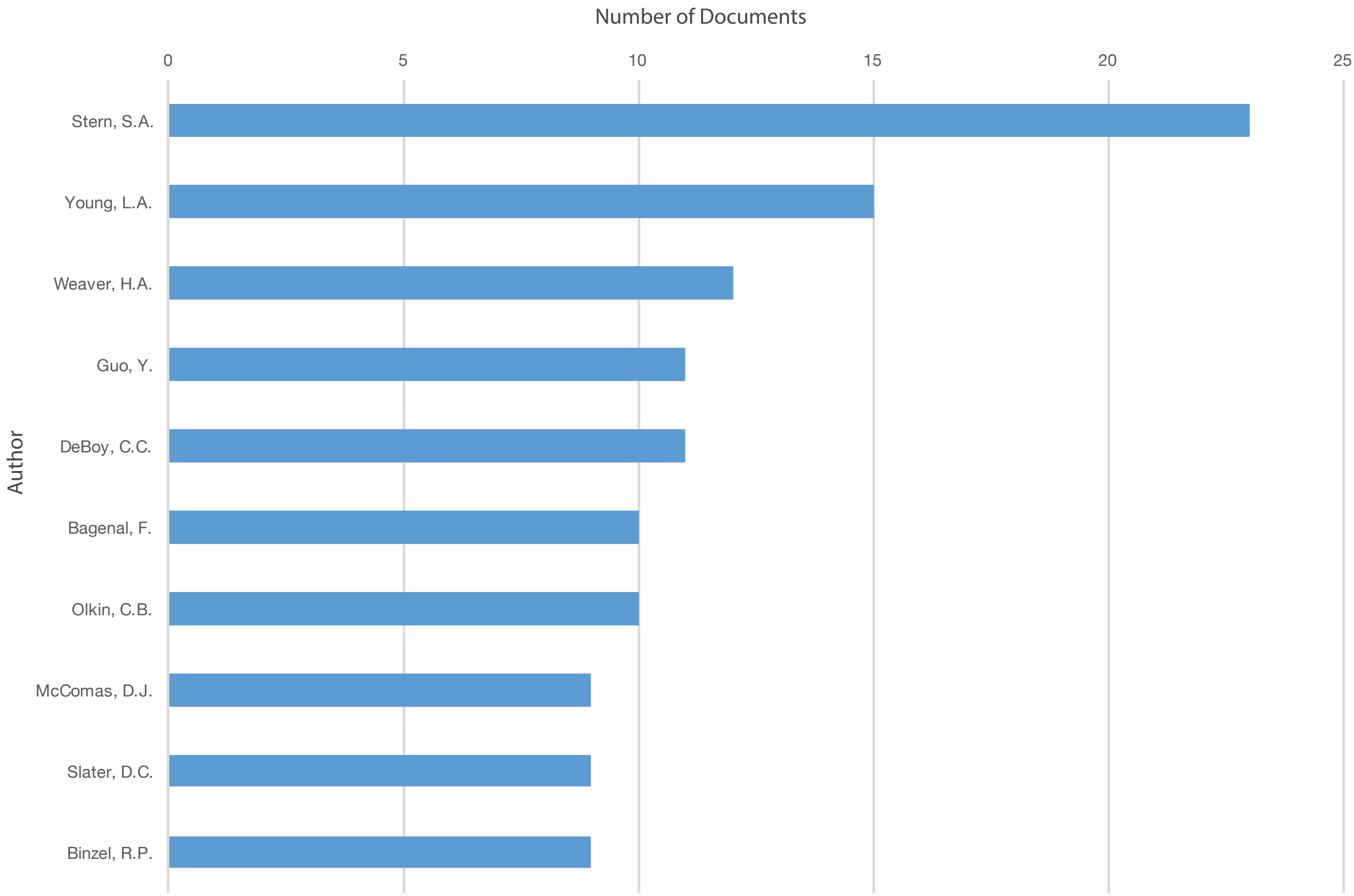
Scientific output increased as the 2006 launch date approached, ultimately building to an initial peak of 29 publications in 2008. This peak follows the release of a number of observations of Jupiter, made during the spacecraft's gravity assist phase - an indication that New Horizon's scientific legacy was not limited to its encounter with Pluto, but was also producing valuable data on other bodies in the solar system.

The extremely long flight time of New Horizons may be responsible for the lapse in output observed from 2009 to 2013. Following the Jupiter flyby, the probe was put into hibernation, being only periodically 'woken' to perform an annual checkout (ACO) procedure. During this time new data being generated by the mission was limited - meaning that observers were restricted to anticipating the Pluto encounter or considering data already released.

Output began to build again from 2013 onwards as the close approach of Pluto drew nearer, building to a new high of publications in 2014 - peaking at 36 Scopus entries at year end.

We can see that the overall trend across time has been for the scientific output around New Horizons to increase - indicating that the mission has been and continues to be a valuable source of new data.

Key Contributors



Perhaps unsurprisingly, New Horizons' Principal Investigator Alan Stern has been the most prolific author in connection with the mission. Of the 23 papers on which he is listed, he is the first author on 6 items. His most cited article - referenced by 35 other publications - was published in 2008[6]. The paper provides an overview of the mission and its objectives - see page 8 for some indication as to how influential it has been.

Project Scientist for the mission, Hal Weaver, has a total output of 12 documents for the period under consideration, being first author on three of those items. His work has mainly focused on New Horizons' payload[7] (see page 3) - with an emphasis on LORRI - the long-range reconnaissance imager.

Women in STEM

Of the top ten contributing authors to the body of work surrounding New Horizons, four are female.

This is a particular accomplishment for a field in which women are traditionally under-represented. A 2011 study by the US Department of Commerce stated that just 24% of all STEM jobs are held by women[12].

The graph above shows that, when it comes to published output, Leslie Young of the Southwest Research Institute (SWRI) (15 papers) just edges out Yanping Guo of the John Hopkins Applied Physics Laboratory (APL) (11). They are joined on the list by Fran Bagenal - University of Colorado Boulder - and Cathy Olkin (both 10).

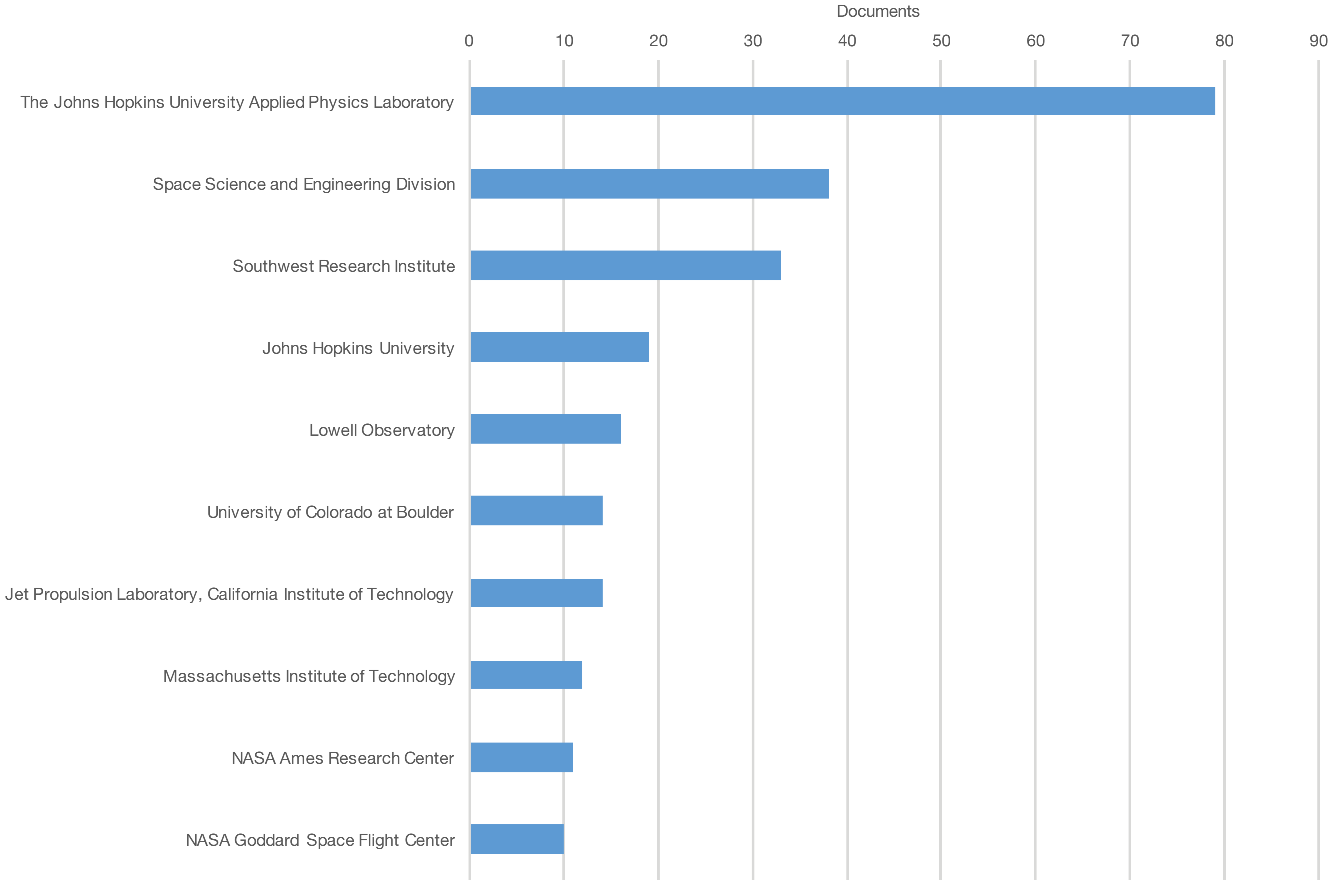
Young is Deputy Project Scientist on the mission, Co-Investigator and Team Lead for Pluto Encounter Planning (PEP). Guo is New Horizons Mission Design Lead. Bagenal is Co-Investigator and Team Lead for the Particles and Plasma (P&P) Theme. Olkin is Deputy Project Scientist, Co-Investigator, Deputy Team Lead for PEP and Office of the Principal Investigator (OPI) Team Lead[13].

When considering just the Science Team[13] - 3 out of 5 (60%) of the scientists in senior roles are female - Young, Olkin and Deputy Project Scientist Kimberly Ennico of the NASA Ames Research Center.

Collaboration

Science is, of course, not an individual effort. The vast majority of papers recorded in Scopus have more than one author - with one paper[14] having 47 co-authors listed. Output can also be grouped by institution to show where productive research clusters exist.

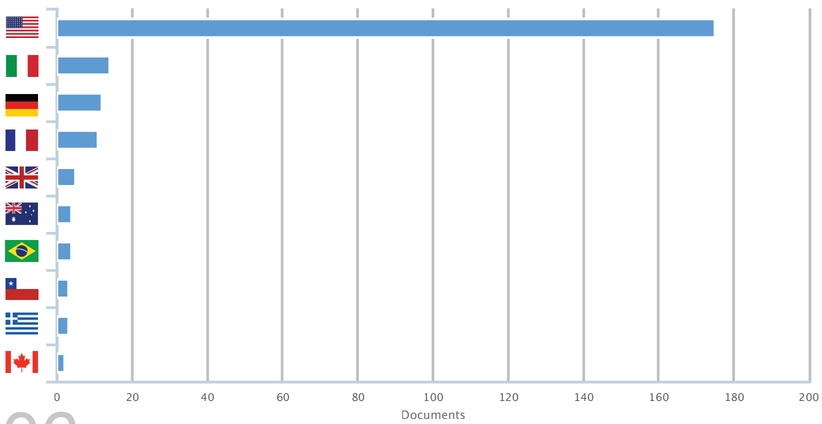
The graph below shows the most productive institutions associated with the New Horizons body of work.



Notably, all of the top ten affiliated bodies are based in the U.S.A., and many of the institutions responsible for contributing to the scientific output around New Horizons already have close connections with the mission.

The John Hopkins University APL - a mission partner - tops the list with 78 author affiliations, with the SWRI Space Science and Engineering Division - also a mission partner - coming next with 38.

NASA research centers also feature prominently in the list (3 institutions, with a total of 35 documents) - indicating that the agency continues to directly contribute to the process of important scientific output. The presence of the Lowell Observatory high in the list, with 16 publications, is also worth highlighting; as an institution with such strong historical links to Pluto (see page 2), it's positive to see that the observatory continues to be closely involved in its investigation.



International Collaboration

As noted above, the scientific output has been overwhelmingly American in origin - hardly surprising for a mission launched and financed by an agency of the U.S. government.

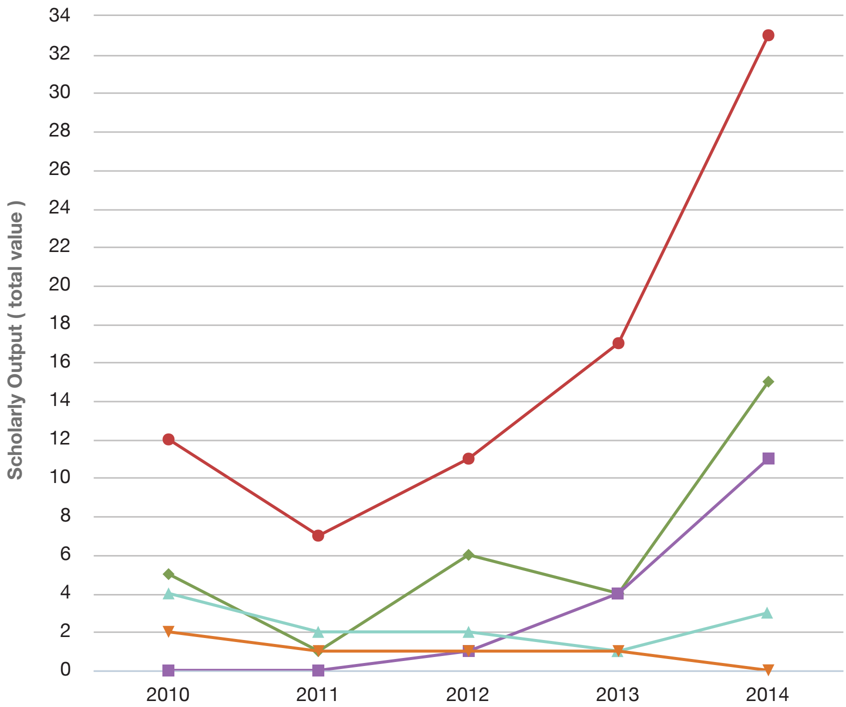
However, contributions have also been made by several European countries. Italy, Germany and France top the list of non-U.S. contributing authors, with 14, 12 and 11 publications respectively. SciVal analysis indicates that France's involvement in recent years (2010-2014) has accelerated.

See the next page for more SciVal trends.

Research Trends

When considering a research topic such as New Horizons or any other deep-space mission, we would expect different aspects of that topic to gain and lose importance over time. Certain theories or predictions may hold prominence for a while, before being disproved by further observations. Changes to a mission's profile or equipment issues experienced during flight may also result in different measurements being expected.

By using SciVal's trend analysis module (powered by the Elsevier Fingerprint Engine - see below) it's possible to examine the ways in which the last five years (2010-2014) have seen the literature around the Pluto mission behave and to look at which topics have become more significant, while others have seen a reduction in their frequency of use.



Keyphrases Becoming More Significant

- Pluto (planet)
- Charon
- Pluto atmosphere

Keyphrases Becoming Less Significant

- trans-Neptunian objects
- Jupiter (planet)

The above keyphrases were selected to demonstrate the instances of both increasing and declining keyphrases associated with the mission.

The term Pluto (still labeled as a planet by the Elsevier Fingerprint Engine) has always held prominence in the literature. Since every paper in the research area was selected for its relationship to New Horizons and Pluto, this is to be expected. After recording a slight decline from 2010 to 2011 (a trend reflected in the overall reduction of New Horizons content from 2008 to 2013 as noted on page 4), it has accelerated steeply in recent years. This reflects the increased anticipation of New Horizons' encounter with Pluto.

References to Pluto's moon Charon have noticeably increased during the period, indicating an expectation within the scientific community that examinations of Charon will yield important data. The gradual increase in the references to "Pluto atmosphere" as a keyphrase also reflect the significance that researchers also attach to the atmospheric observations.

SciVal identifies "trans-Neptunian objects" as being of slightly declining significance to the research area. This may indicate that the term is becoming less commonly used, perhaps due to an increase in the use of precise names for Kuiper Belt objects - such as Pluto and its moons - as objects in their own right, rather than using the catch-all term.

References to the planet Jupiter are also slightly declining in the literature produced during this period. This can be potentially attributed to the relative prominence of Jupiter early in the New Horizons mission. During its gravity assist maneuver, the probe made a close approach of the gas giant - transmitting important data and images back to its mission controllers. The spacecraft's scientific payload (see page 3) made over 700 observations of the planet (twice the amount of activity planned for Pluto itself), including the taking of several important high-resolution images of the planet and its moons.

The early significance of Jupiter has, however, been surpassed by anticipation for the Pluto encounter. Jupiter continues to be included in discussions, especially considering that most examinations of New Horizons' trajectory reference the gravity assist maneuver in some fashion - but is of less overall importance to the literature being generated in recent years.

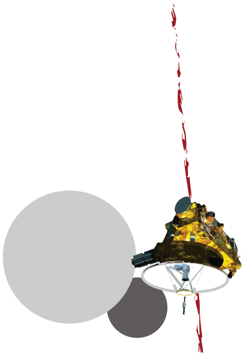
How does SciVal identify research trends?

The Elsevier Fingerprint Engine is the sophisticated back-end software behind SciVal. It applies a variety of Natural Language Processing (NLP) techniques to mine the text of scientific documents. Key concepts are identified in thesauri spanning all major disciplines - and this set of concepts is used to create a "fingerprint" for the publication.

Mendeley also analyzes the metadata of papers in its catalog. This information can then be used to to recommend new papers to users and to aid the discovery of new research.

New Horizons: High-impact Papers

Since its launch in January 2006, the New Horizons spacecraft has inspired a high volume of academic research. Many of these papers have, in their turn, contributed to further study with their contributions appearing as citations.
In the table below we have assembled a list of the most cited papers from each complete year of New Horizons' journey. We've also identified where one paper has cited another item in the list.



Year	Paper	Cited By (Source: Scopus, July 2015)
2014	**The formation of Pluto's low-mass satellites**[15] S. J. Kenyon, B. C. Bromley Astronomical Journal Volume 147, Issue 1, January 2014	7
2013	**Application of reflectron time-of-flight mass spectroscopy in the analysis of astrophysically relevant ices exposed to ionization radiation: Methane (CH4) and D4-methane (CD4) as a case study**[16] B. M. Jones Journal of Physical Chemistry Letters Volume 4, Issue 11, 2013	11
2012	**Circumbinary Chaos: Using Pluto's newest moon to constrain the masses of Nix and Hydra**[17] A. N. Youdin, K. M. Kratter, S. J. Kenyon Astrophysical Journal Volume 755, Issue 1, 10 August 2012	12
2011	**On a giant impact origin of Charon, Nix, and Hydra**[18] R. M. Canup Astronomical Journal Volume 141, Issue 2, February 2011	12
2010	**Chemical composition of icy satellite surfaces**[19] J. B. Dalton et al. Space Science Reviews Volume 153, Issue 1-4, June 2010	25
2009	**TNOs are cool: A survey of the transneptunian region**[20] T. G. Müller et al. Earth, Moon and Planets Volume 105, Issue 2-4, 2009	30
2008	**The New Horizons Pluto Kuiper Belt mission: An overview with historical context**[6] S. A. Stern Space Science Reviews Volume 140, Issue 1-4, October 2008	35
2007	**Changes in Pluto's atmosphere: 1988-2006**[21] J. L. Elliot et al. Astronomical Journal Volume 134, Issue 1, July 2007	39
2006	**Baseline design of new horizons mission to Pluto and the Kuiper belt**[22] Y. Guo, R. W. Farquhar Acta Astronautica Volume 58, Issue 10, May 2006	14

Mendeley Readership Statistics

Top disciplines
- Astronomy / Astrophysics / Space Science: 88%
- Computer and Information Science: 13%

Top demographics
- Ph.D. Student: 50%
- Librarian: 13%
- Post Doc: 13%

Top countries
- Chile: 13%
- China: 13%
- United Kingdom: 13%

Mendeley Readership Statistics

Top disciplines
- Astronomy / Astrophysics/ Space Science: 67%
- Physics: 13%
- Materials Science: 7%

Top demographics
- Ph.D. Student: 33%
- Post Doc: 13%
- Associate Professor: 7%

Top countries
- Chile: 7%
- France: 7%
- Russia: 7%

Comparisons With Other Missions

We've examined the body of work produced around New Horizons and also looked at how this research has changed over time. However, is it possible to use this information to predict how the output of scientific research will behave after the spacecraft reaches its primary objective?

New Horizons is unique for a number of reasons - not least of which being the extremely long duration of the mission - but by using other NASA missions as comparators, we may be able to gain a sense of how academic output is likely to behave.

Naturally, the rate at which new material is likely to be produced is highly susceptible to influencing factors. Should the mission fall at the last hurdle, before a close approach of Pluto can be achieved, output would be significantly lower than expected - except, perhaps, in the form of lessons learned. Of course, it's equally possible that an unprecedented discovery could spur an extremely high volume of academic output. We eagerly await the results of July 14.

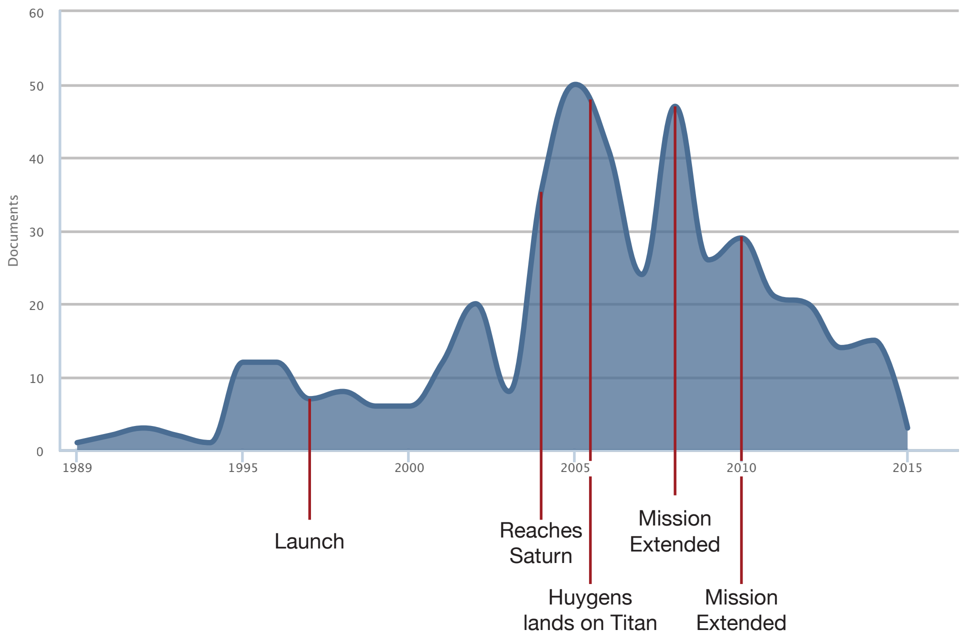
Comparison missions

Two other NASA missions offer the potential for comparison with New Horizons:

Cassini-Huygens - launched in 1997, its objective was the planet Saturn[23]. The spacecraft consisted of an orbiting probe (Cassini) and a lander (Huygens) intended to visit the surface of Saturn's moon Titan. The craft entered orbit around Saturn on July 1 2004 before separating, with the lander reaching Titan on January 14 2005, where it successfully made its way to the surface of the moon. Cassini continues to study Saturn to the present day.

Ulysses was a robotic probe, launched via space shuttle release in October 1990[24] before burning out of low-Earth orbit and using a gravity assist from Jupiter to achieve the desired orbit around its principal objective: the Sun. It completed three scans of the Sun during 1994/1995, 2000/2001 and 2007/2008. Its last day of official operations was June 30 2009.

Cassini-Huygens
Scientific Output (Scopus)



By visualizing the rates of output, it seems to be the case that peaks in document publishing tend to coincide with major mission events.

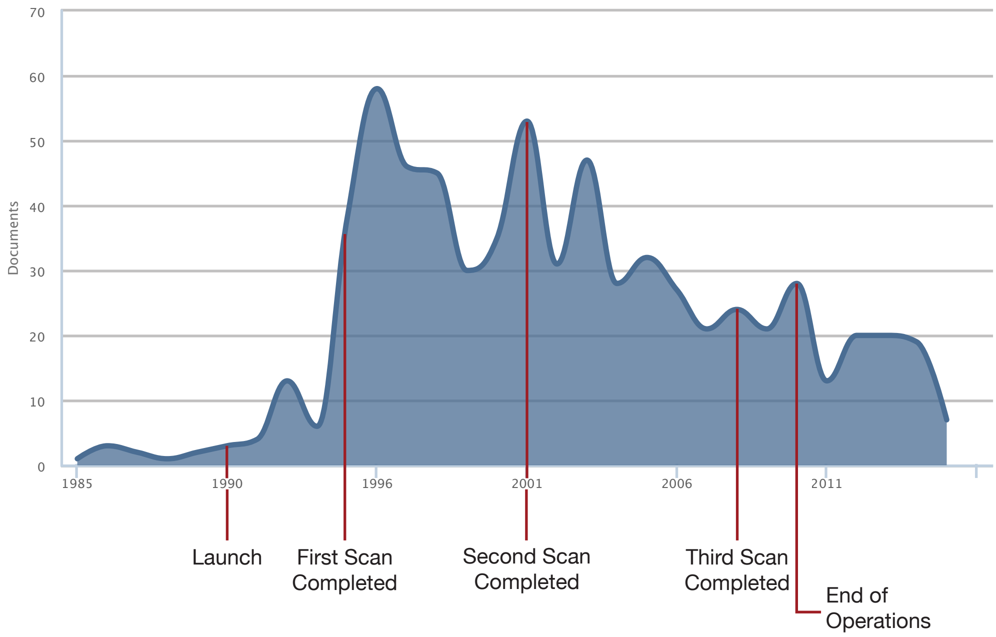
In the case of Cassini-Huygens, the highest number of documents were published shortly after the probe reached Saturn. This suggests that mission data from the encounter with Saturn was quickly disseminated to the scientific community and used to assess theories put forward in anticipation of the spacecraft's arrival.

Additional peaks can be observed during years in which the mission was officially extended by NASA (as Cassini Equinox in 2008 and Cassini Solstice in 2010).

Although the mission continues to the present day, there has been a gradual downward trend in the rate of scientific output since the major events of 2004. The mission continues to produce data, which is still utilized by researchers, but it seems fair to say that there is a "timeliness" component to the level of research output. Peaks of scientific output coincide with mission events - and it seems likely that this trend would apply to any deep space mission.

Simply put - scientists are excited by the opportunities these missions could offer to their studies. The rate of output builds in anticipation of launch, and during the probe's flight time. We then see major peaks shortly after the probe arrives at its target and data is released. This data allows researchers to revisit and reassess their predictions, resulting in the recorded peaks.

Ulysses
Scientific Output (Scopus)



Although the Ulysses mission output takes place across a shorter expanse of time (due to the shorter flight times involved) it demonstrates many similar features to that of Cassini-Huygens.

Again, we see a major peak in publication shortly after the primary objective has been achieved - in this case the first observations of the Sun.

Further observations - completed in 2001 and 2008 - saw further peaks in output.

The end of operations in 2009 also seems to have triggered a final increase in the amount of documents being published.

Year	Ulysses	Cassini-Huygens	New Horizons
1985	1		
1986	3		
1987	2		
1988	1		
1989	2	1	
1990	3	2	
1992	4	3	
1993	13	2	
1994	6	1	
1995	38	12	
1996	58	12	
1997	46	7	
1998	45	8	
1999	30	6	
2000	35	6	
2001	53	12	
2002	31	20	2
2003	47	8	4
2004	28	36	10
2005	32	50	16
2006	27	41	27
2007	21	24	25
2008	24	47	29
2009	21	26	25
2010	28	29	14
2011	13	21	13
2012	20	20	13
2013	20	14	18
2014	19	15	36

Year of Launch
Year Objective Achieved
Year of Peak Output

Predictions for New Horizons

Given these comparison missions, what predictions can we make for the output around New Horizons?

By taking the Scopus data for each of the three missions (see the table to the left), we can compare when output occurred for the two comparators, and use their peaks to estimate when a similar increase can be expected for the Pluto mission.

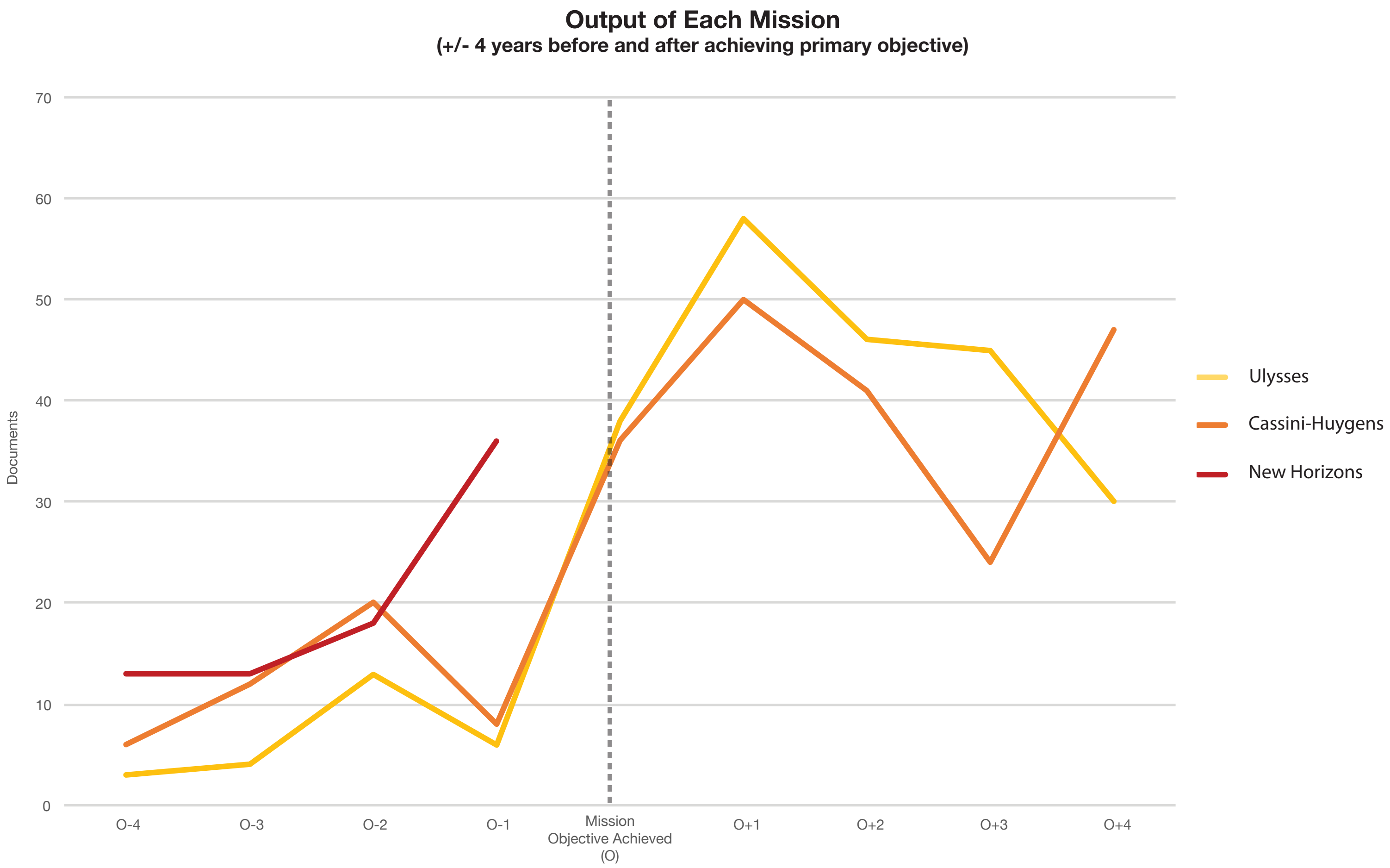
In each instance, the year of launch has been highlighted in orange: 1990 for Ulysses, 1997 for Cassini-Huygens and 2006 for New Horizons.

The year in which each mission achieved its primary objective is then highlighted in green. 1995 for Ulysses' first scan of the Sun[25] and 2004 for Cassini-Huygens achieving orbit of Saturn[26]. New Horizons is yet to reach its primary objective - the close approach of Pluto - but this is timetabled to take place in July 2015.

For each of the comparison missions, the main peak of scientific output has been highlighted in yellow - 1996 for Ulysses, 2005 for Cassini Huygens. In both instances, this peak takes place in the year immediately after achieving the primary objective.

Both comparators also saw additional research peaks later in their mission as secondary objectives were delivered. While secondary objectives for New Horizons have been set - inspecting other Kuiper belt objects - no specific target has yet been announced, meaning that we cannot reliably predict when any secondary peaks might occur.

However, by mapping the output of each of the previous mission onto New Horizons, we can make predictions about the expected output of the primary objective (see next page).



The graph above compares a subset of the output for each of the three missions. For each series, we have plotted the number of published documents for four years either side of the year in which the primary objective was met (O). For the two comparison missions the post-objective (O+) data is available, while complete year data only exists for New Horizons up to O-1. This allows us to compare the behavior of the scientific output in the run up to mission objective, and how it behaves after an objective has been achieved.

This visualization reveals a few interesting features. Firstly, all three missions seemed to encounter a downward trend in output shortly before the primary objective was reached. This could be attributed to researchers anticipating new mission data being made available and holding off on publishing before this data is released. It could also be that observers expect their work to have greater impact if it is published during the same year as a major mission event. This downwards trend for New Horizons is less appreciable in this mapping, but can be clearly seen in the whole mission output (see graph on page 4).

Secondly, New Horizons has the highest level of output of the three missions for the years mapped. Although Cassini-Huygens exceeds the Pluto mission in O-2, it's important to note that New Horizons was experiencing a particularly protracted pre-objective slump (again, see page 4). In O-1, New Horizons bucked the trend of a pre-objective slump and began accelerating to a new peak. This puts it ahead of schedule compared to the other two missions, which did not start to accelerate towards their peak until the year in which their objective was met.

Thirdly, based on the behavior of the two comparison missions, we can predict that New Horizons will experience a major output peak in 2015-2016. Both Ulysses and Cassini-Huygens saw large upswings in output in the years during which their primary objectives were met, with the upwards trend continuing into the following year to achieve peak output. It seems likely that New Horizons will follow the same trend.

In conclusion, it seems obvious that research output would peak shortly after a deep-space mission achieves its objective, but by mapping the output for each of the three missions under consideration we have demonstrated that the output rate follows a fairly predictable model - with peak output occurring around O+1. Obviously a year-by-year comparison does not offer the highest level of precision, but each of the three missions achieved their primary objectives during the month of July - which helps to mitigates concerns.

The level of output to date suggest that New Horizons holds a great deal of interest for the community of observers - and this implies that its output peak is likely to be high. Depending on the magnitude of the discoveries made by the mission, it could easily become one of the most significant missions ever launched by NASA.

Conclusions

The body of work associated with New Horizons is already impressive and, judging by the analysis on the previous pages, we can expect this output to increase substantially over the next two years.

The obvious omission from the data set is all of the material that has contributed to New Horizons becoming a reality, prior to its approval as a mission - i.e. any paper that does not specifically reference the mission name. The ability to launch deep space missions depends entirely on the efforts of scientists and researchers who have gone before, who have done their work and published it for public consumption. Cutting edge technologies and techniques are only enabled by a long tail of incremental studies. Several of the scientists who ultimately contributed to this mission have been acknowledged in this guide, but the vast majority have not.

To build a more complete picture, we would need to map not only the papers directly associated with the mission, but also the documents that those papers relied on to build their arguments. Analysis tools, such as Scopus, and publishing archives, such as Science Direct, offer us the means to achieve this, although such a project is beyond the scope of this report.

Advancement Through Technology

What is clear, however, is that the connections between academic documents - both those explicitly cited by authors and the commonalities of theme that can be identified using tools like Mendeley and SciVal - are very significant. They represent the links between significant ideas, acting as a “nervous system” for collective human thought. These lines of collaboration and inspiration reflect the evolution of ideas and the emergence of dominant themes that leap from the theory of the paper to the reality of the probe.

The more we understand about these connections, the more effectively science can be performed. By mapping them - and making these connections navigable by other researchers - scientists have the ability to retrieve not just the papers they know, but also the works that underpinned those papers. In addition, an understanding of the thematic connections between documents enables software systems to recommend materials to a reader based on their interests or reading habits - resulting in academics being alerted to relevant research of which they were previously unaware.

The possibilities for machine learning in this regard are exciting. If a computer can be taught to understand what links papers, along with the content and conclusions of the research those papers contain, there’s a very real possibility of machines being able to make their own discoveries in the not too distant future.

Societal Impact

Another area in which technology can help to enhance the scientific process is by improving the ability of authors to connect with one another, to promote & distribute their research and to track the impact they make.

The societal impact of research is significant for a number of reasons. Funding considerations - even for organizations such as NASA - continue to be a significant concern. Being able to easily track the ways in which research is being distributed, shared and consumed allows scientists to demonstrate the importance of their work. Increasingly tools such as NewsFlo also allow scientists to navigate the blurred interface between academic and mainstream consumption. By looking at new metrics, such as news stories and social media sharing, authors are able to show the ways in which lay audiences are responding to their work.

Having tools that provide a more complete picture of research impact, makes it easier to justify further funding. Important research can then receive the support it requires to produce further valuable output.

An awareness of societal impact also helps to improve how a paper behaves in this regard - allowing new methods of access and sharing to be tested and improved. The easier it is for an audience to read a paper, the more informed the audience is likely to become - resulting in an overall expansion of the scientific community. This can only be a positive thing for authors.

Crossing New Horizons

With the mission objective nearly upon us, we stand on the edge of a new era of space exploration. The excitement generated by New Horizons will hopefully build a wider public awareness of the importance of such missions, and an appreciation of the research being conducted.

For observers who wish to learn from New Horizons, the software tools available to them allow a range of new opportunities to make the most of the research being made available and to understand that research in new ways.

We look forward to the accomplishments of July 14 and the results that will follow soon after. We also enthusiastically anticipate the possibilities that the mission data will unlock, and to taking a step into a new age of space exploration.

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This reference information has also been shared via a Mendeley Group:

http://mnd.ly/1CaDWsW

Additional Resources

www.mendeley.com
www.scopus.com
www.sciencedirect.com
www.scival.com
www.newsflo.net

www.nasa.gov
solarsystem.nasa.gov/planets/plutotoolkit.cfm
pluto.jhuapl.edu

NASA's New Horizons mission, part of the New Frontiers Program, is expected to reach its primary target - the dwarf planet Pluto - on July 14 2015.

Mendeley was invited to visit NASA during the close approach of Pluto and will be at NASA HQ on the day of the encounter. This report was written to mark the occasion and to share our excitement at being present for the event.

This accomplishment - flinging a probe across unfathomable expanses of space with extreme precision - would not be possible were it not for the work of a dedicated team of men and women working tirelessly to turn science fiction into science fact.

This report is intended to shine a light on the contributions made by those scientists and the debts they owe to those who have gone before. It examines their inspiration, their publications and the way their works are linked. It also discusses what we will learn from New Horizons and where this knowledge might take us in future.

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