Human Spaceflight in Social Media: Promoting Space Exploration Through Twitter

Pierre J. Bertrand,[1] Savannah L. Niles,[2] and Dava J. Newman[1,3]

[1]Man-Vehicle Laboratory, Department of Aeronautics and Astronautics; [2]Media Lab, Department of Media Arts and Sciences; and [3]Department of Engineering Systems, Massachusetts Institute of Technology, Cambridge, Massachusetts.

ABSTRACT

While space-based technologies for Earth applications are flourishing, space exploration activities suffer from a lack of public awareness as well as decreasing budgets. However, space exploration benefits are numerous and include significant science, technological development, socioeconomic benefits, education, and leadership contributions. Recent robotic exploration missions have positively influenced public perception by utilizing video and social media communication. How can these new communication technologies be used to better serve human spaceflight? How can space agencies and astronauts inspire tax-paying citizens, and thus politicians, to commit to an ambitious, global human spaceflight program based on international collaboration? This article analyzes how the Twitter network related to human spaceflight is organized, measuring how influence and relationships are linked, to better capture the best practices and enhance the promotion of space exploration. We outline the Twitter network and organization related to human spaceflights and show how the use of media (i.e., photos and videos) in tweets can affect the notoriety and popularity of Twitter accounts. We investigate the cultural differences of astronaut followers. This article crystallizes the study performed on the Twitter human spaceflight network. This is the first study analyzing the use of social media to communicate about human spaceflight and its potential. Future work needs to be done to characterize the effectiveness of using such a platform to build adequate support for human spaceflight, in comparison to more conventional communication tools.

INTRODUCTION

Human Space Exploration

"We cannot be indifferent to space, because the grand slow march of intelligence has brought us, in our generation, to a point from which we can explore and understand and utilize it. To turn back now would be to deny our history, our capabilities," said James Michener.[1] The aerospace industry has successfully commercialized Earth applications for space technologies, but human space exploration seems to lack support from both financial and human public interest perspectives. Space agencies no longer enjoy the political support and public enthusiasm that historically drove the human spaceflight programs. If one uses constant year dollars, the $16B National Aeronautics and Space Administration (NASA) budget dedicated for human spaceflight in the Apollo era has fallen to $7.9B in 2014, of which 41% is dedicated to operations covering the International Space Station (ISS), the Space Launch System (SLS) and *Orion*, and commercial crew programs.[2] The European Space Agency (ESA) maintains a budget of 400M€ for human spaceflight, approximately 10% of its total budget.[3] While mission successes continue under these constraints, financial as well as renewed public support is required for human exploration to become a strategic and high priority among many nations. Exploration is the expansion of the realm of human experience, the redefinition of what it means to be human,[4] and despite the nondirect benefits for society, numerous rationales rely on it. Primary and secondary rationales justify human spaceflight.[4] Primary ones, which rely on the presence of humans, include national pride, international leadership, and inspiration. Secondary rationales where humans augment the benefits of missions include science, economic development, and education.[4]

Human spaceflight is an efficient way to build identity and contribute to national stature.[5,6] Human spaceflight remains a powerful instrument for international diplomacy, which can promote peaceful international relations. The ISS is the best example, currently. Space exploration also offers an "extraordinary opportunity to stimulate math, science and engineering excellence"[6,7] in countries involved in these programs, a significant benefit, as many governments currently place high priority on science, technology, engineering, and mathematics (STEM) education.[8] The rationales of human spaceflight are more topical than ever, but the paradigm needs to change in order to build a strong and ambitious space exploration program. In the time of a flat world within a global economic crisis,[9] international collaboration appears to be the

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framework for the new exploration era. As a coordination of financial and intellectual resources, international collaboration increases the scope of programs beyond the capabilities of individual space agencies.[5,6] "Engage the public in exploration" is one of the 8 common goals and objectives that the International Space Exploration Coordination Group defined,[1] in order to build a sustainable human space exploration endeavor that will last for decades.

Communication in Human Spaceflight

Astronauts are the incarnation of space exploration; they embody national prestige, inspire younger generations, and represent a very efficient way to gain public support, therefore providing an incentive for nations to fund human spaceflight programs. However, astronauts remain very nationalistic: their influence is difficult to spread across borders, especially due to language barriers and lack of identification. This issue presents an obstacle for ambitious international cooperation. As astronaut Gerhard Thiele states in the "European Identity through Space" report, "while in the astronauts' country the news coverage is usually very broad and at a prominent place in the newspaper or the TV news, in other European media the space mission usually receives hardly more than a short mention."[5] What is true among the European countries collaborating within ESA is an even greater reality between different agencies. In addition to the cultural gap that can form between an astronaut and the public, a loss of general awareness about astronauts and their activities is observed. For example, Americans are currently less able to name an American astronaut than was the case right after the Apollo era.[10] According to Gabriel Almond, the engagement of the citizens depends on a combination of interest in the topic and a sense of being adequately informed about it,[6,11,12] and recent studies have shown that both the well-informed public and the public interested in human spaceflight have relatively low awareness compared to other public policy issues.[6] However, the communication paradigm is rapidly changing with the development of the Web 2.0, an expression referring to the interactive and collaborative evolution of the Internet.

Information is now exchanged through blogs, social networks, web applications, and wikis. Li and Bernoff[13] define it as "the social trend in which people use technologies and get the things they need from each other, rather than traditional institutions." They call it the "*groundswell*." These new interactive tools are changing the way space agencies communicate and the way the public perceives human spaceflight: the *groundswell* is crossing borders, gathering people from all over the world, and broadcasting inspiring videos and pictures. Already several examples have reached the public in a very inspiring way: Canadian astronaut Chris Hadfield gained more than 22 million views on his "Space Oddity" YouTube video,[6,14,15] and inspired the entire space community, especially the Anglo-Saxon world. The video of the *Curiosity* landing,[16] demonstrating both the technological challenge of the mission and the human joy of the ground control staff, has gone viral and was part of the Google Zeitgest 2012,[17] summarizing the year 2012. Other salient examples have demonstrated an effective use of social network to convey messages, make the space community react, and inspire the Web: the Rosetta campaign during the summer of 2014 was a case in point.[18]

The interactive tools provided by the Internet are also very useful to educate and provide informal education supplemental to a classroom activity.[19] Different social phenomena are involved in this new communication tool: public information, public education, public engagement, public support, and public participation.[10] However, one does not necessarily lead to another. Public participation seems to be a key phenomenon to endure public involvement. Some campaigns have successfully demonstrated the benefits of public participation: the #HumansInSpace campaign, where Twitter users were asked to provide ideas for human spaceflight program,[6] or NASA spacesuit design vote.[20] The *groundswell* is a relatively inexpensive communication tool, prone to cross the borders of culture and language, and appears to be the adapted tool to build the space exploration program of tomorrow, based on international collaboration.

Twitter for Human Spaceflight Communication

One of the common objectives that space agencies share is to use interactive communication tools to provide virtual experiences using real and live exploration data.[1] Google + or Youtube are particularly adapted to inform, communicate, interact, and inspire large and different communities of Internet users. However, they are all different in the way they work and connect people. Twitter, launched in March 2006, is one of the most notable and used real-time message routing platforms,[21] also known as a microblogging service. The principle is that users can communicate to their network through short instant messages called tweets, limited to 140 characters. The network is based on the "following principle," in which each user chooses who to "follow" to receive tweets from this account.[22] The nature of Twitter, through its simplicity, utility, and mobility,[21] makes it particularly effective platform to disseminate brief information,[23] unlike other user-declared networks like Facebook. Used for many different purposes, from daily chatter to mentioning news,[24] it gathers a broad and diverse public of 271 million monthly active users,[25,26] the most meaningful metric[27] in social

media. Among these users, approximately 25% are from the United States, 10% from Japan, 6% from the United Kingdom, 4% from Spain, 2.6% from Russia, and 2.1% from France.[26] The 18–24-year-old population represents 20% of the daily users in the United States and the 25–34 years old, 11%.[26] The gender distribution is approximately 47% male and 53% female.[28,29] There are on average 500 million tweets posted per day,[24] making Twitter one of the top 10 most visited websites.[30]

Twitter has already been exploited by most of the space agencies to promote space exploration. It started with the NASA campaign around the Mars *Phoenix* landing in 2009, followed by the first tweet from space by astronaut Mike Massimino. Twitter has also been used for live tweets events (TweetUp, Social, Hangout, *etc.*) where Twitter users are invited by agencies such as NASA, ESA, or CNES to tweet about a subject. Astronauts using Twitter are particularly efficient communicators: they inspire followers by writing their space experiences, they inform by reporting news, and they make the public feel closer to them by sharing their personal life and by replying to people. Astronauts' Twitter accounts represent a good means to "take the public along for the ride" as the Space Studies Board workshop suggested.[10] "Providing the widest and appropriate dissemination of information" concerning its activities is one of the most important duties of a space agency,[31] and using communication tools such as Twitter is an efficient way to achieve it. In addition, the social media environment, and Twitter in particular, can be used for active political discussions[32,33] and can be a useful tool to assess public opinion and perception on a policy topic. Being actively involved in this environment is thus an incredible chance for agencies to build the future of human space exploration.

The analysis of how people interact within Twitter is particularly easy compared to other social networks, and numerous studies have analyzed the influence,[22,23,34] diffusion of information,[23] or nature of networks.[24,35] A particularly relevant study is to analyze who the most influential Twitter users are likely to spread information at low cost. According to traditional communication theory,[34,36] by targeting "influentials" in the network, a large-scale chain reaction of influence driven by word of mouth is more likely to happen.[23,34] *Influentials* are usually well informed, respected, and well connected. Another view states that influence depends on both the "interpersonal relationship among ordinary users and the readiness of a society to adopt an innovation,"[34] relying less on influential people. Influence is defined as "the power or capacity of causing an effect in indirect or intangibles ways," according to the Merriam-Webster dictionary.

When it comes to Twitter, however, there are no standards to measure influence. Some studies focus on different metrics such as the number of followers, or the number of interactions between accounts.[22,29,34,37] Four types of influence are the most relevant: 1 state and 3 actions. The state is the number of followers that an account has, which directly indicates the size of the audience for that user.[34] The 3 actions available on Twitter that are relevant to measure influence are the reply, the retweet, and the favorite. The reply measures the ability of the user to be close to his/her followers and involved in his/her relationships. It defines what some agencies call the engagement of the account, or the ability to create and follow a conversation.[37] The retweet indicates the ability of that user to generate content with pass-along value,[34] called content or reach influence.[37] Finally, the favorite metric represents the personal impact that a tweet can have on users and why they would choose to keep that special tweet. Analyzing these different metrics provides a better understanding of Twitter influence.

While performance-tracking services are provided to agencies and general Twitter statistics are available online, there is a lack of investigation on the Twitter environment related to human spaceflight and how this network is organized. This article aims to provide a general analysis of this environment by quantifying the general existing practices and revealing the trends in the network. To serve this goal, the Twitter network related to human spaceflight was studied. The Twitter network related to human spaceflight is defined by the content generator accounts from official space agencies related to human spaceflight and human space exploration. All the official accounts covered by a space agency were determined using data provided by the space agency directly.

The space agencies considered were NASA, ESA, JAXA, CSA, and Roscosmos, being the only current agencies having official Twitter accounts. These accounts were official space agency accounts, astronaut accounts, and mission or entities accounts related to human spaceflight. A detailed list of the accounts studied can be found in *Appendix A*. The first part of the article provides general results about the different Twitter accounts related to human spaceflight, such as number of followers, following, favorites, tweets, and date of creation. The second part quantifies the impact of the tweets for each account revealing the percentage of tweets using media, the number of retweets, and favorites by tweet posted. The third part presents a network analysis among the accounts and across the agencies based on different metrics: followers/following, replies, and retweets. Finally, the last part analyzes the nationality of the followers for each account. Besides giving a broad understanding of how the network is

organized, this study aims at showing that Twitter is a powerful tool to cross-cultural and linguistic frontiers that inspires an international community. We pay particular attention to quantifying how sharing media tweets affects the popularity of the account and how the nationalities of an account's followers spread over many different countries.

METHODS

We analyzed the data from 86 different Twitter accounts related to human spaceflight across 5 different space agencies: NASA, ESA, Canadian Space Agency (CSA), Japan Aerospace Exploration Agency (JAXA), and Roscosmos. These included the accounts of astronauts, human spaceflight missions, and space agencies. These 86 accounts represent all the official Twitter account currently related to human spaceflight. For each of these 86 accounts, we used the Twitter application programming interface (API) to collect the number of followers the account has, the number of accounts the account follows, tweets sent, and tweets that have been favorited. These results were used in the first part of our analysis, describing the general tendency of the network, and were collected on July 1, 2014. For the second part, we gathered the last 200 tweets posted by each account, the number of favorites, and retweets of these tweets, and also if the tweet shared media (picture or video) and if the tweet was a reply. This was recorded on July 1, 2014. The third part used both the first and second set of data to define the interactions. Finally, the nationality of the account followers was collected on August 1, 2014, and analyzed in the final part of the article. We used a Kruskal–Wallis test ($\alpha = 0.05$) to assess the significance of the results, followed by a Mann–Whitney *U* test with a Bonferonni correction for the pairwise comparison when needed.

RESULTS

General Analysis

This first part aims at quantifying the current situation of the astronauts and other human spaceflight-related missions and entities using Twitter. It is divided into two sections. In the first section we present the distribution of these accounts over the different agencies, over their types (astronauts, missions, and official accounts), and their date of creation and last flight (if astronauts). In the second section, we analyzed the basic metrics of a Twitter account: the number of followers, following, tweets, and favorites.

Figure 1 shows the 86 accounts as distributed among 5 space agencies: NASA, ESA, CSA, JAXA, and Roscosmos. NASA has the largest number of accounts (56 in total with 40 astronaut accounts), likely due to the agency's size large astronaut corp. ESA and CSA have 13 and 9 total accounts, with 10 and 7 astronaut accounts, respectively, while JAXA and Roscosmos have, respectively, 6 and 5 total accounts, with 5 and 4 astronaut accounts, respectively. *Appendix A* lists all of the accounts studied.

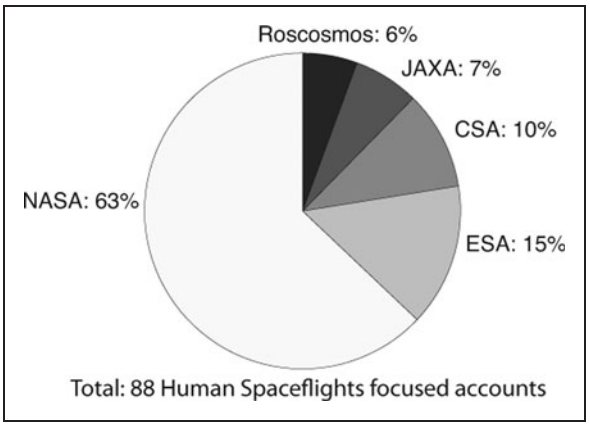

Fig. 1. Distribution of the Twitter accounts focused on human spaceflight by agencies. Percentages given with respect to total number of accounts studied.

The date of creation of the Twitter account and the date of the last flight of the astronaut can play a significant role in the influence of the account as shown in *Figures 2* and *3*, revealing the distribution of accounts according to creation and last flight. We observe that the most represented categories are the candidates, and astronauts who have last flown in 2011 and in 2010.

Figure 3 presents the date of creation of the accounts, by agency, displaying only the name of the first and last account

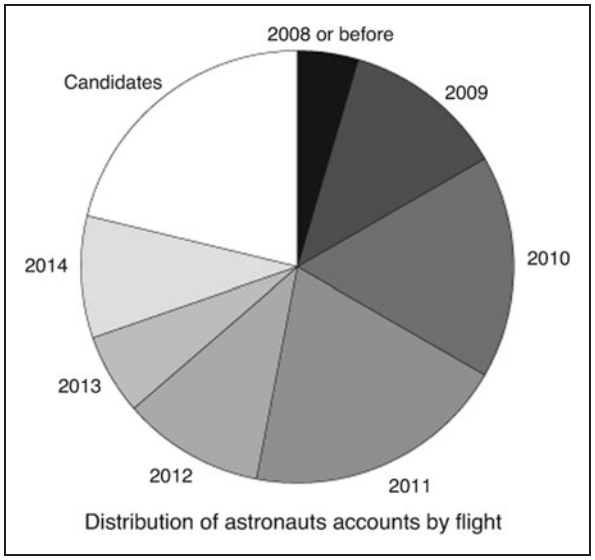

Fig. 2. Date of the last flight of the astronaut accounts.

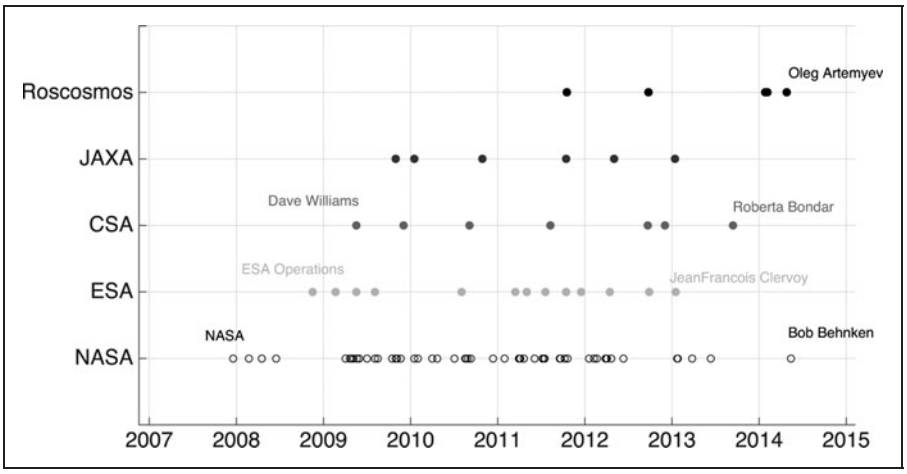

Fig. 3. Date of creation of Twitter accounts by agency.

created by agency. We observe that, in general, NASA was the first agency to create accounts, followed by ESA, and then CSA and JAXA, and finally Roscosmos. Accounts were created between 2007 and early 2014.

Figure 4 displays the distribution by agency of the basic metrics defining an account: number of followers, following, tweets, and favorites. The graphs show, for each metric, the accounts having the largest number of units.

A Kruskal–Wallis statistical analysis was performed to assess the significant difference between the agencies in terms of followers, following, favorites, and tweets. There was significant difference between agencies in terms of number of followers ($P=0.0063$, $X^2(4)=14.34$), number of favorites ($P=0.0124$, $X^2(4)=12.79$), and the number of tweets ($P=0.0361$, $X^2(4)=10.27$). However, only the pairwise comparison between JAXA and Roscosmos for the number of followers is statistically significant according to the Mann–Whitney U test with a Bonferonni correction ($P=0.0043$). There is no significant difference between agencies for the number of following ($P=0.1677$, $X^2(4)=6.45$).

A statistical test was performed to determine if the date of the last flight was an explanatory variable of the basic metric. There are no significant differences between categories about the number of following ($P=0.7274$, $X^2(7)=4.44$), the number of tweets ($P=0.4184$, $X^2(7)=7.1$), or the number of favorites ($P=0.3471$, $X^2(7)=7.9$). However, there is a significant difference between these groups when it comes to the number of followers ($P=0.0115$, $X^2(7)=18.1$). We observe that the astronauts who last flew in 2013 have significantly more followers than the astronauts who are still astronaut candidates and have not flown ($P=0.0026$). *Figure 5* shows the distribution of the number of followers according to the year of the last flight, for the astronaut accounts only.

Tweet Impact

In order to understand how and why an account reaches more people, we analyze the impact of the tweets. In this section, we analyzed the impact of the last 200 tweets of each account, collecting information such as the number of times other Twitter users retweeted a tweet from the account, which we call number of retweets by tweet; the number of times other Twitter users favored a tweet of the account, which we called number of favorites by tweet (in this study); the percentage of tweets containing media (photos and videos); and the percentage of tweets that are replies to a Twitter user.

Figure 6 displays the distribution by agency of the impact metrics that we studied: number of retweets by tweet, number of favorites by tweet, percentage of tweets with media, and percentage of tweets that are replies. Despite the fact that JAXA seems to have a largest number of retweets and favorites by tweet, and the lowest percentage of tweets that are replies, the statistical test performed does not find any significant differences between agencies for these metrics: number of retweets by tweet ($P=0.677$, $X^2(4)=2.32$), number of favorites by tweet ($P=0.336$, $X^2(4)=4.58$), percentage of tweets with media ($P=0.6048$, $X^2(4)=2.73$), and percentage of tweets that are replies ($P=0.6048$, $X^2(4)=2.73$).

The relationship between the year of the last flight and the impact metrics was studied to assess any impact the astronaut's last flight date has on these metrics (shown in *Fig. 7*). We observe a significant difference for the number of favorites by tweet ($P=0.0005$, $X^2(7)=26.12$), between the accounts when an astronaut flew last in 2010 and the astronaut candidates ($P=0.0019$), and between the accounts when an astronaut flew last in 2009 and the astronaut candidate accounts ($P=0.0027$). When it comes to the percentage of tweets with media ($P=0.0056$, $X^2(7)=19.88$), the accounts of astronauts who are currently flying share significantly more media than those who flew in 2009 ($P=0.0027$). There is no significant difference between years of flight for the number of retweets by tweet. Finally, there is a significant difference in the percentage of tweets that are replies ($P=0.0039$, $X^2(7)=30.93$), between the astronaut candidate accounts and the accounts of astronauts who last flew in 2012.

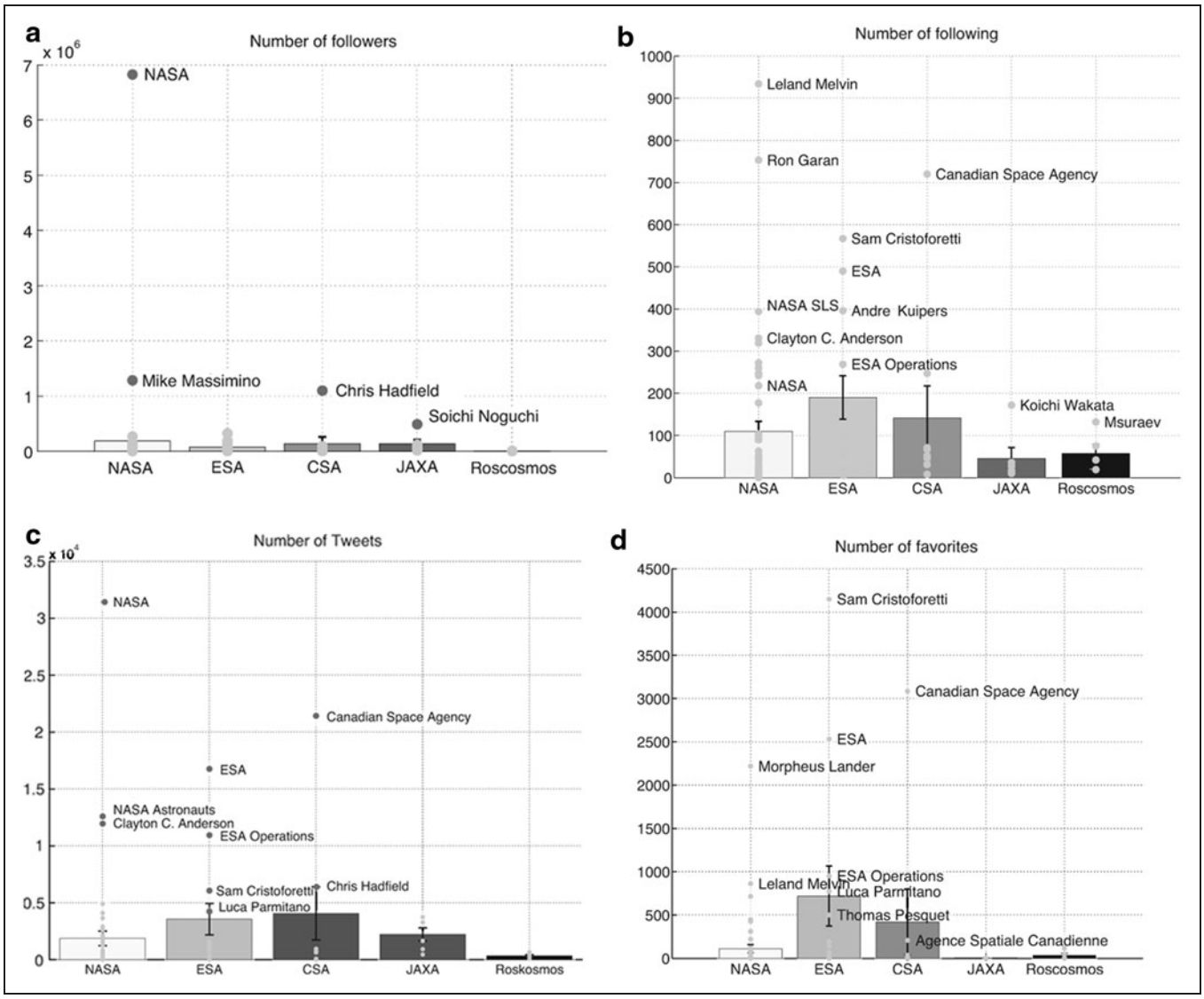

Fig. 4. Basic metrics of the Twitter accounts. **(a)** Number of followers. **(b)** Number of following. **(c)** Number of favorites. **(d)** Number of tweets. The bar graphs represent the mean of each agency, the error bars represent the standard error of each agency, and the gray point the accounts.

Assessing the reasons why tweets are retweeted and how an account gains in influence is crucial to better reach and interact with the public. Sharing media such as pictures or video seems an efficient way to interact and inspire the public. In this section, we quantified this effect. *Figure 8a* relates how often an account has been retweeted with how often media was shared in a tweet. Accounts that tend to share more media are retweeted more. *Figure 8b* similarly shows how the percentage of tweets with media affects the number of retweets and favorites received by tweet.

There is a significant difference between the groups that share $<30\%$ of media, between 30% and 60%, and those that share $>60\%$ (retweets: $P<0.001$, $X^2(2)=31.2$; favorites: $P<0.001$, $X^2(2)=21.92$). Pairwise comparison reveals that accounts sharing $>60\%$ media are significantly more often retweeted than the accounts sharing between 30% and 60% media ($P=0.005$) and that share $<30\%$ ($P<0.001$), and significantly more favored than the accounts sharing less than 30% media ($P<0.001$). The accounts sharing between 30% and 60% are also significantly more retweeted ($P<0.001$) and more favored ($P<0.001$) as compared to the ones that share $<30\%$. A linear regression relating the number of retweets or favorites and the percentage of tweets with media is shown in *Figure 8c*. We observe that the logarithm of both the retweets and the

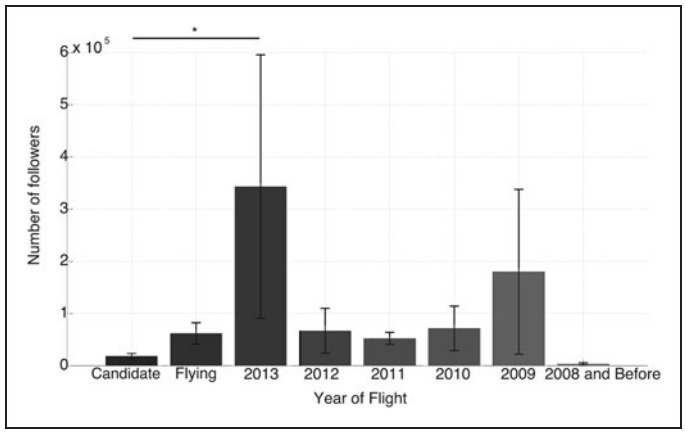

Fig. 5. Number of followers by last flight of astronauts. The error bars represent the standard error and the asterisk shows significant difference ($\alpha = 0.05$).

favorites metrics is linearly related to the percentage of tweets with media, each by a slope of 0.04 (*t*-statistics performed to test the slope gives $P < 0.001$ for both retweets and favorites). However, as the coefficient of determination is relatively low due to the large variance between accounts ($R^2 = 0.3489$ for the number of retweets and $R^2 = 0.2504$ for the number of favorites), the linear relationship cannot be claimed to be significant.

Network Analysis

We define two different methods to better understand the nature of the interaction between accounts: the *following link*, or how accounts follow each other, and the *retweets/replies link*. While the *following link* focuses on how much people are interested in each other, the *retweets/replies* focuses on how accounts interact with each other. These two different methods are very complementary. The first section focuses on the individual interactions between accounts. *Figure 9* shows chord diagrams of the interactions of the two different methods: following and retweets/replies. *Figure 9a* shows the chord diagram of the *following links* for the ESA official account: the gray links stand for "follows" and black for "is followed." For example, between two accounts A and B, 4 types of interactions are possible: A follows B without B following A, B follows A without A following B, A and B follow each other, and finally no interactions between A and B. When we select account A, the link with account B will be black if A is followed by B, will

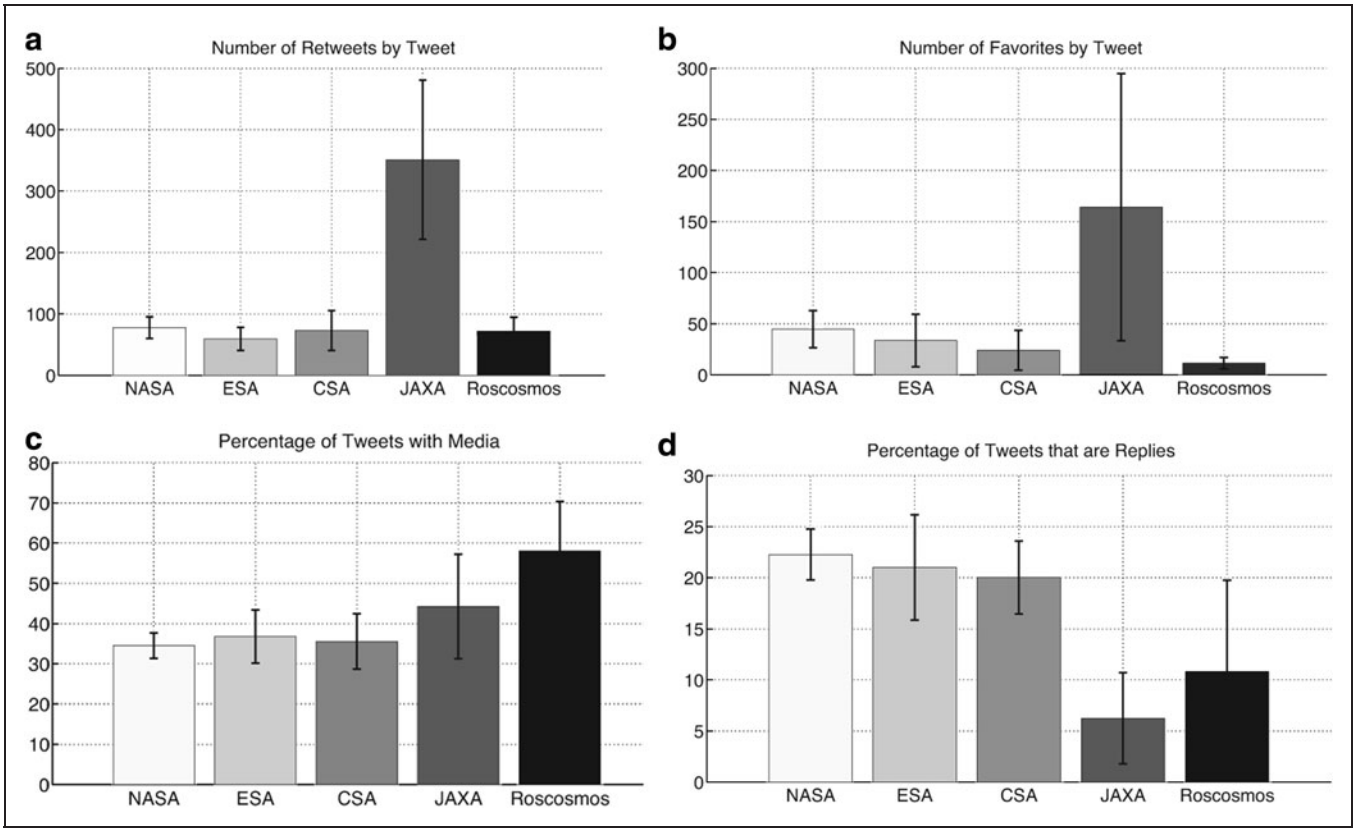

Fig. 6. Impact metrics of the Twitter accounts. **(a)** Number of retweets by tweet. **(b)** Number of favorite by tweet. **(c)** Percentage of tweets with media. **(d)** Percentage of tweets that are replies. The error bars represent the standard error of the accounts within an agency.

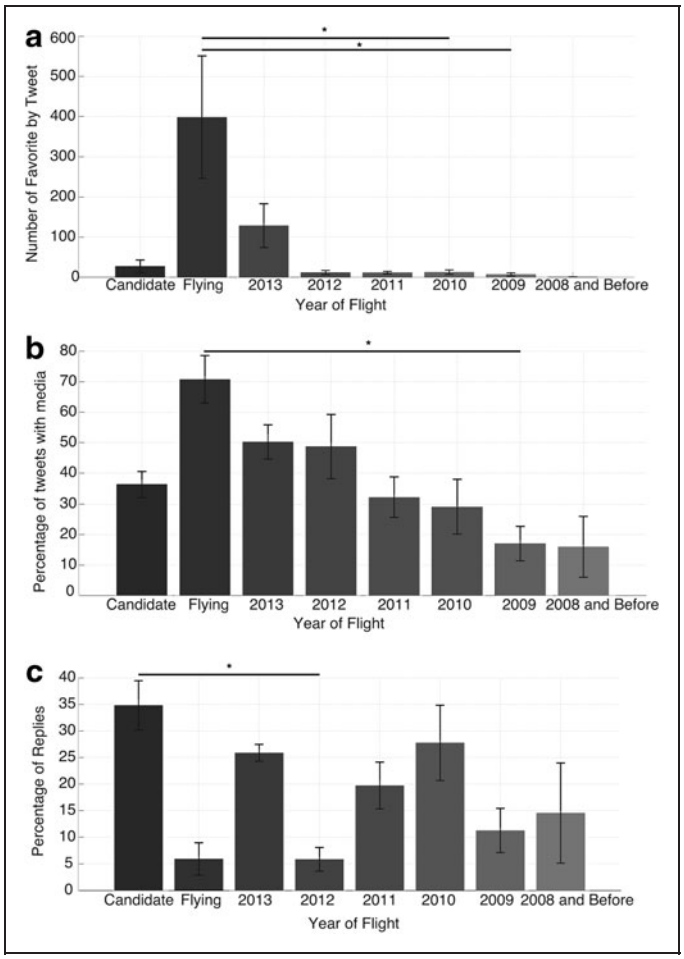

Fig. 7. Effect of astronaut's flight on the impact of the tweets. **(a)** Number of favorites by tweet. **(b)** Percentage of tweets with media. **(c)** Percentage of tweets that are replies. The error bars represent standard error and the asterisks show significant difference ($\alpha = 0.05$).

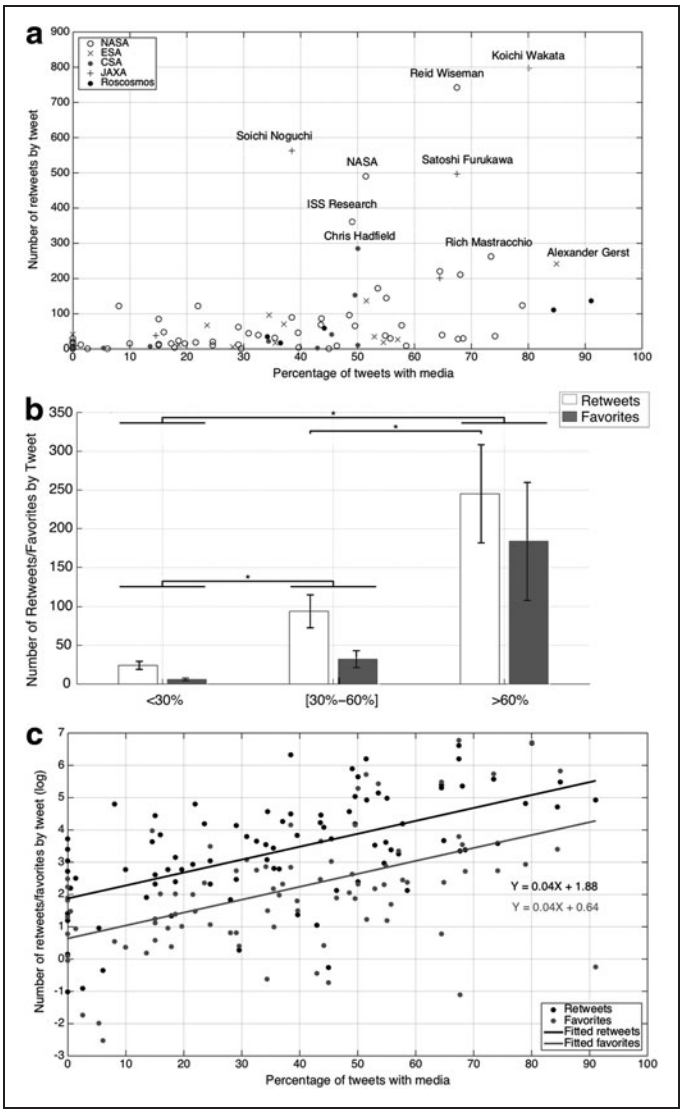

Fig. 8. **(a)** Effect of sharing media on retweets for different accounts. **(b)** Quantification of the effect of sharing media in tweets. **(c)** Linear regression between the logarithm of retweets and favorites and the percentage of tweets with media. The error bars represent standard error and the asterisks show significant difference ($\alpha = 0.05$).

be gray if A follows B or if they mutually follow each other, and there will be no links if there are no interactions. Consequently, the link appears black if account A is only followed by B (no reciprocity). *Figure 9b* shows the chord diagram of the *retweets/replies* for the NASA official account: the gray links mean that NASA sent a reply or retweeted a tweet from the corresponding account. The black links mean that NASA received a reply or has been retweeted by the corresponding account (without replying or retweeting it).

Figure 10 presents the same information but gathered by agencies. All of the accounts within an agency are gathered and the interactions are studied. The root of the link represents the percentage of interactions coming from the source agency dedicated to the target agency linked by the link. If the source agency follows more than is followed by the target agency (*Fig. 10a*) or if it replies and retweets more than the target agency has retweeted or replied to the source agency (*Fig. 10b*), the color of the link will be the color of the target agency. Consequently, the agencies followed less than they themselves follow other accounts from different agencies will have links of their own colors (*Fig. 10a*). Similarly, agencies that have received less replies and have been retweeted less times than have sent replies or retweets will have a link with other agencies of their own color. The color displays thus an exocentric state. For example, NASA follows ESA less than ESA follows NASA, but NASA retweets and replies to ESA more than ESA does. The length of the agency chord is proportional to the number of

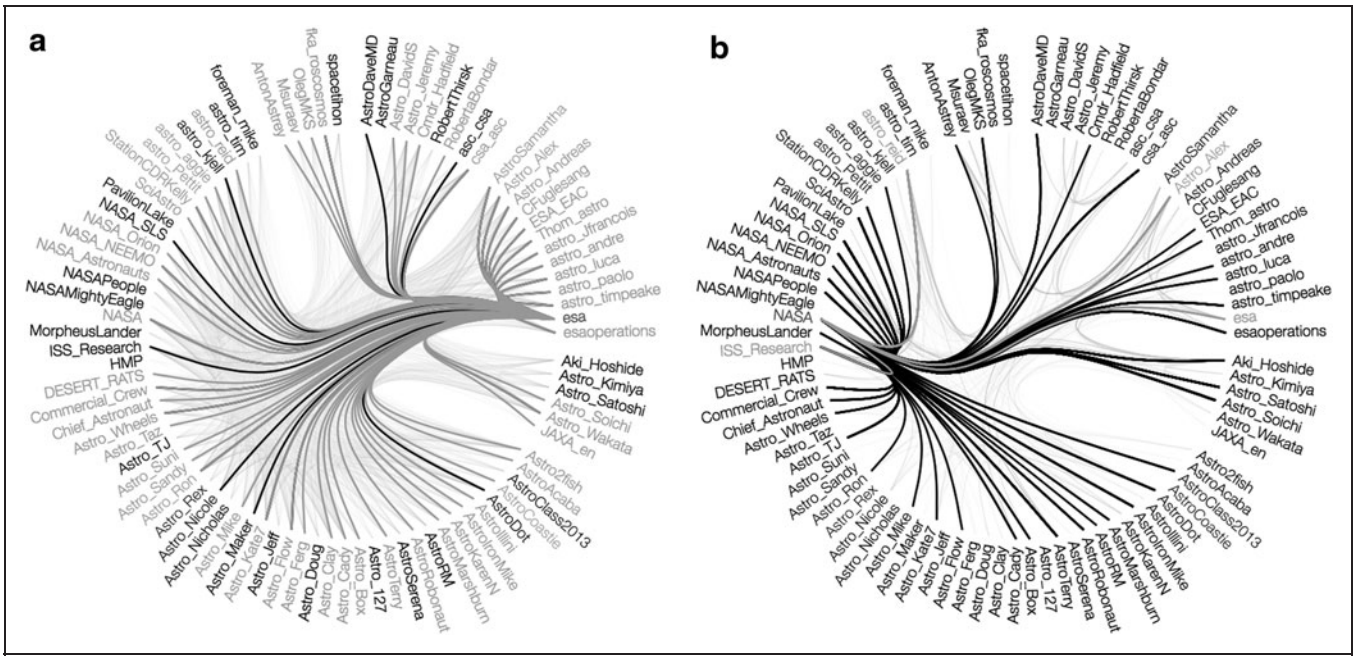

Fig. 9. Individual interaction chord diagram. **(a)** Following interactions. **(b)** Replies–retweets interactions.

interactions involving the agency: "follows" or "is followed" for *Figure 10a* and replies/retweets for *Figure 10b*.

Nationality of the Followers

It is crucial to understand the demographics of the people with whom the accounts interact for several reasons, such as understanding the spectrum of the public that is missing or better designing communication campaigns appropriate to the public. When it comes to astronauts, the impact that they can have on the public, informing and inspiring them about exploration, seems closely related to the nationality of the astronaut and the nationality of the public. Investigating the nationality of the followers according to the astronaut nationality is valuable to better understand the Twitter public and to verify the hypotheses formulated in this article claiming that social media is an efficient way to reach a broader public in terms of nationality.

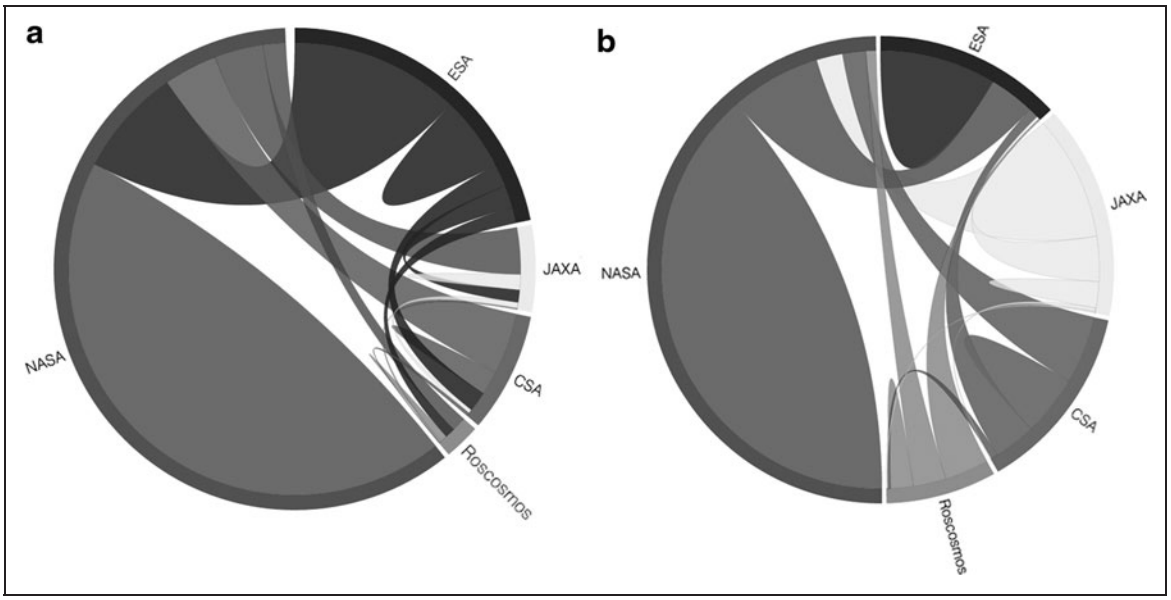

Fig. 10. Agencies interaction chord diagram. **(a)** Following interactions. **(b)** Replies–retweets interactions.

This study focuses on 9 different accounts: the official accounts of 5 space agencies and the following astronaut accounts: NASA astronaut Reid Wiseman, ESA astronaut Alexander Gerst, and JAXA astronaut Koichi Wakata. These astronauts were selected both to represent the different agencies and because they were showing interesting characteristics: Reid Wiseman and Alexander Gerst are onboard the ISS during the study, and Koichi Wakata represents a good practice using Twitter. *Table 1* presents the 5 more frequent nationalities of an account's followers. ESA is the only agency studied that is not exclusively representing a single country; consequently, *Table 1* also indicates the percentage of followers represented from ESA member states. Finally, some followers' nationality is unknown, which may skew the results, and is indicated in *Table 1*. Percentages are based on the total number of followers, except for NASA official account, where only 1 million followers were processed. For this reason, the percentage of unidentified nationalities was not computed. *Figure 11* shows an example of the geographic distribution of the followers for the space agency accounts: ESA, CSA, JAXA, and Roscosmos. Detailed interactive maps for each accounts can be found on the website.

DISCUSSION

General Twitter Analysis

General analysis first reveals the distribution of the accounts between agencies, showing that NASA has substantially more accounts than any other agency and is also aggressively using Twitter accounts for astronauts, official entities (NASA People, ISS Research, *etc.*), and specific missions (NEEMO, Desert Rats, *etc.*). This policy, first used for the *Phoenix Rover*, is called "giving a voice to a flagship product,"[38] where the accounts speak in the first person. We also notice that despite the large number of cosmonauts, Roscosmos is not very involved in Twitter, currently, compared to other space agencies with fewer astronauts. The analysis of year of last flight among the astronaut accounts shows a dominant minority among astronaut candidate accounts. All NASA and ESA astronauts from the 2009 class have Twitter accounts (Jeanette Epps's and Mark Vande Hei's accounts have not been included in this article because they are not yet officially recognized). Results show the importance of astronauts as inspirational figures when involved in social media to inspire and interact with the public. Considering the current astronauts flying onboard the ISS (Expedition 40), 4 of 6 have Twitter accounts and 2 of them (ESA astronaut Alexander Gerst and NASA astronaut Gregory Wiseman) tweet frequently, sharing pictures and news with their followers.

Table 1. Distribution of the Nationality of the Followers for the Five Space Agencies' Official Twitter Accounts and Four Astronauts (Reid Wiseman, Alexander Gerst, Chris Hadfield, and Koichi Wakata)

Astronaut/Account	NASA	ESA	CSA	JAXA	Roscosmos	Reid Wiseman	Alexander Gerst	Koichi Wakata
Top 5	US: 37%	US: 15%	US: 27%	Japan: 29%	Russia: 14%	US: 25%	US: 15%	Japan: 26%
	UK: 9%	UK: 7%	Canada: 5%	US: 14%	US: 5%	UK: 6%	Germany: 10%	US: 11%
	Japan: 7%	The Netherlands 5%	UK: 2%	Russia: 4%	Greece: 2%	The Netherlands: 2%	UK: 5%	Russia: 5%
	The Netherlands: 6%	Greece: 3%	The Netherlands 1%	UK: 2%	Iraq: 1%	Canada: 2%	The Netherlands: 4%	UK: 4%
	Greece: 4%	Italy: 2.64%	Greece: 1%	The Netherlands: 1%	The Netherlands: 1%	Turkey: 2%	Greece: 3%	Turkey: 1%
Total ESA member nations	36%	28%	6%	7%	7%	16%	28%	9%
Unidentified	N/A	47%	57%	40%	63%	45%	45%	43%

The percentage of the followers part of ESA member states is also displayed, with the percentage of unidentified followers.
NASA, National Aeronautics and Space Administration; ESA, European Space Agency; CSA, Canadian Space Agency; JAXA, Japan Aerospace Exploration Agency.

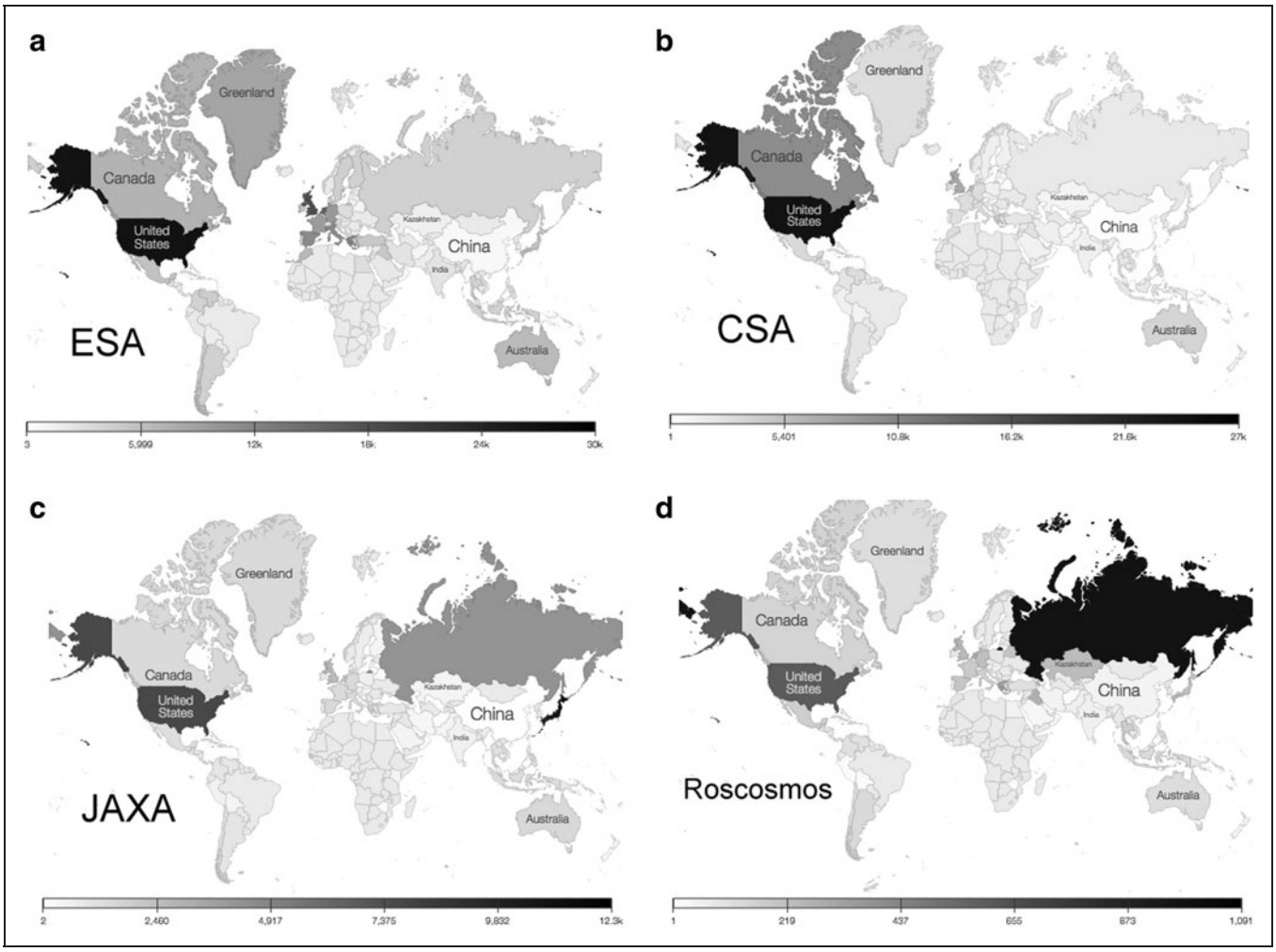

Fig. 11. **(a)** Nationality of the followers of ESA official account. **(b)** Nationality of the followers of CSA official account. **(c)** Nationality of the followers of JAXA official account. **(d)** Nationality of the followers of Roscosmos official account.

The basic metrics given by Twitter (number of followers, following, tweets, and favorites) also provide interesting information. Statistical analysis shows only a significant difference between agencies for the number of followers between JAXA and Roscosmos; therefore, it is deemed more useful to focus on individual accounts for further analysis. Four accounts have a high number of followers: the NASA official account particularly with almost 7 million followers, followed by the individual accounts of NASA astronaut Mike Massimino, CSA astronaut Chris Hadfield, and JAXA astronaut Soichi Noguchi with approximately 1 million followers each. The trends for the number of following, tweets, and favorites are less obvious. NASA astronaut Leland Melvin is highest in terms of following, having around 900 Twitter accounts followed, while most accounts follow <200 accounts. ESA astronaut Samantha Cristoforetti has the highest number of favorites, with approximately 4000 favorites, whereas most of the accounts have <500 favorites. Considering that following other Twitter users and having a large number of favorite tweets (tweet that the account likes) indicate the involvement of an account with the public, we find that Samantha Cristoforetti (ESA), the CSA official account, the ESA official account, and Leland Melvin's account (NASA) seem to be very involved with the public. The accounts tweeting the most are the official accounts NASA, CSA, and ESA, which was expected as they are tweeting not only about the human spaceflight but also about the sum of all space activities. Most of the accounts have tweeted <2000 tweets.

Finally, we observe that, in general, the astronauts who flew in 2013 have a larger number of followers compared to astronaut candidates. It can be explained by the "flight effect":

an astronaut in flight attracts much more media attention than astronauts who have not flown yet or who flew many years ago. The CSA astronaut Chris Hadfield, NASA astronaut Karen Nyberg, and ESA astronaut Luca Parmitano are examples of astronauts who have flown onboard the ISS in 2013 with a significant number of followers.

Tweets Impact

JAXA tweets seem to be frequently retweeted and favored compared to the other agencies and, on average, reply less to other tweets. However, this trend is not significant. When we look at the individual accounts, JAXA astronauts Koichi Wakata, Satoshi Furukawa, and Soichi Noguchi are massively retweeted, along with NASA astronaut Reid Wiseman, currently onboard of the ISS. As the data represent the last 200 tweets and correspond to the period of the flight of NASA astronaut Reid Wiseman and ESA astronaut Alexander Gerst, the fact that they are often retweeted and favored is explained by their flight and the opportunity to reach a broader public by sharing experiences and media in their tweet. On average, tweets are retweeted approximately 90 times and favored by 50 people. The accounts, in general, share almost 40% tweets containing media, such as photos or videos, and 20% of the tweets are replies. The astronauts sharing the most media are Roscosmos cosmonauts Oleg Artemyev and Anton Shkaplerov, ESA astronaut Alexander Gerst, NASA astronaut Terry Virts, and JAXA astronaut Koichi Wakata. All these accounts are owned by astronauts who have flown recently or who are going to fly soon (Expedition 39, 40, 41, and 42).

The statistical analysis shows that the astronauts currently flying or who flew in 2014 are favored more often, which confirms the "flight effect," and use media more often. It is almost an intuitive result since they can share pictures of the Earth from the ISS, of their life, and of scientific experiments onboard. We also observe that the candidate astronauts reply most frequently to their public, which is important since they are inspiring people and taking them along for the ride.

Sharing media in tweets definitively increases the popularity of the accounts in terms of favorites and retweets. Between the accounts sharing less than 30% media and the accounts sharing more than 60%, the tweets are approximately 5 times more retweeted and favored. The linear regression shows that the number retweets and the favorites followed the same linear relationship with the exponential of the percentage of tweets with media. Our hypothesis is thus verified. Many accounts sharing media in tweets are the accounts whose astronauts have recently flown, which could explain why they are massively retweeted. However, we observe that some accounts sharing an important amount of media, whose astronauts did not fly yet or have flown a long time ago, are still retweeted and favored. Despite the "flight effect," sharing media is thus an efficient way to inspire people and to have a broader impact on the Twitter public.

Finally, taking into account the three different metrics (number of followers, number of favorites, and number of retweets), we selected the top 10 astronaut accounts presenting the best practice. We then defined a last metric taking into account these three parameters. The number of followers indicates the size of its audience and its potential reach, the retweet metric indicates the reach of the account and the ability to generate content with pass-along value, and the favorites indicate the personal impact that tweets can have on users. *Table 2* shows these 4 different top 10 lists. We notice that four astronaut accounts, JAXA astronauts Koichi Wakata and Soichi Noguchi, NASA astronaut Reid Wiseman, and CSA astronaut Chris Hadfield, are well ranked in the 3 different scales, and so we can qualify them as the astronauts with best practices in terms of profiles on Twitter.

Network Analysis

At first glance, the following and reply–retweet interaction graphs show different results: while the following interactions are linking a lot of people in the network, we observe that the retweet–reply interactions link many less accounts together. We observe that the following interaction graph is difficult to interpret using the static version and is particularly useful to use in the interactive version in order to visualize which interactions are missing, or the tendency of the direction of the interactions. For example, *Figure 10a* shows that the ESA official account follows a majority of the accounts of the network. We can also observe the accounts following ESA that are not followed by ESA: for example, ISS Research account is one of them. However, some trends can be observed on the reply–retweet interaction chord diagram.

First of all, some accounts have a lot of interactions linking them: NASA, NASA Astronauts, astronaut Reid Wiseman (Astro_Reid), astronaut Alexander Gerst (Astro_Alex), and astronaut Akihiko Hoshide (Aki_Hoshide). We can also observe a group of interactions linking the JAXA accounts with the NASA official account and the NASA_Astronaut account. The NASA official account is retweeted more often than it retweets and receives more replies than it makes, except for astronauts Reid Wiseman and Alexander Gerst, ISS Research, and ESA official account. These accounts are typically content generators because they are closely linked to the current crew on the ISS. The NASA Astronauts account has nearly equal incoming and outgoing retweets and replies. Astronauts Reid Wiseman and Alexander Gerst are massively retweeted and

Table 2. Top Ten of the Astronaut Twitter Accounts According to Four Different Scales: Number of Followers, Number of Retweets, Number of Favorites, and Total

Ranking	Number of Followers	Number of Retweets	Number of Favorites	Total
1	Mike Massimino	Koichi Wakata	Reid Wiseman	Koichi Wakata
2	Chris Hadfield	Reid Wiseman	Koichi Wakata	Reid Wiseman
3	Soichi Noguchi	Soichi Noguchi	ESA Alexander Gerst	Chris Hadfield
4	ESA André Kuipers	Satoshi Furukawa	Rick Mastracchio	Soichi Noguchi
5	Nicole Stott	Chris Hadfield	Karen Nyberg	Mike Massimino
6	ESA Luca Parmitano	Rick Mastracchio	Mike Hopkins	Rick Mastracchio
7	Koichi Wakata	ESA Alexander Gerst	Chris Hadfield	ESA Alexander Gerst
8	Douglas Wheelock	Karen Nyberg	Thomas Marshburn	Karen Nyberg
9	Reid Wiseman	Akihiko Hoshide	Soichi Noguchi	ESA André Kuipers
10	Ron Garan	Mike Hopkins	Kimiya Yui	Satoshi Furukawa

replied to, while the only person who they retweet or reply to is each other (Alexander Gerst retweeting and replying to Reid Wiseman and vice versa). Finally, astronaut Akihiko Hoshide retweets and replies more than he is retweeted or replied to.

The agency interactions show interesting trends. First of all, the two metrics show different results. While NASA and ESA accounts are involved in more than 80% of the following interactions, they are only involved approximately 60% of the reply–retweet interactions. JAXA, CSA, and ESA accounts are equally involved in the reply–retweet interactions (approximately 14%), while NASA holds 50% of the interactions. NASA accounts are, in general, responsible for approximately 50% of the following interaction flux in the other agencies, while 72% of the interactions involving NASA accounts are linking two NASA accounts. The other agencies' following interactions are linking two of their own accounts 20% of the time, on average. In addition, ESA accounts follow other agencies' accounts more than other agencies' accounts follow ESA accounts, while Roscosmos and JAXA show the opposite trend. However, these relationships are different for the reply–retweet metric: Roscosmos, CSA, and JAXA accounts send more replies and retweets than they receive, while NASA and ESA receive more than they send toward other agencies' accounts. Seventy-eight percent of the time NASA speaks to itself (one NASA account speaking to another NASA account), while it is 66% of the time for ESA, 34% for CSA, 21% for Roscosmos, and 13% for JAXA. Sixty-two percent of the retweet–reply interactions involving JAXA are directed to NASA. The interactive graph is very useful for the understanding of these interactions, and this article could only present the static version.

Nationality of the Followers

Astronauts and space agencies tend to be followed in majority by Twitter users from their own country (for ESA official account or ESA astronaut Alexander Gerst, the total ESA member nations is taken into account). Only CSA account is more followed by American Twitter users than Canadian ones. However, the percentages indicate that the followers are well distributed within different countries with a significant amount of followers from different countries. In general, American people are the Twitter users following the most other accounts related to human spaceflight, followed by people from the United Kingdom, which is in accordance to the Twitter demographics. In addition, the Netherlands and Greece are particularly active at following Twitter accounts related to human spaceflight. Surprisingly, Iraqi Twitter users represent one of the largest follower community for Roscosmos account and Turkish Twitter users following both NASA astronaut Reid Wiseman and JAXA astronaut Koichi Wakata. Followers from ESA member nations follow massively NASA and ESA accounts, which is less true for the Roscosmos, JAXA, and CSA accounts. This analysis shows that the public following Twitter account is very diverse and do not only represent citizens from the space agency or astronaut's country. Finally, deeper

analyses need to be done, using the nationality of the followers from all the astronauts' accounts. Particular attention is paid on ESA astronaut and the distribution of their followers over the European countries. More results of this study is available on the website in an interactive fashion.

CONCLUSIONS

This study aims at giving a good understanding of the human spaceflight environment on Twitter, quantifying the trends in the network and presenting the good practices of the existing accounts. Only the 5 space agencies studied (NASA, ESA, CSA, JAXA, and Roscosmos) seem to be active on Twitter, with NASA being highly represented with more than 60% of the accounts. The candidate astronauts of the different agencies seem to be aware of the importance of communicating and inspiring people on Twitter. Using Twitter actively to share personal experiences and information or to interact with the public is now a widely spread practice in the human spaceflight world. While only a few accounts have more than 1 million followers, some accounts show good practices in terms of following their followers back and being involved with their audience, such as ESA astronaut Samantha Cristoforetti, who flew to the ISS in November 2014, or NASA astronaut Leland Melvin. Being close to one's audience helps broadcasting the astronaut prestige and promoting the space exploration endeavor.

It is also a powerful way to inspire the young generation to undertake STEM studies. The content study has verified the hypothesis stating that sharing videos or pictures fosters the spread of the tweets and increases both the audience size and people's interest. It has also shown the "flight effect" to be particularly visible during the summer of 2014 with astronauts Reid Wiseman and Alexander Gerst onboard of the ISS, who intensively shared media from the station about Earth views (typhoons, northern lights, *etc.*), World events (World Cup game United States–Germany), or daily life in the ISS. The best practice analysis highlights 4 astronaut accounts reaching and interacting a broad audience: Koichi Wakata, Reid Wiseman, Chris Hadfield, and Soichi Noguchi.

The network analysis showed how these accounts were linked to each other. The network can be qualified as a mix between a unified network and an In-Hub & Spoke network, according to the last Pew Research Center report,[39] classifying the 6 types of Twitter networks. The unified network captures close communities where participants strongly connect to one another for information, ideas, and opinions, while the In-Hub & Spoke network is a more star-shaped network where loyal followers retweet the main accounts, at the center of the star. Finally, the followers' nationality analysis gives a good understanding of which nations are very active on Twitter and who is the audience of the astronauts. Citizens from countries like the United Kingdom, the Netherlands, or Greece, participating in ESA budget of, respectively, 7%, 1.9%, and 0.4%, in 2013,[3] are among of the largest follower communities of the human spaceflight accounts. This excitement about human spaceflight should be an incentive for governments to be more involved in an ambitious space exploration program. Twitter accounts are able to reach a diverse public in terms of nationality as the percentage showed. Twitter users from the United States and the United Kingdom are among of the largest followers minority following the different accounts.

This study gives a first insight of the human spaceflight Twitter accounts. However, some limitations are inherent to the study. First of all, Twitter is only one example of social media, and, despite its popularity, communication campaigns need to cover numerous existing social media to reach different types of people, or to promote human space exploration in different ways. The tweet content analysis was time restricted and only took into account the most tweets. Finally, the number of identified followers' nationalities was also limited.

Further studies need to be performed on different social media, with extended data collection in terms of time. A study aiming at more intensively characterizing the demographics of the influencers and their relative influence would be very useful to improve the public impact of communication campaigns on social media.

Communicating on social media is a promising way to inform, interact, and inspire people and society, and thus seems to be very appropriate to take the public along for the ride of human space exploration. The Web 2.0 is a formidable tool to move advocates, ambassadors, and collaborators and can be the place to start building an international collaboration to develop an ambitious space exploration program.

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AUTHOR DISCLOSURE STATEMENT

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Address correspondence to:
Pierre J. Bertrand
Man-Vehicle Laboratory
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology
13 Haviland Street, Apt 7
Cambridge, MA 02115

E-mail: pjbertra@mit.edu

(*Appendix follows*→)

Appendix A: List of the Twitter Accounts Studied

Twitter Name	Name
NASA	NASA
NASA_Astronauts	NASA Astronauts
NASAPeople	NASA People
AstroClass2013	2013 Astronaut Class
SciAstro	John Grunsfeld
Astro_Flow	Leland Melvin
Astro_Cady	Cady Coleman
Astro_Ferg	Christopher Ferguson
Astro_Clay	Clayton C. Anderson
AstroCoastie	Dan Burbank
astro_Pettit	Don Pettit
AstroDot	Dorothy Lindenburger
Astro_Wheels	Douglas H. Wheelock
Astro_Doug	Col. Doug Hurley
Astro_Taz	Gregory E. Chamitoff
Astro_Box	Gregory H. Johnson
Astro2fish	Jack Fischer
Astro_Jeff	Jeff Williams
AstroAcaba	Joseph M. Acaba
AstroKarenN	Karen L. Nyberg
Astro_Kate7	Kate Rubins
astro_kjell	Kjell Lindgren
Astro_127	Mark Polansky
AstroIronMike	Col. Mike Fincke
foreman_mike	Capt. Mike Foreman
astro_aggie	Mike Fossum
AstroIllini	Mike Hopkins
Astro_Mike	Mike Massimino
Astro_Nicholas	Nicholas Patrick
Astro_Nicole	Nicole Stott
astro_reid	Reid Wiseman
Astro_Rex	Rex J. Walheim

(*continued*)

Appendix A. (Continued)

Twitter Name	Name
AstroRM	Rick Mastracchio
Astro_Ron	Ron Garan
Astro_Sandy	Sandy Magnus
AstroSerena	Serena Aunon
StationCDRKelly	Scott Kelly
Astro_Maker	Scott D. Tingle
Astro_Suni	Sunita Williams
AstroTerry	Terry W. Virts
astro_tim	Col. Tim Kopra
AstroMarshburn	Thomas H. Marshburn
Astro_TJ	T.J. Creamer
Chief_Astronaut	Bob Behnken
Commercial_Crew	NASA Commercial Crew
DESERT_RATS	NASA Desert RATS
HMP	HaughtonMars Project
ISS_Research	ISS Research
NASAMightyEagle	Mighty Eagle
NASA_NEEMO	NASA NEEMO
NASA_Orion	Orion Spacecraft
PavilionLake	Pavilion Lake
MorpheusLander	Morpheus Lander
AstroRobonaut	Robonaut
NASA_SLS	NASA SLS
Astro_Satoshi	Satoshi Furukawa
Astro_Wakata	Koichi Wakata
Astro_Soichi	Soichi Noguchi
Astro_Kimiya	Kimiya Yui
JAXA_en	JAXA Web
Aki_Hoshide	Akihiko Hoshide
fka_roscosmos	Roscosmos
Spacetihon	Nikolay Tikhonov
OlegMKS	Oleg Artemyev

(*continued*)

Appendix A. (Continued)

Twitter Name	Name
Msuraev	Maksim Suraev
AntonAstrey	Anton Shkaplerov
astro_Jfrancois	Jean-Francois Clervoy
astro_timpeake	Tim Peake
Thom_astro	Thomas Pesquet
Astro_Alex	Alexander Gerst
AstroSamantha	Sam Cristoforetti
astro_luca	Luca Parmitano
astro_andre	André Kuipers
astro_paolo	Paolo Nespoli
Astro_Andreas	Andreas Mogensen
CFuglesang	Christer Fuglesang
ESA_EAC	ESA Astronaut Centre
Esa	ESA
esaoperations	ESA Operations
csa_asc	CanadianSpaceAgency
asc_csa	Agence spatiale can.
Astro_Jeremy	Jeremy Hansen
Astro_DavidS	David Saint-Jacques
AstroDaveMD	Dave Williams
Cmdr_Hadfield	Chris Hadfield
RobertaBondar	Roberta Bondar
RobertThirsk	Robert Thirsk
AstroGarneau	Marc Garneau