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Sharing and re-using open data: A case study of motivations in astrophysics

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ABSTRACT

Open data sharing and re-use is currently more common in some academic disciplines than others. Although each discipline has unique challenges and characteristics which can influence data sharing and re-use behavior, it may be possible to gain transferable insight from disciplines where these practices are more common. Several studies of the motivations underlying data sharing and re-use have been conducted, however these studies often remain at a high level of abstraction rather than providing in-depth insight about discipline-specific challenges and opportunities. This study sought to provide in-depth insight about the complex interaction of factors influencing motivations for sharing and re-using open research data within a single discipline, namely astrophysics. We focused on this discipline due to its well-developed tradition of free and open access to research data. Eight factors were found to influence researchers' motivations for sharing data openly, including the researcher's background, personal drivers, experience, legislation, regulation and policy, data characteristics, performance expectancy, usability, and collaboration. We identified six factors that influence researchers' motivations to re-use open research data, including the researcher's background, facilitating conditions, expected performance, social and affiliation factors, effort and experience. Finally, we discuss how data sharing and re-use can be encouraged within the context of astrophysics research, and we discuss how these insights may be transferred to disciplines with low rates of data sharing and re-use.

1. Introduction

The widespread availability of open research data offers many novel research opportunities, including; analysing large volumes of data, testing novel hypotheses, research replication and avoiding duplication of effort (Campbell, 2015; Rouder, 2016; Von St. Vieth, Rybicki, & Brzezniak, 2017). The combination of data from multiple sources and disciplines enables generation of new datasets, information and knowledge (Jaeger & Bertot, 2010; Krotoski, 2012; Uhlir & Schröder, 2007; Zuiderwijk, 2018). Further, the availability of open data facilitates innovation, and offers opportunities "to governments, business and entrepreneurs to harness the power of data for economic, social and scientific gains" (Sadiq & Indulska, 2017, p. 150).

Academic researchers can have diverse motivations to share their data, and to re-use research data already available. Researchers may be motivated to share data if this results in greater visibility of their work and increased citations (Patel, 2016; Piwowar & Vision, 2013; Piwowar, Day, & Fridsma, 2007; Viseur, 2015). Conversely, they may be demotivated from fear of not receiving appropriate credit (Molloy, 2011), losing publishing opportunities (Ceci, 1988; Mooney & Newton, 2012; Savage & Vickers, 2009), encountering technical issues (Arzberger et al., 2004), or finding the effort required is too great (Childs, McLeod, Lomas, & Cook, 2014).

Similarly, the motivations for re-using open data are also diverse, for example, researchers may be motivated to re-use open data as it enables the generation of novel data combinations (Yu & Robinson, 2012; Zuiderwijk, 2015). If the data is findable, accessible, interoperable and reusable, meeting the FAIR data principles (Force11, 2016; Wilkinson et al., 2016), the motivation to re-use open data is expected to be even greater (Luyben, 2018). However, researchers may also be hindered in open data re-use because of skill-gaps (Zuiderwijk, 2015).

The prevalence of data sharing and re-use differs between disciplines (Curty, Crowston, Specht, Grant, & Dalton, 2017; Fecher, Friesike, & Hebing, 2015; Jarolímková, Drobíková, & Souček, 2018). For example, atmospheric science and oceanography have well-developed traditions of open access, while disciplines such as wildlife ecology, medicine and many of the social sciences do not (Nelson, 2009; Tenopir et al., 2011). Although the unique challenges and characteristics of each discipline need to be carefully considered (for instance, some disciplines examine large volumes of highly-sensitive data) disciplines with low sharing rates may learn from disciplines where sharing is common (Piwowar, 2011).

Prior research has already provided some insight about the factors underlying the motivation to share and re-use data in some disciplines, including genomics (Piwowar & Vision, 2013), genetics and life sciences (E. G. Campbell & Bendavid, 2002), global change ecology

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(Wolkovich, Regetz, & Oöconnor, 2012) and neuroimaging (Poldrack & Gorgolewski, 2014). However, few studies to date have examined the challenges and opportunities within a single research discipline in-depth. In this study, we aimed to provide in-depth insight about the complex interaction of factors influencing motivations for sharing and re-using open research data within the single discipline of astrophysics. We identified the following research questions.

1 What discipline-specific characteristics influence researchers' motivations for sharing and re-using open research data in astrophysics?
2 What factors influence researcher's motivations to openly share their data in astrophysics?
3 What factors influence researcher's motivations to re-use open research data shared by others in astrophysics?
4 How can researchers in disciplines with low rates of open data sharing and re-use be encouraged to share and re-use more?

These research questions are addressed through a case study consisting of nine in-depth interviews with astrophysics researchers and through observations of researchers in this discipline.

2. Research background: motivation theories

We define open research data as structured, machine-readable, quantitative data, that is actively published on the internet for public re-use, and that is freely accessible, usable, modifiable, and sharable by academic researchers, in line with pre-existing definitions (Geiger & von Lucke, 2012; Open Knowledge Foundation, 2015; Research Council UK, 2016; Zuiderwijk, 2015). Open research data can be raw/primary, derived from primary data for subsequent analysis or interpretation, or derived from existing sources held by others (Research Council UK, 2016). Qualitative research data is outside the scope of this study.

Many diverse concepts, constructs and theories exist to explain motivation (Keller, 2009), making studying this topic challenging. Moreover, factors influencing a person's motivations, including environmental, cultural and personal factors, interact with each other (idem). It is commonly agreed that the study of motivation "attempts to explain the deeply held concern among people as to why we do the things we do" (Keller, 2009, p. 3). As stated by Deci (1975), motivations are a primary impetus for people to engage in certain behavior. Motivations can be both intrinsic (e.g. fun) (Ryan & Deci, 2000) and extrinsic (e.g. reward) (idem). Another distinction often made is that between hedonic motivations (e.g. social interaction and emotions) and utilitarian motivations (e.g. convenience) (Batra & Ahtola, 1991; Hirschman & Holbrook, 1982; Holbrook & Hirschman, 1982).

The role of motivations in human decision-making has been studied for many years, and from many perspectives. For example, motivation has been studied in the area of Information Systems usage behaviour (Nkwe & Cohen, 2017) and knowledge sharing behaviour (Gagne, 2009; Sayogo & Pardo, 2012). Keller (2009) categorized motivational theories as studies of genetics, psychological processes of arousal and regulation; behavioral approaches (e.g. positive reinforcement, classical conditioning, incentive motivation); cognitive theories, including expectancy-value theories, social-motivation, attribution theories and competence theories; and studies of emotion and affect (Keller, 2009). Here, we focus on the second category mentioned by Keller (2009), namely: behavioural psychology. This assumes that an adequate theory of human behaviour can be developed by examining the reaction of people to environmental stimuli (idem). Zuiderwijk and Shinde (unpublished) provide a comprehensive overview of behavioural motivation theories that may be relevant in the area of open data research. These include, for example, Innovation Diffusion Theory (Rogers, 1962), Equity Theory (Adams, 1963; Walster, Berscheid, & Walster, 1973), Reinforcement Theory (Ferster & Skinner, 1957; Skinner, 2014), Expectancy Theory (Vroom, 1964), the Incentive theory of Motivation (Bernstein & Nash, 2008), the Hedonic-Motivation System Adoption Model (Lowry, Gaskin, Twyman, Hammer, & Roberts, 2013), the Multi-Motive Information Systems Continuance model (Lowry, Gaskin, & Moody, 2015) and Keller's ARCS Motivational Model (Keller, 1983, 2009).

For example, in the Hedonic-Motivation System Adoption Model (Lowry et al., 2013), perceived ease of use positively influences perceived usefulness, curiosity, joy and control. Then perceived usefulness, curiosity and joy positively influence the behavioral intention to use systems, and curiosity, joy and control positively influence immersion in using these systems. This model goes beyond extrinsic motivations (Lowry et al., 2013) and stresses the importance of more process-oriented intrinsic motivations. Motivations such as perceived usefulness, joy and curiosity (personal drivers and expected performance) may motivate researchers to share their research data or not. For example, a researcher may be motivated to share research data because he or she enjoys doing so, or may re-use open research data out of curiosity or because the data can be used to test new hypotheses.

Another example of a motivation theory that is relevant in the context of research into data sharing and re-use is the Multi-Motive Information Systems Continuance model (Lowry et al., 2015). This model explains how fulfilling intrinsic and extrinsic motivations affects systems-use outcome variables in different ways through met expectations (idem). The expectations and disconfirmation of three major types of user motives are included in this model, namely those of hedonic (via joy), intrinsic (via learning), and extrinsic (via productivity) motives. Lowry et al. (2015) found that beliefs about the performance of systems are differently affected, depending on user motives and expectations and system intent. This model is relevant in the area of open data research because factors of this model, such as ease of use (effort), the extent of collaboration and support, and successful experiences, may motivate researchers to share and re-use research data, as shown in the open data literature (Zuiderwijk, 2019; Zuiderwijk & Shinde, unpublished) .

A third example of a motivation theory relevant in the context of this study is Keller's Macro Model of Motivation and Performance (Keller, 1983, 2009). This model distinguishes four major motivation aspects: interest (e.g. curiosity), relevance (e.g. satisfying personal needs), expectancy (e.g. the likelihood of success) and satisfaction (intrinsic motivations and reactions to extrinsic rewards) (idem), that may also influence motivations of researchers for opening up and using research data (see for example Zuiderwijk, 2019; Zuiderwijk & Shinde, unpublished).

These three theories illustrate how various factors can influence the motivations underlying human behavior. Each of these theories postulate that motivation is typically influenced by the complex interaction of multiple factors, both intrinsic and extrinsic, rather than by a single factor. In this study we use the various concepts from these motivational models and theories to create a conceptual model appropriate for the analysis of our interviews.

3. Conceptual model applied in this study

The conceptual model used here was developed in prior research exploring which factors drive academic researchers to share and re-use open research data or not (Zuiderwijk, 2019; Zuiderwijk & Shinde, unpublished). This model was developed through a systematic review of the open data literature (information science and information systems) and behavioral motivation (psychology) literature. This review identified 52 factors that influence motivations for *openly sharing* research data or not, and 48 factors that influence motivations for *re-using* open research data or not (see Appendix A). These factors were designated to 12 categories which related both to the provision and use of research data, as detailed in Fig. 1.

4. Case study approach

In this study, we apply a qualitative research methodology – the case study – which we define as "an empirical inquiry that investigates

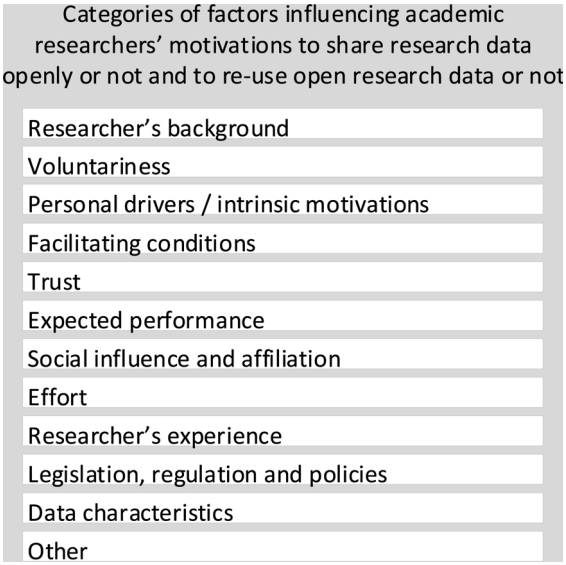

Fig. 1. Conceptual model of factors influencing academic researchers' motivations to share and re-use open research data or not (derived from Zuiderwijk, 2019; Zuiderwijk & Shinde, unpublished).

a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (Yin, 2009, p. 13). Case studies are useful for investigating various broad and complex real-life contemporary events which require a holistic and in-depth examination (Dubé & Paré, 2003; Yin, 2009). Case study research is particularly appropriate for problems in which experiences of actors and the context of action play an essential role (Benbasat, Goldstein, & Mead, 1987; Bonoma, 1983).

Utilizing a case study approach here is essential for the identification of researchers' motivation perspectives, since the motivations of individual researchers to openly share and re-use research data are strongly influenced by contextual factors (Sayogo & Pardo, 2012). Examples of contextual factors influencing researchers' motivations for opening up and using research data or not may be the support for openly sharing and re-using research data given by university libraries (e.g. data stewards who advise on whether to openly share certain data), university policies and guidelines (e.g. university regulations on openly sharing research data), and the degree to which researchers' supervisors and colleagues encourage them to share and re-use open research data. For these reasons, researchers' motivations cannot be isolated from their institutional context, which is why case studies are an appropriate method to obtain insight in motivations for open data sharing and re-use.

4.1. Case study selection

Clearly describing the case study selection procedure helps to determine the limits for generalising the research findings (Eisenhardt, 1989). Cases can be selected either using statistical sampling or theoretical sampling (idem). Statistical sampling refers to the selection of cases based on the objective to obtain accurate statistical knowledge of the distribution of variables within a particular population. Theoretical sampling refers to selecting cases because of the aim to replicate previous cases, extend emergent theory, fill theoretical categories, or provide examples (idem). Since this research aims to contribute to theory building and filling theoretical categories in the field of open research data rather than to test the distribution or frequency of variables in this field, we selected a case using theoretical sampling.

A single case study approach is used since we were examining the unique circumstances in which research data is already extensively shared openly and re-used. Our first criterion for selecting the case was that it involves the collection and/or creation of quantitative, machine-readable and structured research data. We focus on this specific type of research data since it has much potential for creating benefits. Openly sharing and re-using other types of data, such as qualitative and unstructured data has other issues, such as difficulties with data processing in an automated way, and it may be more sensitive to privacy violation. The second criterion was that the case involves both the openly sharing and re-using research data. This criterion is critical to be able to investigate motivations for sharing and re-using open research data. Third, the case should allow for investigating factors influencing motivations for sharing research data openly and open data re-use for a discipline in which data sharing and re-use is already a common practice, so that we can compare the practices of a discipline in which data sharing and re-use is common to those in which it is not.

Based on these criteria, we selected a case study of open research data in astrophysics. This discipline has been selected because of its apparent advancement in open research data sharing and re-use (Accomazzi, 2011; Henneken, 2015; Pepe, Goodman, Muench, Crosas, & Erdmann, 2014). Since open research data sharing and re-use is already on-going in the astrophysics discipline, a case study in this discipline allows for investigating factors influencing motivations for openly sharing and re-using research data. The astrophysics case also allows for investigating motivations for *not* sharing and re-using research data, since, as in many research disciplines, various factors may play a role in motivating researchers to not share and re-use open research data.

4.2. Case study information sources

The case study was conducted at the Physics department of the University of Oxford. The main information source of the case study was from interviews and observations, complemented with an examination of data platforms that the interviewees referred to and documentation about the case that was available online (e.g. the department website and websites of projects that the interviewees worked on). We created the interview questions based on the conceptual model detailed in Section 3. Questions were asked about motivations for each of the twelve categories depicted in Fig. 1, both concerning open research data sharing and re-use (see Appendix B for the interview questions). Nine researchers with varying positions, age and experience were interviewed, since previous research shows that these factors

Table 1
Overview of interviewees (where 'I' refers to the interviewee number).

	Interviewee position	Interviewee age category	Experience in astrophysics (years)	Shared data openly?	Re-used open data?
I1	Full professor	46–50	24	Yes	Yes
I2	Full professor	36–40	14	Yes	Yes
I3	Full professor	66–70	27	No	Yes
I4	Postdoctoral researcher	31–35	8	Yes	Yes
I5	Postdoctoral researcher	31–35	5	Yes	Yes
I6	Postdoctoral researcher	26–30	1	Yes	Yes
I7	Postdoctoral researcher	26–30	5	Yes	Yes
I8	Postdoctoral researcher	31–35	9	Yes	Yes
I9	PhD student	20–25	2	No	Yes

might influence sharing and re-using open research data (Jarolímková et al., 2018). Most interviewees were British, and some held Israeli, Italian, American and Swedish nationalities. Table 1 provides an overview of the interviewees. The interviews were conducted from November 20 until November 24, 2017. The interview length varied from 39 to 65 minutes.

Seven out of nine interviewees had already shared research data openly themselves by putting data on their own web page, by archiving data in their institutional repository, by publishing codes on Github and by publishing data in repositories related to specific journals or astronomical topics. The shared data concerned, among others, data about telescopic observations, codes, simulations and surveys. All interviewees had re-used open research data, including those from statistical tests, astronomical measures, the outcome of simulations, galaxy data from Hubble, data from the SLOAN Digital Sky Survey, code produced by other researchers, data about classified galaxy images, spectra, radio images and data about properties of materials. This data was mainly derived from public archives, but other sources had been used as well (e.g. Github).

4.3. Interview transcript analysis

With permission of the interviewees, all interviews were recorded, and these recordings were transcribed. The interviewees were offered the possibility to check the transcripts. This did not result in any changes to the transcripts. The checked transcripts were imported into the ATLAS.ti software, which is commonly used for qualitative data analysis based on document analysis (Alasseri, Joji Rao, & Sreekanth, 2018), and particularly for interviews and focus groups (Stafford, Houghton, & Stull, 2009). ATLAS.TI allows systematic analysis of qualitative data and of the relevant data derived from this analysis (Stafford et al., 2009). ATLAS.TI software was used for open, axial, and selective coding. The following three steps for theory-driven coding were taken, as recommended by DeCuir-Gunby, Marshall, and Mcculloch (2011):

Creating codes using open coding. Open coding took place after reading each interview transcript. We followed procedures recommended by Lindlof and Taylor (2002): the transcripts were analyzed line by line, relevant chunks of text were marked and categorized, categories were built and named and attributes were assigned to each category. We created a codebook (following guidelines by Macqueen, McLellan-Lemal, Kay, and Milstein (1998) and DeCuir-Gunby et al. (2011)), which included a comprehensive list of all codes, properties of each code, and phrases (i.e. representative quotations) (see Lindlof & Taylor, 2002). Information on motivations was coded and representative quotations were highlighted.

Reviewing and revising the codes in context using axial coding. Axial coding is a way of coding that "relates categories to subcategories, specifies the properties and dimensions of a category, and reassembles the data you have fractured during initial coding to give coherence to the emerging analysis" (Charmaz, 2006, p. 60; Corbin & Strauss, 1988). The relationships between the properties of the categories of motivations were extracted through this process. Moreover, several additional codes were added to the original list and some code labels were revised, based on the notes made during the first round of coding. The most important changes can be found in Appendix C.

Determining reliability using selective coding. Following guidelines from (Derville Gallicano, 2013, p. 223) the final step of our research included identifying the final core variables from the data, reading all the transcripts again and selectively recoding any data in the transcripts that pertained to the core variables. This third step resulted in the final codes (see Appendix D). Applying the final codes, several changes were made in the coding of each of the nine transcripts. This concerned mainly the application of the newly created and changed codes. A few times, new insights resulted in changing already assigned codes slightly. For example, effort-related motivations and facilitating conditions-related motivations are closely related. Many quotes fitted in both codes. The specification of these motivation categories after the first round of coding was applied in the second round of coding.

5. Case study background: characteristics of astrophysics influencing the sharing and re-use of open data

In this section we address our first research question – *what discipline-specific characteristics influence researchers' motivations for sharing and re-using open research data in astrophysics?*

5.1. Typical characteristics of astrophysics research influencing the motivation to share and re-use open research data

To contextualise the motivations for sharing research data openly and for re-using open research data in astrophysics, we first discuss the typical characteristics of astrophysics research. We identified six factors that motivate astrophysics researchers to openly share their research data and to re-use open research data, namely: the raw data is infrequently collected directly by the researchers, the limited resources encourages collaboration, exterior public data is shared automatically, the existence of a supportive data sharing culture, a lack of concerns about ethics and commercial potential of data and a positive experience with open data re-use (Table 2). We also identified two factors that demotivate astrophysics researchers to openly share and re-use open research data, namely the enormous volume of some datasets and the lack of facilitating conditions. We will explain these factors below.

The first typical characteristic of research in astrophysics is that the data is often not collected by the researchers. For example, interviewee 4 stated: *"I mainly use exterior data […] they all actually come from satellites. That means that I do not actually collect data myself. […] I just submit to the committee. What the committee does is they respond to calls for proposals and they ask for certain observations. A panel decides if those observations are going to be taken or not […] you basically just download the data from an archive. […] This is pre-processed data."* Moreover, in astronomy, "data collection tends to be well planned, well curated, highly visible, and collected by highly automated instrumentation." (Wallis, Rolando, & Borgman, 2013, p. 3). Researchers themselves need to write a proposal but they do not need to put considerable effort into the collection of raw data, as is common in other scientific disciplines

Table 2
Factors motivating the sharing and re-use of open research data in astrophysics.

Motivating factors	Demotivating factors
• Raw data is infrequently collected directly by the researchers • Limited resources encourages collaboration • Exterior public data is shared automatically • Supportive data sharing culture • Lack of concerns about ethics and commercial potential of data • Positive experience with open data re-use	• Enormous volume of some datasets • Lack of facilitating conditions

such as many sub-disciplines in social sciences. For example, in the disciplines of psychology and criminology researchers often create surveys or study records (e.g. of patients or offenders) to obtain research data. We hypothesize that researchers who have not collected the research data themselves feel less responsible for the data quality and feel less reluctant to open up the processed data. Furthermore, if researchers did not collect their data, and they have received it from an external repository, they may feel less ownership and entitlement over the data, and feel they have less of a right to be protective of something they were readily given.

Second, the limited amount of data available within astrophysics increases collaborations between researchers. Interviewee 5 puts it in this way: *"The discipline is such that astronomical resources are limited. So there is a limited number of telescopes and a limited amount of data. So if you want to do science then sometimes you have to use other people's data."* Interviewee 1, 6 and 8 provided similar responses. There is an enormous investment in resources in the fields of astronomy (I1[1]). The interviewees indicate that the small size of the field leads to the necessity of data sharing (I6). There is a shared feeling of 'we are all in this together', providing much incentive to share and re-use research data (I8).

Third, for government-collected data, researchers do not always have an influence on the decision to share their data or not. For instance, interviewee 9 stated that he used data from an ESA telescope. This data was exclusively accessible for him for a few years and then it became public by default. Interviewee 1 provides a similar experience and several interviewees assessed this as a good practice, since there is no debate about whether to open up the data or not. In the discipline of astrophysics, large quantitative datasets are being collected using for instance telescopes of National Aeronautics and Space Administration and the European Space Agency. These organizations have policies in place that often enforce data sharing after a certain period of time, which has resulted in much data already being accessible and usable. For example, the Astrophysics Data System provides a Digital Library portal for researchers in Astronomy and Physics, operated by the Smithsonian Astrophysical Observatory of Harvard University (http://adsabs.harvard.edu/). Other examples include the SIMBAD Astronomical Database of the Strasbourg astronomical Data Center (http://simbad.u-strasbg.fr/simbad/), VizieR of the Strasbourg Astronomical Observatory of the University of Strasbourg (http://vizier.u-strasbg.fr/) and the Virtual Observatory of the International Virtual Observatory Alliance (http://www.ivoa.net/). Because large amounts of data is already being shared, it is possible to examine why researchers share, rather than why they do not.

Fourth, many interviewees refer to the existence of a data sharing culture in astrophysics. For example, interviewee 2 states: "*In astronomy there is a strong culture sharing of data when possible. So if I compare to friends who are not astronomers we do a lot more of that. And so I think I clearly act within the norms of my discipline.*" The interviewees indicate that this data sharing culture is supported by journals and journal services in their discipline. Journals in astronomy have the presumption of openness. Several journals in this discipline have data scientists on staff whose job it is to help people share data. Interviewee 2 states: *I think the journals in astronomy play a strong role in a way that they don't in other fields as far as I can tell. […] There is an infrastructure of services around that which then take data published to the journals and make them easily cross-accessible. […] That seems important.*" (I2).

Fifth, one of the interviewees made a comparison of obstacles for opening up research data in astronomy compared to other disciplines: "*In other disciplines I imagine the obstacles are about concerns about sort of ethics of sharing information or about the commercial potential of data. I don't think we have any of those problems. I think the barriers are more towards effective sharing of data: sharing data in a way that it is actually usable to a different researcher*" (I2). Furthermore, astrophysics does not so much involve the collection of personal data, and as a result there are usually no privacy issues in opening up research data.

Finally, the interviewed astrophysics researchers all had positive experience with open data use and stated that this motivated them to use open data more. This finding is commensurable with previous research into the experience with data sharing and use, since Dai et al. (2018) and Wolkovich et al. (2012) also found that authors are most likely to share data if they have prior experience sharing or reusing data.

A factor that demotivates astrophysics researchers to openly share and re-use open research data concerns the enormous volume of some datasets. The interviews showed that many datasets in astrophysics are big and they cannot easily be stored and downloaded. This confirms research by de Almeida et al. (2017) who state that "astrophysics is becoming increasingly dominated by "big data" (p. 90). Thus, data characteristics (particularly their volume) contribute to the motivations to open up and use research data or not. Several interviewees stated that some datasets are too large to download or that it takes a long time to download them - some datasets are terabytes or petabytes in size (I1). A second factor demotivating open data sharing and re-use in astrophysics was the lack of facilitating condition. We found that sharing data in a way that it is useful for other researchers can be difficult. One interviewee states explicitly that the lack of useful metadata and tools to understand the meaning of the data are important obstacles particularly for astrophysics and he states that in other disciplines ethical aspects are more of an obstacle than facilitating conditions (I2).

5.2. Benefits and barriers to sharing and re-using open data in astrophysics

In this section we describe the benefits of and barriers for sharing and re-using open research data in astrophysics identified through our case study (Table 3). From the perspective of our interviewees, the main benefits of sharing research data openly in astrophysics relate to effort, expected performance and personal drivers and the mentioned benefits of re-using open research data all relate to expected performance. The table also shows that we found more barriers than benefits. The opinions about the benefits were relatively consistent, whereas the views on barriers were more divided. Barriers for sharing research data openly related to the expected performance, social influence, facilitating conditions, experience, data characteristics and personal drivers. Barriers for open research data re-use were found in the categories of data characteristics, facilitating conditions and effort. The above-mentioned benefits and barriers for sharing and re-using open research data concerned the discipline of astrophysics in general. After asking for these general benefits and barriers for their discipline, interviewees were asked for their individual specific motivations, as we will describe in the next section.

6. Case study analysis: individual researcher motivations

6.1. Motivations of researchers driving them to openly sharing their research data or not

In this section we answer the second research question, namely: w*hat factors influence researcher's motivations to openly share their data in astrophysics?* We found eight factors that have an influence on the interviewed researchers' motivations to openly share research data or not, including: the researchers' background, personal drivers, experience, legislation, regulation and policy, data characteristics, performance expectancy, usability and collaboration (see Table 4). In the conceptual model that we used to create the interview questions, we did not have *usability* and *collaboration* as a separate factor category, yet a few interviews showed the importance of these factor categories, so we added them. We also found one factor that was less of an issue for the

[1] We refer to the interviews with 'I', followed by the interview number, to indicate which and how many interviewees provided certain information.

Table 3
Overview of benefits of and barriers for opening up and re-using research data in astrophysics.

	Benefits	Barriers
Sharing research data openly	Effort: ● Preventing duplication of effort (I1, I5, I6, I8). There is an enormous investment in resources in the field of astronomy. The duplication of resources can be reduced re-using open data, so that less time and resources are wasted (I1, I5, I6). Moreover, one dataset may be reused by other researchers for other purposes than the original one (I1). Expected performance: ● Visibility: research work done gets more attention after it has been shared openly (I2, I7, I8, I9), noticed for example by an increased number of citations (I7, I9) and an increased profile (I9). Trust: ● Reproducibility of results and the fact that anyone can access the data (I4, I7). This allows other researchers to build upon your work. Furthermore it helps to have your research results cross-checked, so that the quality of research improves (I7). Personal drivers / intrinsic motivations: ● Better science (I2, I8). Open research data makes it possible to conduct new, innovative types of high quality research. Open astrophysics data helps to move the field forward more quickly and easily.	Expected performance, social influence / affiliation: ● Competition and the fear of being scooped (I4, I5, I6, I7). In the academic system publications are valued more than datasets: "*there is this bad kind of system in place where people have to publish or perish*" (I7). This may lead to lower quality research: "*sometimes it is more important to publish first and to publish more than to publish interesting and correct solid science […]. So they rush and that means that science can kind of decrease in quality*" (I4). Facilitating conditions: ● Lack of time, including lack of time to cleanse the data and to share it openly (I2, I3). ● Authorship issues and getting permission from all partners in large collaborations (I7). If researchers are working in a big collaboration, they need to talk to many parties to get permission to share the data openly (I9). Facilitating conditions and experience: ● Lack of facilitating platforms for data that is not created in the context of for instance large collaborations or in the context of ESA telescopes (I9): "*I have observations that I have taken of two other galaxies from a different telescope. If I did want to make this public, I'm not sure I would know where to put them*" (I9). Data characteristics: ● Limited data usability: "*sharing data in a way that it's actually usable to a different researcher, so both in terms of providing adequate metadata so you can quickly understand what's there and therefore whether you want to use it, but also providing tools that allow you to access the data, and which get beyond 'here is the raw output from the telescope'* (I2). ● The large volume and size of the datasets (I4). Datasets in astrophysics are large, resulting in increasing time it takes to load and store the data and additional machine space needed. Personal drivers / intrinsic motivations: ● The fear that others will find mistakes: "*some people don't feel completely comfortable having their research fully scrutinized. So they don't want to have people looking in detail to what they did. They just want their final nice presentable results. […]"* (I7).
Re-using open research data	Expected performance: ● Access to more data and obtaining new insights. Since many researchers are sharing research data openly, researchers have access to data that they would otherwise not have and they can test new ideas (I1, I2, I5, I9) and obtain new insights (I9). Access to open research data in astrophysics is not only essential (I2), it also makes it easier to start projects without having to write a proposal and collect data yourself (I9). One researcher stated explicitly that he is motivated to use open research data because he sees that more and more researchers openly share their data (I1). ● Being aware of the state of the art and not reinventing the wheel. Examining which open data is already available is also used as a way to ensure that researchers are not doing something similar as other researchers (I1, I3, I5, I6, I7). ● Feedback on the need for certain data and facilities. Sharing research data openly gives data providers insight in the extent of interest in the data by the community, for example: "*if a satellite is not used this is just a cost since it doesn't give anything back*" (I4).	Data characteristics: ● Lack of data standards, inconsistency between datasets and limited documentation (I2, I5, I7, I9). Some databases are very good on standardizations and documentation, but many are not. There are many differences between the way each archive describes the data and how the data can be analyzed and re-used. Facilitating conditions, effort: ● The large volume and size of the datasets and required skills to analyze them. Some of the datasets in astrophysics are very big (I1, I2). Data users need to spend much time to answer a simple question using the raw data, no software is available. Using large datasets also requires certain skills that researchers need to learn (I2). ● Difficulties with finding the data (I5, I6, I7). The interviewees stated that there are quite a lot of diffused repositories and that is takes much time to find what they are looking for. ● Too much time and effort required to re-use the data (I6, I8). For example, "*there can be analytical barriers, so you may not have looked at a particular dataset before and there can be quite a lack time in learning how to handle these datasets appropriately* (I6) and "*there is always going to be a learning curve in terms of using the data*" (I8). ● Low ease of use. "*The biggest problem I think is […] there are very few examples of data that is well-curated and easy to use"* (I2).

interviewed researchers, namely *trust*. For some categories of factors, the interviewed researchers disagreed whether they drive them to share their research data openly, namely: effort, facilitating conditions, voluntariness, performance and social and affiliation-related factors.

6.2. Motivations of astrophysics researchers driving them to re-use open research data or not

In the section below, we answer the third research question, namely: *what factors influence researcher's motivations to re-use open research data shared by others in astrophysics?* We found that the following six factors have an influence on the interviewed researchers' motivations to re-use research data or not: the researchers' background, facilitating conditions, expected performance, social and affiliation factors, effort and experience (Table 5). We also found five factors that were less of an issue for the interviewed researchers, namely voluntariness, personal drivers, collaboration, usability and legislation, regulation and policy. The categories *collaboration* and *usability* were added to the conceptual model that we initially used. For two categories of factors the interviewed researchers disagree whether they drive them to re-use research data or not, namely: trust and data characteristics.

6.3. Most important motivation categories

During the interviews we asked researchers to state the most important driver categories for sharing research data openly and for re-

Table 4
Overview of motivations for openly sharing research data in astrophysics or not.

Type of factors	Factor category	Factors driving researchers to openly share their research data or not
Influencing factors	The researchers' background (I2, I6, I7, I8, I9)	We found that culture, discipline and age influence motivations for sharing research data. In the discipline of astrophysics it is tradition and existing practice to share research data openly and this motivates some researchers to openly share their research data (I2, I6, I7, I8, I9). Researchers in this discipline often work in small groups that tend to share data more often than larger groups and it is a very collaborative field. The field of astrophysics is relatively small and collaboration in the form of data sharing is a requirement to move the field forward (I6). Yet not all data in this discipline that can be open is actually open (I7). As far as age is concerned, younger researchers tend to share more. The interviewees disagree about whether academic position has an influence on their motivations to share research data openly.
	Personal drivers (I1, I2, I3, I4, I5, I6, I7, I8)	Some researchers share their data openly because they strongly believe that "*science should be open*" (I4, I5). One particular reason for this is that much of the data collection has been funded by the state: "*people are paying for your research, so […] at least make your data available for other researchers. That should be kind of mandatory in my opinion if you are publicly funded*" (I7). Some interviewees explicitly state that sharing research data openly is an ethical or moral issue for them (I1, I4, I5, I6, I7). Interviewee 5 mentions that the frustration of not being able to access the data of other researchers motivates her to share her own data: "*I am really frustrated when other people do not do it. It is a motivation for me to do it.*"
	Experience (I2, I4, I7, I8)	Gaining experience with sharing data during training, for instance academic education, plays an important role (I7). It helps to know what to do and what not to do when sharing data openly (I4). Sharing data openly for the first time appears to be the main hurdle (I8). Experience also helps in not worrying about potential negative effects of sharing data (I2). Interviewee 9 states that having a bad experience may discourage him from sharing data openly, whereas interviewee 7 states that even if he would have a bad experience he would still be sharing his data.
	Legislation, regulation and policy (I2, I3, I4, I5, I6, I7, I8, I9)	Some interviewees state that regulation is definitely an issue in astronomy (I9). Some data being collected is personal data (I2, I6), such as IP-addresses and user names (I2) and thus this data cannot be shared openly. Regulations may come along from collaborations with external partners (I8). Three interviewed researchers state the regulation does not have any influence on their motivation to openly share research data at the moment (I3, I4, I5). Interviewee 7 states that if it would become mandatory to openly share data through legislation he would definitely share all his data (I7).
	Data characteristic (I2, I4, I5, I6, I8, I9)	There is less of an incentive to openly share very large datasets (I2, I4, I6). Another data-related factor demotivating researchers to openly share their data is that data needs to be explained in a particular format (I5). In addition, privacy of sensitive information influences researchers' willingness to share data (I2, I6). Researchers are also less inclined to publish low quality data or incomplete datasets (I5, I8, I9), since these datasets are less likely to be re-used and since this is bad for the reputation of the researcher sharing the data (I9). On the other hand interviewee 8 states that this usually sorts itself out since "*people in the community are very good at spotting what is good work and what is bad work*".
	Performance expectancy (I2)	Interviewee 2 refers to the strong influence of journals for sharing research data openly. The journals that this interviewee refers to have staffed data scientists who help authors with sharing their data related to a certain publication. The existing infrastructure definitely helps to share more data openly.
	Usability (I1, I2)	Whether the data is useful to people is an important factor in the decision to share data openly or not (I1), although some researchers have shared data openly without knowing how useful the data was to people who re-used the data (I2). If the data is not considered useful, sharing it openly up is considered a waste of time (I2).
	Collaboration (I1, I2, I4, I7)	Factors concerning collaboration include collaborations in projects with a shared openness desire (I1), collaborations in small groups (I2, I4, I7), collaboration through open data (I8), and new collaboration opportunities resulting from openly shared data (I2, I4).
Less influencing factor	Trust (I1, I2, I3, I4, I5, I6, I7, I8, I9)	Six out of nine interviewees state that trust does not play a role for them personally (I1, I2, I3, I4, I7, I9), but it may play a role for other researchers in their community (I5). Two interviewees (I6, I8) state that if there was misinterpretation of the data it would probably be captured before someone publishes a paper about it: "*usually if someone is sloppy enough that they are not using the data correctly other parts of their paper are going to be sloppy as well and people can easily spot that.*" (I8) Peer

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Table 4 (*continued*)

Type of factors	Factor category	Factors driving researchers to openly share their research data or not
		review of scientific papers helps to establish trust between researchers sharing and re-use open data.
Factors on which the interviewees' opinions were divided	Effort (I1, I2, I3, I4, I5, I6, I7, I8, I9)	Some of the astrophysics data becomes public after a certain period automatically (e.g. for Hubble space telescope data – I1, I2). This does not count for all the data in astrophysics. For some interviewees, effort appears to have a strong effect on the motivation to openly share such research data, mainly because of the time it takes to openly share data (I2, I3, I4) and because there are too many other things to do (I5). Sometimes the data needs to be explained in a different format than the original one (I5) and having help of someone to format the data would make it easier to share data (I4). The lack of a standard process to know how to share the data also makes opening up research data cost additional efforts (I2). At the same time, three interviewees stated that effort did not demotivate them to openly share research data that much (I1, I6, I8). For example, interviewee 1 stated that openly sharing data is not much work usually. Moreover, effort appears to be a factor that is very much weighed against other factors in the decision to openly share data or not: "*It is kind of balancing: time expended versus expected reward. […] So if I do not think this data is going to be used by many people then it has to be easy to share. If it was a main project in my PhD to […] make a new dataset that […] lots of researchers are going to use, then the effort really would be off because it was my main driving goal […].*" (I9) If certain rewards would be in place the efforts would play a smaller role (I7).
	Facilitating conditions (I1, I2, I3, I4, I6, I7, I8)	Many different facilitating conditions appear to influence researchers in their decision to open up research data or not. The interviewed researchers refer to: a system to share data files permanently (I7), clear and sufficient metadata (I2), servers to host large datasets (I1), a supporting infrastructure (I2, I6), also in five years from now (I1), data scientists offering (free) support (I2), e.g. with data formatting (I4), a platform in place (I4, I6, I7) and their own interface (I6). On the other hand, some interviewees state that facilitating conditions do not influence them that much (I6, I8) and/ or that they are all in place and therefore do not hinder them (I3, I6, I8).
	Voluntariness (I1, I2, I3, I4, I5, I6, I7, I8)	Sharing data openly is often voluntary in astrophysics, although data is usually shared anyway. Several interviewees mention that openly sharing data is natural in astrophysics and that there is no compulsion from funding bodies, research councils or the university they worked with (I1, I4, I5, I7, I8). The situation is different for two interviewees, who did mention there was a requirement to share the data for government-funded research they had carried out (I2, I6). One interviewee (I3) states that data cannot be released before patenting, because of university regulations.
	Social and affiliation factors (I1, I2, I3, I4, I5, I7, I9)	For most of the interviewed researchers, social and affiliation-related factors do not play a role at all (I4, I7) or they only play a role to some extent (I1, I3, I5). Two interviewees state that social and affiliation factors do play a role (I2, I9), because they are motivated by supervisors and colleagues (I9) or by their peers: *"certainly there is a tight-knit group of people in astronomy who think hard about open science and openness and I want to feel part of that group. […] Currently there is sort of a social law within that group. It would be embarrassing to have a dataset that was not properly open without a reason. But that is a very small subset of the field.*" (I2) Family and friends do not influence any of the interviewed researchers in their decision to share data openly.
	Expected performance (I1, I2, I3, I4, I6, I7, I8, I9)	Many interviewees referred to the fear of somebody else using their data to publish about it before they do, so their data would result in a career advantage for other researchers. This was the most important performance-related factor that demotivated interviewees to share their data openly. One interviewee also stated that there is a lack of credit and acknowledgement for sharing data, but that it does not keep him from sharing his data (I7). After the publication was out, most of interviewees believed that sharing research data openly would be beneficial for their performance and for their career as an academic. Benefits mentioned included increased citations (I1, I2, I4, I7, I8, I9), bigger profile (I9) and more visibility of the researcher (I8), increased credit and recognition (I1, I4), improved work since others can spot mistakes (I4), and making it easier to get papers published in good journals (I6, I7). On the other hand, some interviewees state that performance does not really play into their motivations for sharing research data openly (I3, I6).

Table 5
Overview of motivations for re-using open research data in astrophysics or not.

Type of factors	Factor category	Factors driving researchers to openly share their research data or not
Influencing factors	The researchers' background (I2, I6, I7, I8, I9)	Four interviewees mention that their discipline motivates them to re-use open research data (I2, I6, I8, I9), since people often produce complementary datasets (I6) and since there are big programs for open data in astronomy (I9). Gender and country appear not to play a role (I6, I7), yet some interviewees state that age does have an influence on the motivation to re-use open research data (I7, I9). Younger researchers appear not only to be more willing to re-use open data (I9), they also have better data processing and use skills: "*Some people are not as skilled as others in reading this data format. And particularly in the case of code I would say again the younger generation has an edge over the older generation.*" (I7) The lack of access to particular astrophysics data for researchers from certain countries was also mentioned.
	Facilitating conditions (I1, I2, I4, I5, I7, I9)	In the category of facilitating conditions, the following factors were stated as influencing the interviewees' motivations for re-using open research data: a supportive helpdesk (i.e. the support helpdesk of the Space Telescope Science Institute, I1), the availability of fast internet (I1, I2), running overnight (I1), a good user interface (I5), the availability of data products/software that can answer questions rather than a very large dataset with raw data only (I1), accessible and well-organized data (I9), good databases and user account access (I5), a good platform to find the data (I7), human assistance (I7) and a tutorial on the platform (I7). According to the interviewees, the archives used in astrophysics support users well in facilitating open data re-use. These archives have fast internet to support the download of large datasets. The space telescope archives have a pretty good helpdesk that gets back to researchers within a day if they have issues while re-using the data. Factors that demotivate researchers to re-use open research data are the lack of technical literacy (I2), the lack of a friendly interface (I4), the lack of a platform (I7) and particularly the lack of a platform where the publications and data are provided together and are linked (I7).
	Expected performance (I1, I2, I3, I4, I5, I6, I9)	The expectance that a researchers' performance improves plays an important role in the motivation to re-use open research data (I1, I9). Researchers want to work with relevant and cutting-edge data that is interesting to the community: "*there is always a desire or maybe a professional pressure to use the best data available […]. If we are interested in what the fundamental answers are in astrophysics were are to work with the cutting edge data.*" This can help setting up new projects or answer certain questions (I9). Instead of competing for telescope time, researchers can then re-use existing data (I2, I5). This gives more understanding which benefits the researchers' research (I3). Furthermore, the access to many interesting datasets and combinations of them can lead to the publication of an high-impact journal article that leads to many citations. Higher publication rates are very motivating (I4, I5, I6). It was stated that citations and publications are among the most important metrics in the evaluation of an astrophysics researcher's performance.
	Social and affiliation factors (I1, I5, I6, I7, I8, I9)	Social and affiliation-related factors do play a role mainly in terms of influence of the supervisor or colleagues (I5, I6, I8) or research groups (I7). Interviewee 6 also points at the positive influence of success stories. Family and friends barely motivate researchers to use open data (I1, I7, I9).
	Effort (I2, I3, I4, I5, I6, I7, I8, I9)	Some researchers state that effort has not been an issue for them personally (I5, I8). Effort can also be a demotivating factor in re-using open research data, but it depends on the amount of effort and the relevance of the data: "*it will be a kind of cost benefit of a particular analysis. If it was something that I did not have the skills immediately to do, if it was a high impact very interesting project, then I would make time to allow getting these skills. But if it was kind of trivial then I might use the effort elsewhere*" (I6). This is also stated by interviewee 9, who had to learn how to use SQL for the use of a particular dataset and "*there was quite a steep learning curve*", but it did not stop him from re-using that data. Interviewee 3 also stated that he will take the effort if he really needs the data (I3). Yet usually if the data is hard to process (I4, I9), non-user friendly (I8) difficult to get (I4) or takes a lot of time to process (I7) then researchers will not re-use it. Data needs to be clear (I4), understandable and easy (I2) to stimulate re-use. It was also mentioned that researchers can be motivated more to re-use open research data if the article and the data would be better connected (I7).
	Experience (I1, I2, I5, I6).	All of the interviewed researchers have a good experience with re-using open research data. Two researchers explicitly state that their good experience in the past motivates them to continue re-using public data (I1, I5). Obtained data management skills particularly enabled interviewee 6 to use different types of data from different repositories. One interviewee stated that training into open data re-use should have been better and that researchers need skills particularly to use big datasets (I2).

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Table 5 (*continued*)

Type of factors	Factor category	Factors driving researchers to openly share their research data or not
Less influencing factors	Voluntariness (I2)	Some of the interviewees strongly depended on open research data. Interviewee 2 stated "*I could not do any of my science without open data. So most of what I do depends on access to large catalogues of information that others have compiled and made available.*" Other interviewees were less dependent on open research data and mainly used it as an interesting additional resource to improve their own research.
	Personal drivers (I4, I5, I9)	We found that personal drivers are less influencing for open data re-use than for openly sharing data (I9). Two interviewees stated that they re-use open data simply because of curiosity (I4, I5) and for giving context to the research done (I4).
	Collaboration (I6)	Whereas collaboration was considered an important motivating factor for openly sharing research data, it appeared to be less important for the re-use of open research data. This factor was only mentioned by one interviewee who stated that she re-used open research data to collaborate with other researchers (I6).
	Usability	Usability was not mentioned as a factor influencing motivations for open data re-use.
	Legislation, regulation and policies (I1, I2, I5, I6, I8, I9)	Six of the interviewees state that legislation does not or barely has an influence on their motivations to use open research data (I1, I2, I5, I6, I8, I9).
Factors on which the interviewees' opinions were divided	Trust (I1, I2, I3, I4, I6)	Trust does not play an important role in the re-use of open data for some interviewed researchers (I1, I3). One interviewee states that if he would really need the data, reliability and trust would not play a role anymore (I3). For other interviewees, trust does play a role. Whether the data can be trusted partly depends on the data provider and whether it concerns the raw data or the processed data product. For example: "*public datasets are far bigger and perhaps better than the small individual programs. They are usually very well quantified and calibrated. Because it is a very objective field, there is no such worry about the biased observations - you know exactly where the data has come from. And to be competitive you have to use these datasets.*" (I1) Interviewee 4 states that raw data from certain data providers and facilities sometimes cannot be trusted. Researchers tend to trust the raw data more than the processed data (I1) and tend to trust more if other people also rely on the data (I2). Researchers become very skeptical if it is not clear how the data has been produced or if it is not accurate (I6).
	Data characteristics (I1, I2, I5, I6, I7, I8, I9)	Bad quality data demotivates researchers to re-use open data (I1, I9). The size also plays a role and can be a barrier for re-using data (I1, I2, I5, I7). How the data is organized, its accessibility (I9) and how one can analyse and access it also plays into this (I2). At the same time, the data characteristics are weighed against other factors, for example: "*the quality … if you do not think the data is good then you are not going to use it. […] Surely you want the data to be given to you cleanly and that is usually the case. But then again if the data is sufficiently interesting you are probably going to be willing to push through all of that*" (I8). Other researchers state that the metadata is usually sufficient (I1) and that data characteristics have not played much of a role (I6).

using open research data. Some interviewees mentioned multiple categories that they considered equally important. The opinions about which factors are most important in motivating the interviewed researchers to openly share and re-use research data were relatively divided (see Table 6), although many interviewees stated that personal drivers, such as that the data is useful to other people and that science should be open, and expected performance, such as getting more citations and becoming more visible as a researcher, were most important in motivating them to open up research data. The re-use of open research data is mainly driven by the researcher's expectance that their performance will increase and that it is good for their career.

The interviewed researchers agreed more regarding which factor categories demotivated them to openly share research data. Effort appeared to be the most important factor here (mentioned by six

Table 6
Most important categories motivating and demotivating the interviewed researchers to share and re-use open research data.

Type of factor	Sharing research data openly	Re-using open research data
Motivating factor categories	Personal drivers (I1, I2, I3, I5, I7, I9) Expected performance (I4, I8, I9) Social and affiliation (I1, I2) Voluntariness (I4) Collaborations (I4) Experience (I6)	Expected performance (I1, I2, I3, I4, I5, I8) Data characteristics (I2, I5) Effort (I1, I9) Trust (I7) Personal drivers (I6)
Demotivating factor categories	Effort (I1, I2, I4, I5, I6, I7) Experience (I3) Facilitating conditions (I6) Regulation (I9) Data characteristic (quality) (I8)	Trust (I4, I6, I7) Effort (I7, I9) Data characteristics (I1, I6) Expected performance (I1, I8) Facilitating conditions (I5) Social and affiliation (I3) Experience (I2) Researchers' background (I2)

Table 7
Demotivations that can be overcome through motivations in other categories.

	Demotivation category	Quote to illustrate how demotivation might be overcome
Demotivations for sharing research data openly	Regulation, legislation and policies	*"If I had to I would share because of legislations but no legislation would prevent me from sharing" (I7)*
	Regulation, legislation and policies / voluntariness / effort	"*The data that I have shared in the past has been a requirement of publications. So regardless of how easy or not it was to share it – it was quite a difficult process to be honest […] – but it was necessary so it would not have really mattered whether it had been easy or hard, I would have done it anyway.*" (I6)
	Facilitating conditions	"*The person who really wants to share will probably find a way. It is not hard to make a website nowadays. […] If you really want it you can do it.*" (I7)
Demotivations for re-using open research data	Data characteristics	*"The quality … if you do not think the data is good then you are not going to use it. […] Surely you want the data to be given to you cleanly and that is usually the case. But then again if the data is sufficiently interesting you are probably going to be willing to push through all of that"* (I8).
	Effort and data characteristics	"*If I need the data, I will make the effort […]. I really do not think anything will demotivate me. For example, I wouldn't worry about reliability of the data because I think I can find out."* (I3)
	Facilitating conditions	"*If I think the data is important for my analysis then I would just find a way to get it eventually."* (I6) "*If my whole PhD project was based around using this sky survey data or if my whole PhD was about answering a question that I could only answer using this survey data then those facilitating conditions would not be so much of an issue because I would just have to get around*". (I9)

interviewees) and all other factors were only mentioned by one interviewee. The interviewees were again more divided regarding which factors were most important in their demotivation to re-use open research data. Factors that were mentioned by at least two interviewees included trust, effort, data characteristics and expected performance.

6.4. Overcoming demotivations

Our findings show that some drivers for not sharing research data openly and drivers for not re-using research data can be overcome if motivations in other categories are strong. Table 7 provides an overview of how these demotivations might be overcome, exemplified by a quote from the interviewees. It shows that legislation, regulation and policy and requirements to openly share research data can be an extra motivation for researchers to share their data openly, regardless of the effort it takes. Moreover, if facilitating conditions are limited, they can be overcome by finding support elsewhere. We also found that if researchers are really interested in a certain dataset and need to re-use it for their own research, obstacles regarding data quality, reliability, effort and facilitating conditions will be overcome.

6.5. Comparing perceived benefits and barriers for astrophysics to individual motivations

Finally, we compared the perceived benefits of and barriers for open research data sharing in astrophysics (Section 5) to the individual factors driving the interviewed researchers to share their research data openly (Section 6.1) and to the individual factors driving the interviewed researchers to use open research data (Section 6.2). The interviewees expect that the benefits and barriers of openly sharing research data in astrophysics are mainly in the categories of reducing effort, increasing expected performance, increasing trust and personal drivers, whereas the factors that motivated them personally were mainly in other areas. Of the perceived benefit and barrier categories, only personal drivers was mentioned as an important factor driving them to openly share research data themselves. A possible explanation is that the interviewees were first asked the open questions about which benefits and barriers they perceived to the typical for the discipline of astrophysics, and only when specific pre-defined categories of motivations were presented to them thereafter they may have realized that more issues play a role than they had thought of upfront.

On the other hand, the comparison between the perceived benefits of and barriers for re-using open research data in astrophysics (Section 5) to the individual factors driving the interviewed researchers to re-using open research data themselves (Section 6.2) provides different results. The benefits and barriers of the astrophysics discipline were perceived to be mainly in the categories of expected performance, data characteristics, facilitating conditions and effort. All of these motivation factors were also mentioned when the interviewed researchers were asked for the factors influencing their personal motivations on the individual level.

7. How to stimulate open data sharing and re-use?

In this section we address our fourth research question: *how can researchers in disciplines with low rates of open data sharing and re-use be encouraged to share and re-use more?* Naturally, this requires consideration of the particular characteristics and challenges of individual disciplines. The best practices used in astrophysics cannot simply be copied to other disciplines without considering the characteristics and challenges of the discipline. For example, the forms of collaboration in astrophysics are partly the result of the limited amount of datasets available and the dependence on external data collectors. This is different from many other disciplines, such as social sciences and humanities. Other aspects that may be different in other disciplines include the variation of artifacts and the practices of scholarship (Borgman, 2007), the extent of privacy and security considerations of the research (Zuiderwijk, 2015), the degree of commercialization of the research (Lam, 2011) and the centralization of costly research facilities.

Another important finding is that the motivations for openly sharing research data and for re-using open research data are interrelated to each other in a complex manner. There are many dependencies, and Section 6.4 highlights that some demotivations can be overcome if motivations in other areas are strong. For instance, if researchers are demotivated because it takes great effort to interpret a particular open dataset, they may still be motivated to re-use that particular dataset if it is strongly relevant to their research. Thus, the different factors have different weights and their combinations need to be considered rather than looking at individual motivation categories in a 'stand-alone fashion'.

Several motivations appeared to relate to personal drivers – therefore, these intrinsic motivations may not be generalizable across astrophysics and other disciplines. At the same time, taking into account the previously mentioned aspects, there are several extrinsic

motivations with the potential to stimulate open data sharing and re-use in other disciplines. While taking into account the particular challenges and characteristics of each discipline, decision makers involved in policy development to incentivize open data sharing and re-use may find the following recommendations useful.

7.1. University reward culture

Our interviewees stated that the expected benefits of sharing and re-using open research data in astrophysics are mainly related to the expected performance of researchers. They expect gains for their job, more visibility, a better reputation and more rewards for sharing and re-using open research data. Having a better reward structure in place in disciplines with low rates of open data sharing and re-use could increase these rates. We found that if open data sharing and re-use is not being rewarded by universities or in another form, most researchers will not openly share their data. Therefore, we recommend universities covering all sorts of disciplines to better reward researchers for sharing and re-using open research data. Rewards can be provided in multiple forms. For example, these can be rewards in the form of acknowledgement by a researcher's supervisor in their yearly evaluation, so the number and type of shared datasets become a specific evaluation metric. Another form of acknowledgement is having clear dataset reference mechanisms in place. If openly shared datasets are being referred to in publications and are being cited just like articles this could motivate researchers to share their data openly. Universities or faculties may also provide awards for researchers who are active with regard to open data sharing and re-use. This can then also be an example or good practice for other researchers who do not yet share or re-use open research data. In this way a culture should be created that stimulates research data sharing and re-use.

7.2. Pro-active free support by journals and research data centres in making research data FAIR and open

Many of the benefits of and barriers for sharing and re-using open research data in astrophysics relate to experience, facilitating conditions and effort. In fact, some of the most important demotivating factors for open data sharing and re-use include effort and facilitating conditions. These findings suggest that if we want to see more open data sharing and re-use behavior in disciplines with low rates of this type of behavior, open data sharing and re-use should be made as easy as possible for researchers. This is also suggested in a study by Van Horn and Gazzaniga (2013) who state that "depending on busy investigators to re-format their data specifically for your database is unlikely to be a sound model." (p. 681). Furthermore, it supports previous research by Harper and Kim (2018) who showed that the merely the availability of a data repository and pressure from an open science journal did not have a significant relationship with the intention of researchers in the discipline of psychology to engage in data sharing behavior by sharing data and/or other materials in an open access repository (idem). Although we did not investigate the relationship between a journal's or university's open data policy and actual open data sharing behavior, our case study suggests that more research data may be published if journals and research data centers play a more pro-active role than they currently do. A pro-active form of support, for example providing authors with free support of data scientists associated to journals or to data repositories, helps to share more data. Journal editors and universities should encourage data sharing through pro-actively supporting authors to make their underlying research data openly available by offering this support as a free service. They should also support researchers in making their data Findable, Accessible, Interoperable and Reusable (FAIR) (Force11, 2016), so that the usability of openly shared data will improve. Usability was also an mentioned as a important factor influencing researchers' motivations for sharing data openly. With pro-active support for researchers, various challenges, such as 'the fear of accidentally publishing privacy-sensitive data', 'not knowing where to upload the data due to a lack of experience' and 'a lack of time to publish the data' can be overcome.

7.3. Catalogue data services in addition to open data

Several interviewees mentioned that they need to spend much time to answer a simple question when the re-use raw open research data. They stated that it would be useful to have access to certain software that can help answer these simple questions, in addition to the access to the data itself. This factors influences the motivation to re-use open research data and can be used to stimulate open data sharing and re-use in disciplines without well-developed traditions of open data. Several projects and initiatives have already started cataloguing data services linked to the original data (for example, EOSC-hub, 2019; INDIGO-DataCloud Project, 2019; VRE4EIC Project, 2018), that can support the data user by executing the service and obtaining appropriate data products. This avoids some of the difficulties of detailed technical understanding of access to and re-use of the raw dataset. We recommend policy makers to encourage initiatives in which data services are being created.

8. Discussion and conclusions

In this study, we aimed to provide in-depth insight about the complex interaction of factors influencing motivations for sharing and re-using open research data within a single discipline, namely astrophysics. Through taking a case-study approach, we sought to improve understanding of the underlying motivations and demotivations of open data sharing and re-use in this discipline.

Our first research question was: *what discipline-specific characteristics influence researchers' motivation for sharing and re-using open research data in astrophysics?* We identified six factors that motivate astrophysics researchers to openly share their research data and to re-use open research data, namely: the raw data is infrequently collected directly by the researchers, the limited resources encourages collaboration, exterior public data is shared automatically, the existence of a supportive data sharing culture, a lack of concerns about ethics and commercial potential of data and a positive experience with open data re-use. Two factors that demotivate astrophysics researchers to openly sharing and re-use open research data are the enormous volume of some datasets and the lack of facilitating conditions. Furthermore, our interviewees stated that the expected benefits of sharing and re-using open research data in astrophysics are mainly related to the expected performance of researchers. While the interviewees' opinions about the benefits were relatively consistent, their views on barriers were more divided. Many of the mentioned barriers for open data sharing and re-use relate to facilitating conditions.

Then we examined *what factors influence researcher's motivations to openly share their data in astrophysics? And what factors influence researcher's motivations to re-use open research data shared by others in astrophysics?*

Factors driving researchers to openly share research data or not concern the following eight categories: the researchers' background, personal drivers, experience, legislation, regulation and policies, data characteristics, performance expectancy, usability and collaboration. The opinions about which factors are most important in motivating the interviewed researchers to openly share research data were relatively divided, although many interviewees stated that personal drivers (for example, that the data is useful to other people and that science should be open) and expected performance (for example, getting more citations and becoming more visible as a researcher) were most important in motivating them to openly share their research data. The researchers agreed more regarding which factor categories demotivated them to openly share research data. Effort appeared to be the most important factor here. Trust was a factor with less influence on sharing data

openly. For the factors related to effort, facilitating conditions, voluntariness, performance and social and affiliation-related factors, the interviewed researchers disagreed whether they drive them to openly share research data or not.

Factors driving researchers to re-use open research data or not include the researchers' background, facilitating conditions, expected performance, social and affiliation factors, effort and experience. The use of open research data is mainly driven by the expectance that their performance will increase and that it is good for their career, since these factors were considered the most important ones. Just like for sharing research data, the interviewees were more divided regarding which factors were most important in their demotivation to re-use open research data. Factors that were mentioned by at least two interviewees included trust, effort, data characteristics and expected performance. Factors that had less influence on the motivation to re-use open research data concerned voluntariness, personal drivers, collaboration, legislation, regulation and policy and usability. The interviewees disagreed about whether trust and data characteristics influenced their motivations to re-use open research data or not.

Surprisingly, when we look at researchers' personal motivations, not only more but also other factors appear to play a role than when we ask for factors important for astrophysics researchers in general. The comparison between the perceived benefits of and barriers for re-using open research data in astrophysics to the individual factors driving the interviewed researchers to re-using open research data themselves showed only minor differences. It is not so clear why some differences were found and we recommend future research to address this issue.

Finally, we investigated *how researchers in disciplines with low rates of open data sharing and re-use can be encouraged to share and re-use more?* While taking into account the particular challenges and characteristics of each discipline, we identified several extrinsic motivations that do have potential to stimulate open data sharing and re-use in other disciplines. Decision makers involved in policy development to incentivize data sharing and re-use are recommended to developed better reward structures for sharing and re-using open research data. If the sharing and re-use of open research data is not being rewarded by universities or in another form, a part of the researchers will not share their data. Moreover, we state that journal editors and universities should not only make data sharing mandatory by developing a policy for this, but in addition we recommend them to actively support authors to make their underlying research data openly available and offer this support as a free service. They should also support researchers in making their data Findable, Accessible, Interoperable and Reusable (FAIR), so that the usability of openly shared data will improve. Finally, we recommend policy makers to encourage initiatives in which data services are being created, so that some of the difficulties of detailed technical understanding of access to and re-use of the raw dataset can be avoided.

Our findings and recommendations are based on a single case study in a single country in astrophysics and whether they are useful for cases in other disciplines than astrophysics needs to be examined case-by-case. Best practices used in astrophysics cannot simply be copied to other disciplines without considering the characteristics and challenges of the discipline. The motivations for openly sharing research data and for using open research data that we identified are interrelated to each other in a complex manner, as there are many dependencies and trade-offs. We found that the different factors have different weights and their combinations need to be considered rather than looking at individual motivation categories in a 'stand-alone fashion'. Furthermore, several motivations appeared to relate to personal drivers – therefore, these intrinsic motivations may not be generalizable across astrophysics and other disciplines. There were many individual differences in motivations and demotivations between our interviewees, and sometimes there was disagreement about the influence of a certain factor. In future research, we recommend to compare our findings to other cases in the same discipline and to cases in other disciplines and in other countries. Additionally, future studies could examine to which extent our conceptual model needs to be adjusted and refined in other contexts. Finally, the effects of open data sharing and re-use over time should be examined.

This article contributes to the open data literature by providing in-depth insight into factors influencing motivations and demotivations related to openly sharing and re-using research data in astrophysics. We contribute to theory building and filling theoretical categories by testing and further developing the conceptual model developed by Zuiderwijk (2019) and Zuiderwijk & Shinde (unpublished). Moreover, this paper contributes to practice by deriving recommendations for stimulating researchers to openly share and re-use open research data more from our findings in an astrophysics case study.

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Data statement

The data underlying this research is available through the 4TU. Centre for Research Data, see http://doi.org/10.4121/uuid:21b6bf8a-a14e-49ce-a31a-ec0e1366cf46.

Declaration of interest statement

The authors have no competing interests to declare.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ijinfomgt.2019.05.024.

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