Evaluation of the Global Relay of Observatories Watching Transients Happen (GROWTH) PIRE: 2017-18 Annual Progress Report

A California Institute of Technology
Partnerships for International Research and Education (PIRE) project
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Table of Contents

List of Figures

List of Acronyms

NSF = National Science Foundation
PIRE = Partnerships for International Research Education
Caltech = California Institute of Technology
GROWTH = Global Relay of Observatories Watching Transients Happen
SNA = Social Network Analysis
LIGO = Laser Interferometer Gravitational-Wave Observatory
EF = Standard Eigenfactor
EFn = Normalized Eigenfactor
SURF = Summer Undergraduate Research Fellowships Program

Executive summary

GROWTH is an international scientific collaborative project in astronomy, studying the physics of fast-changing events in the cosmos like supernovae, neutron stars or black hole mergers, and near-earth asteroids. The intention of this project is to continuously observe and gather data of cosmic transient events in the first 24-hours after detection, before many of them fade away in intensity below the sensitivity of telescopes. Project activities are conducted among undergraduate students, graduate students, postdocs, partner institution faculty, and researchers.

The current report includes feedback on project implementation and progress made towards stated goals in year three of five. Findings from this report should be used by project leads to demonstrate the impact of the project to NSF and to discuss ways to enhance the impact of the overall project.

Project goals:

Goal 1: Research – Increase knowledge and make progress in identified research areas (astronomy/astrophysics).

Goal 2: Education and Workforce Development – Accelerate education and training in this scientific area and contribute to the development of the STEM workforce.

Goal 3: Capacity Building (Partnerships & Sustainability) – Develop a model for building international scientific teams and create a strong collaborative network of scientists/telescopes that catalyzes scientific and educational achievements.

Project highlights since the last Annual Report:

- Project members **successfully produced high-impact scientific publications** and **exceeded the targeted number of publications for the lifespan of the project**. As of May 8, 2016, project members had produced 82 publications in journals with an impact ranging from 0.5 to 164.4 times that of the average journal. High impact journals published in include *Science* and *Nature*.
- The discovery of GW170817 was a **notable event that resulted in follow-up activity that served as a catalyst for advancing GROWTH research, resulting in many publications and presentations**.
- GROWTH **trained and promoted graduate students and postdocs** through involvement in the publication process. Postdocs were featured on 82% of publications and graduate students on 41% of cumulative publications.
- GROWTH courses continued to increase undergraduate and graduate students' knowledge about astronomy/astrophysics and skills in research and data analysis through **utilizing project data** to teach students **through hands-on and real-world applications** in the classroom.
- The internship programs continued to advance postdoc, graduate, and undergraduate students' research skills. Undergraduate students, graduate students, and postdocs reported **increased understanding of how to collaborate with multidisciplinary international teams**.

Overall, project participants served as research leaders in their fields through support from the GROWTH project. Similar to previous project years, project leads supported participants in both individual and collaborative research activities. Young scientists were also given opportunities to engage in and learn the research process. These efforts led to high quality international research in high impact journals.

Consider these sample adjustments:

While collaboration on publications continued to increase, the project participants from the Asian institutions were listed less often in the publications compared to participants from other regions.	→	Project leads should **find mechanisms to encourage further collaboration** between members across institutions, countries, and continents. This could be through better **integration of all partners' research areas or encouraging more research planning meetings in locations outside of the United States**, so that a wider range of participants from other partner institutions can be present.
Young researchers in the project were interested in pursuing graduate school and, eventually, careers in astronomy and astrophysics. However, some were unsure how to find information about STEM-related careers.	→	Project leads should consider **providing career information to students** by incorporating this into existing project structure and activities, **such as a panel at project annual meetings or as part of the internship programs**.
Project leads likely anticipated the overall vision of advancing scientific achievements in these fields will sustain past the current funding period as the project has helped implement an infrastructure at the partner institutions to support this. However, project leads may be less sure if the infrastructure is regularly adapting strategies based on changes in environment.	→	Project leads should **assess sustainability mechanisms to put into place to continue use and sharing of research in this field**, such as supporting use of the GROWTH Marshal, seeking out additional funding to institutionalize these collaboration activities, and discussing which portions of the project leads envision carrying out beyond the current funding period.

Evaluation activities for the upcoming year: Surveys for GROWTH SURF Program, Graduate/Postdoc Exchange Program, 2018-19 courses, Winter School, as well as the Annual Progress Survey, and publication network analysis.

Evaluation and report overview

Background

In 2015, the California Institute of Technology (Caltech) received funding for a Partnerships for International Research and Education (PIRE) grant from the National Science Foundation (NSF) for the Global Relay of Observatories Watching Transients Happen (GROWTH) project. GROWTH is an international scientific collaborative project in astronomy, studying the physics of fast-changing events in the cosmos like supernovae, neutron stars or black hole mergers, and near-earth asteroids. GROWTH is led by Caltech and has partnered with fourteen universities and research institutions (six in the USA and eight internationally in India, Sweden, Taiwan, Japan, Israel, Germany, and the United Kingdom). The intention of this project is to continuously observe and gather data of cosmic transient events in the first 24-hours after detection, before many of them fade away in intensity below the sensitivity of telescopes. Project activities are conducted among undergraduate students, graduate students, postdoctoral researchers (hereafter referred to as postdocs), and partner institution faculty and researchers. The intended outcome of the project is two-fold: 1) to educate and train researchers and contribute to the development of the STEM workforce and 2) to develop a strong network of scientists and telescopes that catalyze scientific and educational achievements. SmartStart Evaluation and Research serves as the external evaluator, contracted through the primary institution (Caltech). The external evaluation is intended to provide an objective assessment of the project, so that it remains accountable to both the funder and project participants.

Evaluation approach

The current report includes formative evaluation which provides feedback on project implementation and a summative evaluation which assesses the impact of the project and progress made toward reaching stated goals. Findings from this report should be used by project leads to demonstrate the impact of the project to NSF and to discuss ways to enhance the impact of the overall project. The summative evaluation is driven by the three goal areas. The corresponding evaluation questions for each goal area are listed below.

Goal 1: Research – Has the PIRE grant advanced new knowledge, collaboration, and discoveries in astronomy/astrophysics?

- To what extent has project research advanced scientific discovery?
- To what extent have young researchers been included in research and publishing opportunities?
- To what extent has the project impacted research capabilities of participants?

Goal 2: Education and Workforce Development – Has the PIRE grant developed a sustainable STEM workforce by creating a pipeline of STEM-trained students, educators, and workers?

- To what extent have undergraduate students, graduate students, and postdocs increased their knowledge and skills through research experiences?
- To what extent have undergraduate students, graduate students, and postdocs developed or further increased interest in the field, scientific careers, and continuing education?

Goal 3: Capacity Building (Partnerships & Sustainability) – Has the PIRE grant enabled GROWTH scientists to collaborate and develop international relationships to strengthen research that will support educational and scientific achievements in the field of astronomy/astrophysics?

- To what extent has the project facilitated collaborations between partner institutions?
    - To what extent has the project facilitated research and education (mentorship) collaborations?
- To what extent is the project planning for sustainability?

Evaluation measures

Evaluators developed survey questions and interview protocols in conjunction with project leads and activity leads. Surveys contained Likert scale items and open-ended questions that measured participants' knowledge and skills related to research, interest in careers and continuing education, and collaborations in research and education-related activities. Unless otherwise noted, participants rated all Likert scale questions on a five-point scale. Publications and articles were accessed through the project's online library, and bibliometrics were researched and reported from the Scimago Journal Rankings,[1] and Eigenfactor websites.[2]

Data collection and analysis

Surveys were administered through online platforms. Surveys assessed Graduate/Postdoc Exchange Program, the GROWTH Summer Undergraduate Research Fellowship (SURF) Program, collaborations through a Social Network Analysis (SNA), all GROWTH affiliated courses, and progress made in research and other project activities (Progress survey). This report includes summaries of course and internship evaluation reports on activities conducted between the last annual report (May 2017) and this annual report (May 2018). Quantitative results were analyzed using means and response frequencies, and qualitative data were coded for themes. The SNA and progress surveys were administered together during the October 2017 annual meeting. The progress survey was sent to all 58 participants active in the project at the time of the annual meeting and was completed by 48 respondents (83% response rate). The social network data were analyzed through the network analysis software, Gephi. Interviews were conducted during the project annual meeting in October 2017 with project leadership and those who participated in the internship programs. The interviews asked questions about the successes of GROWTH, current collaborations, barriers to collaboration, training students and the internship programs, and project facilitation of research and academic competitiveness. Internship participants were asked how the internship impacted their research, and education and career planning. These

1. http://www.scimagojr.com/journalrank.php
2. http://www.eigenfactor.org/projects/journalRank/journalsearch.php

interviews are referenced throughout the report to supplement quantitative findings. Tracking data on participants' institution and role in the project was also collected by the project administrator and the evaluators.

It should be noted that starting in Year 3, undergraduate students were not counted as project participants, per project leads' request. Undergraduates are included in some sections of the report, when activities they were involved with are discussed.

All information collected by SmartStart Evaluation and Research is kept confidential. Participant information and data is kept on a secure server. Any identifying information is password protected and kept separate from data analysis through use of random IDs. Results are reported in aggregate only.

Project timeline

The timeline below displays major events in the GROWTH project's lifespan. GROWTH is currently in Year 3 of the five-year grant. Year 3 milestones included 40 publications produced by project participants, almost 1.5 times the number of publications in Year 2 and almost three times those in Year 1. The notable increase in publications can be partially attributed to the GW170817 discovery made in August 2017, which helped to stimulate research and academic scholarship across the GROWTH project. In August 2017, GROWTH was involved in the follow-up activity of GW170817 event, which has served as the catalyst for achievements in Year 3. Additionally, Inter-University Centre for Astronomy and Astrophysics (IUCAA) was replaced by another partner institution in India, Indian Institute of Technology Bombay (IITB), due to a key project participant changing institutions. Except for the participation summary of project participants in the following section, IUCAA and IITB were reported jointly in this report.

Year 1 (2015-16)	
October	
November	
December	
January	UG[a]- First course (AY3) affiliated with the GROWTH project begins at Caltech (7 students were enrolled in this course).
February	
March	
April	
May	Project wide- A total of 15 articles were published by GROWTH members.
June	UG- First undergraduate students (8 students) participated in the GROWTH SURF Program.
July	Project wide- 1st GROWTH Conference (annual meeting) held at Caltech (U.S.).
August	UG/GS- Second set of GROWTH affiliated courses (ASTRO 310, ASTRO 680, AY122a) began (51 students were enrolled in these courses).
September	
Year 2 (2016-17)	
October	

November	
December	GS/PD- 8 graduate students and postdocs completed internships.
January	UG/GS- Third set of GROWTH affiliated courses (AY3, YSC2217, A51, AS6005) began (37 students were enrolled in these courses).
February	
March	Project wide- Liverpool John Moores University joined GROWTH.
April	
May	Project wide- A cumulative total of 42 articles were published by members of GROWTH. Twenty-seven of these were published in Year 2.
June	UG- 7 undergraduate students participated in GROWTH SURF Program. Project wide- Texas Tech University joined GROWTH.
July	
August	UG/GS- Fourth set of GROWTH affiliated courses (PHYS 194, ASTR 680, ASTRO 310) began (42 students were enrolled in these courses). Project wide- GW170817 observed.
September	GS/PD- 6 graduate students and postdocs completed internships.
Year 3 (2017-18)	
October	Project wide- 2nd GROWTH Conference (annual meeting) held at the University of Wisconsin, Milwaukee (U.S.). Project wide- Interviews with project leadership and internship participants
November	
December	Project wide- First GROWTH article written about GW170817
January	UG/GS- Fifth set of GROWTH affiliated courses (ASTRO 350, ASTR 498S, YSC6005) began (29 students were enrolled in these courses).
February	
March	
April	Project wide- Indian Institute of Technology Bombay joined GROWTH, replaced Inter-University Centre for Astronomy and Astrophysics.
May	Project wide- A cumulative total of 82 articles were published by members of GROWTH. Forty of these were published in Year 3. UG- 7 undergraduate students will participate in GROWTH SURF Program.
June	GS - 2 graduate students will participate in the internship program.
July	
August	
September	

a. Activity targeted populations: UG- Undergraduates, GS- Graduate students, PD- Postdocs, Project wide

Figure 1. GROWTH project timeline

Project participation

The following table displays background information for active GROWTH participants by year. Year 3 includes Year 1 and 2 participants who stayed in the project and new Year 3 participants. A new American partner institution, Texas Tech University, joined the project in Year 2, bringing in an additional investigator. One PI changed institutions in Year 3, from Inter-University Centre for Astronomy and Astrophysics to Indian Institute of Technology Bombay. One graduate student moved into a postdoctoral position at Caltech and continues to work with the project. One undergraduate that participated in Year 1 started a graduate program at the University of Maryland in Year 2.

	Year 1 (n = 64)		Year 2 (n = 67)		Year 3 (n = 66)	
Participant backgrounds	#	%	#	%	#	%
Institution						
California Institute of Technology	16	25%	14	21%	12	18%
Humboldt University	1	2%	3	4%	4	6%
Indian Institute of Astrophysics	1	2%	1	2%	1	2%
Inter-University Centre for Astronomy and Astrophysics/Indian Institute of Technology Bombay[a]	3	5%	3	4%	2	3%
Liverpool John Moores University	--	--	5	7%	5	8%
Los Alamos National Laboratory	1	2%	1	2%	1	2%
Max Planck Institute for Astronomy	1	2%	1	2%	--	--
Montgomery College	2	3%	--	--	--	--
NASA Goddard Space Flight Center	1	2%	1	2%	1	2%
National Central University, Taiwan	1	2%	1	2%	4	6%
Oscar Klein Centre, University of Stockholm	11	17%	11	16%	13	20%
Pomona College	2	3%	1	2%	--[b]	--
San Diego State University	3	5%	2	3%	1	2%
Texas Tech University	--	--	--	--	1	2%
Tokyo Institute of Technology	9	14%	9	13%	10	15%
University of Maryland, College Park	6	9%	7	10%	5	8%
University of Wisconsin, Milwaukee	3	5%	4	6%	4	6%
Weizmann Institute of Science	3	5%	3	4%	2	3%
Role in Project						
Graduate students	21	33%	21	31%	17	26%
Postdocs	17	27%	15	22%	18	27%
Senior investigators/researchers	18	28%	24	36%	31	47%
Undergraduate students	8	13%	7	10%	--[c]	--

a. Per project leads' request, these institutions are reported together due to the proejct lead from IUCAA moving to IITB during project Year 3.
b. The co-project lead from Pomona College withdrew from the project in July 2017 and did not complete the SNA or annual progress survey in Year 3.
c. Per project leads' request, undergraduate students were not counted as project participants in Year 3 due to the nature of their participation in the project. Undergraduates were not expected to take part in more than the SURF program or courses.

Figure 2. Project participation by gender, institution, and role

GROWTH partner institutions

The map below displays the **current Year 3 GROWTH partner nations**, with the number of participating institutions noted. The U.S. has the largest number of institutions (n=6), followed by India (n=2), and all other partner nations have only one institution. Since Year 1, two institutions have left the project and three have joined. Interest in joining the collaboration has continued to grow both within the U.S. and internationally each year of the project, as demonstrated by the addition of one U.S. institution and one U.K. institution in Year 2. While there was one new institution in India in Year 3, the overall number of institutions did not change. This is due to one project lead switching institutions.

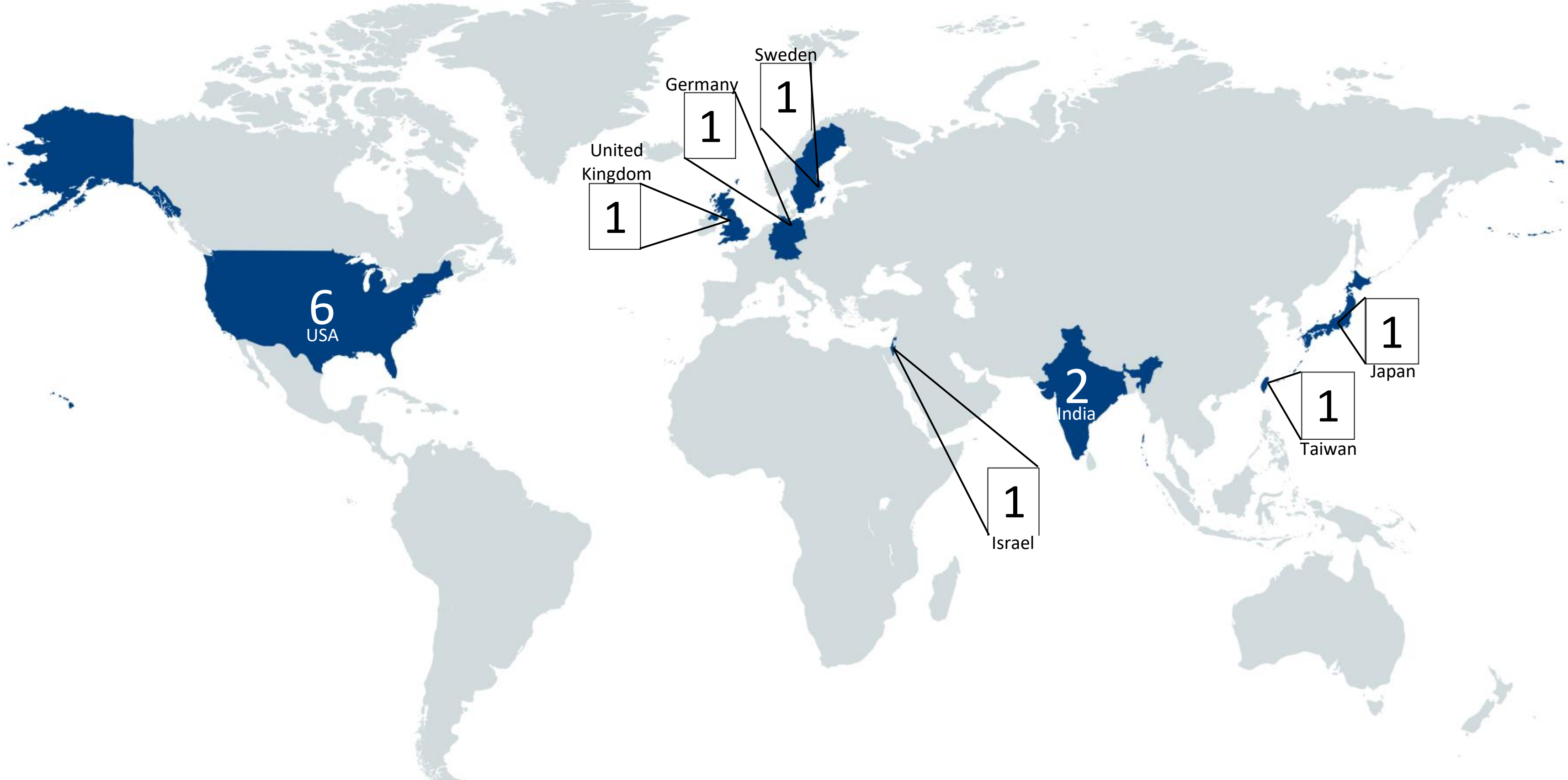


Figure 3. Year 3 GROWTH partner institutions and nations

Progress made towards research as explored through research products (Goal 1)

To assess Goal 1, evaluators examined the volume and impact of research products from project members, including publications, and conference presentations/colloquium talks, workshops, and poster presentations. It should be noted that only published articles were identified, as there was no available information on manuscripts that have been prepared and/or submitted. Contributions made by young researchers (graduate students and postdocs) on publications were also explored, as supporting these individuals in their research and collaboration skills is a key focus for the project. The annual progress survey results were also used to determine if participants are submitting grants within GROWTH research areas and the project's influence on participants' research capabilities.

Publications

Publishing in academic, peer-reviewed journals is one major indicator of the strength and productivity of the GROWTH project. Project leads have targeted 55 publications across the life of the project. As of Year 3, project members exceeded this target for published articles in astronomy/astrophysics. In Year 3 alone, 40 articles were published by participants, which was 1.5 times that of Year 2 and almost three times that of Year 1. The table below shows the number of publications produced by project members each year. Appendix A includes a full list of publications and Appendix B lists the citations, number of authors, and number of postdocs and graduate students on each publication.

Project year[a]	Annual publications	Cumulative publications	Cumulative project members as authors[b]
Year 1 (2016-17)	15	15	29
Year 2 (2017-18)	27	42	30
Year 3 (2018-19)	40	82	43
Year 4 (2019-20)	Not Yet Reported	Not Yet Reported	Not Yet Reported
Year 5 (2020-21)	Not Yet Reported	Not Yet Reported	Not Yet Reported

a. Publication information was pulled for analysis on May 7, 2018 and does not reflect any changes made to database after this date.

b. Project members may have published multiple times in a single year, but the number provided represents unduplicated counts.

Figure 4. Publications by year and number of GROWTH authors

In August 2017, LIGO detected the gravitational wave signal from the merger of two neutron stars, later called GW170817. This merger unveiled to project researchers the first concrete proof of one of the processes for the synthesis of heavy elements in the universe, such as gold and platinum. The follow-up on this event by GROWTH researchers served as the major catalyst for new knowledge and resulted in many publications. The following information more specifically details the ways in which project participants' research have advanced scientific knowledge.

Publication impact was assessed using three bibliometrics: Eigenfactor (standard [EF] and normalized [EFn]), Impact Factor, and h-index, as well as the number of GROWTH articles published in each journal. For all bibliometrics used, there is no set range of values, rather each factor is computed within themselves and allows for comparisons between journals. **Eigenfactor** measures the importance a journal has in the scientific community and includes the number of articles published in a journal and its citations compared to all scientific articles published. **Normalized Eigenfactor (EFn)** is the same measure as Eigenfactor, except all scientific journals are standardized, so that the average journal has a score of 1. Journals with EFn>1.0 are more influential than the average journal. **Impact Factor** measures how frequently the average article published by a journal is cited. **H-index** measures the number of articles published in a journal and the journal impact. H-index can also be applied to individual authors to assess their work's impact.

The table below displays the journals where all 82 GROWTH articles have been published and the respective bibliometrics (only published submissions are included in the table). All but one of the journals (arXiv[3]) that published GROWTH articles had available Eigenfactor scores. Almost all journals that published work of project members had above average Normalized Eigenfactor (EFn = 1.0). The most impactful journal based on all bibliometrics was *Nature*, which had a Normalized Eigenfactor of 164.4, indicating this is highly influential journal (about 164 times as influential as the average journal). GROWTH members continued to publish in *Science*, also an influential journal, with three new publications in the journal in Year 3. The average Normalized Eigenfactor for all listed journals was 38.

Journal	Eigenfactor	Normalized Eigenfactor	Impact Factor	h-index	Published articles
arXiv[a]	N/A	N/A	0.698	N/A	9
Astronomy & Astrophysics	0.24	27.4	5.014	231	5
Monthly Notices of the Royal Astronomical Society	0.303	34.5	4.961	258	10
Nature	1.443	164.4	40.137	1011	3
Nature Physics	0.13	14.8	22.806	202	1
Publications of the Astronomical Society of Australia	0.004	0.5	4.095	43	1
Publications of the Astronomical Society of Japan	0.01	1.2	1.972	80	1
Publications of the Astronomical Society of the Pacific	0.019	2.2	4.446	124	4
Science	1.154	131.5	37.205	978	4
The Astronomical Journal	0.063	7.2	2.609	204	2
The Astrophysical Journal	0.426	48.6	5.533	352	31
The Astrophysical Journal Letters	0.139	15.9	5.522	96	10
The Astrophysical Journal Supplement Series	0.071	8.1	8.955	199	1
Average for all journals	0.334	38.0	11.073	315	6.3

a. arXiv is not a peer-reviewed journal, but is instead moderated to ensure submissions are on-topic and scientifically valid.

Figure 5. Year 3 cumulative publication bibliometrics by journal

3 arXiv is not a peer-reviewed journal, but is instead moderated to ensure submissions are on-topic and scientifically valid.

GROWTH publications included anywhere from 1 to 29 participants as authors and were cited anywhere from 0 to 271 times per article. Years 1-3 GROWTH articles were cited 1615 times. This was more than four times the number of citations reported previously for Years 1 and 2 combined (articles cited 382 times). All publications were cited on average 20 times, which was more than double the average of 9 citations per article reported at the end of Year 2 and above the average number of citations for articles published in the fields of astrophysics and astronomy from 2015-18 (3.43 citations).[4] Twenty-four project publications have been cited more than 9 times, and two of those have been cited more than 100 times.

Of the 82 GROWTH publications, 68 articles (83%) listed postdocs as authors and 34 (41%) listed graduate students as authors. Of the 35 postdocs and graduate students currently in the project, 27 (77%) were listed as authors. Compared to Year 2, postdocs increased their authorship on publications by 13% (from 69%), while graduate students decreased their authorship by 14% (from 55%). Some of this change may be attributed to the increase in overall publication numbers and the greater inclusion of these young researchers this year compared to the early years of the project. The change could also be attributed to one graduate student who shifted into a postdoc position. This individual was listed as an author on six publications while a graduate student, which would account for 7% of the 14% decrease in graduate student authorship. Additionally, some of the graduate students worked as interns to develop the GROWTH Marshal, which will serve as a hub for live streaming data and analysis and to further connect researchers together. Students' time may have been devoted to developing this platform more so than to writing publications this year.

4. Citation report can be found at https://apps.webofknowledge.com/CitationReport.do?action=home&product=WOS&search_mode=CitationReport&cr_pqid=10&qid=10&SID=1BPqhTChDg5w2oNuH3C

While the internships may not be the deciding factor when determining who published among the young researchers, it is important to note that all but one of the interns (90%) were authors on publications. This indicates that the GROWTH project has continued to foster an environment where young scientists have opportunities to contribute to impactful research and publications.

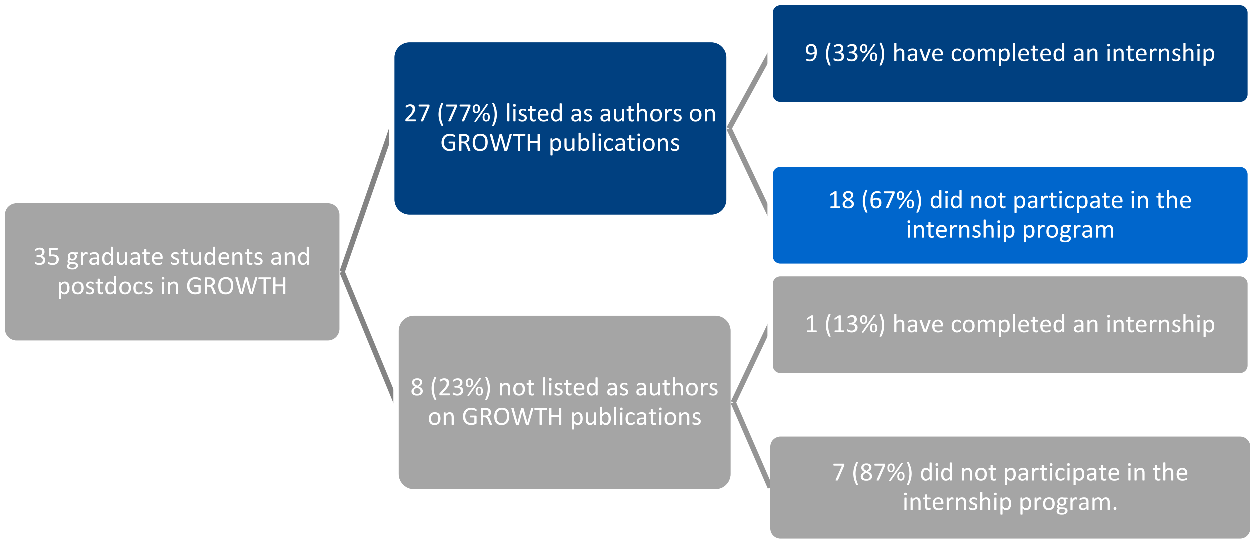


Figure 6. GROWTH graduate students and postdocs as authors on cumulative publications

In order to understand other ways in which GROWTH participants have worked toward furthering the advancement of research and educational achievements, participants were asked on the project annual progress survey how many grants related to GROWTH research they have submitted and how many were funded. In total, 17 respondents (35%) indicated they submitted 45 grants related to GROWTH research. Most of the 17 respondents had submitted one grant, but five had submitted more than one. Two respondents submitted two applications, two submitted four, and one submitted 20. Of those respondents submitting grants, nine received funding for 21 grants.

Presentations and talks

In addition to disseminating research and work through academic journals and publications, GROWTH project members gave presentations around the globe. During Year 3, 34 project members gave 88 presentations in 12 nations, of which six are not partner nations (see Figure 8). Within the United States, project members have presented in ten states and the District of Columbia. A majority of these locations (nine) were not affiliated with partner institutions. Overall, project participants have increased their information dissemination activities compared to Year 2. This is especially true for the number of talks by participants, which increased from 47 to 78. Moreover, the number of participants presenting almost tripled, from 13 in Year 2 to 32 in Year 3. While it may not be the sole reason for the increase in presentations, project leads explained in a project planning meeting that they have received a high volume of invitations to speak since GW170817. By reaching out to nations and U.S. states not affiliated with the project, members are expanding the visibility of GROWTH, as well as its research, beyond the scope of the project. For detailed information on the number of presentations for each location, see Appendix C.

Presentation type	Number of presentations[ab]		Number of GROWTH members participating[c]	
	Year 2	Year 3	Year 2	Year 3
Talk	47	78[d]	13	32
Plenary speaker	--	1	--	2
Poster	6	9	4	9
Workshop	2	--	2	--

a. Presentations were pulled for analysis on May 7, 2018 and do not reflect any changes made to database after this date.
b. Year 1 data was not requested by evaluators during the first year of the project. If available, it will be requested in Year 4.
c. Project members are counted once per category, even if they gave multiple presentations of that type
d. One presentation was categorized as a talk and poster. It is counted as a talk.

Figure 7. GROWTH presentations and talks for Years 2 and 3

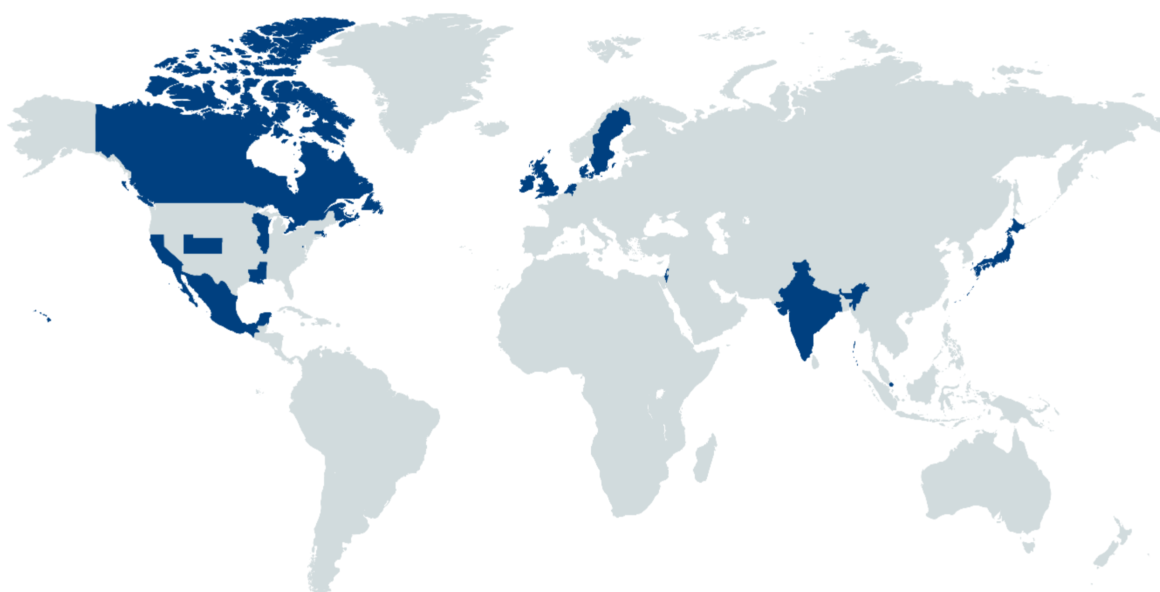


Figure 8. Locations of GROWTH presentations and talks in Year 3

Impact of project on participants' research capabilities

GROWTH participants (n=48) indicated whether the project benefited their research activities and improved their academic competitiveness. A majority of respondents (57%-63%) indicated it was true that they participated in dissemination practices and improved their academic competitiveness as a result of participating in the project. While most (52%) also indicated it was true they achieved greater academic output, slightly fewer indicated it was true they had made scientific discoveries in the field or that their findings were used by others. Participants may be unsure how to determine if others are using their findings. While the number of publications across project participants increased, some may need more time to develop proposal submissions and make scientific discoveries.

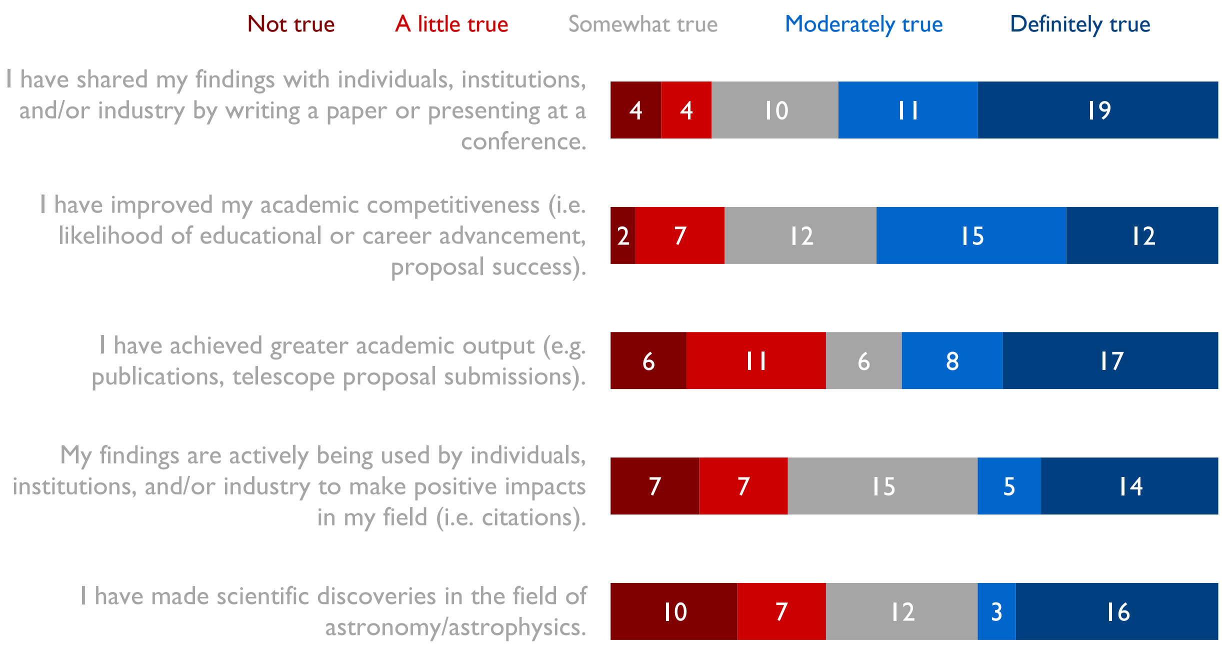


Figure 9. Impact on participants' research capabilities

Scientific and educational achievements will continue to be a primary focus for evaluation activities as the project enters the final two grant years. In a project planning meeting, project leads explained that they do not anticipate publishing as many articles in a given year as they did in Year 3. While they still expect number of publications to grow, they recognize the impact the GW170817 discovery had on publications and presentations cannot be expected every year.

Progress made towards increasing student knowledge/ skills and interest in astronomy/astrophysics (Goal 2)

Project leads posited that mentorship and training of young researchers is integral to continuing project research and expanding the numbers of researchers in the field. GROWTH project leads seek to develop a STEM workforce by educating students through project affiliated courses and providing hands-on research experiences through summer internship programs. To assess progress made in this goal, undergraduate students, graduate students, and postdocs who completed the following GROWTH-affiliated courses and internships completed short surveys to assess the extent to which these activities increased their knowledge and skills and influenced their interest in astronomy/astrophysics careers and education. Results from these surveys were already reported in previous activity reports (noted by parentheses). Due to the alignment between the annual report deadline and the courses and GROWTH SURF and Graduate/Postdoc Exchange Programs timelines, this report includes summaries of activities that occurred between Spring 2017 and Fall 2017.

- GROWTH SURF Program and Graduate/Postdoc Exchange Program
  - 2017 GROWTH SURF Program: 5 students (Year 2 Quarter 4 GROWTH Summer Undergraduate Research Fellowship Evaluation Report)
  - 2017 Graduate/Postdoc Exchange Program: 4 postdocs and graduate students (Year 2 Quarter 3 GROWTH Graduate Student & Postdoc Internship Evaluation Report)
- GROWTH affiliated courses
  - Spring 2017 courses: 32 students (Year 2 Quarter 2 Course Evaluation Report)
  - Fall 2017 courses: 46 students (Year 2 Quarter 4 Course Evaluation Report)

Trends in education and workforce development

Overall, respondents to course and internship surveys, especially undergraduate student respondents, reported increased knowledge and skills related to astronomy/astrophysics. These skills generally were in coding and scientific communication. Most respondents were motivated to continue pursuing education and careers in the field. Shared in a more recent survey, only about half of the graduate students and postdocs respondents indicated that they know where to look for career information and who to contact about careers. This is likely because respondents were focused on research and would not be career planning until they finish their programs or current positions. These respondents will likely be pursing career opportunities within the next few years and additional career support may be needed at that time. These findings suggest that project leads should assess ways of assisting graduate students and postdocs in finding information about careers and who to contact. The subsequent sections summarize the activity report findings. Results of interviews conducted with internship participants, in which they were asked questions regarding how the internship impacted their research as well as their education and career plans, supplement the activity evaluation findings.

GROWTH Graduate/Postdoc Exchange and SURF programs

Since the Year 2 Annual Report, three graduate students, one postdoc, and five undergraduate students participated in the GROWTH internship programs. The table below displays the following for each intern: project role, home institution, visiting institution, and length of internship. The map below displays the locations of the internships over the past year and number of interns at each location. Over the past year, the interns visited four partner nations and institutions.

Student	Project role	Home institution	Visiting institution	Internship length
Intern 1	Postdoc	Stockholm University, Sweden	Caltech, US	21 weeks
Intern 2	Graduate	University of Wisconsin, Milwaukee, US	Caltech, US	7 weeks
Intern 3	Graduate	University of Maryland, US	Caltech, US	17 weeks
Intern 4	Graduate	Tokyo Institute of Technology, Tokyo	Caltech, US	29 weeks
Intern 5	Undergraduate	Caltech, US	National Central University, Taiwan	9 weeks
Intern 6	Undergraduate	Caltech, US	Tokyo Institute of Technology, Tokyo	8.5 weeks
Intern 7	Undergraduate	University of Wisconsin, Milwaukee, US	Humboldt University of Berlin, Germany	10.5 weeks
Intern 8	Undergraduate	University of Maryland, US	Humboldt University of Berlin, Germany	9 weeks
Intern 9	Undergraduate	Liverpool John Moores University, UK	Caltech, US	7 weeks

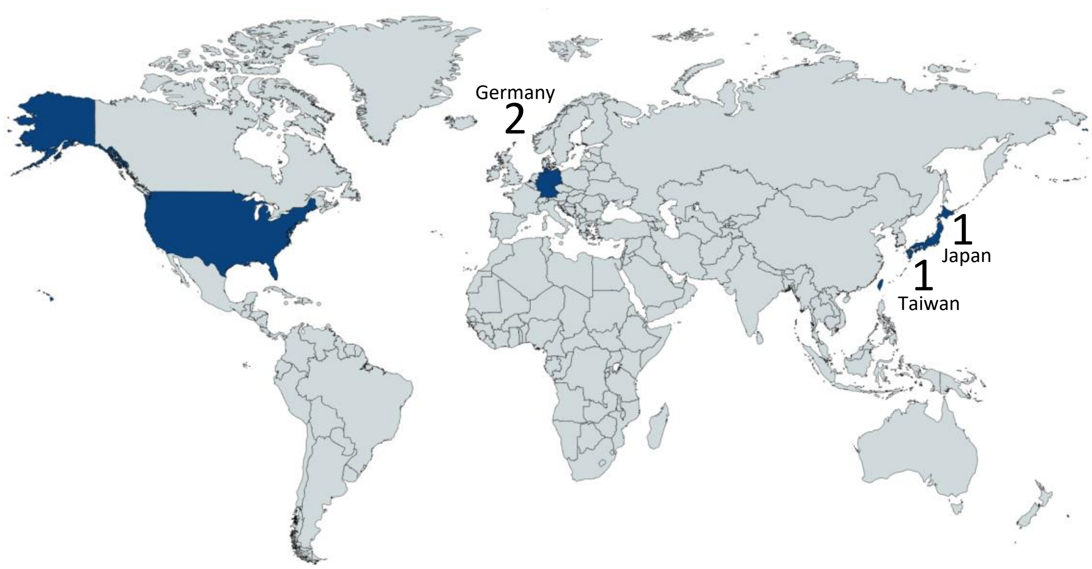


Figure 10. GROWTH internship locations and number of interns hosted in Year 3

Summary of findings from internship programs

Internships took place between May and November 2017, with the average internship lasting 7-10 weeks for undergraduates and 7-29 weeks for graduate students and postdocs. The internship programs focused on increasing students' astronomy/astrophysics skills and knowledge, increasing their interest in astronomy/astrophysics careers and continuing education, and positively influencing students' intercultural competencies and their ability to successfully work in diverse international teams. The extent to which the internships impacted these areas is summarized below. Overall, findings from this year are comparable to findings from previous annual reports, which may be due to students with similar skills and backgrounds participating in the internship programs in both years.

Increased knowledge and skills

Undergraduate student respondents had a moderate increase in their research and technical skills, sharing they learned a wide variety of important skills, such as Python and LaTex. Findings indicate the internship was less effective at increasing research and technical skills for graduate students and postdocs. This is likely because respondents already possessed a highly developed skillset before participating in the internship.

Continued interest in astronomy/astrophysics careers and education

While findings from all respondents indicated the internship was less effective in increasing career and education interests, this is likely due to these respondents having a high level of interest in astronomy/astrophysics before participating in the internship. Graduate students and postdocs in particular have already invested much of their time in their respective fields. Some undergraduate student respondents indicated they were more prepared for attending graduate school and entering careers and they planned to participate further in astronomy/astrophysics research after participating in the internship.

Increased intercultural competencies and the ability to successfully work in diverse international teams

Overall, all undergraduate student respondents had an increased understanding of how to collaborate with researchers who are from different disciplines and countries and had increased global research competencies (understanding different cultural backgrounds' influences on research perspectives, how cultural backgrounds influence communication, and ability to modify communication styles to fit culturally diverse audiences). In fact, one respondent shared these were the most important skills he/she learned during the internship. Graduate student and postdoc respondents also had an increased understanding of how to collaborate with researchers from different disciplines and countries, as well as global competencies. One respondent shared that through collaborating with people who were on different parts of the project, he/she has a better understanding of the research process.

GROWTH undergraduate and graduate courses

GROWTH courses are designed to engage the students through data-driven discovery, which is the use of real data in the classroom. By working with real data, students are given the opportunity to design their own research questions and engage in the research process from the initial design phase to presenting their results though presentations and papers. The GROWTH project's connections and network allow the students involved in the affiliated course the opportunities to use data they would not otherwise be able to. The diagram below displays how GROWTH courses are meant to impact student learning.

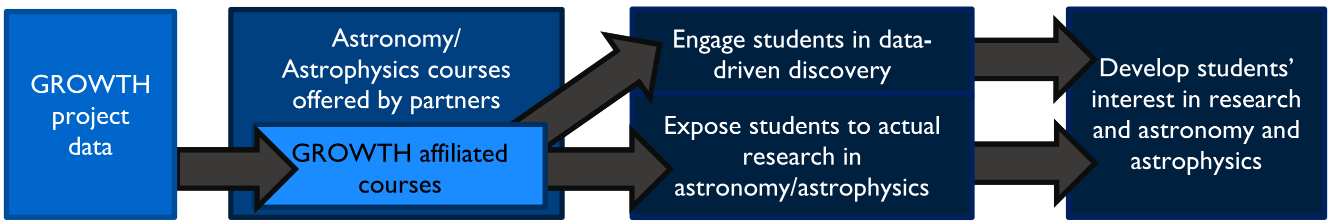


Figure 11. Intended impact of GROWTH courses on student learning

Since the Year 2 Annual Report, seven GROWTH courses have been offered. Four courses were offered in Spring 2017 and three in Fall 2017. Of the four spring courses, evaluation findings for one course (AY3: Automated Discovery of the Universe) were presented in the Year 2 Annual Report, and thus are not included in this report. Results from evaluations of the other three Spring 2017 courses and the three Fall 2017 courses are summarized in the following sections. The table below displays all project courses in 2017.

Course	Institution	Date offered	Student level
AY3: Automated Discovery of the Universe[a]	Caltech, USA	1/4/2017-3/17/2017	Undergraduate
Observational Astronomy (YSC2217)	Yale-NUS College, Singapore	1/9/2017-4/14/2017	Undergraduate
Advanced Introductory Astronomy (A51)	Pomona College, USA	1/17/17-5/12/17	Undergraduate
Advanced Astronomical Observations (AS6005)	National Central University, Taiwan	2/14/2017-6/14/2017	Graduate
Astronomical Techniques (ASTR 680)	San Diego State University, USA (SDSU)	8/22/17-12/21/17	Graduate
Observational Astronomy (ASTR 310)	University of Maryland, College Park, USA (UMD)	8/28/17-12/19/17	Undergraduate
Clocking Dead Stars with Radio Telescopes (PHYS 194)	University of Wisconsin, Milwaukee, USA (UWM)	9/5/17-12/23/17	Undergraduate

a. Evaluation results previously reported in the Year 2 Annual Report.

Figure 12. GROWTH courses, institutions, dates offered, and student levels

Summary of findings from courses

The six GROWTH course evaluations were completed by 55 out of 78 students (71%). Of the 55 respondents, 44 (80%) were undergraduate students and 11 (20%) were graduate students. Overall, the courses increased respondents' astronomy/astrophysics skills and knowledge and increased their interest in astronomy/astrophysics careers and continuing education. The extent to which these courses impacted these areas is reported below. Overall, findings from this year are comparable to findings from previous annual reports. This may be due to students with similar skills, abilities, and interests enrolling in the courses in both years.

Increased knowledge and skills in astronomy/astrophysics

Nearly all respondents agreed the courses increased their knowledge and skills related to astronomy/astrophysics. Respondents shared that having the opportunity to utilize real-world data and the hands-on component of collecting their own data were essential to gaining new knowledge and skills. Specifically, respondents shared they used data analysis tools and techniques such as image reduction techniques and Python/UNIX. Respondents' agreed they had increased ability to present scientific findings through written or oral presentations. Quotes from respondents who had increased knowledge and skills are presented below:

- "This class has improved my understanding of how to ask scientifically interesting questions, work with real data, write scientific papers, and give good scientific talks."
- "…Taking this course gave me a strong introduction to the astronomical research process, particularly photometry and source detection with algorithms like DAOphot."
- "Being able to use the astronomical tools put a lot of astrophysics into perspective…which makes for a more sophisticated understanding of the physics of the cosmos."
- "I never really had a full glimpse into the whole research process before this class. Through this course I was able to work through the whole process and have a much greater understanding of the process."

Increased interest in astronomy/astrophysics careers and education

Overall, almost all respondents agreed the course increased their interest in astronomy/astrophysics research, careers, and continuing education in the field. The courses enabled them to learn about areas of research that were of interest to them, which likely contributed to their increased interest in the field and continuing education. Undergraduate and graduate student respondents shared that receiving hands-on experience with real data and engaging in the research process were also instrumental in increasing their interest in conducting astronomy/astrophysics research. In particular, increased interest among the undergraduate respondents is a positive sign, as this can be an early indicator that students may continue to pursue STEM education and careers. A sample of respondents' comments regarding their continued interest in STEM are below:

- "I am very interested in continuing learning how to conduct research in astronomy/astrophysics. I will be taking ASTR101, Techniques in Observational Astronomy, next year."
- "I was already planning on becoming an astronomer, but this course helped me solidify that plan by exposing me to some of the things I might do as an astronomer."

Progress made towards strengthening partnerships (Goal 3)

Evaluators examined progress made towards strengthening partnerships by analyzing individual-level collaborations and by assessing publications that came out of those collaborations. The publication network analysis is used as a measure of the products of scientific and educational collaborations, while the Social Network Analysis (SNA) is used as a measure of participant and institutional collaboration. These analyses help provide insight into how the project is progressing towards its vision of a strong collaborative network that catalyzes scientific and educational achievements. Both will explore two evaluation questions: 1) To what extent has the project facilitated collaborations between partner institutions; and 2) To what extent has the project facilitated research and education (mentorship) collaborations? Project leads did not have specific targets for partnerships but did expect collaborations to continue to grow across the project's lifespan. Additionally, project planning for sustainability was examined using responses from the annual progress survey. Responses by project leads in the progress survey were used to assess the projected sustainability of the project.

Collaborations assessed through products (publications)

Publications that have resulted from the project members and partner institutions were used as a proxy measure for collaborations, especially international collaborations, as these publications can be used to show both the frequency of collaboration and the extent that a publication involves international partners. Figures 13 and 14 display actual publications, which does not take into account developed and/or submitted manuscripts. There could be more publication collaboration occurring among project members than displayed in the map and diagram.

The partner institutions involved in publications have been mapped on their exact geolocation. Circles depict institutions, while lines depict the publication collaborations which have occurred between institutions. The circles and lines are further distinguished by color, with American institutions colored **blue**, European institutions colored yellow, and Asian institutions colored **red**. Collaboration lines between institutions of the same continent are colored the same as the circles. For example, publications between two American institutions have a blue line between two blue circles. Collaboration lines between institutions on different continents are colored as follows:

- **Green** lines signify collaborations between American and European institutions.
- **Purple** lines signify collaborations between Asian and American institutions.
- **Orange** lines signify collaborations between European and Asian institutions.

The frequency of collaboration is how many times an institution has collaborated with another institution on individual publications. The thicker lines signify more collaborations on publications and thinner lines signify fewer collaborations on publications. The frequency of collaboration between institutions ranged from 1 to 35 publications.

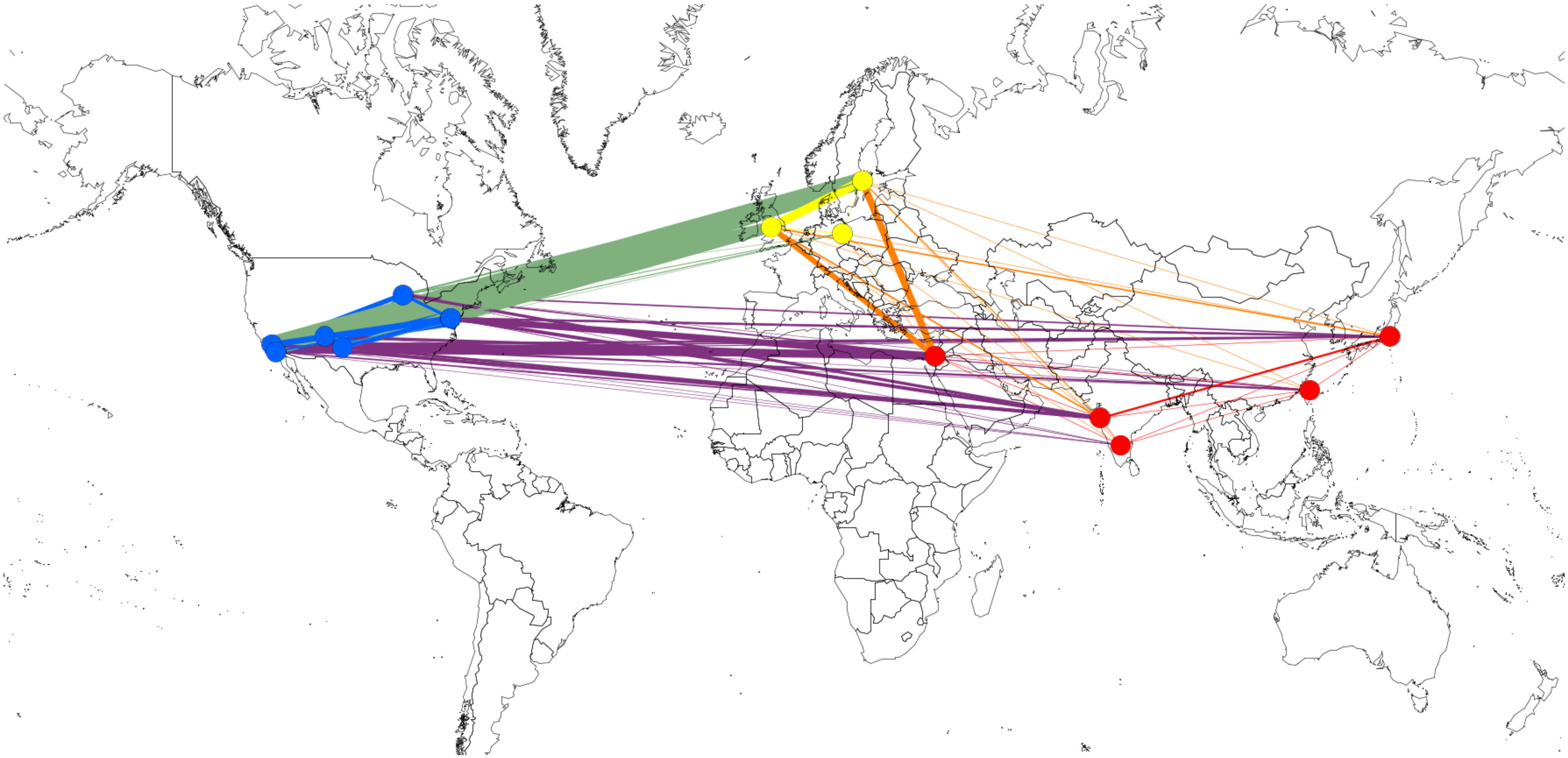


Figure 13. GROWTH international publication network map for Year 3 cumulative publications

Institution continents

- American
- European
- Asian

Institution continent collaborations

- American
- European
- Asian
- American and European
- European and Asian
- Asian and American

Since the United States was the location of six of the 14 partner institutions, a diagram of the United States partner institutions is displayed below. Each partner institution is labeled in the diagram. The frequency of collaboration between institutions ranged from 1 to 34 publications. The width of the lines represents the frequency of collaboration between the partner institutions.

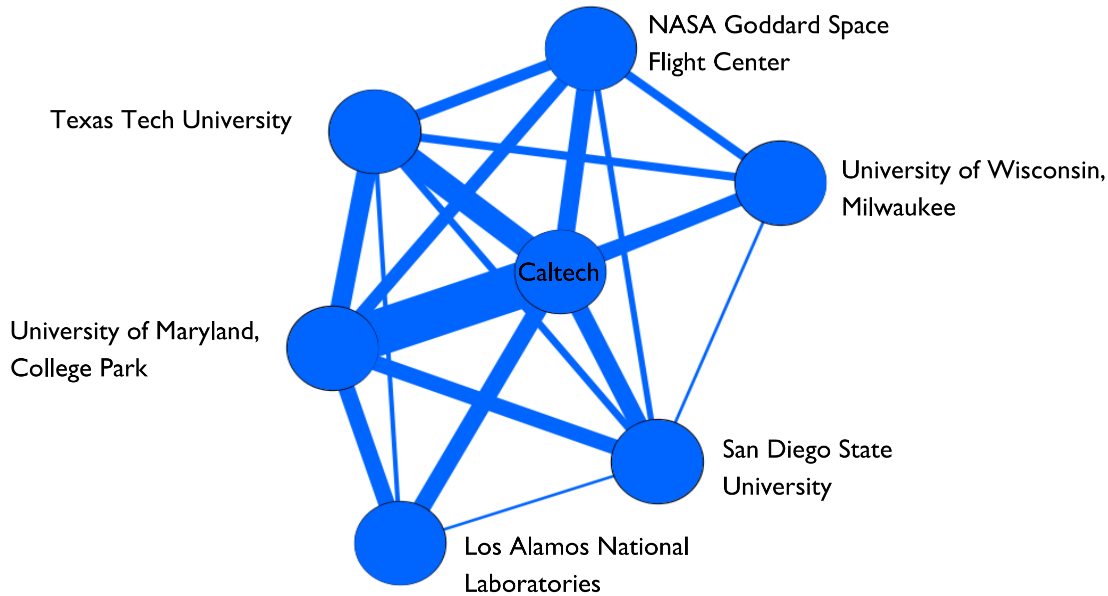


Figure 14. GROWTH U.S. publication network diagram for Year 3 cumulative publications

Key findings from the publication maps:

- Overall, Year 3 publication networks were very similar to Year 2 networks, with the noticeable exception that there was a higher frequency of collaboration occurring between partners.
- Most institutions were collaborating with all other partner institutions on publications.
- American institutions published most frequently together, especially Caltech and the University of Maryland, College Park which collaborated the most frequently together (33 publications).
- American and European institutions were the most frequent intercontinental publication partners, with the Oscar Klein Centre (39 publications) and Liverpool John Moores University, (24 publications), publishing most frequently with American institutions.
- American and Asian institutions also published frequently with each other, with Weizmann Institute being the most frequent institution from Asia publishing with American institutions.
- Asian and European institutions published the least together, with the most publications occurring between National Central University and Oscar Klein Centre (14 publications).
- Overall, Caltech (62 publications) and the Oscar Klein Centre (39 publications) appeared most frequently on publications.
- Asian institutions appeared less frequently on publications than American and European institutions (39 publications).
- Of all partners, Humboldt University, appeared the least on publications (2 publications).

Participant-level collaborations

At the beginning of Year 3, evaluators investigated the collaborations among the members of the project using a SNA survey. Fifty-eight project members were sent the link to the progress survey, and 45 (78%) completed it. The social network map (on the following page) displays those who completed the survey (n=44), those who partially completed the survey (n=1), and those who did not complete the survey but were selected by the survey completers (n=14). If a participant did not complete the survey and was not selected by anyone else as a collaborator, they did not appear in the network (n=1). By conducting the SNA, evaluators were able to visualize the collaborative network of the GROWTH project. Participants identified with which institution they were affiliated, with the option to specify one not listed, which was different than previous years where they were assigned their institution. They were also asked to identify how they collaborate with other project members with regard to research and education.

Analysis of participant Eigenvector scores, which is a measure of an individual's influence on the network, was conducted. From this analysis, evaluators were able to determine that project members from Caltech were the most influential members in the project's collaborative network, with four of the ten most influential individuals being from Caltech. The others were from the following:

- Oscar Klein Center (2 participants)
- Weizmann Institute
- University of Maryland, College Park
- Liverpool John Moores University
- NASA Goddard Space Flight Center

Tokyo Institute of Technology was the most isolated institution within the GROWTH network, as only four out of 11 members identified connections with others outside of their institution and almost all members were working with one another.

While original intent of the network analysis was to analyze growth of the networks across project years, the low response rate for the baseline SNA limited this comparison. The baseline map of responses is an incomplete representation of the GROWTH network and can therefore not serve as a sound baseline for network collaboration. It should also be noted that the baseline SNA was collected near the end of Year 1 and this year's SNA was collected at the beginning of Year 3, both at the project annual meetings. In a planning meeting, the evaluator and project leads agreed that the SNA would be conducted once more in Year 5 to allow more time for collaborations to develop and grow.

California Institute of Technology (U.S.)
Indian Institute of Astrophysics (India)
Liverpool John Moores University (U.K.)
Los Alamos National Laboratory (U.S)
National Central University (Taiwan)
San Diego State University (U.S.)
Tokyo Institute of Technology (Japan)
University of Wisconsin, Milwaukee (U.S.)
Humboldt University of Berlin (Germany)
Indian Institute of Technology/Inter-University Centre for Astronomy and Astrophysics (India)
NASA (U.S.)
Oscar Klein Centre at Stockholm University (Sweden)
Texas Tech University (U.S.)
University of Maryland, College Park (U.S.)
Weizmann Institute of Science (Israel)

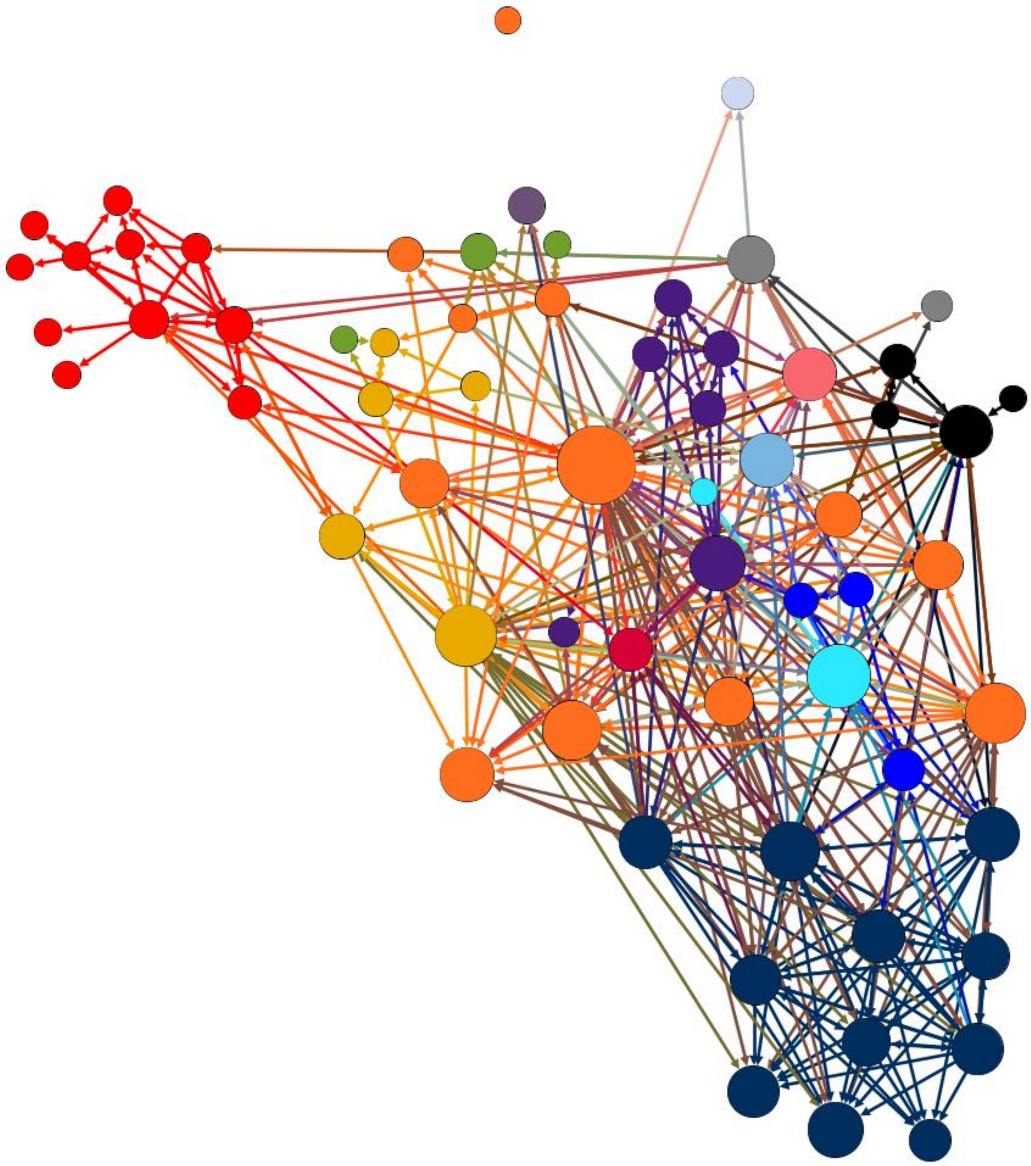


Figure 15. Year 3 GROWTH collaboration network

All project members, except undergraduate students, (n=43) shared their thoughts on collaborations with other GROWTH participants. All but one respondent thought that their GROWTH collaborations were key in achieving project goals. Among these respondents, 28 planned to further enhance their collaborations in the future and 14 were satisfied with their level of collaboration and plan to maintain it. In addition to achieving project goals, all but two respondents (n=41) viewed their GROWTH collaborations as beneficial to their research careers. Thirty-one planned on further enhancing collaborations that were beneficial to their research and 10 were satisfied with their collaborations and plan on maintaining them. Of the two who did not find the collaboration beneficial to their research, one thought collaborations were important but not essential, and the other thought the collaborations were not key to achieving their research goals.

Research and education collaborations

Respondents indicated how they were collaborating in research or education activities with the individuals they selected in the SNA. For each person they collaborated with, respondents selected all activities they were engaged in with that individual from a list developed by the project leads. Totals were generated for each type of activity. In total, there were 1295 research and 202 education collaborations. The frequencies for specific collaboration types are displayed in boxes to the right in the appropriate section. Project leads do not have specific goals for number of collaborations or the type of activities they collaborate on, only that collaboration continues to expand.

Research collaborations

Six primary means of research collaboration were identified by project leads. Overall, most research collaborations were in writing and submitting publications, observing and data collection, or data processing and analysis collaborations. This was expected, as supporting the observations of transients and solar system bodies is the main thrust of the GROWTH project. Interviews with project leads also supported that these were the main ways in which participants collaborated. One senior investigator stated that GROWTH was extremely helpful in getting high quality papers out after the LIGO discovery. Another stated that GROWTH provided a strong collaborative network and gave participants possibilities to publish papers that would have been harder for participants to do alone.

Types of research collaborations

- 334 writing and submitting publications
- 332 observing and data collection
- 328 data processing and analysis
- 197 submitting telescope or grant proposals
- 97 theory and modeling
- 7 other (group meetings, technical work, and research management)

A network analysis map of research collaborations was also developed. These results very closely reflected the participant-level collaboration map as described previously, therefore the map was not included. This is likely due to most of the collaborations in the project being research oriented.

Education collaborations

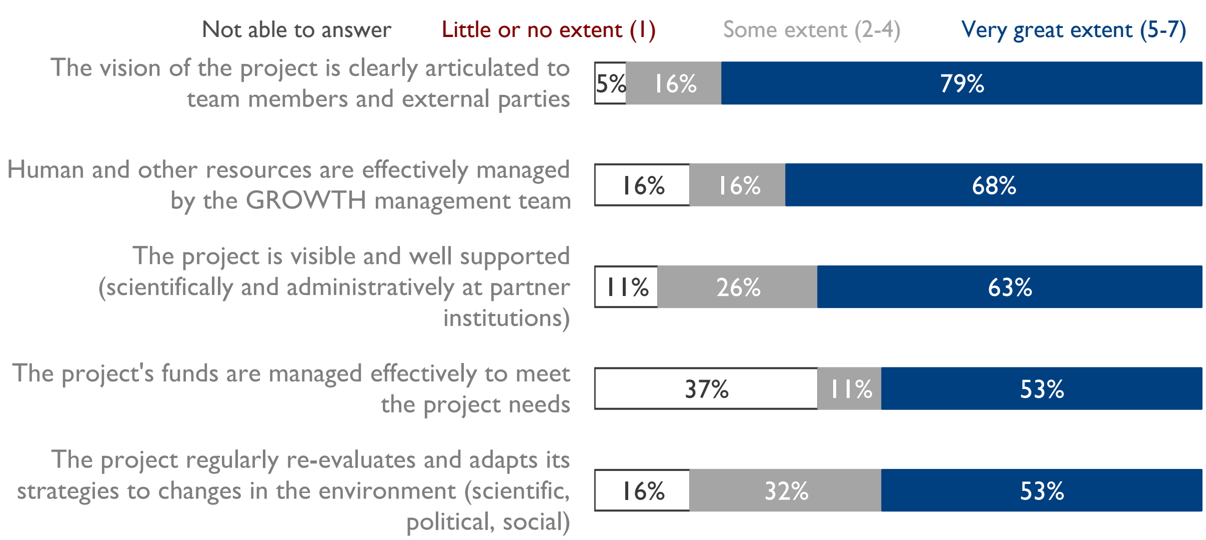
Project leads identified mentorship as the primary education collaboration activity, which included mentoring students or being mentored by other researchers. Moreover, the majority of all possible education collaborations was in mentorship and advisement. Two project members in interviews also described the project as a successful way of exposing young researchers to the field and teaching them how to conduct research. One member also highlighted that the international aspect of the project allows students to gain a greater awareness of how science is conducted in other regions and countries and to learn how to take these ideas and apply them to their research. Appendix D contains the other types of education collaborations beyond mentorship as well as the education collaboration network map.

Types of mentorship/education collaborations

- 89 mentoring or advising students
- 31 being mentored or advised by project members
- 26 other (such as providing computer facilities for instruction, academic advising, growth management, and other forms of mentorship)

Project sustainability

Sustainability is an important aspect of NSF-funded projects. By planning for sustainability now, project leads can contemplate the ways in which project infrastructure can be maintained and how outcomes can continue to be facilitated after funding. Project lead respondents to the annual progress survey (n=19) were asked to assess the sustainability capacity of GROWTH in five areas (on a 7-point scale from "little or no extent" to "some extent"). Overall, most respondents (53-79%) indicated GROWTH has the capacity for sustainability in all areas. Respondents indicated that the articulation of the vision to members, effective management, and support are some of the strongest areas. Evaluation and adaptation of strategies in changing environments and effective management of project funds are the areas that should continue to be focused on over the next two years.



Evaluator recommendations

Goal 1: GROWTH research

- As of Year 3, project members have produced a cumulative total of 82 published astronomy/astrophysics articles, exceeding the targeted 55 publications for lifespan of the project. Participants produced 40 publications in Year 3, which was almost three times more than in Year 1 and 1.5 times more than in Year 2. GROWTH participants continued to publish in high impact journals, which ensured members' research was widely distributed. The GW170817 discovery served as the major catalyst for project discoveries in the past year which contributed to increased publications and presentations. Project leads predicted that this may serve to be the ultimate discovery of the project's span, and the volume of publications in Year 3 reflects this phenomenon. At the time of this report, the project leads did not anticipate that the publications in Year 4 or 5 would match or exceed the number produced in Year 3. Young researchers have been very involved in the publication process, with more than three-quarters of graduate students and postdocs listed as authors on cumulative publications.

  Recommendations:

  - Continue to support research activities and submissions to high impact journals by sharing best practices and tips for disseminating work.
  - Encourage researchers to continue the positive effects of GW170817 through continued publications and presentations.
  - Continue to help young researchers engage in publishing activities by ensuring their research and internship mentors provide guidance on publishing.

Goal 2: Education and workforce development

- GROWTH continued to provide students and young researchers with excellent opportunities to both learn in the classroom and conduct research in various settings. The internship programs for undergraduates, graduate students, and postdocs provided young researchers with opportunities to network with leading researchers in the field and to explore the international scope of the research. The incorporation of hands-on learning in the classroom was beneficial to students, as this helped them understand how to conduct research from the beginning of the process to conclusion.

- Young researchers in the project were interested in continuing to pursue their career and education plans in areas related to astronomy and astrophysics. However, some did not know where to seek out this information or who to talk to.

  Recommendations:

  - Consider additional methods of providing or incorporating STEM career information for graduate students and postdocs into existing project structure, such as through a panel at the GROWTH annual meeting, asking internship advisors to share career advice as part of the internship programs, or identifying resources (career centers, job listservs, etc.) containing STEM career opportunities that can be shared.

- Given that the purpose of the GROWTH SURF program is to provide students with opportunities to engage in international research and develop collaborations skills they can apply in the future, program leads can focus on continuing to provide research opportunities with mentors and exposing participants to new research areas.
- Given the success of hands-on learning through data-driven discovery, continue to introduce this concept into additional astronomy and astrophysics courses. The upcoming GROWTH winter school in India provides an additional opportunity to bring data-driven discovery into the classroom and give students hands-on learning experience.

Goal 3: Collaboration capacity and sustainability

- Publications served as one of the major ways for project members to collaborate with each other, but many primarily published with others from within their own institutions. Overall, the participant-level collaborations SNA map (Figure 15) displayed similar results to the baseline, such as American and European partners collaborating the most and Asian partners collaborating and publishing the least among the different participant groups.

- Results from the sustainability assessment of the progress survey indicated that project leads likely anticipate the overall vision of advancing scientific achievements in these fields will sustain past the current funding period as the project has helped implement an infrastructure at the partner institutions to support this. Findings also indicated that the adaptability of project infrastructure and effective management of project funds are areas for continued focus in the last two years of the project.

Recommendations:

- Foster further collaboration by facilitating more opportunities for members at different institutions to collaborate on research. Those that are more isolated both with regard to publishing and in the social network may need additional support with integrating their research with other areas. More meetings and activities that allow Asian and European partners to become more involved may help to facilitate this. Use the upcoming meeting in India as a chance to foster collaboration among members who have had fewer opportunities to get involved with those at more central institutions in the project.
- As the project moves into its final years, leadership should assess mechanisms to put into place to continue use and sharing of research in this field, such as supporting use of the GROWTH Marshal, seeking out additional funding to institutionalize collaboration activities, and discussing which portions of the project leads envision carrying out beyond the current funding period.

Appendix A. Project Published Articles and Corresponding Numbers for Years 1-3

Article number	Article title
1	Detection of Broad Hα Emission Lines in the Late-time Spectra of a Hydrogen-poor Superluminous Supernova
2	Long-rising Type II supernovae from PTF and CCCP
3	Flash Spectroscopy: Emission Lines from the Ionized Circumstellar Material around <10-day-old Type II Supernovae
4	Optical and Near-infrared Observations of SN 2013dx Associated with GRB 130702A
5	Type II Supernova Energetics and Comparison of Light Curves to Shock-cooling Models
6	Galaxy Strategy for LIGO-Virgo Gravitational Wave Counterpart Searches
7	The bolometric light curves and physical parameters of stripped-envelope supernovae
8	Absence of Fast-moving Iron in an Intermediate Type Ia Supernova between Normal and Super-Chandrasekhar
9	iPTF Search for an Optical Counterpart to Gravitational-wave Transient GW150914
10	PTF13efv—An Outburst 500 Days Prior to the SNHunt 275 Explosion and Its Radiative Efficiency
11	Localization and Broadband Follow-up of the Gravitational-wave Transient GW150914
12	The peculiar Type Ia supernova iPTF14atg: Chandrasekhar-mass explosion or violent merger?
13	Time-varying sodium absorption in the Type Ia supernova 2013gh
14	iPTF15dtg: a double-peaked Type Ic supernova from a massive progenitor
15	Going the Distance: Mapping Host Galaxies of LIGO and Virgo Sources in Three Dimensions Using Local Cosmography and Targeted Follow-up
16	Radio Follow-up of Gravitational-wave Triggers during Advanced LIGO O1
17	iPTF16geu: A multiply imaged, gravitationally lensed type Ia supernova
18	Radio Observations of a Sample of Broad-line Type IC Supernovae Discovered by PTF/IPTF: A Search for Relativistic Explosions
19	Intermediate Palomar Transient Factory: Realtime Image Subtraction Pipeline
20	PS1-14bj: A Hydrogen-poor Superluminous Supernova With a Long Rise and Slow Decay
21	SN2002es-like Supernovae from Different Viewing Angles
22	Systematic Study of Gamma-ray-bright Blazars with Optical Polarization and Gamma-Ray Variability
23	Large Super-fast Rotator Hunting Using the Intermediate Palomar Transient Factory
24	Dead or Alive? Long-term evolution of SN 2015bh (SNhunt275)
25	Common Envelope Ejection for a Luminous Red Nova in M101
26	Confined Dense Circumstellar Material Surrounding a Regular Type II Supernova: The Unique Flash-Spectroscopy Event of SN 2013fs
27	On the Early-time Excess Emission in Hydrogen-poor Superluminous Supernovae
28	A novel method for transient detection in high-cadence optical surveys: Its application for a systematic search for novae in M31
29	PTF1 J082340.04+081936.5: Hot Subdwarf B Star with a Low-mass White Dwarf Companion in an 87-minute Orbit
30	A measurement of interstellar polarization and an estimation of Galactic extinction for the direction of the X-ray black hole binary V404 Cygni

31	iPTF Discovery of the Rapid "Turn-on" of a Luminous Quasar
32	Two New Calcium-rich Gap Transients in Group and Cluster Environments
33	Type Ibn Supernovae Show Photometric Homogeneity and Spectral Diversity at Maximum Light
34	Color Me Intrigued: the Discovery of iPTF 16fnm, a Supernova 2002cx-like Object
35	Geographic and Annual Influences on Optical Follow-up of Gravitational Wave Events
36	Small Near-Earth Astroids in the Palomar Transient Factory Survey: A Real-Time Streak-detection System
37	An Enhanced Method for Scheduling Observations of Large Sky Error Regions for Finding Optical Counterparts to Transits
38	SN2015bp: adding to the growing population of transitional Type Ia supernovae
39	A Search of Reactivated Comets
40	Far-Ultraviolet to Near-Infrared Spectroscopy of A Nearby Hydrogen Poor Superluminous Supernova Gaia16apd
41	Confirmation of a Large Super-fast Rotator (144977) 2005 EC_{127}
42	Revisiting Optical Tidal Disruption Events with iPTF16axa
43	Infrared Emission from Kilonovae: The Case of the Nearby Short Hard Burst GRB 160821B
44	iPTF16fnl: A Faint and Fast Tidal Disruption Event in an E+A Galaxy
45	The bumpy light curve of supernova iPTF13z
46	A Tale of Two Transients: GW 170104 and GRB 170105A
47	Light curves of hydrogen-poor Superluminous Supernovae from the Palomar Transient Factory
48	Early Observations of the Type Ia Supernova iPTF 16abc: Evidence for Strong Ejecta Mixing or Interaction with Diffuse Material
49	A Multiwavelength Study of Nearby Millisecond Pulsar PSR J1400-1431: Improved Astrometry and an Optical Detection of Its Cool White Dwarf Companion
50	iPTF17cw: An Engine-driven Supernova Candidate Discovered Independent of a Gamma-Ray Trigger
51	Hydrogen-poor Superluminous Supernovae With Late-time H-alpha Emission: Three Events From the Intermediate Palomar Transient Factory
52	Multi-messenger Observations of a Binary Neutron Star Merger
53	Census of the Local Universe (CLU) I: Characterization of Galaxy Catalogs from Preliminary Fields
54	The first direct double neutron star merger detection: implications for cosmic nucleosynthesis
55	Spectroscopic identification of r-process nucleosynthesis in a double neutron-star merger
56	Energetic eruptions leading to a peculiar hydrogen-rich explosion of a massive star
57	Hunting Electromagnetic Counterparts of Gravitational-wave Events Using the Zwicky Transient Facility
58	The OmegaWhite Survey for Short-period Variable Stars. V. Discovery of an Ultracompact Hot Subdwarf Binary with a Compact Companion in a 44-minute Orbit
59	iPTF 16asu: A Luminous, Rapidly Evolving, and High-velocity Supernova
60	1I/2017 U1 (‘Oumuamua) is Hot: Imaging, Spectroscopy, and Search of Meteor Activity
61	Follow Up of GW170817 and Its Electromagnetic Counterpart by Australian-Led Observing Programmes
62	Illuminating gravitational waves: A concordant picture of photons from a neutron star merger
63	Swift and NuSTAR observations of GW170817: Detection of a blue kilonova
64	A radio counterpart to a neutron star merger

65	PTF11mnb: First analog of supernova 2005bf. Long-rising, double-peaked supernova Ic from a massive progenitor
66	ASASSN-16fp (SN 2016coi): a transitional supernova between Type Ic and broad-lined Ic
67	iPTF Archival Search for Fast Optical Transients
68	Short-timescale γ-Ray Variability in CTA 102
69	The double-peaked radio light curve of PTF11qcj
70	Highly reddened Type Ia supernova SN 2004ab: another case of anomalous extinction
71	Exploring the optical behaviour of a Type Iax supernova SN 2014dt
72	A mildly relativistic wide-angle outflow in the neutron-star merger event GW170817
73	Spectra of Hydrogen-poor Superluminous Supernovae from the Palomar Transient Factory
74	A Preliminary Analysis of the Shangri-La Bolide on 2017 Oct 4
75	A turnover in the radio lightcurve of GW170817
76	From $gamma$ to Radio - The Electromagnetic Counterpart of GW 170817
77	Optical spectroscopy of the recurrent nova RS Ophiuchi - from the outburst of 2006 to quiescence
78	iPTF Survey for Cool Transients
79	Finding Long Lost Lexell's Comet: The Fate of the First Discovered Near-Earth Object
80	Breaking the Habit: The Peculiar 2016 Eruption of the Unique Recurrent Nova M31N 2008-12a
81	Broad-line Type Ic supernova SN 2014ad
82	Spitzer observations of SN 2014J and properties of mid-IR emission in Type Ia supernovae

Appendix B: GROWTH Publication Citations and Authors

Article #[a]	Project year published	# times cited	# GROWTH participant authors	# of GROWTH postdoc authors	# of GROWTH graduate student authors
1	Year 1	49	6	0	0
2	Year 1	0	6	3	0
3	Year 1	35	7	1	0
4	Year 1	16	5	0	0
5	Year 1	33	8	0	0
6	Year 1	39	2	0	0
7	Year 1	31	6	1	0
8	Year 1	6	6	1	0
9	Year 1	36	13	3	2
10	Year 1	19	6	0	1
11	Year 1	167	9	2	0
12	Year 1	16	6	2	0
13	Year 1	7	6	0	2
14	Year 1	17	8	3	1
15	Year 1	47	3	0	0
16	Year 2	11	5	0	0
17	Year 2	28	1	0	0
18	Year 2	11	7	1	0
19	Year 2	20	1	0	0
20	Year 2	34	1	1	0
21	Year 2	10	1	0	1
22	Year 2	9	1	1	0
23	Year 2	2	3	0	0
24	Year 2	22	1	0	0
25	Year 2	23	6	3	0
26	Year 2	27	7	1	0
27	Year 2	21	9	3	0
28	Year 2	2	2	0	0
29	Year 2	7	1	0	0
30	Year 2	5	1	1	0
31	Year 2	18	8	3	1
32	Year 2	8	5	2	1
33	Year 2	11	9	2	1
34	Year 2	5	8	2	1
35	Year 2	2	1	0	0
36	Year 2	8	2	0	0
37	Year 2	12	2	0	1

Article #[a]	Project year published	# times cited	# GROWTH participant authors	# of GROWTH postdoc authors	# of GROWTH graduate student authors
38	Year 2	2	1	0	0
39	Year 2	1	1	1	0
40	Year 2	27	6	2	0
41	Year 2	3	4	1	0
42	Year 2	21	7	3	1
43	Year 2	13	1	0	0
44	Year 2	22	9	3	2
45	Year 2	8	6	2	1
46	Year 2	9	11	3	0
47	Year 2	12	9	1	0
48	Year 2	3	9	4	1
49	Year 2	2	1	0	0
50	Year 2	4	12	3	0
51	Year 3	17	7	2	0
52	Year 3	277	15	4	2
53	Year 3	4	5	2	0
54	Year 3	9	5	2	0
55	Year 3	83	4	0	0
56	Year 3	10	12	5	1
57	Year 3	1	4	2	1
58	Year 3	1	3	2	0
59	Year 3	7	12	5	1
60	Year 3	22	1	1	0
61	Year 3	15	5	1	0
62	Year 3	61	29	9	3
63	Year 3	48	2	0	0
64	Year 3	56	8	0	3
65	Year 3	2	6	2	1
66	Year 3	0	1	0	0
67	Year 3	0	9	2	1
68	Year 3	0	1	0	0
69	Year 3	0	3	0	0
70	Year 3	1	1	0	0
71	Year 3	1	1	0	0
72	Year 3	45	6	0	1
73	Year 3	1	5	1	0
74	Year 3	0	1	1	0
75	Year 3	6	3	0	0
76	Year 3	4	1	0	0
77	Year 3	1	1	0	0
78	Year 3	1	15	5	4

Article #[a]	Project year published	# times cited	# GROWTH participant authors	# of GROWTH postdoc authors	# of GROWTH graduate student authors
79	Year 3	0	1	1	0
80	Year 3	2	1	0	0
81	Year 3	0	1	0	0
82	Year 3	29	5	0	0
Cumulative article total[a]		1,645	430	106	35
Average for all articles		20.1	5.24	1.29	0.4

a. Totals are cumulative and count each time a project member is listed as an author; therefore individual project members are counted multiple times in the total amount.

Appendix C: Presentations given by location

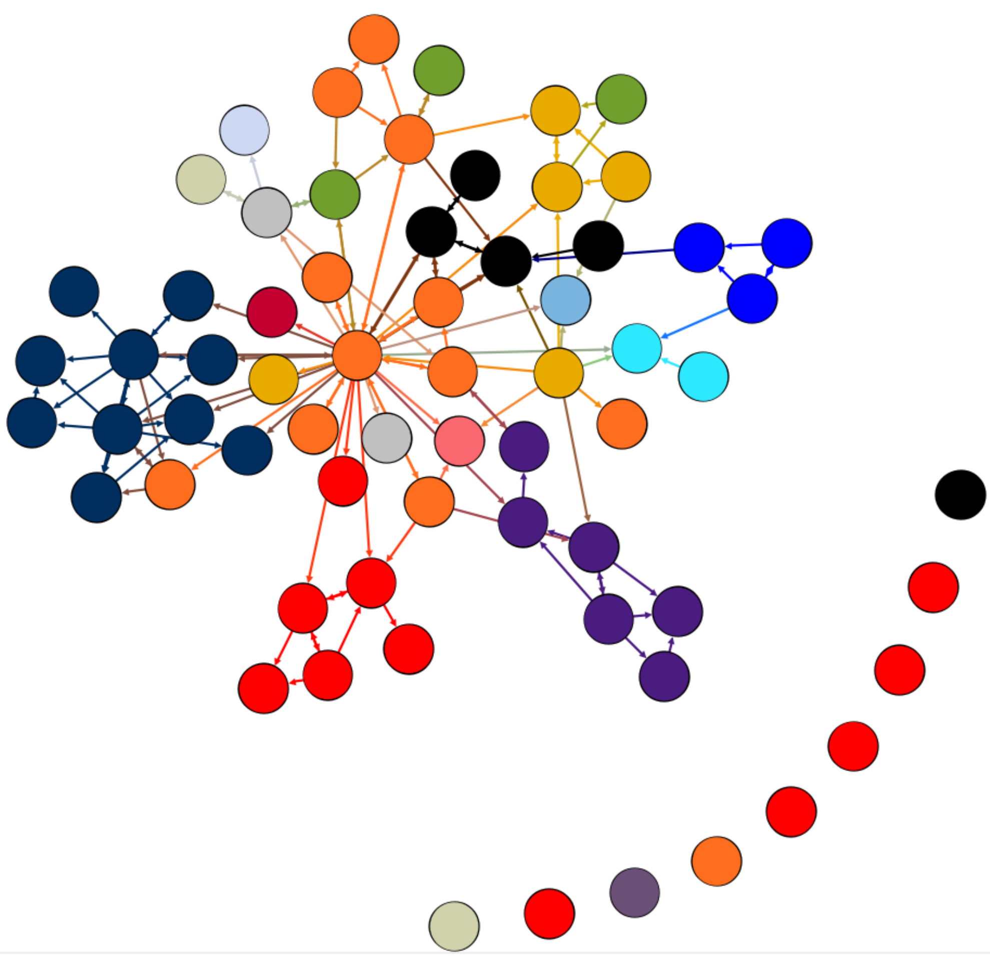
Location of presentation	# of presentations	Home of a partner institution
Canada	1	No
Denmark	1	No
India	8	Yes
Israel	1	Yes
Ireland	1	No
Japan	7	Yes
Mexico	4	No
Netherlands	4	No
Singapore	1	No
Sweden	4	Yes
United Kingdom	13	Yes
United States	43	Yes
California	8	Yes
Colorado	1	No
Hawaii	2	No
Illinois	1	No
Louisiana	1	No
Massachusetts	1	No
Mississippi	1	No
New York	2	No
Utah	1	No
Washington, D.C.	5	No
Wisconsin	20	Yes

Appendix D: GROWTH education collaborations and network map

Education collaboration type	Total collaborations
Total	202
Mentoring or advising students	89
Being mentored or advised by project members	31
Sharing teaching approaches and strategies	18
Developing new course materials for existing or new courses	16
Sharing course material	12
Education activities at annual meeting	10
Other[a]	26

a. Other includes: Coordinating GRAD-MAP program; He/She is my undergraduate advisor; providing computer facilities for instruction; Academic Advising; Teaching at summer school; Outreach; He/She was department chair for the astronomy department of [institution]; growth management; I was the mentor of [student]; mentoring postdocs; I mentored him/her; and outreach - coffee shop discussion.

Types of Caltech education collaborations



Caltech Education Network Map