The 2016-20 Summative Evaluation Report of the California Institute of Technology (Caltech) Global Relay of Observatories Watching Transients Happen (GROWTH) Partnerships for International Research and Education (PIRE) project

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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 Project

Executive summary

GROWTH is an international scientific collaborative project in astronomy that was implemented from 2015 to 2020, studying the physics of fast-changing events in the cosmos like supernovae, neutron stars or black hole mergers, and near-earth asteroids. Funded by the NSF Partnerships for International Research and Education (PIRE) program, the objective of the GROWTH project was to continuously observe and gather data from 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 were conducted among undergraduate students, graduate students, postdoctoral researchers, and faculty and researchers at 15 partner institutions around the world, with Caltech as the lead institution.

The current summative report summarizes achievement of goals over the life of the project, utilizing cumulative evaluation data and some of the latest findings from the internship programs and GROWTH Astronomy School.

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:

- Over the course of the grant, the GROWTH project published a total of 167 articles authored by 81 GROWTH project members.
- Overall, the proportion of GROWTH member authors on publications that were GROWTH postdocs or PhD students increased over the life of the project. Over one-third of total publications were co-authored by active or former postdoc or PhD students.
- GROWTH activities such as the internship programs, courses, and Astronomy School helped students gain knowledge and skills in astronomy as well as increase their interest in the field, science careers, and continued education.
- GROWTH fostered a notable number of intercontinental collaborations that supported the development of publications. Of the 167 publications, 111 were produced by two or more partner institutions in different continents.

Recommended next steps for GROWTH leadership:

Goal 1: GROWTH research

- Develop a plan for disseminating project-related results to specific fields, conferences, or disciplines that the project has not yet disseminated results to. This can help create partnerships that continue the work of the grant.

Goal 2: Education and workforce development

- For future Astronomy Schools or similar events, consider holding the event online to increase the reach of the event especially since the majority of evaluation respondents in the 2020 virtual Astronomy School reported that their experience participating in the School via an online format was good or very good. Also, consider using the recorded lectures created during the 2020 School in the next School so that participants can watch the lectures in advance.
- Consider inviting GROWTH graduate students to provide testimonials via short videos or blurbs that summarize how they have benefitted from participating in the project and how it influenced their future career goals to help motivate undergraduate students to continue participating in GROWTH activities.
- In future projects, implement a follow-up survey in the final years to assess whether students pursued continued education or scientific careers in the field of astronomy/astrophysics to more fully capture the impact of the project on the career and educational trajectories of students.

Goal 3: Capacity building (partnerships & sustainability)

- Ensure that GROWTH members know where they can go to find contact information of other GROWTH members and stay up to date on the accomplishments of GROWTH members.
    - Develop a communication method for the purpose of sharing research and additional funding opportunities. This may be a Google sheet or a separate tool to which GROWTH members have access. Or, consider asking if individuals would be willing to dedicate the time to help pursue additional funding opportunities.
- Consider developing a committee of volunteers that will help plan future conferences or other events that will help develop new collaborations and maintain existing ones. This may be something as simple as a virtual networking event with the purpose of sharing new discoveries and/or opportunities for collaboration.

Evaluation and report overview

Background

In 2015[1], 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 was led by Caltech and partnered with fifteen universities and research institutions (six in the USA and nine internationally in India, Sweden, Taiwan, Japan, Israel, Germany, Australia, and the United Kingdom). The objective of this project was to continuously observe and gather data from 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 were 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 was 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. The Mark served as the external evaluator, contracted through Caltech. The external evaluation was intended to provide an objective assessment of the project, so that it remains accountable to both the funder and project participants.

Evaluation approach

This report provides an overview of the impacts and outcomes of the project across all project years and recommendations for future similar projects. Findings from this report should be used by project leads to demonstrate the impact of the project to NSF and to the scientific community. The summative evaluation is driven by the three project goals. Evaluation questions for each goal are listed below.

Goal 1: Research – Has the GROWTH project 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 GROWTH project developed a sustainable STEM workforce by creating a pipeline of STEM-trained students, educators, and workers?

[1] The project received funding in 2015 and evaluation began in 2016.

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

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

- To what extent has the project facilitated research collaborations between partner institutions?
- 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 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 Web of Science.

Data collection and analysis

Surveys were administered through an online platform. Activity surveys assessed the Graduate/Postdoc Exchange Program, the GROWTH Summer Undergraduate Research Fellowship (SURF) Program, all GROWTH affiliated courses, and the Astronomy School. The annual progress survey assessed progress made in research and other project activities. This report includes summaries of evaluation reports on activities conducted between the last annual report (May 2019) and this summative report (September 2020). Quantitative results were analyzed using means and response frequencies, and qualitative data were coded for themes. It should be noted that some respondents provided comments that were coded as more than one theme. Therefore, the number of responses per theme may exceed the total number of respondents for the survey questions.

The Year 5 annual progress survey was administered in July 2020 to 56 participants who were active in the project at that time. Participants included principal/co-principal investigators, management team members, associate researchers, postdoctoral fellows, and PhD students. A total of 37 respondents (66% response rate) completed this annual progress survey. This summative report is also based on findings from previous annual progress surveys: Year 1 (July 2016, 55% response rate); Year 2 (October 2017, 83% response rate); Year 3 (December 2018, 75% response rate); Year 4 (September 2019, 77% response rate). Tracking data on participants' institution and role in the project was also collected by the project administrator and the evaluators. Publications were

analyzed using three bibliometrics from the Web of Science: Eigenfactor, Impact Factor, and h-index.

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 discussing activities they participated in. All information collected by The Mark is kept confidential. Participant information and data are kept on a secure server. Any identifying information is password protected and kept separate from data analysis through use of random IDs. Responses are not reported with any identifying information.

Project timeline

The timeline below displays major events in the GROWTH project's lifespan. GROWTH is currently in the last year of a five-year grant.

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

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 exchanges.
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 exchanges.
Year 3 (2017-18)	
October	Project wide- 2nd GROWTH Conference (annual meeting) held at the University of Wisconsin, Milwaukee (U.S.).
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.
June	UG- 6 undergraduate students participated in GROWTH SURF Program.
July	
August	Project wide- University of Washington, Seattle and University of Sydney, Australia joined GROWTH. UG/GS- Sixth set of GROWTH affiliated courses (ASTRO 310, ASTRO 680) began (31 students were enrolled in these courses). GS/PD- 2 graduate students and postdocs completed exchanges.
September	
Year 4 (2018-19)	
October	
November	
December	Project wide- 1st GROWTH Astronomy School held at the Indian Institute of Technology Bombay (India). Project wide- 3rd GROWTH Conference (annual meeting) held at the Indian Institute of Technology Bombay (India).
January	UG/GS- Seventh set of GROWTH affiliated courses (ASTRO 350, ASTR 498S, AS6005) began (29 students were enrolled in these courses).
February	
March	
April	GS/PD- 5 graduate students and postdocs completed exchanges.
May	Project wide- A cumulative total of 114 articles were published by members of GROWTH. Thirty-two of these were published in Year 4.
June	UG- 6 undergraduate students participated in GROWTH SURF Program.
July	
August	Project wide- 2nd GROWTH Astronomy School was held at San Diego State University (U.S.). Project wide- 4th GROWTH Conference (annual meeting) was held at San Diego State University (U.S.).
September	GS/PD- 3 graduate students and postdocs participated in the exchange program.
Year 5 (2019-20)	
October	UG/GS- Eighth set of GROWTH affiliated courses for Fall (ASTR 680, ASTRO 310, 36 total students were enrolled).
November	

December	
January	UG/GS- Ninth set of GROWTH affiliated courses for Spring (ASTRO 350, AS 6005, PH 556, 64 total students were enrolled).
February	GS/PD- 2 graduate students and postdocs completed internship exchanges.
March	GS/PD- 1 graduate student and postdocs completed an internship exchange.
April	
May	
June	
July	Project wide- A cumulative total of 167 articles were published by members of GROWTH. Fifty-three of these were published in year 5.
August	Project wide- 3rd GROWTH Astronomy School was held virtually. UG- 6 undergraduate students completed the GROWTH SURF Program.

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. A total of 22 institutions have been reported to participate in the project.

Participant backgrounds	Year 1 (n = 64)		Year 2 (n = 67)		Year 3 (n = 66)		Year 4 (n=69)		Year 5 (n=67)	
Institution[a]	#	%[b]	#	%	#	%[b]	#	%[b]	#	%[b]
California Institute of Technology (Caltech), US	16	25%	14	21%	12	18%	10	14%	8	12%
Humboldt University, Germany	1	2%	3	4%	4	6%	4	6%	4	6%
Indian Institute of Astrophysics, India	1	2%	1	1%	1	2%	2	3%	5	7%
Indian Institute of Technology Bombay, India	3	5%	3	4%	2	3%	4	6%	2	3%
Liverpool John Moores University, UK	--	--	5	7%	5	8%	6	9%	6	9%
Los Alamos National Laboratory, US	1	2%	1	1%	1	2%	1	1%	--	--
Max Planck Institute for Astronomy, Germany	1	2%	1	1%	--	--	--	--	--	--
Montgomery College, US	2	3%	--	--	--	--	--	--	--	--
NASA Goddard Space Flight Center, US	1	2%	1	1%	1	2%	1	1%	1	1%
National Central University, Taiwan	1	2%	1	1%	4	6%	4	6%	3	4%
Oskar Klein Centre, University of Stockholm, Sweden	11	17%	11	16%	13	20%	10	14%	7	10%
Pomona College, US	2	3%	1	1%	--[c]	--	--	--	--	--
San Diego State University, US	3	5%	2	3%	1	2%	1	1%	1	1%
Texas Tech University, US	--	--	--	--	1	2%	1	1%	1	1%
Tokyo Institute of Technology, Japan	9	14%	9	13%	10	15%	7	10%	7	10%
University of Maryland, College Park, US	6	9%	7	10%	5	8%	6	9%	6	9%
University of Wisconsin, Milwaukee, US	3	5%	4	6%	4	6%	3	4%	5	7%
Weizmann Institute of Science, Israel	3	5%	3	4%	2	3%	2	3%	3	4%
University of Sydney, Australia	--	--	--	--	--	--	3	4%	3	4%
University of Washington, US	--	--	--	--	--	--	4	6%	4	6%
South African Astronomical Observatory, South Africa	--	--	--	--	--	--	--	--	1	1%
Role in project										
PhD students	21	33%	21	31%	17	26%	20	29%	18	27%
Postdocs	17	27%	15	22%	18	27%	16	23%	15	22%
Senior investigators/researchers	18	28%	24	36%	31	47%	33	48%	34	51%
Undergraduate students[d]	8	13%	7	10%	--	--	--	--	--	--

a. All participating institutions are included in the table, including those who were no longer active in Year 5.
b. Percentages in table do not always add up to 100% due to rounding.
c. 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.
d. Per project leads' request, undergraduate students were not counted as project participants after Year 3 due to the nature of their participation in the project. Undergraduates are not expected to take part in more than the SURF Program or courses.

Figure 2. Project participation by institution and role

GROWTH partner institutions

The map below displays the current and former participating institutions by country over the life of the project. The number of participating institutions in each country is noted. The U.S. had the largest number of participating institutions (n=7), followed by India (n=2). All other partner nations have one institution. Interest in joining the collaboration grew both within the U.S. and internationally each year of the project, as demonstrated by the addition of new partner institutions in years 2 (one in the U.S. and one in U.K.) and 4 (one in the U.S. and one in Australia), and 5 (one in South Africa). 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.

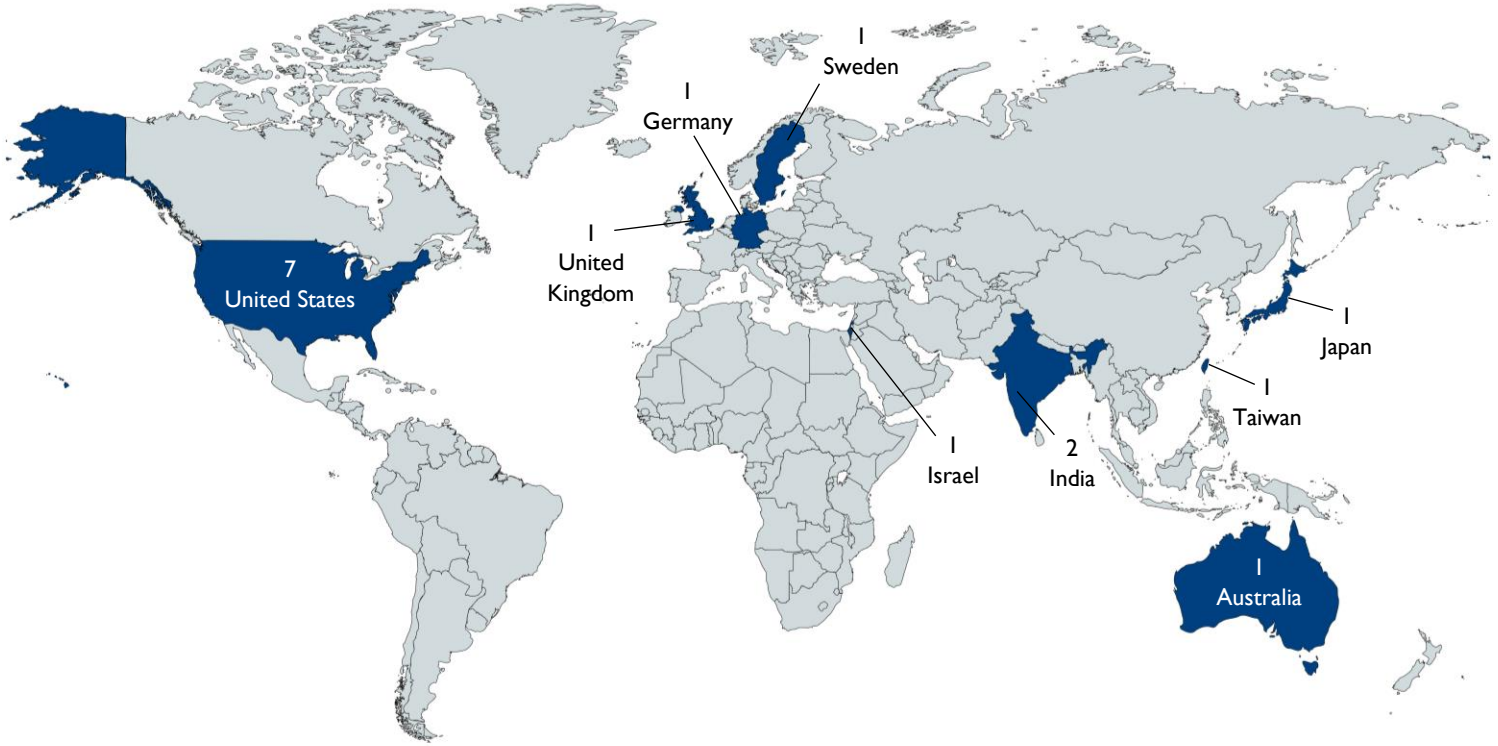


Figure 3. All GROWTH partner institutions and nations

Goal 1: Research

To assess Goal 1, evaluators examined the volume and impact of publications from project members. It should be noted that only published articles were included, as there was no available information on manuscripts that have been prepared and/or submitted. Contributions made by junior 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 used to determine if participants were submitting grants within GROWTH research areas and the project's influence on participants' research capabilities and scope. Further information on other research products from project members, including conference presentations/colloquium talks, workshops, and poster presentations will be reported by project leads.

Publications and grants

Publishing in academic, peer-reviewed journals is one major indicator of the strength and productivity of the GROWTH project. Overall, the GROWTH project has produced a total of 167 publications, more than triple the target of cumulative publications, 55. Appendix A lists all GROWTH publications. The number of publications in each project year generally increased over the course of the project, with the most publications (53) being produced in Year 5. A notable number of publications (40) was also seen in Year 3, partially attributable to the GW170817 discovery made in August 2017 which helped to stimulate research and academic scholarship across the GROWTH project. The table below shows the number of publications produced by project members each year.

Project year[a]	Annual publications	Cumulative publications	Cumulative project members as authors[b]
Year 1	15	15	29
Year 2	27	42	30
Year 3	40	82	43
Year 4	32	114	68
Year 5	53	167	81

a. Publication information was pulled from GROWTH's online database on August 3rd, 2020 and does not reflect any changes made to the database after this date. The originally reported Year 1-4 publication dates are reflected in this report. Any updates to publication dates are not included. One article was removed from the database but is recorded here for reporting purposes.
b. Project members may have published multiple times in a single year, but the number provided represents unduplicated counts. The cumulative number of project members as authors in years 1-4 only included those whom the project leads identified as active project participants at the time. For this final summative report, evaluators counted active and former GROWTH PIs, associate researchers, postdocs, and PhD students as authors across all publications.

Figure 4. Publications by year and number of GROWTH authors

The project has successfully included junior researchers in research and publishing opportunities. Overall, the proportion of GROWTH PhD students and postdocs among all GROWTH member coauthors on GROWTH publications has increased over the life of the project (67%-94% in Years 2-5), as illustrated in Figure 5. Of the 167 total GROWTH publications, PhD students and postdocs represented 42% of GROWTH member authors.

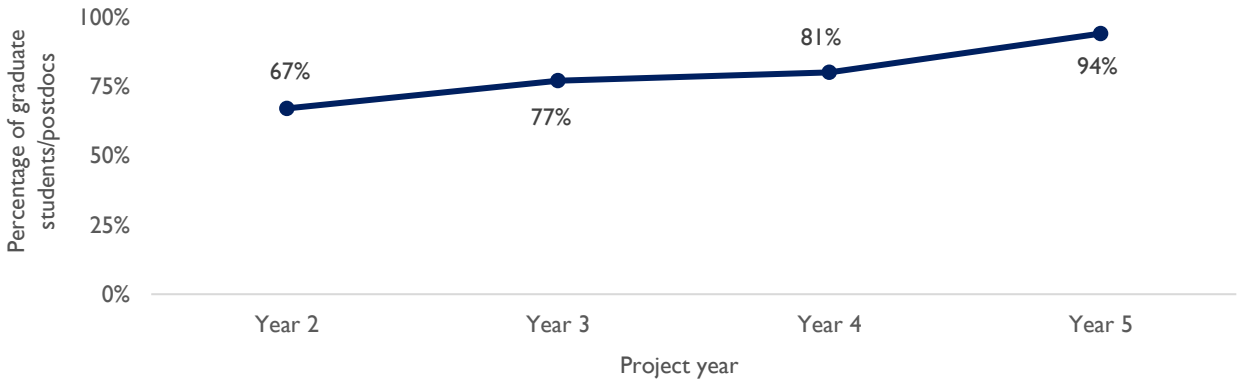


Figure 5. Percentage of graduate students and postdocs listed as coauthors on GROWTH publications by year

Total number of citations of GROWTH publications by year published:

- Year 1: 835
- Year 2: 834
- Year 3: 3739
- Year 4: 1036
- Year 5: 360

GROWTH publications over the project have accrued an impressive number of citations. The figure to the right displays the number of citations for GROWTH publications as of August 3, 2020. The number of citations has increased in later years of the project (i.e., Years 3 and 4) as the number of publications has also increased. Project Year 3 had the most cited articles compared to publications in other years, likely because of the large number of manuscripts published this year (40) and also likely because of the GW170817 discovery. The number of citations in Year 5 may have been impacted by the COVID-19 pandemic, resulting in less publications and opportunities for citations. It is expected that the number of citations of work published in Year 5 will increase substantially over the next few years. These citation data suggest that the articles published through the GROWTH project have been valuable to researchers in the fields of astronomy and astrophysics and will continue to be valuable in the future. Appendix B lists the number of citations for all publications along with the number of GROWTH authors on each.

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 167 GROWTH articles have been published and the respective bibliometrics. Seven of the journals that published GROWTH articles did not have Eigenfactor or other journal impact scores available. The most impactful journal based on all bibliometrics was Nature, which had a Normalized Eigenfactor score of 148.44, indicating that this was a highly influential journal (about 148 times as influential as the average journal). GROWTH members published three articles in Nature.

The second most influential journal that members published in was Science (EFn = 124.76). GROWTH submitted a total of five articles in Science over the life of the project. The average Normalized Eigenfactor for all journals, excluding Nature and Science, was 16.04.

Journal	Eigenfactor	Normalized Eigenfactor	Impact Factor	h-index	Published articles
Nature	1.21	148.44	42.77	1159	3
Science	1.02	124.76	41.84	1124	5
Physical Review Letters	0.51	62.7	8.38	602	1
Monthly Notices of the Royal Astronomical Society	0.25	30.82	5.35	301	20
Physical Review D	0.20	25.36	4.833	338	1
Astronomy & Astrophysics	0.17	21.28	5.64	243	9
Nature Physics	0.11	14.05	19.25	256	1
Nature Astronomy	0.01	1.54	11.51	28	1
Publications of the Astronomical Society of the Pacific	0.01	1.43	3.98	144	10
Publications of the Astronomical Society of Japan	0.01	1.31	5.02	N/A	1
Planetary and Space Science	0	1.11	1.78	87	1
Publications of the Astronomical Society of Australia	0	.79	5.06	53	1
arXiv[a]	N/A	N/A	N/A	N/A	29
GRB Coordinates Network	N/A	N/A	N/A	N/A	5
Research Notes of the American Astronomical Society[b]	N/A	N/A	N/A	N/A	1
The Astronomical Journal	N/A	N/A	N/A	N/A	5
The Astrophysical Journal	N/A	N/A	N/A	N/A	51
The Astrophysical Journal Letters	N/A	N/A	N/A	N/A	21
The Astrophysical Journal Supplement Series	N/A	N/A	N/A	N/A	1
Average for all journals	0.30	37.11	12.98	394.09	8.79

a. arXiv is not a peer-reviewed journal but is instead moderated to ensure submissions are on-topic and scientifically valid.
b. Research Notes of the American Astronomical Society is a non-peer reviewed, indexed and secure record of progress, comments and clarifications, null results, or timely reports of observations in astronomy and astrophysics.

Figure 6. Year 5 cumulative publication bibliometrics by journal

GROWTH participants also worked toward the advancement of research and educational achievements through the submission of grants related to GROWTH research. Seventeen (46%) Year 5 annual survey respondents reported submitting at least one grant during the project for a total of 44 grants submitted related to GROWTH science themes. Of the 17 respondents on the annual survey who submitted at least one grant:

- One submitted 10 grants
- Two submitted six grants
- Three submitted three grants
- Two submitted two grants
- Nine submitted one grant

Eight of the 17 Year 5 annual progress survey respondents who submitted grants had at least one funded. A total of 19 submitted grants have been funded as of August 2020. Findings from annual progress surveys in previous project years indicate that respondents have submitted as many as 45 grants total and have had as many as 21 of them funded. It should be noted that the numbers of grants reported here is based on responses to the annual progress surveys and likely underestimate the total number of grants submitted and awarded.

In the Year 5 annual progress survey, respondents were asked how the GROWTH project has advanced the field of time-domain astronomy and contributed to the field. Eighteen Year 5 annual progress survey respondents shared that the project has advanced the field by bringing together world-class teams (11 respondents), facilitating cross-observatory work (9 respondents), and through publications and discoveries (6 respondents). Examples of bringing together world-class teams include creating a standard for international collaborations, a collaborative environment, and student opportunities. Examples of cross-observatory work included setting up a network of telescopes, being able to do follow-up work, and obtaining datasets. Two others gave general praise and one other said they could not comment from having minimal contact but did not specify further.

Impact of project on participants' research capabilities

In general, findings from the annual progress surveys suggest that the project has positively impacted participants' research capabilities by supporting their research activities and improving their academic competitiveness. Over the course of the project, respondents consistently shared that the project largely impacted their research capabilities through broadening their network and developing collaborations. This enabled respondents to continue as well as broaden their research and obtain access to data, telescopes, and other informational resources that they otherwise might not have had.

Findings over the course of the project also suggest that the project has positively impacted participants' academic competitiveness such as the likelihood of educational or career advancement or proposal success. Throughout the project, annual survey respondents consistently indicated that they shared their research findings by writing a paper or presenting at a conference. Compared to

earlier years of the program, more respondents towards the end of the program indicated that they had made scientific discoveries in the field of astronomy/astrophysics and that their findings were actively being used by others in their field (i.e., citations). These findings are consistent with the increase in citations and publications in later years of the project.

Overall, findings suggest that the project has successfully met Goal 1 through the publication of impactful research in the field, the inclusion of young researchers in research and publishing opportunities, and the positive impact on participants' research capabilities, all of which advanced new knowledge, collaboration, and discoveries in astronomy/astrophysics.

Goal 2: Education and Workforce Development

Project leads recognized 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 sought to develop a STEM workforce by educating students through project affiliated courses and providing hands-on research experiences through summer internship projects and Astronomy Schools.

To assess progress made in this goal, undergraduate students, graduate students, and postdocs who completed GROWTH-affiliated courses, internships, and the Astronomy School 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.

Course faculty respondents to the annual progress survey assessed whether GROWTH increased their ability to develop, share, and implement new teaching resources/practices and whether it helped them engage more frequently in educational collaborations. Findings are summarized in the final subsection of this goal area and are meant to support student findings related to knowledge and skill development through courses.

GROWTH Graduate/ Postdoc Exchange and SURF Programs

Under the Graduate Student Postdoc Exchange internship program and the Summer Undergraduate Research Fellowships (SURF) internship program, 64 participants had the chance to do an internship across nine countries over the course of the project. As indicated in the figures below, the U.S. hosted the most internships.

	# of students	% of students
Level		
Undergraduate	36	56%
Graduate	20	31%
Postdoc	8	13%
Host institution		
Caltech, US	25	39%
National Center University, Taiwan	8	13%
University of Maryland, College Park, US	8	11%
Liverpool John Moores University, UK	5	8%
Tokyo Institute of Technology, Japan	5	8%
Weizmann Institute of Science, Israel	3	5%
University of Stockholm, Sweden	3	5%
Humboldt University, Germany	2	< 1%
University of Sydney, Australia	2	< 1%
University of Washington, US	2	< 1%
Indian Institute of Astrophysics, India	1	< 1%
IUCAA	1	< 1%
Pomona College, US	1	< 1%

Note: n=64. One student split their internship at Caltech and University of Maryland. One other student split their internship at IUCAA and Pomona College.

Figure 7. Graduate/Postdoc Exchange and SURF participants level of education and number of students hosted by institutions

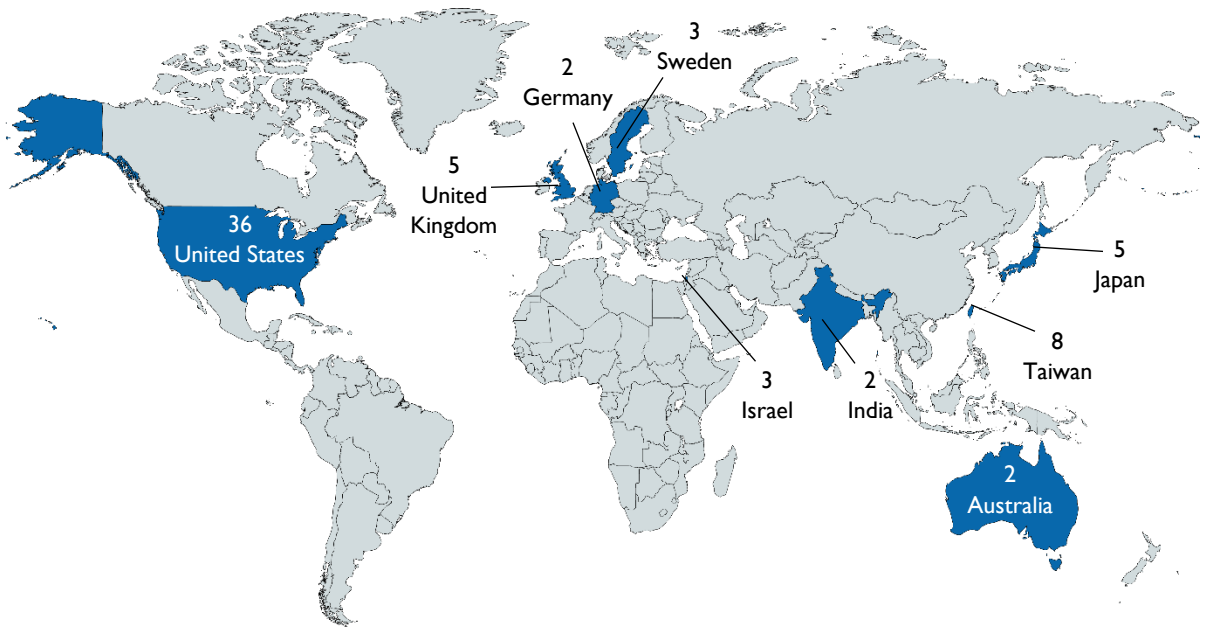


Figure 8. GROWTH internship locations and number of interns hosted during the project

Increased knowledge and skills

Over the course of the project, the annual progress survey results have indicated that SURF undergraduate respondents experienced increased astronomy/astrophysics research knowledge and abilities after participating in their internship experiences. SURF respondents generally reported that they learned and increased a variety of skills (e.g., data analysis and technical skills), were intellectually challenged, and that the overall experience met their expectations. Respondents who participated in the Graduate Student and Postdoc Exchange program generally reported that their experience was helpful in improving their research skills and understanding and enthusiasm for large collaborative research work.

Continued interest in astronomy/astrophysics careers and education

Overall, the majority of SURF undergraduate respondents indicated that the internship was effective in increasing their interest in pursuing a graduate degree and a career in astronomy/astrophysics. In general, Graduate Student Postdoc Exchange respondents reported less increased interest in astronomy/astrophysics careers and education compared to SURF respondents. However, this was likely because the graduate students and postdocs already had high interest in these areas before starting their internship and the internship likely confirmed their plans.

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

Overall, the majority of SURF respondents reported an increased understanding, as a result of participating in their internship, of how different cultural backgrounds influence research perspectives. Moreover, the internship experience helped them develop the skills and competencies needed for the global workplace. Findings also suggest that the internship had a great impact on SURF respondents' understanding of international scientific collaborations and their motivation to collaborate with researchers from other countries.

Similarly, Graduate Student Postdoc Exchange respondents generally indicated that they had an increased understanding of how to collaborate with different disciplines and were motivated to collaborate on international projects after participating in their internships. Respondents also indicated that they were likely to either keep in touch or collaborate with their host mentors in the future and that their experience was useful for making connections with the larger scientific community and within their institution.

Overall, findings from internship participants suggest that the SURF and Graduate Student Postdoc Exchange programs have contributed towards GROWTH's goals of increasing student knowledge, skills, and interest in collaboration in astronomy/astrophysics.

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 taking the affiliated courses to use data they would not otherwise be able to. Figure 9 displays how GROWTH courses are meant to impact student learning.

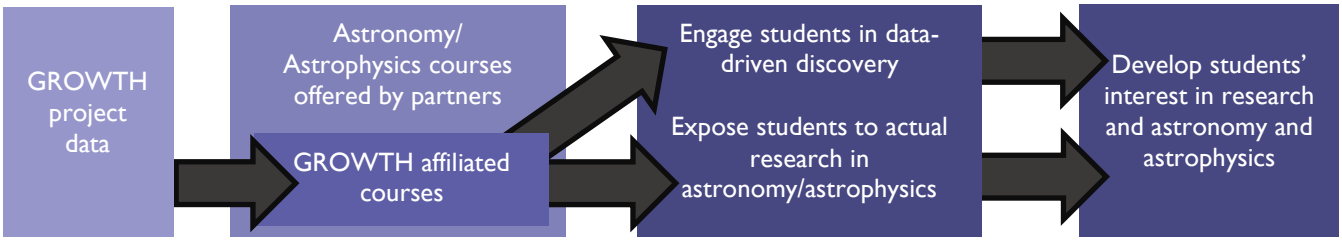


Figure 9. GROWTH student learning model

A total of 12 unique courses were offered to graduate and undergraduate students under the GROWTH project. Figure 10 displays all of the courses offered, the number of times they were offered and the semesters in which they were offered throughout the project, and the levels of students who attended the courses. Astronomical Techniques, Advanced Astronomical Observations, and Observational Astronomy were offered the most at four times each. Detailed findings were provided in previous evaluation reports and individual course reports.

Course	Total # of times offered	Semesters offered	Student level
Astronomical Techniques (ASTRO 350)	3	Spring 2018, 2019, 2020	Undergraduate
Astronomical Techniques (ASTR 680)	4	Fall 2016, 2017, 2018, 2019	Graduate
Advanced Astronomical Observations (ASTRO 6005)	4	Spring 2017, 2018, 2019, 2020	Graduate
Observational Astronomy (ASTR 310)	4	Fall 2016, 2017, 2018, 2019	Undergraduate
Astrophysics (PH-556)	1	Spring 2020	Undergraduate Graduate
Advanced Research Course in "Big Data Surveys" (ASTR498S)	1	Spring 2018	Undergraduate
Clocking Dead Stars with Radio Telescopes (Phys 194)	1	Fall 2017	Undergraduate
Advanced Introductory Astronomy (A51)	1	Spring 2017	Undergraduate
Observational Astronomy (YNC2217)	1	Spring 2017	Undergraduate
Automated Discovery of the Universe (AY3)	1	Spring 2017	Undergraduate
Astronomical Measurements and Instrumentation (AY122a)	1	Fall 2016	Graduate
Automated Discovery of the Universe (AY3)	1	Spring 2016	Undergraduate

Figure 10. Summary of all GROWTH courses offered over five years

Increased knowledge and skills in astronomy/astrophysics

Results from course surveys throughout the project indicated that the courses increased students' knowledge, skills, and interest in continuing their education related to astronomy/astrophysics. For example, student respondents reported improved understanding of the research process and gaining skills such as using astronomical techniques, writing, presenting, and data analysis using

Python/UNIX. These findings indicate that the project was successful in offering courses that equipped students with foundational skills in astronomy/astrophysics.

Increased interest in astronomy/astrophysics careers and education

Overall, findings throughout the project indicated that the majority of respondents had an increase in their interest in astronomy/astrophysics careers. Examples of activities that helped increase their interests included getting hands-on experience working with and collecting real data, conducting basic telescope observations, image processing and reduction techniques, and photometry. Respondents generally reported feeling more confident in capabilities and more comfortable doing their own astronomy/astrophysics research.

GROWTH Astronomy School

The Astronomy School was designed for participants to gain astronomy knowledge, connect with to peers and experts, and learn about the tools and techniques used currently in the field. In project Years 4 and 5, the project held 3 Astronomy Schools. Findings from Astronomy School activity surveys suggested that the School increased respondents' skills, abilities, and knowledge related to observations of multiwavelength events. In each of the Schools, sessions were generally rated as high quality and useful for generating new research ideas as well as for gaining an understanding of multiwavelength astronomy and how it is related to respondents' own research goals. Respondents shared that they planned to use the knowledge and experience they gained during the school in future research, including using data analysis and coding tools (e.g., Python), imaging and image processing, and interpreting spectroscopic data.

In August 2020, the Astronomy School was held virtually due to the COVID-19 pandemic. Despite the virtual format of the School, which was different than the first two in-person Astronomy Schools, the majority of respondents reported that the School had a positive influence on their observational astronomy skills and abilities. The majority (89%) also reported that their experience participating in the School via an online format was good or very good. Detailed findings of previous Astronomy School activity survey results have been provided to project leads.

Development of education and teaching resources

GROWTH faculty members were encouraged to develop and share new course resources and best practices to increase students' knowledge and skills. The annual progress survey in Years 4 and 5 asked about faculty members' perceptions on the impact of the GROWTH project on their teaching practices in the area of astronomy/astrophysics. Overall, the majority of faculty members agreed that the project increased their knowledge about teaching resources/practices, that other members provided them with new teaching resources/practices in the area of astronomy/astrophysics, and that they engaged more frequently in educational collaborations.

Faculty member respondents further explained that GROWTH impacted their teaching/learning practices by enabling them to create new teaching materials from time-domain data, develop a new research-based course, make activities and projects for students to work with an astronomical

database, refer to modules from the Astronomy/GROWTH school, and improve student self-assessment. Faculty member respondents also commented that the integration of data-driven resources helped students apply their new skills to feel more prepared to work in the field, appreciate using modern data, practice new techniques (did not specify further), and integrate research into their thesis projects.

Overall, findings suggest that the project has successfully met Goal 2 through the creation of a pipeline of STEM-trained students, educators, and workers. GROWTH activities such as the internship programs, courses, and Astronomy School have helped students gain knowledge and skills in astronomy as well as increase their interest in the field, science careers, and continued education.

Goal 3: Capacity Building (Partnerships & Sustainability)

Evaluators examined progress made towards strengthening partnerships by assessing GROWTH collaborations on publications. The analysis helps provide insight into how the project is progressing towards its vision of a strong collaborative network that increases scientific and educational achievements. Project leads did not have specific targets for partnerships but did expect collaborations to continue to grow across the project's lifespan.

A publication network analysis, described below, was used to map the number of times pairs of institutions collaborated on publications (e.g., Pair 1: Caltech and University of Maryland College Park, Pair 2: University of Stockholm and Texas Tech University). However, this analysis does not represent when three or more partners (e.g., Caltech, Tokyo Institute of Technology, and University of Washington) collaborated with one another on publications. Therefore, additional analyses were conducted using the publication information to assess the full breadth of collaborations across multiple partner institutions and continents and are reported below with other results.

To assess capacity building, project planning for sustainability was examined using responses from the annual progress survey.

Collaborations assessed through products (publications)

The following figures present the publication network analysis maps from project Years 1 through 5. The Year 5 international map and U.S.-only distribution graph include both former partner institutions and GROWTH members for this summative report. Figures include publications listed in GROWTH's publication database, which does not include manuscripts that have been developed and/or submitted. Therefore, there could be more publication collaboration occurring among project members than displayed in the maps and diagrams.

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 continents of the institutions are distinguished by color. Collaboration lines between institutions on the same continent are colored the same as the circles. Collaboration lines between institutions on different continents are colored as shown in the legend in the following figures. The frequency of collaboration is how many times an institution has collaborated with another institution on individual publications. Thicker lines signify a higher frequency of collaborations on publications and thinner lines signify fewer collaborations on publications.

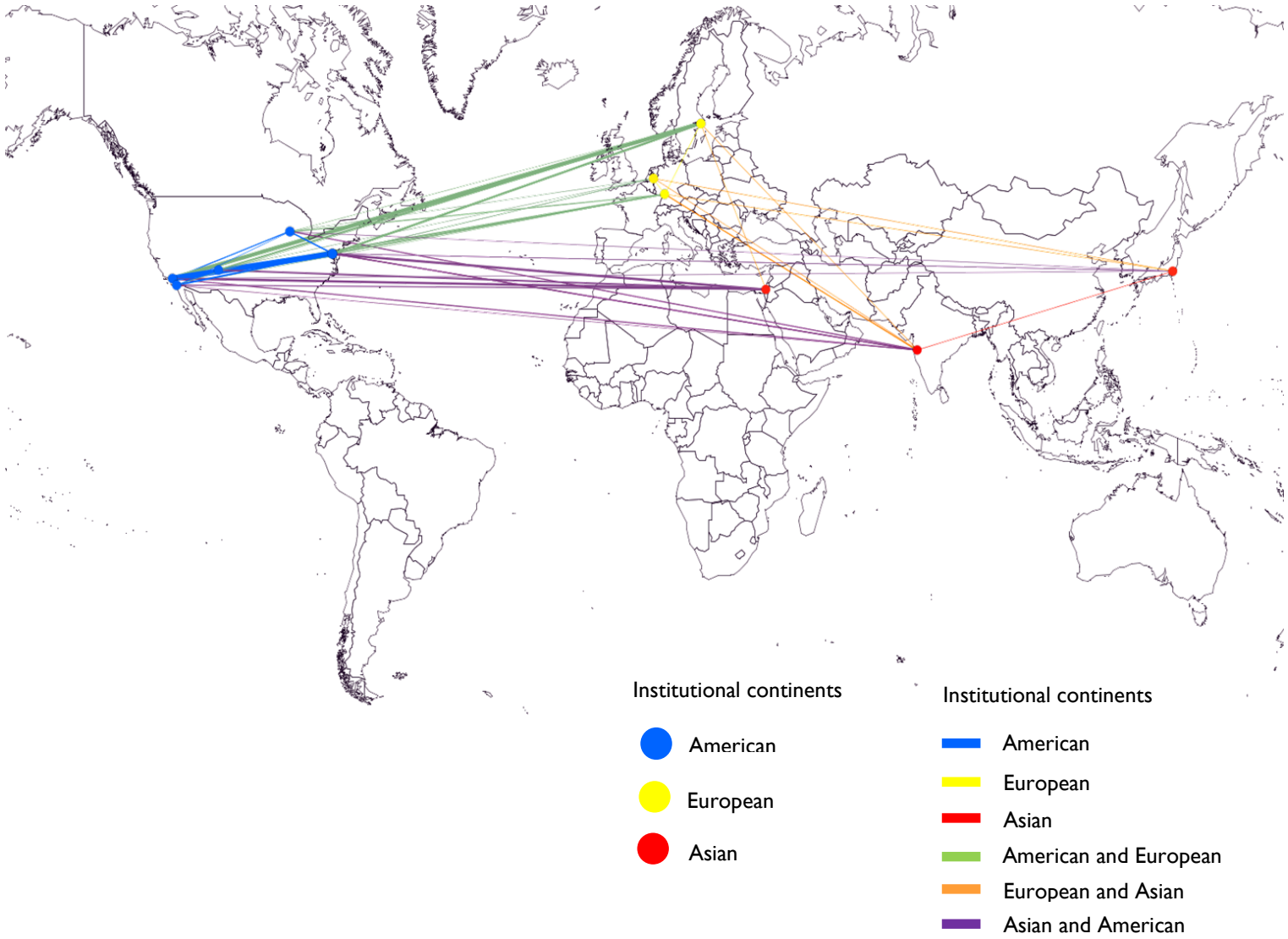
Across the five years, pairs of institutions collaborated on publications anywhere from 1 to 78 times. The pair that collaborated the most was Caltech and the Oskar Klein Centre, University of Stockholm, at 78 times. Therefore, the most publications occurring between intercontinental collaborations were those between the U.S. and Europe. The most publications among non-U.S. intercontinental collaborations were between Asia and Europe, 28 times. The American institutions that were collaborating the most within the U.S. were Caltech and the University of Maryland, College Park, 73 times.

The institution that collaborated the most overall was Caltech, which was on 118 publications with other institutions. The institution that collaborated the least was the South African Astronomical Observatory with five publications, likely due to not joining the project until Year 5.

Of the 167 GROWTH articles published:

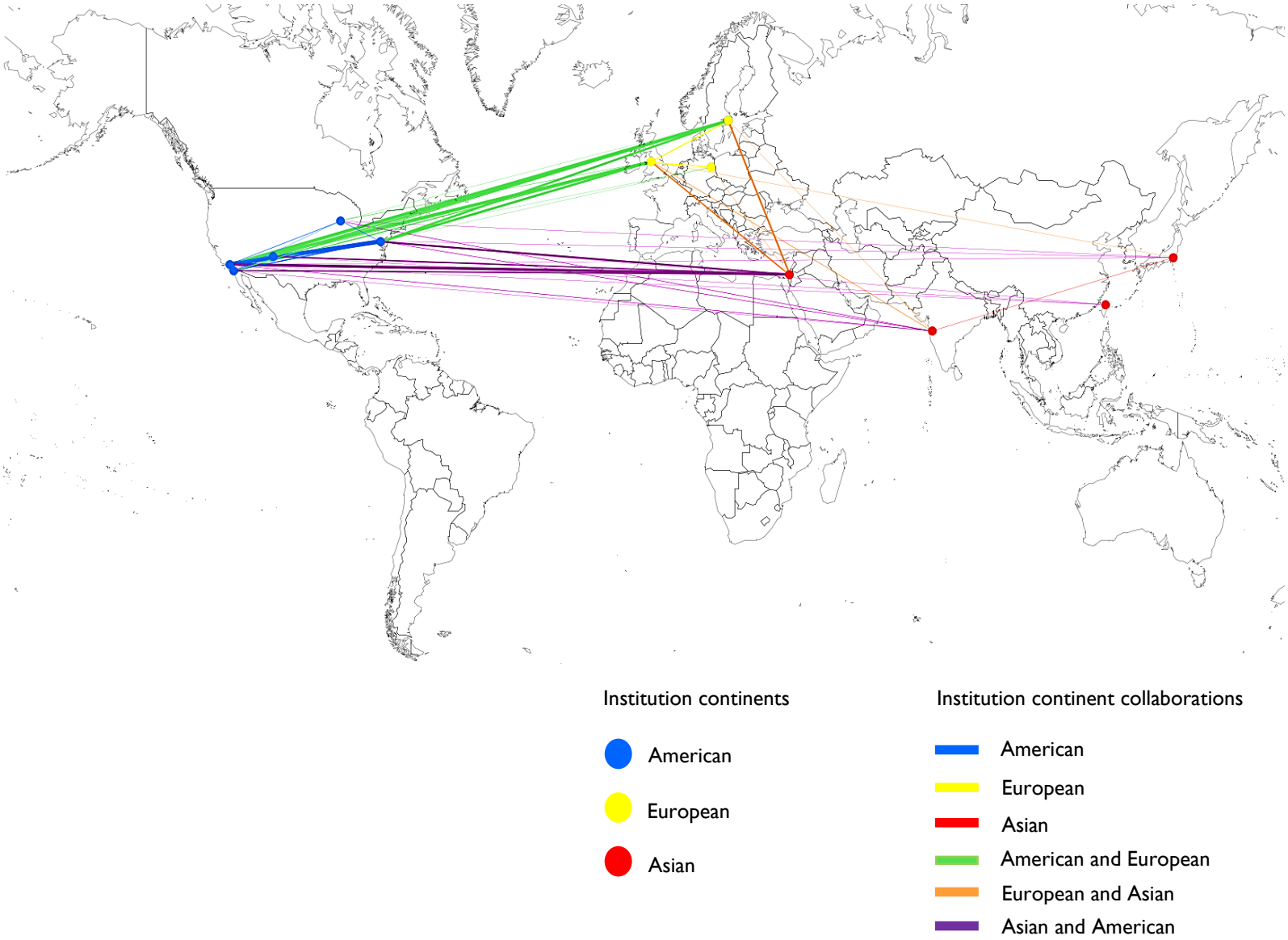
- 111 publications were produced by two or more partner institutions in different continents.
- 18 publications were produced by partners at different institutions but within the same continent (14 within the U.S. and 4 within Asia).
- 33 publications were produced by only one GROWTH author and 5 additional publications were produced by GROWTH authors from the same institution. It should be noted that these 38 publications are not included in the publication maps below.

Figures 11-15 display the publication maps for Years 1-5 of the project. As the project matured, it can be seen that the lines representing collaborative publications became thicker, indicating increased publications. Particularly in Years 4 and 5, more lines were connected to continents that were new to the project, illustrating the increased diversity in collaborative publications.



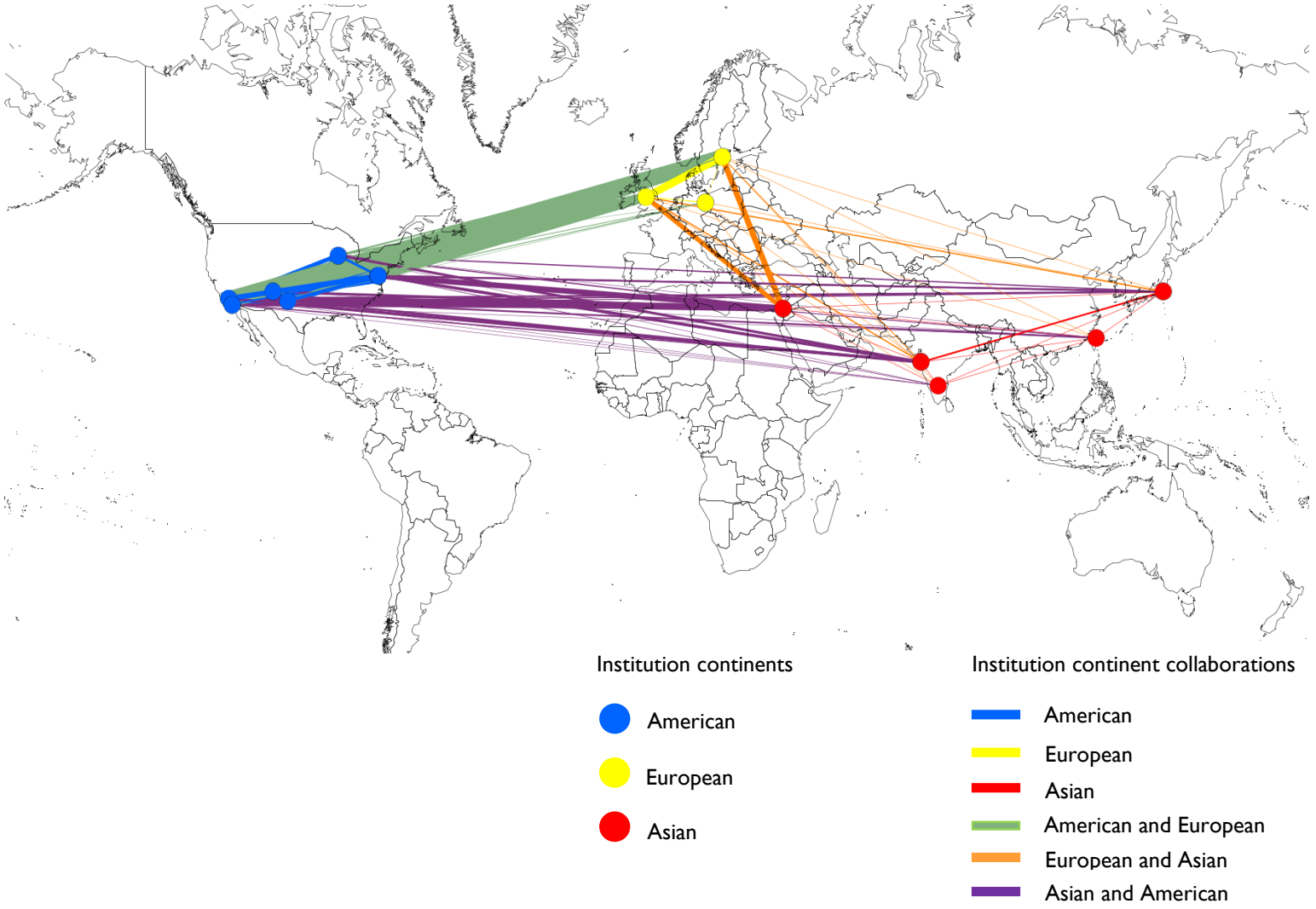
During year 1, growth leads were interested in tracking everyone affiliated with the project but this decision was later revised to only include those who were identified as GROWTH members.

Figure 11. Year 1 GROWTH international publication network map



Starting in year 2, evaluators did not track or include publication collaborations from external advisory members.

Figure 12. Year 2 GROWTH international publication network map



Starting in year 3, evaluators did not track or include undergraduates in publication collaborations.

Figure 13. Year 3 GROWTH international publication network map

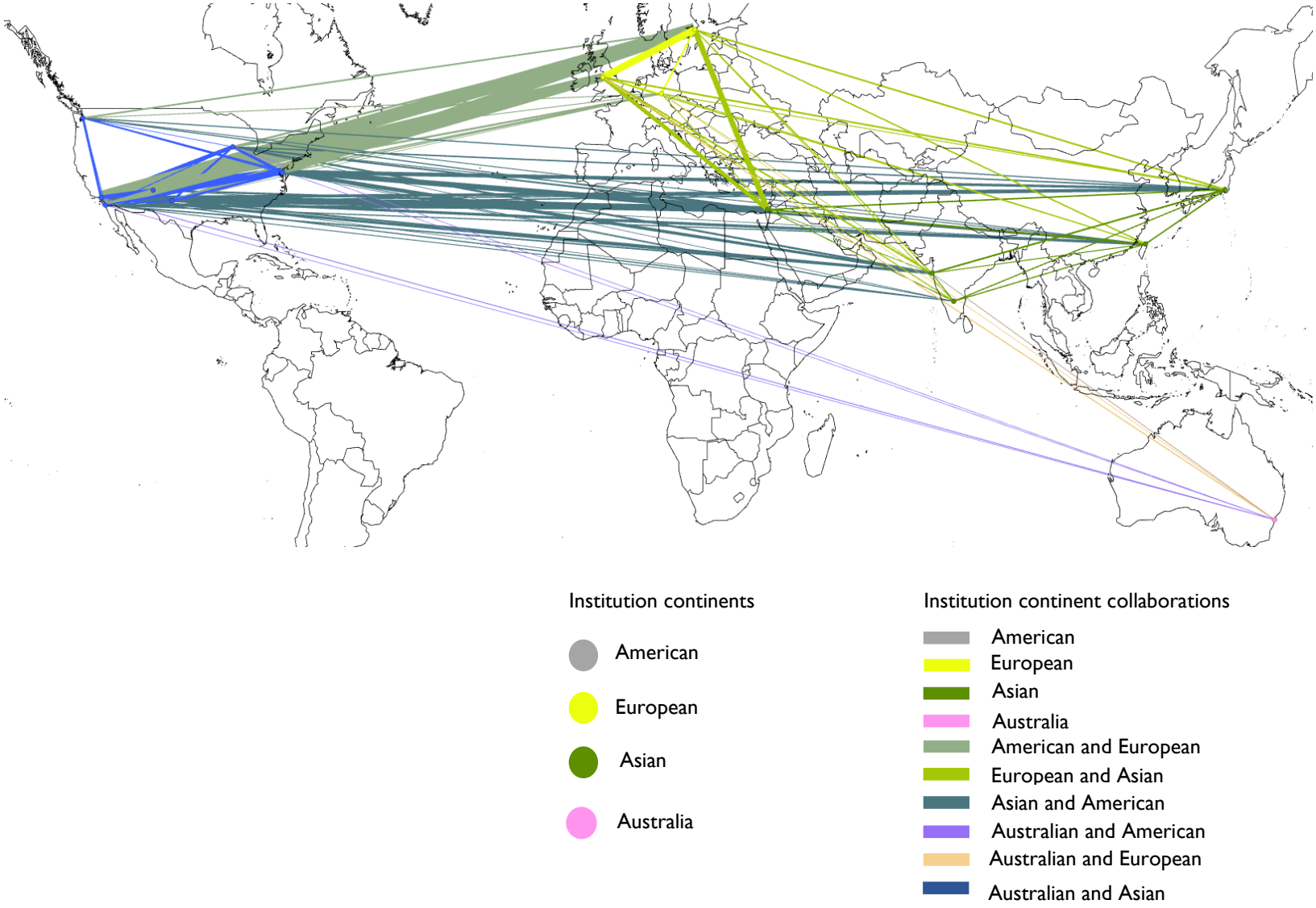


Figure 14. Year 4 GROWTH international publication network map

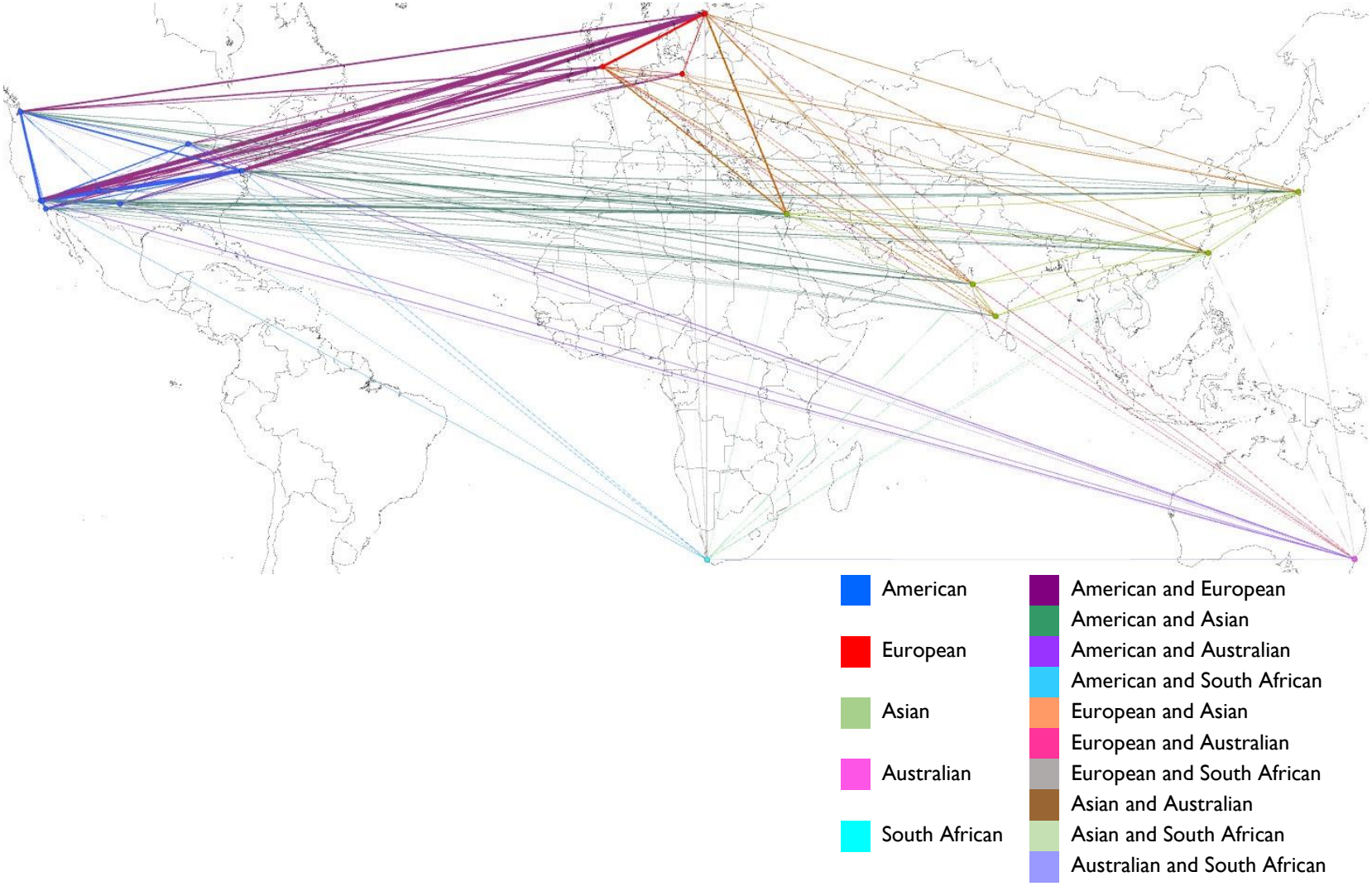


Figure 15. Year 5 GROWTH international publication network map

A figure depicting collaborations among United States partner institutions is displayed below since the United States was the location of nine of the 16 partner institutions. Each partner institution is labeled in the diagram. Pairs of these US institutions collaborated on publications anywhere from 1 to 73 times. The proximity of the circles and width of the lines represents the frequency of collaboration between the partner institutions.

It should be noted that the NASA Goddard Space Flight Center is not an official GROWTH partner institution and that Pomona College is a former partner institution (participated in years 1 and 2 of the project).

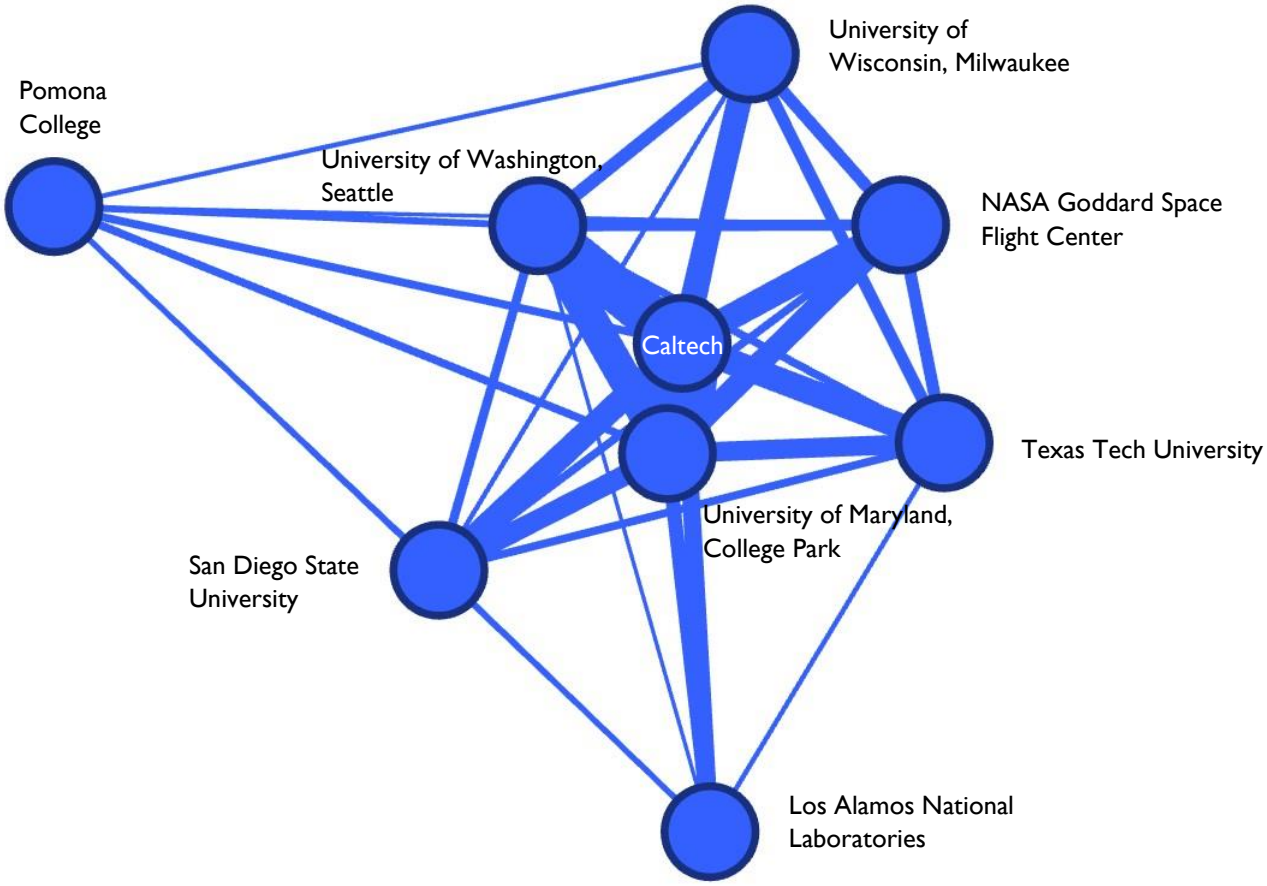


Figure 16. Cumulative GROWTH U.S. publication network diagram

Participant-level collaborations

In Years 4 and 5, annual progress survey respondents indicated the frequency of collaborative activities within their institution, their country, and internationally to assess the extent to which participants were collaborating as part of the project more generally. Respondents assessed these collaborations across three categories: improving their scientific knowledge through collaboration with others, improving their ability to further scientific discoveries through collaboration with others, and obtaining insights into their research through collaboration with others.

Findings indicated that from Year 4 to Year 5, respondents were collaborating more frequently across all levels (i.e., within institution, within country, and internationally). In both years, within-institution collaborations were more frequent than other types of collaboration, particularly improving scientific knowledge through collaborations with other researchers. This may be because roughly half of institutions were the only participating GROWTH partner in their country.

Annual progress survey respondents also selected the level of interdisciplinary research that they were conducting within the GROWTH project. The majority of respondents were either mostly working with researchers within the same field or sometimes working with researchers in other fields.

Ninety-seven percent of Year 5 annual progress survey respondents agreed that they viewed their collaborations with other GROWTH partners as a key component in achieving the research and education goals of the project. Of those who agreed, 57% plan to further enhance their collaborations in the future and 41% plan to maintain their current level of collaboration in the future. One other respondent (3%) indicated that collaborations were important but not essential.

Project sustainability

Sustainability is an important aspect of capacity building for NSF-funded projects. Seventeen project lead respondents in the Year 5 annual progress survey assessed the sustainability capacity of GROWTH in five areas (on a 7-point scale from "little or no extent" to "very great extent").

As displayed in Figure 17, the majority of respondents (65%- 89%) rated GROWTH as having a great or very great capacity for sustainability across all areas. These percentages slightly declined compared to those in Year 4 (71%-94%) but the number of respondents who indicated that they were not able to answer also decreased as respondents likely had more knowledge and opinion about project sustainability towards the later years of the project.

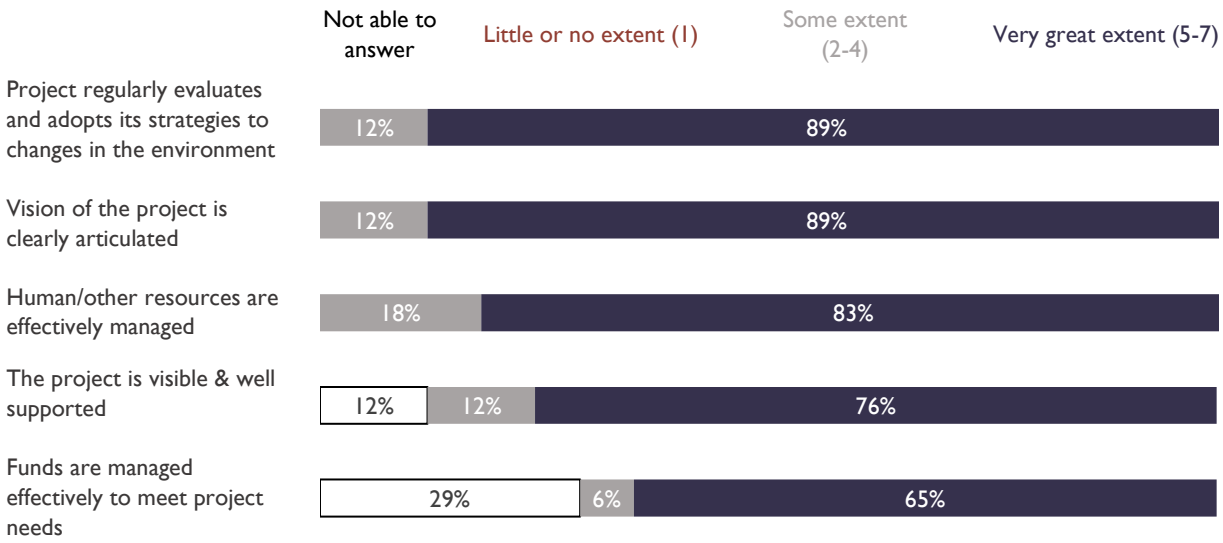


Figure 17. Year 5 project sustainability attitudes (n=17)

Twelve of the seventeen project lead respondents shared their plans for sustaining GROWTH activities on the annual progress survey. Four explained that they were either in discussion or searching for funding options but did not specify further. Three others were already awarded grants to continue the activities. Two were in the process of applying for small grants. One planned to keep the internship programs but did not specify how they planned to financially sustain it. One other shared that they were receiving institutional support (but did not specify the type of support) and one other shared that they were continuing their collaborations but did not specify how they were doing so. Five other respondents did not have plans for sustaining GROWTH activities with some sharing that COVID-19 made future plans uncertain.

On the Year 5 annual progress survey, additional questions were added to assess all respondents' likelihood to continue GROWTH activities and collaborations. Seventy-six percent of Year 5 annual survey respondents were very or extremely likely to remain in GROWTH related activities and 70% were very or extremely likely to continue to contribute to international collaborations after the project ends. These findings indicate that the project has influenced the majority of respondents to continue to contribute to astronomy/astrophysics research and has helped establish international collaboration efforts that will continue on beyond the NSF PIRE grant.

Overall, findings suggest that the project has successfully met Goal 3 by enabling GROWTH scientists to collaborate and develop international relationships to strengthen research that will support scientific achievements in the field of astronomy/astrophysics. Findings indicate that project participants were positively impacted by their experience collaborating with other institutions through publications and plan to continue collaborating on research activities after the grant ends.

Other feedback/final reflections

On the Year 5 annual progress survey, 36 respondents shared the most important outcome of the GROWTH project. The most recurring responses were furthering scientific collaborations (20 respondents), gaining research experience and developing skills (14 respondents), gaining access to resources (6 respondents), getting publication experience (5 respondents), taking part in discoveries (4 respondents), sharing information (2 respondents), and getting teaching and leadership experience (1 respondent each). Examples of furthering scientific collaborations included making emotional connections with others, the ability to conduct thorough data analysis, collaborative efforts on events, making international connections, involvement of students, and involvement of people from minority groups. Examples of research experience included getting exposed to different fields of work, experiencing personal growth in science, preparing guidelines and activities, training students in astronomy/astrophysics research, and being part of front-line efforts on follow-up events and objects. Examples of gaining access to resources included using telescopes at other facilities and having access to other data. Examples of publication experience included writing several papers, publishing in several journals, and being the lead on a paper. Examples of discoveries included the GW170817 and other discoveries that were not specified.

Key Findings and Recommendations

Goal 1: GROWTH research

Overall, findings suggest that the project successfully met Goal 1 which stated that the GROWTH project would advance new knowledge, collaboration, and discoveries in astronomy/astrophysics. The cumulative sum of articles published by GROWTH project members over the course of the project totaled 167. This is over triple the overall target of 55 publications. In total, 81 active or former GROWTH project members authored publications. Overall, the proportion of GROWTH member authors on publications that were GROWTH postdocs or PhD students increased over the life of the project. Over one-third of total publications were co-authored by active or former postdoc or PhD students. For future projects, consider the following recommendations:

- Develop a plan for disseminating project-related results to specific fields, conferences, or disciplines that the project has not yet disseminated results to. This can help create partnerships that continue the work that the PIRE grant established.

Goal 2: Education and workforce development

Overall, findings suggest that the project successfully met Goal 2 which stated that the GROWTH project would develop a sustainable STEM workforce by creating a pipeline of STEM-trained students, educators, and workers. The Astronomy School was consistently very useful for increasing evaluation respondents' skills, abilities, and knowledge related to observations of multiwavelength events. GROWTH activities such as the internship programs, courses, and Astronomy School helped students gain knowledge and skills in astronomy as well as increase their interest in the field, science careers, and continued education.

- For future Astronomy Schools or similar events, consider holding the event online to increase the reach of the event especially since the majority of evaluation respondents in the virtual 2020 Astronomy School reported that their experience participating in the School via an online format was good or very good. Also, consider using the recorded lectures created during the 2020 School in the next School so that participants can watch the lectures in advance.
- Consider inviting GROWTH graduate students to provide testimonials via short videos or blurbs that summarize how they have benefitted from participating in the project and how it impacted their future career goals. These can help motivate undergraduate students to continue participating in GROWTH activities.
- In future projects, implement a follow-up survey in the final years to assess whether students pursued continued education or careers in the field of astronomy/astrophysics to more fully capture the impact of the project on the career and educational trajectories of students.

Goal 3: Capacity building (partnerships & sustainability)

Overall, findings suggest that the project successfully met Goal 3 which stated that the project would enable GROWTH scientists to collaborate and develop international relationships to

strengthen research that will support scientific achievements in the field of astronomy/astrophysics. Over time, the project added new partners which helped contribute to increased international collaborative publications. Findings suggest that project participants were positively impacted by their experience collaborating with other institutions through publications. A large majority of Year 5 annual survey respondents reported that they plan to further enhance their collaborations or to maintain their current level of collaboration in the future.

- Ensure that GROWTH members know where they can go to find contact information of other GROWTH members and stay up to date on the accomplishments of GROWTH members.
    - Develop a communication method for the purpose of sharing research and additional funding opportunities. This may be a Google sheet or a separate tool to which GROWTH members have access. Or, consider asking if individuals would be willing to dedicate the time to help pursue additional funding opportunities.
- Consider developing a committee of volunteers that will help plan future conferences or other events that will help develop new collaborations and maintain existing ones. This may be something as simple as a virtual networking event with the purpose of sharing new discoveries and/or opportunities for collaboration.

Appendix A. Published GROWTH articles

Article number[a]	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: A 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 Transients
38	SN 2015bp: 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 Large Super-fast Rotator (144977) 2005 EC127
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 Type IIn supernova iPTF13z over 3 years
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: A Case of Interaction with Nearby, Unbound Material and/or Strong Ejecta Mixing
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 Hα 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) Narrow-Band Survey I: 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	11/2017 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 Supernova 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 Light Curve of GW170817
76	From γ to Radio: The Electromagnetic Counterpart of GW170817
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
83	An Upper Limit on the Linear Polarization Fraction of the GW170817 Radio Continuum
84	The SED Machine: A Robotic Spectrograph for Fast Transient Classification
85	Optical and Infrared Photometry of the nearby SN 2017cbv
86	Discerning the binary neutron star or neutron star-black hole nature of GW170817 with Gravitational Wave and Electromagnetic Measurements
87	A UV resonance line echo from a shell around a hydrogen-poor superluminous supernova
88	iPTF 16hgs: A Double-peaked Ca-rich Gap Transient in a Metal-poor, Star-forming Dwarf Galaxy
89	Oxygen and helium in stripped-envelope supernovae
90	A hot and fast ultra-stripped supernova that likely formed a compact neutron star binary
91	A Strong Jet Signature in the Late-time Light Curve of GW170817
92	Meteor showers from active asteroids and dormant comets in near-Earth space: A review
93	A Morphological Classification Model to Identify Unresolved PanSTARRS1 Sources: Application in the ZTF Real-time Pipeline
94	Analysis of broad-lined Type Ic supernovae from the (intermediate) Palomar Transient Factory
95	AT2018cow: A Luminous Millimeter Transient
96	Full Orbital Solution for the Binary System in the Northern Galactic Disk Microlensing Event Gaia16aye
97	Spitzer Mid-Infrared Detections of Neutron Star Merger GW170817 Suggests Synthesis of the Heaviest Elements
98	The Zwicky Transient Facility: System Overview, Performance, and First Results
99	The First Tidal Disruption Flare in ZTF: From Photometric Selection to Multi-wavelength Characterization
100	The Zwicky Transient Facility: Science Objectives
101	Tidal interactions between binary stars drives lithium production in low-mass red giants
102	The Broad Absorption Line Tidal Disruption Event iPTF15af: Optical and Ultraviolet Evolution
103	Debris of Asteroid Disruptions Close to the Sun
104	ZTF 18aaqeasu (SN2018byg): A Massive Helium-shell Double Detonation on a Sub-Chandrasekhar-mass White Dwarf
105	ZTF18aalrxas: A Type IIb Supernova from a very extended low-mass progenitor
106	Probing the extragalactic fast transient sky at minute timescales with DECam

107	R-band light-curve properties of Type Ia supernovae from the (intermediate) Palomar Transient Factory
108	The fast, luminous ultraviolet transient AT2018cow: extreme supernova, or disruption of a star by an intermediate-mass black hole?
109	The GROWTH Marshal: A Dynamic Science Portal for Time-domain Astronomy
110	Prediction of Meteor Activities from (101955) Bennu
111	Multiple Outbursts of Asteroid (6478) Gault
112	Transient processing and analysis using AMPEL: Alert Management, Photometry and Evaluation of Lightcurves
113	Discovery of an intermediate-luminosity red transient in M51 and its likely dust-obscured, infrared-variable progenitor
114	A Strategy for LSST to Unveil a Population of Kilonovae without Gravitational-wave Triggers
115	Tidal Interactions between Binary Stars Can Drive Lithium Production in Low-mass Red Giants
116	DeepStreaks: identifying fast-moving objects in the Zwicky Transient Facility data with deep learning
117	Toward Rate Estimation for Transient Surveys. I. Assessing Transient Detectability and Volume Sensitivity for iPTF
118	GROWTH on S190426c: Real-time Search for a Counterpart to the Probable Neutron Star-Black Hole Merger using an Automated Difference Imaging Pipeline for DECam
119	GROWTH on S190510g: DECam Observation Planning and Follow-up of a Distant Binary Neutron Star Merger Candidate
120	A New Class of Changing-look LINERs
121	Distinguishing the nature of comparable-mass neutron star binary systems with multimessenger observations: GW170817 case study
122	Four (Super)Luminous Supernovae From the First Months of the ZTF Survey
123	The Two LIGO/Virgo Binary Black Hole Mergers on 2019 August 28 Were Not Strongly Lensed
124	The Zwicky Transient Facility Bright Transient Survey I: Spectroscopic Classification and the Redshift Completeness of Local Galaxy Catalogs
125	GROWTH on S190425z: Searching Thousands of Square Degrees to Identify an Optical or Infrared Counterpart to a Binary Neutron Star Merger with the Zwicky Transient Facility and Palomar Gattini-IR
126	Comet 240P/NEAT Is Stirring
127	Real-bogus classification for the Zwicky Transient Facility using deep learning
128	ZTF Early Observations of Type Ia Supernovae. I. Properties of the 2018 Sample
129	Supernova 2014C: Ongoing Interaction with Extended Circumstellar Material with Silicate Dust
130	Evidence for Late-stage Eruptive Mass Loss in the Progenitor to SN2018gep, a Broad-lined Ic Supernova: Pre-explosion Emission and a Rapidly Rising Luminous Transient
131	An ASKAP Search for a Radio Counterpart to the First High-significance Neutron Star—Black Hole Merger LIGO/Virgo S190814bv
132	Constraints on the Spin-Pole Orientation, Jet Morphology and Rotation of Interstellar Comet 2I/Borisov with Deep HST Imaging
133	Full orbital solution for the binary system in the northern Galactic disc microlensing event Gaia16aye
134	An Optimized Radio Follow-up Strategy for Stripped-envelope Core-collapse Supernovae
135	ZTF Early Observations of Type Ia Supernovae III: Early-Time Colors as a Test for Explosion Models and Multiple Populations
136	ZTF Early Observations of Type Ia Supernovae II: First Light, the Initial Rise, and Time to Reach Maximum Brightness
137	Seventeen Tidal Disruption Events from the First Half of ZTF Survey Observations: Entering a New Era of Population Studies

138	Early Ultra-Violet observations of type IIn supernovae constrain the asphericity of their circumstellar material
139	A Twilight Search for Atiras, Vatiras, and Co-orbital Asteroids: Preliminary Results
140	GROWTH on S190814bv: Deep Synoptic Limits on the Optical/Near-infrared Counterpart to a Neutron Star—Black Hole Merger
141	Probing the extragalactic fast transient sky at minute time-scales with DECam
142	Palomar Gattini-IR: Survey Overview, Data Processing System, On-sky Performance and First Results
143	DECam-GROWTH Search for the Faint and Distant Binary Neutron Star and Neutron Star-Black Hole Mergers in O3a
144	The Broad-lined Ic Supernova ZTF18aaqjovh (SN 2018bvw): An Optically Discovered Engine-driven Supernova Candidate with Luminous Radio Emission
145	The Zwicky Transient Facility Census of the Local Universe I: Systematic search for Calcium rich gap transients reveal three related spectroscopic sub-classes
146	SN2020bvc: a Broad-lined Type Ic Supernova with a Double-peaked Optical Light Curve and a Luminous X-ray and Radio Counterpart
147	Constraining properties of neutron star merger outflows with radio observations
148	Cataclysmic Variables in the First Year of the Zwicky Transient Facility
149	The Koala: A Fast Blue Optical Transient with Luminous Radio Emission from a Starburst Dwarf Galaxy at z = 0.27
150	A high-energy neutrino coincident with a tidal disruption event
151	AT 2016dah and AT 2017fyp: the first classical novae discovered within a tidal stream
152	Dynamic scheduling: target of opportunity observations of gravitational wave events
153	Characterization of the Nucleus, Morphology, and Activity of Interstellar Comet 2I/Borisov by Optical and Near-infrared GROWTH, Apache Point, IRTF, ZTF, and Keck Observations
154	SN2019dge: a Helium-rich Ultra-Stripped Envelope Supernova
155	GRB200514B: Zwicky Transient Facility Follow-Up of a Fermi Short GRB (Trigger 611140062)
156	GRB 200514B: Zwicky Transient Facility Follow-Up of a Fermi Short GRB (Trigger 611140062) - More Candidates
157	ZTF Discovery of ZTF20abbiixp: The Likely Optical Afterglow to GRB 200524A
158	IceCube-200530A: Candidate Counterparts from the Zwicky Transient Facility
159	Zwicky Transient Facility Constraints on the Optical Emission from the Nearby Repeating FRB 180916.J0158+65
160	ZTF20aajnksq (AT2020blt): A Fast Optical Transient at z≈2.9 With No Detected Gamma-Ray Burst Counterpart
161	Kilonova Luminosity Function Constraints based on Zwicky Transient Facility Searches for 13 Neutron Star Mergers
162	Discovery of a Sample of Helium-rich Superluminous Supernovae by Zwicky Transient Facility
163	Multi-wavelength Photometry and Progenitor Analysis of the Nova V906 Car
164	IceCube-200620A: One Candidate Counterpart from the Zwicky Transient Facility
165	Candidate Electromagnetic Counterpart to the Binary Black Hole Merger Gravitational-Wave Event S190521g*
166	Constraining the X-ray - Infrared spectral index of second-timescale flares from SGR1935+2154 with Palomar Gattini-IR
167	Implications of the search for optical counterparts during the second part of the Advanced LIGO's and Advanced Virgo's third observing run: lessons learned for future follow-up observations

a. Two entries from the library database are not included as they were presentations, not publications. Article numbers do not reflect what the GROWTH library database has for each article and instead represents the evaluators' record for reporting purposes.

Appendix B: GROWTH publication citations and authors

Article #[a]	Project year published	# times cited[b]	# GROWTH authors	# GROWTH postdoc authors	# GROWTH PhD student authors	# Former Postdoc authors	# Former PhD student authors
1	Year 1	75	8				1
2	Year 1	0	5	2			
3	Year 1	77	7				1
4	Year 1	29	8				2
5	Year 1	59	8				1
6	Year 1	78	2				
7	Year 1	60	7	1			1
8	Year 1	12	6	1			1
9	Year 1	48	13	1		1	2
10	Year 1	30	8	1			2
11	Year 1	211	10			1	1
12	Year 1	32	4	1			
13	Year 1	13	6				3
14	Year 1	34	7	2			1
15	Year 1	77	3				
16	Year 2	17	5				
17	Year 2	84	1				
18	Year 2	25	6				1
19	Year 2	40	3				1
20	Year 2	55	1	1			
21	Year 2	16	2				2
22	Year 2	26	1	1			
23	Year 2	8	3				
24	Year 2	37	1				
25	Year 2	51	5	1			1
26	Year 2	86	7				1
27	Year 2	40	9	2			1
28	Year 2	3	3				
29	Year 2	15	2				
30	Year 2	9	1	1			
31	Year 2	59	8	1		1	2
32	Year 2	35	6	2			2
33	Year 2	30	8	1			2
34	Year 2	20	8	1			2
35	Year 2	3	1				

36	Year 2	18	1					
37	Year 2	21	2					1
38	Year 2	5	2				1	
39	Year 2	4	1				1	
40	Year 2	43	5	1				
41	Year 2	9	4				1	
42	Year 2	75	7	2				2
43	Year 3	30	1					
44	Year 3	71	9	2				3
45	Year 3	30	5	1				1
46	Year 3	18	10	1			1	
47	Year 3	59	8					
48	Year 3	34	8	2				2
49	Year 3	8	3					
50	Year 3	15	10	1				
51	Year 3	45	8	2				
52	Year 3	1454	21	5	4			
53	Year 3	20	4				1	
54	Year 3	64	5	1			1	
55	Year 3	344	4					
56	Year 3	60	11	3				1
57	Year 3	8	4	1	1	1		
58	Year 3	6	3	1				
59	Year 3	36	10	2				2
60	Year 3	53	1				1	
61	Year 3	77	9	2	1			
62	Year 3	322	31	3	4	4		1
63	Year 3	224	2					
64	Year 3	240	10		2			2
65	Year 3	11	5	1				1
66	Year 3	10	4	1	1	1		
67	Year 3	11	10	1		1		1
68	Year 3	20	1					
69	Year 3	3	3					
70	Year 3	1	1					
71	Year 3	4	4	2		1		
72	Year 3	203	8		2			
73	Year 3	35	5	1				
74	Year 3	0	1			1		
75	Year 3	87	5		1			
76	Year 3	51	1					

77	Year 3	5	1				
78	Year 3	10	13	2		1	5
79	Year 3	0	1			1	
80	Year 3	24	1				
81	Year 3	13	2			1	
82	Year 3	33	5	1			1
83	Year 4	19	3				
84	Year 4	51	4	1			
85	Year 4	2	1				
86	Year 4	41	1				
87	Year 4	15	7	2			
88	Year 4	16	6	1	1		1
89	Year 4	14	10	3			1
90	Year 4	33	10	1	1		2
91	Year 4	59	6		2		
92	Year 4	7	1			1	
93	Year 4	27	1		1		
94	Year 4	17	8	3			1
95	Year 4	33	7		1		1
96	Year 4	7	6	1			
97	Year 4	22	6				
98	Year 4	210	32	5	3	6	2
99	Year 4	33	10	1	2		1
100	Year 4	210	36	7	4	6	2
101	Year 4	18	1				1
102	Year 4	23	3	1			1
103	Year 4	3	1				1
104	Year 4	19	7	1	1	1	1
105	Year 4	9	9	2	1		
106	Year 4	6	1	1			
107	Year 4	11	9	1		1	3
108	Year 4	46	29	4	8	2	2
109	Year 4	41	7	2		1	1
110	Year 4	2	1			1	
111	Year 4	14	4	1		1	
112	Year 4	11	8	2	1	2	
113	Year 4	10	12	4	2	1	2
114	Year 4	7	5	1	1		
115	Year 5	18	1				1
116	Year 5	5	2			1	
117	Year 5	0	3		1		

118	Year 5	16	8	2	3		
119	Year 5	12	8	4	2		
120	Year 5	15	9	1	1	1	1
121	Year 5	41	1				
122	Year 5	8	13	3	2	1	1
123	Year 5	6	1				
124	Year 5	13	12	2	2		1
125	Year 5	27	30	3	8	1	1
126	Year 5	0	3			1	
127	Year 5	15	1				
128	Year 5	18	14	2	2	1	2
129	Year 5	2	3	1	1		
130	Year 5	19	17	4	3		2
131	Year 5	10	10	2	3		
132	Year 5	3	1	1			
133	Year 5	7	5	1			
134	Year 5	0	1				
135	Year 5	5	6	1			1
136	Year 5	6	4	2			
137	Year 5	18	13	2	3		2
138	Year 5	1	14	4	2		
139	Year 5	4	5			1	
140	Year 5	26	18	4	6		
141	Year 5	6	1	1			
142	Year 5	9	4		1	1	
143	Year 5	1	7	2	2		
144	Year 5	1	8	1	1	1	2
145	Year 5	5	12	3	1	1	1
146	Year 5	1	14	4	3		1
147	Year 5	3	3		1		
148	Year 5	0	7		1		1
149	Year 5	8	7	2	1		1
150	Year 5	4	17	1	5		1
151	Year 5	1	1				
152	Year 5	3	2		1		
153	Year 5	11	15	4	1		
154	Year 5	2	7	1	1		1
155	Year 5	0	6	2	4		
156	Year 5	0	10	2	5		
157	Year 5	0	2				1
158	Year 5	0	4		2		

159	Year 5	1	5	1			
160	Year 5	0	11	2	1		1
161	Year 5	2	37	7	12	1	
162	Year 5	0	13	3	3		1
163	Year 5	0	2				
164	Year 5	0	3		2		
165	Year 5	7	5		1		
166	Year 5	0	4	1	1		
167	Year 5	0	2	1	1		
	Cumulative article total[a]	6804	1117	181	135	56	100
	Average for all articles	40.74	6.69	1.93	2.33	1.37	1.45

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.
b. As of August 3rd, 2020.