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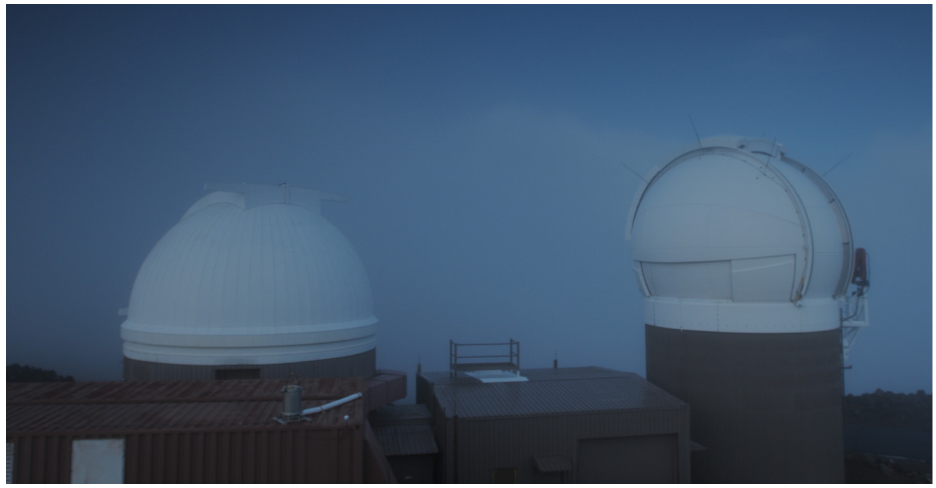

The Economic Impact of Astronomy in Hawai'i

AUGUST 28, 2014

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Executive Summary

The astronomy sector in Hawaii generates economic activity through its purchases from local businesses, its payment to its employees, and spending by students and visitors. In collaboration with the Institute for Astronomy, a survey was designed to obtain information from astronomy related entities about in-state expenditures. The collected survey data was used to estimate the astronomy sector's total economic activity in each of Hawaii's counties for the calendar year 2012. Following a standard Input-Output approach, we define economic impact to be the direct, indirect, and induced economic activities generated by the astronomy sector's expenditures in the state economy, taking into account inter-county feedback and spillover effects.

Local astronomy related expenditures in calendar year 2012 were $58.43 million, $25.80 million, $1.28 million, and $2.58 million in Hawaii, Honolulu, Kauai, and Maui counties respectively. Total astronomy related spending in the state was $88.09 million. Including indirect and induced benefits and adjusting for inter-county feedback and spillover effects, the astronomy sector had a total impact of $167.86 million statewide. The largest impact was found to be in Hawaii County ($91.48 million), followed by Honolulu County ($68.43 million). Impacts were found to be relatively small in Maui County ($5.34 million) and Kauai County ($2.61 million). In addition to contributing to output, astronomy activities generated $52.26 million in earnings, $8.15 million in state taxes, and 1,394 jobs statewide.

Astronomy Activities by County

The State of Hawaii has one of the largest astronomy sectors in the United States, with world class observatories attracting scientists, research funds and visitors to the islands. The Institute for Astronomy (IfA) was founded at the University of Hawaii (UH) in 1967 to manage the Haleakala Observatory on Maui and to guide the development of the Mauna Kea Observatories on Hawaii Island, as well as to carry out its own program of fundamental research. It has a total staff of 250, including 55 faculty members. The IfA has an annual budget comprising approximately $10.5 million in funds allocated by the University and $22 million in external funds (mostly federal grants and contracts). There are several University of Hawaii departments with research programs and degrees in astronomy, and five public facilities open to visitors on Oahu and Hawaii Island (Bishop Museum Planetarium, Aerospace Lab and Planetarium at Windward Community College, Mauna Kea Observatory Visitor Information Station, ʻImiloa Astronomy Center of Hawaiʻi, and Onizuka Space Center).

Astronomy has been identified as an emerging industry in Hawaii. In 2007, the astronomy and space science sector accounted for 885 jobs, with an average salary of $70,951.[1] In addition, astronomy activity creates employment for hundreds of people in related industries, purchases goods and services from local businesses, and invests in capital improvements. Finally, the research and education components contribute to Hawaii through investment in human capital and the spillovers of knowledge important in a budding technology and innovation community. The objective of this study is to quantify the economic impact of astronomy to the state of Hawaii. Using survey data collected from the IfA, UH Manoa, UH Hilo, and other astronomy-related entities in Hawaii, we conducted an input-output analysis to estimate astronomy's contribution to local business sales, employee earnings, tax revenues, and number of jobs throughout the State.

In order to accurately quantify the economic impact of astronomy, the input-output framework requires information about expenditures for all astronomy-related activities throughout the State. The scope of astronomy includes mountaintop observatory activities, astronomy research including instrument development and assessment, graduate and undergraduate astronomy programs, astronomy spin-off companies, bookstore operations, visitor operations, and the ʻImiloa Astronomy Center of Hawaiʻi.

Hawaii County

Currently, UH Hilo offers the only undergraduate astronomy major in the state of Hawaii and tops the nation in the number of undergraduate astronomy degrees awarded per year (44 students were declared astronomy majors in Fall 2012).[2] The program emphasizes training in observational astronomy, physics, mathematics, and computer science. Astronomy majors get hands-on experience by participating in research that makes use of the University Park of Science and Technology and the Hubble Space Telescope. Students also benefit from the astronomy department's numerous international collaborations, including the All-sky Survey High Resolution Air

1 DBEDT "Benchmarking Hawaii's Emerging Industries: Astronomy and Space Sciences." December 2009.

2 Of the 35 departments where the bachelor's degree was the highest astronomy degree offered, only five averaged five or more degrees annually from 2008-2010. UH Hilo was at the top of that list with an annual average of 10 degrees per year (http://www.aip.org/statistics/trends/reports/astro2010.pdf).

Shower (ASHRA) cosmic ray detection program, the Panoramic Survey Telescope and Rapid Response System (PanSTARRS) asteroid detection system, the Pacific International Space Center for Exploration Systems (PISCES) that focuses on sustainable human habitats for the Moon and Mars, and the Taiwan-American Occultation Survey (TAOS) that studies the outer solar system.

The summit of Mauna Kea is an ideal location for ground-based astronomical research because of its dark skies, low humidity, clean air, good weather, and proximity to the equator. The Mauna Kea Observatories (MKO) are an independent collection of roughly one dozen astronomical research facilities, including the UH 2.2-m telescope, the NASA 3.0-m Infrared Telescope Facility, the Canada-France-Hawaii 3.6-m Telescope, the United Kingdom 3.8-m Telescope, the W.M. Keck Observatory 10-m Telescopes, the Subaru 9.3-m Telescope, the Gemini Northern 9.1-m Telescope, the Caltech Submillimeter 10.4-m Telescope, the James Clerk Maxwell 15-m Telescope, the Submillimeter Array 8x6-m Telescope, the 25-m Very Long Baseline Array Antenna, and the planned $1.4 billion Thirty Meter Telescope spearheaded by the University of California system, California Institute of Technology, and Association of Canadian Universities for Research in Astronomy in partnership with China, India and Japan. The MKO is located in the 525-acre Astronomy Precinct within the 11,288-acre Mauna Kea Science Reserve, which is overseen by the Office of Mauna Kea Management (OMKM). OMKM was established in 2000 as part of a master plan to provide responsible stewardship of Mauna Kea, including protecting cultural, natural and scientific resources, monitoring public access, and decommissioning astronomical facilities. Under the direction of OMKM, the Mauna Kea rangers monitor the external activities of the observatories, commercial tour operators, and the activities of the visiting public to promote safety and prevent harm to the resources. Mauna Kea Observatories Support Services (MKSS) operates and maintains mid-level food and lodging facilities at Hale Pohaku, maintains the summit access road, provides administrative services for the weather center and communications network, and operates the Onizuka Center for International Astronomy Visitor Information Station, which is located at the 2,800 m level and is open 365 days a year.

A number of foreign countries conduct research at MKO including Canada, France, the United Kingdom, Japan, Argentina, Australia, Brazil, Chile, Taiwan, Korea, and soon China and India. The University shares in the scientific use of all of the telescopes, except the VLBA, at the level of 10-15% of the observing time. This use is available to anyone within the University system who has a valid proposal; the observing time is awarded on a competitive basis. The observatory base facilities are located at lower elevations such as Waimea and Hilo, where hundreds of employees contribute to the local economy. The research facilities also participate in outreach activities such as field trips, stargazing programs, classroom visits and science nights at libraries.

While most astronomy facilities focus on generating research and providing community outreach from a purely scientific standpoint, the 'Imiloa Astronomy Center of Hawaii was designed specifically to promote the integration of modern astronomical science and the Hawaiian culture. Open since 2006, the $28 million, 42,000-square-foot exhibition and planetarium complex is located in the University of Hawaii's Science and Technology Park. Since opening, 'Imiloa has served thousands of students in a number of educational programs including field trips, family workshops, afterschool programs, other extra-curricular activities, robotic tournaments, and overnight sleepover events.

The observatories typically either develop their instruments in-house or outsource them to out-of-state companies or labs. Some, however, contribute to the local economy by requesting services from astronomy spinoff companies in Hawaii. Mauna Kea Infrared (MKIR), LLC has been building custom hardware since 1985. Their 3,500-square-foot facility in Hilo is equipped with instrument design, assembly, and testing areas. MKIR's biggest project to date was a $4 million coronagraphic camera for the Gemini South 8-m Telescope in Chile.

Honolulu County

While not a suitable location for observatories, Honolulu County does house a large number of the State's astronomy researchers. The Institute for Astronomy (IfA) headquarters, located at UH Manoa, includes a library, labs, a machine shop for building instruments, computing facilities, and remote observing facilities. With a staff of 81 PhDs from 26 different countries, IfA is one of the largest university astronomy programs in the world. IfA has an annual budget of roughly $32 million ($22 million of which comes from federal grants and contracts) and a total staff of 250, including 55 faculty members. IfA also has offices and laboratories on Maui and Hawaii Island, as well as observatories on the summits of Mauna Kea and Haleakala.

IfA shares responsibility for the UH Manoa graduate astronomy program with the University's Department of Physics & Astronomy. In Fall 2012, the program had 45 students working for MS or PhD degrees. In addition to teaching and advising graduate level research, IfA provides research opportunities to undergraduate students. Beginning in 2015, IfA will offer undergraduate degree programs in astronomy and astrophysics. The UH Manoa College of Engineering also engages in some space-related activities, including the Small Satellite Program, which was established in 2001. Sponsored by NASA's Educational Launch of Nanosatellites Program, 30 engineering students have spent the past three years designing and building a cube satellite, dubbed Hooponopono 2 or H2, to calibrate and monitor US Department of Defense radar stations that track objects in space.

Like MKIR in Hawaii County, GL Scientific, Inc. in Honolulu designs, manufactures, and services precision scientific instruments and custom components, many of which are used for astronomy research. Customers include Gemini Observatory, Canada-France-Hawaii Telescope Corporation, W.M. Keck Observatory, University of California, and California Institute of Technology.

Maui County

The IfA operates the Advanced Technology Research Center located in Pukalani, on the slopes of Haleakala. The Maui branch of IfA houses over $3 million in advanced optical instrumentation and test equipment. Other ATRC assets include a welding shop and full machine shop with over $2 million of fabrication instruments.

The Haleakala Observatory (HO), located above the tropical inversion layer at the summit of Haleakala, has been managed by IfA for over four decades. HO has partnerships with the National Science Foundation, NASA, the Pan-STARRS consortium, Space Telescope Science Institute, Tohoku University and the Air Force[3], and hosts over half a dozen telescopes. HO's location is favorable for a variety of purposes, which makes it a very desirable destination for unique and cutting edge research. For example, the Mees Solar Observatory and Solar-C are used specifically for solar observation, whereas the TLRS-4 Laser Ranging System measures distances to the Moon and artificial Earth satellites. The Faulkes Telescope provides free access to robotic telescopes and a fully supported education program to encourage teachers and students to engage in hands-on research-based science education.

Most recently, the PS1 and PS2 telescopes were completed for the Pan-STARRS wide-field survey program. Among other things, the Pan-STARRS telescopes will search for large asteroids long before possible impact with Earth. The planned Asteroid Terrestrial-Impact Last Alert System (ATLAS) will search the sky in a closer and wider region to help identify smaller asteroids that hit Earth much more frequently. Funding from NASA will provide $5 million over five years to a UH Manoa team for the development of ATLAS. The Haleakala Observatory is also the site for the 4-m Advanced Technology Solar Telescope (recently officially named the Daniel K. Inouye Solar Telescope), currently under construction.

With the many facilities dedicated to space surveillance atop Haleakala, Maui has hosted the Advanced Maui Optical and Space Surveillance Technologies Conference – the premiere space surveillance conference in the nation – every year since 2001. The focus of the conference is space situational awareness, i.e. keeping track of man-made space junk and asteroids that could damage or destroy commercial and government satellites. The conference attracts top names in the aerospace industry and aerospace research.

3 The Air Force activities are not included in this impact study.

Methodology and Data

The astronomy sector generates economic activity in the community through local business sales, employee earnings, tax revenues, and job creation. We used data on labor earnings and astronomy-related expenditures for three major spending categories -- astronomy operations, students and visitors -- to calculate the total local expenditures by industry for each county. Expenditure types were classified using the North American Industry Classification System (NAICS) industry descriptions. The total amount of economic activity generated in each county (Hawaii, Honolulu, Maui, and Kauai) was then estimated using the 2007 inter-county input-output (I-O) model of Hawaii's economy. [4]

Operation expenditures for astronomy related entities

In collaboration with the IfA, a survey was designed to obtain information from astronomy related entities about in-state expenditures for the calendar year 2012 (see Appendix A). Expenditure categories included salaries and wages, rent on facilities and equipment, capital purchases, supplies, information services, utilities, professional services, repair and maintenance, and construction. Data was collected from mountain-top observatories on Mauna Kea and Haleakala, other astronomy research facilities, Mauna Kea Observatories Support Services (MKSS), Office of Mauna Kea Management (OMKM), the UH

4 An I-O model accounts for all sales and purchases made by firms in each sector of the economy, thus creating a comprehensive picture of the interdependence among industries in the economy.

Manoa graduate astronomy program, the UH Hilo undergraduate astronomy program, the 'Imiloa Astronomy Center of Hawaii, astronomy spin-off companies in Hawaii, and the Visitor Information Station at Hale Pohaku. Collected expenditure data was organized by county and by spending category, each of which corresponds to one of 20 industries. Individual responses were then aggregated for each industry-county combination.

To best calculate the economic impacts, one must convert the in-state retail level expenditure data collected from the survey into producer level expenditures by industry categories. This conversion must be done since all transactions in the DBEDT I-O model are valued at producer prices. Therefore, the economic multipliers that were used to estimate economic impacts are based on producer level rather than retail level data. Producer price expenditures equal retail price expenditures less retail, wholesale, and transportation margins.[5]

Student expenditures

There are three astronomy degree programs in the state of Hawaii: the UH Manoa MS and PhD programs and the UH Hilo undergraduate program. Fall 2012 enrollment data for each of the programs was obtained from the UH System Institutional Research and Analysis Office Data Portal.[6] The number of students from each county, 45 and 44 for Honolulu and Hawaii respectively, was then multiplied by average spending by category – "graduate student on Oahu" for PhD students and "undergraduate student on all neighbor islands" for undergraduate students – to calculate total student expenditures in each of the 20 NAICS-classified industries.[7]

Visitor expenditures

Ideally visitor expenditure calculations would include data on tourist visitors who spent a portion of their vacation participating in astronomy related activities. However, identifying the proportion of total vacation spending attributed only to astronomy activities would be very difficult, given that most visitors do not come to Hawaii specifically to visit observatories or other astronomy facilities. Instead, visitor expenditures were based on visitors who come to Hawaii specifically to work at astronomy facilities. The final values and corresponding impacts can therefore be viewed as a lower bound for total visitor expenditures on astronomy related activities in Hawaii.

Using data on the number of visitors and average duration of stay collected by the IfA, we calculated total visitor spending by multiplying the total number of person-days in each county by the corresponding 2012 visitor average personal daily expenditures in that county.[8] Because we are interested in the economic impacts to Hawaii specifically, total expenditures were adjusted in each county for out-of-state imports (15.5% for all counties) and within-state imports (1.0% for Honolulu, 13.9% for Hawaii, 9.3% for Maui, and 17.8% for Kauai). Within-state imports for each county were redistributed across 20 industries in that county using fixed visitor expenditure (VE) shares that can be calculated from the 2007 Hawaii Inter-County I-O Transactions table.[9]

5 Appendix C in "The Hawaii State Input-Output Study: 2007 Benchmark report," Department of Business, Economic Development, and Tourism, July 2011.
6 https://www.hawaii.edu/institutionalresearch/home.action

7 Average spending numbers were obtained from a survey conducted as part of "The Contribution of the University of Hawaii at Manoa to Hawaii's Economy in 2012," University of Hawaii Economic Research Organization, January 2013.
8 Table 83 in "2012 Annual Visitor Research Report," Hawaii Tourism Authority, August 2013.
9 Transaction table is part of the "2007 Hawaii Inter-County I-O Study," Department of Business, Economic Development, and Tourism, May 2012 and can be downloaded at

Labor earnings and personal consumption expenditures

The survey on astronomy related in-state expenditures included specific questions on total salaries and wages, employee benefits, retirement contributions, and FICA taxes. Using this information, net labor earnings were calculated for each county as the sum of wages, salaries, and benefits, less FICA taxes. Total labor earnings in each county were then adjusted for out-of-state imports (14.6% for all counties) and within-state imports (4.4% for Honolulu, 13.8% for Hawaii, 16.5% for Maui, and 22.3% for Kauai). Because a substantial portion of labor earnings are injected back into the economy in the form of household purchases of goods and services, within-state imports for each county were redistributed across 20 industries in that county using fixed personal consumption expenditure (PCE) shares that can be calculated from the 2007 Hawaii Inter-County I-O Transactions table. [10]

Total in-state expenditures on astronomy

Total local expenditures by county were calculated as the sum of operations, student, visitor, and personal consumption expenditures, adjusted for out-of-state and in-state imports. The breakdown of the total local expenditures by county is reported in Figure 1. IfA survey data was reported by industry and data from other sources was distributed via fixed industry shares as described above. Therefore, each of the $88.09 million spent locally were assigned to one of 20 industries. Table 1 shows that nearly one fifth of the total local expenditures occurred in the real estate and rental sector, 13% occurred in the retail sector, and 11% occurred in each of the utilities and health services sectors. The resulting 1×80 local expenditure vector that captures all combinations of the 20 industries and 4 counties was used for calculation of the economic impacts. More details on these calculations are provided in Appendix B.

http://dbedt.hawaii.gov/economic/reports_studies/2007-inter-county-io/

10 Ibid 9

Economic impact calculations

Type-II inter-county total requirement tables[11] were used to calculate economic impacts for each county in terms of output, earnings, taxes, and jobs. Each 80×80 requirement table was multiplied by the corresponding local expenditures in county-industry, resulting in four 80×80 matrixes. For a given impact category (e.g. output), total impact for county X was calculated by summing across all rows corresponding to that county (20 rows and 80 columns), i.e. summing over all industries. Total impact for industry Y was calculated by summing all elements for industry Y (4 rows and 80 columns), i.e. over all counties.

11 A total requirements table is a matrix of coefficients showing the sum of direct and indirect purchases required to produce one dollar of output, one dollar of earnings, one dollar of taxes, or one job.

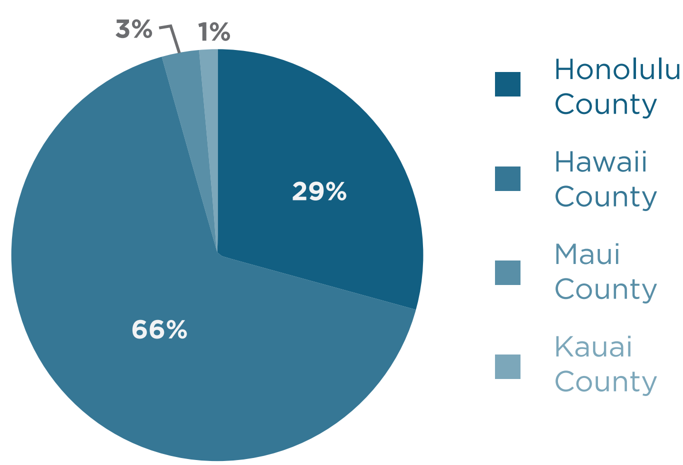

Figure 1 - Share of Local Expenditures by County

The inter-county type II "multipliers" capture the direct, indirect, and induced effects per dollar of spending in each of the 20 sectors of Hawaii's economy.[12] While more computationally intensive than a state-level model, the advantage of using an inter-county model is that it accounts for both flows of goods and services within each county and between counties, and it can therefore capture spillover and feedback effects. When a new economic activity in Hawaii County, for example, increases an industry's final demand and the produced output in that county, new flows of goods and services are required from other counties (in this case, Honolulu, Kauai, and Maui), resulting in increased output in those counties as well – a spillover effect. The increased production in those counties might, in turn, create new demand for goods and services produced in Hawaii County (for example, via purchase of inputs). This boost in Hawaii County's economic activity is in addition to the initial change in output, and is therefore considered a feedback effect.

Astronomy's Impact on Hawaii's Economy

In calendar year 2012, astronomy related local expenditures totaled $88.09 million. Together with additional indirect and induced benefits from these activities, astronomy had a total im-

Table 1. Total Local Expenditures by Industry

Industry	Local expenditures in 1,000$
Agriculture	$614
Mining and construction	$928
Food processing	$1,438
Other manufacturing	$3,847
Transportation	$2,878
Information	$2,425
Utilities	$9,561
Wholesale trade	$4,638
Retail trade	$11,877
Finance and insurance	$3,102
Real estate and rentals	$15,711
Professional services	$4,485
Business services	$1,089
Educational services	$1,788
Health services	$9,737
Arts and entertainment	$1,100
Accommodation	$4,522
Eating and drinking	$2,151
Other services	$3,960
Government	$2,241
TOTAL	**$88,093**

12 To illustrate the relationship between "direct," "indirect," and "induced" effects, consider the following example: I spend $10 at a local grocery store; the "direct effect" of my expenditure on business sales in the economy is the $10 received by the grocery store. In turn, the grocery store purchases $5 worth of goods from its wholesaler. The additional sale in the economy by the wholesaler to the grocery store is an "indirect" effect of my grocery purchase. Both the grocery store and the wholesaler pay their employees, and with their pay the employees purchase goods and services in the economy. These are the "induced" effects. Similarly, the grocer and wholesaler pay rent, interest on loans, and take home profits; those incomes are eventually spent in the economy as well. Type II multipliers capture the "multiplier," or sometimes referred to as the "ripple," effects of any initial spending.

pact of $167.86 million on Hawaii's economy. Table 2 shows that the $88.09 million in expenditures generated $52.26 million of employee earnings, $8.15 million in state tax revenues and 1,394 jobs.

Nearly 70% of local spending occurred in Hawaii County. The $58.43 million of expenditures attributed to astronomy activities in Hawaii County alone generated $91.48 million in local business sales (or 55% of the total impact on the business sales), $27.98 million in employee earnings (or 54% of the total effect), $4.00 million in state tax revenues (50% of the total effect), and over 800 jobs or 60% of the total effect (Table 2).

Table 3 reports the breakdown of the initial local spending and the overall impacts on the state of Hawaii by industry. Most of the astronomy activity spending occurred in the real estate and rentals industry (17.84%), the retail trade sector (13.48%), and the health services sector (11.05%). The impact this spending had to the state was not proportional to the spending, due to structural differences in the way each sector allocates spending throughout the state and four counties. For example, while expenditures to the retail sector was significant at over 13% of total astronomy activity spending, the impact to total output to the state was less than 10%, versus a sector such as other manufacturing which saw just over 4% of total spending but had an output impact to the state of almost 9%. The immediate nature of retail spending, in many cases, is that most of the funds received go directly out of state to the original seller. Spending to the manufacturing sector, on the other hand, may go largely towards paying for the produced good in Hawaii and/or may generate larger indirect and induced effects.

To properly assess the impact of astronomy activities in Hawaii, it was essential to focus on "local" expenditures and exclude payments to out-of-state vendors. Because many of the calculations detailed in the study are based on reported local expenditures from survey participants, the accuracy of the estimated impact depends largely on whether participants were able to successfully distinguish local and out-of-state expenditures. The estimated impact also depends on how expenditures are disaggregated across industries, since the output of the I-O model is sensitive to where inputs are coming from.

Table 2. Economic Impacts of Astronomy-Related Local Expenditures by County

	Local expenditures (millions of 2012 $)	Impacts			
		Output	Earnings	State Taxes	Jobs
		(millions of 2012 $)			(#)
Hawaii County	58.53	91.48	27.98	4.00	806
Honolulu County	25.80	68.43	21.50	3.75	509
Kauai County	1.28	2.61	1.06	0.12	32
Maui County	2.58	5.34	1.72	0.29	46
TOTAL	**88.09**	**167.86**	**52.26**	**8.15**	**1,394**

Table 3. Economic and Impact Shares Among the Industries

	Local expenditures (%)	Output	Earnings	State Taxes	Jobs
		Industry's share (%)			
Agriculture	0.70	0.77	0.53	0.33	2.08
Mining and construction	1.05	1.61	1.77	1.73	1.16
Food processing	1.63	1.31	1.63	0.65	1.74
Other manufacturing	4.37	8.94	2.51	1.19	1.97
Transportation	3.27	3.15	3.28	2.43	2.85
Information	2.75	3.08	2.63	2.89	2.00
Utilities	10.85	8.01	3.09	4.88	1.20
Wholesale trade	5.27	4.28	5.49	10.90	4.12
Retail trade	13.48	9.88	11.04	12.15	14.91
Finance and insurance	3.52	4.75	3.90	3.68	3.49
Real estate and rentals	17.84	19.91	4.54	14.04	6.65
Professional services	5.09	4.99	8.58	7.08	7.10
Business services	1.24	3.69	6.26	5.28	7.49
Educational services	2.03	1.50	3.12	2.28	3.96
Health services	11.05	9.43	15.53	1.30	12.51
Arts and entertainment	1.25	0.94	1.80	7.01	2.83
Accommodation	5.13	3.16	3.85	3.45	2.74
Eating and drinking	2.44	2.66	3.32	4.26	5.45
Other services	4.50	4.68	7.82	2.19	10.31
Government	2.54	3.26	9.32	2.58	5.43

Astronomy: A Sizable Economic Sector in Hawaii

Figure 2 shows the astronomy sector's contribution to Hawaii's economy compared with other similar sized sectors throughout the state. In 2012, astronomy's output was roughly equal to half of the output estimated for the agriculture, forestry, fishing, and hunting sector; one third the size of the output from the arts, entertainment, and recreation sector; and nearly one fourth of the output attributed to either the educational services or the management of companies and enterprises sector.

Figure 3 illustrates that the total impact of astronomy to the state ($167.86 million) is nearly twice the size of the impact estimated for the Natural Energy Laboratory Hawaii Authority Tenants ($87.7 million)[13], and larger than the cumulative impact of the UH system on Maui ($85.16 million) and Kauai ($61.53 million) counties.[14] It is also approximately one third the size of the UH system's impact on Hawaii County. The astronomy sector is a significant contributor to Hawaii's economy, and will likely to continue to be one in the foreseeable future, given the continued interest in ongoing and planned astronomy related projects throughout the state.

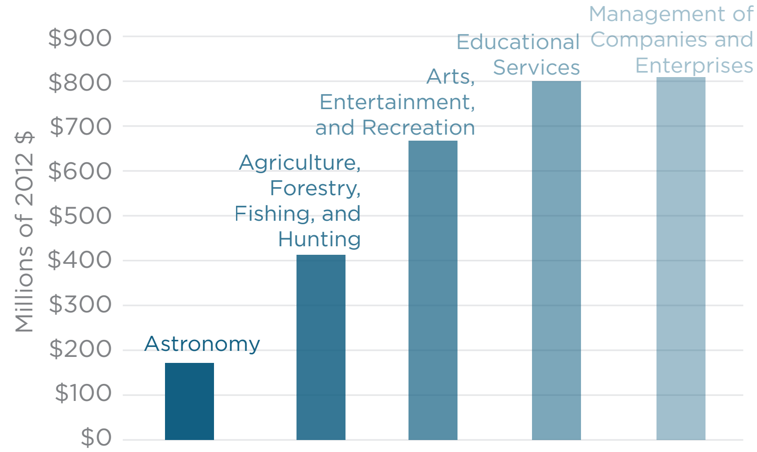

Figure 2 - A Comparison of Astronomy to Other Sectors in the Economy

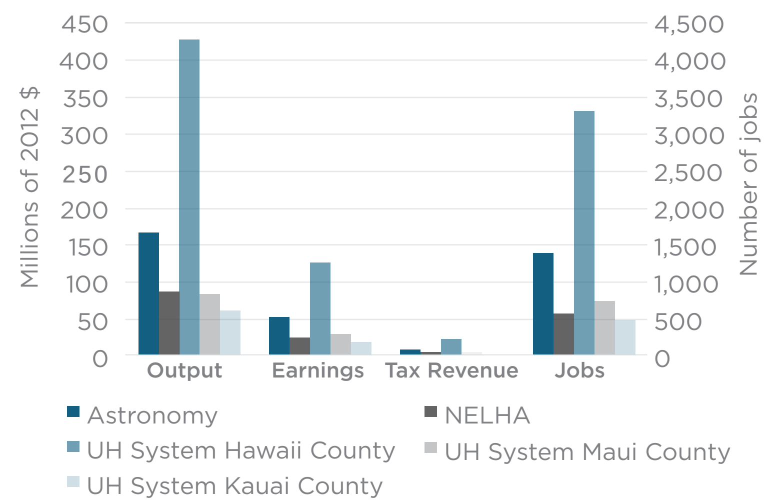

Figure 3 - The Relative Size of Astronomy's Impact

13 "Economic Impact of the Natural Energy Laboratory Hawaii Authority Tenants on the State of Hawaii," University of Hawaii Economic Research Organization, May 2012.
14 "The Economic Impact of the University of Hawaii System," University of Hawaii Economic Research Organization, April 2013.

Appendix A: Expenditure Survey

Organization name: ______________________________
Name of contact: ______________________________
Phone: ______________________________
Email: ______________________________

Category	**Description and examples ***	Total calendar year 2012 expenditures (to the nearest 1,000 $)	% of total calendar year 2012 expenditures by county**			
			Honolulu	**Hawaii**	**Maui**	**Kauai**
Salaries and wages	Salaries and wages paid to employees, including other taxable payments such as high altitude allowances, merit awards, etc. **Do not** include fringe.					
Employee benefits	Fringe benefit payments, expenditures for business and employee insurance coverage, employee benefit programs and services. **Do not** include FICA.					
Retirement contributions	State of Hawai'i Employees' Retirement System (ERS), TIAA-CREF, etc.					
FICA taxes	Federal Insurance Contributions Act					
Rent	Expenditures for rental of facilities, equipment, vessels, cars, etc.					
Equipment	Expenditures for capital purchases - durable goods, equipment, motor vehicles, furniture, construction materials, metals and minerals (except petroleum), laboratory equipment, scientific instruments, etc.; include raw and intermediate materials and supplies used in production of astronomy related equipment					
Supplies	Office supplies, consumables, minor equipment					
Information	Internet, telecommunications, media services					
Utilities	Electricity, gas, water					
Professional services	Expenditures for services such as payroll and accounting; computer support; research; consulting; engineering, architectural					

Category	**Description and examples ***	Total calendar year 2012 expenditures (to the nearest 1,000 $)	% of total calendar year 2012 expenditures by county**			
			Honolulu	**Hawaii**	**Maui**	**Kauai**
Financial & insurance services	Investment management services, expenditures for interest on loans or leasing arrangement s					
Business services	Waste management and remediation services; security and surveillance services, cleanin g					
Transportation	Expenditures to transport materials and equipment via air, water, truck, rail, etc.; include warehousing and storage en rout e					
Repair & Maintenance	Equipment and machinery repairs and maintenance; Observatory and other building repair and maintenance ; Safety inspections					
Construction	Heavy & civil engineering construction; Construction costs incurred for observatory and other buildings					
Taxes	Payroll taxes other than FICA, real property taxes, income taxes, import taxes					
Travel	Expenditures for airfare, lodging, meals & incidentals paid on behalf of employees and others such as event participants, invited guests, etc. Please provide total and breakdown of lodging costs and airfare/ground transportation if available OR provide a best estimate for lodging and airfare %. **Total travel**					
	Lodging (amount or %)					
	Airfare/gr transportation (amount or %)					
Other***	(Please describe)					

Please report the number of FTE employees in each category, by county

FTE Category	**Examples**	**Honolulu**	**Hawaii**	**Maui**	**Kauai**
Scientific research	Researchers, faculty, graduate students, post docs, etc.				
Technical support	Engineers, technicians, other trades, etc .				
Administrative support	Managers, clerical and financial workers, etc.				

* **For Mauna Kea observatorie s**, do not include M auna Kea Observatories Support Services payments. These will be handled separately.

** If the actual dollar amount spent in each county is not available, please estimate the percentage.

*** “Other” expenditure category is a catch-all to account for all institution expenditures in calendar year 2012. Use this category for expenditures that were not captured in the above specifie d categories and provide as best as possible a brief description of the expenditure. Use this category if you are not sure whether a particular expenditure belongs to any other above specified categories.

Please note that you can make more than one entry in this category. For each entry, please provide a description/explanation along with each expenditure amount e.g., tuition payments for employees - $XXX”, x%; publication costs - $YY, y%. We encourage you to make multiple entries in situations where there is more than one expenditure typ e that cannot be included in one of the specified categories. If you need more space for the category “Other” please attach a nother page.

Appendix B: Economic Impact Calculations

We use data on labor earnings and astronomy-related expenditures for three major spending categories - students, astronomy operations, and visitors - to calculate the total local expenditures by industry for each county. The economic impact of astronomy in each county is then determined using the 2007 Inter-County Type II multipliers for output, earnings, state taxes, and jobs. This appendix provides a detailed explanation of the computations undertaken to arrive at our final impact estimates.

Student expenditures

Fall 2012 enrollment data for the UH Manoa PhD program and the UH Hilo undergraduate program was obtained from the UH System Institutional Research and Analysis Office Data Portal. The number of students from each county was then multiplied by average spending by category – "graduate student on Oahu" for PhD students and "undergraduate student on all neighbor islands" for undergraduate students – to calculate total student expenditures in each industry (m=1, … , 20).

For example, student expenditures in county i in industry m were calculated as

$$(\text{student exp})_{i,m} = [(\text{\# graduate students})_i \times (\text{avg spending for grad student in county } i \text{ in industry } m)] + [(\text{\# undergraduate students})_i \times (\text{avg spending for undergrad student in county } i \text{ in industry } m)] \qquad \text{(B1)}$$

Operation expenditures for astronomy related entities

In-state expenditure data collected from astronomy related entities was organized by county (i) and by spending category, each of which corresponds to one of 20 industries. k=1,..,18 individual responses were then aggregated for each county-industry combination. So for county-industry combination i-m, total operation expenditures are given by

$$(\text{op exp})_{i,m} = \Sigma^{18}_{k=1} [(\text{operations expenditures})_{i,m}]_{k}, \qquad \text{(B2)}$$

Since all transactions in the DBEDT I-O model are valued at producer prices, we converted the collected retail level data into producer level expenditures by industry categories according to the following formula:

$$\text{producer price exp} = \text{retail price exp} - \text{retail margin} - \text{wholesale margin} - \text{transport margin} \qquad \text{(B3)}$$

Visitor expenditures

Visitor expenditures were based on visitors who come to Hawaii specifically to work at astronomy facilities. The final values and corresponding impacts can therefore be viewed as a lower bound for total visitor expenditures on astronomy related activities in Hawaii. Total visitor-spending in county i is calculated as follows:

$$(\text{gross visitor exp})_i = (\text{\# person-days})_i \times (\text{2012 visitor personal daily expenditures})i \quad \text{(B4)}$$

Because we are interested in the economic impacts to Hawaii specifically, total expenditures were adjusted in each county for out-of-state imports (15.5% for all counties) and within-state imports (1.0% for Honolulu, 13.9% for Hawaii, 9.3% for Maui, and 17.8% for Kauai). Then within-state imports for each county were redistributed across 20 industries in that county using fixed visitor expenditure (VE) shares that can be calculated from the 2007 Hawaii Inter-County I-O Transactions table.[15] The transactions table records transactions between Hawaii's industries, final-payments sectors, and final-demand sectors. The table keeps track of industry sales, final consumers, and intermediate goods sold to local industries for use in producing the finished goods. The sum of a row is the total output or total sales of an industry.

Then for county-industry combination *i-m*, in-state visitor spending is

$$(\text{visitor exp})_{i,m} = [(\text{gross visitor exp})_i \times (1 - 0.155 - \alpha_i)] \times VE_{i,m} \quad \text{(B5)}$$

where α_i is the percentage of expenditures attributed to within-state imports in county *i* and VE_{im} is a share of industry *m* in visitor expenditures in county *i*.

Labor earnings and personal consumption expenditures

The survey on astronomy related in-state expenditures (Appendix A) included specific questions on total salaries and wages, employee benefits, retirement contributions, and FICA taxes. Using this information, net labor earnings for all k respondents were calculated for each county *i* as

$$(\text{net labor earnings})_i = (\text{wages} + \text{salaries} + \text{benefits})_i - (\text{FICA taxes})_i \quad \text{(B6)}$$

Total labor earnings in each county were then adjusted for out-of-state imports (14.6% for all counties) and within-state imports (4.4% for Honolulu, 13.8% for Hawaii, 16.5% for Maui, and 22.3% for Kauai). Within-state imports for each county were redistributed across 20 industries in that county using fixed personal consumption expenditure (PCE) shares.[16] Analogous to (B5), for county-industry combination *i-m*, in-state labor earnings are

$$(\text{labor})_{i,m} = [(\text{net labor earnings})_i \times (1 - 0.146 - \beta_i)] \times PCE_{i,m} \quad \text{(B7)}$$

where β_i is the percentage of labor earnings attributed to within-state inputs in county *i* and

15 Ibid 9

16 Ibid 9

PCEim is a share of industry *m* in personal consumption expenditures in county *i*.

Total in-state expenditures on astronomy

Total local expenditures by industry-county were calculated as the sum of student, operations, visitor, and personal consumption expenditures, adjusted for out-of-state and in-state imports. The resulting 1×80 local expenditure vector captures all combinations of the 20 industries and 4 counties. Each element of the vector is calculated as follows:

$$(\text{total exp})_{i,m} = (\text{student exp})_{i,m} + (\text{op exp})_{i,m} + (\text{visitor exp})_{i,m} + (\text{labor})_{i,m} \quad \text{(B8)}$$

Economic impacts of local astronomy expenditures

Type-II inter-county total requirement tables[17] were used to calculate economic impacts for each county in terms of output, earnings, taxes, and jobs. The direct requirement tables are derived from the transactions tables, and represent the amount of inputs purchased directly to produce one dollar of output. Total requirement tables represent the sum of direct and indirect purchases required to produce a dollar of output. Each 80×80 requirement table (one for output, one for earnings, one for taxes, and one for jobs) was multiplied by the corresponding local expenditures in each county-industry, resulting in four 80×80 matrixes. For a given impact category (e.g. output), total impact for county *i* was calculated by summing across all rows corresponding to that county (20 rows and 80 columns). The 20 rows correspond to the 20 industries in the county, and the 80 columns correspond to the inter-county effects (4 counties × 20 industries). Total impact for industry m was calculated by summing all elements for industry m (4 rows and 80 columns). The 4 rows correspond to the 4 counties, and the 80 columns again correspond to the inter-county effects.

To illustrate the methodology, the example matrix below illustrates calculated impacts for a 3 county - 3 industry model. C-*i* denotes county *i* where *i* = 1, … , 3 and IND-*j* denotes industry *j*, where *j* = 1 , …, 3. Each cell shows the relationship between two counties and two industries. For example, C1C1-11 corresponds to the within county (C1) within-industry (IND1) relationship; C1C1-12 corresponds to the within county (C1) across-industry relationship (between IND1 and IND2); C2C1-11 corresponds to the across county but within-industry relationship; and so on.

IO tables allow one to identify the breakdown of each industry's output multiplier by county-industry combination. Focusing on C1, the IND1 output multiplier will consist of C1C1-11, C1C1-21, C1C1-31, C2C1-11, … where transactions within IND1 in C1 (i.e. C1C1-11) will contribute the largest share to the total IND1 output multiplier in C1. Although $X1 was initially spent only in C1, the impact effect goes beyond IND1 in C1 due to the linkage between industries within the county and industries across counties, thus having an effect on IND2 and IND3 in C1, as well as IND 1, IND2, and IND3 in C2 and C3.

The impacts are calculated by multiplying the corresponding local expenditures in a county-industry by the Type II inter-county total requirement table. This means that $X1 of local expenditures in

17 Ibid 11

county C1 in IND1 is multiplied by components of the output multiplier for IND1 in C1; $X2 of local C1, and so on. The resulting matrix will contain output impacts for all county-industry combinations associated with all local expenditures.

The row C1, IND1 will contain impacts on IND1 in C1 associated with all local expenditures $X1, $X2, etc. spent across all industries in all counties (i.e., $X1 in IND1 in C1; $X2 in IND2 in C1; $X3 in IND3 in C1; $X4 in IND1 in C2; so on); the row C2, IND1 will contain impacts on IND1 in C2 associated with all local expenditures across all industries and all counties; etc. So to obtain the total impact on IND1 one has to sum impacts in IND1 across the counties (i.e., sum of shaded rows).

Matrix for output impacts

		C - 1 IND 1	C - 1 IND 2	C - 1 IND 3	C - 2 IND 1	C - 2 IND 2	C - 2 IND 3	C - 3 IND 1	C - 3 IND 2	C - 3 IND 3
C - 1	IND 1	C1C1-11	C1C1-12	C1C1-13	C1C2-11	...				
C - 1	IND 2	C1C1-21	...							
C - 1	IND 3	C1C1-31								
C - 2	IND 1	C2C1-11								
C - 2	IND 2	...								
C - 2	IND 3									
C - 3	IND 1									
C - 3	IND 2									
C - 3	IND 3									

Local exp	C1, IND1	C1, IND2	C1, IND3	C2, IND1	...
Local exp $	X1	X2	X3	X4	...

