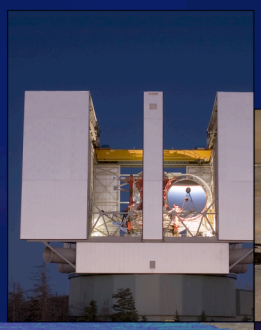
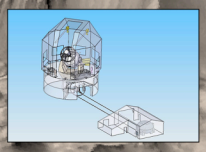
Astronomy, Planetary Sciences, and Space Sciences Research Opportunities to Advance Arizona's Economic Growth





prepared by
The Arizona Arts, Sciences and Technology Academy

The Cover

Credit: Pete Marenfeld, National Optical Astronomy Observatory

NOTICE: The Board of Governors of the Arizona Arts, Sciences and Technology Academy (AASTA) approved the project that is the subject of this report. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

Support for this project was provided by: The Arizona Department of Commerce, The University of Arizona, the Large Binocular Telescope Observatory, John* and Ginger Giovale (*Chairman Lowell Observatory Advisory Board), William** and Kathryn Putnam (**Lowell Observatory Trustee), Northern Arizona University, the National Optical Astronomy Observatory, Research Corporation, and the Vatican Observatory. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the AASTA Writing Committee and do not necessarily reflect the view of the organizations or agencies that provided support for this project.

This report is based on a joint survey conducted by AASTA and the Economic and Business Research Center at the University of Arizona Eller College of Management.

Additional copies of this report are available from:
The Arizona Arts, Sciences and Technology Academy
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The Arizona Arts, Sciences and Technology Academy

The Arizona, Arts, Sciences and Technology Academy is a private, nonprofit organization that seeks to coalesce the cultural, scientific and technical wisdom of Arizona in service to its citizens and to promote the growth of an intellectual community within the State. AASTA is nonpartisan and broadly based in cultural, behavioral and social sciences, the arts and humanities, physical and biological sciences, health sciences, administration, law and engineering. AASTA is a volunteer-led, member-based, service organization specializing in the creation and growth of a high-value scholarly society.

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Acknowledgements

AASTA acknowledges the contributions of Vera Pavlakovich-Kochi, Alberta H. Charney and Lora Mwaniki-Layman at the Economic and Business Research Center, Eller College of Management, The University of Arizona, as well as the participants in this study:

- Arizona State University: School of Earth and Space Exploration
- Fred Lawrence Whipple Observatory
- Large Binocular Telescope Observatory
- Lowell Observatory
- MDM Observatory
- Multiple Mirror Telescope Observatory
- National Optical Astronomy Observatory
- National Solar Observatory
- Northern Arizona University: Department of Physics and Astronomy
- Planetary Science Institute
- Southern Association for Research in Astronomy
- Steward Observatory
- University of Arizona: Department of Astronomy; Department of Planetary Sciences; Lunar and Planetary Laboratory; Arizona Remote Sensing Center; Optical Sciences Center; and Flandrau Science Center
- USGS Astrogeology Research Program
- US Naval Observatory
- Vatican Observatory
- WIYN (Wisconsin, Indiana, Yale, and NOAO) Observatory

AASTA further acknowledges the generous support of the project's sponsors:

- The Arizona Department of Commerce
- The Large Binocular Telescope Observatory
- John and Ginger Giovale (Lowell Observatory)
- William and Kathryn Putnam (Lowell Observatory)
- Northern Arizona University
- The National Optical Astronomy Observatory
- Research Corporation
- The University of Arizona
- The Vatican Observatory

Robert Millis, *Chair*
Project Planning and Oversight Committee

Abstract

Kitt Peak: (U of A)

Mars Launch: (ASU)

This report is the result of an original research effort led by the Arizona Arts, Sciences and Technology Academy (AASTA).

The goal of the research effort was to quantify, for the first time, the overall economic impact of research activities in the fields of astronomy, planetary sciences and space sciences (APSS) in the State of Arizona.

AASTA contracted with the Economic and Business Research Center at the University of Arizona Eller College of Management to conduct the data collection and economic impact analysis portions of the study. The findings of the U of A team are appended to this report.

AASTA analyzed the ancillary economic data also collected during the study.

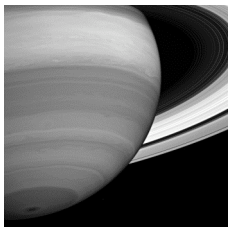
The scope of the study was limited to impacts generated by investments and expenditures associated with APSS research at Arizona's three universities, federal laboratories, and astronomical observatories. The economic impact of related industrial activity (e.g., optics) are not included in this study.

For definitional purposes, these fields of study include ground based astronomy, space based astronomy, solar system missions, earth observing missions, instrumentation and data analysis, related studies such as astrogeology and astrobiology where clear connections to planetary and solar system research can be drawn, and space related technology development.

This study found substantial capital investment (in excess of $1 billion) in, and economic return (nearly a quarter of a billion dollars annually) from APSS research in Arizona. The data also suggest the untapped potential of these research fields to expand the State's economic base. The study revealed levels of active research funding that well exceed other fields in the State, such as bioscience funding from the National Institutes of Health.

Executive Summary

Sub Millimeter Telescope:
(ARO)



Saturn Image: Cassini-
Huygens Mission:
(U of A)

Phoenix Lander:
(U of A)

The State of Arizona urgently requires the development and implementation of a science and technology roadmap as well as an investment strategy to leverage the exceptional base of research assets it has amassed in the fields of astronomy, planetary sciences and space sciences.

Arizona's world-class leadership in astronomy, planetary sciences and space sciences features an extraordinary investment of facilities and equipment that yield a significant economic return to the State.

The depth and breadth of research talent and innovation in these fields, however, has not yet been successfully tapped by the State to expand and diversify its high wage, advanced technology economic base.

Further, ever-growing levels of light pollution associated with urban development are degrading the State's competitiveness as a site for ground based optical astronomy.

This report's findings strongly suggest the need for policymakers to act affirmatively to effectively leverage Arizona's competitiveness in these fields while protecting the unique research base that exists within the State.

Specifically:

Recommendation 1

The Arizona Department of Commerce and the Arizona Aerospace and Defense Commission, working in collaboration with the APSS research institutions in the State, should immediately begin developing a strategic plan and roadmap for investing in and leveraging Arizona's competitive research assets in the fields of astronomy, space sciences, planetary sciences and related technologies.

Recommendation 2

The Arizona Department of Commerce, Arizona's APSS research institutions and APSS related industry organizations should immediately begin a cooperative effort with Arizona's federal delegation to ensure stable and growing funding for the fields of astronomy, space sciences and planetary sciences, and it should also encourage additional funding for the federal installations located in the State (NOAO, NSO, U.S.G.S., and the U.S. Naval Observatory) so that new collaborations can be formed. Furthermore, the State should act aggressively in partnership with its federal delegation to maintain these federally-funded installations in Arizona.

Recommendation 3

Research institutional leaders and scientists based in the State's astronomy, space sciences and planetary sciences facilities should create a formal collaborative organization to more effectively compete for limited federal APSS research funding to Arizona. APSS institutional leaders from across the State should form a development committee, establish goals for this organization and a timetable for its implementation.

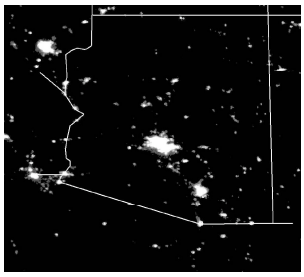
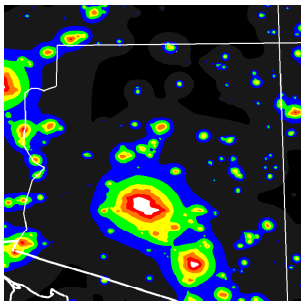


Photo taken from space (Elvidge et al. 1999) sowing Arizona outdoor lighting as seen from overhead.

Recommendation 4

The Arizona Legislature, counties, municipalities and Tribal Nations should revisit the adequacy and enforcement of existing statutes and ordinances in a new effort to reduce light pollution associated with rapid industrial and population growth as well as old lighting installed before effective codes were in place. Arizona Title 49, Chapter 7 calls for the elimination of mercury vapor lighting fixtures by 2011. All counties in the State and many municipalities have used the 1973 State law to enact light control ordinances. However the sheer rate of population growth, particularly in Maricopa County, and more recently in Pinal County, as well as lax enforcement of many existing ordinances, threaten to undo that protection. State law also severely limits the ability of authorities to bring old, obsolete and badly polluting lighting into compliance with modern codes and professional lighting standards.

Purpose



The 2nd *figure, (Cinzano, P. et al. 2000) demonstrates how the effects of light pollution spread far from the source of the lighting in cities*

The purpose of the study is to provide quantitative measures of the importance of astronomy, planetary sciences and space sciences research in Arizona's economy in an effort to stimulate public policies designed to preserve and enhance the State's competitive advantages in this domain. This report summarizes common measures of economic activity and associated impacts such as the number of jobs, wages, output and tax revenues.[1] It further analyzes trends in capital investment and other measures not normally associated with economic impact models.

The public benefit of this project is to underpin decision-making and future policy development aimed at exploiting Arizona's world-class research talent and facilities in astronomy, planetary sciences, space sciences, and related technology fields. By better defining the economic opportunity that exists and the future directions that these research units plan to pursue, business and policy leaders will be better positioned to attract, grow and retain engineering and technical firms that provide services and instrumentation for these fields.

The project oversight consortium, coordinated by AASTA, consisted of leading scientific representatives from Arizona's three State universities, three federal research organizations based in Arizona, and a number of other university related and independent observatories.

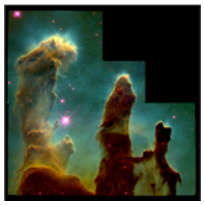
[1] See Appendix A for the full University of Arizona report.

Background

The study builds on the findings of Battelle's 2003 report entitled, "Positioning Arizona and its Universities: Science and Technologies Core Competencies Assessment", an analysis for the Arizona Department of Commerce to better quantify the level of capital investment, degree of external funding, technology development, partnering, and production of highly skilled talent that can be leveraged by the private sector.

Mars Rover: (ASU)

This study's premise rests on the strong anecdotal information already available and Battelle's conclusion suggesting, "(t)he combination of astronomy and planetary sciences at U of A, ASU, and NAU makes the state a national leader in space science and engineering." Battelle further noted, "(c)ompetitors include the University of Colorado, Cornell, and the University of Chicago, but Battelle could not find any state university system that possessed the combined strengths of astronomy and planetary sciences that Arizona has, hence the interest in the integration of these research capabilities."



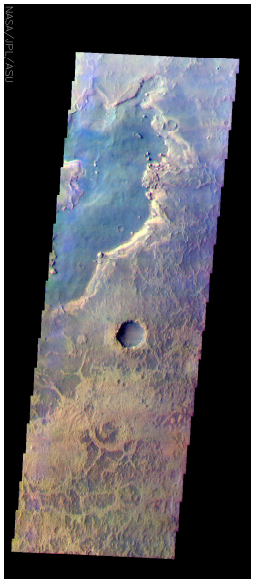
Hubble Image: Pillars of Creation (ASU)

Battelle's report summarized the core competencies and competitiveness of Arizona's universities as follows, "(a)ll three universities are engaged in very valuable basic science concerned with observations in our solar system and the emerging area of biogeochemistry to study materials on earth and other planets. However, the focus of this core competency is the engineered devices and systems that are the means to that end (i.e., powerful telescopes and satellites, measuring instruments, and related materials, optics and electronics developments). The combination of astronomy and planetary sciences at the U of A, and ASU makes the State a national leader in space science and engineering. This unique position is supported by the fact that, of four proposals selected in December 2002 for final consideration by NASA for its Mars Scout mission, two are from Arizona, U of A and ASU, while the other two are from NASA laboratories. The Arizona proposals offer innovative instruments to both examine and retrieve materials from Mars." Battelle's report, however, did not closely examine the possibilities associated with other observatories and federal research groups based in the State.

Only one institutional study documenting the economic impact of an Arizona based observatory has been completed in recent years. That study[2], completed in 2004 for the National Optical Astronomy Observatory and the National Solar Observatory, noted average salaries of $50,515 and total external funding of $21.2 million. It also noted several examples of technology transfer including optical coatings, solid state devices, software and hardware.

For the fiscal year ending June 30, 2006, new contractual obligations from NASA[3] and the Jet Propulsion Laboratory[4] to institutions in the State of Arizona totaled $147.45 million. Additional astronomy related expenditures from the National Science Foundation into the State were approximately $60 million[5]. The combined total of these new obligations for expenditures compares favorably with the State's total new awards from the National Institutes of Health for biosciences research, $160.7 million[6], for the same period.

[2] The Arizona Economic Impact of the National Optical Astronomy Observatory and the National Solar Observatory, NOAO, 2004
[3] NASA Procurement Data View (http:// prod.nais.nasa.gov/cgi-bin/npms/npms.cgi)
[4] Data provided by JPL.
[5] NSF Awards Search (https://www.fastlane.nsf.gov/a6/A6Start.htm)
[6] NIH Award Trends (http://grants.nih.gov/grants/award/awardtr.htm)



Mars Image: (ASU)

Research in astronomy (ground and space based), planetary sciences, space sciences and associated technologies is acknowledged as one of Arizona's key competitive strengths. Scores of millions of dollars have been invested in talent and infrastructure to build this capacity, but limited advantage has been taken to grow corollary industries and businesses in the State. The participants in the survey conducted by AASTA and the University of Arizona reported the spin-off of 17 companies.

General Dynamics, Orbital Sciences and Raytheon stand out as significant employers benefiting from Arizona's research base in these fields, however companies such as Lockheed Martin and Ball Aerospace, both located in Colorado, are much more likely to be the beneficiaries of research and mission related awards won by Arizona scientists than are companies located in State.

The Commission on the Future of the U.S. Aerospace Industry noted that the State of Arizona was ranked 2nd in the nation in 2001 for total employment in the market segments of guided missiles, space vehicles and related parts manufacturing. This same report noted average salaries of approximately $65,000 for these sectors[7]. Expanding this base of high value jobs can add significantly to Arizona's economic vitality.

APSS technologies embedded within Arizona based research institutions include biosensing, communications, computing, imaging, instrumentation, materials, microelectronics, navigation, optics, power, propulsion, sensors, software and systems integration.

Unpublished data from the University of Arizona indicates that the optics industry has grown tenfold in the past decade in both annual revenue and employment.

Arizona risks losing ground and consigning itself to a "grant funding pass-through" state unless steps are taken to develop investment strategies and better leverage its competitive advantages.

Finally, federal agencies such as NASA, and the civilian/defense private sector both face an aging technological workforce[8]. Arizona graduate students and undergraduates with significant experience on federally funded projects from NASA, the Department of Defense, and the National Science Foundation related to space science, space based astronomy, earth orbiting missions, and space technology development are aggressively recruited. Creating additional economic opportunity for this talent in Arizona will both preserve the investment that has been made to train them and expand the State's economic base.

[7] Final Report of the Commission on the Future of the United States Aerospace Industry, 2002 (http://trade.gov/td/aerospace/aerospacecommission/aerospacecommission.htm)

[8] Issues Affecting the Future of the U.S. Space Science and Engineering Workforce: Interim Report, Committee on Meeting the Workforce Needs for the National Vision for Space Exploration, National Research Council, 2006

Overview

In July, 1896, Percival Lowell installed the 24-Inch Clark Telescope in Flagstaff, Arizona. The capital investment for this first instrument in the territory amounted to $20,000.

Eleven decades later:

- The total cumulative APSS investment in instruments, land and facilities in the State of Arizona has expanded to $1.199 billion, with an additional $635.7 million of capital investment planned or underway.
- The total annual economic impact of research in astronomy, planetary sciences and space sciences in Arizona has reached $252.8 million.
- The total employment impact of APSS research in Arizona exceeds 3,300 jobs.
- A flourishing optics industry cluster has been created in Pima County.
- The State has developed a strategically competitive private sector capacity in the fields of missiles systems, space telecommunications, space vehicles and instrumentation.

DCT Mirror: (U of A)

Discovery Channel Telescope: (Lowell Observatory)

Lowell's original small team of astronomers has expanded to 1,830 researchers, professionals, support personnel, and students spread across the State. Many are recognized internationally for their continuous record of groundbreaking discoveries regarding the origins and physics of the universe, our solar system and our own planet. Arizona is the setting for world-class facilities in astronomy, optics, astrogeology and astrobiology.

Battelle has reported[9] that "Arizona ranks among the top ten of all states in the physical sciences (7th), led by astronomy (2nd) in which Arizona has nearly 18 percent of all university research activities nationwide". Battelle further noted that "(a)nalysis of publications/citations in the ISI Thomson Scientific Database shows significant diversity across research fields… Key strengths in publications/citation analysis are found in environment/ecology, earth sciences, plant sciences, space sciences and physics". Finally Battelle summarized, "Space Sciences has two areas of world class research:

- Design of remotely operated instruments for measurements in space; and
- Advanced land-based and space telescope design and mirror construction."

[9] Positioning Arizona and Its Research Universities: Science and Technology Core Competencies Assessment, 2003 (http://www.azcommerce.com/SiteSel/Reports/Home.htm)

Threats and Opportunities

Nationally and internationally, the competition in these fields of exploration and knowledge creation has become increasingly intense. In the U.S., a number of other states are more advantaged by virtue of possessing one or more large Federally Funded Research and Development Centers (FFRDC's), deep university-based infrastructures, and/or large space-related industrial bases. Arizona has only one FFRDC, the National Optical Astronomy Observatory (NOAO), but a number of world class astronomical observatories. The State is also home to a portion of the National Solar Observatory (NSO) operated by the Association of Universities for Research in Astronomy (AURA). Arizona's industrial capacity in space systems is relatively small but competitive.

Night Image: Kitt Peak

Arizona's rapid growth threatens the future of the State's observatories due to increasing problems associated with light pollution. This unabated growth is eroding a key competitive advantage for the placement of future world-class observatories in the State. Even though most facilities are located at some distance from large cities or metropolitan areas, these developments increasingly threaten the astronomical facilities due to the long-range propagation of light pollution and the extremely sensitive nature of much astronomical research.

Historically, Arizona has been blessed with near-ideal conditions for optical astronomy. Roughly 1/3 of the nights are absolutely clear and another 1/3 are only partly marred by clouds. We have high mountains, a dry (naturally transparent) atmosphere, and a population that is supportive of astronomy and appreciative of the unspoiled night sky. These conditions, which initially caught the attention of Percival Lowell, founder of the Lowell Observatory, and A. E. Douglass, founder of Steward Observatory, eventually attracted astronomers from across the nation and beyond.

During the period from approximately 1955 to 1985, a boom in construction of astronomical facilities occurred in Arizona, and for awhile our State was the undisputed center of optical astronomy in the world. The Steward Observatory of the University of Arizona populated the mountains surrounding Tucson with a variety of telescopes and developed programs of research and education in astronomy that remain today among the best in the nation. Arizona State University and Northern Arizona University also developed notable programs. The Kitt Peak National Observatory and the National Solar Observatory were established on Kitt Peak west of Tucson. The Smithsonian Astrophysical Observatory built a number of telescopes on Mt. Hopkins and joined with Steward Observatory in building the innovative Multiple Mirror Telescope, also at that site. The U. S. Naval Observatory built its Flagstaff Station on a small mountain west of town. Lowell Observatory established a dark sky site on Anderson Mesa east of the city and moved the 1.8-meter Perkins Telescope, then the 12th or 13th largest in the world, to that site from Delaware, Ohio.

Large Binocular Telescope: (U of A)

LBT Image: Crab Nebula

Arizona's position of unchallenged leadership in optical astronomy began to slip in the late 1980s. Growing light pollution from metropolitan areas was degrading observing conditions at established major observatory sites in the vicinity of Tucson and Flagstaff. A bitter environmental and cultural controversy, ignited by the proposal to build telescopes on Mount Graham, seriously delayed Steward Observatory's efforts to establish and demonstrate a world-class observatory site within the State. These troubles encouraged the world's astronomers to cast their eyes elsewhere as they contemplated the location of the coming generation of giant telescopes. Hawaii and Chile, which also possess excellent observatory sites, have successfully lured new major telescopes in recent years.

Meanwhile, committed Arizona institutions, including Steward Observatory, NOAO, the U.S. Naval Observatory, Lowell Observatory, and others, went to work to address the problems confronting astronomy in Arizona. Astronomers sought and received strong lighting ordinances in Flagstaff, Coconino County, Tucson, and Pima County specifically designed to protect the observatories from unchecked growth in light pollution. Steward Observatory was especially active in forming partnerships to bring major new telescopes to Arizona. The LBT and MMT are fruits of that effort. NOAO also was instrumental in bringing the 3.5-meter WIYN Telescope to Kitt Peak. Recently, Lowell Observatory began building the 4.2-meter Discovery Channel Telescope near Happy Jack on the Mogollon Rim. As a result of these efforts, Arizona can still boast the largest optical telescope in the world (LBT) and the 3rd and 5th largest telescopes in the continental United States (MMT and DCT, respectively). In addition, Arizona still has the largest solar telescope in the world (the NSO McMath-Pierce Solar Telescope on Kitt Peak), although a project under NSF consideration for the newest and largest solar telescope in the world has selected a Hawaiian site.

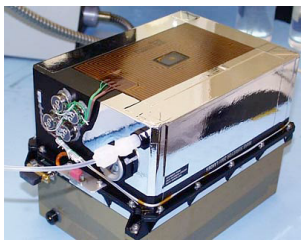
While Hawaii and Chile contain concentrations of very large telescopes, Arizona has more active observatory sites than any other state, and has a substantially greater number of telescopes engaged in professional level research than do either Hawaii or Chile. Moreover, an impressive list of out-of-state universities and research institutes have invested in Arizona facilities (see Appendix D).

In space and planetary sciences, federal funding for missions has been unstable[10]. NASA has reprogrammed its exploration menu more than once in recent years, creating some discontinuity and much uncertainty in the space science research community.

Additionally, recent federal funding for earth observing missions has resulted in a circumstance wherein "(b)etween 2006 and the end of the decade, the number of operating missions will decrease dramatically and the number of operating sensors and instruments on NASA spacecraft, most of which are well past their nominal lifetimes, will decrease by some 40 percent".[11]

[10] American Association for the Advancement of Science (http://www.aaas.org/spp/rd/nasa08s.htm)
[11] Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond
Committee on Earth Science and Applications from Space; A Community Assessment and Strategy for the Future, Space Studies

HIRISE Camera:
(U of A)



Mini TES: (ASU)

Nevertheless, Arizona's record of participation in space science and planetary sciences missions, both within the U.S. and internationally, is as deep as it is impressive. NASA's most recent mission to Mars, "Phoenix", launched on August 4, 2007 and operated by the University of Arizona, is but the latest example of this legacy of leadership. Arizona institutions have played a world-leading role in Mars research over the past decade. Other research teams have recently made notable discoveries within the Jupiter system while a firm legacy has been established by Arizona based astronomers using orbital telescopes.

Some states have aggressively supported their APSS research capacities through the creation of permanent organizations, advisory councils and strategic plans[12]. Arizona is supported by the Arizona Aerospace and Defense Commission, but has yet to put into place a roadmap or strategic plan for leveraging the State's research assets in these fields to develop and diversify its economic base. It is critical and timely that Arizona takes steps to both develop *and* protect its scientific, educational, and economic assets in the space sciences that currently reside in the State. For example, the National Solar Observatory, with staff and facilities in Arizona and New Mexico, plans to consolidate its staff at a single headquarters site during the next 5 years. The states of New Mexico, Colorado, and Hawaii, as well as others have already expressed through state, federal and university representatives a strong interest in serving as the host site for the federally-funded National Solar Observatory. We note that just over 70% of the $10M (FY07) annual budget for the National Solar Observatory is currently administered and/or expended in Arizona.

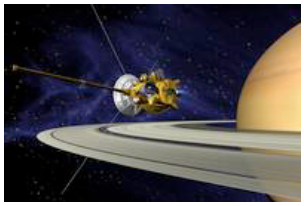
Findings and Recommendations

NASA and the National Science Foundation underwrite most of the astronomy, planetary sciences and space sciences research in the State. Direct impacts result as observatories, other research organizations, and university departments and units hire professionals, faculty, staff and students and thus contribute to Arizona's overall employment. Additional jobs in Arizona are generated through purchases of equipment, office supplies, utilities and various professional and business services necessary for daily operations. Furthermore, a significant number of jobs are created through consumption by both employees in observatories, other research organizations, and university departments and units, and employees in businesses that supply goods and services.

Key Findings:

- The total dollar impact (sales or output) in Arizona that was attributed to Arizona's astronomy, planetary sciences and space sciences was estimated at $252.8 million in FY 2006. This includes $138.6 million in earnings, and $12 million in tax revenues.

[12] Space: California's Competitive Frontier 2004; California Space Enterprise Strategic Plan, California Space Authority (www.californiaspaceauthority.org), Florida Space Research Institute (http://www.fsri.org), The Ohio Aerospace and Defense Advisory Council.



Cassini-Huygens:
(ASU and U of A)

Hubble Space Telescope:
(ASU and U of A)

- During FY 2006, Arizona's observatories and related research organizations spent a total of $135.4 million on operations, including wages and salaries. An additional $28.8 million was spent on capital investment/construction-related items. Thus, for FY 2006, total expenditures amounted to $164.2 million. Of that amount, $69.3 million was spent in Arizona.

- During FY 2006, astronomy, planetary sciences and space science related departments and centers at the three universities spent in Arizona a total of $60.5 million (including wages and salaries). Of that amount, $33.9 million was spent in Arizona.

- The organizations participating in the survey employed a total of 1,830 persons, (including 168 jobs associated with the overhead charges) of which 320 were students. The total FY 2006 payroll was $83.9 million.

- Observatories, space sciences, planetary sciences and related technology facilities in Arizona received a total of 200,805 visitors during FY 2006, out of which 6,668 were professional visitors and 194,137 were public visitors. Twenty-two percent of the public visitors were from outside Arizona. Out-of-Arizona visitors spent $16.4 million during FY 2006, generating an economic impact of $25.7 million dollars in total. The out-of-state visitors' spending generated 286 jobs and $8.1 million in earnings in Arizona.

- Astronomy, planetary sciences and space-related observatories, centers, departments and units generated $11.9 million dollars in revenues to State and local governments.

- The total cumulative investment of astronomy, space sciences and planetary sciences in instruments, land and facilities in the State of Arizona equal $1.199 billion, with an additional $635.7 million of capital expansion planned or underway.

Recommendation 1

The Arizona Department of Commerce and the Arizona Aerospace and Defense Commission, working in collaboration with the APSS research institutions in the State, should immediately begin developing a strategic plan and roadmap for investing in and leveraging Arizona's competitive research assets in the fields of astronomy, space sciences, planetary sciences and related technologies.

Recommendation 2

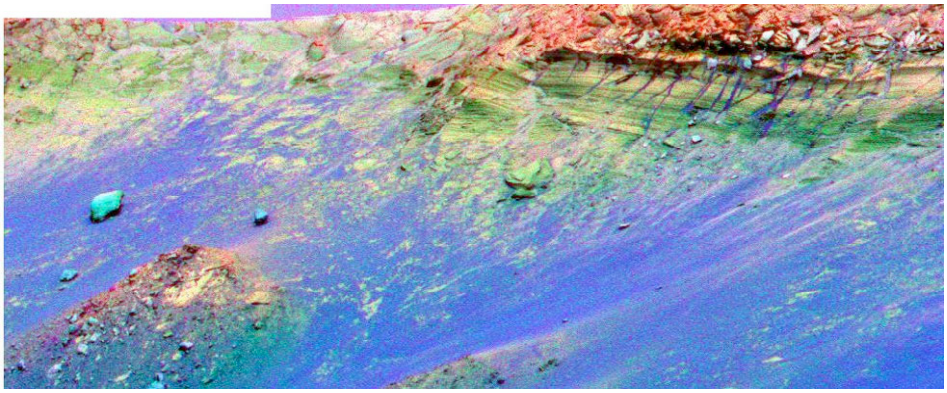
The Arizona Department of Commerce, Arizona's APSS research institutions and APSS related industry organizations should immediately begin a cooperative effort with Arizona's federal delegation to ensure stable and growing funding for the fields of astronomy, space sciences and planetary sciences, and it should also encourage additional funding for the federal installations located in the State (NOAO, NSO, U.S.G.S., and the U.S. Naval Observatory) so that new collaborations can be formed. Furthermore, the State should act aggressively in partnership with its federal delegation to maintain these federally-funded installations in Arizona.

Recommendation 3

Research institutional leaders and scientists based in the State's astronomy, space sciences and planetary sciences facilities should create a formal collaborative organization to more effectively compete for limited federal APSS research funding. APSS institutional leaders from across the State should form a development committee, establish goals for this organization and a timetable for its implementation.

Recommendation 4

The Arizona Legislature, counties, municipalities and Tribal Nations should revisit the adequacy and enforcement of existing statutes and ordinances in a new effort to reduce light pollution associated with rapid industrial and population growth as well as old lighting installed before effective codes were in place. Arizona Title 49, Chapter 7 calls for the elimination of mercury vapor lighting fixtures by 2011. All counties in the State and many municipalities have used the 1973 State law to enact light control ordinances. However, the sheer rate of population growth, particularly in Maricopa County, and more recently in Pinal County, as well as lax enforcement of many existing ordinances, threaten to undo that protection. State law also severely limits the ability of authorities to bring old, obsolete and badly polluting lighting into compliance with modern codes and professional lighting standards.



Opportunity Rover Image: (ASU)

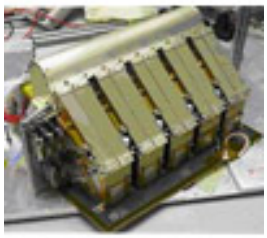
Concluding Observations

This is the first study conducted to assess the economic impact of the astronomy, planetary sciences and space sciences research on the economy of Arizona.

Other states with comparable importance in the fields of astronomy, planetary sciences and/or space sciences research are Hawaii, Colorado, California, and Washington. The University of Hawaii Institute for Astronomy conducted an economic impact on the State's economy in 2001 and since then provides annual updates.[13] No other state has issued any similar reports.

While this study is the first to present the most comprehensive assessment of the economic activity of Arizona's astronomy, planetary sciences and space sciences, the scope of the study was limited to "measurable" impacts. This study only traces money associated with APSS organizations in Arizona and visitors to those organizations.

An important segment of APSS-related activity in the State has not yet been measured, specifically manufacturers and other industries that are the result of APSS activity in the State. But there are many private sector impacts associated with astronomy, planetary and space sciences. In some instances, entire economic sectors, e.g., the optics industry, are the direct result of the strong presence of APSS organizations in Arizona. In other instances, parts of certain Arizona industries, such as missiles, electronics and computers, scientific instruments, engineering services, and robotics have close connections to astronomy, planetary and space sciences. These connections are due to graduates in these scientific fields working in the private sector. Skills learned in these sciences are transferable to the private sector.[14]



Robotic Arm Camera:
(U of A)

Astronomy, planetary sciences and space sciences have been important economic clusters in Arizona for decades. Despite the limitations and narrow focus of this study, the measured economic impacts are substantial, with astronomy, planetary and space sciences activities directly or indirectly contributing over 3,300 jobs to the Arizona economy, $138.6 million in wages, $114.2 million in other value added, (including $11.9 million in taxes). Combined, astronomy, planetary and space sciences contribute over a quarter of a billion dollars in output (sales) to the State.

Policy makers are encouraged to put into place the necessary infrastructure, protection, advocacy and investment required to sustain Arizona's competitiveness in these research fields and to grow the industrial economic base that this substantial research platform in Arizona's universities, federal laboratories, astronomical observatories, and nonprofit research organizations affords.

[13] Kudritzki, Rolf-Peter and Bob Joseph. 2003. Update to 2001 Self-Study report. (http://www.ifa.hawaii.edu/publications/self-study/self-study_Update-oct03.pdf) on 5/13/2007.

[14] ARA Group. 1999. A Division of KPMG Consulting LP. Estimation of the Economic Impacts of Canadian Astronomy. Report prepared for the National Research Council. Accessed at http://www.casca.ca/lrp/vol2/economic/Economic.htm on 2/6/2006.

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The Arizona Economic Impact of the National Optical Astronomy Observatory and the National Solar Observatory, NOAO, 2004

Appendix A: University of Arizona Report

Astronomy, Planetary and Space Sciences in Arizona

An Economic and Tax Revenue Impact Study

Prepared for

The Arizona Arts, Sciences and Technology Academy

Prepared by

Vera Pavlakovich-Kochi, Alberta H. Charney and
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September 2007

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Acknowledgements

This study would not have been possible without the assistance of many individuals.

Foremost, our thanks go to the heads of observatories, university departments and directors of research centers for participating in the survey: Arizona State University's School of Earth and Space Exploration; Fred Lawrence Whipple Observatory; Large Binocular Telescope Observatory; Lowell Observatory; MDM Observatory; Multiple Mirror Telescope Observatory; National Optical Astronomy Observatory; National Solar Observatory; Northern Arizona University's Department of Physics and Astronomy; Planetary Science Institute; Steward Observatory; Southern Association for Research in Astronomy (SARA); University of Arizona's Department of Astronomy, Department of Planetary Sciences, Lunar and Planetary Laboratory, Arizona Remote Sensing Center, Optical Sciences Center, and Flandrau Science Center; US Geological Survey's Astrogeology Research Program; US Naval Observatory; Vatican Observatory, and WIYN Observatory.

Specifically, we thank the individuals in the participating organizations who actually collected financial data and provided additional information required for this study: Jodie Kwong, Robin Melena, Steven Magee, Douglas Isbell, Mark Giampapa, Terry D. Oswalt, Mark Buglewitz, Jeff Pier, Christopher Corbally, Leslie Feldman, George Jacoby, Bruce Barett, Mark Sykes, Lisa Gaddis, Stuart Marsh, Tony Major, Lynn Lane, Gary Esham, Camellia Sciba, Daniel Matlaga and Jamie Householder.

We also thank the following individuals in the Arizona universities' financial and procurement offices for compiling detailed expenditure data associated with the participating units: Johanna Valdez, Gail Hanson, Robert Norton, Cheryl Conover and John Riley.

Valorie Rice in the Economic and Business Research Center helped with the literature search and statistical data, while Juliet King assisted in the early phase of the project.

We thank the following sponsors for supporting this project:

The Arizona Department of Commerce
John and Ginger Giovale (Lowell Observatory)
The Large Binocular Telescope Observatory
Northern Arizona University
The National Optical Astronomy Observatory
William and Kathryn Putnam (Lowell Observatory)
Research Corporation
The University of Arizona
The Vatican Observatory

Last, but not least, we thank Patrick J. Burkhart and Robert Millis representing The Arizona Arts, Sciences and Technology Academy for the opportunity to work on this study and for their continuing support throughout the project.

The authors

Astronomy, Planetary and Space Sciences in Arizona
An Economic and Tax Revenue Impact Study

Executive Summary

What is the main purpose of this study?
The purpose of the study is to provide quantitative measures of the importance of astronomy, planetary and space sciences research in Arizona's economy. The study provides common measures of economic activity and associated impacts such as the number of jobs, wages, output and tax revenues.

How is the "Astronomy, Planetary and Space Sciences" defined for this study?
The scope of the study is limited to economic impacts associated with astronomy, planetary and space sciences research at Arizona's three universities, astronomical observatories and related research organizations such as federal laboratories. Although a considerable number of companies in Arizona are involved in astronomy, planetary and space sciences related research, these were not included in this study.

How is the economic "impact" defined in this study?
We define "impact" in its strict sense which implies that a given economic activity generates jobs and wages. This occurs when money is brought into a region's economy either through exports of goods and services to markets outside the region, or when outside visitors purchase the region's goods and services while staying in the region.

How do astronomy, planetary and space sciences generate new jobs, wages and output in the Arizona economy?
Astronomy, planetary and space sciences receive most of its funding from federal institutions, such as the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF). By definition, these funds are injected into Arizona's economy, and thus capable of creating jobs, wages and output. Direct impact is when observatories, related research organizations, and university departments and units hire professionals, faculty, staff and students and thus contribute to the overall employment in Arizona. Additional jobs in Arizona are generated through purchases of equipment, office supplies, utilities and various professional and business services necessary for daily operations of these organizations. Furthermore, a significant number of jobs are created through spending by out-of-state visitors who were attracted to observatories and universities. The consumption by both employees in observatories, related research organizations, and university departments and units, and employees in businesses that supply goods and services to these organizations and visitors generates additional jobs.

How do Arizona's astronomy, planetary and space sciences generate tax revenues for the State?
Revenue impacts are generated when visitors, university departments/units, observatories and other entities make purchases and pay taxes to state and local governments (referred to as direct revenues). In addition, the employees whose jobs are generated by astronomy, planetary and space sciences activity pay taxes to state and local governments in Arizona (referred to as induced revenues). Direct revenues include sales taxes paid to cities and the state; the state, in turn, shares some of the state revenues with cities and counties. Induced revenues to the state are derived from state sales and personal income taxes. Induced revenues to counties are collected from state-shared sales taxes, state-shared fuel/highway taxes and property taxes. Induced revenues to cities include proceeds from state-shared sales taxes, state-shared fuel/highway taxes and local sales taxes.

What are the main sources of economic impacts identified in this study?
Astronomy, planetary and space sciences in Arizona generate economic impacts through three main sources. These include; (a) spending by employees in observatories, related research organizations, and university departments and units, (b) operations-related purchase of goods and services from Arizona businesses, and (c) spending by visitors such as visiting scholars, conference attendees, and general public attracted to observatories, planetariums and specialty museums.

How were data obtained on Arizona-based expenditures?
Because expenditure data are not readily available, a combination of methods were applied. Financial data from observatories and related research organizations were collected through a survey instrument detailing operations-related and capital investment-related expenditures in Arizona. Data also included payroll, benefits and number of employees. For university departments and units we obtained financial data on all expenditures from respective central offices and combined these with purchases-in-Arizona-only data. University departments and units also received a survey instrument with additional questions.

Who participated in the study?
A total of 22 organizations responded to the survey: eleven observatories, three related research organizations, and eight university departments/centers/labs are included in the economic impact analysis. (List of participant organizations is attached.)

How much did Arizona's observatories and related research organizations spend in FY 2006, and how much of that was spent in Arizona?
Arizona's observatories and related research organizations spent a total of $135.4 million on operations, including earnings and benefits. An additional $28.4 million was spent on capital investment/construction-related items. Thus, in FY 2006, total expenditures amounted to $164.0 million. Of that amount, $69.3 million was spent in Arizona.

How much did Arizona's university departments and units spend in Arizona during FY 2006?
Astronomy, planetary and space related departments and centers at the three universities spent a total of $60.5 million (including earnings and benefits). Of that amount, $33.9 million was spent in Arizona.

How many direct jobs and wages are related to astronomy, planetary and space sciences in Arizona?
The participating organizations employed a total of 1,830 persons (including 168 jobs associated with overhead expenses), of which 320 were students. The total payroll was $83.9 million.

What is the impact of employee spending (employees in astronomy, planetary and space sciences) on Arizona's economy?
Not all the wages and salaries paid in Arizona are available for spending in Arizona: payroll includes contribution to Social Security, FICA, Medicare, and federal taxes, all of which represent a leakage. The amount of payroll that was actually spent in Arizona was estimated at $64.8 million in FY 2006. This spending generated 720 jobs and $26.3 million in wages in Arizona.

How many jobs in Arizona do observatories (including other research organizations), and university departments and units generate through purchases of operations-related goods and services?
The total direct operations-related spending (excluding wages and salaries) of the participating organizations was $21.4 million. This spending generated 274 jobs and $10.8 million in wages.

In addition, the capital investment-related expenditures in FY 2006 generated 137 jobs and $5.9 million in wages.

How many out-of state visitors are attracted to Arizona's astronomy, planetary and space sciences and how much they spend?
In total, observatories, space sciences and related sciences and technology facilities in Arizona received a total of 200,805 visitors in FY 2006, out of which 6,668 were professional visitors and 194,137 were public visitors. Twenty-two percent of the public visitors were from outside Arizona. For the purpose of this study, only the economic activities of professional visitors and public visitors from outside Arizona were assessed to determine the effects of new money injected into Arizona's economy.

How many jobs are generated through visitors spending in Arizona?
Out-of-Arizona visitors spent $16.4 million dollars, generating an economic impact of $25.7 million dollars in total. The out-of-state visitors' spending generated 286 jobs and $8.1 million in wages and salaries in Arizona in FY 2006.

What is the impact of locally spent benefits?
Out of total benefits available, about $5.2 million is spent locally on health services. This generated 81 jobs and $3.5 million in wages.

What are the tax revenue impacts associated with Arizona's astronomy, planetary and space sciences?
Astronomy, planetary and space-related observatories, centers, departments and units generate almost $11.9 million dollars in revenues to state and local governments. Approximately $2.6 million is attributable to the operations of university departments and units, $5.9 million to observatories and similar organizations, and $2.1 million to visitors. Capital investment in 2006 generated approximately $1.2 million in revenues.

How are tax revenue impacts distributed among state and local governments?
The State of Arizona receives 57 percent of the revenues ($6.8 million); Arizona counties receive 16 percent ($2.0 million), and cities receive 26 percent ($3.1 million).

What was the total monetary impact (output) of astronomy, planetary and space sciences in Arizona's economy in FY 2006?
The total dollar impact (sales or output) in Arizona that was attributed to Arizona's astronomy, planetary and space sciences was estimated at $252.8 million in FY 2006. This includes $138.6 million in earnings, and $11.9 million in tax revenues.

The economic activity of astronomy, planetary and spaces sciences generated a total of 3,328 jobs. Of those, 1830 were employed in observatories, university departments and centers carrying astronomy, planetary and space sciences research (APSS organizations), while 1,498 jobs (or 45 percent) were spread throughout all sectors of the state economy.

Economic and Tax Revenue Impacts of Astronomy, Planetary and Space Sciences In Arizona, FY 2006

Non-earnings expenditures (dollars in millions)		
Operations-related expenditures in Arizona	$21.4	
Capital investment	$11.8	
Locally spent benefits	$5.2	
Out-of-state visitor spending	$16.1	
Total direct expenditures	**$54.5**	
Earnings (dollars in millions)		
Earnings in APSS organizations	$84.0	
Indirect and induced earnings	$54.6	
Total earnings impact	**$138.6**	
Tax revenues (dollars in millions)		
State revenues	$6.8	
County revenues	$2.0	
City revenues	$3.1	
Total tax revenue impact	**$11.9**	
Additional value added	**$47.8**	
Total monetary impact	**$252.8**	**million**
Employment impact		
Direct jobs in APSS organizations		1,830
Indirect and induced jobs		1,498
Total employment impact		**3,328**

Astronomy, Planetary and Space Sciences in Arizona

An Economic and Tax Revenue Impact Study

Introduction

Astronomy, planetary and space sciences in Arizona
Since the early beginnings of Lowell Observatory in Flagstaff in 1896, Arizona has become home to a number of world-renowned observatories, state-of-the-art telescopes, and leading university departments and centers carrying out research in astronomy, planetary and space sciences.

Today Arizona has nearly 30 observatories, with the State's largest and world's most visited cluster of telescopes located on Kitt Peak (Sage 2003). Each of the three state universities has at least one major department of astronomy, planetary and/or space sciences, with the largest number of academic and research centers at the University of Arizona (Figure 1).

> "All three universities are engaged in very valuable basic science concerned with observations in our solar system and the emerging area of biochemistry to study materials on earth and other planets…The combination of astronomy and planetary sciences at UA and ASU makes the state a national leader in space science and engineering. "
> Battelle report, 2003.

A combination of factors has contributed to the development of astronomy, planetary and space sciences research in Arizona. Mountain peaks, dryness and wide-open skies have been and still are important factors for the location of telescopes. Arizona also benefited from the stimulus for space exploration and increases in federal government funding for astronomical research since mid 1950s, mainly through the National Aeronautics and Space Administration (NASA) (Schnee 1977). But it is also the result of quality of researchers able to attract both funding and talent.

More than 350 scientists with doctoral degrees and another 600 professional and technical personnel conduct research and educational activities in Arizona's observatories and academic units. In addition, between 350 and 400 students annually work on different research projects carried out in observatories and academic units.

The actual number of people involved in astronomy, planetary and space sciences research in Arizona is higher than the number of employees in observatories and academic units whose research/educational activity is entirely or predominantly devoted to astronomy, planetary and space sciences; these figures exclude a large number of collaborators from other disciplines and organizations in both the public and private sectors.

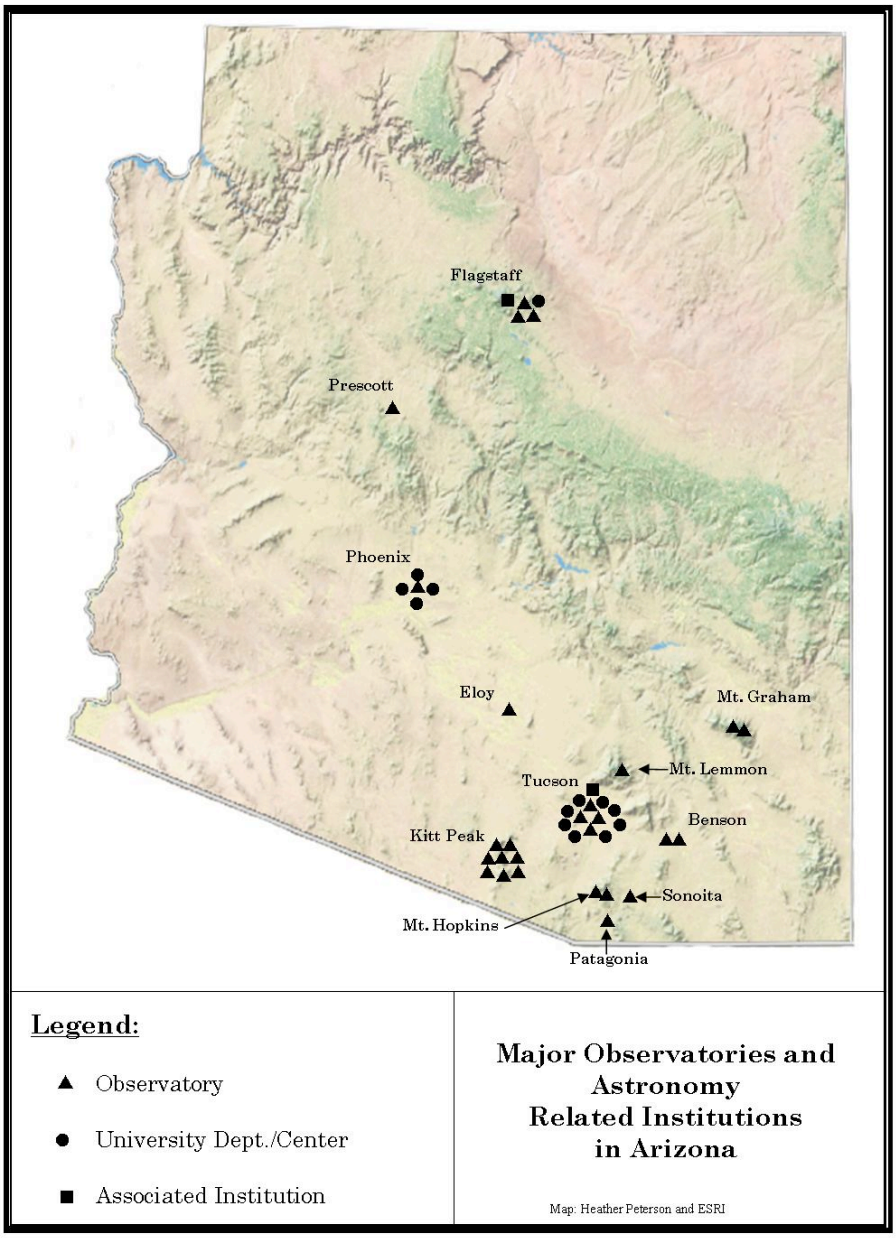
From 2002 to 2005, Arizona observatories and academic organizations carrying astronomy, planetary and space sciences research attracted more than $600 million in grants and contracts.[1] The major funding organizations are NASA, NSF, and US Department of Defense. Needless to say, these grants are achieved in an increasingly competitive environment, and thus by itself attest to the quality and creativity of Arizona's scientific community.

The Battelle (2003) report identified space sciences as one of the six core competencies critical for Arizona's position in research innovation. It identified leading areas of research activity and emphasized the importance of innovation in the economic development of the State.

[1] Based on data provided by surveyed organizations.

Building on the findings of Battelle's report, this study provides an assessment of astronomy, planetary and space sciences research as an economic activity and thus provides another perspective on its importance in the state's economy.

Figure 1 Major Observatories and Astronomy Related Institutions in Arizona



Purpose and objectives of this study
The study was initiated by The Arizona Arts, Science and Technology Academy and overseen by a Project Planning Committee comprised of representatives of astronomy, planetary and space sciences organizations with a purpose to assess the economic impacts of astronomy, planetary and space sciences research on Arizona.

This is the first study in Arizona that identifies the monetary and employment impacts of the State's largest observatories, university departments and other research activity directly involved with astronomy, planetary and space sciences research.

By assessing the economic impact, that is, the impact that these institutions' activities have on the flow and level of spending in the Arizona's economy, the study provides common benchmarks in terms of jobs, labor income, tax revenues and output (sales). These benchmarks allow the public and policy-makers to gain a better understanding of the importance of these activities in Arizona's economy beyond their contribution to education and scientific knowledge.

Study design
A major task was to collect and collate financial and other data from astronomy-related organizations in order to develop a set of baseline data depicting the economic activity of these organizations in Arizona.

The project involved the following stages:

- Identification of a comprehensive list of organizations (observatories; university departments, centers and programs; and other institutions) involved in astronomy, planetary and space sciences research and related activities;
- Design of a survey instrument to collect financial and other relevant data from observatories and related organizations (a copy of the questionnaire is available upon request);
- Collection of expenditure data from Arizona universities' financial and procurement offices pertinent to departments, centers and programs involved in astronomy, planetary and space sciences research and related activities;
- Modification of the observatory survey instrument to collect additional relevant data from university departments, centers and programs involved in astronomy, planetary and space sciences research;
- Preparation of survey and other financial data for estimation of economic impacts;
- Estimation of job, labor income and output impacts using an Arizona input-output model;
- Estimation of tax revenue impacts using an Arizona-specific tax revenue model;
- Preparation of a summary report.

Participating organizations

Observatories and related research organizations
An initial list of 21 organizations including observatories and other organizations carrying astronomy, planetary and/or space sciences research in Arizona was compiled with assistance from AASTA. Cover letters explaining the purpose of the study and questionnaires requesting detailed expenditure data in addition to general information were sent to all.

Of the targeted organizations, 14 responded to the survey and provided the requested information: Fred Lawrence Whipple Observatory, Large Binocular Telescope Observatory (LBTO), Lowell Observatory, MDM Observatory,[2] Multiple Mirror Telescope Observatory

[2] Consortium of University of Michigan, Dartmouth College, the Ohio State University, Columbia University and Ohio University.

(MMTO), National Optical Astronomy Observatory (NOAO), National Solar Observatory (NSO), Steward Observatory, Planetary Science Institute, Southern Association for Research in Astronomy (SARA), USGS Astrogeology Research Program, US Naval Observatory, Vatican Observatory, and WIYN.[3] After reviewing the response rate, the Project Planning Committee concluded that the participating organizations were the major players in this field and their combined expenditures were representative of approximately 90 percent of economic activity associated with the Arizona observatories.

University departments and units

The research team identified departments and units involved with astronomy, planetary and space sciences at each of the three Arizona state universities: Department of Physics and Astronomy at Northern Arizona University (NAU); the newly established School of Earth and Space Exploration at Arizona State University (ASU); and a total of six units at The University of Arizona -- Department of Astronomy; Department of Planetary Sciences; Lunar and Planetary Lab; Optical Sciences Center (in the College of Optical Sciences); Arizona Remote Sensing Center (in the Arid Lands Studies), and the Flandrau Science Center.

A total of eight university departments/units participated in the study. Although there were several programs in other departments that were also related to astronomy, planetary and space sciences research, e.g., in Hydrology, these units were not included because their fiscal year 2006 expenditures were nonexistent or negligible.

Expenditures data, by category, for all university departments and units were obtained from the financial and procurement service offices of each university. Additional data were collected through the questionnaire.

The total number of participating survey units, including observatories, university departments and related research centers, was 22. This group of 22 organizations is referred in the reminder of this report as APSS organizations.

Characteristics of participating organizations

The majority of observatories are organized as research consortia, followed by government laboratories and government funded R&D centers, and independent research centers. University based organizations include four major departments, four science research centers, and a laboratory (Table 1).

Table 1: Participating Organizations by Type

	Number
Research consortium	6
Government laboratory/Federally funded R&D center	5
Independent research organization	3
University departments	4
University science centers/labs	4
Total	22

Source: Survey 2007.

[3] Consortium of the University of Wisconsin-Madison, Indiana University and Yale University.

About one half of the participating organizations were established before 1980, among them, all university departments.[4] The majority of research consortia are relatively new organizations, established in the 1990s.

APSS organizations represent economic clusters in terms of their inter-organization collaborative efforts. Almost all APSS units reported having relationships with other similar organizations. These relationships are not only with out-of-Arizona organizations, but also with other in-state APSS organizations. Most commonly, APSS organizations collaborate in joint research projects. APSS organizations frequently share development and engineering resources, which is also a characteristic of economic clusters. Four of the responding APSS organizations reported purchasing inputs from out-of-state APSS units and three purchased inputs from in-state units. In some instances, an APSS organization subcontracts to or receives a subcontract from another unit or participated in a coordinated research and development project.

Framework for analysis

Assessing the impact of APSS organizations

Economic impact studies have most often been used in situations where a change in economic activity is being planned, such as the opening of a new company, expansion of an existing industry, or shutting down a military base. They have also been used in assessing the economic impact of various cultural and sports events, as these tend to attract visitors and increase economic activity. As noted by Ilze Groves (2005) in her study of worldwide science centers, institutions with an ongoing presence and year-round activities in a region are increasingly carrying out economic impact studies to assess and demonstrate the contribution that their activities make to their local economies.

In general, the economic contribution of APSS organizations to their local communities can be assessed through the flow and level of spending. These organizations pay their employees, purchases supplies, contract for services, and acquire assets within the local community. They also attract out-of-area visitors. These activities, in turn, support local jobs, create household income and generate tax revenues to their local and state governments (Groves 2005, Americans for the Arts 2004a).

The concept of "impact" in its strict sense implies that a given economic activity generates new output and associated jobs and earnings. This occurs when new money is injected into a region's economy either through exports of goods and services to markets outside the region, or when outside visitors purchase the region's goods and services while staying in the region. This type of economic activity is also referred to as "basic" as opposed to economic activity that serves the needs of local population (such as retail and housing construction).

Because the activity of APSS organizations is largely (and in many cases exclusively) supported by out-of-state grants and contracts, they fit the definition of an economic impact-generating activity. Predominantly, this kind of research is funded by federal and international funds, and thus brings new money into the state. By definition, it is a basic (export) activity, and therefore it is appropriate to measure its impact on the creation of new jobs and associated earnings and expenditures (sales).

[4] School of Earth and Space Exploration at the Arizona State University was established in 2006, but the departments and programs go back to the 1970s.

Types of economic impacts
Economic impact is comprised of direct, indirect and induced impacts. The direct impact is also referred to as the primary impact, while indirect and induced impacts combined are referred to as secondary impacts.

In this study, direct impact refers to the expenditures made by APSS organizations, including payroll to APSS's employees and purchases of goods and services from local suppliers. Spending by out-of-state visitors is also a direct impact. Associated with these direct expenditures are jobs in APSS organizations and jobs in supplying businesses, referred to as direct jobs in this report.

Indirect jobs are generated as the first-round of expenditures are spent purchasing goods and services from various other businesses in the local economy. They are also called inter-industry purchases as businesses respond to the new demands of the directly affected entities. Wages and salaries paid to employees in these supporting businesses are called indirect earnings, and by analogy, the output (sales) generated through these monetary transactions are called indirect output (sales). The magnitude of these indirect impacts depends upon the percentage of goods and services purchased and/or produced locally. The more locally produced goods and services used, the larger the indirect impacts.

Induced jobs result from spending by APSS employees and those in supplying (i.e., economically-linked) businesses. This spending generates additional jobs and associated earnings (i.e., induced earnings). Typically, most induced jobs are generated in retail and services sectors, reflecting households' consumption patterns.

Total economic impacts represent the sum of direct, indirect and induced impacts. Figure 2 illustrates economic impact by showing the flow of money from APSS organizations into the regional economy.

Tax revenue impact refers to changes in government revenues associated with changes in the economy due to APSS organizations. When APSS organizations make purchases in the state (or in some instances purchase equipment from out of state), they pay taxes. They pay contracting taxes (a component of sales taxes) when they build new or modify existing facilities. Taxes paid by the APSS organizations are referred to as direct revenues. Direct tax revenues accrue to both state and local (county and city) governments.

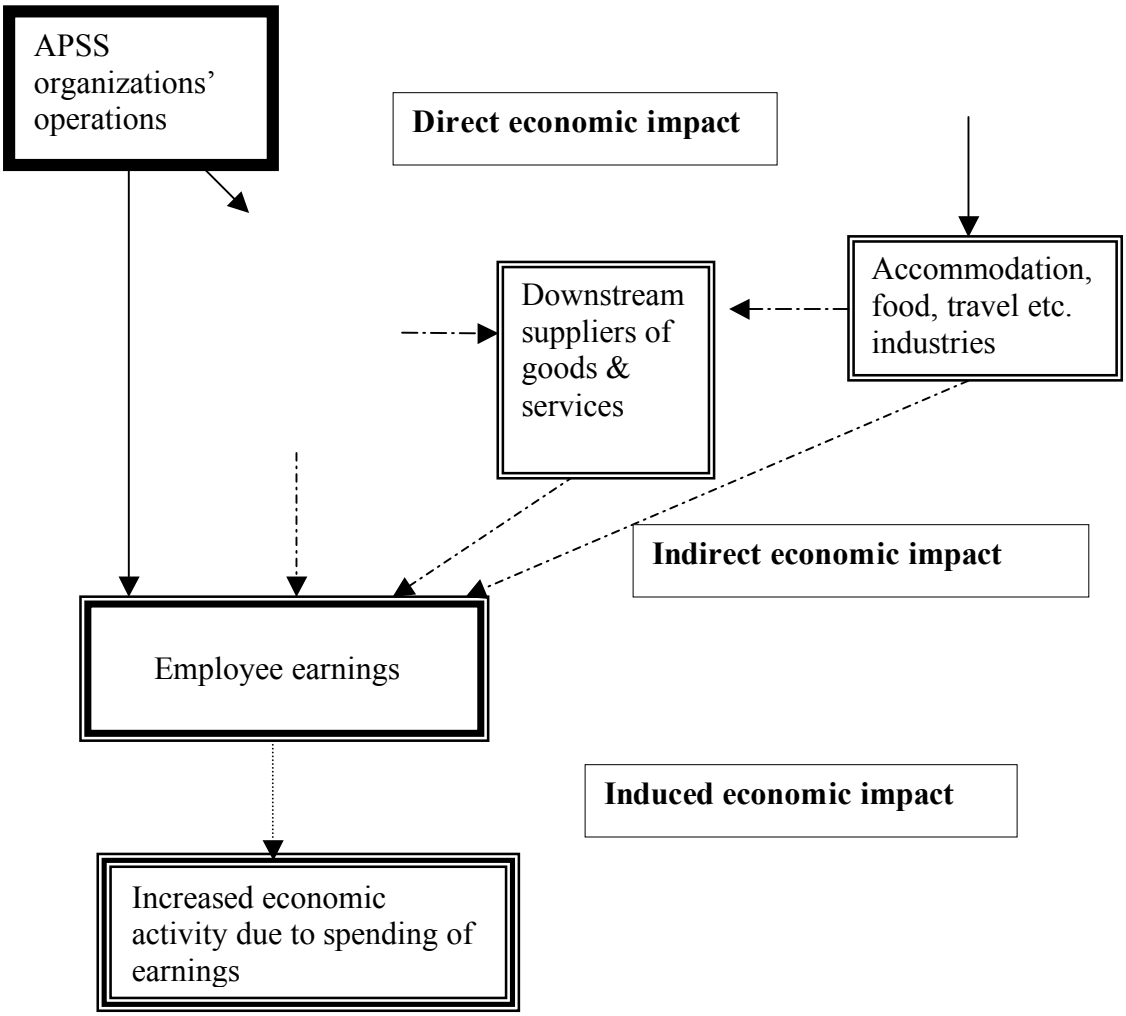
When employees of APSS organizations and firms that are economically-linked to APSS through indirect and induced jobs spend money, they generate additional revenues as they pay sales, fuel, motor vehicle, and a wide variety of other taxes. The revenues generated to state and local governments due to employee spending are referred to as induced revenues.

Concept of multiplier
The term multiplier is used to describe the total impacts associated with a unit change in a particular economic activity. The definition of a multiplier is total impact (direct plus indirect plus induced) divided by the direct impact. Although the definition is a simple mathematical formula, multipliers actually represent the sum of an infinite number of economic impacts as the direct economic activity iterates through the economy.

When APSS organizations make purchases, the industries making the sales have to hire additional workers, pay additional wages and, in turn, make additional purchases locally. When those first-round impacted firms make additional purchases locally, another round of hiring, wages and local purchases is initiated. Indirect impacts incorporate an infinite number of these

iterations; however, the impact is not in magnitude because leakages occur at each iteration, as some purchases are made out of the local area.

Figure 2



Framework for Analysis
Adapted from Groves (2005).

Induced effects also represent the sum of an infinite number of rounds of spending. As employees of the direct and indirect sectors spend money locally, those impacted industries experience higher sales, increased employment and higher wages. Again, the wages of those new employees are spent locally and the money continues to circulate through the local economy. The size of the impact diminishes each round as workers purchase goods and services out of the area or buy products that are not made locally.

Multipliers can be calculated using several different economic measures as the direct economic stimulus, e.g., jobs, earnings, and sales. It is important to note, however, that a multiplier calculated for one measure, e.g., earnings, cannot be used to assess the impact of another measure, such as jobs or sales.

By definition, multipliers are greater than or equal to one. In application, the direct effect is multiplied by the "multiplier" to get total economic impacts. The resulting estimate of total economic impacts *includes* the direct effect. For example, suppose the jobs multiplier for a particular exporting activity is 1.4 and 100 new jobs are added to the local economy in that sector. The total local impact of those jobs is 140 jobs, a figure that includes the 100 direct jobs plus 40 additional jobs that represent the multiplier or so-called "ripple" effect. The 40 additional jobs include both indirect (economically-linked) and induced (employee spending) jobs.[5]

Application of input-output model for Arizona

Input-output methodology is one of the most common approaches in estimating economic impacts. Input-output (I-O) models are based on inter-industry relationships in a given region and trace transactions between industry sectors that are caused by changes (increase or decrease) in demand for goods and services.

The choice of "local economy" or "region" can affect both the absolute and relative size of the estimated economic impact. Thus, geographic boundaries have important effects on the analysis (Siegfried, Sanderson and McHenry 2006).

As the geographic area expands, multipliers grow. Smaller regions, such as counties, have considerably more leakage out of the area than larger regions, such as states. A state economy is relatively more diversified so it tends to have fewer leakages than a county economy. As a result, relatively higher shares of purchases made and related production are retained within a state rather than a county. Thus, the economic impact of a given amount of spending will be higher using the state as the analysis "region" instead of a county. The same amount of expenditure will generate higher total impacts when analyzed at state level compared to a county level.

On the other hand, the relative size of a given impact will be larger for smaller regions. Thus, the impact of a particular industry will be assessed as more "important" if measured relative to a small region than a large one.

The selection of a state-based analysis in this study was dictated by the principal purpose of the study – to assess the impact on the State's economy. Although largely concentrated within Pima County, there are APSS activities spread throughout the State of Arizona so the State is the geographical area used in this study.

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[5] In general, multipliers should only be calculated for and applied to activities that sell outside the region (i.e., exporting sectors). Activities that sell to persons living in or businesses located in the region, such as most retailing, many services, etc., tend to be part of the ripple effect and do not create their own set of iterative impacts. There are exceptions to this general rule, particularly in rural areas. In a rural area, the entry of a new retailer may increase the amount of goods purchased within the region. In this situation, the new retailer increases the amount of money that stays within the community.

The IMPLAN[6] I-O model of Arizona applied in this study provides a portrait of the State's economy in terms of 500 industry sectors, including government and households.

Specifically, the IMPLAN model was used in this study to estimate the following impacts on Arizona's economy:

- Number of jobs, labor income and output generated through APSS organizations' spending on goods and services in Arizona;
- Number of jobs, labor income and output generated through spending of APSS organizations' employees;
- Number of jobs, labor income and output generated through out-of-state visitors associated with APSS organizations; and
- One-time impact (jobs, labor income and output) generated through capital investment and construction activity associated with APSS organizations.

The results of the I-O model are used to calculate job, earnings and output multipliers.

Tax revenue model

The revenue impact model computes state, county and city tax revenues associated with changes in business activity. The model is designed to be used in conjunction with other economic assessment information, e.g., the wage impact results obtained from the input-output model and other specific information about changes in business activity.

Two types of input data are required to run the model. The first type of data consists of community and tax information, such as county, city and state property tax rates, net assessed valuations, taxable sales, county and incorporated city population.

The second type of input is project-specific information. The required input consists of the following types of data inputs: total wage impact of the project or activity obtained from the input-output model (direct, indirect and induced impacts), taxable expenditures, by category, construction costs and, for retail sales, the portion of sales spent in cities, counties, the state and outside the state. In some instances, assumptions are made to geographically distribute sales within the state.

Direct tax revenues are those associated with direct expenditures, e.g., APSS organizations' or visitor purchases. Thus, when a visitor makes purchases locally, a portion of those purchases is taxable, and those taxes accrue to state and local governments. Direct tax revenue impacts reported for the state in this report are revenues retained by the State of Arizona following distribution to cities, towns and counties.

Induced tax revenues are revenues that accrue to the state or local governments due to the spending of employees in the affected industries. When visitors spend money in a restaurant, more workers are required in the restaurant industry and when those workers spend their earnings, they generate induced tax revenues. The same is true when university employees and observatory employees spend locally.

Note that the revenue impact model does not estimate revenues that will be distributed to special districts or school districts. However, it should be recognized that these governmental units will receive induced tax revenues.

[6] Developed and maintained by Minnesota IMPLAN Group, Inc., the IMPLAN I-O models are widely used in academic and applied research.

Data

For the purpose of estimating the economic impacts of APSS organizations on Arizona's economy, the following types of data were collected:

Expenditures by category
For observatories and related research organizations (i.e., non-university organizations), we used a questionnaire to gather data on (a) payroll, (b) operations-related expenditures in Arizona (such as professional services, professional development expenses, facility expenses, equipment, materials and supplies), and (c) capital expenditures (such as remodeling/construction and equipment).

For university departments and units, we obtained data on expenditures by object code from their respective financial services offices. The U of A Financial Services Office's data provided detailed expenditures, including employee payroll. However, these data included expenditures both in Arizona and outside Arizona, so additional data – expenditures by object code and zip code – were obtained from the U of A Procurement and Contracting Services Office. Although these two data series did not match perfectly, the latter provided the best estimate of what was spent in Arizona. Financial services offices at ASU and NAU provided less detail than U of A, but were able to identify Arizona-only expenditures.

Because a large portion of the expenditures made by APSS units at universities is derived from grants, it is necessary to assess the impact of both the expenditures made by units/departments using those funds and the overhead-related dollars that are spent elsewhere in the university. Specifically, at universities, grant budgets include not only the direct costs of completing the requirements of the grant (e.g., wages, benefits, travel, and supplies) but also an "indirect charge," which is designed to cover the overhead costs of administering the grant and to pay for university operating expenses related to fulfilling grant requirements, such as utilities, laboratory expenses, and administrative support. Since the indirect charges on federal grants can be 50 percent of the direct costs, assessing the impacts of these charges is important.

Only Arizona expenditures were entered into the I-O model.

Employee expenditures
Data on wages and salaries paid to employees in APSS organizations and the amount of employee benefits were collected though the survey or from university financial services offices as described above. Student wages and associated benefits were treated separately from other employee wages because the expenditure patterns of these two groups differ.

To estimate the impact of local (Arizona) spending, we first estimated disposable income by applying the Arizona's average of 76 percent to wages and salaries of regular employees, and an estimated 85.2 percent to student wages. This means that about 25 and 14.8 percent respectively leaks out of state in the form of federal tax, FICA and other contributions.

Survey-based expenditure patterns for university employees and students obtained in a recent UA impact study (Pavlakovich-Kochi and Charney 2005) were used to estimate categories of spending in this study.

A portion of employee benefits that is spent on health insurance and services, estimated at 24.4 percent of wages, was added to the local expenditures associated with the employee impacts.

Number of visitors and dollars spent

The survey confirmed that the APSS organizations have been an important attraction for visitors to Arizona.

Information on number of visitors and average spending in FY 2006 in Arizona was obtained from questionnaires; separate questions were asked about professional visitors and public visitors. Estimates of average daily expenditures were requested only for professional visitors, while in regard to public visitors, secondary sources were used to estimate the number of days/nights spent and average daily expenditures.

Since the questionnaire asked only basic questions, the expenditure breakdowns and spending characteristics for each type of visitors were obtained from other sources, most notably the Travel and Tourism Satellite Accounts (TTSA), published by the U.S. Bureau of Economic Analysis, and the Arizona Tourism Statistical report.

Estimates of average daily spending of public visitors were based on domestic overnight non-resident leisure visitors' spending in Arizona, as reported in the Arizona Tourism Statistical report (2006). A detailed breakdown by spending category for both the professional and public visitors, was obtained by using the TTSA breakdown of non-resident visitors' spending by 24 commodities.[7] These estimated volumes of spending by category were entered in Arizona I-O model to estimate impact on jobs, earnings and output.

Economic impact of APSS organizations in FY 2006

Direct expenditures

The direct economic impact in this study includes: payroll of APSS employees, additional payroll at universities associated with grant overhead expenses, APSS operations-related expenditures for goods and services purchased in Arizona (including overhead expenses), locally spent benefits, and direct spending of out-of-state visitors. Also included is FY 2006 capital investment, i.e., expenditures in Arizona for equipment, remodeling & construction (Table 2).

Table 2. APSS Organizations and Related Expenditures, FY 2006 ($)

APSS employee payroll (including students)	75,560,152
Additional payroll at universities (overhead)	8,418,297
APSS operation-related expenditures (including overhead)	21,413,158
Benefits	5,181,620
Total APSS	***110,573,227***
Visitor Spending	16,078,009
One-time capital investment (APSS)	11,799,784
Total direct impact (output)	***138,451,020***

Source: APSS survey; university FSOs.

[7] For a more detailed account of methodology, please contact the authors.

The APSS organizations contributed to the economy of Arizona $84.0 million in direct wages and salaries, and spent $21.4 million on operations-related goods and services purchased from Arizona businesses. In addition, $5.2 million worth of employee benefits was spent locally, mostly in the health services sector.

Out-of-state visitors attracted to APSS organizations for either professional reasons, such as conferences and research, or as the general public, spent an estimated $16.1 million in Arizona. Assuming that FY 2006 is representative of on-going annual expenditures, APSS organizations contribute annually over $126.6 million directly to the Arizona economy.

In FY 2006, APSS organizations spent an additional $11.8 million in Arizona for equipment, remodeling and construction. Thus, the total direct impact on the State's economy was $138.5 million.

Direct jobs

APSS organizations employed 1,830 persons (including 168 jobs associated with overhead charges), of which 320 were graduate and undergraduate students. Operations-related local purchases supported an additional 156 direct jobs in local businesses, and 44 jobs through a portion of locally spent benefits. Visitor spending generated an additional 202 direct jobs. Thus, 2,232 jobs in Arizona are directly related to APSS organizations every year. In FY 2006, due to capital investment, an additional 78 direct jobs were generated in the State increasing the number of direct jobs associated with APSS economic activity to 2,310.

Table 3. Direct Impact of APSS Organizations, FY2006:

	Jobs	Wages ($)	Other Value Added (incl. taxes) ($)	Output ($)
Employees in APSS (including students)	1,662	75,560,152	-	75,560,152
Additional employees at universities (overhead)	168	8,418,297	-	8,418,297
APSS operation-related expenditures	156	6,300,803	15,112,354	21,413,157
Benefits	44	2,524,834	2,656,786	5,181,620
APSS direct impact	***2,030***	***92,804,084***	***17,769,142***	***110,573,226***
Visitor spending	202	4,993,291	11,084,718	16,078,009
One-time capital investment (APSS)	78	3,514,971	8,284,813	11,799,784
Total direct impact	***2,310***	***101,312,346***	***37,138,673***	***138,451,019***

Source: APSS survey; IMPLAN I-O.

Indirect impacts

The indirect impact in this study includes expenditures for goods and services in the local economy triggered by the initial direct expenditures of APSS organizations and visitor spending. Because every initial dollar is spent and re-spent, the impact on output, jobs and earnings is felt throughout the economy. It usually takes at least a year for the last cent to be spent locally.

These inter-industry impacts are generated through increases in economic activity (output, jobs and earnings) associated with each initial dollar of local purchases. The magnitude of indirect impacts depends upon diversity of the state economy and intensity of transactions between in-state industries. The more in-state industries buy from each other, the higher the multiplier and the resulting indirect impact.

Based on FY 2006 expenditures, it was estimated that APSS organizations generated 71 indirect jobs and $2.7 million in indirect wages in Arizona on an annual basis. Visitors to these organizations indirectly created 37 jobs and $1.5 million in wages. Adding these impacts to the indirect impact of capital investment, the combined number of indirect jobs in FY 2006 was 133 with $5.3 million in wages (Table 4).

Table 4. Indirect Impacts of APSS Organizations in FY 2006

	Jobs	Wages ($)	Other Value Added (incl. taxes) ($)	Output ($)
APSS employee spending	-	-	-	-
Additional university employees' spending	-	-	-	-
APSS operation-related expenditures	57	2,270,537	3,663,212	6,226,975
Benefits	14	405,219	1,226,887	1,632,106
APSS indirect impact	***71***	***2,675,756***	***5,183,325***	***7,859,081***
Visitor spending	37	1,467,406	3,075,760	4,543,166
One-time capital investment (APSS)	25	1,161,919	2,103,419	3,265,338
Total indirect impact	***133***	***5,305,081***	***10,362,504***	***15,667,585***

Source: IMPLAN

Indirect output, including wages, taxes and other value added, was $15.7 million. This includes the one-time impact of capital investment in FY 2006.

Induced impacts

Induced impacts include jobs, earnings and output that are being generated as employee earnings are re-spent in the local economy.

The combined induced impact of APSS organizations' operations and employee spending was 804 jobs and $29.1 million in earnings. In addition, visitor spending added another 47 jobs and $1.7 million in earnings. Thus, 836 induced jobs and $30.8 million in earnings are generated annually through APSS related economic activity.

In FY 2006, capital investment generated an additional 34 induced jobs and $1.2 million in earnings. The combined induced impact in FY 2006 was 885 jobs and $32.0 million in earnings (Table 5).

Table 5: Induced Impacts of APSS Organizations FY2006

	Jobs	Wages ($)	Other Value Added (incl. taxes) ($)	Output ($)
APSS employee spending	636	23,486,688	45,877,818	69,364,506
Additional university employees' spending	84	2,821,716	8,400,980	11,222,696
APSS operation-related expenditures	61	2,219,847	4,568,788	6,788,635
Benefits	23	551,278	1,933,880	2,485,158
APSS induced impact	***804***	***29,079,529***	***60,781,466***	***89,860,995***
Visitor spending	47	1,662,423	3,400,138	5,062,561
One-time capital investment (APSS)	34	1,219,266	2,494,184	3,713,450
Total induced impact	***885***	***31,961,218***	***66,675,788***	***98,637,006***

Source: IMPLAN

Tax revenue impacts in FY 2006

Tax revenue impacts are estimated for different levels of government. In Arizona several major sources of city and county government revenues are state-shared revenues. These are taxes imposed by the State, collected by the State and partially redistributed by the State to cities and counties according to legislated formulas. The primary state-shared taxes are:

- State-shared sales tax revenues, which are distributions of state sales taxes;
- Highway User Revenue Fund revenues, which are fuel tax collections, use fuel (primarily diesel) tax collections, truck fees and a variety of other highway-related tax and fee collections that are shared with counties and incorporated cities and towns; and
- Urban Revenue Funds, which are portions of the state income tax distributed to incorporated cities and towns.

Other local tax revenue sources include city sales taxes and city and county property taxes.

Direct tax revenue impact

Direct tax revenue impacts, as shown in Table 6, are those paid concurrently as expenditures are made. For example, an observatory pays a contracting tax (a component of sales taxes) on its construction activity, a retail tax for supplies purchased locally, and use taxes on certain equipment purchased from out of state. Astronomy-related spending by universities and observatories generated a total of $1.7 million dollars to state, county and city governments. Astronomy-related visitor spending is estimated to have generated $1.6 million in revenues to various levels of governments and capital expenditures generated $0.9 million in revenues.

Table 6. Direct Tax Revenue Impact of Astronomy-Related Expenditures, FY2006 ($)

	University Spending	Observatory Spending	Visitor Spending	Capital Spending	
State of Arizona					
Privilege Taxes Retained by State	151,165	701,230	714,145	435,388	
Privilege Tax Revenues Dedicated to Education	21,394	108,378	96,358	70,799	
Motor Fuel and HURF Revenues	-	15,133	13,486	-	
Direct State Tax Revenues	***172,558***	***824,741***	***823,989***	***506,187***	***2,327,475***
Counties in Arizona					
State-shared Privilege Tax Revenues	22,681	144,686	166,735	95,602	
State-shared Motor Fuel and HURF Revenues	-	1,349	5,806	-	
Transient Occupancy Taxes	2,086	28,533	39,446	-	
Direct County Tax Revenues	***24,768***	***174,567***	***211,986***	***95,602***	***506,923***
Cities in Arizona					
City Privilege Taxes	64,301	327,023	289,075	212,396	
Transient Occupancy Tax	8,345	27,974	157,782	-	
State-shared Privilege Tax Revenues	13,997	89,290	102,898	58,999	
State-shared Motor Fuel and HURF Revenues	-	2,165	9,319	-	
Direct City Tax Revenues	***86,643***	***446,452***	***559,074***	***271,395***	***1,363,564***
Total Direct Tax Revenue	***283,969***	***1,445,760***	***1,595,049***	***873,184***	***4,197,962***

Induced tax revenue impact

Not only do operations of observatories and universities generate revenues, employees at these institutions and economically-related industries (via indirect and induced economic impacts) generate revenues as they spend their income within the State. In addition, the spending of employees in visitor-related industries, such as restaurants and hotels, generate revenues. Revenues created by employees spending their income are referred to as induced revenues in this study and are shown in Table 7.

Table 7. Induced Tax Revenue Impact of Astronomy Related Expenditures, Fy 2006

	University Spending	Observatory Spending	Visitor Spending	Capital Spending	
State of Arizona		-	-	-	
Income Tax	474,969	900,838	96,227	69,846	
Privilege Tax Retained (excludes prop. 301 0.6%)	691,235	1,311,013	140,041	101,649	
Privilege Tax Revenues Dedicated to Education	106,492	201,976	21,575	15,660	
Motor Fuel Tax and HURF (State Highway Fund)	94,365	178,976	19,118	13,877	
Induced State Tax Revenues	***1,367,061***	***2,592,802***	***276,961***	***201,032***	***4,437,857***
Counties in Arizona					
State-shared Privilege Tax	122,904	233,102	24,900	18,073	
State-shared Motor Fule Tax and HURF	40,622	77,045	8,230	5,974	
Vehicle License Tax for General Fund	33,922	64,338	6,873	4,988	
State-shared Vehicle License Tax for Highways	7,860	14,908	1,592	1,156	
Property tax (excludes personal property taxes)*	240,360	455,873	48,696	35,346	
Induced County Tax Revenues	***445,669***	***845,266***	***90,291***	***65,537***	***1,446,763***
Cities in Arizona					
Urban Revenue Sharing**	83,818	158,971	16,981	12,326	
State-shared Privilege Tax	5,848	143,855	15,366	11,154	
State-shared Motor Fule Tax and HURF	65,209	123,678	13,211	9,589	
State-shared Vehicle License Tax	33,922	64,338	6,873	4,988	
Property tax (excludes personal property taxes)	29,729	56,385	6,023	4,327	
City Privilege Tax (excludes transient occupancy)	259,329	489,952	52,336	37,988	
Transient Occupancy Tax	1,183	2,244	240	174	
Induced City Tax Revenues	***548,038***	***1,039,422***	***111,030***	***80,591***	***1,779,082***
Total Induced Tax Revenues	***2,360,768***	***4,477,491***	***478,282***	***347,161***	***7,663,702***

*Amounts for propoerty taxes represent long-term impact associated with real property improvements (I.e., amounts exclude taxes on personal property). Revenues will increase over time to amounts shown in table.

** Impact associated with Urban Revenue Sharing will have 2 year lag.

Spending by employees at observatories and universities, by employees in economically-linked sectors, and employees associated with astronomy-related visitors generates $4.4 million to the State, $1.4 million to counties, and $1.8 million to city governments. The combined induced tax revenue derived from all earnings was $**7.7** million to State, county and city governments.

Total tax revenue impact

Total revenue impacts are summarized in Table 8. The State of Arizona receives $6.8 million and cities and counties receive another $5.1 million.

Table 8. Total Tax Revenue Impact of Astronomy-Related Expenditures, FY2006 ($)

	University Spending	Observatory Spending	Visitor Spending	Capital Spending	Total
State of Arizona	1,539,620	3,417,543	1,100,950	707,219	6,765,333
Counties in Arizona	470,436	1,019,833	302,277	161,139	1,953,685
Cities in Arizona	634,681	1,485,875	670,104	351,986	3,142,646
Total Tax Revenue	***2,644,737***	***5,923,251***	***2,073,332***	***1,220,345***	***11,861,664***

Summary

Total monetary impact in FY 2006

The total monetary impact of APSS organizations' economic activity in Arizona in FY 2006 was an estimated $252.8 million (Table 9). This includes total earnings impact of $138.6 million and other value added of $114.2 million, which includes the $11.9 million in tax revenues. Value

added includes proprietary income, e.g., income to business owners and other self-employed work; benefits such as retirement payments and health insurance; and indirect business taxes.

Table 9: Total Economic Impacts (Direct, Indirect and Induced)

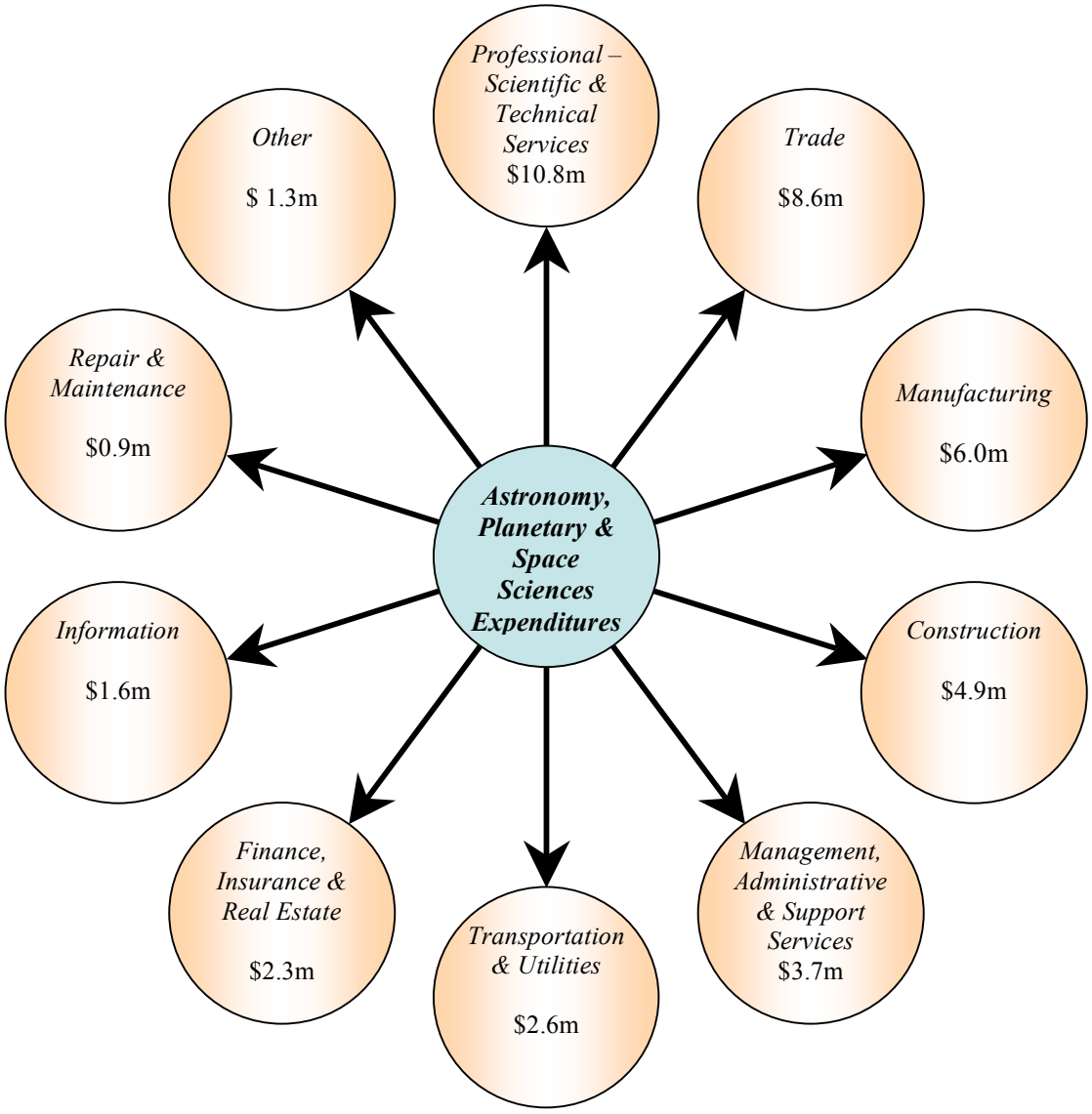
	Jobs	Wages ($)	Other Value Added (incl. taxes) ($)	Output ($)
Employees in APSS (including students)	1,662	75,560,152	-	75,560,152
Additional employees at universities (overhead)	168	8,418,295	-	8,418,295
APSS employee spending	720	26,308,404	54,278,798	80,587,202
APSS operation-related expenditures	274	10,791,187	23,637,580	34,428,767
Benefits	81	3,481,331	5,817,553	9,298,884
APSS total impact	***2,905***	***124,559,369***	***83,733,931***	***208,293,300***
Visitor spending	286	8,123,120	17,560,616	25,683,736
One-time capital investment (APSS)	137	5,896,156	12,882,416	18,778,572
Total impact	***3,328***	***138,578,645***	***114,176,963***	***252,755,608***

Source: IMPLAN

Linkages with industry

Figure 3 portrays economic linkages between APSS organizations and industry sectors in the regional economy. It shows indirect output in various industry sectors as a result of direct expenditures for goods and services by APSS organizations (including capital investment). Practically every industry sector has been affected, with the largest economic benefit accruing to professional, scientific and technical services ($10.8 million), followed by trade (combined wholesale and retail, $8.6 million), manufacturing ($6.0 million), construction sector ($4.9 million), and administrative, support and waste management services ($3.7 million). Other sectors benefit as well, such as transportation and utilities ($2.6 million), finance, insurance and real estate services ($2.3 million), and information services ($1.6 million). The remaining $2.4 million is spread over other sectors, such as repair and maintenance services, accommodation and food services, and government services.

Figure 3 Linkages with Industry

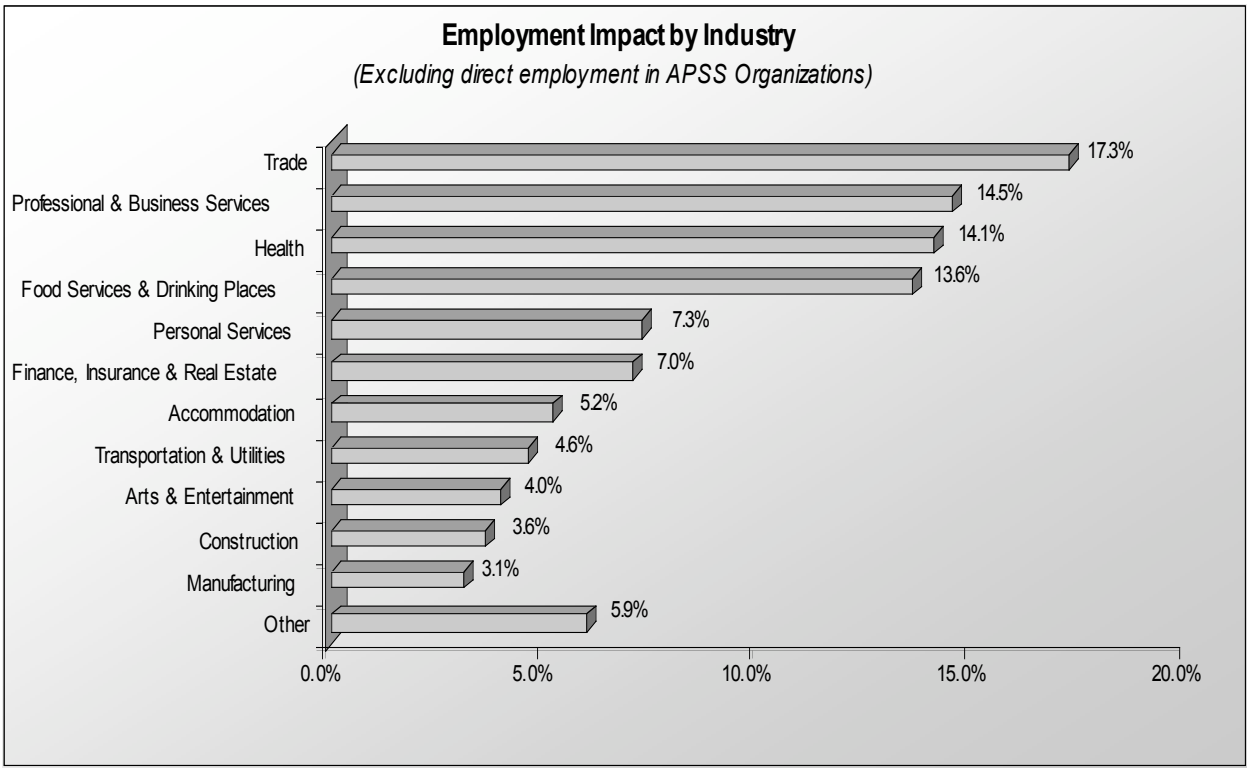


Source: IMPLAN I-O for Arizona. Inter-industry impacts measure the direct and indirect interaction of the Astronomy, Planetary and Space Sciences organizations with other industries as well as interaction among industries. "Other" includes: food and accommodation, government, art and entertainment, education, health, agriculture and mining industries.

Employment impact by sector

Figure 4 shows employment impact by industry sector associated with the economic activity of APSS organizations, including visitor impact, but excluding direct employment in APSS organizations. As reported earlier, 1,498 jobs in FY 2006 were generated outside APSS organizations. The distribution of these jobs by industry sector reflects a significant contribution of APSS payroll being spent locally as well as the impact of visitors' spending. About 17 percent of all indirect and induced jobs were generated in Trade industry (retail trade and wholesale), another 14.5 percent in Professional and business services, 14.1 percent in Health services, and 13.6 percent in Food services and drinking places. These four industries accounted for close to 60 percent of all indirect and induced jobs. Other jobs were generated in Personal services (7.3 percent), Finance, insurance and real estate (7.0 percent), Accommodation industry (5.2 percent), Transportation and utilities (4.6 percent), Arts and entertainment (4.0 percent), Construction (3.6 percent), and Manufacturing (3.1 percent). The remaining 5.9 percent jobs were in other services such as Education, Publishing, Postal Services, and government, as well as Agriculture and Mining.

Figure 4 Employment Impact by Industry



Employment impact includes jobs generated by APSS organizations' employee and visitors' spending and spending by employees in affected businesses (indirect wages). Direct employment in APSS organizations is excluded. The category "other" includes education services, publishing, postal services, government, agriculture and mining.

APSS multipliers for FY 2006

Composite multipliers reflect the ripple effect of the economic activity associated with the APSS organizations, including purchases made by those organizations, spending by employees, visitor spending, and 2006 construction activity. The composite job multiplier is 1.6, which means that for every 10 direct jobs in the APSS organizations, another 6 jobs are generated in the Arizona economy. For every dollar of direct wages, another 50 cents in earnings are generated throughout the economy (wage multiplier of 1.5). When tax revenues and other value are added, an additional $1.30 dollars in sales is created by every dollar of direct expenditures (output multiplier of 2.3).[8]

Conclusions and limitations of the study

As mentioned in the introduction, this is the first study conducted to assess the economic impact of the astronomy, planetary and space sciences research on the economy of Arizona.

Impacts of university departments and units have been regularly included in the overall impacts of the three Arizona universities, but they were merged with economic activities of other departments and programs.

Certain observatories provide selected information on their websites about their economic activity, such as the number of scientists and students, visitors, cost of telescopes, or even estimates of total monetary contribution to the local area.

Other states with comparable importance of the astronomy, planetary and space sciences research are Hawaii and New Mexico. The University of Hawaii Institute for Astronomy conducted an economic impact on the State's economy in 2001 and since then provides annual updates.[9]

However, without the accessibility to full reports and detailed methodology, any comparison becomes meaningless. As noted in many economic impact studies, only if exactly the same analytic methodology is used, can estimated values from different reports be compared (ARA Group 1999).

While this study is the first one to present the most comprehensive assessment of the economic activity of Arizona's astronomy, planetary and space sciences, the scope of the study was limited to "measurable" impacts. This study only traces money associated with APSS organizations in Arizona and visitors to those organizations.

An important segment of APSS-related activity in the State is not measured, specifically manufacturers and other industries that are the result of APSS activity in the State. This study measures the impact on the private sector only if APSS organizations purchase goods or services from them or if employees make purchases from them. But there are many more private sector impacts associated with astronomy, planetary and space sciences. In some instances, entire economic sectors, e.g., the optics industry, are the direct result of the strong presence of APSS organizations in Arizona. In other instances, parts of certain Arizona industries, such as missiles,

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[8] Reported multipliers are calculated by dividing the total impact (bottom row in Table 9) by APSS direct impact (fifth row in Table 3).

[9] Kudritzki, Rolf-Peter and Bob Joseph. 2003. Update to 2001 Self-Study report. (http://www.ifa.hawaii.edu/publications/self-study/self-study_Update-oct03.pdf) on 5/13/2007.

electronics and computers, scientific instruments, engineering services, and robotics have close connections to astronomy, planetary and space sciences. Sometimes the connections are due to graduates in these scientific fields working in the private sector. Skills learned in these sciences are surprisingly transferable to the private sector.[10] Sometimes the relationships involve APSS scientists working with private sector companies.

In addition, this study does not capture all the broad benefits that the APSS organizations bring to the State of Arizona. For many years, these organizations have increased the visibility of the state to the rest of the country and the world. It is not possible to place a monetary value on the role APSS has played in helping to establish Arizona as a center of research and technology.

Nor can this study measure the economic impact or benefits that are derived from new innovations and inventions associated with APSS organizations. And certainly this study can't put a value on the new knowledge about the world and universe that these organizations are creating.

Astronomy, planetary and space sciences has been an important economic cluster in Arizona for decades. This is the first study that attempts to assess the state-wide economic impact of these organizations. Despite the limitations and narrow focus of this study, the measured economic impacts are substantial, with astronomy, planetary and space sciences activities directly or indirectly contributing over 3,300 jobs to the Arizona economy, $138.6 million in earnings, $114.2 million in other value added, including $11.9 million in taxes. Combined, astronomy, planetary and space sciences contribute over a quarter of a billion dollars in output (sales) to the local community.

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Appendix B: Arizona's Space and Planetary Sciences Centers and Institutes

University of Arizona
The University of Arizona's Lunar and Planetary Laboratory (LPL) was founded in 1960 by the eminent planetary astronomer, Gerard Kuiper. LPL is dedicated to the goal of understanding and teaching about the formation and evolution of the planetary system. Its faculty, research staff, and graduate student body are drawn from the diverse backgrounds of astronomy, chemistry, geology, physics, and engineering.

The University of Arizona is one of the nation's major research universities. LPL has developed a well-deserved reputation for world-class research and graduate education.

Arizona State University
The School of Earth and Space Exploration (SESE) at Arizona State University was launched in July, 2006. SESE is a bold initiative to combine science and engineering research and education in order to achieve a better understanding of the universe and, especially, our home world. At present, the School unites earth and planetary scientists with astronomers, and has strong collaborative ties with several other academic units at ASU, especially the Fulton School of Engineering. Through an aggressive program of expansion, the faculty will grow by 60% over the next few years. While maintaining core strengths and developing new transdisciplinary linkages among the sciences, we will broaden our scope to include engineering faculty with research interests in the development and deployment of scientific instrumentation on Earth and in space.

Northern Arizona University
The Department of Physics and Astronomy at NAU is home to active research programs in surface physics and astrophysics. Many opportunities for original research exist for undergraduates through the NASA Space Grant, the National Undergraduate Research Observatory (NURO), REU (Research Experiences for Undergrads) and as a part of the degree programs offered in physics and astronomy. Students work in partnership with faculty and are often published in scientific journals. The facilities for use in the astrophysics research program include:

- 31-inch telescope at nearby Lowell Observatory,
- 24-inch telescope at the Atmospheric Research Observatory on the NAU campus.

Planetary Sciences Institute
The Planetary Sciences Institute is a nonprofit science research institute focusing on the exploration of the solar system. PSI scientists are distributed in 12 states, the United Kingdom, Italy, Russia and Japan. PSI is headquartered in Tucson, Arizona, where it was founded in 1972. PSI is involved in numerous NASA missions, the study of Mars, asteroids, comets, interplanetary dust, the origin of the solar system, planet formation about other stars, dynamics, impact physics, and the rise of life. PSI scientists conduct field work in North America, Australia and Africa. They are also actively involved in science education and public outreach through school programs, children's' books, popular science books and art.

U.S.G.S.

The mission of the USGS Astrogeology Research Program is to establish and maintain geoscientific and technical expertise in planetary science and remote sensing to perform the following tasks:

- scientifically study and map extraterrestrial bodies,
- plan and conduct planetary exploration missions, and
- explore and develop new technologies in data processing and analysis, archiving, and distribution.

The Astrogeology Research Program conducts and participates in a wide range of scientific research. The primary areas of focus are the geological and geophysical processes on the rocky planets and satellites, including not only our neighbors in the solar system, but also the Earth itself. Areas of study include geology, remote sensing, monitoring, astrobiology, and ices and other materials. Such research leads to an understanding of the character of our neighboring planets, the origins of the solar system, and a better comprehension of our own planet, Earth.

Arizona Science Community's Participation in Orbital and Planetary Missions

Solar System Missions

Advanced Composition Explorer
Cassini/ Huygens
Champollion
Contour
Deep Impact
Deep Space 1
EPOXI (DIXI)
Explorer 6
Galileo
Giotto
Helios
IMAGE (Imager for Magnetopause-to-Aurora Global Exploration)
ISEE-3/ICE (International Sun-Earth Explorer)
Magellan
Mariner 2
Mariner 5
Mariner 10
Mars Climate Orbiter
Mars Exploration Rovers
Mars Express
Mars Global Surveyor
Mars Observer
Mars Odyssey
Mars Pathfinder
Mars Phoenix
Mars Polar Lander
Mars Reconnaissance Orbiter
NEAR
NExT
New Horizons
Phobos 2
Pioneer 1-4

Pioneer 10 and 11
Space Shuttle Spectrometry
Ulysses
Vega 1 and 2
Venera 2-16
Viking 1 and 2
Voyager 1 and 2

Lunar Missions

Apollo 8-17
Clementine
Explorer
Lunar Orbiter
Lunar Prospector
Ranger 1-9
Surveyor 1-7

Earth Observing Satellites

Terra
Landsat-7
SeaWiFS

Arizona Participation in Space Telescopes

Chandra
Hubble
Kepler Telescope
James Webb Space Telescope
Spitzer Space Telescope

Appendix C: Arizona's Astronomical Observatories

Kitt Peak
Kitt Peak National Observatory (KPNO), part of the National Optical Astronomy Observatory (NOAO), supports the most diverse collection of astronomical observatories on Earth for nighttime optical and infrared astronomy and daytime study of the Sun. Founded in 1958, KPNO operates three major nighttime telescopes, shares site responsibilities with the National Solar Observatory and hosts the facilities of consortia which operate 19 optical telescopes and two radio telescopes.

The Calypso Observatory
The Calypso Observatory is a private observatory founded in 1992. In 1999, Calypso Observatory started the operation of its 1.2-meter altitude-azimuth telescope. The telescope design and its optics have been optimized for high resolution imaging in visible wavebands. An adaptive optics system attached to the high resolution camera (HRCAM) was installed in the fall of 1999. A wider field camera (WFCAM) useful for survey work came online in the fall of 2001.

MDM Observatory
MDM Observatory has two telescopes: the 2.4-m Hiltner telescope and the 1.3-m McGraw-Hill telescope. The Observatory is owned and operated by a consortium of five universities: the University of Michigan, Dartmouth College, The Ohio State University, Columbia University, and Ohio University.

Robotically Controlled Telescope (RCT)
The RCT Consortium is a group of universities and research institutions that have assumed control of the 1.3-m (50-inch) telescope. Consortium members are Western Kentucky University, the Planetary Science Institute, South Carolina State University, Villanova University and Fayetteville State University. The telescope, originally called the Remotely Controlled Telescope,

has been renamed the Robotically Controlled Telescope to reflect the change in operational control and mode of use.

SARA

The SARA consortium was officially formed in 1989 with members Florida Tech, ETSU, UGA, and VSU. The fifth institution, FIU, joined SARA in 1992, and the sixth, Clemson University, joined in 1999.

The SARA consortium operates the No. 1 36-inch telescope at the Kitt Peak National Observatory. The 0.9-meter SARA telescope was the first major research telescope installed at Kitt Peak, and since 1960 has been of service to thousands of astronomers.

The Bok Telescope

The 90" (2.3 m) Bok Telescope on Kitt Peak is the largest telescope operated solely by Steward Observatory. The telescope was dedicated on June 23, 1969. The telescope operates every night of the year except Christmas Eve and a maintenance period scheduled during the summer rainy season. The Bok Telescope is available for use by astronomers from the University of Arizona, Arizona State University, and Northern Arizona University.

Spacewatch Telescopes

The primary goal of Spacewatch is to explore the various populations of small objects in the solar system, and study the statistics of asteroids and comets in order to investigate the dynamical evolution of the solar system. Spacewatch also finds potential targets for interplanetary spacecraft missions, provides follow-up astrometry of such targets, and finds objects that might present a hazard to the Earth. CCD-scanning observations are conducted 20 nights each lunation with the Steward Observatory 0.9-meter Spacewatch telescope and the new Spacewatch 1.8-m telescope, both on Kitt Peak.

12 Meter Telescope (ARO)

The Arizona Radio Observatory operates and maintains a 12 meter diameter telescope on Kitt Peak for astronomical observations at millimeter wavelengths. The ARO 12 Meter Telescope began as the 36 Foot Telescope, the telescope responsible for the birth of millimeter-wavelength molecular astronomy. During a period of explosive growth in this new area of astronomical research, dozens of molecular species known to exist in the interstellar medium were first detected at the 36 Foot. In 1984, the telescope's reflecting surface and surface support structure were replaced and the 36 Foot was re-christened the 12 Meter. Subsequently, the scientific program has evolved from one dominated by observing programs in astrochemistry to one with a broader mix of studies of molecular clouds and galactic star formation, evolved stars, astrochemistry, and external galaxies.

The Very Long Baseline Array

The Very Long Baseline Array (VLBA) is a system of ten radio telescopes controlled remotely from the Array Operations Center in Socorro, New Mexico, that work together as the world's largest dedicated, full-time astronomical instrument. The ten VLBA sites range from Hawaii to the Virgin Islands. Each VLBA station consists of an 82-foot (25- meter) diameter dish antenna and an adjacent control building which houses the station computer, tape recorders and other equipment associated with collecting the radio signals gathered by the antenna. Each antenna weighs 240 tons and is nearly as tall as a ten story building when pointed straight up.

The Burrell Schmidt

Case Western University owns and operates the 24"/36" Burrell Schmidt wide field telescope, located at Kitt Peak. It is used for deep wide-field imaging and surveys.

The Wisconsin H-Alpha Mapper (WHAM)
WHAM is a custom-built observatory located in Arizona on Kitt Peak. Designed for studying gases, the WHAM Northern Sky Survey is now the basis for a number of projects. Most of these ongoing projects combine new WHAM emission-line observations of elements other than hydrogen (primarily sulfur, nitrogen, oxygen, and helium).

The WIYN 0.9M
A consortium led by the University of Wisconsin-Madison, Indiana University and Yale University has assumed operational responsibility for the historic 0.9-meter (36-inch) telescope at the Kitt Peak National Observatory. In 2001 the WIYN Consortium took over operations of the 0.9m telescope.

Lowell Observatory
Lowell Observatory, located in Flagstaff, is among the oldest observatories in the United States, and was designated a National Historic Landmark in 1965. The Observatory's original 24-inch Alvan Clark Telescope is still in use today for public education. Lowell Observatory hosts 70,000 visitors per year who take guided daytime tours and view various wonders of the night sky through the Clark Telescope and other telescopes.

The observatory operates several telescopes at two locations in Flagstaff. The main facility, located on Mars Hill just west of downtown Flagstaff, houses the original 24-inch (0.61-meter) Clark Refracting Telescope. Also located on the Mars Hill campus is the 13-inch (0.33-meter) Pluto Discovery Telescope, used by Clyde Tombaugh in 1930 to discover the dwarf planet Pluto.

Lowell Observatory currently operates four research telescopes at its Anderson Mesa dark sky site, located 12 miles southeast of Flagstaff, including the 72-inch (1.8-meter) Perkins Telescope (in partnership with Boston University) and the 42-inch (1.1-meter) John S. Hall Telescope. Lowell is a partner with the United States Naval Observatory and NRL in the Navy Prototype Optical Interferometer (NPOI) also located at that site. The Observatory also operates smaller research telescopes at its historic site on Mars Hill and in Australia and Chile. Lowell Observatory is currently building the 4.2-meter Discovery Channel Telescope in partnership with Discovery Communications, Inc.

The Discovery Channel Telescope (DCT) is a 4.2-meter telescope being built for Lowell Observatory in Flagstaff, Arizona and will be the fifth largest telescope in the continental United States once completed in 2009. The DCT is currently under construction at a dark sky site on the Coconino National Forest near Happy Jack, Arizona. The project is a partnership with Discovery Communications and Lowell Observatory.

Mt. Bigelow
Kuiper Telescope
The 61" telescope was built in the early 1960's to survey the Moon in preparation for the upcoming lunar spacecraft missions. The atlas of the Moon thus produced has been called "the finest ground-based photographic lunar survey ever done" by Sky & Telescope magazine. Astronomers from the University of Arizona, Arizona State University, and Northern Arizona University compete for observing time on the telescope.

The Catalina Sky Survey
The CSS Schmidt telescope is located on Mt. Bigelow in the Catalina Mountains just north of Tucson, Arizona. The site is owned and operated by Steward Observatory at the University of Arizona. The Catalina Sky Survey began operation in April 1998. At present, CSS typically covers over 800 square degrees of sky in a single night of observing. CSS has detected 182 known (Near Earth Objects) NEOs and 19,350 main belt asteroids.

Mount Graham International Observatory

Large Binocular Telescope Observatory

The Large Binocular Telescope (LBT) is a collaboration between the Italian astronomical community (represented by the Instituto Nazionale di Astrofisica), The University of Arizona, Arizona State University, Northern Arizona University, the LBT Beteiligungsgesellschaft in Germany (Max-Planck-Institutfür Astronomie in Heidelberg, Landessternwarte in Heidelberg, in Potsdam, Max-Planck-Institut für Extraterrestrische Physik in Munich, and Max-Planck-Institut für Radioastronomie in Bonn), The Ohio State University, Research Corporation in Tucson, and the University of Notre Dame.

The goal of the LBT project is to construct a binocular telescope consisting of two 8.4-meter mirrors on a common mount. This telescope will be equivalent in light-gathering power to a single 11.8 meter instrument. Because of its binocular arrangement, the telescope will have a resolving power (ultimate image sharpness) corresponding to a 22.8-meter telescope.

The Vatican Observatory

The Vatican Observatory Research Group (VORG), in Tucson, is one of the world's largest and most modern centers for observational astronomy. In 1993 the Observatory, in collaboration with Steward Observatory, completed the construction of the Vatican Advanced Technology Telescope (VATT) on Mt. Graham, Arizona. This was the first optical-infrared telescope of the Mount Graham International Observatory.

VATT truly lives up to its name. Its heart is a 1.8-m f/1.0 honeycombed construction, borosilicate primary mirror. This was manufactured at the University of Arizona Mirror Laboratory, and it pioneered both the spin-casting techniques and the stressed-lap polishing techniques of that Laboratory which are being used for telescope mirrors up to 8.4-m in diameter. The primary mirror is so deeply-dished that the focus of the telescope is only as far above the mirror as the mirror is wide, thus allowing a structure that is about three times as compact as the previous generation of telescope designs.

Submillimeter Telescope (SMT)

SMT consists of two telescopes that routinely cover the entire millimeter and submillimeter windows from about 4.6 mm to about 0.6 mm, and is capable of observations all the way to 0.3 mm with instruments. The telescopes are operated around-the-clock for about 9 to 10 months per year for a combined 10,000 hours per observing season.

Mt. Hopkins

Fred Lawrence Whipple Observatory (FLWO)

The Fred Lawrence Whipple Observatory is the largest field installation of the Smithsonian Institution Astrophysical Observatory (SAO) outside Cambridge, MA. Since October 1968, the FLWO has been used as the site for experiments requiring extremely dark skies, dry climate, and good "optical seeing".

Located near Amado, Arizona, FLWO has the following facilities:

- The 6.5-meter MMT (256-inch) , a joint facility operated with the University of Arizona and SAO , for solar system, galactic and extragalactic astronomy,

- The 1.5-meter Tillinghast (60-inch) and 1.2-meter (48-inch) reflector telescopes, for solar system, galactic and extragalactic astronomy,

- The 1.3-meter (51-inch) PAIRITEL (Peters Automated IR Imaging Telescope, ex-2MASS) reflector, for infrared observations, especially of gamma-ray bursts, supernovae and other variable sources,

- The 10-meter reflector for gamma-ray astronomy in the 100GeV-10TeV energy range,
- VERITAS, an array of four 12-meter reflectors for gamma-ray astronomy in the 50GeV-50TeV energy range,
- The HAT (Hungarian-made Automated Telescope) network of optical refractor telescopes, used for robotic searches for variable stars and exoplanets, and
- The MEarth Project – eight robotic .4-meter telescopes searching for Earth-like planets orbiting nearby M-type stars. (under construction)

Mt. Lemmon
Mt. Lemmon Infrared Observatory
Located on a 20-acre site, the observatory was formerly a Radar Base of the Air Defense Command and was converted into an observatory for infrared astronomy in October 1970. The Mt. Lemmon Observatory houses the following instruments:

The 20-inch Jamieson reflector features a German-equatorial mount and produces exquisite images. It can be used simultaneously for both infrared and visible observations.

The 40-inch Cassegrain reflector. The f/16 optical design of this telescope features an inverted Dall-Kirkham (Pressman-Camichel) arrangement with a single-arch spherical primary mirror (f/2) and oblate ellipsoid secondary. Equipped with relative encoders on a German equatorial mount, the 40-inch has a fast speed, motorized slew motion in right ascension but is hand-slewn in declination.

The 60-inch Cassegrain reflector incorporates a parabolic primary mirror (f/2) with interchangeable secondaries to achieve Cassegrain focal ratios of either f/16 or f/45. The telescope can also be used at prime focus where a CCD-mosaic camera captures images of a one degree wide field-of-view down to magnitude 22. This camera is used routinely by the Catalina Sky Survey to discover and monitor near-earth asteroids and minor planets in the solar system. The latter is used for infrared observations. The telescope has a motorized equatorial mount equipped accurate with encoders for positioning on the sky. An adjacent warm room is used by Astronomy Campers to analyze their data by computer image processing and to plan the details of their observations.

The Mount Lemmon Observing Facility (MLOF)
The MLOF is located close to the summit of Mount Lemmon in the Catalina Mountains north east of Tucson. The telescope consists of a 1.5-m primary mirror with a chopping secondary mirror for infrared observations at the f/16 Cassegrain focus. The MLOF is funded and operated jointly by UCSD's Center for Astrophysics & Space Sciences (CASS), and the Astronomy Department of the University of Minnesota.

NOAO
The National Optical Astronomy Observatory was formed in 1982 to consolidate all AURA-managed ground-based astronomical observatories (Kitt Peak National Observatory, Cerro Tololo Inter-American Observatory, and the National Solar Observatory with facilities at Kitt Peak in Arizona and Sacramento Peak, New Mexico) under a single Director. NOAO is funded by the National Science Foundation and operated by the Association of Universities for Research in Astronomy, Inc. NOAO has its headquarters in Tucson.

NSO
Since 2000, the National Solar Observatory (NSO) has been an independent national center, funded by the National Science Foundation and operated by the Association of Universities for Research in Astronomy, Inc (AURA). The mission of the National Solar Observatory is to advance our understanding of the Sun in its astrophysical context as a star, as the driver of conditions in interplanetary space, in its influence on the terrestrial atmosphere, and in its role in long-term climate change. NSO conducts research at Kitt Peak and at Sacramento Peak in New Mexico. Over 70% of the NSO budget and 65% of its employees are administered through programs located at its Tucson and Kitt Peak sites, co-located with the headquarters of the NOAO on the University of Arizona campus.

USNO
The US Naval Observatory was established in 1955 a few miles west of Flagstaff. The Flagstaff station is the US Naval Observatory's dark-sky site for optical and near-infrared astronomy. There are presently two USNO sites in the Flagstaff area: the NOFS and the Navy Prototype Optical Interferometer (NPOI). NPOI is an interferometer operated by the US Naval Observatory, the Naval Research Laboratory and the Lowell Observatory.

Private and Other Observatories

Desert Eagle Observatory is a private amateur observatory, situated near Benson, Arizona. The observatory's primary purpose is the observation and discovery of asteroids, which include but are not limited to comets and Near Earth Asteroids (NEA). To date the observatory has discovered 1,732 new asteroids.

The Desert Beaver Observatory is a private observatory near Eloy, Arizona. The asteroid 25893 Sugihara was discovered at the Desert Beaver Observatory.

Embry-Riddle Observatory
This observatory helps prepare ERAU undergraduate students in the use of astronomical telescopes for the collection and analysis of astronomical data for publication in professional peer reviewed research journals, thereby contributing to the body of scientific knowledge, and partially fulfilling the requirements for a Bachelors of Science degree in Space Physics. Additionally, it provides a vehicle for faculty professional development, and a means for effective public education and outreach within the local community.

Fairborn Observatory. The Tennessee State University Automated Astronomy Group conducts a variety of astronomical research projects with automatic telescopes located in southern Arizona. This research program began in 1988 with a NASA grant from Marshall Space Flight Center to study chromospherically active stars in collaboration with Vanderbilt University. The Center now operates seven 0.25m to 0.80m automatic photoelectric telescopes (APTs) in the Patagonia Mountains near Washington Camp, Arizona. The unique capabilities of these telescopes permit long-term observing programs to measure luminosity cycles in solar-duplicate and lower-main-sequence stars, to search for extra-solar planets, and to monitor chromospherically active single and binary stars, semi-regular variable stars, and several other kinds of objects.

The Goodricke-Pigott Observatory is a private observatory in Tucson. It was formally dedicated on October 26th, 1996 and observations began that evening with imaging of Comet Hale-Bopp.

The Gov Aker Observatory opened its doors on November 18th, 1995, marking a major milestone in astronomy and education. The observatory features a 20-inch reflecting telescope available for public use, the world's largest known Camera Obscura, as well as an exhibit gallery, gift shop and educational facilities.

The Tenagra Observatories The astronomical community has always dreamed of automated and robotic telescopes doing the work that people cannot. Since 2001 Tenagra Observatories has offered time on its 0.81-m (32") automated system to academic institutions.

Tenagra Observatories is a complex of privately owned telescopes in southern Arizona, Oregon, Norway and Western Australia. Tenagra is well known for its photometric studies and supernovae/minor planet (MPC code 848) discoveries. The observatory is 100% automated. Data is taken unattended and immediately provided to users for real-time FTP download.

The Tenagra site was chosen specifically for its excellent seeing averaged over the S. Arizona observing season from September 15 to June 15. The site is in close proximity with Mt. Hopkins, Kitt Peak and other major observatories.

Vega-Bray Observatory is an astronomical observatory owned and operated by Astronomers Inn located on a small hill overlooking the San Pedro River Valley, just east of Benson, Arizona. Founded in 1990, it is home to the Hoot-Vega Radio Telescope.

Winer Observatory is an astronomical observatory near Sonoita, Arizona. It is a private, non-profit observatory, operating since 1983. It has been the site of a number of significant small telescopes and famous robotic telescopes. It has been the site of the Iowa Robotic Observatory. The observatory houses a 14.5-inch telescope owned by the University of Iowa used primarily for undergraduate student labs, a 20-inch telescope owned by the Washington University in St. Louis, the Kilodegree Extremely Little Telescope (KELT) owned by The Ohio State University, and one 20-inch telescope operated jointly by Winer Observatory and the Rincon Ranch Observatory.

Appendix D: Out of State Partners in Arizona Based Astronomy

Boston University (Lowell Observatory)
Colorado College (NURO)
Columbus State University (NURO)
Dickinson College (NURO)
Franklin and Marshall College (NURO)
Gettysburg College (NURO)
McMurry University (NURO)
Truman State University (NURO)
University of Puerto Rico Humacao (NURO)
University of South Carolina, Lancaster (NURO)
Western Connecticut University (NURO)
Widener University (NURO)
William Jewell College (NURO)
University of Wisconsin (KPNO)
Indiana University (KPNO)
Yale University (KPNO)
Dartmouth College (MDM on Kitt Peak)
University of Michigan (MDM on Kitt Peak)
Ohio State University (MDM on Kitt Peak, LBT on Mt. Graham, Winer Obs.)
University of Virginia (LBT)
University of Notre Dame (LBT)
Max-Planck Institute for Astronomy, Heidelberg (LBT)

Max-Planck Institute for Extraterrestrial Physics, Munich (LBT)
Max-Planck Institute for Radioastronoie, Bonn (LBT)
National Institute of Astrophysics, Italy (LBT)
Columbia University (MDM)
Ohio University (MDM)
Western Kentucky University (RCT on Kitt Peak)
South Carolina State University (RCT on Kitt Peak)
Villanova University (RCT on Kitt Peak)
Fayetteville State University (RCT on Kitt Peak)
Florida Institute of Technology (SARA on Kitt Peak)
Clemson University (SARA and KPNO)
Florida International University (SARA)
University of Georgia (SARA)
Valdosta State University (SARA)
Ball State University (SARA)
Agnes Scott College (SARA)
University of Alabama (SARA)
Valparaiso University (SARA)
East Tennessee State University (SARA)
University of Maryland (KPNO)
Case Western University (Kitt Peak)
Center for Astrophysics/SAO (Mt. Hopkins/MMT/Whipple)
University of California, San Diego (Mount Lemmon)
Tennessee State University (Fairborn Obs.)
Vanderbilt University (Fairborn Obs.)
University of Iowa (Winer Obs.)
Washington University (Winer Obs.)
University of Minnesota (Mt. Lemmon)
The Vatican (Mt. Graham)
Purdue University (VERITAS)
Iowa State University (VERITAS)
Washington University in St. Louis (VERITAS)
University of Chicago (VERITAS)
University of Utah (VERITAS)
University of California, Los Angeles (VERITAS)
McGill University (VERITAS)
University College Dublin (VERITAS)
University of Leeds (VERITAS)
Adler Planetarium (VERITAS)
Argonne National Lab (VERITAS)
Barnard College (VERITAS)
DePauw University (VERITAS)
Grinnell College (VERITAS)
University of California, Santa Cruz (VERITAS)
University of Iowa (VERITAS)
University of Massachusetts (VERITAS)
Cork Institute of Technology (VERITAS)
Galway-Mayo Institute of Technology (VERITAS)
National University of Ireland, Galway (VERITAS)

TELESCOPE	LOCATION	OWNER	STATUS
Optical/Infrared Telescopes			
Twin 8.4-meter Large Binocular Telescope	Mt. Graham	LBT Corporation	in commissioning
6.5-meter MMT	Mt. Hopkins	UAZ/SAO	operational
4.2-meter Discovery Channel Telescope	Happy Jack	Lowell Observatory	under construction
4-meter Mayall Telescope	Kitt Peak	NOAO	operational
3.5-meter WIYN Telescope	Kitt Peak	WIYN Corporation	operational
2.4-meter Hiltner Telescope	Kitt Peak	MDM Consortium	operational
2. 3-meter Bok Telescope	Kitt Peak	UAZ	operational
2.1-meter Telescope	Kitt Peak	NOAO	operational
1.8-meter Perkins Telescope	Anderson Mesa	Lowell Observatory	operational
1.8-m Spacewatch Telescope	Kitt Peak	UAZ	operational
1.8-meter VATT	Mt. Graham	Vatican Observatory	operational
1.55-meter Kuiper Telescope	Mt. Bigelow	UAZ	operational
1.55-meter Kaj Strand Astrometeric Reflector	Flagstaff	Naval Observatory	operational
1.5-meter Cassegrain Reflector	Mt. Lemmon	UAZ	operational
1.5-meter Tillinghast Telescope	Mt. Hopkins	SAO	operational
1.3-meter McGraw-Hill Telescope	Kitt Peak	MDM Consortium	operational
1.3-meter Robotically Controlled Telescope	Kitt Peak	RCT Consortium	operational
1.3-meter PAIRITEL	Mt. Hopkins	SAO	operational
1.3-meter Navy Telescope	Flagstaff	Naval Observatory	operational
1.2-meter Calypso Telescope	Kitt Peak	private	inactive
1.1-meter Hall Telescope	Anderson Mesa	Lowell Observatory	operational
1.0-meter Navy Telescope	Flagstaff	Naval Observatory	operational
1.0-meter Cassegrain Reflector	Mt. Lemmon	UAZ	operational
0.9-m SARA Telescope	Kitt Peak	SARA Consortium	operational
0.9-m Spacewatch Telescope	Kitt Peak	UAZ	operational
0.9-meter WIYN Telescope	Kitt Peak	WIYN Corporation	operational
0.8-meter Lowell Reflector	Anderson Mesa	Lowell Observatory	operational
0.8-meter (and smaller) APTs	Washington Camp	Tennessee State Univ.	operational
0.8-meter Tenagra II Telescope	Patagonia	Tenagra Observatories	operational
0.7-meter Catalina Schmidt	Mt. Bigelow	UAZ	operational
0.6-meter Burrell Schmidt	Kitt Peak	Case Western Reserve	operational
0.6-meter LONEOS Schmidt	Anderson Mesa	Lowell Observatory	operational
0.5-meter Jamieson Reflector	Mt. Lemmon	UAZ	operational
0.5-meter Lowell Reflector	Mars Hill	Lowell Observatory	operational
0.5-meter Astrograph	Mars Hill	Lowell Observatory	operational
0.5-meter U. Washington Telescope & others	Sonoita	Winer Observatory	operational
[0.4-meter MEarth Project Reflectors (8)	Mt. Hopkins	SAO	under construction
Wisconsin H-Alpha Mapper	Kitt Peak	U. Wisconsin	operational
HAT (Hungarian-made Automated Telescope) 5 refractors	Mt. Hopkins	SAO	operational

The Arizona Arts, Sciences and Technology Academy
2007