UC Investment in Astronomy vs. Other Sciences: A Comparative Cost Analysis

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Executive Summary

This report was originally motivated by a presentation by ORGS to the UC Committee on Research Policy (UCORP) in June 2011. That presentation claimed that the cost to UC of Astronomy and Astronomy research facilities was disproportionately high compared to other UC science research areas. However, there were three significant errors in the methodology of that report that invalidated its conclusions.

(1) The ORGS report generally failed to separate Astronomy faculty from Physics faculty.

(2) The ORGS report is incomplete in that it shows only certain selected disciplines and ignores many other UC-supported research sciences.

(3) The ORGS report included capital costs for Astronomy (UC's contribution to Keck capital costs were counted as operating costs), but failed to include capital costs for other UC science faculty.

These errors in the ORGS report led to a very significant bias against Astronomy. Once they are corrected, it is clear that the total UC investment in Astronomy research and also the cost per faculty are comparable to those in multiple other science fields.

Overview

Motivated by recent discussions within the UC system about the level of state funding for systemwide research in Astronomy, we have conducted an in-depth analysis of the cost to UC of supporting its Astronomy programs and have compared it to the cost of other sciences supported with UC funds. ***We conclude that the total UC investment in Astronomy research and also the cost per faculty are comparable to those in multiple other science fields.***

Our analysis uses two methodologies. Section 1 compares research expenditures supported by UC funds to those supported by external grant funds, averaged over a 5-year period. This section basically follows the methodology used by the Office of Research and Graduate Studies (ORGS) to analyze science expenditures, but with important corrections that change the conclusions. The new results are then compared to the original ORGS results in Section 2, corrections are highlighted and explained, and deficiencies in the basic ORGS methodology are pointed out. To avoid these deficiencies, Section 3 presents an improved methodology that estimates the *true cost per faculty to UC* of scientists in different fields, averaged over their careers. Taking advantage of available data, this second approach focuses on faculty in Astronomy vs. faculty in the laboratory sciences, such as biology and chemistry. Although this new approach differs markedly from the ORGS-based approach presented in Sections 1 and 2, both methodologies agree in showing that UC's investment and returns in Astronomy are comparable to other science fields.

As noted, this report was originally motivated by a presentation by ORGS to the UC Committee on Research Policy (UCORP) in June 2011. That presentation claimed that the cost to UC of Astronomy and Astronomy research facilities was disproportionately high compared to other UC science research areas. Our reconstruction of the ORGS analysis identifies three significant flaws:

> (1) In compiling the totals for expenditures and external funds for different fields, no notice was taken of the fact that most campuses within the UC system lack separate Astronomy departments but instead house astronomers within Physics departments. The application of standard NSF reporting codes, as in the ORGS analysis, thus resulted in the attribution to Physics of funding that should have been attributed to Astronomy.
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> (2) The ORGS report is incomplete in that it shows only certain selected disciplines and ignores many other UC-supported research sciences.
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> (3) Neither the ORGS analysis nor our reanalysis using the ORGS methodology in Sections 1 and 2 gives a full and fair analysis of *true* UC science costs, which should properly include the total cost of facilities and startup. In the ORGS approach, the UC costs for providing Astronomy facilities *are* explicitly included in the form of the UC's annual contribution to Keck Observatory (as explained in Section 3, UC pays its share of both capital costs and operating costs of the Keck telescopes via the annual contribution). However, the equivalent facilities costs on campuses (e.g., experimental labs) are not included for other fields, nor are startup costs included for any field.

These omissions lead to a very significant bias against Astronomy. These methodological flaws motivated the new approach presented in Section 3, which presents a head-to-head *career-averaged* comparison of total UC costs per science faculty in different fields, including research facilities and startup costs.

Correcting flaws 1) and 2) is sufficient to alter the conclusions of the ORGS analysis on its own terms, and adding the career-averaged costs from the methodology described in Section 3 strongly reinforces this view. Collectively, the three flaws lead to the incorrect view that Astronomy takes a disproportionate share of science research funds available to UC, and they may significantly under-report its success in generating external funds as well**.**

Finally, we note that Astronomy has been criticized as receiving a disproportionately large fraction of the UC research budget compared to other sciences**.** This report demonstrates that this conclusion is false. However, it is worth noting that ORGS is specifically intended to support *systemwide* research. As has become clear from this and other analyses, the use of common research facilities at Keck and Lick Observatories by astronomers from eight campuses and two national laboratories is a *pre-eminent example of systemwide science* in UC. As such, it would be entirely understandable and appropriate if Astronomy were to receive a substantial fraction of the ORGS budget.

Section 1. UC Research Expenditures

The goal in this section is to present, insofar as is possible across different disciplines, a like-for-like comparison of UC research expenditures from UC funds and from external funds *in UC-operated* *laboratories*. This section carries out this comparison using the methodology used by ORGS, which is explained in greater detail in the Appendix to this document. "UC funds" include all discretionary allocations to support research by local UC officials, as well as certain systemwide funds. For example, included in the systemwide category are OP state funds, overhead funds, etc., whereas grants or gift funds are considered external funds. Not included in the systemwide category are subcontracts and subawards, since they are not expended at UC labs. Finally, we divide the Astronomy funds into two parts for clarity: the University of California Observatories (UCO) budget, which flows directly from ORGS, and all other Astronomy funds (non-UCO), which represent the campus allocations. Note that roughly two-thirds ($5 M/yr) of the UCO budget pays for running costs at Lick Observatory and for instrumentation costs at both Lick and Keck Observatories (new instruments for telescopes are effectively capital costs). In contrast to the original ORGS analysis, the Keck annual contribution is not included in our accounting because it includes the payment of a capital cost (see Section 3). Moreover, if it were to be included, a corresponding (large) amount of external funds that have been leveraged by this investment of UC resources (from partners, gifts, awards, etc.) would also have be added to the tally of external funds, and capital costs for other disciplines would have to be estimated and included (this was omitted from the ORGS analysis). We address these other issues in Section 3.

Our sample of disciplines was selected in an attempt to compare a wide range of sciences that are reasonably similar to Astronomy. We did not include Medical Sciences as they are structured and run very differently and many campuses do not host Medical Sciences. We did not include Engineering as it encompasses such a diverse range of activities, from theoretical to applied, with a wide variety of funding sources, from industry to federal. Biology is also excluded on similar grounds; biology reporting codes can include medical, veterinary, engineering, and other sub-disciplines, and the mix varies from campus to campus. We decided to include Agricultural Sciences even though it operates on a much larger scale than the other sciences in our analysis, to illustrate and caution that a particular discipline suite may be selected to make a particular point. Nonetheless, the inclusion or exclusion of Agricultural Sciences, Engineering, or Biology would not alter the overall finding of this report that Astronomy falls in the mid-range of cost for scientific research enterprises supported by UC funds.

Figure 1 is a pie chart of these research expenditures for fiscal years 2006-2010 inclusive. The total amounts shown in Figure 1 average to approximately $130 M/yr over the period shown. The starting data were taken from the UCOP Current Fund Expenditures database that is used to report research expenditures to the NSF on an annual basis, i.e., they are derived from the UC corporate financial system. Each entry is categorized by source and by NSF discipline code, as entered by the campus. Research expenditures are defined in the Current Fund Expenditures database and the Fund Group Codes as all operations costs; they cover salary and wages, start-up packages, capitalized inventorial equipment, and other operating expenditures. It is very important to note that they do *not* in general include facilities construction or facilities running costs, which means that inclusion of the UCO budget (which is largely devoted to such costs) already makes Astronomy look more expensive. We return to this issue in Sections 2 and 3.

In the course of the analysis it became clear that the initial NSF codes needed revision, since most astronomers in UC are faculty in Physics departments – only Santa Cruz and Berkeley have separate Astronomy departments – and many Astronomy expenditures (in the non-UCO category) were wrongly classified as Physics. The method used for identifying expenses that were properly classified as attributable to Astronomy was as follows:

1) We first collected all expenses labeled with the "Astronomy" NSF code. A second pass then looked at the "Physics" NSF codes and viewed the breakdown by departmental grouping.
    - In some cases, a campus has a specific "sub-department" called Astronomy or another category that can be clearly associated with Astronomy. These expenses were reclassified from Physics to Astronomy.
    - In other cases, campuses only have departments called "Physics & Astronomy". Sometimes such departments include an "Astronomy group" that was used to identify Astronomy faculty.
    - Otherwise, the listed research focus for each faculty member was reviewed to determine whether it was primarily Astronomy or primarily Physics.
    - After this review, the total Physics expenses for that department were multiplied by the ratio of Astronomy-to-total faculty, and that amount was reclassified to Astronomy.
    - Lastly, a few other small adjustments to the categories were made as described in the caption to Figure 1.

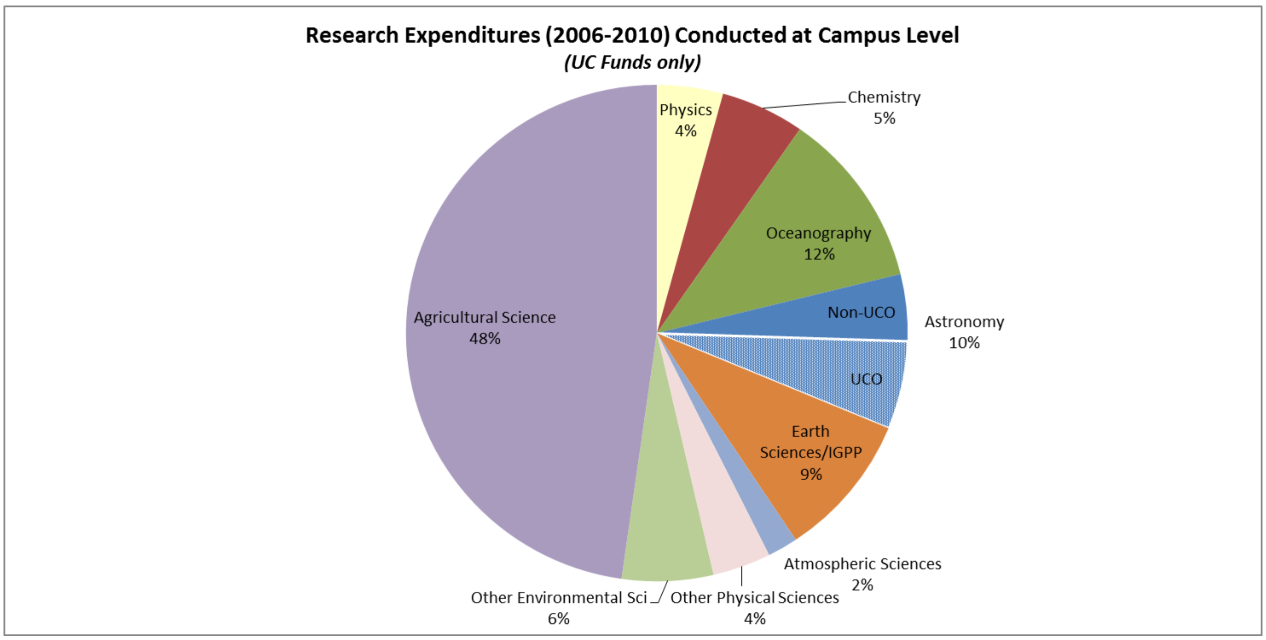

Figure 1. UC Research Expenditures for FY2006 through FY2010 for selected sciences. The sample of disciplines was selected in an attempt to compare a wide range of sciences that are reasonably similar to Astronomy. Medical Sciences, Engineering, and Biology are not included because of the wide diversity of sub-fields and funding sources within each discipline and the lack of comparability from campus to campus. This figure compares research expenditures by discipline and represents *discretionary research expenditures funded by UC funds at UC-operated laboratories*. Definitions of the fund categories and the methodology used to compute them are described in the text. Astronomy funds are in two parts: research support provided by local campus funds ("non-UCO"), and funds that support the University of California Observatories flowing directly from UCOP ("UCO"). Non-UCO Astronomy figures have been adjusted from Physics as explained in the text. In addition, expenses for the Institute of Geophysics and Planetary Sciences (IGPP) are coded with different NSF codes across campuses and, for consistency, have all been reclassified under Earth Sciences. Pharmaceutical Chemistry at UCSF has also been removed from the Chemistry total for better comparability, since UCSF is a health sciences campus without counterparts elsewhere. Sub-contracts/sub-awards from UC to another institution are excluded since the expenditures do not occur at a UC-operated site. Once these equalizations have been carried out, the figure gives a more comprehensive picture of discretionary research funding from state funds. Astronomy research expenditures are much smaller than Agricultural Sciences and are comparable in size to Oceanography and Earth Sciences.

Figure 1 shows that by far the largest fraction of UC-funded discretionary research expenditures is for Agricultural Sciences. Oceanography, Astronomy (UCO + non-UCO), and Earth Sciences are next in size and are comparable to one another.

We turn next to the question of external funds generated by these disciplines, which are interesting because their overhead tends to partially offset UC-funded research costs. Figure 2 explores this by comparing expenditures supported by external funds (shown in blue) to the UC-supported expenditures from Figure 1 (shown in red). The green line in Figure 2 is the ratio of external to UC-provided funds.

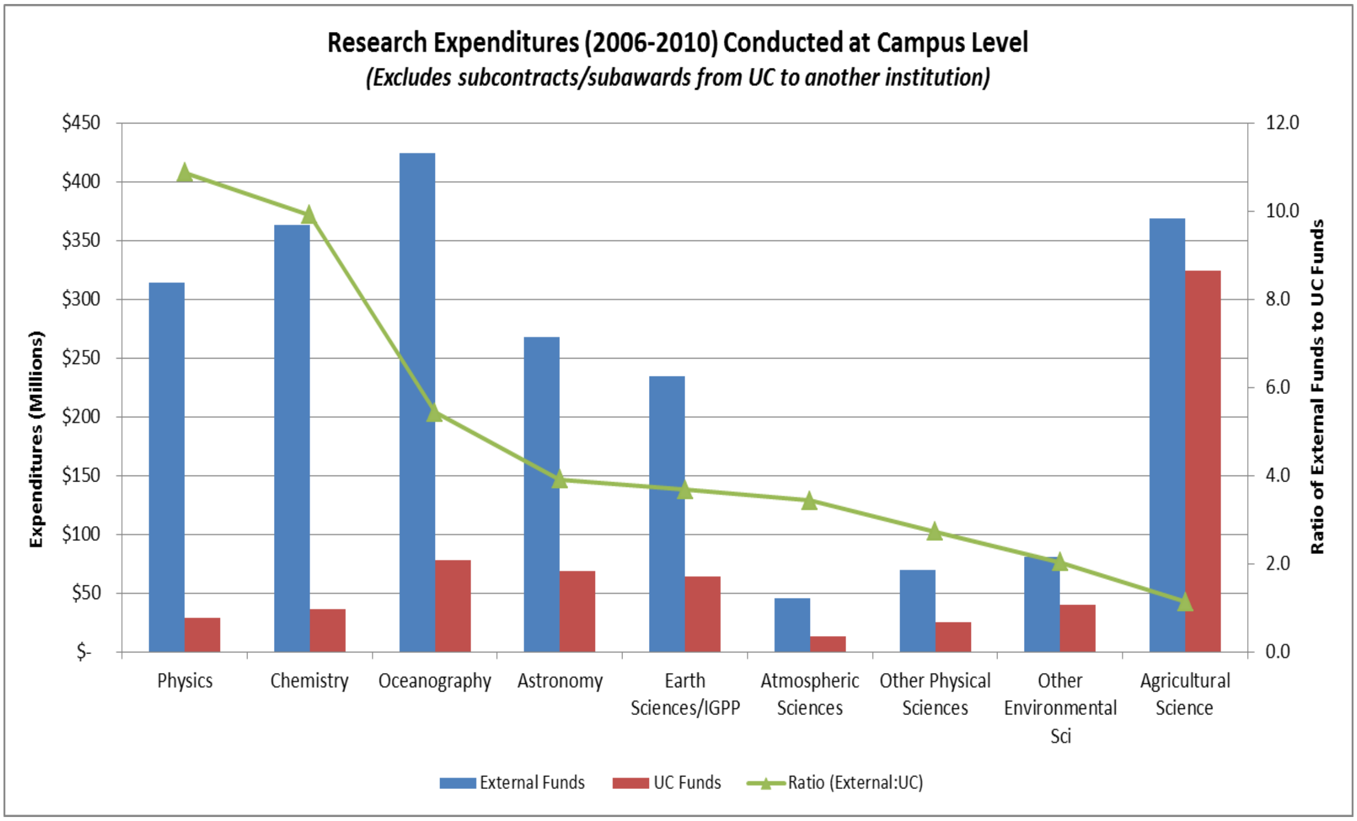

Figure 2. Research Expenditures Supported by External Funds vs. UC Funds. External funds generated by each discipline are shown as the blue bars. UC funds used to support the discipline are shown by the red bars and are the same as Figure 1. The green line is the ratio of external-to-UC funds. External fund sources include federal, private gifts and grants, local government, state agencies and other restricted sources. All other funds are considered to be UC funds. It is seen that Astronomy values and the Astronomy external-to-UC ratio are both near the median of other UC sciences.

Figure 2 shows a large range in the ratio of external to UC funds, ranging from a high of 10-11 for Physics and Chemistry to a low of 1 for Agricultural Sciences. Most sciences lie in a mid-range between 3 and 5, among which Astronomy's ratio of 4 is typical.

To summarize, Figures 1 and 2 show that Astronomy is similar to other UC sciences in terms of investment from UC funds and ability to generate external funding. We note further that Astronomy's share of UC funds is, if anything, overrepresented since a large fraction (two-thirds) of the UCO budget is used for facilities capital and running costs at Keck and at Mt. Hamilton. These costs are proportionately much larger for Astronomy than for other sciences. We return to this issue in Section 3.

Section 2: Research Expenditure Analysis by the Office of Research and Graduate Studies

In this section, we redo the charts of Section 1 but use the exact choices made by ORGS for the UCORP presentation (see Appendix 1). Figure 3 is the ORGs version of the pie chart for UC-funded expenses and is to be compared to Figure 1.

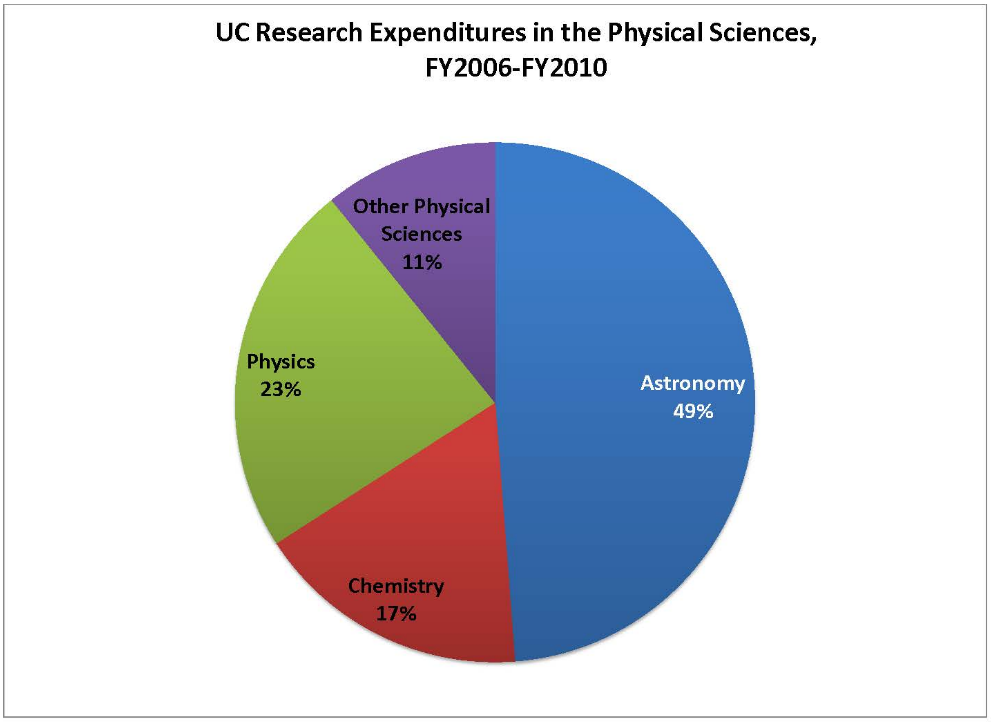

Figure 3. UC-funded Research Expenditures as Summarized by ORGS. This figure is ORGS version of UC-funded research expenditures, as presented to UCORP in June 2011. It is to be compared with Figure 1 above. A major difference is that the ORGS number for Astronomy includes capital and running costs for Astronomy facilities (Keck and Lick Observatories) whereas no such costs have been included for the other sciences, owing to the manner in which UC-funded expenditures are defined (see Section 1). The decision to limit the presentation to the Physical Sciences only has also left out large shares to Agricultural Sciences, Oceanography, and Earth Sciences, which are larger than or comparable to Astronomy. The net effect of both decisions is to exaggerate Astronomy's share.

First, the ORGS report includes facilities capital and running costs for *both* Astronomy observatories, Keck and Lick, adding UC's contribution of $11-12 M/yr for Keck to the UCO budget shown in Section 1. This difference will be corrected in Section 3. The second big difference is the decision to limit this plot to the Physical Sciences, which highlights the small shares of Physics and Chemistry but misses the larger shares of Agricultural Sciences, Oceanography, and Earth/Planetary Sciences. The net result of both decisions is to exaggerate Astronomy's share, but with no obvious methodological justification.

Figure 4 is ORGS's version of the bar chart in Figure 2. The same choices – including facilities capital and running costs for Astronomy but not for other sciences and limiting the plot to a few selected physical sciences – present Astronomy's ratio of UC-funded vs. externally funded research costs in an unfavorable light.

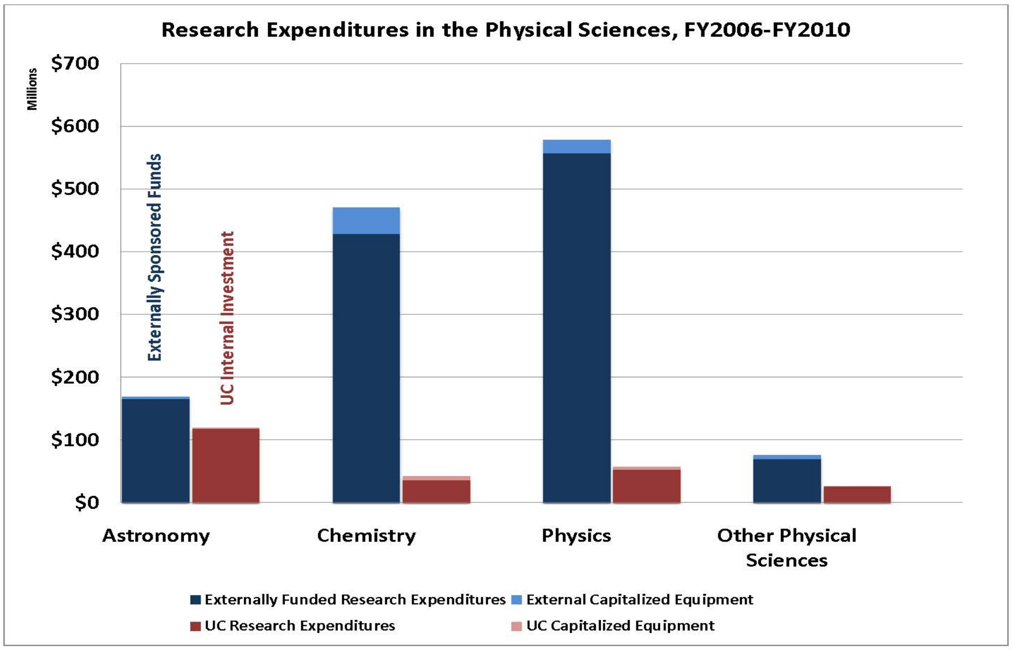

Figure 4. Comparison of UC-Funded vs. Externally-funded Research Expenditures as Summarized by ORGS. This figure is ORGS version of Figure 2 comparing UC-funded vs. externally-funded research expenditures. This figure repeats the choices used in Figure 3 by including only the Physical Sciences and by including facilities capital and running costs for Astronomy but not for the other sciences ("capitalized equipment" in the figures refers to moveable items of equipment above $5000, not the capital costs of buildings and laboratories). As a result of both choices, the ratio of UC-funded to externally-funded research expenditures for Astronomy appears more unfavorable than it really is.

To summarize, the dramatic differences between Figures 1 and 2 on the one hand and Figures 3 and 4 on the other underscore the need for a careful accounting to avoid a misleading "apples and oranges" effect when gauging research costs. Three errors and omissions in the ORGS analysis contributed to problems inherent in Figures 3 and 4: 1) incorrect classification of many astronomers as physicists, 2) inclusion of capital and facilities running costs for Astronomy without consideration of analogous expenditures for other sciences, and 3) failure to consider a more comprehensive suite of scientific endeavor funded within UC. These errors and omissions in turn led to the incorrect conclusion that UC Astronomy is funded at a disproportionately high level and that it has generated only modest financial returns on that investment, criticisms that are now frequently repeated in many quarters of UC. In fact, Astronomy produces a healthy level of grant funding, around average for the UC sciences, and its operational cost is also well within the average range.

Section 3. Lifetime Costs per Researcher: Astronomy vs. Laboratory Sciences

The preceding sections looked at research expenditures in aggregate for entire fields without taking size of field (i.e., number of UC faculty) into account. Research expenditures could be high simply due to having more faculty, and it is important to separate out this effect. The previous analyses also did not treat facilities costs fairly between Astronomy and other fields. Similarly, no account has yet been taken of different startup costs in different fields.

This section attempts to remedy these problems by estimating the total investment from UC funds *per scientist* in Astronomy versus other sciences. Taking advantage of readily available information, we have chosen to identify the costs of faculty in Biology, Chemistry and Biophysics as examples to represent "other sciences". We focus on these fields because two new laboratory buildings housing a collection of such scientists have recently been constructed at UCSC. Having these buildings on our campus has allowed us, with the assistance of local staff, to drill down and understand the funding allocations in detail, something that is difficult to do when aggregating costs at the systemwide level across many campuses and across different sciences. While the specifics in these fields may not apply to all sciences across the UC system, these examples clearly illustrate the fact that the costs per faculty in "other sciences" can be very significant and comparable to those required to support astronomers. Note that, although we elected not to include Biology in our analyses for Figures 1 and 2, the complexity of the reporting codes and the lack of consistency from campus to campus that led to its exclusion do not apply for this particular calculation; here we have access to the same details of funding and activities of UCSC Biology faculty that we have for other faculty.

For both astronomers and laboratory scientists, UC state-funded investment is in three parts: capital costs, running costs, and startup costs. These areas are considered separately for each type of scientist.

3.1 Optical/infrared astronomer costs

UC optical/infrared astronomers (hereafter O/IR astronomers) are supported by facilities in two locations, Keck Observatory and Lick Observatory. Keck is particularly instructive since it is relatively new (built in the 1990's), and the capital and running costs are well known. We start by estimating the costs per Keck observer and correct this figure for additional costs expended at Lick Observatory below.

3.1.1 Keck costs to UC

Keck Observatory was constructed in the 1990's in partnership with Caltech, UC, and NASA. Caltech and NASA provided the construction costs. Caltech received two gifts from the Keck Foundation in the amount of $70.0 M in 1985 and $74.6 M in 1991. This constituted 5/6 of the initial capital costs; the remaining 1/6 was provided by NASA. Correcting for inflation and adding in NASA's share yields a total capital cost for both 10-m telescopes of $331 M in 2012 dollars.

UC receives 38% of the observing time (this is also Caltech's share; the remainder is split between NASA and the University of Hawaii in return for use of the site). UC did not contribute to construction but, in lieu of contributing capital costs, instead has provided greater than its share of annual operations in the early years of use. By mutual agreement, Caltech and UC have agreed that, after UC pays 5/6 of the operating costs for 25 years, UC and Caltech will have contributed equally to the sum of both capital and operating costs through that date (2018). Their shares in the facility will then be equal, and their contributions to operating costs will be the same after that date. UC currently pays 5/6 and NASA pays 1/6 of operating costs. The total operating costs are $15.1 M/yr for the two telescopes, and UC's share is $13 M/yr in 2012 dollars. This sum is provided by ORGS directly to Keck. However, because of the agreement, UC's investment in Keck is *as though* it had paid 5/12 of the initial construction costs and 5/12 of the operating costs for the first 25 years, at a rate of $6.5 M/yr. In other words, UC is paying a higher share of operations now because it did not pay for the initial construction, but this will end in 2018, at which point the two partners will be considered to have contributed equally to capital and operating costs (and the difference between the higher annual contribution now being paid and the lower annual contribution due subsequent to 2018 will be freed up for UC to invest in other opportunities or priorities.). We find it easier to think of lifetime costs under this second model and have used this formulation below.

3.1.2 Keck capital costs per researcher

Given this introduction, we next estimate the UC capital investment per researcher. UC's share of the construction costs, averaged over time, is 42%. During the three-year period 07-01-2010 to 06-30-2013[1], 64 ladder faculty and 11 research astronomers and adjunct professors applied for and received observing time as PI's at Keck. Thus, UC's Keck share is currently and *directly* supporting the careers of 75 PI researchers, of whom 85% are ladder faculty. In estimating the capital investment *per researcher,* we need to know how long telescopes last. We assume that telescopes have a useful life of 60 years and support *two full generations* of researchers. This assumption is based on experience: the Palomar 200-inch is now 65 years old and the Lick 3-m is now 55 years old; both are still useful, albeit less competitive than during their first 30 years. The initial capital investment is therefore divided among 2 × 75 = 150 PIs, for a total capital investment of $331 M × 0.42/150 = $0.93 M per PI.

3.1.3 Keck running costs per researcher

UC's share of annual operations provided directly by ORGS is 0.42 × $15.1 M = $6.34 M. (This is mostly running costs with a small amount for new instrumentation. Technically, new instruments should be considered as capital costs since they contribute to basic telescope capabilities, but, since the distinction does not matter for our purposes, we combine them.) In addition, approximately $1.2 M of the annual UCO budget is spent on Keck instrumentation and assisting UC researchers to observe there[2]. Hence the total UC annual contribution to Keck operations is $6.34 + $ 1.2 = $7.54 M/yr. At any one time, the number of Keck researchers is 75, so these funds need to be divided by 75 to yield the annual running cost of $0.10 M per researcher per year.

3.1.4 Astronomer startup costs

The last area where state funds contribute to O/IR astronomers is startup funds. These are one-time funds analogous to capital costs. We obtained startup data for the last 8 years from UCSC for astronomy, biology, and chemistry, and from UCLA for astronomy and chemistry. The average

[1] This 3-year period was selected to match the Portfolio Review Group (PRG) review period.
[2] Activities A1 + A2 in UCO Portfolio Review Group report, March 2013.

astronomer startup is \$247 K[3] at UCSC and \$437 K at UCLA. The mean of these two numbers gives \$342 K for an astronomer, the value shown in Table 1.

3.1.5 Keck lifetime costs per researcher

The lifetime costs per Keck researcher are the one-time capital costs (\$0.93 M), one-time startup costs (\$0.34 M), plus the lifetime running costs. The latter are \$0.100 M/yr × 30 years = \$3.00 M assuming a career duration of 30 years. The lifetime total cost of Keck per researcher is thus \$4.27 M. These numbers are summarized in Table 1.

Table 1
UC State Funds Invested per UC Scientist

	Astronomer	Laboratory Scientist
(a) Capital costs	\$0.93 M	\$1.74 M
(b) Start-up	0.34	1.63
(c) Operations over 30 yr	3.00	0.84
Lifetime total (a+b+c)	\$4.27 M	\$4.21 M

3.2 Laboratory scientist costs

3.2.1 Building capital costs

The major capital cost for laboratory scientists is the construction of buildings that house their laboratories. To estimate this, we have used data for the two most recently constructed laboratory science buildings at UCSC. The Physical Sciences building was completed two years ago; the Biomedical Sciences building is being finished now. Together, these buildings will house researchers in molecular and cell biology, developmental biology, chemistry and biochemistry, environmental toxicology, and biomolecular engineering. The building data are summarized in Table 2. We emphasize that these estimates do not include office, administrative, or instructional spaces, which do not contribute to research. The average fraction of space devoted to research laboratories in the two buildings is 57%, and we apportion all costs to research proportionately.

Table 2
Two Laboratory Science Buildings at UCSC

	Cost	Tot sq ft	Research sq ft	Number faculty
Biomedical Sciences	\$83.7 M	59,700	36,600	23[4]
Physical Sciences	59.9	80,800	42,870	24[5]

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[3] No recent observer hires have been made at UCSC, so the previous 8 year average was inflated by 3% per annum to arrive at this figure.

[4] Currently occupied by 16 faculty, of whom one is a theorist. Projected full occupancy is 24. Since the proportion of theorists at full occupancy is unknown, we conservatively assume that the one currently in place is the only one.

In addition to original construction, buildings also require renovations and major maintenance over time. We assume a building lifetime of 60 years (2 generations of faculty, like a telescope) and use renovation records at UCSC to show that 10-15% of a building is renovated every ten years at a cost per square foot that is comparable to the original construction cost. Hence, over 60 years, 0.75 × original cost is added to the cost of the building. This is the amount we are attributing specifically to capital costs. More is spent on custom renovations to individual laboratories. These are mostly paid for out of campus (startup) funds that are counted elsewhere (section 3.2.2). Some grant funds may also be used for this purpose but we do not include these because they are not a burden on UC.[6]

Finally, the lifecycle cost model for buildings at UCSC adds another factor of 0.25 to the original cost to pay for major maintenance (new roof, plumbing, electrical system, etc.). Adding this to renovations thus doubles the original cost.

Combining these numbers and using average numbers for the two UCSC buildings gives a building capital cost of $1.74 M per researcher in 2012 dollars.

3.2.2 Laboratory scientist startup costs

The average biology/chemistry startup is $0.601 M at UCSC and the average chemistry startup is $2.665 M at UCLA. Taking the mean of these two, we find an average of $1.63 M per laboratory scientist, which is entered in Table 1. This number is highly uncertain since average startups are over 4 times higher at UCLA than at UCSC, and it is unclear what the systemwide average would be. UCLA is probably at the high end, and UCSC is definitely at the low end, but high-end departments have more faculty, so the systemwide mean is if anything probably higher than we have assumed.

3.2.3 Running costs for laboratory scientists

Running costs for laboratories consist of routine maintenance, deferred building maintenance, custodial services, grounds-keeping, refuse and recycling, and utilities. The average running cost for each new UCSC building is $1.15 M/yr. Multiplying by 57% (research fraction) and dividing by the number of occupying faculty gives $0.028 M/researcher per year.

3.2.4 Laboratory scientist lifetime costs per researcher

Converting running costs to a lifetime cost assuming a 30-year career gives $0.84 M/researcher. Adding building costs and start-up, we find a total lifetime cost per laboratory scientist of $4.21 M.

3.3 Comparison: Keck astronomers vs. UC laboratory scientists

The final sums are given in Table 1. They show that the labs of laboratory scientists cost more to build than telescopes, but much less to operate. The startups of laboratory scientists are also more expensive, presumably to fully equip those laboratories, whereas astronomers rely on the shared-facility instrumentation to perform their experiments. The net costs of the two classes of scientists, though

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[5] Currently occupied by 26 faculty, two of whom are theorists.

[6] Most telescope renovation costs are typically paid for out of operations funds.

different in detail, in aggregate are virtually identical, \$4.27 M per astronomer vs. \$4.21 M per laboratory scientist. Given the rough nature of many of the assumptions, the near equality of the two numbers must be considered coincidental, although indicative that costs per astronomer are approximately the same as costs per laboratory scientist.

3.4 Addition for Lick Observatory usage

We have just seen that the cost of building and running the Keck telescopes and setting up researchers to use them is comparable to the cost of building and running laboratories for UC laboratory scientists and setting up researchers to use them. However, UC also spends funds to operate and equip facilities at Lick Observatory. The amount spent there is \$2.6 M/yr.[7] Two circumstances make it difficult to carry out the same kind of cost estimate per faculty/senior researcher as was carried out for Keck. First, the clientele at Lick is more varied. The number of Lick PI's on the three research telescopes at Lick is 69[8] over the three year period 07-01-2010 to 06-30-2013[9]. This is very similar to Keck but, unlike Keck, they are spread over ladder faculty, research scientists, postdocs, and graduate students. This is because students and postdocs are allowed to run their own programs at Lick, which is a uniquely valuable training experience.

More specifically, the number of faculty + researcher scientist PI's at Lick is 34, while the number of student + postdoc PI's is 35. To whom should the costs of these extra non-faculty/non-researcher PI's be assigned? A few of them work for the 34 faculty/researcher PI's, but most do not, having either separate projects and/or different supervisors; it would seem inappropriate to assign their research costs to the 34 faculty/researcher PI's, who in general are not benefitting from their work. Except for postdocs with independent funding (with named fellowships like Hubble Fellows, etc.), each of these junior PI's has a senior supervisor who is generally not a Lick PI but who is benefitting, either through direct collaboration or diffuse association. There are no records of the identities of these senior supervisors who are not Lick PI's, but an informed rough estimate based on the identities of the 35 junior PI's is, conservatively, that the research of 29 additional senior researches/faculty is being supported by Lick Observatory, with some allowance for duplicates (more than one junior PI working with a single senior supervisor). We thus adopt 34 + 29 = 63 as the number of "equivalent" faculty + senior researcher PI's at Lick, with considerable uncertainty. The annual Lick operations costs per researcher are then \$2.6 M/yr/63 = \$0.041 M/yr, or \$1.24 M over a 30-year career.

Capital costs for Lick are difficult to include in a consistent way. The three research telescopes (Shane 3-m, Coude Auxilliary Telescope, and the Nickel 40-inch) were built far back in time, in both new and existing buildings, and with a mix of in-house vs. external labor. The nominal facility lifetime that we have assumed throughout this report (two generations of astronomers, or 60 years) is all but up, even for the most recent telescope (the Shane was commissioned in 1960). However, to be scrupulous in our avoidance of underrepresenting astronomy costs, we have estimated a maximum capital cost value by applying to Lick the construction-to-running cost ratio for Keck from Table 1. The data from that Table indicate that Keck construction costs are roughly 31% of Keck lifetime operating costs. If we add construction costs for Lick estimated in the same way, then the total cost of Lick (construction +

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[7] Activities A5 + A6 in UCO Portfolio Review Group report, March 2013.
[8] Non-UC PI's are not included in this tally.
[9] This 3-year period was selected to match the Portfolio Review Group (PRG) review period.

operations) would increase to 1.31 × \$0.041 M/yr = \$0.054 M/yr per researcher, for a total lifetime telescope cost over 30 years of 30 × \$0.054 M/yr = \$1.62 M. However, given our report assumptions and the fact that the capital cost of 50+ year old facilities would no longer be "carried on the books" (debt servicing for construction loans are usually reckoned over 30 years), we feel it is more reasonable to adopt the lifetime Lick cost per researcher of \$1.24 M derived above. At any rate, the difference in these two numbers illustrates the range of costs associated with Lick.

The next question is how to add startup funds for Lick faculty + senior researchers. This depends on the degree of overlap between the community of Keck faculty + senior researchers and the community of Lick faculty + senior researchers. Two scenarios will illustrate the extremes.

Communities are completely separate: Assume that startup funds for the Lick researchers are the same as startup funds for the Keck researchers, namely, \$0.34 M. In this case, the total lifetime costs for a Lick researcher are \$1.24 M + \$0.34 M = \$1.58 M, compared to \$4.27 M for a Keck researcher. Weighting these by the number of Lick vs. Keck PI's, the systemwide weighted average is then reduced to \$3.04 M for astronomers as a whole. *Communities are identical:* in that case, startup costs for the Lick PI's have already been counted, but the additional lifetime cost of Lick should be added to Keck, giving a total lifetime cost per researcher of \$4.27 M + \$1.24 M = \$5.51 M.

The actual situation is somewhere in between – observing records show that about two-thirds of the PI researchers at Lick and Keck overlap. Adopting this assumption, we therefore estimate a rough systemwide average of \$4.69 M for UC research costs per astronomer. This is somewhat larger than \$4.27 M for Keck alone but still comparable to the cost of \$4.21 M for a laboratory scientist, especially given the many uncertainties involved.

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Appendix

Methodology Used by ORGS to Estimate Cost of UC Sciences
UCORP Presentation by VPRGS Beckwith, June 2011

The following text was kindly provided by the Office of Research and Graduate Studies to describe their methodology for comparing expenditures funded by UC vs. external funds for various UC sciences. We have successfully reproduced their results when using the definitions here but recommend several important changes, as described in Sections 1 and 2.

The data come from the UCOP Current Fund Expenditures database and are used to report research expenditures to the NSF on an annual basis. They tie into the annual Campus Financial Schedules reports (found on the UCOP website at http://www.ucop.edu/corpacct/finschd/). It is important to note that each annual report is a compilation of financial schedules prepared by each campus and that each campus schedule may use differing methods of rounding which do not affect the accuracy of the data presented, but may produce the appearance of minor inconsistencies in various subtotals. That said, as the data is reported to the federal government, it is extremely important that they are correct.

The data was supplied by the UCOP Institutional Research department, categorized by source and by NSF discipline code. There may be some discipline overlap depending on who categorized the data by NSF discipline code at the campus level; if the data categorization is being done by people in the departments with high levels of familiarity with the PI research topics, the NSF discipline code is likely to be more accurate than if the data categorization is being done by someone in campus accounting departments.

Categorizing the Fund Group Codes as UC funds and External funds takes place at the UCOP Institutional Research level. UC funds consist of money from multiple sources (the major categories are General Funds, Student Tuition and Fees, Endowments and All Other Funds). The External Funding category is also a combination of fund sources (Federal Funds, Gifts, Other Contracts/Grants, and Special State Appropriations). The UCOP Institutional Research group worked to more accurately re-calibrate the UC/External source fund breakdown, which resulted in some fund redistribution between the initial set of charts sent out and the current version. This recalibration does not largely affect the Astronomy figures, although has some impact on other sciences.

Research expenditures are defined in the Current Fund Expenditures database and the Fund Group Codes as all operations costs; they cover salary and wages, start-up packages, capitalized inventorial equipment and other operating expenditures. Capitalized inventorial equipment expenses are a subcategory in the stacked research expenditure bar. Within this category, equipment must be "moveable" and becomes a capitalized expense at the $5,000 level. Other capitalized expenses are incorporated into the research expenditures category. We are continuing to look into the facility expenditure definitions within the corporate financial system to more accurately categorize specific facility expenditures, but it is doubtful that we will be able to provide more granularity than what has been presented here.