Comparison of Science Metrics among Observatories

A comparison of various scientific metrics is presented. In particular, we examine the impact of the HST and VLT observatories through publication rates, citation rates and the number of highly cited publications. Both observatories are major contributors to today's astrophysics research endeavour and currently rank among the most successful astronomical facilities as measured by the above categories.

Uta Grothkopf[1], Bruno Leibundgut[1], Duccio Macchetto[2], Juan P. Madrid[2], Claus Leitherer[2]

[1]European Southern Observatory, Garching, Germany
[2]Space Telescope Science Institute, Baltimore, MD, USA

The European Southern Observatory (ESO) and the Space Telescope Science Institute (STScI) have developed science metrics tools to measure and monitor the scientific success of their telescopes. Two recent papers outline the methodology used to produce the metrics and evaluate the results: "Metrics to Measure ESO's Scientific Success," by Leibundgut, Grothkopf & Treumann (2003) and "Hubble Space Telescope Science Metrics", by Meylan, Madrid & Macchetto (2004).

In an attempt to put the results into a broader context, we present here a comparison between the individual science metrics of HST (*Hubble Space Telescope*) and VLT (*Very Large Telescope*). The two facilities have rather different, yet often complementary, capabilities. They also serve a similar community of optical and near-IR astronomers. It is generally acknowledged that they have leading roles in astronomical research. Here we try to assess the relative roles and the scientific impact of the two observatories.

The Hubble Space Telescope, launched in April 1990, is the product of collaboration between NASA and the European Space Agency. During its lifetime HST has had nine extremely successful instruments, six of which are by now decommissioned. Unique capabilities of HST include the access to UV wavelengths, the unmatched large-field, high spatial resolution and the low background at near-infrared wavelengths.

The Very Large Telescope is one of the major ground-based observatories, with four 8 m unit telescopes and the capability of combining them (and smaller auxiliary telescopes) for interferometry. In operation since 1999, the VLT has grown to include all four unit telescopes and ten instruments are currently offered to the community. The instrument suite covers most wavelengths accessible from the ground, adaptive optics instruments for small-field high spatial-resolution imaging, high-resolution spectroscopy and multi-object spectroscopy.

Methodologies for assessment of scientific impact have been developed by several authors for individual observatories (Meylan, Madrid & Macchetto 2003, 2004; Leibundgut, Grothkopf & Treumann 2003, Crabtree & Bryson, 2001), comparisons between observatories (Trimble 1995, Benn & Sanchez 2001, Trimble, Zaich & Bosler 2005) or generally the impact of journals or astronomical subfields (Abt papers, Schwarz & Kennicutt 2004). Almost all investigations converge on the basic data input for the metrics: numbers of papers published, citations to these papers, and impact measured through highly cited papers. Differences in the analyses mostly stem from different input databases and weighting of stated goals of the investigation, e.g. which audience is addressed. For observatories, the prime interest is, of course, to evaluate how the data collected with their facilities contribute to scientific progress.

In the following we use the number of refereed publications as one measure of the productivity of the VLT, HST and other observatories, which provided us with the appropriate input data. We then proceed to investigate the number of citations these papers generate, which measures their impact within the scientific astronomical community. Further investigations try to find the high-impact papers based on observatory data.

As of the end of 2004, 120 refereed papers combined data from HST and VLT. The complementarity of these two observatories is reflected in these papers. We performed an analysis to investigate what projects make use of both observatories.

Our study is based on databases that are *complete* in the sense that they collect all papers that use data from the respective observatory. The databases are maintained at ESO and STScI separately and we made an effort to homogenize them for the comparison.

Number of papers based on HST and VLT data

In order to compare publication statistics among different observatories, it is essential to assess the selection criteria applied by each observatory and to relate the different criteria to each other in a meaningful way. The first ingredient is a complete list of papers based on observatory data. One might think that it would be easiest to rely on the mentioning of facility usage by the authors, for instance through acknowledgements in footnotes or through the use of data set and facilities identifiers[1]. However, these linking initiatives are voluntary for the authors. They will only help facilities to derive metrics when they are applied widely and reliably.

Automated searches in the NASA Astrophysics Data System (ADS) do not lead to complete lists of papers. A 2002 study at ESO showed that retrieval of papers through ADS alone missed approx. 20 % of relevant papers, while at the same time an equal number of papers was erroneously included (Grothkopf & Treumann 2003). Similar findings have been confirmed in various further trials. The main reason for the unreliability of automated searches is not so much the unavailability of full texts (ADS currently covers only title, abstract and keywords of recent papers), but rather the fact that retrieval tools are not capable of interpreting the context in which search terms appear. Thus, we still need human as-

[1] Identifiers for data sets and facilities are currently being introduced by AAS journals. They are meant to improve navigation between scientific papers and online data, see for instance Eichhorn et al. (2003).

sessment in order to distinguish between papers that meet our selection criteria and those that mention search terms in contexts that are irrelevant for our purpose.

At most large observatories, librarians or dedicated personnel screen the literature and identify all articles based on data from the respective facilities. These databases are used for multiple purposes including, for example, the Annual Report's section on scientific articles published by the observatory. At ESO and STScI, we have achieved a high reliability through manual screening of print journals in combination with searches using ADS, and created comprehensive databases.

The HST publication database contains papers since the special HST *Letters* issue of the *Astrophysical Journal* in March 1991; the ESO telescope bibliography contains publications from 1996 onwards for La Silla papers and from 1999 onwards for VLT papers.

Our databases list refereed papers that use HST or VLT data pertaining to at least one of the following data categories: (i) PI/CoI (Principal Investigator/Co-Investigator) data, i.e. publications in which at least one of the authors was a participant of the original proposal; (ii) archival data, i.e. papers using data where none of the authors was a member of the original proposal group; and (iii) papers using public data sets. We do not include papers that merely cite results published in previous articles. ESO excludes conference proceedings, even if published in refereed journals. STScI, in contrast, includes conference proceedings in refereed journals.

One would expect that the HST numbers of publications are somewhat enhanced compared to those of ESO due to this slight difference. At the same time the citation rates are possibly decreased as citations to conference papers, even if refereed, are typically lower than in the refereed literature (e.g. Schwarz & Kennicutt 2004). Despite these differences, the statistics derived from the two databases are comparable, bearing in mind that the overall aim is to compare them in a broader context rather than on the basis of cross-checks among individual papers. We believe that the metrics we derived are objective and reproducible.

At ESO, papers are categorized by telescopes, instruments and observing modes (visitor or service). It is also noted whether these are original observations or archival data. For all papers using VLT data, the programme IDs that generated the data are obtained either from the publication, from the observing schedule or from the authors.

The ESO and STScI databases are publicly available. The ESO bibliography can be searched using the web interface described by Delmotte et al. on page 50 of this Messenger issue. In addition, but without search options for specific telescopes or instruments, both databases are available through the ADS Abstract Service by activating the filters ESO/Telescopes and HST, respectively. Active links to the corresponding archives are provided for all papers using HST and VLT.

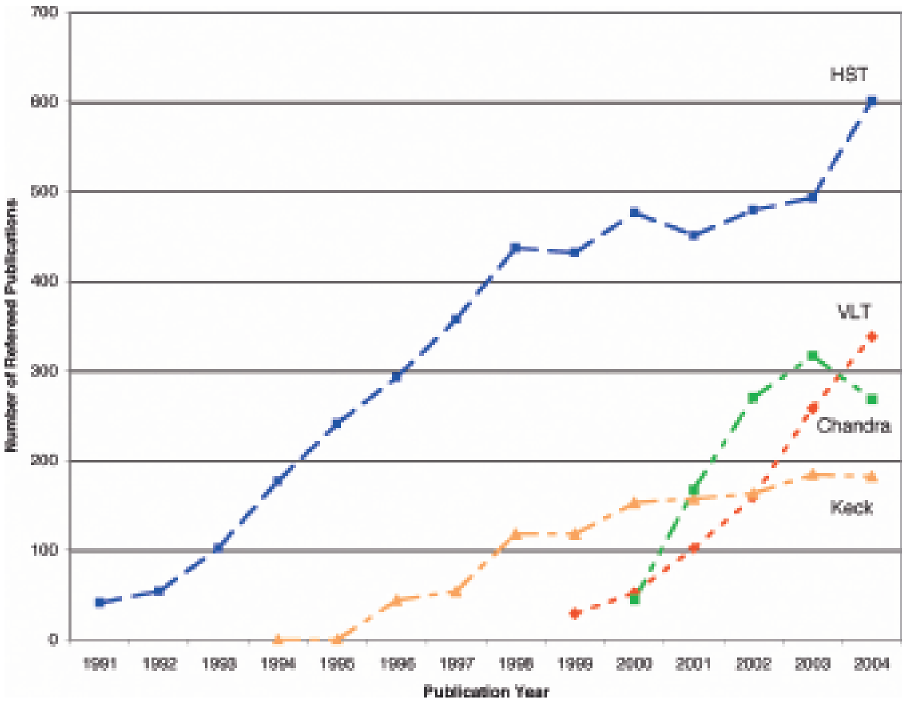


Figure 1: Number of refereed papers using VLT, HST, Keck, and Chandra data (as of January 2005).

Figure 1 gives the total numbers of papers per year for the VLT and the HST. For comparison, we also include publication numbers for the Keck Observatory and the Chandra X-ray Observatory. We obtained these values from the Keck Science Bibliography (*http://www2.keck.hawaii.edu/library/keckpub00.html*) and from the Chandra Data Archive (*http://cxc.harvard.edu/cgi-gen/cda/bibliography*; see also the article by Green and Yukita 2004).

The VLT and the HST are both very productive telescopes: as of January 2005, HST has provided data for a total of 4634 refereed papers (over 14 years), VLT for a total of 938 (over six years). Both observatories, as well as Chandra, profit from a large user community. The start-up years of the VLT are nearly identical in numbers of papers published compared to the early years of HST operations showing a strong and regular increase per year. In the case of the VLT, part of this increase is due to the continuous expansion of the facility and the addition of new telescopes and instruments. The instrument complement increased from two instruments in the first year to four for the second, third and fourth year of operations, with a further increase to today's complement of ten instruments.

The HST reached a publication rate of about 500 refereed papers per year, eight years after launch. The impressive contribution of the HST reflects the fact that it provides unmatched spatial resolution imaging at ultraviolet through near-infrared wavelengths as well as spectroscopic observations at wavelengths that ground-based telescopes cannot access. Furthermore, the HST has been regularly refurbished with new generations of instruments through successive servicing missions, maintaining state-of-the-art technology.

The publication rate for the VLT is still increasing at the rate HST was displaying during its first eight years. As an aside we note here that up to 2004 there are still more papers published per year based on data obtained with telescopes at La Silla than from the VLT (337 vs. 344 in 2004).

	HST (1991–2004)		VLT (1996–2004)	
	# of papers	%	# of papers	%
ApJ/ApJS	2269	48.9	235	25.1
AJ	851	18.4	52	5.5
A&A	586	12.6	527	56.2
MNRAS	369	8.0	74	7.9
PASP	106	2.3	1	0.1
Nature	47	1.0	18	1.9
Others	406	8.8	31	3.3
Total	4634	100.0	938	100.0

Table 1: Distribution (absolute numbers and percentages) of refereed HST and VLT papers published in the five core astronomy journals as well as *Nature* (as of January 2005). Note that these are the total numbers of papers published over the current lifetime of the observatories, i.e. 14 years for HST and six years for the VLT.

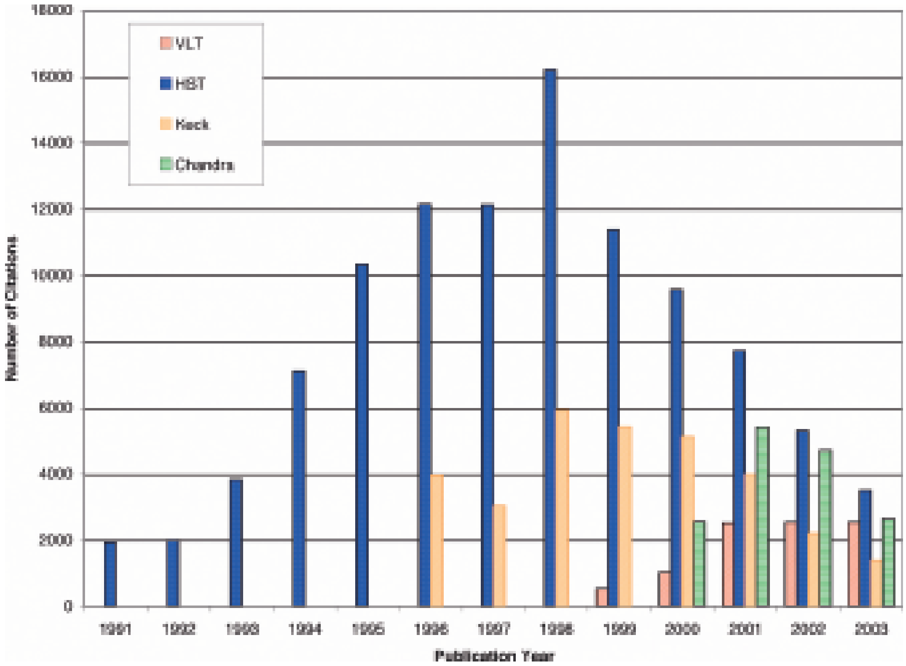
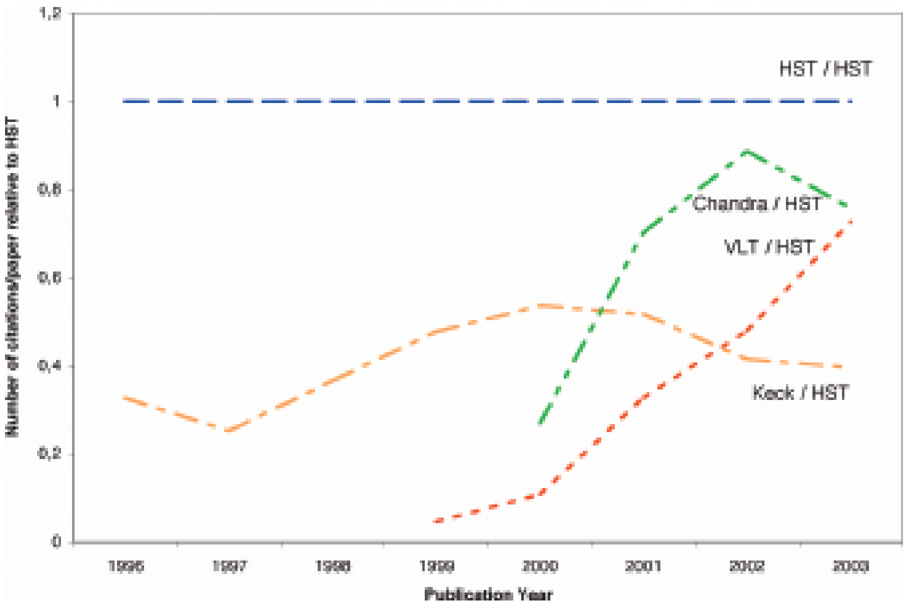


Figure 2 (above): Total number of citations to VLT, HST, Keck and Chandra publications by year (as of December 2004).

Figure 3 (below): Number of citations per paper relative to HST citations (as of December 2004).



A direct comparison is difficult at this stage. The HST is a mature observatory with a large user community and has operated over more than a decade. The VLT is still in its ramp-up phase. Neither the total numbers of papers nor the numbers of papers per year provide a good indication how the two observatories compare to each other. Figure 1 needs to be interpreted rather carefully in this respect. It will have to be seen what level the VLT will reach after several years.

About 90 % of the HST papers and 95 % of the VLT papers that were published until the end of 2004 appeared in the five major astronomical journals, i.e. *Astrophysical Journal* and its *Supplements (ApJ/ApJS)*, *Astronomical Journal (AJ)*, *Astronomy & Astrophysics (A&A)*, *Monthly Notices of the Royal Astronomical Society (MNRAS)* and *Publications of the Astronomical Society of the Pacific (PASP)*. Table 1 shows the absolute numbers and percentages of HST and VLT publications in these journals. For comparison, the corresponding numbers for publications in *Nature* are also included. The table reflects the partly different affiliations of the user communities of the two observatories. *ApJ* continues to be the preferred journal for most authors of HST-based papers. On the other hand, the ESO user community prefers to publish in *A&A* in which it is exempt from page charges.

Citations

In order to assess the scientific impact of refereed papers based on HST and VLT data, we obtained the number of citations for each paper in our databases from ADS. We are aware that the set of citations provided by ADS is not complete, mainly because some citing journals are not within the ADS database. However, with regard to the major *refereed* astronomical journals ADS is a very reliable source of citations. For many major astrophysics journals, the coverage is even complete back to volume 1.

Recently, Trimble, Zaich & Bosler (2005) argued that the contribution to papers based on several observatories should be apportioned and split according to the contributions from each observatory. This is a reasonable approach for investigations which aim to deduce general trends in astronomy publishing. For observatories such an approach is not really suitable as the weighting process (like the one in Trimble et al.) would require resources that are not available at the moment. The critical information for observatories is how often their data have made a contribution to the scientific literature. Hence we chose to count every paper as a full contribution in our databases and analysis, even if several telescopes provided data. This of course means that papers making use of VLT and HST data will show up in both databases (see section "Papers based on VLT and HST data at the same time"). For the high-impact papers (see below) we actually do weight the contribution by each observatory.

Figure 2 shows the total number of citations for HST and VLT papers by year. Both observatories are contributing significantly to astrophysics research and the publications based on their data form an integral part of the astrophysical literature. The HST still leads in the total citations (as it does in the number of papers published, cf. Figure 1). However, there have been significant changes over the past few years. The VLT has a steadily increasing citation rate compared to other observatories, while Chandra has made a substantial impact right from the start. The Keck citation rates remain constant at a high level. This is illustrated in Figure 3 which shows the evolution of the numbers of citations relative to HST. This figure removes the 'history' effect inherent in citation statistics and allows a direct comparison of the observatory statistics.

Average citation rates are a highly simplified means of assessing the success of publications. The distribution of citations per paper is highly non-uniform and hence averages and standard deviations are only crude, if at all appropriate, means for such an analysis. One should also keep in mind that there are severe differences in the way papers are cited per astronomical subfield and other secondary effects. A very good analysis of such additional parameters is given by Schwarz & Kennicutt (2004). To offset these statistical distortions we decided to use the median, which is in general a much more robust statistical indicator. Hence, Figure 4 shows the median number of citations per paper. The steady increase of the VLT citations is an indication of the non-static situation of these statistics. At the moment, the VLT and the HST are nearly identical considering the mean citations of papers. The differences might be a signature of the different age of the two observatories, although a more detailed analysis might be warranted here.

We further analyzed the 100 most frequently cited papers based on VLT and HST data, respectively. Interesting trends are shown in Figure 5. Almost half of the most cited papers based on VLT data (1999–2004) were published in *A&A* (43 % of the top 100 VLT papers, citations from ADS), reflecting the preference of publishing VLT data in *A&A* (cf. Table 1). Many of the most-cited publications appeared in *ApJ* (39 %). The share of highly cited papers published in *Nature* (9 %) is large compared to the overall percentage of VLT papers published in this journal (approx. 2.0 %, cf. Table 1). In fact, half of the VLT papers published in *Nature* made it into the top 100.

A clear majority of the top 100 HST papers (1991–2004) were published in *ApJ/ApJS* (67 %); this fraction is even larger than the already high percentage of all papers published in these journals as given in Table 1 (approx. 50 %). As with VLT, articles published in *Nature* are highly represented among the most cited papers: 1 % of all HST articles are published in this journal vs. 5 % among the top 100.

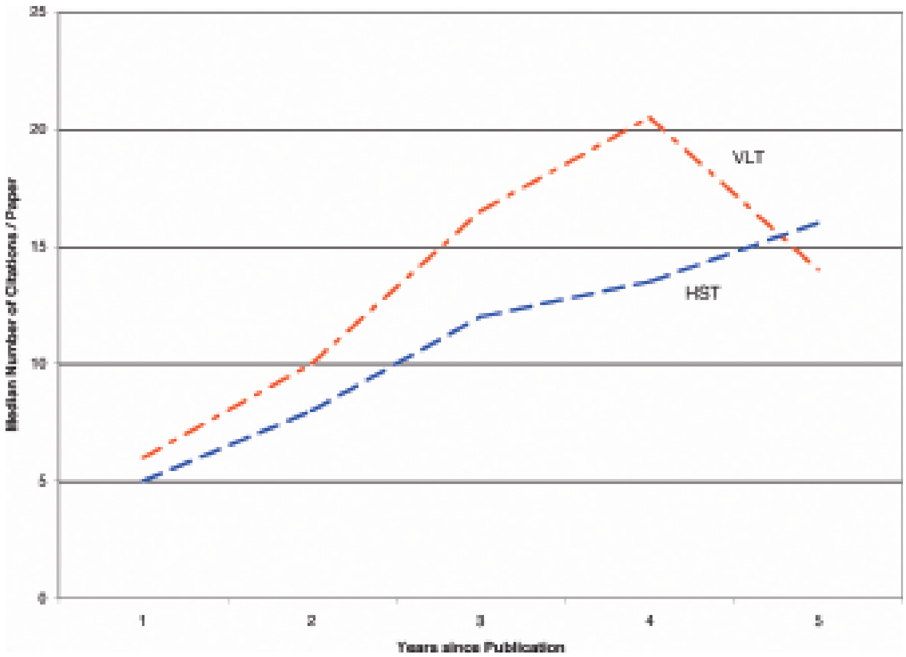
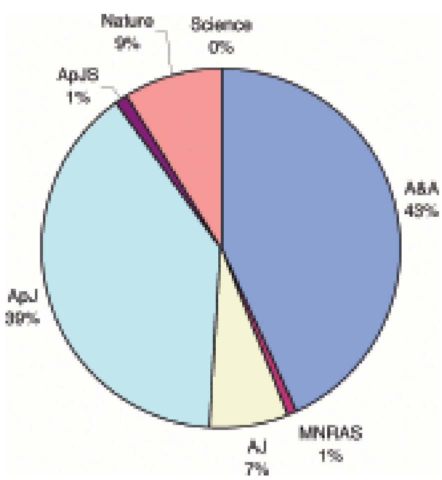


Figure 4 (above): Median number of citations for VLT and HST papers as a function of years since publication (publication years 2003–1999, as of January 2005).



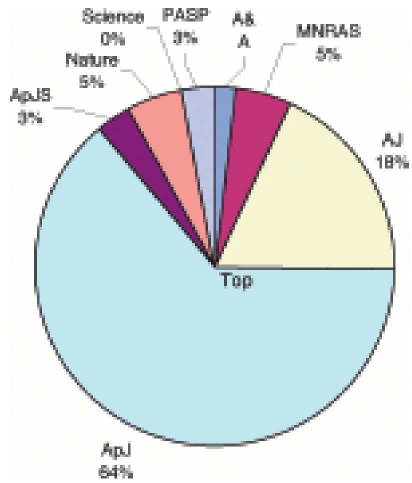


Figure 5 (below): Fraction of most cited VLT (left) and HST papers (right) published in various journals.

High-Impact Papers

The term High-Impact Papers (HIP) was coined by the Institute for Scientific Information (ISI) (see *http://www.isinet.com/rsg/hip/*). It defines the 200 most cited papers for a given year. The numbers presented here were obtained from the ADS by querying the database for 200 papers, sorted by descending citation count. The method we used is described in greater detail in Meylan, Madrid & Macchetto (2004). These 200 most cited publications could be refereed or unrefereed, observational or theoretical papers. For each of them we read the full text, selected those that present observations, and attributed the citations to the facility or facilities that contributed the data. In the case of usage of data from multiple observatories, citations are distributed according to a weight corresponding to the amount of data provided by each facility. As a result, each observatory received a normalized percentage of its contribution to high impact papers.

The citations for each year were obtained 16 months after the year ended, i.e., citations for the year 2001 were retrieved in April 2003, for the year 2002 in April 2004 etc. At this time, the citations had not yet reached their peak (typically after two years, see Meylan, Madrid & Macchetto 2004). To make sure that the relative impact per facility remains the same also over a longer time, we cross-checked the high impact papers published in 1999 and 2001 in December 2004 (five and three years respectively after publication) and found that only 3 % of the 100 most cited 1999 papers and 7 % of the 100 most cited 2001 papers had changed.

In Figure 6 we present the evolution of the contribution of selected facilities to these HIP. The number of available facilities, both ground- based and in space, is increasing and many of them contribute to high impact papers. For instance Chandra and the VLT contributed to HIPs for the first time in 2000. Accordingly, the share of already existing facilities becomes smaller.

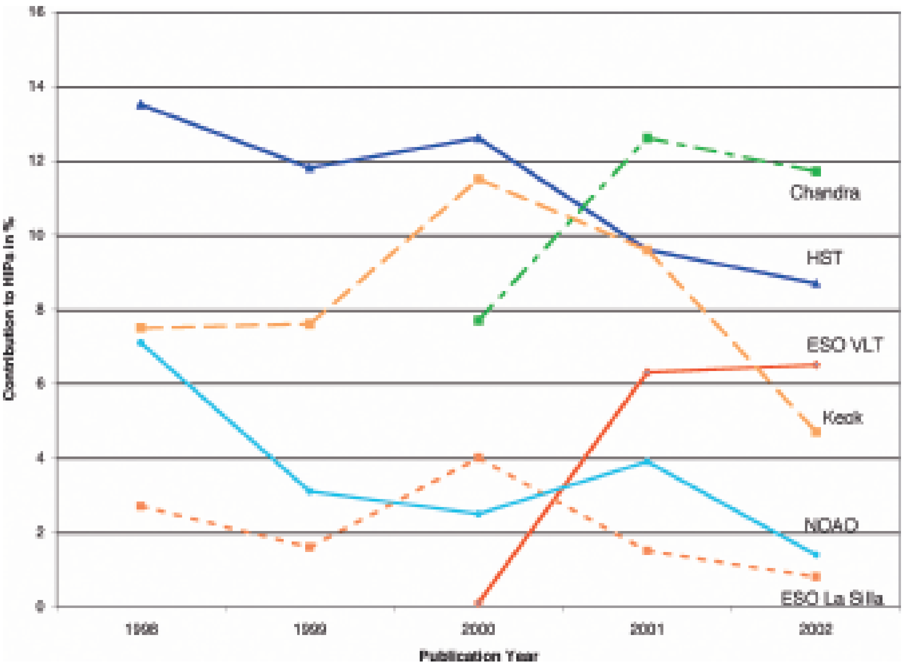


Figure 6: Contribution of selected space and ground-based facilities to the total citations of the 200 most cited papers per year. NOAO includes papers based on Kitt Peak Observatory and CTIO.

Papers based on VLT and HST data at the same time

HST and VLT data are increasingly combined in the same paper. The collation of multi-wavelength datasets and the comparison of complementary observations across the electromagnetic spectrum have significantly improved the physical picture that astronomers obtain from celestial objects. This leads to publications based on observations coming from several sources. The interdependence between ground- and space-based observations is steadily increasing. This trend was confirmed by Trimble, Zaich & Bosler (2005) and reflects a change in the way astrophysical research is being conducted. This can further be seen in the science cases for future facilities, which typically explore the expected synergies with other projects. Up through the end of 2004, 120 refereed papers used data from both observatories. Many authors combine the unique capabilities of the two facilities to obtain new astronomical knowledge. The most common cases we encountered were papers where high-resolution VLT spectra are combined with HST archival images; several papers presented follow-up VLT spectroscopy of objects previously observed with HST. This pattern had previously also been observed between HST and Keck. The deep fields are prime examples. In particular ISAAC and the FORS instruments are used in parallel with data obtained with WFPC2, ACS and NICMOS. These papers show clearly that ground-based telescopes and space missions do not compete, but support and complement each other and lead to higher scientific productivity through effective use of collaborations.

Conclusion

HST and VLT are amongst the most prolific observatories and are fully competitive with other large facilities like Chandra and Keck. They also have taken the leadership role from older observatories, although the rate of publication of data for example from La Silla telescopes still remains high.

After slightly more than five years of operations, the VLT shows a similar development observed in other successful observatories. Soon after First Light, publication statistics started to rise steeply and are rapidly approaching 1000 refereed publications by the end of 2004. These first five years are nearly identical to the development of HST during its early years.

An equally positive trend can be noticed for citations made to publications based on ESO data. The mean number of citations per refereed paper tends to be at the level of established observatories. The citation rate is still rapidly increasing and is approaching the HST citation rate.

A study of the contributions to high impact papers from some of the major telescopes available at present shows that the VLT contributes to a considerable fraction of them and thus occupied a place among the most important facilities only a few years after the start of its operations. Interesting differences can be seen regarding where papers from the VLT and HST are published. While for the European community, the prime user of the VLT, *Astronomy & Astrophysics* remains the journal of choice, the majority of HST data are published in the *Astrophysical Journal*. Most other journals are used with a comparable frequency.

HST continues to dominate the number count of published papers per year and shows no sign of contributing less than in past years to the overall impact that these papers have on astronomical research.

Acknowledgements

This article has made use of NASA's Astrophysics Data System. We are grateful to Angelika Treumann, who maintains the ESO telescope bibliography and gave essential comments on the manuscript. Our thanks also go to the STScI librarian Sarah Stevens-Rayburn, who has made invaluable contributions to the HST bibliography; Sarah also kindly removed the non-native English speakers' flavour from the manuscript. We thank Karen Levay from MAST for her help in handling the database of the HST bibliography. Arnold Rots from Harvard/Smithsonian Center for Astrophysics, as well as Peggi Kamisato from W. M. Keck Observatory kindly provided information on Chandra and Keck publication and citation statistics.

References

Abt, H. A. 1981, PASP, 93, 207
Abt, H. A. 1985, PASP, 97, 1050
Benn, C. R. & Sanchez, S. F. 2001, PASP, 113, 385
Delmotte, N. ,Treumann, A., Grothkopf U. et al. 2005, The Messenger, 119, 50
Crabtree, D. R. & Bryson, E. 2001, JRASC, 95, 259
Eichhorn, G., Accomazzi, A., Grant, C. S. et al. 2003, BAAS 35 #5, 20.04
Green, P. J. & Yukita, M. 2004, Chandra Newsletter, issue 11, March 2004
Grothkopf, U. & Treumann, A. 2003, LISA IV proc., Corbin, B., Bryson E., Wolf, M. (eds.), Washington, DC: U. S. Naval Observatory, 193
Leibundgut, B., Grothkopf, U. & Treumann A. 2003, The Messenger, 114, 46
Meylan, G., Madrid, J. P. & Macchetto, D. 2003, STScI Newsletter, 20, no. 2, 1
Meylan, G., Madrid, J. P. & Macchetto, D. 2004, PASP, 116, 790
Schwarz, G. J. & Kennicutt, R. C. 2004, BAAS, 36, 1654
Trimble, V. 1995), PASP, 107, 977
Trimble, V., Zaich, P. & Bosler, T. 2005, PASP, 117, 111