

Commentary

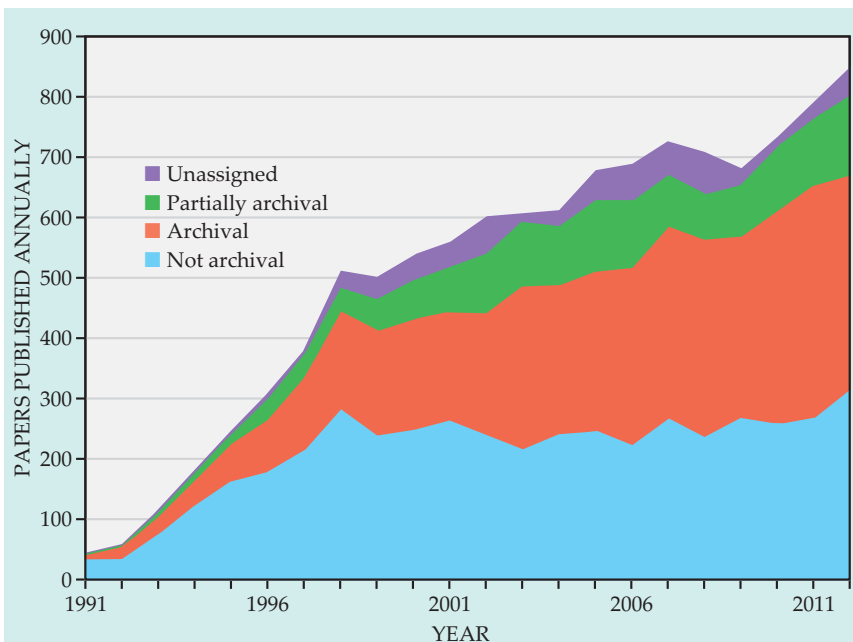
Flattening the astronomy world

Riccardo Giacconi, who received the 2002 Nobel Prize in Physics, believed we could hugely increase the scientific impact and productivity of a space telescope—and science facilities in general—if the broader scientific community were given direct access both to the facility and to calibrated data taken with it. His crucial insight, combined with the mission-planning concept he termed “science systems engineering,”¹ was first fully applied to the science operations of NASA’s *Hubble Space Telescope* by the Space Telescope Science Institute, which had Riccardo as its first director.

His belief is now validated: Twenty-three years after its launch, the *Hubble* remains the most productive telescope in history, with a community of more than 11 000 registered users worldwide. Of the published papers each year that draw on *Hubble* data, half exploit the data archive in new and sometimes unanticipated ways (see the figure at right).

To give the broad community access to a facility as complex as the *Hubble* and to its data archives requires thinking differently about a science experiment in two conceptually different ways.

First, the principal investigator-led (PI-led) model in which the science team that originally conceived of the mission or experiment is considered the sole beneficiary of the result has to be re-evaluated. The science team and the agency funding the facility both have to commit to the concept that they are designing a complete system for other, nonexpert scientists to use. This is



Refereed journal papers based on *Hubble Space Telescope* data. Nonarchival data (blue in this stacked-line chart) are acquired as part of a planned observation to answer a particular question. Archival data (red) are retrieved to answer a specific question possibly unrelated to the initial observations. Partially archival (green) papers combine current and archived data. Unassigned (purple) are those papers whose ratio of archival to nonarchival data is not known. Note that 50% of publications in 2012 that related to the *Hubble* were derived from purely archival data.

where the phrase, “science systems engineering” comes in. Factored into the design of a facility such as the *Hubble* must be a complete “end-to-end” analysis of all the steps an astronomer takes: from defining the science problem in detail to preparing the proposal; planning and executing the research program; and specifying how the data will be reduced, calibrated, and disseminated.

The advantage of the science systems engineering approach is that the nonexpert end user is now part of the system, so some previously hidden costs can be revealed during the overall design optimization. For example, if changes are proposed to the optical quality of the telescope to reduce manufacturing costs while still achieving the science objectives, more sophisticated data analysis and calibration will be required; the cost of that additional work can be factored in, at design inception, to the decision about whether

the cost savings are worth the reduction in optical quality.

The second key concept is to recognize and appreciate that an undertaking of such scope and focus as the *Hubble*, for instance, will require a different institutional arrangement than is traditionally found in PI-led missions or experiments. The observatory staff’s responsibility becomes to plan, build, and support an end-to-end science operation—from defining the problem to disseminating the results—that allows the community to make efficient use of current, complex telescope data and then make repeated use of the archival data.

The *Chandra* and *Spitzer* space telescopes and the science operations for the *James Webb Space Telescope* have followed the science systems engineering model, as have such major ground-based facilities as the European Southern Observatory’s Very Large Telescope and the international Gemini Observatory.

Letters and commentary are encouraged and should be sent by email to ptletters@aip.org (using your surname as the Subject line), or by standard mail to Letters, PHYSICS TODAY, American Center for Physics, One Physics Ellipse, College Park, MD 20740-3842. Please include your name, work affiliation, mailing address, email address, and daytime phone number on your letter and attachments. You can also contact us online at <http://contact.physicstoday.org>. We reserve the right to edit submissions.

Today many of us in astronomy look at the above two conceptual changes to the way we do science as normal, but actually they have produced a radical realignment in the way astronomy is done. For the large and, in the US, substantially federally funded telescopes, the science systems engineering approach is the most effective way to increase the science return on the very expensive facilities being built for scientists. The approach particularly recognizes that the original scientists and engineers who conceived of and built the facility do not have a lock on what science will get done, nor do they have unique insight on how best to undertake any given experiment. Through a peer review process, any astronomer can gain access to the facilities and use them in new and innovative ways.

More important, even, than facility access, the science systems engineering approach is a commitment to make calibrated and crucially trusted data accessible to anyone with an internet connection. In addition, adopting common standards across observatories, as the astronomy community has done, allows the combination and comparisons of astronomical data from different facilities, which in turn can lead to unanticipated discoveries. One example is the use of ground- and space-based telescopes that led to the discovery and confirmation of the accelerating universe, for which Saul Perlmutter, Brian Schmidt, and Adam Riess received the 2011 Nobel Prize in Physics.

Many people may well argue that the science systems engineering approach adds real costs to a project. When the sole scientific objective is to deliver a set of cosmological parameters, such as with the *Wilkinson Microwave Anisotropy Probe* (WMAP), that may be true, and the added expense may add little science value. Even the WMAP team, though, has released calibrated maps, and the original data, for others to reanalyze. However, if a planned facility is intended to have multifaceted exploration and discovery capabilities, certainly in astronomy it is now hard to imagine walking back from the model of broad access to trusted observational data archived under a common standard.

Thomas Friedman described in his book *The World Is Flat: A Brief History of the Twenty-First Century* (Farrar, Straus and Giroux, 2005) how commerce and entire industries are being radically changed because today anyone with an internet connection can, in principle,

participate and even compete with more established industries. He describes the world as being “flattened” by this enabled global access. In astronomy, we are creating a similar paradigm, where anyone with a good idea and an internet connection can get access to fully calibrated data taken with the *Hubble Space Telescope*.

The continued commitment to a “flattened” approach to large astronomy is not without its own issues, however. Over the decades, astronomy has become very much about data and less about machines, in the sense that astronomers have generally become more distanced from the hardware that is taking the data. As Giacconi noted in a 2013 commentary,² “Most of the results have been good, except for a separation between builders and users, which I believe is not healthy for the field.”

A second issue lies at the extreme of the science systems engineering model, with the enormous possibilities that will be opened up by the Large Synoptic Survey Telescope (LSST), which in the early 2020s will continually scan and image the sky. That facility will produce approximately a petabyte of archived, calibrated images every two months.³ As our new tradition demands, those data will be made available almost instantly to the entire community over the internet. According to Mario Juric, the LSST data management project scientist, that data stream will contain an estimated 2 million events per night, which could include, for example, a supernova, a gamma-ray burst, a flaring star, or a fast-moving near-Earth asteroid.

To enable the innovation and enormous scientific productivity that have characterized a community now accustomed to using large astronomy facilities, astronomers outside of the LSST science team will have to find a way to effectively filter the 2 million events into coherent individual projects. How to bring all astronomers into the new big-data era is the next challenge for the Giacconi model.

References

1. R. Giacconi, *Secrets of the Hoary Deep: A Personal History of Modern Astronomy*, Johns Hopkins U. Press, Baltimore, MD (2008).
2. R. Giacconi, *Mem. Soc. Astron. Ital.* **84**, 472 (2013).
3. “LSST: A New Telescope Concept,” http://www.lsst.org/lsst/public/tour_software.

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Letters

Notes on the glass-forming ability of bulk metallic glasses

The article “Bulk metallic glasses” by Jan Schroers in the February 2013 issue of *PHYSICS TODAY* (page 32) was very enjoyable. The author’s remarks on the recent progress of bulk metallic glasses are much appreciated. However, the author made no mention of original work from Baixin Liu’s group at Tsinghua University in China. I offer this short note as a supplement to Schroers’s article.

Schroers concludes that one can describe a material’s glass-forming ability (GFA) as being either inversely proportional to its critical cooling rate or proportional to its critical casting thickness. Liu and coauthors argued that, more broadly, the GFA of a metal alloy system is quantitatively related to its glass-forming range.^{1,2} The GFR not only shows whether metallic glasses could be obtained in a system, it also indicates the alloy composition range within which metallic glasses could be formed by some specific glass-producing techniques. The wider the GFR, the greater the GFA of a metal system.

Indeed, Jia Hao Li and coworkers from Liu’s group have shown through computations and simulations based on the interatomic potentials of some 10 representative binary metal systems that each system has two critical solid solubilities that define the GFR: For the composition range bounded by the two values, metallic glass formation is energetically favored. The predicted GFRs from the interatomic potentials are well supported by the experimental observations.² A similar approach applied to some ternary metal systems that form bulk metallic glasses showed not only that the favored composition region (GFR) could be located, but also that an optimal composition, defined as the one having the maximum driving force for crystal-to-amorphous transition, could be pinpointed.³ I think the predicted optimized composition could be correlated to the maximum size of the metallic glass obtained by copper-mold casting with a specific cooling rate. If so, the physical and technical definitions of GFA could then be bridged.

References

1. Q. Zhang, W. S. Lai, B. X. Liu, *Phys. Rev. B* **59**, 13521 (1999).
2. J. H. Li, Y. Dai, Y. Y. Cui, B. X. Liu, *Mater. Sci. Eng. R.* **72**, 1 (2011).