A Vision for the US Virtual Astronomical Observatory

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I. The Underlying Structure

Origins

During the first years of the new Millennium the idea of a Virtual Observatory rapidly gained momentum, fueled by a growing awareness of a technical and sociological revolution in astronomy. Faced with the emerging reality of planned or existing large scale projects and facilities that would produce terabytes and even petabytes of data, the idea of a Virtual Observatory that could access such datasets in an integrated and coherent manner had compelling virtues that were quickly recognized within the astronomy community. In mid 2000 a White Paper appeared that outlined the basic philosophy and structure of a US National Virtual Observatory (NVO), capitalizing on the exponential growth of computing capability and information technology concurrent with the data explosion in astronomy. By 2002 a report from the NVO science definition team was in place, providing a definitive response to the Decadal Survey recommendation supporting the establishment of a US VO. The NVO was on its way.

The NVO constructed the essential foundations for an operational VO. It provided an environment in which the elements of a VO infrastructure could be conceived, and it then supplied the organizational structure to support the prototyping and testing of these structural elements. This function of the NVO was clearly defined in the Science Definition Team report, where it was recognized that the operational aspects of the NVO could only be realized at end of a five-year period at the earliest. The foundational and infrastructure problems had to be solved before any operational VO could be put in place, and the NVO made this possible.

The final months of the NVO funding were devoted to solving the problems of moving into an operational VO, and the successor to the NVO, the US Virtual Astronomical Observatory (VAO), is completing this transition "from Framework to Facility." The emphasis in the initial years of the VAO will be strongly focused on delivering research capability to the astronomy community, but basic philosophical elements of the NVO will remain as a legacy within the VAO. These include institutional characteristics first

enunciated in the 2000 White Paper: the VAO will be evolutionary, distributed yet integrated, global, and provide a path to the future. Thus the VAO will clearly build upon the foundation provided by the NVO, and the two institutions form a continuity of effort to bring into being a vibrant and effective US Virtual Observatory.

Major Themes and Guiding Principles of the VAO

1. Enabling Research

The VAO is an astronomy research facility. All of its activities are oriented toward enabling astronomy research in a manner that is more efficient, more effective, and more productive than has been possible in the past. This enabling function has two major components. The first is that of providing depth. Astronomical research activity covers a vast range in level of effort, and within the solution path of a given problem the cadence and intensity of effort has a large variation as well. Essential elements of creative research range from very quick reconnaissance activity to assess the feasibility of an idea or project to intensive, in-depth pursuits of information that cover a vast range of types, quality, and amounts of data. The research may involve one or two persons or a large international team, or both, depending upon the stage in the evolution of the research effort. A successful VO must support all of these activities with integrity, coverage, and speed; intensive research activity is often characterized by a deep desire for accurate results as quickly as possible.

The second enabling function for research involves breadth. By its very nature the VAO is accessible to any persons in any place where electronic communication is available, and thus almost the entire body of current astronomy data, data handling and analysis tools, and published literature are also available. This means that for the first time in the history of astronomy, creative and productive research is essentially place independent. Any investigator with a good idea can pursue that idea without regard to affiliation or privileged access to facilities. While the essential research component of interaction and consultation with colleagues still remains, much (but not all) of this can also be carried out remotely as well. The VO concept, and the VAO in particular, will be a major force in making astronomy research a truly egalitarian activity.

2. Education and the VAO

The concerns about excellence in science education and the decline in interest by students in pursuing careers in the sciences is well known, and astronomy has always played a prominent role in the promotion of science education because of the nearly universal appeal of astronomy as an entry-level science. The capability of the VAO, with its rapid access to vast numbers of spectacular astronomy images, its easy retrieval of astronomy data at all levels, and its provision of a wide spectrum of tools for data handling and analysis make it an ideal vehicle for the advancement of science education at all levels,

from K-12 to graduate studies. The VAO provides a golden opportunity to address a critical national priority in the 21st century.

3. Outreach and Public Awareness of Science

In addition to the specific problem of science education, there is also widespread concern about the science literacy in society at large, and again the VAO provides a capability that can be applied to this enduring problem. Because astronomy is a science with widespread public interest and support, it is an ideal venue for the creation of science programs that will have public appeal and that will convey concepts of scientific methodology in addition to specific scientific information. The VAO will be an invaluable resource in any effort to address public science literacy through the use of astronomy; its rapid access to astronomy data, archives, images and literature through a single point of contact will facilitate the creation and maintenance of programs designed to increase public awareness of science.

4. International Collaboration and Leadership

The development of the VO concept has been an international effort from its earliest days, and this is reflected in the early formation and subsequent growth of the International Virtual Observatory Alliance (IVOA). Since 2002 the IVOA has acted as the international forum for establishing standards, maintaining communication, and fostering collaboration among the various VO projects around the world. The US VO was a co-founder of the IVOA, and it has provided support and leadership to this organization since that time. The VAO will continue this very strong participation in the IVOA and will continue to support the development of international cooperation and collaboration among VO efforts.

5. Liaison with Other Initiatives

The concepts of integrated tools and services to facilitate all levels of research from initial reconnaissance to intensive and extensive large scale investigations originated in the astronomy community, but these ideas are now being examined by other disciplines as a promising new way to conduct research. From solar and planetary physics to earth sciences to biophysics, to library science and museum collections, the ideas of centralized access and integrated research capability are being explored. The VOA will continue to act as a leader and as a liaison and coordinating agency with these other efforts, both national and international, as they grow and mature.

II. Making it Happen – The Near Term Objectives in Years 1 and 2

Scientific Areas of Emphasis

The translation of the above major themes into specific objectives is accomplished via internal VAO leadership discussions together with intensive consultations with external advisory groups. Because science research capability is the most important theme of the VAO, the determination of the areas of scientific emphasis is particularly critical. Thus the definition of these areas was carried out in collaboration with the VAO Science Council, through formal meetings and informal follow-up discussions. This activity resulted in the following list of scientific areas of emphasis in the near term. Details of implementation can be found in the current VAO Program Execution Plan.

1. The Portal

The VAO Portal is an essential component of the VAO science capability. It is the electronic entry point to the VAO for the first-time user and thus must be transparent, easy to use, and able to provide meaningful results quickly. It is also the point of entry for returning users, and as such it must also be able to supply rapid access to extensive data archives, handle sophisticated queries quickly and accurately, and provide reliable links to other VO and astronomy facilities. The Portal must also be able to direct queries in the areas of education and public outreach with a minimum of intermediate steps and a maximum delivery of useful information. Thus the Portal is the primary interface between the VAO and the communities of astronomy research, education, and public information, and its effective design and operation is essential to the success of the VAO.

2. Time Domain Astronomy

Time domain astronomy, which includes the study of variable phenomena on all time scales, from microseconds to millennia, as well as single astronomical events, is becoming one of the most rapidly growing subfields in astronomy. It constitutes a major motivation for several new facilities and initiatives, including the Large Scale Synoptic Telescope (LSST). Personnel associated with the VAO bring existing worldwide leadership in this emerging field into the scope of VO activities, and it is clear that the VAO is in a position to maintain leadership in the timely development of tools and protocols in this field. Development of this capability will be a major area of effort during the first few years of the VAO project.

3. Spectral Energy Distributions

Spectral energy distributions (SEDs) are one of the most essential tools in determining which astrophysical processes are dominant in a given object or class of objects. A single glance at a featureless power-law distribution from radio to x-ray frequencies will provide instant insight into the energy production and loss mechanisms, as will a similar quick look at an SED that is rich in emission and absorption lines. The VAO will construct the capability to create SEDs for both galactic and extragalactic objects, expanding upon the NASA Extragalactic Database SED capability. An essential

component of this effort will be close communication and collaboration with other SED development efforts that are taking place in VO projects in other countries and with the SED standards development underway in the IVOA.

4. Large Scale Cross Match Capability

Cross matching is basically a comparison of the properties of astronomical objects at different wavelengths, sensitivities, and resolutions. When performed on an individual object it can provide suggestive results; when performed on many tens of thousands of objects, the cross matching among many different source catalogs can prove to be a powerful if somewhat serendipitous discovery tool. Large scale cross match capability is in great demand by the astronomy community, and it is the intent of the VAO to provide this capability through an extension of the expertise developed within the NVO and at other organizations. The goal is to provide all-sky cross matching capability, which is only now feasible due to advances in computing technology.

5. Development of Other Science Capabilities

In addition to the above areas of emphasis, there will be pilot programs and feasibility studies in other areas, some of which have arisen from discussions with the VAO Science Council, while others have become apparent through interactions with members of the astronomy community. Among these are a comprehensive integration of desktop tools, efficient links between bibliographic information and astronomical source attributes, improved interconnection of visualization capabilities, and advanced "data mining" and statistical analysis tools. These last two topics are closely coupled, and they are an area of growing interest in the astronomy community; from them a new paradigm for the conduct of statistical and serendipitous research may emerge.

Engagement with the Astronomy Community

If the VAO is to succeed, it must accomplish in fairly short order a task that was left undone by the NVO, and that is to accomplish the engagement of the US astronomy community in VO activities. To that end, one of the highest priorities, if not the highest priority, in the early years of the VAO is to achieve this integration with the research astronomers in the US. The above scientific areas of emphasis are clearly an essential part of this effort, but in addition to this there are activities that are specifically geared toward community engagement.

1. Scientific Partnerships

One of the most efficient ways to promote awareness of, and engagement with, the VAO and to simultaneously obtain detailed and continuing feedback from astronomy research groups is through the establishment of scientific partnerships. The intent is that these associations be constructed for the mutual benefit of the research group and the VAO,

and their origins cannot be forced but must come about through a cultivation of mutual interests. Their duration will be varied, as will their specific scientific subtopics, but the objective is to have a continuous effort in this area, with one or more partnerships in existence at all times.

At present there are two such partnerships being developed. The first of these is a deep multi-wavelength study of the evolution of galaxies and black holes from their earliest epochs at a redshift of about 8 to the peak of star formation and galaxy starbursts around a redshift of 1.5. This topic is currently of great interest to the extragalactic astronomy community, and the partnership here is between the VAO and a Hubble Space Telescope Multi Cycle Treasury Program, CANDELS, which is led by S. Faber (UC Santa Cruz) and H. Ferguson (STScI). The complete program will entail use of large scale cross-matching, the construction of SEDs, multi-wavelength imaging, and other VO related tools. It is expected that this high-profile project will provide very valuable feedback to the VAO in defining future areas for scientific emphasis.

The second project concerns stellar evolution and the dynamical and chemical evolution of dwarf galaxies. It is a deep study of the Small Magellanic Cloud that will explore its three dimensional structure and how that structure evolves as a result of interactions with the Large Magellanic Cloud and other dynamical entities of the Local Group. The effects of these interactions upon star formation and stellar evolution will also be explored. Again it is anticipated that this partnership will provide new opportunities for further VAO developments that will be of interest to the stellar dynamics, stellar evolution, and galaxy evolution communities.

2. Ongoing Efforts

In addition to specific scientific partnerships, the VAO will support ongoing and more generic activities that focus on engagement of the astronomy community. One of the most important of these will be the formation of a VAO Users Group, which is an important path to learn of the interests of the community and to obtain community suggestions for improvements in the services provided by the VAO. Other activities will include a continuing effort to improve the effectiveness of the VAO Portal which will rely on feedback from the user community as well as including new technological developments as they mature. In addition, the VAO will continue the tradition of VO summer schools established by the NVO, and it will maintain a "VO presence" at professional meetings in the US and abroad. Finally the VAO will maintain and expand existing liaison activities in the area of professional outreach that are being conducted by other VO projects worldwide.

Education and Public Outreach

The enormous potential of the VAO as a resource for both education and for public outreach has been described above. To enable rapid utilization of this assent, the education program of the VAO will integrate existing structures from programs at Space Telescope Science Institute, the Johns Hopkins University, and NASA HEASARC. This will facilitate the rapid launch of a VAO education program and permit it to be populated with experienced and knowledgeable EPO personnel whose expertise spans the full wavelength range of ground and space-based datasets. For public outreach, a dedicated website for this purpose will be created, and its relevance, effectiveness, and timeliness will be enhanced by additional collaborations with entities such as Google Sky, the WorldWide Telescope, ComPADRE and Zooniverse. As the VAO effort in EPO gains experience, it is expected that a unique VAO "flavor" will develop in this area that will allow full exploitation of the capabilities of the VAO to contribute to public outreach and education.

III. The VAO in 2015 and Beyond

After five years of operation, it is expected that the major themes outlined above will have been largely realized. By 2015 the VAO should be a permanent feature in the landscape of astronomy research in the US, and it should also be seen as a permanent leader in the international VO community. The astronomy community will not only be familiar with the VAO but will use it as an essential tool in their daily research. The VAO will be taken for granted, as will be the expectation that the VAO will continue to evolve, to respond quickly to the needs and demands of the astronomy community, and to be a source of innovative and effective technical solutions to research problems. This view of the VAO in 2015 and beyond is not a casual projection or an optimistic wish. For the VAO to succeed, this view must be taken as a firm commitment and a mandate that directs work in the project on a daily basis.