JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
38: 85 ∼ 88, 2005

USING VIRTUAL OBSERVATORY TOOLS FOR ASTRONOMICAL RESEARCH

SANG CHUL KIM[1,2], JOHN D. TAYLOR[2], BENJAMIN PANTER[3], SANGMO TONY SOHN[1],
ALAN F. HEAVENS[2], & ROBERT G. MANN[2]
[1]Korean Virtual Observatory, Korea Astronomy and Space Science Institute, Taejon 305-348, Republic of Korea
E-mail: sckim@kasi.re.kr, tonysohn@kasi.re.kr
[2]Institute for Astronomy, University of Edinburgh, Blackford Hill,
Edinburgh EH9 3HJ, United Kingdom
E-mail: jdt@roe.ac.uk, afh@roe.ac.uk, rgm@roe.ac.uk
[3]Max Planck Institute für Astrophysik, Garching, Germany
E-mail: bdp@mpa-garching.mpg.de

(Received January 31, 2005; Accepted January 31, 2005)

ABSTRACT

Construction of the Virtual Observatory (VO) is a great concern to the astronomical community in the 21st century. We present an outline of the concept and necessity of the VO and the current status of various VO projects including the 15 national ones and the International Virtual Observatory Alliance (IVOA). We summarize the possible science cases that could be solved by using the VO data/tools, real science cases which are the results of using current VO tools, and our own work of using AstroGrid, the United Kingdom national VO, for a research on star formation history of galaxies.

Key words : astronomical data bases — methods: data analysis — methods: statistical — galaxies: fundamental parameters — galaxies: statistics — galaxies: stellar content

I. INTRODUCTION

Astronomers have been experiencing an avalanche of data since 1990s as the numbers of larger telescopes, larger detectors, survey projects, and space telescopes increase. The needs for new data storage facilities with larger capacity and for new analysis tools with faster speed have also been raised by researchers. Naturally, the astronomical community commenced to build a virtual observatory (VO) composed of a virtual sky (collection of ground- and satellite-based, multi-wavelength observation data and catalogs) and a virtual telescope system (softwares and tools for data storage, data mining, effective search, downloading, analysis and computing). It is hoped that, when the construction of the VO is finished, new type of astronomical research will become possible by observing the digital universe having multi-wavelength, multi-epoch, and all-sky data.

In this proceeding paper, we introduce the basic concepts of the VO, current VO projects, possible sciences and real science cases using VO, and our own work using the VO in doing astronomical research.

II. WHAT IS A VIRTUAL OBSERVATORY?

Although the amount of data *Hubble Space Telescope* produces a day is only about 5 GB (Gigabyte), it is expected that the 6 to 8 m Large Synoptic Survey Telescope (LSST, www.noao.edu/lsst/) will produce more than 10 TB (Terabyte) of data a day. The TB-sized databases of current data centers will almost certainly be increased to PB(Petabyte)-size in the not so distant future. As the data capacity of each data center and the number of data centers increase, astronomers get more difficulties in accessing and getting specific data for researches. If all the data centers are linked to a certain master data center, then the user can log in only once and achieve what (s)he wants. Currently astronomical community is trying to build such an 'International Virtual Observatory' (IVO).

It is expected that various archives and data centers can be accessed through the IVO just as people can have access to any datum in the world as if it is in his/her own computer only by linking his/her computer to an internet port. Ideally, IVO will possess multi-wavelength, multi-epoch, all-sky observational data, simulated data, catalogs, and information in journals and books. Using new tools for query, visualization, comparison, analysis and computation, astronomers will be able to do new types of researches and educations as well as amateur and public people can also access modern astronomical data for their own purposes.

VO will affect astronomical researches in the following aspects: (1) astronomers can do real multi-wavelength studies to produce huge catalogs of objects, and do follow-up observations for them; (2) unbiased, homogeneous and best-quality data can help studies on various objects, e.g. studies on stellar populations of our Galaxy and extra-galaxies; and (3) new types of objects and/or new objects of known types can be discovered from multi-wavelength, multi-epoch, and wide-

---

Proceedings of *the 6th East Asian Meeting of Astronomy*, held at Seoul National University, Korea, from October 18-22, 2004.

TABLE 1.
CURRENT NATIONAL VIRTUAL OBSERVATORY PROJECTS

Name	Country	Internet Address
AstroGrid	United Kingdom	www.astrogrid.org
Aus-VO	Australia	www.aus-vo.org
Canadian VO (CVO)	Canada	services.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/cvo/
China-VO	China	www.china-vo.org
Datagrid for Italian Research in Astrophysics and Coordination with the Virtual Observatory (DRACO)	Italy	wwwas.oat.ts.astro.it/draco/
Euro-VO[a]	Europe	www.euro-vo.org
German Astrophysical VO (GAVO)	Germany	www.g-vo.org
Hungarian VO (HVO)	Hungary	hvo.elte.hu/en/
Japanese VO (JVO)	Japan	jvo.nao.ac.jp
Korean VO (KVO)	Korea	kvo.kasi.re.kr
National VO (NVO)	U.S.A.	www.us-vo.org
Russian VO (RVO)	Russia	www.inasan.rssi.ru/eng/rvo/
Spanish VO (SVO)	Spain	laeff.esa.es/svo/
VO France	France	www.france-vo.org
VO-India	India	vo.iucaa.ernet.in/~voi/

[a] Astrophysical VO (AVO) during 2002 to 2004

color ranges of data.

III. CURRENT STATUS OF VIRTUAL OBSERVATORY PROJECTS

(a) Virtual Observatory Projects

The VO projects are mainly being deployed by each nation. There are 15 national VO projects currently, which are listed in Table 1. U.S.A., United Kingdom and Europe started their projects earlier (~2001) and have more funds than others. The Korean VO (KVO) was established in 2003 by Korea Astronomy and Space Science Institute and a few universities in Korea (Kim et al. 2003a, 2003b).

Besides these national projects, there are some other projects by small units, such as, institutes, observatories, etc. Some examples are (i) Sky View VO (skyview.gsfc.nasa.gov), (ii) Digital Sky VO (www.jpl.nasa.gov/iae/highlights/yr-end99/DigitalSky/digitalsky.htm), (iii) Mt. Wilson VO (www.astrophys-assist.com/wilobs), and (iv) Spectroscopic VO (SVO, www.spectraheritage.org).

(b) International Virtual Observatory Alliance

During the initial three to five years of National VO (NVO, U.S.A.), AstroGrid (UK), and Astrophysical VO (AVO, Europe) projects, the amount of funds being used by these three projects were over $20M (US). Furthermore, since the contents of the project activities were not so different, it seemed to be more efficient for the projects to work together in order to utilize the funds and personnel more effectively. In a meeting of "Toward an International Virtual Observatory: Scientific Motivation, Roadmap for Development and Current Status" (www.eso.org/gen-fac/meetings/vo2002/) held in 2002 June 10-14 at Garching, Germany, these three projects agreed to construct the 'International VO Alliance' (IVOA, www.ivoa.net). Soon after the birth of IVOA, the number of member countries increased rapidly, and now it is more than fifteen (Table 1). Recent technical developments and the roadmap of the IVOA are summarized in Quinn et al. (2004).

There are nine working groups (WG) and five interest groups (IG) in IVOA. The WGs are

- Resource Registry
- Data Modeling
- Unified Content Descriptor (UCD)
- Data Access Layer (DAL)
- VOTable
- VO Query Language (VOQL)
- Grid & Web Services
- Standards & Processes
- VOEvent,

and the IGs are

- VO Architecture
- VO Applications
- VO Theory
- GGF Astro-RG (Global Grid Forum Astronomical Grid Community - Research Group)
- Data Curation & Preservation.

IV. SCIENCE USING VIRTUAL OBSERVATORY

The final object of the construction of the VO is doing real science, and since the commencement of the VO projects, many tried to find possible applications of VO data/tools for real cases. In this section, we outline the efforts, outputs, and our own application

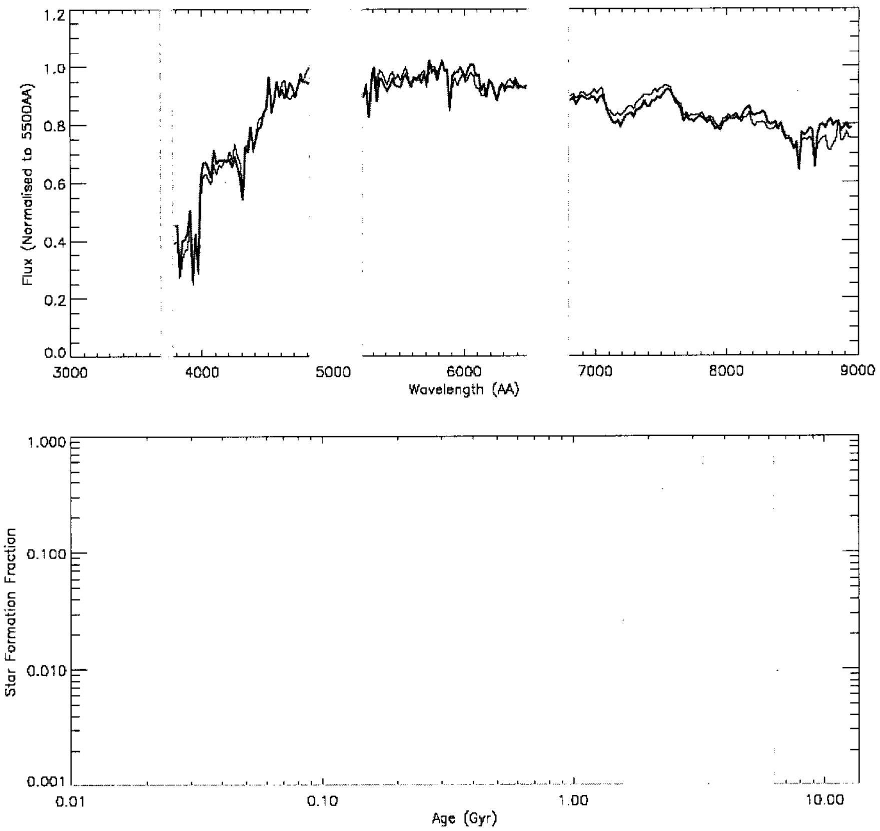

Fig. 1.— *Upper panel* shows the reconstructed spectrum of a SDSS galaxy – the thin line is the galaxy spectrum, the thick line the synthetic fit curve generated by MOPED code. The grey areas correspond to regions omitted from the study due to emission line contamination. *Lower panel* gives a barchart representing the distribution of SF among different aged bins – the SF history of the spectrum. The ages quoted are the lookback times from the present day (Panter 2004).

case in this aspect.

(a) Possible Science

Among the various VO projects, we summarize the efforts of AstroGrid for applying VO data/tools to real science cases. AstroGrid lists ten science problems abstracted from more general science problem list held in the VO area, which AstroGrid aims to provide capabilities to meet (http://wiki.astrogrid.org/bin/view/Astrogrid/ScienceProblems). These are

(1) Brown dwarf selection
(2) Deep field surveys
(3) Studying clusters of galaxies
(4) Discovering high-redshift quasars at z=6-10
(5) Low surface brightness galaxy discovery
(6) Geomagnetic storms and their impact on the magnetosphere
(7) Deciphering solar coronal waves
(8) Solar-stellar flare connection
(9) Solar/Terrestrial Phenomena - Solar event coincidence
(10) Galaxy environment of supernovae at large distance.

(b) Real Science Cases

ASTROVIRTEL (www.stecf.org/astrovirtel) has been used for the first time in the discovery of a Kuiper Belt Object, 2001 KX76 (www.eso.org/outreach/press-rel/pr-2001/phot-27-01.html), now known as 28978 Ixion (www.noao.edu/outreach/press/pr01/pr0110.html). In calculating the accurate orbit of this newly found (in 2001 July 2) object, a research group (G. Hahn, K. Muinonen, C.-I. Lagerkvist, L. L. Christensen, & R. West) have used the old plates and old CCD images in ASTROVIRTEL to find data spanning about 18 years starting from 1982. Finally, they have shown that this object is of diameter $\sim$ 1200 km, larger than the largest known asteroid, Ceres.

Schuecker, Böhringer, & Voges (2004) have used German Astrophysical VO (GAVO) in matching ROSAT All-Sky Survey and Sloan Digital Sky Survey (SDSS, Early Data Release) galaxies to detect X-ray clusters of galaxies. Padovani et al. (2004) used AVO (the former Euro-VO) tools to discover 68 type 2 active galactic nuclei (AGN) candidates in the two Great Observatories Origins Deep Survey (GOODS) fields of Hubble Deep Field-North (HDF-N) and Chandra Deep Field-

South (CDF-S). These newly found AGNs are ~3 mag fainter than previously known type 2 AGNs. These two research papers are the first output cases in real science using the VO tools.

Padovani (2004) has shown that the VO can also be used for the research of A-type stars in determining the membership of these stars to an open cluster and assessing if chemically peculiar A-type stars are more likely to be X-ray emitters than normal A-type stars.

(c) Our Work

The Data Release Two of SDSS (released in 2004 March) contains 367,360 spectra (including 260,490 galaxies and 32,241 quasars), and the Data Release Three of SDSS (released in 2004 October) contains 528,640 spectra (including 374,767 galaxies and 45,260 quasars). The spectra of the galaxies in these data can be used to determine the star formation (SF) history of the Universe and the mass function of the stellar component of galaxies, provided that we can efficiently extract appropriate information from the spectra.

Among the many spectral fitting algorithms, the optimal parameter-extraction method, MOPED (Multiple Optimized Parameter Estimation and Data compression), developed by Heavens, Jimenez, & Lahav (2000) can be used for the above purpose (Reichardt, Jimenez, & Heavens 2001). Figure 1 shows an example of a reconstructed spectrum of a SDSS galaxy (Panter 2004). The spectrum, of an aged galaxy which has not had a recent star burst, illustrates just how good MOPED can be at recovering the SF history of a galaxy. The reconstructed spectrum fits the majority of the line strengths in the observed spectrum (Panter 2004). Panter, Heavens, & Jimenez (2003) have used the MOPED code in studying over 37,000 galaxy spectra of SDSS Early Data Release (EDR) to study the SF and metallicity history of the galaxies. Heavens et al. (2004) and Panter, Heavens, & Jimenez (2004) have used the code in analyzing the spectra of 96,545 galaxies of SDSS Data Release One (DR1) to study the SF history of the Universe and the mass function of the stellar component of galaxies, respectively.

Recently, we have started to upgrade and deploy the MOPED code into the AstroGrid system, for the purpose of analyzing the latest release of SDSS galaxy spectra for the determination of the SF and metallicity history, and the mass function of galaxies. We hope this study reveals much larger quantity of information regarding the nature of galaxies at various redshifts, and also be used for the test of the efficiency of AstroGrid system for real astronomical researches.

ACKNOWLEDGEMENTS

SCK is grateful to the members of AstroGrid and Royal Observatory Edinburgh for their kind hospitalities during his stay in ROE.

REFERENCES

Heavens, A. F., Jimenez, R., & Lahav, O., 2000, MNRAS, 317, 965

Heavens, A., Panter, B., Jimenez, R., & Dunlop, J., 2004, Nature, 428, 625

Kim, S. C., Sung, H.-i., Kim, B. G., Chun, M.-Y., Park, J.-H., Cho, S.-H., Byun, Y.-I., & Koo, B.-C., 2003a, in Highlights of Astronomy, Vol. 13, 25th meeting of the IAU, Joint Discussion 8, in press

Kim, S. C., Sung, H.-i., Kim, Y.-S., Yim, I. S., Kim, J., Nam, H.-W., Kim, B. G., & Ahn, Y. S., 2003b, Technical Report of the Korea Astronomy and Space Science Institute, No. 03-005-055

Padovani, P., 2004, in The A-Star Puzzle, Proceedings of the IAU Symposium 224, eds. J. Zverko, W. W. Weiss, J. Žižňovský, and S. J. Adelman, (astro-ph/0408575)

Padovani, P., Allen, M. G., Rosati, P., & Walton, N. A., 2004, A&A, 424, 545

Panter, B., 2004, Ph. D. thesis, University of Edinburgh

Panter, B., Heavens, A. F., & Jimenez, R. 2003, MNRAS, 343, 1145

Panter, B., Heavens, A. F., & Jimenez, R., 2004, MNRAS, 355, 764

Quinn, P. J., Barnes, D. G., Csabai, I., Cui, C., Genova, F., Hanisch, B., Kembhavi, A., Kim, S. C., Lawrence, A., Malkov, O., Ohishi, M., Pasian, F., Schade, D., & Voges, W., 2004, SPIE, 5493, 137

Reichardt, C., Jimenez, R., & Heavens, A. F., 2001, MNRAS, 327, 849

Schuecker, P., Böhringer, H., & Voges, W., 2004, A&A, 420, 61