ADASS XIII
ASP Conference Series, Vol. XXX, 2004
F. Ochsenbein, M. Allen and D. Egret eds.

Searching for a cosmic string through the graviational lens effect: Japanese Virtual Observatory science use case

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Abstract. This paper describes a method to search for a cosmic string using its unique gravitational effect and its implementation to the Japanese Virtual Observatory (JVO). Grand unified theory predicts that super-heavy cosmic strings with linear mass density of 10^{22} g/cm were produced at a phase transition in the early universe. The lensing effect by a long straight object can be characterized by undistorted double images which are almost co-aligned in a direction of the string network and distributed in a very large scale. Because of its large scale nature, wide field deep survey is crucial for its discovery, and also the automatic detection system is required to survey the large amount of deep sky data. We have constructed databases of Subaru Suprime-Cam catalog/image for selected areas and applied our search method on the JVO prototype.

1. Introduction

The standard theory of particle physics predicts a symmetry breaking in the early universe and, as a result, the production of topological defects (Vilenkin and Shellard 2000). If the defects were generated at the GUT energy, the cosmic string can be observed as an origin of gravitation lensing (Vilenkin 1984) and its detection can be an observational confirmation of the standard theory. The recent observations of cosmic microwave background radiation rule out pure topological defects model as the origin of large scale structure of the universe, however, they still do not rule out the existence of the defects (Pogosian et al. 2003). So it is of great importance to constrain the existence experimentally.

Several gravitational lens candidates by a cosmic string have been reported (e.g. Sahzin et al. 2003), however, none of them have not been confirmed yet. Huterer and Vachaspati (2003) pointed out that a deeper observation of the vicinity of the candidate event reveals several additional lensing events. They predicts that, for a string located nearby ($z < 0.5$), future wide-field surveys such as SNAP and LSST find 5 objects lensed by a string in 1 arcmin^2 region, compared to 0.1 lensed by conventional sources.

The Subaru Suprime-Cam has also a great advantage in observing the wide field of view (30×30 arcmin^2) with high sensitivity (R<26 400s exposure), so it is

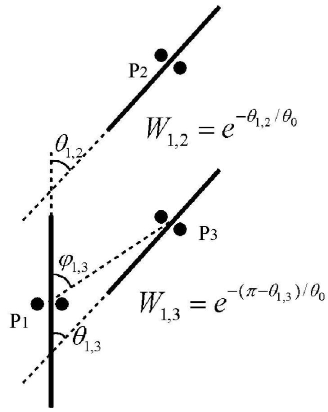

Figure 1. Definition of the weight parameter $W_{i,j}$. A pair of the solid circles represents an object lensed by a cosmic string. The expected directions of a cosmic string for each pair are shown with solid lines. $\theta_{i,j}$ is an angle between the two expected string directions for object i and j. $\varphi_{i,j}$ is an angle between the string direction for i and the line from i to j. If $\varphi_{i,j} < \theta_{i,j}$, $W_{i,j} = e^{-\theta_{i,j}/\theta_0}$. Otherwise, $W_{i,j} = e^{-(\pi-\theta_{i,j})/\theta_0}$.

suitable for this research. At present, three and half years of Suprime-Cam data are publicly available, so it is interesting to search for a cosmic string in the archived data. In addition, the Japanese Virtual Observatory (JVO) project has been started and will provide automatic access to the Subaru Suprime-Cam database and also provide unified environment for the DB access and data analysis (Mizumoto et al. 2003, Ohishi et al. 2004). We are now developing tools to search for a cosmic string on the JVO system. The current status of such activity is presented here.

2. Search Strategy

Features of a string lens event are characterized as non-distorted equal-brightness double images which are aligned in the direction of the string network. So the search strategy is simply summarized as follows: 0) Prepare an object catalog for given images using a source detection software such as the SExtractor. 1) Select closely located pair objects of similar brightness, color, and morphology. Use the following parameters for selection of the pair objects: separation angle, maximum difference of brightness for each band, maximum difference of color, and reduced chi-square for a difference of the pair images. 2) Calculate a degree of positional and directional coherence C_{obs} for a set of pair objects. The coherence is defined as $C = \sum_i \sum_{j \neq i} W_{i,j}$ where $W_{i,j}$ is calculated as shown in Fig. 1. 3) Calculate chance probability for C_{obs}. This can be estimated by simulating 1000 sets of pair objects whose separation directions are randomized to the observational ones and by obtaining the distribution of the degrees of coherence for them.

3. Simulation and Application to the Observational Data

We examined ability of the proposed method by simulating lens effect by a cosmic string. The assumed string model is described as follows: 1) Three kinds of configuration as shown in Fig. 2 (Left). 2) Mass density is assumed to be 10^{22} g/cm which corresponds to the maximum separation angle of $5''$. 3) The string direction is perpendicular to the line of sight. A model of background galaxies

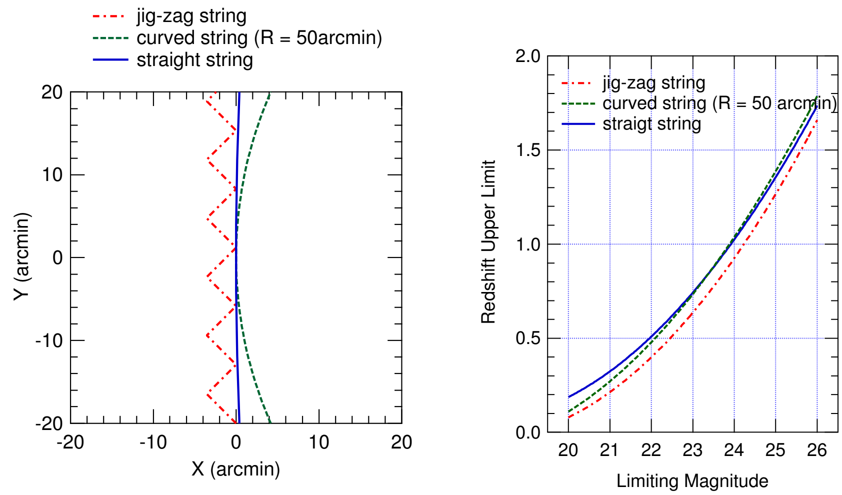

Figure 2. Left: String configuration tested for the string detection method presented here. Right: Maximum redshift of the cosmic string detected by this method as a function of limiting magnitude (R band) of observations.

is provided by the Numerical Galaxy Catalog (νGC) based on a N-body/semi-analytic model with a Λ-CDM cosmology, $\Omega_\lambda = 0.7$, $\Omega_m = 0.3$, $\sigma_8 = 1$.

In Fig. 2 (Right), maximum redshift, where cosmic string can be proved by the proposed method in 99% confidence limit, are calculated according to the sensitivity of the observation. We applied this method to the data of Subaru-XMM Deep Survey (SXDS), Subaru Deep Field (SDF), AGASA 10^{20} eV Field, and 2 deg^2 Field. No candidates of the string lens events were detected.

4. Cosmic String Search on the JVO

Since the detection rate of the GL candidates by a cosmic string is expected to be very small, a survey of large amount of data is crucial and development of the automatic detection system is required. The Japanese Virtual Observatory (JVO) is now being constructed at National Astronomical Observatory of Japan and it will provide an interface to the Subaru Suprime-Cam database, which enable us to do an automatic search on the whole Suprime-Cam image data.

We developed several tools to implement a GL search on the JVO prototype. The following tools were developed: (1) JVO Query Language Editor specialized for GL search. (2) GL candidate viewer. (3) GL candidate search engine. In Fig. 3, schematic diagram of cosmic string search system is shown. A search request is written in JVO Query Language (JVOQL, Mizumoto et al. 2003) and the results are returned in VOTable and FITS format. JVOQL can be generated by a JVOQL editor (Fig 4), which uses a web browser as an input method. On the JVOQL editor, one can browse meta data of registered DBs and can select a DB, a table and columns you want. The requested table is retrieved from a DB server and pair objects are selected on the JVO system server, and the result is

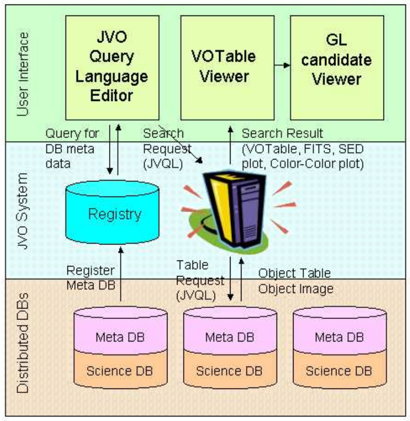

Figure 3. A schematic diagram of the cosmic string search system.

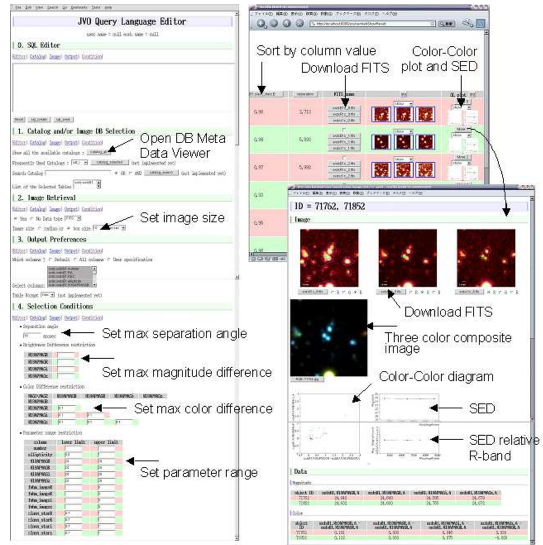

Figure 4. JVOQL Editor (left), VOTable viewer (right top), GL candidate viewer (right bottom)

saved as a VOTable. Image data are also retrieved for the pair objects as a FITS format and the FITS images are converted to JPEG images. User can access to the VOTable, FITS image and JPEG images through the VOTable viewer shown in Fig 4. A color-color diagram, a SED plot and a three-color composite image are also generated in accordance with a user's request. Although the search procedure described in section 2 is still not fully introduced in the current JVO prototype, complete implementation will be done in the second version of the JVO prototype.

Acknowledgments. This research was supported by Grant-in-aid "Information Science" carried out by the MEXT (14019092 and 15017289).

References

Vilenkin, A., & Shellard, E. P. S. 2000, *Cosmic Strings and Other Topological Defects, Cambridge University Press*

Vilenkin, A. 1984, ApJ 282

Pogosian, L. et al. 2003, Phys. Rev. D68 023506

Sazhin, M., et al., 2003, Mon. Not. Roy. Astron. Soc. 343 353

Huterer, D., & Vachaspat, T. 2003, Phys. Rev. D68 041310

Mizumoto, Y. et al. 2003, in APS Conf. Ser., Vol. 295, Astronomical Data Analysis Software and Systems XII, ed. H. E. Payne, R. I. Jedrzejewski, & R. N. Hook (San Francisco: ASP), 96

Ohishi, M. et al. this volume, [P3-11]