EC Status for DES

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A. Name(s) of Project(s) :

- Lens Search in DES - Arcfinding, Quasar lenses and Space Warps
- Mass distribution of groups-scale lenses
- Quasar lenses

B. Brief description of the project(s) :

Lens Search in DES: *i) Arcfinding*: The arc-finding algorithms detect elongated features in images which can be used to find lensed arcs. Currently, we have a few Arcfinders in the literature. We would like to assess the performances of individual Arcfinders and provide a comparison between them and find a best algorithm which will be applied to the DES data. *ii) Quasar lenses*: Developing an algorithm to find quasar lens candidates which will be optimized for completeness. *iii) Space Warps*: Space Warps is a citizen science project and is mainly aimed towards providing a lens discovery service to the survey teams. The DES collaboration is going to use Space Warps as an additional tool to find various kinds of lenses systematically e.g., arcs, quasar lenses and galaxy-scale lenses.

I would like to emphasize that systematic search of strong lens systems from DES will yield a lens sample which will be unprecedented given the combination of areal coverage and depth. This data product will be available to the wider community within DES to pursue several interesting science projects of their own ranging from galaxy formation and evolution (e.g. distant faint galaxies with high lensing magnification, lens environments, constraints on stellar IMF), quasars (e.g. BLR characteristics) to Cosmology (e.g. Hubble constant, Dark Energy).

Science projects with DES:

This section provides a general context for the projects to be carried out eventually with the full DES data.

Mass distribution of Groups-scale lenses: Groups are one of the most abundant massive bound structures in the Universe. Understanding their mass distribution is very important in understanding growth of structure. Although there are many statistical measurements of group properties, strong lensing provides an independent and a relatively more accurate mass measurement. I would like to use a sample of strong lensing groups to better constrain their mass distributions by using following techniques a) Lens statistics: The profile of the image separation distribution of lenses is known to be sensitive to the average mass distribution of the lens population (e.g. Oguri 2006). Lenses at group-scales lie at the transition regime where both the baryonic mass and dark matter mass become equally dominant. Therefore, statistics of groups-scale lenses can provide interesting constraints on the concentration-mass relation of groups-scale halos (e.g. More et al. 2012). Given the large survey area of DES, we will find a signficantly larger sample of groups-scale lenses than the currently known sample of ~ 50. The image separation distributions of lensing groups from DES can provide better

constraints on the c-M relation and the average mass distributions in groups. and b) joint analysis of multiple mass probes: I would be interested in following a subsample of lenses to measure spectroscopic redshifts of lensed sources and group members to combine strong lensing with group dynamics. Ideally, I would like to further combine these measurements with other complementary mass probes such as X-rays and weak lensing in order to measure the mass distributions of lensing groups in unprecedented detail.

Quasar lenses: Gravitational lens systems are known to show flux ratio or astrometric anomalies attributed to substructure within foreground lensing halos. The subhalo properties are sensitive to the nature of dark matter and the quadruply lensed quasars with anomalies are apt systems to probe the low end of halo mass function. We can measure the substructure mass fraction (e.g. More et al. 2009) or even the substructure mass function (e.g. Vegetti et al. 2009). I would be interested in following up a subsample of quasar lenses, which have evidence for flux ratio anomalies based on initial mass models, to measure the substructure mass function. On the other hand, quasar lenses can also be used as a probe of the Hubble constant (e.g. Suyu et al. 2010) from the time delay measurements of their intrinsic flux variations. A larger sample of quasar lenses from a survey like DES will allow us to cherry pick the best suited subsample of quasar lenses. Such a sample, upon a systematic follow up, will provide better than 5 per cent accuracy in the measurement of the Hubble constant. I will be contributing to this effort by doing observations and making mass models.

C. Applicant's contribution to date to the project(s) :

Arcfinding: I am working with M. Makler and his group on the comparison of Arcfinders. I am also testing the performance of Arcfinders in the cases when a substantial fraction of the arcs flux or morphology is affected by proximity in projection to large bright or small galaxies in the foreground. The tests so far indicate that the Arcfinder (Alard 2006, further developed by More et al. 2012) performs better than others in finding fainter arcs blended with smaller galaxies or buried in the envelopes of brighter galaxies. This code also takes the least amount of computation time. I would like to optimize this Arcfinder to provide a highly complete sample of arc candidates, which when forwarded to the Space Warps, will result in a significantly pure arcs sample.

I have developed a java applet for quick inspection of images of a large sample of lens candidates. This applet has several features such as control bars to modify zoom, contrast and brightness, and extracting positions of interesting features in the images with a single click on the interface. This is a general purpose image inspection tool and can be used for inspection of any types of systems (with little or no modification).

Quasar lenses: I am working with H. Lin, E. Buckley-Geer, R. Reyes and M. Makler in building a quasar finding algorithm. In order to test this algorithm, I am simulating a realistic looking sample of lensed quasars using the quasar catalog provided by the DES-QSO working group. I have generated a preliminary sample of lensed quasars with realistic colors and typical lensed image configurations. After testing the quality of the sample, we intend to work on developing algorithms which will be able to select both low and high redshift quasar lens candidates. Currently, along with Reina Reyes, we are testing a quasar finding algorithm by Bovy et al. (2011). One of the tests include understanding the effects of losing the u-band data on the quality of quasar detections by looking at quasars in the CFHTLS u-g-r-i-z catalog.

Space Warps: I am actively involved in building the Space Warps project. I am contributing to various aspects of the Space Warps website e.g. designing the interface which users will use for the visual inspection, the animation and tutorials required for users to understand what are lenses and simulations of lenses which will be added as a training sample and for the purpose of quantifying the performance of the pre-selection algorithms such as the Arcfinder.

The simulations of lenses make use of realistic luminosity functions and colors for the

background sources (e.g. galaxies and quasars). Similarly, properties of lenses such as ellipticities and Luminosity-σ are preserved in the lens models. The resulting images will have realistic looking lensed features in multiple bands, with telescope limitations (e.g. PSF, noise) accounted for. This tool is going will also be made available to interested people.

We have also developed tools to make small, uniform, color cutouts in various formats (e.g. jpgs,pngs) centered on the candidates such that WCS information is filtered out. These tools will readily create images in a format required by the citizen science project, starting with regular FITS images generated by any imaging survey.

D. Duration of the proposed collaboration and data set to be used :

- Duration of collaboration : I request for collaboration at least a year after the first season data is received.
- Data set : Photometric data up to full depth in all bands for the complete first season.

E. Timeline for completion of the project(s) and submission of paper(s) :

1. In the paper on comparison of Arcfinders, one of our simulated datasets come from DES-DC6. The paper is expected to be submitted in the latter half of 2013.

2. The data from the first season ($\sim$ 200 sq. deg.) will have overlap with other surveys such as the CFHTLS and SPT. This will provide a sample of known lens systems which will be used for calibrating the lens finding algorithms to find lenses (e.g. arcs, quasars) in the early DES data.

3. Complemented with DES cluster catalog, the adapted Arcfinder will find all the cluster lenses in the data from the first season. Given the comparable sky coverage and sensitivity of the CFHTLS data, consistency checks can be performed among the two lens catalogs. New lensing cluster detections will be reported in an early DES-SL paper within several months after receiving access to the data and catalogs. Similarly, in parallel, using a quasar catalog, the first quasar lens sample can be reported (perhaps, in the same paper) to demonstrate the status and success of various lens finding algorithms.

4. The data from the first season can be injected into the Space Warps project as the first DES data instalment. The resulting complete lens sample (e.g. galaxy, quasar, cluster lenses) will be reported within several months after receiving the candidates from the Space Warps project. This paper will also provide statistical properties of the lens sample such as the image separation distributions and lens redshift distributions.

F. Additional information useful in justifying the proposed collaboration :

My current affiliation with the University of Tokyo, Japan and probable collaboration with IUCAA, India allows/will allow me to have access to large telescopes such as Subaru and SALT for follow-up of strong lens systems. This complements with my DES-SL collaborators since they are mainly based at US or Brazil.