Gravitational lensing science with WISH

Masamune Oguri
Dept. of Physics & Kavli IPMU
University of Tokyo

2013/12/3  WISH science workshop @ NAOJ
Lensing benefits from space missions

• sharp images lead to accurate astrometry and morphology, crucial for both strong and weak lensing!
Weak gravitational lensing

- key science for Euclid/WFIRST
- thought to be a main probe of dark energy and modified gravity for these missions
- what about WISH?
Weak lensing: optical vs near-IR

• in ground observations the sensitivity is much better in optical so that weak lensing in NIR is much less competitive

• in space optical and NIR sensitivities are similar, so weak lensing power can be comparable
Optical/NIR depth comparison

(based on HUDF photo-z by Coe et al.)

- in NIR number density is slightly less, but mean redshift is higher!
WISH and weak lensing

• WISH has a potential to produce significant weak lensing results comparable to Euclid and WFIRST

• current WISH survey design is not optimized for cosmology

• but weak lensing is not just for cosmology, there are many applications
Galaxy-dark matter connection

- **stacked weak lensing** provides powerful means of studying the connection between galaxies (or clusters, quasars) and dark matter halos
- with WISH we can do this at higher redshifts!

Miyatake et al. (2013)
Dark matter density profile

- $\Lambda$CDM model predicts NFW-like radial profile and very non-spherical 2D shape
- Stacked weak lensing can test this at high precision
  $\rightarrow$ constraints on DM collision cross section, coldness, ...

Oguri et al. (2012)
Strong gravitational lensing

• many applications
  - cosmology from e.g., time delays
  - galaxy structure and evolution (IMF, dark matter fraction, ...)
  - study of sources with help of magnification ("natural telescope")
**Stellar and dark matter distribution**

- average mass profile of elliptical galaxies from 161 strong lens
- breaking degeneracy btw stellar and dark matter dist. by quasar microlensing
- prefer Salpeter IMF and NFW-like DM profile without adiabatic contraction
Lensing as a natural telescope

- strong lensing magnifies distant sources
- provide a unique tool to study distant and/or faint galaxies

Kneib et al. (2004)
“Most distant” galaxy!

z~11 galaxy lensed into 3 images!

Coe et al. (2013)
Hubble Frontier Fields

- ultra deep imaging of 4+2 cluster cores with HST (140 orbits per cluster)
- much deeper than HUDF with help of lensing magnification
- observations started from 2013 Oct – stay tuned!
“Frontier fields” with WISH?

• ultra deep imaging of massive cluster cores with WISH is an interesting option

• however the WISH FOV is much larger than Einstein radii of clusters, so this might not be an efficient use of WISH
Strong lenses in wide-field surveys

• blind wide-field surveys provide an opportunity to find very bright lensed objects

• these are very useful targets for follow-up
Lessons from SDSS

“8 o’clock arc”
$z_s=2.73$ $z_l=0.38$
(Allam et al. 2007)

“clone”
$z_s=2.00$ $z_l=0.422$
(Lin et al. 2009)

“cosmic horseshoe”
$z_s=2.38$ $z_l=0.446$
(Belokurov et al. 2007)

• SDSS is a shallow survey targeting galaxies at $z<0.7$, yet very bright strongly lensed galaxies at $z \sim 2-3$ have been discovered!
Strongly lensed galaxies in WISH

- ~100 z\sim8 lensed galaxies
- ~10 z\sim10 lensed galaxies
- discovered even in wide!
Gravitationally lensed supernovae

• for type-Ia, we can obtain magnification factor thanks to its standard candleness, which can break various degeneracies

• first strongly lensed SNla PS1-10afx was discovered recently!

• many more will be discovered in WISH

Quimby, Werner, Oguri et al. (2013)
Synergy with Subaru

• these gravitational lensing sciences require deep optical images for photo-z etc

• excellent synergy with Subaru Hyper Suprime-cam (HSC) survey
Wide-field Imaging with Subaru HSC
(again another WISH!)

Figure 1: Left: The limiting magnitudes (in r) and solid angle soft of the HSC-Wide, Deep and Ultradeep (UD) layers, compared with other existing, on-going, and planned surveys. The three layers are complementary to each other, and each of the three layers covers a significantly wider area than the on-going surveys for comparable depth. The narrow-band components of the Deep and Ultradeep layers are unique; no other project is planning a major survey to comparable depth.

Right: The HSC bands, including the reflectivity of a film mirror, transmission of all optics and filters, and response of the CCDs, assuming an airmass of 1.1. Both the broad-band and narrow-band filters are shown. The lower panel shows the spectrum of sky emission lines, demonstrating that the red narrow-band filters lie in relatively dark regions of the sky spectrum.

- To derive stringent dark energy constraints from the combination of the HSC WL observables and the galaxy clustering information from the BOSS survey to precision of $\sigma_{w_{\text{pivot}}}(z_{\text{pivot}}) \approx 0.03$ and the dark energy figure-of-merit FoM $\equiv 1 / [\sigma_{w_{\text{pivot}}} \sigma_{w_{a}}] \approx 100$.
- To use WL to constrain deviations from General Relativity to a higher precision than the current SDSS constraint (Reyes, Mandelbaum et al. 2010) by a factor of 4.
- To study SDSS-like volumes of galaxies in a series of redshift slices observed through broad- and narrow-band filters to carefully-tuned depths, in order to understand the properties and evolution of galaxies from $z \sim 7$ to today, as well as to constrain the physics of cosmic reionization at high redshift, $z \approx 5-7$.

To achieve these scientific goals, we propose a 'wedding-cake' survey with three layers:

- The Wide layer will cover 1400 deg$^2$ and will be done in five broad-bands, g, r, i, z, and y, to a depth of $r \approx 26$, and to similar depths in the other bands. This is designed to characterize the $z<2$ galaxy population, and to measure WL shear as a function of redshift and spatial scale.

- The Deep layer will cover 27 deg$^2$ in four carefully selected fields distributed over a range of right ascensions (RA). It will go a magnitude deeper than the Wide layer in the broad-bands, and will also use three narrow-band filters to look for Lyman-α emitters (LAEs) at $z=2.2, 5.7, 6.6$ to study their evolution and the topology of cosmic reionization. Its multiple repeat exposures will enable powerful testing and mitigation of systematic lensing errors.

- The Ultradeep (UD) layer will image two fields (3.5 deg$^2$) in both the five broad-band filters and three narrow-band filters, going a magnitude fainter still, to discover $\sim 6000$ LAEs at $z=5.7$ and 6.6, several tens of LAEs at $z=7.3$, and about 120 Type Ia supernovae to $z \sim 1.4$.

The left panel of Figure 1 shows that these three layers are complementary to each other and are significantly more powerful than are the previous, competitive on-going, and upcoming surveys. Combining the three layers allows us to cover a broad range of science topics spanning a wide range of length scales and redshifts.

We need about 200 nights in total (including overheads and assuming that 30% of nights will have poor weather) to carry out the Wide layer, and 100 nights for the Deep and Ultradeep layers. Table 1 summarizes the survey parameters and main science drivers for each layer.

Our two scientific themes, cosmology and galaxy evolution, are intimately tied together, which is why both area and depth are in excellent match with WISH survey.
Summary

• WISH is an excellent project from the perspective of gravitational lensing science

• its weak lensing power comparable to Euclid and WFIRST satellites, useful both for cosmology and galaxy studies

• many strongly lensed high-redshift galaxies will be discovered in WISH, which will be interesting targets for follow-up with TMT/JWST/...