New Gravitational Lenses for Dark Matter Research

Using data collected by the Hubble Space Telescope (HST), Dr. SHU Yiping and Prof. MAO Shude from the National Astronomical Observatories of China, Chinese Academy of Sciences (NAOC) and their collaborators have recently discovered a sample of 17 new strong gravitational lens systems, which is of unique significance to the study of the nature of dark matter and high-redshift Lyα emitters.

Dark matter is believed to contribute to more than 80% of the total mass in our Universe. However, unlike the ordinary matter we see in daily life, dark matter does not emit or interact with electromagnetic radiation, and therefore appears to be completely invisible to most of the astronomical instruments. One way to detect dark matter is through its gravitational effects. According to the general relativity theory, light rays from a distant object (the "source") will be deflected by the gravitational field of an intervening object (the "lens") and eventually form distorted, multiple images (**Figure 1**), called the "strong gravitational lensing phenomenon".

"The image separations can provide a robust and accurate measurement of the total mass of the lens object, including dark matter," said Prof. Adam Bolton from the US National Optical Astronomy Observatory, who is a member of the research team.

The phenomenon can also help to determine the nature of dark matter by constraining the properties of dark matter subhalos (**Figure 2**). Dark matter subhalos are satellites around galaxies that primarily consist of dark matter, and their abundance and mass distribution hold important clues to the nature of dark matter.

"In our experiment, the capability to detect low-mass dark matter subhalos is crucial because predictions by different dark matter models become distinguishable only for low-mass subhalos," explained co-author Prof.

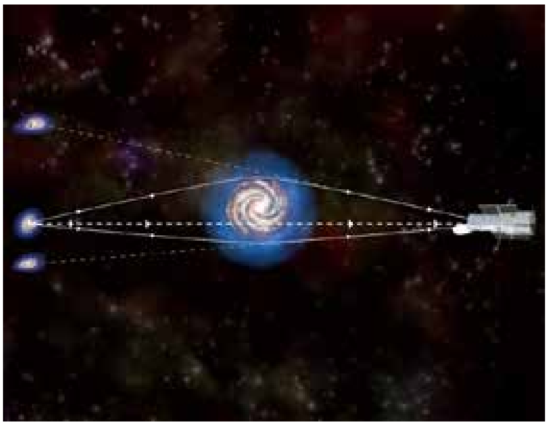

Figure 1. Illustration of the gravitational lensing phenomenon. Light rays from a distant object (the "source") are bent by the gravity of an intervening galaxy (the "lens") and form multiple images. (Credit: NASA/CXC/M. Weiss)

Figure 2. A galaxy like the Milky Way is surrounded by an extended halo of dark matter. High-resolution numerical simulations indicate that each dark matter halo consists of a smooth central component, sprinkled by many clumps of dark matter, termed as subhalos; their abundance depends on the nature of dark matter (Credit: Virgo consortium; Volker Springel).

Christopher Kochanek from Ohio State University.

According to previous studies, the smaller the background source is, the lower the mass limit can be achieved. However, the sizes of background sources in previously identified strong-lens samples were still not small enough to reach a decisive conclusion on the nature of dark matter.

In order to bring down the detection limit, SHU and coworkers selected 21 strong-lens candidates involving redshift 2-3 (corresponding to the age of the Universe from 2 to 3 billion years) Lyα emitters as the background sources from approximately one million galaxies. Lyα emitters are young galaxies that emit strong Lyα emission due to the transition of the electron of a hydrogen atom from the first excited state to the ground state. Compared to the sources in previous samples, these Lyα emitters are intrinsically smaller by a factor of 3 to 5, and therefore can reduce the detection limit by roughly an order of magnitude.

Follow-up HST imaging observations confirmed that 17 out of the 21 candidates are definite strong lenses (**Figure 3**). “This is the very first discovery of galaxy-scale strong lenses made by Chinese astronomers using the HST data,” noted Prof. MAO, a co-author who is also a professor at Tsinghua University.

By analyzing the HST data, the researchers found that the background Lyα emitters are generally irregular and clumpy. With the help of lensing magnification, they resolved the Lyα emittersin exceptional detail with sizes from a hundred to several thousand light years.

“We hope that follow-up observations of the Lyα emitters in the future will increase our understanding of how galaxies form and evolve,”said ZHENG Zheng from the University of Utah. “We plan to systematically search for dark-matter substructures in this new sample.”

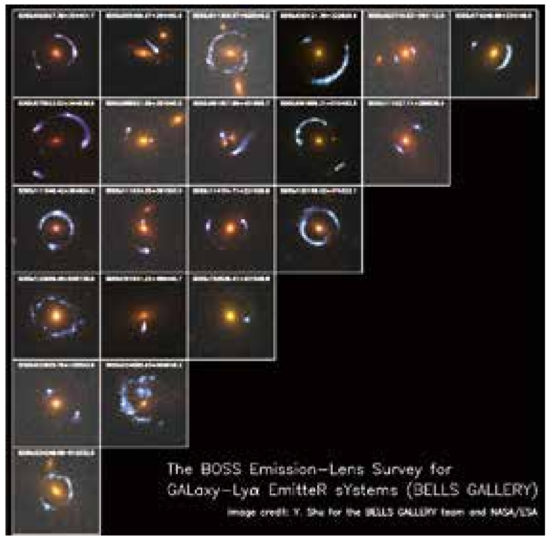

Figure 3. Mosaic of HST images of the 21 strong lens candidates. The orange-ish components are the foreground lens galaxies, while the surrounding structures are multiple images of the background Lyα emitters (enhanced in blue).

The team has also submitted another HST proposal to observe 15 new, gravitational lensed LAEs candidates at even high redshifts from 4 to 6 identified with the same selection technique. By combining the unmatched spatial resolution and sensitivity of HST and lensing magnification, this new sample will hopefully be an invaluable resource for studying faint, small-scale structures of star forming regions of LAEs and probing the properties of intergalactic medium since the first ~1 billion years of the Universe.

Their work was supported by the Strategic Priority Research Program ofthe Chinese Academy of Sciences and the National Science Foundation of China. The findings have been published in *The Astrophysical Journal* (Shu *et al*., 2016, *ApJ*, 833, 264). (Text courtesy: Dr. SHU Yiping from NAOC, CAS)