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MIND THE GAP: A DRASTIC CHANGE COMING IN OUR VIEW OF CLUSTERS BROUGHT BY EUCLID

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Abstract. Galaxy clusters are tracers of the matter density peaks in the cosmic web. They additionally provide efficient tests for cosmological models as they form via gravitational collapse in the expanding Universe. Identification of galaxy clusters from large extragalactic surveys (e.g., SDSS, ROSAT, Planck, SPT, DeCALS, KIDS, DES, VHS, LOFAR, ACT, HSC,) has proven to be a powerful way of detecting new clusters, potentially discovering new clusters acting as strong gravitational lenses. For nearly 30 years, the Hubble Space Telescope has remained the field's workhorse for appropriate modeling of individual clusters, with some renowned observing campaigns dedicated to them (e.g. LOCUSS, CLASH, Hubble Frontier Fields). In this article, I will discuss the upscale brought by Euclid, opening the statistical Era in cluster cosmology. With the launch schedule for summer 2023, we are on the verge of a significant transformation, which should boost the observed number of clusters to about two orders of magnitude and drastically affect our approach to cluster analysis. I will briefly discuss how this affects our way of doing astronomy as some pixels might never meet the human eye.

Keywords: subject, verb, noun, apostrophe

1 Introduction

Clusters of galaxies are located at the nodes of the cosmic filaments and represent the densest structures of dark matter; their merging history and evolution shape the properties of their mass distribution. They additionally provide efficient tests for cosmological models as they form via gravitational collapse in the expanding Universe. Identification of galaxy clusters from large extragalactic surveys (e.g., SDSS, ROSAT, Planck, SPT, DeCALS, KIDS, DES, VHS, LOFAR, ACT, HSC) has proven to be a powerful way of detecting new clusters, potentially discovering new strong gravitational lenses. Strong lensing galaxy clusters can play a key role in our understanding of the Universe, from mapping the distribution of matter in its densest regions, to the study of the earliest galaxies that they magnify.

An apparent discrepancy between the observed and expected number of giant arcs, known as the "arc statistics problem", has motivated studies of the correlation between strong lensing efficiency, cosmology, and cluster properties (see Meneghetti et al. 2013 for a review). Cosmological analyses reveal that the number of giant arcs is sensitive to Ω_m and σ_8 (Wambsganss et al. 2008; Li et al. 2006; Oguri et al. 2009; Boldrin et al. 2016), self-interacting dark matter cross section (Wyithe et al. 2001), primordial non-Gaussianity (D'Aloisio & Natarajan 2011), and dark energy (Bartelmann et al. 2003). Giocoli et al. (2012) found that halo concentration is the most important factor for the lensing cross sections for the production of large arcs, with more concentrated halos having larger strong lensing cross sections.

For nearly 30 years, the Hubble Space Telescope (HST) has remained the field's workhorse for appropriate strong lensing mass modeling of individual clusters, with some renowned observing campaigns dedicated to them (e.g. LOCUSS, CLASH, Hubble Frontier Fields). This Era might come to an end with the advent of Euclid, a space-based observatory, surveying the all-sky at nearly HST resolution and therefore offering direct access to modeling from the survey images themselves.

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Origin	Nb of clusters	Survey area (deg^2)	Density (#/deg^2)	Human time (hours)
Abell (Abell et al. 1989)	4 073	41 253	0.01	34
SDSS (Bahcall et al. 2003)	799	400	2	6.65
DES+unWISE (Wen & Han 2022)	151 244	5 000	30	1 260
Euclid (Euclid Collaboration et al. 2022)	2 000 000	15 000	400	16 666

Table 1. Non-exhaustive comparisons between previous sky surveys. The last column aims to grasp the necessary time needed to observe an image with the human eye. In this computation, I assumed that a cluster would be watched for 30 seconds. It clearly demonstrated the unrealistic expectation of looking at all clusters that Euclid will observe.

2 Euclid prospective

Euclid surveys aim to identify, catalog, and study the universe observing about 15 000 deg^2 with its imagers, VIS and NISP, and spectrographs (Racca et al. 2016). In comparison to previous studies, which identified potential strong-lensing line-of-sight, Euclid imaging should be able to provide at the same time, a full sky coverage and the necessary resolution to identify giant arcs as illustrated in Figure 1.

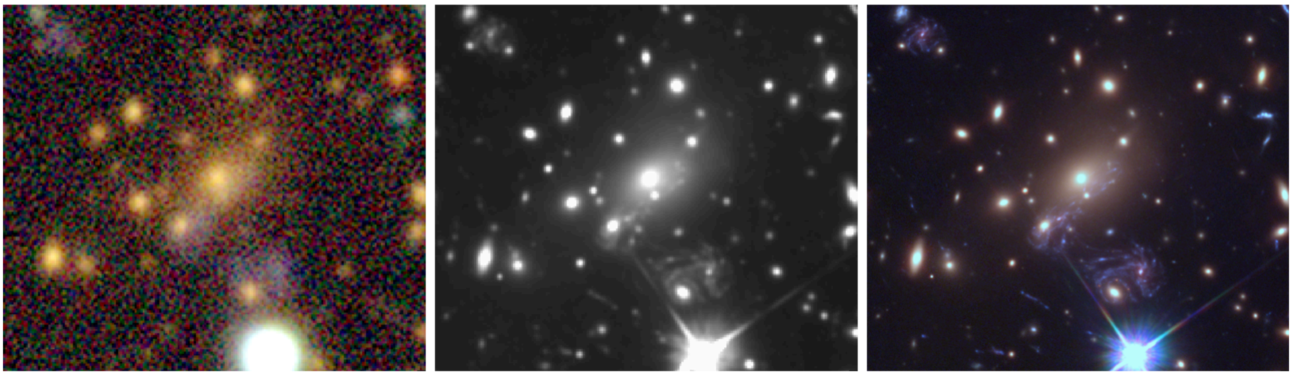

Fig. 1. Image of the famous multiply-imaged spiral galaxy hosting supernova Refsdal (Kelly et al. 2015). This image illustrated the resolution of the VIS instrument on board Euclid. **Left:** Field of view based on the DESI legacy survey, `https://www.legacysurvey.org/` **Middle:** Euclid mock VIS resolution (0.1' per pixel) images. **Right:** HST images using frontier fields data

The number of strong lensing clusters is estimated to be of the order of 10 000 (Boldrin et al. 2016). This is a dramatic change compared to the approximately 10^2 strong lensing clusters known today (see Fox et al. 2022 for the largest compilation grasping maybe aiming half of the known strong lensing cluster). This large upcoming dataset is challenging to review in the traditional visual inspection and is triggering a change of methods. Table 1 is trying to grasp the change of scale Euclid survey is presenting us, by looking at the time needed to watch all the clusters.

3 Conclusions

In summary, the forthcoming Euclid space observatory represents a significant breakthrough in observational astrophysics. It will substantially enhance our ability to study the universe with a tenfold increase in resolution, a vast expansion of surveyed regions, and the capability to probe cosmic phenomena at much greater distances compared to previous instruments like the Sloan Digital Sky Survey (SDSS).

However, this surge in data volume poses a challenge. To effectively utilize Euclid's observations, we must develop advanced software tools for data analysis. These tools are essential for analyzing a large dataset and extracting meaningful scientific information.

Furthermore, Euclid's capabilities demand a reevaluation of our existing modeling techniques. Current software may not handle the wealth of data Euclid will provide. Thus, as a community, we must adapt to make the rise to this wealth of upcoming information. In essence, Euclid's launch signifies a pivotal moment in astrophysics.

The Legacy Surveys consist of three individual and complementary projects: the Dark Energy Camera Legacy Survey (DECaLS; Proposal ID #2014B-0404; PIs: David Schlegel and Arjun Dey), the Beijing-Arizona Sky Survey (BASS; NOAO Prop. ID #2015A-0801; PIs: Zhou Xu and Xiaohui Fan), and the Mayall z-band Legacy Survey (MzLS; Prop. ID #2016A-0453; PI: Arjun Dey). DECaLS, BASS and MzLS together include data obtained, respectively, at the Blanco telescope, Cerro Tololo Inter-American Observatory, NSF's NOIRLab; the Bok telescope, Steward Observatory, University of Arizona; and the Mayall telescope, Kitt Peak National Observatory, NOIRLab. Pipeline processing and analyses of the data were supported by NOIRLab and the Lawrence Berkeley National Laboratory (LBNL). The Legacy Surveys project is honored to be permitted to conduct astronomical research on Iolkam Du'ag (Kitt Peak), a mountain with particular significance to the Tohono O'odham Nation.

NOIRLab is operated by the Association of Universities for Research in Astronomy (AURA) under a cooperative agreement with the National Science Foundation. LBNL is managed by the Regents of the University of California under contract to the U.S. Department of Energy.

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