# Time-Domain Cosmology with Strong Gravitational Lensing

# Report of Contributions

Contribution ID: **1** Type: **Talk**

# Welcome

*Monday 25 January 2021 22:00 (5 minutes)*

**Presenter:** WONG, Kenneth

Contribution ID: **2** Type: **Talk**

# Summary / closing

*Tuesday 2 February 2021 23:50 (9 minutes)*

**Presenter:** OGURI, Masamune

Contribution ID: **3** Type: **Talk**

# Cosmology and Stellar Physics with Lensed Supernovae

*Monday 25 January 2021 22:05 (25 minutes)*

Strongly lensed supernovae (SNe) provide great opportunities for constraining cosmological parameters and SN progenitors. The time delays between the multiple images of a lensed SN allow a measurement of the Hubble constant (H0), which is complementary to lensed-quasar studies. An independent measurement of H0 is important for assessing the current H0 tension and the possible need for new physics. I will present the results of a new program on lensed SNe, including recent developments in the search for these rare events, and new techniques for analyzing such systems for cosmography. The time delays also facilitate early-phase observations of SNe, which are crucial for deciphering SN progenitors. Using various models of SN explosions, I will quantify the impact of microlensing on SN for both progenitor and cosmological studies. I will show the bright prospects of lensed SNe as an independent and competitive probe of cosmology and SN progenitors.

**Presenter:** SUYU, Sherry

Contribution ID: **4** Type: **Talk**

# Lessons learned from iPTF16geu

*Monday 25 January 2021 22:30 (25 minutes)*

Wide-field time domain surveys are well-suited to find strongly lensed systems, without the need for high spatial resolution, as demonstrated by the discovery of the first multiply-imaged Type Ia supernova, iPTF16geu. Yet, in spite of significant efforts, four years have passed without a sequel. I will summarize the circumstances surrounding the discovery of SN2016geu using the Palomar Transient Facility and the follow-up with HST and ground-based facilities, with focus on the observational challenges.

**Presenter:** GOOBAR, Ariel

Contribution ID: **5** Type: **Talk**

# Lens Searches for transients and variable sources

*Monday 25 January 2021 23:00 (25 minutes)*

I will give an overview of systematic lens searches (including machine learning based approaches) being conducted in the ongoing imaging surveys to find transients or variable sources which can allow us to put constraints on cosmological parameters or often times, give insight into the astrophysics. I will also talk about new methods proposed to be used in upcoming surveys such as LSST, their strengths, complementarity and possible directions for improvements.

**Presenter:** MORE, Anupreeta

Contribution ID: **6** Type: **Talk**

# Extremely Magnified Stars and Flashlights

*Tuesday 2 February 2021 23:25 (25 minutes)*

Observations with the Hubble Space Telescope (HST) have now definitively identified two blue supergiant stars, Icarus and Warhol, at cosmological distances which are extremely magnified by foreground Hubble Frontier Field (HFF) galaxy clusters. Moreover, several less well characterized stars have also been detected briefly when their magnification temporarily increased due to microlensing by an object in a foreground cluster. I will discuss the two-cycle Flashlights 192-orbit HST program, which is obtaining two epochs of ultra-deep, unfiltered imaging of all six HFF cluster fields. These observations, with a single-visit five-sigma limiting magnitude of 31 AB, can be expected to increase the current sample of microlensing events of extremely magnified stars substantially, and detect a sizable sample of pairs of stellar images. If only 2% of dark matter consists of primordial black holes across a broad ranges of masses, then the rate of of detected microlensing peaks should be significantly increased. The pairs of stellar images should stringently test lens models, probe the abundance of low-mass dark-matter halos, and evaluate predictions for dark matter as ultra-light bosons.

**Presenter:** KELLY, Patrick

Contribution ID: **7** Type: **Talk**

# Large-Scale Gravitational Lens Modeling with Bayesian Neural Networks for Accurate and Precise Inference of the Hubble Constant

*Tuesday 26 January 2021 22:55 (10 minutes)*

We investigate the use of approximate Bayesian neural networks (BNNs) in modeling hundreds of time-delay gravitational lenses for Hubble constant (H0) determination. Our BNN was trained on synthetic HST-quality images of strongly lensed active galactic nuclei (AGN) with lens galaxy light included. The BNN can accurately characterize the posterior PDFs of model parameters governing the elliptical power-law mass profile in an external shear field. We then propagate the BNN-inferred posterior PDFs into ensemble H0 inference, using simulated time delay measurements from a plausible dedicated monitoring campaign. Assuming well-measured time delays and a reasonable set of priors on the environment of the lens, we achieve a median precision of 9.3\% per lens in the inferred H0. A simple combination of 200 test-set lenses results in a precision of 0.5 km s−1 Mpc−1 (0.7%), with no detectable bias in this H0 recovery test. The computation time for the entire pipeline – including the training set generation, BNN training, and H0 inference – translates to 9 minutes per lens on average for 200 lenses and converges to 6 minutes per lens as the sample size is increased. Being fully automated and efficient, our pipeline is a promising tool for exploring ensemble-level systematics in lens modeling for H0 inference.

**Presenter:** PARK, Ji Won

Contribution ID: **8** Type: **Talk**

# Constraining the Hubble constant – some lessons learnt from using lensing simulations

*Tuesday 26 January 2021 22:00 (25 minutes)*

Time-domain lensing observations and modeling have turn out to serve an increasingly important role in providing independent constraints on the Hubble constant and cosmology. A couple of issues regarding the modeling technique remain not entirely clear and many good efforts have been made in order to understand various possible key systematics. In this talk, I will briefly discuss a few interesting and potentially important lessons that we learnt from using lensing simulations.

**Presenter:** XU, Dandan

Contribution ID: **9** Type: **Talk**

# Galaxy lens models with offset mass components: implications for time delays and H0.

*Monday 25 January 2021 23:35 (25 minutes)*

Accurate determination of the Hubble parameter from strong lensing depends critically on the mass model of the lensing galaxy. There is evidence that the commonly used elliptically symmetric lenses may not adequately represent the lens galaxy population. I will discuss the recent modeling of the quad Supernova iPTF16geu. Simple models suffer from a few deficiencies: the center and the position angle of the recovered mass are not the same as those of the observed light, and the density profile required by microlensing considerations is rather shallow. We model the lensing galaxy as a superposition of two mass components; allowing them to be offset from each other by up to 0.25 kpc alleviates most of the problems of simple models, and leads to predictions for microlensing magnification and time delays that differ from those of simple models. I will discuss the implications of two offset components lens modeling for H0 estimation.

**Presenter:** WILLIAMS, Liliya

Contribution ID: **10** Type: **Talk**

# Where my DAEMON hides – one explanation to rule all lens models

*Tuesday 26 January 2021 22:25 (10 minutes)*

"A big obstacle to efficiently determine H0 from time-delay cosmography is the lens modelling. When choosing a mass density profile as lens model, we have to select from a multitude of lens model classes and ranges for the model parameter values. A specific choice may bias the confidence bounds on H0 low, a marginalisation over many model classes and parameter ranges is computationally very intensive.
As a first step towards one general mass density profile that replaces the heuristically inferred fitting function lens models, I will introduce the ""DArk Emergent Matter halO explanatioN"" (DAEMON) which is able to explain the self-similar dark matter halo morphologies forming under scale-free gravitational interaction. DAEMON thus allows us to base the power-law mass density profiles and composites thereof, like the famous Navarro-Frenk-White profile on sound mathematically and physically fundamental principles. Consequently, choosing and marginalising over classes of lens models can be simplified to reduce computational costs and obtain realistic confidence bounds on H0 at the same time."

**Presenter:** WAGNER, Jenny

Contribution ID: **11** Type: **not specified**

# Panel Discussion: Time-Delay Cosmography

*Tuesday 26 January 2021 23:10 (55 minutes)*

**Presenters:** TREU, Tommaso; SLUSE, Dominique; WILLIAMS, Liliya; LI, Nan; SUYU, Sherry; BIRRER, Simon

Contribution ID: **12** Type: **Talk**

# Recent studies on the propagation velocity of lensed gravitational waves

*Monday 1 February 2021 22:00 (25 minutes)*

In this talk, we briefly review the propagation velocity of lensed gravitational waves in general relativity, based on recent papers (listed below). We mainly discuss the velocity difference between GWs and electromagnetic waves (EMWs) in the presence of a lens. The lensing of EMWs is usually studied in geometrical optics, while the lensing of GWs should be studied in wave optics if the wavelength is larger than the Schwarzschild radius of the lens. The recent studies reveal that the phase and group velocities of GWs can exceed the velocity of EMWs, but the wave front never arrives before the EMWs if both waves were emitted simultaneously from the source. Finally, we discuss an observational possibility to detect the arrival-time difference. References: RT (2017), Morita & Soda (2019), Suyama (2020), Ezquiaga+ (2020)

**Presenter:** TAKAHASHI, Ryuichi

Contribution ID: **13** Type: **Talk**

# Using transients at extreme magnifications to constrain dark matter

*Monday 1 February 2021 22:25 (25 minutes)*

Events at cosmological distances, undergoing extreme magnifications have become a reality since the discovery of Icarus, the first strongly lensed star at redshift larger than 1. Since the discovery of Icarus, similar events have been observed in the last years, and many more are expected in the upcoming years. The large magnification factors present in these events allow to study not only the background source, but also the small-scale perturbations in the lens plane. This type of observations allow to constrain certain models of dark matter, like those postulating that primordial black holes with masses similar to those found by LIGO/Virgo can account fro a fraction of the dark matter. In this talk I will review some of the possibilities offered by extreme magnified events to constrain the abundance of primordial black holes. In particular I will consider the case of extremely magnified stars, supernovae and gravitational waves.

**Presenter:** DIEGO, Jose

Contribution ID: **15** Type: **Talk**

# Beyond-WIMP DM models and constraints from anomalous strong-lens systems

*Monday 1 February 2021 23:05 (25 minutes)*

"A weakly interacting massive particle (WIMP) from electroweak-scale new physics have been a promising candidate of cold dark matter (CDM).
Meanwhile beyond-WIMP DM models attract interests partially because they may explain the possible issues in CDM: tension between early and late cosmology in H0; and challenges in explaining the observed Galactic-scale structure.
I overview beyond-WIMP DM models and their cosmological implications, particularly explaining a relatively new possibility: late-decaying dark matter (LDDM).
I stress that anomalous strong-lens systems have a good potential to probe beyond-WIMP DM models, by showing the constraints from existing data."

**Presenter:** KAMADA, Ayuki

Contribution ID: **16** Type: **Talk**

# Real-time cosmology with lensed repeating Fast Radio Bursts

*Tuesday 26 January 2021 22:45 (10 minutes)*

Real-time cosmology refers to measuring the evolution of the universe in real time. Given the short human lifetime compared to the age of the universe, measuring such changes is very challenging. Thanks to their short duration and the typical time delays involved, lensed repeating FRBs may offer a unique opportunity to do so. I will review this possibility and discuss its feasibility using existing and upcoming facilities.

**Presenter:** ZITRIN, Adi

Contribution ID: **17** Type: **Talk**

# Phase shift of lensed gravitational waves

*Monday 1 February 2021 23:30 (25 minutes)*

Several gravitational wave signals of binary black hole coalescence in LIGO/Virgo O2 are found to show surprisingly coincident intrinsic and extrinsic parameters. Could they be multiple images of a gravitationally lensed source? Lensed gravitational waveforms are subject to a topological phase shift called the Morse phase shift. While the absolute Morse phase is degenerate with the source orbital phase, the relative Morse phase is measurable under the lensing hypothesis. We find that the candidate signals have relative Morse phases consistent with geometrical lensing, but the results point toward a peculiar configuration of multiple lensed images that are rarely realized by galaxy or galaxy cluster lenses. The Morse phase information will help with lens reconstruction for future detection of lensed gravitational waves.

**Presenter:** DAI, Liang

Contribution ID: **18** Type: **not specified**

# Panel Discussion: Dark Matter Science with Upcoming Surveys/Telescopes

*Tuesday 2 February 2021 22:00 (55 minutes)*

**Presenters:** KAIKI INOUE; GOOBAR, Ariel; KAMADA, Ayuki; XU, Dandan; DIEGO, Jose; COLLETT, Thomas

Contribution ID: **19** Type: **Talk**

# Microlensing in lensed quasars

*Tuesday 2 February 2021 23:00 (25 minutes)*

"The observation of gravitationally microlensed quasars provides direct measurements of the accretion disk structure. The flux variations of the quasar images, induced by the source crossing through the microlens caustics, produce variations on timescales of years. There are two techniques to measure those variations: photometric monitoring and single epoch spectroscopy/photometry. The first one measures the magnification changes by comparing the light curves of the lensed images after correcting by the time delay between the images. The second one uses emission lines (or a smooth macrolens model) as a reference to estimate the microlensing variability. These techniques have been successfully applied to investigate the inner structure of a few dozen of systems, improving the analysis of systematic uncertainties. In the upcoming decade, with the discovery of thousands of new systems, quasar microlensing could offer a comprehensive view of the accretion disk structure."

**Presenter:** MOTTA, Veronica

Contribution ID: **20** Type: **Talk**

# The effect of dark matter substructure on strong lensing measurements of the Hubble constant

*Monday 1 February 2021 22:50 (10 minutes)*

The particle nature of dark matter manifests in the abundance and density profiles of dark matter structure on sub galactic scales, both in the form of subhalos and field halos along the the line of sight. The lensing effects of these structures leaves subtle imprints on the arrival time delays and flux ratios between images in quadruply imaged quasars (quads). I will describe recent work that quantifies the effects of dark substructure on strong lensing measurements of the Hubble constant, showing that substructure contributes an small additional source of uncertainty - but does not bias - strong lensing measurements of H0. Time permitting, I will also describe an analysis framework that constrains the particle nature of dark matter by forward modeling flux ratios in quads, with an emphasis on how it can be applied to a variety of structure formation scenarios based on dark matter theory.

**Presenter:** GILMAN, Daniel

Contribution ID: **21** Type: **Talk**

# Gravitational Lensing of Gravitational Waves: Effect of Microlensing Population

*Monday 1 February 2021 23:55 (10 minutes)*

In this work, we investigate the effect of microlensing in strongly lensed gravitational wave signals due to the population of microlenses present in lensing galaxies. We consider a wide range of realistic strong lens magnification and the corresponding density values of the microlens population. We find that the effects of microlensing become increasingly significant with the increase in the strong lens magnification for both minima and saddle type of images. Hence, for notable microlensing features in the gravitational wave signals, the strong lensing magnification also needs to be substantial. The mismatch analyses suggest that only in very rare scenarios, the waveforms will be missed; otherwise, only its parameter estimation will be affected. We also study the effects of different IMFs (Salpeter and Chabrier) on the amplification curve caused by the corresponding microlens population.

**Presenter:** MISHRA, Anuj

Contribution ID: **22** Type: **Talk**

# Auto-identification of unphysical source reconstructions in strong lens modelling

*Tuesday 26 January 2021 22:35 (10 minutes)*

With the advent of next-generation surveys and the expectation of discovering huge numbers of strong gravitational lens systems, much effort is being invested into developing automated procedures for handling the data. The several orders of magnitude increase in the number of strong galaxy-galaxy lens systems is an insurmountable challenge for traditional modelling techniques. Whilst machine learning techniques have dramatically improved the efficiency of lens modelling, parametric modelling of the lens mass profile remains an important tool for dealing with complex lensing systems. In particular, source reconstruction methods are necessary to cope with the irregular structure of high-redshift sources. In this paper, we consider a Convolutional Neural Network (CNN) that analyses the outputs of semi-analytic methods which parametrically model the lens mass and linearly reconstruct the source surface brightness distribution. We show the unphysical source reconstructions that arise as a result of incorrectly initialised lens models can be effectively caught by our CNN. Furthermore, the CNN predictions can be used to automatically re-initialise the parametric lens model, avoiding unphysical source reconstructions. The CNN accurately classifies source reconstructions with a precision P>0.99 and recall R>0.99. Using the CNN predictions to re-initialise the lens modelling procedure, we achieve a 69 per cent decrease in the occurrence of unphysical source reconstructions. This combined CNN and parametric modelling approach can greatly improve the automation of lens modelling.

**Presenter:** MARESCA, Jacob

Contribution ID: **23** Type: **Talk**

# Lens searches with Gaia and variability

*Monday 25 January 2021 23:25 (10 minutes)*

Lens searches with Gaia and variability

**Presenter:** LEMON, Cameron

Contribution ID: **25** Type: **Talk**

# Probing the nature of dark matter with galaxy-galaxy strong gravitational lensing

While a direct detection of the dark-matter particle remains very challenging, the nature of dark matter can potentially be constrained indirectly – by comparing the properties of substructure in galactic haloes with predictions from the phenomenological dark-matter models, such as the cold, warm or hot dark matter. Whereas these models are practically indistinguishable with respect to the predicted characteristics of high-mass substructure, the critical difference lies in the abundance and statistical properties of low-mass galactic substructure. Galaxy-galaxy strong gravitational lensing provides a unique opportunity to search for gravitational signatures of such low-mass substructure in lens galaxies beyond the Local Group. In this talk, I will present a novel approach to observationally constrain the statistical nature of low-mass sub-galactic structure in the inner regions of massive elliptical lens galaxies, based on the power spectrum of surface-brightness anomalies measured in highly-magnified galaxy-scale Einstein rings and gravitational arcs. A future comparison of these results with the predictions from hydrodynamical simulations might either verify the CDM paradigm or require its substantial revision.

**Presenter:** DOROTA BAYER

Contribution ID: **26** Type: **Talk**

# Line-of-sight Lensing -a New Window to Dark Matter and Distant Dwarf Galaxies

Kaiki Inoue

Matter fluctuations on scales of <10 kpc are important for understanding the nature of dark matter and dwarf galaxies residing at cosmological scales. Gravitational lensing is a powerful tool for directly probing the nature. However, the lensing signal is too small for current and near future observations. To circumvent the problem, I propose to use massive galaxy-scale strong lensing systems to amplify the weak lensing effects due to dwarf galaxy-scale halos and troughs(voids) in the line of sight. Recent studies suggest that the major cause of anomaly in flux ratios in quasar-galaxy quadruple lens systems is line-of-sight structures rather than subhalos in the primary lensing halos. Moreover, the observed anomaly is turned out to be consistent with perturbations due to line-of-sight structures in cold dark matter models. In this talk, I will review the recent studies of theoretical and observational line-of-sight lensing , present on-going projects and discuss future prospects.

**Presenter:** KAIKI INOUE

Contribution ID: **27** Type: **Talk**

# Variability of the lens quasar QJ0158 : microlensing or reverberation ?

Microlensing of strongly lensed quasars offers a unique window into AGN structure and its connection to the physical mechanisms behind quasar variability. The extrinsic variability it adds to the different images can, for example, give constraints on the radius of the accretion disk.
The current state-of-the-art light curve fitting method of Kochanek 2004 tends to overlook high frequency signals present in microlensing light curves even though they contain information about the source structure.
In my talk, I will present a new way to analyse microlensing light curves using their power spectrum. The aim of this method is to measure the radius of the quasar's accretion disk by taking into account the full range of frequencies present in the light curves.
I applied this new approach to the microlensing light curve of the doubly lensed quasar QJ0158-4325, using the full range of frequencies available in the monitoring signal, which yielded a measurement of the accretion disk radius of 2.67e14 cm, 10 times lower than previous results. I show that a plausible explanation for the observed high frequency signal is an additional reverberated and unmicrolensed signal from the Broad Line Region. This effect, in turn, allows one to measure the radius of the BLR in agreement with previous measurements.

**Presenter:** ERIC PAIC

Contribution ID: **28** Type: **Talk**

# Strategies for precise and accurate measurements of the Hubble constant with strong lensing

Strong lensing time delays can measure the Hubble constant H0 independent of any other probe. Assuming commonly used forms for the radial mass density profile of the lenses, a 2% precision has been achieved with 7 Time-Delay Cosmography (TDCOSMO) lenses, in tension with the H0 from the cosmic microwave background. However, without assumptions on the radial mass density profile – and relying exclusively on stellar kinematics to break the mass-sheet degeneracy – the precision drops to 8% with the current data of the 7 TDCOSMO lenses, insufficient to resolve the H0 tension. With the addition of external information from 33 Sloan Lens ACS (SLACS) lenses, the precision improves to 5%.
I highlight the assumptions that went into the recent measurements and present strategies to improve the precision of time-delay cosmography without relying on mass profile assumptions to break the mass sheet degeneracy.

**Presenter:** SIMON BIRRER

Contribution ID: **29** Type: **Talk**

# Time Delay Lens Modeling Challenge

Strong gravitational lenses with measured time delay are a powerful tool to measure cosmological parameters, especially the Hubble constant (H0). Recent studies show that six multiply-imaged AGN systems can determine H0 to 2.4% precision in a flat LCDM. Furthermore, the number of time-delay lens systems is growing rapidly, enabling, in principle, the determination of H0 to 1% precision in the near future. However, it is important to ensure that systematic errors and biases remain subdominant. I will present "Time Delay Lens Modeling Challenge"(TDLMC), which is aiming to assess the level of accuracy of inferred cosmological parameters given realistic mock datasets. I will give an overview of the challenge design and present the result.

**Presenter:** XUHENG DING

Contribution ID: **30** Type: **Talk**

# Contribution of primordial black holes to quasar microlensing considering a bimodal mass-spectrum of BHs and stars

The amplitude and frequency of gravitational microlensing can be used to detect Primordial Massive Black Holes (PBHs). However, they can be mixed with the normal stellar population that can also contribute to microlensing. To separate the contributions from both populations, we perform numerical simulations to study the possible degeneracy of a bimodal distribution of masses with a single-mass function plus a smooth component. This degeneracy is supported by analytical calculations in the low mass surface density case but needs to be studied with numerical simulations in the general case. From this analysis and the experimental microlensing results by Mediavilla et al. (2017), we discuss the possible existence of a PBHs population mixed with the stellar component.

**Presenter:** ANA ESTEBAN GUTIÉRREZ

Contribution ID: **31** Type: **Talk**

# Revealing the Structure of the Lensed Quasar Q 0957+561

We use signatures of microlensing (induced by stars in the foreground lens galaxy) on different wavelength regions in the gravitationally lensed quasar Q 0957+561 to infer the size of the accretion disk and to study the structure and kinematics of the broad-line region (BLR). We analyze the well-sampled 21-year GLENDAMA optical light curves of the double-lensed quasar (which so far has provided the longest available light curves of a gravitational lens system) and multiple spectroscopic observations obtained between April 1999 and January 2017, and from the statistics of microlensing magnifications we use a Bayesian method to derive the size of the regions emitting the continuum and the C IV, C III], and Mg II lines. The relatively low strength of the magnitude differences between the images indicates that the quasar has an unusually big optical accretion disk. In several epochs of observation we found clear differences between the line profiles of images A and B in the high-ionization line C IV. Measuring the amplitude of microlensing in different velocity bins in the wings of C IV and C III], we conclude that they are produced in at least two spatially distinct regions, the most compact one giving rise to the broadest component of the line. These regions have different geometries (the more extended one being spherically symmetric) and hence, do not share the same kinematics. We also intend to use the impact of microlensing on the Fe IIIλλ2039-2113 emission line blend together with a measure of its gravitational redshift to estimate the mass of the quasar's central supermassive black hole (SMBH). We obtain a mass for the central SMBH of M_BH = 1.5×10^9 M_sun, consistent within uncertainties with previous mass estimates based on the virial theorem.

**Presenter:** CARINA FIAN

Contribution ID: **32** Type: **Talk**

# Imperfect models and constraints: stellar kinematic constraints fail to correctly break the mass sheet degeneracy at the 1% level

Because of the mass sheet degeneracy (MSD), lensing information alone is incomplete to constrain H_0. To break the degeneracy, assumptions are made through the modeling process about the mass profile of a galaxy e.g. it follows a power law. If the actual galaxy does not perfectly match the model profile, the recovered value of H_0 can be biased. Common practice is to improve the fit using constraints from stellar kinematic information, but this practice also must include assumptions about a profile shape which may be imperfect. I present results from a test study where synthetic lenses are created and fit with a power-law model which does not perfectly match the true profile. Through placing constraints on the fitting process analogous to stellar kinematic constraints, I find that the velocity dispersion constraint can actually introduce more bias than its omission if the kinematic model is misinformed. This surprising result may indicate that the constraints from stellar kinematics could be biasing the lensing determinations of H_0. This concerning finding merits further investigation.

**Presenter:** MATTHEW GOMER

Contribution ID: **33** Type: **Talk**

# Astrometric lensing signatures of IMBHs with the Gaia space mission

Intermediate mass black holes represent the apparent mass gap (10-10000 solar masses) between the well known populations of black holes: stellar-mass and supermassive black holes. They are thought to be the 'seeds' from which SMBHs grow, necessary to explain why there are SMBHs observed in the early Universe. There could be primordial black holes in the IMBH range; although observational constraints exclude sufficient representation of PBHs to contribute significantly to dark matter in most mass ranges, the main ones still considered are the asteroid-like and the IMBH mass range. However, despite their importance, IMBHs are still an obscure class of objects with only a handful of candidates.

We are proposing to search for dark matter in the form of IMBHs. For this purpose, we plan to look for lensing events caused by black holes from the mass range of 100-10000 solar masses. These events could be observed in the upcoming Gaia data as astrometric lensing, and some of them could be resolved. With this approach, new IMBH candidates could be discovered and their properties measured. I will show simulations of potential events and discuss plans for the future of this project.

**Presenter:** ZOFIA KACZMAREK

Contribution ID: **34** Type: **Talk**

# The impact of line-of-sight structures on measuring H0 with strong lensing time-delays

Measurements of The Hubble-Lemaitre constant from early- and local-universe observations show a significant discrepancy. In an attempt to understand the origin of this mismatch, independent techniques to measure H0 are required. One such technique, strong lensing time delays, is set to become a leading contender amongst the myriad methods due to forthcoming large strong lens samples. It is therefore critical to understand the systematic effects inherent in this method. In this paper, we quantify the influence of additional structures along the line-of-sight by adopting realistic lightcones derived from the CosmoDC2 semi-analytical extragalactic catalogue. Using multiple lens plane ray-tracing to create a set of simulated strong lensing systems, we have investigated the impact of line-of-sight structures on time-delay measurements and in turn, on the inferred value of H0. We have also tested the reliability of existing procedures for correcting for line-of-sight effects. We find that if the integrated contribution of the of line-of-sight structures is close to a uniform mass sheet, the bias in H0 can be adequately corrected by including a constant external convergencek_{ext} in the lens model. However, for realistic line-of-sight structures comprising many galaxies at different redshifts, this simple correction over-estimates the bias by a factor of approximately three. We therefore conclude that lens modelling must incorporate multiple lens planes to account for line-of-sight structures for accurate and precise inference of H0.

**Presenter:** NAN LI

Contribution ID: **35** Type: **Talk**

# The COSMOGRAIL project: past, on-going and future lensed quasars monitoring campaigns

I will present the latest release of the COSMOGRAIL lensed quasar light curves. This dataset constitutes a unique sample of decade long and well sampled light curves, useful for time-delay cosmography, to measure the size of the quasar accretion disk and to study the quasar variability. I will show how we robustly measure the time delays in the presence of microlensing and how this microlensing signal can be extracted from the data. I will also explain how the monitoring strategy is now changing with high cadence observations that allow us to obtain accurate time-delay estimates in only one season. I will conclude my talk with the future prospects to achieve the goal of building a sample of 50 strongly lens systems with known time delays.

**Presenter:** MARTIN MILLON

Contribution ID: **36** Type: **Talk**

# Efficient mass modeling of strong lenses through deep learning

Strong gravitational lensing is a very powerful, widely used tool for understanding several open questions including properties of dark matter, dark energy, and the expansion of the universe (Hubble constant H0). For all of these applications one needs a mass model of the lens, which is currently often obtained with Markov-chain Monte-Carlo (MCMC) methods via likelihood sampling. This is a very time and resource consuming approach and will be not sufficient for the expected number of lens detections with upcoming surveys like the Rubin Observatory Legacy Survey of Space and Time (LSST) with around 100,000 lenses. Especially for planning follow-up observations of strongly lensed supernovae, which can be used to constrain the Hubble constant H0, a good mass model of the lens system is needed in a very short time. Therefore, we trained a Convolutional Neural Network (CNN) on images of lens galaxy and lensed source galaxy together to predict the five parameters of the Singular Isothermal Ellipsoid (SIE) model (lens center x and y, complex ellipticity which is equivalent to the axis ratio and position angle, and the Einstein radius) as shown in Schuldt et al. (2020). To train, validate, and test the network, we mock up images based on real observed galaxies from the Hyper Suprime-Cam (HSC) for the lens galaxy and from the Hubble Ultra Deep Field (HUDF) as source galaxy with corresponding redshifts. The velocity dispersion and redshift for the lens galaxies are taken from the Sloan Digital Sky Survey (SDSS). We tested different network architectures and also the effect of using only double or quads as images. We find in all tested cases that the neural network perform well for the tested SIE profile, with the Einstein radius recovered within $0.07"(1\,\sigma)$. Based on the obtained model, we can predict the other appearing image positions and corresponding time delays with a fractional difference between the predicted and true time-delay of $\sigma = 0.04$. Based on these promising results, we investigate now a CNN that predicts the parameter values of the SIE profile plus external shear. Our final network is able to estimate the parameter values in fractions of a second on a single Central Processing Unit (CPU), such that we are able to process the huge amount of expected lens detections in the near future.

**Presenter:** STEFAN SCHULDT

Contribution ID: **37** Type: **Talk**

# Extended continuum emission in quasars and its impact on time-delay lightcurves

The accurate photometric monitoring of lensed quasars is instrumental to high precision cosmography from time-delay measurements, and to quasar continuum source size measurements with microlensing. We report recent evidence, from the microlensing spectroscopic study of two broad absorption line quasars, that the quasar continuum emission does not only originate from a compact accretion disc as generally thought. Instead, we show that a substantial fraction of the continuum flux is light emitted in regions much larger than the compact continuum. We briefly discuss non lensing-based evidence for such an "extended continuum emission", supporting its presence in all Active Galactic Nuclei. Because the extended continuum source is less prone to microlensing than the compact emission thought to arise from the accretion disc, the microlensing signal will differ from our models that assume microlensing of a single compact region. We show that this effect distorts time delay-lightcurves in a subtle way and discuss its potential impact on time-delay measurements.

**Presenter:** DOMINIQUE SLUSE

Contribution ID: **38** Type: **Talk**

# The H0 bias due to angular structures in lenses

Time-delay cosmography studies generally assume axi-symmetry of the deflector. However, nearby elliptical galaxies show deviation from ellipticity that can be captured by expanding the ellipitical isphotes into higher order Fourier modes. Multipoles of order 4, corresponding to disky or boxy shapes, are the most commonly observed perturbations. We have studied how such azimuthal structures manifest in extended lensed images, and if ignoring them yields any bias on H0 in time delay cosmography studies. Specifically, we have mocked images of a QSO+host source lensed by an elliptical mass distribution perturbed by multipolar components. We assess the detectability of those multipoles by modeling the lensed images without angular structure, using state-of-the-art lens modeling technique. When the S/N of the data is too low, the imprints of those multipoles on the lensed images are hidden in the noise, and the value of H0 inferred from the model is biased by up to several percent. Finally, we discuss the impact of angular structure on H0 inference for the TDCOSMO/H0LICOW sample.

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