

The COSMOS-Web Lens Survey (COWLS) II: Depth, resolution, and NIR coverage from *JWST* reveals 17 spectacular lenses

Guillaume Mahler^{1,2,3}, James W. Nightingale⁴, Natalie B. Hogg⁵, Ghassem Gozaliasl^{6,7},
Jacqueline McCleary⁸, Qiuhan He^{2,3}, Edward Berman⁸, Maximilien Franco⁹, Daizhong Liu¹⁰,
Richard J. Massey^{1,2,★}, Wilfried Mercier¹¹, Diana Scognamiglio¹², Marko Shuntov^{13,14},
Maximilian von Wietersheim-Kramsta¹², Louise Paquereau¹⁵, Olivier Ilbert¹¹, Natalie Allen^{12,13},
Sune Toft^{12,13}, Hollis B. Akins⁹, Caitlin M. Casey^{9,13,16}, Jeyhan S. Kartaltepe¹⁷, Anton
M. Koekemoer¹⁸, Henry Joy McCracken¹⁵, Jason D. Rhodes¹², Brant E. Robertson¹⁹, Jorge
A. Zavala²⁰, Nicole E. Drakos²¹, Andreas L. Faisst²², Georgios E. Magdis^{13,14,23} and
Shuowen Jin^{13,23}

Affiliations are listed at the end of the paper

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ABSTRACT

The COSMOS-Web Lens Survey (COWLS) presents the first systematic search for strong gravitational lenses in the COSMOS-Web field using data from the *James Webb Space Telescope* (*JWST*). Using high-resolution NIRC*am* imaging, we visually inspected over 42 660 galaxies and identified over 400 lensing candidates. Here, we report the 17 most obvious and spectacular strong lensing systems, distinguished by large Einstein rings, arcs, and distinct lens and source colours. These diverse lenses, identified only through visual inspection of lens-light-subtracted images, represent the extremes of lens parameter space. Exceptionally high signal-to-noise, multiwavelength imaging enables unprecedented lensing analysis, including ‘*HST*-dark’ source galaxies that are also invisible in deeper but bluer *JWST* wavebands: enabling clean deblending between the lens and the source. Some sources exhibit dramatic morphological changes across wavelengths, and patterns of dust absorption within lenses. No other current facility, including the *Hubble Space Telescope*, can discover or image such lenses with comparable detail. We estimate that *JWST* uncovers a new spectacular lens approximately every 10 to 12 NIRC*am* pointings, suggesting that over 40 similar lenses remain undiscovered within its first three years of observations. All COWLS data are publicly available on GitHub.

Key words: Gravitational lensing: strong – galaxies: structure.

1 INTRODUCTION

Observations of strong gravitational lensing enable a wealth of science. The underlying mass distribution of the deflectors can be probed (Auger et al. 2010; Oguri, Rusu & Falco 2014; Sonnenfeld et al. 2015; Van de Vyvere et al. 2022; Etherington et al. 2023), the stellar-to-halo mass relation and the initial mass function of galaxies can be constrained (Smith, Lucey & Conroy 2015; Wang et al. 2024), and sub-structure present in the halo of the deflector or along the line of sight can be detected (Vegetti et al. 2012; Hezaveh et al. 2016; Nierenberg et al. 2020; Nightingale et al. 2024). Strong lensing systems enable detailed study of distant, magnified sources, from star-forming galaxies (Jones et al. 2013; Zavala et al. 2018) to Type Ia supernovae (Goobar et al. 2017, 2023) and quasars (Sluse et al. 2019); the latter two are particularly significant as they provide a cosmological model independent measurement of the Hubble parameter H_0 via the delay between the arrival times of

the multiple images (Refsdal 1964; Treu & Marshall 2016; Birrer et al. 2020, 2024).

All of this science relies on the search for lenses. These searches can commence with ground-based observations, or directly from space. Often, promising lens candidates identified in ground-based surveys are followed up with imaging from space for higher spatial resolution: the most prominent example of this strategy is the Sloan Lens ACS (SLACS) survey (Bolton et al. 2006), which followed-up candidates identified in the Sloan Digital Sky Survey (SDSS) with the *Hubble Space Telescope* (*HST*). Commencing directly from space, the COSMOS survey imaged a 1.64 deg² area of sky with *HST*, making it, at the time, the largest contiguous high-resolution astronomical imaging survey ever performed from space (Koekemoer et al. 2007; Scoville et al. 2007). The single-band COSMOS *HST* imaging revealed 271 strong gravitational lens candidates (Faure et al. 2008; Jackson 2008; Pourrahmani, Nayyeri & Cooray 2018). Space-based *HST* imaging offered a clear boost in resolution for lens searches (50 mas pixel^{−1} for the ACS camera) compared to ground-based imaging (which is limited by $\gtrsim 0.6$ arcsec

* E-mail: r.j.massey@durham.ac.uk

seeing), however it is still insufficient to unambiguously confirm true lenses.

More recently, the *Euclid* space mission (Euclid Collaboration 2022, 2024) starting surveying 15 000 deg² with a resolution similar to that of *HST*. Such a large sky coverage enables the discovery of very nearby lenses (O’Riordan et al. 2025). The *Euclid* early release observations (Cuillandre et al. 2024), already yielded numerous candidate based on visual inspection (Acevedo Barroso et al. 2024) and machine learning detection algorithms (Pearce-Casey et al. 2024; Nagam et al. 2025). Over the entire 15 000 deg² of the *Euclid* survey, about $\mathcal{O}(10^5)$ strong lenses are expected to be observed (Collett 2015; Holloway et al. 2023; Ferrami & Wyithe 2024). More recently, the *Euclid* quick data release, Q1, delivered the first searches and algorithm development for this large data challenge (Euclid Collaboration 2025a, b, c, d, e, f, g).

As part of the COSMOS-Web survey (Casey et al. 2023), *JWST* observed a 0.54 deg² subset of the COSMOS field using its near infrared camera (NIRCam) and mid-infrared instrument (MIRI).¹ We present results from the COSMOS-Web Lens Survey (COWLS), demonstrating how many ‘spectacular’ strong lenses are immediately recognizable by eye in *JWST* NIRCam imaging with minimal pre-processing. Starting with deep *JWST* imaging uncovers lenses at the extremes of lensing parameter space, that ground-based or wide-field imaging based selection (e.g. *Euclid*) will miss. NIRCam offers 5 to 10 times higher resolution than *Euclid*, with 63 and 31 mas.pixel⁻¹ for NIRCam long and short wavelength channels). Additionally, the 200–1000s exposures of the COSMOS web survey Casey et al. (2023) reach 3 to 4 mag deeper than *Euclid* NISP survey (Euclid Collaboration 2022, 2024). NIRCam provides unmatched resolution and signal-to-noise over four wavebands, which we show enables unique studies of high redshift source galaxies, detailed lens mass modelling and even dust absorption. Comparison with COSMOS F814W *HST* imaging shows that only a fraction of these lenses would be confidently identified as strong lenses from *HST*, and none would offer the visible-to-NIR wavelength coverage essential for rich scientific study. We found our 17 spectacular strong lenses in just 0.54 deg² of COSMOS-Web NIRCam data, we therefore estimate how many unreported spectacular lenses *JWST* has observed over 3 yr since launch.

In COWLS Paper I (Nightingale et al. 2025), we present the inspection campaign using the automated lens modelling software PyAutoLens (<https://github.com/Jammy2211/PyAutoLens>) (Nightingale & Dye 2015; Nightingale, Dye & Massey 2018; Nightingale et al. 2021). This campaign identifies over 100 highly ranked candidates, including the highest redshift lenses ($z > 2$) and sources ($z > 5$) known to date. All lenses are located within the 0.54 deg² COSMOS-Web field, which allows for joint strong and weak-lensing analyses (Birrer et al. 2017; Fleury, Larena & Uzan 2021; Hogg et al. 2023, 2025b). A sub-set of these lenses have small lens-source separations, providing the potential for measuring supermassive black hole masses (Nightingale et al. 2024). In COWLS Paper III (Hogg et al. 2025a), we compare the observed properties and abundance of COSMOS-Web strong lenses with predictions based on the COWLS catalogue. One spectacular lens, the COSMOS-Web Ring (Mercier et al. 2024; van Dokkum et al. 2024), was recently spectroscopically confirmed to be the highest redshift known galaxy-scale lens galaxy ($z = 2.02$) and have a $z = 5.10$ source galaxy (Shuntov et al. 2025b), highlighting the unique nature of the lenses presented in this letter.

This work is organized as follows: in Section 2 we describe how our data was taken and catalogued; in Section 3 we present the spectacular strong lenses and the method used to identify them; in Section 4 we discuss our results and conclusions. All magnitudes are given in the AB system (Oke 1974).

2 THE COSMOS-WEB DATA

2.1 Imaging

The *JWST* Cycle 1 programme COSMOS-Web (GO#1727, PI: Casey & Kartaltepe, Casey et al. 2023), is a photometric survey that consists of imaging in four NIRCam filters (*F115W*, *F150W*, *F277W*, *F444W*) and one MIRI filter (*F770W*). The NIRCam (MIRI) filters reach a 5σ point source depth of AB mag 27.2–28.2 (25.7), measured in empty apertures of 0.15 arcsec (0.3 arcsec) radius.

2.2 Photometric catalogue

The COSMOS-Web team produced a unified photometric catalogue including an automated morphological analysis, based on SourceExtractor++ photometric software (Bertin et al. 2020; Kümmel et al. 2020), which is fully described in Shuntov et al. (2025a). We provide here the relevant characteristics of the catalogue used for our selection. The initial morphological analysis includes a morphological profile fit of the galaxy in each band with one or two Sérsic profiles. In addition, the software produces a stellarity coefficient ranging from 0 to 1 based on how close to a point-like feature the detection is; for example, an object with a stellarity of 1 is star-like. This process yields a robust photometry for galaxies, and an image with the model of the light distribution derived from the fitted profile. This model is then subtracted from the original image and visually inspect for deviations from the profile. All three types of image (original, model image, and model-subtracted images) are used during our search for strong lenses (see fig. 4 of COWLS Paper I, Nightingale et al. 2025).

2.3 Selection of objects to inspect

Starting from this photometric catalogue presented in Shuntov et al. (2025a), we selected all galaxies brighter than 23 AB mag in *F277W* and with a stellarity strictly below 1. A galaxy with an apparent magnitude of 23 is relatively faint; we chose this as a conservative cut-off to select for objects massive enough to be strong lenses whilst still imposing a reasonable limit on the total number of objects to visually inspect. This selection resulted in 42 660 objects to be inspected for signs of strong lensing. A magnitude cut of 23 in the *F277W* band represents a median and 68th percentile stellar mass of $(3.8 \pm 3.3) \times 10^8 M_\odot$, $(2.9 \pm 2.6) \times 10^9 M_\odot$, and $(6 \pm 6) \times 10^9 M_\odot$ at $z = 0.3 \pm 0.05$, $z = 1.0 \pm 0.1$, and $z = 2.0 \pm 0.1$. For the estimated number of galaxies acting as a lens within this parameter space, we refer the reader to COWLS Paper III, Hogg et al. (2025a).

3 SPECTACULAR STRONG LENSES IN COSMOS-WEB

Visual inspection of the COSMOS-Web field was carried out in two stages and is fully described in the overview paper (COWLS Paper I, Nightingale et al. 2025). We here provide a short description of the process which led to the systems highlighted in this paper. In the first stage, inspectors examined the original image, model image, and model-subtracted image of each object. This round of inspection

¹The MIRI observations cover a 0.19 deg² area.

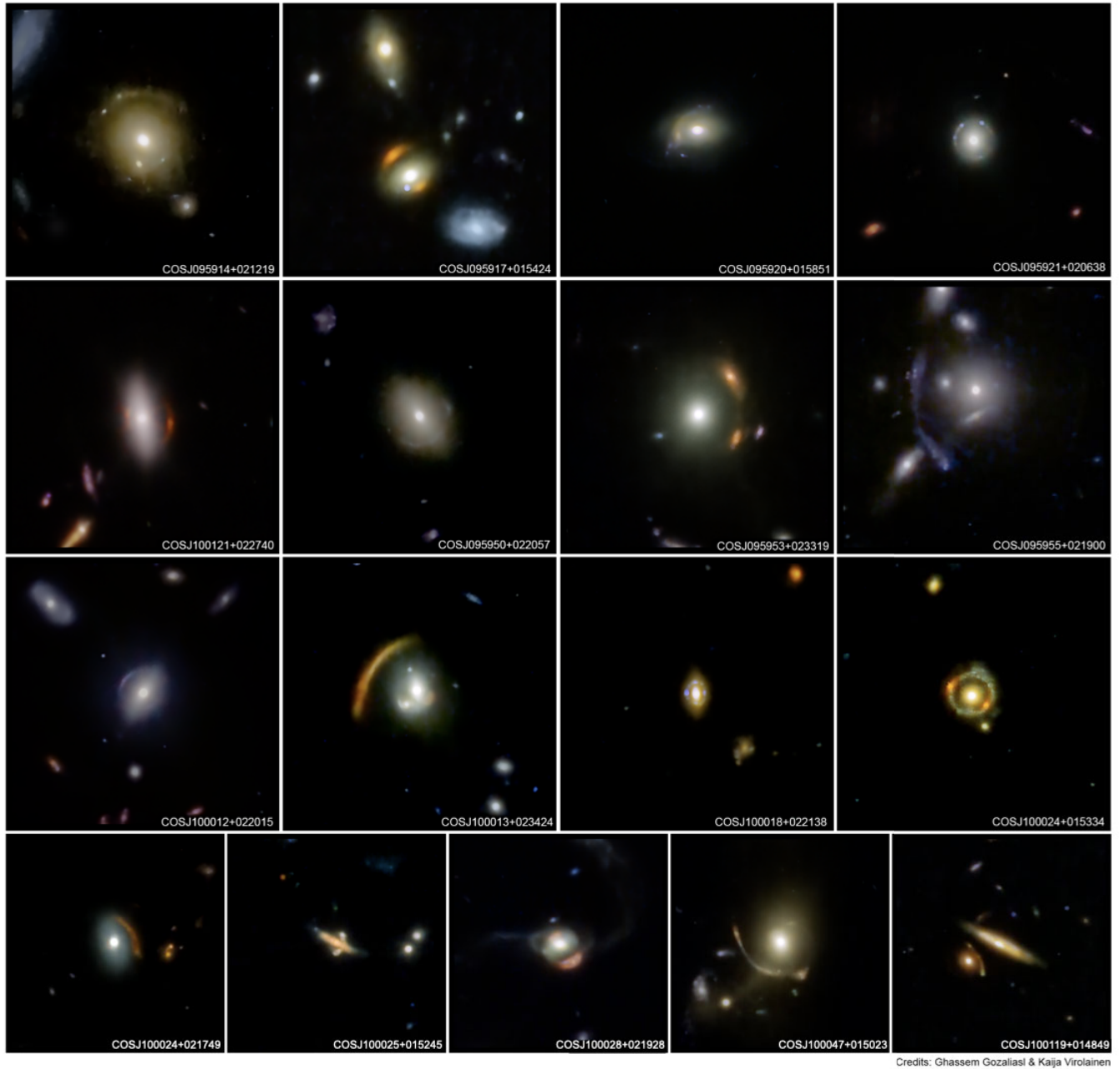


Figure 1. The 17 most spectacular lenses from the COWLS sample, revealed by the *JWST* imaging through our visual inspection of the COSMOS-Web field. Each images were resampled on to a North up and East left orientation from the native 20 deg orientation. Each panel is 18.9×18.9 arcsec. The images are produced combining the four filters (*F115W*, *F150W*, *F277W*, *F444W*) for an ideal rendering of the lensing evidence.

relied on a rapid visualization of all 42 660 objects, designed to yield a decision by each inspector within a few seconds. Each object was presented to the inspectors with six different images: the image data, model, and model-subtracted images in two different filter combinations: *F115W/F150W/F444W* and *F115W/F277W/F444W*. Using the model-subtracted image meant inspectors were better able to spot lensed light closer to the central part of the lens, usually much brighter in the detection image. Fig. 3 demonstrates how lens-light subtraction is able to reveal counter images close to the centre of a lens (see also fig. 4 in COWLS Paper I, Nightingale et al. 2025, showing COSJ100024+015334, which is also known as

the COSMOS-Web ring; Mercier et al. 2024; Dokkum et al. 2024; Shuntov et al. 2025b).

Each galaxy was classified by at least four inspectors as: ‘Yes, this is a lens’, ‘No, this is not a lens’, ‘Maybe this is a lens’, ‘Revisit later’, and ‘User category’. Revisit later offered the inspectors the chance to go back and spend more time on the inspection of ambiguous objects, and the ‘User category’ allowed inspectors to flag galaxies of interest beyond the search for strong lenses. The data for the first round of visual inspection were split in half, with the first half inspected by four people (GM, JWN, QH, and JMcC) and the second half by five people (GM, JWN, NBH, QH, and JMcC).

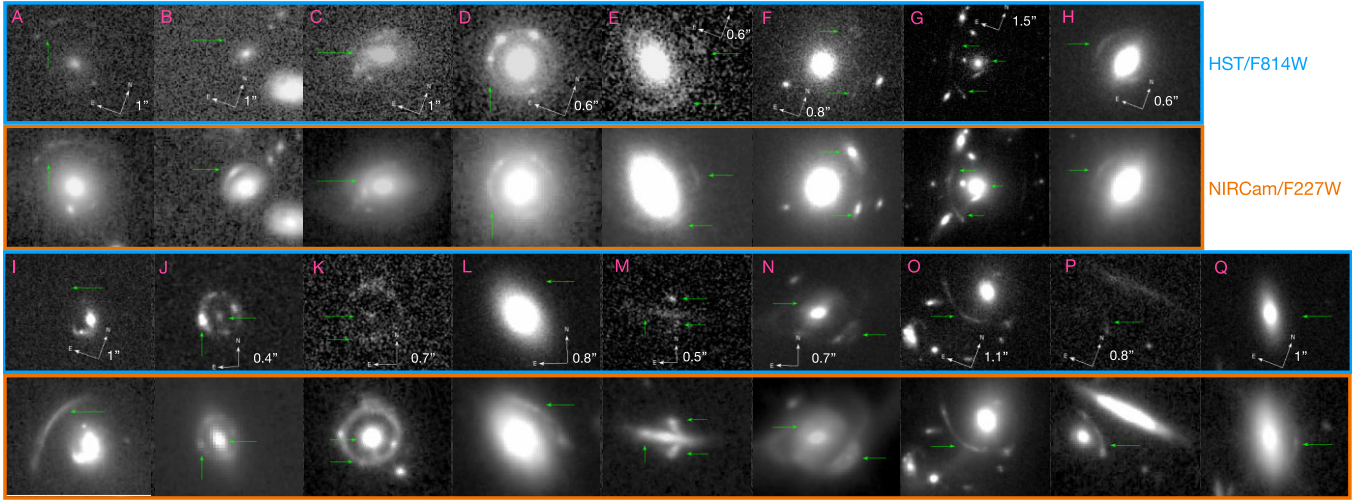


Figure 2. A comparison of features from the *HST* ACS/F814W filter and the *JWST* NIRCAM/F227W filter for the 17 lenses presented in this work. We emphasize the power of *JWST* images to reveal clear evidence of gravitational lensing, showing how this observatory has the capacity to discover new, spectacular lenses. The greyscale scaling has been tuned for each image in order to better see the lens, the lensed images and a visual appreciation of the noise level. So as not to clutter the image we use a letter designation for each target, reported in Table 1.

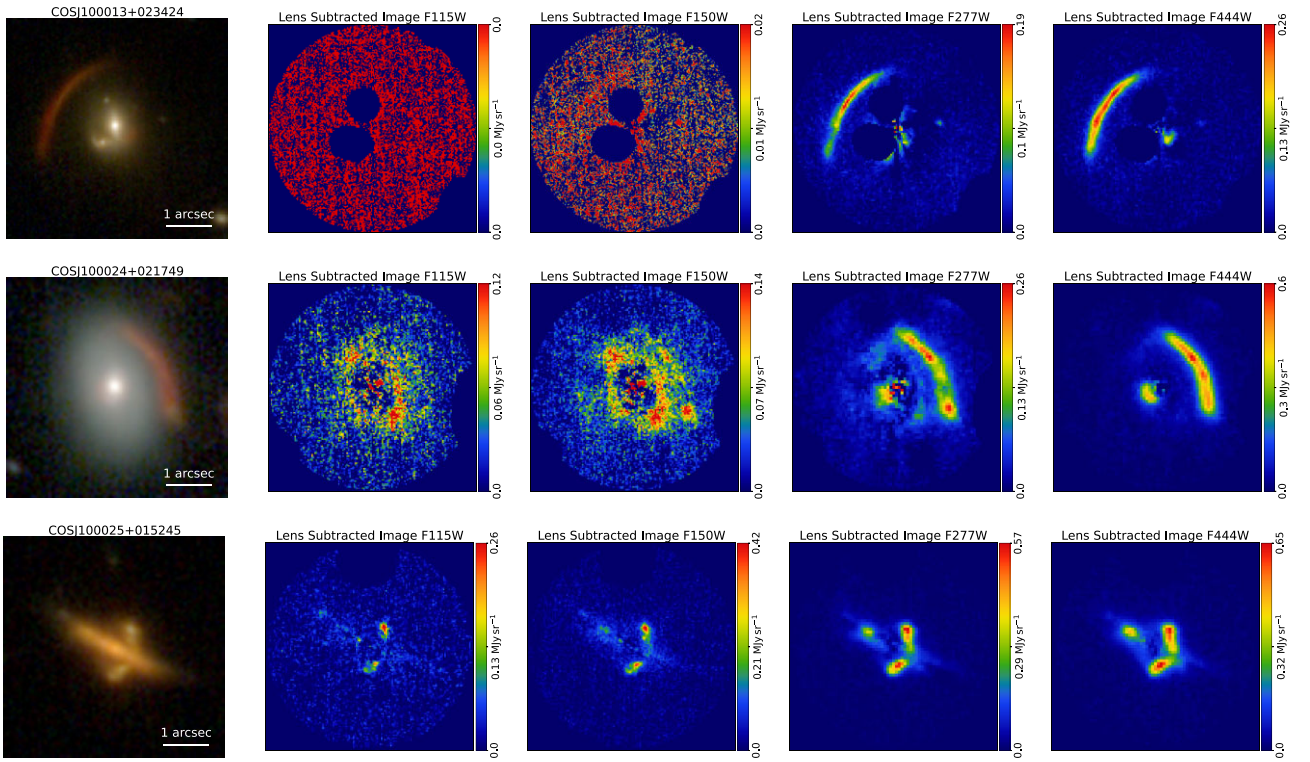


Figure 3. Three illustrative examples demonstrating how the high S/N multiwavelength imaging of *JWST* provides new insights for lens modelling. The left column shows RGB images constructed from all four wavebands, the next four columns display lens-subtracted images for individual wavebands (F115W, F150W, F277W, F444W), using PyAutoLens lens models from COWLS Paper I. The three example lenses from top to bottom illustrate: (i) COSJ100013+023424: how *HST*-dark sources are also invisible in shorter wavelength F115W and F150W imaging, leaving only the lens light visible and making lens and source deblending easier. (ii) COSJ100024+021749: how the source morphology may change significant across different wavelengths, where in this lens at F115W/F150W wavelengths a quadruply imaged ring is observed compared to cusp like giant arc at F277W/F444W wavelengths. Combining multiwavelength data sets like this will provide significantly more constraints on the lens mass model. (iii) COSJ100025+015245: how shorter wavelength emission from the source can be absorbed by dust in the lens galaxy.

Table 1. The 17 spectacular lenses from the COWLS sample revealed by our visual inspection, ordered by Right Ascension. The first column gives the ID from the larger catalogue published in Shuntov et al. (2025a). The second column gives the ID letter matching Fig. 2. The third and fourth columns show the Right Ascension and Declination of the lenses, respectively. The fifth column gives the Einstein radius of the lens derived from the lens modelling performed in Nightingale et al. (2025). The sixth column gives the lens redshift where known, where ^a denotes a spectroscopic redshift from DESI (Dey et al. 2019), ^b denotes a photometric redshift from the COSMOS-Web catalogue (Shuntov et al. 2025a), and ^c denotes a spectroscopic redshift from van der Wel et al. (2013). The seventh column gives the source redshift where known, where ^d denotes a spectroscopic redshift from Shuntov et al. (2025b) and ^e denotes a spectroscopic redshift from Jin et al. (2024). Object L was first reported as a bright source in Jin et al. (2018), and identified as a lens in Simpson et al. (2020), and Gillman et al. (2024) and later model in Pearson et al. (2024). The last column gives references to systems that were previously known from other wavelength surveys.

COWLS ID	ID	RA (deg)	Dec. (deg)	Lens m_{F277W}	$\log_{10}$ ($M_*/M_\odot$)	θ_E (arcsec)	z_{lens}	z_{source}	Identification
COSJ095914+021219	A	149.811421524	2.205440107	16.81	11.300	1.48	1.053 ^a		Faure et al. (2008)
COSJ095917+015424	B	149.821462195	1.906873033	18.02	10.898	0.58	1.252 ^b		This work
COSJ095920+015851	C	149.833887486	1.980927007	16.57	11.244	0.45	0.974 ^a		This work
COSJ095921+020638	D	149.840689409	2.110652506	16.21	10.650	0.71	0.469 ^a		Faure et al. (2008)
COSJ095950+022057	E	149.961430320	2.349411544	16.47	11.150	1.04	0.939 ^a		Pourrahmani et al. (2018)
COSJ095953+023319	F	149.974678146	2.555445653	15.62	11.500	1.44	0.731 ^a		This work
COSJ095955+021900	G	149.983162054	2.316880570	15.98	10.400	2.11	0.577 ^b		More et al. (2012)
COSJ100012+022015	H	150.052588227	2.337706469	15.54	11.050	0.75	0.377 ^a		Faure et al. (2008)
COSJ100013+023424	I	150.055775328	2.573347012	17.02	10.950	1.45	0.890 ^b		This work
COSJ100018+022138	J	150.076934522	2.360757128	18.89	10.794	0.38	1.53 ^c	3.42 ^c	van der Wel et al. (2013)
COSJ100024+015334	K	150.100467215	1.893029318	18.64	10.250	0.77	2.02 ^b	5.10 ^d	Mercier et al. (2024)
COSJ100024+021749	L	150.100088848	2.297132757	16.53	10.500	0.73	0.362 ^a	2.63 ^e	Simpson et al. (2020), Jin et al. (2024)
COSJ100025+015245	M	150.106707900	1.879287103	19.23	10.396	0.53	2.449 ^b		This work
COSJ100028+021928	N	150.119067171	2.324503234	16.28	11.000	0.66	0.604 ^a		This work
COSJ100047+015023	O	150.198584092	1.839784559	16.08	11.441	1.62	0.893 ^a		Faure et al. (2008)
COSJ100119+014849	P	150.330525811	1.813616188	19.17		1.14			This work
COSJ100121+022740	Q	150.341363020	2.461297053	15.89	10.819	0.86	0.371 ^a		This work

From the initial 42 660 objects, 32 objects were flagged as ‘Yes’ by more than 50 per cent of inspectors. These candidates were reviewed again by six members of the COSMOS-Web Lensing Working Group (GM, JWN, NBH, QH, MvWK, and RJM), who each flagged which systems they thought were the most obvious lenses, showing dramatic lensing evidence, even in the absence of spectroscopy. Of these 32 objects, 17 were confidently flagged by three or more inspectors as secure lenses. This sample, based solely on NIRCам imaging inspection, was dubbed the 17 most spectacular lenses and is presented in Fig. 1. In the next section, we discuss the specific features that support this ranking.

4 DISCUSSION

The sample selection resulting from visual inspection is not simple. Selection relies on a combination of pattern recognition, including multiwavelength colour-contrast between a lens and source galaxy; the characteristic arc-shaped morphology, or recognition of multiple images in predictable locations from known lensing configurations; and patterns in separate images. Multiwavelength imaging in particular means that lenses can be unambiguously selected based on the distinct colour differences between the lower redshift lenses and higher redshift sources. The combination of depth, resolution and near-infrared coverage provided by NIRCам allows for clear identification of lensing features that were in the past ambiguous, thanks to well-resolved spatial separations between lens galaxies and their respective lensed source light, and the colour separation enabled by the multiwavelength coverage.

The lenses have stellar masses ranging from $10^{10.3}$ to $10^{11.5} M_\odot$; Einstein radii 0.45 to 2.11 arcsec; lens $F277W$ magnitudes 19.23 to 15.89 AB_{mag} ; and lensed image (in the band with the highest signal-to-noise ratio) from 24.5 to 20.5 AB_{mag} . Interestingly, no combination of such parameters clearly isolates our selection function. The only marginal correlation we find is that securely identified systems tend to have high-stellar mass: this is merely indicative of the fact that massive lenses produce a clearer lensing pattern than less-massive counterparts. A larger sample, or an in-depth analysis of pattern recognition might make it possible to quantify the human selection function, but that is beyond the scope of this work.

The larger sample of 100 lenses is more predictable, at least in number. The prediction of about 100 lenses initially estimated to be in the COSMOS-Web field (Casey et al. 2023; see also Holloway et al. 2023; Ferrami & Wyithe 2024), is well-matched by the full COWLS sample (COWLS Paper I, Nightingale et al. 2025). The estimation of Casey et al. (2023) was a simple calculation based on previous visual inspection efforts of *HST* observations in the same field. In COWLS Paper III, Hogg et al. (2025a), we present a simulation-based estimate of lens abundance and properties in the COSMOS-Web field, and compare the result with the observed COWLS lenses. This paves the way for characterization of the larger sample’s selection function.

Some lenses were previously known or suspected, (see Table 1, and a comparison of NIRCам images with previous *HST*/*F814W* coverage in Fig. 2). Lens J was confirmed with *HST* (van der Wel et al. 2013) and shows clear evidence for lensing in both *HST* and *JWST* data. Lens L was confirmed using sub-millimetre and far-infrared deblending techniques (Jin et al. 2018, 2024), but is not

detected in *HST* (or NIRC*am*/F115*W* imaging, which is ~ 1 mag deeper). Lens G was discovered in ground-based Canada–France–Hawaii Telescope Legacy Survey imaging (More et al. 2012) and is clearly visible in both *HST* and *JWST*. Five lenses (A, D, E, H, and O) were candidates in searches of *HST* images (Faure et al. 2008; Pourrahmani et al. 2018), with previous classifications ranging from convincing (D and O) to more speculative.

Nine of our lenses were identified for the first time by COWLS, including the COSMOS-Web ring. With hindsight, source emission is visible in *HST* imaging of six of these (C, F, M, N, K, and P), but with insufficient clarity for them to have been previously suspected. Lens C exemplifies the critical role of NIRC*am*'s high-resolution imaging to identify lenses. Its arc is apparent in *HST* but poorly resolved, whilst unambiguously the product of strong lensing in the *JWST* image (Fig. 2). Our sample includes four (B, I, L, and Q) *HST*-dark lensed galaxies (Pérez-González et al. 2023).

The diversity of the 17 lenses presented here, presents an opportunity for a range of scientific investigations (each of which might use a sub-sample of those identified here) lenses. Fig. 3 illustrates this for three example lenses, showing colour images alongside individual lens-subtracted images in each waveband (F115*W*, F150*W*, F277*W*, F444*W*). *HST*-dark sources result in the source being undetected at bluer wavelengths, leaving only the lens visible. This allows for a cleaner deblending of lens and source light than is possible in *HST* lens data sets. For many spectacular lenses, the source morphology changes dramatically across wavelengths, altering the observed image-plane structure and providing significantly more constraints on the lens mass model. Additionally, dust absorption in the source can be directly observed when comparing images from redder to bluer bands, offering insights not previously accessible. Some of our spectacular lenses show near-full Einstein rings (D and K) enabling accurate constraints on the lens mass; a large surface area of lensed images (I, K, N, and O) enabling efficient search dark sub-haloes; or a highly magnified source (E, J, and K) enabling study of resolved properties of distant galaxies.

5 CONCLUSIONS

We present the 17 most spectacular galaxy-scale strong gravitational lenses identified after visual inspection of 42 660 objects observed with NIRC*am*. Not only does *JWST*/NIRC*am* find strong lenses at an unprecedented rate (over 100 high-confidence candidates in the full catalogue; Nightingale et al. 2025), but it reveals spectacular systems that experts classify as unambiguous lenses, even before spectroscopic follow-up. Initial follow-up has shown that the sample includes some of the highest redshift known sources ($z > 5$) and lenses ($z > 2$). It includes systems with small lens-source separations that may enable supermassive black hole mass measurements. Moreover, the lenses all reside within a compact 0.54 deg^2 region, enabling e.g. joint strong and weak-lensing analysis.

This initiates a new era of strong lensing discovery. Multiwavelength NIRC*am* data was key to identifying these spectacular and unique systems, with the promise of more such lenses to be discovered in all future NIRC*am* observations. By extrapolating the number of lenses found per NIRC*am* field of view, we predict that every 10 to 12 extragalactic NIRC*am* pointings will reveal a spectacular strong lens, depending whether or not the chip gap between Module A and B is covered. This means that surveys such as Bias-free Extragalactic Analysis for Cosmic Origins with NIRC*am* (BEACON) should yield six spectacular lenses in its 0.2 deg^2 area; the cosmic evolution early-release science survey (CEERS) and *JWST* advanced deep extragalactic survey (JADES) will each contain three lenses in their 0.1 deg^2 areas. Collecting such a high confidence data set will be a

foundation for further selection on specific properties of the lens or the lensed galaxies.

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DATA AVAILABILITY

The data underlying this article are available in the COWLS repository (https://github.com/Jammy2211/COWLS_COSMOS_Web_Lens_Survey).

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- ¹Department of Physics, Centre for Extragalactic Astronomy, Durham University, South Road, Durham DH1 3LE, UK
- ²Department of Physics, Institute for Computational Cosmology, Durham University, South Road, Durham DH1 3LE, UK
- ³STAR Institute, Quartier Agora – Allée du six Août, 19c B-4000 Liège, Belgium
- ⁴School of Mathematics, Statistics and Physics, Newcastle University, Herschel Building, Newcastle-upon-Tyne NE1 7RU, UK
- ⁵Laboratoire Univers et Particules de Montpellier, CNRS & Université de Montpellier, Parvis Alexander Grothendieck, F-34090 Montpellier, France
- ⁶Department of Computer Science, Aalto University, PO Box 15400, FI-00076 Espoo, Finland
- ⁷Department of Physics, Faculty of Science, University of Helsinki, FI-00014 Helsinki, Finland
- ⁸Department of Physics, Northeastern University, 360 Huntington Ave, Boston, MA 02115, USA
- ⁹Department of Astronomy, The University of Texas at Austin, 2515 Speedway, Austin, TX 78712, USA
- ¹⁰Purple Mountain Observatory, Chinese Academy of Sciences, 10 Yuanhua Road, Nanjing 210023, China
- ¹¹Laboratoire d’astrophysique de Marseille, Aix Marseille University, CNRS, CNES, Marseille 34090, France
- ¹²Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91011, USA
- ¹³Cosmic Dawn Centre (DAWN), Rådmandsgade 64, 2200 København N., Denmark
- ¹⁴Niels Bohr Institute, University of Copenhagen, Jagtvej 128, DK-2200 Copenhagen, Denmark
- ¹⁵Institut d’Astrophysique de Paris, UMR 7095, CNRS, Sorbonne Université, 98 bis boulevard Arago, F-75014 Paris, France
- ¹⁶Department of Physics, University of California, Santa Barbara, CA 93106, USA
- ¹⁷Laboratory for Multiwavelength Astrophysics, School of Physics and Astronomy, Rochester Institute of Technology, 84 Lomb Memorial Drive, Rochester, NY 14623, USA
- ¹⁸Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA
- ¹⁹Department of Astronomy and Astrophysics, University of California, Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, USA
- ²⁰National Astronomical Observatory of Japan, 2-21-1, Osawa, Mitaka, Tokyo 181-8588, Japan
- ²¹Department of Physics and Astronomy, University of Hawaii, Hilo, 200 W Kawili St, Hilo, HI 96720, USA
- ²²Caltech/IPAC, 1200 E. California Blvd., Pasadena, CA 91125, USA
- ²³DTU-Space, Technical University of Denmark, Elektrovej 327, DK-2800 Kgs. Lyngby, Denmark

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