

An ultra-high-resolution map of (dark) matter

Received: 4 June 2025

Accepted: 9 December 2025

Published online: 26 January 2026

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Ordinary matter—including particles such as protons and neutrons—accounts for only about one-sixth of all matter in the Universe. The rest is dark matter, which does not emit or absorb light but plays a fundamental role in galaxy and structure evolution. Because it interacts only through gravity, one of the most direct probes is weak gravitational lensing: the deflection of light from distant galaxies by intervening mass. Here we present an extremely detailed, wide-area weak-lensing mass map covering $0.77^\circ \times 0.70^\circ$, using high-resolution imaging from the James Webb Space Telescope as part of the COSMOS-Web survey. By measuring the shapes of 129 galaxies per square arcminute—many independently in the F115W and F150W bands—we achieve an angular resolution of $1.00 \pm 0.01'$. Our map has more than twice the resolution of earlier Hubble Space Telescope maps, revealing how dark and luminous matter co-evolve across filaments, clusters and underdensities. It traces mass features out to $z \approx 2$, including the most distant structure at $z \approx 1.1$. The sensitivity to high-redshift lensing constrains galaxy environments at the peak of cosmic star formation and sets a high-resolution benchmark for testing theories about the nature of dark matter and the formation of large-scale cosmic structure.

Dark matter forms the gravitational backbone of the Universe, shaping the formation of galaxies and the large-scale structure of the cosmos. Yet, its distribution, particularly on intermediate and small scales, has remained difficult to map. Weak gravitational lensing, the slight but coherent distortion of background galaxy shapes by foreground mass, offers a direct way to probe this elusive component, without relying on assumptions about its physical state. However, weak lensing maps so far have been limited in either resolution or sensitivity, obscuring the fine-grained structures that underpin the cosmic web^{1–3}.

Here, we present a high-resolution mass map over a wide area of sky, derived from weak lensing measurements in the COSMOS-Web field using the James Webb Space Telescope (JWST). By resolving the shapes of 129 galaxies per square arcminute—nearly double the number achieved with the Hubble Space Telescope (HST)—we trace dark matter structures with a spatial resolution of 1 arcmin (Fig. 1). This level of detail enables us to detect not only massive galaxy clusters, but also filamentary structures and underdense regions that were previously inaccessible.

We focus on the COSMOS field—one of the most intensively studied regions of the sky—large enough to encompass a representative

sample of large-scale structure, and covered by deep, high-resolution imaging and spectroscopy from the ultraviolet to the mid-infrared⁴. Located on the celestial equator, it is accessible to observatories in both hemispheres. Decades of observations from nearly all major ground- and space-based telescopes have provided a comprehensive multiwavelength view of this field^{4–10}. These efforts have been substantially extended by 255 h of JWST Near-Infrared Camera (NIRCam) imaging from the COSMOS-Web survey¹⁰, which covers a contiguous area of 0.54 square degrees in four bandpasses (F115W, F150W, F277W and F444W). In this study, we use imaging in the F115W and F150W bands, centred at 1.1 μm and 1.5 μm , respectively, with a spatial resolution of 0.02 arcsec per pixel^{11–13}, to perform shape measurements.

Gravitational lensing affects the path of light from distant galaxies as it travels through the gravitational potential of any mass along the line of sight, including both ordinary baryonic matter (stars, gas and dust) and dark matter^{14,15}. In the weak gravitational lensing regime, this deflection induces a shear distortion of only a few per cent in the apparent shapes of background galaxies¹⁶. This distortion is roughly ten times smaller than the typical intrinsic ellipticity of galaxies, which is shaped by features such as spiral arms or bars. (We ignore ‘intrinsic alignments’

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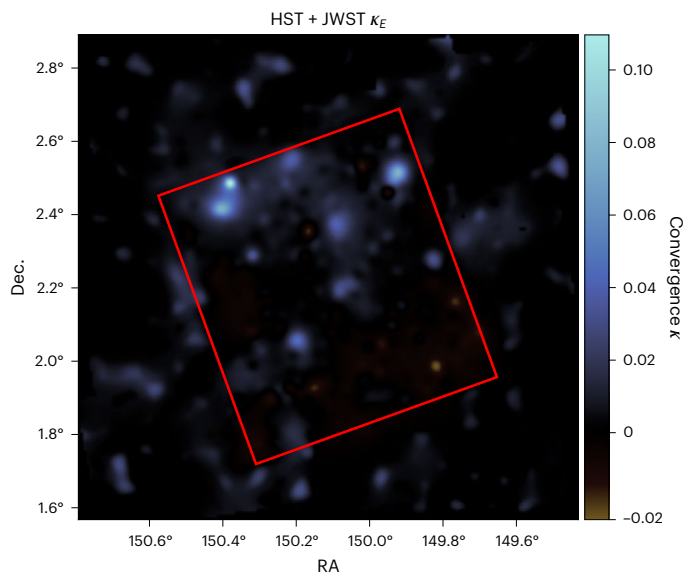


Fig. 1 | Map of cosmic structure, from measurements of weak gravitational lensing with JWST and HST. Colours show the E -mode convergence (κ_E), where positive (blue) regions indicate mass overdensities and negative (brown) regions represent underdensities along the line of sight. The central region, outlined in red, corresponds to the COSMOS-Web footprint observed with JWST at a spatial resolution of $\sigma = 1.0$ arcmin. It is embedded within a wider HST-based map at $\sigma = 2.4$ arcmin resolution, to reduce edge effects and highlight the enhanced resolving power of JWST.

between galaxies that add coherent systematics on smaller scales than probed here but that should be considered in future applications of the shear catalogue.) The resolution of a weak lensing map is therefore the area required to enclose about 100 resolved background galaxies, so that the shear signal rises above the shape noise. This number reflects a trade-off between spatial resolution and statistical uncertainty.

The sensitivity of a weak lensing map also depends on geometry. Like a magnifying glass that works best when held midway between the eye and the object, gravitational lensing is most sensitive to mass located half-way between the observer and the source galaxies. This behaviour is described by the lensing efficiency function $g(z)$, which peaks at lower redshifts (distances) than the distance to typical background objects, described by the source redshift distribution $n(z)$ (Fig. 2a). The lensing efficiency function for JWST peaks at $z = 0.38$, for HST at $z = 0.34$, and for the Subaru Telescope's Hyper-Suprime Camera (HSC) at $z = 0.30$. Unlike most observables, for a fixed angular scale on the sky, weak lensing is insensitive to mass in the very nearby Universe because the lensing efficiency drops to zero as the lens approaches the observer.

Previous weak lensing maps were limited in sensitivity, resolution and area. From the ground, even the best telescopes—such as those used in the HSC, Kilo Degree Survey and Dark Energy Survey surveys—must contend with the blurring effects of Earth's atmosphere and typically resolve the shapes of only 7–19 galaxies per square arcminute (refs. 17–20). These surveys cover a large area of sky, but are limited by coarse angular resolution and are sensitive primarily to structures at low redshift. As a result, only the most massive and extended structures, such as rare superclusters with masses up to 10^{15} masses of the Sun ($M_\odot$), appear prominently in ground-based lensing maps. The HST, which observes above the atmosphere, resolves the shapes of ~71 galaxies per square arcminute (refs. 6, 21, 22), enabling maps with sufficient resolution of ~2.4 arcmin to begin revealing clusters and filamentary features in the cosmic web (using a different definition of resolution⁶, reported 1.2 arcmin resolution; see 'Mass map reconstruction' section in Methods).

JWST's deep, high-resolution imaging enables the measurement of weak lensing from a much larger number of galaxies, and at higher redshifts than previously possible. This improvement is reflected in the relative lensing sensitivity, where JWST outperforms both HSC and HST, particularly at high redshift (Fig. 2b). We measure shear for 108 galaxies per square arcminute in each of F115W and F150W. The final catalogue is constructed from the unique sources in each band, together with those in common for which the two shear estimates are averaged per galaxy, giving an effective density of 129 galaxies per square arcminute. The availability of repeat measurements in two bands helps reduce photon-counting (shot) noise when estimating shear, although the dominant source of uncertainty remains intrinsic shape noise. Multi-wavelength ancillary data provide photometric redshifts for all galaxies (for more details, see 'COSMOS-Web imaging and catalogues' section in Methods). We adopt photometric redshifts from LEPHARE, defined as the median of the likelihood distribution^{23,24}. For the sample of galaxies with measured shapes, this yields a median redshift of $z_{\text{med}} \approx 1.15$ (ref. 12).

Leveraging this dataset, we construct a detailed map of mass in large-scale structure (Fig. 1). Brighter regions indicate lines of sight with higher lensing convergence, which is proportional to the density of dark and luminous matter $\rho(x, y, z)$, multiplied by sensitivity function $g(z)$ and projected on the sky. The JWST shear measurements provide a spatial resolution of 1.00 ± 0.01 arcmin, representing more than a twofold improvement over the previous large-scale COSMOS weak-lensing map obtained with HST⁶. We use a multiscale filtering technique²⁵ that identifies structures at different scales, which are defined as spatial scales in angular units (arcmin), corresponding to physical sizes on the sky. This technique allows us to simultaneously identify both small features, such as halos around galaxy groups at low mass ($\sim 10^{13}$ – $10^{14} M_\odot$) or high redshift ($z \approx 1.1$), as well as the filamentary structures predicted to connect them²⁶.

The enhanced sensitivity to lensing by mass at high redshift ($z > 1$) improves our ability to detect more distant structures, extending the

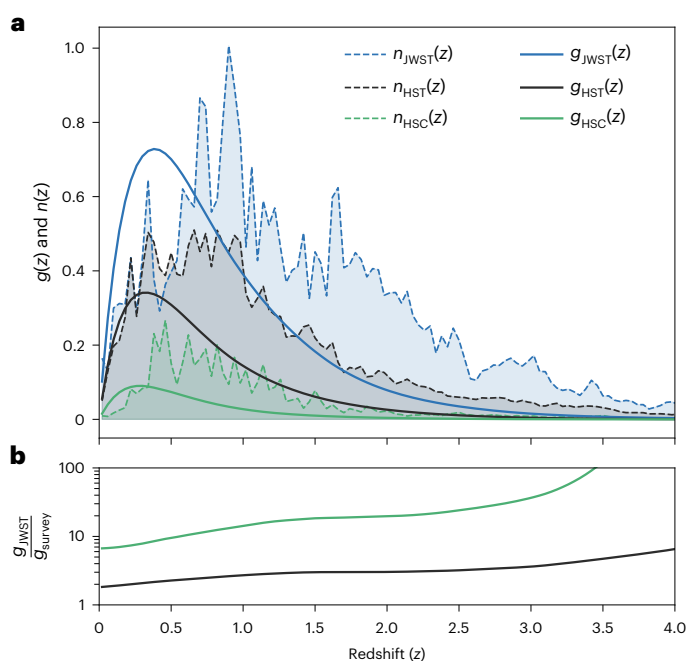


Fig. 2 | Sensitivity of weak lensing to mass at different cosmic distances, quantified by redshift, z . **a**, Dashed lines show the measured number density, $n(z)$ of galaxies whose shapes, distorted by lensing, are resolved by JWST, HST and HSC, in bins of width $\Delta z = 0.04$. JWST resolves the shapes of progressively more distant galaxies than other telescopes. Solid lines show the implied sensitivity functions $g(z)$ to foreground mass. **b**, Ratio of the JWST lensing sensitivity to that of HSC and HST. JWST has higher sensitivity at all redshifts, but especially at high redshift.

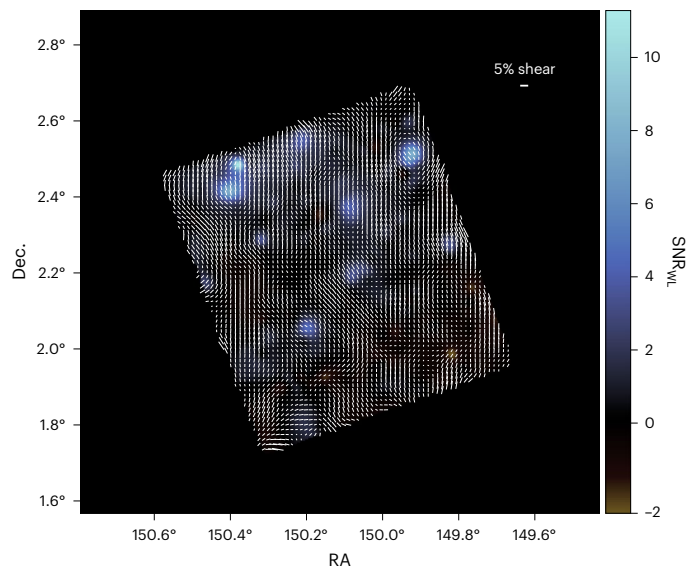


Fig. 3 | Measured shear distortion of distant galaxies. The shapes of all galaxies from F115W and F150W-band imaging are averaged in $1.1' \times 1.1'$ pixels, followed by denoising through smoothing with a Gaussian filter of width $\sigma = 1.2$ arcmin. The white line segments depict the local amplitude and orientation of the shear. The background image shows the signal-to-noise ratio (SNR_{wl}) of the amplitude of the curl-free E -mode component of this pseudo-vector field. The reference bar in the top-right corner corresponds to $\gamma = 0.05$ (5% distortion relative to unlensed shapes).

reach of mass mapping beyond previous observational limits. This advancement enables direct constraints on the growth of structure, the assembly of dark matter halos and the role of environment in shaping galaxy evolution during the peak epoch of star formation. The same sensitivity has already revealed over 100 strong lenses in the COSMOS-Web field^{27–29}, highlighting JWST's exceptional lensing capabilities and opening new avenues for joint weak and strong lensing studies of cosmic shear.

The mass reconstruction is based on the observed weak lensing shear field, which captures the coherent distortions induced by foreground mass on background galaxy shapes. Pronounced shear alignments (Fig. 3) in regions of high signal-to-noise ratio (SNR_{wl}) are consistent with lensing by massive structures at intermediate redshifts ($z \approx 0.2 - 1.1$) and high source density. These features coincide with convergence peaks and trace projected mass overdensities associated with galaxy groups and clusters. To enhance the signal, the shear field is binned into $1.1' \times 1.1'$ pixels and smoothed with a Gaussian of width $\sigma = 1.2'$, highlighting its alignment with the underlying large-scale structure and reinforcing JWST's ability to probe the gravitational imprint of cosmic structure.

To assess the level of residual systematics in mass maps, we note that the reconstructed map is complex-valued. The real part (Fig. 4a,c) corresponds to the so-called E -mode signal, which traces the curl-free component of shear and is produced by the projected foreground mass distribution³⁰. As expected, the HST-based κ_E map (Fig. 4c) reveals large-scale structure, while the JWST-based map (Fig. 4a) shows significantly finer substructures, enabled by higher spatial resolution and deeper imaging. The imaginary part of the shear field represents the divergence-free ' B -mode', which, to first order, is expected to be consistent with zero in standard cosmology. Because E - and B -modes are equally affected by statistical noise and equally likely to be affected by imperfect point spread function (PSF) correction or mask effects, the B -mode is useful as a diagnostic of potential systematics in the data. The measured B -mode amplitude is more than an order of magnitude lower than the E -mode (Fig. 4b),

confirming that potential systematic biases in our analysis have been well controlled.

The gravitational lensing convergence map derived from JWST data (Fig. 5a) reveals the projected distribution of total matter—both dark and baryonic—across the COSMOS field. The increased resolution and source density afforded by JWST enable precise mapping of mass structures across a wide range of spatial scales and redshifts. Notably, 15 known galaxy clusters previously detected via extended X-ray emission with XMM-Newton and Chandra^{5,31} are all recovered at a detection signal-to-noise ratio ($\text{SNR}_{\text{det}} > 3$), considering a matching radius smaller than 2 arcmin. This constitutes a substantial improvement over earlier HST-based reconstructions, which detected only eight of these clusters, and validates the fidelity of our weak lensing measurements (see also Supplementary Table 1).

Beyond isolated peaks, the JWST-based convergence map unveils a network of extended, low-amplitude features (Fig. 5, dashed contours), that bridge cluster-scale overdensities. These structures probably trace dark matter filaments of the cosmic web, too diffuse to emit significant X-ray radiation or host large galaxy overdensities. Their detection is consistent with predictions from gravitational collapse in Λ CDM cosmology and reflects JWST's enhanced sensitivity to the diffuse components of the matter field previously unresolved by HST⁶.

Comparison with X-ray and galaxy overdensity significance maps (Fig. 5b,c) illustrates the coupling between dark matter, hot gas and luminous galaxies. The X-ray map traces thermal emission from the hot intracluster medium in group- and cluster-scale halos, while the galaxy overdensity map, derived from COSMOS2020 photometry³² and weighted by the lensing sensitivity function $g(z)$, shows fluctuations in the projected number density of galaxies. These fluctuations are expressed in units of the local standard deviation (Σ/σ), where Σ represents the projected galaxy density in each pixel, and σ is the standard deviation of the galaxy density within a reference region. This ratio, Σ/σ , is used to quantify the local signal-to-noise ratio, helping to highlight statistically significant structures. Peaks in the weak lensing map align with prominent X-ray emission, including two massive clusters near (right ascension (RA), declination (dec.)) $\approx (150.41^\circ, 2.41^\circ)$ and $(149.92^\circ, 2.52^\circ)$. In addition, elongated contours forming an L-shaped structure—from RA of approximately 150.4° to 149.9° , and dec. of approximately 2.6° to 2.1° —reveal filamentary bridges between clusters, offering a direct lensing-based view of the cosmic web.

The enhanced depth and redshift reach of JWST also reveal previously undetected structures. For example, the mass peak at $(149.94^\circ, 2.60^\circ)$ corresponds to X-ray emission from a low-mass group at $z = 0.342$ despite a paucity of luminous galaxies, and the peak at (RA, dec.) $\approx (150.32^\circ, 2.28^\circ)$ is associated with X-ray sources at $z > 0.9$. These results demonstrate JWST's unique ability to detect massive structures even at redshifts where X-ray emission is dimmed by cosmological distance, and where galaxy overdensities become less prominent. At redshifts $1 \lesssim z \lesssim 2$, the cosmic noon epoch of peak star formation³³, JWST's high lensing sensitivity (Fig. 2b) allows weak lensing peaks to continue tracing large-scale structure. This range is also where our photometric redshift catalogue retains a high density of well-resolved background sources. This opens a new window into the environment of galaxies forming at cosmic noon and their evolution under the influence of active galactic nucleus feedback, gas quenching and dark matter assembly³⁴.

While some weak lensing peaks coincide with regions of high X-ray intensity and galaxy overdensity significance (Fig. 5b,c), we also identify mass peaks without clear counterparts in the projected X-ray emission or galaxy distribution—for example, at (RA, dec.) $\approx (150.21^\circ, 2.06^\circ)$ and $(150.32^\circ, 2.28^\circ)$. These features may arise from underluminous or dark-matter-dominated structures, projection effects from multiple aligned systems along the line of sight, or mass concentrations at redshifts not optimally captured by the galaxy density weighting. In particular, we have identified significant lensing peaks that may result from the alignment of two structures at (RA, dec.) $\approx (150.21^\circ, 2.06^\circ)$ at

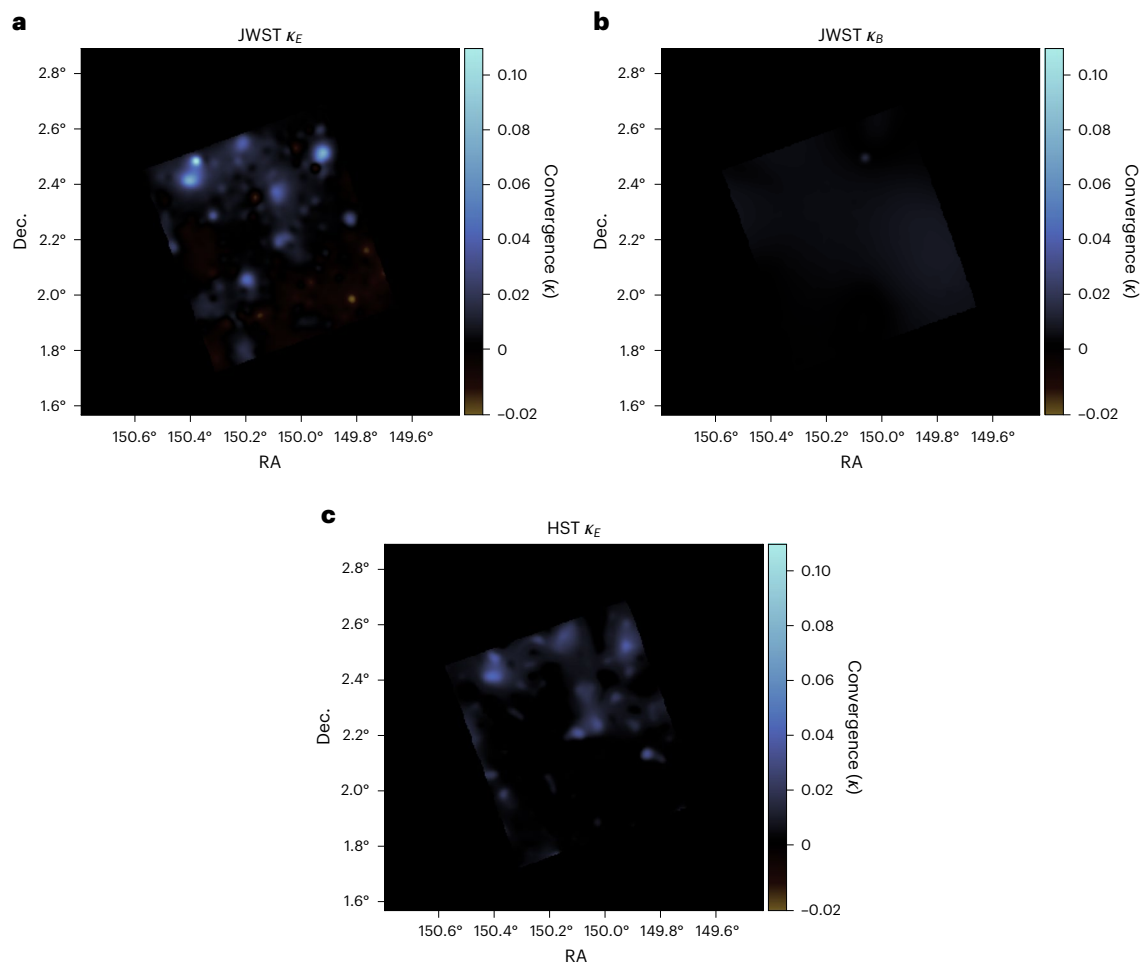


Fig. 4 | Maps of the weak gravitational lensing convergence from JWST and HST. a, JWST-based E -mode convergence map, showing the projected distribution of mass. **b,** JWST B -mode (null test) convergence map, which could contain systematic biases but is more than an order of magnitude lower

in amplitude. **c,** HST-based E -mode convergence map, cropped to the JWST COSMOS-Web footprint, illustrating the same field at lower resolution⁶. In all panels, the colour scale is identical, with brighter tones indicating mass overdensities, and an in-painting technique is applied to handle masked regions.

low redshift (0.186 and 0.370), enabling the detection of these very low-mass objects.

Compared with HST, JWST provides roughly a twofold improvement in angular resolution, source galaxy density and the number of significant detections of lensing structures⁶. At $z \gtrsim 0.7$, JWST's lensing sensitivity exceeds that of HST by a factor of two, and that of leading ground-based surveys by an order of magnitude. While the large-scale structures of dark and baryonic matter are aligned in a manner consistent with theoretical expectations, JWST reveals them with much greater detail, extending into low-density regions and higher redshift regimes. This map provides a detailed view of the dark matter scaffolding underlying galaxy formation and serves as a foundation for future studies of cosmic structure, feedback and the evolution of the matter field over time. Looking ahead, JWST's enhanced sensitivity at $1 \lesssim z \lesssim 2$ (Fig. 2b) will allow tomographic reconstructions of the dark matter environments of galaxies during cosmic noon—the epoch of peak star formation. Such measurements, not attempted in the present work, would provide a direct link between large-scale structure and galaxy evolution, including the effects of active galactic nucleus feedback, gas quenching and dark matter assembly.

Methods

COSMOS-Web imaging and catalogues

The COSMOS-Web survey is a 270-h JWST treasury programme (PID 1727; principal investigators: J.S.K. and C.M.C.¹⁰), originally planned for 255 h, covering 0.54 deg² of the COSMOS field^{4,35} using the NIRCcam and

0.19 deg² with the Mid-Infrared Imager. The NIRCcam imaging data span four filters: F115W, F150W, F277W and F444W³⁶. We use the F115W and F150W filters for weak lensing measurements owing to their superior angular resolution, higher throughput and lower background noise compared with the longer-wavelength bands.

Observations were carried out across three epochs (January 2023, April–May 2023 and January 2024), using a 4TIGHT dither pattern to ensure uniform coverage and depth, reaching AB magnitudes of 26.9–27.4 in each band. All exposures were calibrated and processed through the JWST Pipeline³⁷ v1.14.1, which includes the resample step to combine the individual exposures into mosaics, following standard procedures³⁸, with `pixfrac` = 1 and a pixel scale of 0.02 arcsec per pixel. These choices minimize aliasing of the native pixel scale, which is critical for weak lensing analysis³⁹.

To extend the weak lensing analysis to larger spatial scales and reduce border effects in the mass map, we embed JWST data inside the HST Advanced Camera for Surveys (ACS) COSMOS survey⁶. HST F814W images covering an area of 1.637 deg² provide shape measurements for 71 galaxies per square arcminute, with a median AB magnitude of 25.1. Shapes were measured using the Rhodes, Refregier and Groth (RRG)⁴⁰ method⁴¹, which deconvolves the PSF from galaxy shapes and has been calibrated on HST simulations to recover shear with <6% bias across a wide range of sizes and fluxes.

Source detection was performed with `SExtractor`⁴², using a combined χ^2 image constructed from all four NIRCcam bands (F115W,

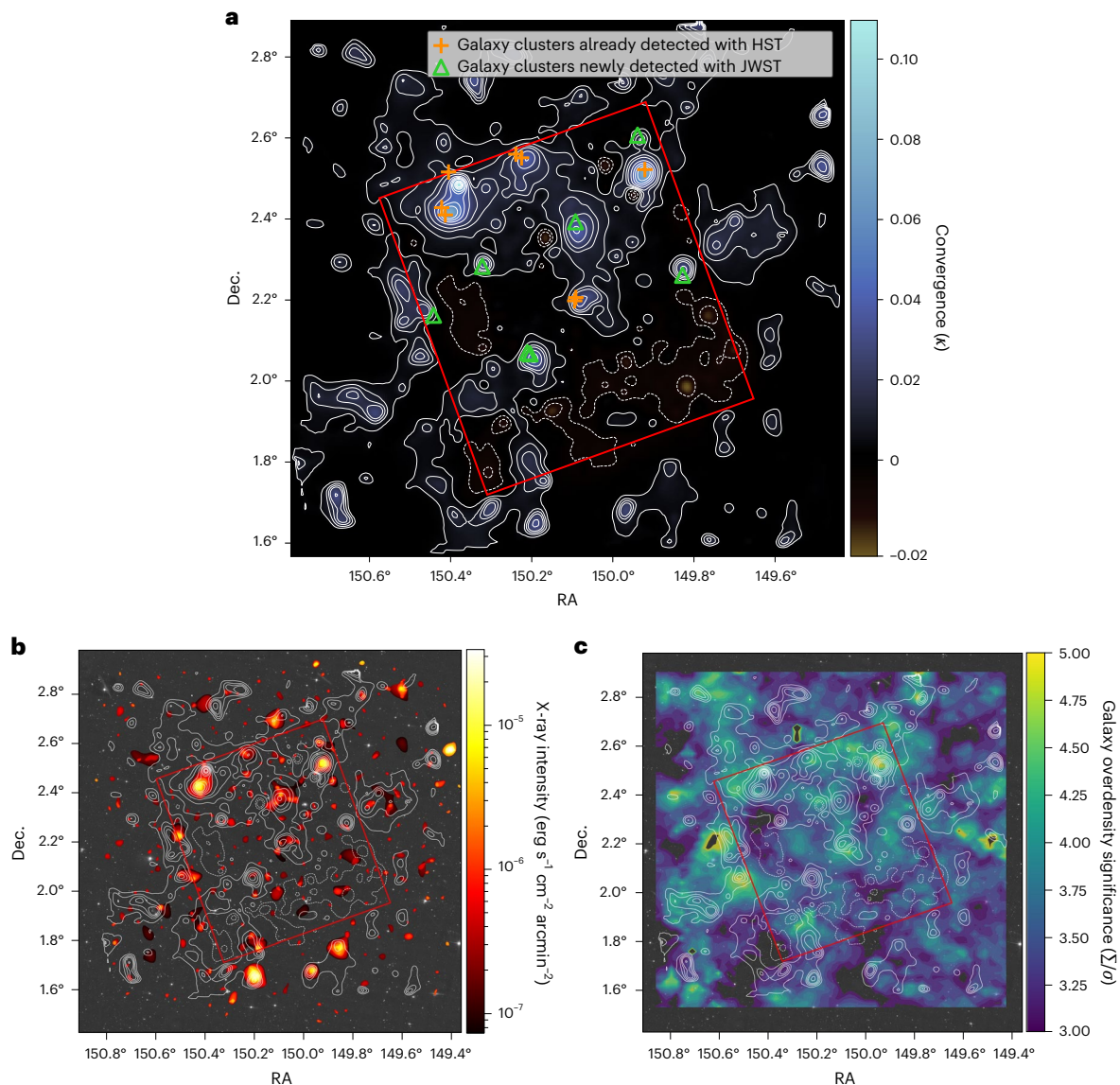


Fig. 5 | Maps of weak gravitational lensing, X-ray emission and galaxy density in the COSMOS field. Combined JWST (red square; F115W+F150W) and HST (surrounding area) weak lensing convergence map (κ), with contours at $\kappa = 0.004$ and uniformly spaced by $\Delta\kappa = 0.005$, matching the levels used in ref. 6 for direct comparison. Dashed sections mark the negative portions of the contours, corresponding to the same first convergence levels. **a**, Green triangles represent galaxy clusters newly detected in the JWST mass map, while orange

crosses indicate clusters detected in both JWST and HST maps and matching known systems from XMM-Newton and Chandra, whose mass and redshift mean they should be (and are) detected at $\text{SNR}_{\text{det}} > 3$ in weak lensing. **b**, X-ray emission from hot gas in massive halos, traced with data from XMM-Newton and Chandra, with overlaid white κ contours. **c**, Galaxy overdensity significance map (Σ/σ), weighted by the weak lensing sensitivity function $g(z)$, tracing the projected distribution of luminous matter, with white κ contours marking the total mass.

F150W, F277W and F444W), leveraging the full wavelength coverage to enhance detection of faint sources. Source detection was performed in single-image mode, using the same image for both detection and photometric measurement. A threshold of 2.33σ above the background was applied to optimize the trade-off between completeness and reliability. Multiwavelength photometry was extracted from PSF-matched images convolved to the F444W PSF, using Kron elliptical apertures fitted to each source. However, for weak lensing shape measurements, only the F115W and F150W images were used, due to their higher spatial resolution and lower background, ensuring optimal shape recovery.

The COSMOS2025 catalogue (Shuntov et al., submitted to A&A) combines COSMOS-Web imaging with ancillary multiwavelength data, providing photometry, photometric redshifts, physical properties and morphological measurements for over 780,000 sources across the field. From this sample, we apply a series of quality cuts based on peak surface brightness (MU_MAX), total flux (MAG_AUTO), effective

diameter (d) and SNR_{det} to select galaxies with robust shape measurements (see ‘Galaxy shape measurement and shear estimation’ section). This yields 209,322 galaxies in the F115W band and 209,893 in F150W, corresponding to a summed raw number density of 216 galaxies per square arcminute across 0.54 deg^2 . From these, we construct a final catalogue of unique galaxies by retaining the shear estimate from single-band detections and averaging the two measurements for galaxies detected in both filters. This reduces scatter while preserving unbiased means, and improves noise characterization by mitigating bias during shear-map smoothing. The final sample comprises 170,386 galaxies detected in both bands, 38,936 detected only in F115W and 42,135 detected only in F150W, yielding an effective number density of 129 galaxies per square arcminute.

We use the LEPHARE photometric redshift estimator^{23,24}, which fits galaxy templates to multiwavelength photometry. The method generates a redshift probability distribution for each galaxy by calculating

the likelihood for each template. The median of this likelihood distribution is then taken as the best estimate of the galaxy's redshift. This approach also enables the simultaneous derivation of galaxies' physical parameters. For stars and artefacts, the redshift is set to 0, as detailed by ref. 12.

To trace the large-scale galaxy distribution, we use the COSMOS2020 catalogue³², which offers consistent multiband photometry and photometric redshifts across the full COSMOS field, to construct a projected galaxy density map (Fig. 5c).

Modelling the PSF

The apparent shapes of galaxies are distorted by gravitational lensing and further convolved with the telescope's PSF, which smears their observed morphology and must be accurately modelled to obtain unbiased shear measurements. The PSF is characterized by its size, R_{PSF}^2 , and shape expressed through its ellipticity components, $\varepsilon_i^{\text{PSF}}$ for $i \in \{1, 2\}$, all constructed from second-order moments with a circular Gaussian weight function with radius $\sigma = 1.5$ pixels. We tested several PSF modelling approaches for JWST, including ShOpt⁴³, PSFEX⁴⁴ and WEBBPSF⁴⁵, and found that the latter yields the lowest residual systematics in the final shear measurements. WEBBPSF enables us to model the PSF in individual exposures and combine them into a composite PSF matched to the full-depth images. This approach remains robust in regions with few bright stars and performs reliably near exposure boundaries, where the PSF varies discontinuously with position on the sky.

To quantify the impact of PSF modelling errors on shear estimation, we analyse the difference throughout the survey between the measured ellipticity of unsaturated stars and that of PSF models, $\delta\varepsilon_i^{\text{PSF}} = \varepsilon_i^{\text{PSF}} - \varepsilon_i^{\text{measured}}$. In the F115W band, we use 5,620 stars, yielding a mean residual ellipticity of $\langle\delta\varepsilon_i^{\text{PSF}}\rangle = (-0.0035, 0.0005)$ and root mean square (RMS) values of $(0.0158, 0.0151)$ for $(\delta\varepsilon_1^{\text{PSF}}, \delta\varepsilon_2^{\text{PSF}})$. For F150W, 6,125 stars yield $\langle\delta\varepsilon_i^{\text{PSF}}\rangle = (0.0005, -0.0001)$ with RMS values of $(0.0104, 0.0094)$. These residuals are interpreted as spurious shear and used to construct PSF-induced E -mode convergence maps, κ^{PSF} , shown in Supplementary Fig. 1.

When using WEBBPSF, the PSF-induced convergence maps exhibit low-amplitude, spatially uncorrelated structure in both bands, with RMS values of $\sigma_{\kappa^{\text{PSF}}} = 1.1 \times 10^{-3}$ for F115W and 0.8×10^{-3} for F150W. These values are more than an order of magnitude smaller than the cosmological lensing signal (Fig. 1), confirming that PSF model errors are subdominant. Meanwhile, we find that empirical methods such as ShOpt and PSFEX can be unstable. This is primarily because stacking multiple exposures introduces sharp discontinuities in the PSF model, occasionally causing localized catastrophic failures in the assumed smooth PSF interpolation. Across the survey footprint, variance in the PSF-induced convergence maps is 2.5× higher for PSFEX and 12.5× higher for ShOpt.

Galaxy shape measurement and shear estimation

We measure the shapes of galaxies using python RRG (pyRRG)^{46,47}, which calculates Gaussian-weighted second- and fourth-order multipole moments, J_{ij} and J_{ijkl} , for $i, j, k, l \in \{1, 2\}$, all corrected for convolution with the PSF and pixel response. An estimator of galaxy size is $R_{\text{gal}}^2 \equiv J_{11} + J_{22}$. The galaxy's ellipticity is defined as

$$(\varepsilon_1^{\text{gal}}, \varepsilon_2^{\text{gal}}) = \left(\frac{2J_{12}}{R_{\text{gal}}^2}, \frac{J_{11} - J_{22}}{R_{\text{gal}}^2} \right), \quad (1)$$

and the estimator of the line-of-sight shear is

$$\hat{\gamma}_i \equiv \varepsilon_i^{\text{gal}}/G, \quad (2)$$

the shear susceptibility G depends on fourth-order moments⁴⁰. Shear susceptibility describes the response of an intrinsically elliptical galaxy

to shear: $\varepsilon_i^{\text{gal}} = \varepsilon_i^{\text{int}} + G\gamma_i$, valid in expectation over a galaxy ensemble with $\langle\varepsilon_i^{\text{int}}\rangle = 0$.

Because the fourth-order shape moments in G are inherently noisy and enter in the denominator of the shear estimator (equation (2)), we use the mean value of G fitted as a function of galaxies' SNR_{det} , $G = A(1 - e^{-B\text{SNR}_{\text{det}}}) + C$, where parameters A, B and C are fitted independently for each filter (Supplementary Fig. 2). We empirically determined this functional form, which captures the expected flattening of G at high SNR_{det} , where measurement noise becomes subdominant. Over the range $5 < \text{SNR}_{\text{det}} < 30$, we find that the mean susceptibility is $\langle G^{\text{F115W}} \rangle = 1.156$ and $\langle G^{\text{F150W}} \rangle = 1.120$.

To reduce measurement biases from noise and PSF modelling uncertainties^{41,48}, we apply galaxy selection criteria on size, magnitude and SNR_{det} , tailored to each NIRC2 filter. For F150W, we retain galaxies with $\text{MAG_AUTO} < 28$, effective diameter $d > 2.2$ pixels and detection $\text{SNR}_{\text{det}} > 4.0$. For F115W, we adopt similar cuts on MAG_AUTO and $d > 2.0$ pixels, but apply a more relaxed SNR_{det} threshold of zero to preserve fainter detections. These thresholds are less restrictive than those used in previous HST analyses⁴¹, owing to the improved automatic catalogue cleaning implemented in pyRRG. The selection cuts were optimized to enhance the weak lensing signal while minimizing systematics, maximizing the $\kappa_E/\sigma_{\kappa_B}$ ratio without diluting the signal by excessive galaxy exclusion.

After applying these cuts, we obtain robust shear measurements for 209,322 galaxies in the F115W band and 209,893 in F150W, that is, 108 galaxies arcmin^{-2} in each band. The amplitude of measured shears (equation (2)) is consistent between band, and consistent with those derived from HST imaging: with mean values $\langle\hat{\gamma}_1^{\text{F115W}}\rangle = 0.0116$ and $\langle\hat{\gamma}_2^{\text{F115W}}\rangle = -0.0073$, and $\langle\hat{\gamma}_1^{\text{F150W}}\rangle = 0.0132$ and $\langle\hat{\gamma}_2^{\text{F150W}}\rangle = -0.0052$. The RMS scatter of shear measurements, $\sigma_{\hat{\gamma}_i} \equiv \langle(\hat{\gamma}_i)^2\rangle$, is also consistent: $\sigma_{\hat{\gamma}_1}^{\text{F115W}} = \sigma_{\hat{\gamma}_2}^{\text{F115W}} = 0.30$, $\sigma_{\hat{\gamma}_1}^{\text{F150W}} = \sigma_{\hat{\gamma}_2}^{\text{F150W}} = 0.31$, and $\sigma_{\hat{\gamma}_1}^{\text{HST}} = \sigma_{\hat{\gamma}_2}^{\text{HST}} = 0.32$ (ref. 41).

Comparing shear measurements between the two JWST bands, we notice that $\langle\hat{\gamma}_i^{\text{F115W}} - \hat{\gamma}_i^{\text{F150W}}\rangle^2 \ll \sigma_{\hat{\gamma}_i}^2$, with ratios of 0.13 for γ_1 and 0.12 for γ_2 , indicating that imaging in the two bands (necessarily) has independent shot noise, but that the intrinsic shapes of galaxies are not significantly different between bands.

To assess the total leakage of PSF modelling, correction and other biases into our shear measurements, we average the final shear estimators $\langle\hat{\gamma}_i\rangle$ in bins of PSF model ellipticity, $\varepsilon_i^{\text{PSF}}$ (Supplementary Fig. 3). To interpret these, note that equation (26) of ref. 49 can be rewritten

$$\begin{aligned} \langle\hat{\gamma}_i\rangle &\approx \left(1 + \frac{\delta(R_{\text{PSF}}^2)}{R_{\text{gal}}^2}\right) \left(\left\langle \frac{\varepsilon_i^{\text{int}}}{G} \right\rangle + \left\langle \gamma_i \right\rangle \right) \\ &- \left\langle \frac{R_{\text{PSF}}^2}{G R_{\text{gal}}^2} \right\rangle \left(\langle\delta\varepsilon_i^{\text{PSF}}\rangle + \left\langle \frac{\delta(R_{\text{PSF}}^2)}{R_{\text{PSF}}^2} \right\rangle \varepsilon_i^{\text{PSF}} \right), \end{aligned} \quad (3)$$

as where δR_{PSF}^2 and $\delta\varepsilon_i^{\text{PSF}}$ are residual errors in the size and ellipticity of the PSF model (compared with the truth rather than noisy, measured values), and where we have assumed that $\delta\varepsilon_i^{\text{PSF}}$ is a function of neither $\varepsilon_i^{\text{PSF}}$ nor R_{PSF}^2 in order to separate uncorrelated terms in angle brackets. Both terms in the first bracket vanish under the assumption that neither intrinsic ellipticity nor true shear depends on PSF ellipticity. This leaves a linear relation $\langle\hat{\gamma}_i\rangle = a_i + b_i\varepsilon_i^{\text{PSF}}$, whose free parameters we fit in Supplementary Fig. 3. Equating coefficients with equation (3) and adopting average values of $(R_{\text{gal}}^2/R_{\text{PSF}}^2) \approx 1.2$ and $\langle G \rangle$ as above, we estimate the residual PSF model ellipticity, averaged across all observations

$$\begin{aligned} \langle\delta\varepsilon_i^{\text{PSF}}\rangle &\approx -1.2\langle G \rangle a_i \\ &= (0.0124, -0.0069) \text{ for F115W, and } (0.0069, -0.0055) \text{ for F150W.} \end{aligned} \quad (4)$$

Assuming a typical PSF ellipticity of $\langle \epsilon_i^{\text{PSF}} \rangle \approx 0.015$, and interpreting equation (26) of ref. 49 as shear measurement biases¹, we estimate additive shear measurement bias $c_i = a_i + b_i \langle \epsilon_i^{\text{PSF}} \rangle = (-0.0011, -0.0098)$ for F115W, and $(-0.0152, -0.0074)$ for F150W. These additive shear systematics are mainly due to the smallest galaxies, but our choice of size cuts ensures they are subdominant to the (statistical noise on the) shear signal in a typical resolution element of the map.

To quantify residual correlations in shear estimators as a function of angular separation θ (not just on average), we use the $\rho_n(\theta)$ statistics²⁰, which quantify residual correlations in PSF-corrected shapes. With WEBBPSF, we find that all ρ_n functions remain below 10^{-5} at separations $\theta > 1'$ (Supplementary Fig. 4), the scales to which weak lensing is sensitive. This indicates that residual PSF correlations are negligible and that additive shear systematics are well controlled, validating the use of WEBBPSF for mass mapping with JWST.

In principle, blending of light from galaxies on adjacent lines of sight can lead to multiplicative shear measurement biases, particularly in regions of high galaxy density. However, JWST's high imaging resolution substantially reduces the impact of blending (compared with HST, JWST's spatial resolution is a factor $\gtrsim 2^2$ higher, and its pixels a factor 2.5² finer, but the density of galaxies is only 1.8 times higher). In addition, the hot/cold source separation used in our analysis helps to mitigate artificial, spurious deblending. To test the impact of blending, we remove adjacent pairs of galaxies from our analysis: we find that even the most conservative cuts change the mean shear in pixels by only $\sim 2\%$. Deep JWST imaging thus provides high-quality shear measurements even in dense environments such as galaxy clusters. Indeed, we found the dominant sources of uncertainty to be in modelling the JWST PSF rather than pixel-scale or astrophysical effects. Consequently, the most informative validation is obtained by comparing JWST shear estimates directly against stable and well-understood HST measurements of the same galaxies (see also ref. 47).

Mass map reconstruction

The reconstruction of the matter distribution begins by binning the observed shear field into $15'' \times 15''$ pixels, each containing approximately eight JWST galaxies. To convert the observed shear field into *E*- and *B*-mode convergence (κ), we apply an enhanced version of the KS+ algorithm^{50,51}. This approach iteratively accounts for the nonlinear relationship between the reduced shear and the true shear, where the reduced shear is defined as $g \equiv \gamma/(1 - \kappa)$ (ref. 30), and uses in-painting to recover the shear field across pixels containing no galaxies (for JWST data, 0.28% of the area, due to bright stars or the survey footprint edge). Missing regions are reconstructed using a wavelet-based sparsity constraint on the power spectrum of the convergence map⁵¹. Notably, binning HST shear measurements in the same $15'' \times 15''$ pixels would leave a 11.4% masked area, owing to more extensive scattered light contamination from stars. However, the brightest star in the region (RA, dec. = 150.23°, 2.63°) lies inside the HST survey footprint, but outside the JWST footprint.

We filter the weak lensing convergence map using the well-tested and widely used MRLens algorithm⁵². This uses the *à trous* wavelet transform and the false discovery rate (FDR) method to filter simultaneously both large-scale and small-scale structures. The FDR method provides a rigorous framework adaptive to the data to suppress noise at each scale and quantify uncertainties⁵³. In this process, some small scales are completely removed, while larger scales are thresholded. The choice of which scales to remove and the level of thresholding applied to each wavelet scale are determined by the FDR method, under the assumption that the noise follows a Gaussian distribution, to limit the fraction of spurious peaks to below 1% at all scales.

The wavelet scales are directly defined by the pixel size and increase in powers of two. So, the pixel size can be optimized to limit the scales to be removed. The resolution of the filtered map is thus defined by the smallest wavelet scale used to build the filtered

convergence map. To optimize the resolution, we vary the pixel scale smoothly, allowing the MRLens algorithm to select which wavelet scales to include. In the final map (Fig. 1) with a pixel size of $15''$, the signal is suppressed in the first two wavelet scales, and we use the following thresholds: $4.63\sigma_\kappa$, $3.34\sigma_\kappa$ and $1.96\sigma_\kappa$ in the next three wavelet scales.

Noise properties of the map vary across scales and are entangled with the local signal in a non-trivial manner. To assess the level of noise in the κ_E map, we use the κ_B map, which ideally contains no cosmological signal³⁰. Applying the same MRLens filtering to the *B*-mode shear component, with identical noise estimates and FDR thresholds for consistency, yields a mean *B*-mode signal more than an order of magnitude smaller than the correspondingly filtered *E*-mode signal. We use its standard deviation, σ_{κ_B} to define the weak lensing signal-to-noise ratio $\text{SNR}_{\text{WL}} = W_{\kappa_E}^j / (\sigma_{\kappa_B} \times \alpha_j)$, where $W_{\kappa_E}^j$ corresponds to the lensing signal measured at wavelet scale j and α_j is a normalization factor that depends on the shape of the wavelet kernel⁵². This approach accounts for spatial variations in galaxy density and imaging depth, enabling accurate assessment of signal significance across the field. Averaged across the map, at the smallest ($W_{\kappa_E}^2$) wavelet scale, $\langle \text{SNR}_{\text{WL}} \rangle = 1.9$ per resolution element.

Alternative map reconstruction algorithms include diffusion-based methods⁵⁴ or other machine-learning techniques⁵⁵. However, these remain dependent on large sets of realistic training simulations and may be sensitive to mismatches between simulated and observed data.

To identify individual dark matter structures, we do not actually use the denoised MRLens convergence maps. Instead, we use a multiscale peak detection algorithm based on wavelet decomposition⁵⁶. This method searches for local maxima ($\text{SNR}_{\text{det}} > 3$) across consecutive wavelet scales, particularly those corresponding to structures with sizes of 1–4 arcmin. Compared with MRLens, this approach is able to isolate compact features associated with galaxy groups and clusters while suppressing large-scale modes.

Several newly detected mass peaks in the JWST weak lensing map are spatially coincident with X-ray-detected clusters observed by XMM-Newton and Chandra³¹, with an average positional offset of 0.78 ± 0.34 arcmin (Supplementary Table 1). This marks an improvement over the HST-based mass map, which yields a mean offset of 1.19 ± 0.54 arcmin when comparing a subset of HST peaks selected with $\text{SNR}_{\text{det}} > 3$ and matched within $2'$. The JWST map includes 15 cluster matches, compared with only up to 8 from the HST-based reconstruction in the same area.

Data availability

The JWST data (Programme ID: General Observer 1727) are publicly available at <https://exchg.calet.org/cosmosweb-public/DR0.5/>. The HST data (Programme IDs: General Observer 9822 and 10092) are publicly available at <http://irsa.ipac.caltech.edu/data/COSMOS/>. The XMM-Newton dataset (Programme ID: 020336) is publicly available in staged releases via the IPAC/IRSA website at <https://irsa.ipac.caltech.edu/data/COSMOS/>. The Chandra data (Programme IDs: 901037) are publicly available at https://irsa.ipac.caltech.edu/data/COSMOS/gator_docs/cosmos_chandraxid_colDescriptions.html. The weak lensing mass maps are publicly available with this article as Supplementary Data 1–6.

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Acknowledgements

D.S. carried out this research at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NMO018D0004). Support for this work was provided by NASA grants JWST-GO-01727 and HST-AR15802 awarded by the Space Telescope Science Institute, operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. G.L., R.M. and M.v.W.-K. acknowledge support from STFC via grant ST/X001075/1, and the UK Space Agency via grant ST/W002612/1 and InnovateUK (grant no. TS/Y014693/1). D.H. was supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 521107294. This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement no. 101148925. French COSMOS team members are partly supported by the Centre National d'Etudes Spatiales (CNES). O.I. acknowledges the funding of the French Agence Nationale de la Recherche for the project iMAGE (grant ANR-22-CE31-0007). G.M. is supported in Durham by STFC via grant ST/X001075/1, and the UK Space Agency via grant ST/X001997/1. S.J. acknowledges the European Union's Marie Skłodowska-Curie

Actions grant no. 101060888, and the Villum Fonden research grants 37440 and 13160. N.E.D. acknowledges support from NSF grants LEAPS-2532703 and AST-2510993. D.B.S. gratefully acknowledges support from NSF Grant 2407752. Z.D.L. acknowledges support from STFC studentship ST/Y509346/1. J.R.W. acknowledges that support for this work was provided by The Brinson Foundation through a Brinson Prize Fellowship grant.

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D.S. led and coordinated the project. C.M.C. and J.S.K. led the observing proposal. M.F. processed the raw JWST observations, and M.S., O.I., H.B.A., J.R.W. and L.P. produced the photometric catalogues used in this analysis. D.H. measured galaxy shapes. G.L. and D.S. generated the mass maps using a Kaiser–Squires technique enhanced by S.P. D.S. created the galaxy density map with contribution from A.F. G.L. and D.S. identified galaxy clusters. D.S., G.L., D.H., R.M., J.R. and E.H. interpreted the maps. D.S., G.L. and R.M. wrote the first draft of the paper, on which all authors commented.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1038/s41550-025-02763-9>.

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Peer review information *Nature Astronomy* thanks Judit Prat and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.

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