Combining Visual and Quantitative Methods to Identify Disc Galaxies at Cosmic Noon in the COSMOS-Web Survey

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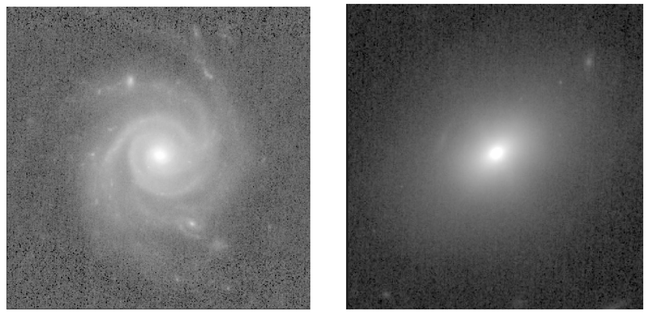
INTRODUCTION

- Galaxies are vast gravitationally-bound systems; understanding their structure across cosmic time reveals how the universe evolved.
- Disc galaxies (spirals) are characterised by rotating stellar discs and ongoing star formation; ellipticals are smooth, pressure-supported spheroids.
- Cosmic noon (z ≈ 2, look-back time ∼ 10 Gyr) marks peak star-formation and black hole accretion — roughly half of all stars formed during this era.
- At high redshift, galaxies appear smaller, fainter, and more irregular, making morphological classification inherently harder.
- JWST COSMOS-Web provides unprecedented NIRCam F150W imaging (0.03"/px) to resolve internal galaxy structure at z ∼ 1–3.
- **Research Goal:** Goal: Test and develop a combined visual + parametric + non-parametric framework to reliably identify disc galaxies around cosmic noon.

DATA & METHODS

- **Survey:** Data: COSMOS-Web NIRCam F150W mosaic, tile A8 (pixel scale 0.03"/px). Galaxies selected in 1 < z < 3 ('cosmic noon').
- **Sample:** Sample: 50 galaxies — 25 visually classified spirals and 25 visually classified ellipticals selected via SAOImage DS9.



Spiral (Disc) Galaxy

Elliptical Galaxy

Fig. 1: (Left) Sample Spiral galaxy: extended disc, visible spiral arms, active star formation. (Right) Sample Elliptical galaxy: smooth, featureless, centrally concentrated profile

Methodology

Preprocessing:

- Postage stamps centered on each target; PSF constructed empirically from bright unsaturated stars in the COSMOS-Web field.

GALFIT:

- fits a single Sérsic profile

$$I(r) \propto \exp[-b_n(r/R_e)^{1/n} - 1)]$$

- Uses χ² minimization to fit model parameters to the observed pixel data.
- Key output: Sérsic index n (disc: $n \sim 1$; elliptical: $n \sim 4$).

statmorph:

- statmorph: measures non-parametric indices C (concentration), A (asymmetry), S (smoothness), G (Gini), and M_{20} within the Petrosian aperture.

– $C = 5 \log_{10}(r_{80}/r_{20})$; $A = \sum|I_0 - I_{180}|/\sum|I_0|$; G = Gini flux-inequality coeff.; M_{20} = moment of brightest 20% of flux; all within Petrosian aperture.

GALFIT RESULTS

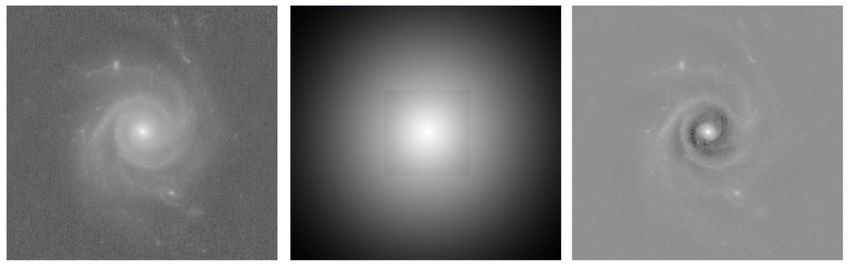


Fig. 2: GALFIT three-panel output. Left: JWST F150W science image. Centre: best-fit Sérsic model (convolved with PSF). Right: residual (data − model).

- **Spiral n:** Spirals: mean $\bar{n} = 1.85 \pm 0.20$; median $n = 1.38$; 68% have $n \leq 2.0$ (exponential disc).
- **Elliptical n:** Ellipticals: mean $\bar{n} = 4.38 \pm 0.40$; median $n = 4.25$; 60% have $n \geq 4$ (de Vaucouleurs).
- **Agreement:** Applying n = 2.5 threshold: 76% of spirals correctly recovered as disc-like; 84% of ellipticals recovered as spheroid-like.
- **Outliers:** Outliers: 4 spirals with n ≈ 3.1–3.8 required two-component bulge + disc fits; ellipticals 5 (n = 1.65) and 18 (n = 1.13) may be hidden discs.

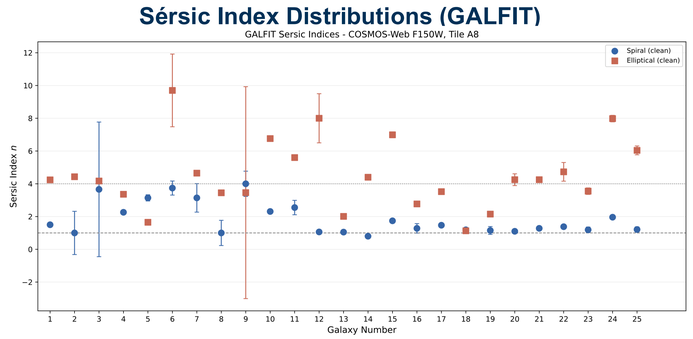


Fig. 2: Sérsic indices for 25 spirals (blue circles) and 25 ellipticals (red squares) vs. galaxy number. Dashed line: n = 2.5 disc/bulge boundary. Dotted: n = 4 de Vaucouleurs threshold.

NON-PARAMETRIC MORPHOLOGY

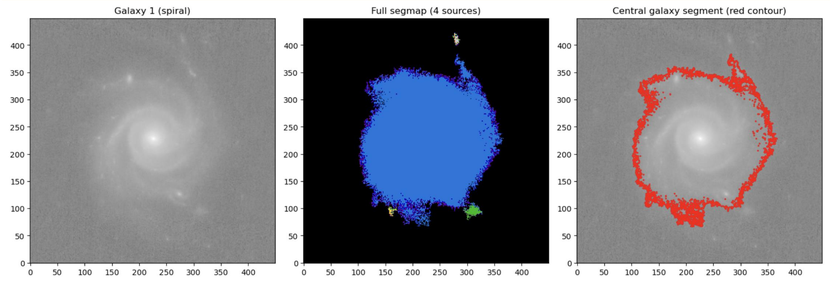


Fig. 3: statmorph output. Left: JWST F150W galaxy (Galaxy 1, spiral). Centre: full segmentation map. Right: central galaxy segment with Petrosian aperture (red contour).

- **Best singles:** C (concentration) and G (Gini) are the clearest individual discriminators: ellipticals cluster at higher C and G than spirals.
- **Asymmetry:** A (asymmetry) adds independent morphological information: ellipticals are tightly clustered near A ≈ 0; spirals span −12 to +0.33, reflecting disturbed/clumpy disc structure.
- **Smoothness:** S (smoothness) is effectively uninformative at z ≈ 2 due to cosmological surface-brightness dimming — omitted from further analysis.
- **Population stats:** Elliptical sample: median G ≈ 0.59, median C ≈ 3.8–4.7. Spiral sample: median G ≈ 0.52, wider C range (2.0–5.8).

RECOMMENDED DIAGNOSTIC: C–A–M_{20}

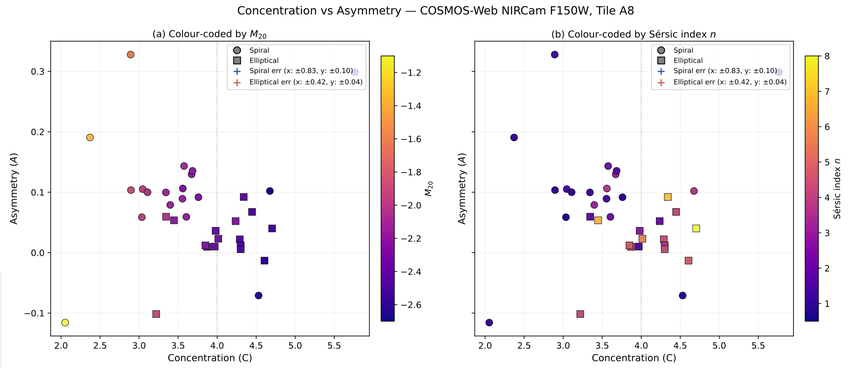


Fig. 4: Concentration C vs. Asymmetry A (colour-coded by M_{20}). Ellipticals (squares) cluster at low A and moderate-to-high C; spirals (circles) span a broader range. The C–A–M_{20} combination is the recommended diagnostic.

- **Why C–A–M_{20}:** The C–A plane (colour-coded by M_{20}) provides the clearest population-level separation — no dependence on GALFIT convergence.
- C encodes global radial concentration; A captures morphological disturbance; M_{20} traces spatial distribution of the brightest flux.

CONCLUSIONS

- Visual classifications agree with GALFIT at 76% (spirals) and 84% (ellipticals) using the n = 2.5 threshold.
- C, G, and A are the most effective non-parametric discriminators; S is uninformative at z ≈ 2.
- The C–A–M_{20} combination is recommended as the primary non-parametric diagnostic — fully non-parametric, scalable to large catalogues.
- Several ellipticals (n ≈ 1.13–1.65) show disc-like profiles, consistent with 'featureless discs' increasingly identified in JWST data at high redshift.
- No single diagnostic is sufficient; a combined visual + parametric + non-parametric framework is necessary for reliable disc identification at cosmic noon.
- Future work will extend this framework to the full COSMOS-Web survey for larger, statistically robust disc catalogues at cosmic noon.

References

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