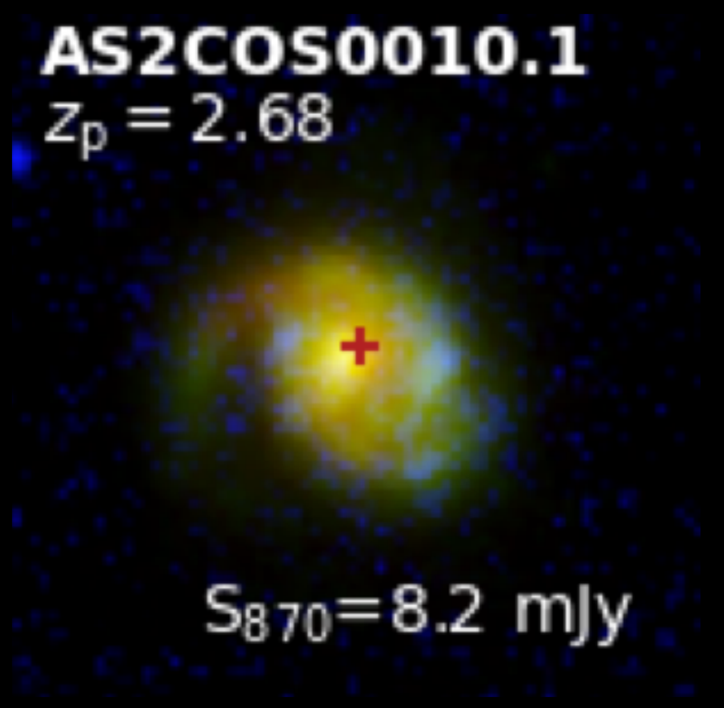
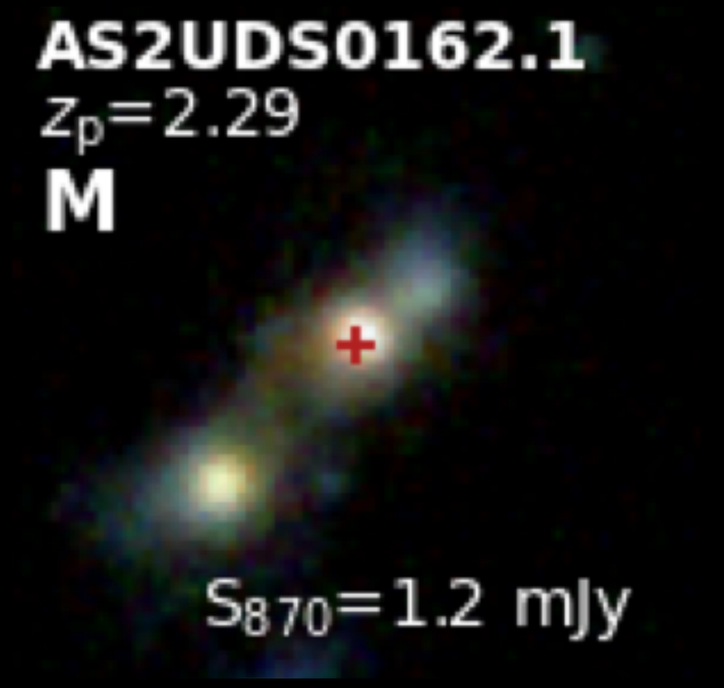
Mapping the multi-wavelength structures of SMGs with JWST



Beyond the Edge of the Universe
24th October 2024

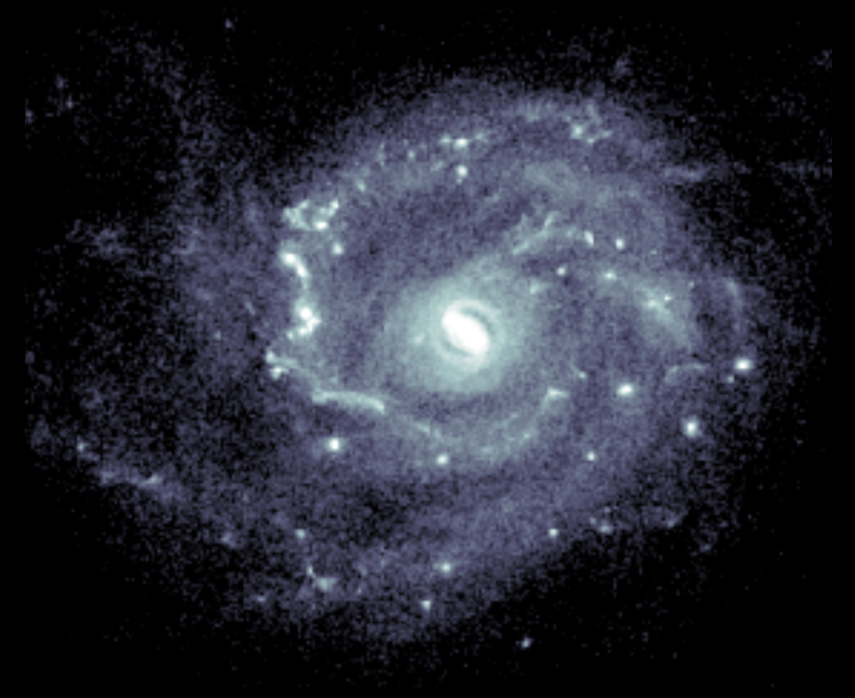
Rachel Cochrane, Columbia University —> University of Edinburgh



with help from the PRIMER Team

Mapping the multi-wavelength structures of SMGs with JWST

Beyond the Edge of the Universe
24th October 2024

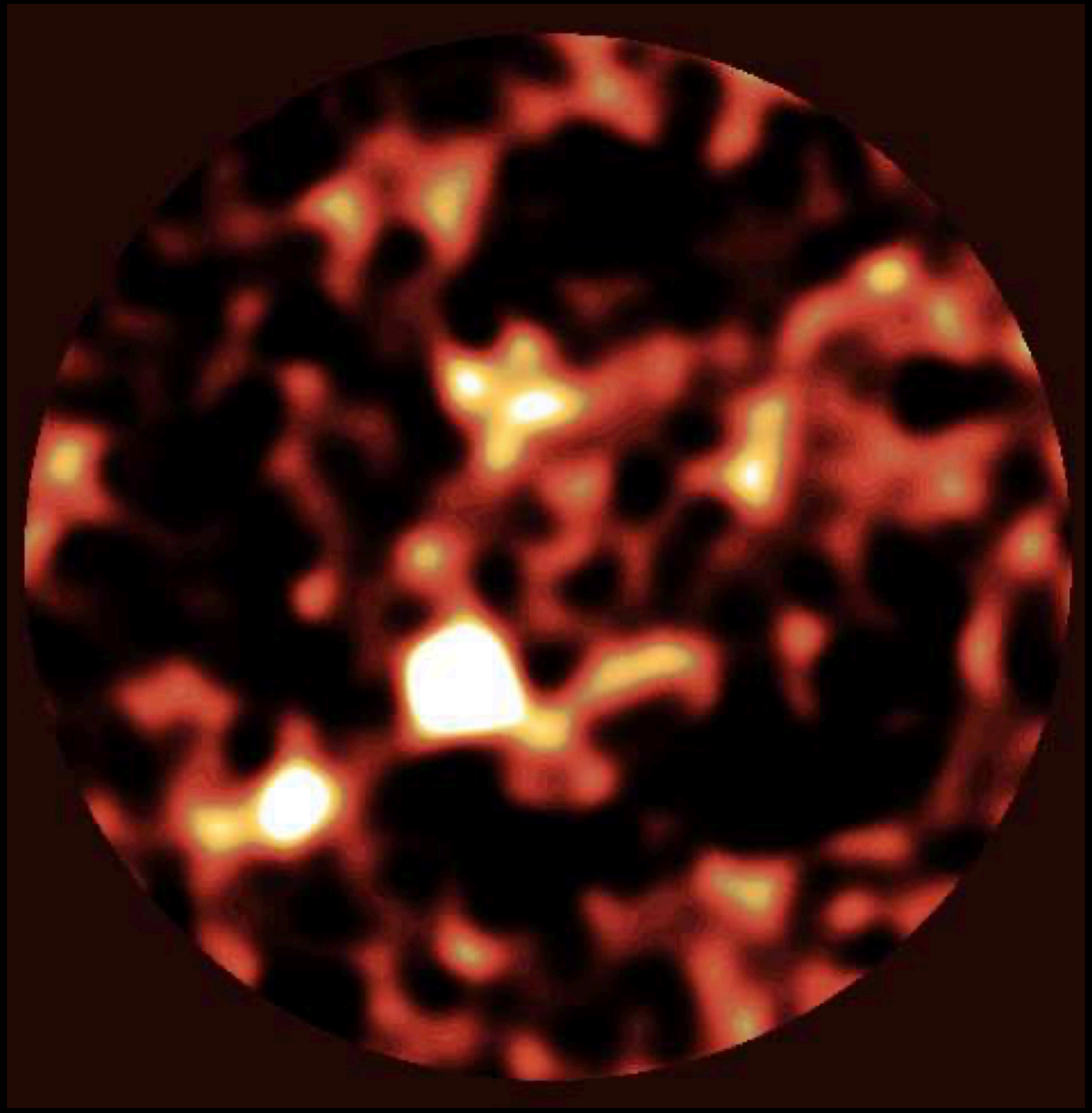


Rachel Cochrane, Columbia University —> University of Edinburgh

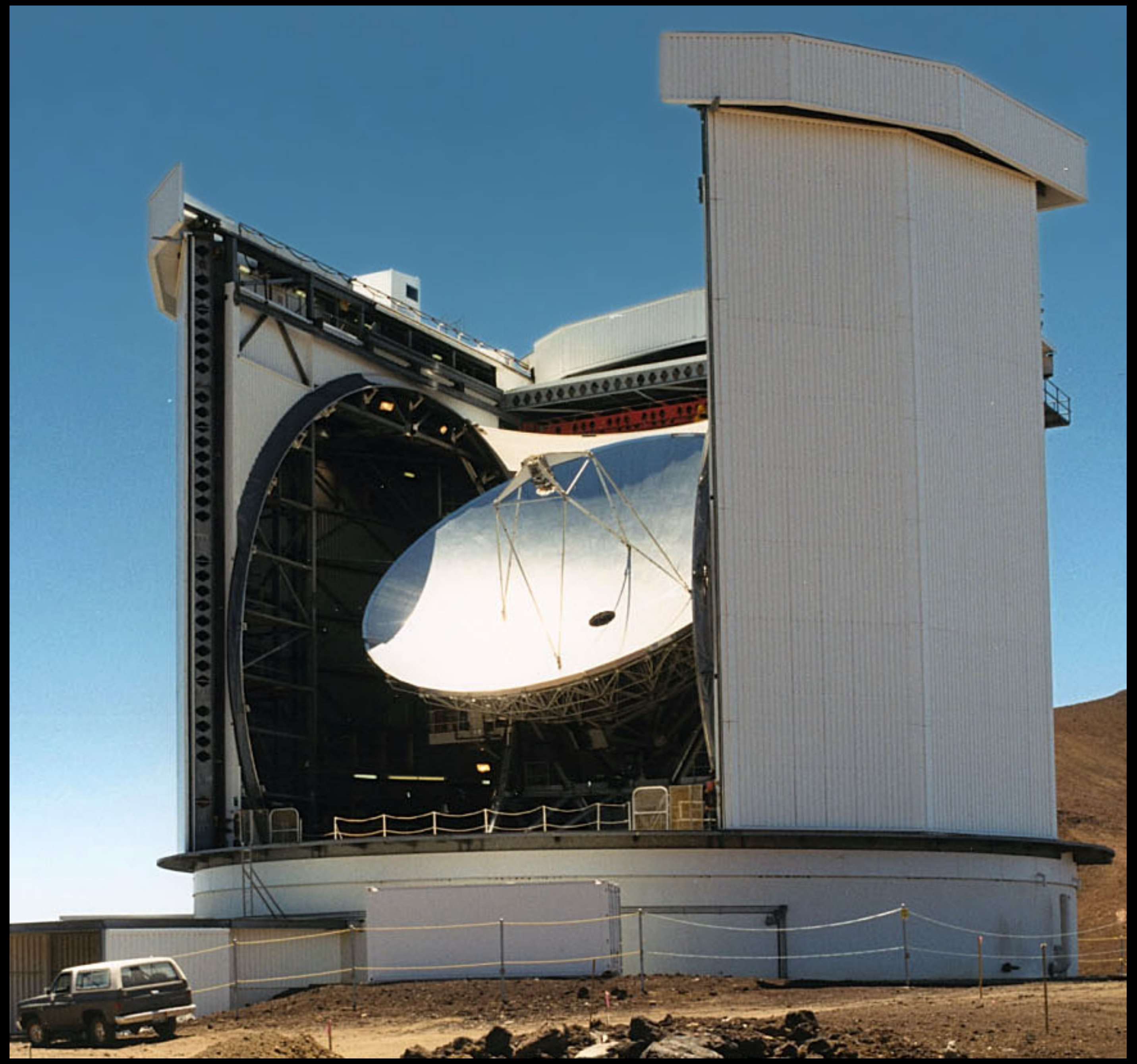
with help from the FIRE Team

Rachel Cochrane, rcochra3@ed.ac.uk

‘Extreme’ sub-millimetre -selected sources



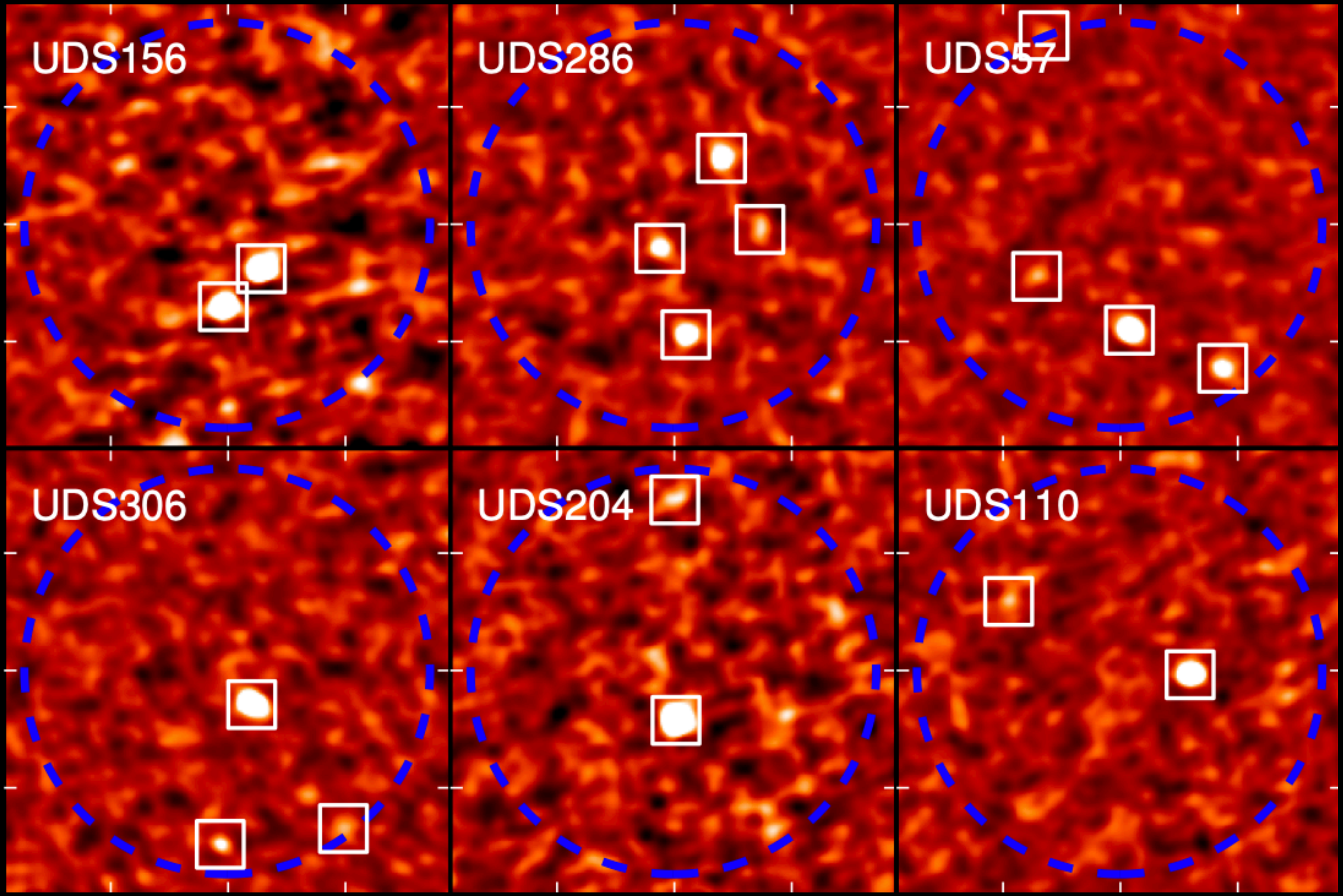
Hughes et al. 1998



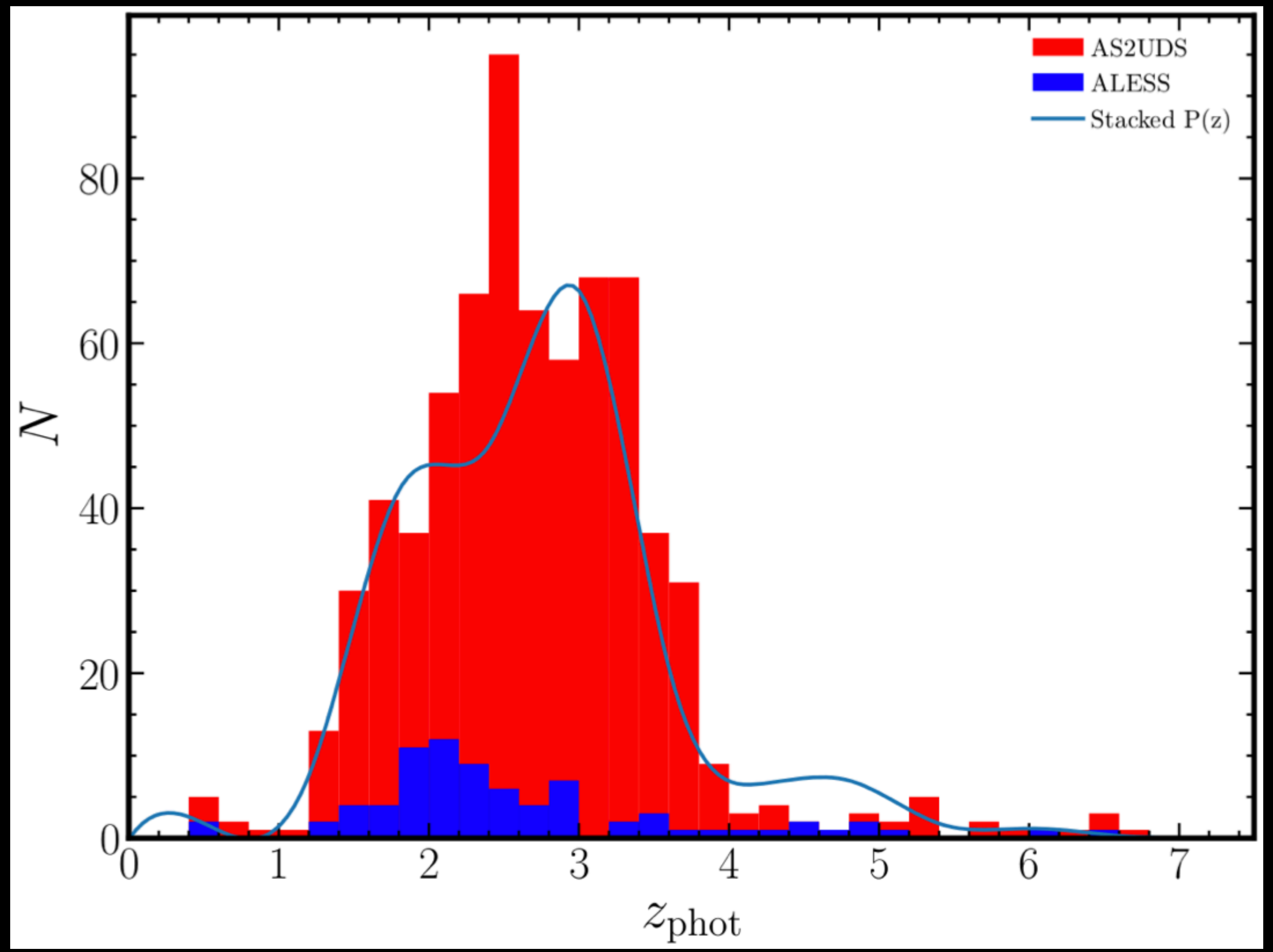
JCMT

Rachel Cochrane, rcochra3@ed.ac.uk

ALMA has located and resolved large samples of SMGs



Simpson et al. 2015



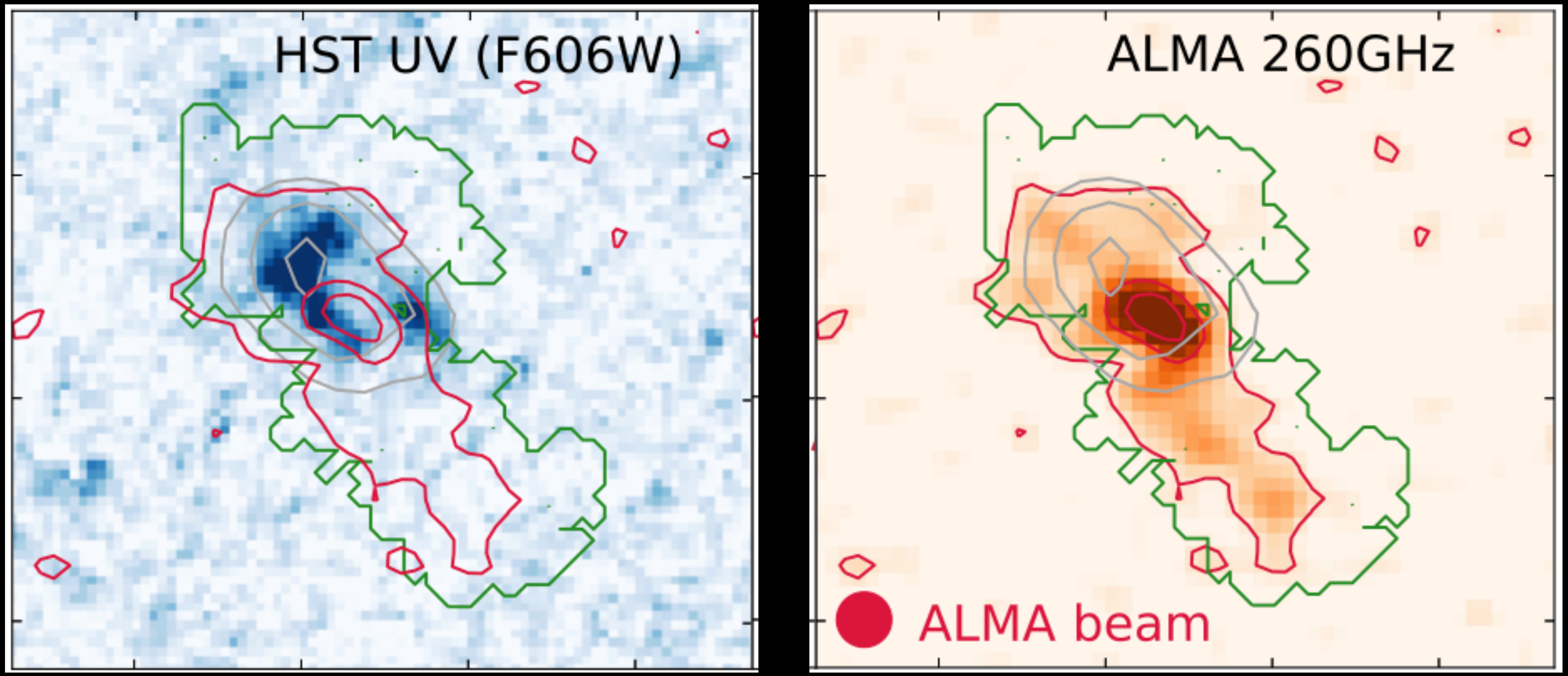
Stach et al. 2019

Typically $M_* \sim 10^{11}\ M_\odot$ galaxies

forming stars at hundreds of solar masses per year at z~2-4

 Rachel Cochrane, rcochra3@ed.ac.uk

But stellar emission was faint…



SHiZELS-14, z=2.24

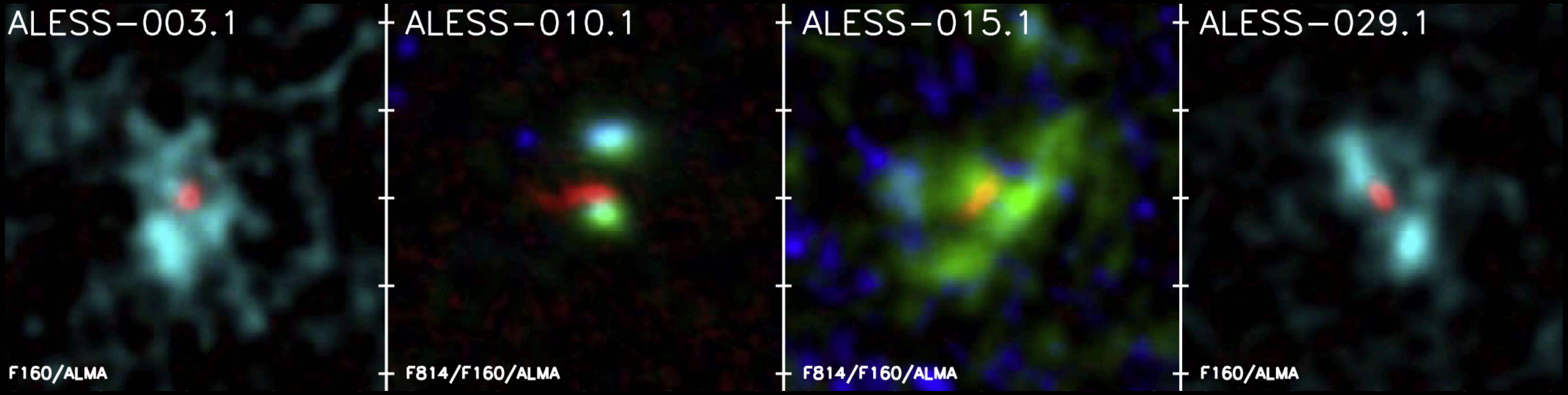
S_{850}~5mJy

Cochrane+21

Rachel Cochrane, rcochra3@ed.ac.uk

But stellar emission was faint…

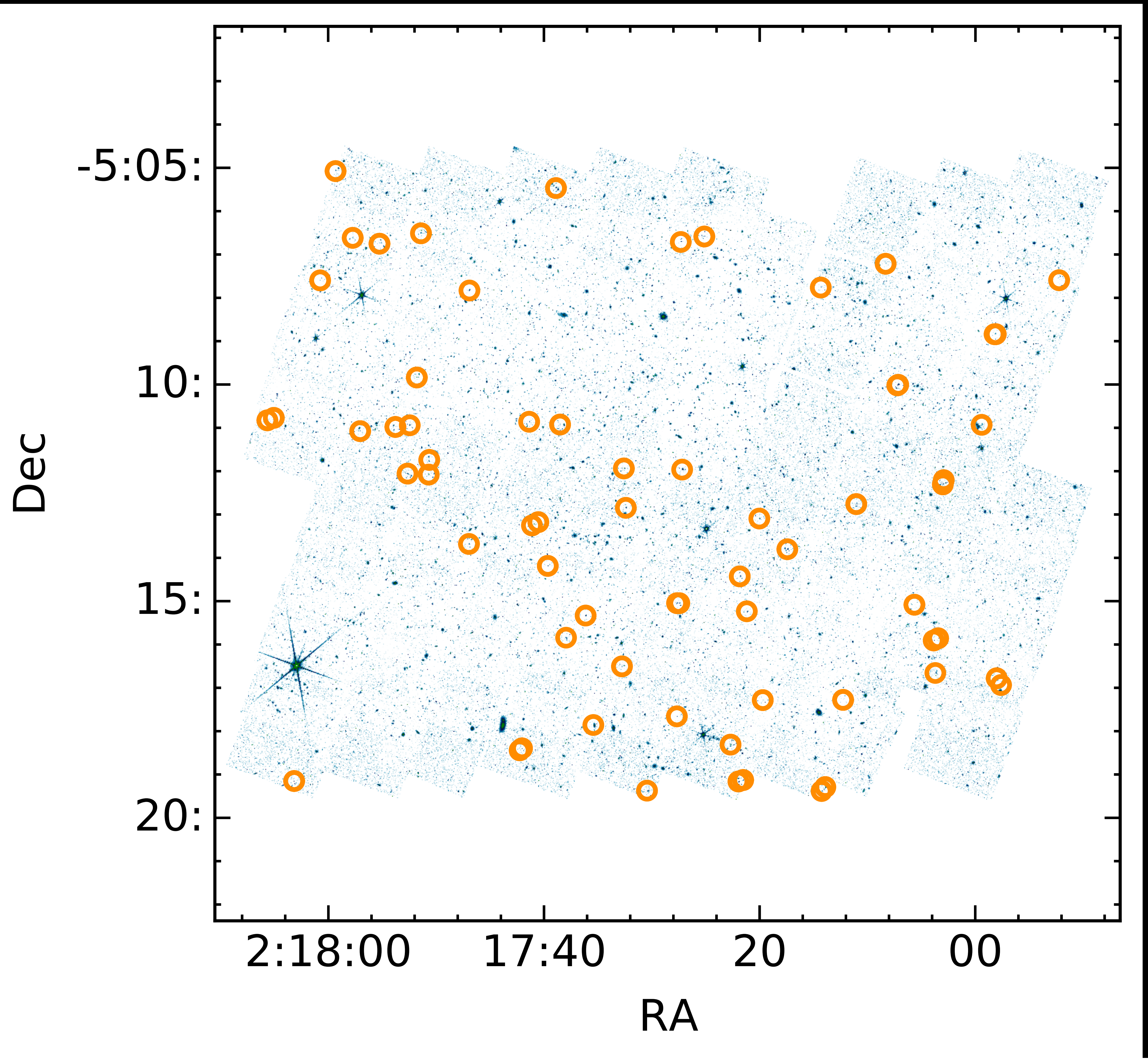
ALMA imaging of ALESS galaxies at z~2.5 *(Hodge et al. 16)*



At ~0.15” resolution, the 870-micron emission appears smooth and compact, whereas the rest-frame optical structures mapped by HST tend to be more extended.

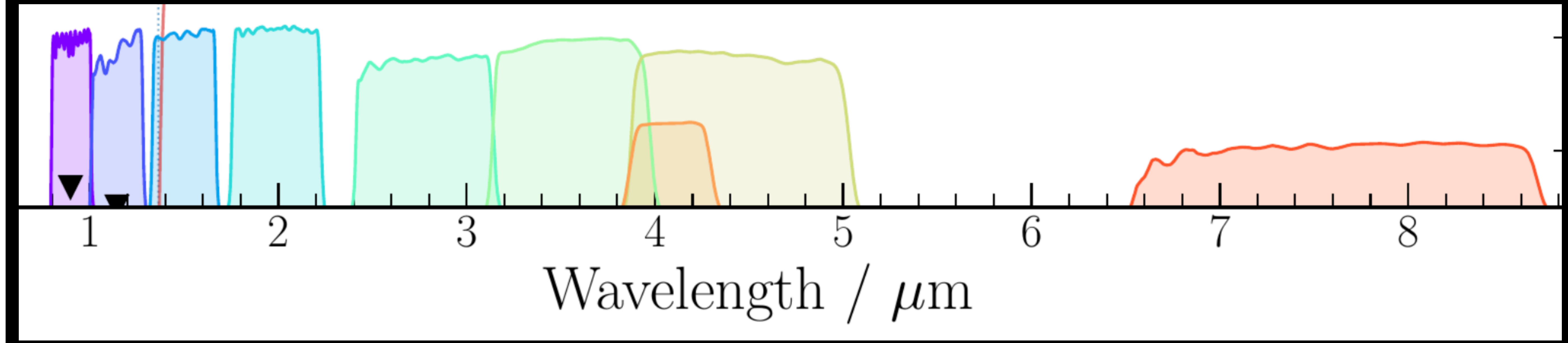
Rachel Cochrane, rcochra3@ed.ac.uk

PRIMER imaging of UDS



Sample of 65 sub-millimetre bright sources from the ALMA-SCUBA-2 Ultra Deep Survey field survey (AS2UDS; Stach et al. 2018; Dudzevičiūtė 2020) with PRIMER NIRCam imaging.

1 spurious source -> 64 SMGs



See also Gillman+24

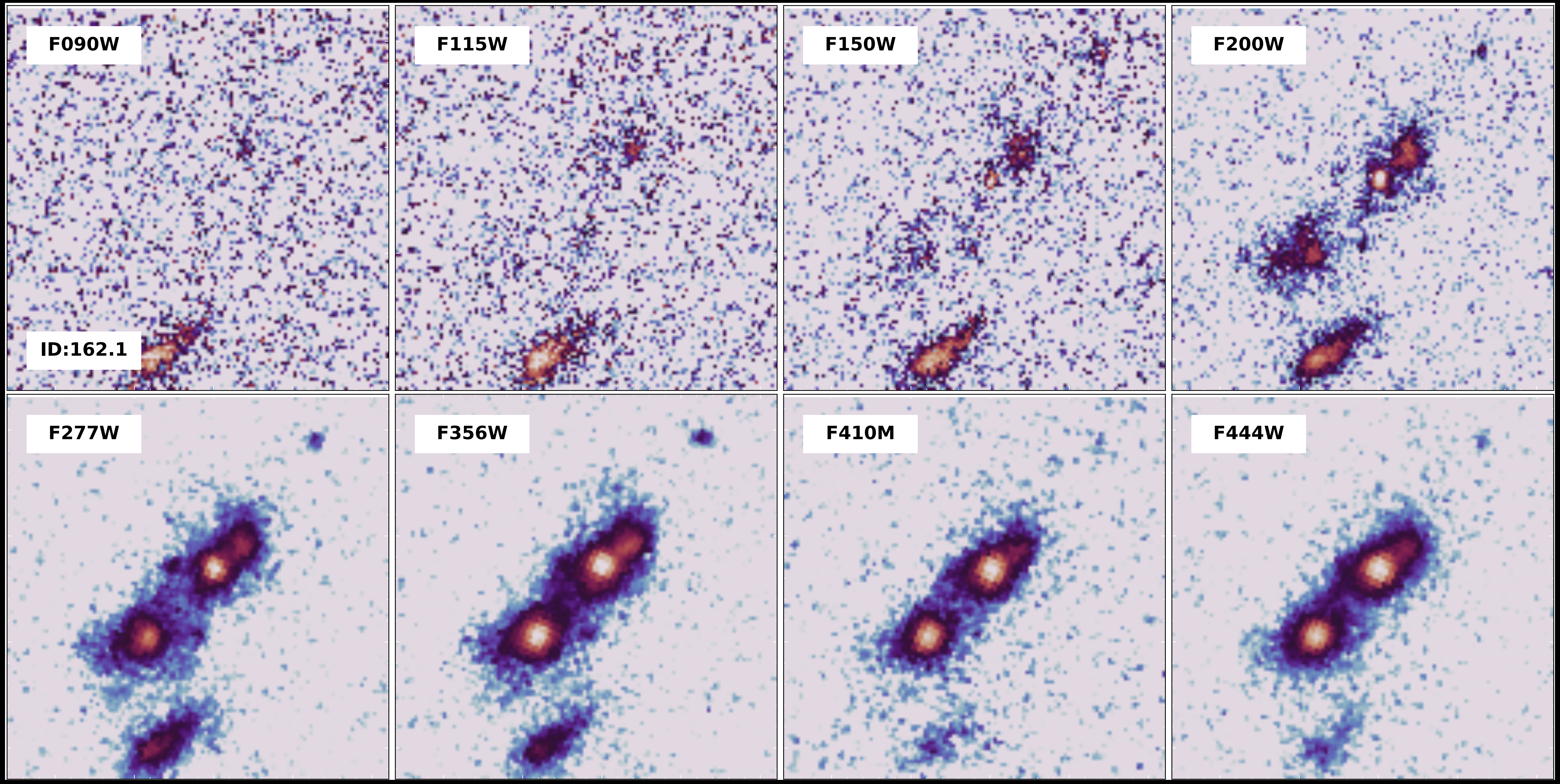
Rachel Cochrane, rcochra3@ed.ac.uk

JWST is revealing stellar structures of more ‘typical’ SMGs in fine detail!

Heterogeneous population:

<u>1/3 Major mergers</u>

See also: Chen+22, Cheng+23, Gillman+23,24, Huang+23, Liu+24, Rujopakarn+23



PRIMER NIRCam imaging of UDS; Jim Dunlop

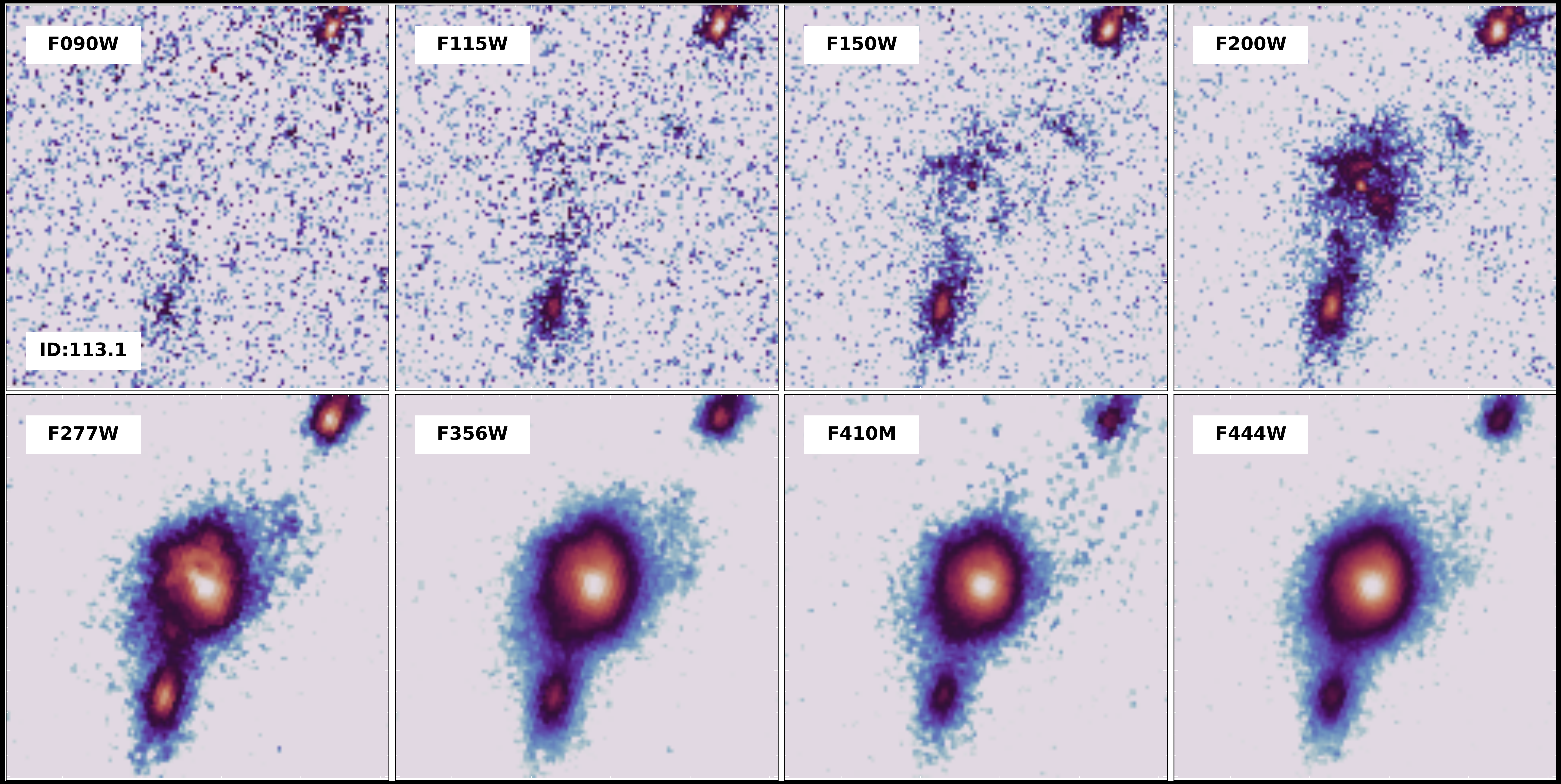
Rachel Cochrane, rcochra3@ed.ac.uk

JWST is revealing stellar structures of more ‘typical’ SMGs in fine detail!

Heterogeneous population:

1/3 Minor mergers/nearby small companions

See also: Chen+22, Cheng+23, Gillman+23,24, Huang+23, Liu+24, Rujopakarn+23



PRIMER NIRCam imaging of UDS; Jim Dunlop

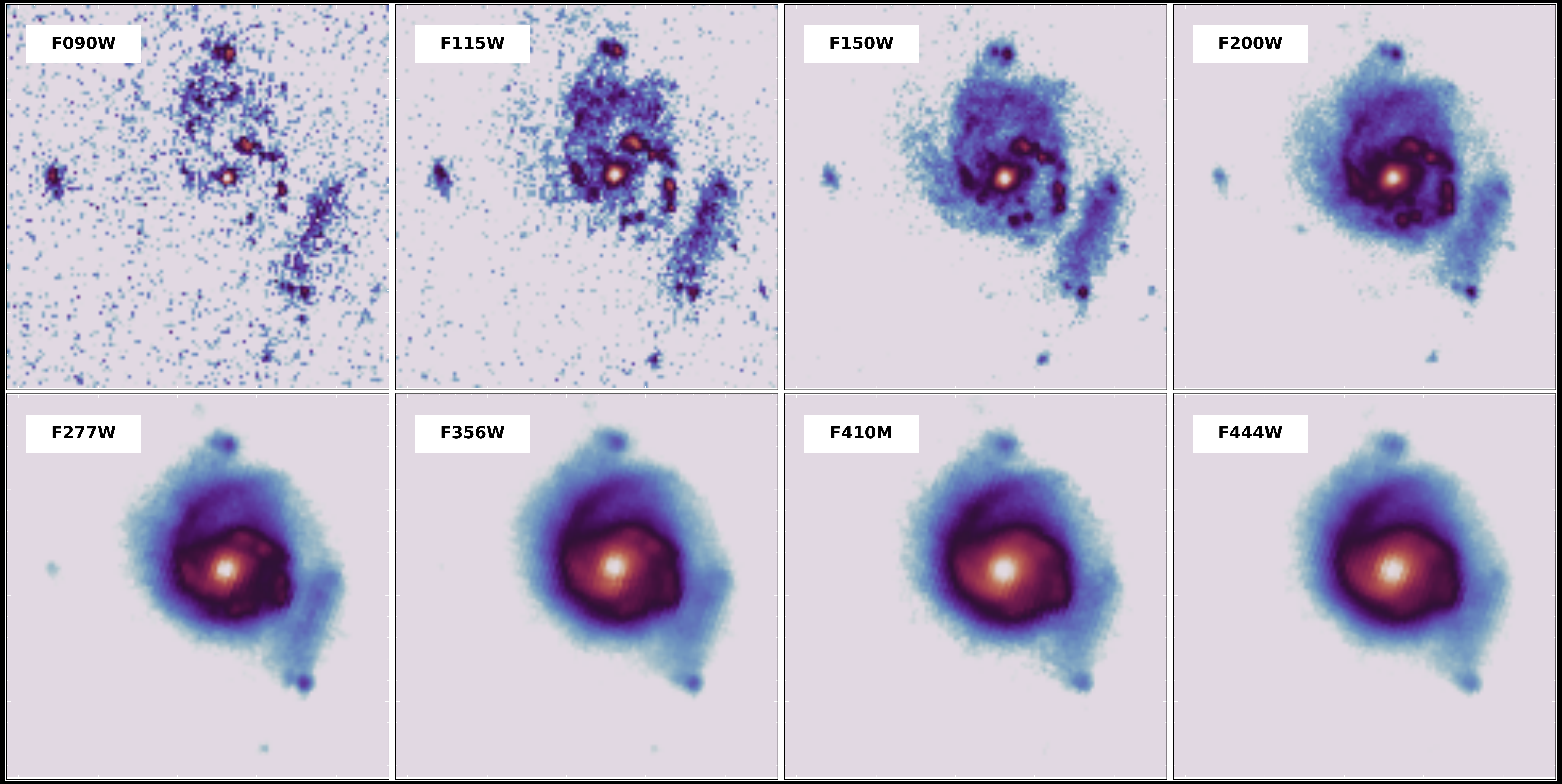
Rachel Cochrane, rcochra3@ed.ac.uk

JWST is revealing stellar structures of more 'typical' SMGs in fine detail!

Heterogeneous population:

<u>1/3 Isolated</u>

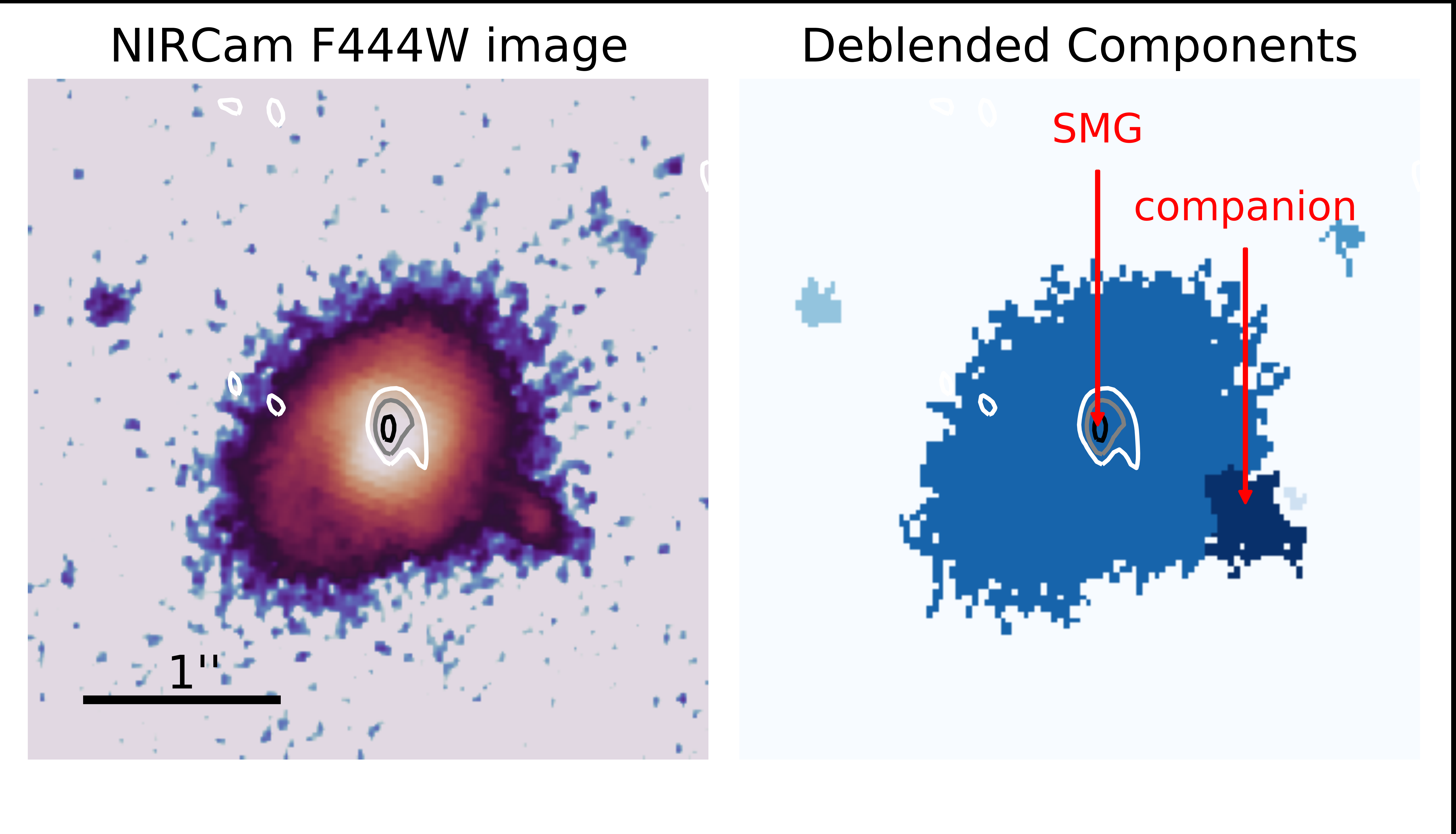
See also: Chen+22, Cheng+23, Gillman+23,24, Huang+23, Liu+24, Rujopakarn+23



PRIMER NIRCam imaging of UDS; Jim Dunlop

Rachel Cochrane, rcochra3@ed.ac.uk

NIRCam photometry

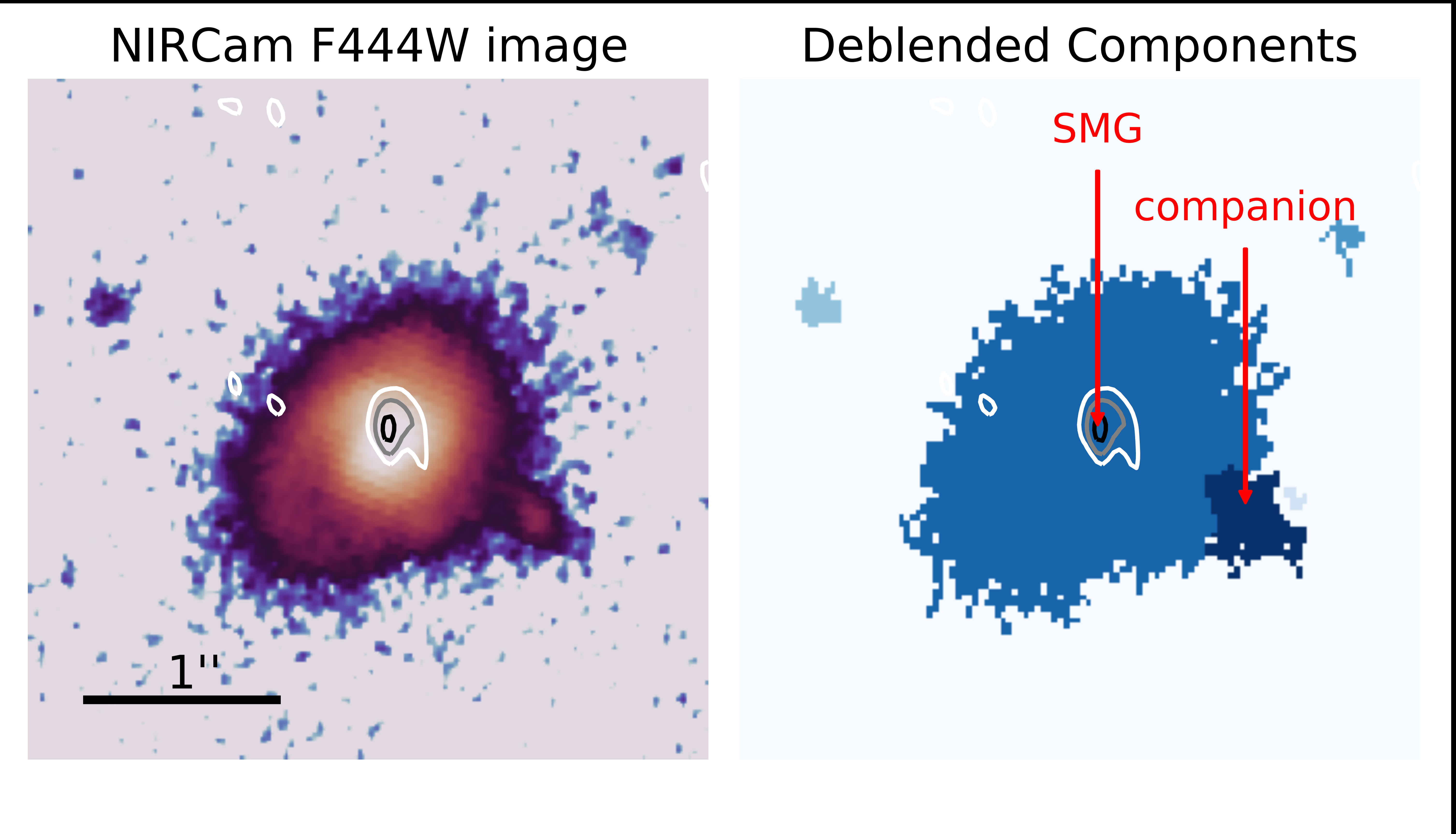


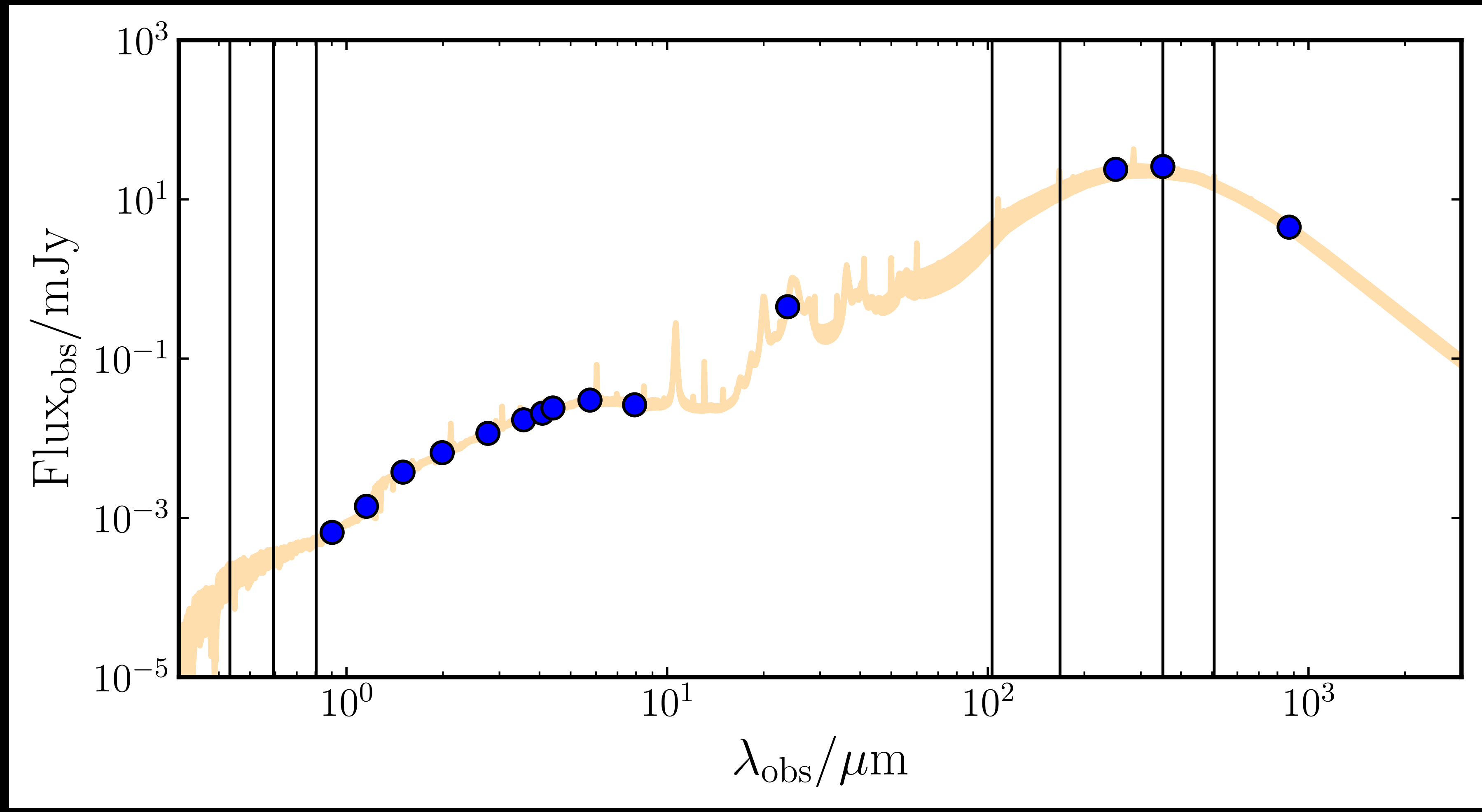
- F444W-based segmentation maps, with further deblending where necessary. Manual SMG identification using ALMA data.
- Also extract photometry for non-SMG companions.
- Some sources showed substantial IRAC blending - can easily identify these by comparing CH2 with F444W and excluding CH3 and CH4 data from SED fit.

→ **1 catalogue of SMGs, 1 catalogue of companions**

Rachel Cochrane, rcochra3@ed.ac.uk

NIRCam photometry

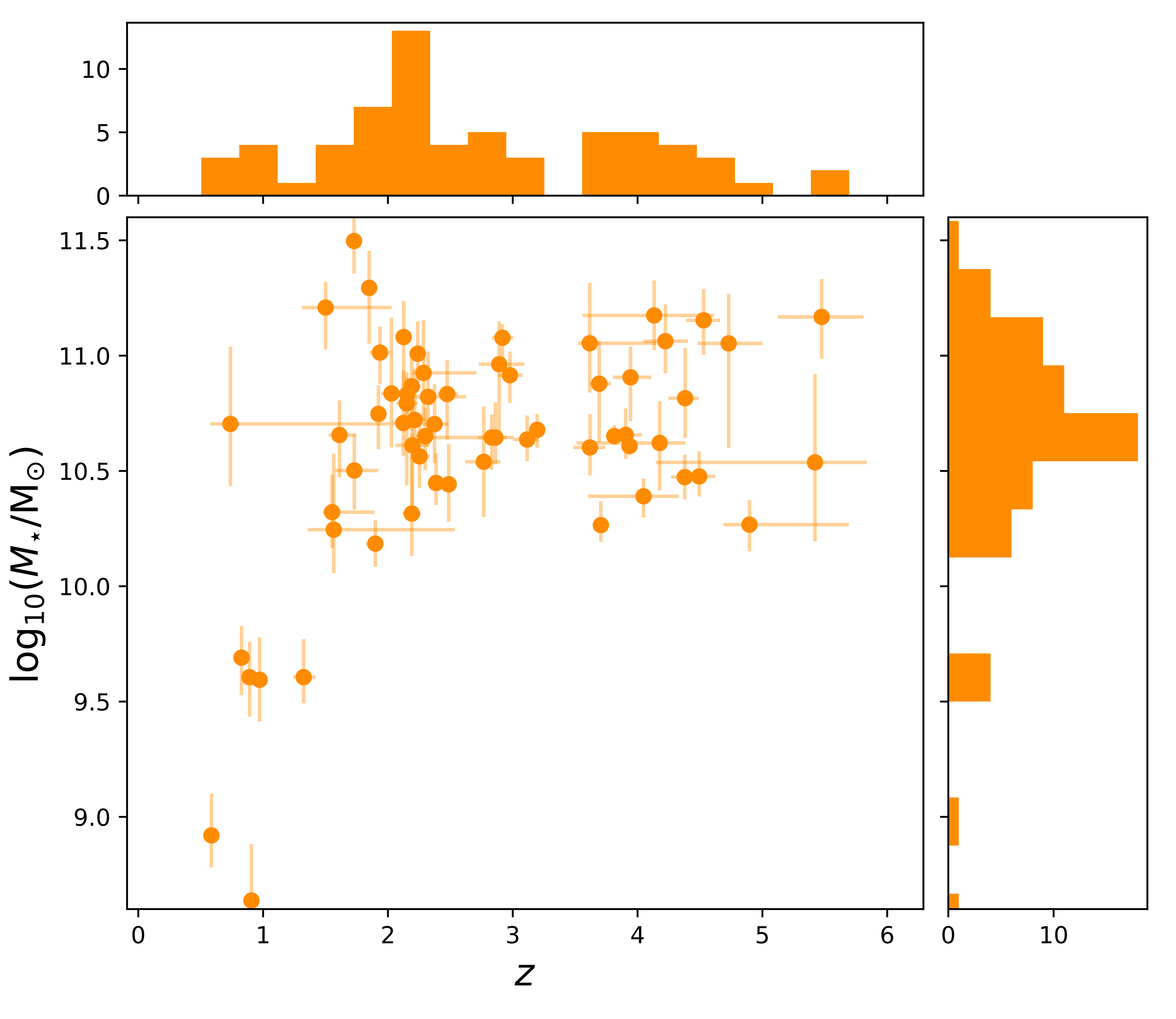


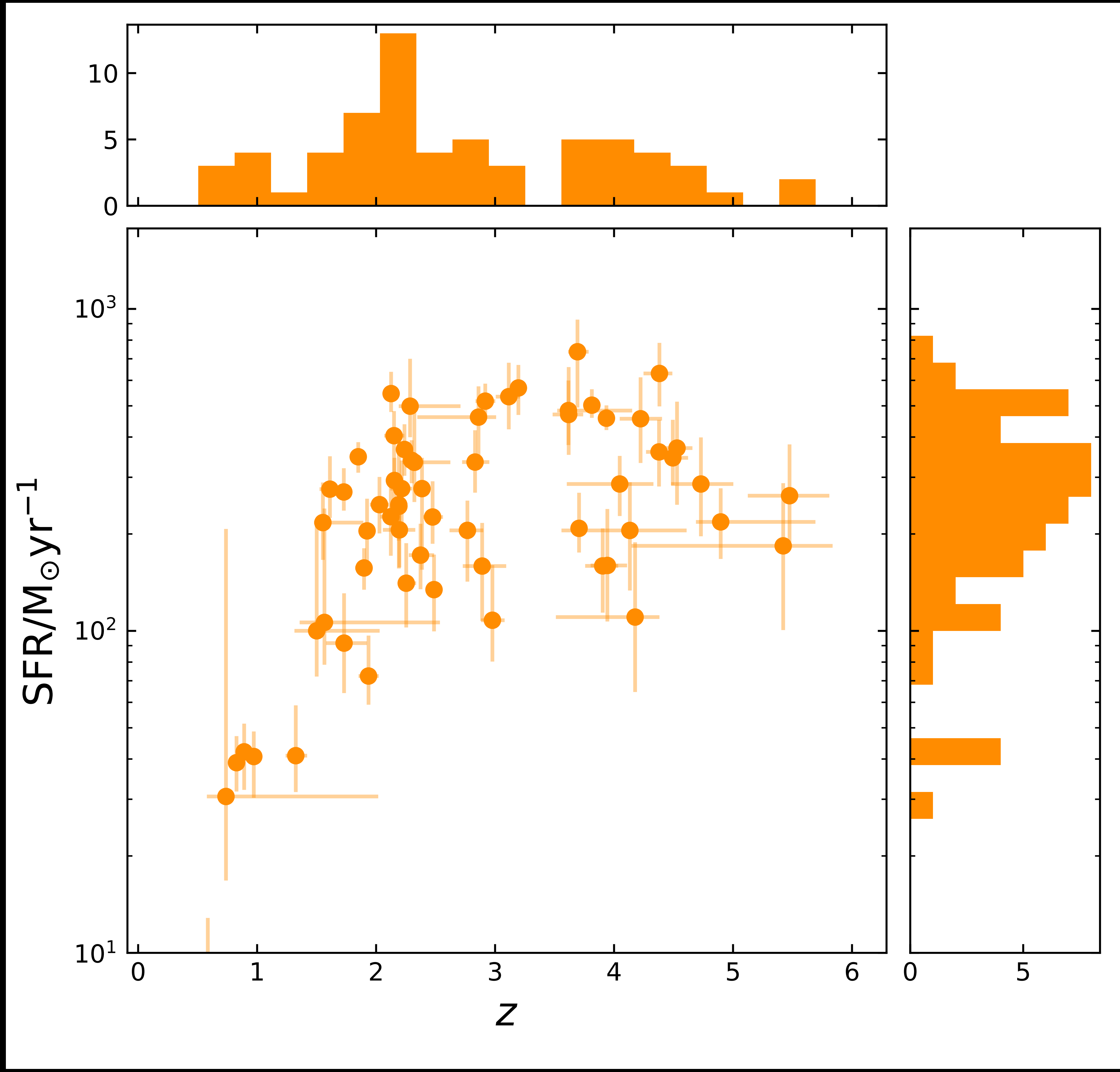


→ 1 catalogue of SMGs, 1 catalogue of companions

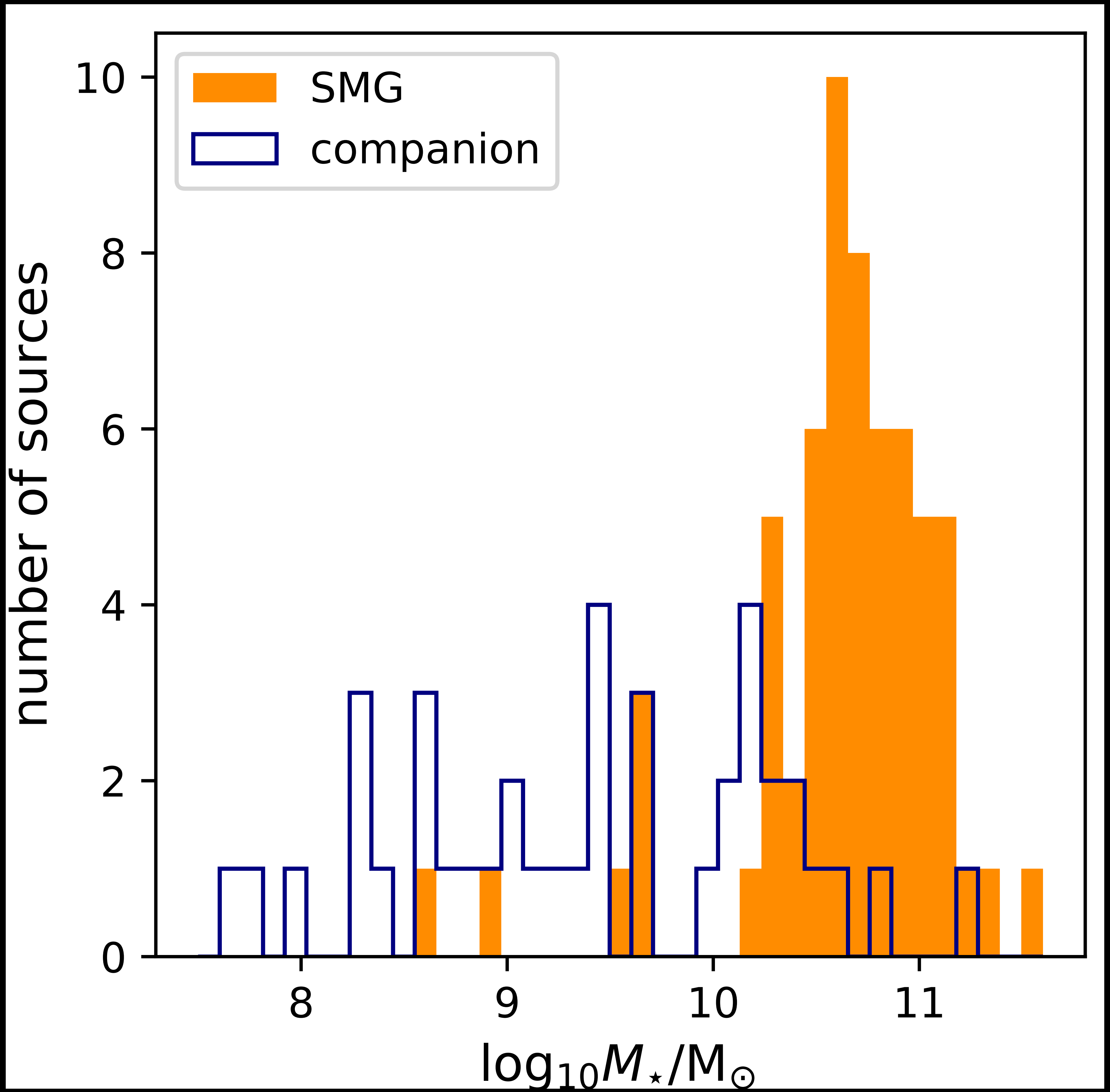
Rachel Cochrane, rcochra3@ed.ac.uk

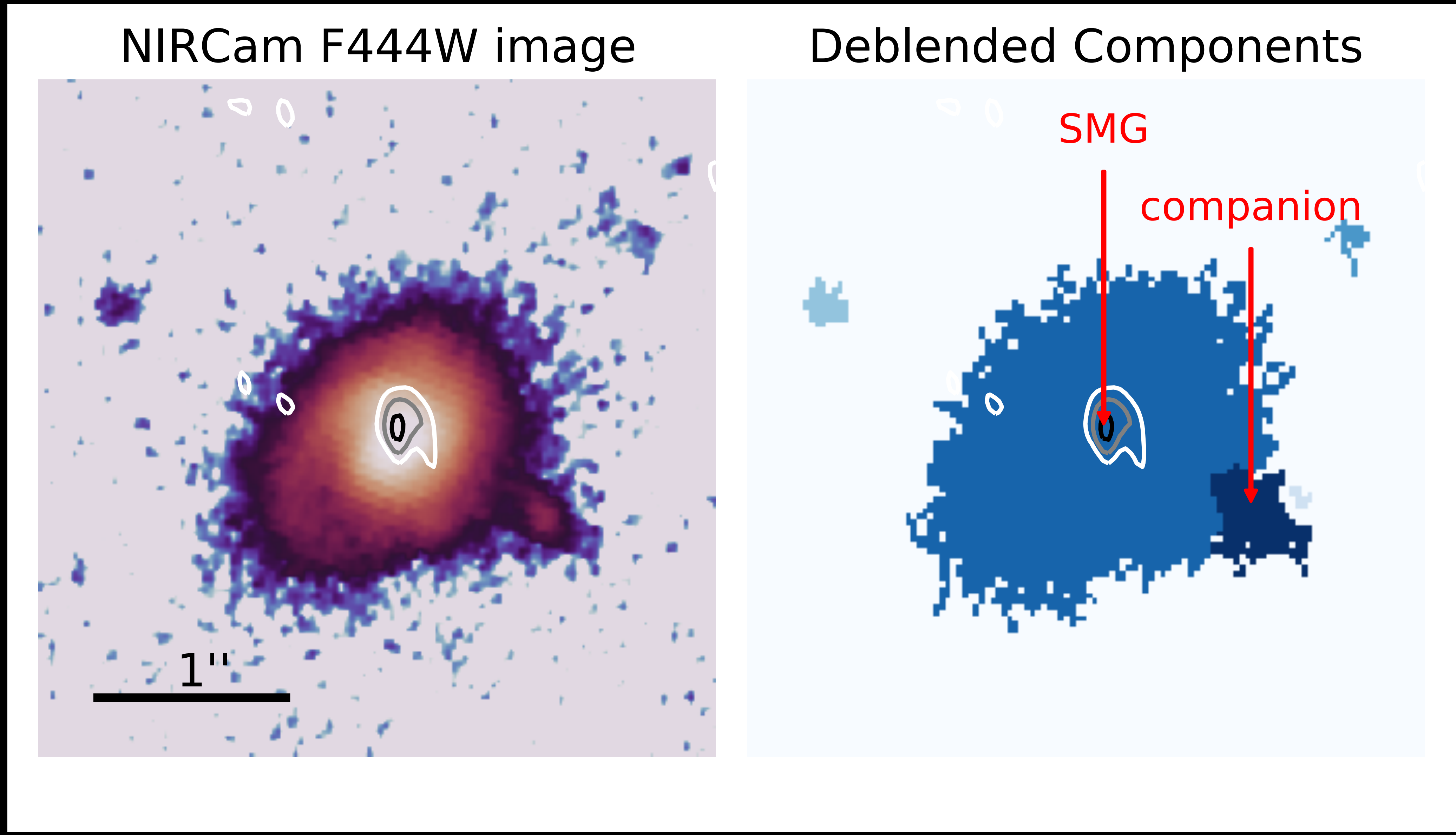
Demographics - SMGs





Demographics - companions

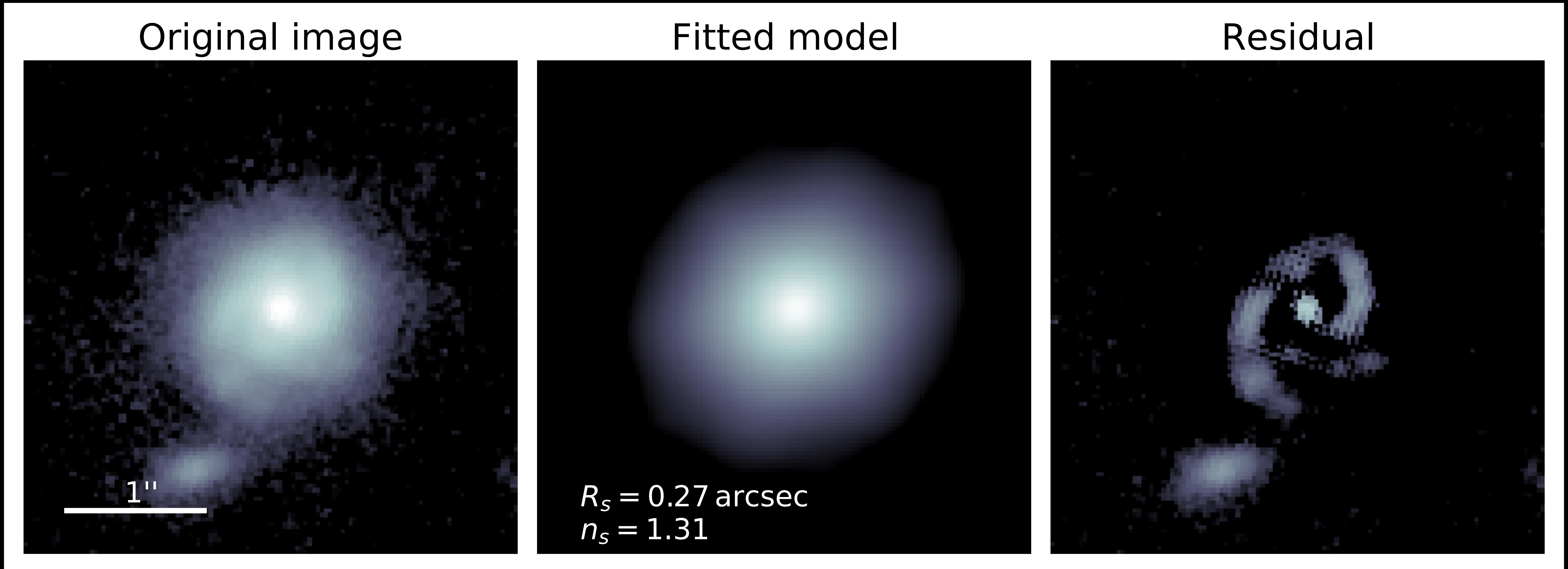




Rachel Cochrane, rcochra3@ed.ac.uk

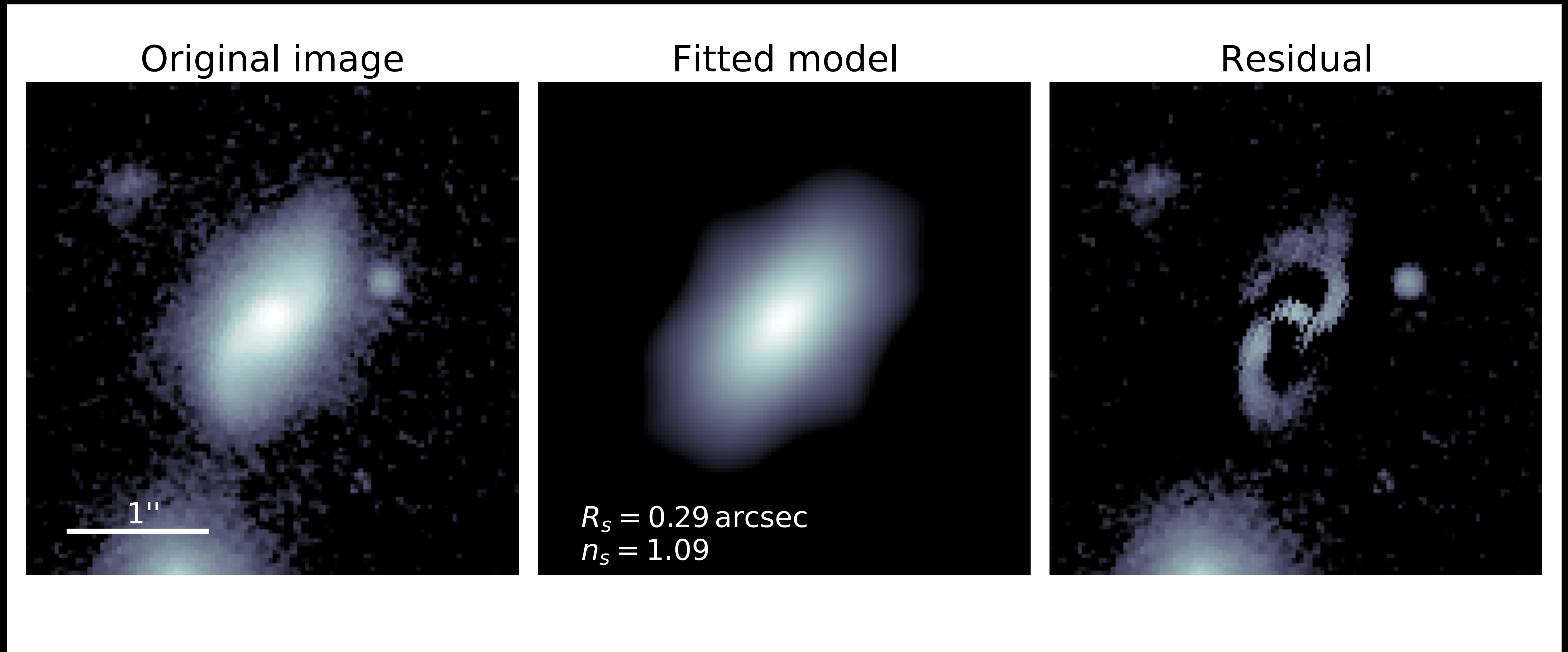
Size/shape measurements

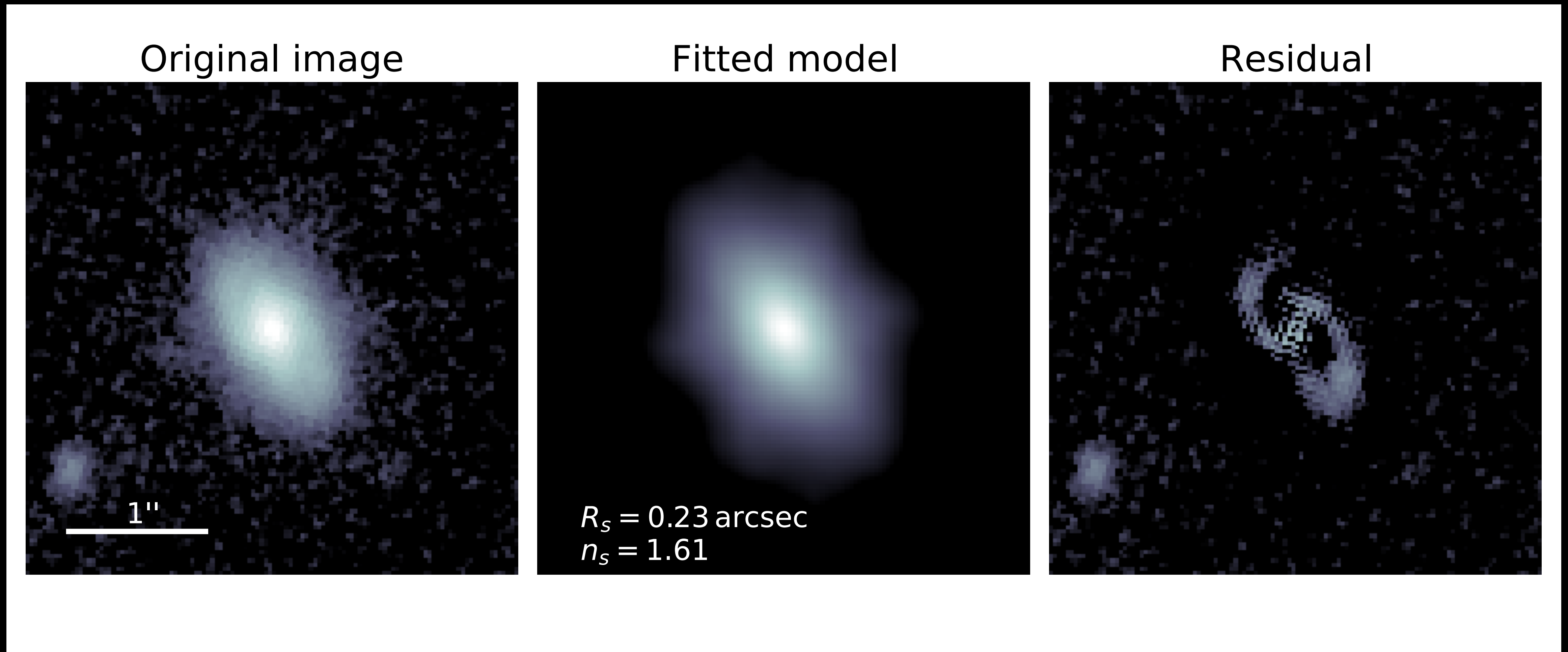
- Using **statmorph** Python package (Rodriguez-Gomez et al. 2019) to characterise sizes and shapes, using the segmentation map to isolate the SMG from companion(s).
- $R_{\text{Sérsic}}$ and $n_{\text{Sérsic}}$ derived from fitting 2D profile

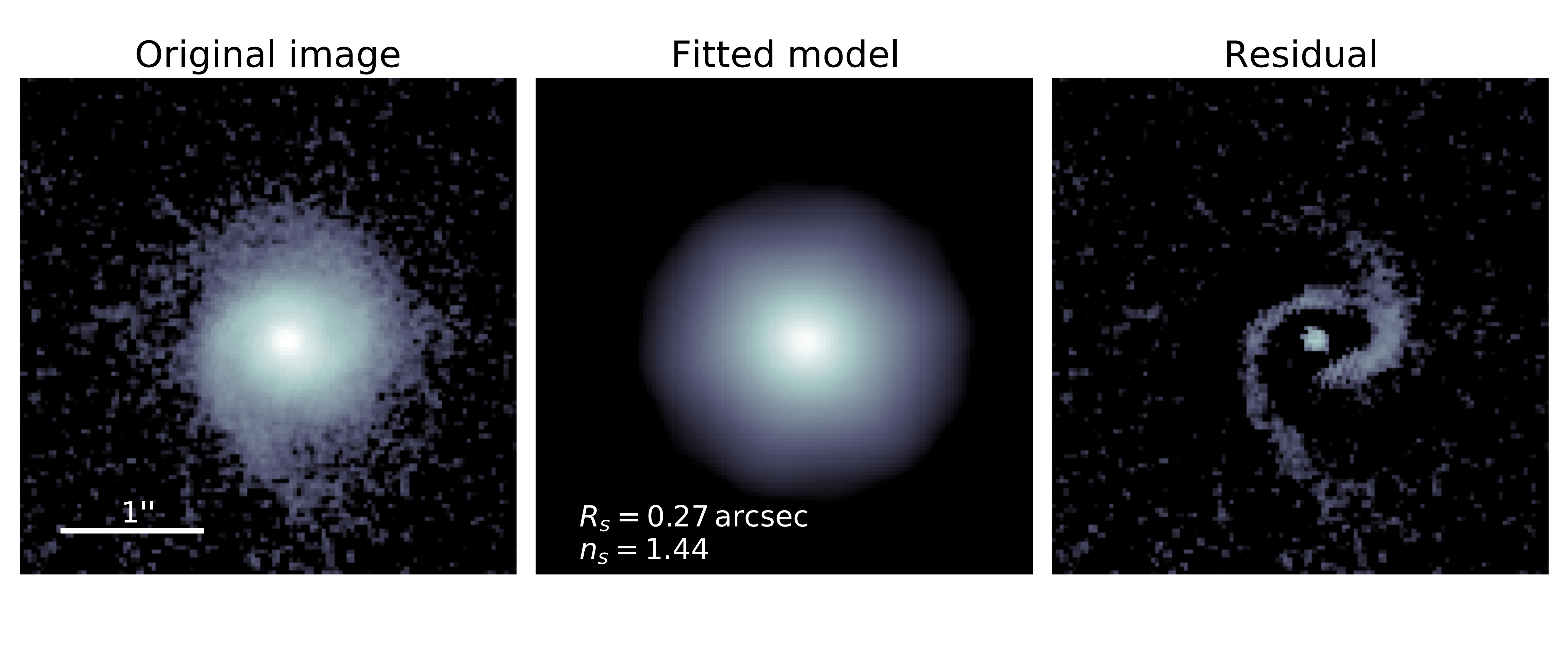


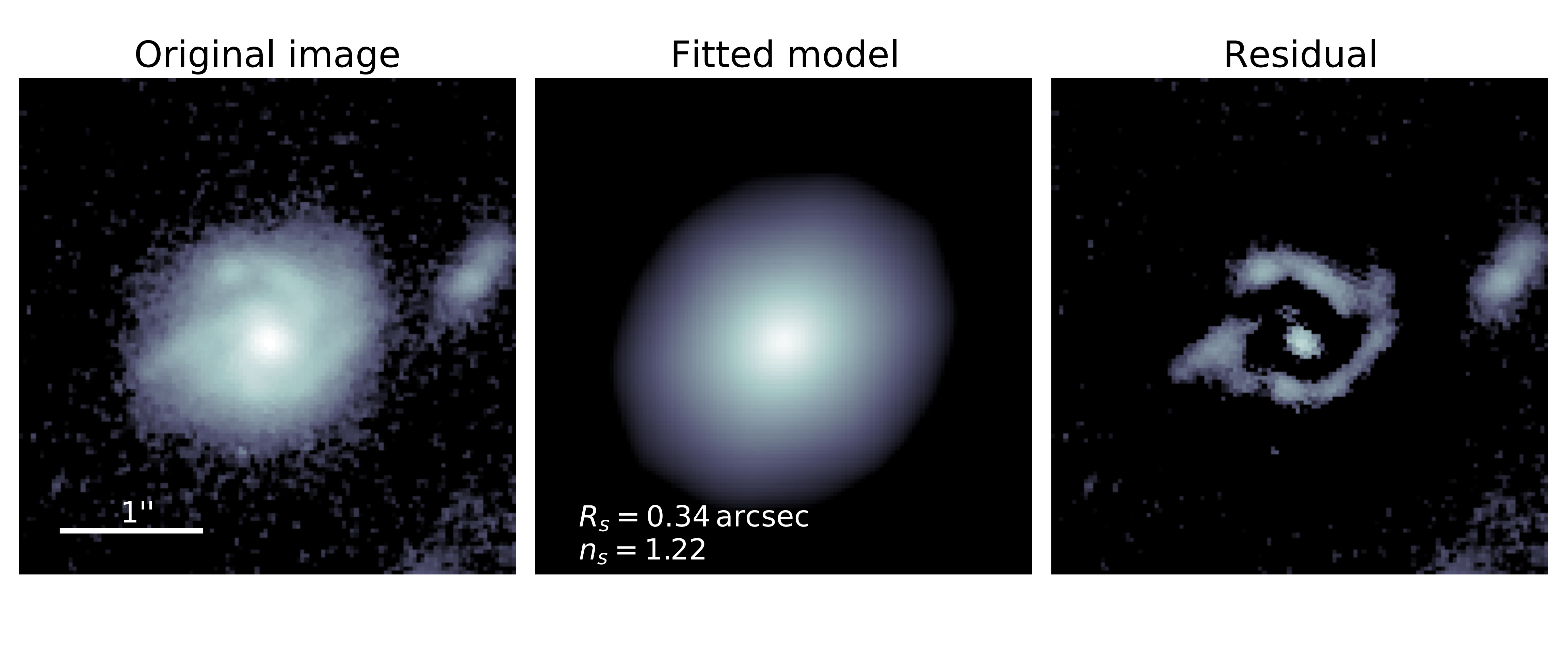
Rachel Cochrane, rcochra3@ed.ac.uk

Many clear spiral arms and bars



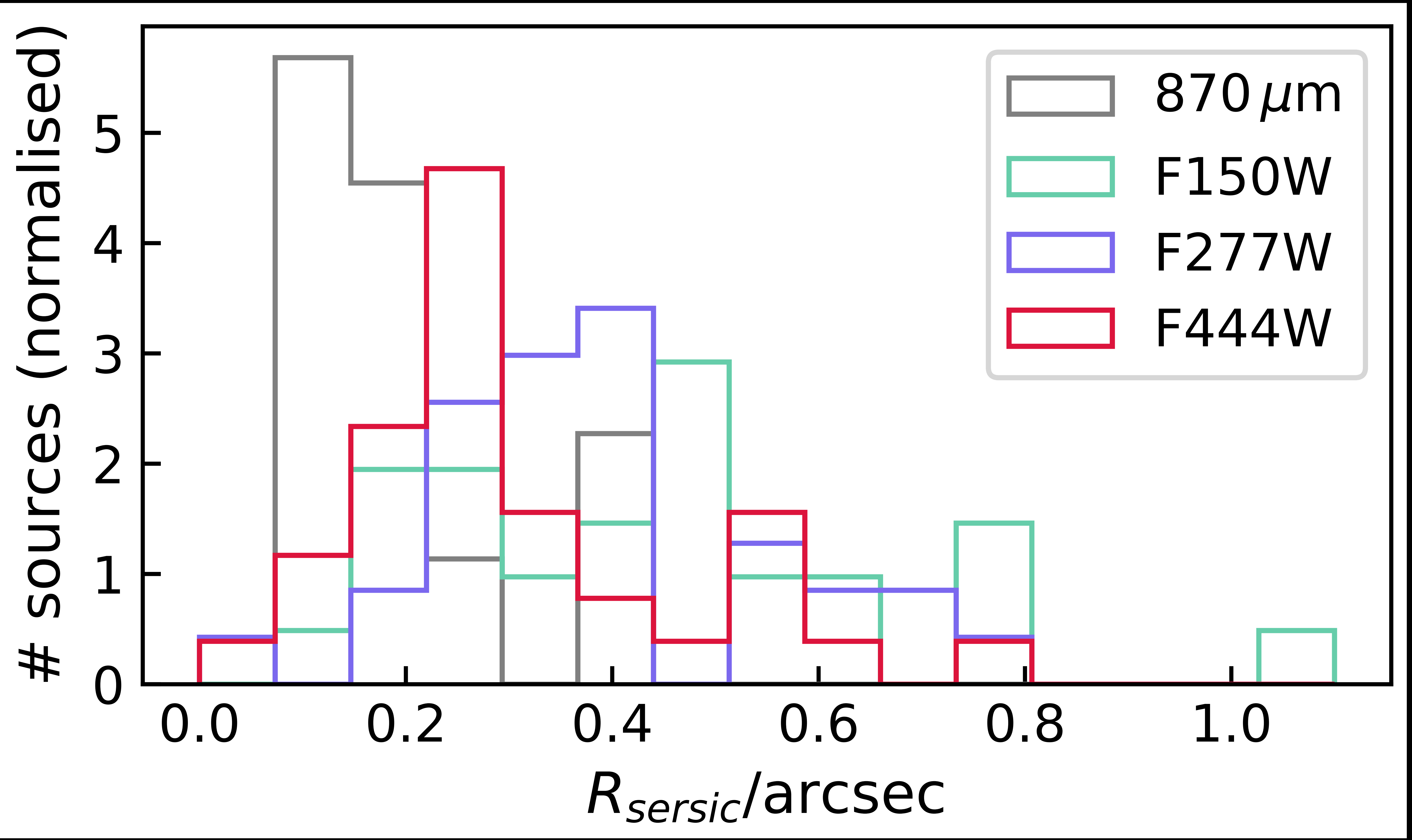






Rachel Cochrane, rcochra3@ed.ac.uk

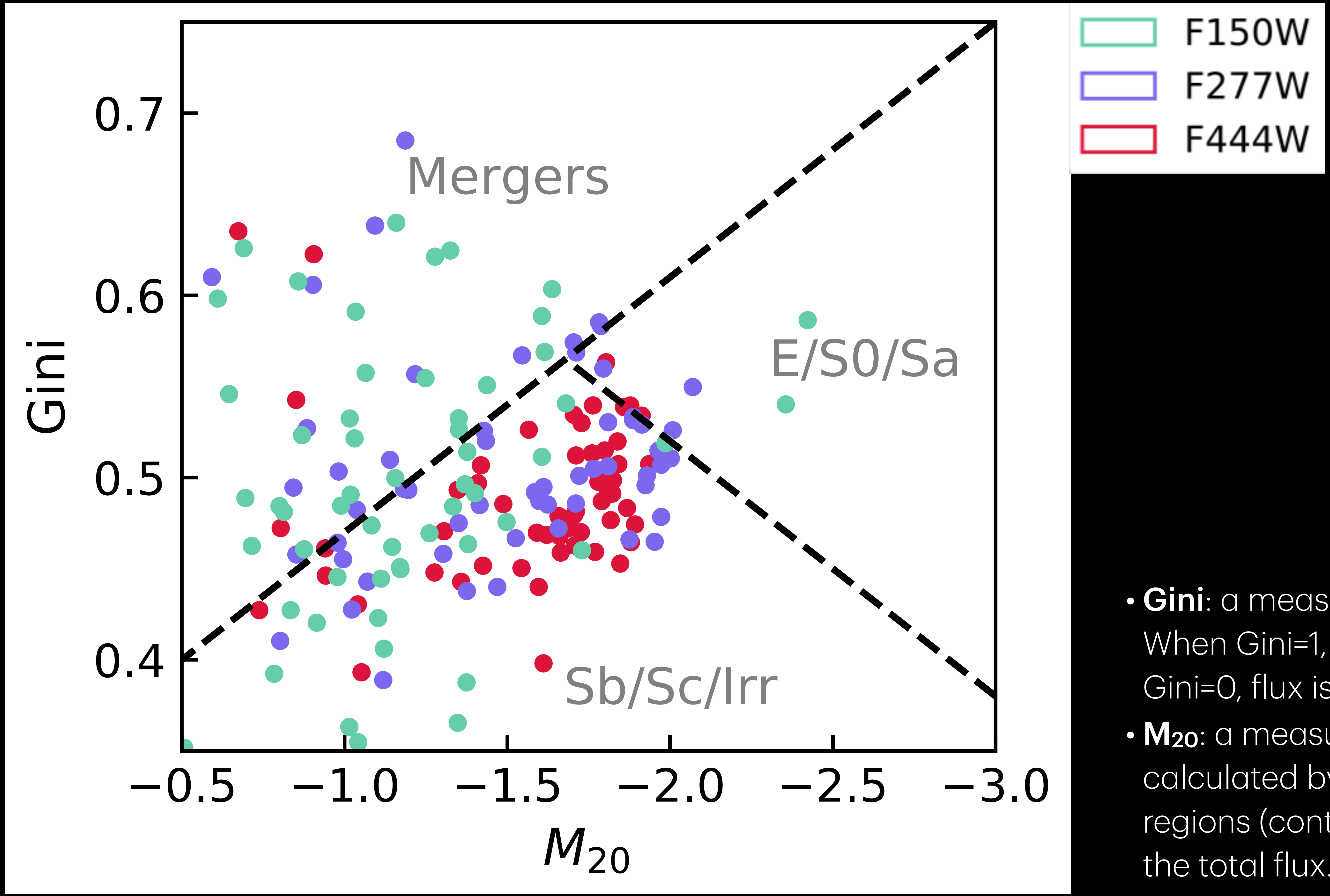
Sizes are strongly wavelength-dependent



- Sizes calculated using several NIRCam bands: **F150W, F277W, F444W.**
- Shorter wavelengths more extended.
- 870um sizes for the subset of sources measured by Gullberg+19 are even smaller than the F444W measurements.

Rachel Cochrane, rcochra3@ed.ac.uk

Shape classfications are also wavelength-dependent



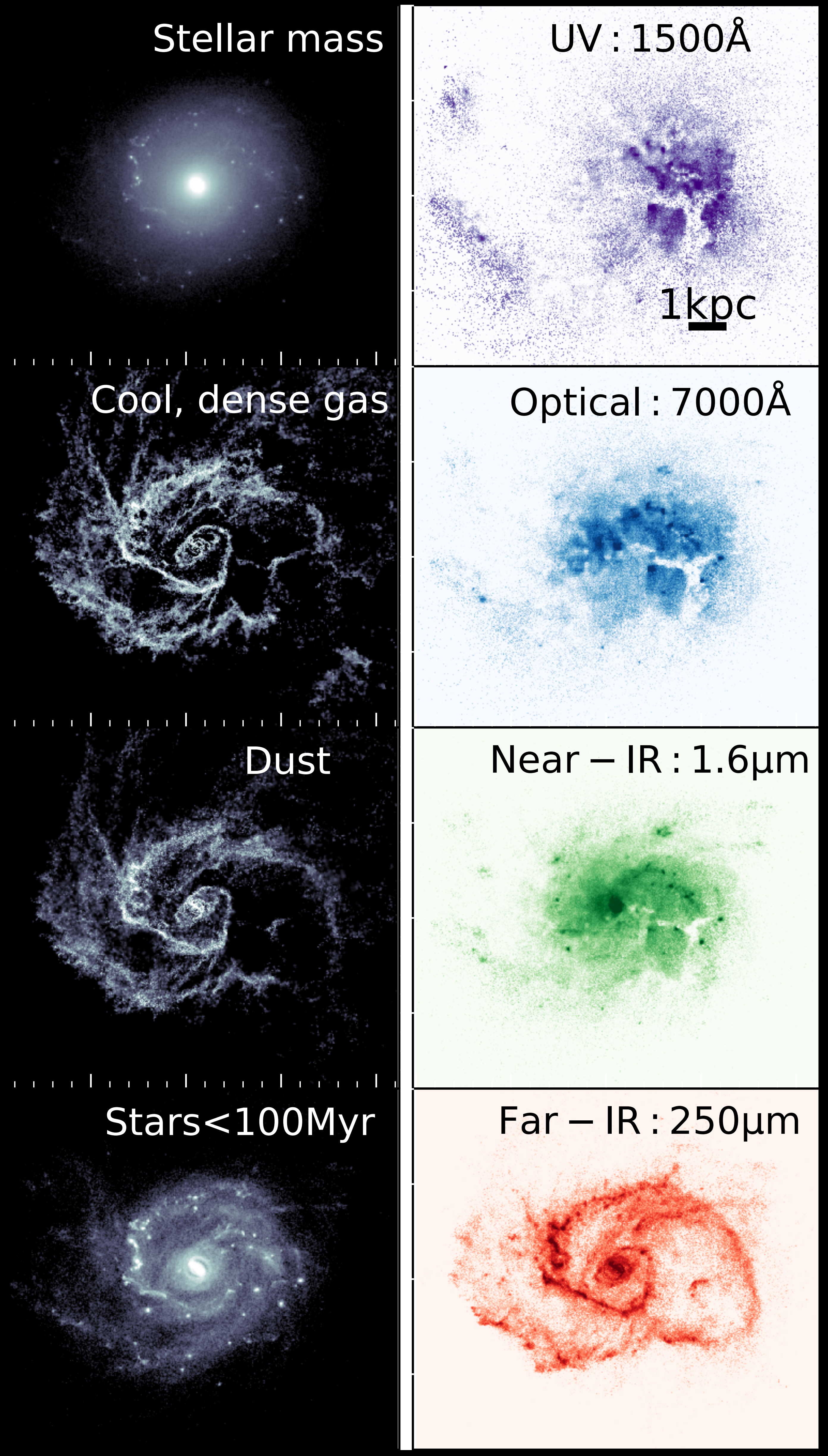
A galaxy seen only in shorter wavelength emission is much more likely to be classified as a merger

- **Gini**: a measure of the degree of distribution of flux amongst pixels. When Gini=1, all flux is measured within a single pixel, and when Gini=0, flux is evenly distributed.
- **M_{20}**: a measure of the concentration of light within an image, calculated by comparing the second moment of the brightest regions (containing 20%) of the total flux to the second moment of the total flux.

Rachel Cochrane, rcochra3@ed.ac.uk

Forward-modelled zoom-in simulations can help with physical understanding of varying size and shape measurements

FIRE simulations of massive galaxies (reaching 10^11M_sol by z~2) + SKIRT continuum radiative transfer

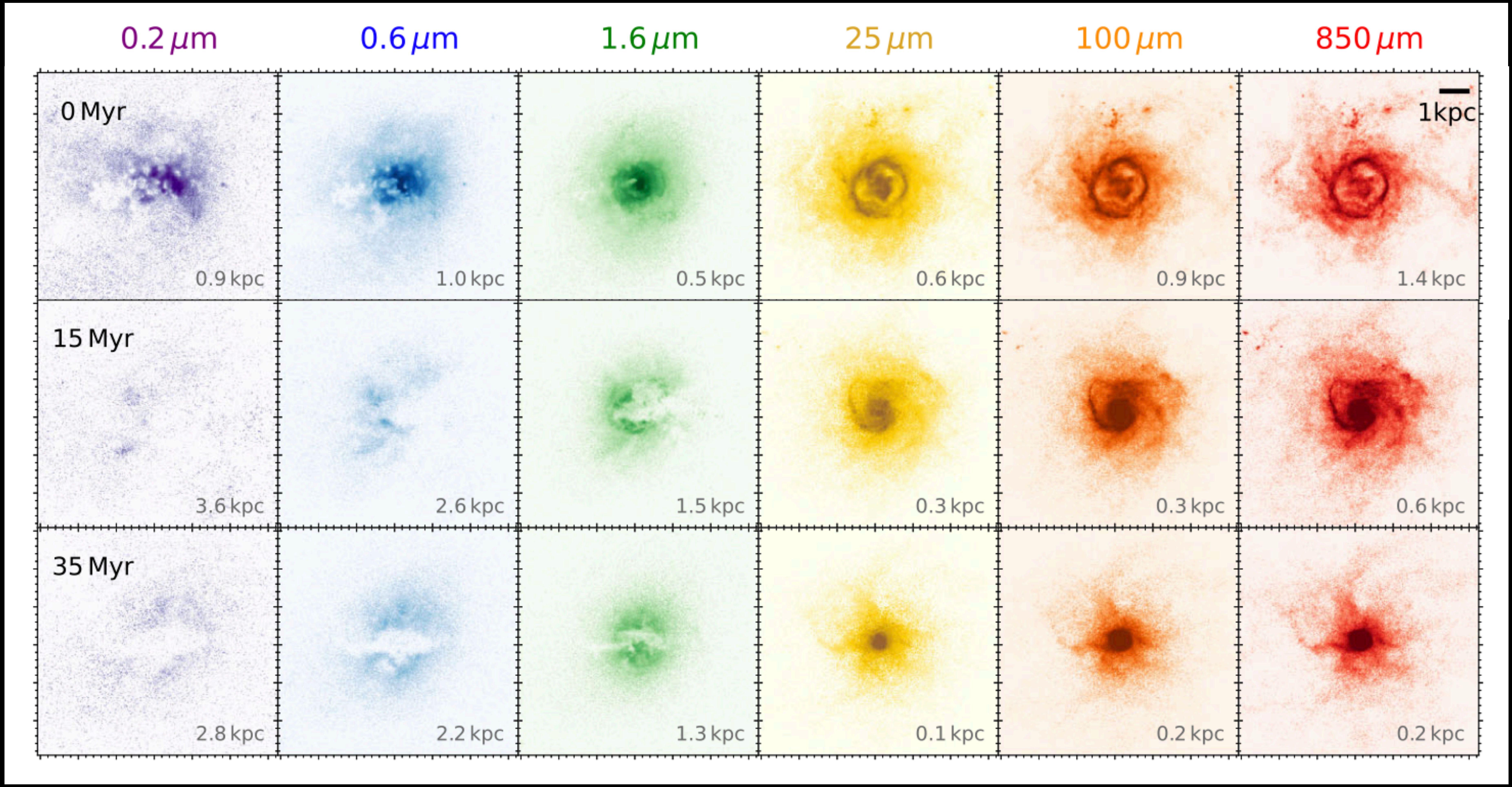


Cochrane *et al. 2019*

Rachel Cochrane, rcochra3@ed.ac.uk

Evolution of multi-wavelength emission with time during a compact, dusty starburst event

Time



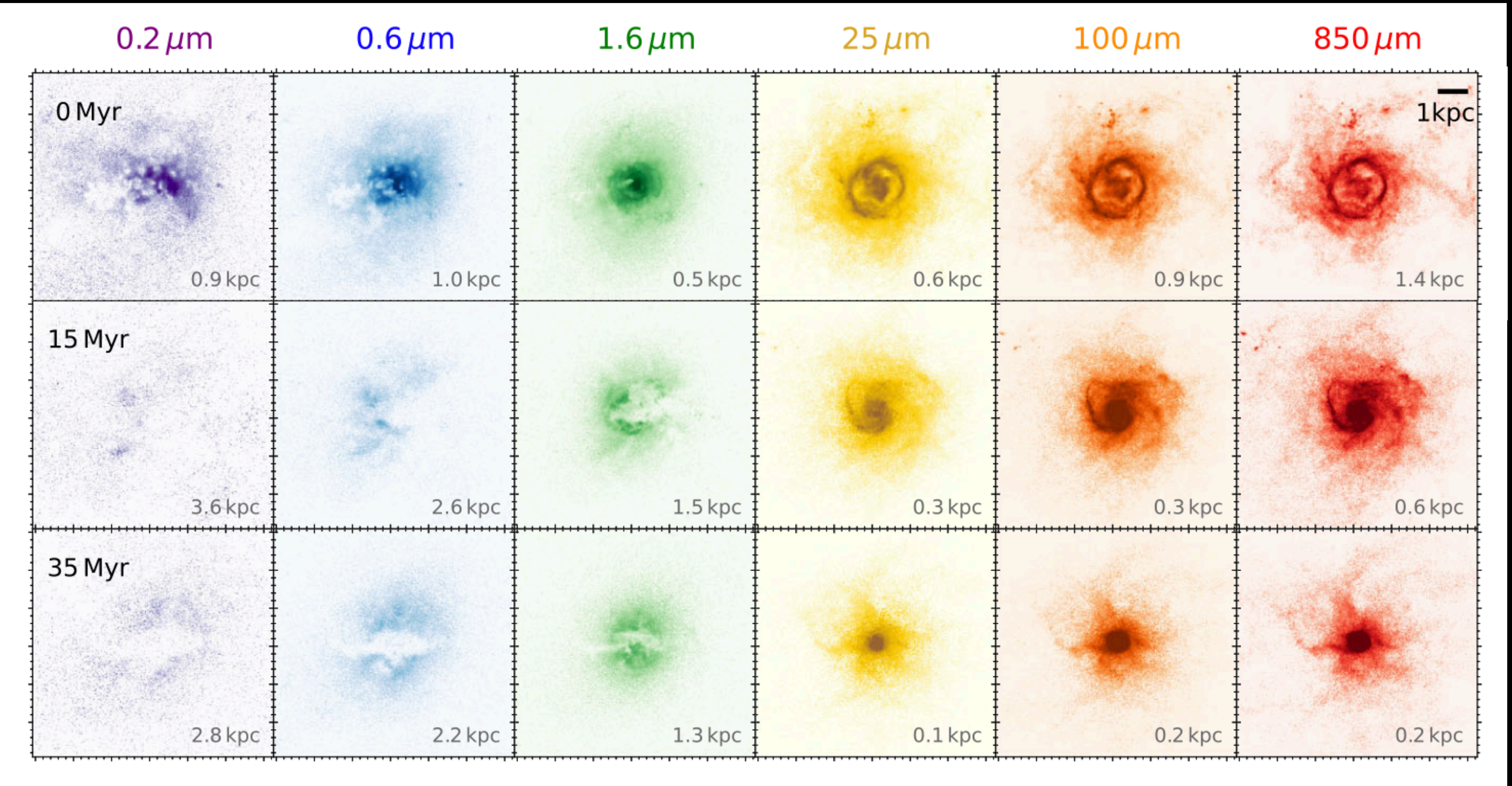
$z=2.3$

$M_* = 10^{10.8}\, M_\odot$

Cochrane et al. 2023b

Rachel Cochrane, rcochra3@ed.ac.uk

Evolution of multi-wavelength emission with time during a compact, dusty starburst event



Kiloparsec-scale offsets between the rest-UV and far-IR are driven by heavy central dust obscuration. Rest-UV light is clumpy and disordered (could be mis-classified as merger once convolved with PSF)

Cochrane et al. 2023b

Rachel Cochrane, rcochra3@ed.ac.uk

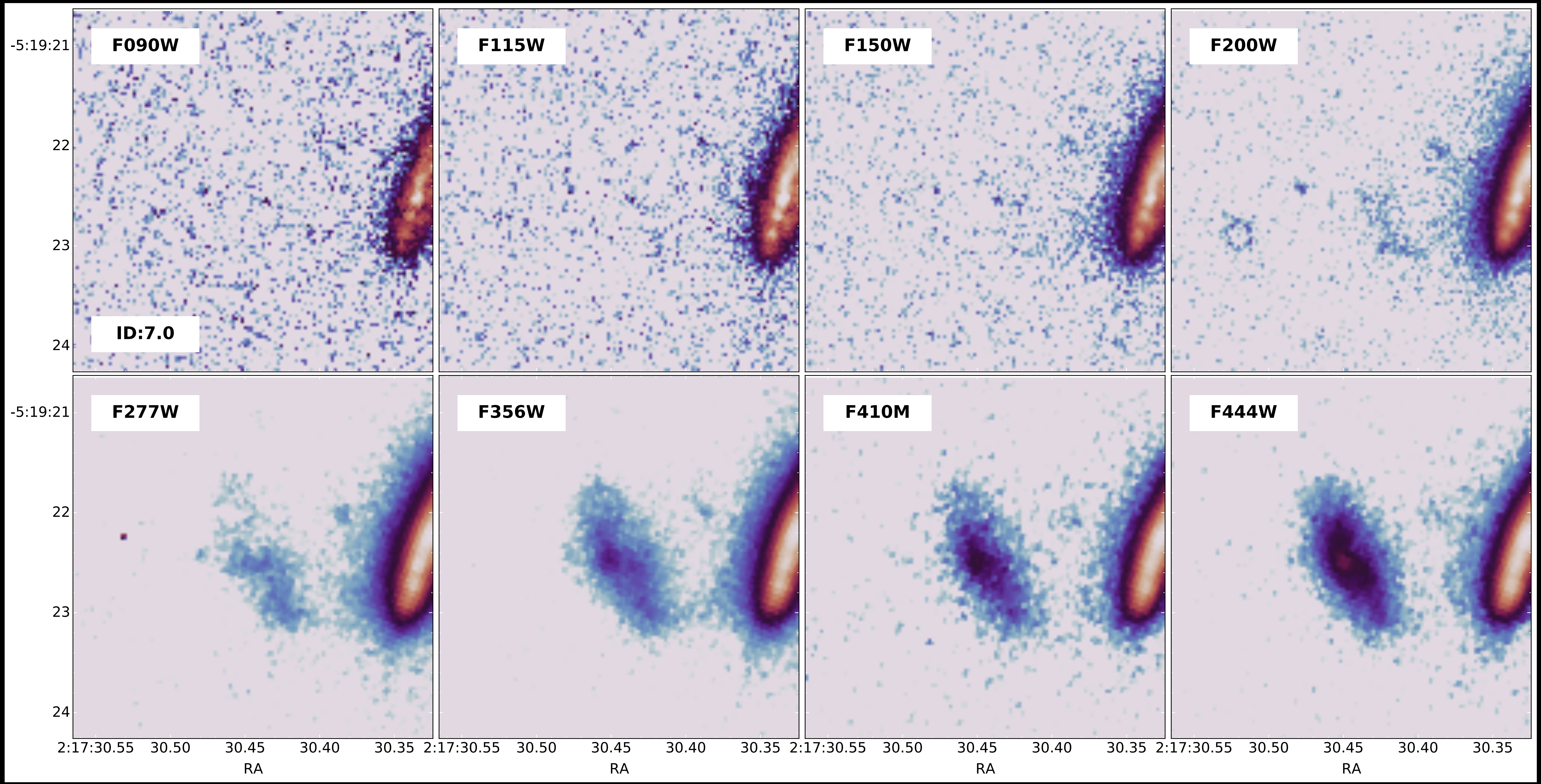
Evolution of multi-wavelength sizes with time during a compact, dusty starburst event

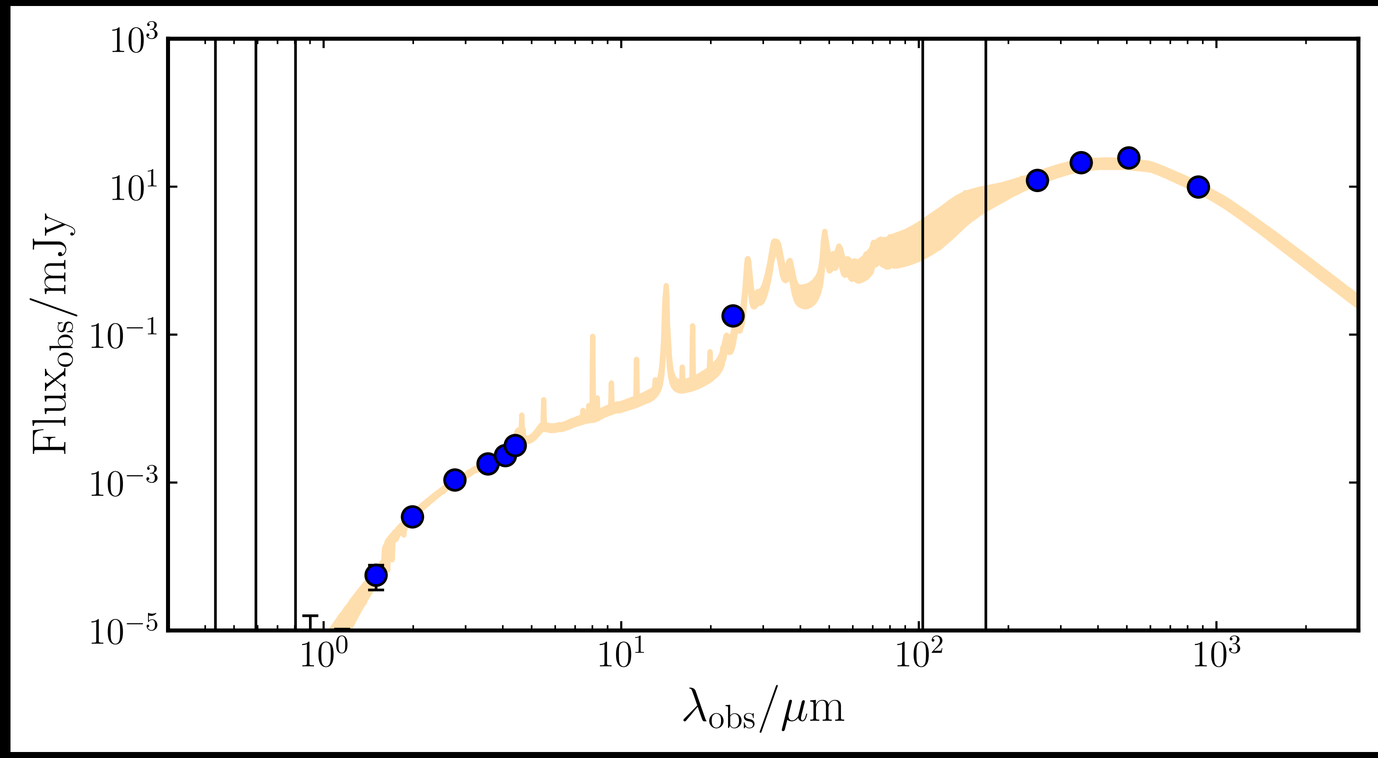
Cochrane et al. 2023b

Observed rest-UV-NIR sizes remain roughly constant, ~2kpc throughout the starburst, even though the intrinsic half-SFR size decreases to 0.1kpc, due to heavy central dust obscuration.

Rachel Cochrane, rcochra3@ed.ac.uk

Resolved SED fitting -> SFR and mass profiles





z=3.3+-0.1

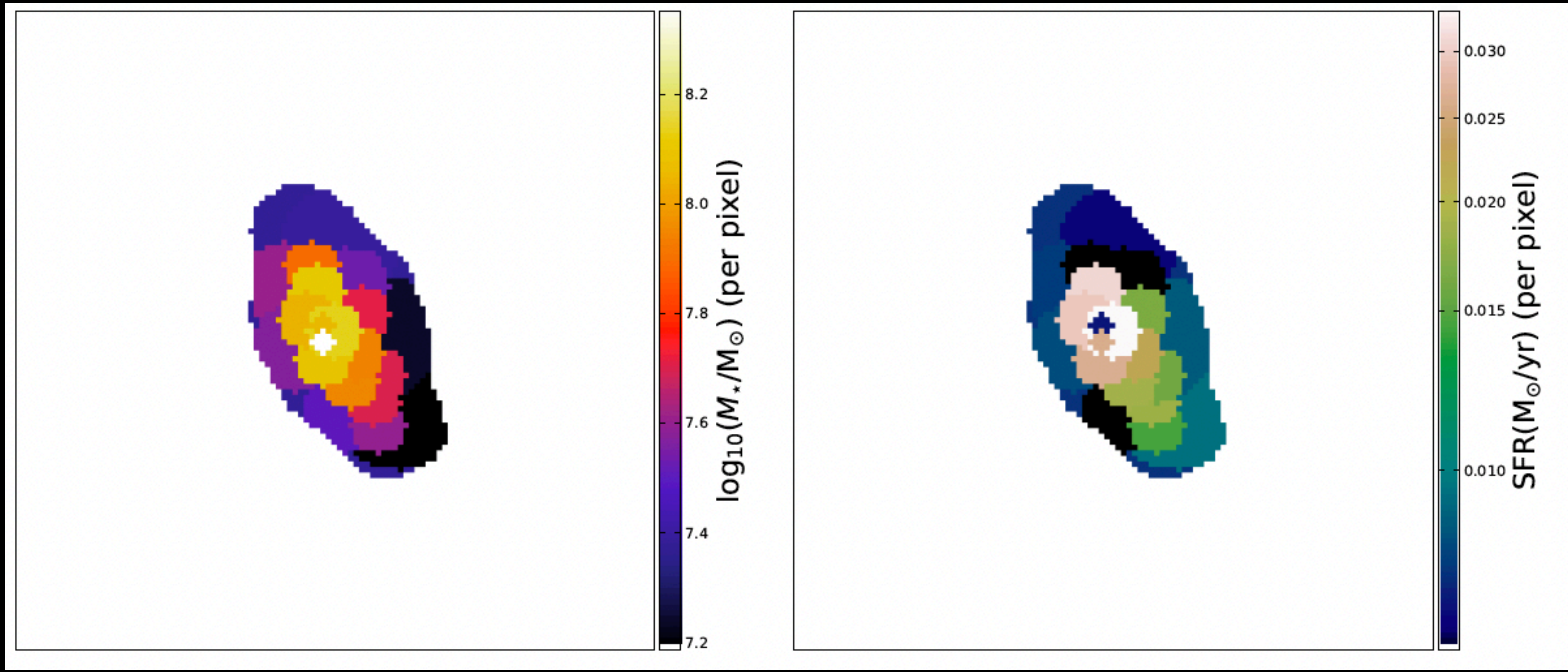
$\log_{10}(M_*/M_\odot)$ =

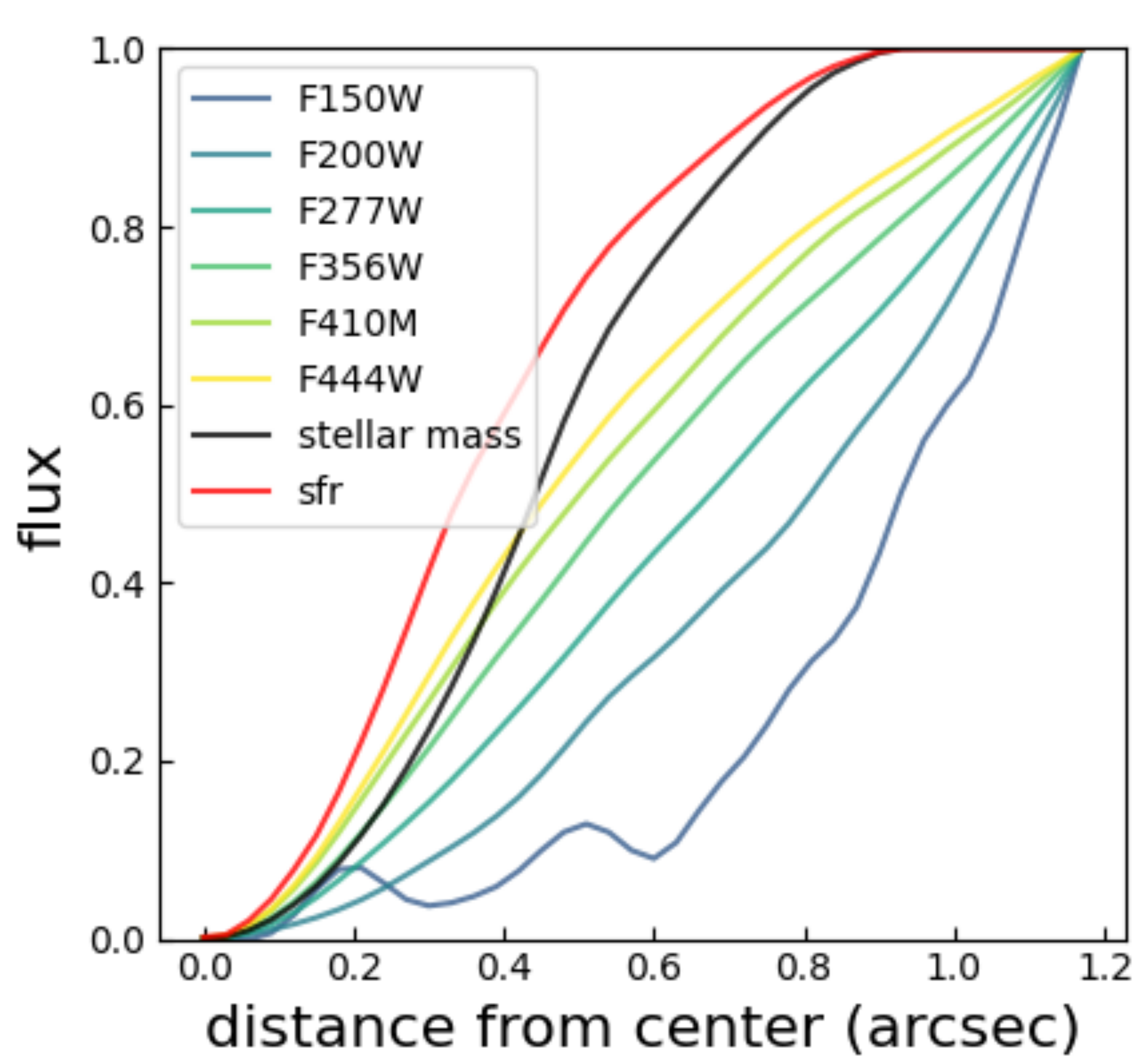
10.7+-0.1

SFR =
550+160-120$M_\odot$/yr

Rachel Cochrane, rcochra3@ed.ac.uk

Resolved SED fitting -> SFR and mass profiles



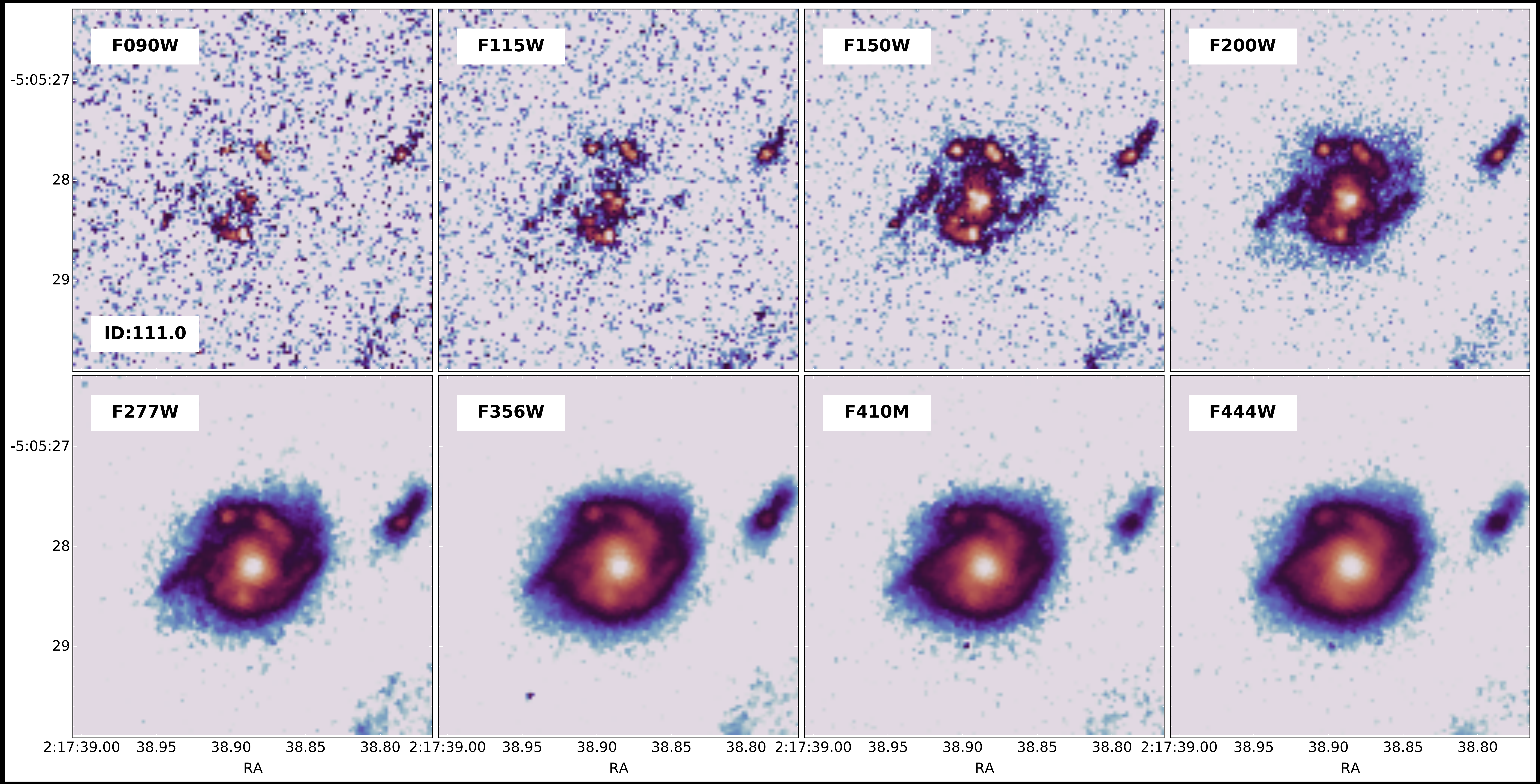


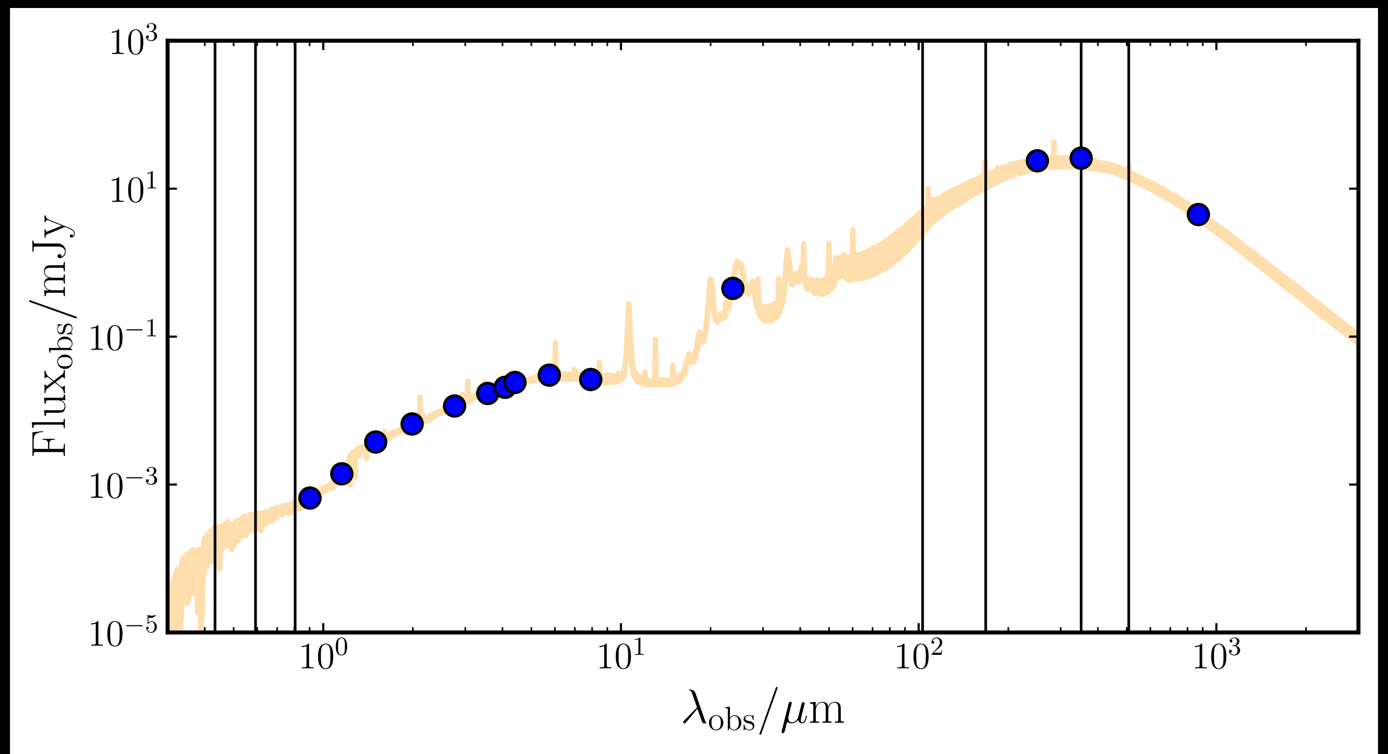
z=3.3
R_{50} (mass) 0.45” = 3.5kpc
R_{50} (SFR) 0.33” = 2.5kpc
R_{50} (light) at different wavelengths (from short to long): [0.93, 0.81, 0.66, 0.57, 0.51, 0.45]” = [7.1, 6.2, 5.1, 4.4, 3.9, 3.5] kpc

half-SFR radius is more compact than stellar mass, and than light at any wavelength

 Rachel Cochrane, rcochra3@ed.ac.uk

Resolved SED fitting -> SFR and mass profiles





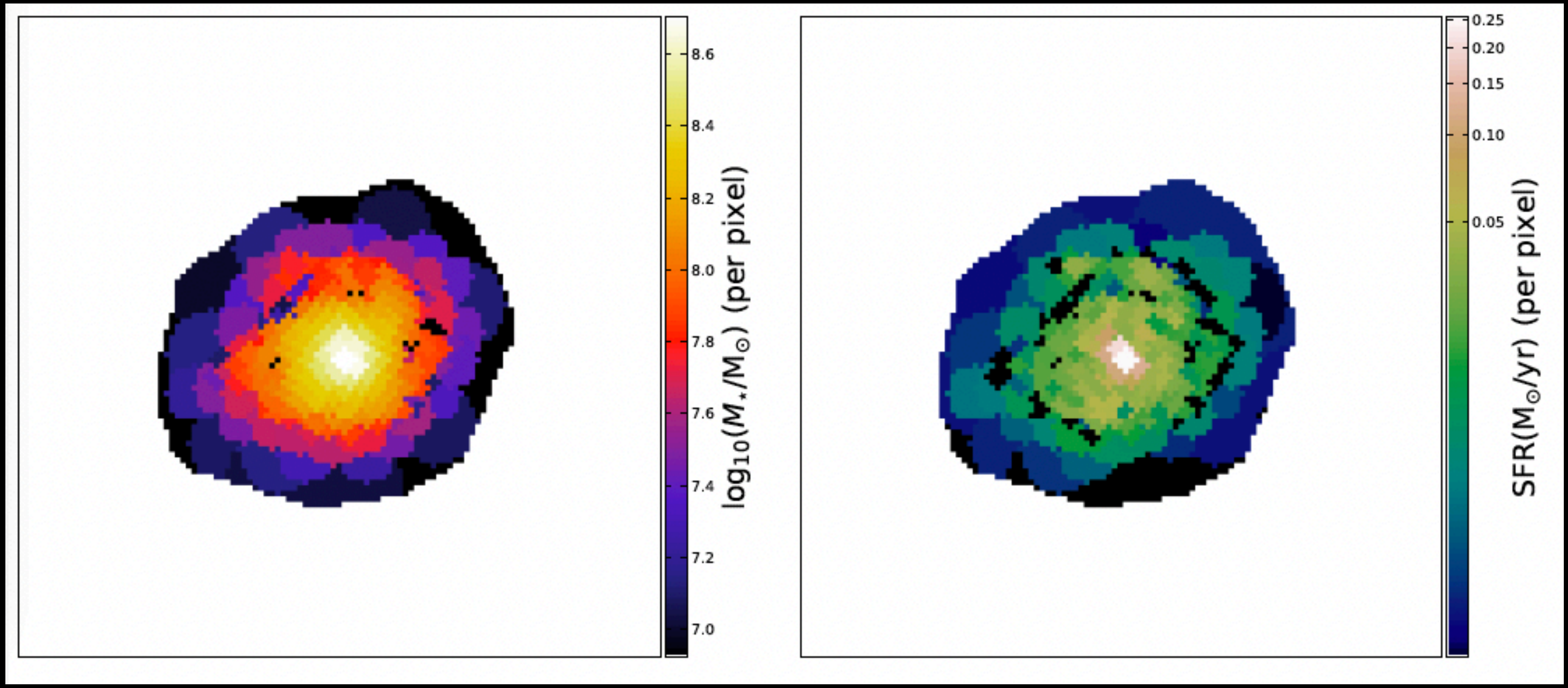
z=2.2+-0.1

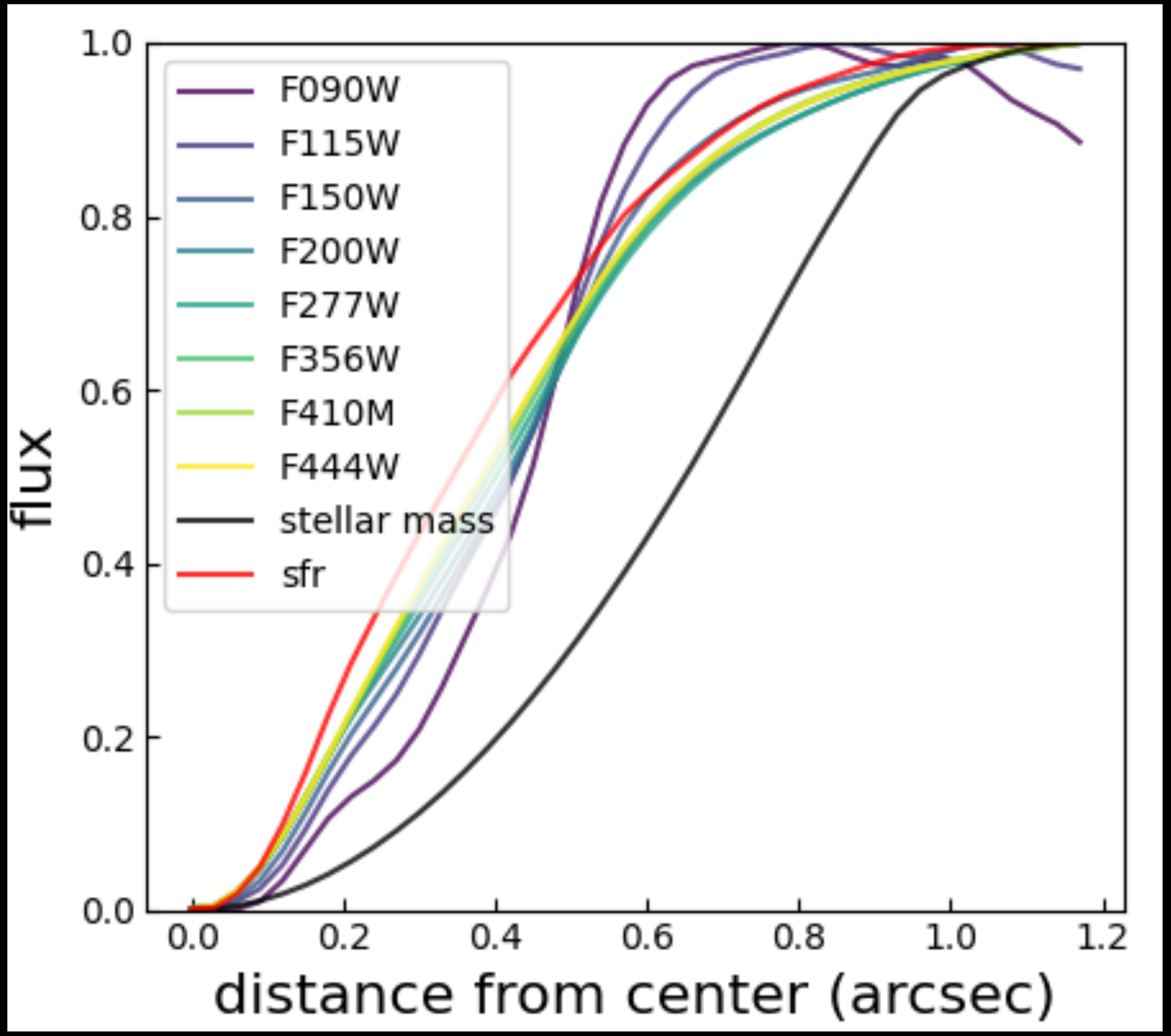
$\log_{10}(M_*/M_\odot)$ = 11+0.1-0.2

SFR = 370+80-70$M_\odot$/yr

Rachel Cochrane, rcochra3@ed.ac.uk

Resolved SED fitting -> SFR and mass profiles



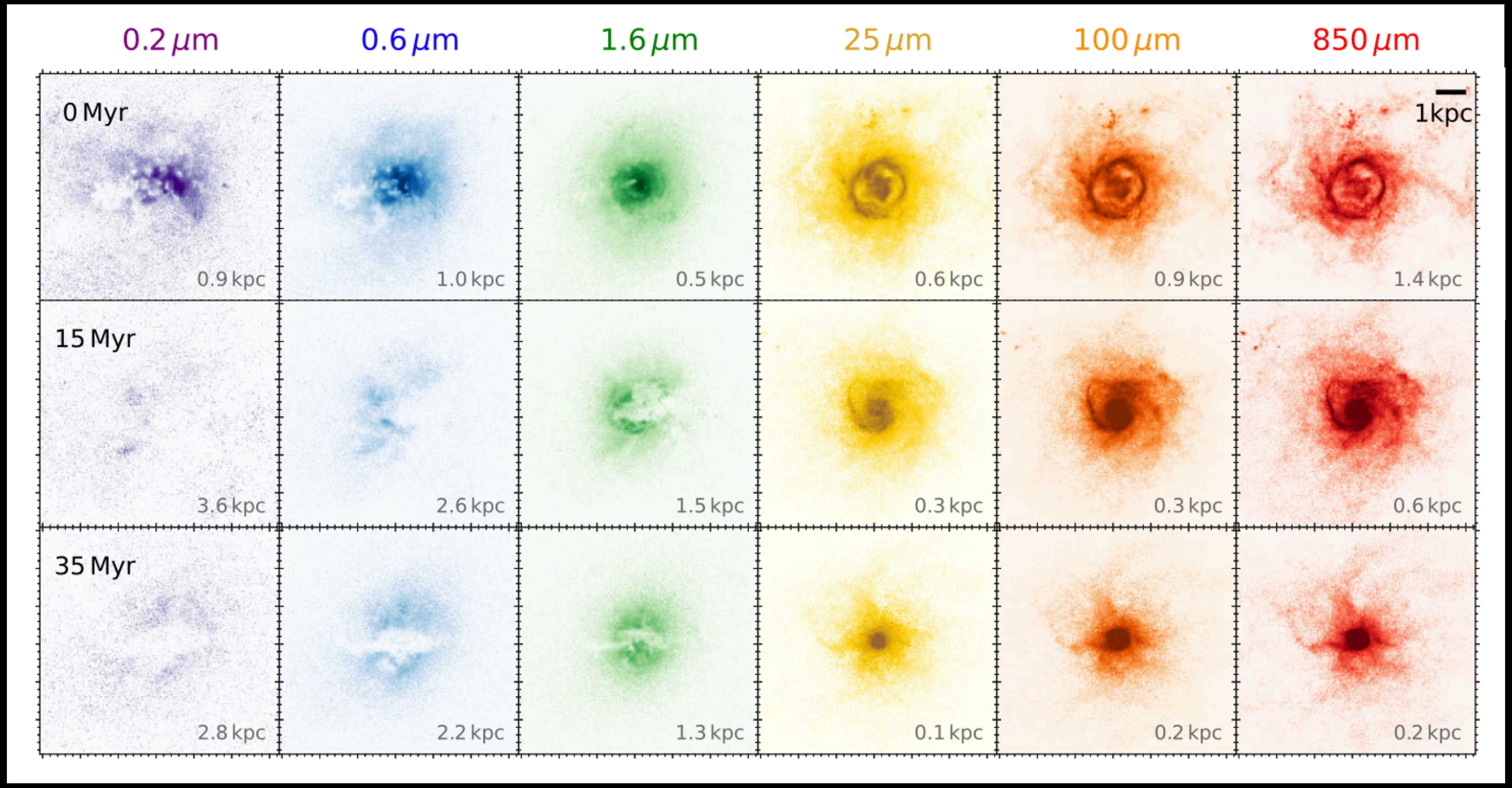


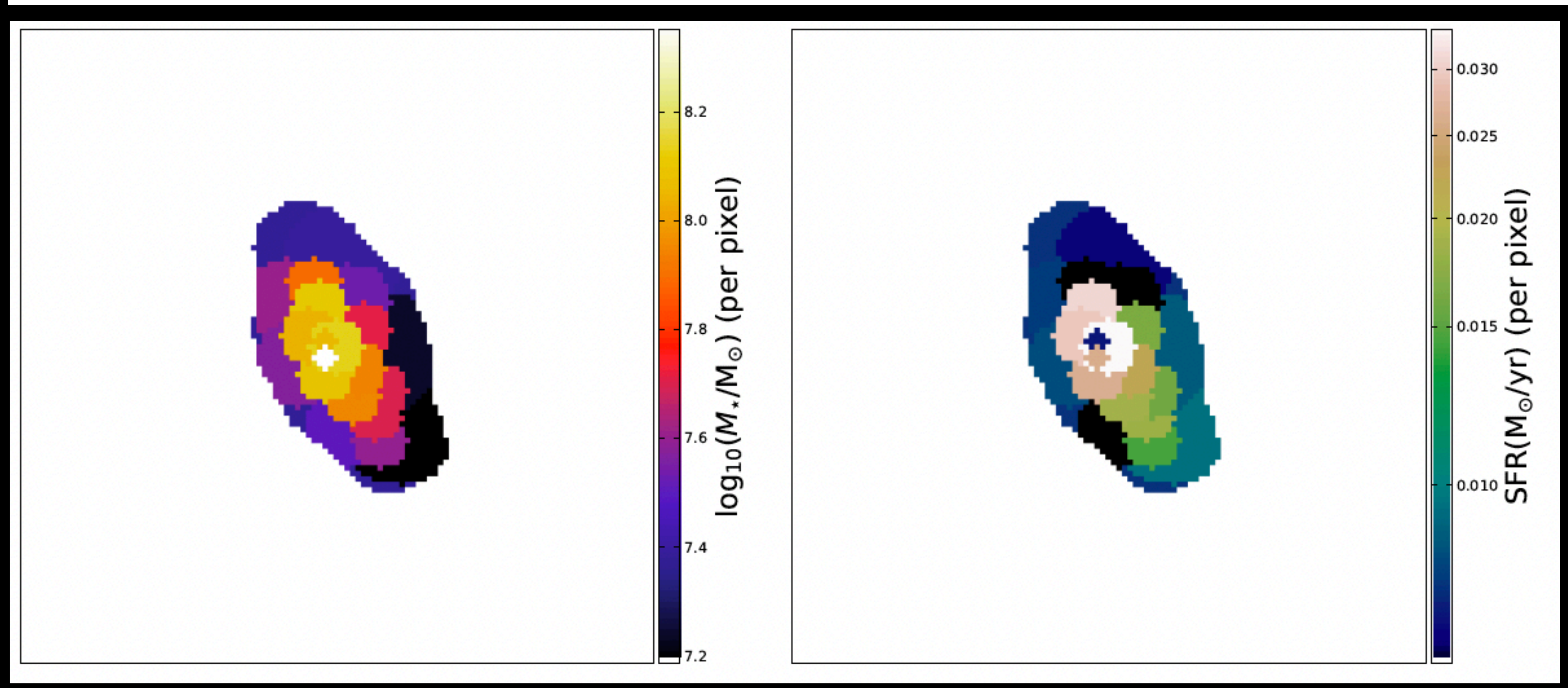
z=2.2
R_{50} (mass) 0.66” = 5.6kpc
R_{50} (SFR) 0.33” = 2.8kpc
R_{50} (light) at different wavelengths (from short to long): [0.45, 0.42, 0.42, 0.42, 0.39, 0.39, 0.39, 0.39]” = [3.8, 3.6, 3.6, 3.6, 3.3, 3.3, 3.3] npc

half-SFR radius is more compact than light at any wavelength, though stellar mass is more extended

Rachel Cochrane, rcochra3@ed.ac.uk

Physical picture





- Rest-frame UV-NIR emission typically more extended than SFR (and sometimes irregular) due to heavy central dust obscuration.

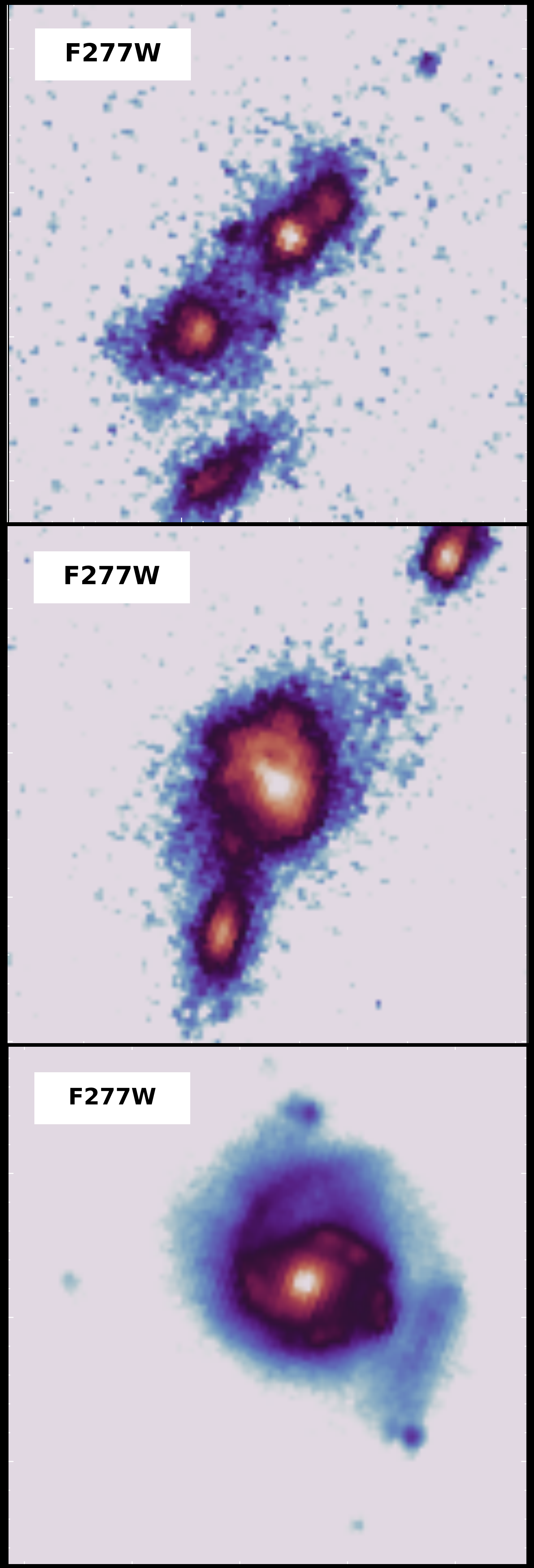
- Sub-mm sizes are even more compact than F444W, due to very compact star formation. Note: these sizes are potentially significantly more compact than the dust itself (emission is biased tracer of dust mass due to steep SFR-driven dust temperature gradients; Cochrane+19)

Rachel Cochrane, rcochra3@ed.ac.uk

Remaining questions

- Physical understanding of submm-triggering - mergers/interactions, disk instabilities?

Challenge: need larger samples of very high-resolution simulated SMGs (ideally at brighter flux densities) than are currently available



Rachel Cochrane, rcochra3@ed.ac.uk

Summary

- Huge progress locating, characterising and spatially-resolving SMGs with sub-mm interferometers and JWST. Emerging picture of a heterogenous population of isolated disks, major/minor mergers and interactions.

- There is a large variation in sizes and morphologies with wavelength, with shorter-wavelength NIRCam emission typically more extended, likely due to heavy central dust obscuration. Sub-mm sizes are typically even more compact than F444W, due to very compact star formation (also inferred from spatially-resolved SED fitting) driving steep dust temperature gradients.

- Paths forward: more high-resolution simulations + RT to understand triggering, validating using JWST-informed merger fractions and multi-wavelength emission.

Rachel Cochrane, rcochra3@ed.ac.uk