Measuring Surface Brightness of Ultra Deep Field Galaxies with Hubble

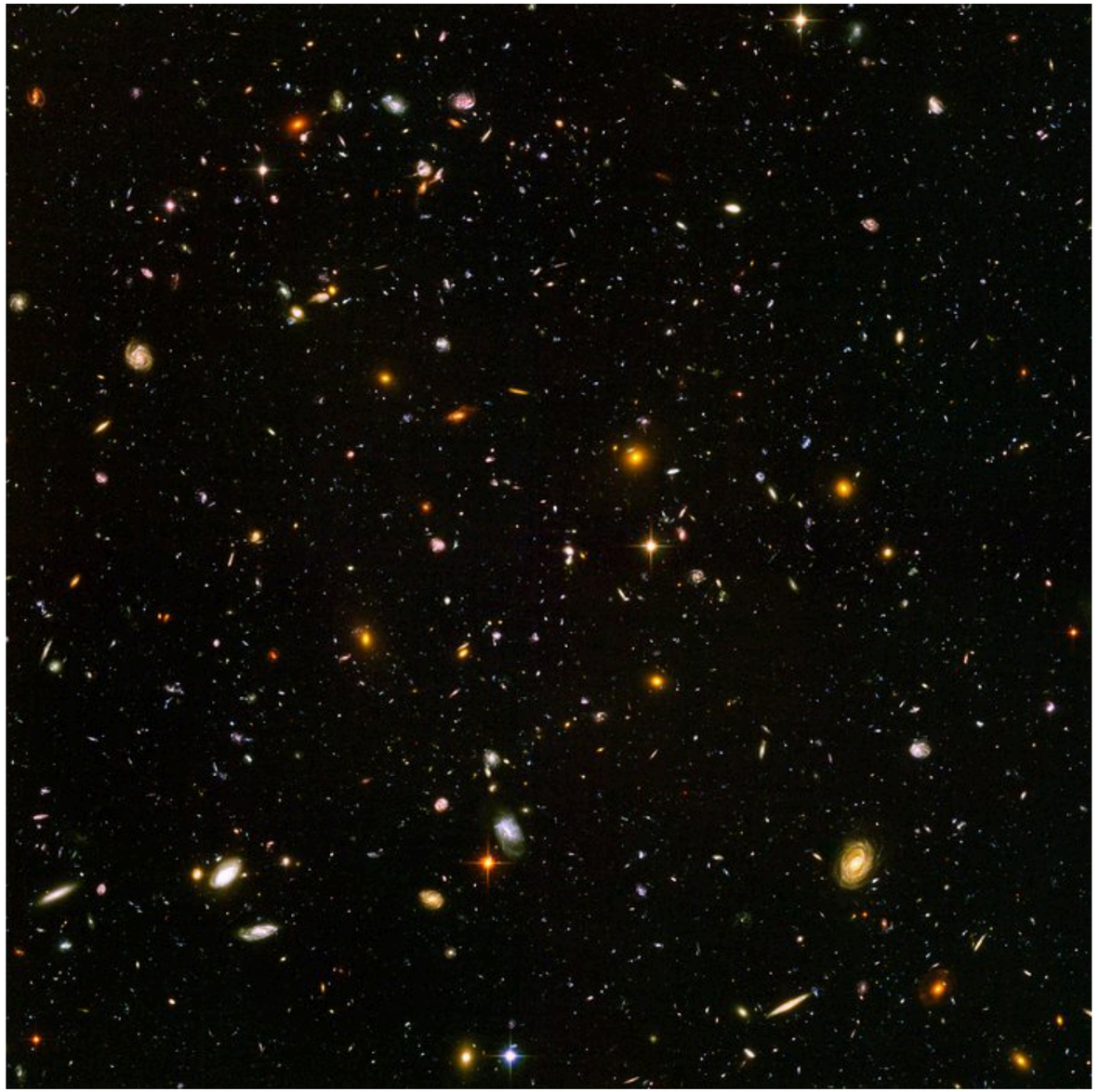
Domenica Quizhpe, Daniel Villarruel, Hanna Lima

Supervisor: Dr. Fernando Buitrago

24th July 2025

46th ISYA Ecuador 2025

Hubble Ultra Deep Field (HUDF)



Credit: NASA, ESA, and S. Beckwith (STScI) and the HUDF Team

Hubble Space Telescope (HST)

Credit: NASA

Sees three different kinds of light

- Near Ultraviolet
- Visible
- Near Infrared

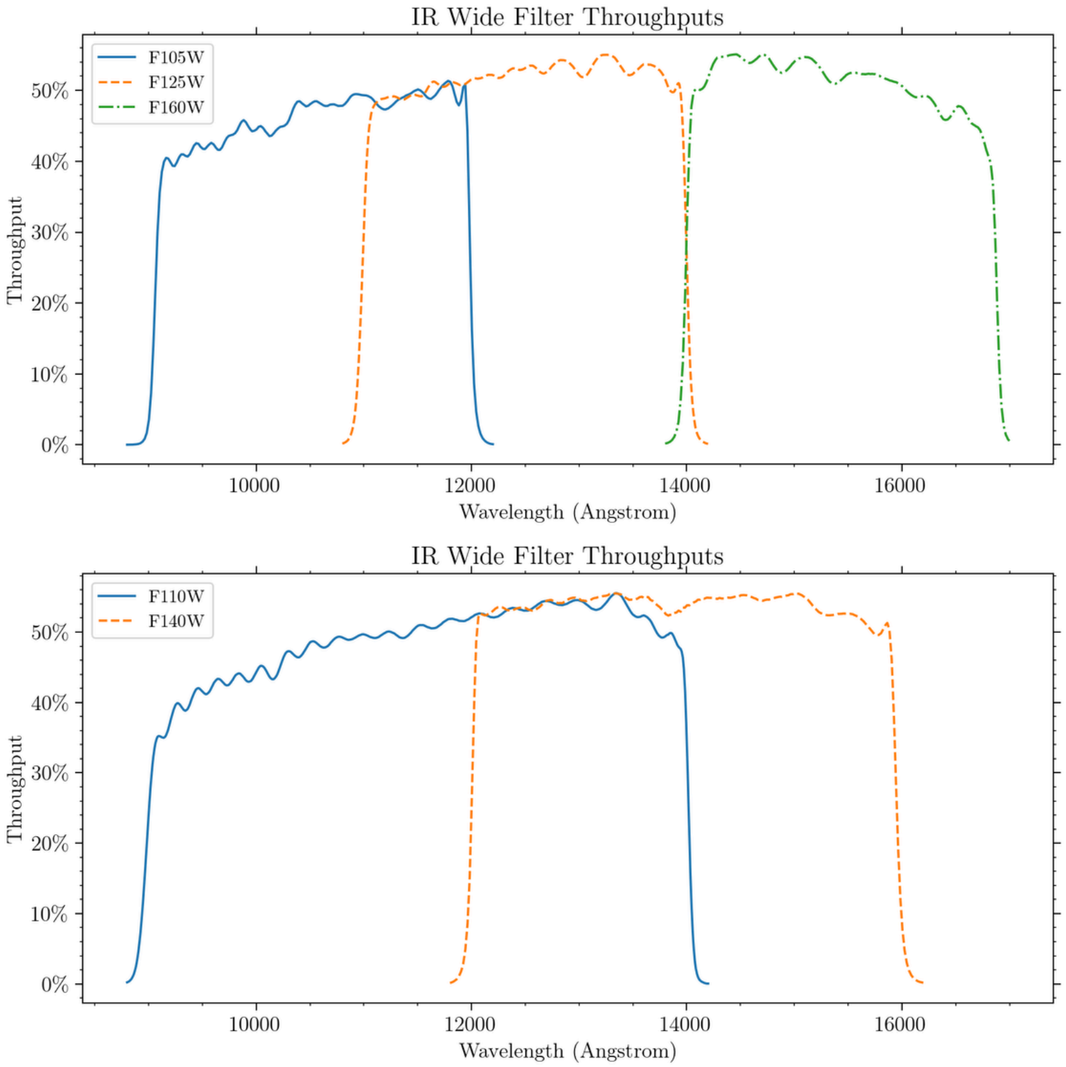
Wide Field Camera 3

Credit: NASA

Contains two channels instrument

- UVIS
- IR

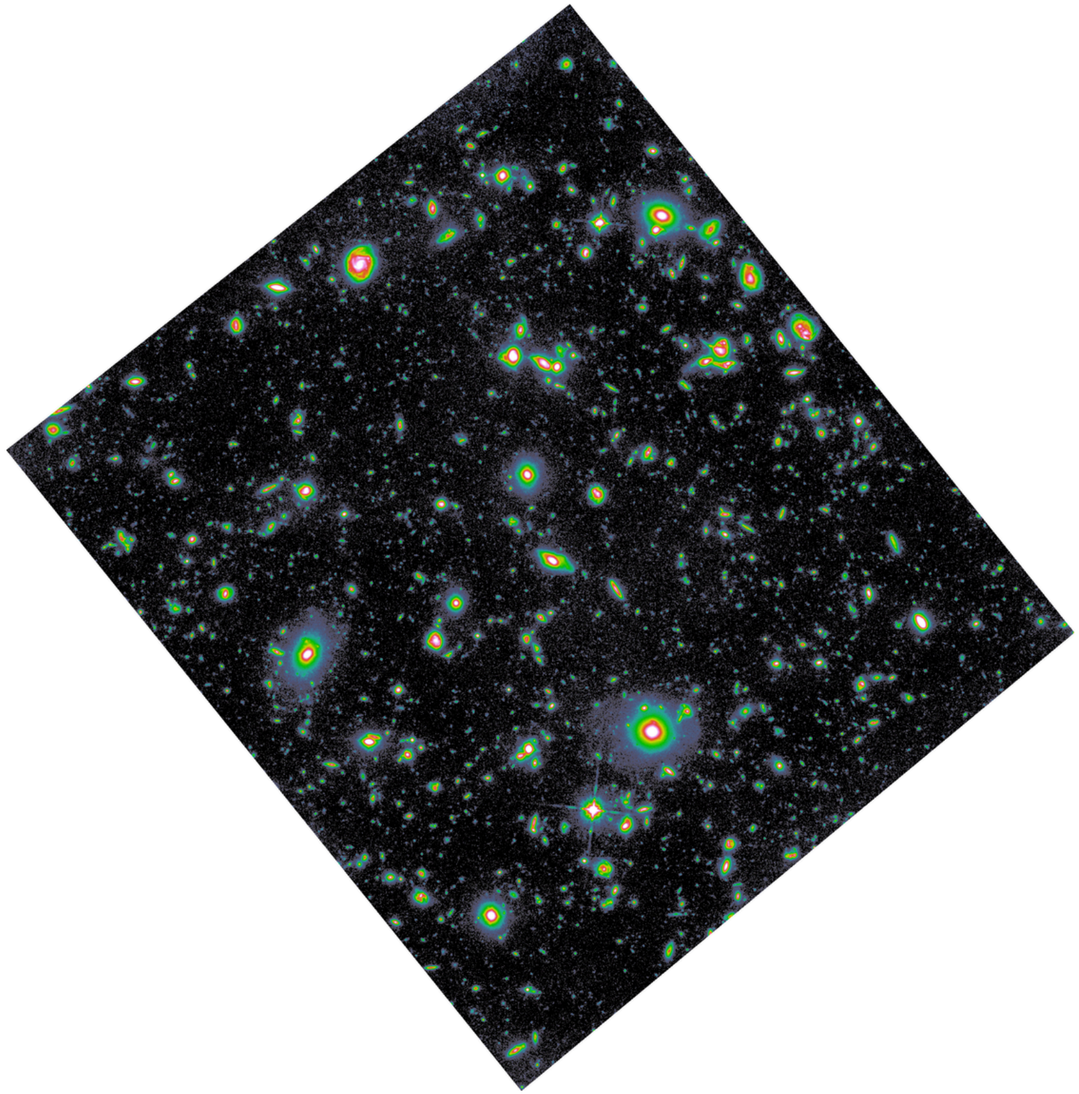
FILTERS OF WFC 3



System throughput curves for WFC3/IR wide-band filters

Credit: NASA, ESA, and the Space Telescope Science Institute (STScI).

- The shorter bands (F105W, F125W) sample bluer stars, i.e., younger stars.
- The longer bands (F140W, F160W) map dust clouds and capture older star populations.
- By combining filters, we obtain dust maps, stellar ages, and photometric redshift estimates.

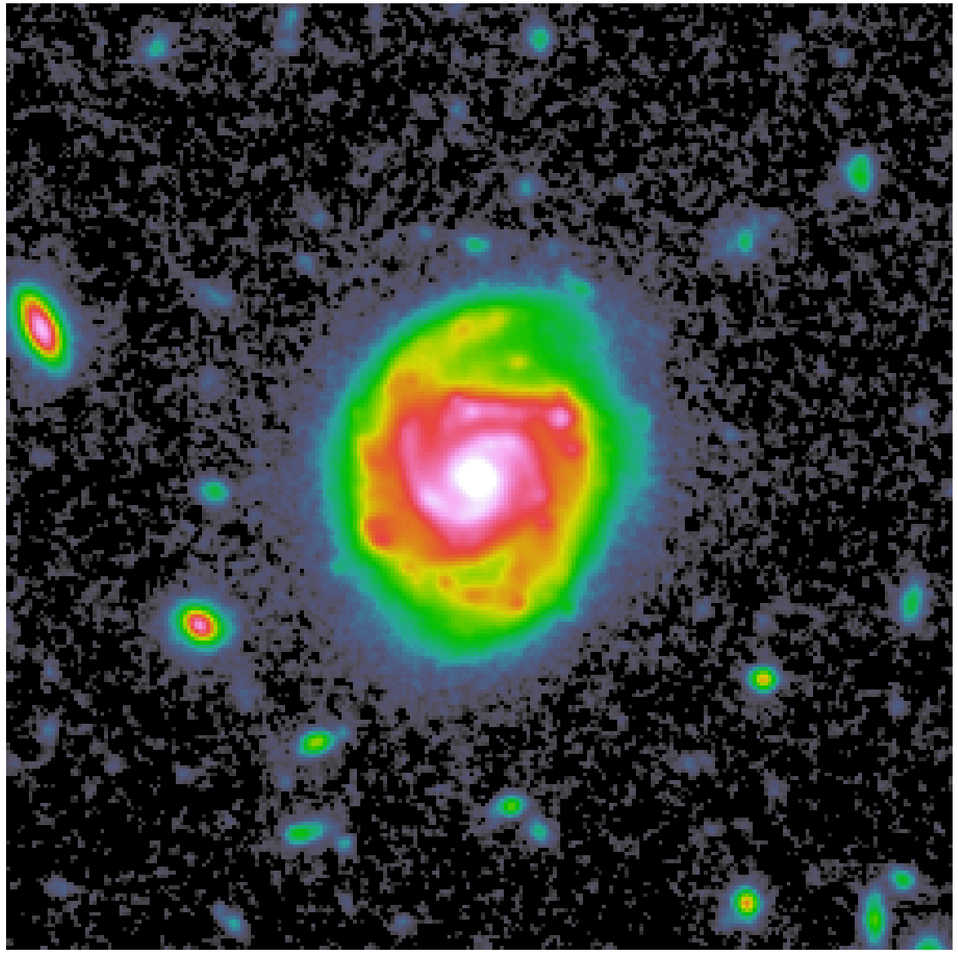


ABYSS HUDF project

- Reduction of the Hubble Ultra Deep Field WFC3/IR data optimised for the study of the Low Surface Brightness Universe.

- Surface brightness is the amount of light we receive from an extended object per unit of area on the sky.

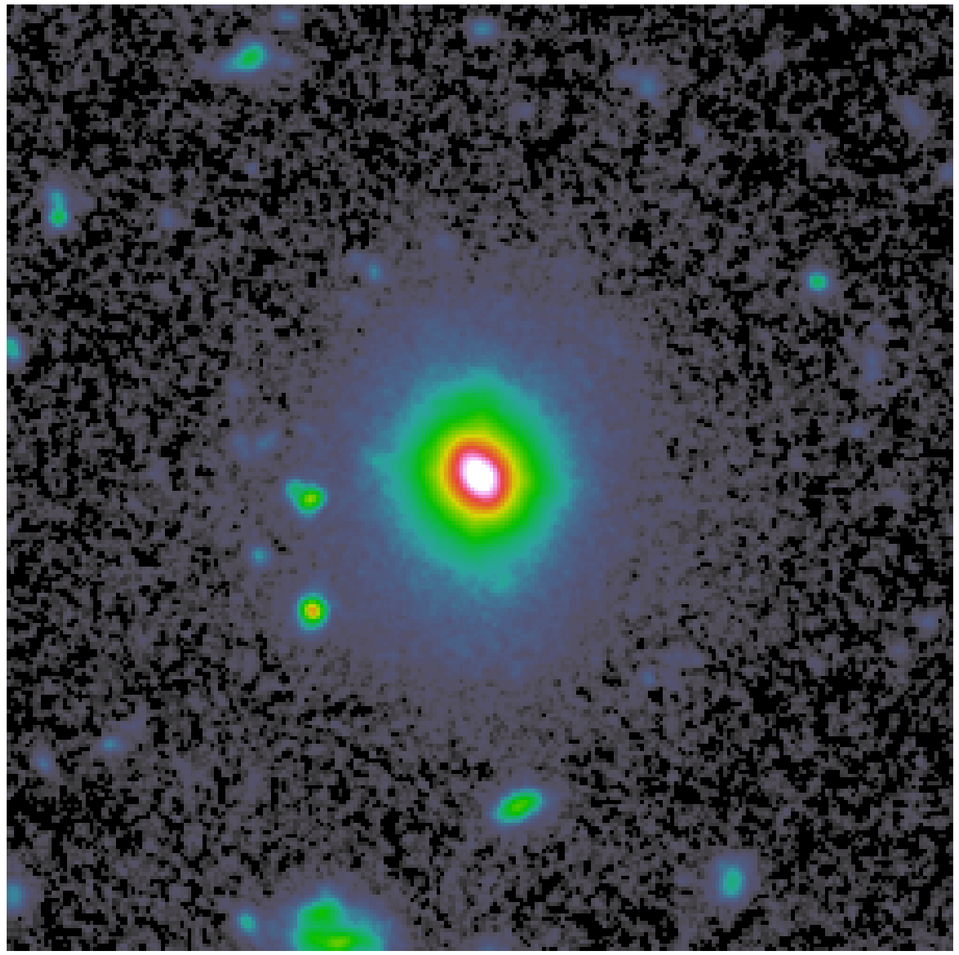
Spiral Galaxy



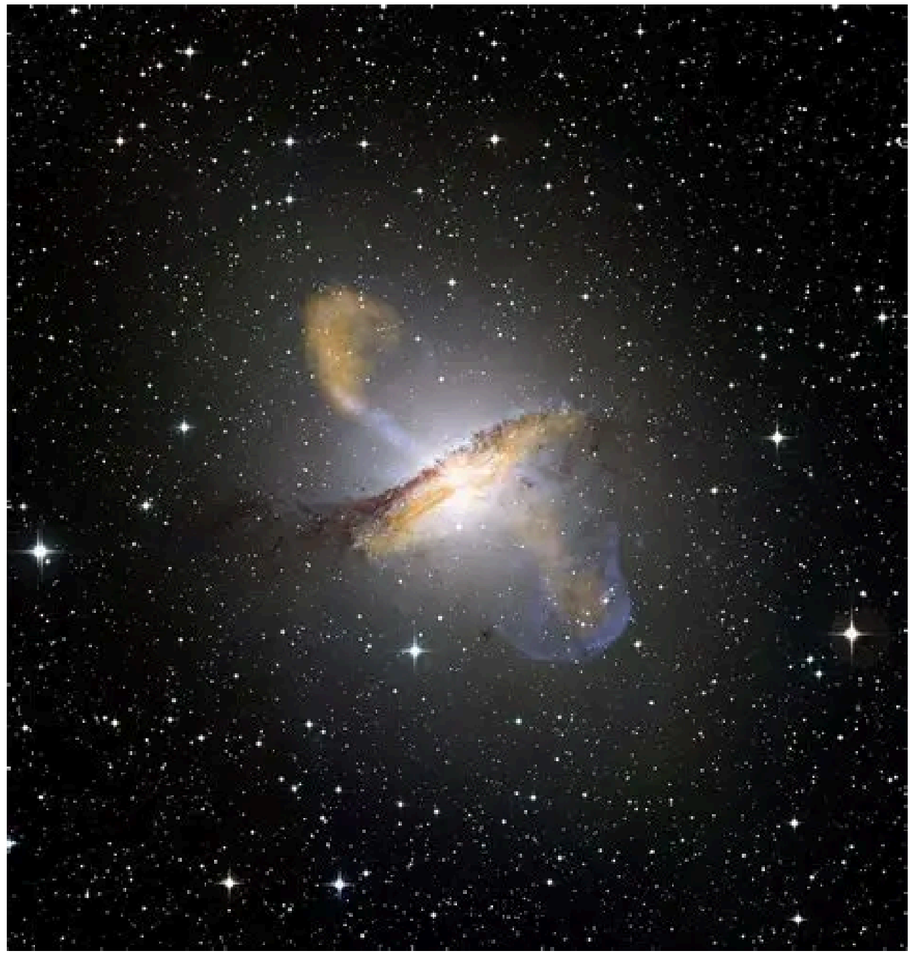
Our Spiral Galaxy with z=0.6218

Credit: NASA

Elliptical Galaxy



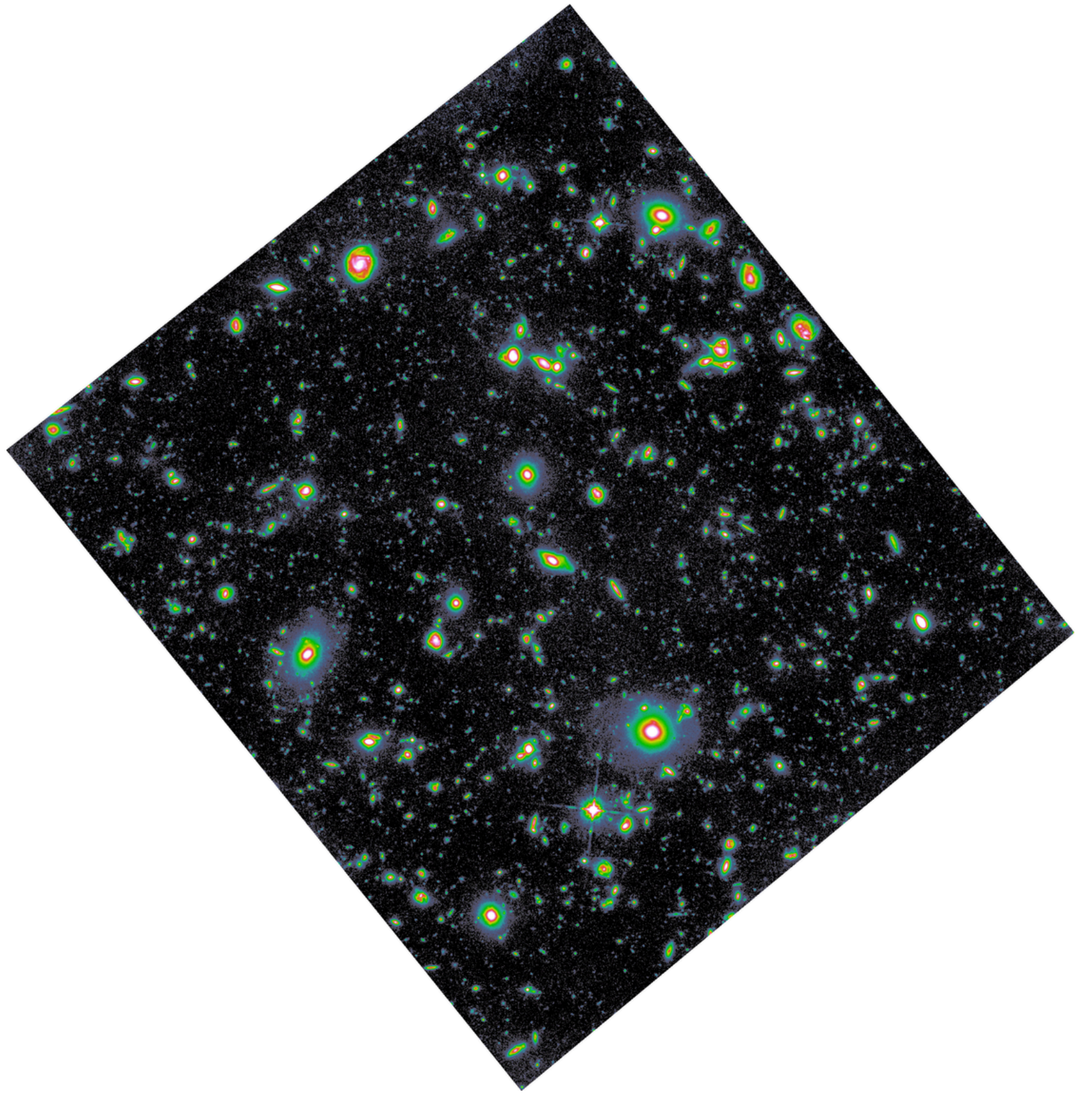
Our Elliptical Galaxy with z=0.619



Credit: NASA

What defines the size of a galaxy?

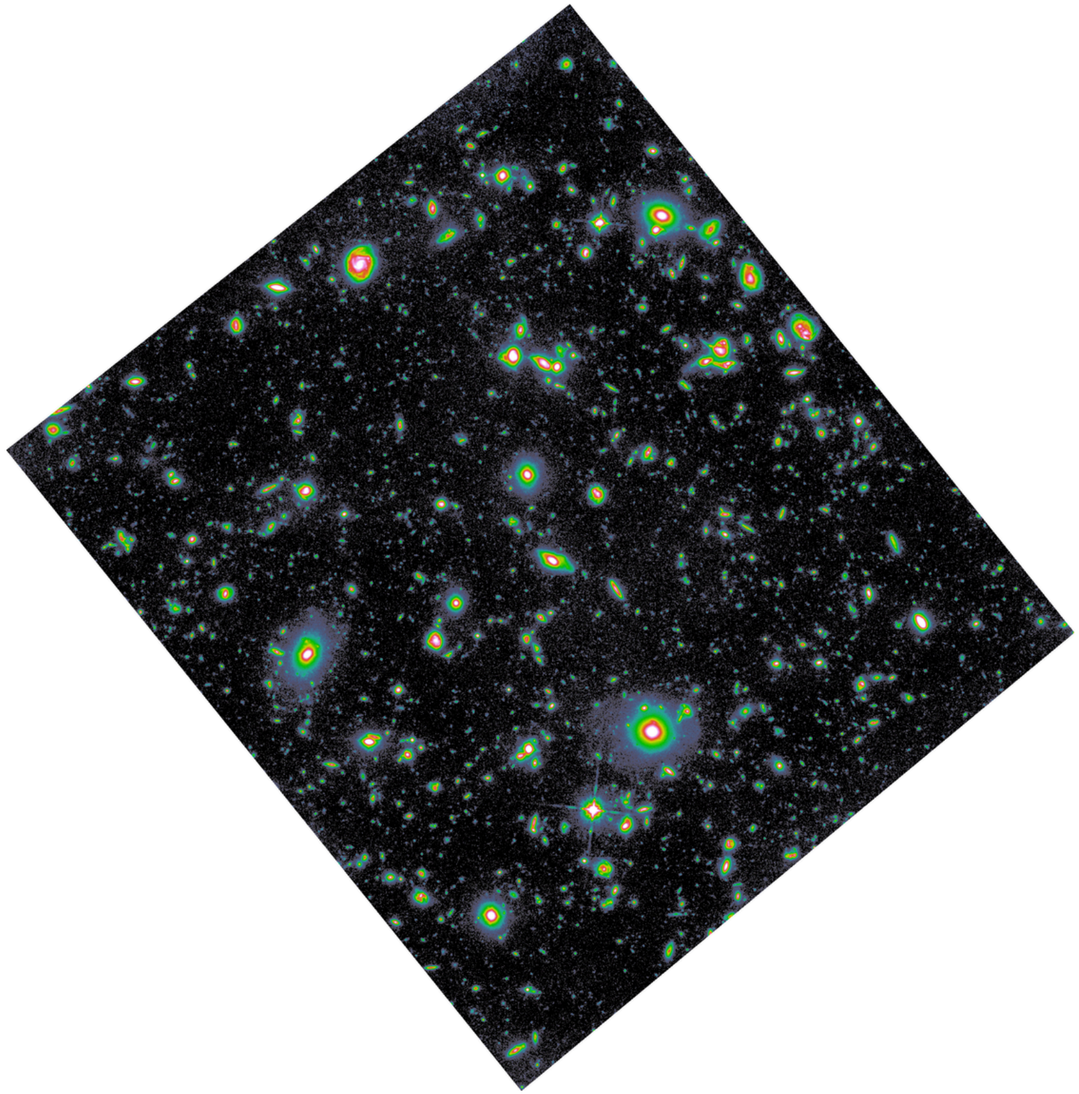
Methods



HUDF

We need to extract galaxies from this image to obtain our surface brightness profiles

Methods

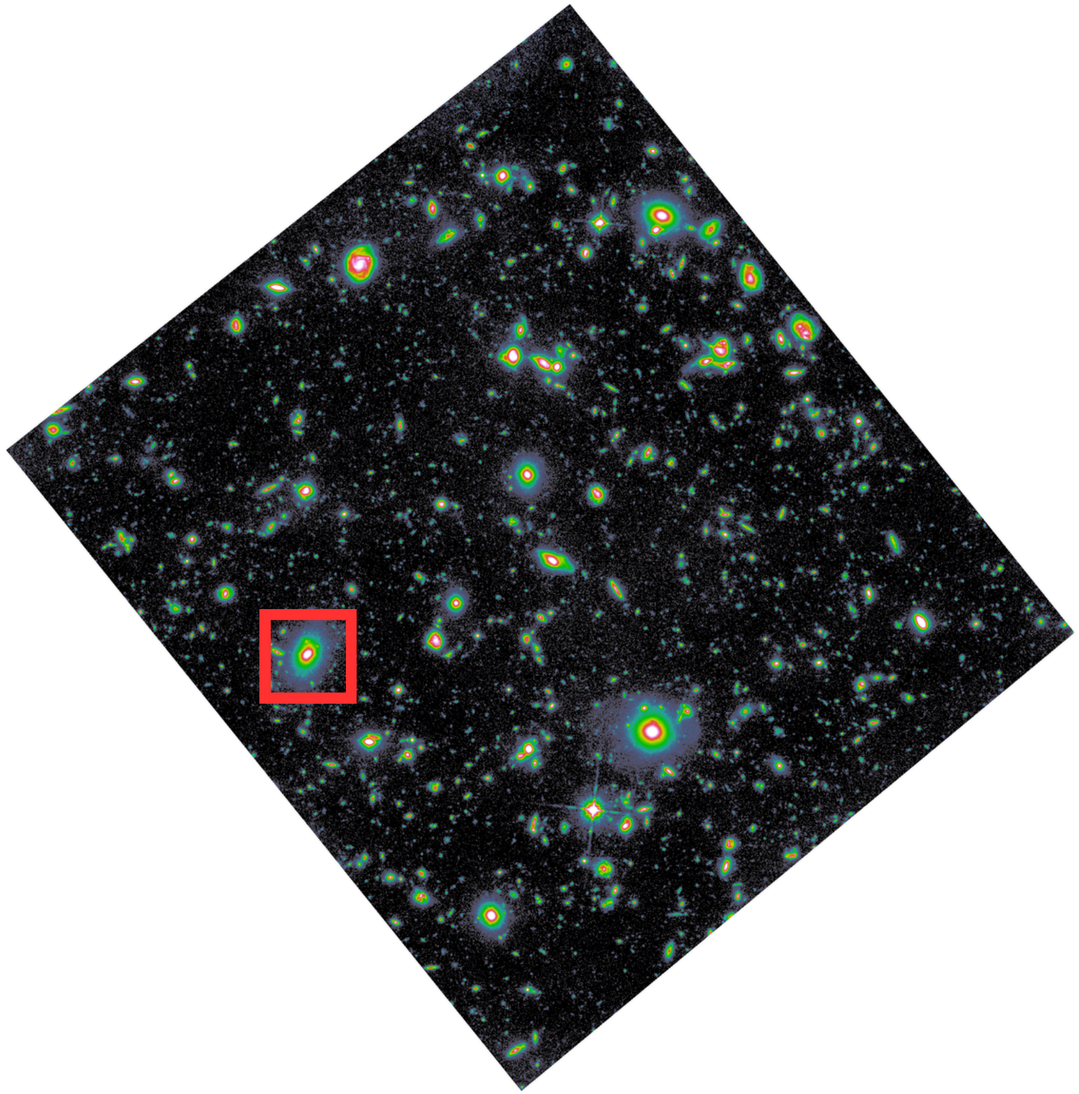


HUDF

We need to extract galaxies from this image to obtain our surface brightness profiles

For that we selected

Methods



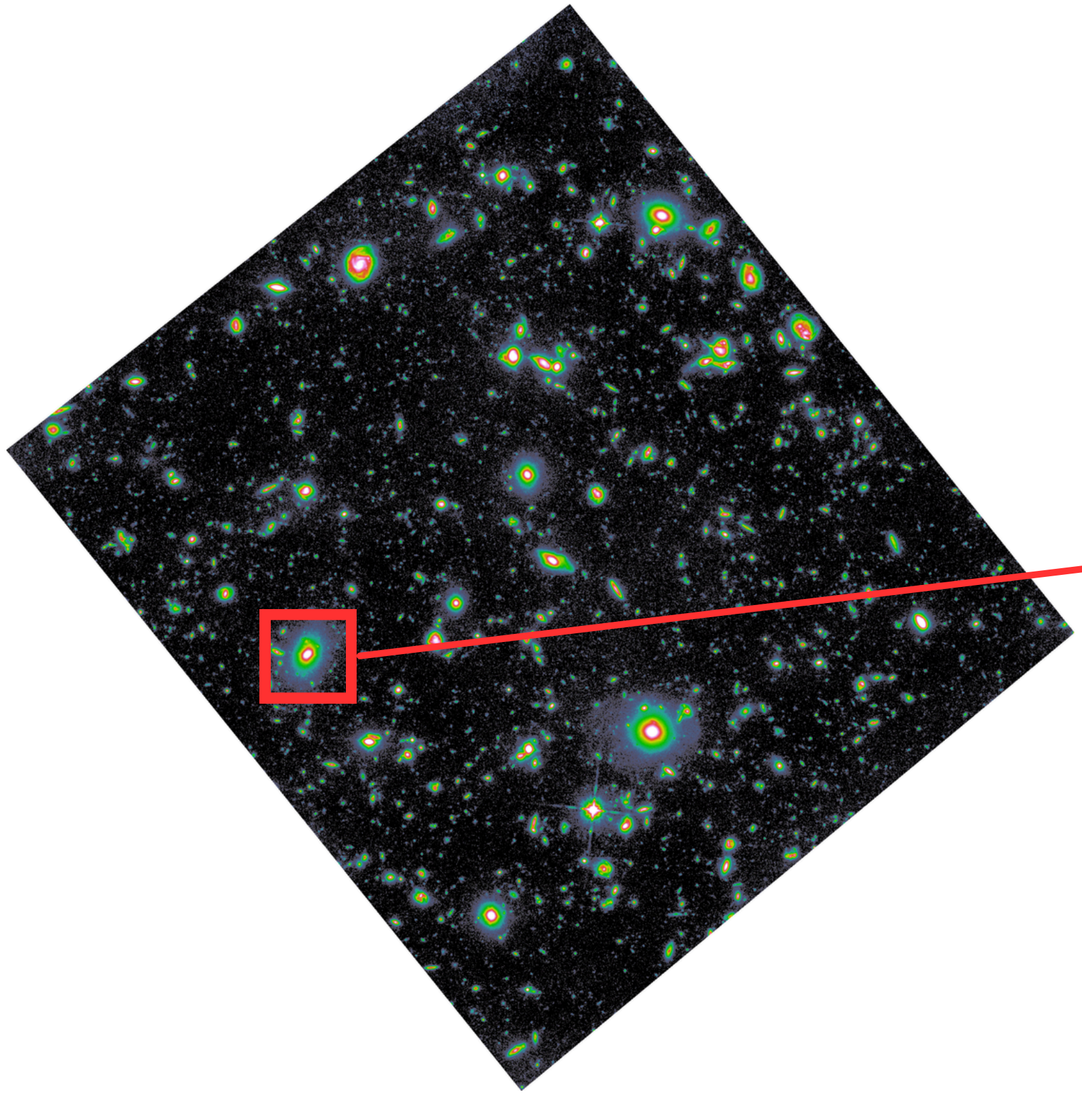
HUDF

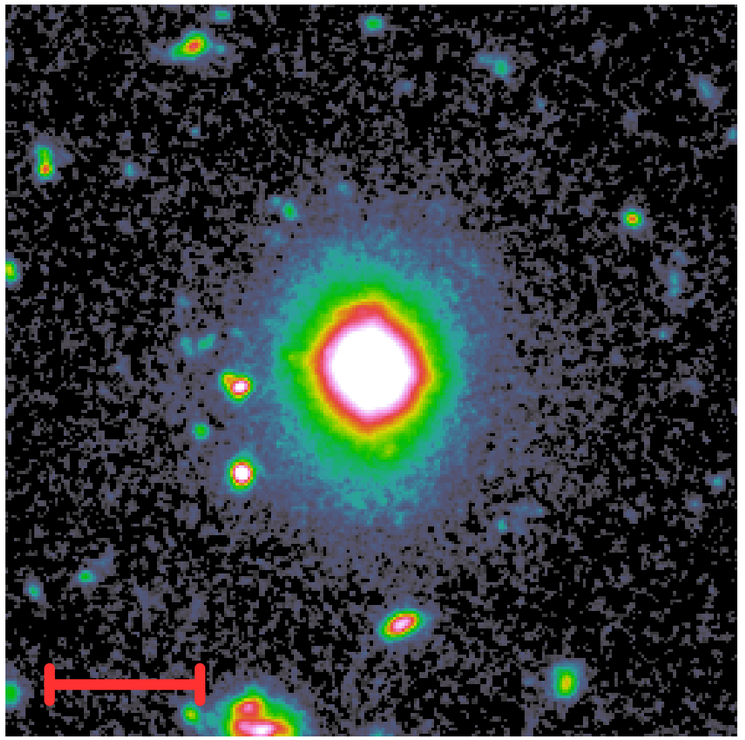
We need to extract galaxies from this image to obtain our surface brightness profiles

For that we selected

- An elliptical galaxy

Methods

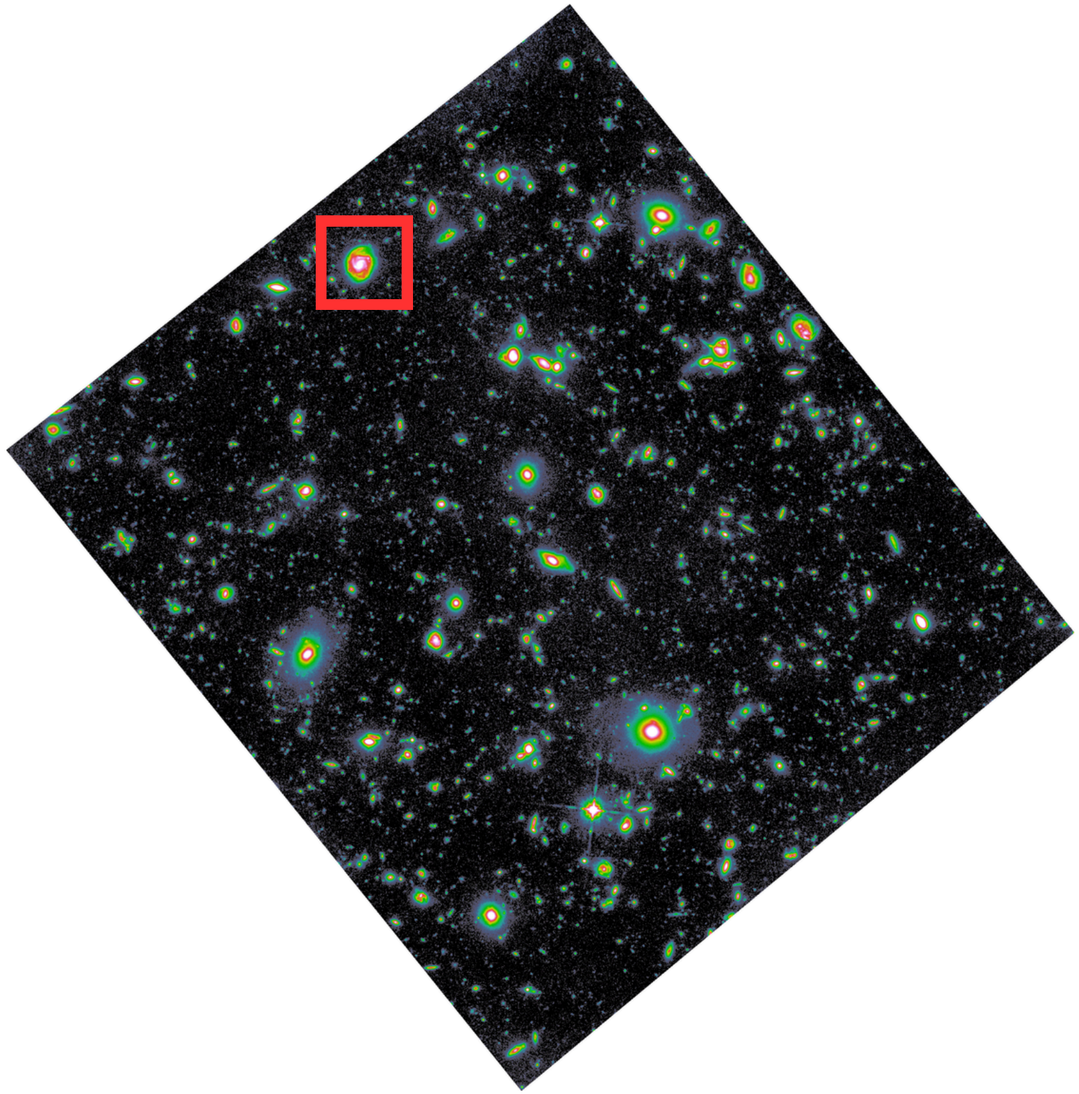




UDF image

our elliptical galaxy

Methods



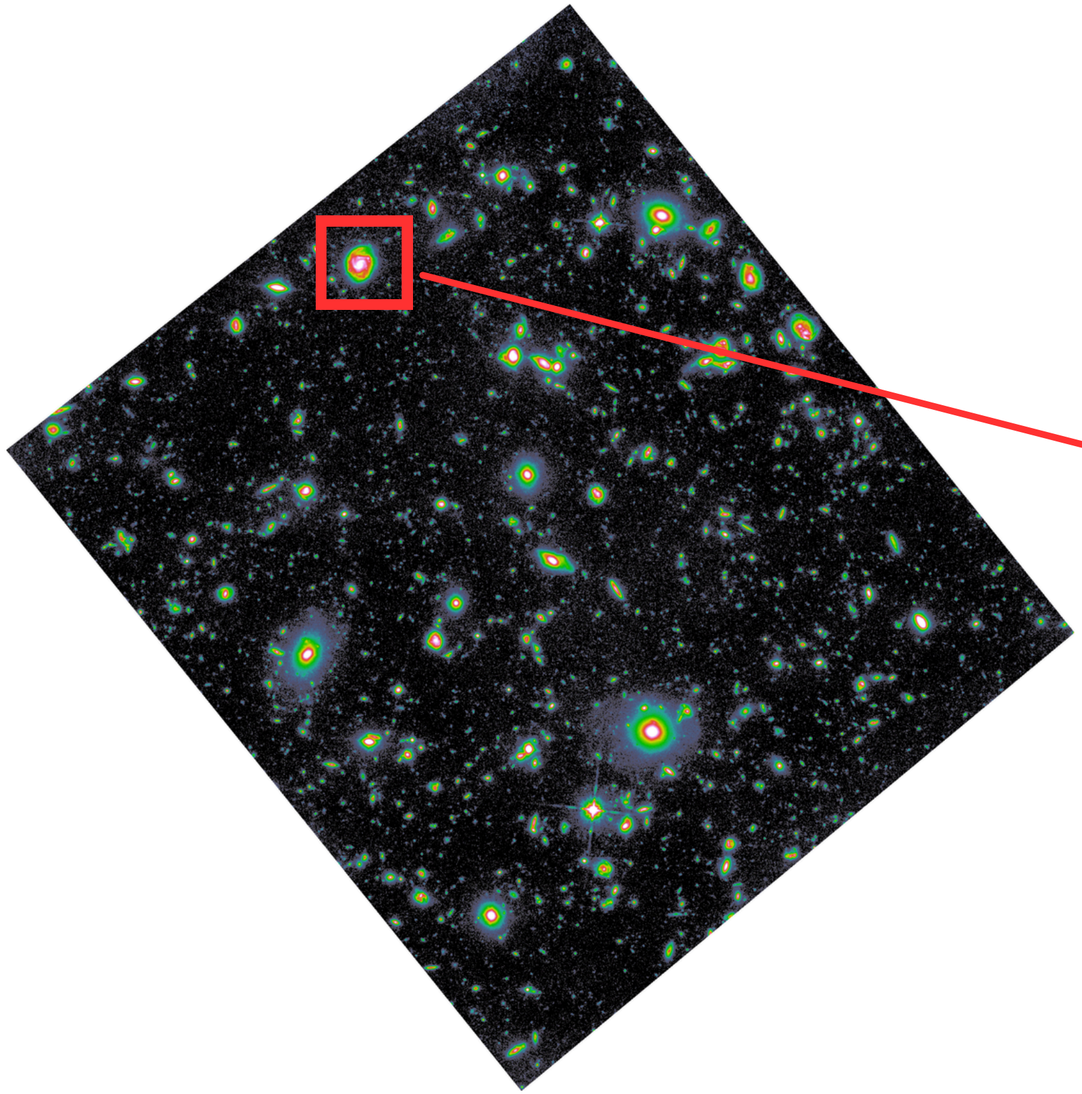
HUDF

We need to extract galaxies from this image to obtain our surface brightness profiles

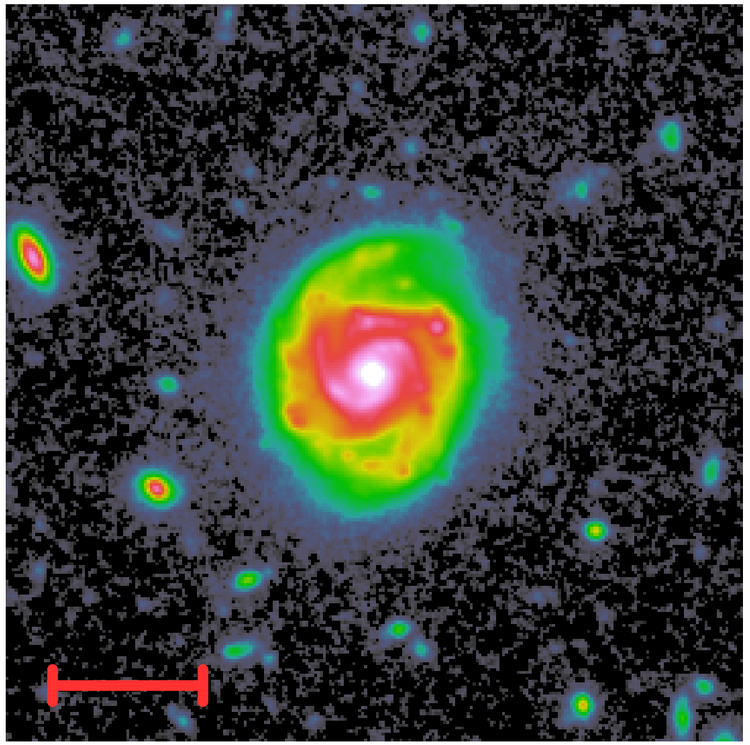
For that we selected

- A (face-on) spiral galaxy

Methods

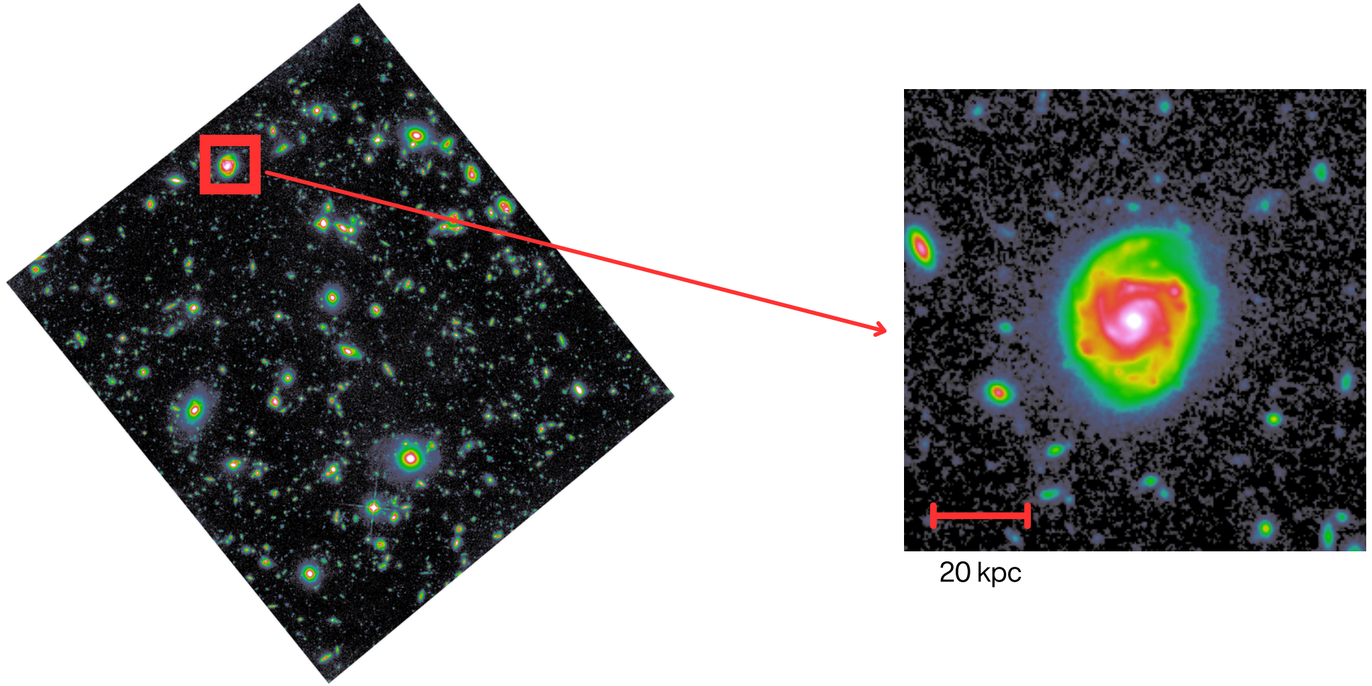


HUDF image



our spiral galaxy

Methods



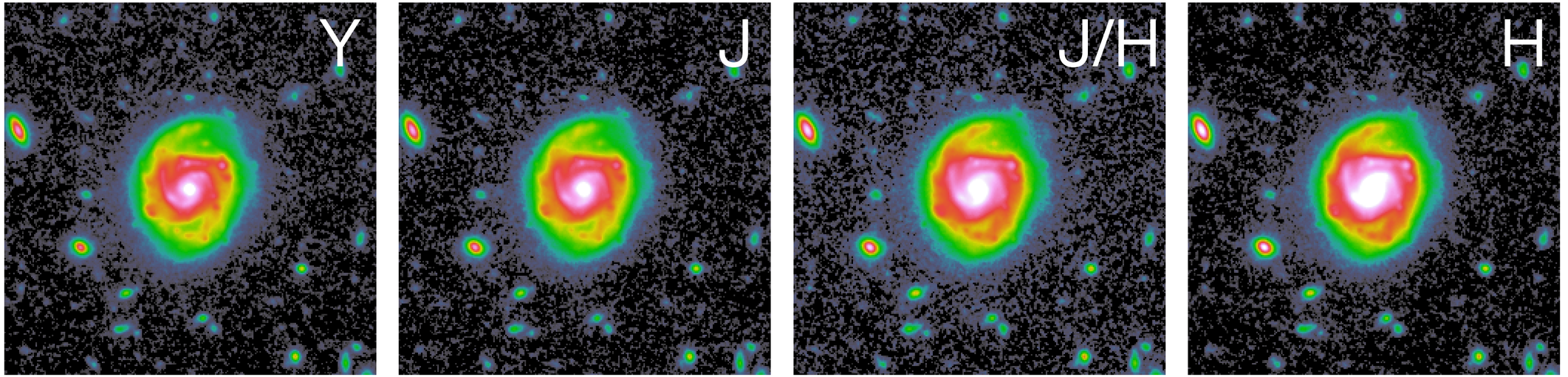
We need to define:

- Coords. of the centre of the galaxy
- Size of the cutout

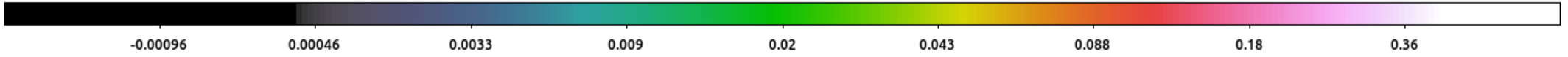
We use **astcrop** of GNU Astronomy Utilities (**GNU astro**), a Unix-based library for astronomy

Methods

We repeat the same process for all our bands



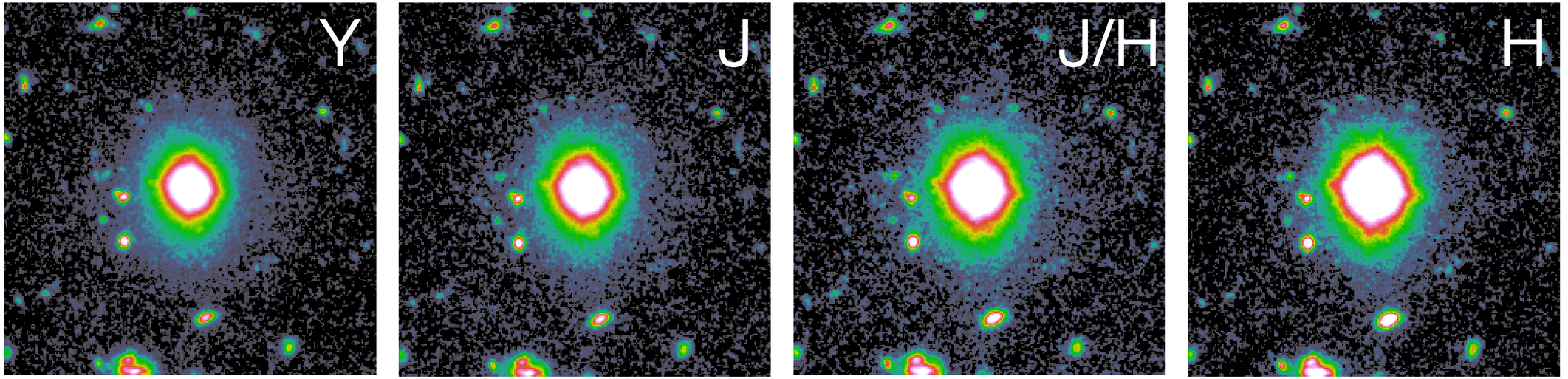
f105w f125w f140w f160w



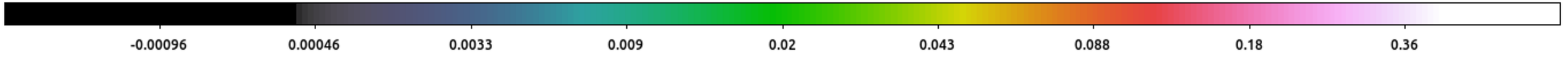
log10 flux

Methods

and for our elliptical galaxy

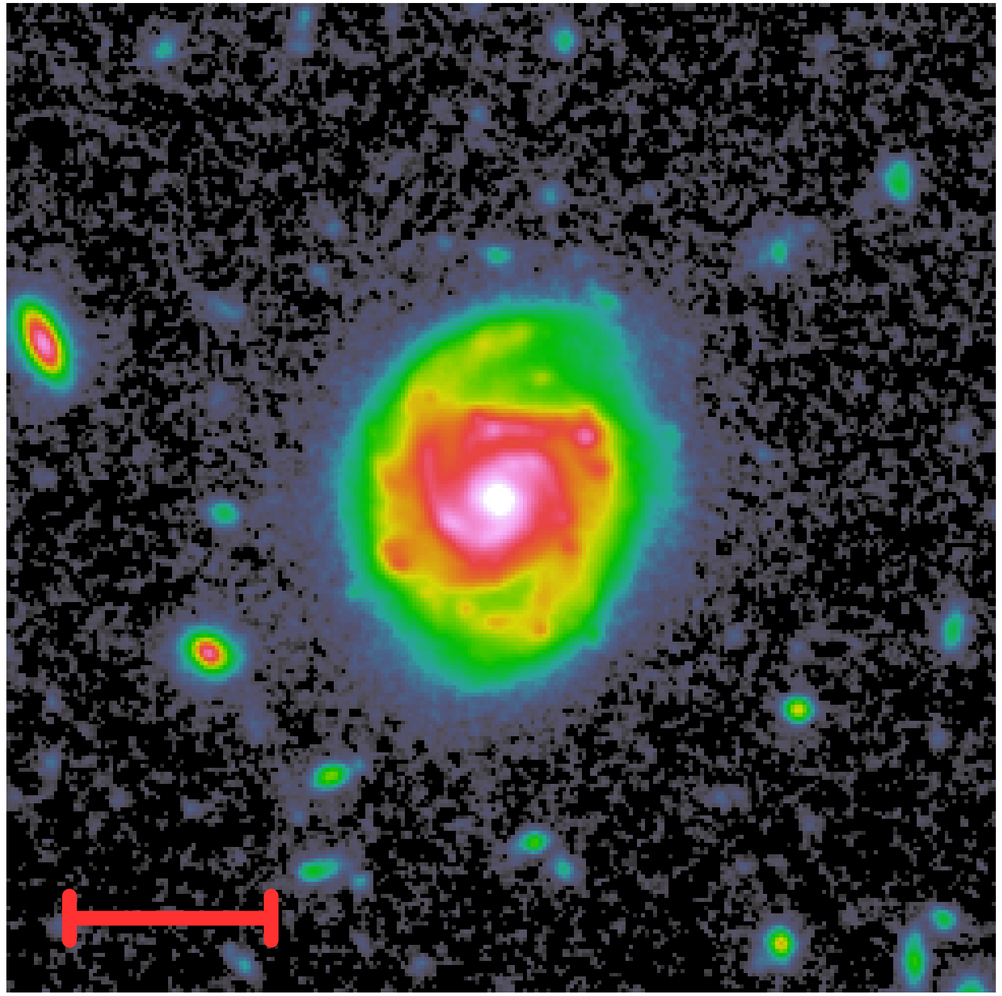


f105w f125w f140w f160w



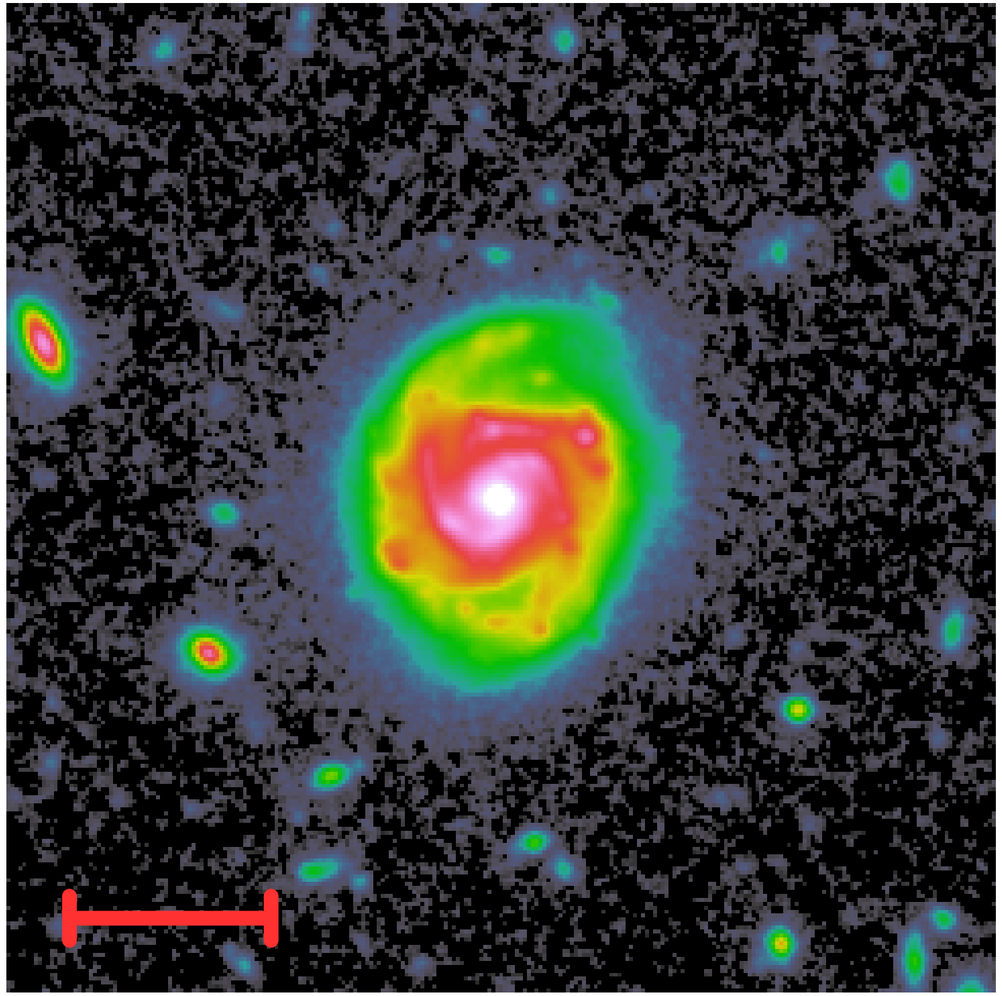
log10 flux

Methods



Methods

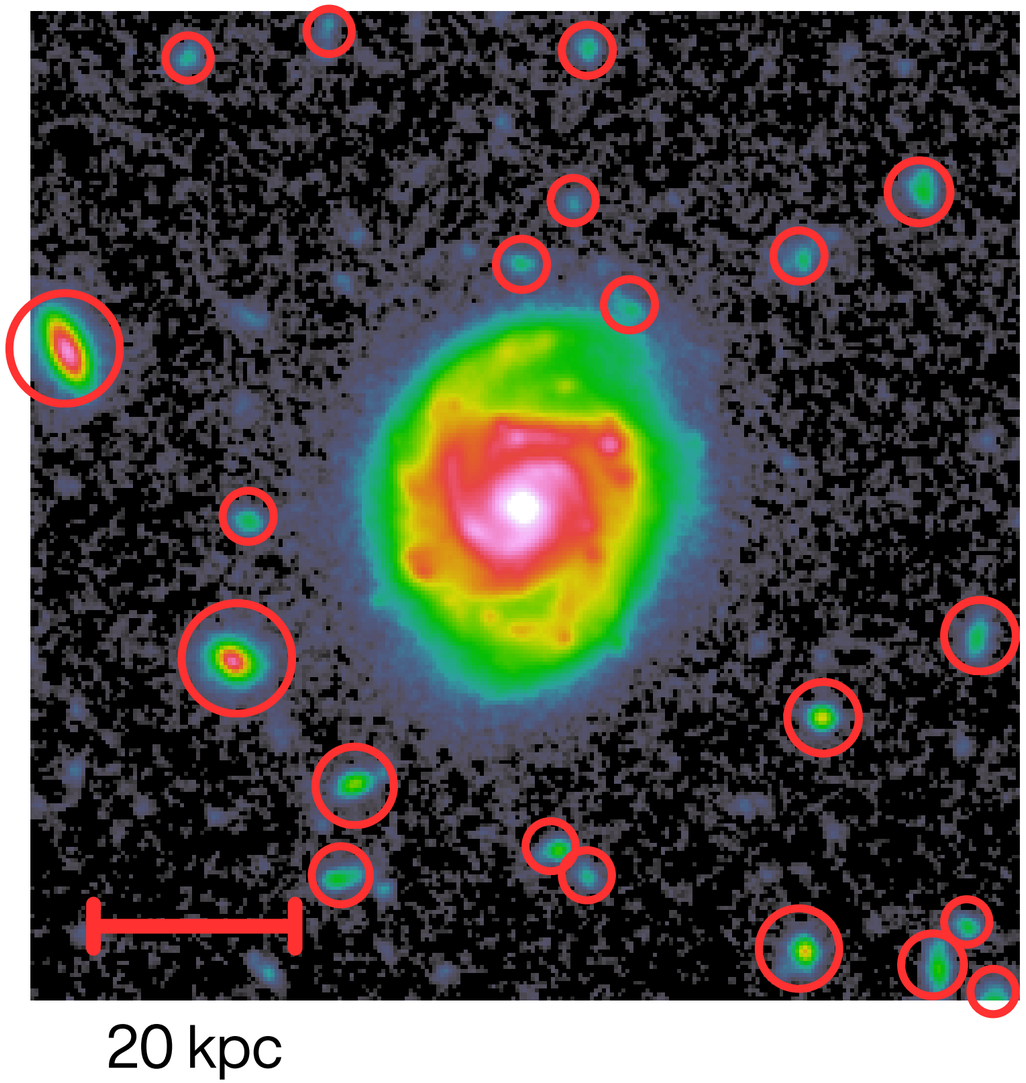
There are **other sources** of flux in our image



Methods

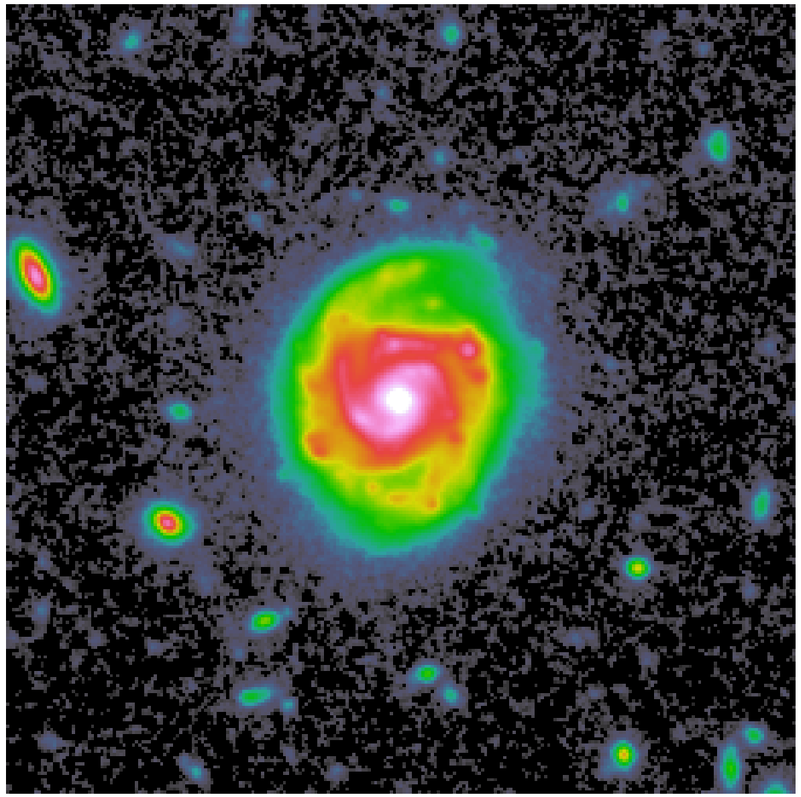
There are **other sources** of flux in our image

We want to **remove all the other sources**



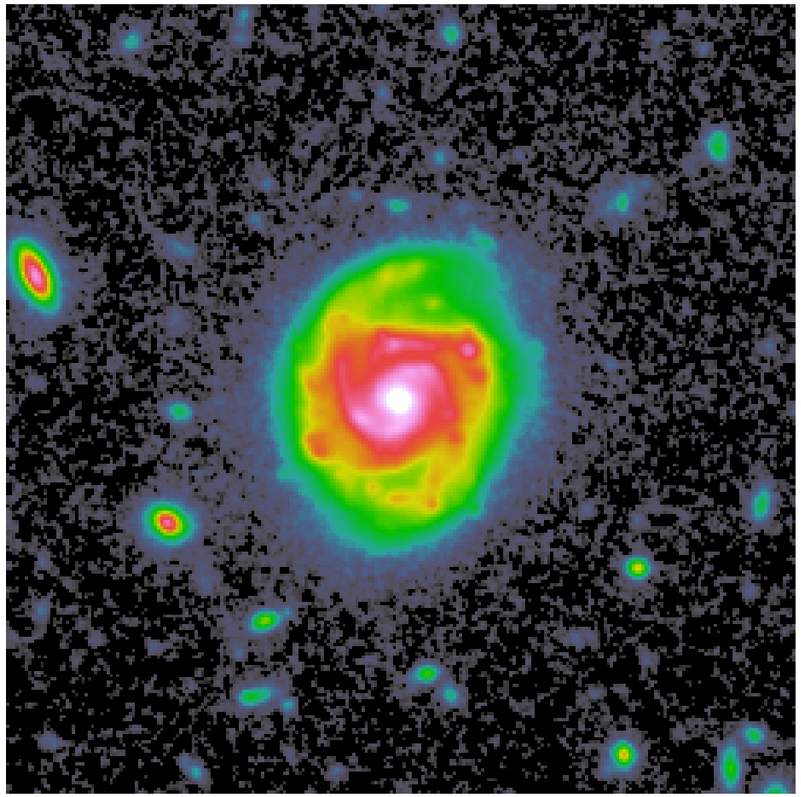
Thus we need to **mask** our image

Methods



Cutout of our galaxy

Methods



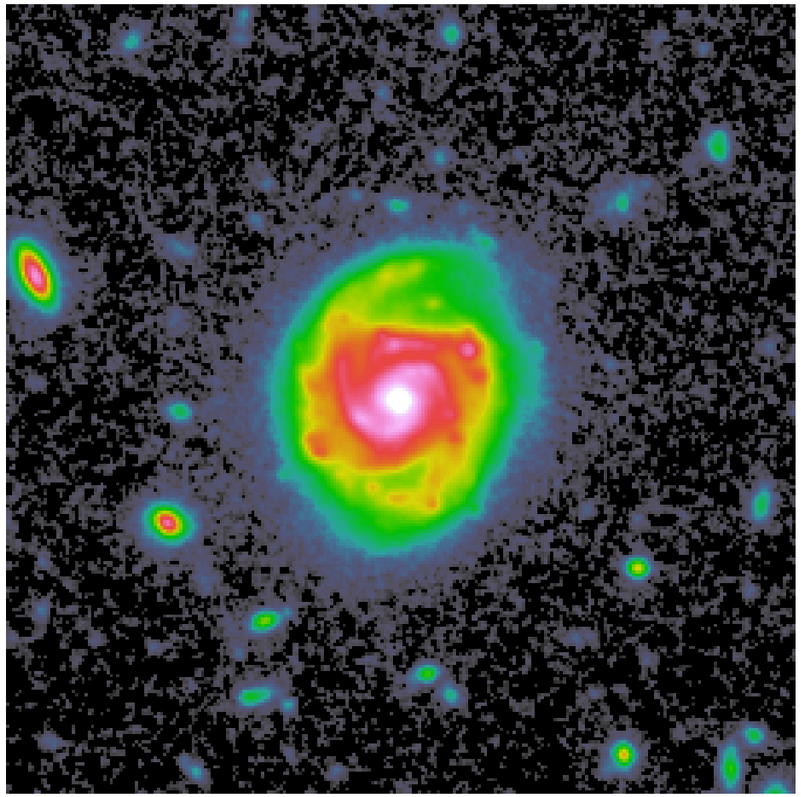
Cutout of our galaxy

AstrOmatic

Source-Extractor

- Detect, identify and measure objects
- Do segmentations to prepare masks

Methods

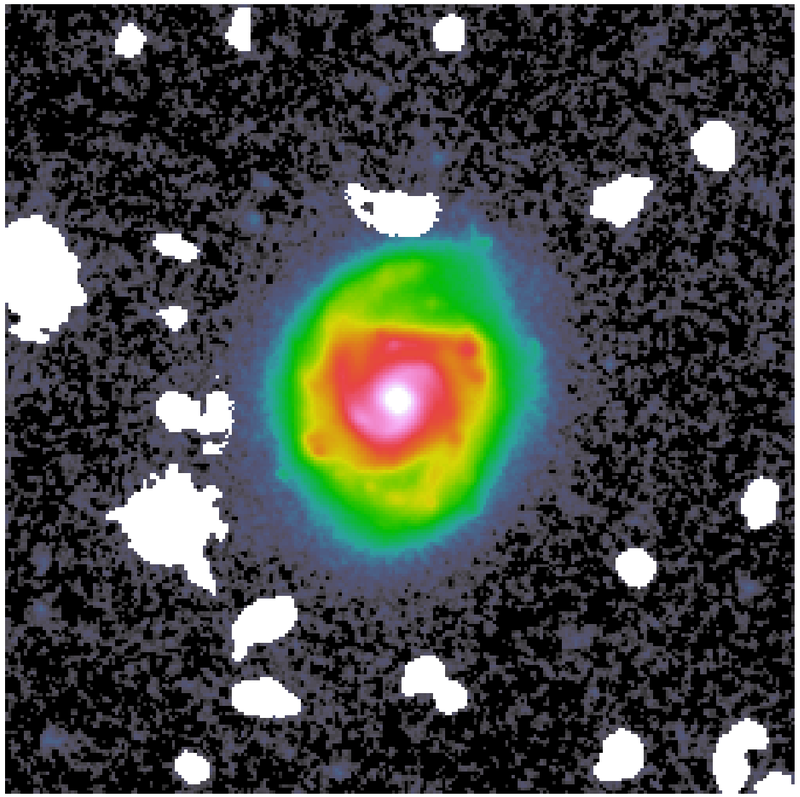


Cutout of our galaxy

AstrOmatic

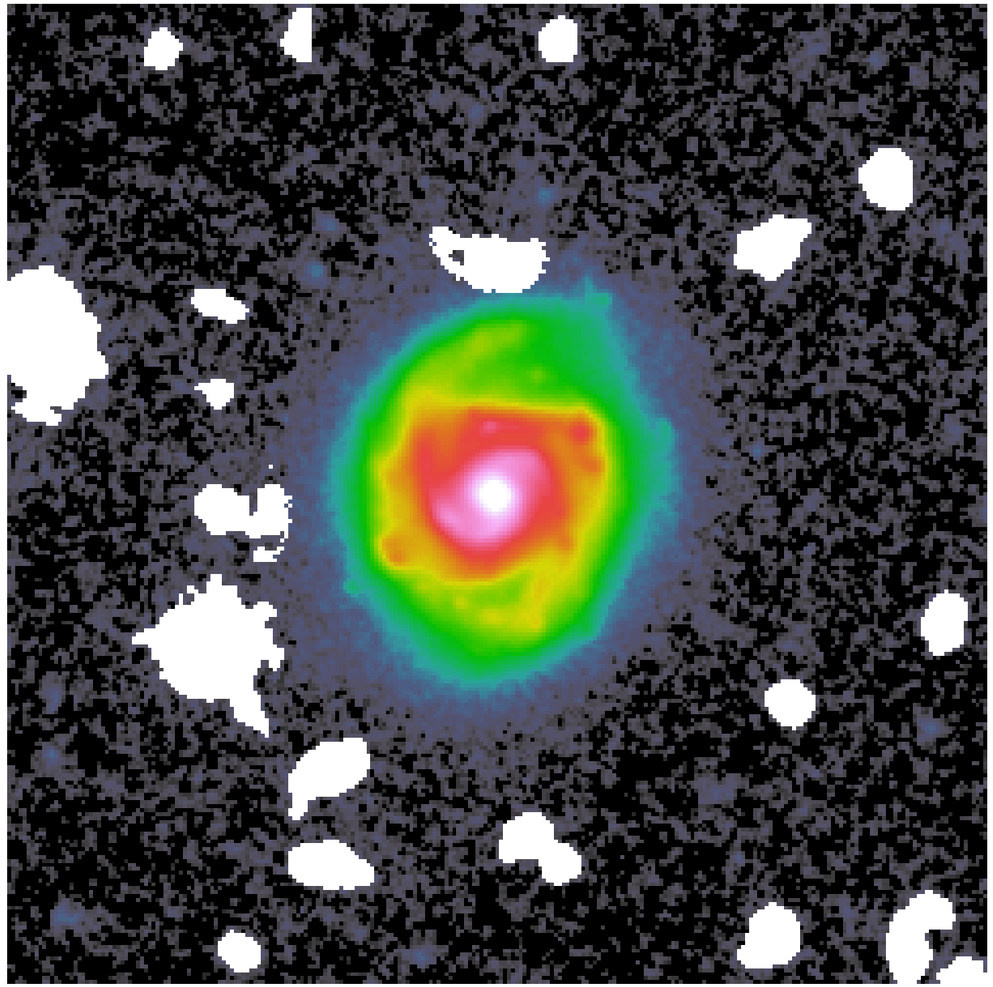
Source-Extractor

- Detect, identify and measure objects
- Do segmentations to prepare masks



Masked image

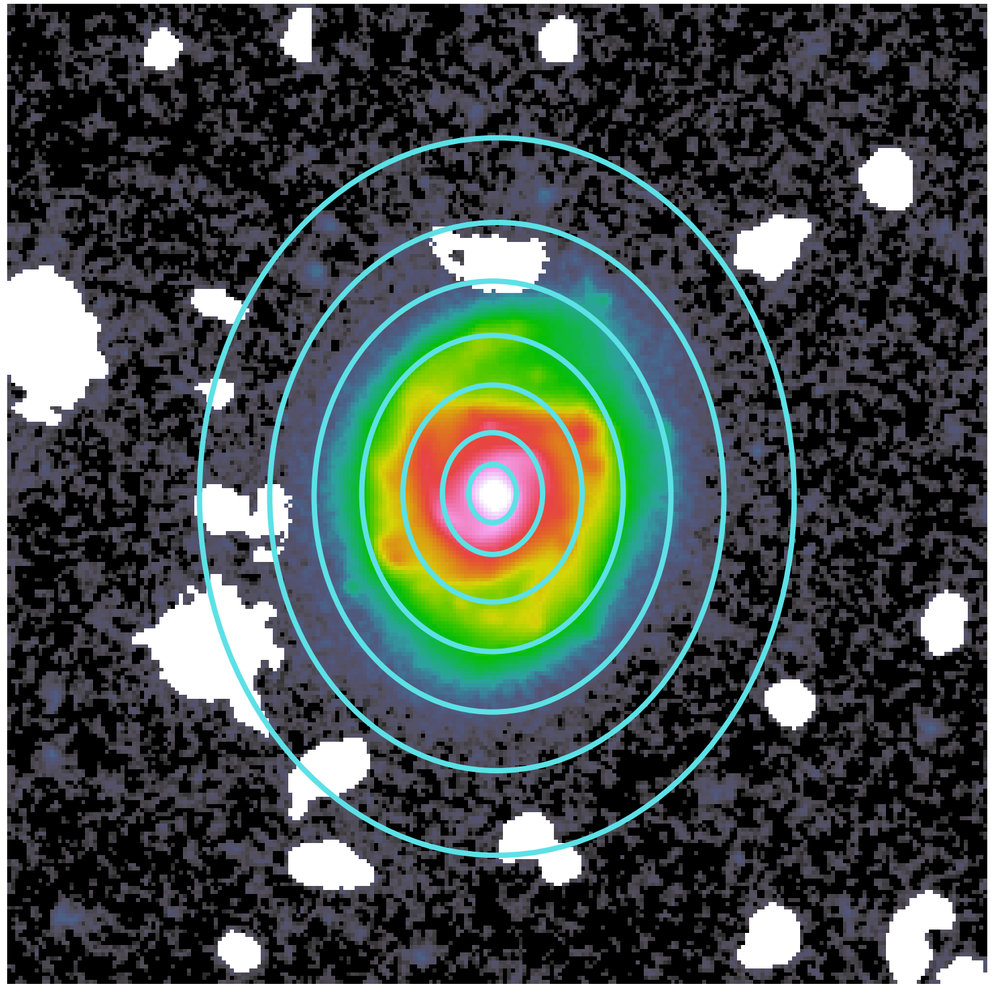
Methods



To obtain **surface brightness** we consider

- Elliptical bins (annuli)
- Flux (in counts) in each annulus

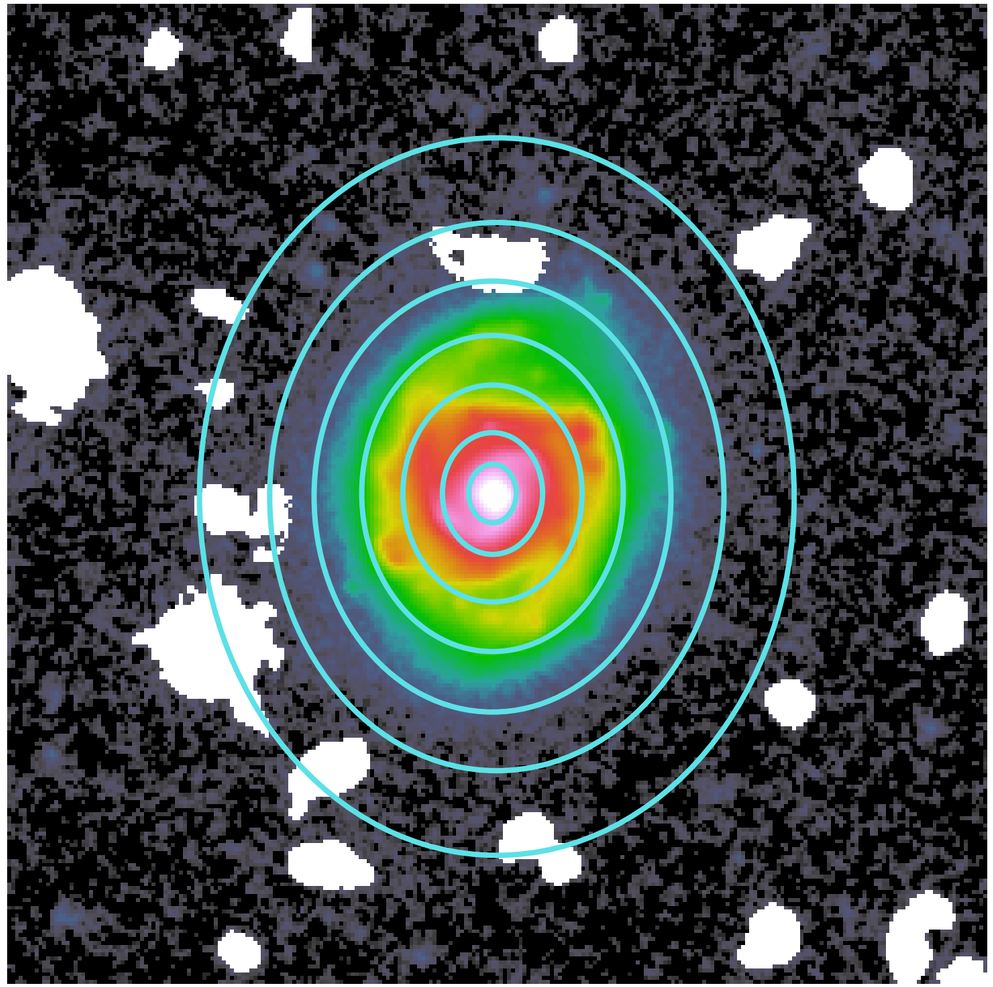
Methods



To obtain **surface brightness** we consider

- Circular bins (annuli)
- Flux (in counts) in each annulus

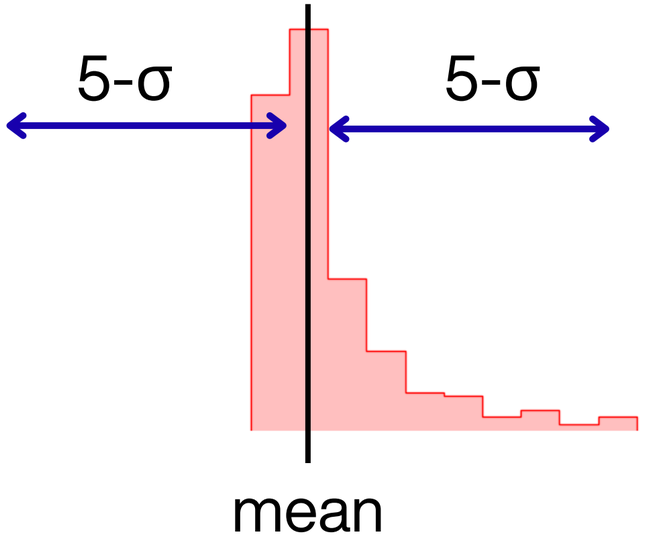
Methods



To obtain **surface brightness** we consider

- Circular bins (annuli)
- Flux (in counts) in each annulus

We use **sigma clip** to get the mean flux



(stop when the difference is 0.1%)

Methods

Zero-point

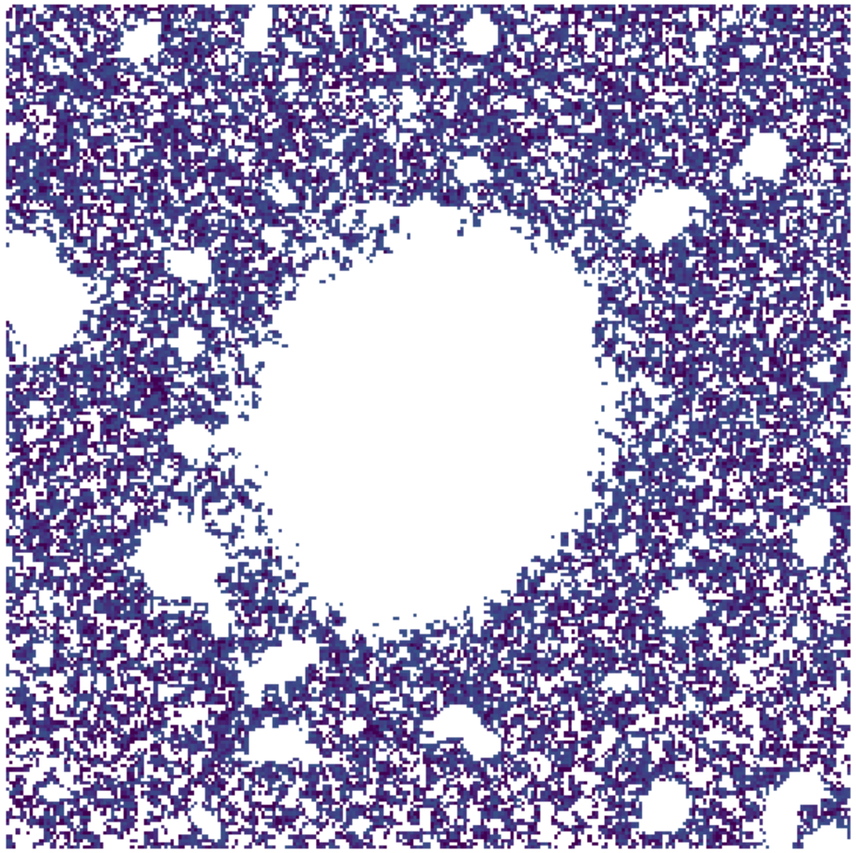
$$m_{\mathrm{AB}} = -2.5 \log_{10}(\mathrm{Flux}) + ZP + 5 \log_{10}(\mathrm{Pix.\,scale})$$

Flux in each annulus

(Obtained from image)

Methods

We need to take into account errors from the mean flux and background sky



$$\Delta F = \sqrt{\sigma_F^2 + \sigma_{\mathrm{SKY}}^2}$$

$$\Delta m_{\mathrm{SB}} = -2.5 \log_{10} \left(\frac{\Delta F}{F} \right)$$

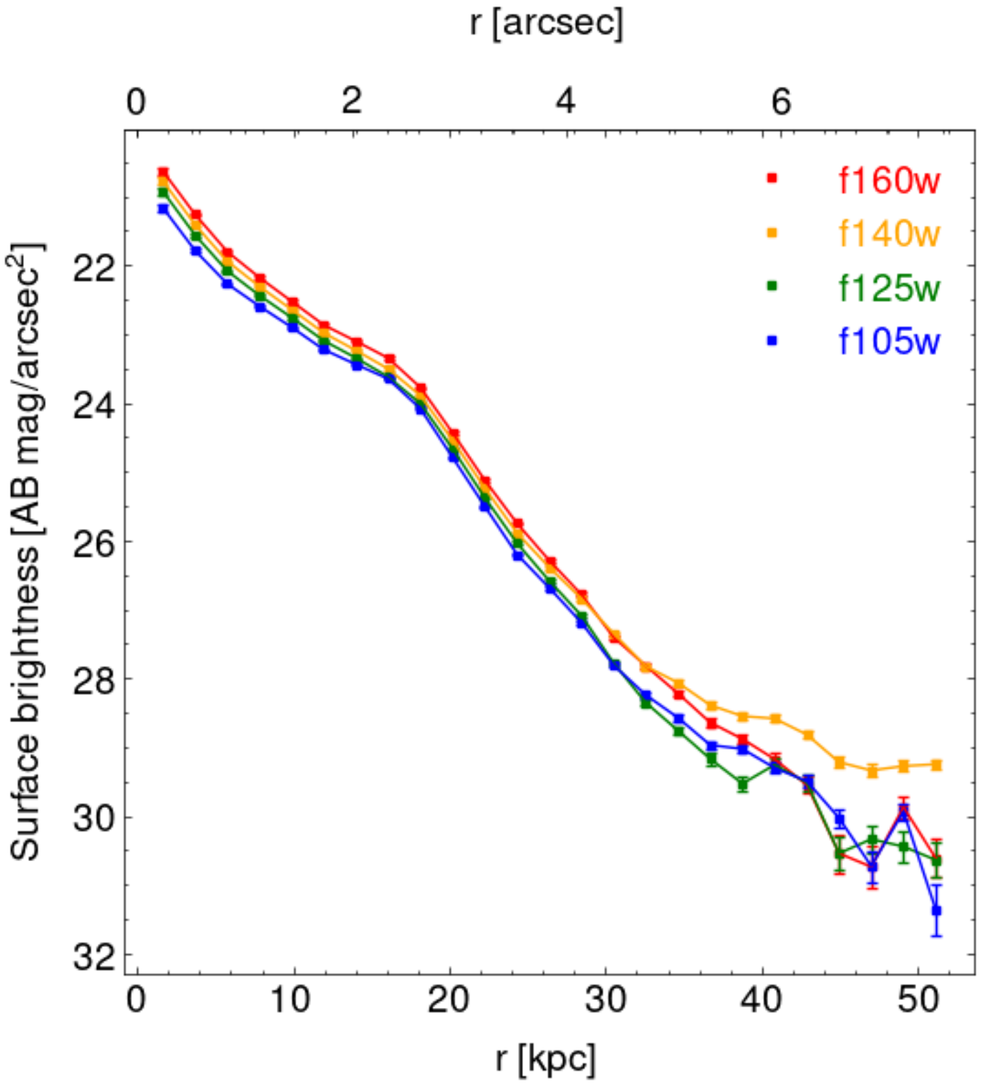
Methods

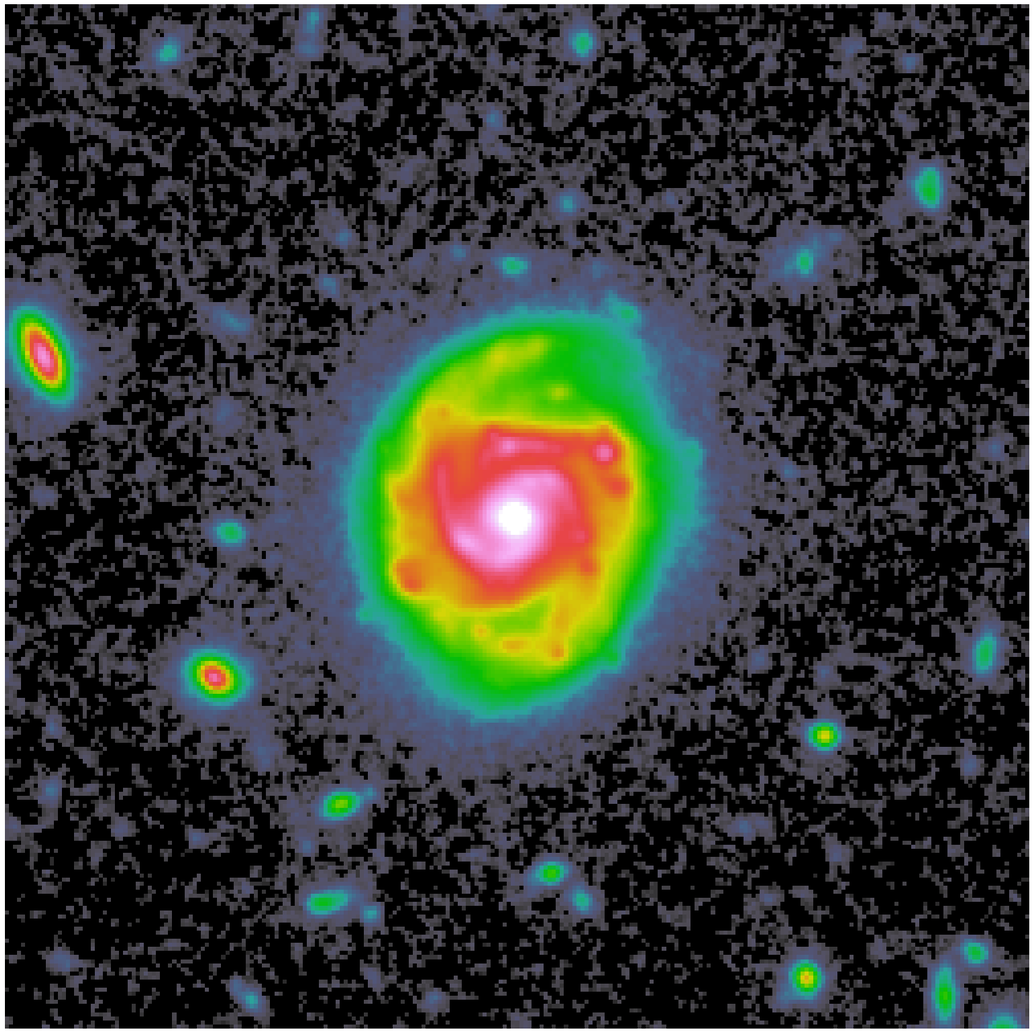
... and we have our own bash + Python scripts!

```bash
#!/bin/bash

# General Parameters

path=$PWD

udfFile="../hst/ah_f105w.fits"

telescope="hst"
filter="f105w"
galaxy="gal2"

genname="${galaxy}_${filter}"

mkdir -p "${path}/${telescope}"
mkdir -p "${path}/${telescope}/${galaxy}"

genpath="${path}/${telescope}/${galaxy}"

# 1 - Galaxy cutout from HST/JWST UDF

xcen=1369.97
ycen=1618.44
width=250

cropped="${genpath}/${genname}.fits"

astcrop ${udfFile} --center=$xcen,$ycen --width=$width --mode=img -o ${cropped}

# 2 - Mask other objects

mask="mask_f105w.sex"

mskpath="${genpath}/masked"

mkdir -p ${mskpath}

source-extractor ${cropped} -c ${mask}

python mask.py  -t ${telescope} -g ${galaxy} -f ${filter} -c ${cropped} -s "segmentation.fits"

# 3 - Surface Brightness
# 3A - Routine for flux [counts]
# FITS table [ r (pix) | F | dF | N ]
```

All our previous steps are carried out **in less than 30 seconds** (after spending hours the first time)

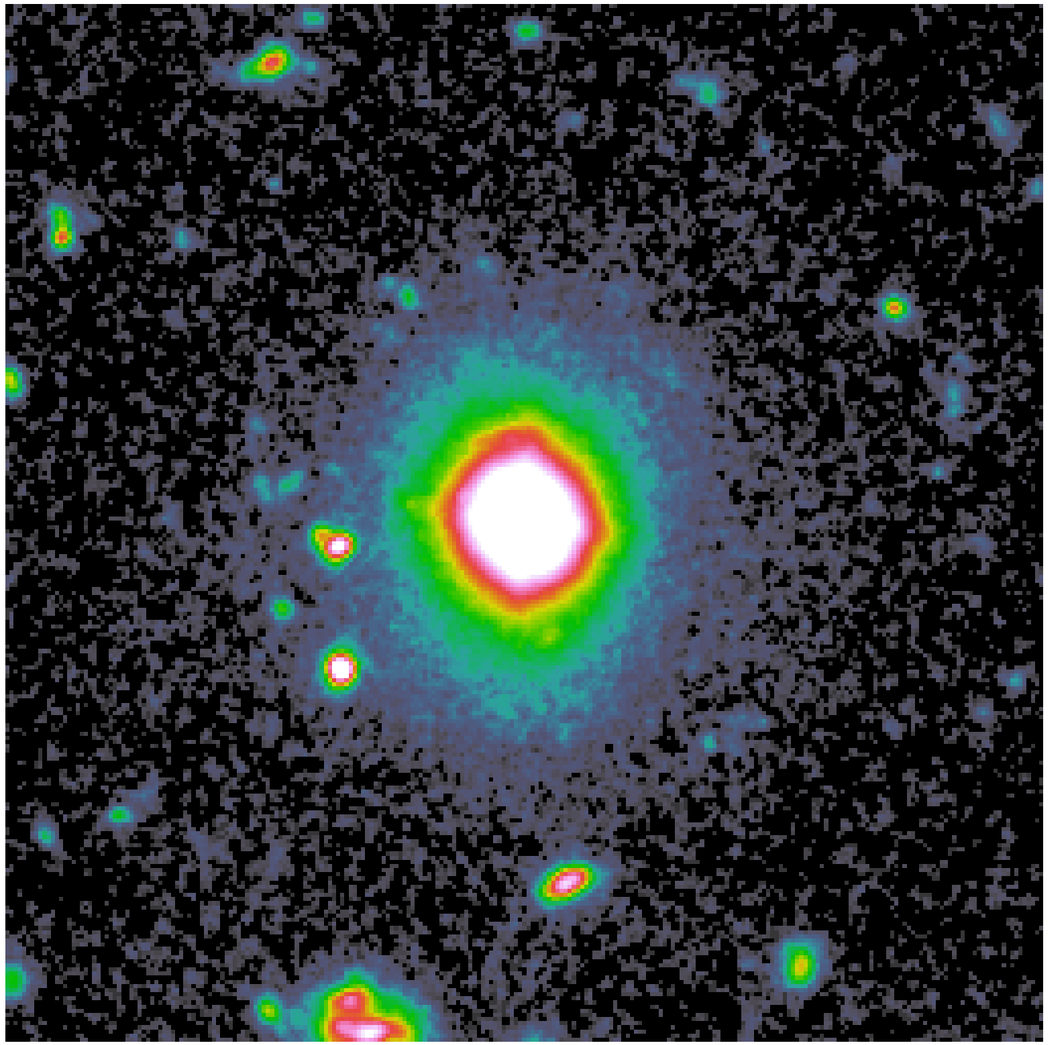
Results

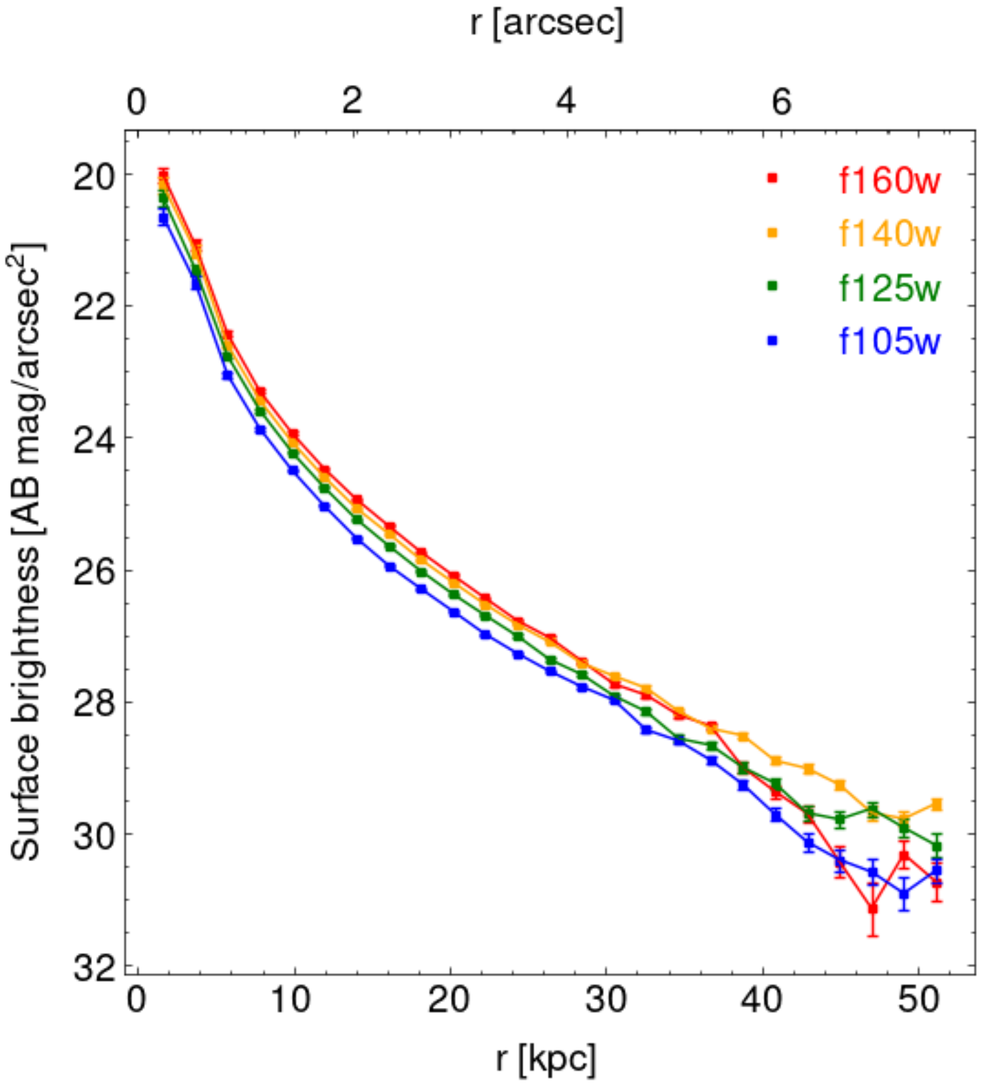




our spiral galaxy

Results

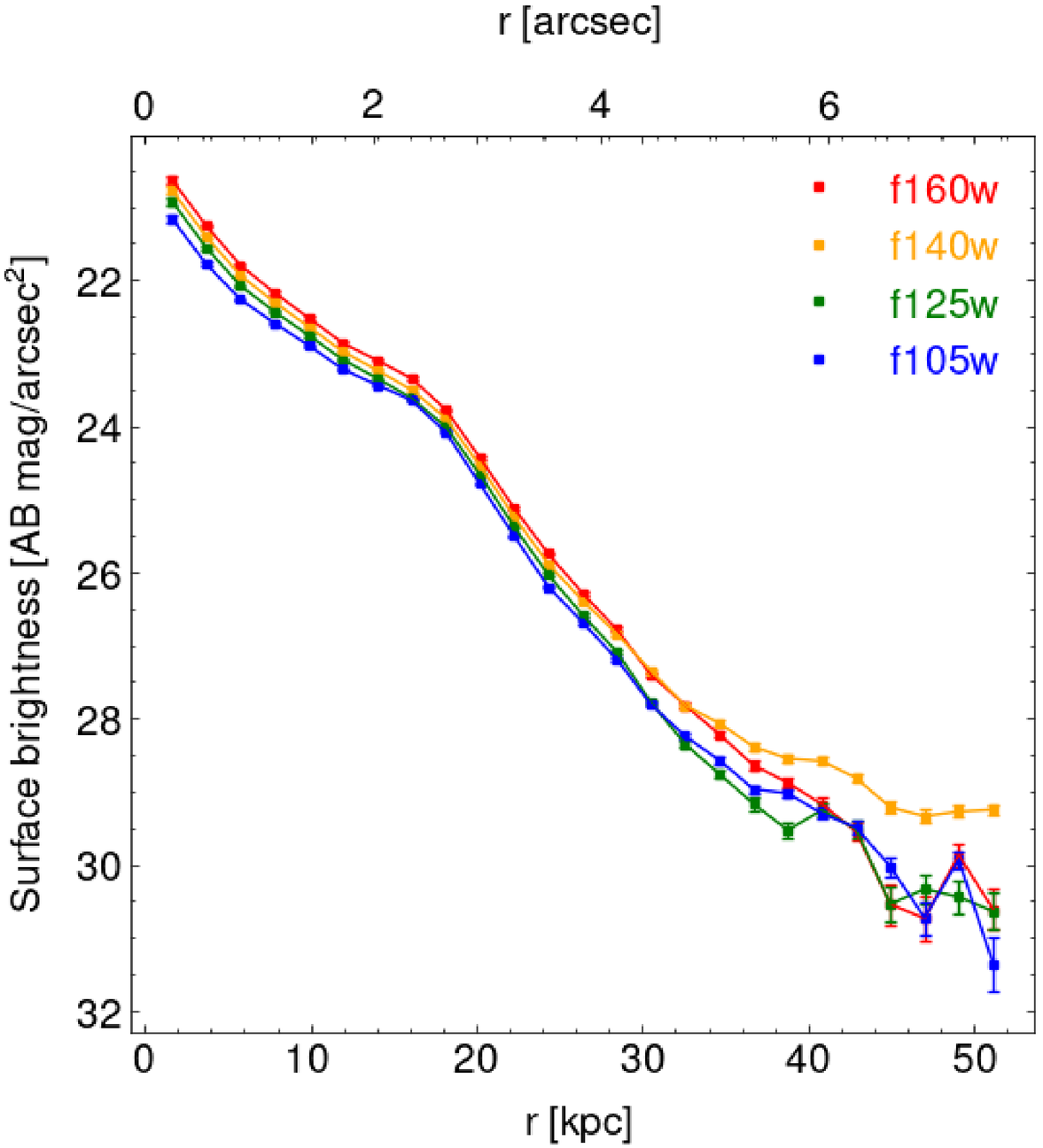




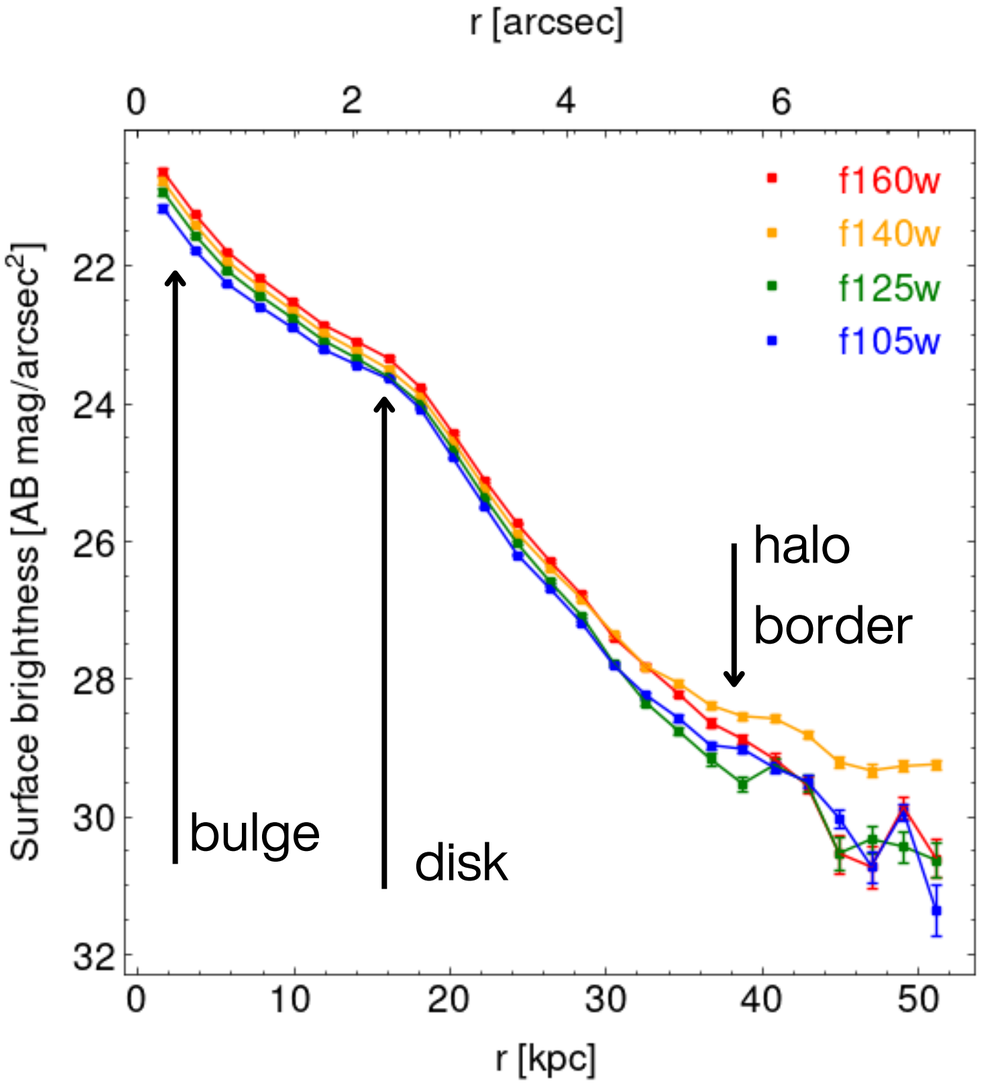
our elliptical galaxy

Discussion

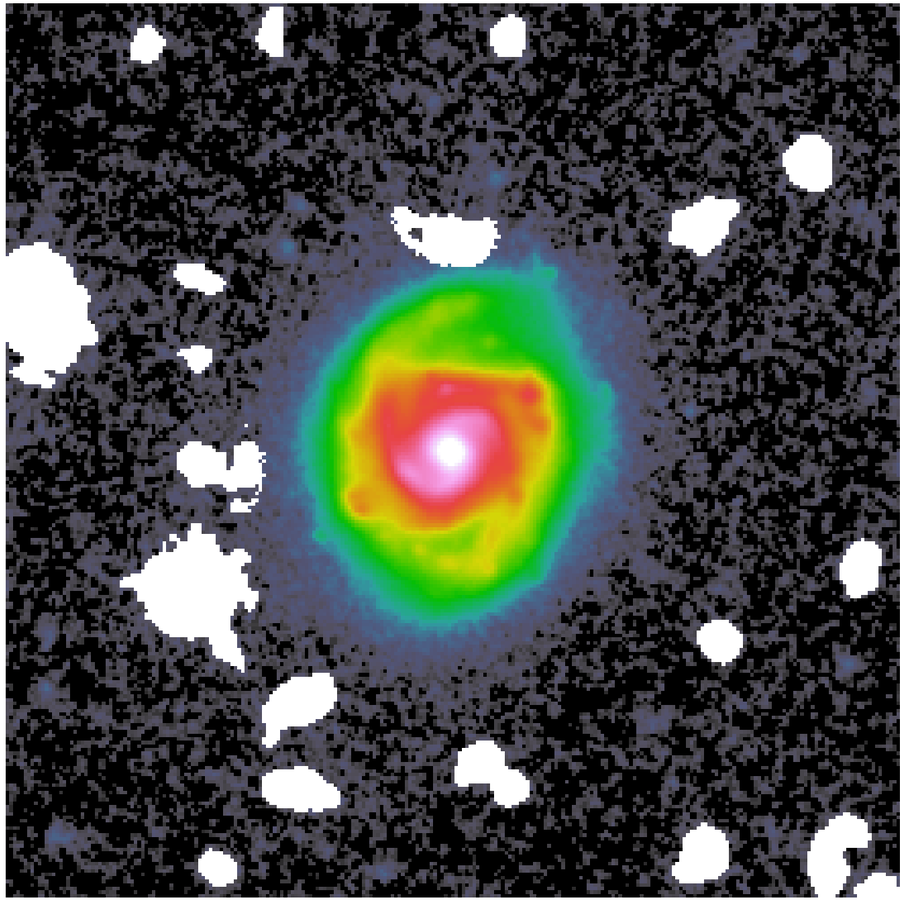
- The limit of the galaxy does not have a clear definition in the image;
- The shorter the wavelengths, the higher the surface brightness;
- Surface brightness in spiral and elliptical galaxies.



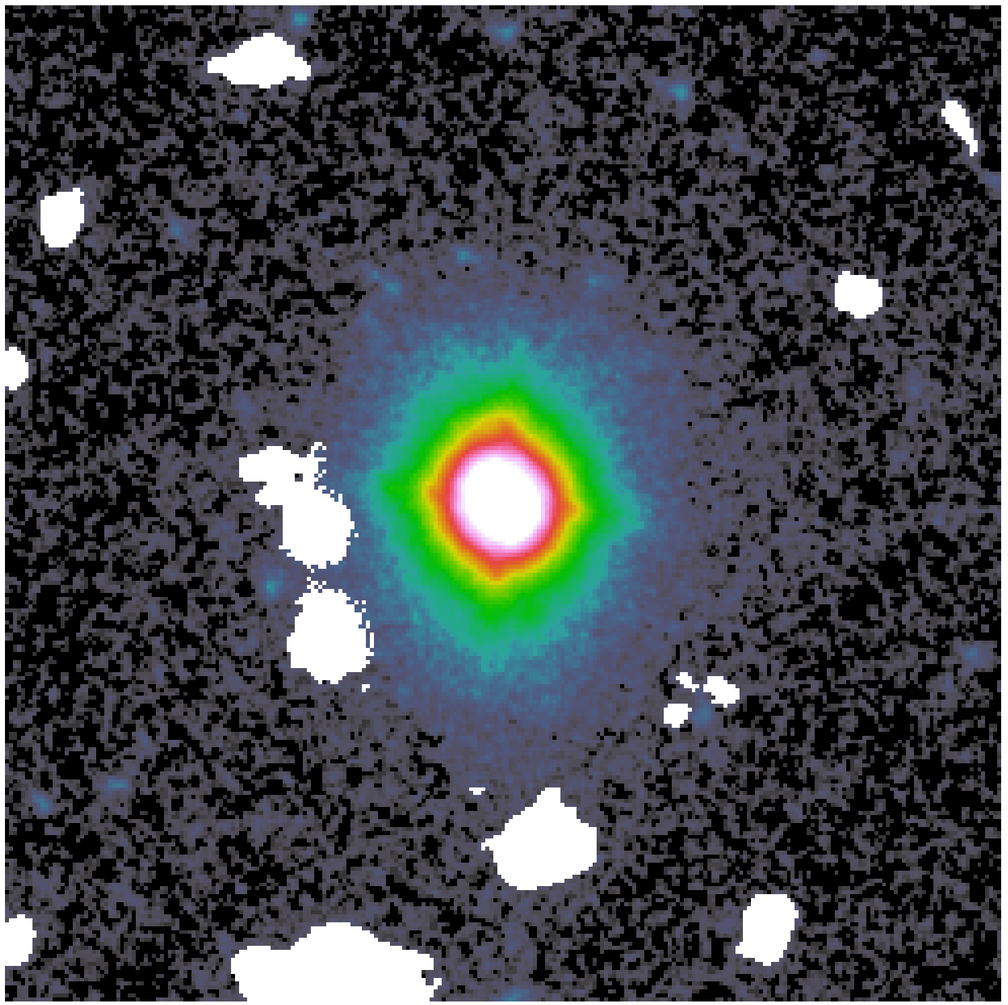
Discussion: spiral galaxy

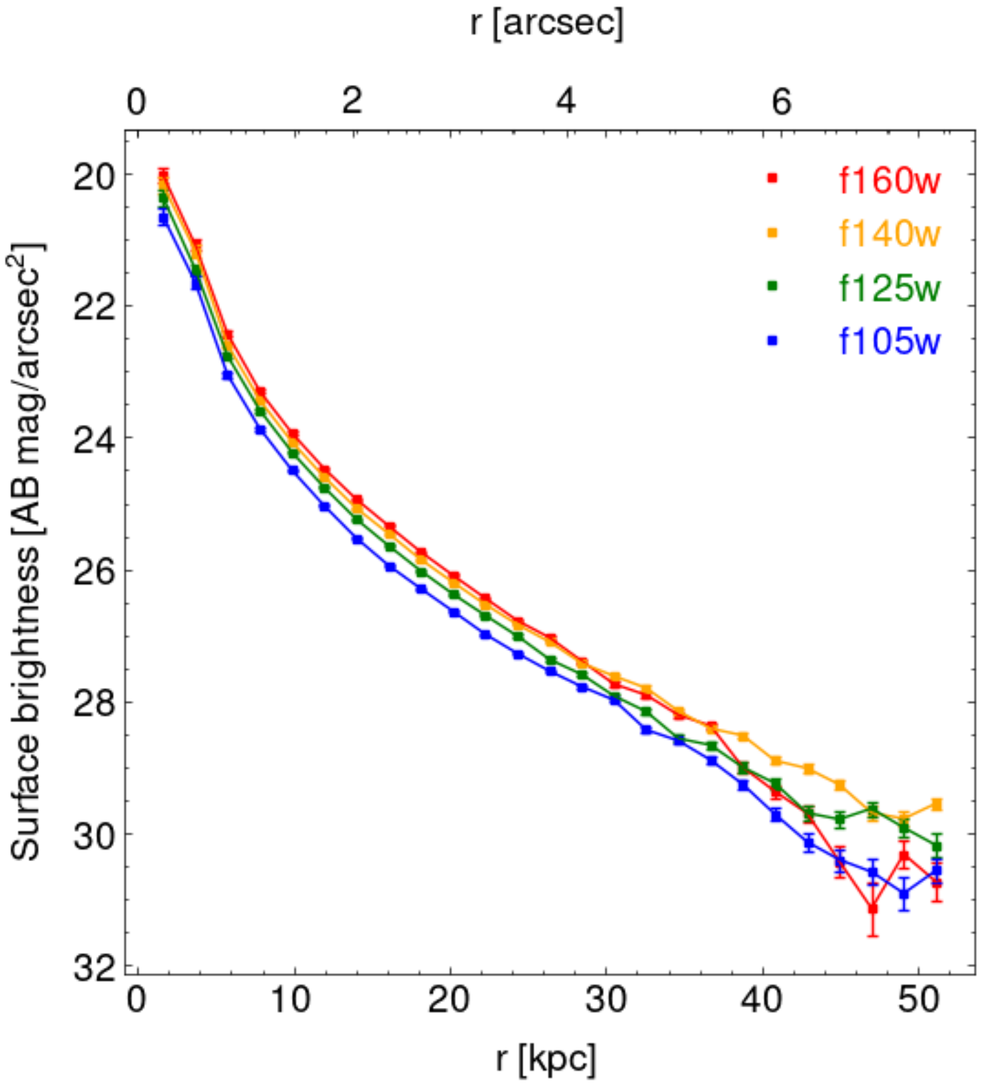


our spiral galaxy



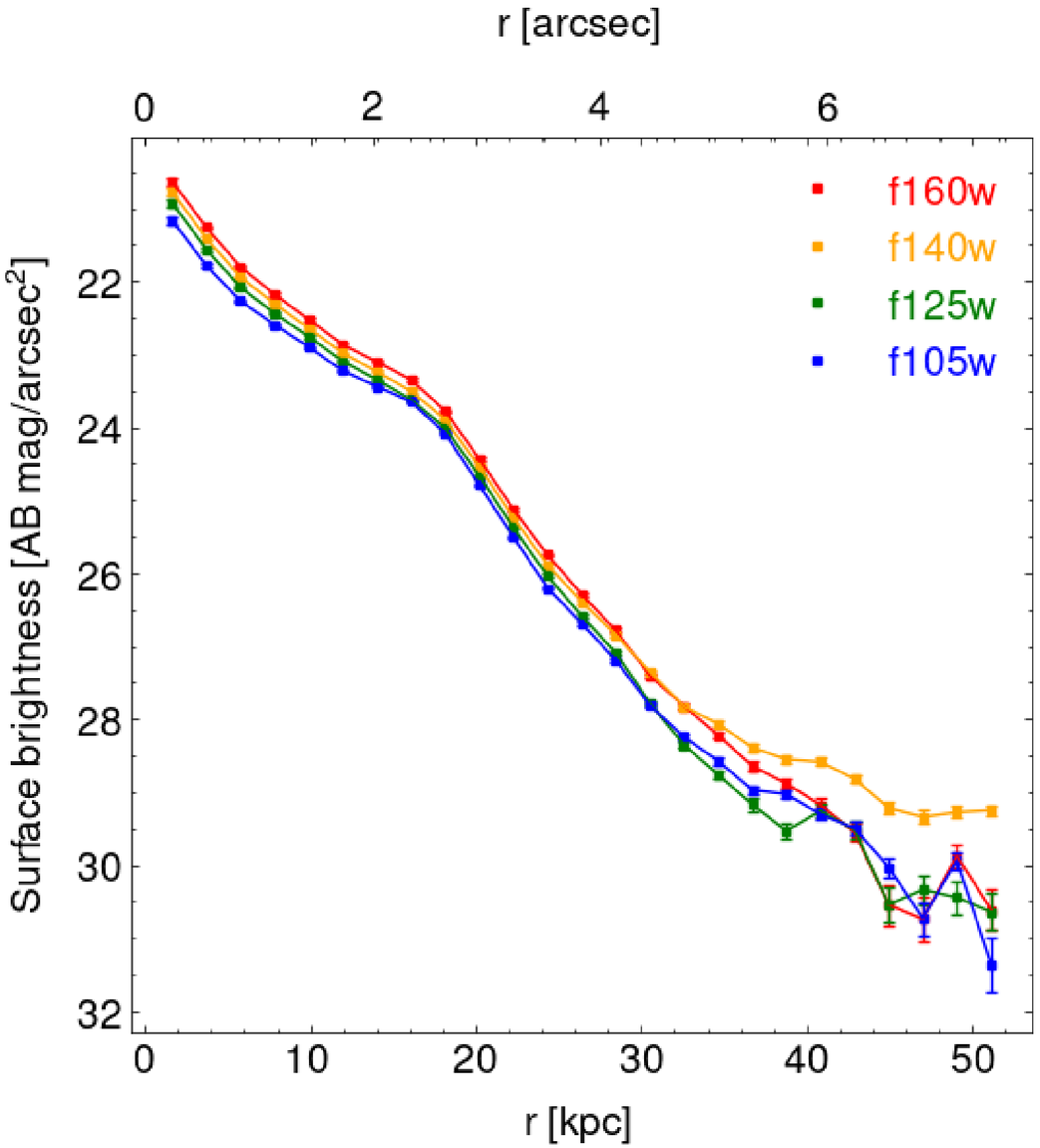
Discussion: elliptical galaxy



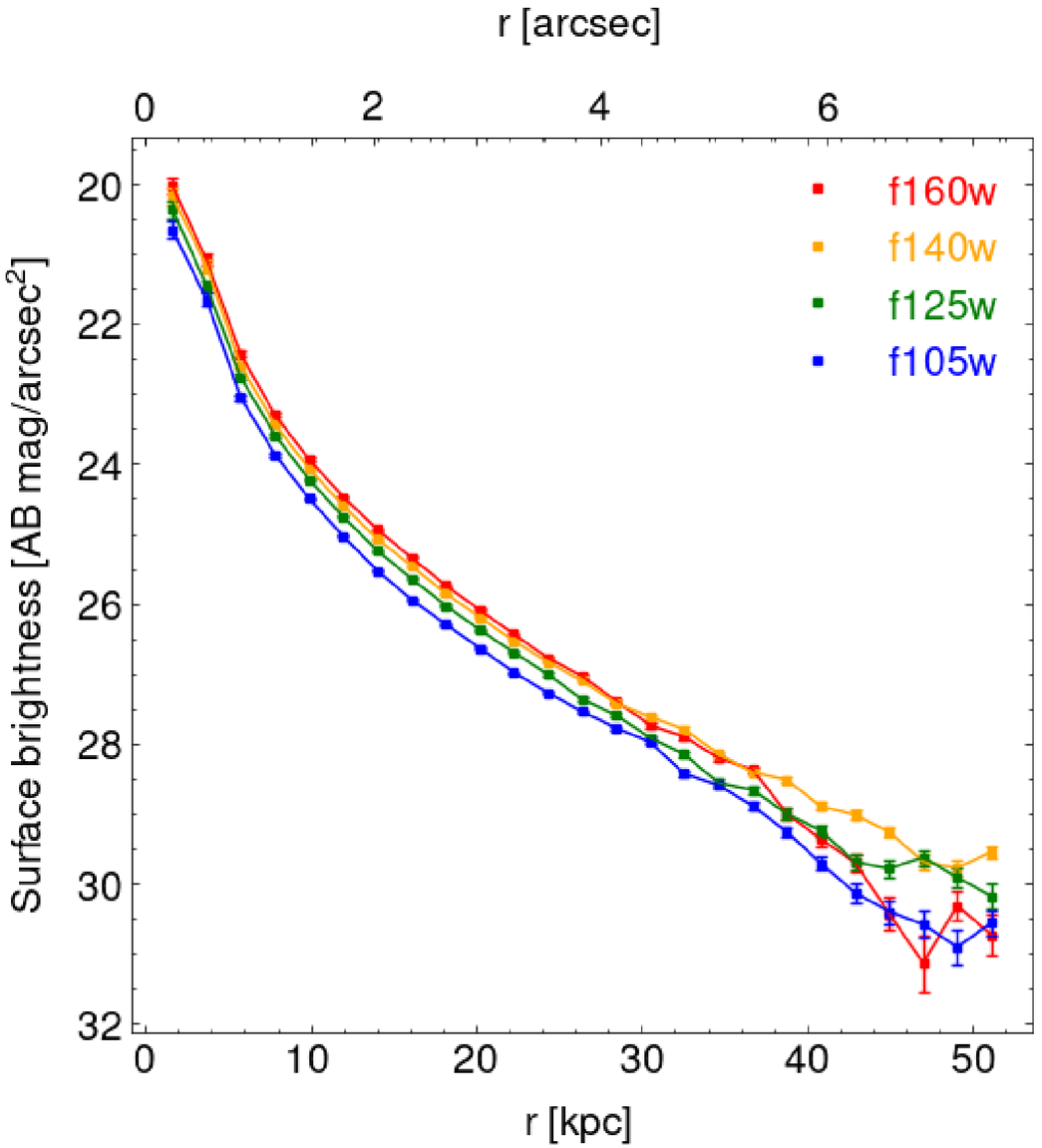


our elliptical galaxy

Spiral galaxy



Elliptical galaxy



Conclusions

- But then... what are the sizes our galaxies?
  - Approximately 40 kpc!

- What did we learn?
  - Understand the process to obtain the surface brightness;
  - Using python in the context of surface brightness;
  - Have a contact with bash scripts;
  - Deal with the difficulties in the research.

References

Borlaff A., Trujillo I., Román J., Beckman J.~E., Eliche-Moral M.~C., Infante-Sáinz R., Lumbreras-Calle A., et al., 2019, A&A, 621, A133.

Buitrago F., et al. “The cosmic assembly of stellar haloes in massive early-type Galaxies”. 2017, MNRAS, 466, 4888–4903.

Trujillo I, Fliri J. “Beyond 31 mag arcsec−2: the frontier of low surface brightness imaging with the largest optical telescopes”, 2016, The Astrophysical Journal, 823, 123.

We acknowledge the use of data of the **ABYSS HUDF WFC3/IR** project (Borlaff et al. 2019) Instituto de Astrofísica de Canarias for this project. http://research.iac.es/proyecto/abyss/

Thank you!