Evolution of the ISM* in quiescent galaxies

Krzysztof Lisiecki under supervision of Darko Donevski

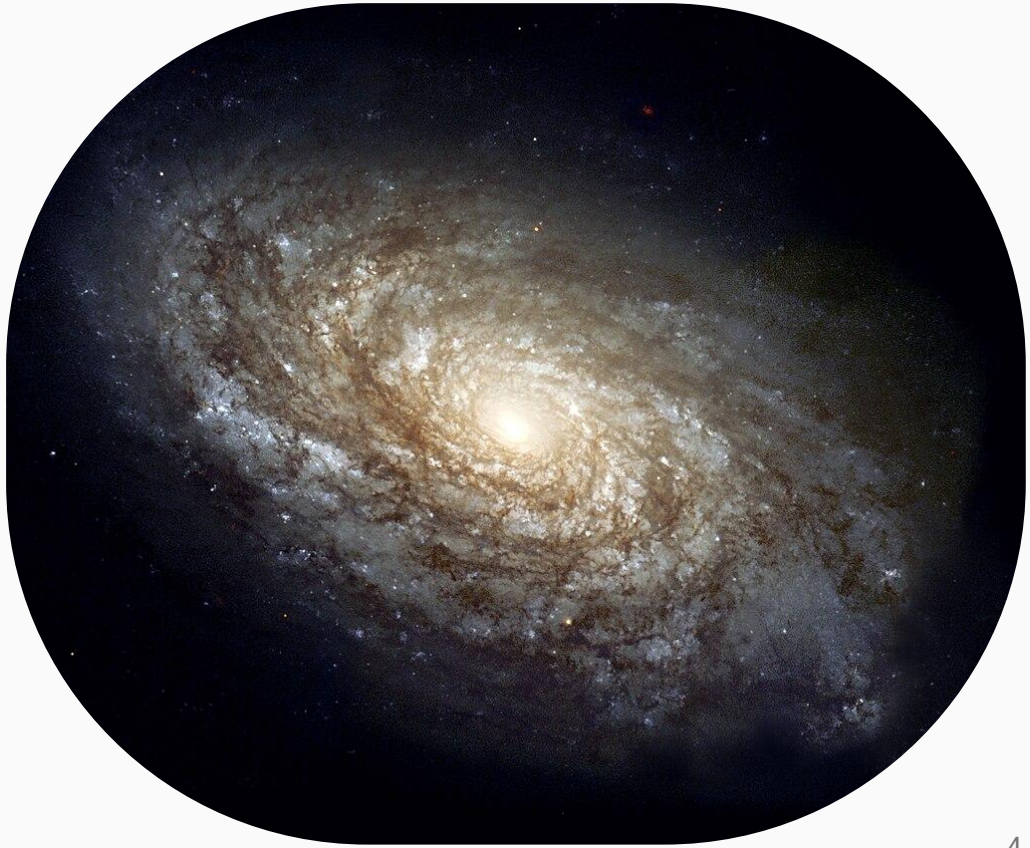
Plan

- Introduction
  - Understanding the title
  - Understanding science case
- Data reduction
  - Exploration of data
  - Data processing
  - Building catalog
- Results
  - So far
  - Future goals

Let’s explore the title…

What is a galaxy?

A galaxy is a complex system of stars, stellar remnants, **interstellar medium** and dark matter bound together by gravity.

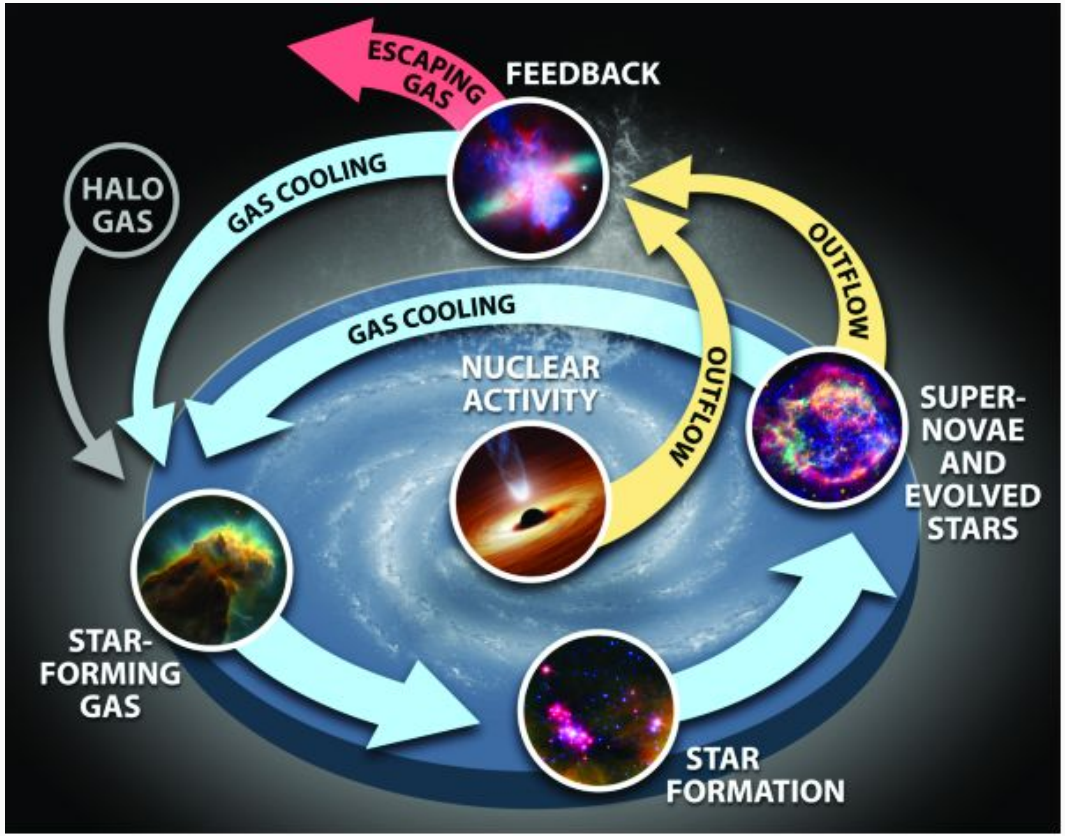


NGC 4414, HST

What is interstellar medium?

Interstellar medium (ISM) is the matter that exists in the space between the stars in a galaxy.

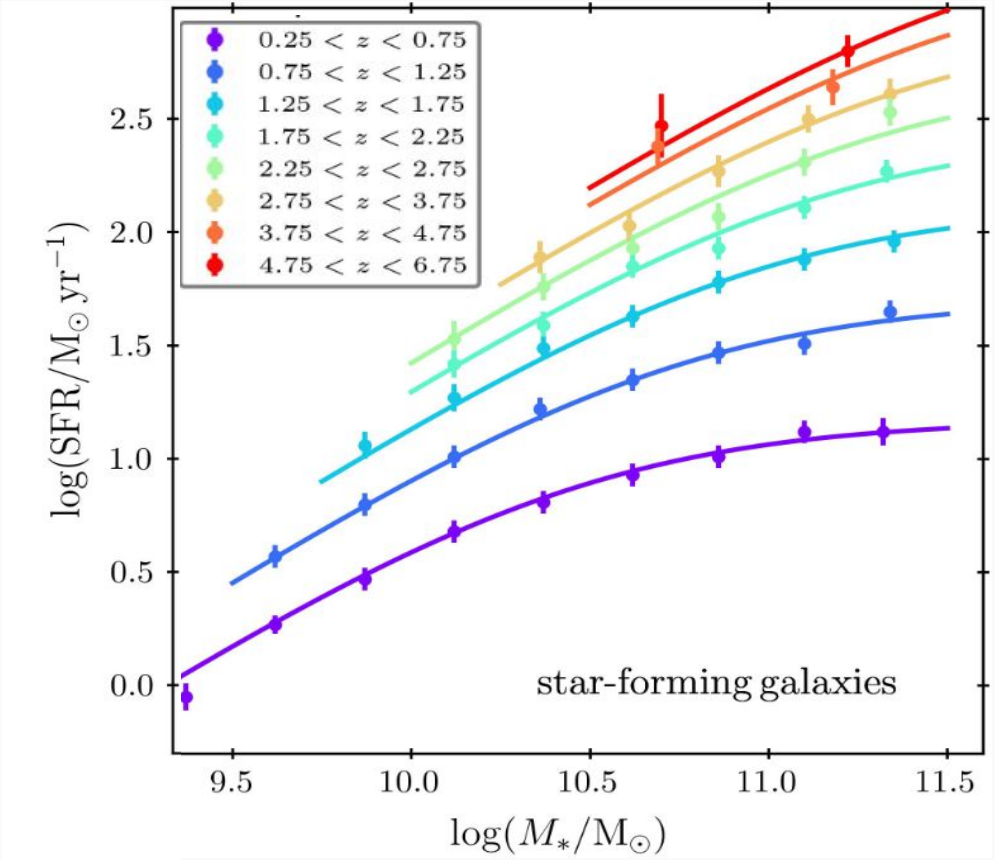
This matter includes atomic, neutral and ionic gas, as well as the dust.



Baryon cycle, Leisawitz+19

What does it mean quiescent?

Years of studies led to a conclusion that there is a relation between stellar mass of a galaxy and its star-formation rate.

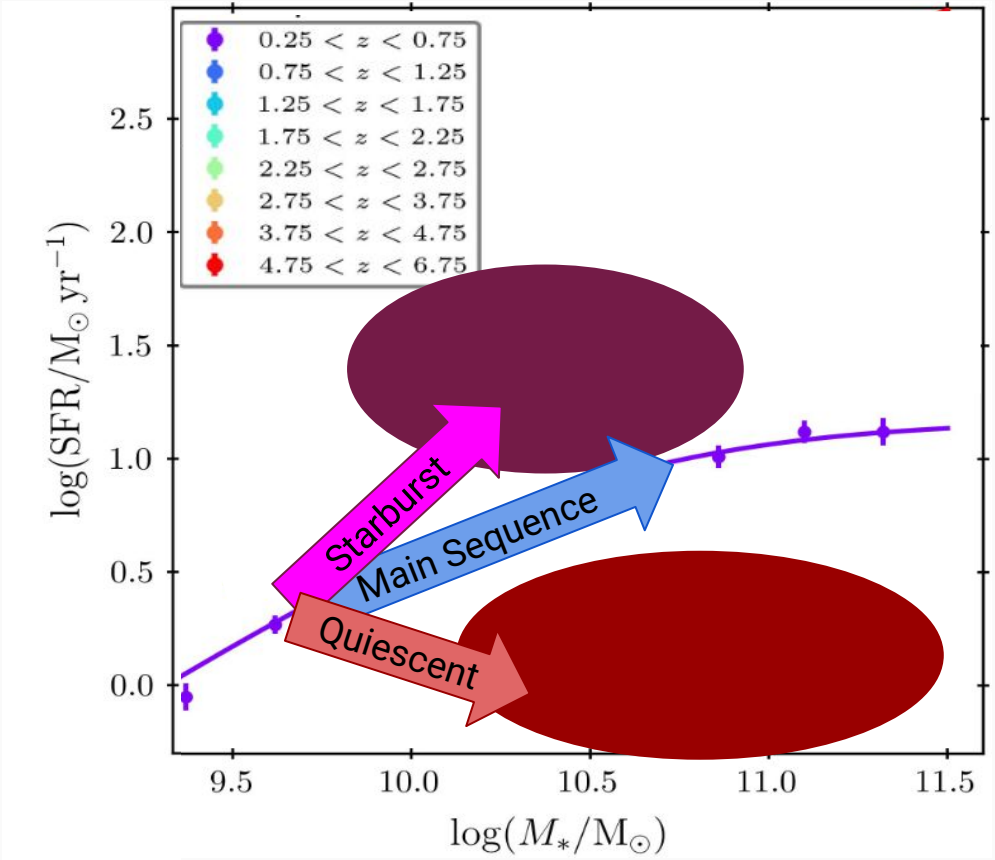


Koprowski+(including Lisiecki) Accepted

What does it mean quiescent?

Years of studies led to a conclusion that there is a relation between stellar mass of a galaxy and its star-formation rate.

The outliers with less starforming than usual are quiescent (passive) galaxies (QGs).



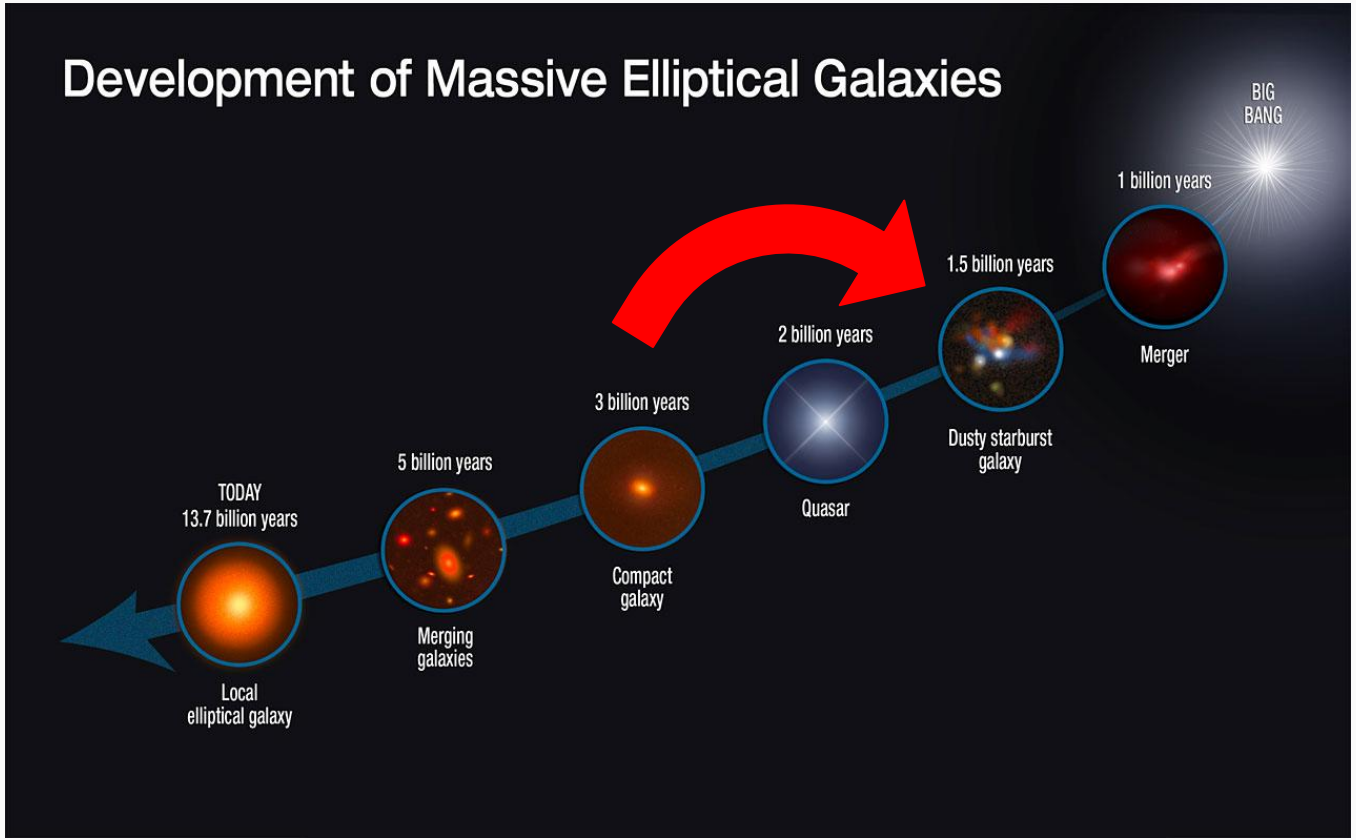
Koprowski+(including Lisiecki) Accepted

Let’s understand the science case

Why is it so interesting?

JWST is exploring new territory of quiescent galaxies!

Already moved the limit for the farthest QG to about 1.5 Gyr after the Big Bang!

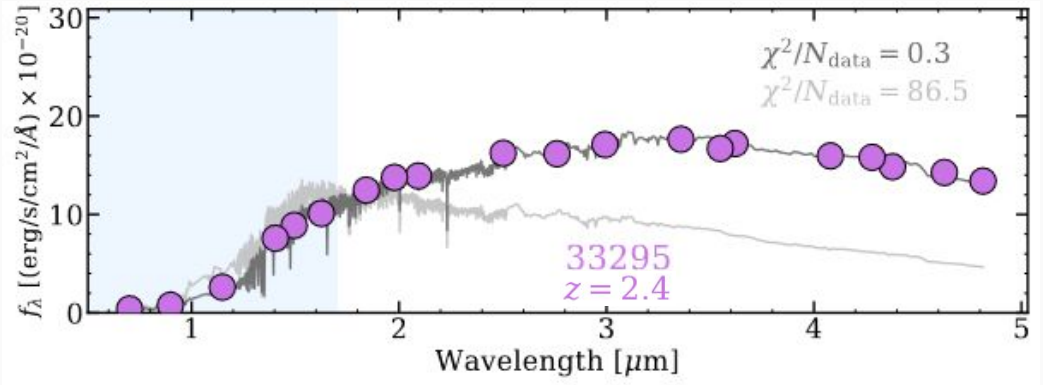


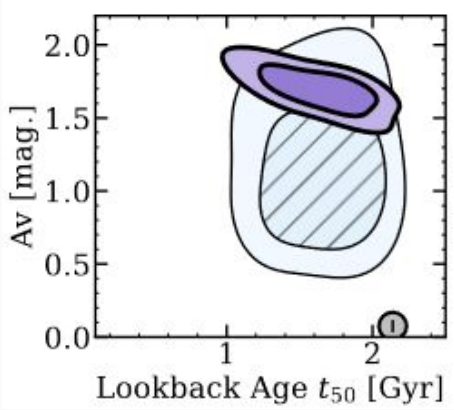
NASA, ESA, HST

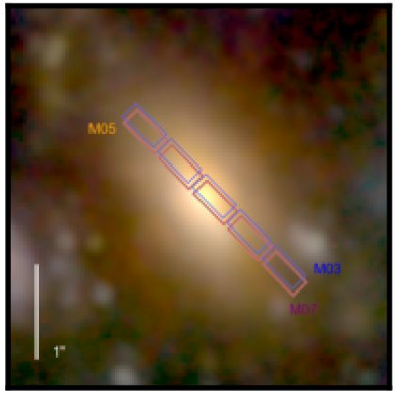
Why is it so interesting?

Also, previously we assumed quiescent galaxies as a ISM-dry objects.

But recent reports from Atacama Large Millimeter Array (ALMA) and James Webb Space Telescope (JWST) show it is not only wrong, but we also find QGs earlier than we expected!





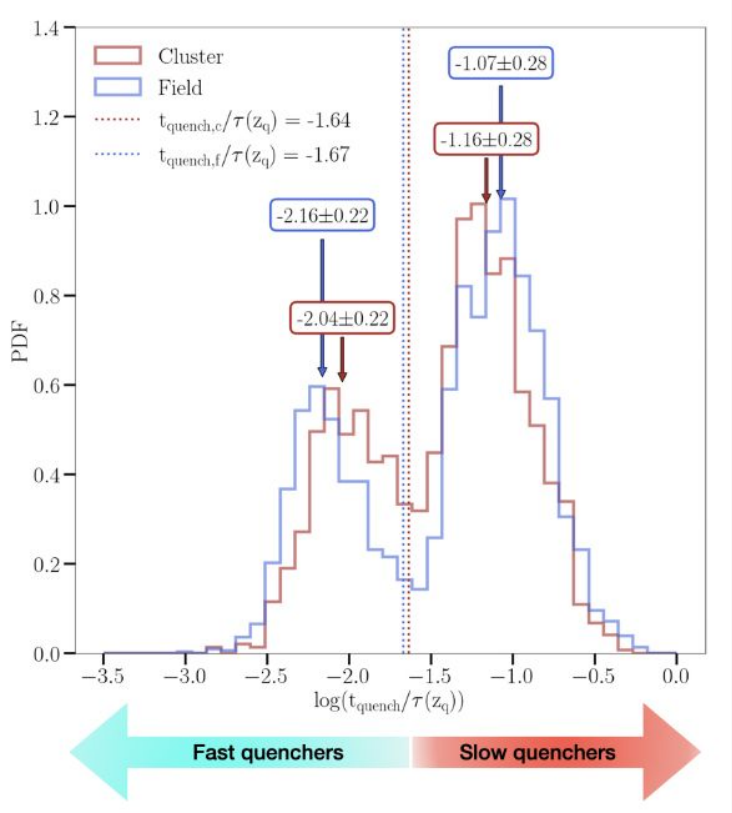


Siegel+24

What I am trying to do?

I aim to understand, statistically, what is the relation between ISM and the quenching process.

It is challenging due to faint nature of QGs and still developing theory of the quenching, but finally doable with JWST and ALMA!

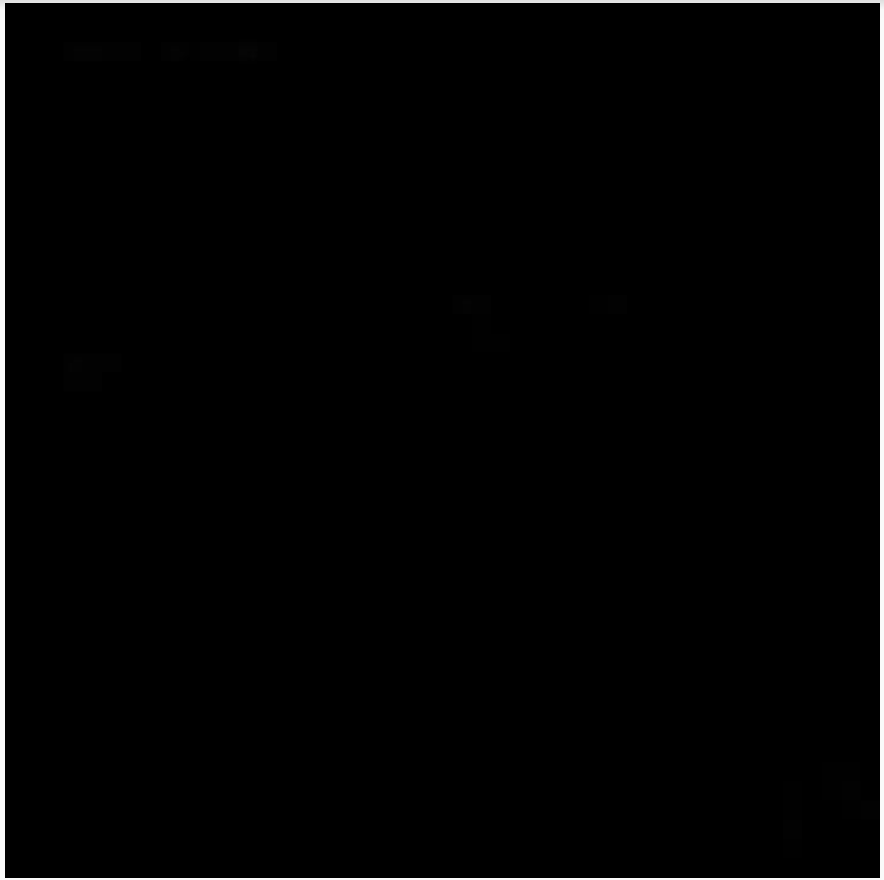


Lorenzon+(inlucing Lisiecki) 2024

How can I do it? Part one

We use cosmological simulation. But all of them are build over some assumptions. Observations are necessary to confirm simulations. Simulations are helpful to understand observations!

Wait for Giuliano's talk (5th of December) or read our paper Lorenzon+(including Lisiecki)24!

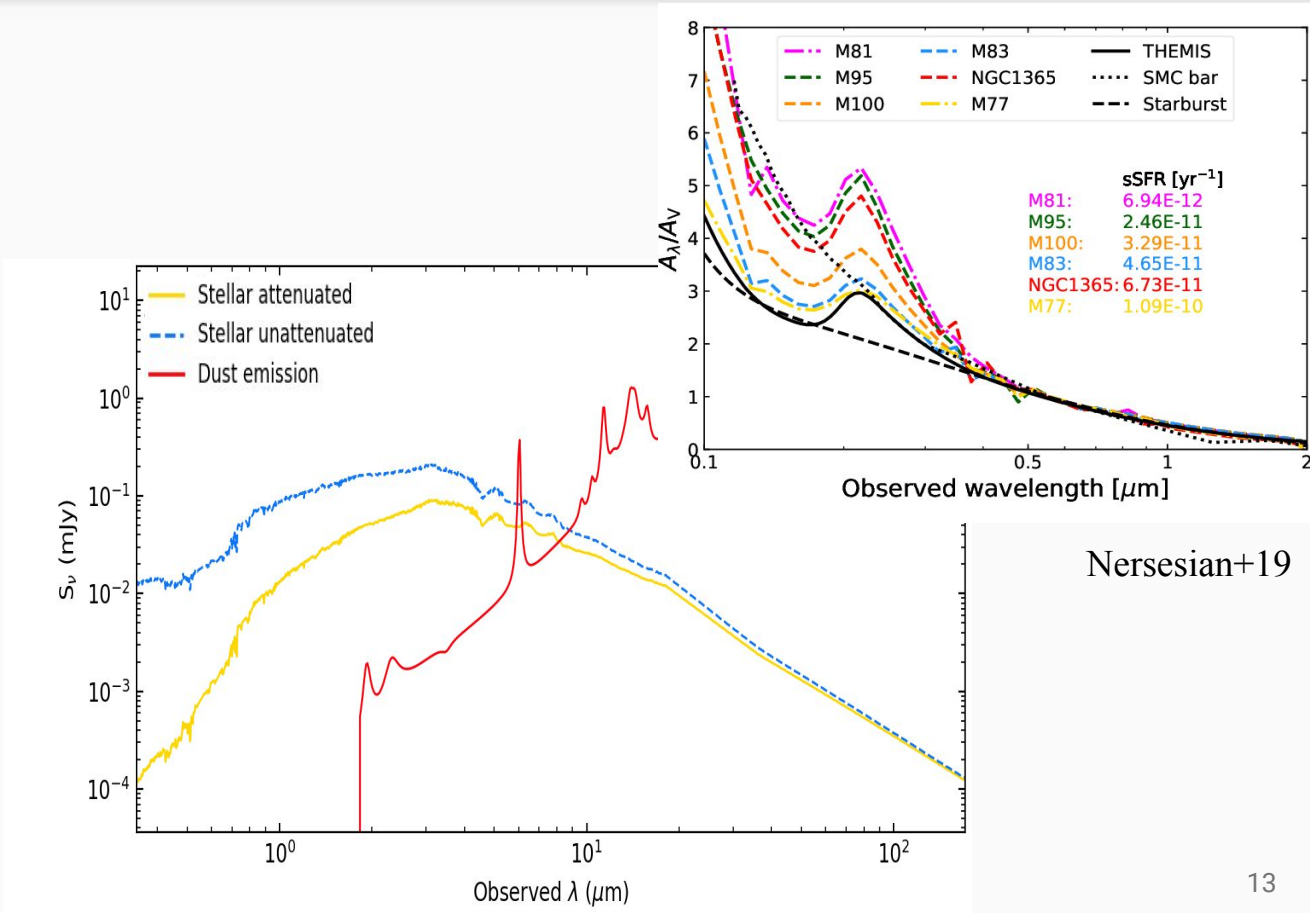


Credits: me

How can I do it? Part two

Dust absorbs shorter wavelengths more than longer. This makes the observed spectrum redder than the emitted one.

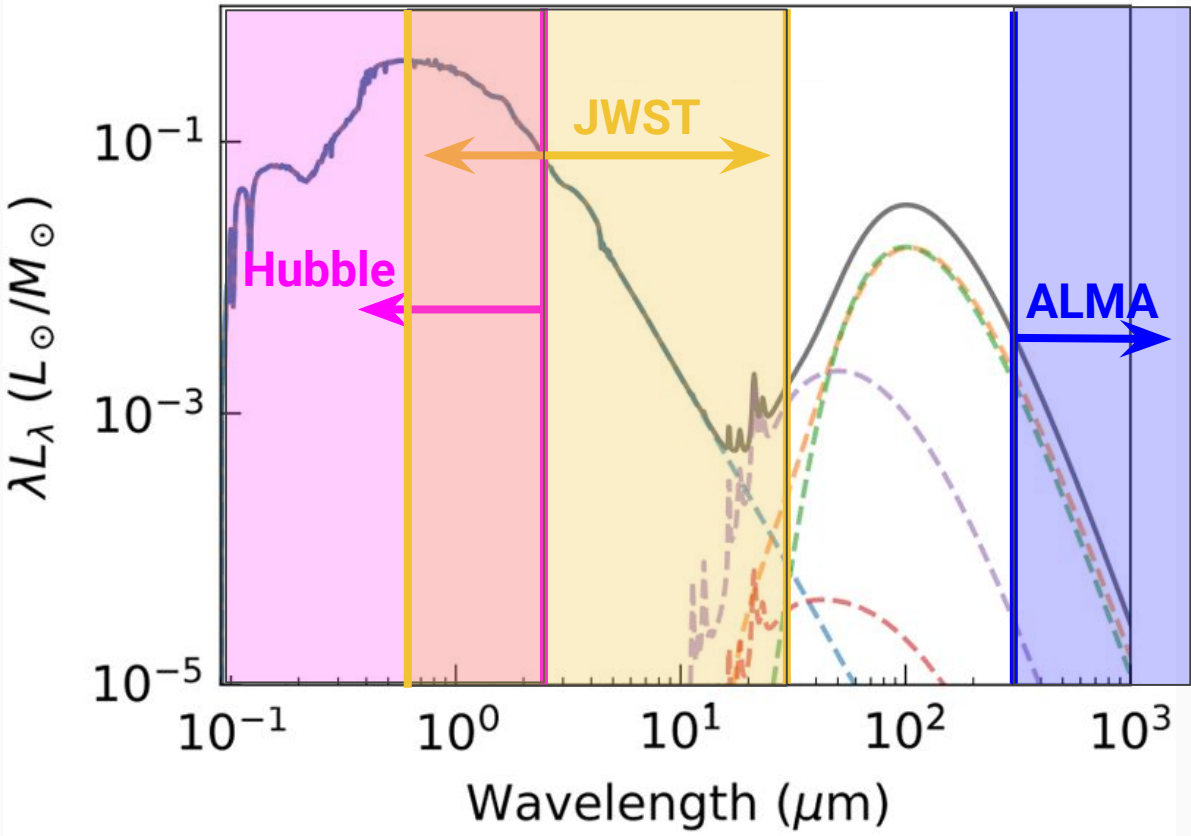
Dust emits the absorbed energy in infrared range.



Nersesian+19

Observational possibilities

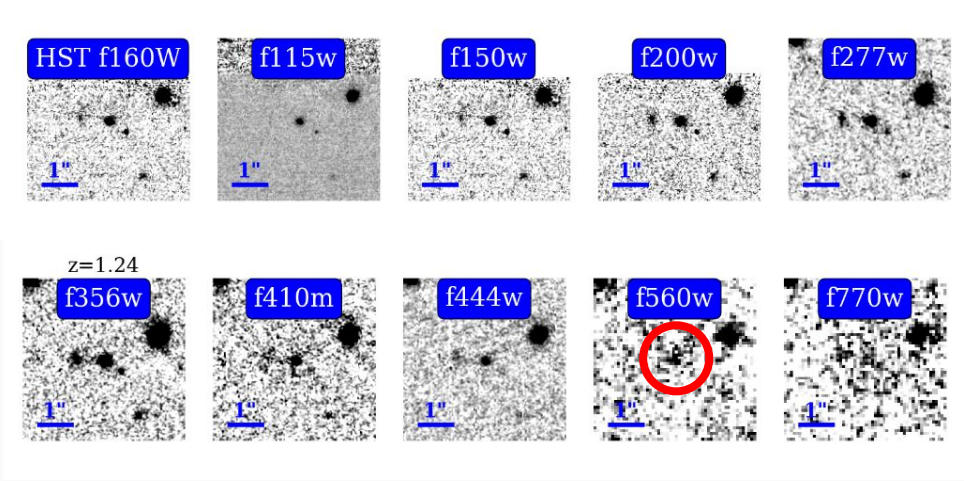
Hubble Space Telescope gave us insight into optical light of galaxies, JWST and ALMA showed dusty Universe for the first time (in such quality).



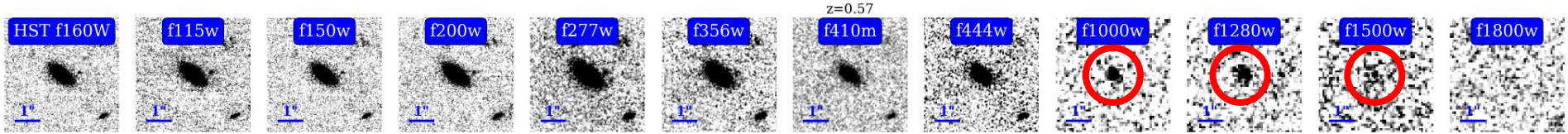
Nishida+19, modified

Observation focus

Since I want to study QGs and their dust, it is necessary to build an observational catalog with wide wavelength coverage (optical-IR) and to include the faintest infrared sources.



Source at redshift ~1.2

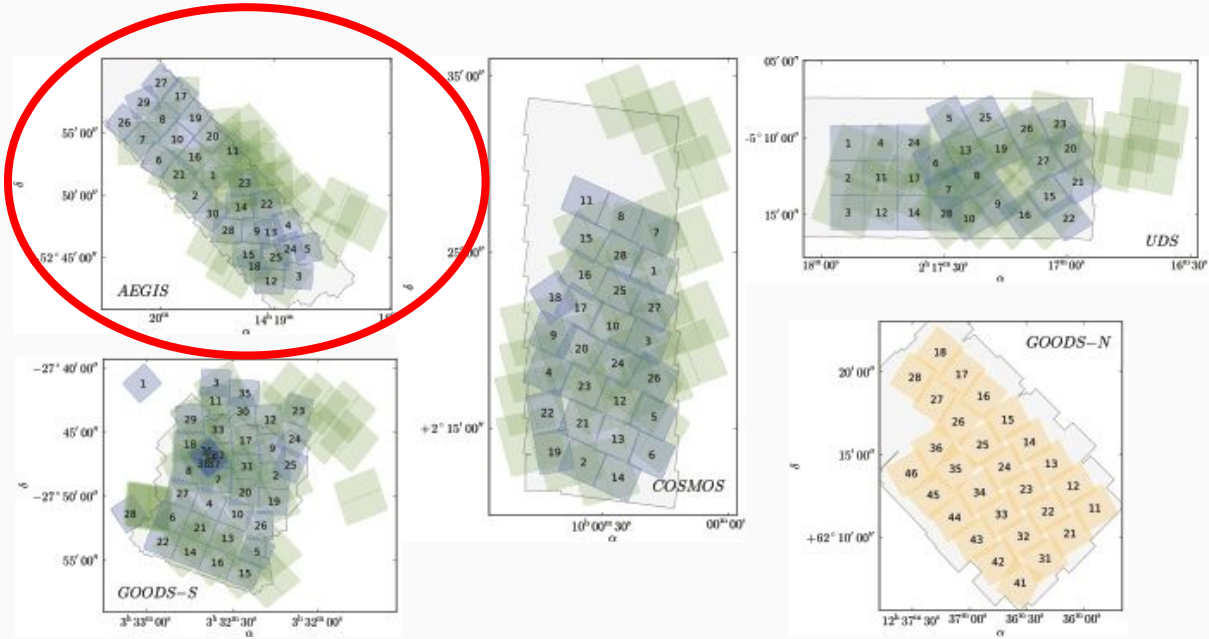


Source at redshift ~0.6

Preparing catalog

Multiwavelength and spectroscopic survey – 3D HST

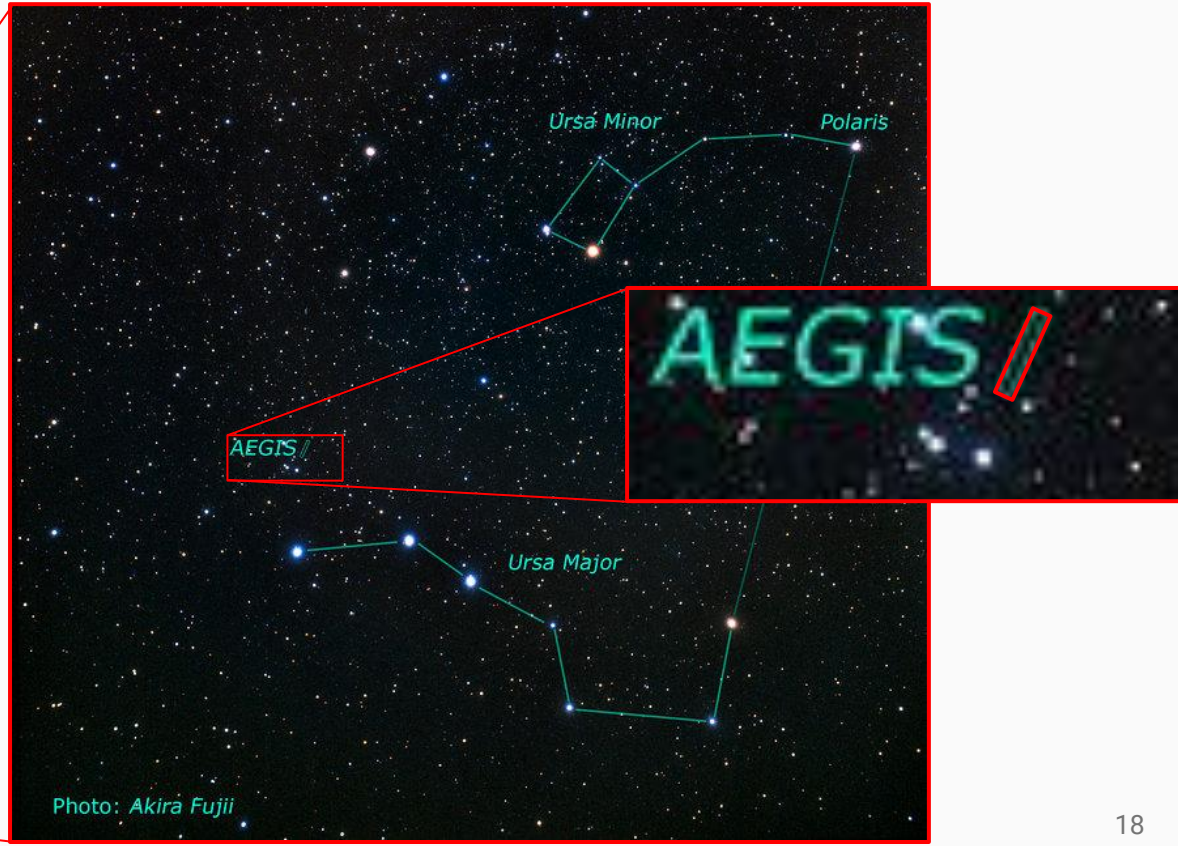
3D-HST is a spectroscopic survey focused on galaxy evolution studies in the distant Universe. It utilizes the previously observed sky areas.



Brammer et al. 2012

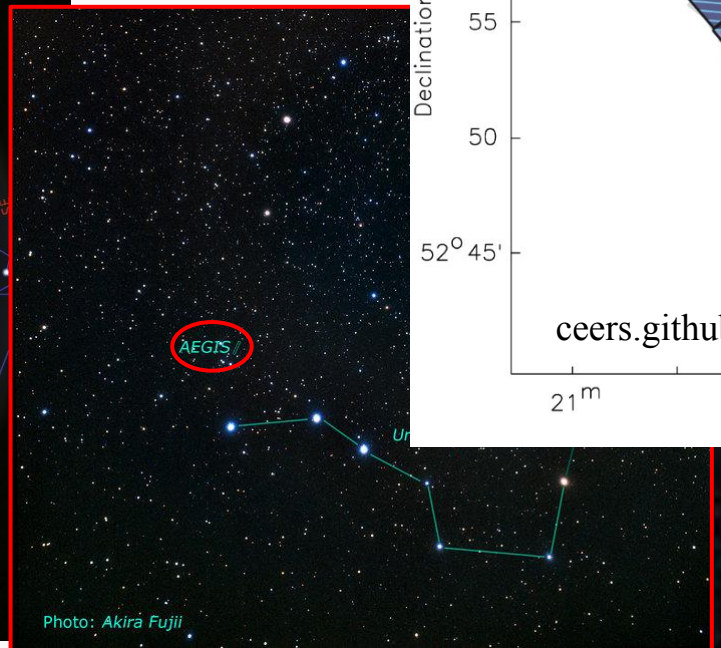
A bit more about AEGIS

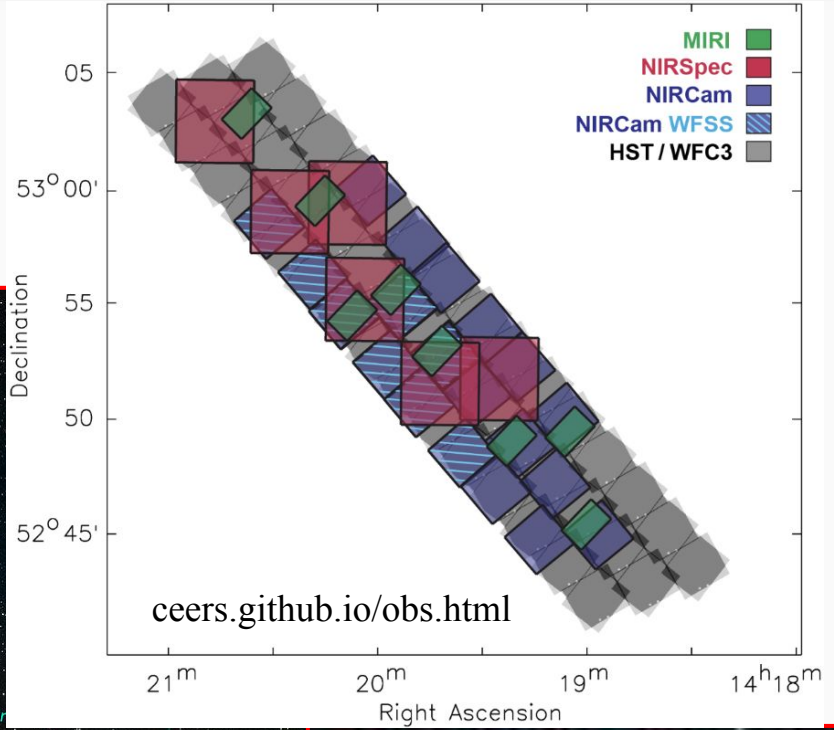
CEERS is a project focused on observing AEGIS field with JWST.

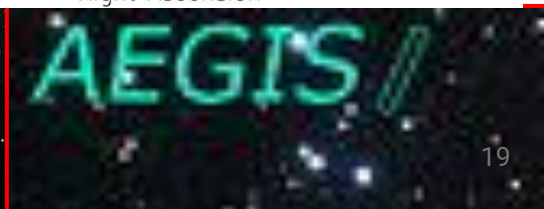


Current science focus – CEERS project

Thousands of high-redshift galaxies observed in plenty different wavelengths, now with great coverage in infrared!



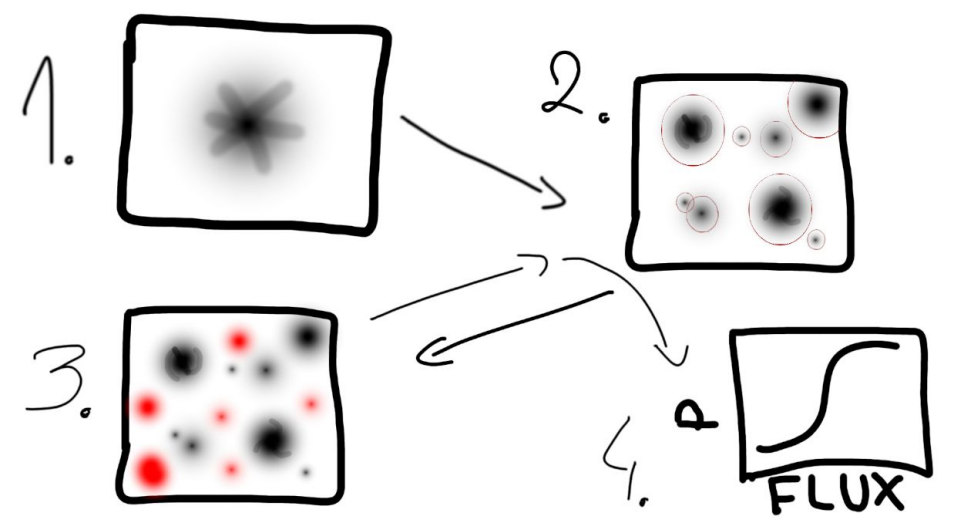




Data proccesing workflow

Once I've chosen the field, it was time for the most technical part of the project: data reduction. It is a multi-step analysis, which can differ depending on your needs in final catalog.

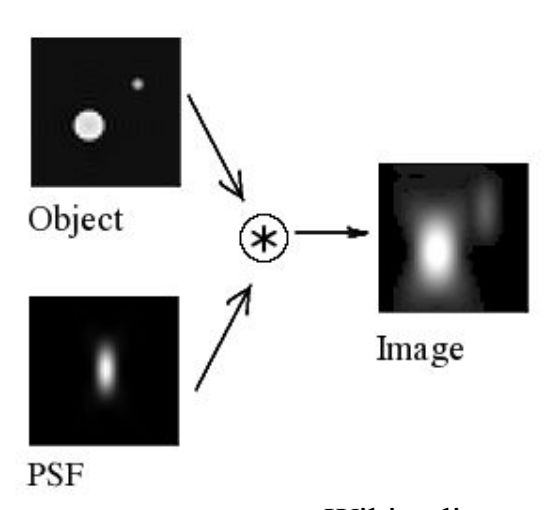
1. Point spread function analysis
2. Detection of real sources
3. Artificial sources analysis
4. Completeness study



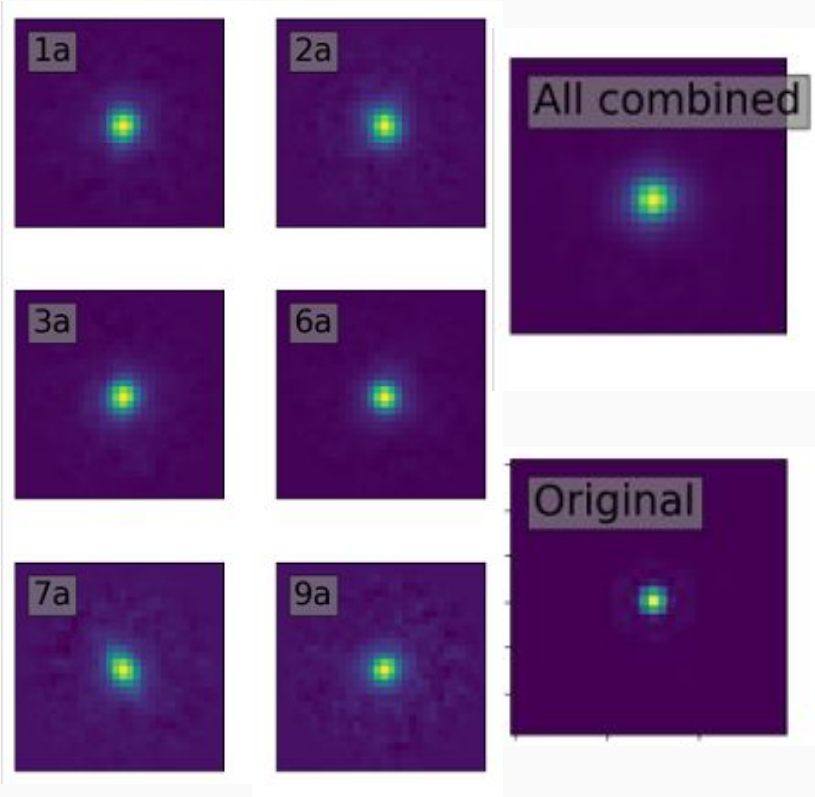
JWST/MIRI observation

Point spread function

PSF describes the response of the imaging system to the point source. For space observatories, we can calculate its model. But nothing is perfect!



Wikipedia.org

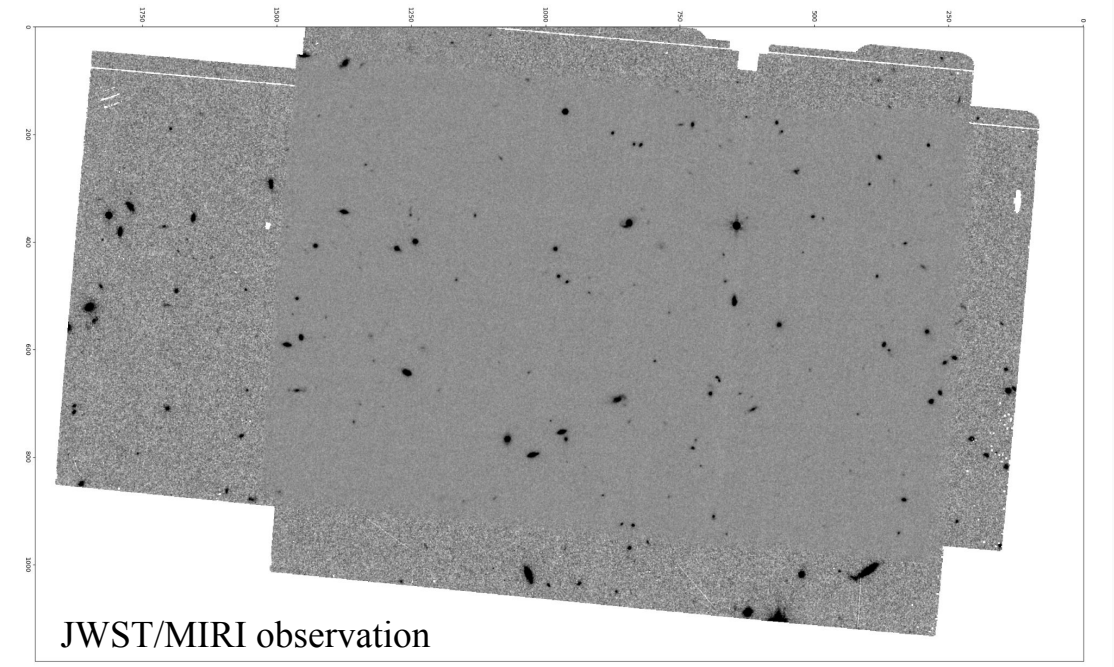


PSF extracted by me

Detection of sources

The images of the sky are not only beautiful, but also contain ridiculous amount of information.

Each blob here is one galaxy.
Question is how to find them?



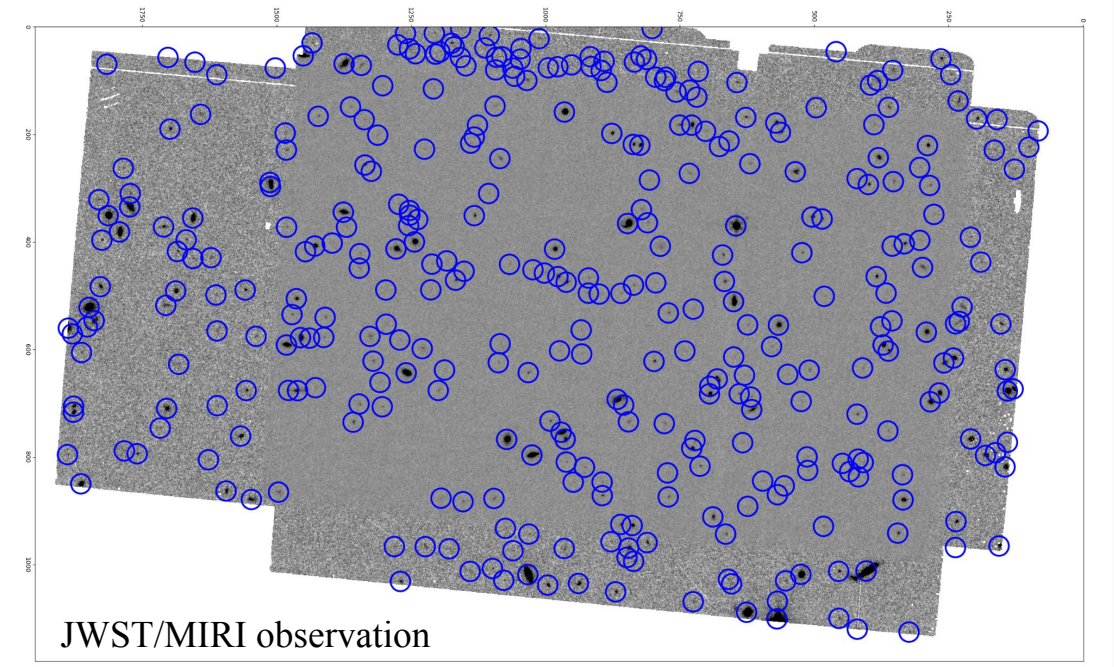
JWST/MIRI observation

Detection of sources

The images of the sky are not only beautiful, but also contain ridiculous amount of information.

Each blob here is one galaxy. Question is how to find them?

Just use some software (or write it yourself), which will find blobs!

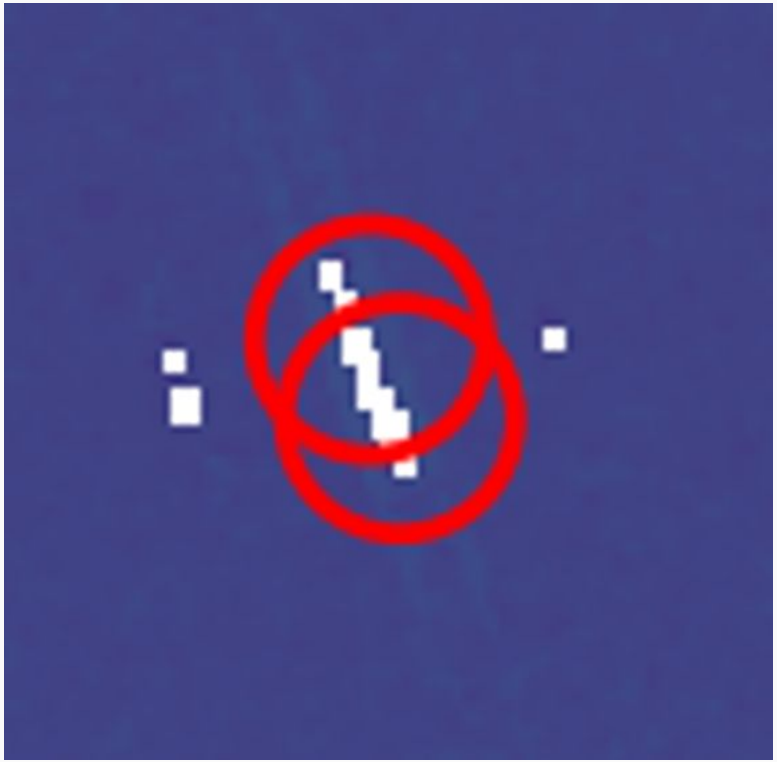


Can we trust everything software will give us?

Of course no!

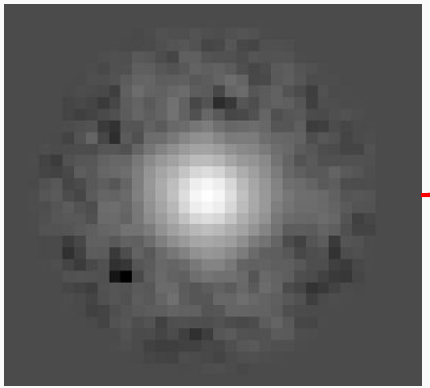
Not all blobs are galaxies, some are artifacts, mistakes etc.

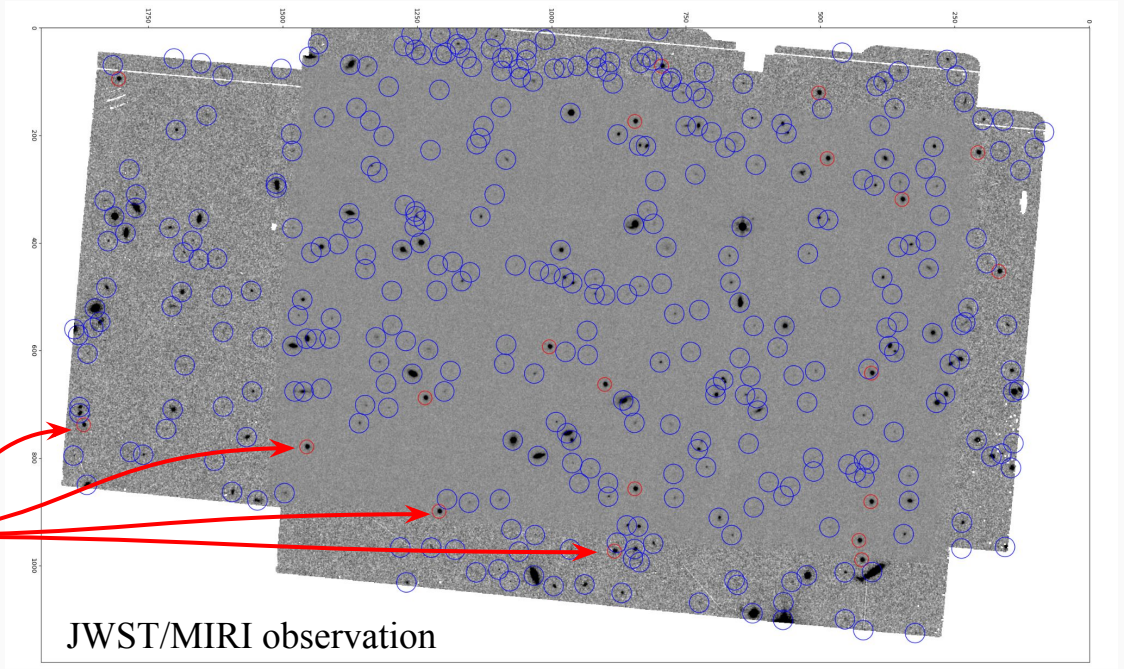
How to check which one we can trust?
We need to go deeper!



Introducing artificial sources!

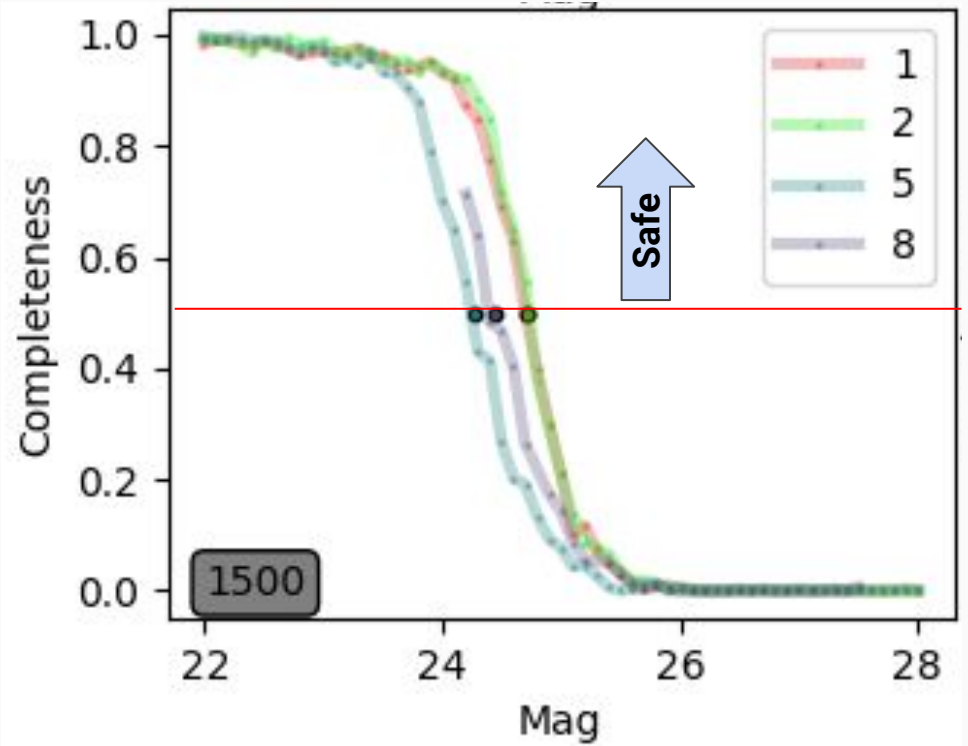
Using PSF and different fluxes I've built models of artificial galaxies. Then randomly placed them on non-overlapping positions on the image and tried to detect them… over and over again.





Completeness calculation

Completeness is a distribution showing what is the probability of observing a source of a given brightness in our image. In other words, how many of galaxies will be visible above the noise.



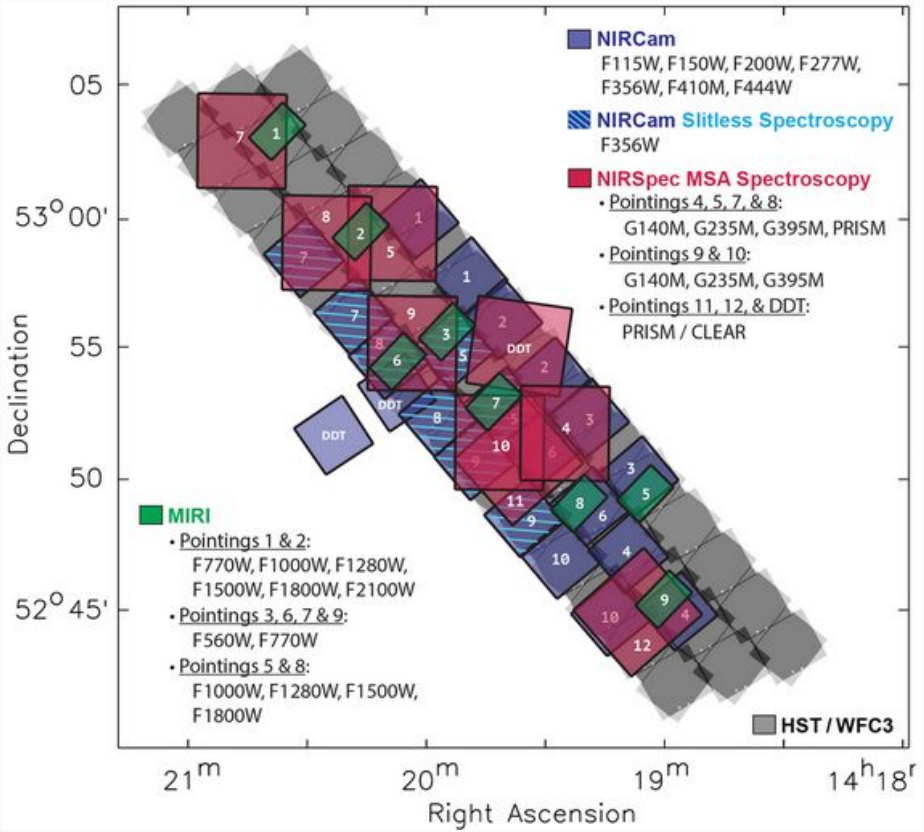
Final catalog of MIRI detected galaxies

Finally, I have the complete, analysis-ready, catalog of ~7,000 galaxies detected in MIRI within CEERS project!

Connecting with other catalogs

Other important observations

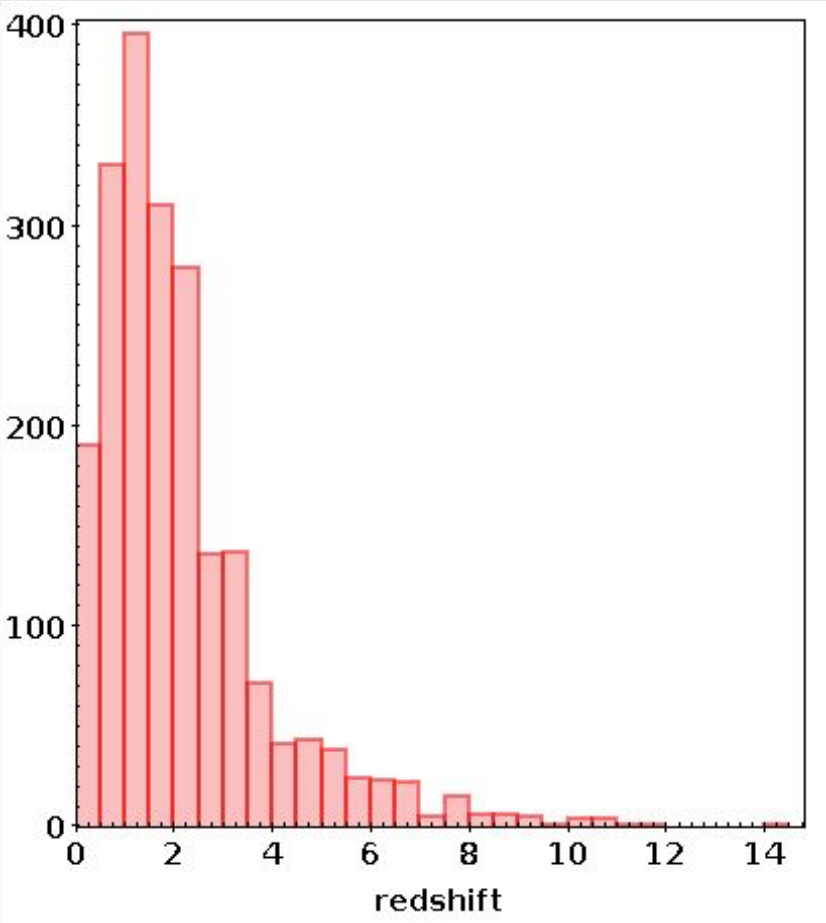
MIRI is not the only instrument, which observed the EGS field. The most interesting ones for this projects are JWST/NIRCam and Hubble Space Telescope. All three together cover optical to MIR observed wavelengths.



Merlin 2024 catalog

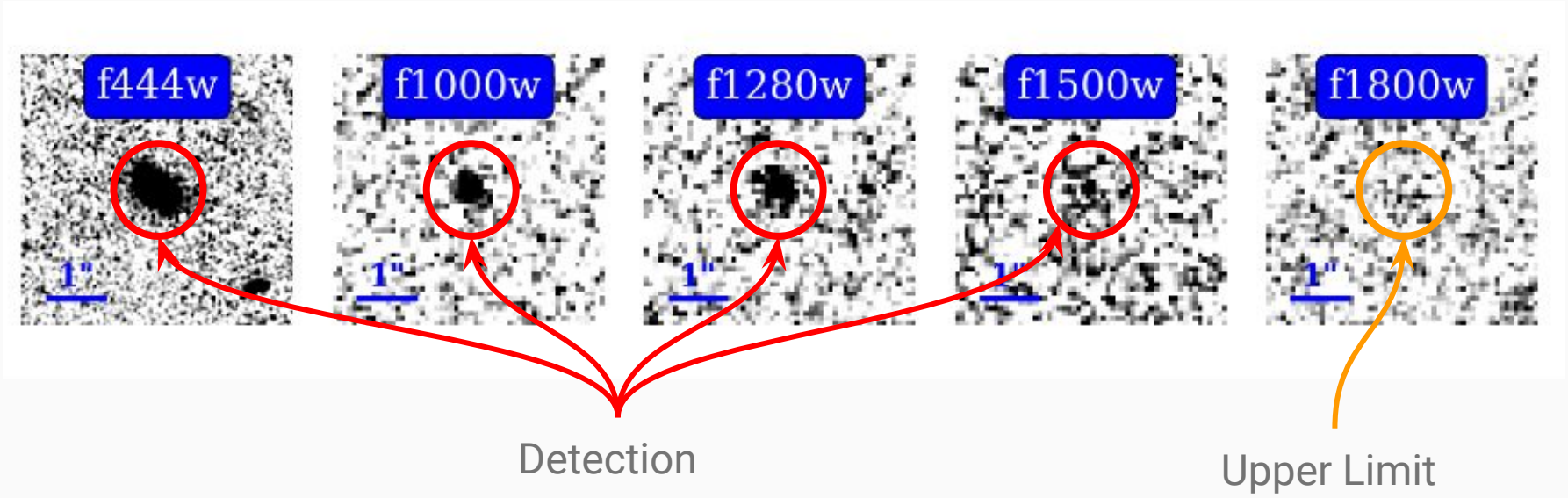
Similar analysis of detecting sources was presented in paper Merlin+24. Authors studied the same field but with HST and NIRCam observations!

Finding counterparts in both, my and Merlin's, catalogs I have ~2,000 sources.



No detection – still an information!

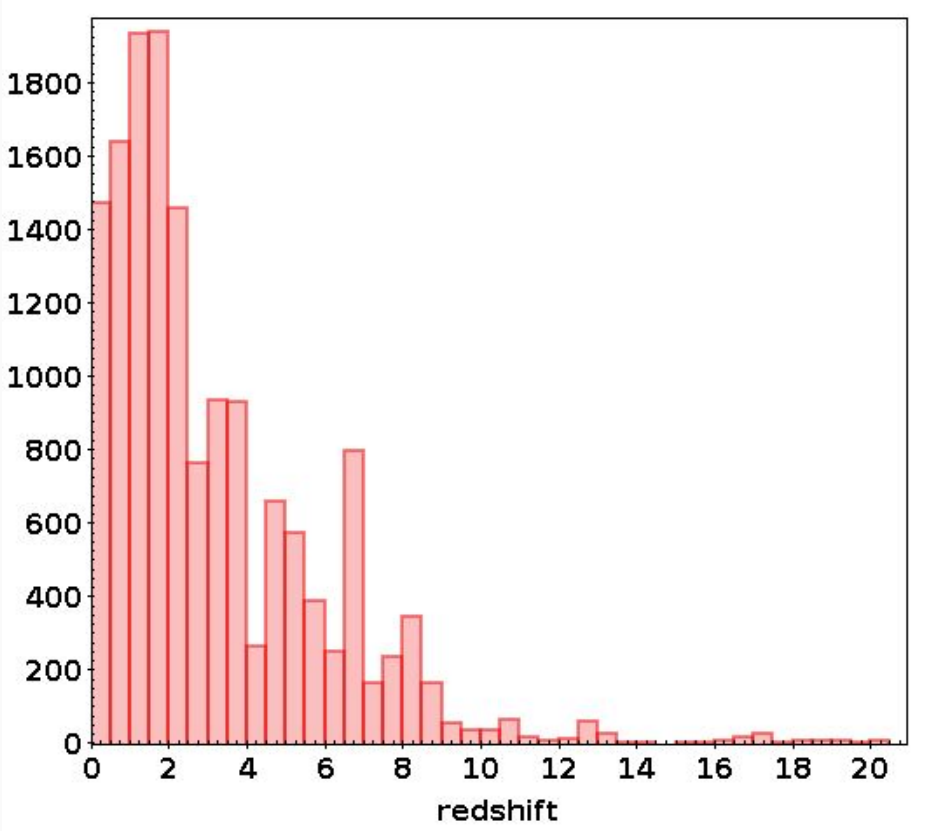
But, for the remaining sources in Merlin's catalog, I checked if they should be observed by MIRI. Upper limits are also important! We can use them to limit the models for our galaxies!



Final Final catalog of interesting (for me) sources

After including upper limits, I have a catalog of fluxes (optical, NIR and MIR) for ~15,000 sources.

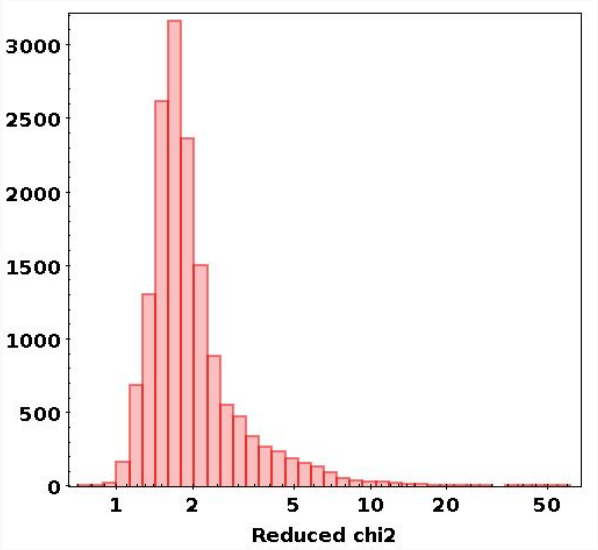
15% of them have direct observations in MIR, the rest, upper limits!

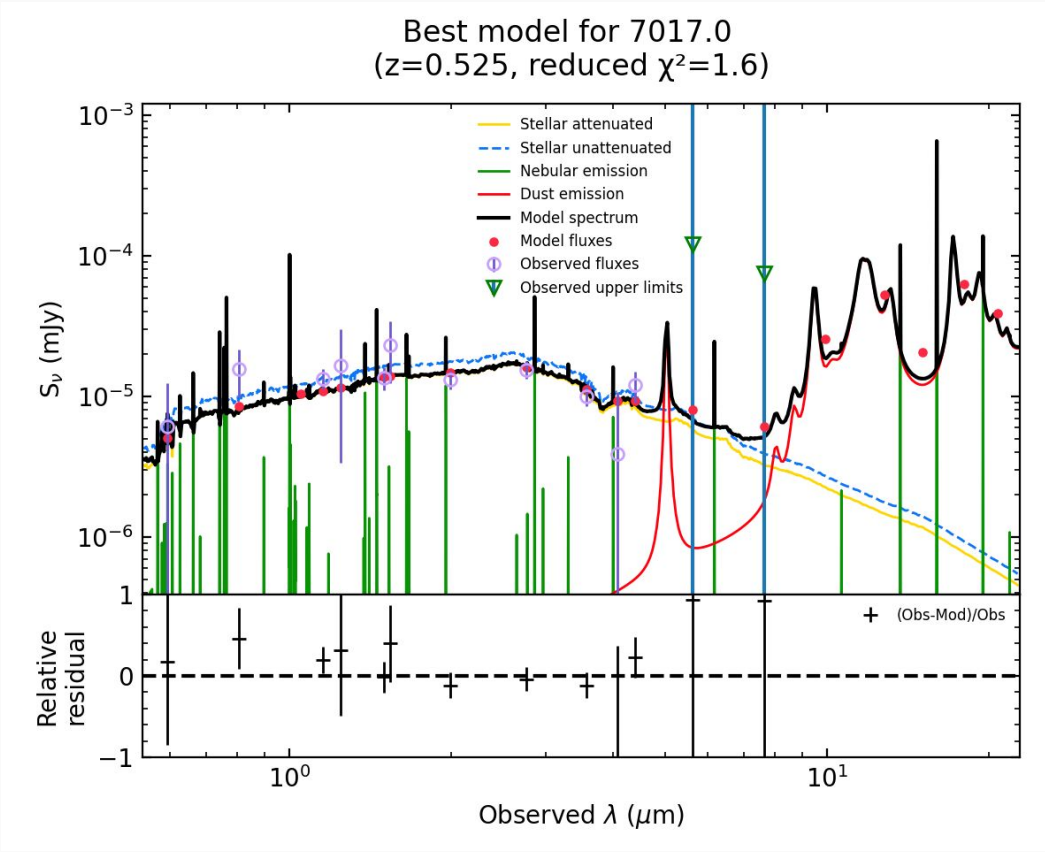


Data analysis

CEERS galaxies SED modelling

I fitted the SED for all ~15,000 galaxies from my catalog. It allows me to estimate the physical properties.

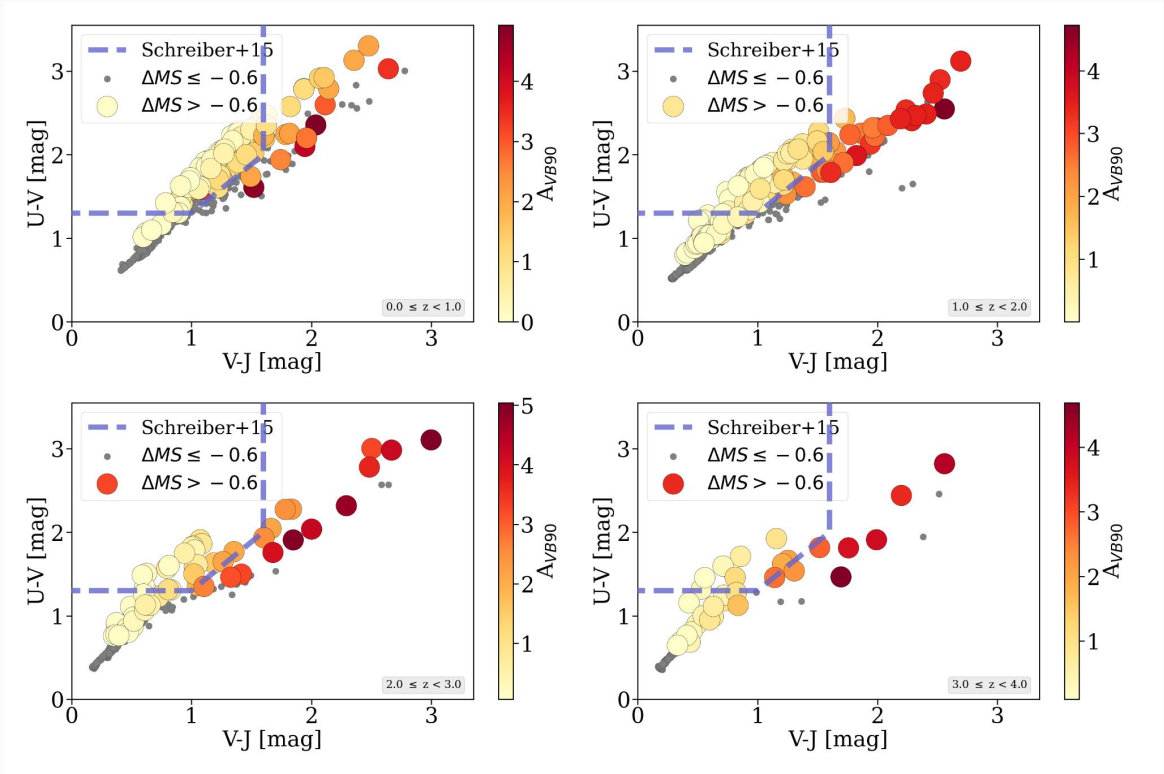




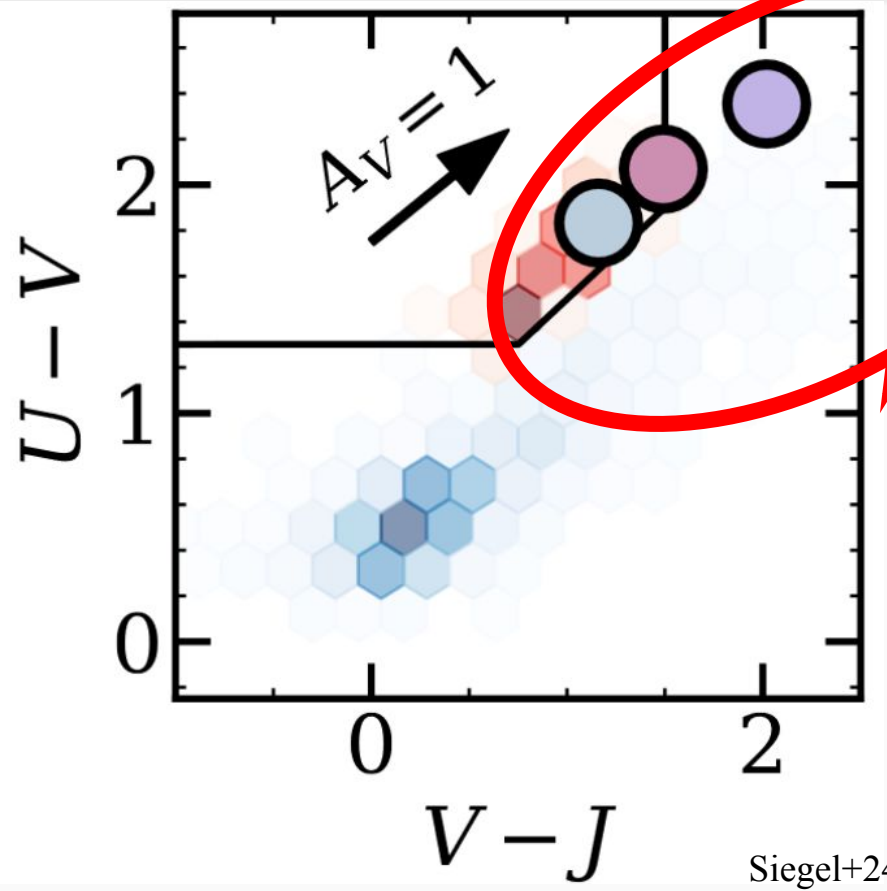
Exemplary SED of one of the galaxies in my catalog

CEERS galaxies SED modelling

I found ~400 galaxies far below the main sequence (QGs). Despite being passive, they show a variety of dust attenuation, which implicates some of them indeed have dust reservoirs!



Comparison to other results



Siegel+24

My sources with non negligible dust attenuation populate this part of the UVJ plane!

Summary

Results so far

- I prepared detailed analysis of CEERS JWST/MIRI fields including PSF modelling and studying completeness
- I prepared the analysis-ready JWST/MIRI catalog
- I cross-matched it with other catalogs, including JWST/NIRCam and Hubble Space Telescope, having in total ~15,000 sources with detection in NIRCam and at least an upper limits in MIRI
- SED fitting shows ~100 of quiescent galaxies with non negligible dust attenuation!

Future goals

- Only few papers show QGs at high-z and we still lack the ISM-quenching explanation! I want to help answer that question!
- Refine the SED fitting and test the influence of SED components, especially star formation history onto ISM models in quiescent galaxies
- Use the available spectroscopic data to confirm results of the SED modeling
- Develop the new analysis approach based on spectra-photometric analysis of near-infrared and mid-infrared data collected with NIRCam, NIRSpec and MIRI

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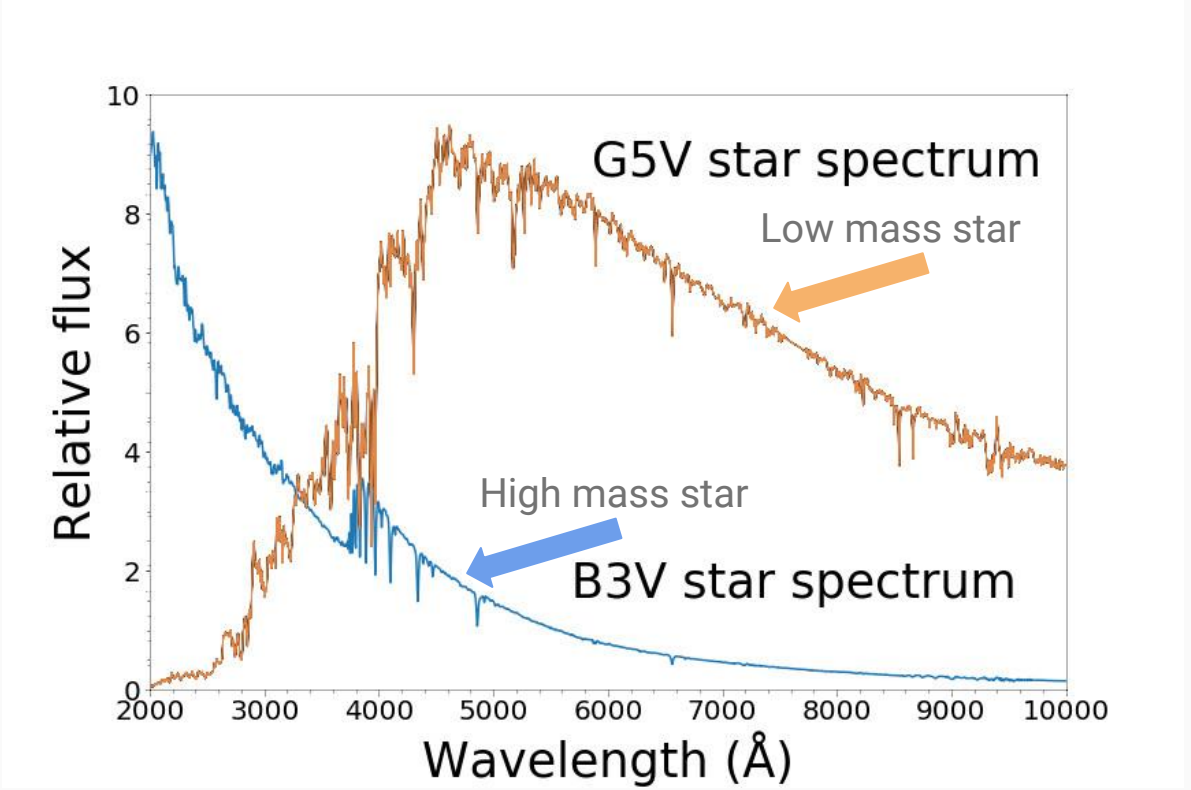
Thank you for attention!

Color – the quick indicator of star formation

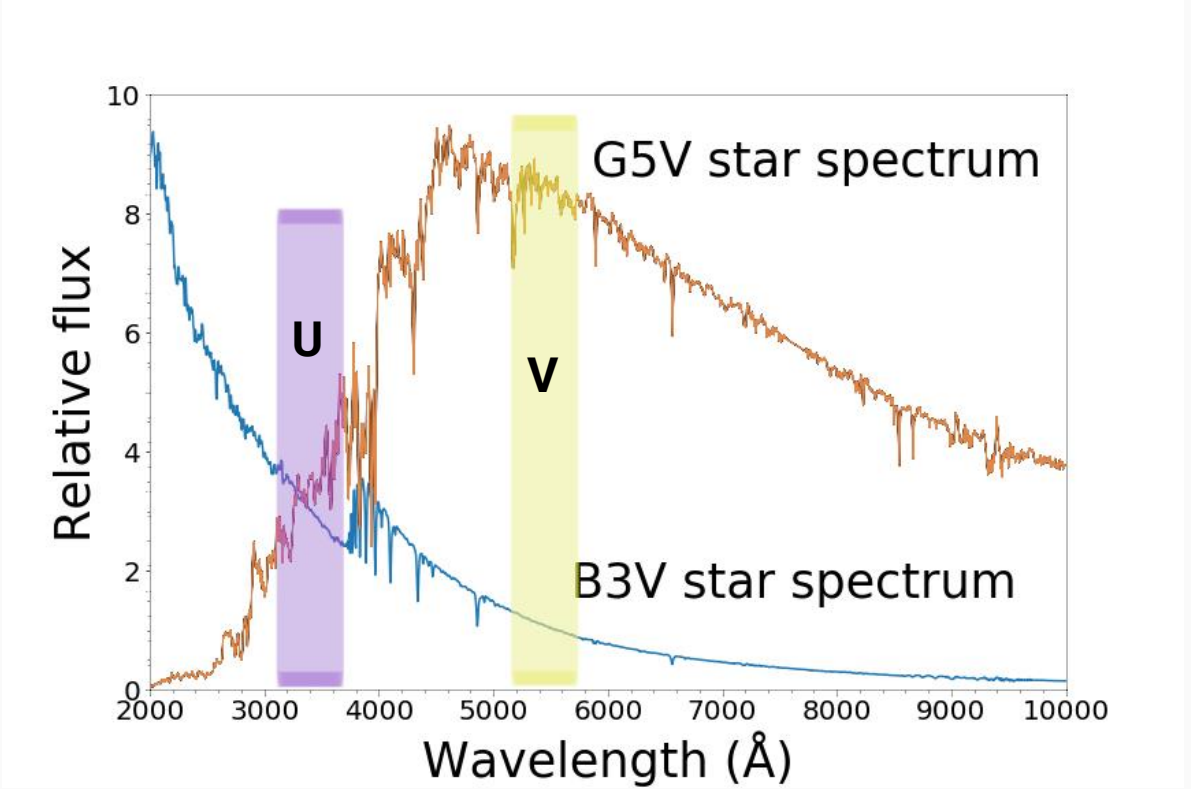
1. Massive stars live short, low mass stars live long.
2. If the galaxy has low starformation rate massive stars die first.
3. Low mass stars are **redder** than the high mass ones.



Color – the quick indicator of star formation

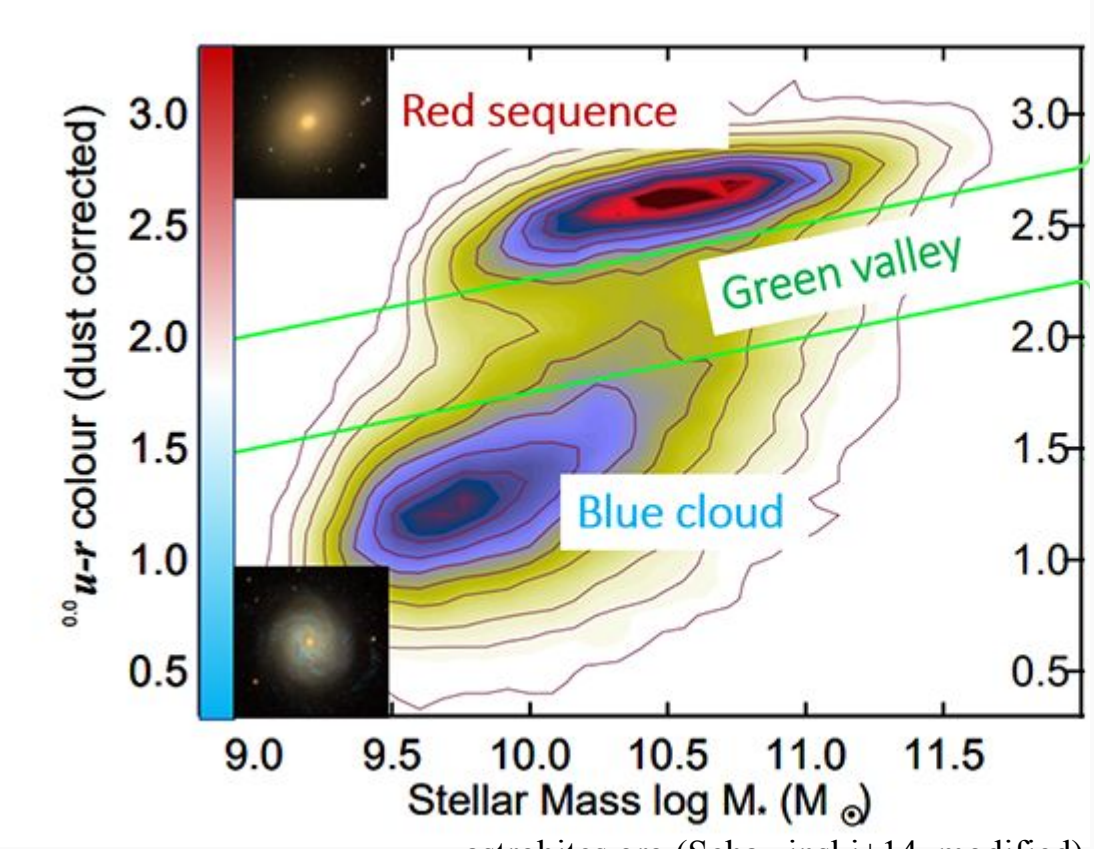
So we can just observe a star, or many stars (their sum of emissions) in two filters and find out which is quiescent.

The difference of fluxes in two different observed bands is what we call color in astronomy.



Color – the quick indicator of star formation

Studies show there is a strong bimodality in color of galaxies correlated with their starformation, but…

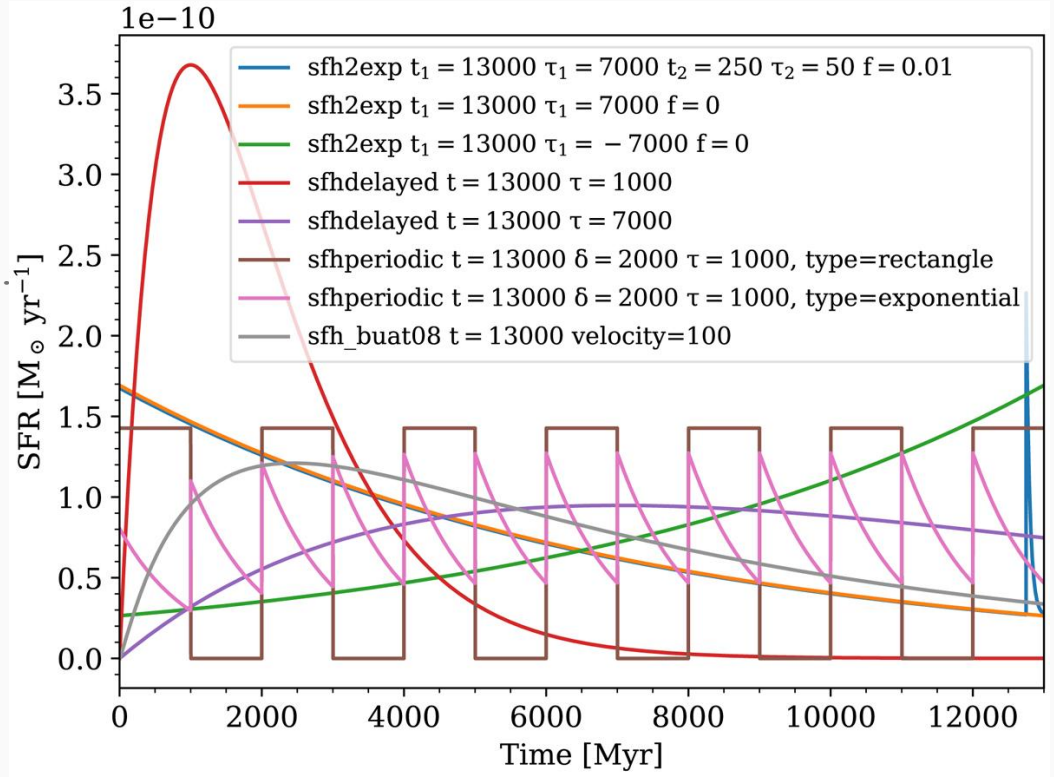


astrobites.org (Schawinski+14, modified)

Next step

But this process is time consuming and the results are model-dependent…

The component, which is currently suspected to be the most influential onto results is starformation history.



Boquien+2019