Dust:
The Enigma Within Galaxies

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About Me

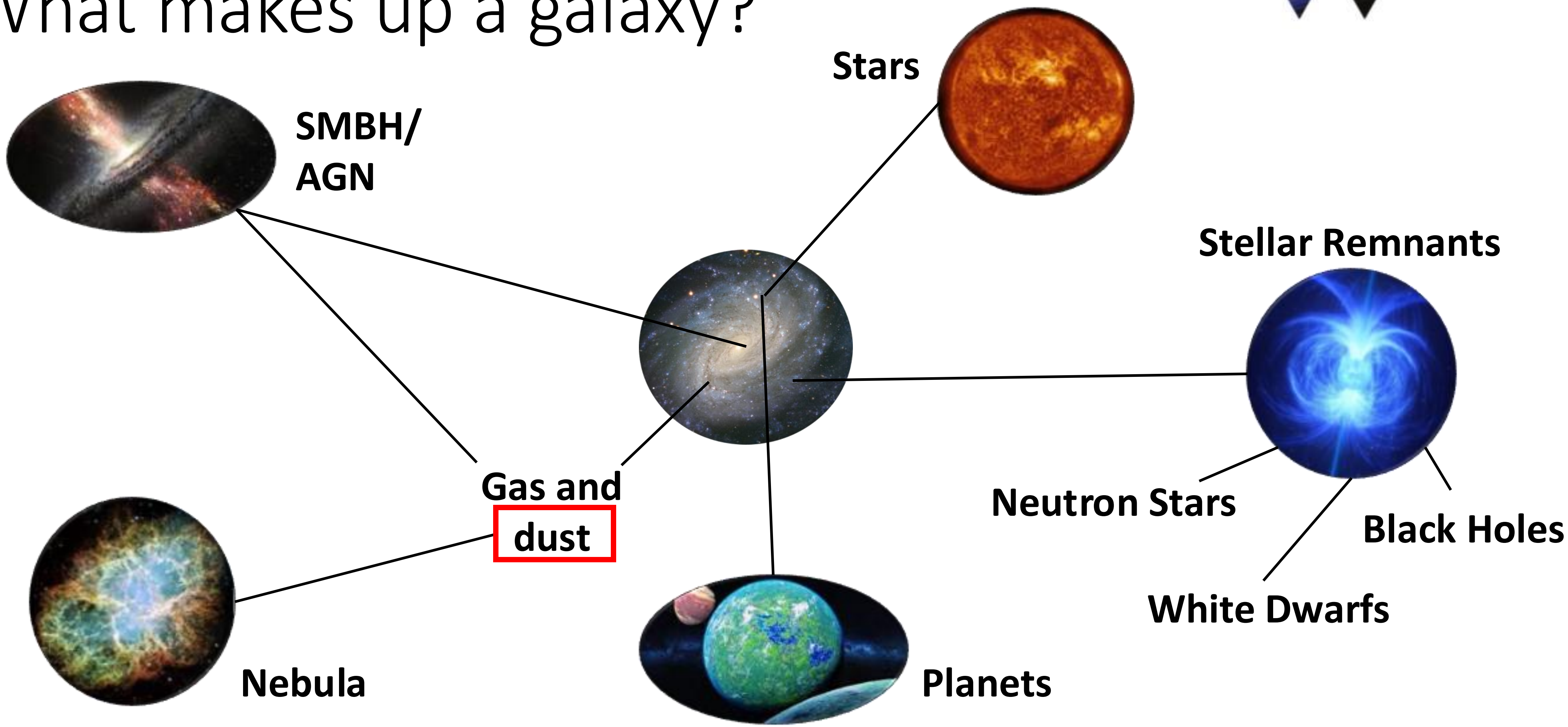
- Fourth year PhD student in the Astronomy & Astrophysics group
- Completed integrated Masters undergraduate at Warwick
- Research interests:
  - Galaxy formation and evolution
  - Dust and its properties
  - Stellar population synthesis models

Talk Layout

- Cosmic Dust: What is it and why does it matter?
- How to Observe Dust
- Modelling Galaxy Populations
- The Difficulties of Observing Dust
- The Future

Cosmic Dust:
What is it and why does it matter?

What makes up a galaxy?

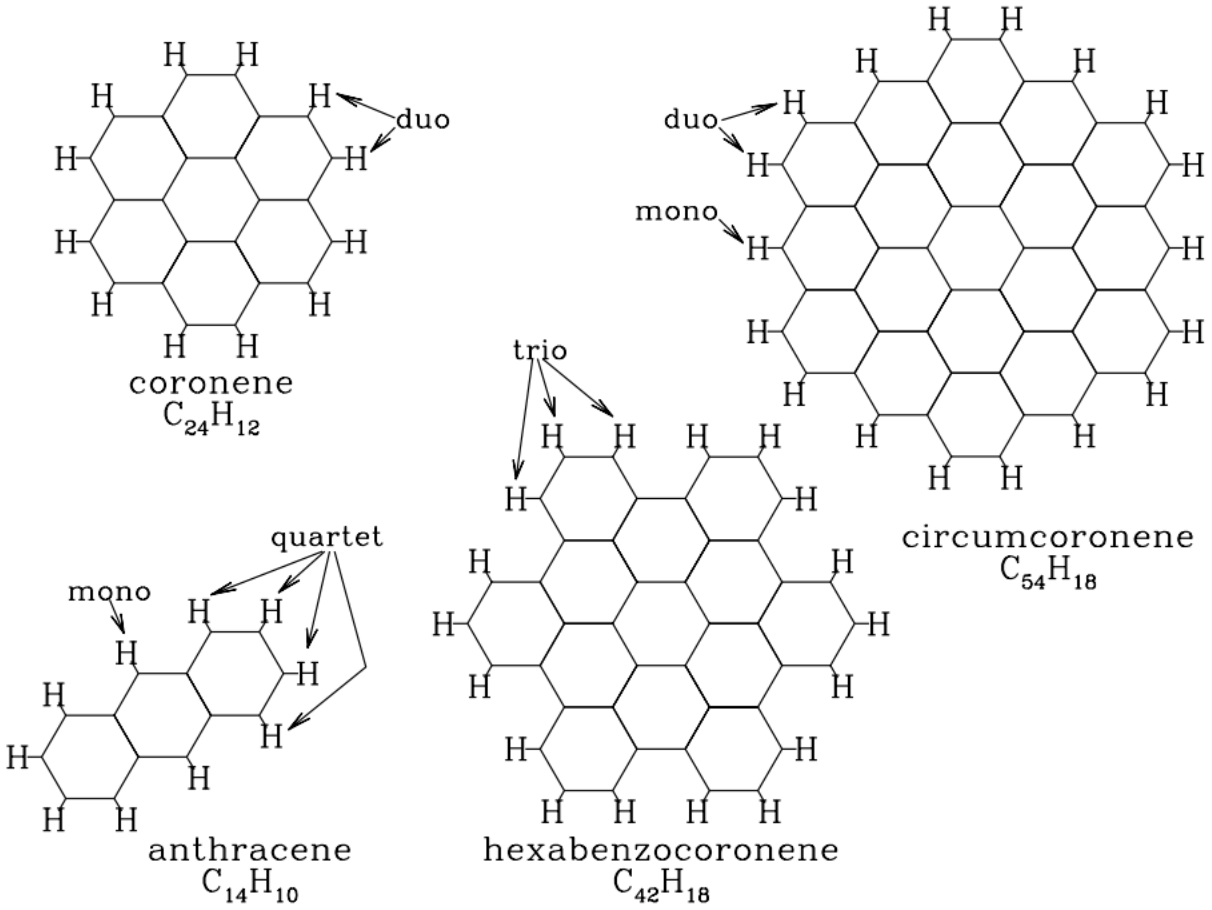


What is dust?

Dust is small grains found in discs, the interstellar medium and the intergalactic medium

Small molecules of a few Angstroms (i.e. containing tens of atoms) up to a couple of microns

Made from silicates and carbonaceous material



Draine et al. (2003)

Why should we care about dust?

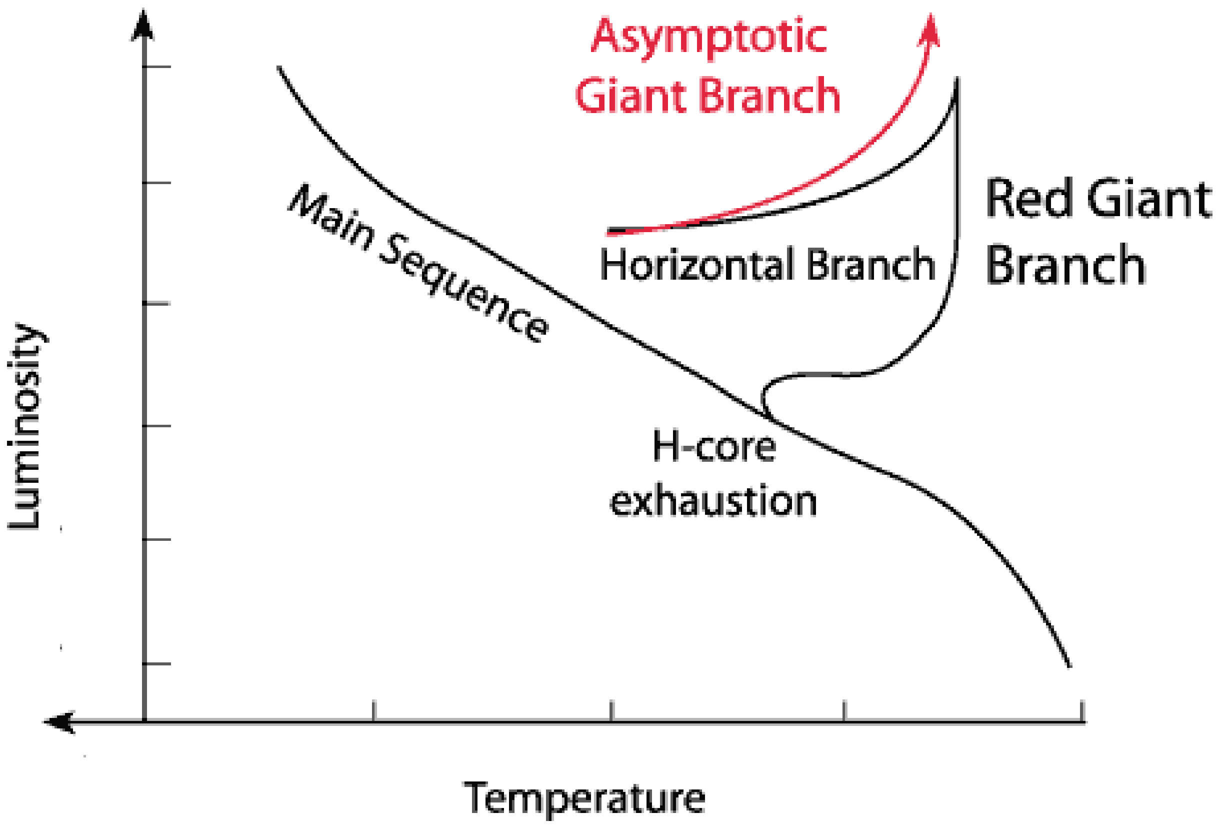
Dust has several vital roles within galaxies affecting its evolution:

- Provides a surface for chemical reactions, acting as a catalyst
- Cooling of the ISM, facilitating the gravitation collapse
- Regulates star formation
- Influences galactic dynamics
- Reprocesses light through absorption, scattering and reemission
- Modifies the spectra of stars and galaxies

Where does this dust come from?

Two main sources:

- Asymptotic giant branch stars
- Supernova



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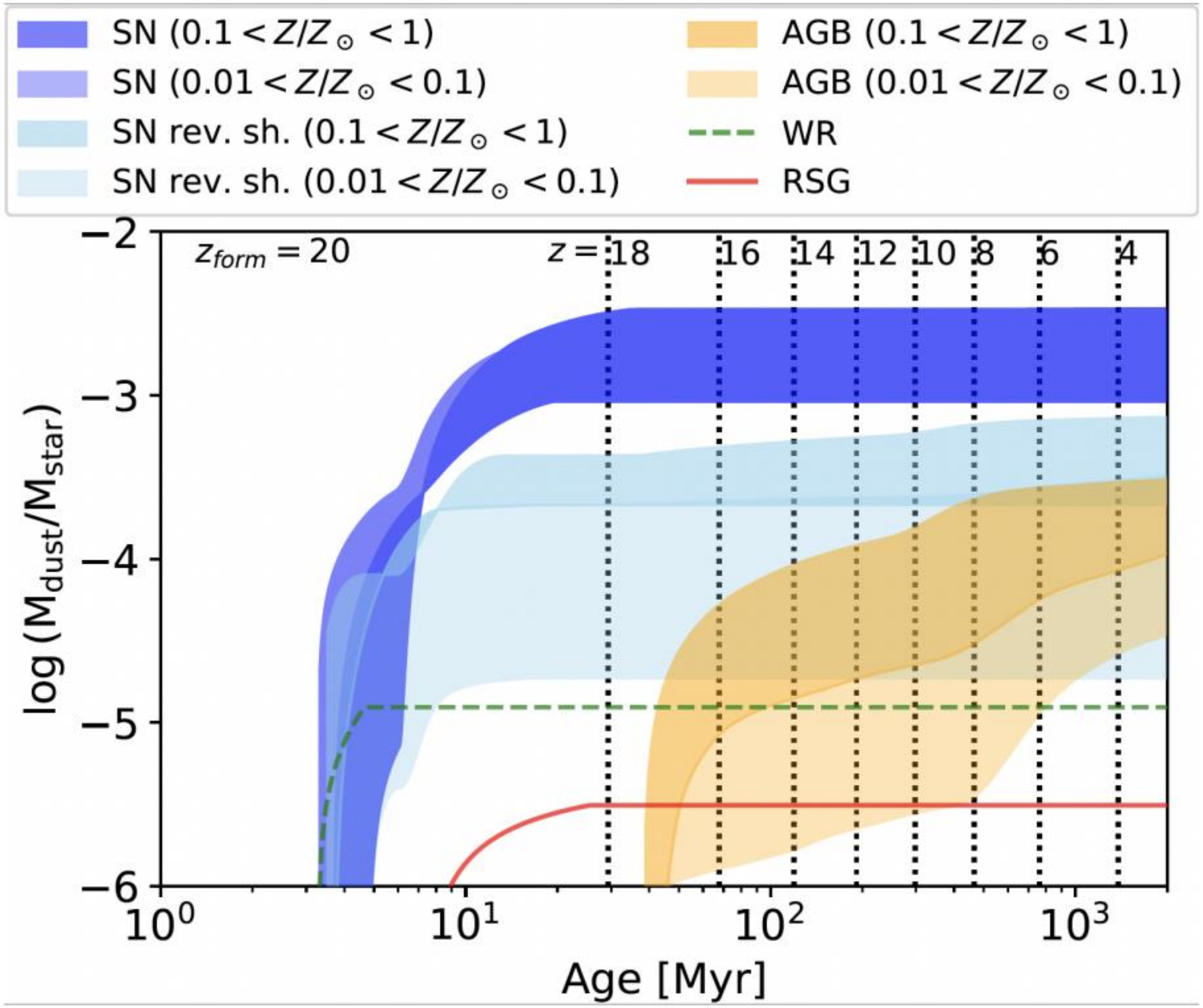


Schneider and Maiolino (2003)

Reprocessing of dust

Dust experiences significant reprocessing once it has been released into the interstellar medium. This affects dust masses and grain size distributions.

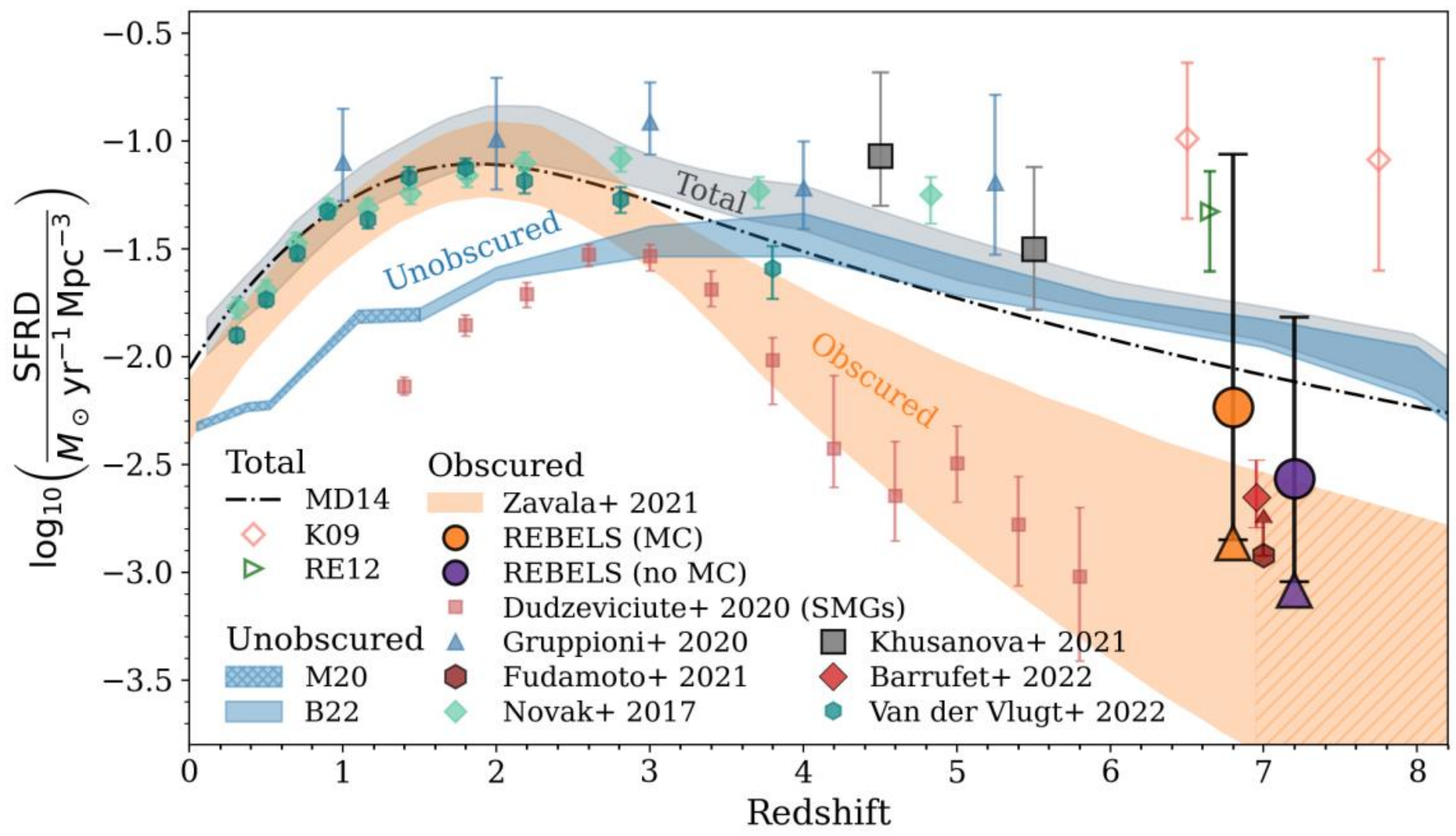
- Astration (incorporation into newly formed stars)
- Thermal or kinetic sputtering when hit by supernovae shocks
- Grain growth from gas accretion
- Grain shattering and fragmentation

Cosmic Star Formation Rate Density History

Tracks the rate at which stars formed over cosmic history

UV traces star formation, but is heavily attenuated by dust

Need to correct for dust to get total SFRD



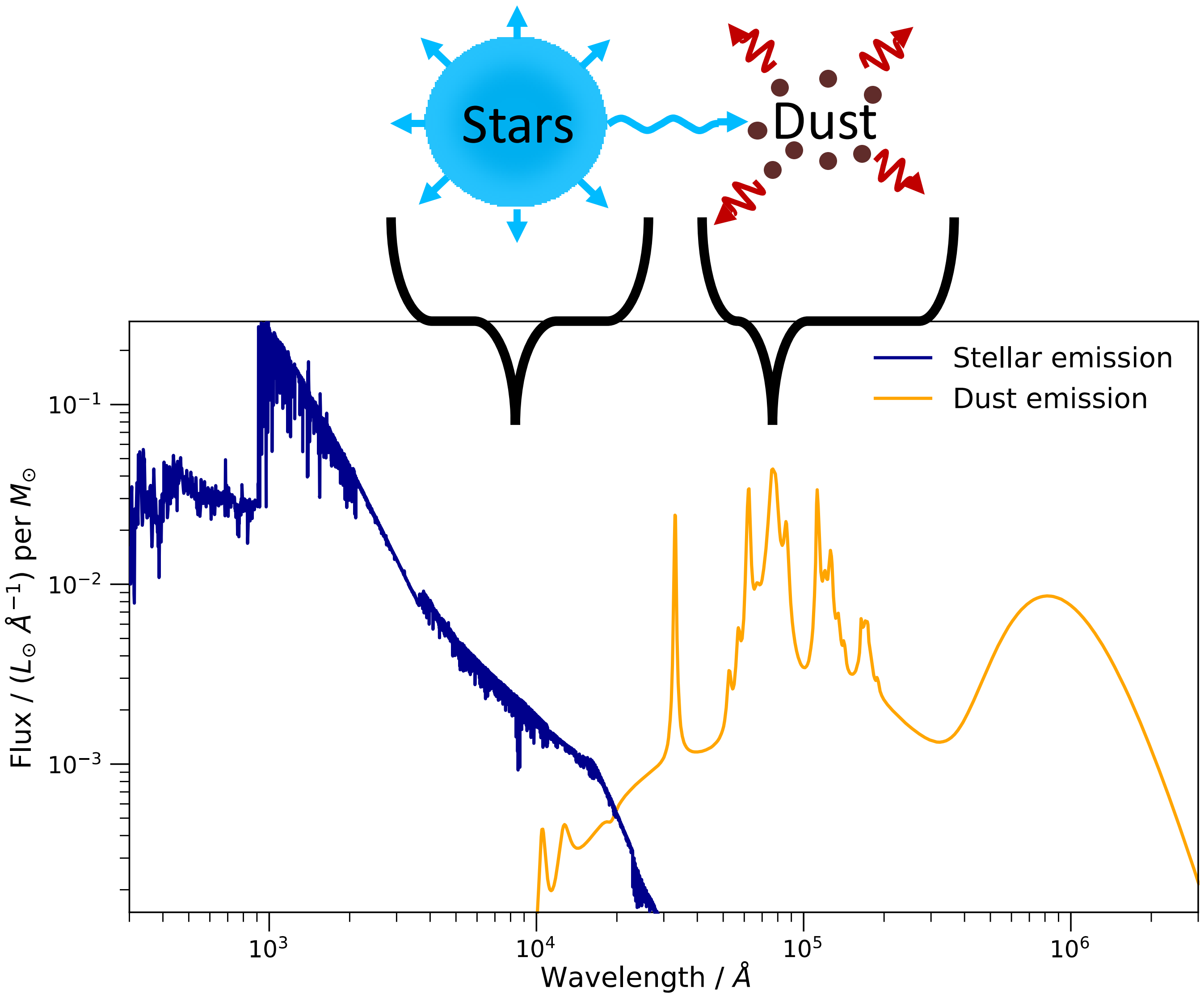
Algera et al. (2022)

How to Observe Dust

Stars as a heating source

Stars act as the main heating source for dust

Dust emission dominates in the infrared and can be observed independently of the stellar emission



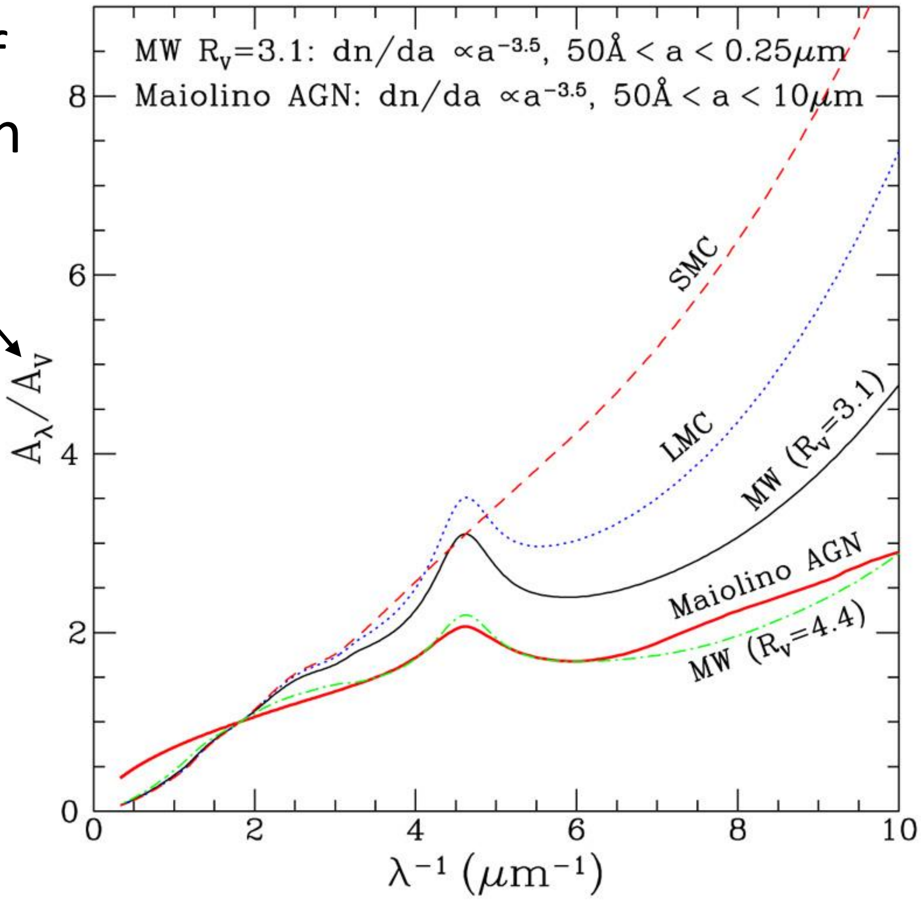
Attenuation of starlight

Li (2007)

Dust causes more attenuation of shorter wavelength radiation

UV-luminous/star forming galaxies will therefore have more dust emission

Relative amount of attenuation

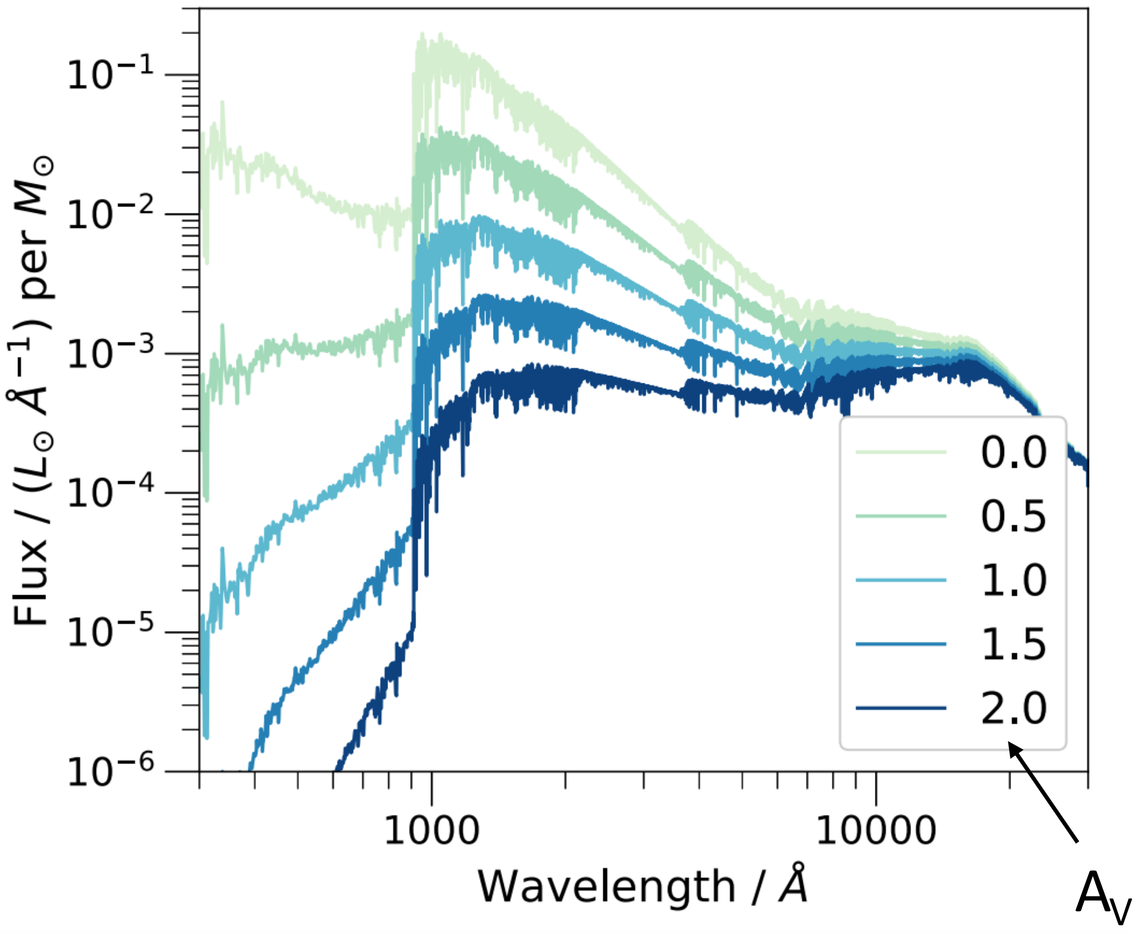


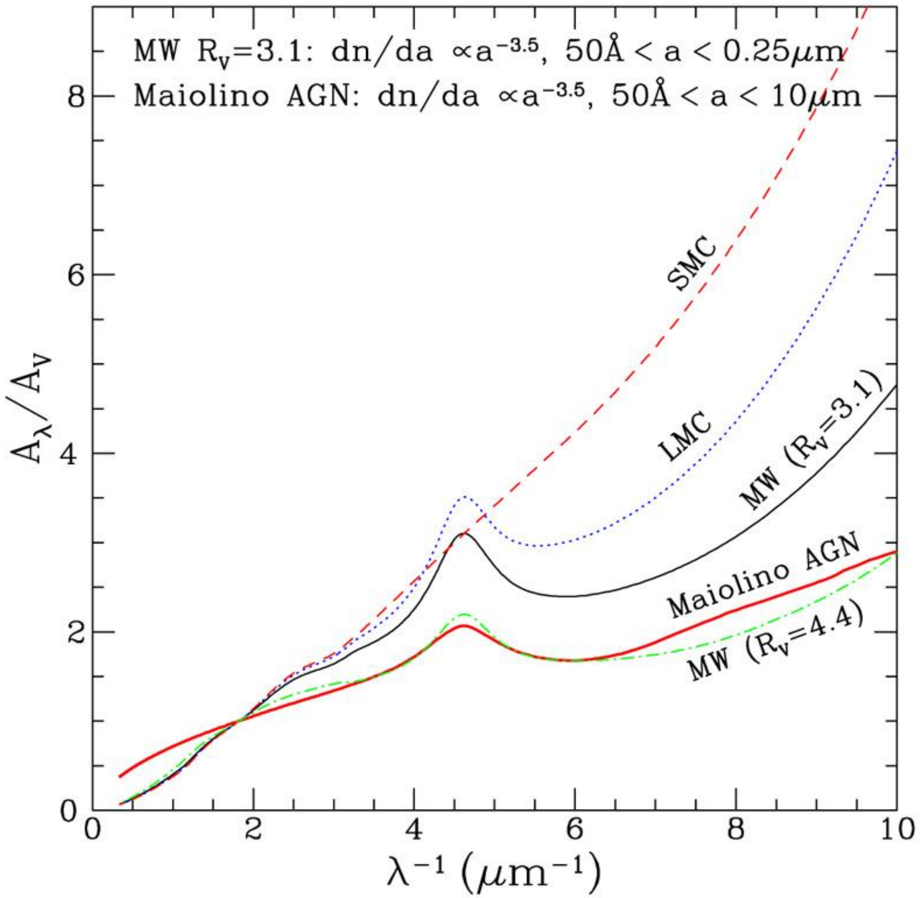
Red light

Blue light

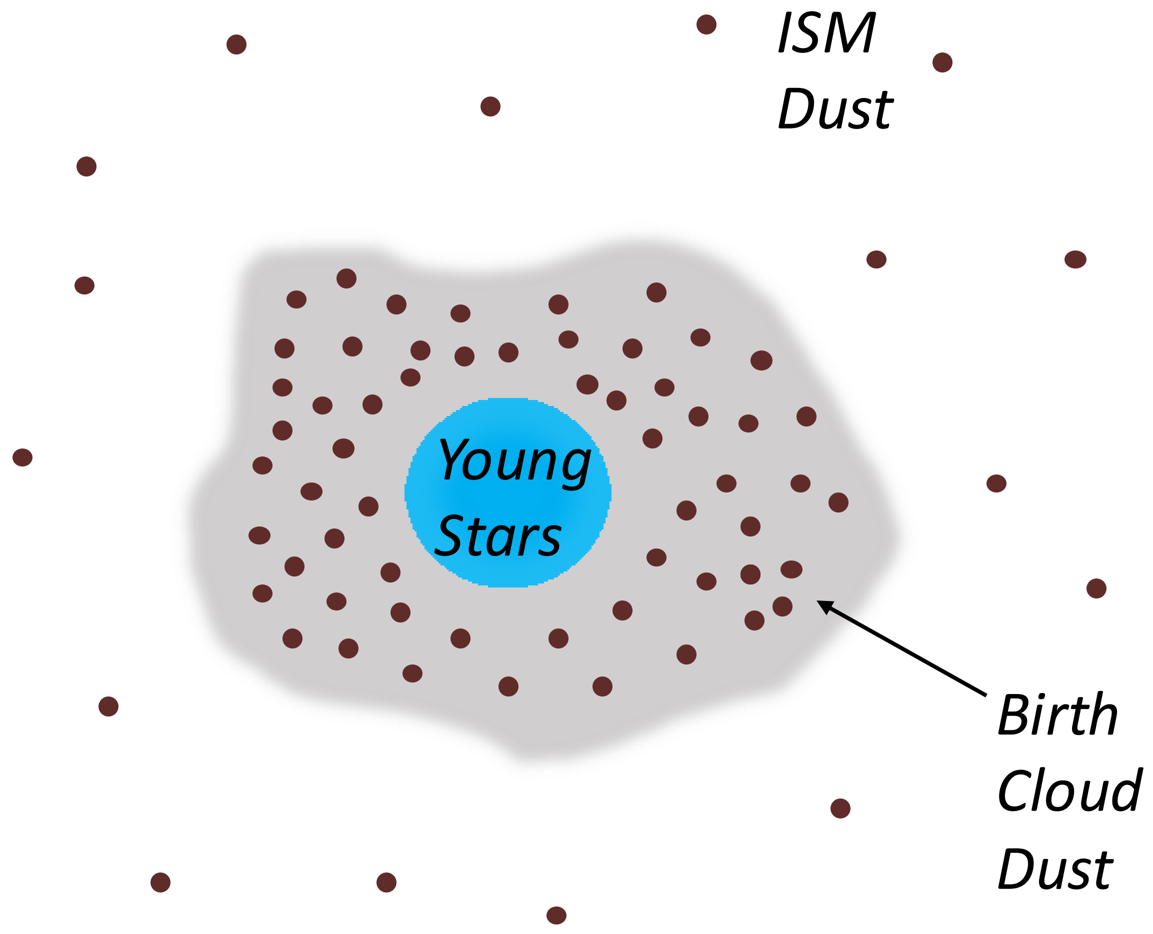
Attenuation of starlight

Li (2007)





Birth clouds



Stars are born with clouds; denser regions of gas and dust

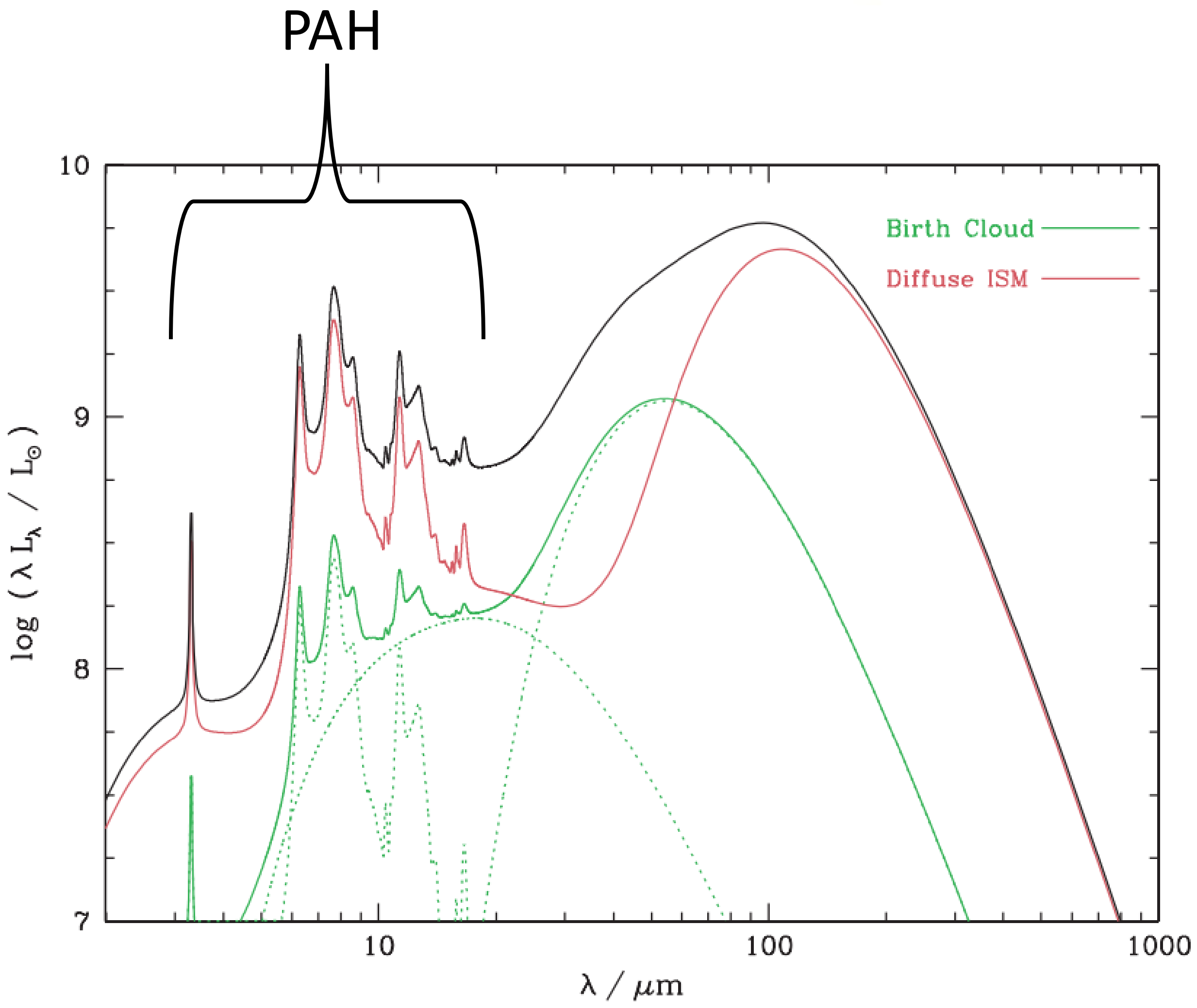
These birth clouds dissipate on the timescale of a few Myr

The increased density thus causes increased attenuation of the starlight from young stars

Dust emission

Dust re-radiates energy at infrared wavelengths (1 – 1000 microns), with two characteristic features:

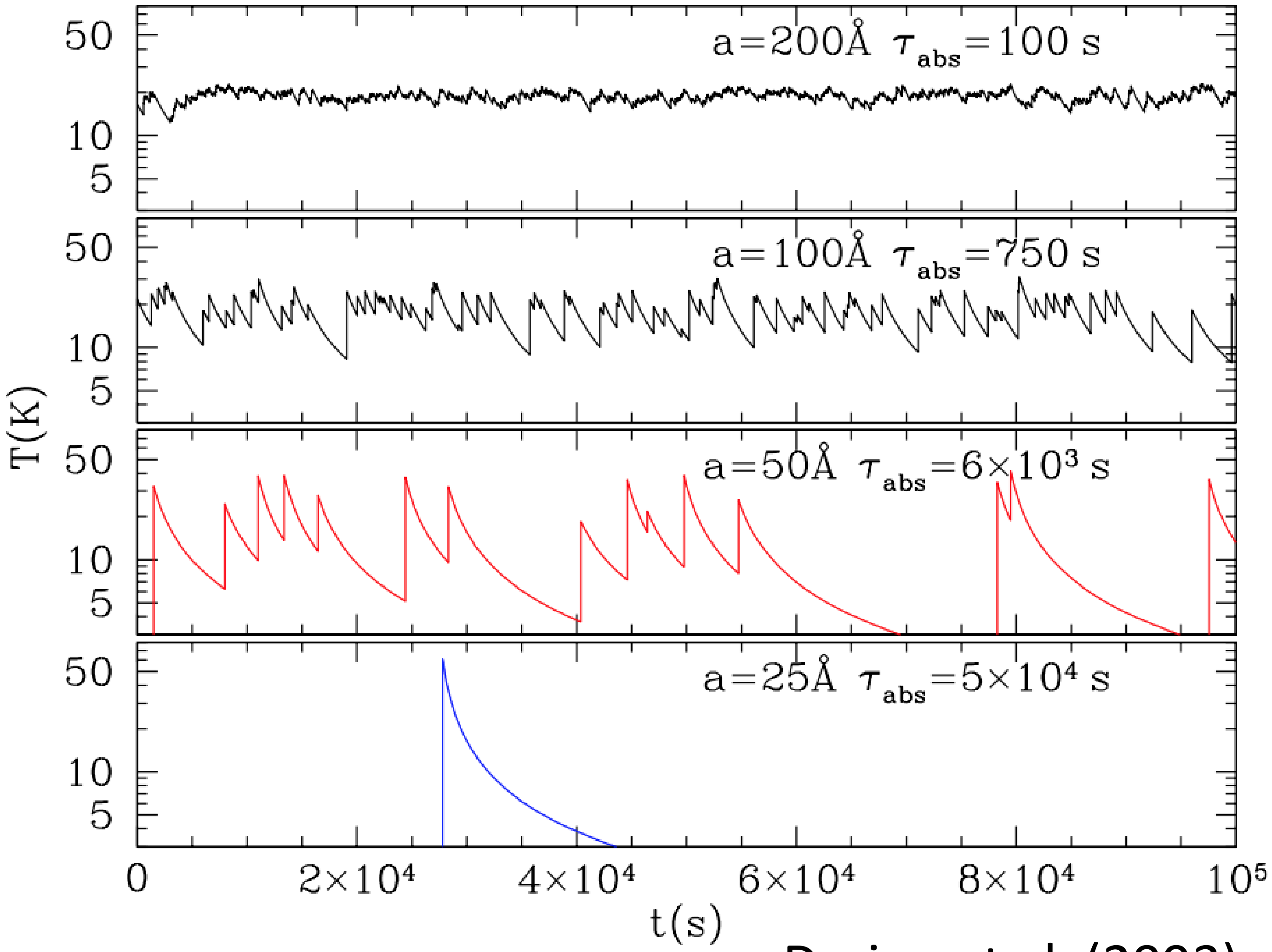
- Thermal, blackbody-like continuum emission
- Polycyclic aromatic hydrocarbon (PAH) emission



da Cunha et al. (2008)

Cooling timescales

Dust cools very efficiently (on order of minutes to hours) so needs a constant heating source

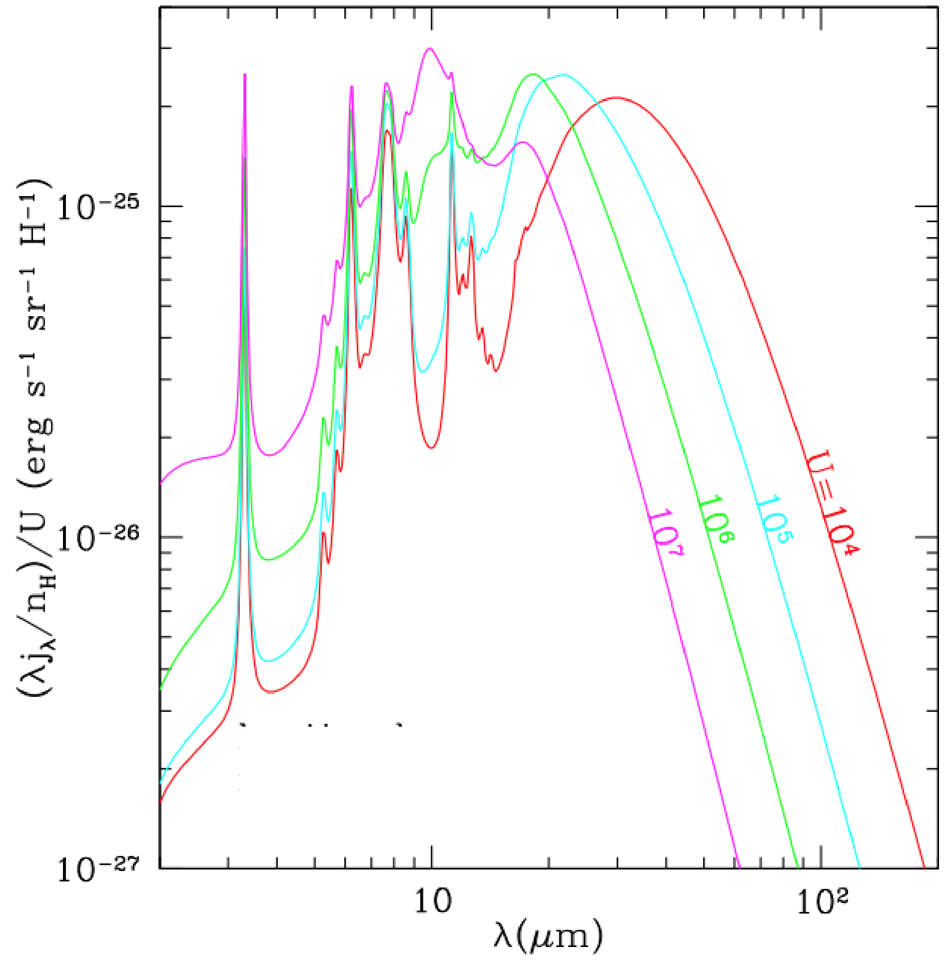


Draine et al. (2003)

How important is the heating source?

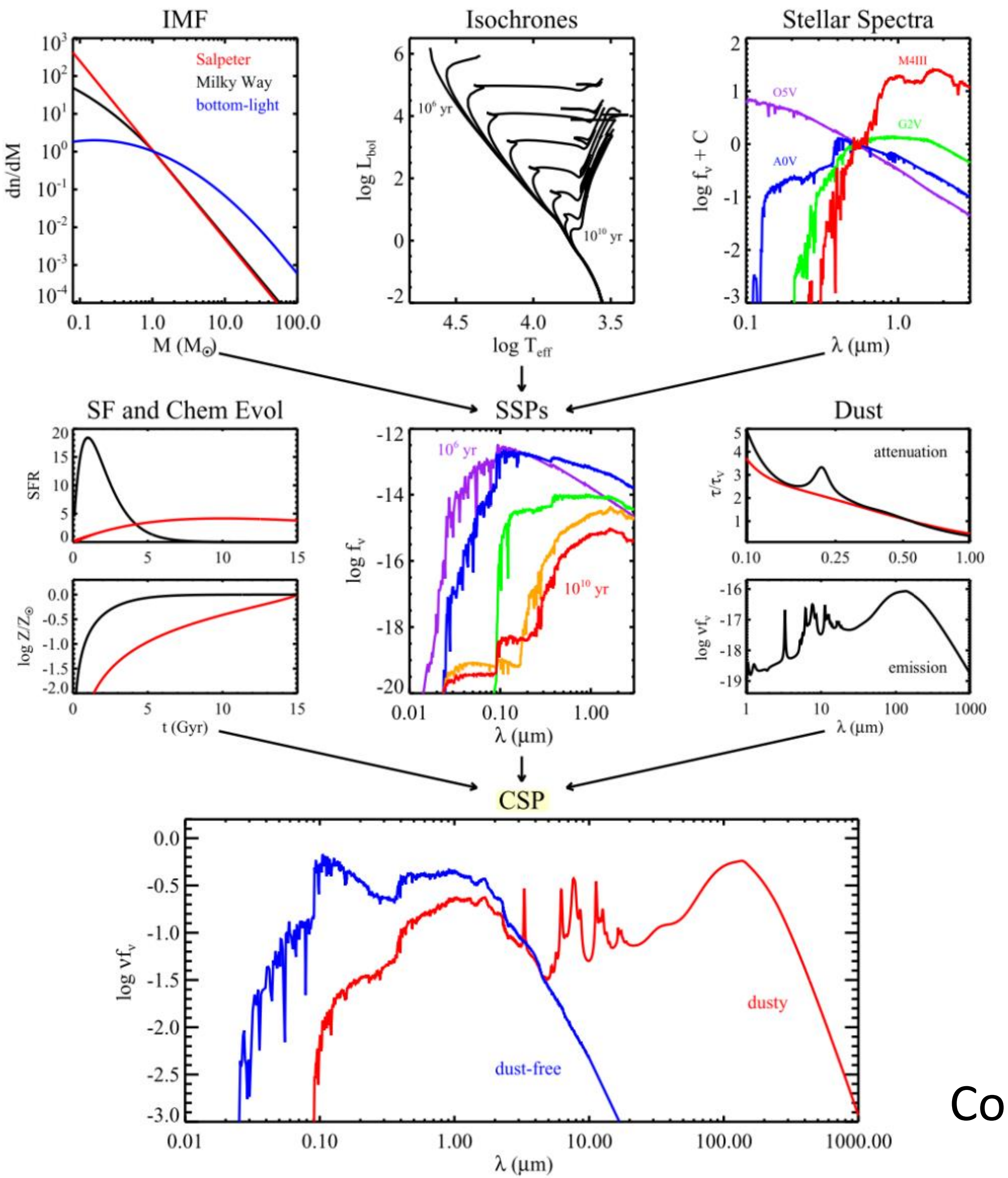
Since dust gains more energy from blue light, sources dominant in the UV generate more dust emission (i.e. young stars)

The hardness of the ionising source will affect the shape of the emission



Draine et al. (2021)

Modelling Galactic Populations



Stellar Population Synthesis Models

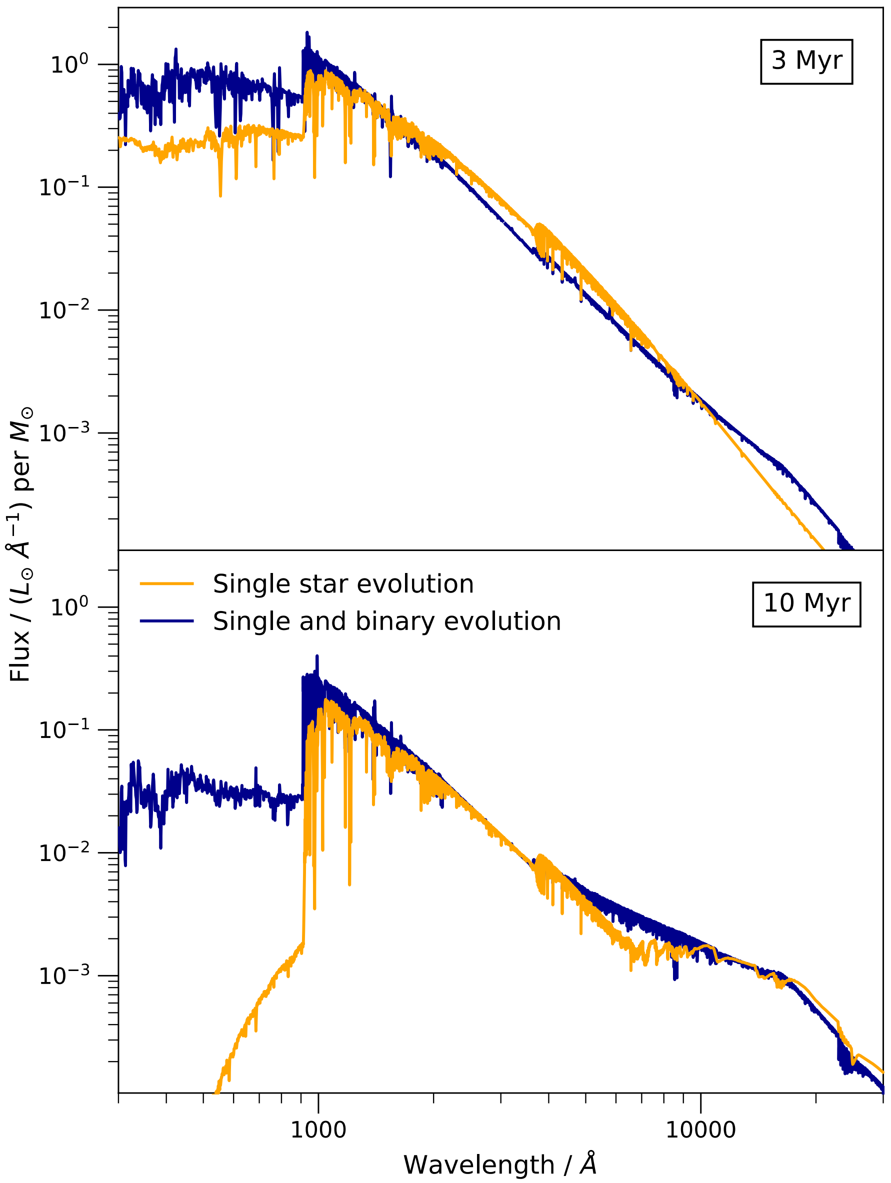
Conroy (2013)

Binaries in SPS modelling

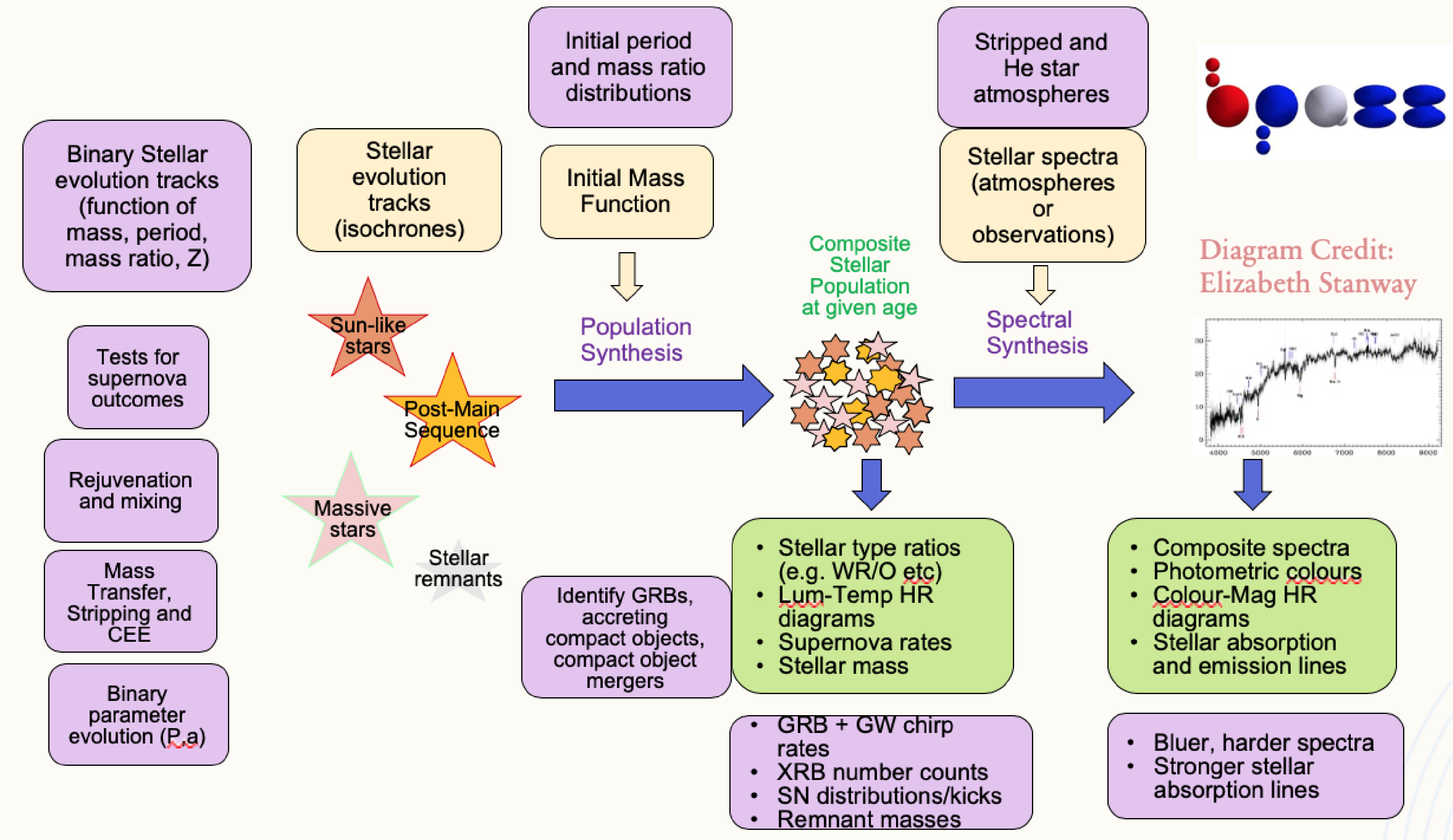
Ignored when modelling for a long time due to complexity

However, most massive stars are found in binaries, and some phenomena (e.g. gravitational waves) require them

The spectra they generate also differ to single stars, which affects the amount of dust emission

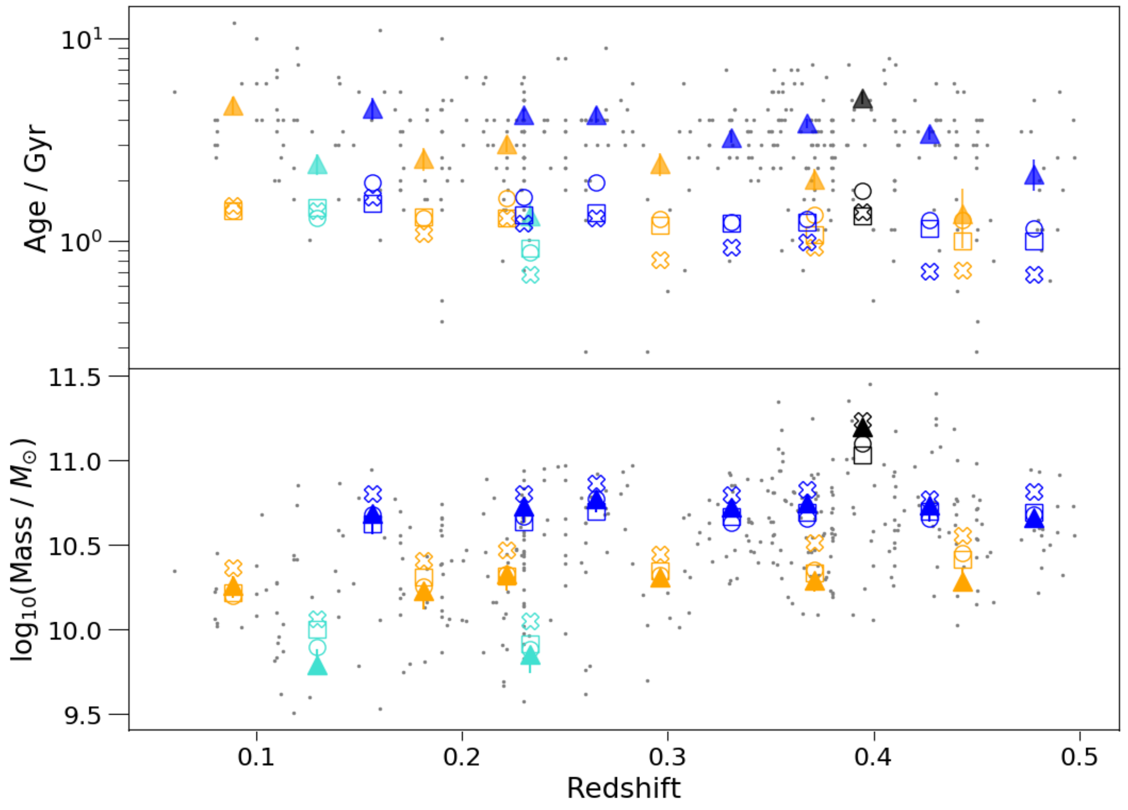


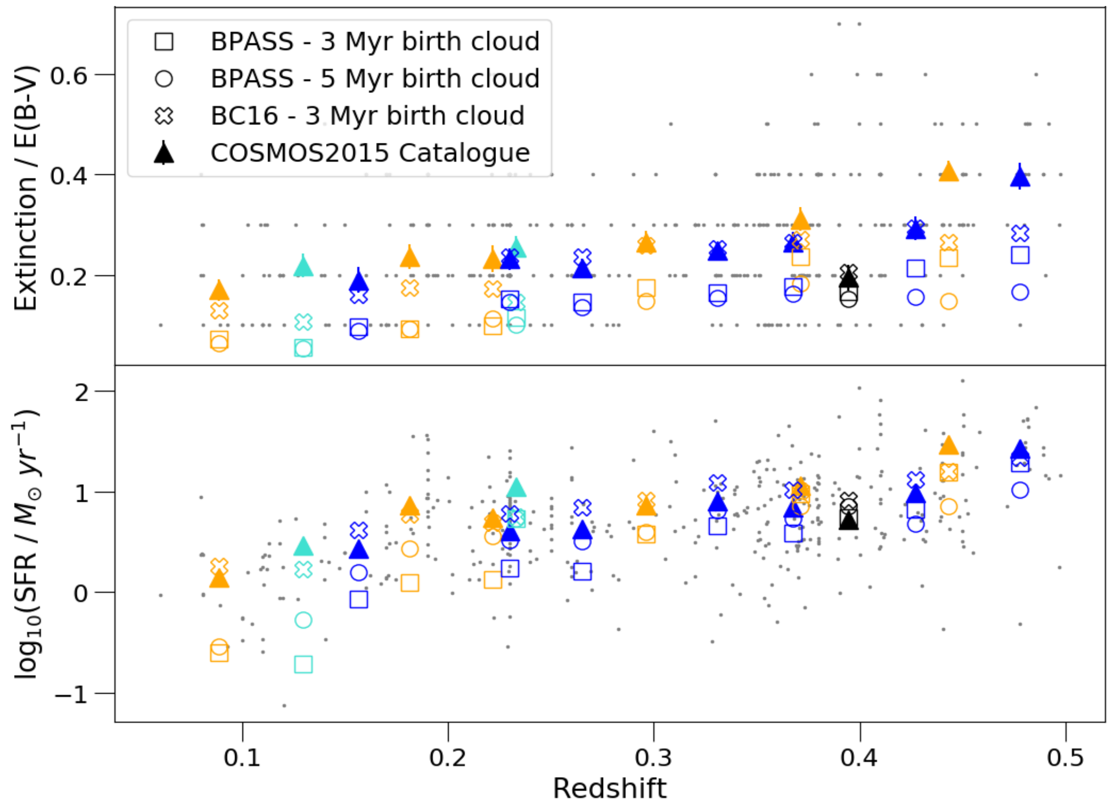
Binaries in SPS modelling



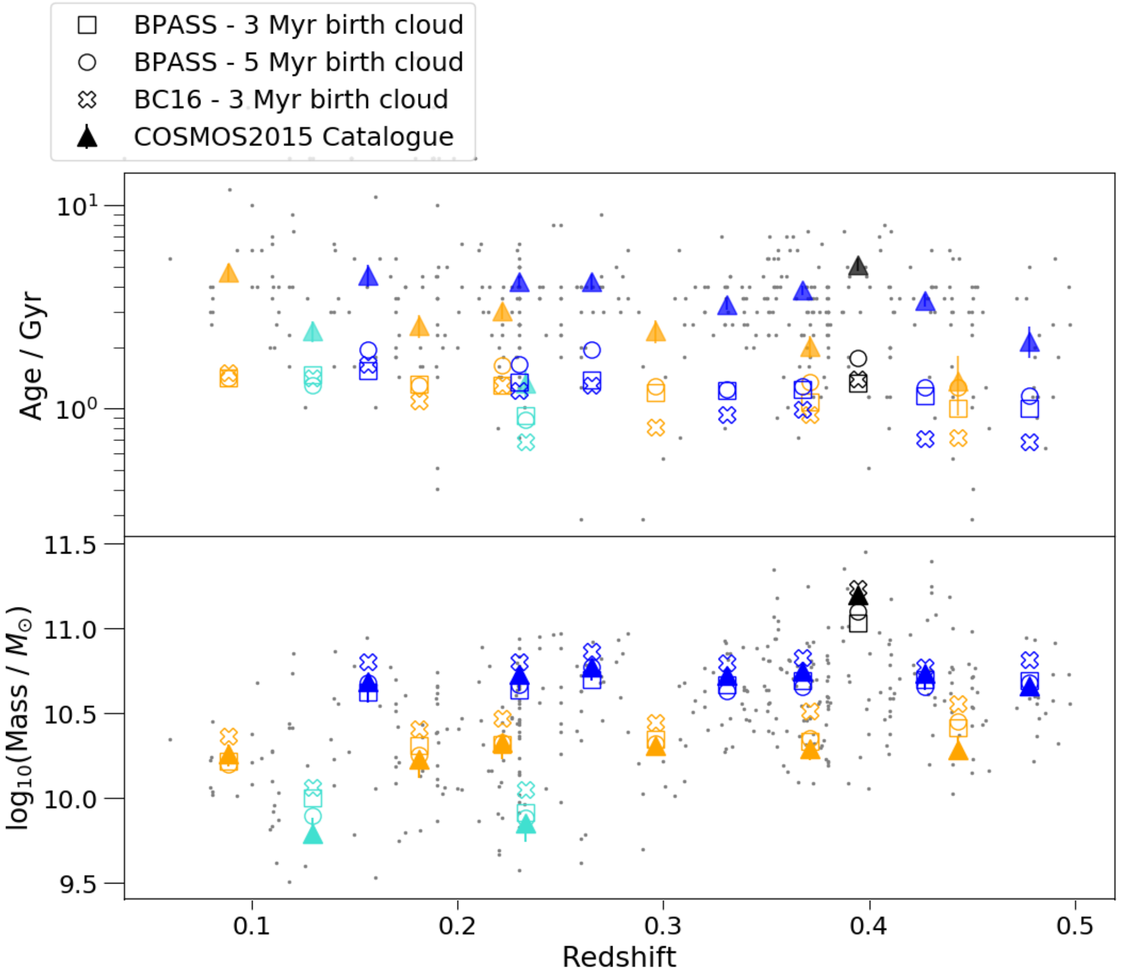
The impact of binaries

BPASS – Binary Population And Spectral Synthesis
BC16 – Bruzual and Charlot (2003) Single Stellar Population Synthesis





The impact of binaries



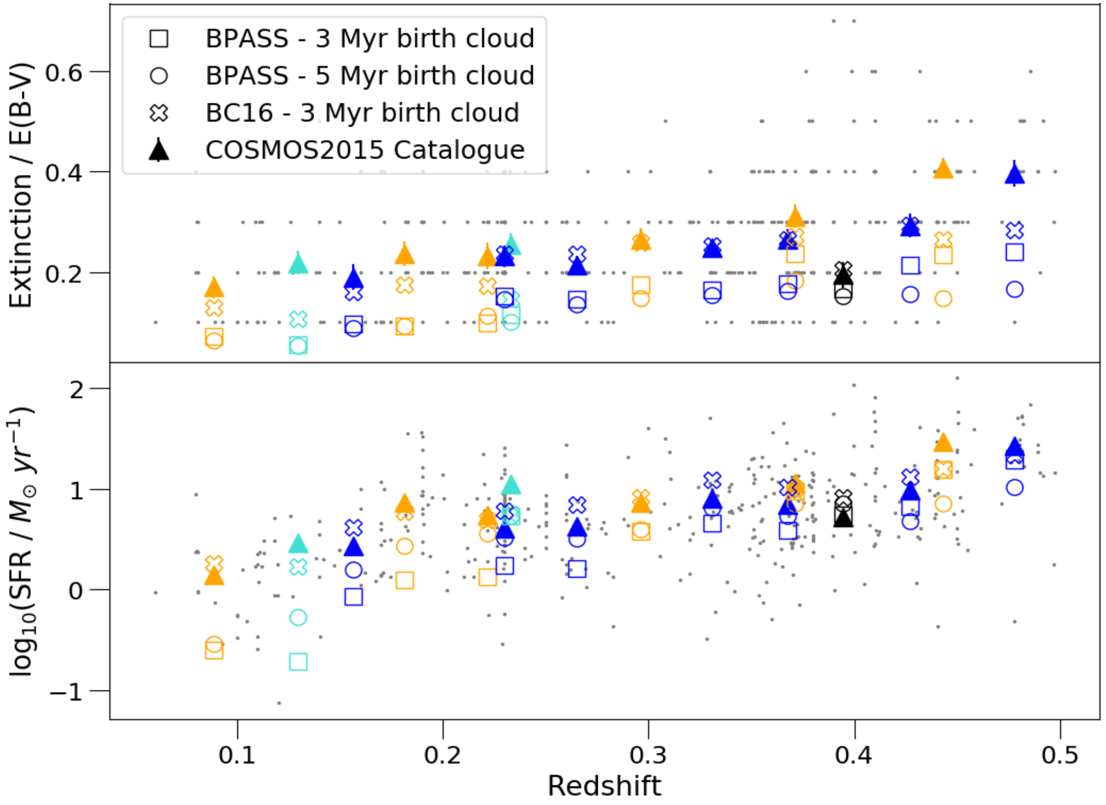
There are no systematic trends in the ages and can be vastly different to previously derived values

Since BPASS has a a lower (optical) mass-to-light ratio than the BC16 models, the derived masses are lower by 0.15 dex for BPASS

The impact of binaries

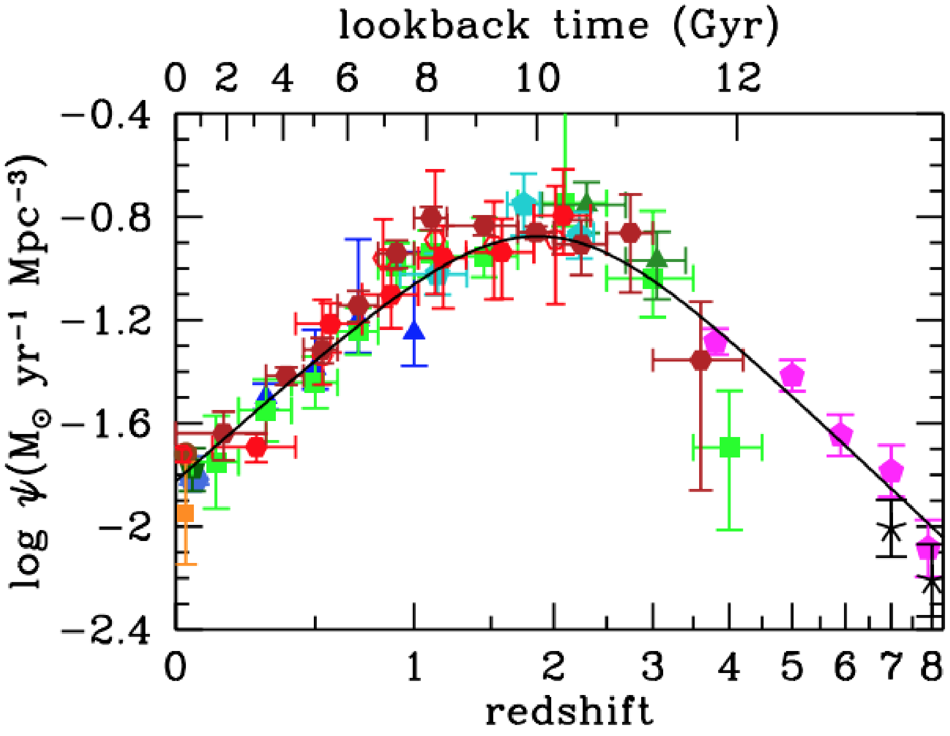
Since BPASS produces more UV flux, it needs lower extinction (attenuation) by E(B-V) = 0.07 to generate the same amount of dust emission

Finally, BPASS has lower derived SFR than BC16 models, with an offset of 0.31 ± 0.18 dex

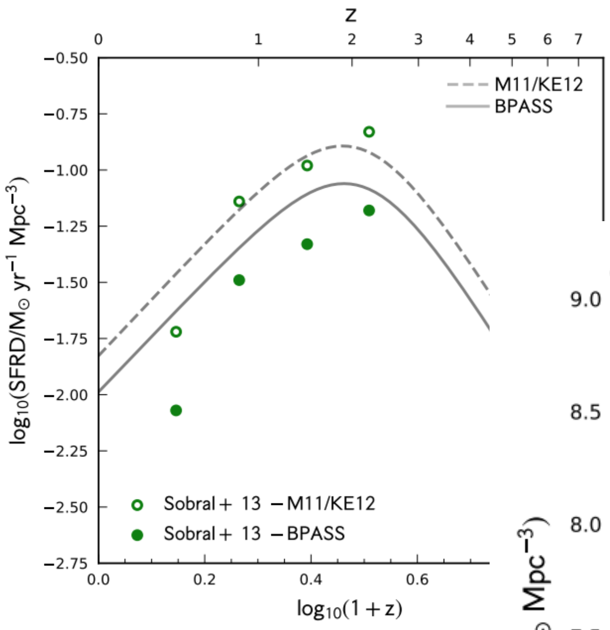


Impact on CSFRD

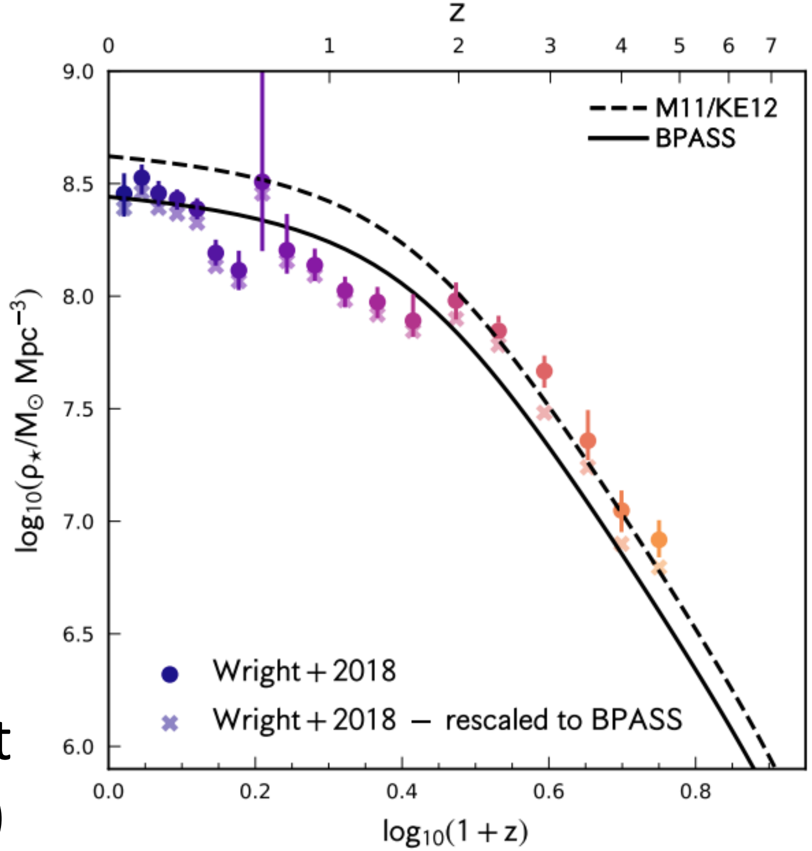
Star formation rate
at different epochs



Madau and Dickinson (2014)



Mass density of Universe
at different epochs



Wilkins et al. (2019)

The Difficulties of Observing Dust

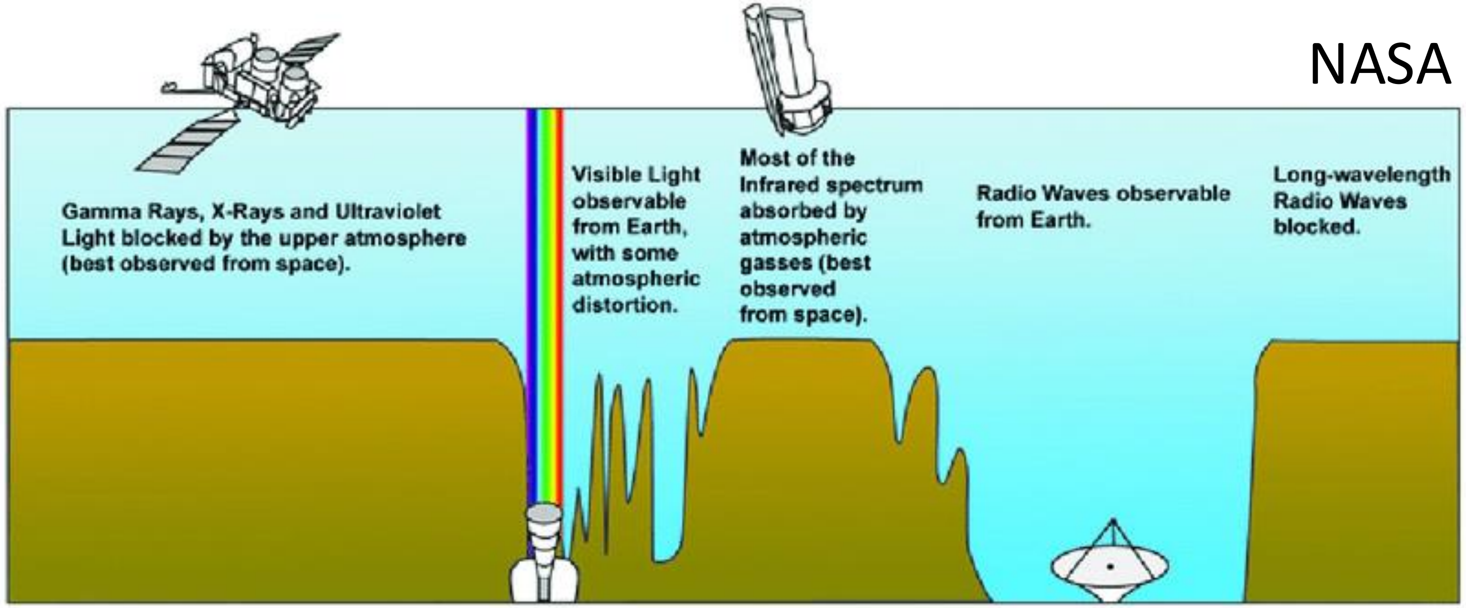
Infrared observations are hard

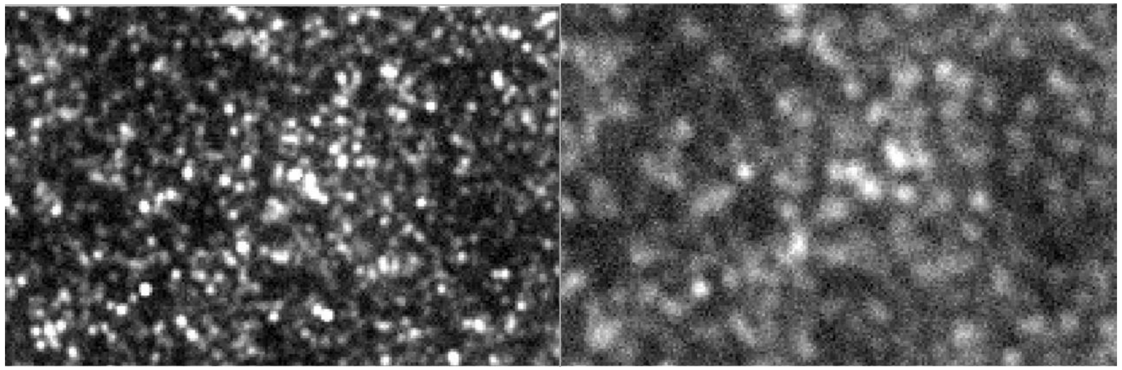
Need to go to space as infrared is absorbed by Earth’s atmosphere

Hard to build infrared telescopes as they need to be cooled

Due to diffraction, objects are more blurred causing them to blend

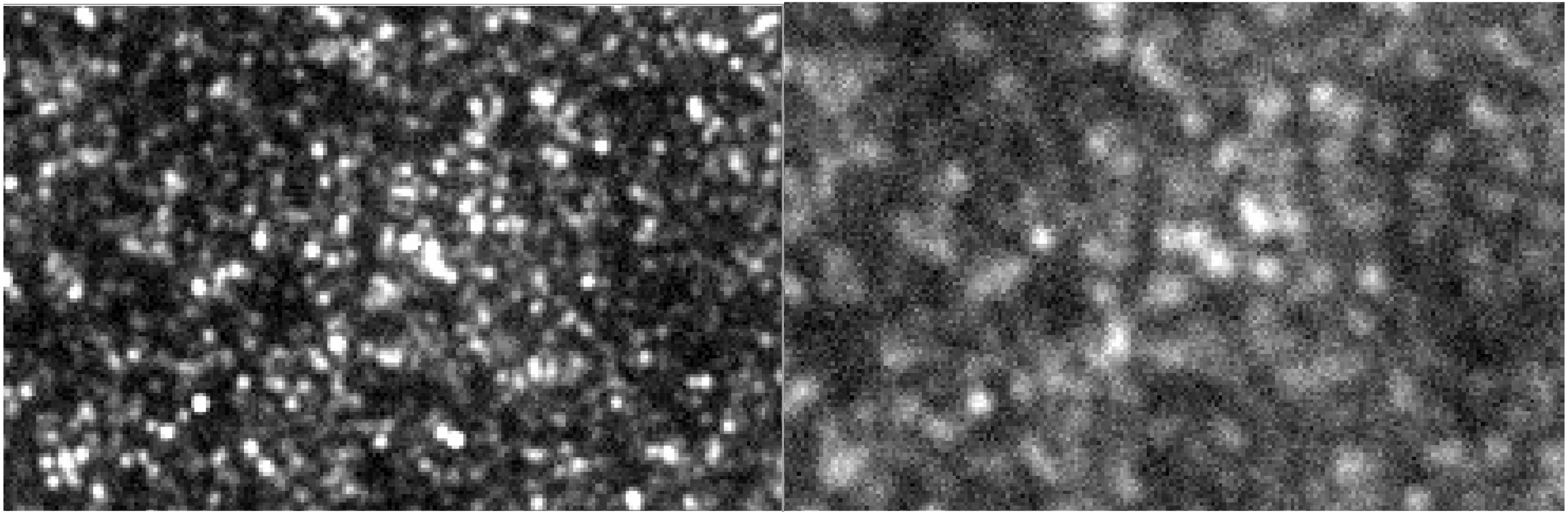
NASA





Herschel SPIRE 250 (left) and 500 (right) micron observations

COSMOS field

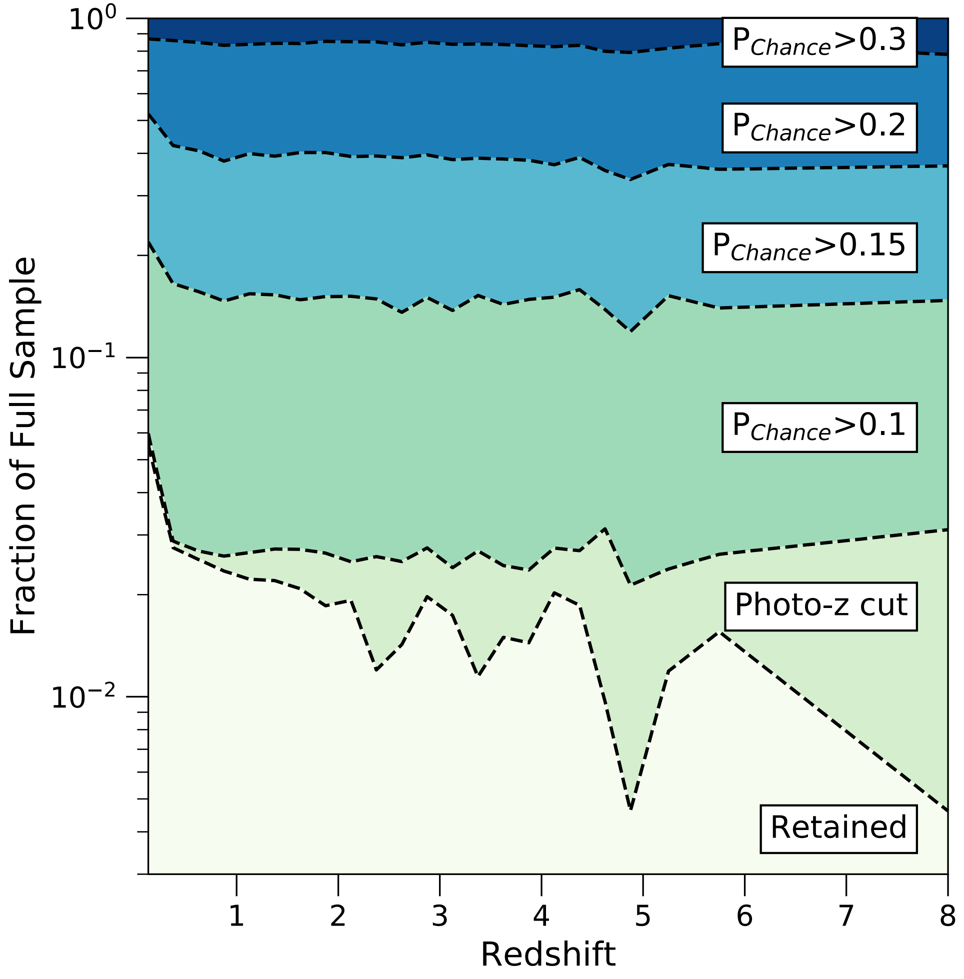


Herschel SPIRE 250 (left) and 500 (right) micron observations in the COSMOS field

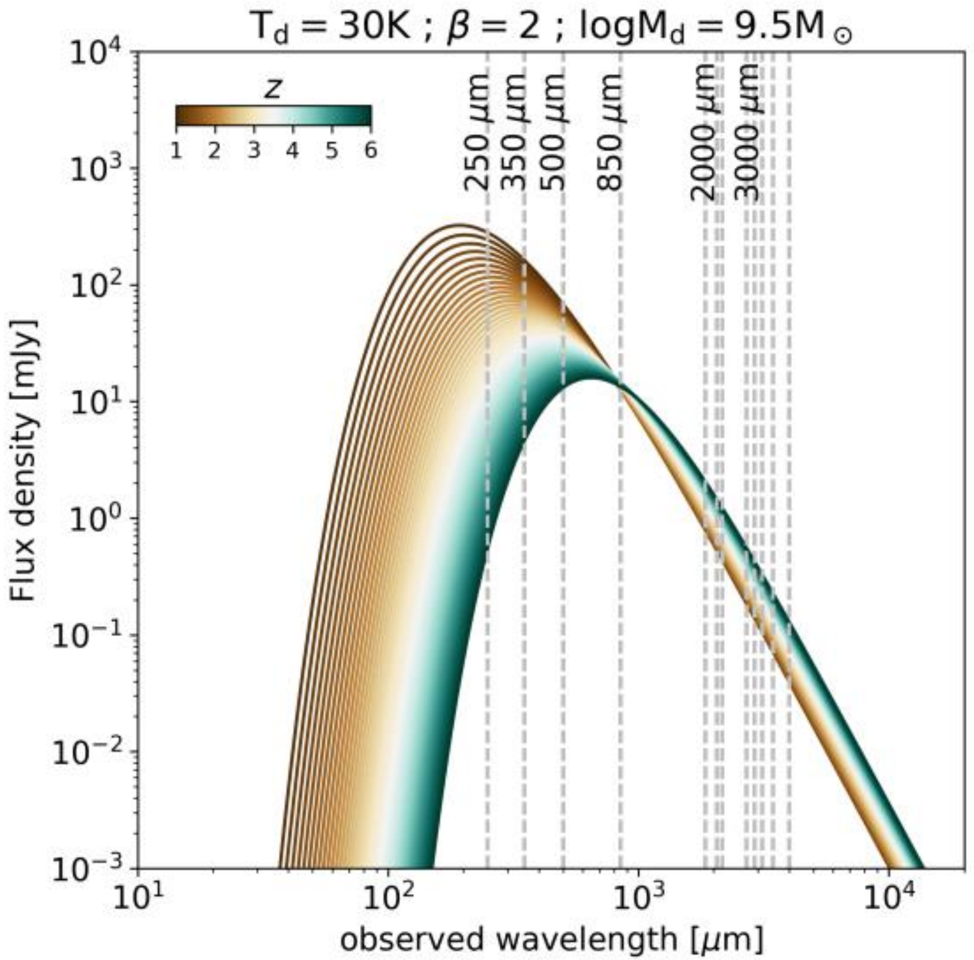
Contamination from nearby galaxies

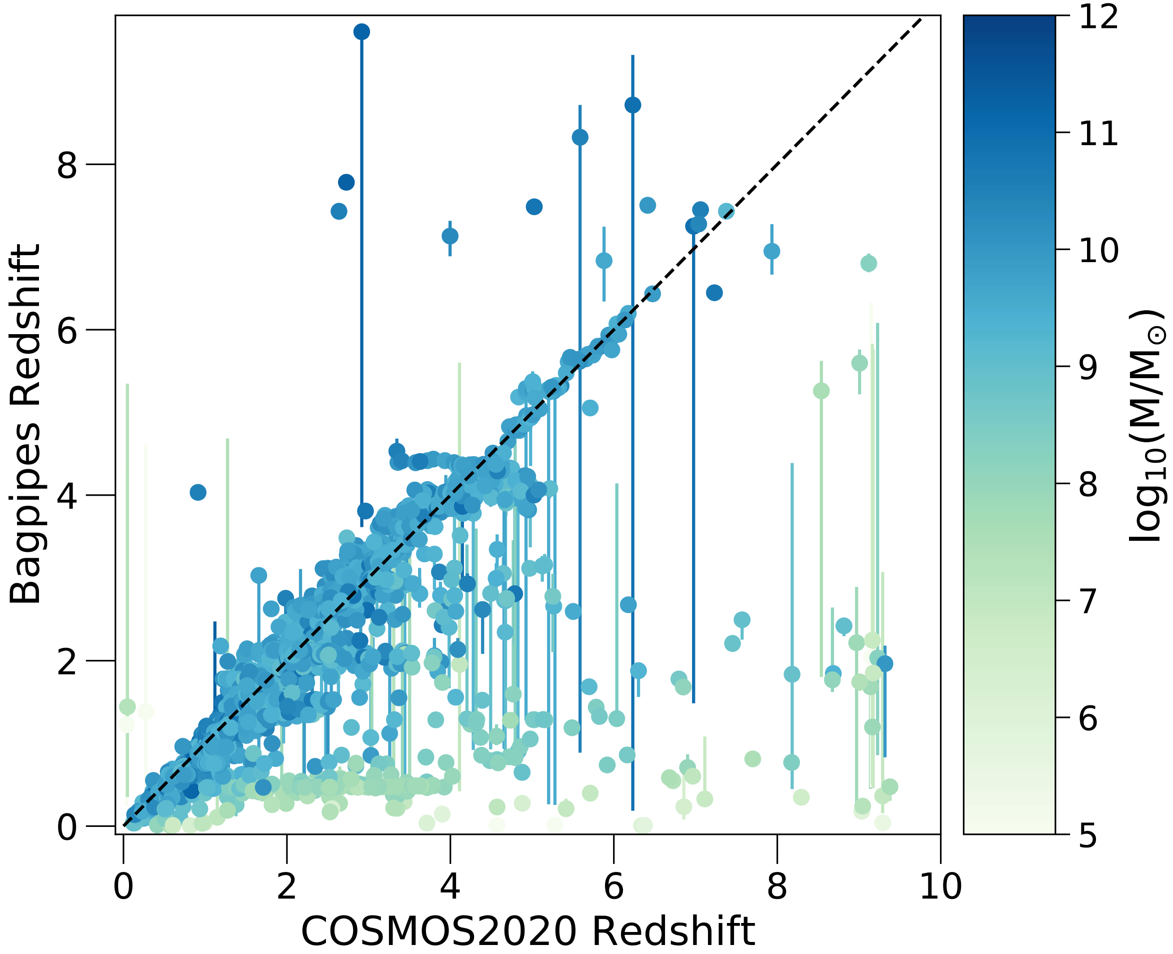
Galaxies in the nearby, local Universe can blend with distant galaxies, contaminating flux measurements

Observational fields are extremely crowded, making the probability of chance alignment (P_{Chance}) between two galaxies high



Determining redshift can be difficult





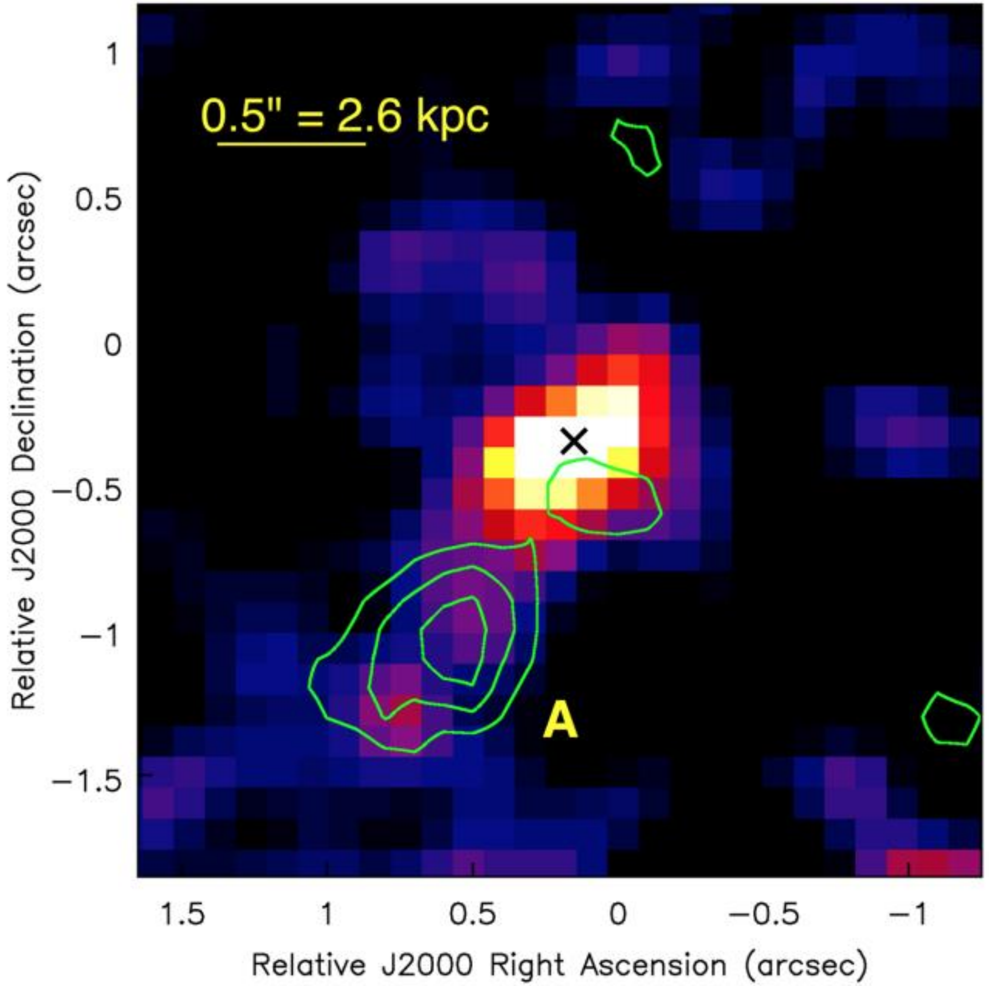
Ismail et al. 2023

UV/Optical-IR disconnection

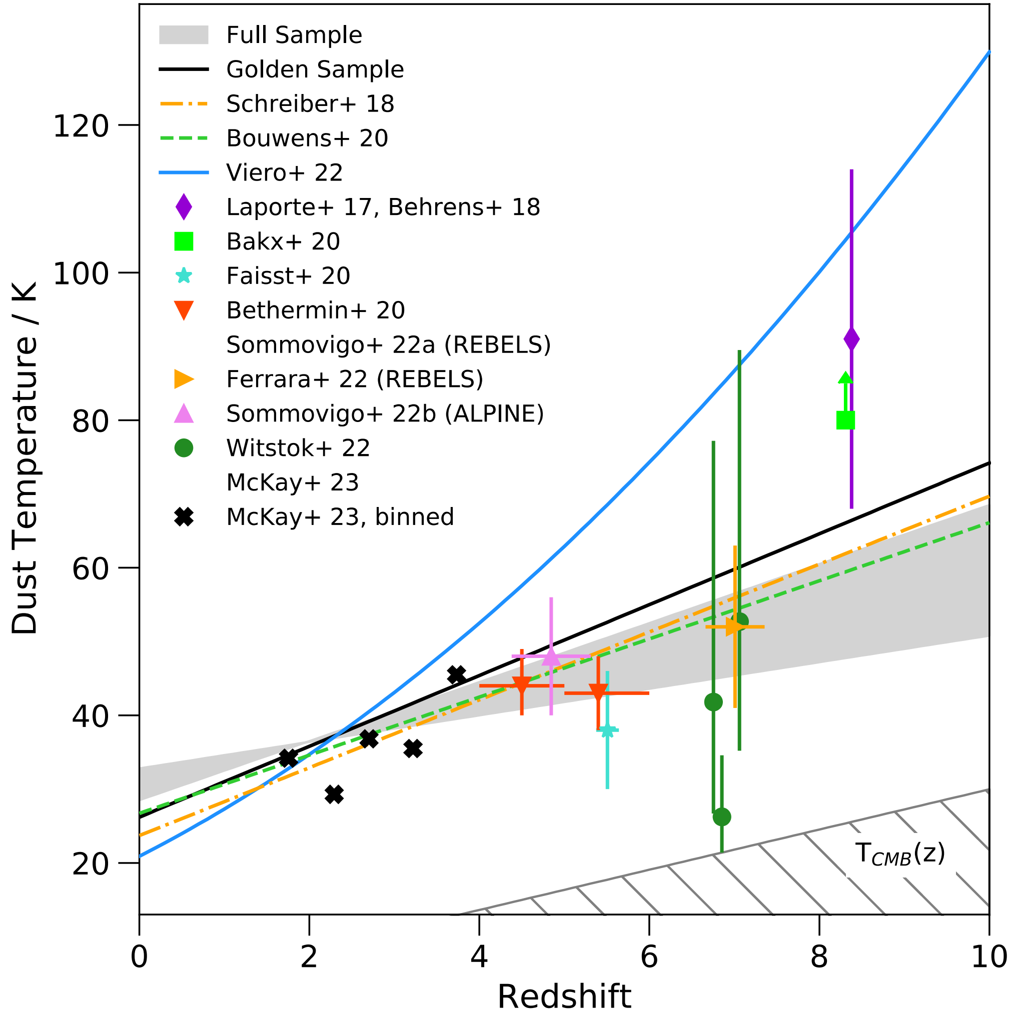
Maiolino et al. 2015

The peak of the UV-optical emission (i.e. the stellar population) can be spatial separated from the peak IR emission (i.e. the dust population).

Therefore, the heating source of the dust is not observed, breaking the energy-balance formalism and thus the fitting methodology.



Result: A lot of uncertainty



The Future

Open questions

- How much dust is there in the distant Universe?
- What are the properties of dust in the distant Universe and how do they evolve with time?
- What is the geometry of dust in galaxies and does this change with galaxy type?
- What is the composition of dust?
- How can we improve our dust emission models to fully capture the dust emission?

Current facilities

Very limited, with no mid-far infrared observatory

- Atacama Large Millimeter Array (ALMA)
    - Radio interferometer of 66 telescopes
    - Can be used to probe the long wavelength tail of dust emission
    - Pro: Deep observations
    - Con: One galaxy at a time

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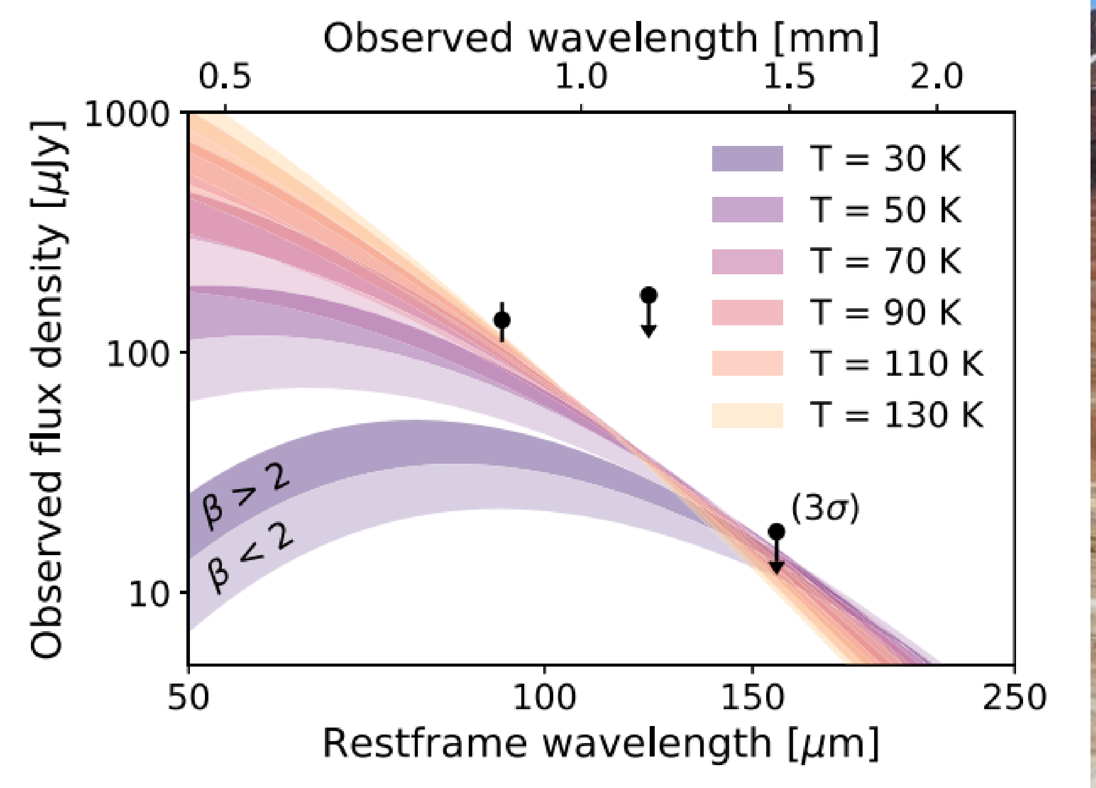
Bakx et al. 2020



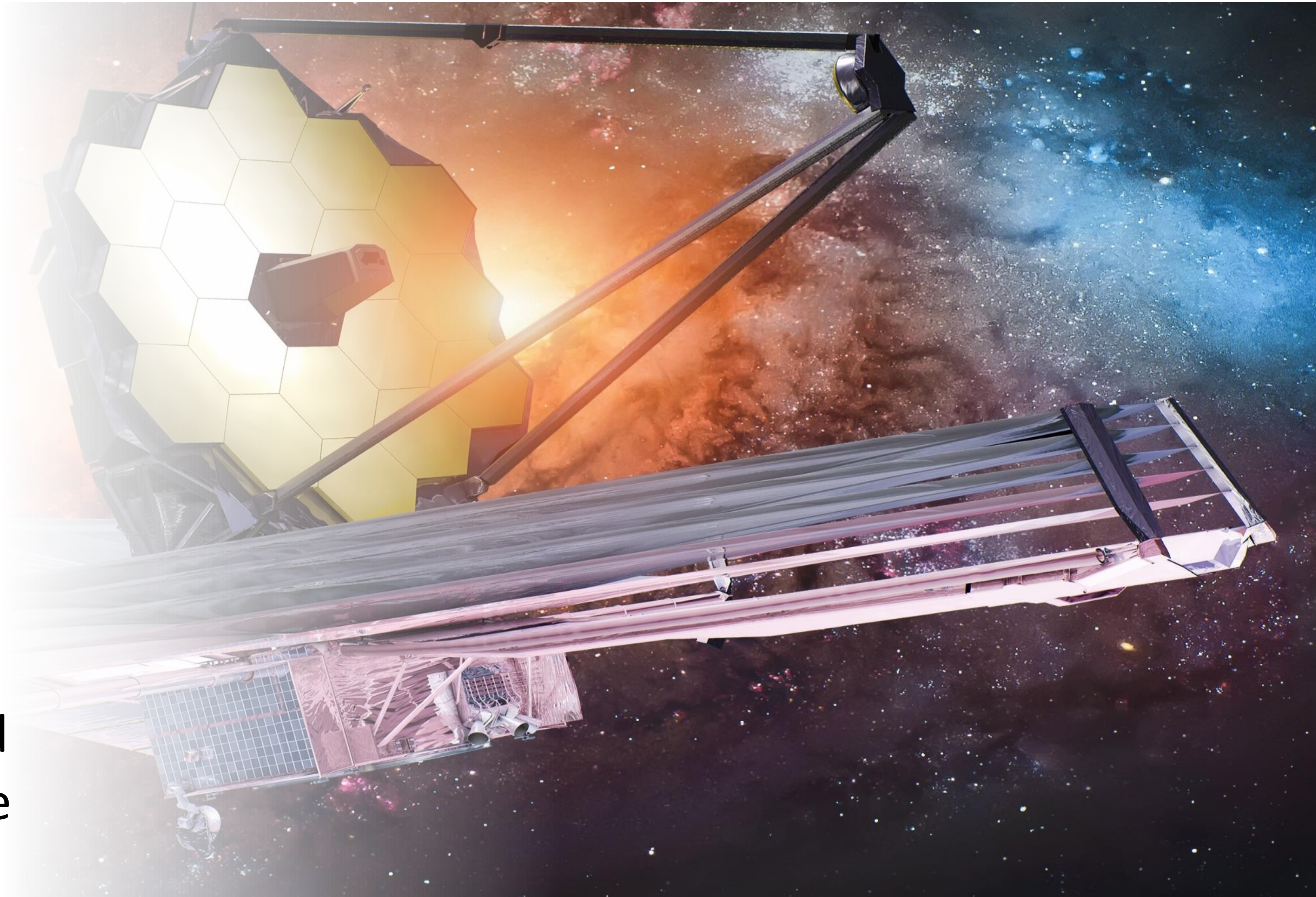
Northern Extended Millimeter Array (NOEMA)

JWST

Launched on 25th December 2021

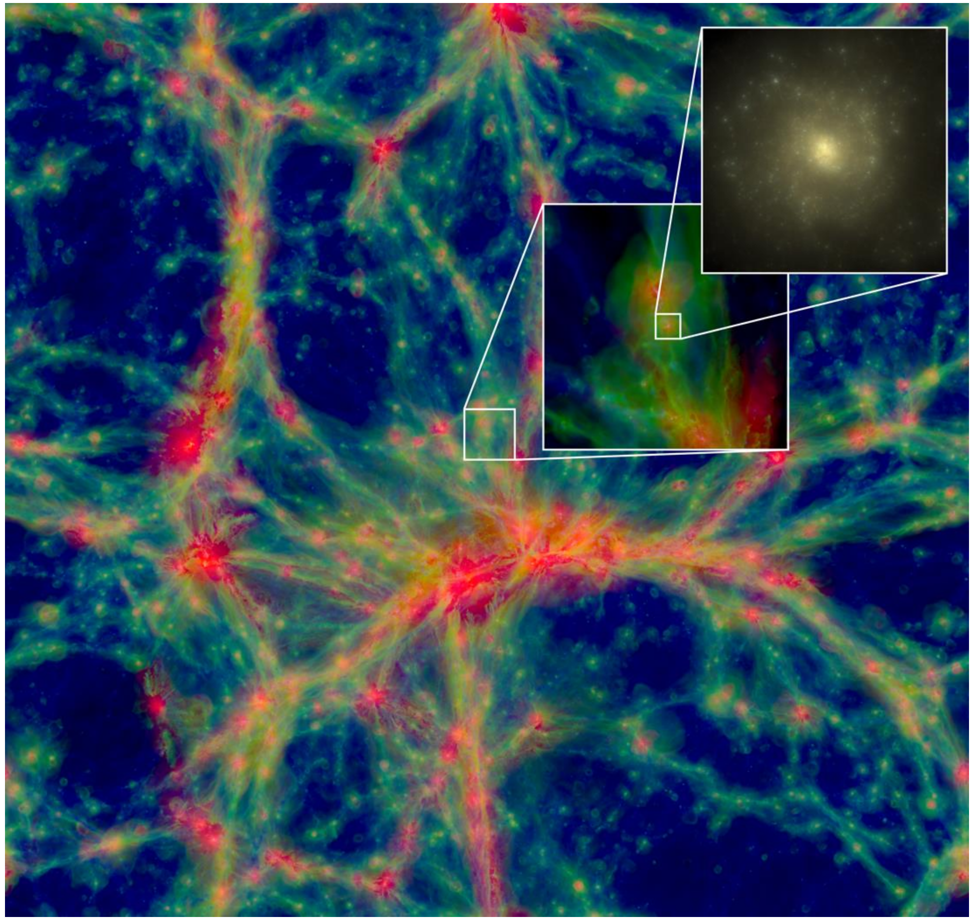
6.5-meter telescope made up of 18 goal-coated mirror segments

Goal to observe the first stars and explore how galaxies emerged and evolved over time



Improved numerical simulations

Run simulations to predict the production and evolution of dust, then compare to observations



EAGLE Project

Conclusions

- Dust plays a vital role in shaping and evolving galactic populations
- Obtaining infrared observations, especially in the distant Universe, is difficult
- The choice of stellar and dust emission models impact the derived properties of a galaxy
- A lot of uncertainty in the properties of dust and their evolution
- Need new facilities to push the field further forward