STUDYING THE PHYSICAL PROPERTIES OF DUSTY STAR-FORMING GALAXIES (DSFGs) FROM THE SOUTH POLE TELESCOPE

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ASTROPHYSICS DEPARTMENT (BP4)

1.

THE PROBLEM

And why should we work on it?

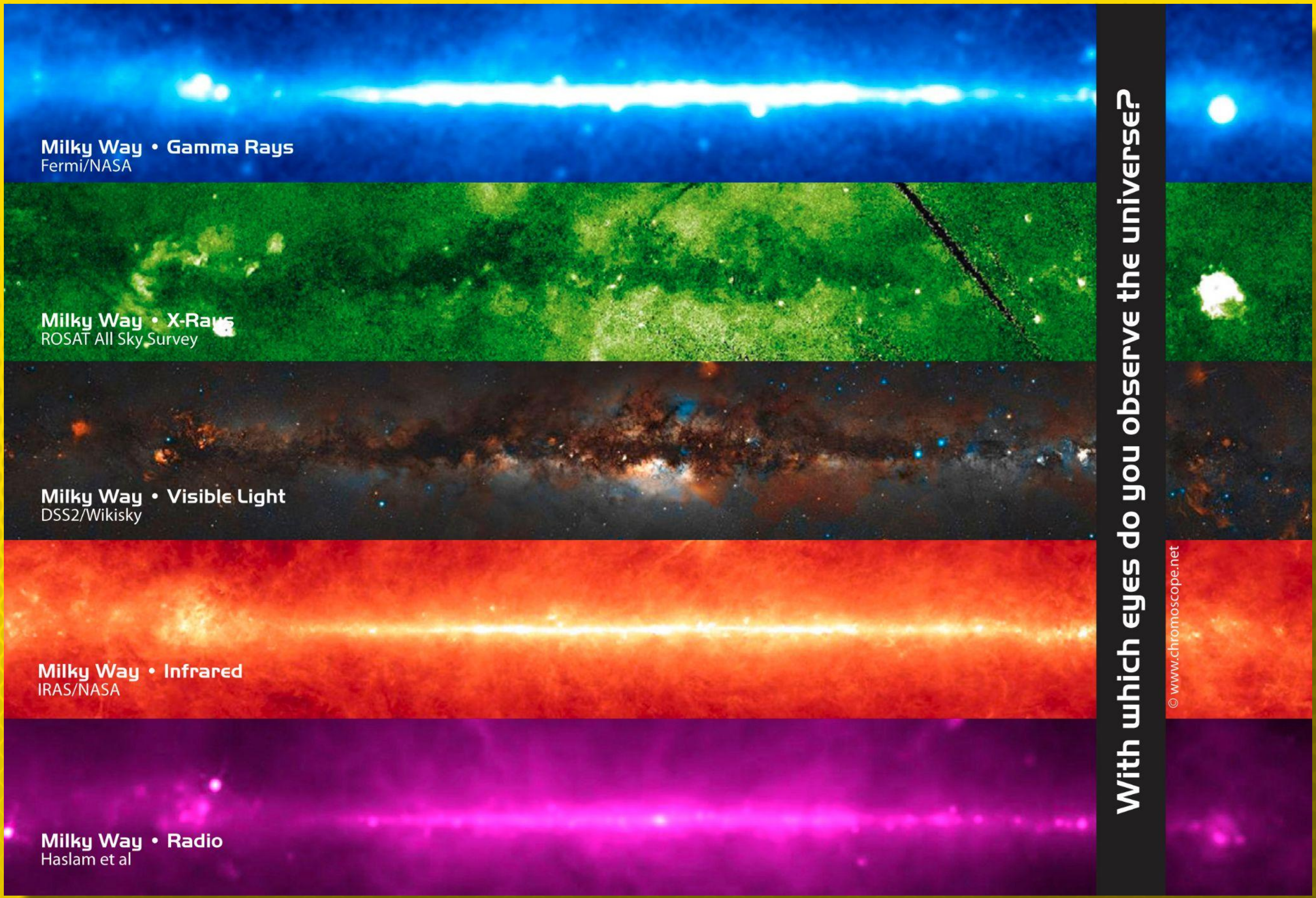
Exploding stars,
Colliding Neutron stars

Hot Gas heated to
million of degrees,
Supernovae Remnants

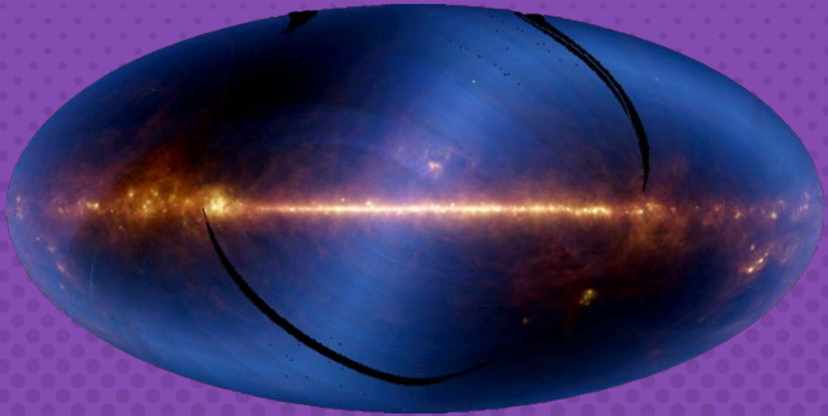
Visible matter – stars,
nebulae

Radiation from dust,
Interstellar Medium

Pulsars, Quasars, Jets
from Active Galactic
Nuclei



Credits: ESO



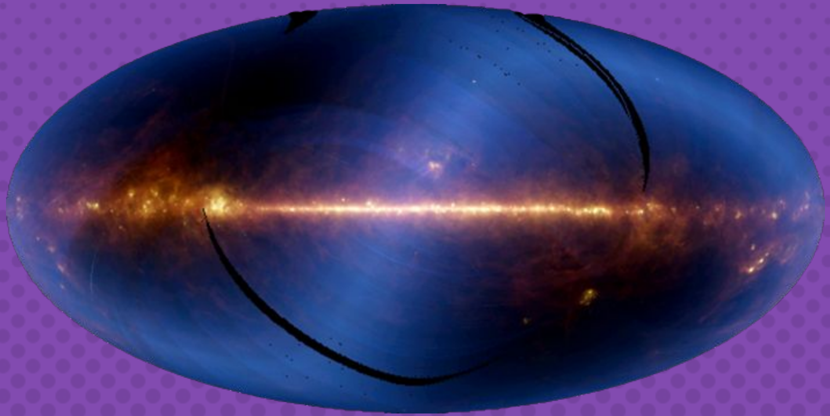
Universe in optical wavelengths

Credits: ESO/Gaia

Universe in infrared wavelengths

Credits: ESO/IRAS

Universe emits a comparable energy density infrared and sub-mm wavelengths as it does in optical and UV.



"UNIVERSE HAS A LOT TO TELL ONLY IF YOU CHOOSE RIGHT EYES TO SEE IT"

SERIOUS STUFF ABOUT DSFGs

What?

Star Formation Rate estimated to few thousand solar masses per year compared to Milky Way (2 Solar Mass per year)

Why?

Unique laboratory for investigating the physics of star formation in environments far more extreme than encountered in local universe.

How?

For DSFGs at high redshift, the rest wavelength peak in the SED is shifted into the observing bands of millimeter and sub-mm instruments.

1 Solar Mass = 1.98×10^{30} kgs

~~SERIOUS~~ STUFF ABOUT DSFGs

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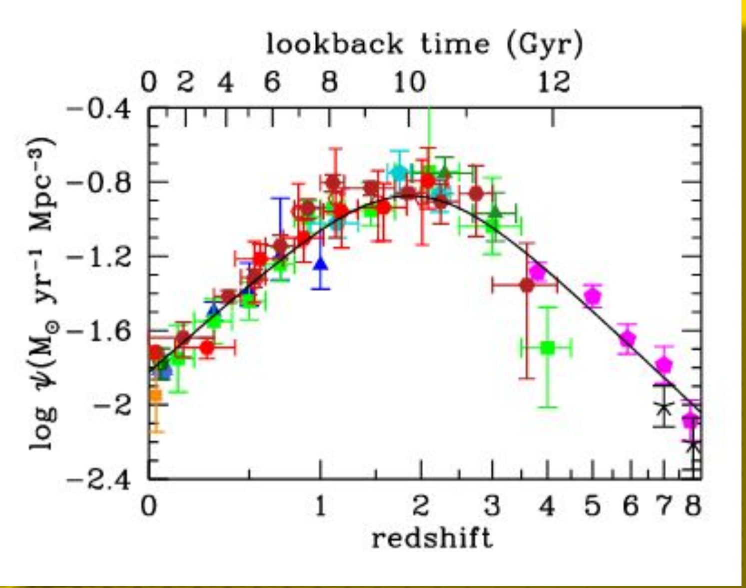
DSFGs be like ----->

Credits: Twitter/Gregory Walth

Problem Statement

- Galaxies in early universe have proven to be a significant challenge for theoretical models of galaxy formation.
- Are these galaxies scaled up version of local extreme galaxies or are completely different structures?
- Are we able to explain the heavy dust content at the beginning of baryon cycle in these galaxies?



Credits: Madau & Dickinson (2014)

2.

THE METHOD

And cups of coffee which come with it :)

Galaxies 101

What can we see?

- Photometric flux
- Spectra
- Angular size
- Motion across the sky

What can we derive?

- Star Formation Rate (SFR)
- Stellar Mass
- Dust Mass
- Metallicity
- Age

SPECTRAL ENERGY DISTRIBUTION

What?

SED of a galaxy contains information about the processes occurred during the formation and evolution of the galaxy.

Why?

SED allows us to derive physical properties of a galaxy.

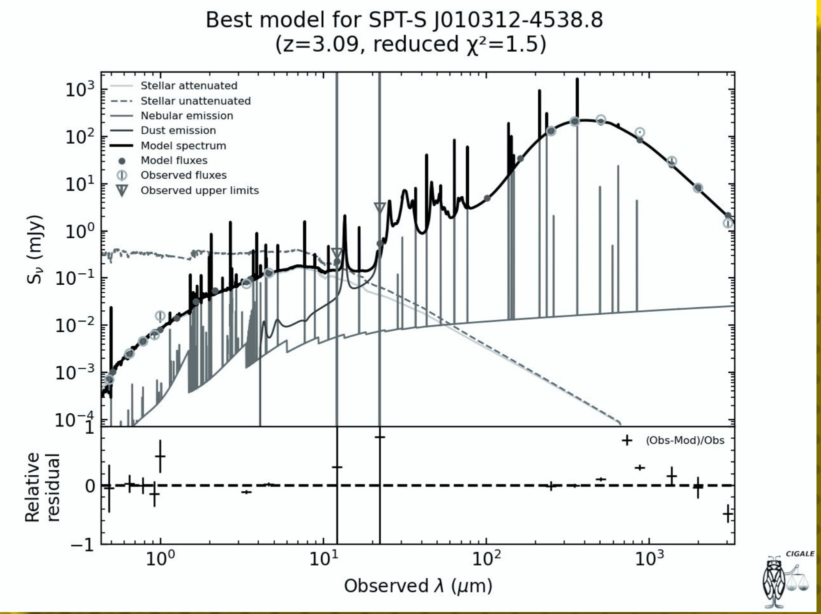
How?

Every physical process occurring in the galaxy dominates at different wavelengths.

SPOILER ALERT!

But how do we construct a SED for galaxies at high redshift?

First of all, what's *high redshift*?

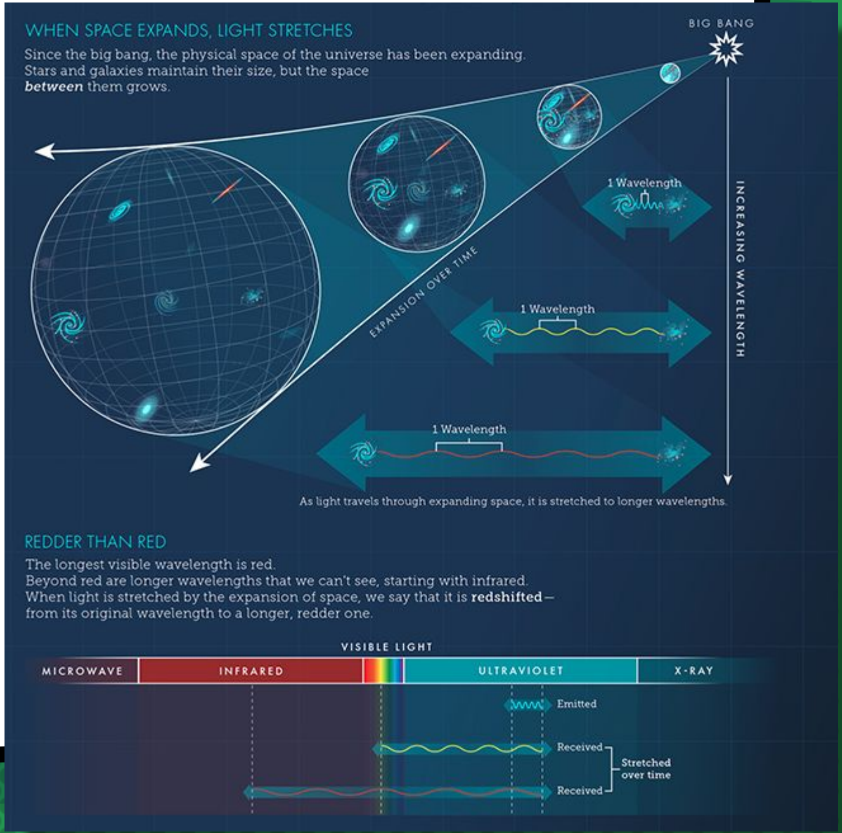


REDSHIFT

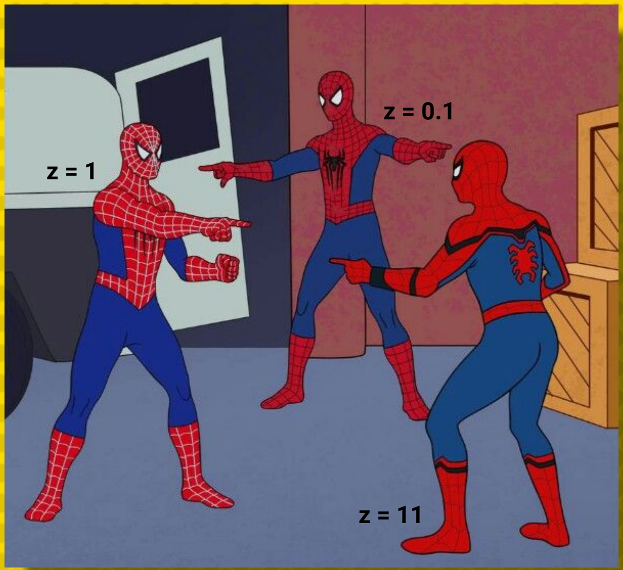
A redshift is an increase in the wavelength, and corresponding decrease in the frequency and photon energy.

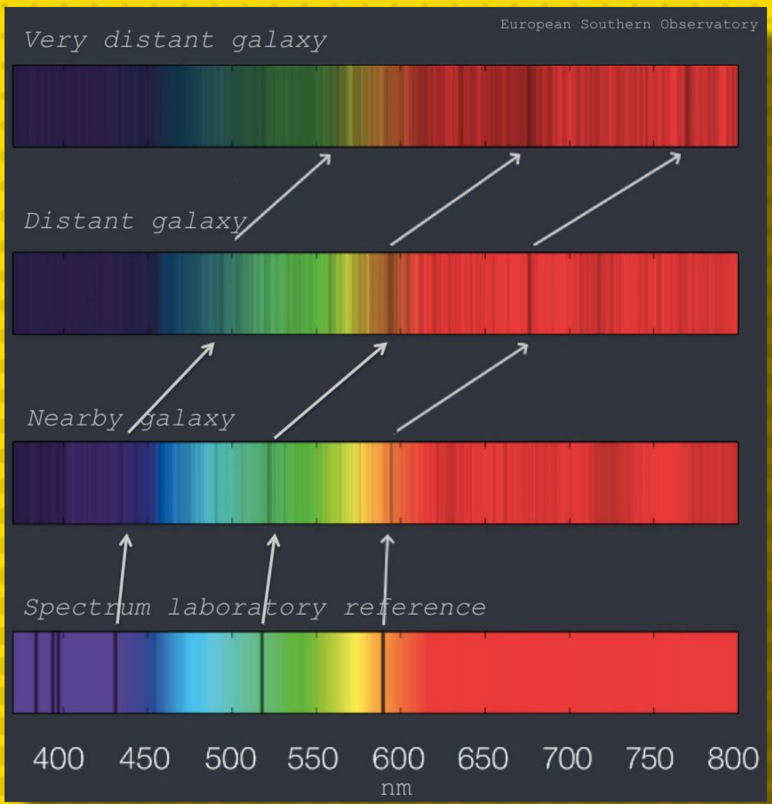
$$z = \frac{\Delta\lambda}{\lambda_{rest}} = \frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}}$$

Credits: webbtelescope.org



HIGH REDSHIFT?





Credits: University of Iowa, ESO

HOW TO CONSTRUCT A SED?

Dust Attenuation: How dust absorbs the radiation from the stars?

Nebular Emission: Lines and Continua from Hot gas emission?

Stellar Populations: How stellar light is distributed across wavelength?

Dust Emission: How dust re-emits the radiation?

Star Formation History: How many stars formed per unit time as a function of time?

Active Galactic Nuclei: How emission from AGNs can affect the SED of a galaxy?

HOW TO CONSTRUCT A SED?

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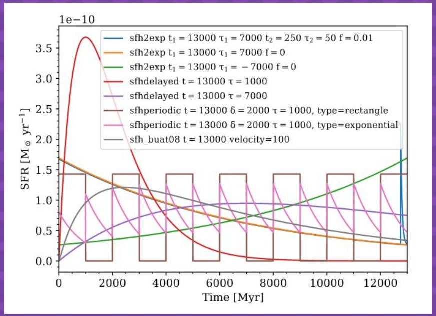

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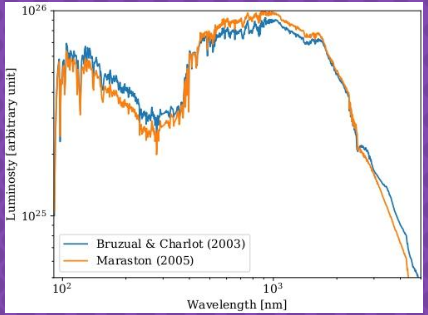

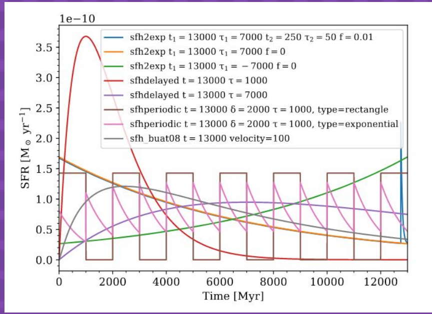

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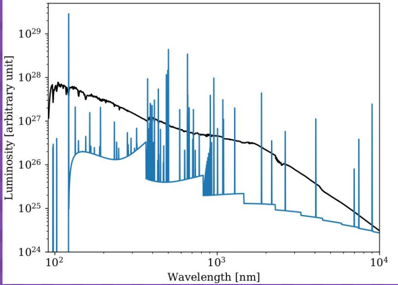

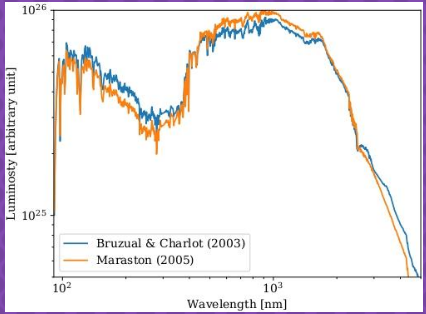

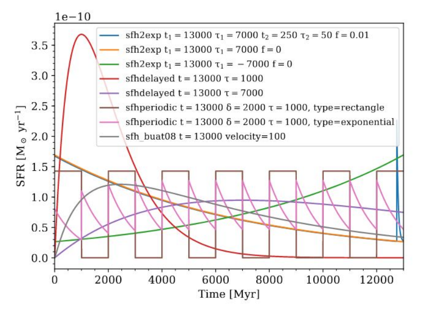

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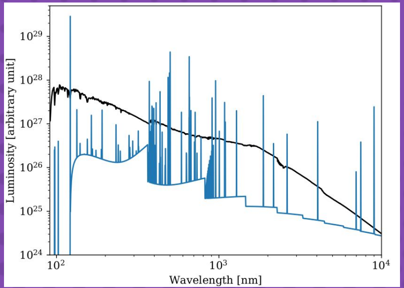

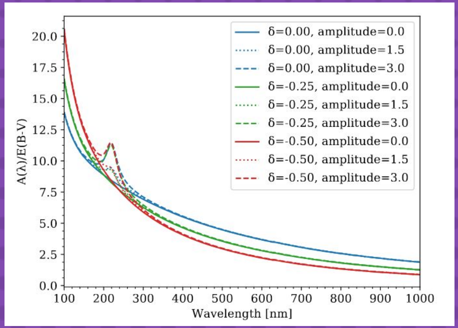

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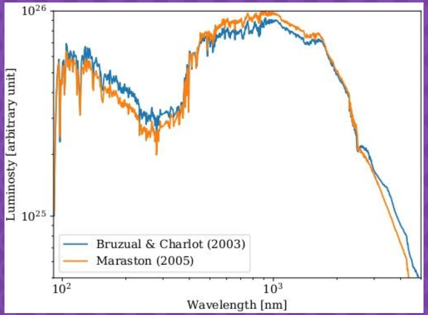

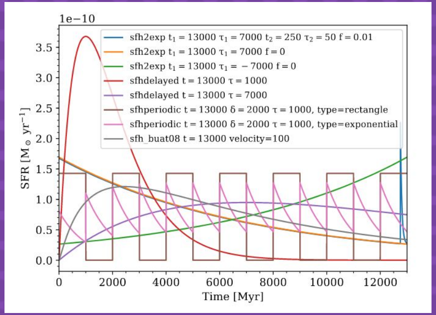

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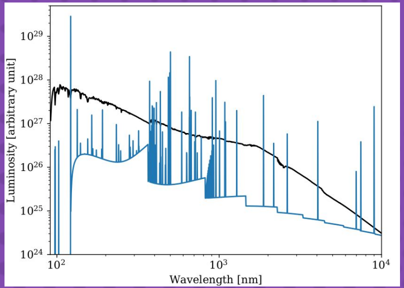

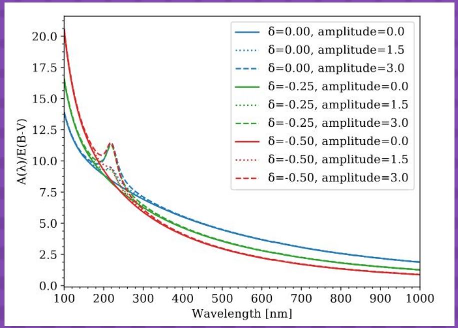

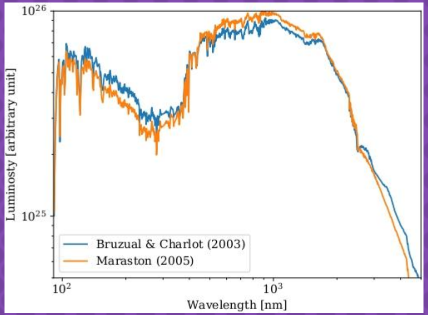

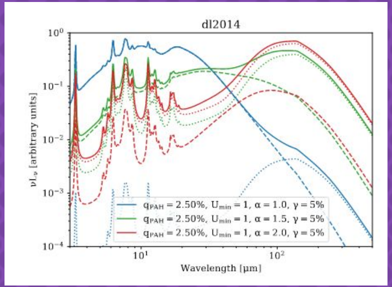

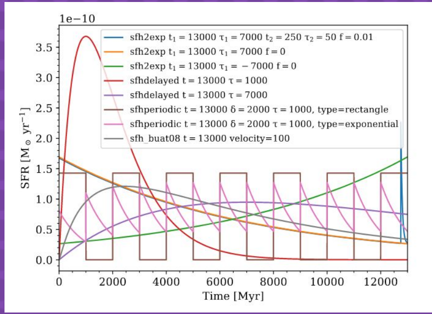

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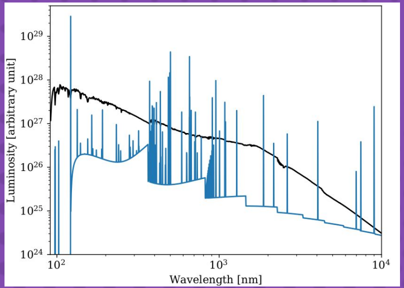

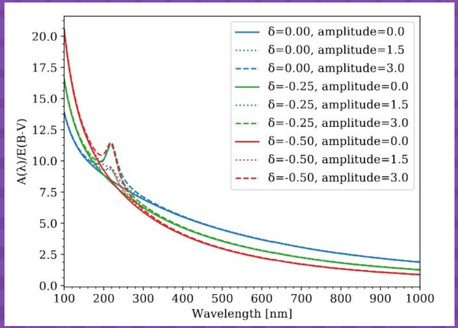

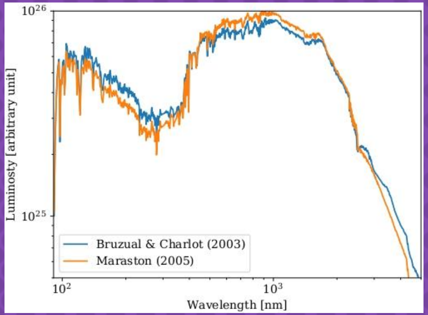

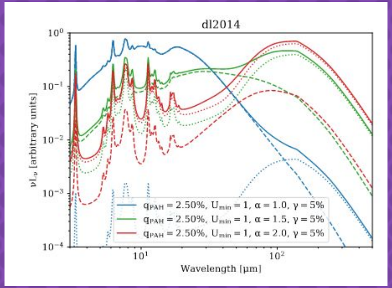

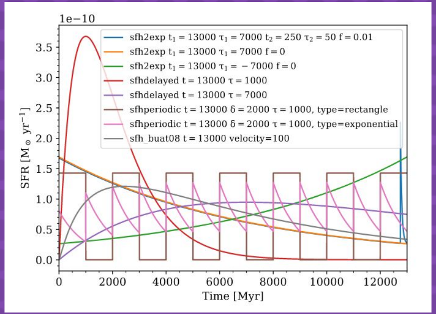

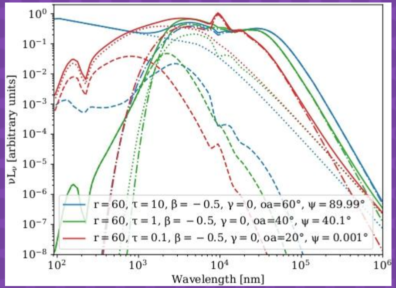

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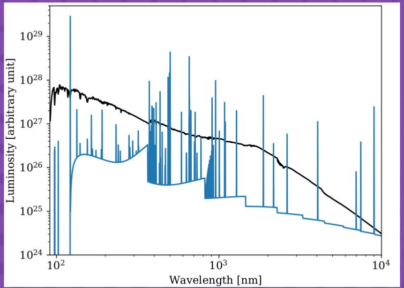
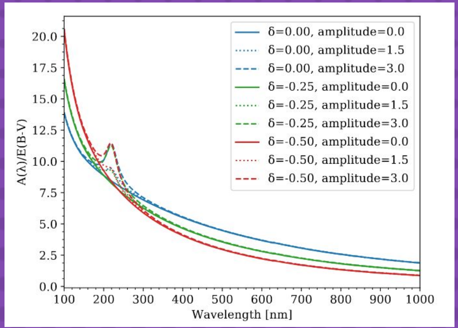
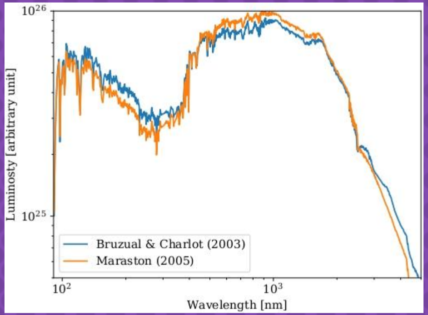
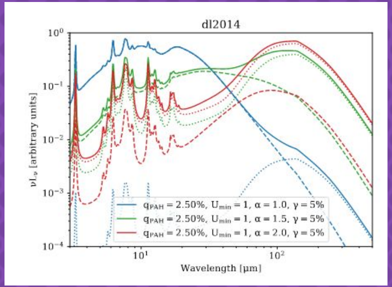
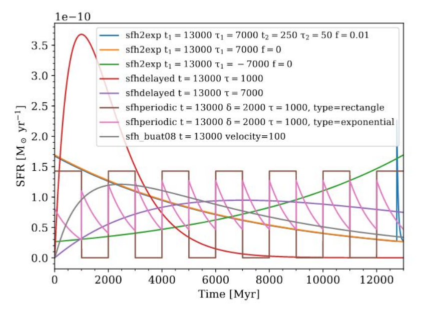




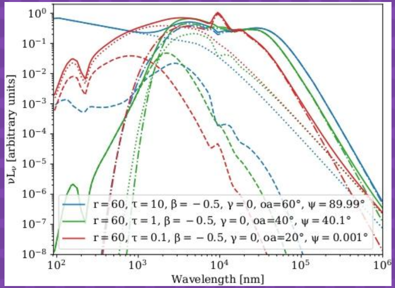






WAIT FOR IT

Add some redshifting



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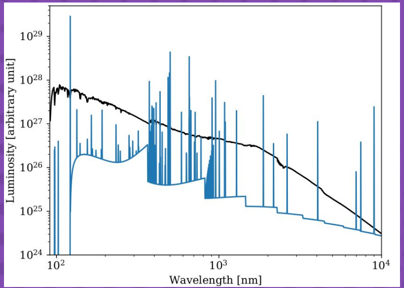
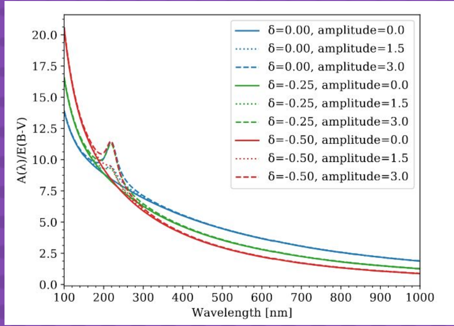
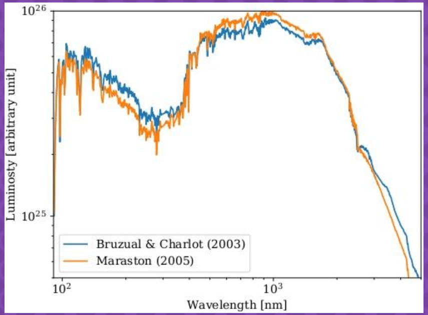
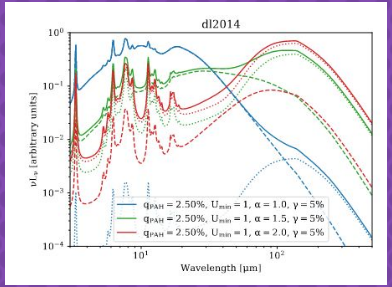
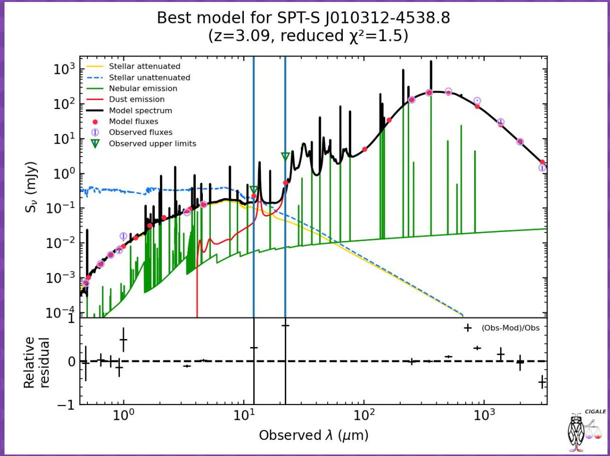


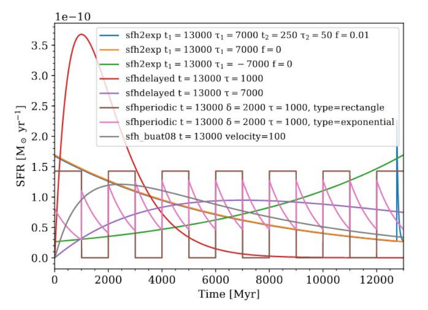


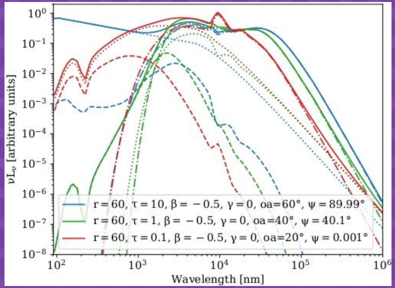
Boquien et al. 2019



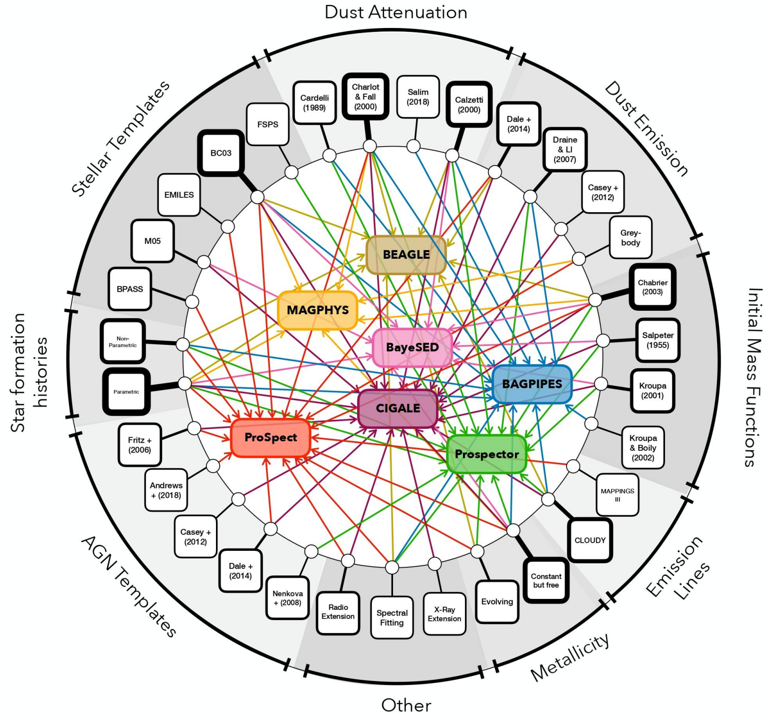








Sawant et al. (in prep)



Buffet Menu of SED fitting

Credits: Jessica Thorne/UWA

CIGALE (Code Investigating GALaxy Emission)

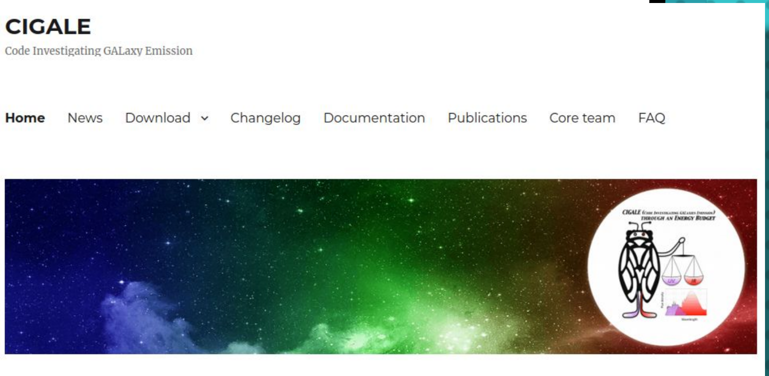
Inputs

- Photometric Flux
- Wavelength
- Redshift
- Prior values for models

Outputs

- SEDs
- Best fit models
- Inferred values of physical parameters

Boquien et al. 2019

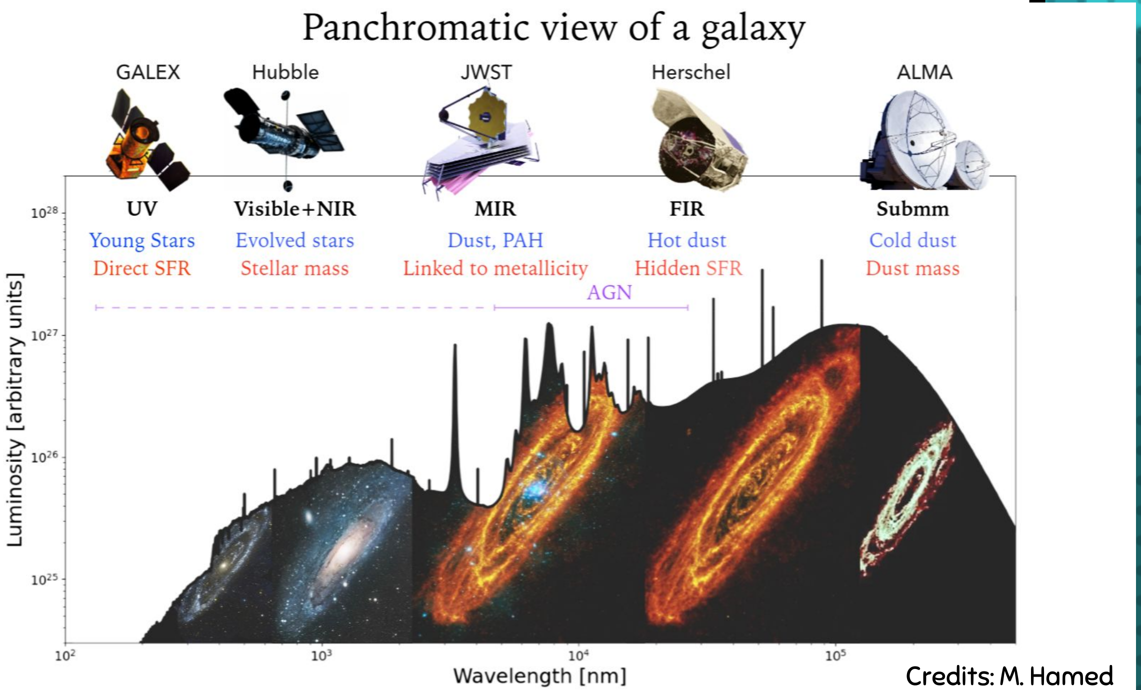


WHAT DO SEDs TELL US

Star Formation Rate

Stellar Content

Dust Content



Credits: M. Hamed

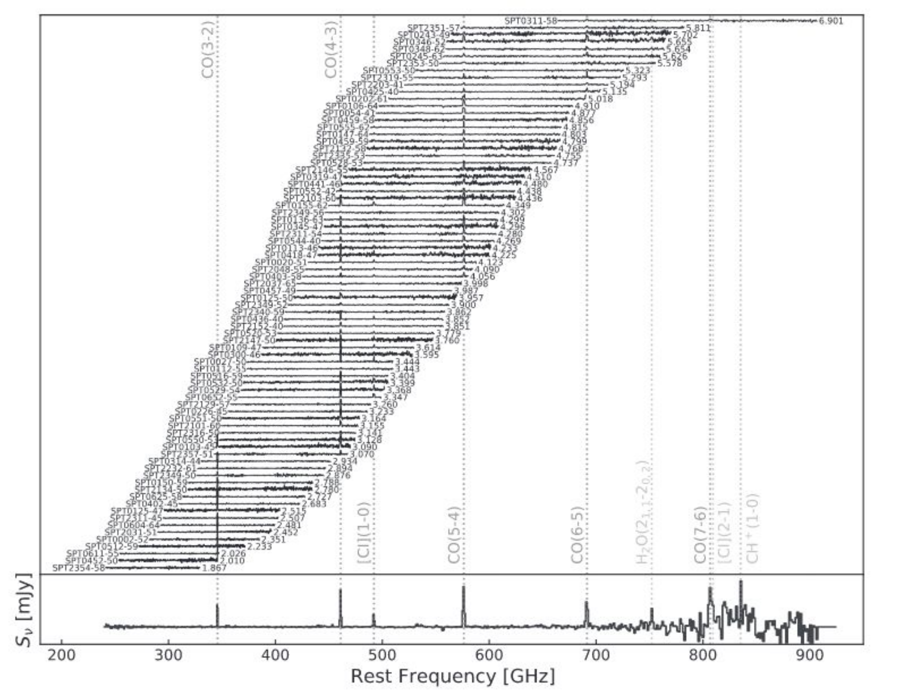
3.

THE DATA

With infinite browser tabs of arxiv and stackoverflow

REUTER ET AL. 2020

- 81 high – redshift galaxies strongly gravitationally lensed DSFGs.
- Galaxies with 1.9 < z < 6.9 with median z ~ 3.9.
- Photometry available from millimeter to far – infrared.



Reuter et al. 2020

- To create a spectroscopic redshift survey for the DSFGs identified by SPT.
- To derive values for SFR and MDust for each source.

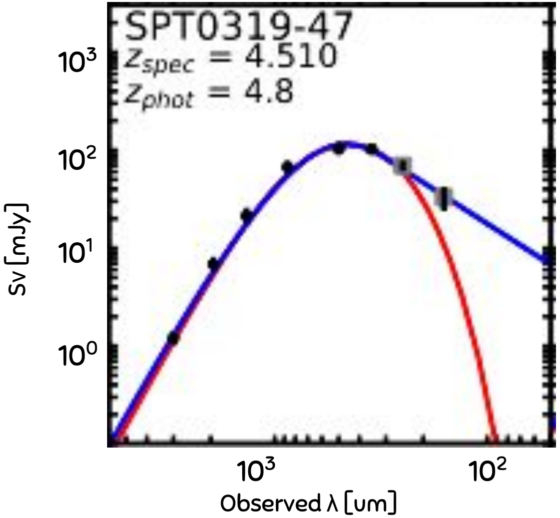
- Sources selected using cuts on flux and signal-to-noise ratio.
- SED fitting performed using modified black body law.

- Obtained values for redshift for 81 sources.
- Derived physical parameters for each source.
- Motivates further studies regarding DSFGs (as current work).

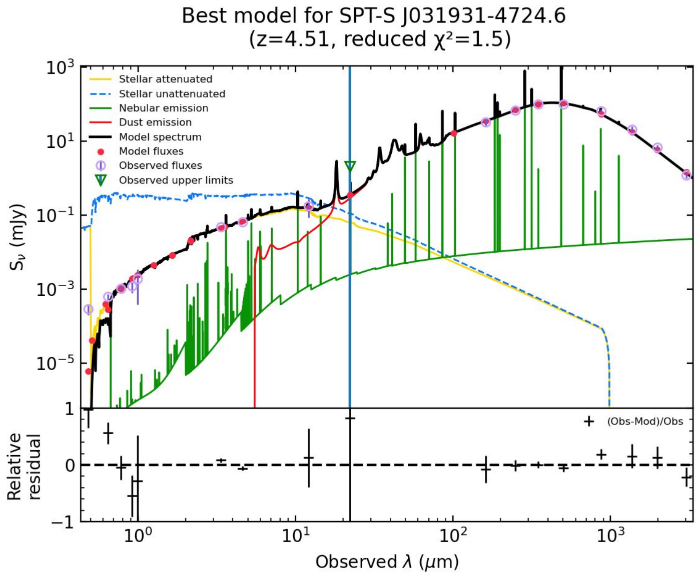
WORKFLOW

1. Using coordinates and redshift, crossmatched with other catalogues
2. 61/81 DSFGs have optical and near infrared data
3. Fitted with CIGALE to derive physical properties
4. Comparison with chemical evolutionary models

A COMPARISON



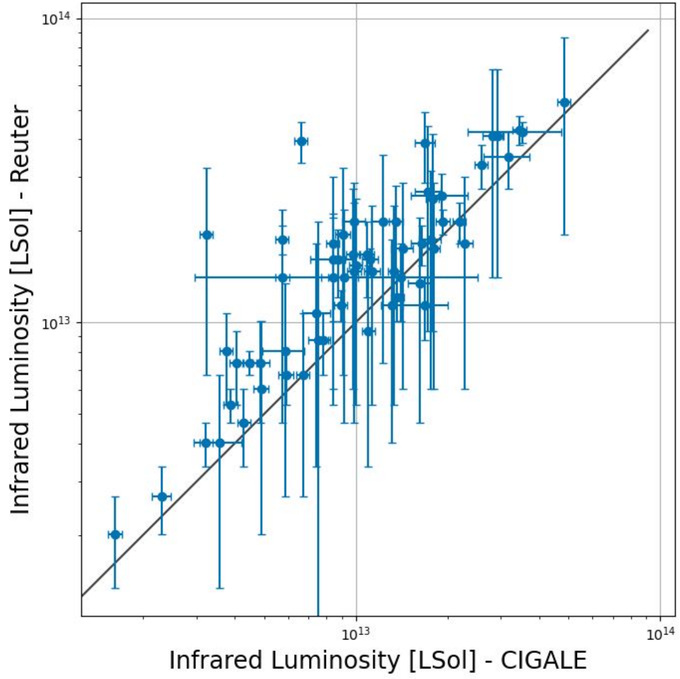
Reuter+20



Sawant et al. (in prep)

INFRARED LUMINOSITY

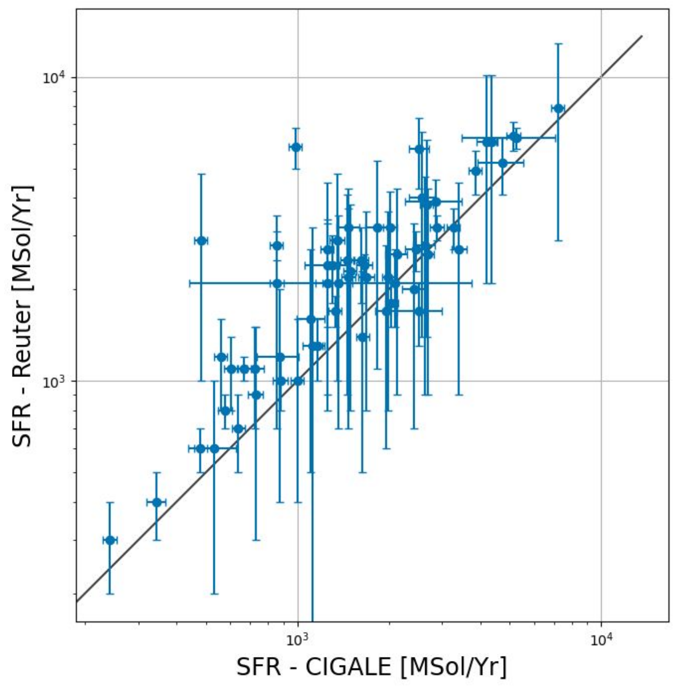
- Agreement with the derived values from Reuter+20
- More constraint on the error bars

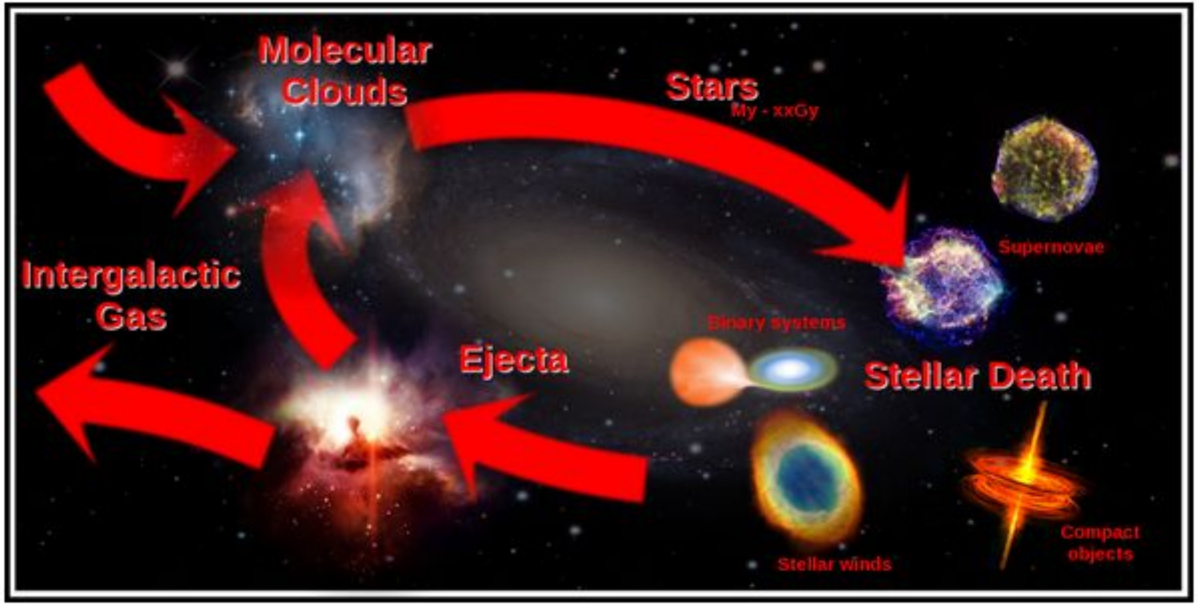


Star Formation Rate

SFR derived from the Infrared Luminosity:

$$\frac{\mathrm{SFR}}{M_\odot\ \mathrm{yr}^{-1}} = 1.49 \times 10^{-10} \mu^{-1} \frac{L_{\mathrm{IR}}[8\text{–}1000\ \mu\mathrm{m}]}{L_\odot}$$





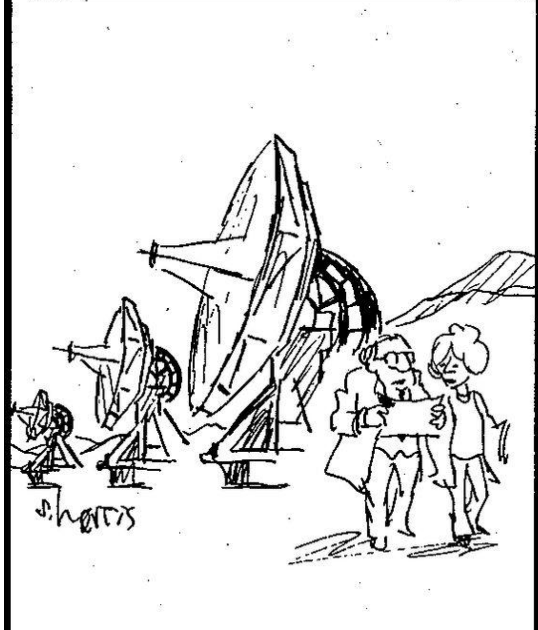
Baryon Cycle

Credits: Richard Longland

EVOLUTIONARY MODELS

Evolutionary models help us to probe the baryonic processes and test our models with observations.

- Enrichment of ISM
- Dust Growth and Destruction
- Inflow/Outflow



" We've discovered a massive dust and gas cloud which is either the beginning of a new star or just a hell of a lot of dust and gas."

Credits: Pinterest

sMDUST VS sSFR

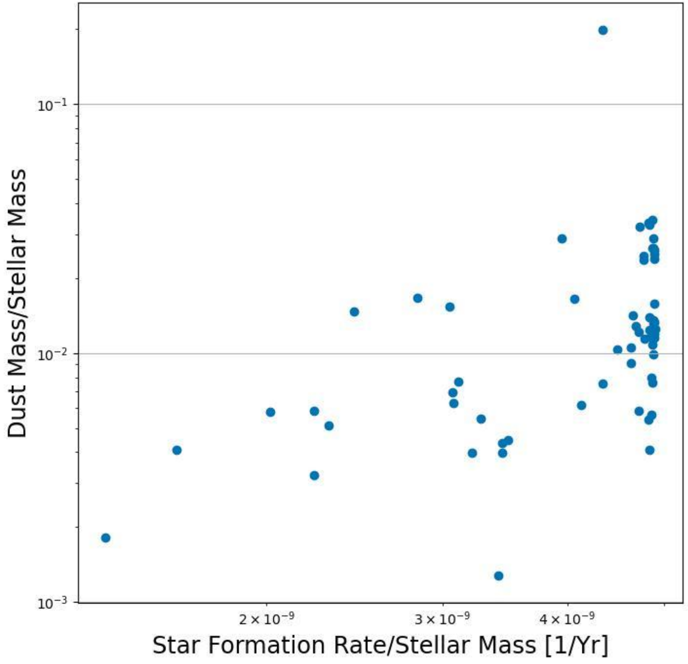
Specific MDust = Dust Mass/Stellar Mass

Gives information about the dust cycle

Specific SFR = SFR/Stellar Mass

Gives information about stellar populations

Useful to probe the baryonic evolution in galaxies

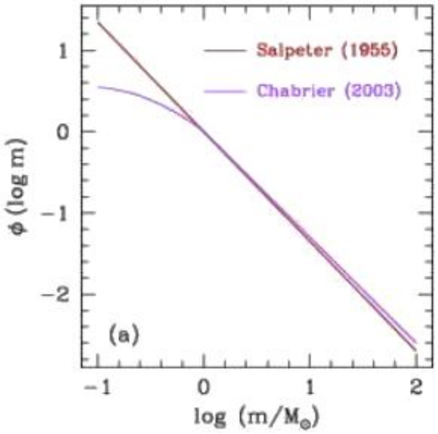


THE IMF STORY

Initial Mass Function is a function that describes the distribution of mass for a population of star.

Salpeter (1955)

Chabrier (2003)



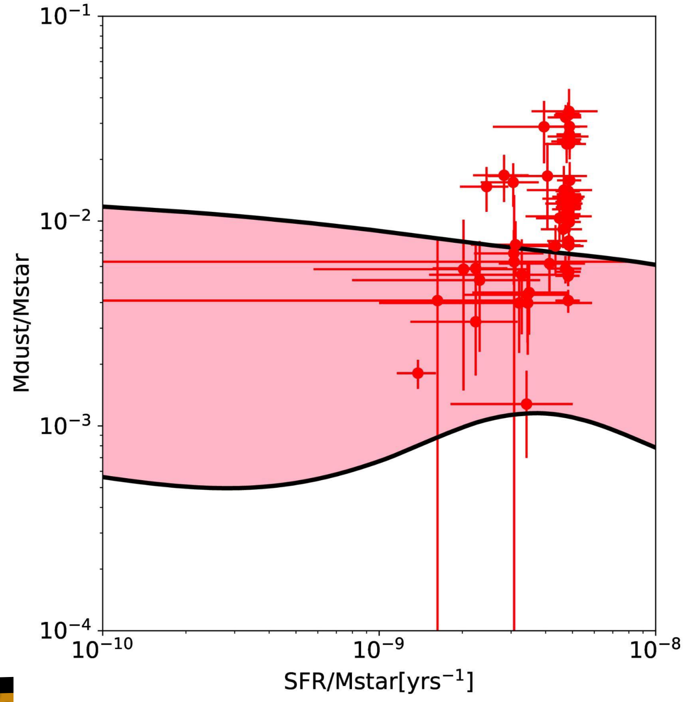
Credits: da Cunha, Elisabete

THE REAL PROBLEM

- The inadequacy of the current models for reproducing the large values of sMDust for large sSFR of DSFGs.

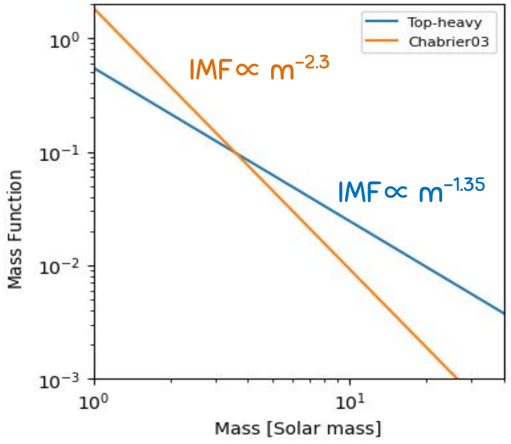
- State-of-the-art framework adopted for interpreting the dust content in these galaxies need to be revised.

Sawant et al. (in prep)



THE SOLUTION*

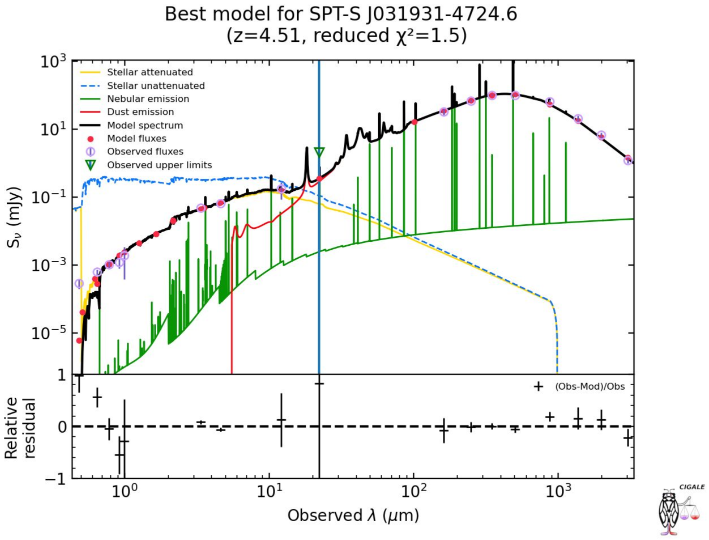
- We adopt a top-heavy IMF
- For this IMF, the Interstellar Medium is rapidly enriched with metals and dust.
- Hence, a large value of sMDust is attained for large values of sSFR.



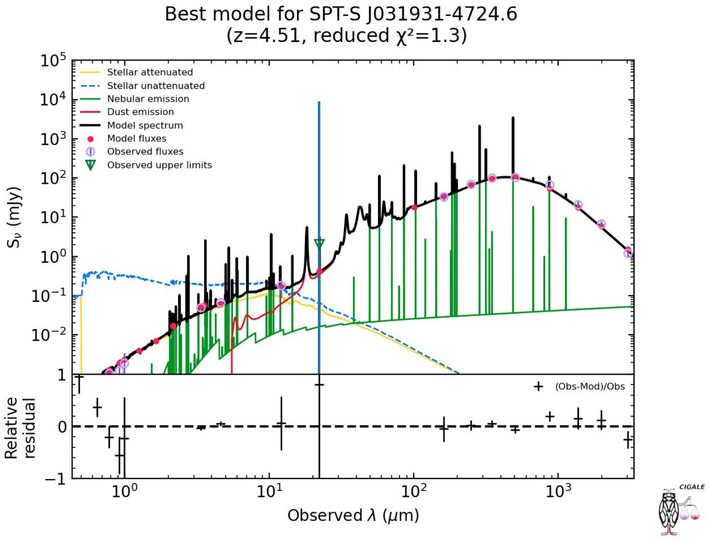
Credits: Nanni, A

*terms and conditions apply

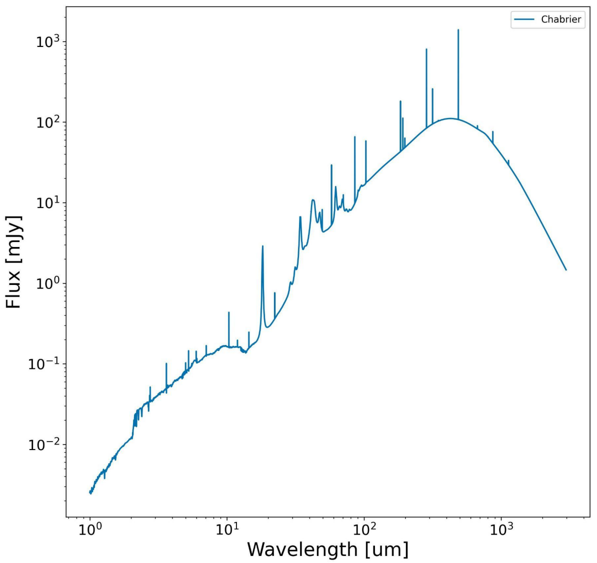
IMF VS IMF



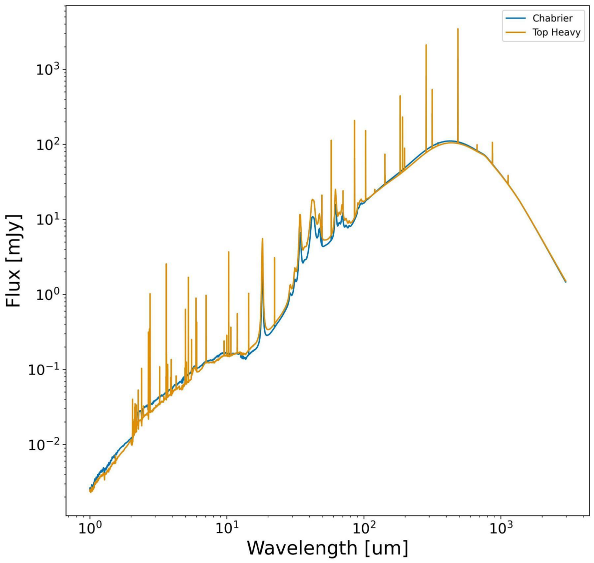
Chabrier



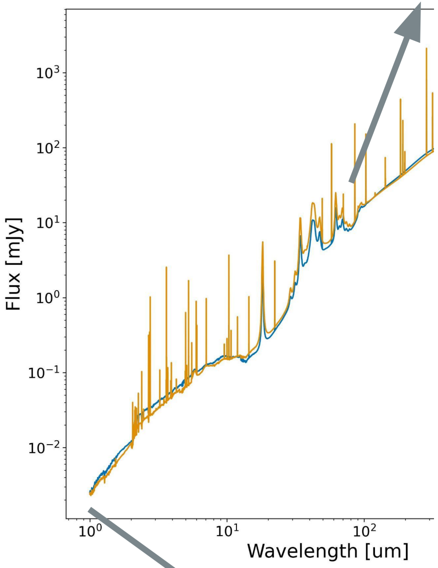
Top Heavy



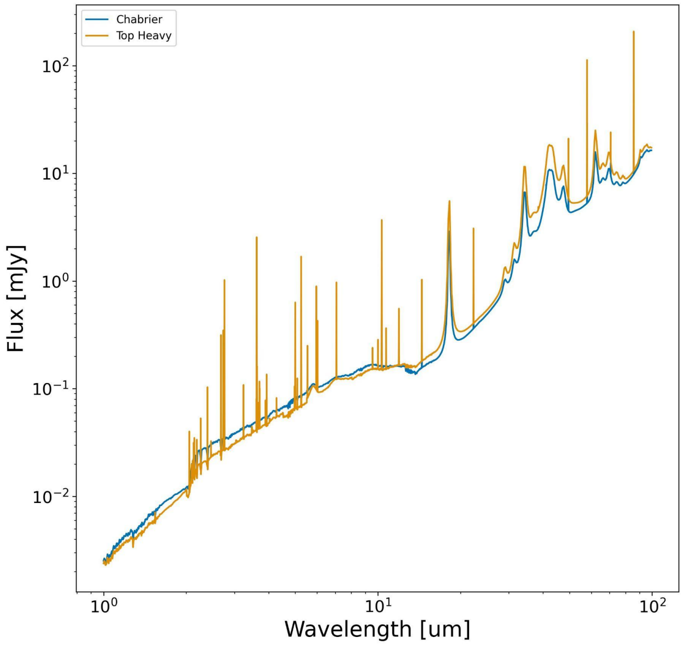
Final fit by assuming Chabrier IMF



Final fits for Top Heavy and Chabrier IMFs

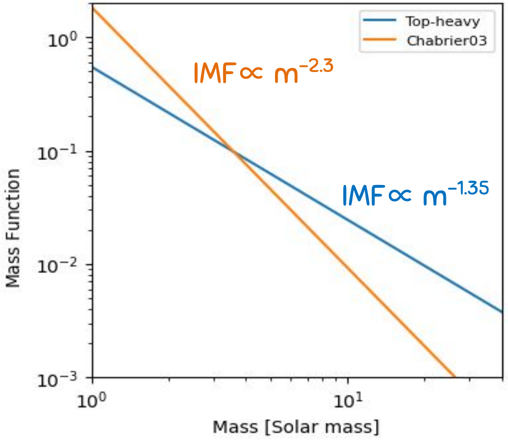


Final fits for Top Heavy and

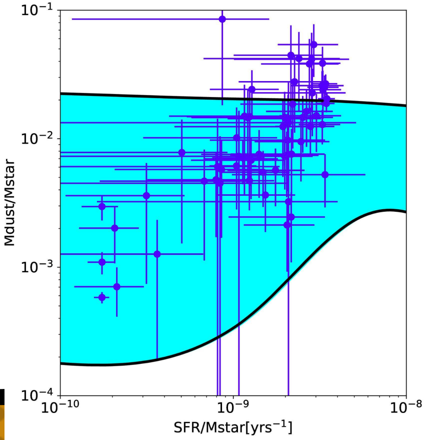


THE SOLUTION*

- We adopt a top-heavy IMF
- For this IMF, the Interstellar Medium is rapidly enriched with metals and dust.
- Hence, a large value of sMDust is attained for large values of sSFR.



Credits: Nanni, A



Sawant et al. (in prep)

*terms and conditions apply

CONCLUSION

FINALLY.

TAKE HOME POINTS

- New Catalog of DSFGs with photometry from optical to FIR bands.
- Revised values for SFR and MDust for the DSFGs from Reuter et. al. 2020.
- Estimates for sMDust and sSFR after obtaining MStar values from CIGALE.
- Study of sources and relevant chemical evolutionary models.
- A top-heavy IMF is able to reproduce the observations (not all).
- Tension in the models and observations motivates further work.
- Drink water, REGULARLY.

"Sure it's beautiful, but I can't help thinking about all that interstellar dust out there."

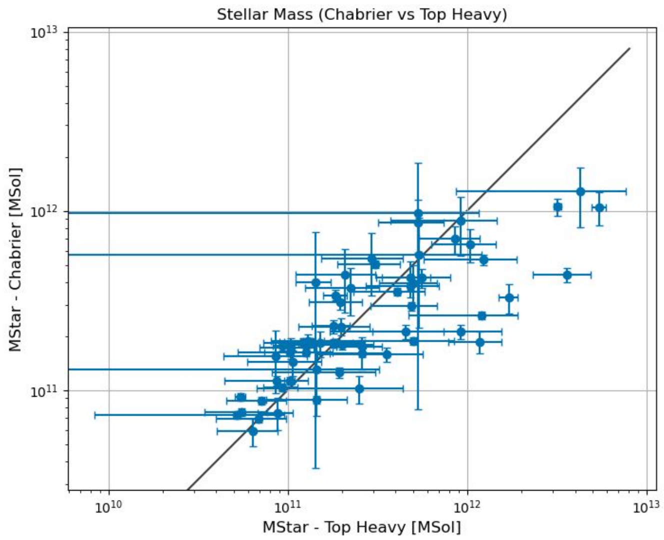
Credits: Pinterest

EXTRA SLIDES

yeah.

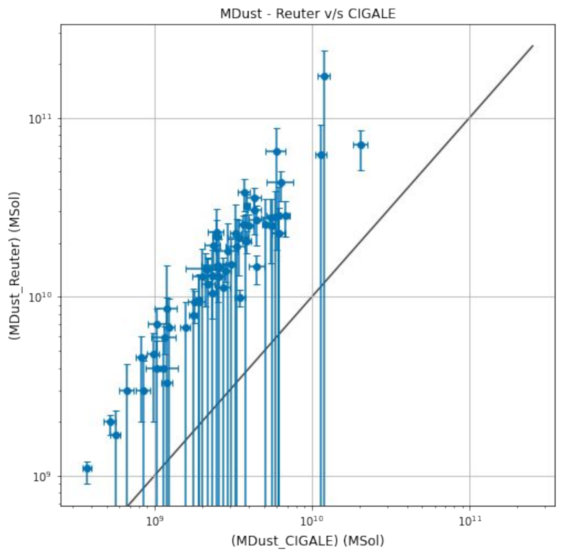
STELLAR MASS

- Stellar mass for some galaxies appears to be more for Top Heavy IMF

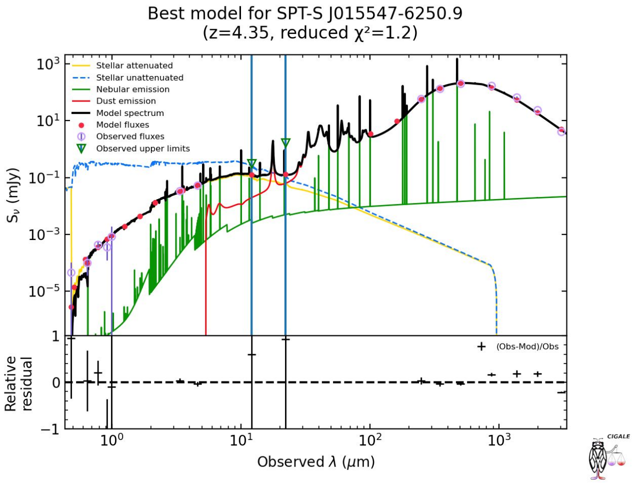


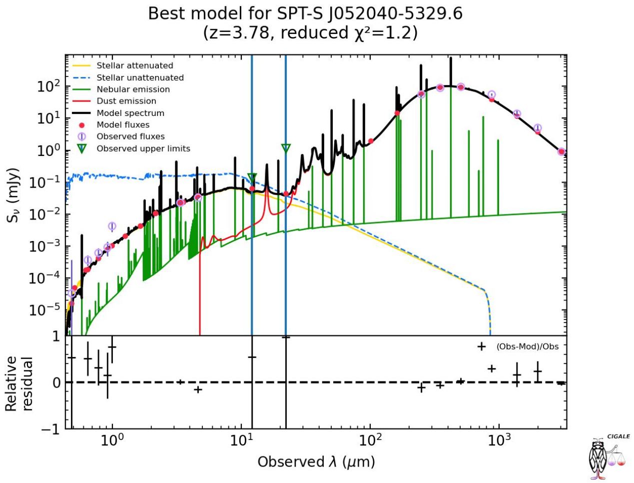
DUST MASS

- Dust Mass is strongly affected by the models used and hence a large discrepancy is found between both analysis.



EXTRA SEDs


Best model for SPT-S J015547-6250.9
(z=4.35, reduced χ²=1.2)
Stellar attenuated
Stellar unattenuated
Nebular emission
Dust emission
Model spectrum
Model fluxes
Observed fluxes
Observed upper limits
Sν (mJy)
Relative residual
(Obs-Mod)/Obs
Observed λ (μm)
CIGALE


Best model for SPT-S J052040-5329.6
(z=3.78, reduced χ²=1.2)
Stellar attenuated
Stellar unattenuated
Nebular emission
Dust emission
Model spectrum
Model fluxes
Observed fluxes
Observed upper limits
Sν (mJy)
Relative residual
(Obs-Mod)/Obs
Observed λ (μm)
CIGALE