The dust continuum properties of zGAL bright dusty star-forming galaxies and their evolution with redshift

Presented by:
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Initiative d'excellence

Faculté des Sciences
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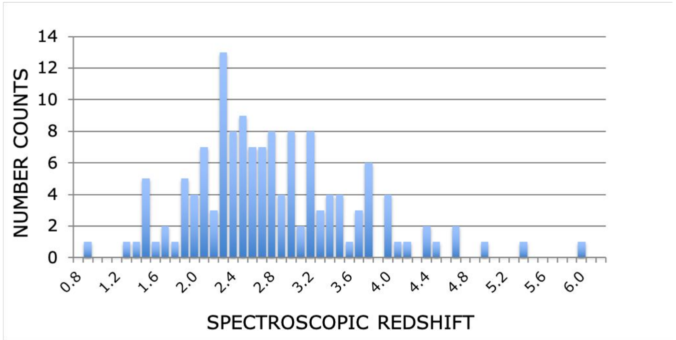
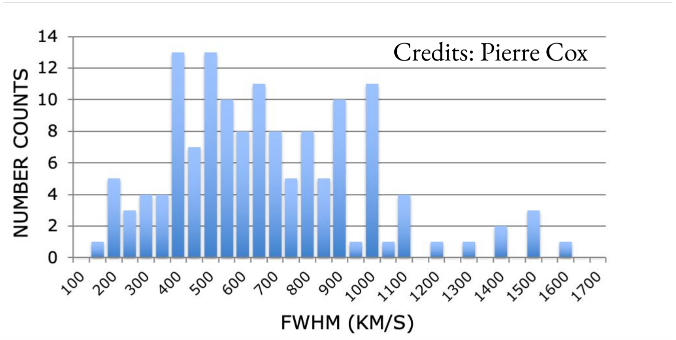
zGAL: A NOEMA Large Program

z-GAL is a NOEMA Large Program that aims for a comprehensive redshift survey of a sample of 126 bright Herschel-selected SMGs selected from H-ATLAS, HerMES & HerS with $S_{500\ \mu m} > 80$ mJy and $z_{phot} > 2$.





Credits: Pierre Cox

The z-GAL Large Program is now completed, with all sources have at least 2 emission lines, yielding robust redshifts.

zGAL: A NOEMA Large Program

Main goals:

- Increase significantly the number of SMGs with known redshifts at the peak of the cosmic star-formation rate density (2<z<3)
- Find a substantial number of high-redshift hyper-luminous infrared galaxies, study their physical properties, and trace other rare objects (e.g., AGN/Starbursts);
- Enable follow-up observations of lensed sources;
- **Explore the physical properties of this complete large sample of dusty luminous star-forming galaxies in the early universe.**

Introduction: Dust in Galaxies

- Dust is present in galaxies and a crucial component of the ISM
- Dust plays an important role in star formation
- Dust varies with redshift: the bulk of light emitted in the high-z universe is in the Infrared domain

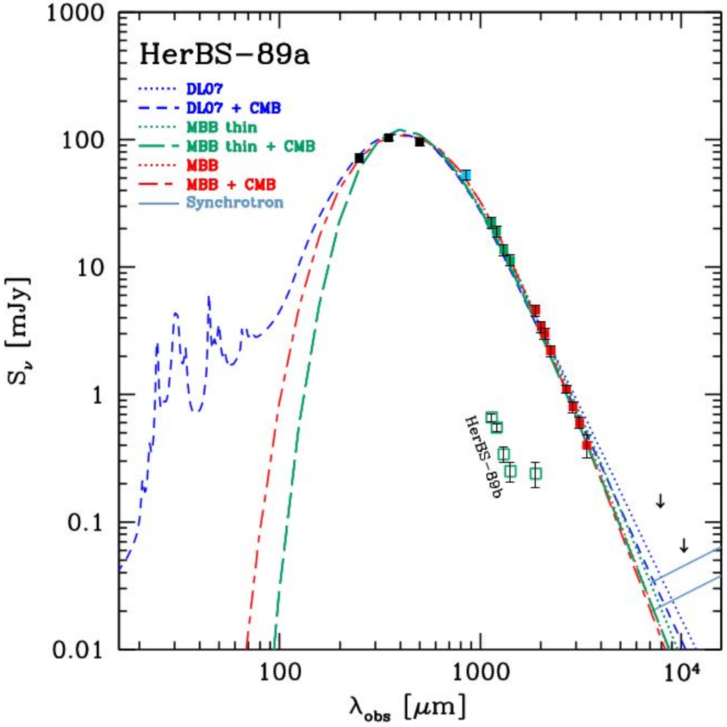
Credits: Judy Schmidt

⟹ High-z galaxies have large reservoirs of dust obscuring the high star-formation rates, absorbing the UV emitted by young stars and re-emitting in the IR domain

Introduction: Importance of studying dust

- Studying galaxies through cosmic time and understanding their properties could help us put together a picture of galaxies' evolution in a cosmological context.
- Dusty star-forming galaxies, at high redshifts, can tell us vital information about the stellar formation rates which is crucial to understanding their nature

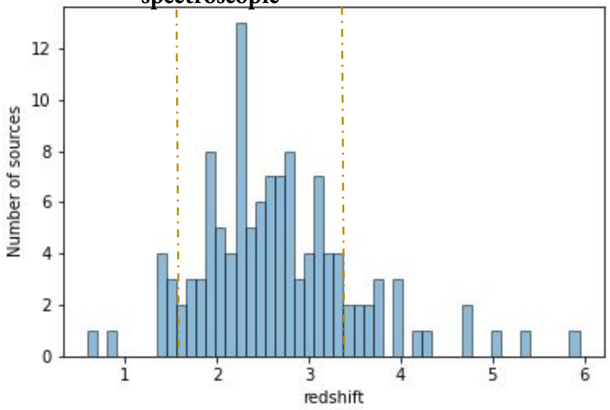
Berta+2020



zGAL Continuum Fluxes

126 sources with observed wavelengths covering:

- Herschel: 250, 350, 500 μm
- SCUBA-2: 850 μm (for the H-ATLAS sources)
- NOEMA: 3mm & 2mm (where most bands have continuum fluxes)



$z_{spectroscopic}$ distribution

Most sources are in the range of the peak of cosmic SFR

Thermal emission by dust

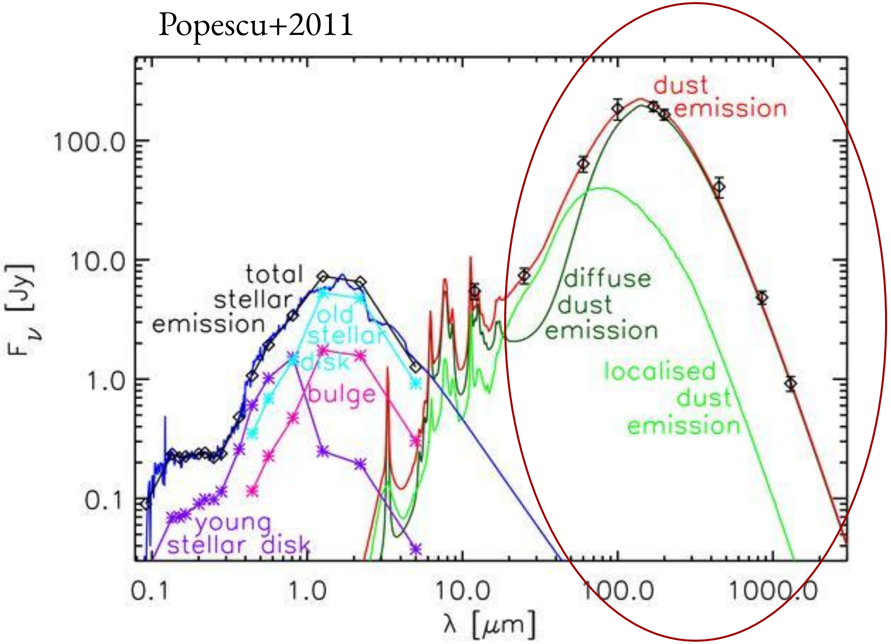
Dust emission is similar to a blackbody modified by a frequency-dependent emissivity

$$S_{\nu} \propto \epsilon_{\nu} B_{\nu}(T_{dust})$$

From which we can estimate dust properties including:

- Temperature
- Mass
- Emissivity index
- Luminosity

Popescu+2011



Thermal emission by dust

$$S_\nu \propto \boxed{\epsilon_\nu} B_\nu (T_{dust})$$

General Modified Blackbody

$$S_\nu = \frac{A}{D_L^2} (1+z) \boxed{\left(1 - e^{-\tau_\nu}\right)} B_\nu \left(T_{dust}\right)$$

$$\tau_\nu = \tau_0 \left(\frac{\nu}{\nu_0}\right)^\beta$$

Where ν_0 is the frequency at which the optical depth is unity (λ_0 is the widely used variable to represent the optical depth and is usually fixed at 100 μm)

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General Modified Blackbody

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Optically Thin Modified Blackbody

$$S_\nu = \frac{M_{dust}}{D_L^2}(1+z)\,\kappa_\nu B_\nu\left(T_{dust}\right)$$

At λ_{rest} >450μm, $\tau_\nu << 1$

$$\tau_\nu = \kappa_0\left(\frac{\nu}{\nu_0}\right)^\beta \frac{M_{dust}}{A}$$

Thermal emission by dust

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Also, corrected for the CMB effect as described in daCunha+2013

Testing the limitations on G-MBB: Mock catalogue

Mock parameters:

- $1 < \beta < 3$
- $20 < T_{dust} < 80$ (K)
- $8.5 < M_{dust}/M_{sun} < 10.5$ (in log)
- $50 < \lambda_0 < 250\,\mu m$
- $1 < z < 5$

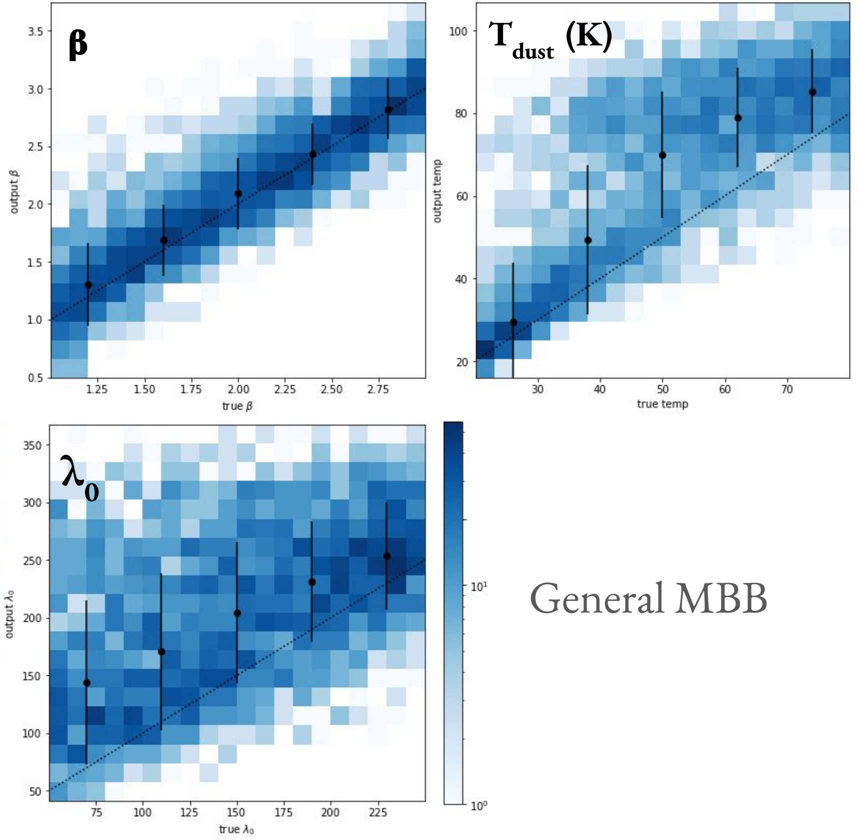
Coverage:

- 250, 350, 500, 850 μm
- 2mm & 3mm

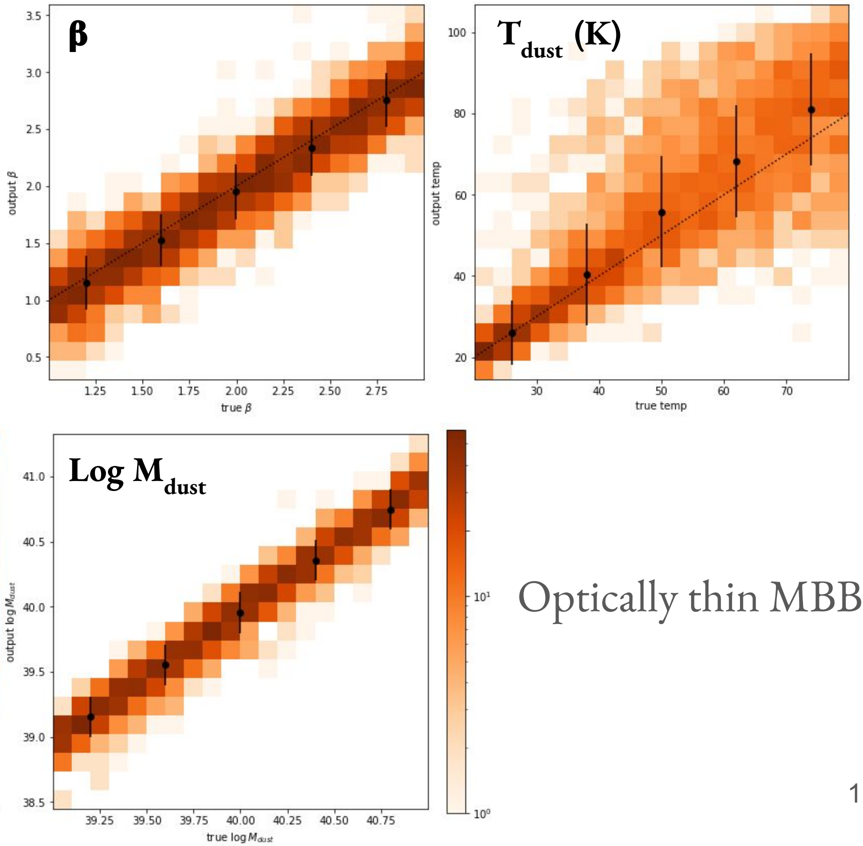
Fluxes are then estimated and chosen from a normal distribution with 1σ given as a 15% error bar

Testing the limitations on G-MBB (Compared to opt. thin)

Using our developed tool along with mcmc to estimate the output parameters



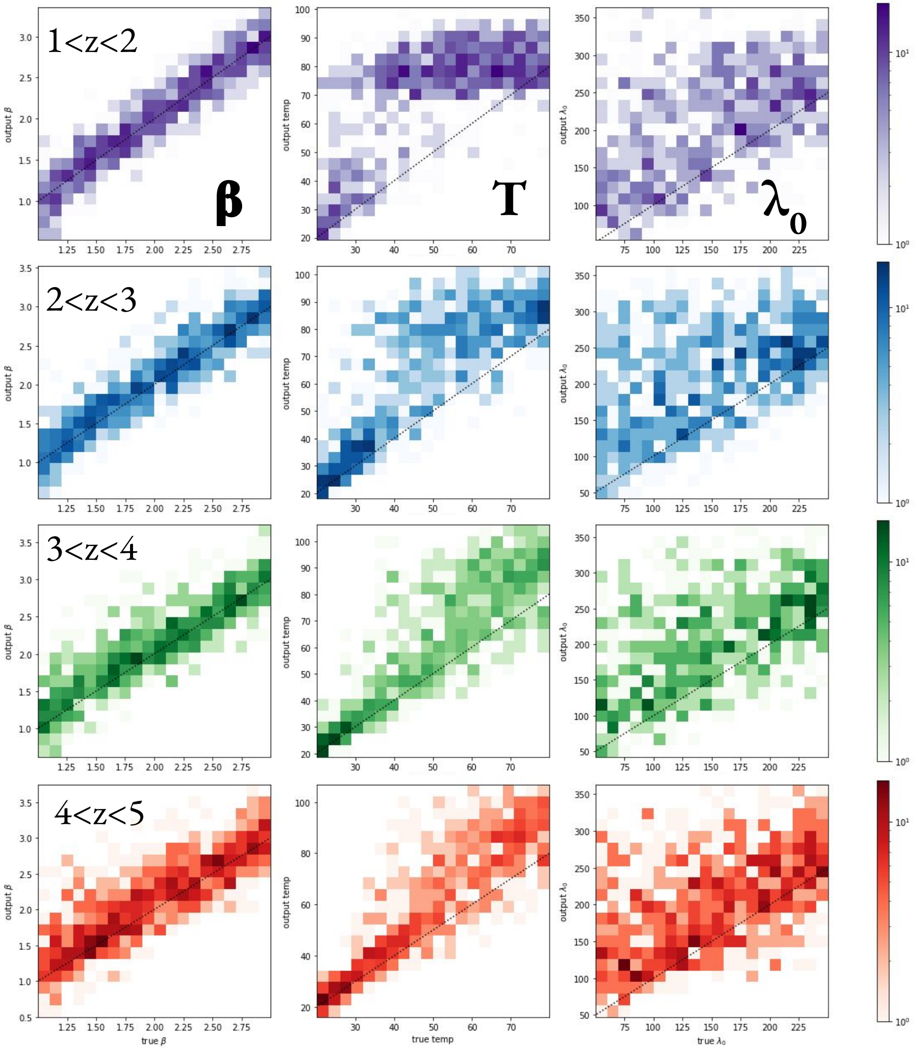
General MBB



Optically thin MBB

Testing the G-MBB:

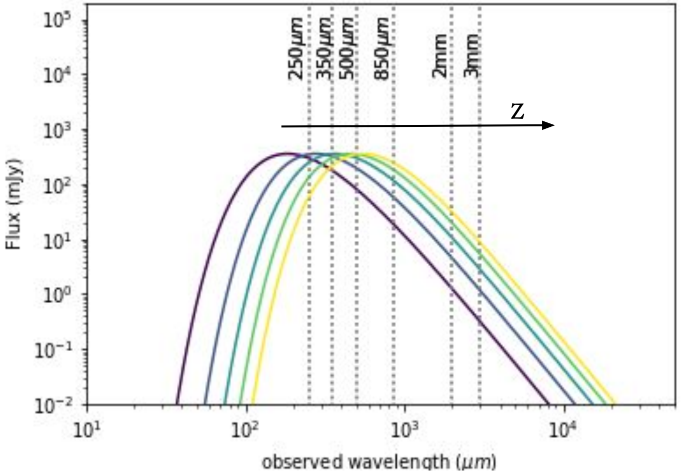
- Redshift binned mock data shows a dramatic scatter in dust temperatures in the range 1 < z < 2
- λ_0 is not constrained across redshift

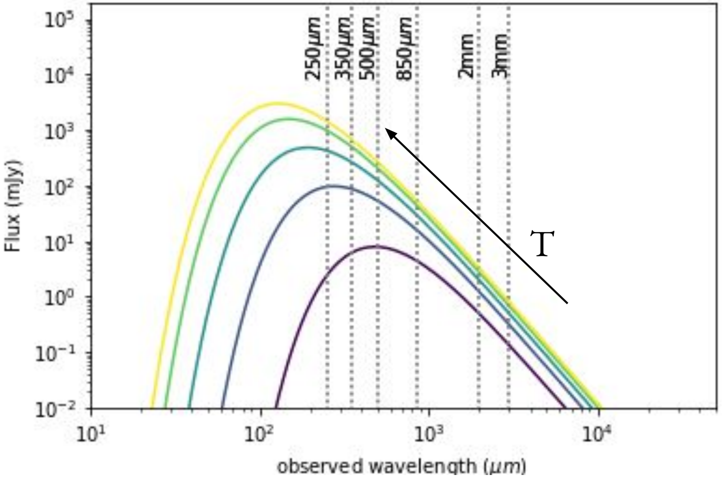


Increasing redshift

Testing the MBB: Why the large scatter of T_{dust}?

Add herschel data , scuba 2, noema





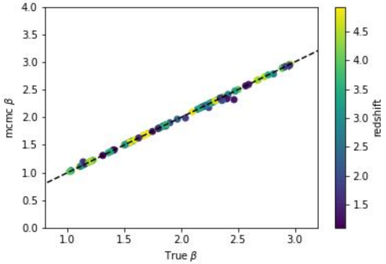
At redshifts < 2 - 2.5 and for intrinsic temperatures > 35-40 K, the peak is poorly sampled

⇨ Unable to constrain T_{dust}

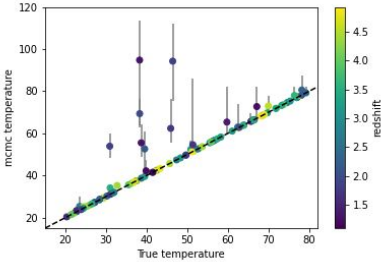
Testing the G-MBB: Mock data

Ideal sample (no error bars)

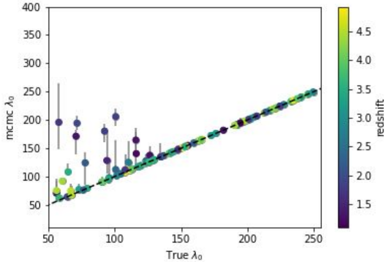
β



T



λ_0

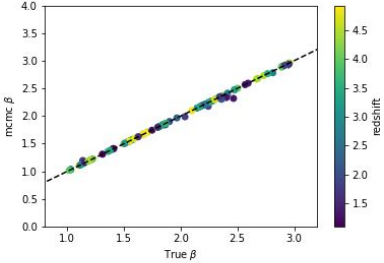


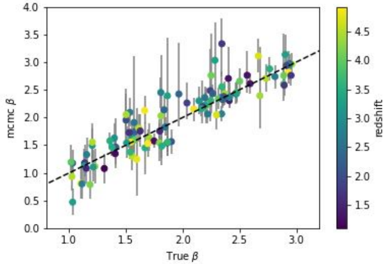
Testing the G-MBB: Mock data

Ideal sample (no error bars)

Missing SCUBA-2 850μm flux

β





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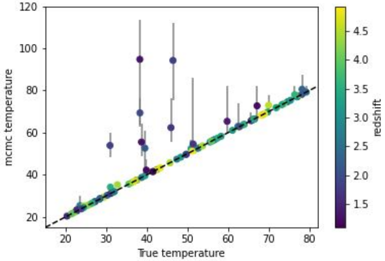
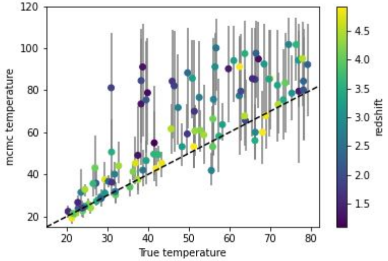
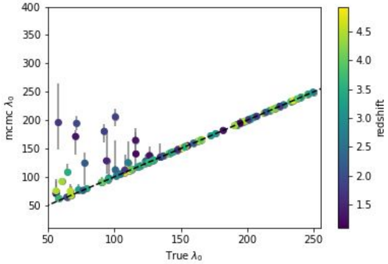
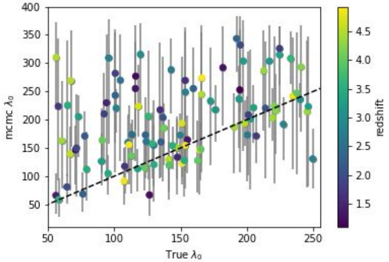




λ_0





Testing the G-MBB: Mock data

Ideal sample (no error bars)

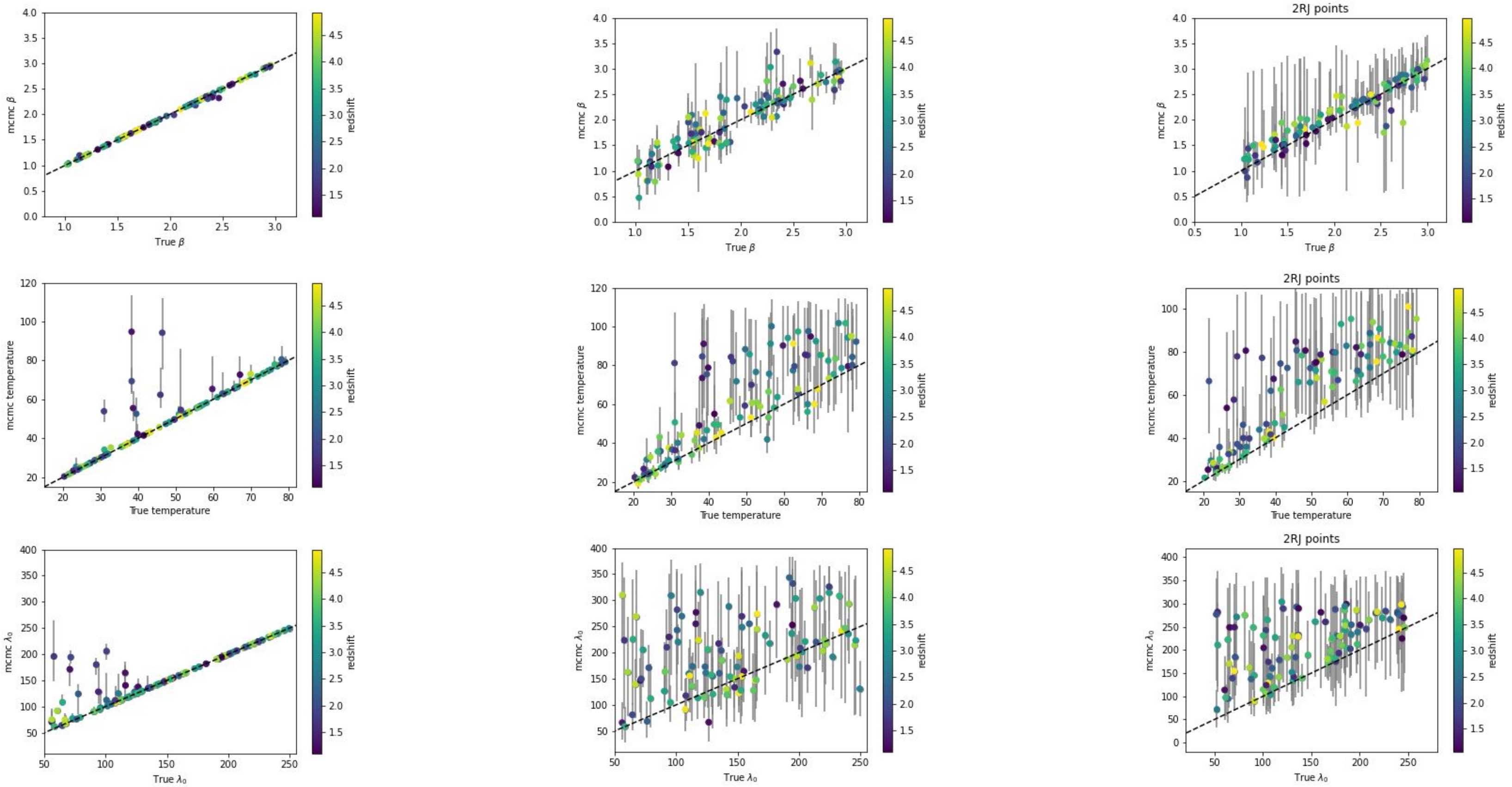
Missing Scuba 850μm flux

Insufficient data along the RJ

β

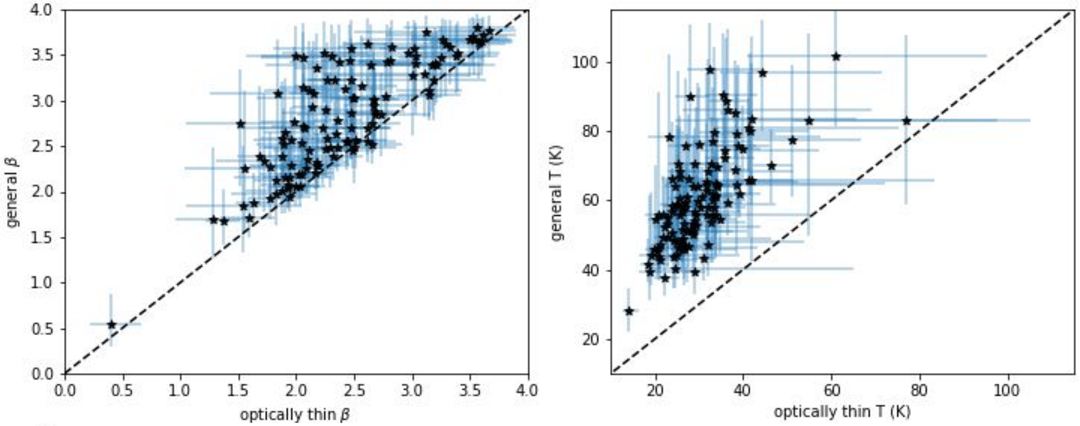
T

λ_0



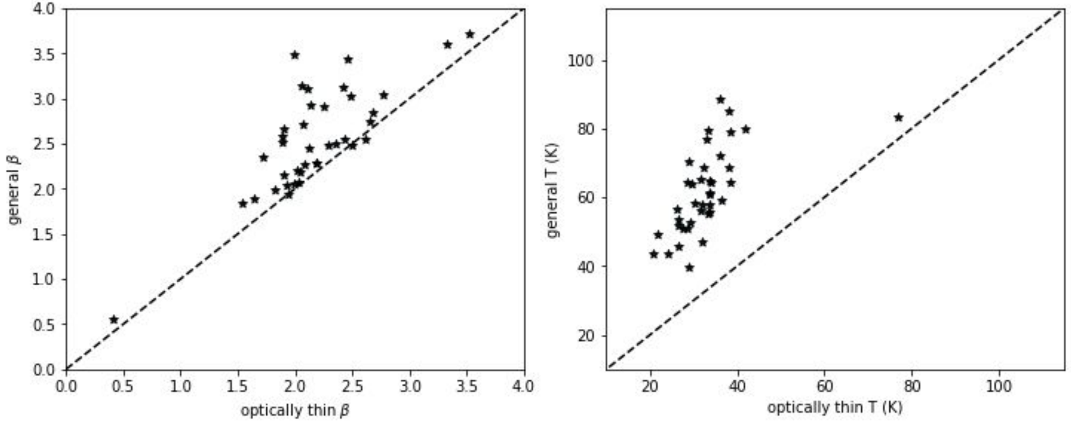
z-GAL dust properties

Full sample



Sources with good sampling:

- At least 2 RJ data points
- Including SCUBA data point



z-GAL dust properties

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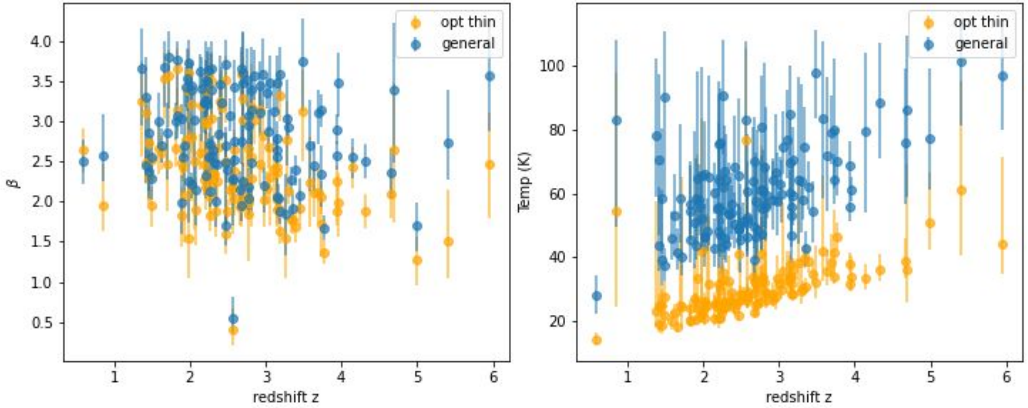

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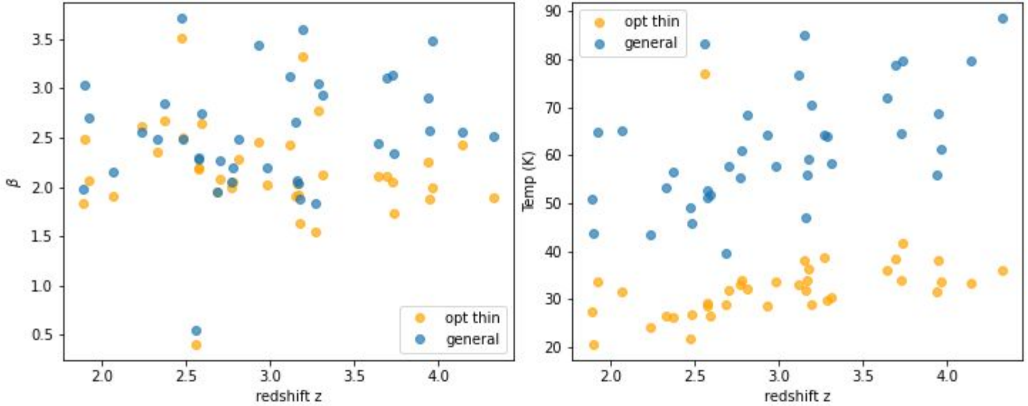

Summary

- **Summary and conclusion:**
  - Estimating dust properties with the G-MBB is challenging due to different factors (mainly redshift & degeneracies) and is dependent on the model.
  - For these galaxies, β can be well estimated taking into consideration a good sampling along the RJ and having SCUBA data that transitions between the peak and the RJ
  - The use of λ_0 without having physical constraints does not yield a good parameter estimation.
- **Further steps:**
  - Estimate dust mass using an optically thin approximation of the flux density at higher wavelengths where the medium becomes optically thin
  - The G-MBB can be written in terms of M_{dust} and a galaxy's physical size.

  How well can we constrain the physical properties having an estimate of a galaxy's size?