DETERMINING THE MASS OF COSMIC DUST: THE SYSTEMATIC ERRORS INDUCED BY TEMPERATURE-DEPENDENT OPACITY

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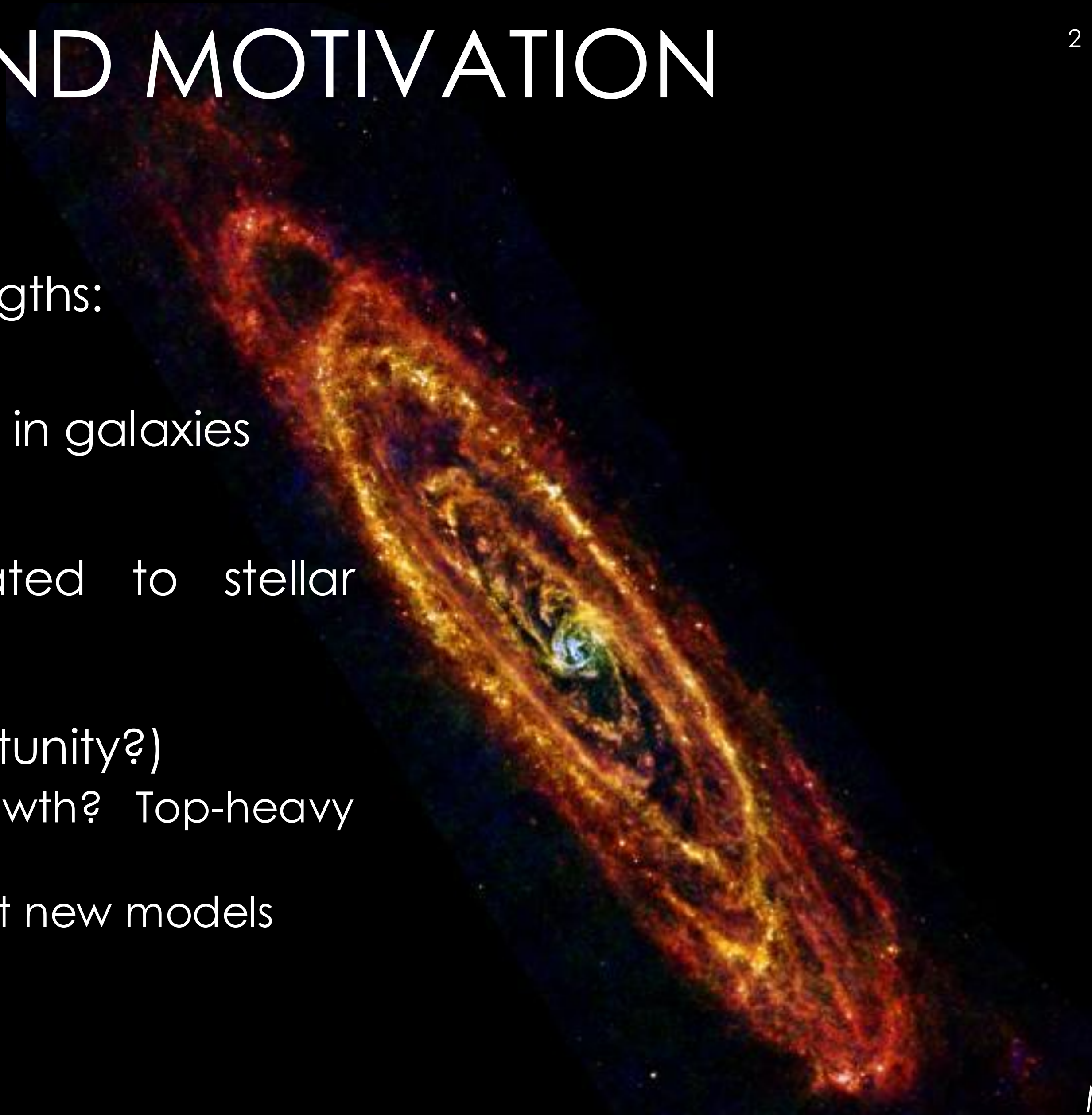
CONTEXT AND MOTIVATION

Interstellar Dust

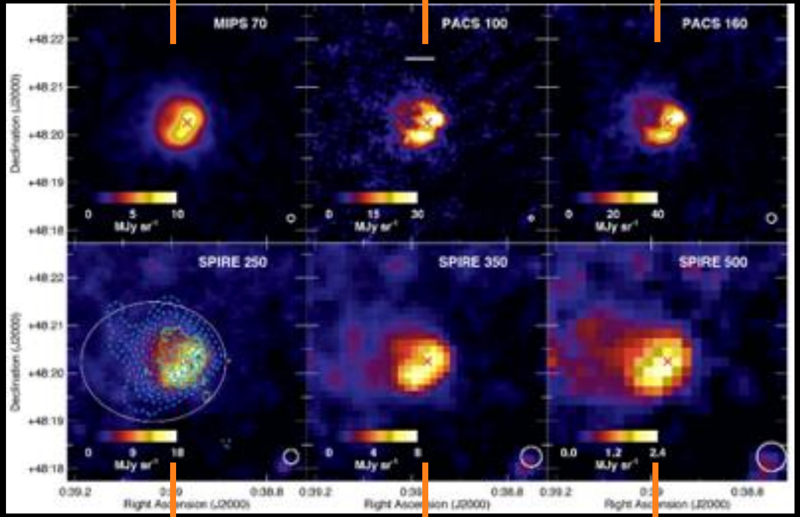
- Observed at FIR/submm/mm wavelengths:
  50 µm – 1+ mm (large grains)
- Reprocesses 25-99% of stellar radiation in galaxies
- Traces all phases of interstellar gas
- Cosmic abundance evolution related to stellar evolution

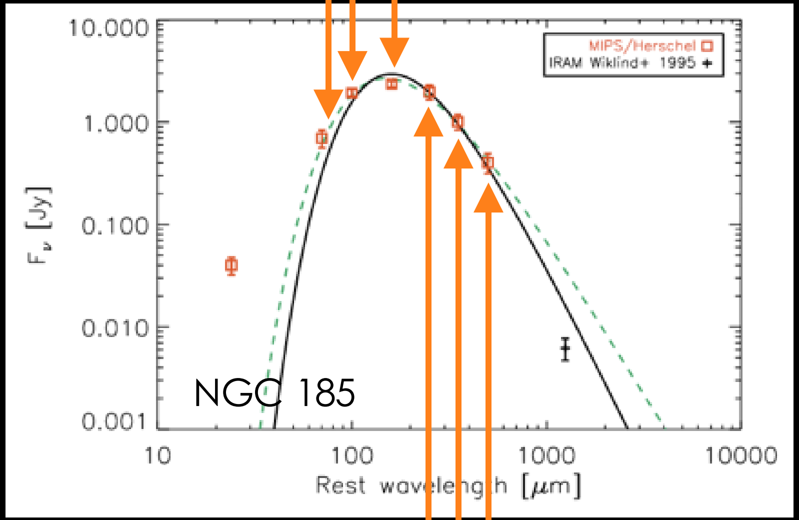
- Dust Budget Crisis (Dust Budget Opportunity?)
  - Supernova contributions? Grain growth? Top-heavy initial mass function?
  - ➢ Dust masses needed to accurately test new models



M31
ESA/Herschel/PACS & SPIRE Consortium, O. Krause, HSC, H. Linz

SED FIT: THE MODIFIED BLACKBODY (MBB)





De Looze+16

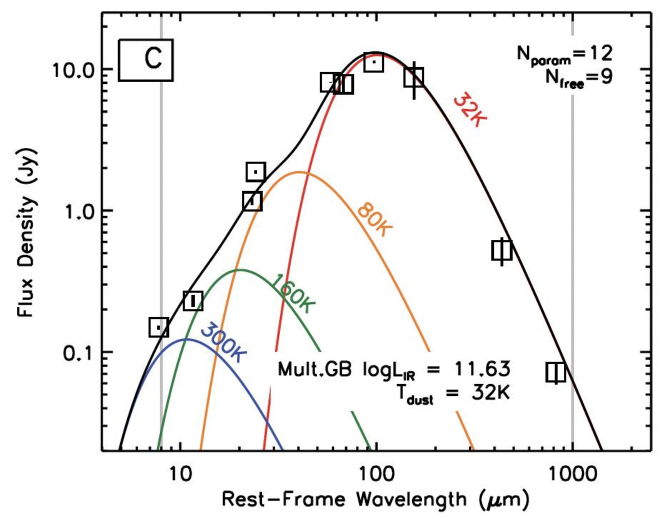
$$F_\nu(T) = \frac{1}{d^2} M \cdot \kappa(\lambda) \cdot B_\nu(T)$$

Power law (PL) opacity: $\kappa(\lambda) = \kappa_0 \left(\frac{\lambda}{\lambda_0}\right)^{-\beta}$

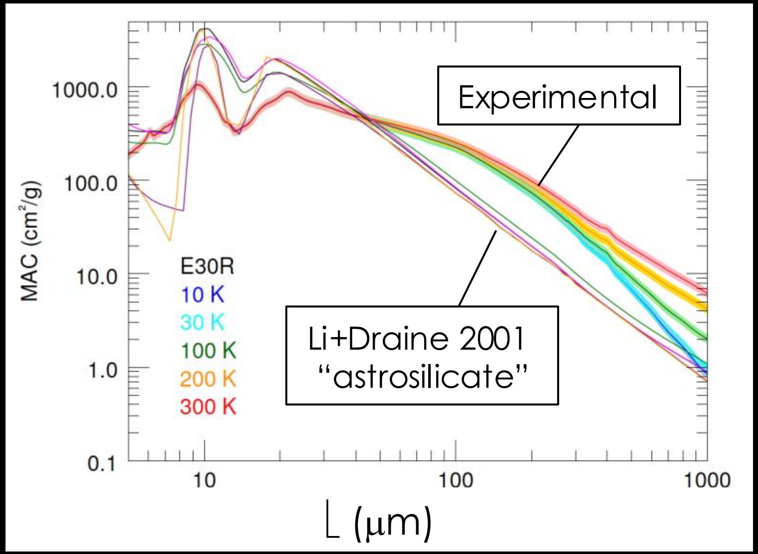
2 – 3 parameters:
M, T, (β)

MBB SYSTEMATICS

Casey+12



Demyk+17



Line-of-sight/beam temperature variations

Fitting a single-temperature SED results in:

- Underestimating β
- Overestimating T
- Underestimating M

  e.g., Shetty+09a,b

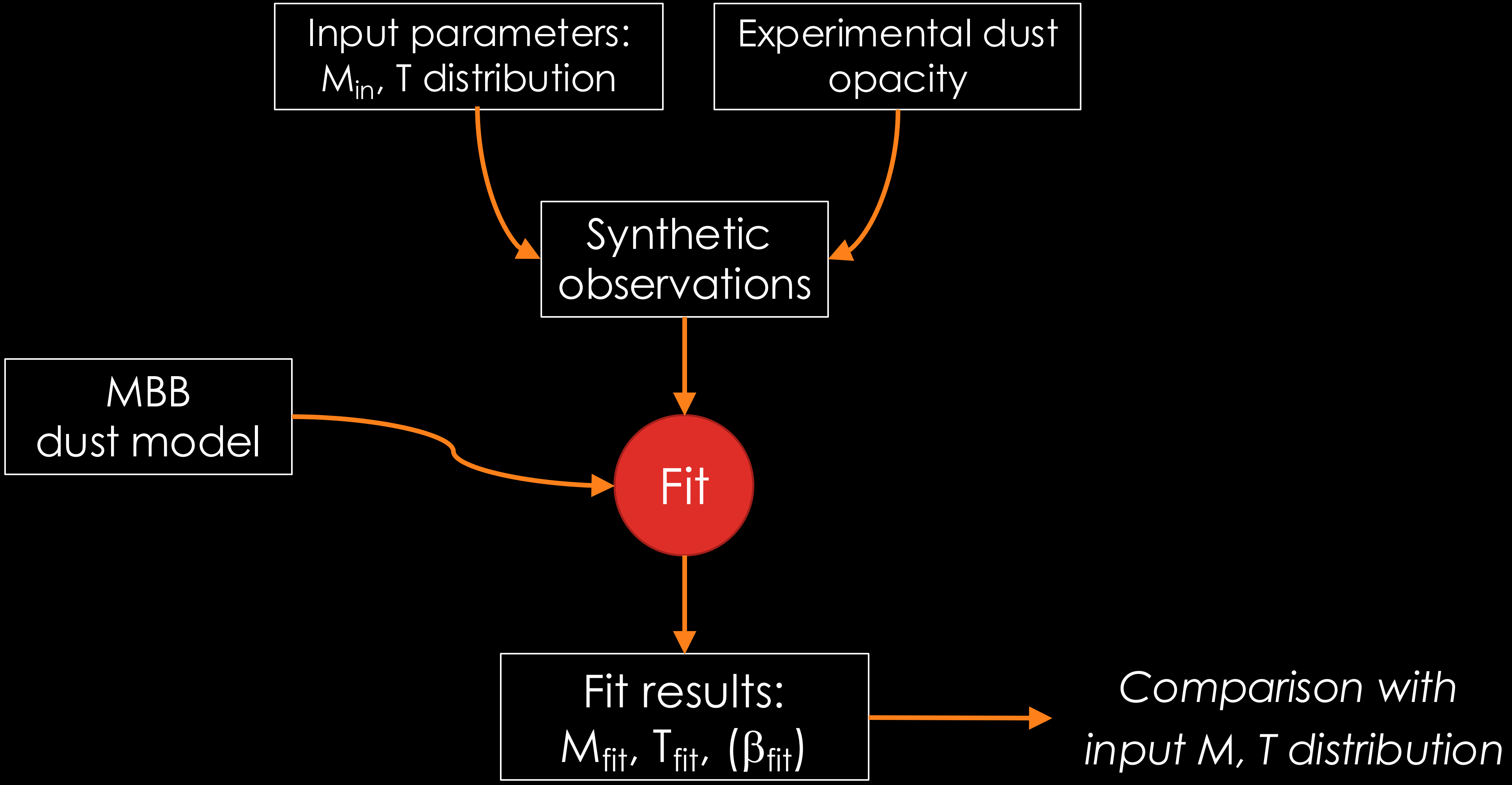
Insights from experimental opacity

FIR/submm opacities measured in the lab tend to be:

- Higher than in most models → overestimated dust M?

  (Demyk+17, 22; Fanciullo+20)
- Temperature-dependent, especially at long wavelengths
- Not a simple power law

HOW TO TEST FOR MBB SYSTEMATICS?



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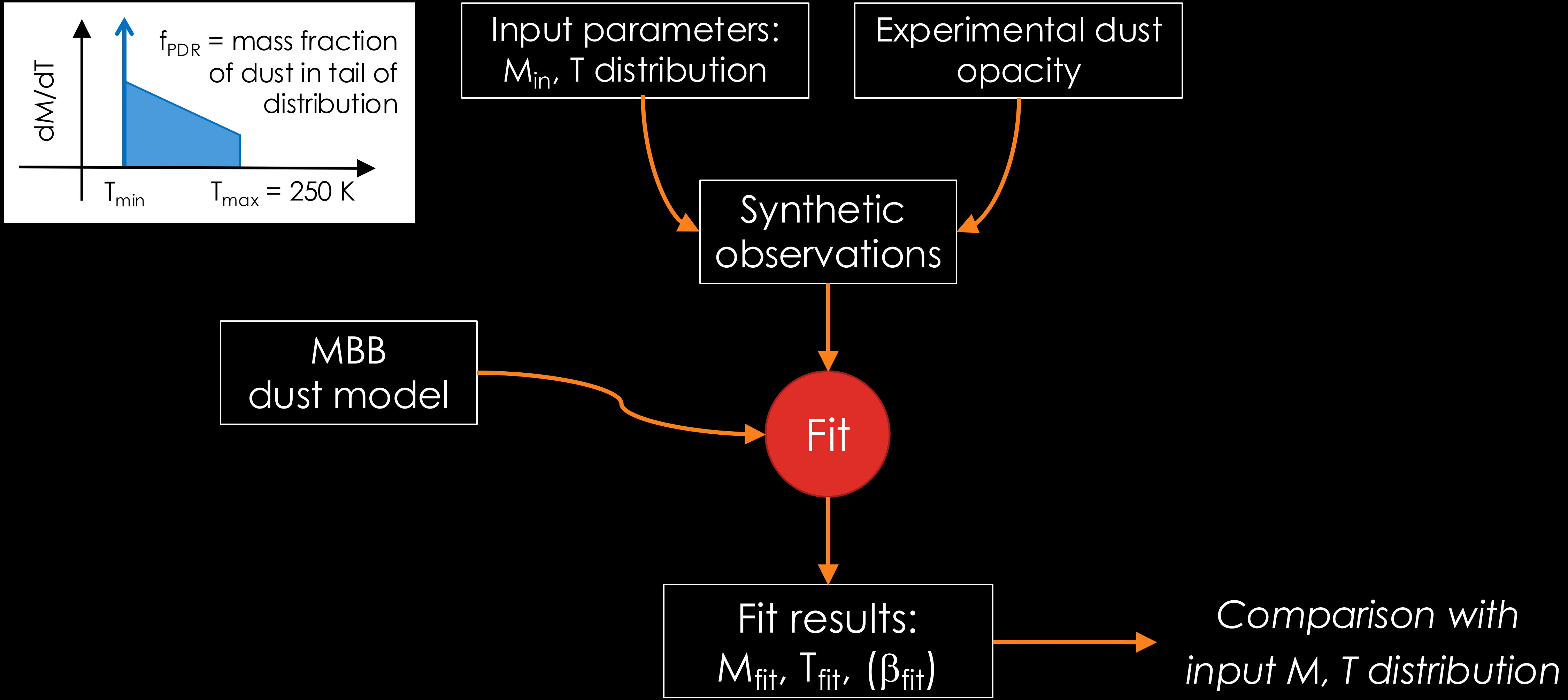

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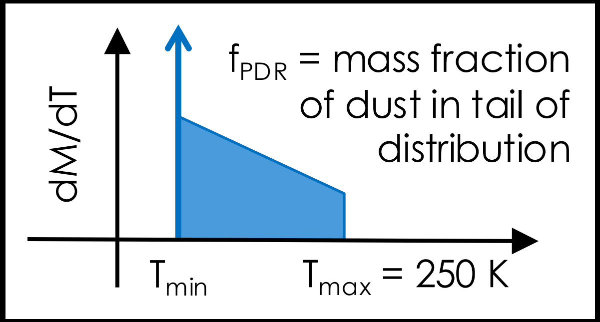


Input parameters: M_{in}, T distribution

Experimental dust opacity

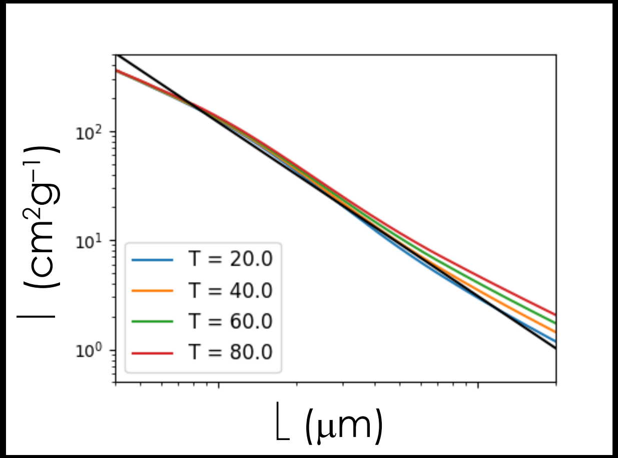
Synthetic observations

MBB dust model

Fit

Fit results: M_{fit}, T_{fit}, (β_{fit})

Comparison with input M, T distribution



70% Fe-Mg silicates: Demyk+17

30% am. carbon: Mennella+98

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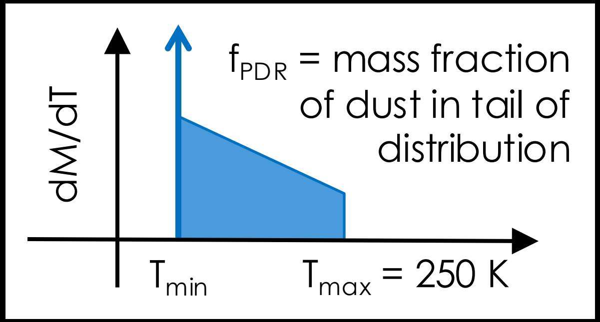

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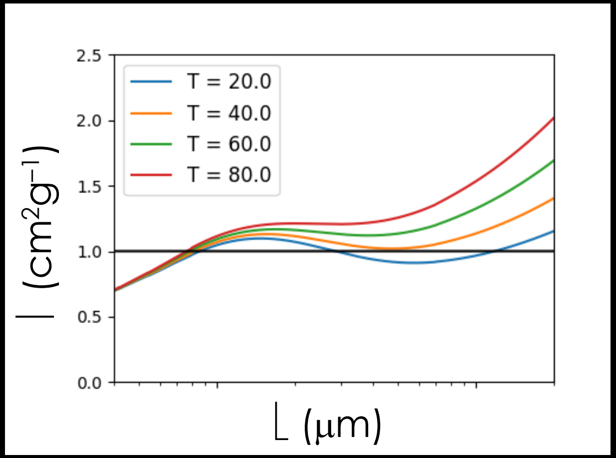

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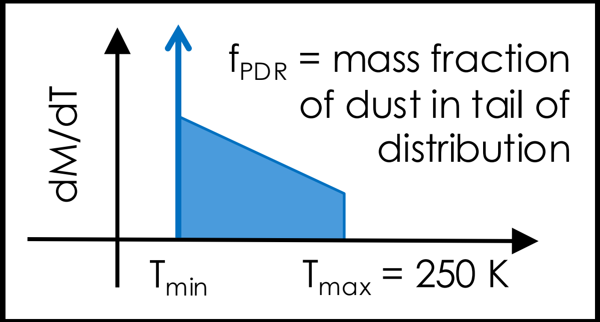

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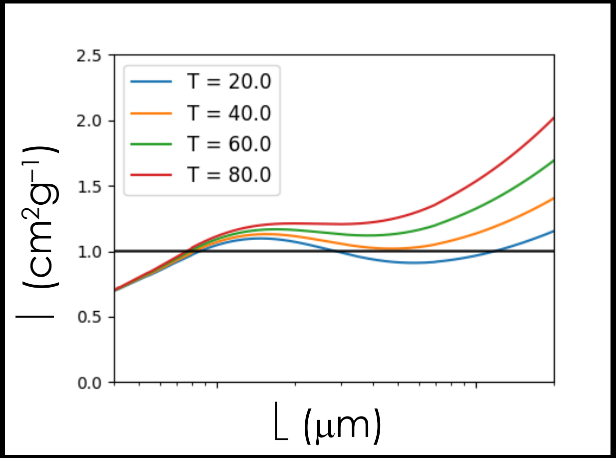

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Single-temperature

Power-law opacity

$\beta = 1.6$

$\kappa_{100\mu m} = 120\ cm^2g^{-1}$

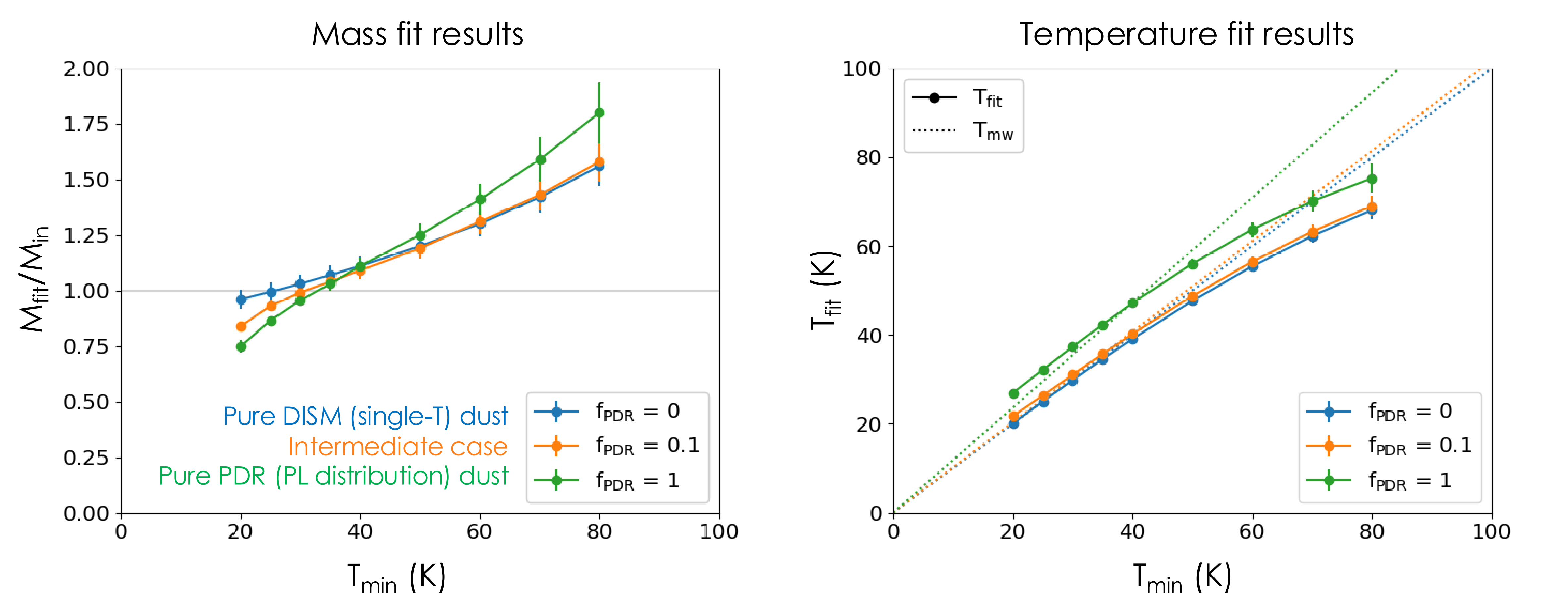
Fit

Fit results: M_{fit}, T_{fit}, (β_{fit})

Comparison with input M, T distribution

FIT RESULTS (I): FIXED β

7 bands (Herschel, SCUBA-2); λ range: 70 – 850 μm



Fanciullo et al., in preparation

FIT RESULTS (II): FREE β

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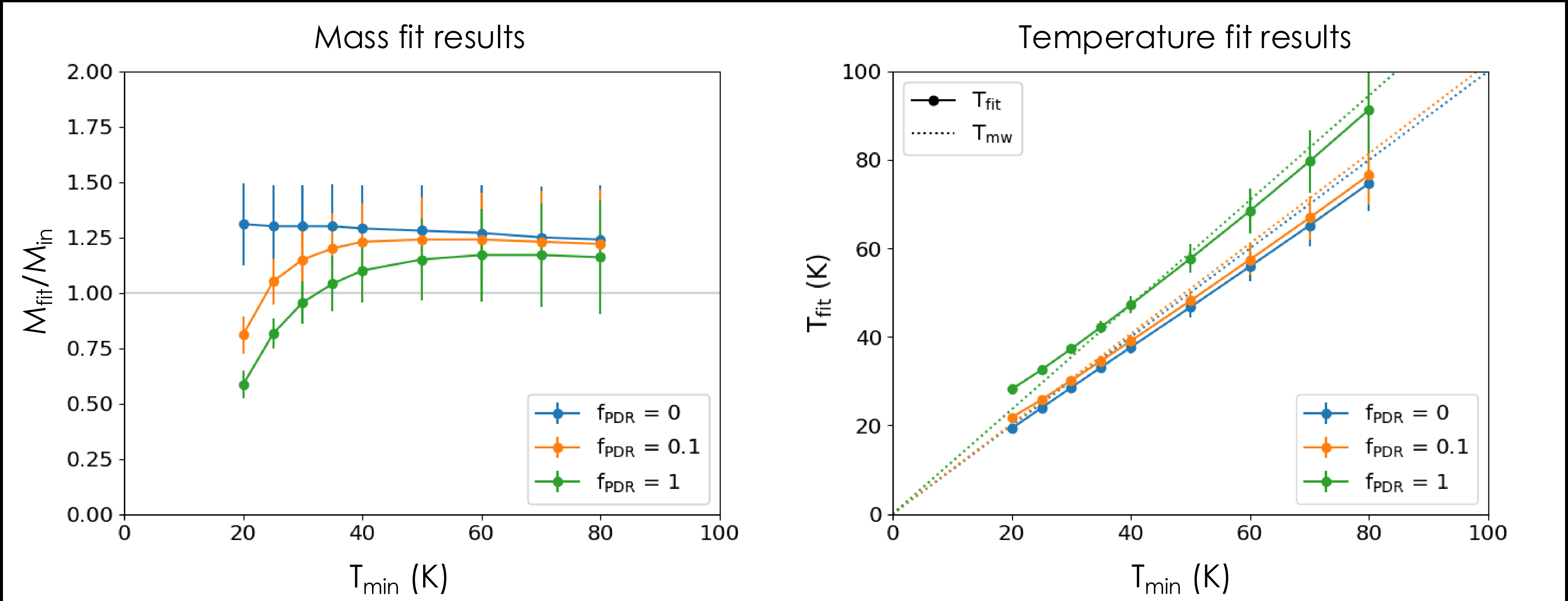

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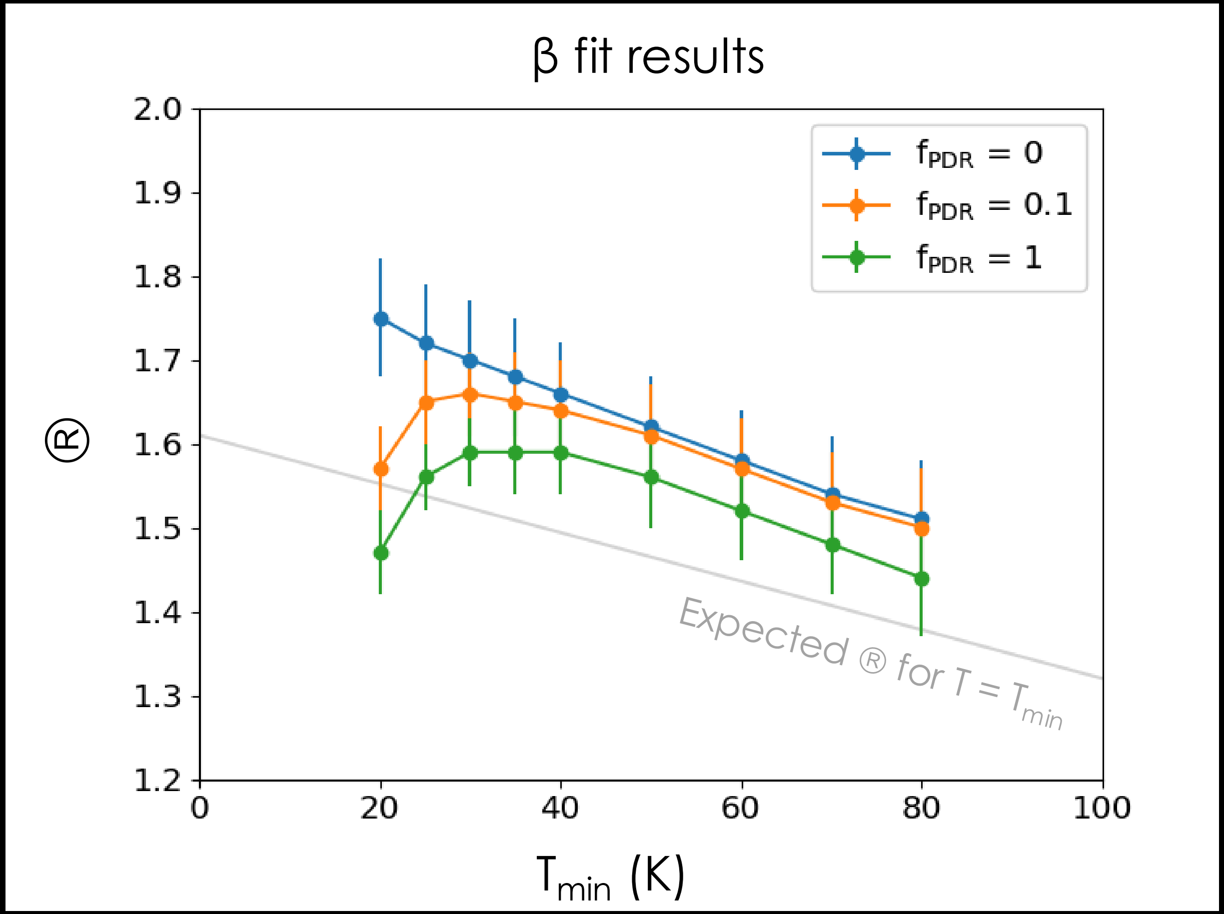

- The systematics on M_{fit} are no longer T-dependent, but still not 0
- Positive bias on β (for our choice of opacity)
- Why? Likely answer: non-power-law opacity

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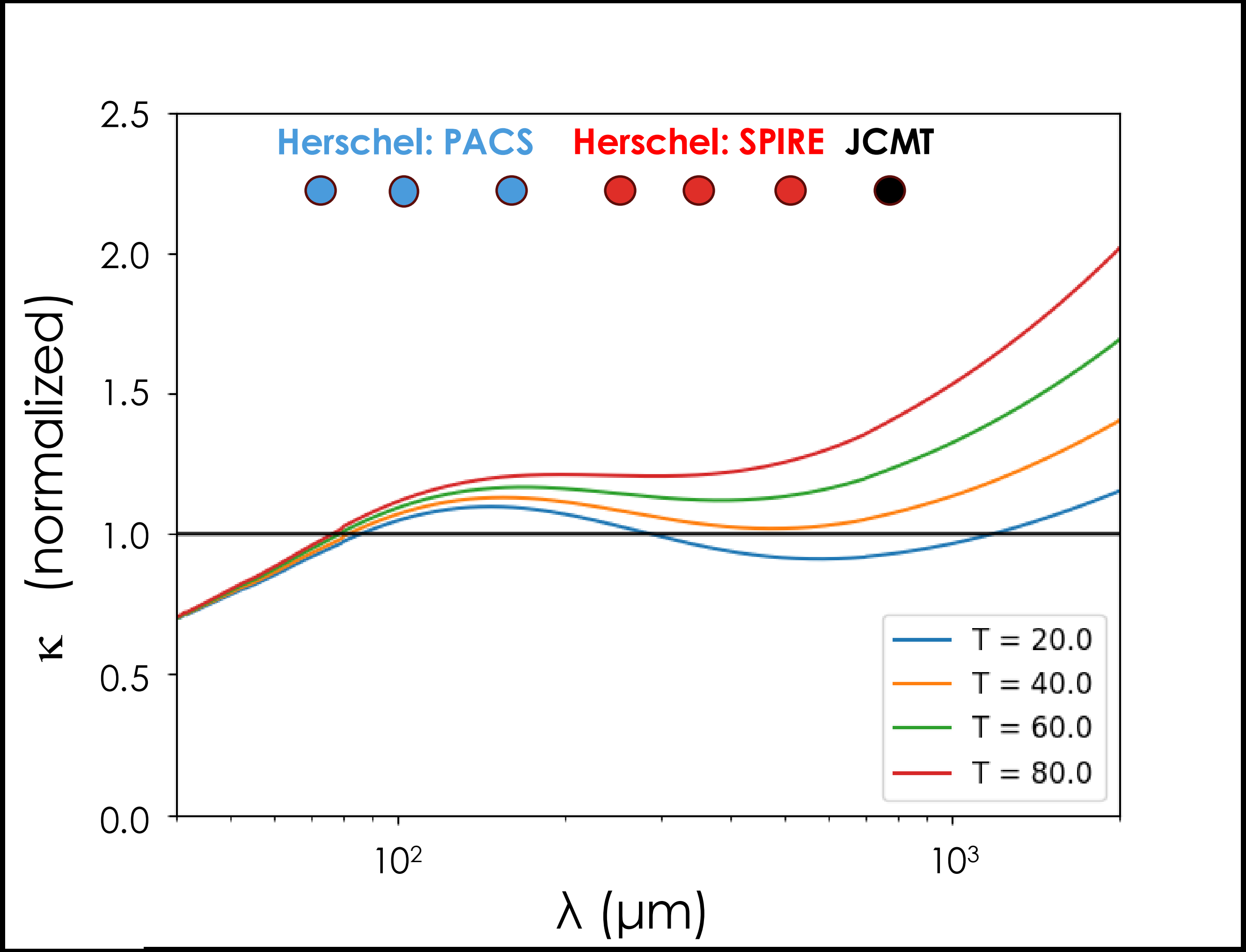
NON-PL OPACITY: EFFECT OF BAND CHOICE

"Short wavelength" range: 70 – 250 μm; "long wavelength" range = 160 – 500 μm



Different wavelength ranges "see" different optical properties

- κ curvature can become more/less evident depending on the range chosen
    - e.g., ~200-μm "bump"

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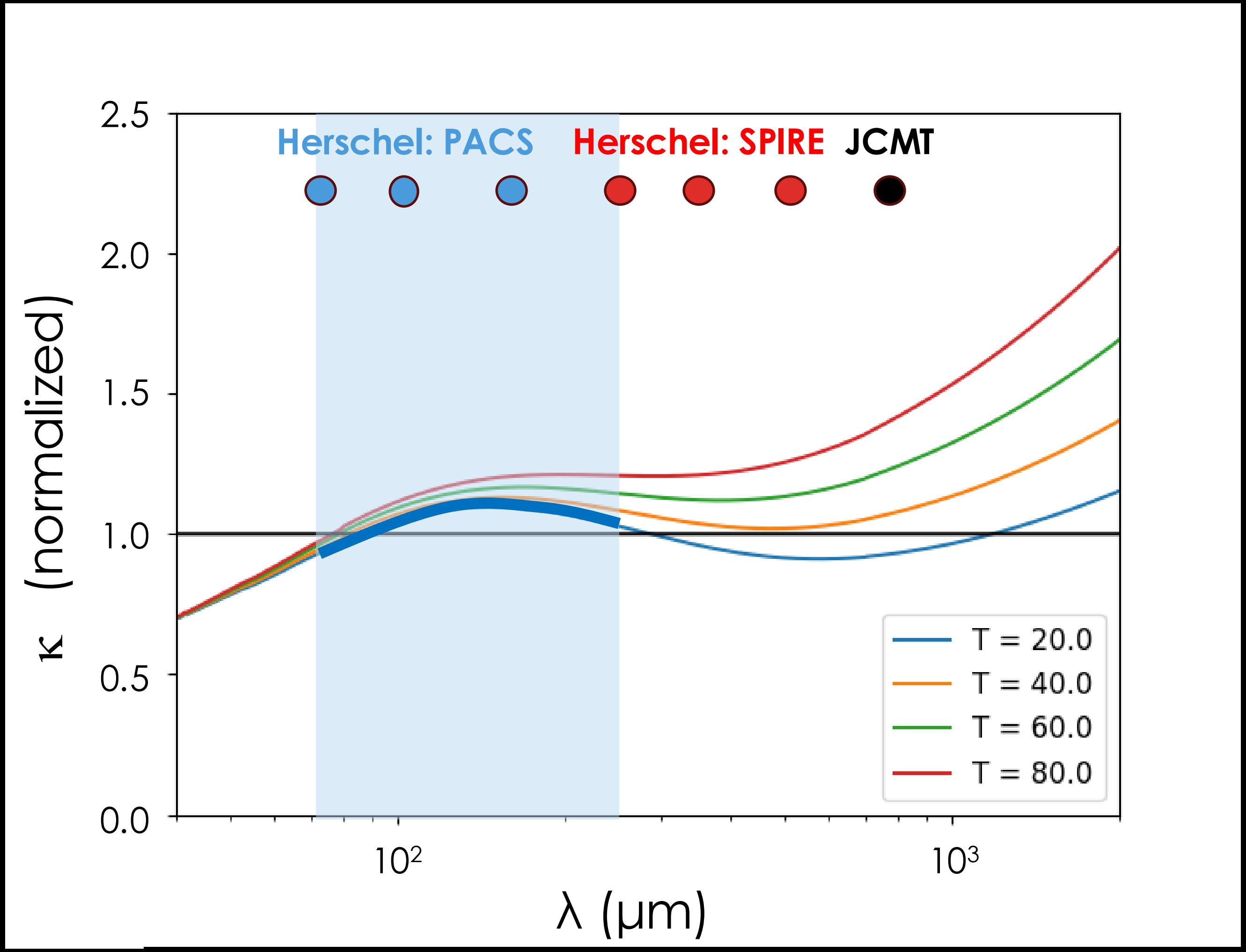

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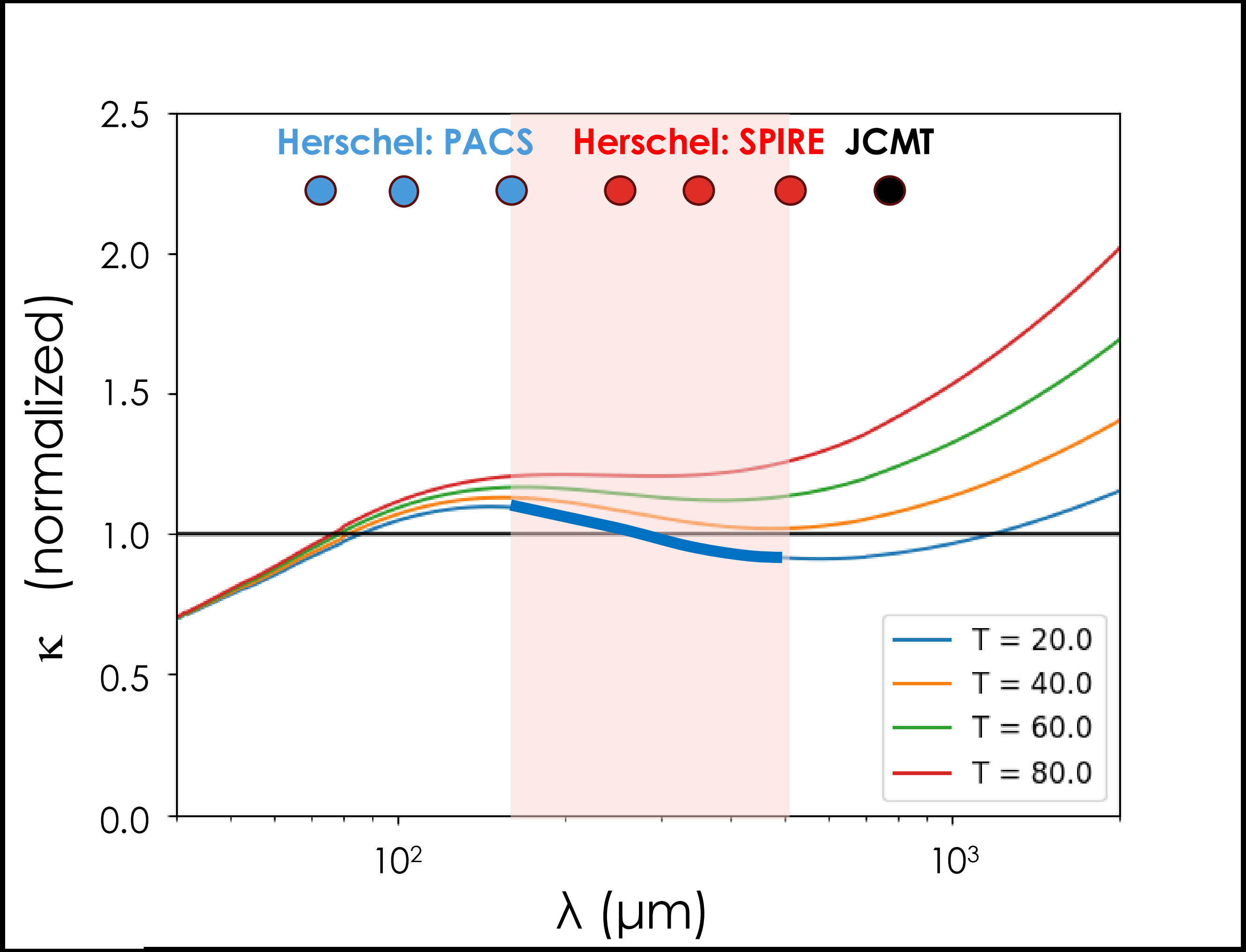

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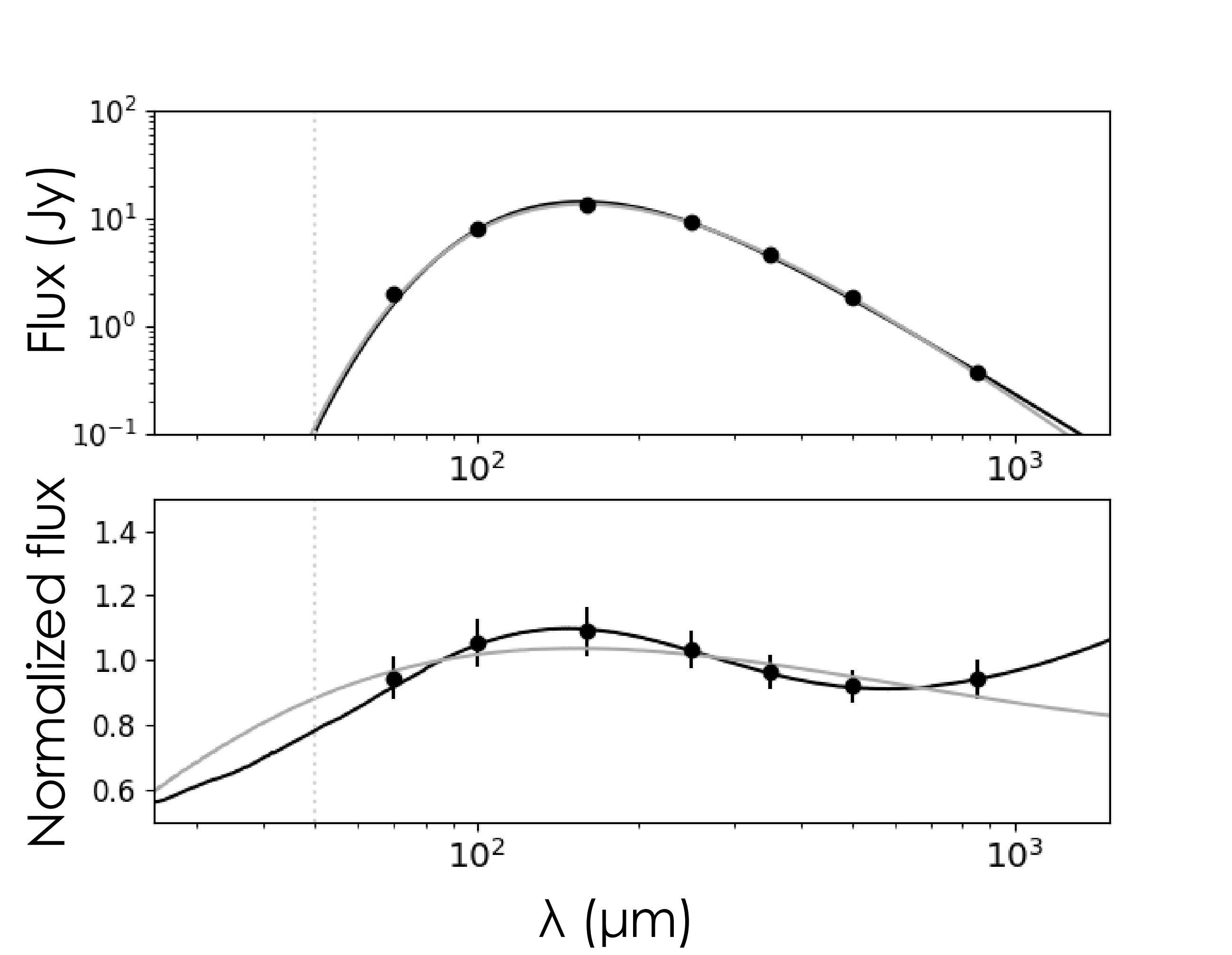

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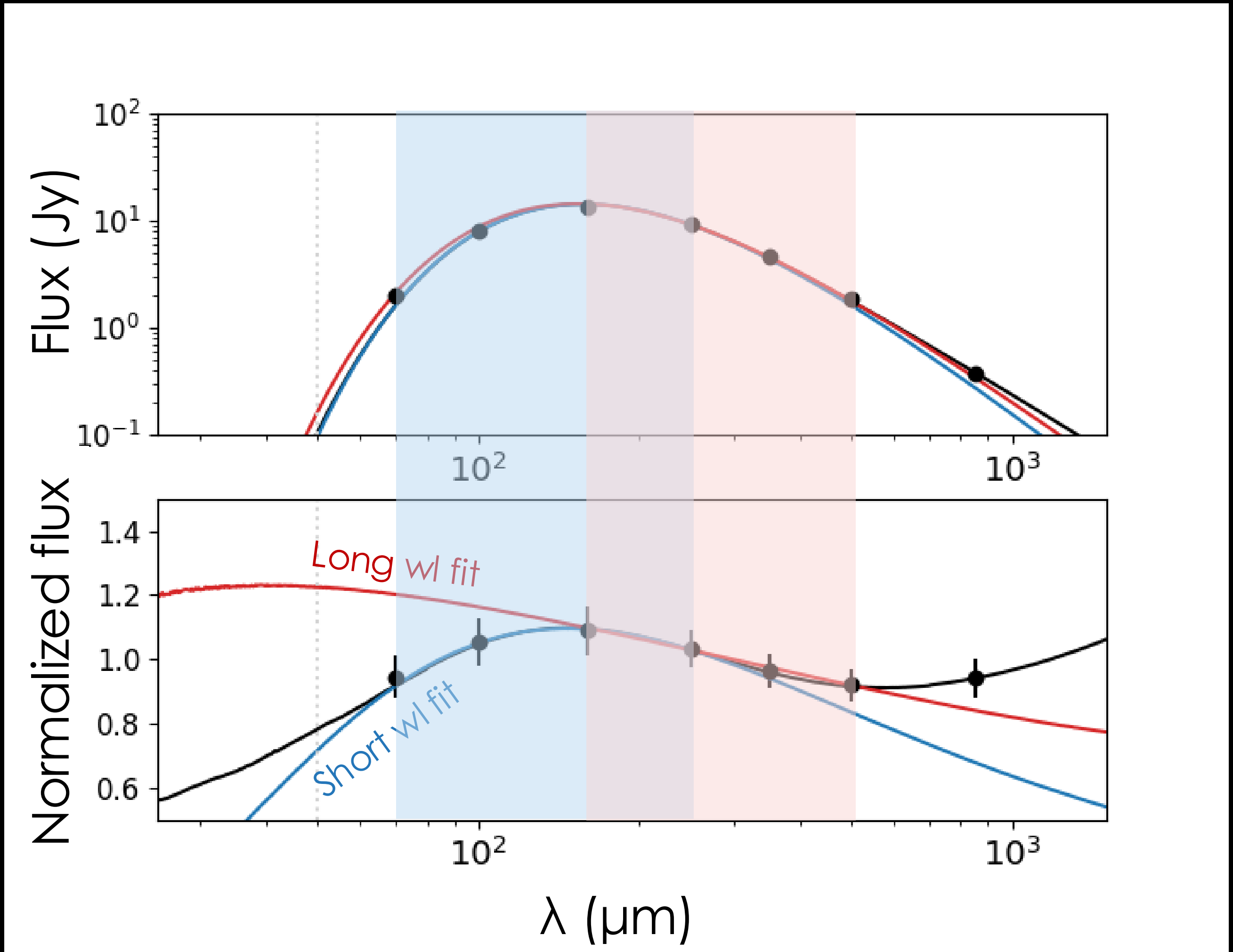

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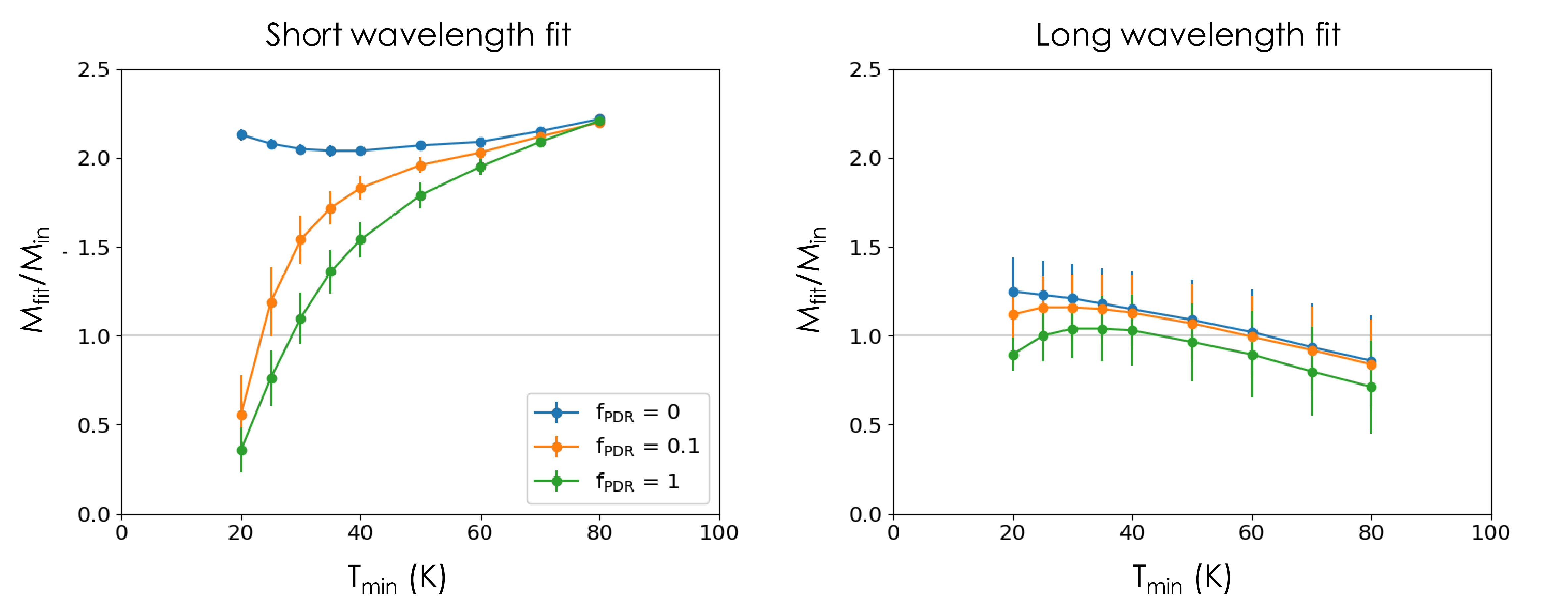
FIT RESULTS (III): FREE β, NON-PL OPACITY

M_{fit} results from free-β fit



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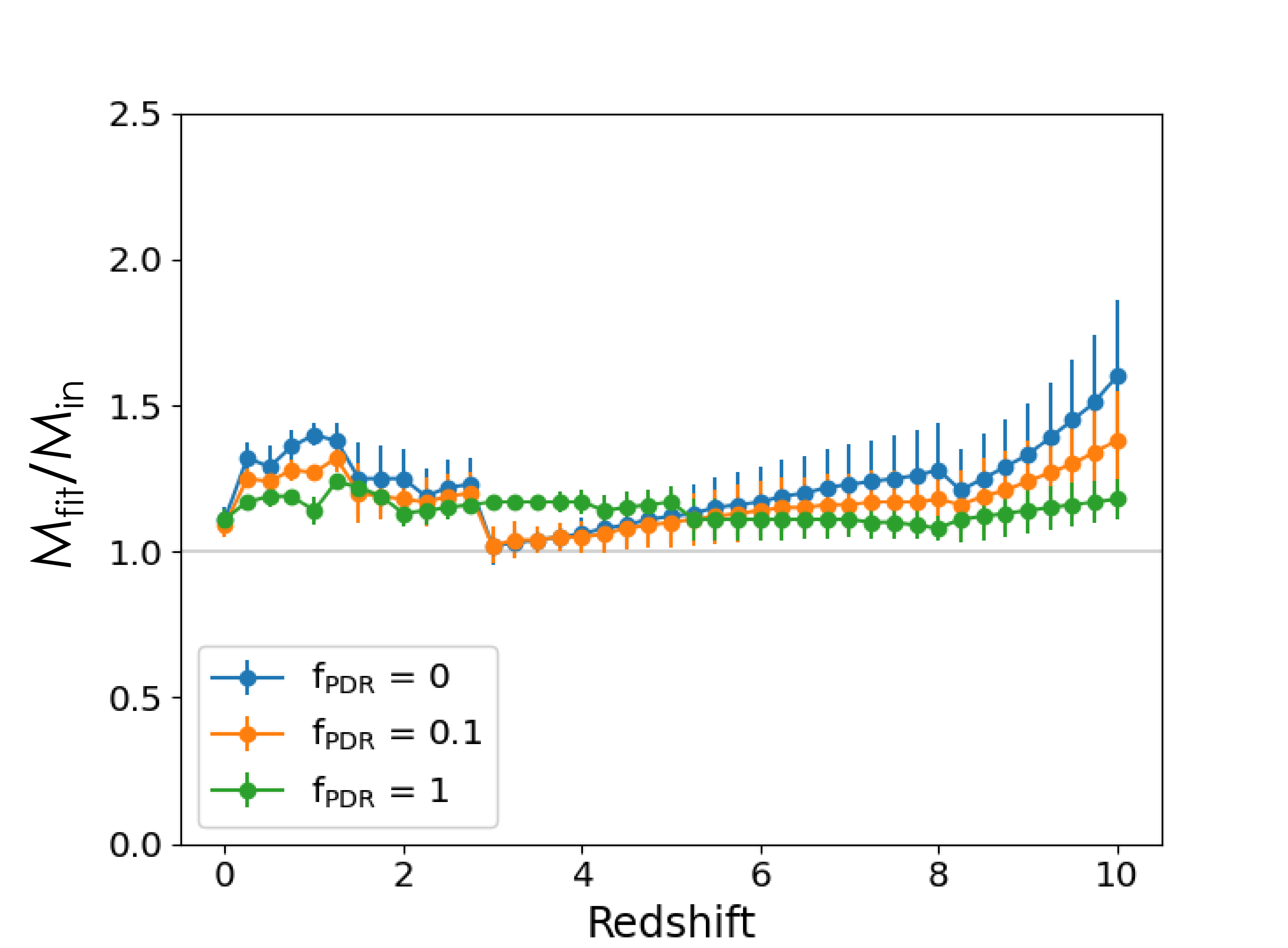
REDSHIFT EFFECTS (FIXED β)



- T_{min} = 40 K
- At each redshift, 4 bands chosen from Herschel+SCUBA-2+ALMA
- Wavelength range determined by combination of band choice and redshift
- Result: M_{fit} systematics depend on z

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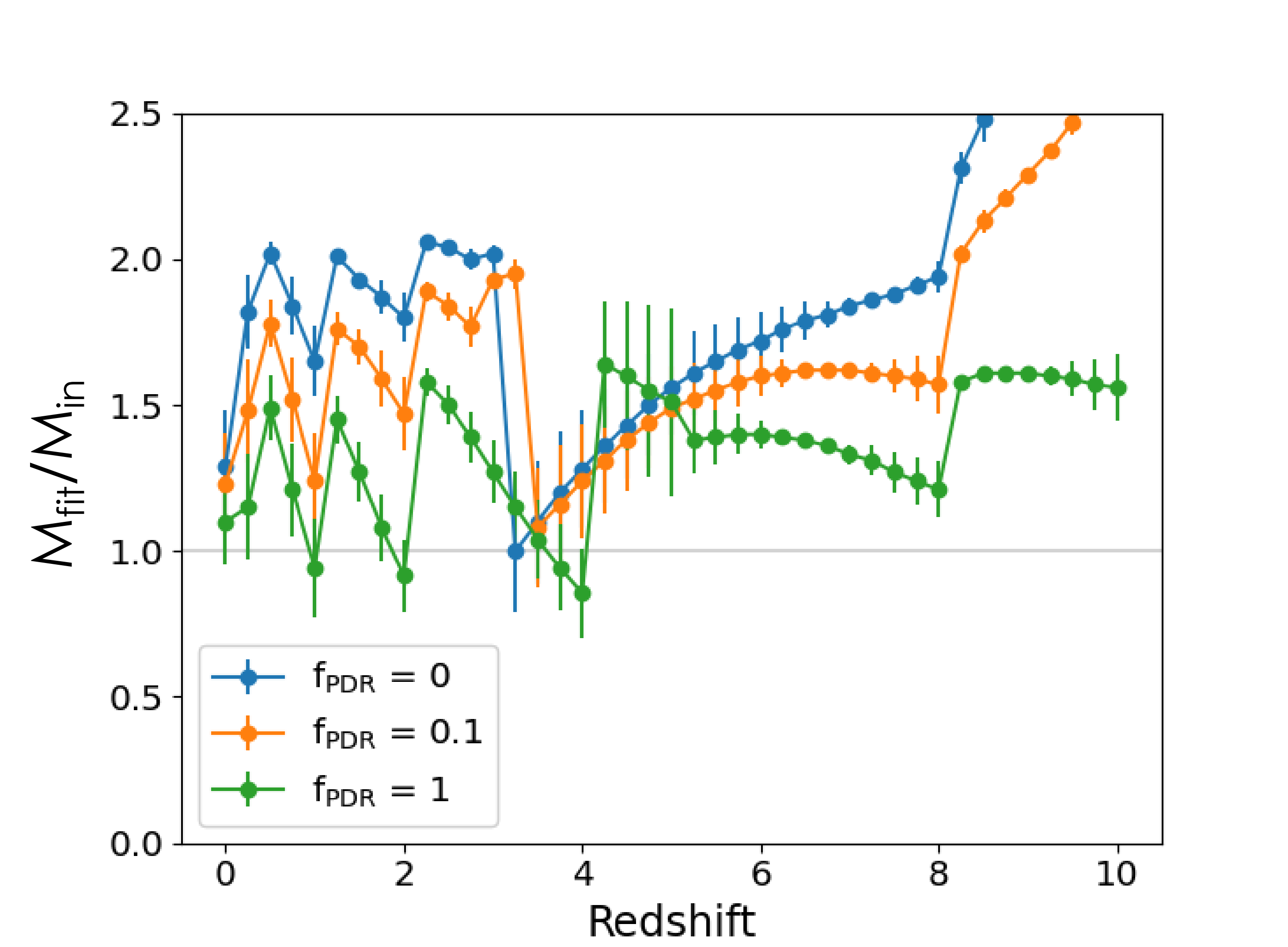

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CONCLUSIONS

- Dust M determination from MBB fits is biased by non-power-law dust opacity, temperature-dependent opacity
- Effects quantified for the first time (?)
  - Fixed-β fits: temperature-dependent bias
  - Free-β fits: bias ~independent of temperature but more sensitive to wavelength sampling
- Specific results depend on chemical composition!
- Need to take realistic, T-dependent opacity into account when comparing systems at:
  - different temperatures
  - different (rest-frame) wavelength sampling > different z

FUTURE WORK

- Effect of alternative dust compositions
- Tool for estimating MBB bias given dust composition
- To what extent do T-dependent properties contribute to the T-β anticorrelation?
- Improvements to synthetic observation model
  - Optically thick emission?
  - Clumpy galaxies?
- Improvements to fitting model
  - Two-temperature fit

THANK YOU FOR YOUR ATTENTION!