Determining the systematic errors in fits of dust thermal emission

The role of laboratory data in upcoming models

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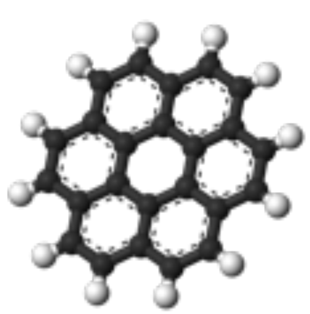
Intro: what is dust?

"Soot and sand in space"
– *A. P. Jones*

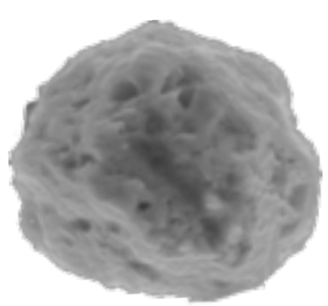
CARBON
- Amorphous?
- Graphite?
- Hydrogenated?

SILICATES
- Mostly amorphous (98%)
- Mineralogy?
- Embedded metals?

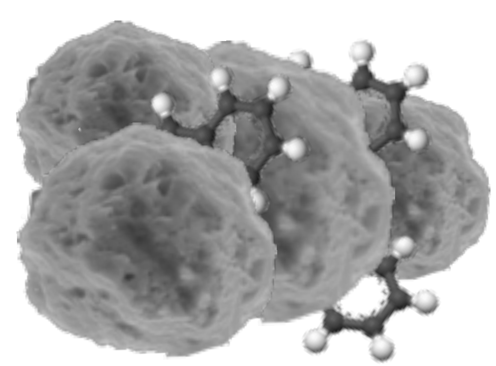
ICES
- Inside dark clouds
- Rich chemistry



Molecules (PAH?)
< 1 nm



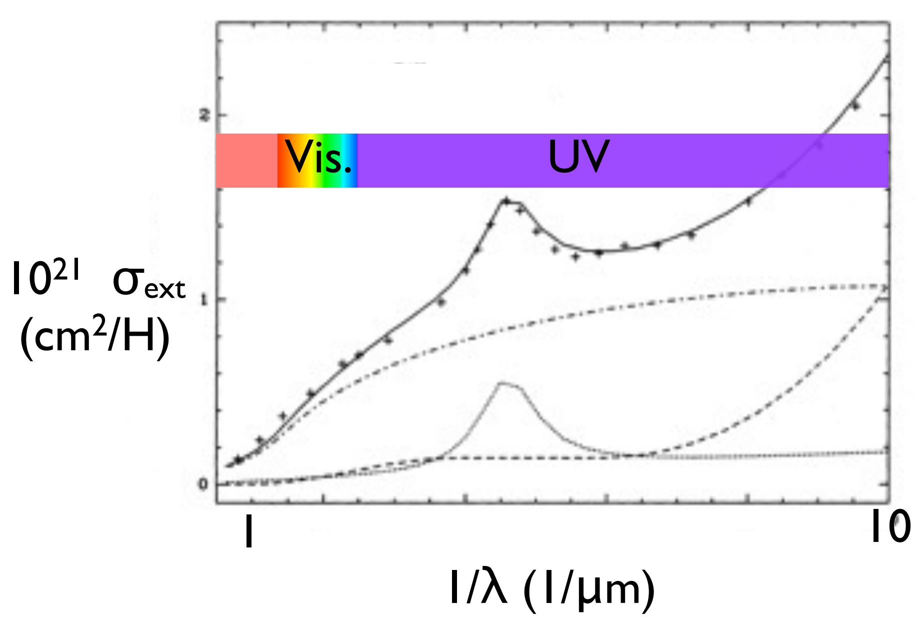
"Big" grains
≳ 100 nm



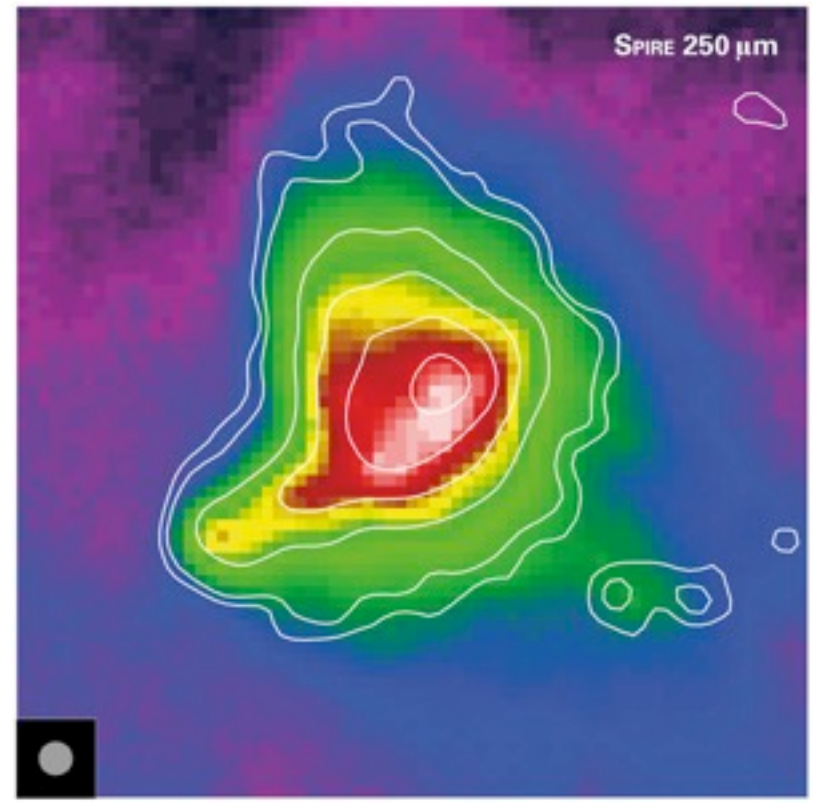
Aggregates

Intro: observing dust

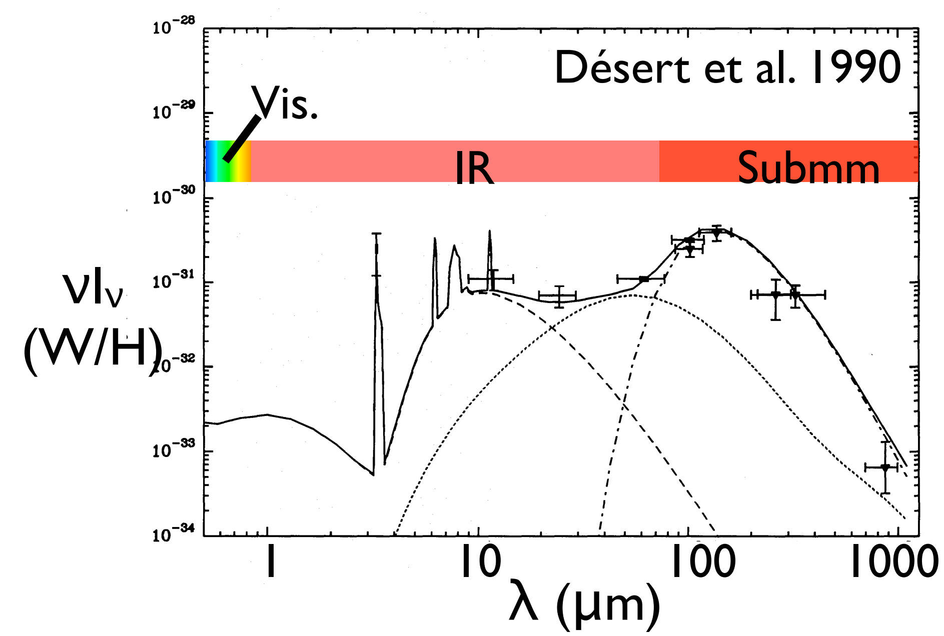
Extinction



Emission

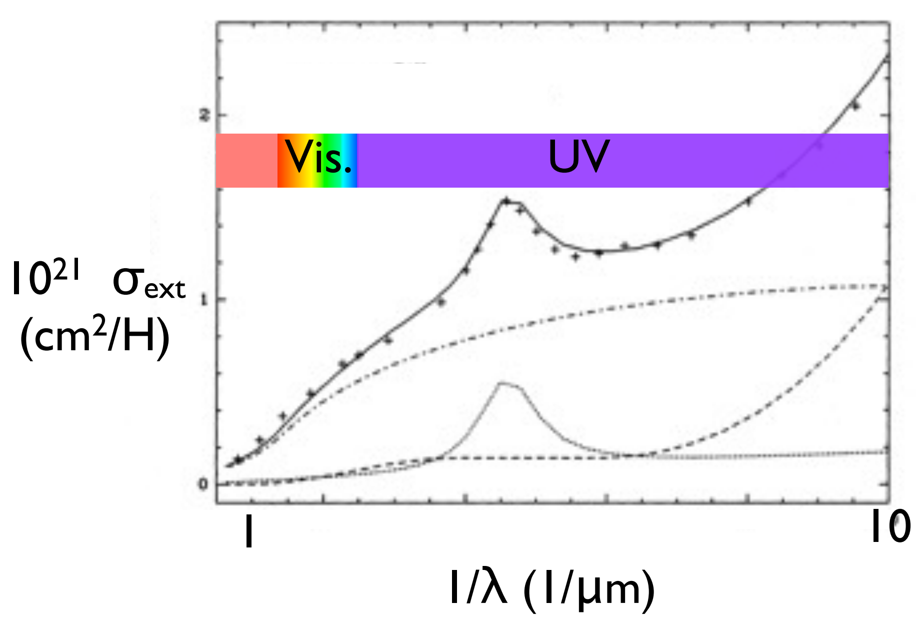


MPIA - Markus Nielbock

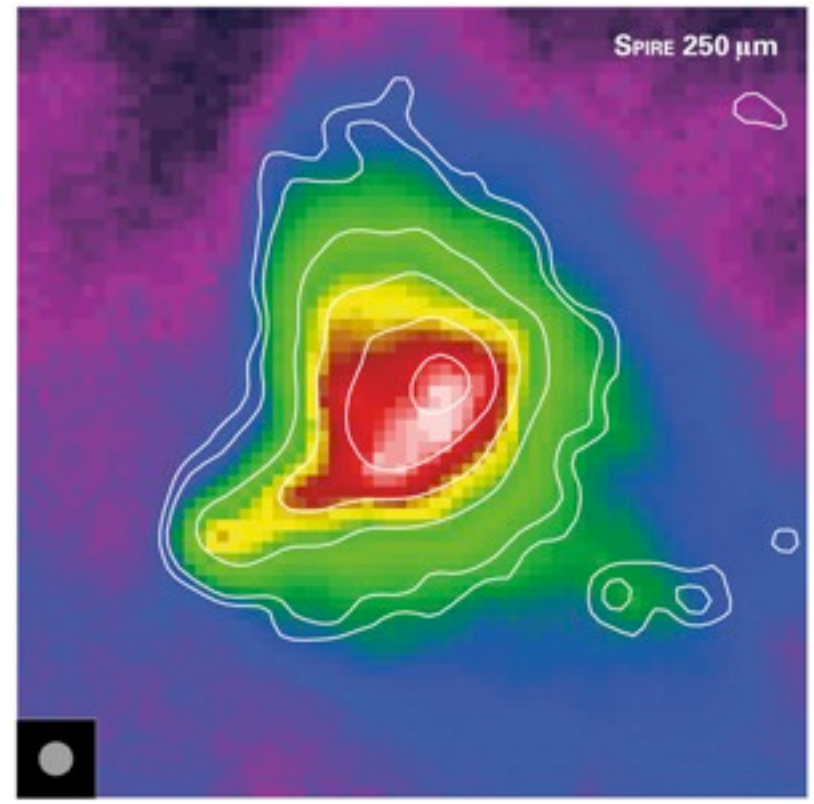


Intro: observing dust

Extinction



Emission



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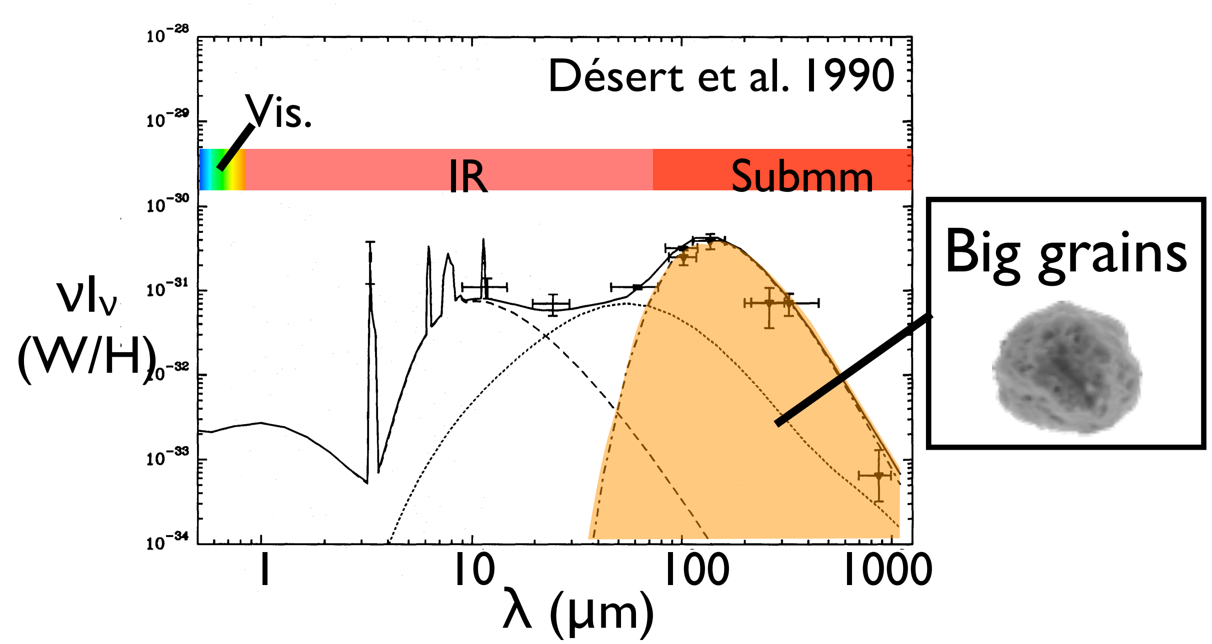
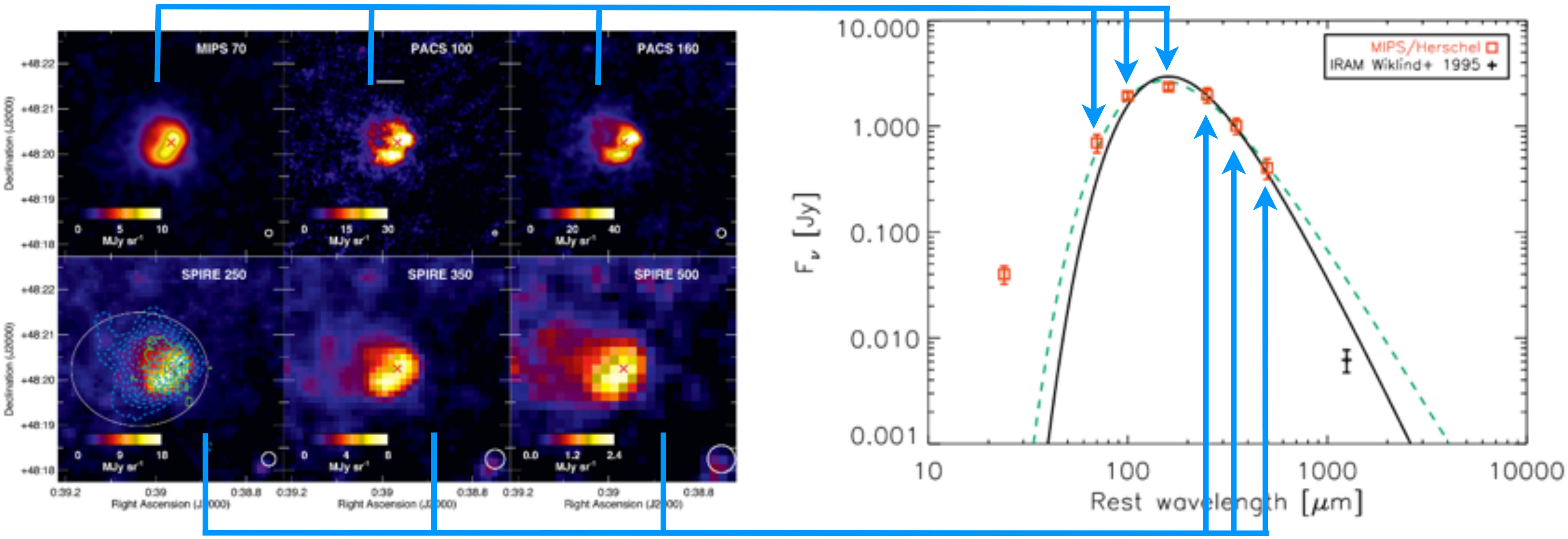


Intro: SED fitting



NGC 185 (De Looze+16)

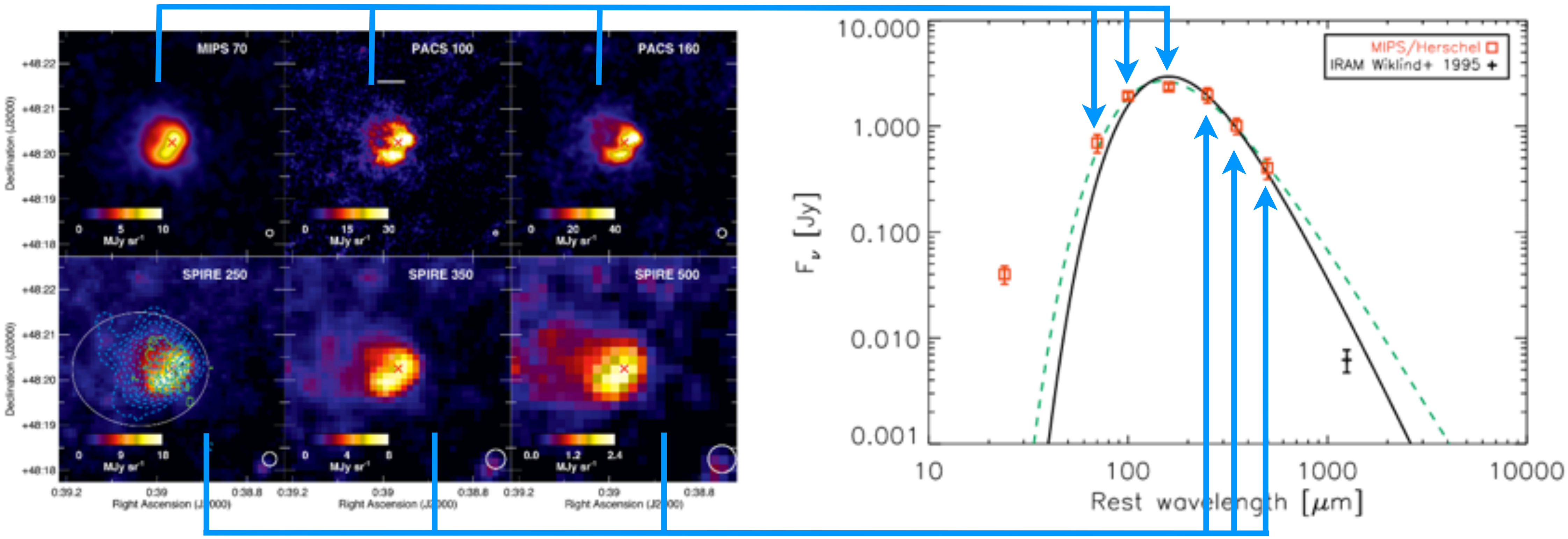
$$F_\lambda = \overbrace{M_{d,surf} \times \kappa_\lambda}^{\tau_\lambda} \times B_\lambda(T)$$

Dust masses ⟶ Gas masses

Dust T ⟶ IS radiation field

Polarization ⟶ Magnetic field

Intro: SED fitting



NGC 185 (De Looze+16)

$$F_\lambda = \overbrace{M_{d,surf} \times \underbrace{\kappa_\lambda}_{\kappa_0 \times (\lambda/\lambda_0)^{-\beta}}}^{\tau_\lambda} \times B_\lambda(T)$$

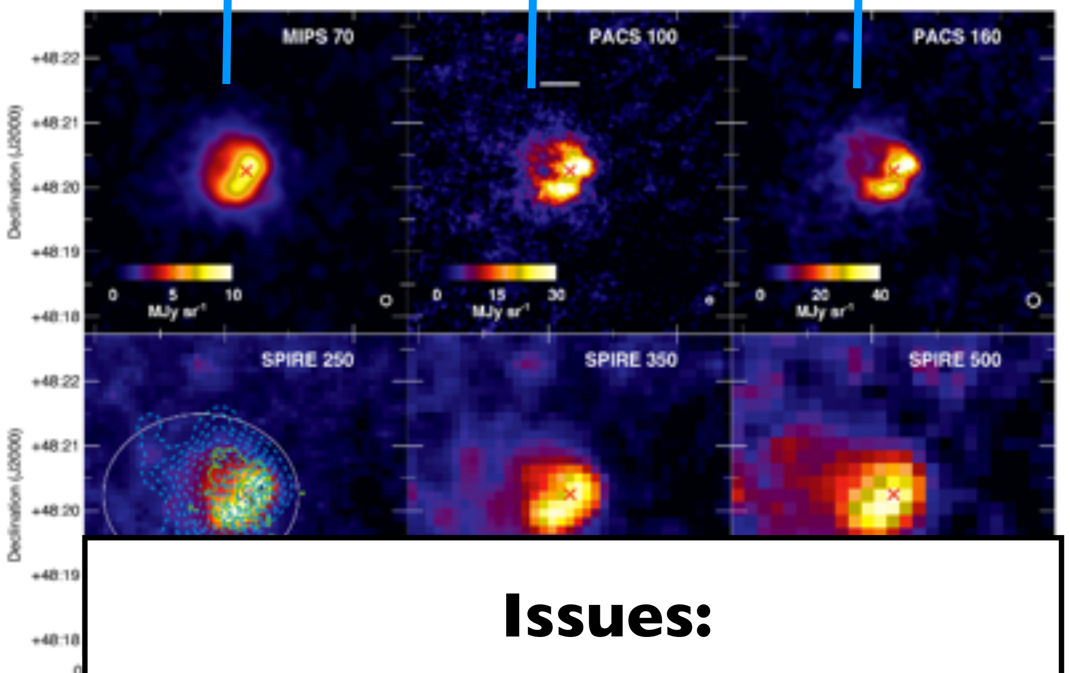
Dust masses → Gas masses

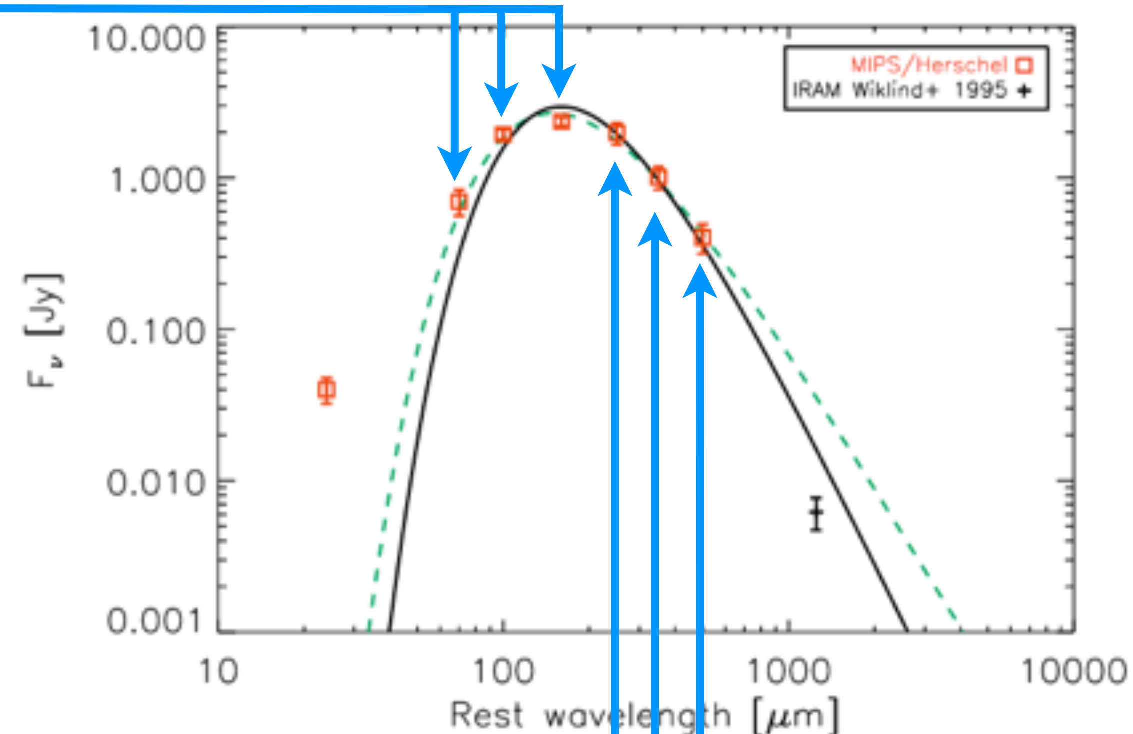
Dust T → IS radiation field

Polarization → Magnetic field

→ $\boxed{T,\ \beta,\ \tau_0\ [\kappa_0]}$

Intro: SED fitting





Issues:

- Parameter degeneracy
- Non-uniform T
  → Bias on β, τ
- No constant β / simple power law
- κ_λ depends on...
  - Composition
  - Grain shape
  - Temperature

- Dust budget crisis
- Creation/destruction timescales

F_λ =

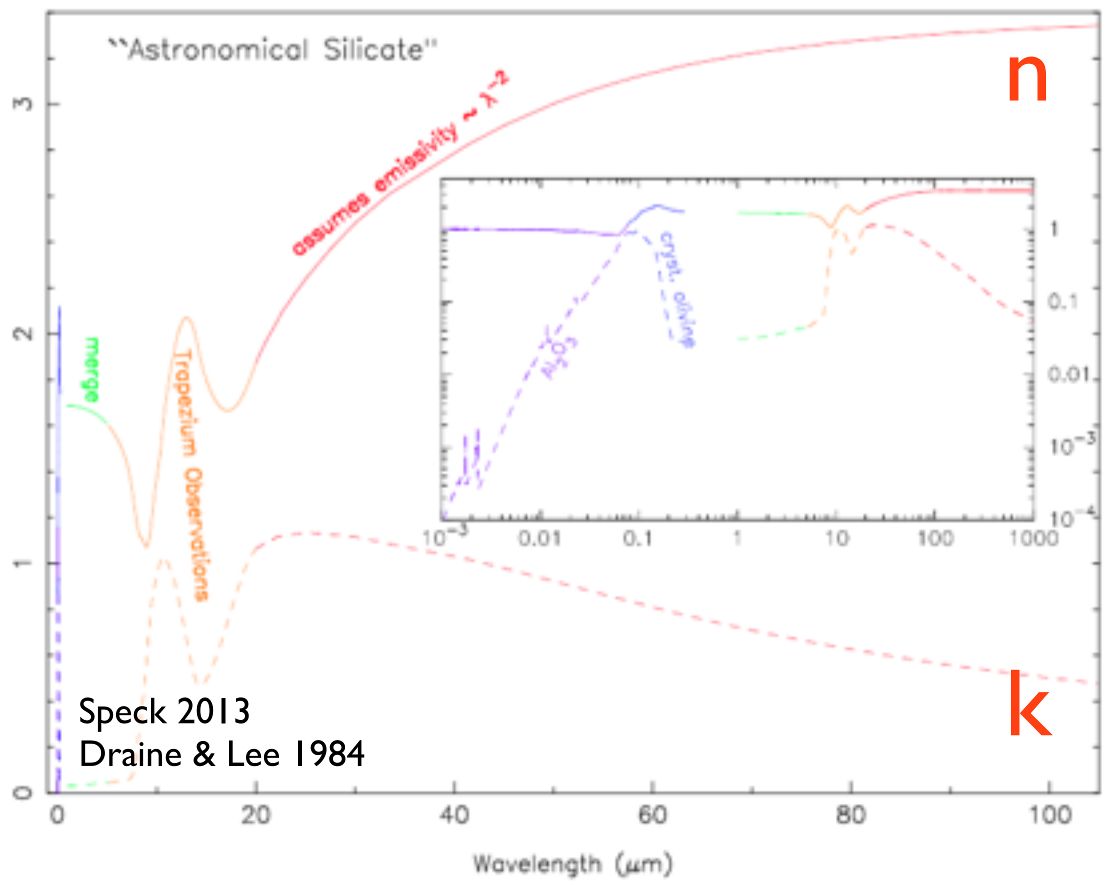
s

Polarization → Magnetic field

→ $T,\ \beta,\ \tau_0\ [\kappa_0]$

Optical properties: lab vs observations

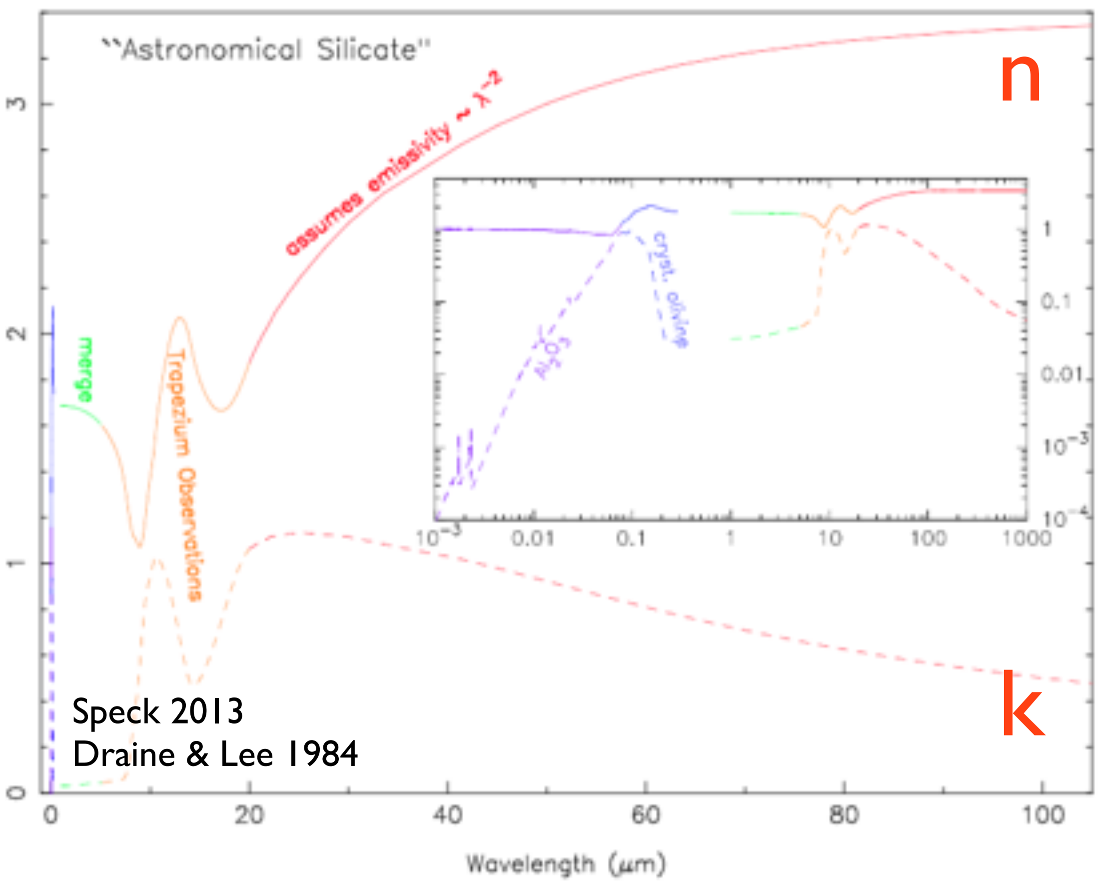
Observationally derived



- Certain to fit (some) observations
- Unknown material
- Cannot track dust variations

Optical properties: lab vs observations

Observationally derived



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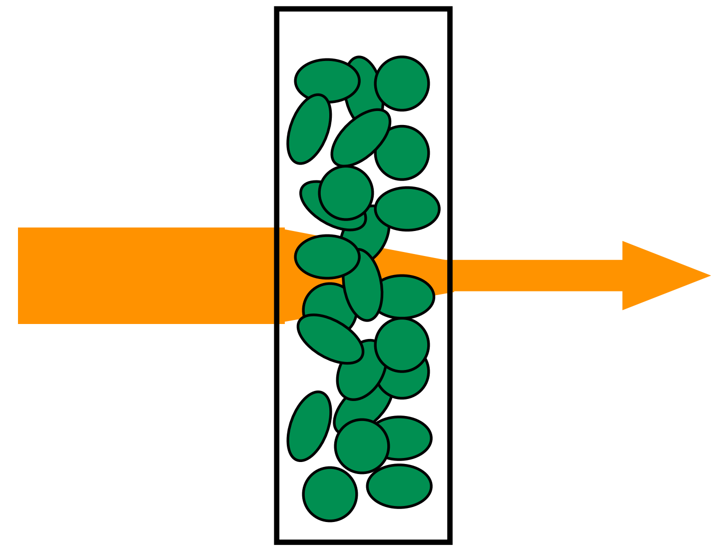
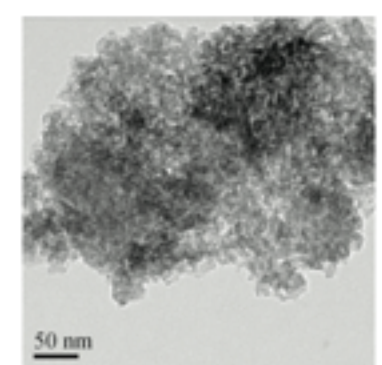
Laboratory measurements



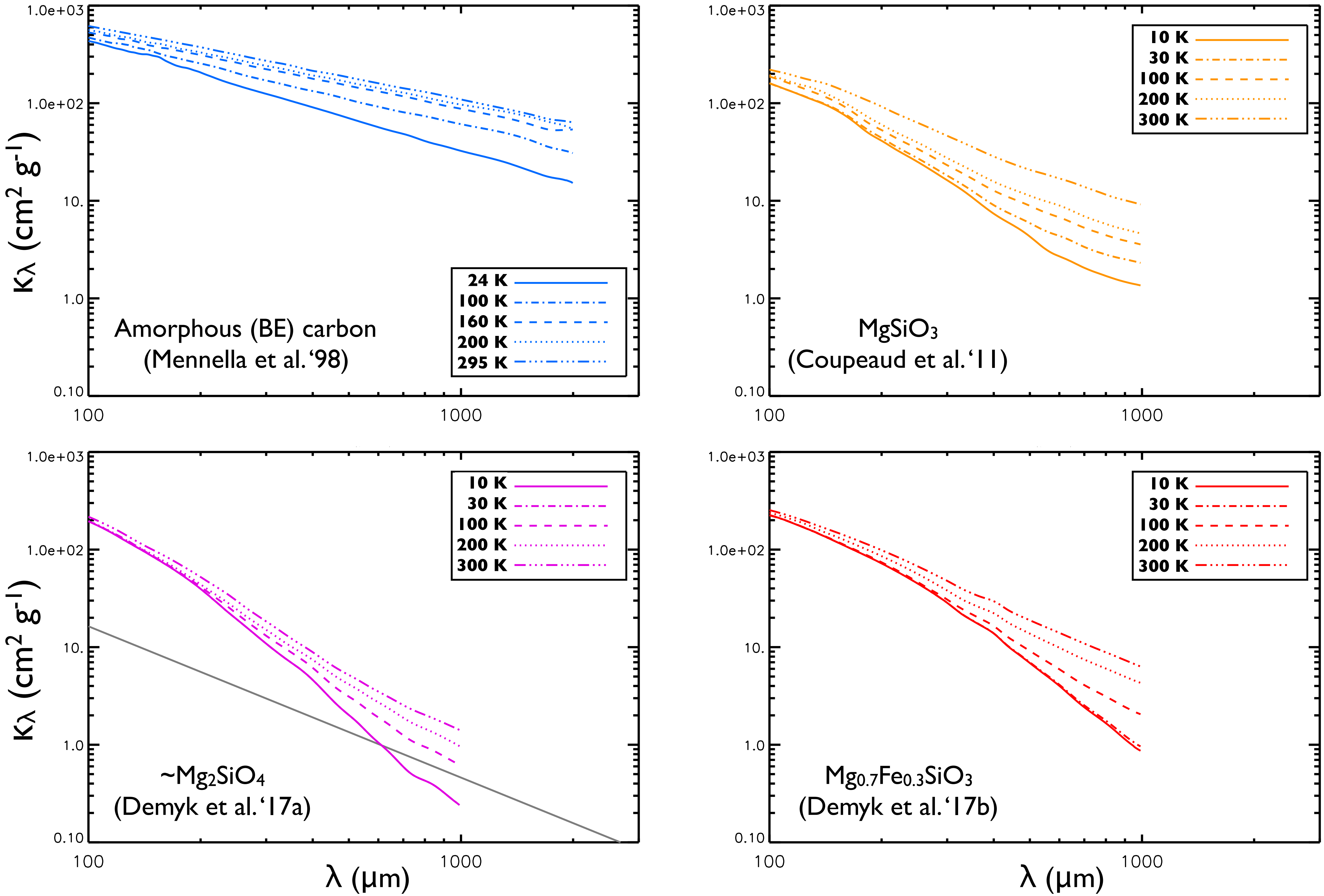
$$I_\lambda = I_0\, e^{-\tau(\lambda)}$$
$$= I_0\, e^{-\kappa(\lambda)\cdot\rho\cdot x}$$

Depends on:

- Optical "constants" (n,k)
- Concentration reduction factor g(ε,f)
- Grain structure, aggregates



Laboratory dust opacities



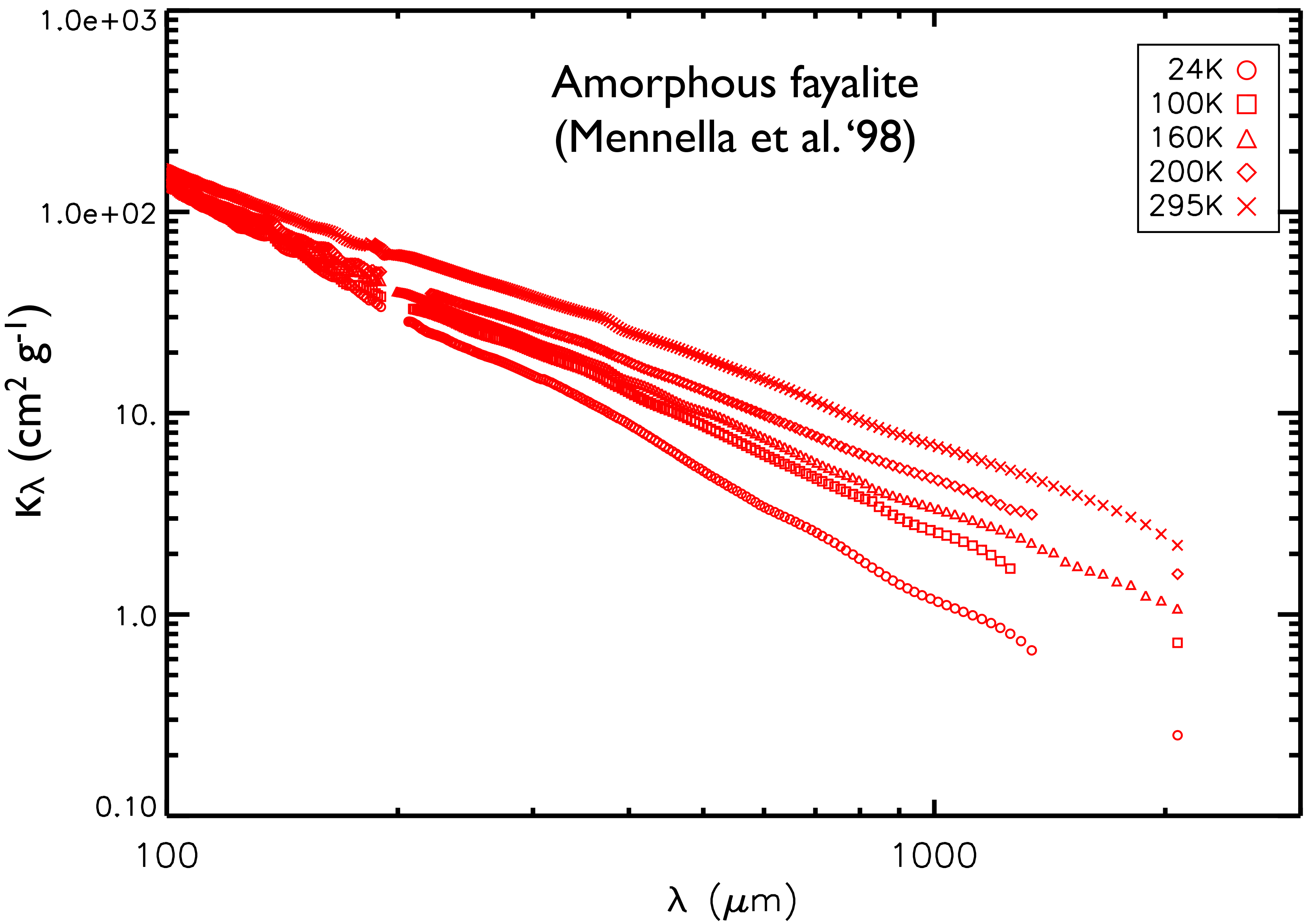
Laboratory dust opacities

Interpolation

- On T
- On wavelength

Smoothing (if necessary)

Correction for artifacts



Laboratory dust opacities

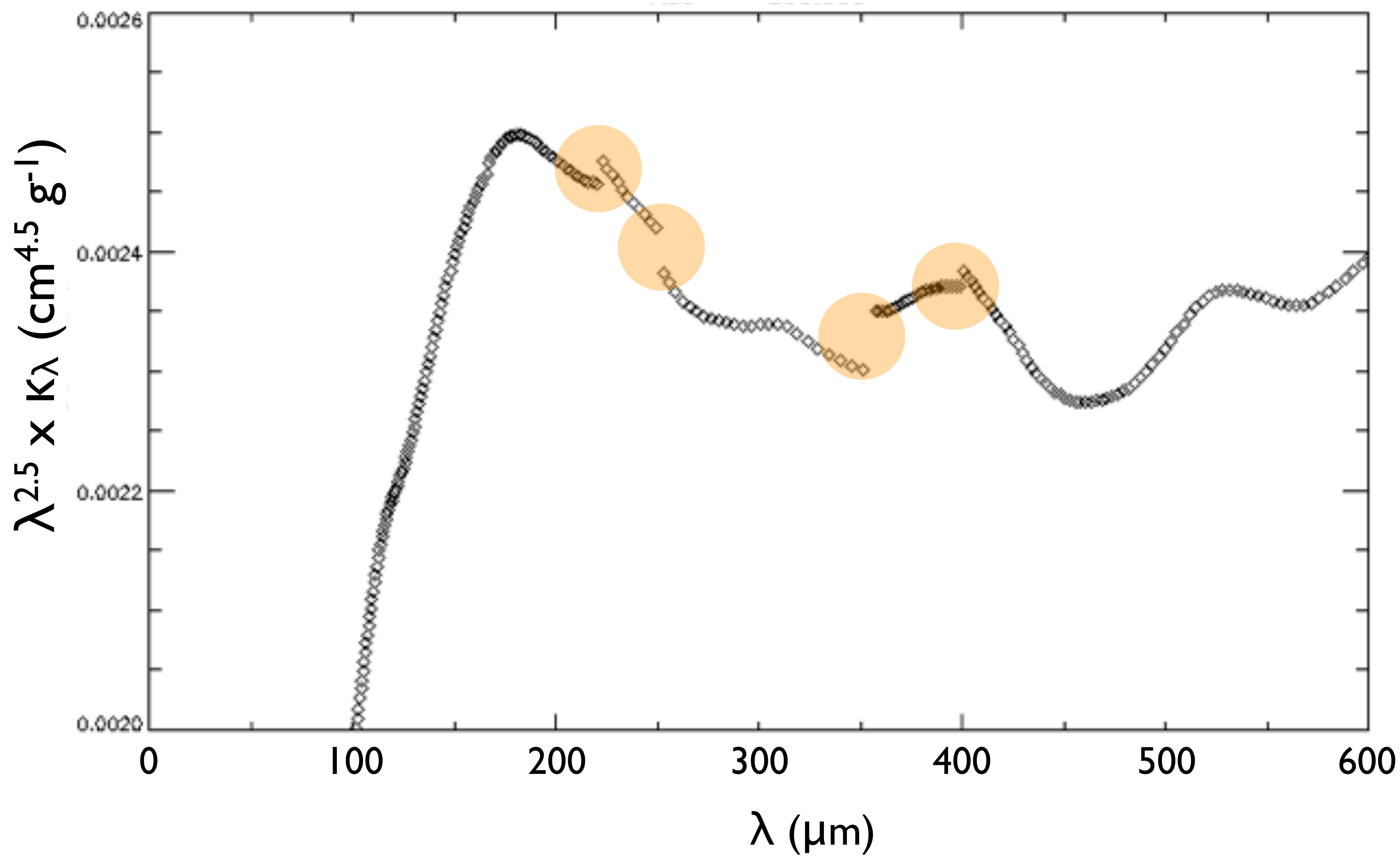
Interpolation

- On T
- On wavelength

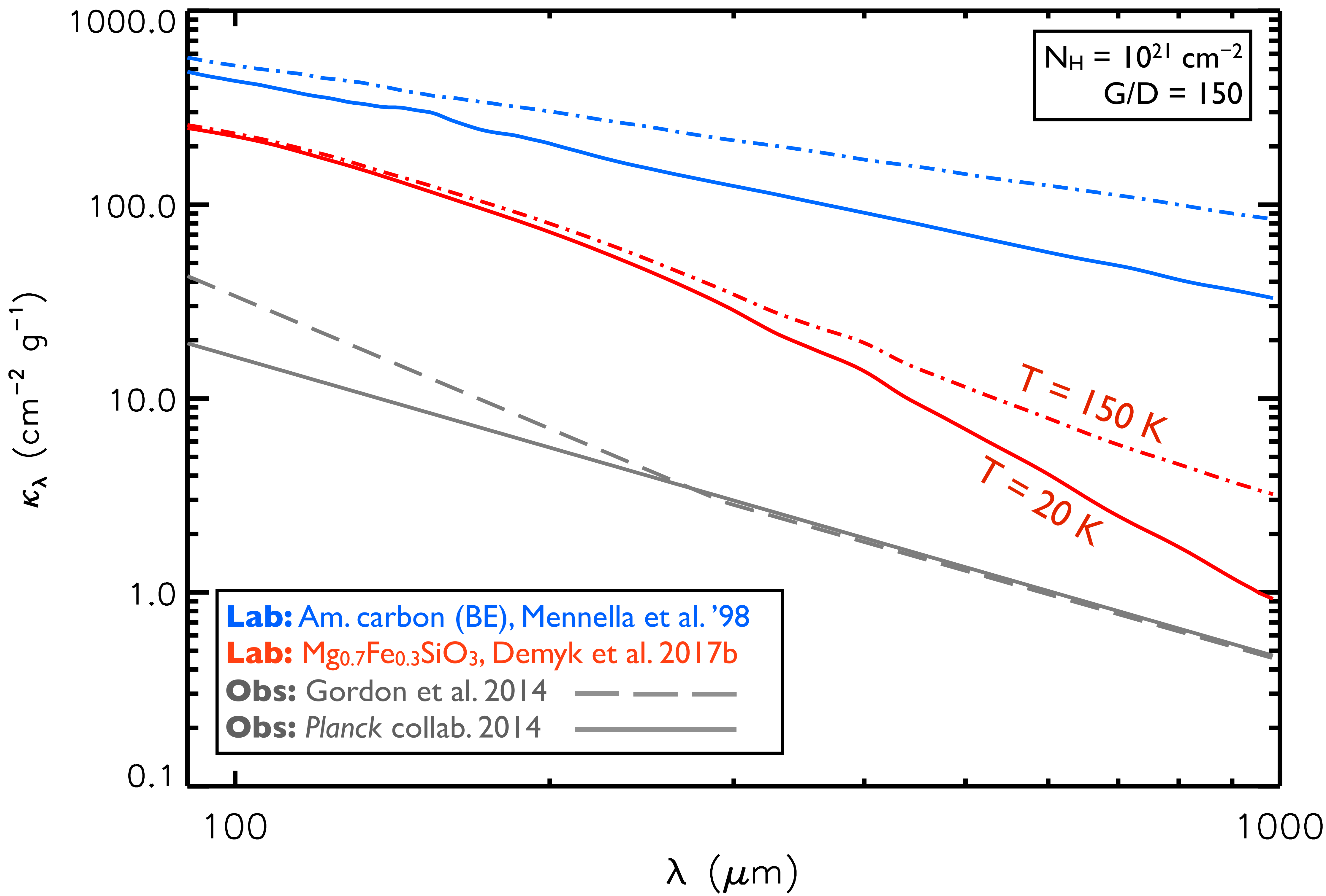
Smoothing (if necessary)

Correction for artifacts

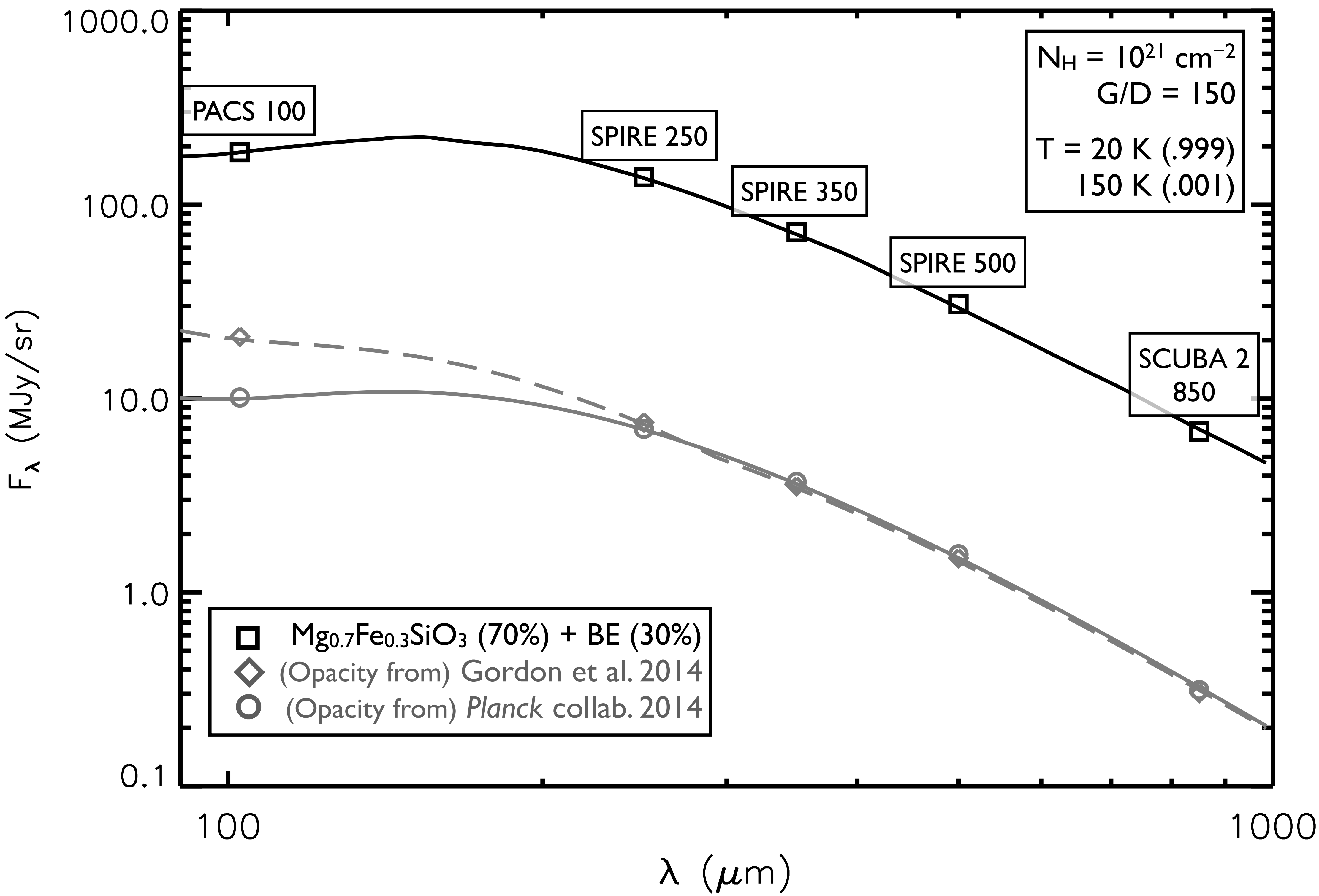
~Mg_2SiO_4 (Demyk et al.'17a), T = 200 K



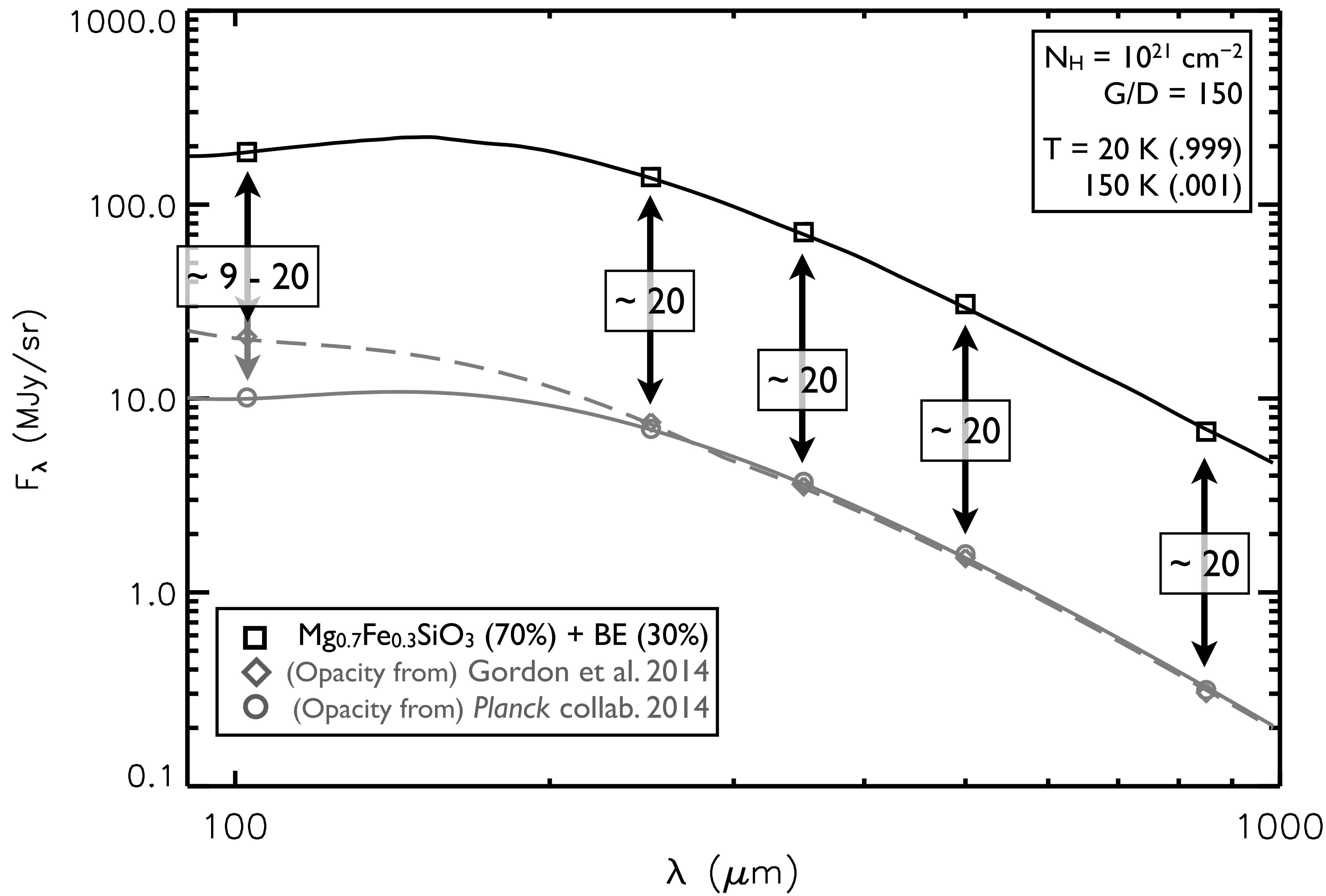
Lab results vs. literature



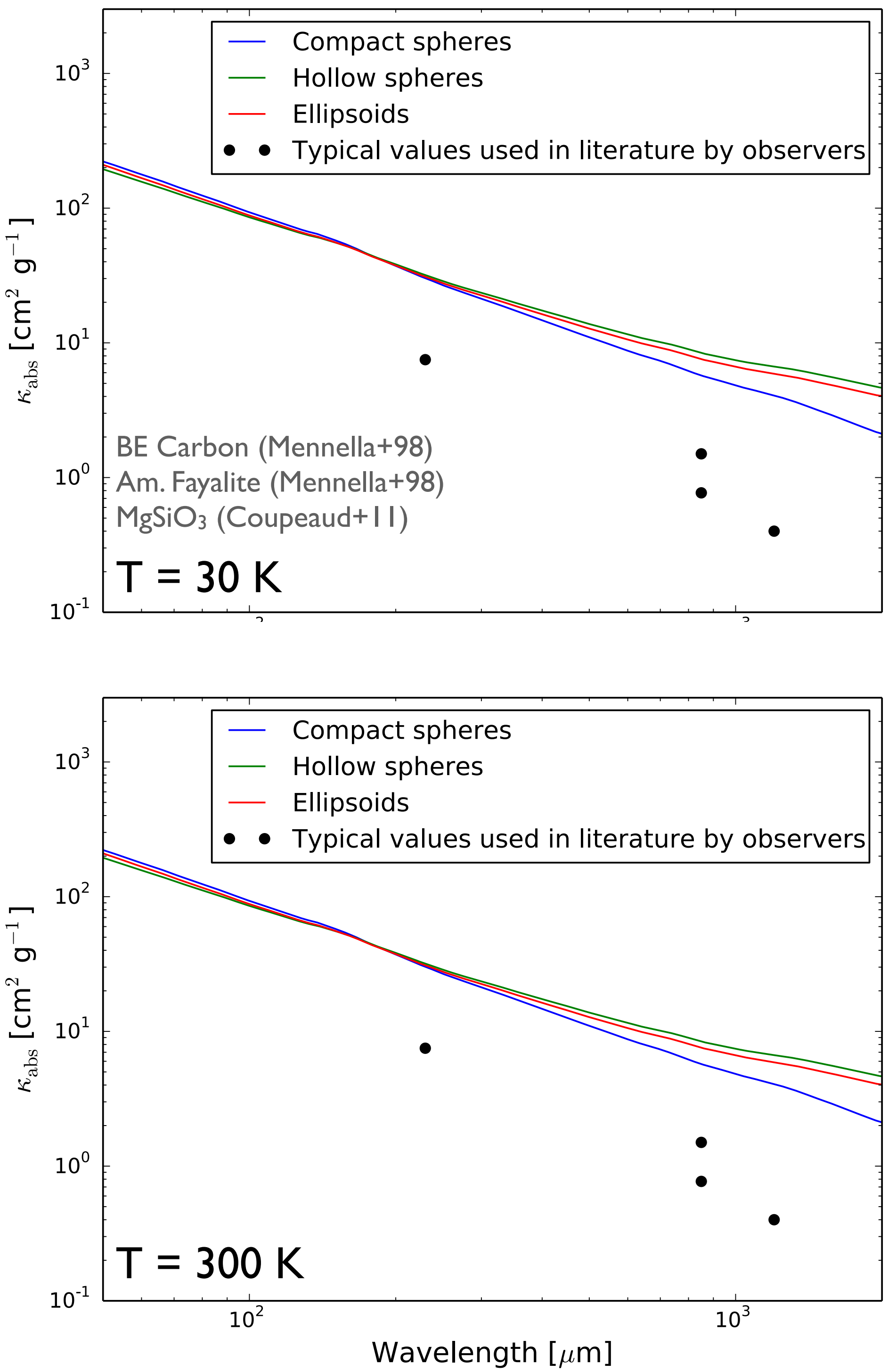
Synthetic observations

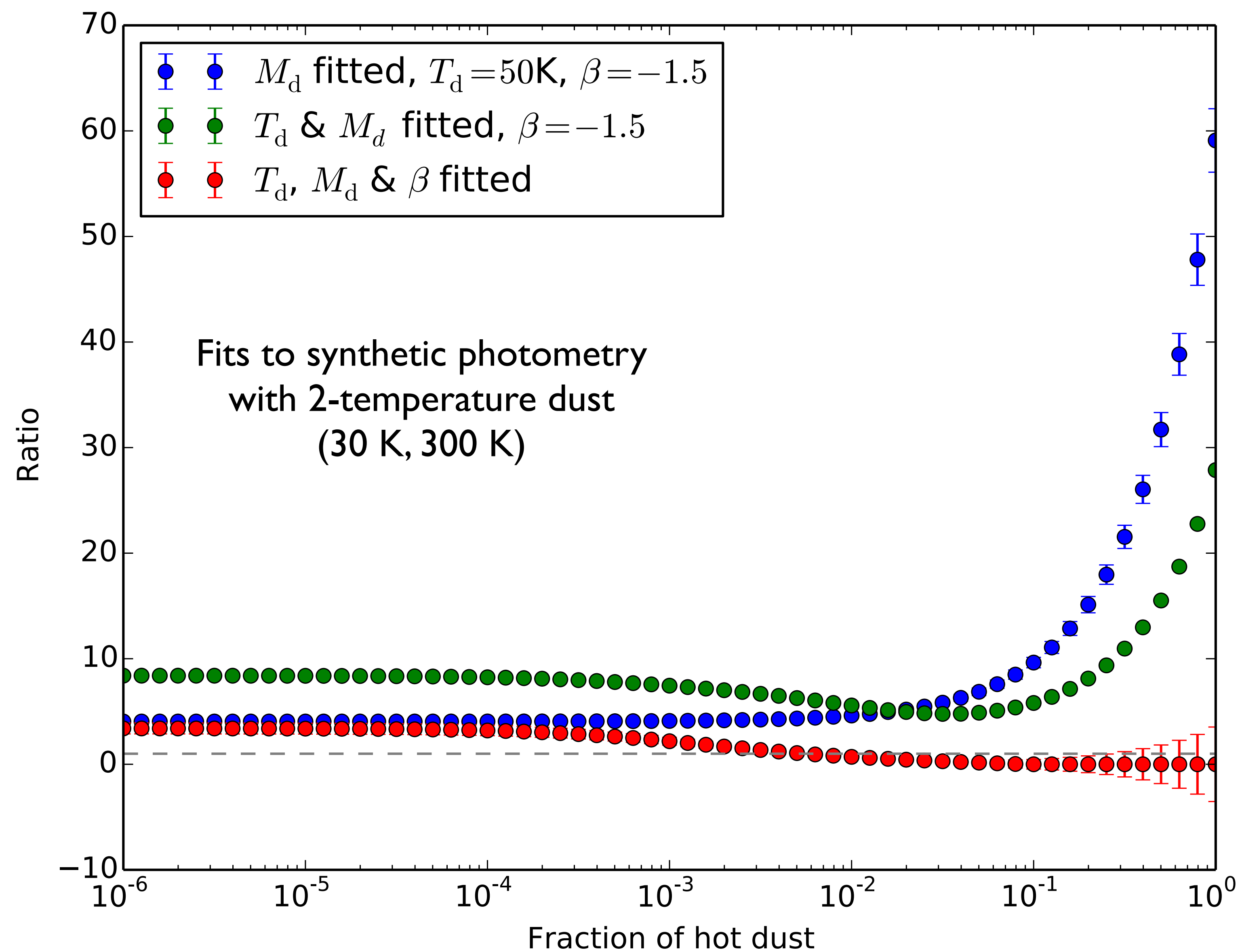


Synthetic observations

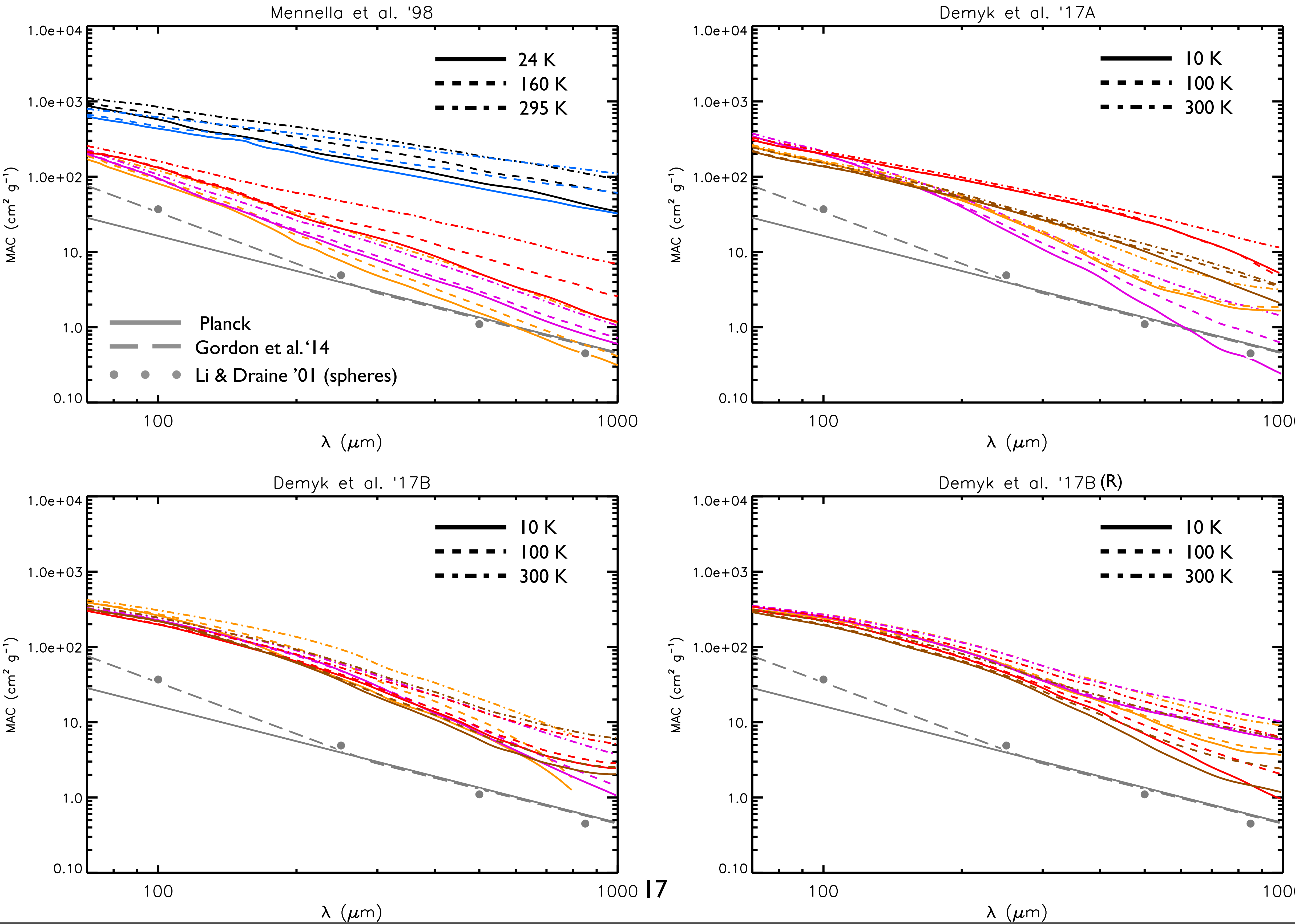


Fit: bias estimation





Ensemble view



Conclusions

- Dust mass determination depends on choice of opacity
- Large differences between lab-derived opacities and typical values used in literature
  - Lab opacities are larger
  - Power law (single-β) model inadequate
  - Dependence on T
- Fits of synthetic photometry

  ➠ Mass overestimated by up to ~10x

Solution to dust budget crisis?

Future work

- Use lab data in galaxy models
    - Grid of galaxy models spanning z, chemical composition, T distribution, …
    - Fit of synthetic SEDs using standard techniques
    - Comparison of fit-recovered mass to input value; how it depends on the model parameters
- Improve treatment
    - Add more materials (e.g. University of Jena)
    - Grain structure effects: $\kappa_\lambda \rightleftarrows$ (n, k)
    - Compare different interpolation / smoothing techniques
- Interpretation
    - Where is dust mass overestimated?
        - Consistency with other tracers (e. g. elemental depletions)
            - *Cold dust component?*
    - The solution requires widespread collaboration between the modelling, observational and experimentalist communities

Gordon et al. 2014

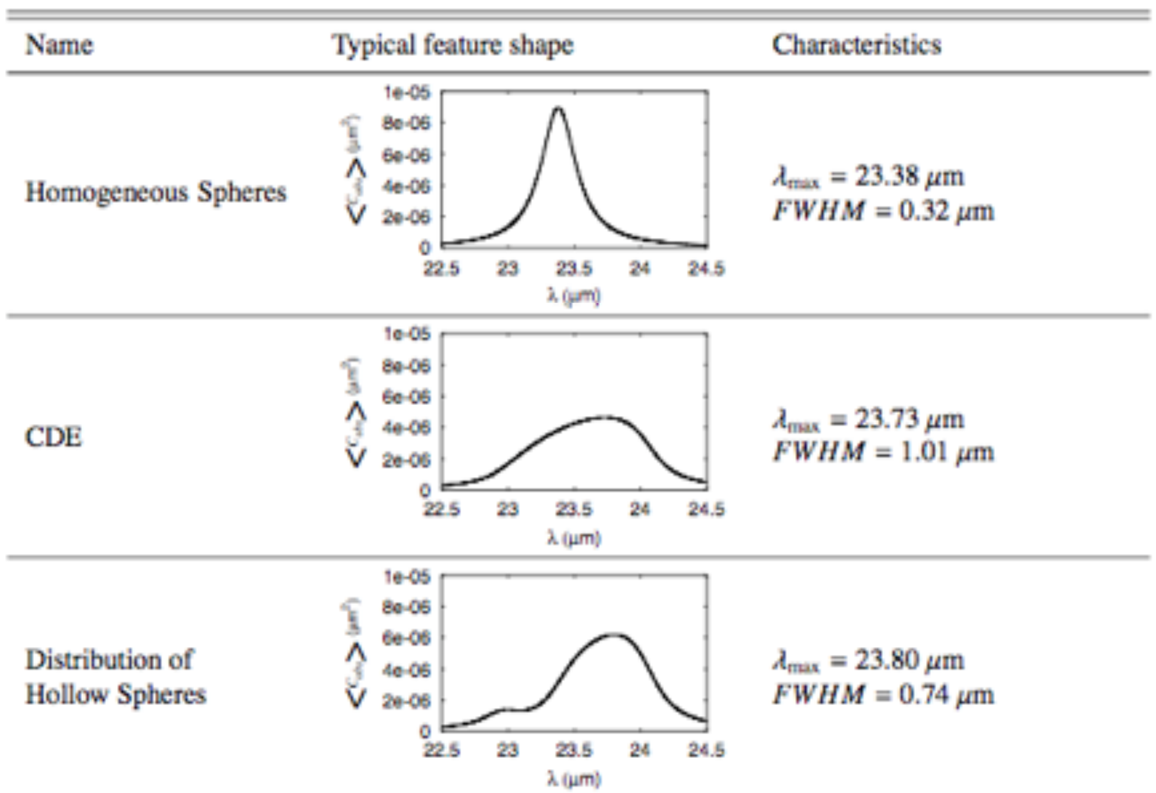
Model	M_d [$M_\odot$]	Gas/Dust[a]
	LMC	
SMBB	$(8.1 \pm 0.07 \pm 2.1) \times 10^5$	340 ± 90
BEMBB[b]	$(6.7 \pm 0.03 \pm 1.7) \times 10^5$	400 ± 100
TTMBB	$(1.2 \pm 0.01 \pm 0.3) \times 10^7$	22 ± 6
	SMC	
SMBB	$(8.1 \pm 0.1 \pm 2.1) \times 10^4$	1440 ± 380
BEMBB[b]	$(6.7 \pm 0.1 \pm 1.7) \times 10^4$	1740 ± 440
TTMBB	$(5.1 \pm 0.3 \pm 1.3) \times 10^5$	230 ± 60

Thank you for your attention!

Extra Material

Laboratory dust opacities

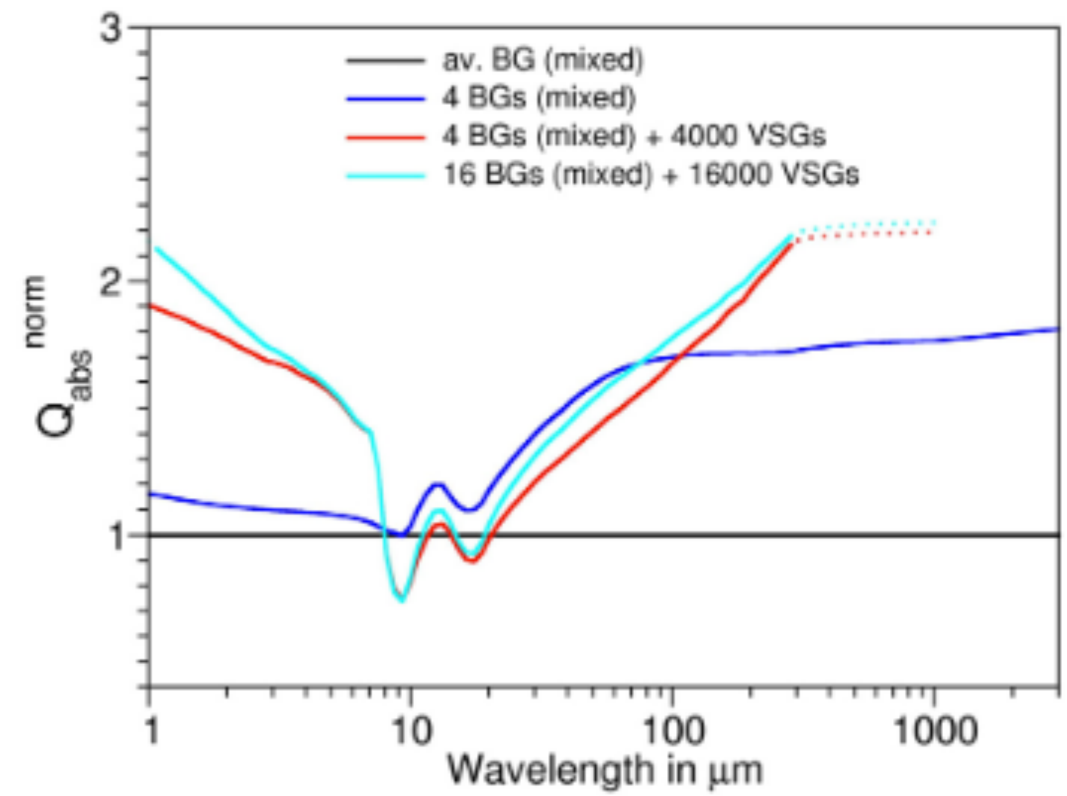
Grain shape and coagulation



Name	Typical feature shape	Characteristics
Homogeneous Spheres		$\lambda_{max} = 23.38\ \mu m$ $FWHM = 0.32\ \mu m$
CDE		$\lambda_{max} = 23.73\ \mu m$ $FWHM = 1.01\ \mu m$
Distribution of Hollow Spheres		$\lambda_{max} = 23.80\ \mu m$ $FWHM = 0.74\ \mu m$

Min et al. 2003

Grain elongation/flattening
Aggregates
} Increased FIR opacity

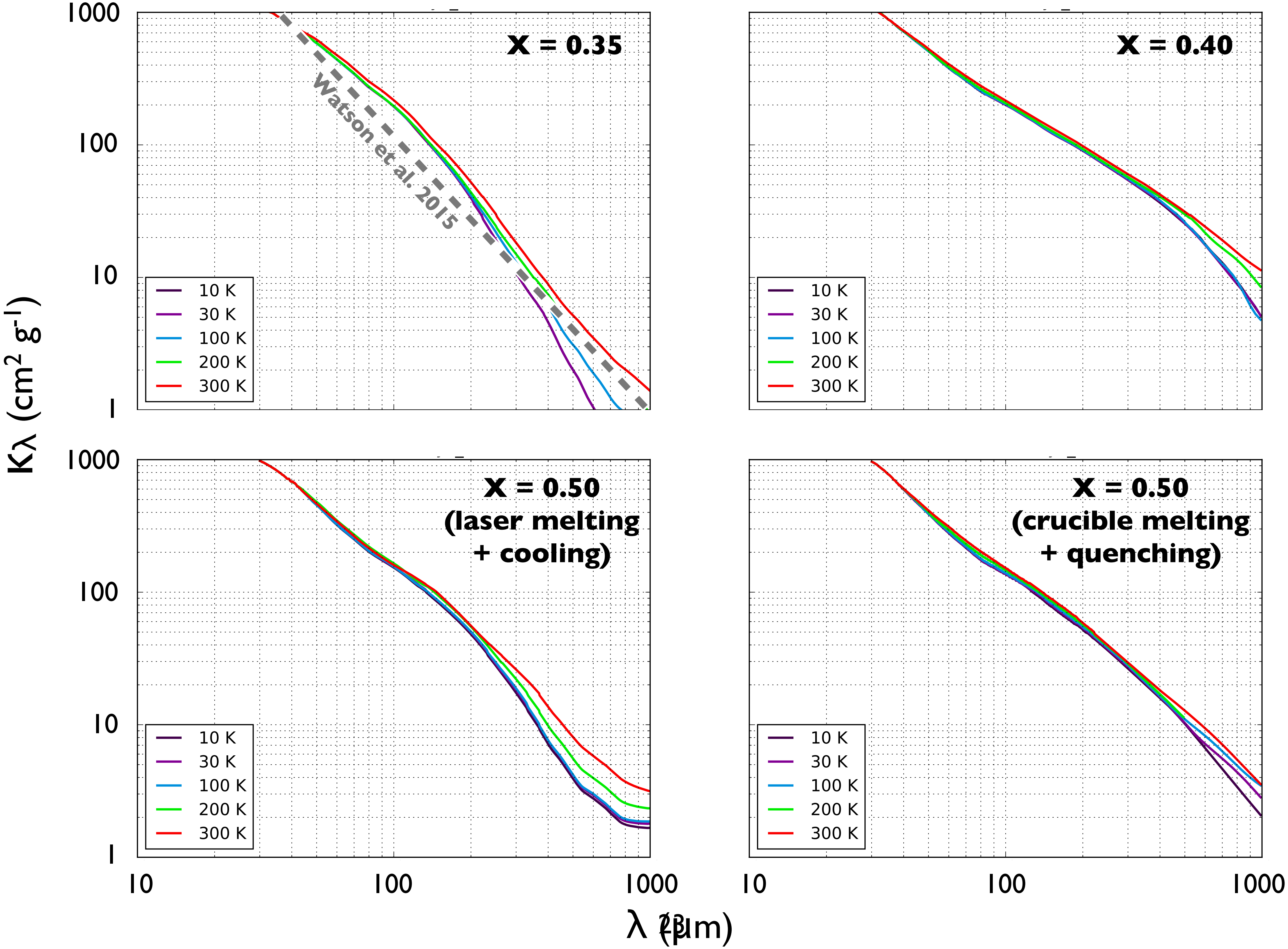


Köhler et al. 2012

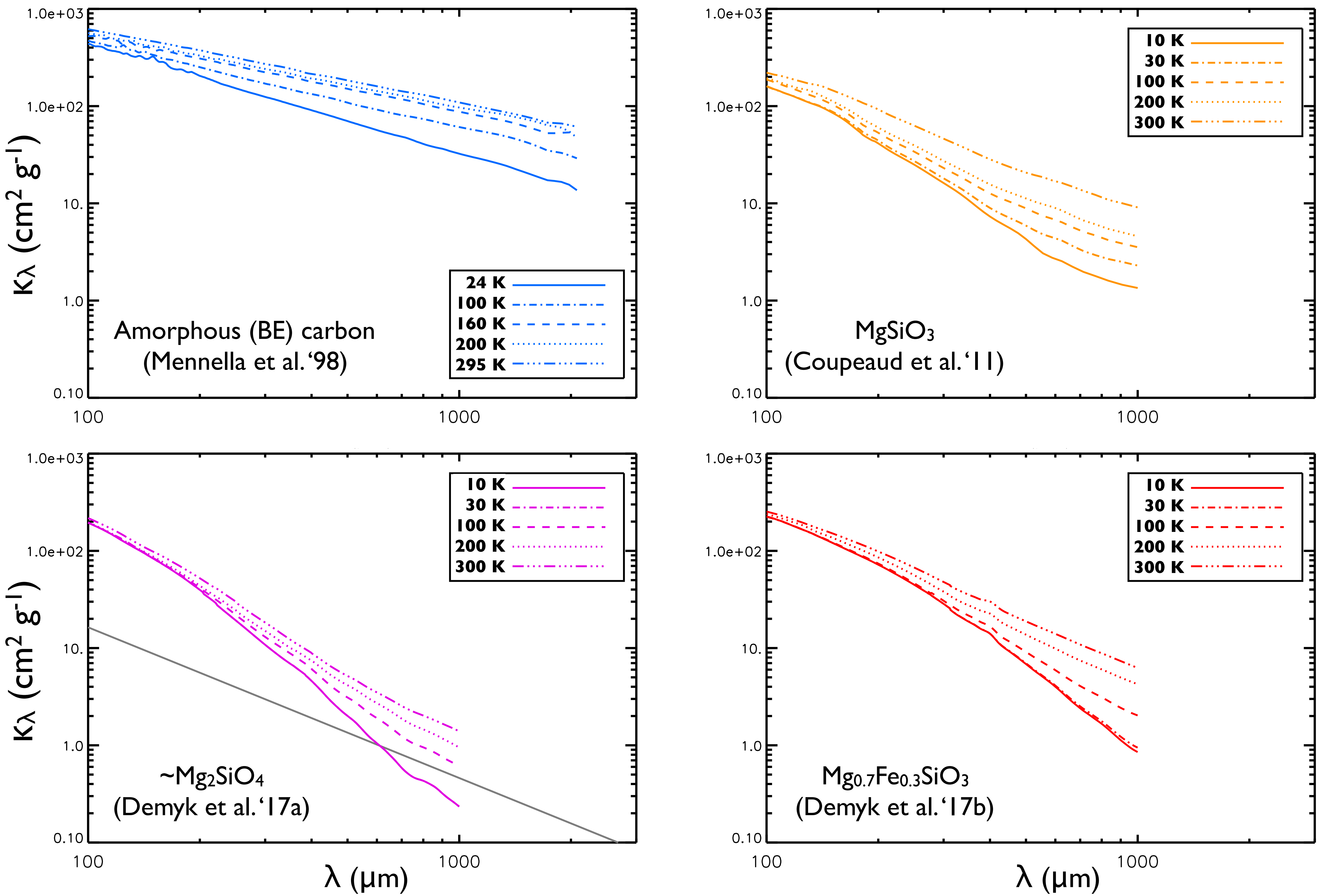
Wednesday 13 June 18

Kλ: Demyk et al. 2017

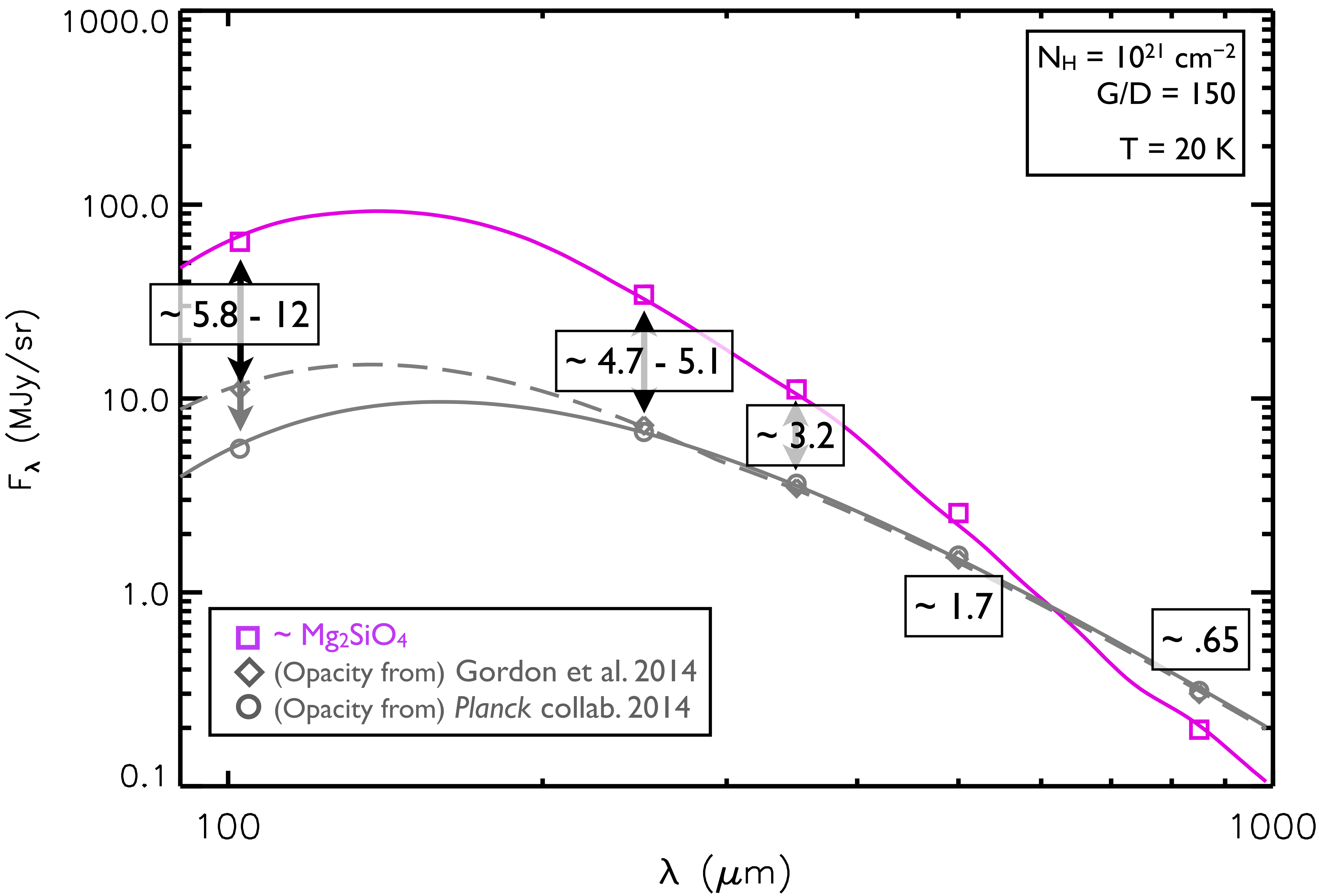
$(1\text{-}x)MgO\text{-}(x)SiO_2$



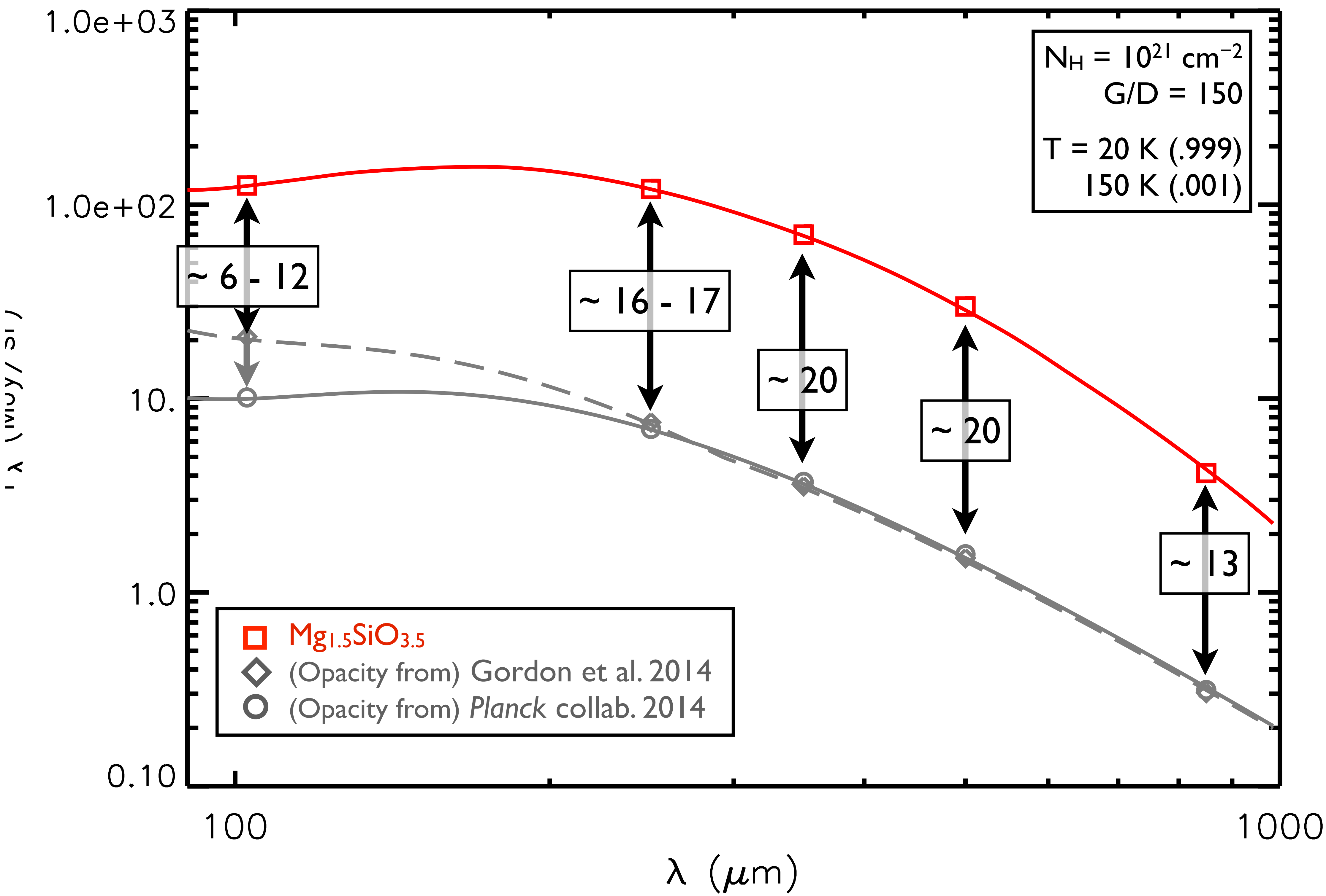
Laboratory dust opacities



“Best case” scenario



$Mg_{1.5}SiO_{3.5}$



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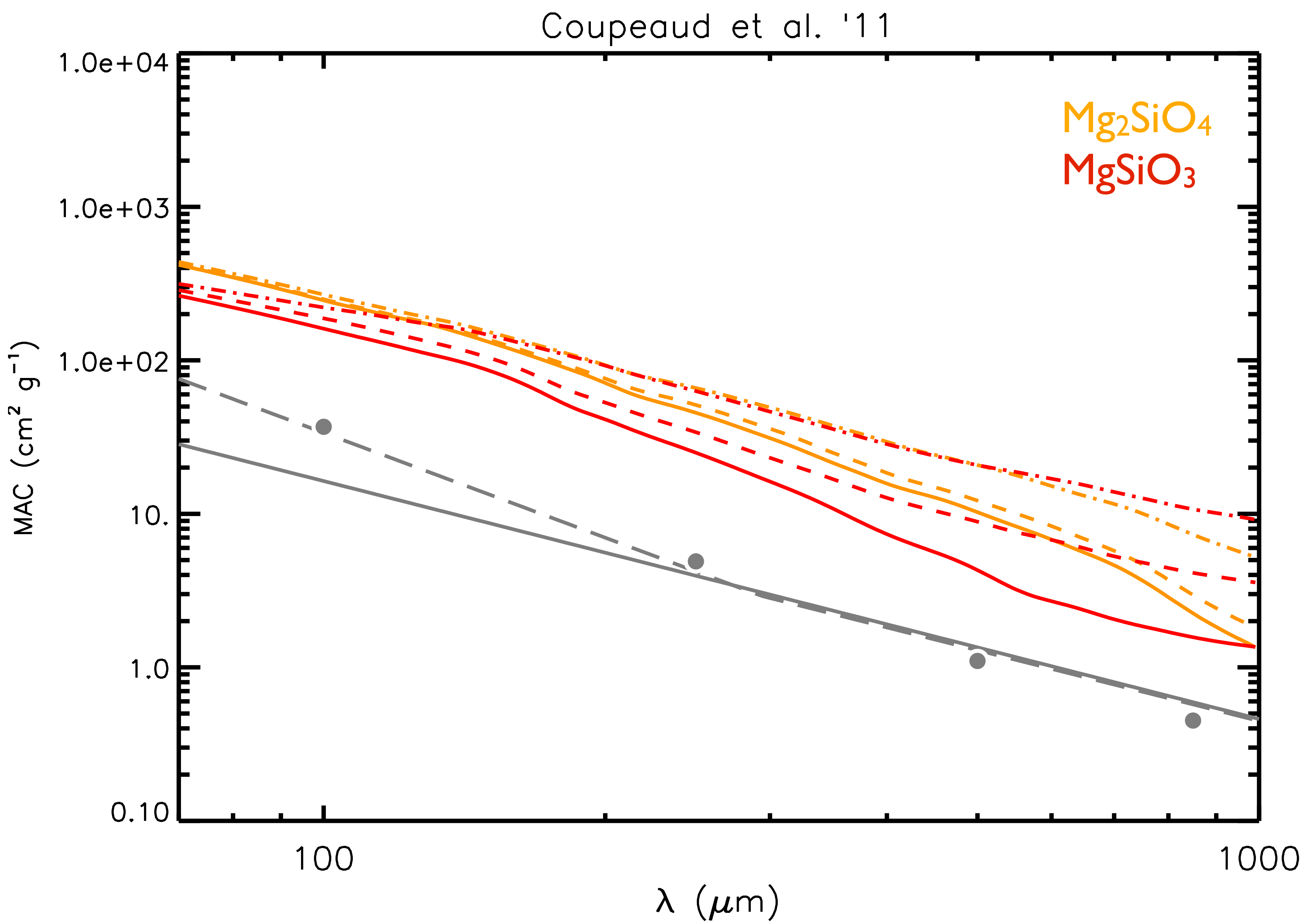
Ensemble view: Coupeaud et al. 2011



Work by Peter Scicluna, z = 1