The Mass of Dust in the Crab Nebula: RT Models with Smooth and Clumped Dust Distributions

DSLG2013

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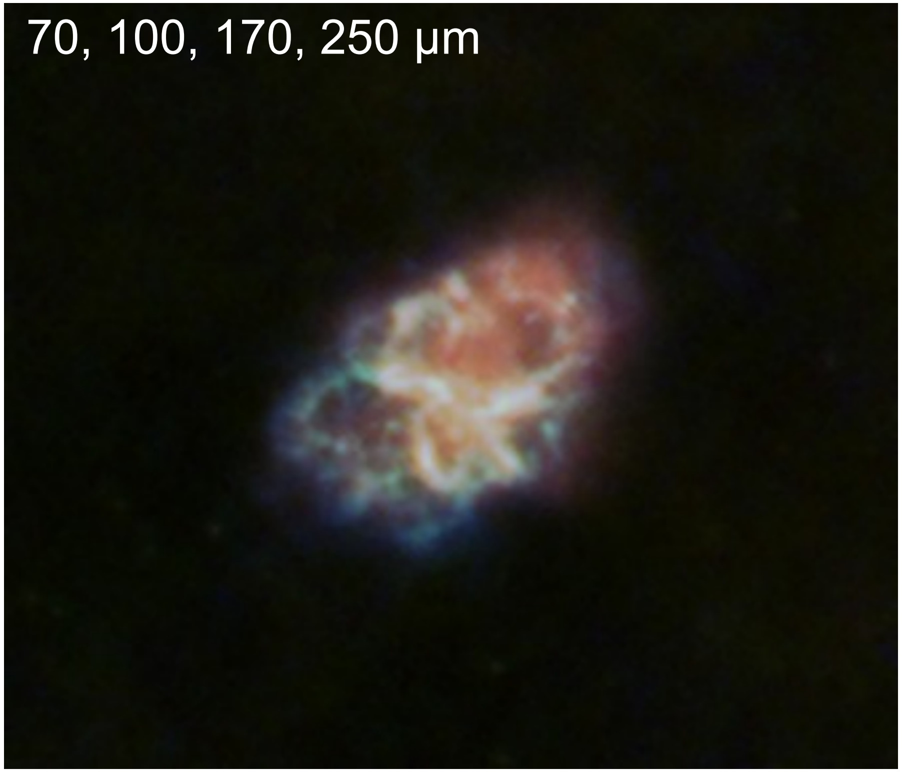
Contents

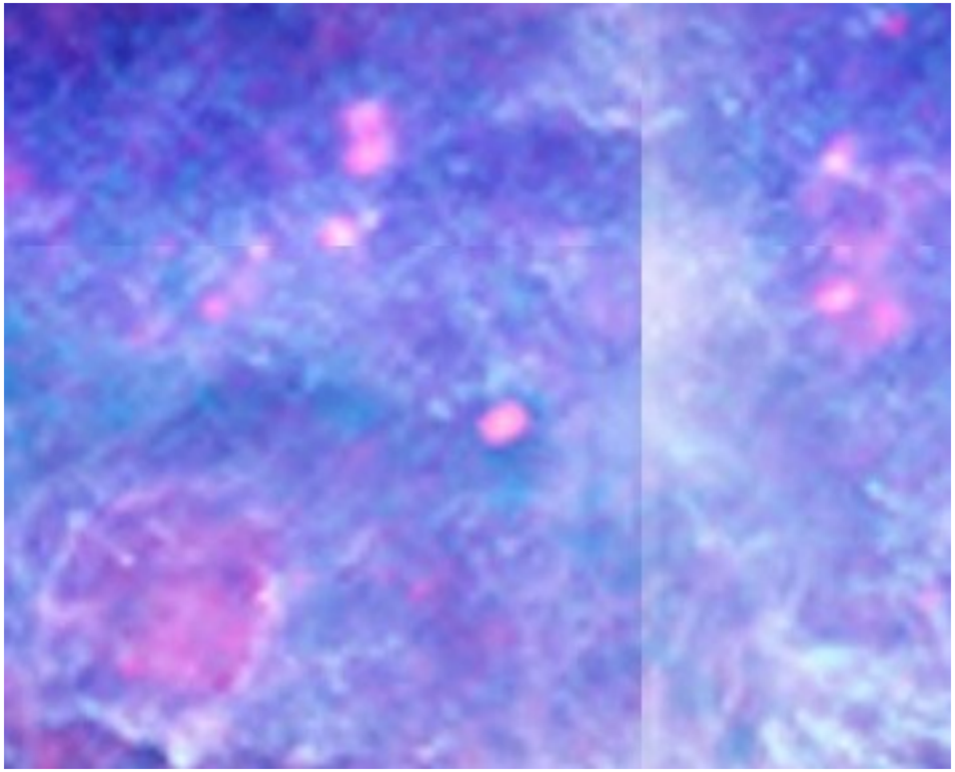
Introduction

- Sub-mm observations of high redshift galaxies have found vast amounts of dust
- Core Collapse Supernovae have been suggested as the source of dust
- Quantifying how much dust a supernova can produce is now very important
- Spitzer observations have been finding $<10^{-3}$ $M_{\odot}$ of warm dust; recent Herschel observations find 0.1 (Cas A) [1] 0.5 $M_{\odot}$ (SN1987A) [2] of cold dust

[1] Barlow et al 2010 A&A [2] Matsuura et al 2011 Science

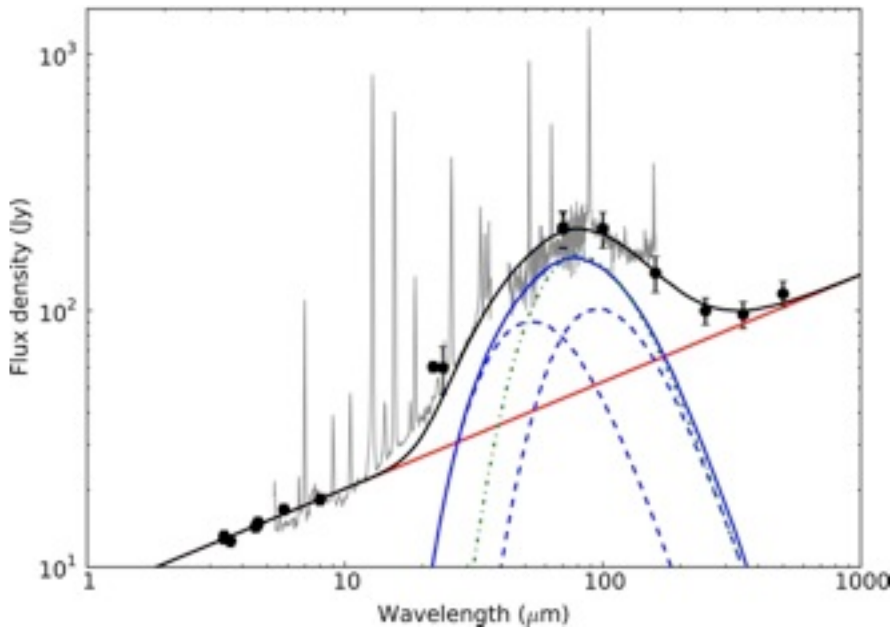
ESA *Herschel* and *Planck* Observations of the Crab Nebula





Estimating the Dust Mass in the Crab

- Amorphous Carbon
  $0.11 \pm 0.01\ M_\odot$ [3]
- Silicates
  $0.24 \pm^{0.32}_{0.08}\ M_\odot$ [3]
- Previous estimates from Spitzer $2.4 \times 10^{-3}\ M_\odot$ of warm dust [4]



[3] Gomez et al 2012 ApJ [4] Temim et al 2012 ApJ

Issues with this estimate of the dust mass

- Fitted with only two temperature components
- Does not take into account grains of different sizes or the distribution of those sizes
- Assumes that the dust is uniformly distributed throughout the nebula

Building a radiative transfer model to estimate the dust mass using MOCASSIN[5]

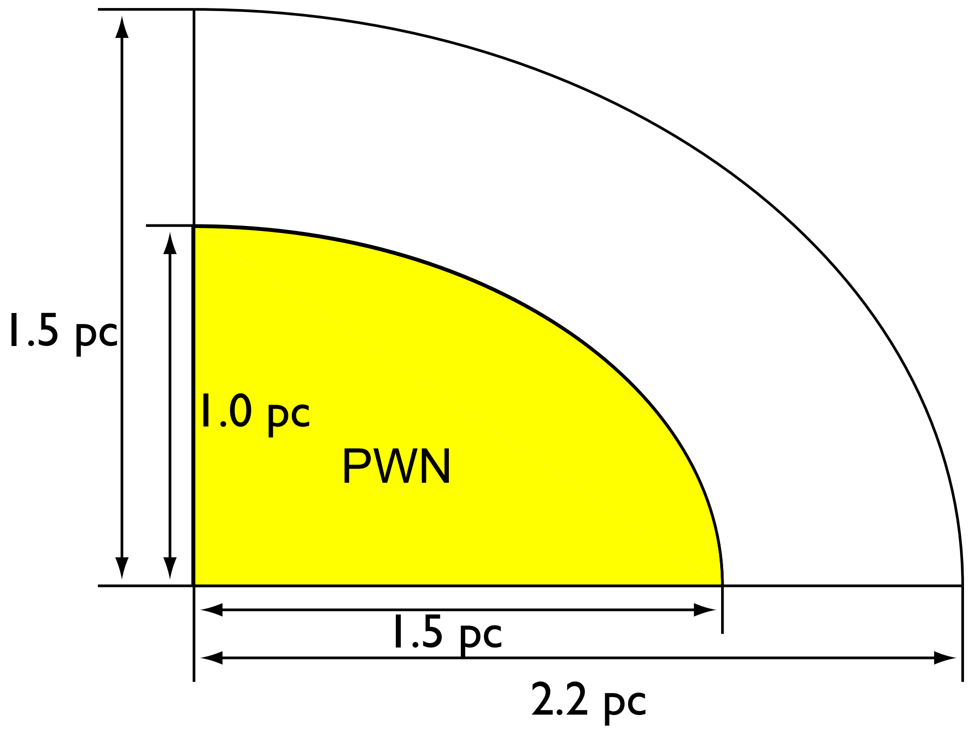
- Heats the dust radiatively rather than assuming temperature
- Varying grain size distribution
- Using different sets of optical properties
- Provides a diffuse photon source
- Using smooth, shell and clumpy density distributions

[5] Ercolano et al 2003, 2005, 2008

Ionisation in the Crab Nebula

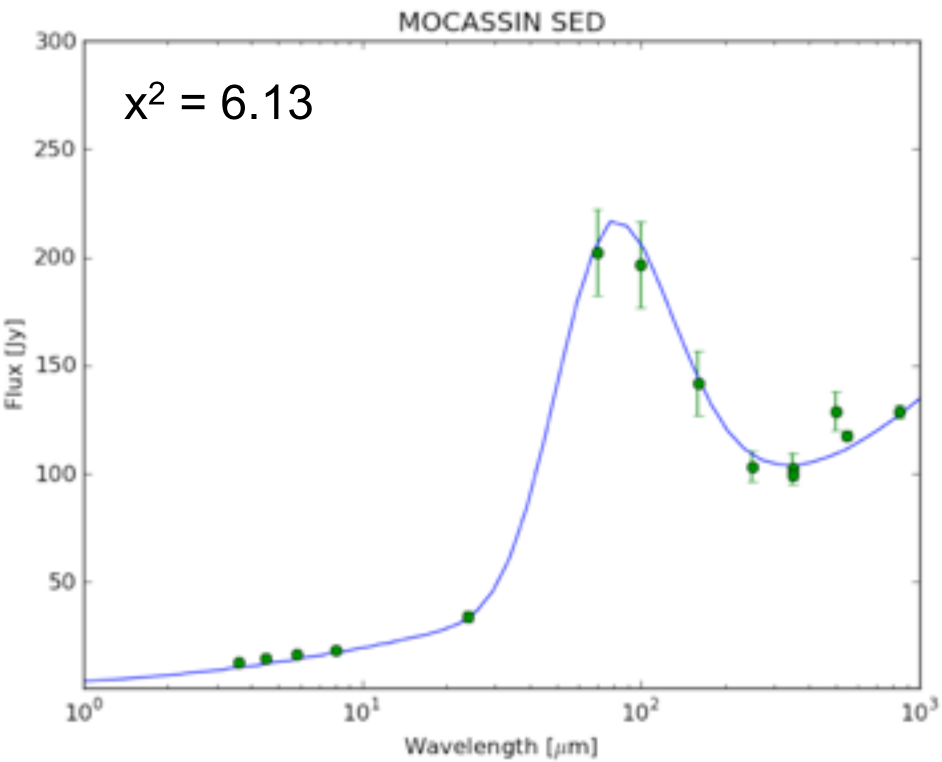
- The Crab contains an inner pulsar wind nebula
- Photoionised rather than shock-ionised
- Diffuse photon source through the central 2/3 of the nebula
- Synchrotron spectrum from Hester 2006, modified to take in to account *Planck* sub-mm and mm observations

Geometry of the model



[6] Hester 2006 ARAA 46

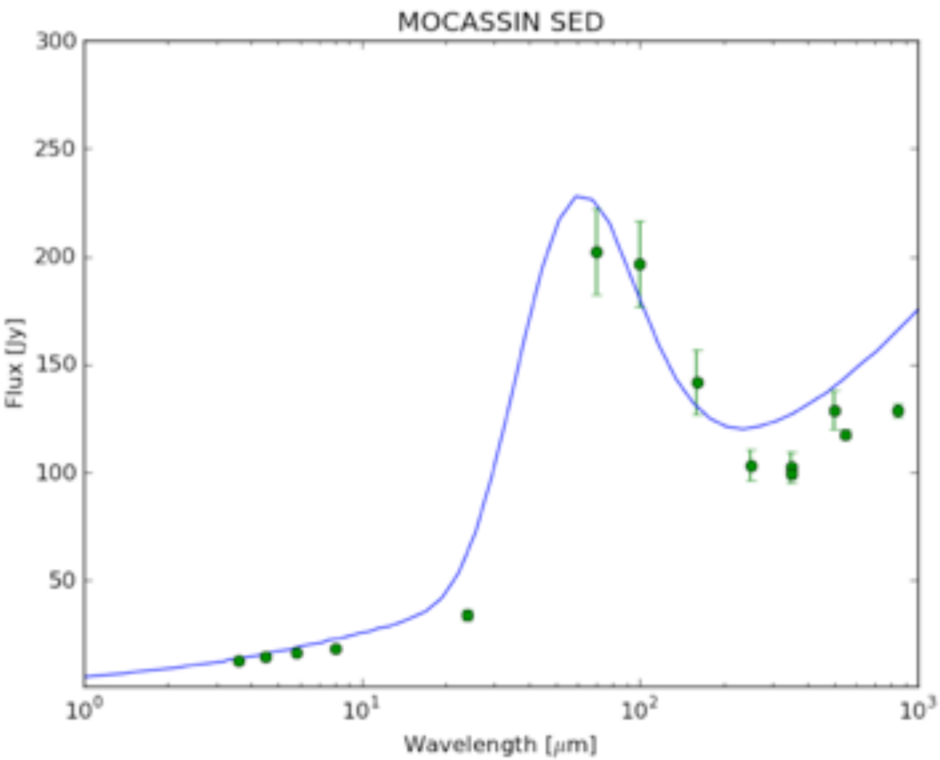
Determining Dust Mass Using MOCASSIN



Smooth models

0.1-0.3 $M_\odot$ of amorphous carbon dust

Amorphous Carbon with Zubko 1[7] optical constants



MRN77 [8] Standard Grain Size Distribution

a_{min} = 0.005 μm

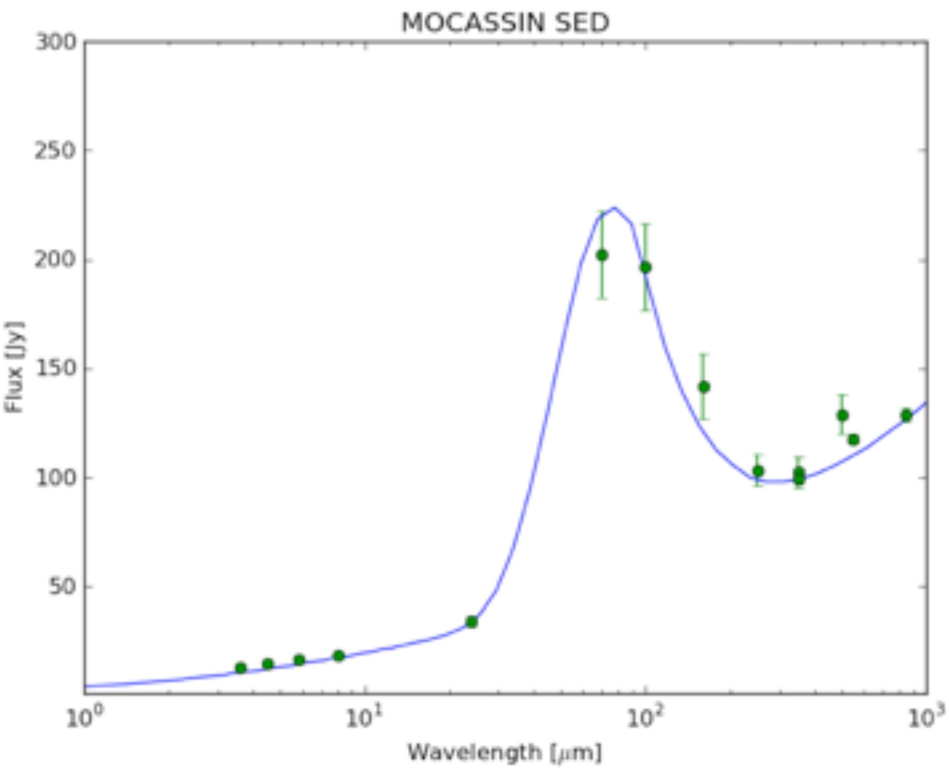
a_{max} = 0.25 μm

$n(a) \propto a^{-\alpha}$ (α = 3.5)

0.11 $M_\odot$ of dust

[7] Zubko, Dwek and Arendt 2004 ApJS
[8] Mathis, Rumpl and Nordseic 1977 ApJ

Fitting the Warm Dust Component - Varying a_{min}



Grain Size Distribution

a_{min} = 0.07 μm

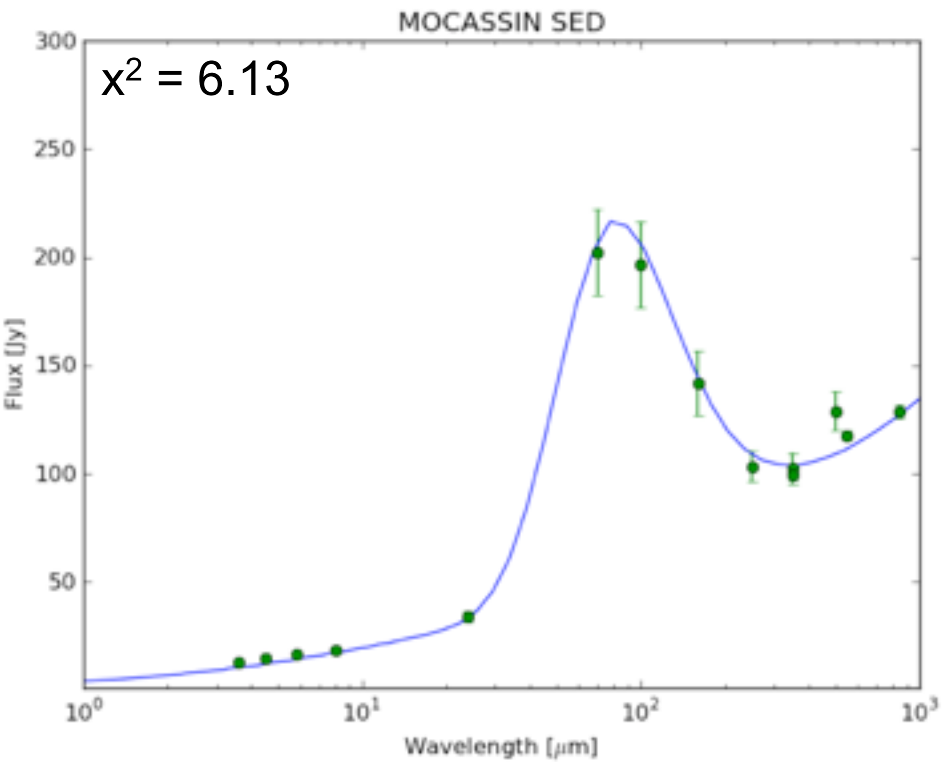
a_{max} = 0.5 μm

α = 3.5

0.18 $M_\odot$ of dust

Zubko 1 Amorphous Carbon optical constants

Fitting the Cold Dust Component - a_{max} and the power law of the grain size distribution



a_{min} = 0.07 μm

a_{max} = 1.0 μm

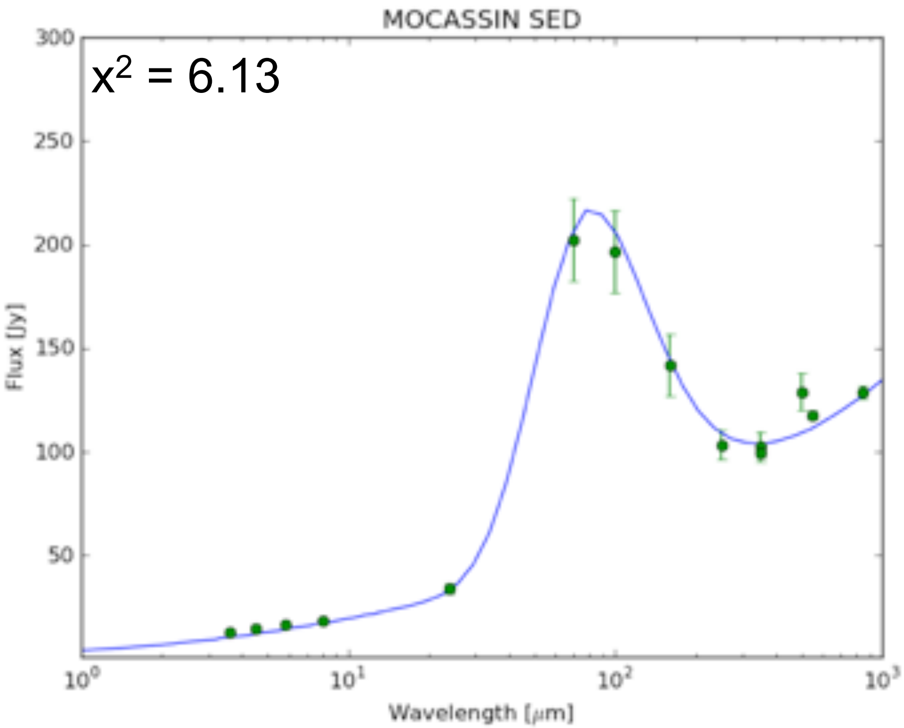
α = 2.9

0.31 M⊙ of dust

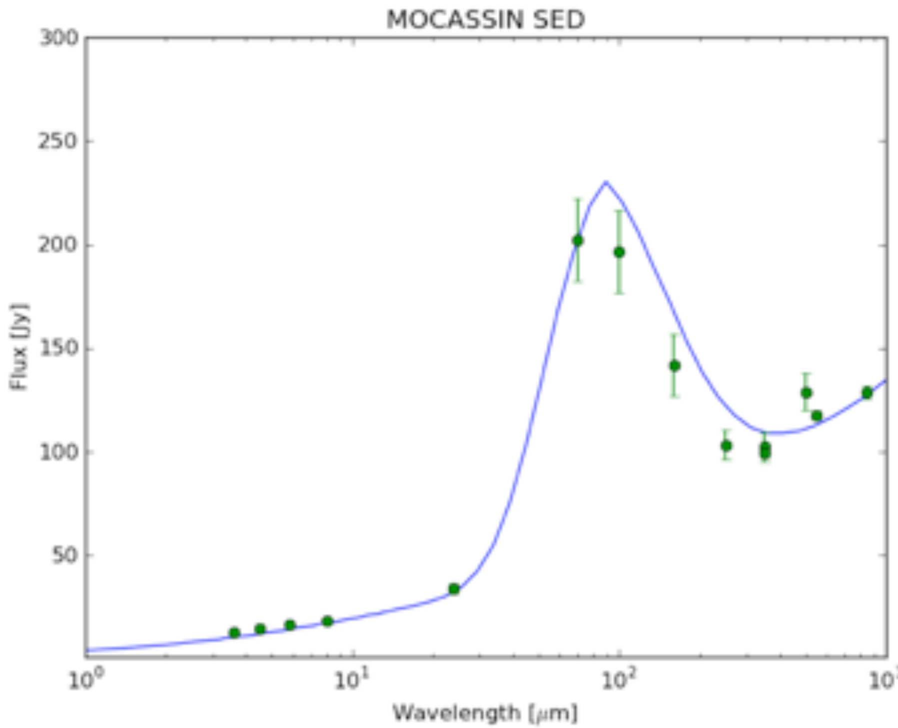
Zubko 1 Optical constants

Different Amorphous Carbon Optical Constants

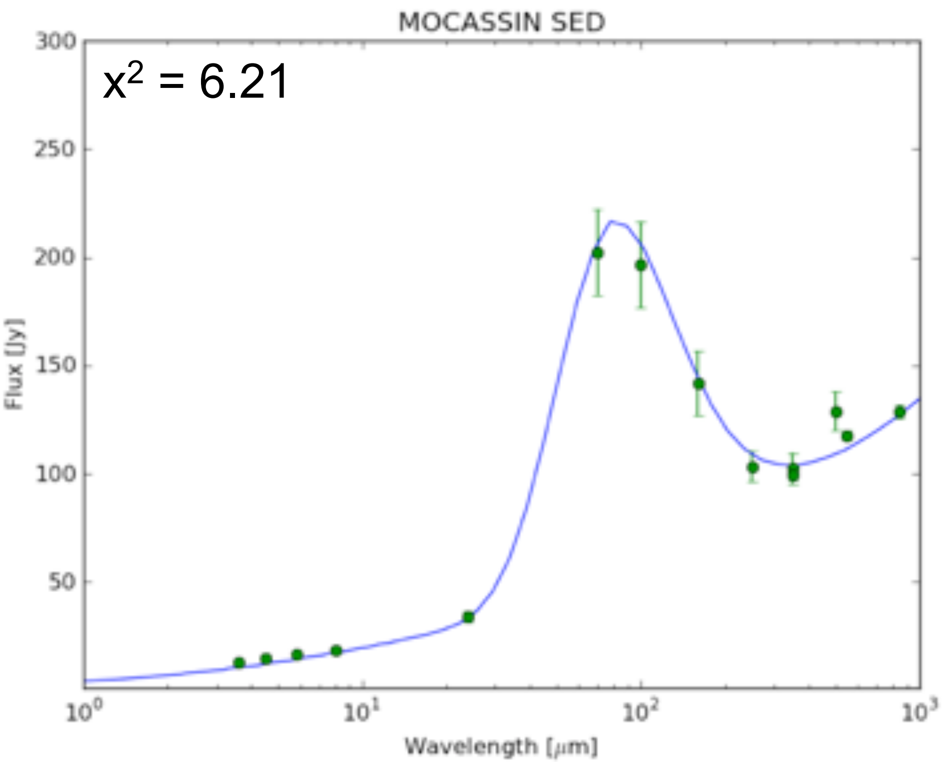
a) Zubko 1 Best Fit



b) Same parameters as a) but with Zubko 2 optical constants



Fitting with Amorphous Carbon with Zubko 2 optical constants



a_{min} = 0.07 μm

a_{max} = 0.2 μm

α = 2.9

0.16 $M_{\odot}$ of dust

Zubko 2 Optical constants

Smooth Model Best Fit Results

	Amorphous Carbon			Silicate[9]	Graphite [9]
	Zubko 1	Zubko 2	Hanner		
a_{min}	0.07 μm	0.07 μm	0.07 μm	0.07 μm	0.001μm
a_{max}	1.0 μm	0.2 μm	1.0 μm	1.0 μm	0.25 μm
α	2.9±0.1	2.9±0.1	2.9±0.1	3.5±0.1	3.0±0.1
dust mass	0.31 $M_\odot$ x^2 =6.13	0.16 $M_\odot$ x^2 =6.21	0.30 $M_\odot$ x^2 =7.01	0.46 $M_\odot$ x^2 =9.48	0.09 $M_\odot$ x^2 =7.16

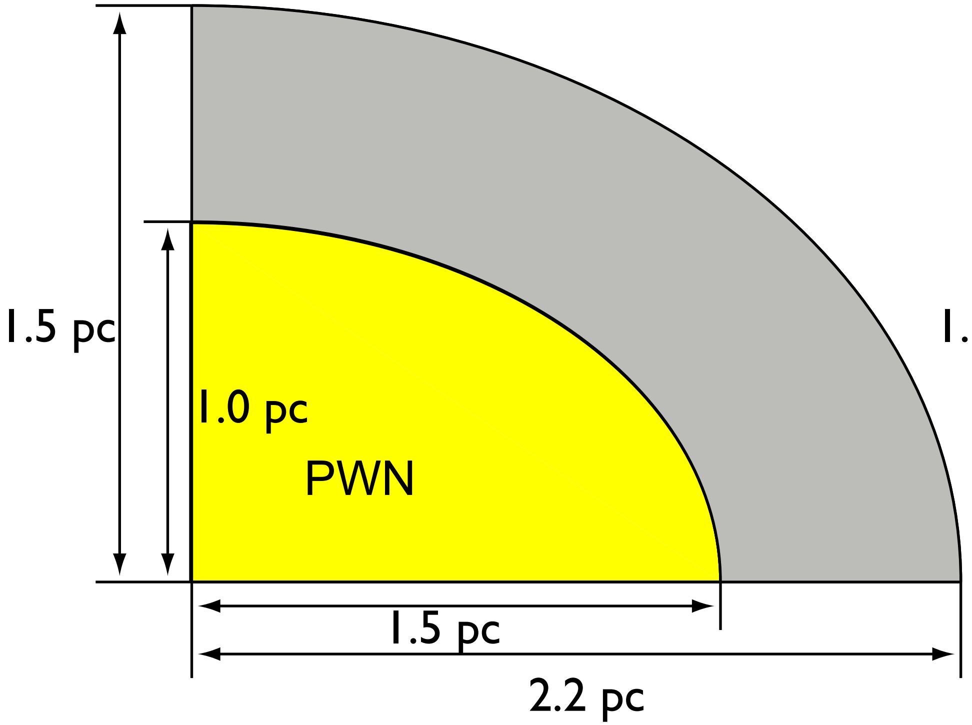
Different optical properties give very different dust masses

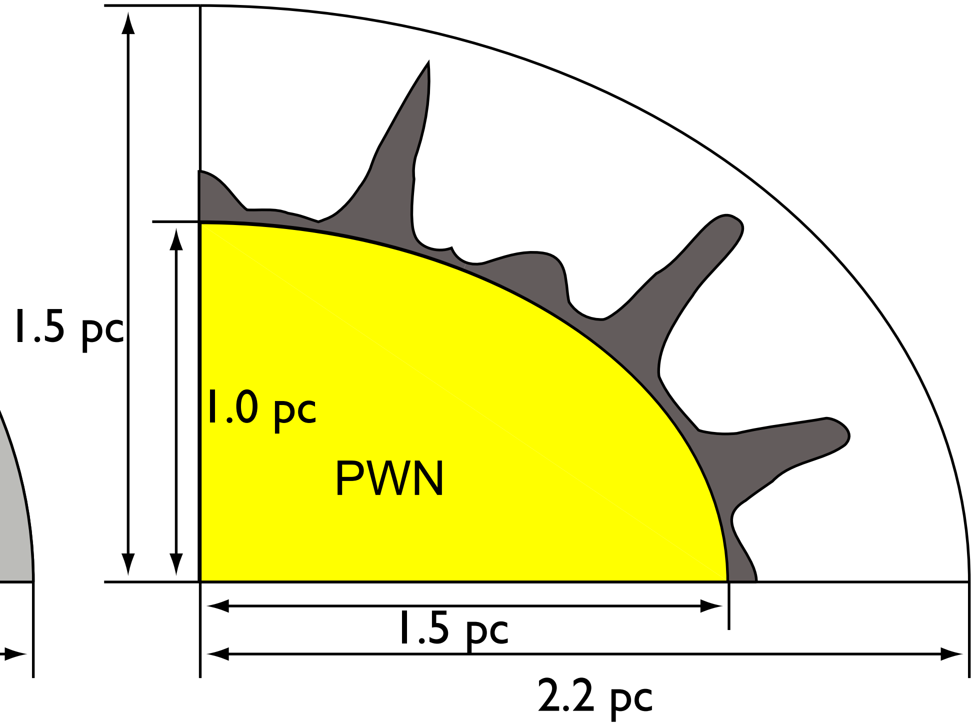
[9] Draine and Lee 1984 ApJ

Line Fluxes

- As well as fitting the SED, the model needs to fit the optical and IR emission line fluxes
- The smooth model (with $N_e = 50\ cm^{-3}$) fits H_β but not other lines
- Changing the density distribution will give a different ionisation structure

Shells: Smooth or Clumpy





All mass outside PWN Photon source
N_e = 50 cm^{-3}

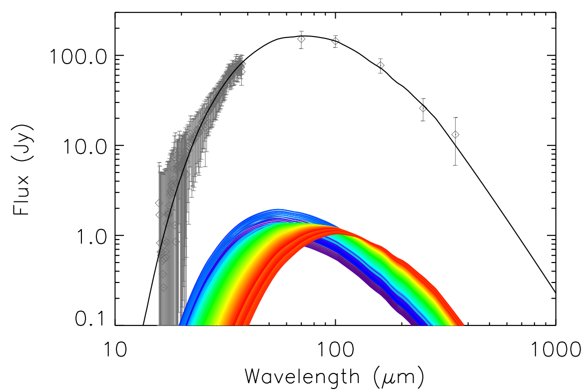
Mass in clumps of radius 0.1 pc
Filling factor of 0.1
Decreasing with r^2
N_e = 250 cm^{-3}

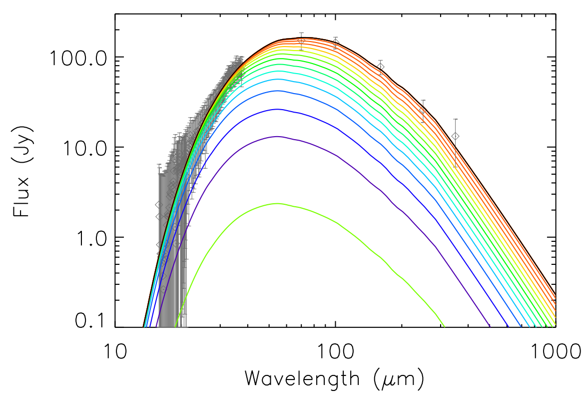
Results of Shell and Clumpy Models

	Amorphous Carbon			Silicate	Graphite
	Zubko 1	Zubko 2	Hanner		
Smooth	0.31 $M_\odot$ x^2 = 6.13	0.16 $M_\odot$ x^2 = 6.21	0.30 $M_\odot$ x^2 = 7.01	0.46 $M_\odot$ x^2 = 9.48	0.09 $M_\odot$ x^2 = 7.16
Shell	0.27 $M_\odot$ x^2 = 9.9	0.11 $M_\odot$ x^2 = 9.7	0.27 $M_\odot$ x^2 = 10.6	0.40 $M_\odot$ x^2 = 11.3	0.08 $M_\odot$ x^2 = 11.0
Clumpy	0.64 $M_\odot$ x^2 = 11.3	0.48 $M_\odot$ x^2 = 11.5	0.60 $M_\odot$ x^2 = 13.1	1.5 $M_\odot$ x^2 = 14.4	0.4 $M_\odot$ x^2 = 13.2

Different density distributions give very different dust masses

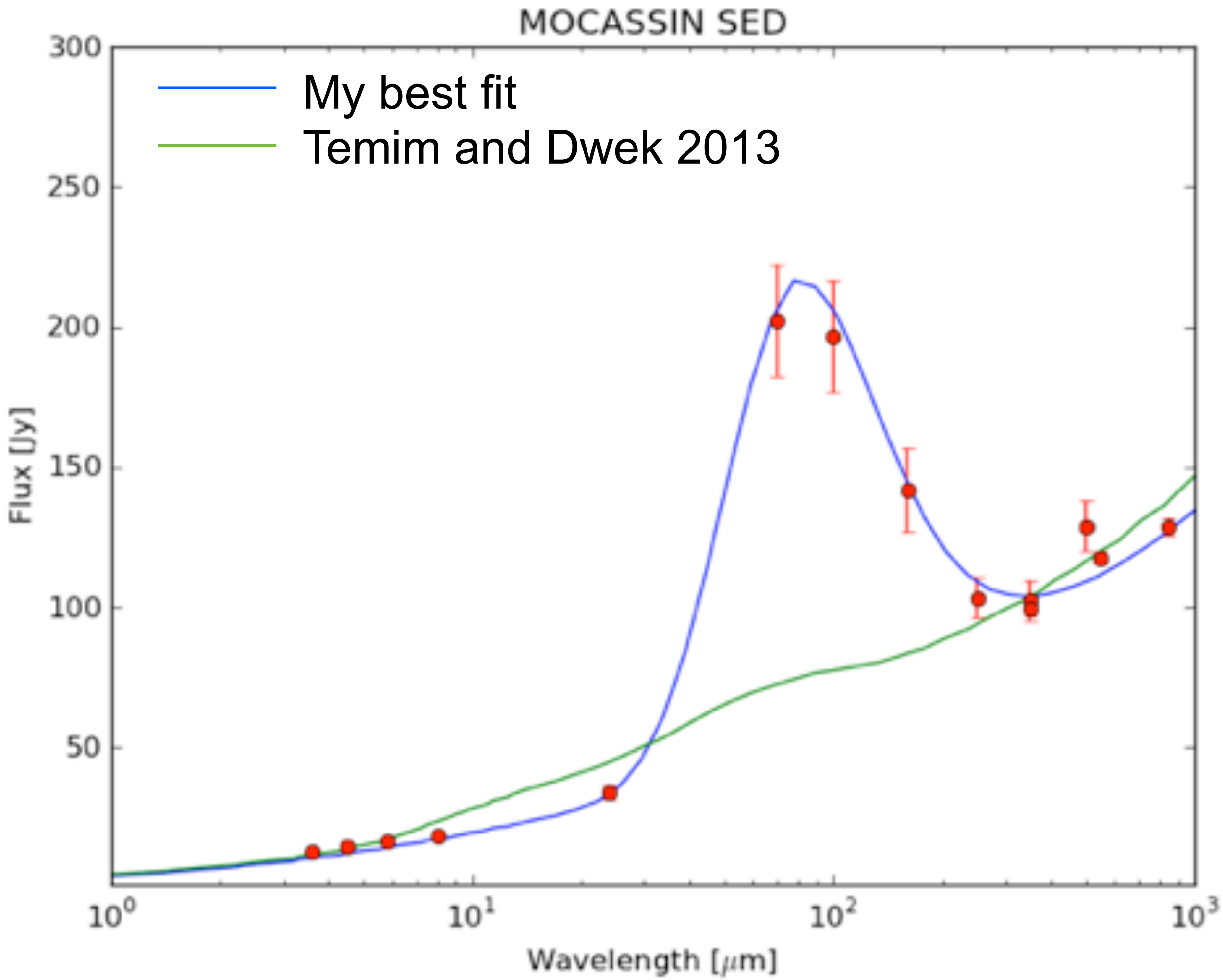
An Alternate View:
Temim and Dwek 2013 arXiv:1302.5452



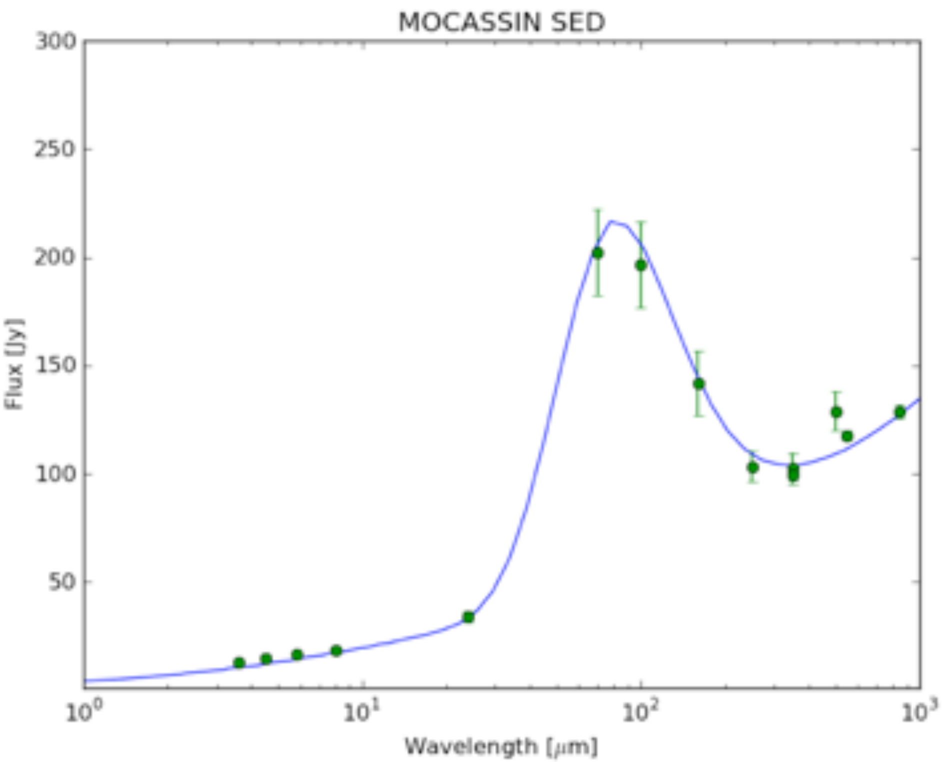


- Fitted a large number of modified black bodies for grain size/temperature distribution
- Central point source
- Zubko 2: 0.05 $M_\odot$ of dust with a distribution α = 3.5 over a range 0.001-1.0 μm

A MOCASSIN model with Temim and Dwek (2013) Parameters



Best Fit Results



Smooth models

0.1-0.3 $M_\odot$ of amorphous carbon dust

Clumpy models

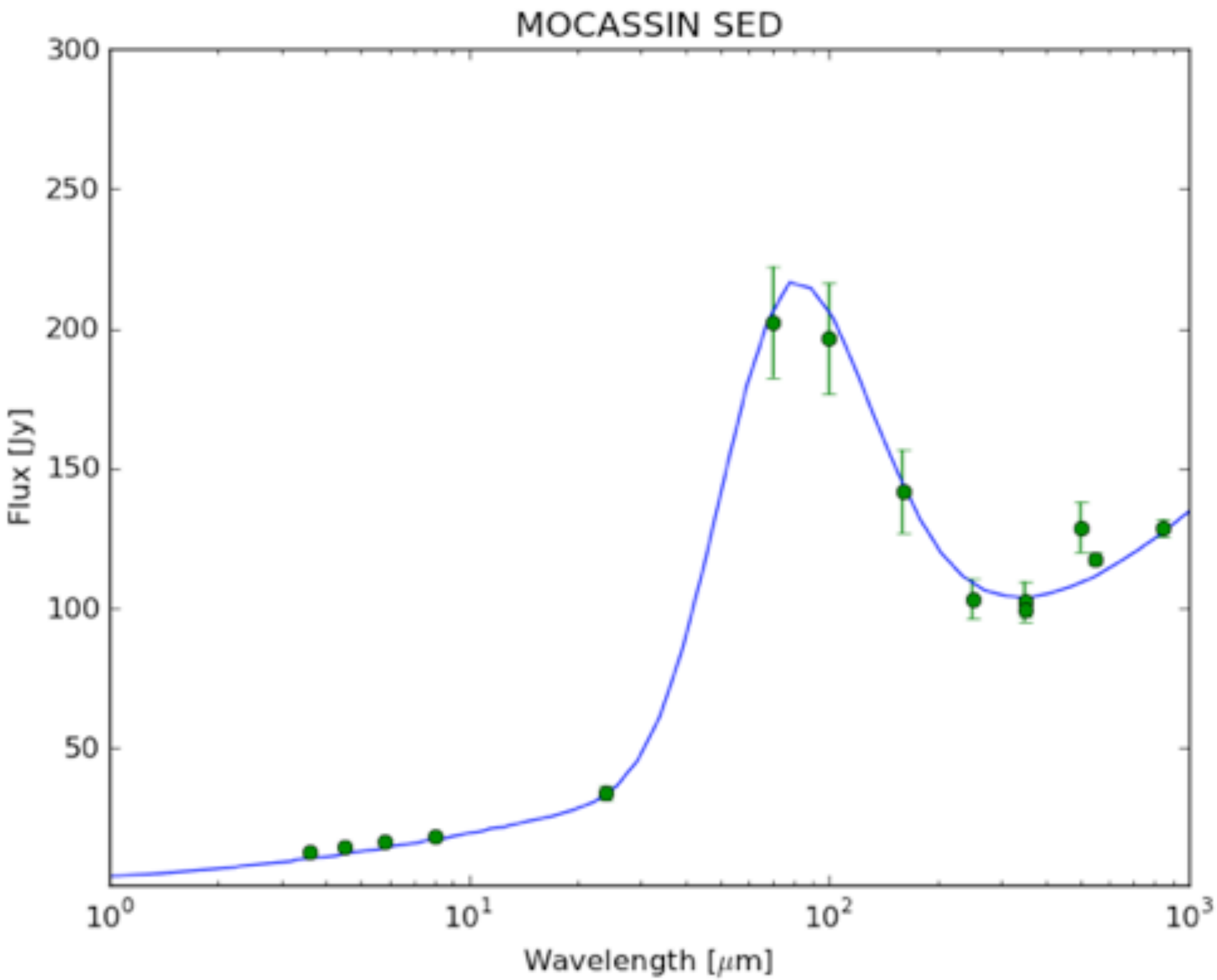
0.4-0.6 $M_\odot$ of amorphous carbon dust

Conclusions

- Determining the dust mass using RT modelling gives higher dust masses than simple SED fits
- Different dust properties give very different dust masses
- Clumped dust density distributions give 2-3 times higher dust masses compared to smooth dust density distributions
- There is a large mass of dust in the Crab

Thank You

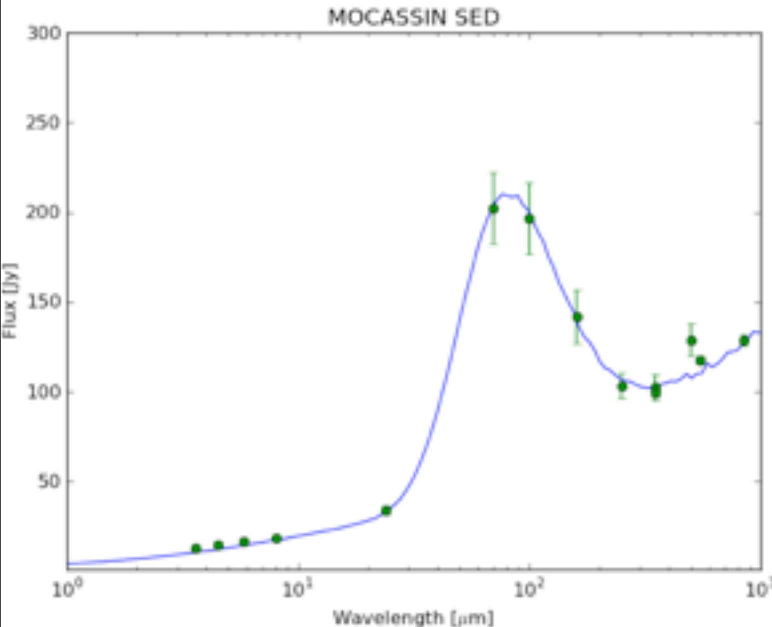
Silicates Best Fit - 0.46 $M_\odot$



Clumps Best Fits

Zubko 1 Amorphous Carbon

Clumps - 0.64 $M_\odot$ dust



Zubko 2 Amorphous Carbon

Clumps - 0.48 $M_\odot$ dust