The Far-Infrared Emission of the First Massive Galaxies

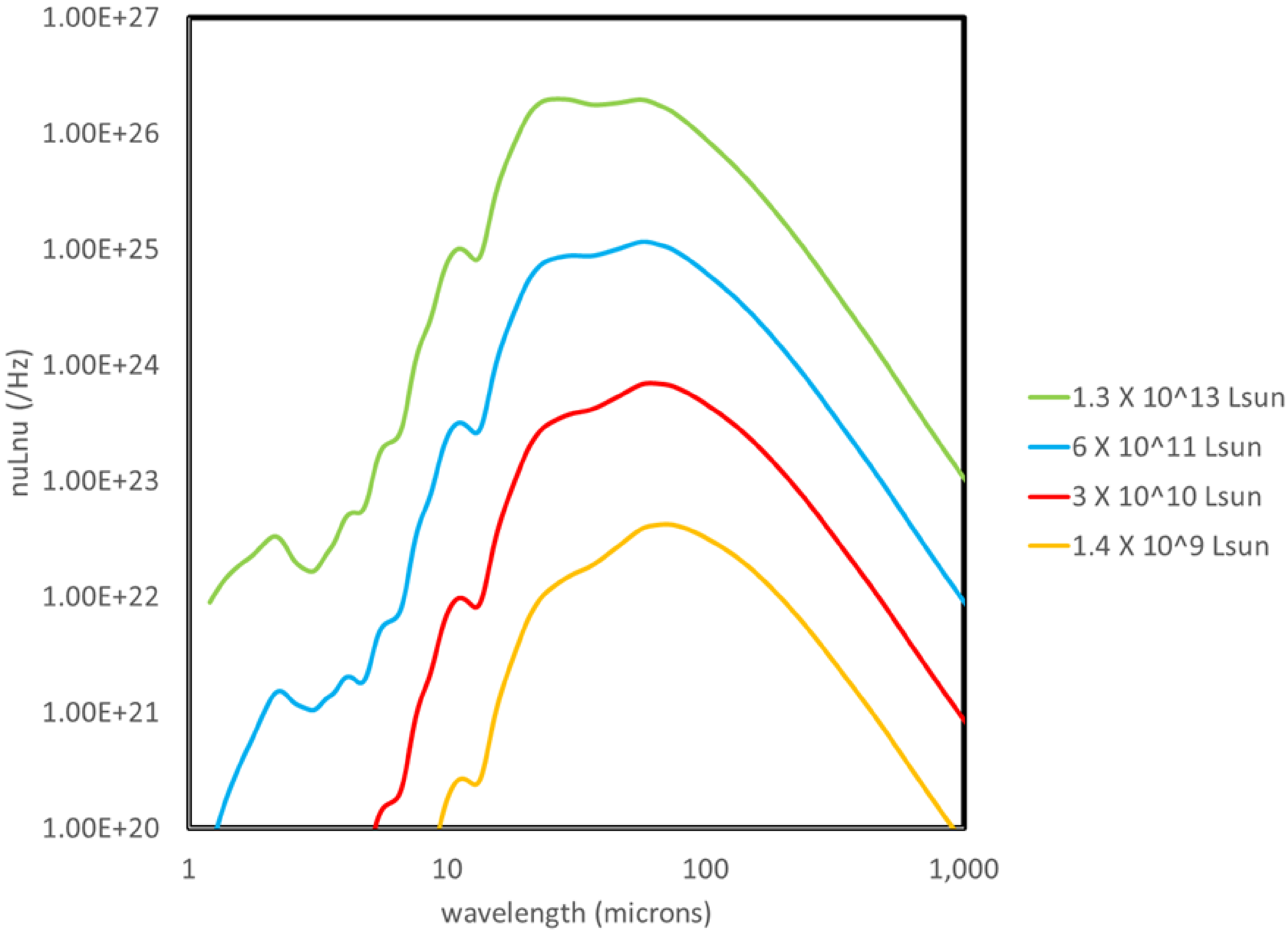
G. Rieke with M. E. De Rossi, I. Shivaei, V. Bromm, J. Lyu: ApJ, 869, 4 (2018)

- Dust will be silicate-rich for first 400 Myr of evolution of a galaxy
  - Large carbon yields only for AGM stars below 3.5 $M_{\odot}$
- Far infrared emission of silicate-rich dust is “warmer” than for 50/50 silicate/carbon
  - Poor emission efficiency of silicate dust outside 8 – 60 μm
- High energy density of early galaxies also favors “warm” far infrared SEDs
- Haro 11 spectral energy distribution is a good surrogate for very high redshift IR galaxies
  - Dominated by very recent star formation, similar energy density
- Haro 11 SED fits the composite SED for $5 < z < 7$ galaxies well
  - Fit with local templates is much worse
- Haro 11 template fit implies much higher star formation rates needed for a given flux density at 1mm, compared with local or blackbody templates

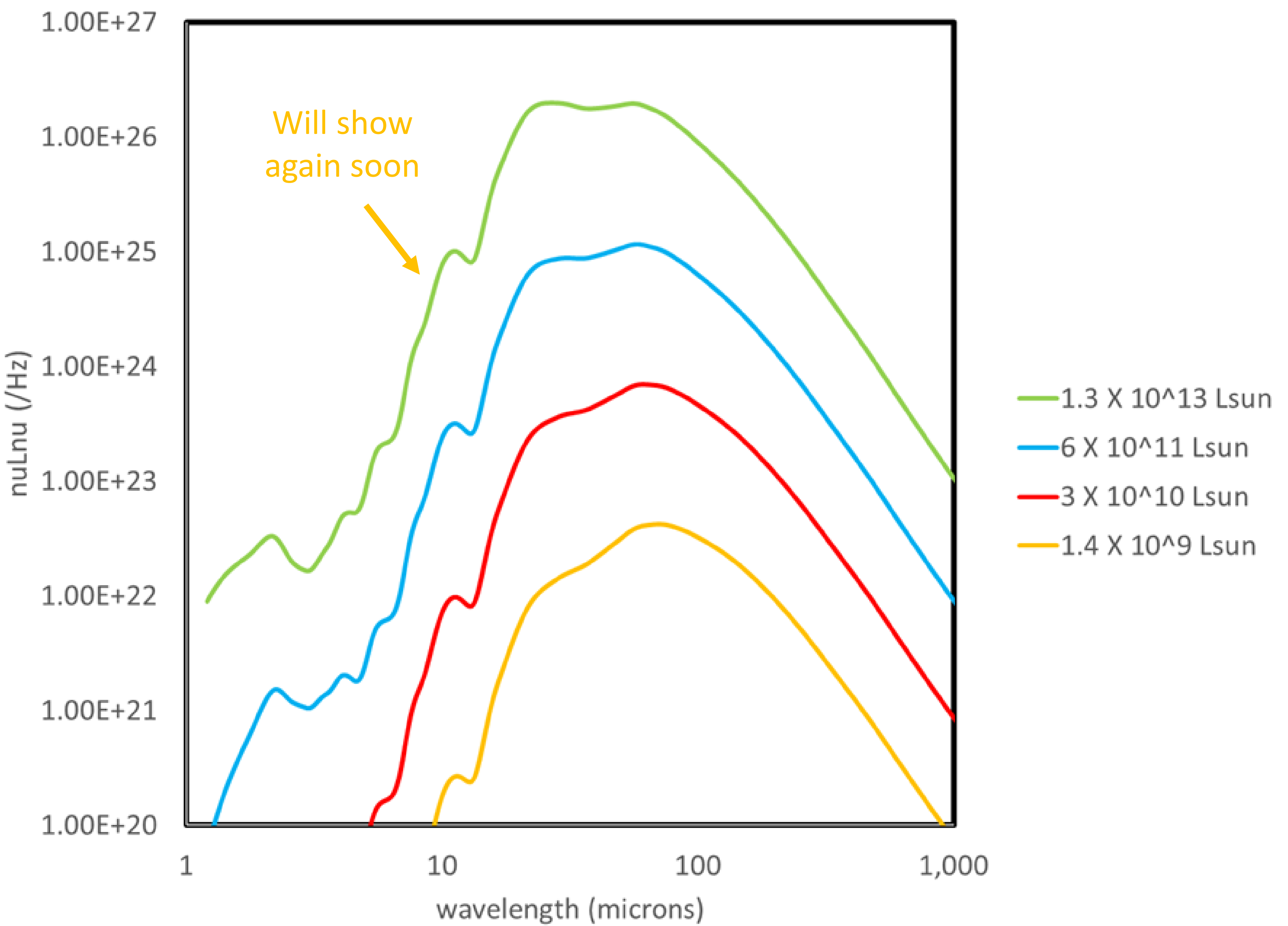
- **Dust will be silicate-rich for first 400 Myr* of evolution of a galaxy**
  - **Large carbon yields only for AGB stars below 3.5 $M_\odot$**
- **Far infrared emission of silicate-rich dust is “warmer” than for 50/50 silicate/carbon**
  - **Poor emission efficiency of silicate dust outside 8 – 60 μm**
- **High energy density of early galaxies also favors “warm” far infrared SEDs**

* 400 Myr corresponds to going from z = 9 to z = 6

Theoretical SEDs for these young galaxies peak between 15 & 100 μm



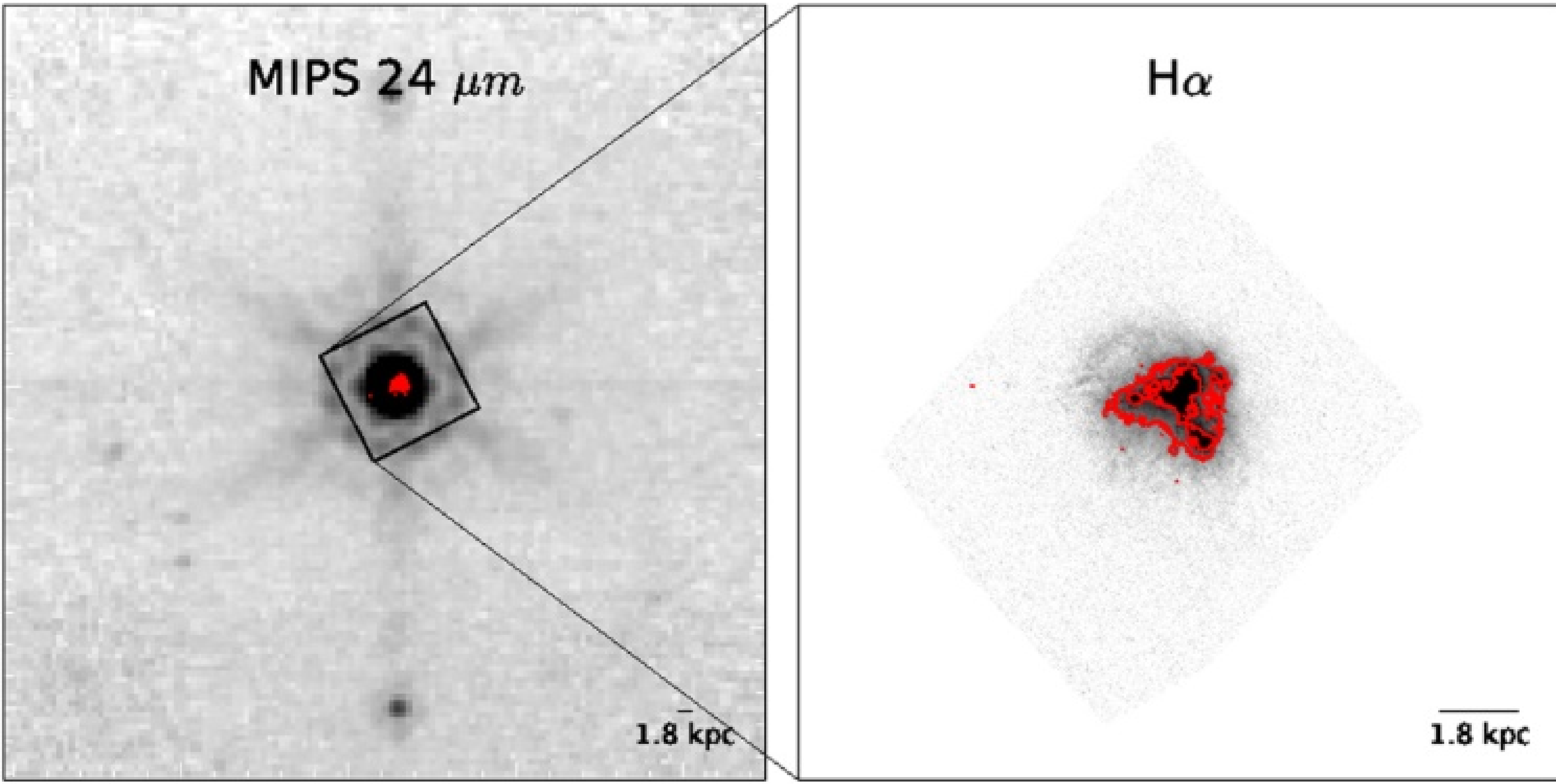
Theoretical SEDs for these young galaxies peak between 20 & 100 μm



- **Haro 11 spectral energy distribution is a good surrogate for very high redshift IR galaxies**
  - **Dominated by very recent star formation, similar energy density**

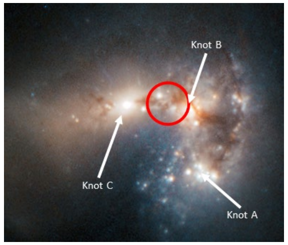
Haro 11

- Black beam is infrared source – unresolved with Spitzer ⇉ $\leq$ 150 pc, SFR = 30 $M_{\odot}$ /yr
- SF surface density 500 $M_{\odot}$ /yr pc^{-2}, mass 2 X 10^{9} $M_{\odot}$, sSFR = 15 Gyr^{-1}, 12 + log(O/H) ~ 8.3



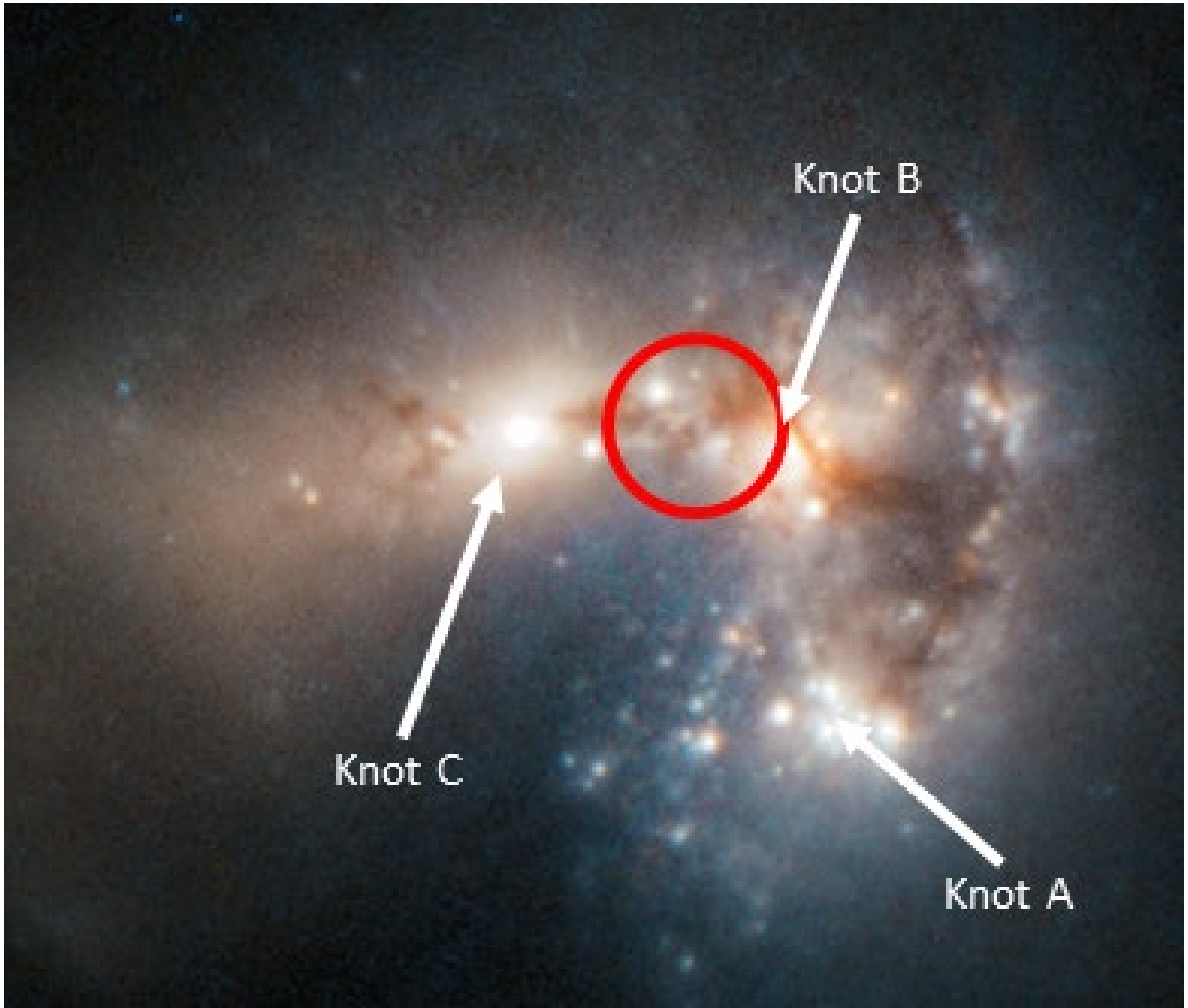
Haro 11

- Red circle is infrared source – unresolved with Spitzer $\rightrightarrows$ $\leq$ 150 pc, SFR = 30 $M_{\odot}$ /yr
- SF surface density 500 $M_{\odot}$ /yr pc^{-2}, mass 2 X 10^9 $M_{\odot}$, sSFR = 15 Gyr^{-1}, 12 + log(O/H) ~ 8.3

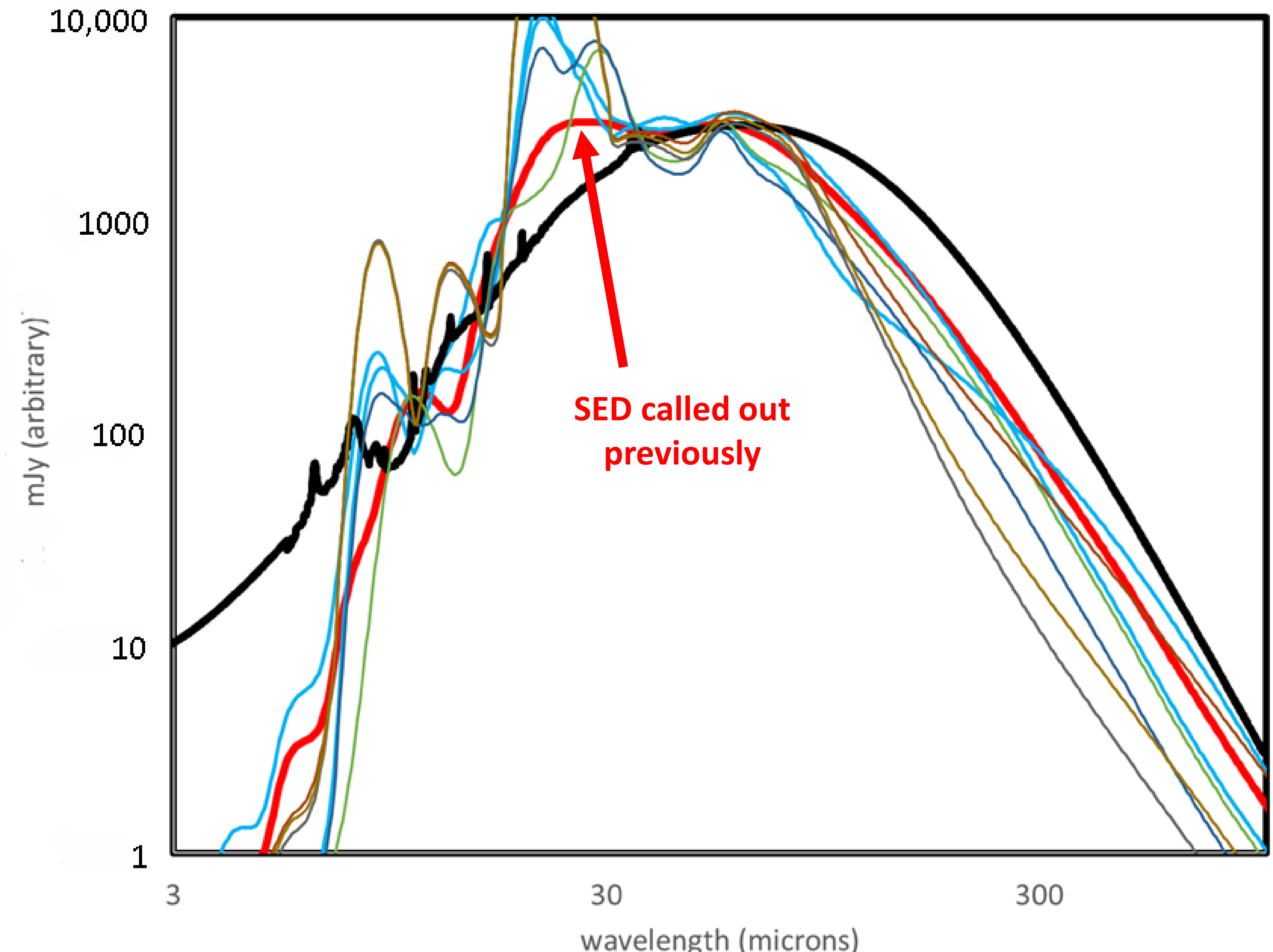


Haro 11

- Red circle is infrared source – unresolved with Spitzer ⇉ $\leq$ 150 pc, SFR = 30 $M_{\odot}$ /yr
- SF surface density 500 $M_{\odot}$ /yr pc^{-2}, mass 2 X 10^9 $M_{\odot}$, sSFR = 15 Gyr^{-1}, 12 + log(O/H) ~ 8.3

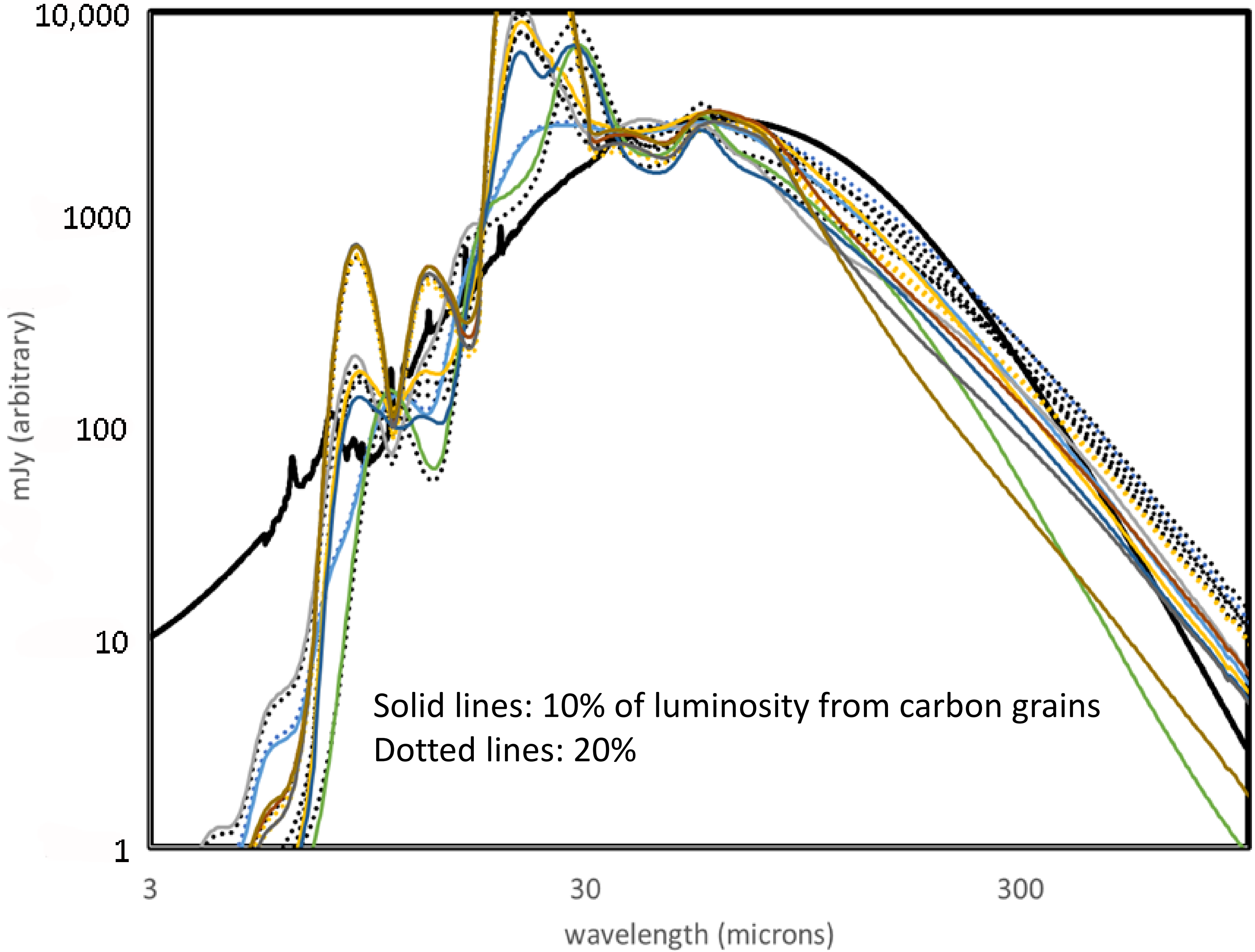


The pure silicate SEDs do not fit the Haro 11 one well.



But just a little carbon makes a big improvement

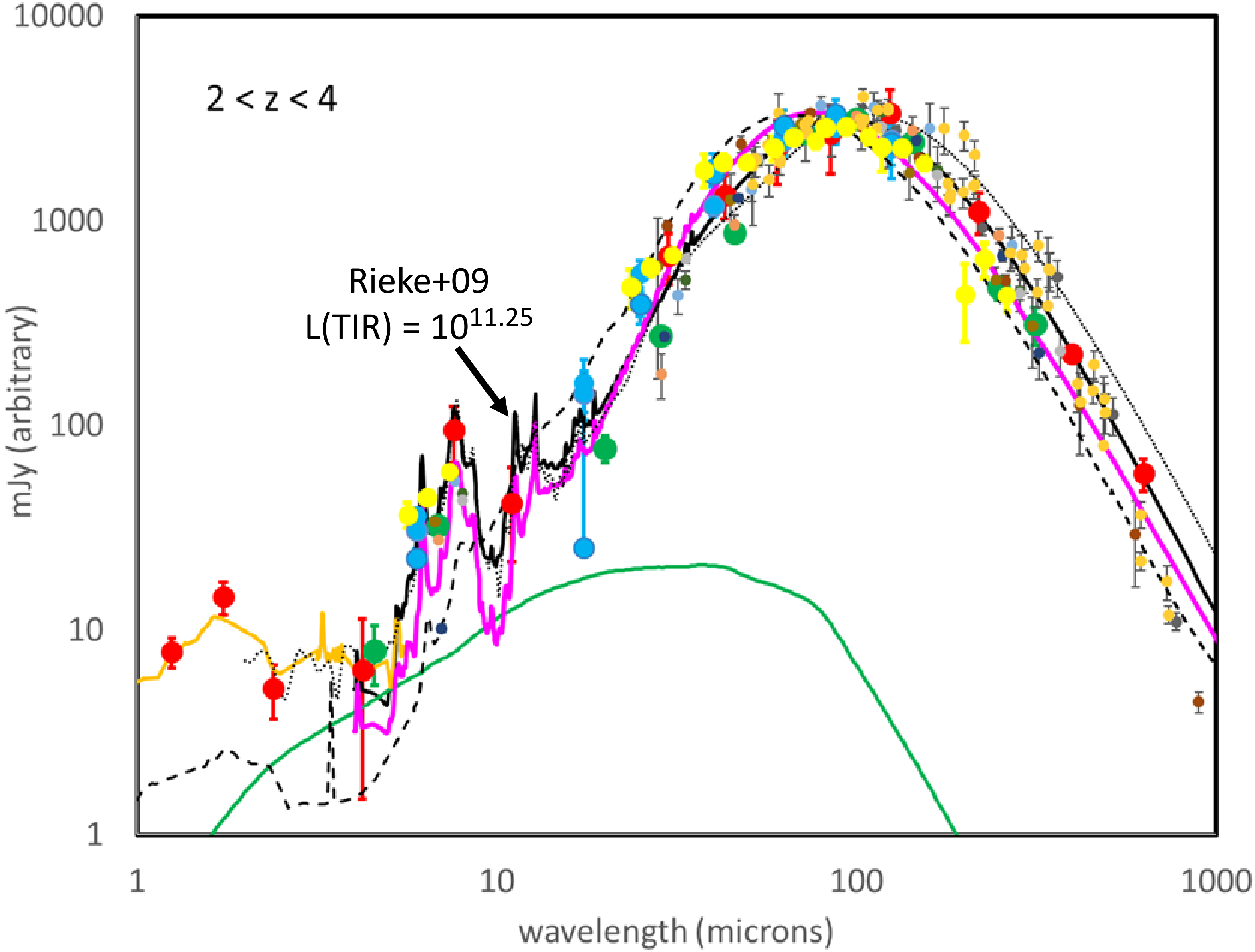
- 156μm line shows there is some carbon and small yields are predicted theoretically



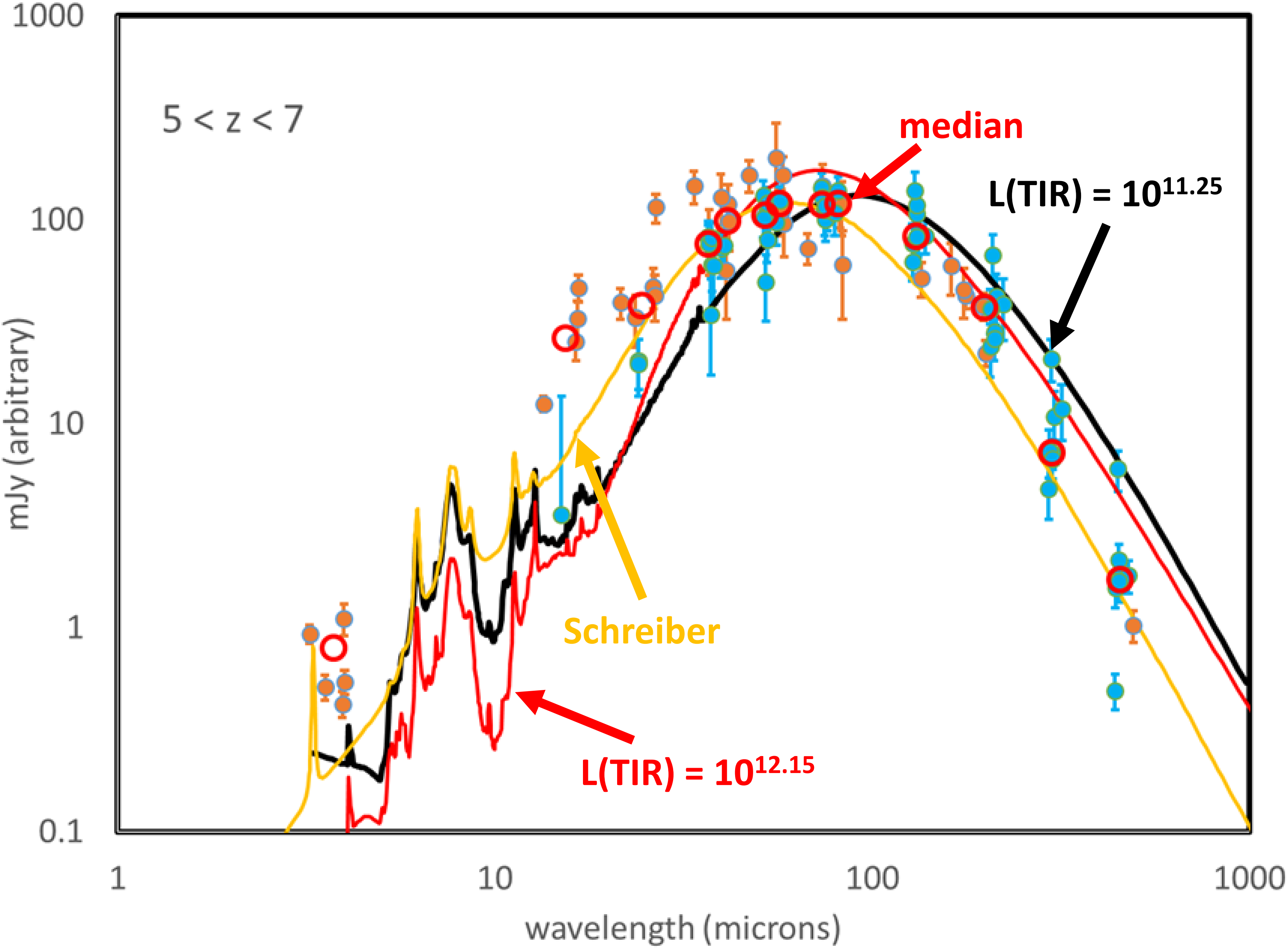
- **“Local” templates fit SEDs well at $z \sim 3$**
- **Haro 11 SED fits the composite SED for $5 < z < 7$ galaxies well**
  - **Fit with local templates is much worse**

"Local" template fits well at z ~ 3

- Measured points have been shifted to rest frame and normalized over 50 < λ < 200μm

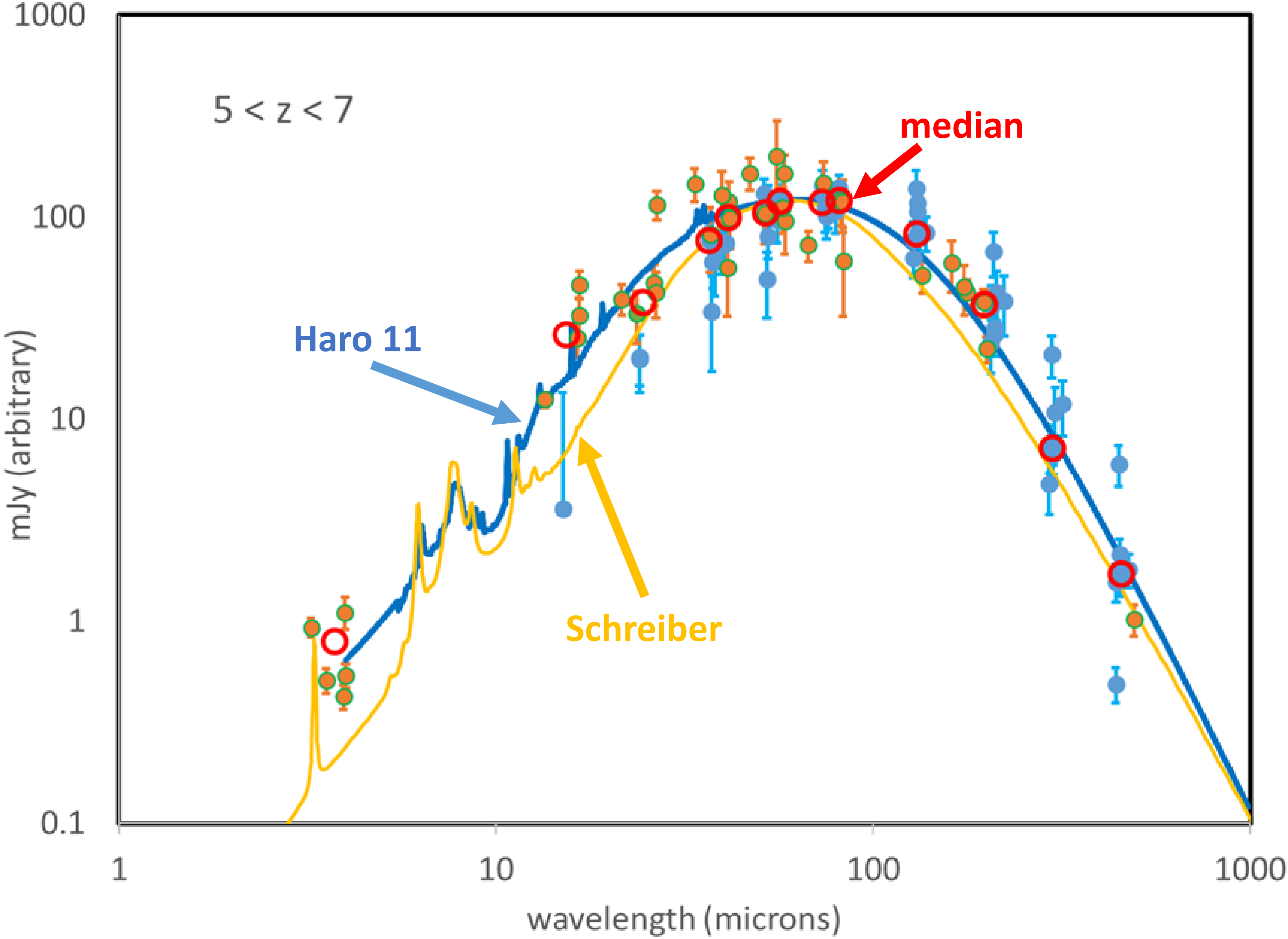


but not at z ~ 6



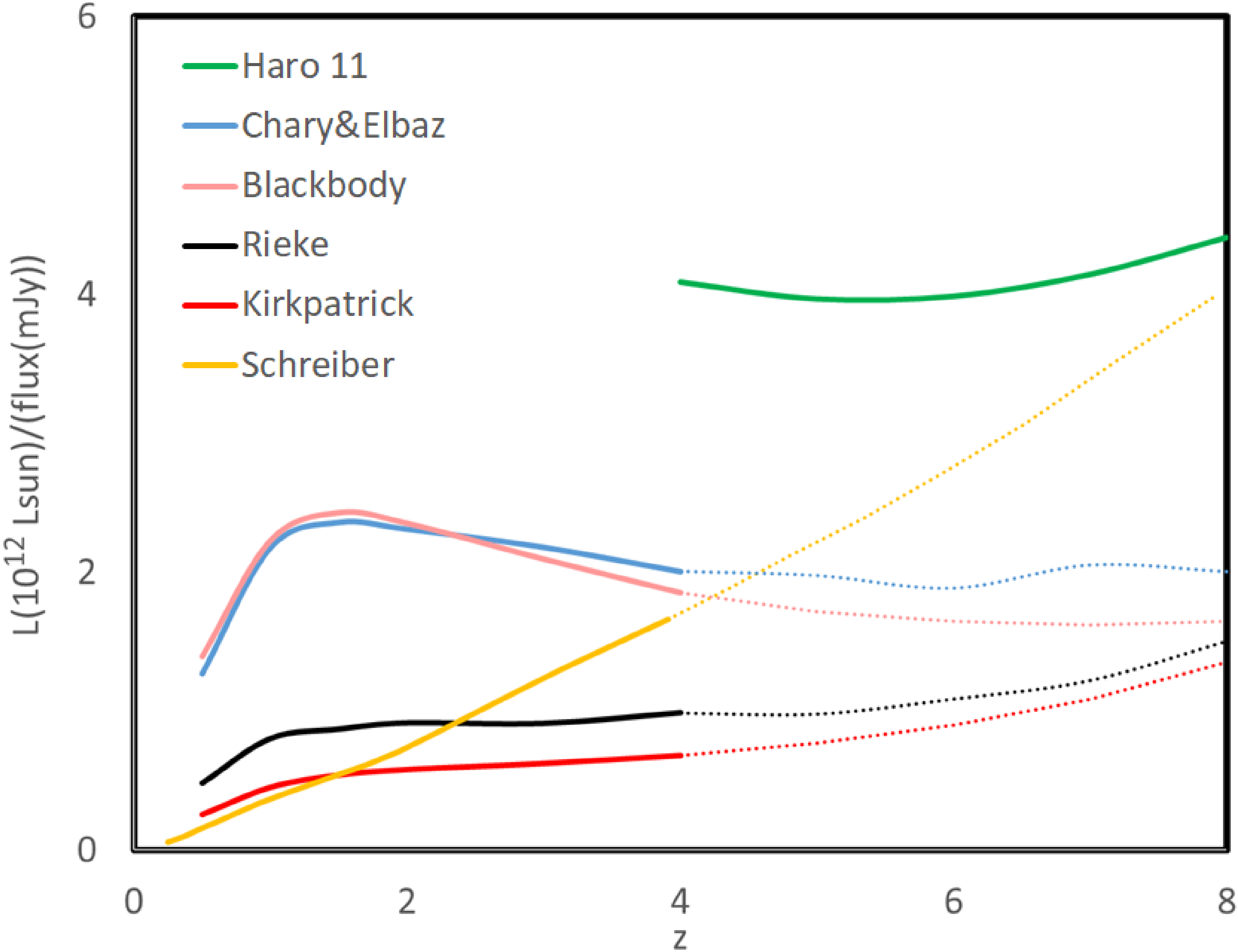
5 < z < 7
median
L(TIR) = $10^{11.25}$
Schreiber
L(TIR) = $10^{12.15}$
1000
100
10
1
0.1
mJy (arbitrary)
1
10
100
1000
wavelength (microns)

Haro 11 based template is much better at z ~ 6



- **Haro 11 template fit implies much higher star formation rates needed for a given flux density at 1mm, compared with local or blackbody templates**

Conversion factor for mJy @ 1mm to L(TIR), as predicted by different templates



Summary

- Dust will be silicate-rich for first 400 Myr of evolution of a galaxy
  - Large carbon yields only for AGM stars below 3.5 $M_\odot$
- Far infrared emission of silicate-rich dust is “warmer” than for 50/50 silicate/carbon
  - Poor emission efficiency of silicate dust outside 8 – 60 μm
- High energy density of early galaxies also favors “warm” far infrared SEDs
- Haro 11 spectral energy distribution is a good surrogate for very high redshift IR galaxies
  - Dominated by very recent star formation, similar energy density
- Haro 11 SED fits the composite SED for $5 < z < 7$ galaxies well
  - Fit with local templates is much worse
- Haro 11 template fit implies much higher star formation rates needed for a given flux density at 1mm, compared with local or blackbody templates