From dust to galaxies

conclusion

- Dust particles: 10^{-7}-10^{-9} m
- Galaxies: 10^{+20} m
- One has to expect "cultural divides"
  - The FIR emission should/can only be used to identify the composition of interstellar dust.
  - We do not care about the actual dust component, we are just looking for a method to obtain the dust mass, or the SFR.

Impressions

- Does such a quantity as "gas-to-dust mass ratio" makes sense?
- Can we move beyond the modified black-body?
- Is there a problem with dust at high redshift?
- Are laboratory measurements any use?

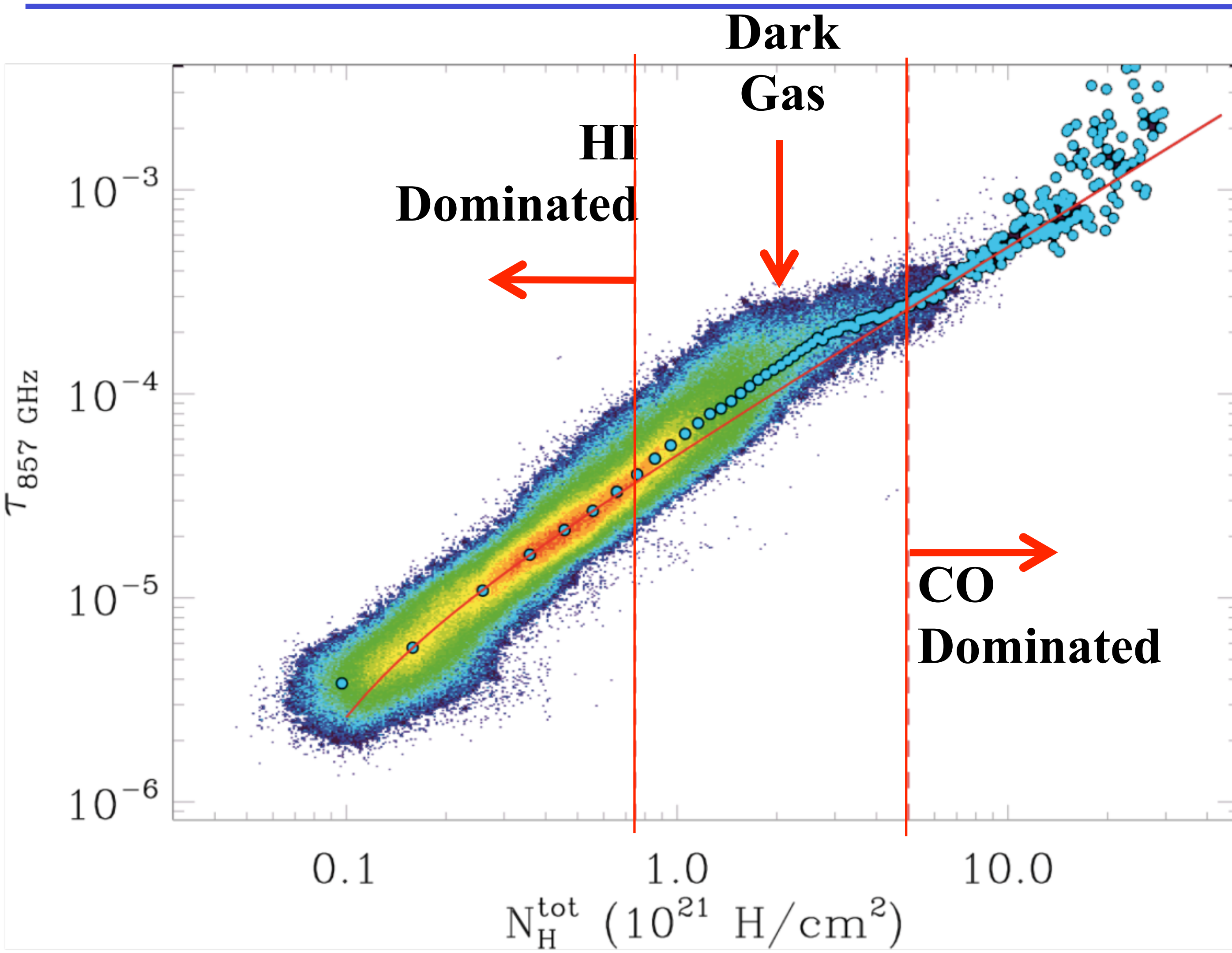
Dust-to-gas mass ratio

- What is the importance of this quantity?
  - Locally it affects the structure of the ISM, and therefore how we derive it from the observations.
  - More generally, we also see it as holding information on the history of a galaxy.

Dust-to-gas mass ratio

- J.P. Bernard, S. Madden: very large fractions (1/2 or more) of the gas mass are undetected:
  - JPB: stick to the solar neighborhood so that one can assume minimal variations of the intrinsic, and unknown, G/D mass ratio.
  - SM: in low metallicity environments, we can fix "reasonable" lower limits to the G/D mass ratio.
- We do not know the gas mass, and whether or not the missing gas can be recovered by a priori prescriptions on X_{CO} is not clear.

Evidence for Dark Gas



See arXiv: 1101.2029. C. author J.Ph. Bernard

- LAB HI data (atomic gas)
- 3 $^{12}CO(J=1-0)$ surveys: *Dame et al. 2001*, Dame unpublished, Nanten (unpublished)
68% of the sky

Very similar plots obtained from IRAS 100 μm, HFI 857, 545, 353 GHz

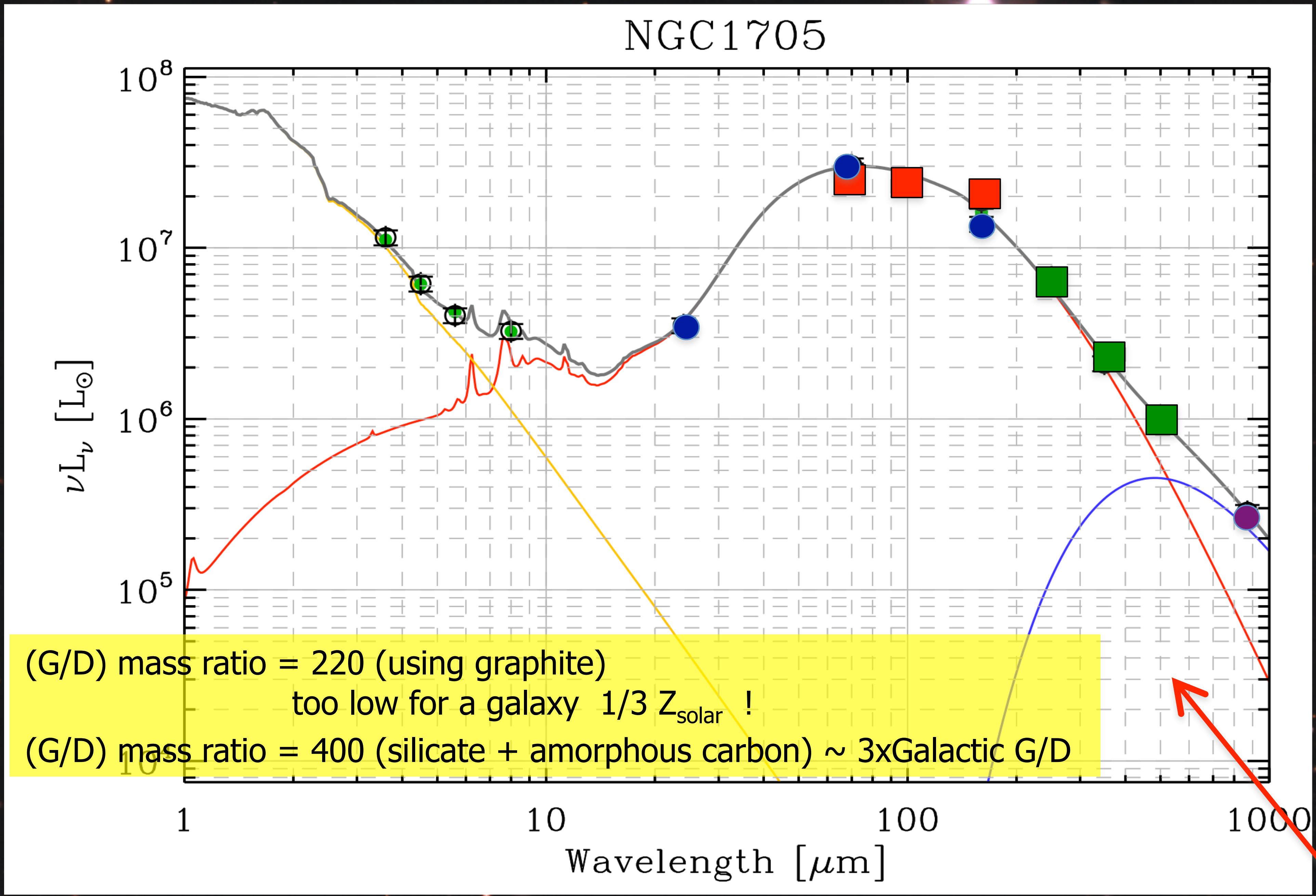
As computed in solar neighbourhood (|b|>10°) and assuming thin HI :
Transition between HI dominated and Dark Gas found at Av=0.4+-0.03 mag
τ/N_H ~power law with β=1.8. Consistent with $\tau/N_H=10^{-25}$ cm^2 @ 350 μm (Boulanger et al 1996).
Average Xco factor Xco=2.54+-0.13 H_2/cm^2/(Kkm/s)
Dark Gas mass fraction: 28%+-2.8% of HI gas, 118%+-1.2% of molecular gas

γ-ray observations find a similar "Dark-Gas" phase, with a similar mass fraction (*Grenier et al 2005, Abdo et al. 2010*)
Herschel GotC+ find similar Dark-Gas fractions in the MW plane (*Langer et al. 2010*)

planck

NGC 1705 Herschel confirms submm excess

IRAC + MIPS + PACS + SPIRE + Laboca 870 mu



(G/D) mass ratio = 220 (using graphite)

too low for a galaxy 1/3 Z_{solar} !

(G/D) mass ratio = 400 (silicate + amorphous carbon) ~ 3xGalactic G/D

Very cold dust component ?:

T dust ~ 10 K

β = 1.0

O'Halloran et al 2010

SED model Galliano et al & Galametz et al 2009

S. Madden

Dust-to-gas mass ratio

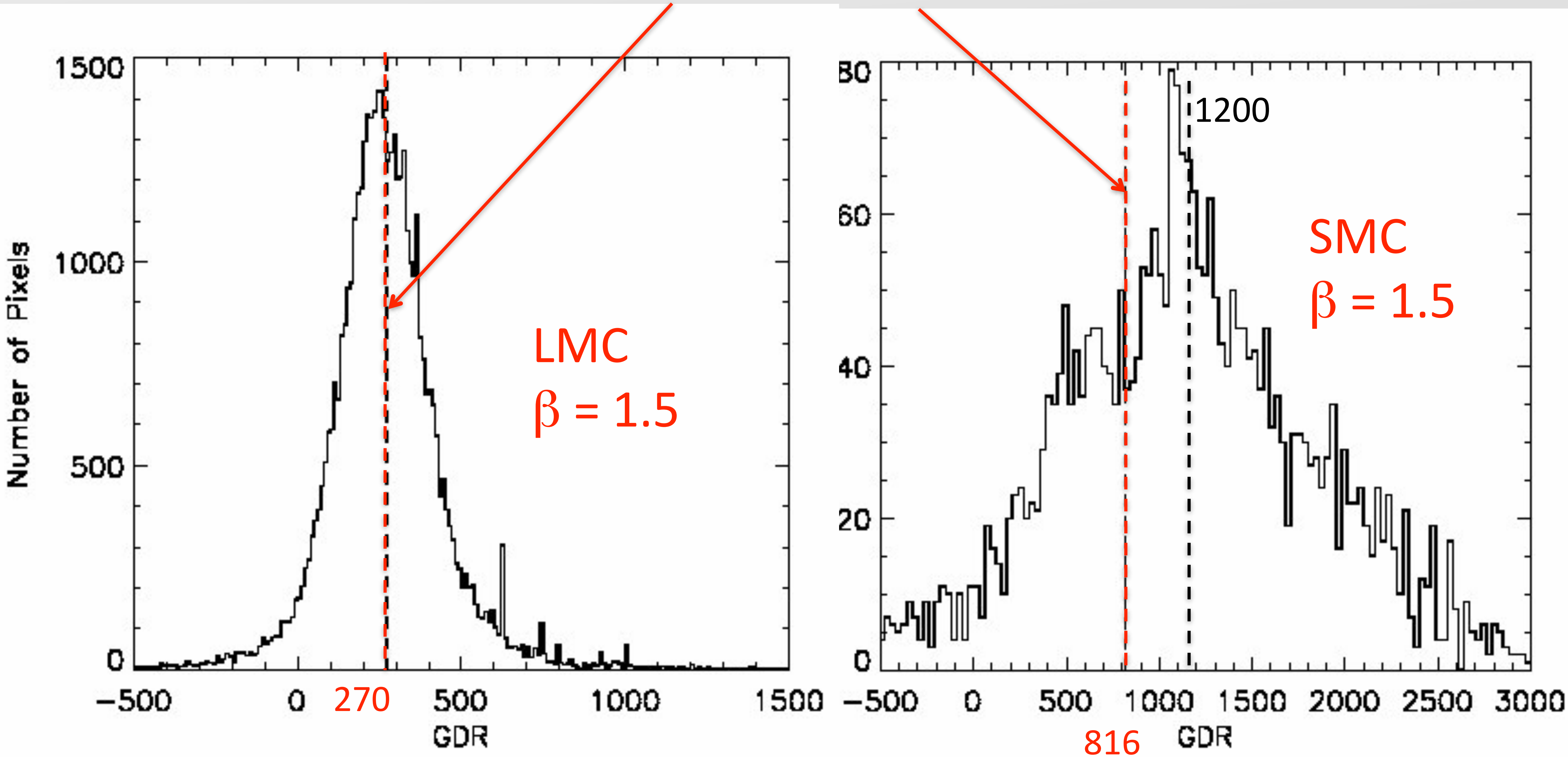
- Strategies are needed to break the usually cyclic reasoning in the D/G determinations:
  - parameterize the D/G equation and extract the parameter values from observations of resolved galaxies (LMC, SMC, by Duval).
  - Assume some local regularity and try an minimize the dispersion of derived G/D (nearby galaxies, by Sandstrom).
  - Call a new player in: CII as a tracer of low Av molecular gas (S. Madden), γ-ray emission from Fermi (essentially limited to our Galaxy).

J. Roman-Duval

GDR Map and Histogram

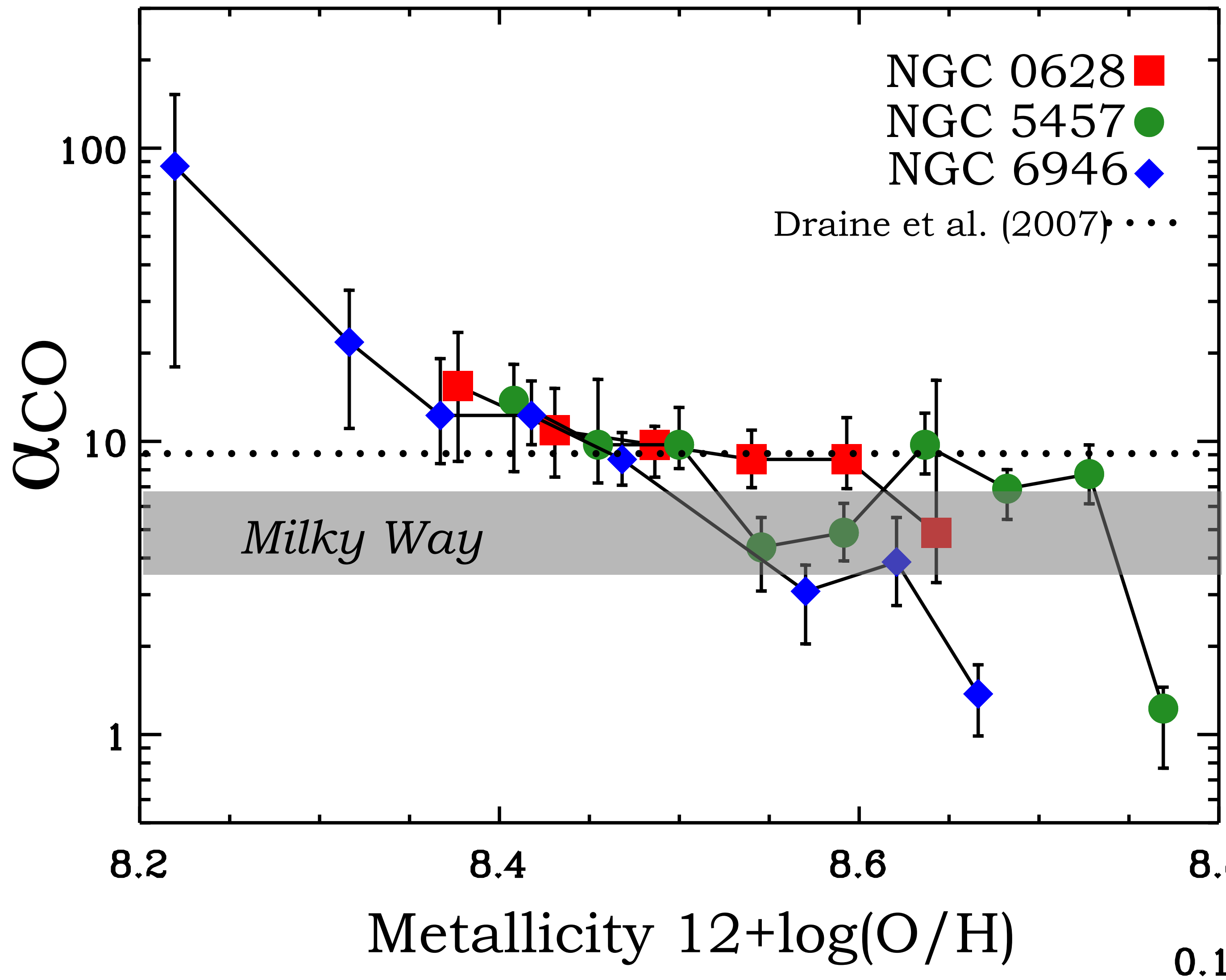
Coarse GDR map obtained from the same correlation method to pixels in aperture of diameter 100 pc (LMC) or 200 pc (SMC)

Prediction from metallicity, assuming GDR α 1/Z



Results

note - no assumption made about either DGR or α_{CO} vs Z!



α_{CO} jump around 12 + log(O/H) ~ 8.3-8.4.

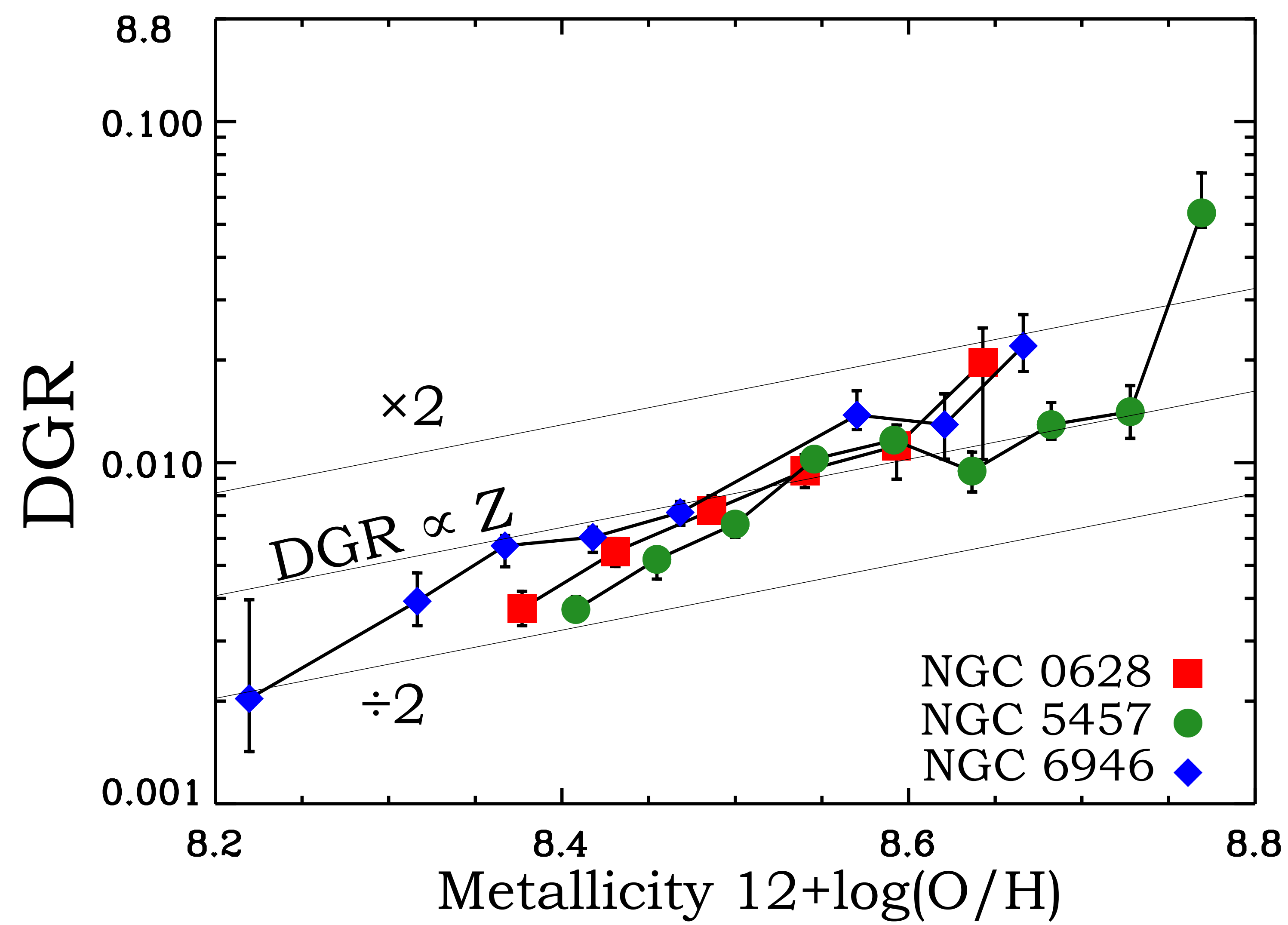
(consistent with Local Group results)

Galaxy centers have low X_{CO}

(cf Dahmen et al. 1998, Regan 2000 Israel 2009a,b)

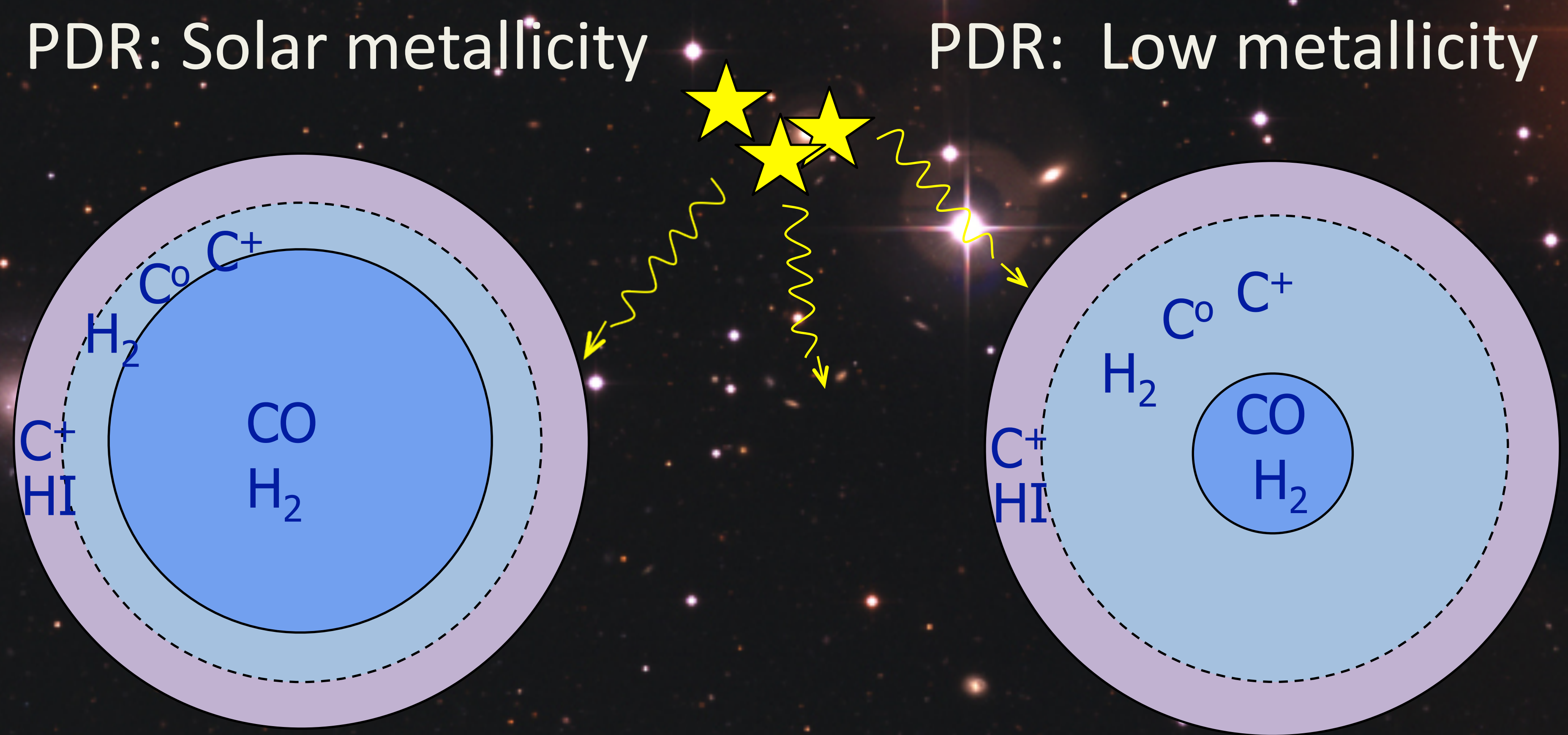
DGR shows smooth, linear (or slightly super-linear) dependence on metallicity.

Constant fraction of metals in dust within factor of 2.



S. Madden

How much H_2 is in the C^+ region ?



Very different C+ & CO filling factors

Critical parameter: Shielding of H2 determines the HI/H2 transition - depends on Go/n vs dust extinction of FUV (i.e Wolfire et al 2010; Kaufman 1999)

Sustantial H2 can exist outside of theCO core – traced by [CII] – the CO-free H2 'Dark Gas'

Excess [CII] - invoke excitation by H_2 => 2 to 50 times more H_2 than that measured by CO alone in the galaxies so far where we have both HI & CO measurements – not strictly a function of Z.

Madden et al. 1993,1997; Poglitsch et al 1995 derived CO-free H_2 from [CII]

Dust-to-gas mass ratio

- Locally, the G/D mass ratio makes sense, but given that it can show large variations, what does it mean globally?
- Should we inspect rather the relation between the dust mass and the stellar mass?

Beyond the modified black-body

- When fitting a thermal emission spectrum, there is a certain level of degeneracy between the emissivity exponent β and the dust temperature.
    - introduced by the Planck function, by its response to the presence of measurement errors.
- However, the underlying physics of the emission process (the dust grains), predicts a relation between β and T_{dust}.

Shetty et al.

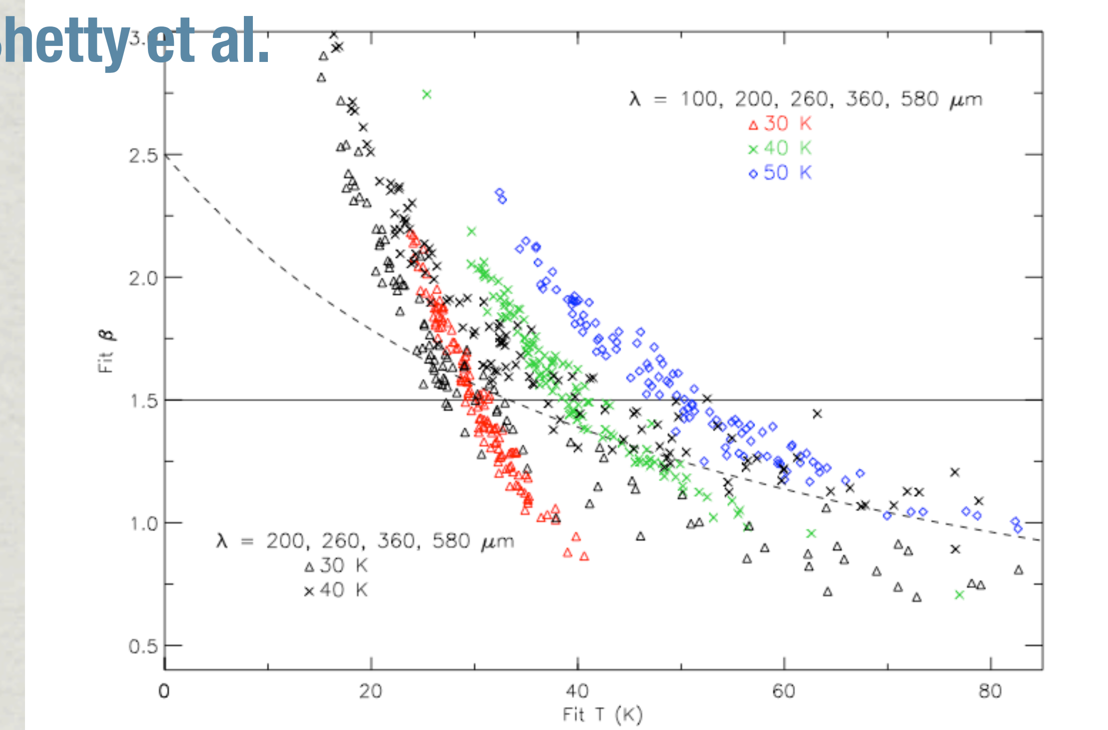
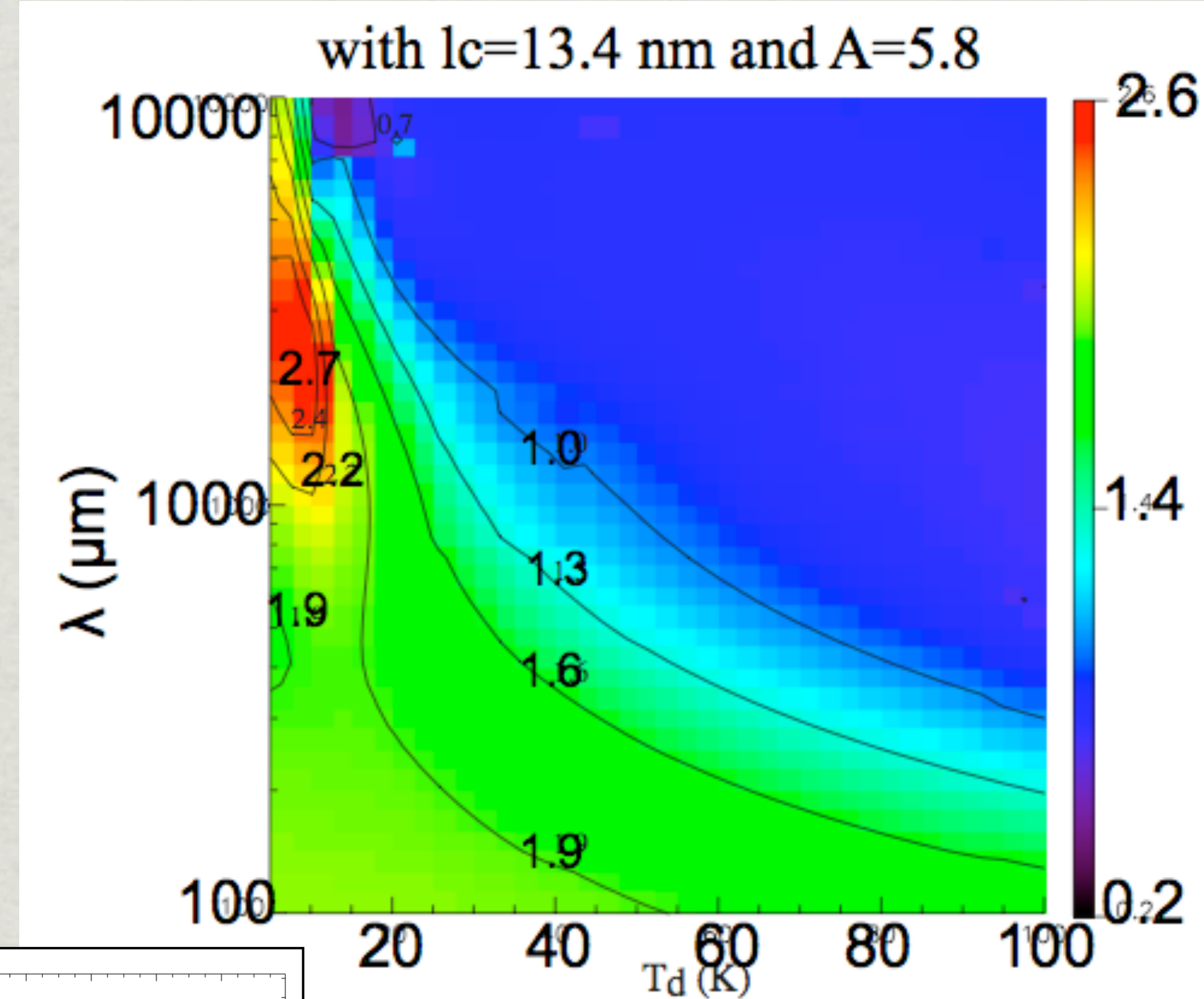
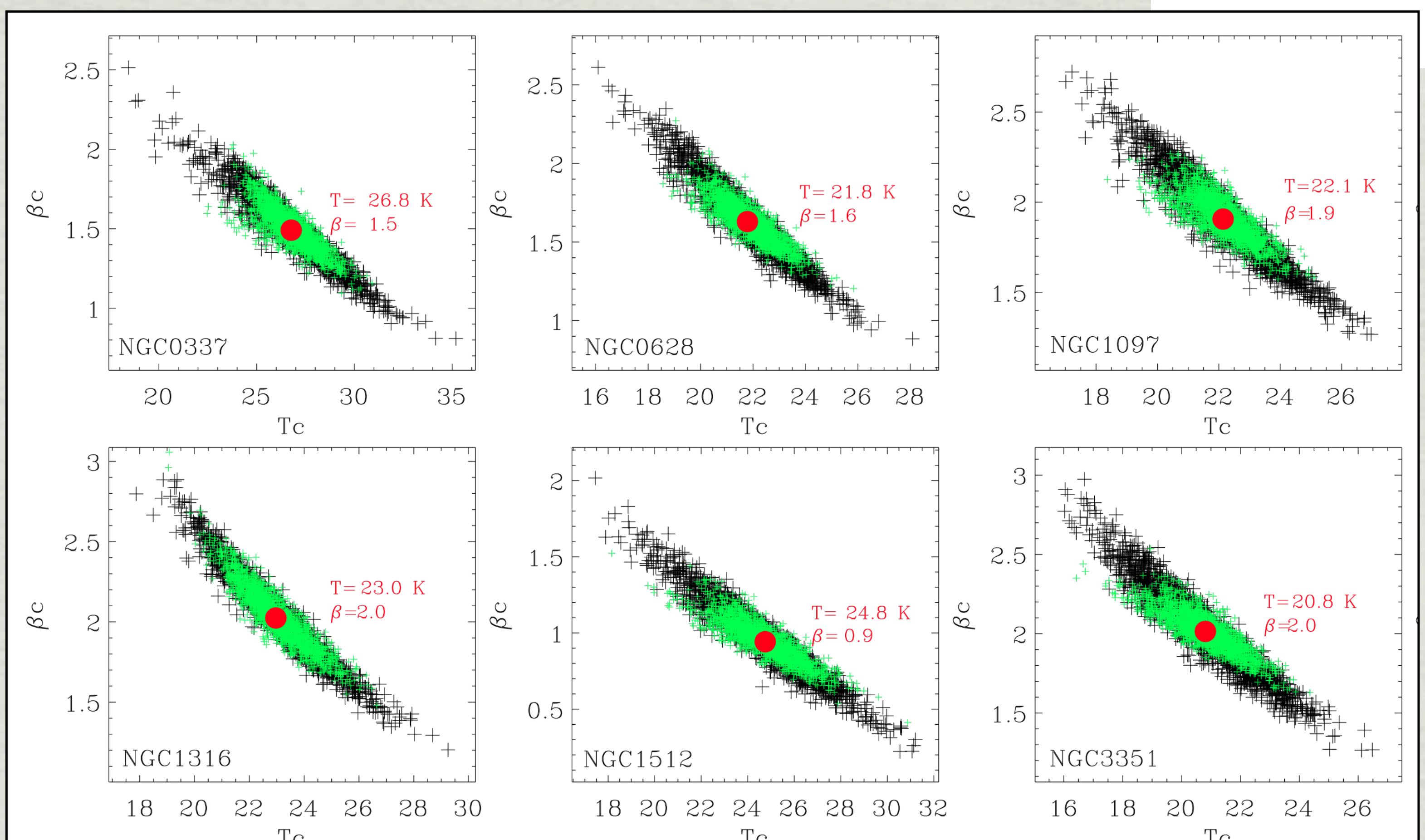


Fig. 4.— Best fit β and T to noisy fluxes (with σ=5%) from isothermal sources with $T \in$30-50 K. Colored points show fits to fluxes with λ=100, 200, 260, 360, and 580 μm. Black points show fits to fluxes from a 30 and a 40 K source excluding the 100 μm flux. The horizontal line indicates the spectral index of the source, β=1.5. The dashed line shows the best fit to data presented by Dupac et al. (2003).



D. Paradis



M. Galametz

Beyond the modified black-body

- When fitting a thermal emission spectrum, there is a certain level of degeneracy between the emissivity exponent β and the dust temperature.
  - introduced by the Planck function, by its response to the presence of measurement errors.
- However, the underlying physics of the emission process (the dust grains), predicts a relation between β and T_{dust}.
- The fact that we are fitting only 2 parameters may give a false sense of certainty.

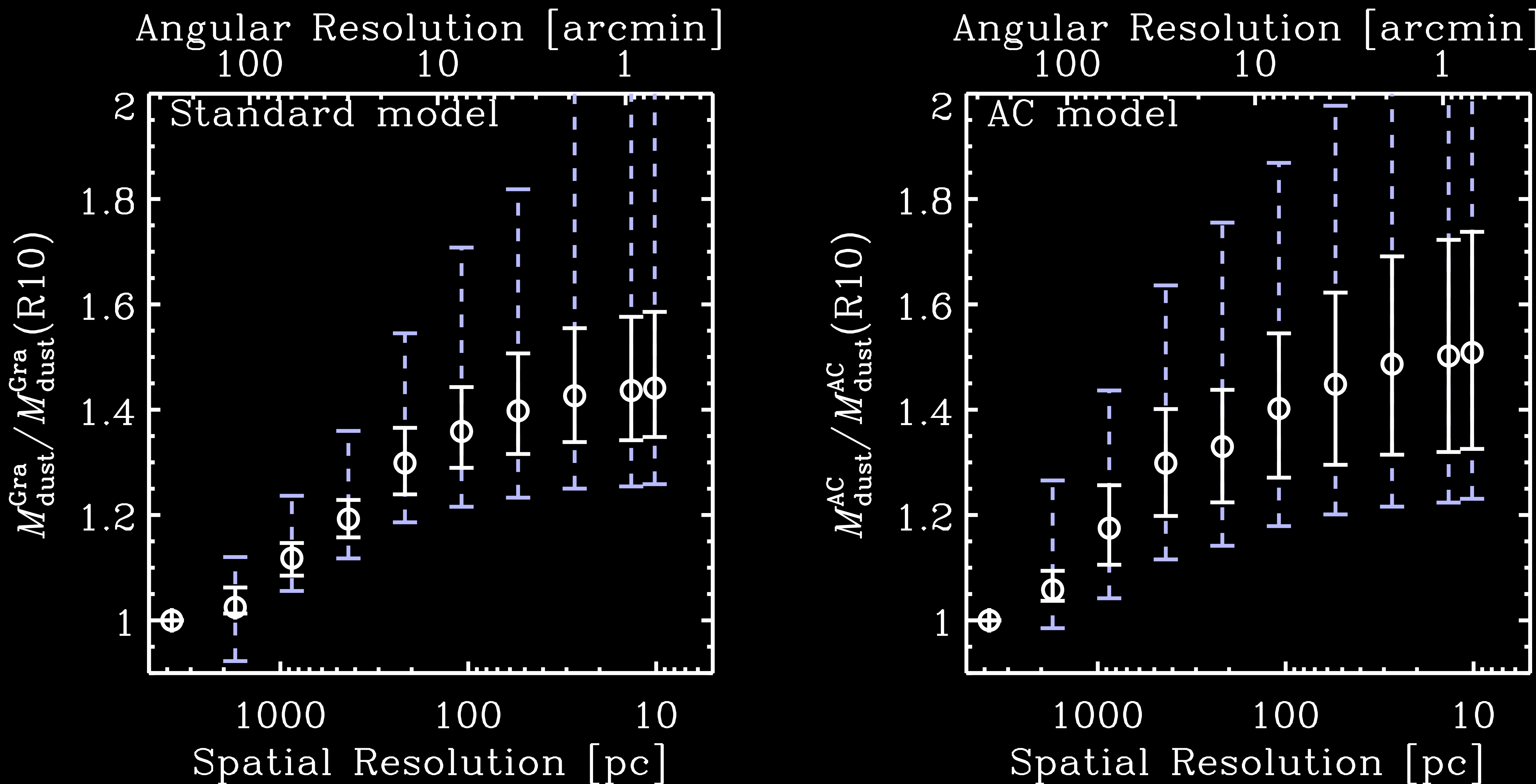
Beyond the modified black-body

- We now have access to a wide coverage of the dust emission spectrum.
  - Well covered UV-optical SED (Galex, SDSS), mid-IR for almost any reasonably nearby object (WISE), and in general Herschel or Spitzer data by "design".
- We have a wide range of dust emission models.
  - and even a benchmark in the coming months...

Beyond the modified black-body

- "Models are as good as we trust them"/"Models should be tested on the data we have".
- Models give out physical parameters that can be tested.
  - Use well resolved galaxies to study the possible spatial resolution bias introduced by the model fit (Galliano).
  - Compare the reconstructed properties to independent knowledge or reasonable assumptions (Draine).
    - e.g. fraction of dust exposed to U_{min} as a function of radius...
  - See if the dust properties agree with our concepts of dust evolution in the ISM of our Galaxy (Paradis).

Trends of Dust Mass with Spatial Resolution



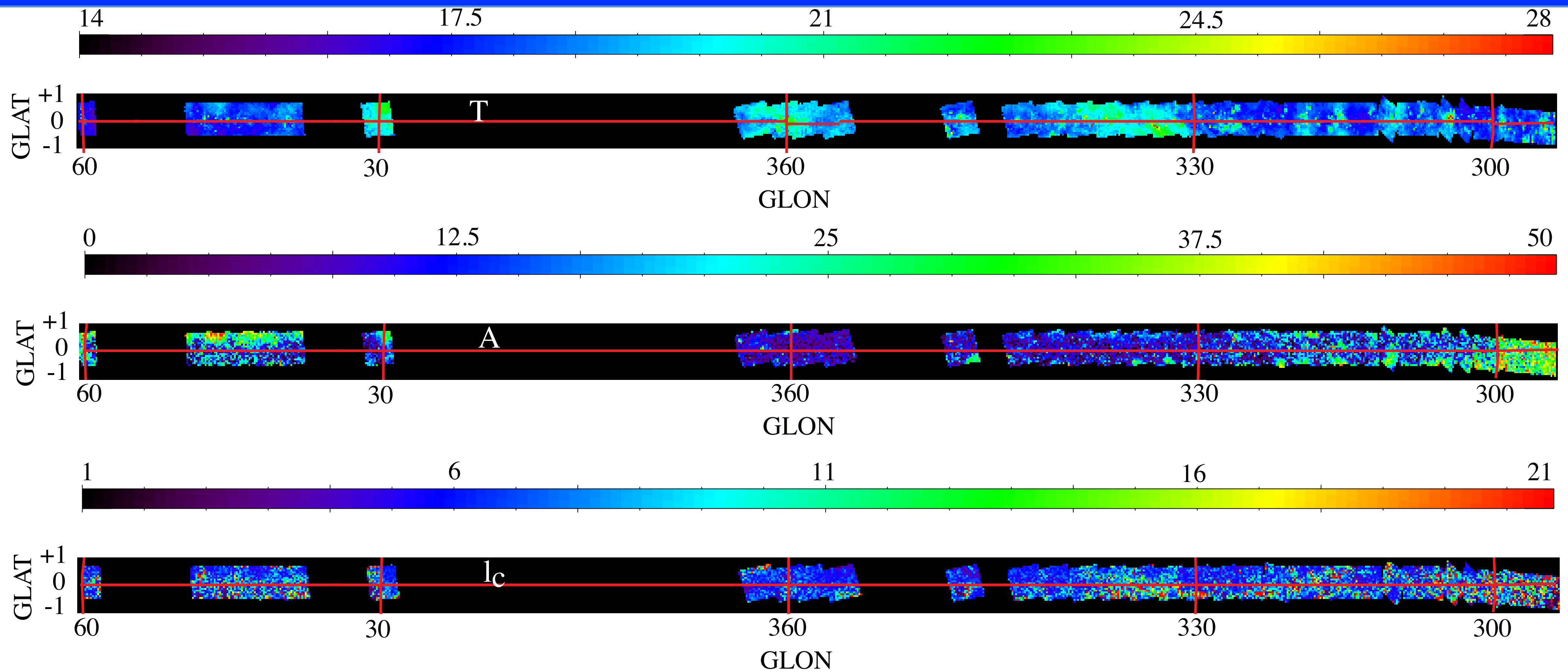
Effect of spatial resolution:

1) Global SED: underestimate M_{dust} by ≈50%;

2) Stabilization around ≈30-50 pc: resolve most of the cold regions.

(Galliano et al., 2011)

Dust properties along the Galactic Plane (GP)



	Td (K)	*lc (nm)*	*A*
All GP	18.5±1.4	7.1±5.9	14.6±11.0
External GP	18.0±1.3	7.5±6.6	19.7±11.5
Inner GP	19.5±1.3	6.8±4.6	9.9±6.5
FIRAS high lat.	17.5±0.02	23.1±22.7	9.4±1.4
Arch. CS	-	5.1±0.1	3.9±0.1
FIRAS & Arch	17.3±0.02	13.4±1.5	5.8±0.1

Paradis, et al., 2011d, A&A in preparation

- Inner parts warmer than outer parts
- Increase of *A* from the inner to the outer GP
 => changes in dust properties
- *lc* ≈ constant along the GP

- *A* larger in the GP compared to high latitudes and CS
 => Following the TLS model, grains in the GP could be characterized by a degree of amorphization more important in the GP, and the degree or amorphization increases in outer parts.

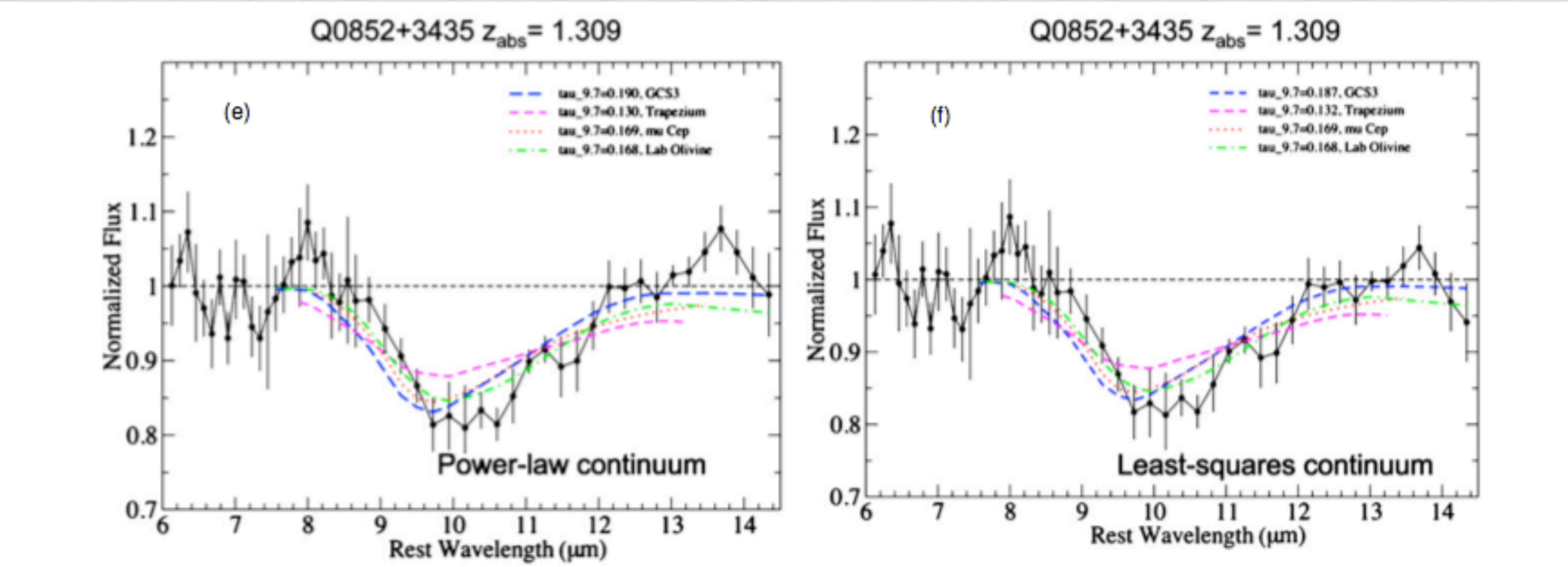
Beyond the modified black-body

- What if you have only one data point per object?
  - All hope is not lost... (Michalowski, Dwek).

Dust at high redshift and dust lifetime

- Detection of of dust at high redshift is now rather "common place":
  - see Noterdaeme presentation).
  - either "indirectly" (color excesses - Hjorth).
  - or "directly" through dust absorption signature (UV bump, silicate features - Buat, Kulkarni).

Kulkarni et al. 2011



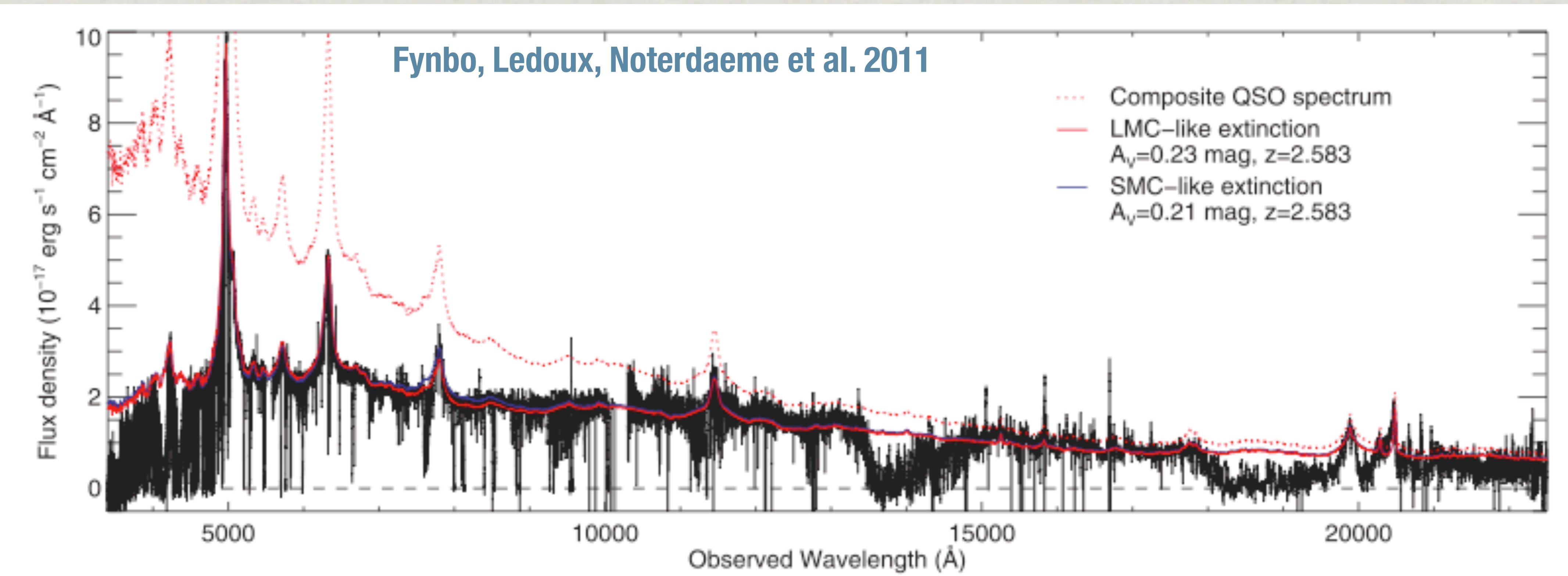


Figure 5. The spectrum of Q 0918+1636 after flux calibration. The overall shape of the spectrum is well fitted by the composite QSO spectrum from Telfer et al. (2002). In the figure, the unreddened composite spectrum is shown with a dashed line, and the same spectrum reddened by SMC- and LMC-like extinction curves with rest frame $A_V = 0.2$ mag is shown with solid red and blue lines, respectively. The inferred dust-to-gas ratio is between those of the LMC and the MW. The spectrum has been corrected for galactic extinction with $E(B-V) = 0.025$ from Schlegel, Finkbeiner & Davis (1998).

Dust at high redshift and dust lifetime

- Detection of of dust at high redshift is now rather "common place":
  - see Noterdaeme presentation.
  - either "indirectly" (color excesses - Hjorth).
  - or "directly" through dust absorption signature (UV bump, silicate features - Buat, Kulkarni).
- This continues to raise the question of how can "so much dust" be formed at "high redshift"?

Dust at high redshift and dust lifetime

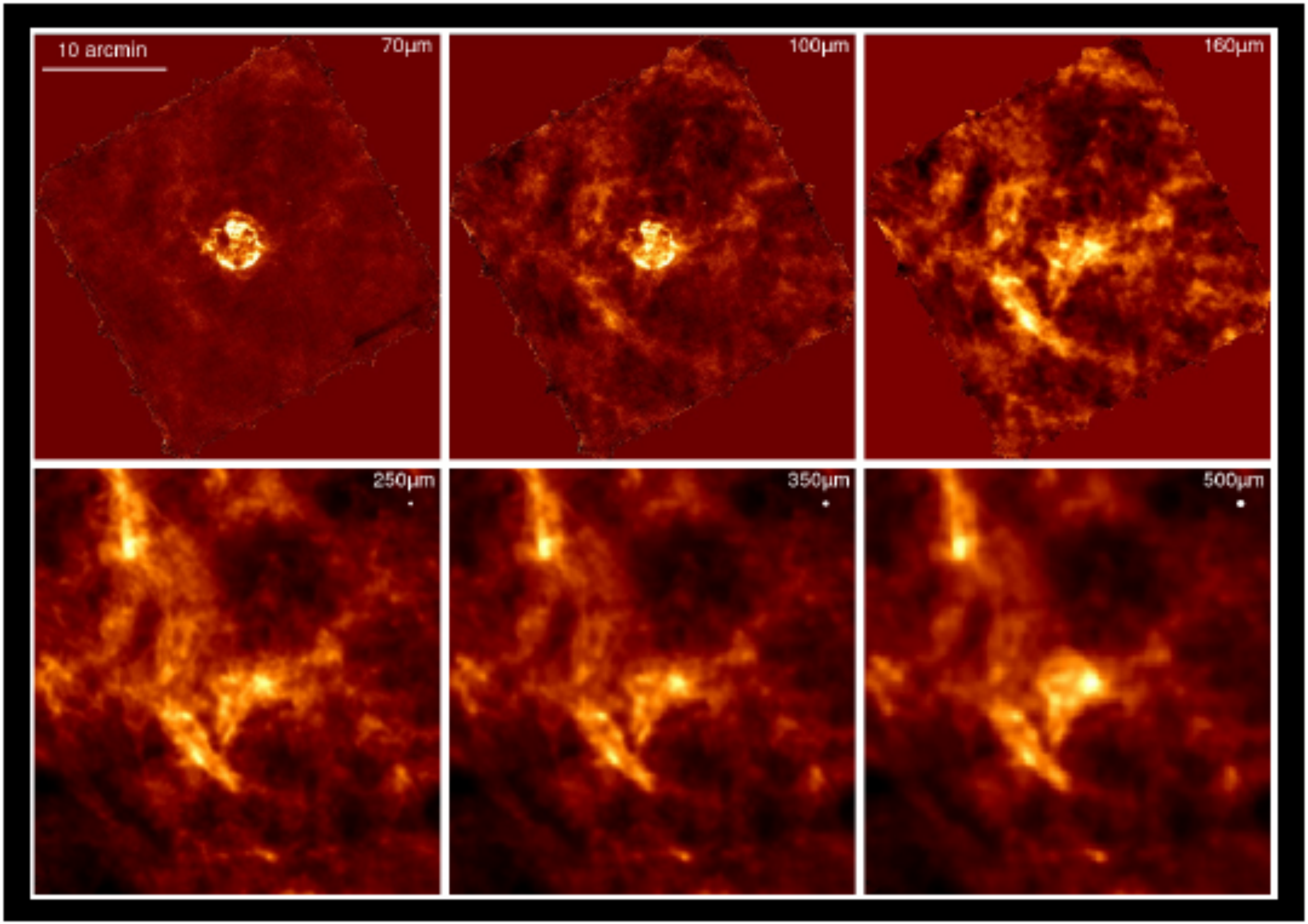
- High redshift still means the object can be up to a Gyr old or more, i.e. many avenues for dust production:
  - SN, Evolved stars, QSO winds...
- It is still hard (for me) to get a precise census of the amount of dust mass that is required.
  - Detecting dust in absorption does not require much of it.
  - Detecting large amounts of dust in exceptional objects does not require that models with "reasonable" parameter values predict these amounts.

Dust at high redshift and dust lifetime

- Even though the production yields are uncertain, it seems the key resides not in the production but in the preservation of dust:
  - Gall: can reach the required dust masses with "moderate" destruction rates
  - Fan: car reach the required dust masses with "dust growth"
- What is missing is really how to build dust back, once it has been destroyed.

0.05-0.1 $M_\odot$ dust in the Cas A SNR

Barlow et al 2010



It's unfortunate that SN tend to explose in ISM-rich environments...

How to incorporate "laboratory data" into our interpretation tools?

- one man's dream is another one's nightmare...
- the wealth of IR observations (spectroscopic) is now reflecting the vast amount of laboratory measurements.

Dust Inventory of the ISM

- Silicates:
  - Amorphous FeMg-silicates
  - Forsterite
  - Enstatite
  - Montmorillonite ?
- Oxides:
  - Corundum
  - Spinel
  - Wuestite
  - Hibonite
  - Rutile
- Sulfides:
  - Magnesium sulfide
  - Iron sulfide ?
- Ices
  - Simple molecules such as H_2O, CH_3OH, CO, CO_2
- Carbides:
  - Silicon carbide
  - Titanium carbide
  - And others
- "Pure" Carbonaceous compounds:
  - Graphite
  - Diamonds
  - Hydrogenated Amorphous Carbon
  - Polycyclic Aromatic Hydrocarbons
  - Fullerenes
- Others:
  - Silicon nitride
  - Metalic iron ??
  - Carbonates ?
  - Silicon (??), silicon dioxide

UV

Carbonaceous dust - hydrogenated amorphous carbons

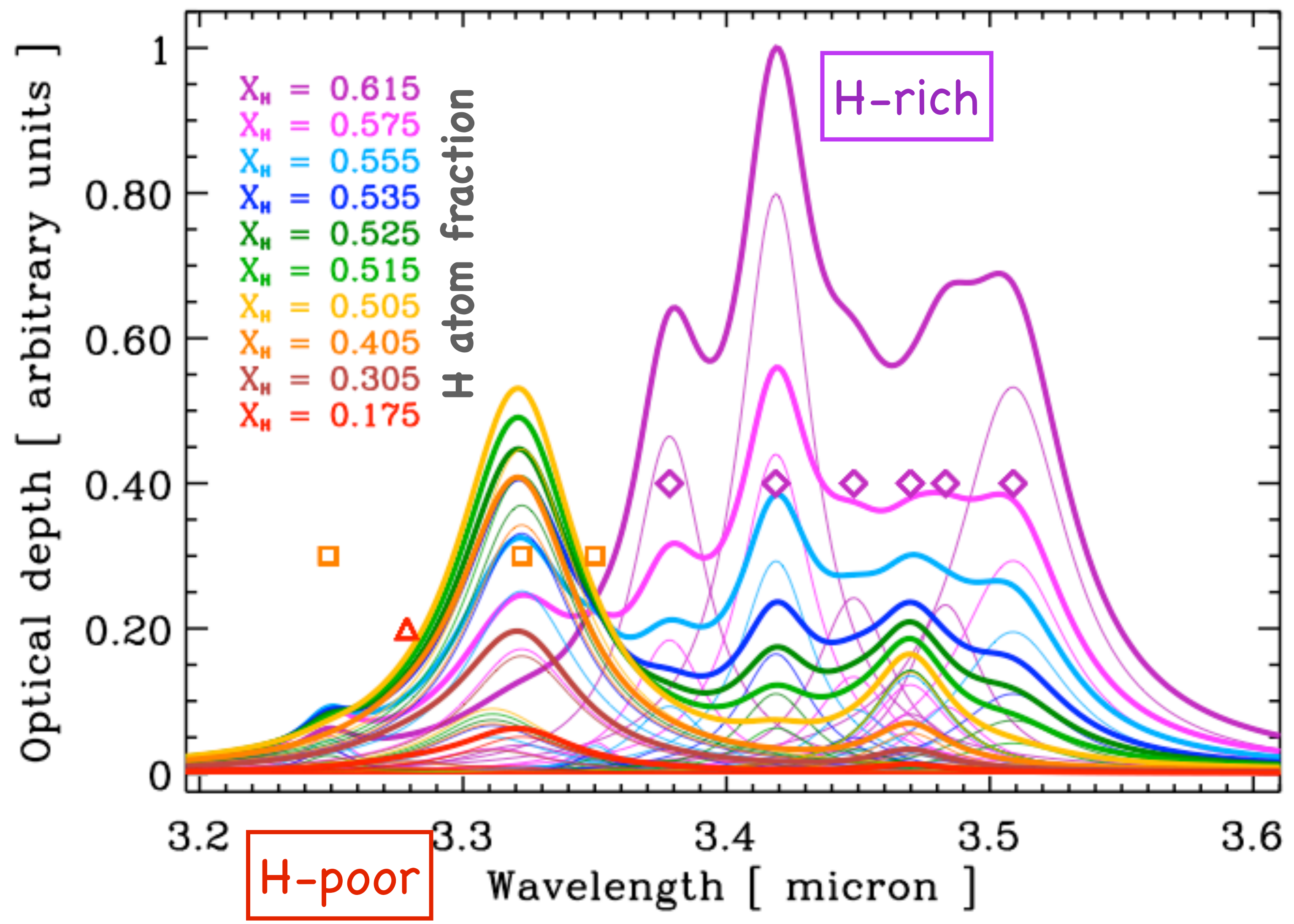


Fig. 8. The predicted eRCN spectrum in the 3.2 – 3.6 μm C-H stretching region as a function of X_H calculated using the structural decomposition described in §2.2.3 and the data in Table 2. The diamonds, squares and triangles indicate the aliphatic, olefinic and aromatic band positions, respectively (see Table 2). Jones (2011a)

However, things are probably going to get rather complicated!

What's good in laboratory data?

- Diagnostic predictions:
  - Silicate band position as temperature tracer (Henning)
  - Emissivity dependence with λ or T (Paradis)
  - Explanation of new emission processes without a need for a new component (Jones)

UV

Carbonaceous dust - hydrogenated amorphous carbons

For H-rich HAC / a-C:H materials

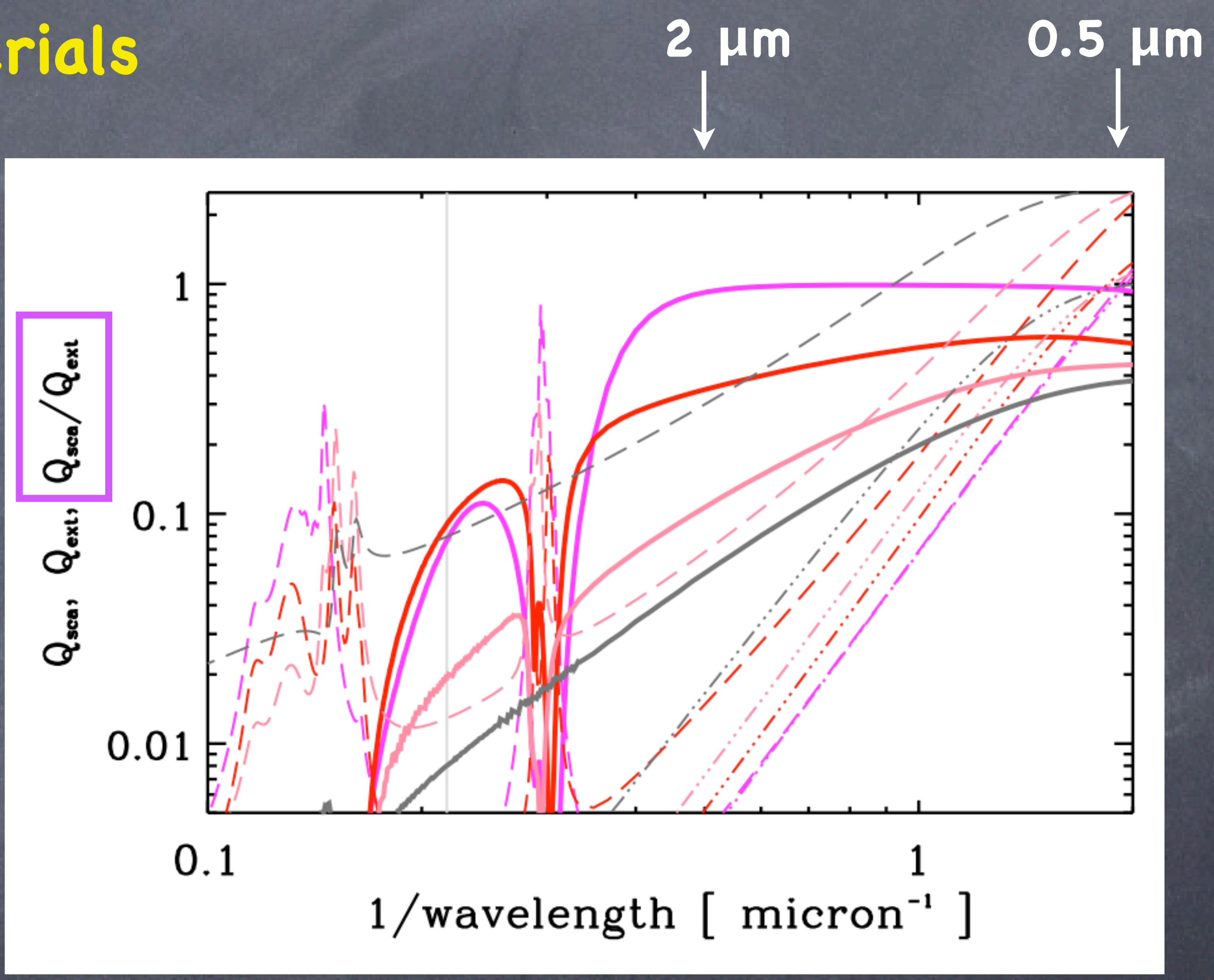
(purple line)

Q_{sca}/Q_{ext} ~ 1 - 0.5 - 2 μm

(i.e., `pure scattering')

Could explain the observed ``coreshine" without the need to invoke grain growth.

This requires the accretion of H-rich a-C:H / HAC materials in denser molecular regions



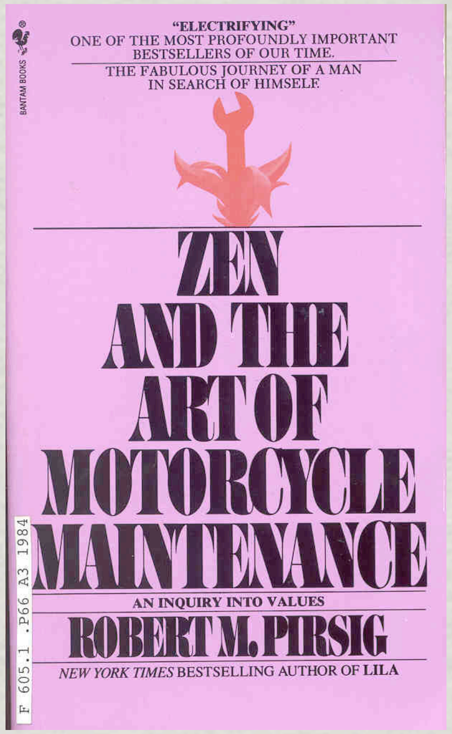
Jones (2011b)

What's good in laboratory data?

- Diagnostic predictions:
  - Silicate band position as temperature tracer (Henning)
  - Emissivity dependence with λ or T (Paradis)
  - Explanation of new emission processes without a need for a new component (Jones)
- Lifecycle scenarios:
  - Confronted with the immense "reservoir" of possible dust analogs, it seems that solid-state physics has no "predictive power" for astrophysics.
  - A lifecycle scenario is a relation between the different evolutionary states of the ISM, and the composition of IS dust.
  - A good lifecycle destruction scenario exists, but clearly a build-up scenario is missing.

Conclusions

* As usual/expected we still have more questions...



What is astrophysics about? answering questions, or finding a more accurate way of asking them?