Non-Standard Grain Properties, Massive Dark Gas Reservoir and Extended Submillimetre Excess, Probed by *Herschel* in the LMC

Frédéric Galliano (AIM, CEA/Saclay)

HERITAGE: Sacha Hony, Jean-Philippe Bernard, Caroline Bot, Margaret Meixner, Suzanne Madden, Maud Galametz, Pasquale Panuzzo, Chad Engelbracht, Julia Roman-Duval, Aigen Li, Bill Reach, etc.

Outline of this Talk

This study in one sentence:

Using the *Herschel* and *Spitzer* observations of the LMC, to demonstrate the various effects that one might encounter, when trying to estimate the dust mass of a galaxy.

1) Introduction & problematics
   a) Dust models
   b) The LMC

2) Methodology: dust mass estimate and SED model
   a) Degeneracy with submillimetre grain properties
   b) Rigorous error propagation
   c) Effect of spatial resolution

3) The unveiled LMC ISM properties
   a) Gas-to-dust mass ratio crisis
   b) Disentanglng dark gas and grain properties
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Summary & Conclusions

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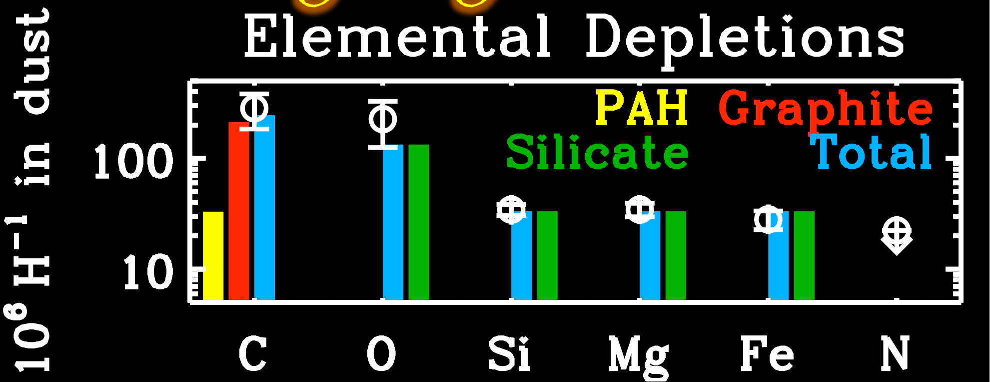
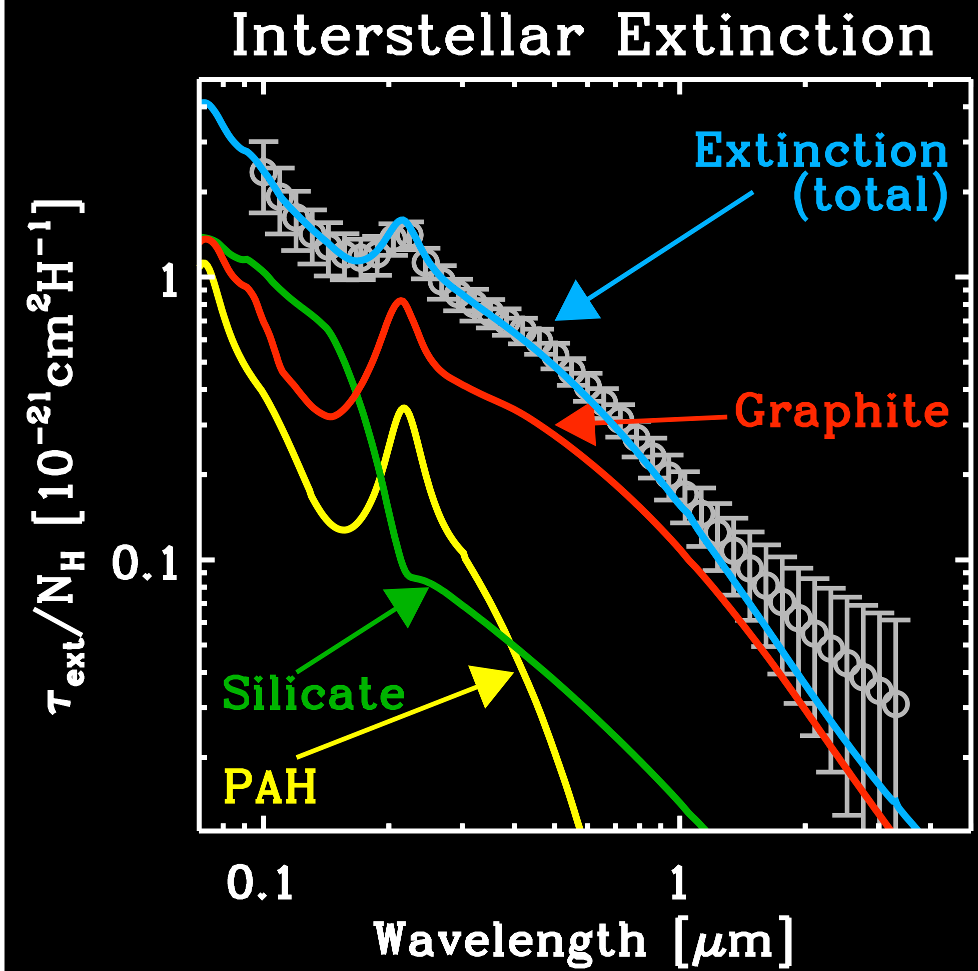
Summary & Conclusions

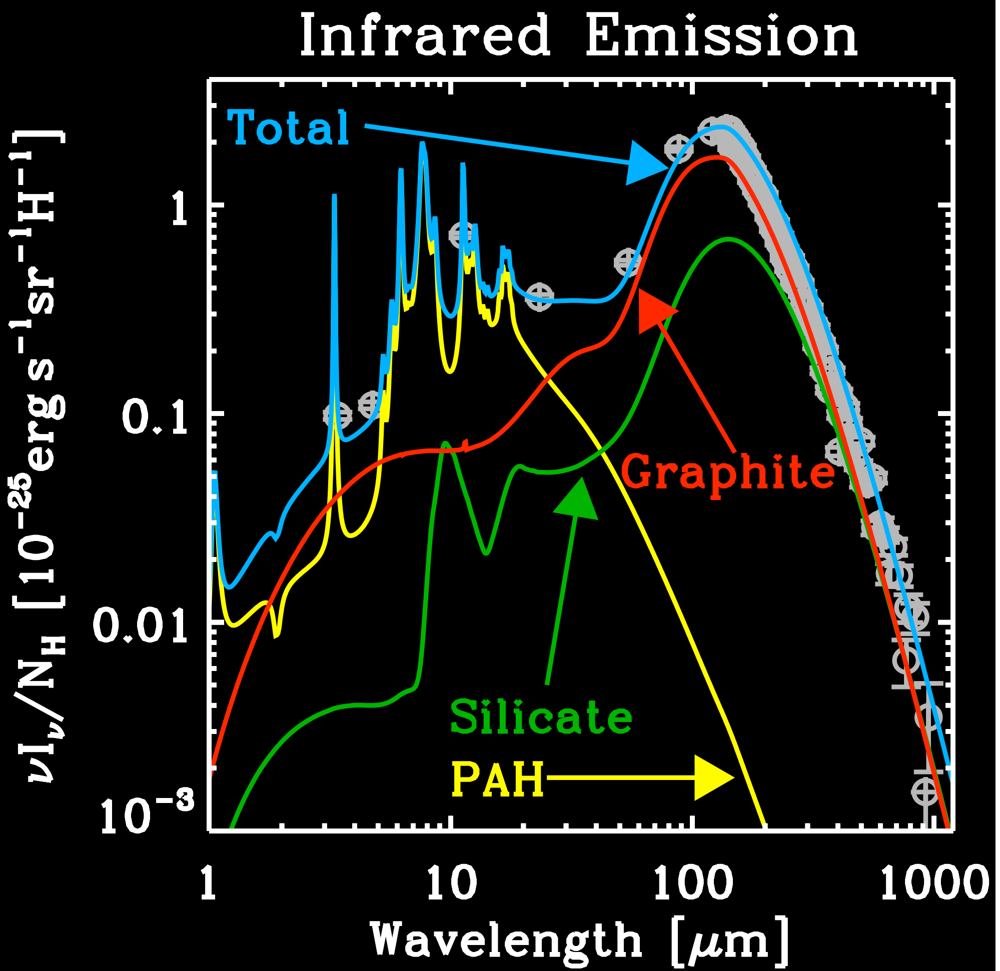
Dust Models in the Milky Way

Simultaneous fitting of the various observational constraints of the diffuse ISM (high latitude cirrus).

(Zubko, Dwek & Arendt, 2004)







The HERITAGE SD Strip

The LMC (Large Magellanic Cloud) is a nearby irregular dwarf galaxy:

- ✓ $d \approx 50$ kpc
- ✓ $Z \approx 1/2\ Z_{\odot}$
- ✓ $8^{\circ} \times 8^{\circ}$

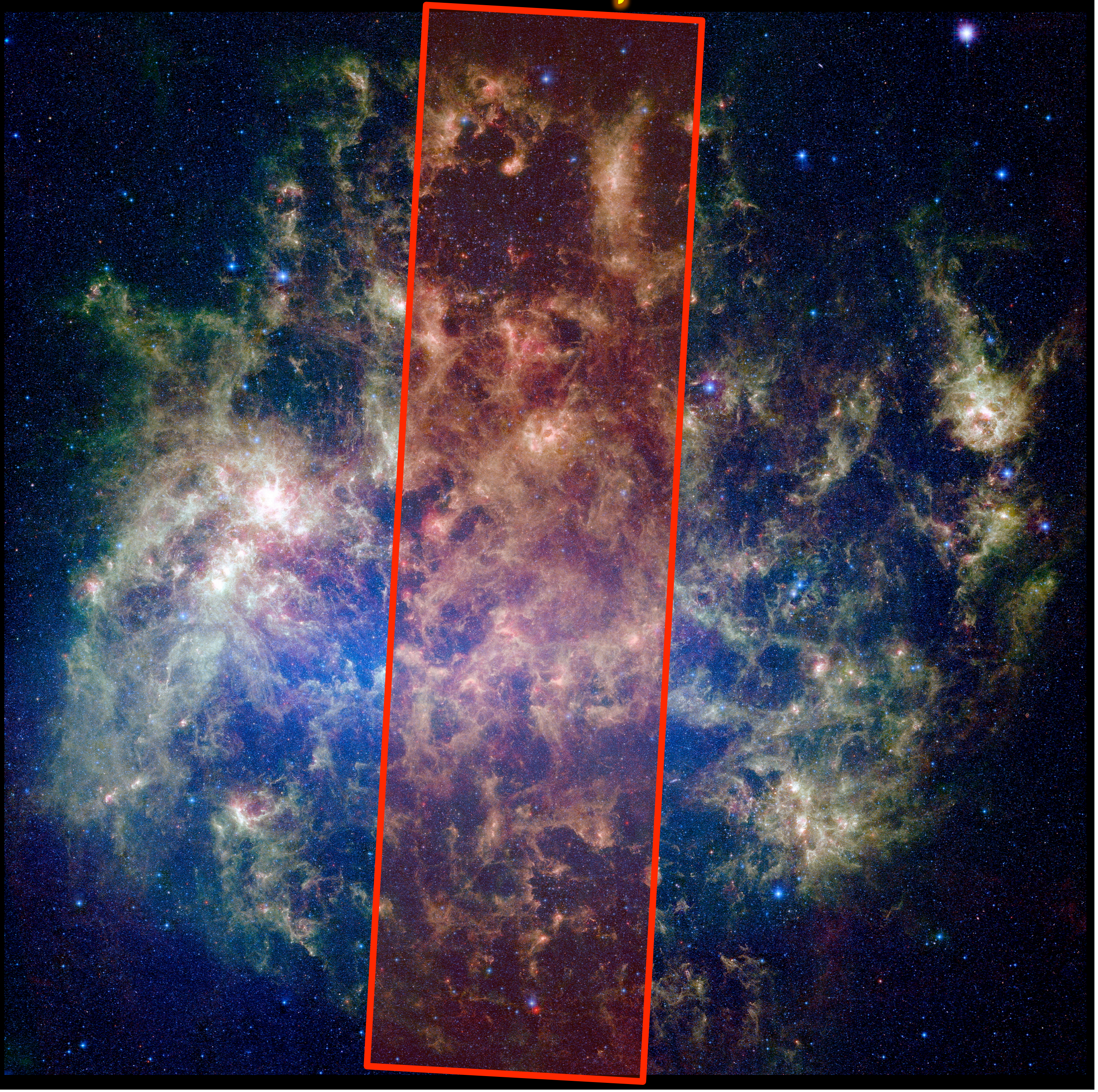
SAGE (*Spitzer* program):

- ✓ Green: PAHs (3.6 μm)
- ✓ Blue: stars (4.5 μm)
- ✓ Red: hot dust (24 μm)

(Meixner *et al.*, 2006)

HERITAGE (program with *Herschel*): $2^{\circ} \times 8^{\circ}$ science demonstration strip.

(Meixner, Galliano *et al.*, 2010)



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Phenomenological SED Model

Demonstration on the integrated strip SED.

1) Stellar continuum: old stars.

2) Distribution of dust conditions:

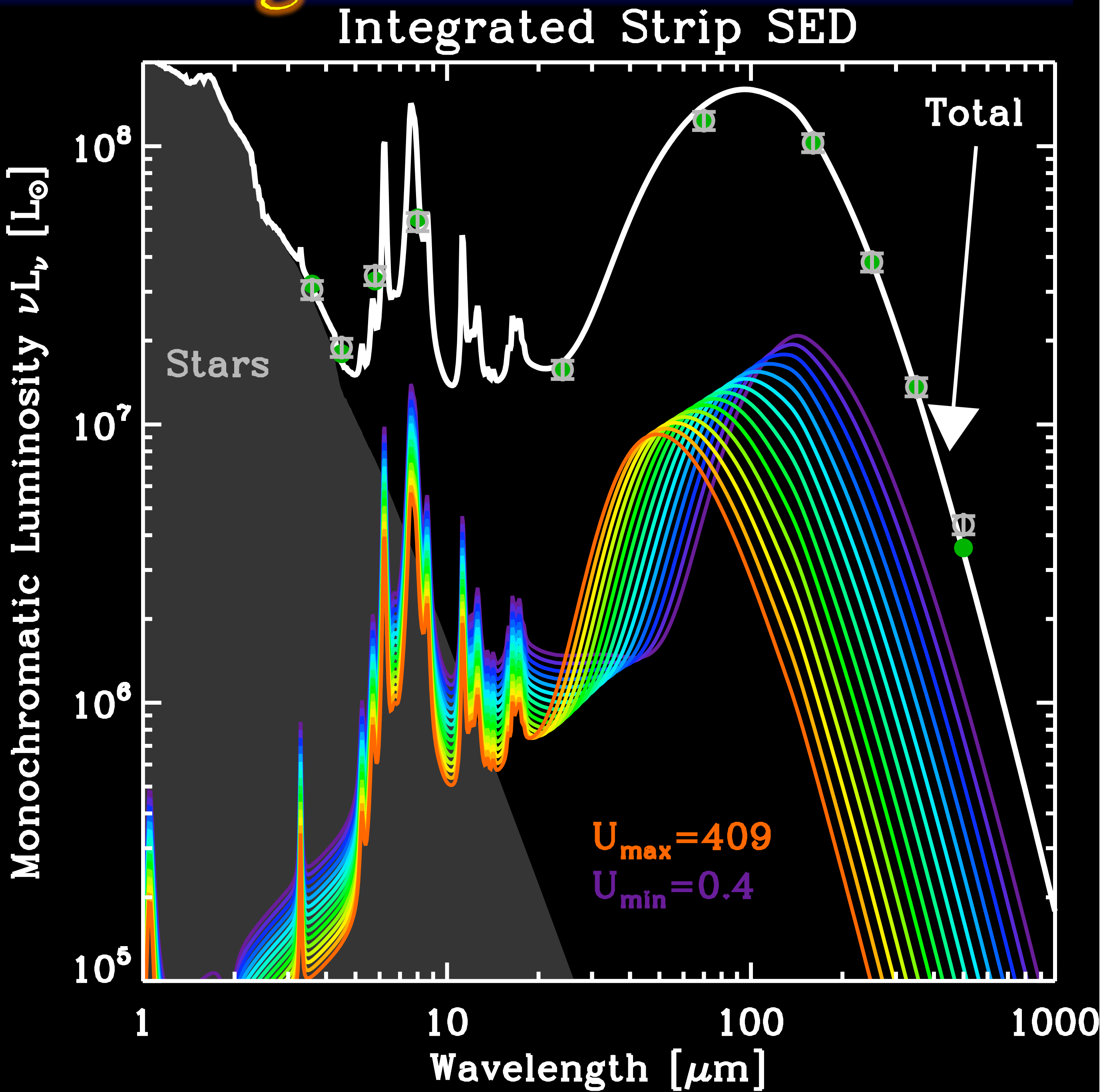
✓ Heating intensity, U (U=1 for the Galactic diffuse ISM):

$$M_{\rm dust} \propto U^{-\alpha}$$

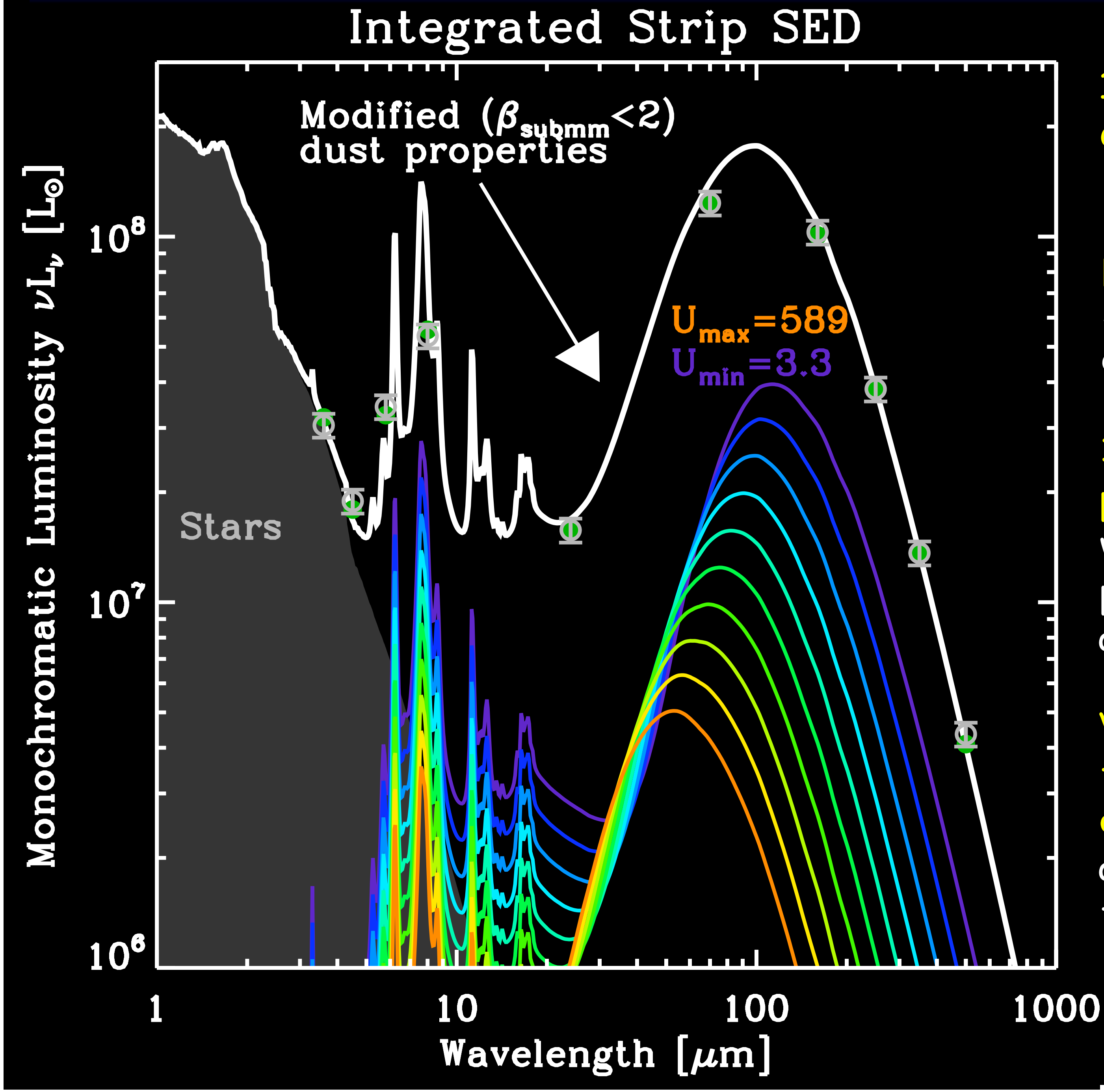
✓ Other main Parameters: total dust mass and PAH fraction.

3) Synthetic photometry.

(Galliano *et al.*, 2011)



The Dilemma of Submillimeter SED Modelling



1) Without SPIRE submm constraints: excess.

2) With standard dust properties: fit the excess by adding cold dust (U<1 or T_{eq}≈15 K).

3) With modified dust properties: fit the excess with intrinsic dust properties => less cold dust is needed.

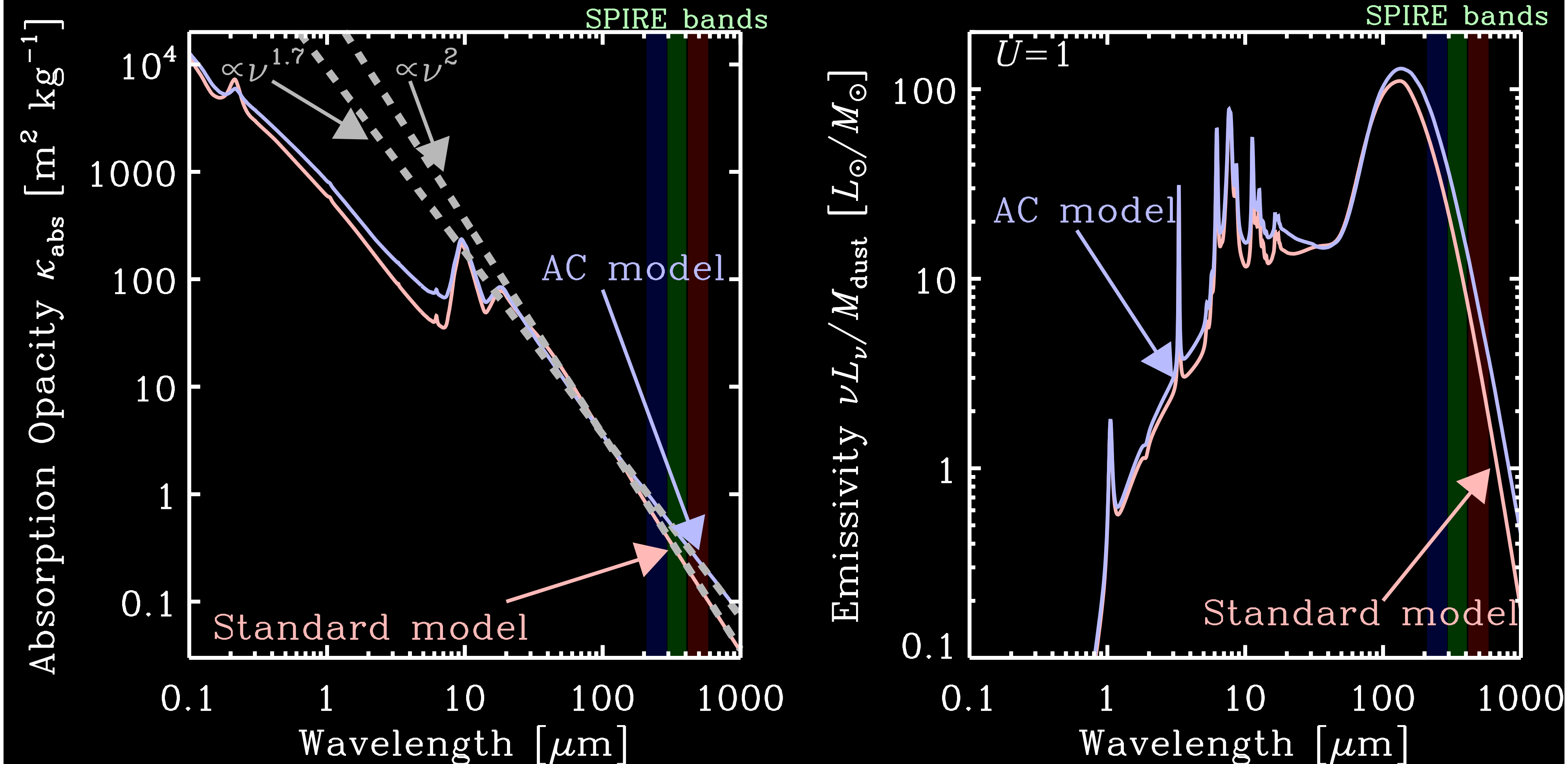
Without more constraints, the two solutions are equivalent => degeneracy dust submm emissivity vs. temperature distribution.

(Galliano *et al.*, 2011)

Two Realistic Dust Compositions

To explore the effect of β: two grain compositions with realistic cross-sections, statisfying the elemental abundances:

1) "Standard model": Graphite, silicate & PAHs (Milky Way; β=2)
2) "AC model": Amorphous carbon (Zubko *et al.*, 1996), silicate & PAHs (β=1.7)



(Galliano *et al.*, 2011)

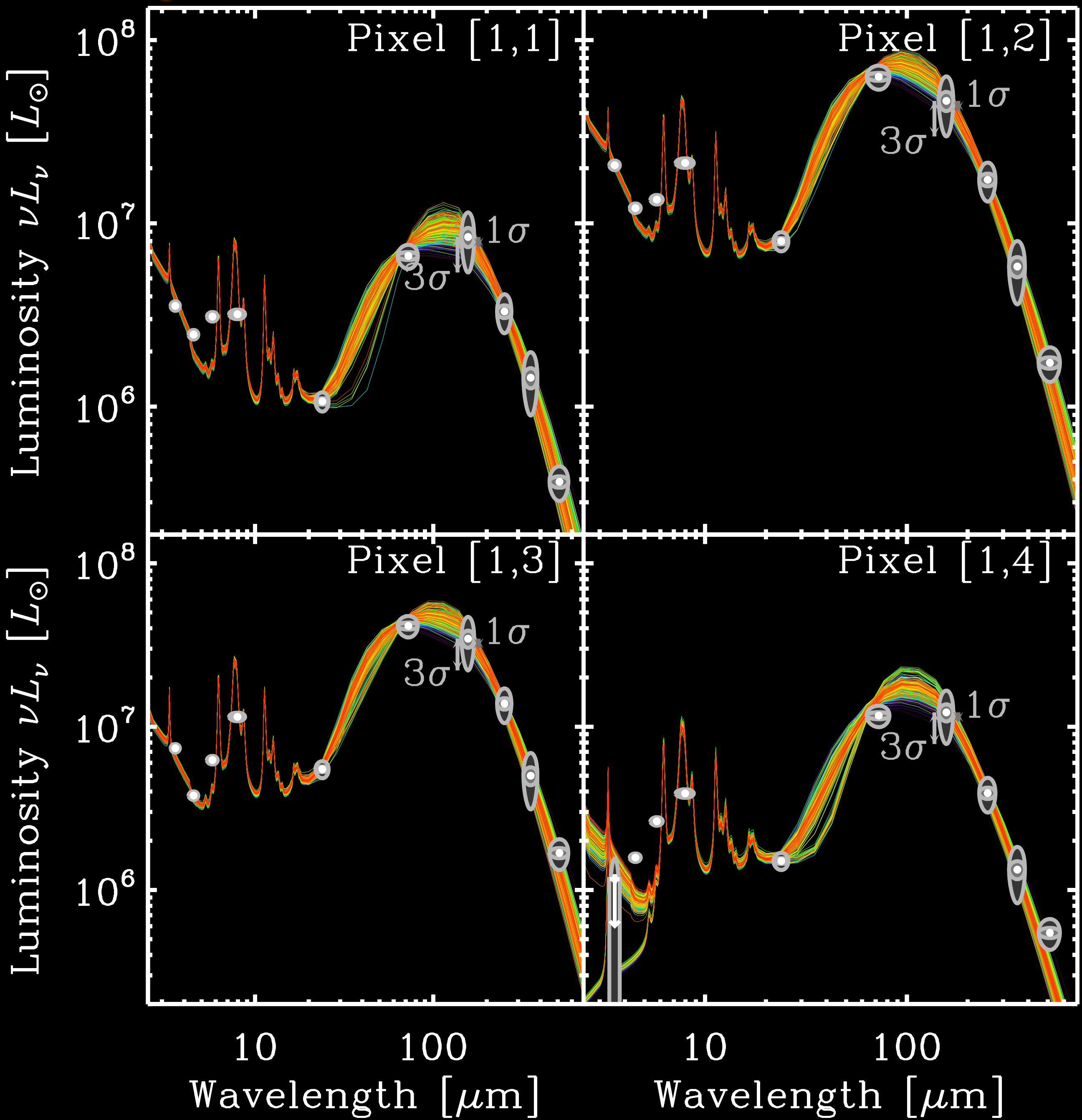
Rigorous Propagation of the Errors

Error on the parameters:

For each pixel, we perform ≈300 fits of the randomly perturbed SED
=> probability distribution of each parameter.

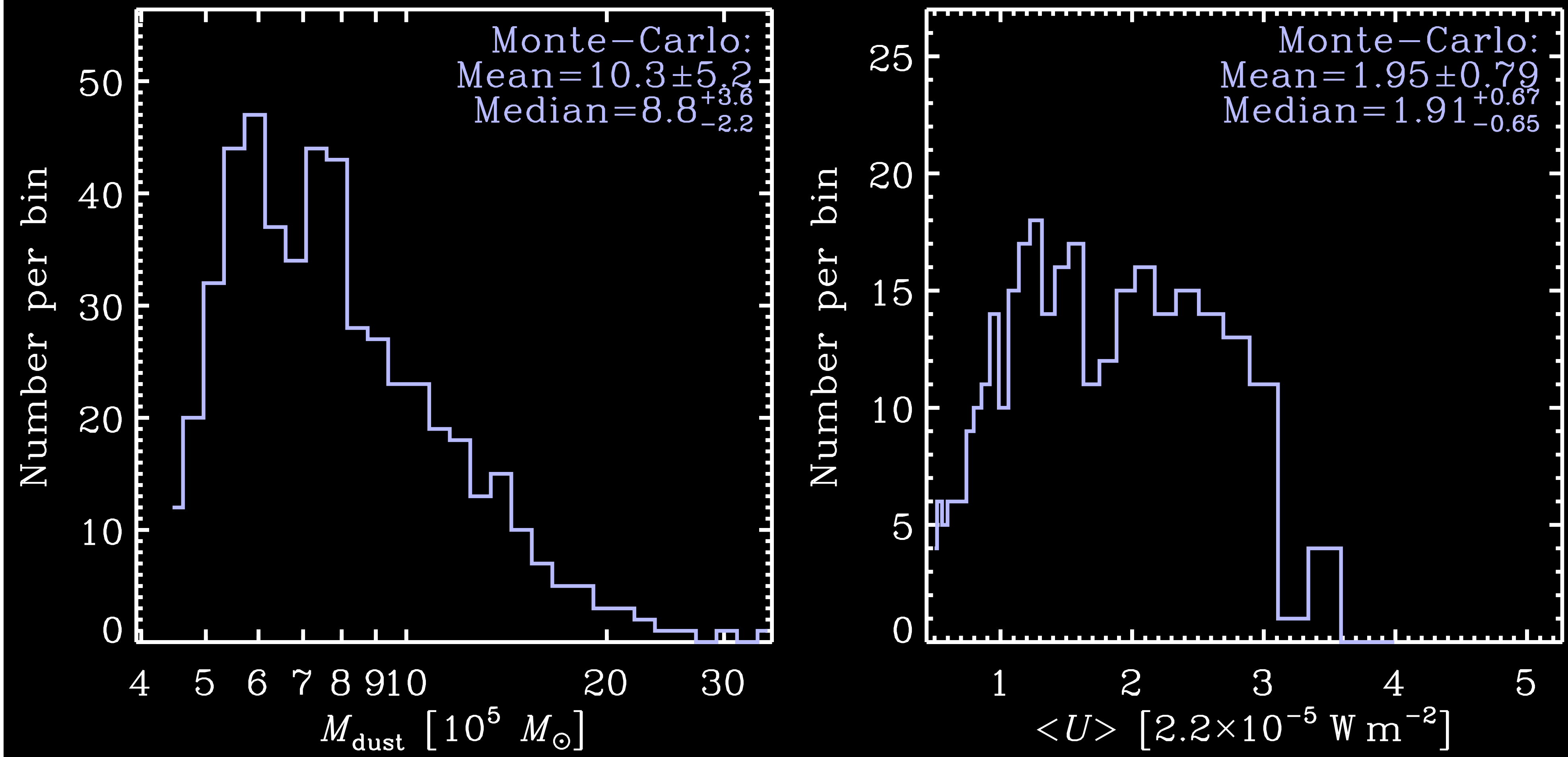
Correlation between observational errors:

Calibration errors are correlated
=> non trivial effect with a non-linear model.



(Galliano *et al.*, 2011)

Probability Distribution of the Main Parameters



Error on the dust mass:

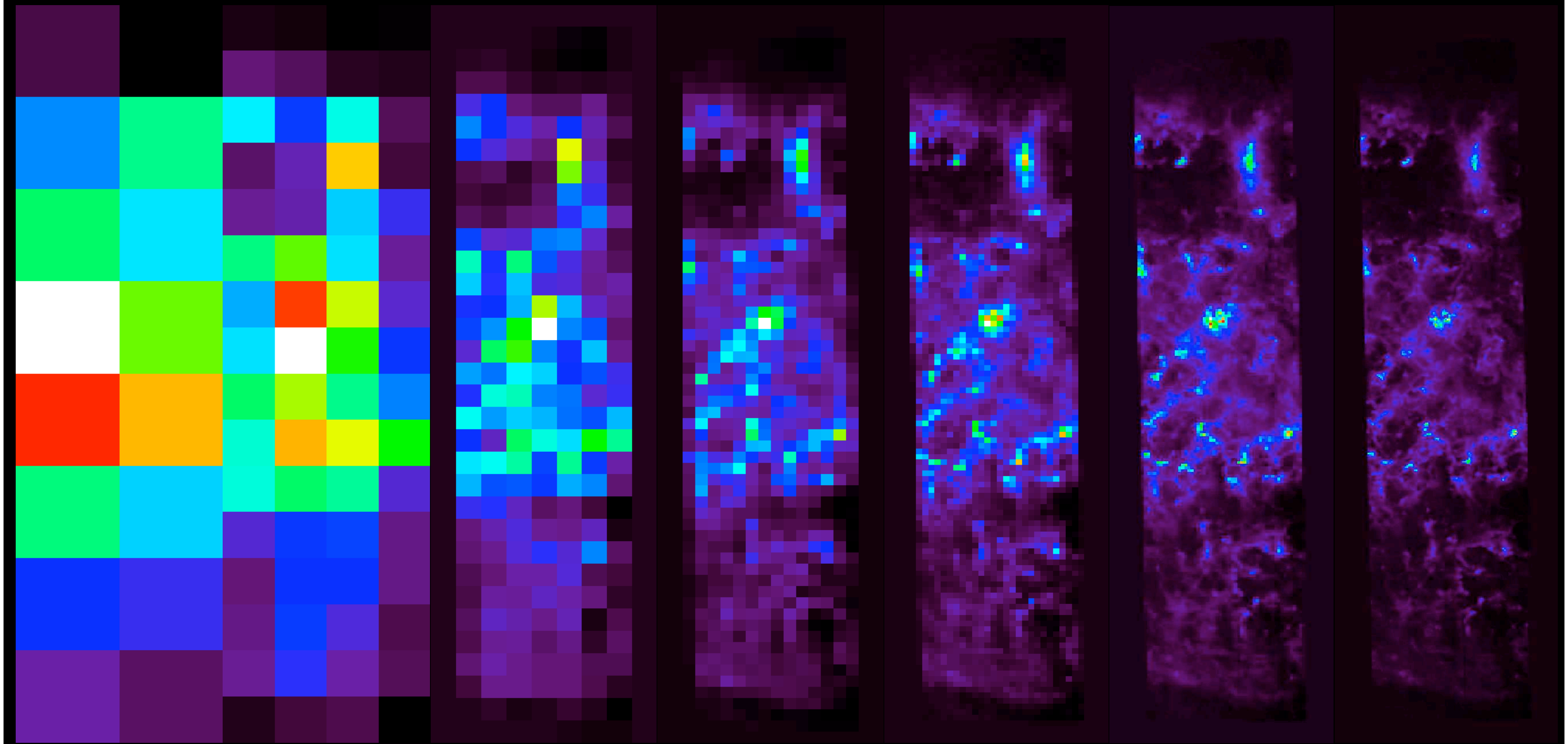
1) Significant ≈ 50% with a good signal-to-noise ratio.
2) Strongly asymetric (non-linearity of the model).

(Galliano *et al.*, 2011)

Exploring the Effects of Spatial Resolution

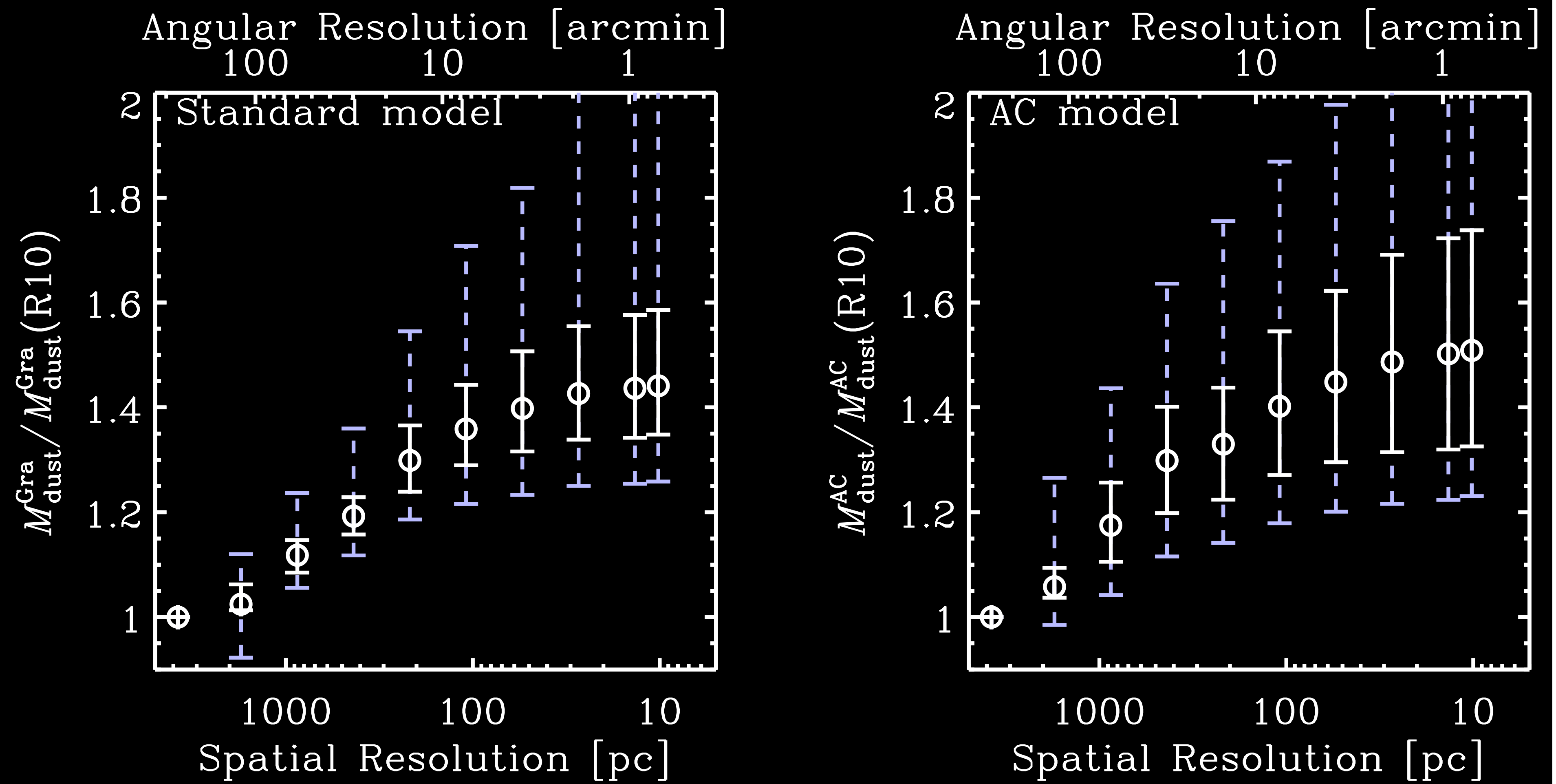
Russian doll modelling:

1) Flux conserved between the different resolutions;
2) Non-linearity of SED model => different masses.



(Galliano *et al.*, 2011)

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)

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The Gas-to-Dust Mass Ratio Crisis

Constraints on gas-to-dust mass ratio:

1) Galactic value:

$$G_{\rm dust}^{\odot} = 158$$

2) Expected LMC value ($Z \approx 1/2 \times Z_{\odot}$):

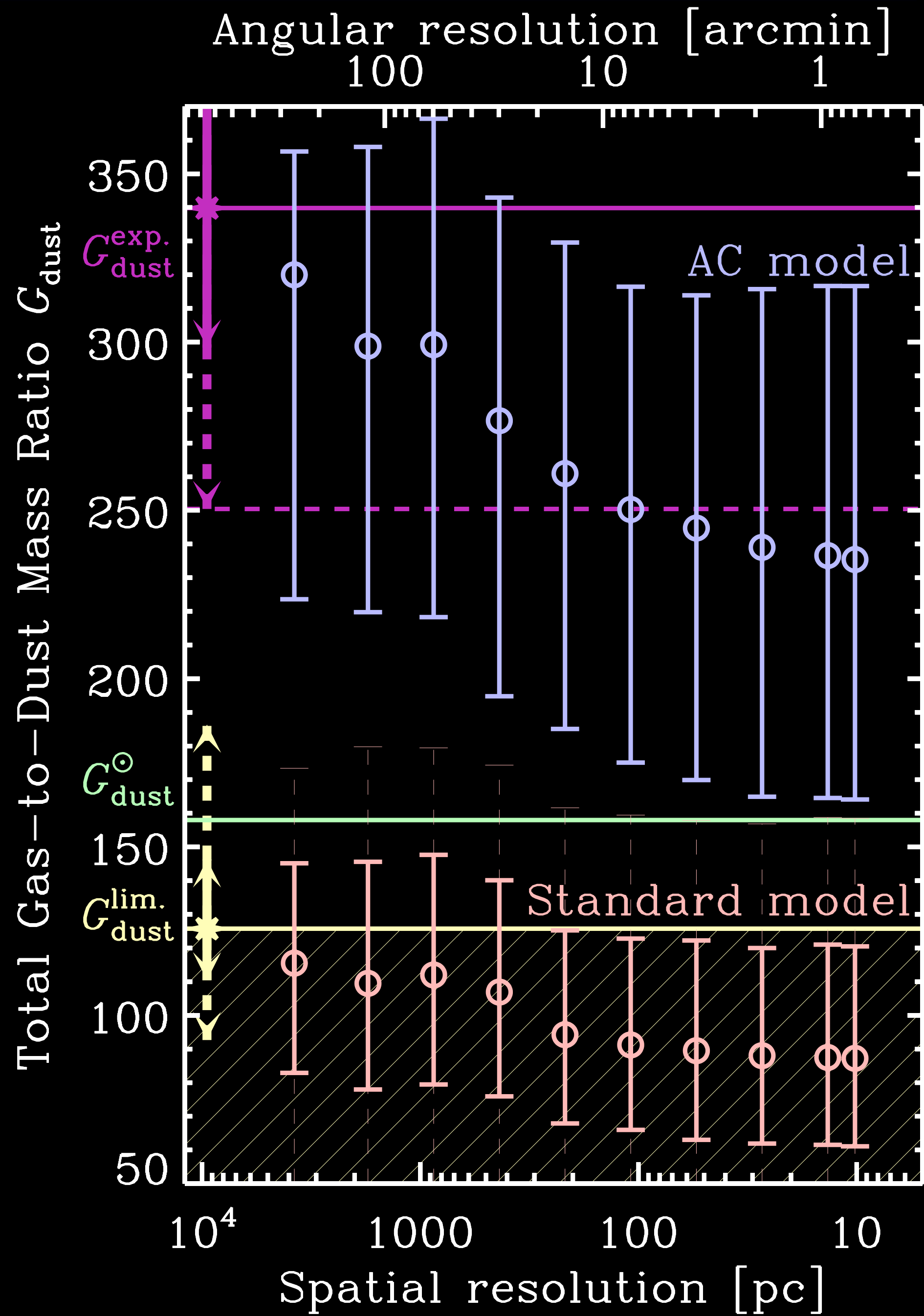
$$G_{\rm dust}^{\rm exp.} \simeq 340$$

3) Elemental violation limit:

$$G_{\rm dust}^{\rm lim.} \simeq 120$$

Assuming that the gas mass is correct, the AC model is consistent, but the standard model violates the elemental abundances.

Or the gas mass can be wrong => look at spatial variations.



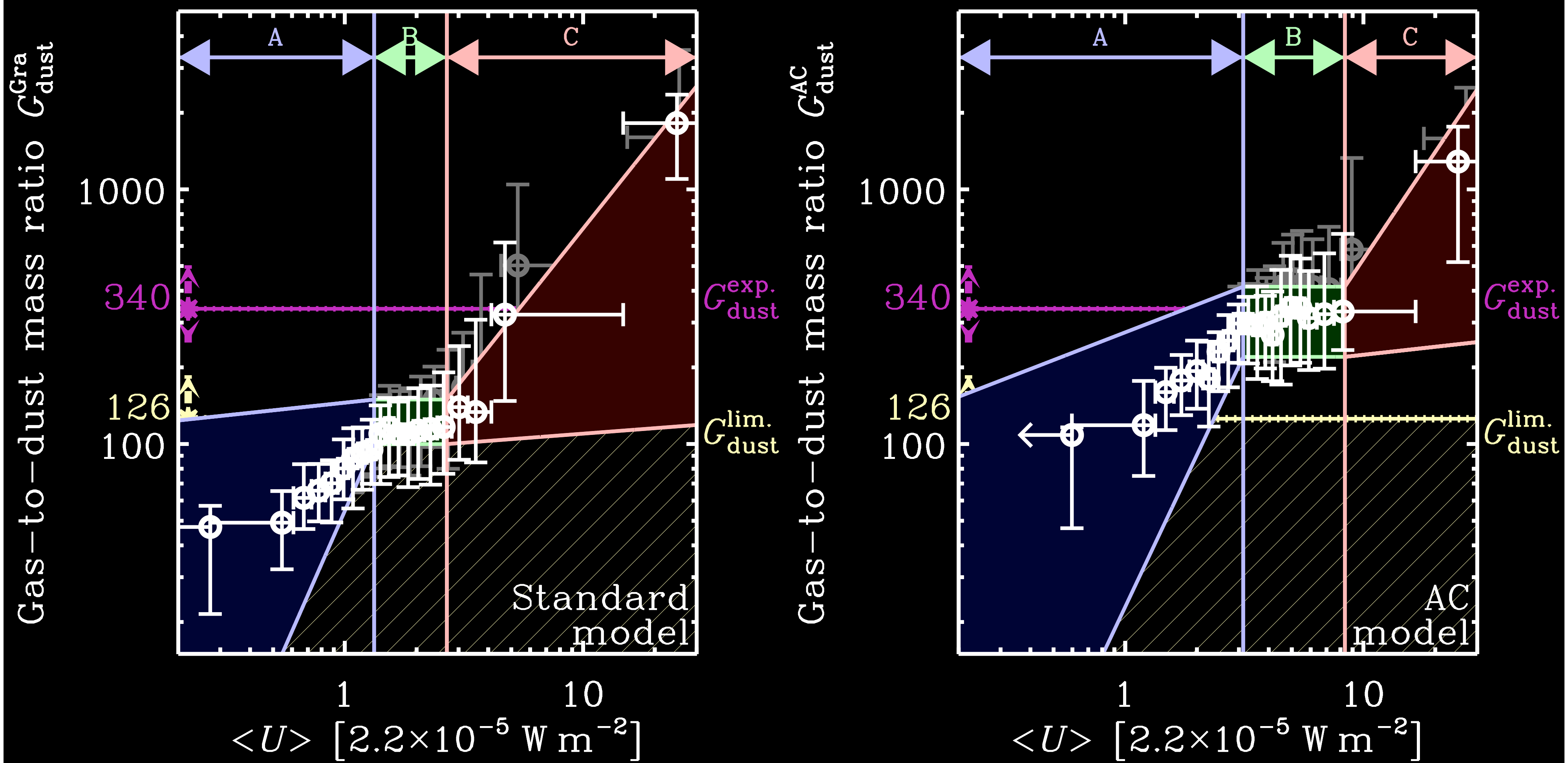
(Galliano *et al.*, 2011)

Disentangling the Different Processes

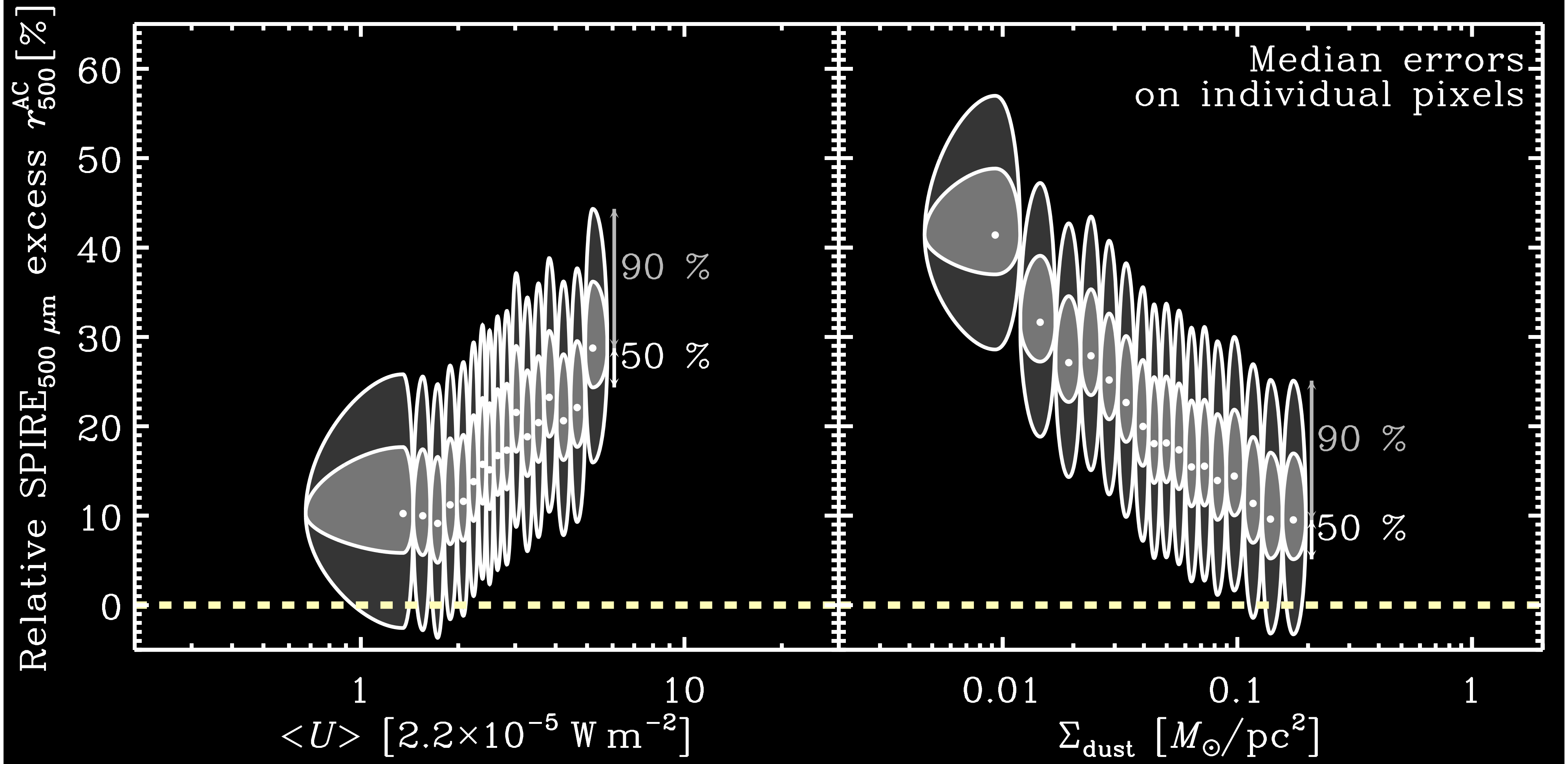
Variation of G_{dust} with mass averaged starlight intensity (<U>):

1) High <U>: model bias, possible dust destruction;
2) Intermediate <U>: diffuse ISM, reference gas-to-dust mass ratio;
3) Low <U>: enhanced dust condensations, contribution of dark gas.

(Galliano *et al.*, 2011)



Origin of the Submillimetre Excess



Submm excess properties (≈15% on average):

a) Anticorrelated with the dust column density;
b) Very cold dust unlikely: no excess in dense regions & not enough shielding;
c) No significant bias of the general dust mass estimate.

(Galliano *et al.*, 2011)

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1) Methodology: modelling of the IR/submm emission of a strip through the LMC:
   a) Rigorous propagation of the error;
   b) Dust mass can be underestimated by ≈50%, without sufficient spatial resolution;
   c) Degeneracy between the intrinsic grain properties (β_{submm}) and their temperature distribution.

2) ISM properties of the LMC:
   a) With standard grain properties (β=2), M_{gas}/M_{dust} violates the elemental abundances;
   b) Spatially, the small M_{gas}/M_{dust} regions are associated to denser regions.
   c) Looking at the physical conditions (<U>), identification of:
      - ✓ Diffuse ISM with no dark gas;
      - ✓ Denser regions with dark gas and excess condensation.
   d) Standard grain properties (β=2) are unphysical, we propose an alternative consistent model (β=1.7), which is realistic but not unique.
   e) 500 μm excess associated to diffuse ISM, and not affecting our conclusions.

3) Consequences and extrapolation of this study:
   The dust mass depends strongly on the assumed grain properties which appear to vary with metallicity;