Modeling and predicting the shape of the FIR-to-submm emission in UCHII regions and cold clumps

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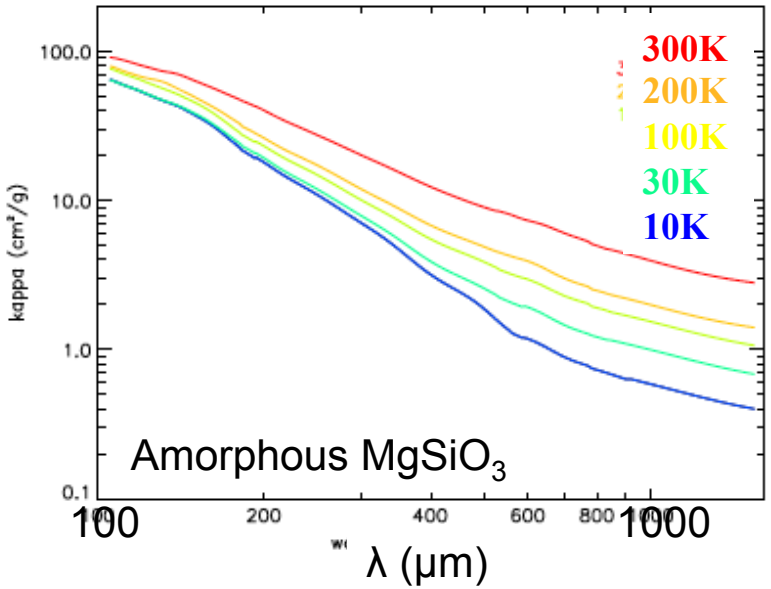
Context

Why not using a T-β (with β=2) model anymore?

★ the FIR/ submm dust emissivity appears to have a more complex dependence on λ than described by the T-β model: emission spectrum flatter in the submm than a modified black-body emission with β = 2

★ The dust emissivity appears to be T-dependent: emissivity spectra flatter with increasing dust T

=> similar variations of β with T and λ in laboratory spectroscopic experiments on amorphous dust analogs *(Mennella et al., 1998; Boudet et al., 2005;Coupeaud et al., 2011)*.



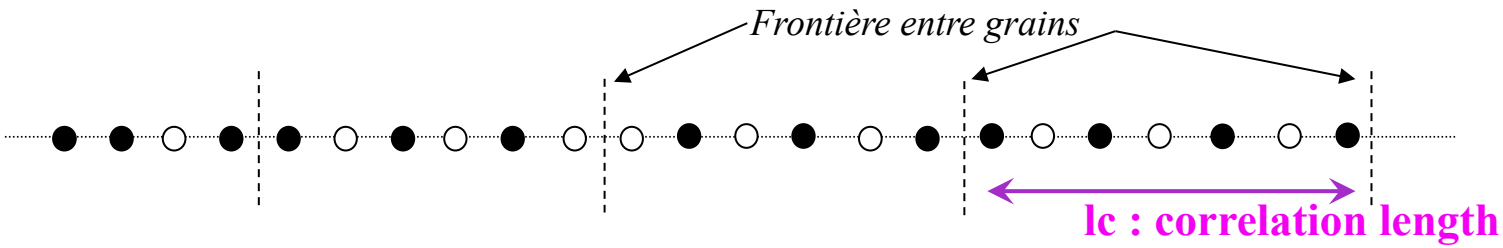
Results confirmed using Herschel and Planck data in the MW *(Paradis et al., 2010, 2012)* and in the MCs *(Galliano et al., 2011; Gordon et al., 2014, Planck Collaboration XVII, 2011)*

A model of amorphous dust: the TLS model

- 98% of amorphous dust in the ISM

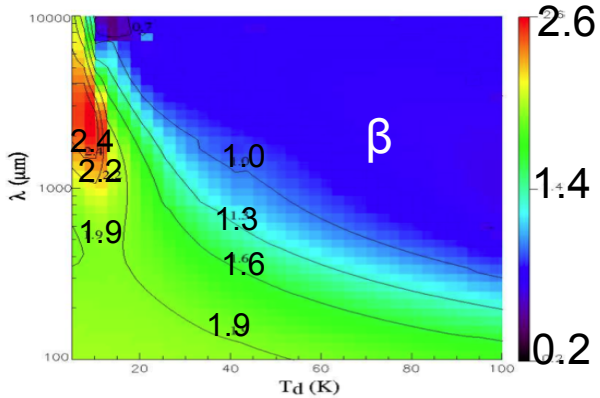
- Double description of disorder in amorphous solids: the TLS model *Mény et al., 2007*

• Disordered Charge Distribution (DCD): interaction between the electromagnetic wave and acoustic oscillations in the disordered charge of the amorphous material (Vinogradov, 1960; Schlomann, 1964) => T-independent



• Two Level System (TLS): interaction of the electromagnetic wave with a simple distribution of asymmetric double-well potential => T-dependent

In the TLS model the emissivity spectral index varies as a function of T and λ



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Parameters of the TLS model:
- Dust temperature
-Correlation length
-Intensity of the TLS process with respect to the DCD part

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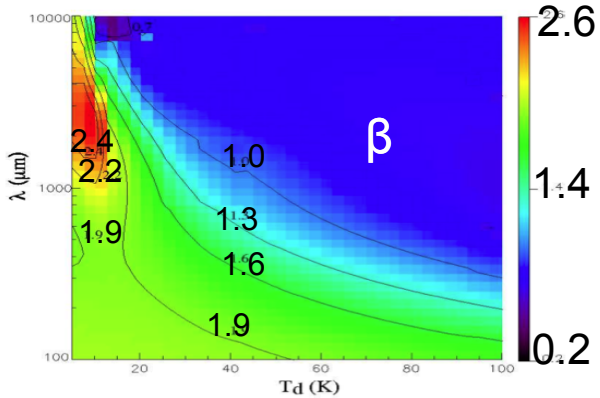


Context

Why comparing dust emission in UCHII regions and cold clumps ?

UCHII regions:

- some of the most luminous objects in the Galaxy at FIR wavelengths
- ideal targets to look for warm/hot dust

=> dust emission and dust processes occurring in warm/ hot environments are poorly known in the FIR/ submm

Cold clumps:

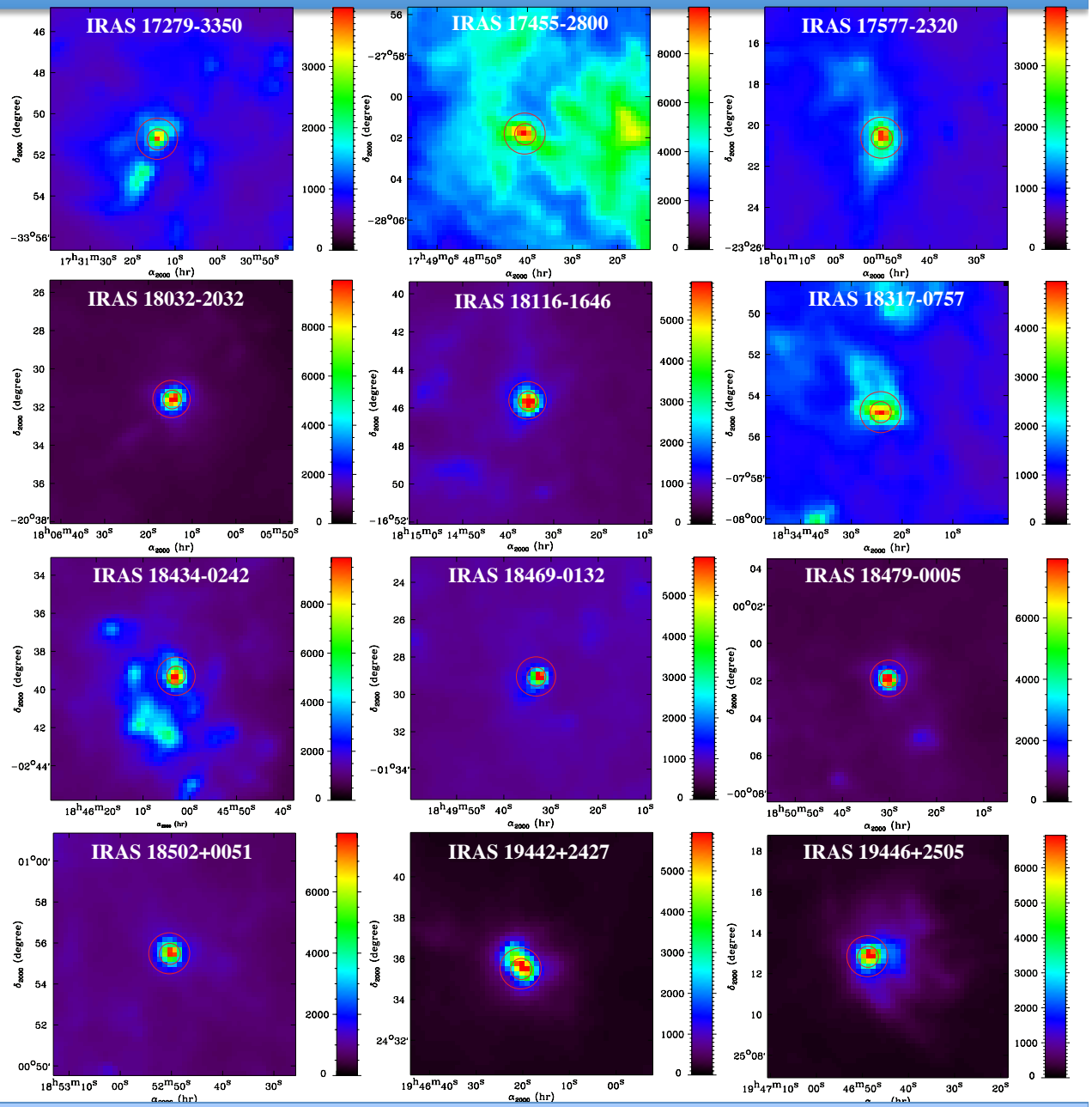
- molecular clouds with cold dust
- ideal targets to study the initial phases of star formation, i.e. pre-stellar core fragmentation

Goal: investigate the potentially distinct dust properties depending on the environment and to be able to predict the FIR-to-mm emission in cold and warm regions.

Selection of regions

UCHII regions

12 targets from the IRAS PSC observed in both Herschel/Hi-GAL and BGPS surveys
100 μm IRAS flux >10^3 Jy



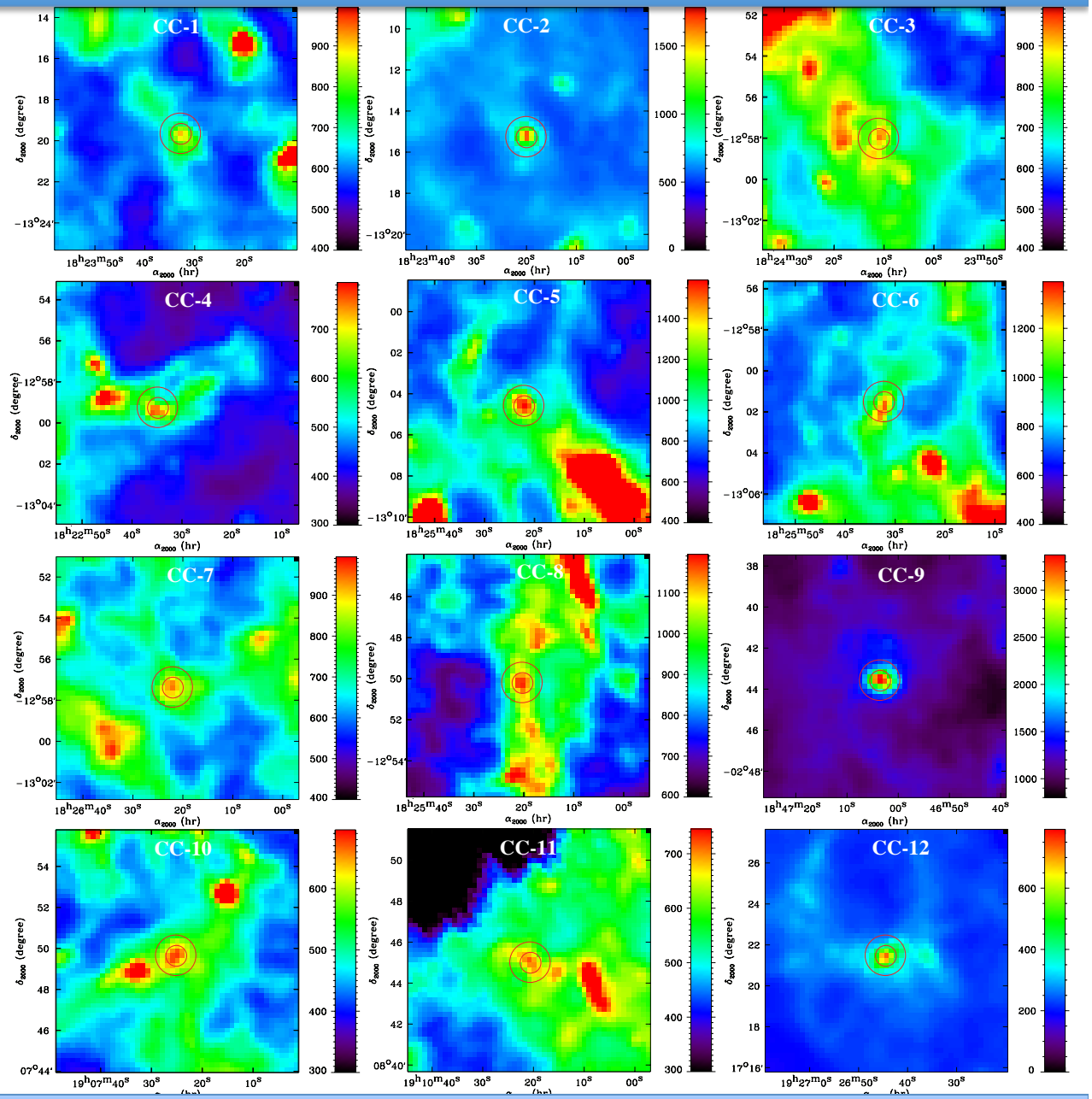
Selection of regions

<u>UCHII regions</u>

12 targets from the IRAS PSC observed in both Herschel/Hi-GAL and BGPS surveys
100 μm IRAS flux >10^3 Jy

<u>Cold Clumps:</u>

12 targets of cold molecular clouds (previously identified from ^{13}CO, recently analyzed using a 3D-Galactic inversion on Herschel observations, based on HI and ^{13}CO data (Marshall et al., 2014 in prep.) => Selection of clumps with cold CO phase



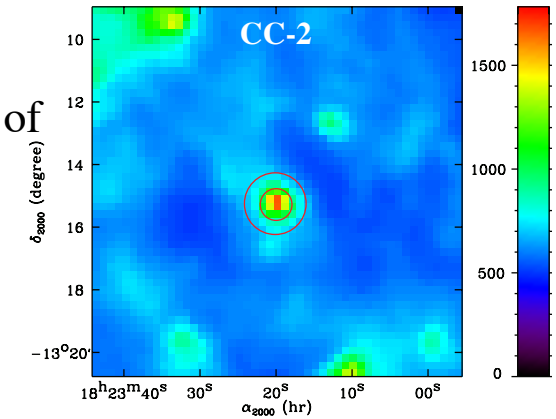
Method

Aperture photometry to extract dust emission:

2 SEDs/region :

- central part that has bright pixels (not intented to describe the core of the region) 2-pixels radius (27.8'')
- annulus surrounding the central part:

inner and outer radius of two and four pixels (27.8'' and 55.6'')



2 models:

❖ TLS model (see Paradis et al., 2011 and Mény et al. 2007)

Diffuse (diff.)	Compact Source (CS)	Standard (Std.)
Used to reproduce the Galactic diffuse medium (FIRAS +WMAP)	Used to reproduce ARCHEOPS compact sources	Used to the Galactic diffuse medium and compact sources
submm $\beta \approx 1.5$ for T=30-40 K	submm $\beta \approx 2.5$ for T=8-13K	submm $\beta \approx 2$ for T=17-25 K

❖ T-β model with β = 2, 2.5 and 1.5

➔ $\chi 2$ minimization between 70 μm-1.1 mm for UCHII regions
160 μm-1.1mm for cold clumps

Dust Temperature

Regions	TLS				T-β			
	Diff.	CS	Std.	1-σ	β=2	β=1.5	β=2.5	1-σ
IRAS 17279-3350 (1)	26.13	25.81	25.85	0.17	25.29	29.17	22.70	3.26
IRAS 17279-3350 (2)	30.72	31.27	30.73	0.31	28.68	35.29	24.71	5.34
IRAS 17455-2800 (1)	29.17	29.17	29.12	0.03	28.21	33.21	24.76	4.25
IRAS 17455-2800 (2)	27.21	26.76	26.75	0.26	24.70	31.72	20.20	5.81
IRAS 17577-2320 (1)	31.10	31.17	30.81	0.19	30.14	35.08	26.67	4.23
IRAS 17577-2320 (2)	27.57	27.67	27.30	0.19	25.78	31.56	22.26	4.70
IRAS 18032-2032 (1)	31.67	31.80	31.66	0.08	30.29	36.22	26.61	4.85
IRAS 18032-2032 (2)	31.19	33.22	31.21	1.17	27.44	36.19	22.53	6.92
IRAS 18116-1646 (1)	31.71	32.03	31.69	0.19	30.57	36.29	26.65	4.85
IRAS 18116-1646 (2)	32.63	34.25	32.68	0.92	29.13	37.68	24.59	6.65
IRAS 18317-0757 (1)	36.65	37.27	36.69	0.35	34.92	42.66	30.03	6.37
IRAS 18317-0757 (2)	27.78	28.25	27.76	0.28	25.72	32.20	21.75	5.28
IRAS 18434-0242 (1)	37.76	38.76	38.19	0.50	36.19	44.21	30.75	6.77
IRAS 18434-0242 (2)	26.20	26.14	26.13	0.04	24.48	30.62	20.69	5.01
IRAS 18469-0132 (1)	28.14	28.15	28.11	0.02	27.21	31.69	24.16	3.79
IRAS 18469-0132 (2)	33.54	34.76	33.63	0.68	30.73	38.73	26.15	6.37
IRAS 18479-0005 (1)	32.69	33.15	32.69	0.27	31.26	37.28	27.24	5.05
IRAS 18479-0005 (2)	29.26	29.75	29.24	0.29	27.03	34.20	22.72	5.80
IRAS 18502 0051 (1)	28.10	28.10	28.06	0.02	27.14	31.72	23.77	3.99
IRAS 18502 0051 (2)	24.04	23.57	23.77	0.24	22.52	27.79	18.78	4.53
IRAS 19442 2427 (1)	31.19	31.26	31.18	0.04	30.17	35.25	26.27	4.50
IRAS 19442 2427 (2)	28.74	29.15	28.71	0.25	26.96	33.23	23.17	5.08
IRAS 19446 2505 (1)	37.20	38.23	37.27	0.58	35.24	43.23	30.20	6.57
IRAS 19446 2505 (2)	37.63	41.25	38.13	1.96	33.56	43.61	27.74	8.03
Mean std. deviation	-	-	-	0.38	-	-	-	5.33
Cold Clump-1 (1)	18.65	17.96	18.52	0.37	18.03	21.56	15.66	2.97
Cold Clump-1 (2)	16.63	15.62	16.38	0.53	15.96	19.94	13.88	3.08
Cold Clump-2 (1)	20.40	19.60	20.17	0.41	19.58	23.78	16.93	3.45
Cold Clump-2 (2)	17.01	15.58	16.59	0.74	16.21	20.64	13.80	3.47
Cold Clump-3 (1)	17.11	15.76	16.86	0.72	16.44	20.17	14.05	3.08
Cold Clump-3 (2)	19.15	17.14	18.66	1.05	18.12	23.25	15.01	4.16
Cold Clump-4 (1)	14.61	13.97	14.47	0.34	14.17	16.50	12.64	1.94
Cold Clump-4 (2)	16.98	15.26	16.52	0.89	16.12	20.18	13.65	3.29
Cold Clump-5 (1)	14.17	13.16	13.98	0.54	13.79	16.13	12.04	2.05
Cold Clump-5 (2)	17.06	14.46	16.52	1.37	16.10	20.73	13.19	3.80
Cold Clump-6 (1)	11.71	10.58	11.54	0.61	11.47	13.20	10.03	1.59
Cold Clump-6 (2)	15.19	13.30	14.89	1.02	14.59	18.18	12.24	2.99
Cold Clump-7 (1)	13.64	12.69	13.55	0.52	13.19	15.25	11.67	1.80
Cold Clump-7 (2)	19.59	17.91	19.13	0.87	18.31	24.16	15.38	4.47
Cold Clump-8 (1)	12.18	11.13	12.04	0.57	11.95	13.70	10.47	1.62
Cold Clump-8 (2)	16.56	14.25	16.04	1.21	15.67	20.16	12.99	3.62
Cold Clump-9 (1)	18.30	17.41	18.04	0.46	17.56	21.22	15.33	2.97
Cold Clump-9 (2)	17.65	15.32	17.12	1.22	16.65	21.74	13.72	4.06
Cold Clump-10 (1)	19.72	19.07	19.63	0.35	19.09	22.75	16.52	3.13
Cold Clump-10 (2)	20.53	18.82	20.10	0.89	19.15	25.17	15.96	4.68
Cold Clump-11 (1)	13.96	13.02	13.67	0.48	13.51	15.71	11.95	1.89
Cold Clump-11 (2)	16.70	15.05	16.45	0.89	16.03	20.18	13.50	3.37
Cold Clump-12 (1)	15.22	14.53	15.07	0.36	14.86	17.22	13.10	2.07
Cold Clump-12 (2)	14.09	12.90	13.79	0.62	13.56	16.55	11.76	2.42
Mean std. deviation	-	-	-	0.71	-	-	-	3.00

mean value of T dispersion:

- **5.3 K** and **3.0 K** for UCHII regions and CC (T-β model with the ≠ β)
- **0.38 K** and **0.71 K** (TLS model)

Examples of T dispersion for SEDs with similar best χ2 for each model

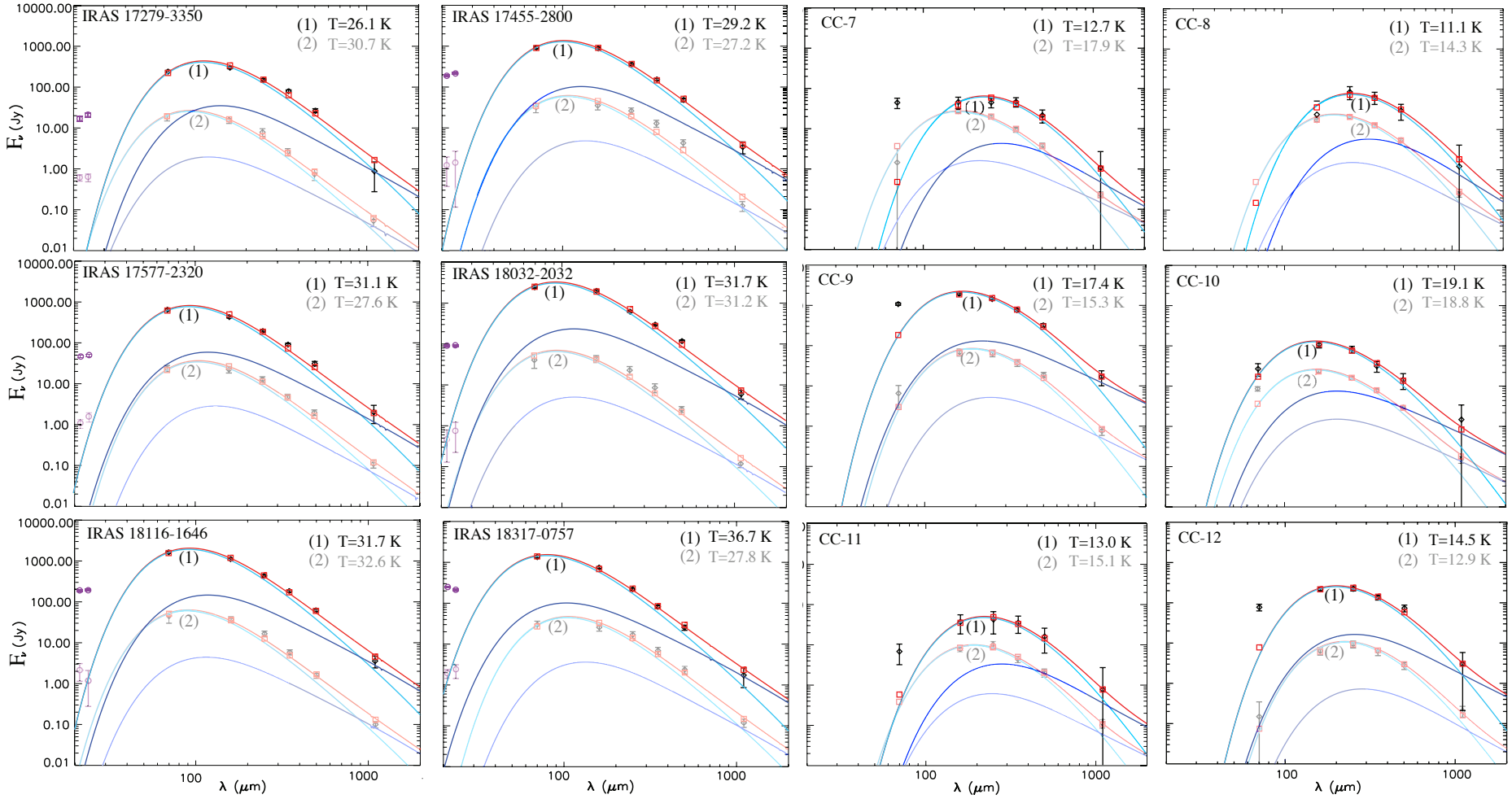
➔ the choice of the model has a real and strong impact on the T determination.

the TLS model does not present the same artifact in terms of temperature determination as a T-β model

Modeling

UCHII regions

Cold clumps



Results: Specific dust properties in each environment

	Regions	Norm. χ^2_{TLS}			Norm. $\chi^2_{T-\beta}$		
		Diff.	CS	Std.	$\beta = 2$	$\beta = 1.5$	$\beta = 2.5$
UCHII regions	Total nb. of best χ^2	13 (52%)	3 (12%)	9 (36%)	9 (37.5%)	15 (62.5%)	0 (0%)
	Total χ^2	15.811	23.817	15.899	24.679	15.478	71.733
Cold Clumps	Total nb. of best χ^2	2 (8%)	14 (56%)	9 (36%)	12 (48%)	1 (4%)	12 (48%)
	Total χ^2	19.730	13.347	15.367	14.502	46.681	17.970

❖**TLS:**

UCHII: CS param. do not give the best description of spectra (best χ2 for only 12% of the SEDs), while diff. param. give better solution (52%).

CC: CS param. satisfactory for 56% of the SEDs (against 8% diff. param.)

=> SEDs from UCHII regions and CC are not reproduced by the same set of parameters

❖**T-β:**

UCHII: 62.5% of SEDs well reproduced using β=1.5, 37.5% using β=2, and 0% with β=2.5.

CC: only 4% of the CC SEDs have the best χ2 using a β of 1.5. number of best χ2 equally distributed between β=2 and β=2.5 (48%)

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=> SED

➔UCHII regions and CC have ≠ dust properties (β changes with the environment)

eters

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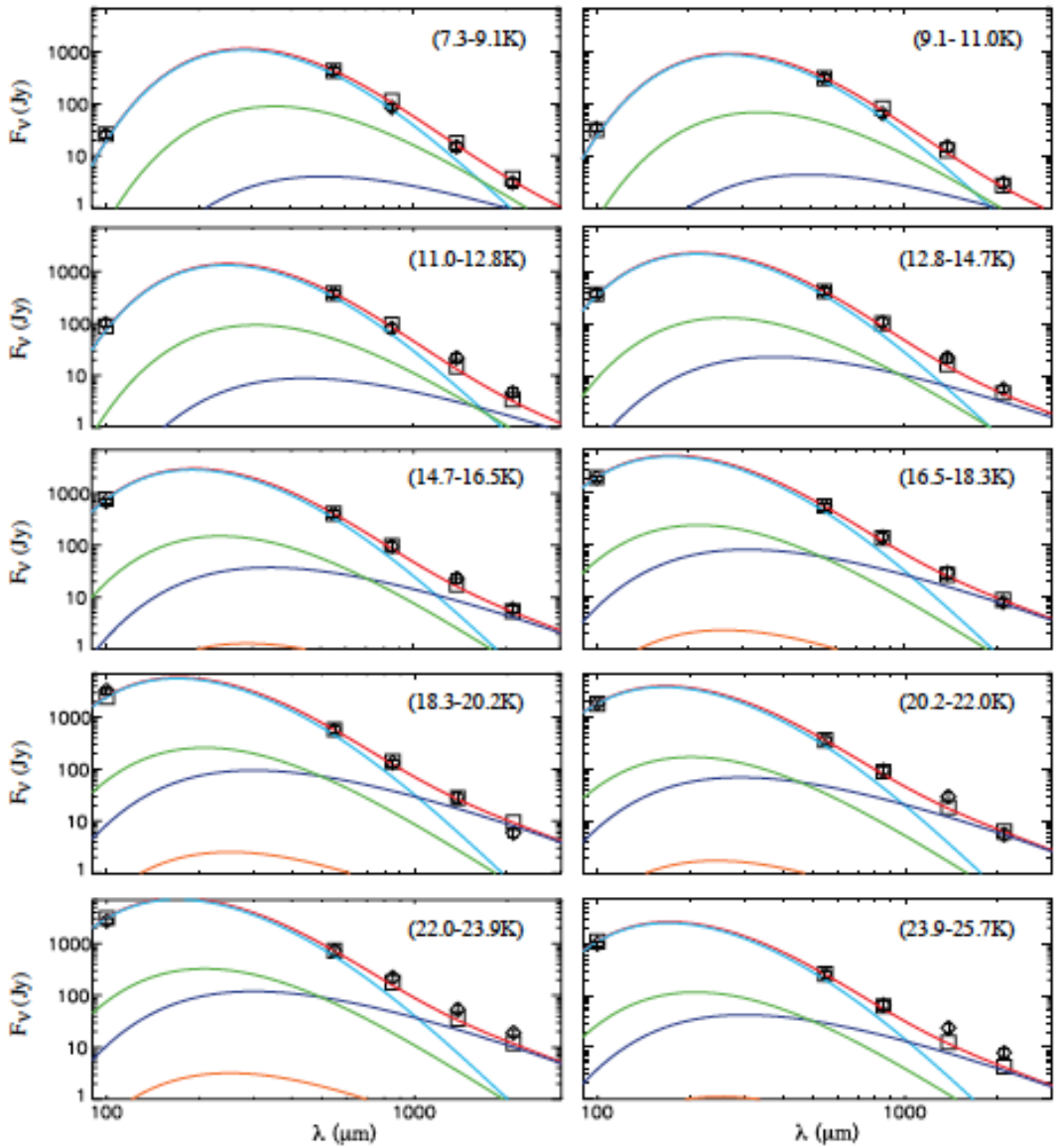
CS parameters used to reproduce the Archeops compact sources in our Galaxy are also the best parameters to describe the Galactic cold clumps analyzed in this work

=> same set of param. able to reproduce various cold sources observed with ≠ instruments at ≠ λ.

Most cold clumps have similar general properties

IRAS-Archeops compact sources



Results: comparing TLS and T-beta models

	Regions	Norm. χ^2_{TLS}			Norm. $\chi^2_{T-\beta}$		
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<u>Modeling with:</u>

★ the TLS model (using the adequate set of params)

or

★ a T-β model (using the adequate β)

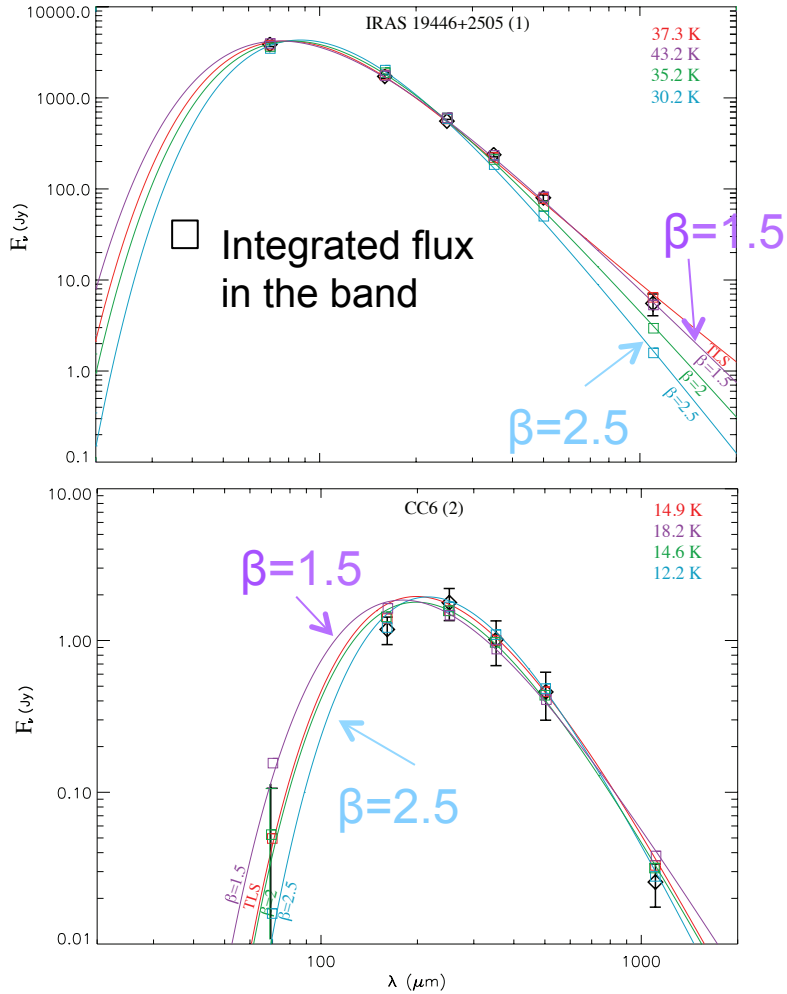
⇒ same result for the goodness of fits because of the lack of strong constraints at long λ

The TLS model takes the flattening of the spectra in the submm/mm into account, contrary to T-β models

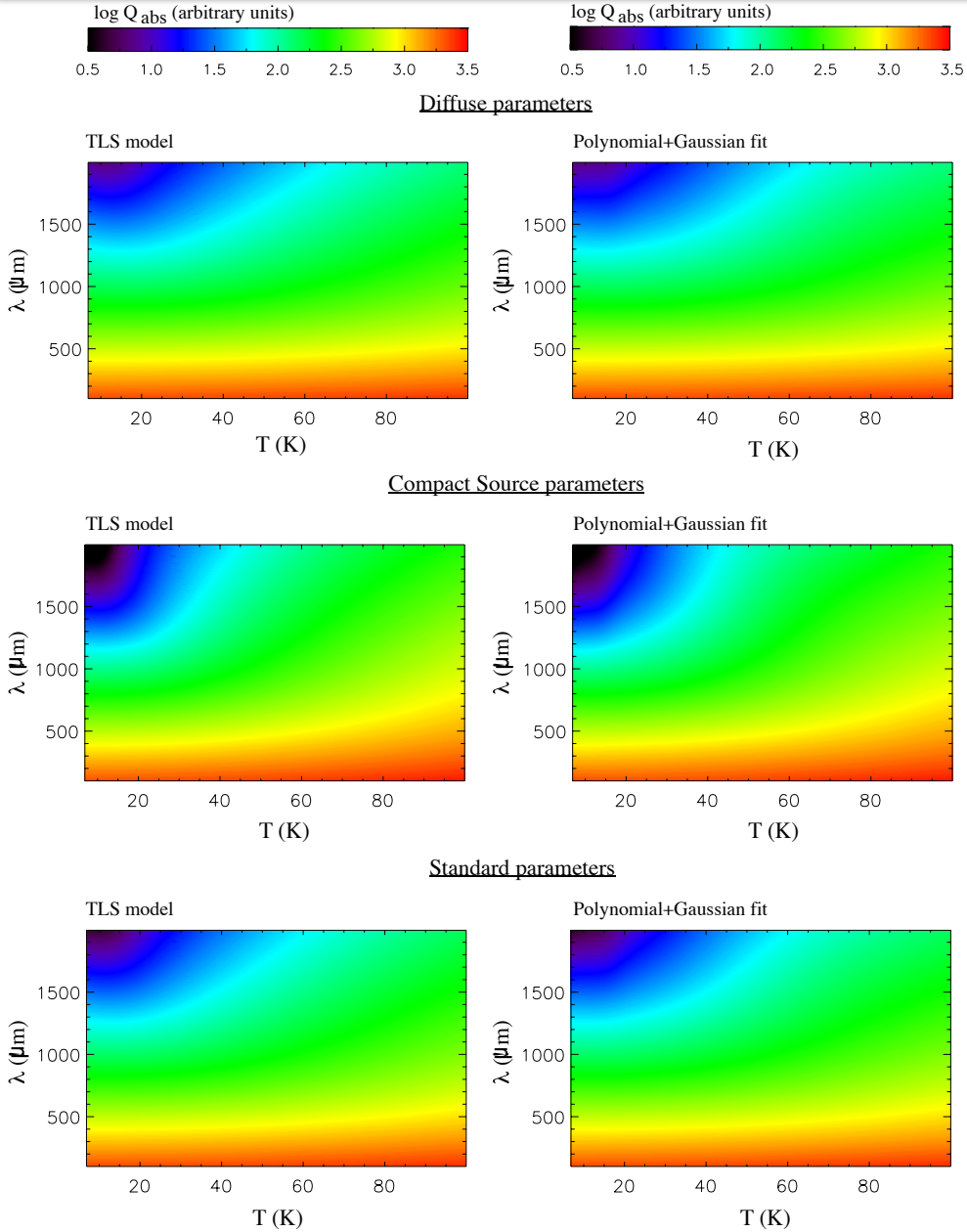
And with an incorrect β, a T-β model can lead to an **incorrect description** of the dust emission (very bad χ2)

TLS model with std param. is able to reproduce the emission of each type of environment well.

=> First model that is able to describe various types of medium with a single set of param. by only changing the dust T.



Polynomial+Gaussian fit of the TLS model



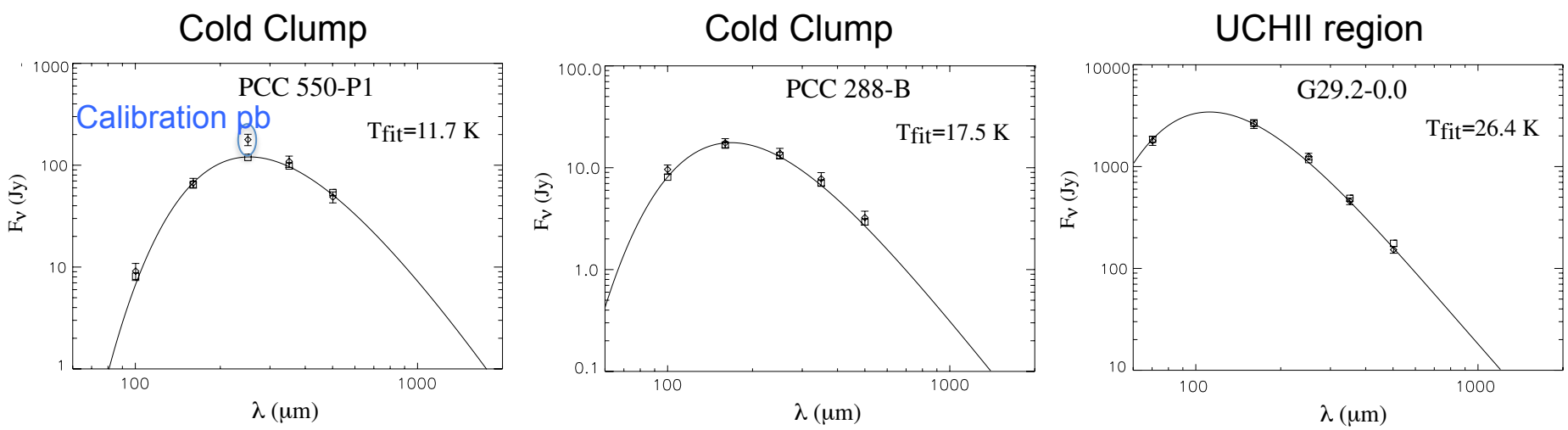
The TLS model predicts emissivity variations as a function of λ and T.

Polynomial+Gaussian fit on the model for each set of parameters (diffuse, cold sources, and standard) [T in the range 7 -100]K; λ [100 μm – 2mm]

IDL code available here:
http://userpages.irap.omp.eu/~dparadis/TLS/
compute_TLS_poly_gaussian_fit.pro

Predictions

Comparison of the Polynomial +Gaussian fit (using std. param.) with known SEDs of UCHII regions (from Paladini et al., 2012) and cold clumps (from Juvela et al., 2010). Only T in our fits varies from one SED to the other.



We are able to predict the dust emission from FIR to submm in various environments

Conclusions

➔ **variations in the dust optical properties with environments**.

➔ **Contrary to any fixed value of β** (1.5, 2 and 2.5) that mostly fails to give good $\chi 2$ in both warm and cold regions, the use of **the standard TLS parameters can give reasonable results in all cases**.

➔ Using a T-β model for which the **β value is unknown** can lead to an **incorrect description** of the dust emission.

➔ the **TLS model does not present the same artifact in terms of T determination** as a T-β model, and is in particular a better description of the FIR-to-mm emission

➔ We also reported an **easy way to determine the emission at any T and λ** for each set of TLS parameters by giving the coefficients of a **polynomial+Gaussian fit**

http://userpages.irap.omp.eu/~dparadis/TLS/compute_TLS_poly_gaussian_fit.pro