Variation in Dust Emissivity Index across M33

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HERM33ES K. P. O.T.

PI: Carsten Kramer (IRAM)

- ~ 200 hours observing time
- Dust continuum with PACS & SPIRE
- Major gas cooling lines:
  C^+, H2O, O, N^+, and N^{++}
  with HIFI & PACS

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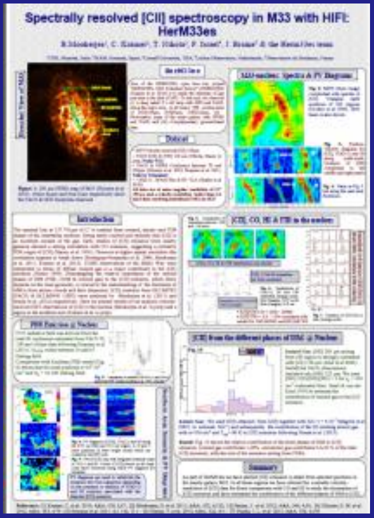
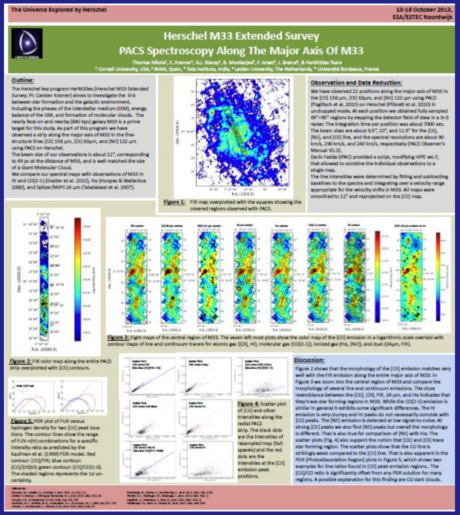
M. Wiedner
M. Xilouris

>15 refereed papers

P20: Mookerjea+



P21: Nikola+



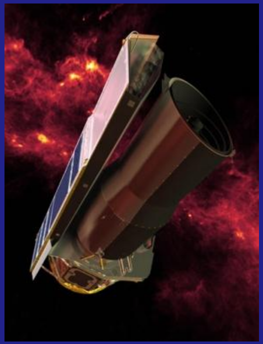
FIR/ Submm Continuum Observations

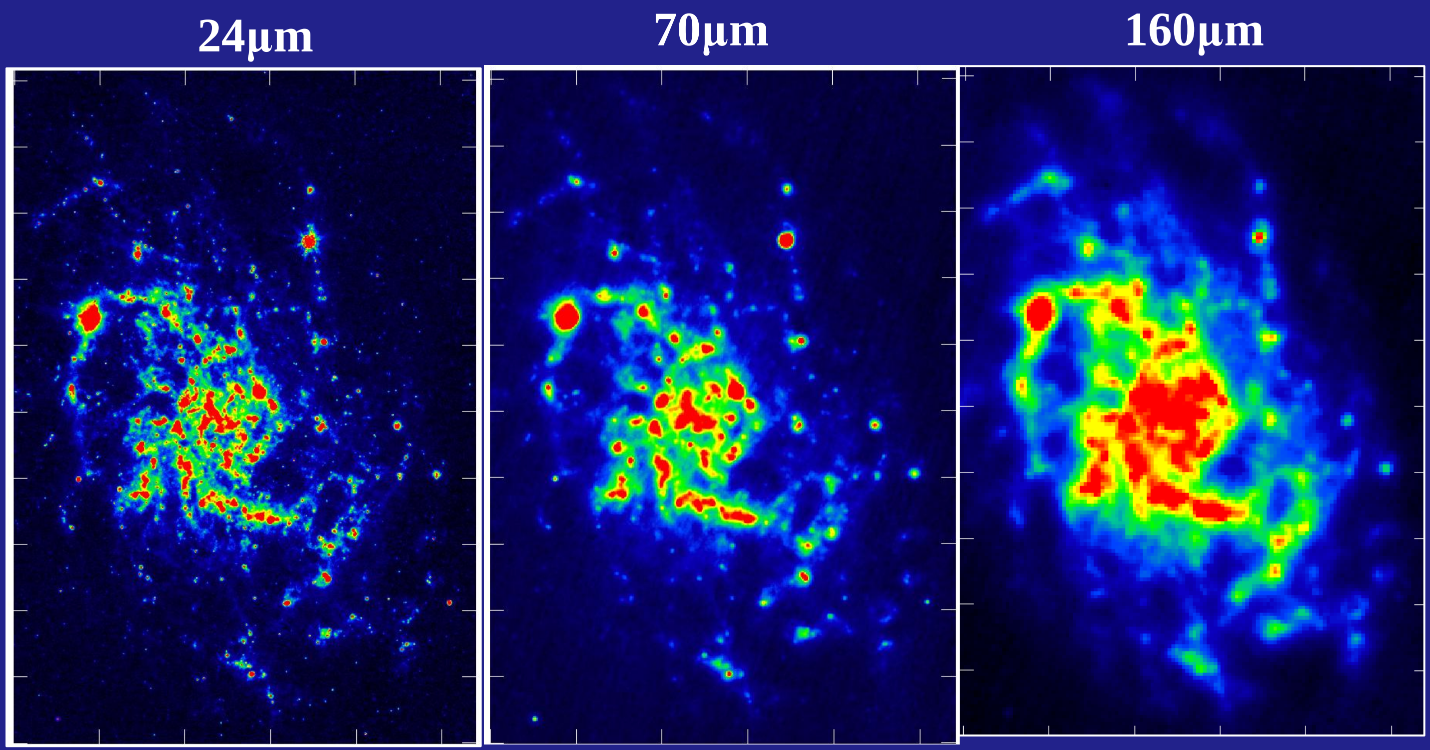
- Heating and Cooling Mechanisms in ISM
- Dust Physcial Properties
- Tracing gas mass in galaxies

Nearest late-type spiral, M33 (NGC598):

- No distance ambiguity + high spatial resolution
- Not as extended and inclined as M31
- Gas rich, metal poor, with several giant HII regions

Spitzer Observations of M33





Spitzer MIPS :
R. Gehrz (PI)

- Dust optical depth <1 at visible light in M33

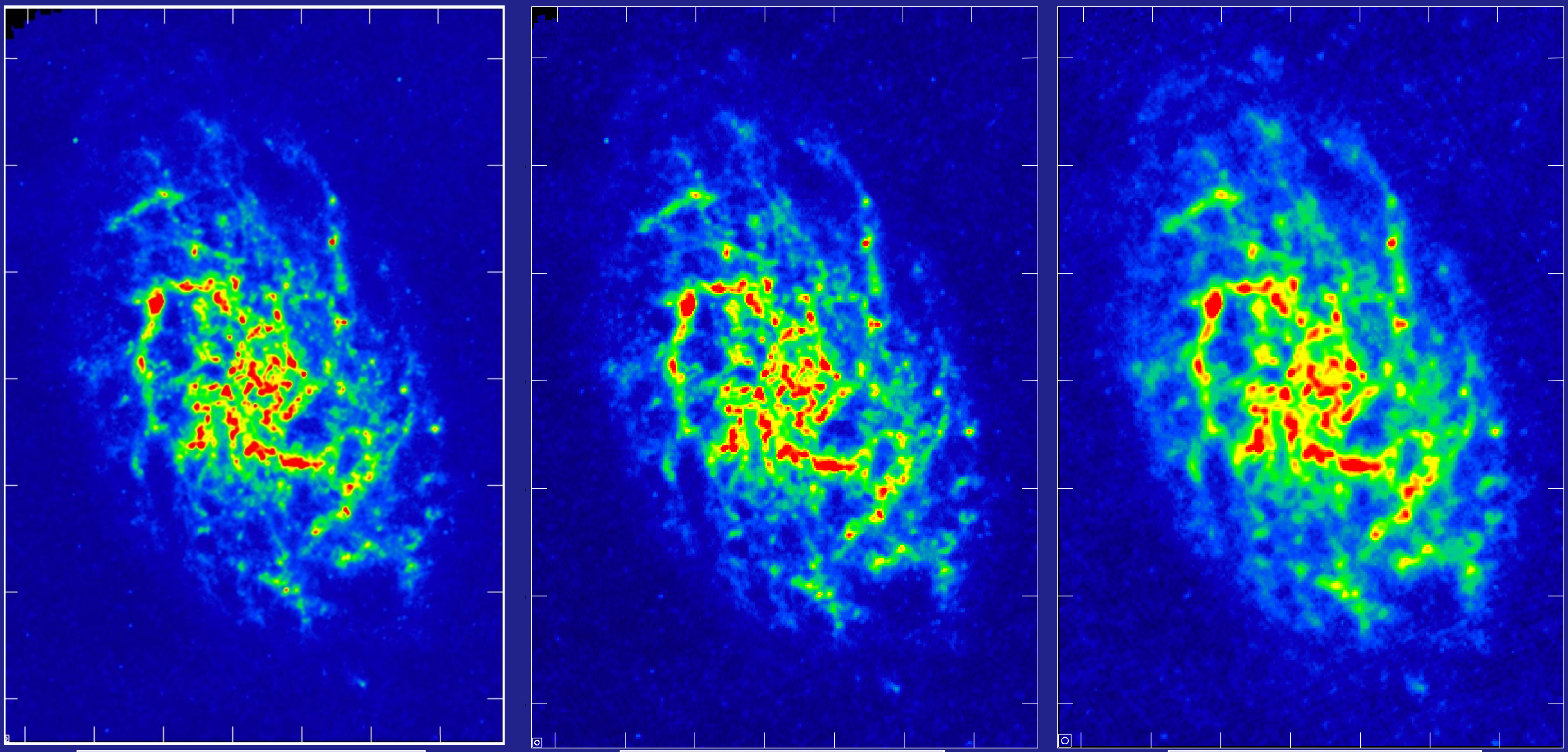
Tabatabaei et al. (2007)

- A radial gradient
- Dust temperature based on 70/160 flux ratio: 18- 30 K
- T(mean)= 21±1 K

SPIRE Unveils Dust Lanes/Filaments

Kramer et al. (2010), Boquien et al (2010), Xilouris et al (2012):

λ = 250μm | λ = 350μm | λ = 500μm



FWHM =18“
rms= 14 mJ/beam

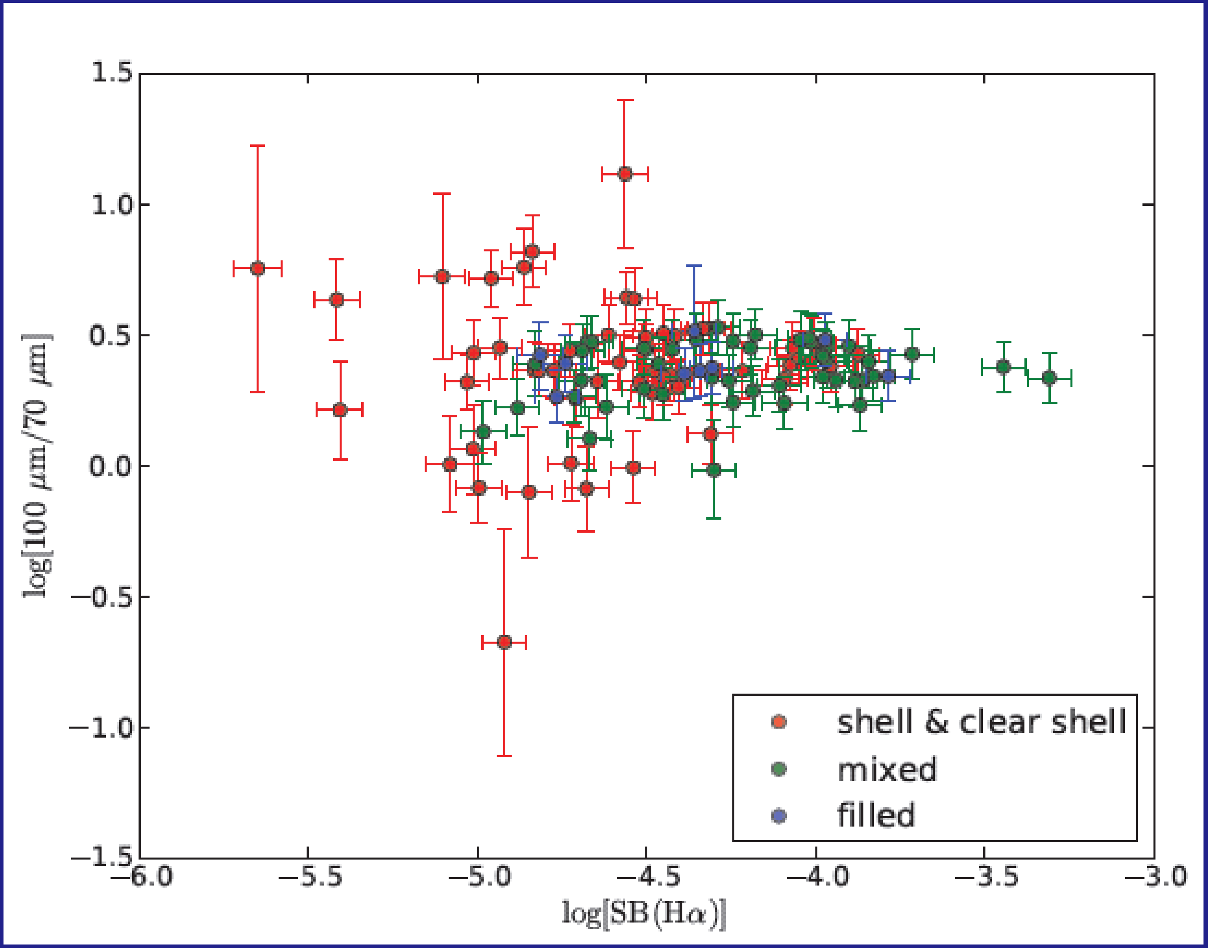
FWHM = 25“
rms= 9 Jy/beam

FWHM = 37“
rms= 8 Jy/beam

PACS Discovered...

HII regions:

shells differs in temperature, filled are similar



Relanõ et al. 2013

HerM33es: First Results

Kramer et al. (2010):

- Global SED-fitting for β=1.5

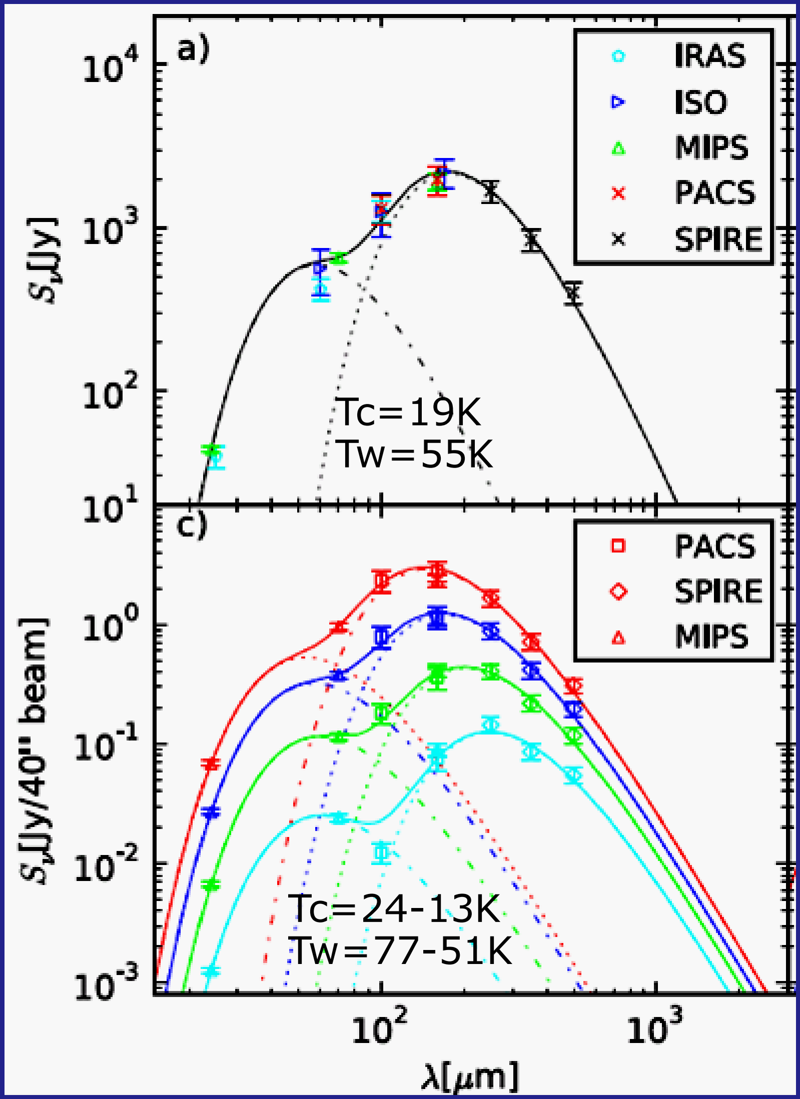
- Two better than one component →

Modified Black Body Emission(MBB)

$$I_\nu = B_\nu(T_c)[1 - exp(-\tau_{\nu,c})] + B_\nu(T_w)[1 - exp(-\tau_{\nu,w})],$$ specific intensity

$$\tau_{\nu,w} = N_w\,\kappa_\nu, \quad \tau_{\nu,c} = N_c\,\kappa_\nu$$ optical depth

$$\kappa_\nu = 0.04(\frac{\nu}{250\mathrm{GHz}})^\beta$$ emissivity



- In radial annuli
Both cold & warm dust components become colder with distance from the center →

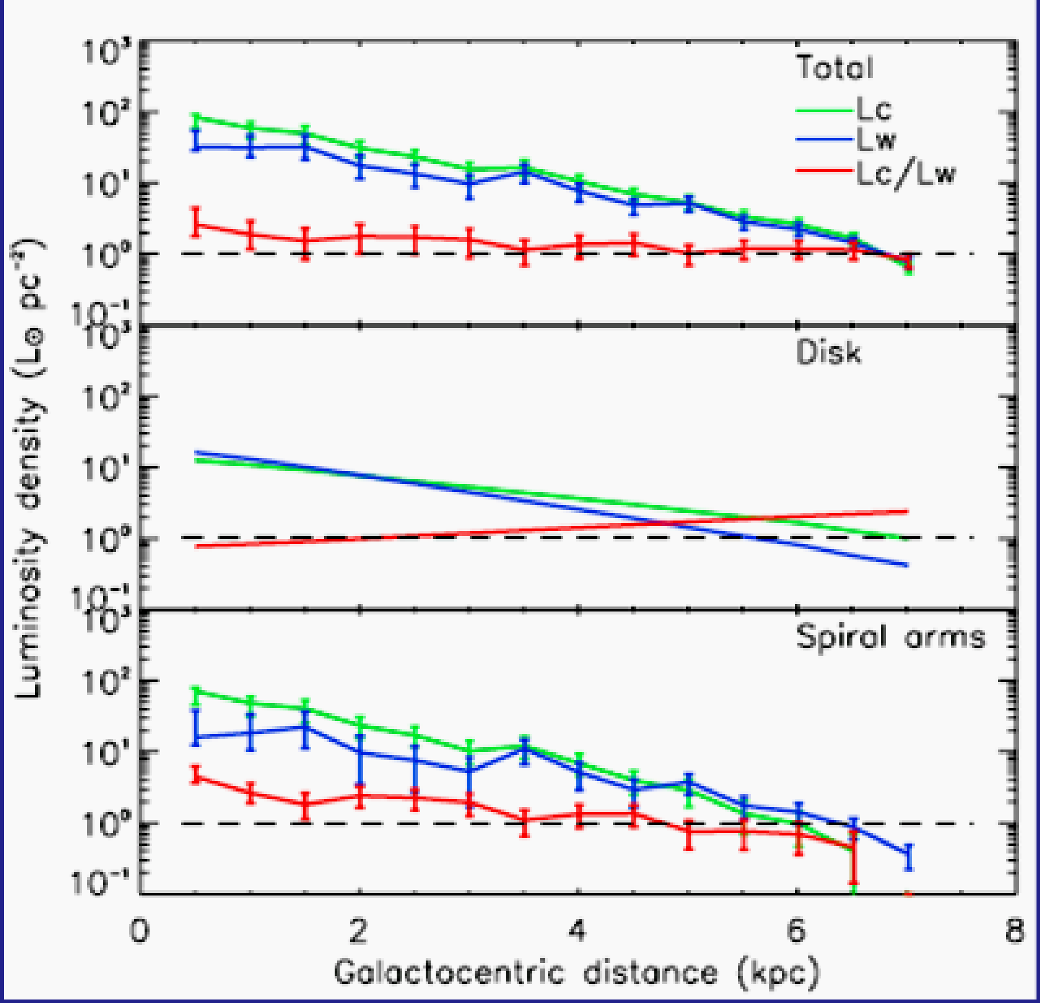
HerM33es: First Results

Xilouris et al. (2012):

Distribution of dust luminosity in M33 and its origin by separating the contributions from spiral arms/extended disk

•The dust in the disk produces ~30% the total luminosity

•Both the arms and the disk luminosities decrease with distance from the center.



A More Complete Sensus of Dust Emission

Does the dust emissivity index remains unchanged
in different environmets in a galaxy?

β depends on grain properties:
structure, size distribution, or chemical composition (e.g. Krügel 2003)

Variations due to:

-destructive processes: shattering, sputtering due to shocks (Jones 2004).

-constructive processes: condensation of molecules onto grains, coagulation (Draine 2006).

→Local variations in β is expected
(arms/ inter-arms, inner/outer disk contrast)

→These can be best distinguished in a
nearby face-on galaxy, like M33, via mapping β
at cloud-scale resolution.

Mapping Dust Temperature, Mass & β: Looking for a Proper Method?

Available DATA :

70, 160, 250, 350, and 500μm
(24μm dominated by vsgs, 100μm low SNR)

Unknown parameters:

1 (2) Temperature(s)
1 (2) Mass surface density(ies)
1 (2) β

Modified Black Body (MBB)

$$I_\nu = B_\nu(T_c)[1 - exp(-\tau_{\nu,c})] + B_\nu(T_w)[1 - exp(-\tau_{\nu,w})],$$ specific intensity

$$\tau_{\nu,w} = N_w \, \kappa_\nu, \quad \tau_{\nu,c} = N_c \, \kappa_\nu$$ optical depth

$$\kappa_\nu = 0.04\left(\frac{\nu}{250\mathrm{GHz}}\right)^\beta$$ emissivity

Mapping Dust Mass, Temperature & β: Looking for a Proper Method?

Approaches:

I-Observed emission is mainly due to dust heated by a general ISRF, explained by a single-MBB (true at the SPIRE bands)

→3 single-MBB equations & 3 unknowns : Newton-Raphson method

II-Observed emission is mainly due to two dust components, one heated by ISRF (cold), other by young massive stars (warm) following double MBB

→5 two-MBB equations & 5 unknowns, if $\beta c=\beta w$ or...

Since most of dust resides in its colder component: $\beta c = \beta$, $\beta w=1, 1.5, 2$

→Solving systems of equations, iteratively for each pixel and using the 4 model approaches

Monte-Carlo Simulation: Systematics of Approaches

Approach	T_c [K]	T_w [K]	$\log(\Sigma_{dust,c})$ [g cm^{-2}]	$\log(\Sigma_{dust,w})$[g cm^{-2}]	β	Statistics
β_w=1	5−25	26−70	(-6)−(-3)	(-9)−(-5)	0.8−2.5	15 000
β_w=1.5	5−25	26−70	(-6)−(-3)	(-9)−(-5)	0.8−2.5	15 000
β_w=2	5−25	26−70	(-6)−(-3)	(-9)−(-5)	0.8−2.5	15 000
$\beta_w = \beta_c$	5−25	26−70	(-6)−(-3)	(-9)−(-5)	0.8−2.5	15 000

1. Generate sets of physcial parameters → input

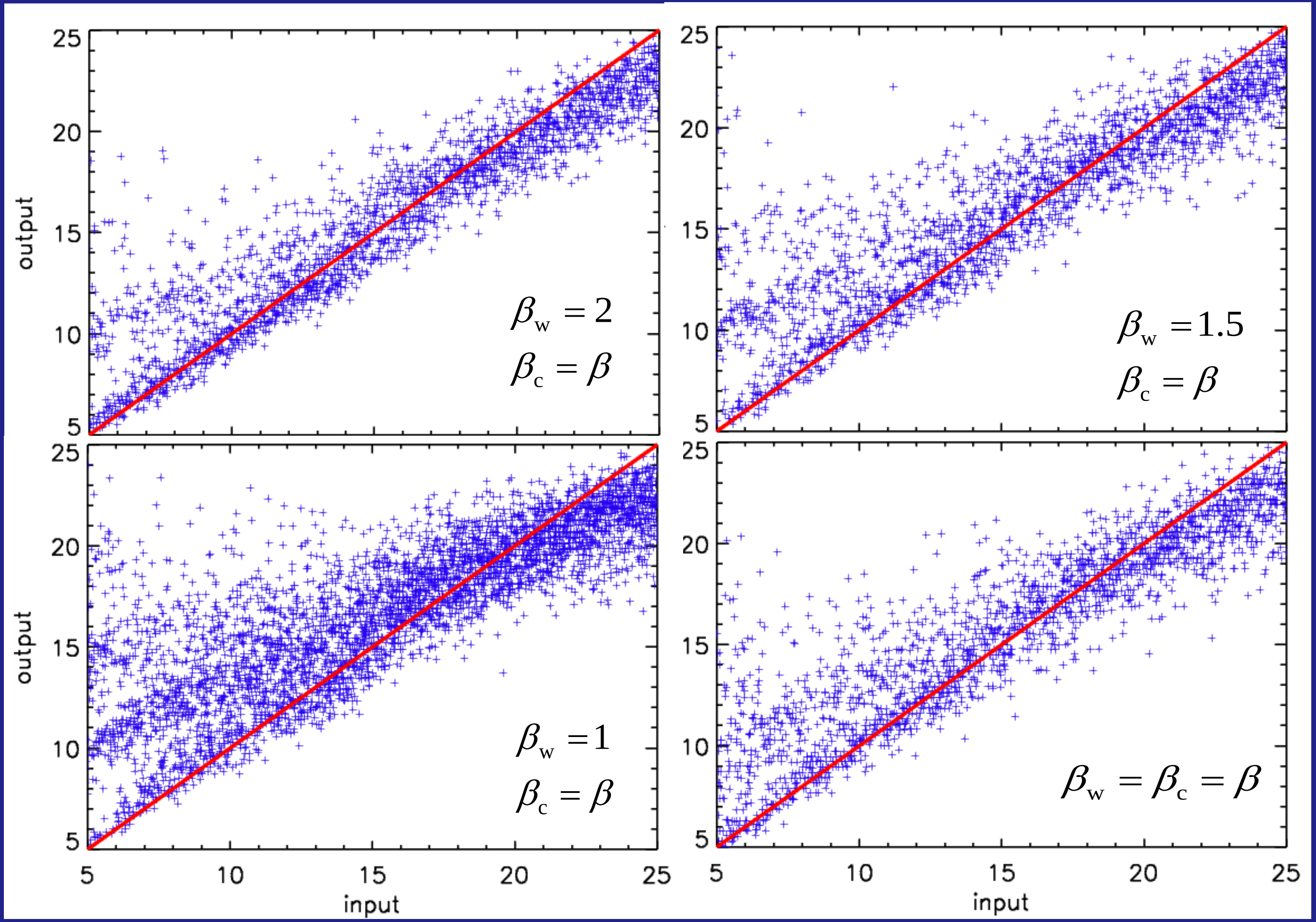
2. Derive synthesized intensities using input

3. Apply Newton-Raphson method to derive sets of physcial parameters → output

An ideal approach leads to output=input

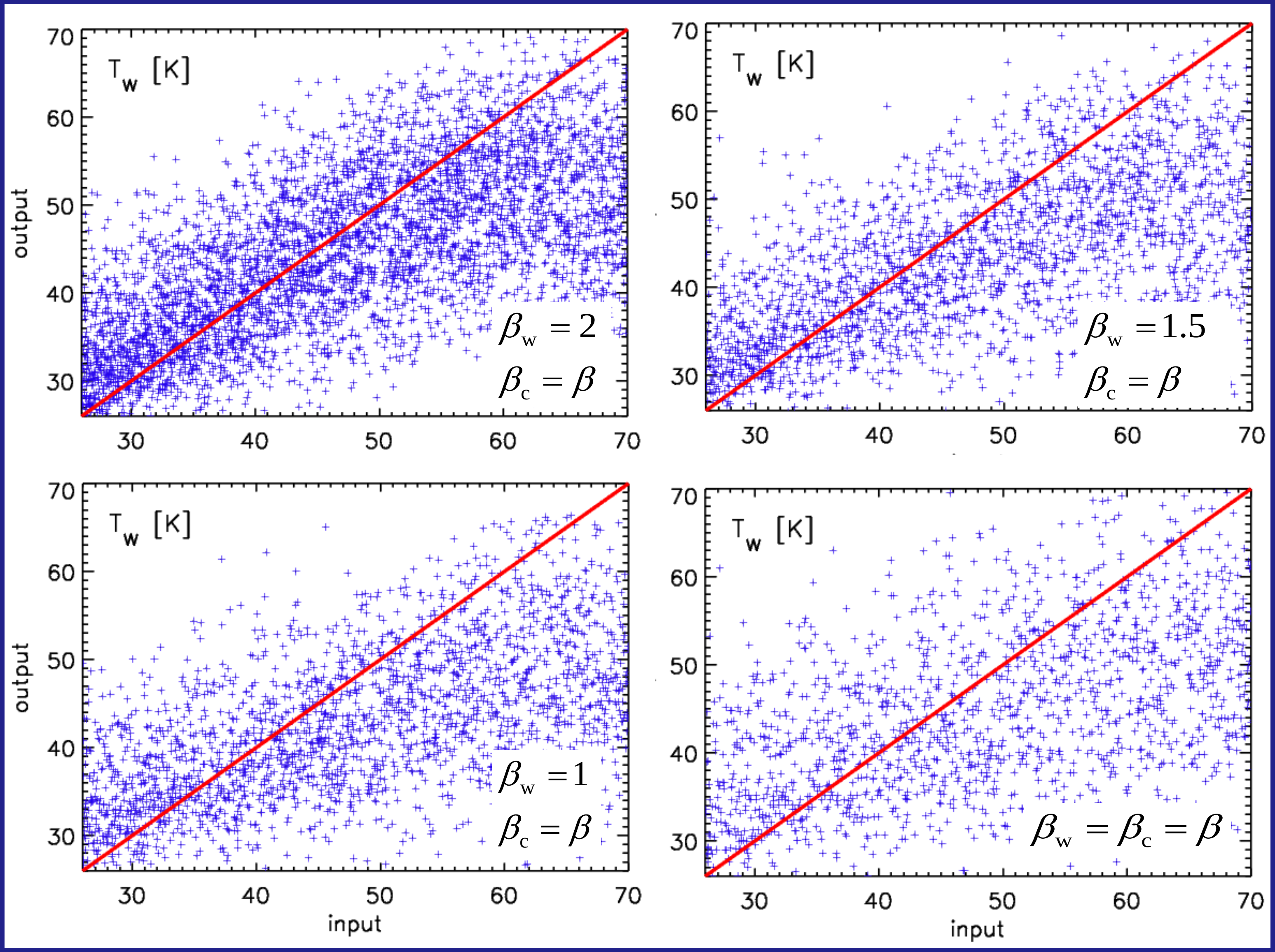
Monte-Carlo Simulation: Systematics of Approaches

Tc



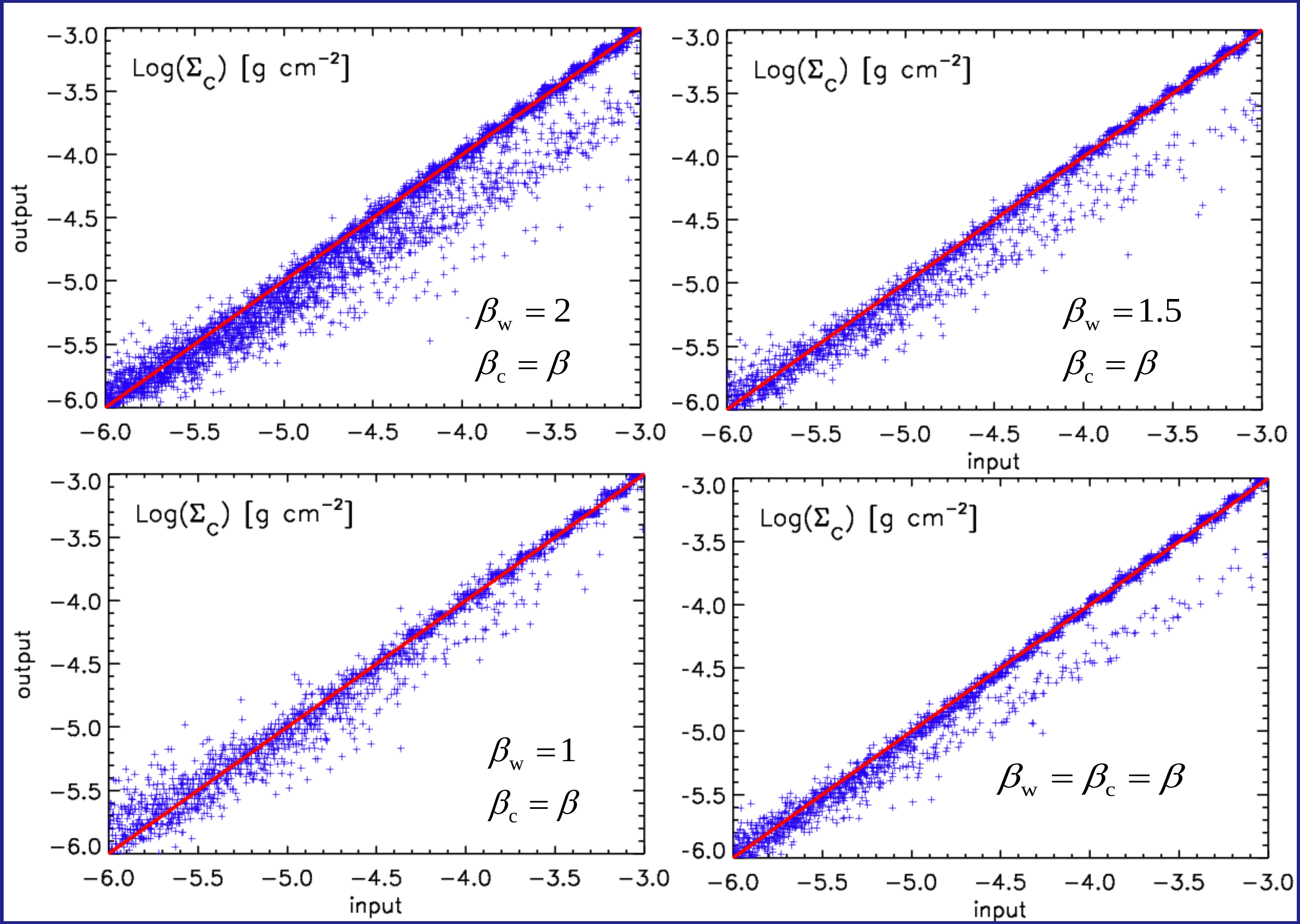
Monte-Carlo Simulation: Systematics of Approaches

Tw



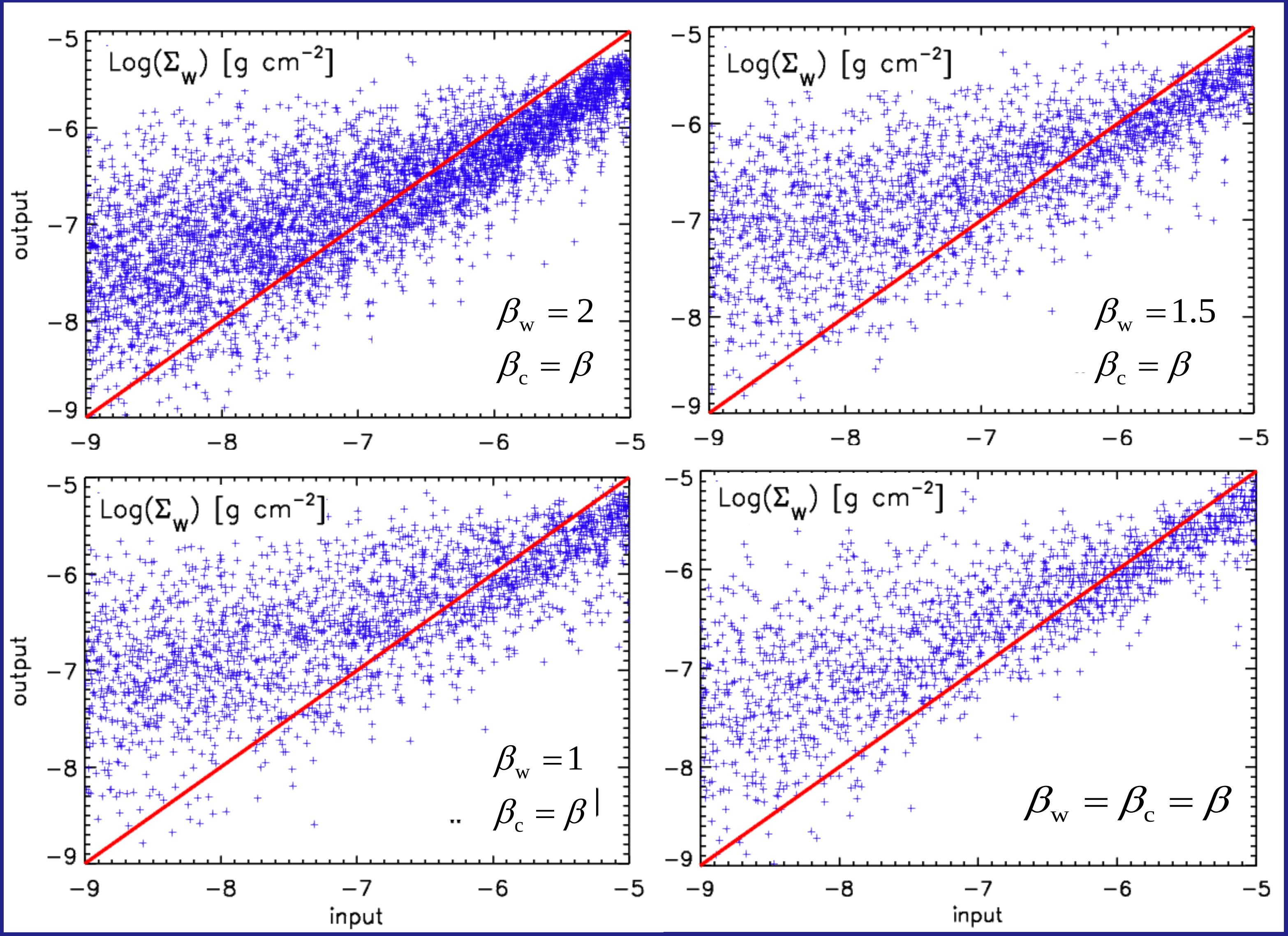
Monte-Carlo Simulation: Systematics of Approaches

Σc



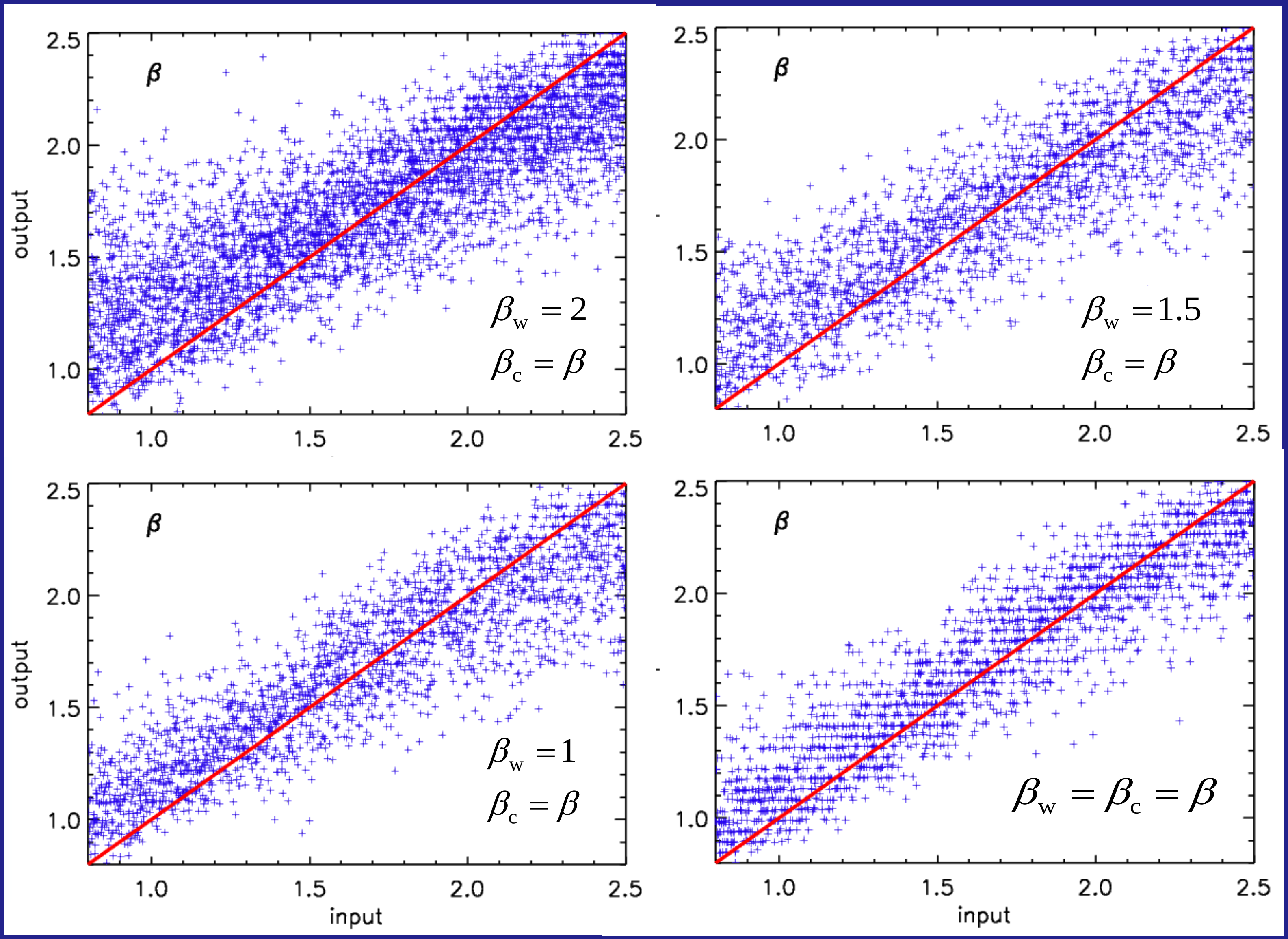
Monte-Carlo Simulation: Systematics of Approaches

Σw



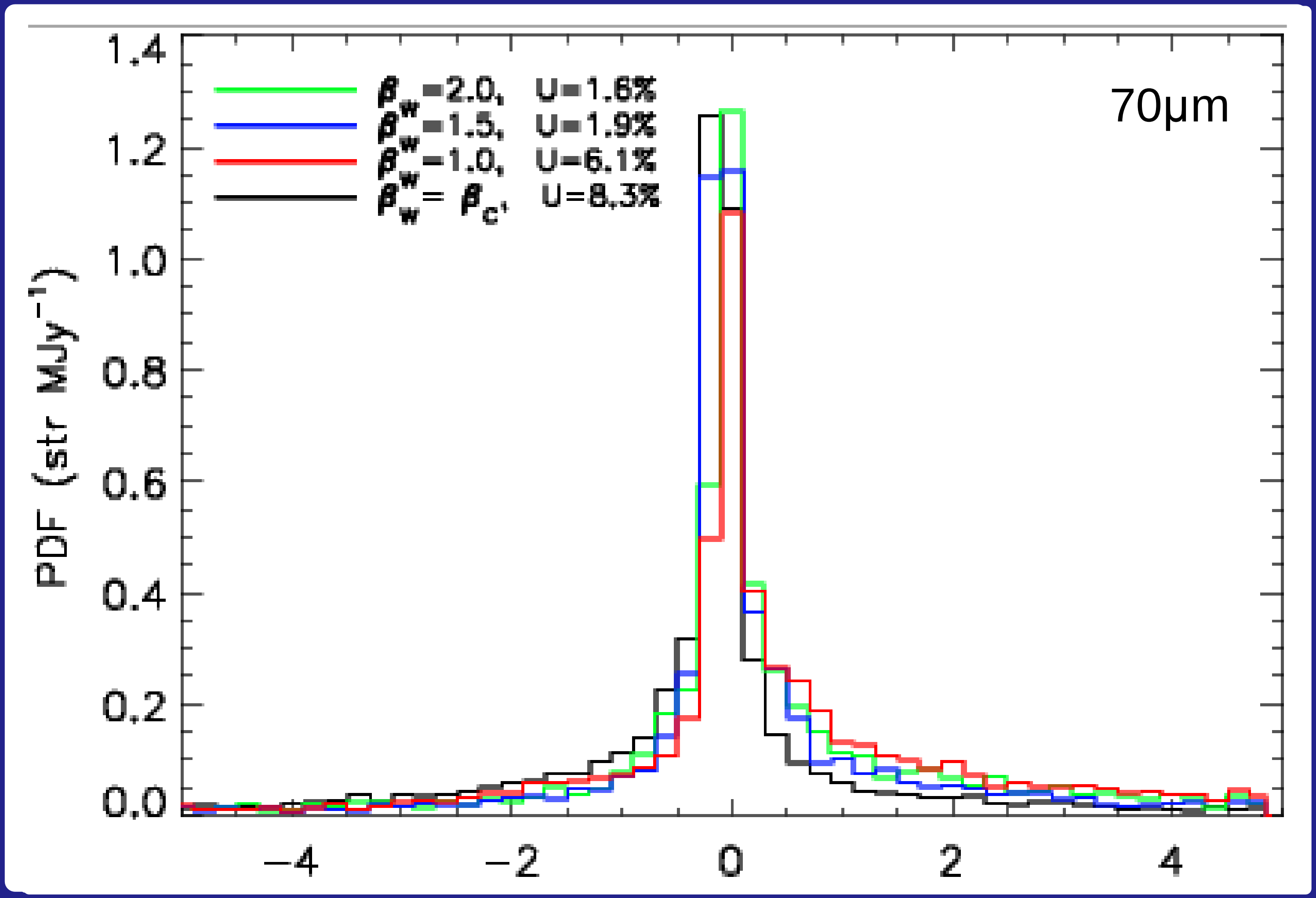
Monte-Carlo Simulation: Systematics of Approaches

β



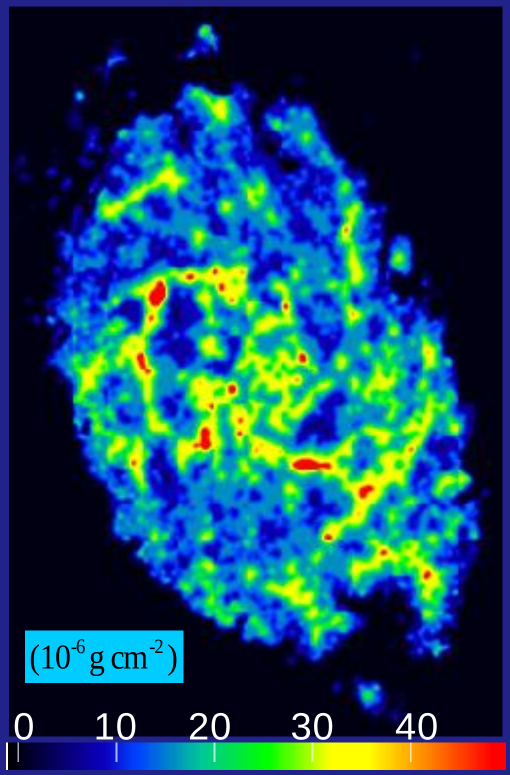
Which Model Approach is Closer to Reality?

PDF of residuals between the observed and modeled intensities shows the preference of βw=2, βc= β case, particularly at shorter wavelengths (70μm)

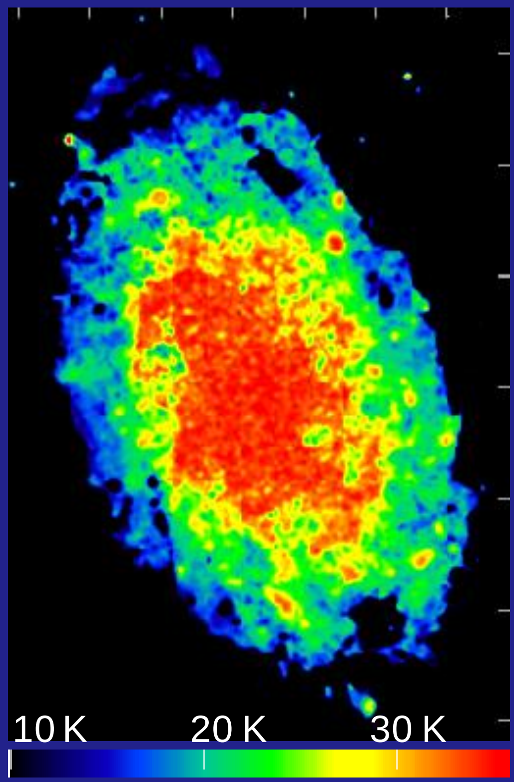


Results: Single MBB

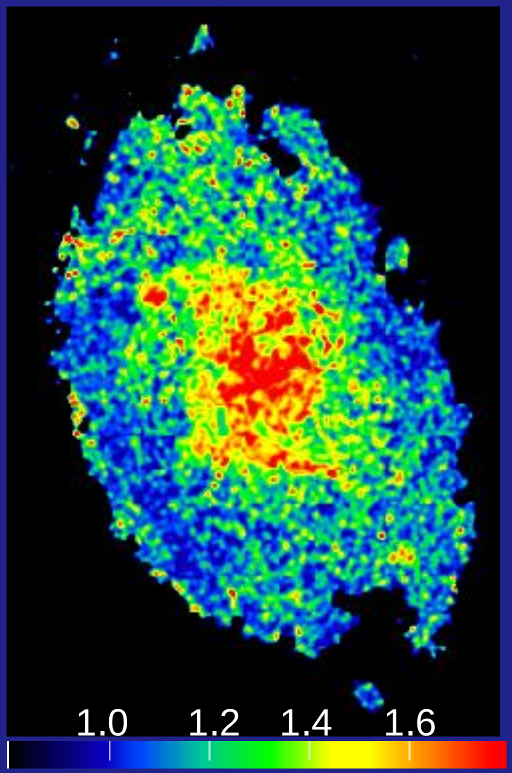
Mass Surface density



Temperature



β



Tabatabaei et al. 2012

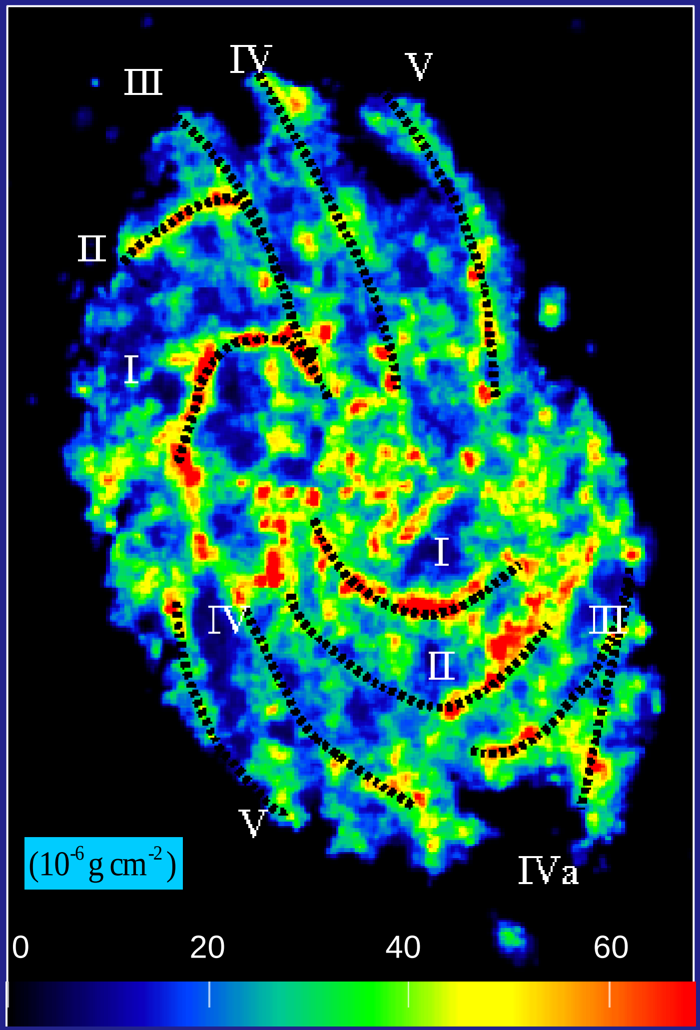
In the central disk, T is high (R<4 kpc, T>30 K), then decreases towards the outer disk.

β also shows outer / inner disk contrast being higher in the inner disk.

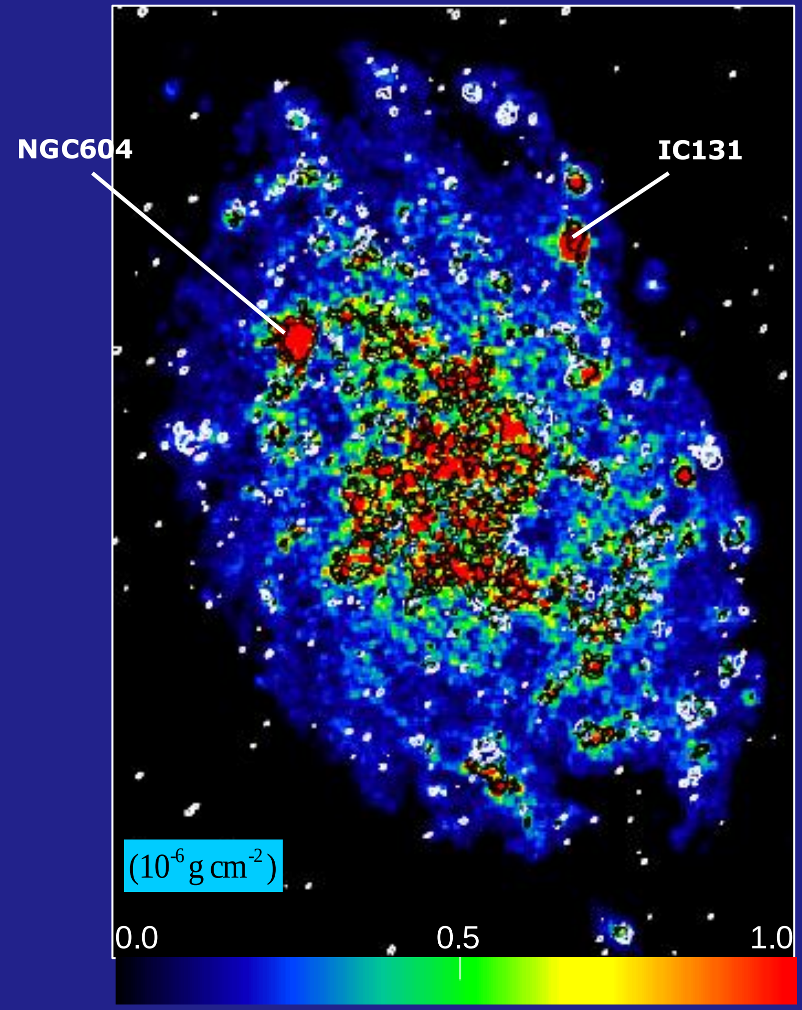
Mean values:
T = 22 ± 9 K
β = 1.2 ± 0.5

Results: Two-Component MBB

Cold dust (Σc)



Warm dust (Σw)

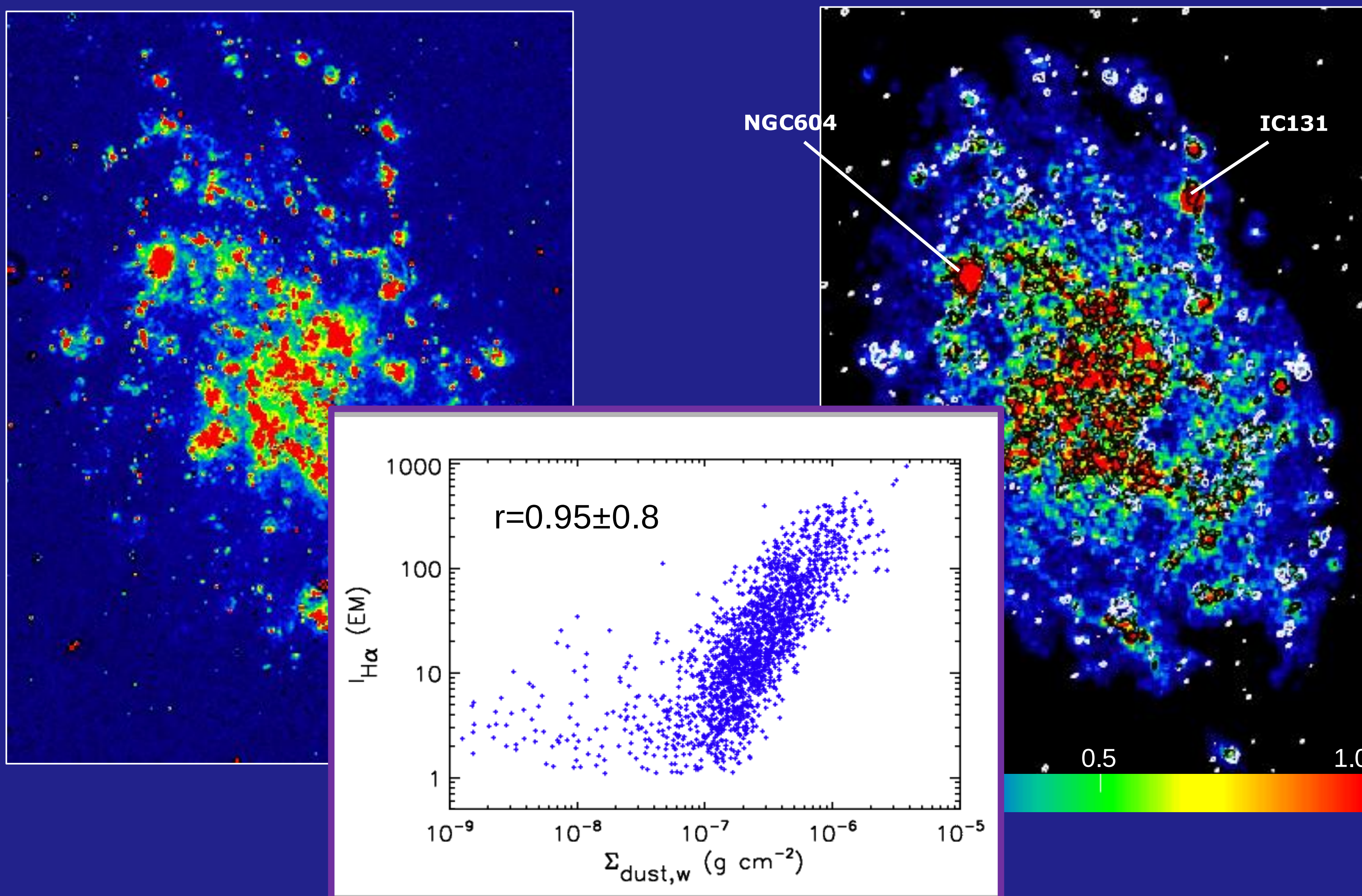


Dust surface density is higher in giant
star forming regions seen in both components

Results: Two-Component MBB

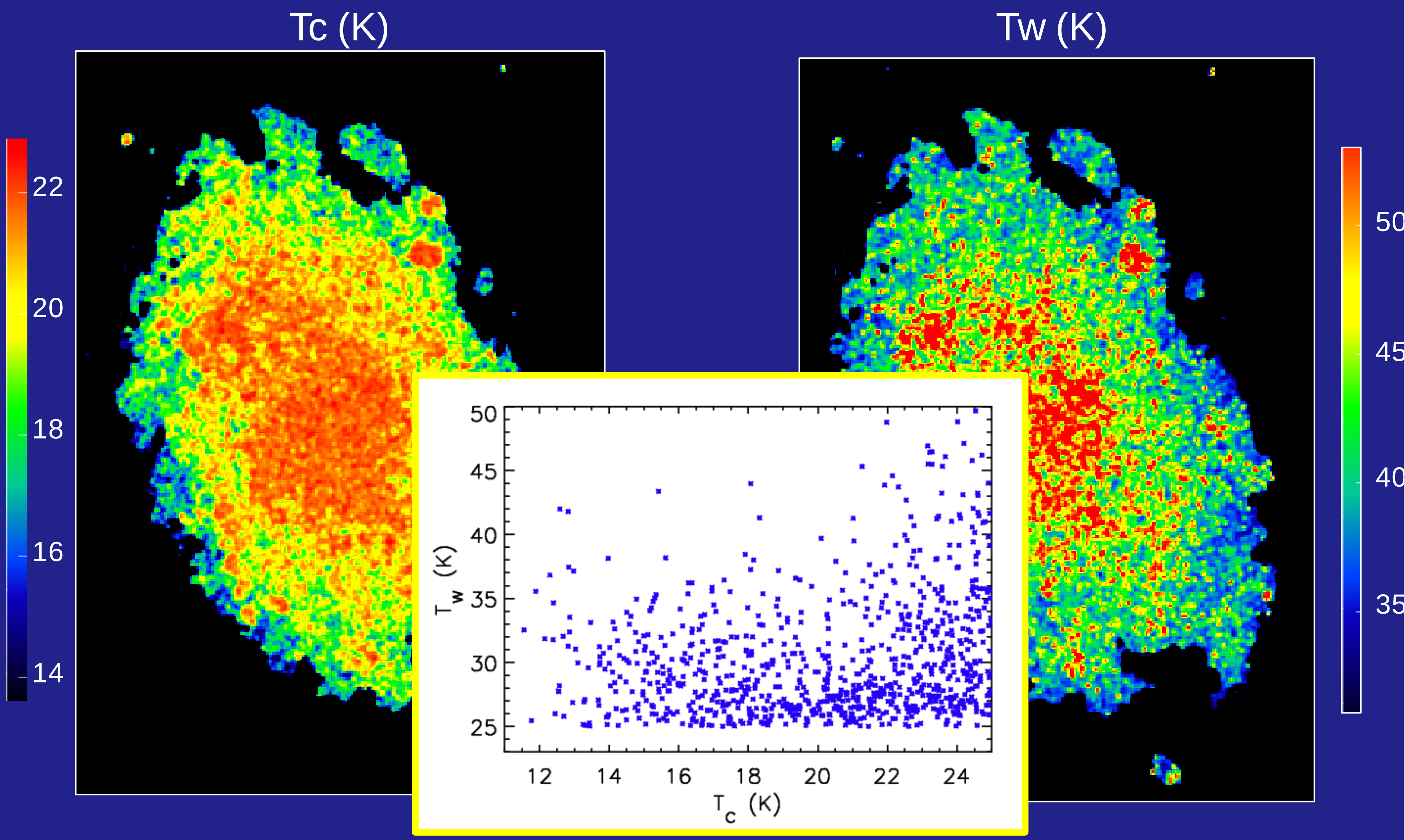
Hα

Warm dust (Σw)



- ✓ A linear correlation
- ✓ Scatter at low Σw coincides with the systematic of the approach

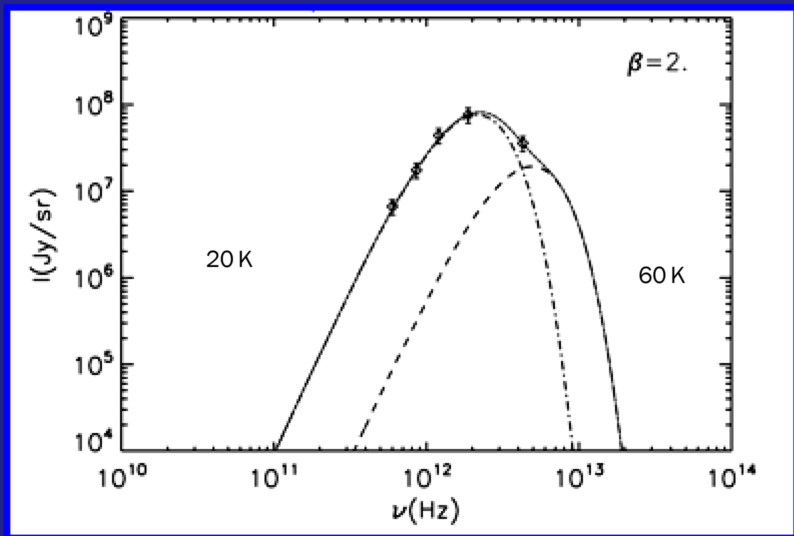
Results: Two-Component MBB



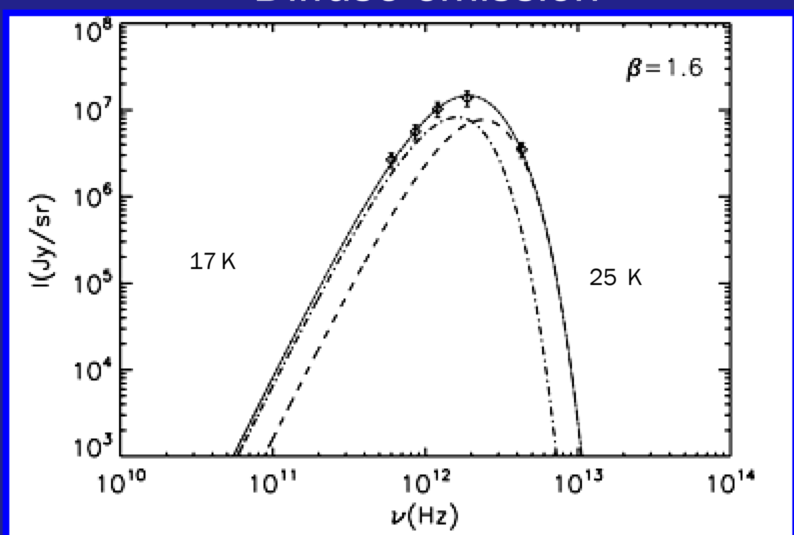
The temperature of both components decreases with distance from the galaxy center, but no correlation

Results: Two-Component MBB

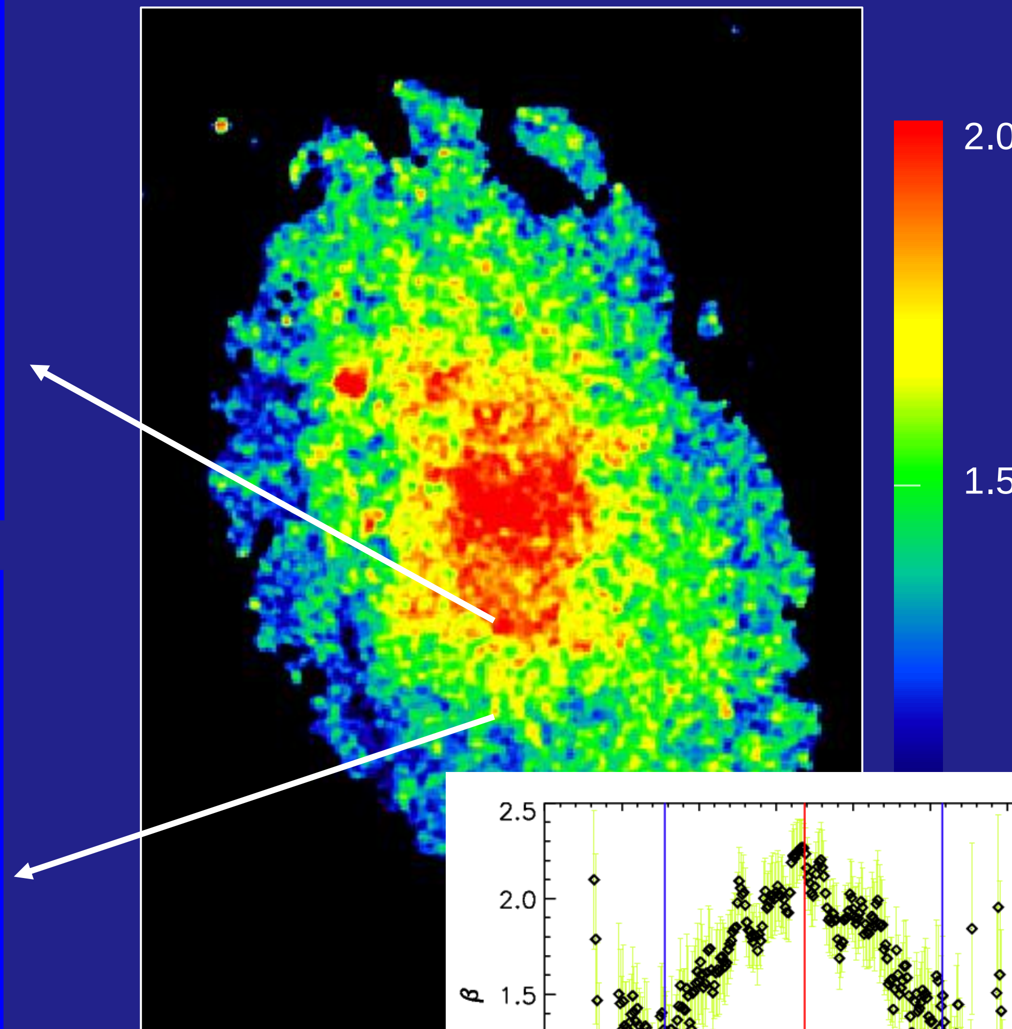
Star forming

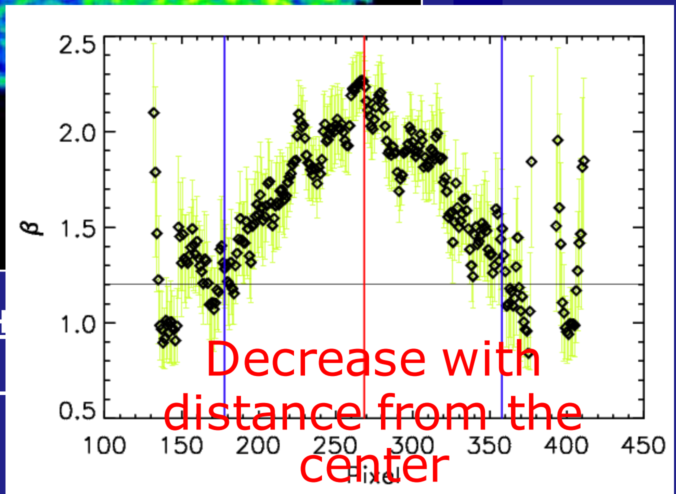


Diffuse emission



β

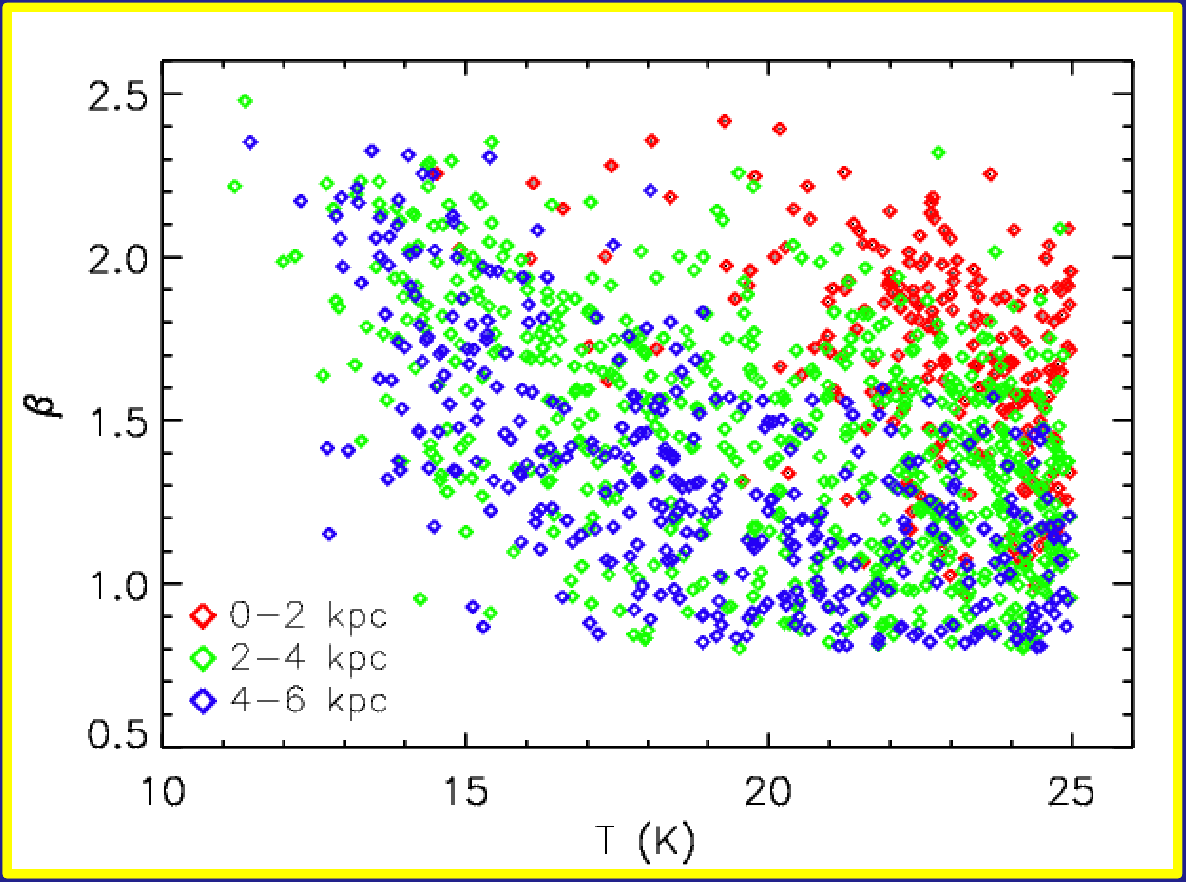




mean β = 1.5±
with Kramer_1

- β higher in star forming regions

β -T Correlation?

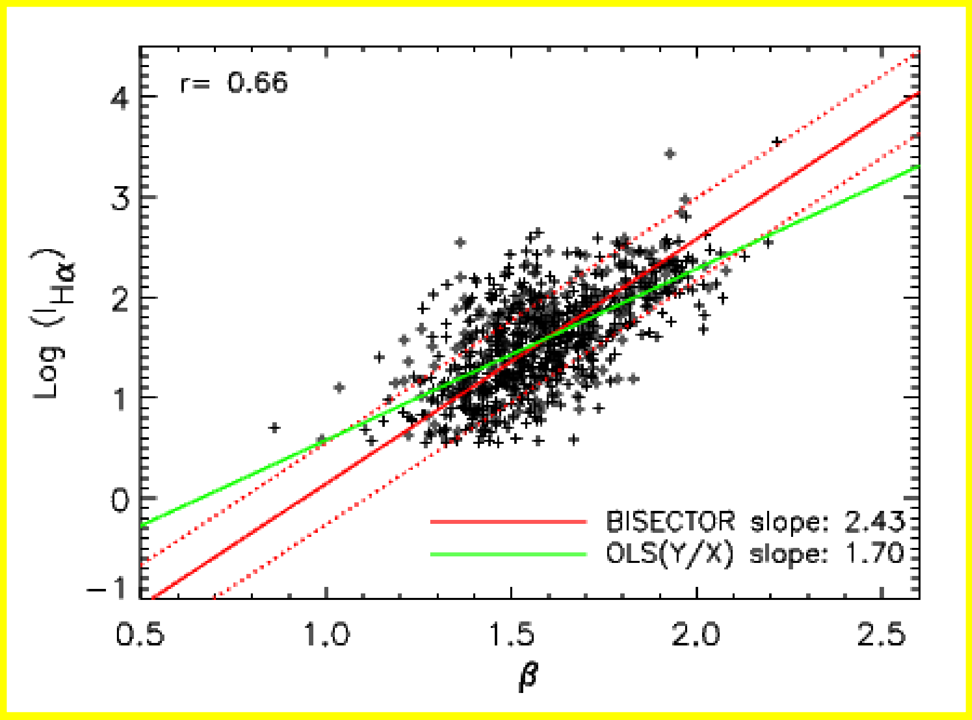


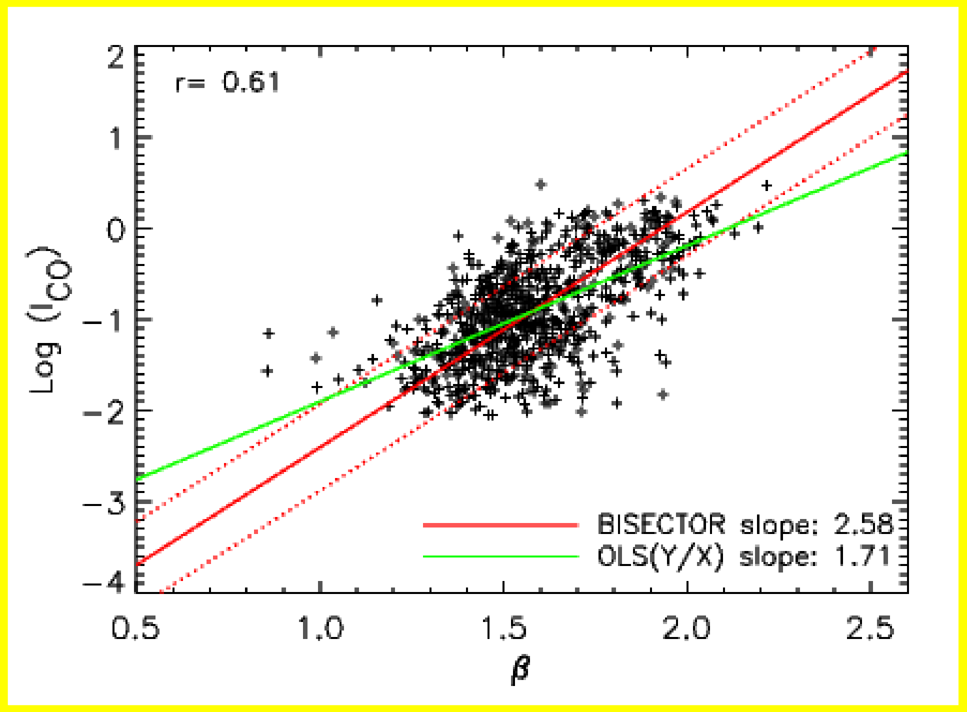
A weak anti-correlation: r ~ - 0.25

→The radial decrease in β is not due to a positive correlation with T

Dust Emissivitiy Index & Star Formation

A good correlation with Hα, CO(2-1), but not with HI.





→Dust spectrum differes in SF and non-SF regions

→Environmental change in β

Inner/Outer Disk Variation of β:

Metallicity, Size Distribution or...?

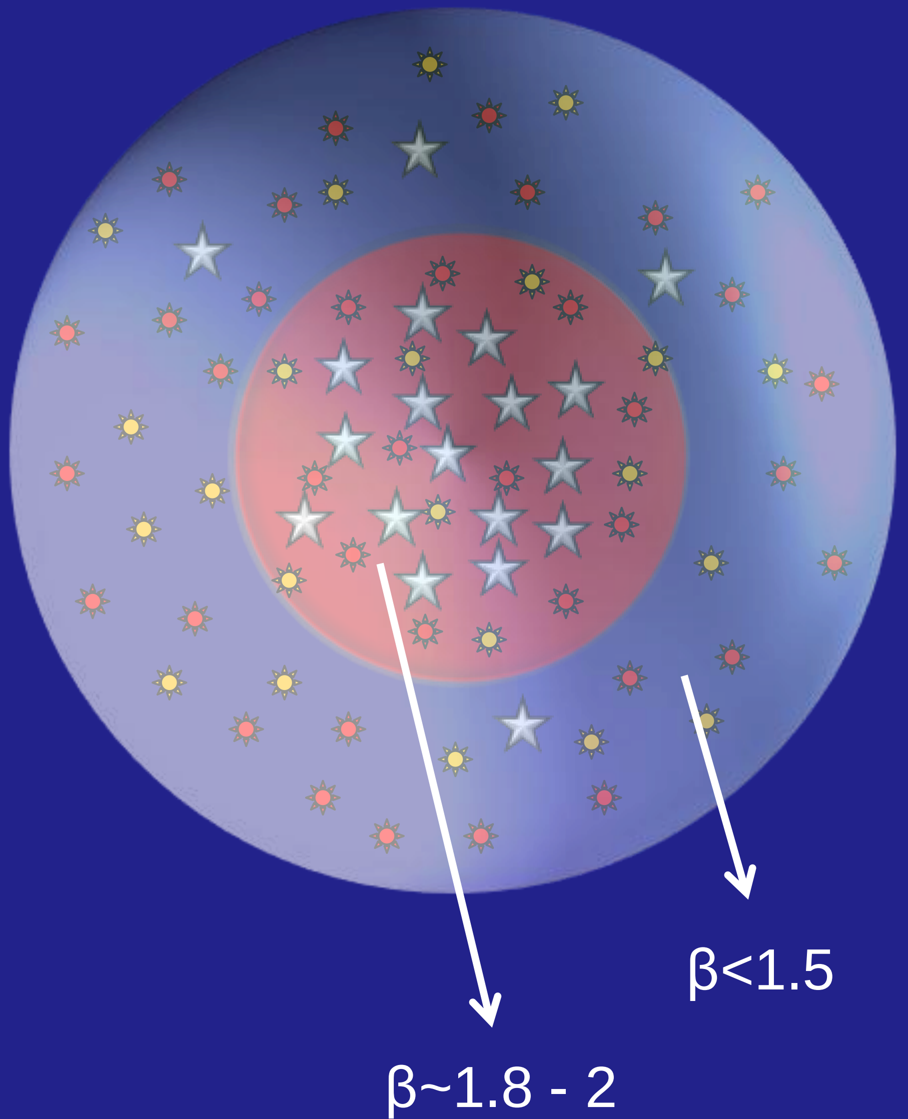
Observational facts:

- β~2 for silicates, β~1 for carbonaceous (Desert et al. 1990)

- Massive SF & gas density higher in inner disk→ Silicates dominates like in MW (β=2)

- Lower metallicty in outer disk (R>4 kpc, Brainer et al. 2010, Gardan et al. 2007) →Flatter β

- Diffuse/low-density ISM is dominated by smaller grains→ Flatter β (Seki & Yamamoto 1980)



Summary

• The approaches used tend to reduce the dynamical range of β, hence the true β is expected to have a higher contrast than that derived.

•The good correlation between SF tracers and β shows that the dust spectrum could differ in starforming and non-starforming environments.

• β and T decrease radially in different ways, no clear correlation.

•The flatter dust spectrum in outer disk is in agreement with that expected from lower metallicity and/or smaller grains dominated in those low-density/diffuse ISM.

Just accepted!

Variation in the dust emissivity index across M33 with Herschel and Spitzer (HerM33es)

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Preprint online version: October 16, 2013

ABSTRACT

We study the wavelength dependence of the dust emission as a function of position and environment across the disk of M33 at a linear resolution of 160 pc using *Spitzer* and *Herschel* photometric data. M33 is a Local Group spiral with a slightly subsolar metallicity, making it an ideal stepping-stone to less regular and lower metallicity objects such as dwarf galaxies and, probably, young universe objects. Expressing the emissivity of the dust as a power law, the power-law exponent (β) is estimated from two independent approaches designed to properly treat the degeneracy between β and the dust temperature. Both β and the dust temperature are higher in the inner disk than in the outer disk, contrary to reported $\beta - T$ anti-correlations found in other sources. In the cold + warm dust model, the warm component and the ionized gas (Hα) have a very similar distribution across the galaxy, demonstrating that the model separates the components in an appropriate fashion. The flocculent spiral arms and the dust lanes are evident in the map of the cold component. Both cold and warm dust column densities are high in star forming regions and reach their maxima toward the giant star forming complexes NGC604 and NGC595. β declines from close to 2 in the center to about 1.3 in the outer disk. β is positively correlated with star formation and with molecular gas column, as traced by Hα and CO emission. The lower dust emissivity index in the outer parts of M33 is likely related to the reduced metallicity (different grain composition) and possibly different size distribution. It is not due to the decrease in stellar radiation field or temperature in a simple way because the FIR-bright regions in the outer disk also have a low β. Like most spirals, M33 has a (decreasing) radial gradient in star formation and molecular-to-atomic gas ratio such that the regions bright in Hα or CO tend to trace the inner disk, making it difficult to distinguish between their effects on the dust. The assumption of a constant emissivity index β is obviously not appropriate.

Key words. galaxies: individual: M33 – galaxies: ISM