[CII] 158 μm Line Emission as a Star Formation Rate Tracer

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KINGFISH collaboration

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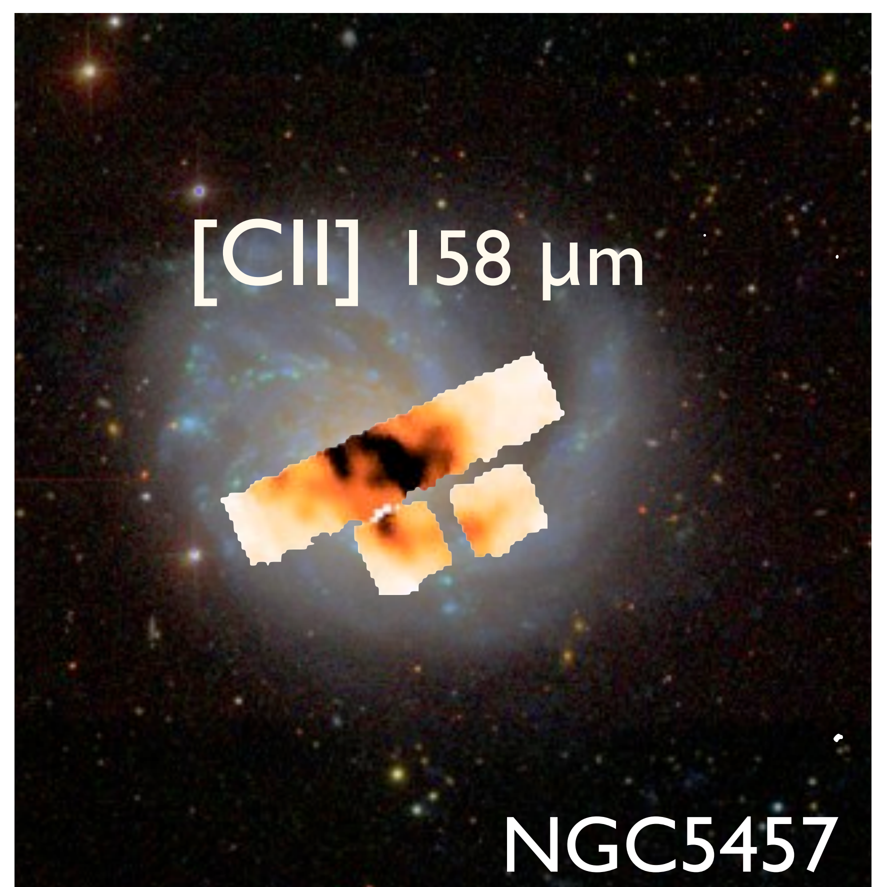
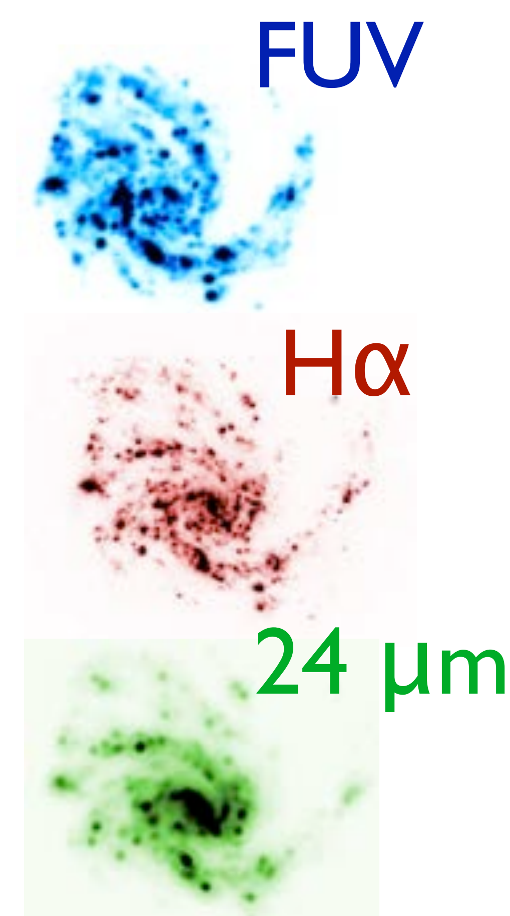
1. Very bright line in star forming galaxies (~0.1 - 1% L_{FIR})
2. Major coolant for the diffuse, neutral ISM
3. ALMA

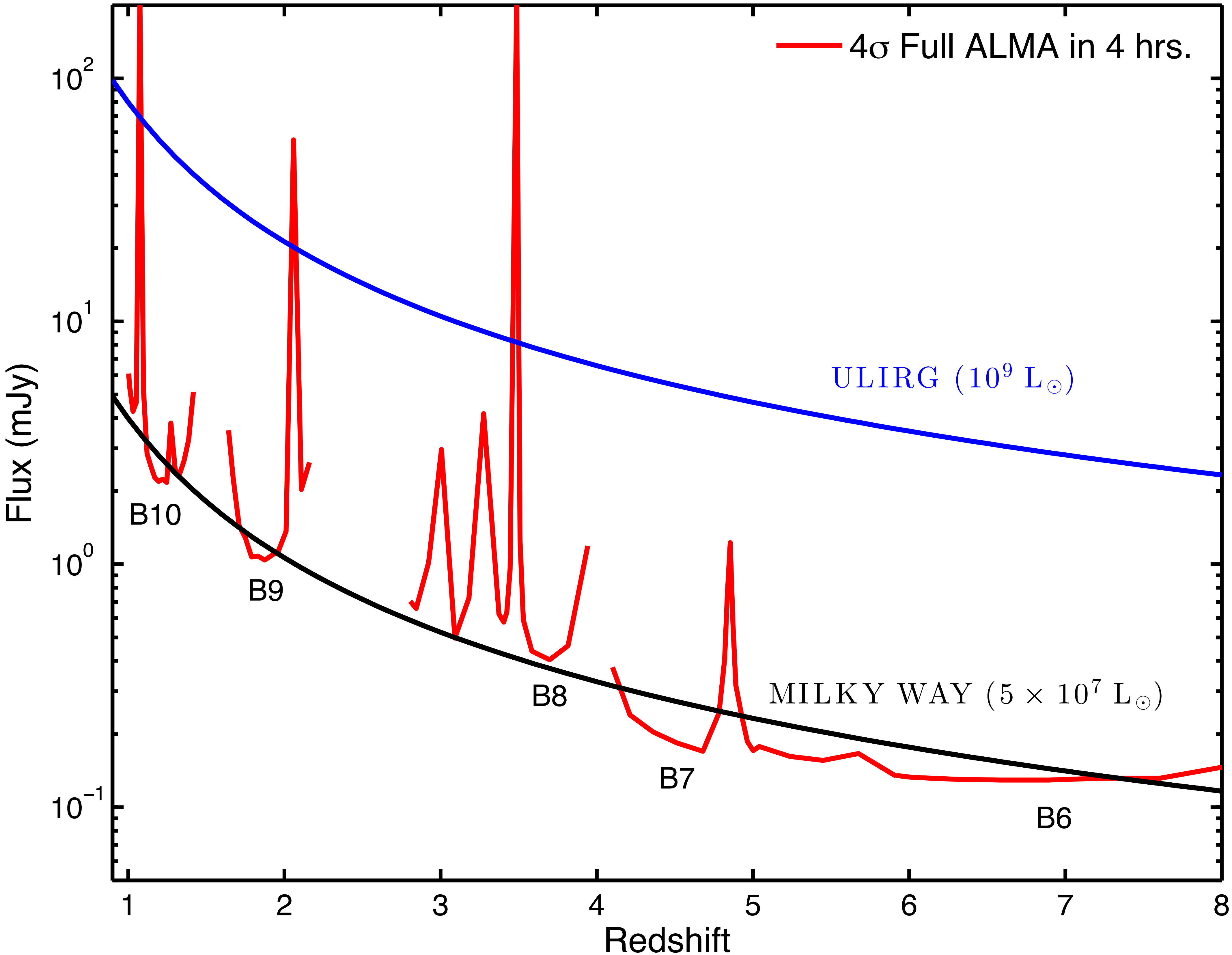
[CII] 158 μm Line Emission as a Star Formation Rate Tracer

Kennicutt & Evans 2012

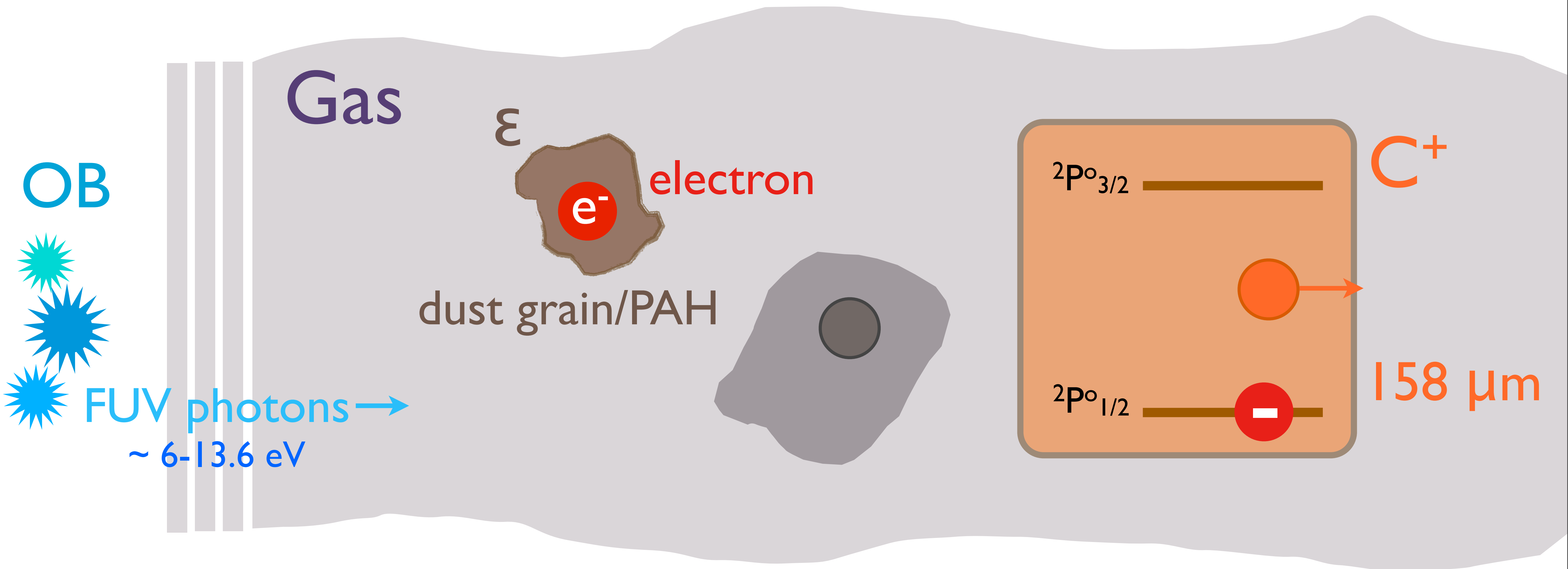


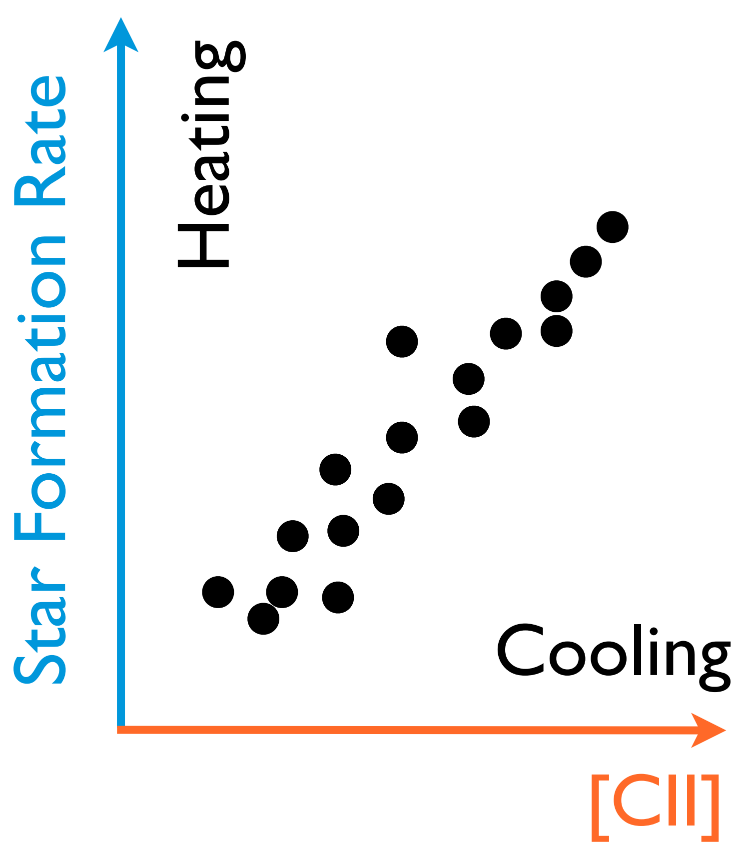


3. ALMA



4σ Full ALMA in 4 hrs.
ULIRG (10^9 L$_\odot$)
MILKY WAY (5×10^7 L$_\odot$)
B10
B9
B8
B7
B6
Flux (mJy)
Redshift
10^2
10^1
10^0
10^{-1}
1
2
3
4
5
6
7
8





The Goal

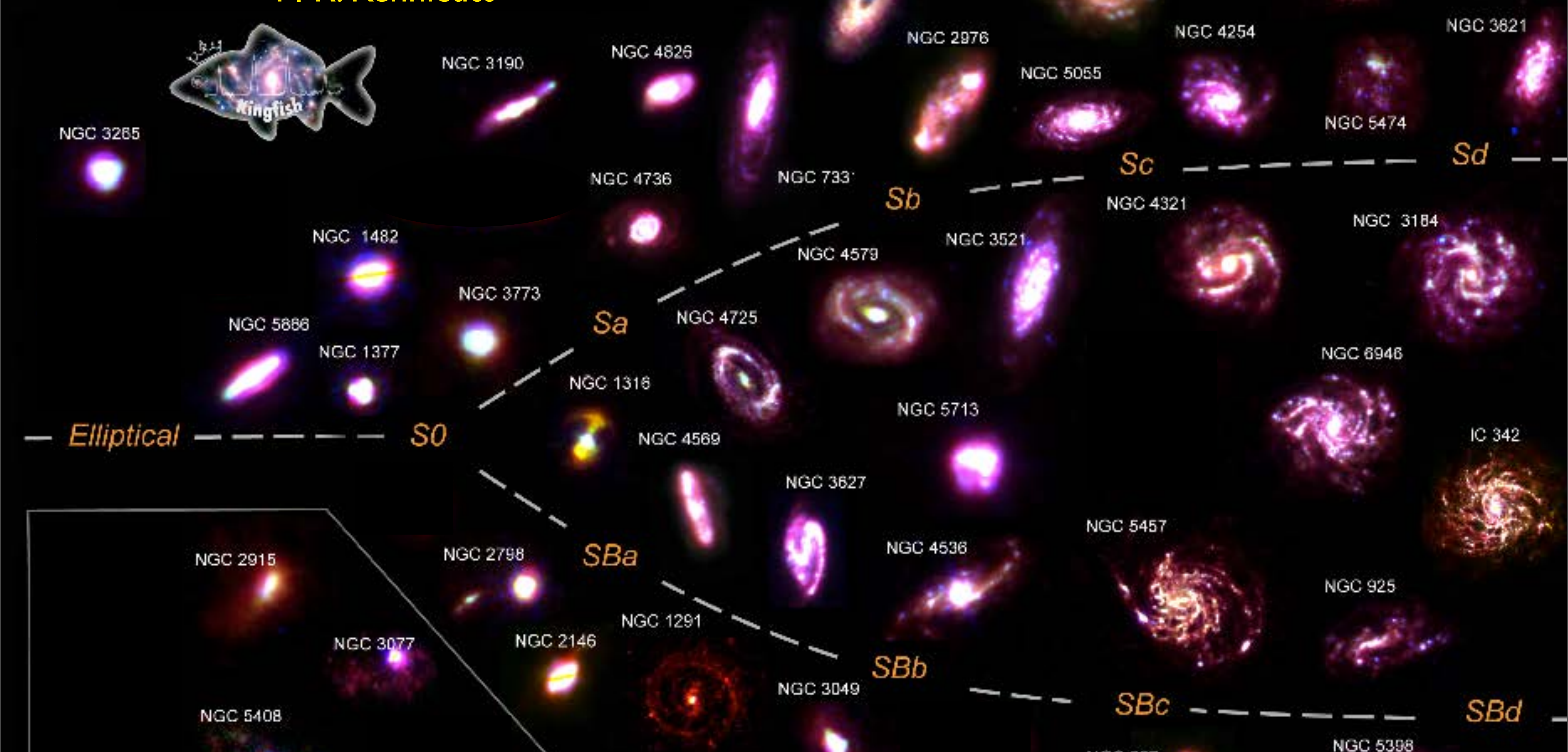
Use resolved regions from a sample of 49 KINGFISH galaxies

Study how [CII] 158 μm emission correlates with other star formation tracers

Derive a SFR calibration based on [CII] 158 μm

Kingfish (Key Insights on Nearby Galaxies: a Far-Infrared Survey with Herschel)

PI R. Kennicutt



Distance [Mpc]

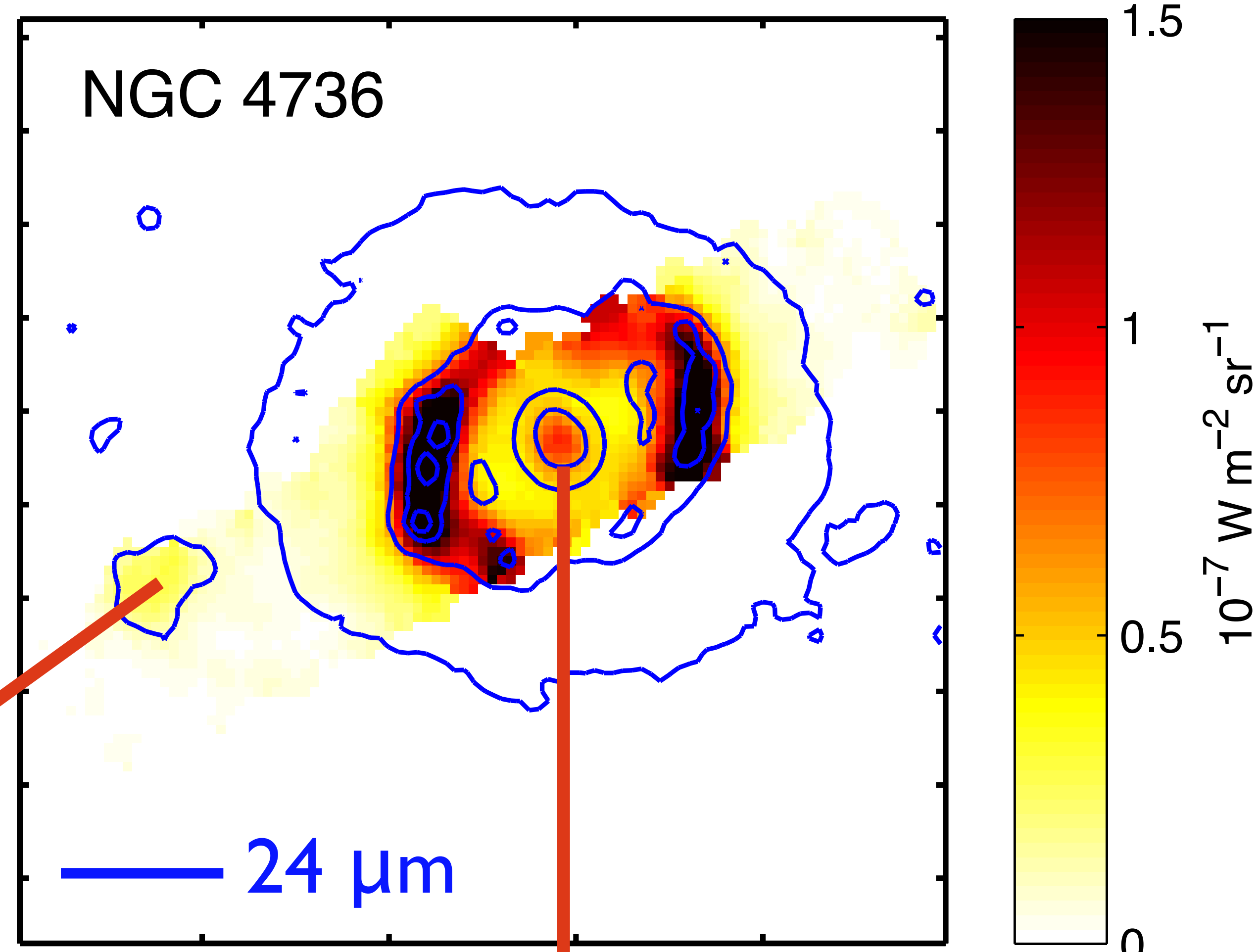
~3 — ~33

IC 2574 — NGC 4254

~0.2 — ~2 Resolution [kpc]

Median ~0.5

[CII] versus 24 µm associated to SF



24 µm

"Cirrus" Contribution

e.g. dust heated by old stars

Fraction of 24 µm associated to cirrus:

avg. f_{cirrus} ~ 20%

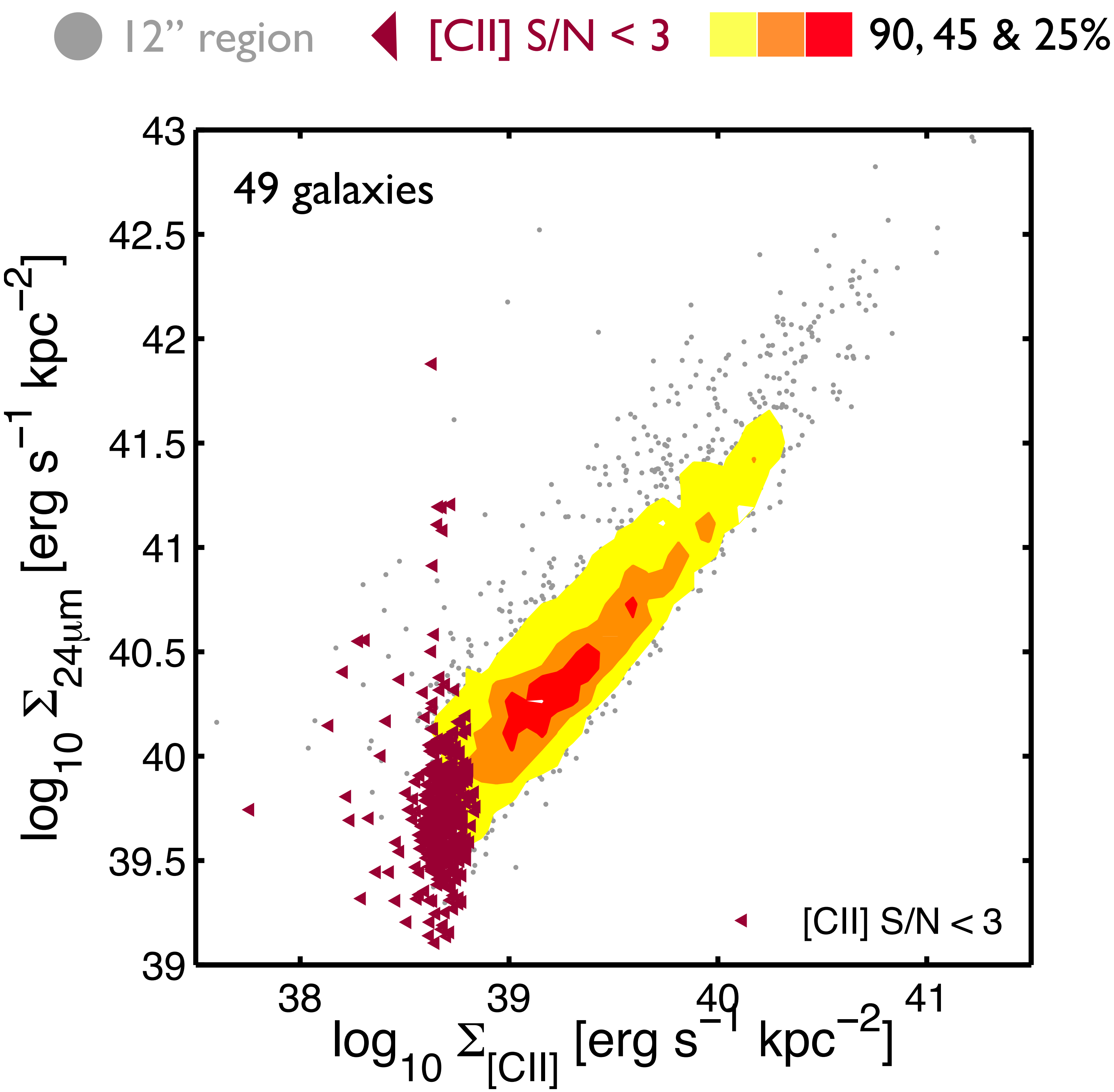
(~19% Leroy+12, 7% Law+11)

AGN Contribution

X-ray Dominated Regions

contribute to 24 µm

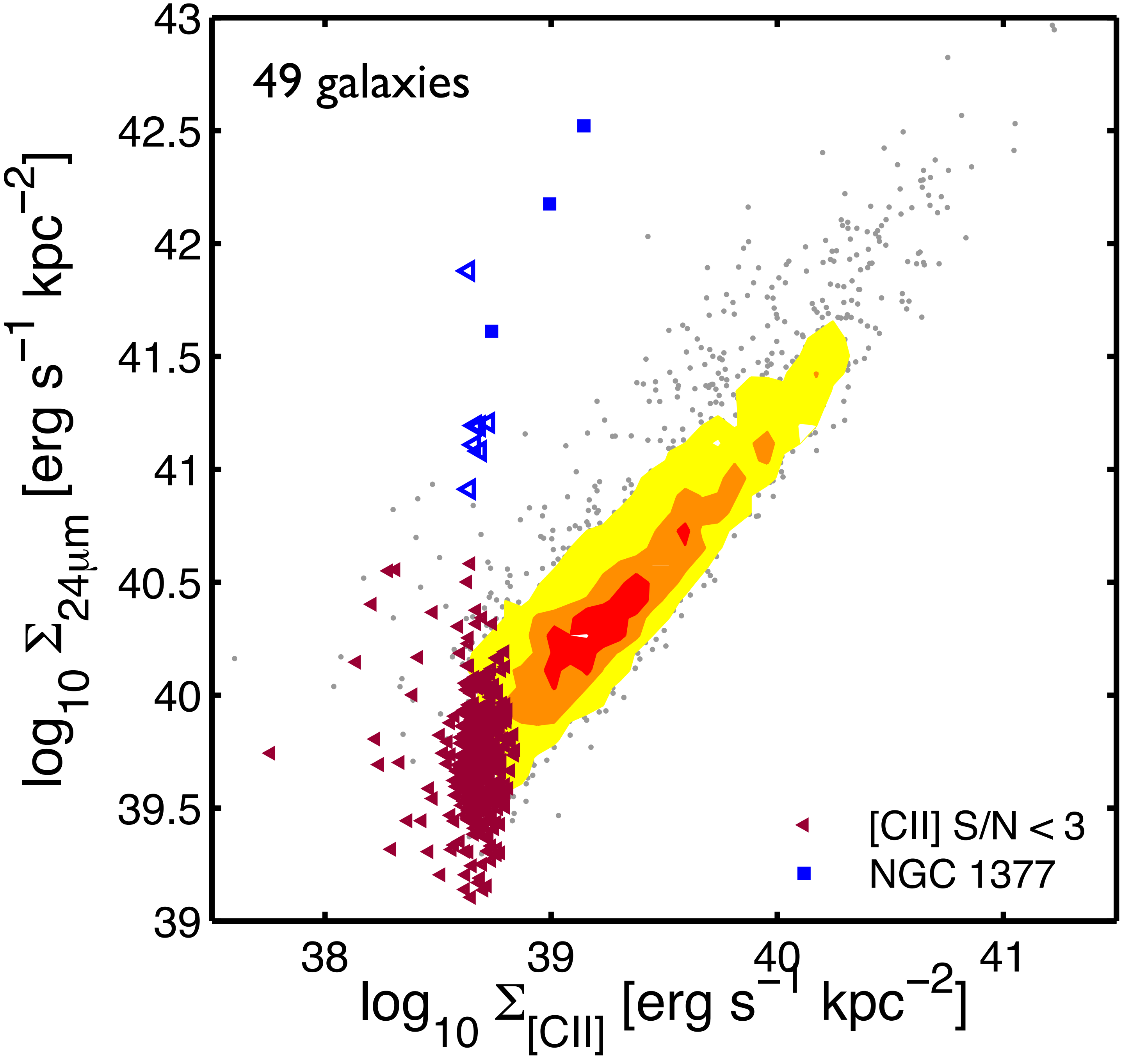
The [CII] - 24μm Correlation



We find good $\Sigma_{[CII]}$ - $\Sigma_{24\mu m}$ correlation. Most of the [CII] upper limits are consistent with the correlation.

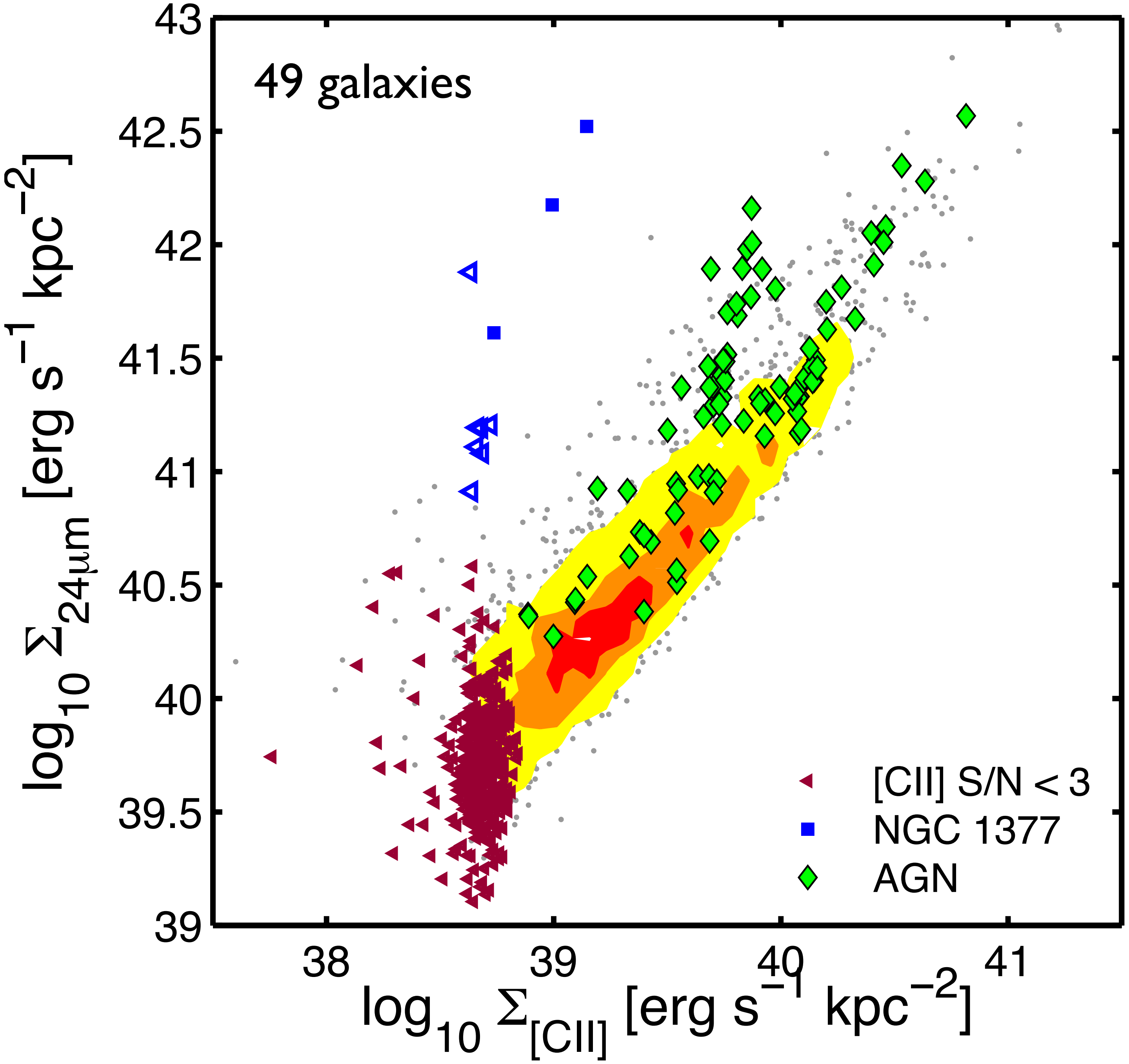
The [CII] - 24µm Correlation

■ NGC 1377: Nascent Starburst or buried AGN?
(Roussel+06; Imanishi+09)



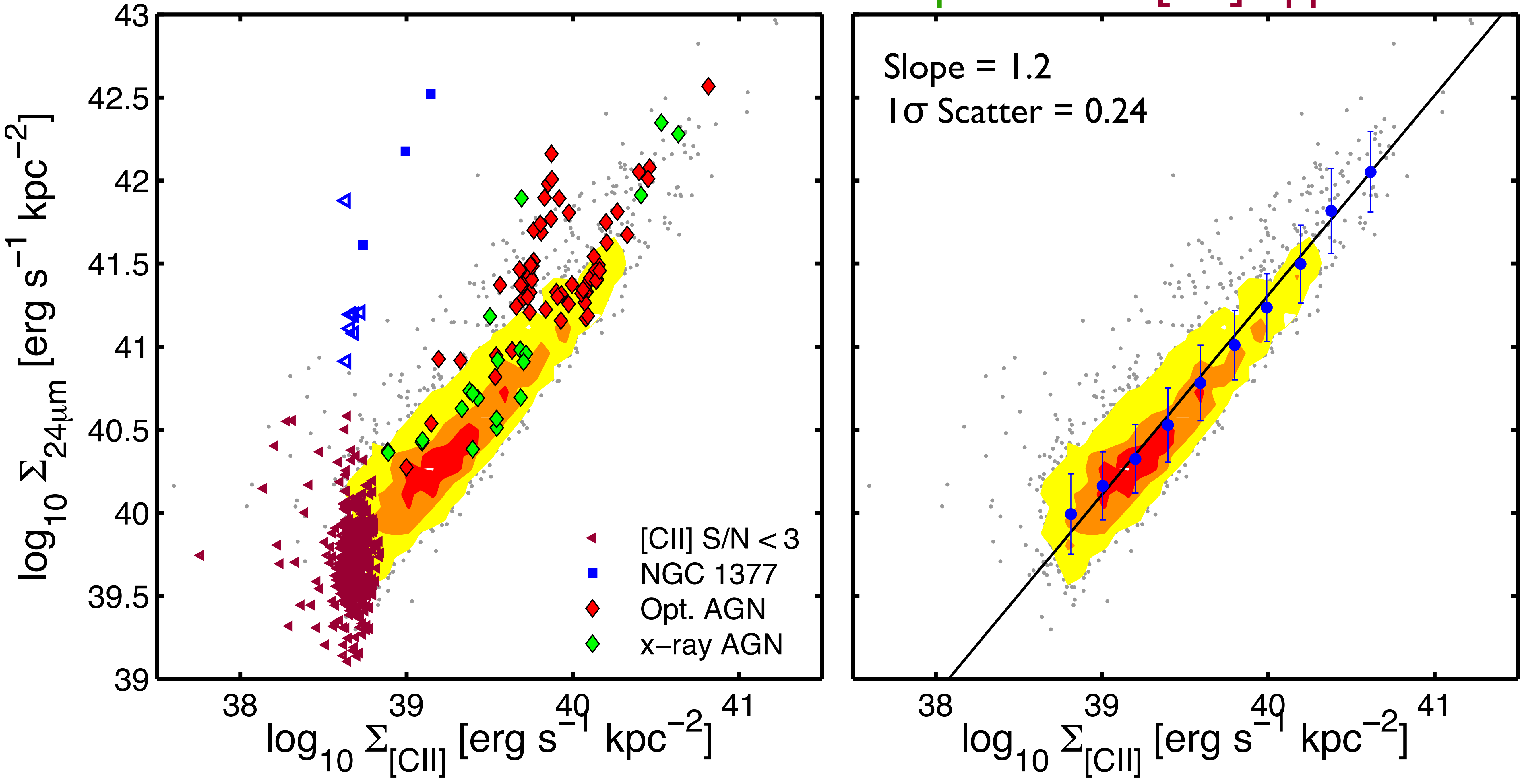
AGN Contribution: mask the central ~0.5 kpc region

About half of the AGN regions show a moderate 24µm excess compared to [CII]



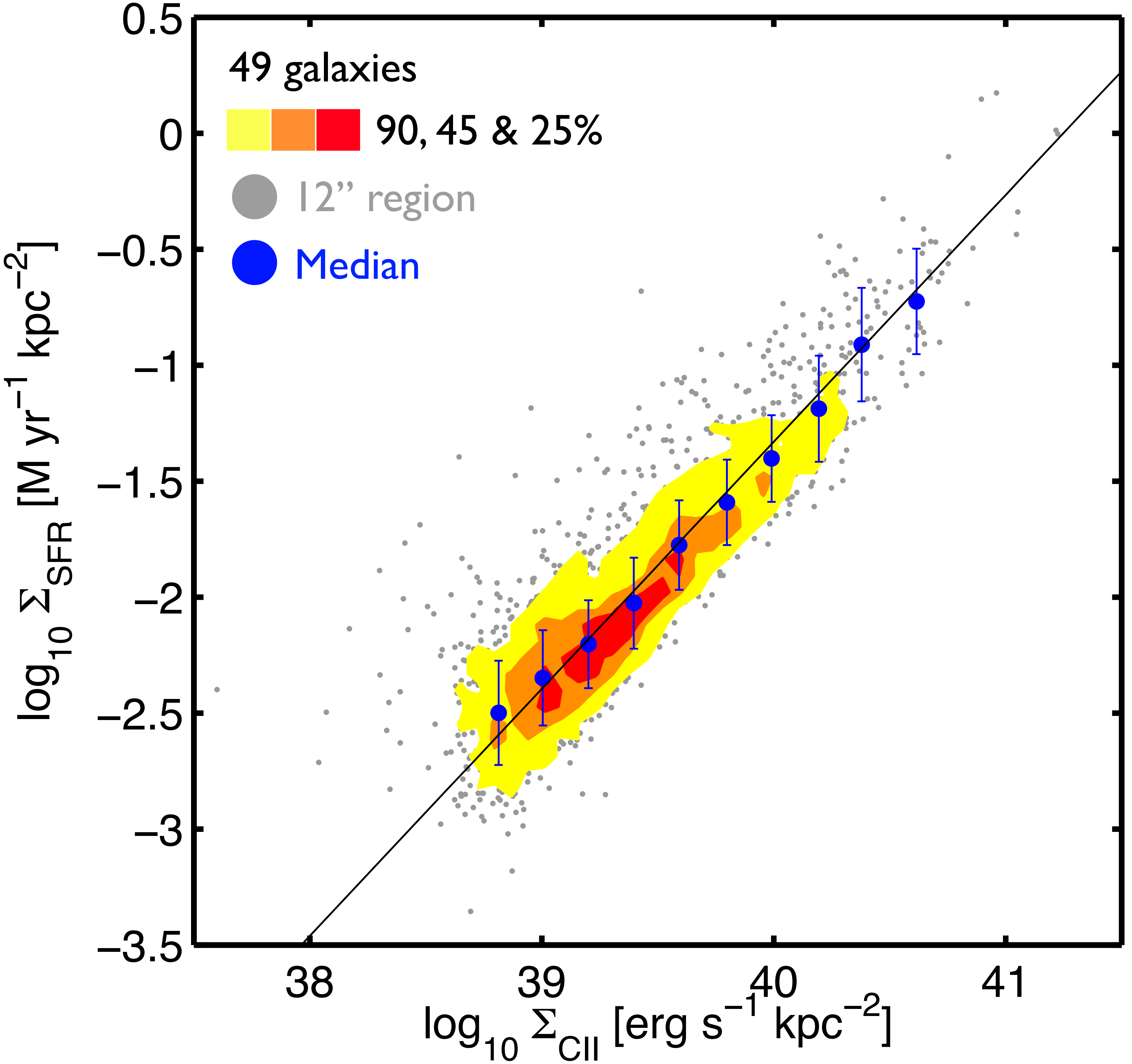
Regions from 28 Galaxies classified as AGNs (Moustakas+10; Grier+11)

Remove NGC 1377, AGN points and [CII] upper limits

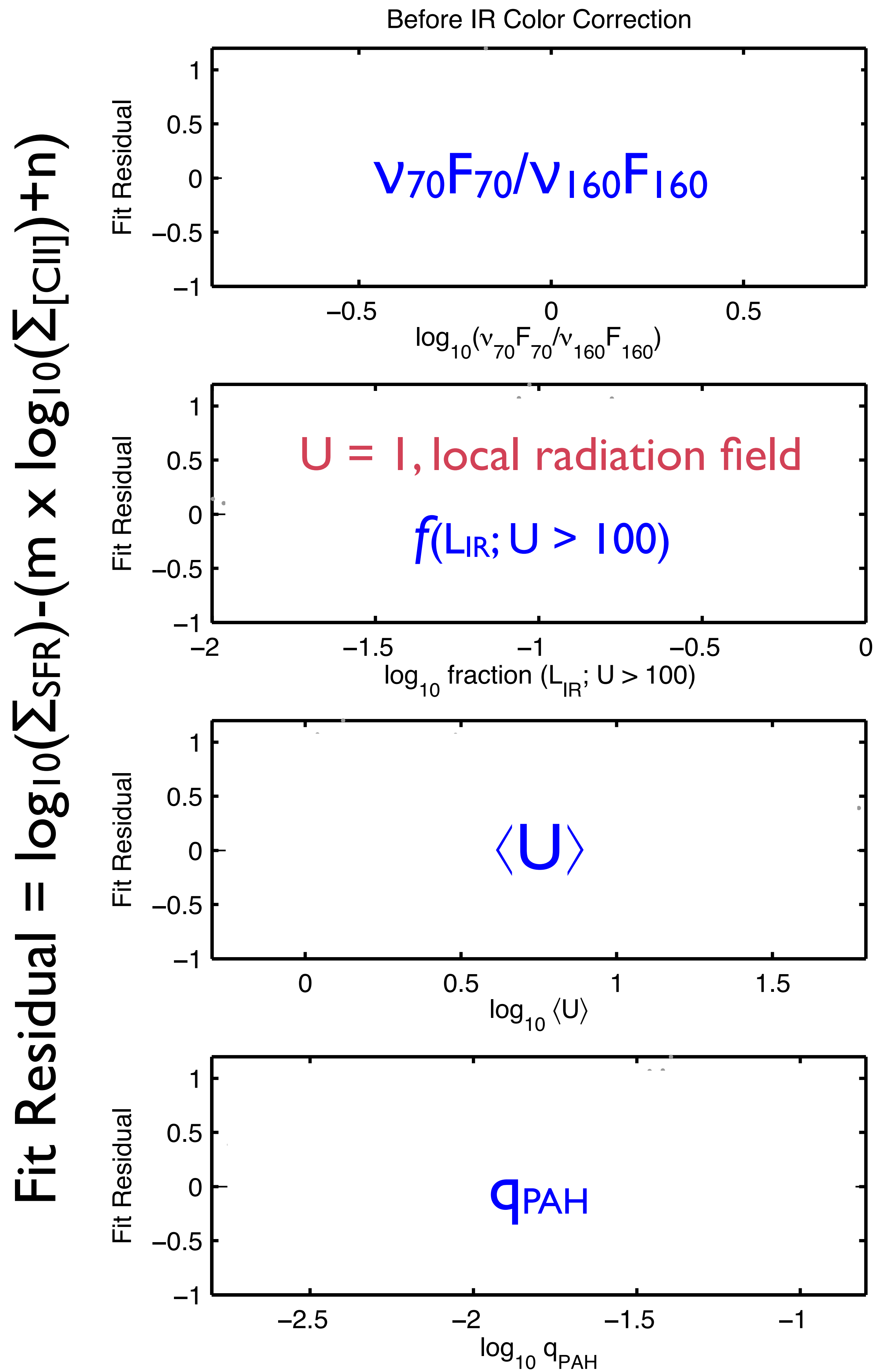


We find good $\Sigma_{[CII]}$ - $\Sigma_{24\mu m}$ correlation with a ~0.24 dex scatter

The [CII] - SFR Correlation



We find tight, nearly linear correlation between $\Sigma_{[CII]}$ and Σ_{SFR} with a ~0.22 dex 1σ scatter



1. FIR color/Dust Temperature

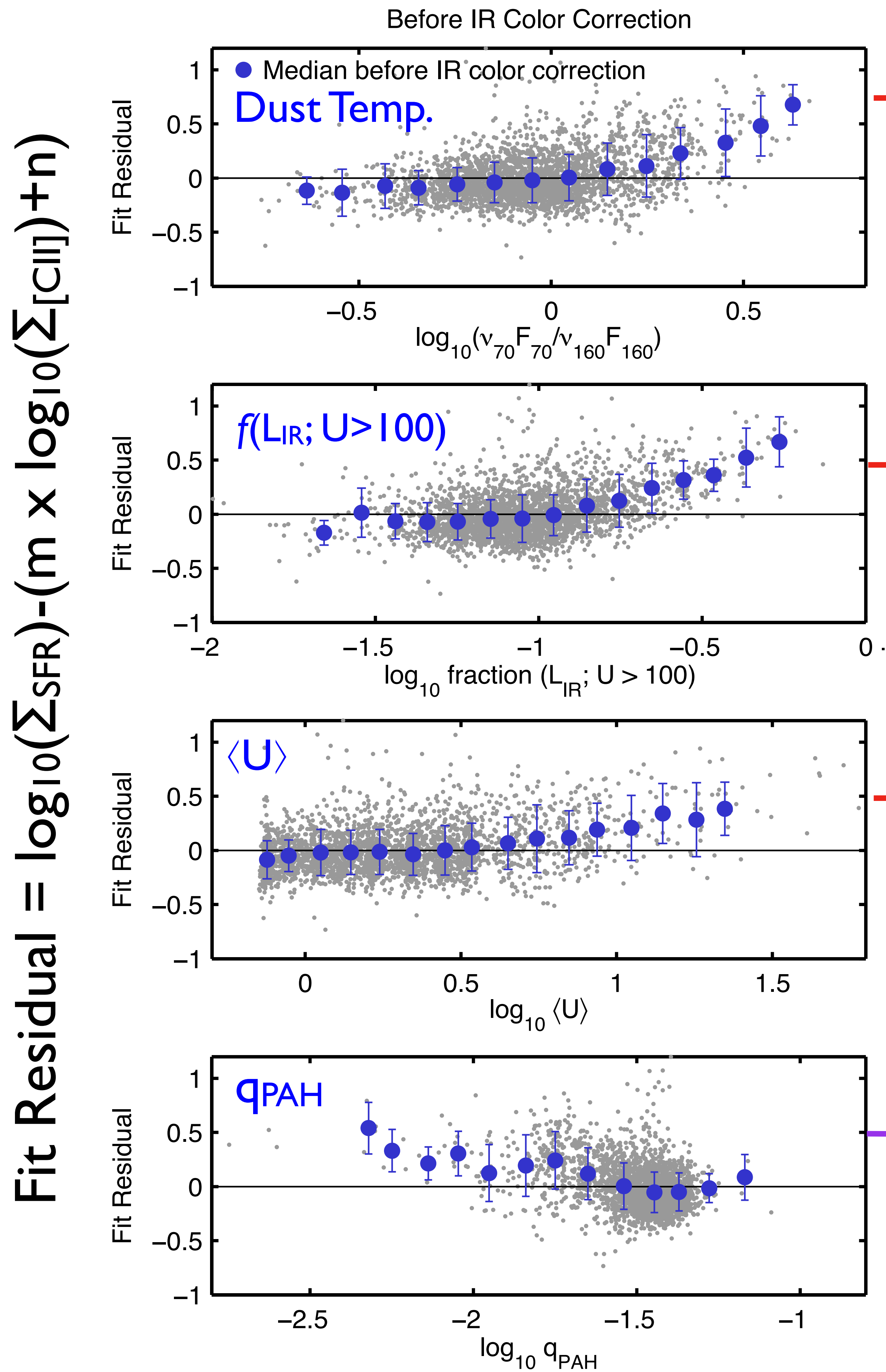
2. Fraction of the dust luminosity radiated from regions with intense radiation fields (U > 100)

3. Mean starlight intensity

4. Percentage of the total grain mass contributed by PAHs

2, 3 & 4: Parameters from Draine & Li Model 2007

Aniano +12



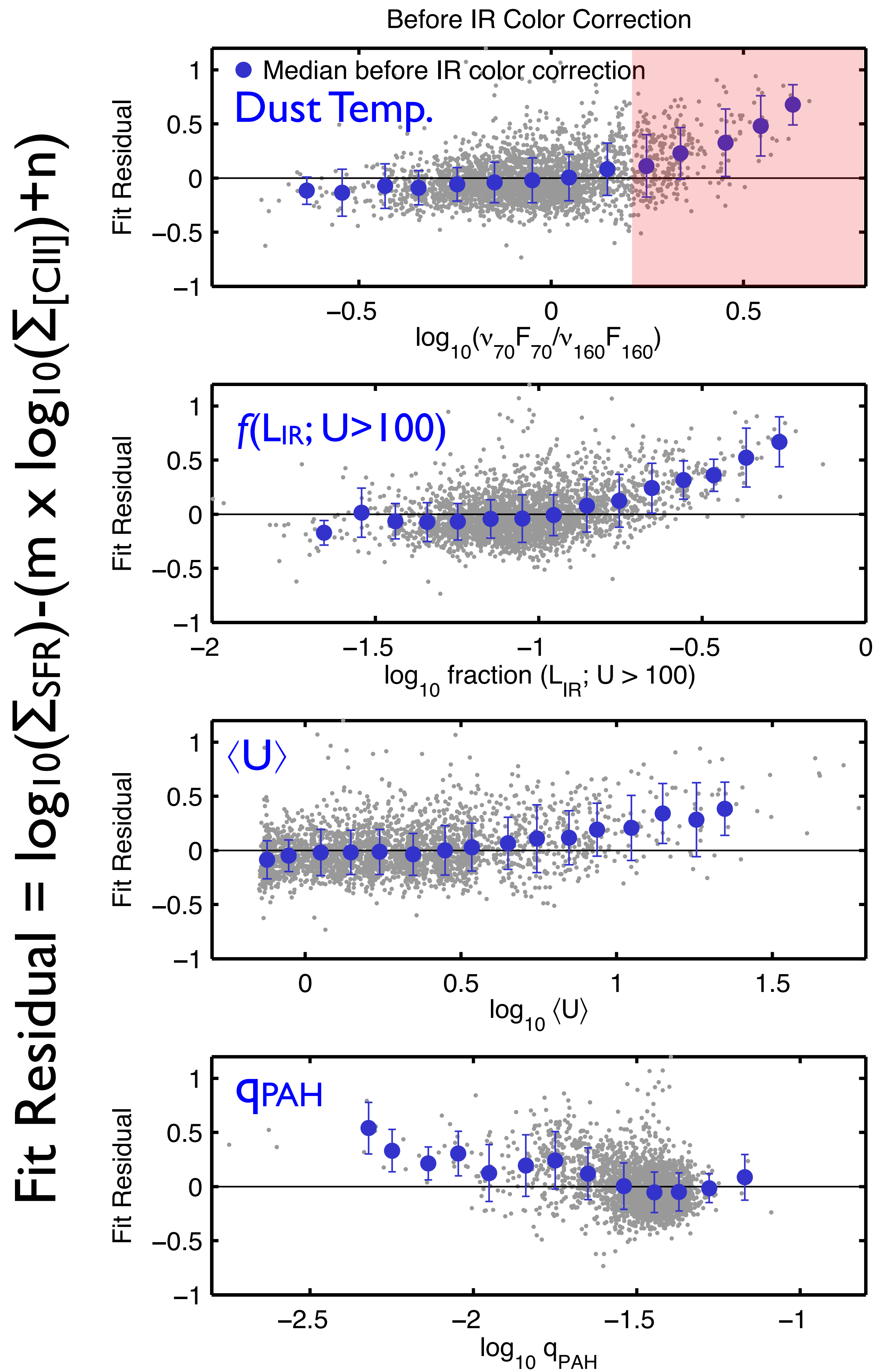
Charged dust grains

a higher charge implies a higher Coulomb barrier to overcome, thus decreasing the energy per ejected electron (Tielens & Hollenbach+95; Malhotra+97; Luhman+03; Croxall+12)

ε_{ph} ↓ Reduced photoelectric heating efficiency

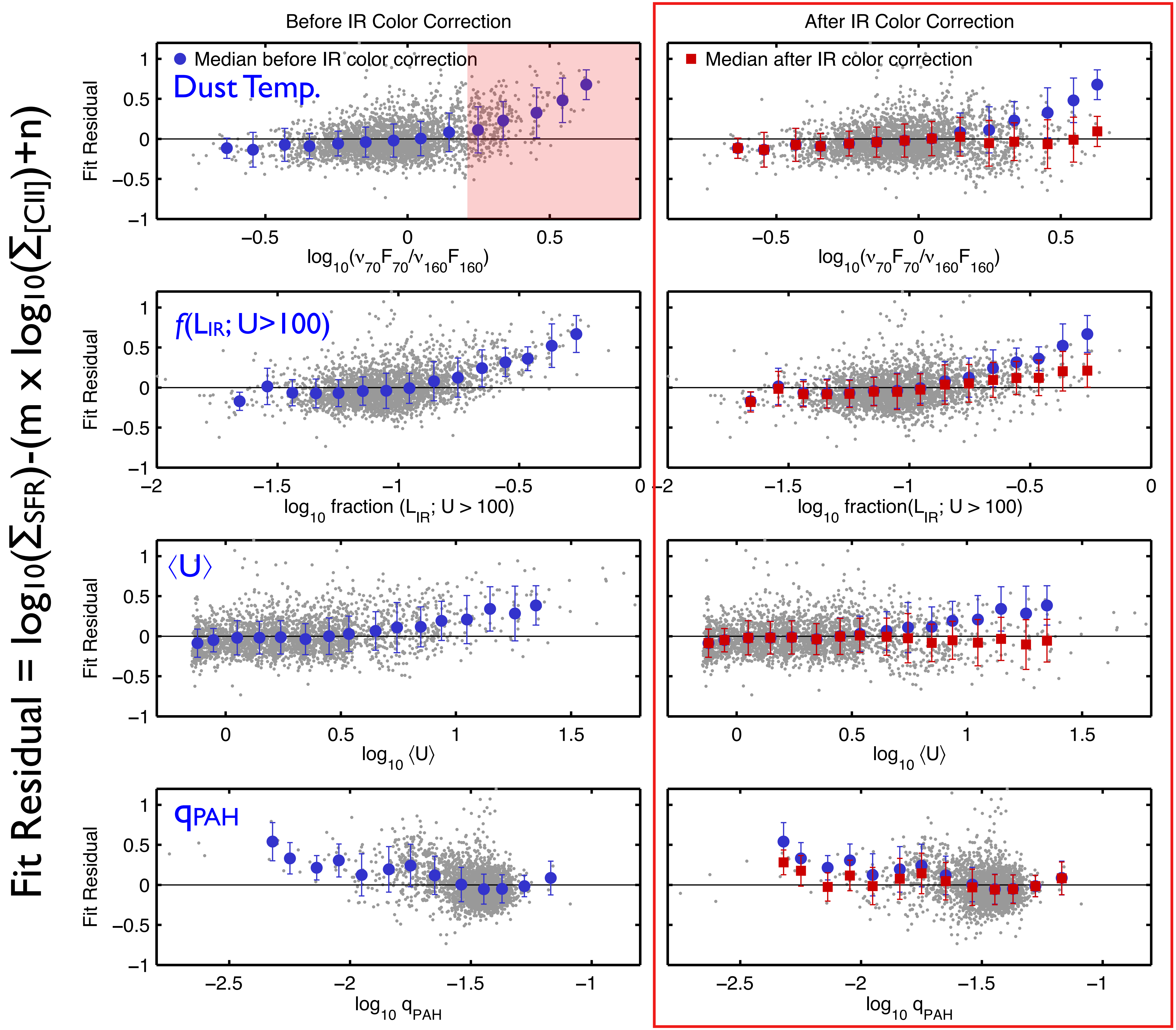
$$L_{CII} = \varepsilon_{ph} \times L_{FUV}$$

Low PAH abundance

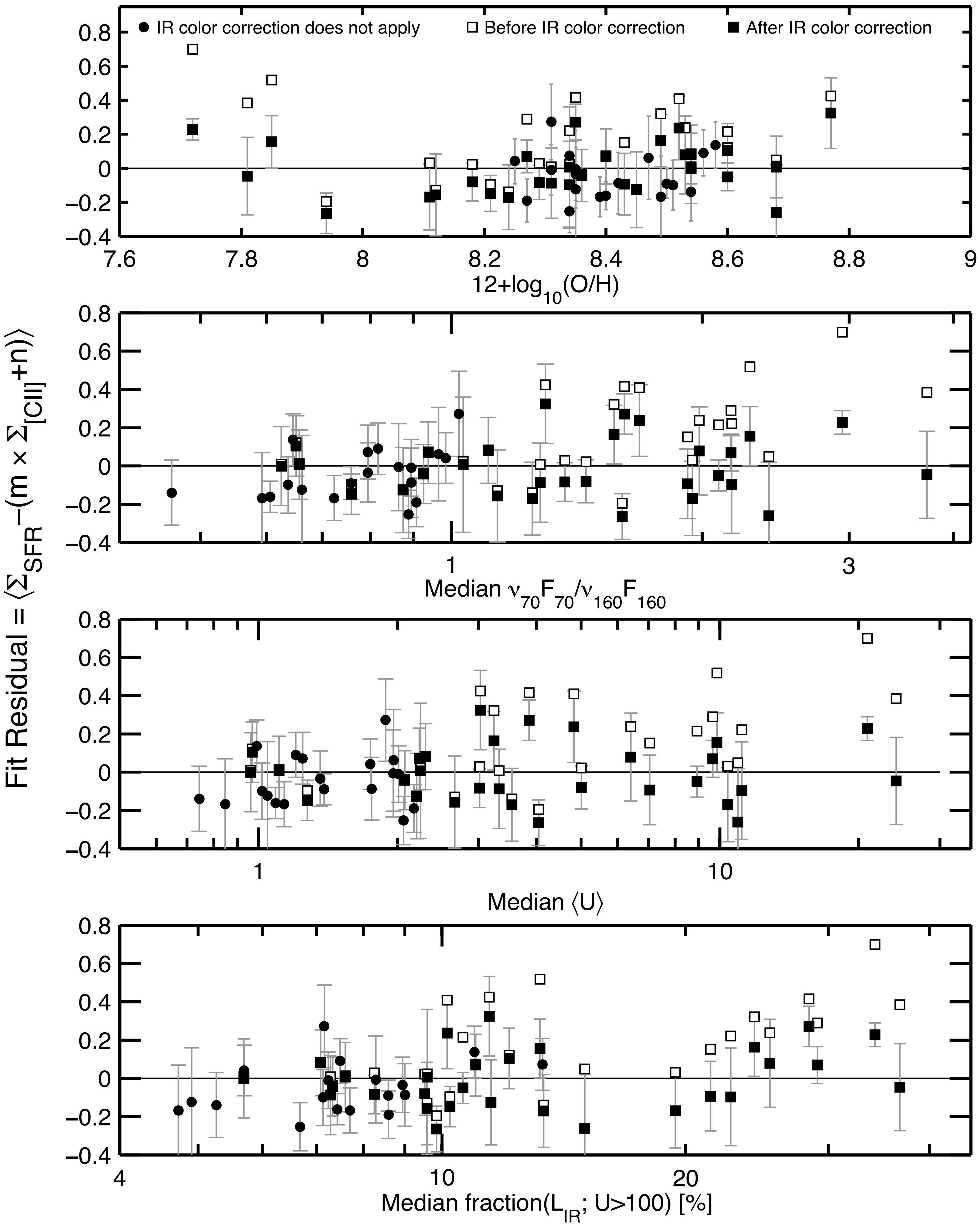


Implement an IR color correction for $\nu_{70}F_{70}/\nu_{160}F_{160} \gtrsim 1.25$

$$\log_{10}\Sigma_{[CII]} \rightarrow \log_{10}\Sigma_{[CII]} + \log_{10}(\nu_{70}F_{70}/\nu_{160}F_{160}) - 0.1$$

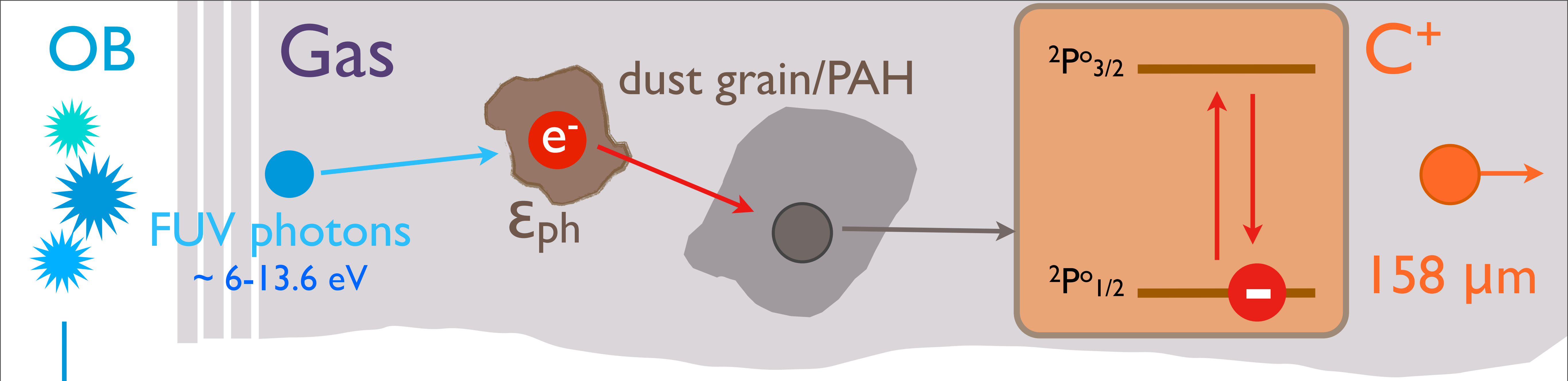


After the FIR color correction



Galaxy to Galaxy Variations

- ● IR color correction does not apply
- □ Before IR color correction
- ■ After IR color correction



Starburst99 code

Leitherer+99

Model stellar populations

$$L_{FUV} = f(\mathrm{SFR}, \mathrm{time})$$

$$L_{FUV} \longrightarrow L_{CII}$$

PE Heating Efficiency

ε_{ph} ~ 0.1 – few %

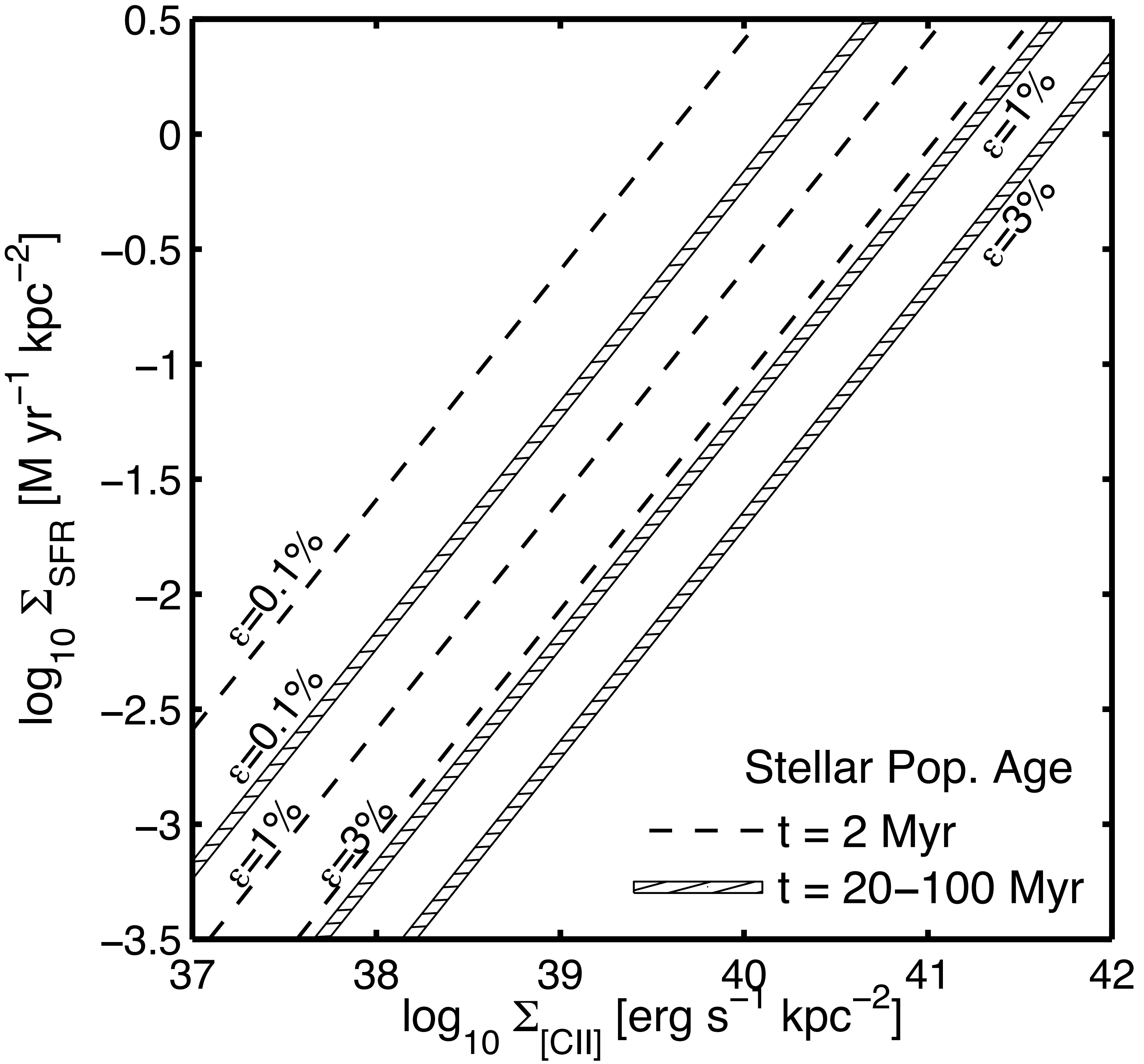
$$L_{CII} = \varepsilon_{ph} \times L_{FUV}$$

$$L_{CII} = \varepsilon_{ph} \times f(\mathrm{SFR}, \mathrm{time})$$

Comparison to SB99 model

- - - - - - Age = 2 Myr, ε_{ph} = 0.1, 1 & 3%

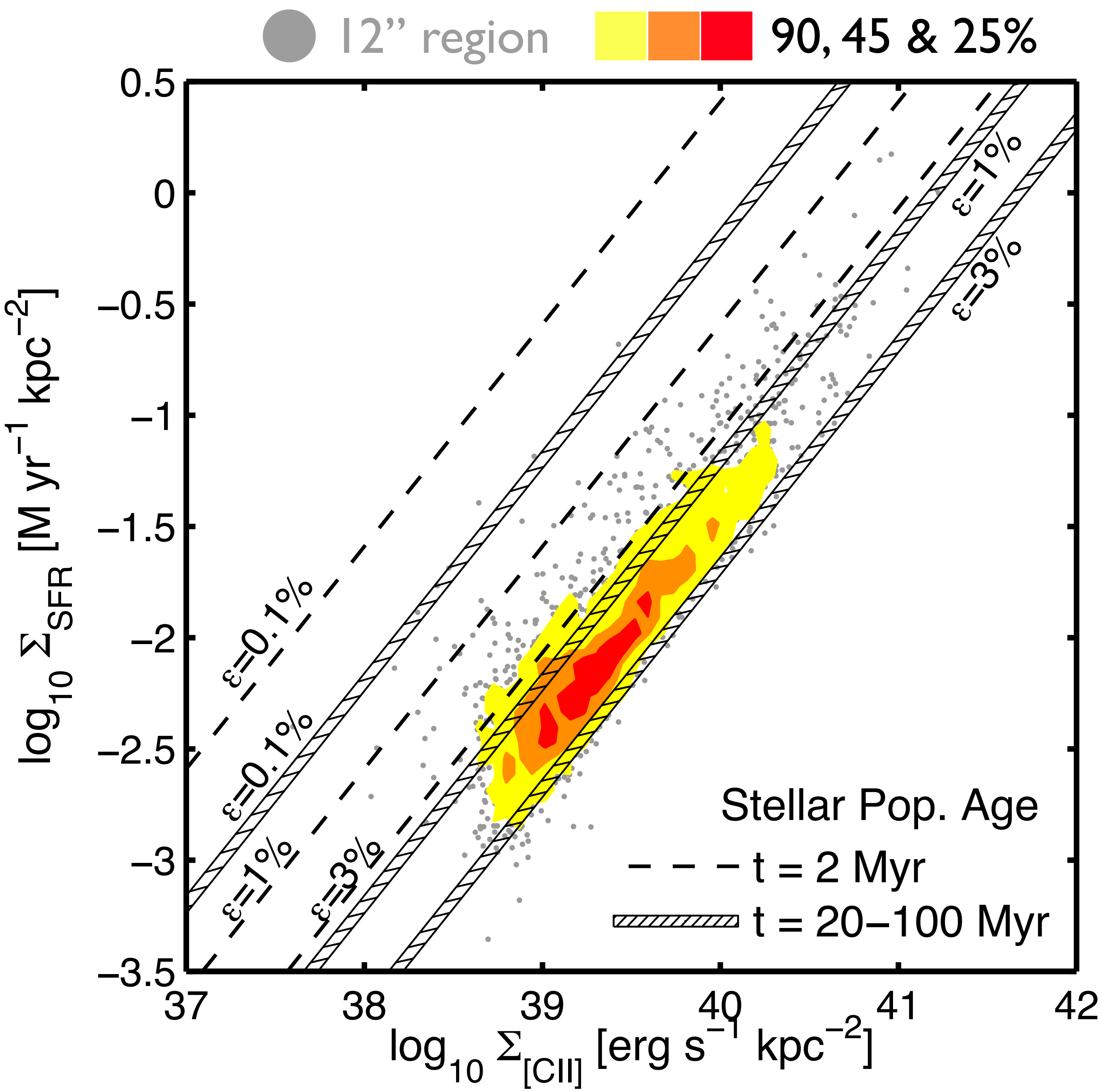
Age = 20-100 Myr, ε_{ph} = 0.1, 1 & 3%



At a given Σ_{SFR}, increasing ε_{ph} implies higher $\Sigma_{[CII]}$

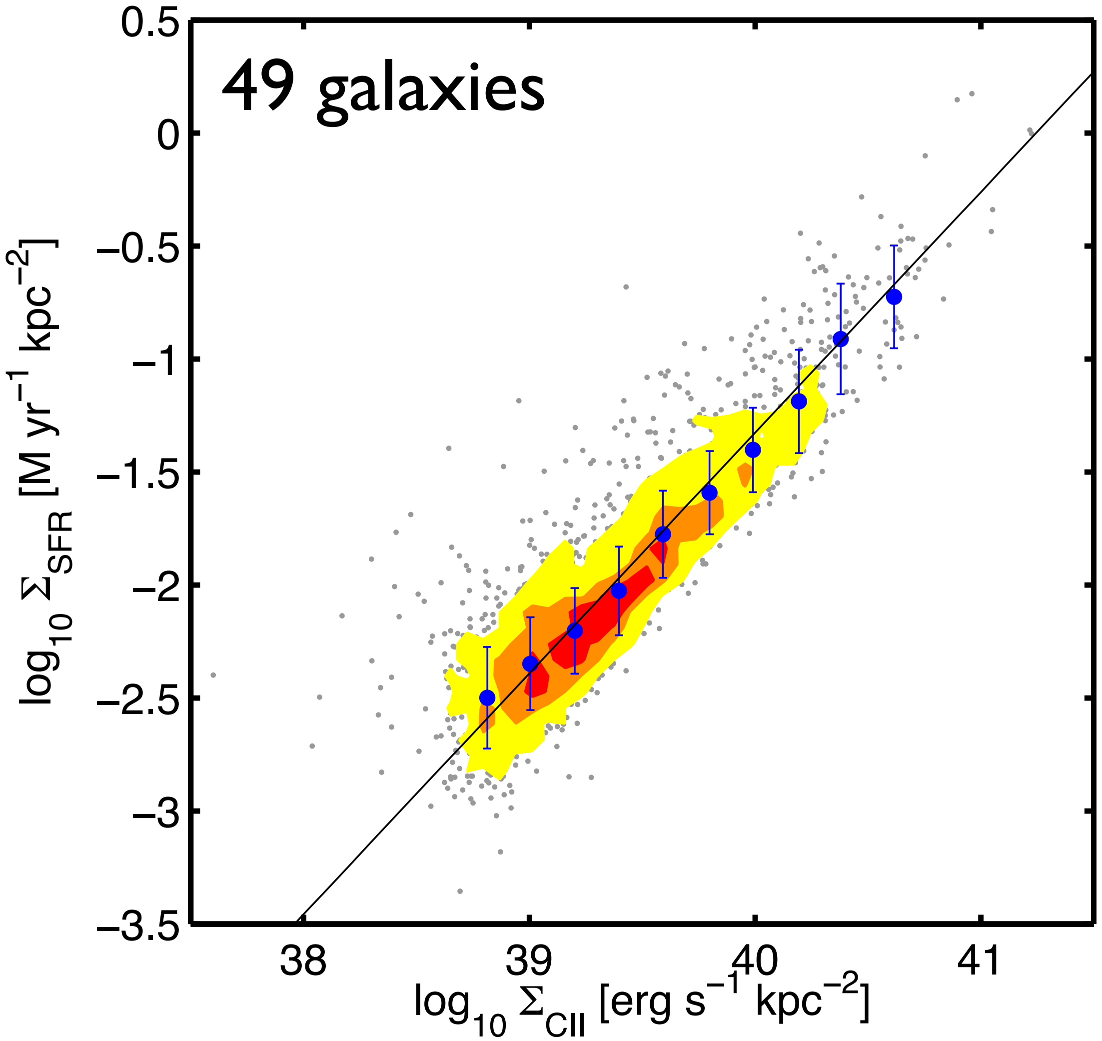
Comparison to SB99 model

Bulk of the data explained by star formation duration episode 20-100 Myr old, and ε_{ph} between 1 and 3%



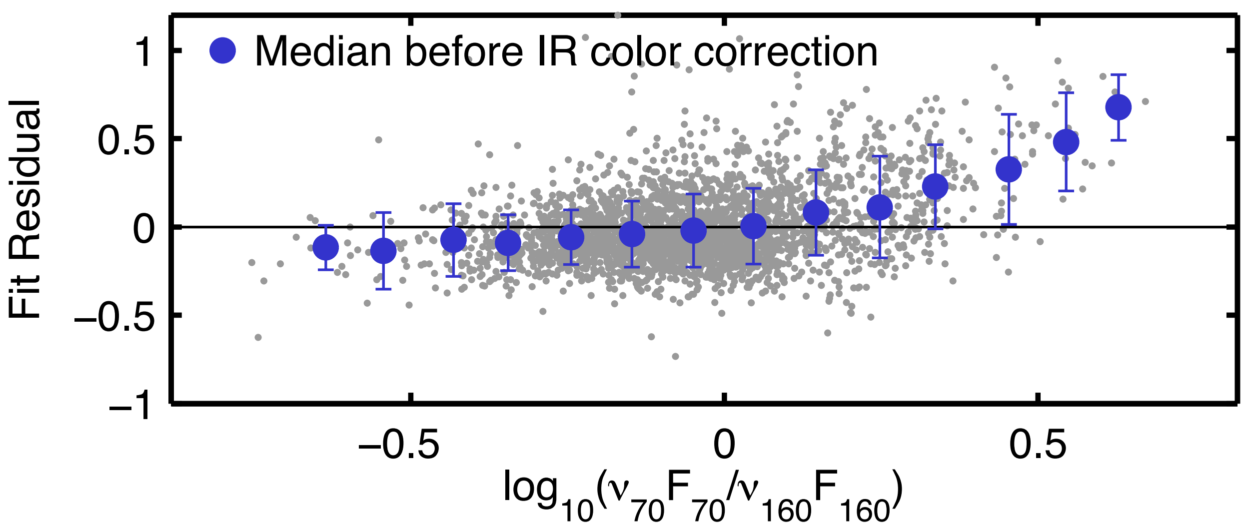
Summary

$\Sigma_{[CII]}$ - Σ_{SFR}



We find a tight, nearly linear correlation between $\Sigma_{[CII]}$ and Σ_{SFR} with a ~0.22 dex 1σ scatter

The data show that the [CII] emission can be used for measurements of SFRs in normal, star forming galaxies in the absence of strong AGNs.



We start to find deviations from the fit in the direction of an IR excess for regions with $\nu_{70}F_{70}/\nu_{160}F_{160} \gtrsim 1.25$

We derive a simple prescription to correct for this deviation.