Using far-infrared transitions to study star formation activity in galaxies

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MPE IR/sub-mm group

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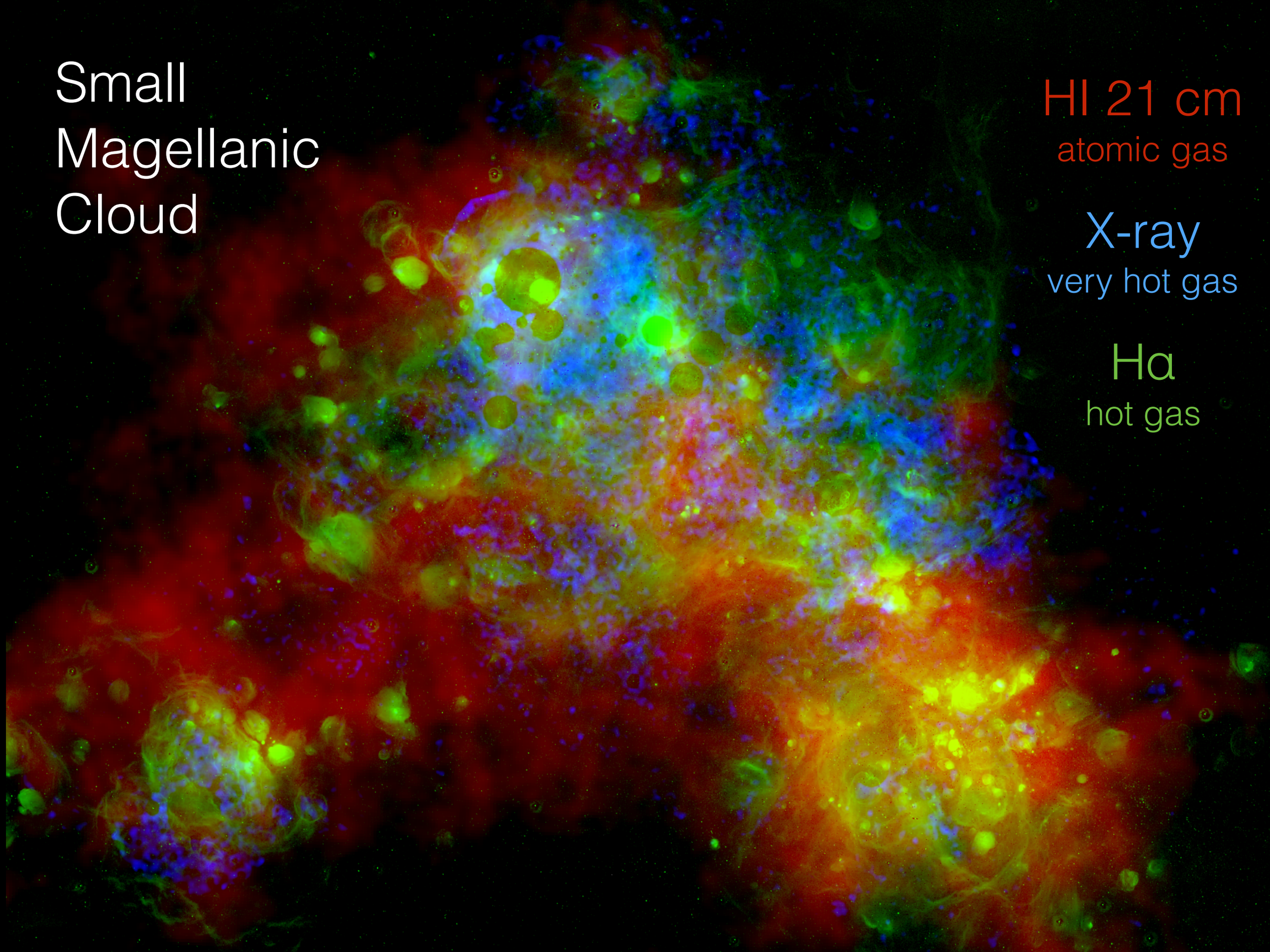
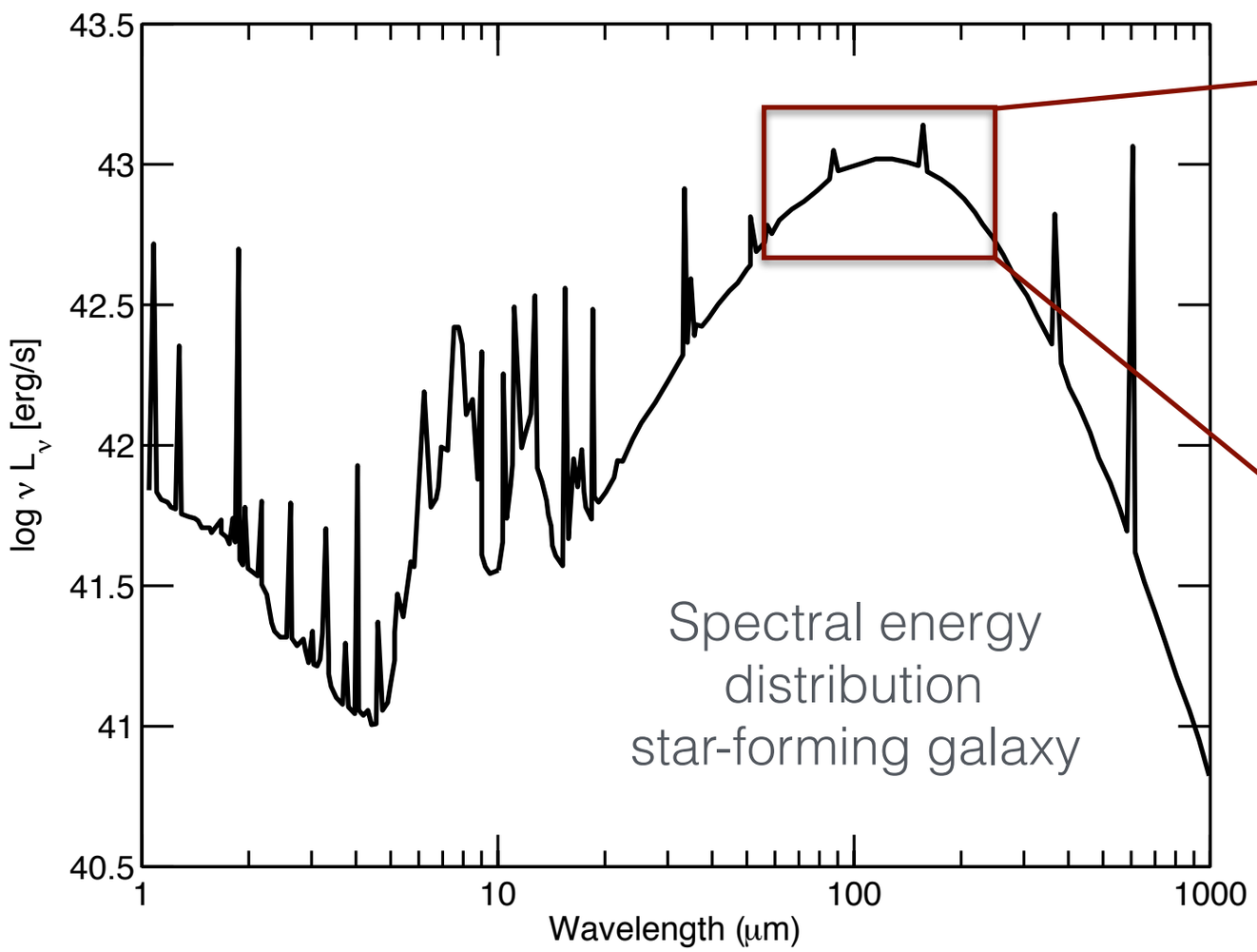
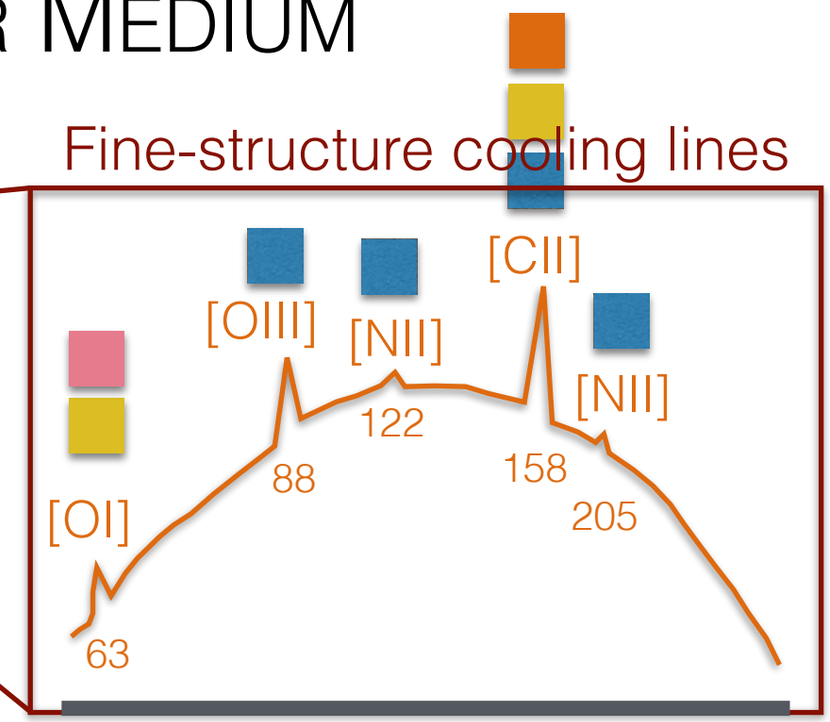
KINGFISH

Beyond the Peak


Small
Magellanic
Cloud
HI 21 cm
atomic gas
X-ray
very hot gas
Hα
hot gas

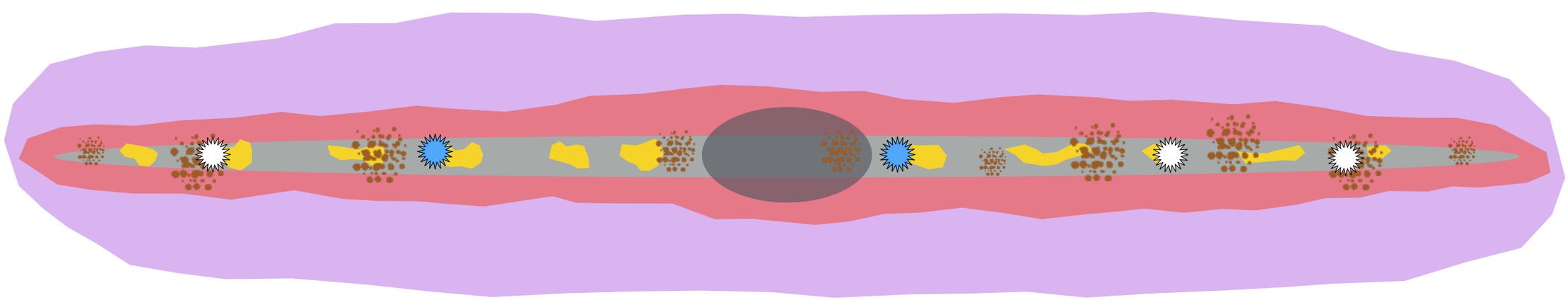
Multiphase Interstellar Medium





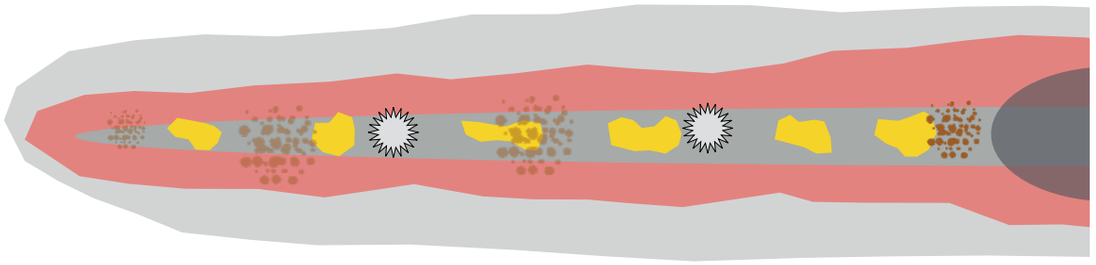
Herschel
Space Observatory

ALMA/NOEMA
high-z



Hot Ionized Medium Warm Neutral Medium Cold Neutral Medium

HII gas Molecular gas Dust



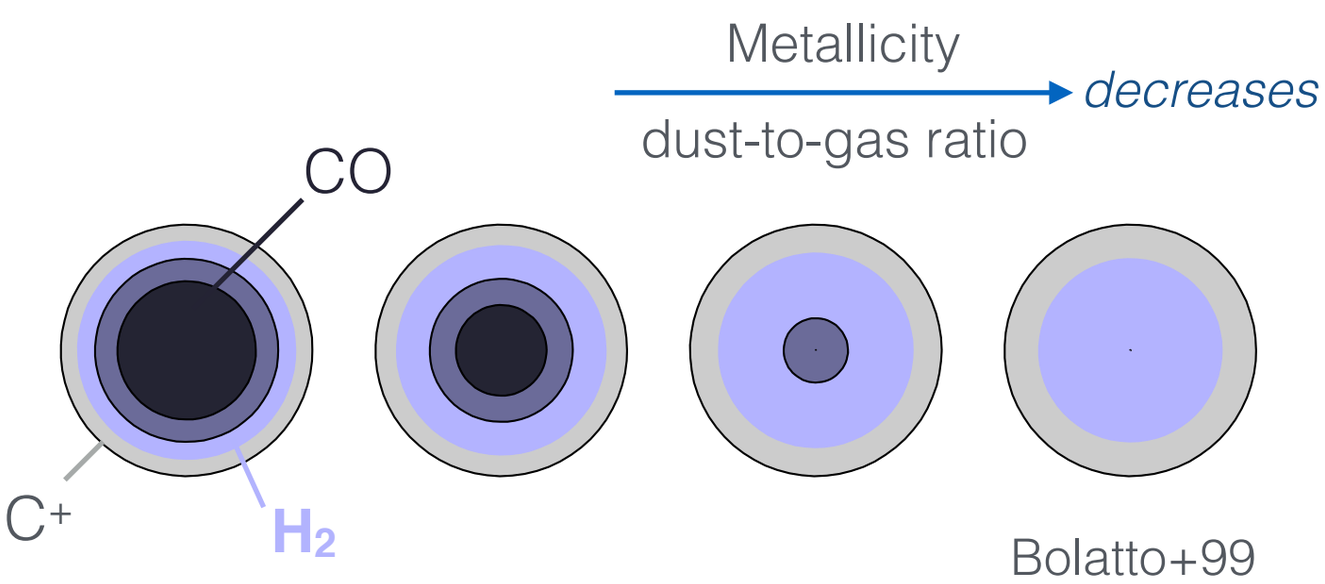
[CII] 158 μm transition

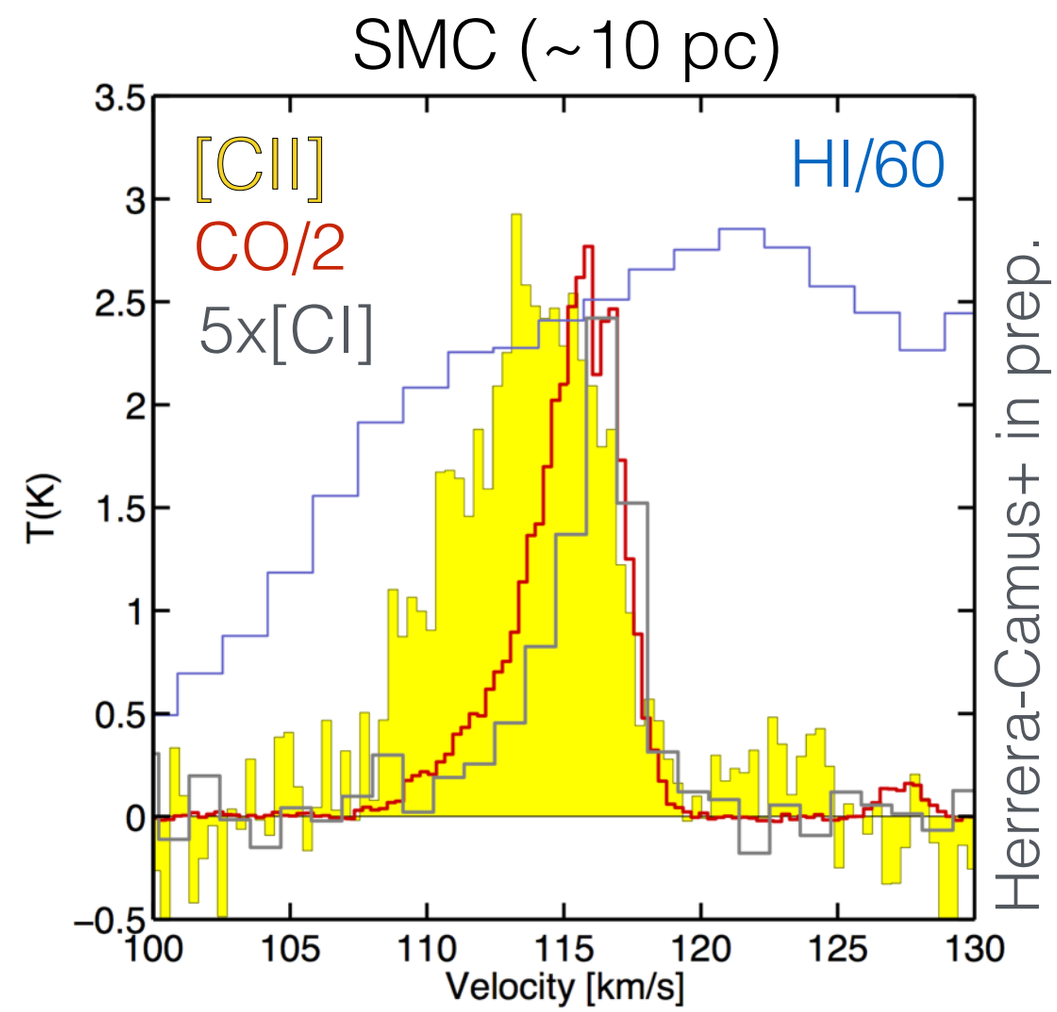
Very bright line (~0.1 - 1% L_{FIR}) — ALMA: z~4-7

e.g. Riechers+2014, Ota+14, De Breuck+15, Capak+15, Diaz-Santos+16, Aravena+16, …

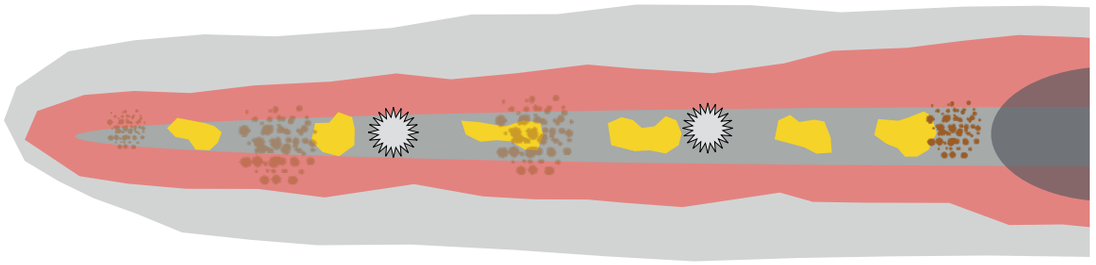
Multiphase origin

neutral (atomic and dense PDRs), molecular and ionized gas





see also: Pineda+13 (MW), Kapala+15 (M31), Requena-Torres+16 (SMC), Accurso+16 (model)…



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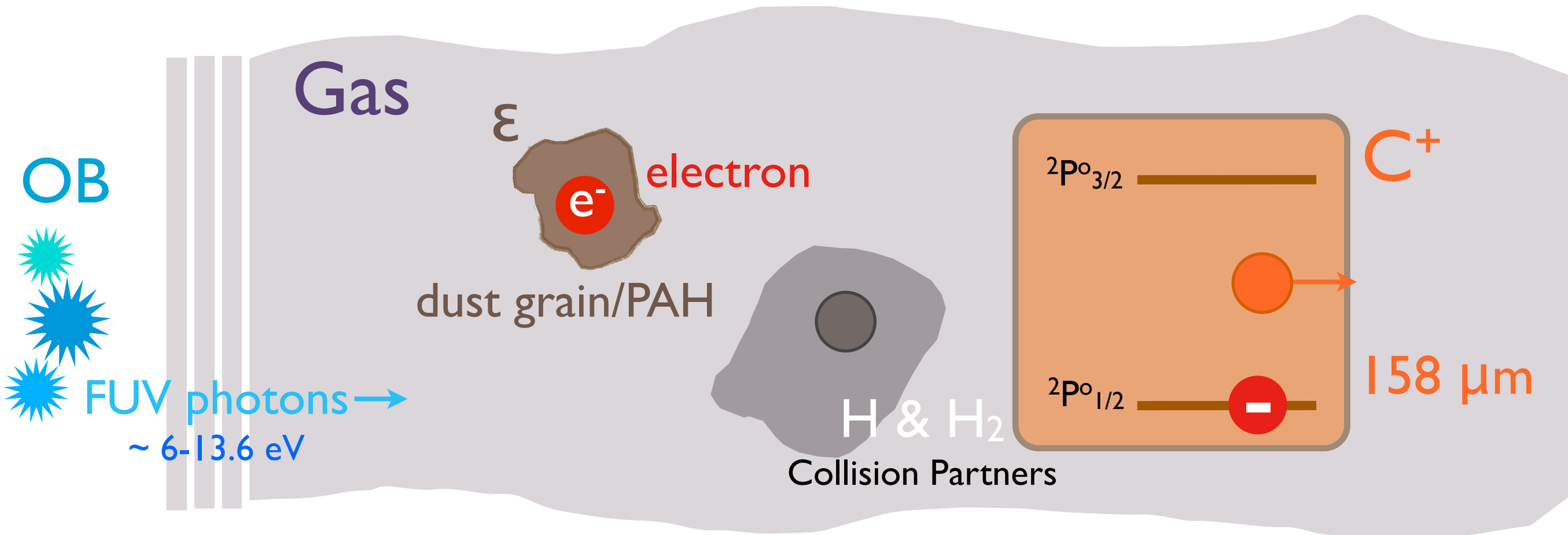
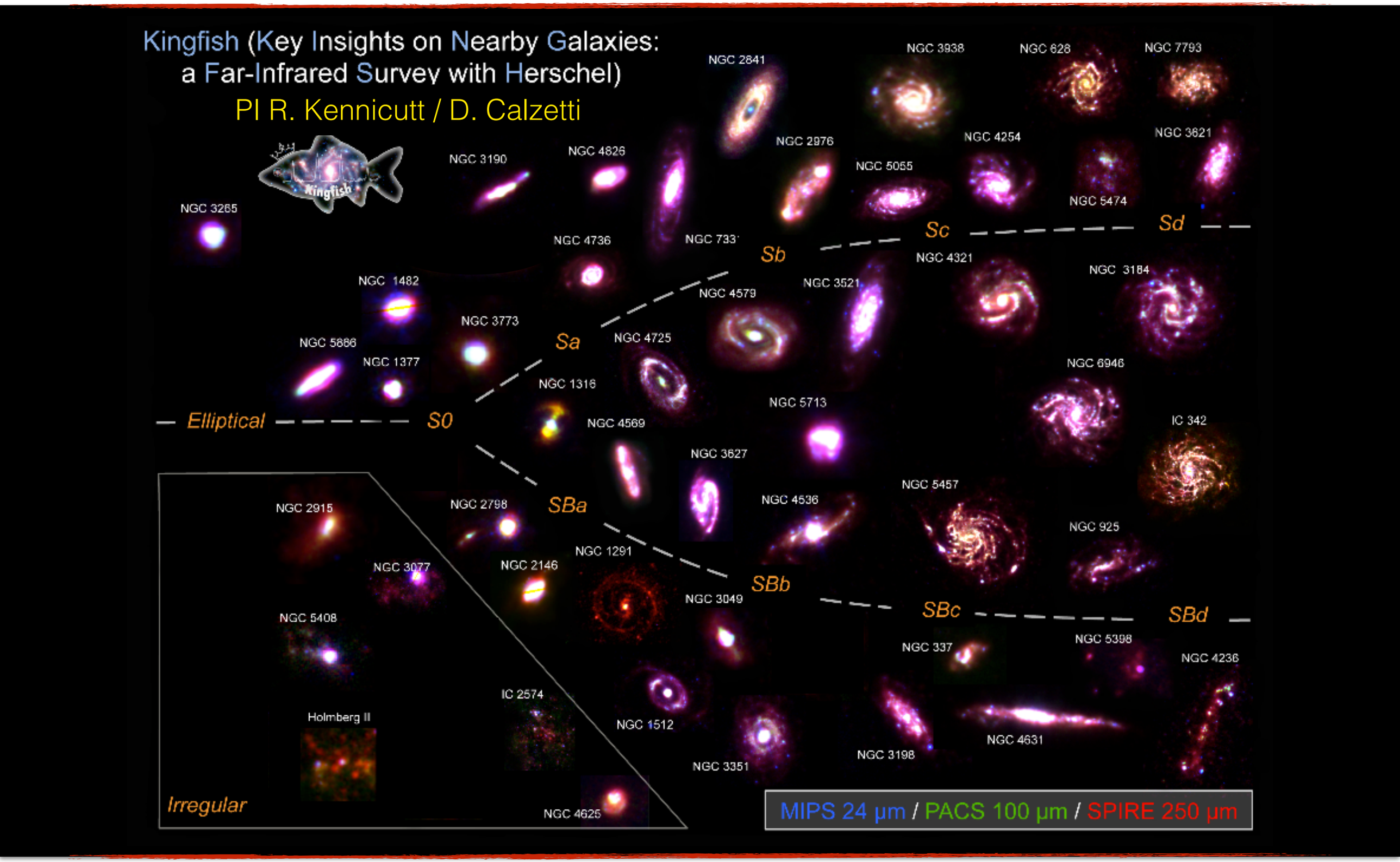


If the gas is in thermal balance: heating ≈ cooling

(star formation) ([CII])

The Sample

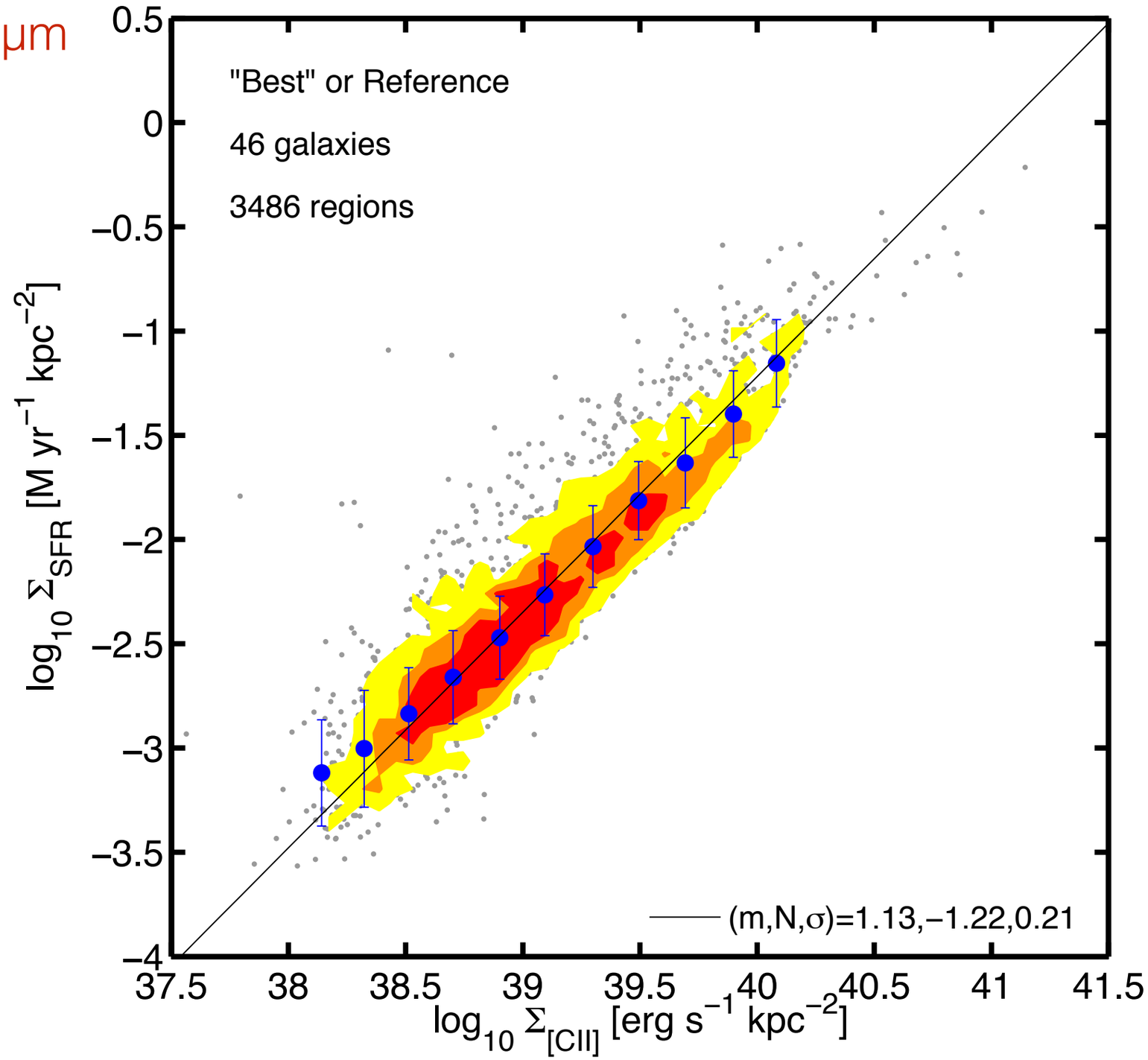


Ancillary data: Hα, FUV, IR (*SINGS*), CO (*HERACLES*), HI (*THINGS*)

[CII] EMISSION AS A TRACER OF SF ACTIVITY

Herrera-Camus+ 2015

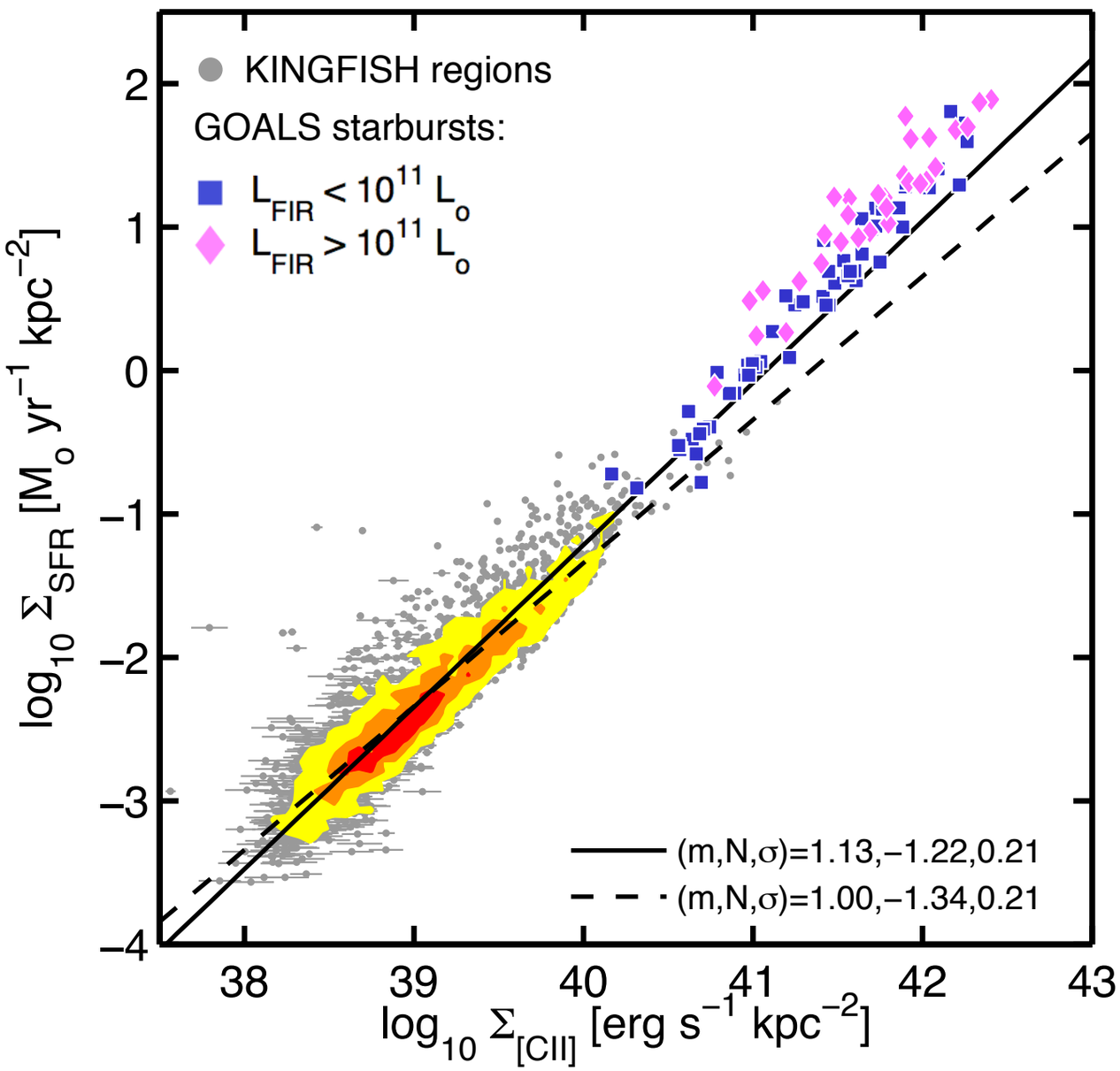
Σ_{SFR}: Hα + 24 μm

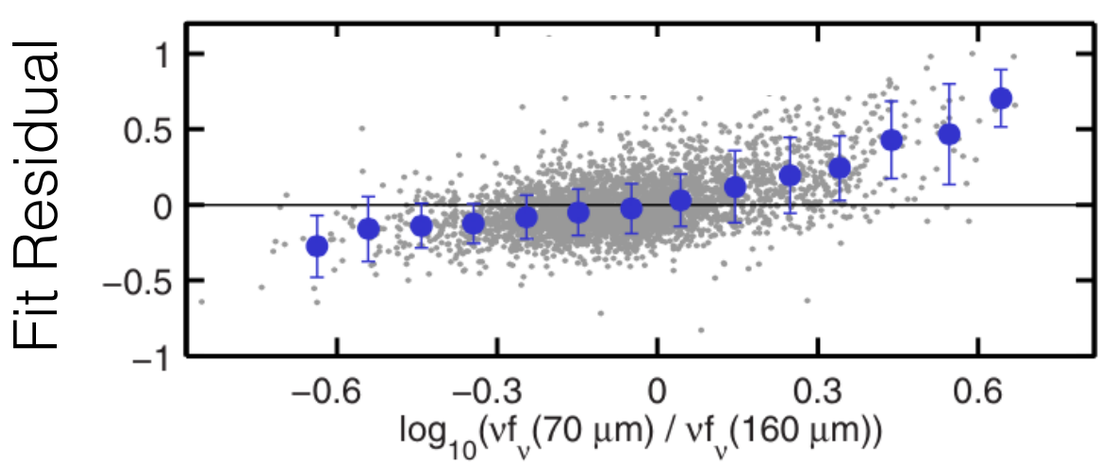


We find tight, nearly linear correlation between $\Sigma_{[CII]}$ and Σ_{SFR} with a ~0.22 dex 1σ scatter

[CII] EMISSION AS A TRACER OF SF ACTIVITY

Herrera-Camus+ 2015

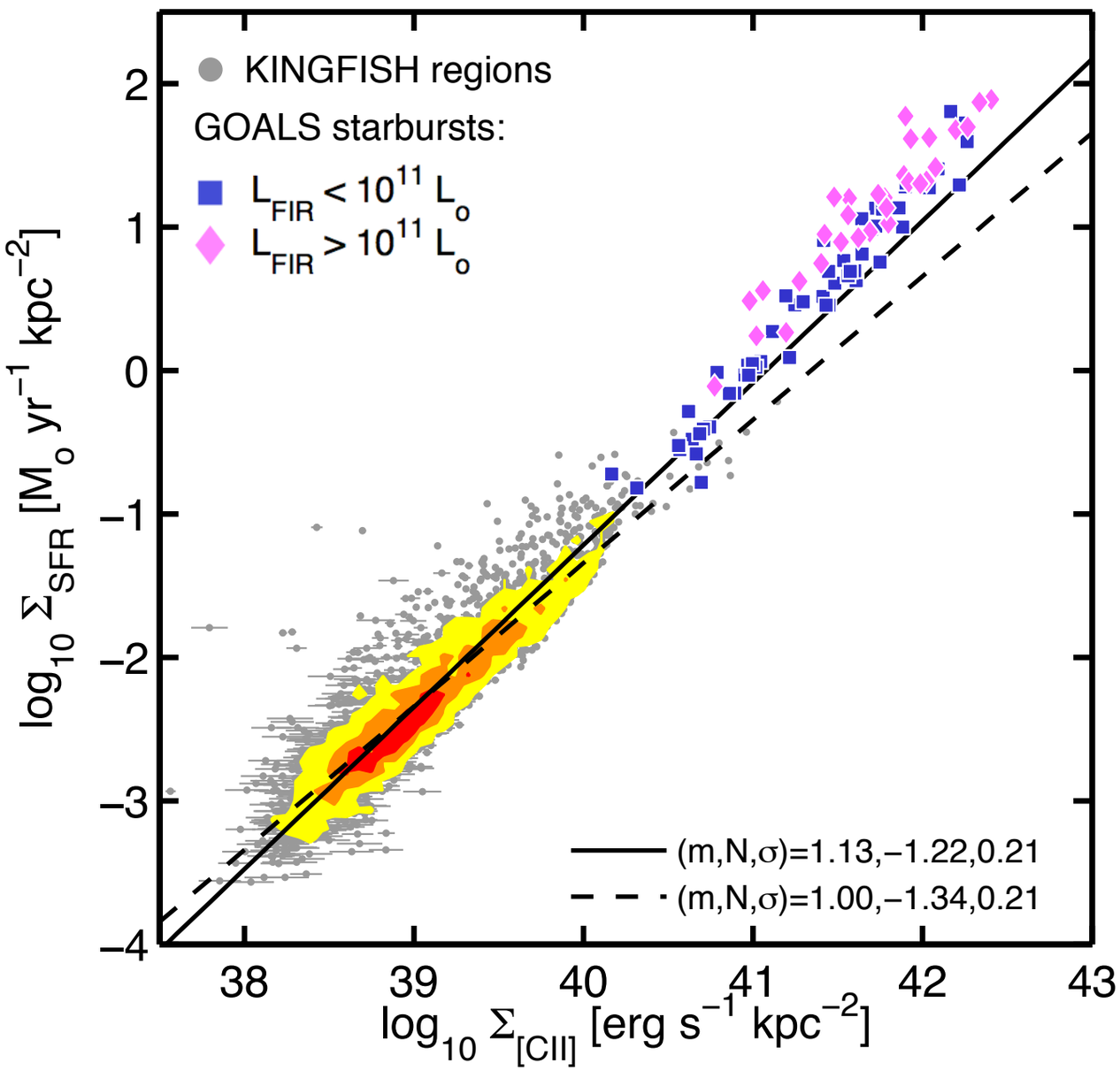


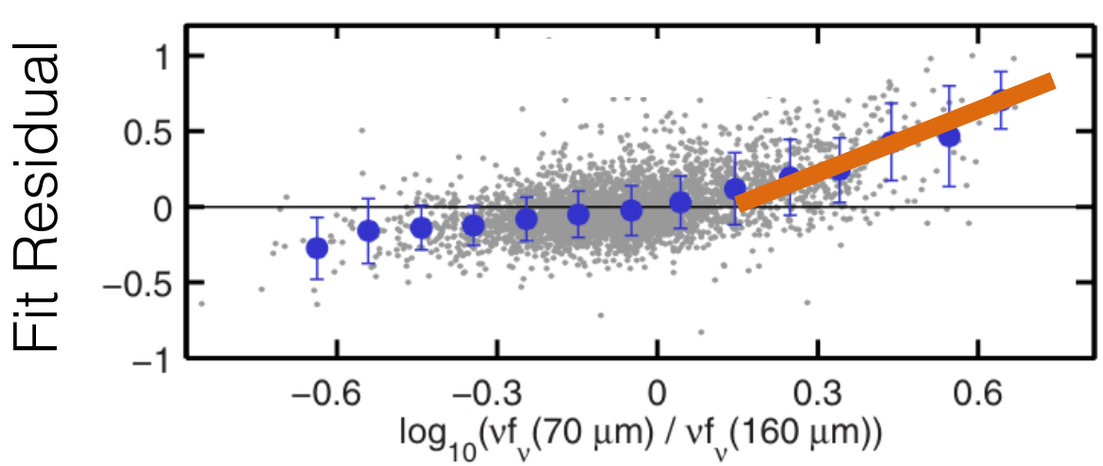


Reduction in the photoelectric heating efficiency due to charging of the dust grains
(Tielens & Hollenbach+95; Malhotra+97; Croxall+12)

[CII] EMISSION AS A TRACER OF SF ACTIVITY

Herrera-Camus+ 2015

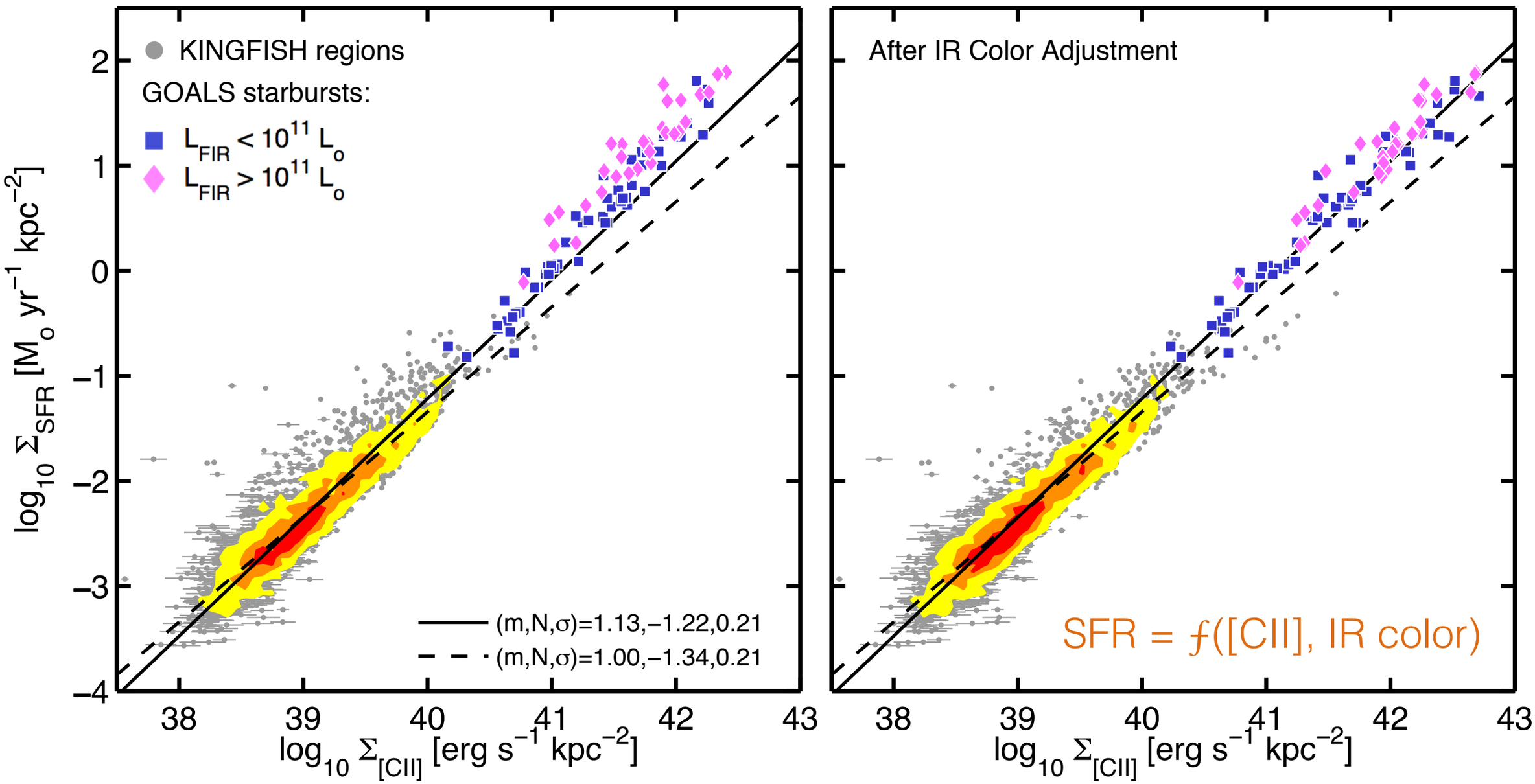




Parametrize the deviations and derive an "IR color adjustment" that reduces the residuals

SFR = f([CII], IR color)

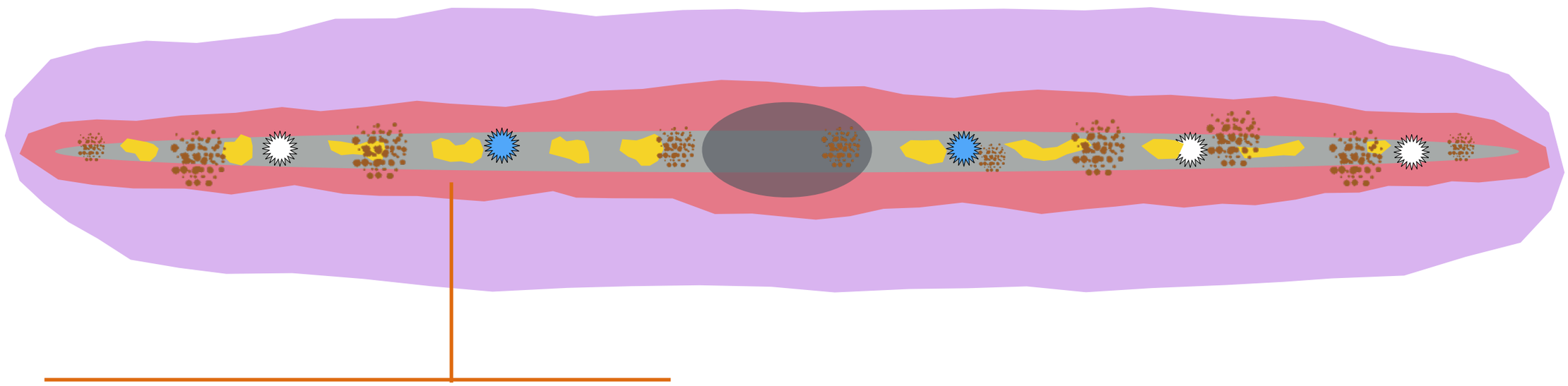
[CII] EMISSION AS A TRACER OF SF ACTIVITY



The color-adjusted $\Sigma_{[CII]} - \Sigma_{SFR}$ correlation is valid over almost 5 orders of magnitude in Σ_{SFR}, holding for both normal star-forming galaxies and non-AGN luminous infrared galaxies (LIRGS).

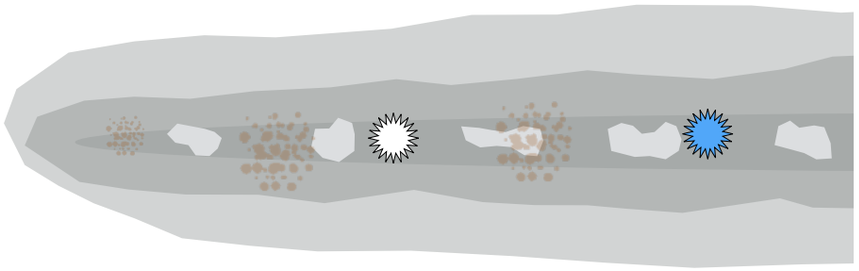
see also: Sargsyan+12, de Looze+14

Summary and Conclusions

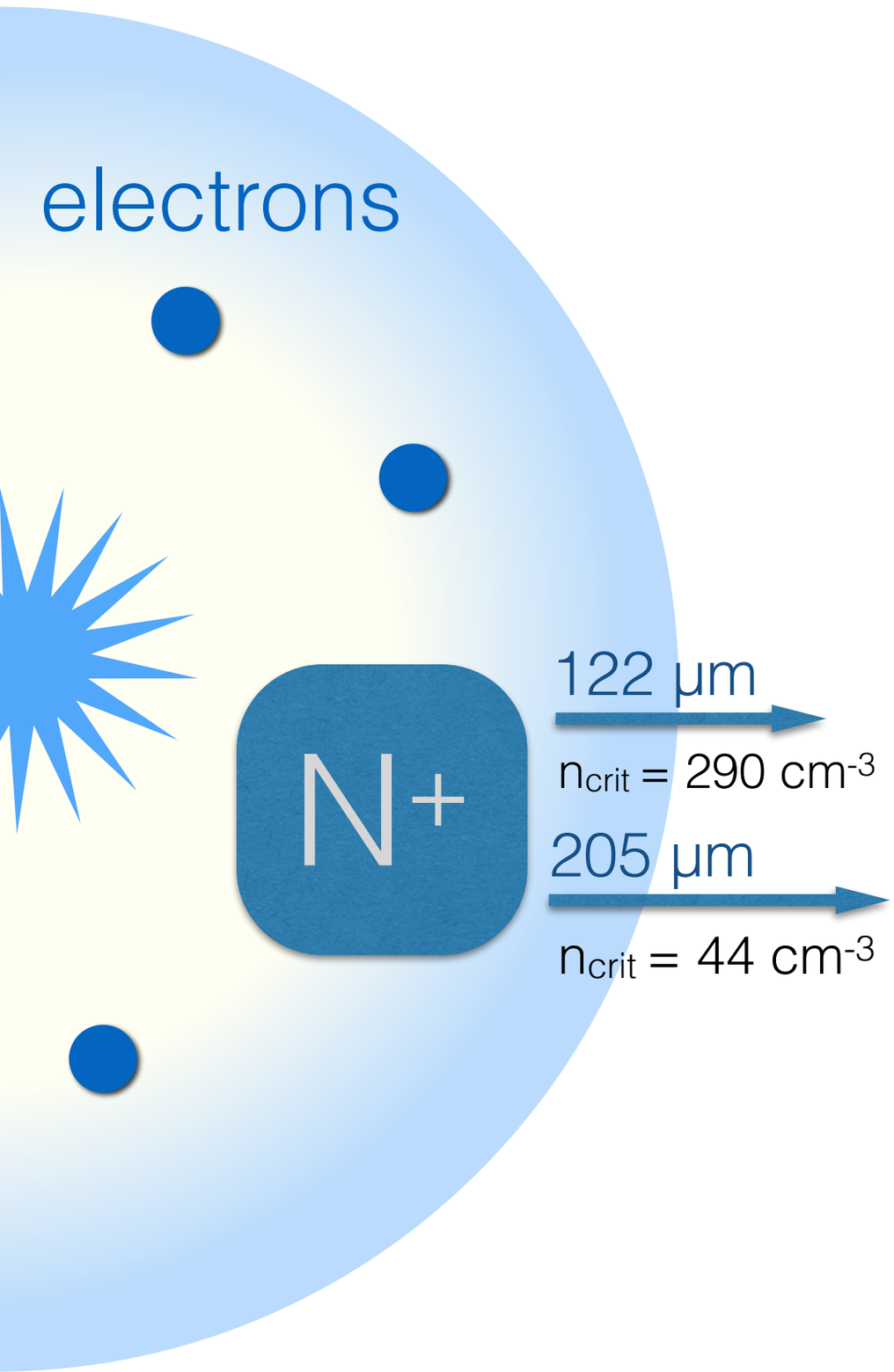


[CII] emission can be used for measurements of SFRs in normal, star forming galaxies in the absence of strong AGNs.

Herrera-Camus+ 2015

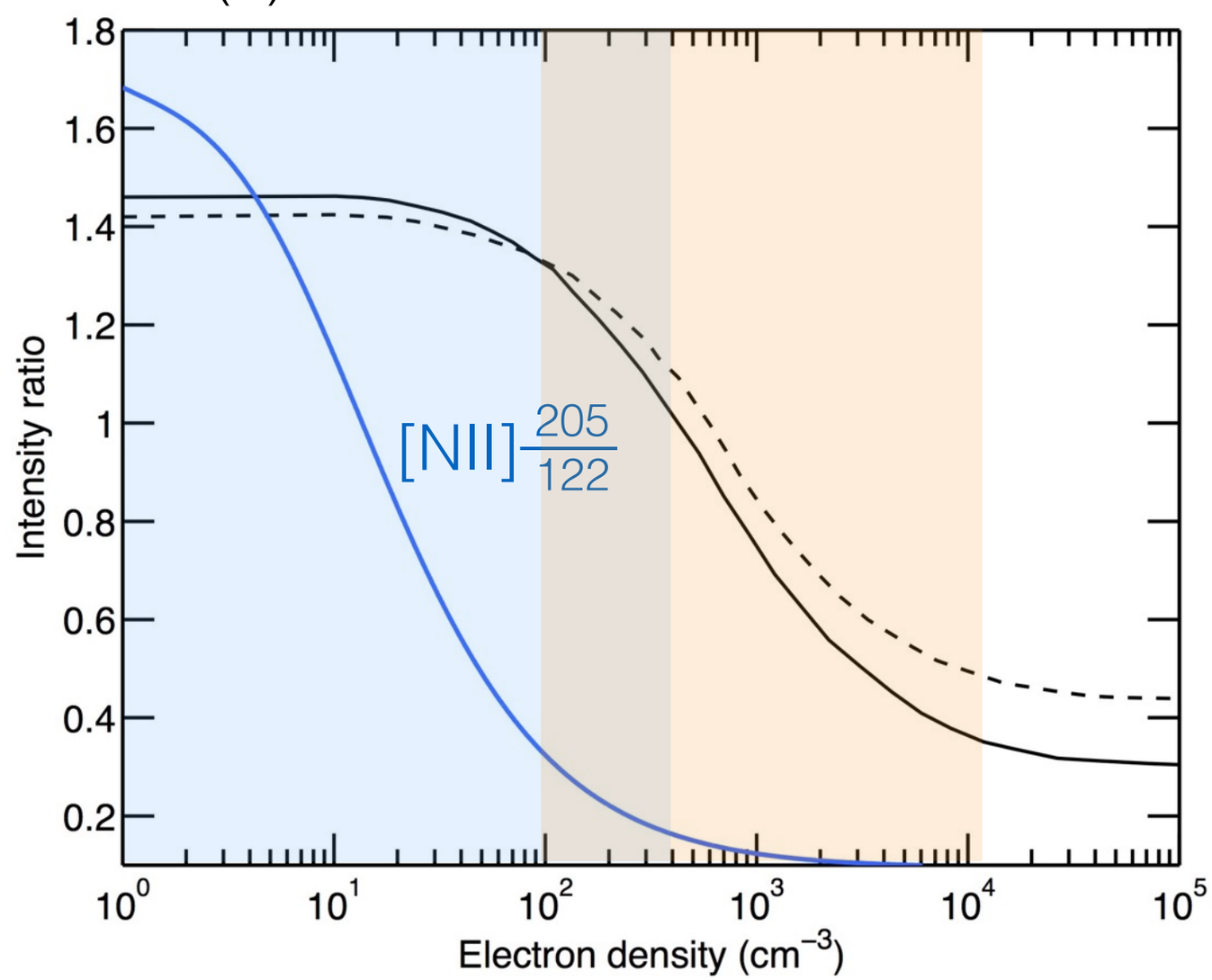


[NII] 122 AND 205 MICRON LINES AS TRACERS OF THE IONIZED GAS



(1) Direct measurement of the ionizing photon rate
(star formation activity)

(2) Measure electron densities

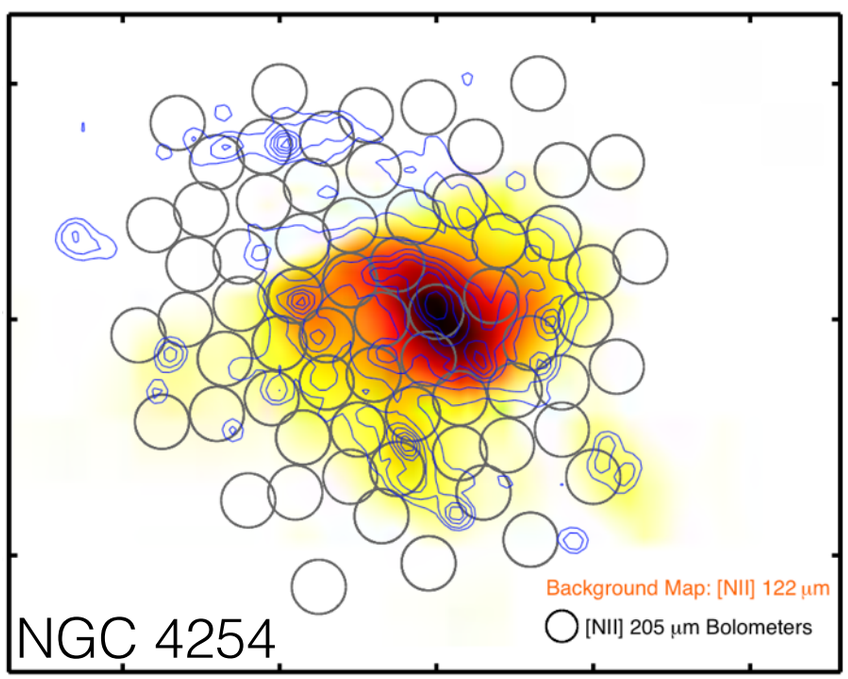


[NII] 122/205 Line ratio and N_E

Herrera-Camus+ 2016

Beyond the Peak
PI JD Smith

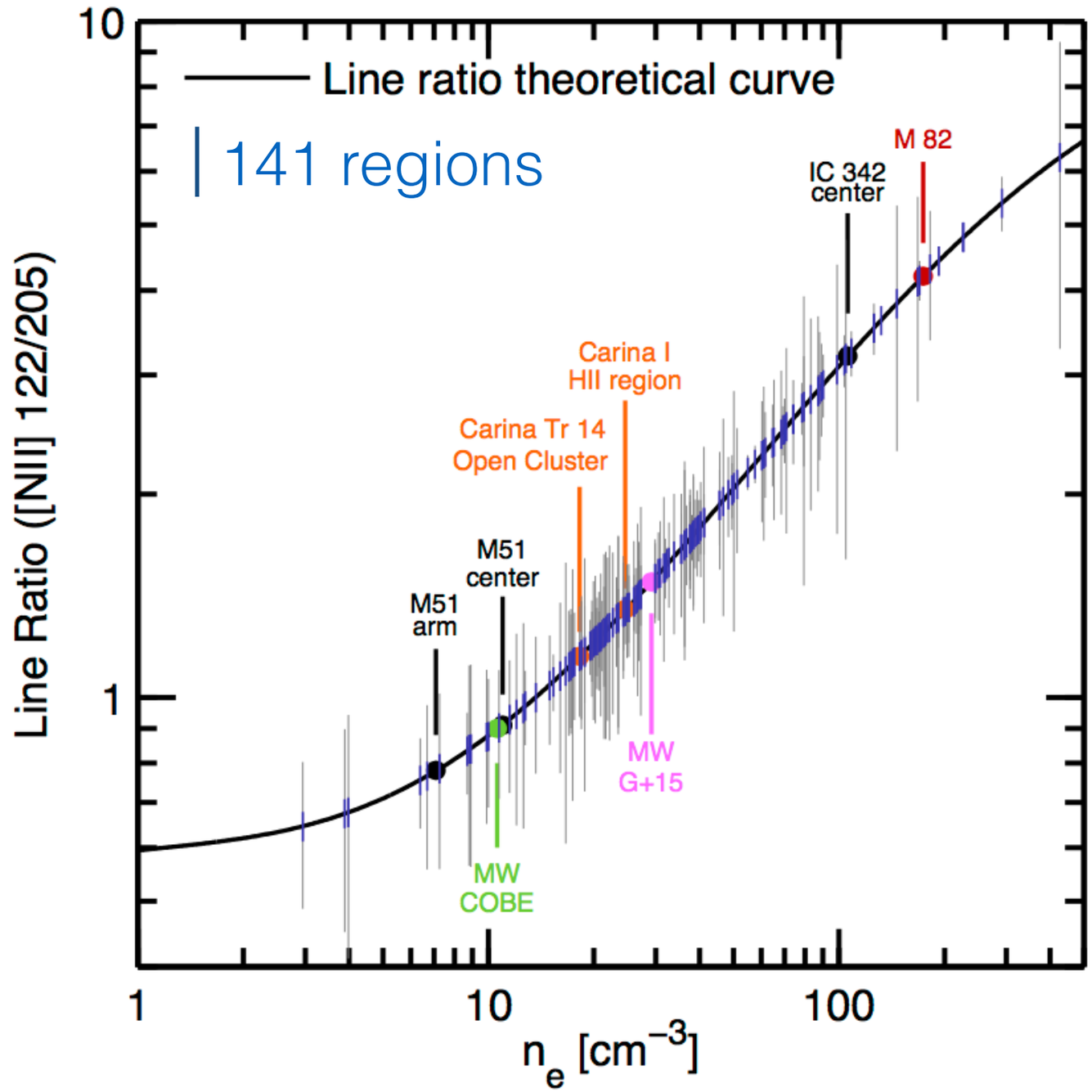
Resolved observations of
21 of the KINGFISH galaxies



Background: PACS [NII] 122 μm

SPIRE FTS [NII] 205 μm

~ 1 kpc size



The median ionized gas density in our sample is $n_e \approx 30$ cm^{-3}

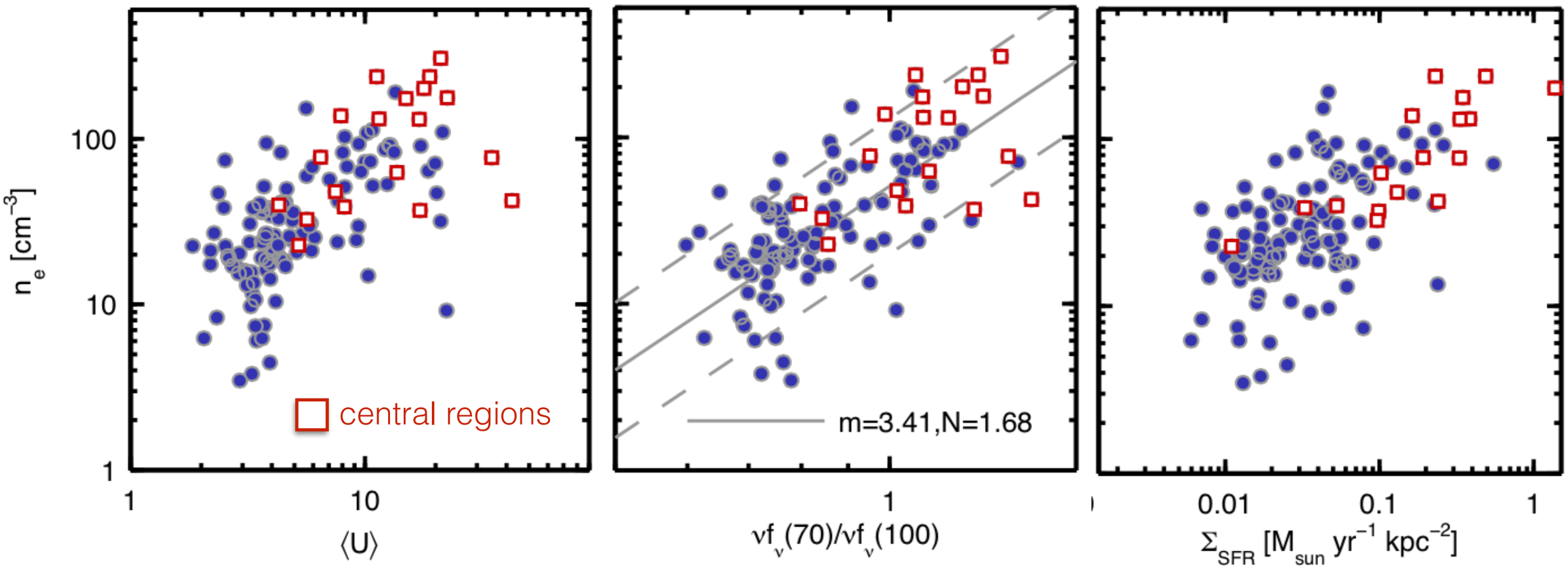
n_e AND ENVIRONMENT

Herrera-Camus+ 2016

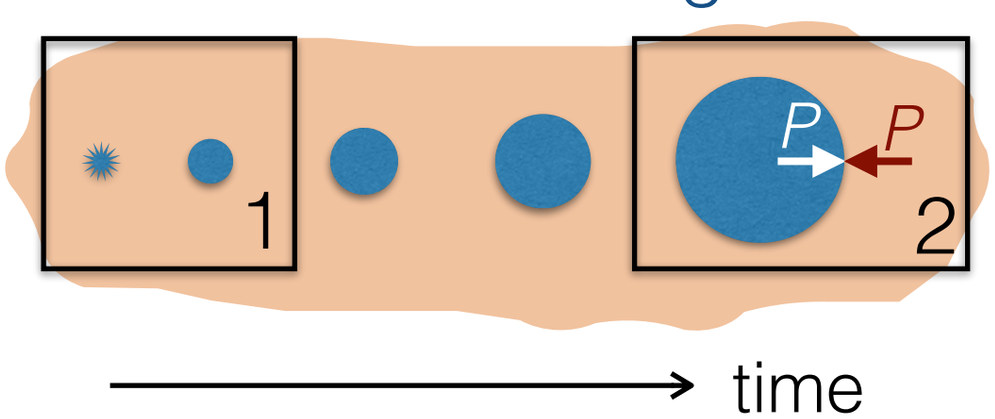
Dust-weighted mean starlight intensity
Draine & Li 07 model

Infrared Color

Star formation Rate Surface Density



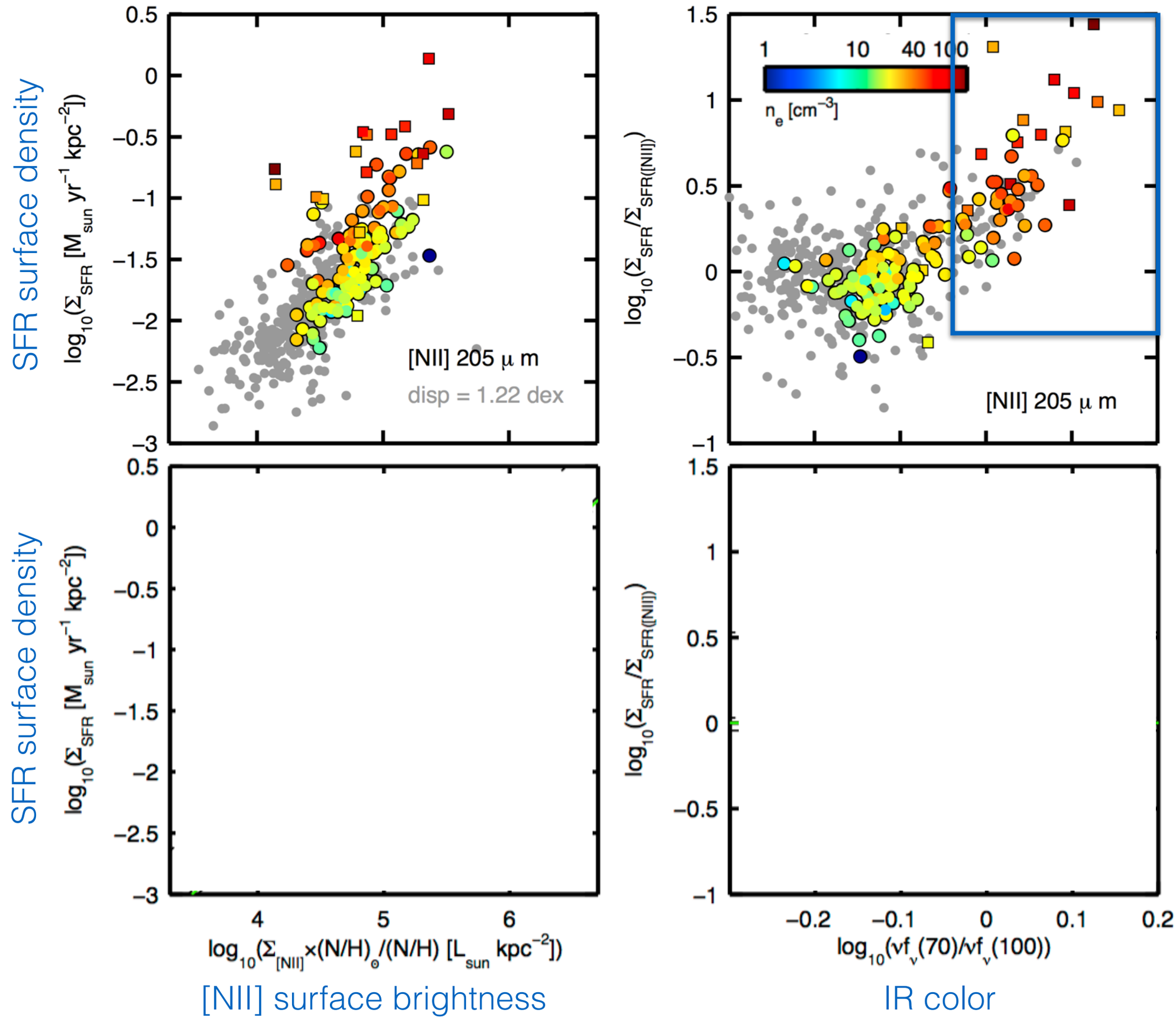
Evolution of HII regions



1 Young HII regions → compact high U, SFR…

2 High n_e → high density of the surrounding neutral gas.

[NII] Transitions as Star Formation Tracers



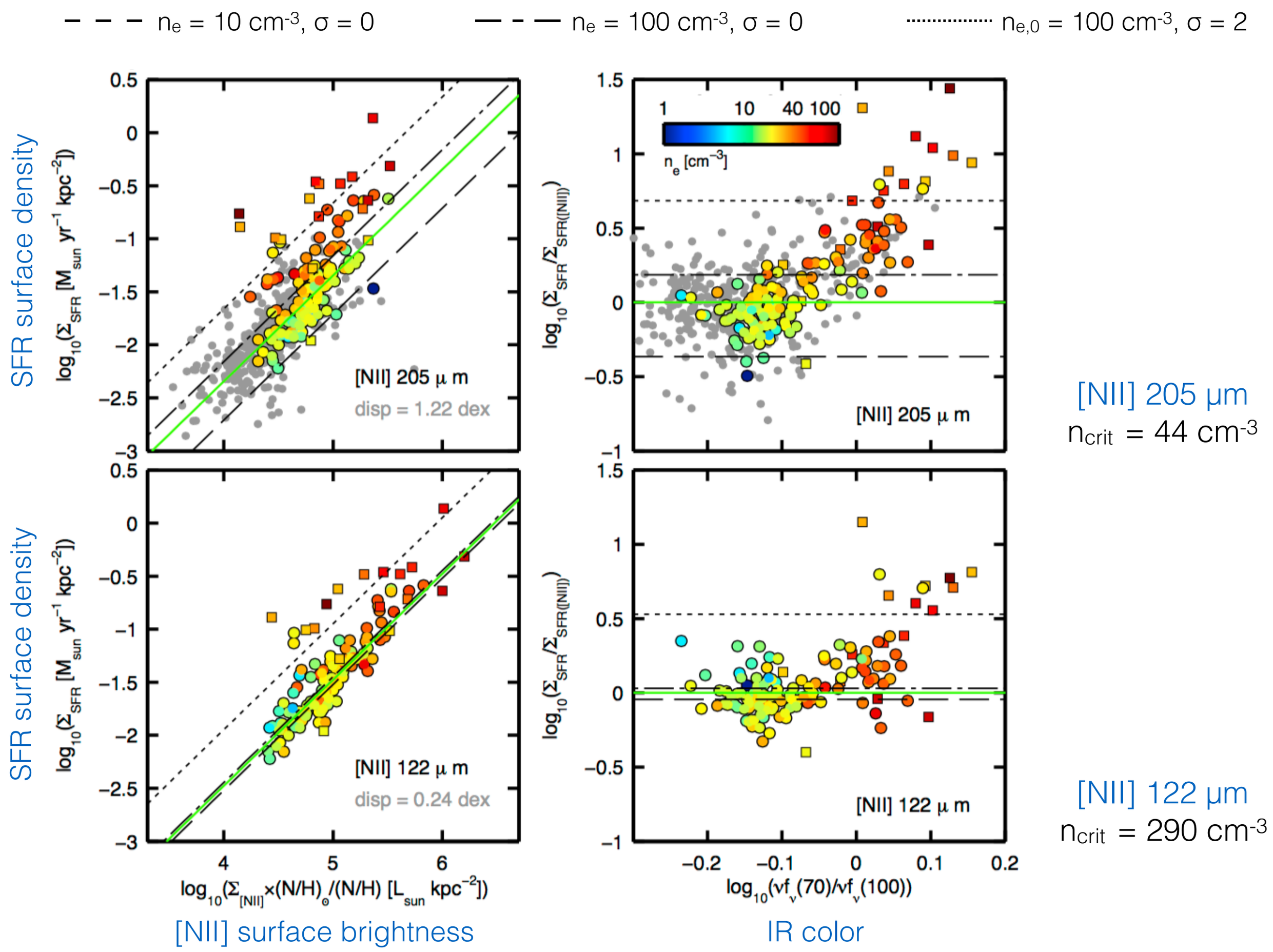
Scatter increases as function of n_e

↓

$n_e > n_{crit}$ collisional quenching of the line

[NII] 205 μm

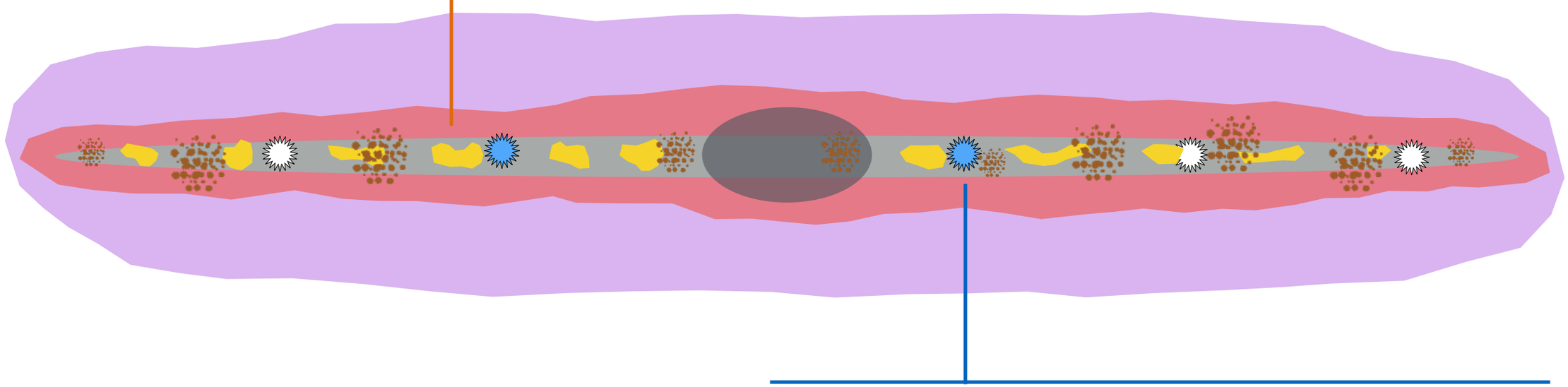
n_{crit} = 44 cm^{-3}


n_e = 10 cm^{-3}, σ = 0
n_e = 100 cm^{-3}, σ = 0
$n_{e,0}$ = 100 cm^{-3}, σ = 2
SFR surface density
$\log_{10}(\Sigma_{SFR}$ [M_{sun} yr^{-1} kpc^{-2}])
[NII] 205 μ m
disp = 1.22 dex
$\log_{10}(\Sigma_{SFR}/\Sigma_{SFR([NII])})$
1 10 40 100
n_e [cm^{-3}]
[NII] 205 μ m
[NII] 205 μm
n_{crit} = 44 cm^{-3}
SFR surface density
$\log_{10}(\Sigma_{SFR}$ [M_{sun} yr^{-1} kpc^{-2}])
[NII] 122 μ m
disp = 0.24 dex
$\log_{10}(\Sigma_{[NII]}\times(N/H)_{\odot}/(N/H)$ [L_{sun} kpc^{-2}])
[NII] surface brightness
$\log_{10}(\Sigma_{SFR}/\Sigma_{SFR([NII])})$
[NII] 122 μ m
$\log_{10}(\nu f_{\nu}(70)/\nu f_{\nu}(100))$
IR color
[NII] 122 μm
n_{crit} = 290 cm^{-3}

Summary and Conclusions

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

Herrera-Camus+ 2015



Distribution of n_e densities of the singly ionized gas with a median n_e ~30 cm^{-3}

We find good correlations between [NII]-SFR. However, note that a [NII]-based SFR calibration depends on [N/H], n_{e0} and σ.

Herrera-Camus+ 2016