[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

NGC5457

FUV
Hα
24 μm
3. ALMA

- Flux (mJy) vs. Redshift
- Redshift range from 1 to 8
- Black line: Milky Way (5 x 10^7 L⊙)
- Red line: ULIRG (10^9 L⊙)
- Red line shows 4σ Full ALMA in 4 hrs.
The Goal

Use resolved regions from a sample of 49 KINGFISH galaxies

Study how \([\text{CII}]\) 158 \(\mu\)m emission correlates with other star formation tracers

Derive a SFR calibration based on \([\text{CII}]\) 158 \(\mu\)m
Fraction of 24 μm associated to cirrus:

avg. $f_{\text{cirrus}} \sim 20\%$

($\sim 19\%$ Leroy+12, 7% Law+11)

AGN Contribution

X-ray Dominated Regions contribute to 24 μm

24 μm

“Cirrus” Contribution

e.g. dust heated by old stars

[ClII] versus 24 μm associated to SF
The [CII] - 24μm Correlation

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

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

49 galaxies

$\log_{10} \Sigma_{24\mu m}$ [erg s$^{-1}$ kpc$^{-2}$]

$\log_{10} \Sigma_{[\text{CII}]}$ [erg s$^{-1}$ kpc$^{-2}$]

$[\text{CII}]$ S/N < 3

NGC 1377
AGN Contribution: mask the central \( \sim 0.5 \text{kpc} \) region

About half of the AGN regions show a moderate 24\(\mu\)m excess compared to [CII]

\[ \log_{10} \sum_{[CII]} \left[ \text{erg s}^{-1} \text{kpc}^{-2} \right] \]

49 galaxies

Regions from 28 Galaxies classified as AGNs (Moustakas+10; Grier+11)
We find good $\Sigma_{\text{[CII]}} - \Sigma_{24\mu m}$ correlation with a $\sim 0.24$ dex scatter.
We find tight, nearly linear correlation between $\Sigma_{\text{CII}}$ and $\Sigma_{\text{SFR}}$ with a $\sim 0.22$ 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

Fit Residual = $\log_{10}(\Sigma_{\text{SFR}})-(m \times \log_{10}(\Sigma_{[\text{CII}]})+n$)
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).

\[ \varepsilon_{ph} \downarrow \text{Reduced photoelectric heating efficiency} \]

\[ L_{\text{CII}} = \varepsilon_{ph} \times L_{\text{FUV}} \]
Implement an IR color correction for $\nu_{70}/\nu_{160} \gtrsim 1.25$

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

Fit Residual = $\log_{10}(\Sigma_{SFR}) - (m \times \log_{10}(\Sigma_{[CII]}) + n)$
Fit Residual = $\log_{10}(\Sigma_{\text{SFR}}) - (m \times \log_{10}(\Sigma_{\text{CII}}) + n)$

After the FIR color correction

Dust Temp.

$f(\text{LIR} ; U > 100)$

$\langle U \rangle$

$q_{\text{PAH}}$
Galaxy to Galaxy Variations

- IR color correction does not apply
- Before IR color correction
- After IR color correction
Starburst99 code

\[ L_{\text{FUV}} = f(SFR, \text{time}) \]

\[ L_{\text{FUV}} \rightarrow L_{\text{CII}} \]

PE Heating Efficiency

\[ \varepsilon_{\text{ph}} \sim 0.1 - \text{few}\% \]

\[ L_{\text{CII}} = \varepsilon_{\text{ph}} \times L_{\text{FUV}} \]

\[ L_{\text{CII}} = \varepsilon_{\text{ph}} \times f(SFR, \text{time}) \]
Comparison to SB99 model

- Age = 2 Myr, $\varepsilon_{ph} = 0.1, 1 \& 3\%$
- Age = 20-100 Myr, $\varepsilon_{ph} = 0.1, 1 \& 3\%$

At a given $\Sigma_{SFR}$, increasing $\varepsilon_{ph}$ implies higher $\Sigma_{[CII]}$.
Comparison to SB99 model

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

Stellar Pop. Age
- 12” region
- 90, 45 & 25%

Comparison to SB99 model

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