The Detection of [C II] emission not Associated with Star-Forming Material in M17 SW

A SOFIA/GREAT, APEX & IRAM 30m synergy - Part I

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Outline

- Massive molecular clouds: M17SW & NGC 3603
- Key questions
- Observations & Analysis
- Results
M17 SW, the Omega or Swan Nebula (in Sagittarius constellation) is one of the most massive and dense molecular cloud cores of the Galaxy.

Illuminated by UV radiation from young, massive stars ~ 6 times hotter and 30 times more massive than the Sun.

Geometry: nearly edge on

Distance~1.98 kpc (Xu et al. 2011) → 1''~0.009 pc

\( n(H_2) \sim 10^4 - 10^6 \text{ cm}^{-3} \) and \( T_K \sim 50 - 300 \text{ K} \)

Mass: \( \sim 1.5 \times 10^4 \, M_{\odot} \) (Stutzki & Güsten 1990)

Location: 18h20m27s -16°12'00" (J2000.0)

Image size ~ 5x5 arcminutes

North (up) - East (left)
NGC 3603 is a star nursery with an open cluster in the Carina spiral arm of the Milky Way.

- It is surrounded by the most massive visible cloud in the Galaxy.
- It has the densest concentration of very massive stars known in the Galaxy.
- Distance ~ 6.1 kpc → 1'' ~ 0.03 pc
- Location: 11h15m09.1s −61°16′17″ (J2000.0)
- Image size ~ 16x18 arcminutes
- North (up) - East (left)
Previous Results on M17 SW

ESO NTT+SOFI

Two main questions:
1) where does the $[\text{C II}]$ comes from?
2) what are the ambient conditions of the $[\text{C II}]$?
Previous Results on M17 SW

ESO NTT+SOFI

(grey - VLA HI 21cm image by Brogan & Troland 2001)
(contours by Pérez-Beaupuits et al. 2010, 2012)
(yellow O/B ionizing stars from Hanson et al. 1997)
SOFIA/GREAT previous results on M17 SW

[$\text{[C II]}$] @ 1.9 THz
- HPBW ~ 15.6"
- Sampling step = 8"
- Pixel size = -4" x 4"

$^{12}\text{CO} J=13-12$ @ 1.4 THz
- HPBW ~ 19.8"
- Sampling step = 8"
- Pixel size = -4" x 4"

$^{12}\text{CO} J=12-11$ @ 1.38 THz
- HPBW ~ 15.6"
- Sampling step = 8"
- Pixel size = -4" x 4"

Published!
Pérez-Beauuuits et al. (2012)

Submitted
Pérez-Beauuuits et al. (2015)
SOFIA/GREAT previous results on M17 SW


SOFIA/GREAT previous results on M17 SW


IRAM 30m/EMIR OTF Survey of M17 SW

Pérez-Beaupuits et al., 2015, A&A 575, A9

4’x 5’ (arcmins$^2$)
APEX OTF maps of [C I] on M17 SW


Pérez-Beaupuits et al. 2015, A&A 575, A9
How to estimate the origin of [C II]?

1) We use the C\(^{18}\)O J=2-1 and [C I] 609 \(\mu\)m to trace the dense molecular gas.

2) At each position (pixel) the two spectra are scaled up to match the [C II] spectra.

3) Subtract the scaled up spectra from [C II].

4) Use the minimum (per channel) of the two residual [C II] spectra to estimate \(N(\text{C}^+)\) and the gas mass not associated with dense molecular gas.

Assume LTE conditions

\((n>n_{cr} \sim 3 \times 10^3 \text{ cm}^{-3} \text{ and } T_k > 91 \text{ K})\)


\[
N([\text{C II}]) = \eta_c^{-1} I([\text{C II}]) \times 6.3 \times 10^{20} \text{ [cm}^{-2}]\]

Pérez-Beauquins et al. 2015, A&A 575, A9
Results on M17 SW

Total $N(C^+)$ channel maps

Pérez-Beaujouls et al. 2015, A&A 575, A9

$M_H = 1.4m_H \frac{N([C\,\text{II}])}{X_{C/H}} A_{beam}$
Results on M17 SW

Residual $N(C^+)$ channel maps

Pérez-Beauuuits et al. 2015, A&A 575, A9

$$M_H = 1.4 m_H \frac{N([C \text{ II}])}{X_{C/H}} A_{\text{beam}}$$
Results on M17 SW

Total gas mass $\sim 4.4 \times 10^3 \, M_\odot$
Residual gas mass $\sim 2.8 \times 10^3 \, M_\odot$

$\sim 64\%$ of the mass traced by [C II] is not associated with star-forming material traced by [C I] and C\textsuperscript{18}O

Pérez-Beauquiuits et al. 2015, A&A 575, A9
New SOFIA/GREAT Results for NGC 3603

Pérez-Beaujouls et al. (in prep.)

\[ \sim 14.3 \times 6 \text{ arcmin}^2 \]
New APEX/FLASH$^+$ Results for NGC 3603

Pérez-Beaupuits et al. (*in prep.*)

$\sim 14.3 \times 6 \text{ arcmin}^2$
Same method on NGC 3603

North

South

Pérez-Beauquuits et al. (in prep.)
Residual [C II] column density in NGC 3603

North

South

Pérez-Beauquots et al. (in prep.)
Results for NGC 3603

Gas Mass

Total: $\sim 7.5 \times 10^3 \, M_\oplus$

Residual: $\sim 4.2 \times 10^3 \, M_\oplus$

Total: $\sim 8.1 \times 10^3 \, M_\oplus$

Residual: $\sim 4.8 \times 10^3 \, M_\oplus$

$\sim 56\%$ and $\sim 60\%$ of the gas mass traced by [C II] is not associated with star-forming material in the northern and southern region, respectively.

Pérez-Beaujauits et al. (in prep.)
[C II] and Atomic Hydrogen in M17 SW

(grey VLA HI 21cm image by Brogan & Troland 2001)
(contours by Pérez-Beaupuits et al. 2010, 2012)
(yellow O/B ionizing stars from Hanson et al. 1997)

Also(!) H I optical depth from Brogan & Troland (2001)

\[
[C \text{ II}] - \{\tau(\text{H I}) + [C \text{ I}]_{609 \mu m} + ^{12}\text{CO} (1-0)\}
\]
\[ [\text{C II}] - \{\tau(\text{H I}) + [\text{C I}]_{609} \mu \text{m} + ^{12}\text{CO} (1 - 0)\} \]
...of [C II] emission (or column density) is associated with the H II, H I and H$_2$ gas phases.

Pérez-Beauquits et al. 2015, A&A 575, A9
Hydrogen Radio Recombination Lines

H39α @ ~106.74 GHz (red contour)
H41α @ ~92.03 GHz (grey background)

from the IRAM 30m survey

Pérez-Beaujouits et al. 2015, A&A 575, A9
Hydrogen Radio Recombination Lines

Pérez-Beauuuits et al. 2015, A&A 575, A9
Hydrogen Radio Recombination Lines

Ionized H II gas extended and well mixed with the neutral and part of molecular gas in M17 SW.

Pérez-Beauquicts et al. 2015, A&A 575, A9
Summary

- Combine IRAM 30m low-J CO data with APEX [C I] data and the GREAT [C II] map to estimate column densities of C$^+$ and gas masses of ionized carbon NOT associated with star-forming material traced by [C I] and C$^{18}$O.

- We found a large \(~64\%\) of the gas traced by [C II] that is not associated with the star-forming material traced by [C I] and C$^{18}$O in M17 SW.

- At larger scales, between 56\% and 60\% of the [C II] emission is not associated with dense star-forming material in the northern and southern NGC 3603. **Implications for the [C II] \(\rightarrow\) SFR (?)**

- **Where does the [C II] comes from?**
  
  About 36\%, 17\% and 47\% of the [C II] emission is associated with the H II, H I, and H$_2$ gas phases.

  **What are the ambient conditions (density/temperature) of [C II] ?**

  Not yet well understood the densities and temperatures of the collision partners H$^+$, H, and H$_2$
CO LSED in M17 SW - C. Guevara’s talk

Pérez-Beauquuits et al. (submitted)