Max-Planck-Institut für Radioastronomie

The Detection of [C II] emission not Associated with Star-Forming Material in Giant Molecular Clouds

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

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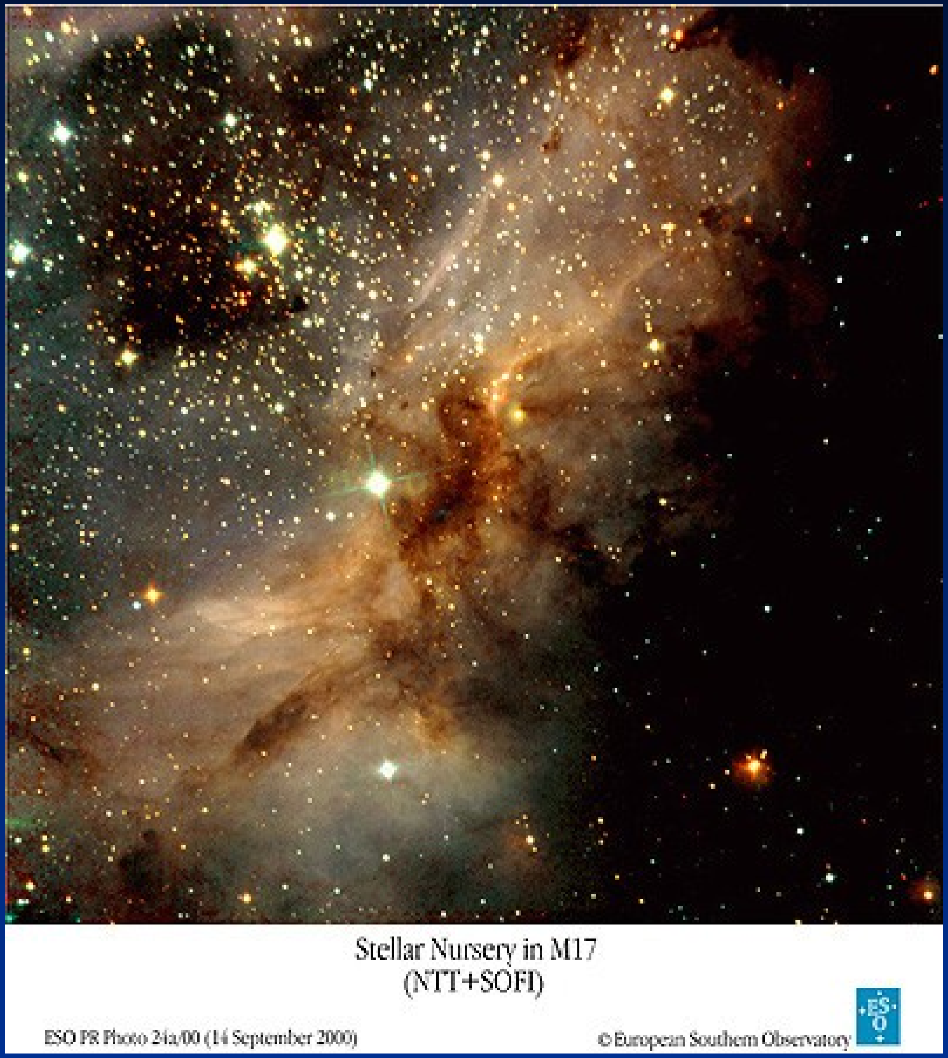
SOFIA Ringberg Workshop **March 16th, 2015**

Outline

- Massive molecular clouds:
  M17SW & NGC 3603
- Key questions?
- Observations & Analysis
- Results
- Future work

M17 SW



- 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) $\longrightarrow$ 1"~0.009 pc
- $n(H_2) \sim 10^4 - 10^6$ cm^{-3} and $T_K \sim 50 - 300$ K
- Mass: ~ $1.5\times10^4\ M_{sun}$ (Stutzki & Güsten 1990)
- Location: 18h20m27s -16°12'00" (J2000.0)
- Image size ~ 5x5 arcminutes
- North (up) - East (left)

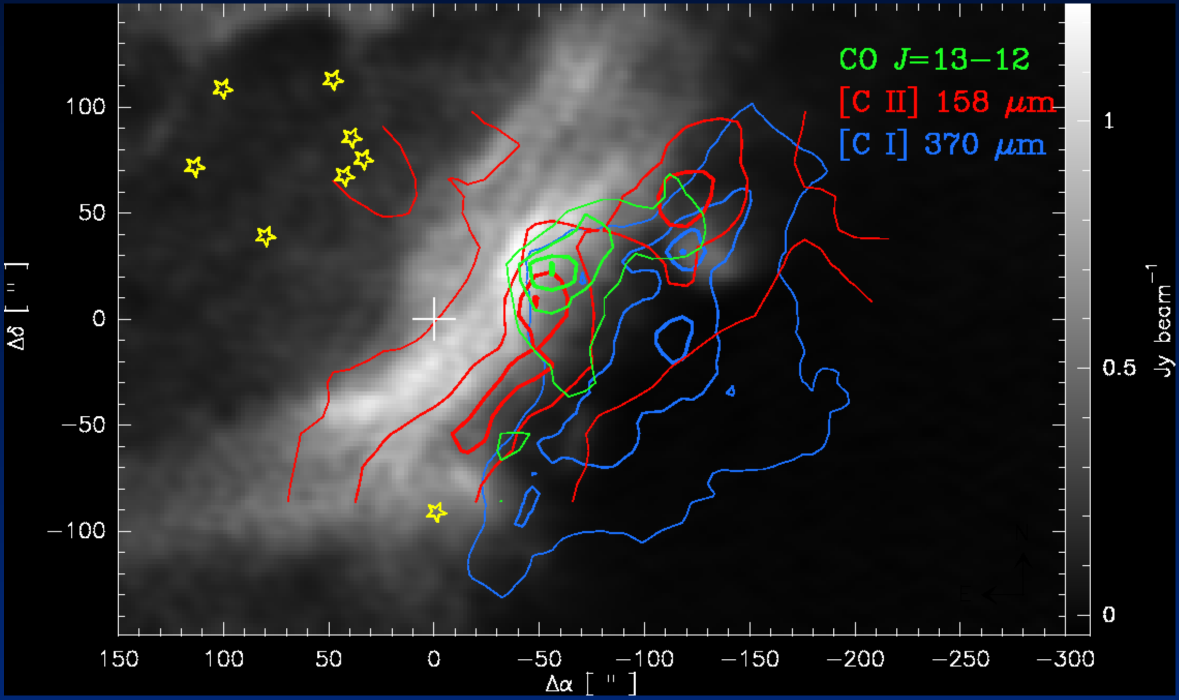
NGC 3603

ESO/VLT – FORS (V, I, R filters)

- 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 have the densest concentration of very massive stars known in the Galaxy.
- Distance~6.1 kpc $\longrightarrow$ 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



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

Two main questions:

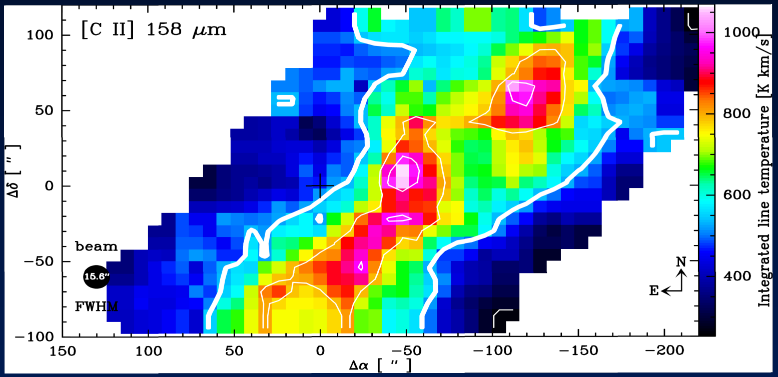
1) where does the [C II] comes from?

2) what are the ambient conditions of the [C II]?

SOFIA/GREAT previous results on M17 SW

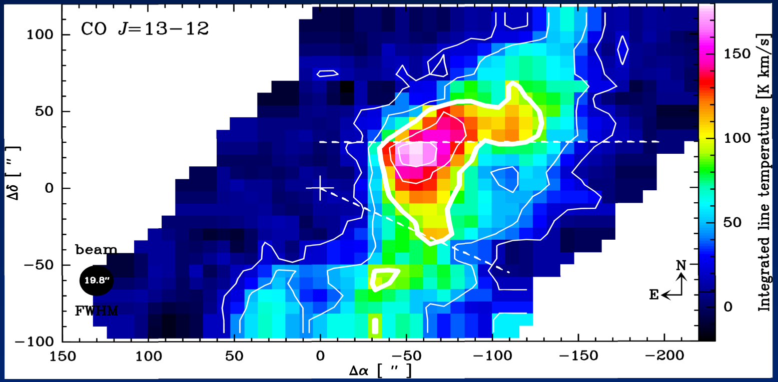
[C II] @ 1.9 THz

- HPBW ~ 15.6"
- Sampling step = 8"
- Pixel size = -4" x 4"



^{12}CO J=13-12 @ 1.4 THz

- HPBW ~ 19.8"
- Sampling step = 8"
- Pixel size = -4" x 4"



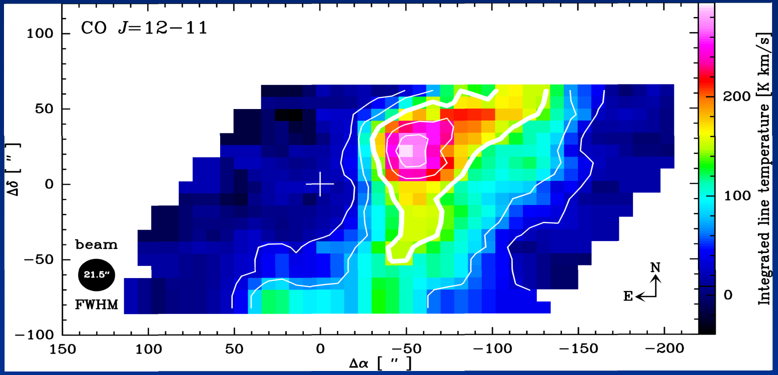
Published!

Pérez-Beaupuits et al. (2012)

A&A, 542, L13

^{12}CO J=12-11 @ 1.38 THz

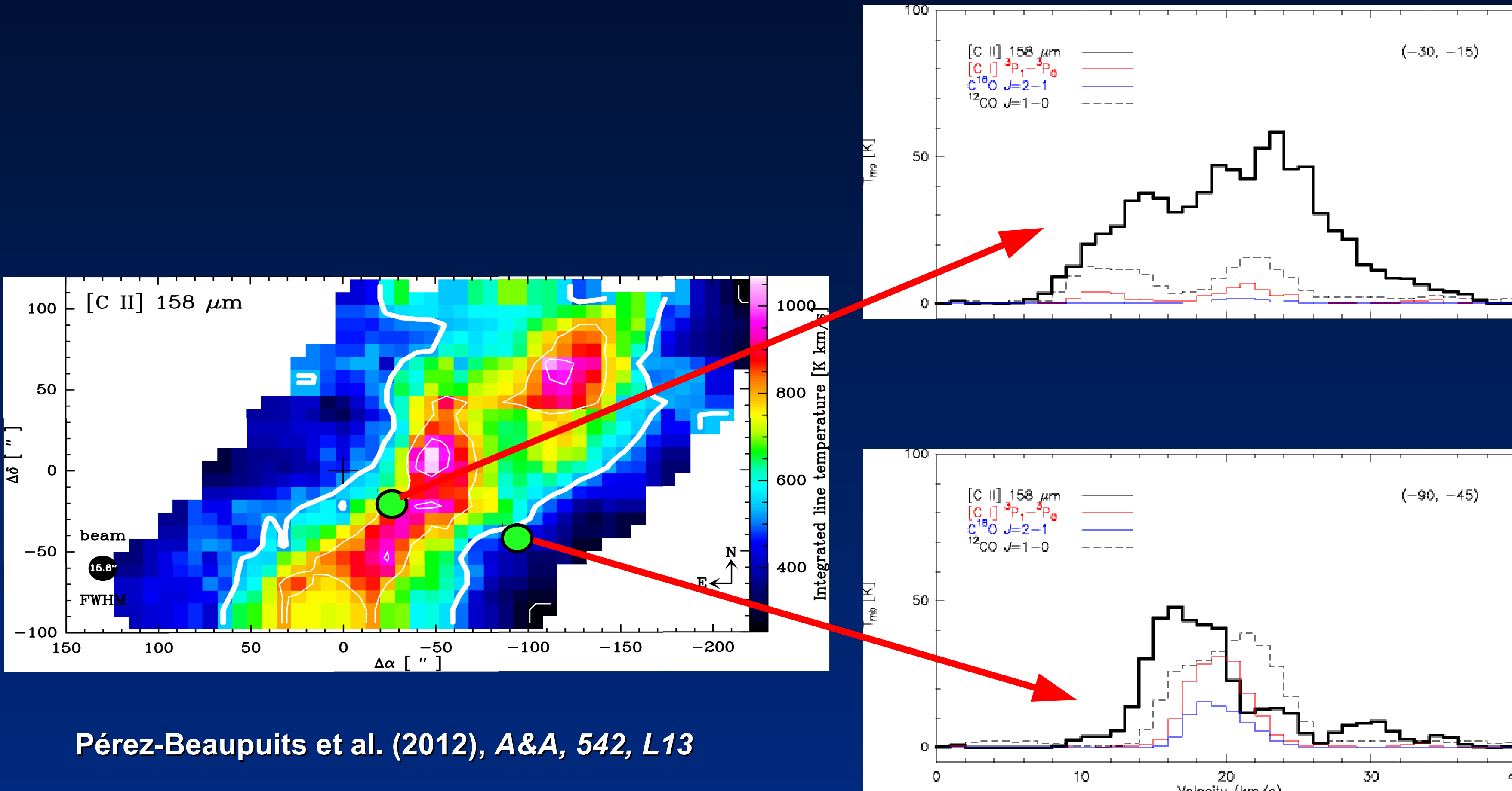
- HPBW ~ 15.6"
- Sampling step = 8"
- Pixel size = -4" x 4"



Not yet Published

Pérez-Beaupuits et al. *(in prep.)*

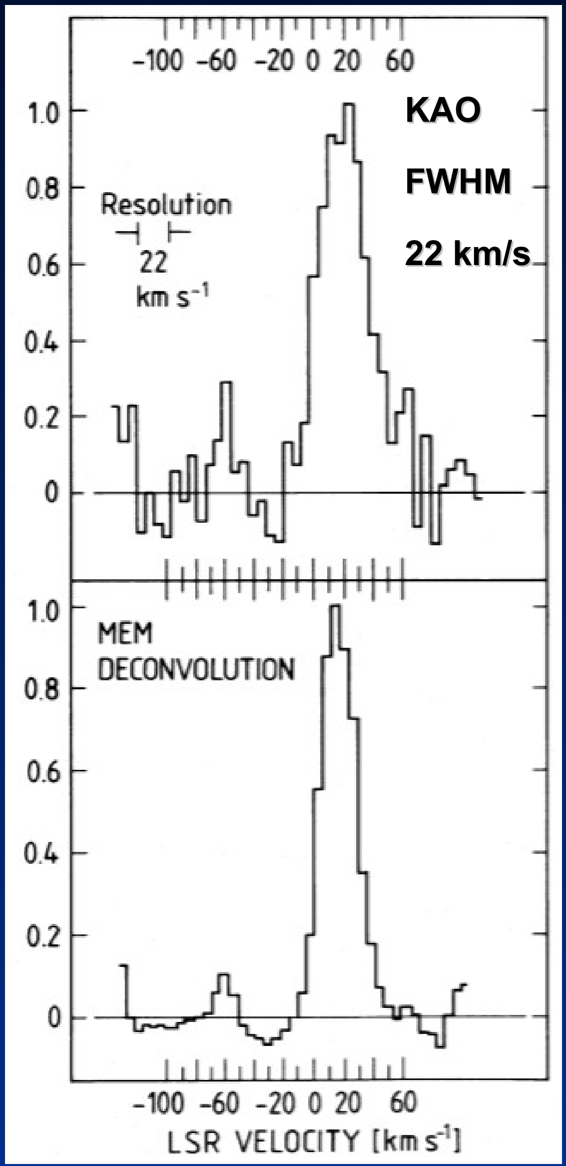
SOFIA/GREAT previous results on M17 SW



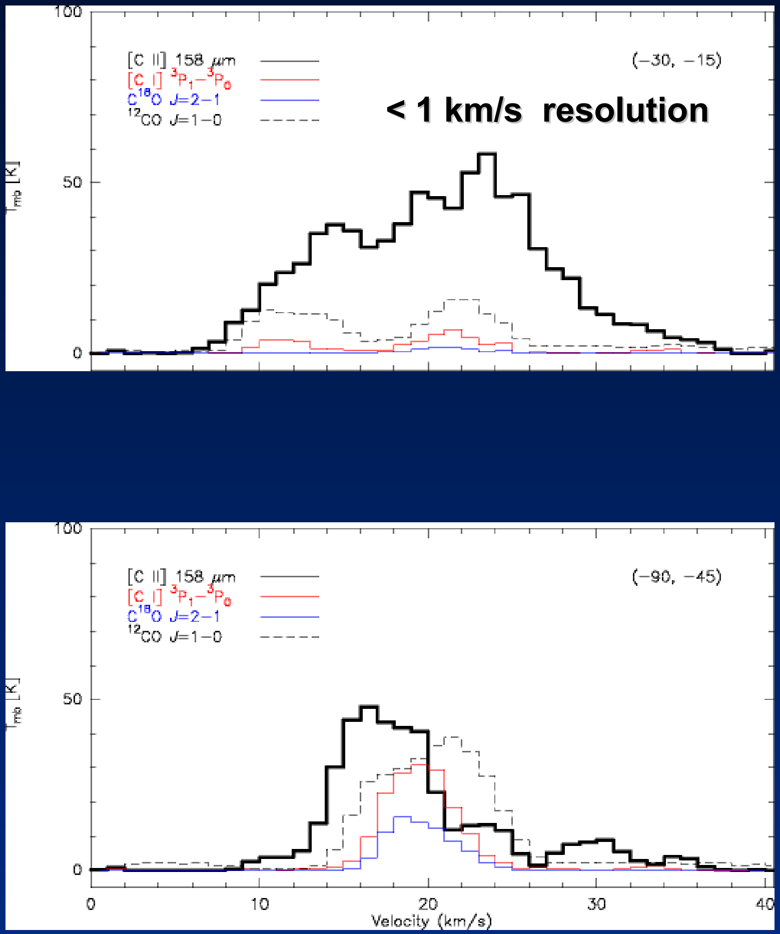
Pérez-Beaupuits et al. (2012), *A&A, 542, L13*

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

SOFIA/GREAT previous results on M17 SW



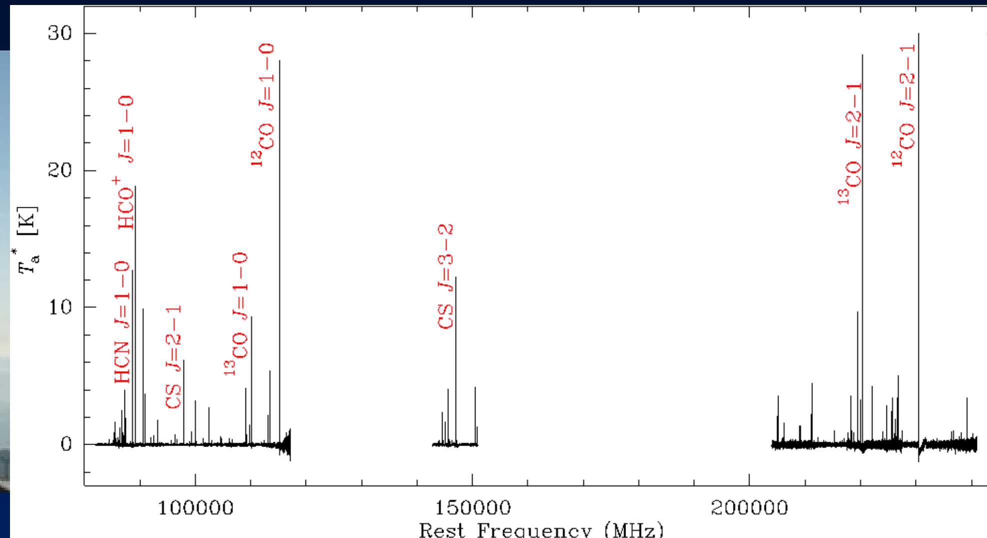
Stutzki et al. (1988), ApJ, 332, 379

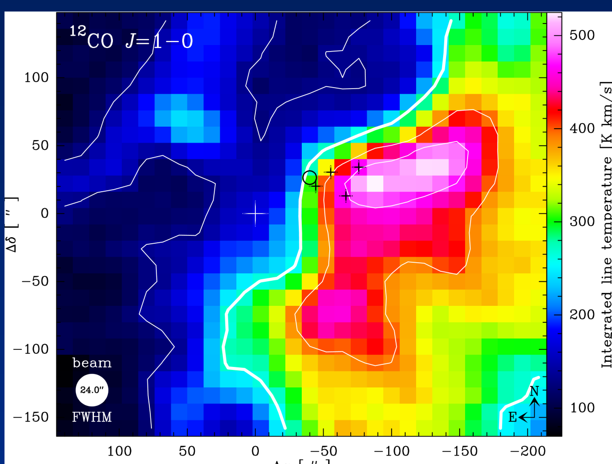


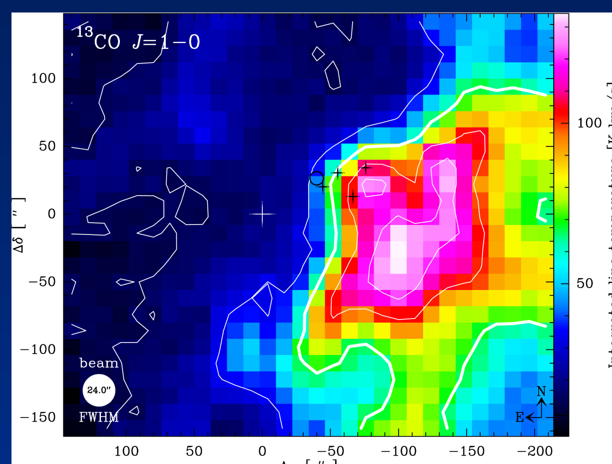
Pérez-Beaupuits et al. (2015), *A&A, 575, A9*

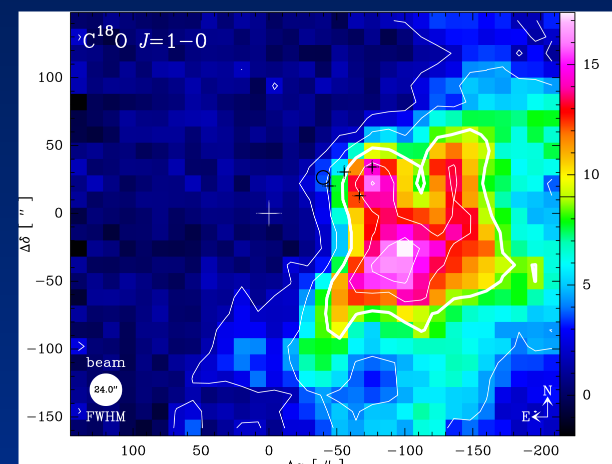
IRAM 30m/EMIR OTF Survey of M17 SW

3mm **2mm** **1mm**





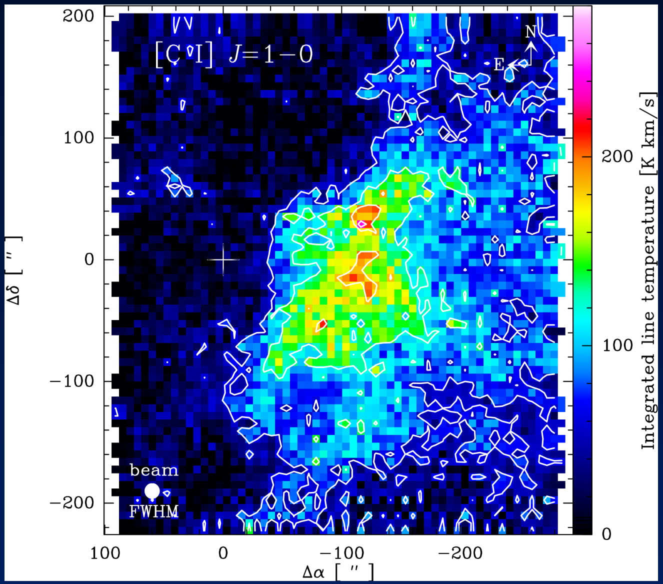




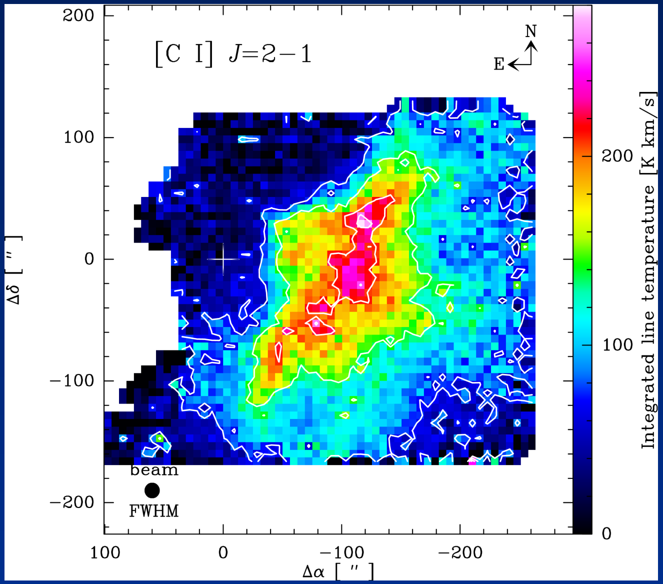
4’x 5’ (arcmins^2)

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

APEX OTF maps of [C I] on M17 SW



[C I] 609 μm
FLASH



[C I] 370 μm
CHAMP+

Pérez-Beaupuits et al., 2010,
A&A, 510, A87

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

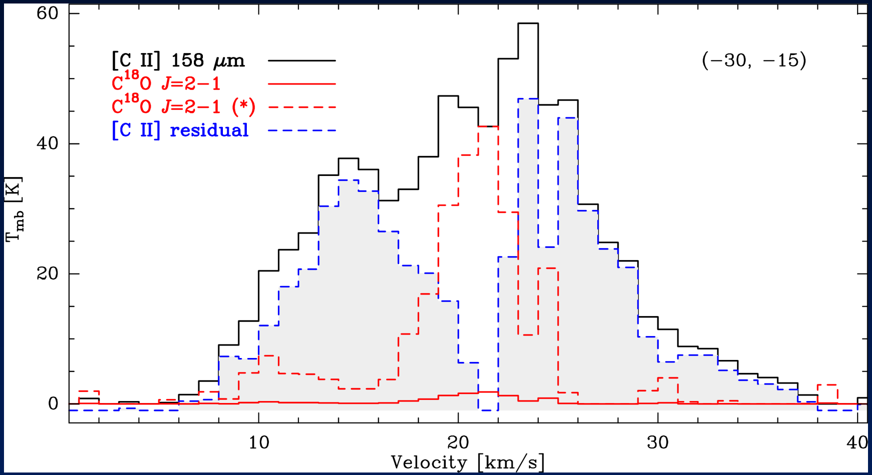
How to estimate the origin of [C II]?

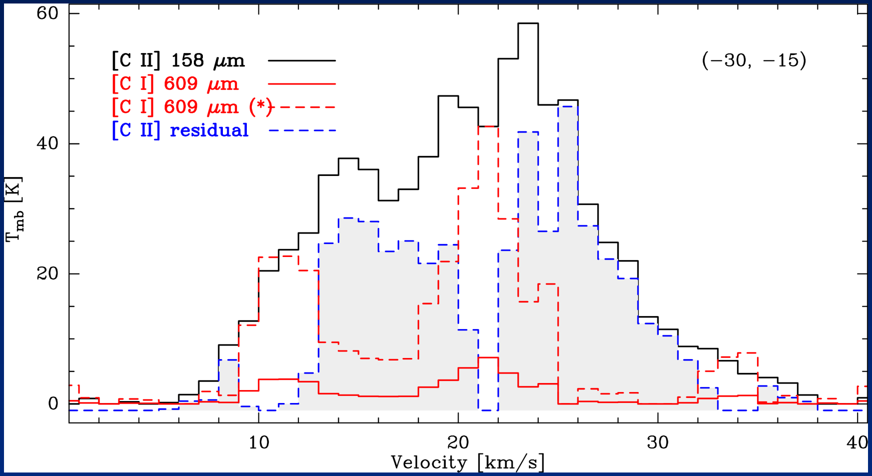
1) We use the $C^{18}O$ J=2-1 and [C I] 609 µm to trace the dense molecular gas.

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 $N(C^+)$ and the gas mass not associated with dense molecular gas.





Assume LTE conditions

($n > n_{cr} \sim 3\times10^3\ \mathrm{cm^{-3}}$ and $T_k > 91$ K)

e.g., Schneider et al. (2015) *A&A, 406, 915*

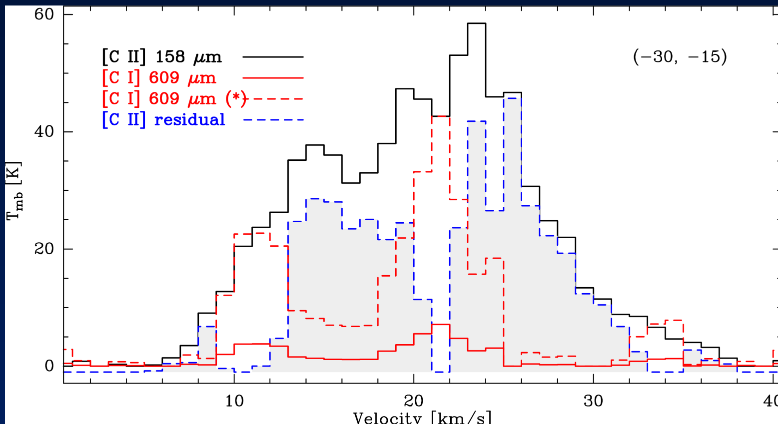
$$N([\mathrm{C\,II}]) = \eta_c^{-1} I([\mathrm{C\,II}])\, 6.3\times10^{20}\ [\mathrm{cm^{-2}}].$$

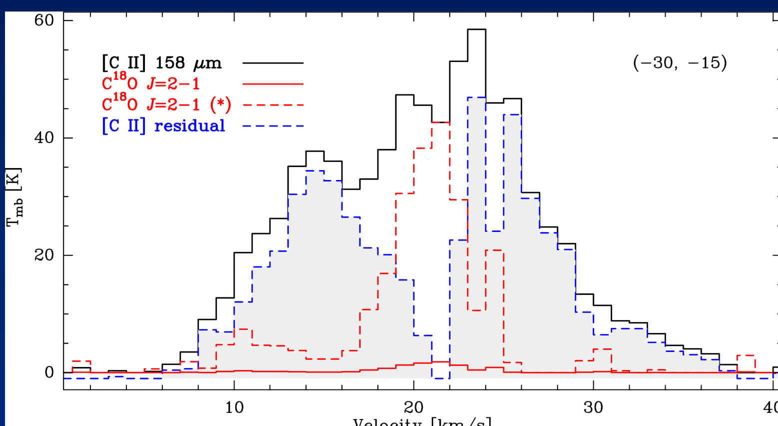
$$M_{\mathrm{H}} = 1.4 m_{\mathrm{H}} \frac{N([\mathrm{C\,II}])}{X_{\mathrm{C/H}}} A_{beam}$$

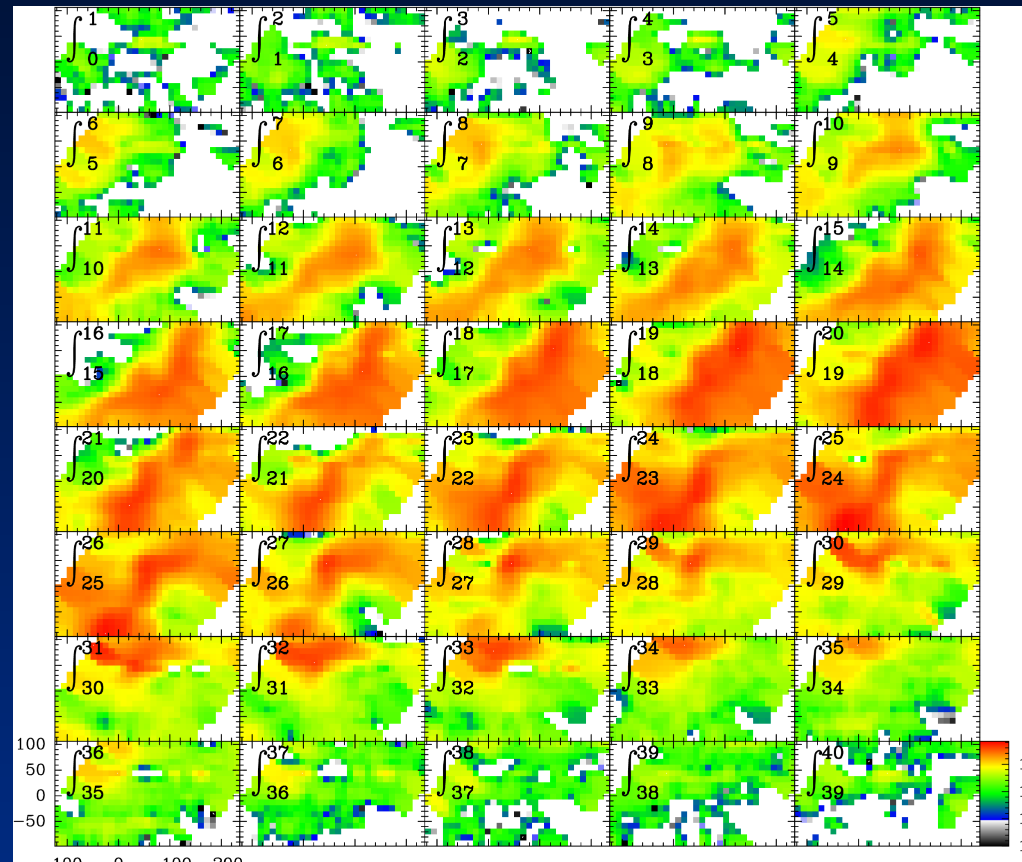
Pérez-Beaupuits et al. 2015, A&A 575, A9

Results on M17 SW

Total N(C⁺) channel maps





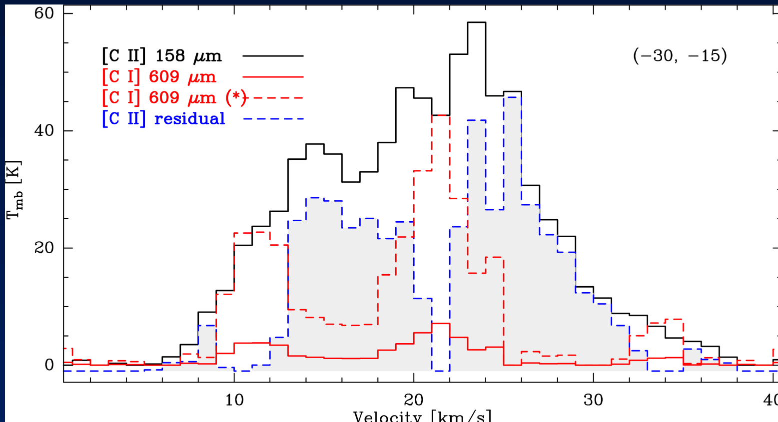


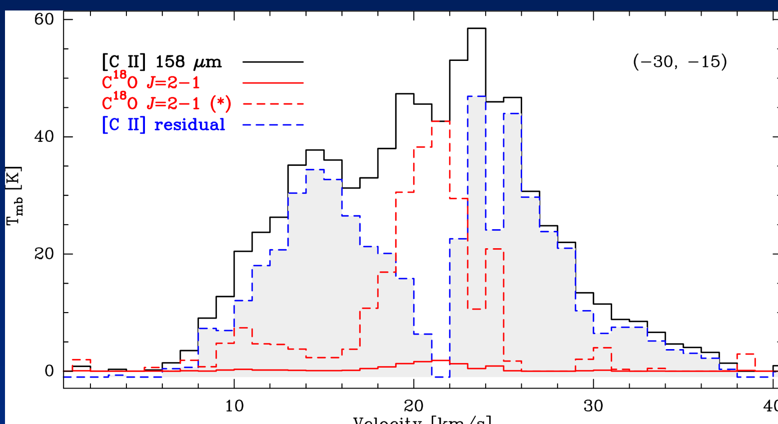
$$M_{\rm H} = 1.4 m_{\rm H} \frac{N([{\rm C\ II}])}{X_{\rm C/H}} A_{beam}$$

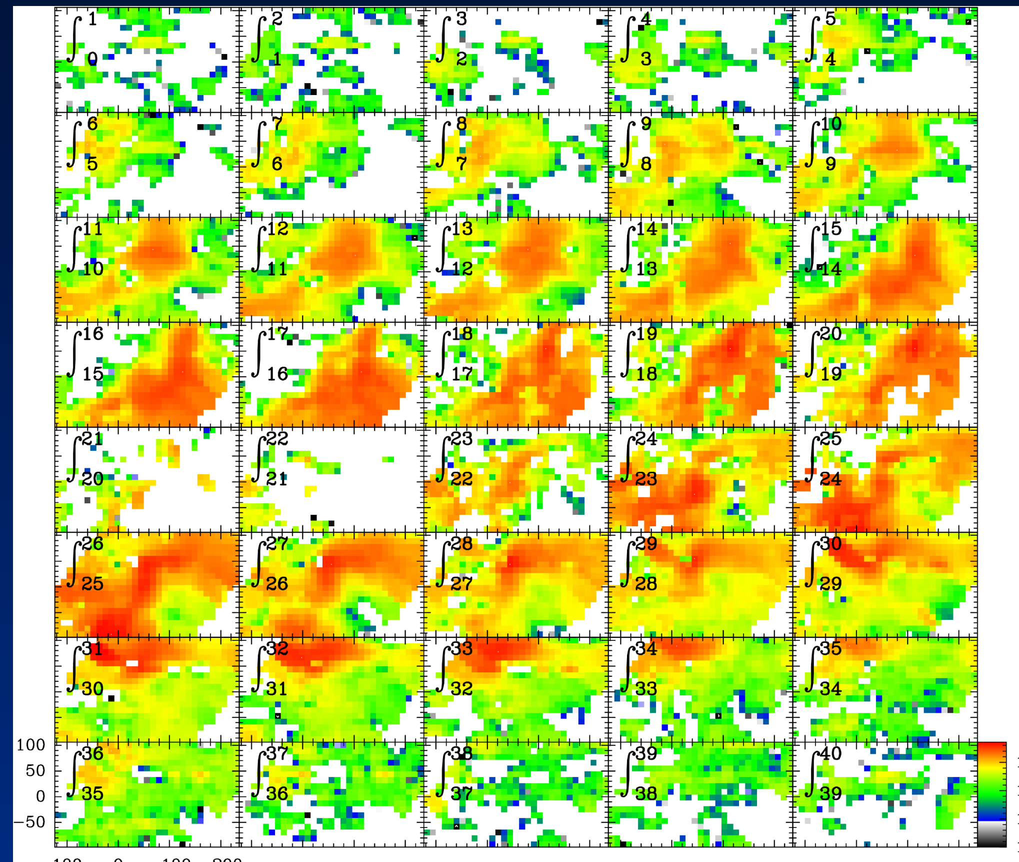
Pérez-Beaupuits et al. 2015, A&A 575, A9

Results on M17 SW

Residual N(C^+) channel maps



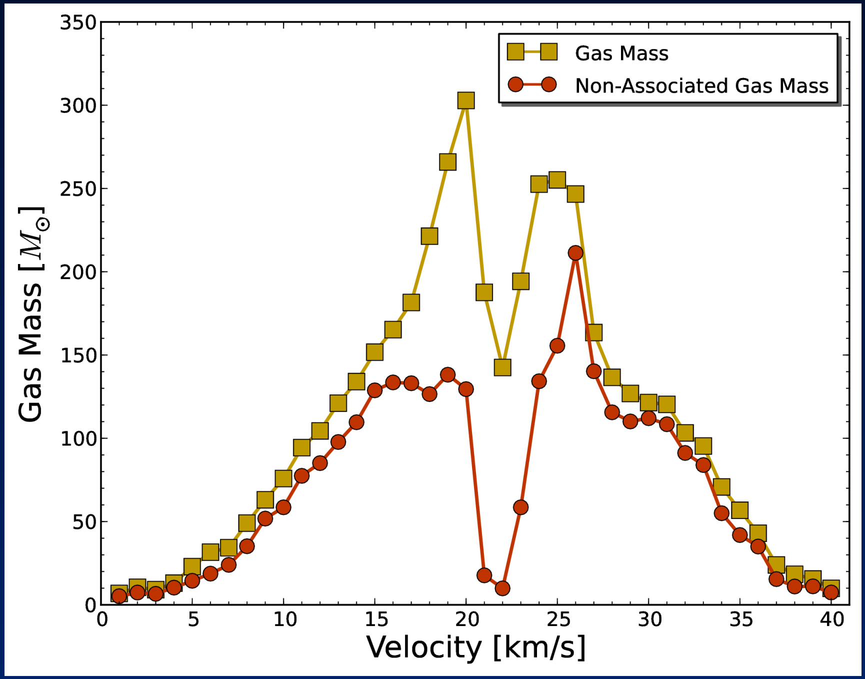


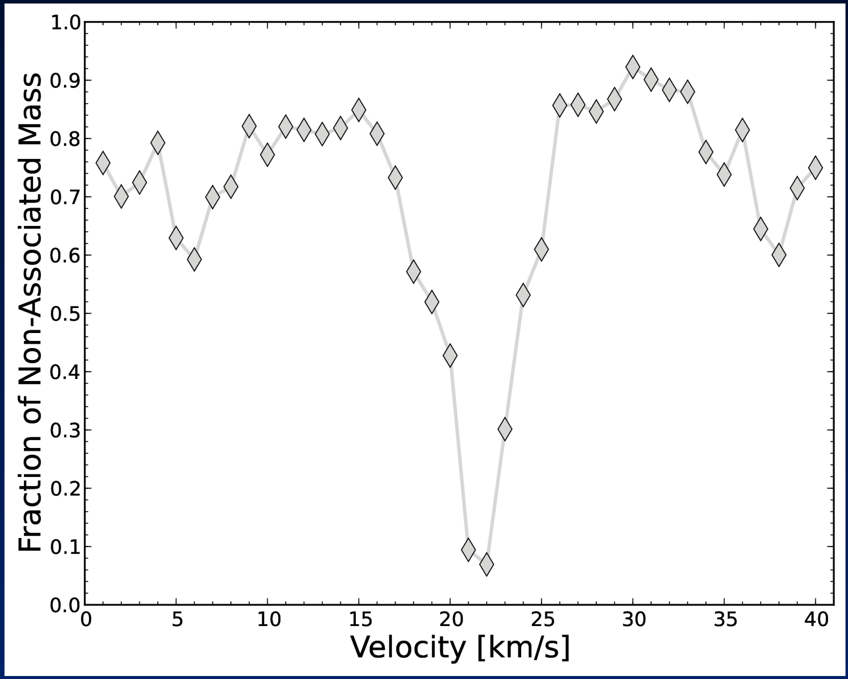


Pérez-Beaupuits et al. 2015, A&A 575, A9

$$M_{\rm H} = 1.4 m_{\rm H} \frac{N([\rm C\ II])}{X_{\rm C/H}} A_{beam}$$

Results on M17 SW



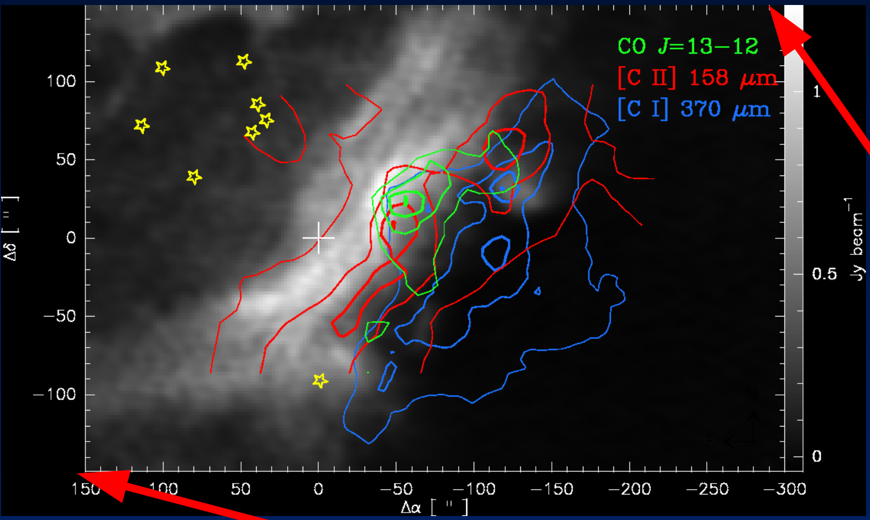


Total gas mass ~4.4 x 10^3 $M_\odot$
Residual gas mass ~2.8 x 10^3 $M_\odot$

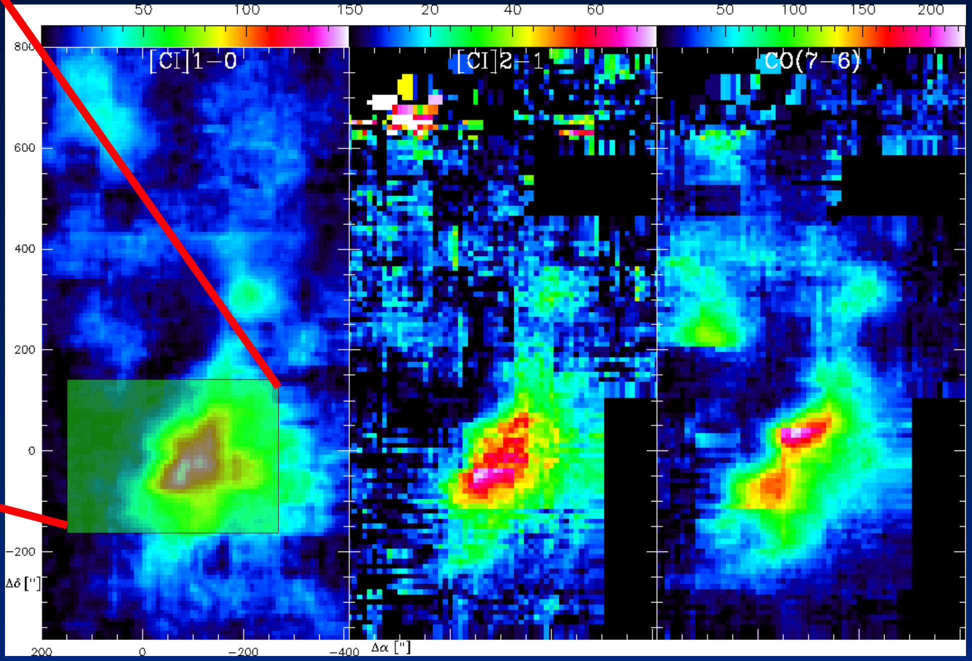
~64% of the mass traced by [C II] is not associated with star-forming material traced by [C I] and $C^{18}O$

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

Larger Scale Maps with NANTEN2 & SOFIA/UpGREAT



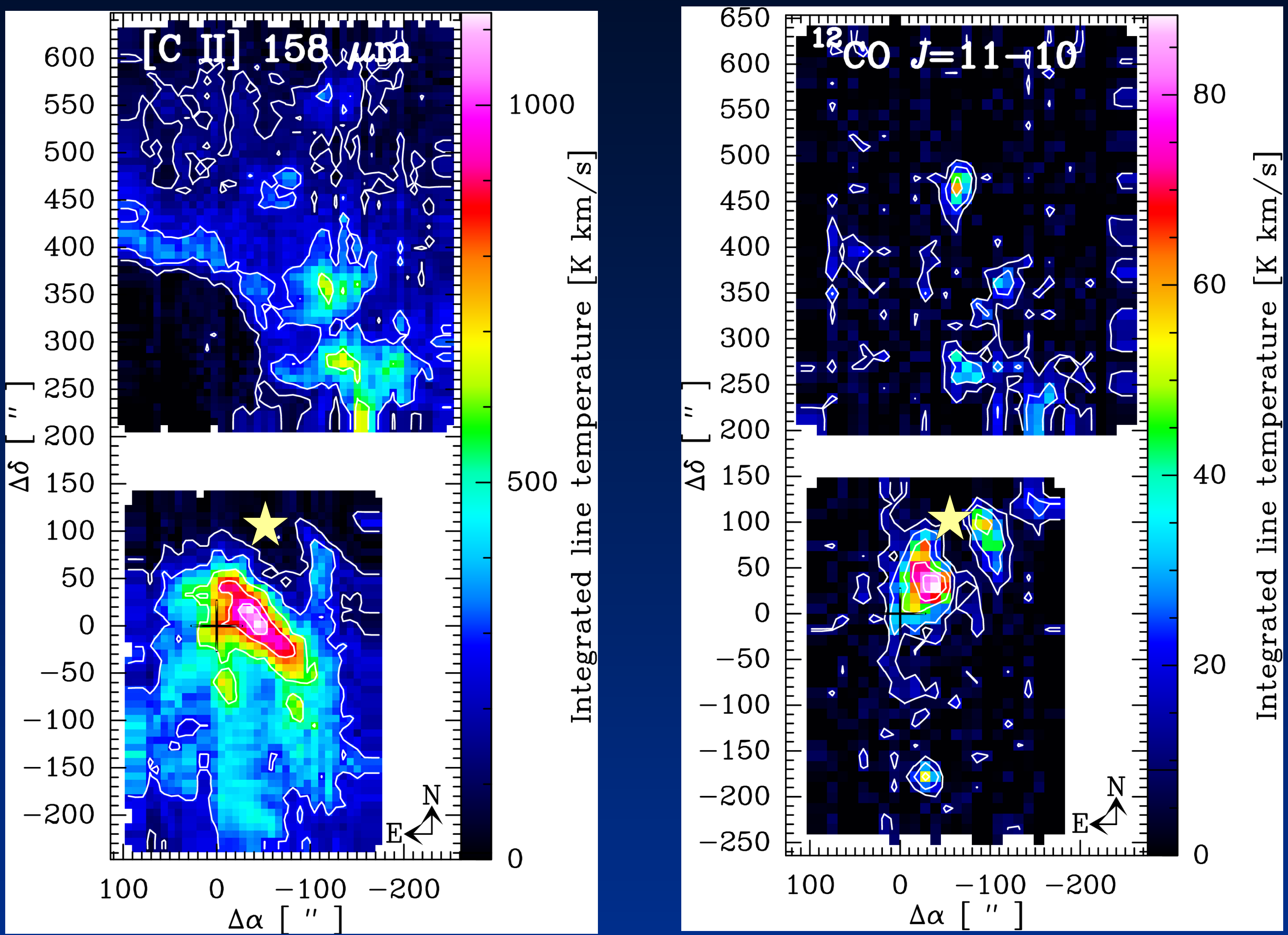
NANTEN2 maps of [CI] $^3P_1$- $^3P_0$ (beam~37 "), [CI] $^3P_2$- $^3P_1$ and CO(7-6) (beam~25 ").



10'x 22' (arcmins^2)

Poster by Cristian Guevara & the team from II.Phys. Inst. Uni. Köln

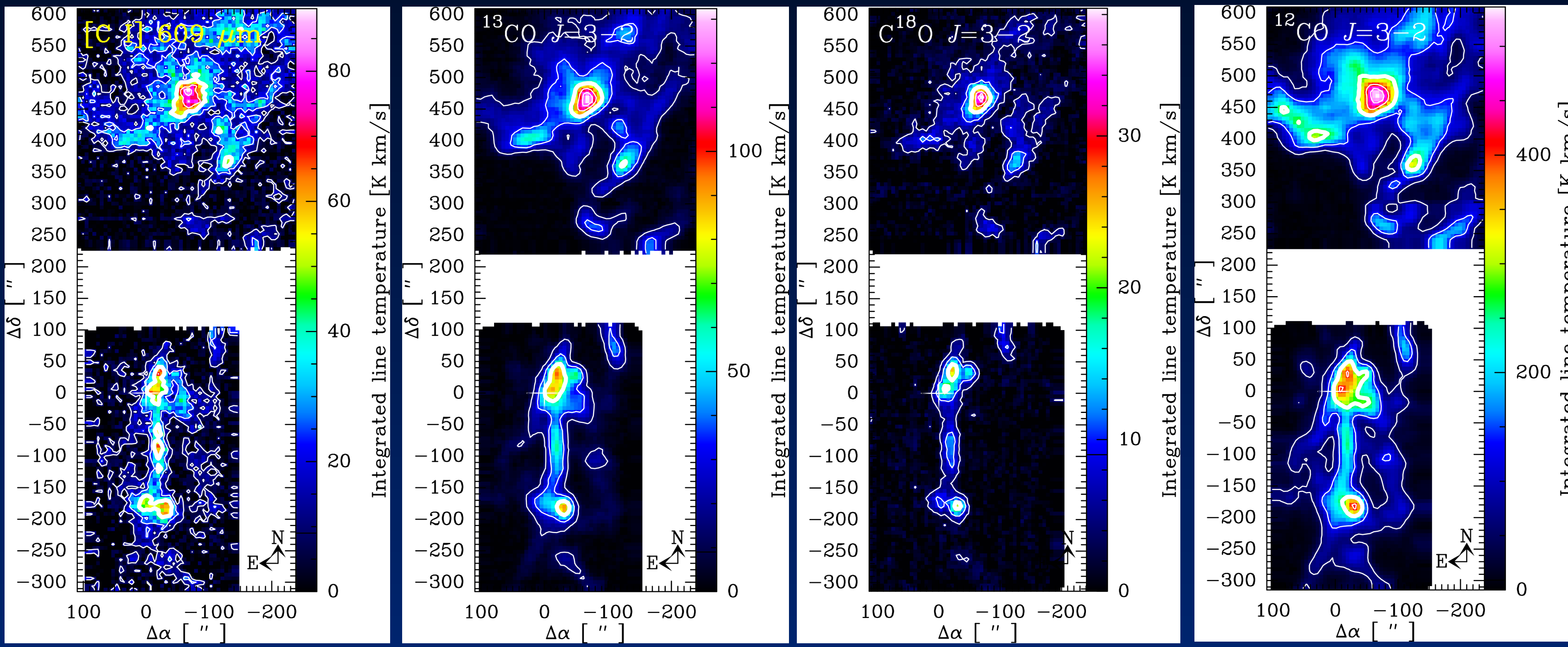
New SOFIA/GREAT Results for NGC 3603



Pérez-Beaupuits et al. (*in prep.*)

~14.3 x 6 arcmin²

New APEX/FLASH+ Results for NGC 3603

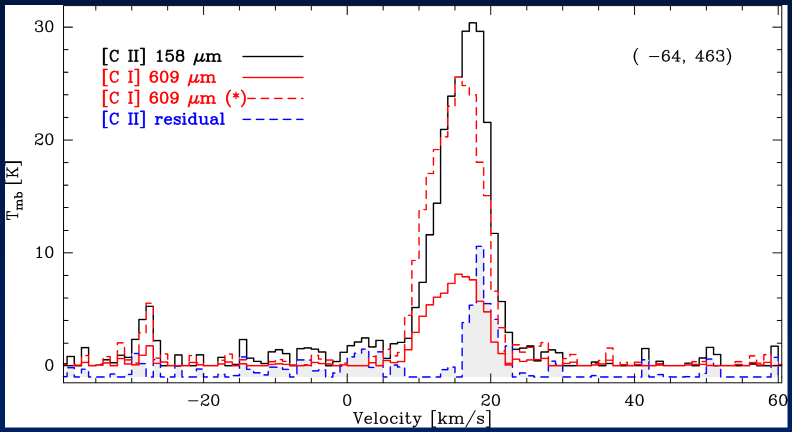


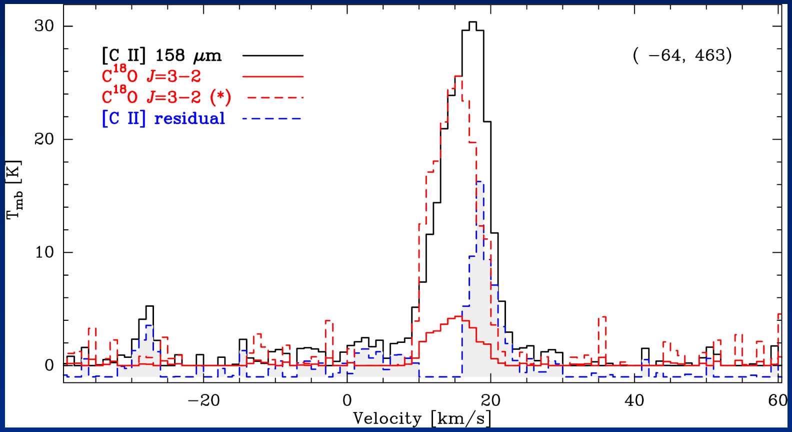
Pérez-Beaupuits et al. (*in prep.*)

~14.3 x 6 arcmin²

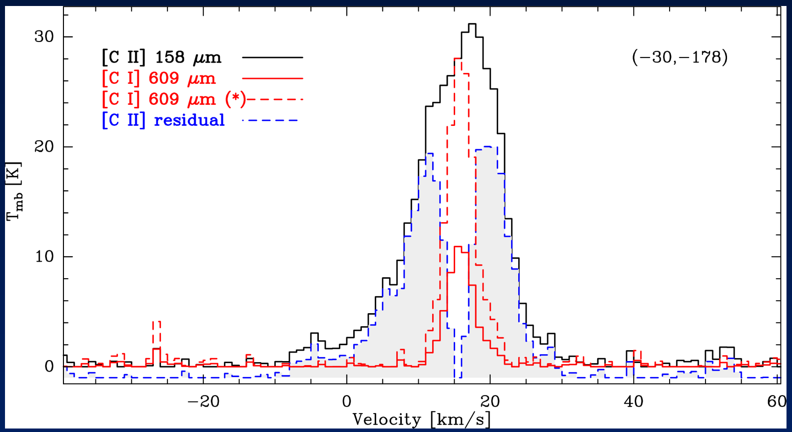
Same method on NGC 3603

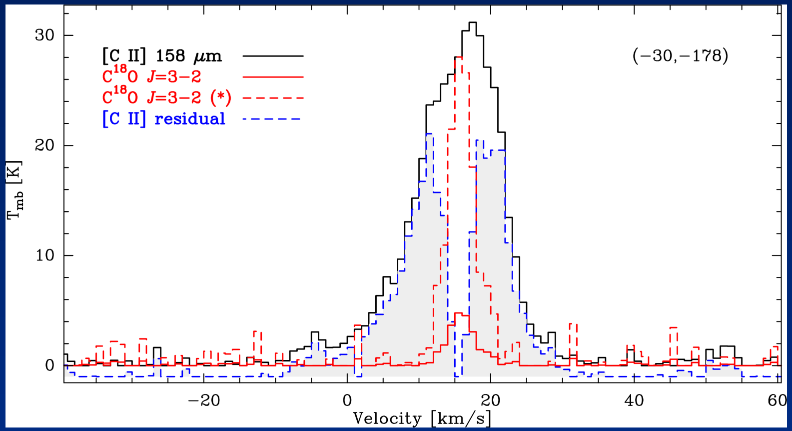
North





South

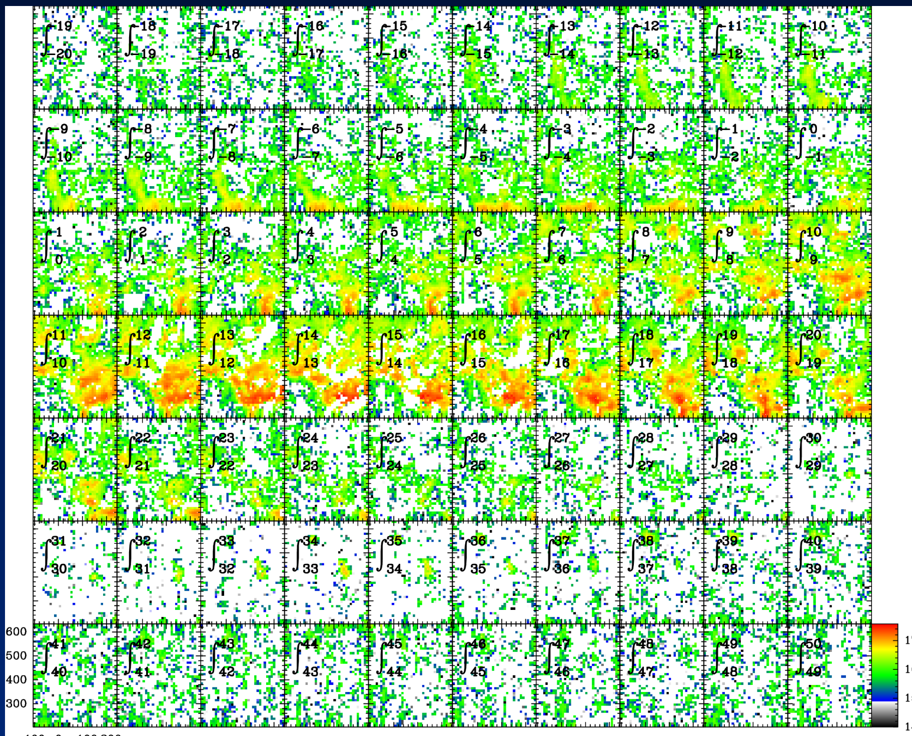




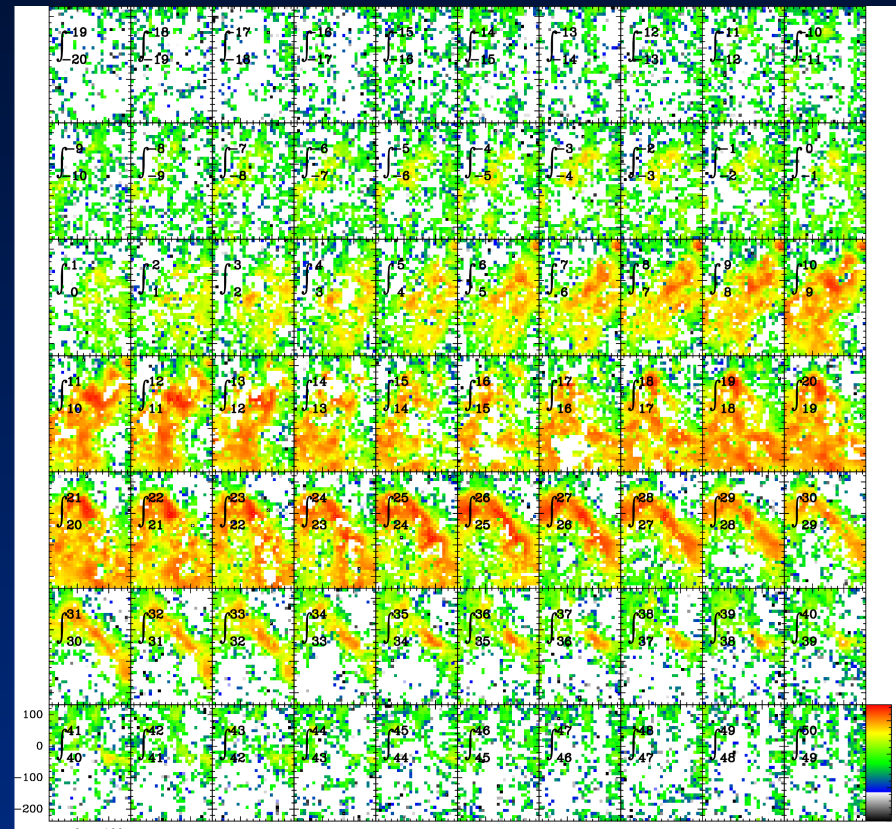
Pérez-Beaupuits et al. (*in prep.*)

Residual [C II] column density in NGC 3603

North



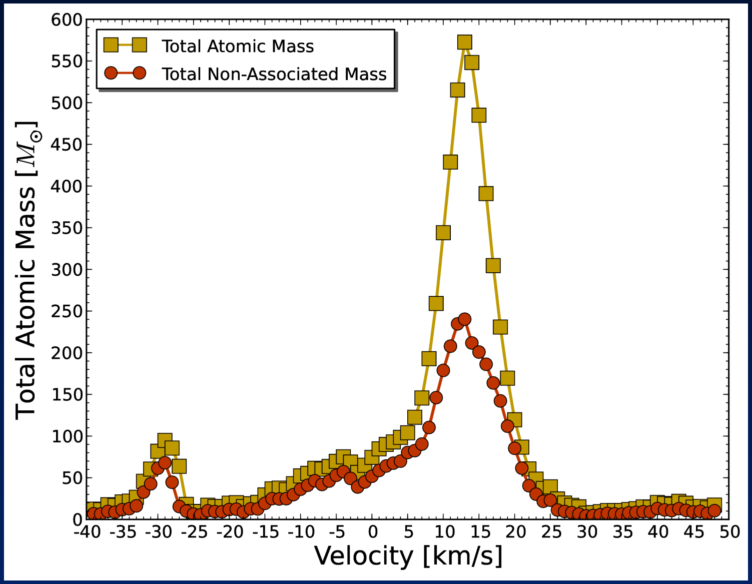
South



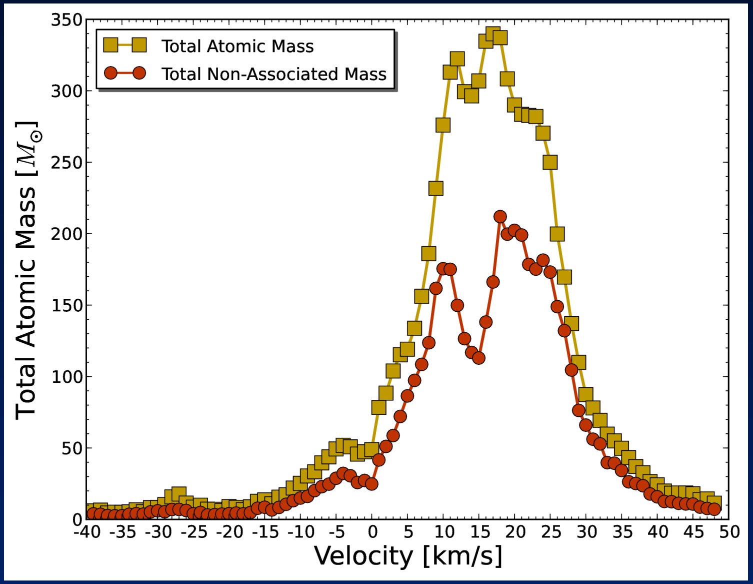
Pérez-Beaupuits et al. (*in prep.*)

Results for NGC 3603

North



South



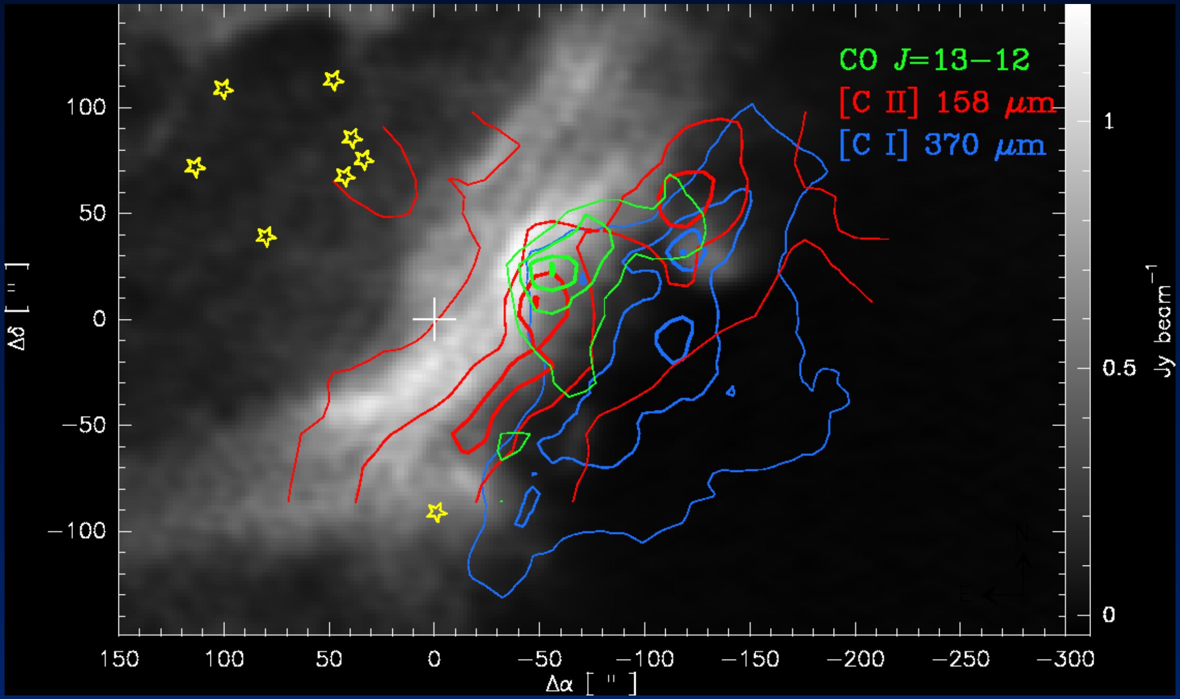
Gas Mass

	North	South
Total	~7.5 x 10^3 $M_\odot$	~8.1 x 10^3 $M_\odot$
Residual	~4.2 x 10^3 $M_\odot$	~4.8 x 10^3 $M_\odot$

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

Pérez-Beaupuits et al. (*in prep.*)

[C II] and Atomic Hydrogen in M17 SW



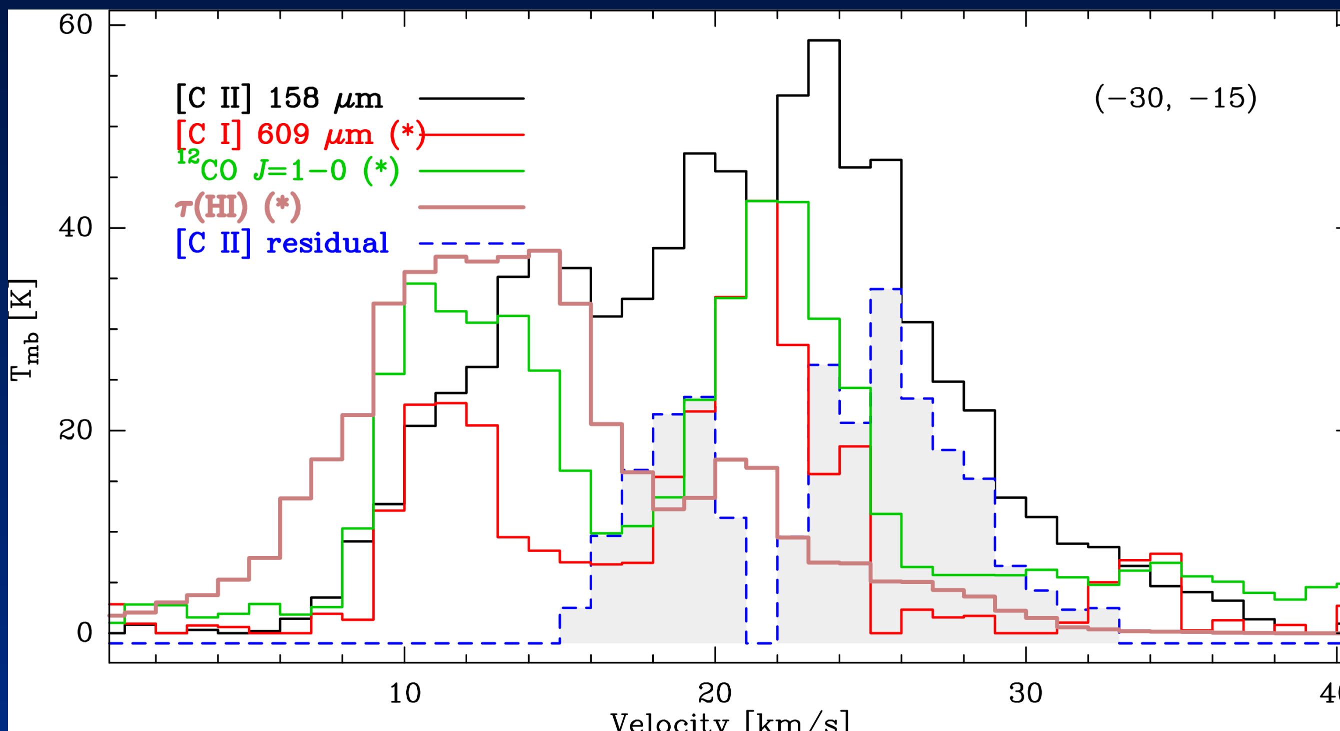
(grey VLA HI 21cm image by Brogan & Troland 2001)
(contours by Pérez-Beaupuits et al. 2010, 2012)
(yelow O/B ionizing stars from Hanson et al. 1997)

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

$$[\mathrm{C\,II}] - \{\tau(\mathrm{H\,I}) + [\mathrm{C\,I}]_{609\,\mu\mathrm{m}} + {}^{12}\mathrm{CO}\,(1-0)\}$$

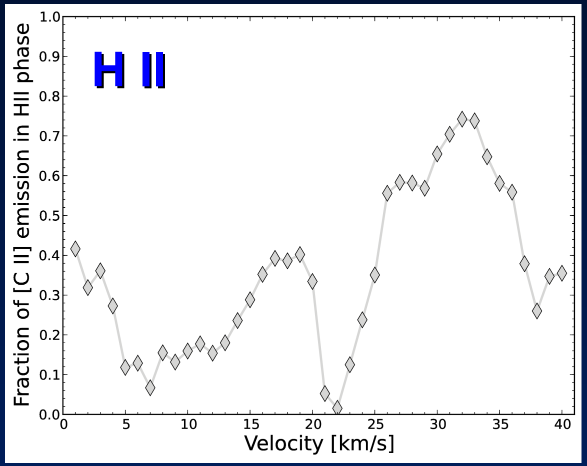
[C II] and Atomic Hydrogen in M17 SW

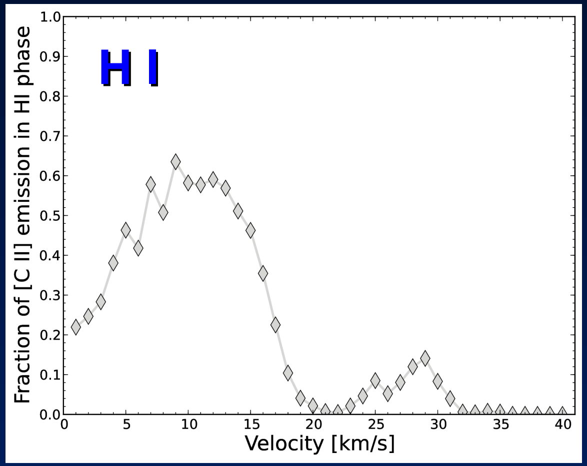
$$[\mathrm{C\ II}] - \{\tau(\mathrm{H\ I}) + [\mathrm{C\ I}]_{609\ \mu\mathrm{m}} + {}^{12}\mathrm{CO}\ (1-0)\}$$

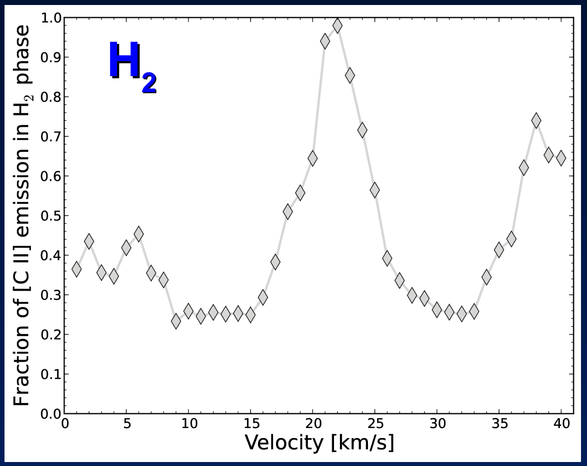


Pérez-Beaupuits et al. 2015, A&A 575, A9

[C II] in the Three Gas Phases





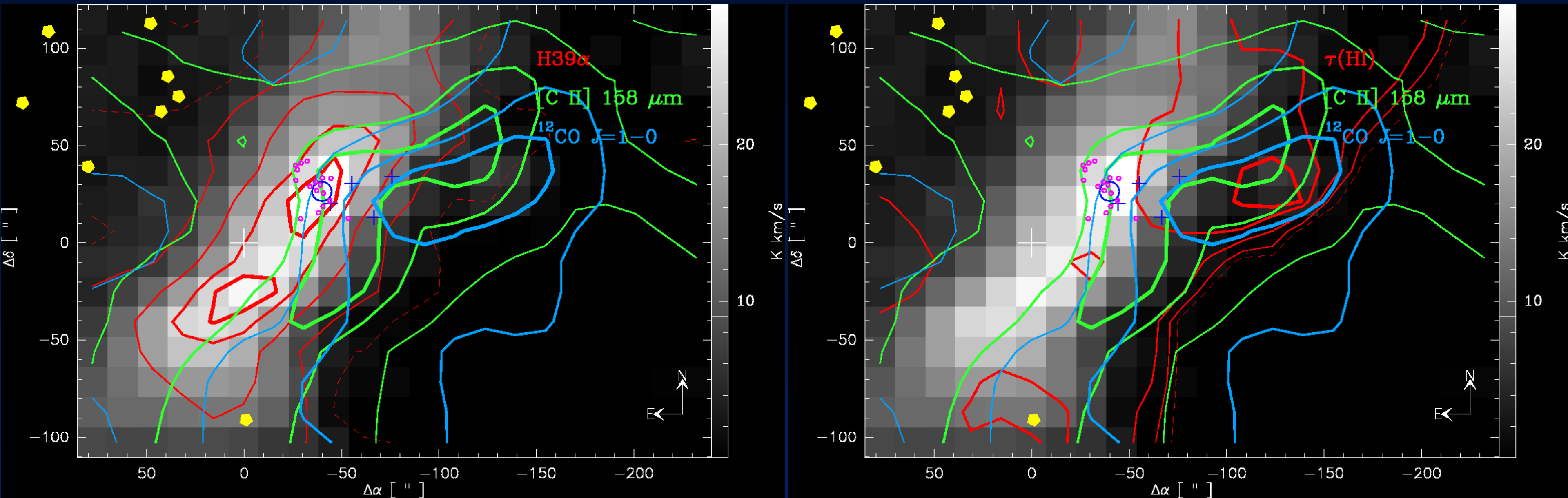


~36% | **~17%** | **~47%**

...of [C II] emission (or column density) is associated with the H II, H I and H_2 gas phases.

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

Hydrogen Radio Recombination Lines

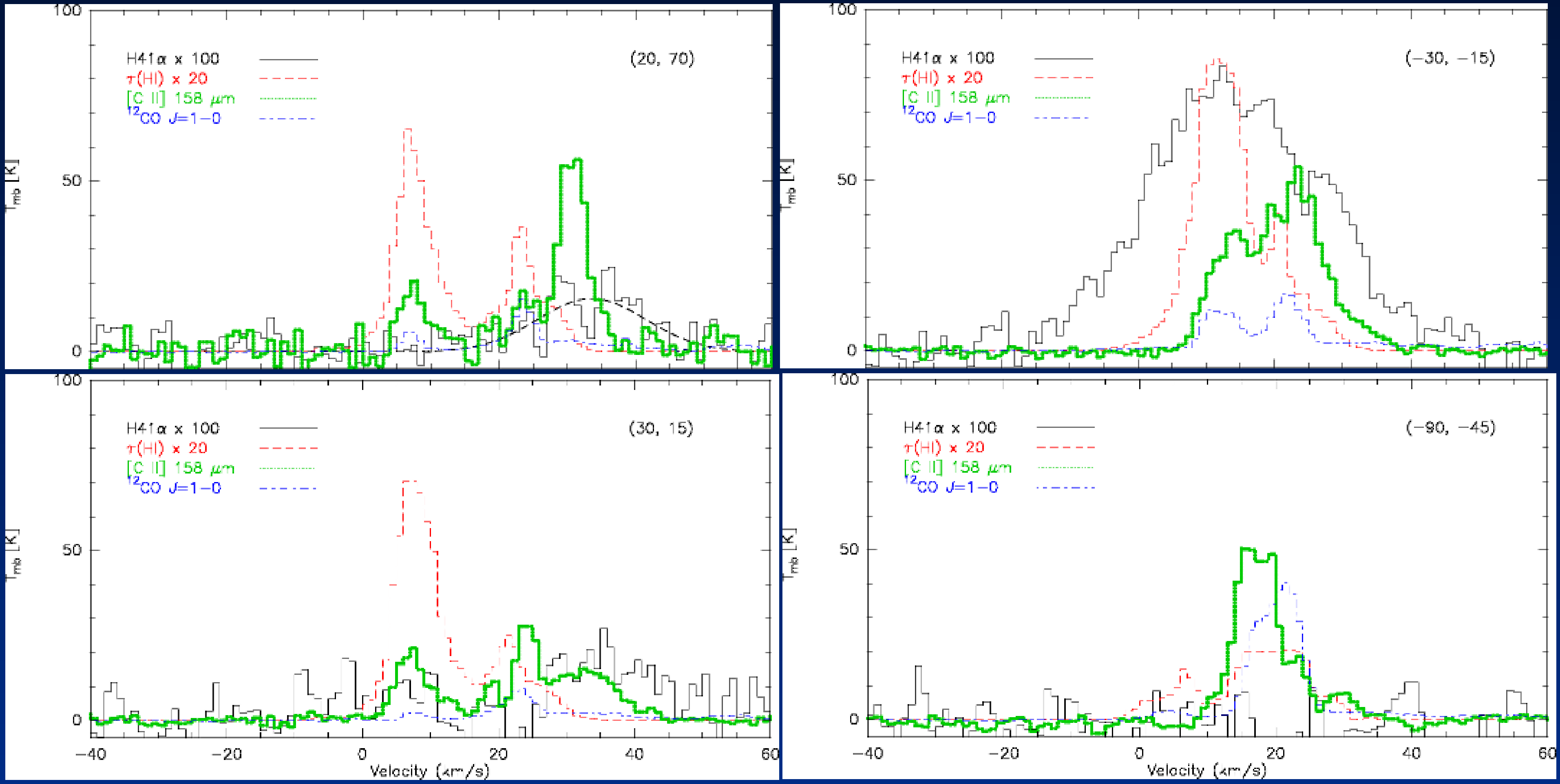


H39α @ ~106.74 GHz (red contour)
H41α @ ~92.03 GHz (grey background)

from the IRAM 30m survey

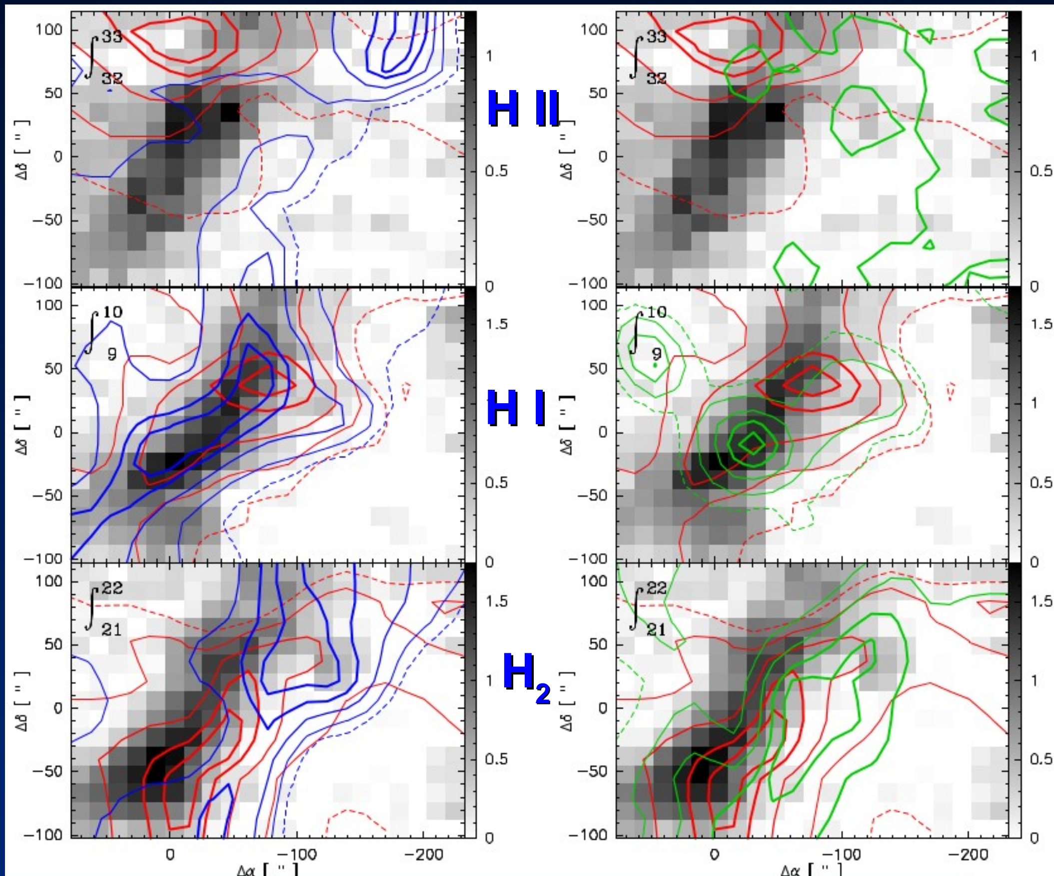
Pérez-Beaupuits et al. 2015, A&A 575, A9

Hydrogen Radio Recombination Lines



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

Hydrogen Radio Recombination Lines



H41α – grey background
[C II] – red contours
tau(H I) – blue contours
$^{12}CO(1-0)$ – green contours

- Extended ionized gas due to clumpiness and advection (Bertoldi & Draine 1996)
- This would lead to a larger contribution of the ionized gas to PDR diagnostics like [C II], as shown in models by Abel et al. (2005)

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

Pérez-Beaupuits 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.

- 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