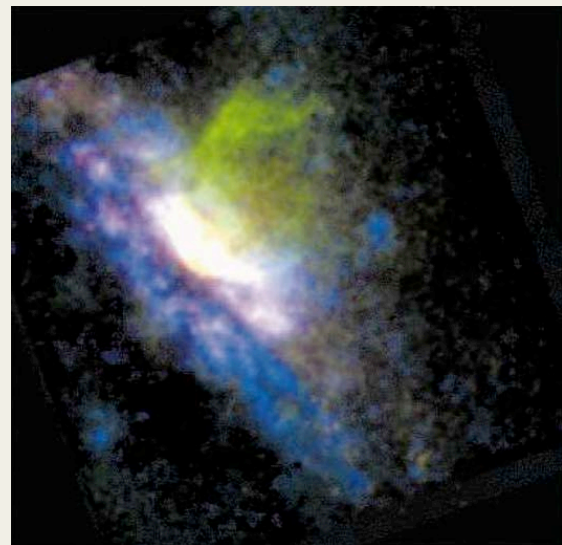
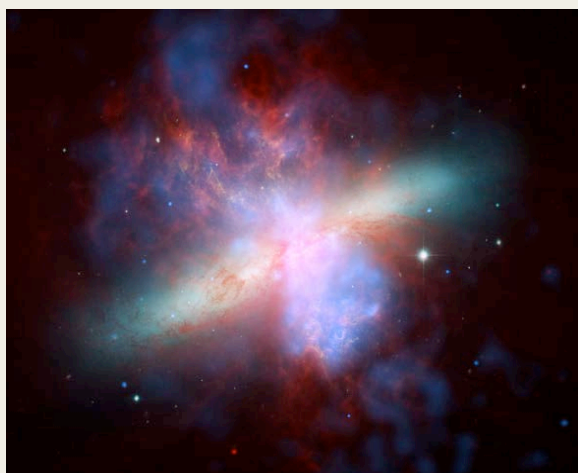


The Herschel/HIFI Insight on the $\text{CH}^+(1-0)$ Puzzle in the Diffuse Medium: the sightlines to nearby starbursts



Edith Falgarone,

Ecole Normale Supérieure & Observatoire de Paris

Godard B., Lesaffre P., Gerin M., (Obs. Paris),

Bergin E. (Michigan Univ.)

Neufeld D. (Johns Hopkins Univ.)

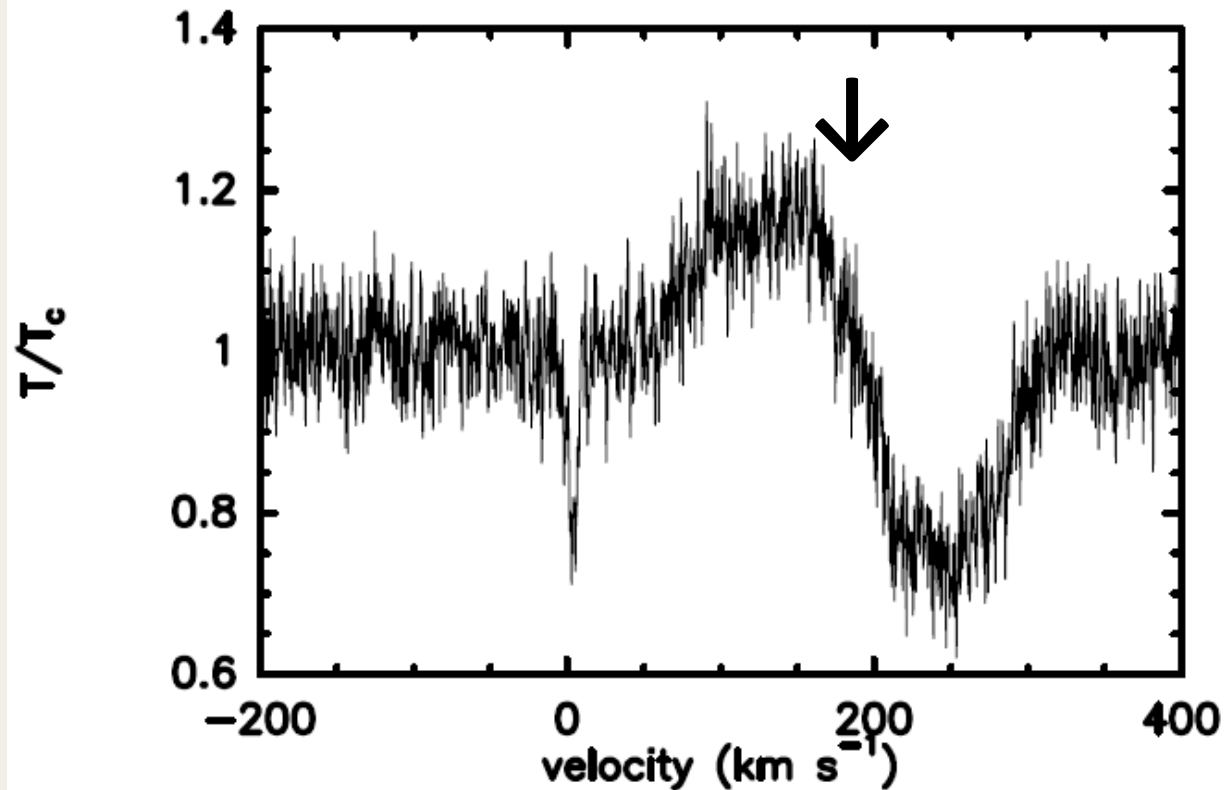
Black J. (Chalmers Univ.)

Lis D., Lord S., Phillips T.G. (Caltech)

Menten K. (MPIfR)

Joncas G. (Univ. Laval)

M 82: high latitude ISM



CH⁺(1-0)

- ⇒ galactic absorption at high latitude
- ⇒ inverse P-Cygni profile in M82



Chandra, HST, Spitzer

$$l = 141.4^\circ$$

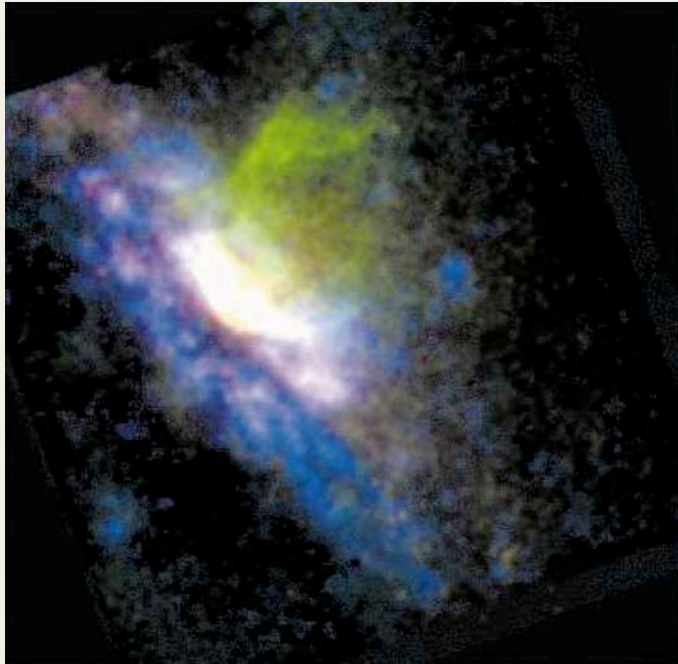
$$b = 40.6^\circ$$

$$A_v = 0.45 \text{ mag}$$

$$T_{\text{cont}} @ 830 \text{ GHz} = 0.1 \text{ K}$$

$$v_{\text{sys}} = 203 \text{ km s}^{-1}$$

NGC 4945: sightline above 4th quadrant



K-band (red), H₂ (green), Pa α (blue)
Marconi et al. 2000

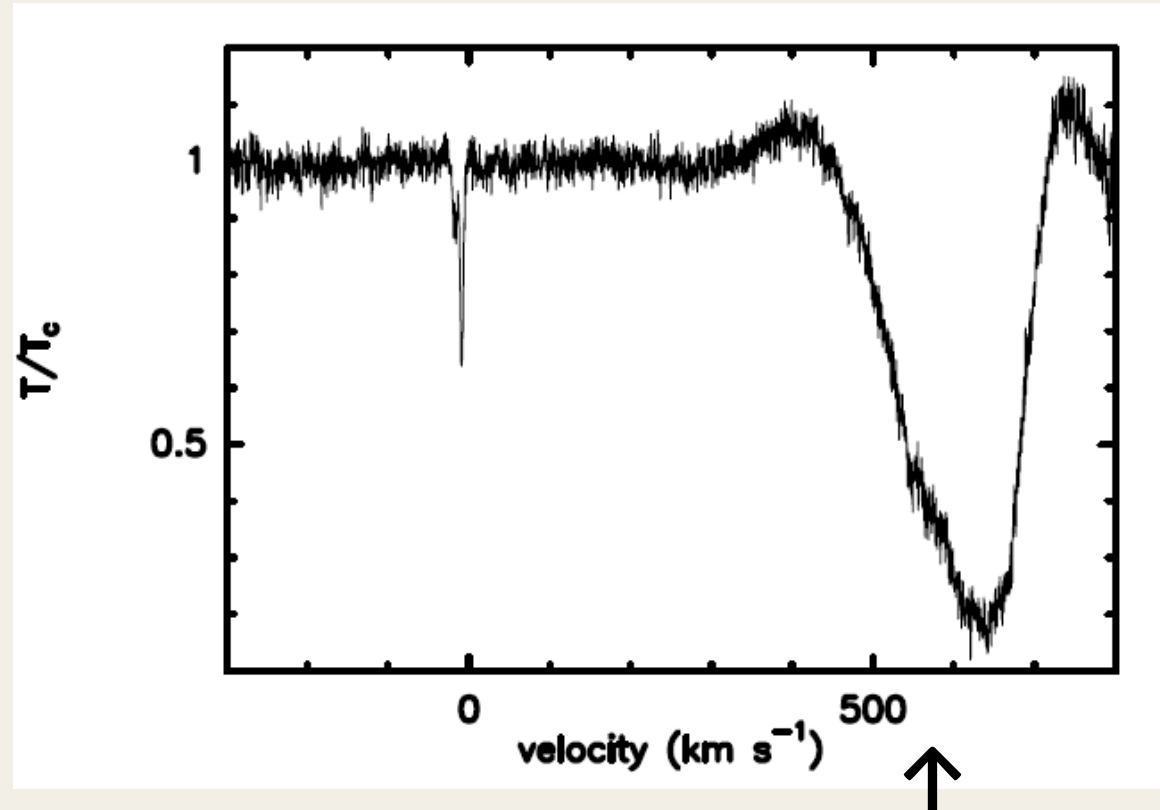
$$l = 305.3^\circ$$

$$b = 13.3^\circ$$

$$A_v = 0.48 \text{ mag}$$

$$T_{\text{cont}} @ 830 \text{ GHz} = 0.23 \text{ K}$$

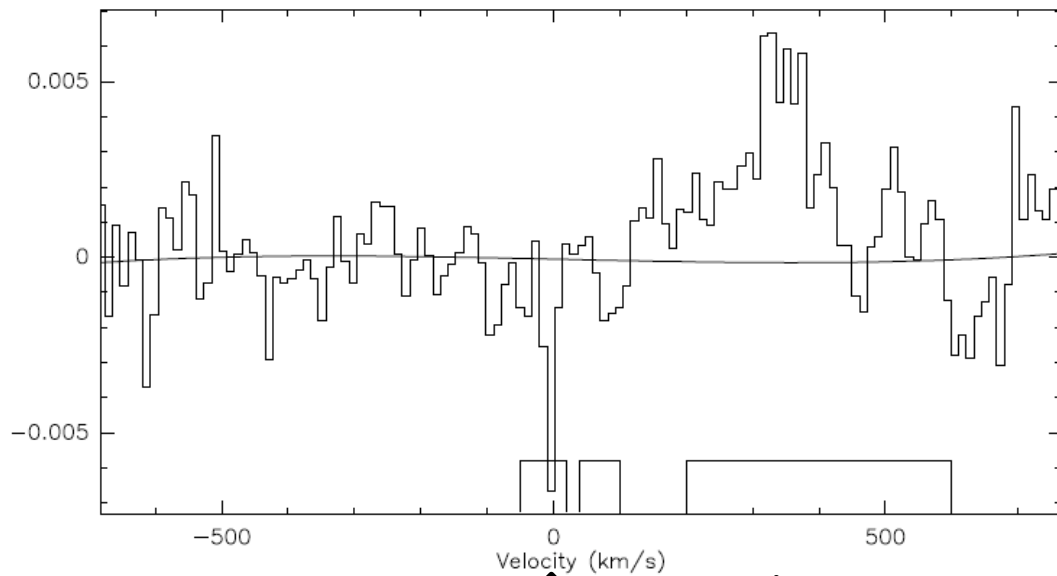
$$v_{\text{sys}} = 563 \text{ km s}^{-1}$$



CH⁺(1-0)

- ⇒ galactic absorption above the 4th quadrant
- ⇒ almost saturated in NGC4945
- ⇒ hints of emission

Circinus Galaxy



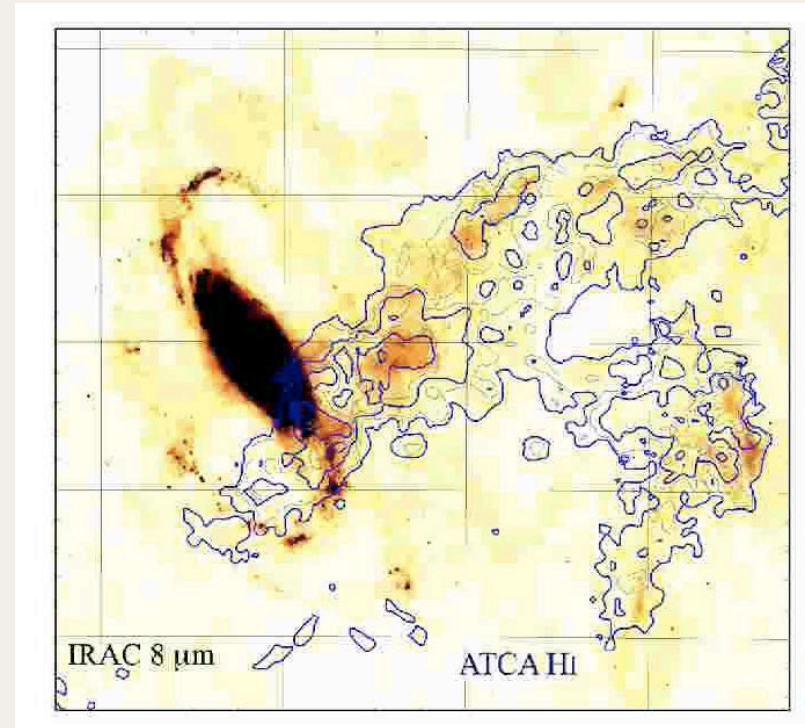
↑
Galactic
velocities

↑
Circinus
Galaxy

CH⁺(1-0)

⇒ galactic absorption

⇒ emission in Circinus



For et al. 2012

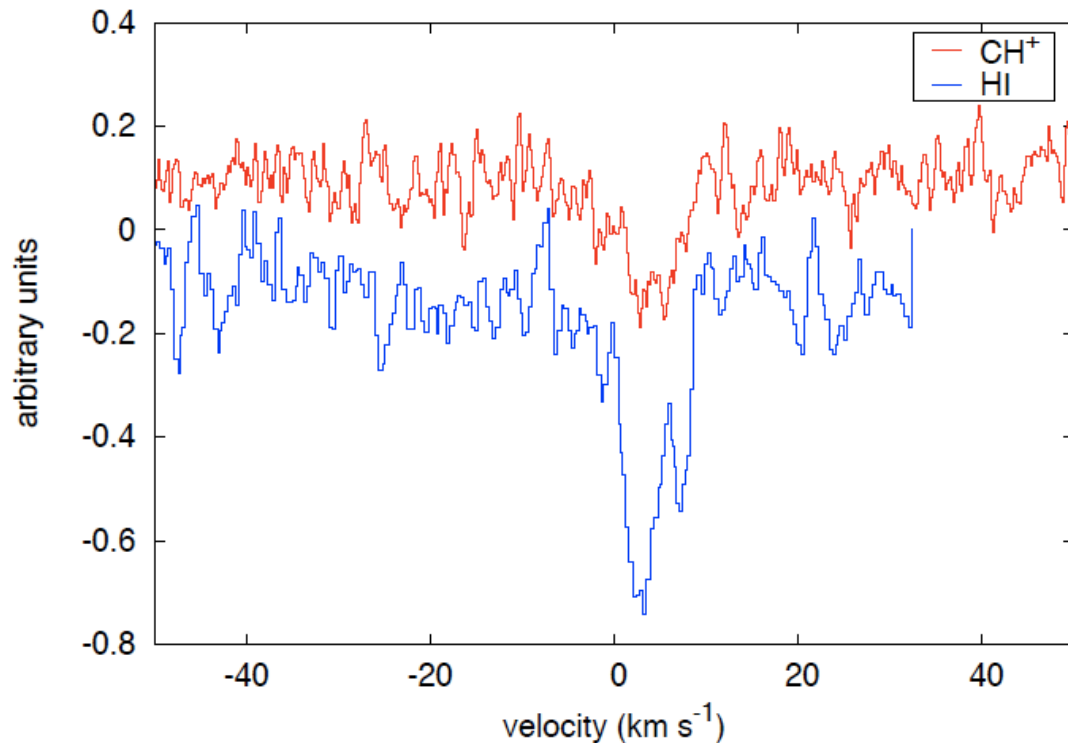
$$l = 311.3^\circ$$

$$b = -3.8^\circ$$

$$A_v = 2.1 \text{ mag}$$

$$T_{\text{cont}} @ 830 \text{ GHz} = 0.03 \text{ K}$$

M82 : Galactic absorption



HI absorption: Penticton (Joncas, priv. comm.)

CH⁺ and HI absorption profiles :
similar broad velocity coverage
~ 15 kms⁻¹

Solar Neighbourhood
at high latitude

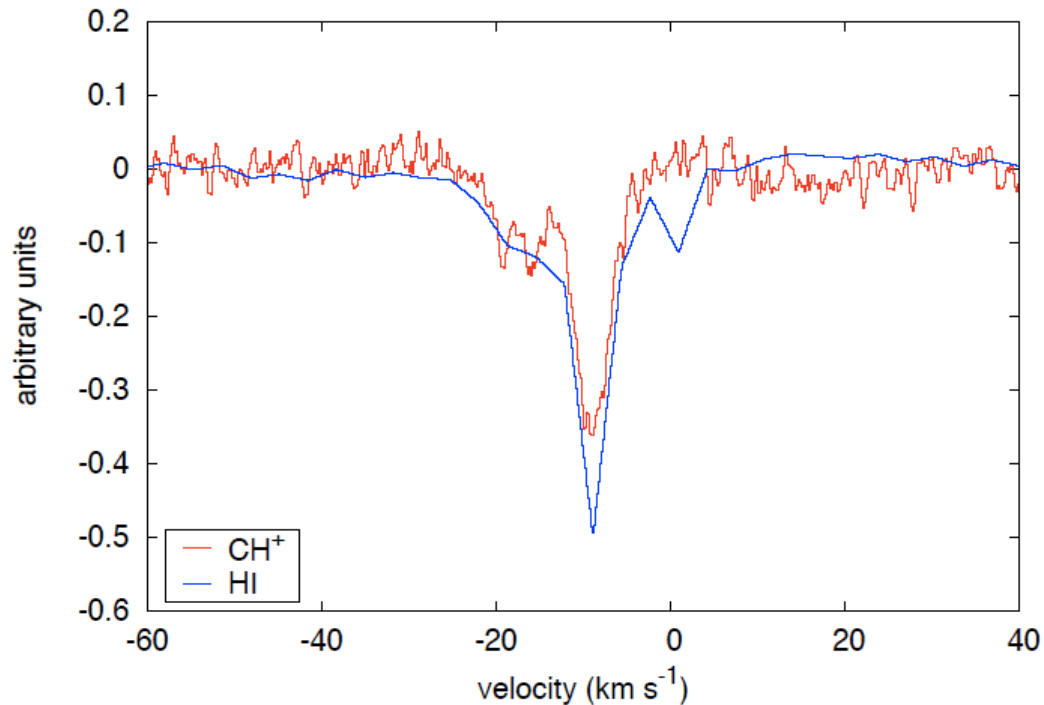
$$N(\text{CH}^+) = 6.7 \times 10^{12} \text{ cm}^{-2}$$

$$[\text{CH}^+] / \text{H} = 2.3 \times 10^{-8}$$

$$[\text{CH}^+] / \text{H}_{\text{tot}} = 7 \times 10^{-9}$$

$$\Rightarrow f_{\text{H}_2} = 0.65$$

NGC4945 : Galactic absorption



HI absorption : Koribalski (ATCA, in preparation)

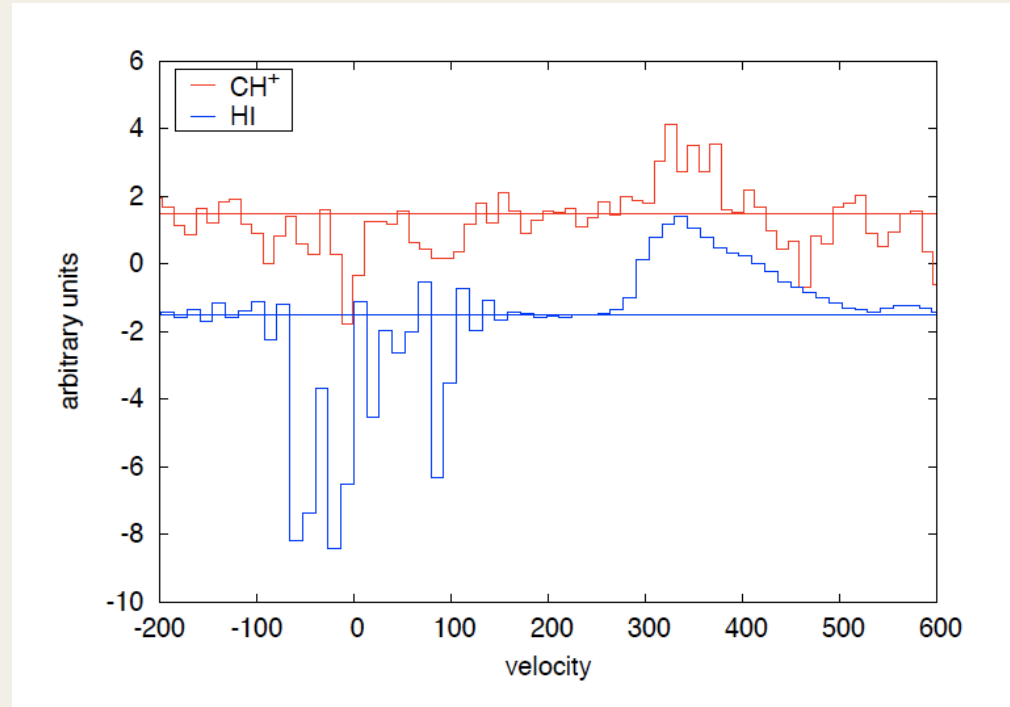
CH⁺ narrowest components

$\Delta v = 2.5 \text{ km s}^{-1}$, $\tau = 0.2$,

$N(\text{CH}^+) = 1.5 \times 10^{12} \text{ cm}^{-2}$

- Gas $v = -20 \text{ km s}^{-1}$ at far distance (8kpc)
 - ⇒ height $z = 1.8 \text{ kpc}$
- Similar shapes CH⁺ and HI absorption profiles
- $N(\text{CH}^+) = 8.9 \times 10^{12} \text{ cm}^{-2}$
- $[\text{CH}^+] / \text{H} \sim 1.3 \times 10^{-8}$
- $[\text{CH}^+] / \text{H}_{\text{tot}} = 1 \times 10^{-8}$
 - ⇒ $f_{\text{H}_2} \sim 0.4 - 0.6$

Circinus Galaxy : Galactic absorption



$$l = 311.3^\circ$$

$$b = -3.8^\circ$$

HI from Park SS

Distances from Sun : -60 km/s : 3 to 7 kpc , -20 km/s : 1 and 9 kpc , 100 km/s : 15 kpc

Scutum arm

Carina arm

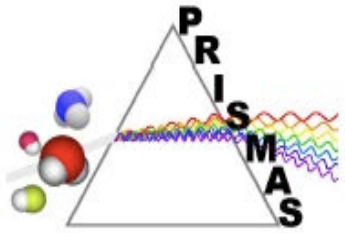
Height below Galactic plane : 200pc to 460pc

SN and 600 pc

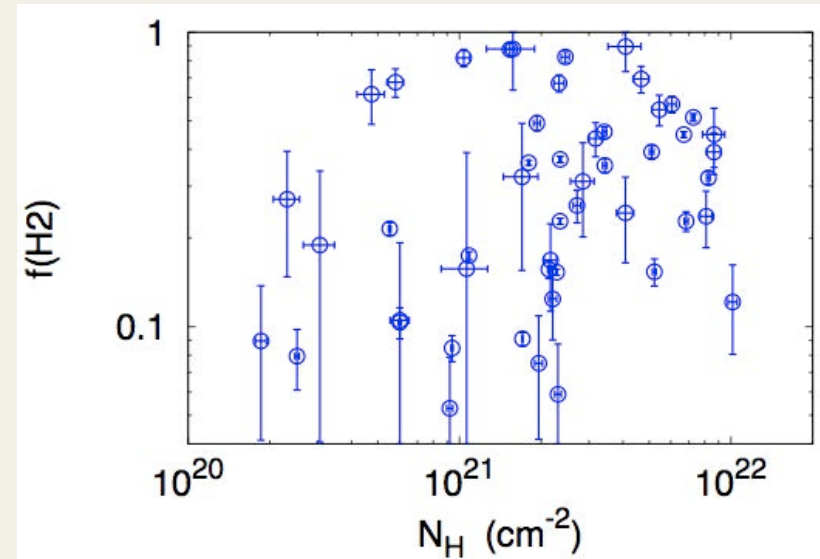
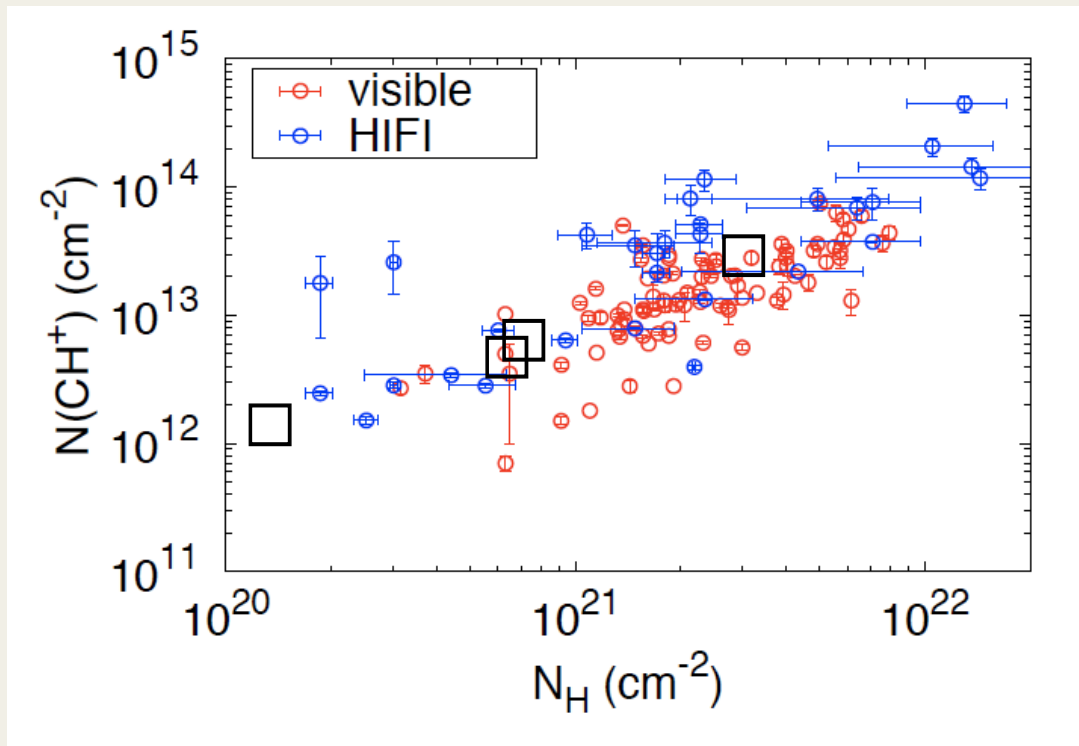
1kpc

$$N(\text{CH}^+) = 2.8 \times 10^{13} \text{ cm}^{-2}$$

$$[\text{CH}^+] / \text{H}_{\text{tot}} = 7 \times 10^{-9}$$



Comparison with Galactic disk results



H₂ from HF and CH
 $0.04 < f_{\text{H}_2} < 1$

CII absorption

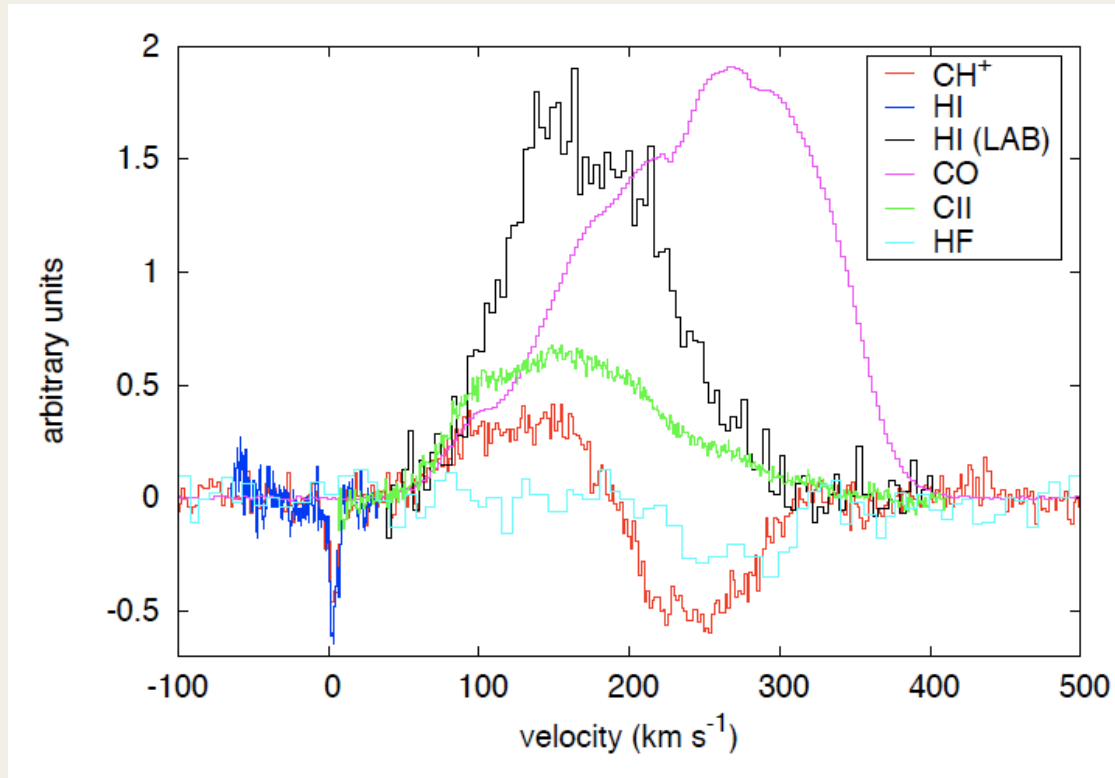
⇒ same velocity coverage as CH⁺ absorption

Excitation conditions of C I lines:

⇒ CH⁺ absorption occurs in the Cold Neutral Medium (CNM)

[Gerin et al. in prep.](#)

M82 : CH⁺ inverse P-Cygni profile



- CO(2-1) IRAM-PdBI [Weiss et al. 2010](#)
- CII Herschel/HIFI [Loenen et al. 2010](#)
- HF Herschel/HIFI [Monje \(priv. comm.\)](#)

- Starburst Galaxy
- SFR ~ 9.8 M_{sun} yr⁻¹
enhanced by
interaction with
M81

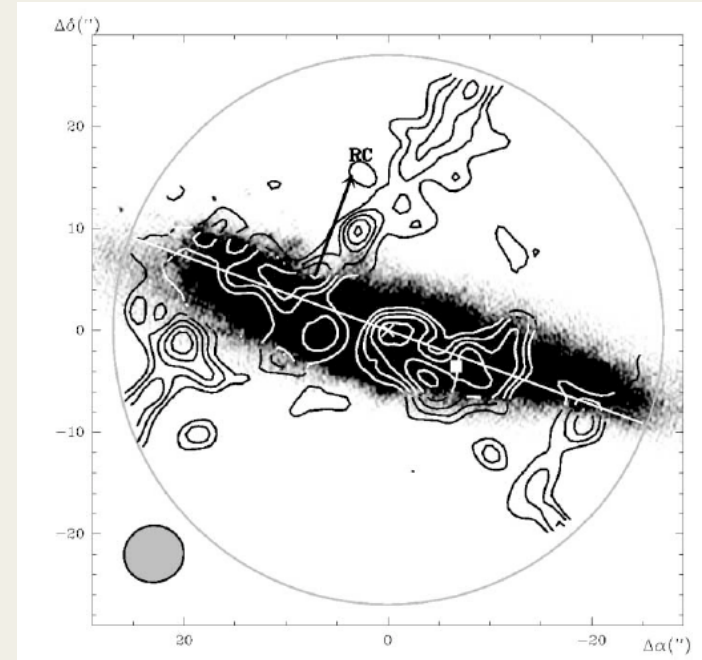
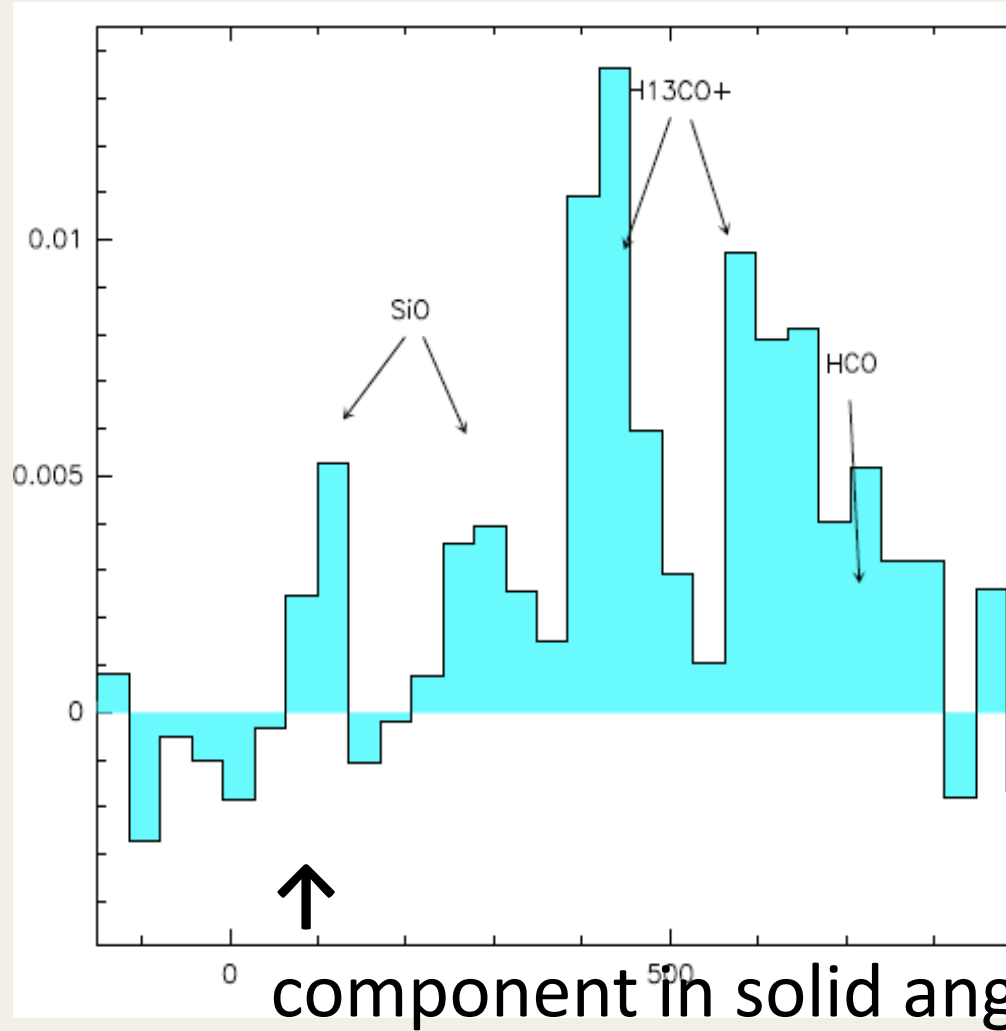
Yun et al. 1993

- Powerful outflow
Walter et al. 2002

- Central HI emission

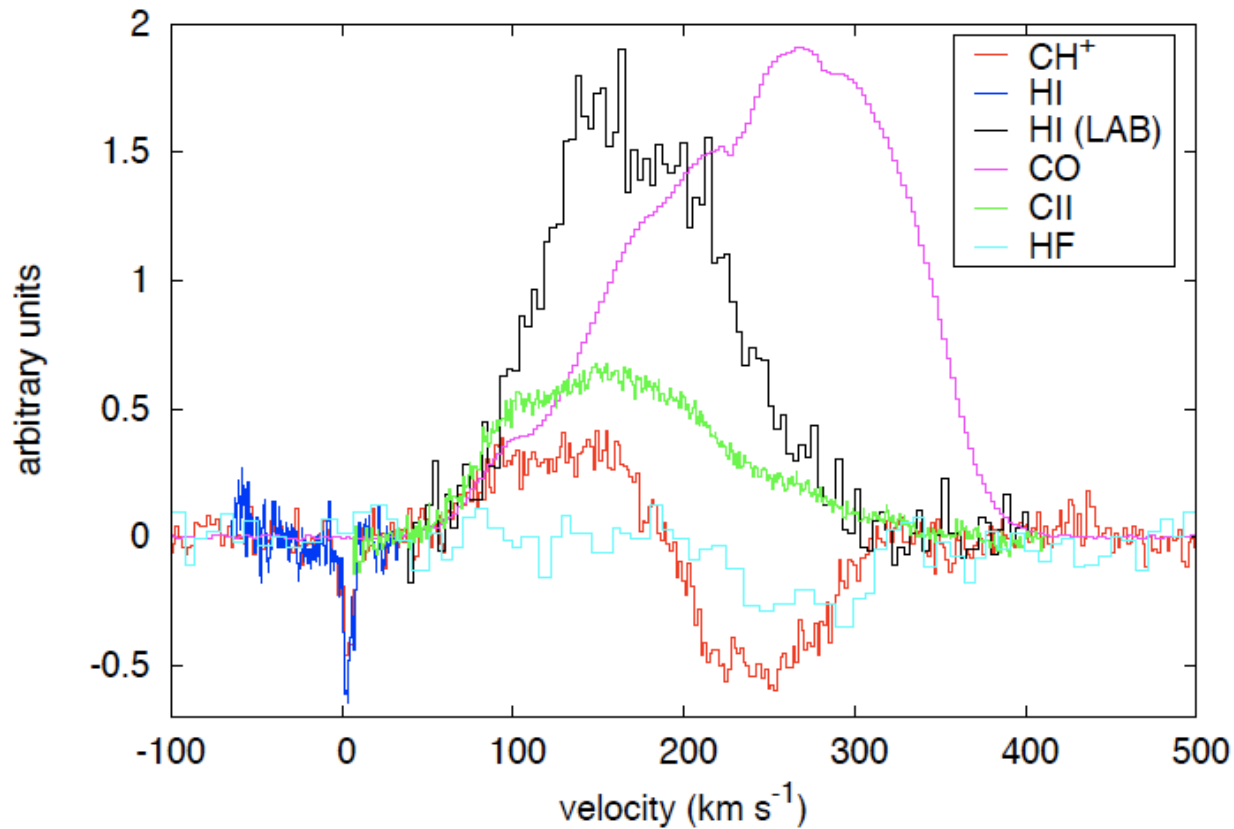
Yun et al. 93, Chynoweth et al 08

M82 : SiO shock signature



SiO emission IRAM-PdBI
Garcia-Burillo et al. 2001

M82 : CH⁺ P-Cygni profile



Velocity range of SiO
in CH⁺ absorption solid angle
[Garcia-Burillo 2001](#)

50 < v < 150 km s⁻¹

CH⁺ emission

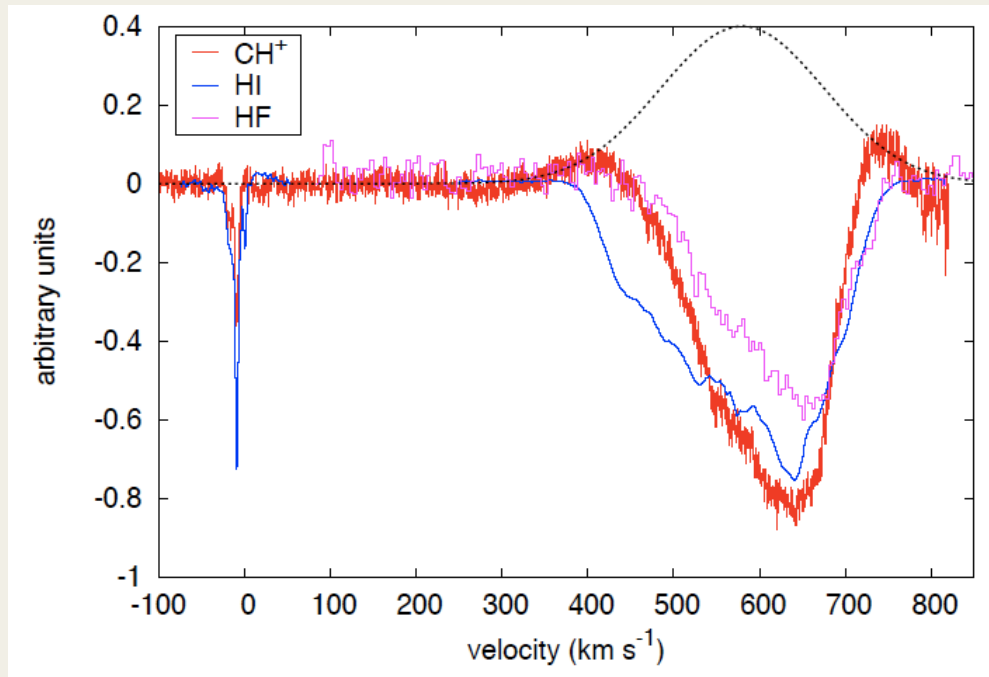
- Similar shape in CII profile
- Kink in the CO(2-1) profile
- SiO emission component
- ⇒ shock-dominated emission

200 < v < 300 km s⁻¹

Redshifted absorption

- ⇒ inflow towards the nucleus
- ⇒ centroid velocity of central HI emission : rotation + large velocity dispersion due to tidally induced bar and disk/wind interaction

NGC4945 : strong CH⁺ absorption



HF

Inflow rate ~ a few $M_{\text{sun}} \text{ yr}^{-1}$

[Monje et al. 2013](#)

- Bright nearby AGN and starburst $\text{SFR} \sim 0.4 M_{\text{sun}} \text{ yr}^{-1}$

[Marconi et al 2000](#)

- Nuclear HI absorption

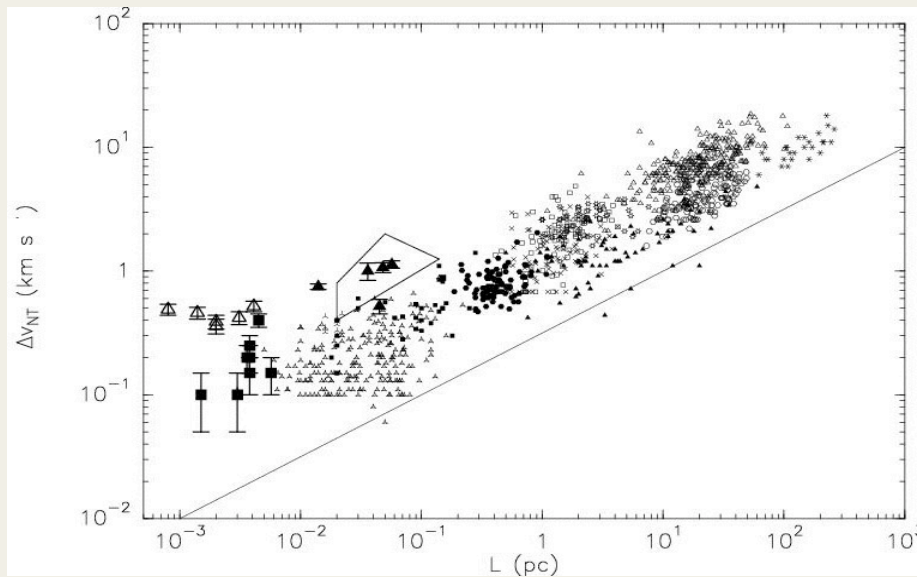
[Ott et al. 2001](#)

- Unknown CH⁺ emission profile symmetric wrt v_{sys}

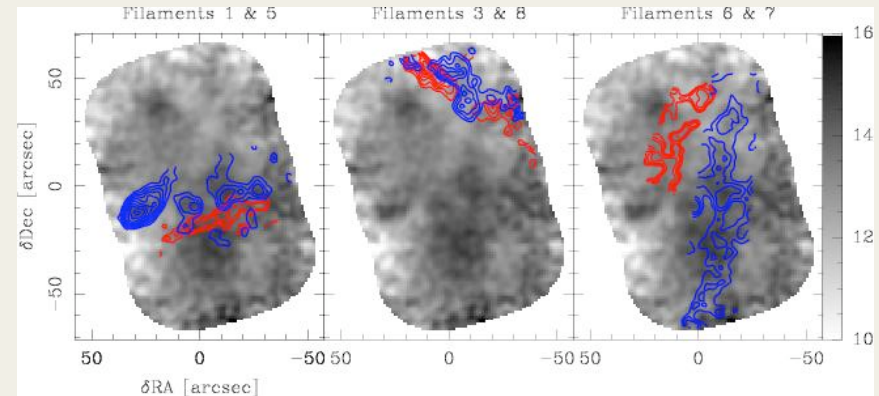
Opacity against dust continuum: $\tau = 0.3$

$$[\text{CH}^+] / \text{HI} > 6 \cdot 10^{-8}$$

Turbulent dissipation: where?



Size-linewidth Larson's relation in diffuse molecular gas blows up below 0.1 pc



Structures detected at different velocities (blue, red)

IRAM-PdBI

CO elongated structures in diffuse molecular gas

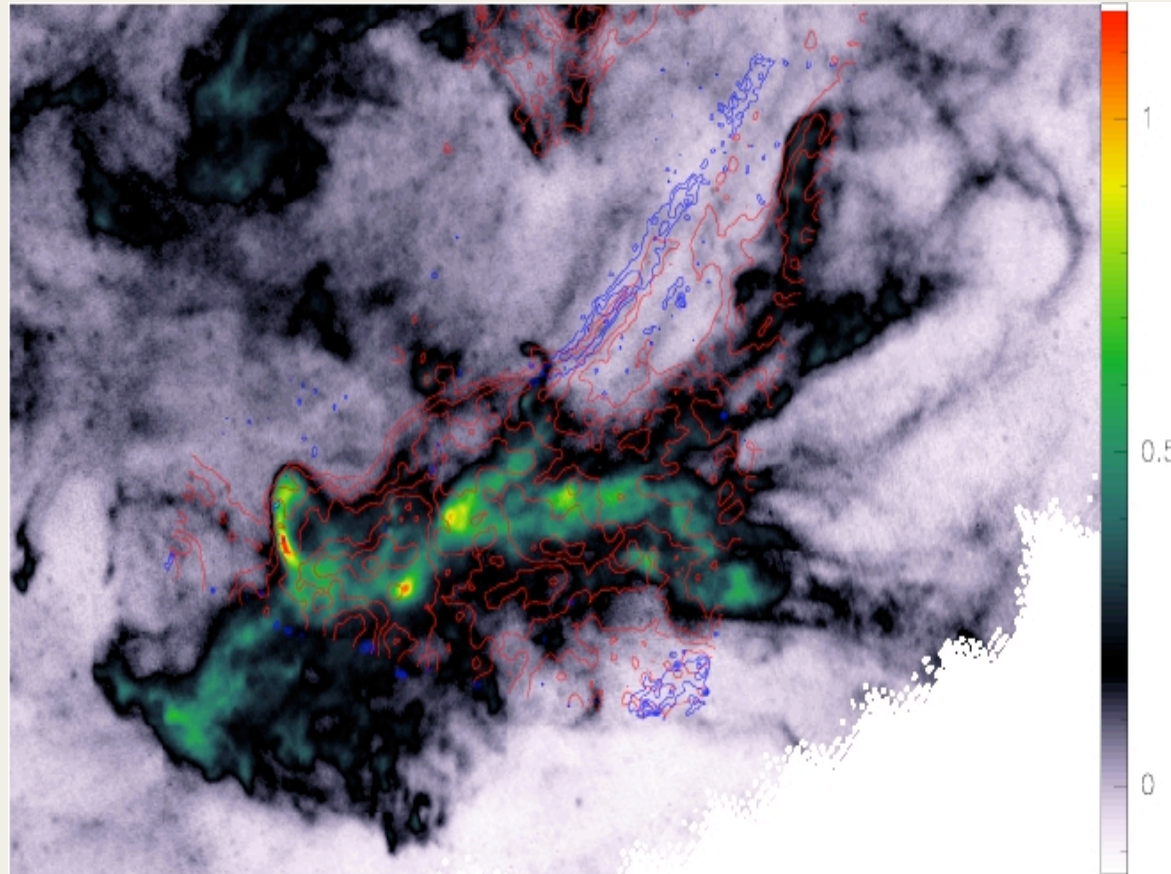
➤ 3 to 10 mpc thick

➤ extremely large velocity shears up to 800 km/s/pc

Rate of strain $a = 3 \times 10^{-11} \text{ s}^{-1}$

Falgarone, Pety, Hily-Blant 2009

Intense velocity-shears: seeds of tenuous filaments?



Herschel/SPIRE 250 μ m map [André et al. 2010](#)

CO(2-1) (red) [Hily-Blant & Falgarone 2009](#)

Intense velocity-shear (blue) [Hily-Blant et al. 2008](#)

Summary and openings

- Turbulent dissipation drives CH⁺ (and other molecules e.g. CO) formation in a broad variety of quasi-atomic environments

$$N_{\text{H}} \sim \text{a few } 10^{20} \text{ to } 10^{24} \text{ cm}^{-2}$$

- Turbulent dissipation occurs at scales <10 mpc in diffuse ISM
- New field of investigation for ALMA: probing the sites of turbulent dissipation (local and high-*z* universe)
- Spectroscopy at low spectral resolution: caution!