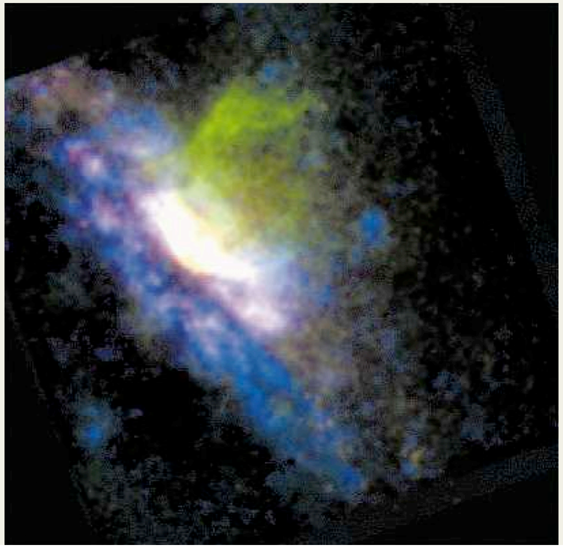
CH^+(1-0) a tracer of turbulent energy dissipation: the sightlines to nearby starbursts



Edith Falgarone,

Ecole Normale Supérieure & Observatoire de Paris

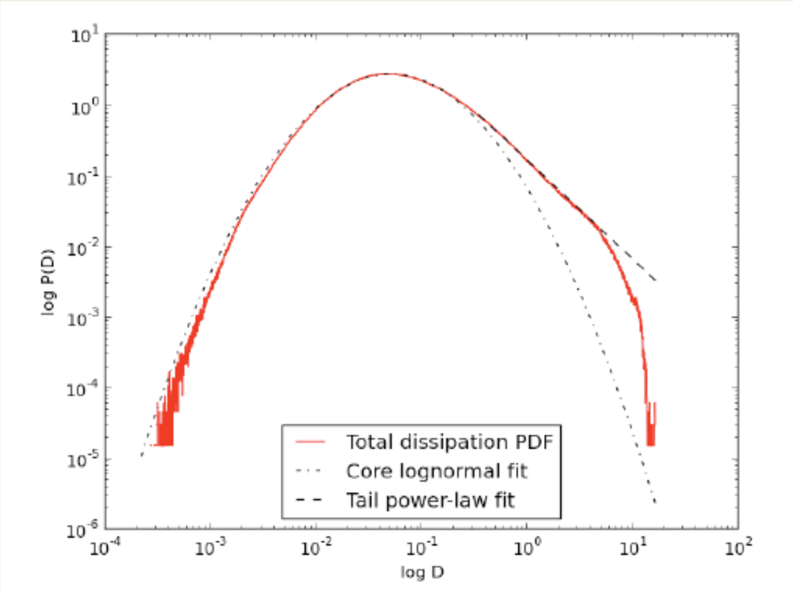
Godard B., Lesaffre P., Gerin M., (Obs. Paris),
Bergin E. (Michigan Univ.)
Neufeld D. (Johns Hopkins Univ.)
Black J. (Chalmers Univ.)
Lis D., Lord S., Phillips T.G. (Caltech)
Menten K. (MPIfR)
Joncas G. (Univ. Laval)

AS ALMA, Grenoble, 12 – 13 November 2013

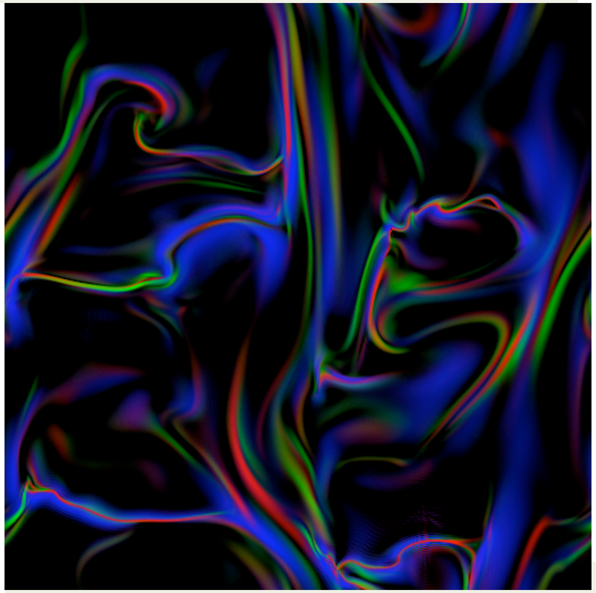
Outline

- Turbulent dissipation = key input to SF & galaxy evolution
- Occurs at very small scales and intermittent in space and time : major challenge for direct observations
- Indirect tracer : CH^+, specific outcome of warm chemistry driven by turbulent dissipation
- Herschel/HIFI observations : absorption spectroscopy
- CH^+(1-0) absorption line survey of bright submm galaxies at high-z with NOEMA and ALMA:
  - ➪ dynamics of low density gas, weakly molecular
  - ➪ turbulent energy dissipation rate

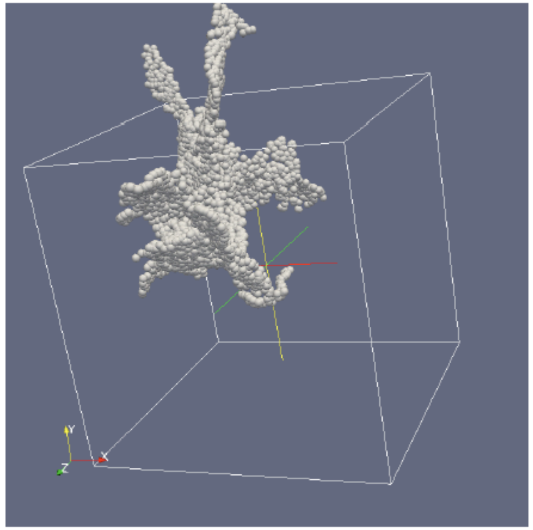
Intermittency of dissipation : ohmic, viscous and ambipolar diffusion



The 10% most dissipative events contribute to 30% of total dissipation



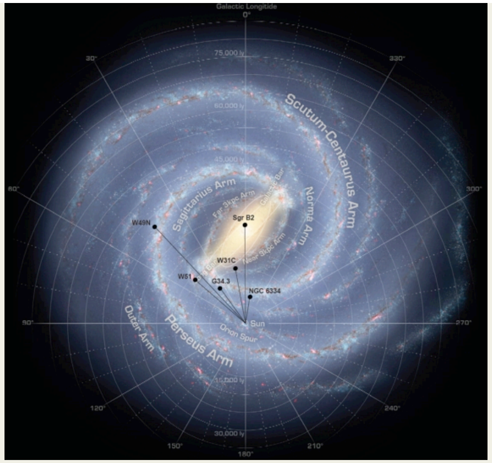
Ohmic dissipation: $D_{ohm} = \eta j^2$
Viscous dissipation: $D_{visc} = \nu\omega^2$
Dissipation by ion-neutral drift :
$D_{AD} = \alpha(j\times B)^2$



Structure of dissipation rate extremum

Spectral NS of non-ideal MHD turbulence
Momferratos et al. in prep.

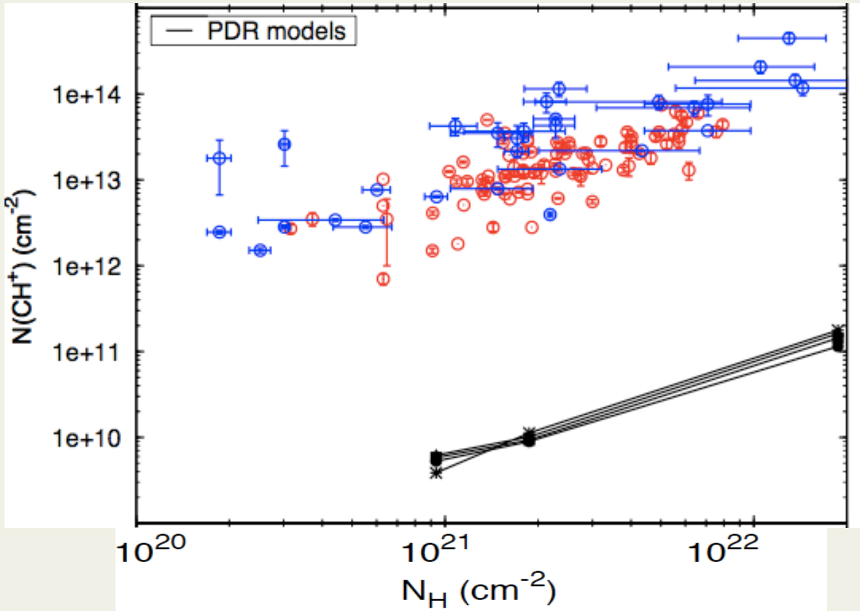
High CH^+ abundances



- Saturated $CH^+(1\text{-}0)$ lines
- Highly endoenergic formation $\Delta E/k = 4640$ K
- Fast destruction by H_2 collisions

$$\tau = 1 \text{ year } f_{H2}^{-1} \, n_{H,50}^{-1}$$

⇨ **extremely short lifetime if not efficiently formed**

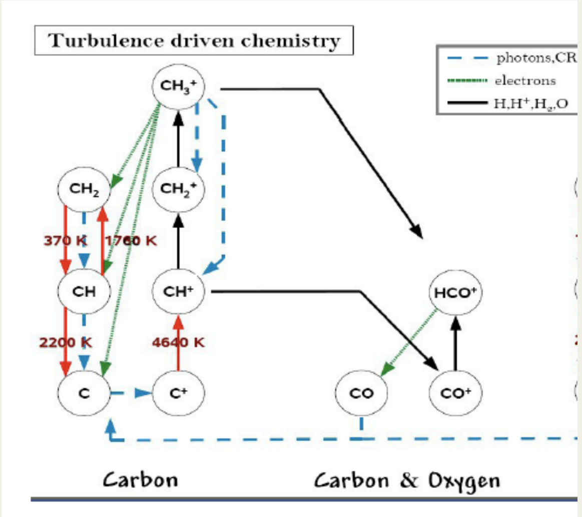


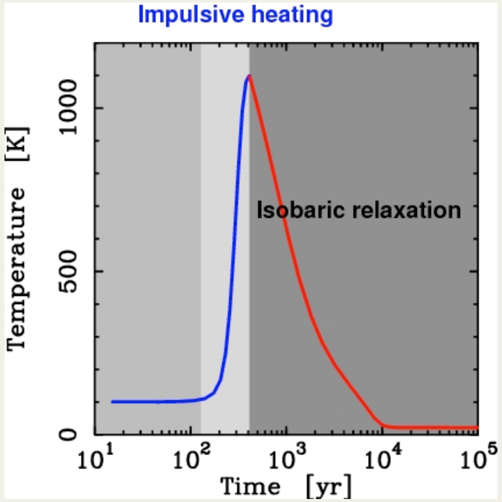
Visible (red) and Herschel/HIFI absorption lines towards the Inner Galaxy (blue) data. PDR models (black) for n_H = 30, 50, 100 cm^{-3}

Falgarone et al. 2010, Godard et al. 2012, 2014

Models of Turbulent Dissipation Regions (TDR)

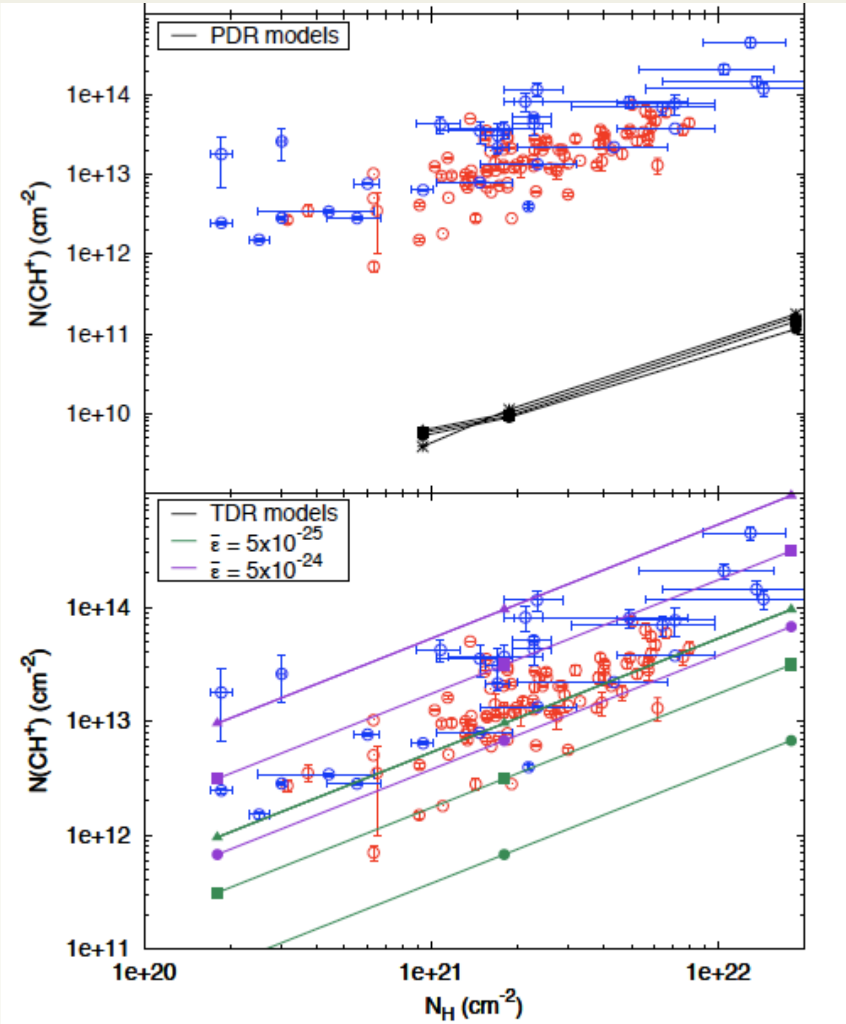
- **Bursts of dissipation** in magnetized vortices
  ~ 10 AU, ~ 100 yr
  ➪ **non-equilibrium chemistry**
- Heating due to dissipation : viscous + ion-neutral friction
  ➪ **warm chemistry**
- Thermal and chemical relaxation :
  100 yr to several 10^4 yr
- **Few free parameters** constrained by ambient turbulence
- **3 phases :** active and relaxation phases (a few %) + ambient medium





Joulain et al. 1998; Godard et al. 2009, 2014

TDR model results : CH^+



TDR models for n_H= 30, 50, 100 cm^{-3}

Godard et al. 2014

- ➪ $N(CH^+)$ increases with UV-field
- ➪ $N(CH^+)$ proportional to **turbulent transfer rate = turbulent dissipation rate**

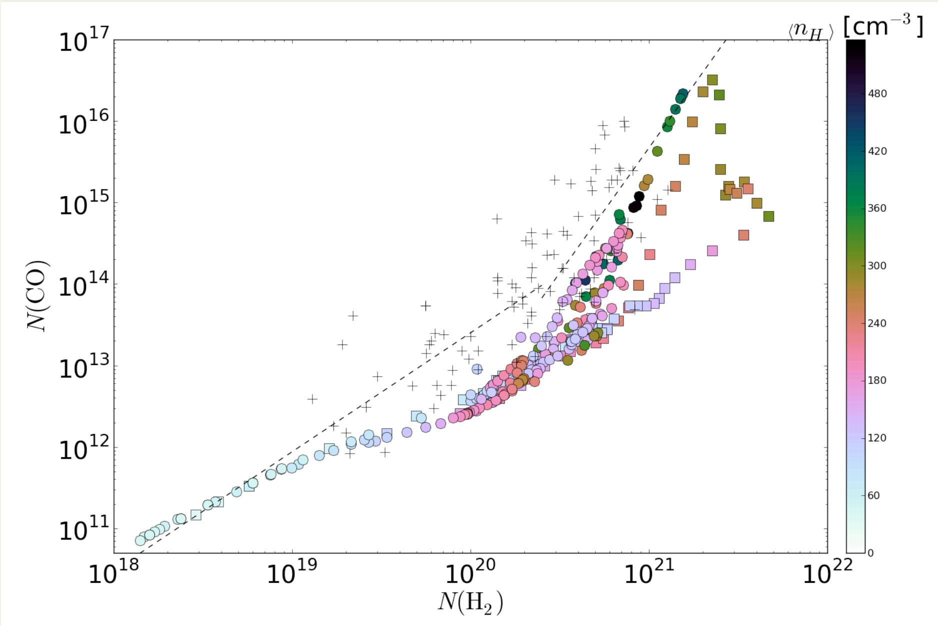
$$N(CH^+)/N_H \sim 2 \times 10^{-9}\ \varepsilon_{24}\ n_{50}^{-2.2}\ (A_V/0.4)^{-0.32}$$

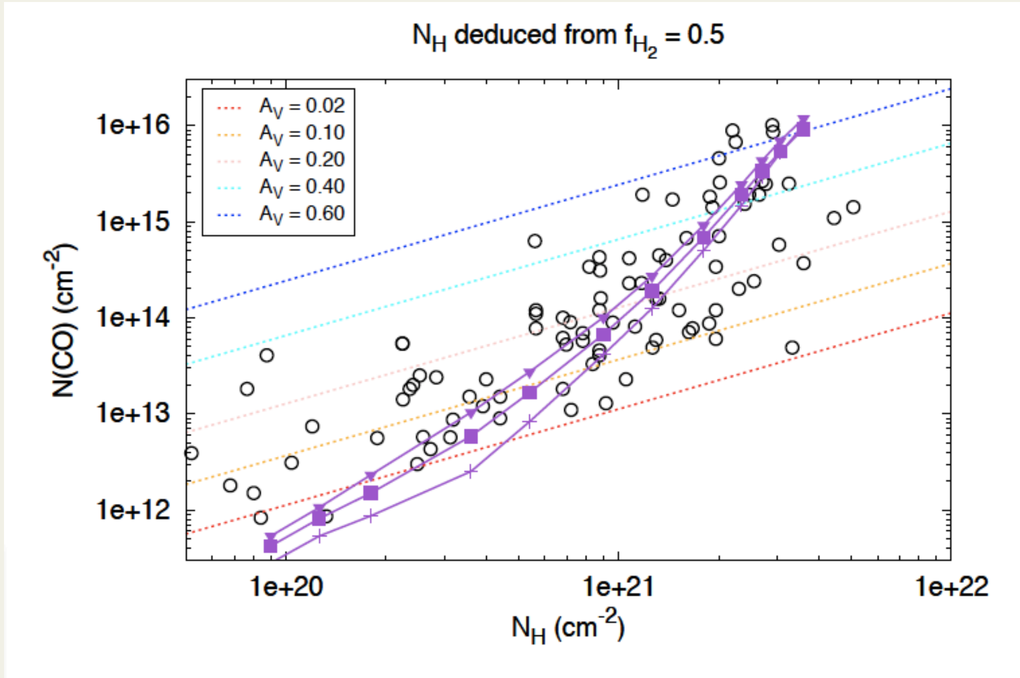
$\varepsilon_{24} = 10^{-24}$ erg cm^{-3} s^{-1}

n_{50}=50 cm^{-3}

➪ only a few % warm gas on LOS

TDR model results : CO





CO : visible data

Sheffer + 08, Pan + 05, Rachford + 09, Snow + 08

Results from PDR models in MHD colliding flow simulations

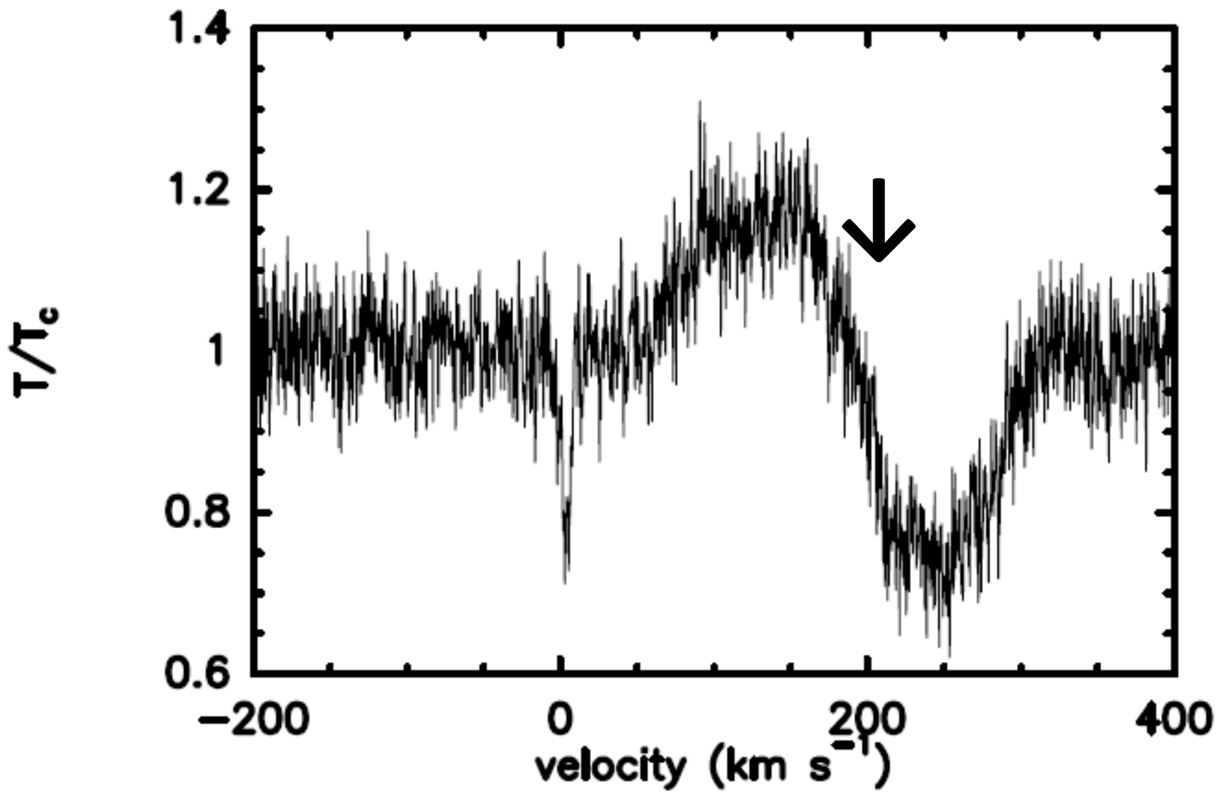
Levrier + 2012

CO : same visible data

TDR model predictions for n_H= 30, 50, 100 cm^{-3} (purple curves)

Godard et al. 2014

M 82



Chandra, HST, Spitzer

l = 141.4°

b = 40.6°

A_v = 0.45 mag

T_{cont}@ 830 GHz= 0.1 K

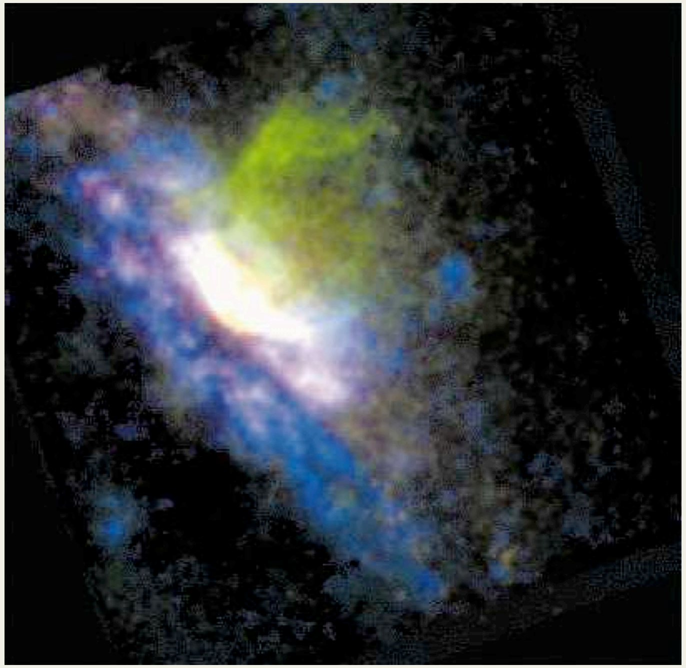
v_{sys} = 203 km s^{-1}

CH^+(1-0) Herschel/HIFI

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

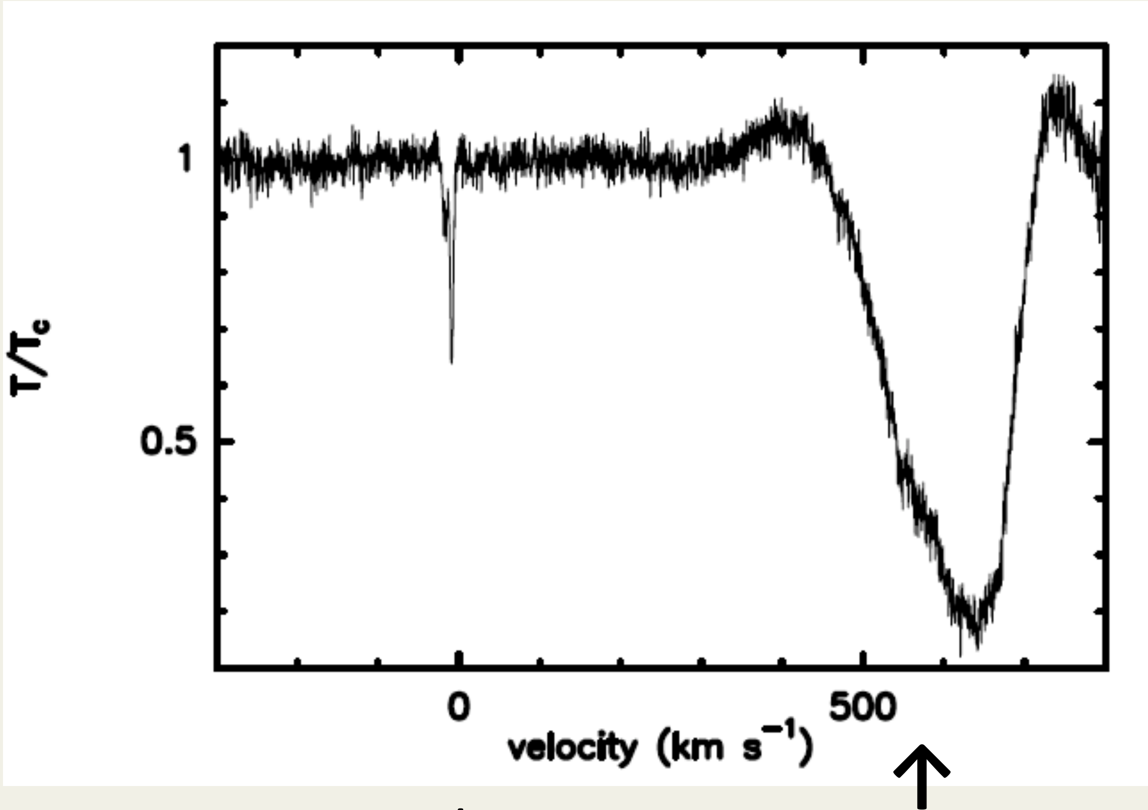
Falgarone et al. in prep.

NGC 4945



K-band (red), H_2 (green), Paα(blue)
Marconi et al. 2000

l = 305.3°
b = 13.3°
A_v = 0.48 mag
T_{cont} @ 830 GHz= 0.23 K
v_{sys} = 563 km s^{-1}

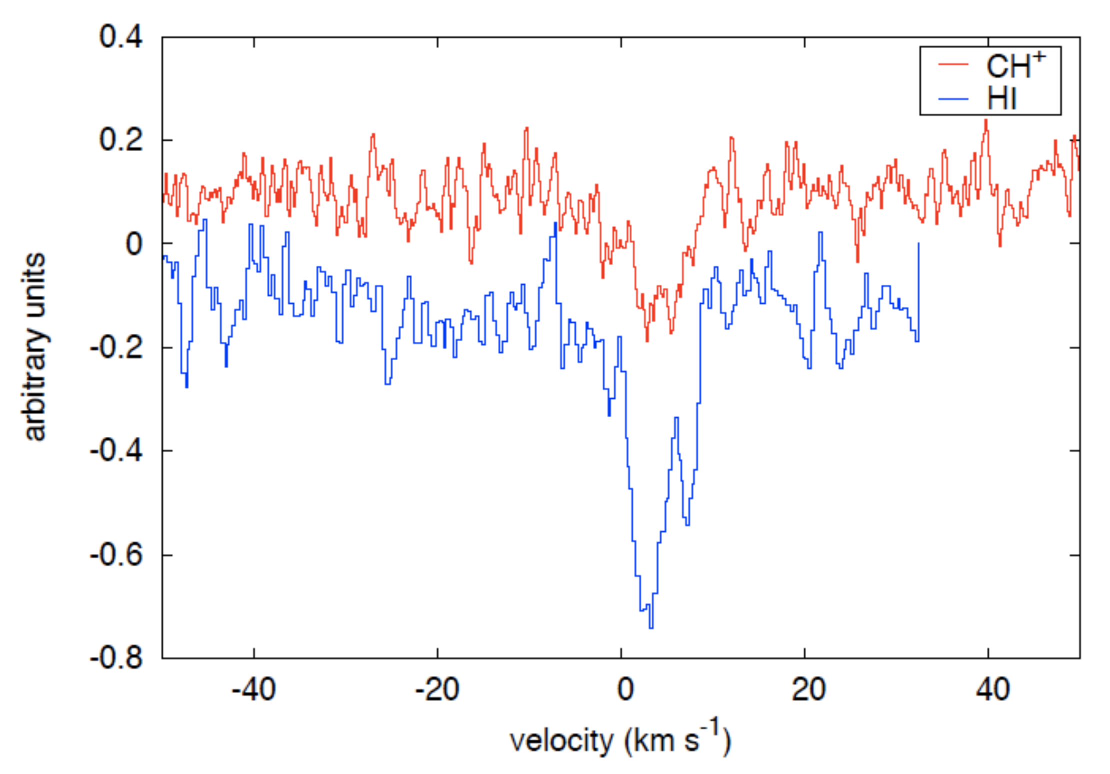


CH^+(1-0) Herschel/HIFI

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

Falgarone et al. in prep.

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

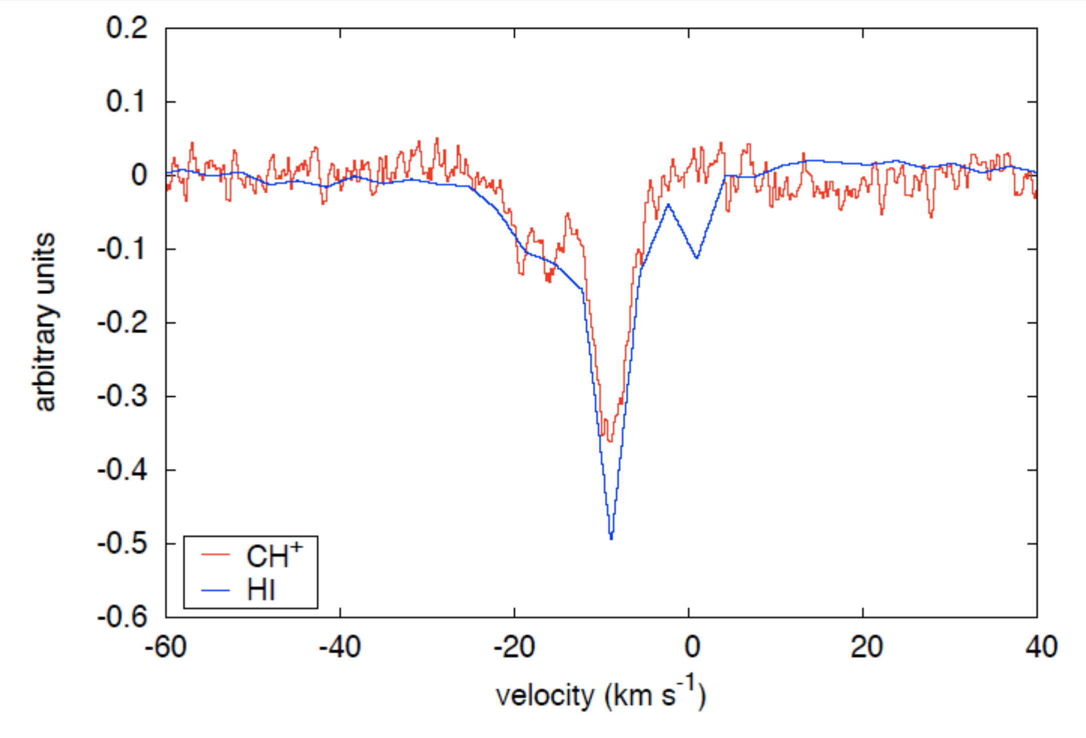
$N(CH^+)=6.7 \times 10^{12}$ cm^{-2}

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

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

⇨ $f_{H2} = 0.65$

NGC4945 : Galactic absorption



HI absorption : Koribalski (ATCA, in preparation)

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

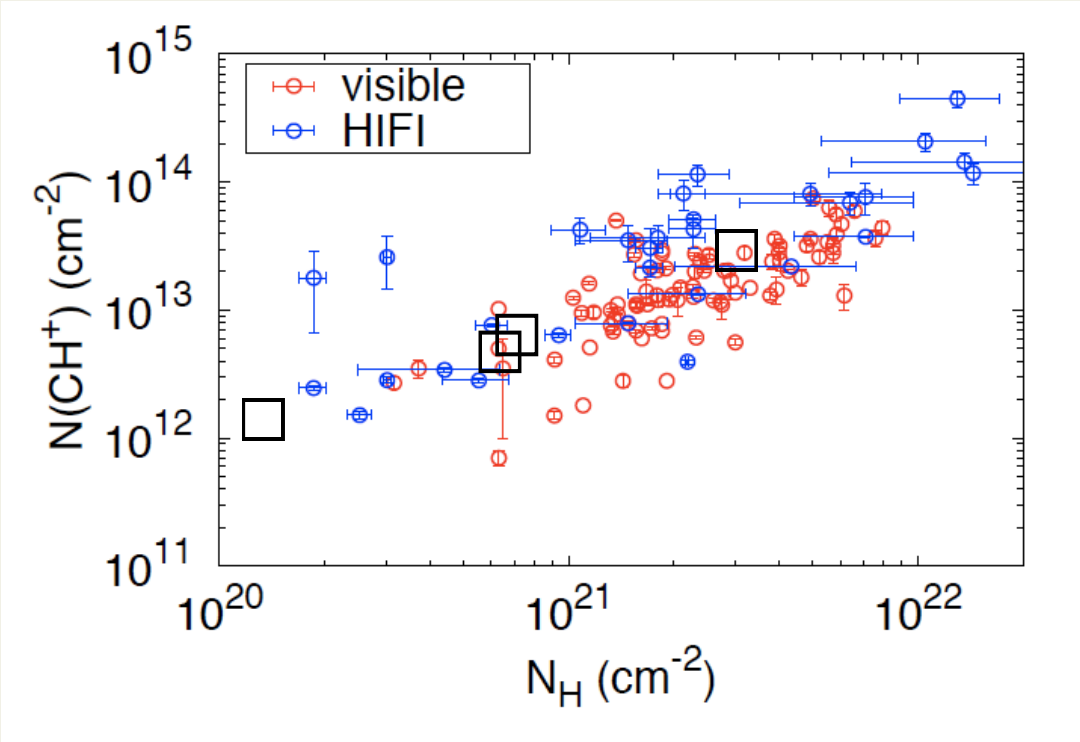
➪ $f_{H2} \sim 0.4 – 0.6$

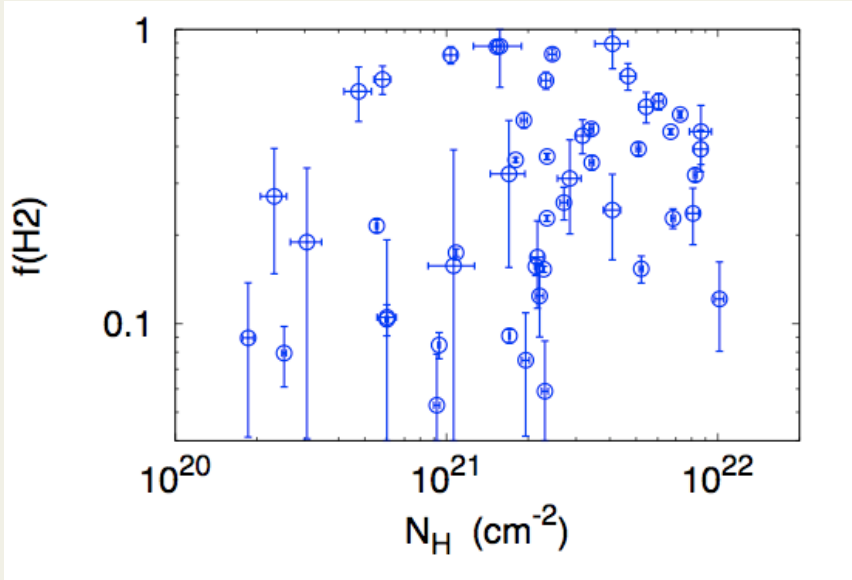
CH^+ narrowest components

Δv=2.5 km s^{-1}, τ=0.2,

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

Comparison with Galactic disk results





H_2 from HF and CH

$0.04 < f_{H2} < 1$

Godard et al. 2012

CII absorption :

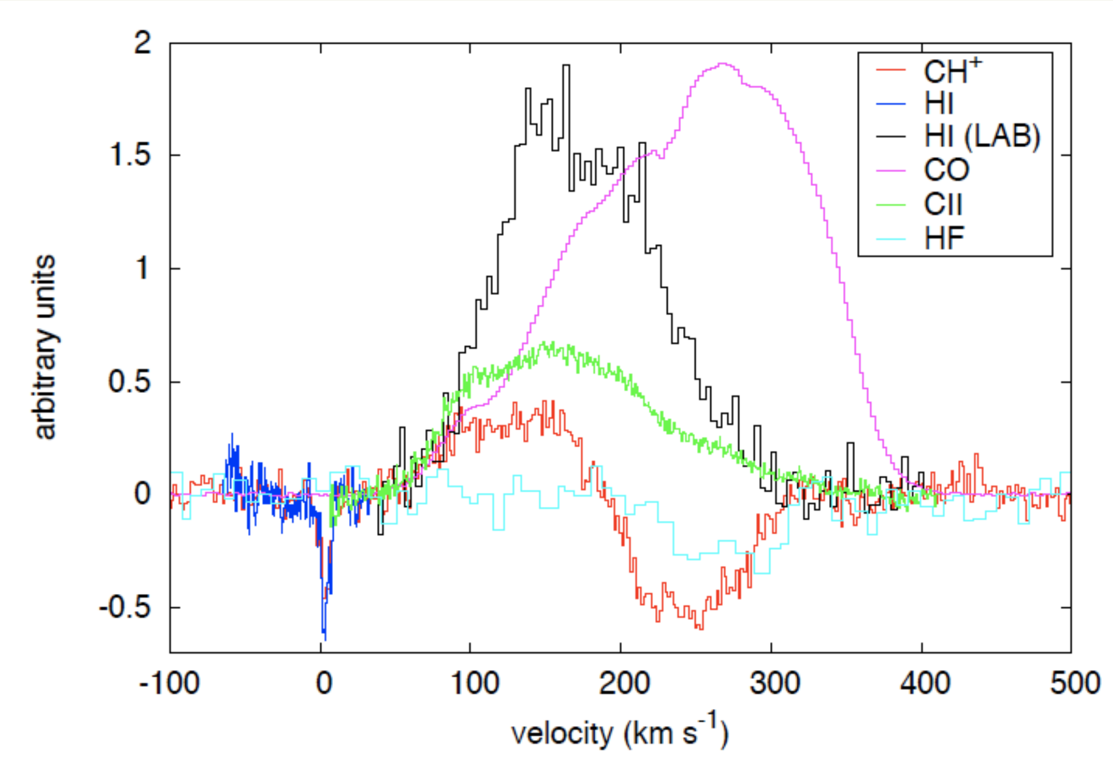
➪ same velocity coverage as CH^+ absorption

Excitation conditions of CI 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.)

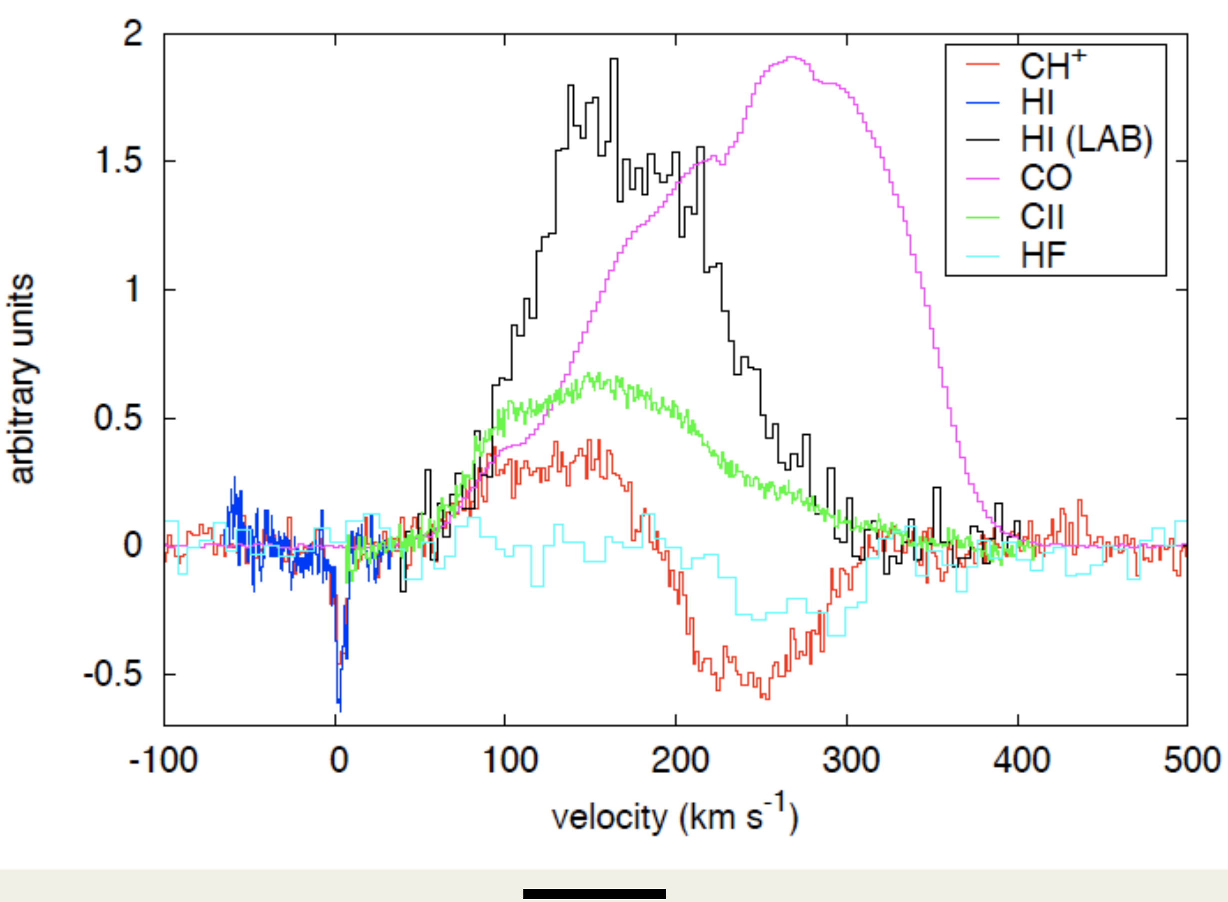
- Starburst Galaxy
- SFR~ 9.8 M_{sun} yr^{-1} enhanced by interaction with M81

  Yun et al. 1993
- Powerful outflow

  Walter et al. 2002
- Central HI emission

  Yun et al. 93, Chynoweth et al 08

M82 : CH^+ inverse P-Cygni profile

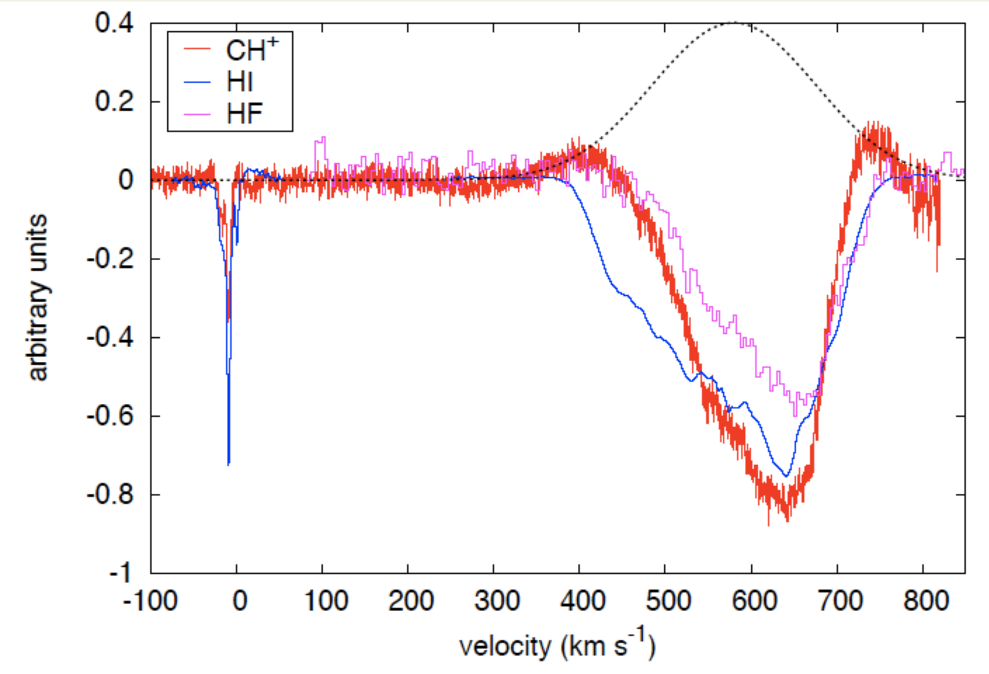


Velocity range of SiO
in CH^+ absorption solid angle
Garcia-Burillo et al. 2001

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_{sun} yr^{-1}
Monje et al. 2013

- Bright nearby AGN and starbust SFR~ 0.4 M_{sun} 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: $\tau = 0.3$

  $[CH^+]$ /HI > 6×10^{-8}

ALMA, PdBI/NOEMA: new field of investigation

- CH^+(1-0) 835GHz blocked by atmosphere
  $^{13}CH^+$(1-0) 830GHz OK in good weather
- Absorption spectroscopy against high-z submm galaxies:

➩ traces low density gas, low H_2/HI fraction

➩ distinguishes inflow/outflow

➩ traces turbulent energy dissipation