Dust properties in the ionized gas of the Large Magellanic Cloud

Déborah Paradis, SSC/CESR
Roberta Paladini, SSC
Alberto Noriega-Crespo, SSC
Guilaine Lagache, IAS

Context

- Detection of dust emission associated with the diffuse H+ gas difficult

A few Galactic detections:

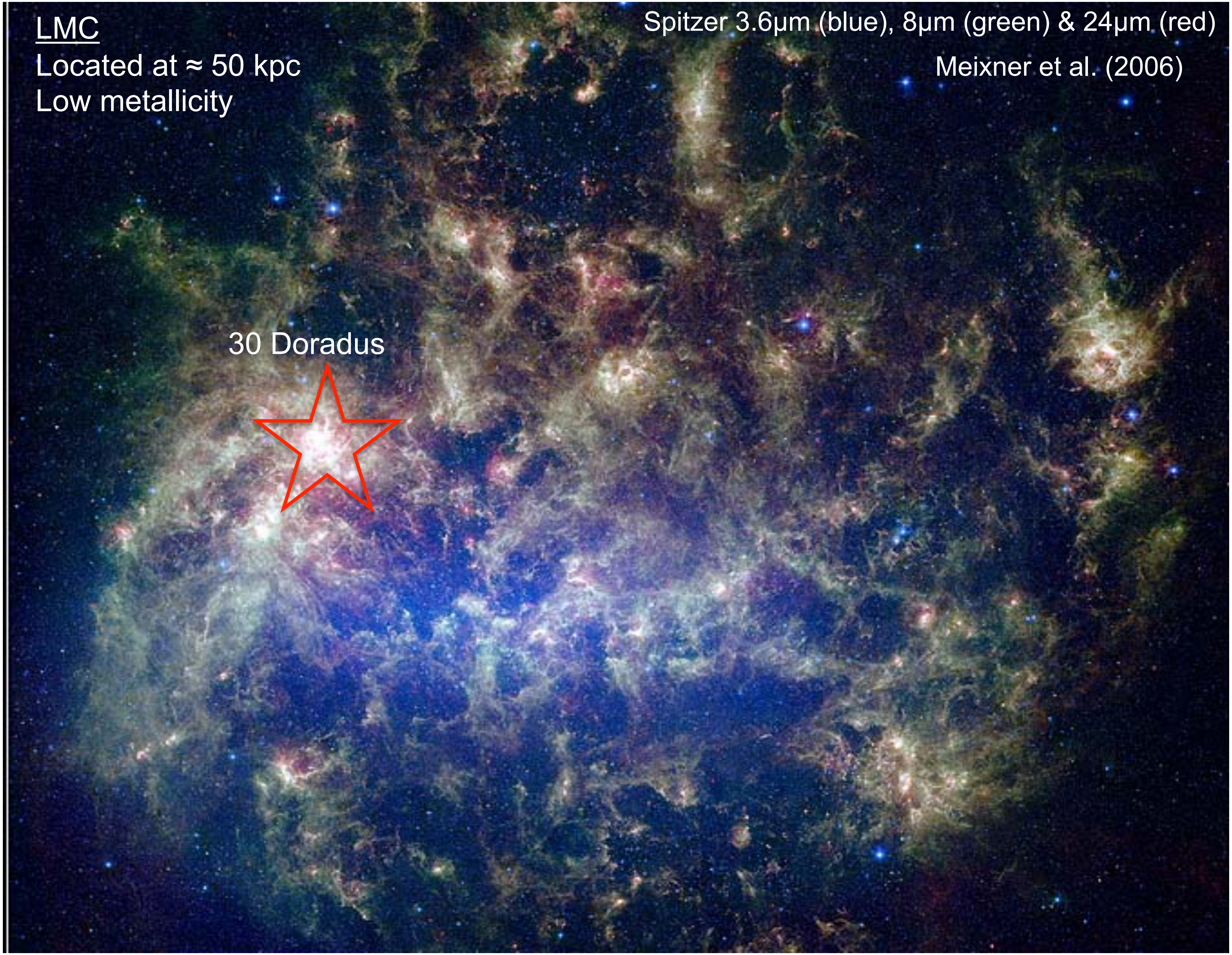
- First indirect detection by Lagache et al. (1999) [100-1000]μm at high Galactic latitudes
- Lagache et al. (2000) confirmed the first detection BUT detection questioned by Odegard et al. (2007)
- Paladini et al. (2007) derived emissivities associated with the HI, CO and H+ gas along the Galactic plane (θ=1°), [60μm-20mm]: $T_d^{H+} \approx 26.7K$ ($T_d^{CO,HI} \approx 19$-$20K$)

➔ First detailed analysis of H+ gas in external Galaxy

⇒ Dust properties could vary according to the gas phase

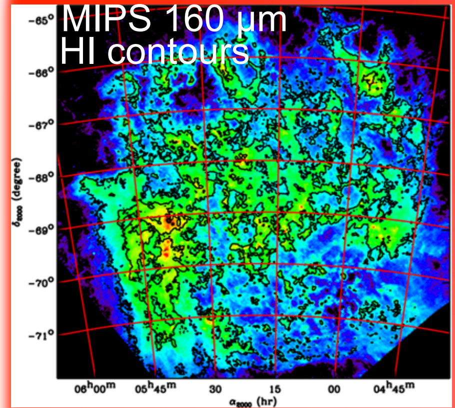
(Depletion of PAHs observed toward some Galactic HII regions (Povich et al. 2007) but disappearance not systematic)

Spitzer (3.6-160μm) data as part of the SAGE (Surveying the Agents of a Galaxy's Evolution, PI: M. Meixner) Legacy Survey


LMC
Located at ≈ 50 kpc
Low metallicity
Spitzer 3.6μm (blue), 8μm (green) & 24μm (red)
Meixner et al. (2006)
30 Doradus

Data

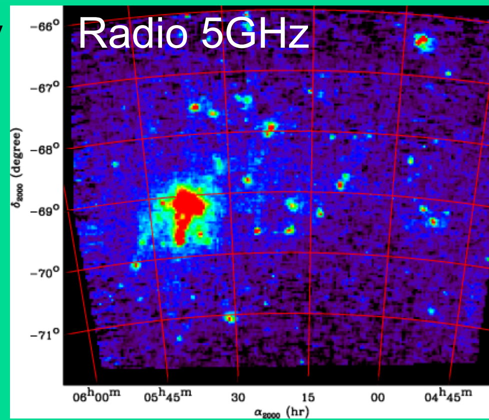
$$IR_\nu = a_\nu(\lambda) N_H^{HI} + b_\nu(\lambda) N_H^{CO} + c_\nu(\lambda) N_H^{H+} + d(\lambda)$$

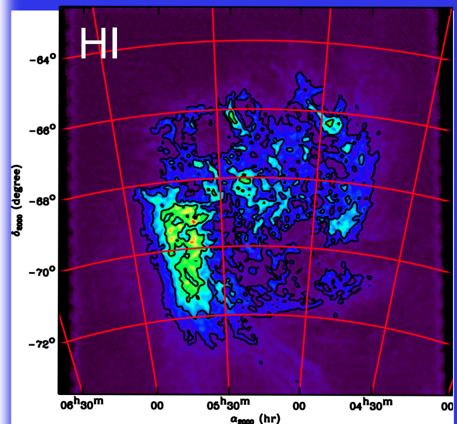


IR : **Spitzer** data from 3.6 to 160 µm, θ=1.6" to 42" (Meixner et al, 2006) combined with **IRIS** 12 and 100 µm data (Improved Reprocessing of IRAS) at 4'.

H_α: **SHASSA** survey (Gaustad et al., 2001) θ=0.8'.

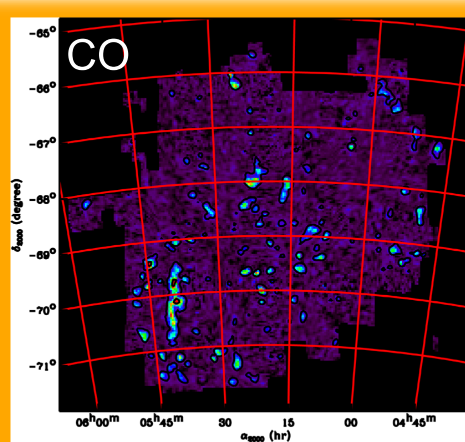
Radio @ 5 GHz : **Parkes** data, θ=5.6' (Filipovic et al., 1995).





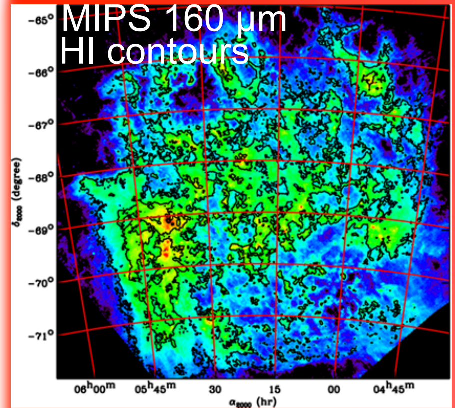
- 21 cm integrated intensity map
- Combination **ATCA** (θ=1', Kim et al, 2003) and **Parkes** data (θ=14'; Staveley-Smith et al., 2003).

$^{12}CO(J=1-0)$ 2nd survey (θ=2.6'), with the 4-m radio **NANTEN** telescope (Fukui et al., 2008).



Data

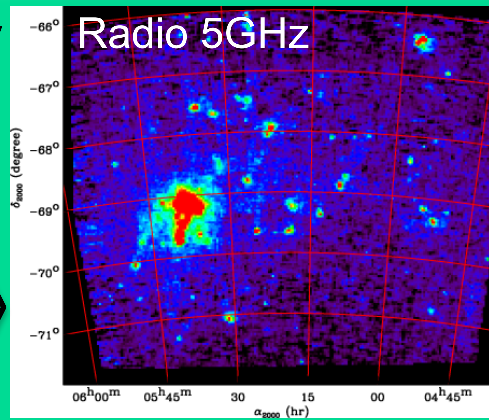
$$IR_\nu = a_\nu(\lambda) N_H^{HI} + b_\nu(\lambda) N_H^{CO} + c_\nu(\lambda) N_H^{H+} + d(\lambda)$$



IR : **Spitzer** data from 3.6 to 160 µm, θ=1.6" to 42" (Meixner et al, 2006) combined with **IRIS** 12 and 100 µm data (Improved Reprocessing of IRAS) at 4'.

H_α: **SHASSA** survey (Gaustad et al., 2001) θ=0.8'.

Radio @ 5 GHz : **Parkes** data, θ=5.6' (Filipovic et al., 1995).

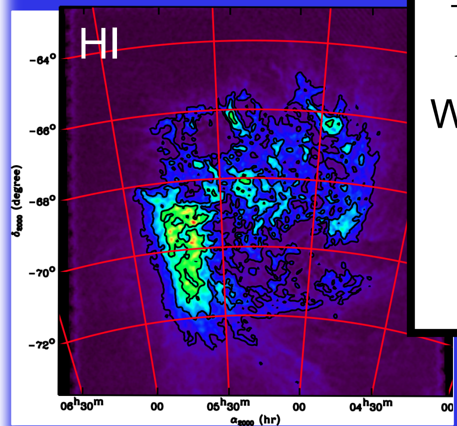


$$\frac{T_b}{I_{H\alpha}} = 8.396 \times 10^3 \nu_{GHz}^{2.1} T_4^{0.667} 10^{0.029/T_4} (1 + 0.08)$$

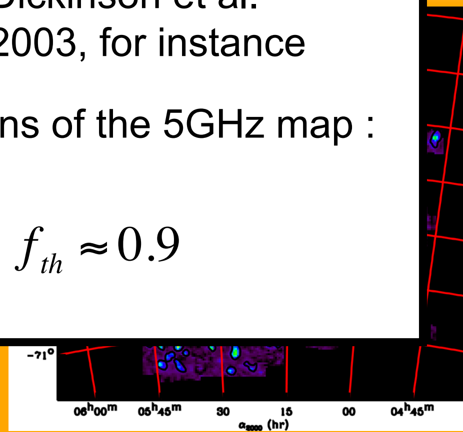
Dickinson et al. 2003, for instance

We estimated the thermal fraction in the bright HII regions of the 5GHz map :

$$\frac{S_5}{S_{1.4}} = f_{th} \left(\frac{\nu_5}{\nu_{1.4}} \right)^{-\alpha_{ff}} + (1 - f_{th}) \left(\frac{\nu_5}{\nu_{1.4}} \right)^{-\alpha_{sync}} \Rightarrow f_{th} \approx 0.9$$

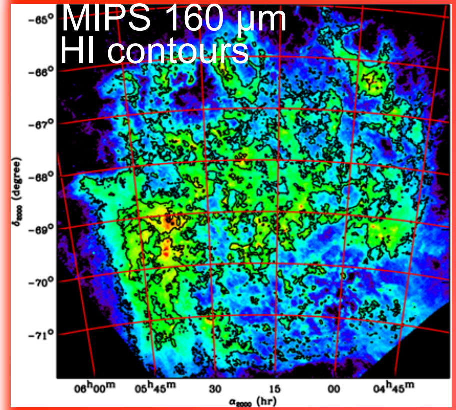


Smith et al., 2003).



Data

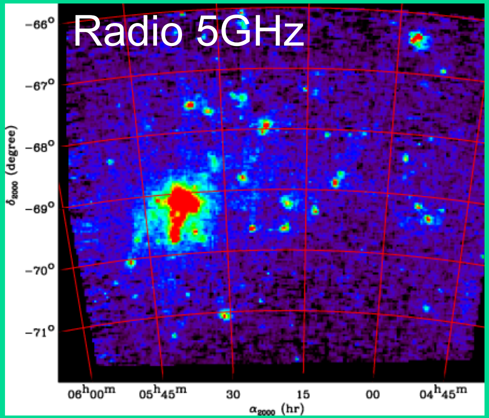
$$IR_\nu = a_\nu(\lambda) N_H^{HI} + b_\nu(\lambda) N_H^{CO} + c_\nu(\lambda) N_H^{H+} + d(\lambda)$$



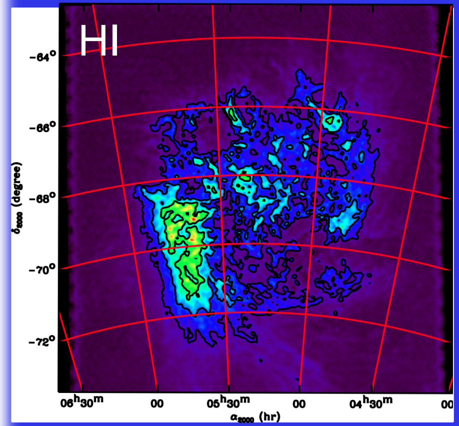
IR : **Spitzer** data from 3.6 to 160 µm, θ=1.6'' to 42'' (Meixner et al, 2006) combined with **IRIS** 12 and 100 µm data (Improved Reprocessing of IRAS) at 4'.

H_α: **SHASSA** survey (Gaustad et al., 2001) θ=0.8'.

Radio @ 5 GHz : **Parkes** data, θ=5.6' (Filipovic et al., 1995).

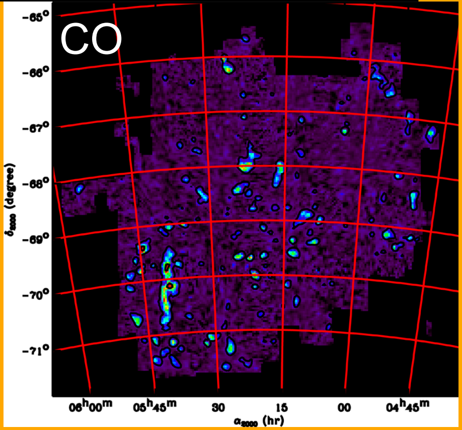


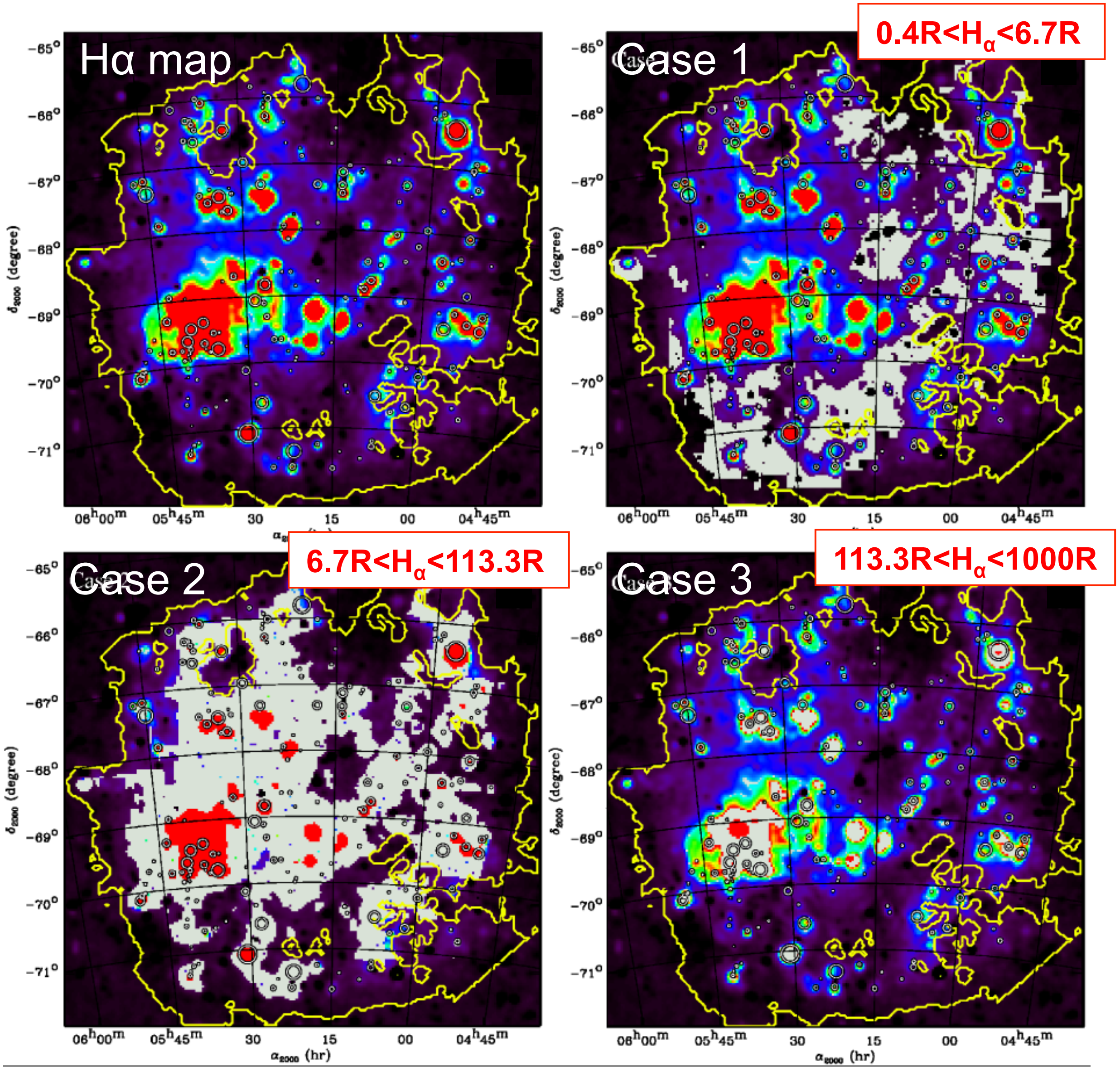
All the data have been convolved to the lowest resolution, θ=5.6'



- 21 cm integrated intensity map
- Combination **ATCA** (θ=1', Kim et al, 2003) and **Parkes** data (θ=14'; Staveley-Smith et al., 2003).

$^{12}CO(J=1-0)$ 2nd survey (θ=2.6'), with the 4-m radio **NANTEN** telescope (Fukui et al., 2008).





3 regimes defined using:

- the SHASSA map
- the Kennicutt & Hodge (1986) catalog

• **case 1: diffuse ionized gas**

n_e = 0.055 cm^{-3} (Galactic average value, Haffner et al. 2009)

• **case 2: typical HII regions**

n_e = 1.52 cm^{-3}

• **case 3: bright HII regions (30 Doradus excluded)**

n_e = 3.98 cm^{-3}

Due to the limited sensitivity, the 5GHz Parkes data can only be used for case 3

Modeling

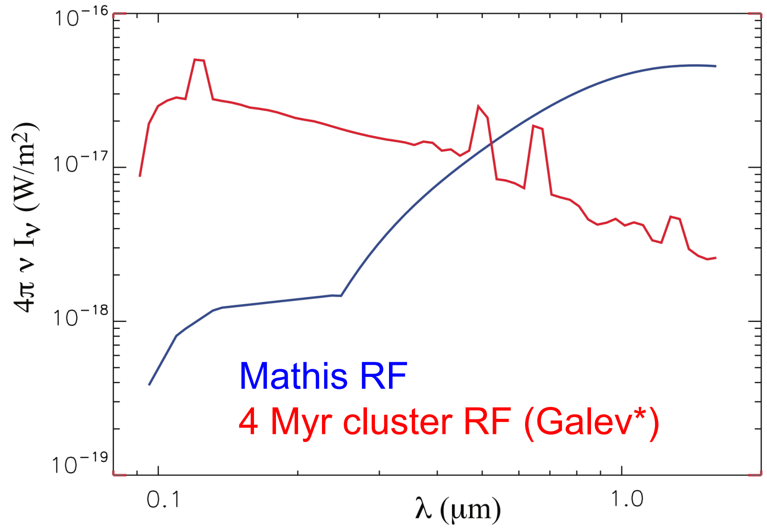
❖ *Single radiation field component along the LOS*

$$I_\nu = Y^{BG} I_\nu^{BG}(X_{RF}) + Y^{VSG} I_\nu^{VSG}(X_{RF}) + Y^{PAH} I_\nu^{PAH}(X_{RF})$$

with Y : mass abundances relative to H

I_ν : computed using an updated version of the Desert et al. (1990) model (*DustEM,* Compiègne et al., 2008)

➔ **Y : determined by fitting to the data for the best X_{RF}**



**available at http://www.galev.org*

❖ *Composite radiation field components along the LOS*

- *Local SED combination (Dale et al., 2001)*
- Model: *DustEM*

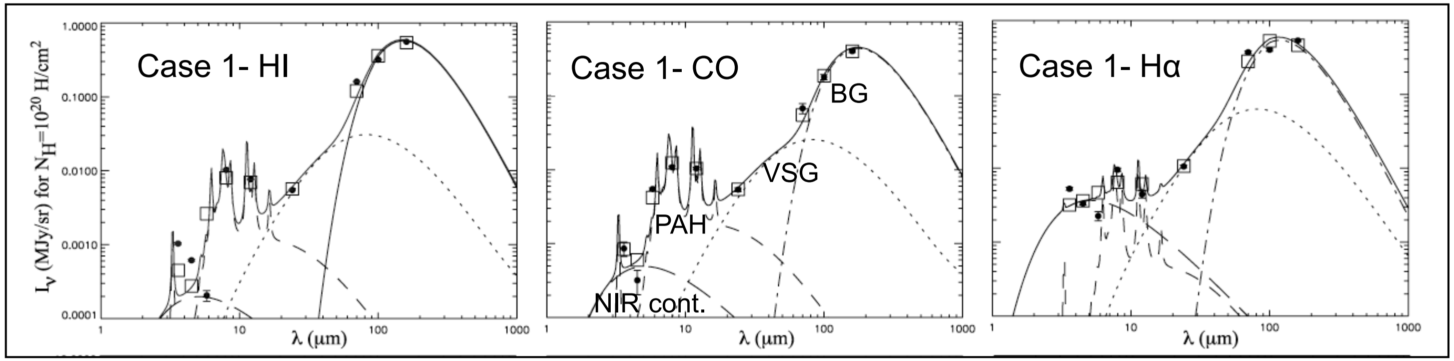
$$I_\nu^{tot} = \frac{\sum_i \sum_j I_\nu^{\mathrm{mod}}\left(X_{RF,i}, RF\right) X_{RF,i}^{-\alpha_j}}{\sum_i \sum_j X_{RF,i}^{-\alpha_j}}$$

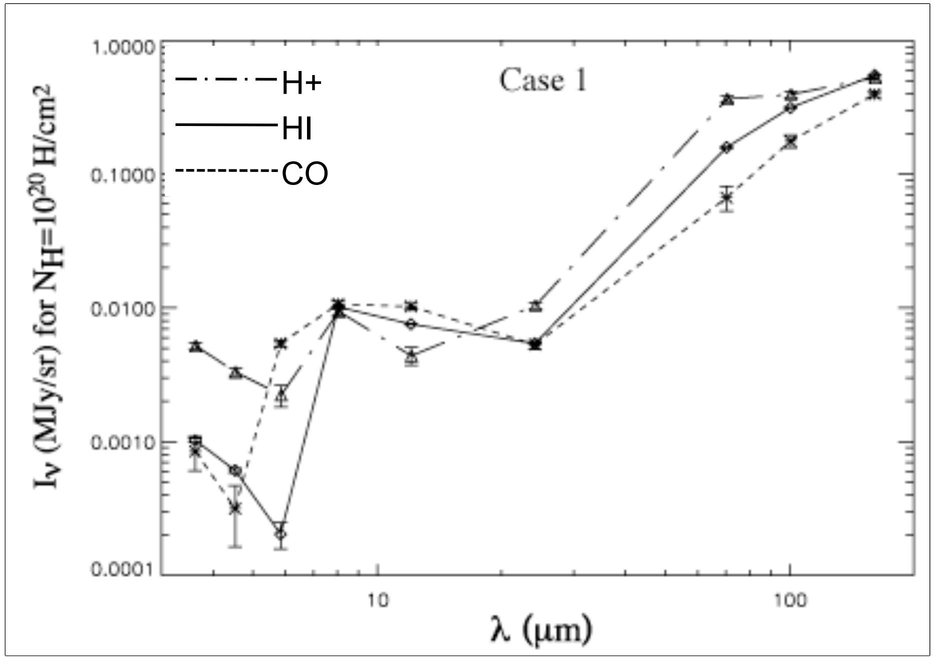
$\sum$ *Solar RFs* $\sum$ *4Myr-cluster RFs* $\sum$ *(Solar RFs+4Myr-cluster RFs)*

➔ **Y : determined by fitting to the data for the best α**

Results: case 1-diffuse ionized gas

Modeling with a single RF

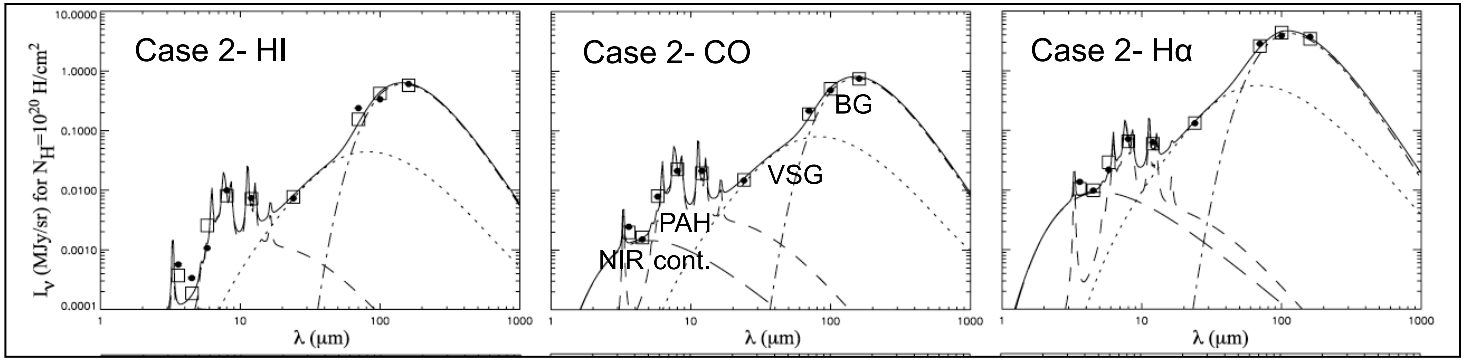


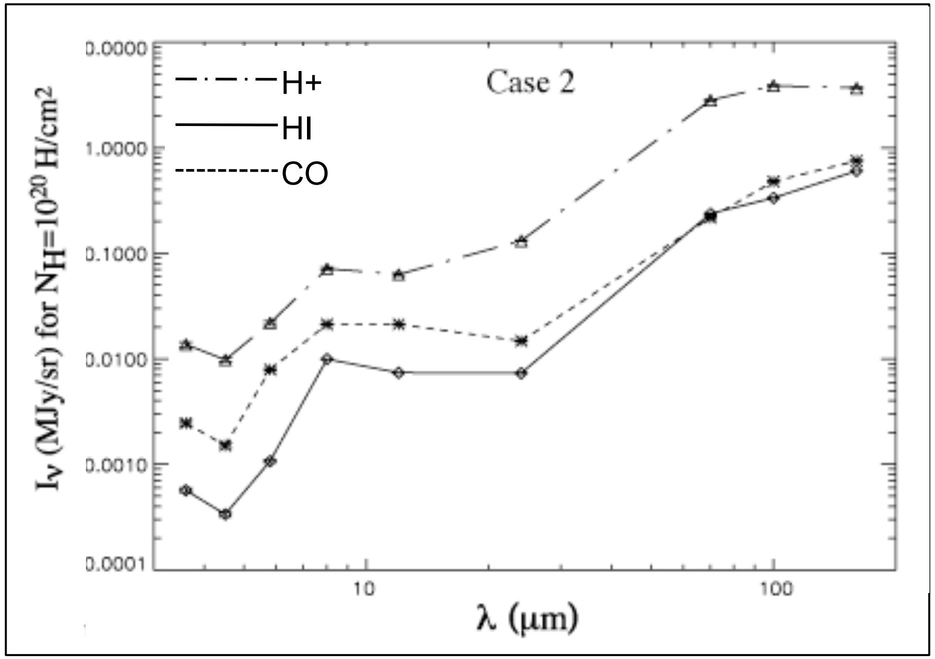


- ✓ Dust emission in H+ dominant in the FIR
- ✓ T_d^{H+}=23.9 K, T_d^{HI}=18.7 K and T_d^{CO}=16.1 K
- ✓ $\varepsilon_{160}^{H+} = 2.3\times10^{-26}$ cm²/H
  => ε_{LMC}=1/10 $\varepsilon_{\odot}$= 1/40 ε_{GAL}
- ✓ $(Y_{PAH}/Y_{BG})^{H+}$ =1/3 $(Y_{PAH}/Y_{BG})^{HI}$
  =1/6 $(Y_{PAH}/Y_{BG})^{CO}$
- ✓ ➚ of the NIR continuum in the H+ phase

Results: case 2-typical HII regions

Modeling with a single RF





✓ Dust emission in H+ dominant

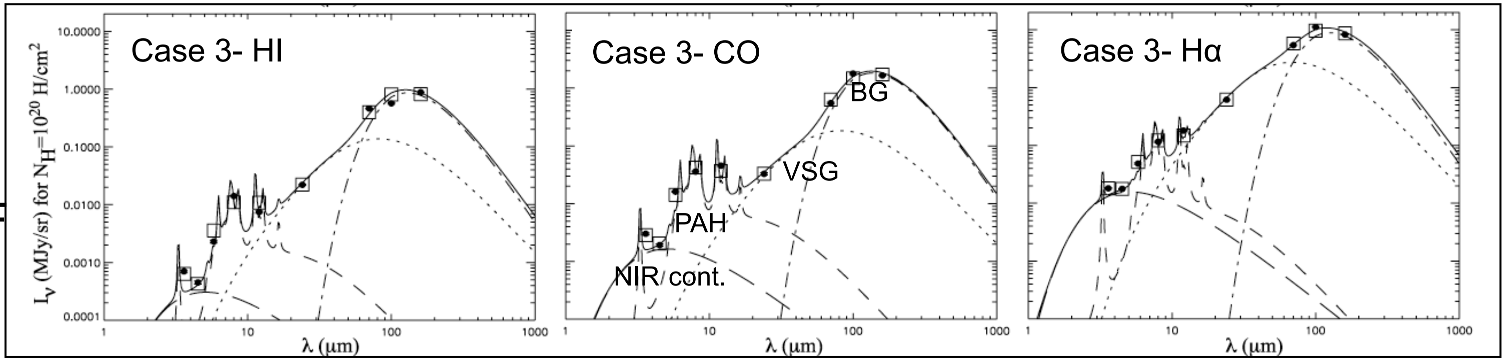
✓ T_d warmer in H+ (23.7 K) than in HI and CO (18-19 K)

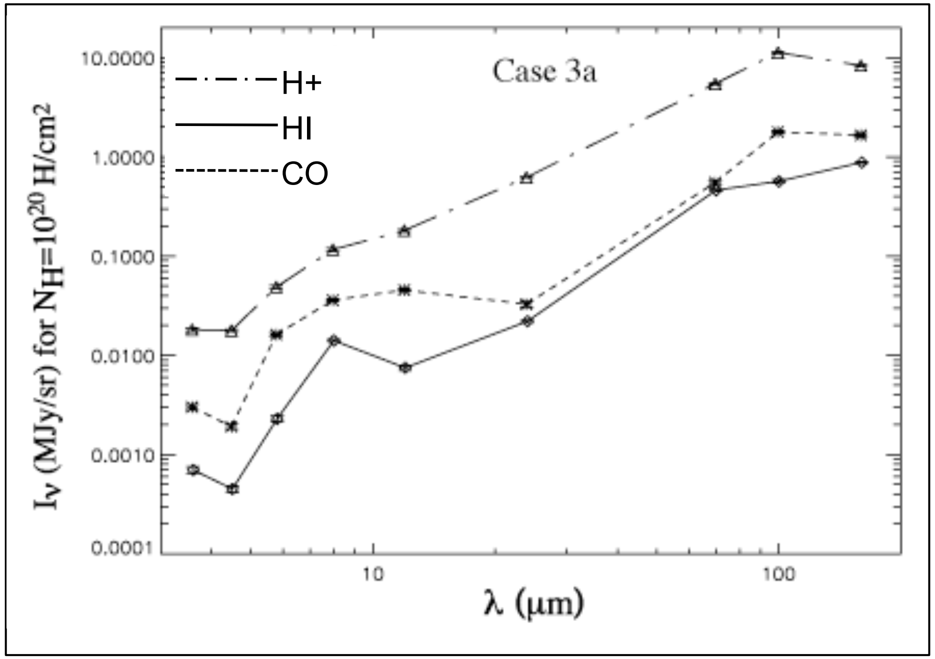
✓$(Y_{PAH}/Y_{BG})^{H+}$ $=1/4\ (Y_{PAH}/Y_{BG})^{HI}$
$=1/10\ (Y_{PAH}/Y_{BG})^{CO}$

✓ ➚ of the NIR continuum in the H+ phase

Results: case 3-bright HII regions

Modeling with a single RF





✓ Results for both gas tracers are in agreement

✓ Same results as in case 2:
- Dust emission in H+ highly dominant
- T_d warmer in H+ phase (26.7 K)
- low $(Y_{PAH}/Y_{BG})^{H+}$
- high $(Y_{PAH}/Y_{BG})^{CO}$
- ↗ of the NIR continuum in the H+ phase

✓ PAH disappearance increases from case 1 to 3

✓↗$(Y_{VSG}/Y_{BG})^{H+}$ by at least a factor of 2 from case 2 to 3

Summary

✔ We have carried out the first detailed analysis of the H+ gas in the LMC

✔ systematic warmer T_d in the H+ phase: ≈ 24K in the diffuse H+/typical HII regions and 27 K in bright HII regions)

✔ ε_{160} in the diffuse H+ gas of the LMC lower than in our Galaxy, with a difference higher than the metallicity ratio

✔ ➘ of $(Y_{PAH}/Y_{BG})^{H+}$ and from the diffuse H+ to the bright HII regions

✔ Survival of the PAHs in the CO phase

✔ Enhancement of the $(Y_{VSG}/Y_{BG})^{H+}$ comparing the bright with typical HII regions

✔ ➚ of the NIR continuum in the H+ phase, which does not correlate with PAH emission