Programme INSU-AA

Physique et Chimie du Milieu Interstellaire

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Physique et Chimie du Milieu Interstellaire

- Activités interdisciplinaires liées à l'étude de la matière interstellaire et circumstellaire (gaz+grains) et des milieux associés

    - des grandes échelles aux petites échelles (inter - circum - stellaire)

    - aspects dynamiques et chimiques

    - compréhension fine des processus physico-chimiques

        * astrophysique de laboratoire (expérience et théorie), bases de données
        * modélisation et simulations numériques

- Communauté qui fédère astrophysiciens, physiciens et chimistes

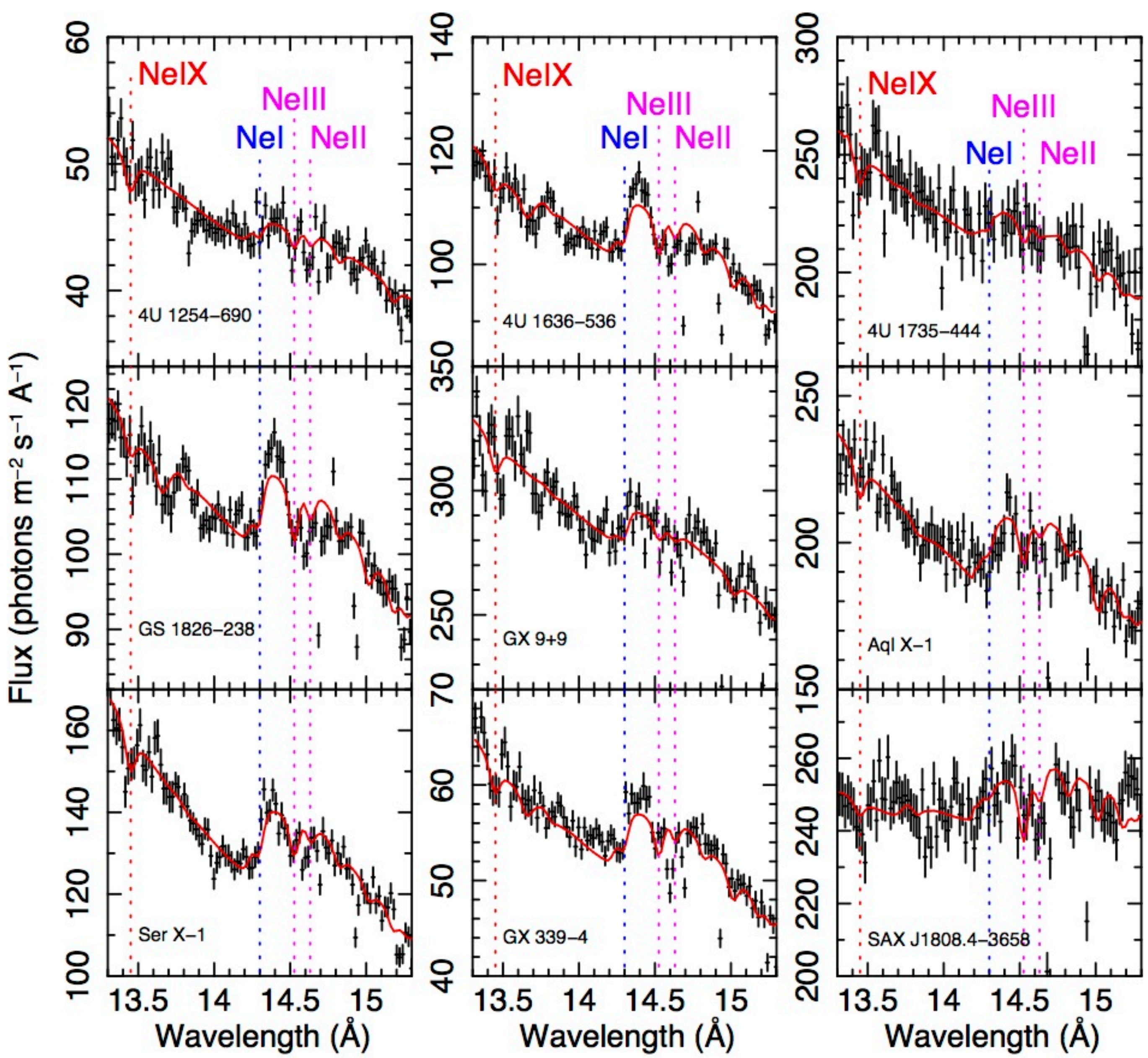
- Traditionnellement très forte implication dans les observations des domaines IR à mm (Herschel, ISO, Spitzer, IRAM, ALMA ...)

X-ray spectroscopy

Observation of X-ray sources to probe interstellar gas in front of sources
• lines in absorption and emission

High resolution with XMM-Newton

Pinto C. et al. (2013) - 9 lines of sight towards Galactic X binaries



Observed transitions :

neutral gas :
NeI edge -> 14.3 Å
NeVII -> ~ 13.7 Å

FeXVII -> 15.0 Å
FeXVIII -> 14.2 Å

Fe L2 -> 17.15 Å
Fe L3 -> 17.5 Å

Oxygen K edge :
OI 1s-2p -> 23.5 Å
OII 1s-2p -> 23.35 Å
OIII -> 23.1 Å
OVII -> 21.6 Å
OVI -> 22.0 Å

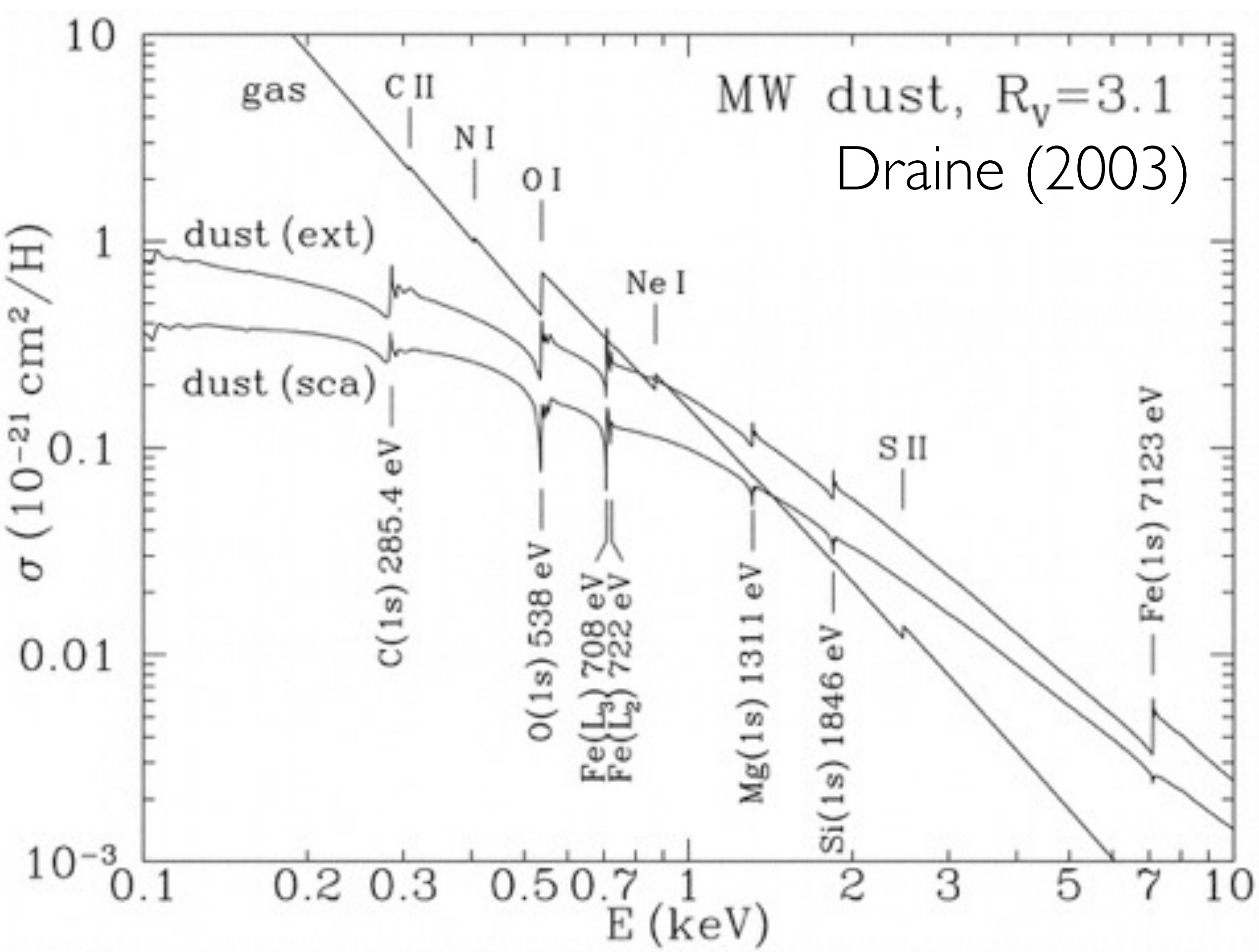
Ionized and neutral gas
OVII beta -> 18.6 Å
OVIII alpha -> 19.0 Å

X-ray spectroscopy

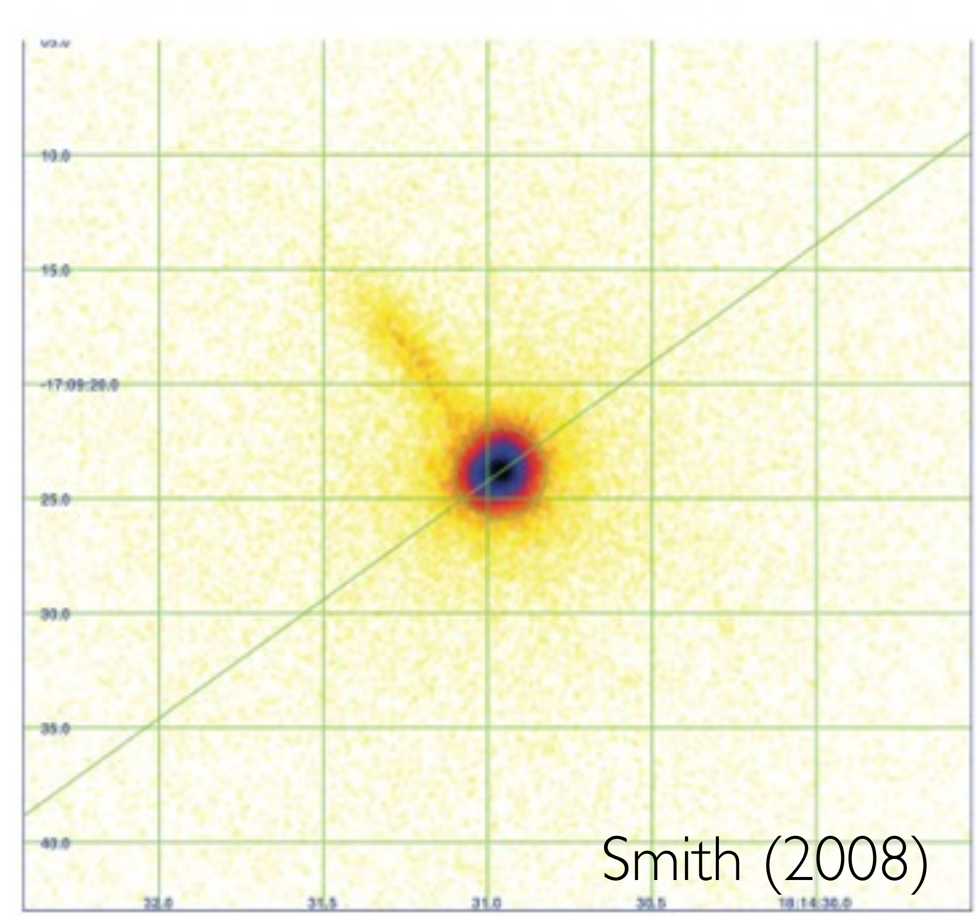
Composition and size distribution of grains are important for interstellar medium physics

- absorption of ionizing radiation field : control atomic / molecular transition
- formation of H2 and other molecules
- photo-electric effect

Extinction and scattering of X-rays by grains



Chandra
X-ray scattering by dust towards GX13+1



X-rays diffusion provides new constraints on grains :

- Test of models of grains
- Size distribution

X-ray spectroscopy

XMM-Newton
Low mass X binaries

Composition of dust
• Observation of Fe in dust between 0.7 - 7 keV

90% of Fe in dust towards QSO IRAS 13349

Observations in absorption towards X sources
• Abundance & gradient : C, O, Mg, Ne, Fe, Si, Al ...
• Depletion of elements in grains
• Composition of grains

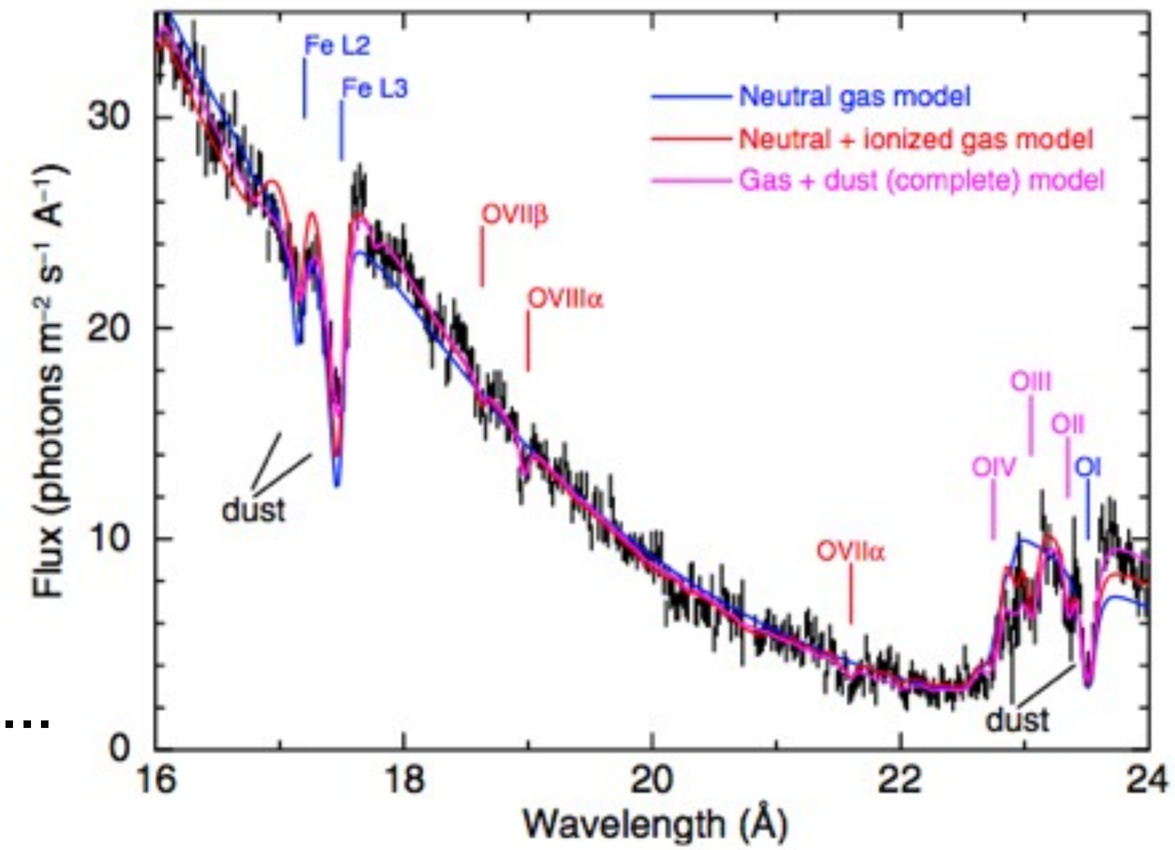


Fig. 5. Spectral fits of the Fe L and O K edges for GX 339-4 (for clarity only one stacked spectrum is shown). For more detail see Sect. 4.2 and Table 2.

Pinto C. et al. (2013)

But
• difficult to detect some key species
  Carbon : filters on detectors made of carbonaceous material

• Need high spectral resolution 0.02 Ang
  • velocity of gas
  • velocity dispersion

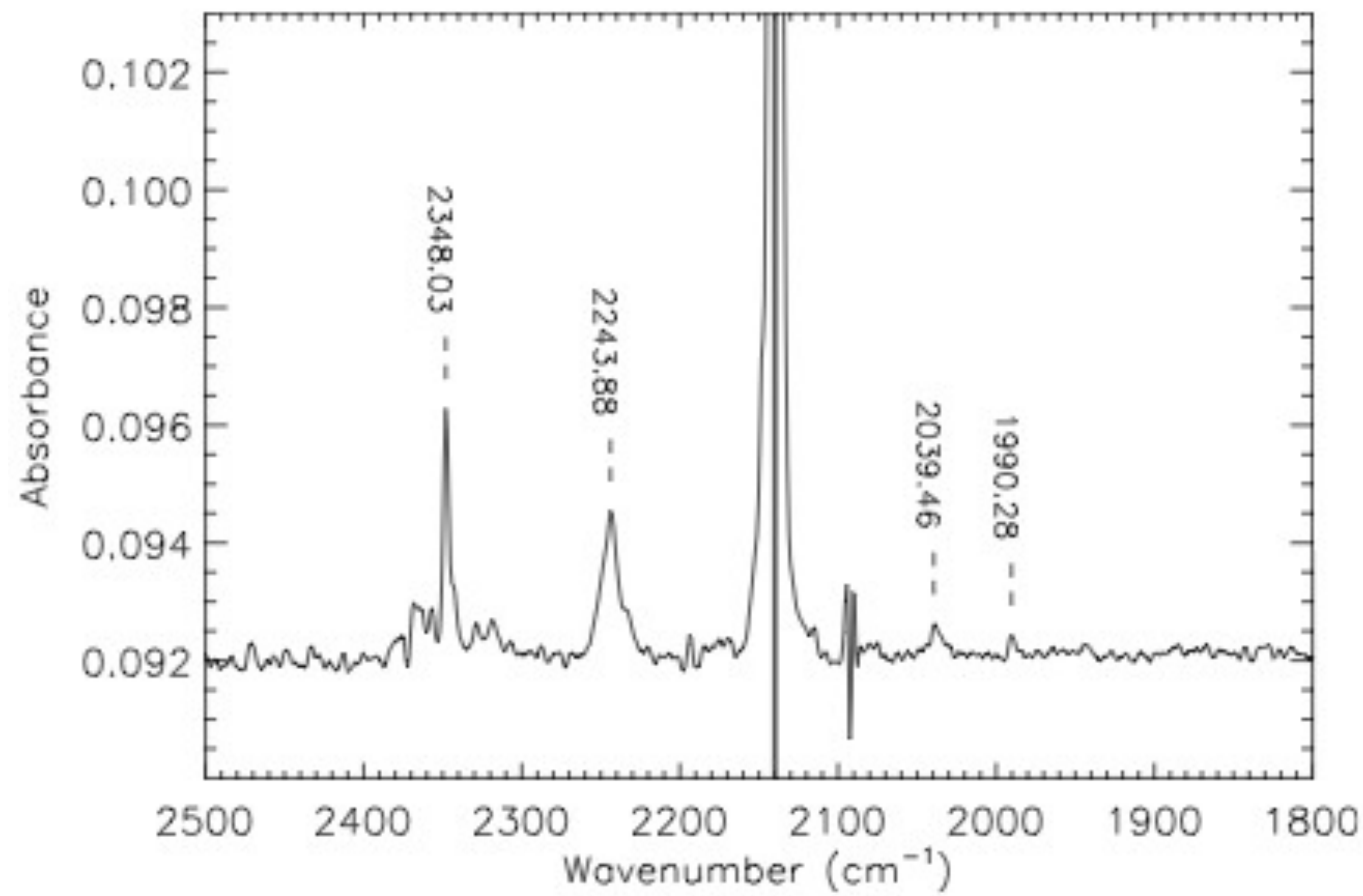
Formation of organic molecules

Some complex organic molecules are formed on grain surfaces

Laboratory experiments
Irradiation of ices by X-rays and UV photons

UV + CO-ice -> CO_2

X-ray + CO-ice -> CO_2, C_2O, C_3O_2, C_3, C_4O, ...



(Ciaravella et al. 2012)

X-rays initiate the formation of organic molecules

Young Stellar Objects environments
- 10 AU : UV absorbed
- Physics of X-rays dominates radiation-matter interaction
- Source of formation of organic molecules ?

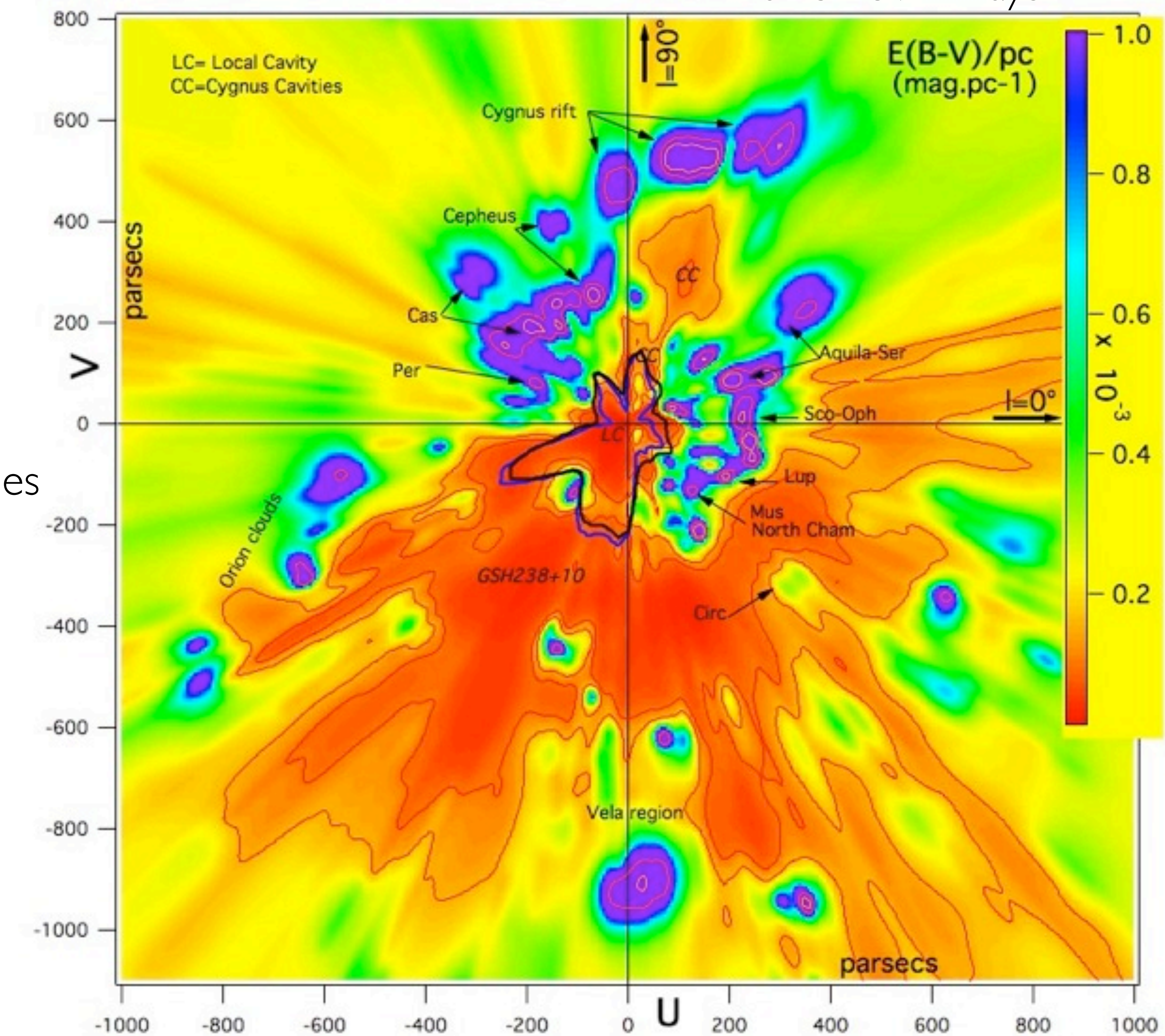
Hot interstellar medium (HIM)

The Hot Interstellar Medium traced by X-rays
- density : 0.0001 - 0.01 cm^{-3}
- temperature : ~ 1 million K

Source of soft X-rays

ROSAT observations
0.25 keV X-rays

3D view of the interstellar medium
- Gaïa and ESO survey
- Preliminary works
  - clouds and cavities
  - X-ray emission in direction of cavities



(R. Lallement - GEPI)

Supernovae remnants

Feedback on the interstellar gas

Induce **shocks** in the gas

- observations from X to radio
  In X domain : forest of lines around 1 keV

- enhance molecule formation
  observations of these molecules in all domains of wavelength (absorption & emission)

- impact on dust evolution
  - grain sputtering behind shocks

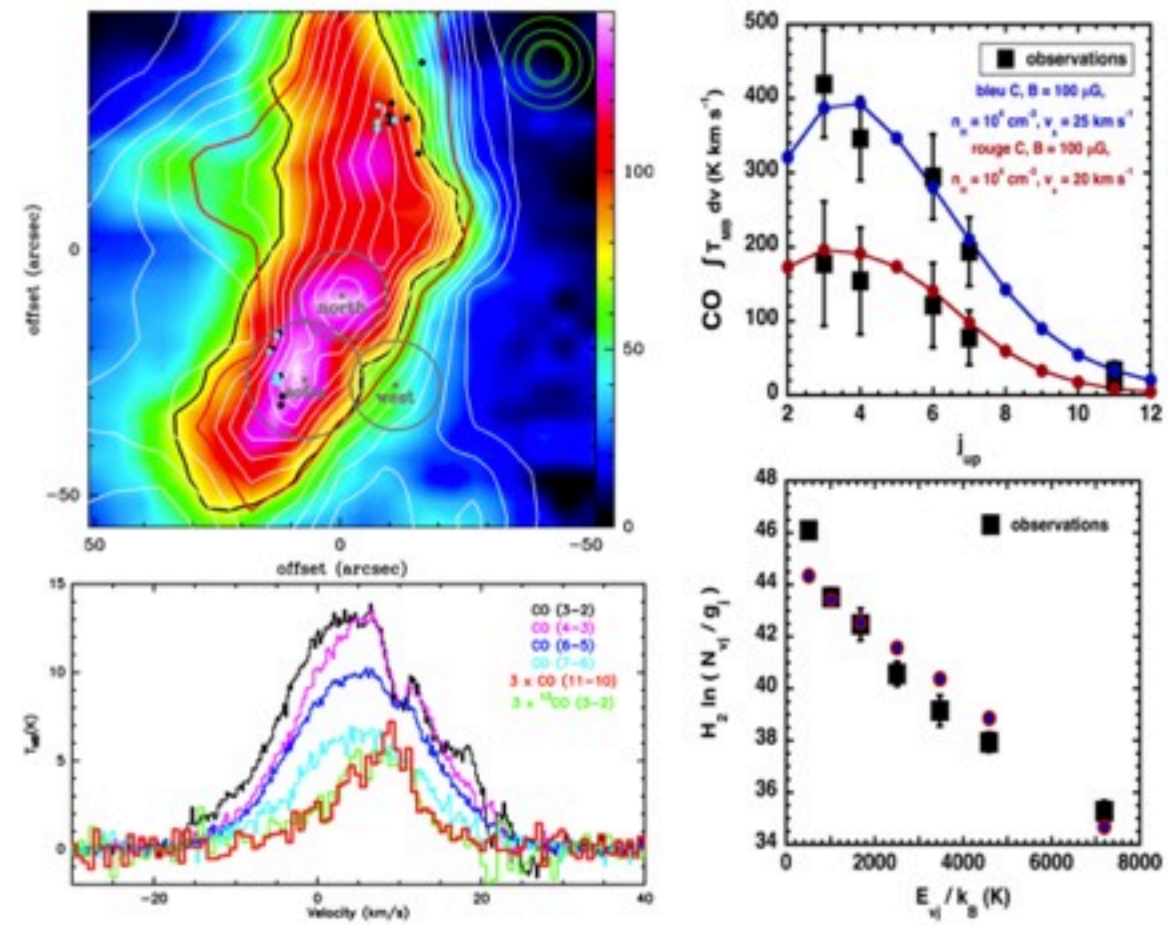


Figure 3: *À gauche :* carte d'émission en CO dans le SNR W28 (W28F, (6–5) couleurs, et (3–2), contours blancs) observée par le télescope APEX (en haut). les spectres (en bas) sont extraits du point 'sofia' sur la carte, qui indique la position des observations SOFIA/GREAT (le cercle indique le beam de SOFIA pour la transition CO (11–10)). *À droite :* la modélisation de ces données fait appel à une composante de choc C par composante de vitesse (bleue-rouge) des observations de CO (en haut), dont la superposition reproduit les données H_2 (*Spitzer*/IRS, en bas).

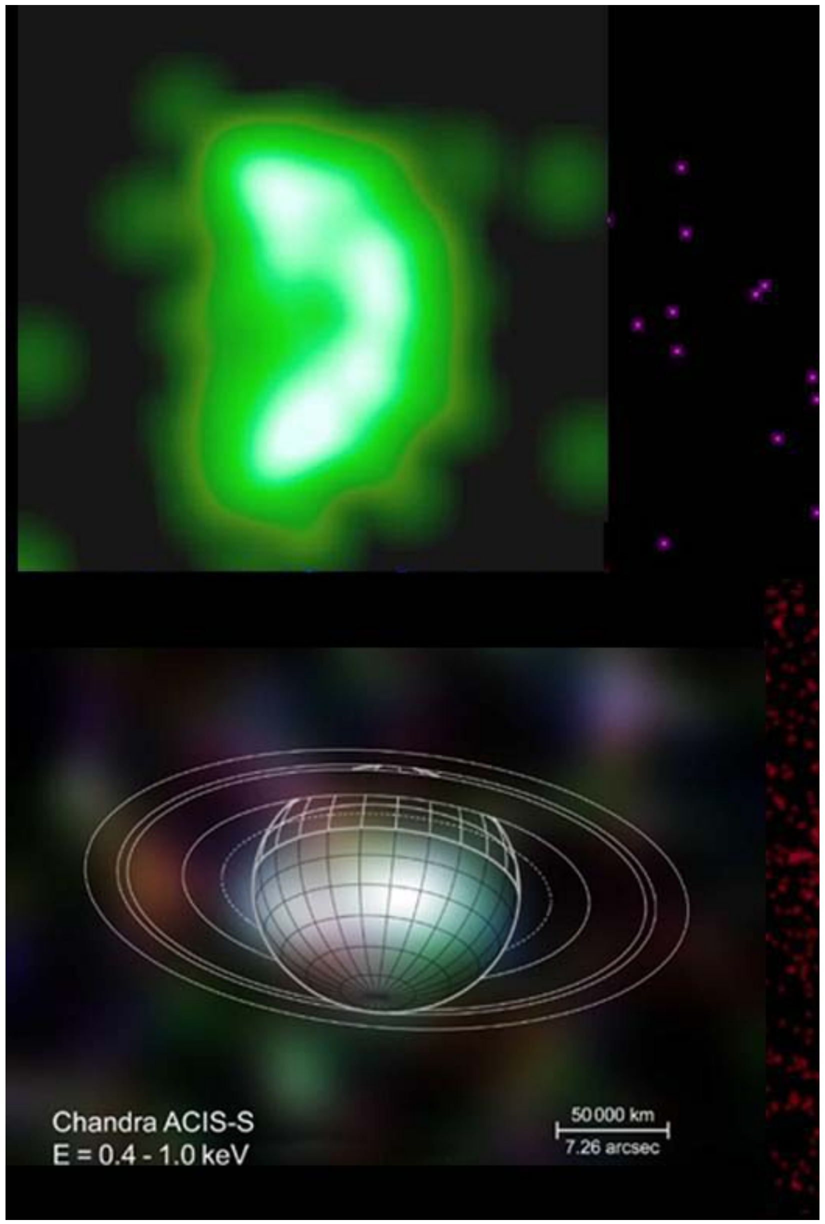
A. Gusdorf et al.

Key informations on chemistry on grains and their evolution

Models need to take into account interaction with X-rays
Requires high spatial ands spectral resolution to investigate this process.

Interaction between hot and cold medium

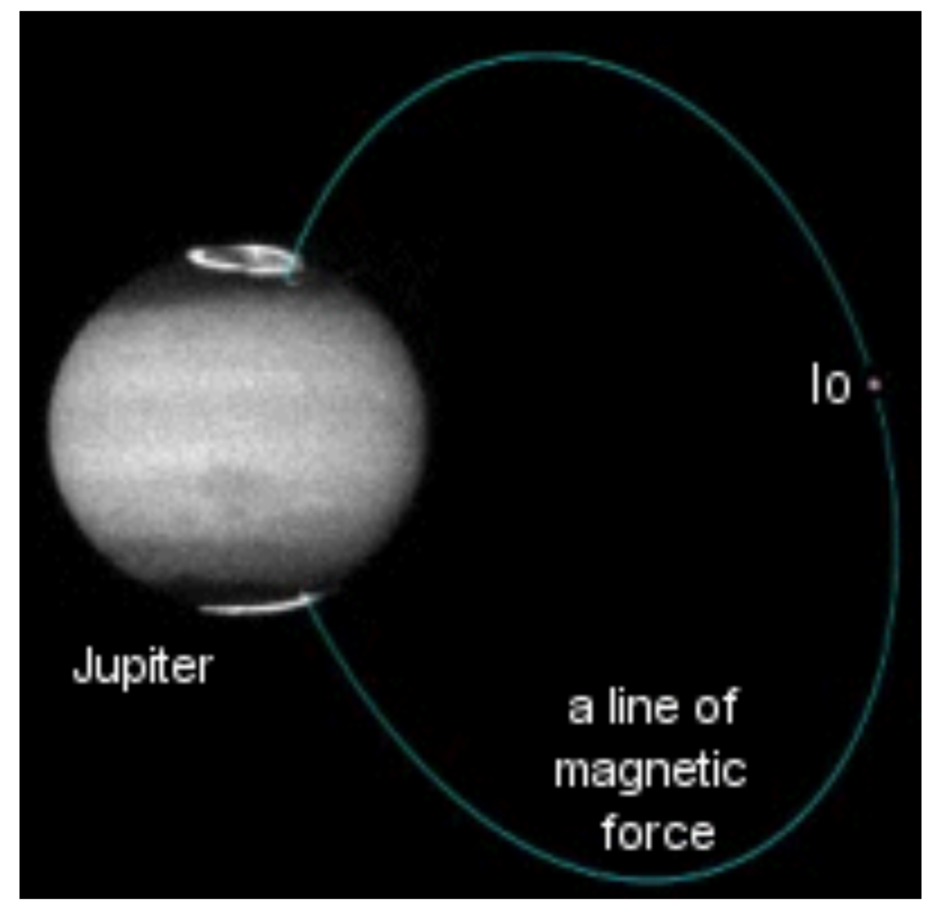
Charge transfer produces X-ray emission
Well known process in the Solar System



Solar wind ions + neutral medium from :

- Comets
- Planetary atmospheres
  Earth, Moon, Mars, Venus, Saturn, ...
- Heliosphere / Interstellar wind

Solar wind and Io's volcanoes ions
+ Jupiter atmosphere



Should be present in other media as ISM

Interaction between hot and cold medium

Diffuse X emission in star forming regions
- Hot gas with dynamics
- Interaction with molecular clouds

Charge transfer ?

First studies done with Chandra
- Emission exclusively lines
- Requires spectral resolution

Such interaction would occur in small layers
- Need spatial resolution

Requirements
- Spectral resolution
- Spatial resolution

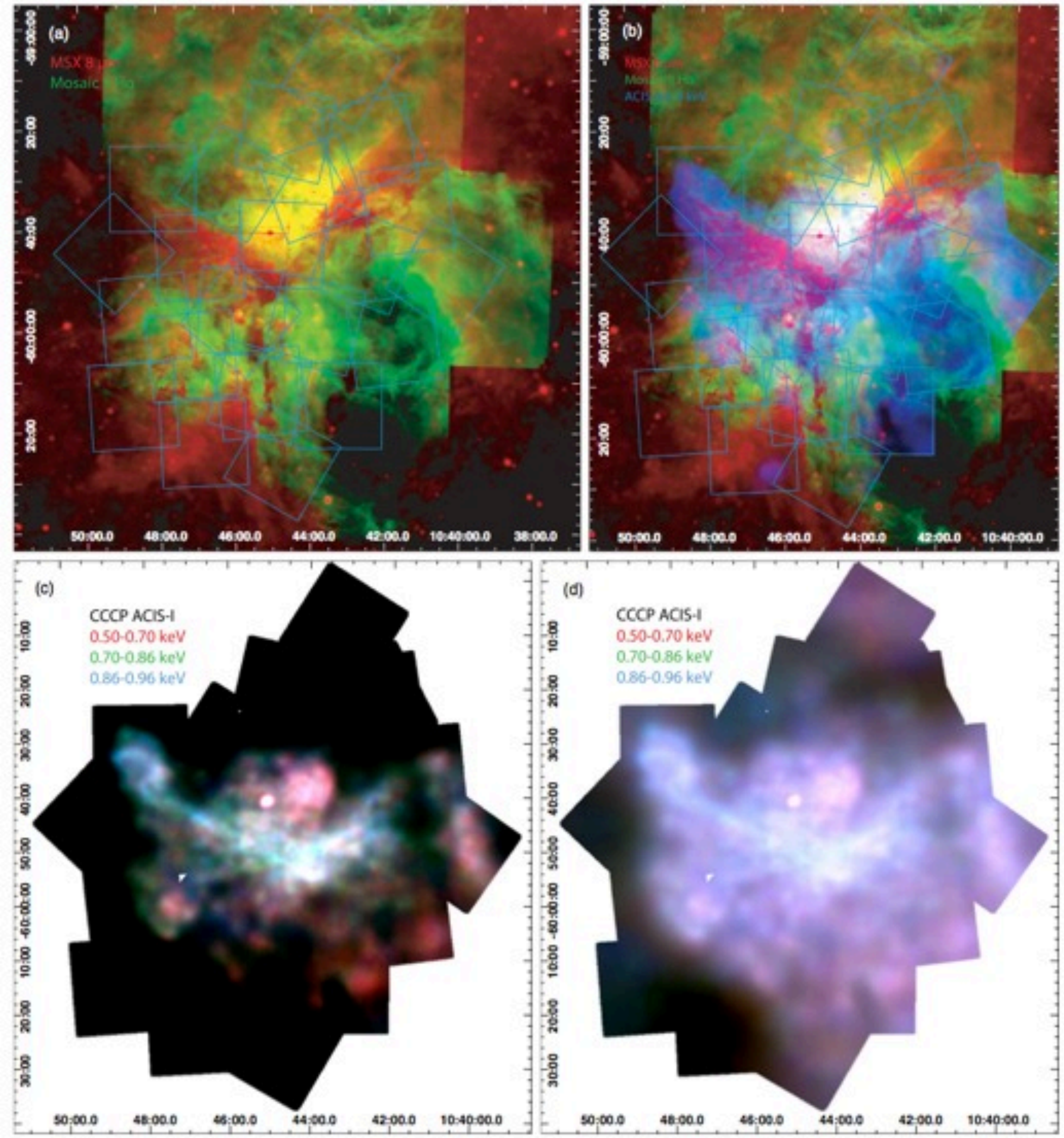


Figure 1. (a) The multiwavelength context of the CCCP. *MSX* 8 μm data in red and Hα from the MOSAIC II camera (CTIO) in green, with the locations of ACIS-I pointings for the CCCP mosaic outlined by blue squares. (b) The same visual and infrared images as (a), now zoomed slightly and with an adaptively-smoothed CCCP soft-band (0.5–2 keV) apparent surface brightness image (point sources excised before smoothing) added in blue. (c) A smoothed apparent surface brightness image of Carina's soft extended X-ray emission (point sources excised) from the CCCP, with red = 500–700 eV, green = 700–860 eV, and blue = 860–960 eV. (d) The same image as (c), scaled now to bring out the faint diffuse structures. At a distance of 2.3 kpc, 10′ ~ 6.7 pc. Here and throughout this paper, coordinates on images are celestial J2000; electronic images reveal substantial detail when zoomed.

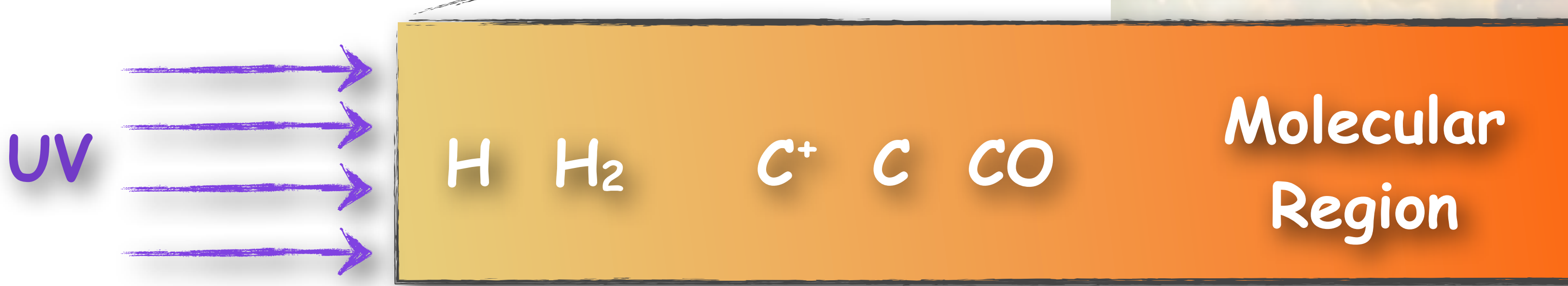
Chandra observations of Carina

Townsley et al. (2011)
T. Montmerle

PDR and XDR

PDR : Photo-dominated regions

UV photons
- photo-dissociate molecules
- heat the gas by photo-electric effect on grains

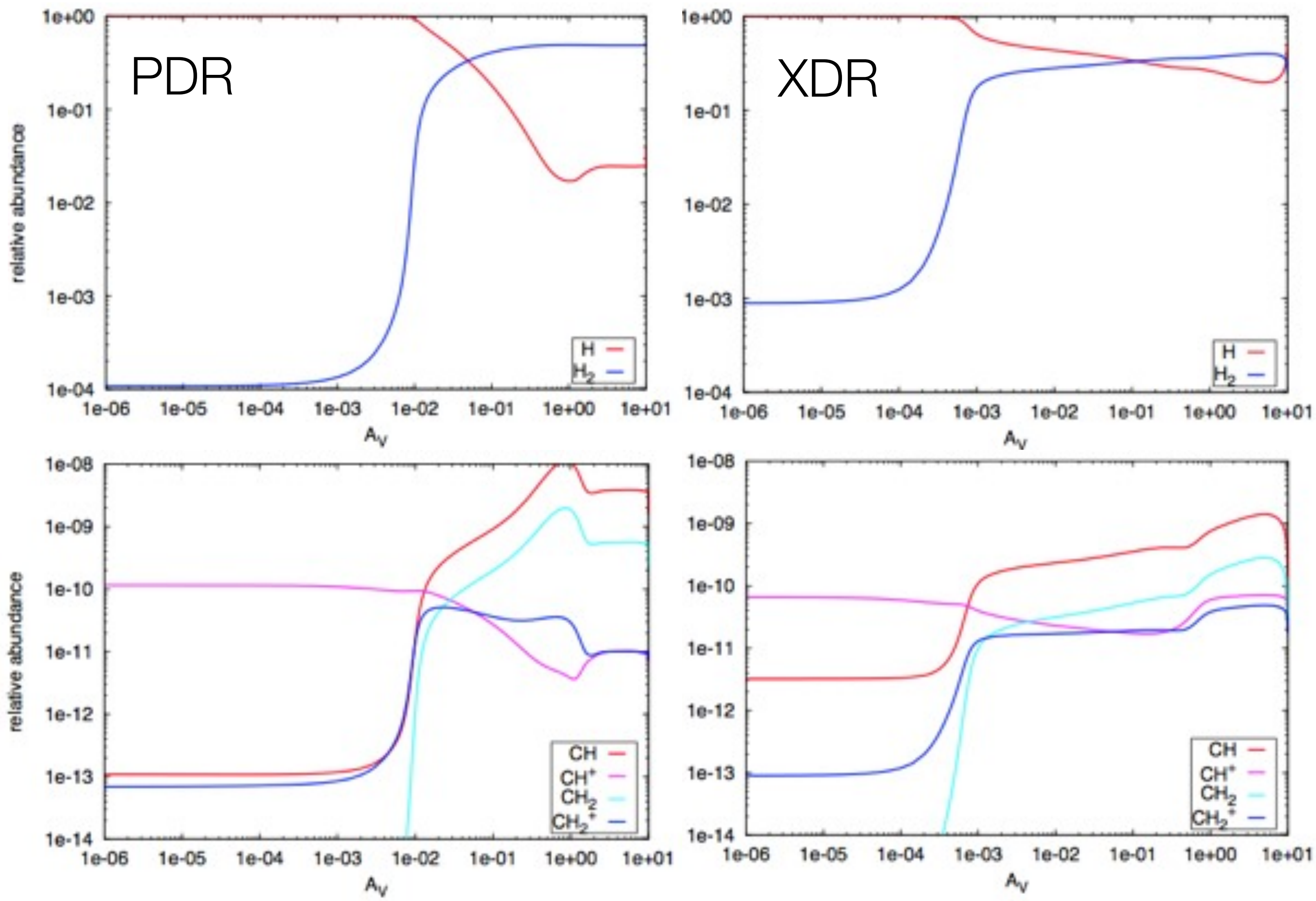


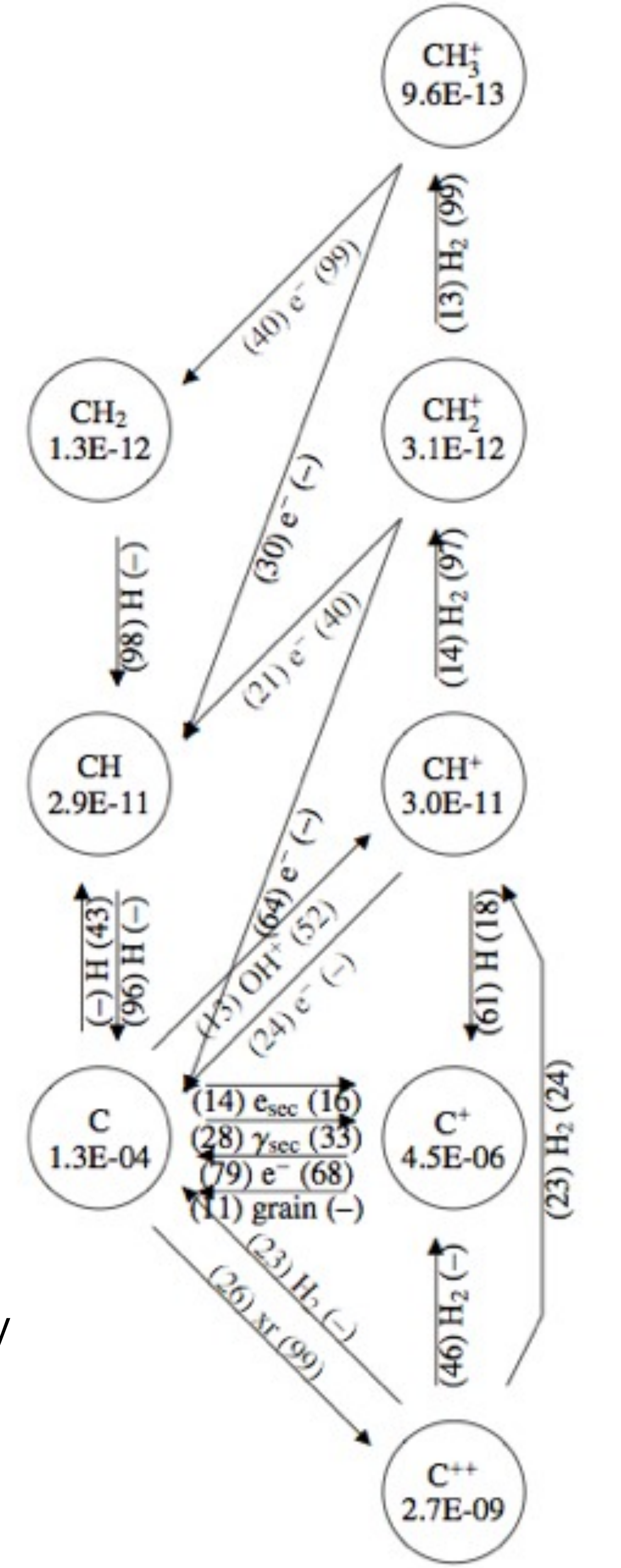
XDR : X-Ray dominated regions

X-Rays penetrate deeper in molecular clouds / disks than UV
Double ionizations (C^{++}) : impact on chemistry

- T Tauri
- Galactic center
- Clouds near X-rays sources

PDR and XDR





Creation of fast electrons / secondary electrons -> heat & chemistry
Double ionization : open chemical routes
Galactic Center / CMZ (?)

Observations of molecules probing chemistry and processes of interstellar gas

- Models for interpretation require flux & spectra of X-rays impinging on clouds

Conclusions

- Nouveaux diagnostics pour l'étude du milieu interstellaire
  - conditions extrêmes
  - abondances et excitation électronique
  - interaction avec les grains
  - étude de la phase chaude du MIS
  - interaction entre les phases chaudes / dynamiques et la phase froide

- Quelques travaux pionniers

- Communauté PCMI intéressée
- Besoins de haute résolution spectrale et spatiale
- Détecteurs sensibles à toutes les espèces (dont le carbone)