Cosmic-ray ionisation of molecular clouds

— Summary of a PhD thesis —

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Presentation of the thesis

Context:

- Cosmic rays (CR) **dominate the ionisation** in dense molecular clouds, which **affects dynamics, temperature, and chemistry**
- Supernova remnants (SNR) W28, W44 and W51C known to **interact with nearby clouds**
- Nearby clouds expected to be irradiated by **CR flux enhanced relatively to isolated clouds**, due to SNR
- **High-energy CRs** (>280 MeV) induce **γ-ray emission** through π^0-decay, **low-energy CRs** (<1 GeV) enter the cloud and **ionise the gas**
  ⇒ Look for **signature of ionising low-energy CRs** in the gas

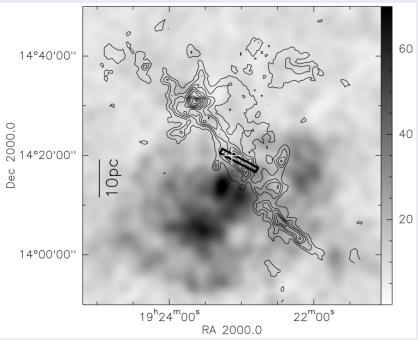
Methods:

- **Millimeter observations** (IRAM) and **comparison** of chemical abundance ratios **to model predictions** (`astrochem` code, OSU network)
- CO lines used to infer **physical conditions**, and DCO^+ and HCO^+ to infer **ionisation fraction** x_e and **CR ionisation rate** ζ

Results:

- We derive ζ values > **100 times higher** than in isolated clouds
- This work brings **unique information on low-energy CRs**, complementary to high-energy observations
- This poster is an **overview of my thesis work**. See below for results in each studied region, and related papers.

1. The SNR W51C region [1,2]



- grayscale: ROSAT X-ray map of SNR W51C
- contours: CO(2-1) 60-75 km s^{-1}
- black box: IRAM 30m observations
- white cross: IRAM PdBI observations

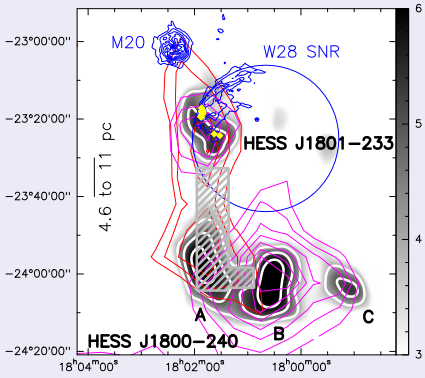
Results:

- **enhanced ionisation** by low-energy CRs
- **compact** SiO emission ⇒ trace **passage of SNR shock**

Perspectives:

- map **across the shock** ⇒ additional compact regions, ionisation gradient?

2. The SNR W28 region [3]



- purple contours: CO(1-0) 5-15 km s^{-1}
- red contours: CO(1-0) 15-25 km s^{-1}
- gray scale and white contours: HESS TeV emission
- blue contours: 20cm free-free emission
- hatched area: IRAM 30m mapping (May 2015)

Results:

- **enhanced ionisation in the North** close to the shock, **standard in the South** ⇒ **constraints** on low-energy CR **diffusion properties**

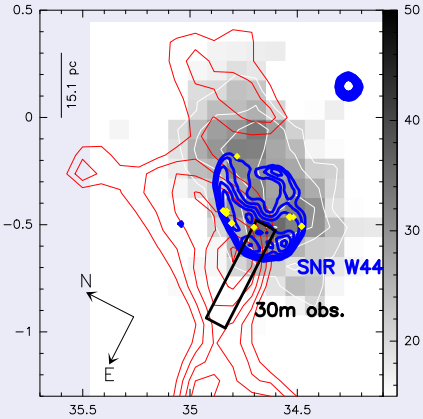
Work in progress:

- study of **tracers** of the ionisation **alternative** to DCO^+/HCO^+
- large mapping towards the South ⇒**ionisation gradient?**

Perspectives:

- ALMA observations ⇒ **D depletion?**

3. The SNR W44 region [4]



- grayscale and white contours: *Fermi*-LAT GeV emission
- red contours: CO(1-0) emission
- blue contours: 10 GHz free-free emission

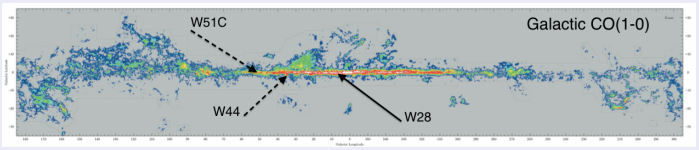
Results:

- Higher gas density than in W28 and W51C
- N_2H^+/HCO^+ used together with DCO^+/HCO^+ brings additional constraints ⇒ **enhanced ionisation** ⇒ no CO depletion ⇒ constraints on volatiles C and N

Perspectives:

- Better understand this region!

Characteristics of these regions



		W51C (49.3, 0.3)	W44 (34.6, -0.5)	W28 (6.3, 0)
SNR	Age [yr]	$\sim 3 \times 10^4$	$\sim 2 \times 10^4$	$\gtrsim 10^4$
	Heliocentric distance [kpc]	~ 5.5	~ 3	$2 - 4$
	Galactic distance [kpc]	~ 6.9	~ 6.3	$4.5 - 6.5$
Cloud	Density n_H [cm^{-3}]	$\sim 10^4$	$10^4 - 10^5$	$10^3 - 10^4$
	Temperature [K]	$21 - 24$	$7 - 17$	$8 - 20$

References

[1] Ceccarelli et al. 2011, ApJ 740 (ADS link)
[2] Dumas, **Vaupré** et al. 2014, ApJL, 786 (ADS)
[3] **Vaupré** et al. 2014, A&A, 568 (ADS)
[4] **Vaupré** et al. 2015, in preparation

Perspectives of the thesis:

Observations:

- Can we observe **CR ionisation gradients** towards the SNR shells?
- Can we identify **alternative molecular tracers** in highly ionised regions?
- Is there evidence of **deuterium depletion** in cold regions with high ζ values?

Modeling:

- Introduce self-consistent **thermal balance** calculation in chemical modeling
- Consider **CR spectrum propagation** into the cloud (link to CRIME project)