Far Infra-Red Interferometer:

What type of astrochemistry can we do?

Serena Viti - UCL

25 – 385 μm (11991 – 779 GHz): examples of interesting atomic and molecular transitions

- H_2O (from 2→1…to 6→5….)
- CO (high J)
- CII
- OI
- OH (4 main rotational doublet lines)
- HD (ground state)
- HCO^+ (high J)
- Deuterated species: HDO, DCN
- CH_3OH, H_2CO (several lines)

Examples of galactic science

1. Water mapping of Infall motions in star forming regions
2. **Mapping the dynamics and kinematics of outflows**
3. PDRs

Examples of extragalactic science

4. Interactions between HII regions and PDRs in nearby galaxies

5. High resolution CO and H_2O maps of nearby galaxies → density and temperature structure?

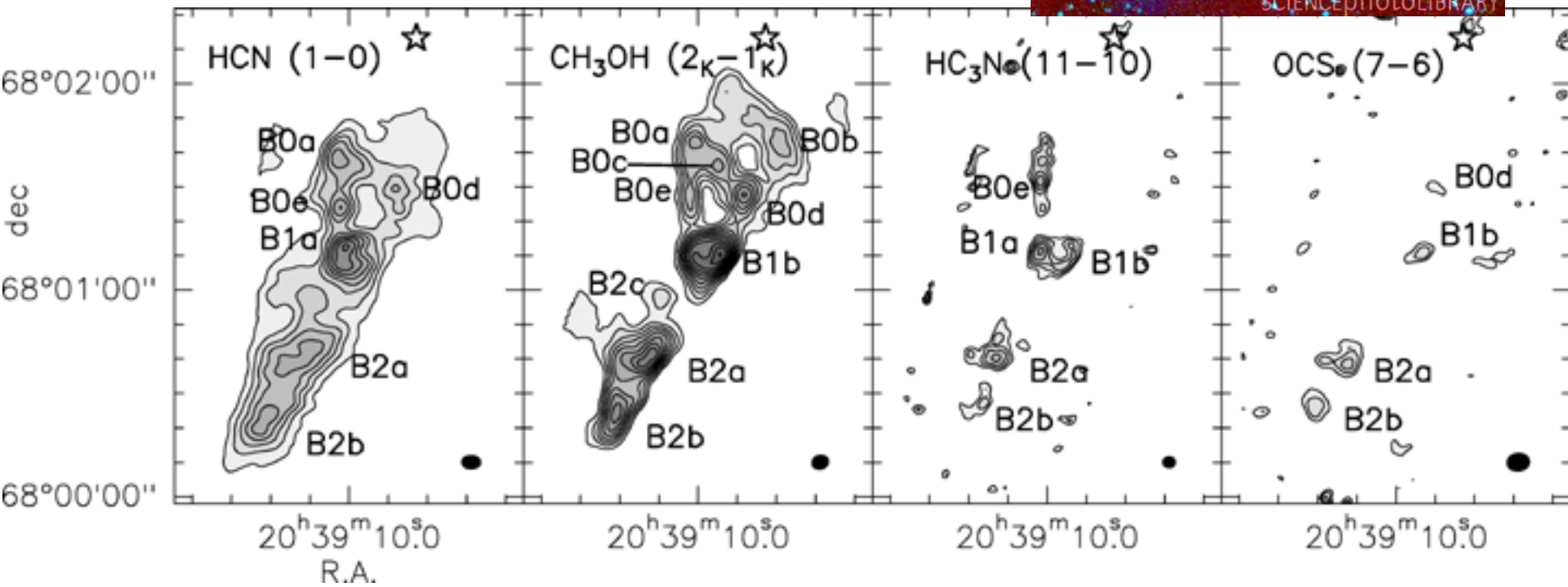
6. 'Mapping' the cosmic ray ionization rate in external galaxies?

Outflows: The water puzzle

L1157
D = 250-440 pc
Class 0 protostar drives a bipolar outlow
Very chemically rich (seen in H_2,CO, SiO, H_2CO, CH_3OH etc)

L1157-B1: very rich and clumpy structure

Benedettini et al. 2007, 2013



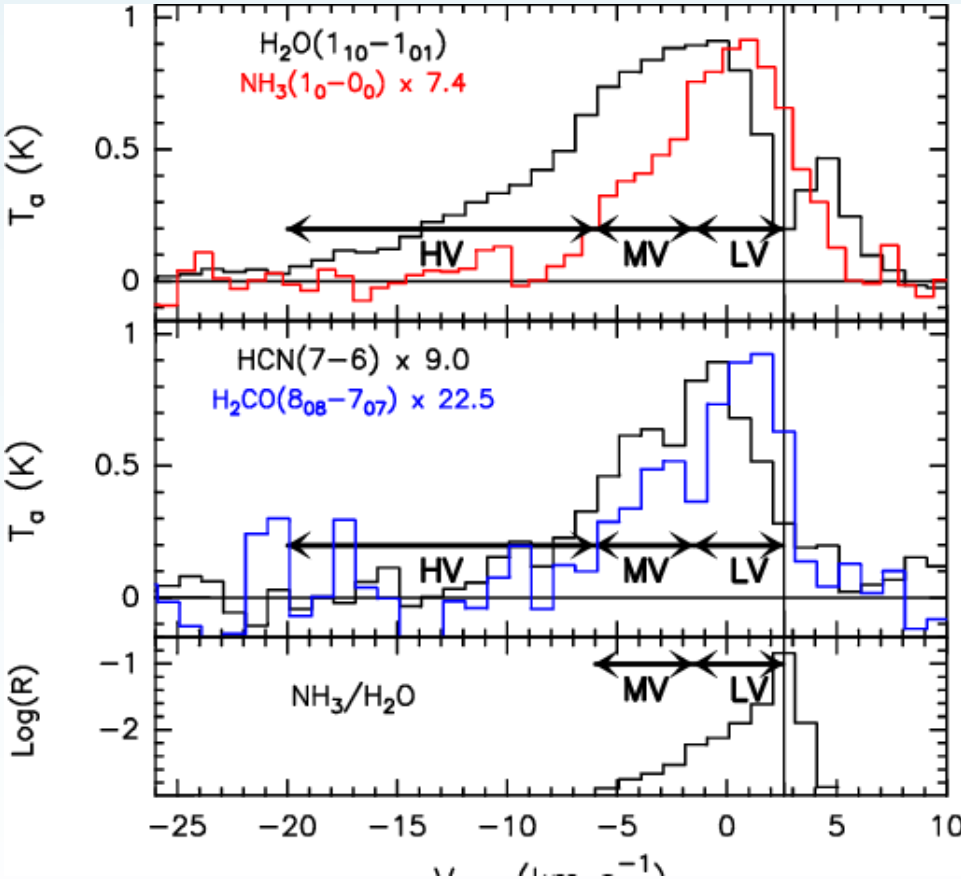
L1157 B1

Based on observations by Herschel Key Program CHESS (Ceccarelli et al. 2010, Codella et al. 2010, Lefloch et al. 2010):

- Revealed the presence of different molecular components at different excitation conditions coexisting in the B1 structure

→ note: HIFI did not directly (spatially) resolve these different structures….but high spectral resolution meant resolving the profiles

Observed abundances of H_20: LVC = 8x10-7; HVC: 8x10-5
High abundance of water also confirmed by PACS observations (Nisini et al .2010)

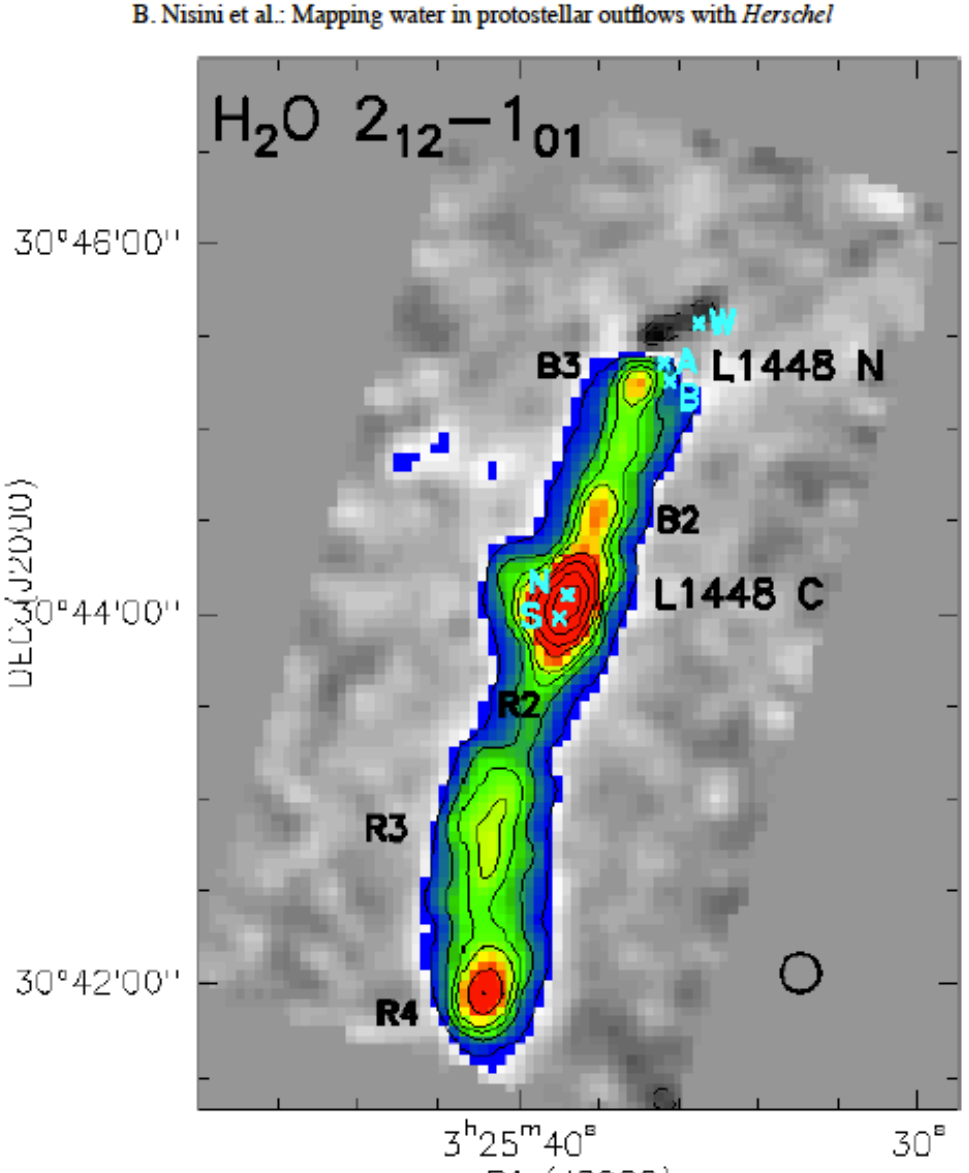


L1448 (should be similar to L1157): class 0 outflow

H_2O PACS observations @ 179.5 micr
H_2O HIFI observations @557 GHz

→ Relatively low water abundances

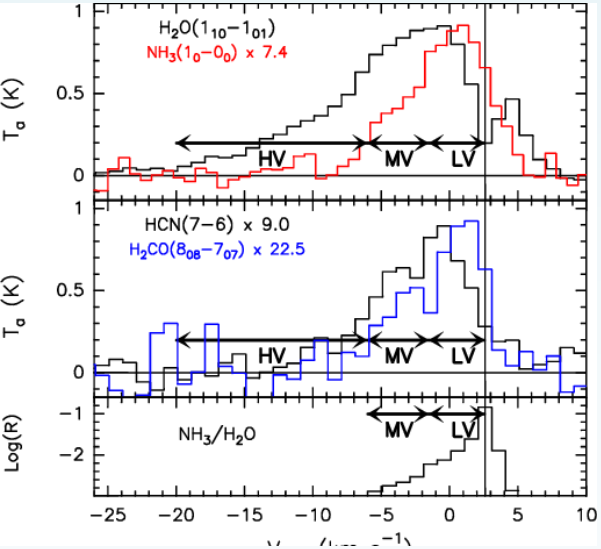
→ 'Patchy' with significant kinematical differences
→ Many indications of strong changes of the chemical and physical parameters across the flow

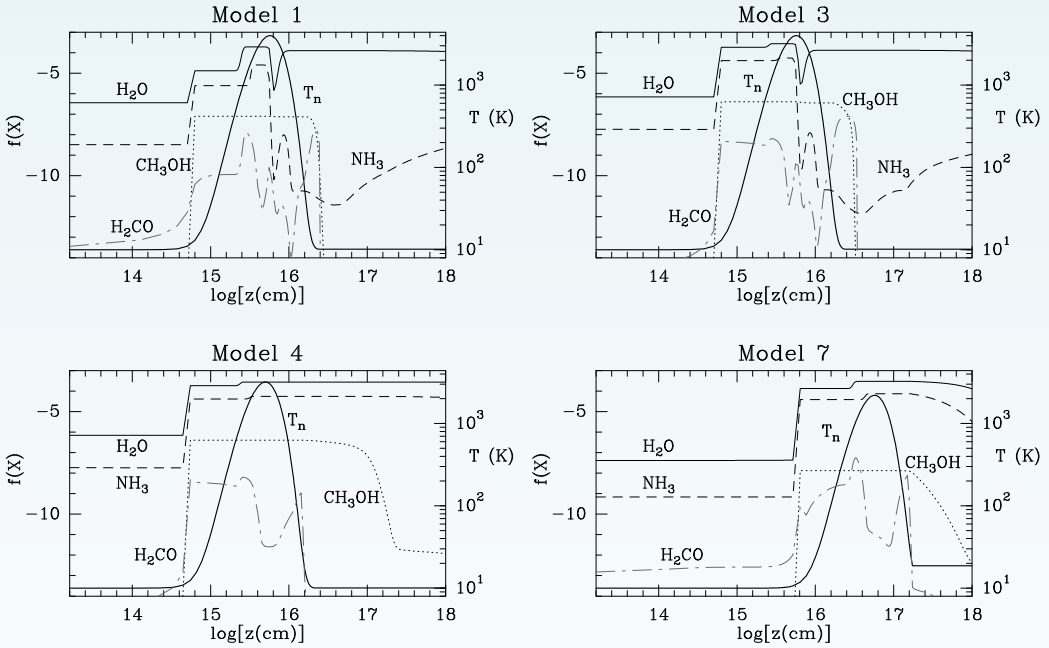


Class 0 L1157: C shock, J shock…or no shock??

1. HIFI observations: (Codella et al. 2010, Viti et al. 2011):

- Difference in line profiles among H_2O and NH_3 at high velocities → decrease in the abundances ratios





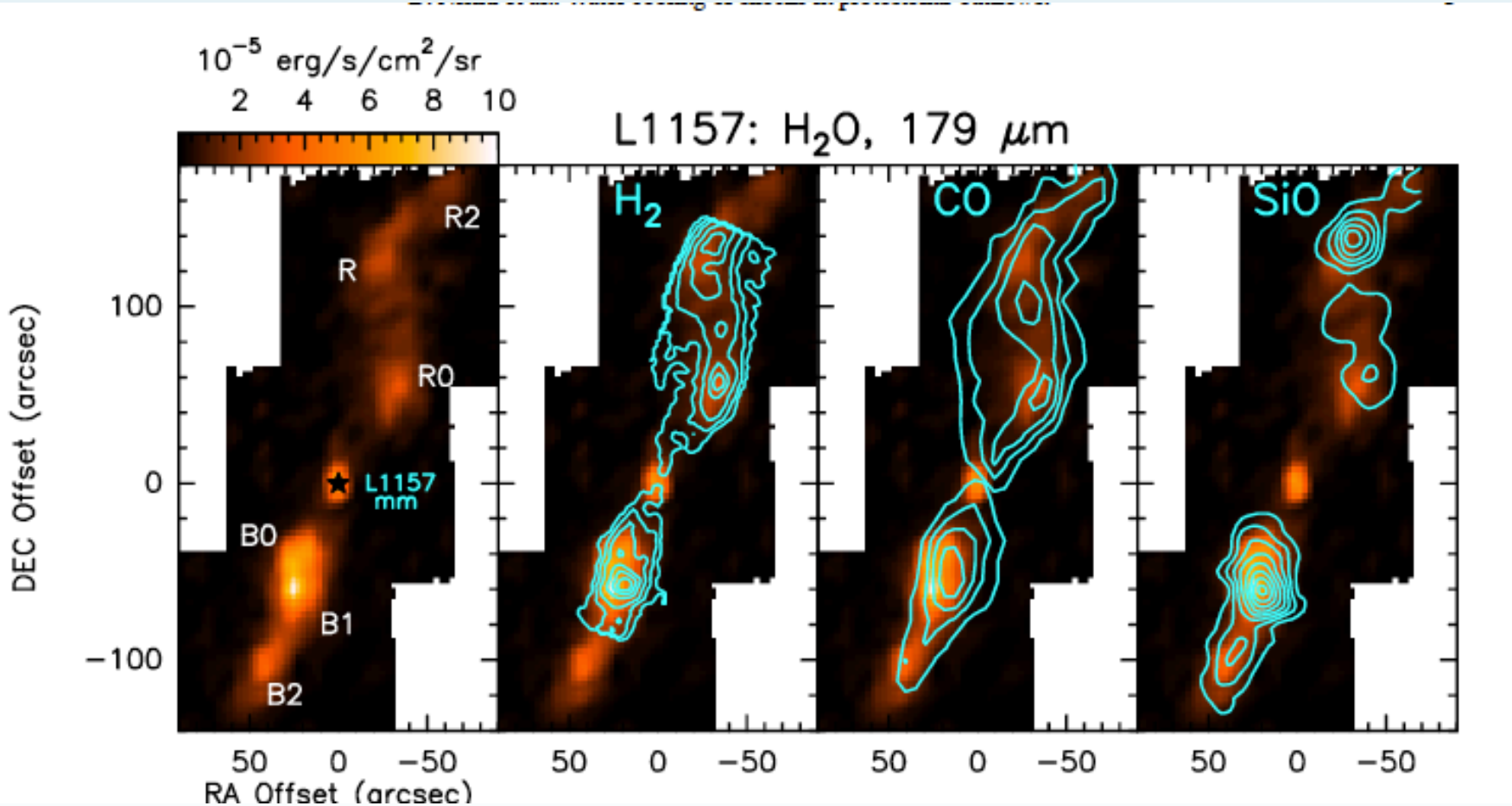
Model 1 abundances of H_20: LVC = $8x10^{-7}$ HVC: 10^{-4}

→

B1: C(-type) shocked

Class 0 L1157: C shock, J shock…or no shock??

2. PACS observations: (Nisini et al. 2010, Benedettini et al. 2012):

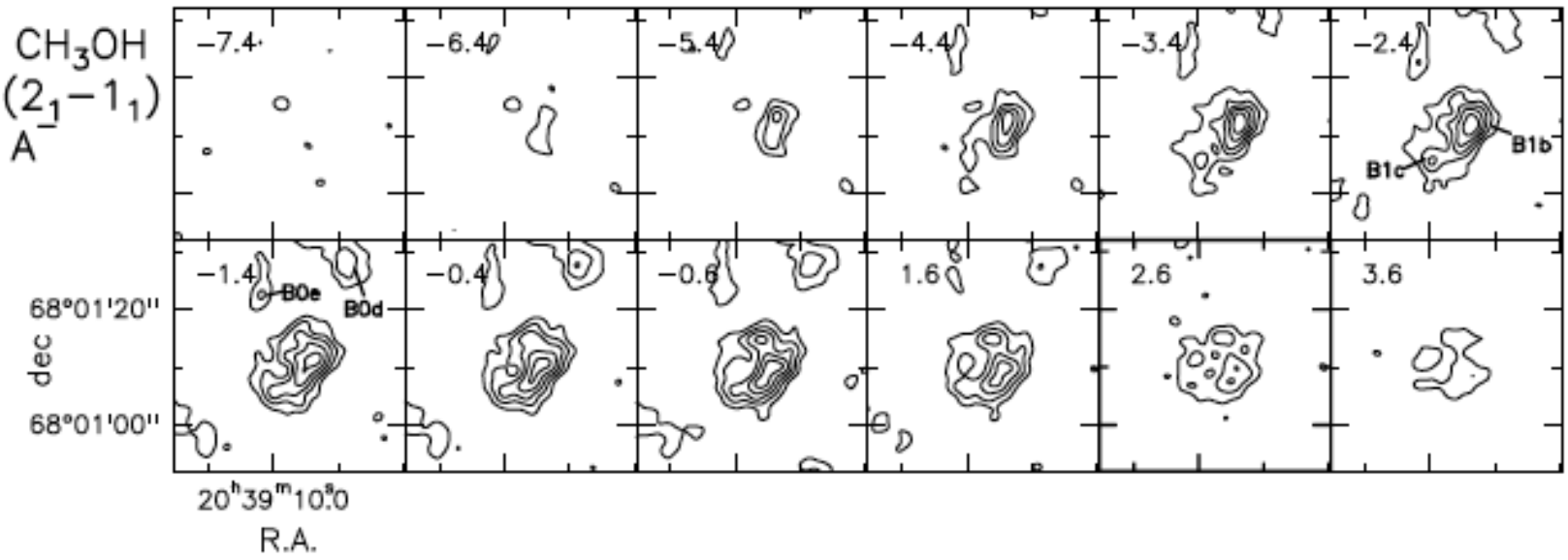


Strong water @ location of H_2 mid-IR lines→ warm compact clumps spatially unresolved by PACS

+ High J-CO → **B1: J(-type) shocked**

Class 0 L1157: C shock, J shock…or no shock??

3. PdB observations: (Benedettini et al. 2007; 2013):



Different species peak in different positions → precession of the outflow, molecules trace the cavities.

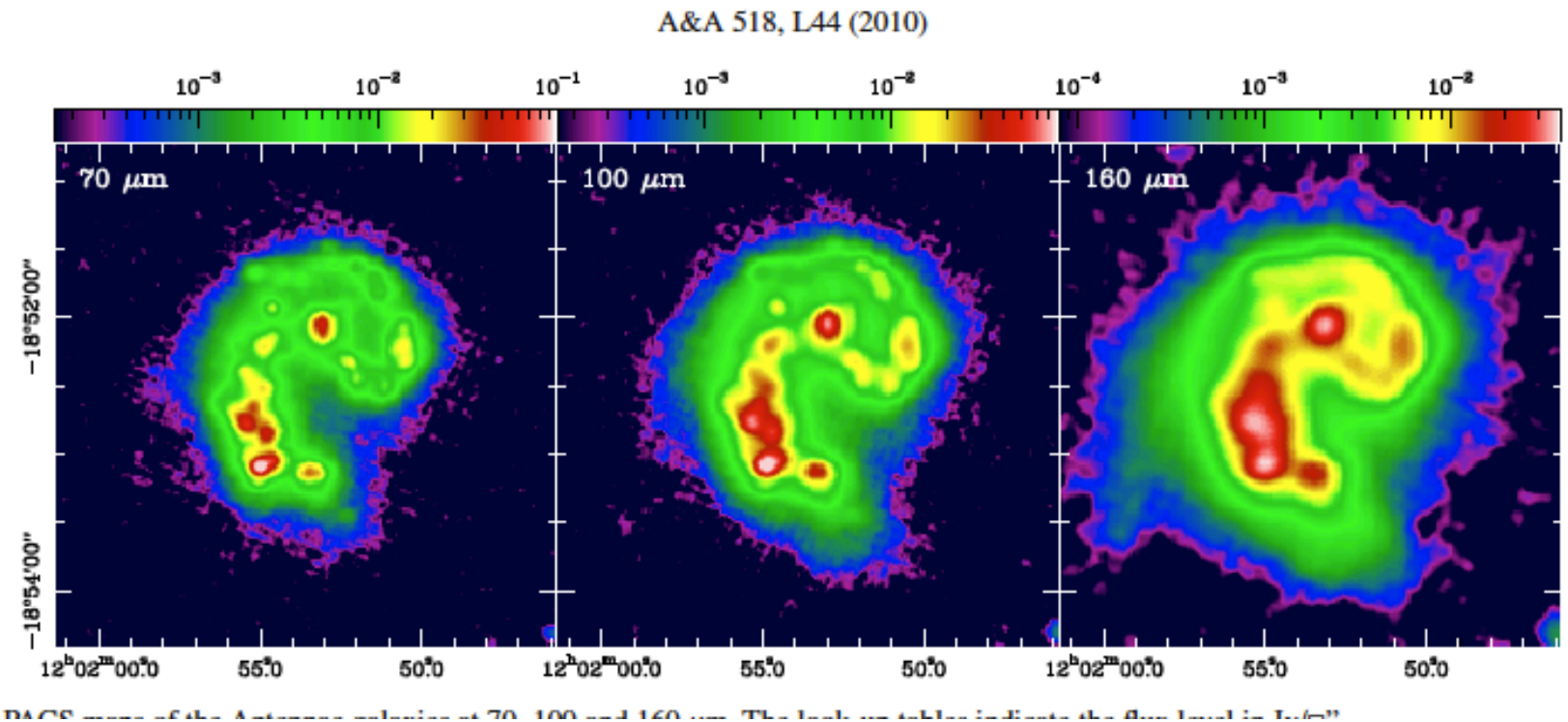
→ **B1: chemistry can be simply explained by clumpiness**

Program for outflows…

- Interferometric maps of whole outflows (inc. interfaces between warm and cold material) in low to high J of CO and H_2O (+ possibly HCO^+ high J lines?) with the aim of spatially locating C, J and non shocked structures.

Star formation properties in nearby galaxies:

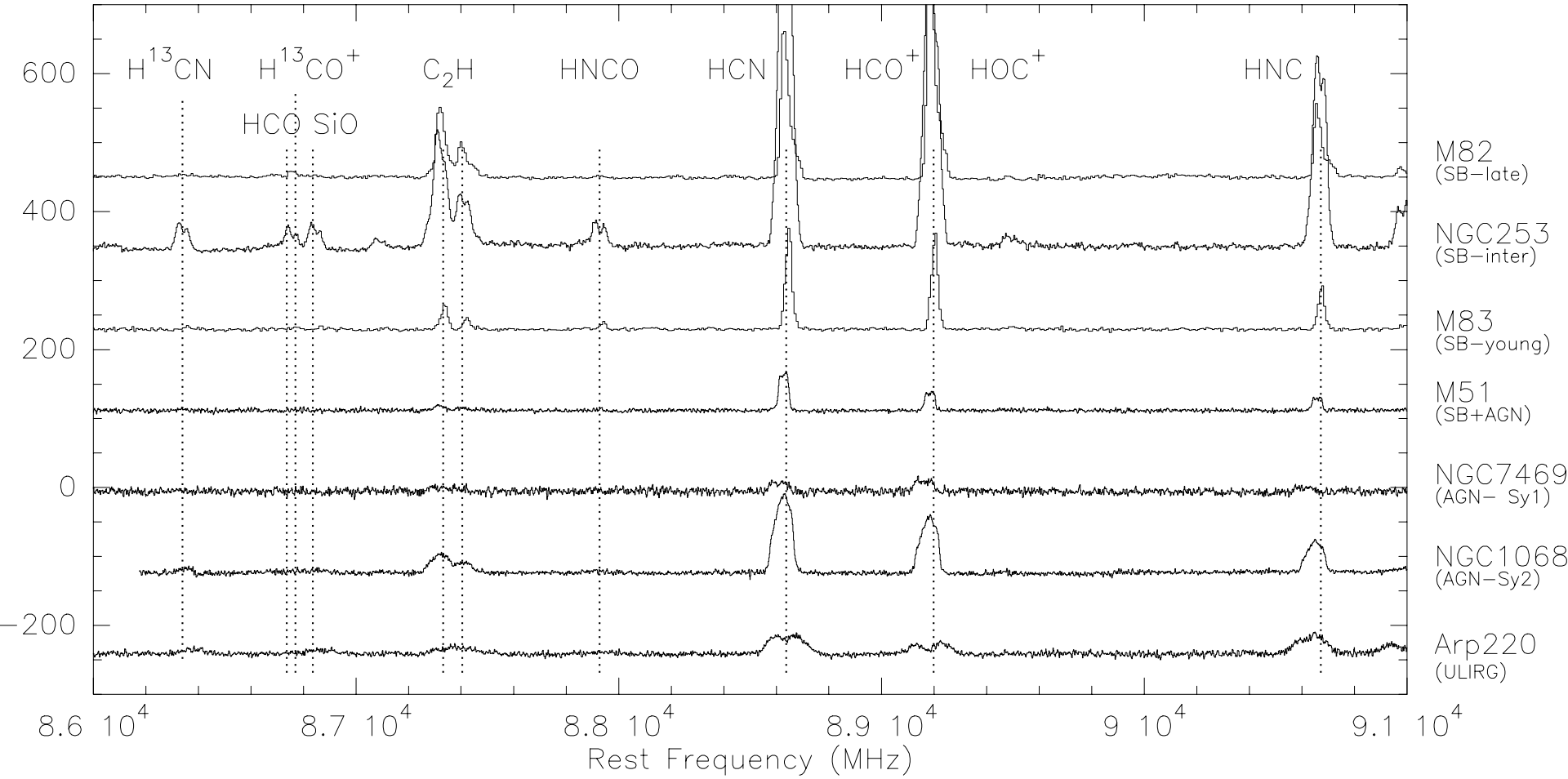
- Ex: PACS 70, 100, and 160 μm maps in the Antennae galaxy (Klaas et al. 2010) → knotty structure of the most recent star formation



What can interferometric observations of FIR and CO lines tell us about the ISM and star formation?

- Large scale emission is an ensemble of PDRs and HII regions
- (mapping of) [N ii] 122 μm can be used to determine the HII region contribution
- (mapping of) [C ii] 158, [O i] 145 and [O i] 63 μm: will trace the PDRs i.e where gas is photodissociated
- CO (ladder – in conjunction with ALMA): pin point where star formation may occur/dense gas

More complex molecules: need the whole ladder to get excitation conditions in galaxies



Note: for extragalactic environments, determining the excitation and density structure is essential to 'disentangle' degenerate solutions of chemical models and hence to determine the dominant energetic process(es)

Aladro et al. 2012

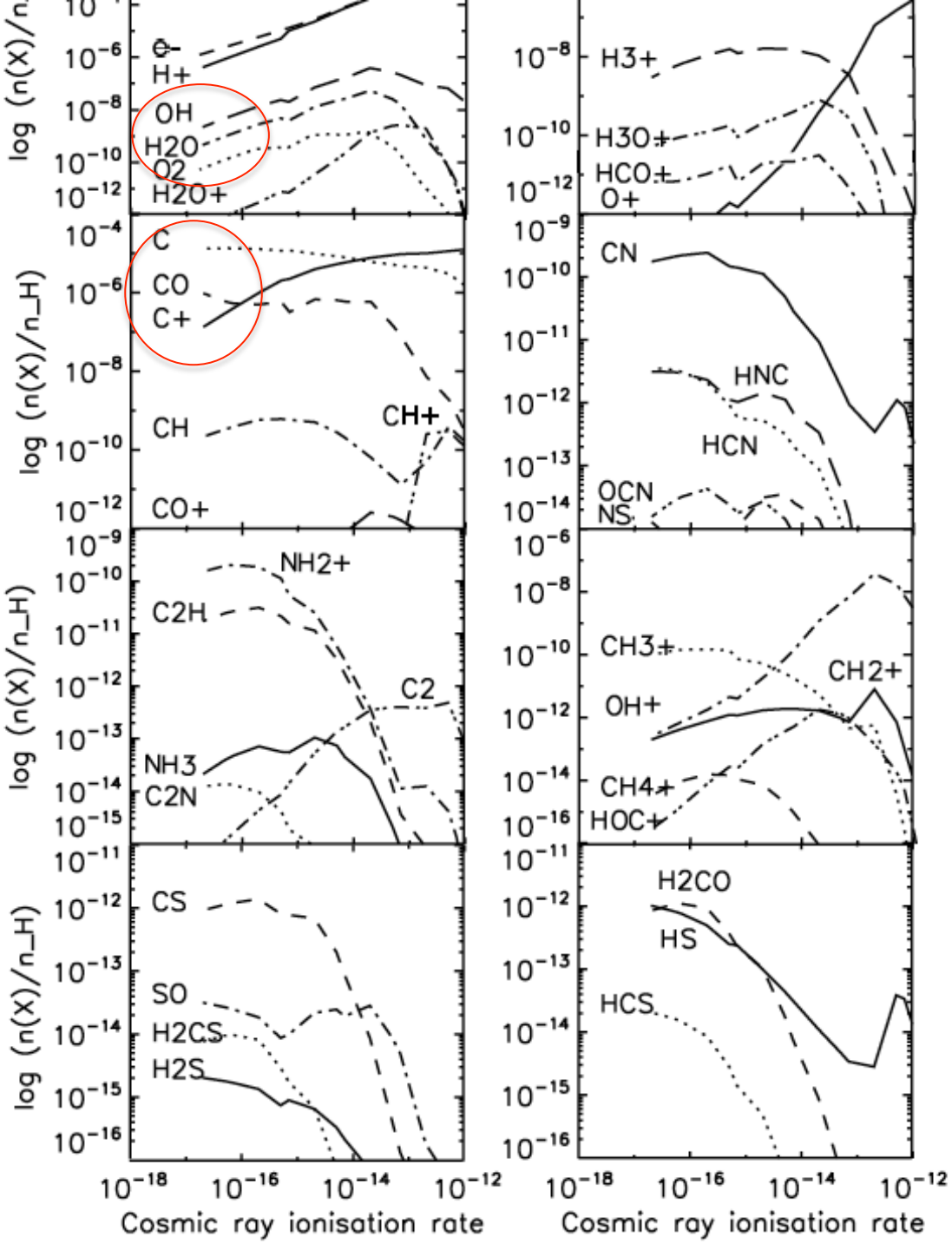
3. Cosmic rays in the context of starburst galaxies

- Starburst galaxies → high spatial density of massive star formation → regions of extremely high cosmic ray energy density → higher heating rates? Higher ionization fractions? → top heavy IMF?

M82: starburst activity enhanced c.r. as demonstrated by e.g. C/C+ and C/CO ratios (e.g. Schilke et al. 1993) ….**but where in M82??**

High c.r. rates will regulate the ionization fraction of the molecular gas (Papadopoulos 2010)

How enhanced is the c.r. rate and is it spatially homogenous?



In low Av

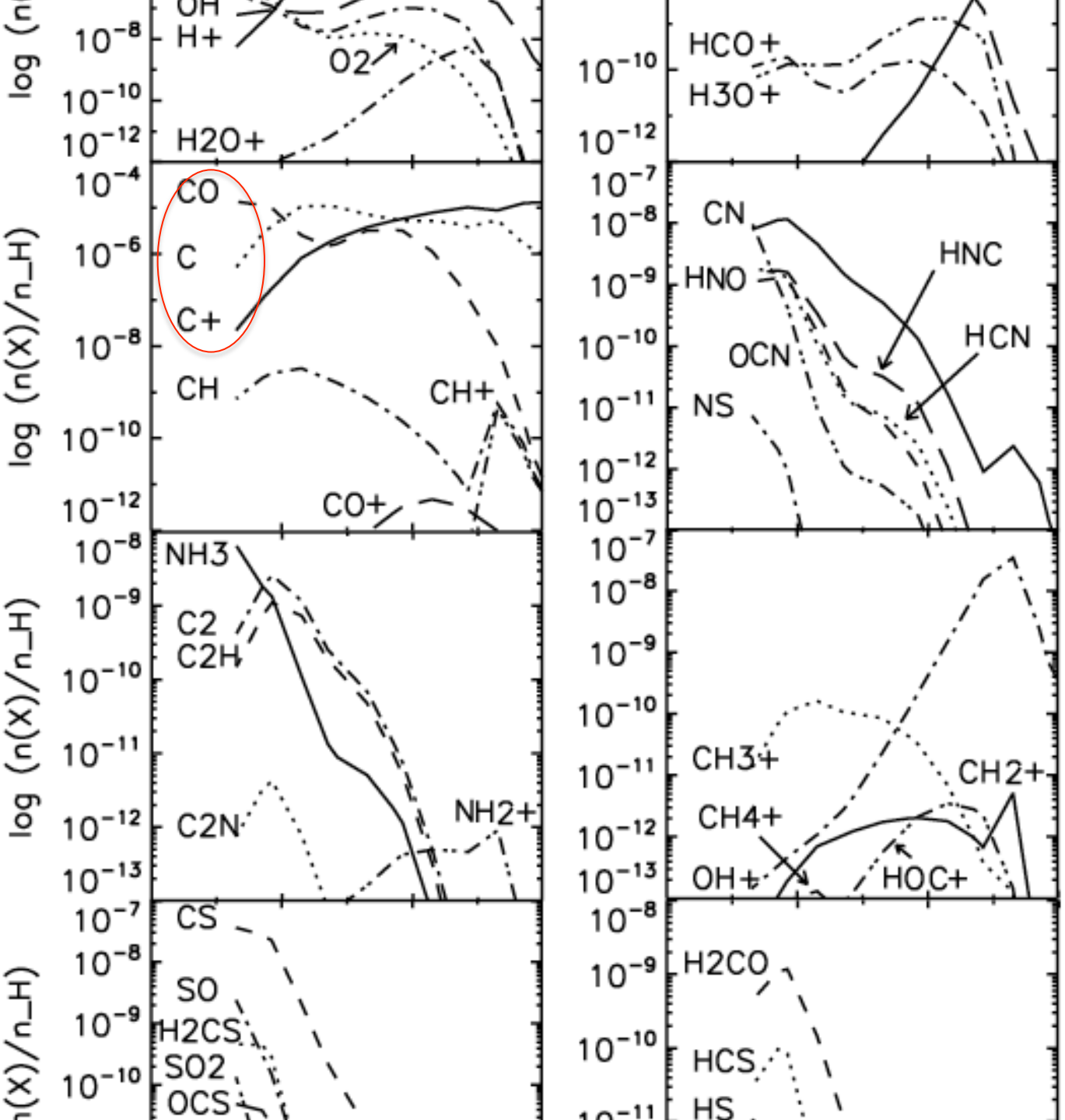
Rich chemistry maintained up to a critical value of ζ of 10^{-12} s^{-1}

The driver of the decline in molecular abundances is H_2, which starts declining at ζ ~ 10^{-14} s^{-1}

Different species decline at different paces and times.

Bayet et al. 2011

…as well as in high Av environments



Bayet et al. 2011

Deuteration

- Observations along different lines of sights give D/H ~ 10^{-5}
- Yet, in the ISM deuteration is enhanced for many molecules more than a factor of 10^5 w.r.t. above ratio
- In clouds, the main removal agent of H_3^+ is CO; but in a very cold dense cloud, CO is (partially) depleted on the surface of the grains → i.e in pre-stellar cores highest levels of deuteration, also 'left' in later phases.

- This is confirmed by several species:
  - D_2CO/H_2CO
  - $HDCO/H_2CO$
  - CD_3OH/CH_3OH
  - ND_3/NH_3

  - etc

- However, water (via observations of hot corinos for example) constitutes a puzzle…
  - $HDO/H_2O < 0.2\%$ in the outer envelope (cold as in pre-stellar cores)
  - $HDO/H_2O \sim 3\%$ the inner envelope (ices evaporates, warm)
- HDO/H_2O: key diagnostic for water evolution during star and planet formation
- It's enhanced in comets and on Earth w.r.t cosmic
- When does the enhancement happen?
- Observations of low mass protostars show that, in the inner 50 AU at least, it must be after the formation of the star
- Ultimately HDO detections are tentative!

HDO with FIRI? (galactic)

- Maps of HDO (low J vs high J) covering the evolutionary sequence of low to high mass protostars, from pre-stellar to hot corinos/hot cores
- Objective would be to determine the spatial distribution of the water fractionation
- One of the main aims could be determination of the water abundance (HDO seems to be the same in ices, so removes the unknown factor of depletion)

Deuteration in nearby galaxies

- Few detections of deuterated species (e.g. Mauersberger et al. 1995; 2mm survey by Martin et al. 2006)
- As D/H depends on degree of processing of the gas → give clues on the evolution of the galaxy

Model predictions: of particular interest for extragalactic studies

- HDO, DCN: very abundant regardless of the environments
- DCO^+: tracer of cosmic-ray enhanced galaxies, with a strong high density gas component
- DCN: abundant only in spirals with a strong high density gas component