Interstellar Medium

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Main Topics

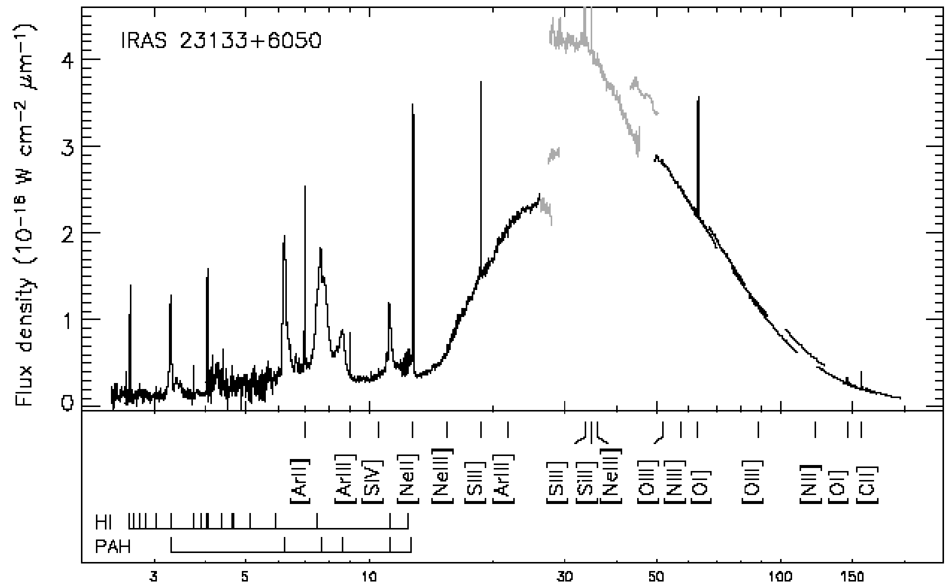
- Elemental abundances in the ionised gas of HII regions
- Interstellar chemistry: Gas phase molecules, Solid phase molecules
- Interstellar dust: Very small particles, Infrared Extinction, Interstellar Silicates
- Photo Dissociation Regions (PDRs): Gas grain coupling, H_2, Evolution of dust
- Shocks
- Supernova
- Signatures of Interstellar turbulence

Search on ADS with “ISO” and “ISM” in the abstract : 561 refereed papers...

Reviews: Abergel et al. 2005, Dartois 2005, Gibb et al. 2004, Habart et al. 2005,
Peeters et al. 2005, van Dishoeck et al. 2004.

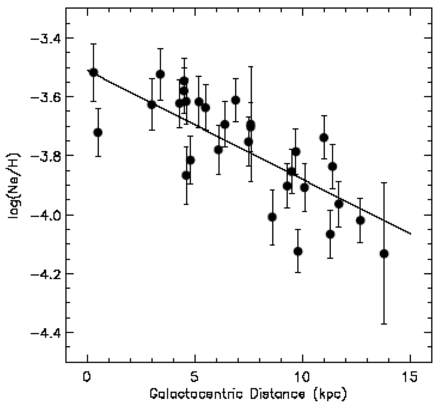
Elemental abundances in the ionised gas of HII regions

Typical spectrum (Peeters et al. 2002):



- Recombination lines of H
- Fine-structure lines: C, N, O, Ne, S, Ar, Si

- Abundances of ionised species
- Abundances = f(Galactocentric distance)



Martin-Hernandez et al. 2002

- Ionisation structure of the HII regions, Spectrum of the ionising star
- Also extended emission from highly ionised species (N^{+}, N^{2+}, O^{2+}, S^{2+})

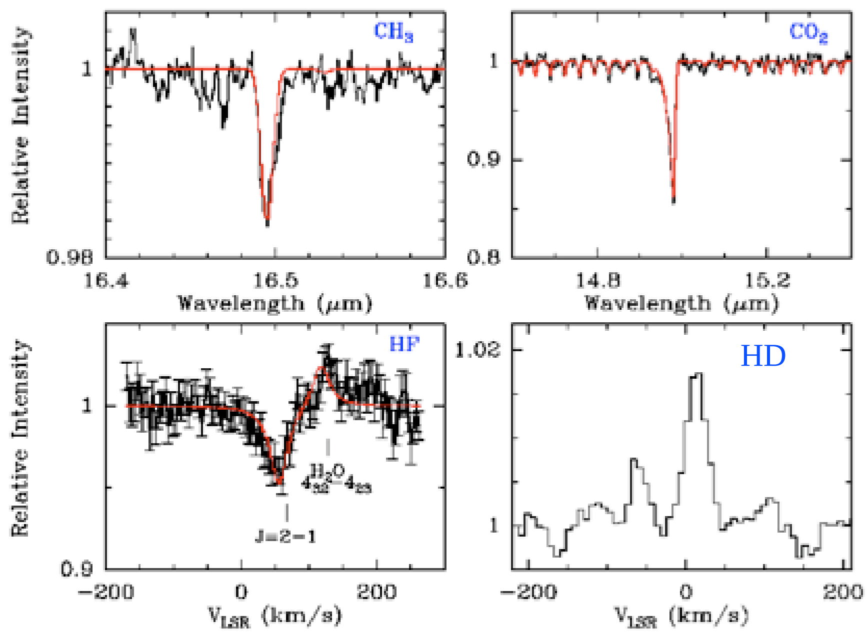
  Highly ionised gas surrounding HII regions denser than the WIM:

  New phase (Mizutani et al. 2002) ?

Interstellar chemistry : Gas phase Molecules I

- Rovibrational and rotational transitions for many light molecules
  Benchmark for models of chemistry, excitation

- New detections:



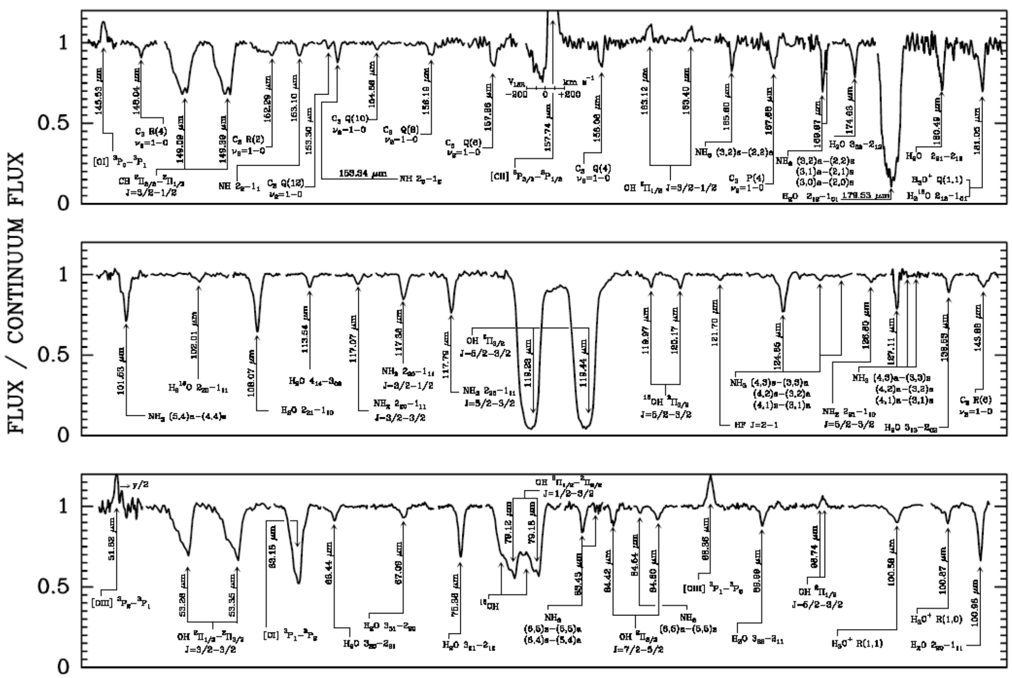
New line at 112 μm

CH_3 toward Sgr A	(Feuchtgruber at al. 2000):	Gas-grain chemistry?
CO_2 in star forming regions	(Van Dishoeck et al. 1996,…):	Comparison with the ice phase
HF toward Sgr B2	(Neufeld et al. 1997):	Only 2% of F in the gas phase
HD (new line) in Orion	(Wright el al. 1999, …):	D/H abundance

Also C_4 (Cernicharo et al. 2005)? Most abundant carbon chain ?

Interstellar chemistry : Gas phase Molecules II

And also in Sgr B2 (Goicoechea et al. 2004, …) :



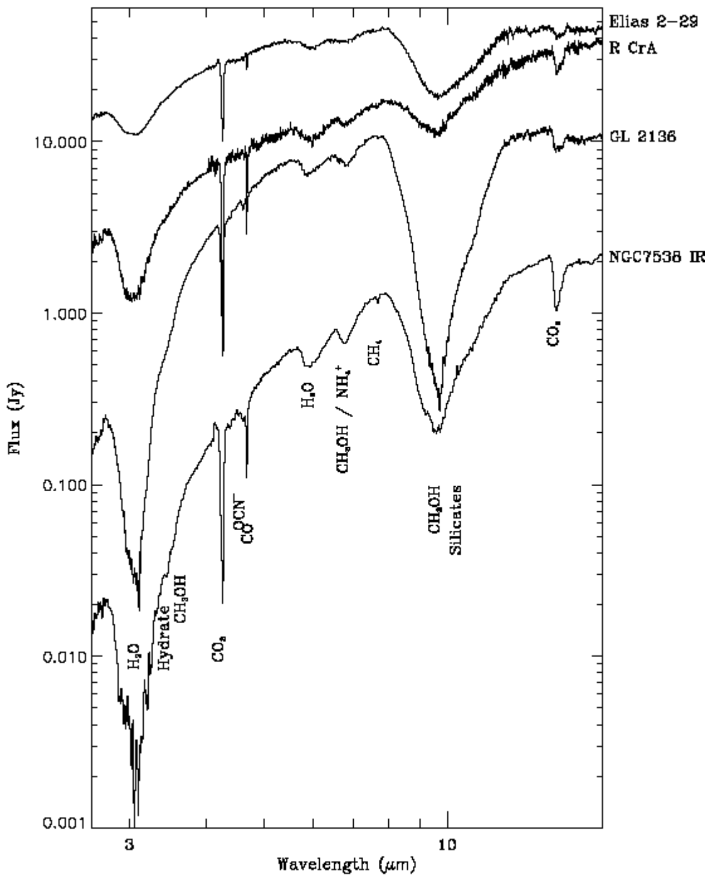
- Hydrides: OH, CH, H_2O at all positions
  HF, H_3O^+, NH_3, NH_2, NH
- Hydrocarbons: C_3, C_4, C_4H

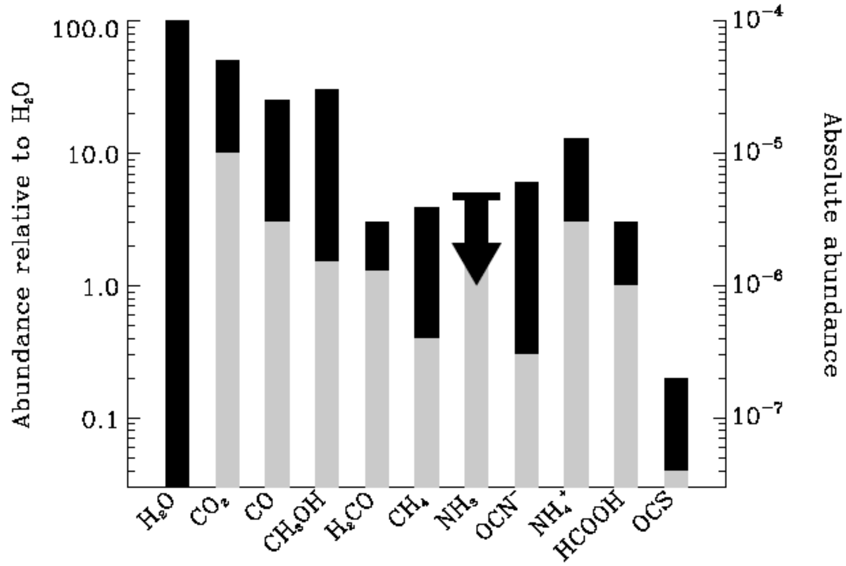
- Abundances and physical conditions of the absorbing layer
- Importance of photo-dissociation processes and shocks chemistry

Interstellar ices

(Review from Dartois 2005, Gibb et al. 2004, …)

- Interface between the very refractory grains and the gas
- In : Evolved star circumstellar shells,
  Field stars behind molecular clouds,
  Embedded protostellar objects
  External galaxies.
- More than 20 detected features from 2.7 to 15.2 μm
  + A few to be confirmed
- Identification using laboratory spectra:
  Remarkable matches in several cases





- Ubiquitous dense medium component

- Large Abundances!

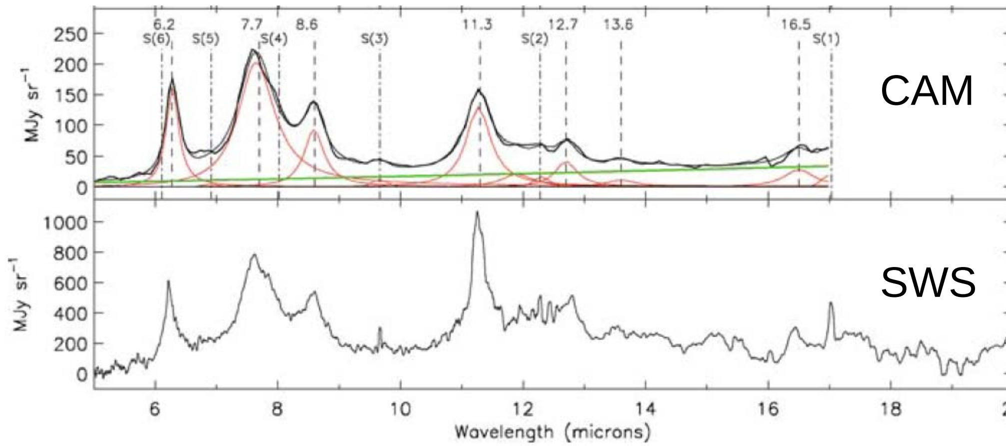
- All detected ices are Major elements in the chemical evolution of the interstellar matter.

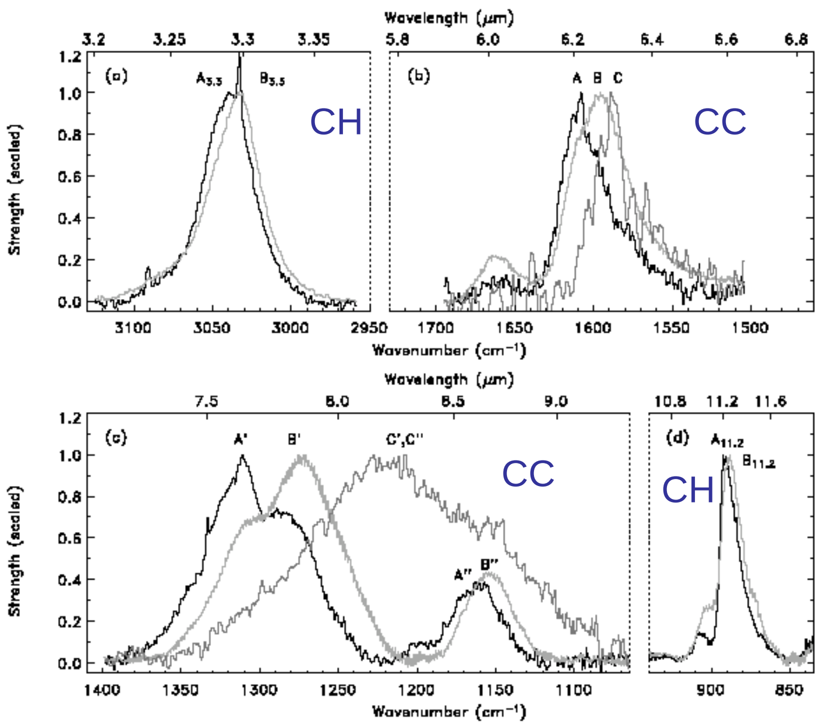
Emission spectrum of very small particles: Aromatic Infrared Bands (AIBs)

- Cool ISM (e.g. Abergel et al. 2005)

- Ubiquitous in the ISM
- Similar global shape for $\chi = 1{-}10^4$ and scale with χ:

→ Stochastic excitation

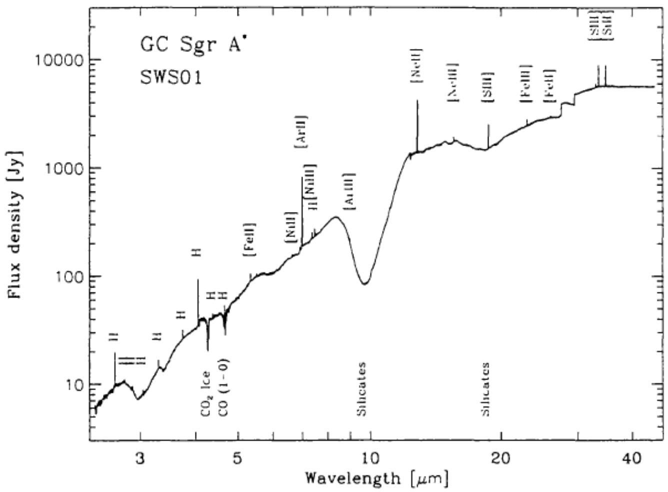


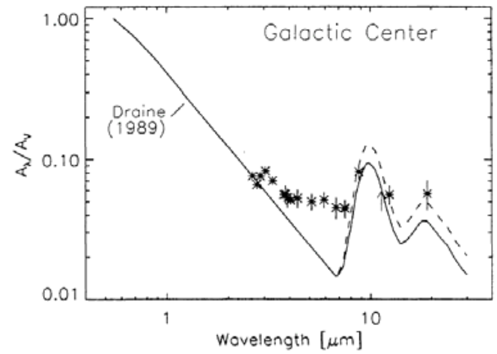


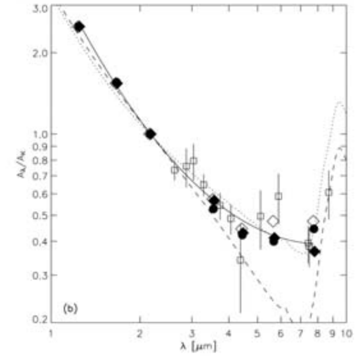
- High excitation ISM : (e.g. Peeters et al. 2005)
  - Different types of profiles:
    - A: HII regions, Reflection Nebulae, ISM
    - B: HAeBe stars and Planetary Nebulae
    - C: post-AGB
  - Variations from objects to object and within objects
  - Depend on the excitation, but not simply
- Spectrally resolved: shape, sub-structure…
  - Medium size PAHs ($N_C < 100$)
  - But no precise identification
- Many weakers bands and subcomponents
- 3.3 and 6.2 μm bands seen in extinction

Infrared extinction

- SWS spectrum of the galactic centre (Lutz et al.1996):

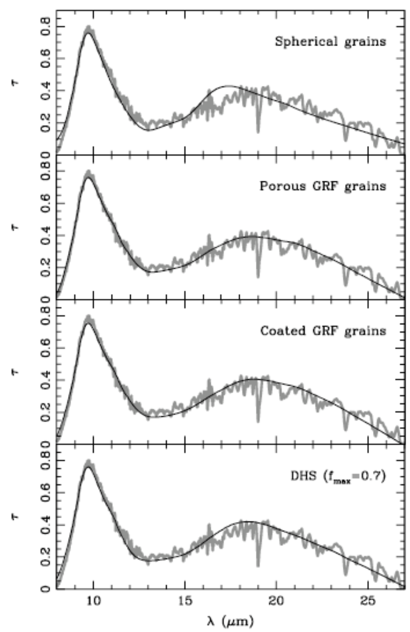






Extinction curve, confirmed with IRAC (Indebetouw et al. 2005)
Also compatible with ISOGAL results

- Crystalline fraction of the interstellar silicates is < a few %
- Infrared extinction used to study the structure of dense cores
- Extinction toward WR stars
  - Irregularly shaped magnesium rich silicates
  Chiar & Tielens 2004, Min et al. 2006



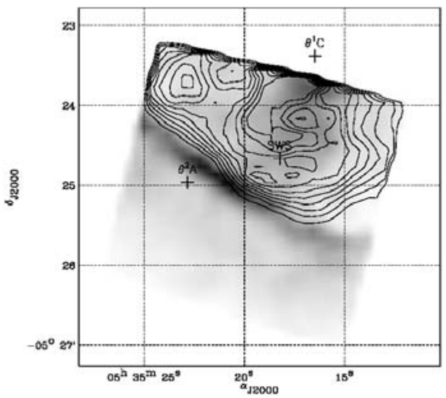
- Aliphatic Hydrocarbons seen in extinction:
  - 3.4 μm: CH stretching
  - 6.85 and 7.25 μm: CH deformation modes
  e.g. Chiar et al. 2000, Dartois et al. 2004

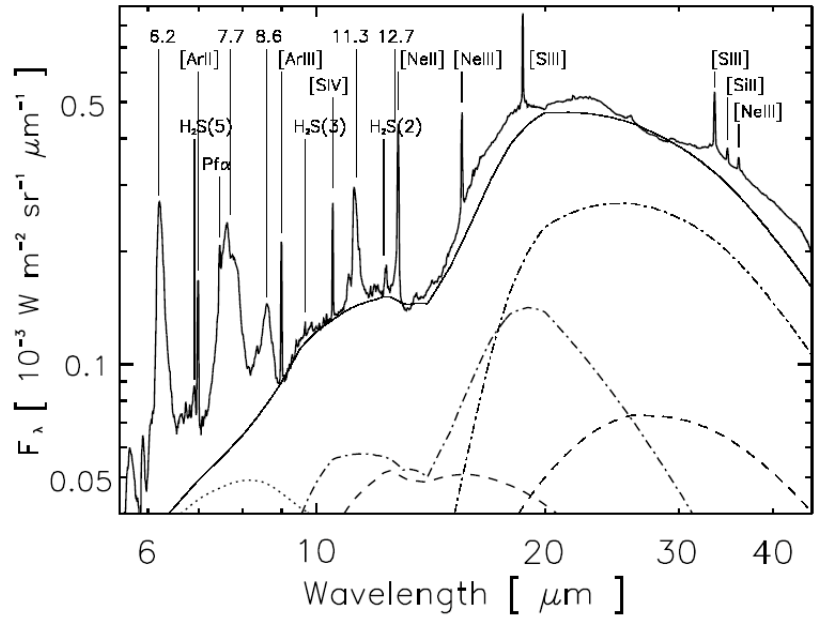
Emission of Interstellar silicates

- Spectroscopy in HII regions: M17, Orion Bar

6.2 μm + NeIII

Cesarsky et al. 2000





- Amorphous Carbon + Amorphous Silicates, possibly cristalline Silicates, while PAHs are depleted

- New features in HII regions: around 8.6, 22, 65, 100 μm

- Far-IR emissivity: Systematic increase in cold clouds (12 K < T < 14 K)
  e.g. Bernard et al. 1999, del Burgo et al. 2003, Ridderstad et al. 2006, Kis et al. 2006

→ Formation of coagulated clusters of dust particles

Photo Dissociation Regions (PDRs)

- Interfaces developed by any illuminated interstellar clouds:

→ Dominate the IR emission of galaxies

With ISO:

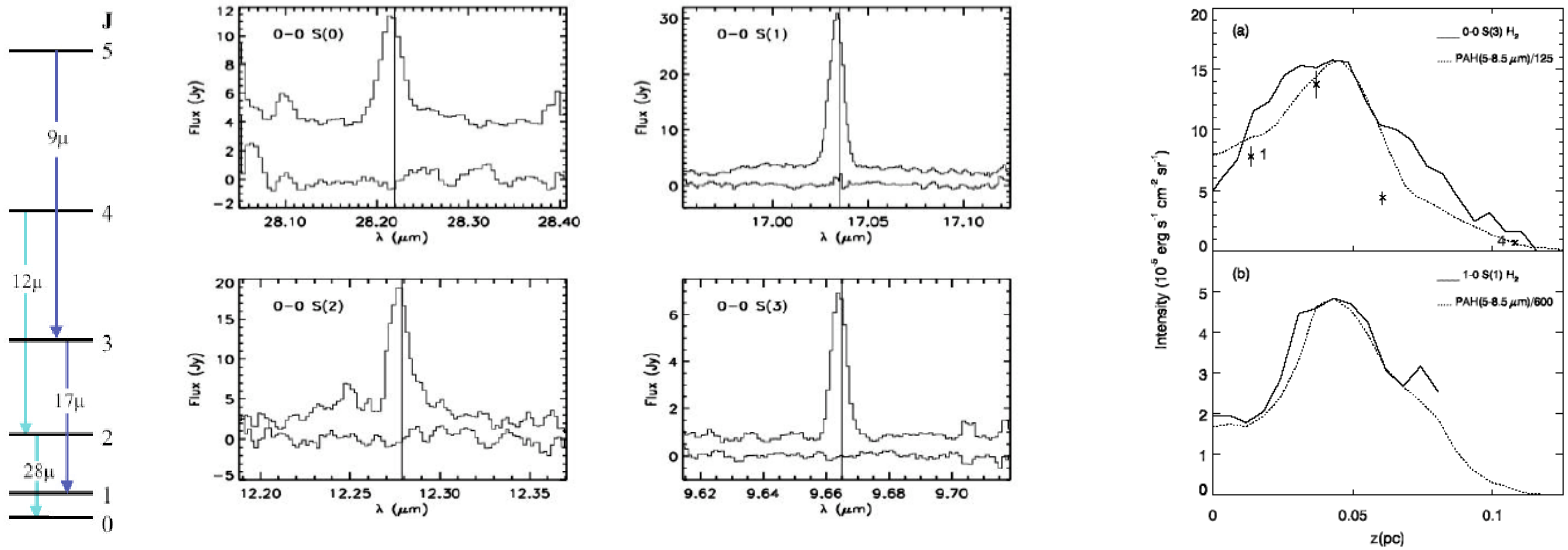
- Detailed analysis of numerous objects spanning a range of physical conditions
- Numerous bright PDRs with HII regions
- Extend the observed sample towards low-excitation regime: $\chi < 10^3$, $n < 10^4$ cm^{-3}
- Physical conditions: heating, cooling, geometry, density structure, …
- Strong improvement of PDR models

- Main results:
  - Gas thermal budget in low excitation PDRs:
    - Cooling: Fine-structure gas lines : C^+ 158 μm, O^0 (63 μm, 145 μm) LWS
    - Heating : Photoelectric effect on dust = trace with the dust emission CAM

    (Assuming gas thermal balance: Heating = Cooling)
    - Observations + PDR models: Photoelectric effect well understood
    - Photoelectric effect dominated by the smallest grains (< 1 nm)
    - The major cooling lines are generally optically thick: radiative transfert, geometry…
  - Mid-IR pure rotational lines of H_2 …

H_2 pure mid-IR rotation lines in PDRs

- Systematic detection from moderate to high excitation PDRs
- Example: ρ Oph (Habart et al; 2003)



- Collisions maintain the lowest rotational levels in thermal equilibrium: Thermal probe.

- H_2 intensity lines and gas temperatures higher than predicted:
  - Enhanced dust-to-gas ratio, and grain photoelectric rate?
  - Non-equilibrium processes?
  - Increase H_2 formation rate (factor 5 found for moderate excitation objects)?
  - Alternative excitation mechanism?

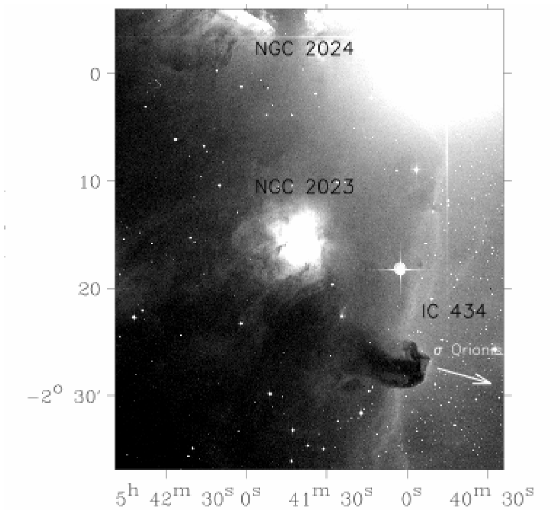
  Are we missing a strong fraction of the coupling between gas and FUV radiation field?

- Constrain on the formation processes: Key role of very small particles

Evolution of very small particles in PDRs

Aromatic / Continuum at 15 μm

L1630 in the visible



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ρ Oph

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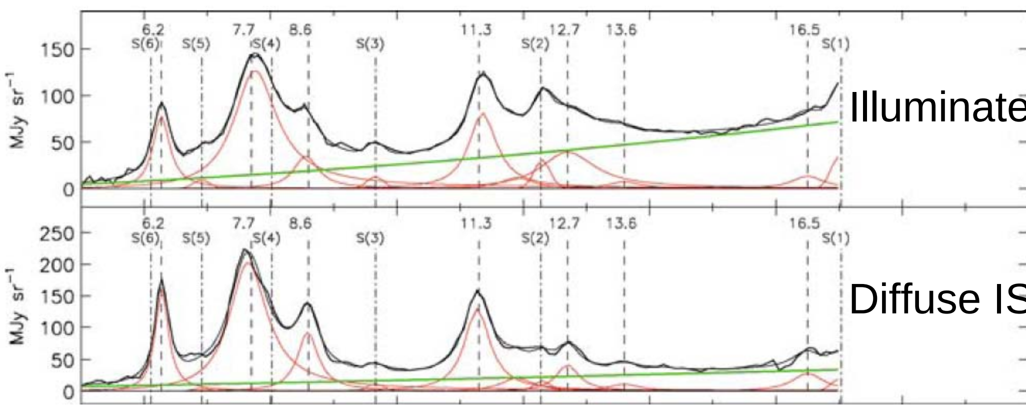


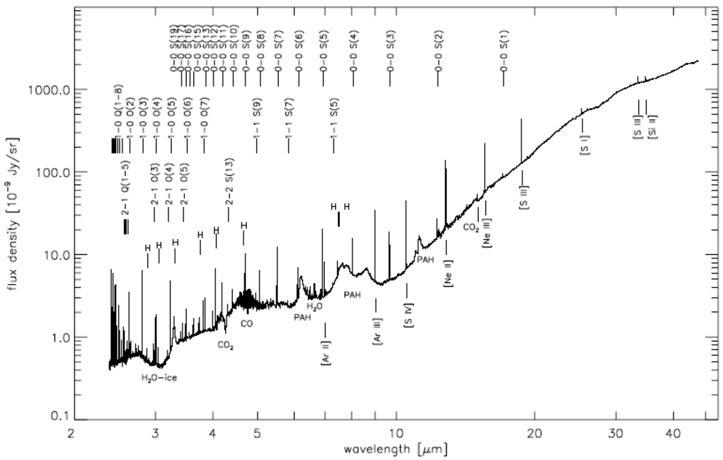
• Release of very small carbonaceous particles in the diffuse ISM?

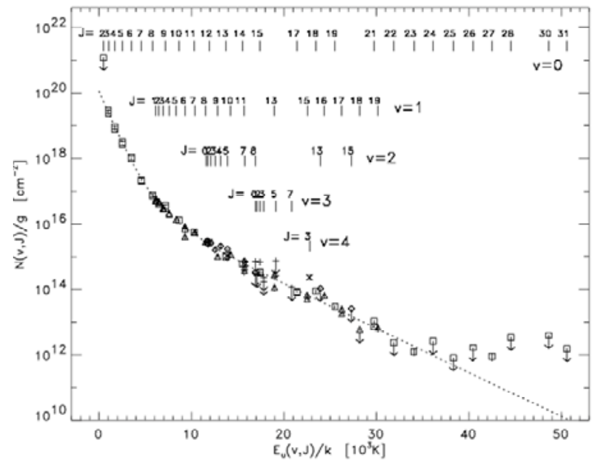
• Effects of anisotropic illumination?

Shocks

- Outflows and jets from young stars, Supernovae, Expanding HII regions
- ISO: H_2 , CO, H_2O , OH lines: C-shocks (Slow: < 20 kms^{-1}, Fast : 30-50 kms^{-1})
  Atomic lines: J-shocks (70-140 kms^{-1})

An example of shocks associated with outflows in Orion (Rosenthal et al. 2000)





56 H_2 lines: Chemistry and excitation of H_2

Two components C-shock model:
- Slow (< 20 kms-1), around 600 K
- Fast (30-50 kms-1), around 3000 K

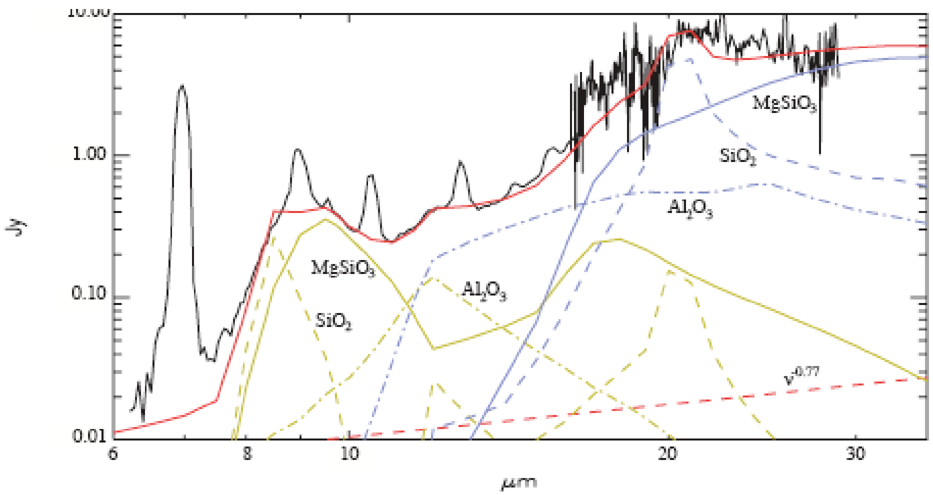
- Shock structure and physical conditions
- Energy budget, contribution of the different species to the cooling (H_2O, H_2, CO, OI)
- Age of the schock (comparing the data with time-dependent shock model)
- Broad sample of objects
- The broad band emission (ISO and IRAS) mainly due to lines (H_2 and OI)
  Detect shocks where they were not expected: e.g. Helix Planetary Nebula (Cox et al. 1998)

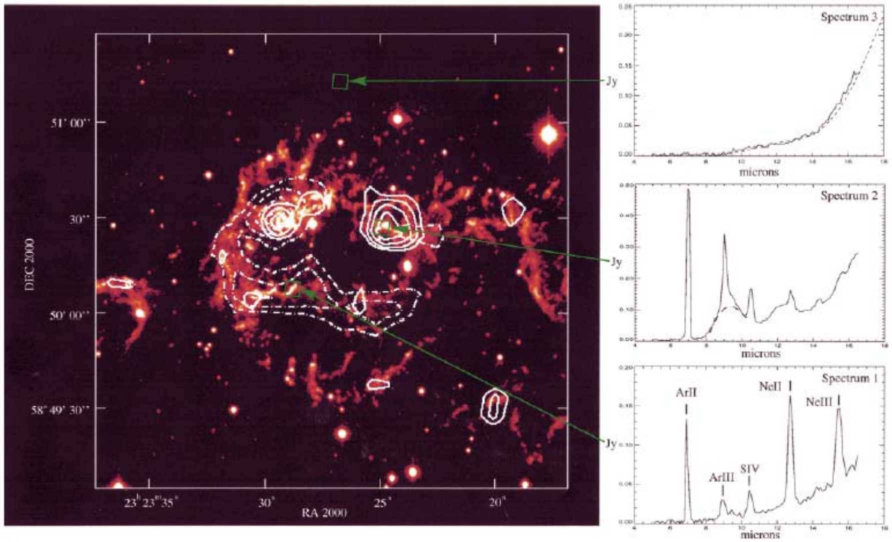
Supernova Remnants

- Example: Cassiopeia A (youngest known SNR in our galaxy) (Douvion et al., and others)

- Fine structure lines correlated to Fast Moving Knots made of nuclear burning products from the progenitor star

- Dust, collisionally heated, likely freshly condensed





NII line: dotted contours
Silicate dust emission: full contours

+ Mineralogic analysis

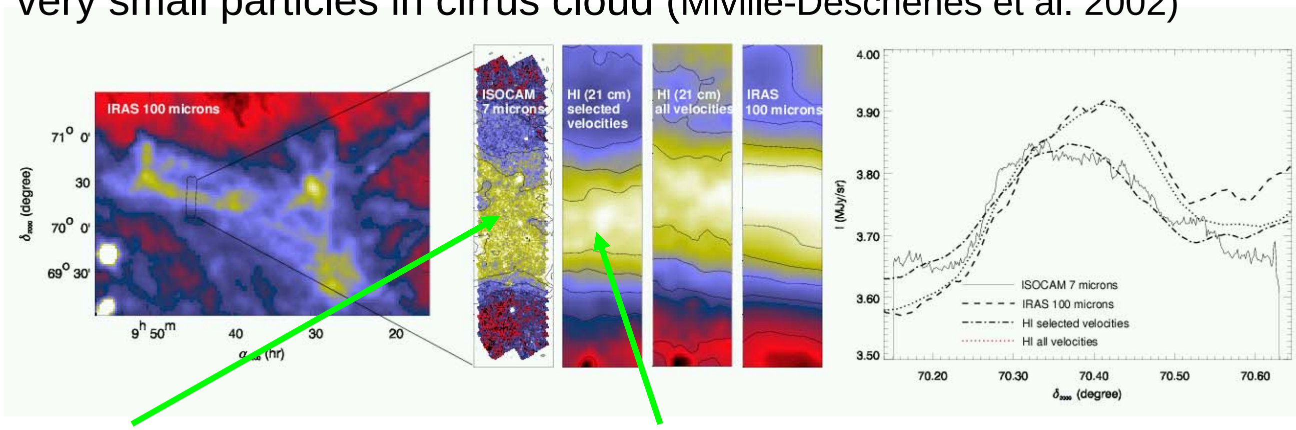
- Others SNRs: Kepler, Tycho: shocked circumstellar or intestellar material
  Crab: synchrotron radiation, no dust in the mid-IR
  RCW 103 (young and fast): post-shock emission

- Interaction with molecular clouds: Pre-shock and Post-schock conditions
- Late emission from SN1987A: Elemental abundances in the stellar ejecta

  Constrains on the modeling of the SN explosion and the explosis nucleosynthesis

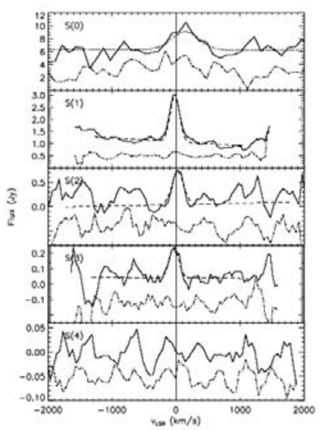
Signatures of the interstellar turbulence ?

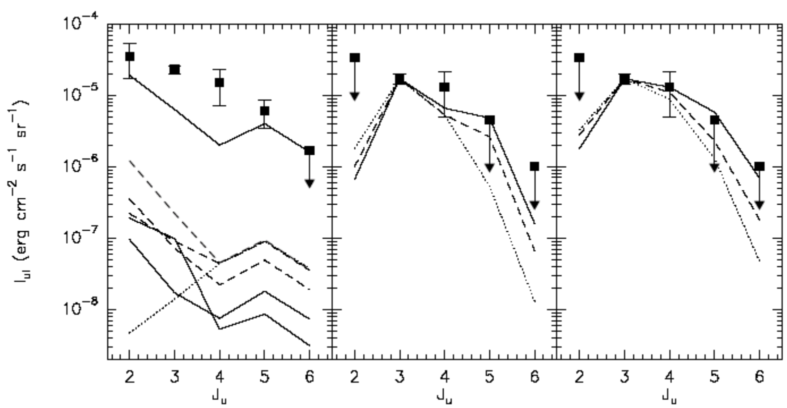
• Evolution of very small particles in cirrus cloud (Miville-Deschenes et al. 2002)



- Aromatic emission correlated to the HI emission with high vorticity
- Turbulence: Grain Shattering and Formation of very small particles?

• Detection of the mid-IR H_2 lines in the cold ISM (Falgarone et al. 1999, 2005)





- A few percent of warm gas: collisional excitation by MHD turlulence?

Conclusions

- Interstellar chemistry, gas and solid phases (ices)
- Nature and Evolution of interstellar grains
- Key role of nanometric carbonaceous particles
- Importance of Gas-Grain couplings
- Understand many key processes in our Galaxy
- H_2 is a new tracer of the interstellar medium
  H2ex, to be submitted to the "Cosmic Vision" call for proposals.

- Federate the ISM European community

- Spitzer: Higher sensitivity and Mapping efficiency
  - Extend the analysis toward faintest regions
  - Complete the analysis on larger scales
  - Physical and chemical processes in external galaxies

- Herschel and ALMA: Extend the spectral window for gas lines,
  Dynamical information
  Spatial and Spectral Resolutions
- ISO+Spitzer+Akari+Herschel+ Planck: Full emission spectrum of interstellar dust