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, H₂, Evolution of dust
- Shocks
- Supernova
- Signatures of Interstellar turbulence

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

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+, N2+, O2+, S2+)

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:

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  \text{CH}_3 \text{ toward Sgr A (Feuchtgruber et al. 2000): Gas-grain chemistry?}
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  \text{CO}_2 \text{ in star forming regions (Van Dishoeck et al. 1996, …): Comparison with the ice phase}
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  \text{HF toward Sgr B2 (Neufeld et al. 1997): Only 2\% of F in the gas phase}
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  \text{HD (new line) in Orion (Wright et al. 1999, …): D/H abundance}
  \]
  \[
  \text{Also C}_4 \text{ (Cernicharo et al. 2005)? Most abundant carbon chain?}
  \]
Interstellar chemistry: Gas phase Molecules II

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

- Hydrides: OH, CH, H₂O at all positions
  HF, H₃O⁺, NH₃, NH₂, NH
- Hydrocarbons: C₃, C₄, C₄H
- 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 $\chi$:
    - 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 $\mu$m 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 \mu m + $ 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 $\mu m$

- 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, $O^0 (63 \mu m, 145 \mu m)$ 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 transfer, 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: $\rho$ 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 \( \mu \text{m} \)

- 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: $\text{H}_2$, CO, $\text{H}_2\text{O}$, 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 $\text{H}_2$ lines: Chemistry and excitation of $\text{H}_2$

- 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 ($\text{H}_2\text{O}$, $\text{H}_2$, CO, OI)
- Age of the shock (comparing the data with time-dependent shock model)
- Broad sample of objects
- The broad band emission (ISO and IRAS) mainly due to lines ($\text{H}_2$ 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

+ Mineralogic analysis

- Others SNRs: Kepler, Tycho: shocked circumstellar or interstellar 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-shock conditions
- Late emission from SN1987A: Elemental abundances in the stellar ejecta

  Constrains on the modeling of the SN explosion and the explosion 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 turbulence?
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
- $\text{H}_2$ 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