Molecular Gas in the ISM of Luminous Infrared Galaxies

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Luminous infrared galaxies (LIRGs, LIR > 10^{11} $L_\odot$) radiate most of their luminosity as dust thermal emission in the infrared (≈ 5 – 500 µm).

LIRGs were first discovery with the *Infrared Astronomical Satellite* (IRAS), first all-sky survey at far-infrared wavelengths in 1983.

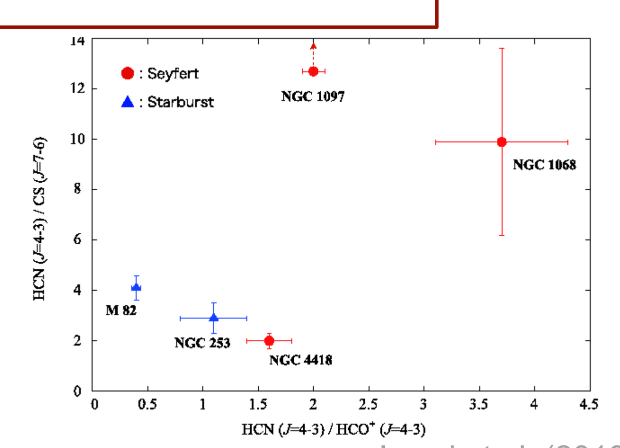
Infrared-luminous galaxies **dominate the cosmic infrared background at high redshifts**. These galaxies can be used to trace the star formation rate, dust content and metalicity in the early universe. Therefore, a thorough understanding of those with analogous properties in our local universe will have a broad impact on our understanding of general galaxy formation and evolution.

Due to its large dust obscuration, it is often **unclear the nature of the nuclear activity**. Molecular line studies at sub- and millimeter wavelengths can be used to trace the physical and chemical conditions of its nuclear region.

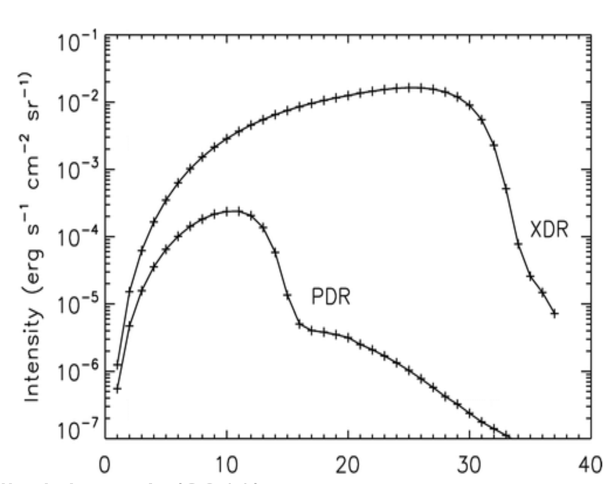
Typical physical processes

Star-forming region -Photon Dominated Regions (PDRs)
AGN excited gas -X-ray dominated regions (XDRs)
Cosmic ray heated gas
Shocks
Hot cores

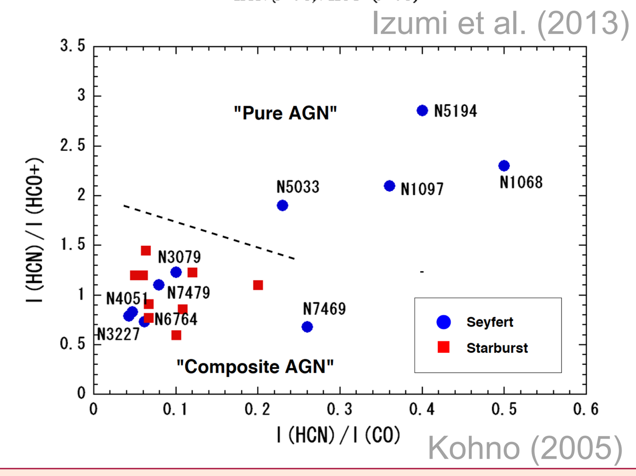
CO is used as the standard tracer of H_2. For high density gas (n>10^4 cm^{-3}) high-J CO transitions are used, as well, as some other tracers such as HCN, HNC, HCO^+, CN and CS. Its molecular line ratio are used as diagnostic tools.



Izumi et al. (2013)



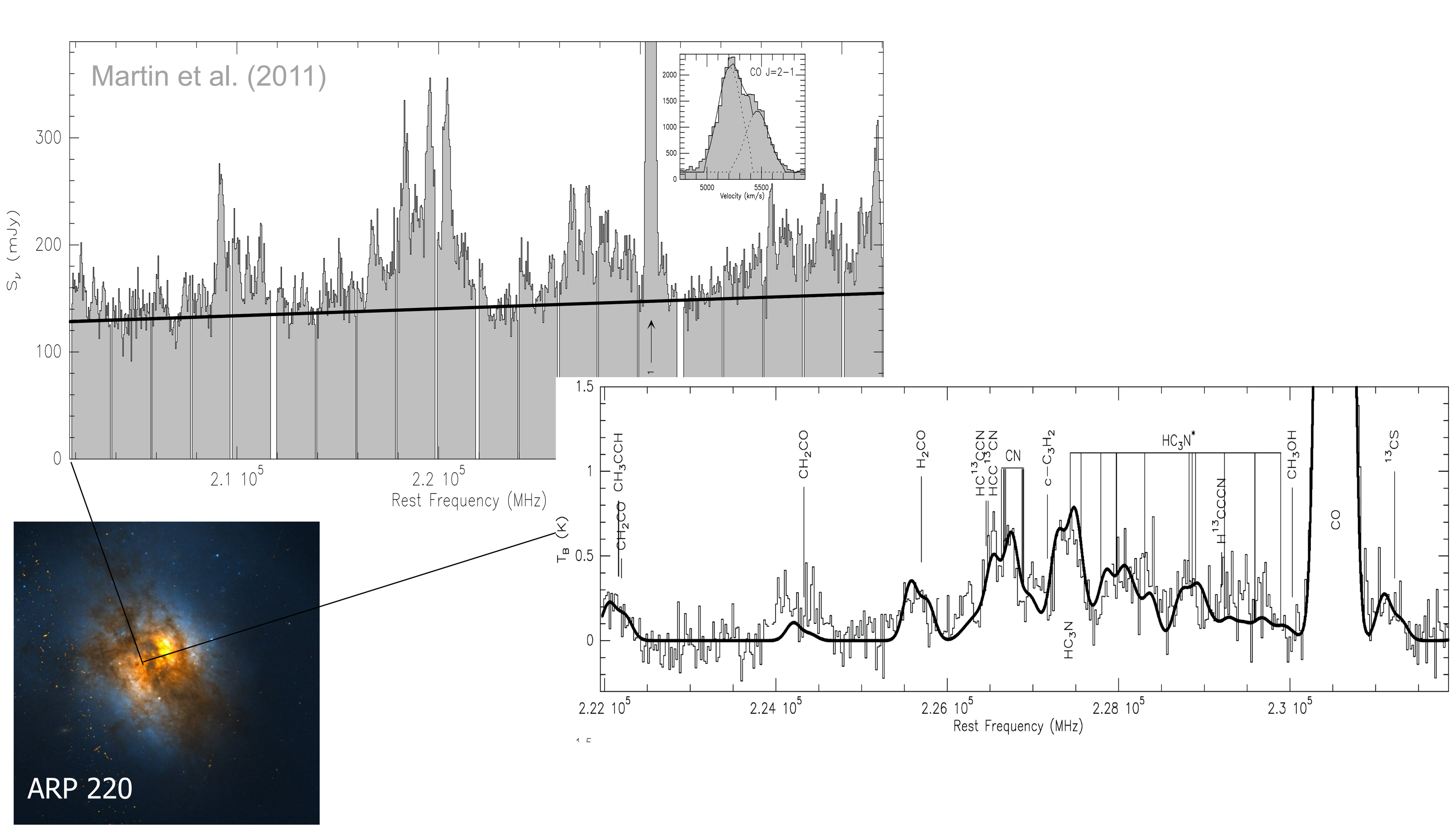
Meijerink et al. (2011)



Kohno (2005)

Present

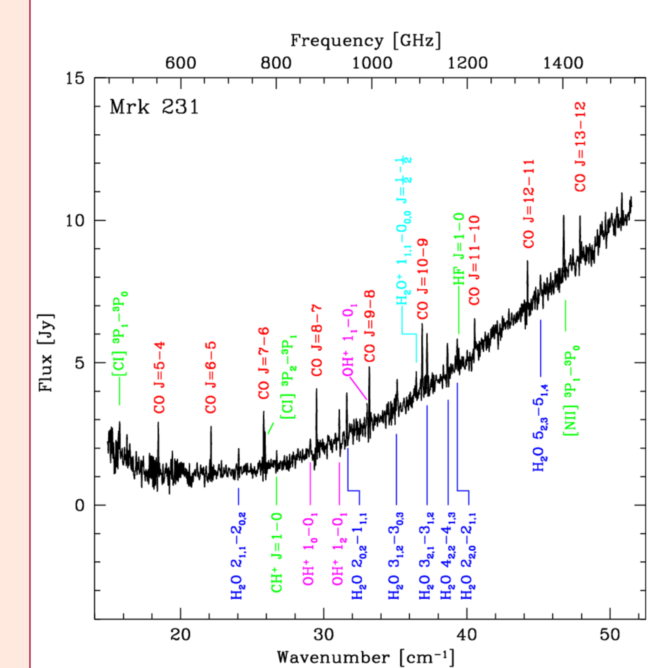
Current facilities (e.g. ALMA, SMA, PdBI) provide access to **spectral line surveys** towards nearby (U)LIRGs. Spectral line surveys are useful tools to characterize the chemical composition and physical parameters of the molecular ISM in extragalactic sources.



Even with exisiting telescope arrays, we are looking at ensembles of clouds and obtaining average properties of the molecular gas within the beam, since The molecular gas is highly concentrated in the nucleus within a typical radius < 1kpc

ALMA full science will provide resolutions of 0.015" (at 300 GHz). This **high angular resolution** will allow GMC-scale studies of the molecular properties of ULIRGs and Seyfert galaxies.

Recent-Herschel



van der Werf et al. (2011)

The *Herschel*/SPIRE FTS instrument, covering a wavelength range between 200-670 µm.

The broad bandwidth provides a good coverage of the CO ladder, with **high-J CO** lines from 5-4 to 13-14.

SPIRE results towards Mrk 231 shows that CO alone it is not robust diagnostic tool to differentiate between PDRs and XDRs.

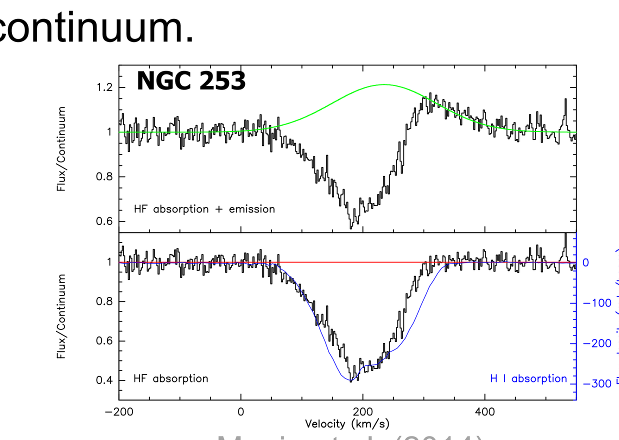
Need for hydrides species such as **water**, hydroxyl (**OH^+**) and water cations (**H_2O^+**) to constrain the excitation condition of the gas.

Highlight results from *Herschel* is first detection of interstellar **hydrogen fluoride**, HF, *J* = 1-0 and the discovery of its ubiquitous nature within the ISM of the Milky Way.

HF is valuable surrogate **tracer for H_2** within diffuse interstellar medium, both in the Milky Way and other galaxies with HF abundances of 1.5 x 10^{-9} in diffuse clouds and two orders of magnitude lower for denser, star forming regions.

Herschel/HIFI

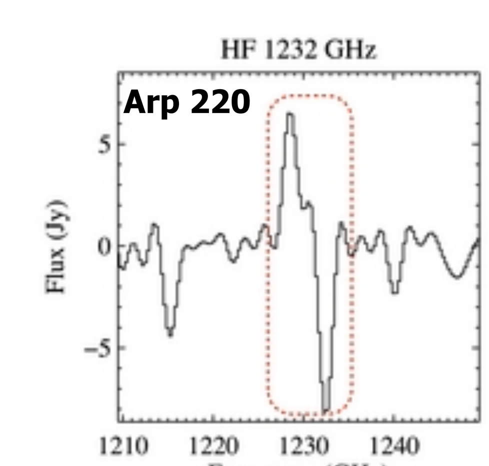
4 detections, high spectra resolution. HF is a good probe of the kinematics of absorbing material along the sight-line to nearby galaxies with bright dust continuum.



Monje et al. (2014)

Herschel/SPIRE

26 detections: 15 in emission 11 in absorption



Rangwala et al. (2011)

Future FIR missions

Interesting lines to observe in future missions

Specie	Transition	Frequency (GHz)
H_2O	1_{11}-0_{00}	1113.342
HF	1-0	1232.476
H_2O^+	1_{11}-0_{00}	1115.204
CH^+	1-0	835.078
H_3O^+	0^-_0-1^+_0	984.711
OH^+	N =1-0	971.803

Future high spectral resolution FIR space facilities housing wideband multipixel heterodyne arrays at THz frequencies will allow **fast mapping capabilities** and **spectral line surveys** on vast number of sources.

Future missions will expand the current molecular line inventory and provide tighter constrains to the physical and chemical models towards a more settled diagnostic of the nature of power sources in (U)LIRGs.

We need access to the **high-*J* transitions of CO and hydride molecules** to distinguish between an AGN and a starburst

Studies with larger statistical samples will be able to establish a correlation between **HF** abundance and the physical conditions, especially density and temperature. To prove the feasibility of HF as a good H2 tracers at z>0.