

Spectral line surveys in Galaxies

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Surveys for ALMA

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Extragalactic chemistry

Extragalactic nuclei are heavily obscured regions

ULIRGS (Arp 220 $A_V > 1000$), Sub-mm Galaxies, ..

Molecular emission as a diagnostic tool of :

- The deeply obscured nuclear power sources: AGN or starburst – XDR, PDR or shock chemistry?
- Starburst evolution
- Type of starburst? Are all starbursts alike – or do their properties vary with environment?
- The feeding of the nucleus
- The conditions and processes leading to the starbursts

Extragalactic chemistry

Most of the diagnostic tools are based just on line intensities

Nearby Galaxies:

- **HCN/HCO⁺ (J=1-0)** as a diagnostic of “pure” vs “composite” AGN or XDRs vs PDRs (Kohno et al. 2001; Imanishi et al. 2006)
- **HCN** seems to be enhanced in Seyferts, LIRGs and ULIRGs. Usero et al. 2004, Graciá-Carpio et al. 2006

Is the HCN emission a tracer of dense gas?

- **HNC/HCN** in luminous galaxies is a diagnostic of XDRs or IR excitation. Aalto et al. 2007
- **SiO** as a diagnostics of XDRs but also of shocks. Martin-Pintado et al. 1997; Garcia-Burillo et al. 2001

High-Z Object:

- **HCN, HNC, CN, and HCO⁺** have been detected towards APM 08279 at $z = z \sim 4$. Weiss et al 2006 García-Burillo et al. 2006, Guélin et al 2006

The intensities can be explained by chemistry and/or excitation

Line surveys

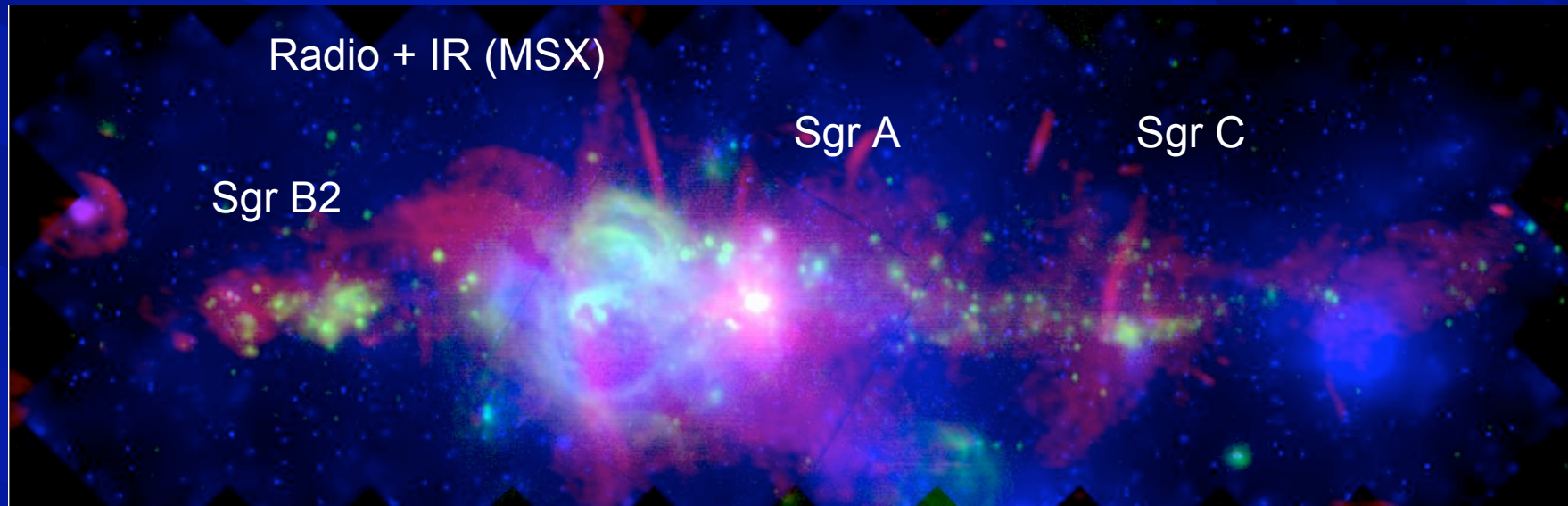
Spectral lines surveys are fundamental for the interpretation of molecular lines towards obscured galactic nuclei. They provide:

- Complete census of molecular species
- Constrain the physical conditions
- Reliable determination of relative abundance

Disentangle the excitation from the chemistry in the extremely complex environment found in galaxies

**Lines surveys are already possible in nearby galaxies:
Galactic center, the starbursts NGC253 and M82 (ongoing)
ULIRG Arp220 (selected molecules 30m, full 1.3 mm SMA)**

The Galactic Center



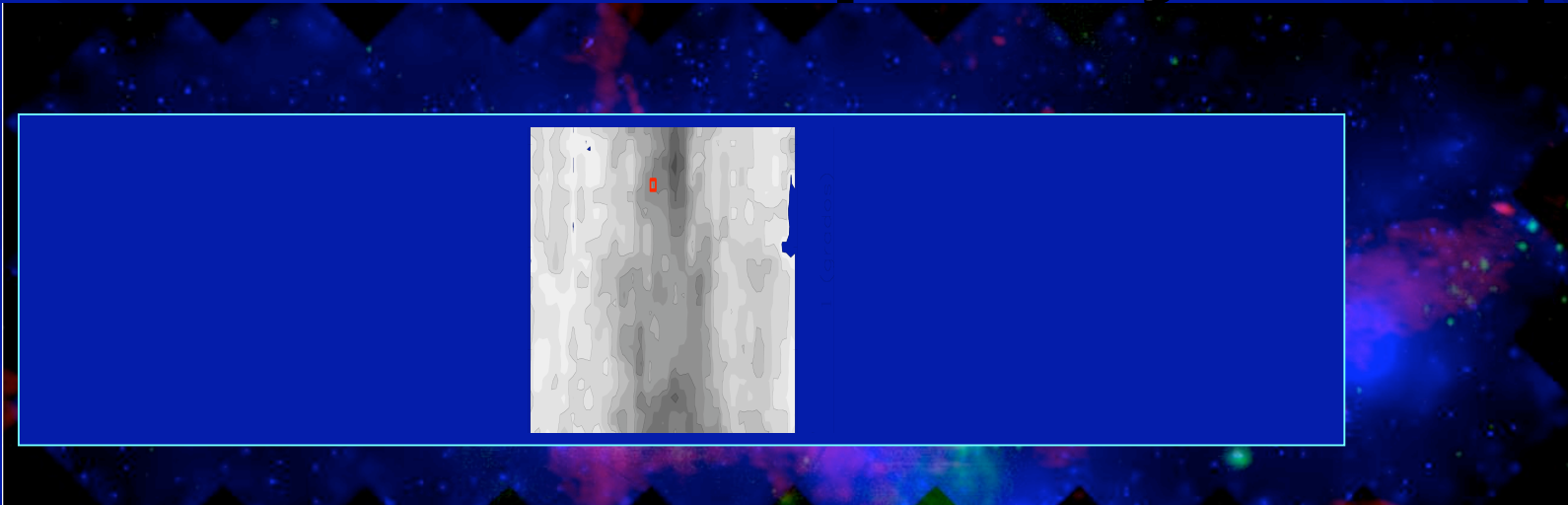
The closest center of a galaxy we can study in detail

In NGC253: $0.040''$ (ALMA) corresponds to $17''$ in the GC

The GC contains all ingredients:

- Star formation seen throughout the region
- Hot cores like Sgr B2N, Sgr B2M ..
- Large PDRs illuminated by clusters of massive stars
- Strong emission of X-rays (Fe 6.4 keV) and gamma-rays (XDRs)

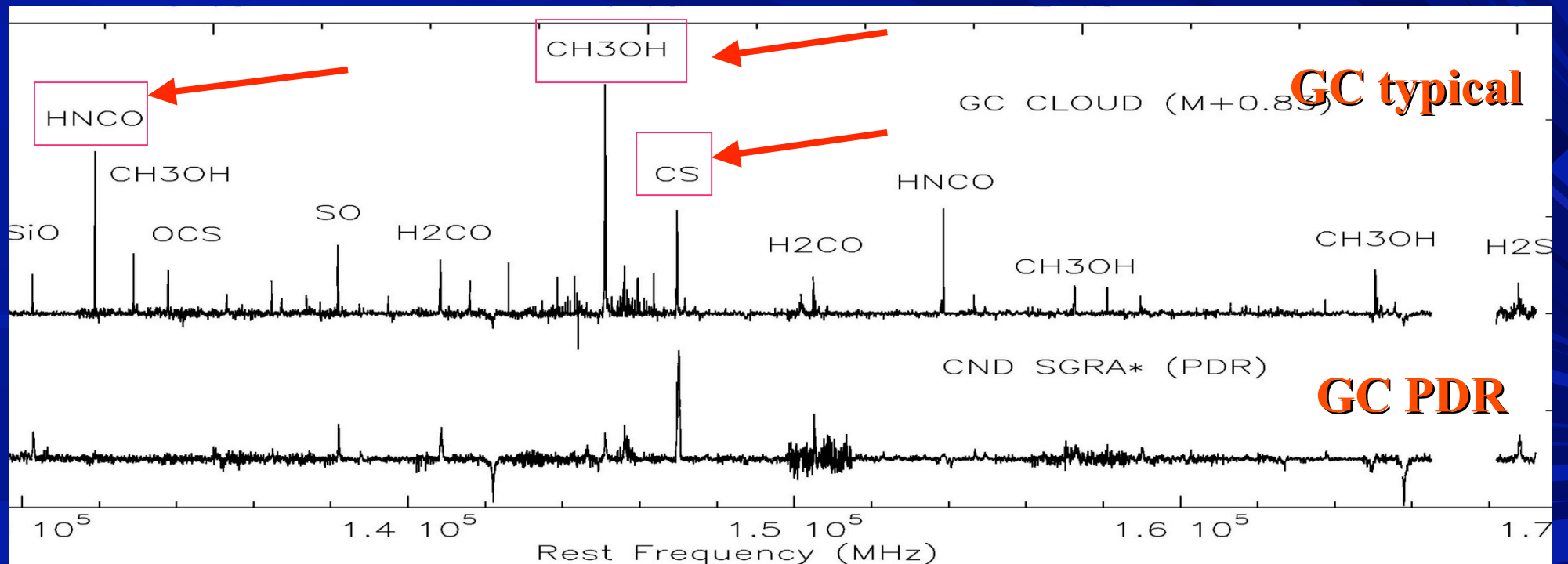
Chemical complexity: Templates



IRAM 30m

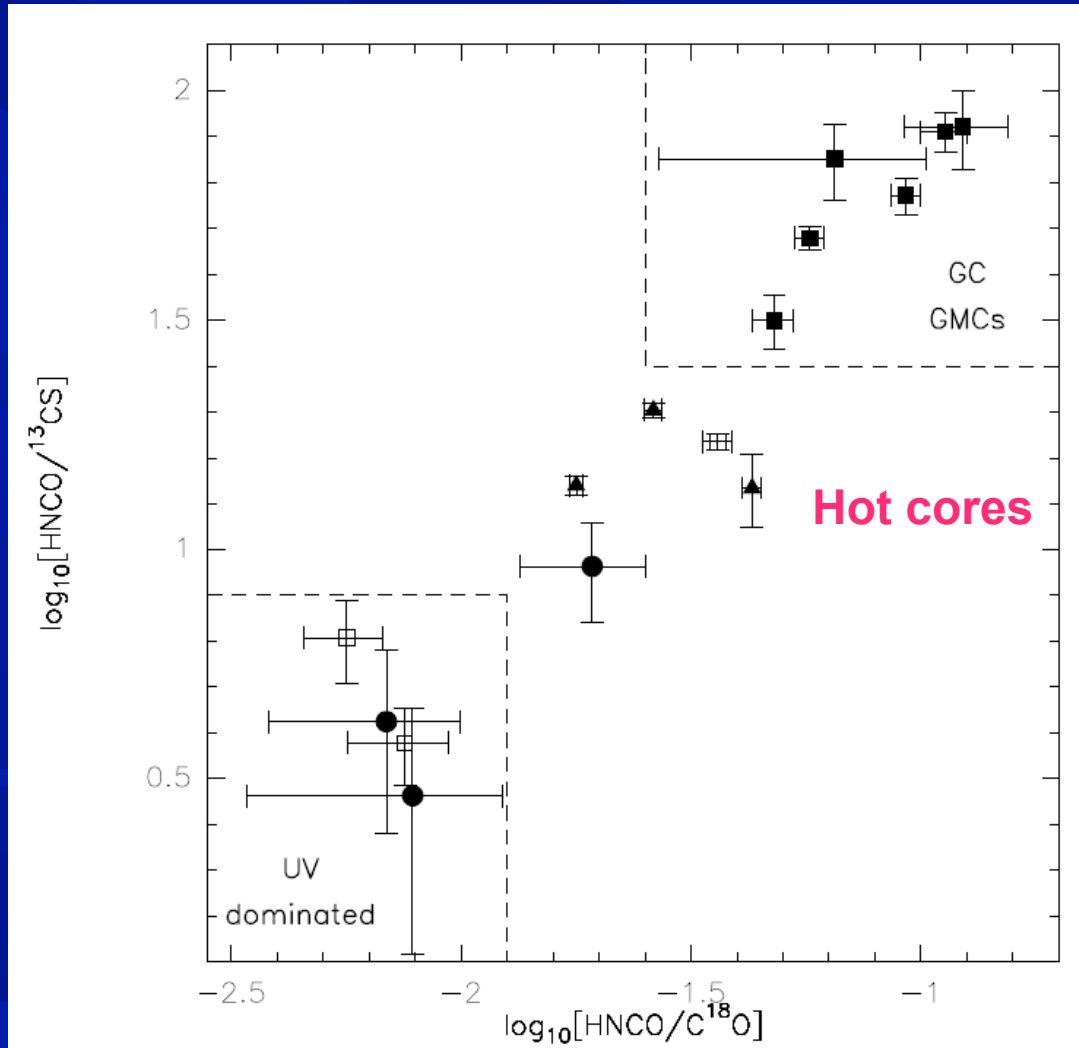
13 surveys
2 mm window

Martin et al, 2007



Diagnostic diagram for PDRs

Significantly constant (factor 4) molecular composition across the Galactic Center



PDRs:

HNCO & CH₃OH ↓↓

CS ↑↑

Complex organic molecules

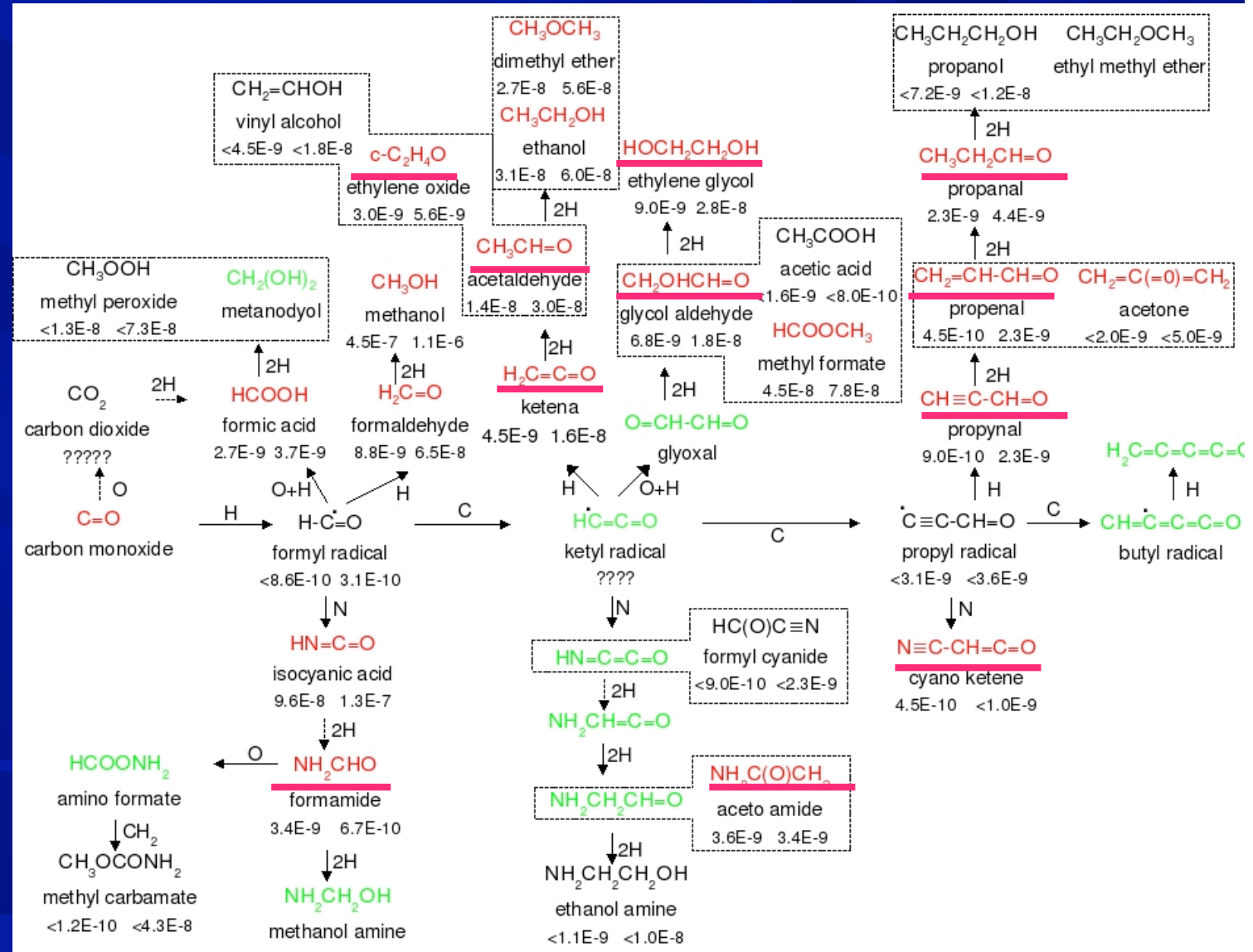
Requena-Torres et al. (2007)

Larger abundance than in Hot Cores

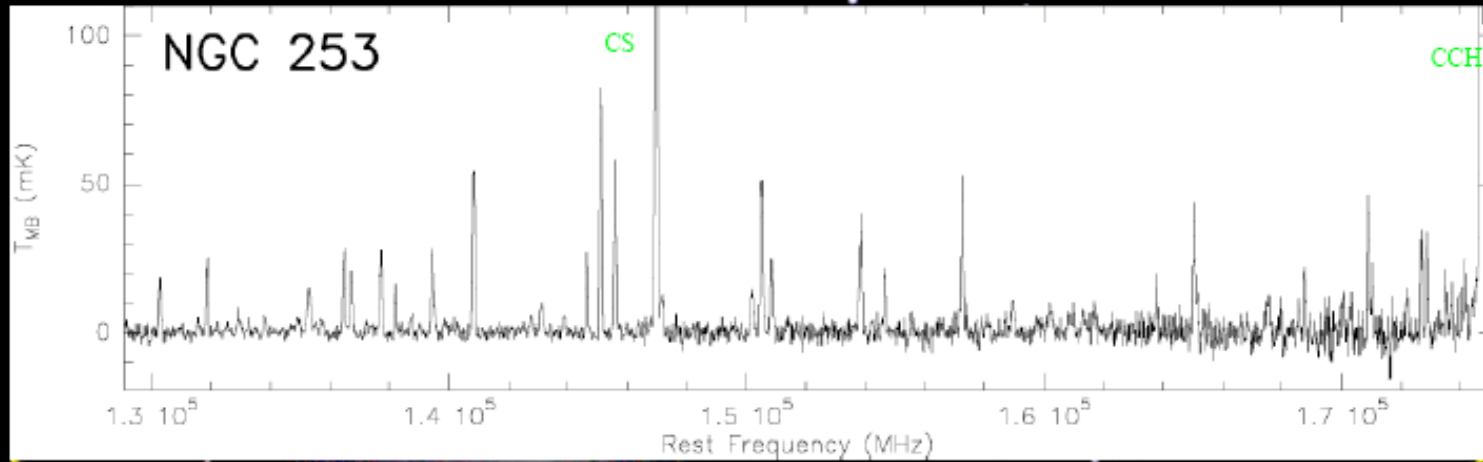
Grain chemistry

Similar ice mantles

FREQUENT SHOCKS

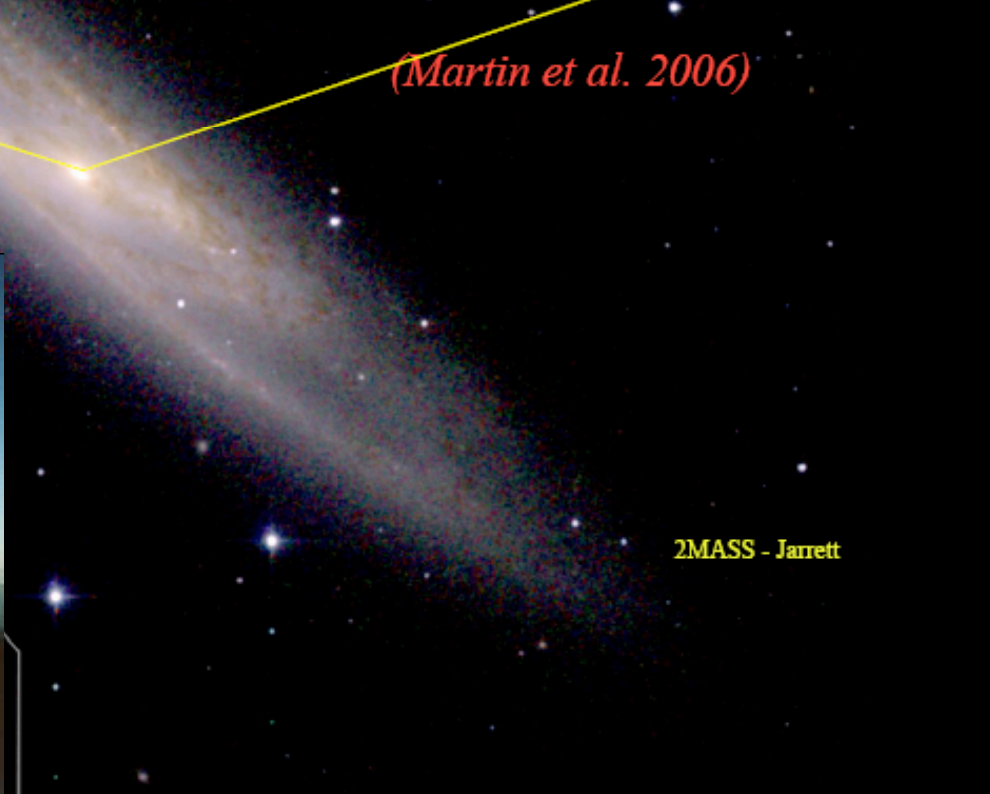


Chemical complexity in NGC253



First unbiased line survey in a galaxy IRAM: 129.1 - 175.2 GHz @ $dv \sim 9$ km/s

(Martin et al. 2006)



DETECTED EXTRAGALACTIC MOLECULES

2 Atoms	3 Atoms	4 Atoms	5 atoms	6 Atoms	7 Atoms
H ₂ (+1)	H ₂ O	H ₂ CO	c-C ₃ H ₂	CH ₃ OH	CH ₃ CCH
OH	HCN (+2)	H ₂ CS	HC ₃ N	CH ₃ CN	
CO (+3)	HNC (+2)	NH ₃	<i>CH₂NH</i>		
CH	HCO	HNCO	NH ₂ CN		
CS (+2)	HCO ⁺ (+3)	<i>C₃H</i>			
CH ⁺	H ₂ S	<i>HOCO⁺</i>			
CO ⁺	SO ₂	HCNH⁺?			
NO	C ₂ H				
CN	HOC ⁺				
NS	C ₂ S				
SiO	N ₂ H ⁺ (+1)				
SO (+1)	OCS				
NH	H ₃ ⁺	NH₂			

* NGC 253's chemistry closely resembles that of the Galactic center

To Date:

* **38** + 4 tentatively detected species

* 13 (+ 2 tentatively) detected rare isotopic substitutions

Italics = tentative

(Compiled: Martin et al 2006; updated by Meier)

DETECTED EXTRAGALACTIC MOLECULES

2 Atoms	3 Atoms	4 Atoms	5 atoms	6 Atoms	7 Atoms
H ₂ (+1)	H ₂ O	H ₂ CO	c-C ₃ H ₂	CH ₃ OH	CH ₃ CCH
OH	HCN (+2)	H ₂ CS	HC ₃ N	CH ₃ CN	
CO (+3)	HNC (+2)	NH ₃	<i>CH₂NH</i>		
CH	HCO	HNCO	NH ₂ CN		
CS (+2)					
CH ⁺					
CO ⁺					
NO	C ₂ H				
CN	HOC ⁺				
NS	C ₂ S				
SiO	N ₂ H ⁺ (+1)				
SO (+1)	OCS				
NH	H ₃ ⁺ NH₂				

No complex organic molecules like ethanol yet detected due to the lack of sensitivity/ line confusion

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(Compiled: Martin et al 2006; updated by Meier)

Chemical complexity in NGC 253

The properties of the ISM in NGC253 are similar to those found in the GC:

- High abundance of ammonia and high T_k of 140 K but low excitation temperatures of 20 K.
- Large abundance of PDR molecules (HNCO, HC₃N, CH₃OH)
- The ISM shows a very rich chemical complexity, very likely produced by ejection of complex molecules from grain mantles
- The heating and the chemistry of the ISM are dominated by shocks
- Heating and chemistry driven by PDRs is marginal in the ISM of NGC253

IC342: PDR+shocks

IC 342

OVRO & PdBI

Shocks

HNC(1-0) $>2[-9]$

$>2[-9]$

HC₃N(10-9)

$2[-9]$

N₂H⁺(1-0)

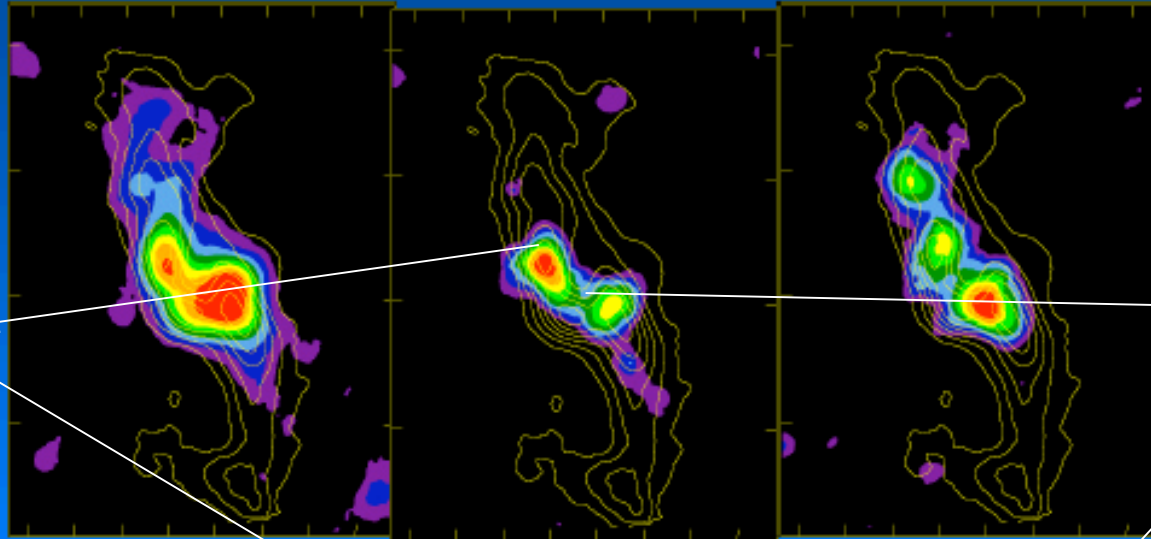
$5[-10]$

SiO

Usero et al 2006

PDRs

Meier & Turner 2005

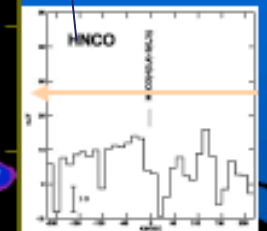
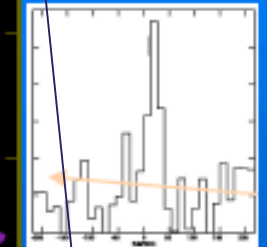
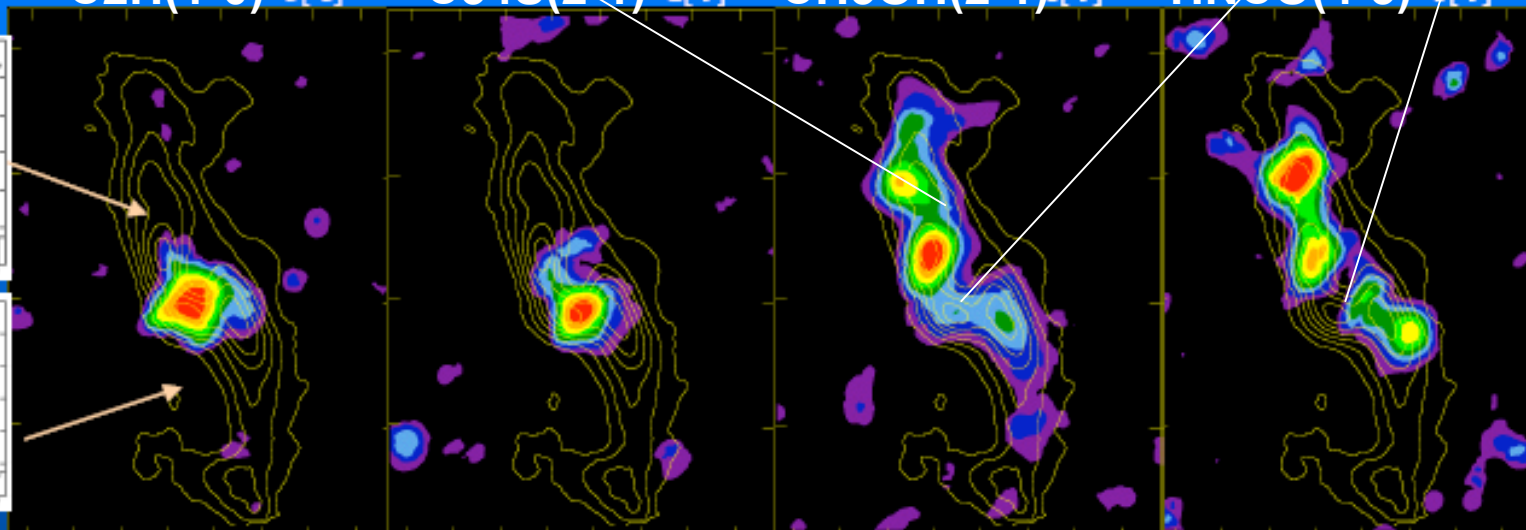
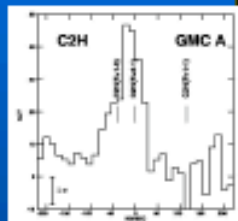
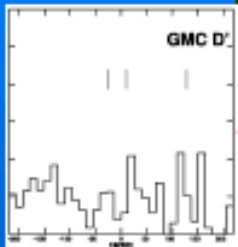


C2H(1-0) $3[-8]$

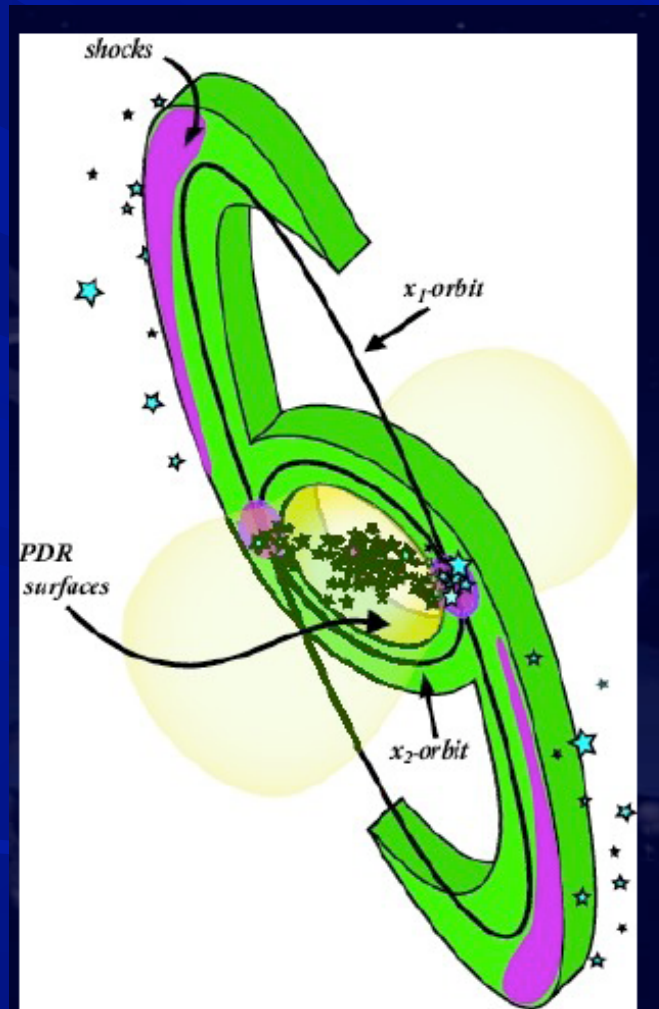
C34S(2-1) $2[-9]$

CH₃OH(2-1) $8[-9]$

HNCO(4-3) $3[-9]$



IC342: PDR+shocks



Meier & Turner 2005

Chemical complexity in ULIRGs: Arp220

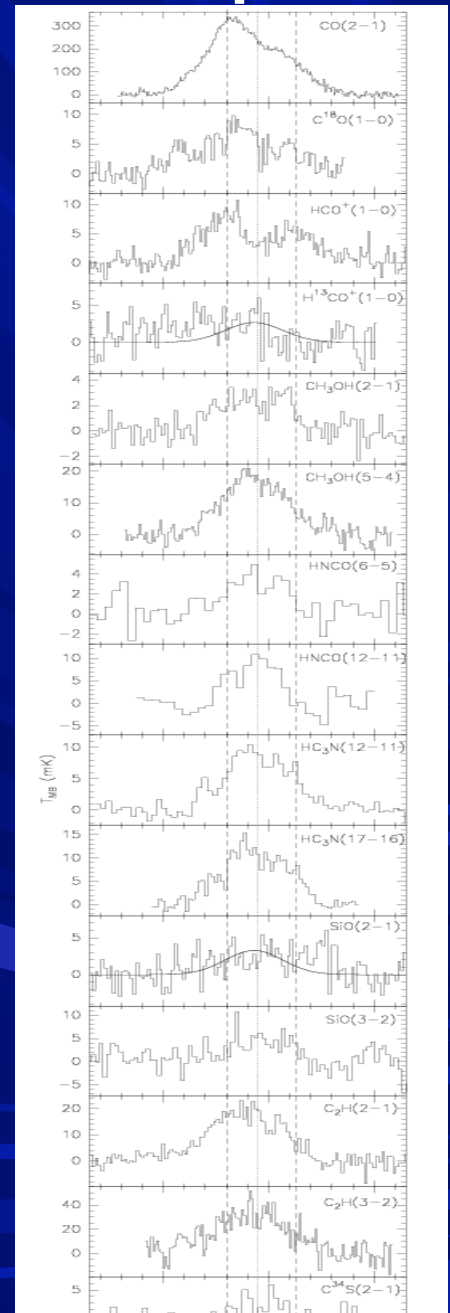
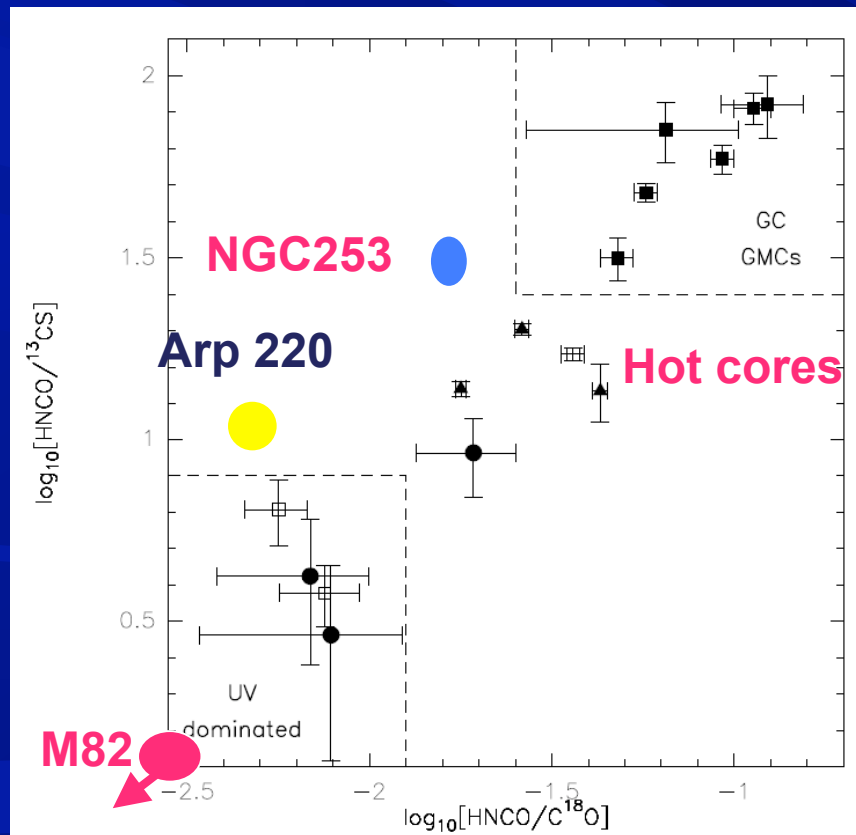
IRAM-30m observations of selected lines

SiO, HNCO, CH₃OH, HC₃N, H₂O, C₂H detected

Large abundance

Line profiles different from those of HCO+, CO,..

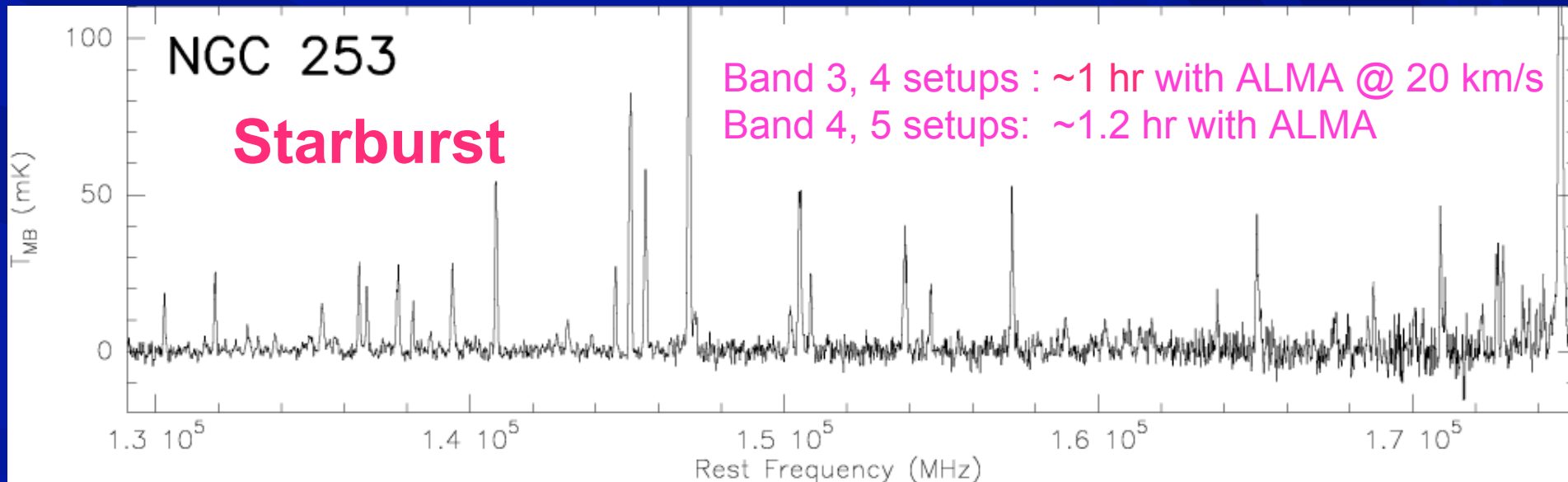
Different evolutionary stages of both nuclei?



Chemistry as a tracer of activity in ULIRGs

- **Very rich chemistry with large abundance of complex molecules**
- **Chemistry in Arp220 is not dominated by UV/Xrays**
- **The SB in Arp220 seems to be young like in NGC253**

Xgal line surveys with ALMA



AGNs: NGC1068

Band 3, 4 setups : ~1 hr with ALMA. Detect HOC+ with 5σ @ 20 km/s

Band 4, 5 setups: ~1.2 hr with ALMA

ULIRGs, Arp220

Band 3, 4 setups : ~1 hr with ALMA. Detect methanol with 20σ @ 20 km/s

Band 4, 5 setups: ~1.2 hr with ALMA

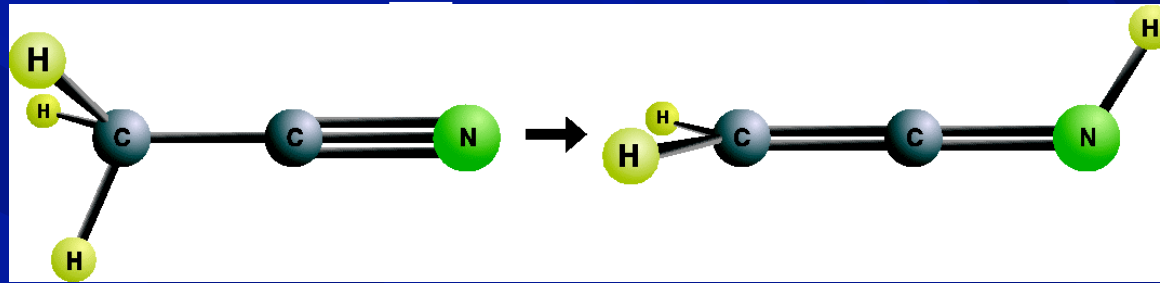
Band 6, 11 setups : ~1.5 hr with ALMA. Detect methanol with 120σ @ 20 km/s

Xgal line surveys with ALMA

ALMA will provide the resolution and sensitivity to:

- Image the chemical complexity and physical conditions in a large sample of nearby galaxies with GMC-scale resolution.
- To depict the spatial distributions of nuclear SB regions dominated e by shocks or/and by UV radiation and XDRs dominated by the AGNs.
- Instead of interpreting individual (or a handful of) lines, will it be possible to develop modeling tools that will deal with whole line-scans **providing the best diagnostic for the different types of nuclear activity**
- Fully characterize the chemical complexity and physical conditions of some high-z objects

DRSPs with Astrochemical



2.3 Chemistry of star-forming regions

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