

Extragalactic line surveys

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Chemical variation are observed over large averaged scales in the central region of galaxies

Dense Gas in Galactic Nuclei

1993

R. Mauersberger and C. Henkel

MPI für Radioastronomie

Auf-dem-Hügel 69, D 53121 Bonn, Germany

Abstract

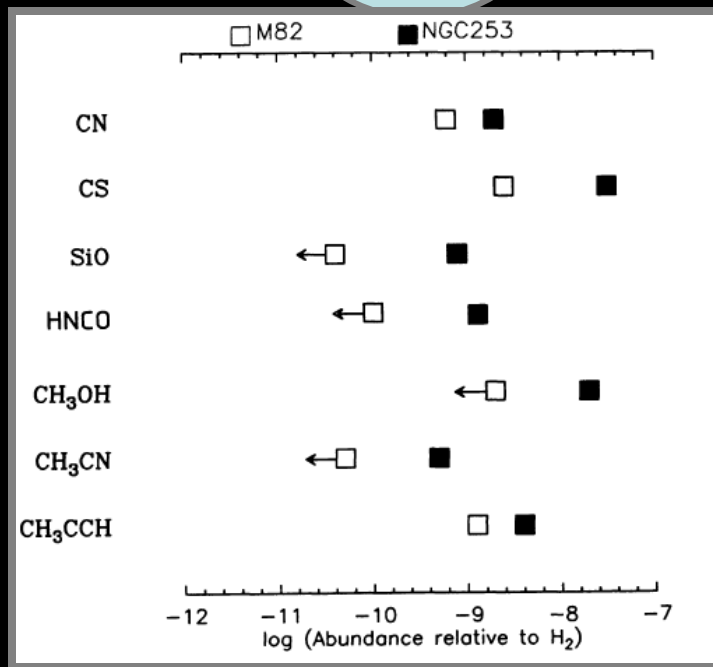
This Review contains recent results on molecular gas in the centers of galaxies and is an update to the review by Henkel, Baan & Mauersberger (1991, *A&A Rev* 3, 47). Following the Introduction, Sect. 2 deals with CO and HCN as tracers of the molecular mass. Included are a comparison of results from other mass tracers and a description of the detailed spatial distribution of the dense molecular gas component. The possible detection of a nearby protogalaxy and molecular observations of the distant “primeval” galaxy IRAS 10214+4724 are discussed in Sect. 3. Sects. 4 and 5 summarize results on molecular chemistry and elemental abundances in external galaxies.

Keywords: *Galaxies: active, nuclei of, formation of — interstellar medium: molecules*

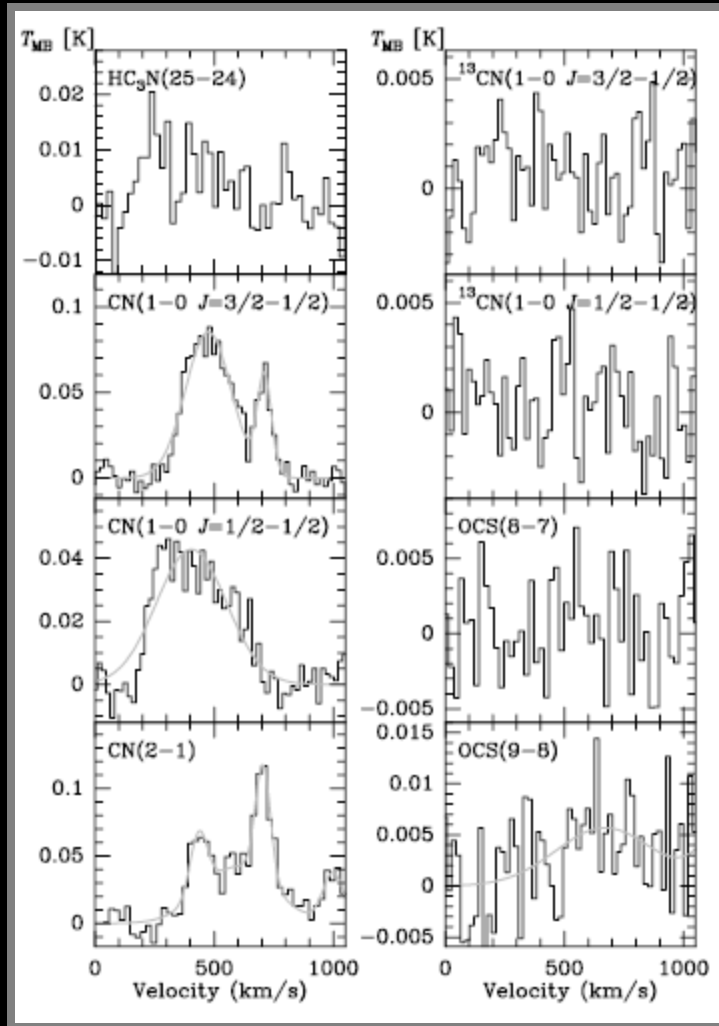
Surprisingly, the variations in chemical composition do *not* cancel out...

23 species + 8 isotopologues

One would naively expect such variations to cancel out when one compares the chemical mixture averaged over larger volumes.



Starburst have been the evident target for large molecular line searches



Wang et al. 2004

Swedish-ESO Submillimeter Telescope (SEST)

2x1 GHz AOS backends

Frequencies 82 to 354 GHz

80 transitions of 19 species

Targeted molecular observations

Molecular abundances and isotopic ratios
comparison with the starbursts

NGC 253 and M 82

Starburst have been the evident target for large molecular line searches

First unbiased mm line surveys of the two brightest extragalactic sources

IRAM 30m

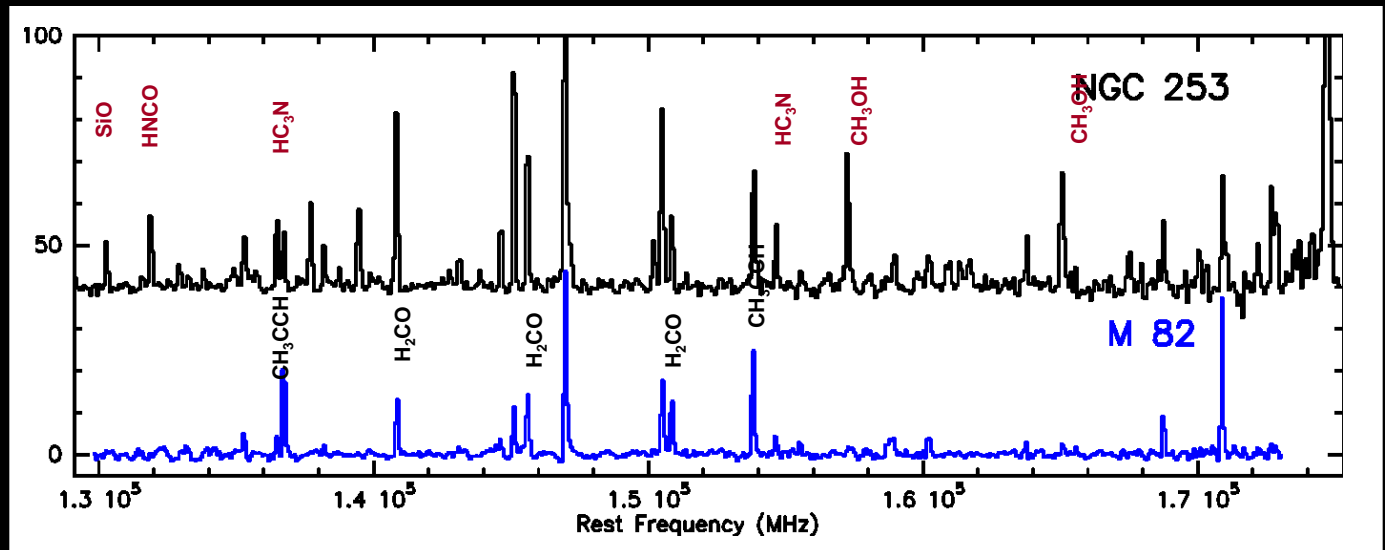
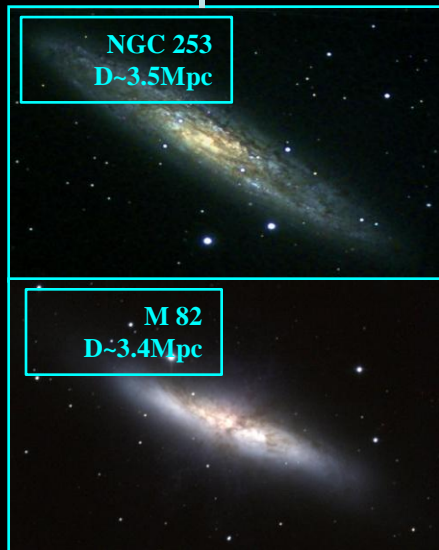
2mm Atm window ~46 GHz (129–175 GHz)

+ 19 GHz (241-260 GHz) in M82

2 x 1 GHz FB

111 lines / 25 species

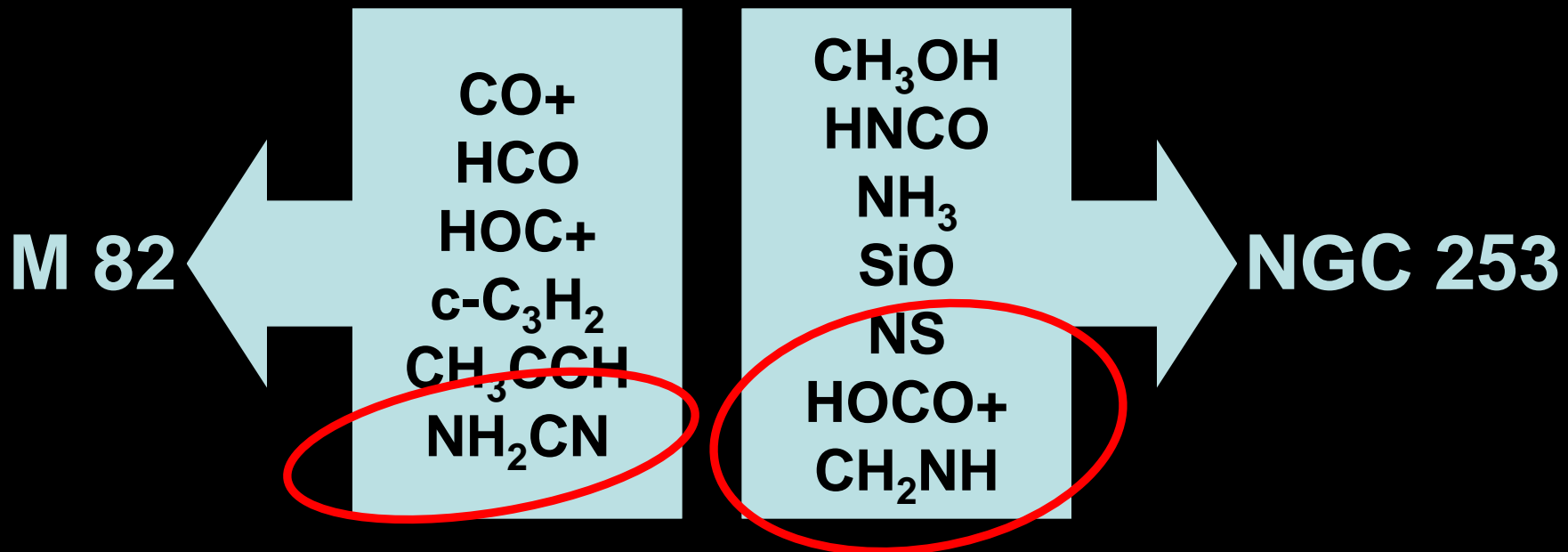
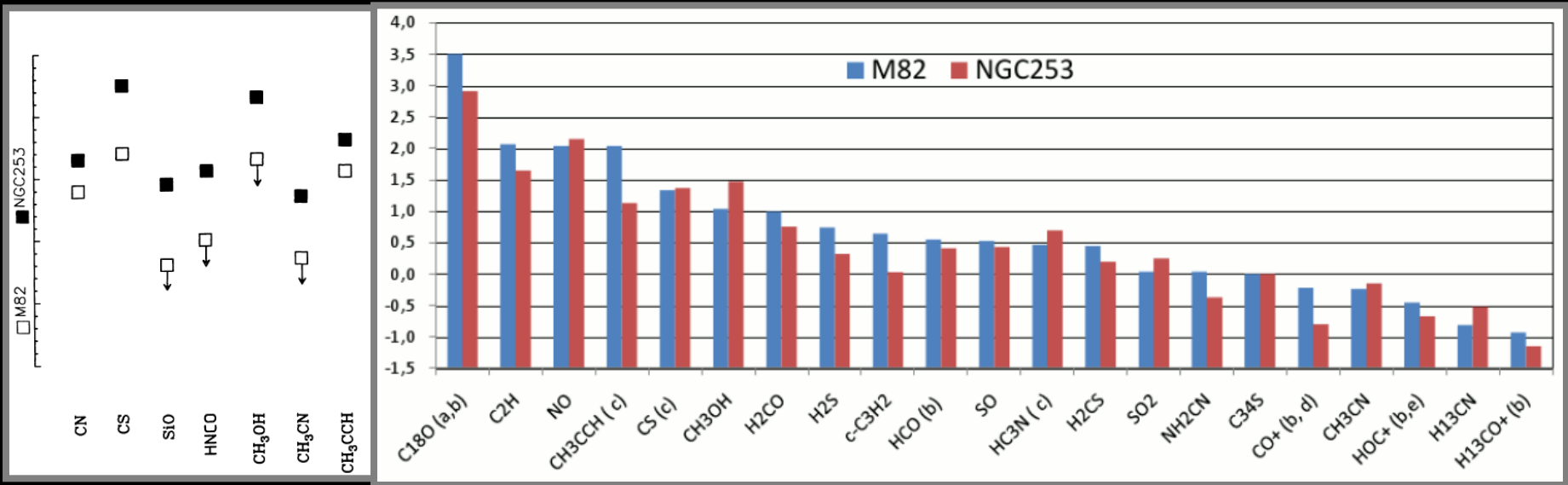
(Martin et al. 2006)



72 lines / 18 species

(Aladro et al. Submitted)

Molecular line surveys provide key information on the differentiation and evolution of the heating mechanisms in galactic central regions



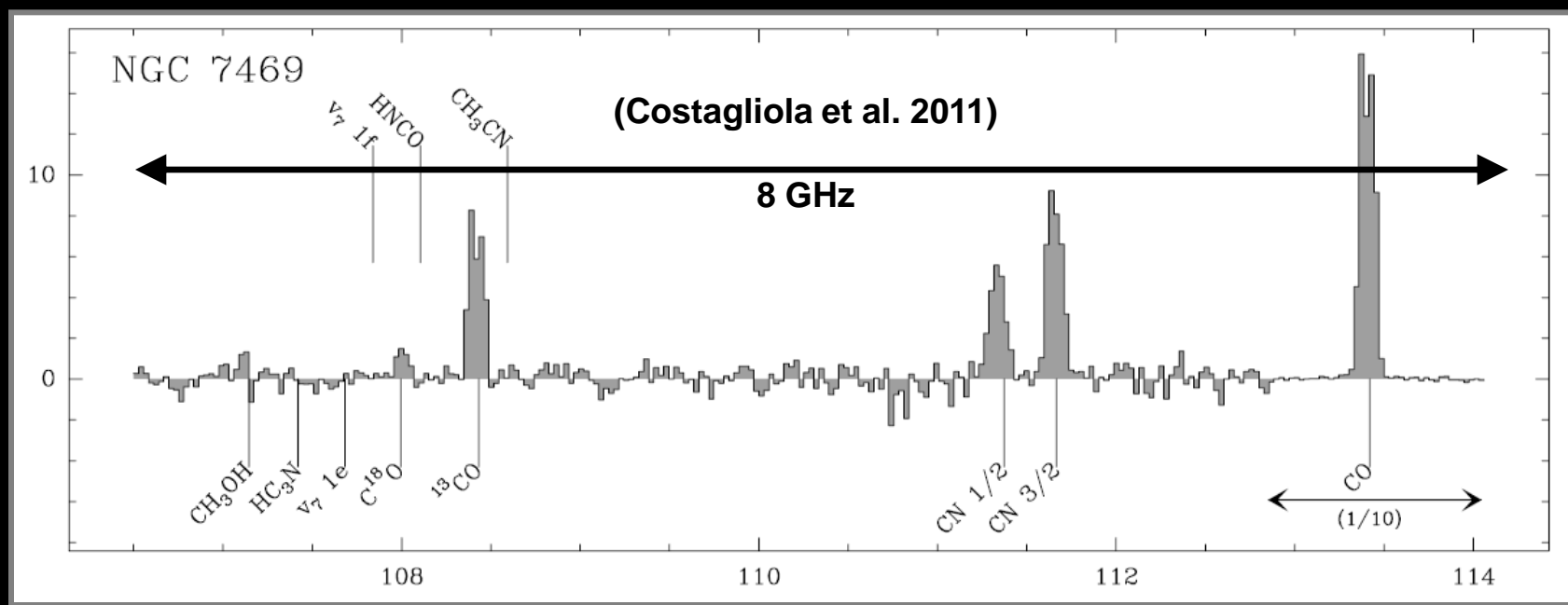
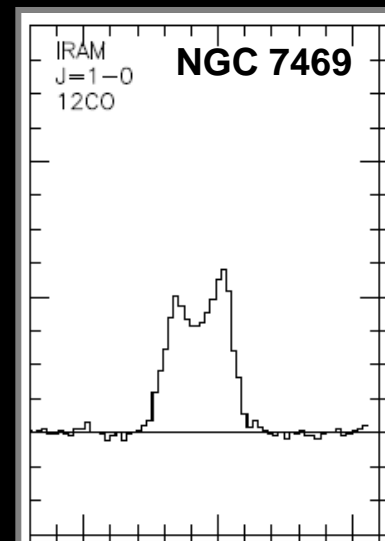
Bandwidth upgrades in most mm and sub-mm

Single dish		Interferometers	
MOPRA	... 8.2 GHz	SMA	... 8 GHz
IRAM 30 m	... 8 GHz	CARMA	... 8 GHz
Nobeyama	... 16 GHz	PdBI	... 4 GHz
APEX	... 2-8 GHz	ALMA	... 8 GHz
JCMT	... 1.8 GHz	ATCA	... 4 GHz

Israel 2009
IRAM 30m

data from 2005-2007

BW= 500 MHz ~ 1300 km/s



Line surveys are now feasible and going on ...

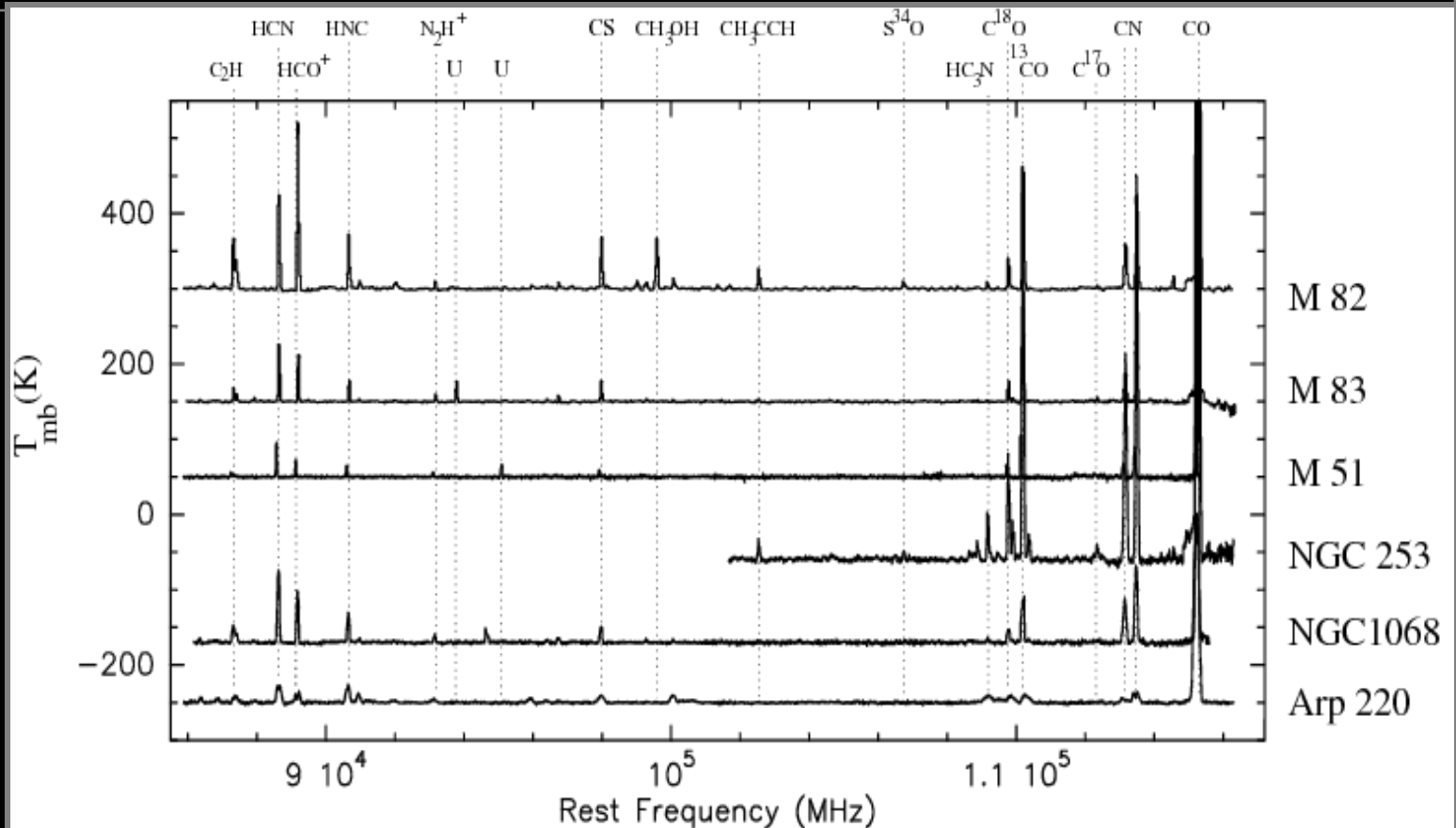
6 Galaxies IRAM 30m high sensitivity surveys :

Roadmap to chemical classification

86 – 116 GHz @ 12 km/s rms~2 mK

36 molecular species detected

(Aladro et al. In Prep.)



Line surveys are now feasible and going on ...

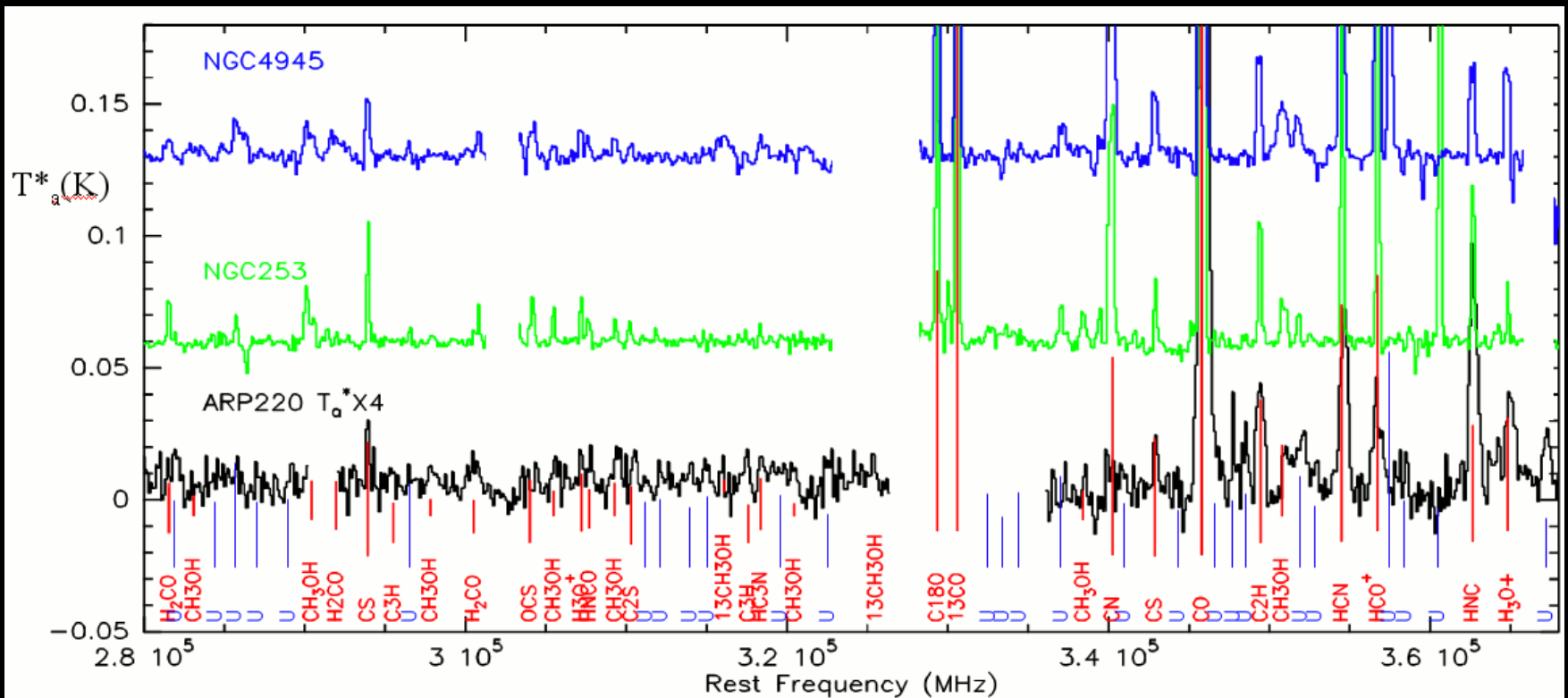
3 Galaxies APEX 12 m:

280 -360 GHz @ 20 km/s rms~2mK

16 molecular species detected

POSTER 2.83

(Requena-Torres et al. In Prep.)



Line surveys are now feasible and going on ...

NGC 253 APEX 12 m:

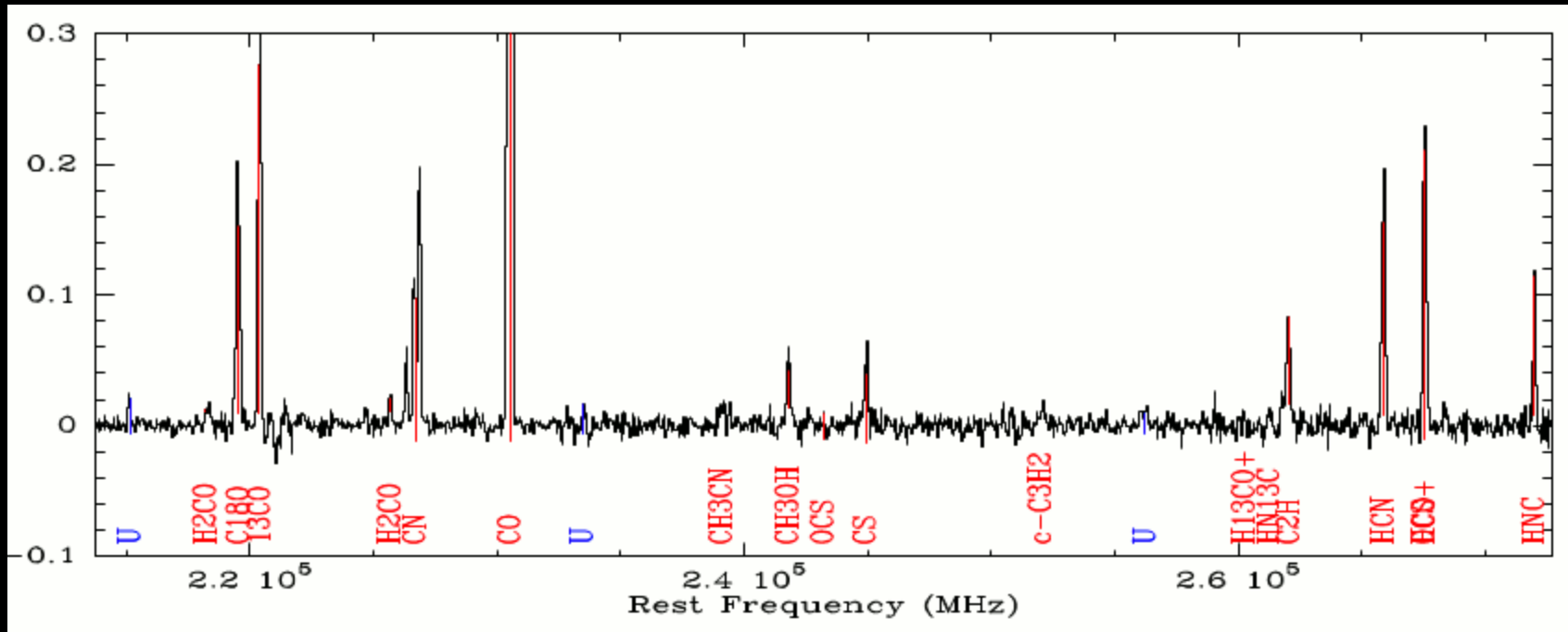
185 - 275 GHz @ 12 km/s

16 molecular species detected

POSTER 2.83

Complete frequency survey from 3mm to 0.9 mm!

(Requena-Torres et al. In Prep.)



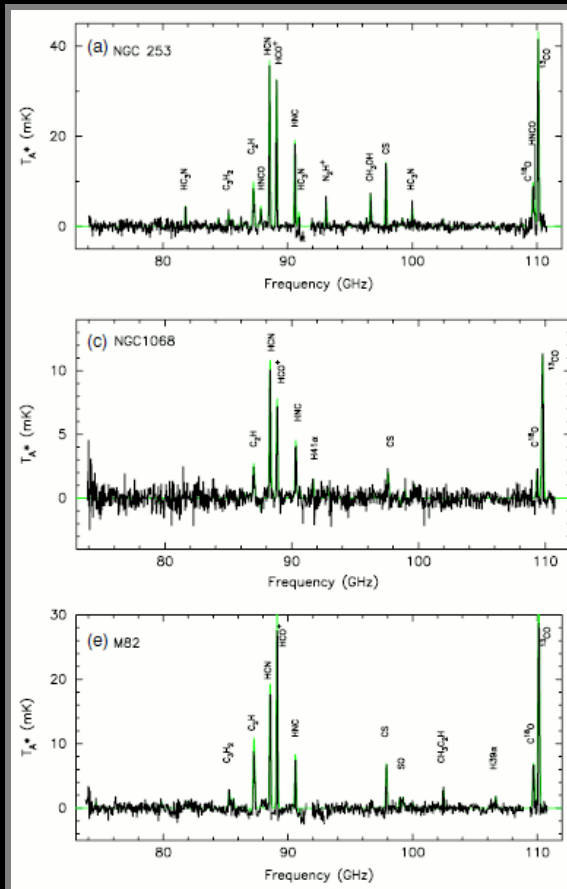
Line surveys are now feasible and going on ...

10 Galaxies with 14 m FCRAO Redshift Search Receiver (RSR)

74 - 111 GHz @ 100 km/s rms~1mK

13 molecular species detected

(Snell et al. 2011)



HCO+/HCN higher in AGN vs SB dominated galaxies.

HCO+/HCN claimed to be enhanced in SB galaxies. (Krips et al. 2008)

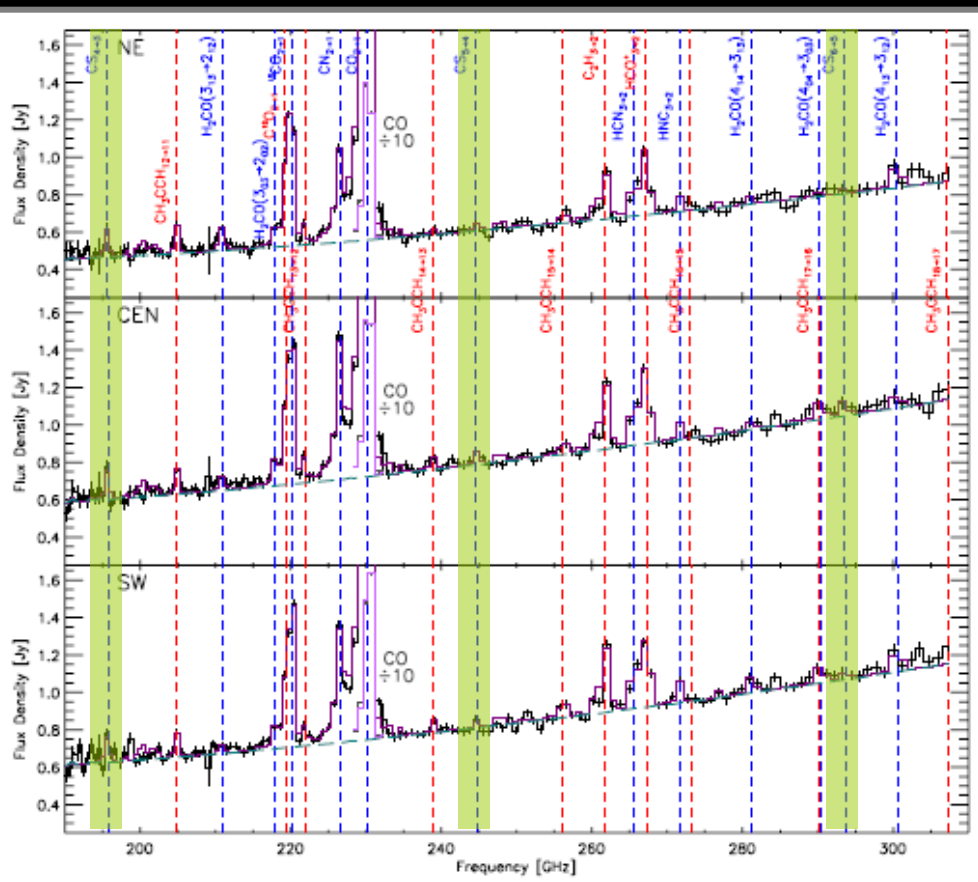
Line surveys are now feasible and going on ...

Z-Spec with the 10.4 m CSO

190 - 307 @ 700 - 1200 km/s

10 molecular species detected

(Naylor et al. 2010)



3 positions towards M82

Simultaneous observations of
three CS transitions.

Low velocity resolution

Line surveys are now feasible and going on ...

Z-Spec with the 10.4 m CSO

190 - 307 @ 700 - 1200 km/s

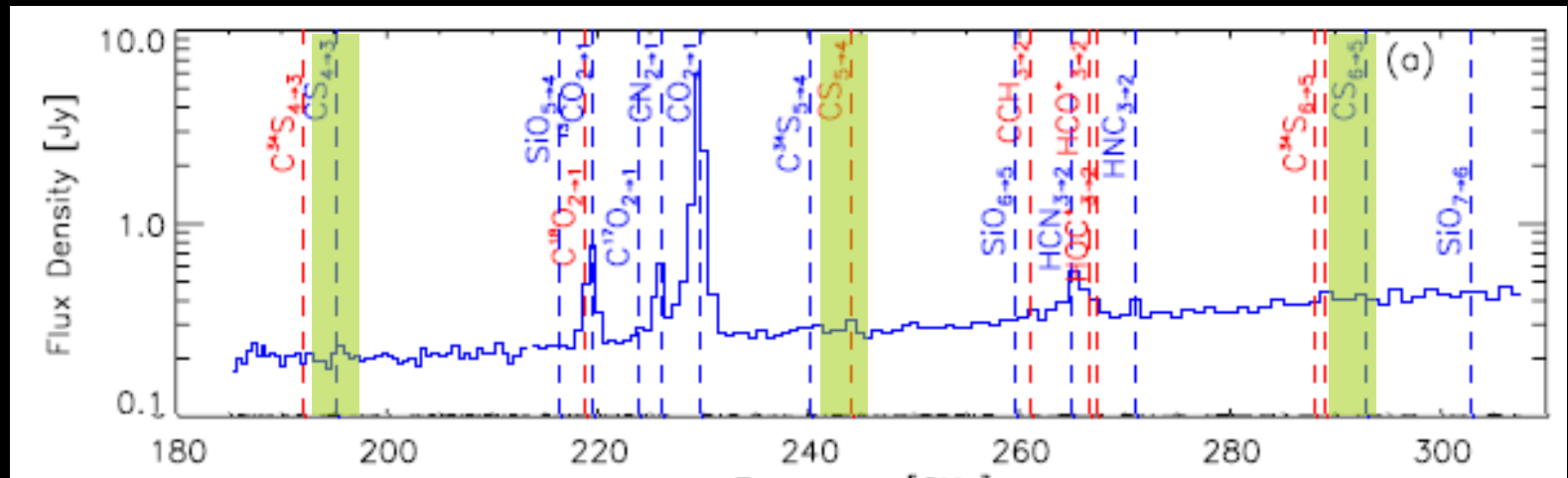
12 molecular species detected

(Kamenetzky et al. 2010)

Central region of NGC1068

Simultaneous observations of
three CS transitions.

Low velocity resolution



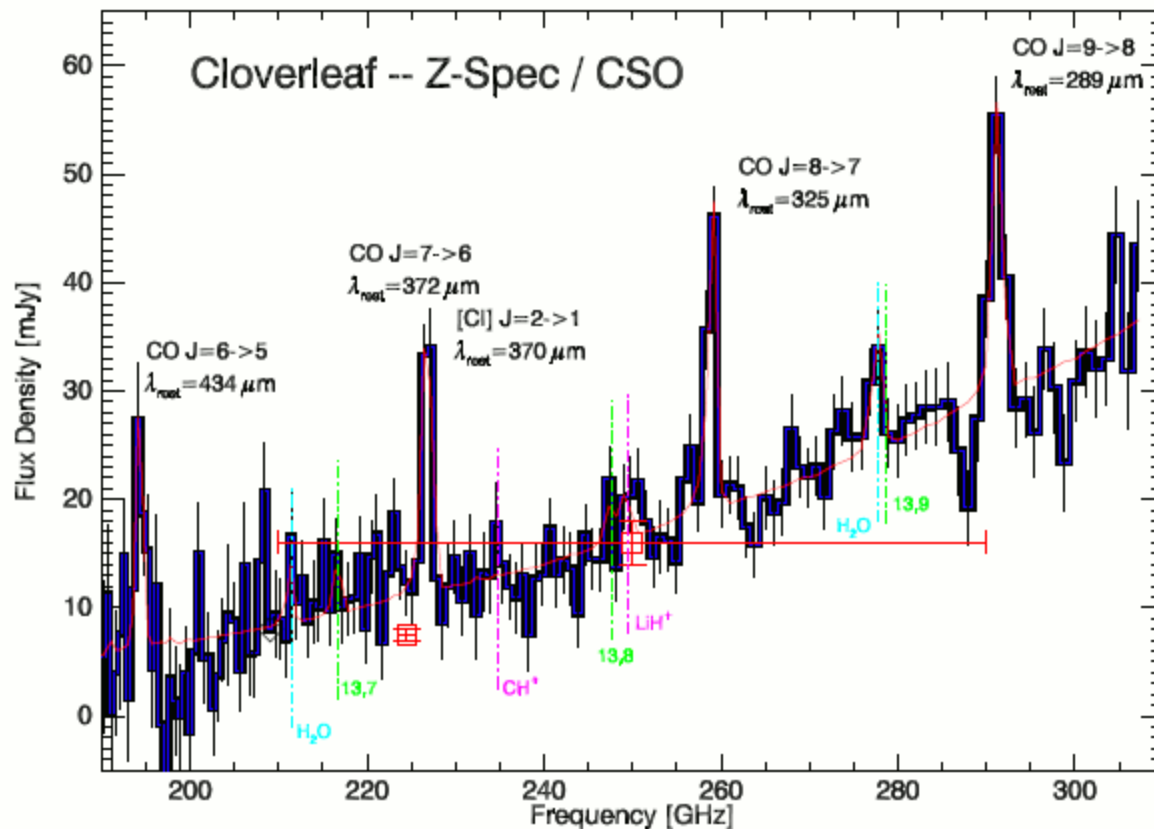
Line surveys are now feasible and going on ...

Z-Spec with the 10.4 m CSO

190 - 307 @ 700 - 1200 km/s

CO, C+ and 4 tentative detections

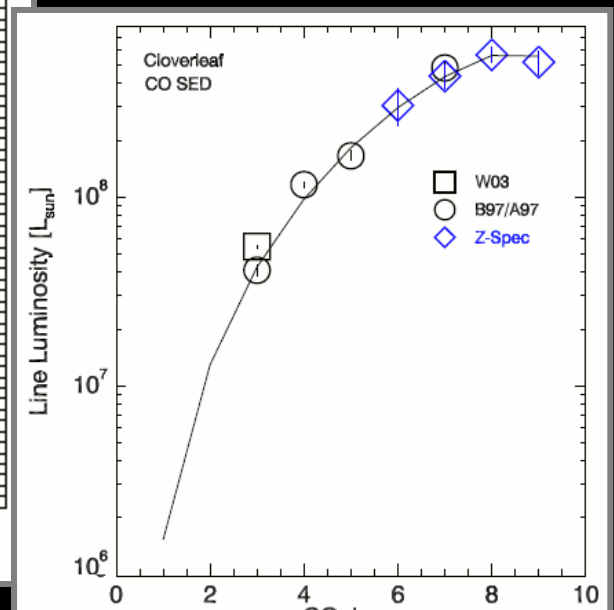
(Bradford et al. 2009)



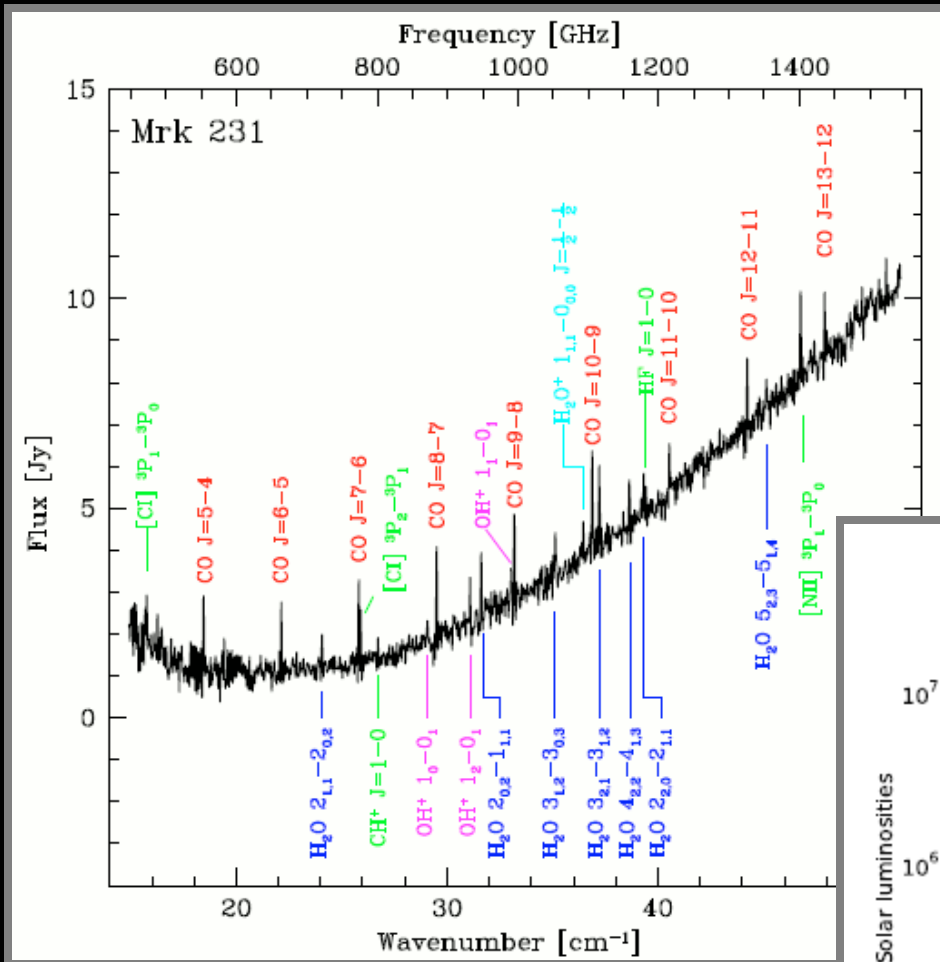
CLOVERLEAF $z=2.56$

Rest frame:

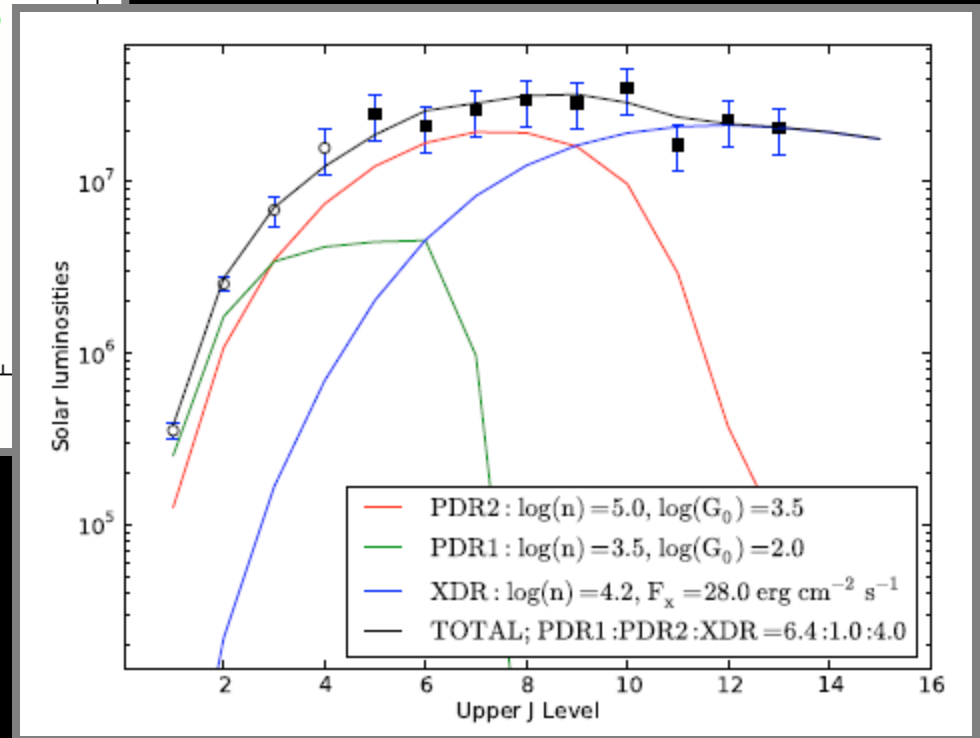
272 – 444 μm



Line surveys are now feasible and going on ... *with Herschel*



(van der Werf et al. 2010)



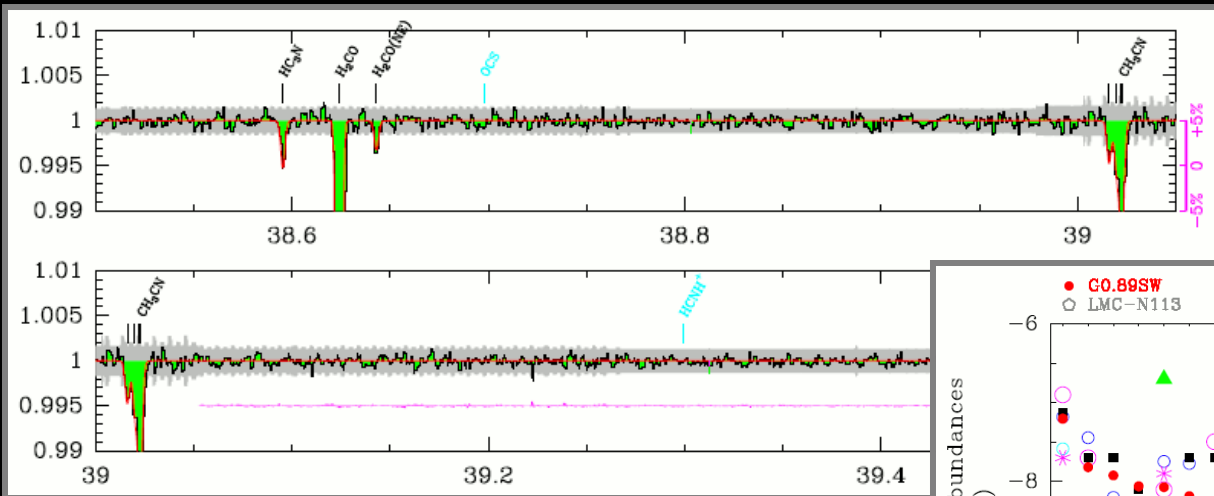
Line surveys are now feasible and going on ... *at intermediate Z*

ATCA

30 – 50 GHz @ 6 - 10 km/s

28 species + 8 isotopologues

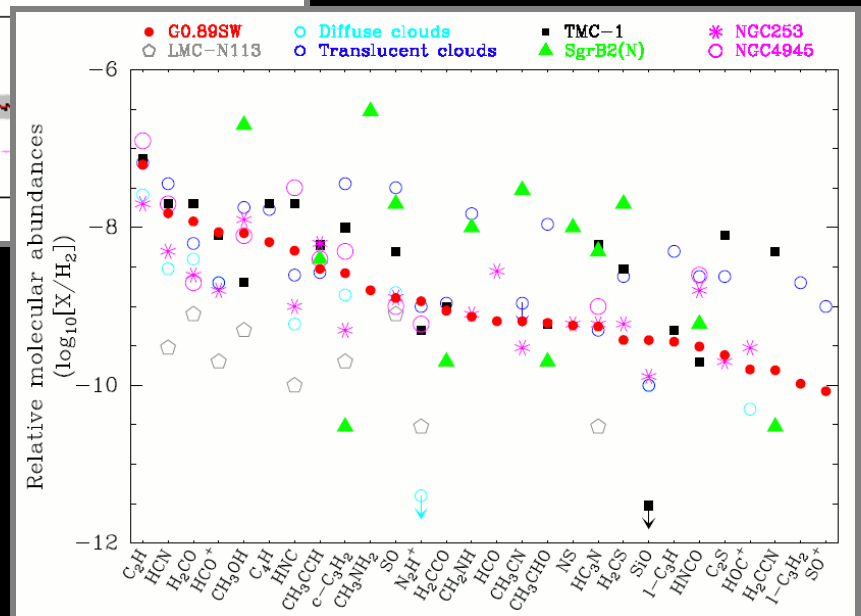
(Muller et al. 2011)



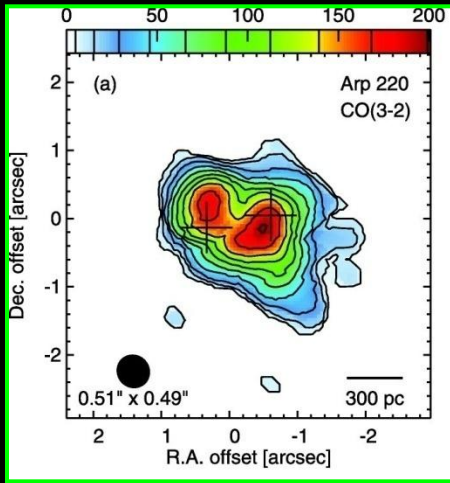
PKS 1830-211 $z=0.89$

Rest frame:

57 – 111 GHz (5-3 mm)

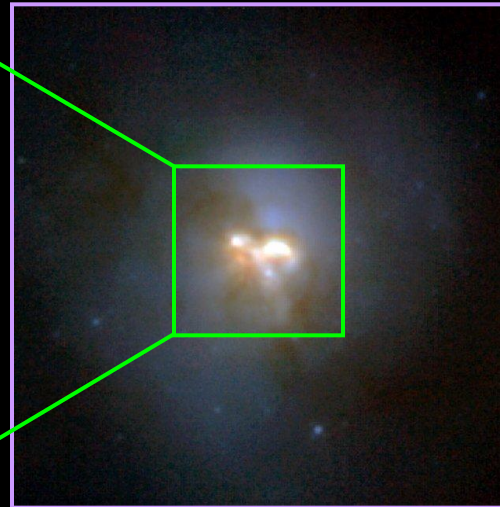


The SMA 1.3 mm line survey of the ULIRG Arp 220 shows the future ALMA/EVLA surveys at high redshift



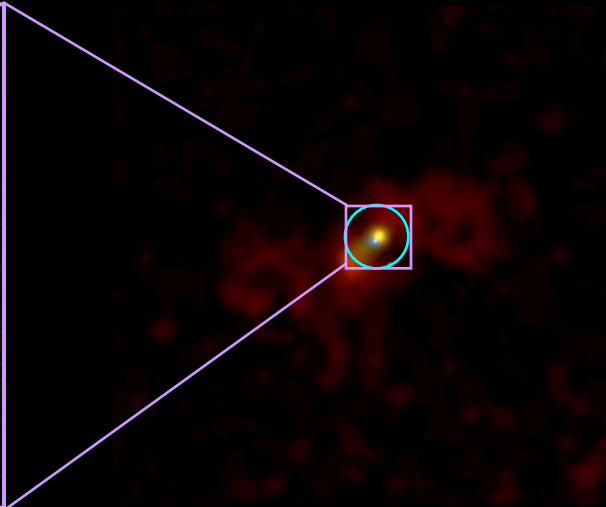
850um – SMA

Sakamoto et al. 2008



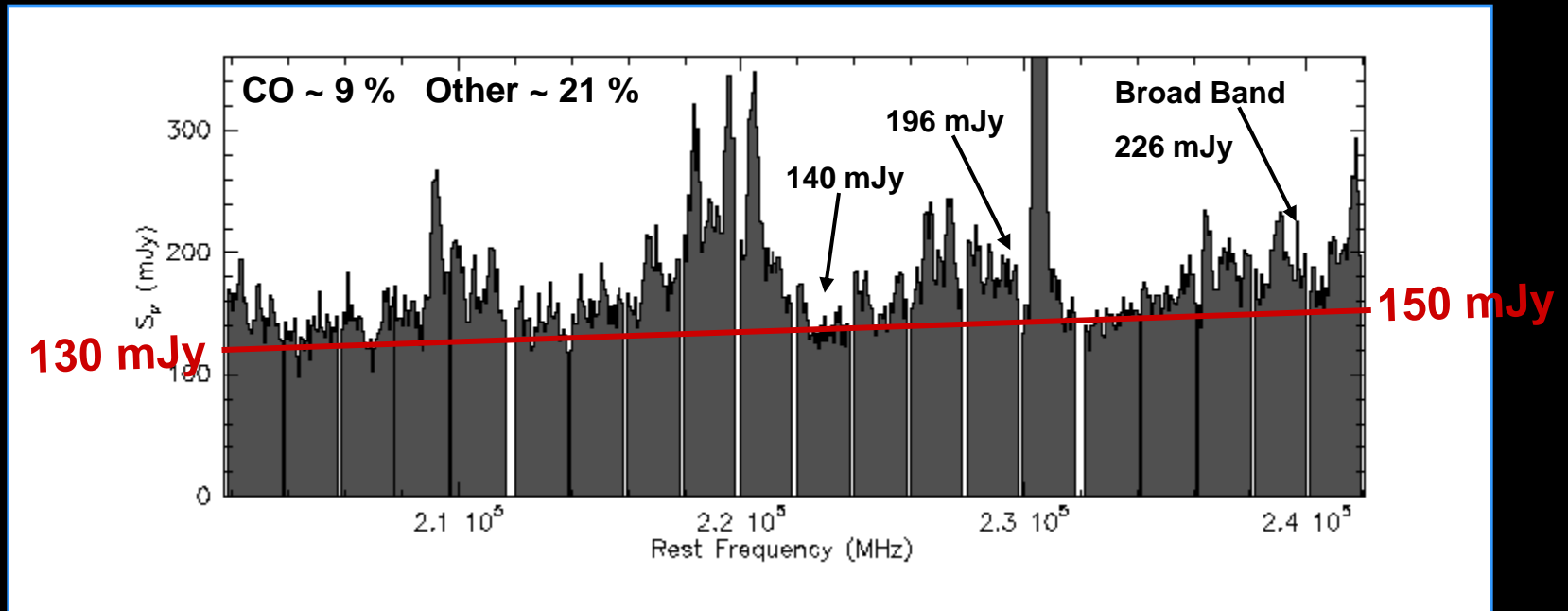
NIR – HST

Scoville et al. 1998



X Rays – CHANDRA

Mc Dowell et al. 2002



The SMA 1.3 mm line survey of the ULIRG Arp 220 shows the future ALMA/EVLA surveys at high redshift

202 – 242 GHz

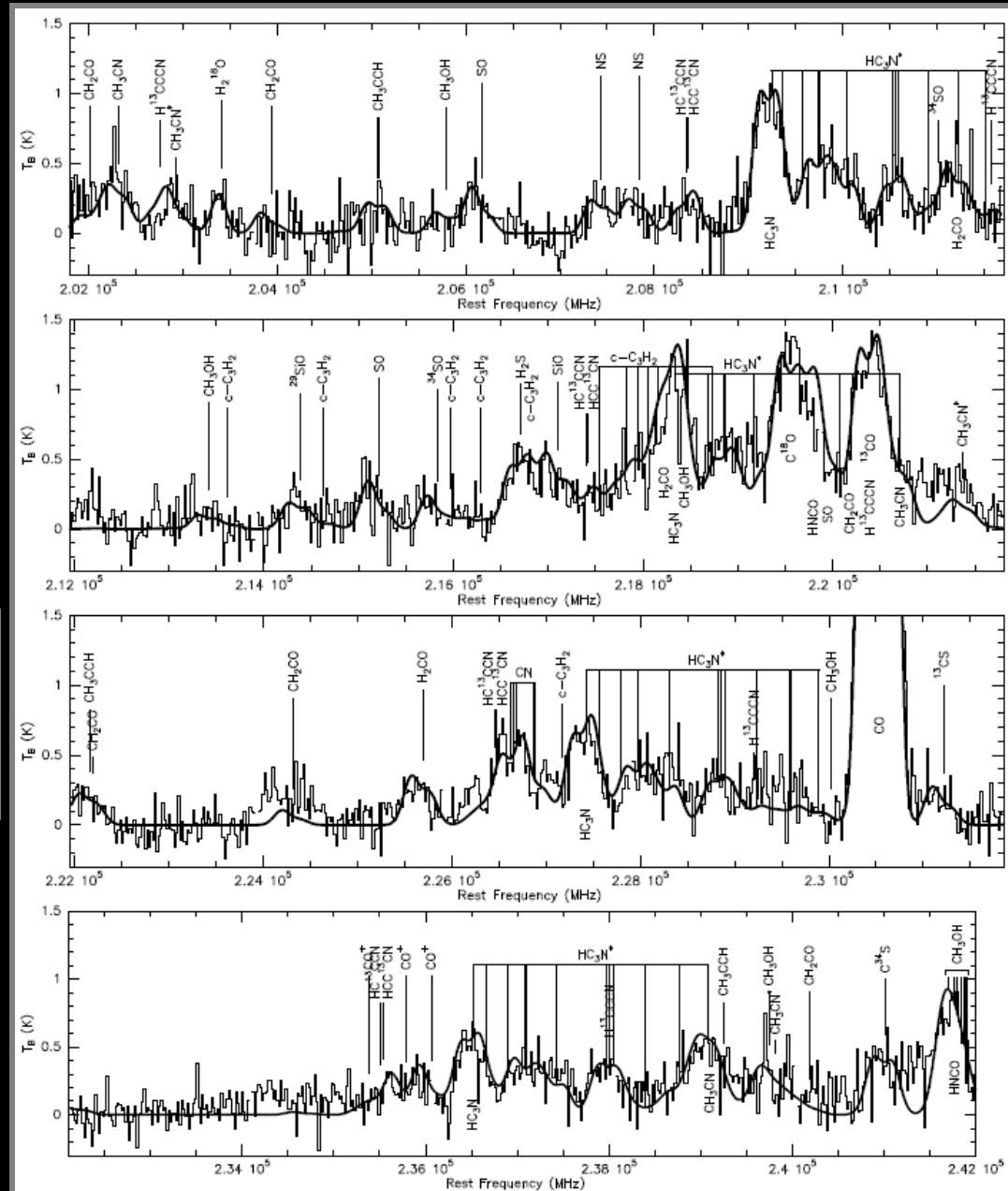
70 individual spectral features

15 species + 6 isotopologues

1.8 lines/GHz = Partially confusion limited

LTE analysis:

Fitting of synthetic spectra of individual molecules



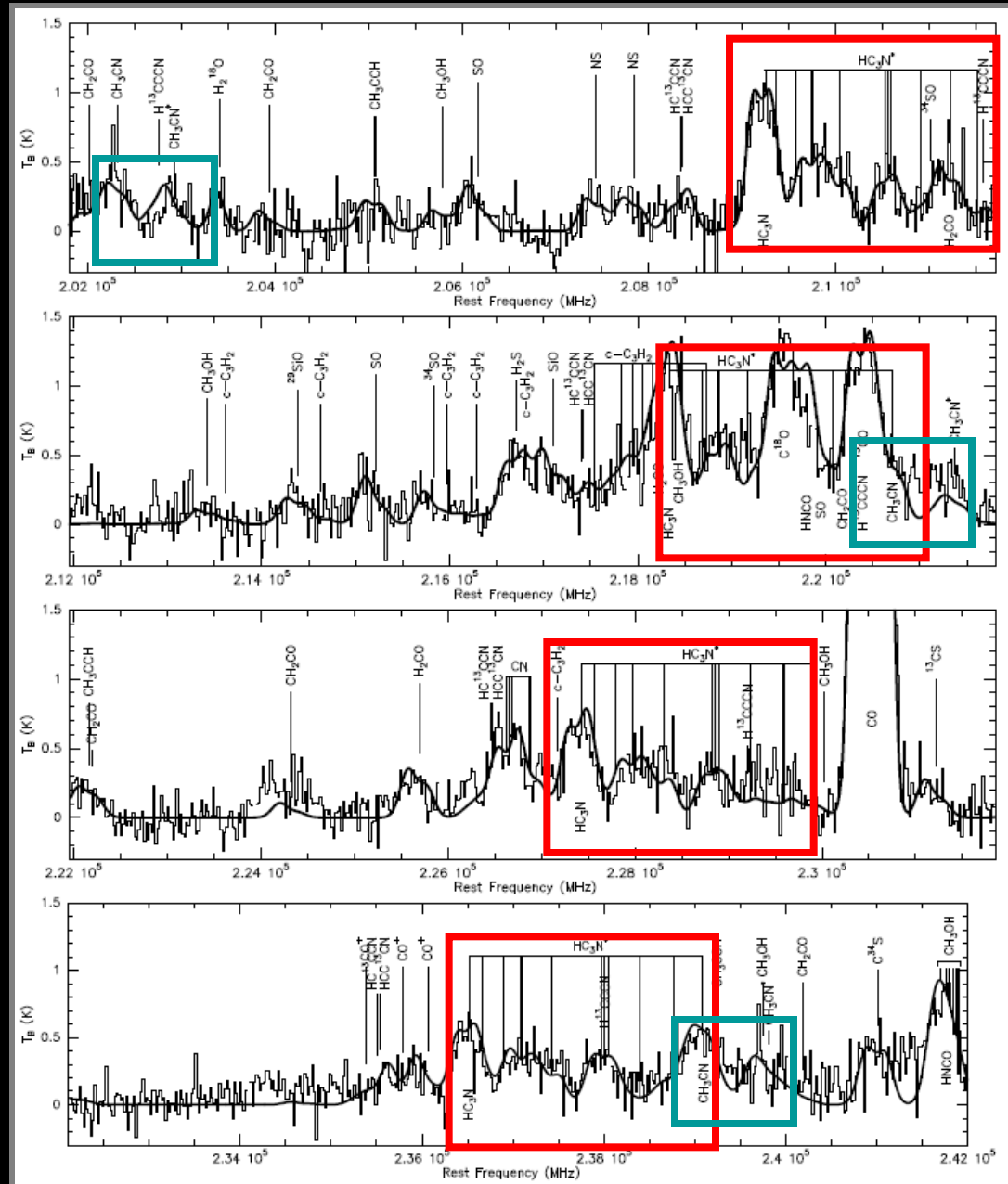
(Martin et al. 2011)

The SMA 1.3 mm line survey of the ULIRG Arp 220 shows the future ALMA/EVLA surveys at high redshift

Vibrationally excited emission of:

HC₃N and **CH₃CN**.

$T_{\text{ex}} \sim 300\text{-}500\text{ K}$



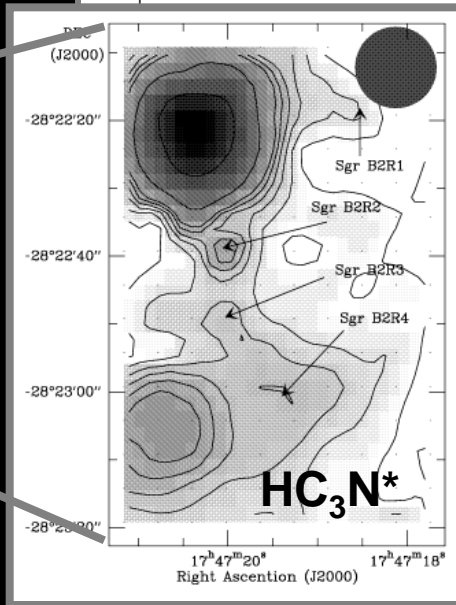
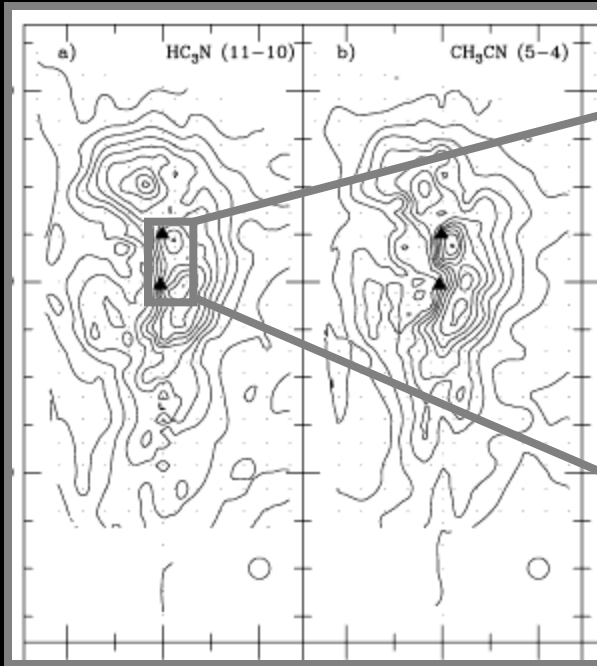
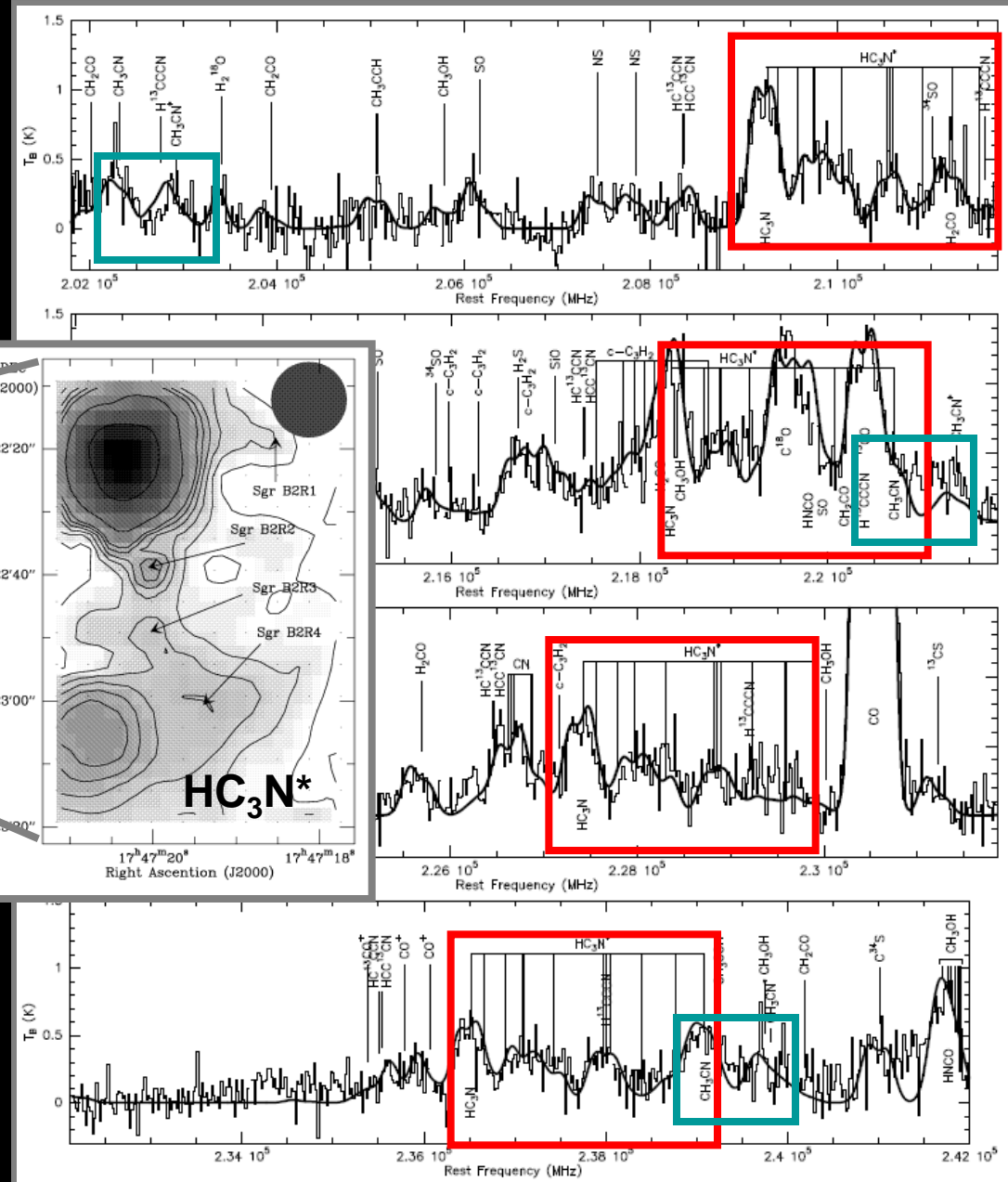
(Martin et al. 2011)

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Sgr B2 region
(de Vicente 1997, 2000)

The SMA 1.3 mm line survey of the ULIRG Arp 220 shows the future ALMA/EVLA surveys at high redshift

Vibrationally excited emission of:

HC_3N and CH_3CN .

$T_{\text{ex}} \sim 300\text{-}500\text{ K}$

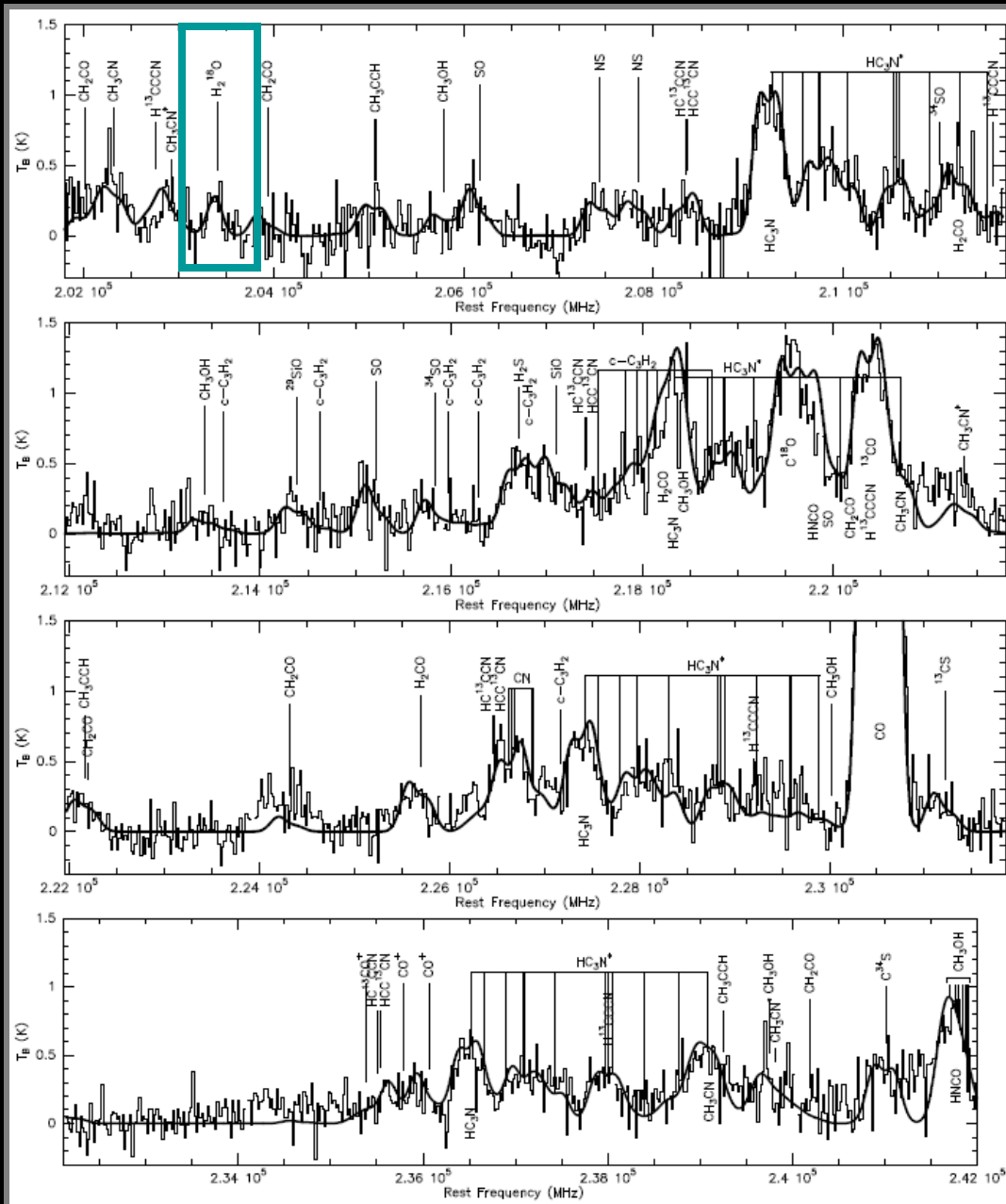
WATER

$\text{H}^{18}\text{O}/\text{C}^{18}\text{O} \Rightarrow$ water abundance
 $\sim 2 \times 10^5$

Similar abundance in Sgr B2 hot core

2 – 8 10^6 Sgr B2-like hot cores

In a 700 pc region !!!



A total of 46 molecular species and 23 isotopologues have been detected in the extragalactic ISM

2 atoms	3 atoms	4 atoms	5 atoms	6 atoms	7 atoms
OH	H ₂ O, H ₂ ¹⁸ O	H ₂ CO	c-C ₃ H ₂	CH ₃ OH, ¹³ CH ₃ OH	CH ₃ C ₂ H
CO $\left\{ \begin{array}{l} {}^{13}\text{CO} \\ \text{C}^{18}\text{O} \\ \text{C}^{17}\text{O} \end{array} \right.$	HCN $\left\{ \begin{array}{l} \text{H}^{13}\text{CN} \\ \text{HC}^{15}\text{N} \\ \text{DCN} \end{array} \right.$	NH ₃	HC ₃ N $\left\{ \begin{array}{l} \text{H}^{13}\text{CCCN} \\ \text{HC}^{13}\text{CCN} \\ \text{HCC}^{13}\text{CN} \end{array} \right.$	CH ₃ CN	
H ₂ , HD	HCO ⁺ $\left\{ \begin{array}{l} \text{H}^{13}\text{CO}^+ \\ \text{HC}^{18}\text{O}^+ \\ \text{DCO}^+ \end{array} \right.$	HNCO	CH ₂ NH		
CH	C ₂ H	H ₂ CS	NH ₂ CN		
CS $\left\{ \begin{array}{l} {}^{13}\text{CS} \\ \text{C}^{34}\text{S} \\ \text{C}^{33}\text{S} \end{array} \right.$	HNC $\left\{ \begin{array}{l} \text{HN}^{13}\text{C} \\ \text{DNC} \end{array} \right.$	HOCO ⁺	CH ₂ CO		
CH ⁺	N ₂ H ⁺ , N ₂ D ⁺	C ₃ H			
CN	OCS	H ₃ O ⁺			
SO, ³⁴ SO	HCO				
SiO, ²⁹ SiO	H ₂ S				
CO ⁺	SO ₂				
NO	HOC ⁺				
NS	C ₂ S				
LiH	H ₃ ⁺				
CH	H ₂ O ⁺				
NH					
OH ⁺					
HF					

(Martin et al. 2011)

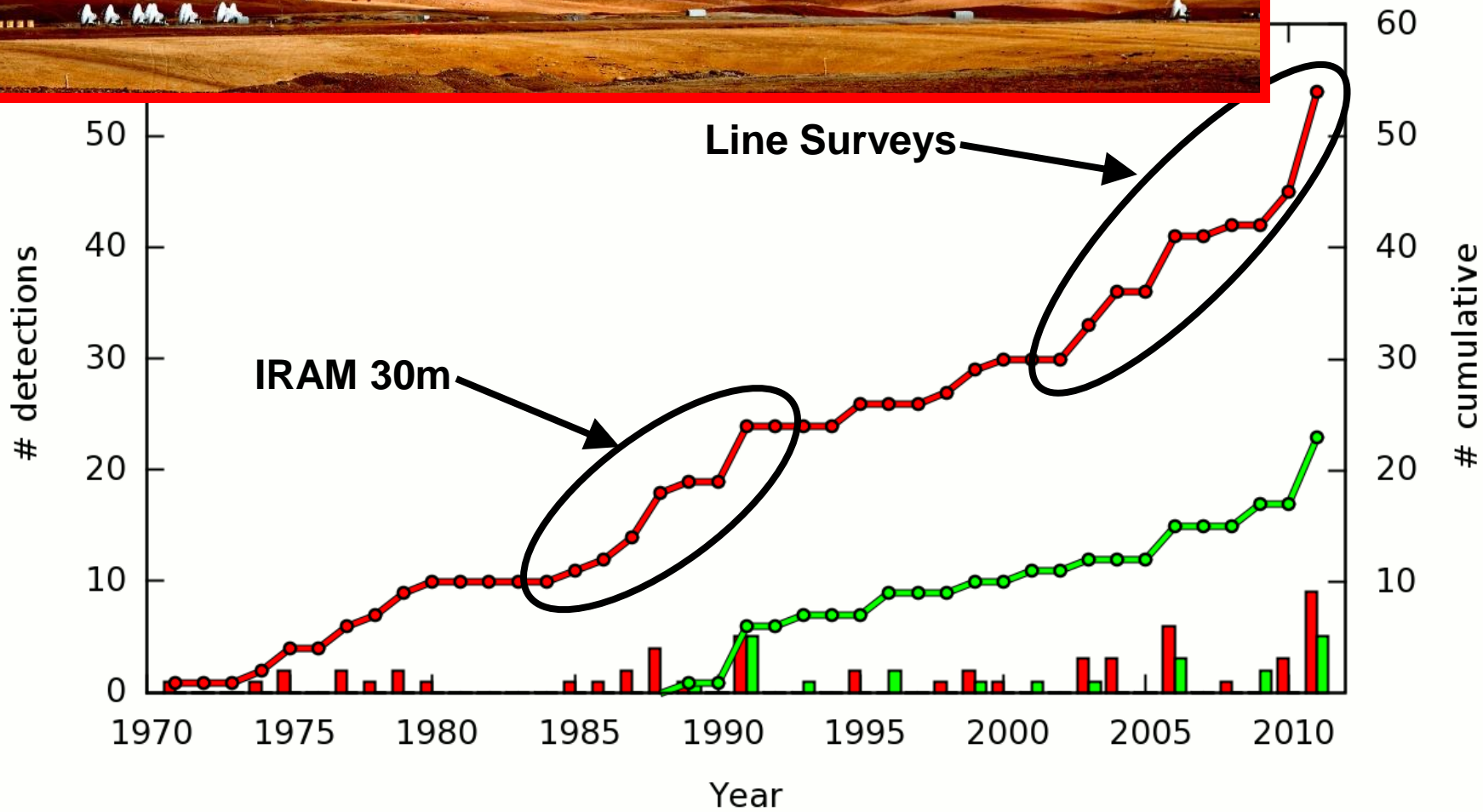
A total of ~~46~~ molecular species and 23 isotopologues have been detected in the extragalactic ISM

54

2 atoms	3 atoms	4 atoms	5 atoms	6 atoms	7 atoms
OH	H ₂ O, H ₂ ¹⁸ O	H ₂ CO	c-C ₃ H ₂	CH ₃ OH, ¹³ CH ₃ OH	CH ₃ C ₂ H
CO $\left\{ \begin{array}{l} ^{13}\text{CO} \\ \text{C}^{18}\text{O} \\ \text{C}^{17}\text{O} \end{array} \right.$	HCN $\left\{ \begin{array}{l} \text{H}^{13}\text{CN} \\ \text{HC}^{15}\text{N} \\ \text{DCN} \end{array} \right.$	NH ₃	HC ₃ N $\left\{ \begin{array}{l} \text{H}^{13}\text{CCCN} \\ \text{HC}^{13}\text{CCN} \\ \text{HCC}^{13}\text{CN} \end{array} \right.$	CH ₃ CN	CH₃NH₂
H ₂ , HD	HCO ⁺ $\left\{ \begin{array}{l} \text{H}^{13}\text{CO}^+ \\ \text{HC}^{18}\text{O}^+ \\ \text{DCO}^+ \end{array} \right.$	HNCO	CH ₂ NH		CH₃CHO
CH	C ₂ H	H ₂ CS	NH ₂ CN		
CS $\left\{ \begin{array}{l} ^{13}\text{CS} \\ \text{C}^{34}\text{S} \\ \text{C}^{33}\text{S} \end{array} \right.$	HNC $\left\{ \begin{array}{l} \text{HN}^{13}\text{C} \\ \text{DNC} \end{array} \right.$	HOCO ⁺	CH ₂ CO		
CH ⁺	N ₂ H ⁺ , N ₂ D ⁺	C ₃ H			
CN	OCS	H ₃ O ⁺			
SO, ³⁴ SO	HCO		I-C₃H₂		
SiO, ²⁹ SiO	H ₂ S		H₂CCN		
CO ⁺	SO ₂		H₂CCO		
NO	HOC ⁺		C₄H		
NS	C ₂ S				
LiH	H ₃ ⁺				
CH	H ₂ O ⁺				
NH					
OH ⁺					
HF					
SO⁺	I-C₃H				
					+
					(Müller et al. 2011)

(Martin et al. 2011)

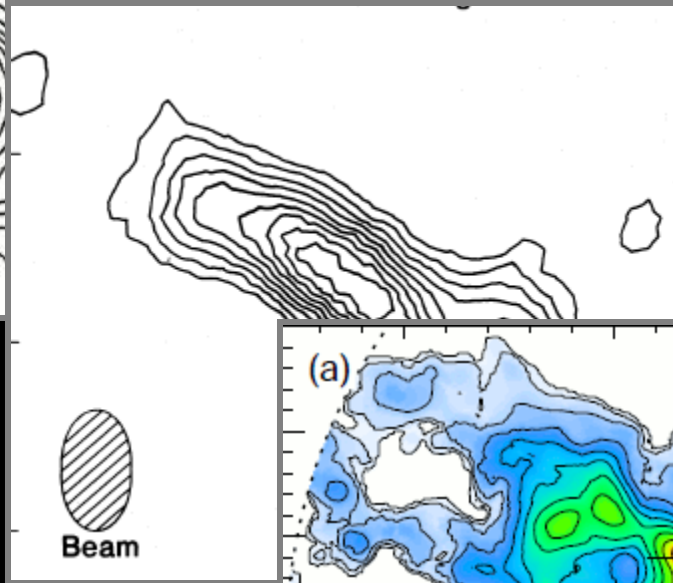
+
(Müller et al. 2011)



The enormous collecting area of ALMA will be the next leap in resolution and sensitivity

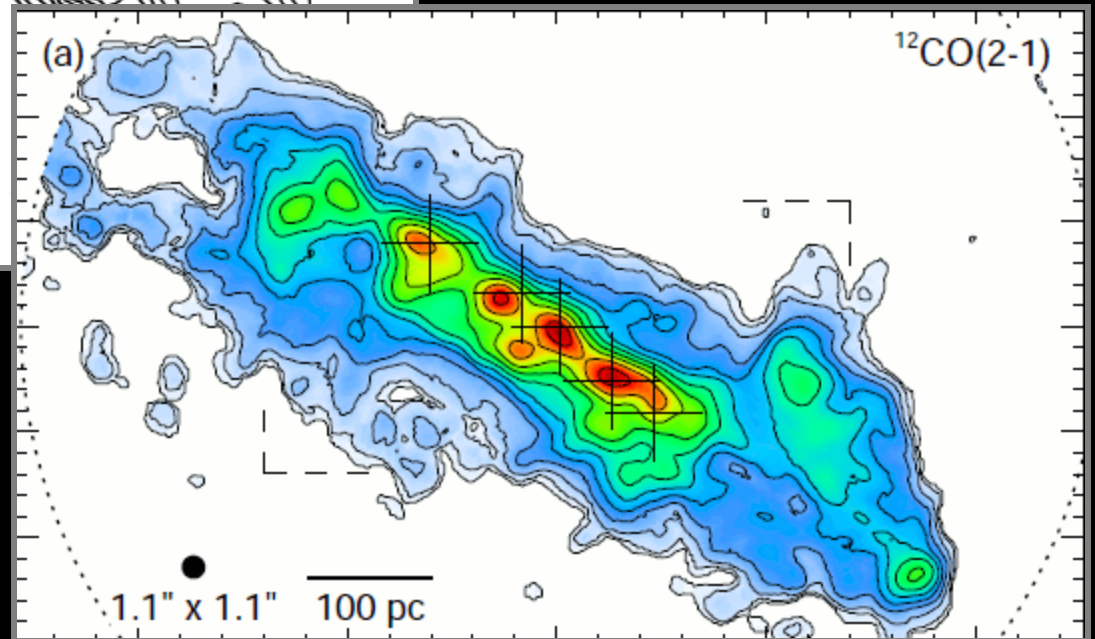


Mauersberger et al. 1996
IRAM 30m CO 2-1
Beam = 12''

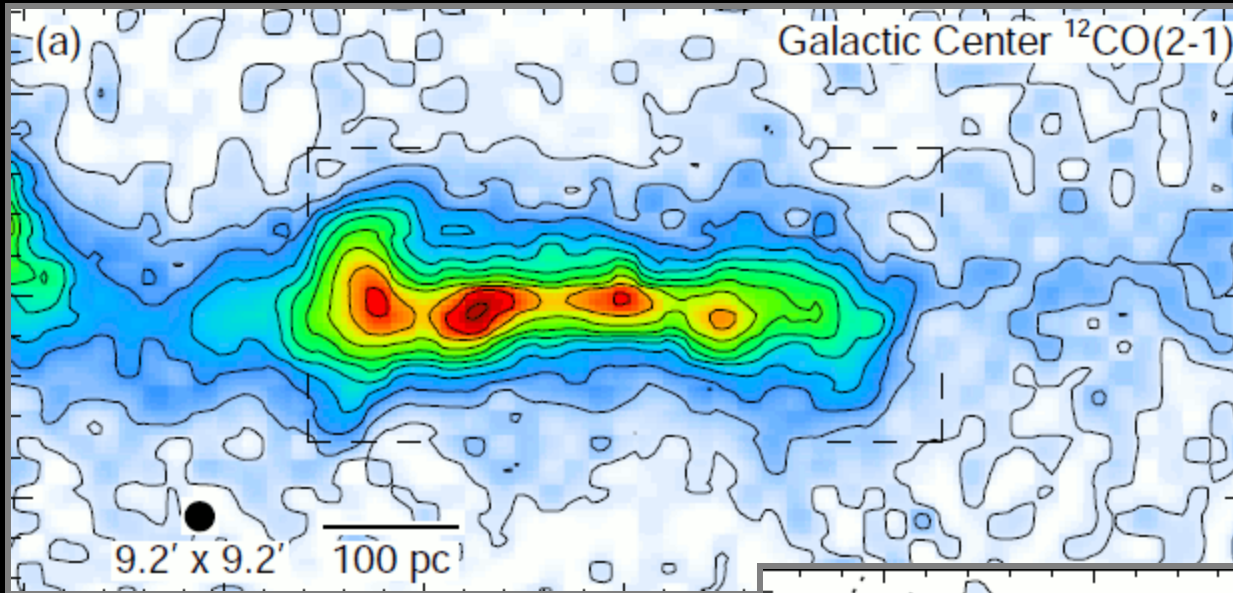


Canzian et al. 1988
OVRO CO 1-0
Beam = 5''x9''

Sakamoto et al. 2011
SMA CO 2-1
12CO, 13CO, C18O, HCN, and HNC0 detected



The enormous collecting area of ALMA will be the next leap in resolution and sensitivity



Sawada et al. (2001)

Tokyo-Onsala-ESO-Calán
Galactic CO J = 2-1
Survey

Sakamoto et al. 2011

SMA CO 2-1

^{12}CO , ^{13}CO , C18O, HCN, and
HNCO detected

