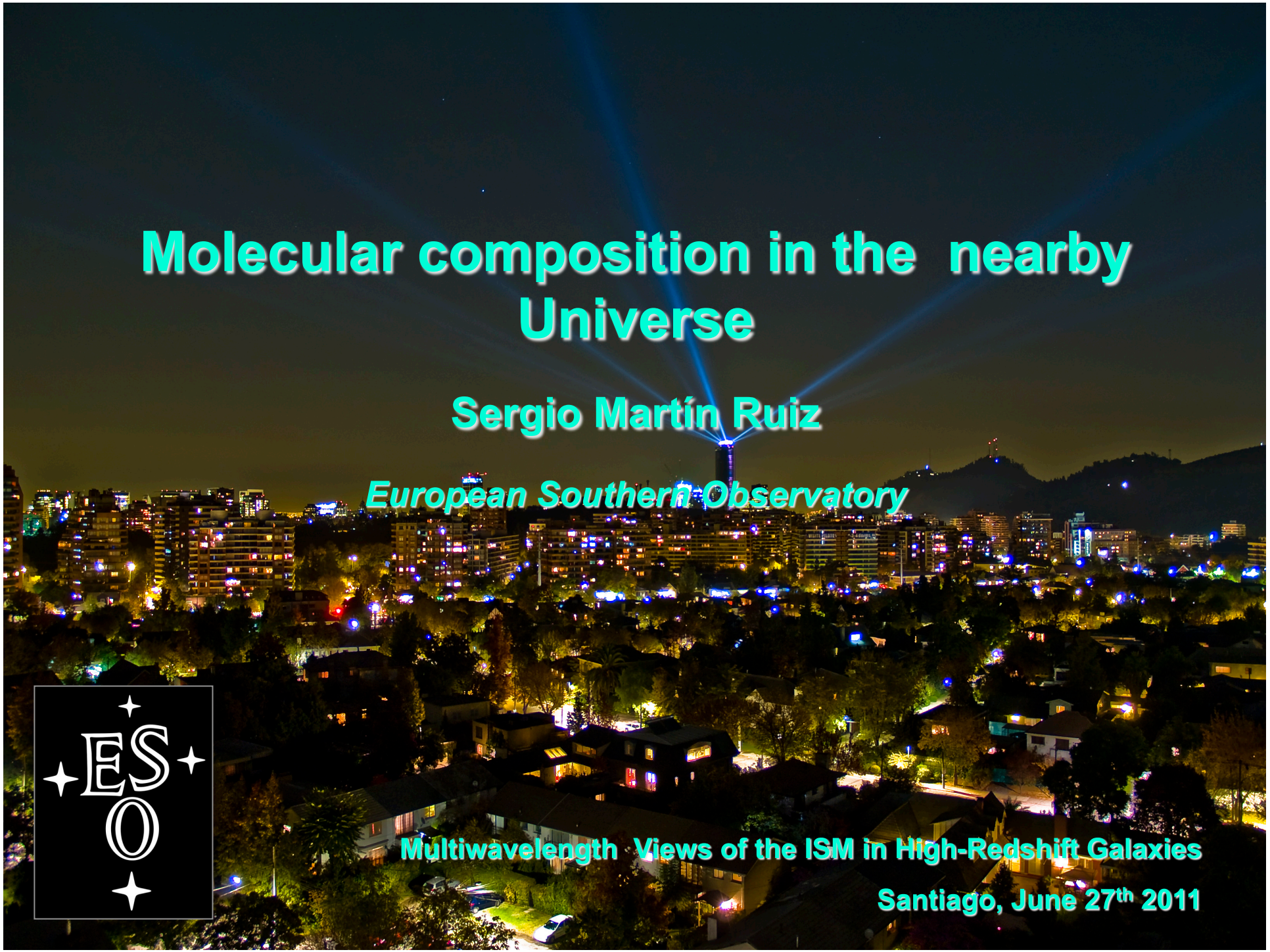


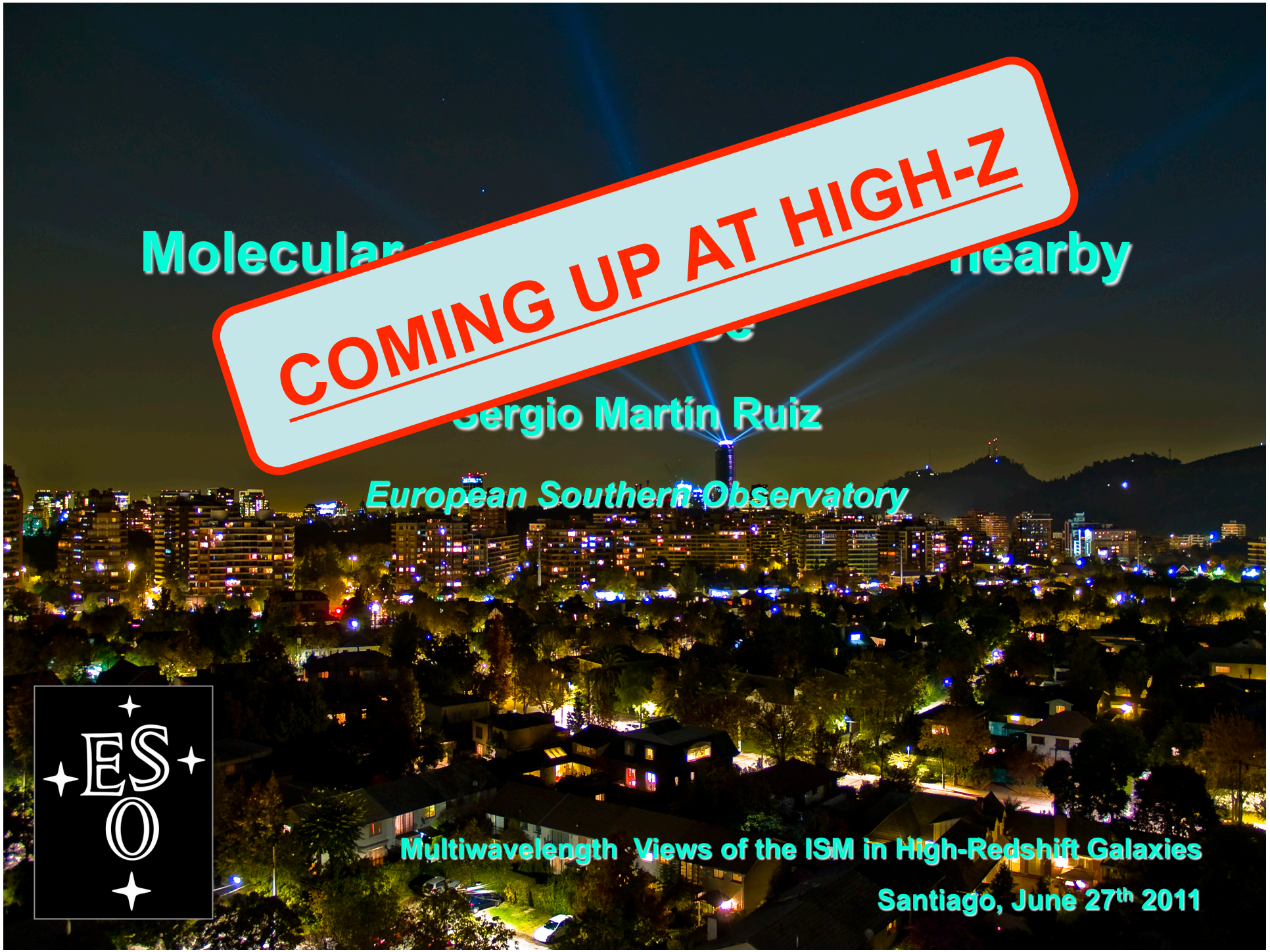
Molecular composition in the nearby Universe

Sergio Martín Ruiz

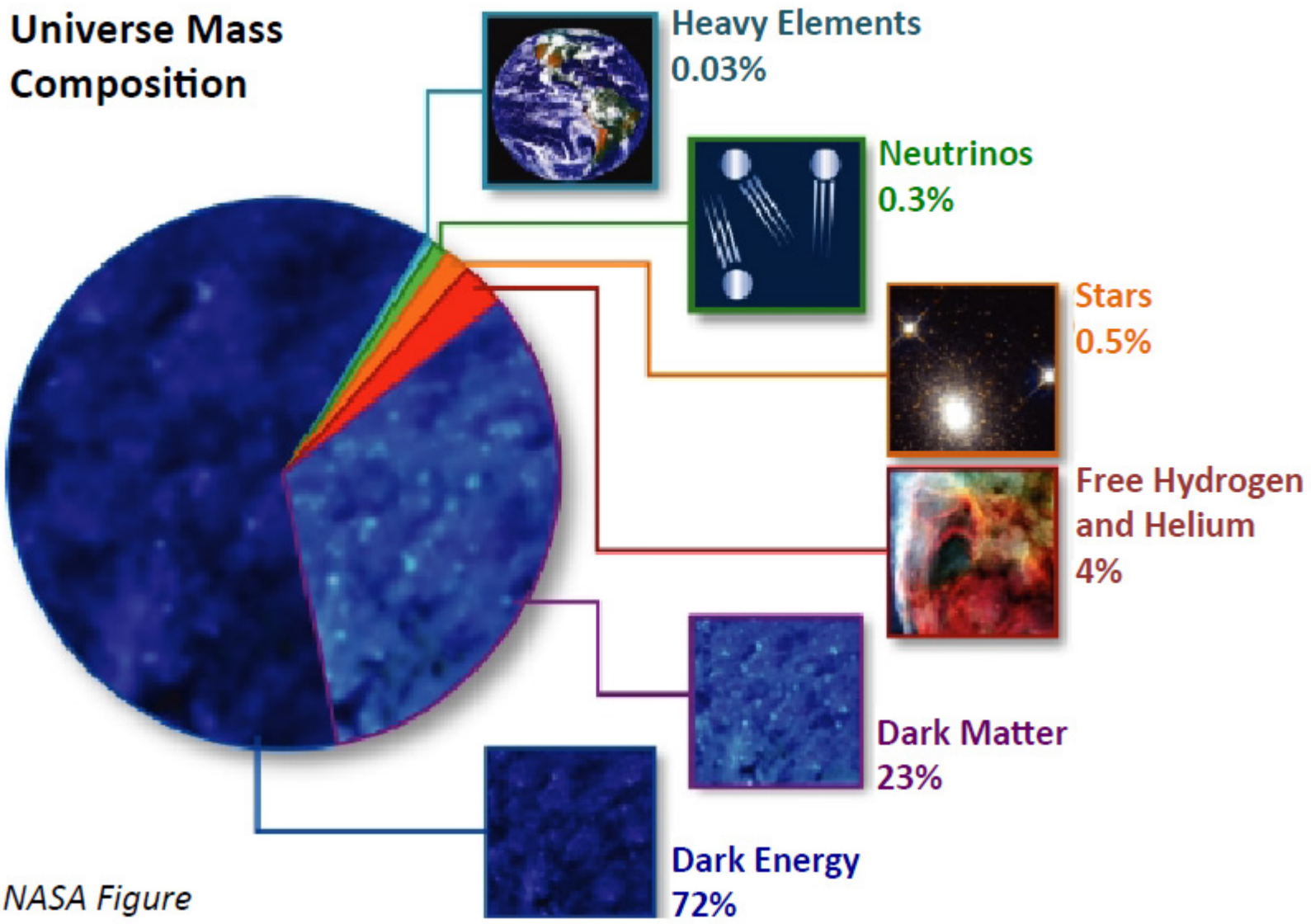
European Southern Observatory

Multiwavelength Views of the ISM in High-Redshift Galaxies

Santiago, June 27th 2011


Molecular
nearby
COMING UP AT HIGH-Z
Sergio Martín Ruiz
European Southern Observatory
ESO
Multiwavelength Views of the ISM in High-Redshift Galaxies
Santiago, June 27th 2011

The Unbearable Lightness of Chemistry

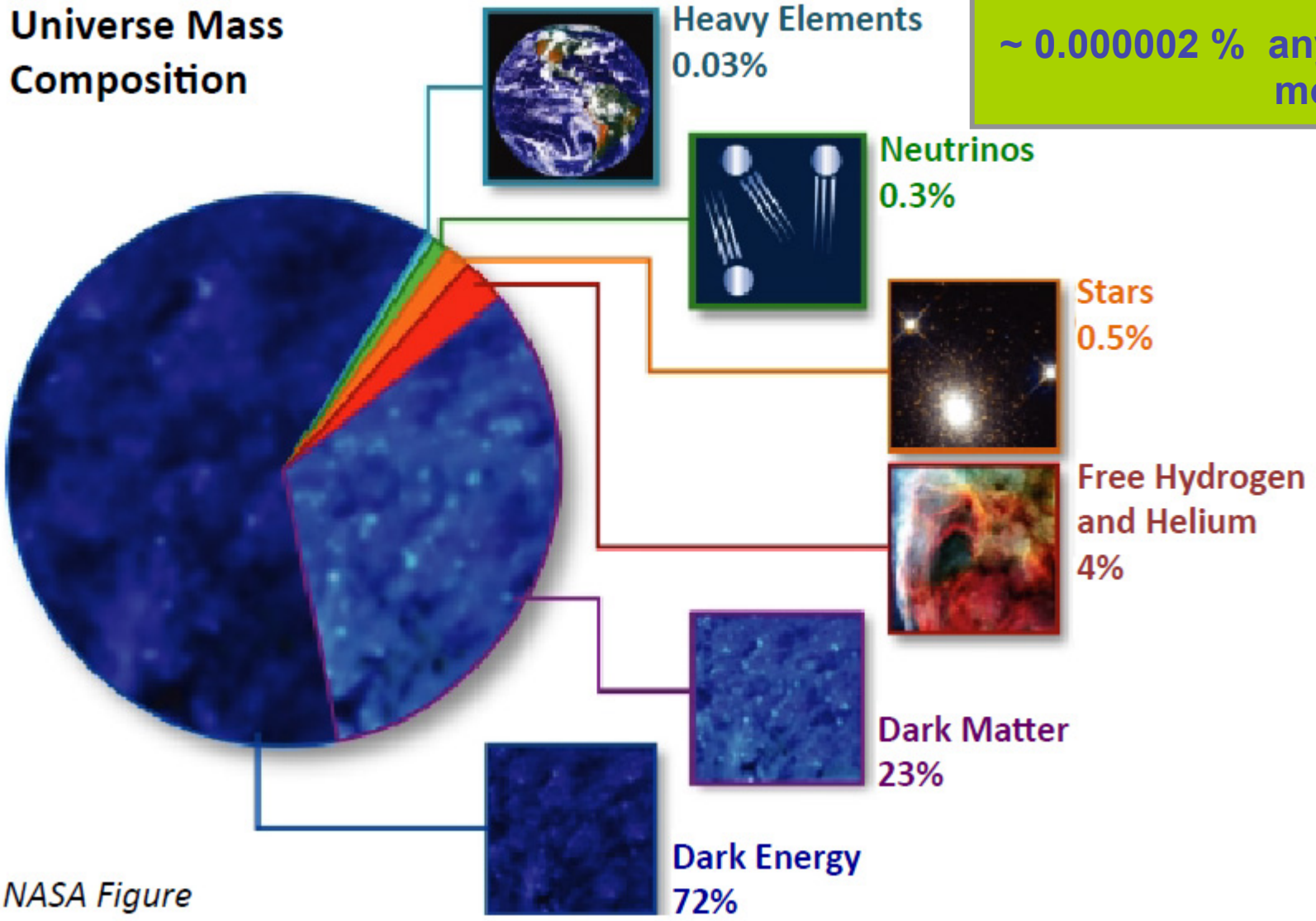


The Unbearable Lightness of Chemistry

~ 0.5 % Molecular (H_2)

~ 0.002 % CO

~ 0.000002 % any other molecule



NASA Figure

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_2O, $H_2^{18}O$	H_2CO	c-C_3H_2	CH_3OH, $^{13}CH_3OH$	CH_3C_2H
CO, ^{13}CO, $C^{18}O$, $C^{17}O$	HCN, $H^{13}CN$, $HC^{15}N$, DCN	NH_3	HC_3N, $H^{13}CCCN$, $HC^{13}CCN$, $HCC^{13}CN$	CH_3CN	
H_2, *HD*	HCO^+, $H^{13}CO^+$, $HC^{18}O^+$, DCO^+	HNCO	CH_2NH		
CH	C_2H	H_2CS	NH_2CN		
CS, ^{13}CS, $C^{34}S$, $C^{33}S$	HNC, $HN^{13}C$, DNC	$HOCO^+$	CH_2CO		
CH^+	N_2H^+, N_2D^+	C_3H			
CN	OCS	H_3O^+			
SO, ^{34}SO	HCO				
SiO, ^{29}SiO	H_2S				
CO^+	SO_2				
NO	HOC^+				
NS	C_2S				
LiH	H_3^+				
CH	H_2O^+				
NH					
OH^+					
HF					

(Martin et al. 2011)

A total of ~~46~~ 54 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_2O, $H_2^{18}O$	H_2CO	c-C_3H_2	CH_3OH, $^{13}CH_3OH$	CH_3C_2H
CO, ^{13}CO, $C^{18}O$, $C^{17}O$	HCN, $H^{13}CN$, $HC^{15}N$, DCN	NH_3	HC_3N, $H^{13}CCCN$, $HC^{13}CCN$, $HCC^{13}CN$	CH_3CN	**CH_3NH_2**
H_2, *HD*	HCO^+, $H^{13}CO^+$, $HC^{18}O^+$, DCO^+	HNCO	CH_2NH		**CH_3CHO**
CH	C_2H	H_2CS	NH_2CN		
CS, ^{13}CS, $C^{34}S$, $C^{33}S$	HNC, $HN^{13}C$, DNC	$HOCO^+$	CH_2CO		
CH^+	N_2H^+, N_2D^+	C_3H			
CN	OCS	H_3O^+			
SO, ^{34}SO	HCO				
SiO, ^{29}SiO	H_2S		**l-C_3H_2**		
CO^+	SO_2				
NO	HOC^+		**H_2CCN**		
NS	C_2S				
LiH	H_3^+		**H_2CCO**		
CH	H_2O^+				
NH			**C_4H**		
OH^+					
HF					
SO^+	**l-C_3H**				

(Martin et al. 2011)

+

(Müller et al. 2011)

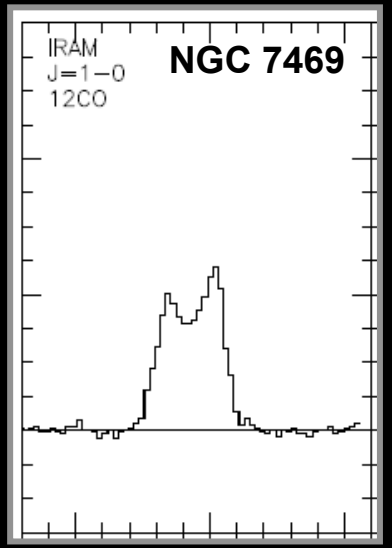
Huge bandwidth upgrades in most mm and sub-mm

Israel 2009

IRAM 30m

data from 2005-2007

BW= 500 MHz ~ 1300 km/s



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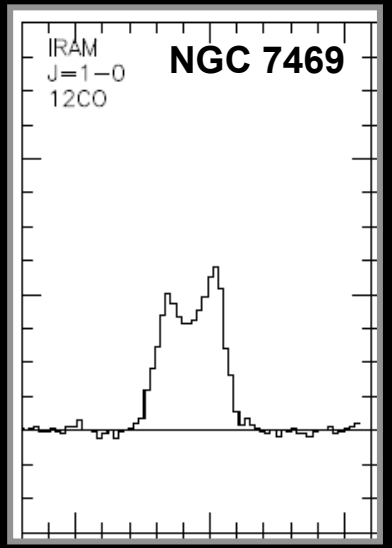

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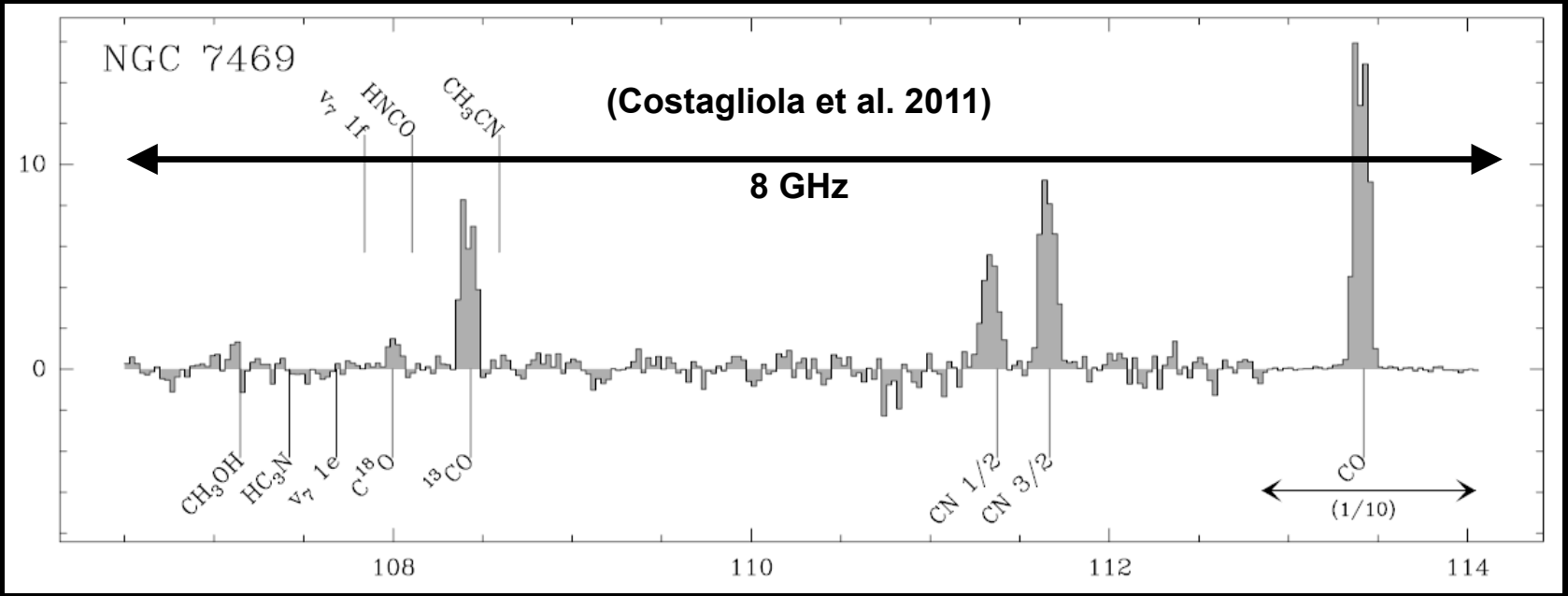


Huge bandwidth upgrades in most mm and sub-mm

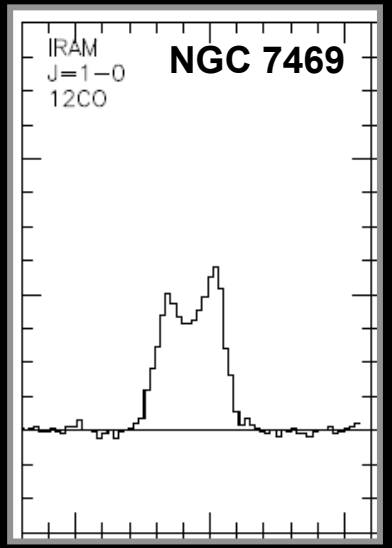
Single dish		Interferometers	
MOPRA	… 8.2 GHz	SMA	… 8 GHz
IRAM 30 m	… 8 GHz	CARMA	… 8 GHz
Nobeyama	… 32 GHz	PdBI	… 4 GHz
APEX	… 2-8 GHz	ALMA	… 8 GHz
JCMT	… 1.8 GHz	ATCA	… 4 GHz

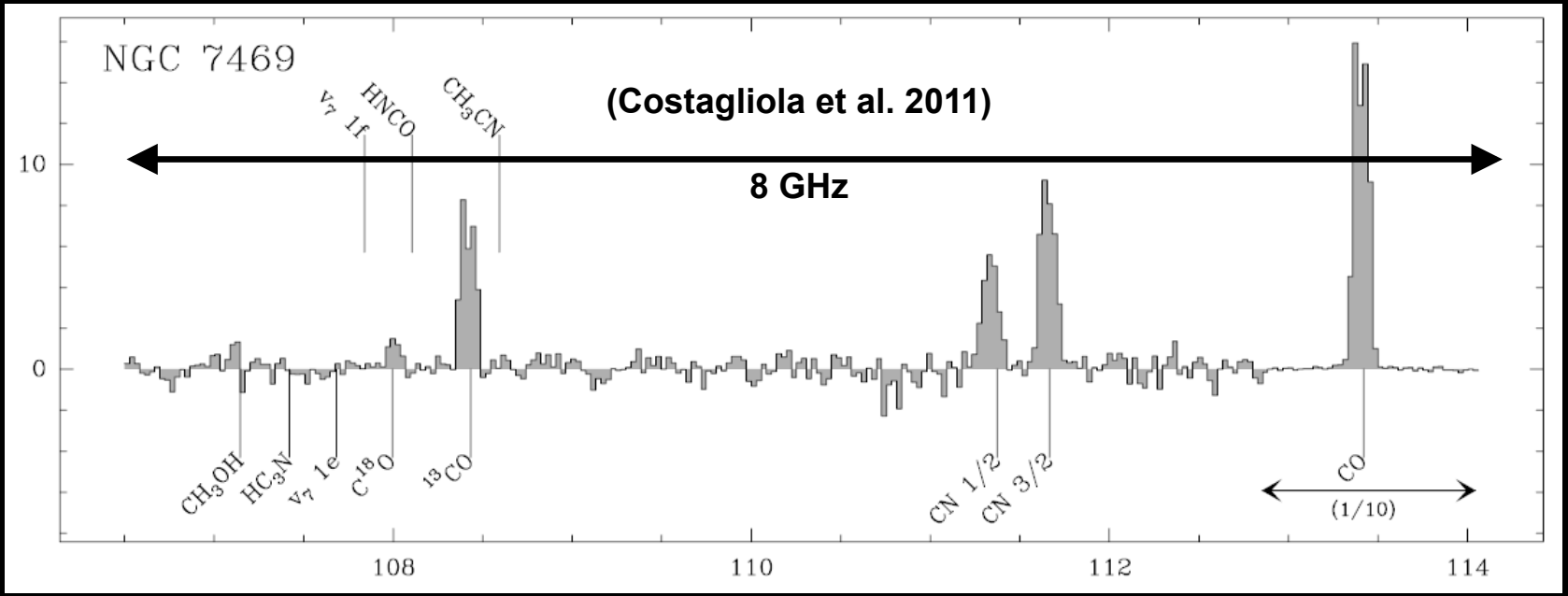
Israel 2009

IRAM 30m

data from 2005-2007

BW= 500 MHz ~ 1300 km/s





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

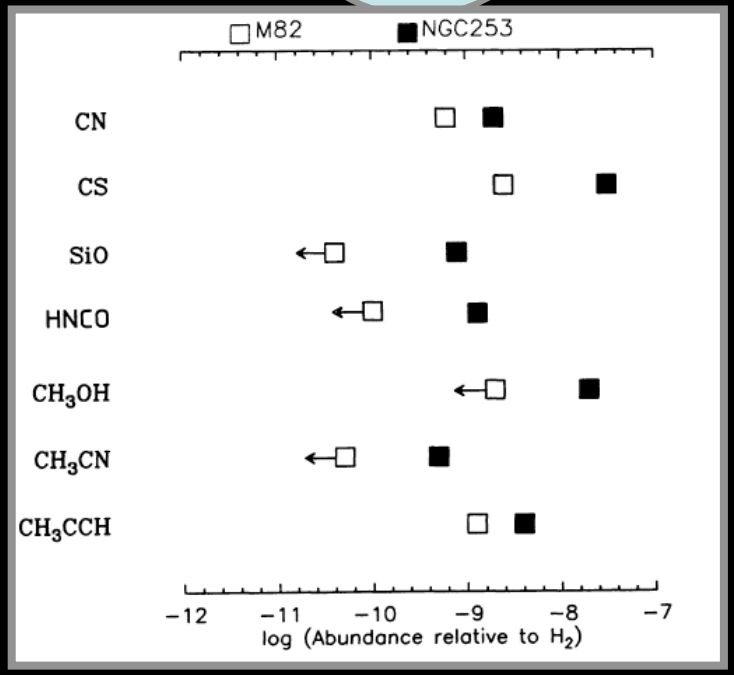
Abstract

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*

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

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



23 species + 8 isotopologues

Starburst have been the evident target for large molecular line searches

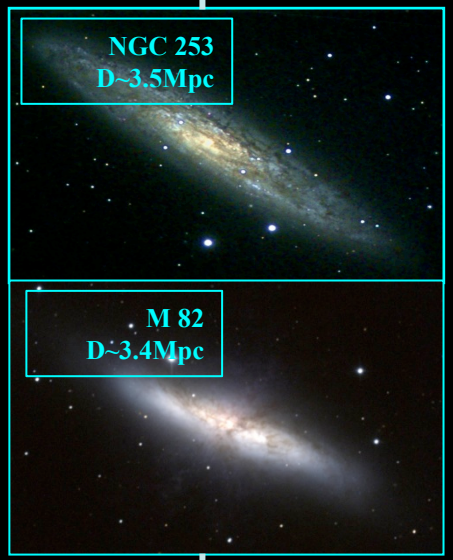
First unbiased mm line surveys of the two brightest extragalactic sources

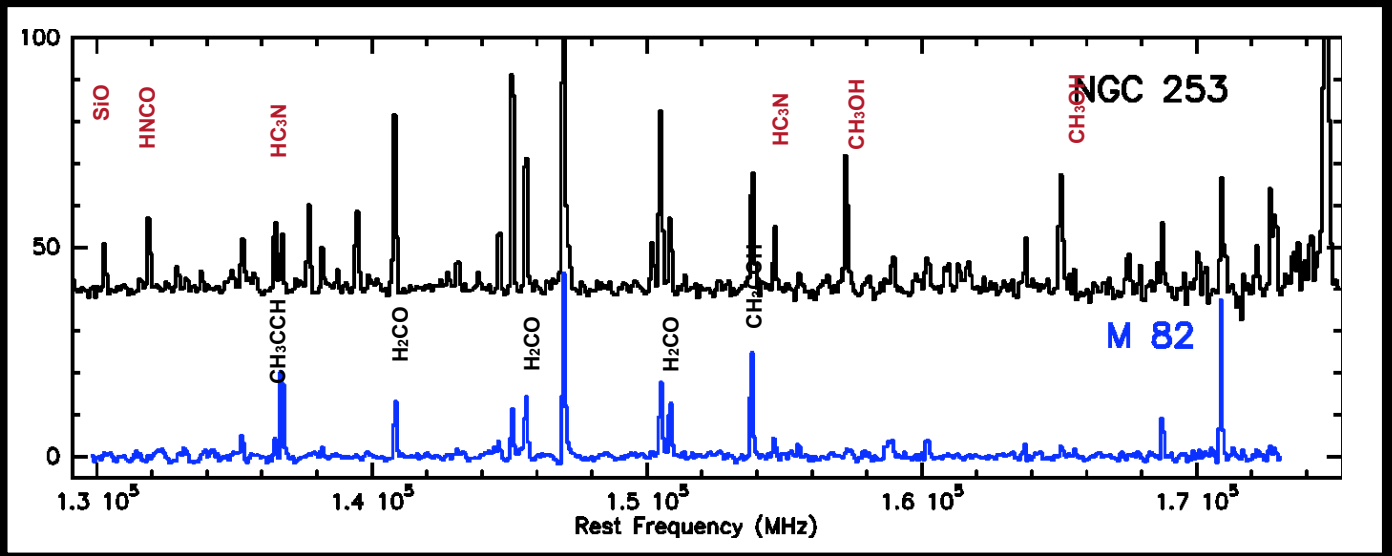
IRAM 30m
2mm Atm window ~46 GHz (129–175 GHz)
+ 19 GHz (241-260 GHz) in M82

2 x 1 GHz FB

→ 111 lines / 25 species

(Martin et al. 2006)

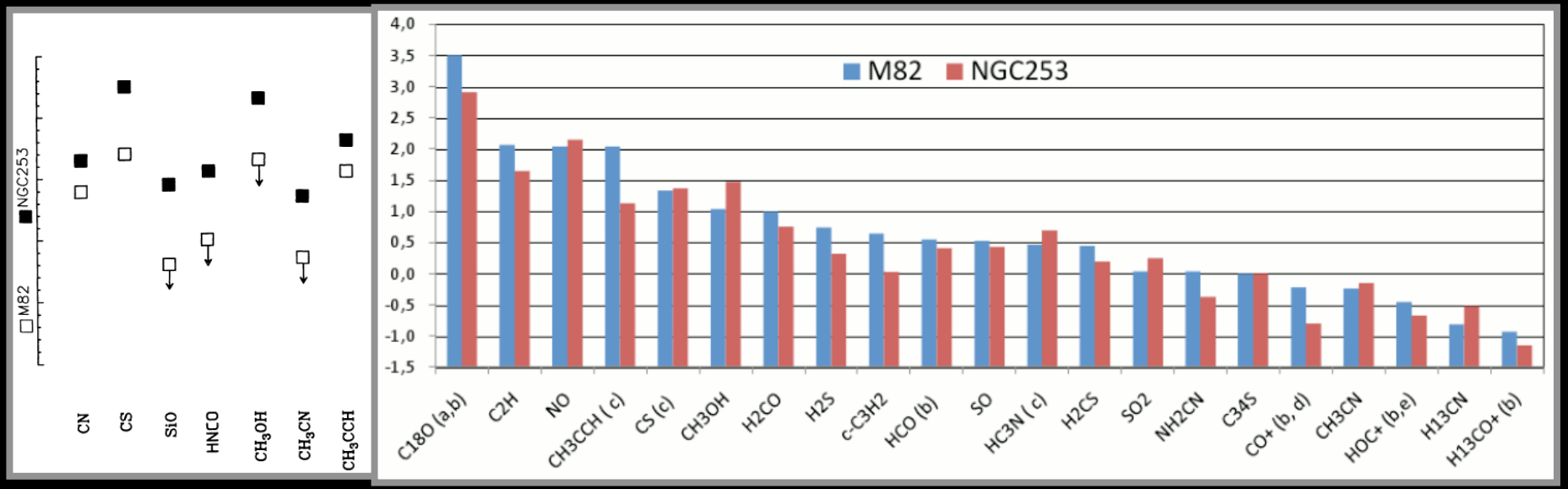




(Aladro et al. Submitted)

→ 72 lines / 18 species

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



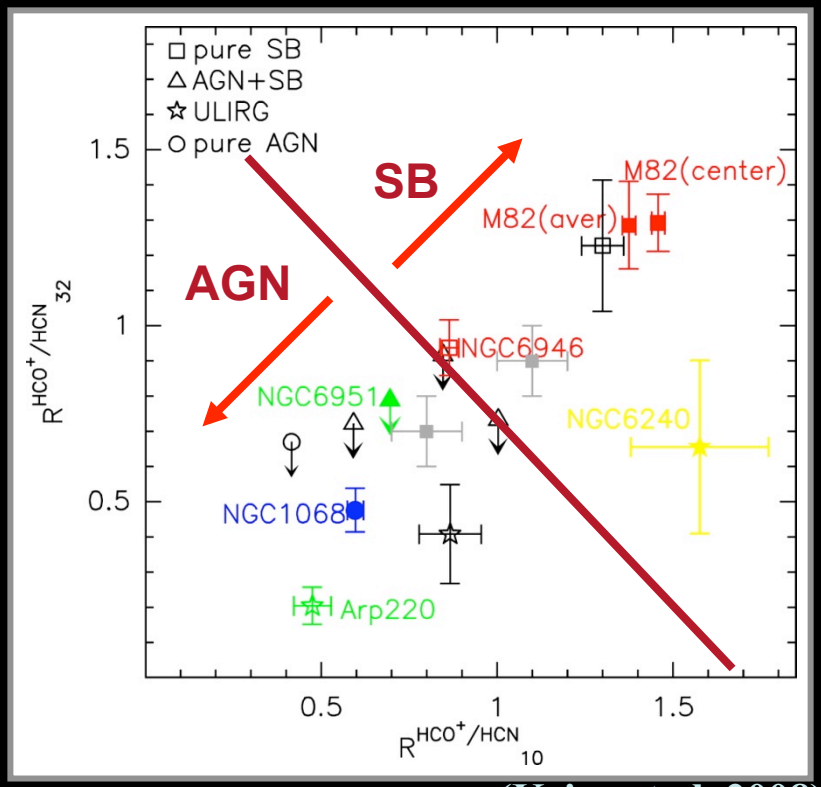
M 82

CO^+
HCO
HOC^+
$c\text{-}C_3H_2$
CH_3CCH
NH_2CN

CH_3OH
HNCO
NH_3
SiO
NS
$HOCO^+$
CH_2NH

NGC 253

Molecular ratios can be used as diagnostic diagrams for different nuclear activities

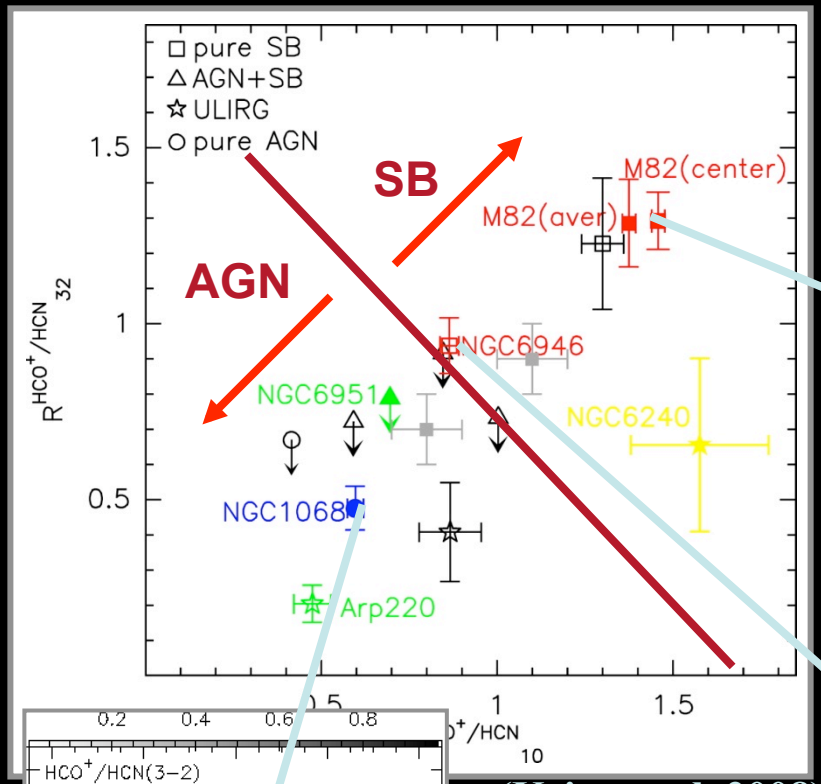


(Krips et al. 2008)

AGN vs SBG

Theoretical models predict $HCO^+/HCN<1$ at the edges of XDRs

Molecular ratios can be used as diagnostic diagrams for different nuclear activities



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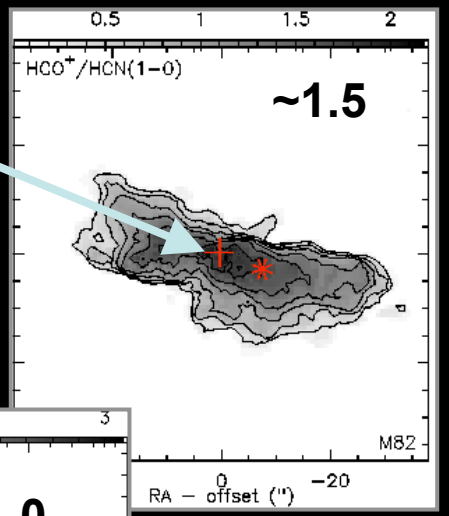
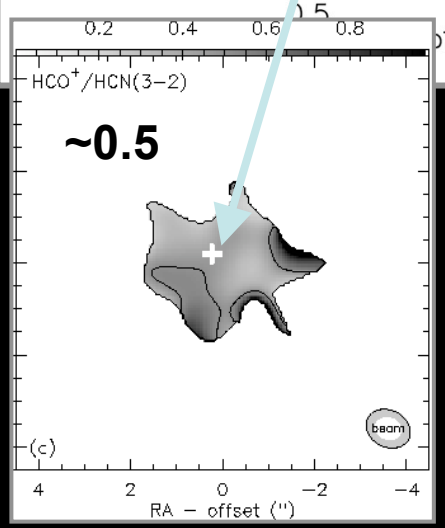
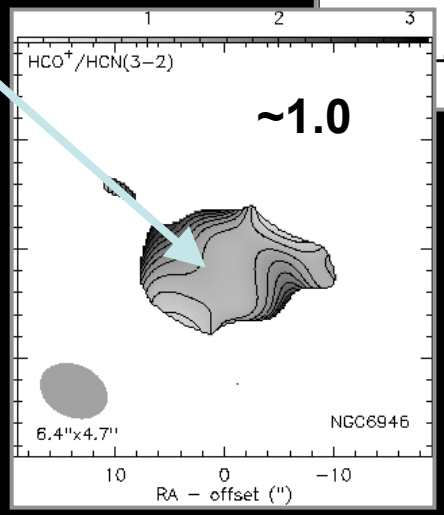




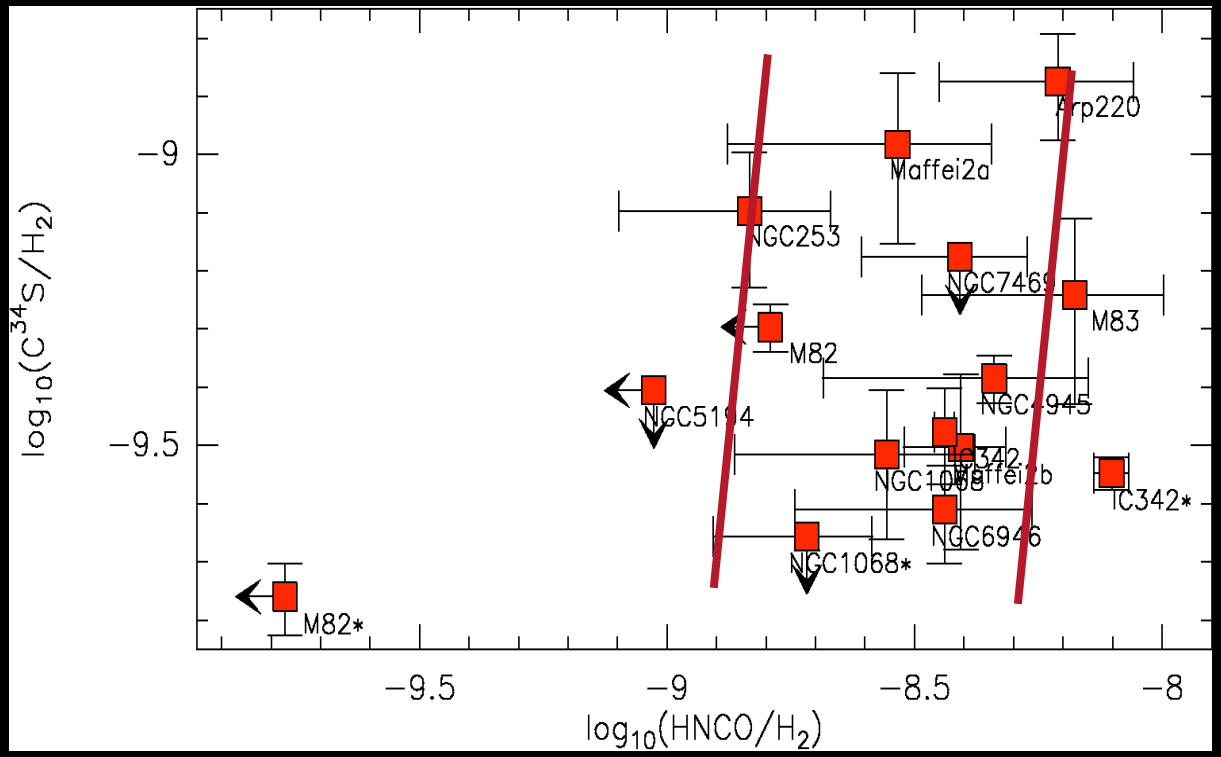


(Krips et al. In Prep)

Molecular ratios can be used as diagnostic diagrams for different nuclear activities

HNCO released from dust grains and highly sensitive to UV radiation

(Martin et al. 2009)



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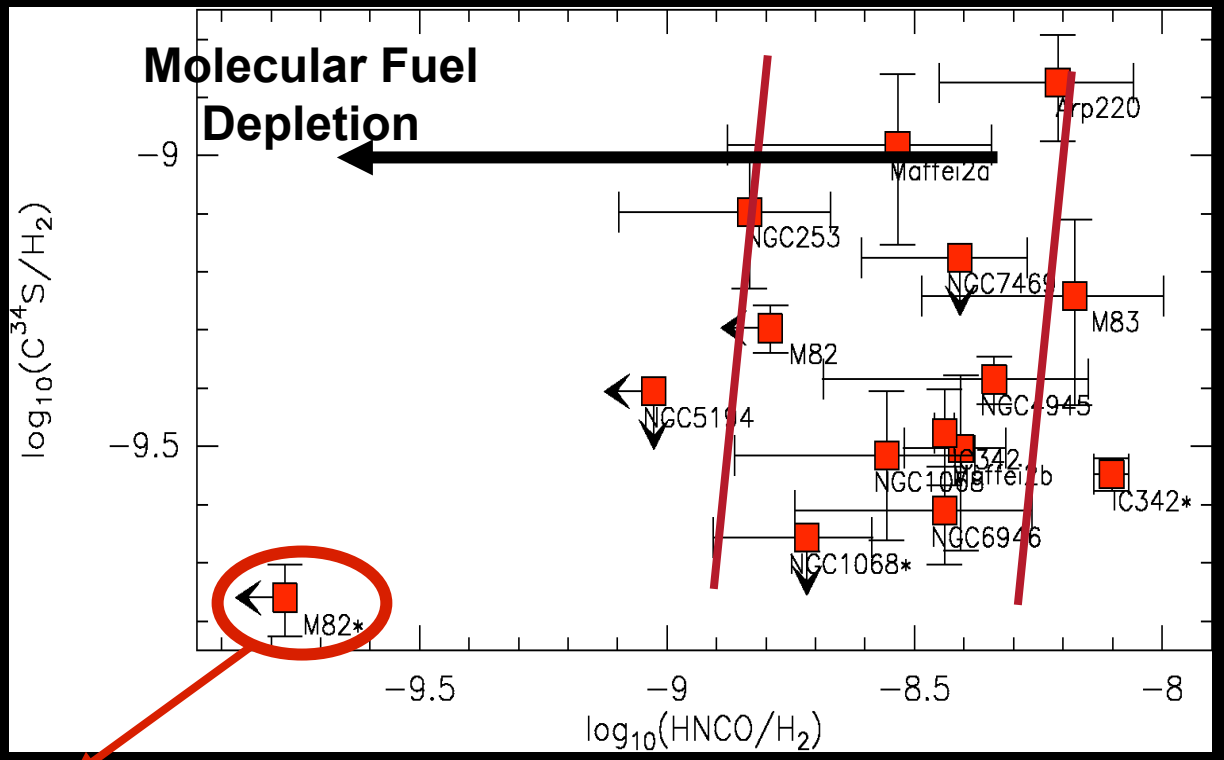


Detected in PDR molecular tracers:

HCO, HOC^+,CO^+,H_3O^+ (Garcia-Burillo et al.02, Fuente et al.05;07, Van der Tak et al. 08)

WHAT ABOUT HIGH-Z?

The ULIRG Arp 220 stands as a template of high redshift

Sakamoto et al. 2008

NIR – HST

Scoville et al. 1998

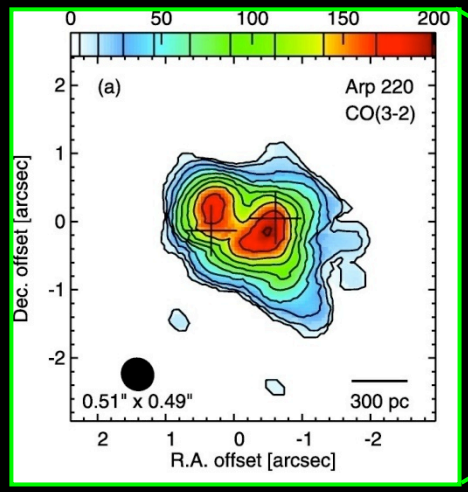
X Rays – CHANDRA

Mc Dowell et al. 2002

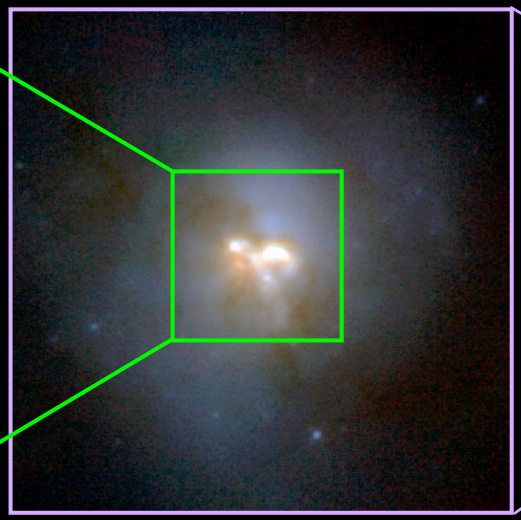
D ~ 70 Mpc (z~0.018)

SFR~ 300 M_o yr^{-1}

The ULIRG Arp 220 stands as a template of high redshift

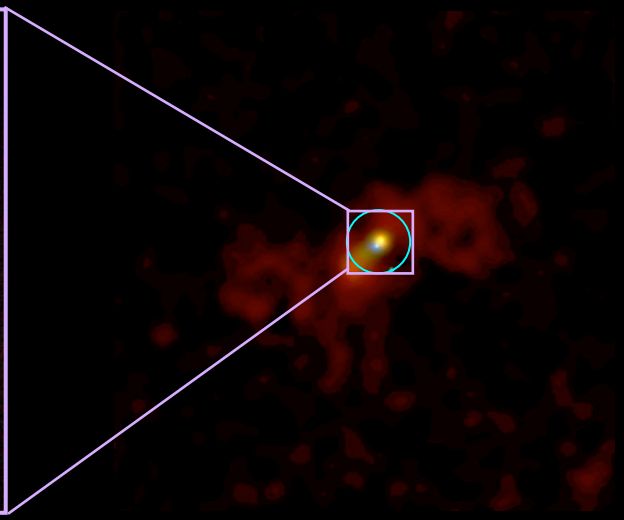


Sakamoto et al. 2008



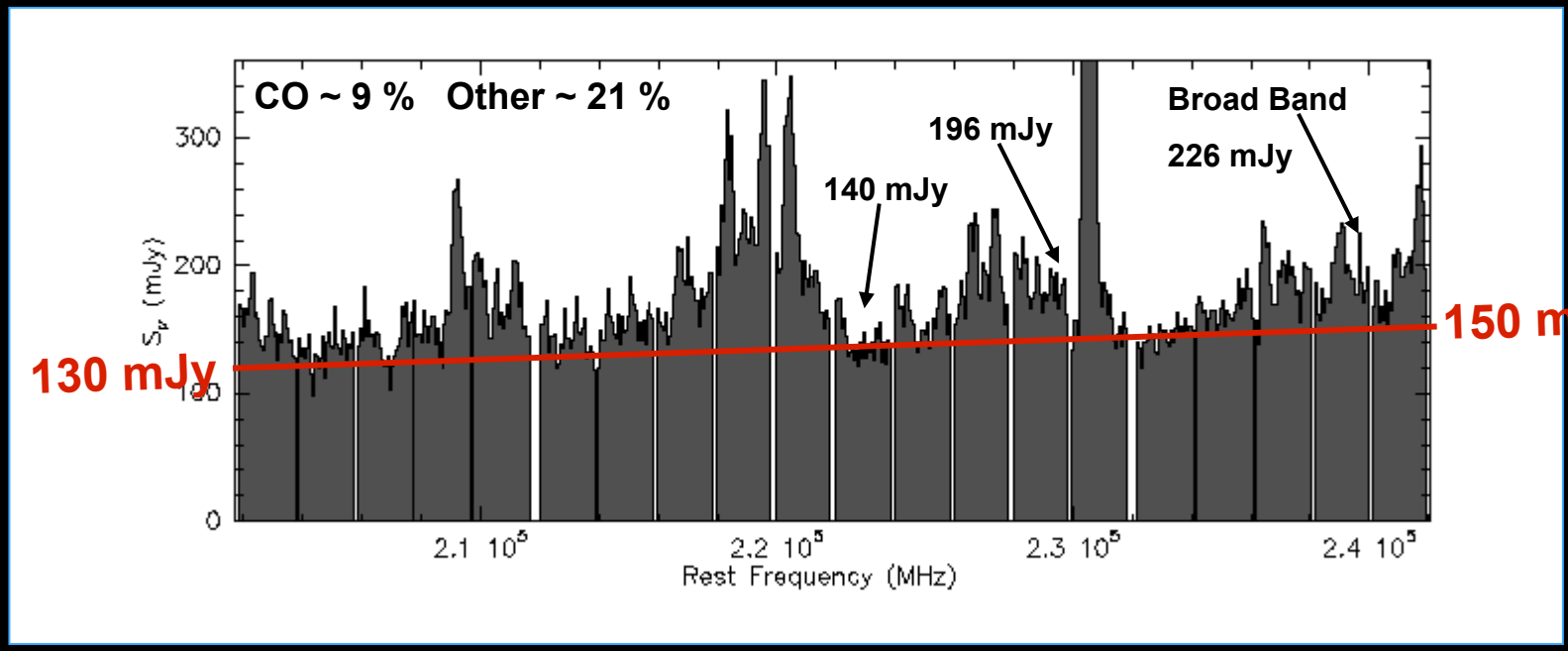
NIR – HST

Scoville et al. 1998



X Rays – CHANDRA

Mc Dowell et al. 2002



The ULIRG Arp 220 stands as a template of high redshift

202 – 242 GHz

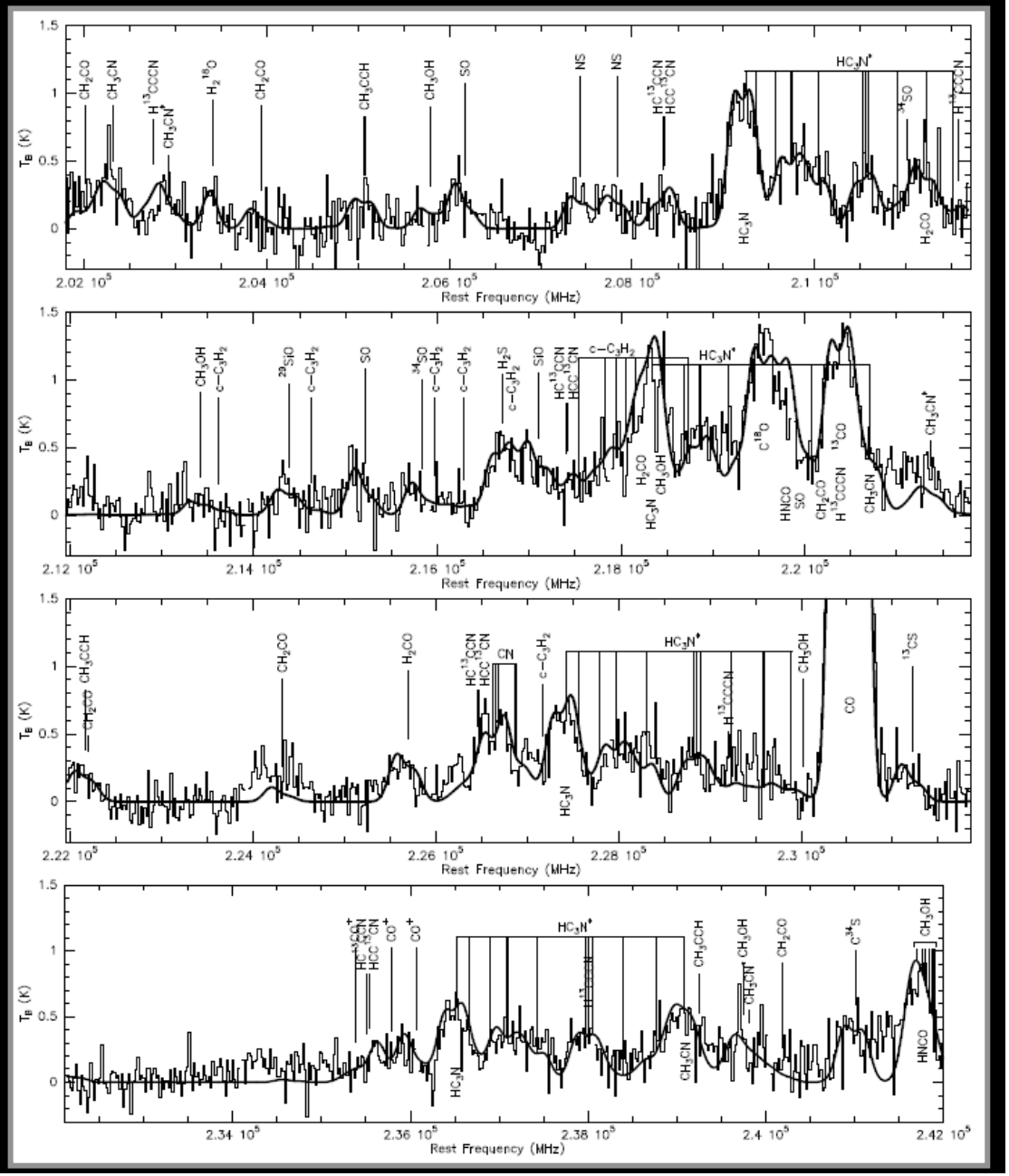
70 individual spectral features

15 species + 6 isotopologues

1.8 lines/Ghz = Partially confusion limited

LTE analysis:

Fitting of synthetic spectra of individual molecules



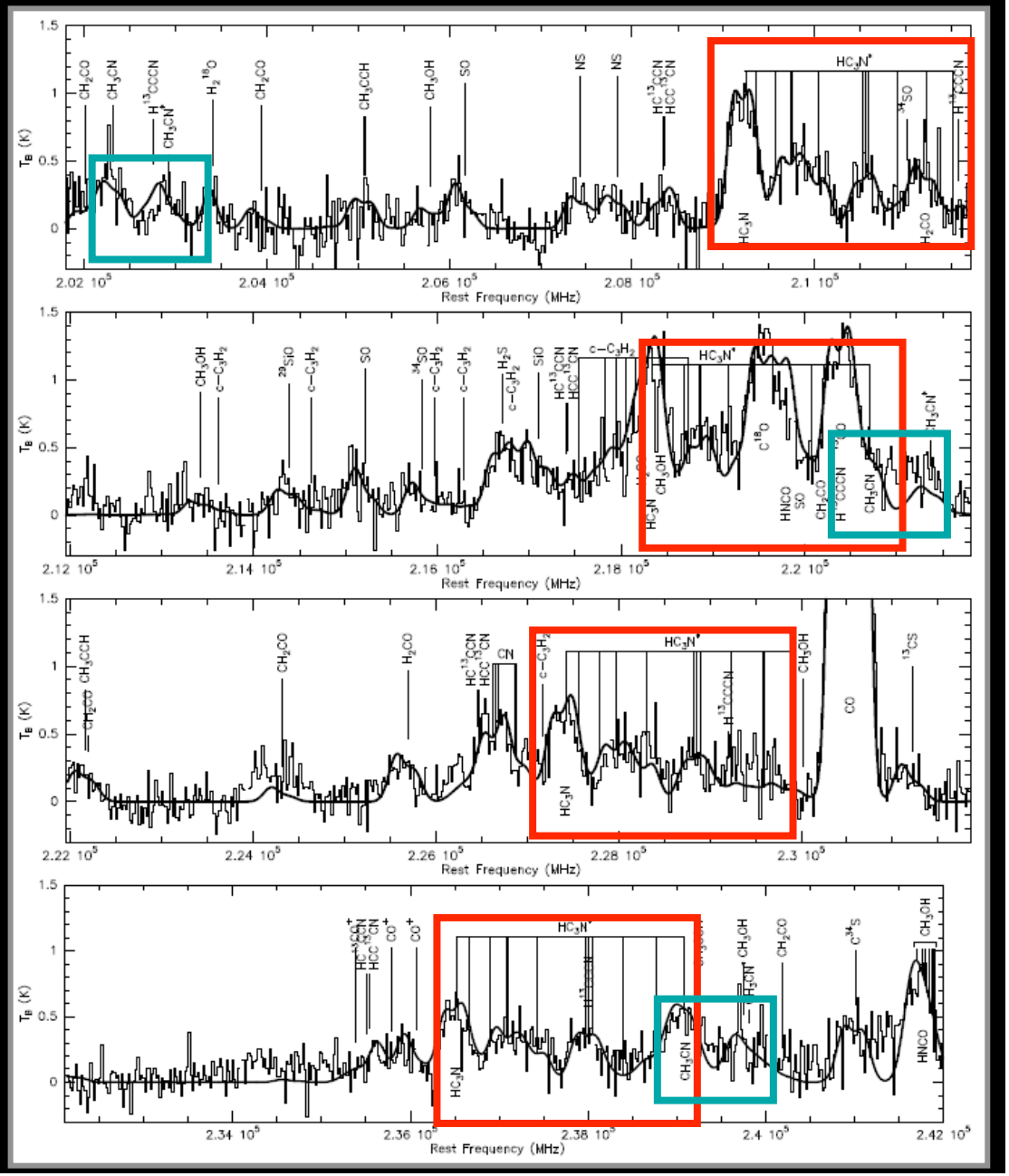
(Martin et al. 2011)

The ULIRG Arp 220 stands as a template of high redshift

Vibrationally excited emission of:

HC_3N and CH_3CN.

T_{ex} ~ 300-500 K



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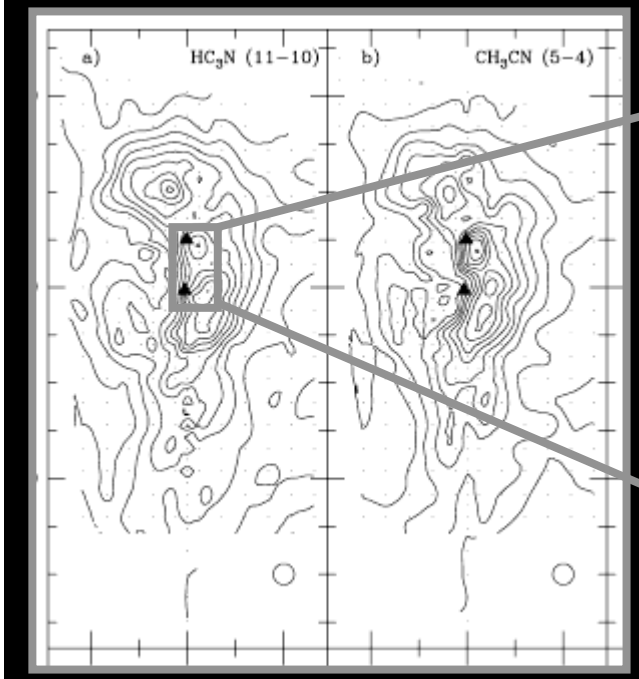
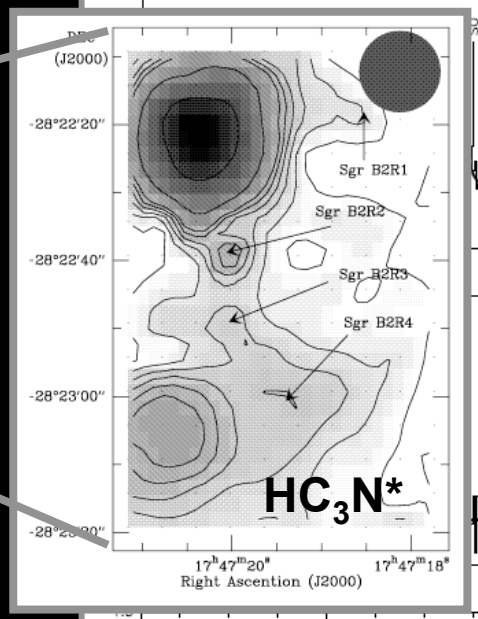


Sgr B2 region
(de Vicente 1997, 2000)



The ULIRG Arp 220 stands as a template of high redshift

Vibrationally excited emission of:

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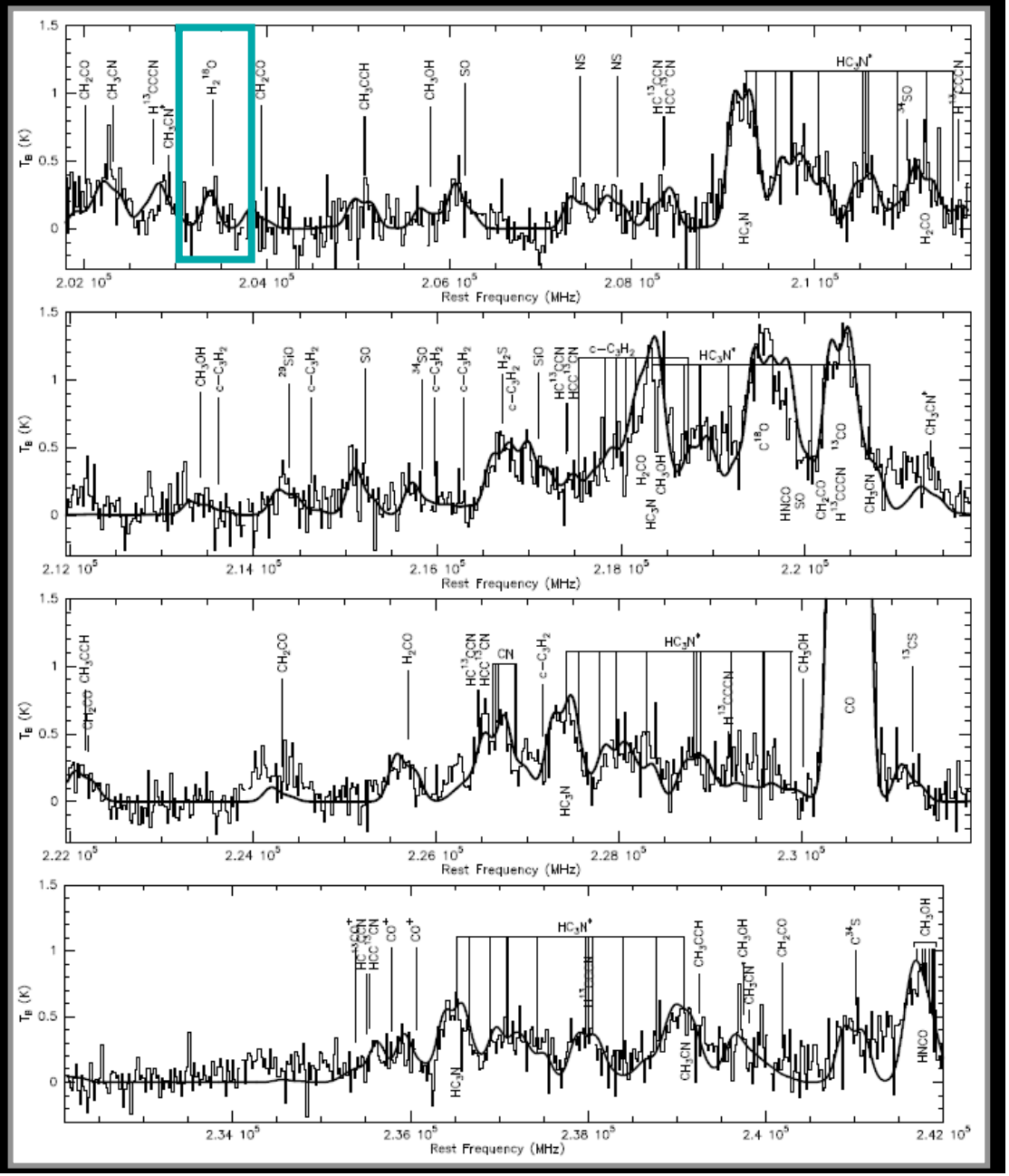
WATER

$H^{18}O/C^{18}O$: water abundance ~$2x10^5$

Similar abundance in Sgr B2 hot core

2 – 8 10^6 Sgr B2-like hot cores

In a 700 pc region !!!



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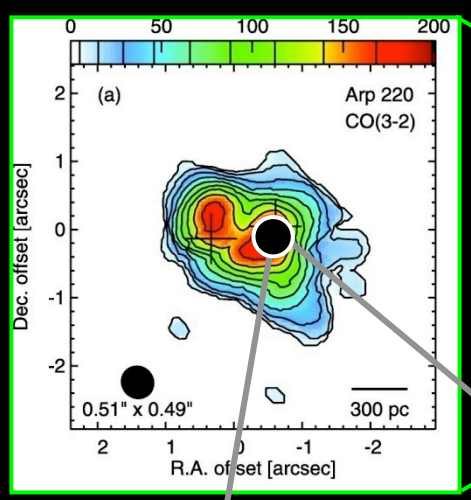
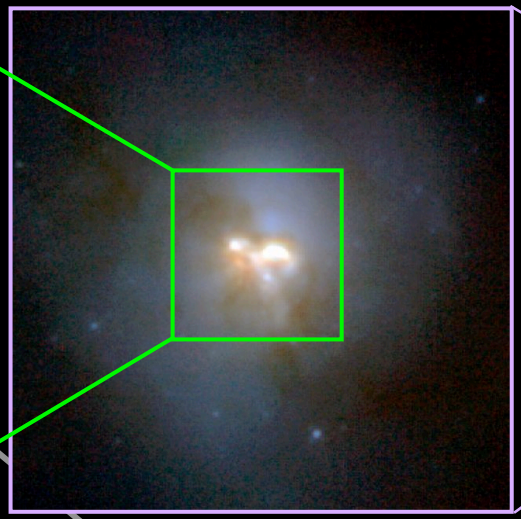


Sakamoto et al. 2008



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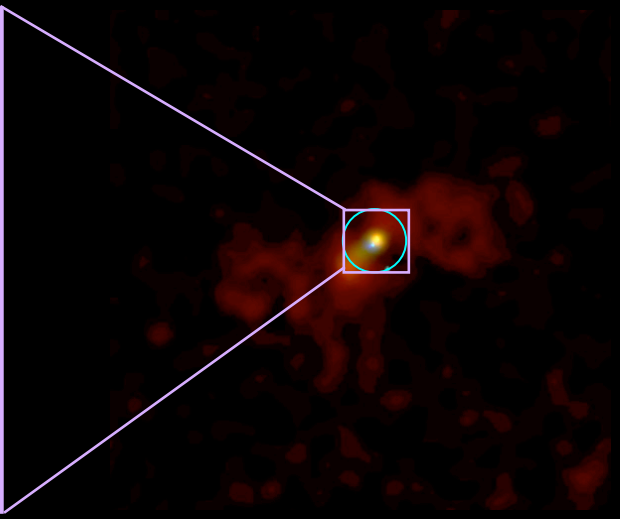

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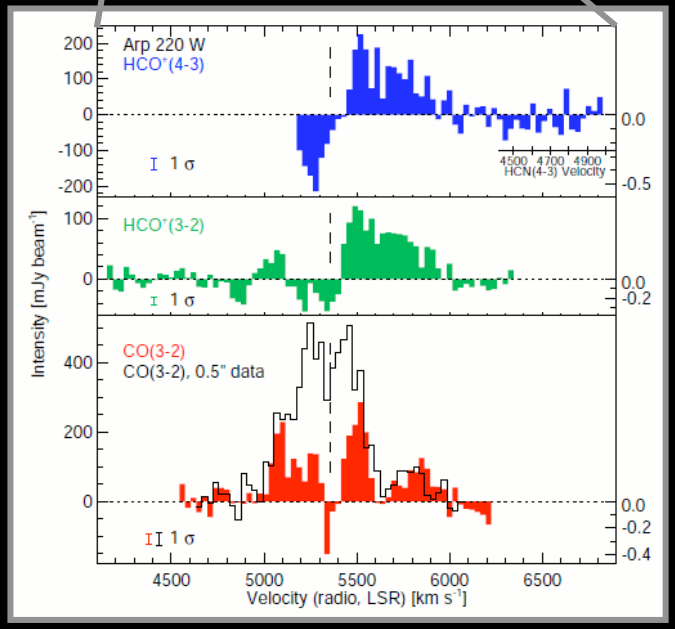


Sakamoto et al. 2009

HCO^+ 4-3

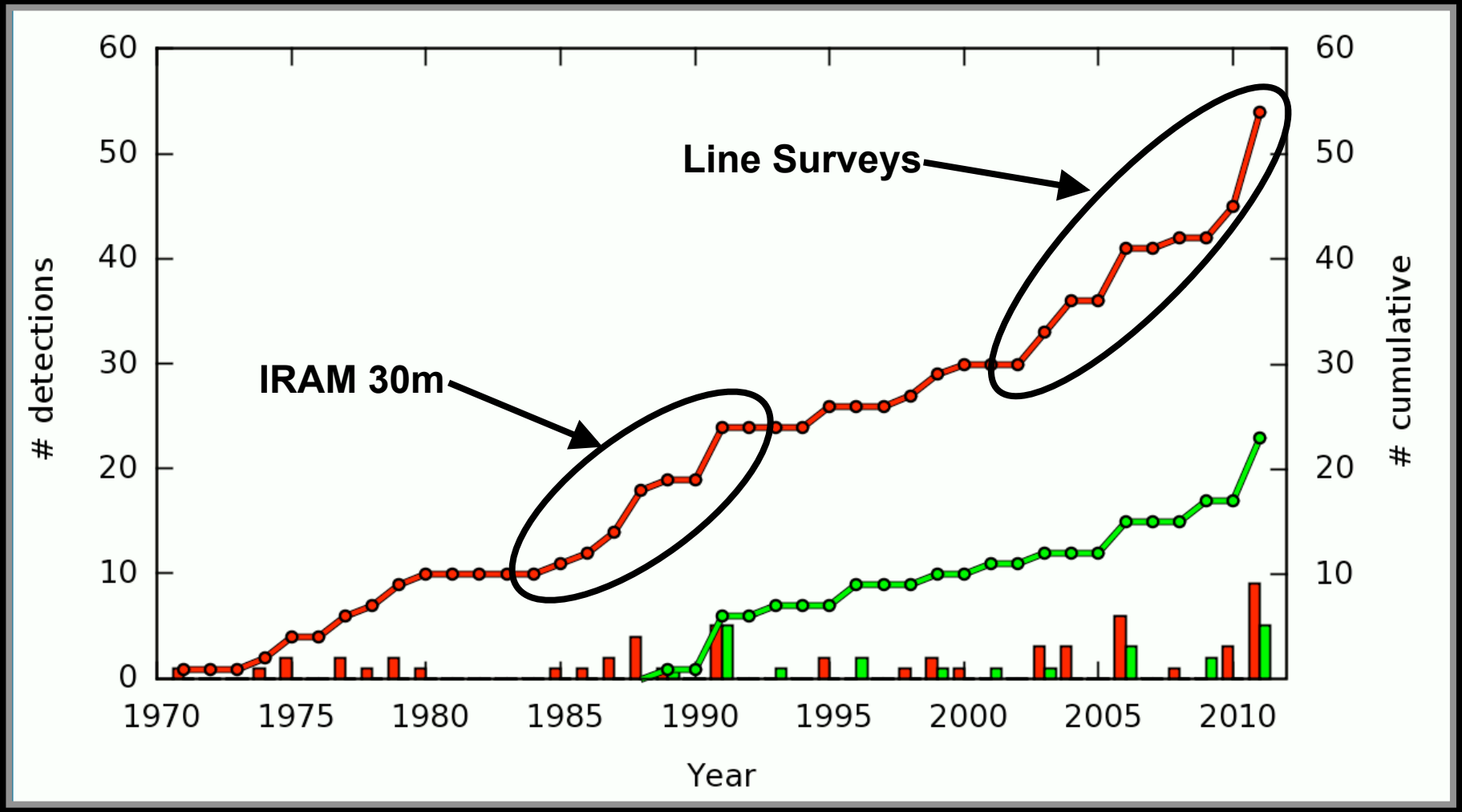
HCO+ 3-2

P-Cygni profiles at high angular resolution observations of HCO^+ "OUTFLOWING MATERIAL"

SO…WHAT IS NEXT?

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

ALMA

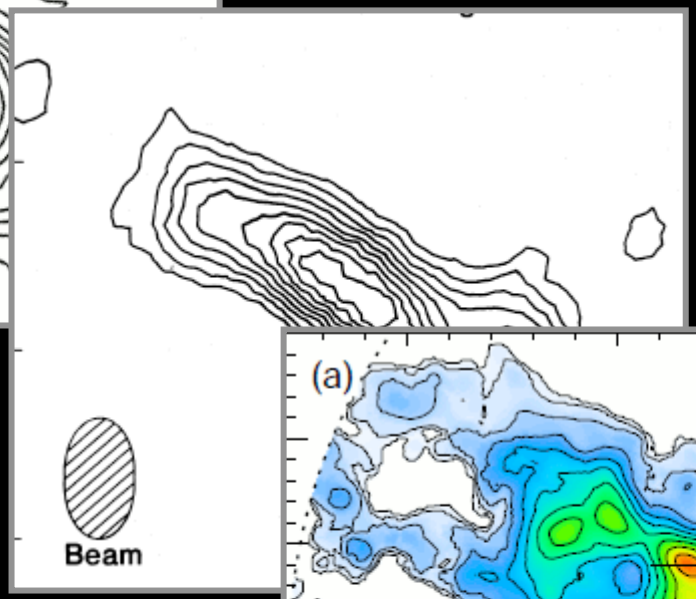


The enormous collecting area of ALMA will be the next leap in resolution and sensitivity

Mauersberger et al. 1996

IRAM 30m CO 2-1

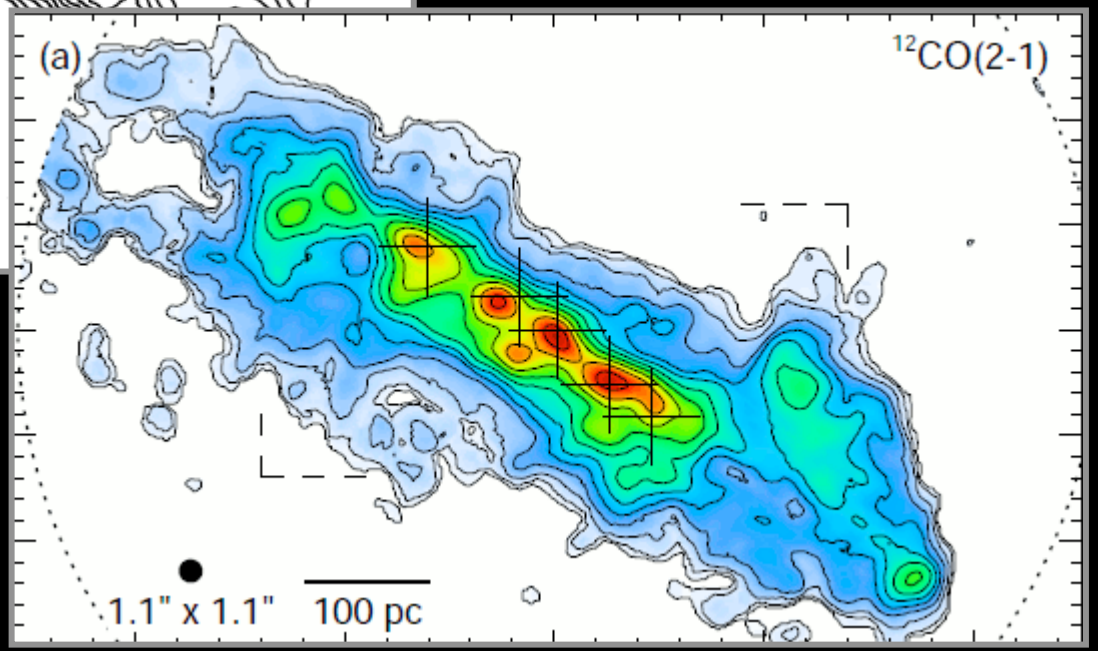
Beam = 12”



Canzian et al. 1988

OVRO CO 1-0

Beam = 5”x9”

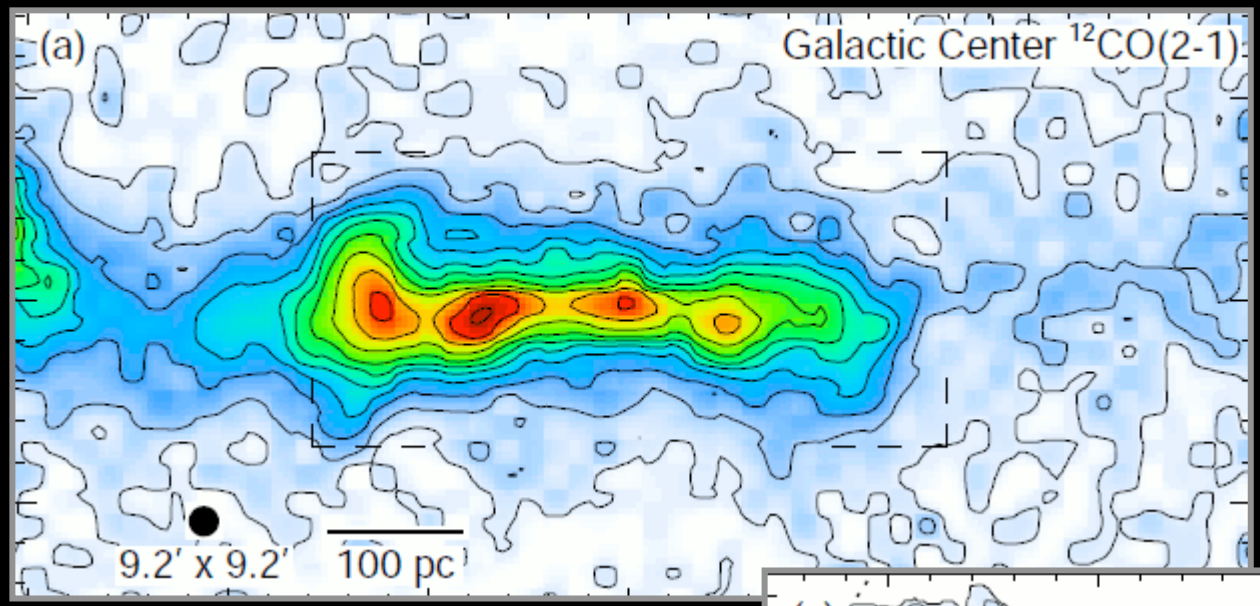


Sakamoto et al. 2011

SMA CO 2-1

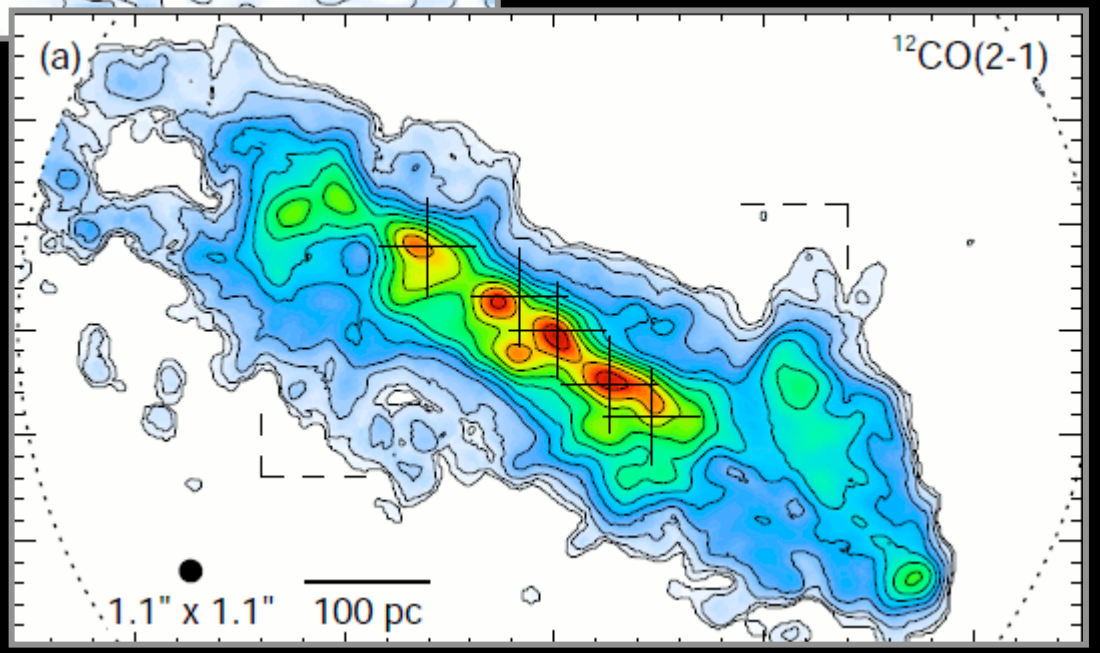
12CO, 13CO, C18O, HCN, and HNCO detected

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



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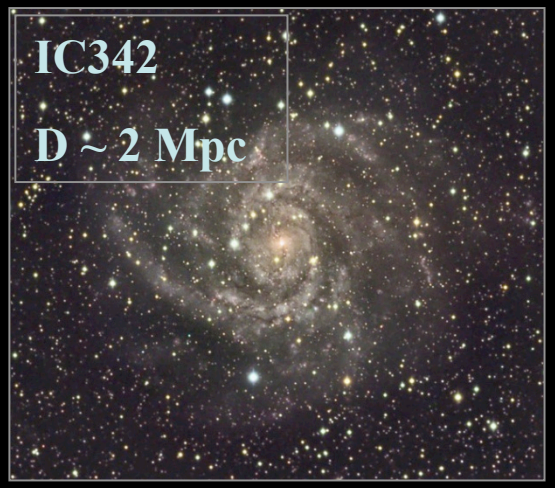
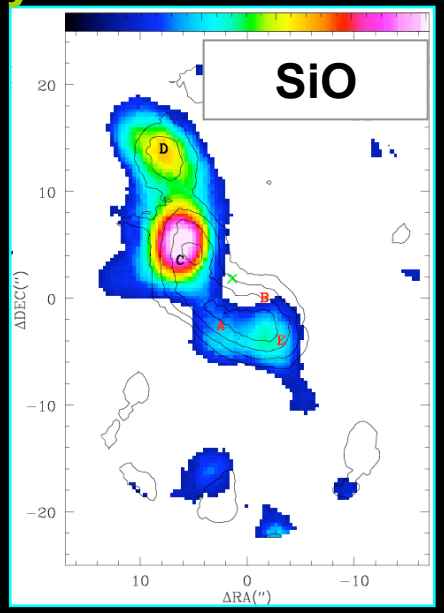
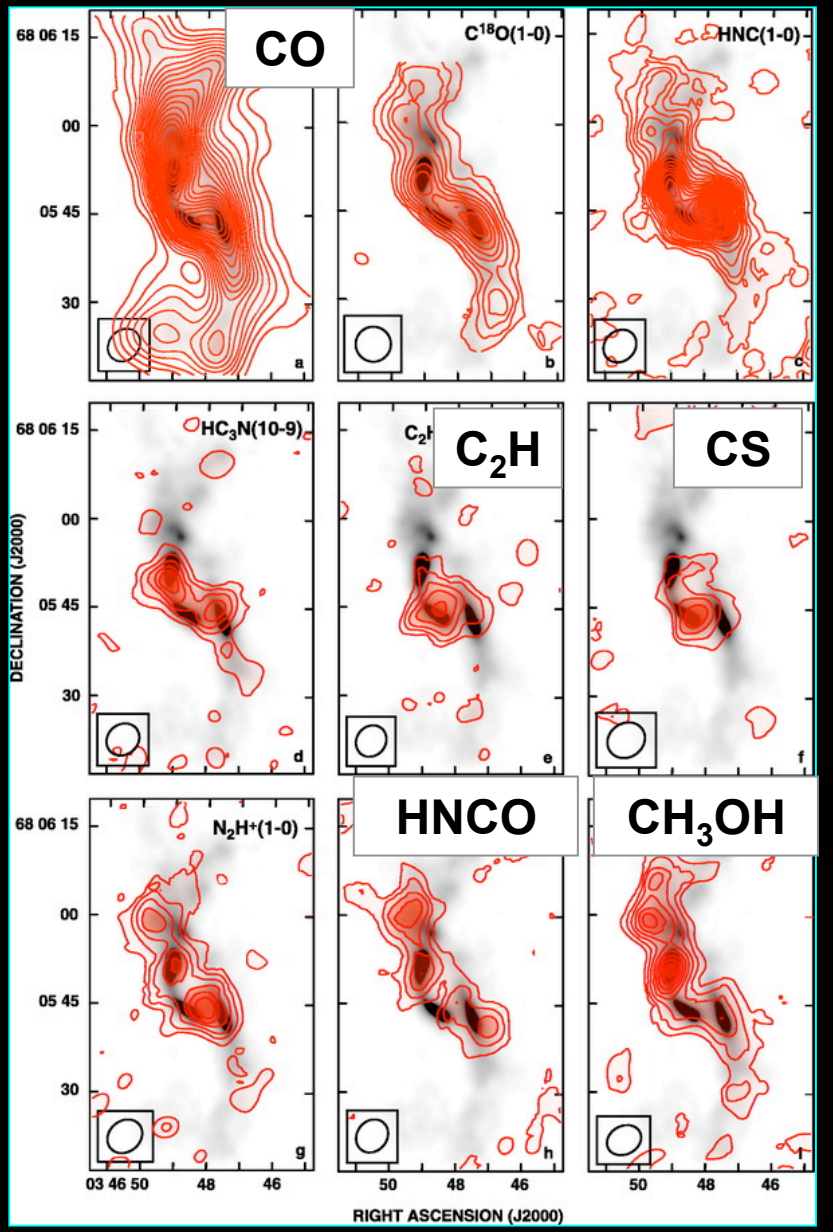




PdBI Usero et al.(2007)



OVRO interferometer, Meier & Turner (2005)

Resolving the heating mechanisms

- UV pervaded material around the central cluster

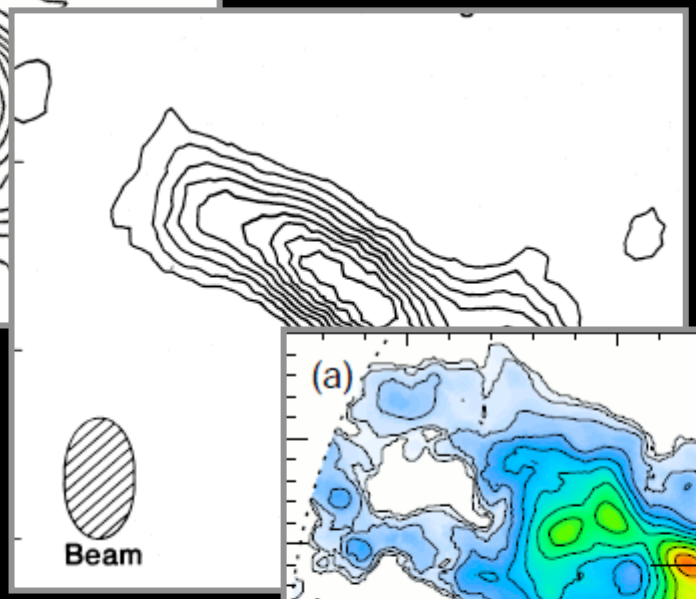
- Shocked material in the circunnuclear spiral arms

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

Mauersberger et al. 1996

IRAM 30m CO 2-1

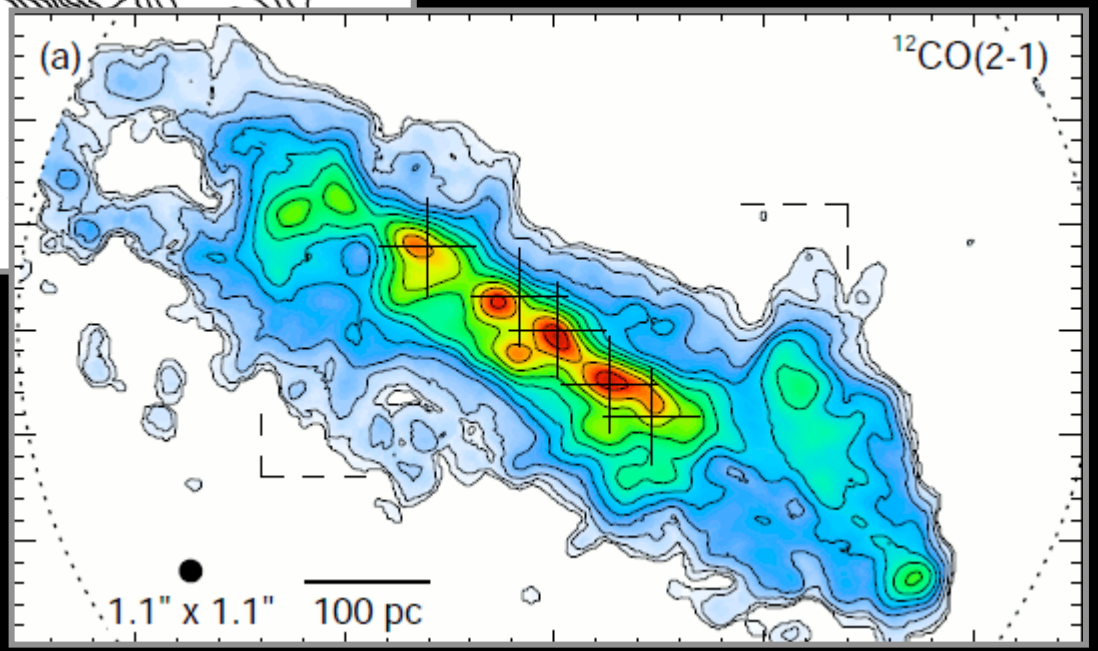
Beam = 12”



Canzian et al. 1988

OVRO CO 1-0

Beam = 5”x9”



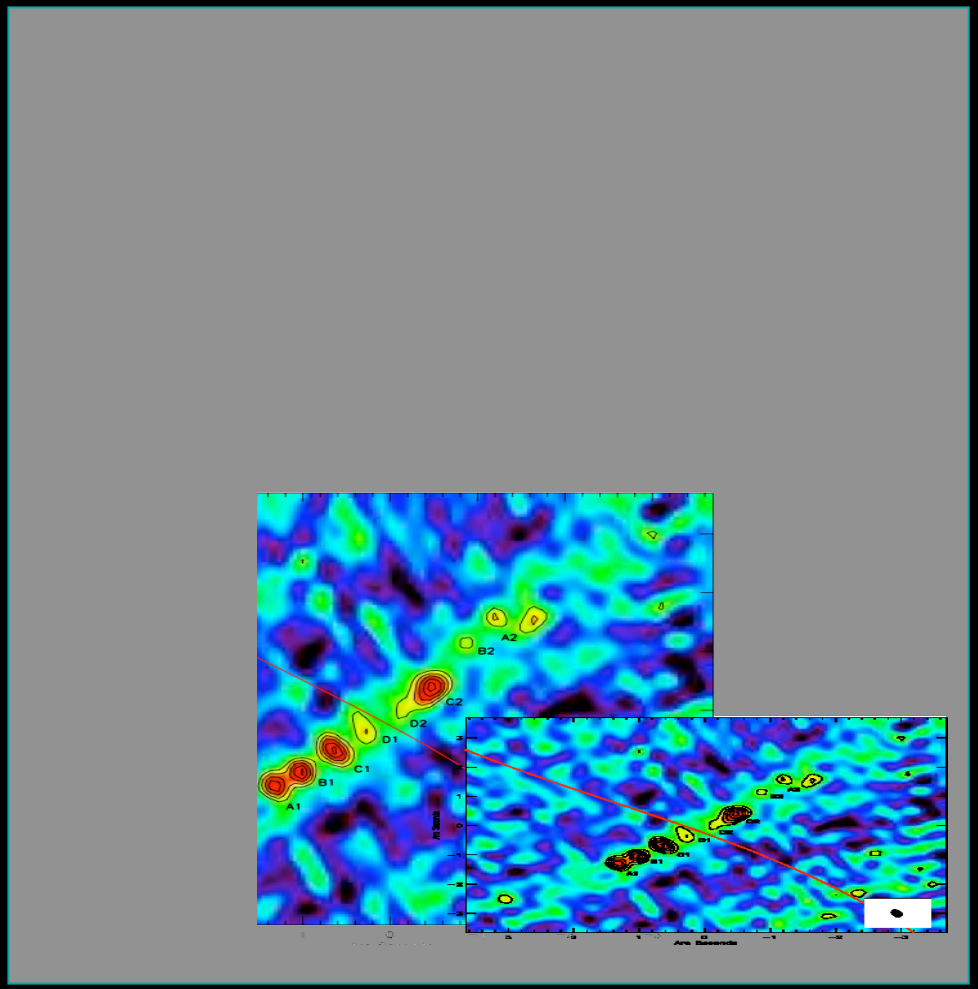
Sakamoto et al. 2011

SMA CO 2-1

12CO, 13CO, C18O, HCN, and HNCO detected

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

SMMJ2135-0102 (Eyelash) @ z=2.3259 (PI M.Swinbank)



LENSING
Galaxy magnification
Source stretching

Intrinsic 870 um flux ~3 mJy
Lense magnification ~32
Observed 870 flux = 106 mJy

Brightest SMG at that time

SMA beam 0.3”x0.2”
8 components