

**EXTRAGALACTIC  
ASTRONOMY  
WITH  
ALMA**

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Special thanks to S. Leon @ ESO & participants in RIA workshop on  
"Impact of ALMA on the Spanish Extragalactic Astronomy"

# ALMA Early Science

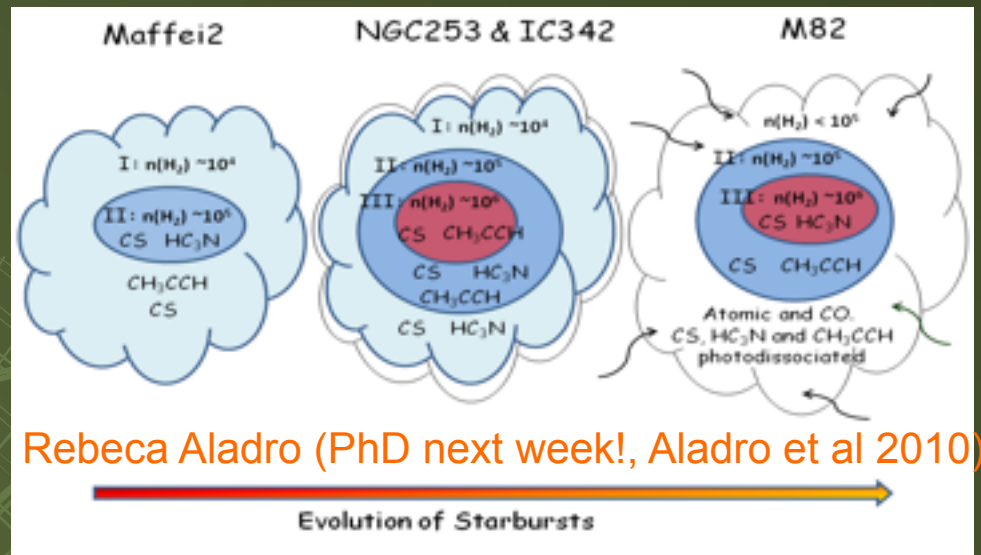
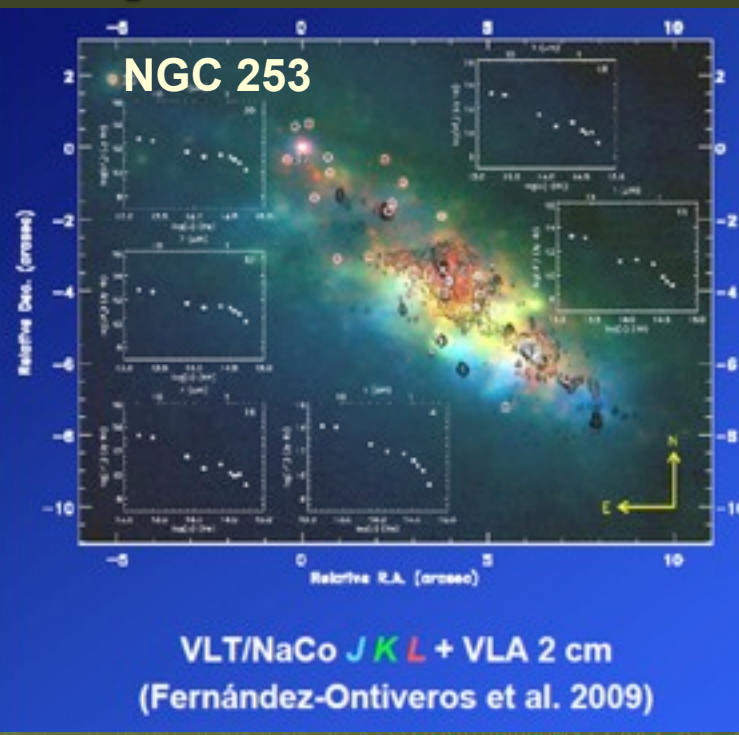
Important Note: Final availability has to wait for the ES Call

□ **16 antennas, 2 compact configurations, single field interferometry, maybe small mosaics**

□ **Bands 3, 6, 7 and 9**

Band	Freq	Wavel.	Ang. Res.	FOV	Largest Scale	Lines
3	84 - 116 GHz	2.6 - 3.6 mm	2.6" 100pc@100 Mpc	56"	37"	CO(1-0)
6	211 - 275 GHz	1.1 - 1.4 mm	1.3" 50pc@100Mpc	27"	18"	CO(2-1)
7	275 - 373 GHz	0.8 - 1.1 mm	0.7"	18"	12"	CO(3-2)
9	602 - 720 GHz	0.4 - 0.5 mm	0.3"	9"	6"	CO(6-5) CII (z > 1)

# Spectral line surveys

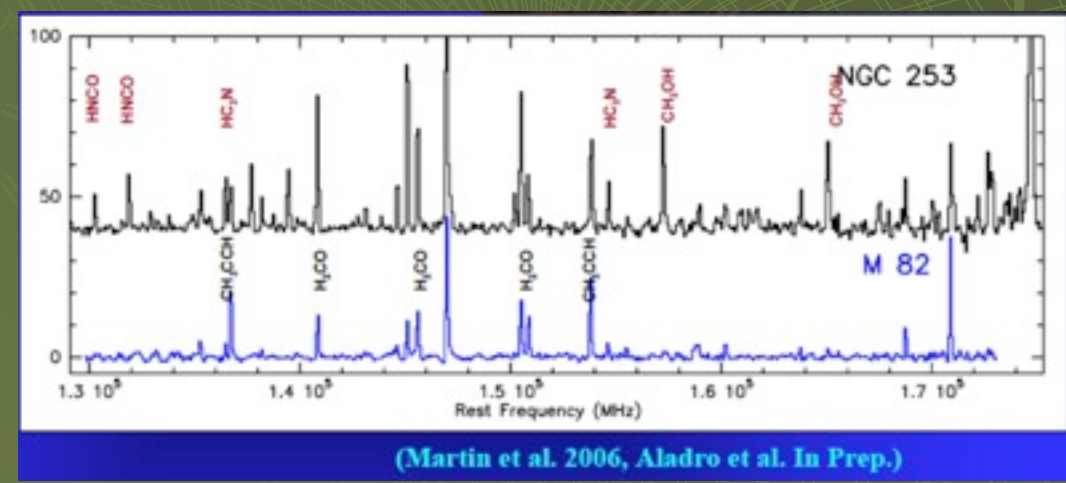


Rebeca Aladro (PhD next week!, Aladro et al 2010)

Different molecular abundances indicative of a different evolutionary stage

Powering source in obscured nuclei:  
HCN/HCO+/CO ratio for AGN vs SB  
HNCO/CS for SB evolution

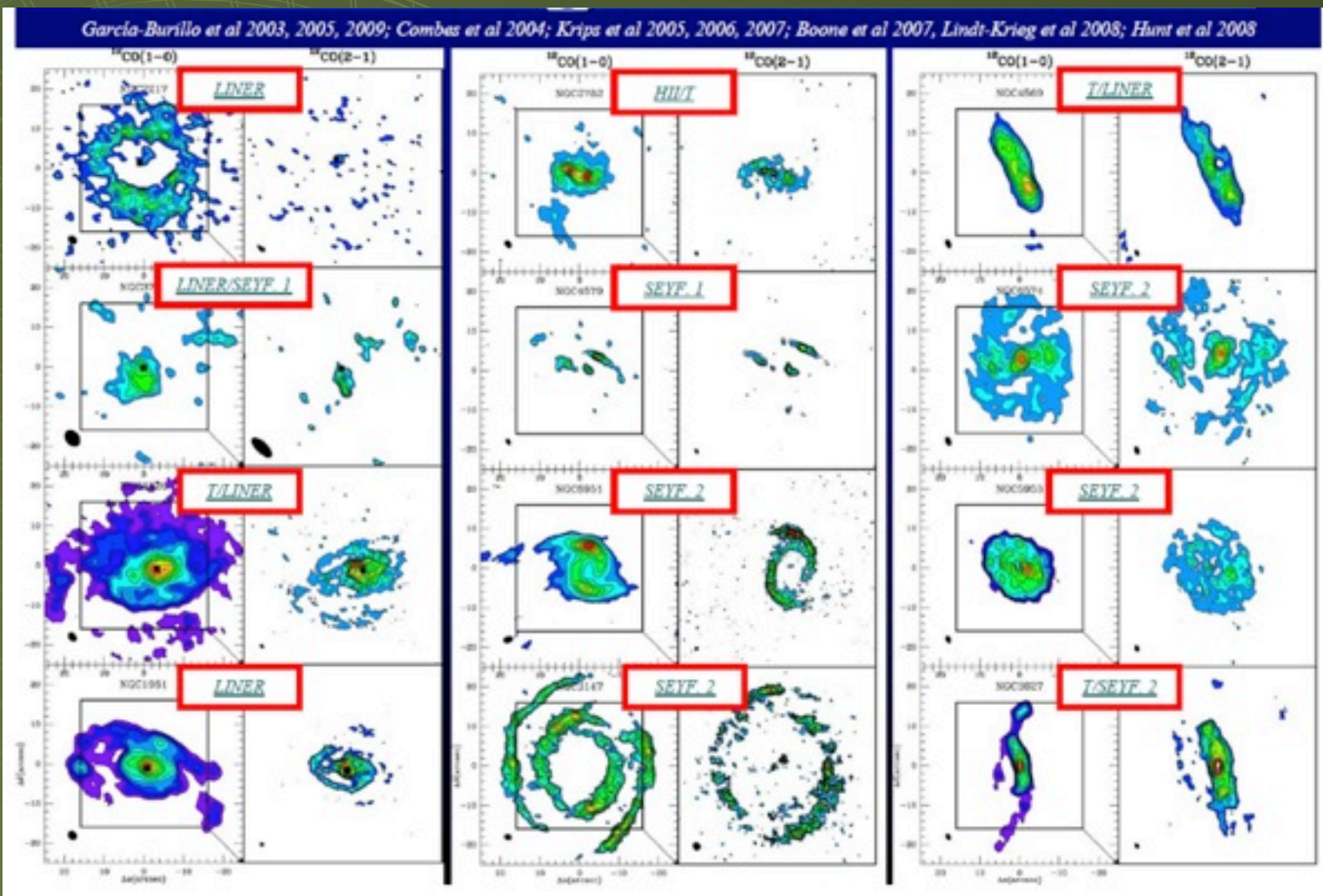
IRAM - 30m = 50h  
ALMA 3h-6h



(Martin et al. 2006, Aladro et al. In Prep.)

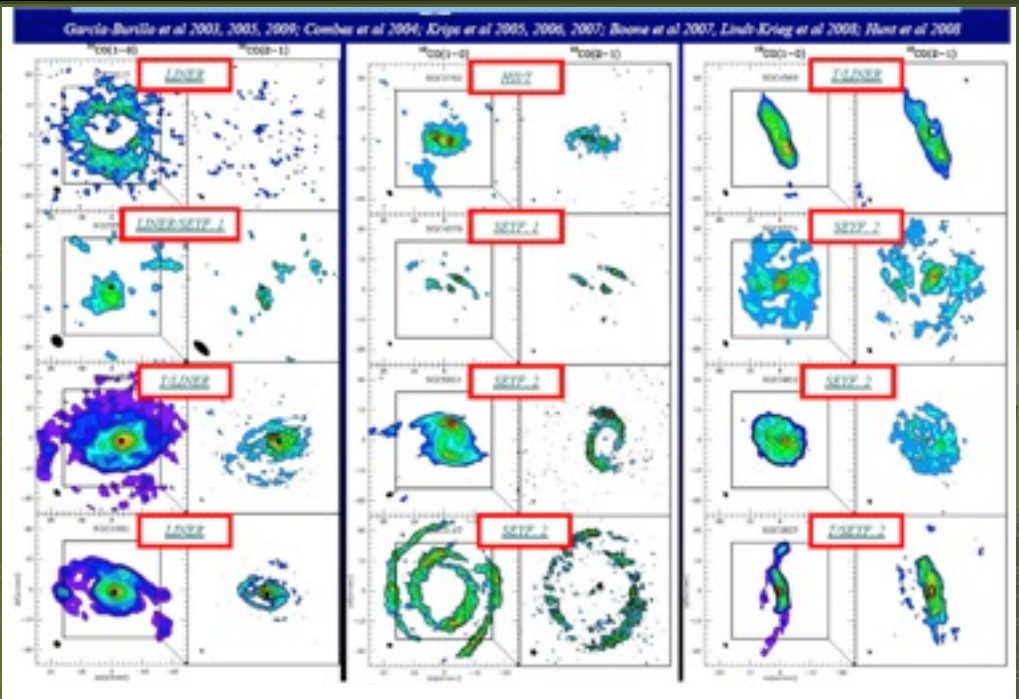
# Resolved studies: NUGA

(García-Burillo et al)



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## Sensitivity

### PdBI

$M(H_2) \sim 10^5 M_{\text{sol}}$  in 15-20h

### ALMA

$\sim 10^4 M_{\text{sol}}$  in  $\sim 1.5h$

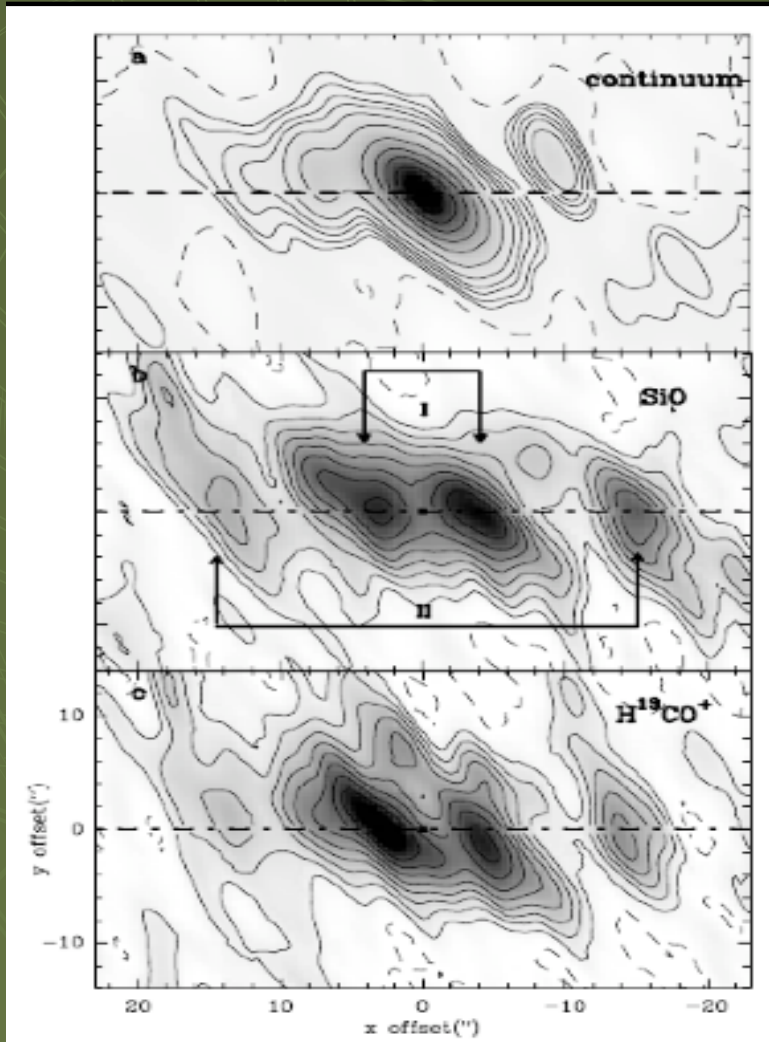
Ang. resolution

PdBI  $0.5'' = 12-72 \text{ pc @ } 5-30 \text{ Mpc}$

ALMA  $0.05''-0.1'' = 1-10 \text{ pc @ } 5-30 \text{ Mpc}$

- CO and NIR maps at  $\sim 0.1''$ : accurate gravity torque maps
- New feeding mechanisms on 1-10pc scales?:  
m=1 modes, gas self-gravity, dynamical friction of GMCs, etc

# Resolved studies



García-Burillo et al. (2000)

NGC253 PdBI maps in  
continuum, SiO and H<sup>13</sup>CO+

Beam size= 7.5" x 2.6" @ 87 GHz

(Courtesy of R. Aladro)

D=3.4 Mpc >> 1" ~ 20 pc

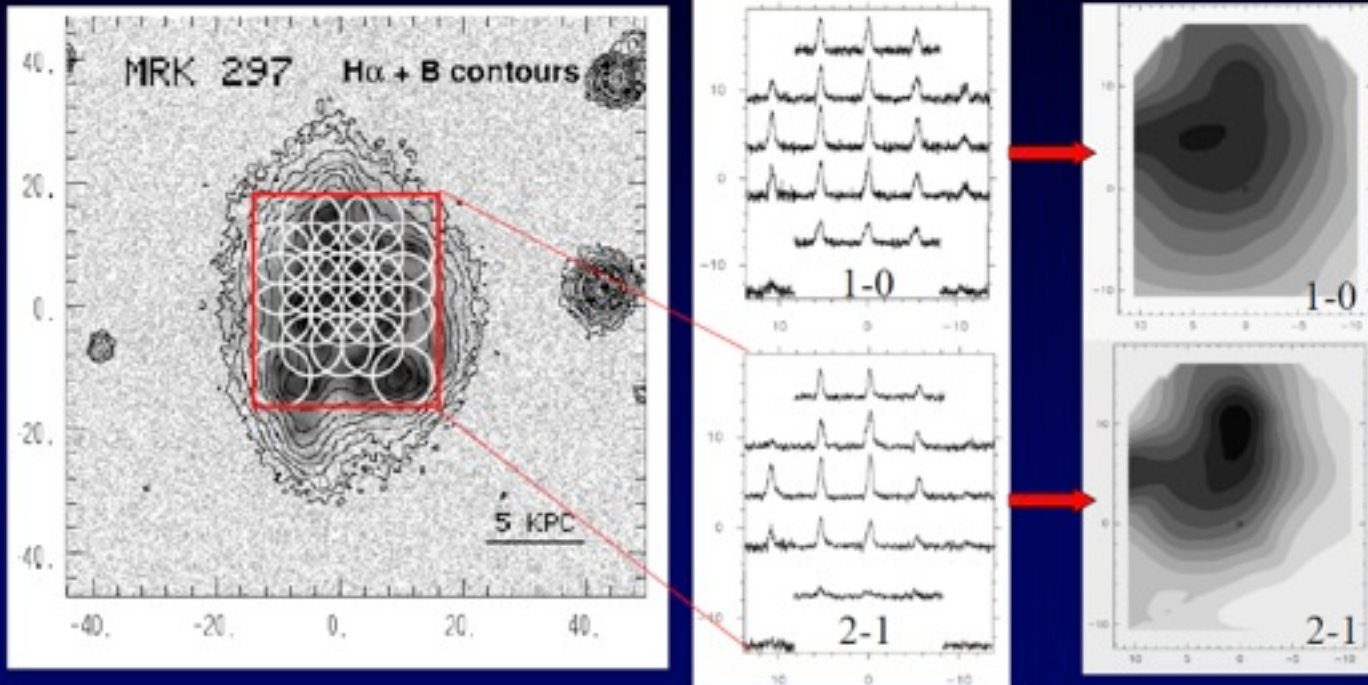
Typical molecular cloud size ~ 10-40 pc

**ALMA**  
**Beam size @ 87 GHz = 0.07"**  
**>> 1.7 pc !**

Molecular clouds resolved and virial mass estimated

# Dwarf galaxies

Blue compact galaxies as part of Estallidos project



Additional info from optical 2D spectroscopy  
(e.g. Martínez-Delgado and Cairós et al. in prep)

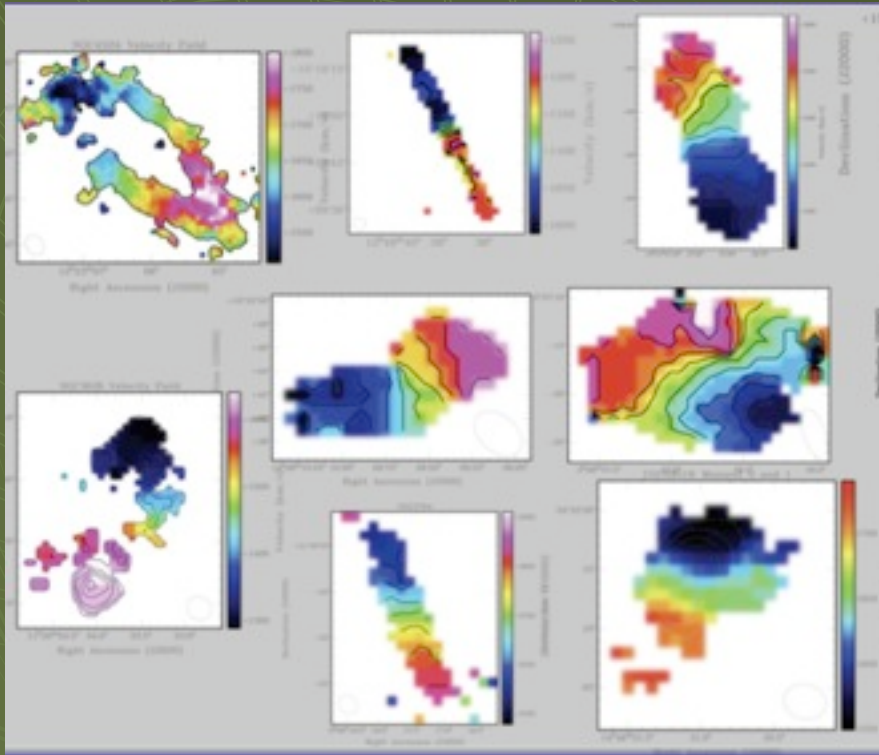
Amorin et al. & PhD

Molecular gas in low mass SBs, with ALMA feasible down to dwarfs and low metallicity targets

# Early type galaxies

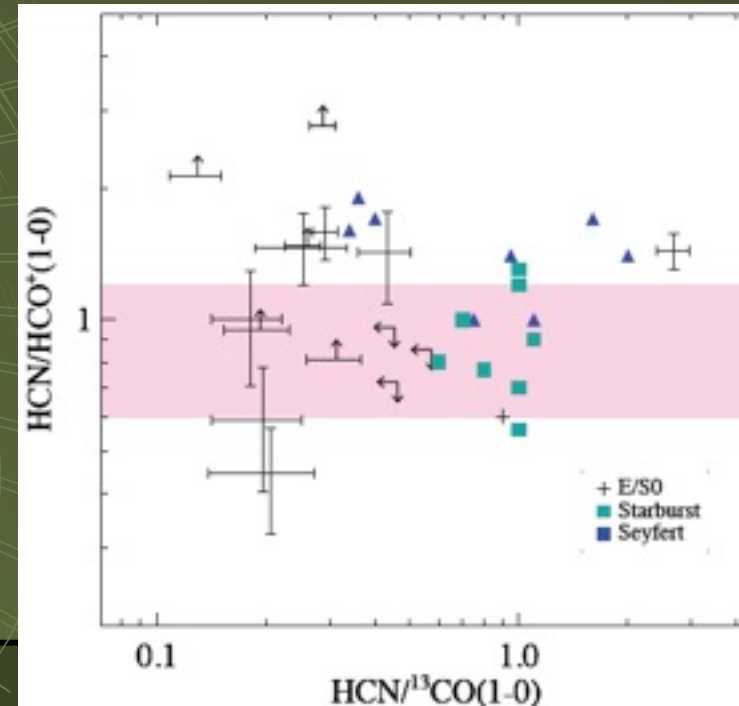
(Bureau et al, Crocker et al)

Atlas3D project: detection of 22% Es on CO(2-1) and (1-0)



Mapping with mm interferometers:  
H<sub>2</sub> and stars:  
aligned in clusters/Virgo  
randomly misaligned in field

- Wider spread in HCN/HCO<sup>+</sup> than in local
- Effect of AGN, but not for all
- Some other chemical effect?





# Reference for environment

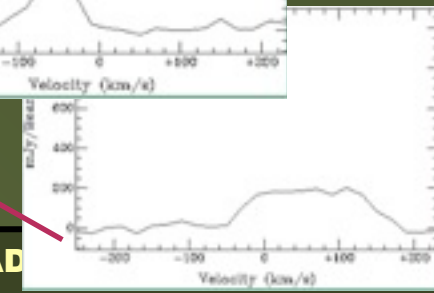
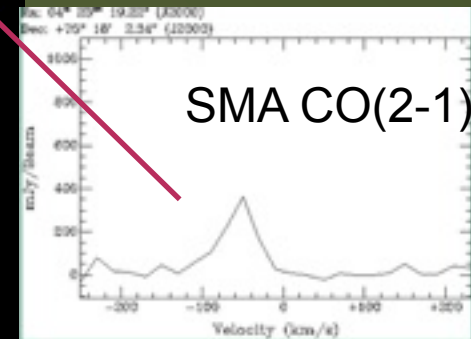
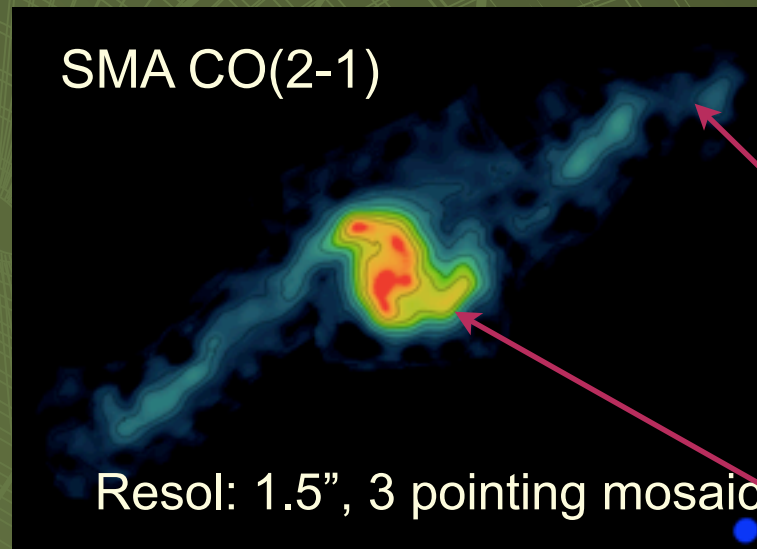
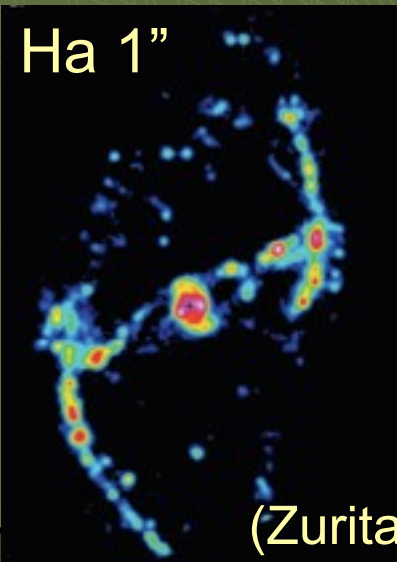
## Isolated galaxies (AMIGA project)

Different physical properties from field & loose groups samples:

- Dominated (66%) by small-bulge Sb-Sc
- 14% low-L early-type galaxies
- Optical asymmetry, clumpiness and concentration minimized
- Lowest: LFIR, 0% radio-excess, rate of AGNs (22%), HI asymmetry (< 20%), molecular gas content

**Unique for ALMA to quantify the role of the environment on galaxy evolution**

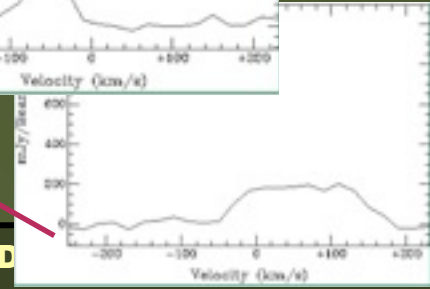
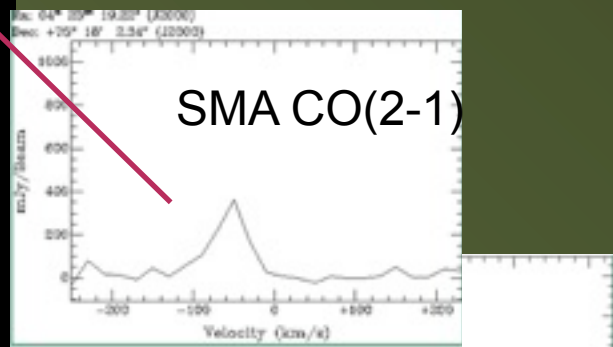
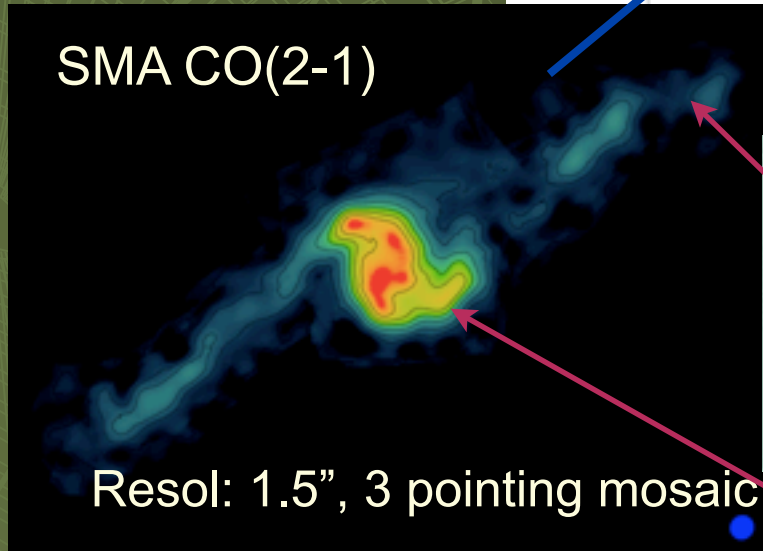
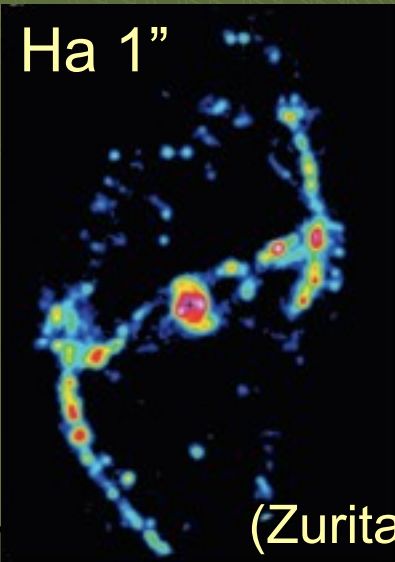
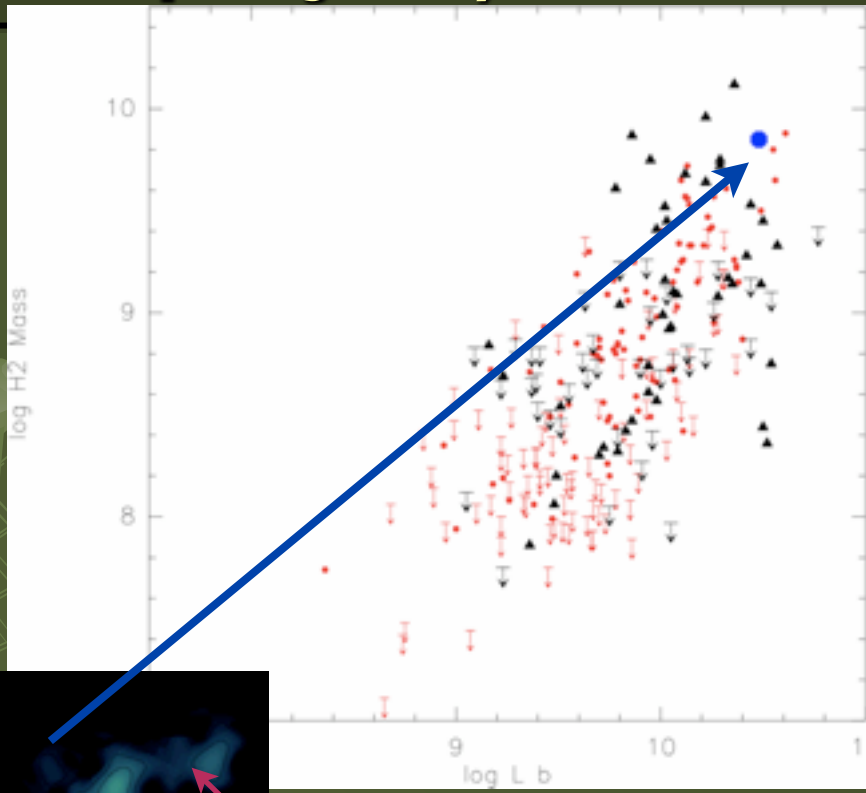
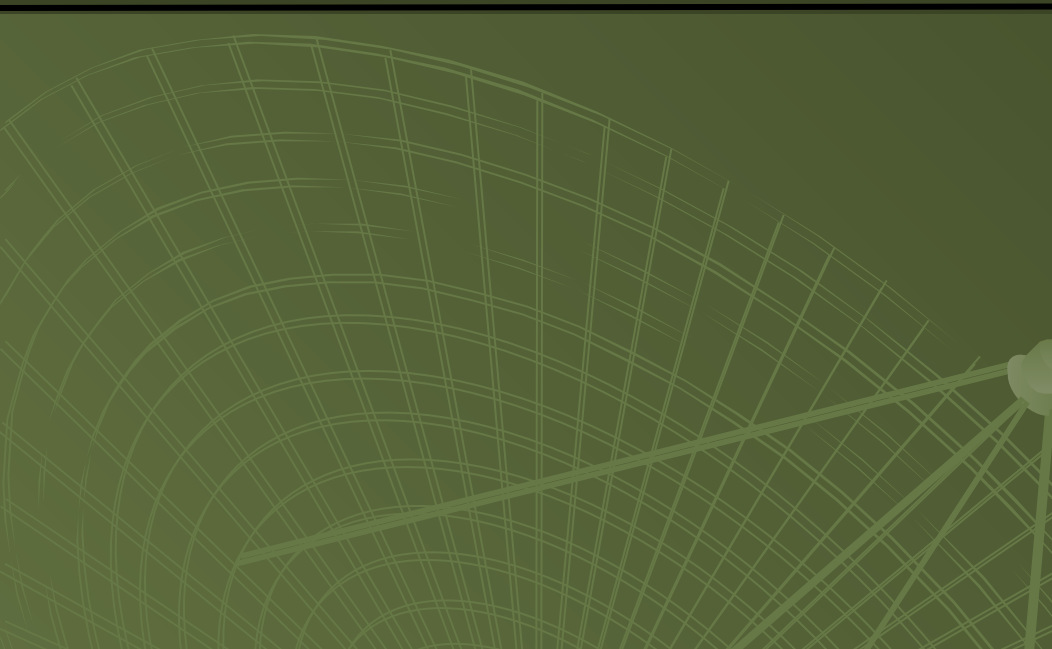
# Isolated galaxies (AMIGA project)



**CIG 147**

JORNAD

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# Isolated galaxies (AMIGA project)

ONLY FEASIBLE WITH ALMA

Dec < 37

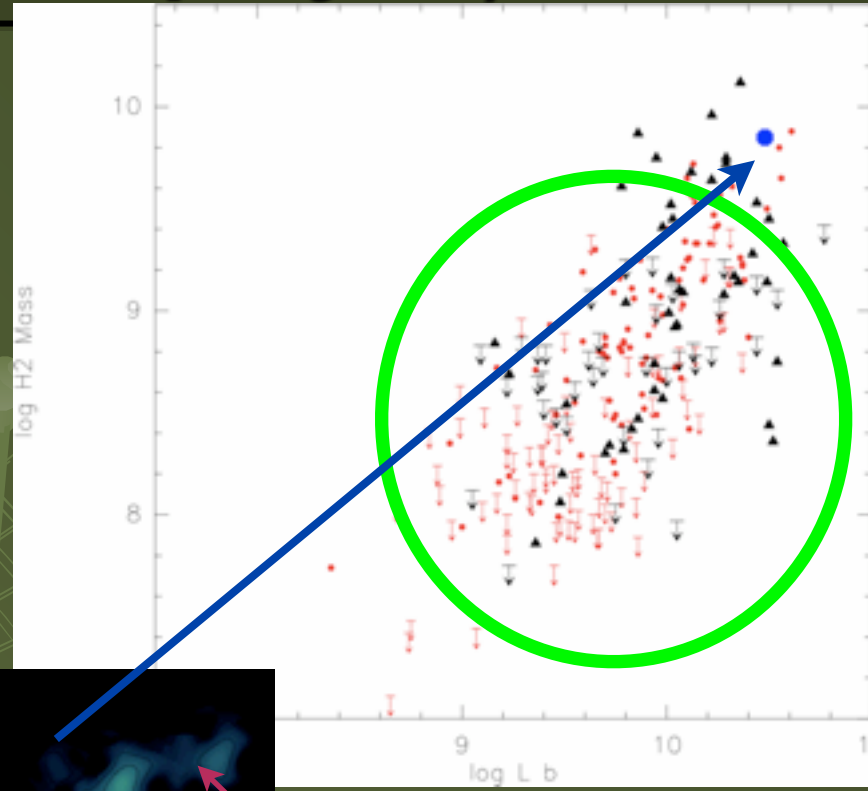
Size < 2'

N = 77 galaxies

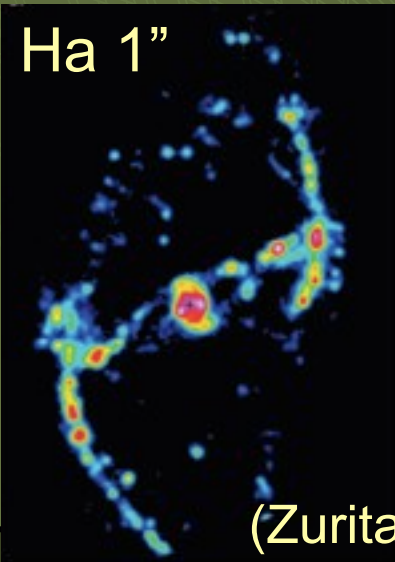
dv = 10 km/s

1" (160 pc @ v = 2500 km/s)

**ALMA CO(1-0) 50h**

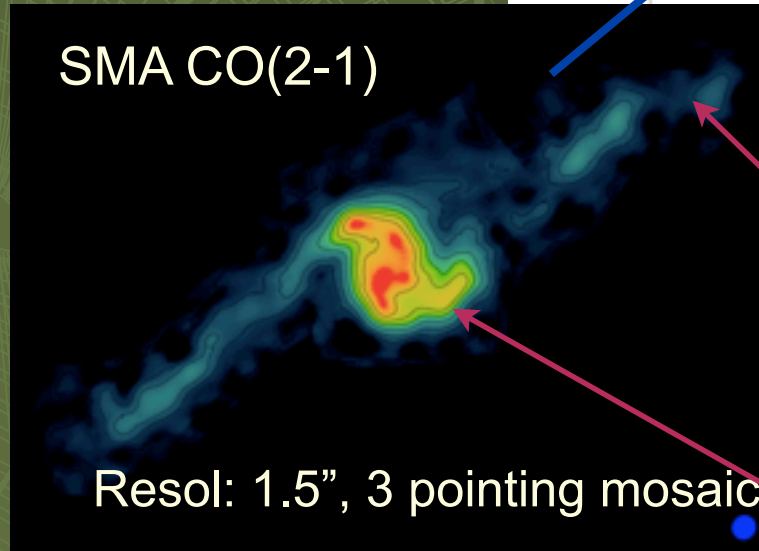


Ha 1"



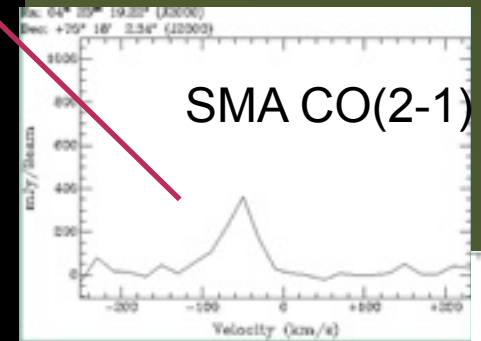
(Zurita et al 2004)

SMA CO(2-1)

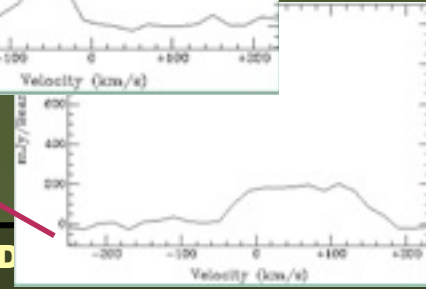


Resol: 1.5", 3 pointing mosaic

**CIG 147**



SMA CO(2-1)



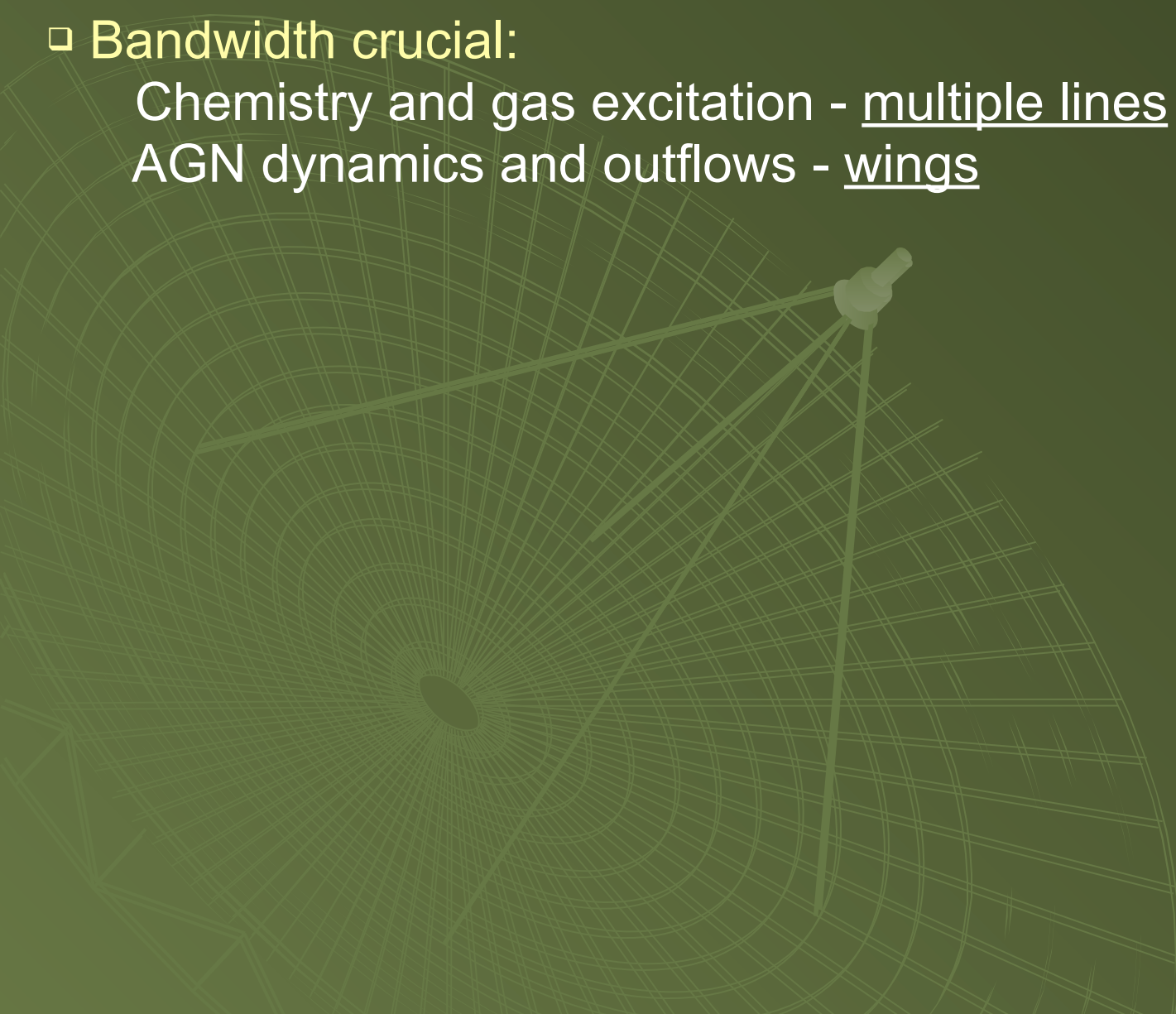
JORNAD

# Role of ALMA

- Bandwidth crucial:

Chemistry and gas excitation - multiple lines

AGN dynamics and outflows - wings



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Chemistry and gas excitation - multiple lines  
AGN dynamics and outflows - wings

- Angular resolution:

Resolve AGN environment with different line ratios:

disentangle XDR (near AGN), PDR and SF regions

(see Usero's talk in RIA's ALMA workshop)

CO concentration in Es

Resolved SF laws and scalings, HCN as tracer

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## □ Sensitivity:

All above plus probing also (faintest) galaxies: isolated, normal Es, etc

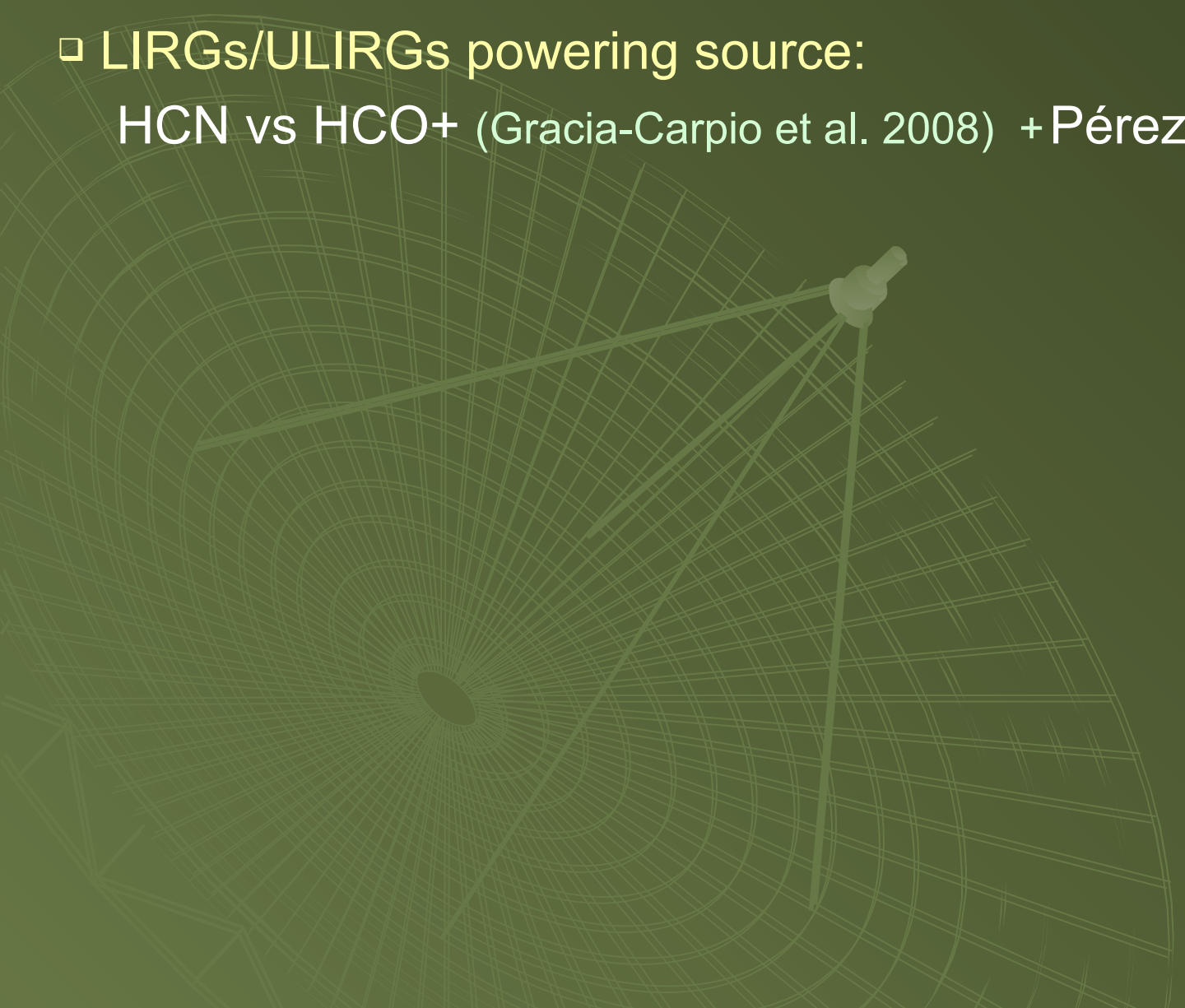
To be combined with chemical models

(see Fuente's talk in RIA's ALMA workshop)

# Extragalactic Astronomy

□ LIRGs/ULIRGs powering source:

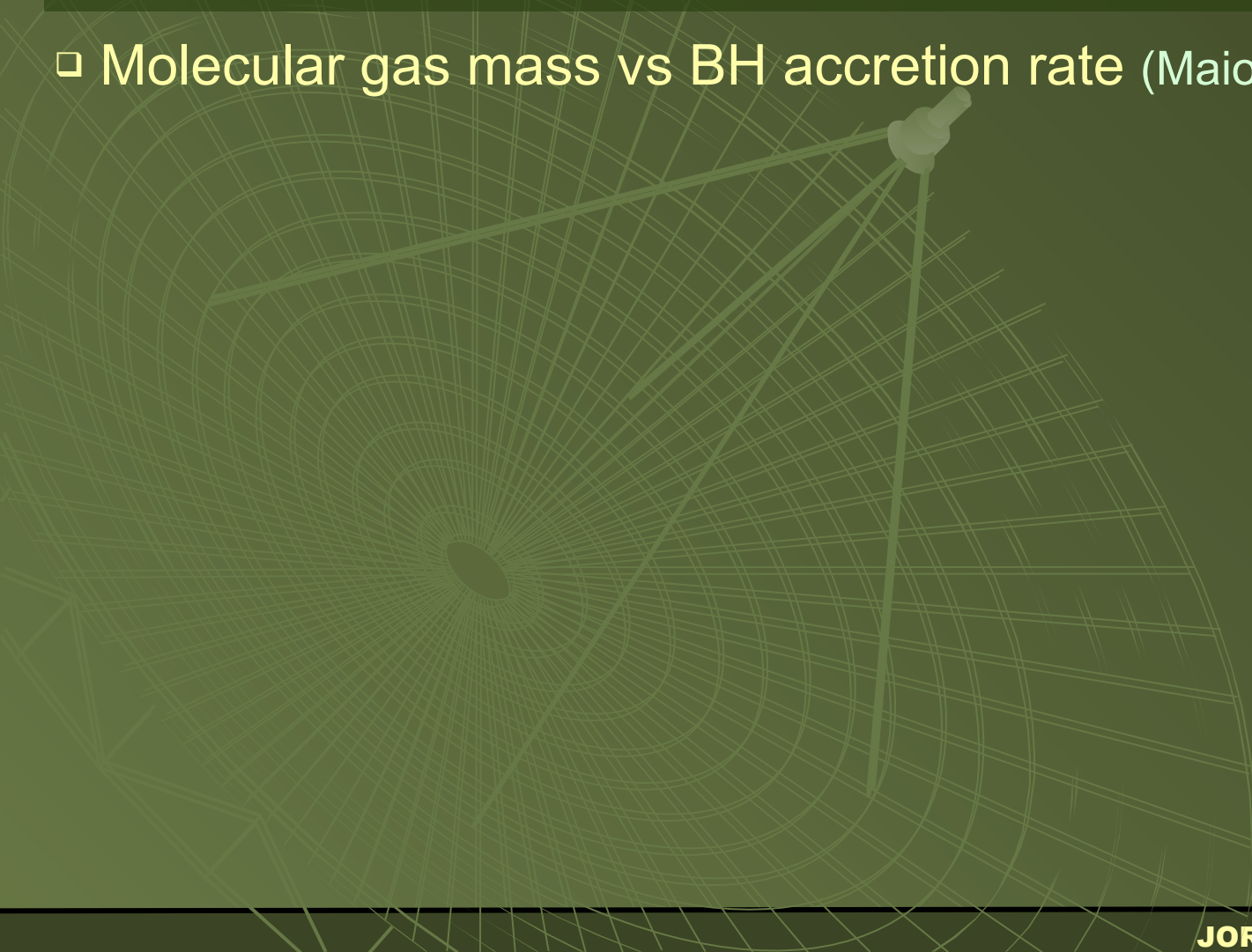
HCN vs HCO<sup>+</sup> (Gracia-Carpio et al. 2008) + Pérez-Torres' talk





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see example on SMGs next + Rodríguez-Espinosa's talk

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see example on SMGs next +Rodríguez-Espinosa's talk
- [CII] atomic ISM cooling line, as a key diagnostic for high-z.  
Strongest submm line for high-z. (Walter et al, Bertoldi, etc)
- Colours between continuum bands -- redshift (Daddi et al 2010)
- Note:  
CO (3-2) only to  $z = 3$ . Higher  $z$ : higher transitions or continuum

# Complementarities



## Herschel vs ALMA ES (full)

Wavelength 0.070 - 0.55 mm (FIR) vs 0.45 (0.35) - 3 (7) mm (submm)

Ang. resolution 6-35" vs 0.4" @ band 9 (0.01) - 1'

FOV several arcmin vs 10" - 1'



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GTC: OSIRIS & EMIR several 6-8' FOV, MOS

FRIDA & CanariCAM diffraction limited imaging & spec

ALMA, FRIDA & CanariCam: follow up of Herschel and OSIRIS & EMIR

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## Be aware of science feasible with PdBI!

**PdBI** 6x15m, **ALMA ES** 16 x 12m

= x2 collecting area (10% of full)

**PdBI** E-W baseline 0.8 km, **ALMA ES** >250m

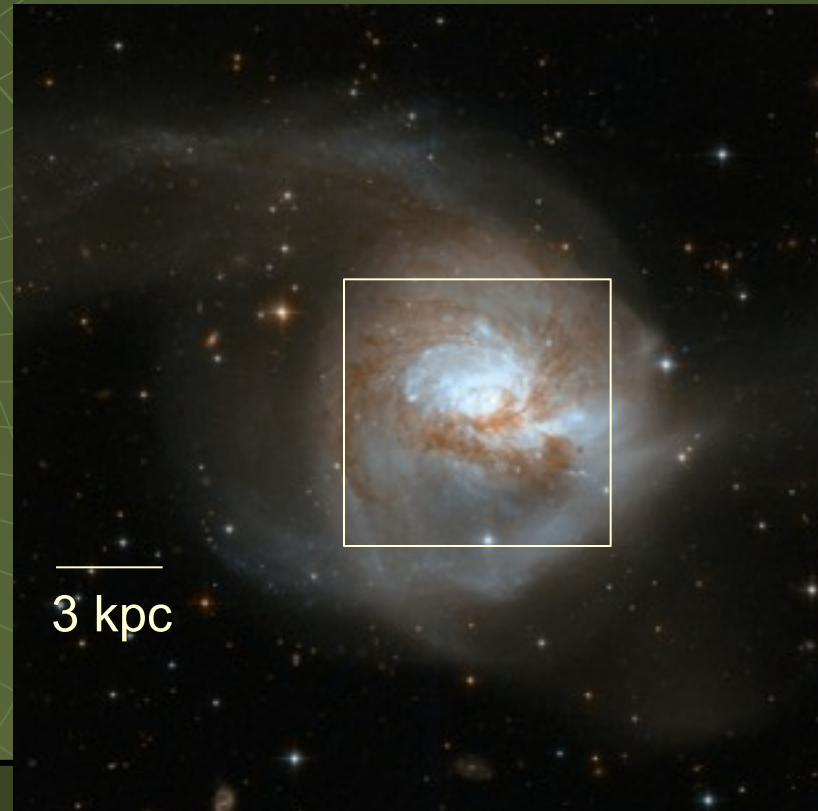
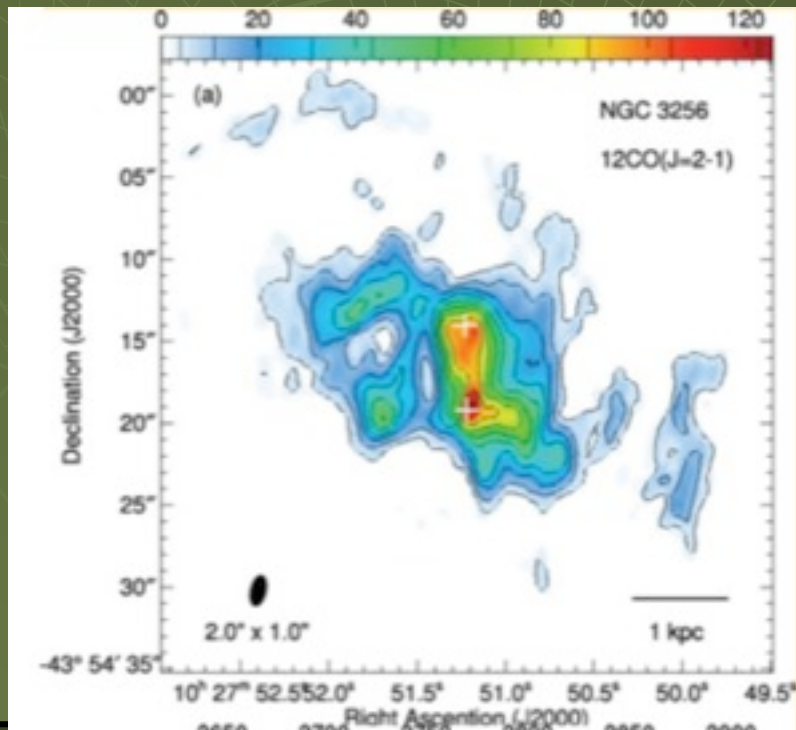
but higher freq. Bands 7 and 9 new in ALMA ES

**PdBI** 33% ALMA ES line sensitivity, 50% ALMA continuum

# Imaging Molecular Gas in a Nearby SB Galaxy

- Aim: physical conditions, dynamics, distribution of gas and dust.
- Typical size 1kpc, distance 10x Mpc
- ALMA ES: the nearest ones
- Starting point: SMA data for NGC 3256 (Sakamoto et al 2006)

$$L_{\text{FIR}} = 10^{11.56} L_{\text{sol}} \quad D = 35.4 \text{Mpc} \quad (1'' = 170 \text{ pc})$$



# Imaging Molecular Gas in a Nearby SB Galaxy

- Excited molecular gas: e.g.  $^{12}\text{CO}$  (2-1),  $^{13}\text{CO}$  (2-1)

Band	Frequency (GHz)	Wave-length (mm)
3	84-116	2.6-3.6
6	211-275	1.1-1.4
7	275-373	0.8-1.1
9	602-720	0.4-0.5

Angular Resolution (") =  
 $0.2'' \times (300/\nu \text{ GHz}) \times$   
 ( 1 km / max. baseline )  
 FOV =  $20.3'' \times (300/\nu \text{ GHz})$

$^{12}\text{CO}(2-1), ^{13}\text{CO}(2-1)$  1" 30"  
 = 220 GHz

Full array  
 Up to 16 km  
 1" --> 0.02"



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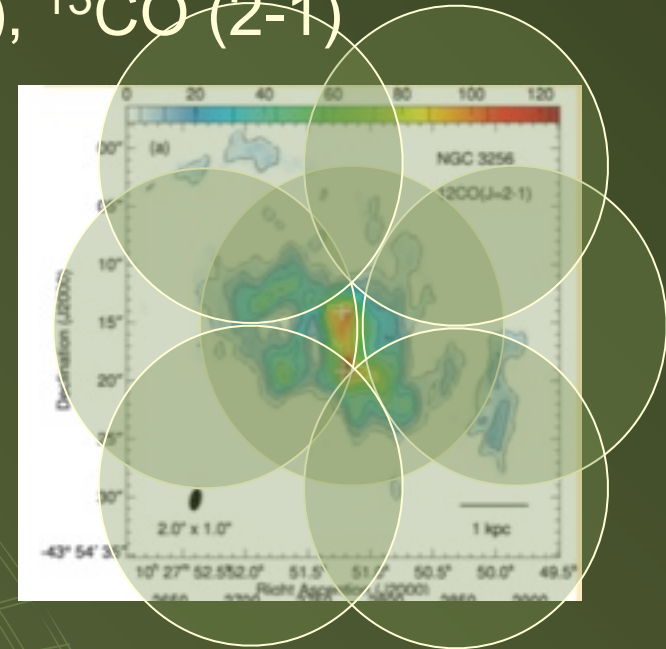
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$^{12}\text{CO}(2-1)$   
mosaic for extended  
emission

# Imaging Molecular Gas in a Nearby SB Galaxy

SMA data:  $^{12}\text{CO}(2-1)$  230 GHz

$dV = 10 \text{ km/s}$

T peak  $> 2\text{K}$  @  $1.5''$  resol

Target: 1 sigma = 0.2 K

$dV = 1.5 \text{ km/s}$

(FWHM SF clouds  $10 \text{ km/s}$ )

$1.5 \text{ km/s @ } 230 \text{ GHz} =$

$1.15 \text{ MHz}$

Dec: -43:54:35.000  
Polarization: Dual  
Observing Frequency: 230.0 GHz  
Bandwidth per Polarization: 1.15 MHz  
Water Vapour Column Density: Calculator Chooses  
tau/Tsky: tau=0,136, Tsky=37,814 K  
Tsys: 155,084 K

## Individual Parameters

	12m Array	<u>Band 6: 1'' resol</u>	7m Array
Number of Antennas	16		0
Resolution	1.0 arcsec		8,961831 arcsec
Sensitivity(rms)	0.2 K		Infinity Jy
(equivalent to)	0,00785 Jy		Infinity K
Integration Time	24,86468 min		Integration Time Unit Option

Calculate Integration Time

Calculate Sensitivity

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$dV = 10$  km/s

T peak 1/10  $^{12}\text{CO}$

Target: 1 sigma = 0.02 K

$dV = 20$  km/s

The screenshot shows a software interface for calculating observation parameters. It includes fields for RA, polarization, observing frequency, bandwidth, and various physical parameters like tau/Tsky and Tsys. Below these are 'Individual Parameters' for two different array configurations: a 12m Array and a 7m Array. The 12m Array parameters are: Number of Antennas: 16, Resolution: 1.0 arcsec, Sensitivity(rms): 0.02 K, (equivalent to): 0,00000 Jy, Integration Time: 3,10593 h. The 7m Array parameters are: Number of Antennas: 0, Resolution: 8,961831 arcsec, Sensitivity(rms): 0,00000 Jy, (equivalent to): NaN K, Integration Time: infinity d. At the bottom are two buttons: 'Calculate Integration Time' and 'Calculate Sensitivity'. Green arrows from the text box on the left point to the observing frequency (230.0 GHz), bandwidth (20.0 km/s), and the 0.02 K sensitivity field in the 12m Array section.

RA	-43:54:35.000
Polarization	Dual
Observing Frequency	230.0 GHz
Bandwidth per Polarization	20.0 km/s
Water Vapour Column Density	Calculator Chooses
tau/Tsky	tau=0,136, Tsky=37,814 K
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Integration Time Unit Option

Calculate Integration Time      Calculate Sensitivity

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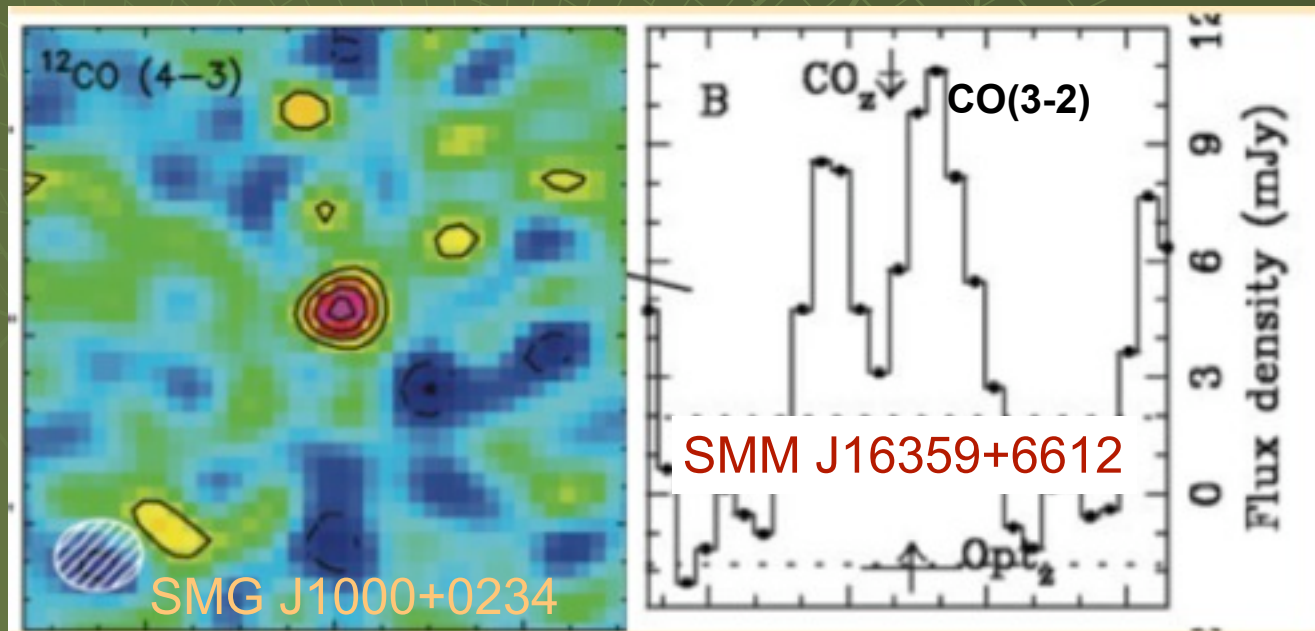
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Resolution	1.0 arcsec	8,961831 arcsec
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(equivalent to)	0,00000 Jy	NaN K
Integration Time	3,10593 h	$\infty$ d

Calculate Integration Time      Calculate Sensitivity

# Molecular Gas & Dust in Submm galaxies

- Submm galaxies trace a large fraction of SF at  $z$  1-3
- Detected with single dish (low-res). Counterpart: deep cm + optical/NIR spec
- Aim: location and redshift, molecular gas and dust mass
- ALMA ES: large band, high- $z$  CO lines
- Full ALMA: spatially resolved obs.

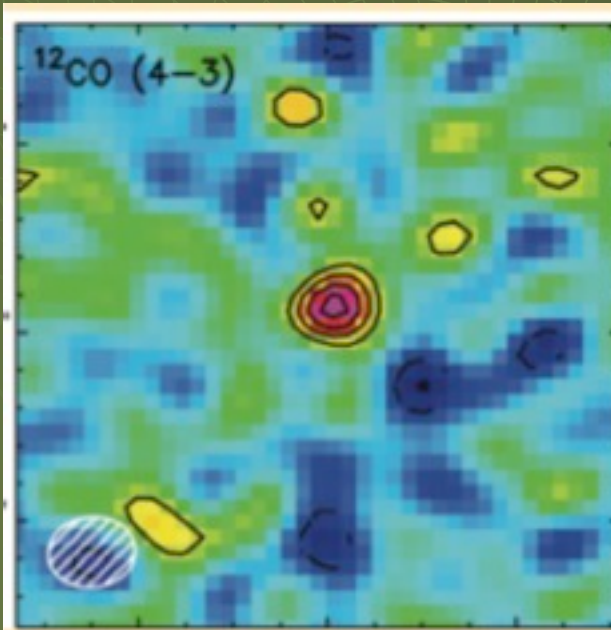


$dv = 50$  km/s  
@OVRO  
(Sheth et al. 2004)

# Molecular Gas & Dust in Submm galaxies

Sample: Survey of COSMOS-AzTEC sources,  $S_{1.1\text{mm}} > 3.5$  mJy

- Brighter at high- $\nu$  --> 345 GHz (0.8 mm).  $S_{0.8\text{mm}} > 5$  mJy ( $\beta = 2$ )
- Extended/resolved?: S/N = 10 for astrometry

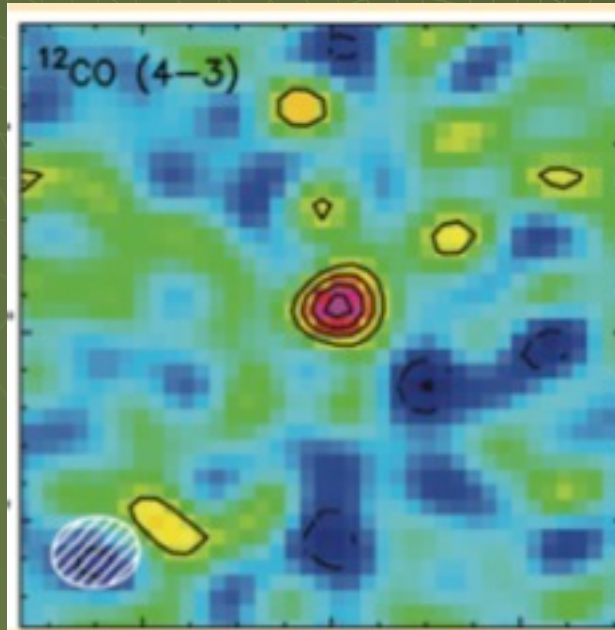




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Continuum observations for location

345 GHz = 0.7''

Continuum mode 69 provides 16GHz bandwidth

S/N = 10 --> 0.5 mJy

Full ALMA: spatially resolved obs.

# Molecular Gas & Dust in Submm galaxies

345 Ghz = 0.7"

Continuum mode 69

provides 16GHz bandwidth

S/N = 10 --> 0.5 mJy

## Common Parameters

Dec	00:00:00.000	
Polarization	Dual	
Observing Frequency	345.0	GHz
Bandwidth per Polarization	8.0	GHz
Water Vapour Column Density	Calculator Chooses	
tau/Tsky	tau=0,211, Tsky=55,786 K	
Tsys	272,332 K	

## Individual Parameters

	12m Array		7m Array
Number of Antennas	16		0
Resolution	0.7	arcsec	5,974554 arcsec
Sensitivity(rms)	0.5	mJy	0,00000 Jy
(equivalent to)	0,01156	K	NaN K
Integration Time	3,13970	min	∞ d

Integration Time Unit Option

Calculate Integration Time

Calculate Sensitivity

# Molecular Gas & Dust in Submm galaxies

Line      Band 3      80-115.5 GHz (3mm)      Ang resol = 2.5"

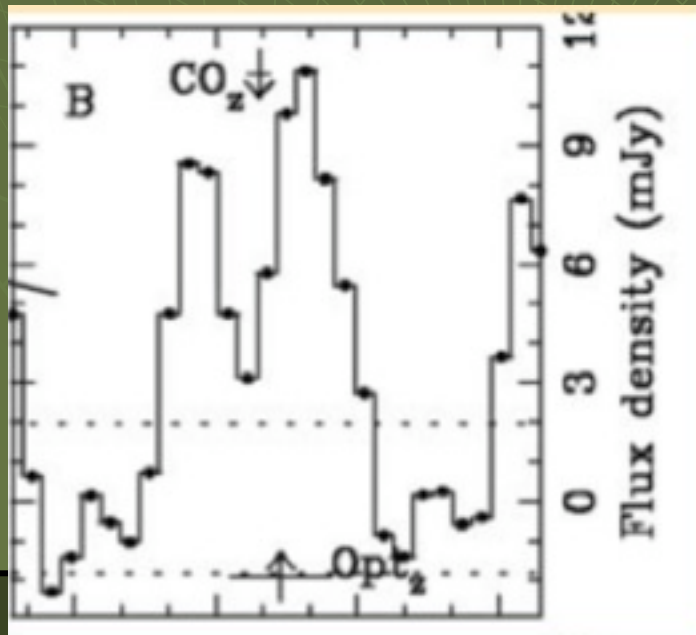
CO(1-0):  $z=0.00-0.44$ , CO(2-1):  $z=1.00-1.88$ , CO(3-2):  $z=1.99-3.32$

Expected CO flux 1 - 4 Jy km/s  $\sim$  2Jy km/s spread in 400 km/s = 5 mJy

rms = 1mJy, or smoothing 1.5 km/s  $\rightarrow$  100 km/s

rms = 8 mJy (67 ch binning)

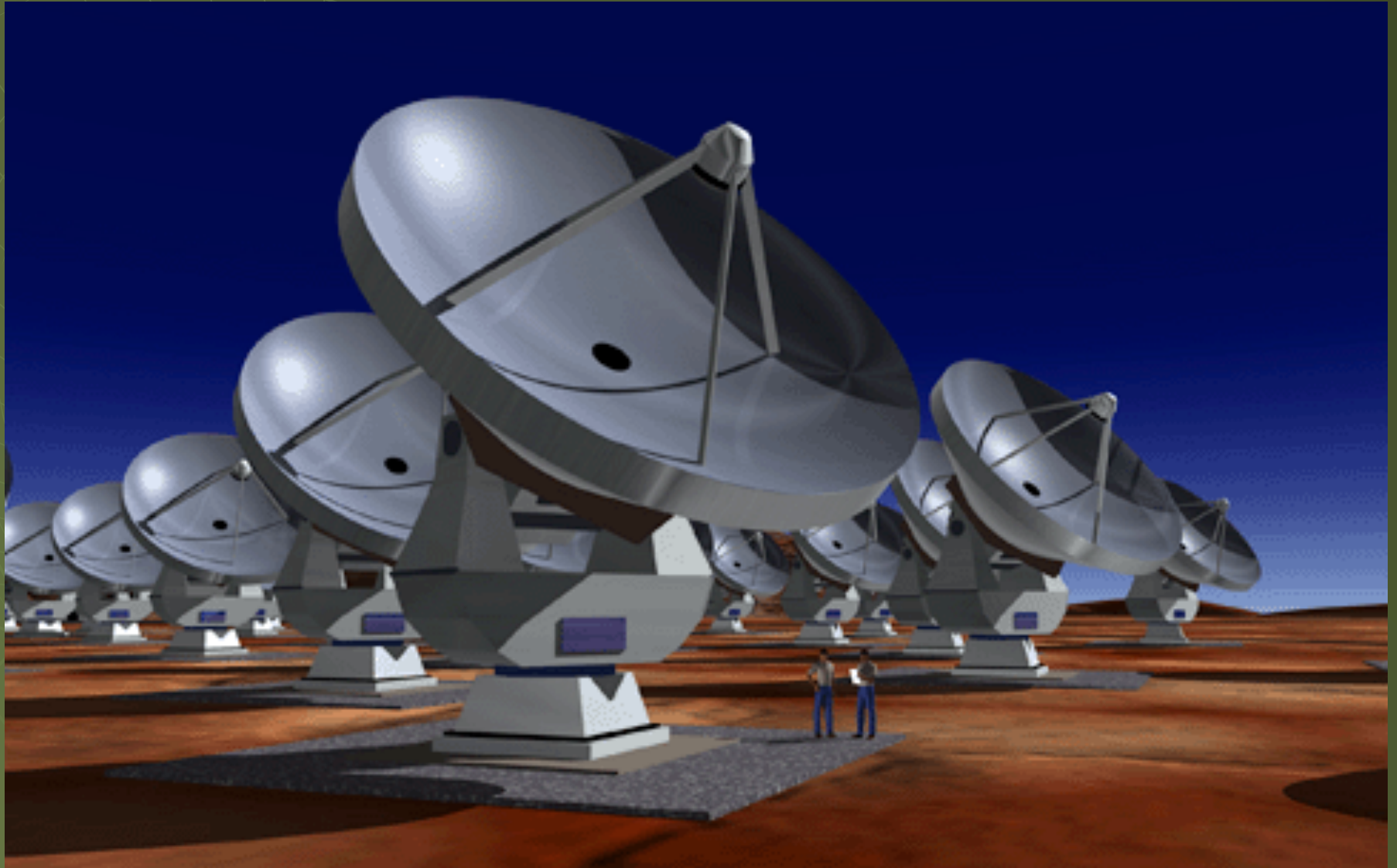
Sensitivity calculator = 10 min



Mode 7 provides 3.75 GHz bandwidth in a sideband  $\rightarrow$  tuning to 5 freq/band

total time = 10 x 5 = 50 min/galaxy

**FOR MANY YEARS WE HAVE SEEN THIS**



**JORNADA ESO 2011 GRANADA**

**AND NOW !!!!**

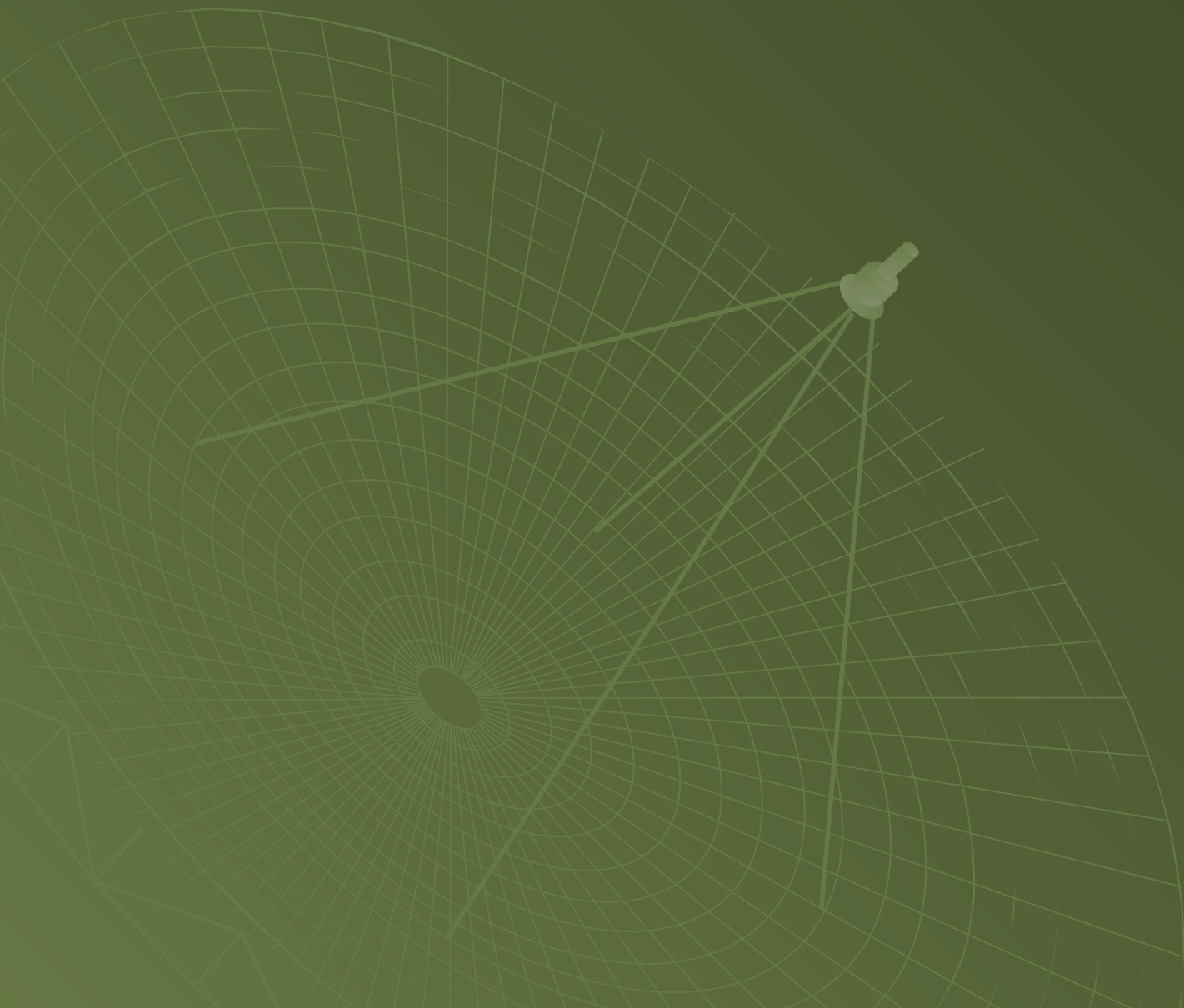


**AND NOW !!!!**



**Hence...**

**let's not wait, let's apply for ES!**



**16:00 Sala de Juntas**  
**Informal meeting of ESO users**

**Give me your feedback on:**

- 1) ANY ISSUE**
- 2) Apex**
- 3) People planning to use VISTA public data**
- 4) GAIA members involved in FLAMES surveys**