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"

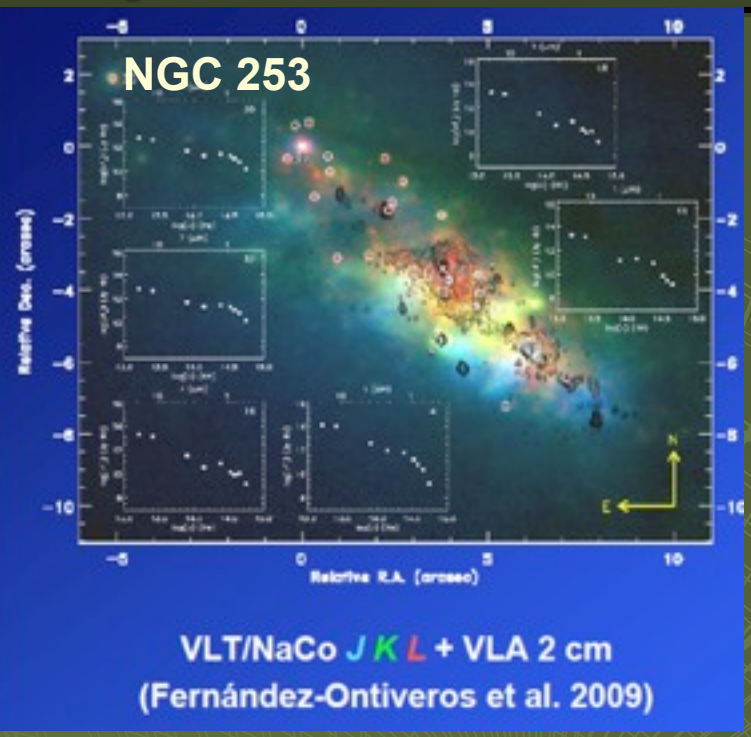
ALMA Early Science

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

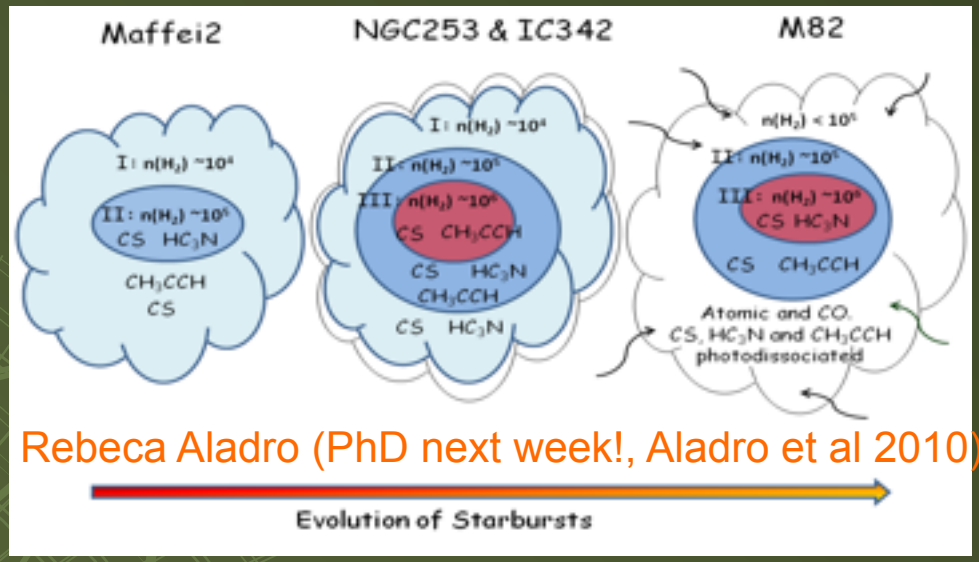
- **16 antennas, 2 compact configurations, single field interferometry, maybe small mosaics**
  - **Bands 3, 6, 7 and 9**

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

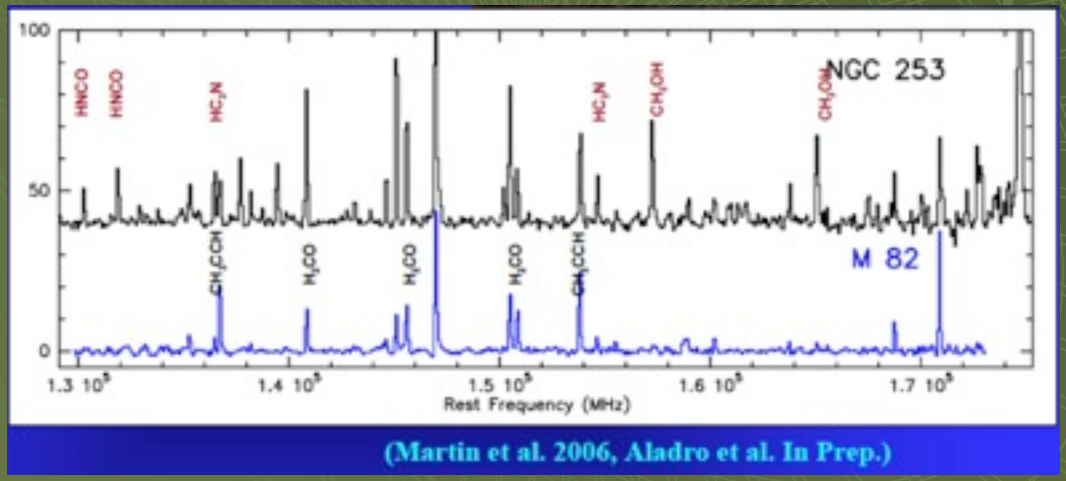


VLT/NaCo *J K L* + VLA 2 cm
(Fernández-Ontiveros et al. 2009)



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

Different molecular abundances indicative of a different evolutionary stage

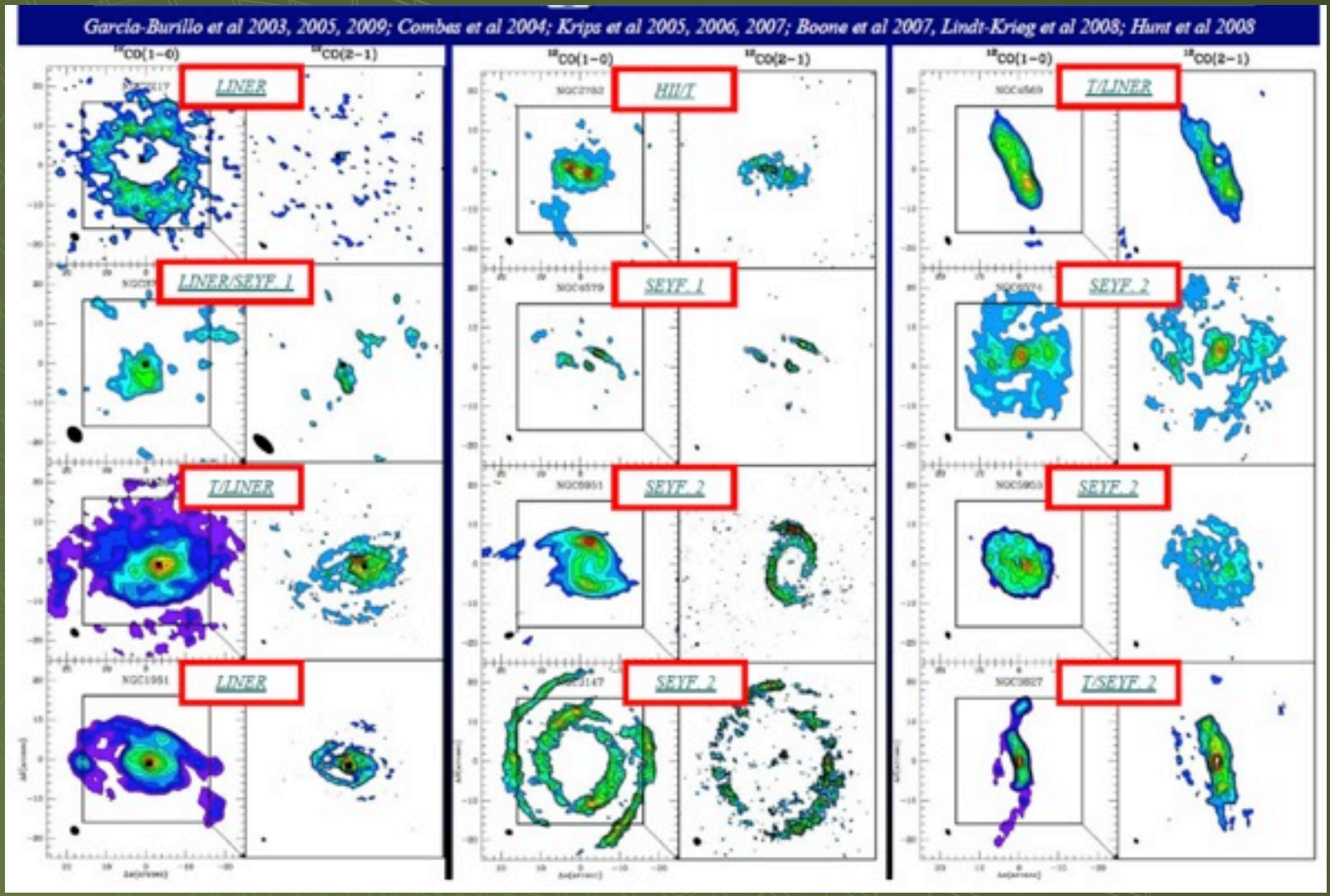


(Martin et al. 2006, Aladro et al. In Prep.)

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

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

Resolved studies: NUGA (García-Burillo et al)



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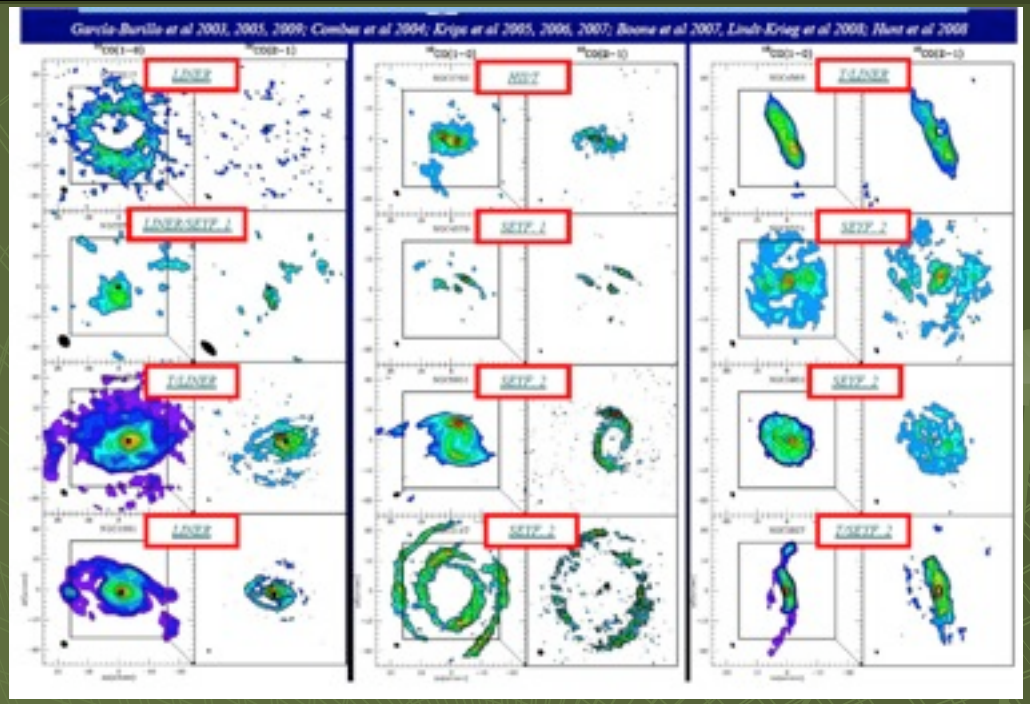


Sensitivity

PdBI

M(H2)~$10^5 M_{sol}$ in15-20h

ALMA

~$10^4 M_{sol}$ in ~1.5h

Ang. resolution

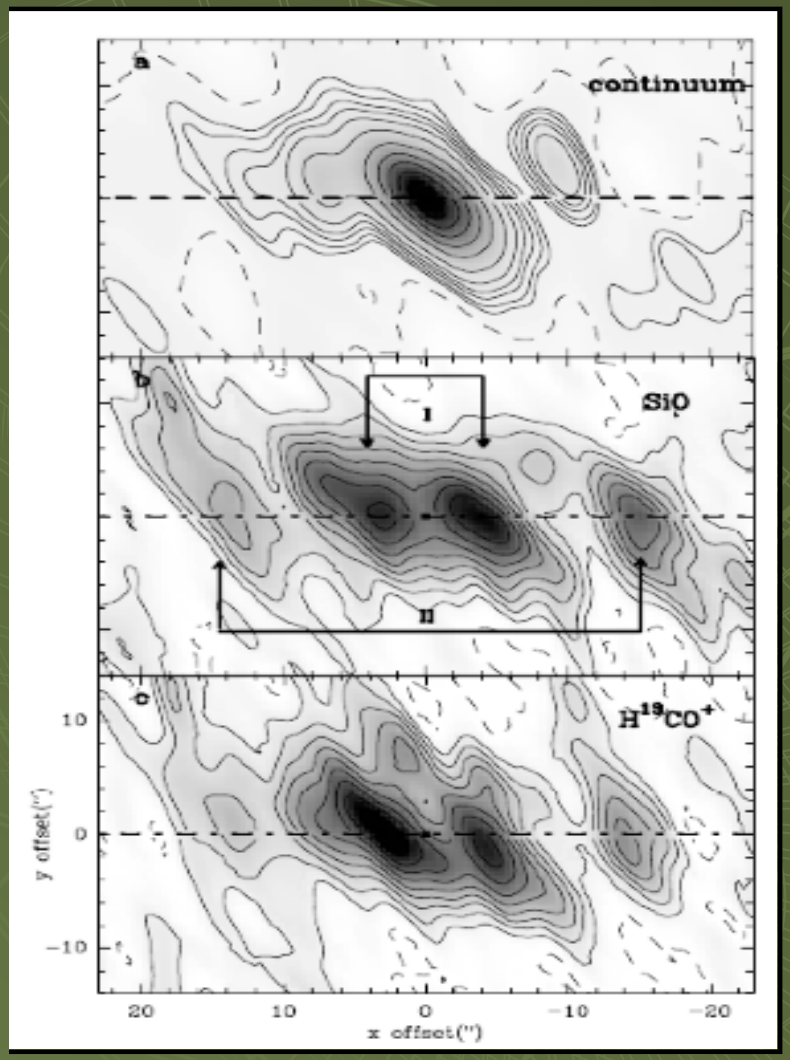
PdBI 0.5´´ = 12-72 pc @ 5-30Mpc

ALMA 0.05´´-0.1´´ = 1-10 pc @5-30 Mpc

- CO and NIR maps at ~0.1´´: accurate gravity torque maps
- New feeding mechanims 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 $H^{13}CO+$

Beam size= 7.5" x 2.6" @ 87 GHz

(Courtesy of R. Aladro)

D=3.4 Mpc >> 1" ~ 20 pc

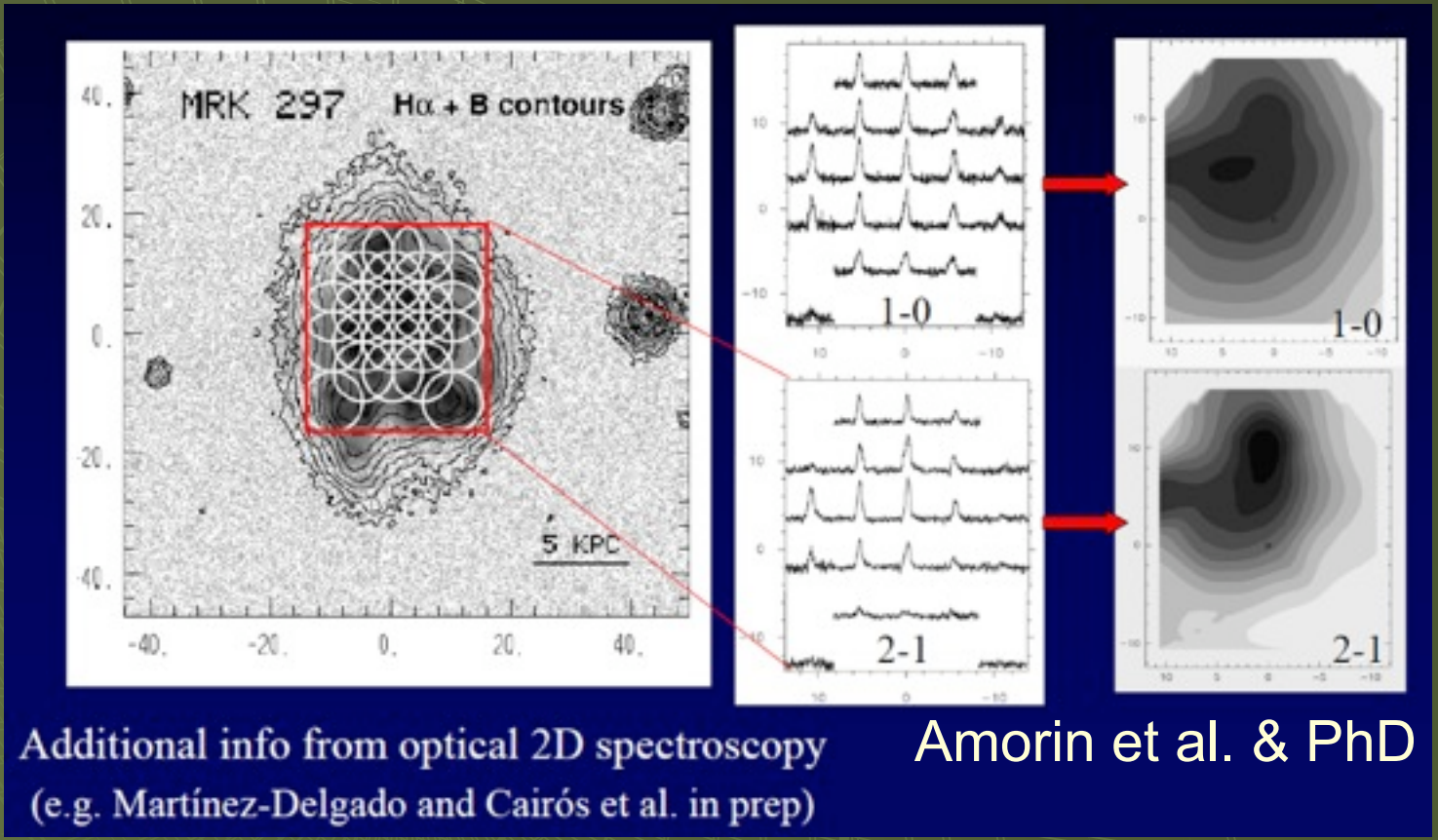
Typical molecular cloud size ~ 10-40 pc

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

Molecular clouds resolved and virial mass estimated

Dwarf galaxies

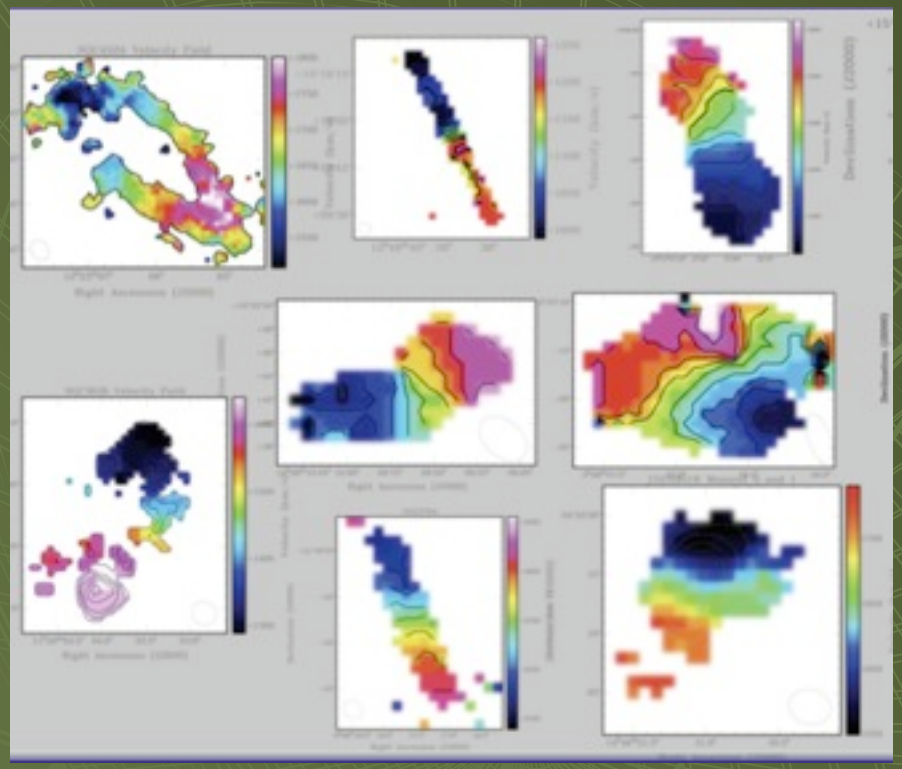
Blue compact galaxies as part of Estallidos project



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)



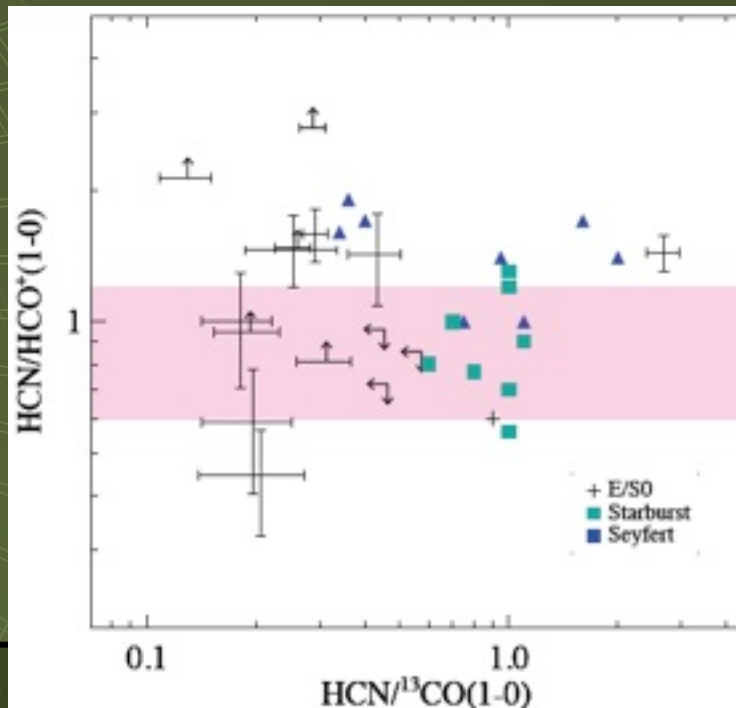
Mapping with mm interferometers:

H_2 and stars:

aligned in clusters/Virgo

randomly misaligned in field

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



Reference for environment

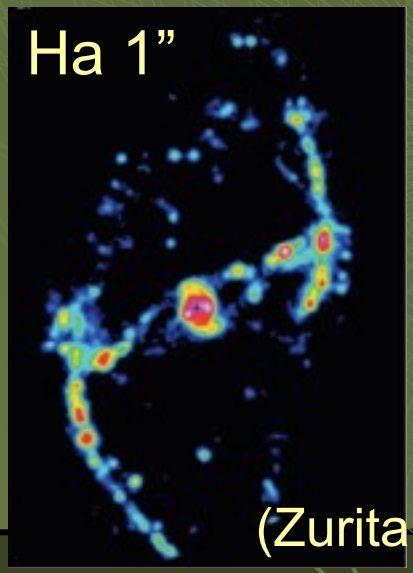
Isolated galaxies (AMIGA project)

Different physical properties from field & loose groups samples:

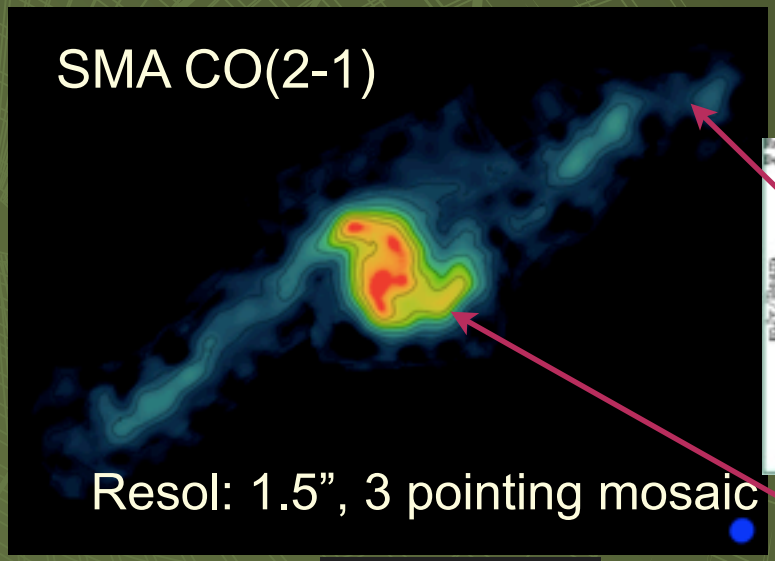
- Dominated (66%) by small-bulge Sb-Sc
- 14% low-L early-type galaxies
- Optical asymmetry, clumpiness and concentration minimized
- Lowest: LFIR, 0% radio-excess, rate of AGNs (22%), HI asymmetry (< 20%), molecular gas content

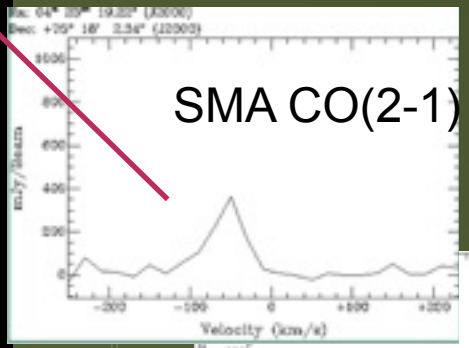
Unique for ALMA to quantify the role of the environment on galaxy evolution

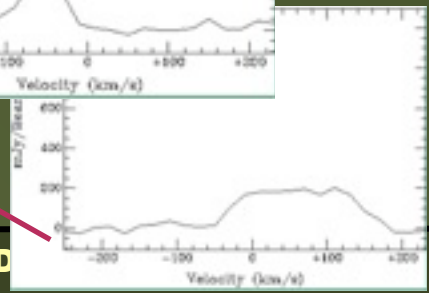
Isolated galaxies (AMIGA project)



(Zurita et al 2004)

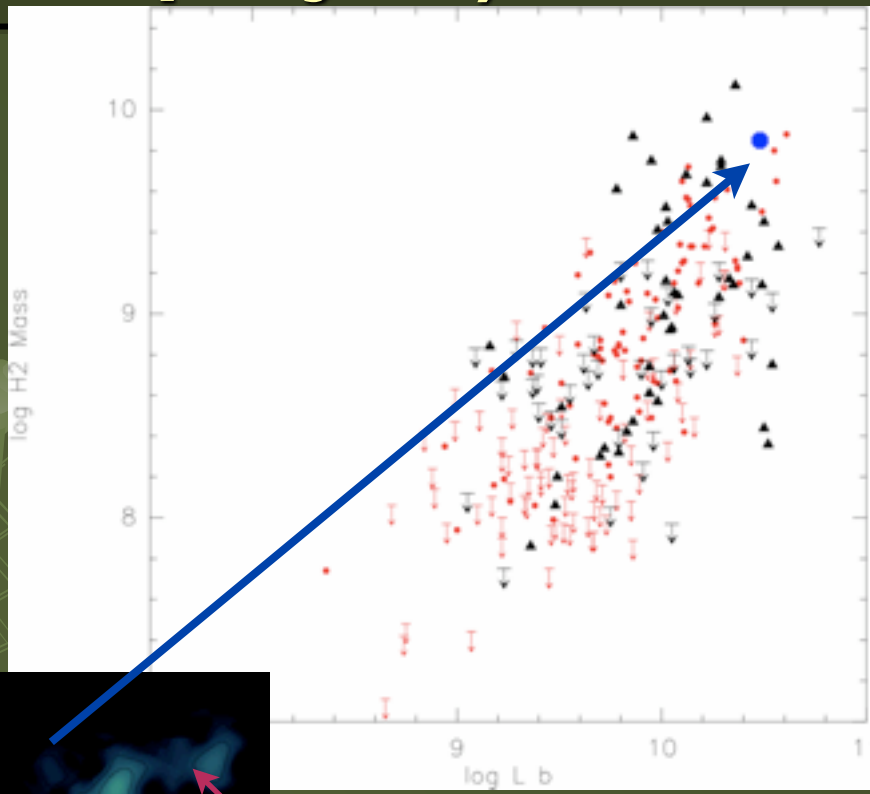


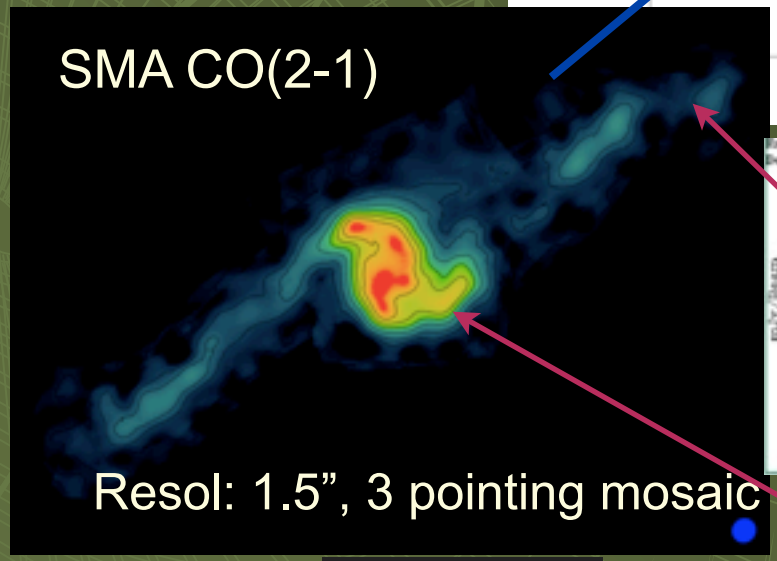


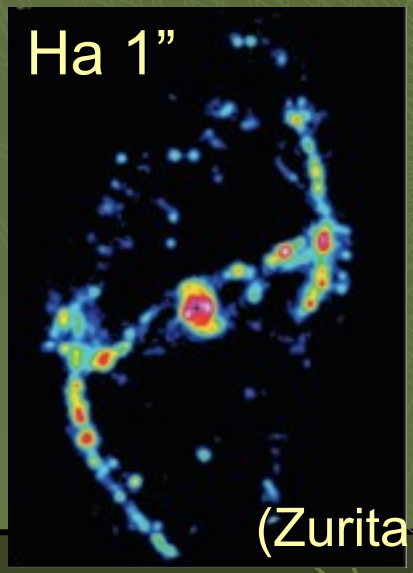


CIG 147

Isolated galaxies (AMIGA project)







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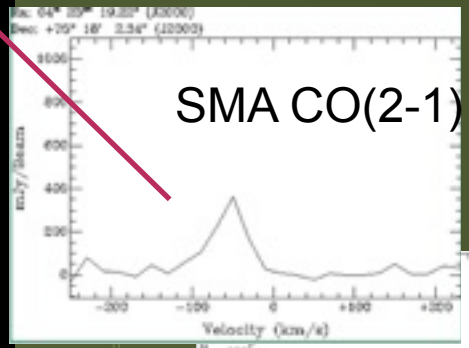
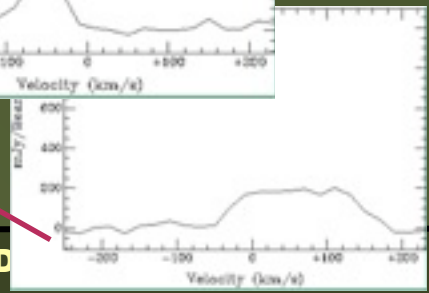


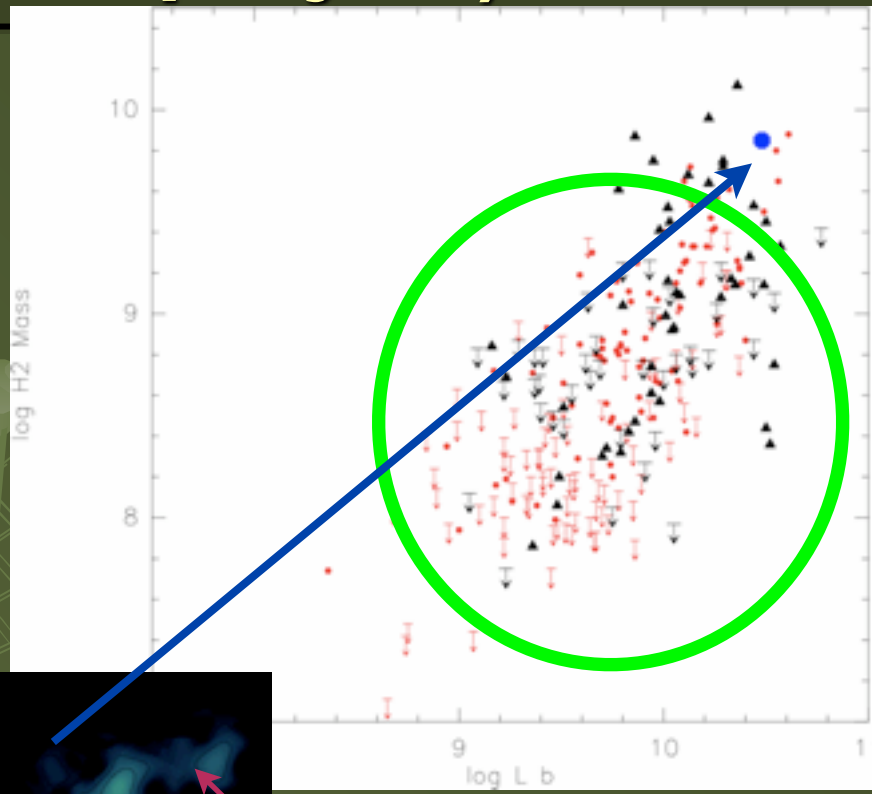


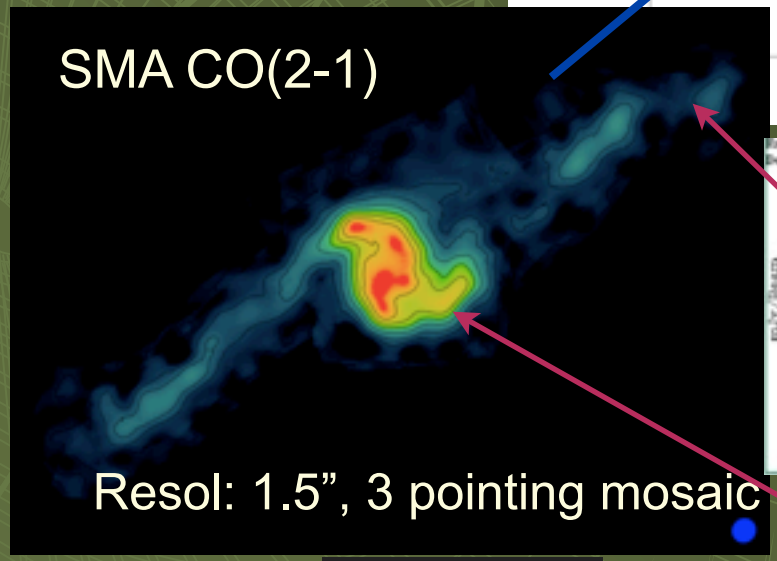
Isolated galaxies (AMIGA project)

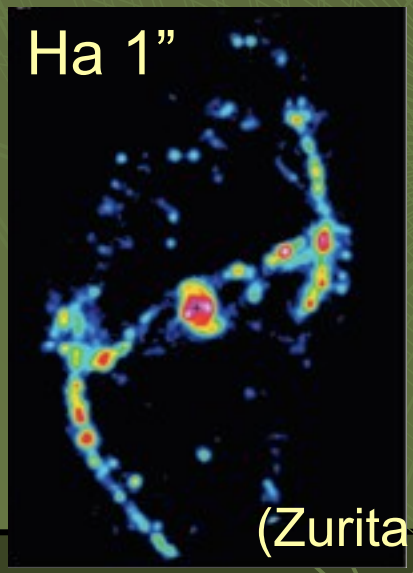
ONLY FEASIBLE WITH ALMA

Dec < 37
Size < 2’
N = 77 galaxies
dv= 10 km/s
1” (160 pc @ v = 2500 km/s)

ALMA CO(1-0) 50h







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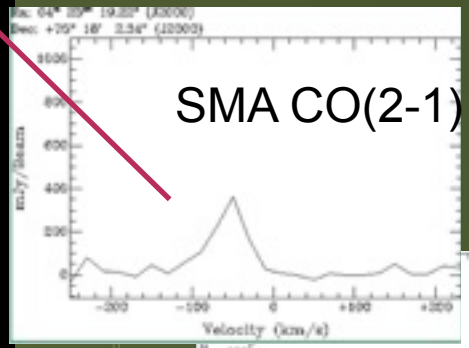
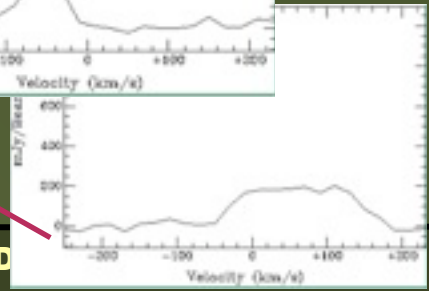
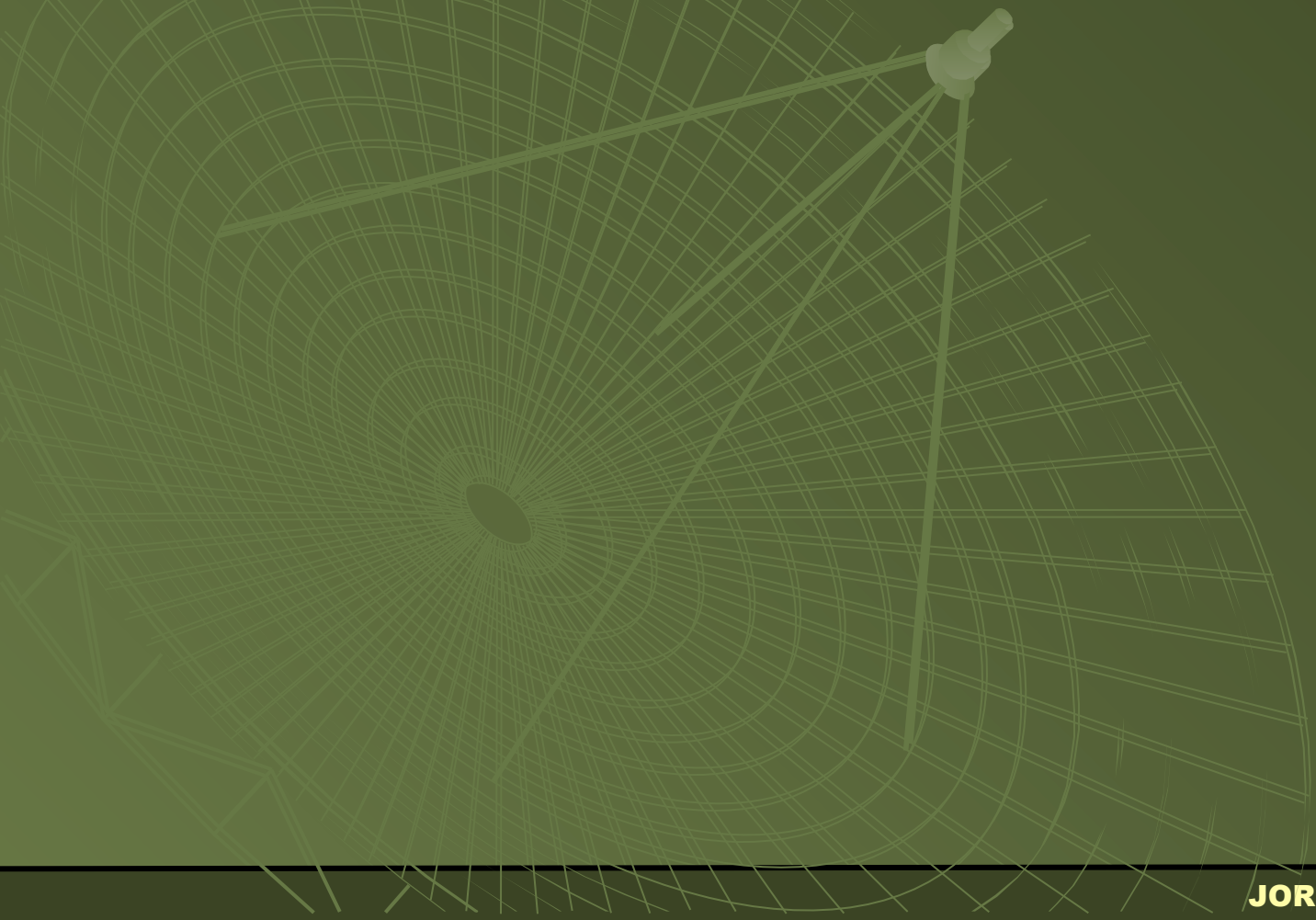




CIG 147

Role of ALMA

- Bandwidth crucial:
  - Chemistry and gas excitation - multiple lines
  - AGN dynamics and outflows - wings



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- 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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  - CO concentration in Es
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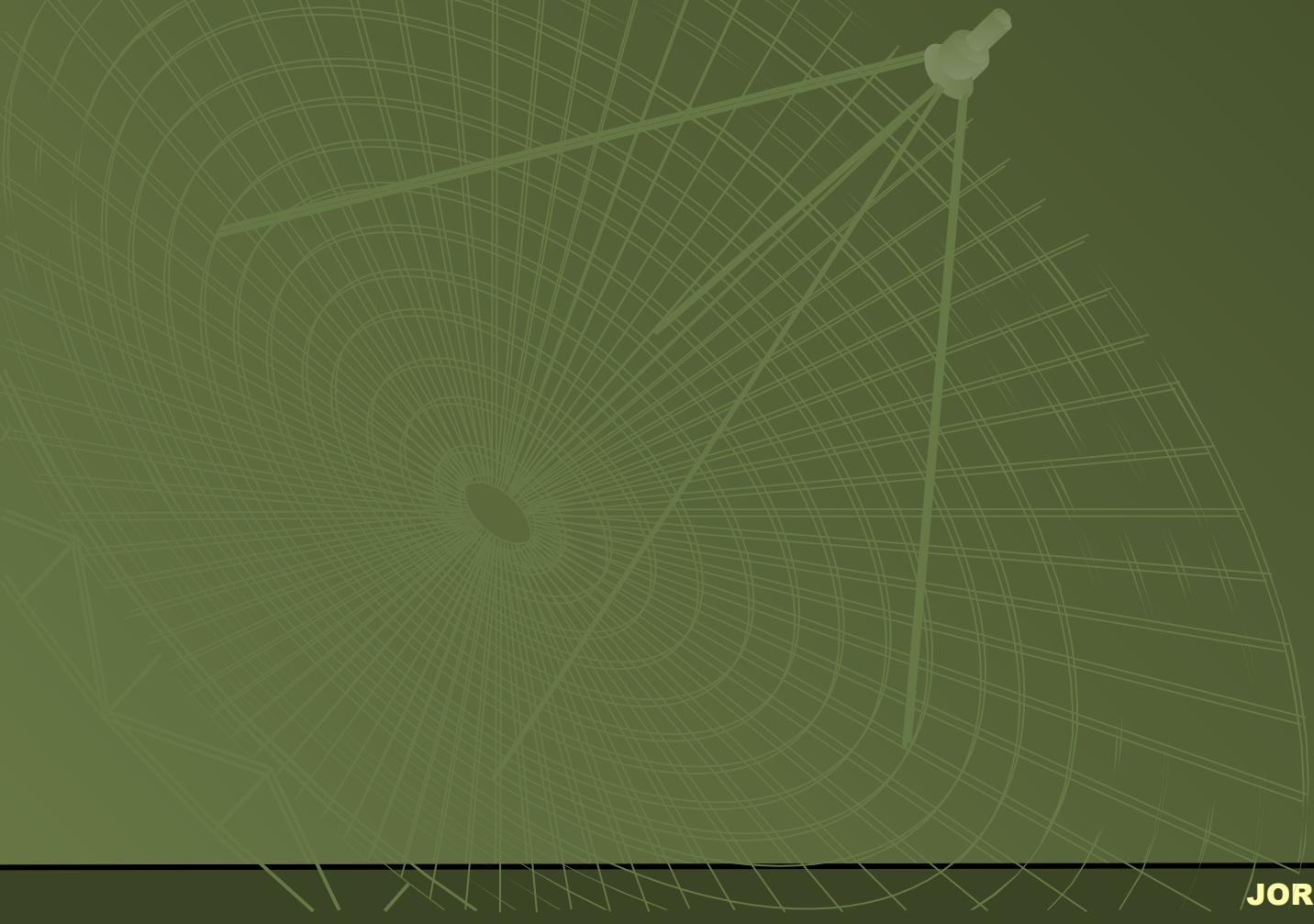
- Sensitivity:
  - All above plus probing also (faintest) galaxies: isolated, normal Es, etc

To be combined with chemical models (see Fuente's talk in RIA's ALMA workshop)

Extragalactic Astronomy

- LIRGs/ULIRGs powering source:

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



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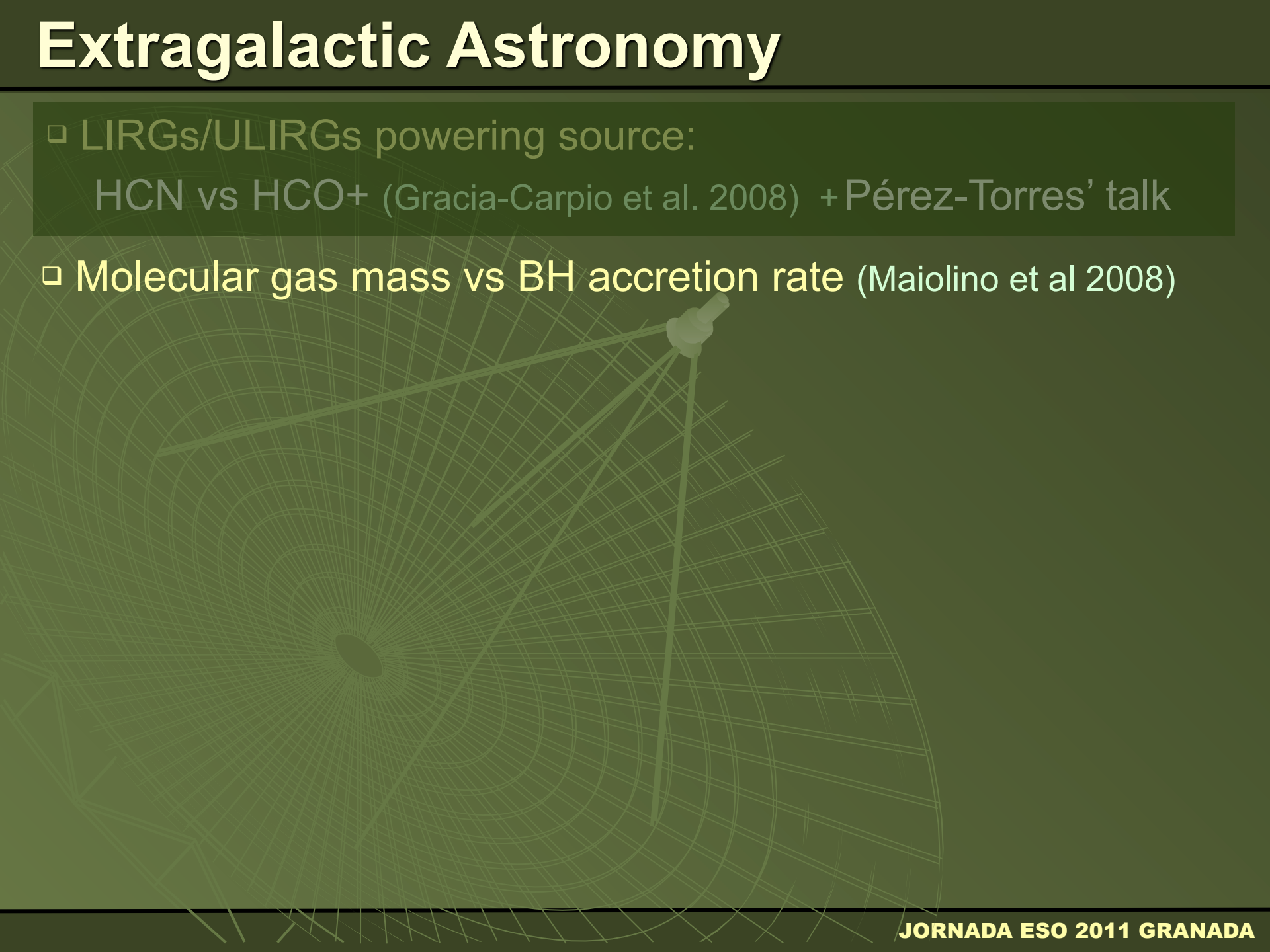

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  see example on SMGs next +Rodríguez-Espinosa's talk

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- [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 arcm 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)

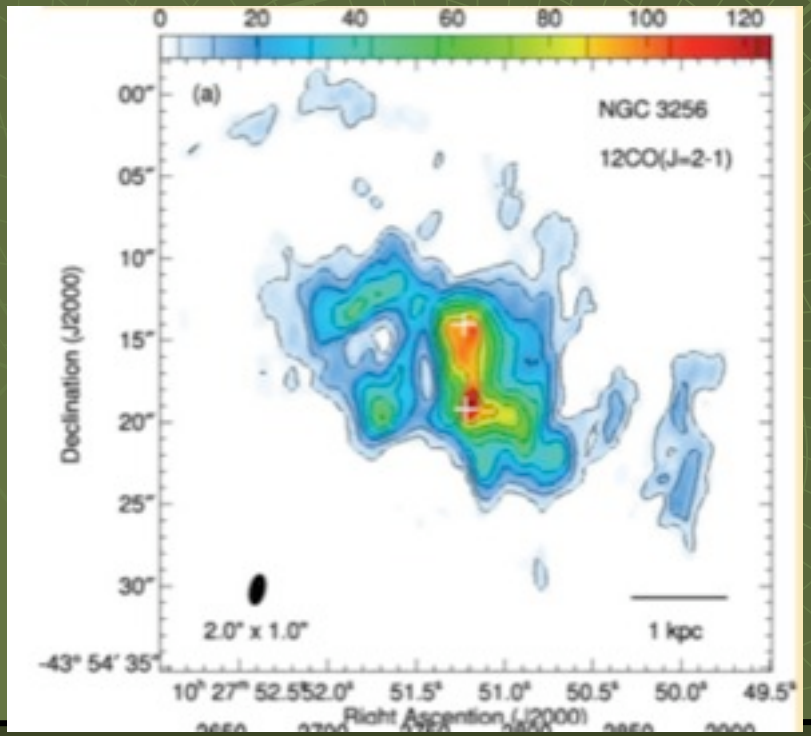
PdBI E-W baseline 0.8 km, **ALMA ES** >250m
but higher freq. Bands 7 and 9 new in ALMA ES

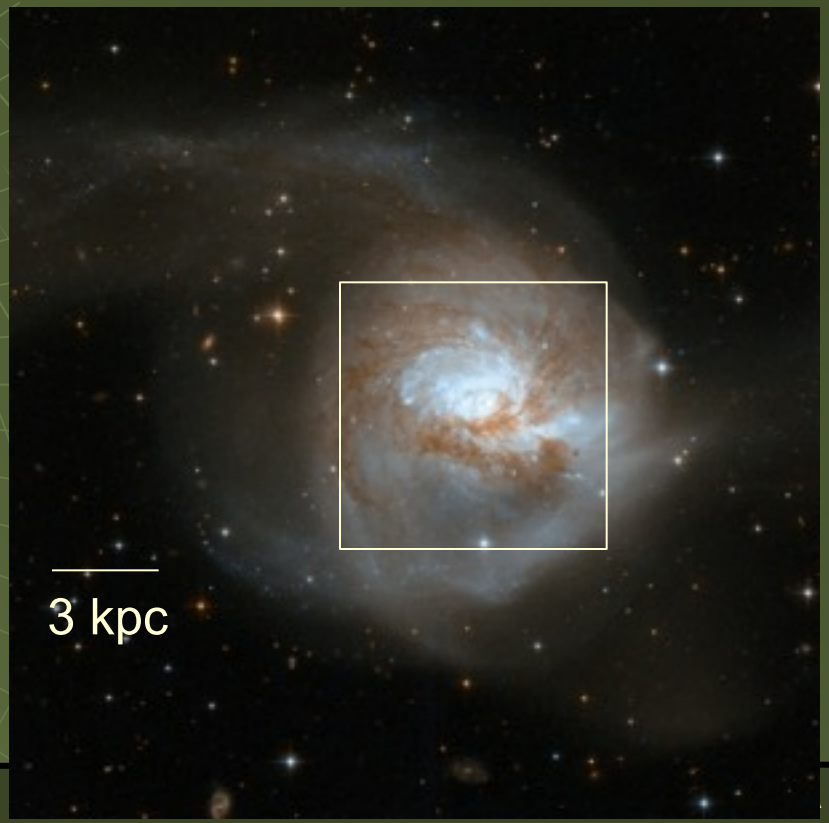
PdBI 33% ALMA ES line sensitivity, 50% ALMA continuum

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)

$L_{FIR} = 10^{11.56}$ Lsol D = 35.4Mpc (1" = 170 pc)





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

Band	Frequency (GHz)	Wave-length (mm)
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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” x (300/ν GHz) x

(1 km / max. baseline)

FOV = 20.3” x (300/ν GHz)

^{12}CO(2-1), ^{13}CO(2-1) = 220 GHz

1”

30”

Full array

Up to 16 km

1” --> 0.02”

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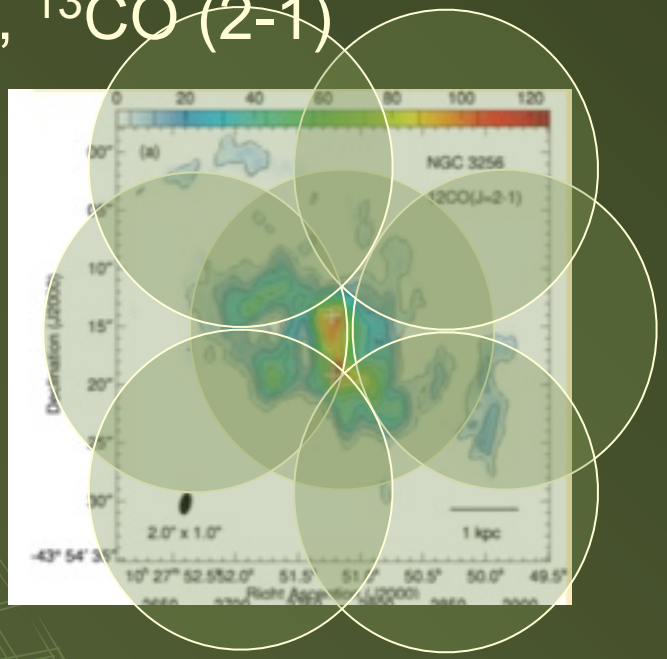


$^{12}CO(2-1)$ mosaic for extended emission

Imaging Molecular Gas in a Nearby SB Galaxy

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

dV = 10 km/s

T peak > 2K @ 1.5” resol

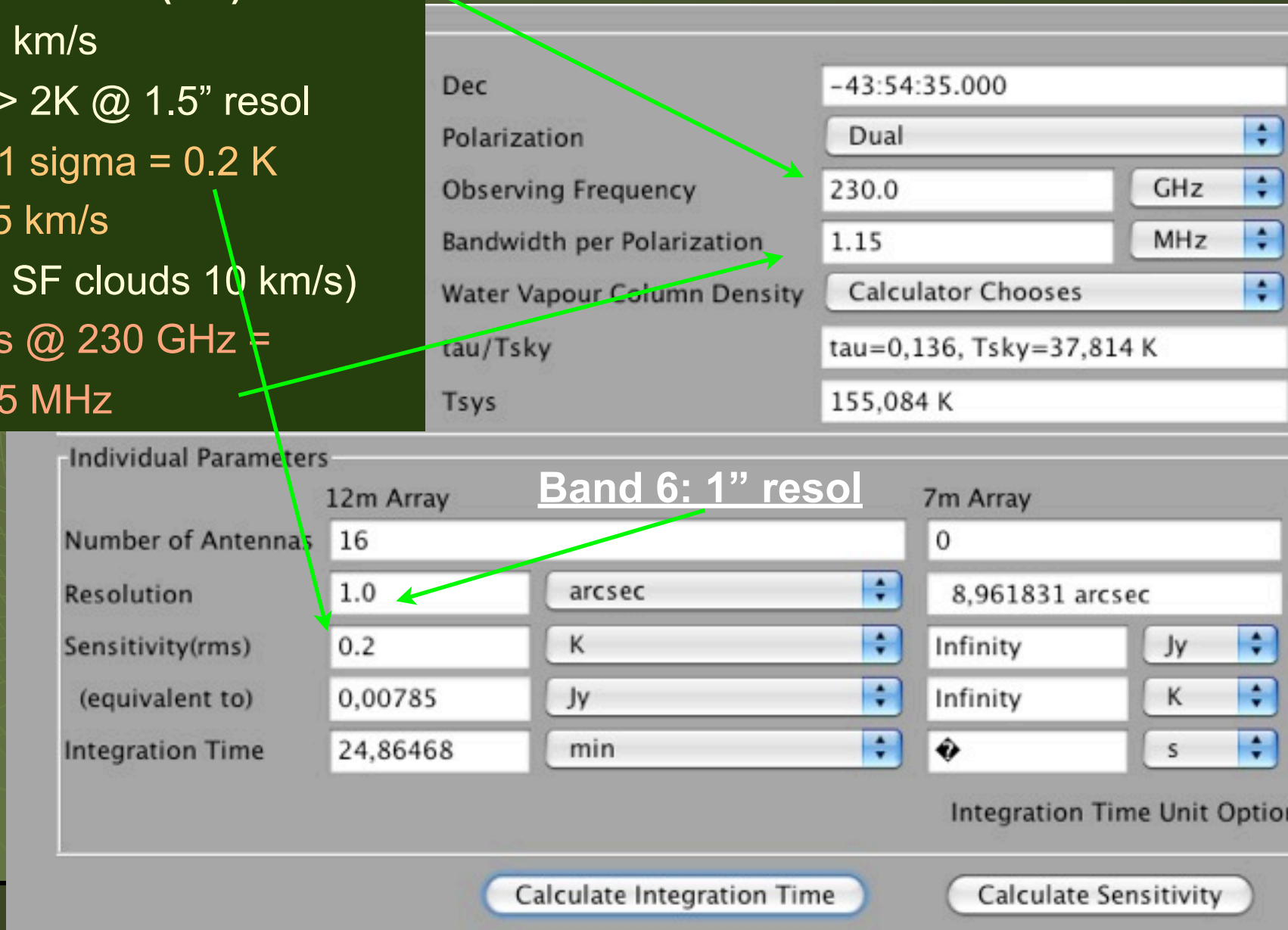
Target: 1 sigma = 0.2 K

dV = 1.5 km/s

(FWHM SF clouds 10 km/s)

1.5 km/s @ 230 GHz =

1.15 MHz



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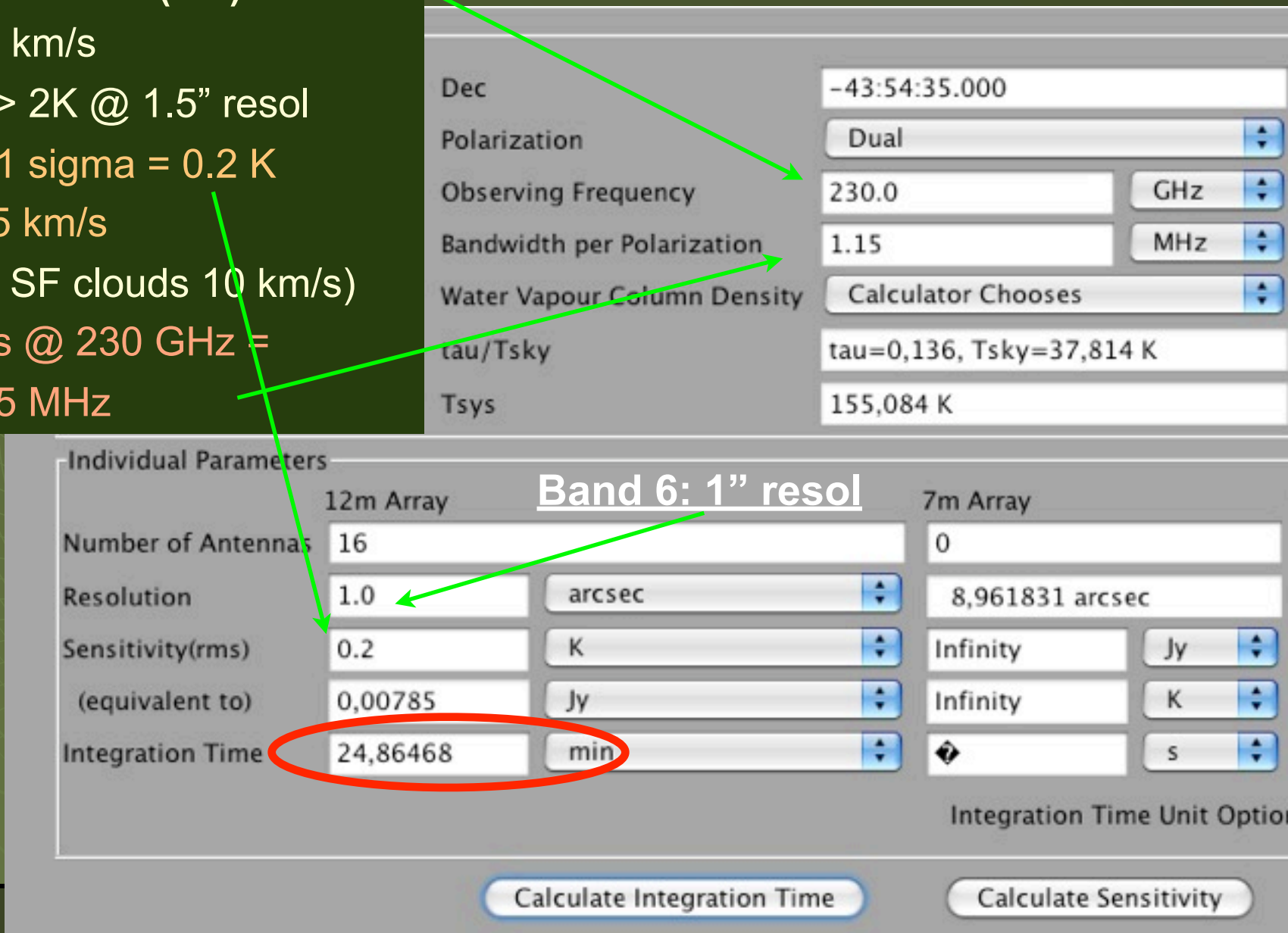

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T peak 1/10 ^{12}CO

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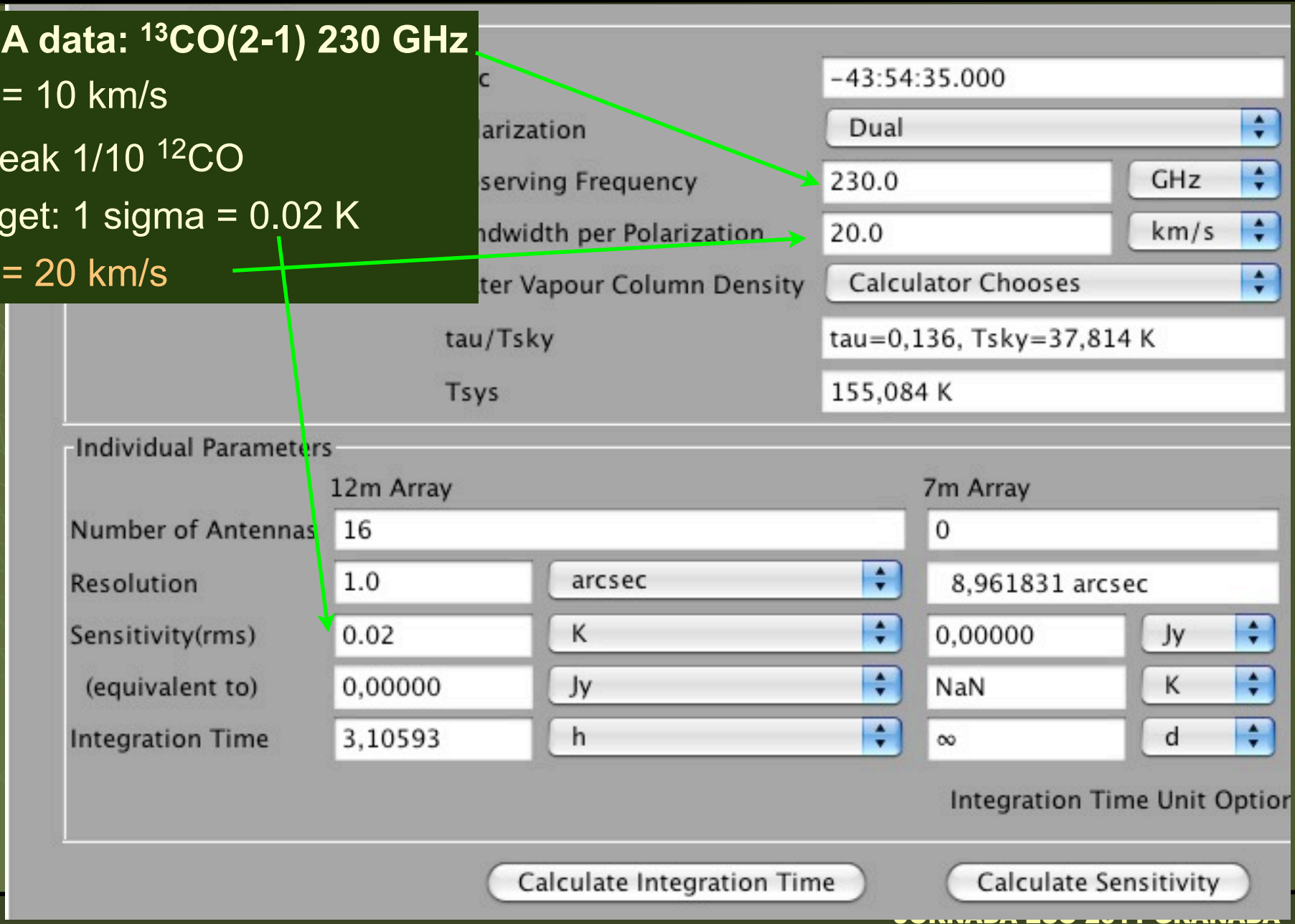

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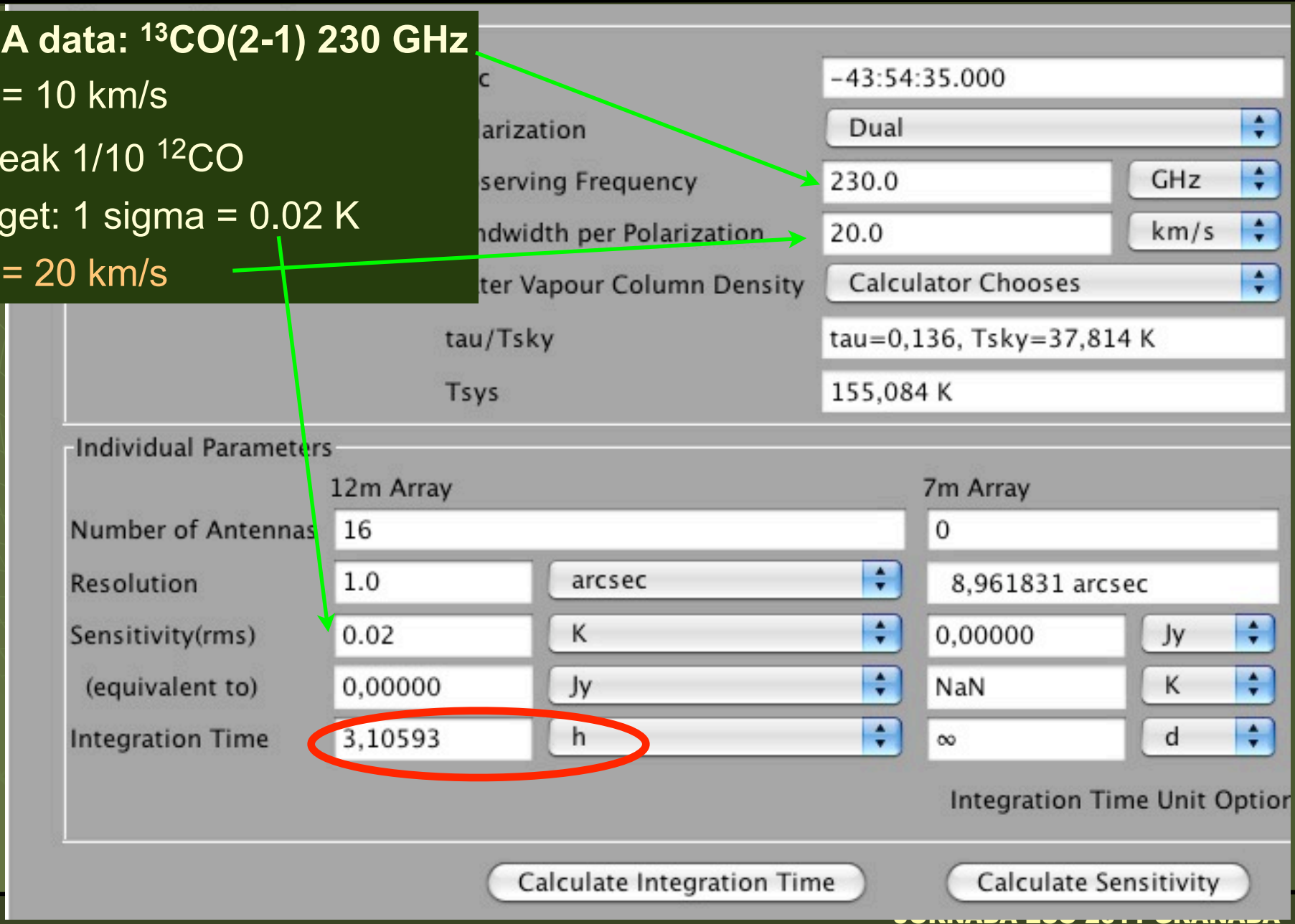
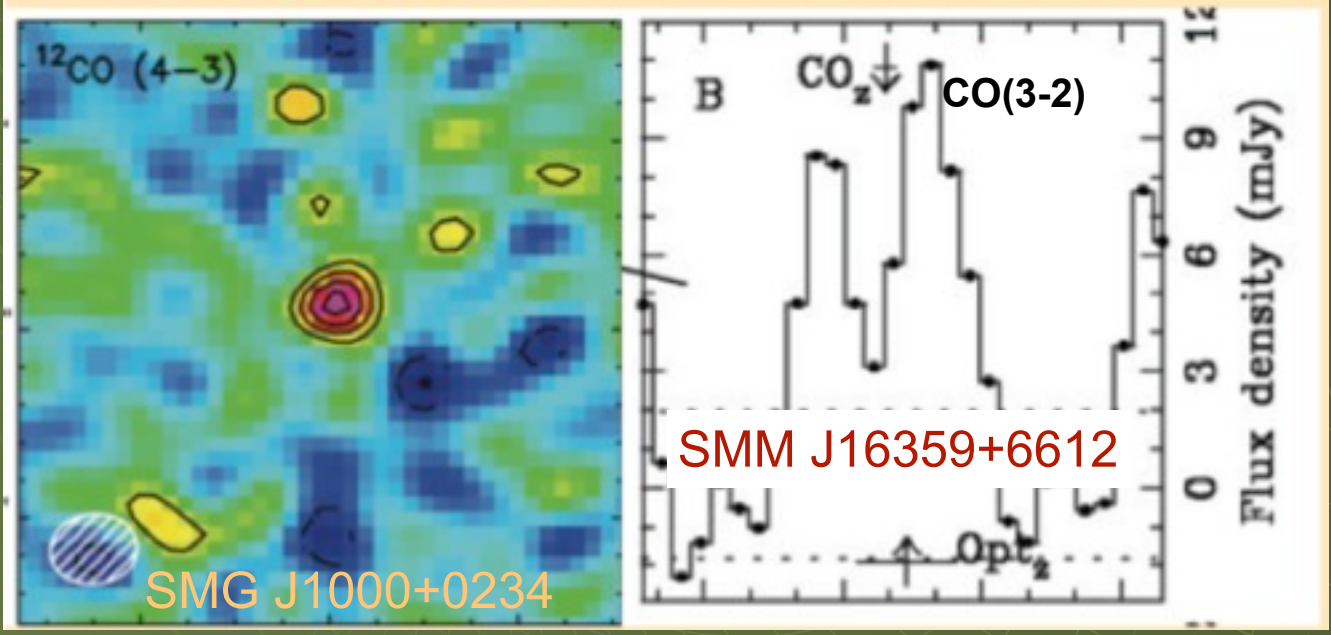


Molecular Gas & Dust in Submm galaxies

- 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.



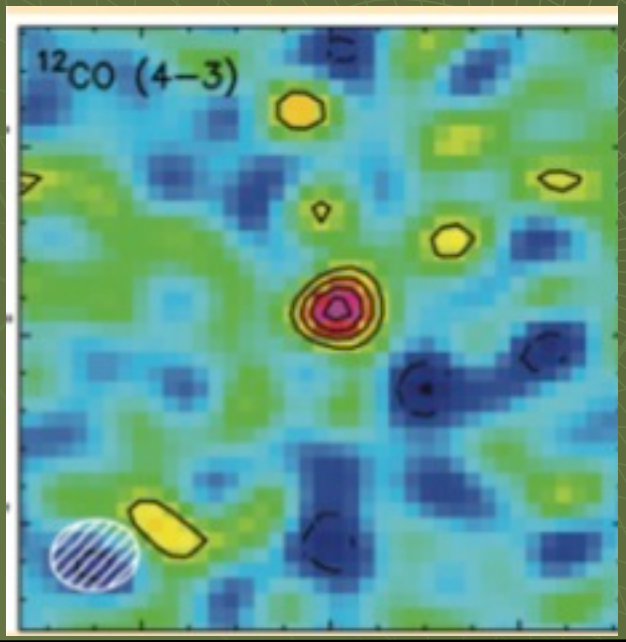
dv = 50 km/s
@OVRO
(Sheth et al. 2004)

z=4.5, PdBI (Schinnerer et al. 2008)

Molecular Gas & Dust in Submm galaxies

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

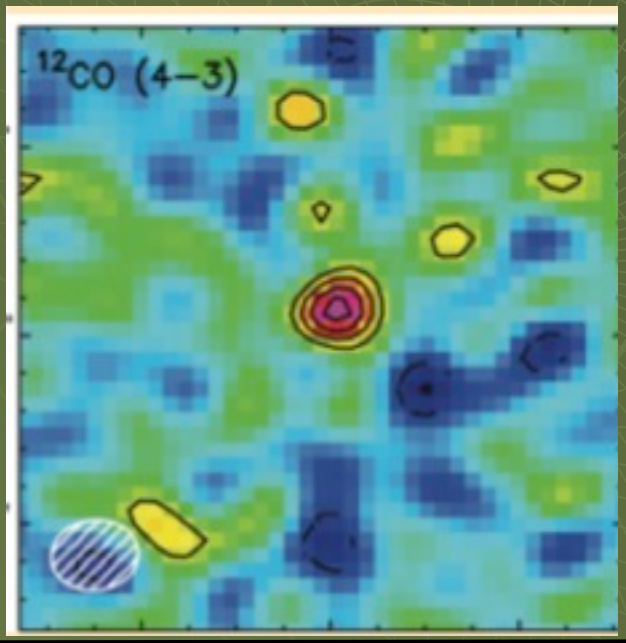
- Brighter at high-ν --> 345 GHz (0.8 mm). $S_{0.8mm} > 5$ mJy ($\beta = 2$)
- Extended/resolved?: S/N = 10 for astrometry



Molecular Gas & Dust in Submm galaxies

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

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



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.

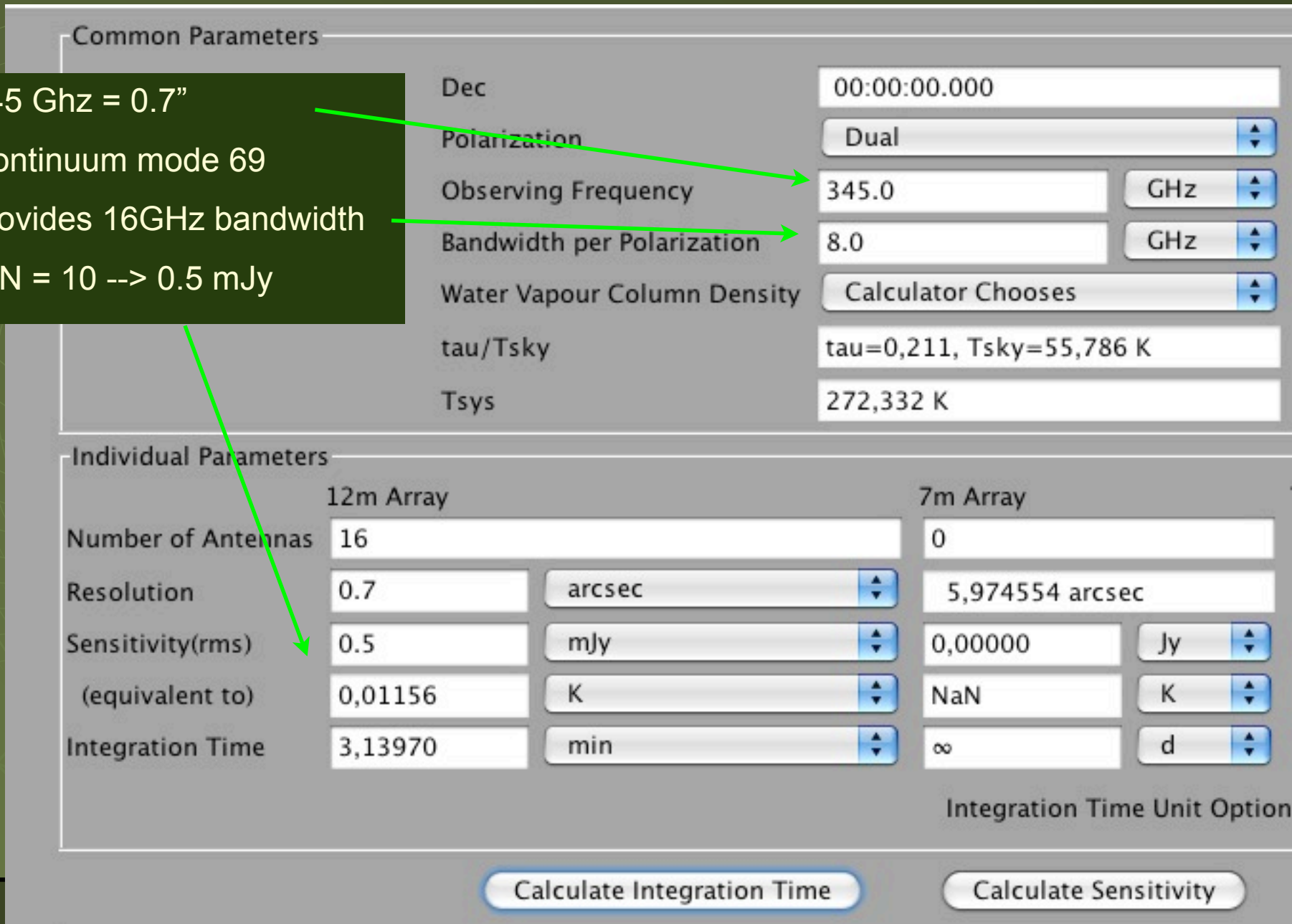
Molecular Gas & Dust in Submm galaxies

345 Ghz = 0.7”

Continuum mode 69

provides 16GHz bandwidth

S/N = 10 --> 0.5 mJy



Molecular Gas & Dust in Submm galaxies

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

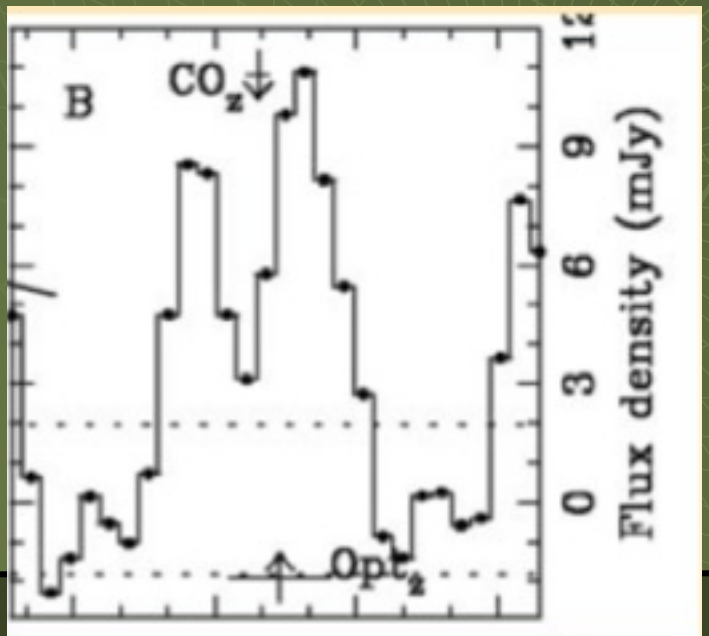
CO(1-0): z=0.00-0.44, CO(2-1): z=1.00-1.88, CO(3-2): z=1.99-3.32

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

rms = 1mJy, or smoothing 1.5 km/s --> 100 km/s

rms = 8 mJy (67 ch binning)

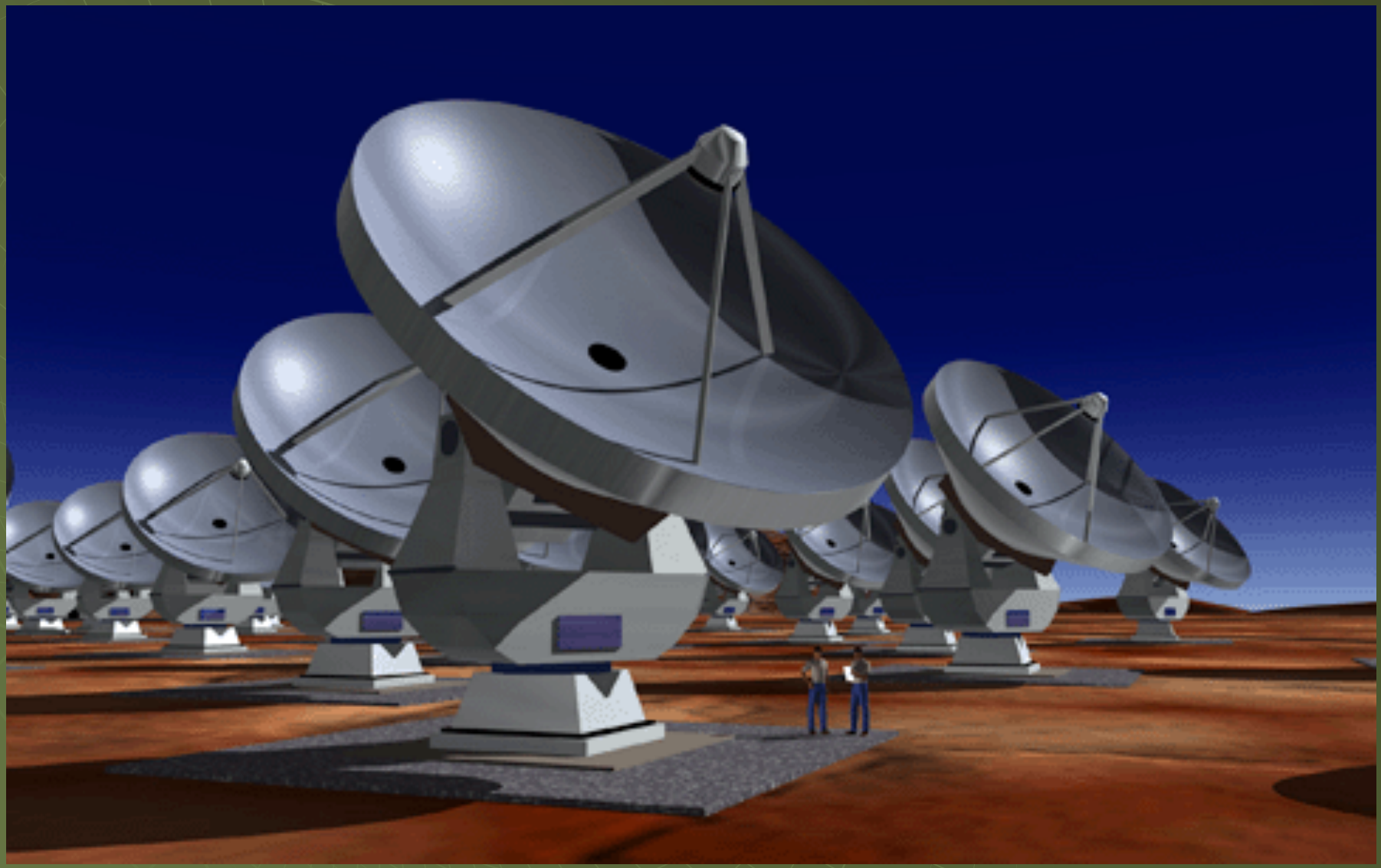
Sensitivity calculator = 10 min



Mode 7 provides 3.75 GHz bandwidth in a sideband --> tuning to 5 freq/band

total time = 10 x 5 = 50 min/galaxy

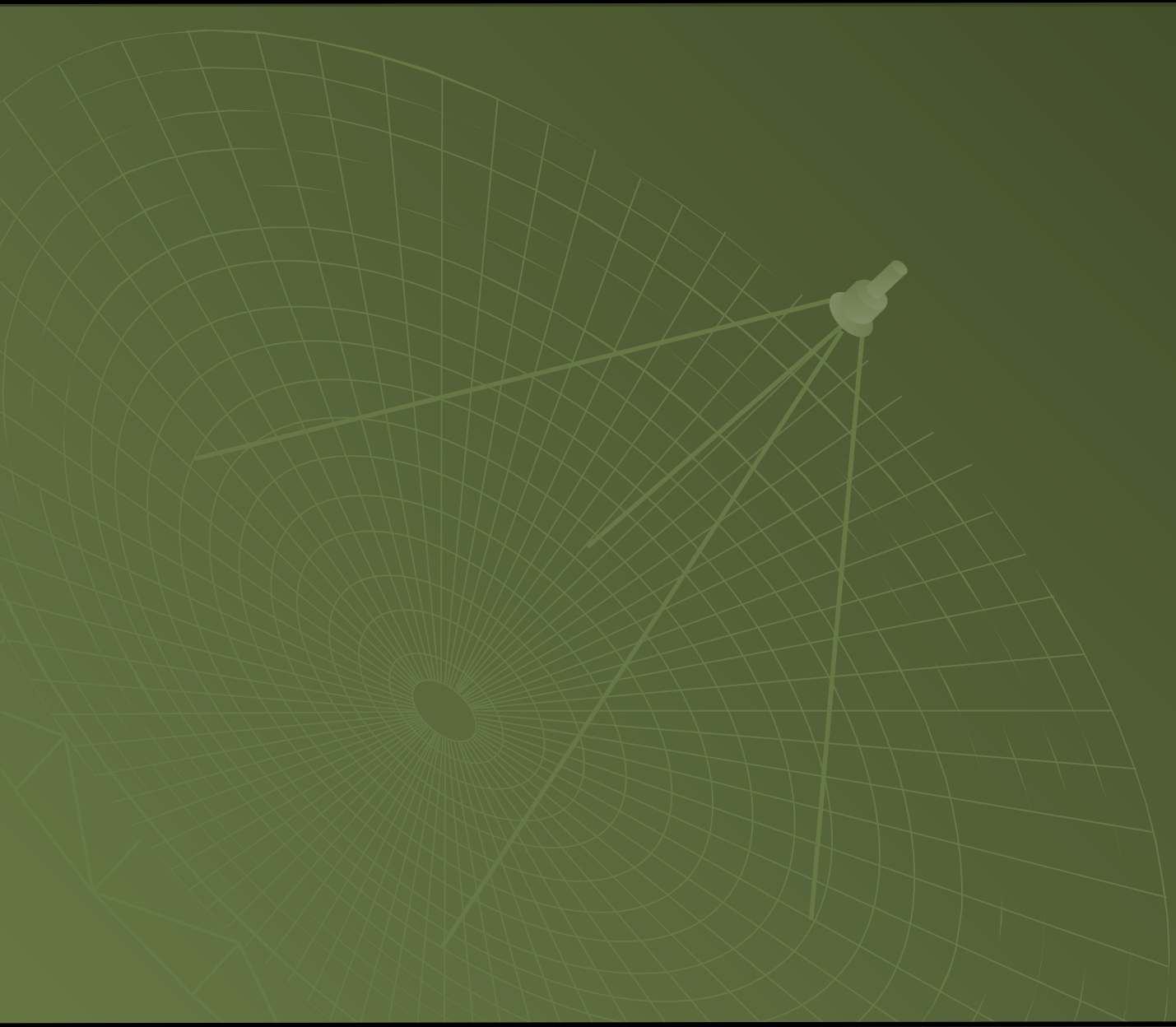
FOR MANY YEARS WE HAVE SEEN THIS



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