Molecular gas imaging in the nearby Universe

Sergio Martín Ruiz

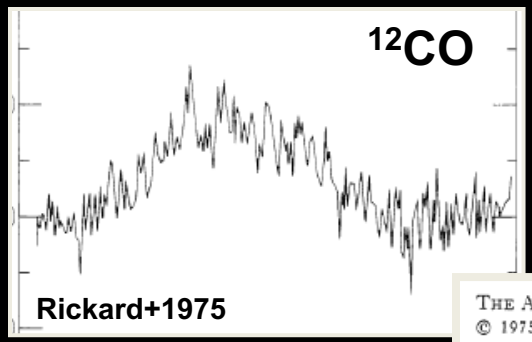
JAO - ESO

The ALMA Quest for Our Cosmic Origins

A Symposium to Honor Pierre Cox

Santiago, Chile, March 27th, 2018

New receivers sensitivity is a game changer in mm/submm astronomy



Rickard+1975

NGC 253 SB prototype at 3 Mpc

THE ASTROPHYSICAL JOURNAL, 199:L75–L78, 1975 July 15

DETECTION OF EXTRAGALACTIC CARBON MONOXIDE AT MILLIMETER WAVELENGTHS

L. J RICKARD AND PATRICK PALMER
University of Chicago

M. MORRIS
Owens Valley Radio Observatory, California Institute of Technology

B. ZUCKERMAN*
University of Maryland, College Park

AND

B. E. TURNER

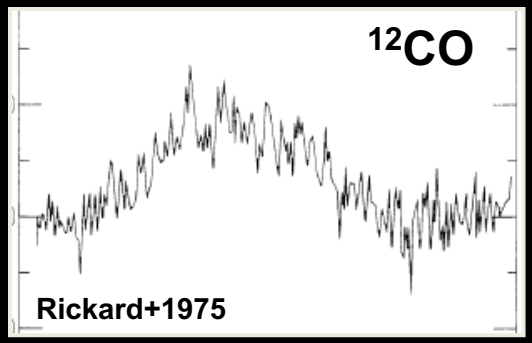
National Radio Astronomy Observatory†
Received 1975 March 6; revised 1975 March 17

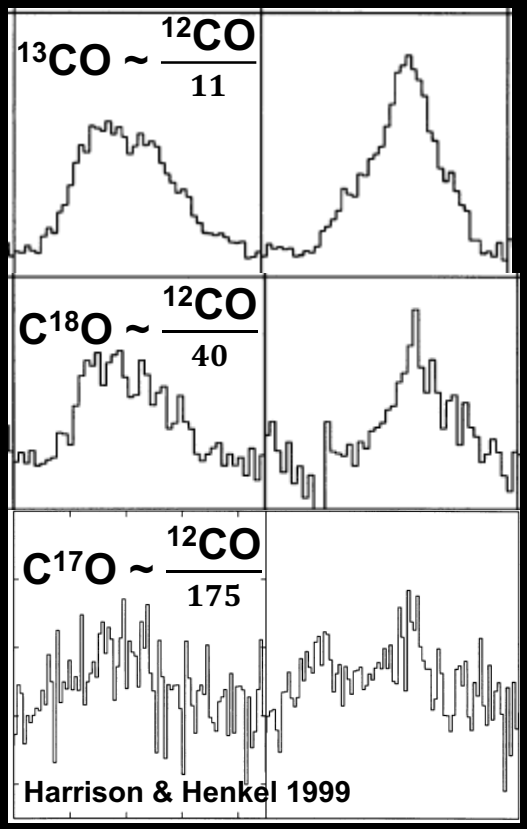
ABSTRACT

We report the discovery of emission from the $J = 1 \rightarrow 0$ transition of $^{12}C^{16}O$ toward the central regions of external galaxies. In this *Letter*, we present preliminary results for two galaxies with active nuclei, M82 and NGC 253, in which the observed emission features are surprisingly strong. In the directions of the nuclear continuum peaks, the velocity range of CO emission is roughly the same as that of 21-cm absorption. For each galaxy, the CO features are spatially extended, and the velocity shift of the emission centroid along the major axis is in the sense of the galactic rotation.

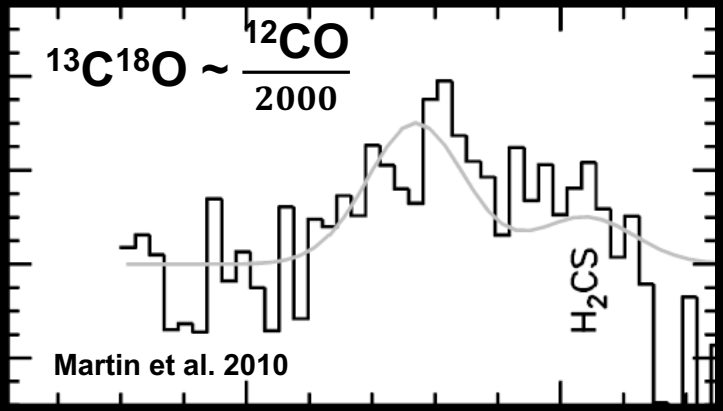
Subject headings: galactic nuclei — molecules

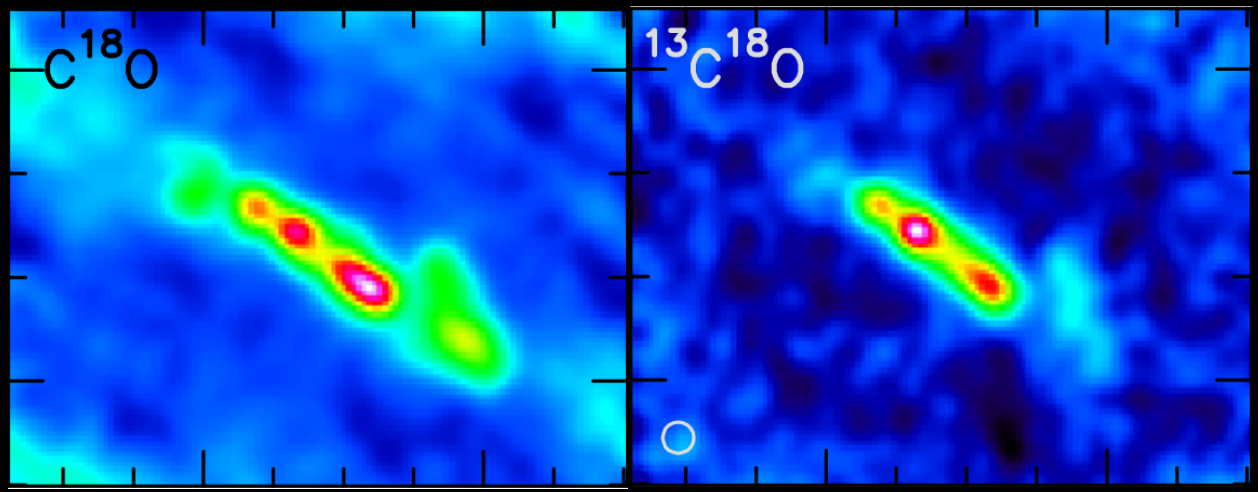
New receivers sensitivity is a game changer in mm/submm astronomy





NGC 253 SB prototype at 3 Mpc

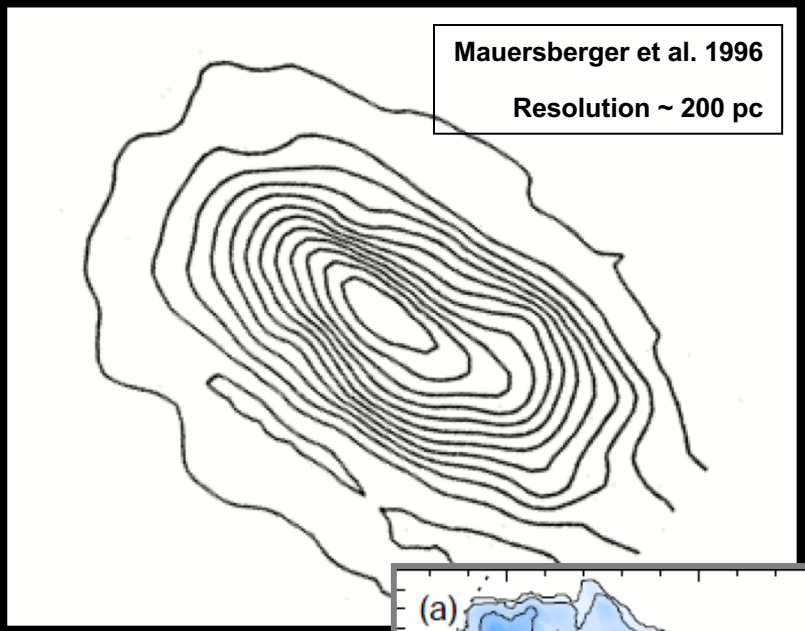


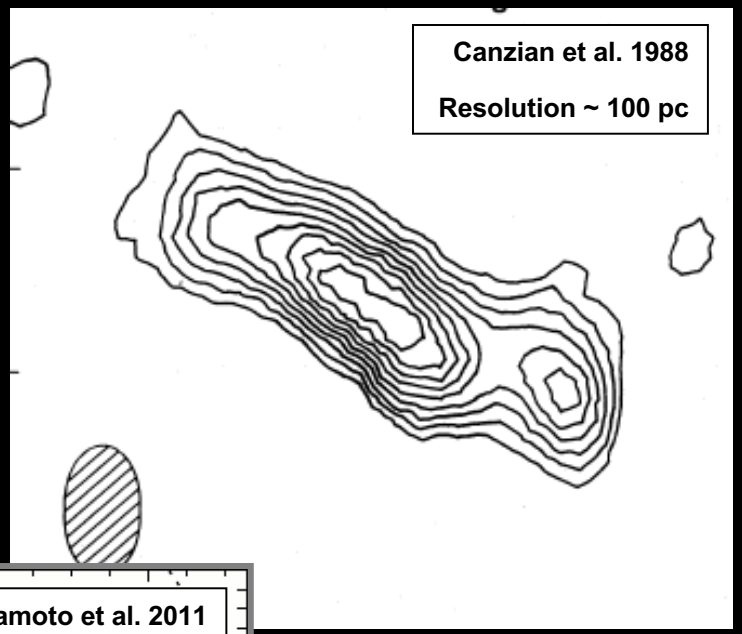


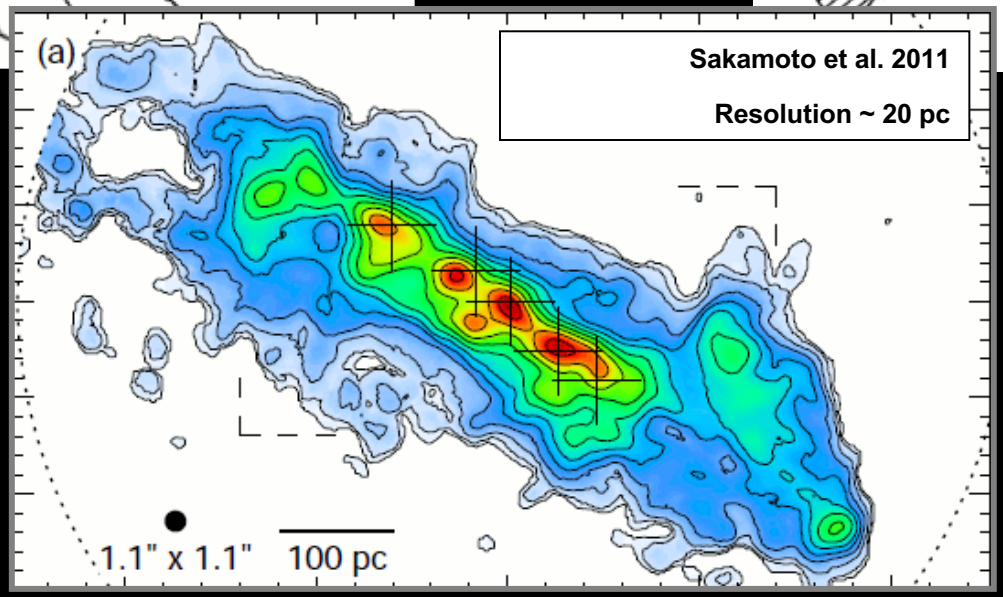
ALMA ; Martin et al. In prep

New receivers sensitivity is a game changer in mm/submm astronomy

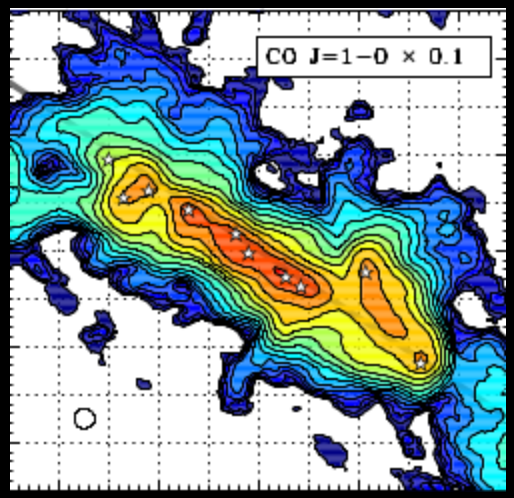
NGC 253 SB prototype at 3 Mpc



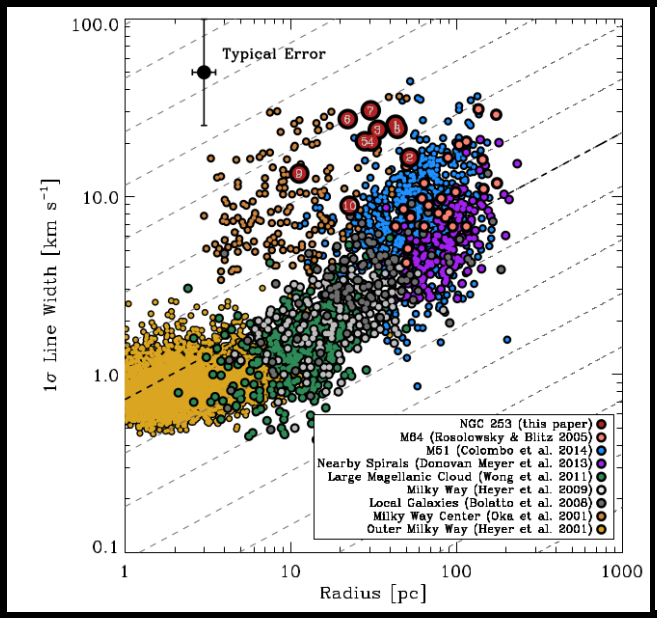


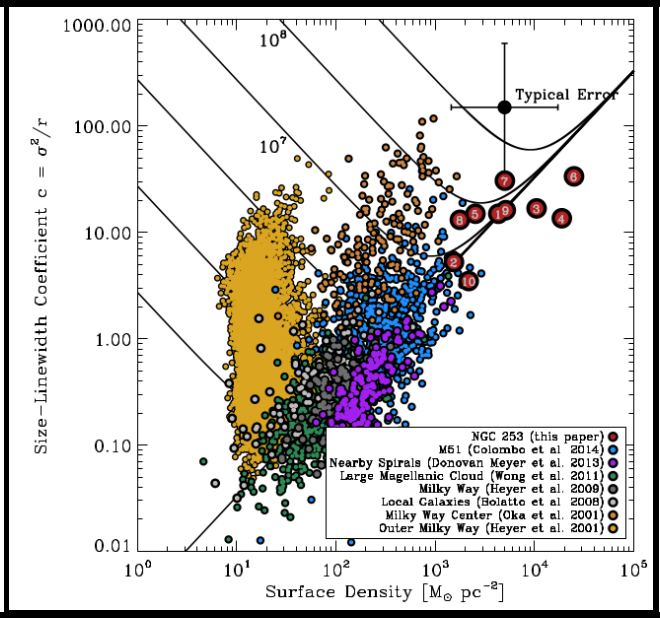


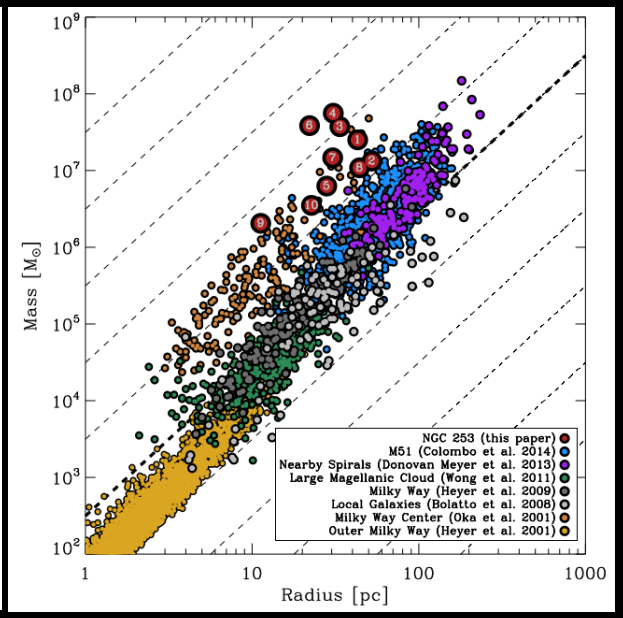
The ALMA view of SB NGC 253: GMCs



- Detailed study of individual GMCs
- Larger line widths, and surface/volumen densities than GMCs in other systems
- T_{ff}~0.7 Myr results in more efficient star formation in this starburst environment

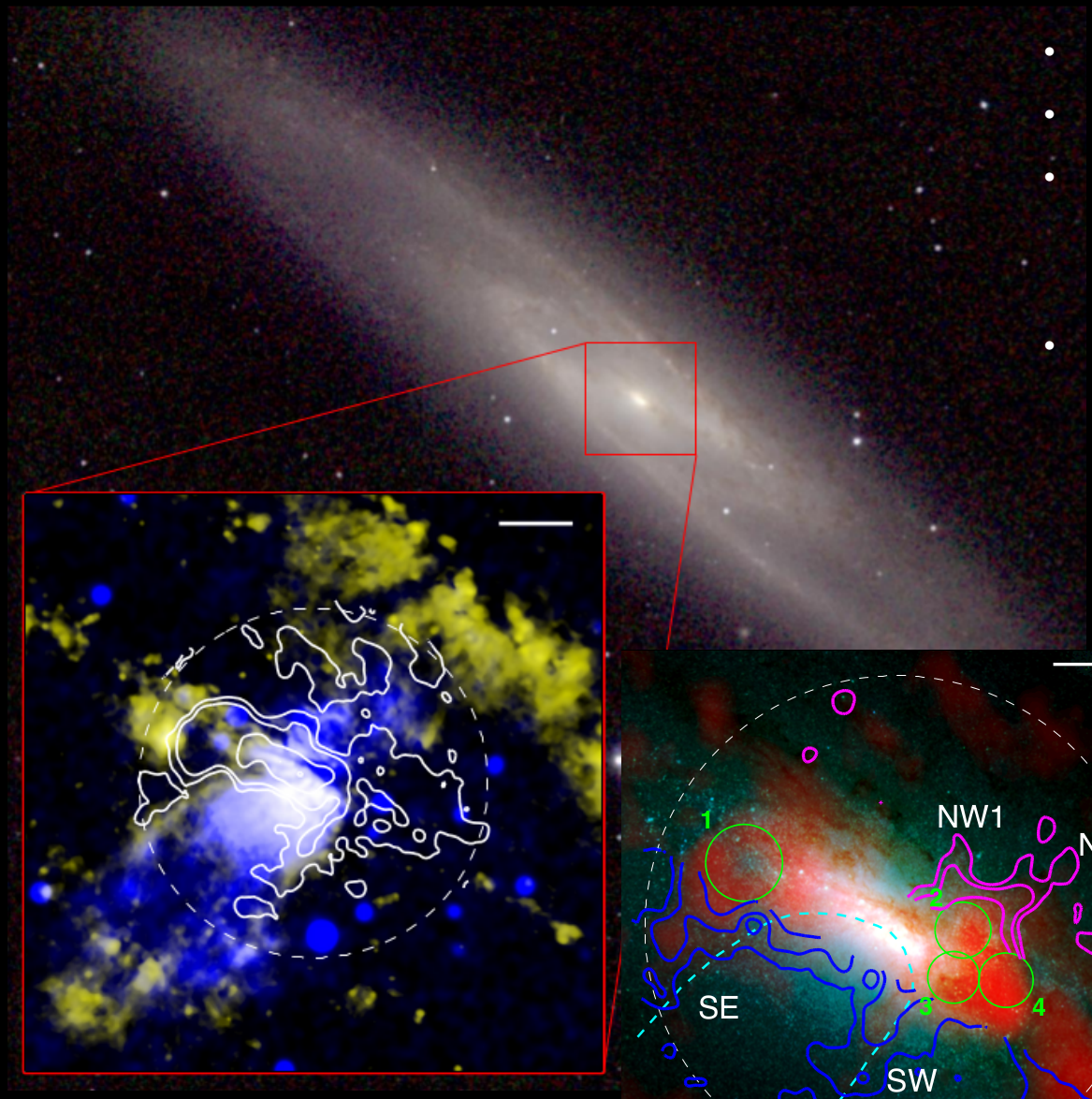






Leroy+2015

The ALMA view of SB NGC 253: The Outflow

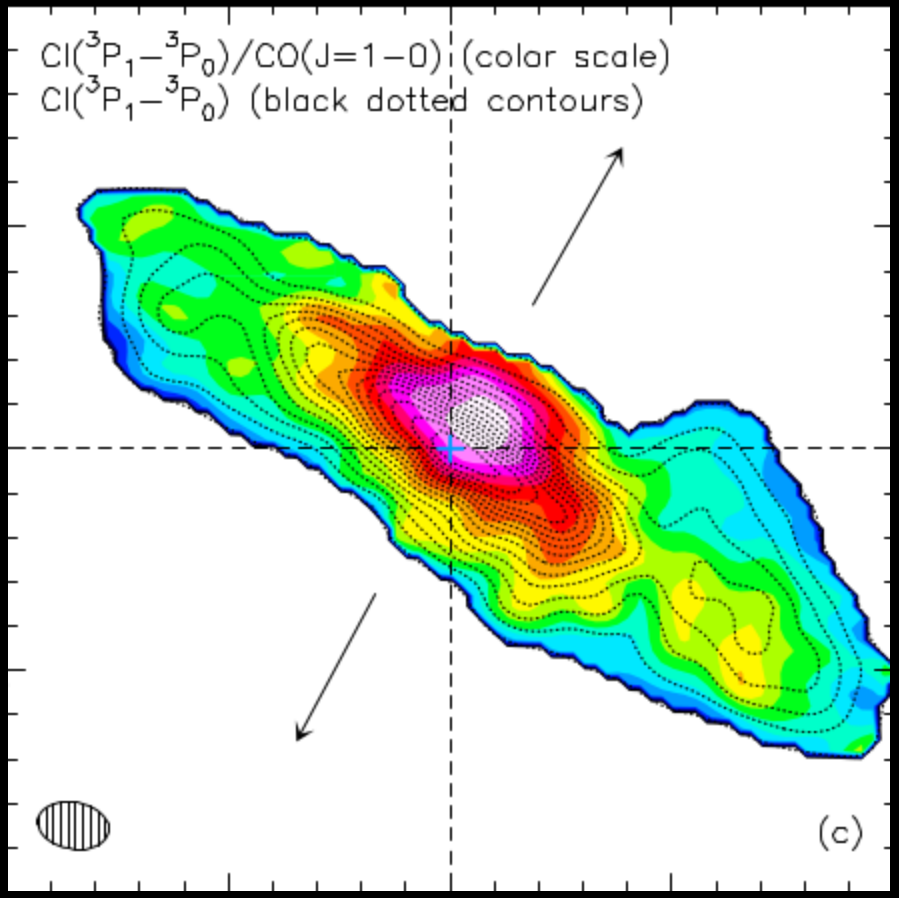


- dM/dt > 3 M_o/yr ~ 9 M_o/yr
- Outflow rate / SFR ~ 1-3
- Likely responsible of Star Formation Supression

- Dense gas tracers also detected in the outflow with ratios similar to the SB region (Walter+2017)

Bolatto+2013

The ALMA view of SB NGC 253: CI with Band 8

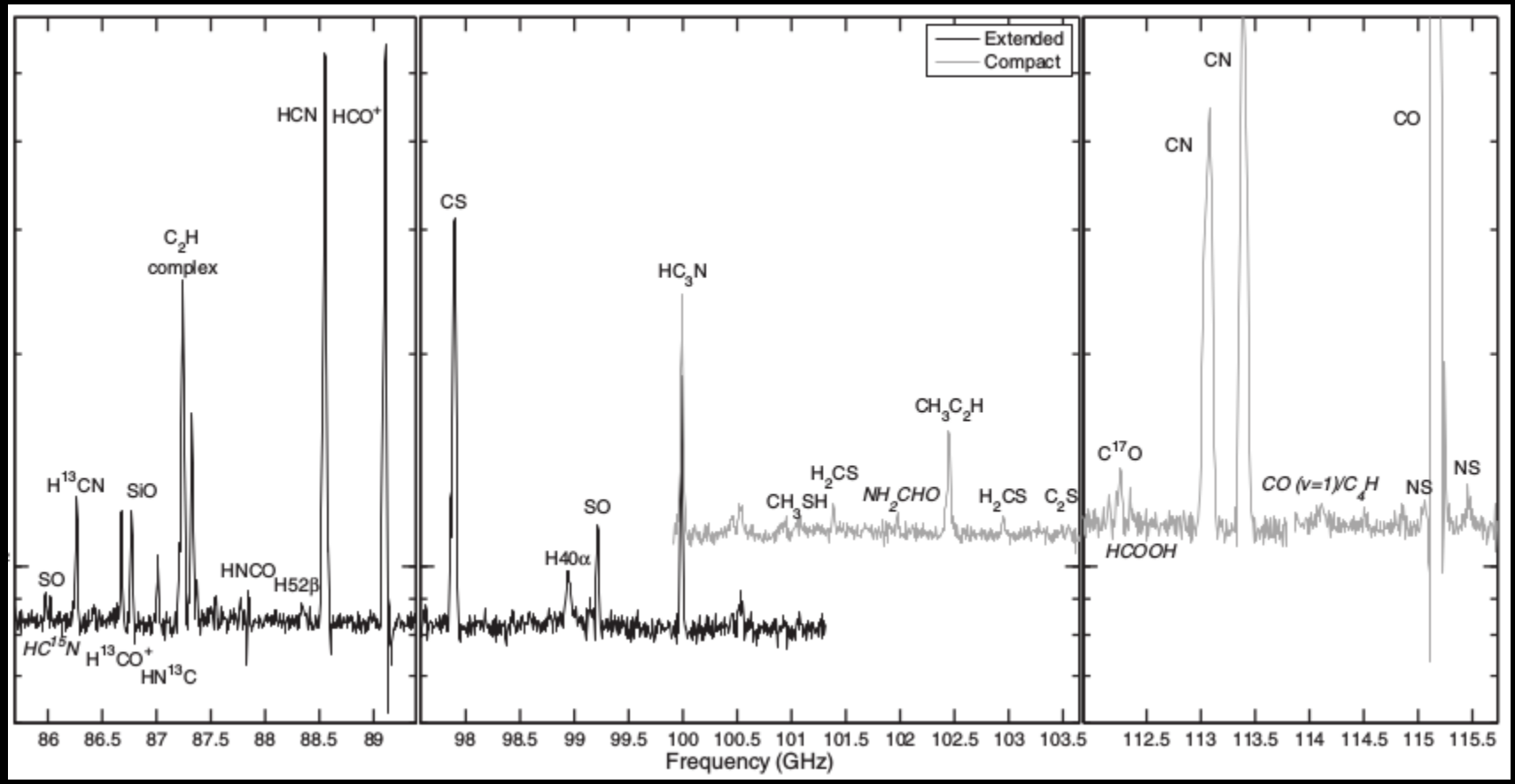


- New window…new potential gas tracer
- Neutral carbon might be a better tracer than CO less affected by optical depth, metallicity dependance and dissociation by radiation

- ACA observations
- CI marginally thick in the disk (tau~
- CI/CO~0.4-0.6 larger than Galactic <0.1

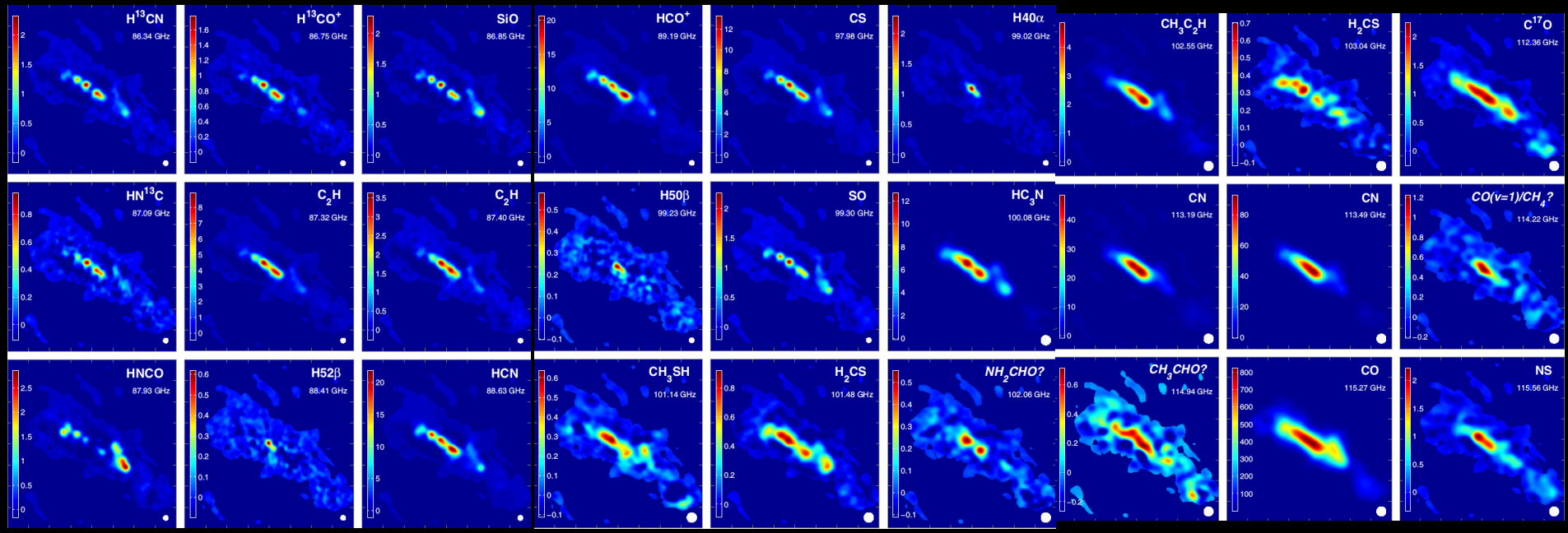
Krips+2016

The ALMA view of SB NGC 253: The most prolific molecular emitter



Meier+2016

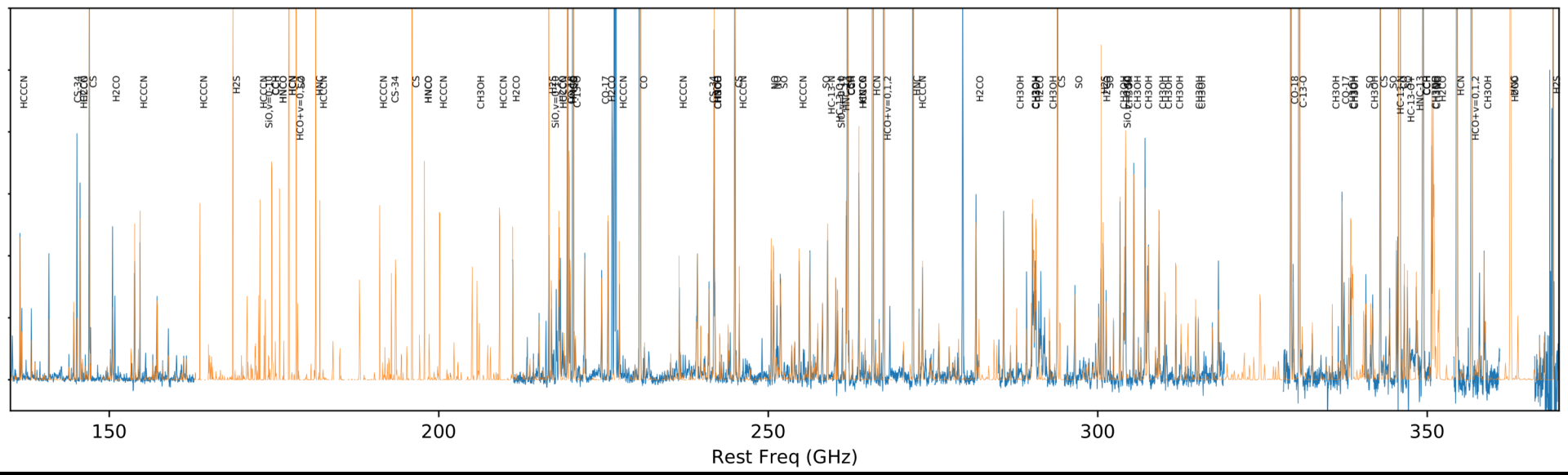
The ALMA view of SB NGC 253: The most prolific molecular emitter



- Molecular spatial information
- HNCO/SiO tracers show how these chemical imprints are erased by the dominating radiation fields in the central region (traced by C_2H, CN)
- Dense gas located at the base of the ouflow.

Meier+2016

The ALMA view on e-astrochemistry



ALCHEMI ALMA Large Program to survey Bands 3,4,6,7 in NGC 253

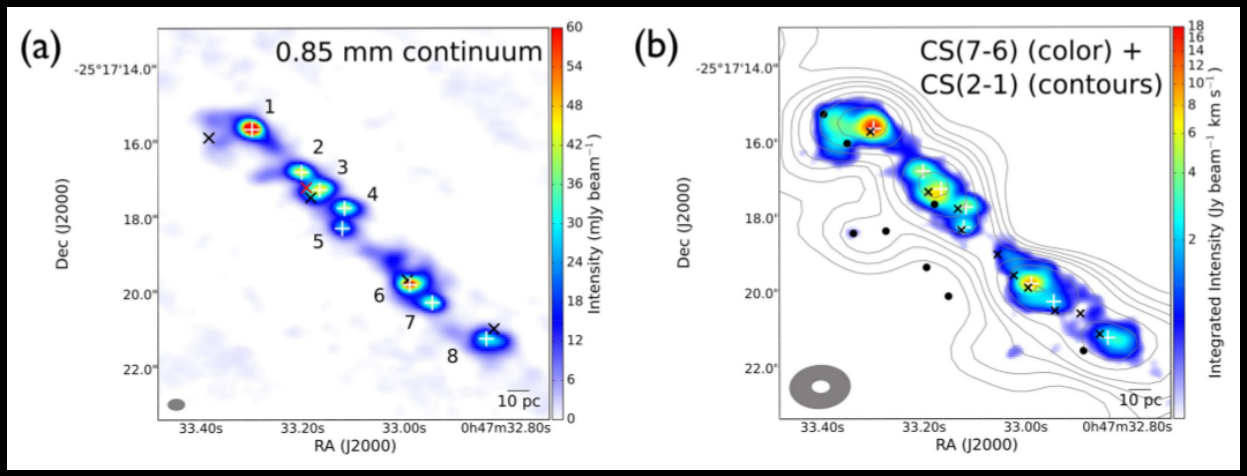
(The ALMA Comprehensive High-resolution Extragalactic Molecular Inventory)

Widest molecular line scan at unprecendented combination of resolution (1”-15pc) and sensitivity (50 mK)

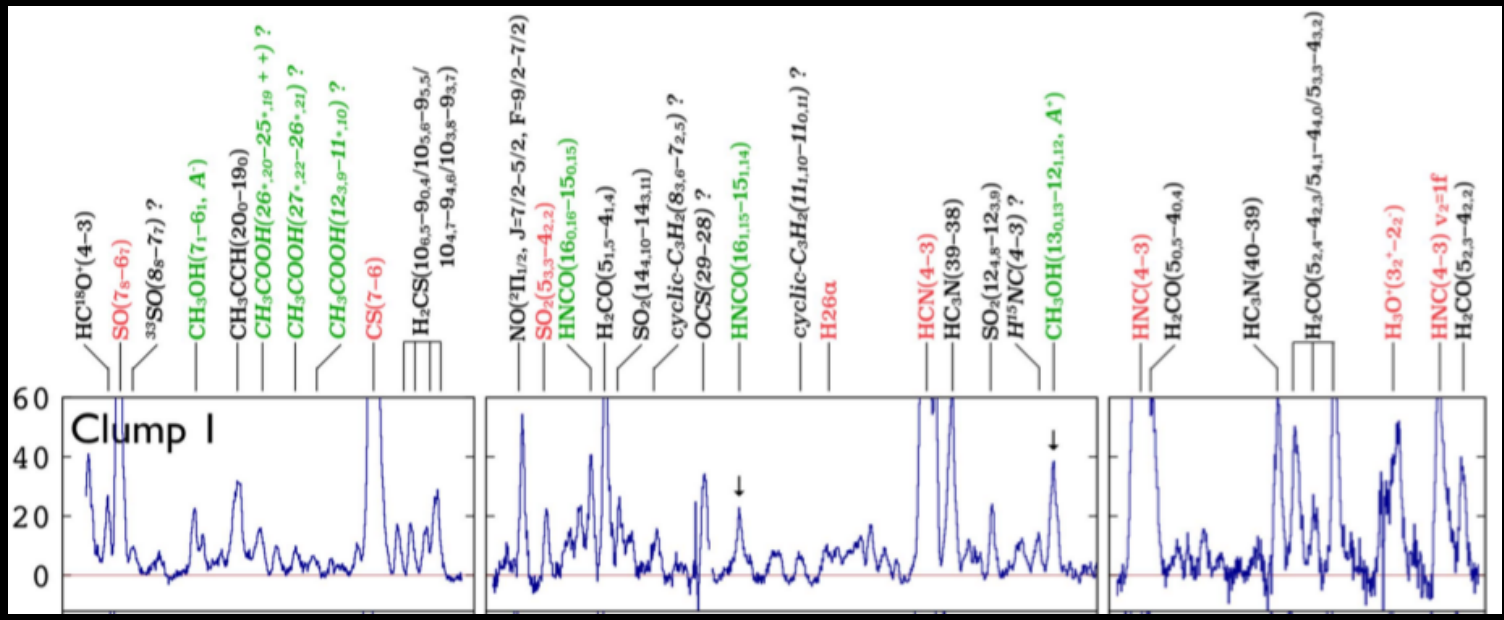
Only the brightest lines are included in the model above with more than 50 species, and >1000 transitions above 1 mJy

Martin, Harada, Mangum+ in Prep

The ALMA view on e-astrochemistry

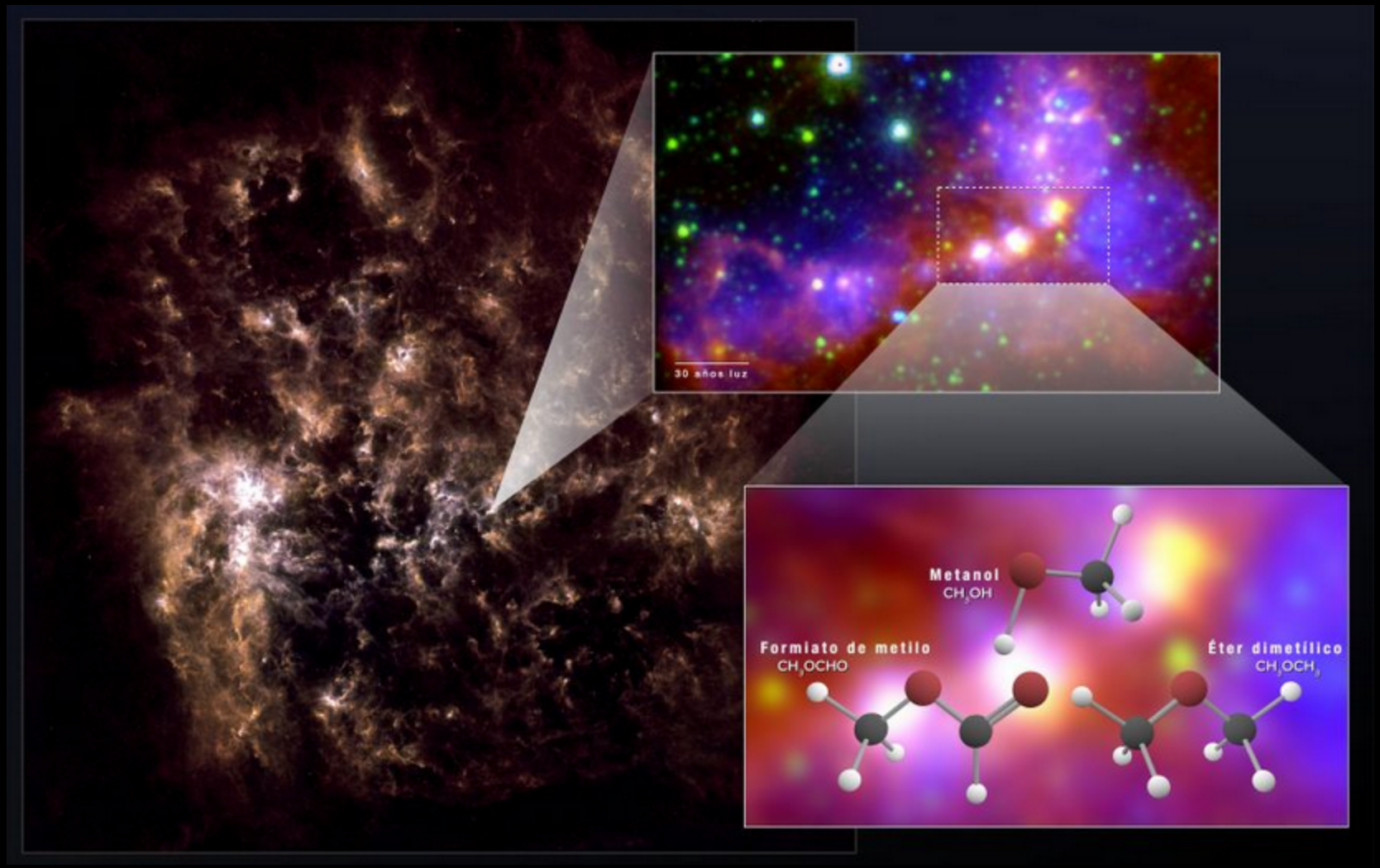


0.4” (6 pc) resolution reveals rich molecular complexes in NGC 253



Ando+2017

The ALMA view on e-astrochemistry

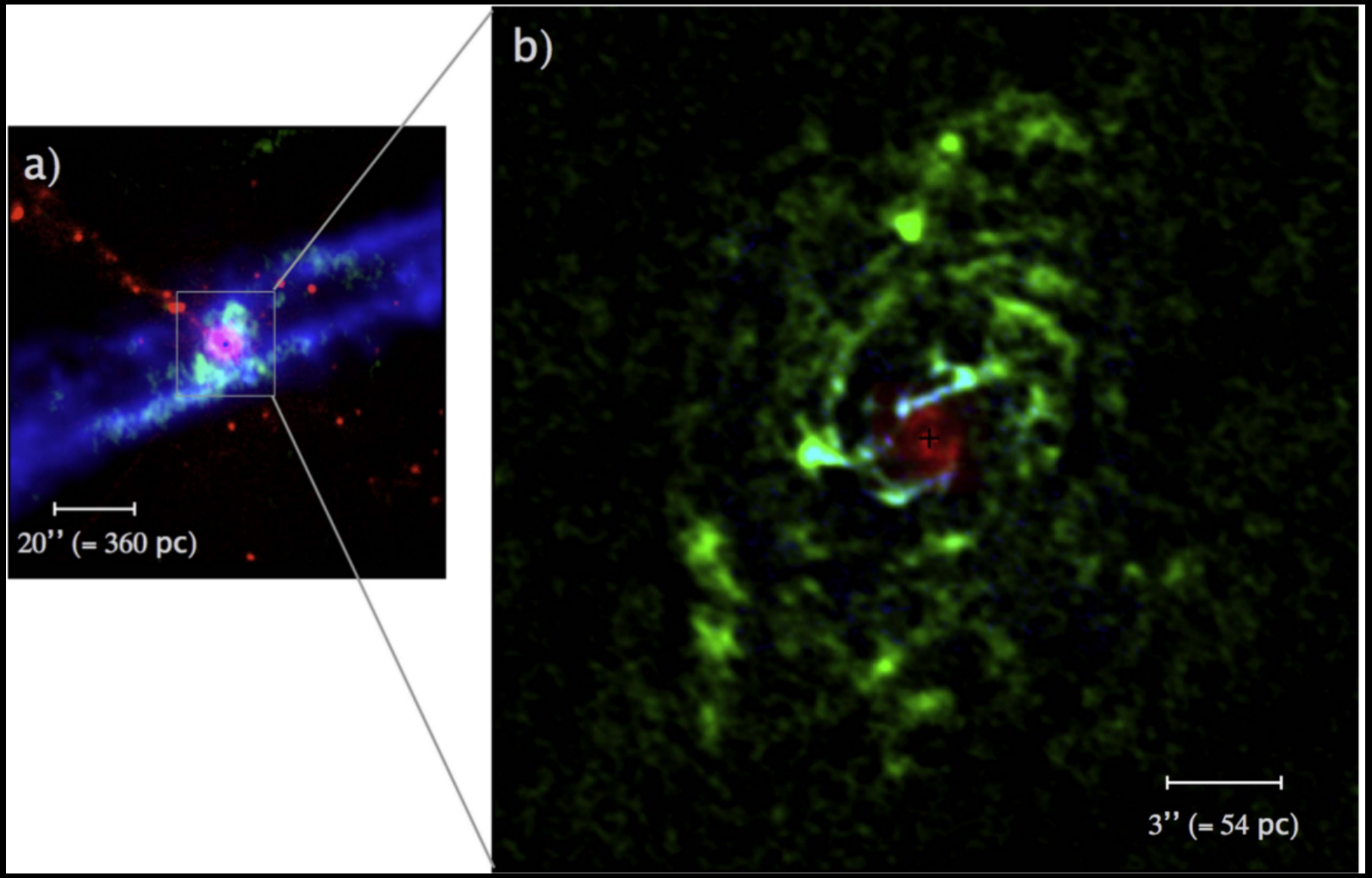


N 113 star-forming region in the low metallicity Large Magellanic clouds.

Detection of Dimethyl ether (CH_3OCH_3) and methyl formate (CH_3OCHO)

Sewilo+2018

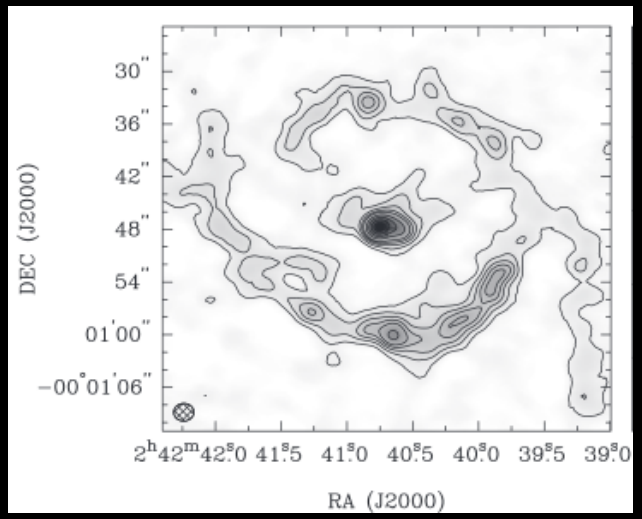
The ALMA view of Centaurus A: The closest radio galaxy



Distance ~ 3.8 Mpc, 5pc resolution

Espada+2017

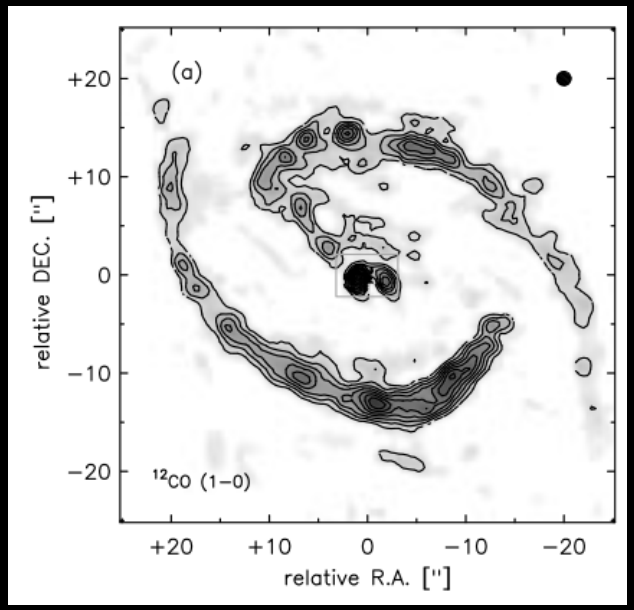
The ALMA view of SB NGC 1068: The prototypical Sy2 nearby AGN



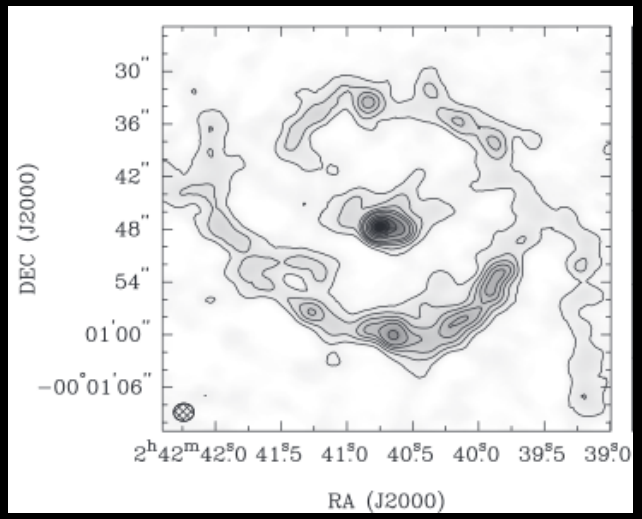
CO 3-2 SMA Tsai+2012

Distance ~ 14.4 Mpc

CO 1-0 PdBI Schinnerer+2012

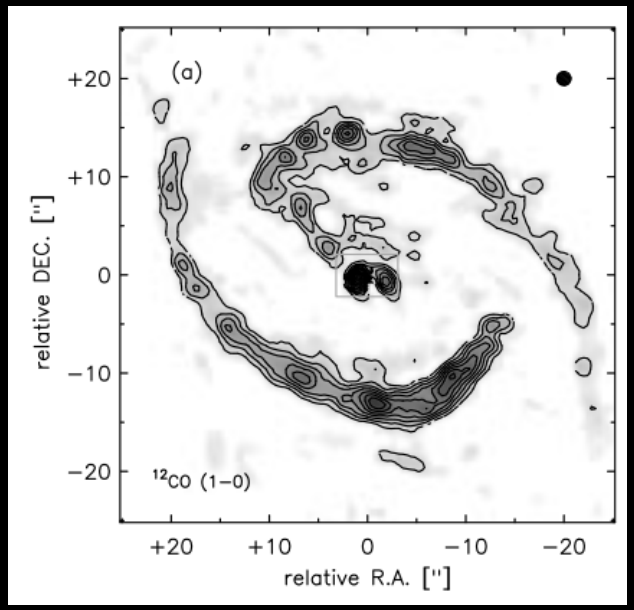


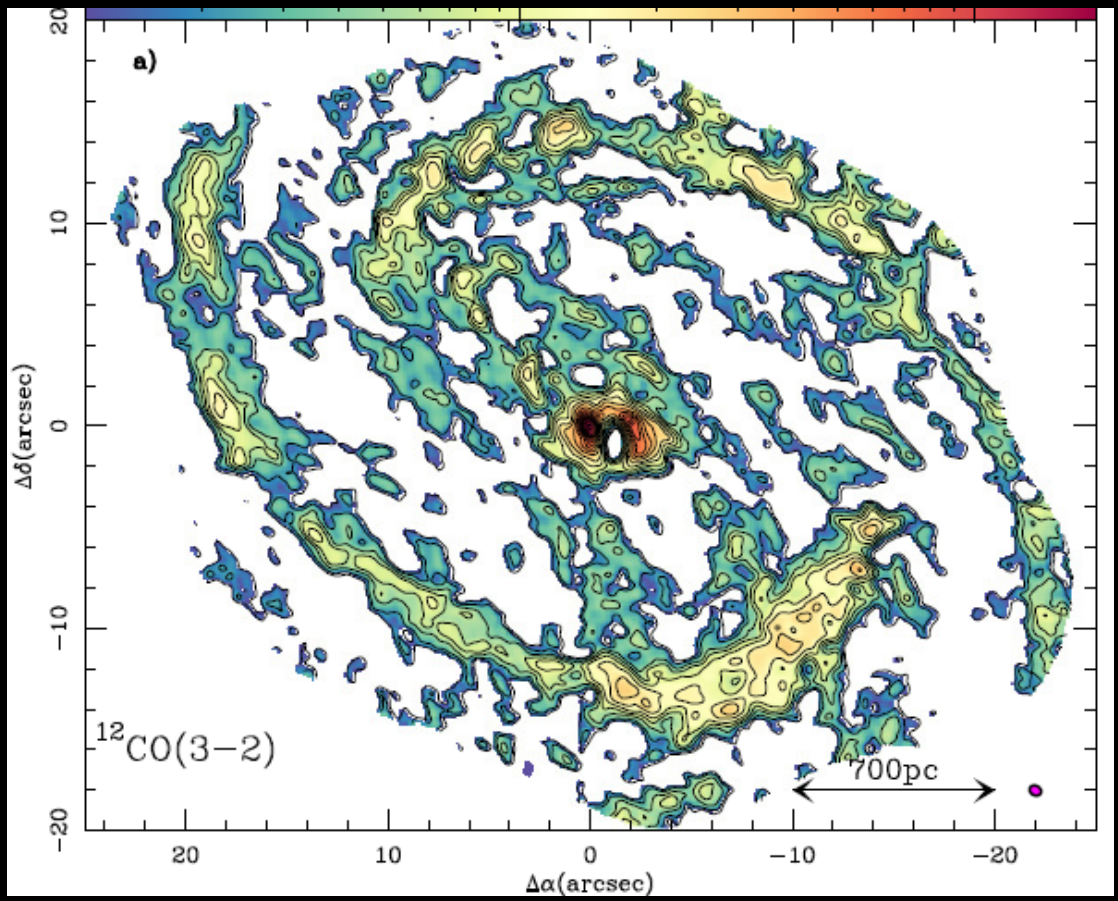
The ALMA view of SB NGC 1068: The prototypical Sy2 nearby AGN



CO 3-2 SMA Tsai+2012

CO 1-0 PdBI Schinnerer+2012



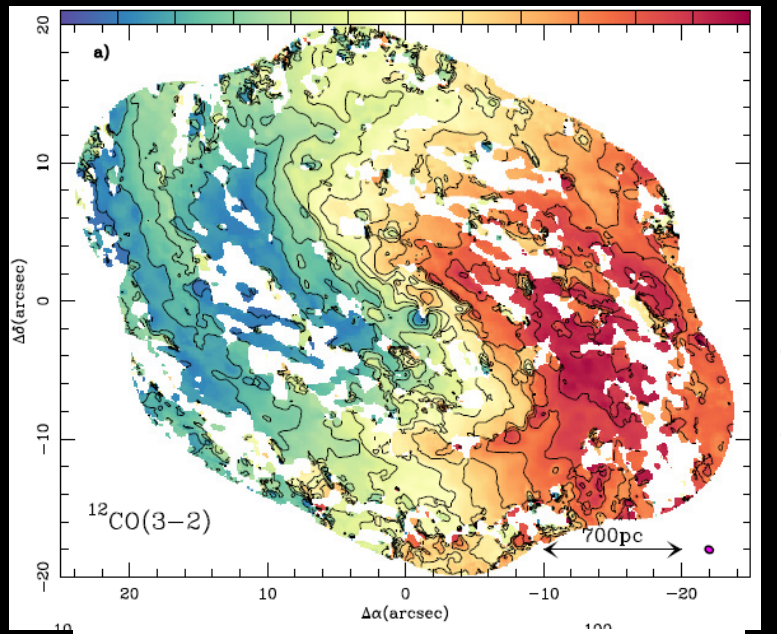


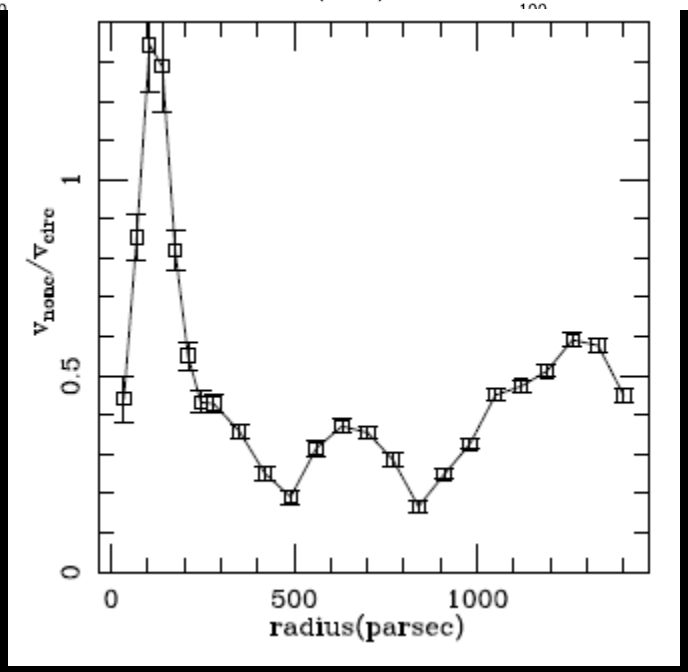
CO 3-2

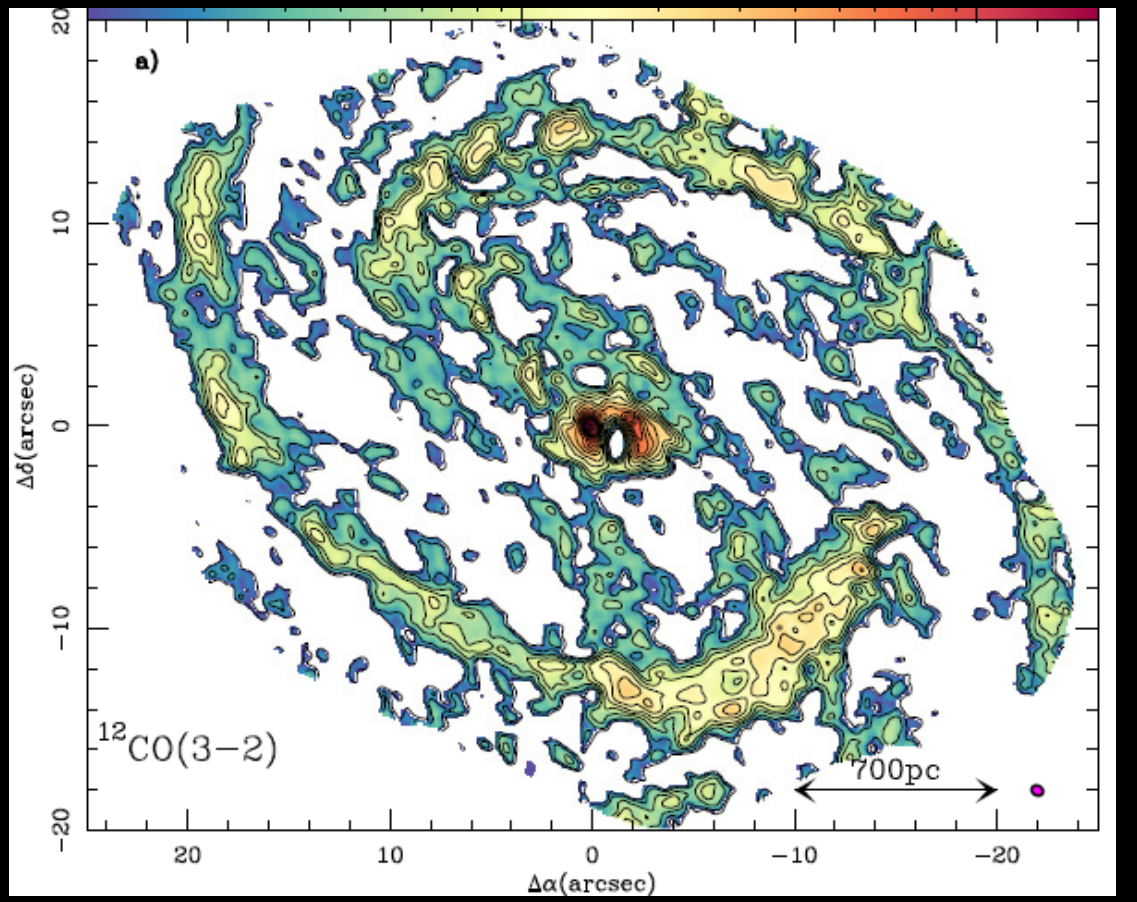
35 pc resolution

García-Burillo+2014

The ALMA view of SB NGC 1068: Kinematics (inflow/outflow)





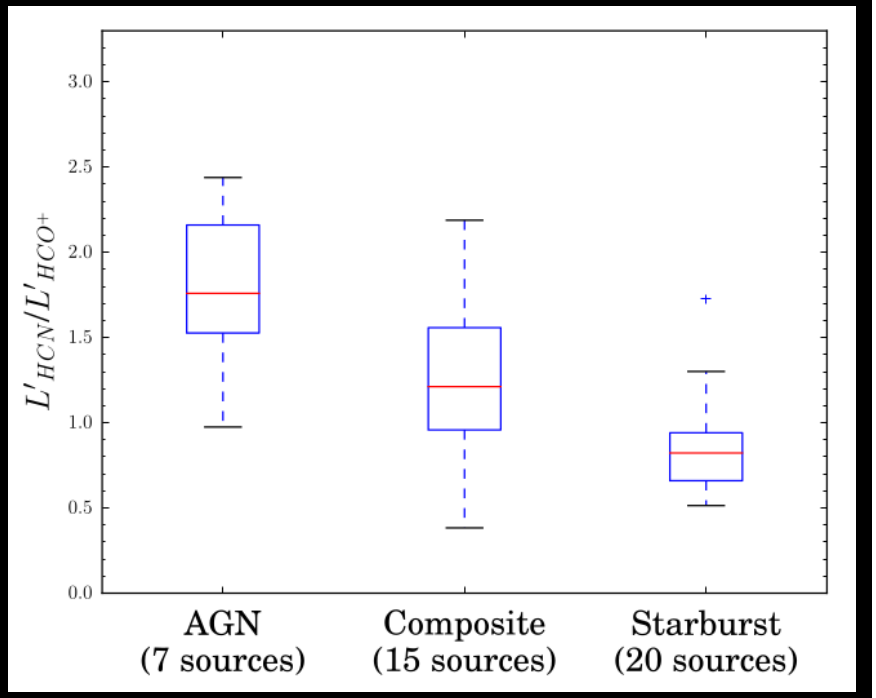


CO 3-2

35 pc resolution

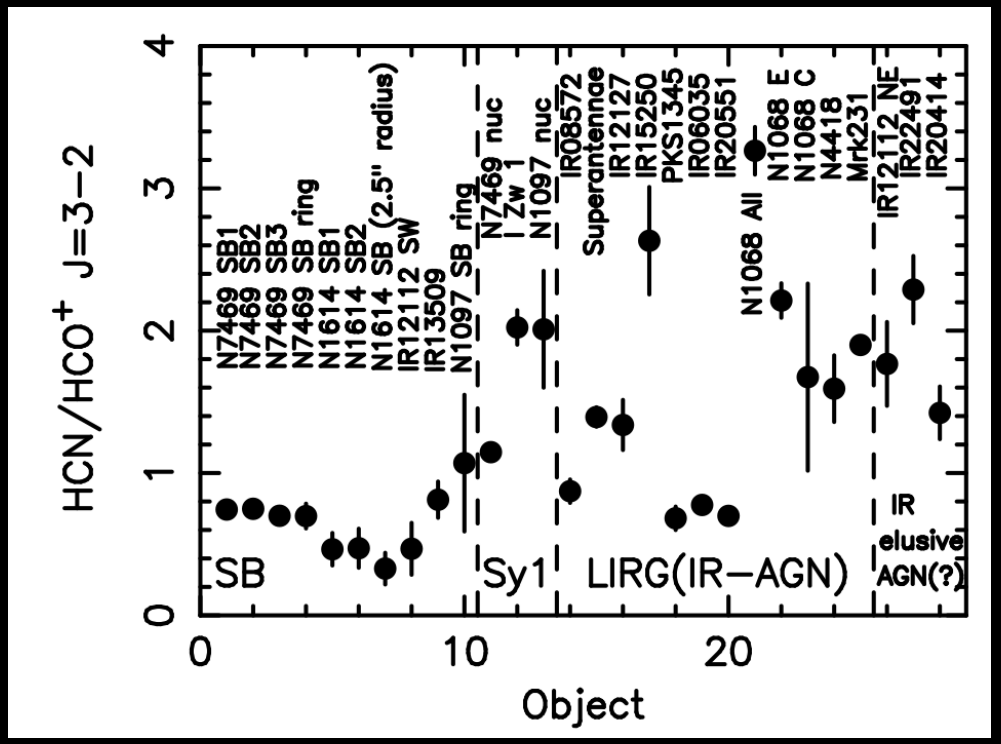
García-Burillo+2014

The ALMA view of AGN molecular abundances: HCN/HCO+



58 local ULIRGs

(Privon+2015)



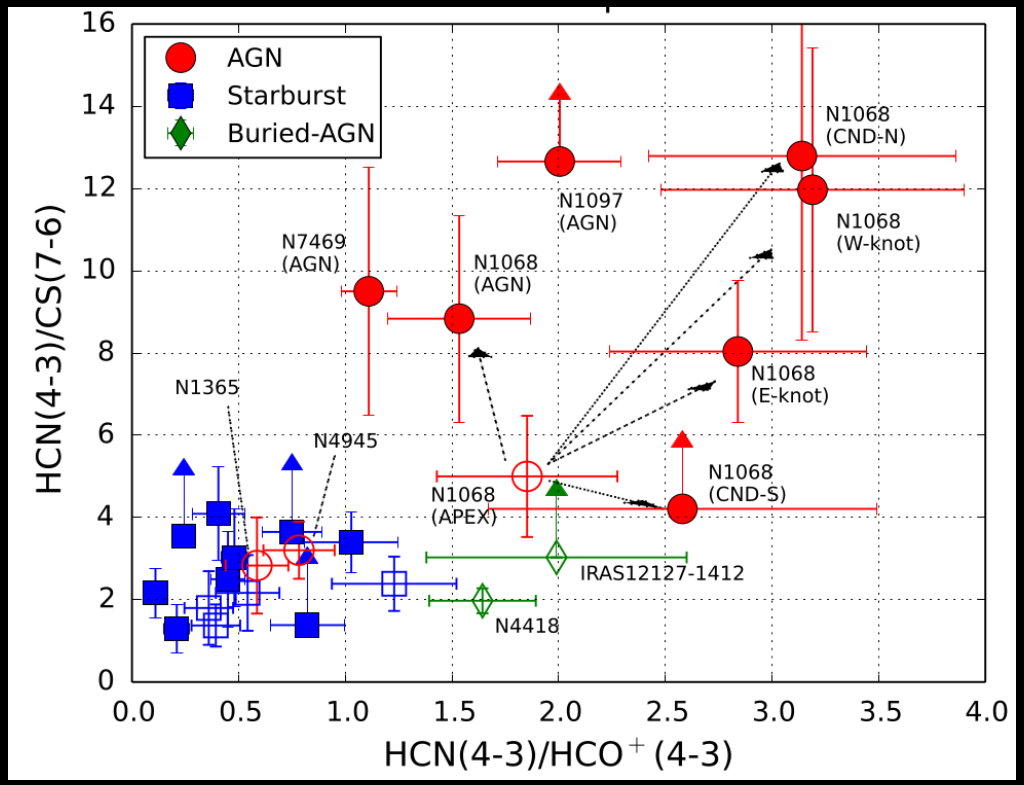
3 Sy 1 + 11 LIRGs

(Imanishi+2016)

The ALMA view of AGN molecular abundances: HCN/HCO+

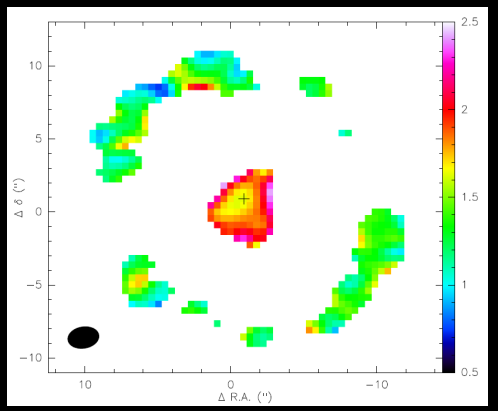
Mechanical enhancement resulting in high temperature chemistry.

Chemical Models: Harada+2010, 2013



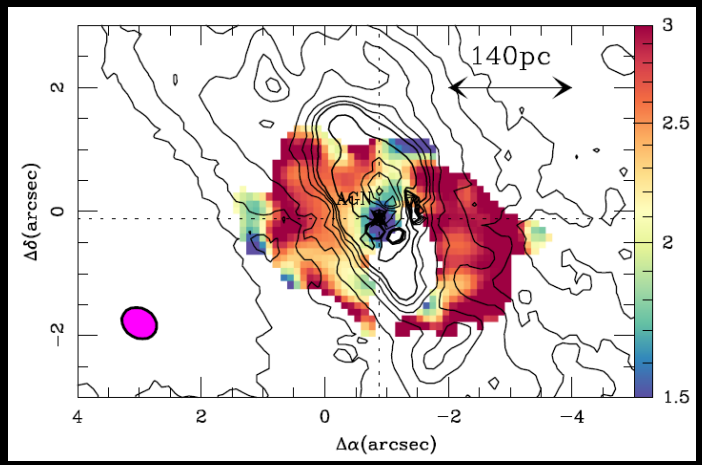
Izumi+2016

Low luminosity AGN: NGC 1097



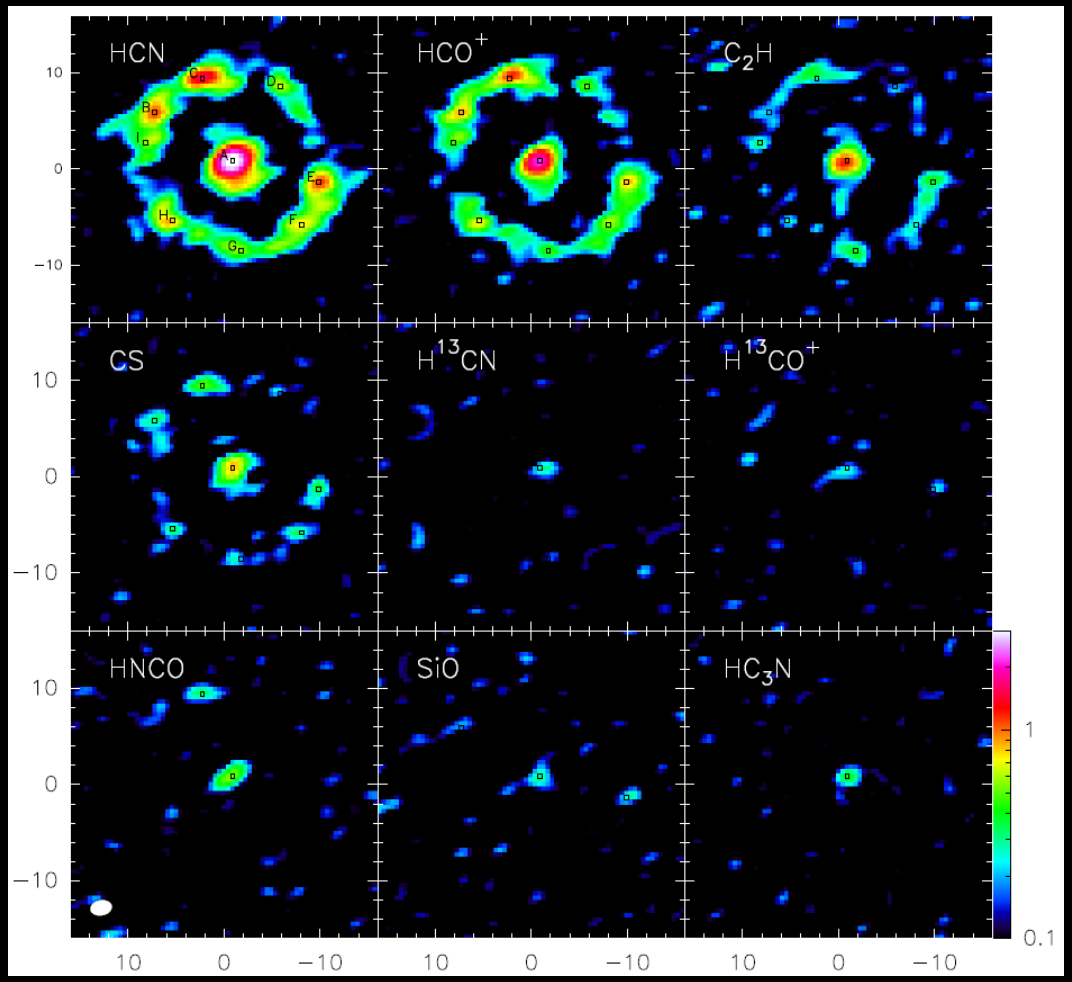
Martín+2015

Lumious AGN: NGC 1068



García-Burillo+2014

The ALMA view of AGN molecular abundances: Multi-molecular studies



Martín+2015

Low luminosity AGN:

NGC 1097

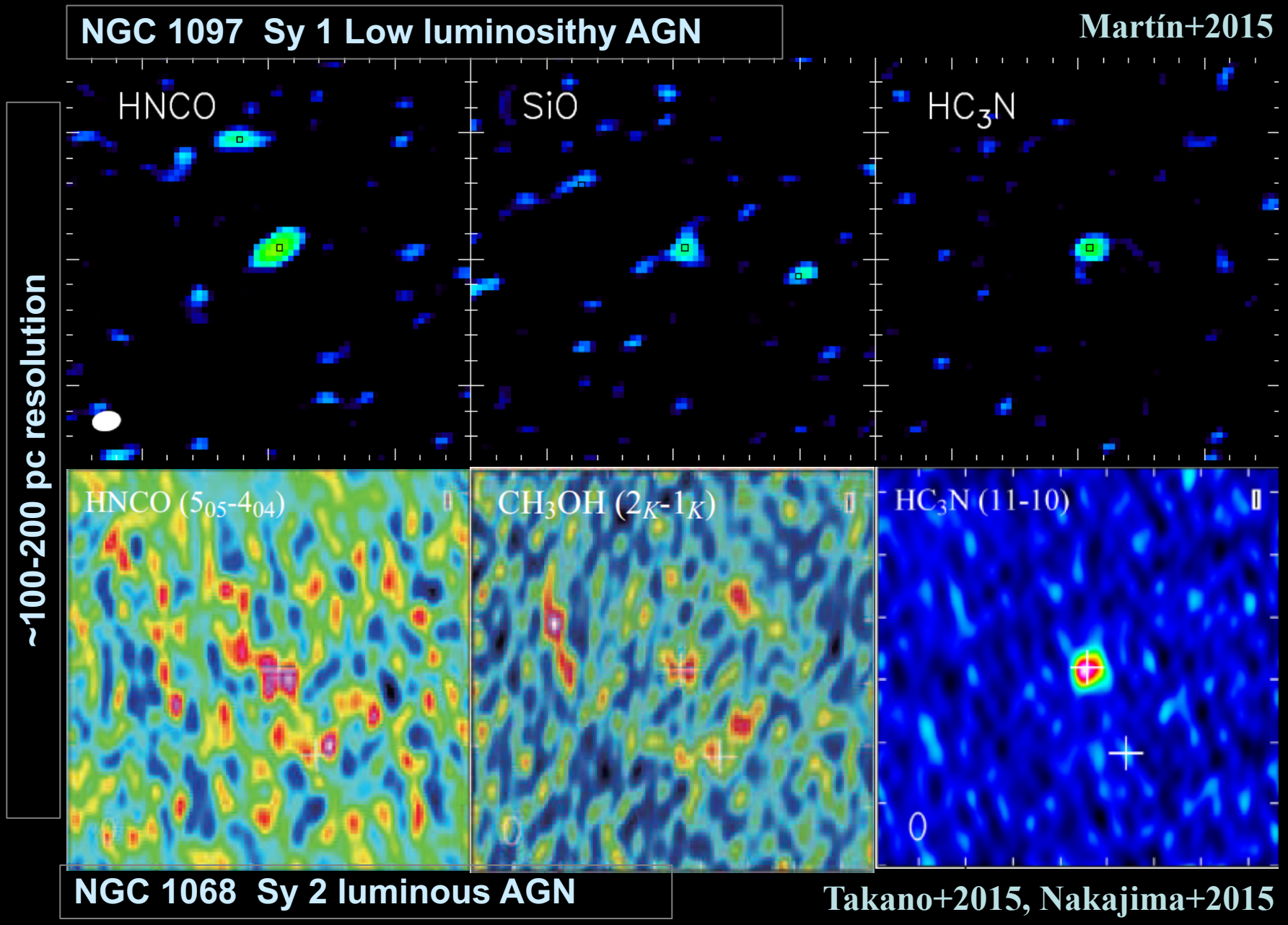
D~ 14 Mpc (1”~70pc)

Seyfert 1 Nucleus

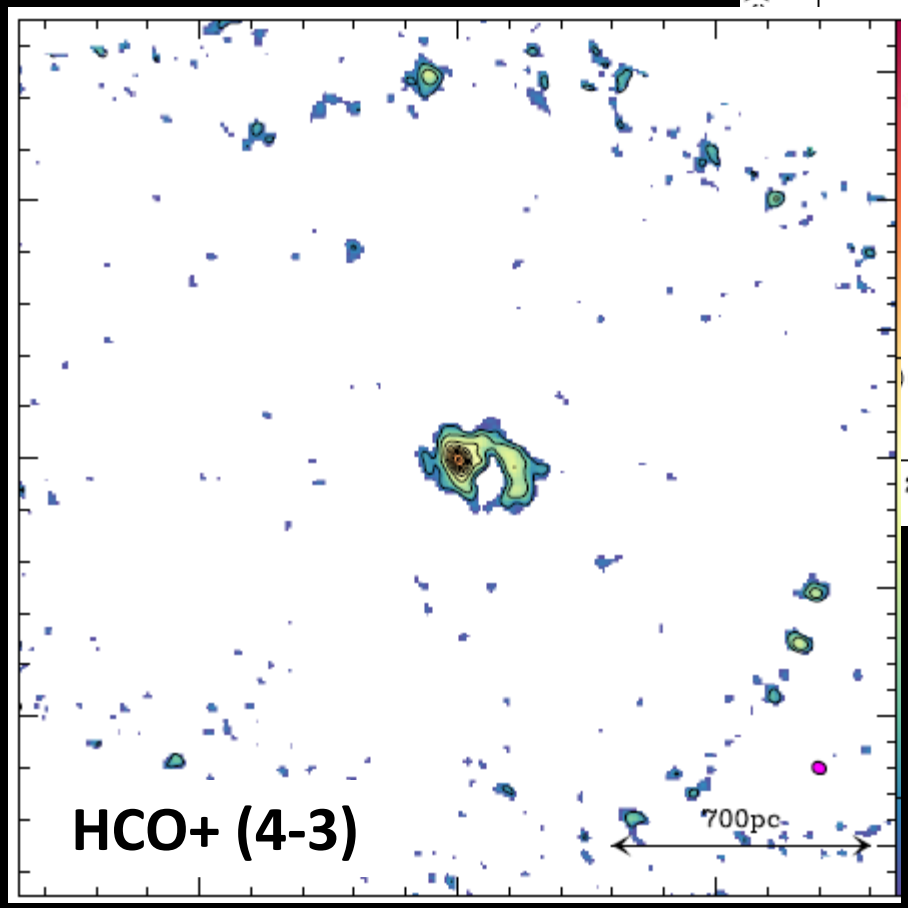
$L_{2\text{-}10\ keV} \sim 4\ 10^{40}$ erg s^{-1}

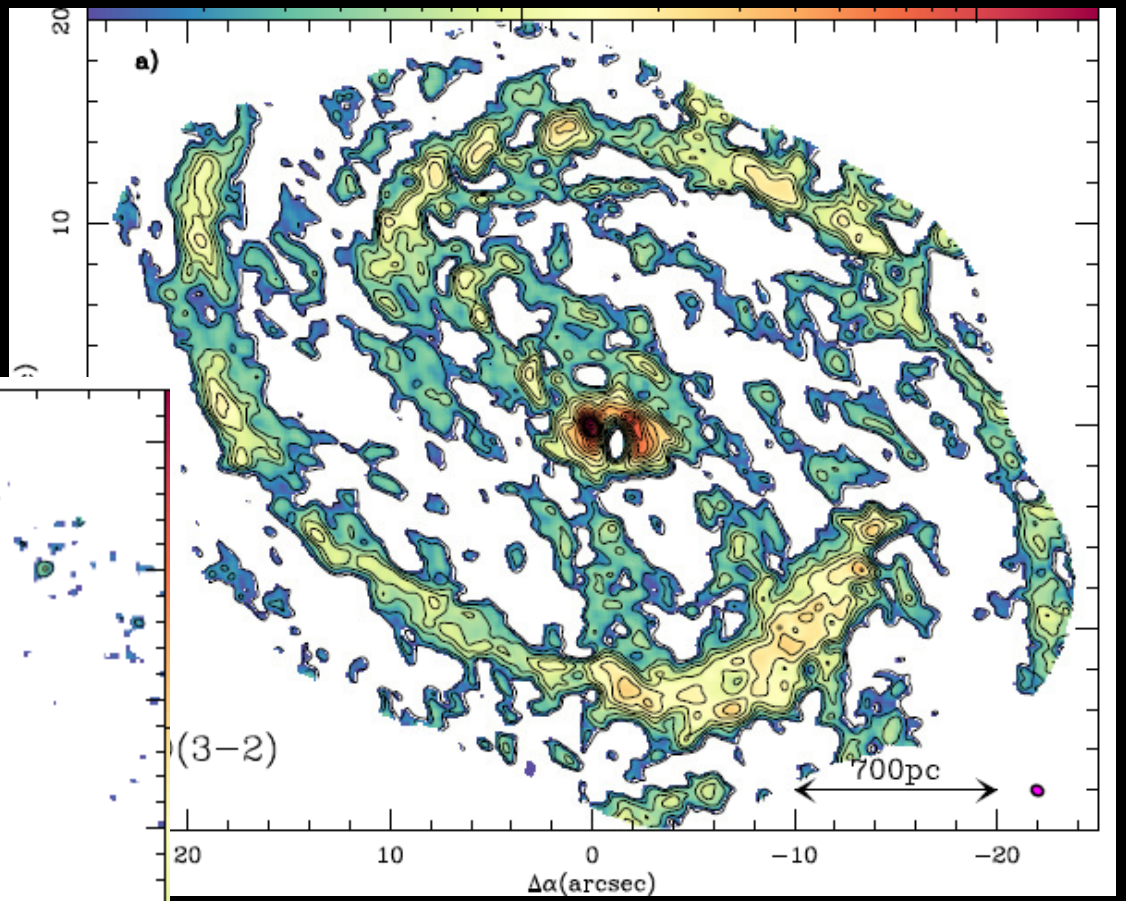
L_{IR} , L_{HCN} ~ 1/10 NGC 1068

The ALMA view of AGN molecular abundances: Multi-molecular studies

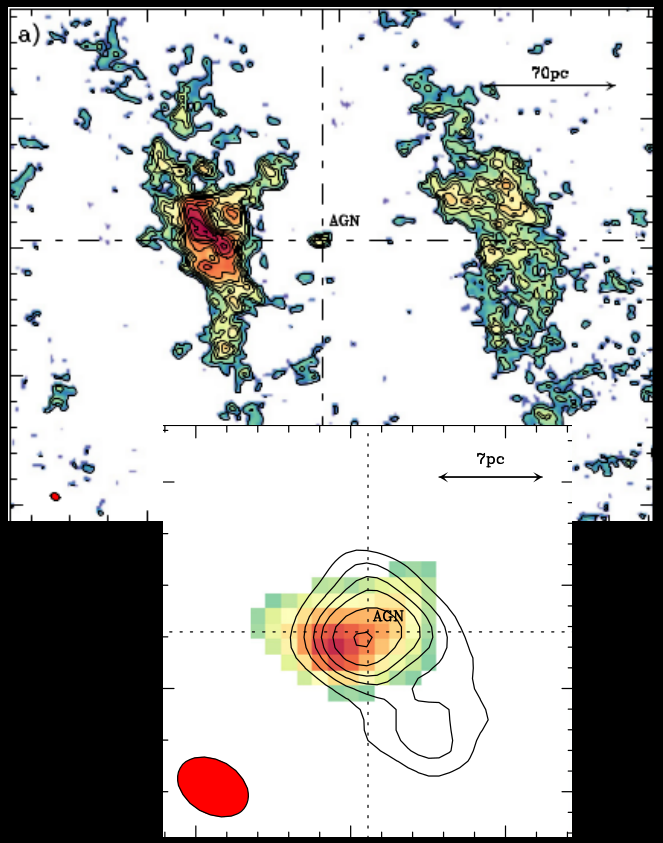


Closer view towards NGC 1068: The “Torus”





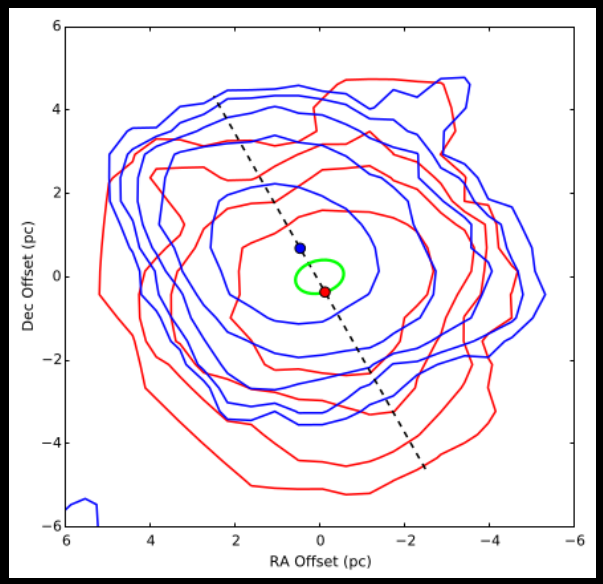
Closer view towards NGC 1068: The “Torus”



CO 6-5 & Continuum
4 pc resolution

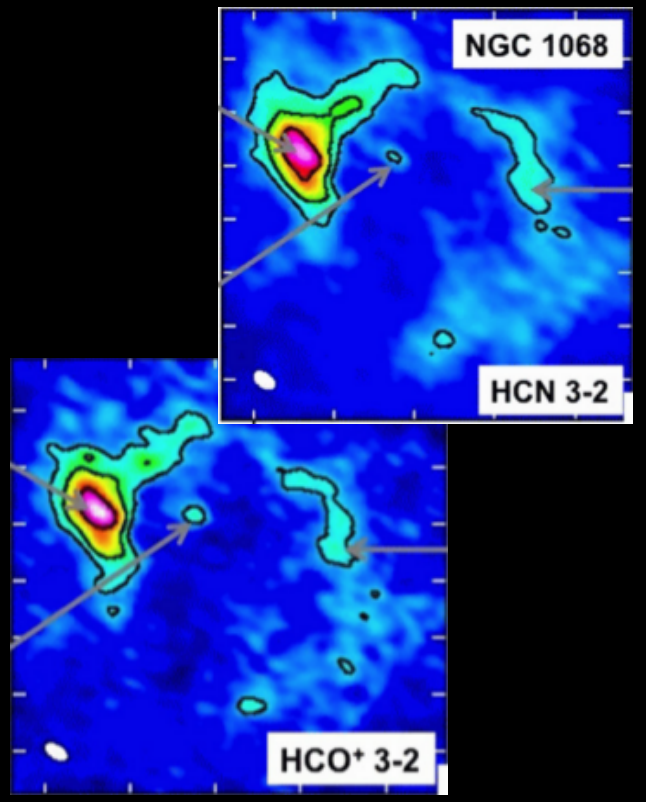
Size~7 pc , Mgas~$10^5 M_o$

Garcia-Burillo+2016



CO 6-5
12x7 pc resolution
Bipolar outflow
perpendicular to the
nuclear disk

Gallimore+2016

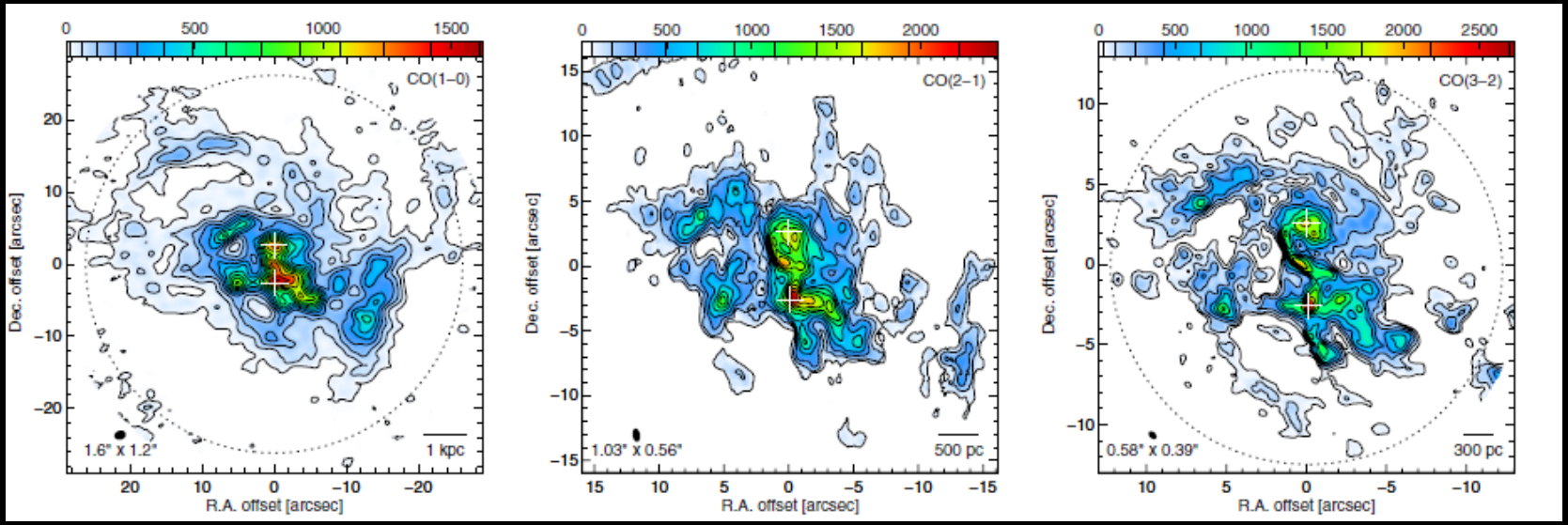


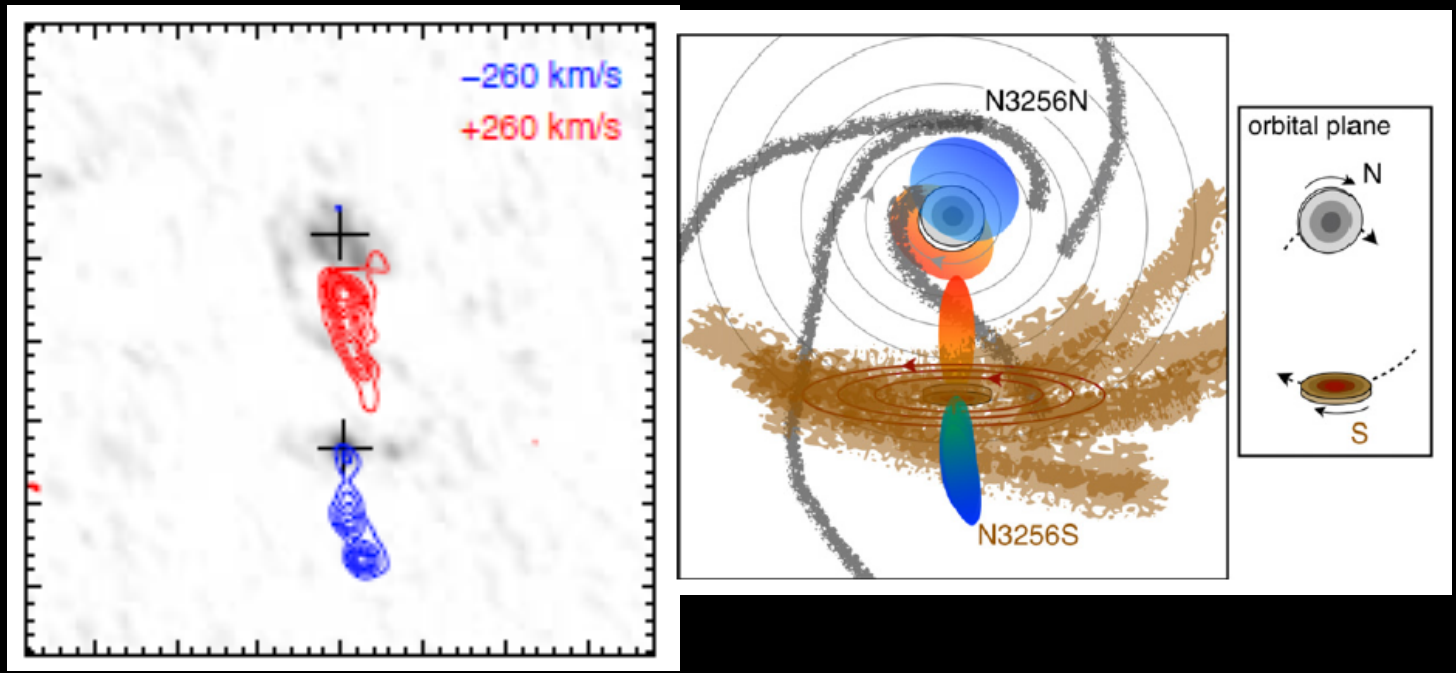
HCN/HCO+ 3-2
14x7 pc resolution
Molecular emission:
Size ~10pc , Mass ~10^5 M_o

Imanishi+2016

ALMA reveals molecular outflows: AGN or SB driven???

ALMA CO 1-0 | SMA CO 2-1 | ALMA CO 3-2





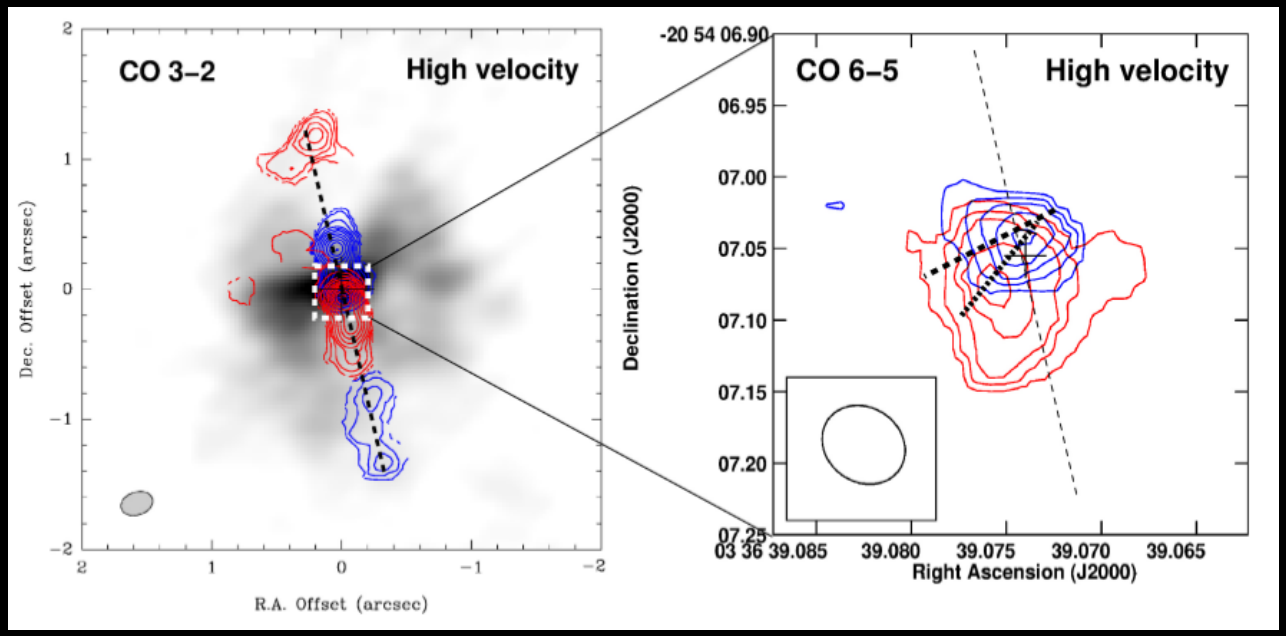
NGC 3256 : Most luminous galaxy within z=0.01

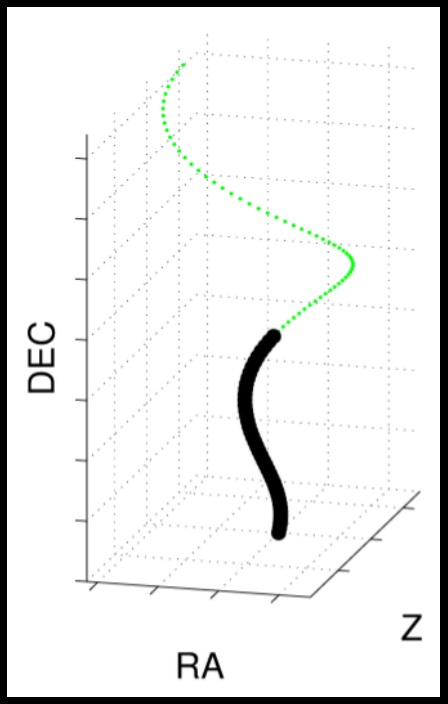
Sakamoto+2014

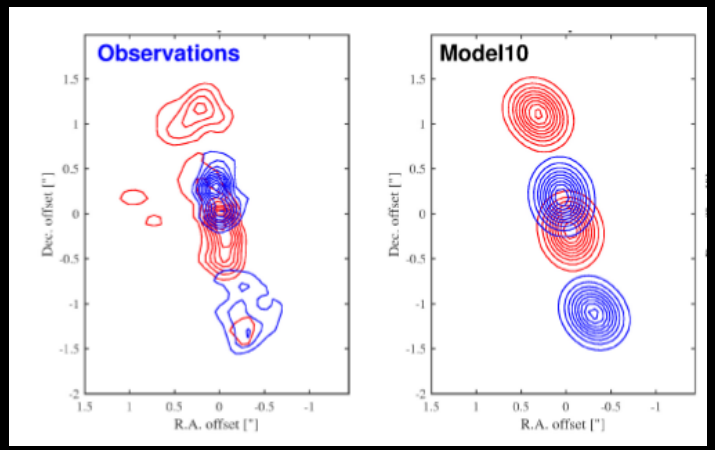
ALMA reveals molecular outflows: AGN or SB driven???

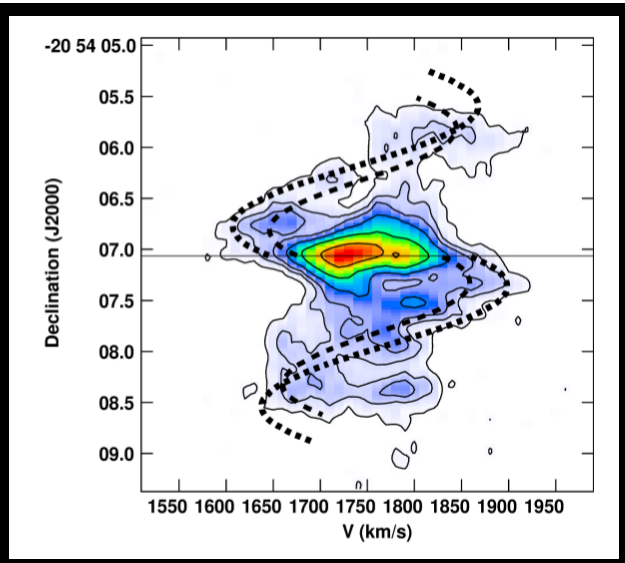
NGC 1377:

Extreme FIR-excess galaxy with radio synchrotron emission deficient by ~40 compared to normal galaxies.









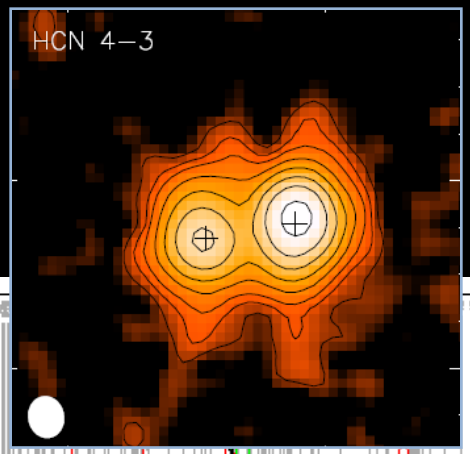
Aalto+2016,2017

ALMA reveals molecular outflows: Arp 220

Arp 220:

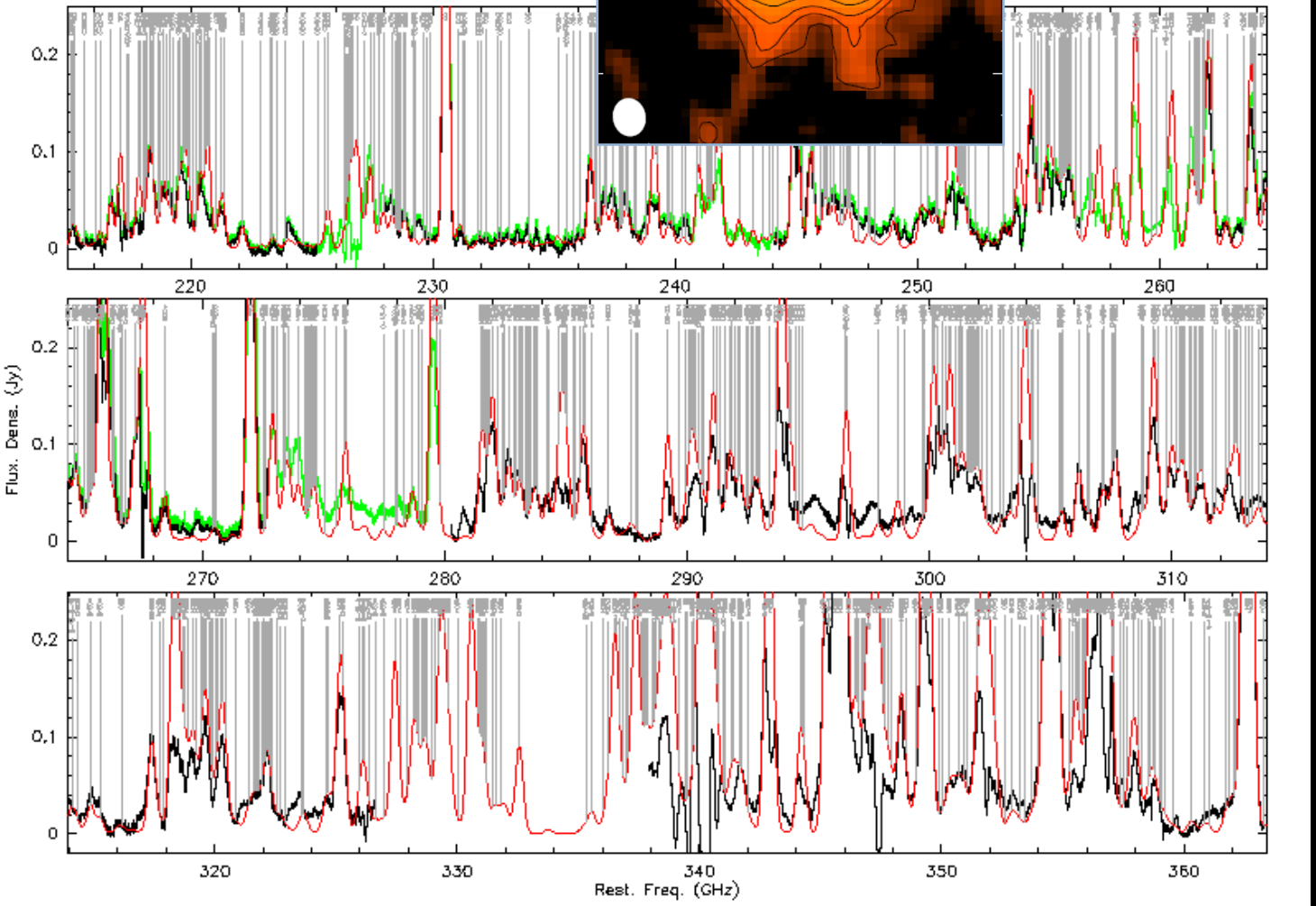
The prototypical ULIRG

Neverending discussion on AGN vs SB powered nuclei



Extreme molecular emitter

at D~70 Mpc



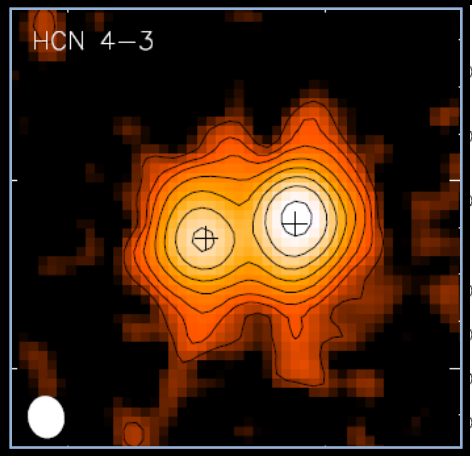
Martin+in prep

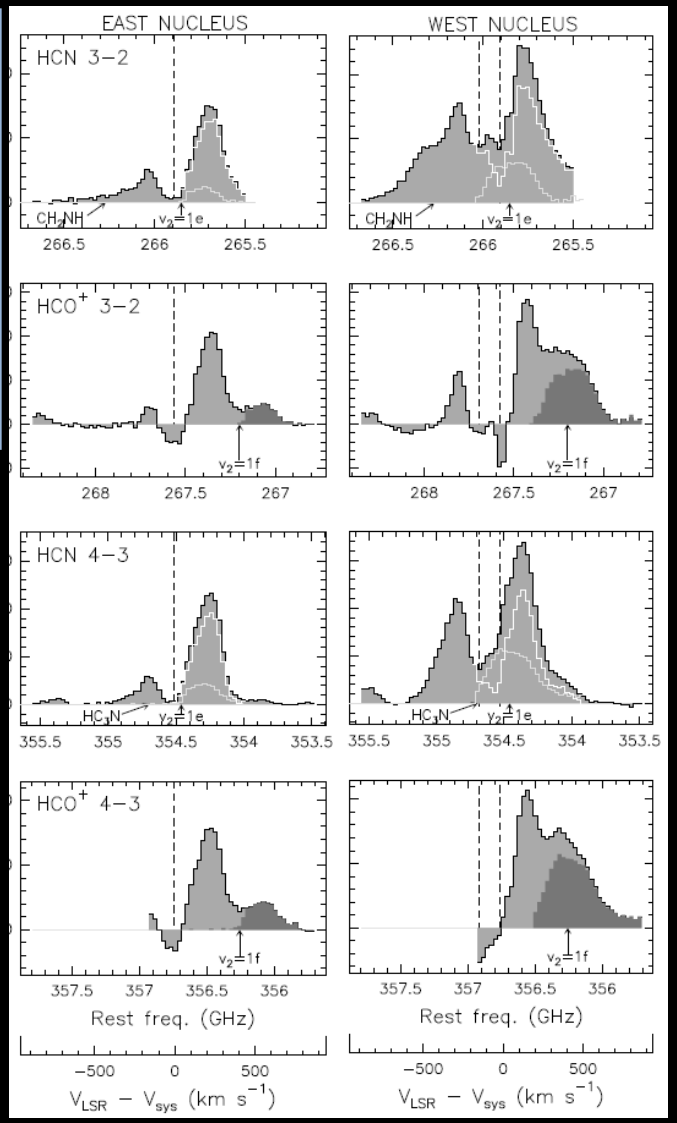
ALMA reveals molecular outflows: Arp 220

Arp 220:

The prototypical ULIRG

Neverending discussion on AGN vs SB powered nuclei





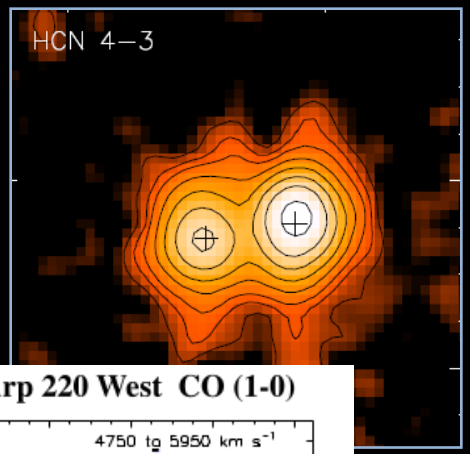
Martin+2016

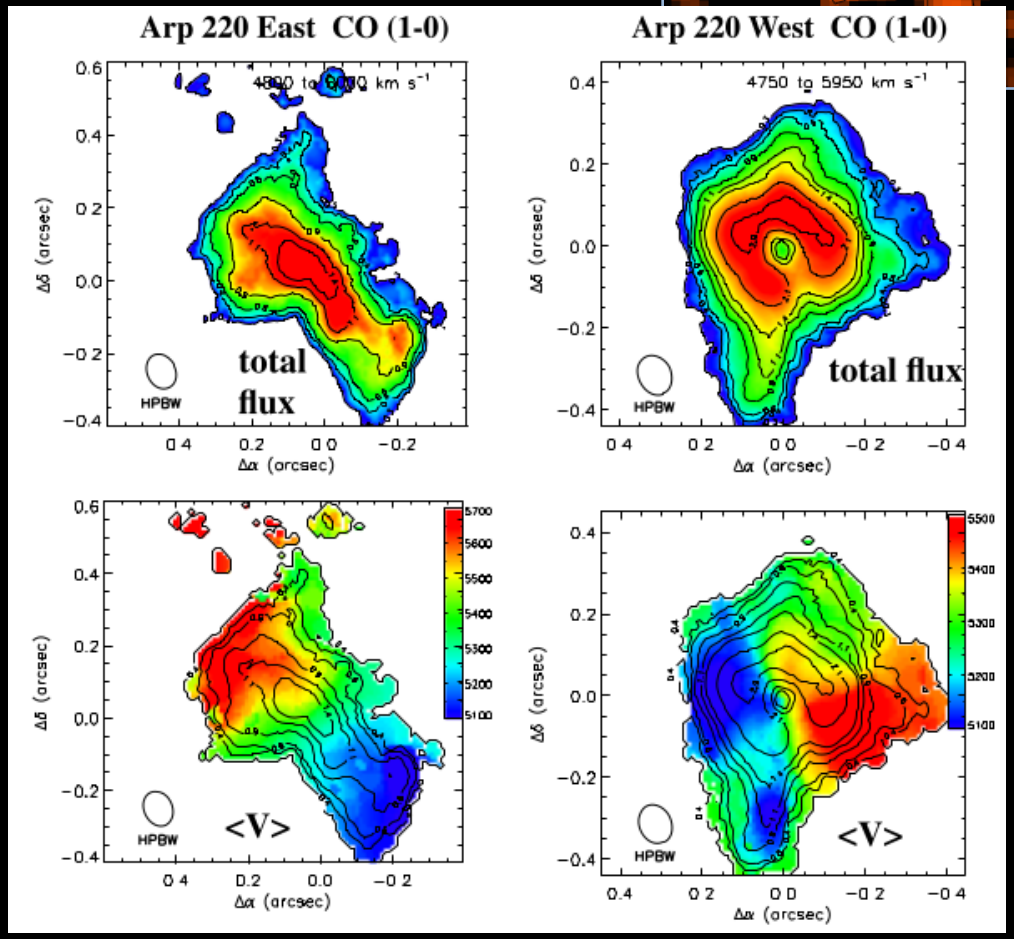
ALMA reveals molecular outflows: Arp 220 at <0.1” resolution

Arp 220:

The prototypical ULIRG

Neverending discussion on AGN vs SB powered nuclei





WESTERN NUCLEUS

$N(H_2) \sim 2 \times 10^{26}$ cm^{-2} (~900 gr cm −2)

Evidence of a central Keplerian component with mass of 8×10^8 M_o

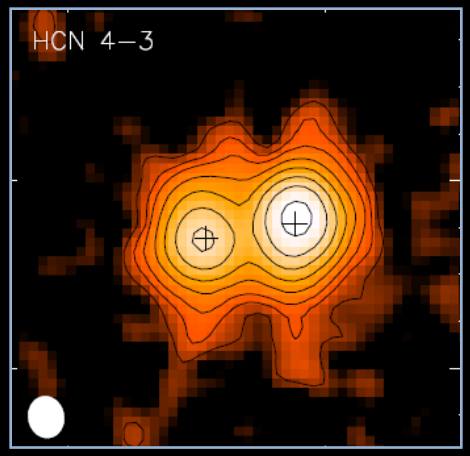
Scoville+2017

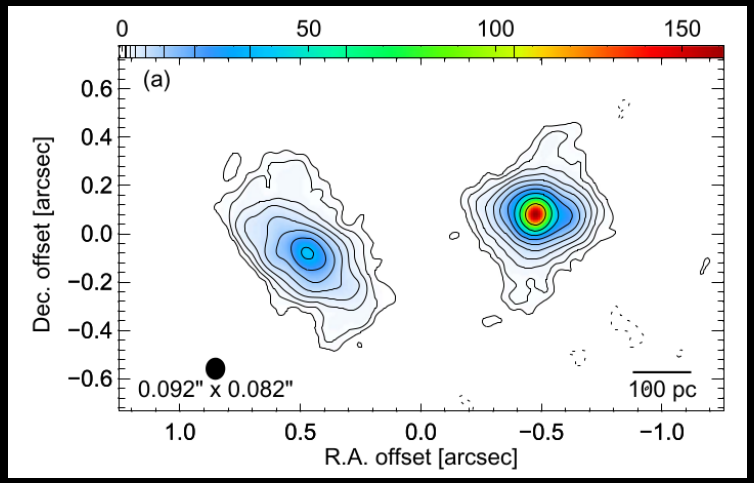
ALMA reveals molecular outflows: Arp 220 at <0.1” resolution

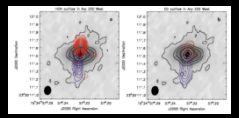
Arp 220:

The prototypical ULIRG

Neverending discussion on AGN vs SB powered nuclei







Sakamoto+2017
(Reprocessing of Archival data)

Barcos-Muñoz+2018
(HCN plus CO from the same archival data!!!)