

# Feeding and Feedback in nearby AGN: From Cycle 0 to Cycle 2

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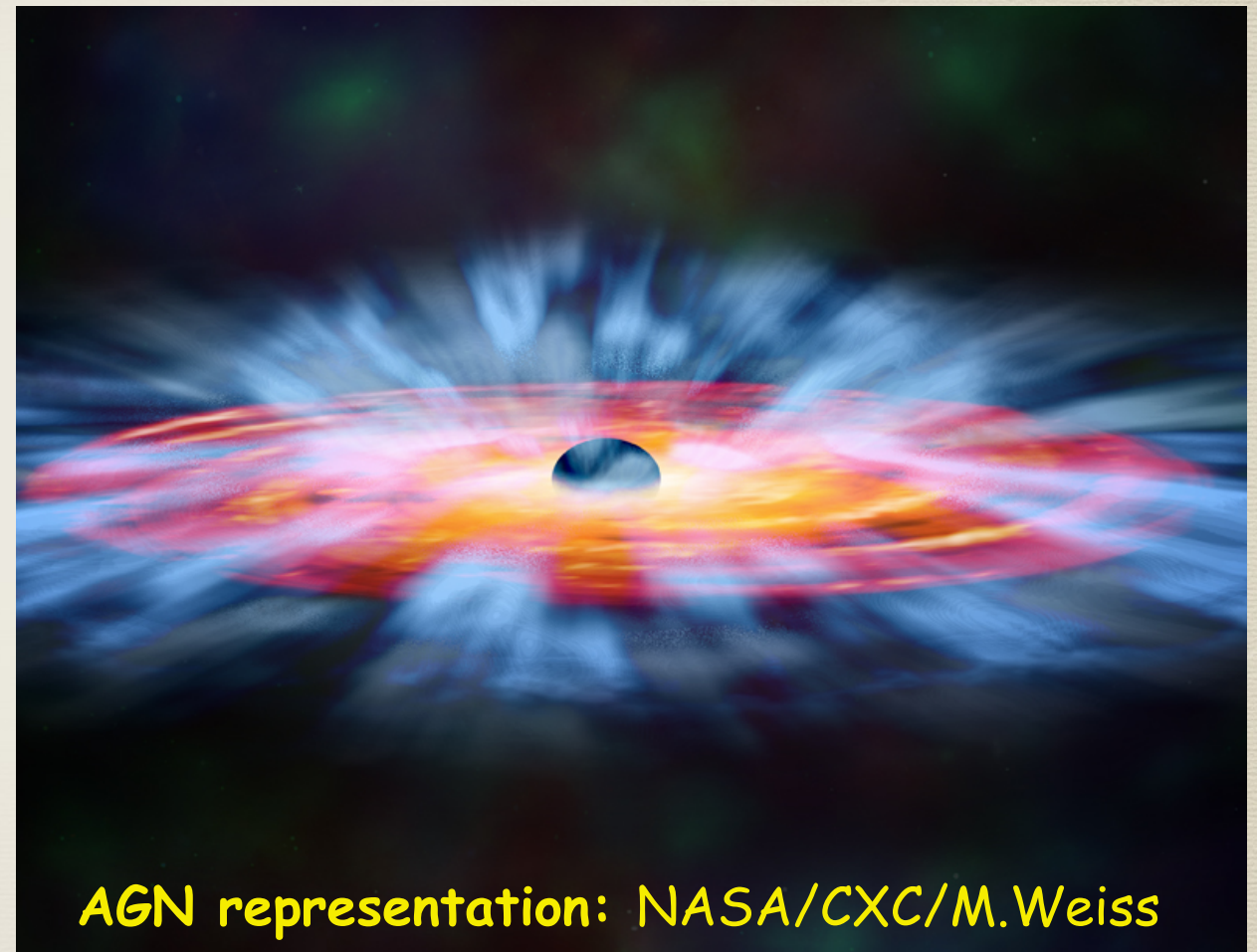
# Outline

- AGN Fueling: Open Problem
- AGN Fueling with ALMA
- ALMA Cycle 0 Results: NGC 1433, NGC 1566, (NGC 1068)
- Waiting for new ALMA results: NGC 1068, Mrk 590



# AGN fueling: Open Problem

- Content, distribution, and kinematics of interstellar gas: fundamental for origin and maintenance of galaxy nuclear activity
- Molecular gas: dominant phase in galaxy nuclei
- mm-interferometers: sharp view of distribution and kinematics of molecular gas (mainly CO)
- Open problem: Removal of the angular momentum from the disk gas and driving infall down to scales of tens of pc (e.g., Garcia-Burillo 05; Haan et al. 2009; Medit et al. 2013)



AGN representation: NASA/CXC/M.Weiss



# AGN fueling: Previous studies

## NUGA: NUclei of GALaxies

A CO IRAM PdBI+30m survey of 25 nearby low-luminosity active galactic nuclei (AGN: Seyfert/Liner galaxies). Spatial resolution: 50 - 100 pc

F. Combes, Obs. Paris, France

S. García-Burillo, Obs. Madrid, Spain

PIs

L. K. Hunt, INAF-Arcetri, Italy

V. Casasola, INAF-IRA, IT-ARC, Italy

M. Krips, IRAM Grenoble, France

A. Eckart, Koln Univerisity, Germany

F. Boone, Toulouse University, France

E. Schinnerer, Max-Planck-Ins., Heidelberg, Germany

L. Tacconi, Max-Planck-Ins., Garching, Germany

A. Baker, Rutgers, USA

R. Neri, IRAM, France

I. Marquez, CSIC-UC, Santander, Spain

S. Leon, JAO/ESO

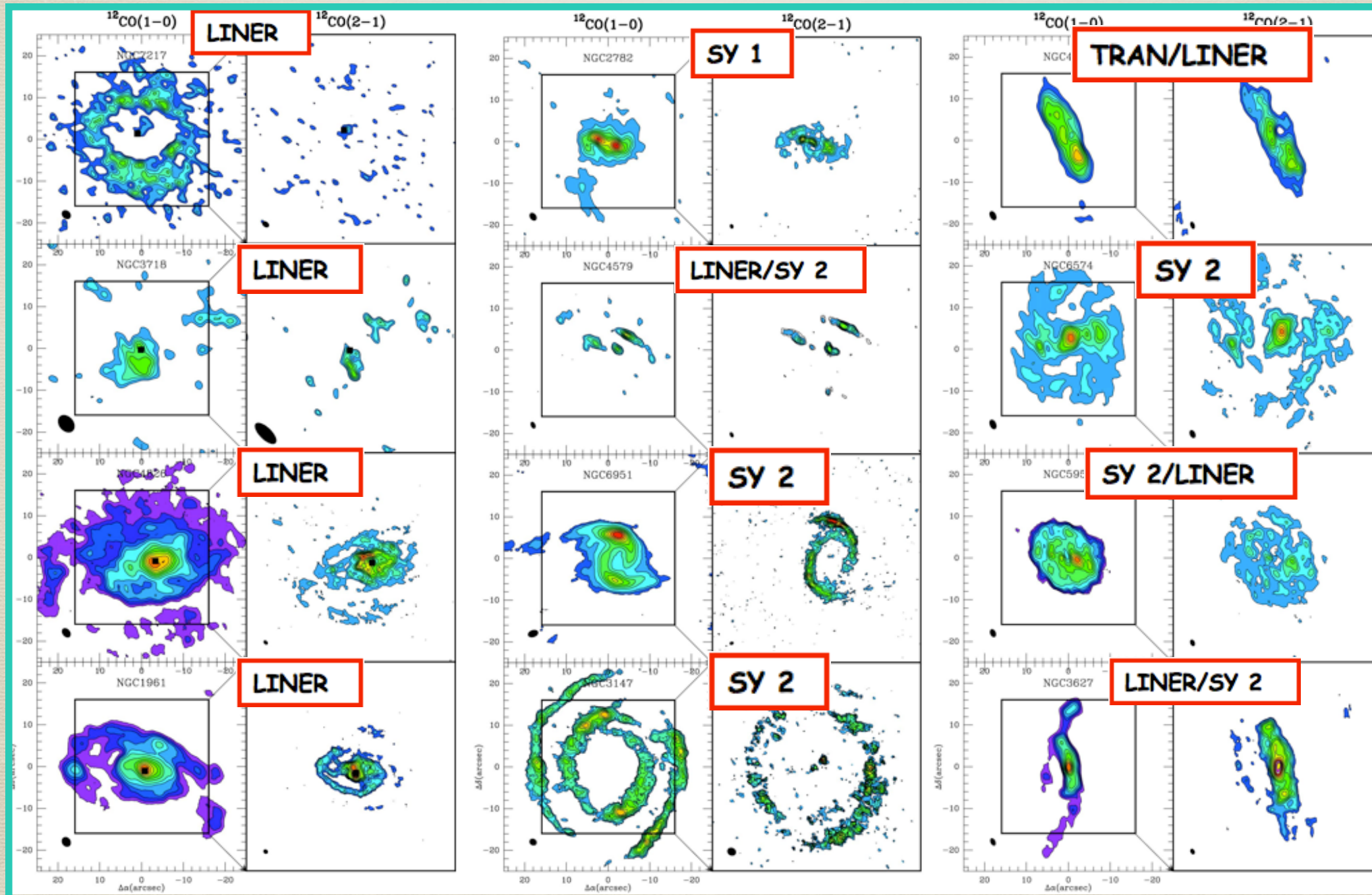
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NUGA Team



# Morphologies found in NUGA

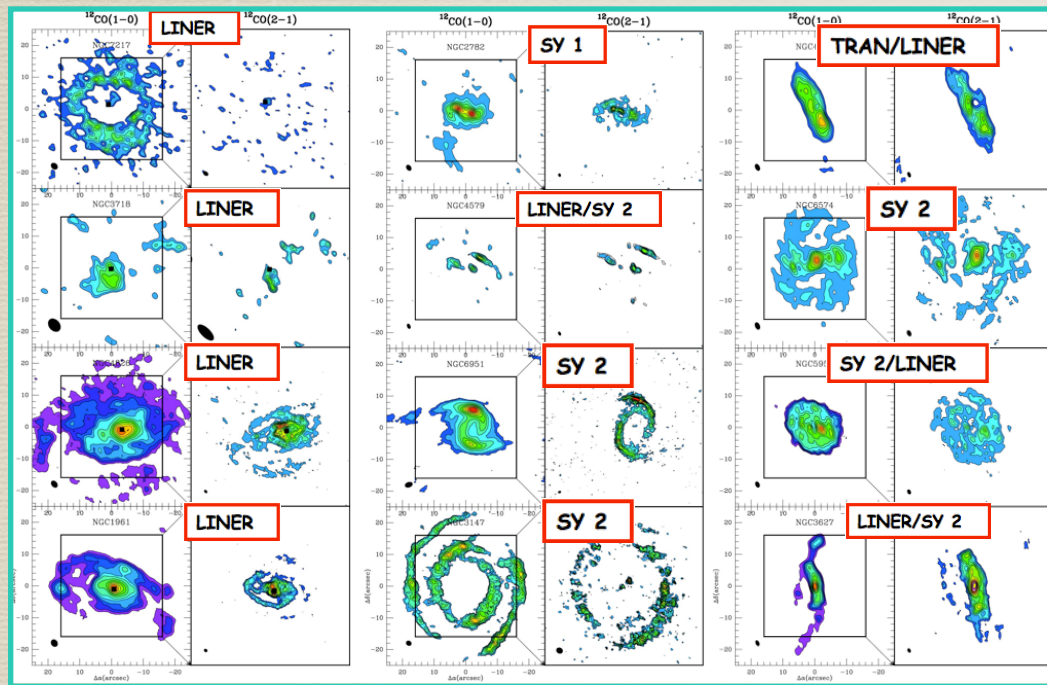
**17 papers:** Boone et al. 07; Casasola et al. 08, 10, 11; Combes et al. 04, 09; García-Burillo et al. 03, 05, 09; Haan et al. 08, 09; Hunt et al. 08; Krips et al. 05, 07a, 07b; Lindt-Krieg et al. 08; Van der Laan et al. 11





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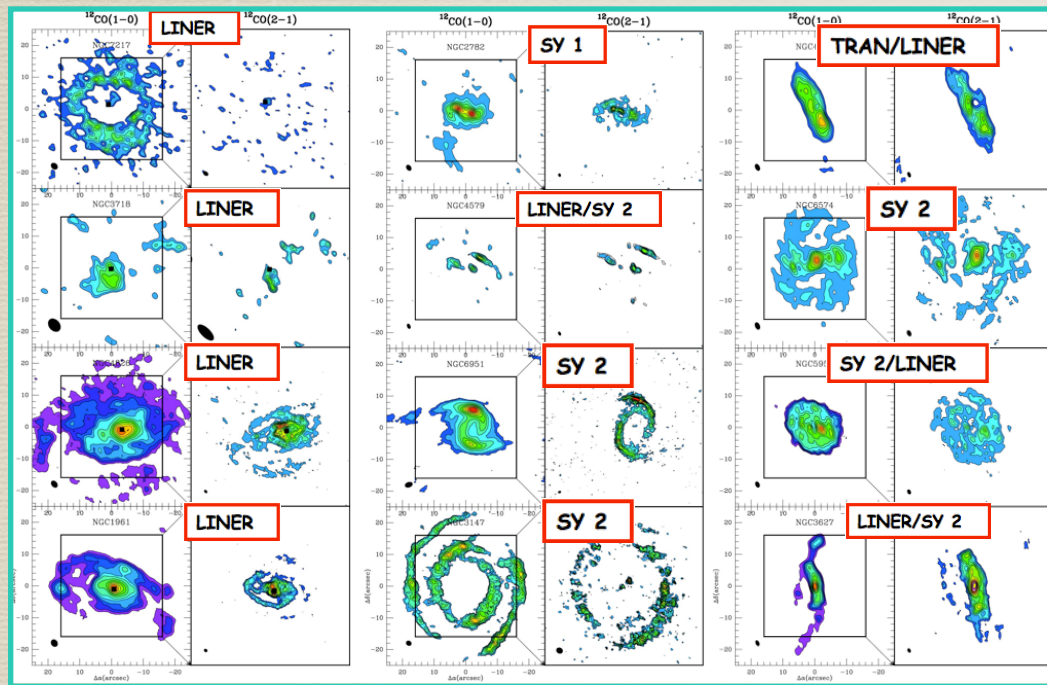
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**17 papers:** Boone et al. 07; Casasola et al. 08, 10, 11; Combes et al. 04, 09; García-Burillo et al. 03, 05, 09; Haan et al. 08, 09; Hunt et al. 08; Krips et al. 05, 07a, 07b; Lindt-Krieg et al. 08; Van der Laan et al. 11



1. Variety of CO morphologies in the central region of AGN
2. The molecular gas is frequently stalled in rings: Gravity torque barriers
3. Gas inflow, assumed ubiquitous in simulations, is seen only in 1/3rd of cases

IRAM observations have **insufficient resolution** to probe the gas within  $\sim 50$  pc of the AGN.



# AGN fueling with ALMA

ALMA Cycle 0 has already offered the opportunity, **FOR THE FIRST TIME**, to examine the ultimate **contenders of nuclear gas fueling** improving spatial resolution by a factor 5 and sensitivity by a factor 2 with respect to our previous results on NUGA



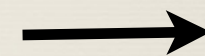
# AGN fueling with ALMA

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1.

Feeding and feedback in nearby Seyfert Galaxies

PI: F. Combes

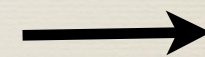


NUGA SOUTH

2.

The footprints of SF and AGN activity in NGC 1068:  
a case study for ALMA

PI: S. García-Burillo



Smoking gun  
evidence of  
feeding

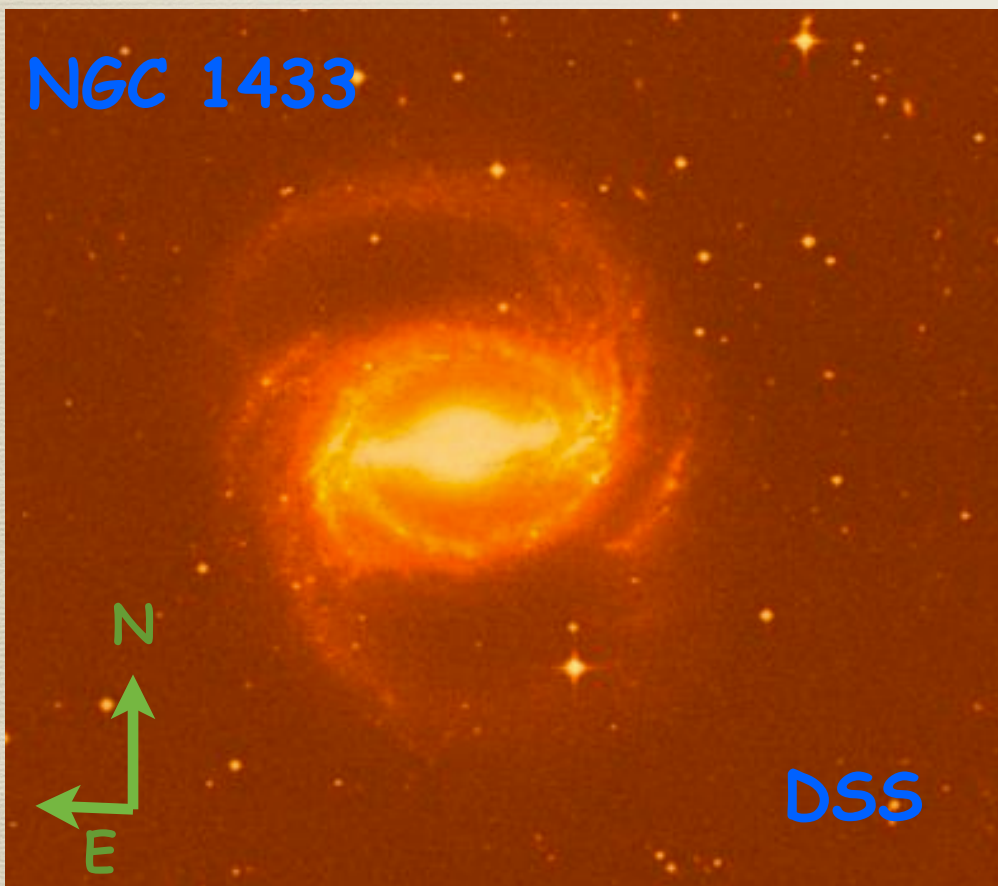


# NUGA SOUTH

Two Targets selected among barred spiral nearby southern AGN with existing wealth of data and CO detection:

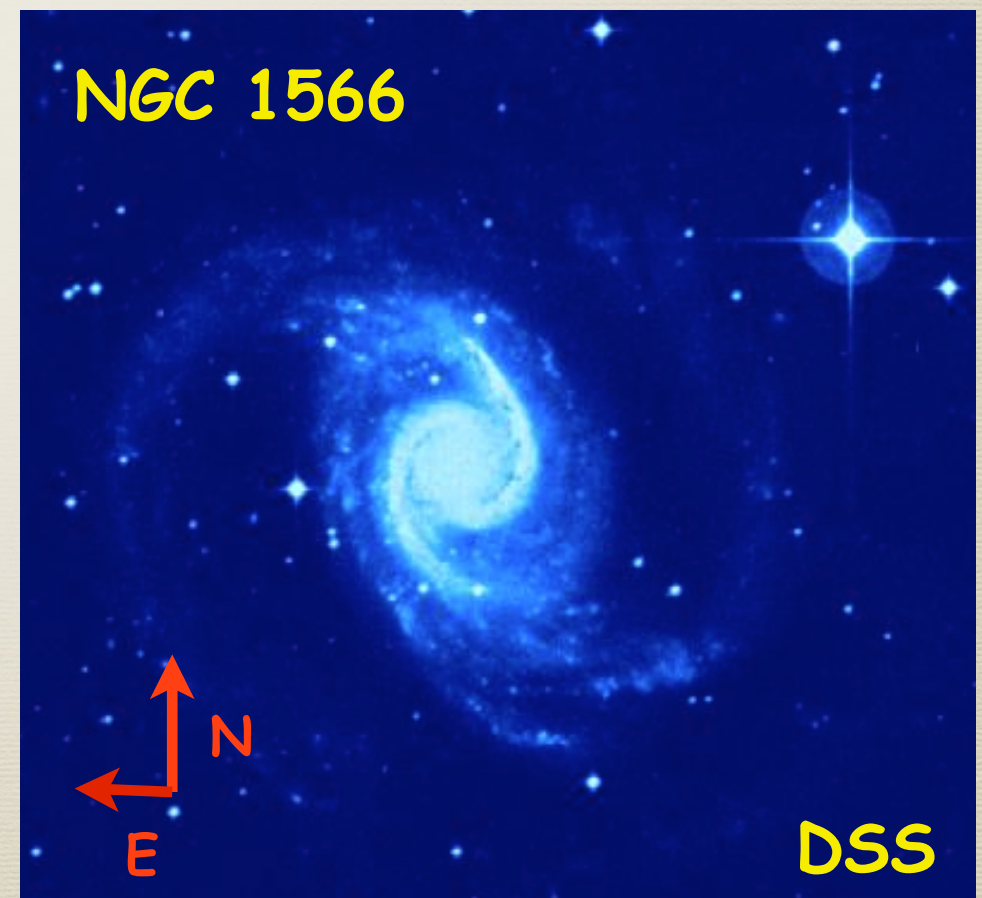
NGC 1433 (Seyfert 2) and NGC 1566 (Seyfert 1)

NGC 1433



Both at  $D \sim 10$  Mpc  
with embedded bars

NGC 1566





## NUGA SOUTH: Observations @ ALMA Cycle 0

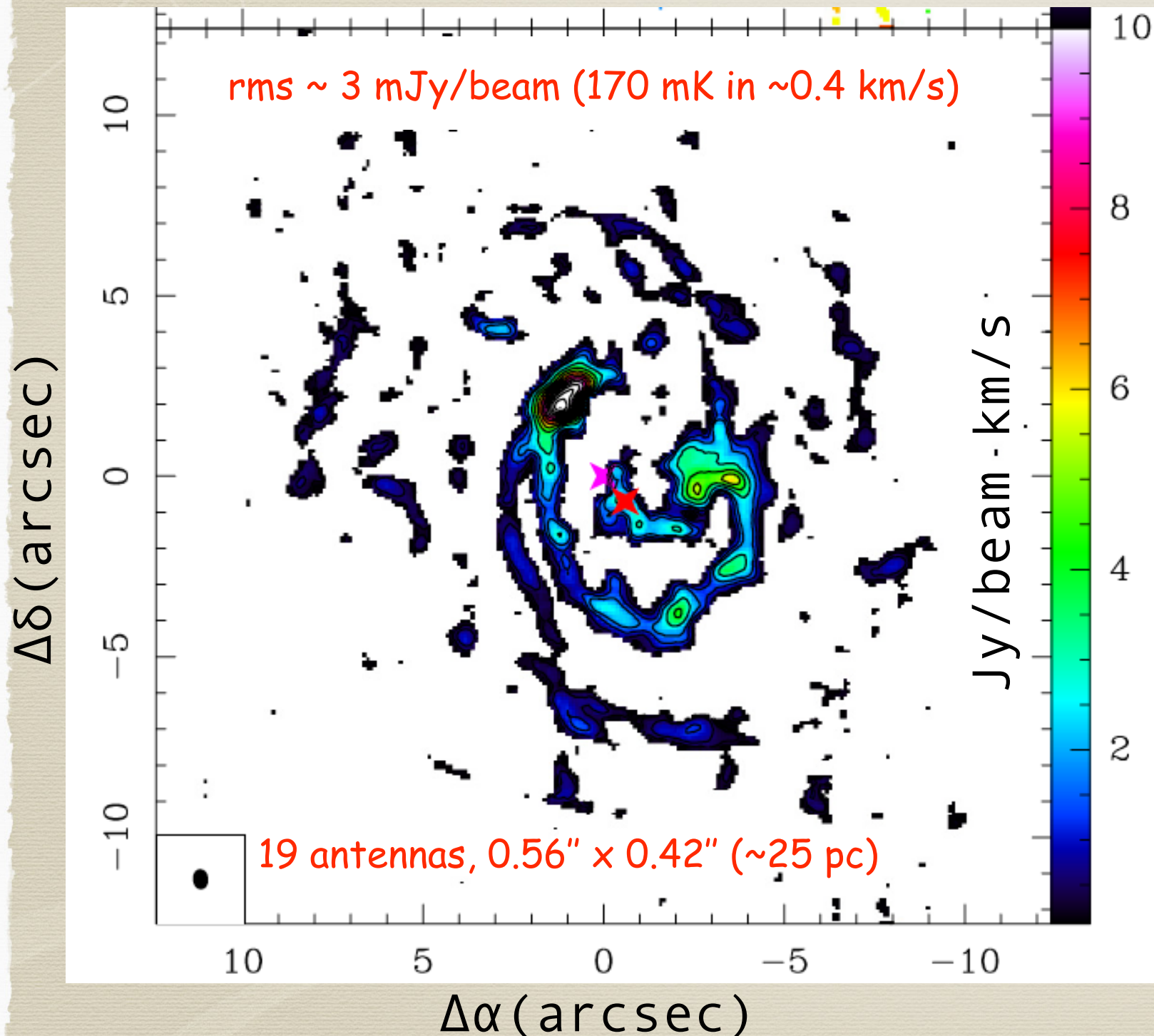
We proposed to map the morphology and kinematics of the cold dense gas in two Seyfert nuclei, at the unprecedented spatial resolution.

- To map the  $\text{CO}(3-2)$  (high density gas,  $10^4 - 10^5 \text{ cm}^{-3}$ ) line in both galaxies, simultaneously with  $\text{HCN}(4-3)$  and  $\text{HCO}^+(4-3)$  (densest clumps, excitation and chemistry)
- Extended Configuration (baselines: 17 - 400 m), Band 7 (275 - 373 GHz)
- Angular resolution  $\sim 0.5''$  ( $\sim 25 \text{ pc}$ ), Spectral resolution  $\sim 0.4 \text{ km/s}$
- One single pointing per galaxy (FOV =  $18'' \lesssim 1 \text{ kpc}$ )
- $\sim 2 \text{ hrs}$  of integration time for each galaxy
- To map continuum emission @  $0.87 \text{ mm}$



# NCG 1433: Gas Distribution

## CO(3-2) distribution

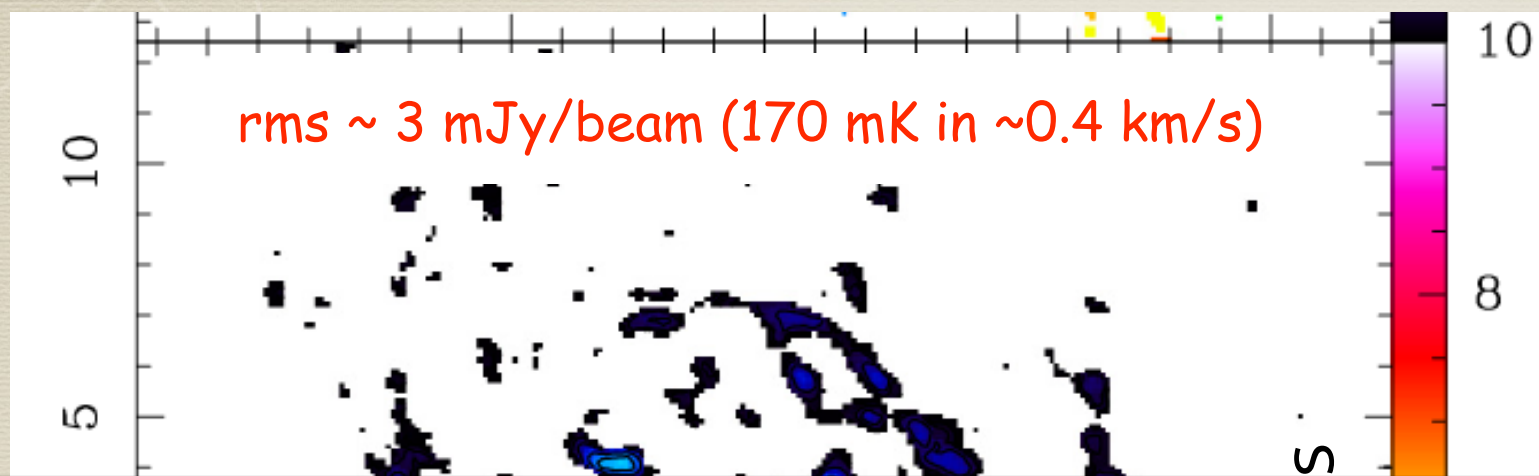


- A nuclear gaseous spiral structure with multiple branches
- A pseudo-ring,  $r = 4''$  (200 pc)
- Asymmetries: peak not in the center, but in a NE cloud complex
- $M(\text{H}_2) \sim 5 \times 10^7 M_\odot$
- Only upper limits for HCN(4-3) and  $\text{HCO}^+$ (4-3): low abundance of very dense gas



# NCG 1433: Gas Distribution

## CO(3-2) distribution

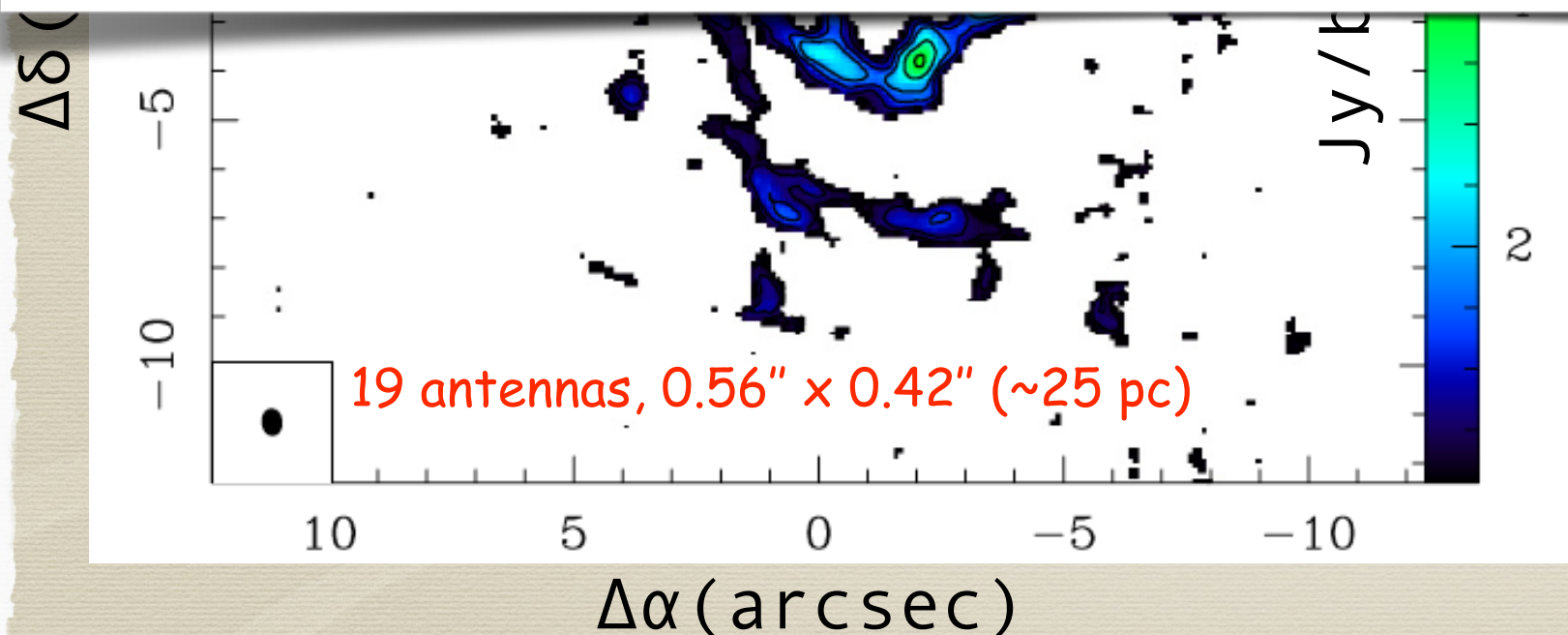


□ A nuclear gaseous spiral structure with multiple branches

□ A pseudo-ring,  $r = 4''$  (200 pc)

□ Asymmetries: peak not in the center, but in a NE cloud complex

This gas is not stalled in the pseudo-ring, but continues to flow towards the very center: **Gas fueling @ resolution of ~25 pc**

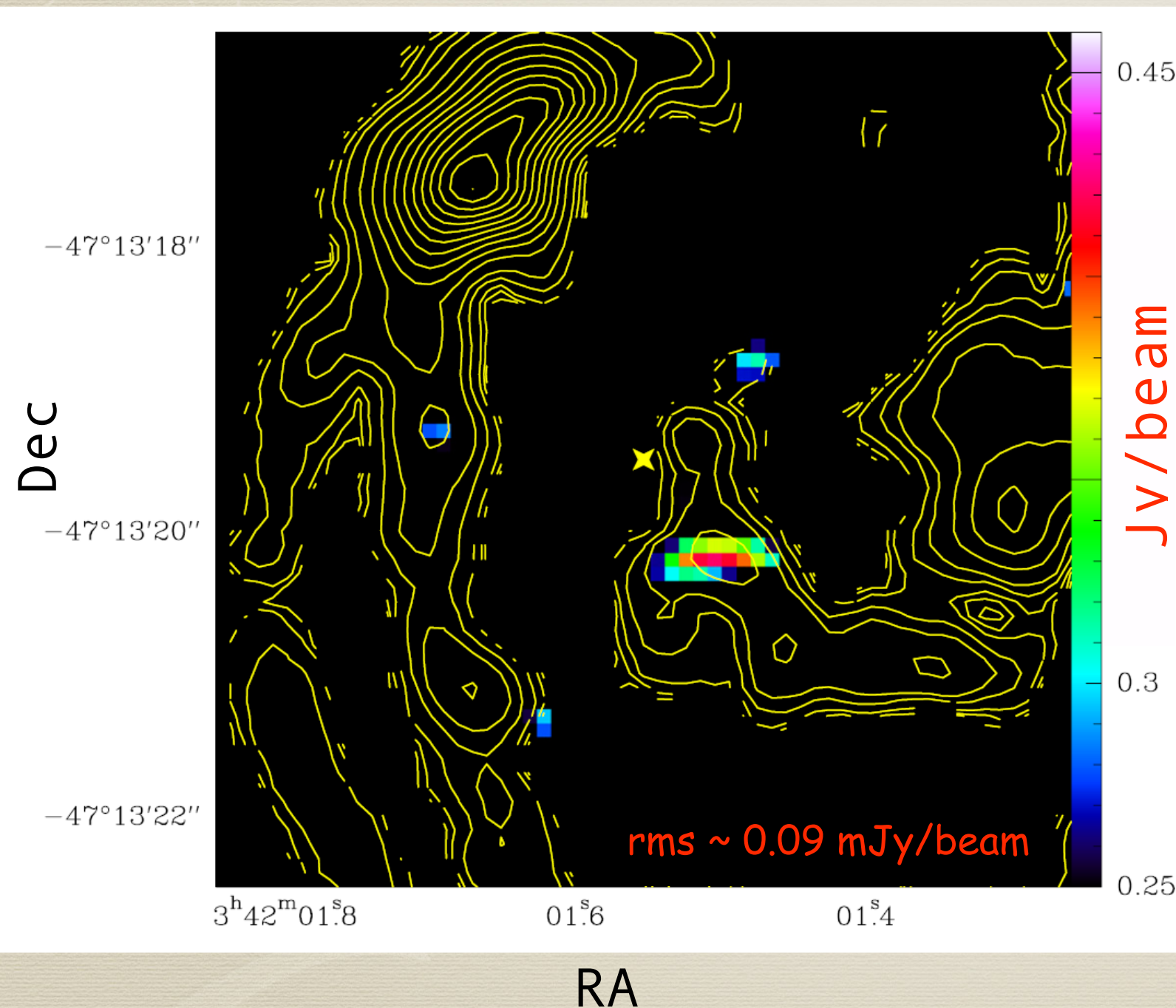


and HCO (4-3): low abundance of very dense gas



# NCG 1433: Continuum Emission

Continuum emission @ 0.87 mm  
+ CO(3-2) contours



- Detection ( $\sim 3\sigma$ ) only at the very center (peak  $\sim 0.5$  mJy)
- Its origin: likely thermal dust emission
- It might correspond to the molecular torus,  $9 \times 10^5 M_{\odot}$



# NCG 1433: Continuum Emission

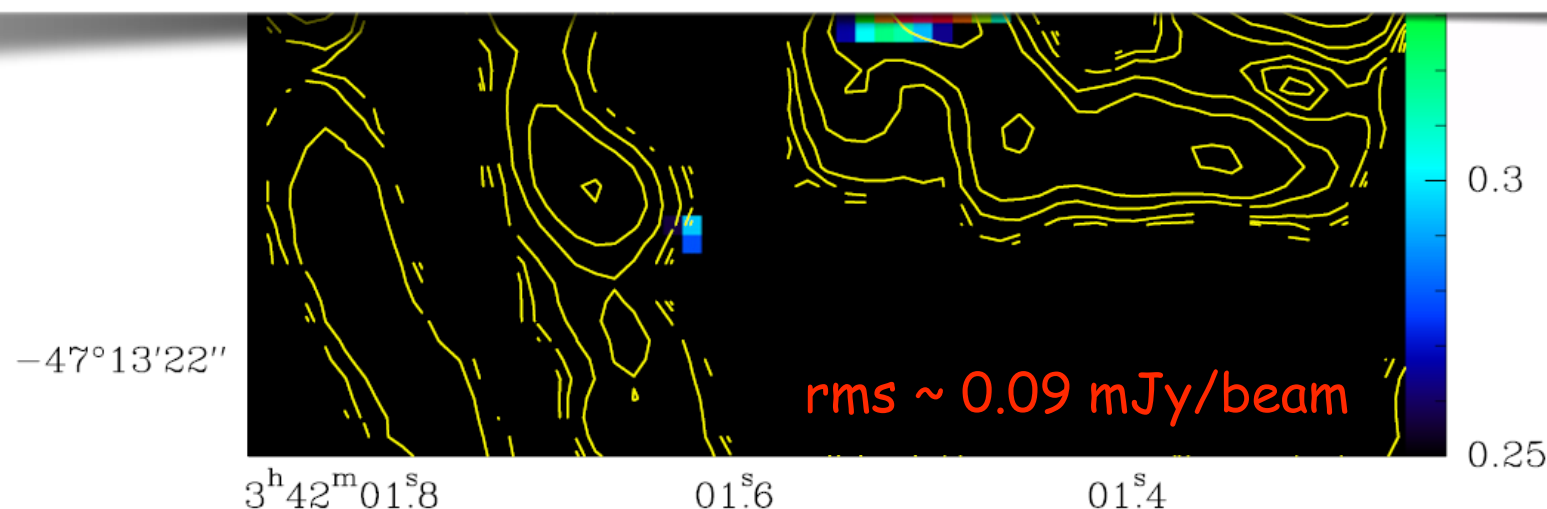
Continuum emission @ 0.87 mm  
+ CO(3-2) contours



□ Detection ( $\sim 3\sigma$ ) only at the very center (peak  $\sim 0.5$  mJy)

□ Its origin: likely thermal dust

Only high-resolution observations with ALMA at several frequencies would be able to settle the origin of the continuum emission and determine whether the AGN is directly detected.

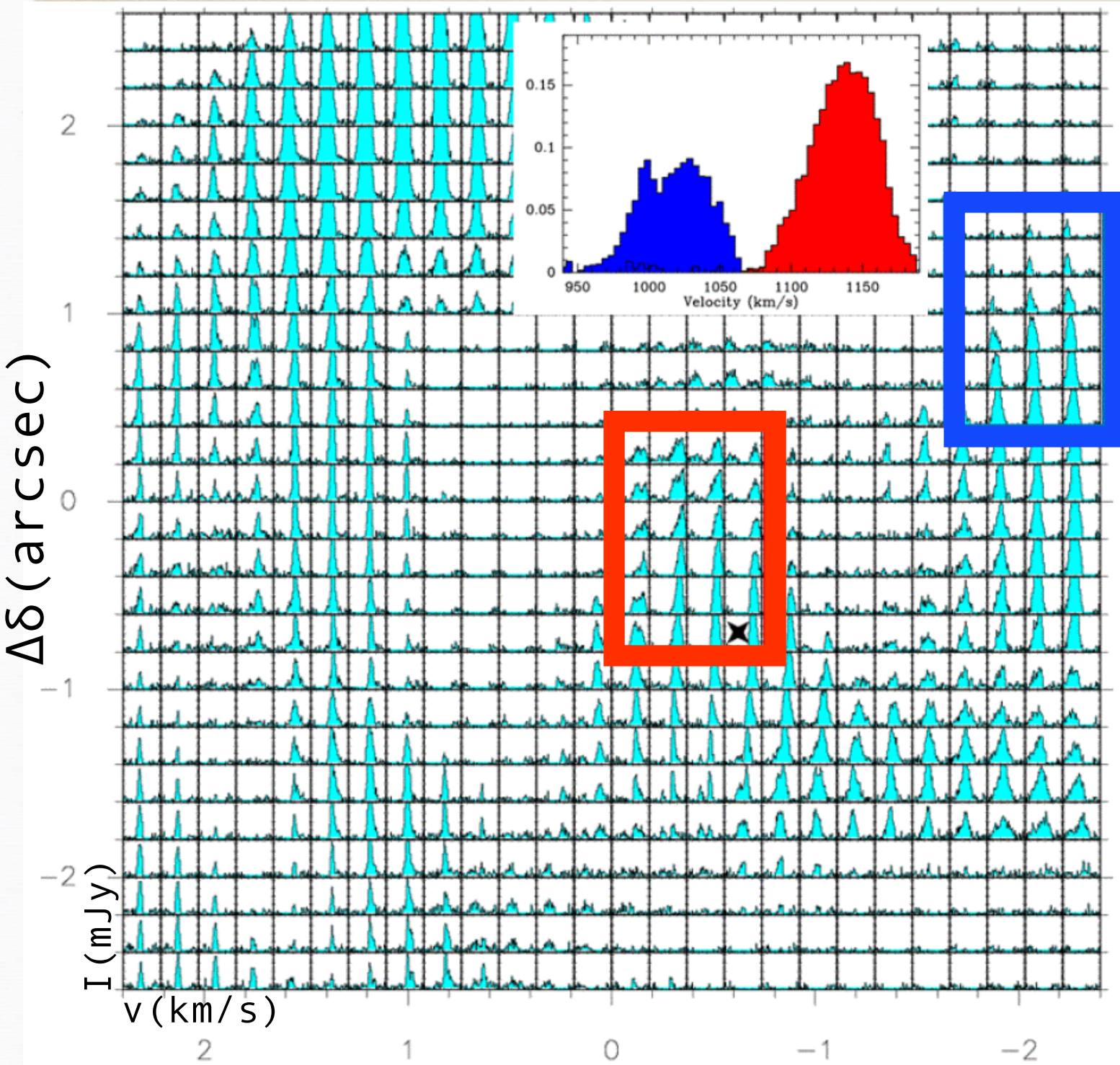


RA



# NCG 1433: CO Kinematics

CO(3-2) spectra within 2.5" of the center

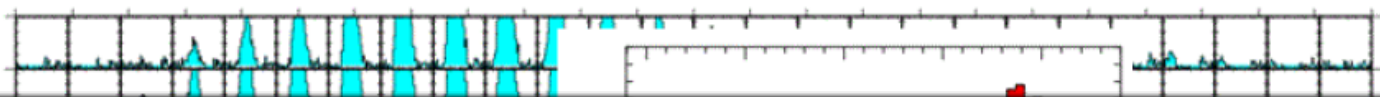


- The velocity field is well described by rotation
- A high-velocity **red-shifted (of 200 km/s) perturbation**, in the center
- A high-velocity **blue-shifted counterpart**, at 2" (~100 pc) from the center



# NCG 1433: CO Kinematics

CO(3-2) spectra within 2.5" of the center



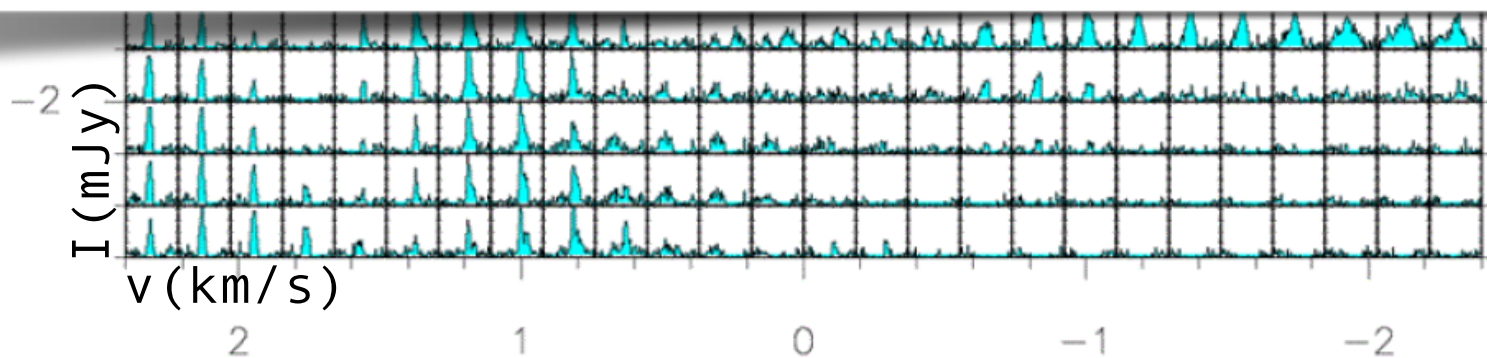
□ The velocity field is well

This high-velocity component is a tentative AGN-driven OUTFLOW:

Mass (outflow) =  $3.6 \times 10^6 M_{\odot}$ , Flow Rate =  $7 M_{\odot}/\text{yr}$

The smallest molecular outflow ever observed in external galaxies!

The discovery of this outflow, dragged along by the jet from the central black hole, shows how such outflows could stop star formation and regulate the growth of the central bulges of galaxies.

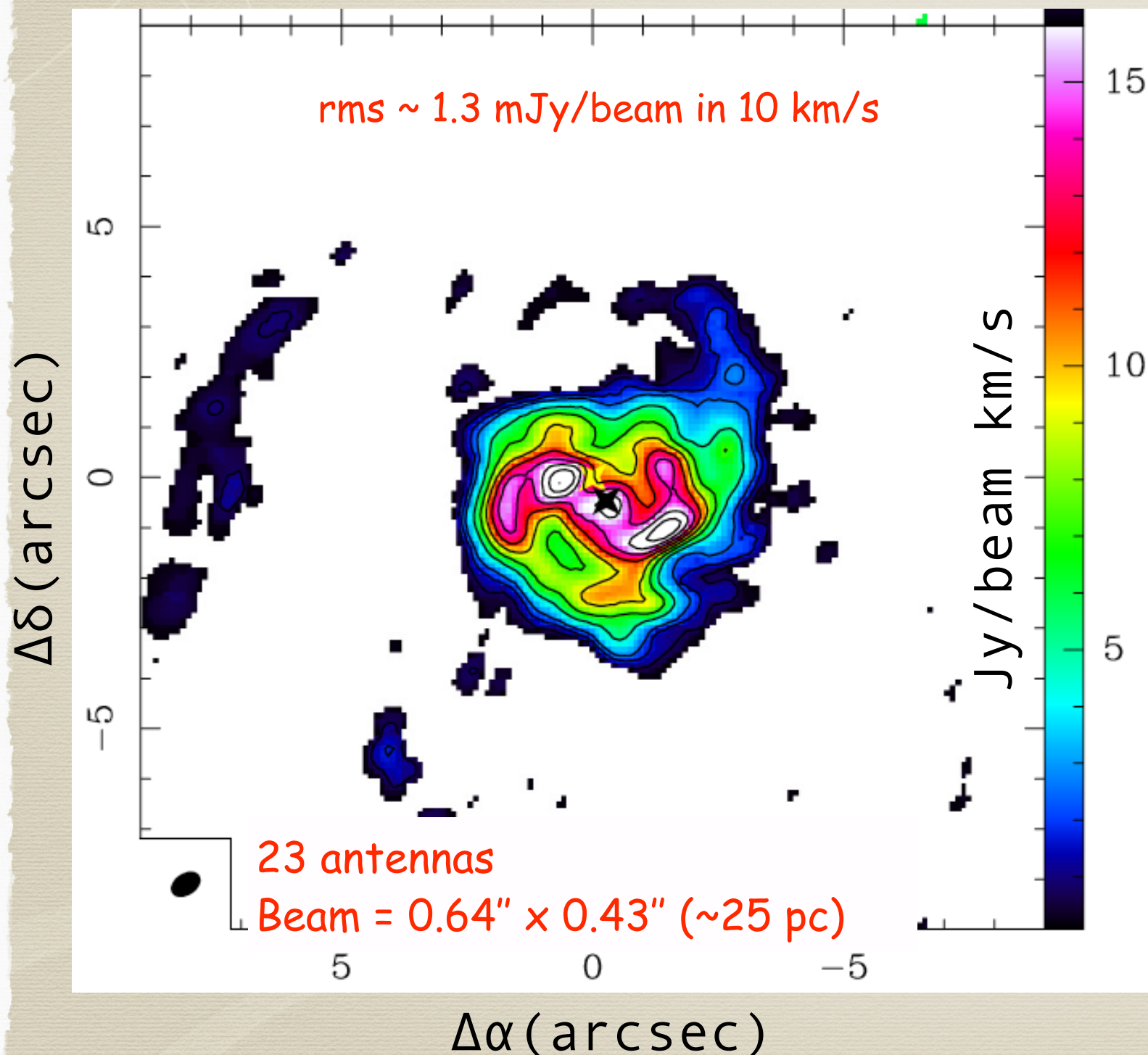


$\Delta\alpha$  (arcsec) Combes, Garcia-Burillo, Casasola, Hunt, + 2013



# NCG 1566: Gas Distribution

CO(3-2) distribution

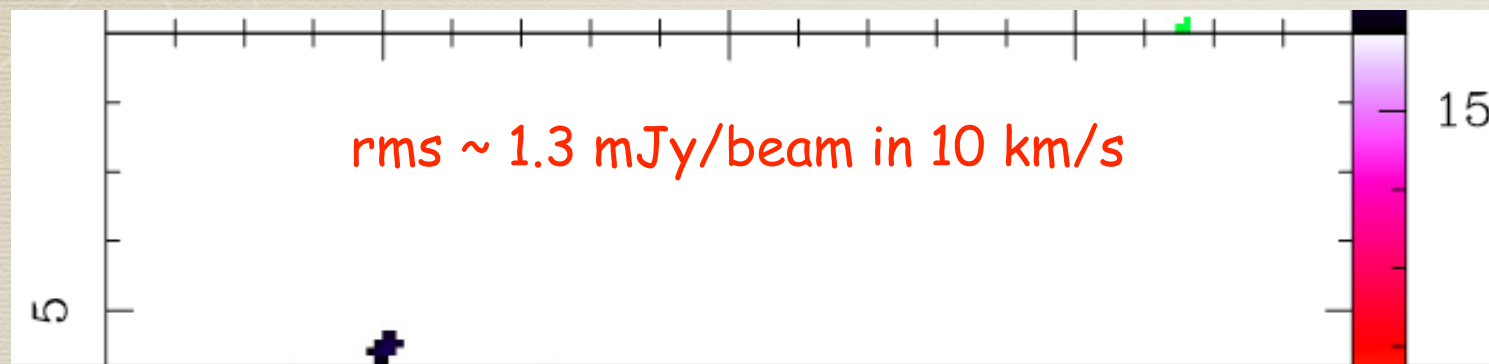


- A nuclear disk,  $r \sim 3''$  (150 pc), a contrasted 2-arm spiral structure
- The two small spiral arms show a faint extension onto a pseudo-ring,  $r \sim 9''$  (430 pc)
- $M(\text{H}_2) \sim 7 \times 10^7 M_\odot$



# NCG 1566: Gas Distribution

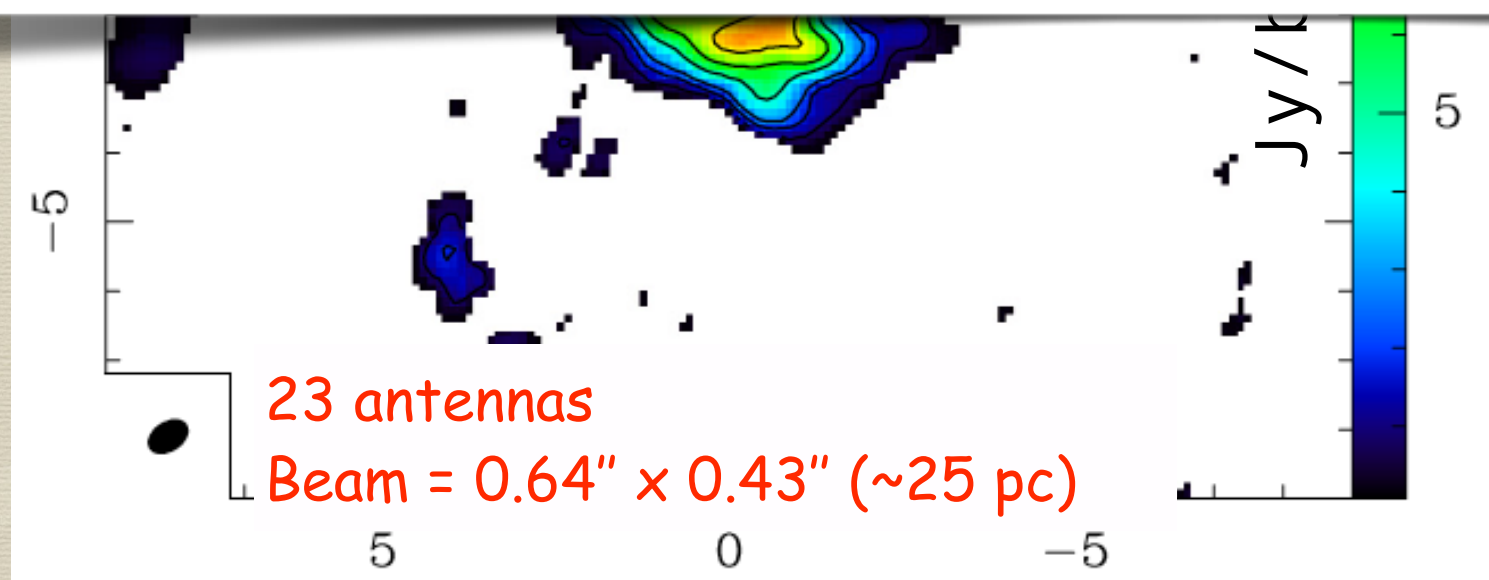
CO(3-2) distribution



□ A nuclear disk,  $r \sim 3''$  (150 pc),  
a contrasted 2-arm spiral  
structure

Gas fueling at the resolution of  $\sim 25$  pc.

NO molecular gas outflow!

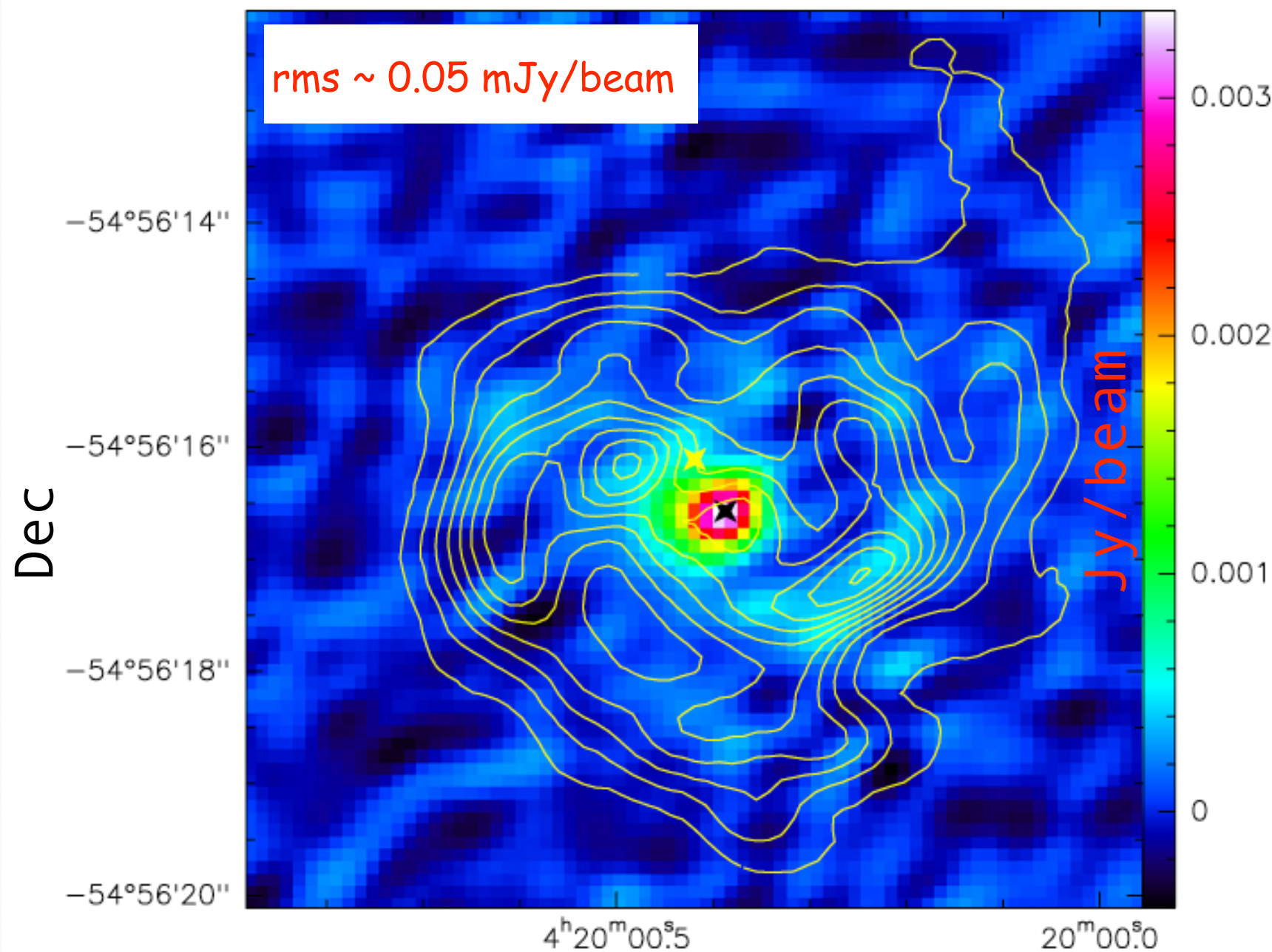


□  $M(\text{H}_2) \sim 7 \times 10^4 M_\odot$



# NCG 1566: Continuum Emission

Continuum emission @ 0.87 mm  
+ CO(3-2) contours



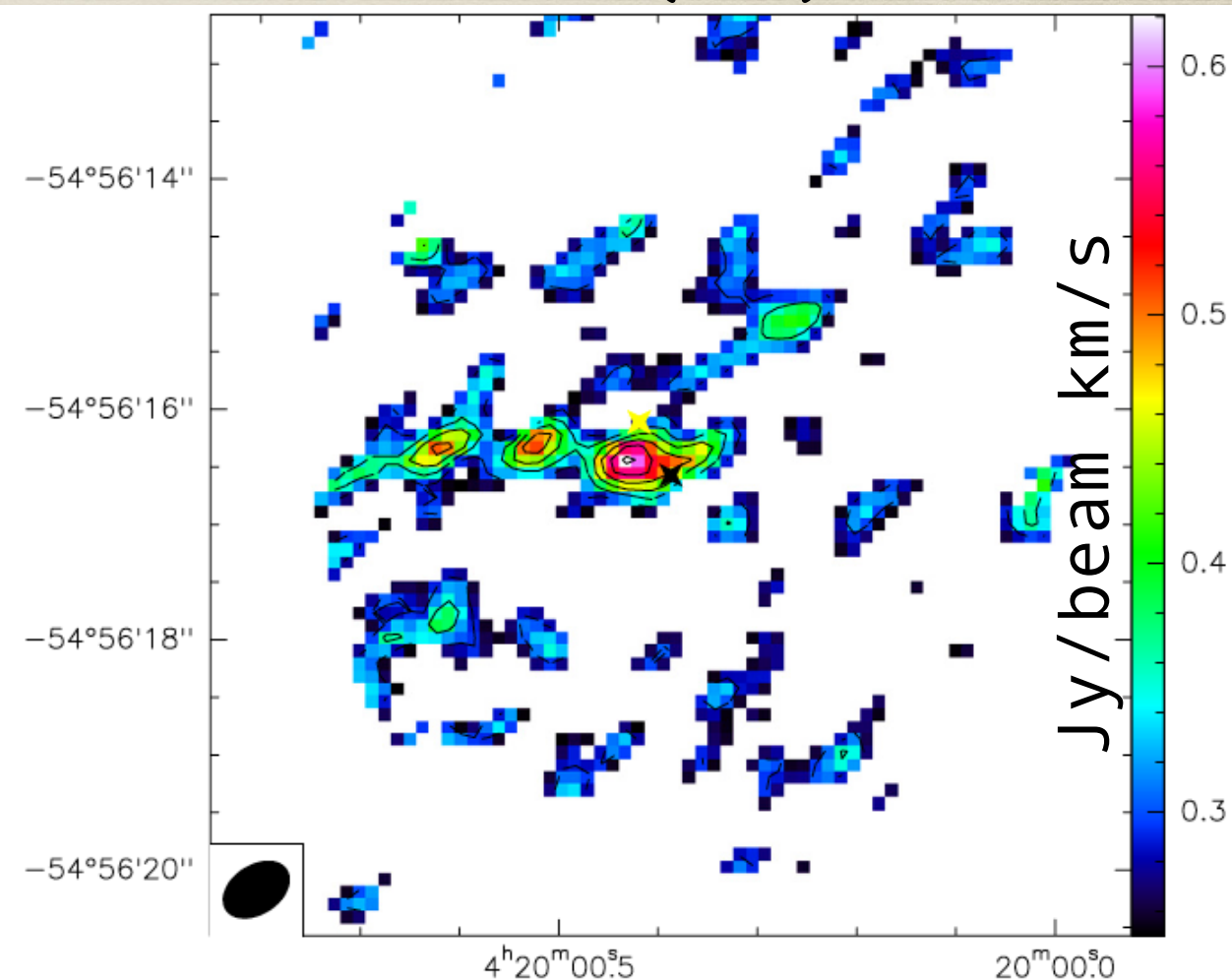
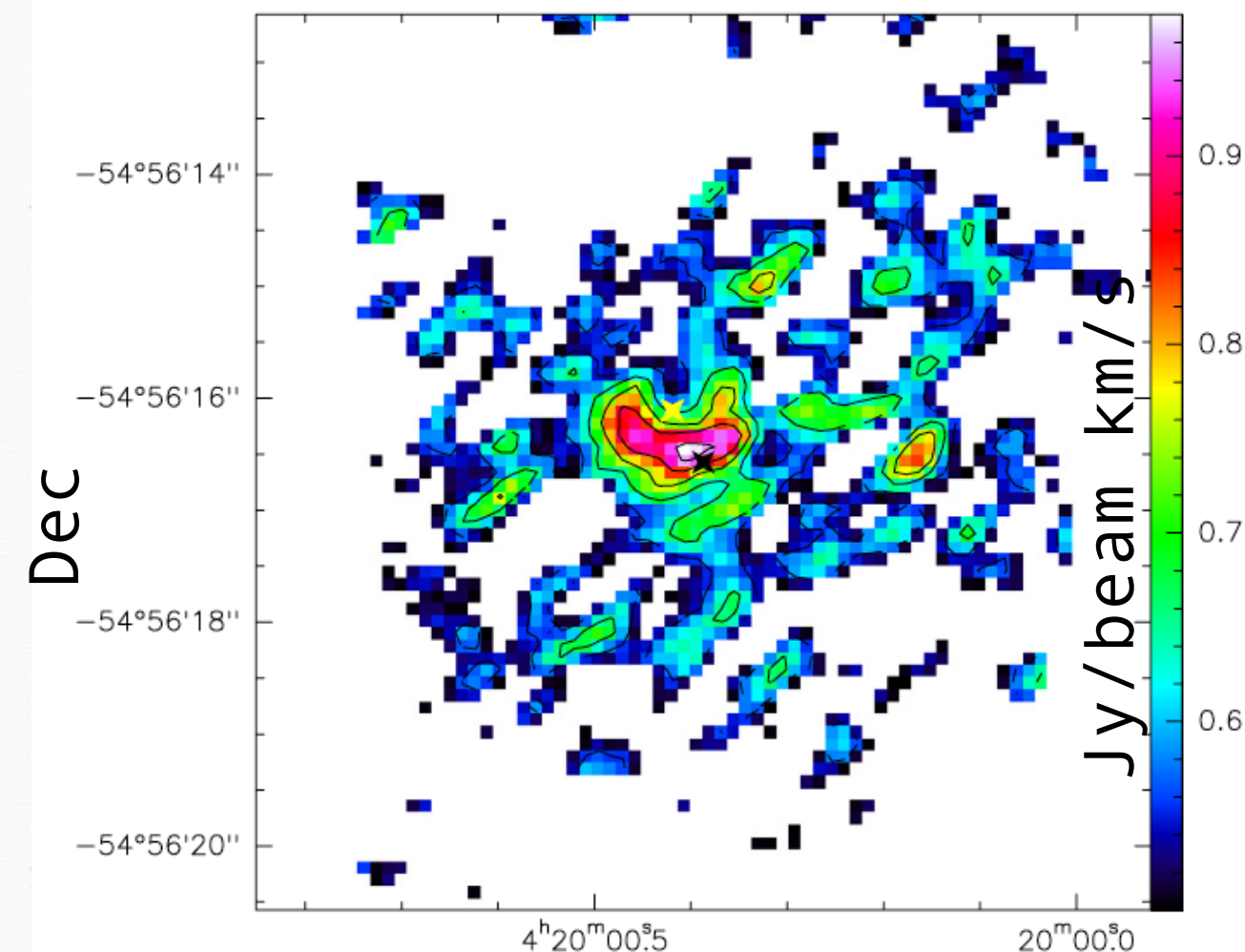
- The central peak emission is  $\sim 3$  mJy ( $> 50\sigma$ )
- The central peak coincides with the peak in CO(3-2)
- The continuum emission is extended, and follows the CO(3-2) 2-arm spiral structure
- The total continuum emission ( $\sim 13$  mJy) comes from cold dust heated by interstellar radiation field



# NGC 1566: Dense gas

HCO<sup>+</sup>(4-3)

HCN(4-3)



RA

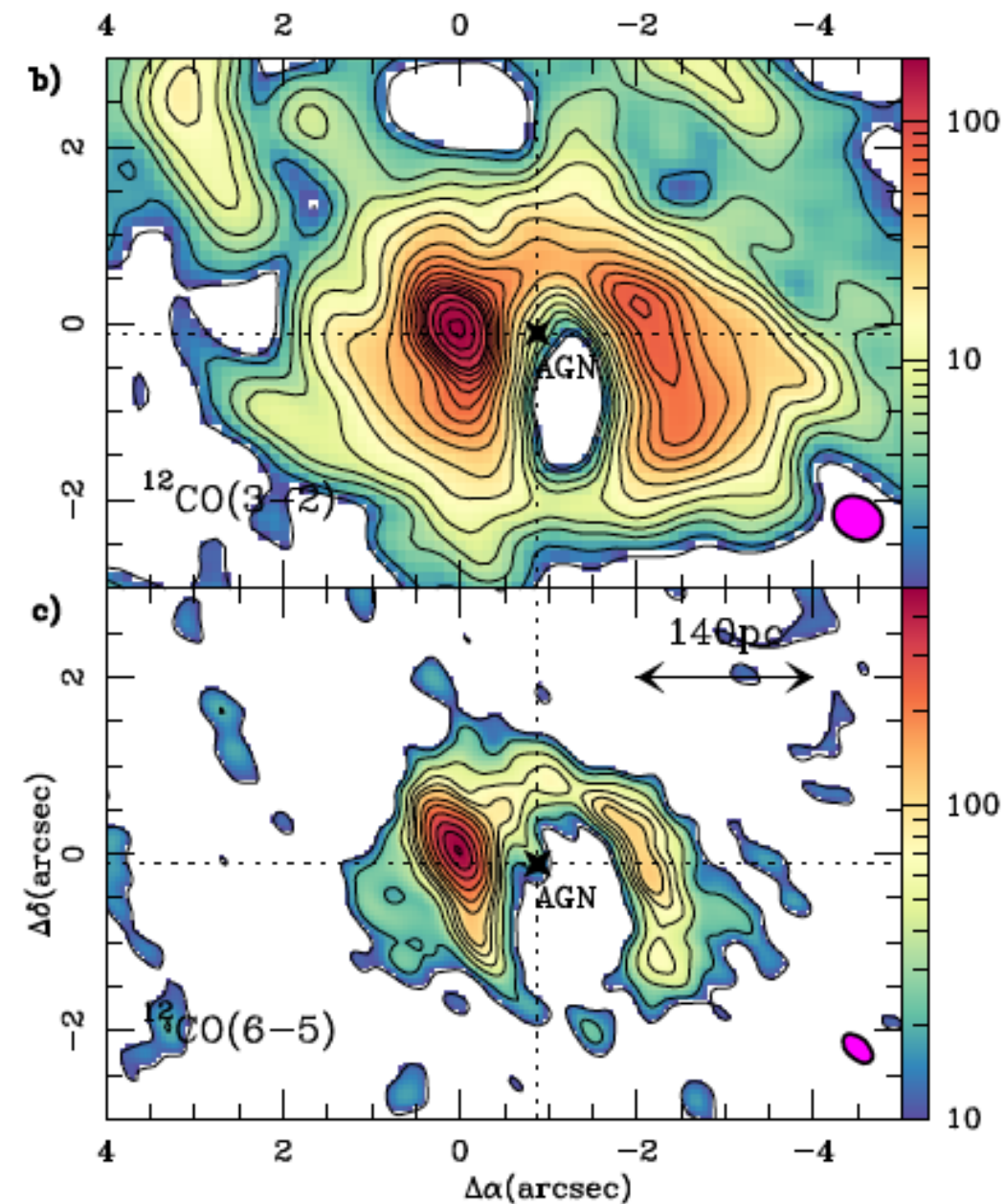
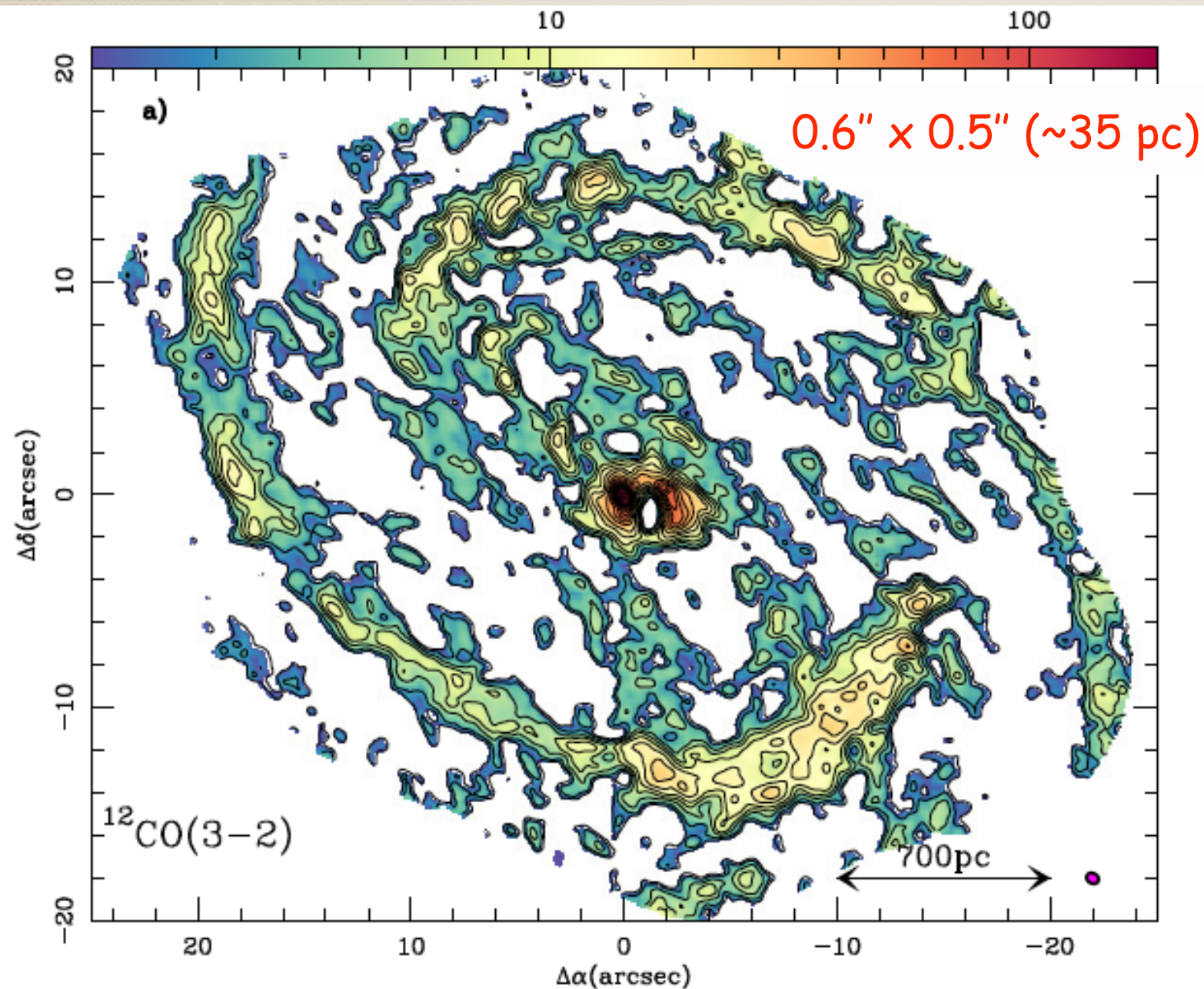
RA

- High proportion of dense gas
- CO/HCO<sup>+</sup> ~ 100, CO/HCN ~ 300: ~3 times less than M82: NGC 1566 is not a starburst (e.g., Gao & Solomon 04)
- HCO<sup>+</sup>/HCN ~ 3: excitation dominated by star formation, not the AGN (e.g., Kohno et al. 03, Krips et al. 08, Garcia-Burillo et al. 10, Imanishi & Nakanishi et al. 13)



# NGC 1068: ALMA Cycle 0

NGC 1068: a prototypical nearby Seyfert 2 galaxy

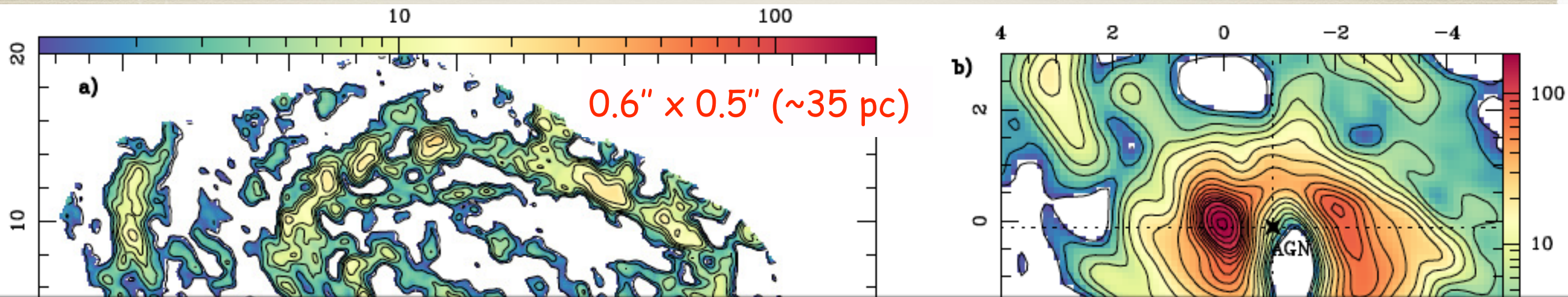


García-Burillo, et al. 2014, see also Viti et al. 2014

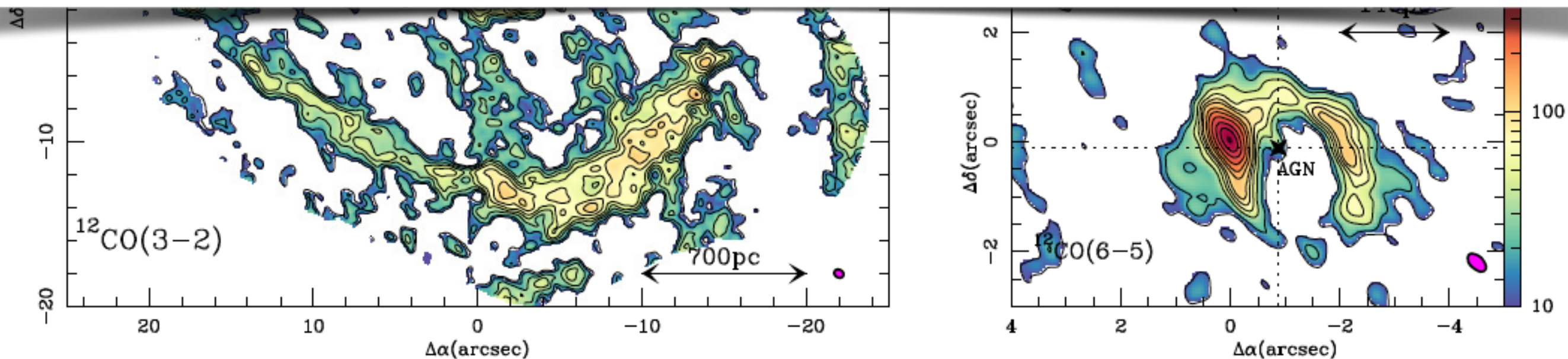


# NGC 1068: ALMA Cycle 0

NGC 1068: a prototypical nearby Seyfert 2 galaxy



A massive molecular AGN-driven outflow in 5 molecular tracers!



García-Burillo, et al. 2014, see also Viti et al. 2014



# waiting for Cycle 2 results

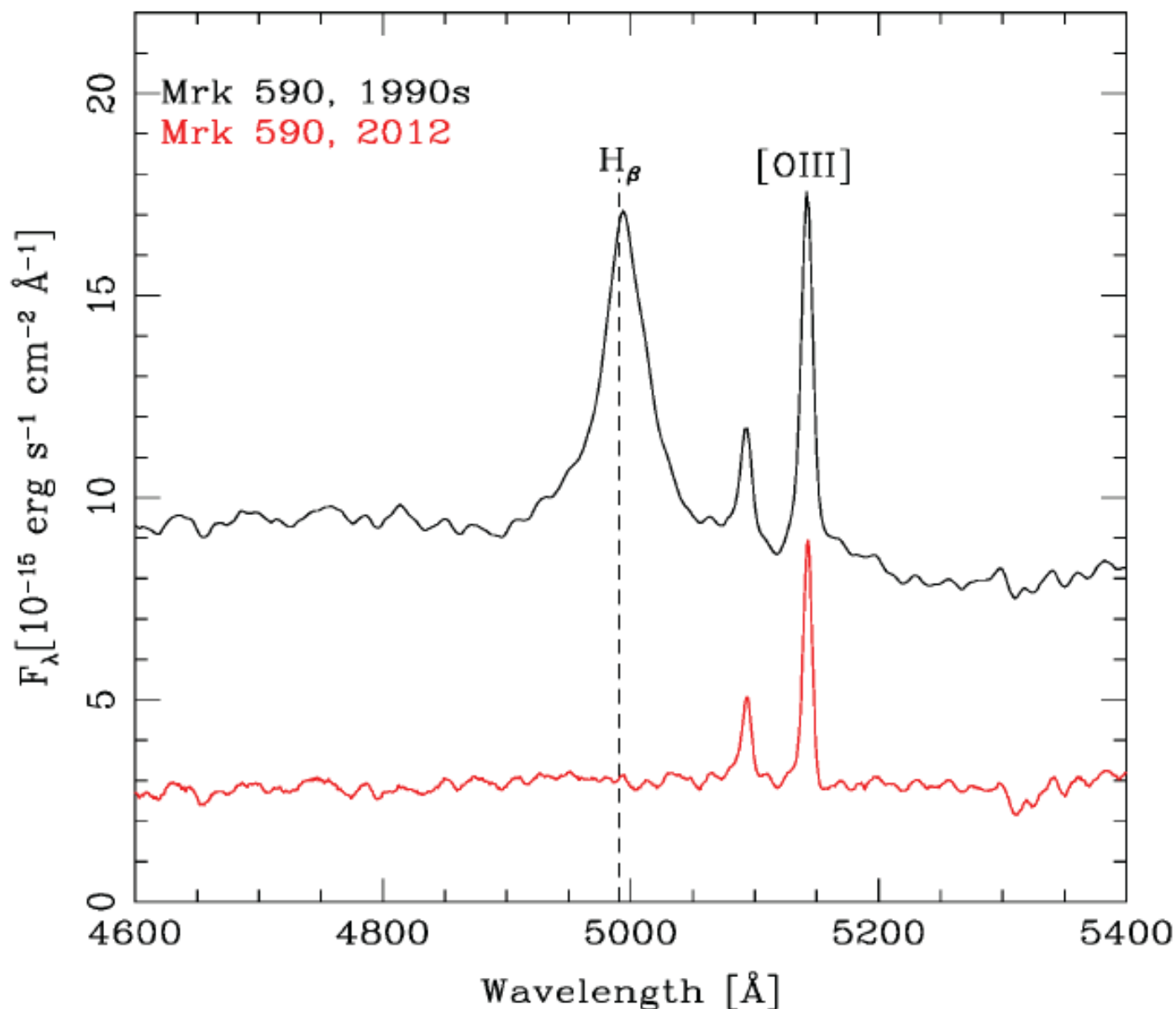
- NGC 1068 (II): to study the signature of gas inflow closer to the nucleus ( $0.1'' \sim 10$  pc), and to spatially resolve the emission of the torus (P.I.: S. García-Burillo, + NUGA team, and many others)



PI: Vestergaard + Koay, Casasola, Peterson

# Markarian 590: ALMA Cycle 2

Mrk 590: A Seyfert galaxy in transition



- Mrk 590, classified as **Seyfert 1** by Weedman (1977) over  $\sim 30$  years
- 1990s: broad  $H_\beta$  emission line and power-law continuum from nuclear region (Peterson+1998)
- 2006 - 2012: the broad  $H_\beta$  emission line of Mrk 590 has completely disappeared!
- The optical-UV continuum emission can be fully accounted for by stellar population models of the host galaxy (Denney+2014)
- Mrk 590 would now be a **Seyfert 1.9 or 2**, against the scheme of AGN classification and unification



# Markarian 590: ALMA Cycle 2

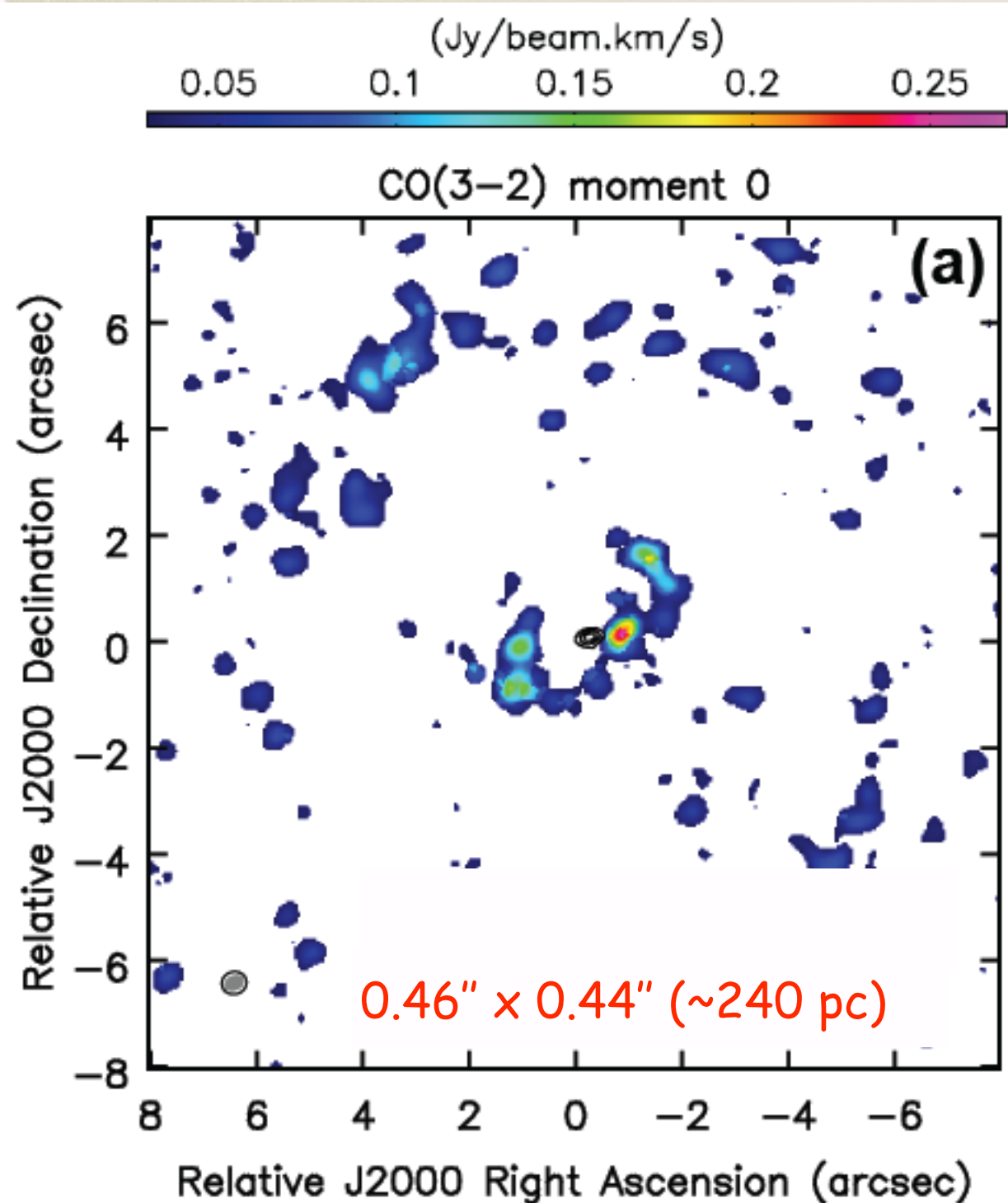
Is Mrk 590 running out of gas?

- This type-transition could be caused by a lack of nuclear gas to fuel the central engine
- If gas in the very center is not replenished feeding, the accretion activity ceases, and the BH is starved and turns quiescent
- **ALMA:** To determine the amount of available nuclear gas and its properties



# Markarian 590: ALMA Cycle 2

Is Mrk 590 running out of gas?



- $M(\text{H}_2) \sim 4.5 \times 10^7 M_\odot$  in the inner ring, consistent with molecular gas mass found in nearby Seyfert nuclei
- Working in progress: behavior of the detected gas, .....

Koay, Casasola, Vestergaard, Peterson, in preparation



# Conclusions

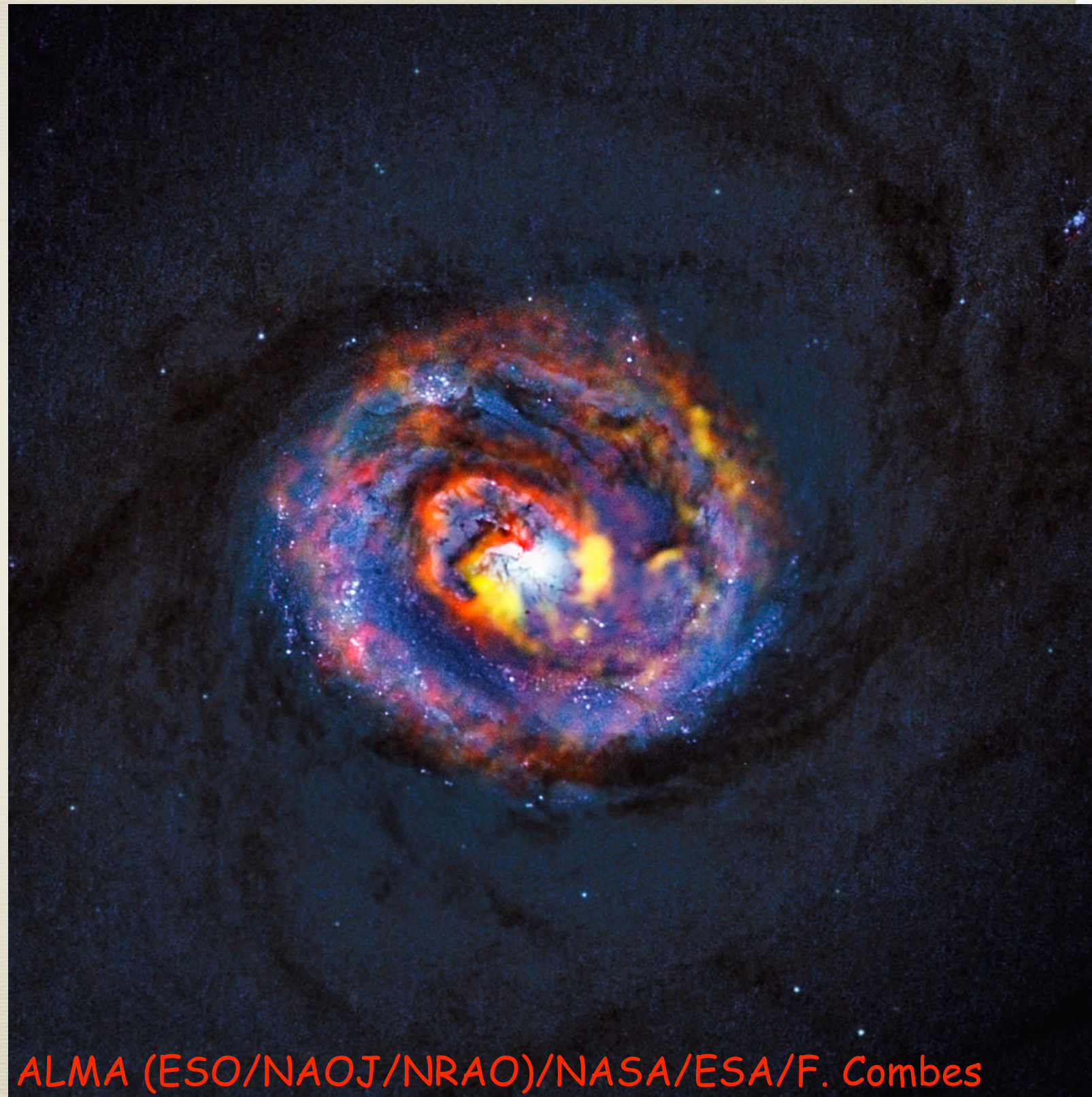
- **NGC 1433:** Gas fueling, a tentative AGN-driven outflow, no dense gas (Combes et al. 2013)
- **NGC 1566:** Gas fueling, No outflow, dense gas (Combes et al. 2014)
- **NGC 1068:** Gas fueling, an AGN-driven outflow in several dense gas tracers (García-Burillo et al. 2014; Viti et al. 2014)
- Waiting for **Cycle 2** results for **NGC 1068** and **Mrk 590**

See also **NGC 1097:** (Martin et al. 2014), and others ....



# NGC 1433: ALMA + HST

Waiting for Cycle 3!



ALMA (ESO/NAOJ/NRAO)/NASA/ESA/F. Combes