AGN fueling with ALMA: From Cycle 0 results to Cycle 2 incoming data

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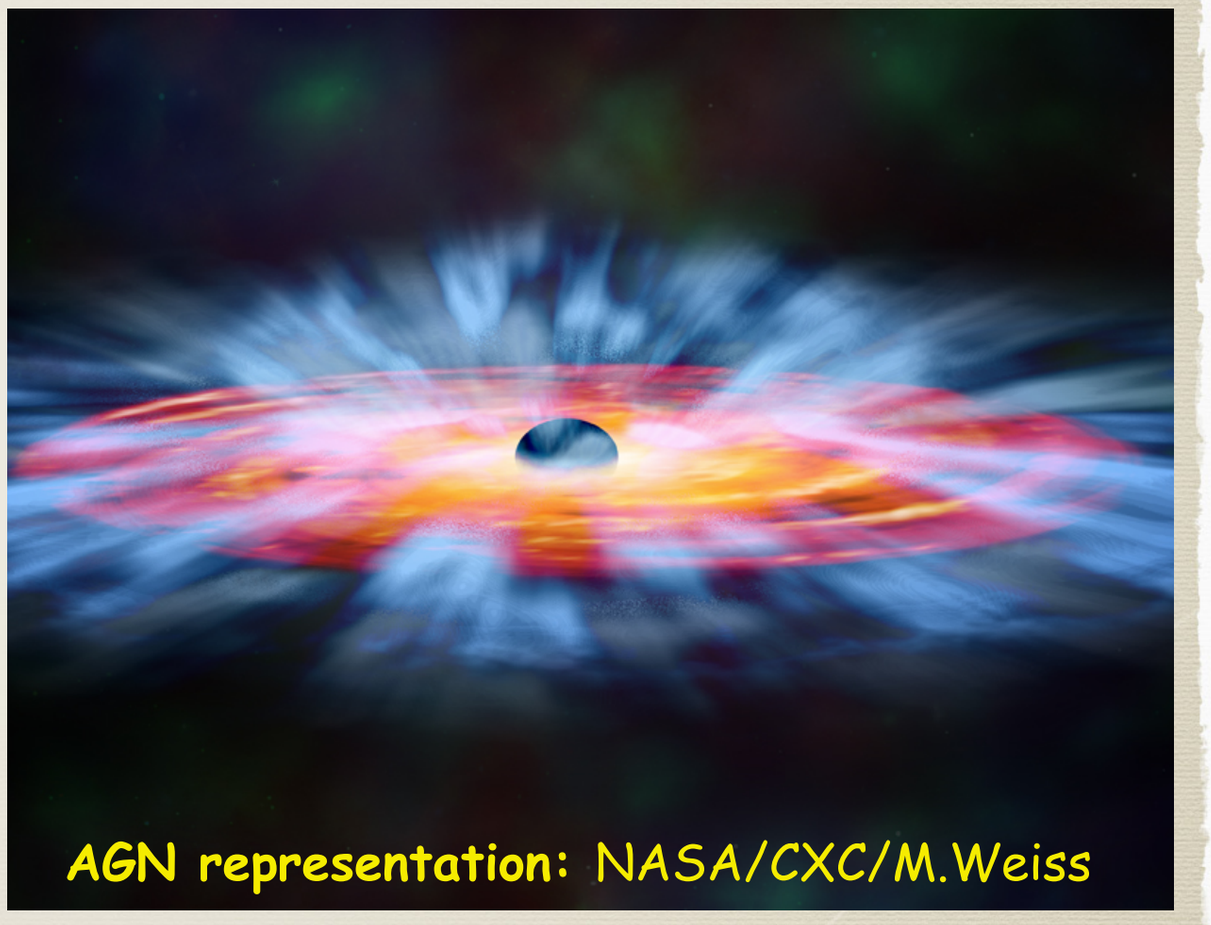
Outline

- 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

PIs

F. Combes, Obs. Paris, France
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NUGA Team

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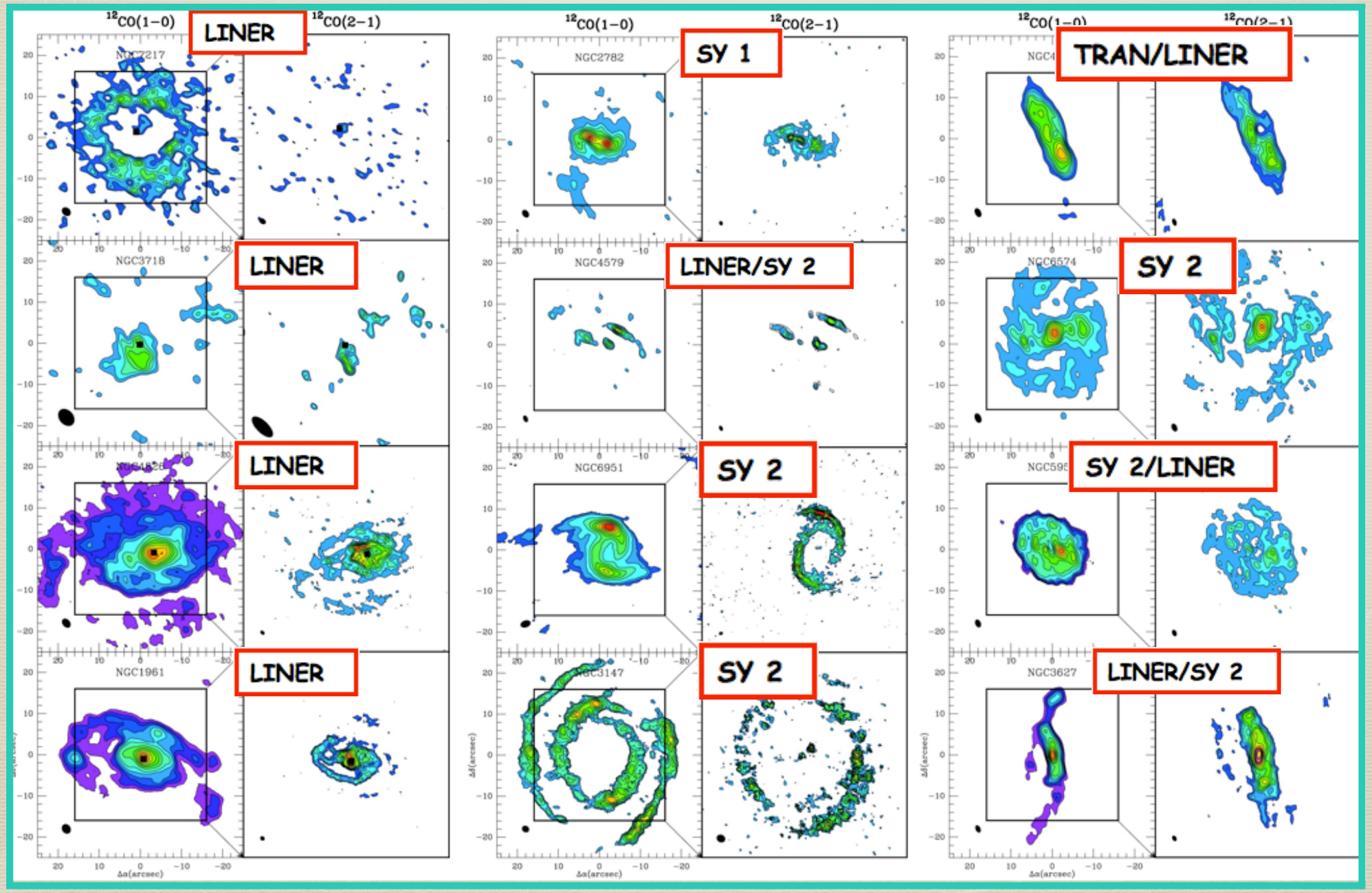
Morphologies found in NUGA

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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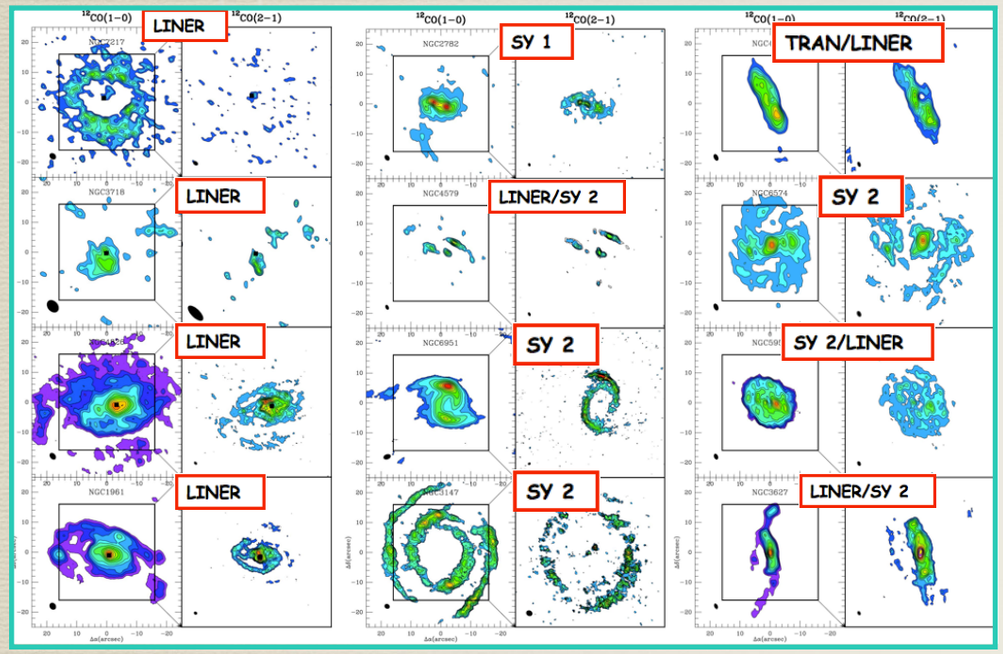

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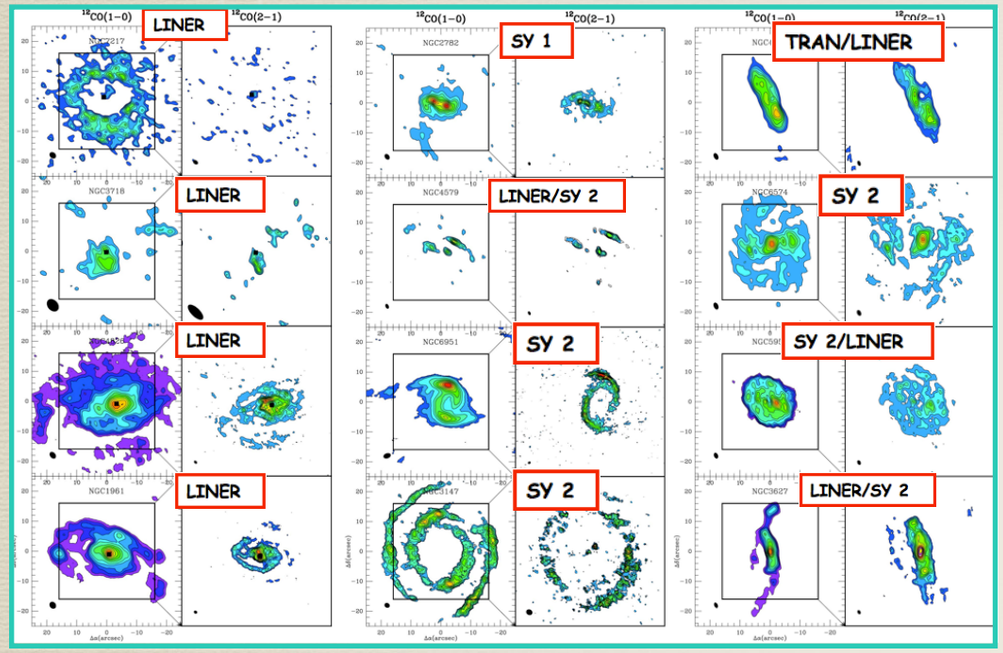

1. Variety of CO morphologies in the central region of AGN

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 ~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

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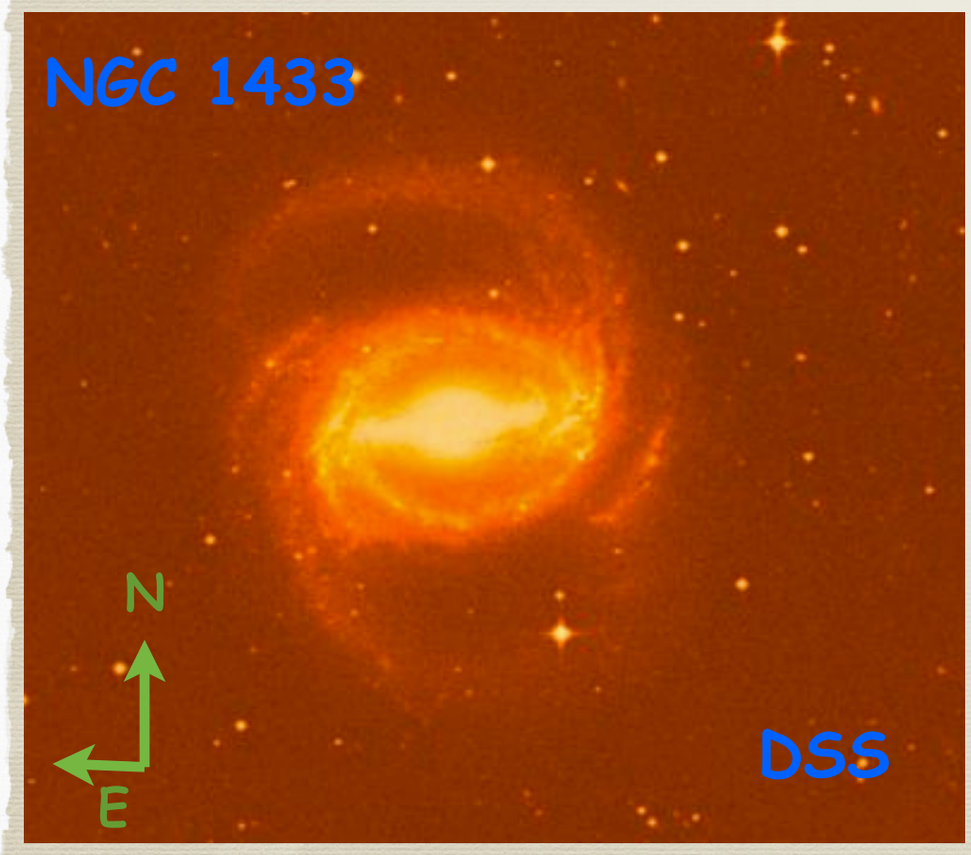
1. **Feeding and feedback in nearby Seyfert Galaxies**
   PI: F. Combes
   → **NUGA SOUTH**

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**

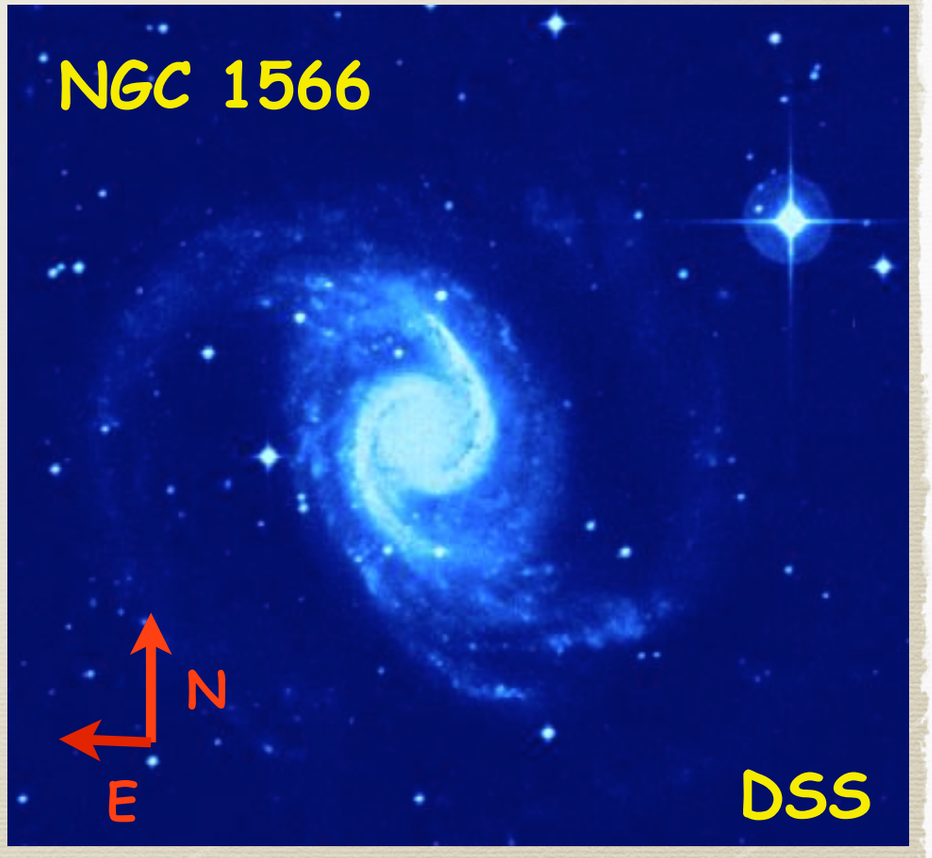
NUGA SOUTH

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)



Both at D~10 Mpc
with embedded bars



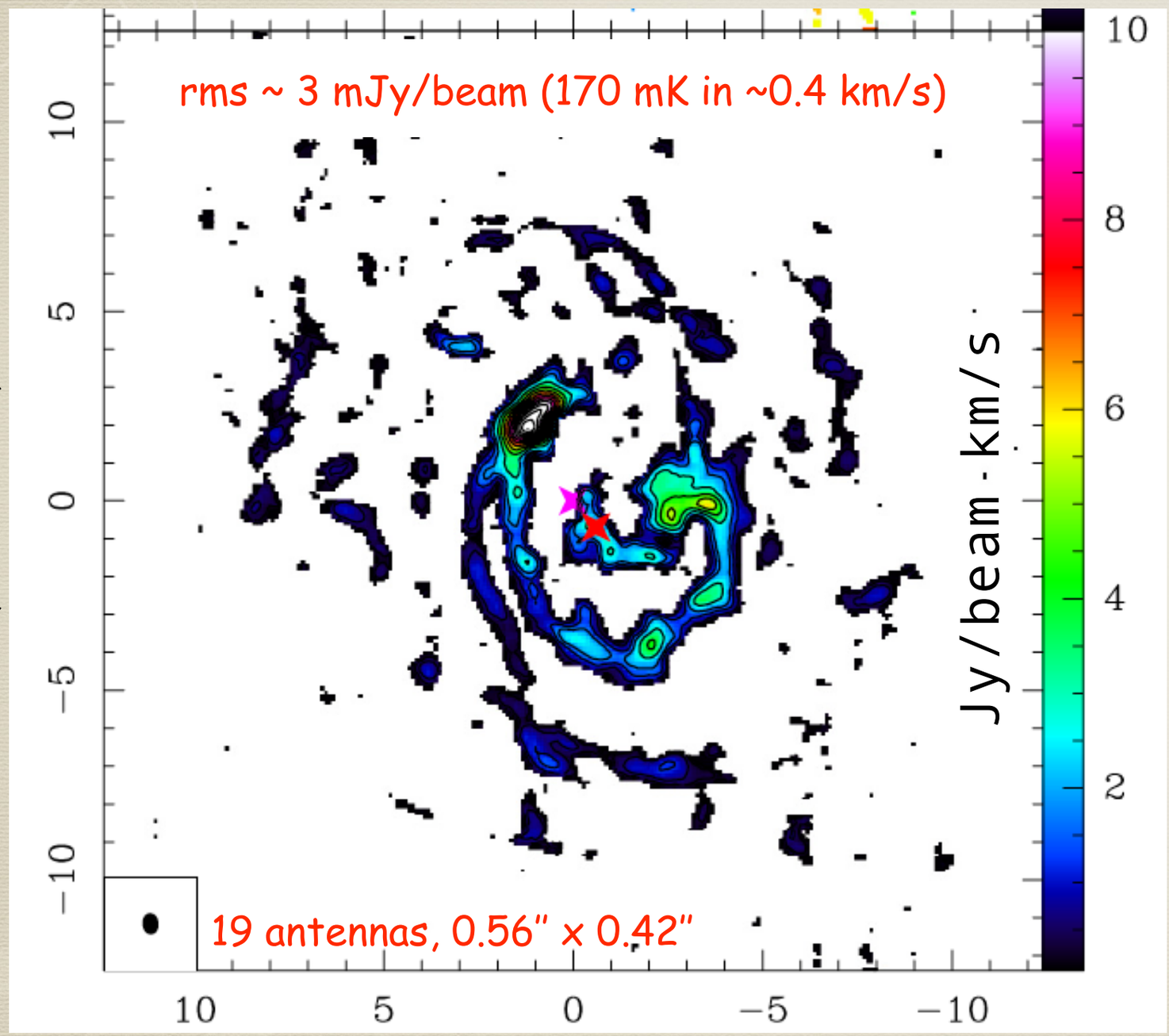
NUGA SOUTH: Observations @ ALMA Cycle 0

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 CO(3-2) (high density gas, 10^4 - 10^5 cm^{-3}) line in both galaxies, simultaneously with HCN(4-3) and HCO^+(4-3) (densest clumps, excitation and chemistry)
- Extended Configuration (baselines: 17 - 40 m), Band 7 (275 - 373 GHz)
- Angular resolution ~0.5" (~25 pc), Spectral resolution ~ 0.4 km/s
- One single pointing per galaxy (FOV = 18" ≤1 kpc)
- ~2 hrs of integration time for each galaxy
- To map continuum emission @ 0.87 mm

NCG 1433: Gas Distribution

CO(3-2) distribution

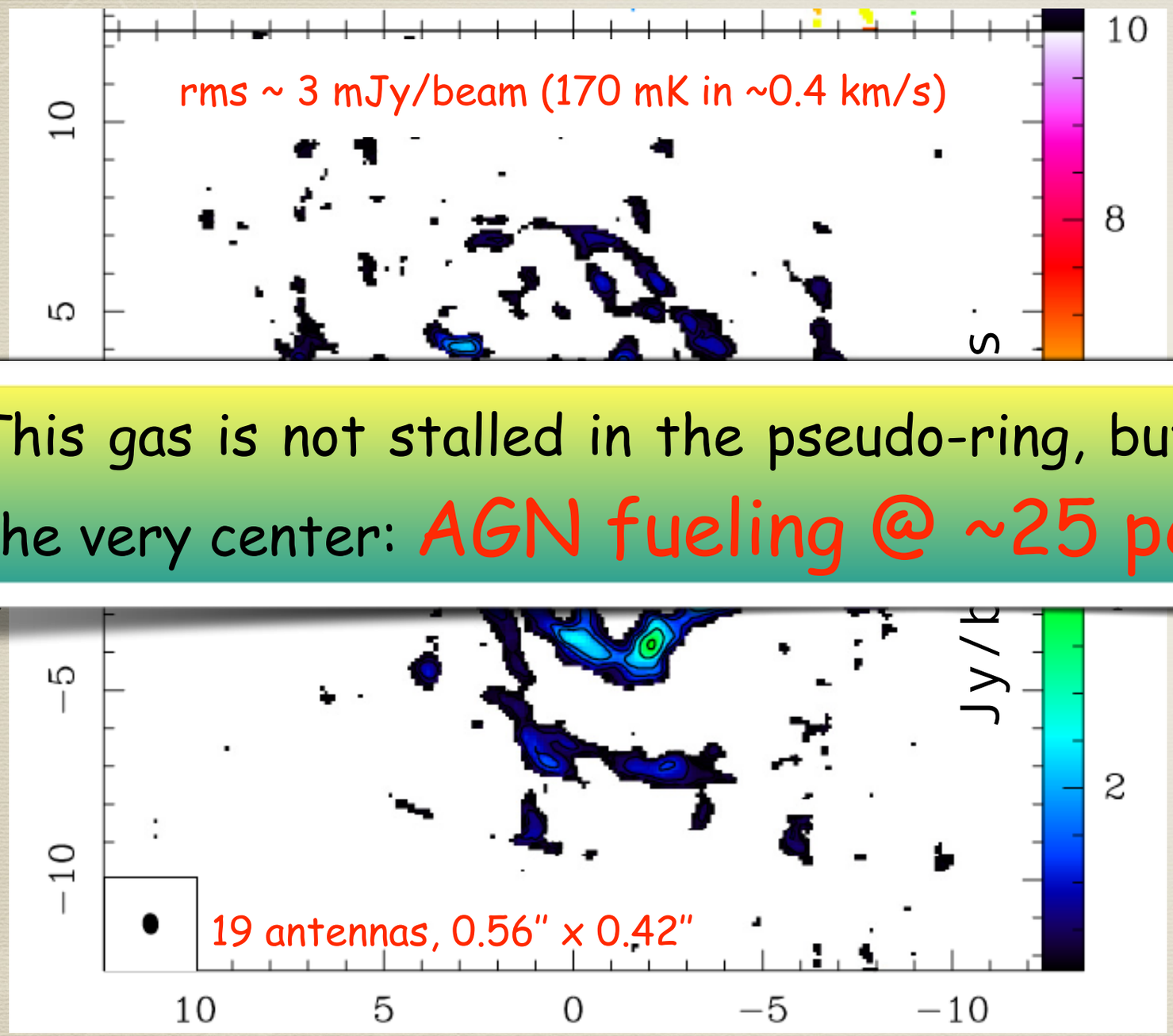


- A nuclear gaseous spiral structure with multiple branches
- A pseudo-ring, r = 4'' (200 pc)
- Asymmetries: peak not in the center, but in a NE cloud complex
- $M(H_2) \sim 5 \times 10^7\ M_\odot$
- Only upper limits for HCN(4-3) and HCO^+(4-3): low abundance of very dense gas

Combes, García-Burillo, Casasola et al. 2013

NCG 1433: Gas Distribution

CO(3-2) distribution



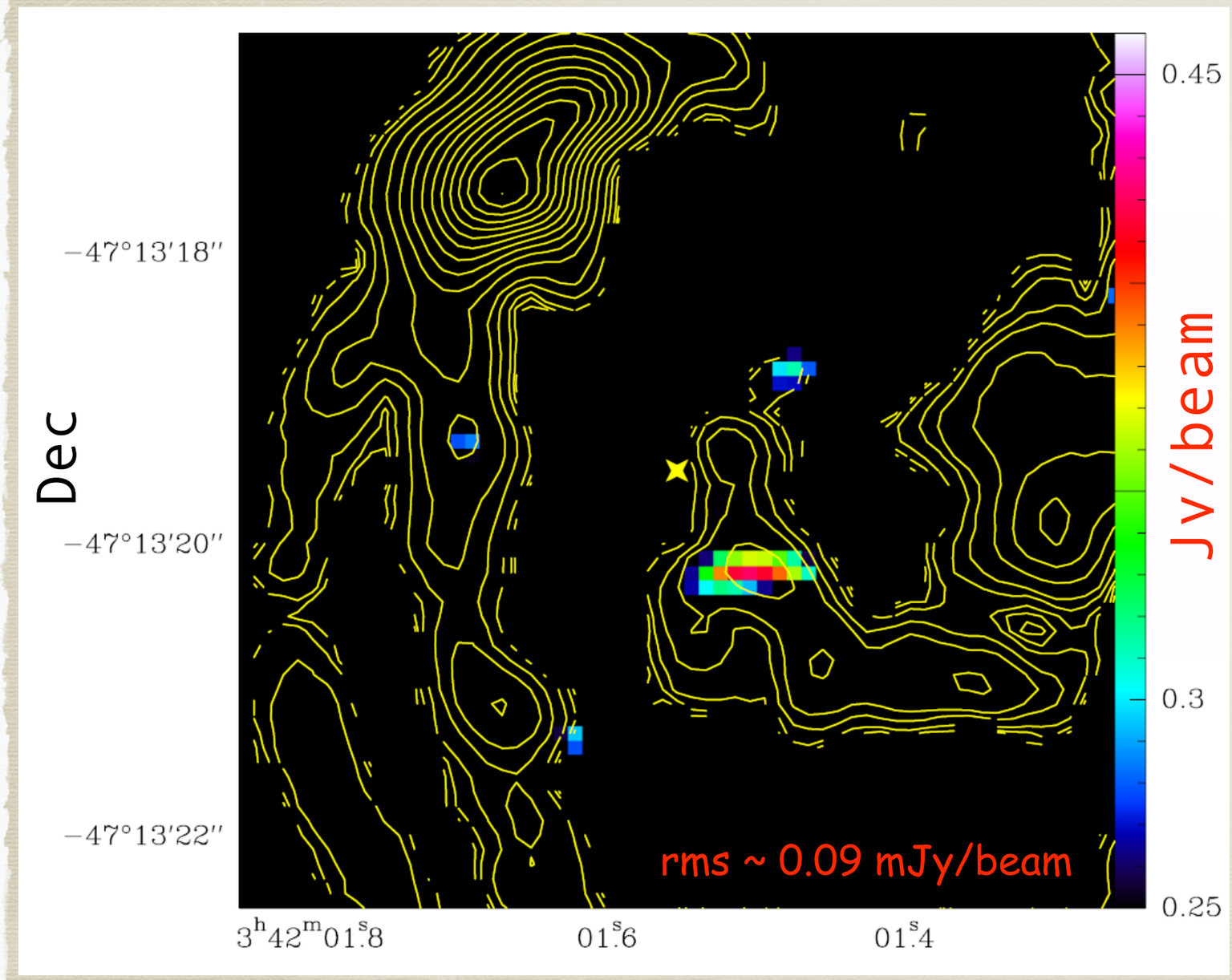
- A nuclear gaseous spiral structure with multiple branches
- A pseudo-ring, r = 4'' (200 pc)
- Asymmetries: peak not in the center, but in a NE cloud complex and HCO (4-3): low abundance of very dense gas

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

Combes, García-Burillo, Casasola et al. 2013

NCG 1433: Continuum Emission

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



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

Combes, García-Burillo, Casasola et al. 2013

NCG 1433: Continuum Emission

Continuum emission @ 0.87 mm
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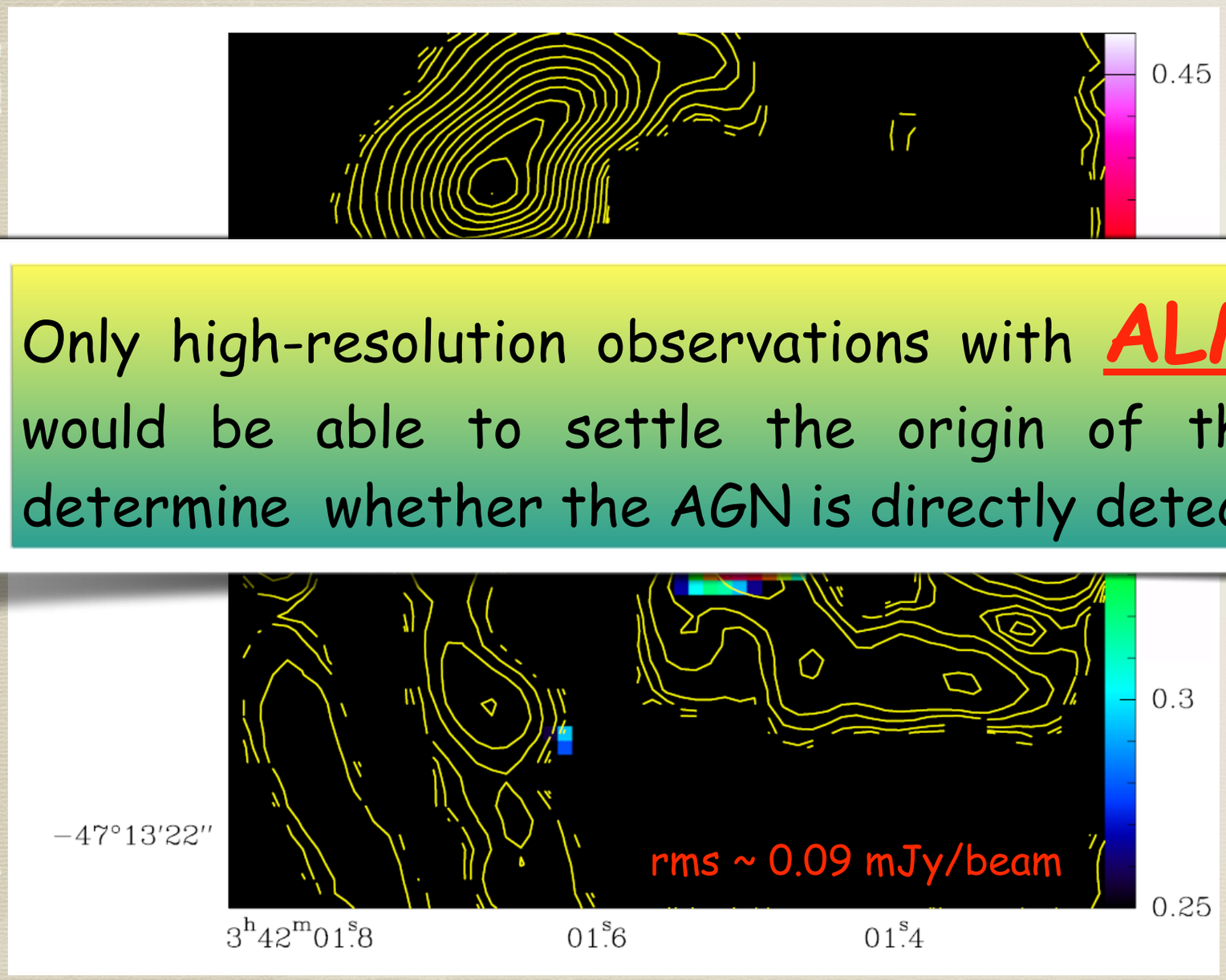


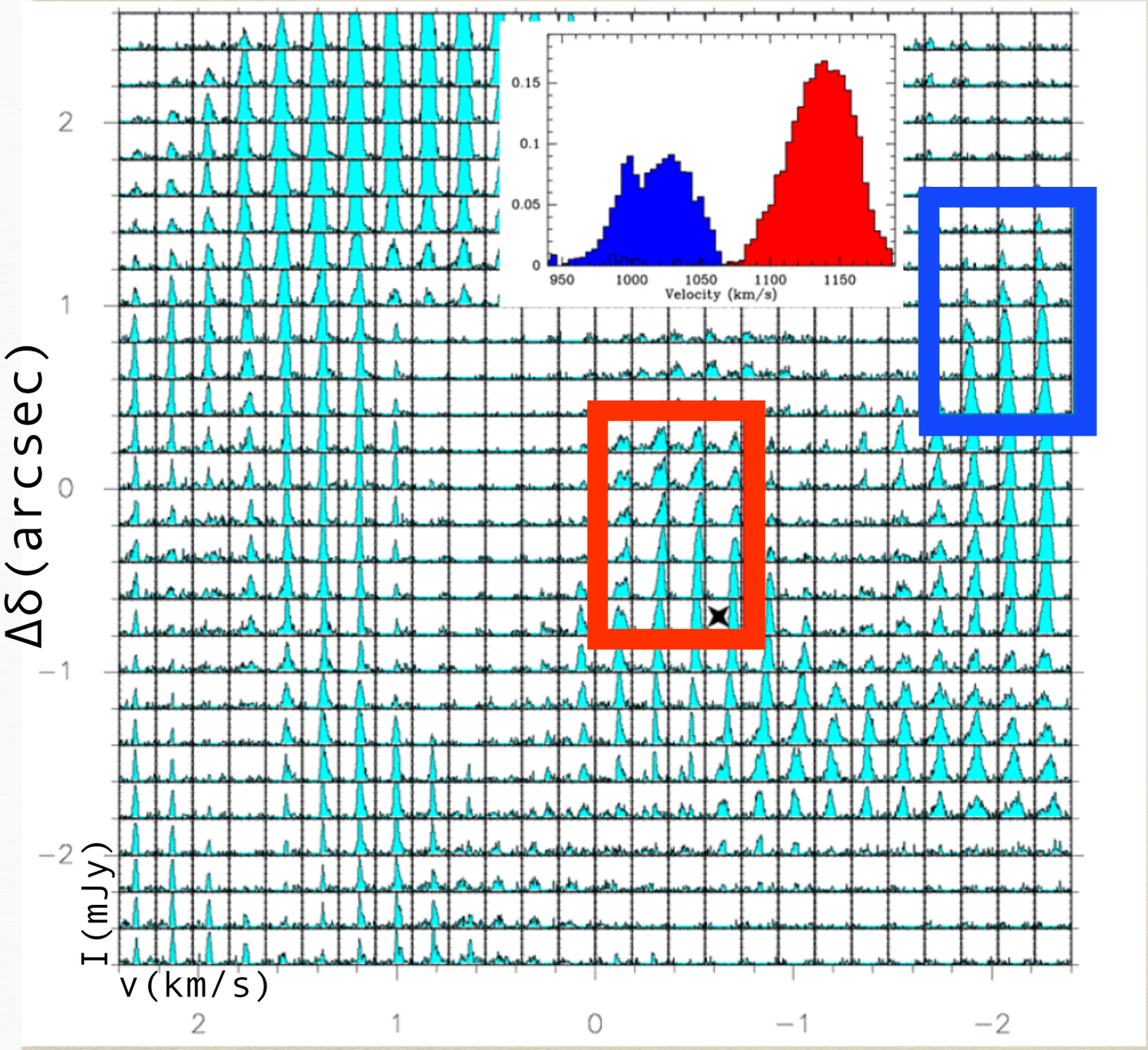
- Detection (~3σ) only at the very center (peak ~0.5 mJy)
- Its origin: likely thermal dust

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.

Combes, García-Burillo, Casasola et al. 2013

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

Combes, García-Burillo, Casasola et al. 2013

NCG 1433: CO Kinematics

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

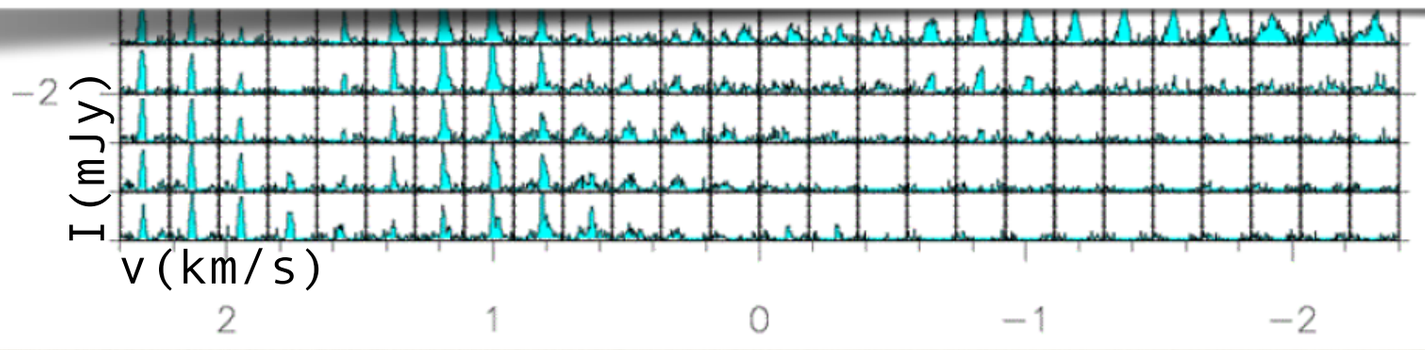
- The velocity field is well

This high-velocity component is an **OUTFLOW**:

Mass (outflow) = 3.6 x 10^6 $M_\odot$, Flow Rate = 7 $M_\odot$/yr

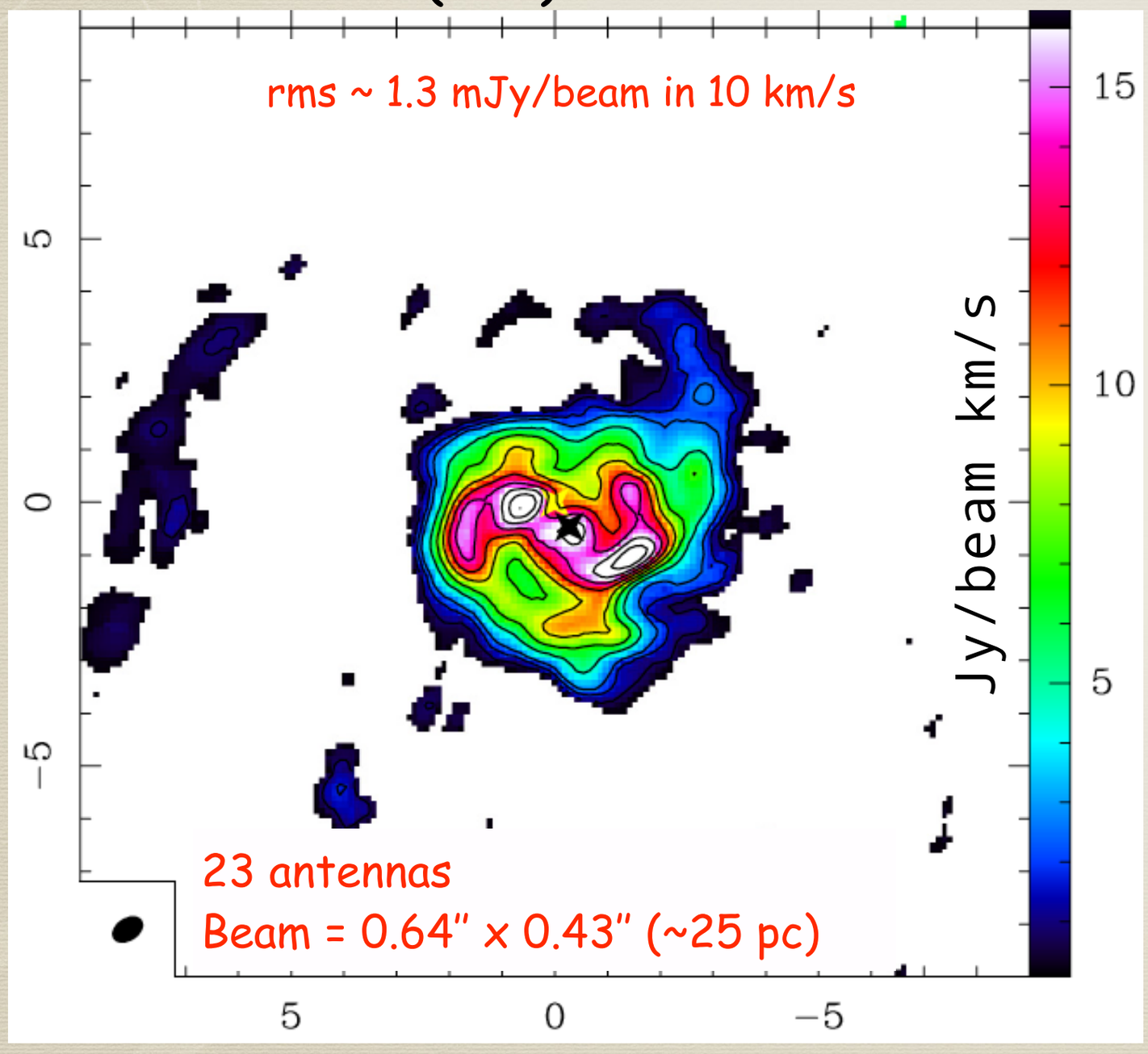
The smallest molecular outflow ever observed in external galaxies!

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



Combes, García-Burillo, Casasola et al. 2013

NCG 1566: Gas Distribution

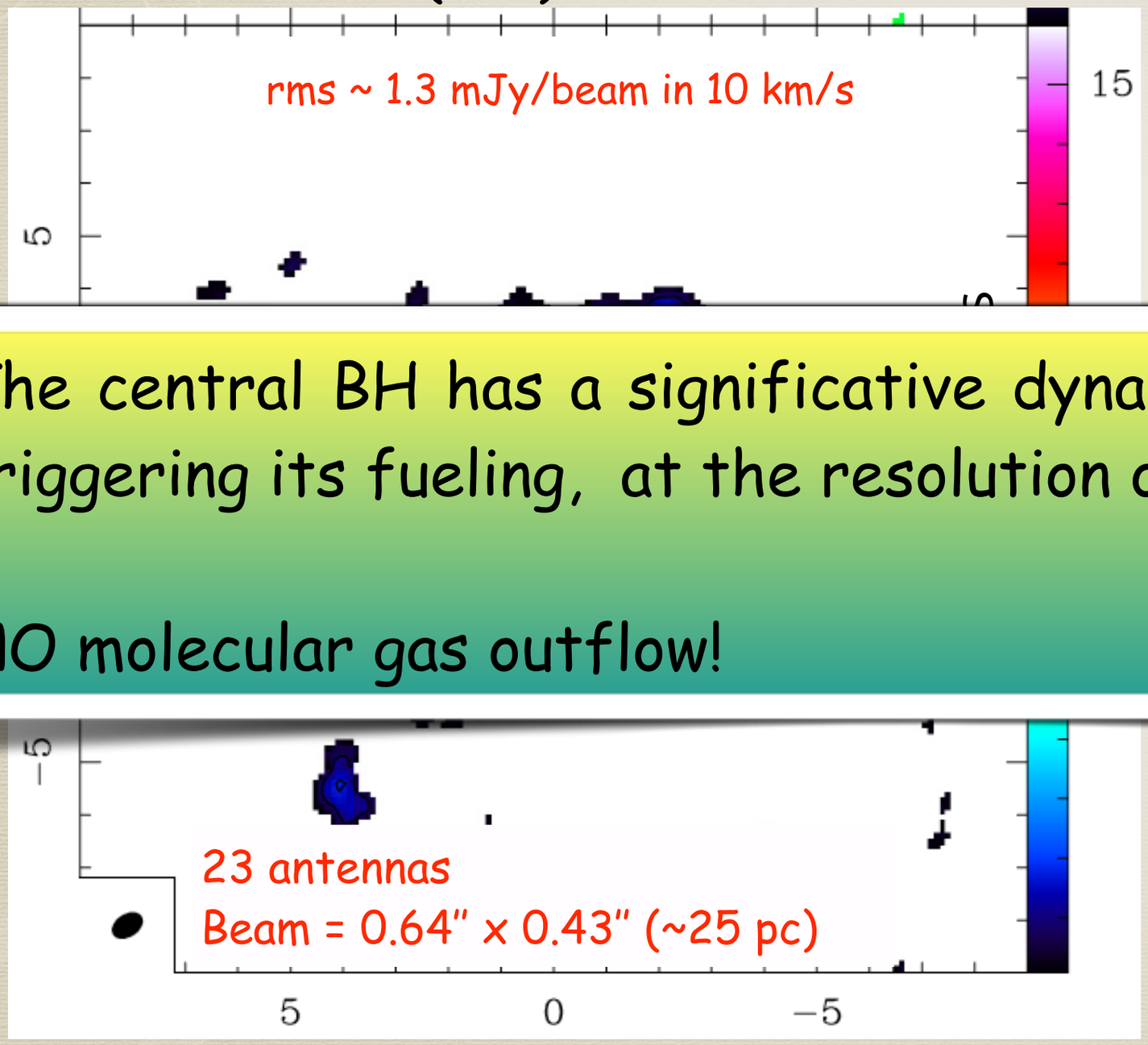


- A nuclear disk, r ~ 3" (150 pc), a contrasted 2-arm spiral structure
- The two small spiral arms show a faint extension onto a pseudo-ring, r ~ 9" (430 pc)
- $M(H_2) \sim 0.7 \times 10^8\ M_\odot$

Combes, García-Burillo, Casasola et al. 2014

NCG 1566: Gas Distribution

CO(3-2) distribution



- A nuclear disk, r ~ 3" (150 pc), a contrasted 2-arm spiral structure

- The two small spiral arms

The central BH has a significative dynamical influence on the gas, triggering its fueling, at the resolution of 25 pc.

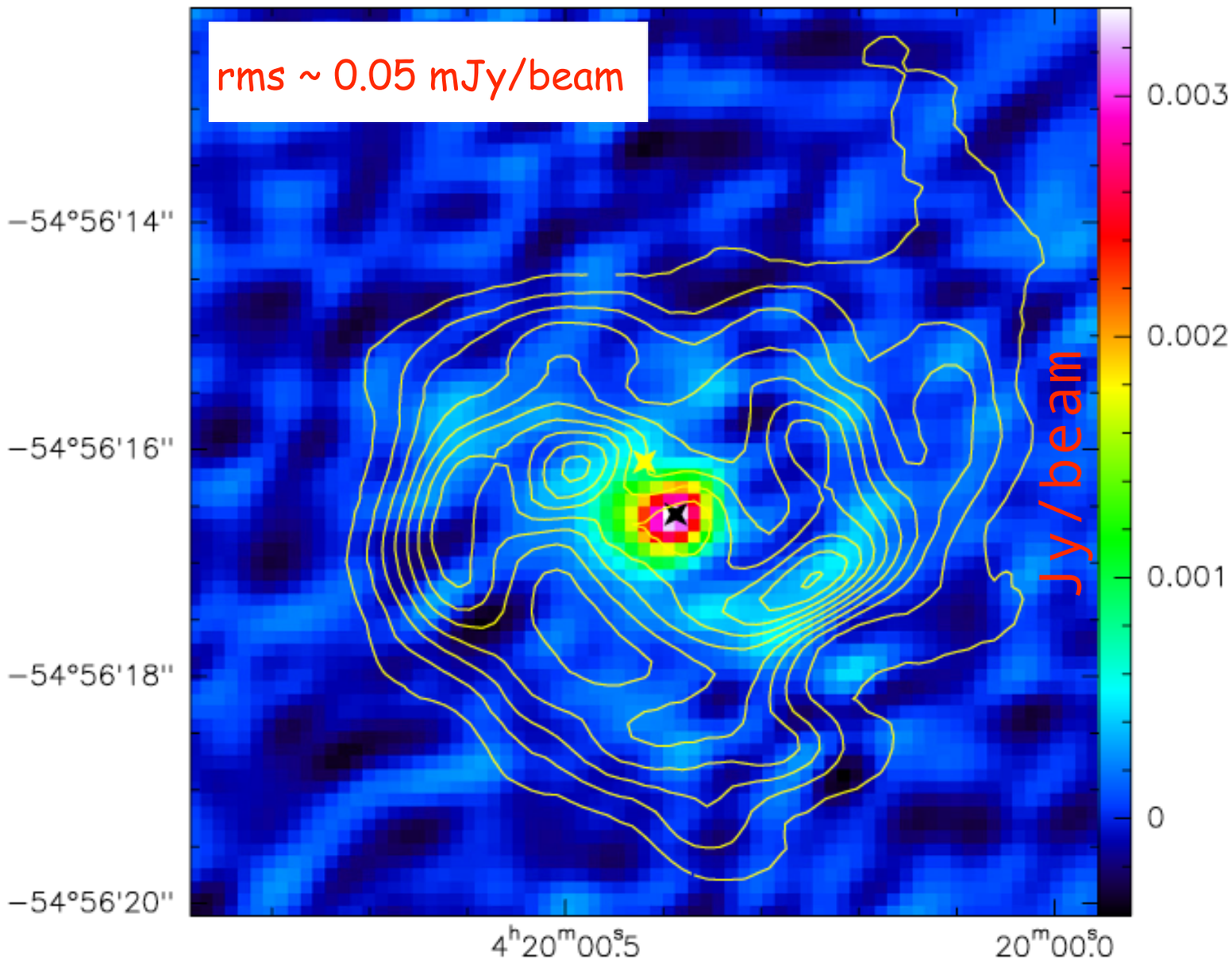
NO molecular gas outflow!

Δα(arcsec)

Combes, García-Burillo, Casasola et al. 2014

NCG 1566: Continuum Emission

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

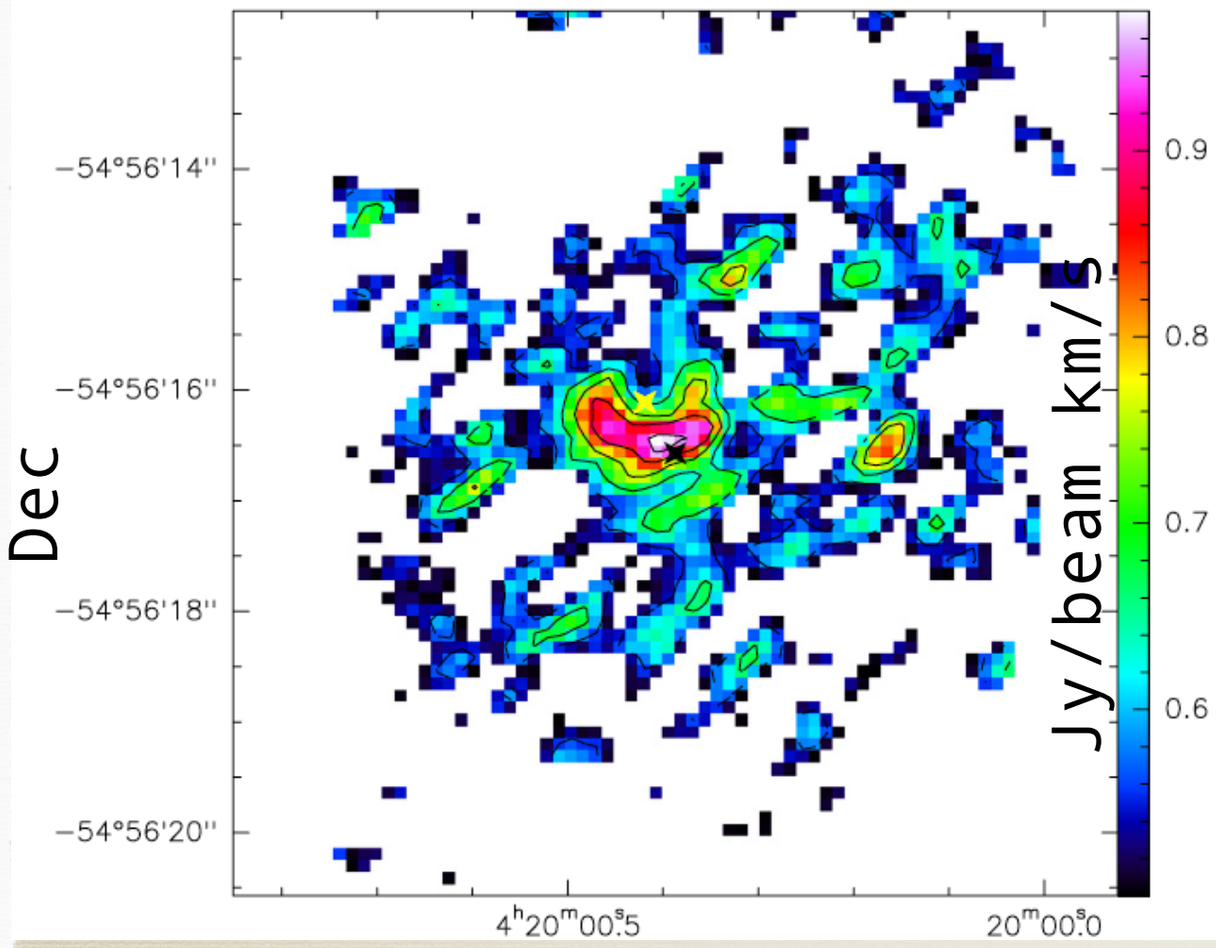


- The central peak emission is ~3 mJy (> 50σ)
- The central peak coincides with the peak in CO(3-2)
- The continuum emission is extended, and follows the CO(3-2) 2-arm spiral structure
- The total continuum emission (~13 mJy) comes from cold dust heated by interstellar radiation field

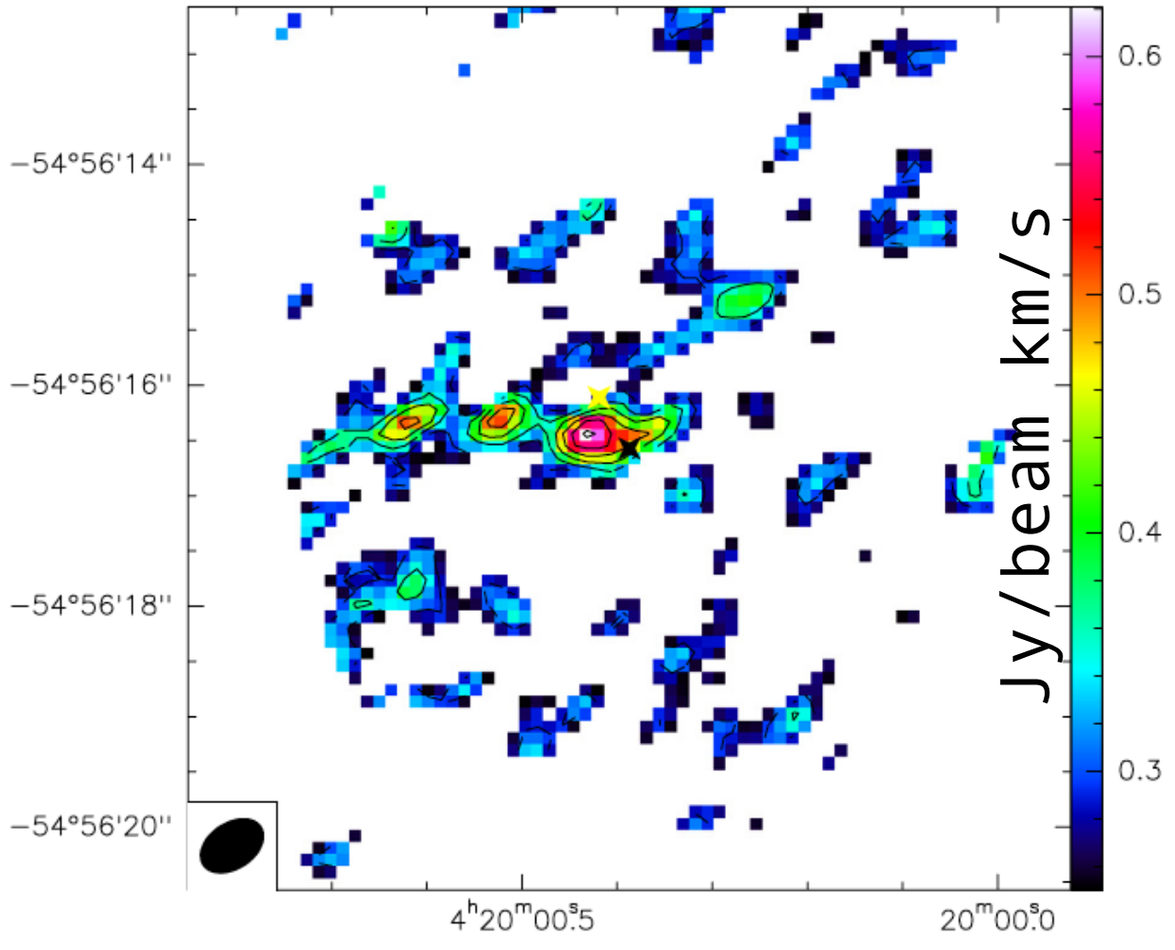
Combes, García-Burillo, Casasola et al. 2014

NCG 1566: Dense gas

HCO^+(4-3)



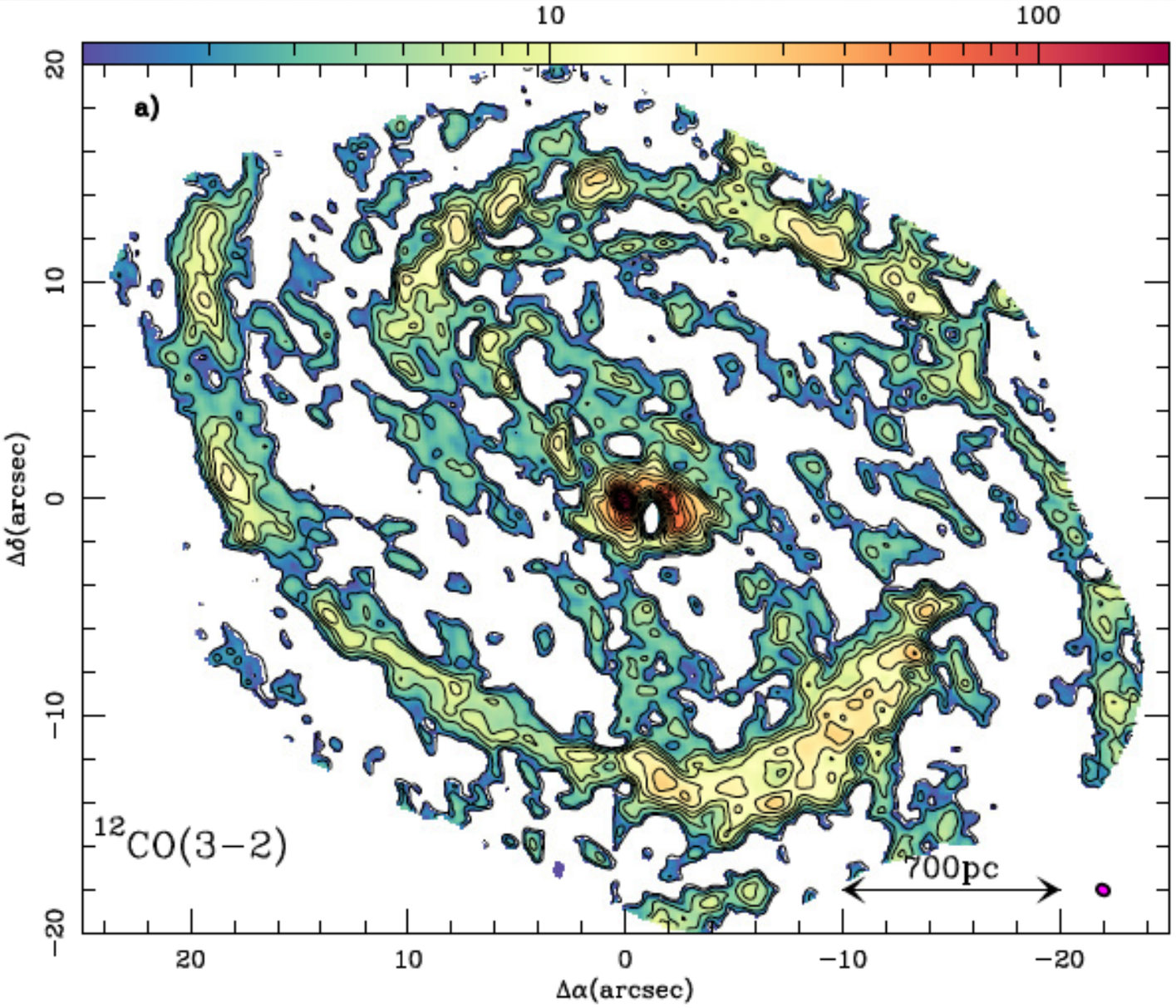
HCN(4-3)



- High proportion of dense gas
- CO/HCO^+ ~ 100, CO/HCN~ 300: ~3 times less than M82: **NGC 1566 is not a starburst** (e.g., Gao & Solomon 04)
- HCO^+/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

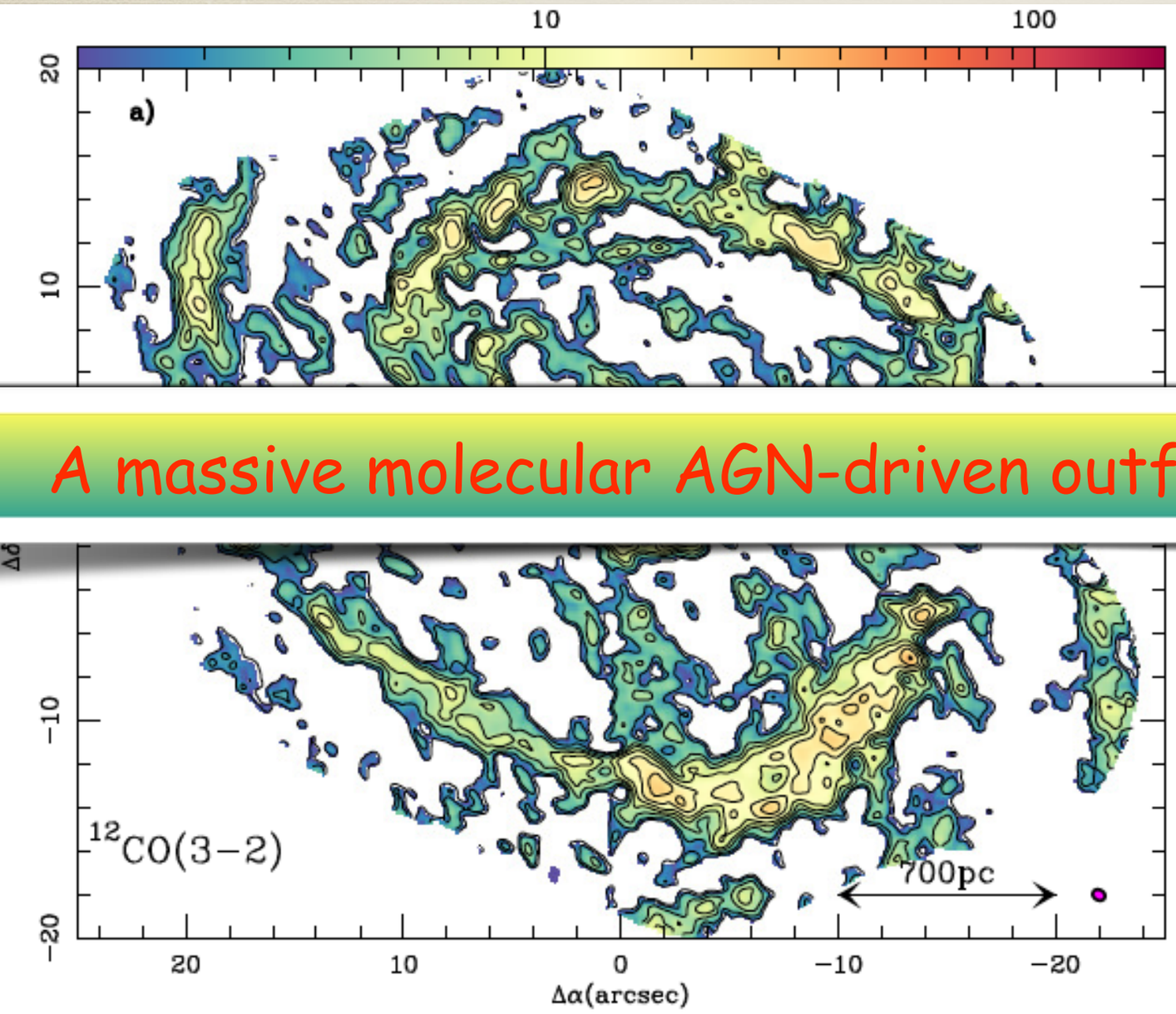
NGC 1068: a prototypical nearby Seyfert 2 galaxy

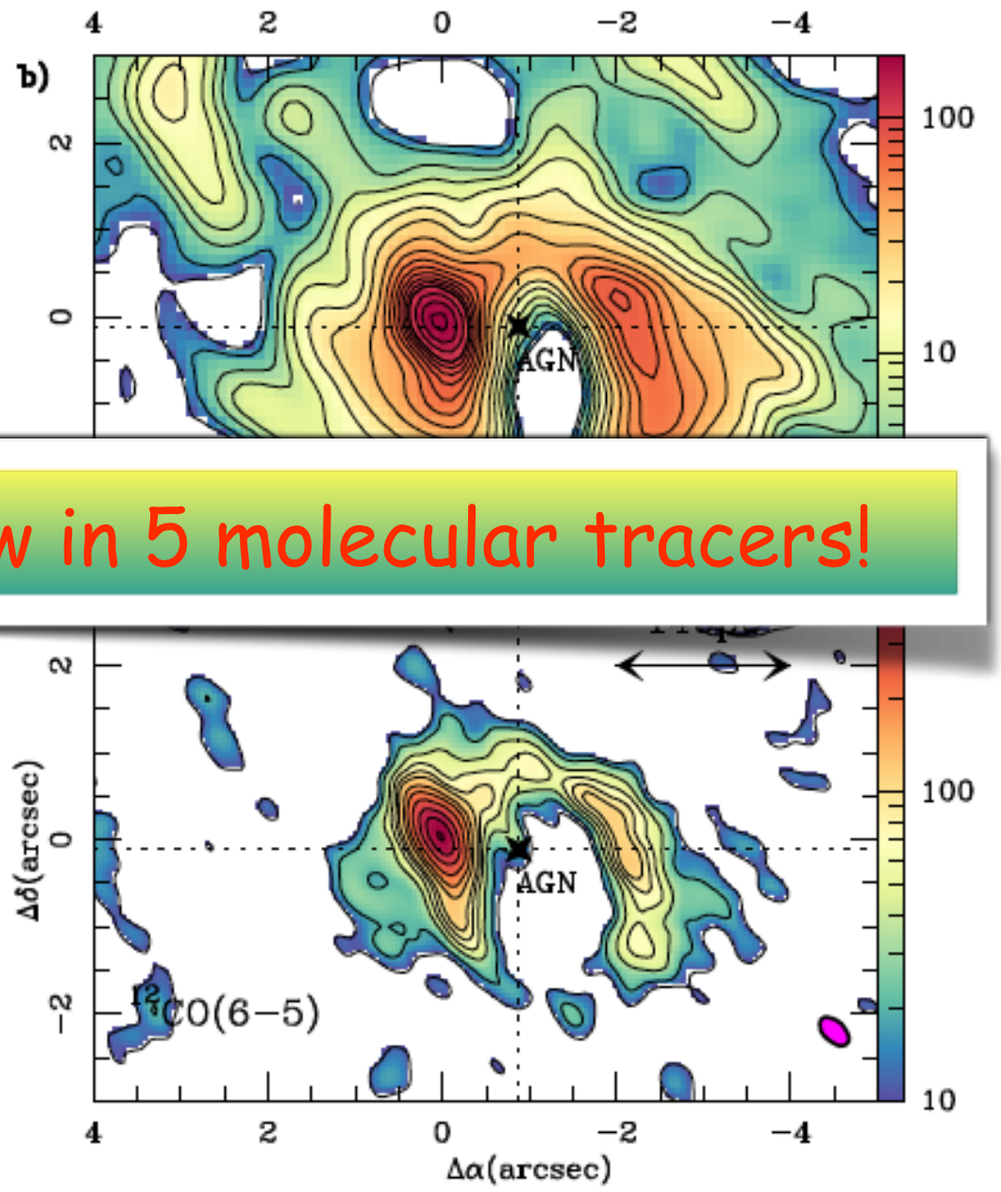


García-Burillo et al. 2014, see also Viti et al. 2014

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 analysis

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

- Mrk 590: The Central Engine of Mrk 590 (P.I.: M. Vestergaard, B. Peterson, J.Y. Koay, V. Casasola)

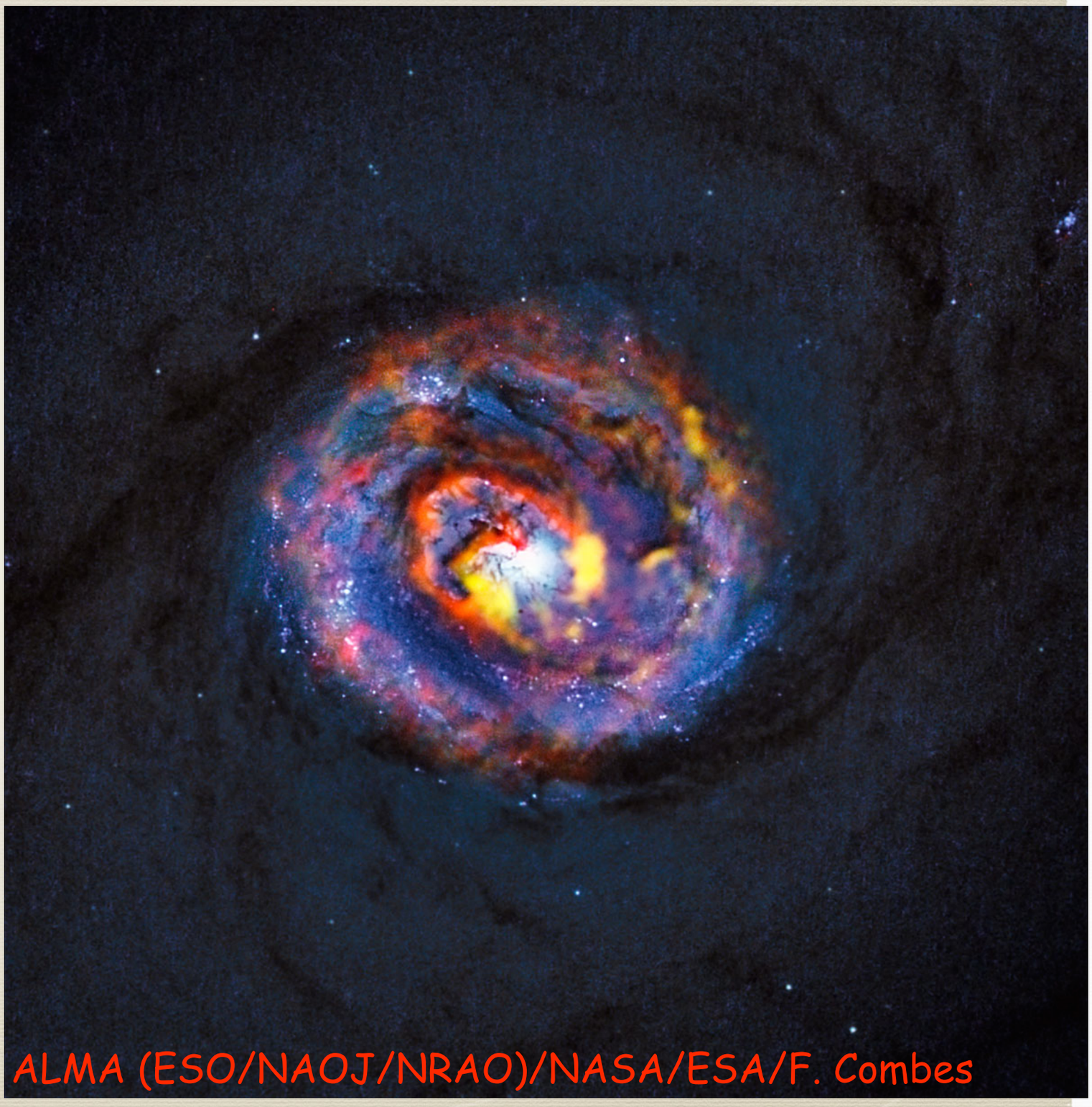
Conclusions

- NGC 1433: AGN feeding and feedback, an AGN-driven outflow, no dense gas (Combes et al. 2013)
- NGC 1566: AGN feeding, No AGN feedback, dense gas (Combes et al. 2014)
- NGC 1068: AGN feeding and feedback, an AGN-driven outflow in several dense gas tracers (Garcia-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, yesterday on astro-ph)

NGC 1433: ALMA + HST

Waiting for ALMA Cycle 3!



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