

PROBING THE GAS FUELING AND OUTFLOWS IN NEARBY AGN WITH ALMA

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AGN FEEDBACK

How the energy generated by the AGN can regulate its gas accretion?

QUASAR MODE

- Through radiative processes or winds
- AGN luminosity is high, close to the Eddington luminosity L_{Edd}
- High z , young QSOs

RADIO MODE

- (kinetic mode) with radio jets, occurring mainly in low-luminosity AGN (LLAGN)
- Appears to maintain the balance between cooling and heating
- Low z massive galaxies

OBSERVATIONS OF OUTFLOWS

far-IR - Herschel (eg., Sturm et al., 2011; Veilleux et al., 2013) & mm-wave with IRAM and ALMA (Combes et al., 2013, García-Burillo et al., 2014, Dasyra & Combes 2012, Morganti et al. 2013, Cicone et al. 2014)

Detected as broad wing components or as residuals along or near the minor axis

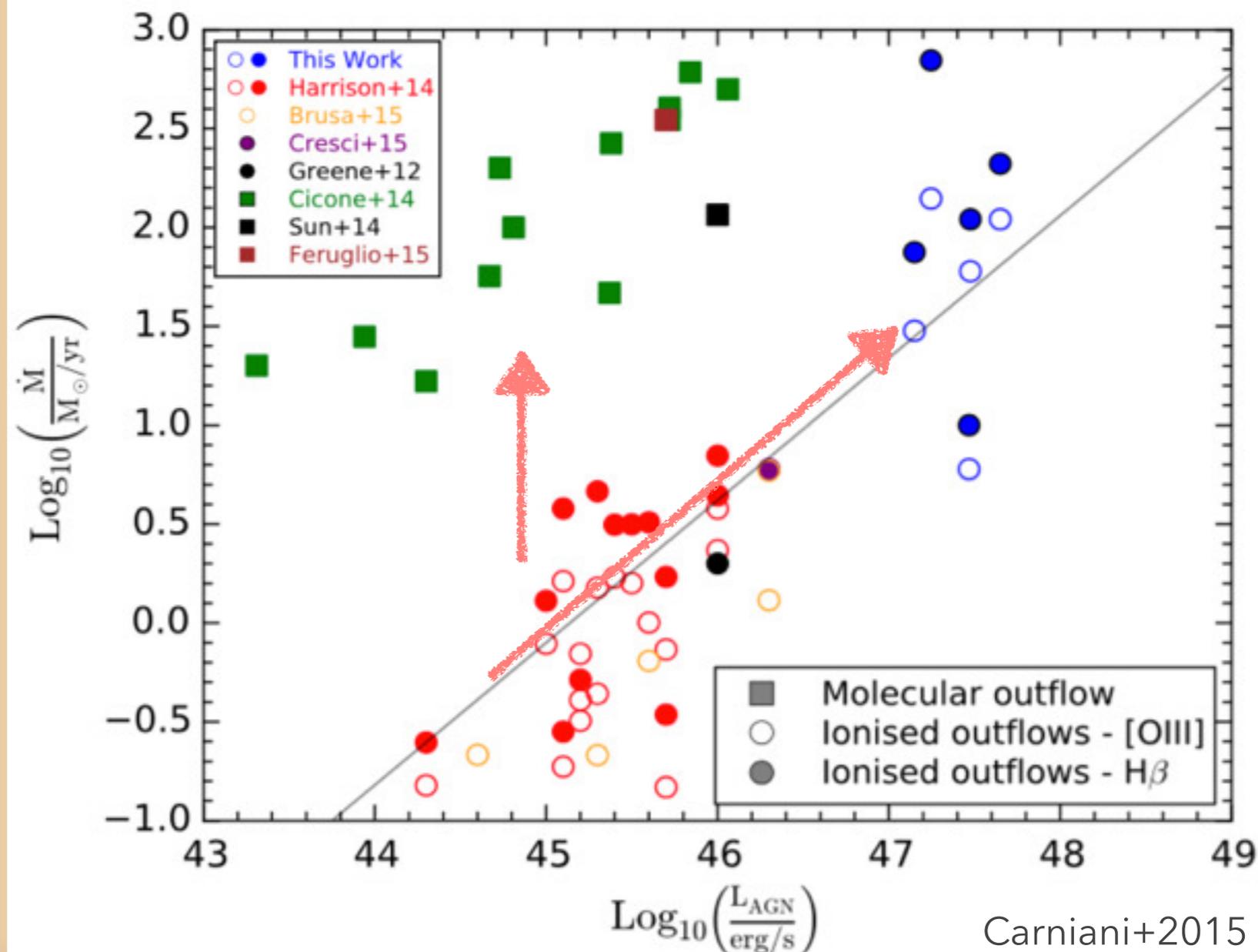
- Outflow rate is correlated with the L_{AGN}

AGN pushes away the gas through a radiatively driven fast wind

$$\dot{E}_{\text{out}} \sim 5\% L_{\text{AGN}}$$

- Offset: indication that the ionised gas only traces a small fraction of the total gas mass.

Ionised gas is a small fraction (< 10%) of the molecular one



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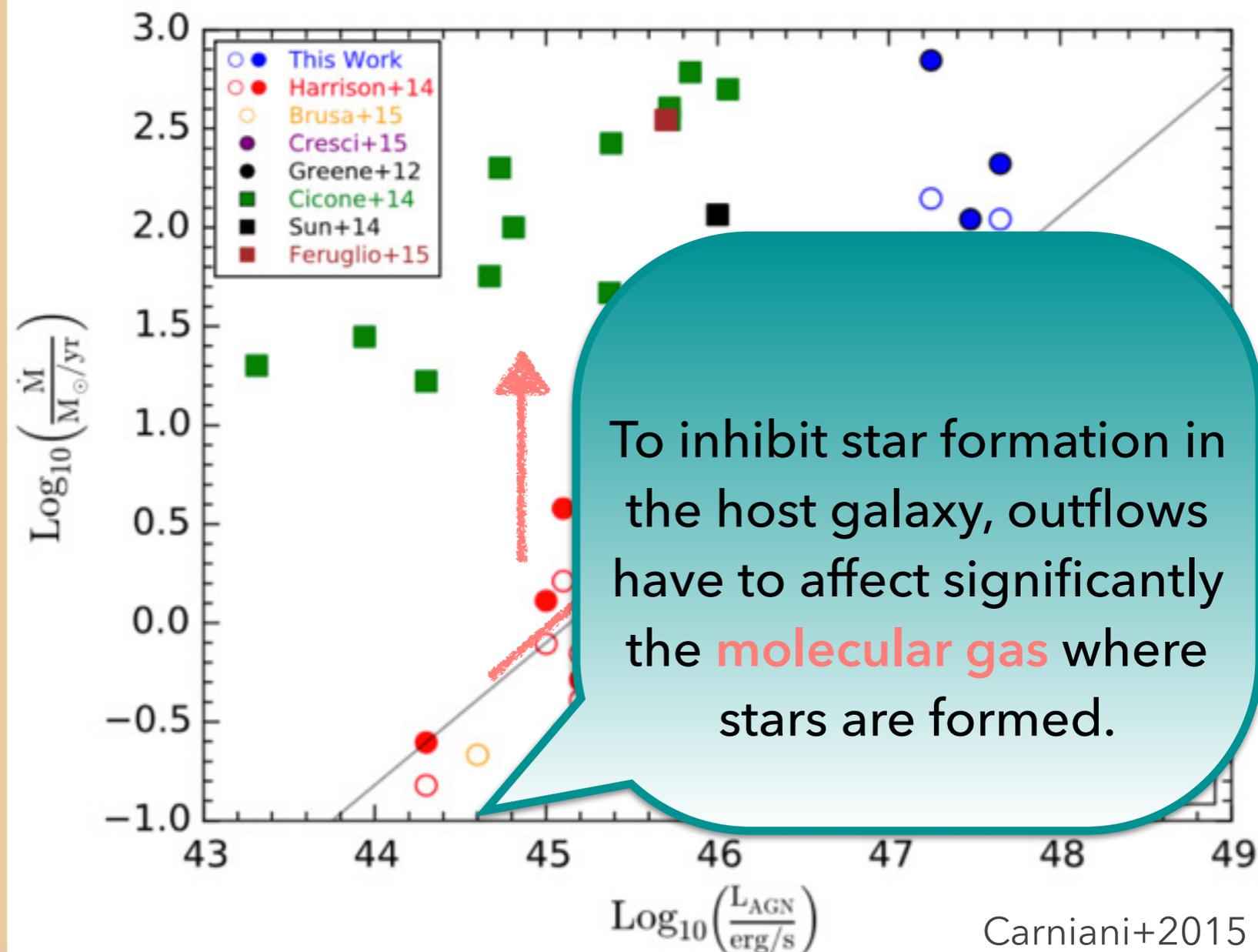
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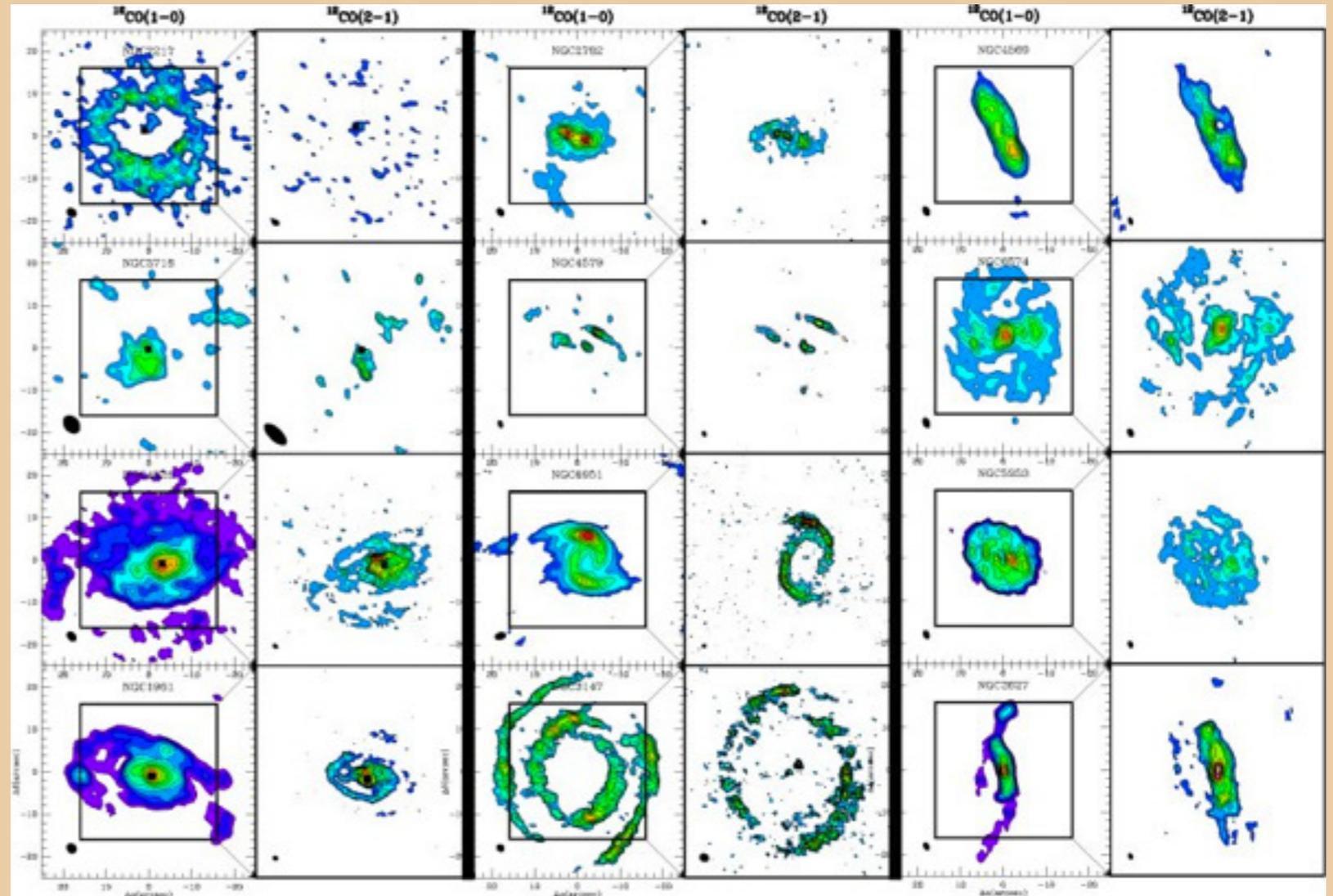
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NUGA - NUCLEI OF GALAXIES

- IRAM PdBI + ALMA CO survey (PI: Garcia-Burillo & Combes)
- nearby LLAGNs covering all stages of nuclear activity
- angular ($0.5''$) and spectral resolution (3 - 6 km/s)
- Torque analysis: gas inflowing
- 1/3 galaxies revealed smoking-gun evidence of AGN fuelling (Garcia-Burillo & Combes 2012)



Credits: IRAM

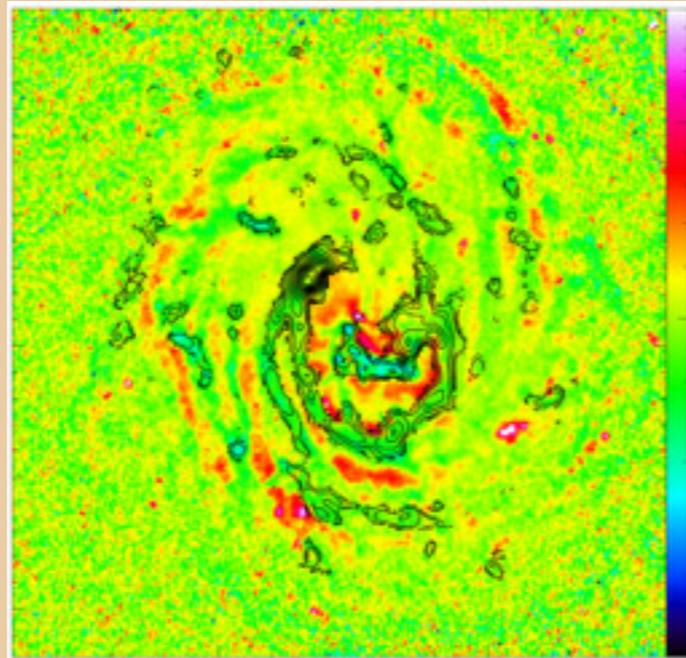
NGC 1433

- D= 9.9 Mpc
- $i = \sim 33^\circ$
- Seyfert 2
- SB(r)ab
- "Lord of the Rings"
(Buta & Combes 1996)
- ALMA Cycle 0
- CO(3-2) @
344.6GHz (Band 7)

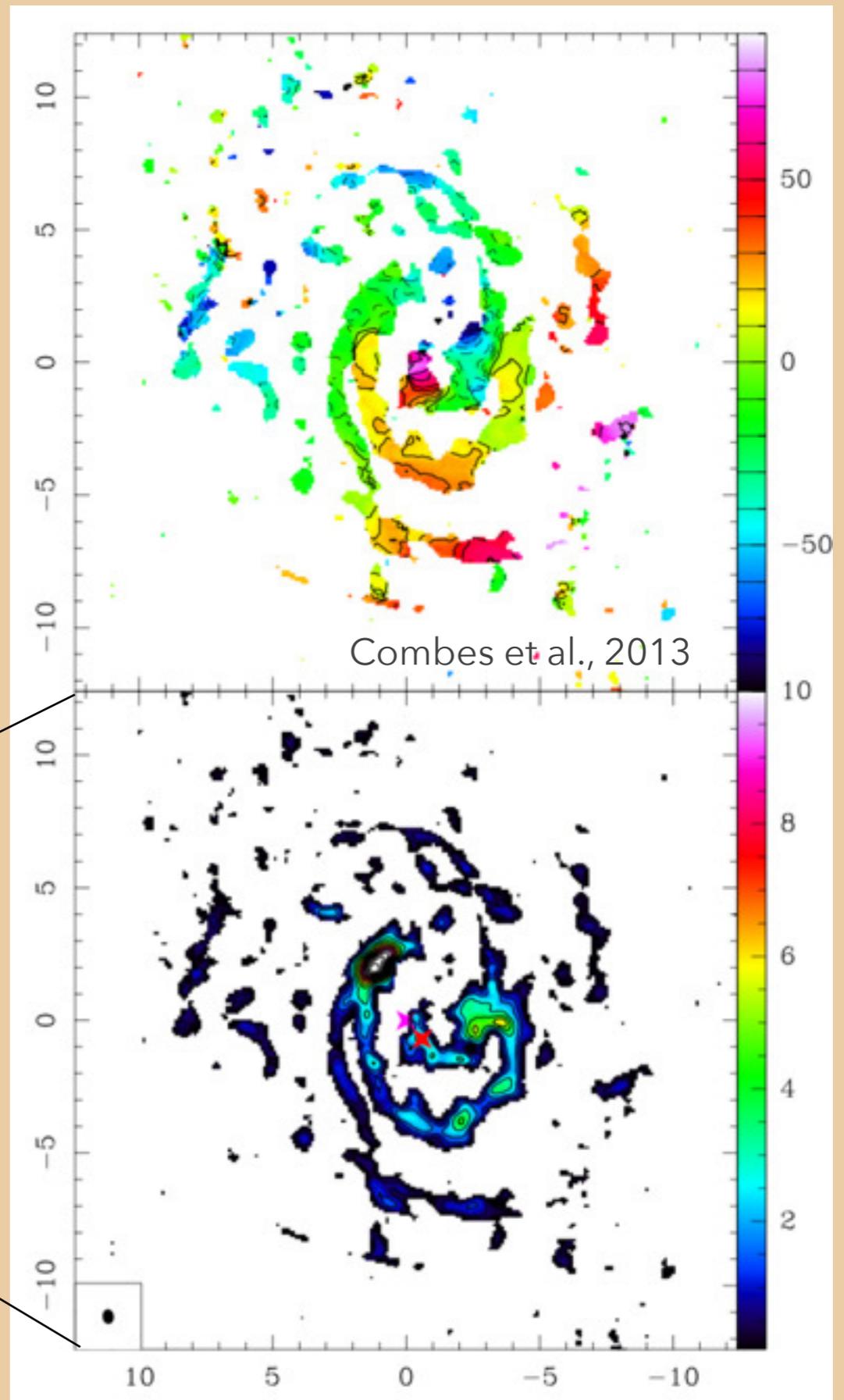
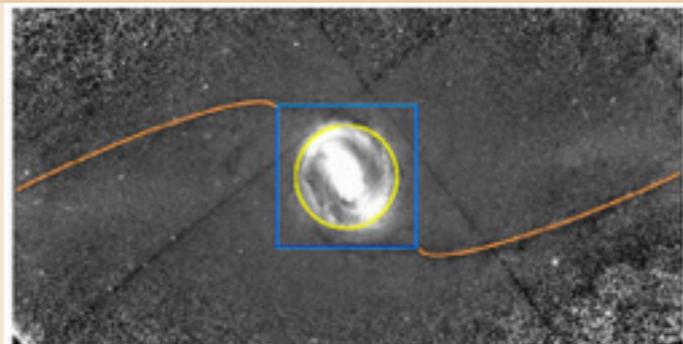


30''

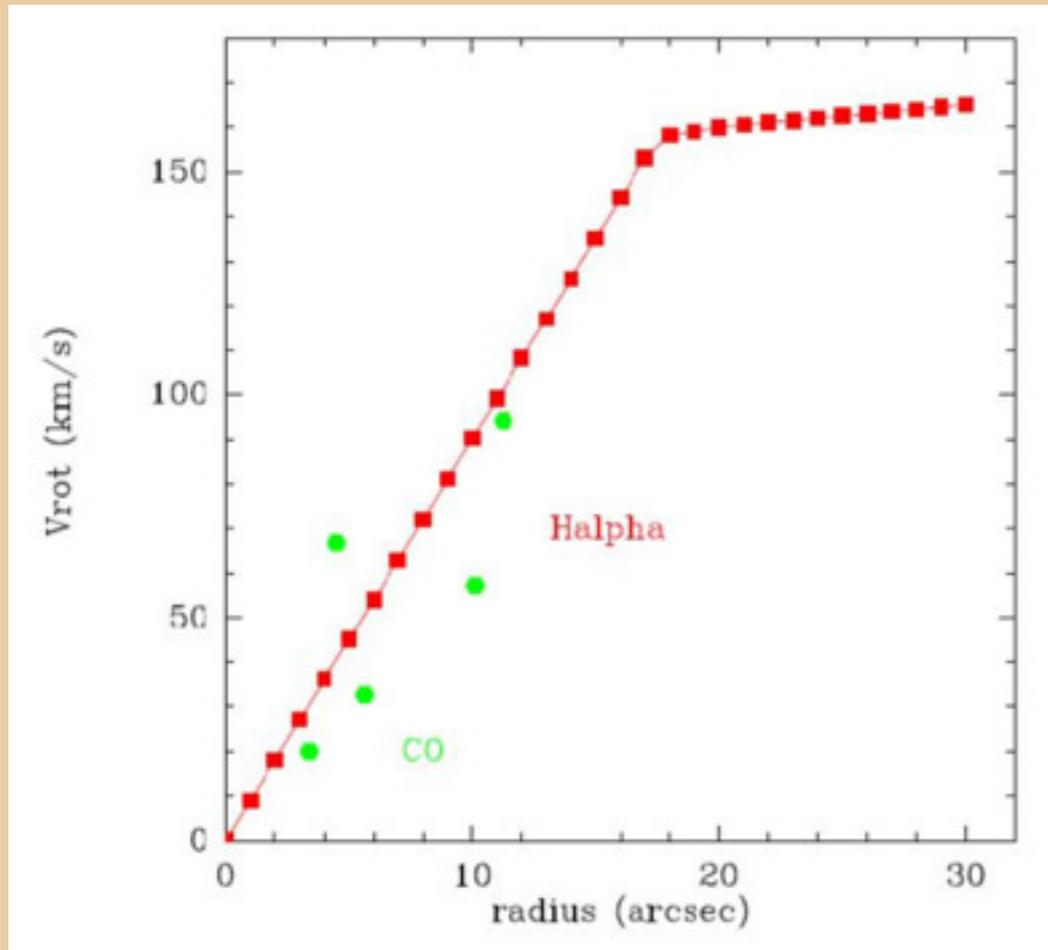
- rms 3mJy/beam & 24pc resolution
- FOV 18" (<1kpc)
- Offset peak: no concentration of molecular gas in the center: widely distributed multiple-arm spiral of CO emission
- gas do not follow the nuclear ring (10"): pseudo-ring at ~ 200pc
- velocity field well described by rotation
- noticeable redshifted perturbation at the very center (~100pc extent)



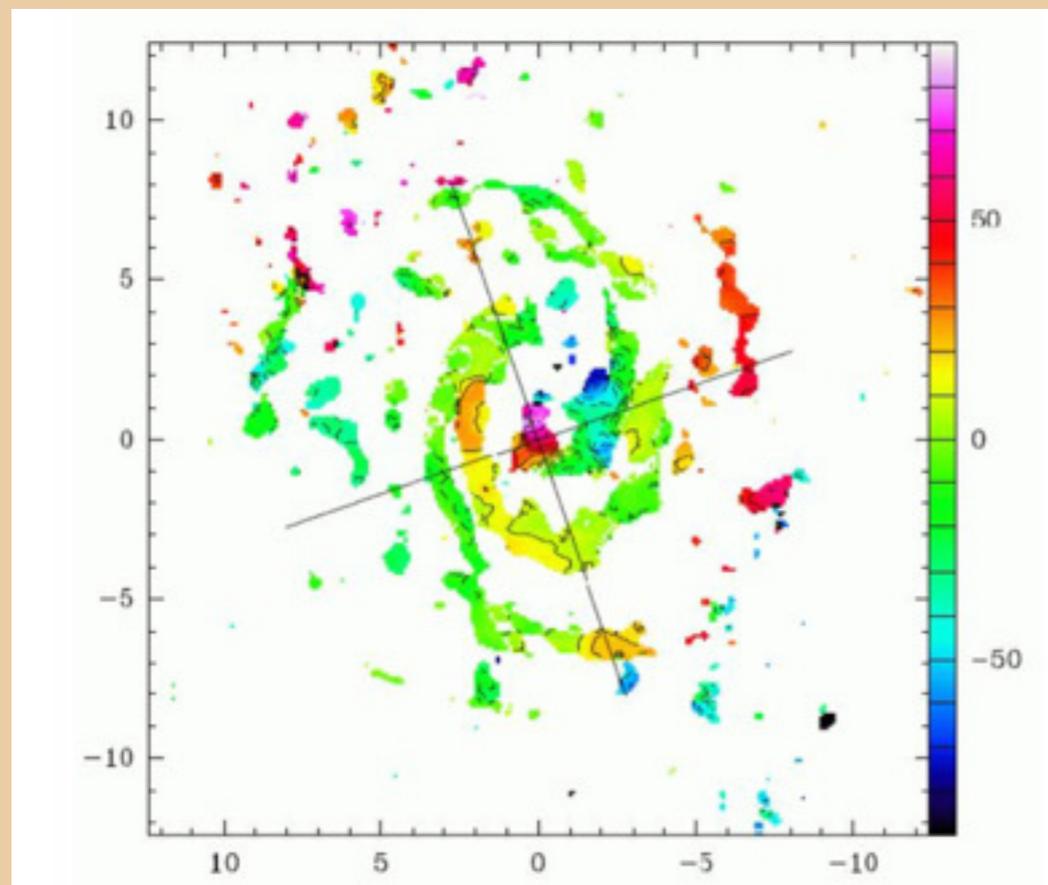
CO(3-2) contours overlaid to F450W HST image and I-image: the nuclear ring, dust lanes leading edge of the main bar (orange)



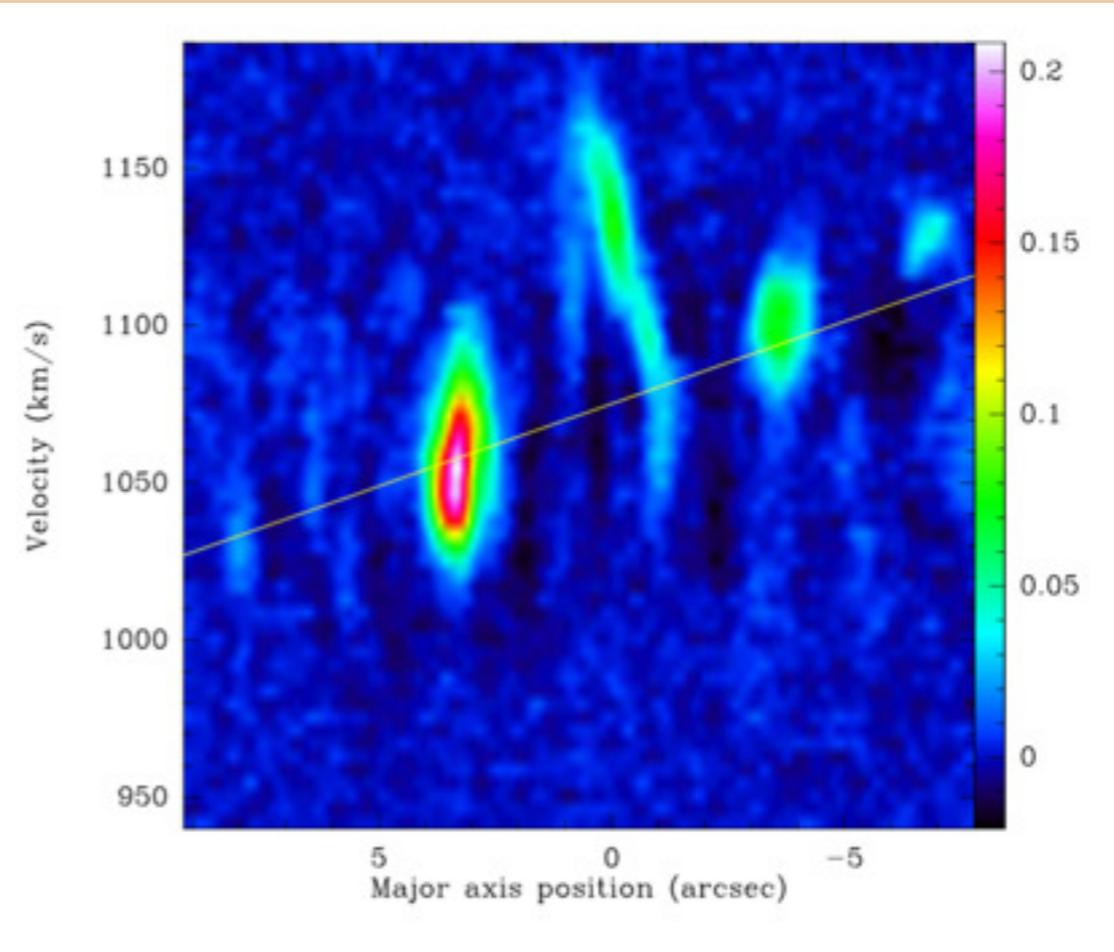
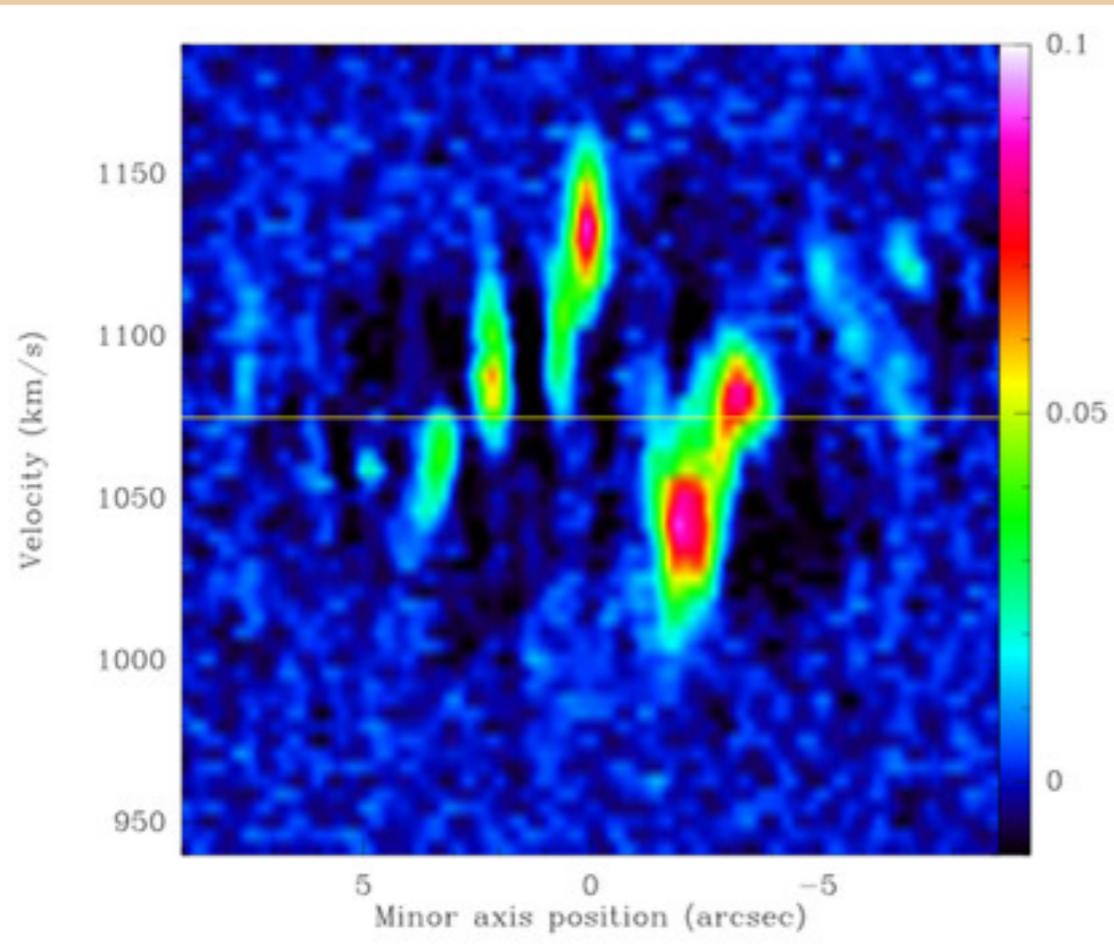
Velocity field and integrated intensity of the CO(3-2) emission clipped at $>2\sigma$



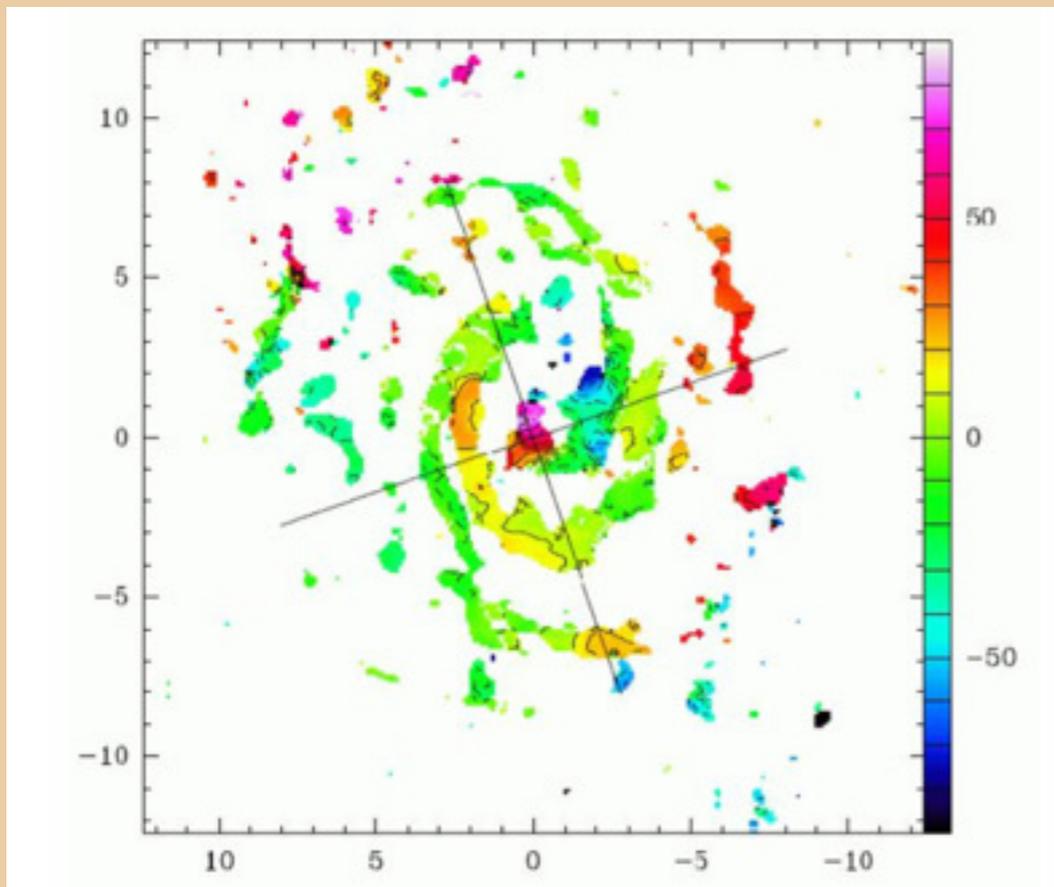
- $H\alpha$ rotation curve (Buta+2001)
- high-velocity CO emission feature redshifted to 200 km/s with a blue-shifted counterpart, at 2" (100 pc)



- The outflow revealed in NGC 1433 is the smallest molecular outflow ever seen in a galaxy nucleus ($3.6 \times 10^6 M_{\odot}$ and $\sim 7 M_{\odot}/\text{yr}$)
- $\text{SFR} \sim 0.2 M_{\odot}/\text{yr}$ (IRAS fluxes, $1.3 \times 10^9 L_{\odot}$)
- Flow mainly boosted by the AGN through its radio jets (1.4GHz continuum detected in the very center, Ryder+1996)



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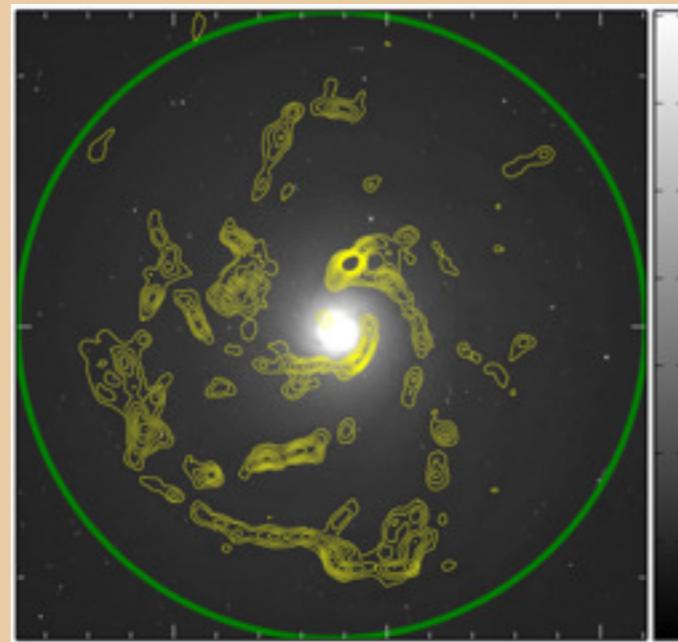
NGC 7213

- D=21Mpc
- $i = \sim 39^\circ$
- Seyfert 1/LINER
- early-type SA(s)a
- ALMA Cycle 1
- CO(2-1) @
229.2GHz (Band 6)

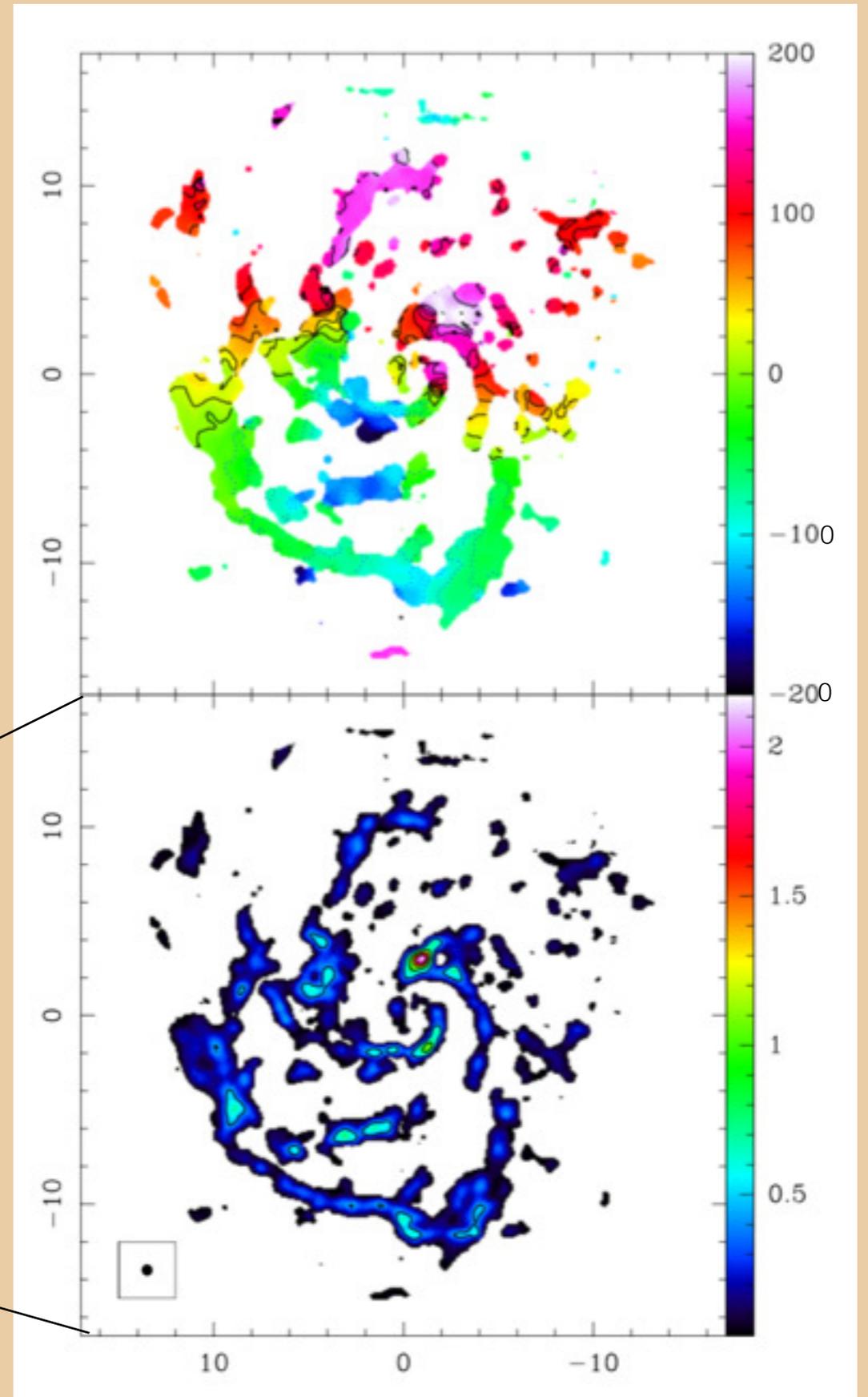


- rms 0.3mJy/beam & 60pc resolution
- FOV 27" (<3kpc)
- Offset peak located at 200pc N from the center
- CO emission reveals a widely distributed multiple-arm spiral structure, tracing the dusty spiral arms, as can be seen in the HST image.

- velocity field well described by rotation
- slightly perturbations along the minor axis ($\sim 10''$) probably due to streaming motions



CO(2-1) contours overlaid on F606W HST image



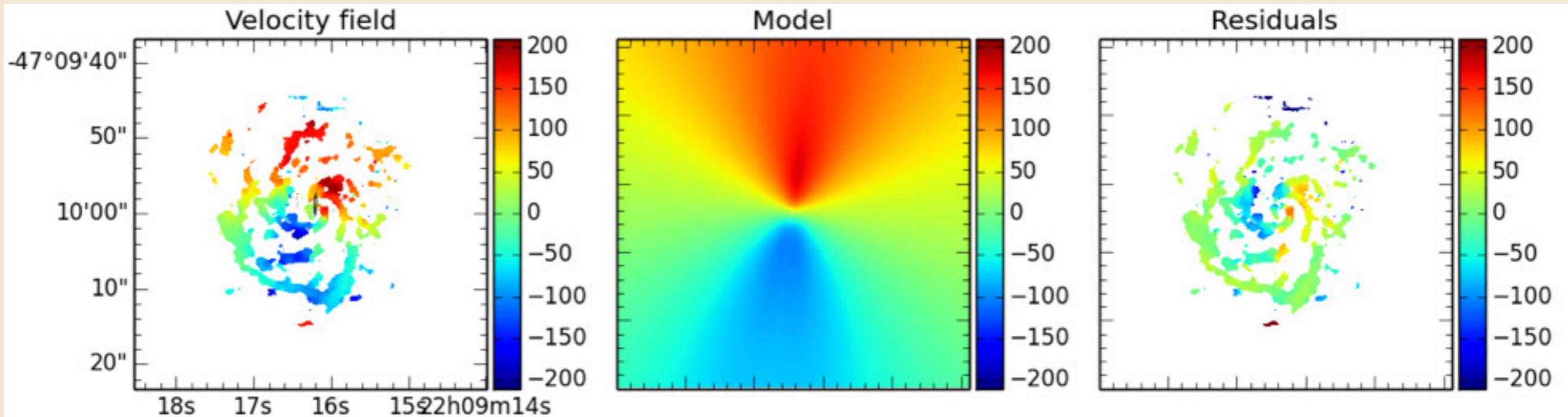
CO(2-1) map obtained with ALMA with a beam of $0.61'' \times 0.57''$ (PA= -100°).

ROTATION CURVE VELOCITY MODEL

$$V = V_s + \frac{AR \cos(\psi - \psi_0) \sin(\theta) \cos^p \theta}{\{R^2 [\sin^2(\psi - \psi_0) + \cos^2 \theta \cos^2(\psi - \psi_0)] + c^2 \cos^2 \theta\}^{p/2}}$$

Bertola et al., 1991

- PA = -7 and $i = 39$ (also tested for tilted ring model)
- Corrected V_{sys} of about $\sim 20 \text{ km/s}$
- The residuals do not indicate hints of a significant blue and/or red-shifted components: probably no molecular flow in NGC7213

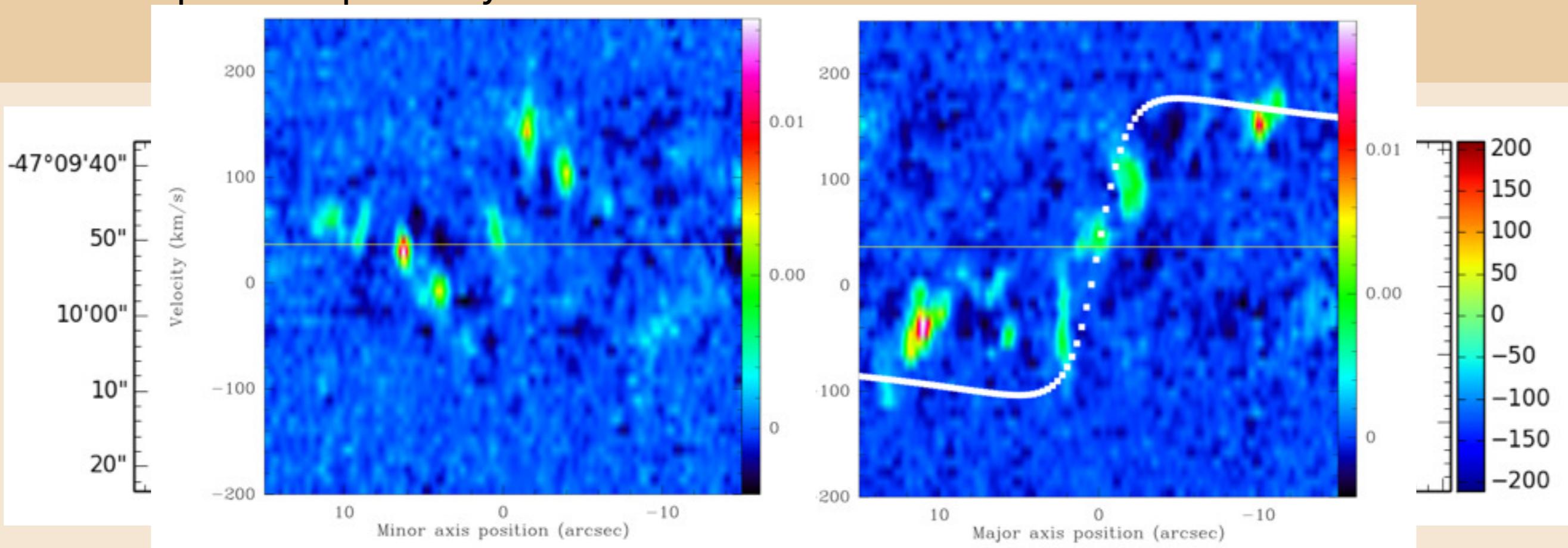


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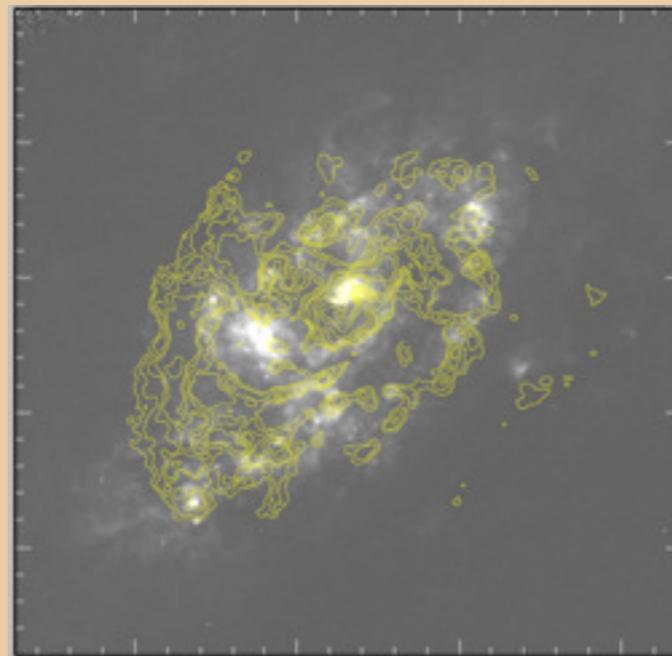
NGC 1808

- D=12.3Mpc
- $i = 57^\circ$
- Seyfert 2
- SAB(s)a
- ALMA Cycle 3
- CO(3-2) @
344.6GHz (Band 7)

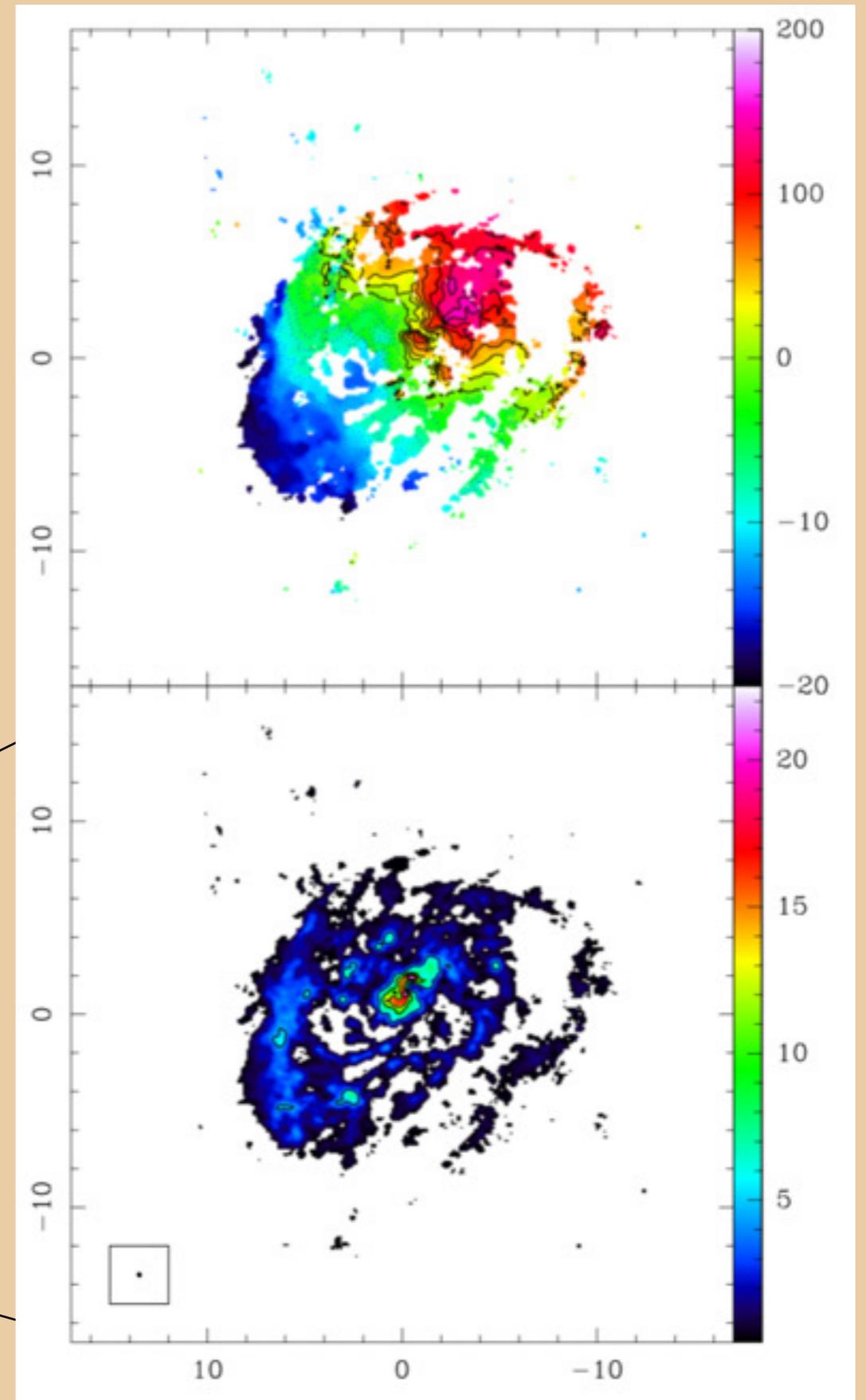


30''

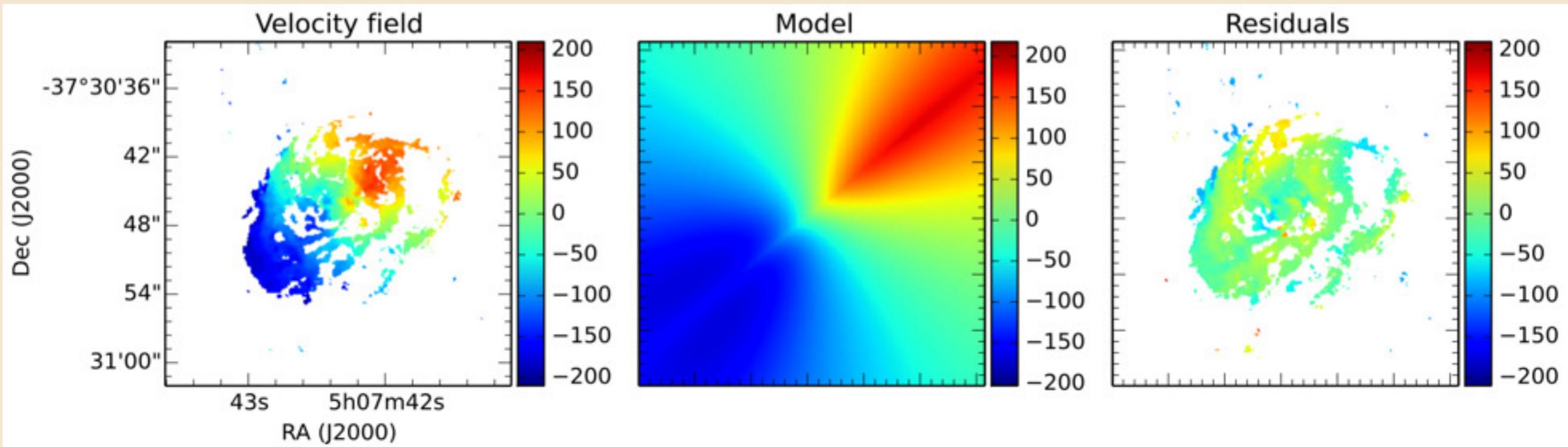
- rms 0.3mJy/beam & 30pc resolution
- FOV 18" (1kpc)
- CO emission follows the star-forming central 500pc ring
- circular rotation in the disk dominates the CO(3-2) emission
- Salak+2016 evidence of an outflow CO(1-0)



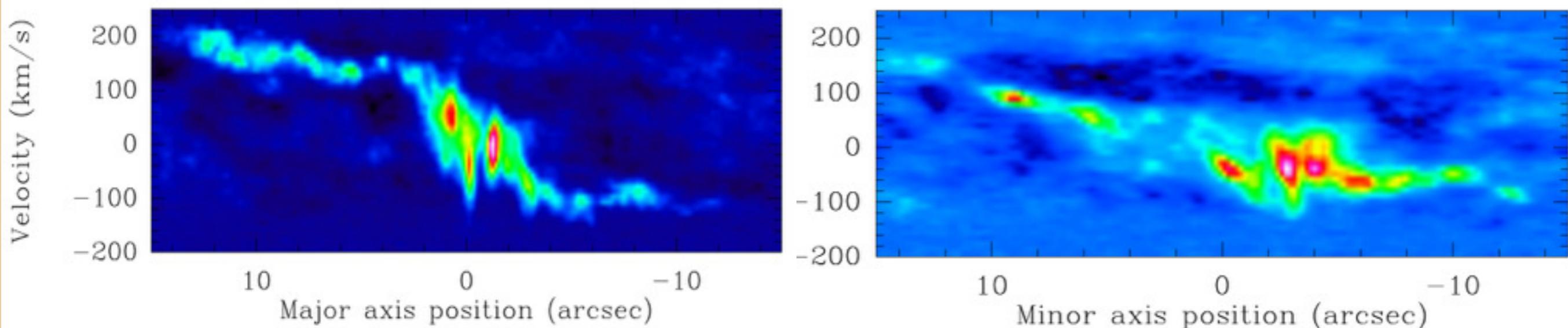
CO(3-2) contours overlaid on a HST image

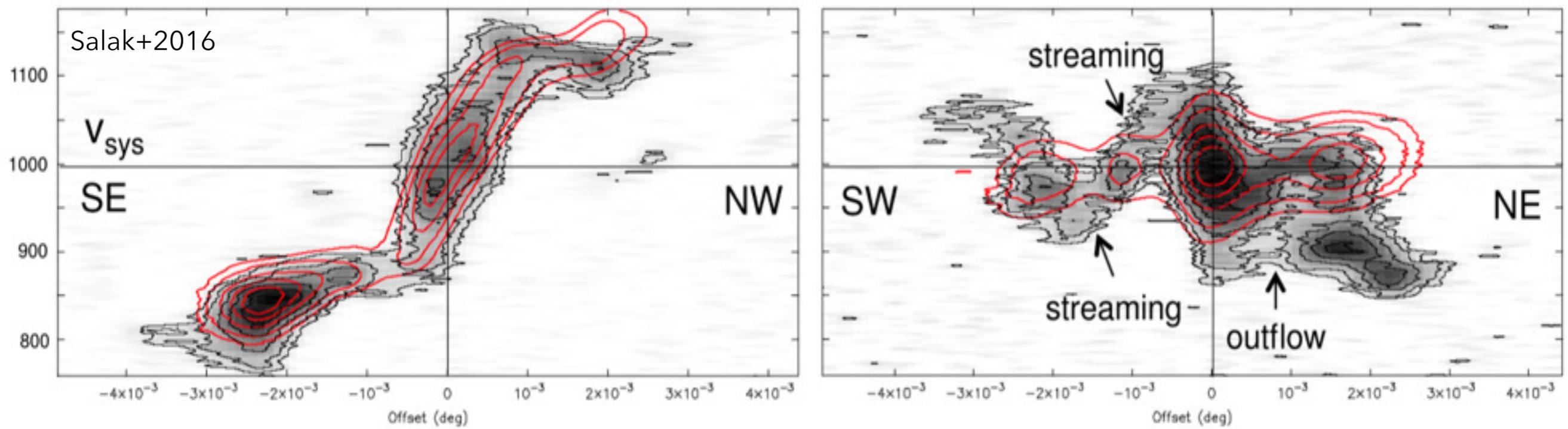


CO(3-2) map obtained with ALMA with a beam of 0.29" x 0.24".

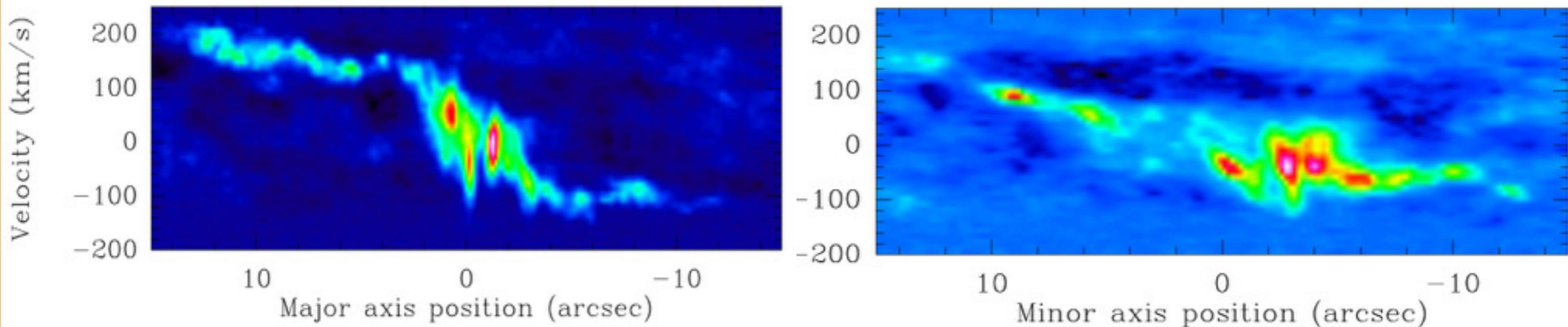


- Residuals do not show evidence of outflows: 1st moment dominated by circular motions
- Salak+2016: evidence of an outflow in CO(1-0) only seen in the PVD \rightarrow a 100km/s blueshifted component in the NE corresponding to $v \sim 48-128$ km/s): outflow off the disk
- Our PVD presents almost same blueshifted pattern along the minor axis.



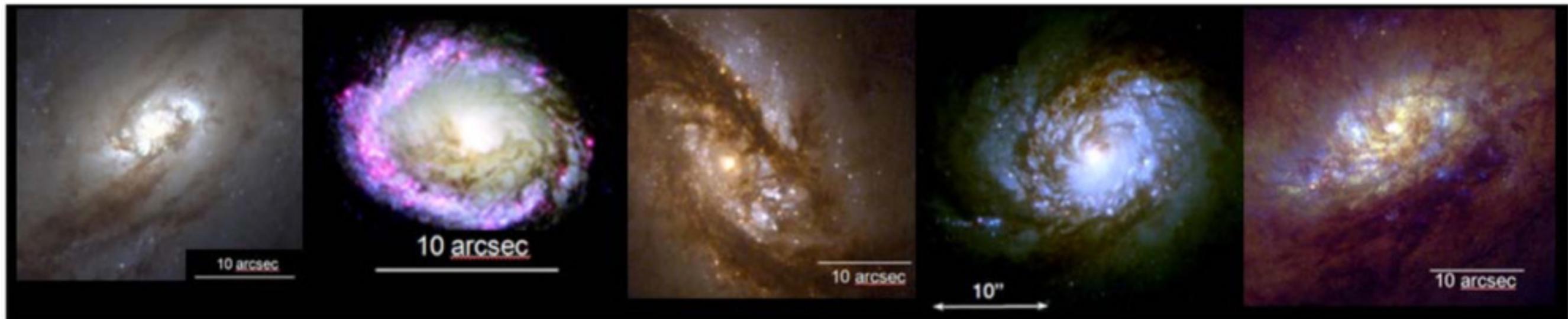


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SUMMARY

- Outflow in NGC 1433: one of the smallest molecular outflow ever seen in a galaxy nucleus ($3.6 \times 10^6 M_{\odot}$ and $7 M_{\odot}/\text{yr}$), **FIRST TIME SEEN IN A LLAGN** (LINERS: NGC1377, Aalto+2012, NGC1266, Alatalo+2011)
- CO(2-1) in NGC7213 is tracing the dusty spiral arms and it seems to be dominated mainly by rotation
- Outflow in NGC1808 ($v_{\text{out}} \sim 180 \text{ km/s}$ and $1-10 M_{\odot}/\text{yr}$) suggested by Salak+2016: to be confirmed with CO(3-2)
- extended NUGA sample: new ALMA observations: $0.14''$ resolution (8-16pc). **STAY TUNED!**



THANK YOU!

