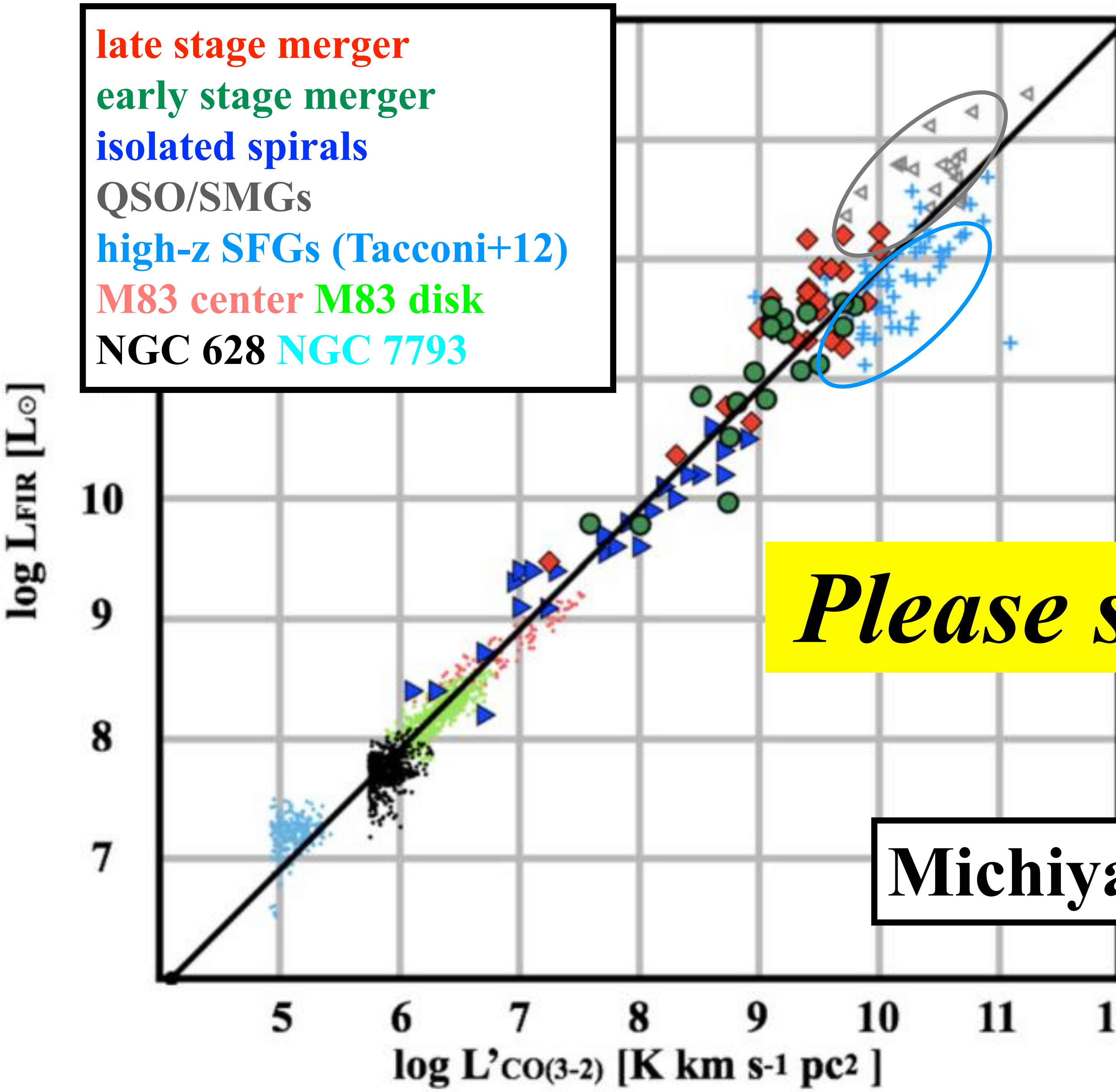
Dense molecular outflows from the merging LIRG NGC3256

Tomonari Michiyama,
(2nd year PhD, NAOJ/SOKENDAI from Japan)
D.Iono, K.Sliwa, A.Bolatto, and etc

Relation between CO (3–2) and Far Infrared Luminosities for Nearby Merging Galaxies Using ASTE and AKARI



Please see Poster

Michiyama et al. 2016

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Star Formation in Different Environments
→

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Dense molecular outflows from the merging LIRG NGC3256

Star Formation in Different Environments
→ star formation inside the galactic scale outflow
→ dense gas outflow

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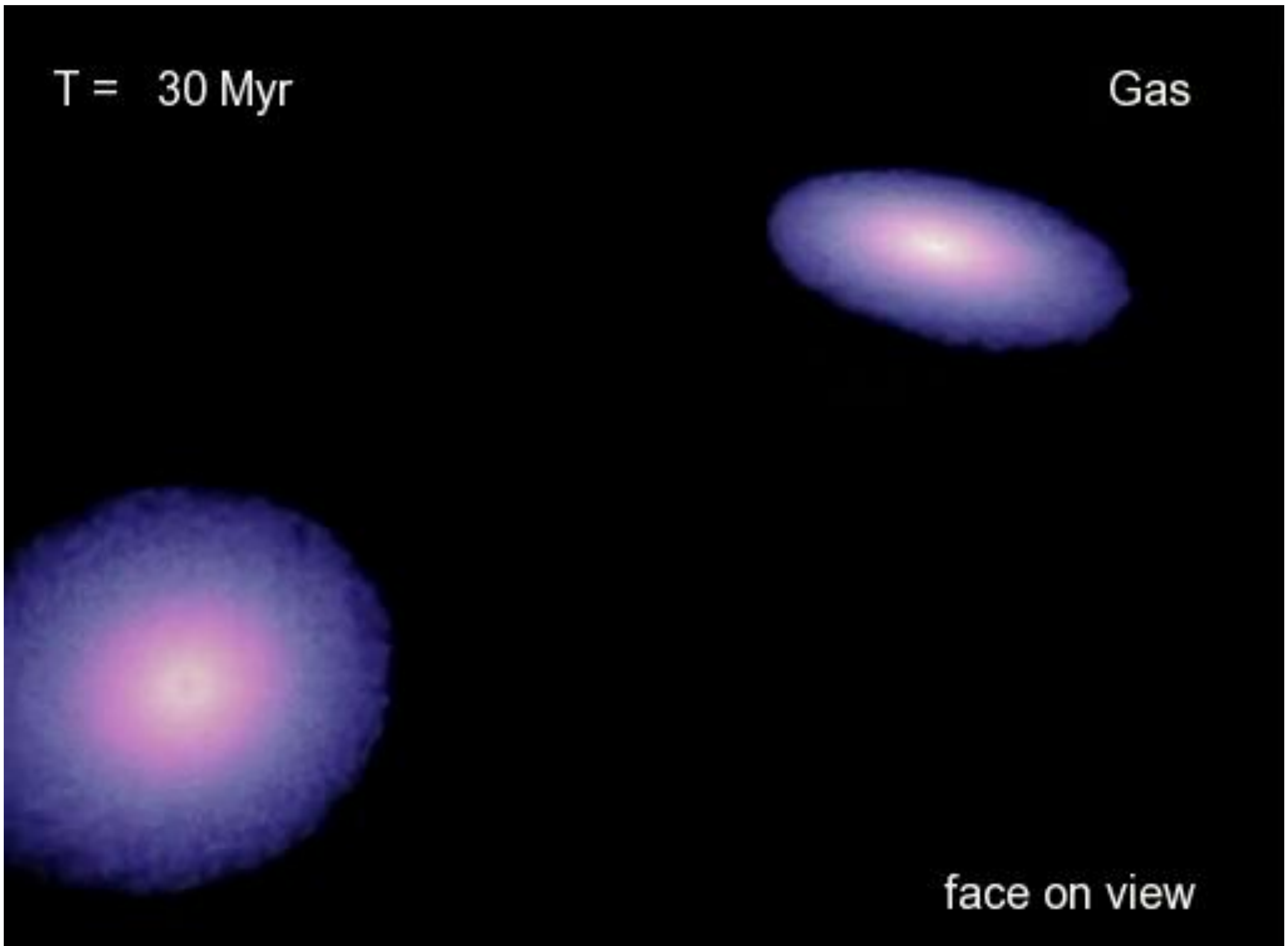
1. Background

(Phil Hopkins' HP)

Galaxy Merger

1. starburst and/or AGN is triggered due to gas concentration (gas inflow)

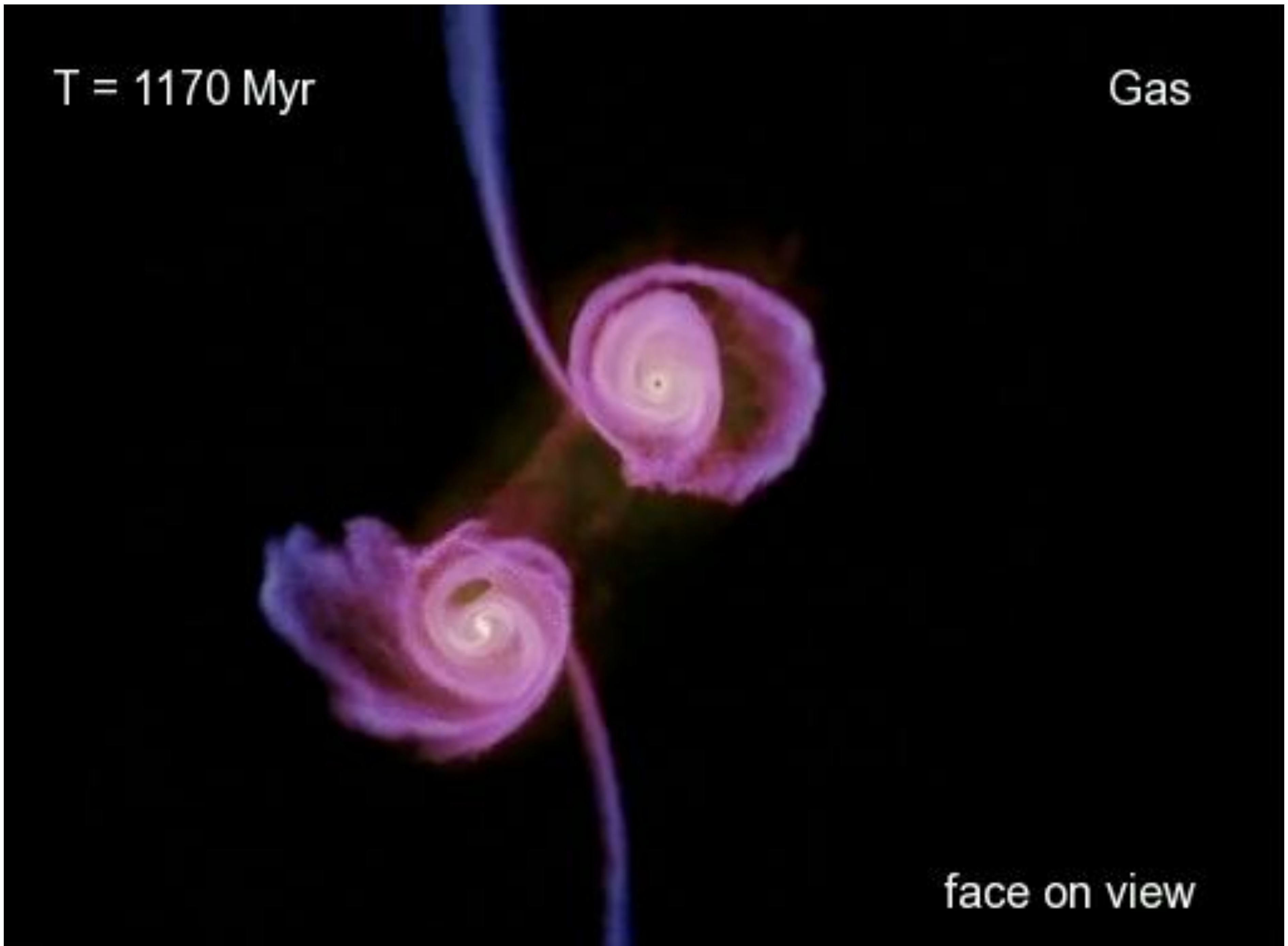


1. Background

(Phil Hopkins' HP)

Molecular Outflow during Galaxy Merger

2. starburst and/or AGN is quenched by expelling the gas (molecular outflow)



1. Background

Feedback Mechanism

What is feedback ? (in dictionary):
the process in which part of the output of a system is returned to its input in order to regulate its further output

merger trigger starburst

↓

starburst trigger molecular outflow

↓

molecular outflow quench starburst

1. Background

Feedback Mechanism

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merger trigger starburst
↓
starburst trigger molecular outflow
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molecular outflow quench starburst

negative feedback

1. Background

Feedback Mechanism

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merger trigger starburst

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starburst trigger molecular outflow

↓

molecular outflow quench starburst

negative feedback

General idea

1. Background

Feedback Mechanism

merger trigger starburst

↓

starburst trigger molecular outflow

negative feedback

molecular outflow quench starburst

1. Background

Feedback Mechanism

merger trigger starburst

↓

starburst trigger molecular outflow

negative feedback

molecular outflow quench starburst

star formation in outflow

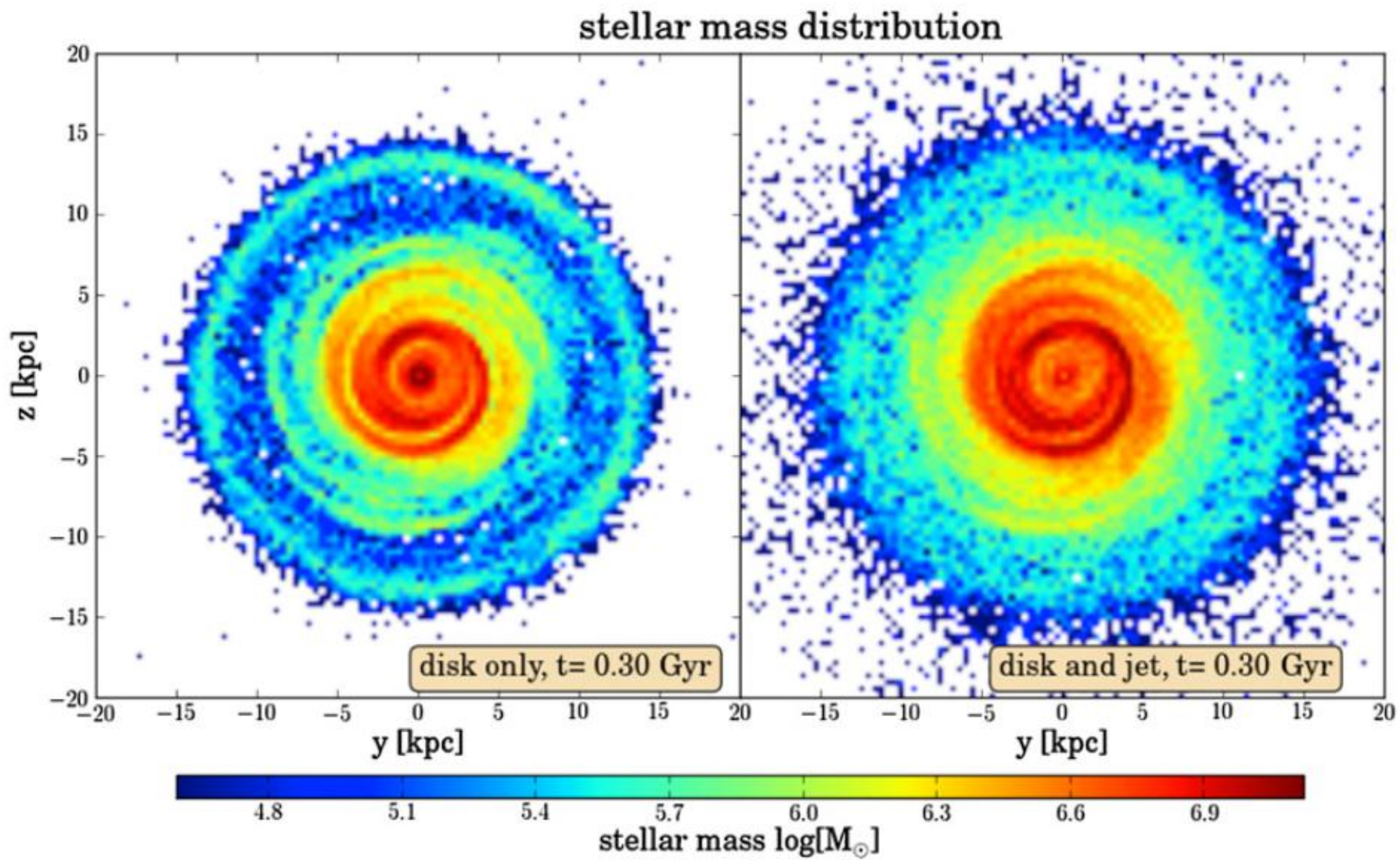
positive feedback

Motivation:
We want to show the star formation in the outflow

1. Background

Why is star formation in outflow important ?

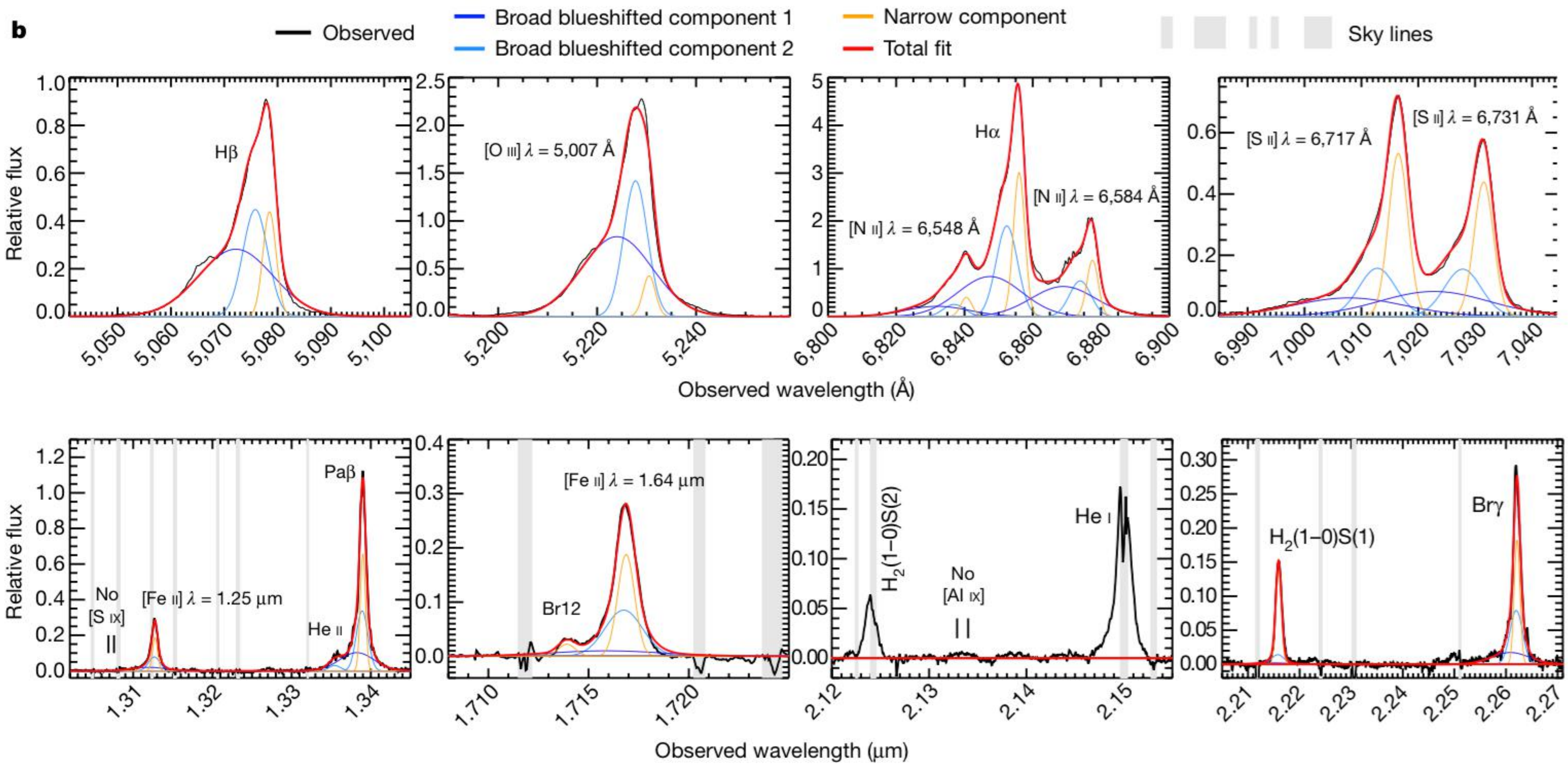
1. contribute to the morphological evolution (Gaibler+12, Dugan+14)
2. high velocity stars which can escape from the galaxy (material of intergalactic medium)
3. contribute to the star formation in the high-z universe (Silk+13)



1. Background

Recent Studies

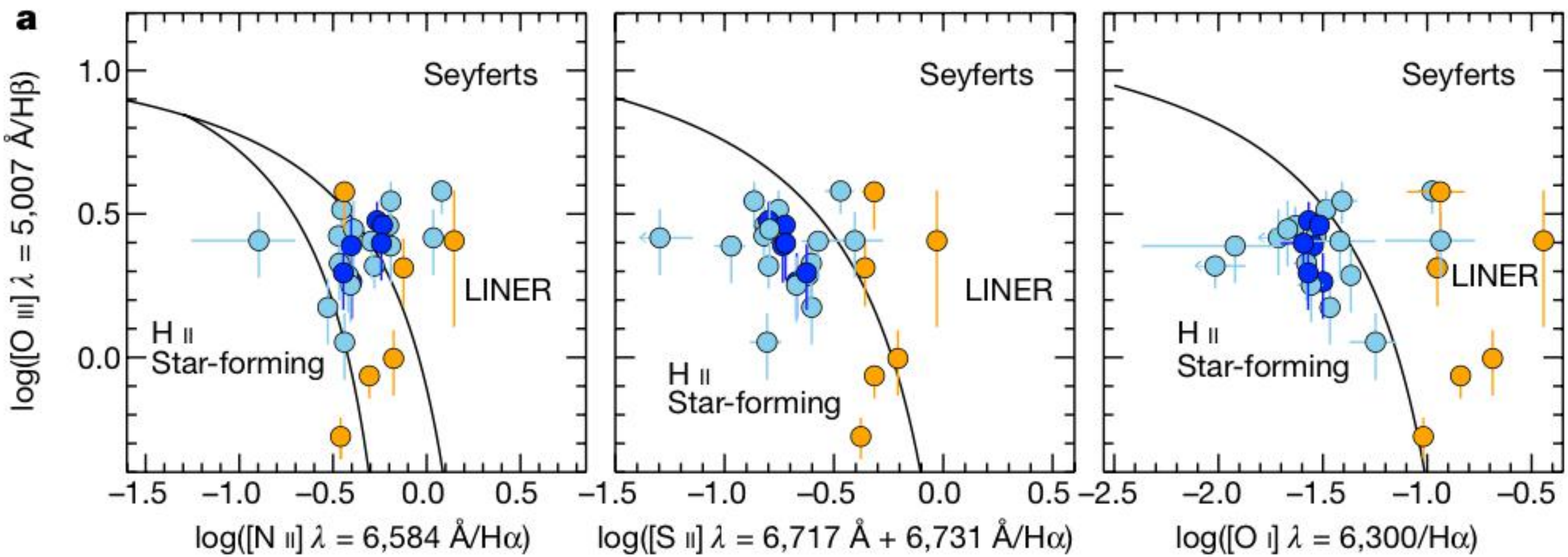
1. Maiolino et al. (2017), X-shooter/VLT observation
   → detect broad lines by optical spectroscopy



1. Background

Recent Studies

Maiolino et al. (2017), X-shooter/VLT observation
→ BPT diagram shows star formation in the outflow



2. Background

My Study

Key Question:
Is outflowing molecular gas enough dense? hot?

[Problem]

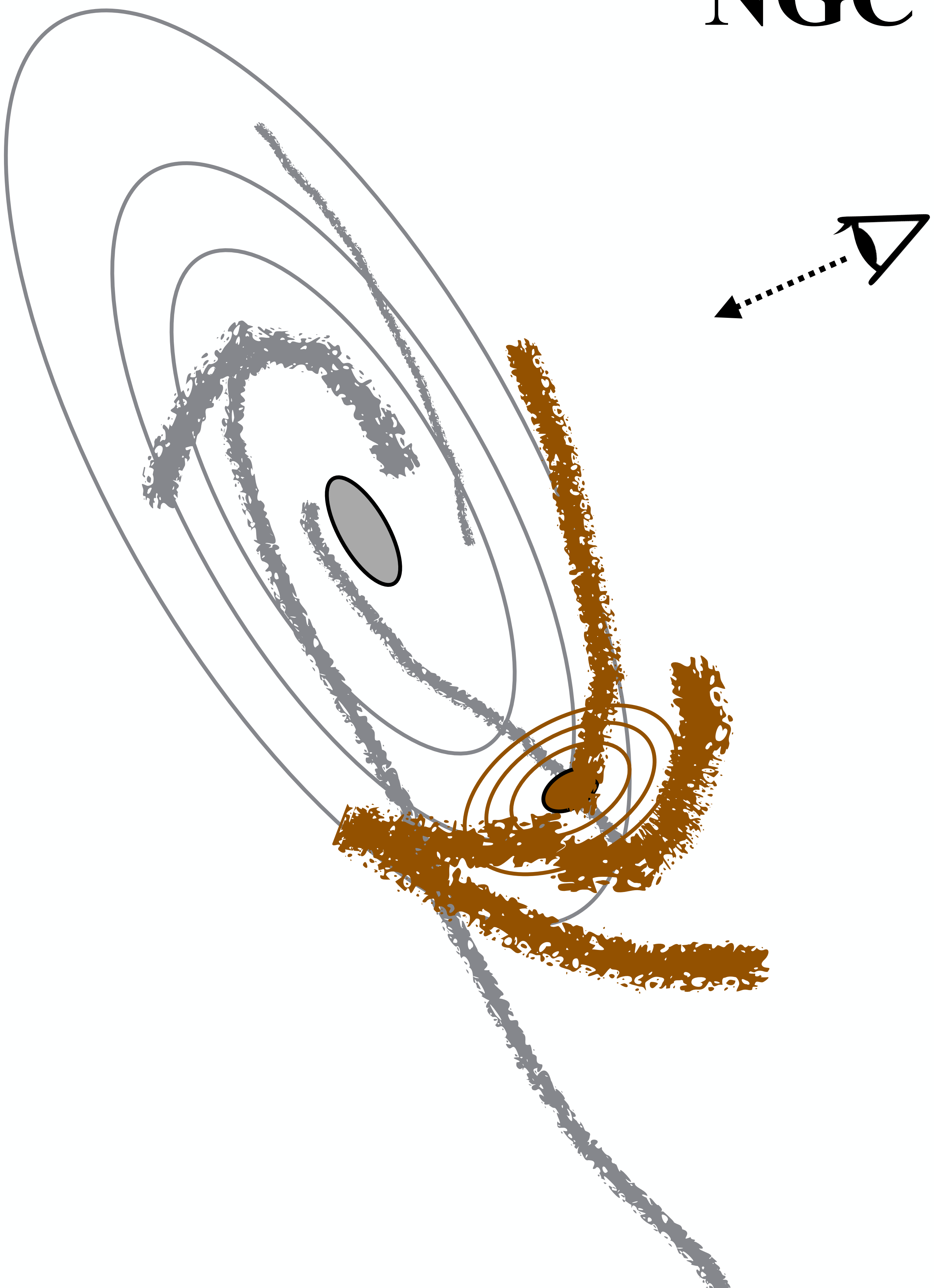
1. The outflows are detected mainly in bright CO lines.
→ detect outflow in multi-molecules (physical properties)
2. The outflow is discussed only in spectrum
→ We have to resolve outflow and other components

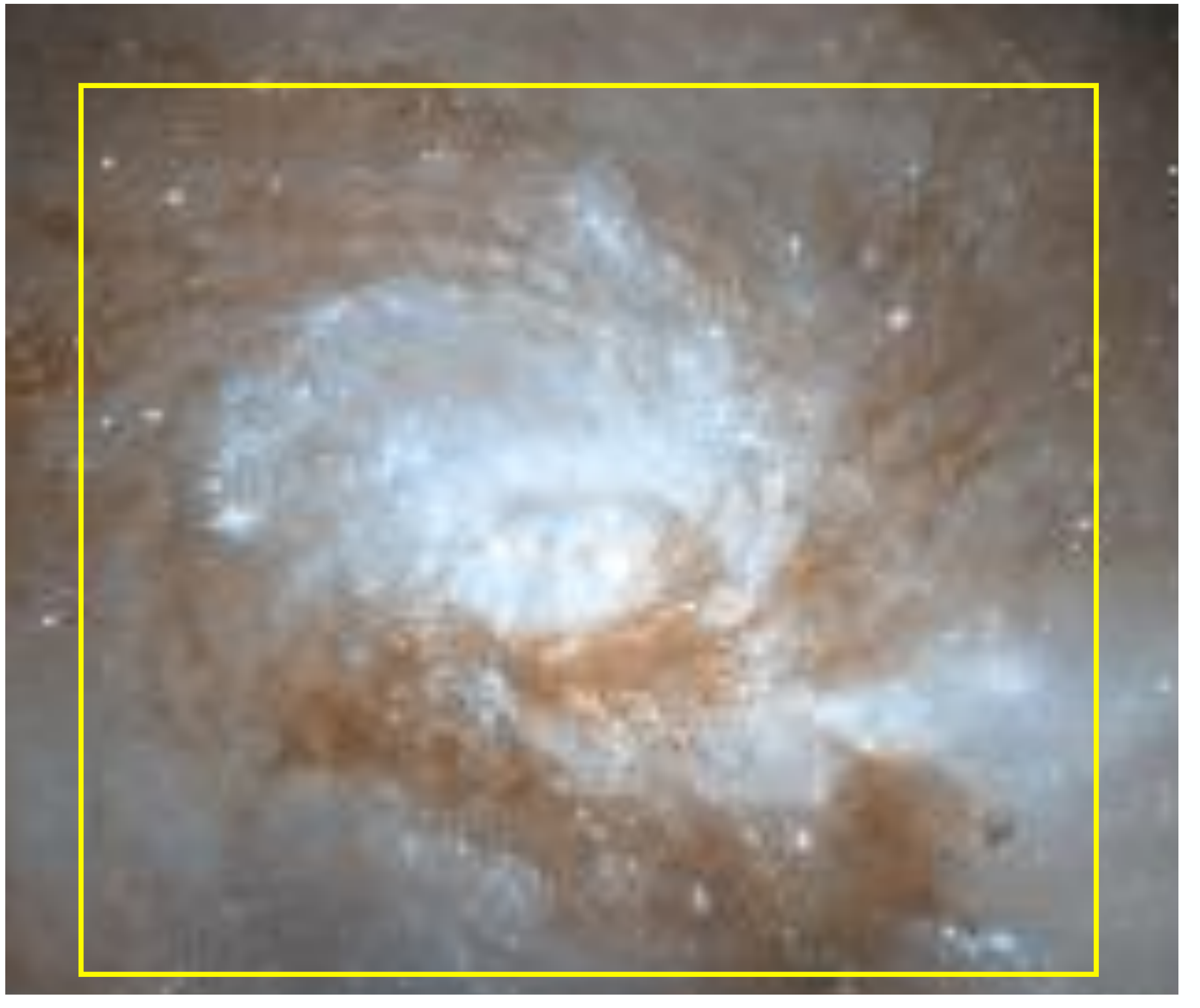
3. Target

NGC 3256

3. Target

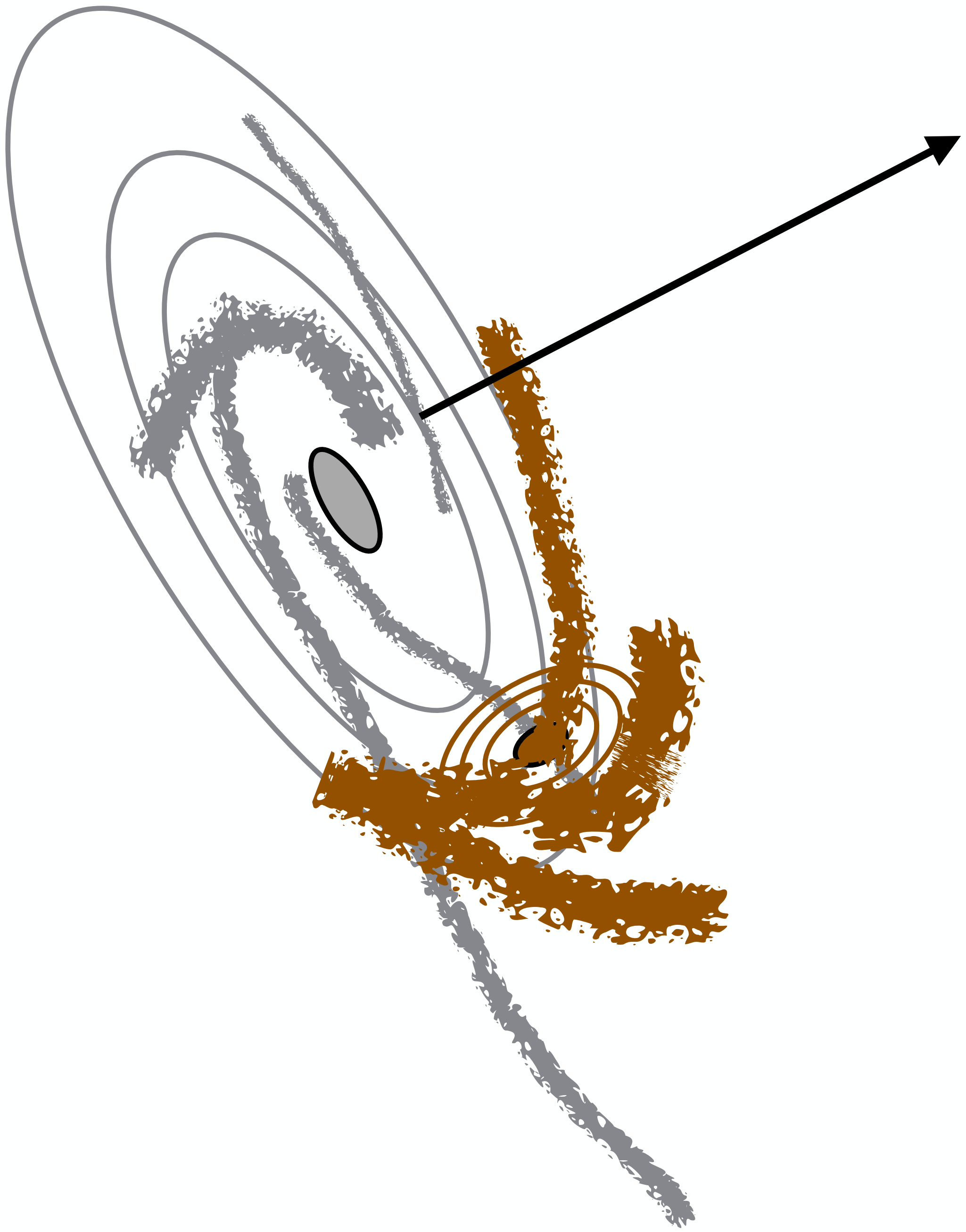
NGC 3256



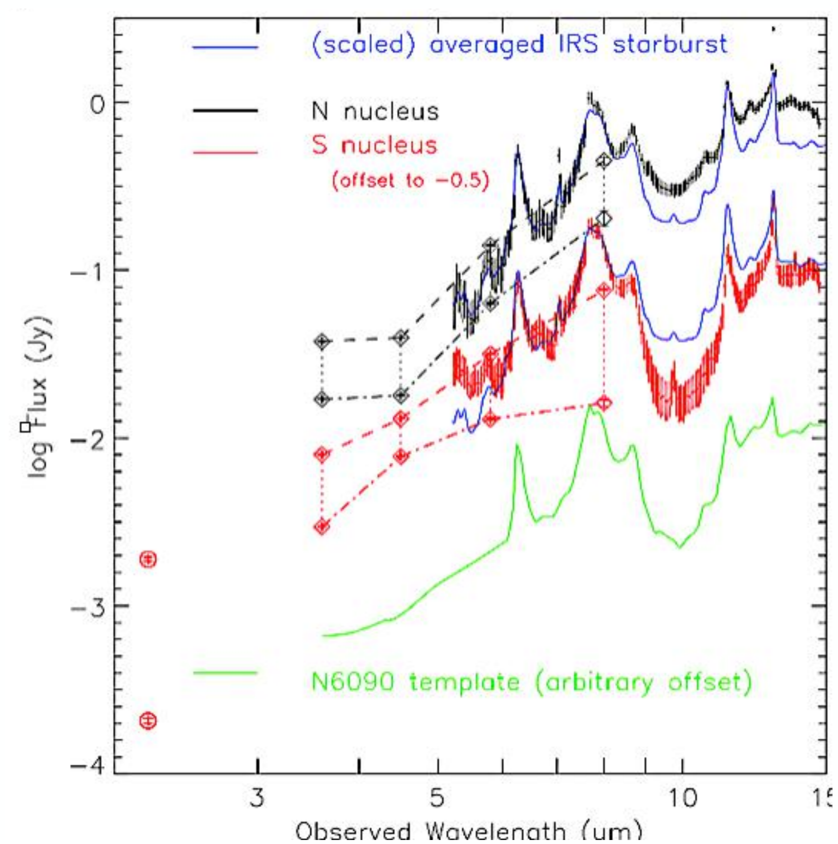


3. Target

NGC 3256



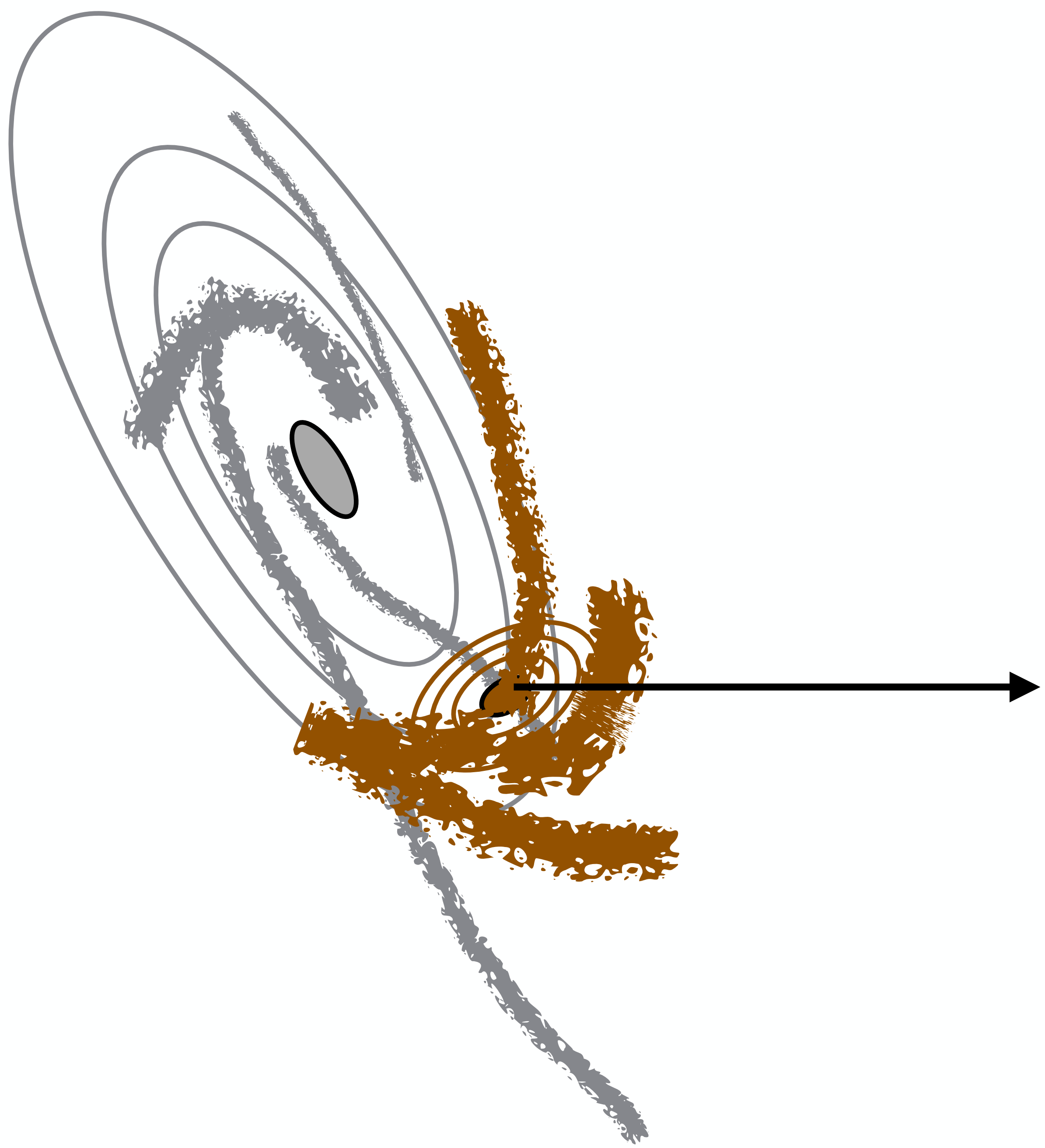
North Nucleus
starburst

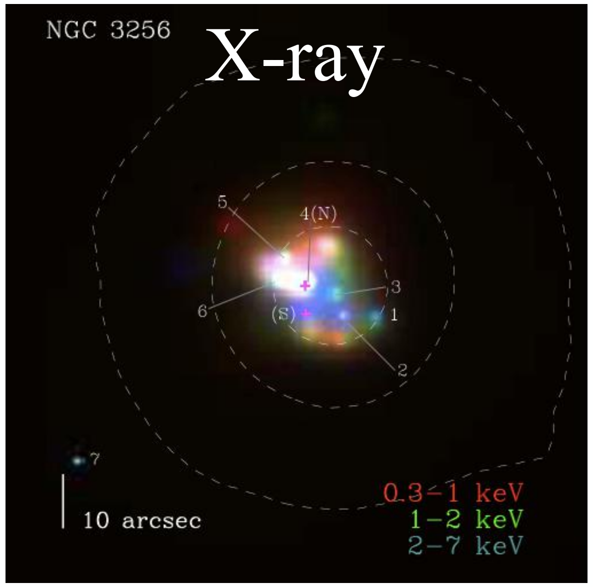


(Ohyama+15)

3. Target

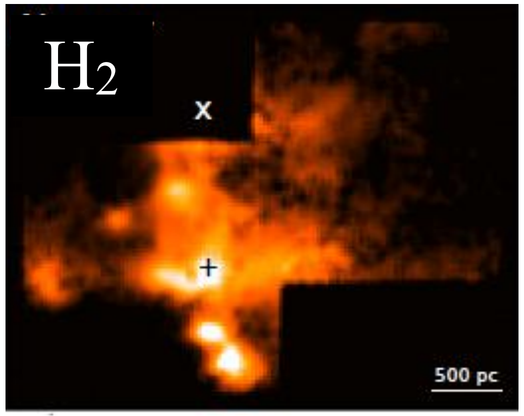
NGC 3256





(Lehmer+15)

South Nucleus
AGN galaxy

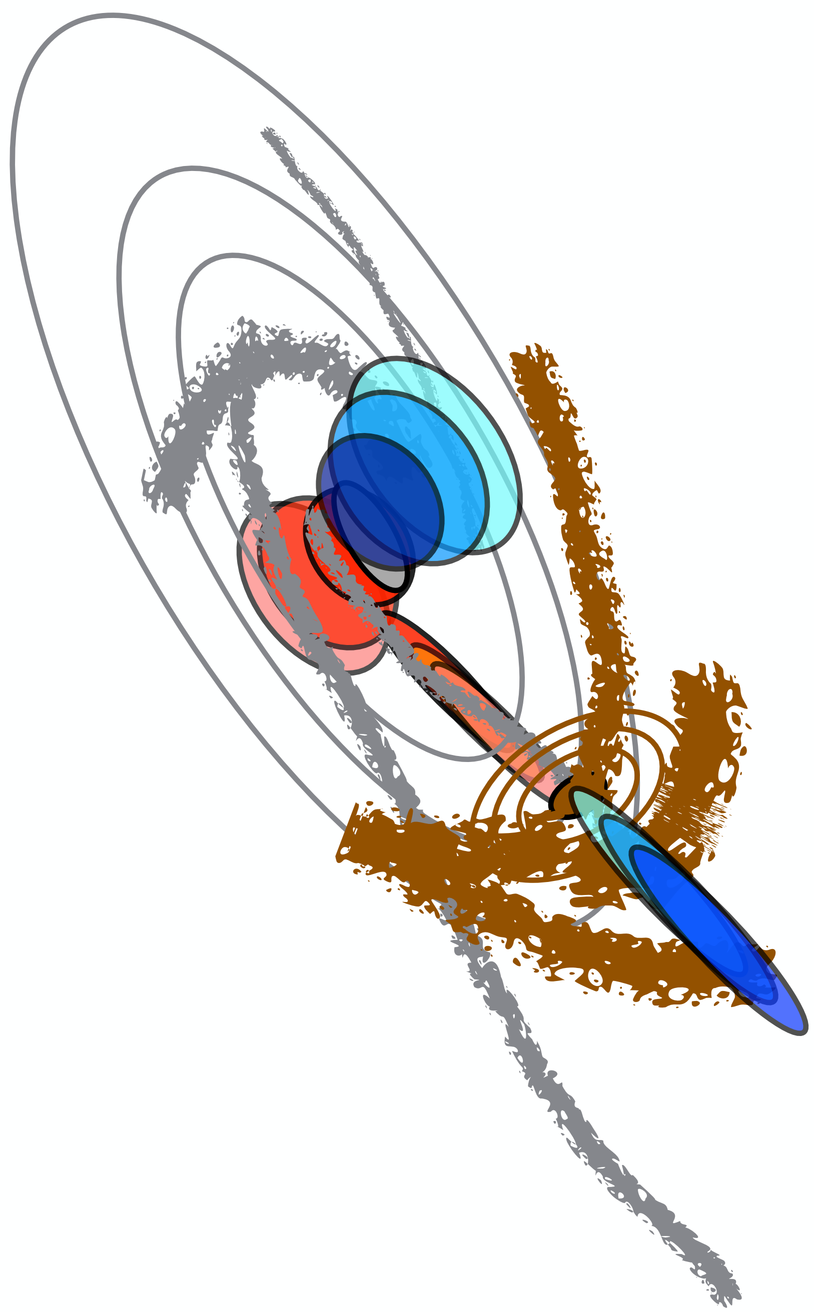


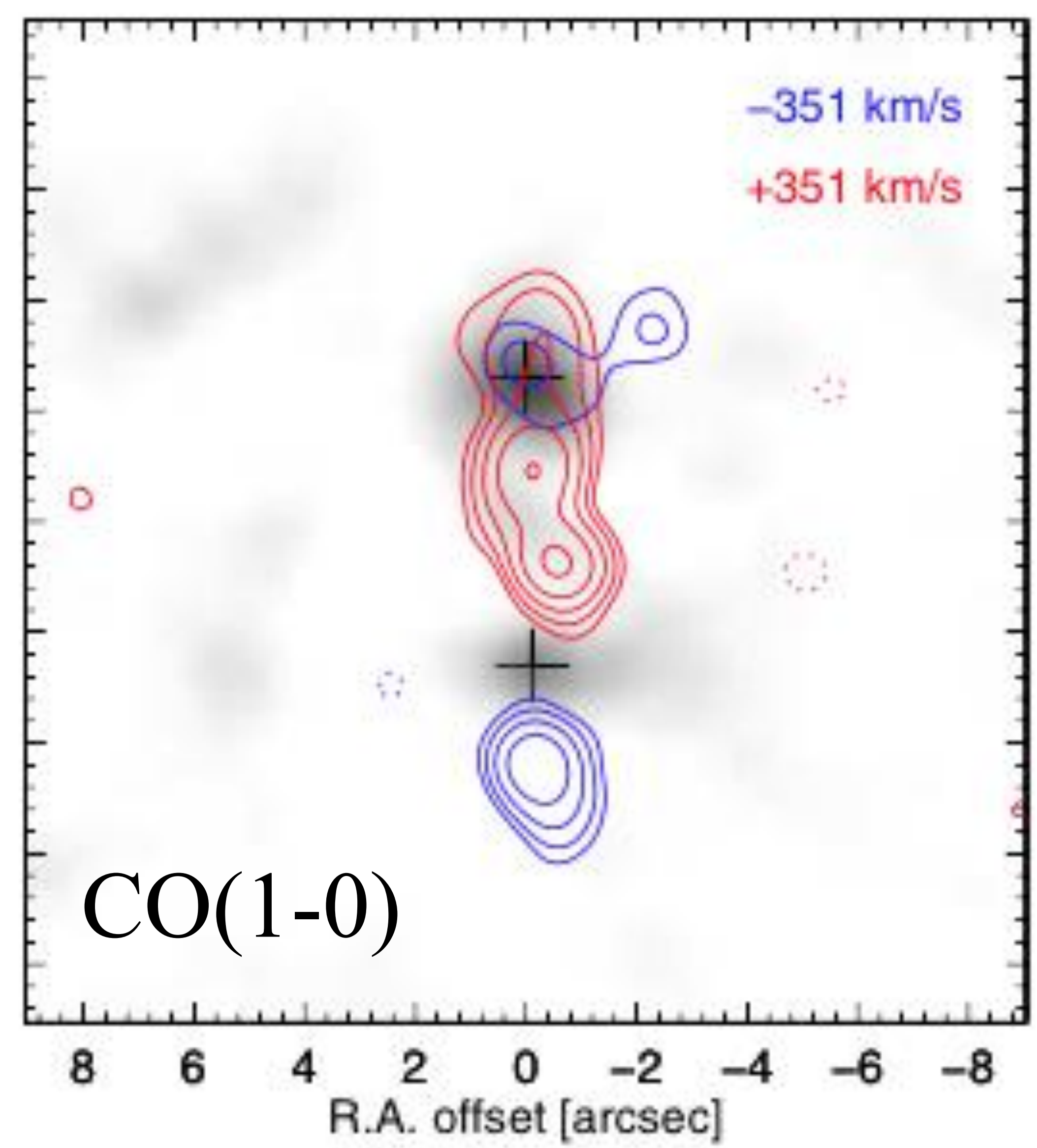
(Emonts+14)

3. Target

NGC 3256

CO outflow have already detected in ALMA cycle0 (Sakamoto+14)

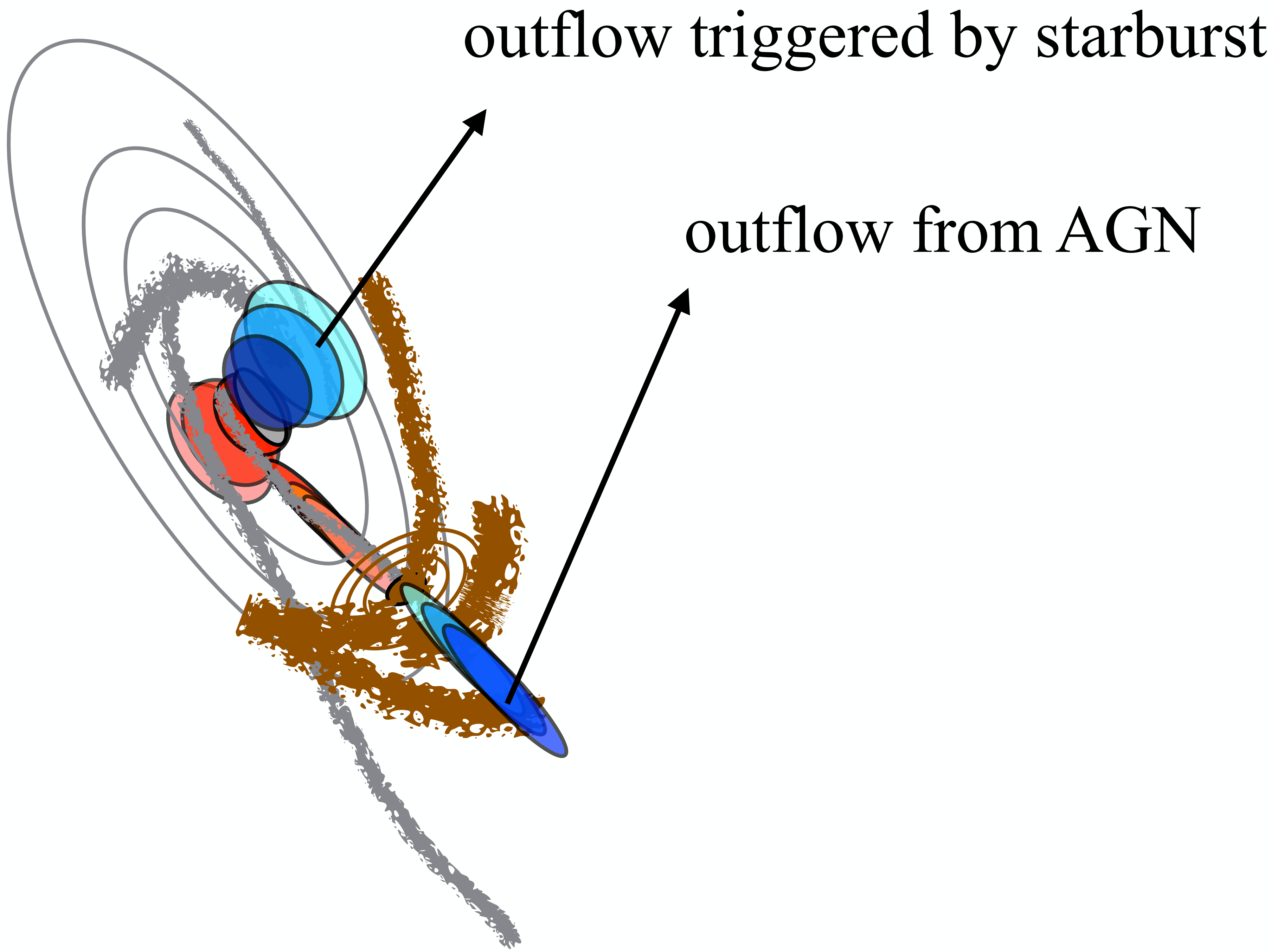




3. Target

NGC 3256

CO outflows have already detected in ALMA cycle3 (Sakamoto+14)



4. Observation

ALMA

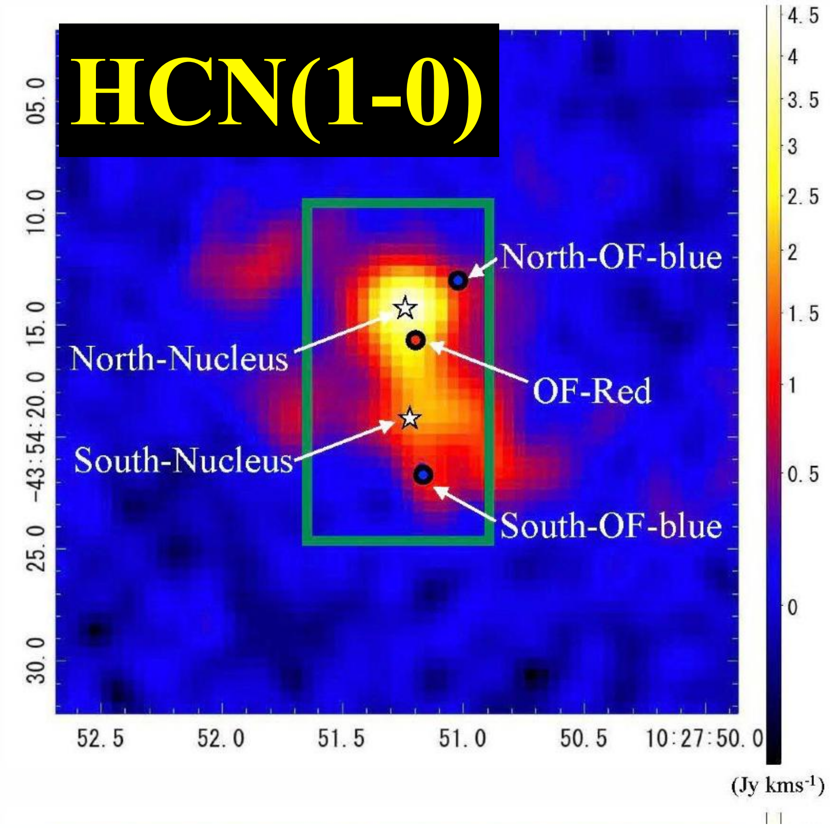
HCN(1-0), HCO^+(1-0) → dense gas tracer (~ 10^5 cm^{-3})
→ ALMA **Cycle3** line survey (Michiyama et al., ID=2015.1.00993.S)
r.m.s = 0.2 mJy → **two hours**

CO(2-1)
→ ALMA **Cycle3** (Sliwa et al., ID=2015.1.00714.S)
r.m.s = 0.3 mJy

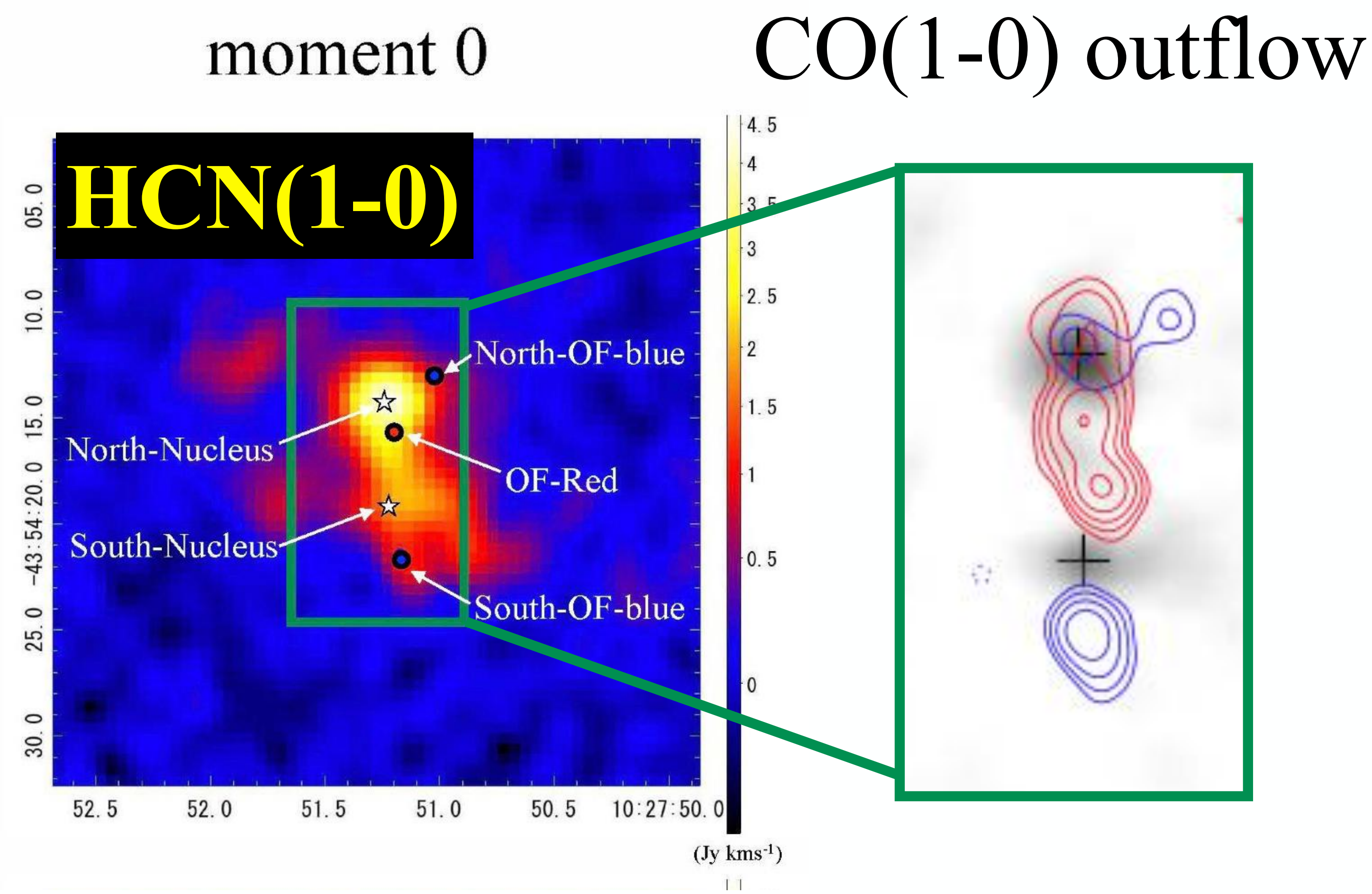
CO(1-0), CO(3-2)
→ ALMA cycle0 (Sakamoto et al., 2014, ID=2011.0.00525.S)
r.m.s = 1 mJy for CO(1-0), 3 mJy for CO(3-2)

5. Results

moment 0

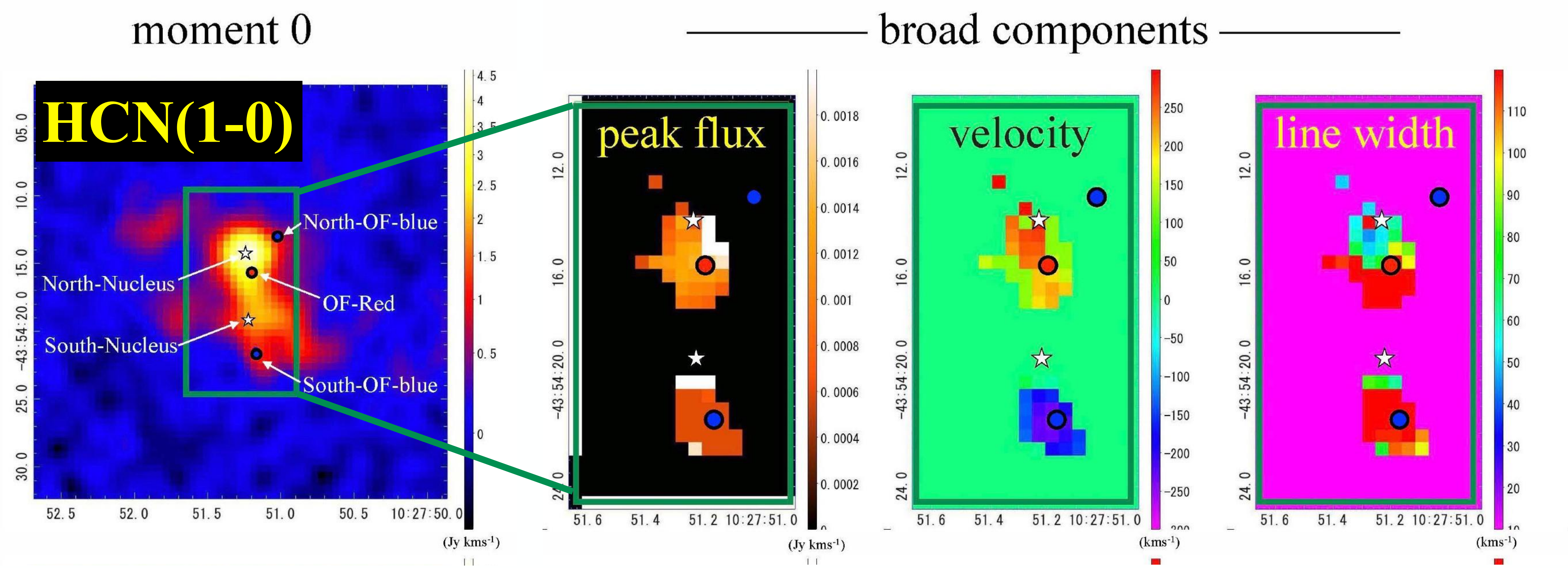


5. Results



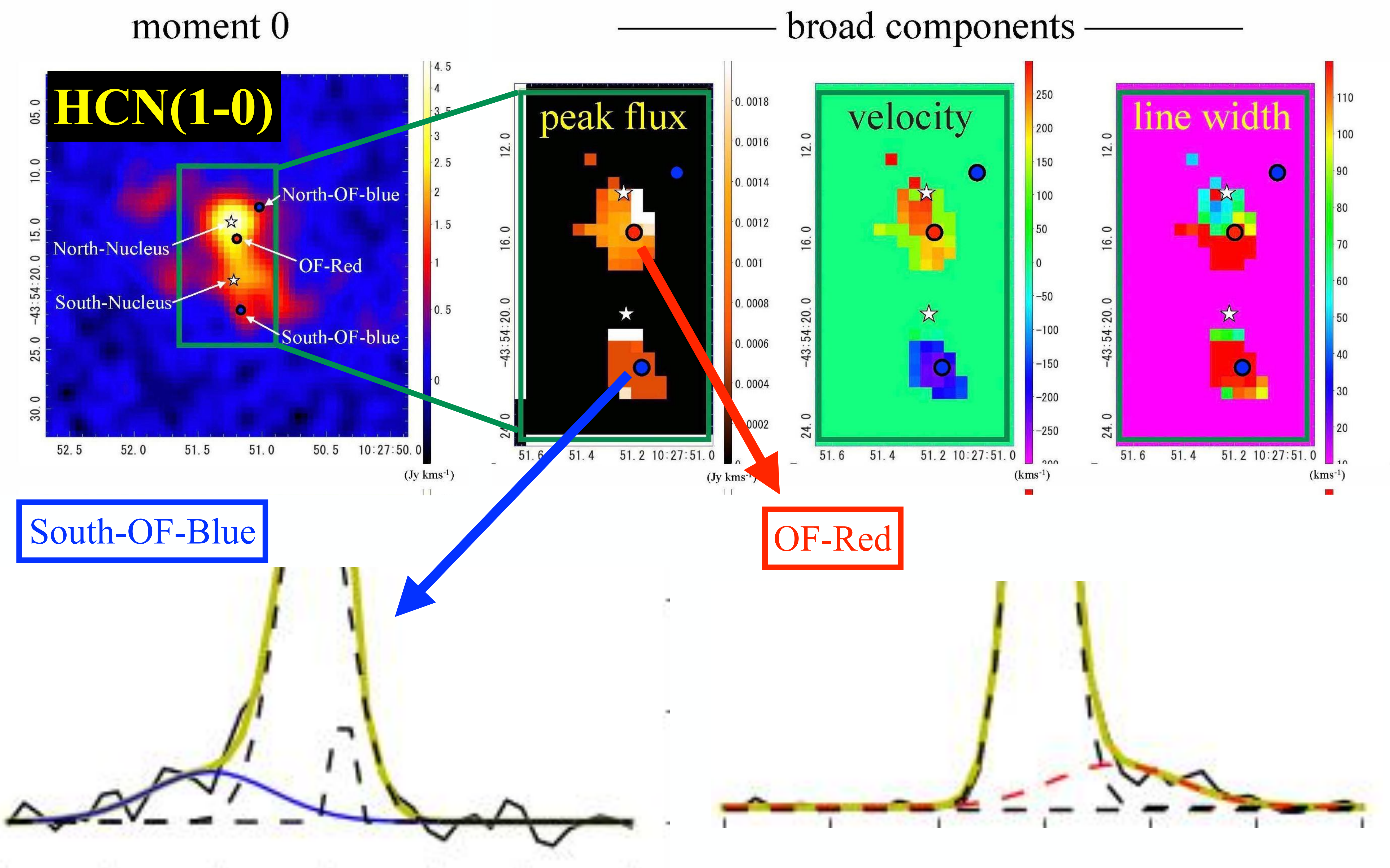
moment 0
CO(1-0) outflow
HCN(1-0)
North-OF-blue
North-Nucleus
OF-Red
South-Nucleus
South-OF-blue
05.0
10.0
15.0
-43:54:20.0
25.0
30.0
52.5
52.0
51.5
51.0
50.5
10:27:50.0
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
(Jy kms-1)

5. Results



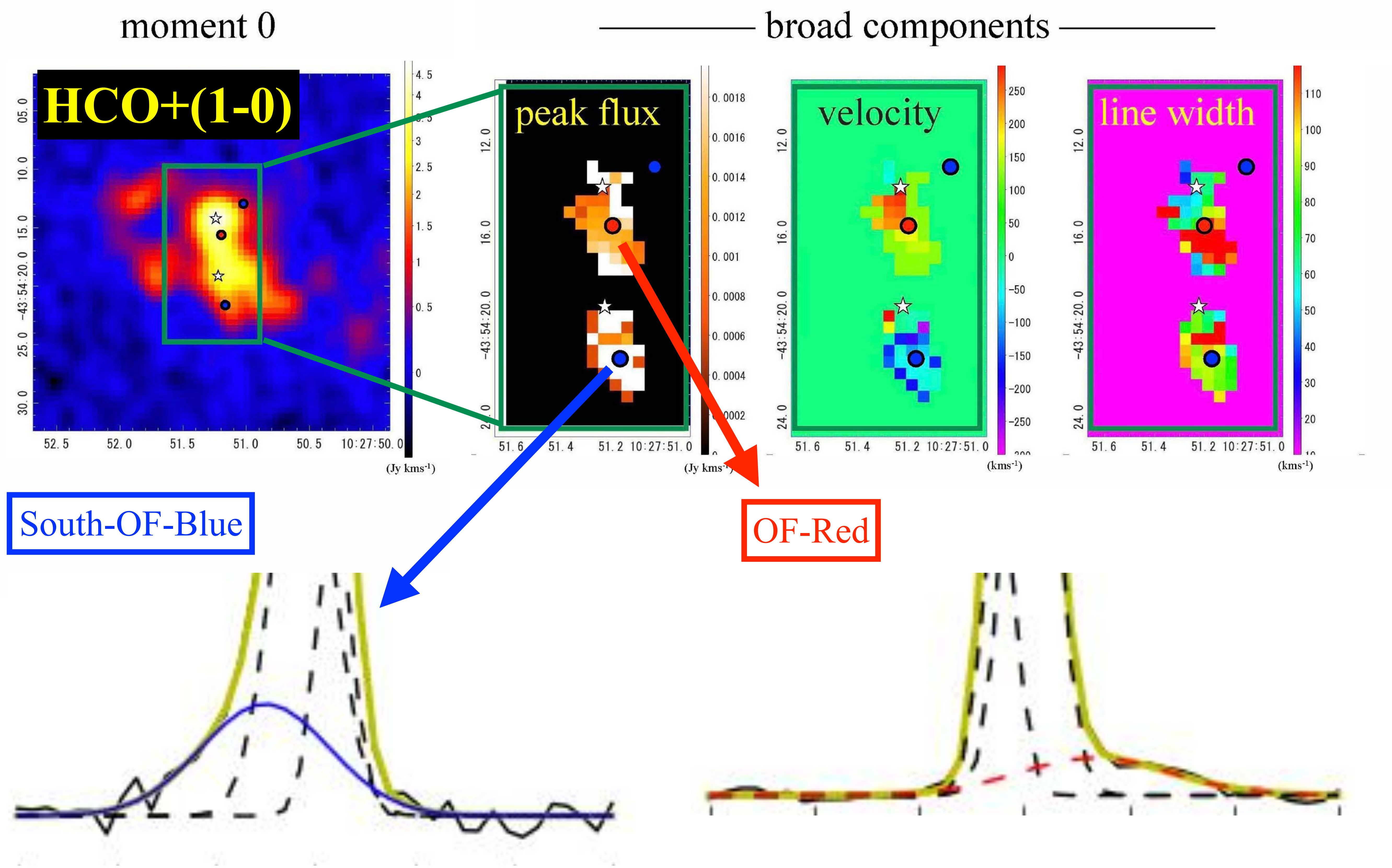
!!!!!!! Detection of Dense Gas Outflow !!!!!!!

5. Results



moment 0
broad components
HCN(1-0)
North-OF-blue
North-Nucleus
OF-Red
South-Nucleus
South-OF-blue
peak flux
velocity
line width
South-OF-Blue
OF-Red

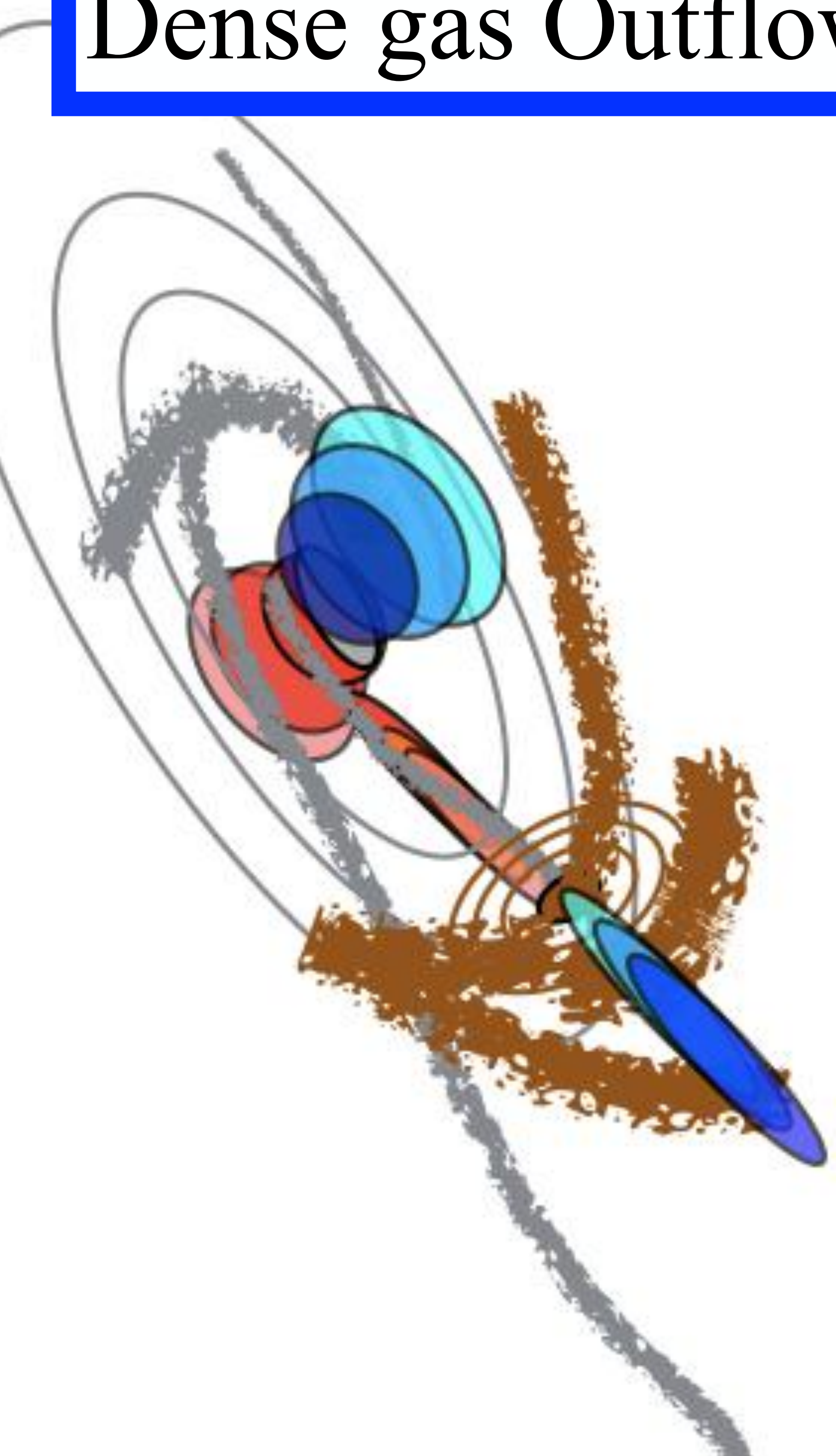
5. Results

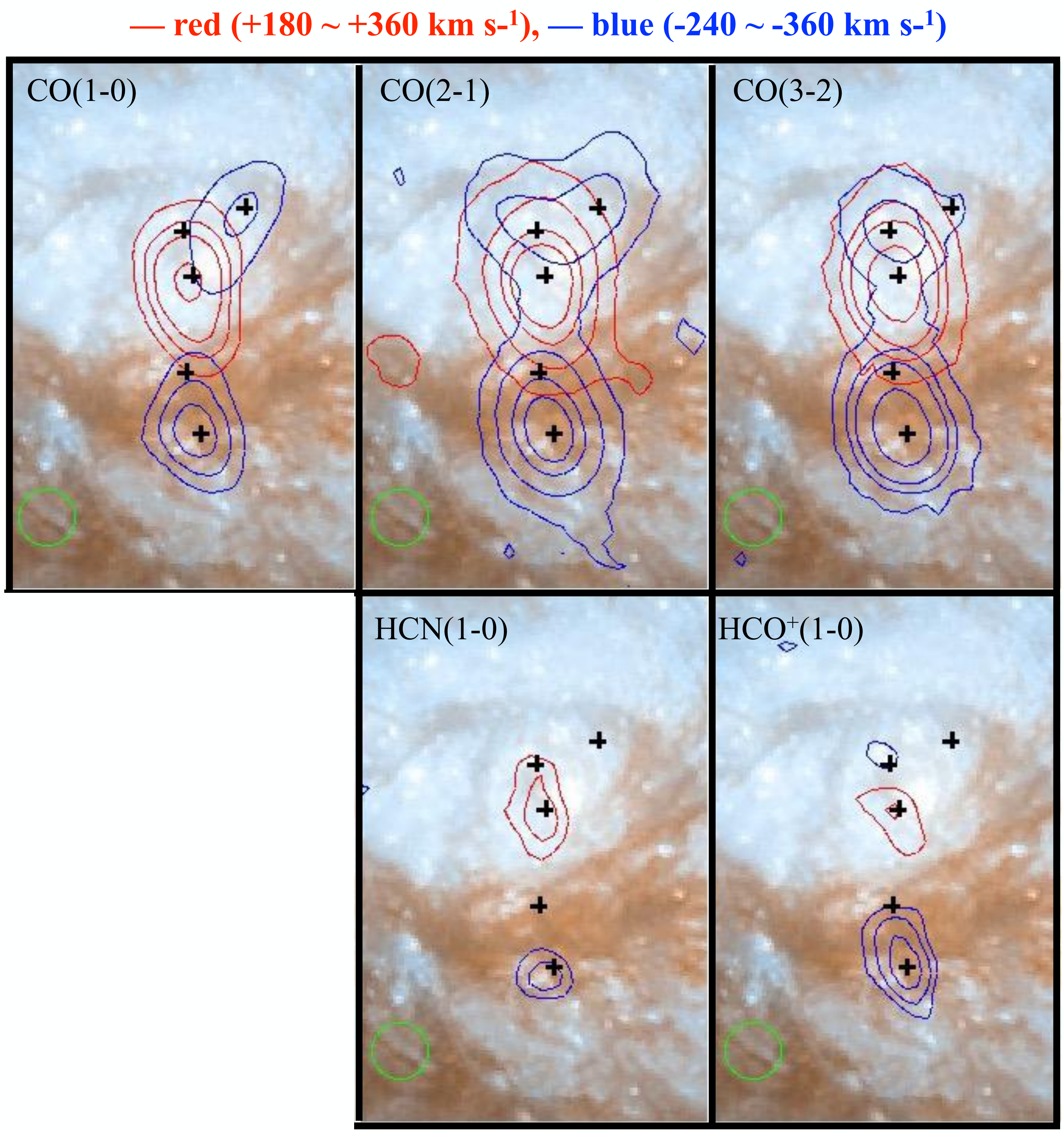


moment 0
broad components
HCO+(1-0)
peak flux
velocity
line width
(Jy kms-1)
(kms-1)
South-OF-Blue
OF-Red

5. Results

Detection of Dense gas Outflow





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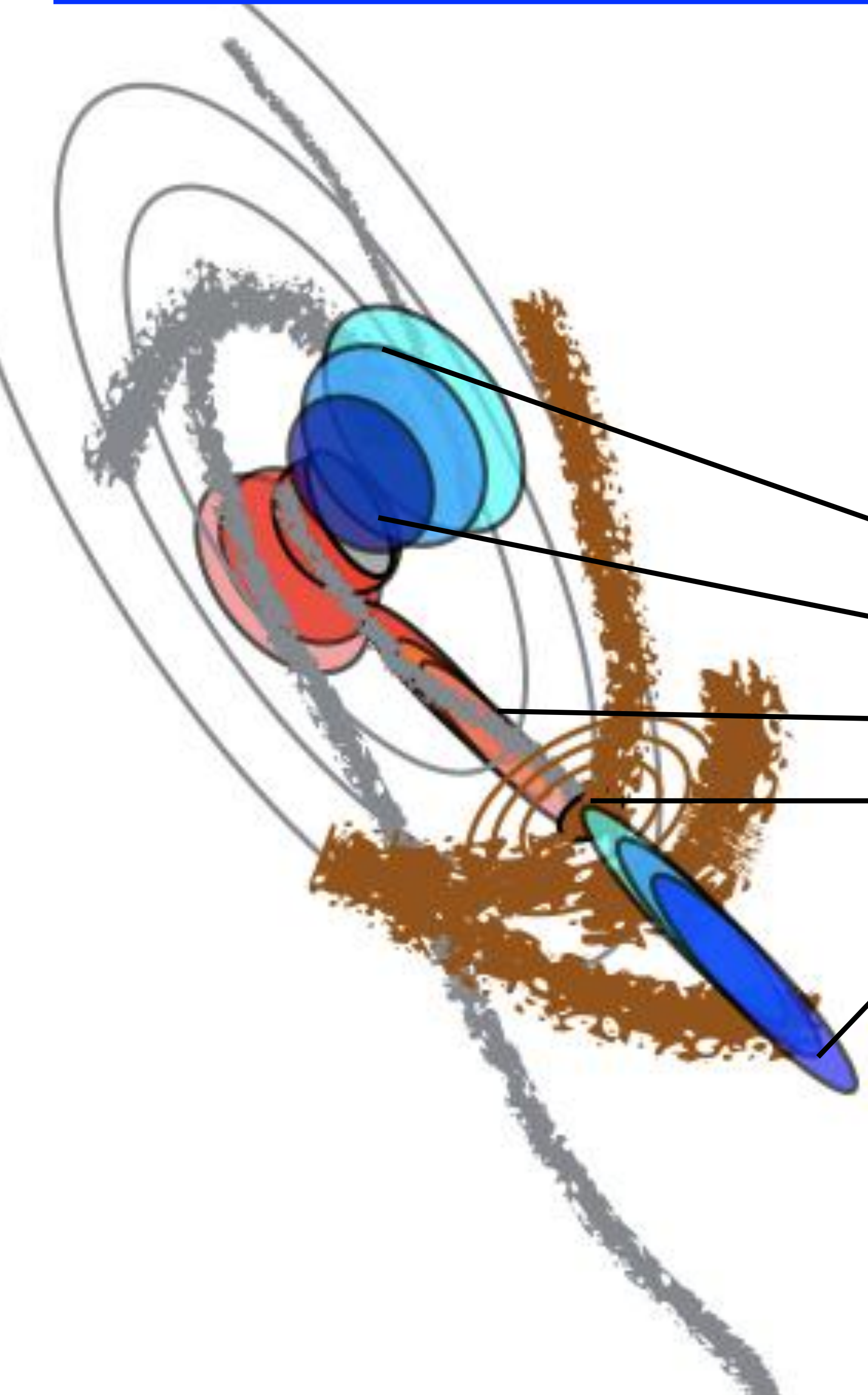
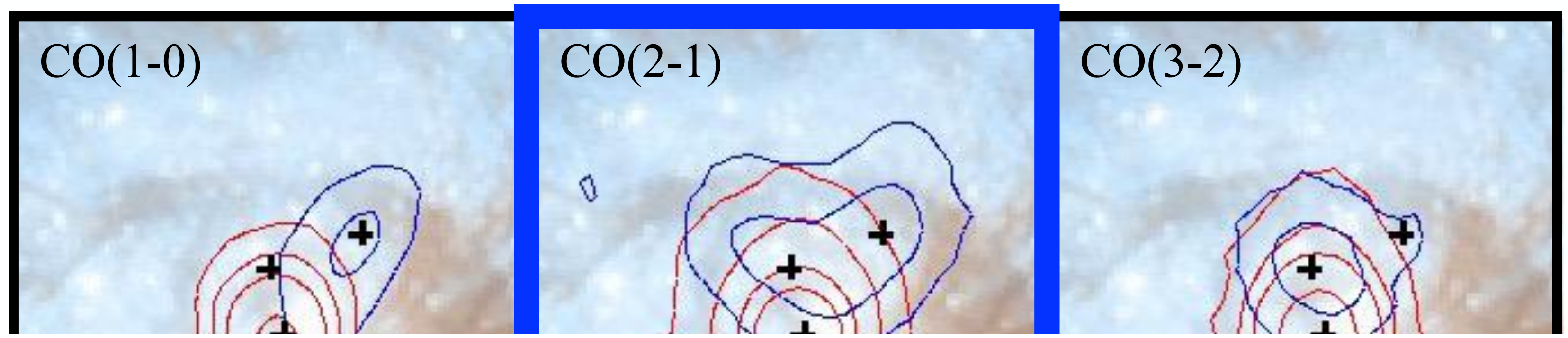
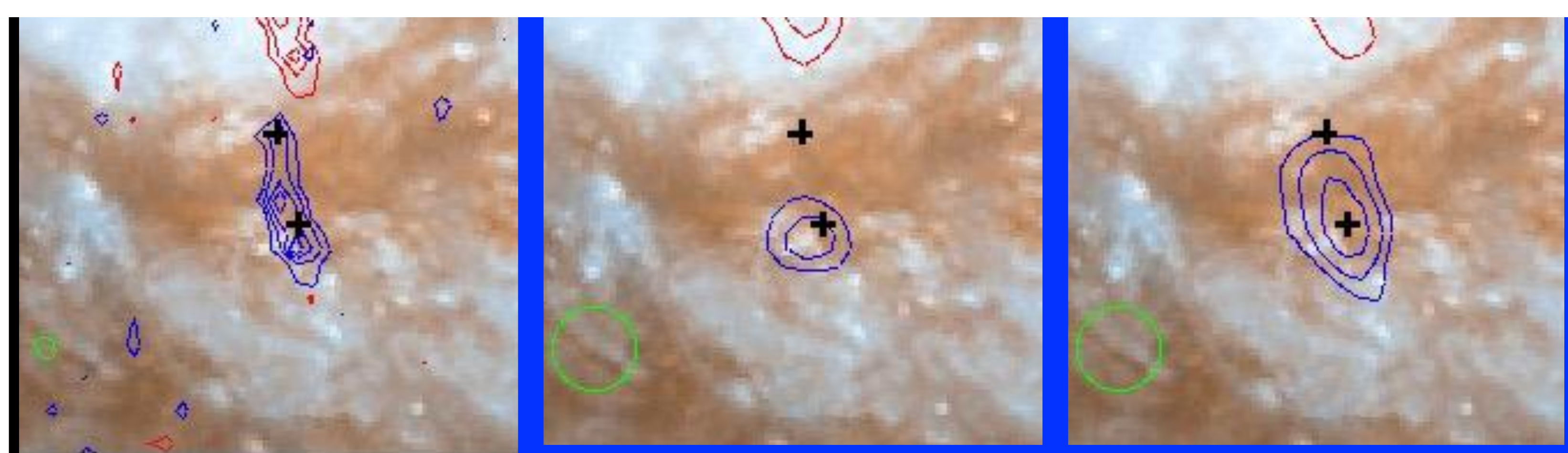
Detection of Dense gas Outflow



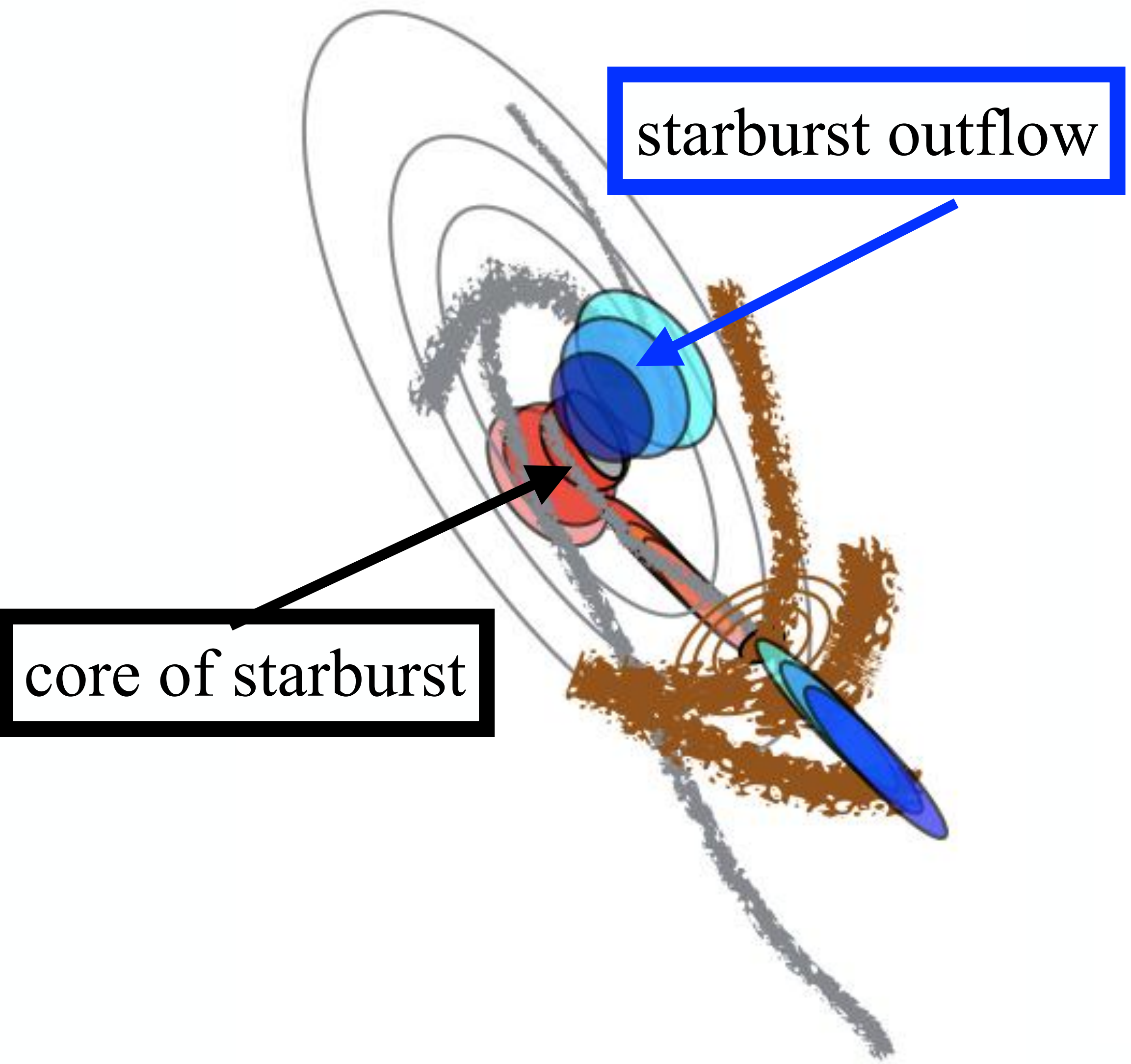
— red (+180 ~ +360 km s-1), — blue (-240 ~ -360 km s-1)

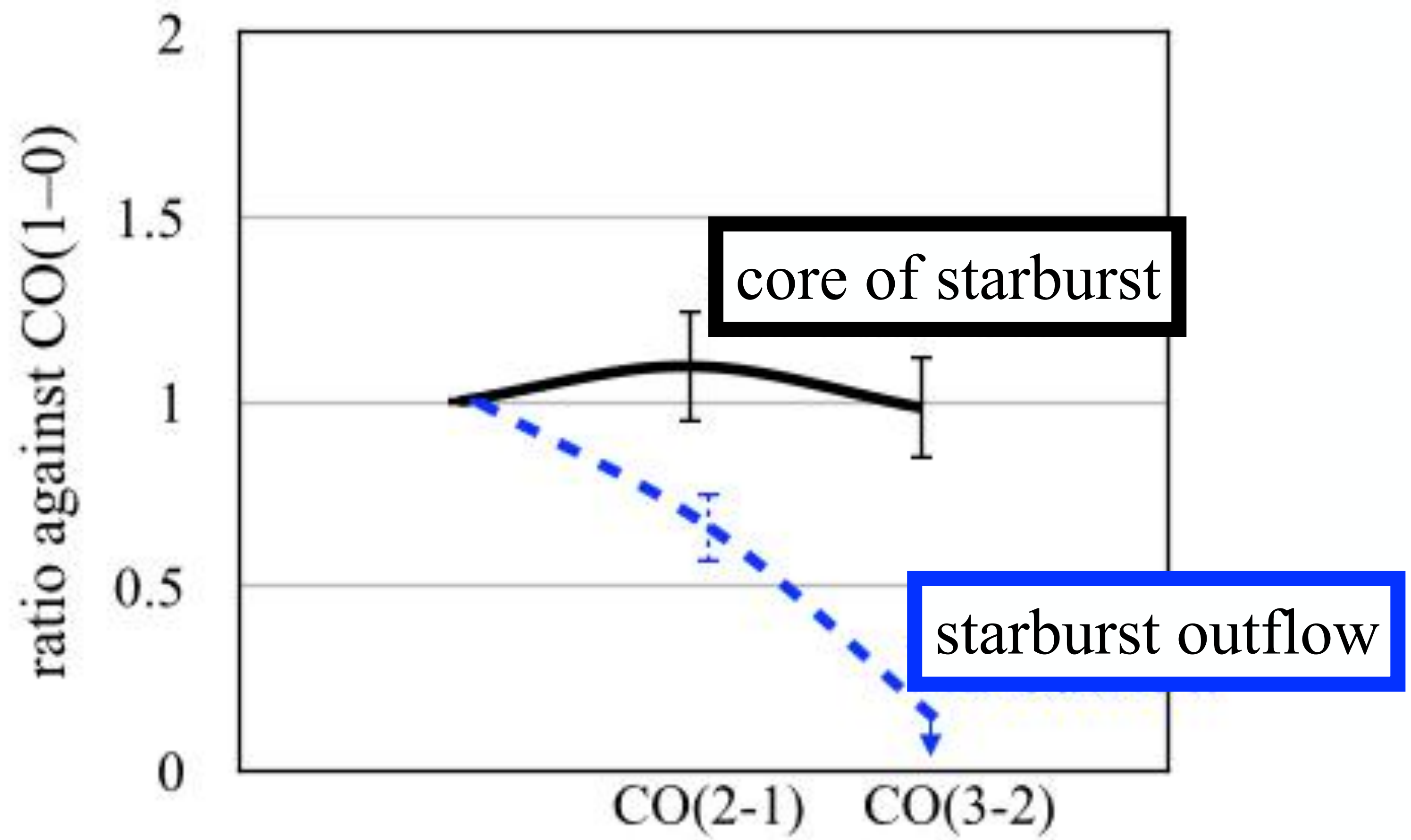


region	integrated velocity km s^{-1}	CO $J = 1$–0	CO $J = 2$–1	CO $J = 3$–2	HCN $J = 1$–0	HCO^+ $J = 1$–0
		Jy $beam^{-1}$ km s^{-1}				
North-OF-Blue	-240~360	0.5 ± 0.1	1.0 ± 0.2	<0.6	<0.06	< 0.06
North-Nucleus	-600~600	36 ± 7	139 ± 28	280 ± 56	2.56 ± 0.51	2.75 ± 0.55
OF-Red	+180~+360	1.5 ± 0.3	5.3 ± 1.1	9.5 ± 1.9	0.08 ± 0.02	0.08 ± 0.02
South-Nucleus	-600~600	39 ± 8	142 ± 28	254 ± 51	1.12 ± 0.22	1.89 ± 0.38
South-OF-Blue	-240~360	0.8 ± 0.2	4.1 ± 0.8	9.9 ± 2.0	0.07 ± 0.01	0.10 ± 0.02



8. Discussion
- Northern outflow (by starburst) -

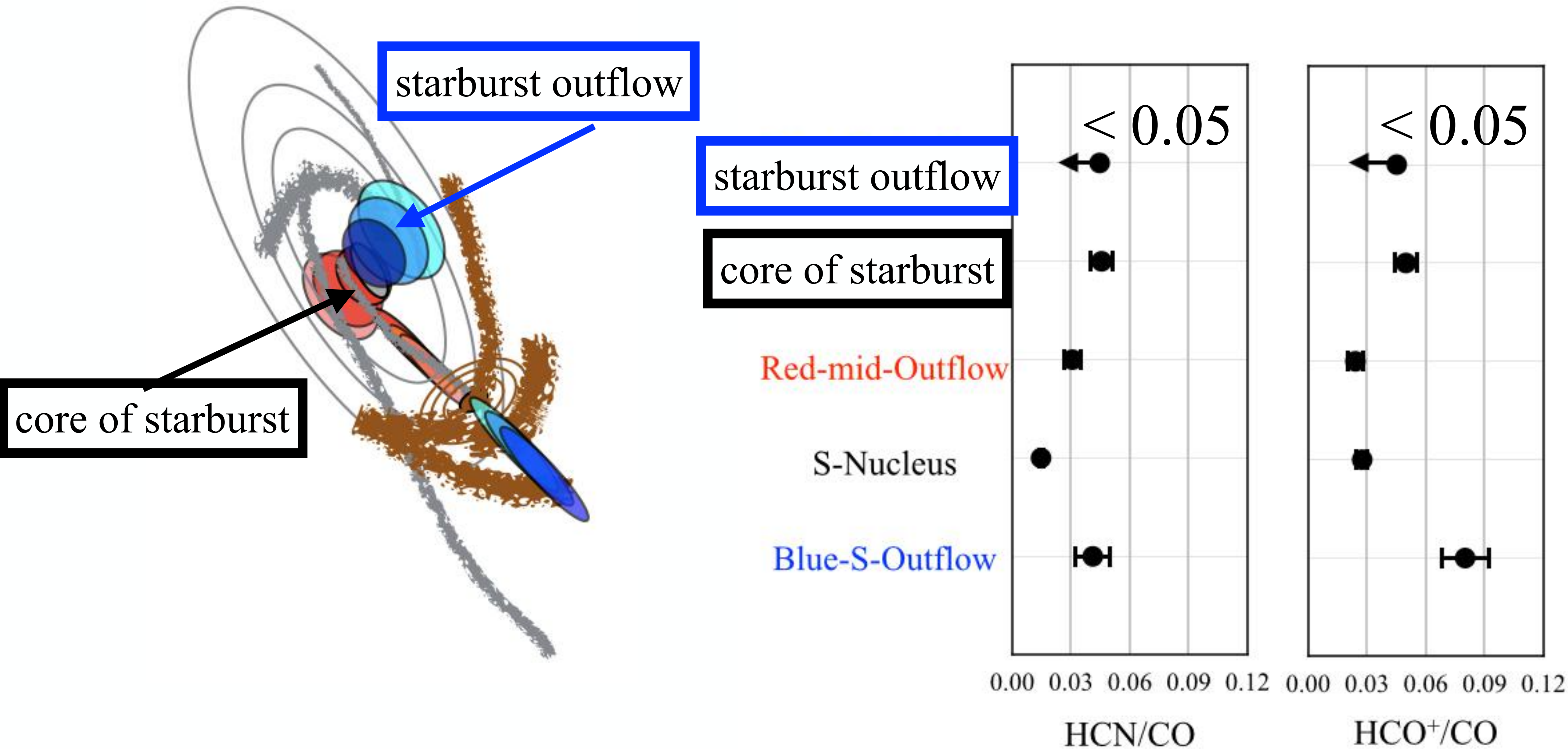




1. Outflow shows lower CO SLED than nucleus.
   → lower excitation condition (since τ_{CO}>>1 even at nucleus)
   → similar with starburst driven outflow in M82 (Weiss+05)

8. Discussion

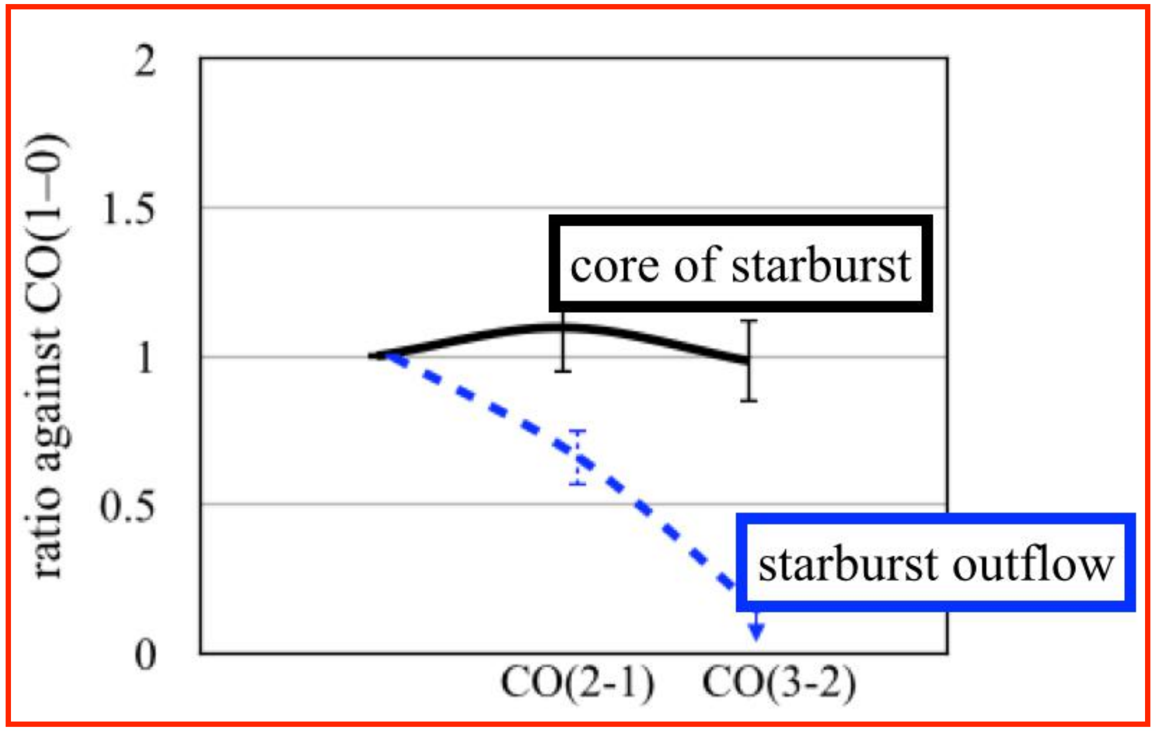
- Northern outflow (by starburst) -

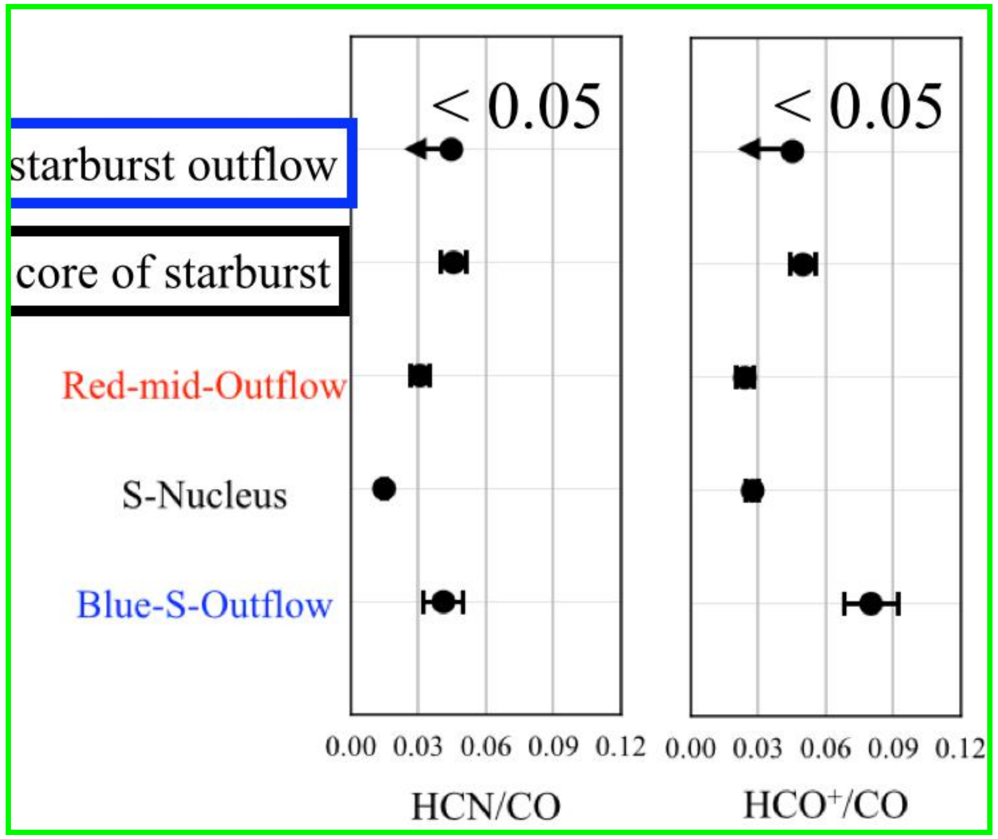


2. Dense gas outflow is not detected
   similar/smaller dense gas fraction (e.g., HCN/CO) in outflow
   → similar with starburst driven outflow in NGC 253 (Walter+17)

8. Discussion

- Northern outflow (by starburst) -



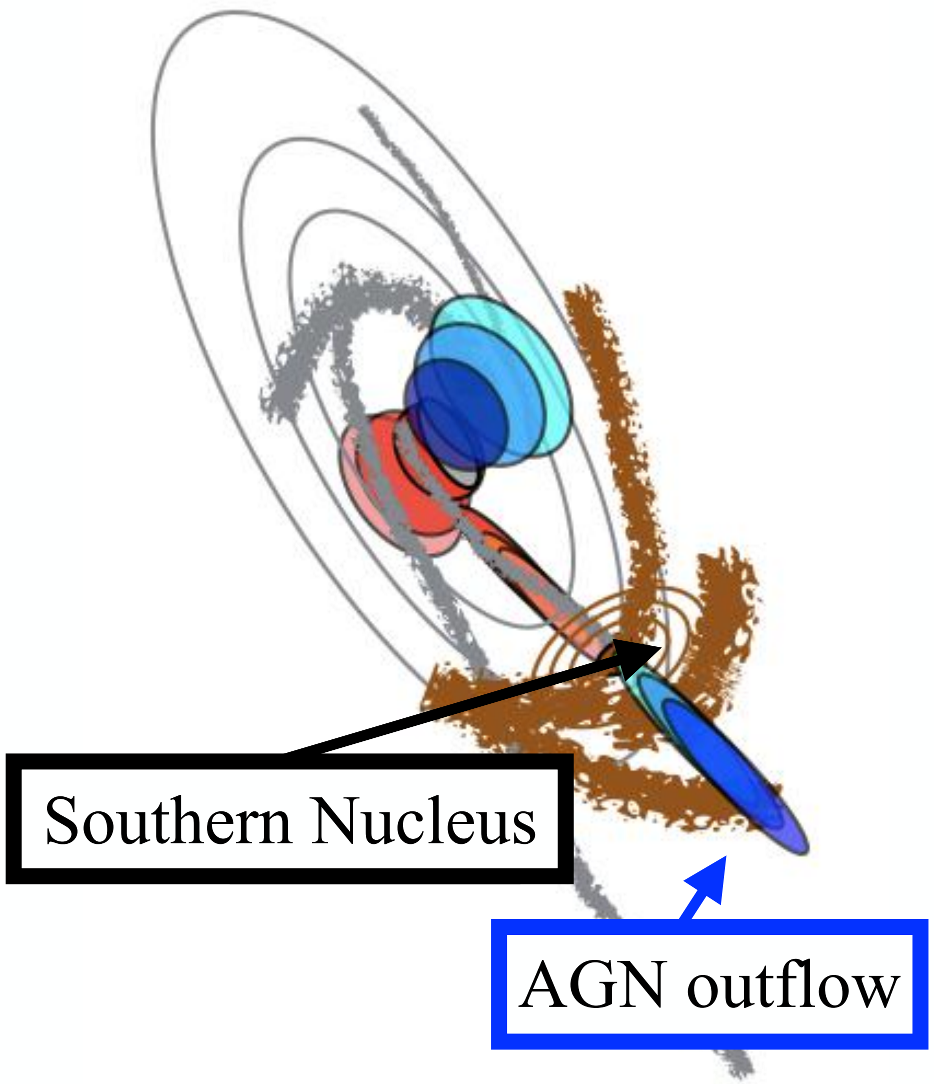


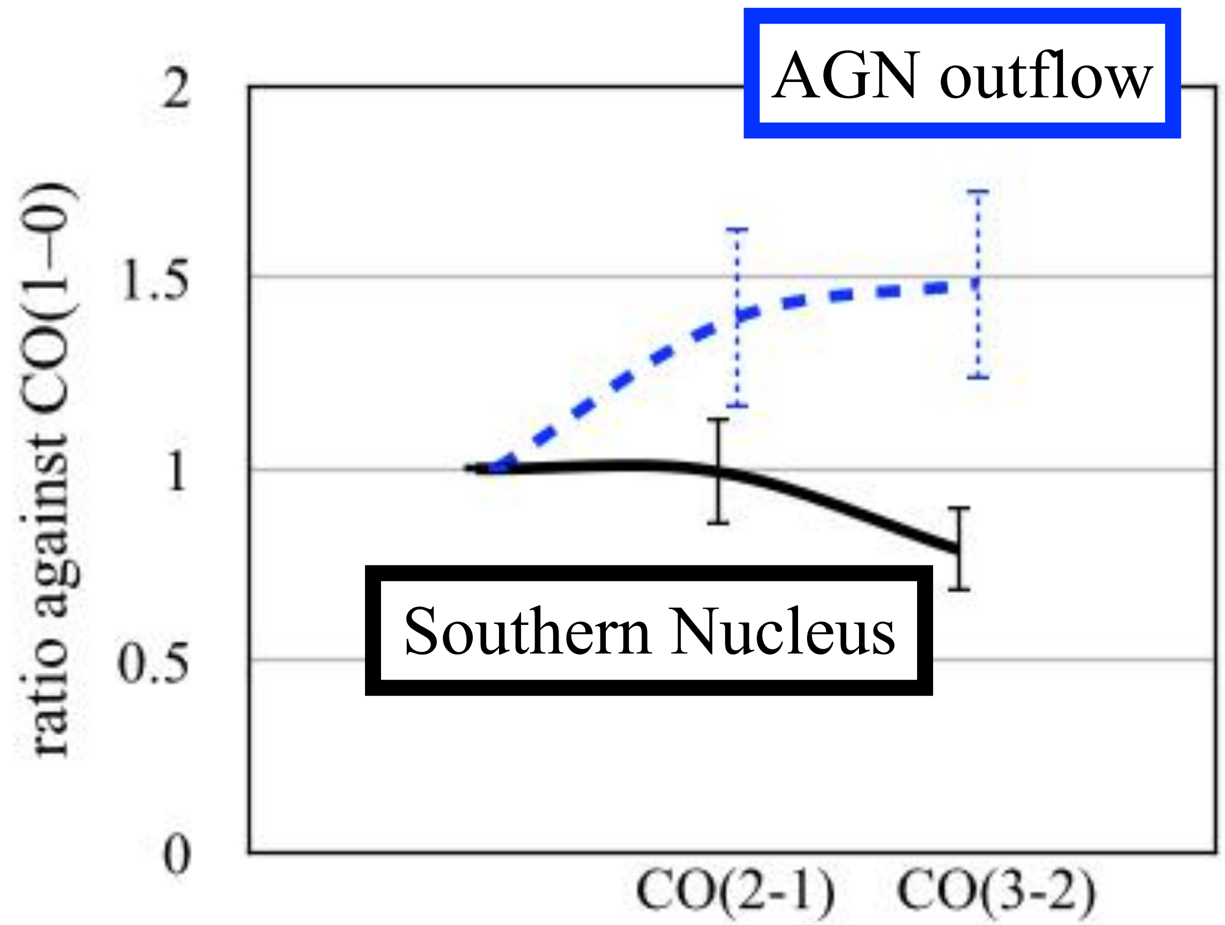
low excitation condition, small dense gas fraction

→ Molecular Outflow is directly expelled from nucleus (negative feedback)

1. expelled from nucleus → expand → low dens. and temp..
2. the diffuse gas is selectively expelled from the core.

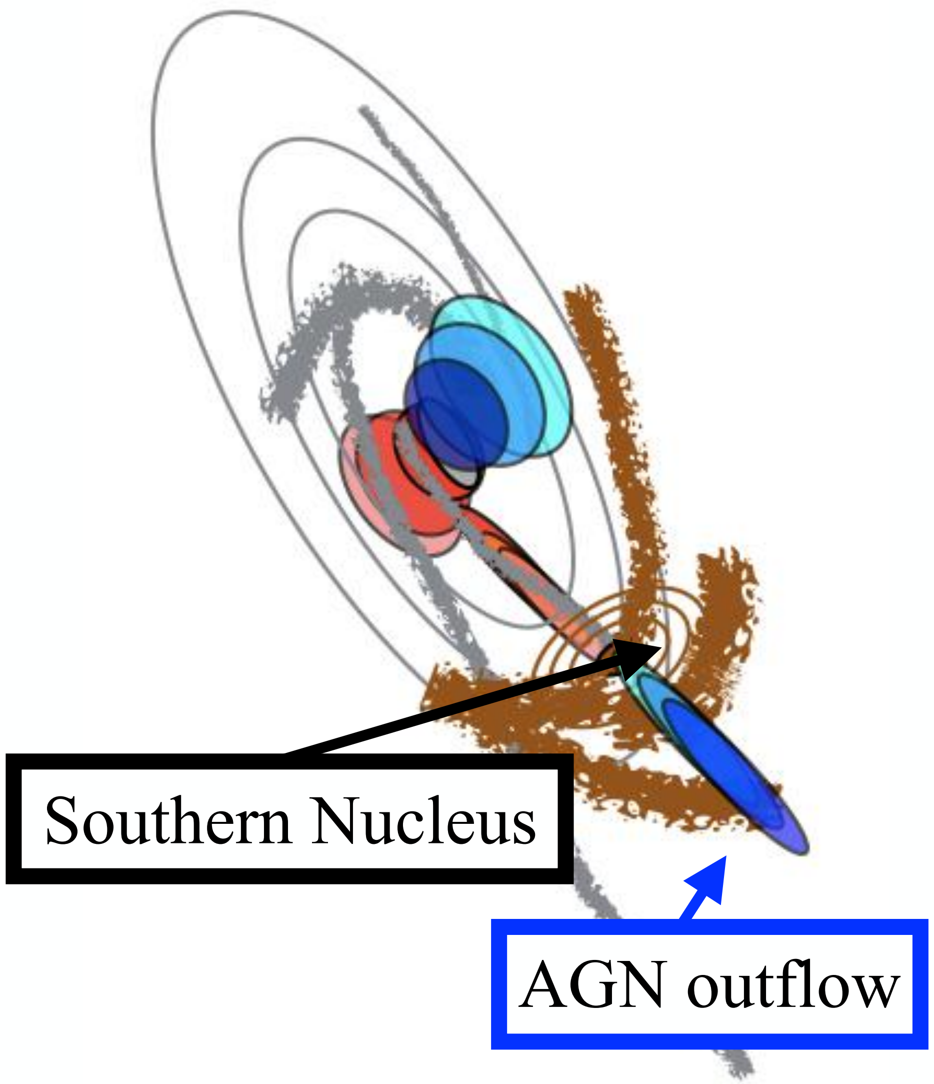
8. Discussion
- Southern outflow (by AGN)-

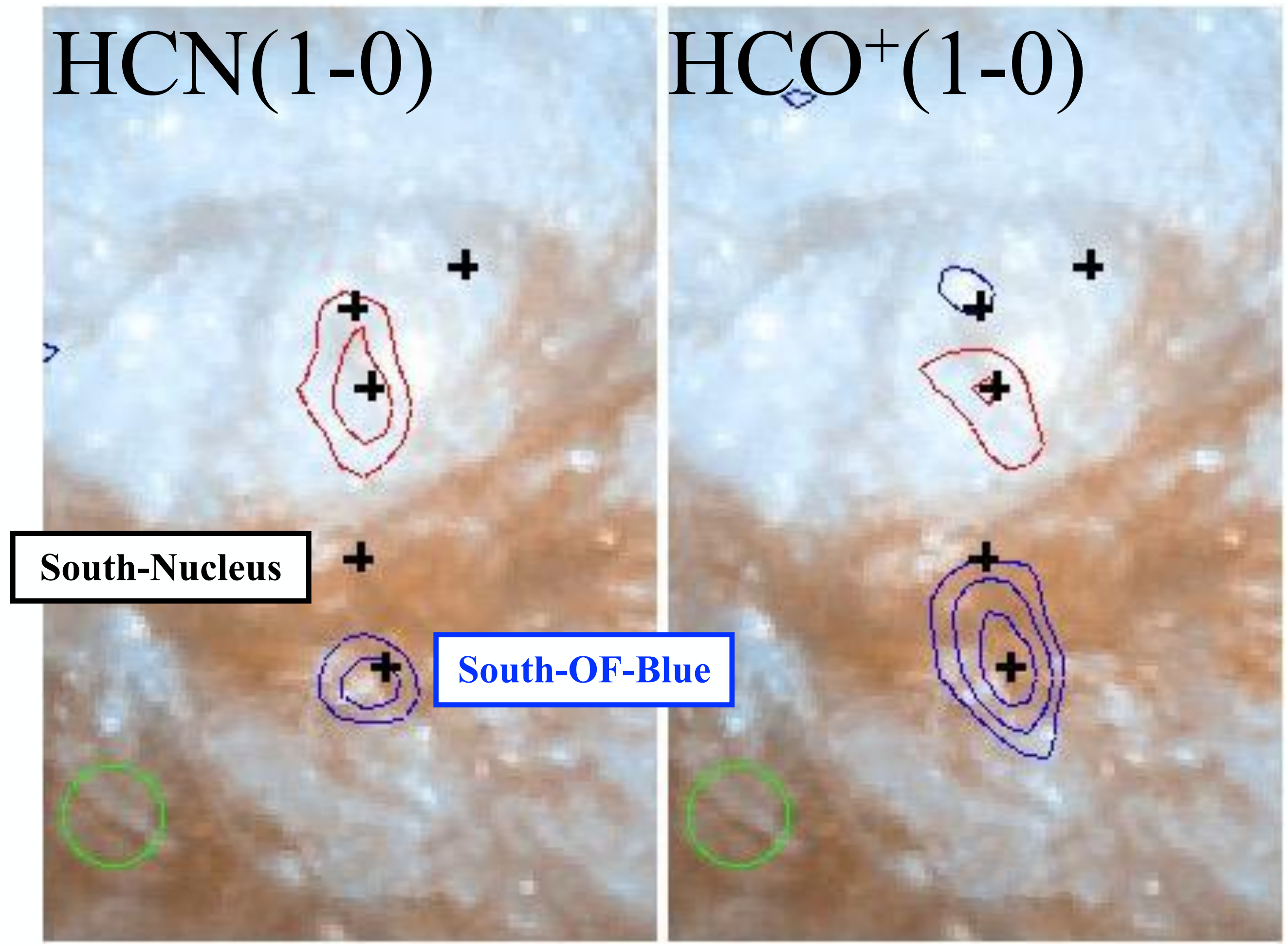




1. Outflow shows higher CO-SLED than nucleus
   → Highly excited and/or optically thin outflow

8. Discussion
- Southern outflow (by AGN)-

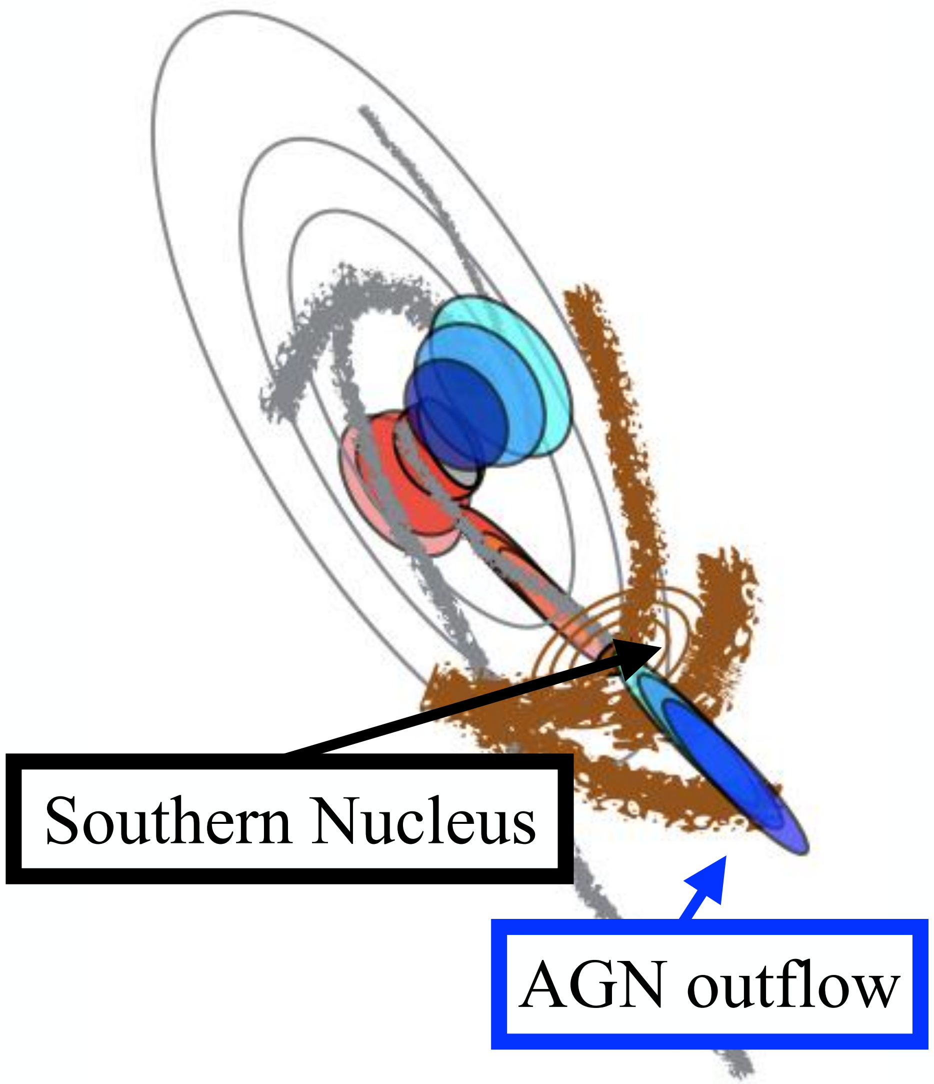


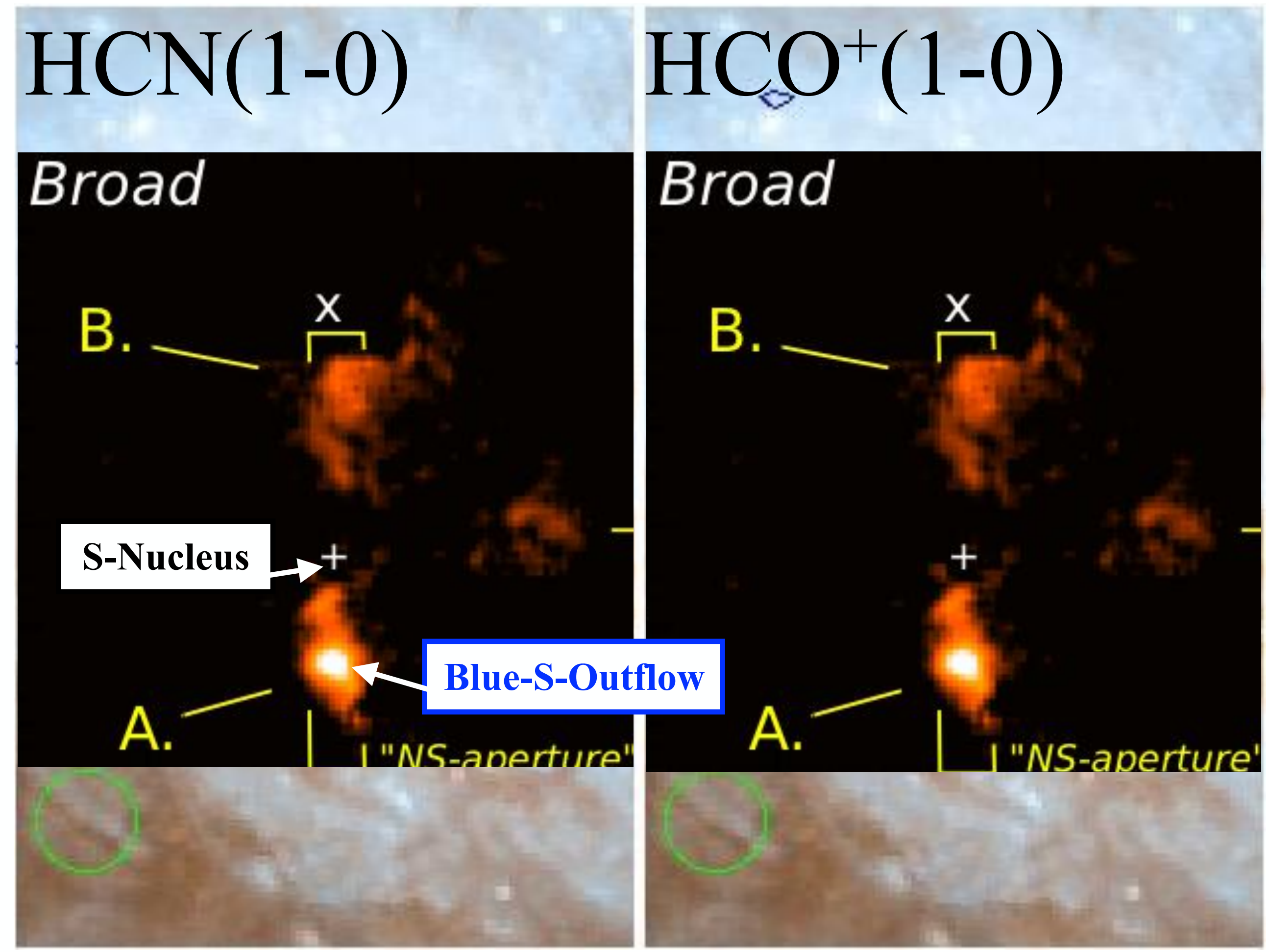


2. Dense gas outflow is detected
→ HCN and HCO+ outflow is mainly from southern galaxy
(spacial distribution is similar with H_2 outflow)
(no clear counter part of blue-shifted gas in northern galaxy)

8. Discussion

- Southern outflow (by AGN)-





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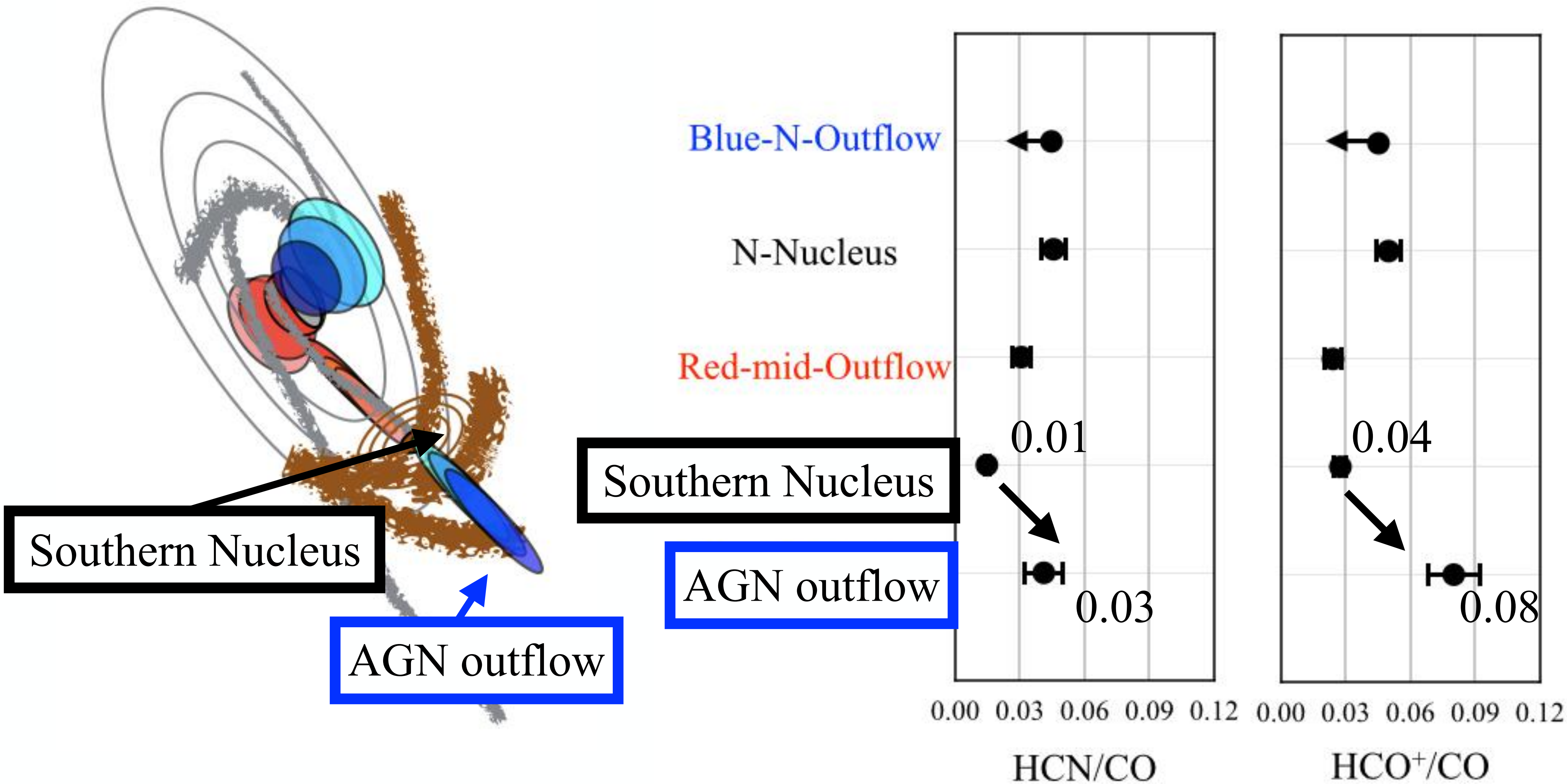
8. Discussion
- Southern outflow (by AGN)-

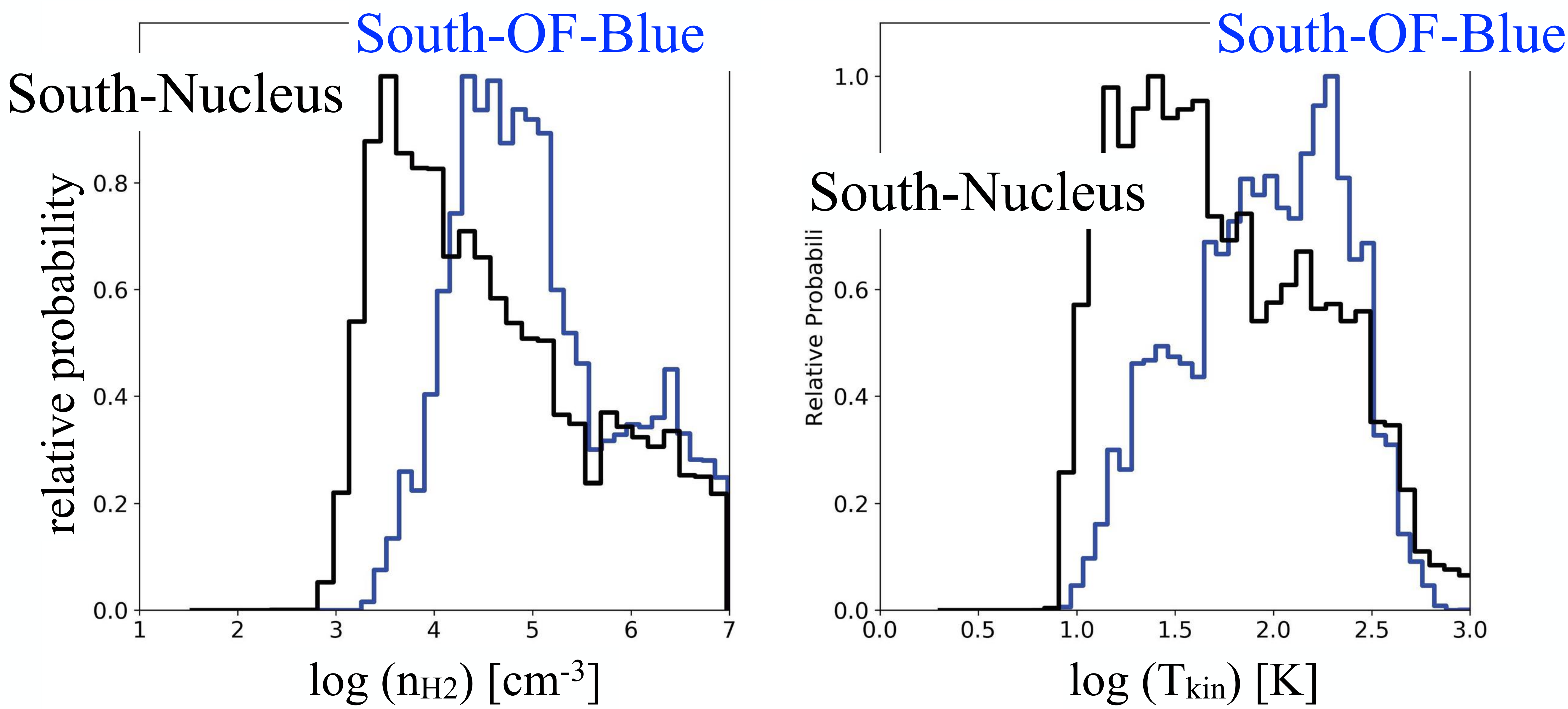


3. Higher dense gas fraction (e.g., HCN/CO) in outflow
   → dense gas is newly formed

8. Discussion

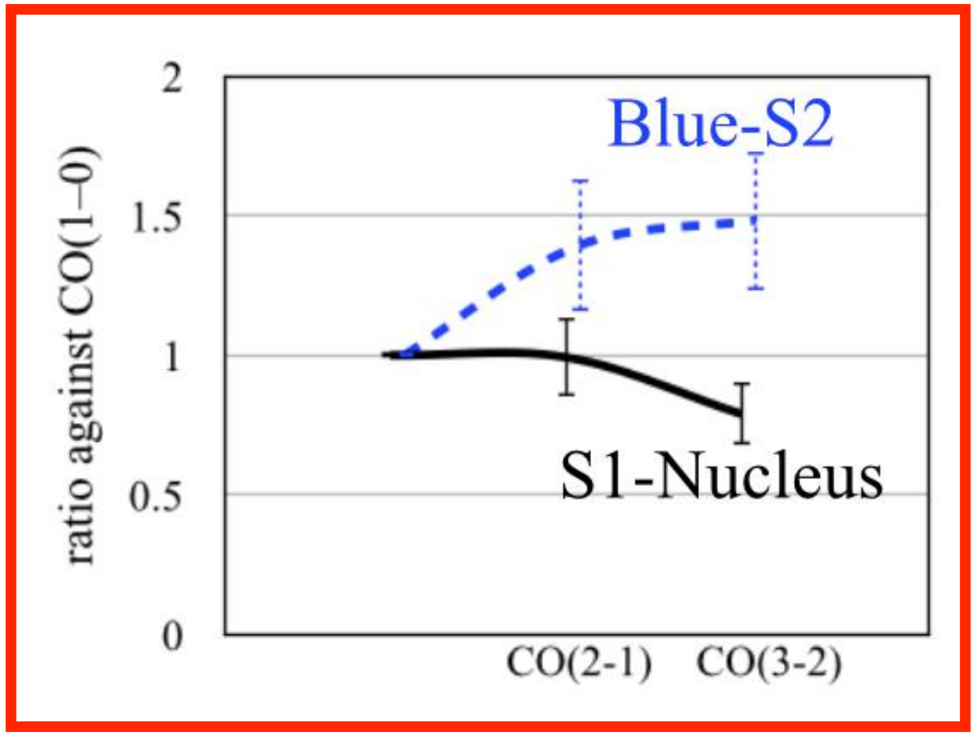
- Southern outflow (by AGN)-

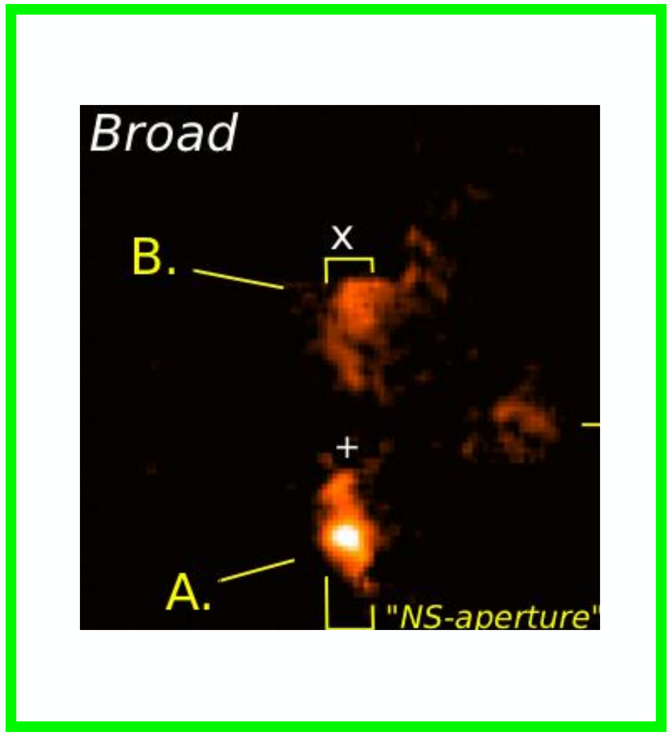
Denser and hotter in outflow than in nucleus

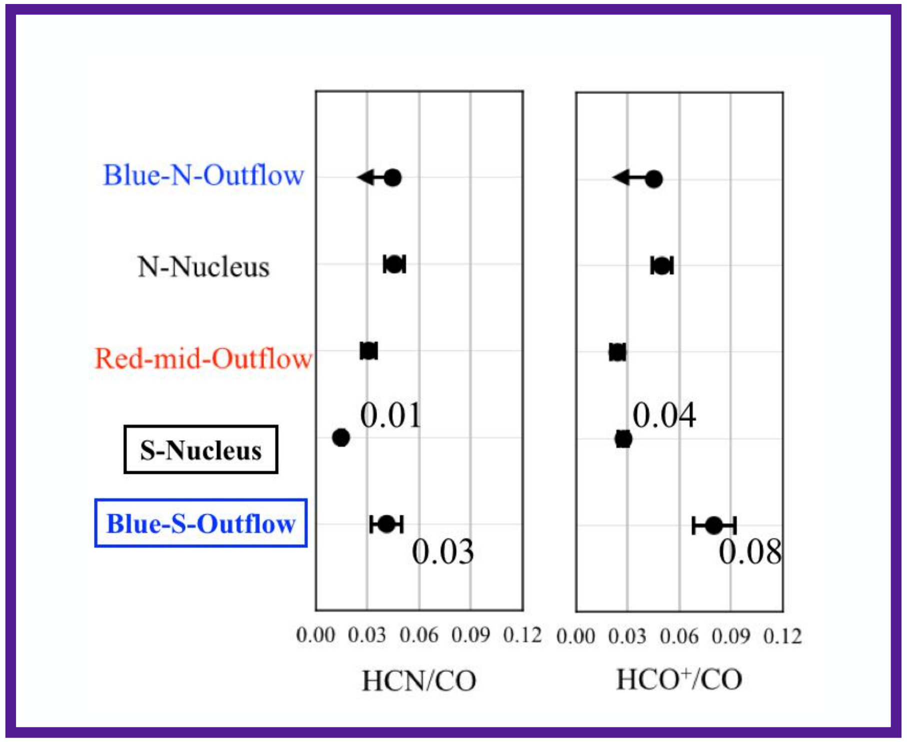


RADEX modeling & Bayessian estimation
(van der Tak et al., 2007, Kamenetzky et al., 2015)

8. Discussion
- Southern outflow (by AGN)-



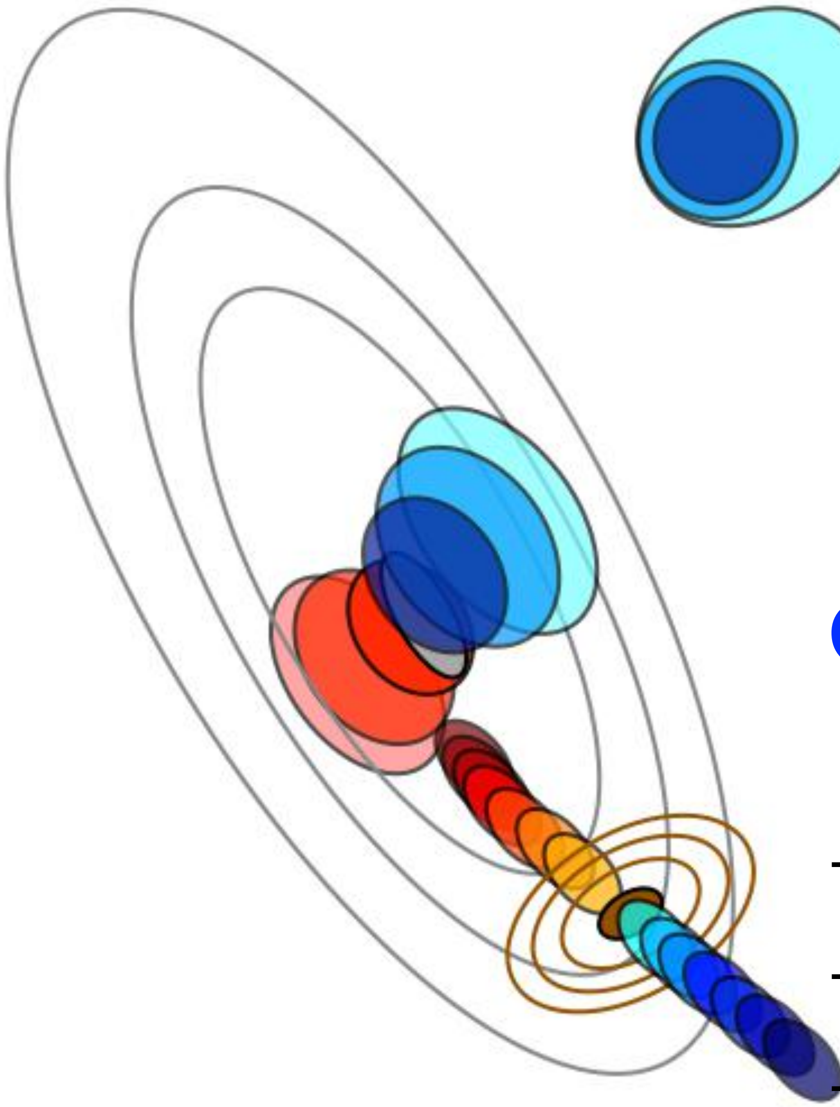




High excitation condition, hot H_2 detection,
high dense gas fraction

jet and ISM interaction → condense gas → star formation
(like IC5063; type 2 AGN elliptical galaxy)(e.g.,Dasyra+16)
(modeled by Wagner et al. 2016)

Summary



Starburst triggered outflow

low CO-SLED, no dense gas

→ low excitation

→ directly expelled from nucleus

→ negative feedback

Outflow associated with AGN jet

increasing CO-SLED (> 1), dense gas outflow

→ high excitation, high dense gas fraction

→ jet and ISM interaction

→ positive feedback?

Michiyama et al., 2017 in prep