

# Circumnuclear gas around the central AGN in a cool-core cluster, A1644-South

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Perseus cool-core cluster (Chandra X-ray)

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# Motivation

- Cluster cooling flow **can deposit** cold molecular gas of 100-1000  $M_{\odot}/\text{yr}$ .  
(Reviewed by Fabian +94, +12)
- While the brightest cluster galaxies (BCGs) are early-type ('red and dead'), **1/3 of BCG** in cool-core clusters contain  $10^8 \sim 10^{10} M_{\odot}$  of cold molecular gas.  
(Single dish observations: Edge +01, Salome & Combes +03)
- c.f. CO detections of **1/5 of early-type galaxies** (w/o cooling flow).  
(ATLAS<sup>3D</sup> project; Cappellari +11, Young +11)

-> What is the origin of cold molecular gas in BCGs?

- ALMA has opened up the gate to **high-resolution detections** of molecular gas in BCGs

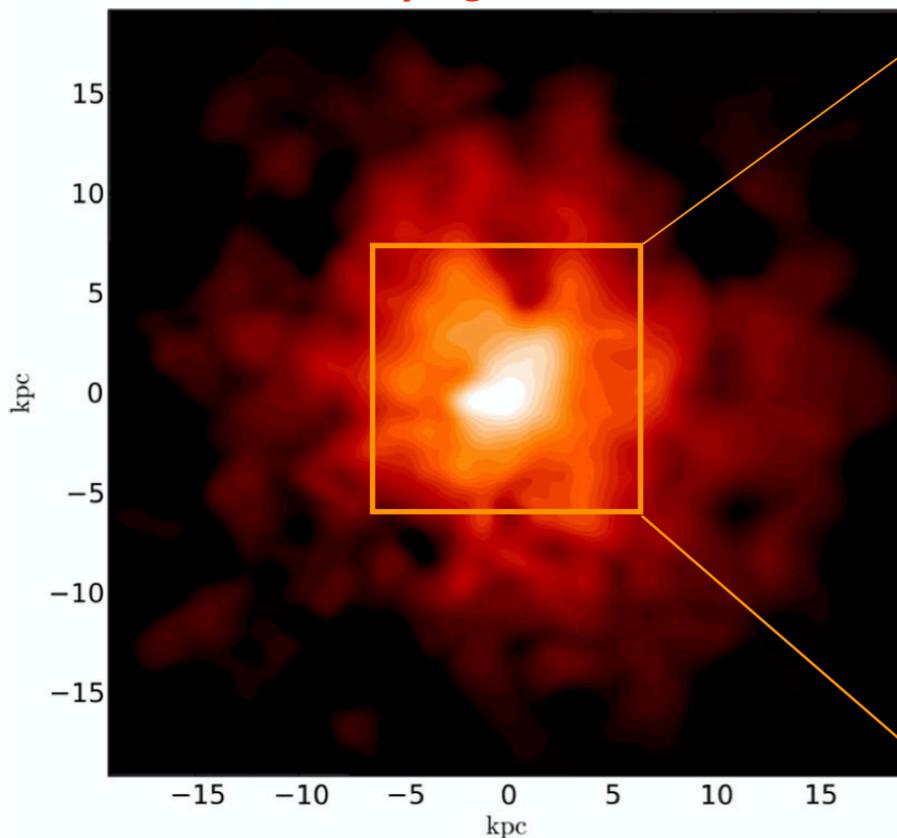
# Motivation

- Simulations expect that “chaotic cold accretion” happens as **a form of filaments.**  
(e.g., Gaspari +13, +17)

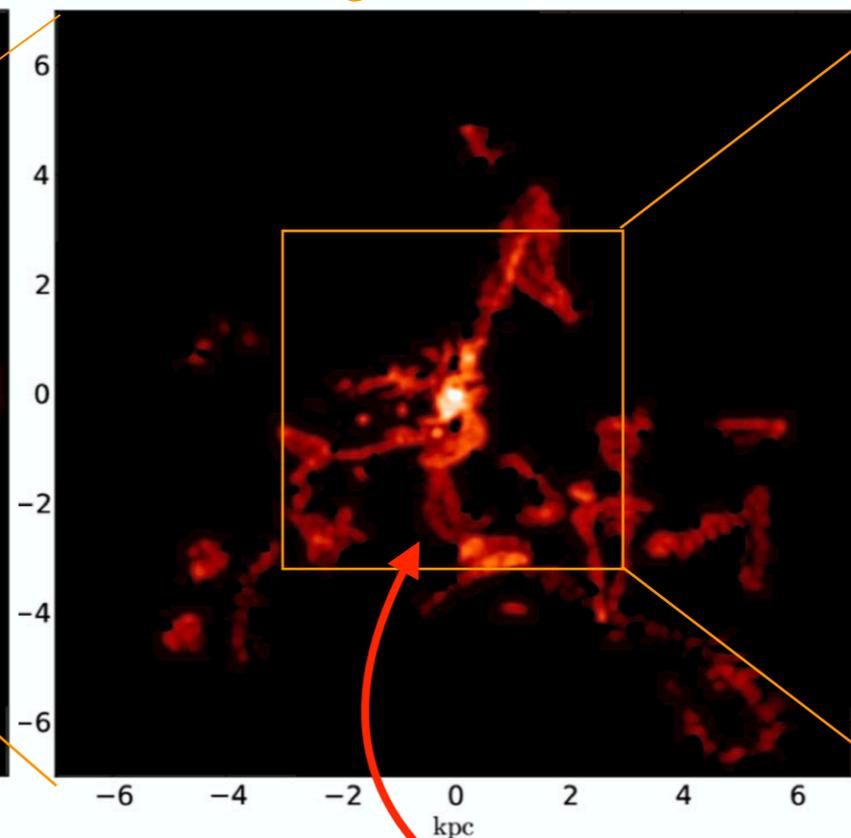
3D high-resolution hydrodynamic simulation with AMR code

- box size:  $52^3$  kpc<sup>3</sup>
- Max. resolution: 0.8 pc
- w. turbulence, gas cooling/heating, AGN heating
- w/o. AGN outburst, galaxy merger

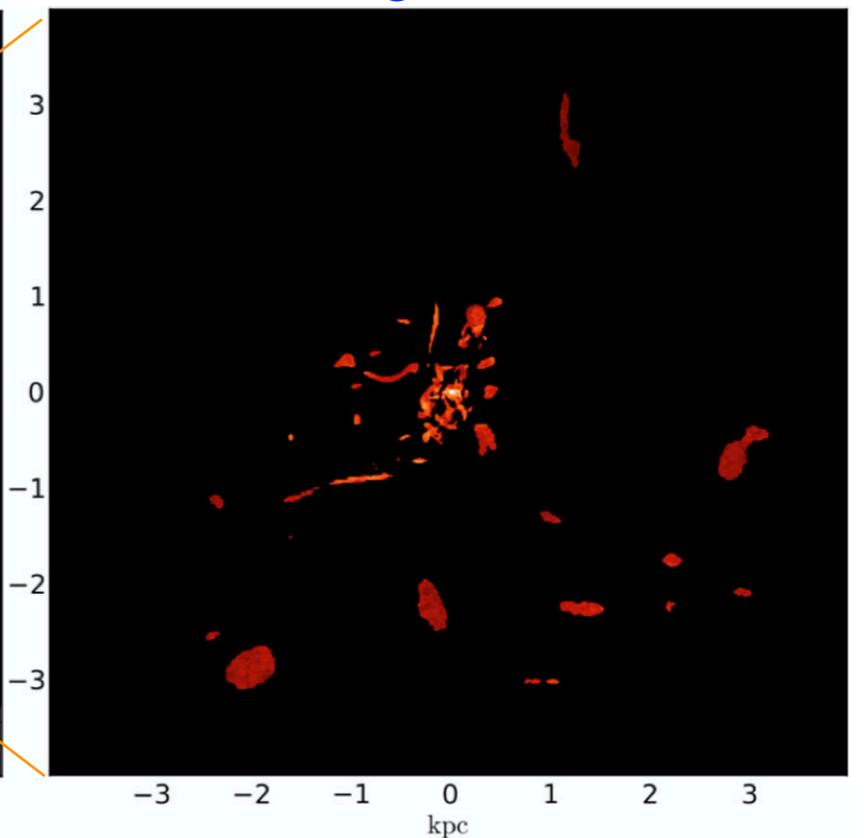
Hot X-ray gas ( $>0.5$  keV)



Neutral gas ( $10^2 \sim 10^4$  K)



Molecular gas ( $10 \sim 10^2$  K)



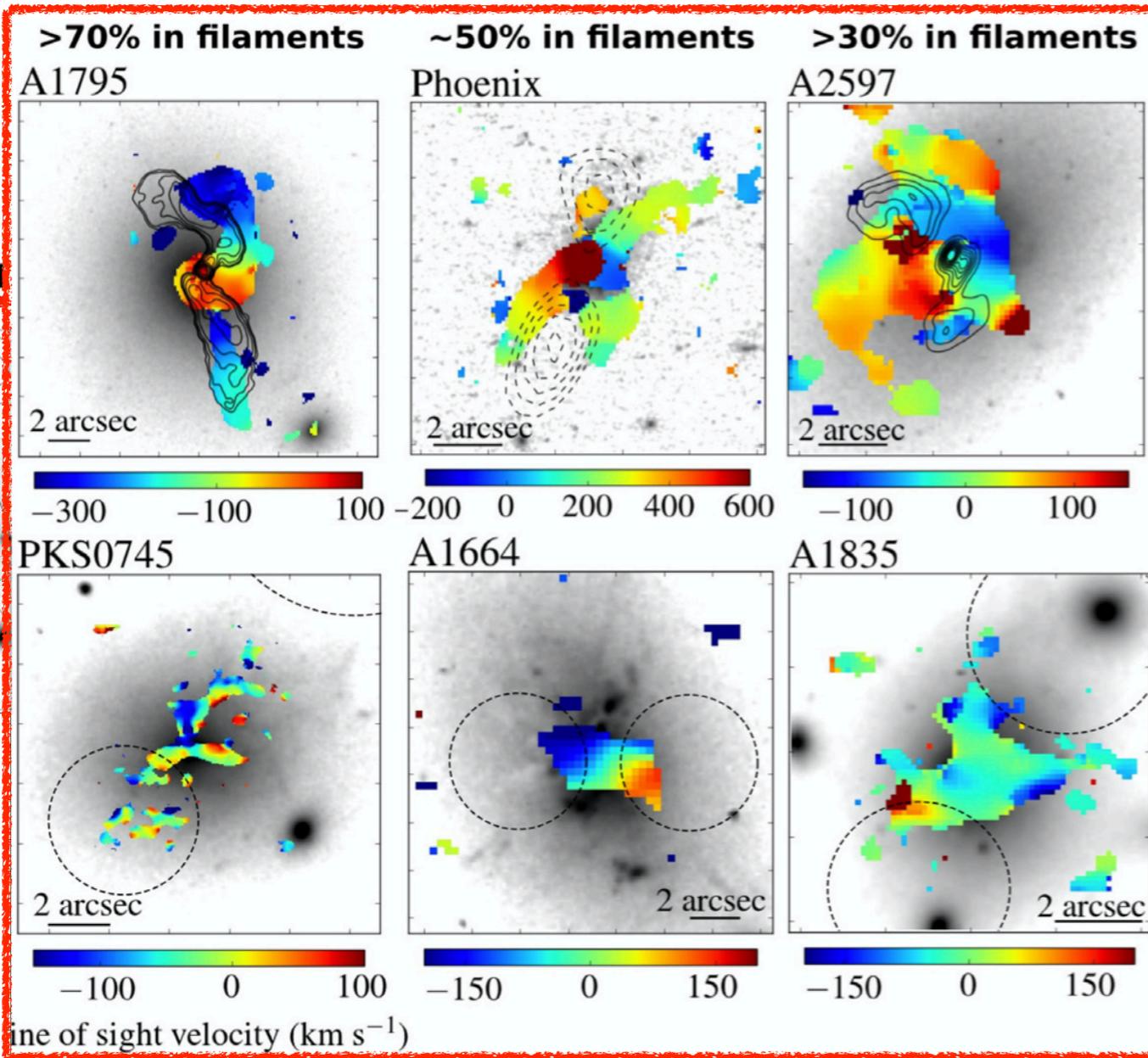
Filaments

# Motivation

- Previous ALMA observations of CO molecules...

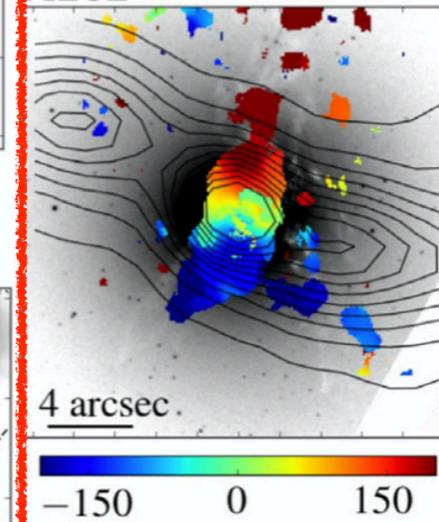
Grey: optical  
 Color: CO velocity map (mom1)  
 Solid: radio continuum  
 Dashed: X-ray cavity

## Filament-dominated



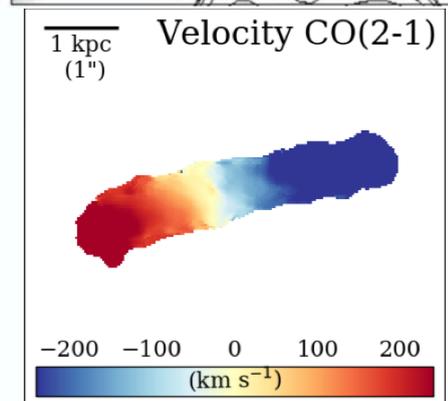
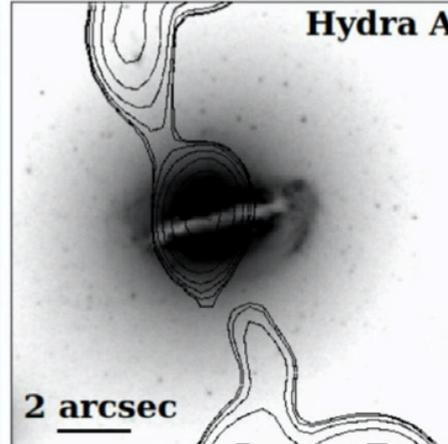
## ~10% in filaments

A262



## Disk-dominated

Hydra A



Russell +19  
 Olivares +19  
 Lim +08

- Huge variety of CO morphologies and kinematics.
- **A complex mixture of gas inflow and outflow** due to the past / current AGN activities

# Sample selection

- In order to study the nature of **pure ICM cooling** in cool-core clusters, selecting targets WITHOUT past / current AGN jet activity is needed.
  - However, radio AGN is ubiquitous in the cool-core systems (Burns +90), we select the target which contains the minimum AGN effect.
- > Today, I would like to share the preliminary results for one of the exciting targets, **Abell 1644-South**.

# Abell 1644

Chandra X-ray 72ks observation

14m00.0s

16m00.0s

18m00.0s

-17d20m00.0s

22m00.0s

24m00.0s

26m00.0s

58m00.0s

50.0s

40.0s

30.0s

20.0s

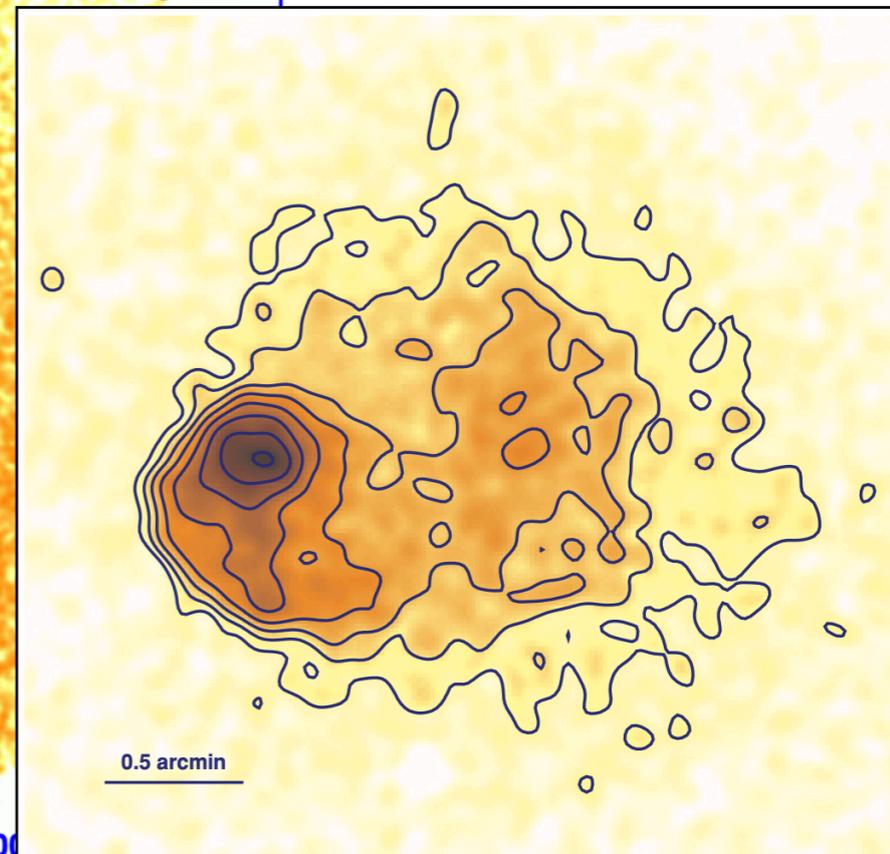
10.0s

12h57m00.0s

5 arcmin (288 kpc)

Abell 1644 - South ( $z=0.046$ )

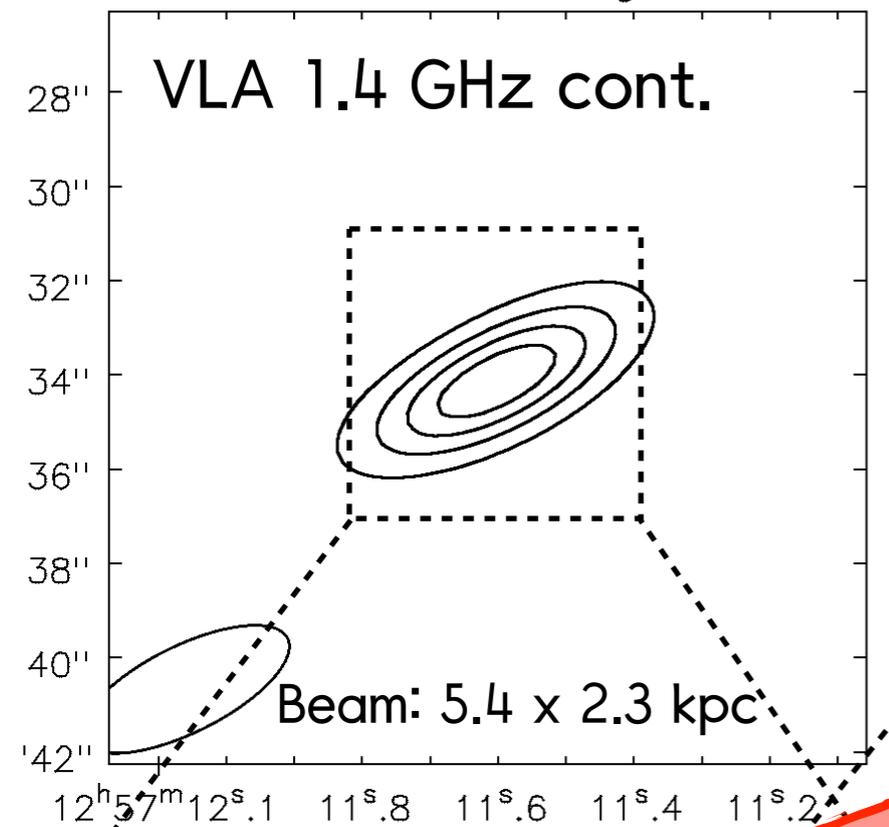
- "Main" cluster
- $M_{500} \sim 3 \times 10^{14} M_{\odot}$
- Cool-core
- Gas sloshing
- Interaction at  $>700$  Myr ago
- Swept ICM out (no cavity)



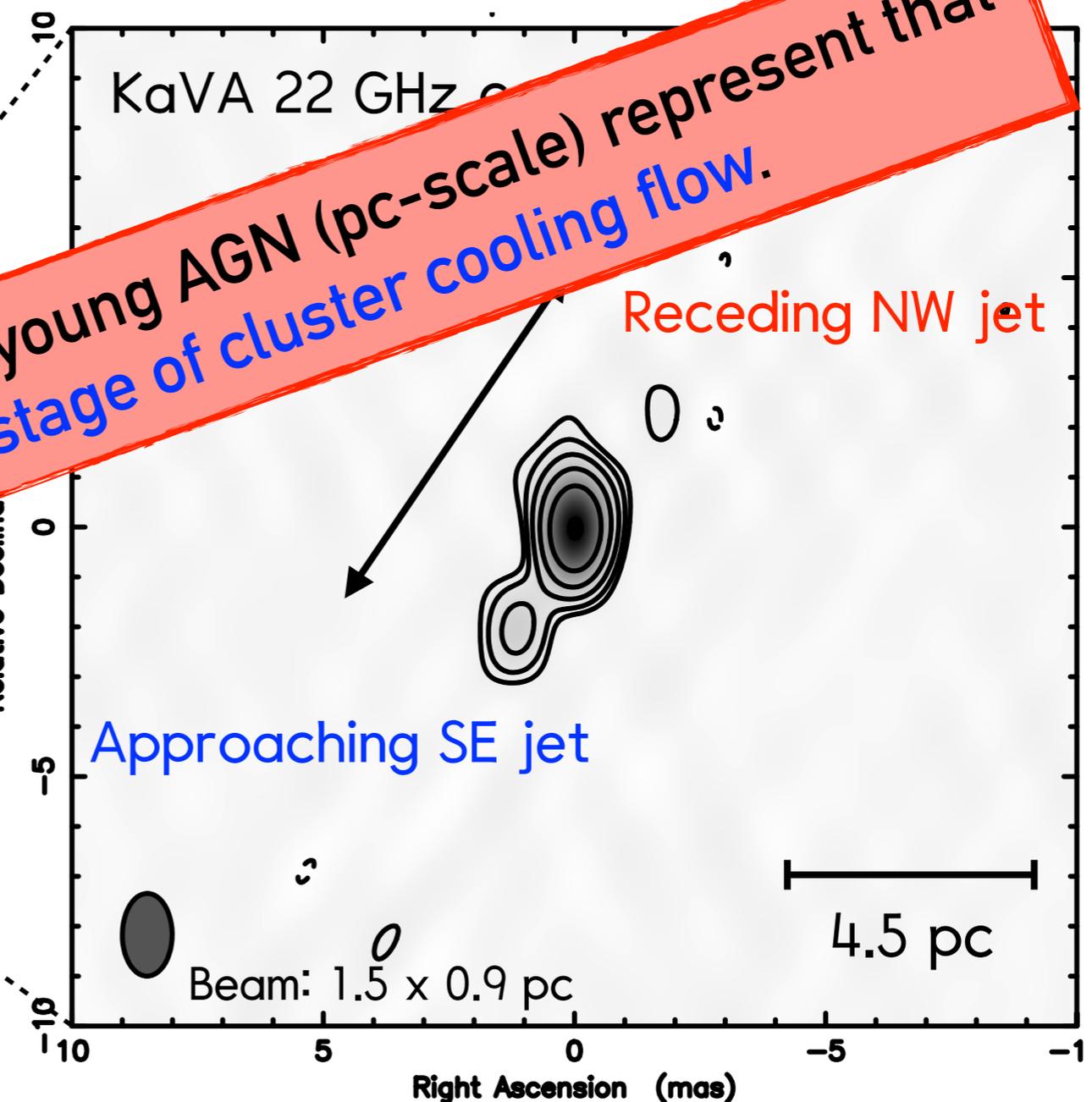
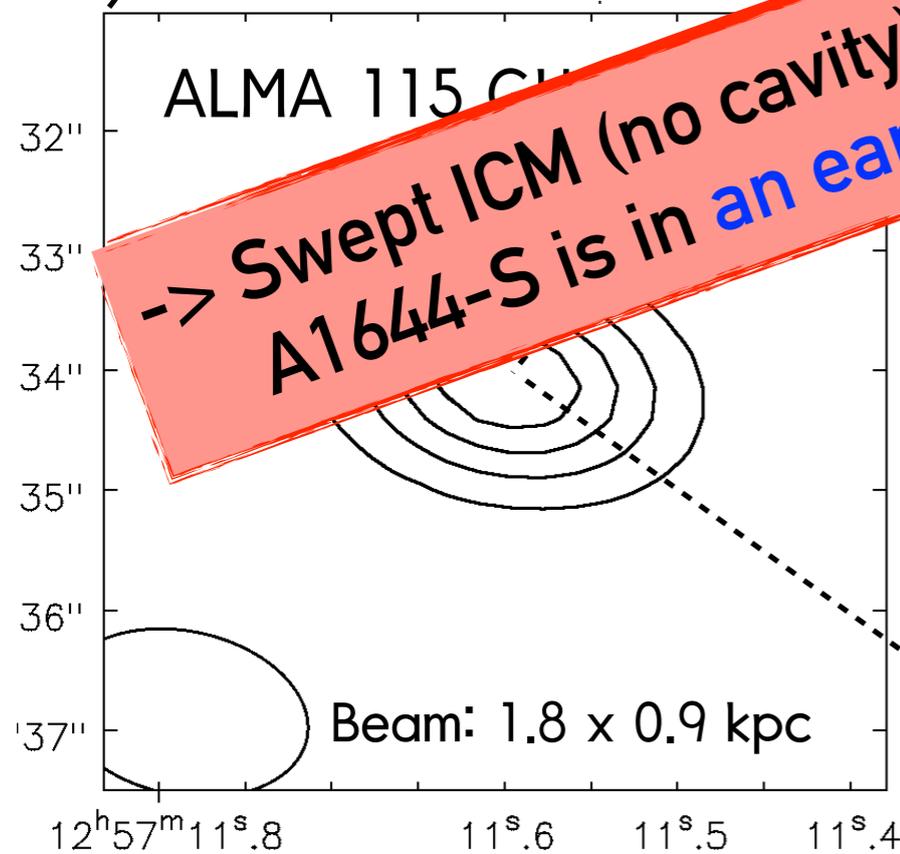
# Observations

- Our KaVA 22 GHz **continuum**
  - Observation date: 2020.04.21.
  - Angular resolution: 1.7 x 1.0 milli-arcsec
  
- Archival VLA 1.4 GHz
  - VLA BnA configuration
  - Observation date: 2015.05.21.
  - Angular resolution: 6.0 x 2.5 arcsec
  - Channel resolution: 7 km/s
  
- Archival ALMA 115 GHz **CO (1-0) (Cold molecular gas)**
  - Observation date: 2018.08.21.
  - Angular resolution: 2.0 x 1.0 arcsec
  - Channel resolution: 1.5 km/s

# Jet structures of the central AGN

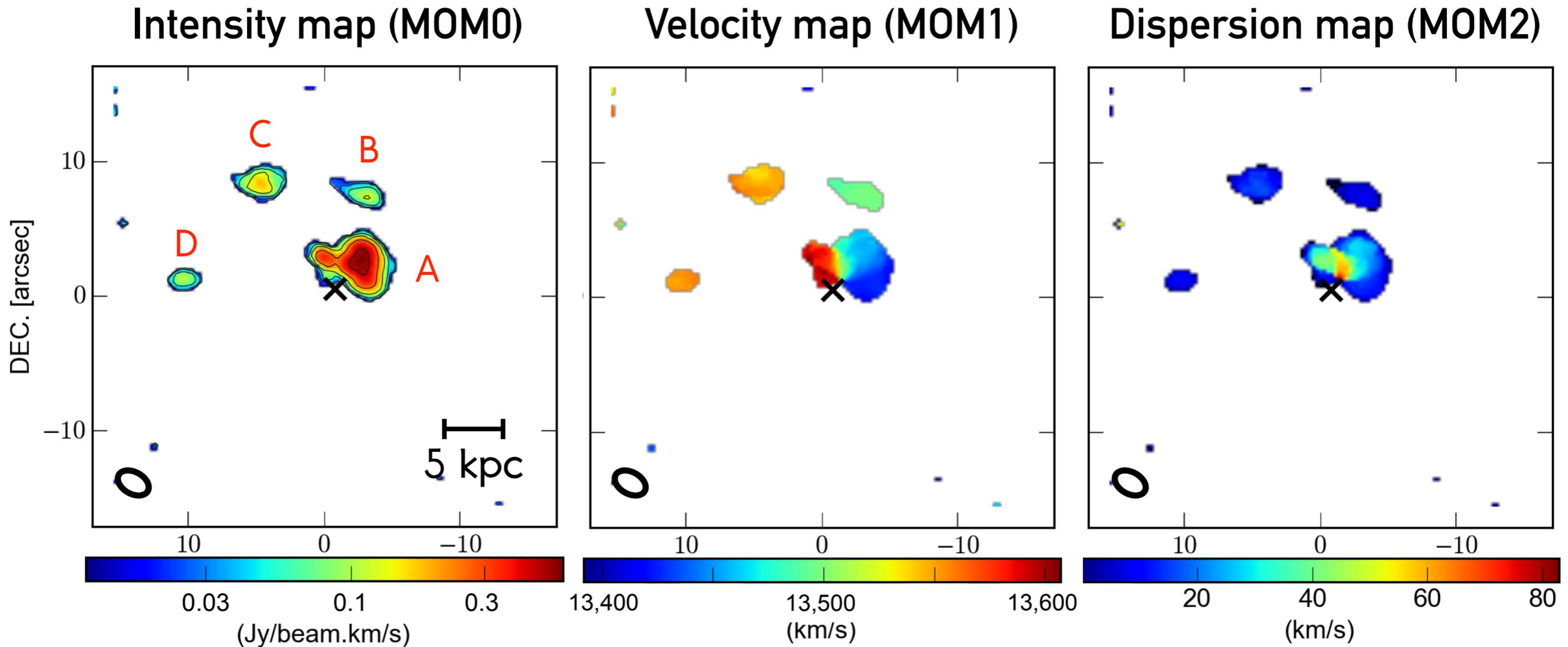


- We resolved the parsec-scale jet structure in the NW-SE direction.
- Its small size -> very young AGN (NO kpc-scale jet extension)



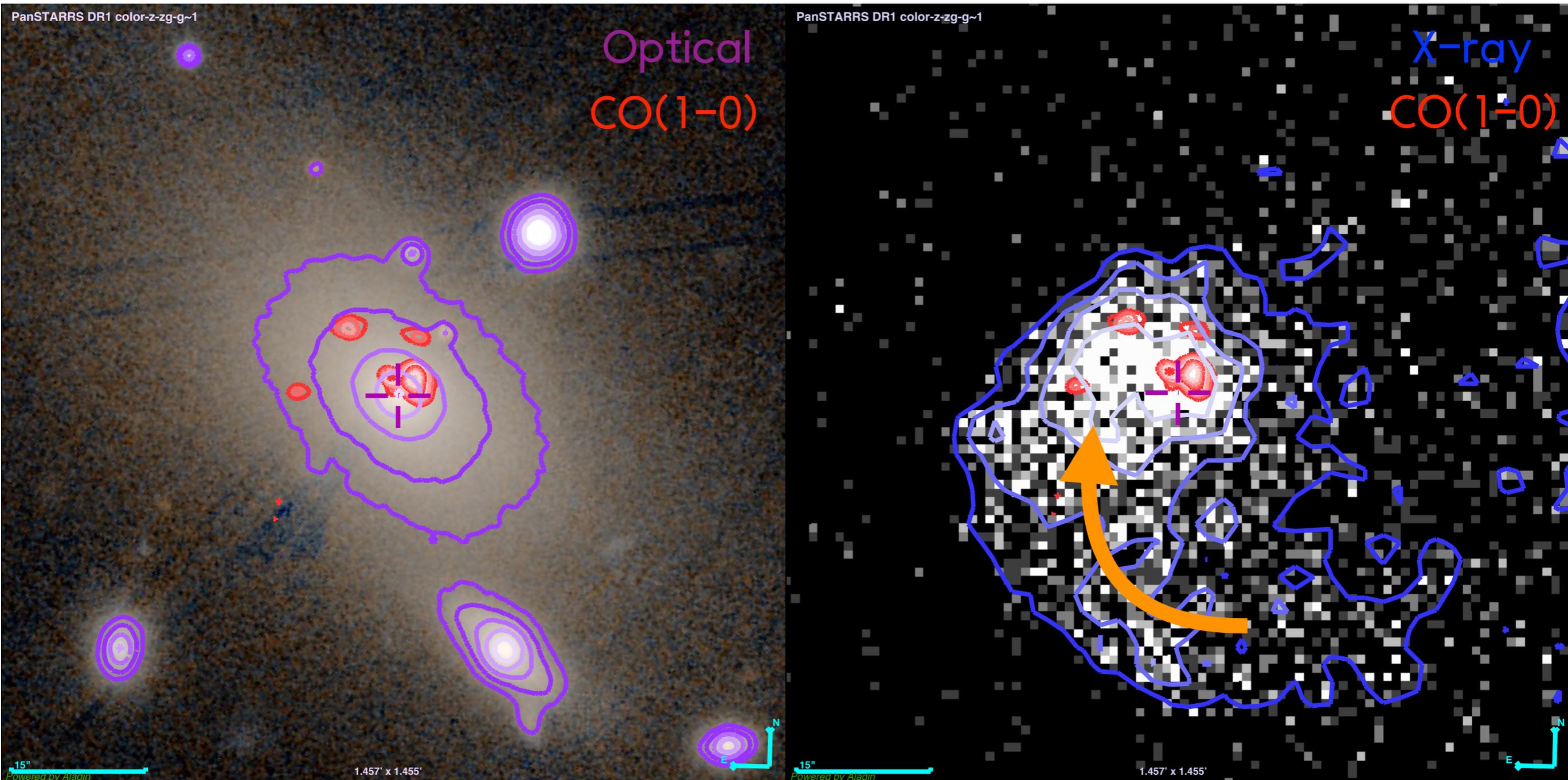
-> Swept ICM (no cavity) & young AGN (pc-scale) represent that A1644-S is in an early-stage of cluster cooling flow.

# Circumnuclear cold CO (1-0) gas



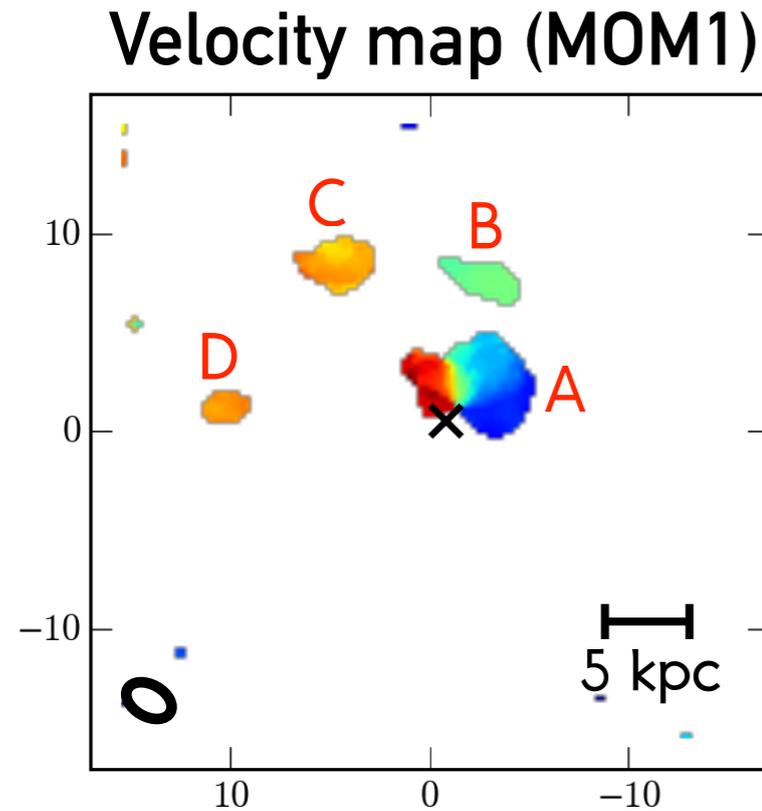
- Clumpy clouds of CO (1-0) emission
- The CO peak is located at 2.3 kpc away from the central AGN
- Cold molecular gas mass of cloud A:  $2 \times 10^8 - 1 \times 10^9 M_{\odot}$  (depending on the  $X_{\text{CO}}$ )
- No CO absorption

# Circumnuclear cold CO (1-0) gas

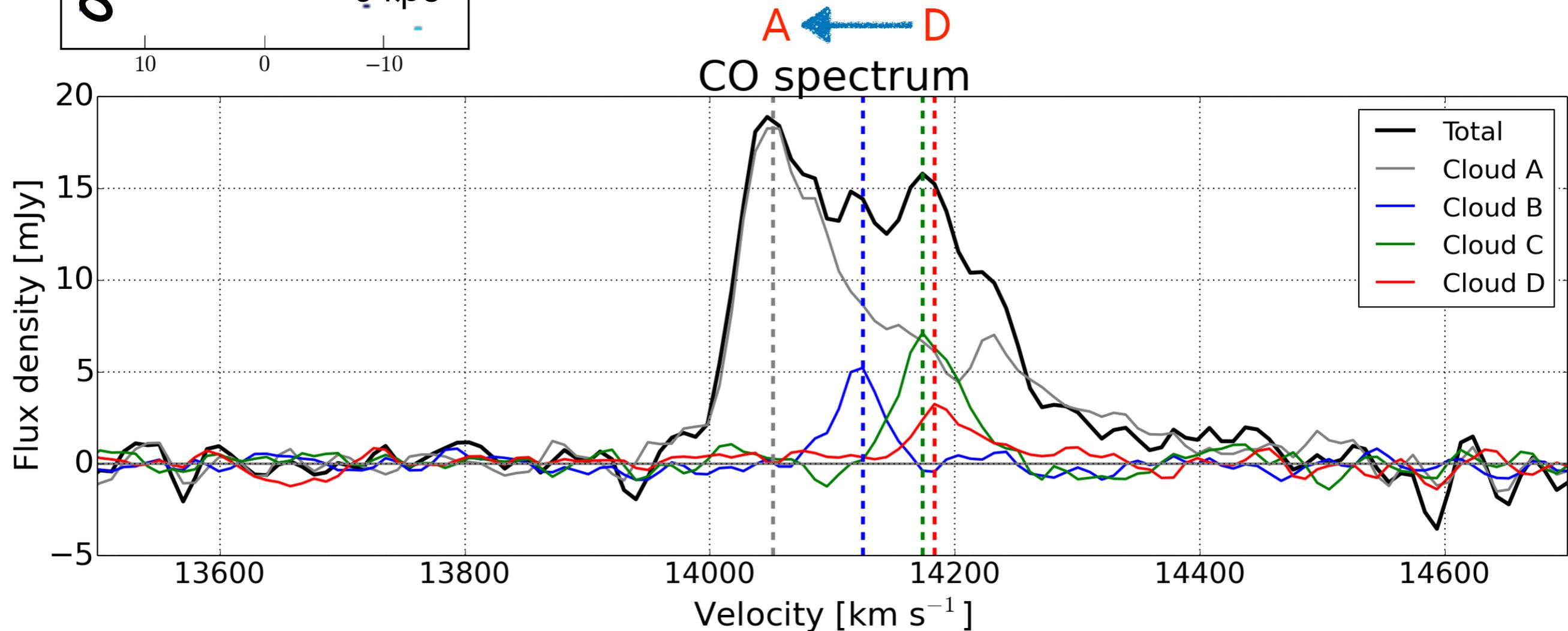


- There is no stellar substructure like spiral arms.
- The CO structure seems to follow the X-ray sloshing feature.

# Circumnuclear cold CO (1-0) gas



- From cloud D to A, the cloud peak velocities gradually move to blue-shifted velocity, which means “they are moving towards us”.



# Summary

- **Using the multi-frequency radio data**, we study the central AGN activity and ambient cold gas properties in the cool-core cluster, A1644-South.
- Based on the absence of cavity and absence of kpc-scale jet activity, we conclude that **A1644-S is in an early-phase of ICM cooling**.
- We found **multiple cold gas clumps** with a smooth velocity gradient, which thought to be **formed by hot ICM cooling** (top-down).
- Strong HI & CN absorptions (but no CO absorption) at the l.o.s. of AGN represent the presence of cool gas accretion to the central AGN, even if it is in the early-phase of cooling (CO position offset).