Osservatorio Astronomico di Cagliari

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ALMA OBSERVATIONS OF AGN FUELLING THE CASE OF PKS B1718-649

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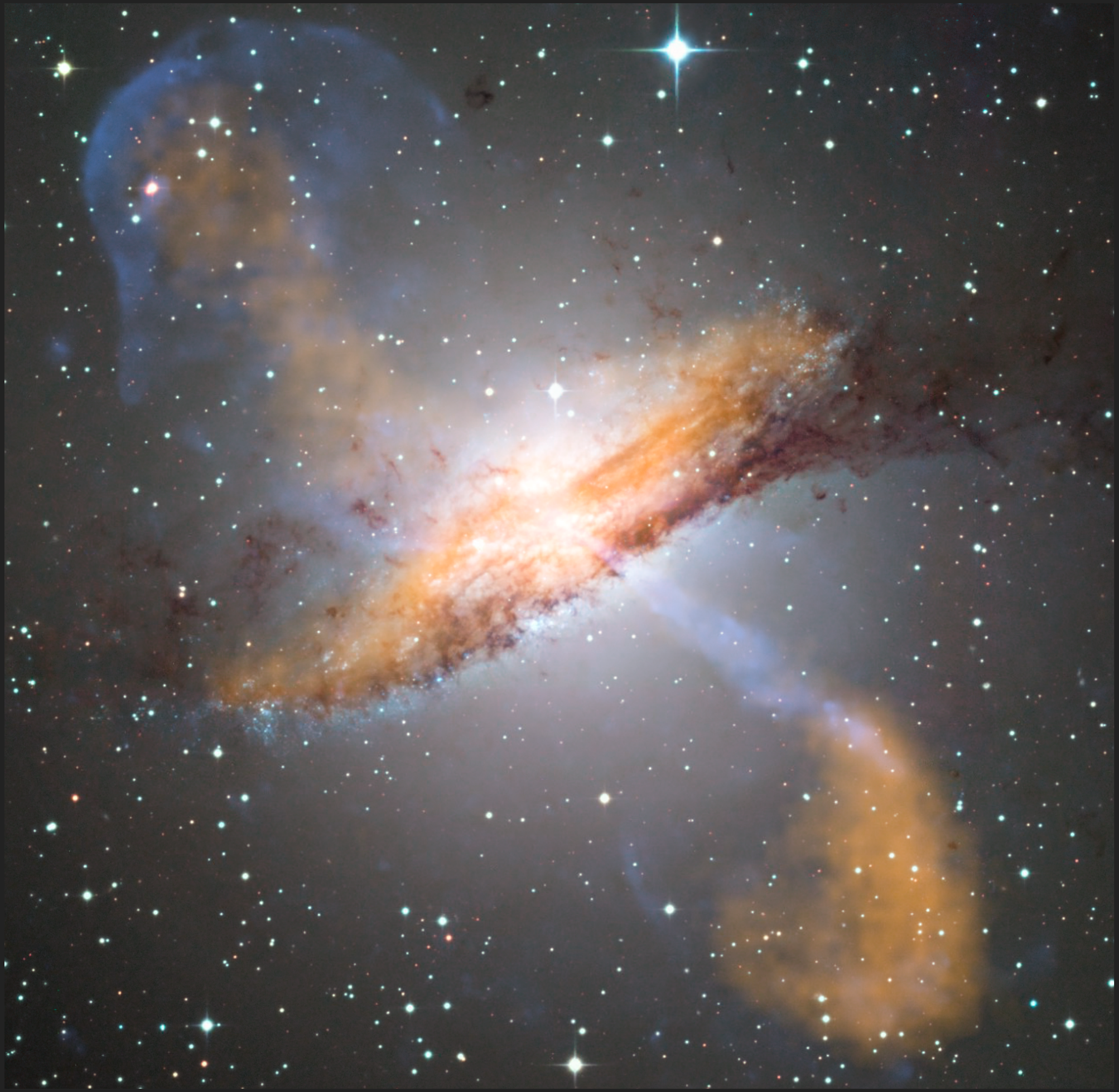
Introduction

- The evolution of a galaxy is influenced by the accretion of gas onto its central SMBH, i.e. an AGN.
- Interest: gas surrounding the AGN
  - physical conditions determine
    - kind of AGN
    - efficiency of the accretion
    - energetic output
  - Cold gas: most massive component
- Radio AGN: radio jets expand through the galaxy
  - know the age of the AGN.
  - study the interplay ISM radio AGN, throughout different stages of its evolution



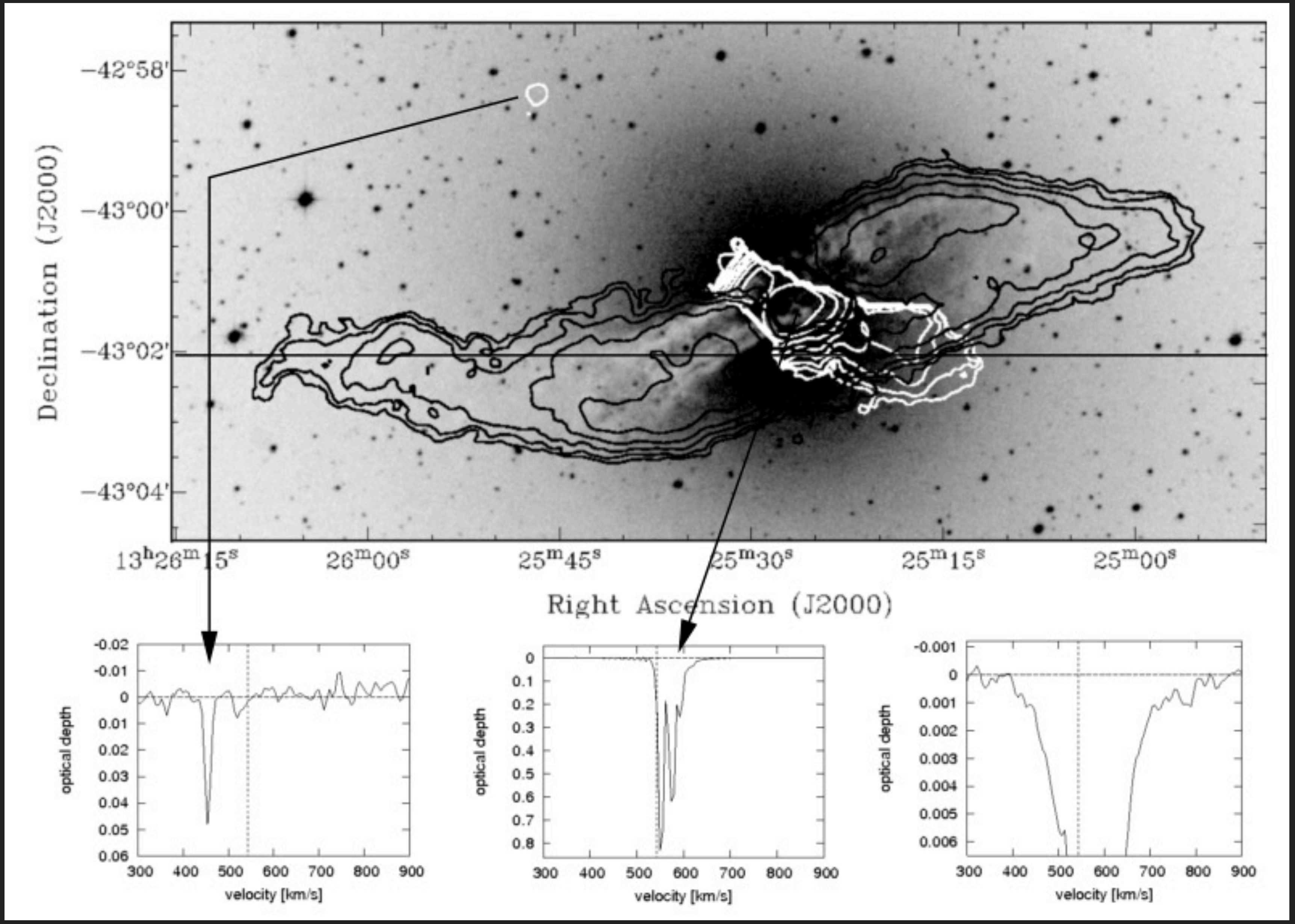
[Centaurus A: https://www.eso.org/public/images/eso0903a/]

Neutral Hydrogen in radio AGN

- Early-type galaxies are the typical host of a radio-AGN
- ~ 40% of early-type galaxies have neutral hydrogen HI [ATLAS^{3D} · Serra et. al 2012]
  - HI absorption traces interplay between the radio source and the ISM

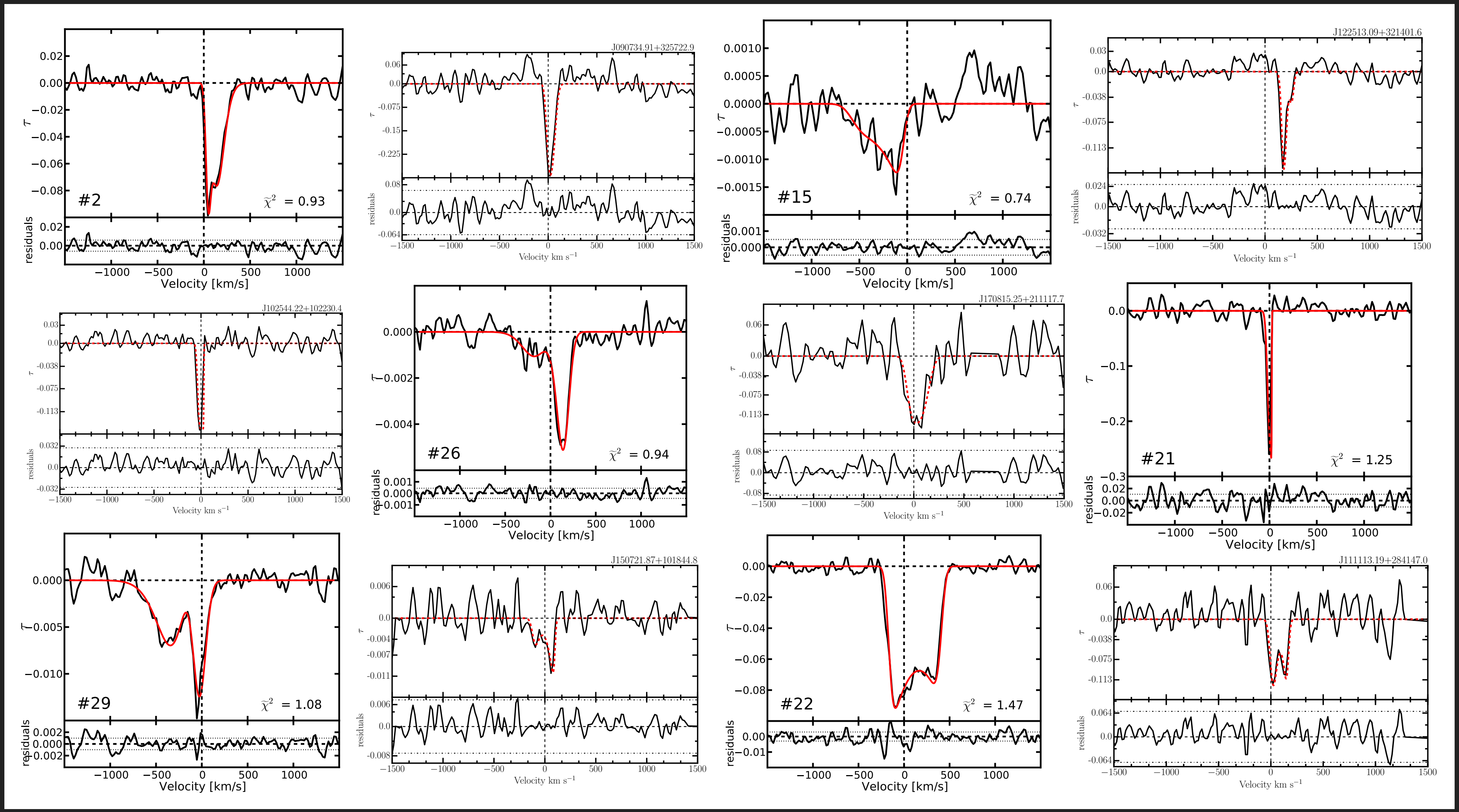
- Narrow lines at systemic velocity
  - rotating disks
- Shallow blue shifted wings
  - outflows pushed by the radio jet
- Redshifted lines
  - inflowing gas

- HI and molecular cold gas components (e.g. CO, H2, etc) show similar kinematics

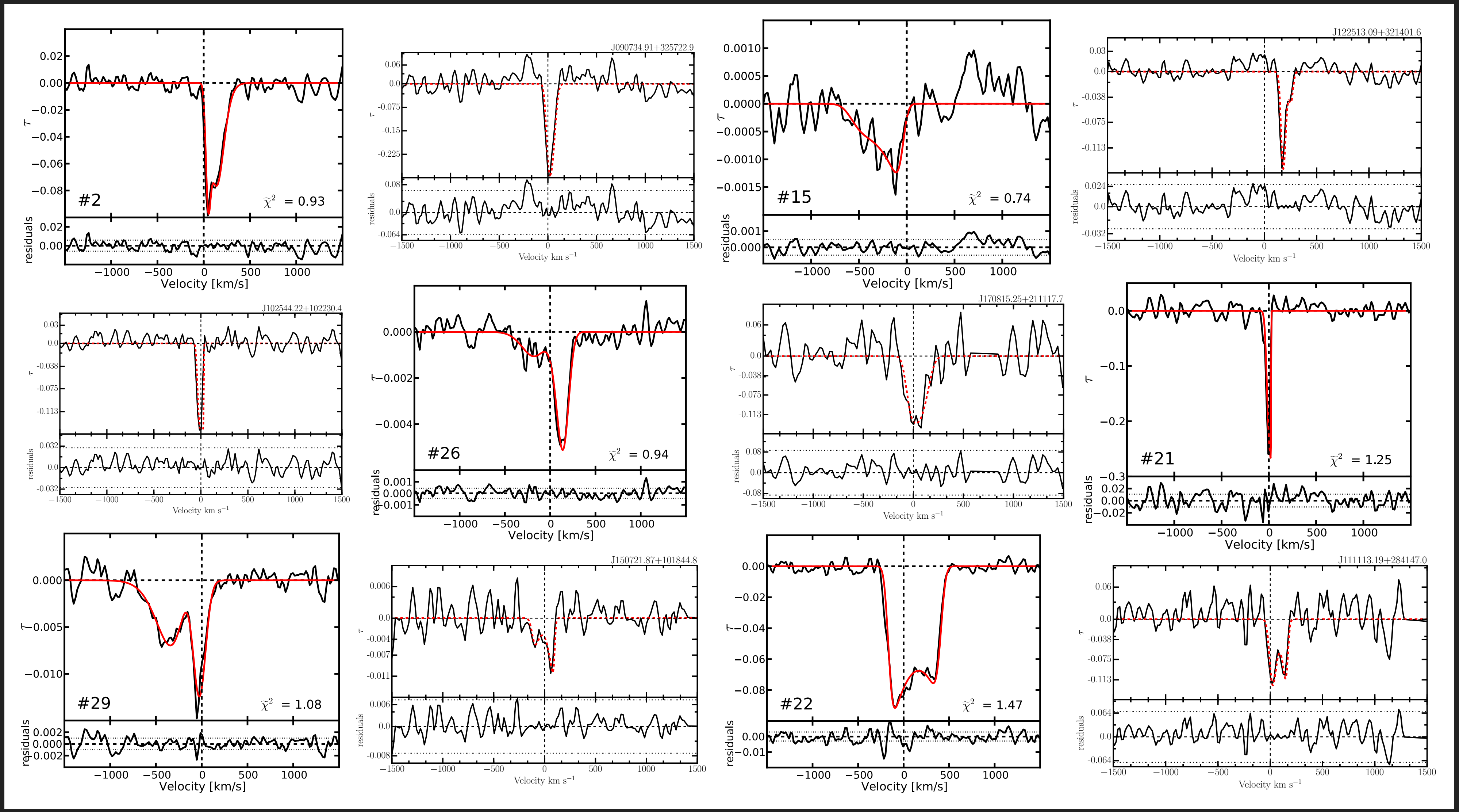


[Centaurus A: Struve et al. 2010]

HI absorption traces gas close to radio AGN



HI absorption traces gas close to radio AGN



- Detect cold gas against the radio continuum emission
  - 30% detection rate
  - Variety of lines with different shapes, widths and optical depths
    - Trace the interaction between the radio activity and the interstellar medium, i.e. Feedback from AGN
      - Circumnuclear disks, fast outflows, inflows.

[Maccagni et al., 2017]

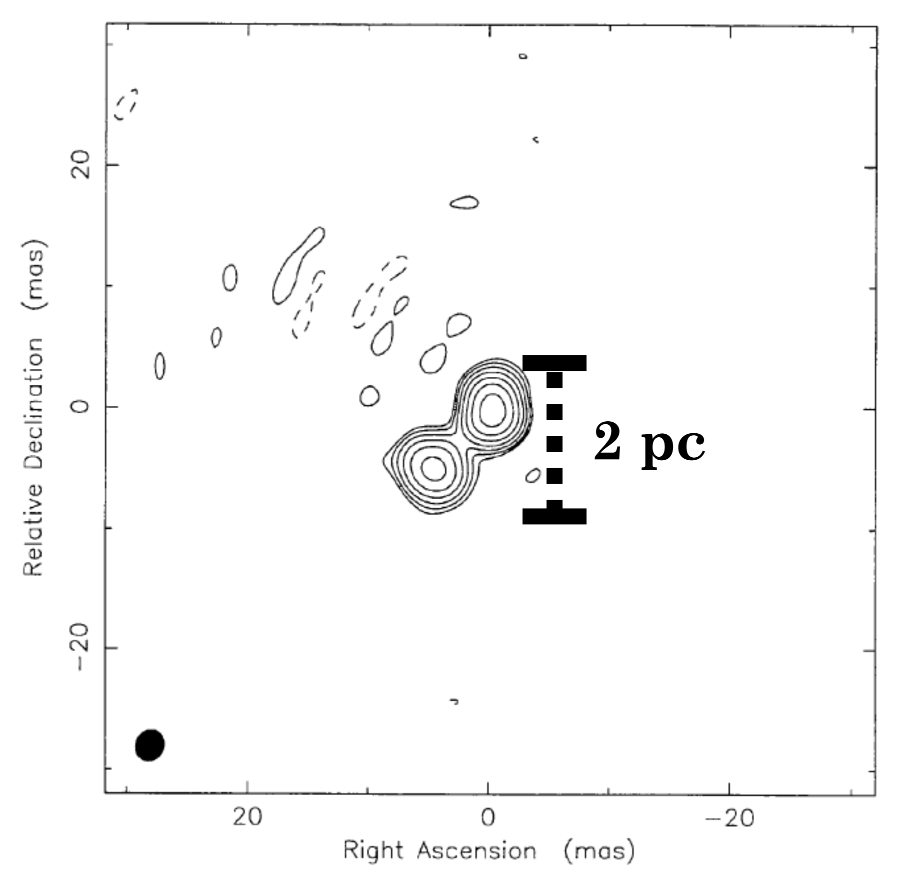
From a shallow survey to high resolution

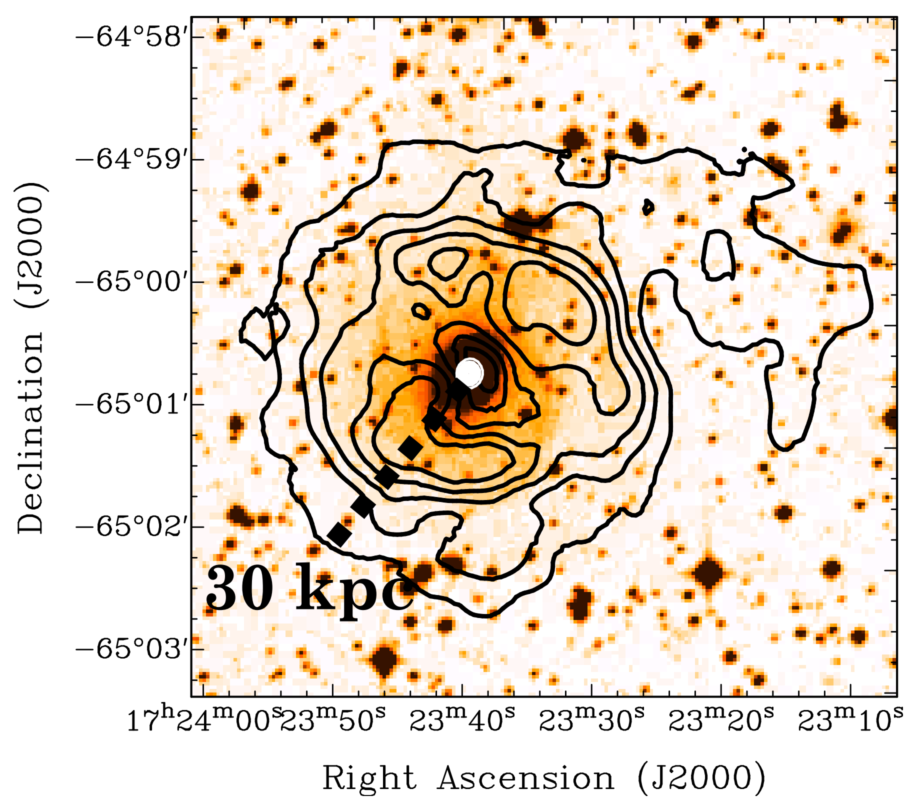
- HI absorption profiles identify sources where interaction between the radio activity and the surrounding ISM is on-going, e.g. inflows, outflows
- Problem: The integrated HI absorption lines do not reveal the overall distribution of all the cold gas close to the radio AGN, as well as its physical conditions.
  - Solution: Multi-wavelength high resolution observations of different phases of the gas in the circumnuclear regions of radio AGN
    - Candidate: PKSB 1718-649, a young radio source
      - ideal candidate to study the triggering and feeding of the AGN

PKS B1718-649: a baby radio galaxy

General properties

- Closest young radio AGN: z=0.0144 (62 Mpc)
- Compact radio source: R = 2 pc
- Young AGN: 10^{2-5} years
  - First phase of radio AGN
    - $S_{1.4GHz}$ (ATCA) = $S_{1.4GHz}$ (VLBI)
- Radio power: 1.8 x 10^{24} W/Hz
- Accretion: jet-mode, (L/L_{Edd}~0.003)
- Optical properties: LINER
- S0 galaxy + massive HI disk

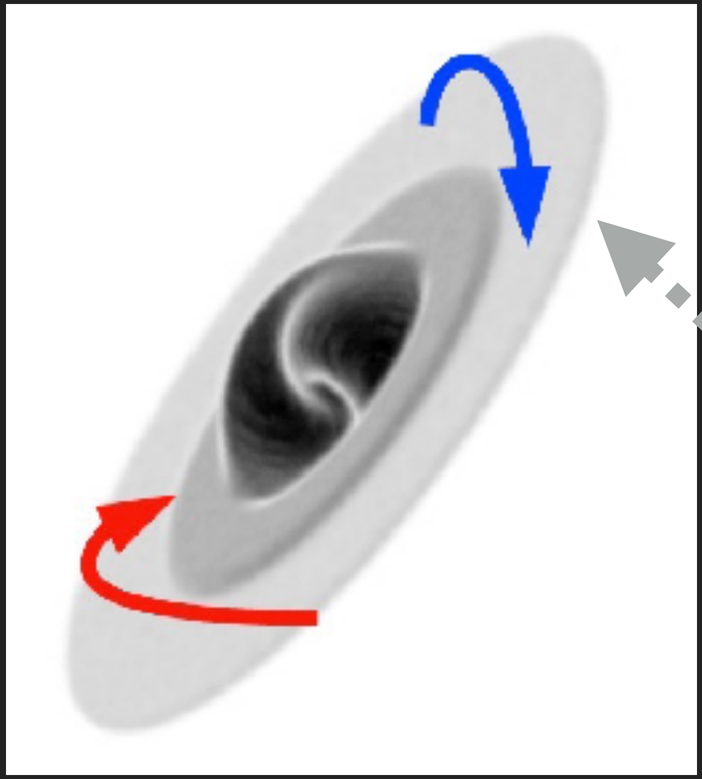


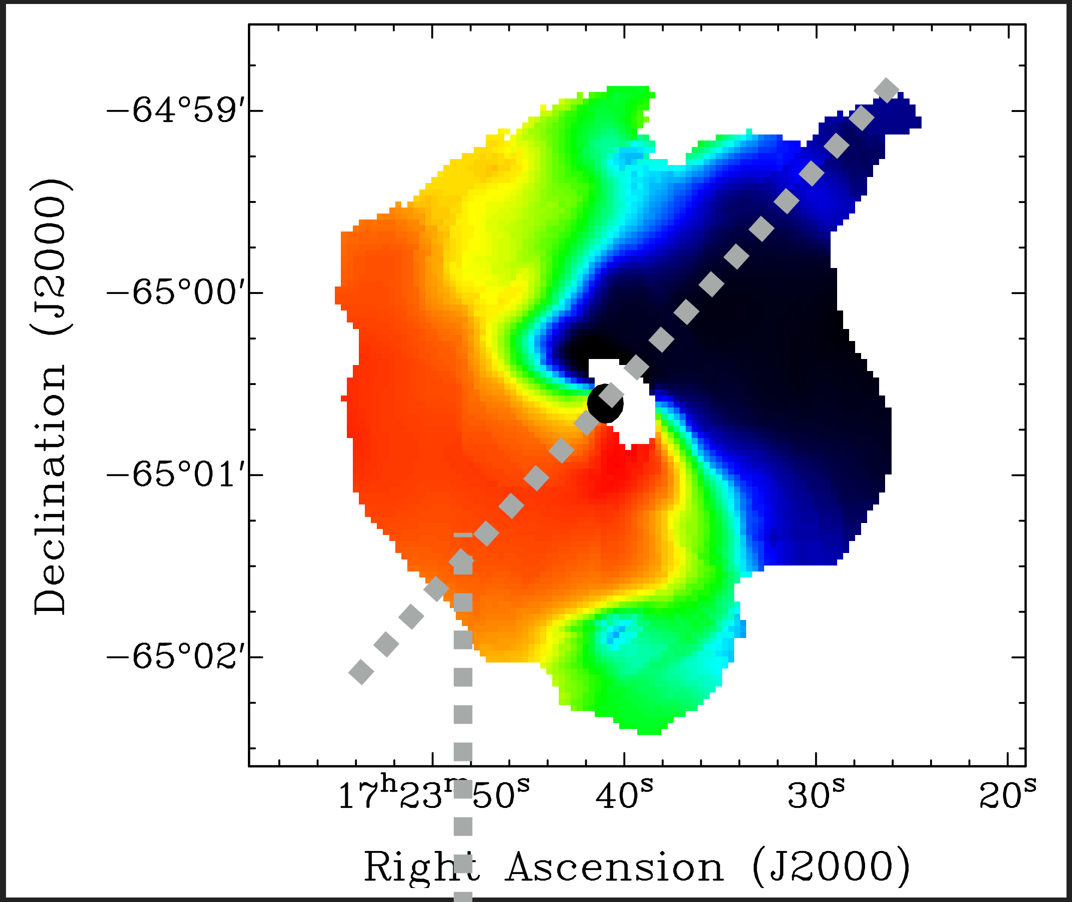


- Multi-wavelength study
  - Neutral Hydrogen [Maccagni et al., 2014]
  - H_2 (2.12 μm) [Maccagni et al., 2016]
  - CO (2-1) [Maccagni et al., submitted]

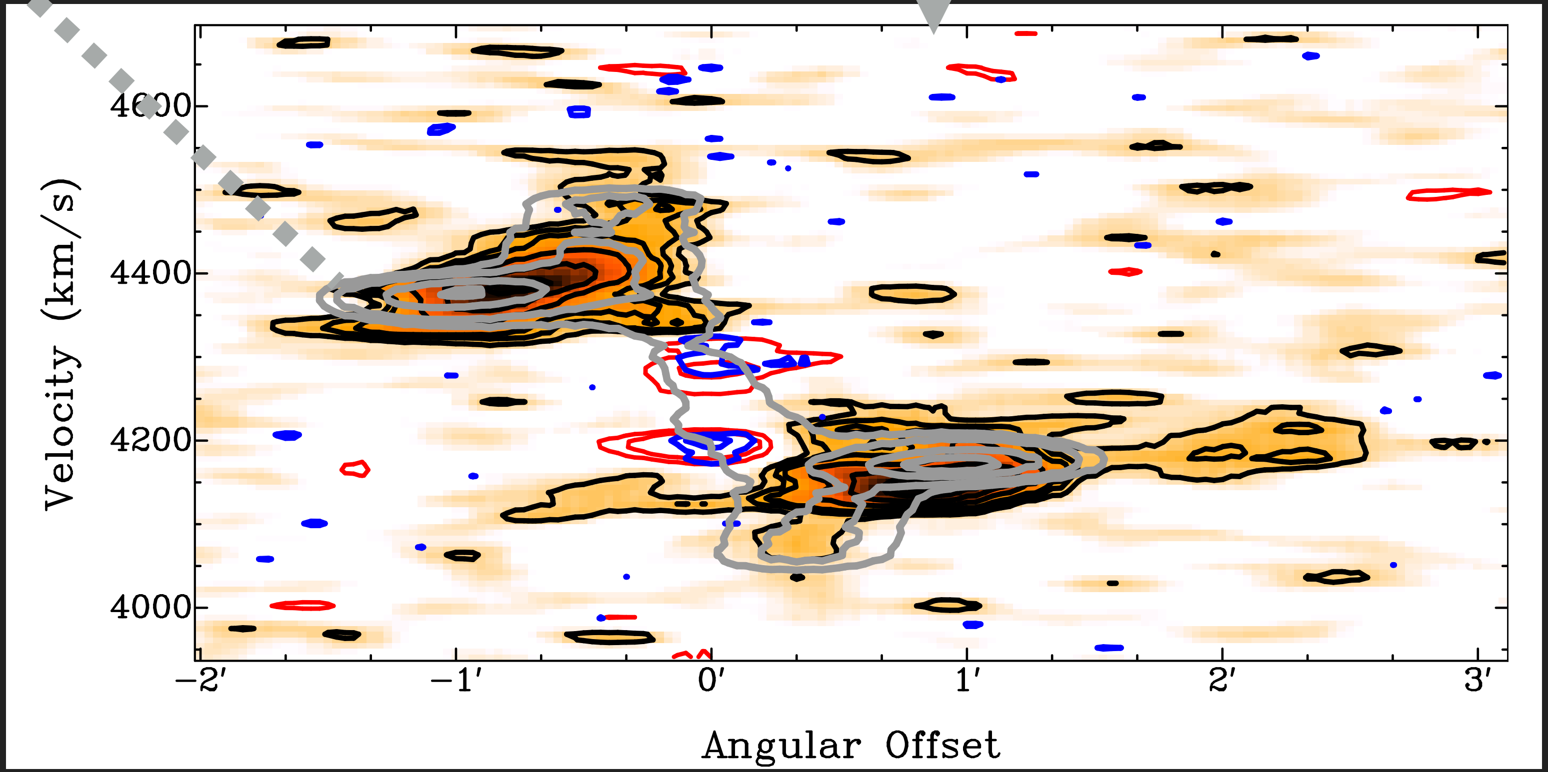
Compact Array HI observations

- In Emission, we don't detect gas close to the radio source deviating from rotation
- Model the kinematics of the HI disk



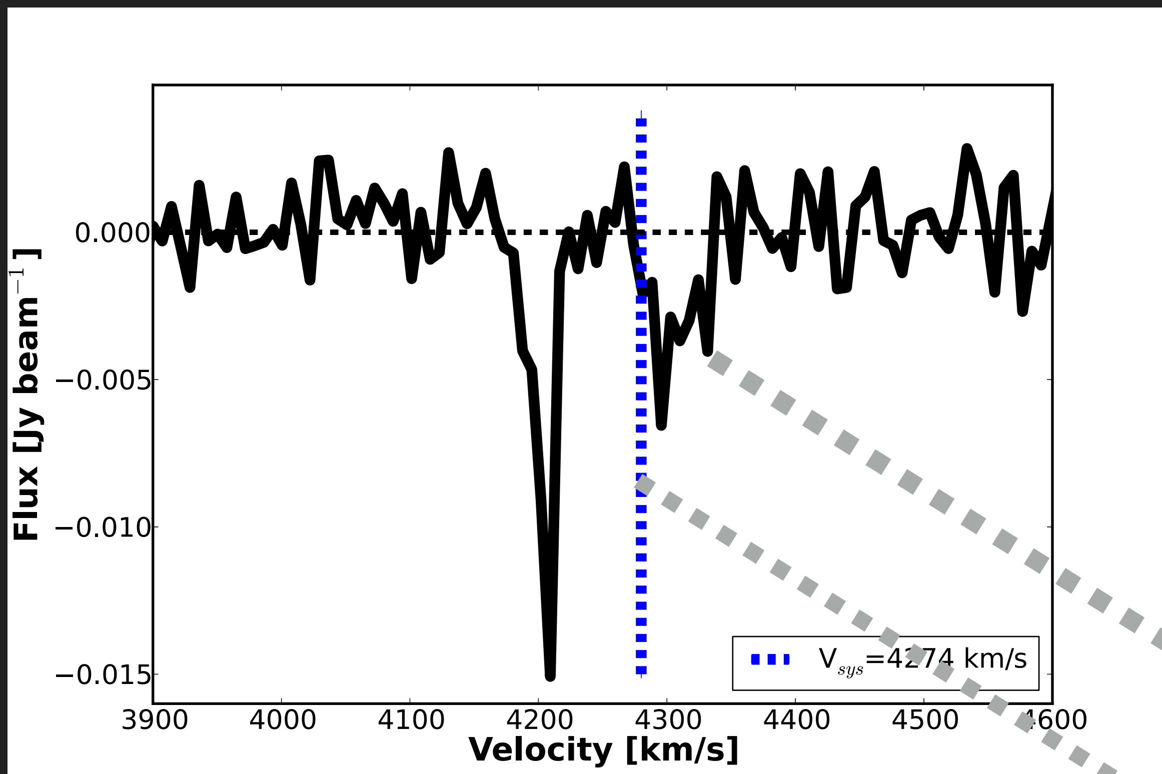


- Timescale of rotation of the HI disk:
  - mergers/bars do not:
    - bring cold gas close to this AGN
    - fuel of this radio source



[Maccagni et al., 2014]

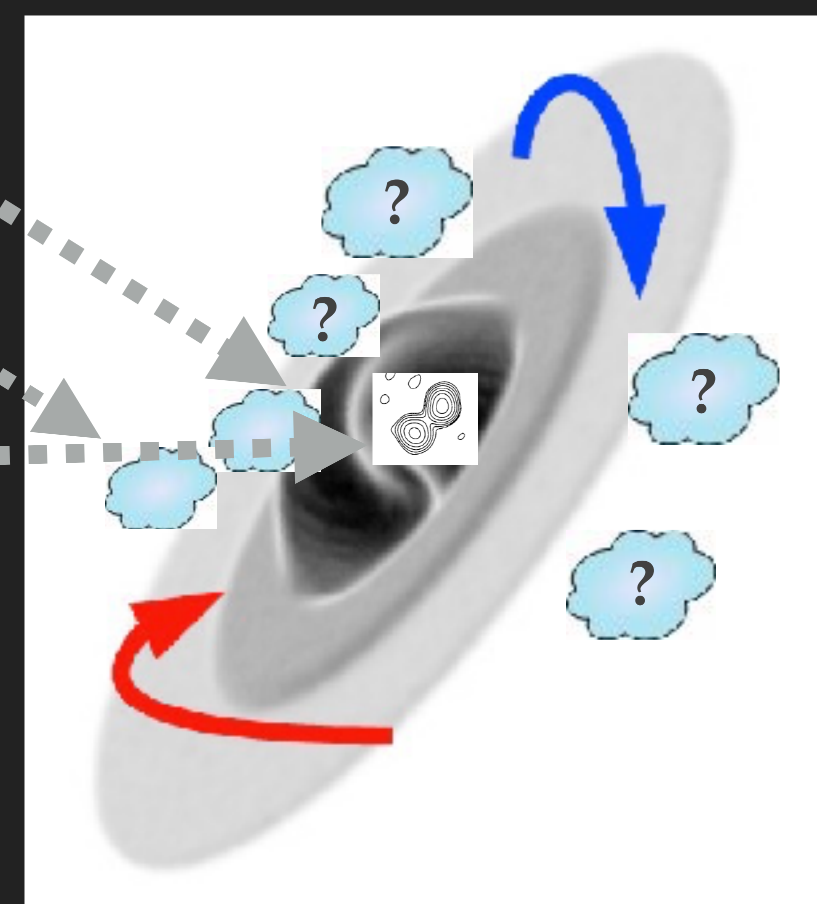
An HI Absorption doublet



2 Absorption lines:

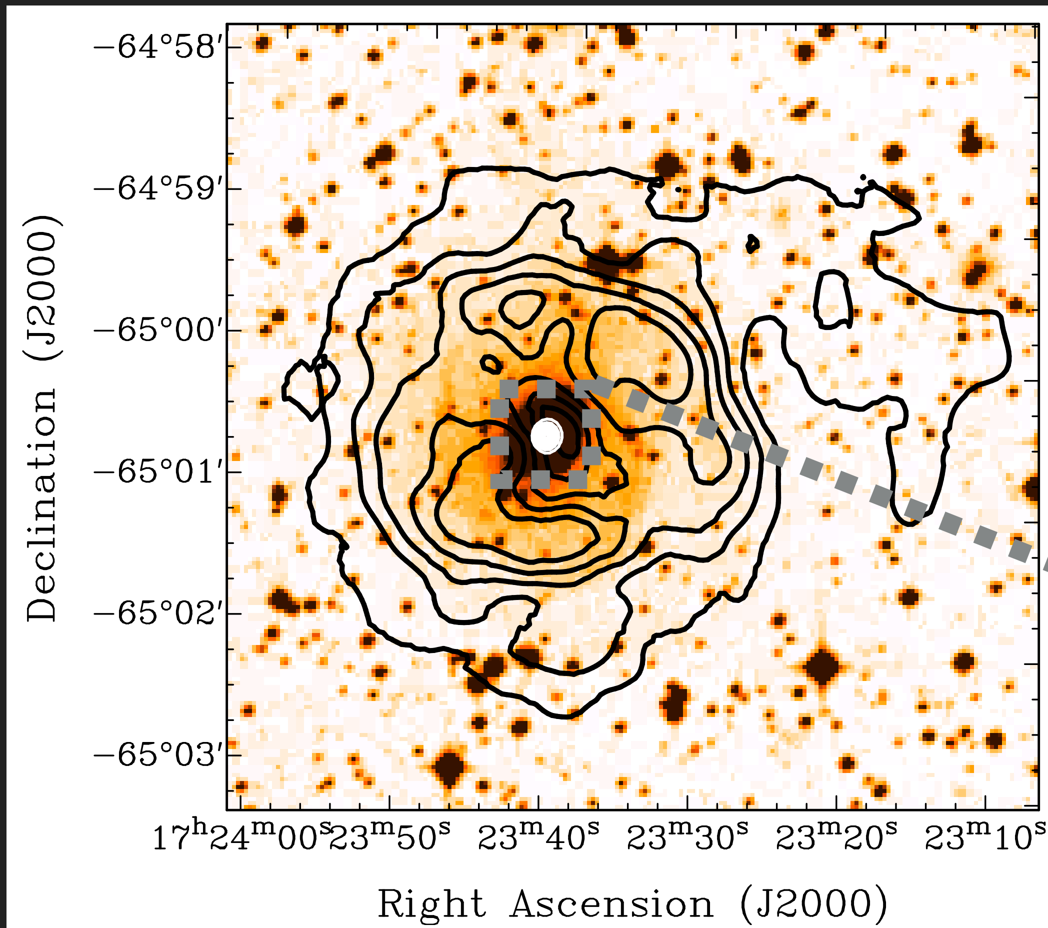
- narrow line blue-shifted
- broad line red-shifted
  - w.r.t systemic velocity (4274 km/s)
  - population of cold clouds of gas potentially fuelling the AGN (?)

line of sight

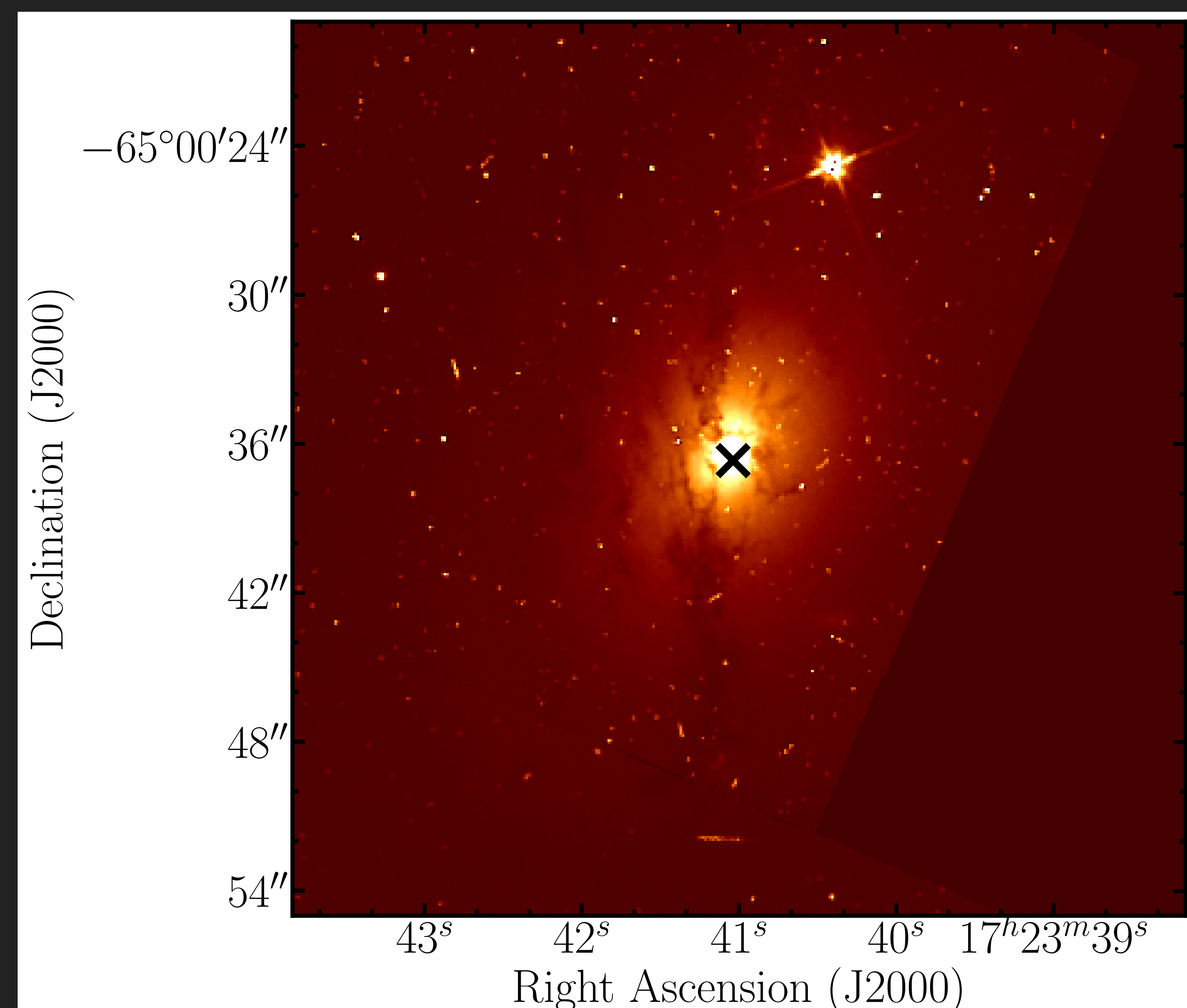


[Maccagni et al., 2014]

Focusing on the centre of the galaxy

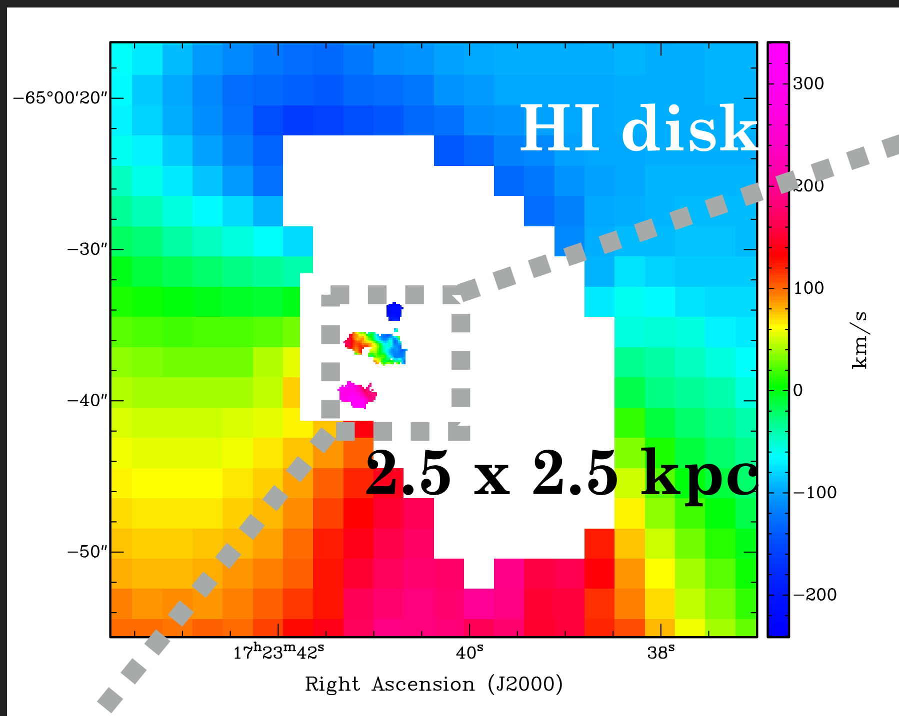


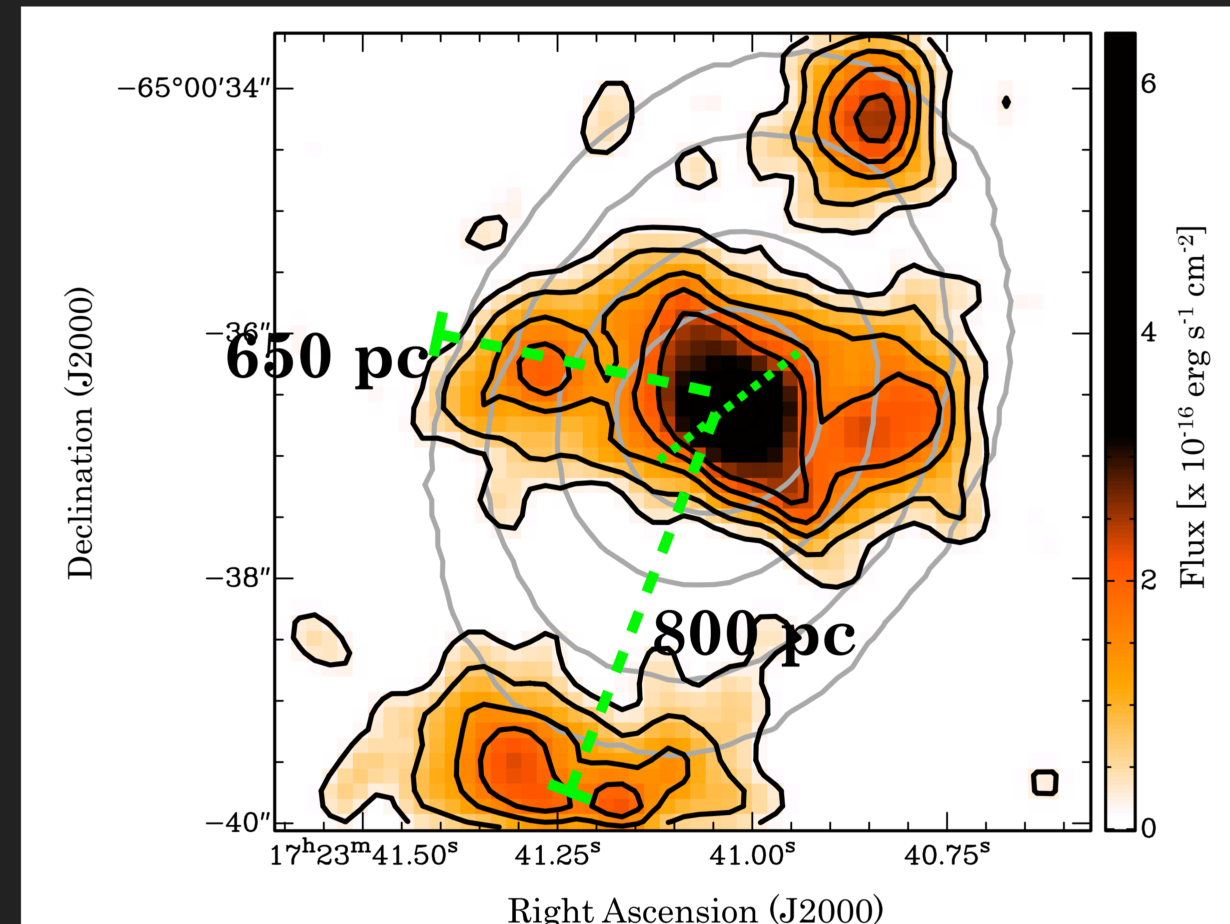
- Investigate the centre of the galaxy
  - Distribution and kinematics of the cold molecular gas

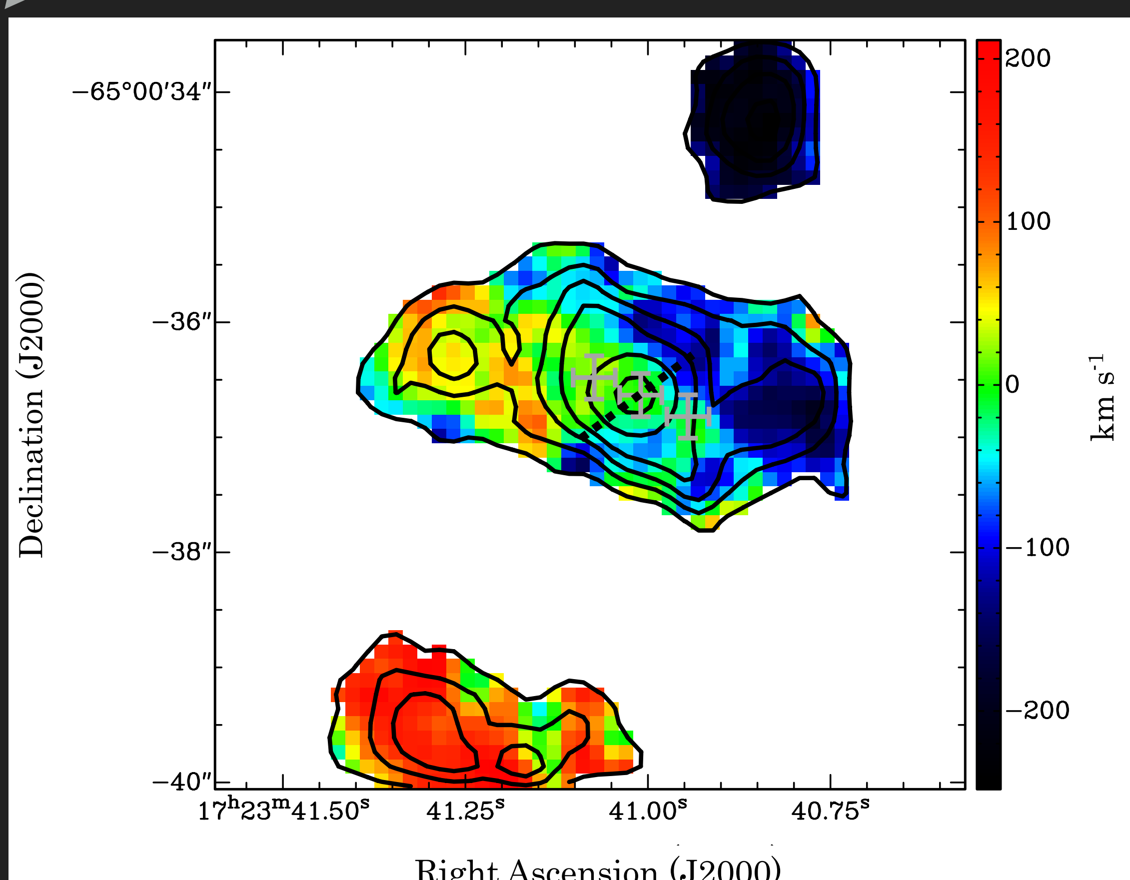


- SINFONI 2.12 µm observations
- Spatial resolution: 0.5” / 150 pc
- FOV : 8x8 kpc

SINFONI: warm H_2 (2.12 μm)



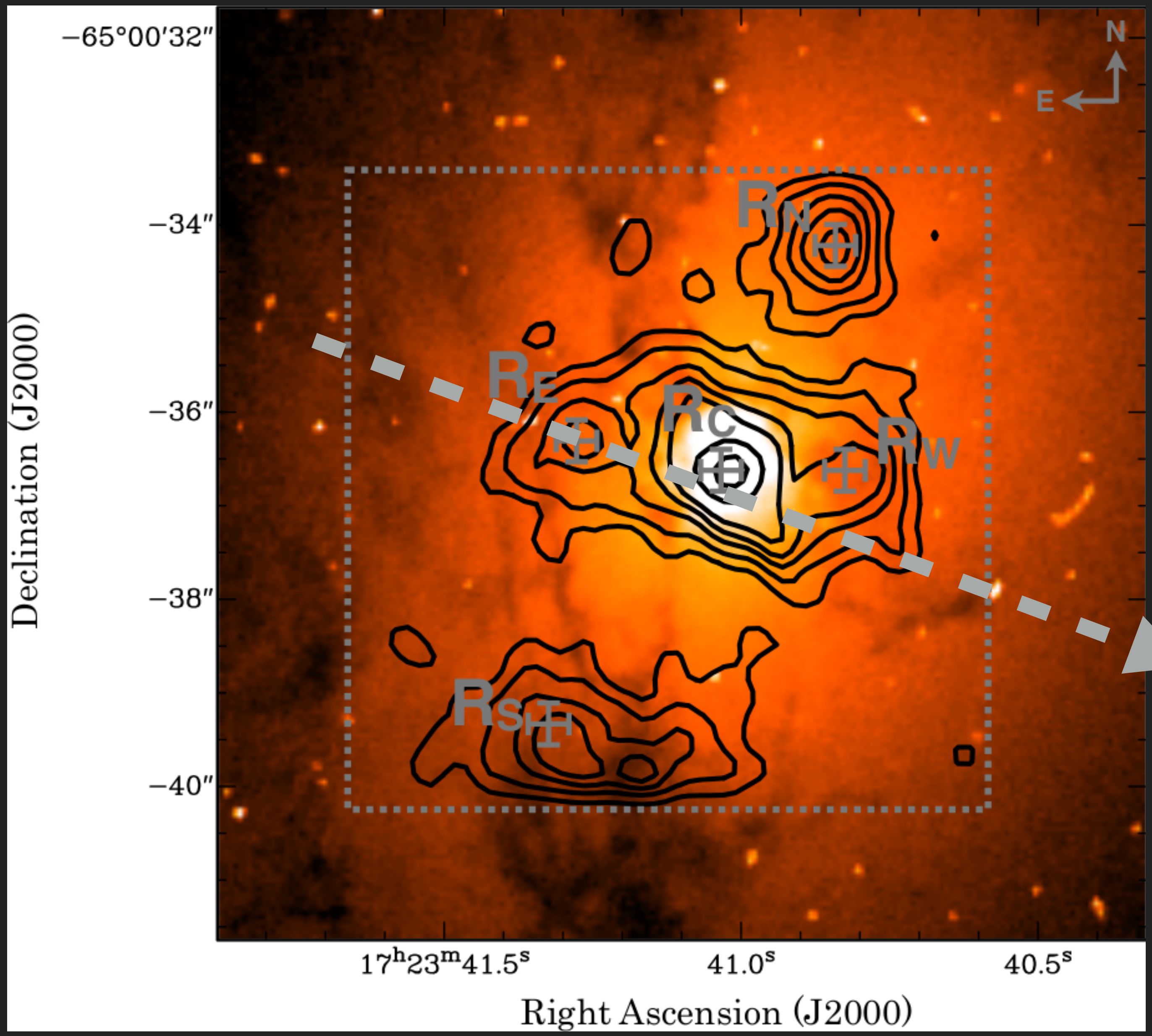




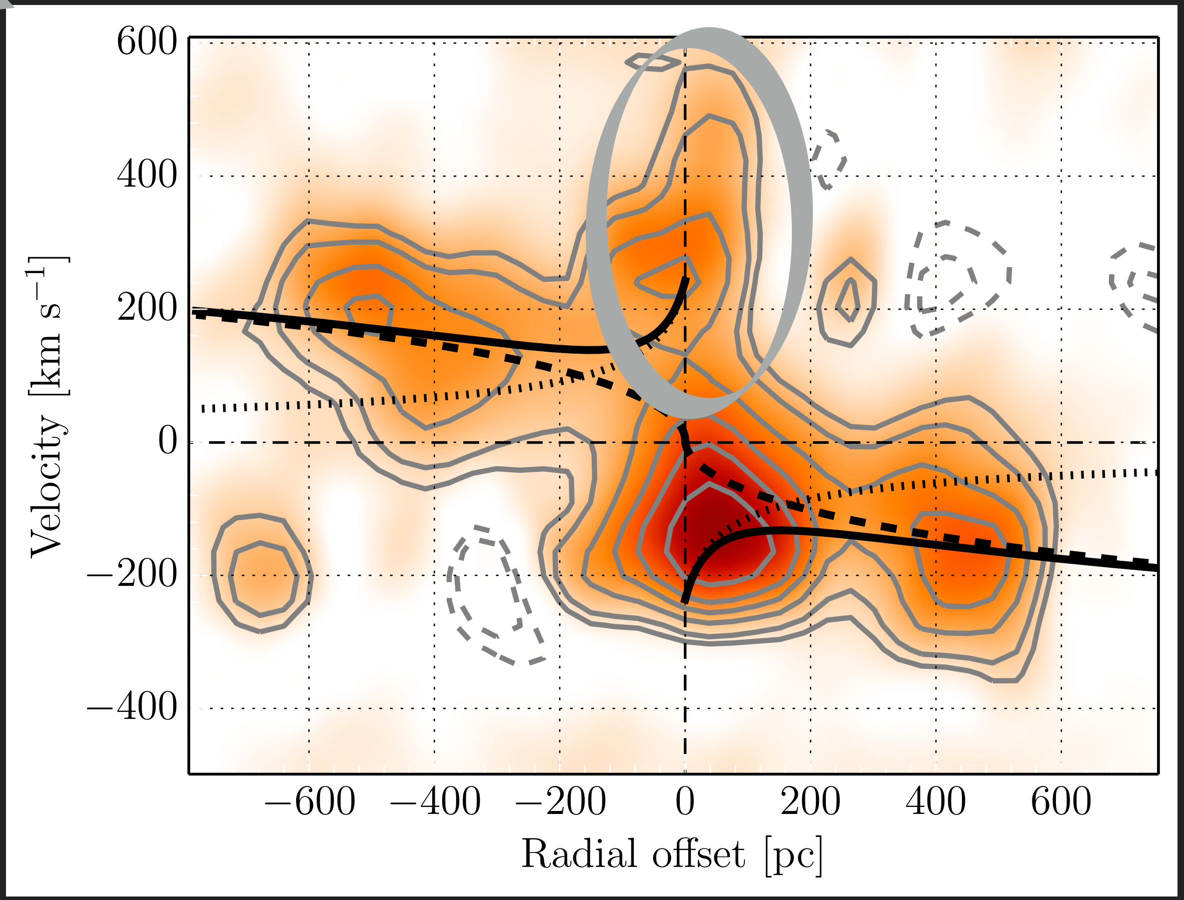
- IFU observations of the H_2 S(1) 1-0 line
  - Spatial resolution: 0.52” / 154 pc
- 2 rotating disks:
  - <u>outer disk</u> (r>650 pc)
    - follows rotation of the stars
  - <u>inner disk</u> (r<600 pc)
    - ⊥ to the outer disk

[Maccagni et al., 2016]

Warm H_2 in PKS B1718–649



- 2 Structures
  - Outer disk
    - follows the kinematics of the HI disk
  - Inner disk
    - ⊥ to outer disk

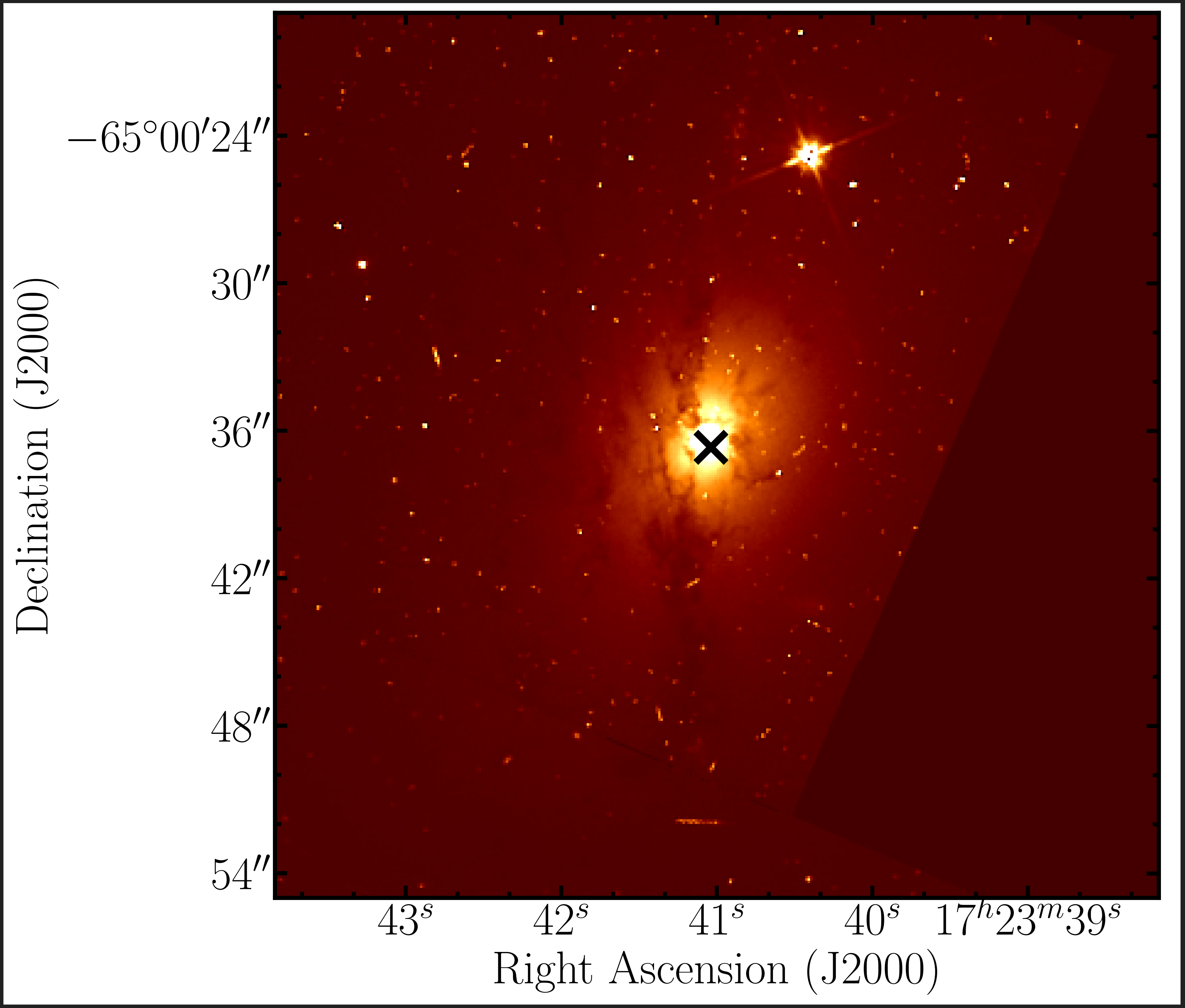


- Inner 75 pc
  - brightest H_2 line
  - component at redshifted velocities
    - gas not rotating within the disk

[Maccagni et al., 2016]

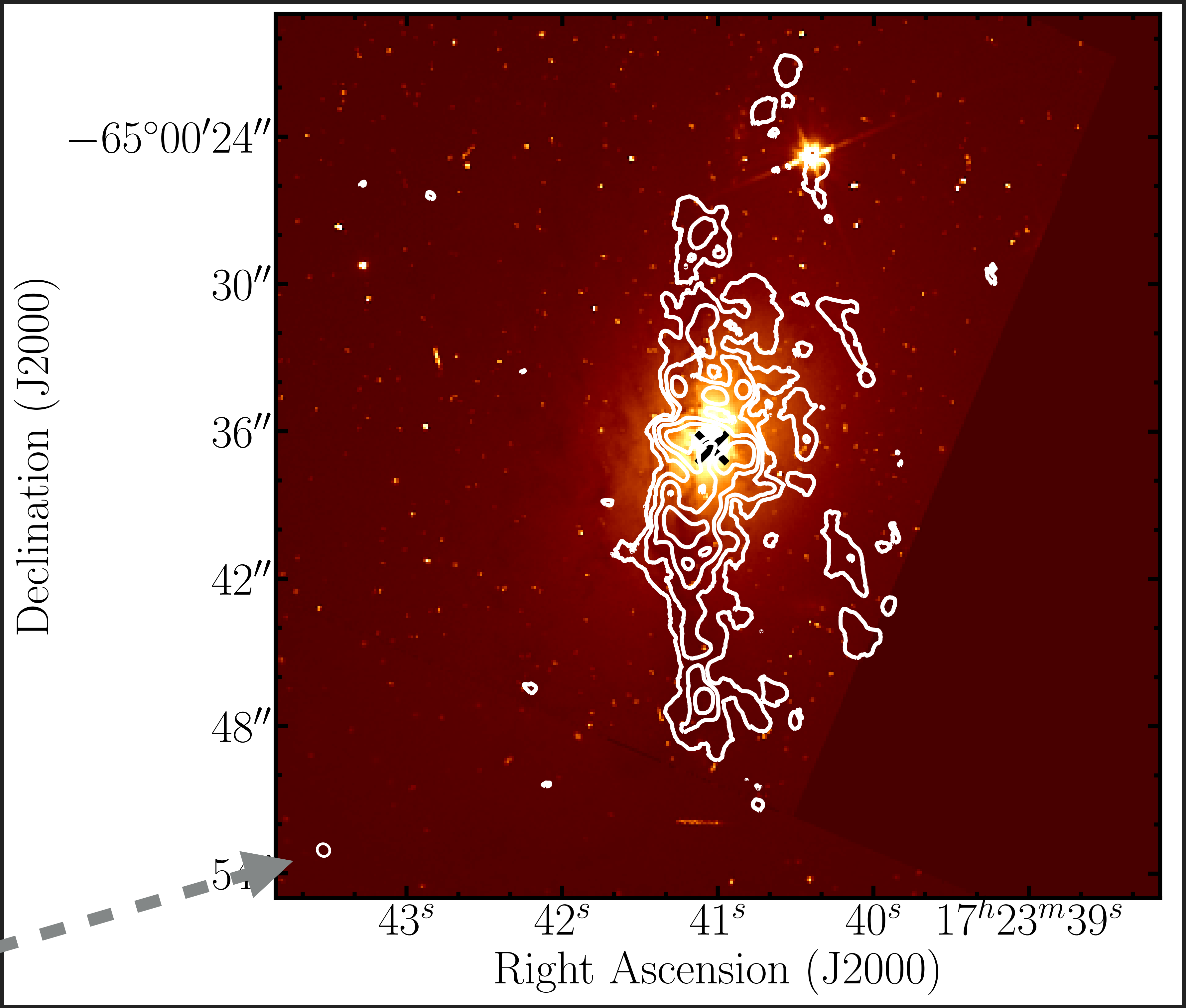
Higher spatial and spectral resolution

- ALMA can observe cold H_2 traced by CO
- Cycle 3 observations: CO (2-1) [P.I. Maccagni]
- Spatial resolution: 0.2" / 82 pc
- FOV : 15x15 kpc
- Δv = 10 km/s



CO (2-1) seen by ALMA

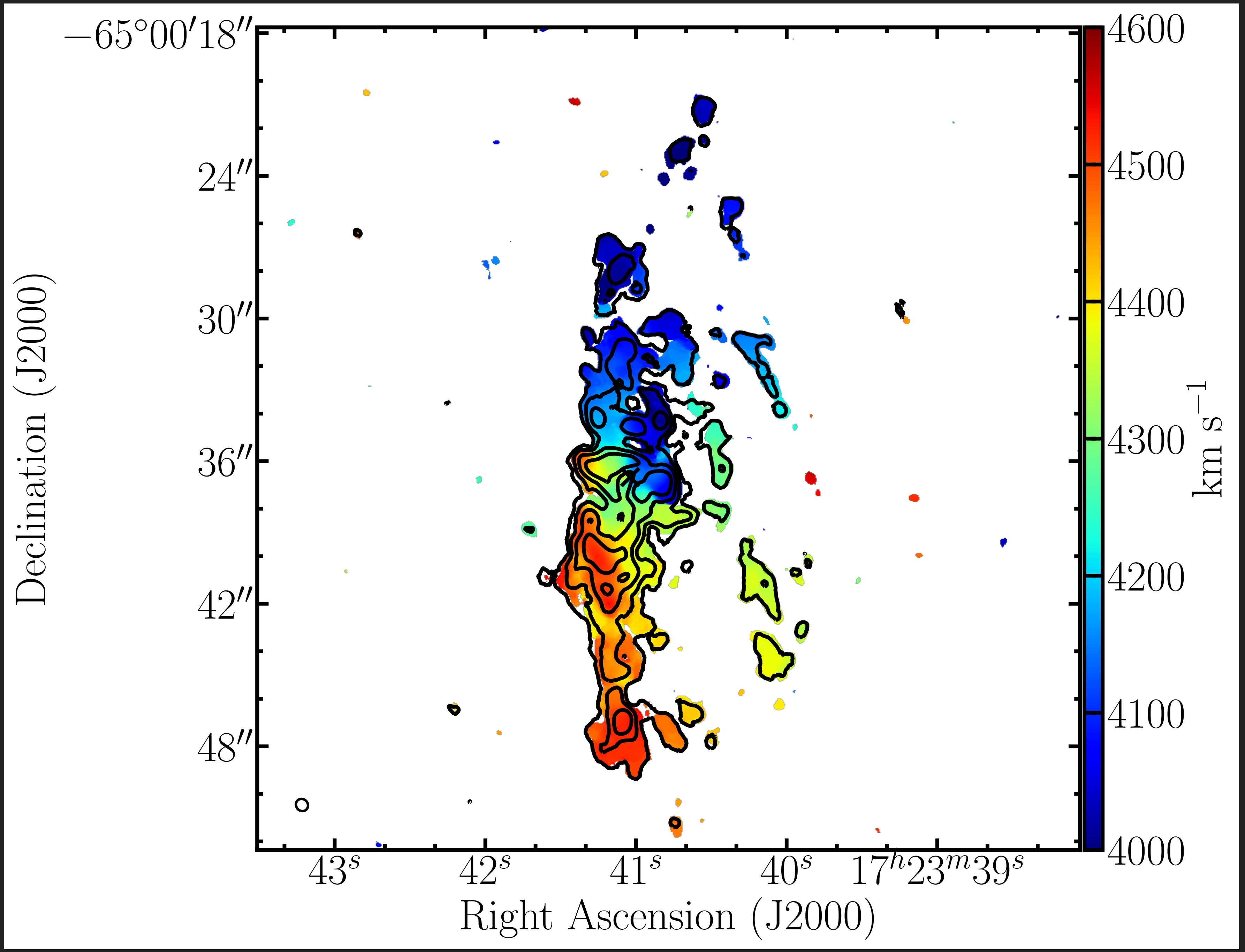
- **Clumpy medium**
  - **Molecular clouds follow the dust lane**
  - **Centre: complex distribution**



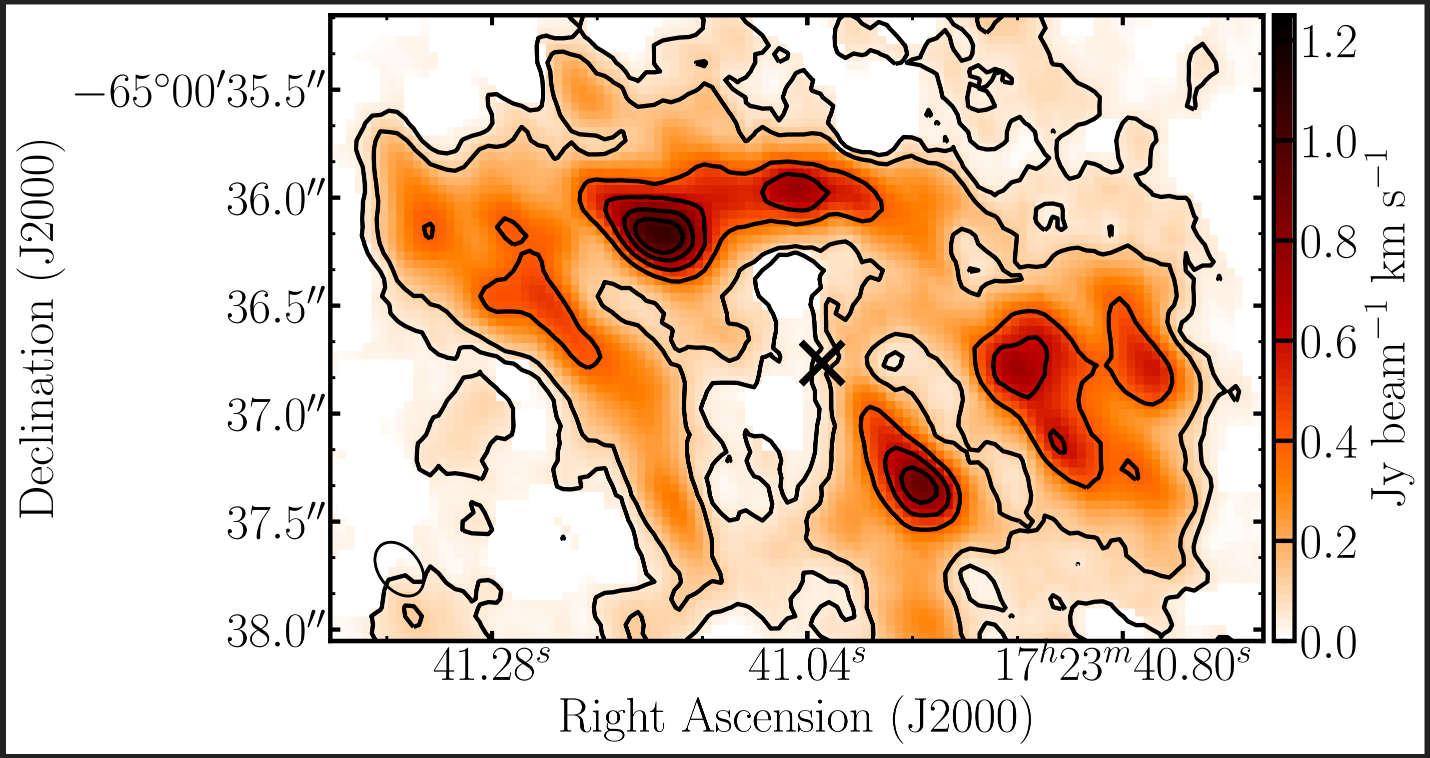
Beam: 0.5”x0.5” (120 pc)

Velocity field of the CO (2-1)

- **CO follows rotation of other components of the galaxy, (stellar body, dust lane, HI disk)**
- **Major axis aligned N/S**
  - **change in the central regions**

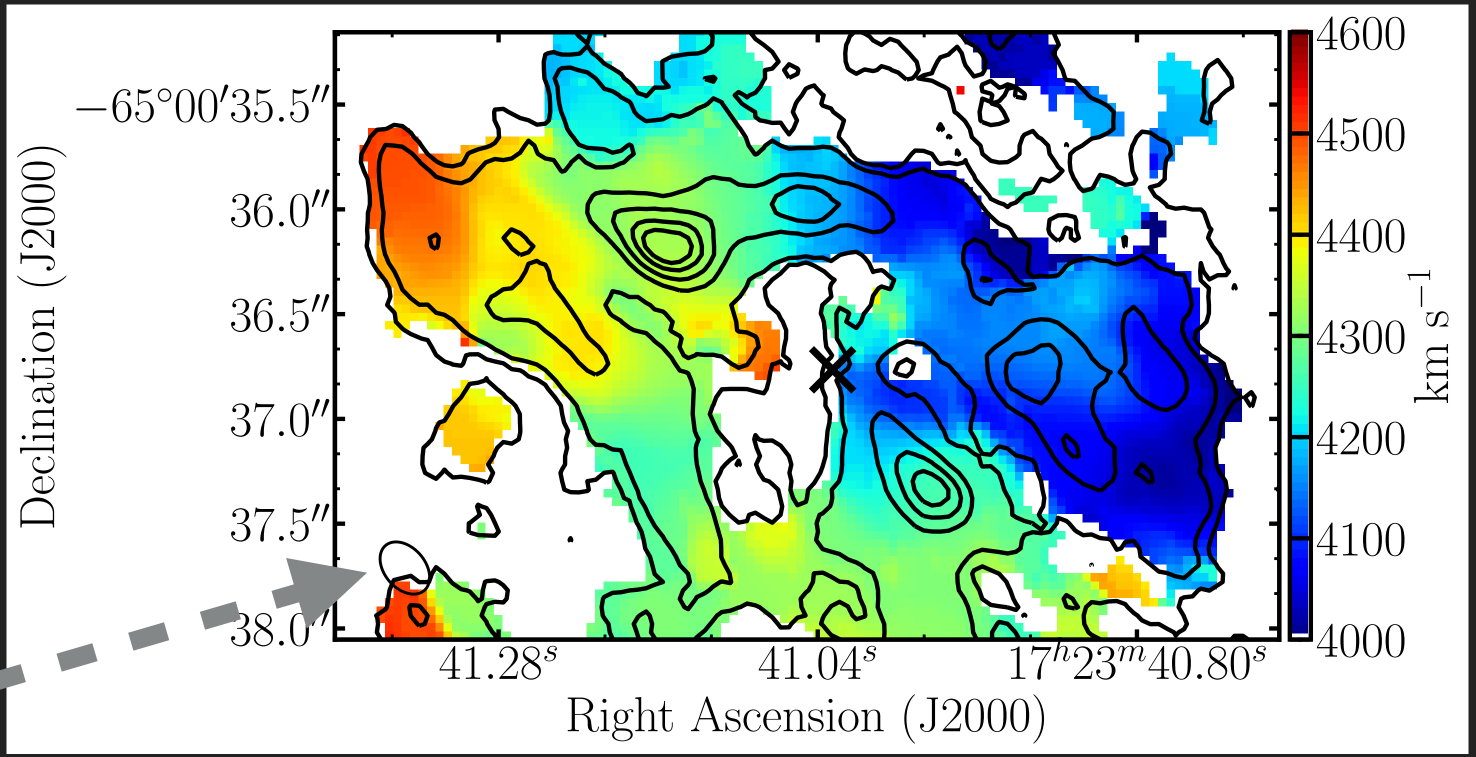


The circumnuclear disk of CO



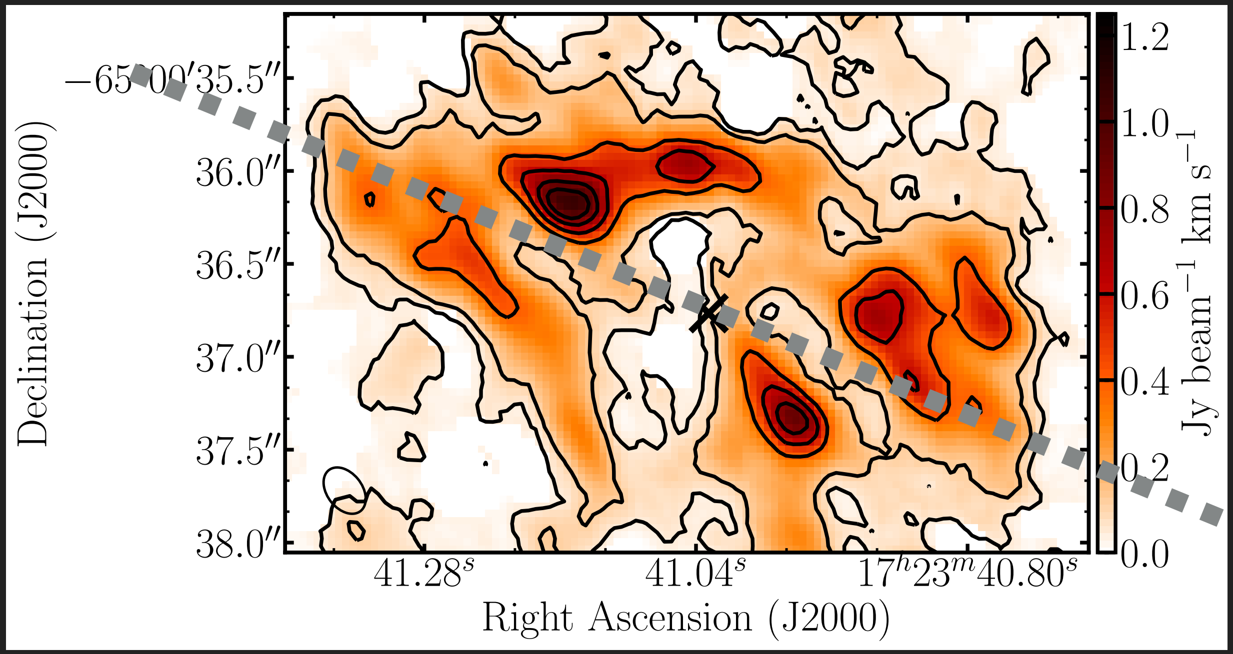
- Clumpy circumnuclear disk
- Resolved molecular clouds
  Size ≤150 pc
  - Velocity width ≤ 80 km/s

- Disk dominated by rotation
  - Major axis ⊥ outer gas

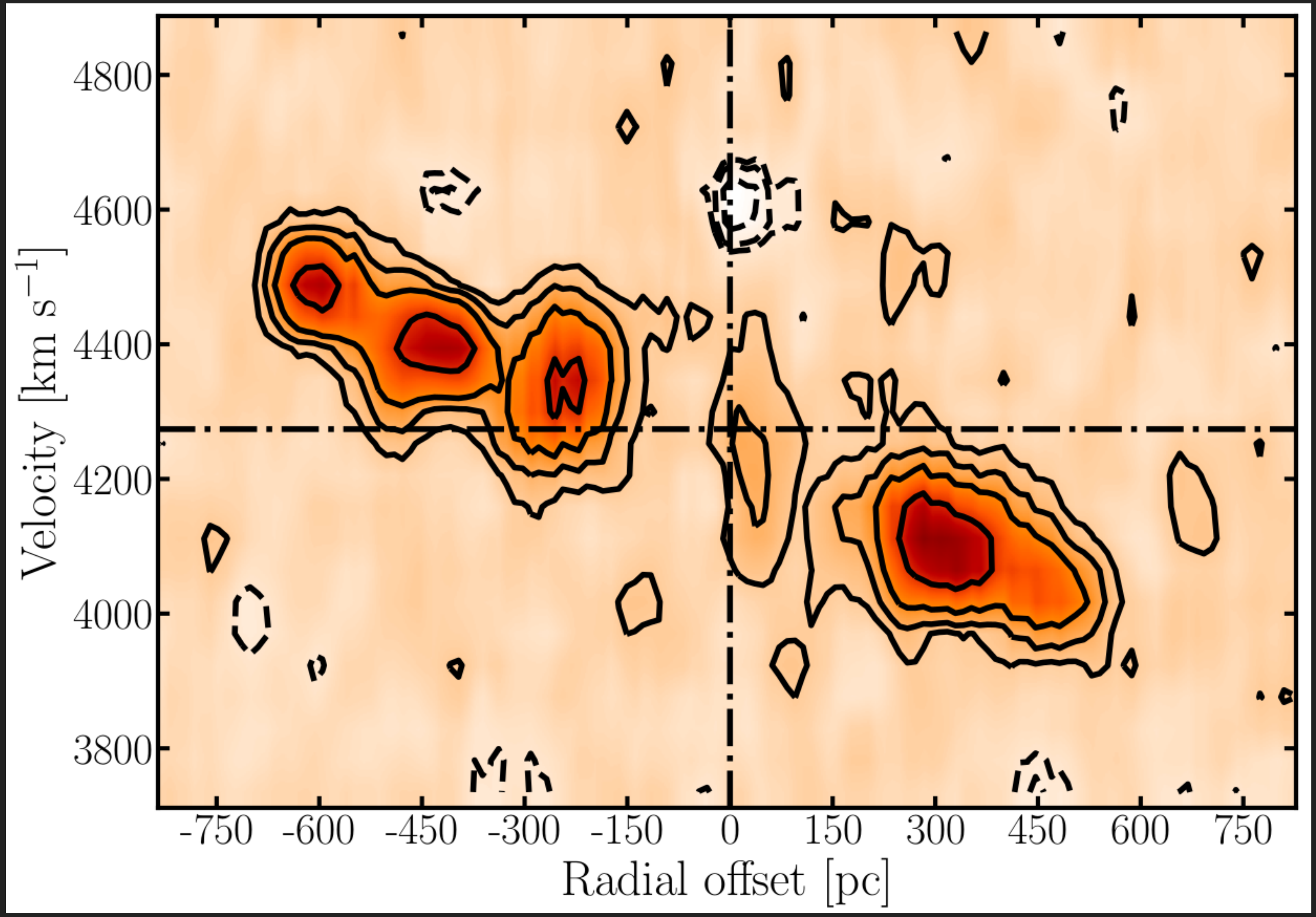


Beam: 0.28”x0.28” (82 pc)

The circumnuclear disk of CO



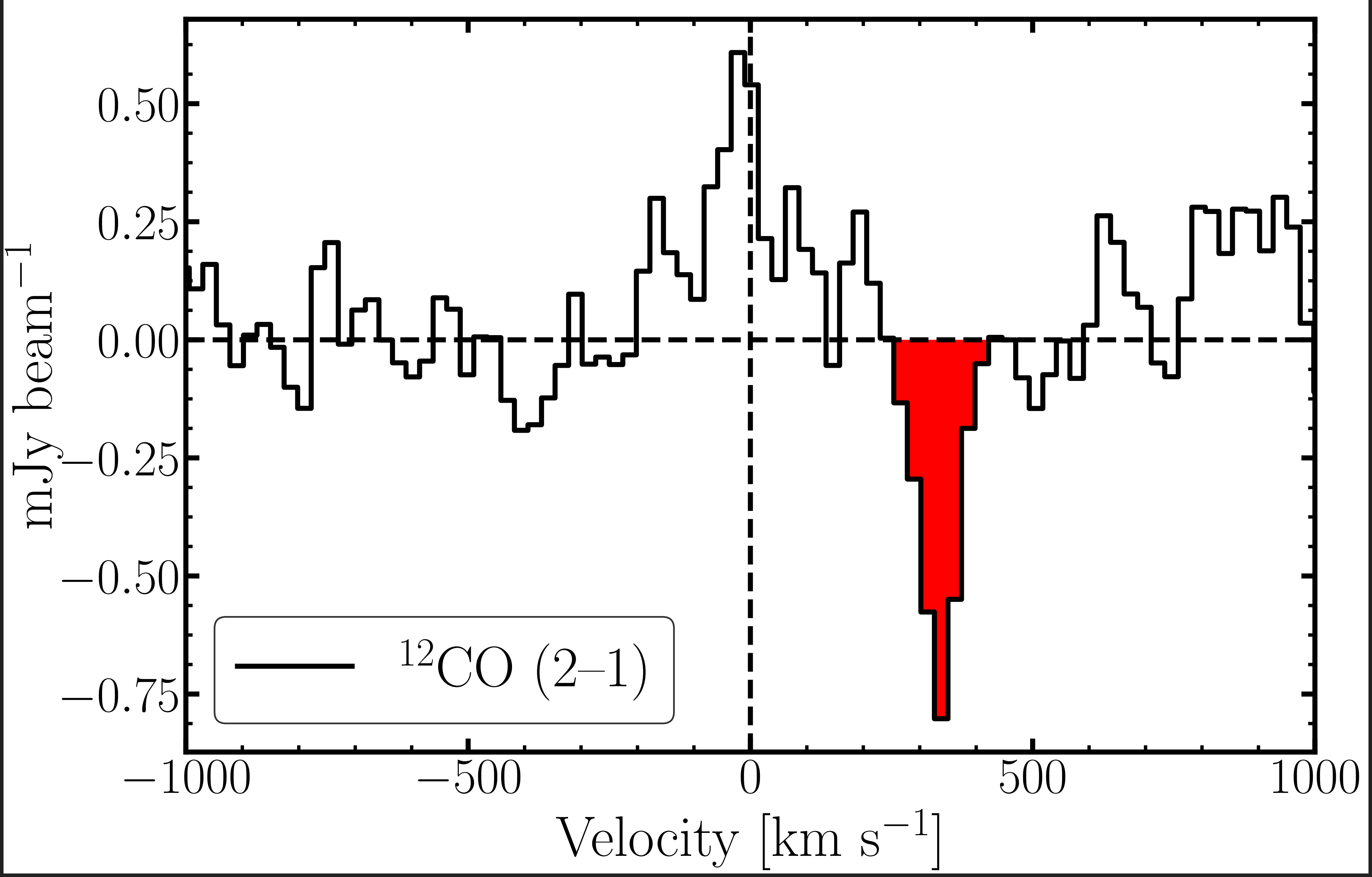
- Position velocity diagram along the major axis of the disk
  - Smooth gradient in velocity
    - Disk in regular rotation



- Redshifted absorption against the radio source
  - In-flowing gas

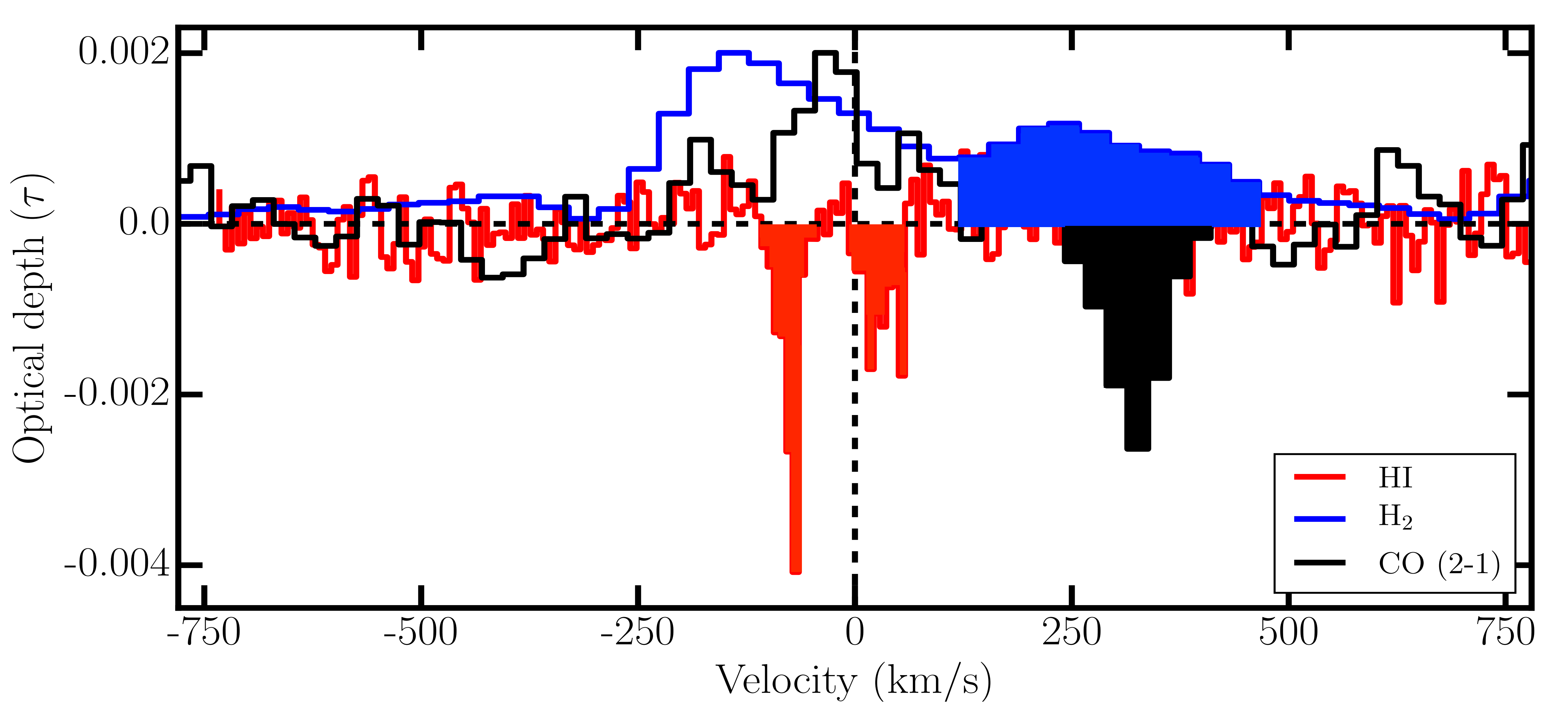
Cold gas clouds falling onto the radio AGN

- **Redshift w.r.t systemic velocity: + 350 km/s -> gas falling towards AGN**
- **FWHM = 54 km/s >> 4 km/s (dispersion molecular clouds)**
  - **Several clouds are falling onto the radio source**
  - **Possibly, the clouds are shredded while falling.**



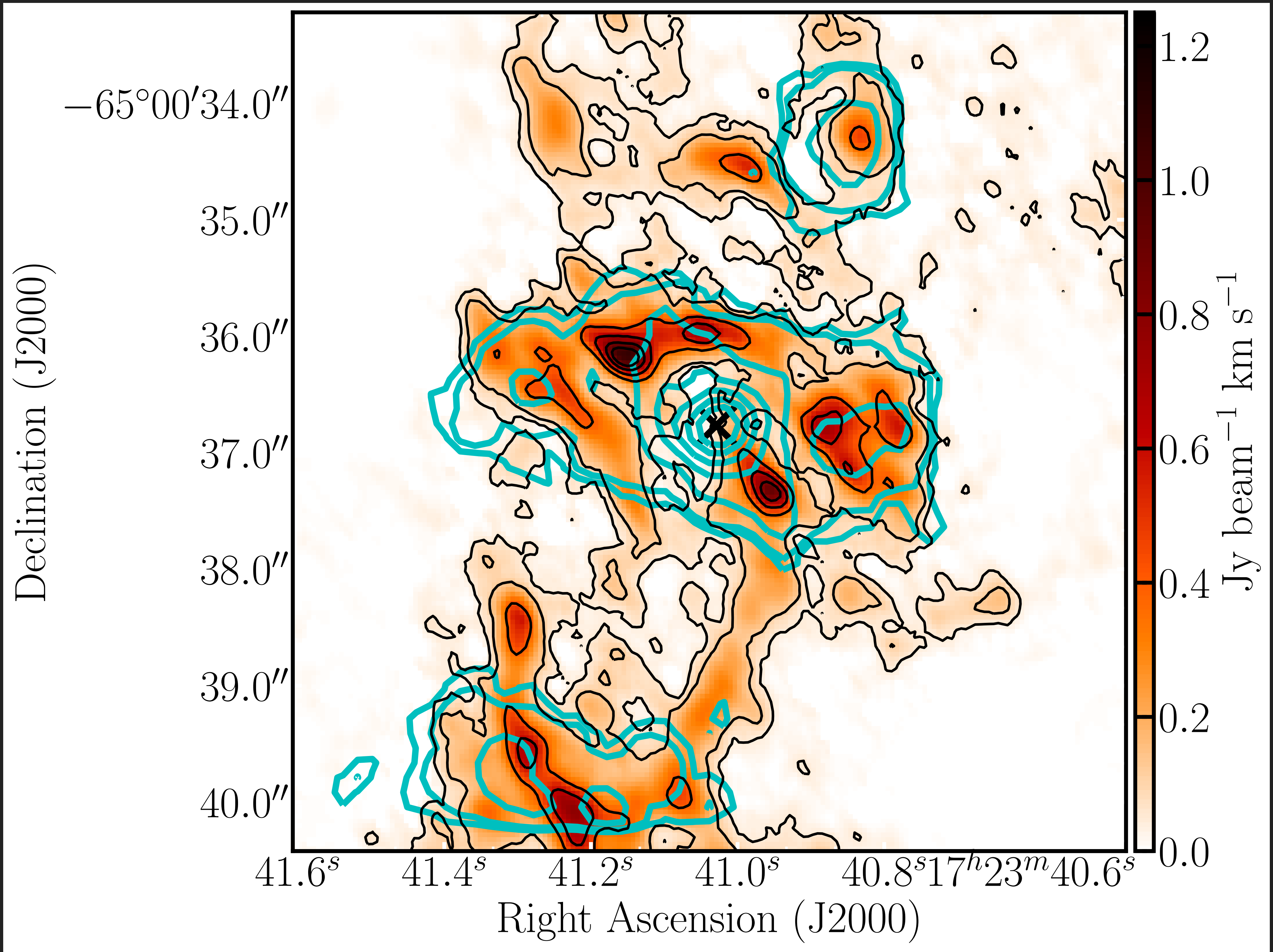
Molecular clouds accreting onto the SMBH

- **HI kinematics differ from the H_2 and CO**
  - **In the centre, there must be multiple clouds of gas with different physical conditions**
    - **Phase of the gas, kinematics, temperature and density**



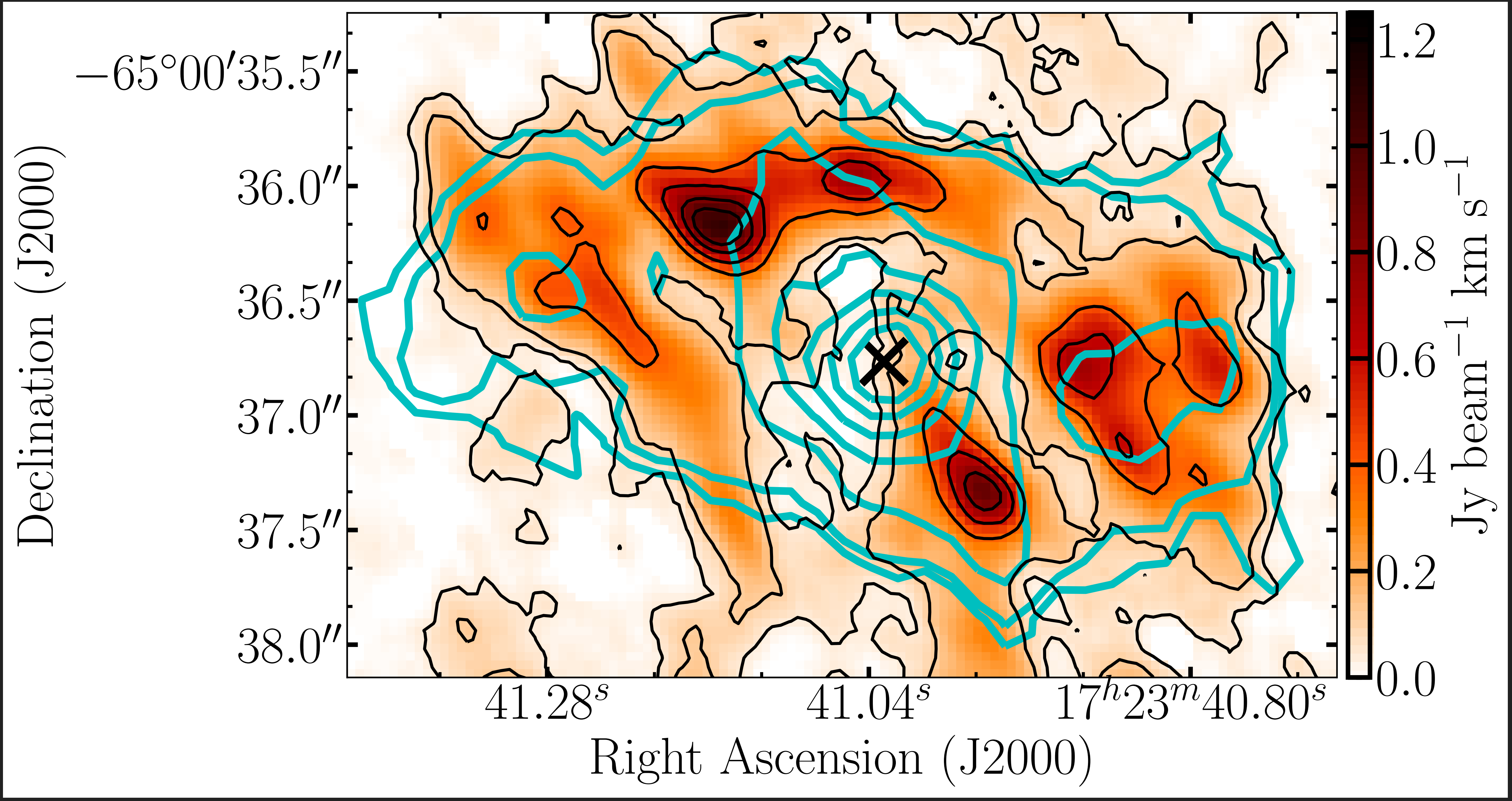
The warm H_2 and the cold CO

Warm H_2 detected only at r<1 kpc



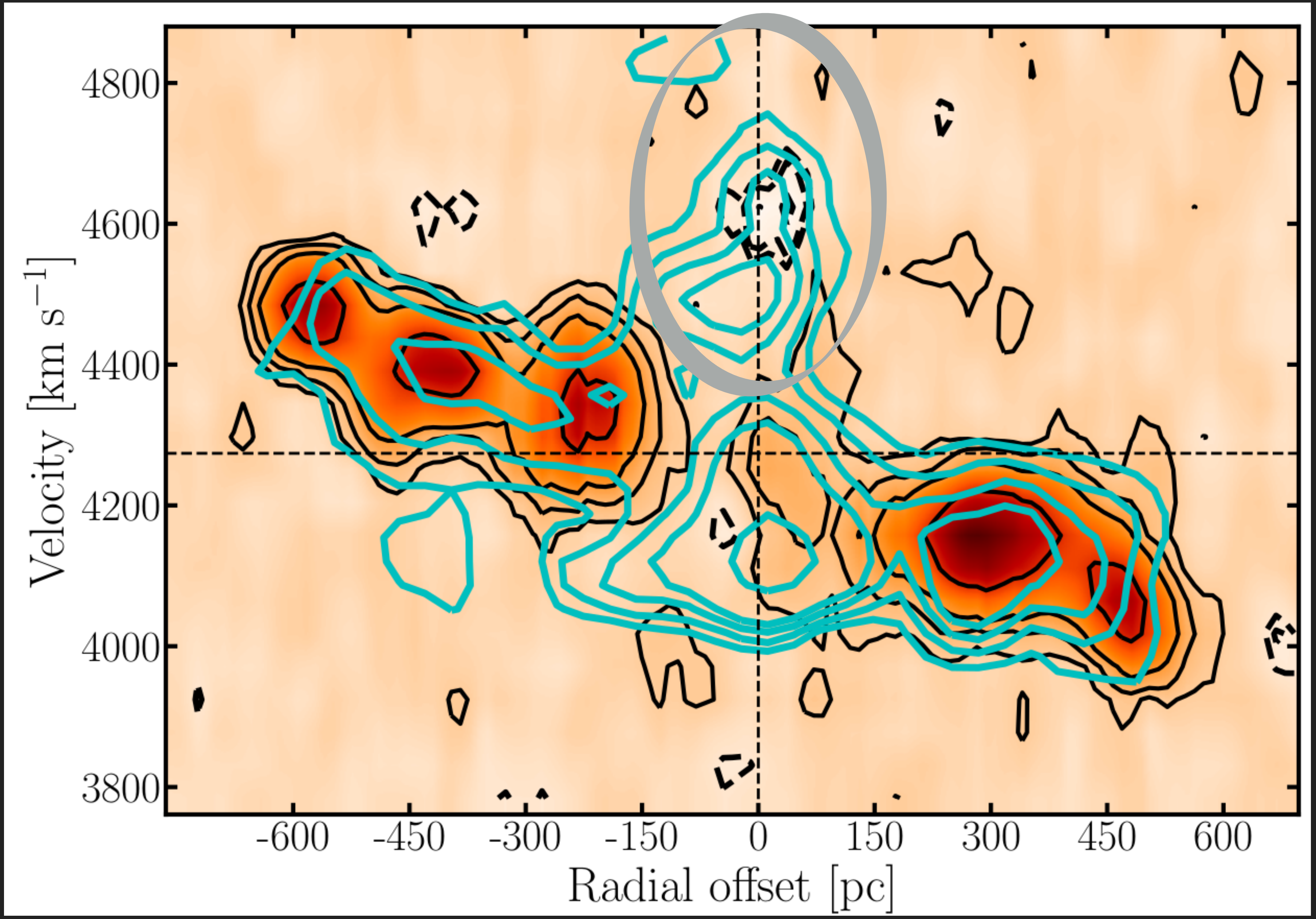
The warm H_2 and the cold CO

- Centre: N_{H2} / N_{CO} ~ 110
- Disk: N_{H2} / N_{CO} ~ 16
  - CO does not trace all the molecular hydrogen in the centre.
- CO ionised before warm H_2.
- The AGN is changing the conditions of the ISM



Molecular clouds accreting onto the SMBH

- CO absorption co-located with warm H_2 in emission with same deviating kinematics
  - Molecular clouds in the innermost 75 pc accrete onto the SMBH
  - Models of chaotic cold accretion (e.g. Gaspari et al. 2017) well match all indications of cold molecular clouds falling onto the SMBH we found.

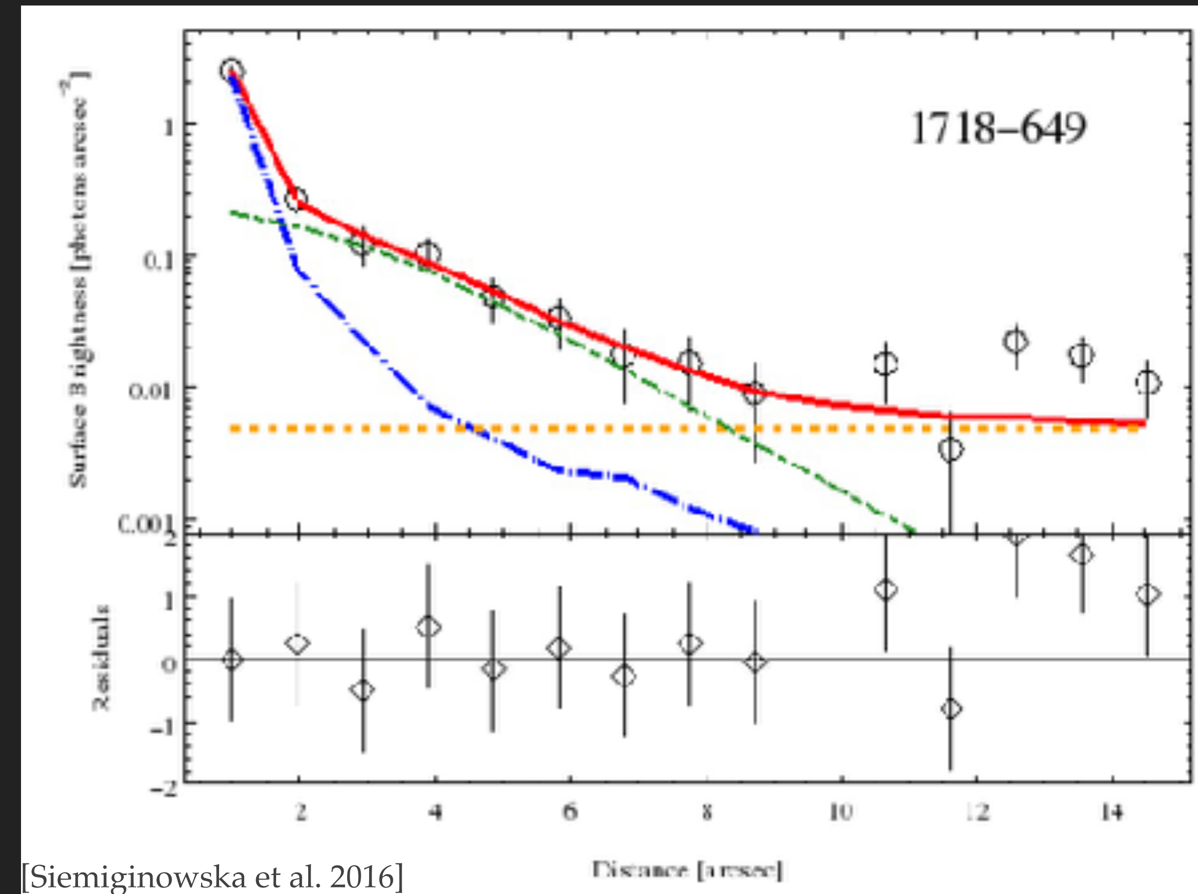


Summary

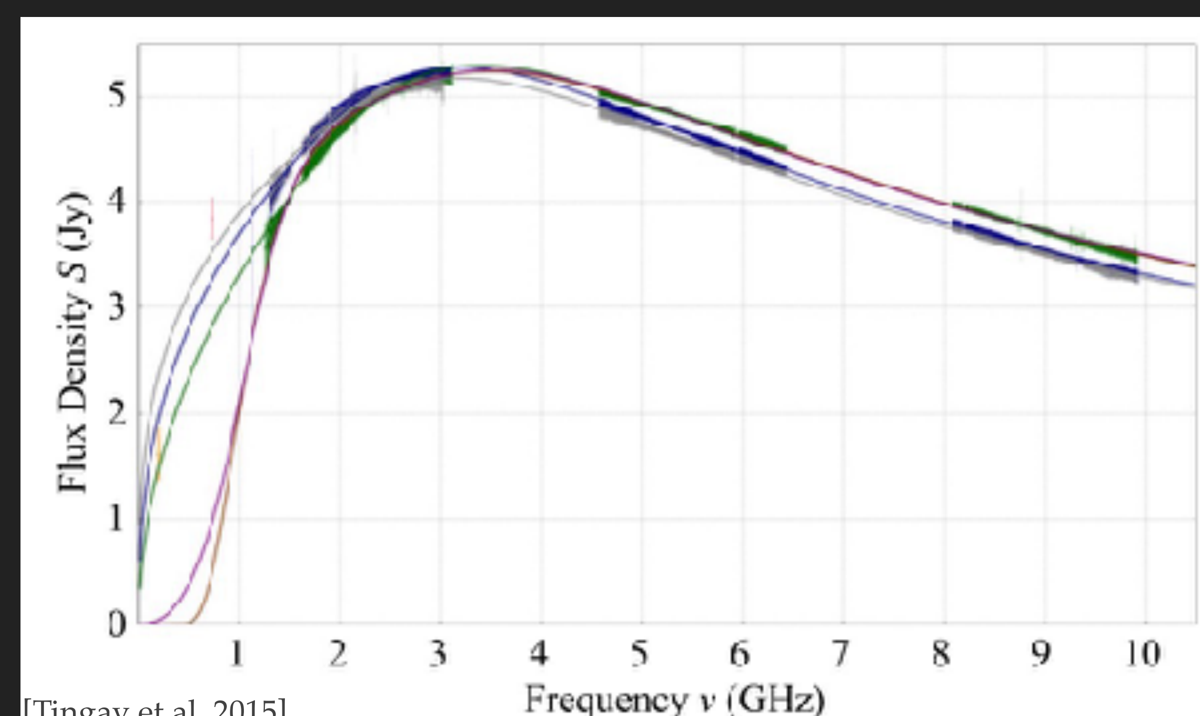
- HI [Maccagni et al., 2014]
  - Mergers/secular events did not trigger this radio AGN
  - In the centre, a population of clouds of HI has strong radial motions
- H_2 [Maccagni et al., 2016]
  - Circumnuclear disk of H2, regularly rotating (r < 650 pc)
  - r < 75 pc: gas deviates from regular rotation with redshifted velocities, may be falling onto the SMBH
- CO (2-1) [Maccagni et al., submitted]
  - Redshifted (+350 km/s) absorption (FWHM ~ 54 km/s)
    - Several clouds of cold gas are falling towards the AGN
    - Clouds close to the SMBH: 75 pc.
      - Molecular gas fuels the AGN through chaotic cold accretion
  - r<75 pc: CO does not trace same H2 than at larger radii.
    - Radio AGN is changing the physical conditions of the gas.
- Future prospects
  - CO (3-2), ALMA cycle 5 observations [P.I. Maccagni]
    - physical conditions of ring (pressure, density, ionisation)
- PKSB 1718-649 is not alone!
  - Centaurus A [Espada et al 2017], NGC 5044 [David et al. 2017], (for example) have warped circumnuclear disks of molecular gas.
    - Within the disk, small clouds have strong radial motions, and could fuel the AGN.

Ancillary Observations

- **Optical** [Filippenko et al. 1985]
  - LINER, weak narrow lines
  - line ratios show different densities / temperatures in the circumnuclear ISM
- **X-Rays** [Siemiginowska et al. 2016]:
  - Compton thick medium ≤ 6” (1.8 kpc)
  - X-Ray variability [Beuchert et al. in prep]
- **Cosmic Rays** [Migliori et al. 2016]
  - generate from IC in circumnuclear ISM
- **Radio Variability** [Tingay et al. 2015]
  - clouds of gas in the central regions
  - link Radio/X-Ray variability under investigation [Moss et al. in prep]



[Siemiginowska et al. 2016]



[Tingay et al. 2015]