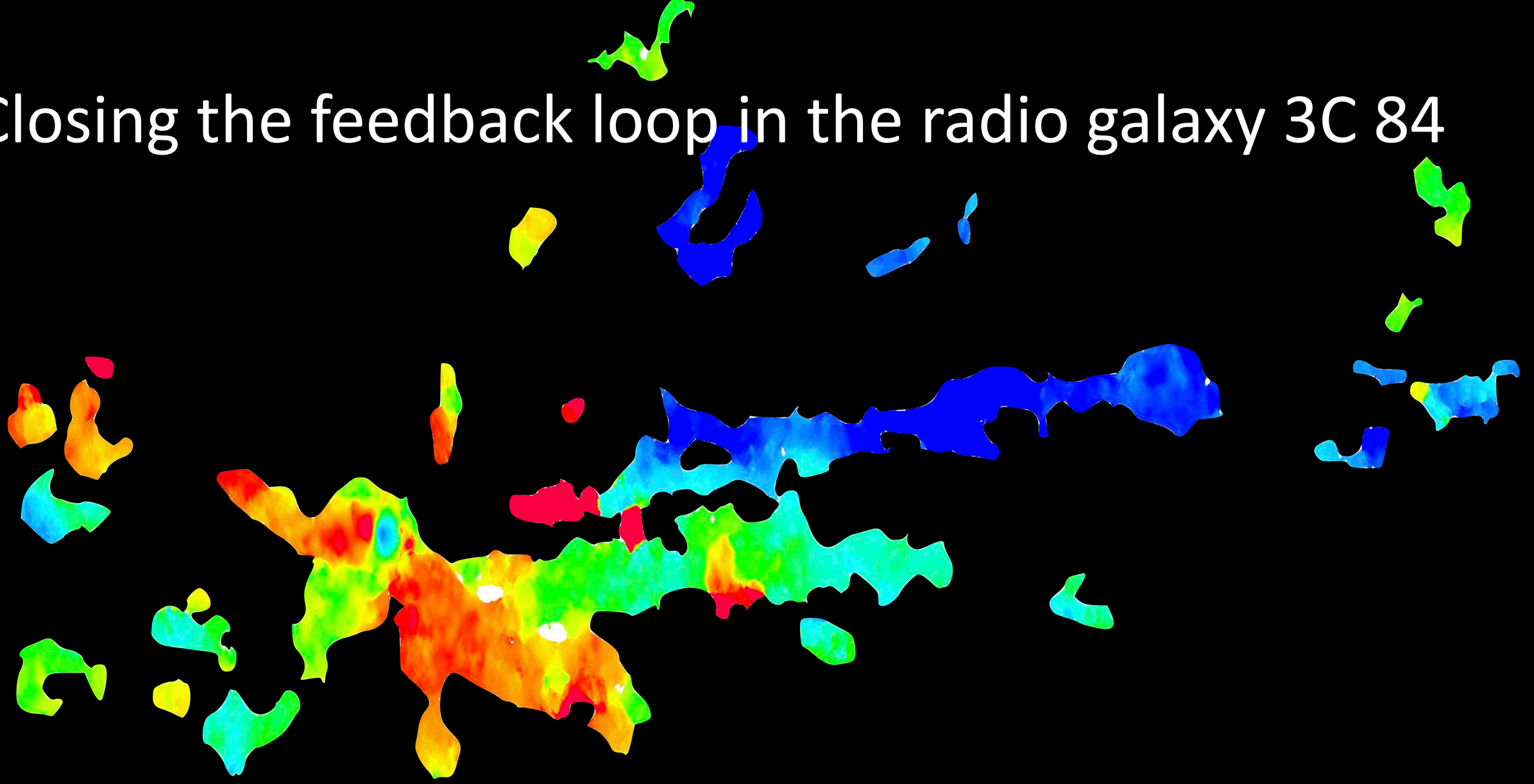
Closing the feedback loop in the radio galaxy 3C 84



Tom Oosterloo & Raffaella Morganti (ASTRON & Kapteyn Inst. Groningen)
Suma Murthy (JIVE)

Context: overall picture of radio AGN feedback in cool-core clusters

Tracing the interplay between radio jets and the ISM/ICM and their role in galaxy evolution

Direct impact from newly born radio jet can drive outflows in all components of the ISM, in particular in the cold ISM

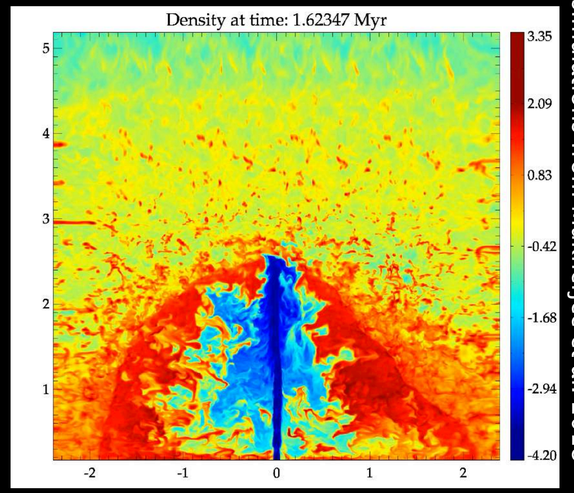
At later stages, the jet evolves and expands to larger scales, inflating bubbles in the CGM/ICM, heating the ICM

Affects star formation and growth of galaxy, but what keeps the AGN active? How does the gas flow toward the AGN to feed it?

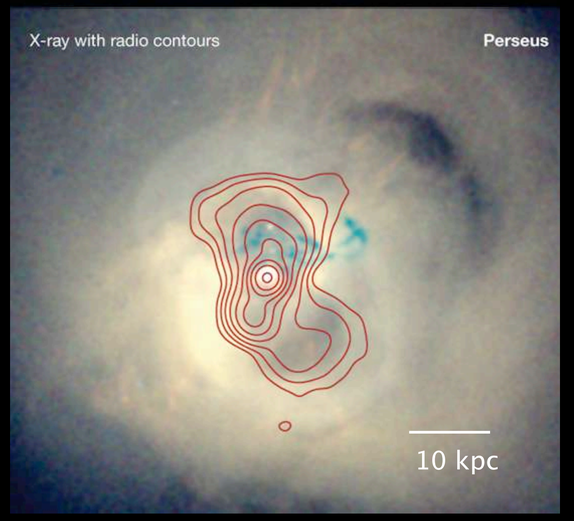
What can we learn about this from the distribution and kinematics of the cold gas in the regions around 3C 84, a radio AGN in a cool-core cluster?

VLA and VLBA observations of H I in absorption
Recalibrated ALMA observations CO(2-1)

Morganti+ 2023
Oosterloo+ 2024



simulations from Mukherjee et al. 2018



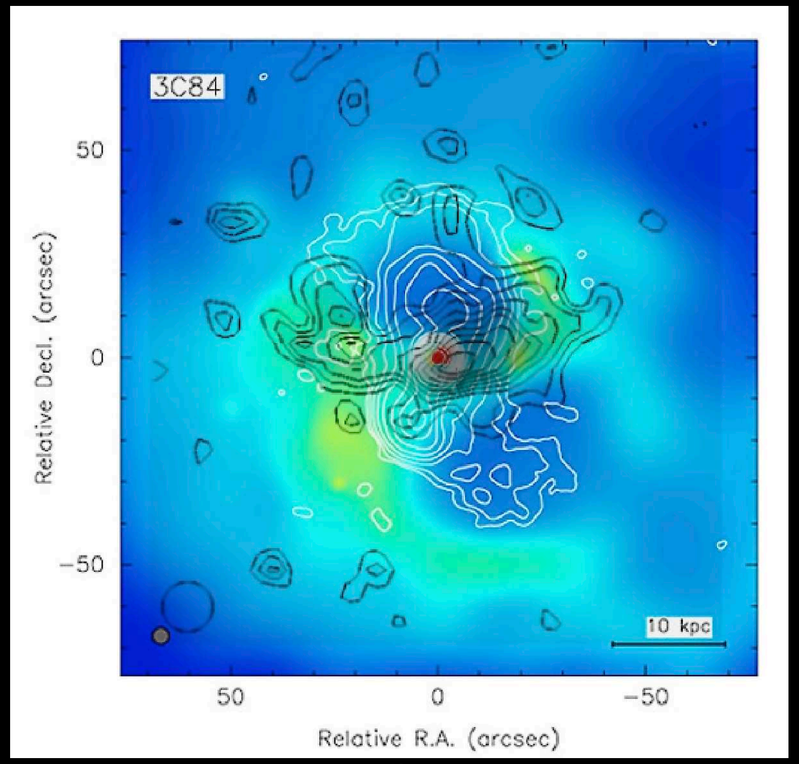
Fabian+ 2006

3C 84 (Perseus A; NGC 1275)

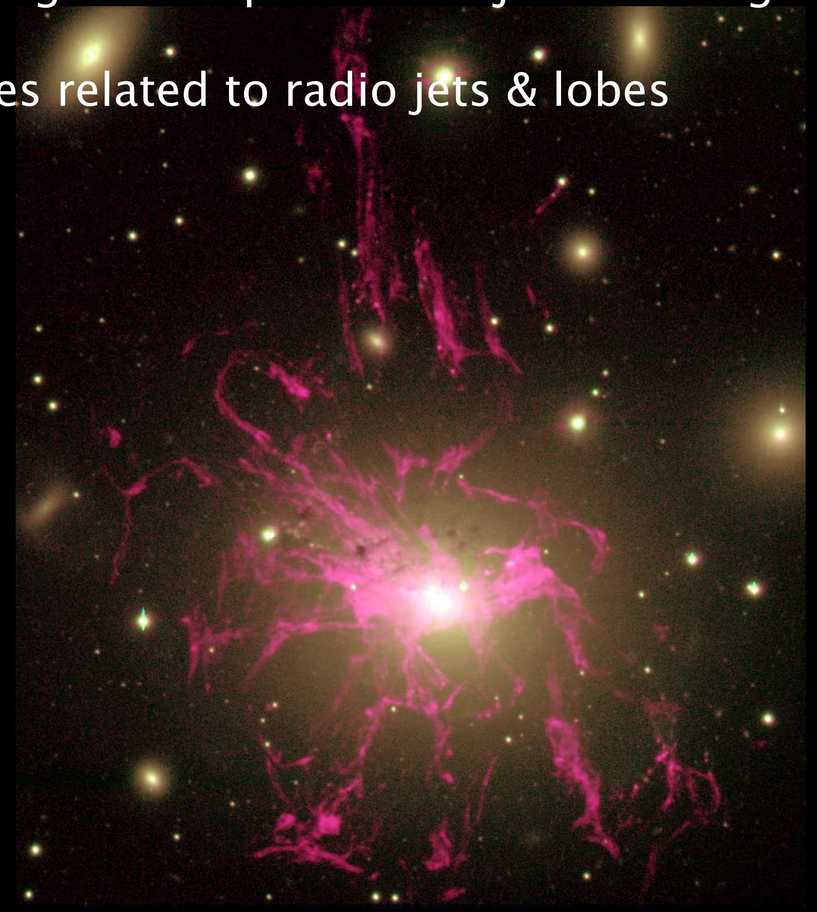
famous radio galaxy in the centre of the Perseus cluster; cool-core cluster, rich in gas in all phases

radio structures on all scales; clear signs of impact of the jets on the gas

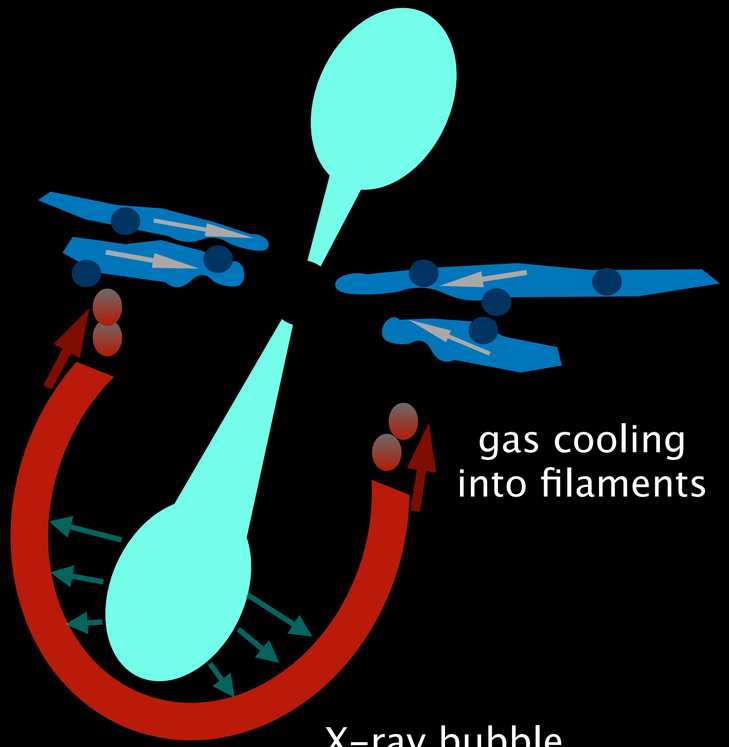
mix of heating and cooling processes related to radio jets & lobes



Radio contours (Pedlar+ 90) on
X-ray image (Fabian+ 06)
Molecular filaments (Salomé+ 06)



Hα image (Conselice+ 01)



What is the fate of the cold gas?
Does it feed the AGN?

Does the cooler gas feed the AGN?

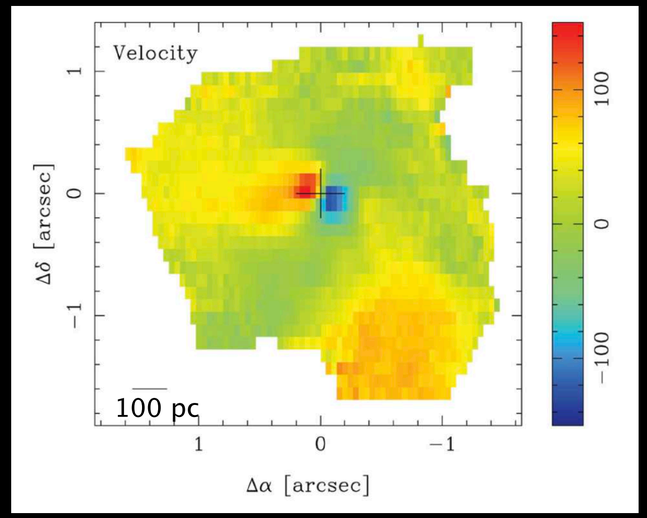
CND seen in molecular gas

fast Keplerian rotating inner component

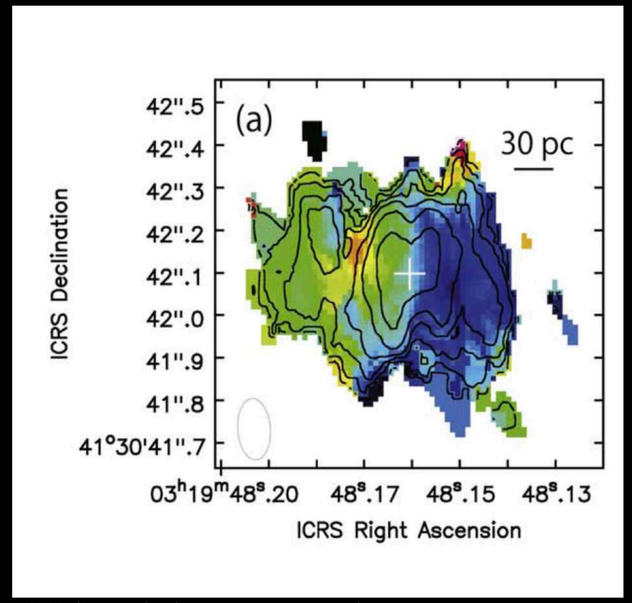
less regular at larger radii

large filaments

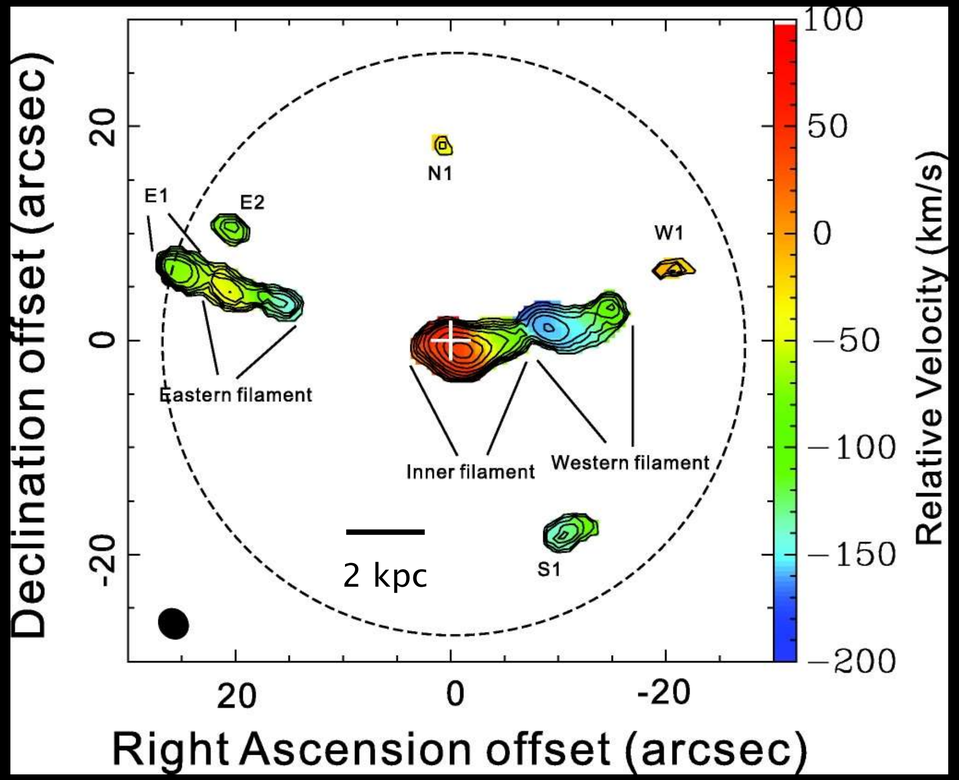
sign of accretion onto CND?



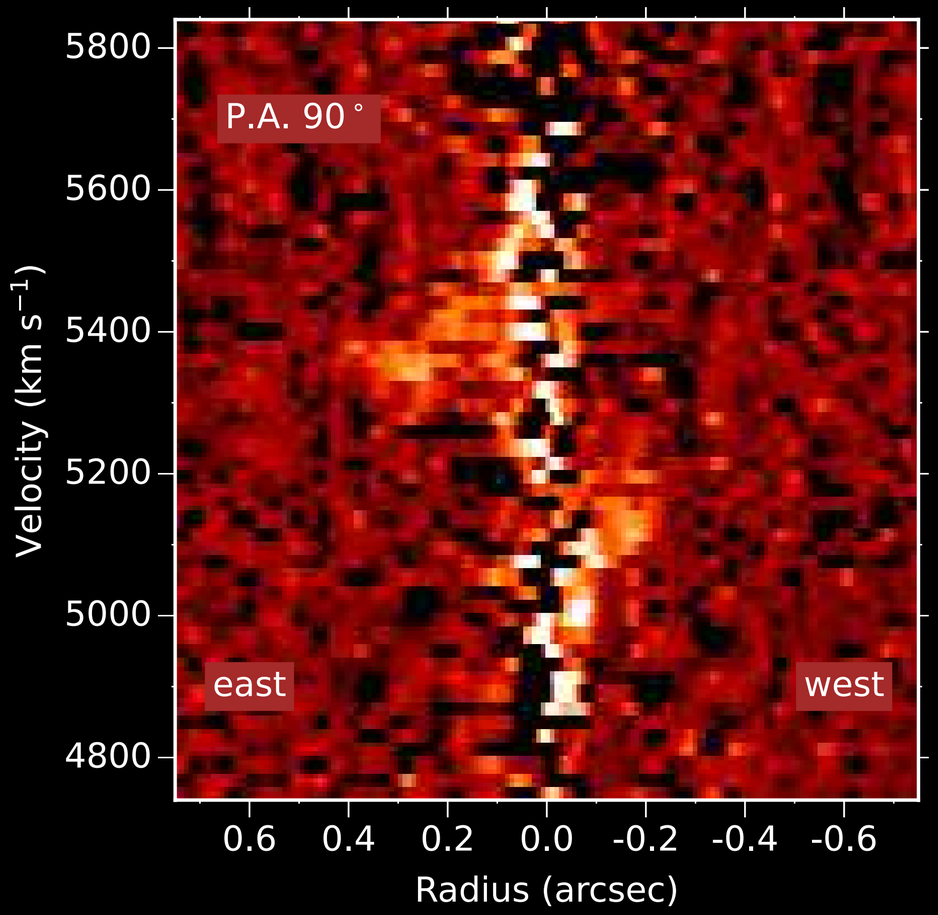
H_2 (Scharwächter+ 13)

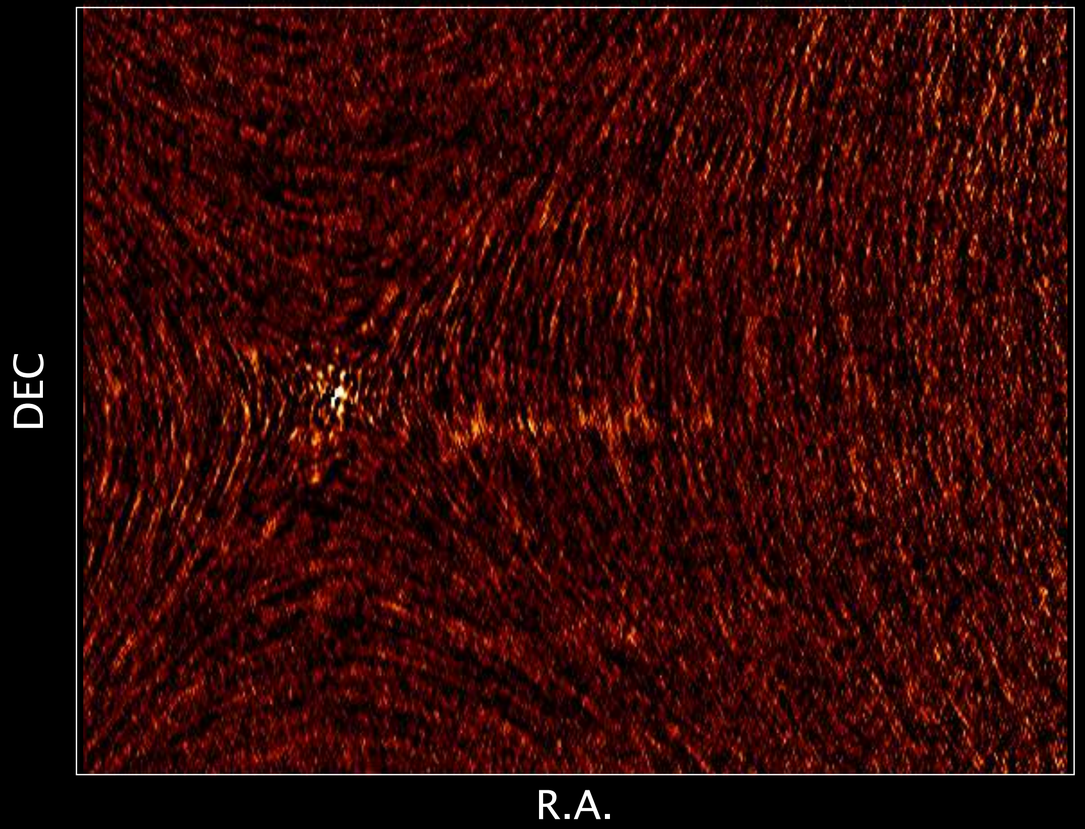


CO(2-1) (Nagai+ 19)



CO(2-1)
SMA 3 arcsec resolution Lim+ 08





Problem with ALMA data: 3C 84 is one of the stronger sources on the sky at 230 GHz.

No suitable spectral calibrator available.

Leaves large spectral artefacts in data cube

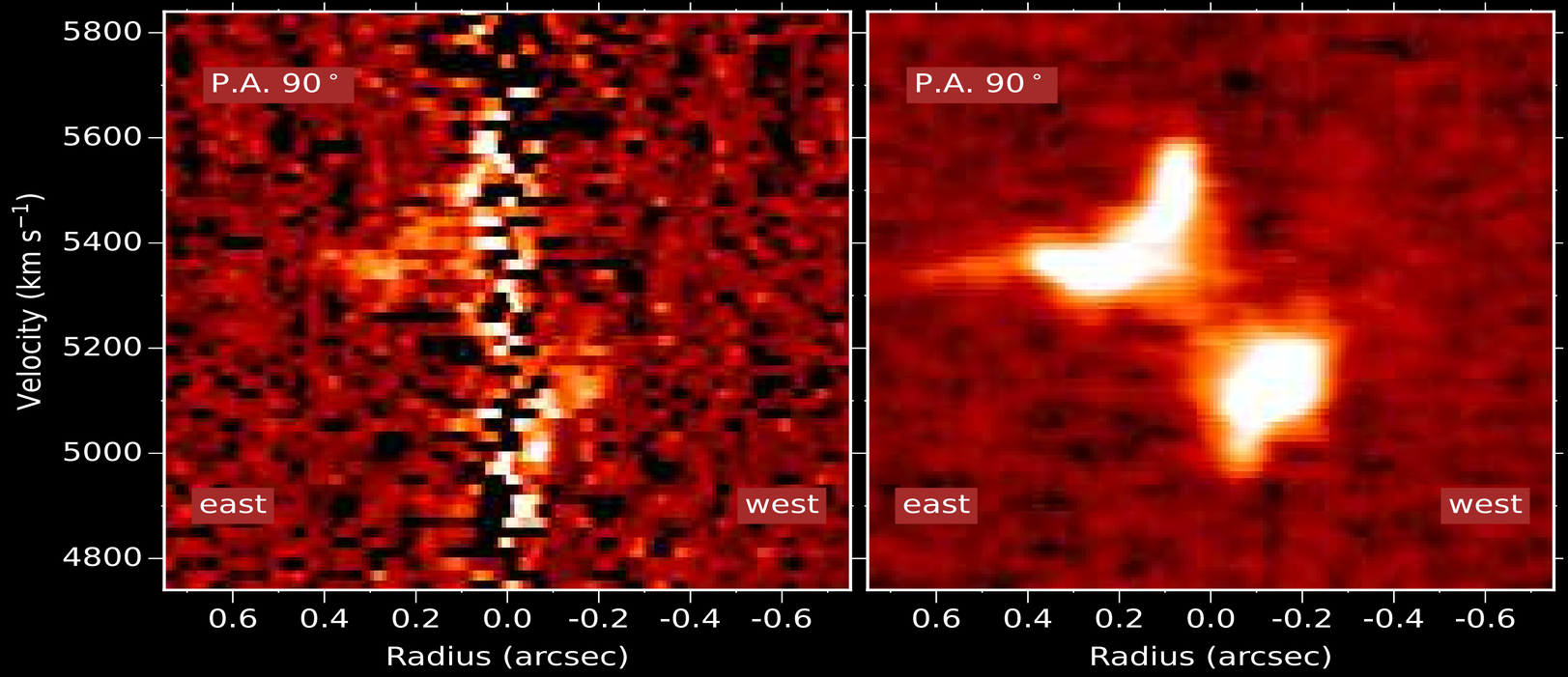
Trick:

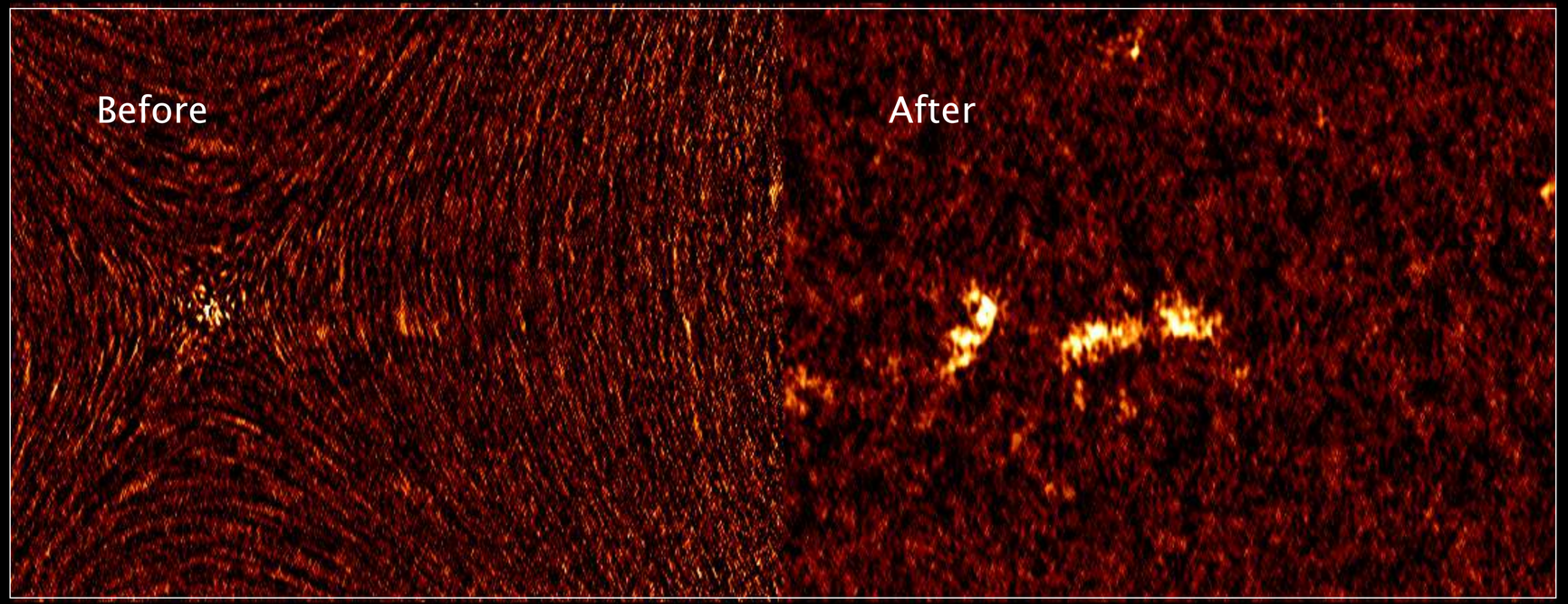
spectral selfcalibration.

Normally this does not work but here big improvement

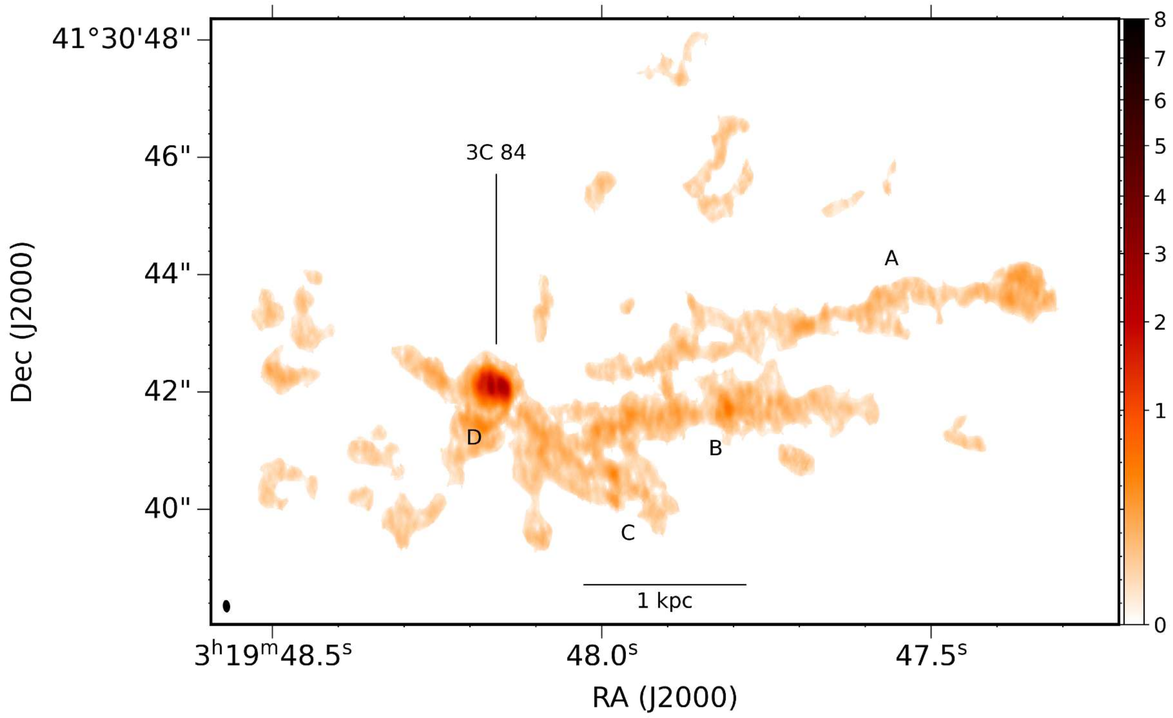
because the continuum is much much stronger than the line emission

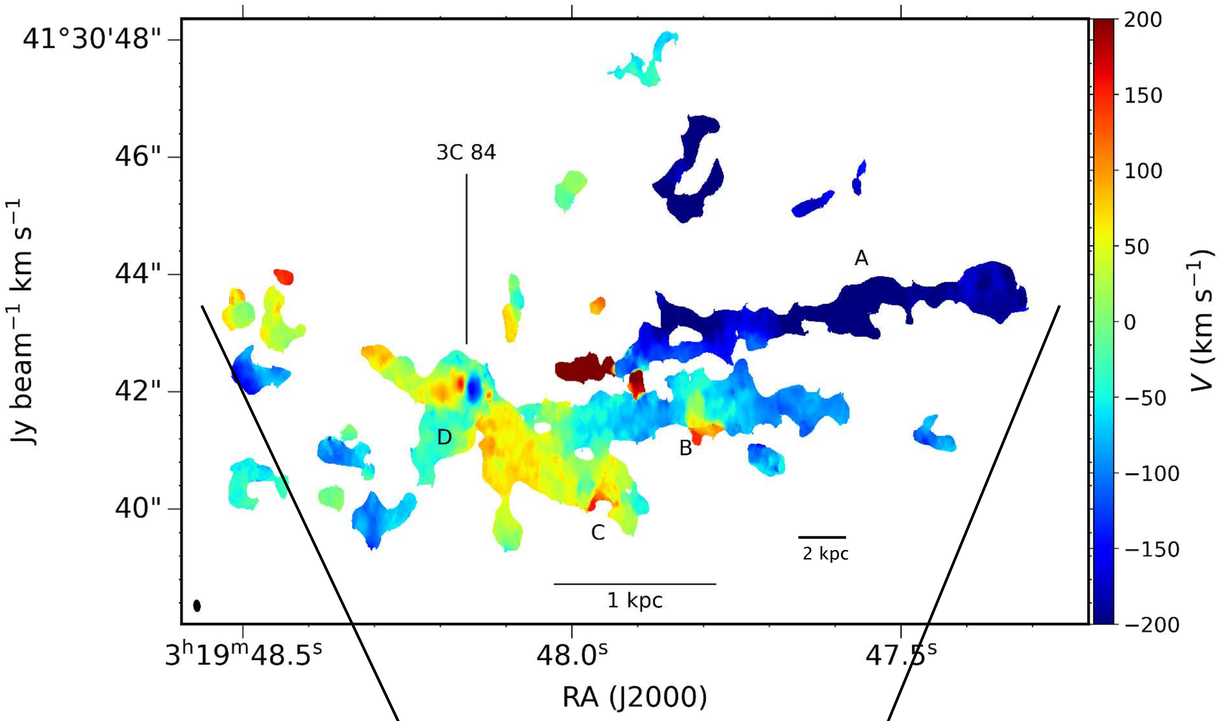
(except for central beam!!)





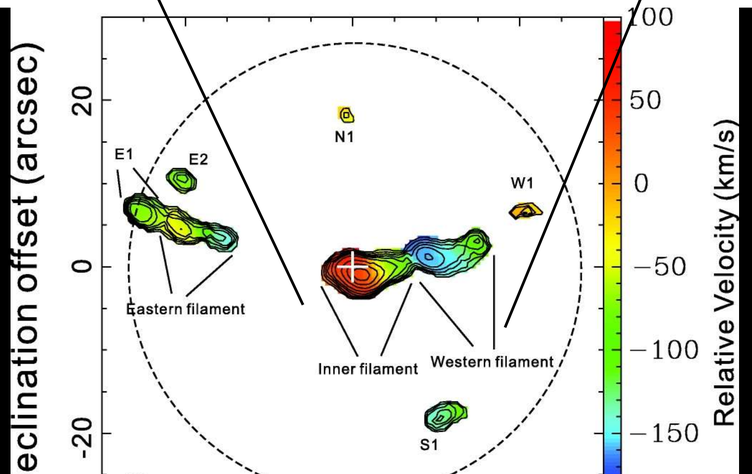
Improved data now show extensive emission filaments of molecular gas in the inner few kpc and much better data on the CND





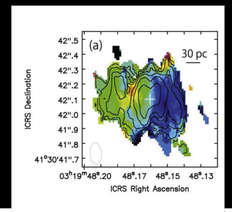
distribution of CO(2–1) over ~20 arcsec (about 7 kpc) with 0.15 arcsec (50 pc) resolution

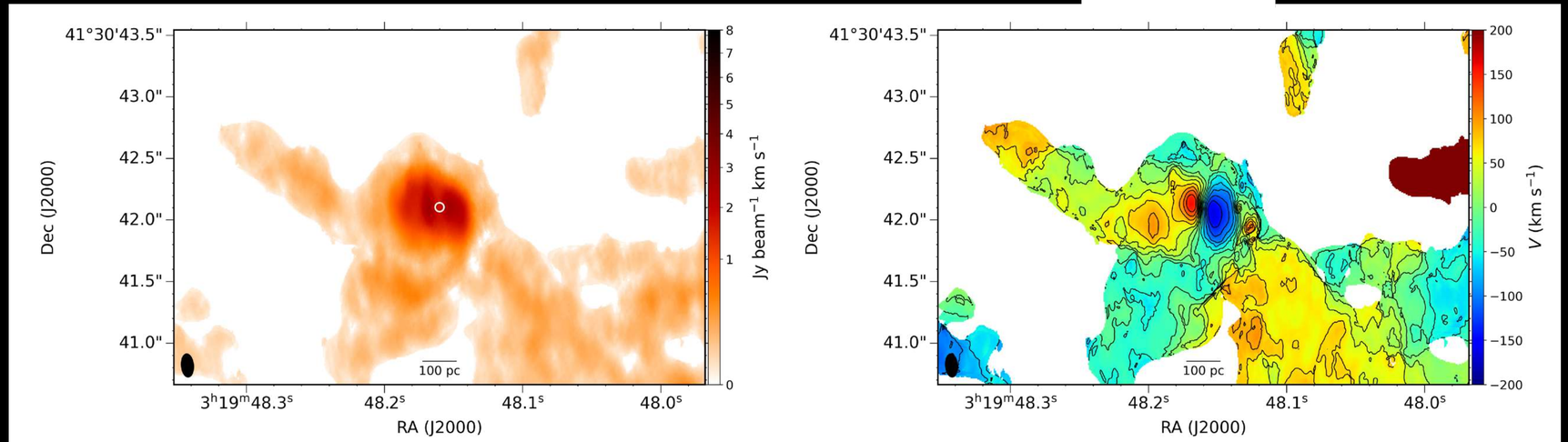
For the first time shows the connection between the circumnuclear disc (300 pc) and the kpc-scale filaments

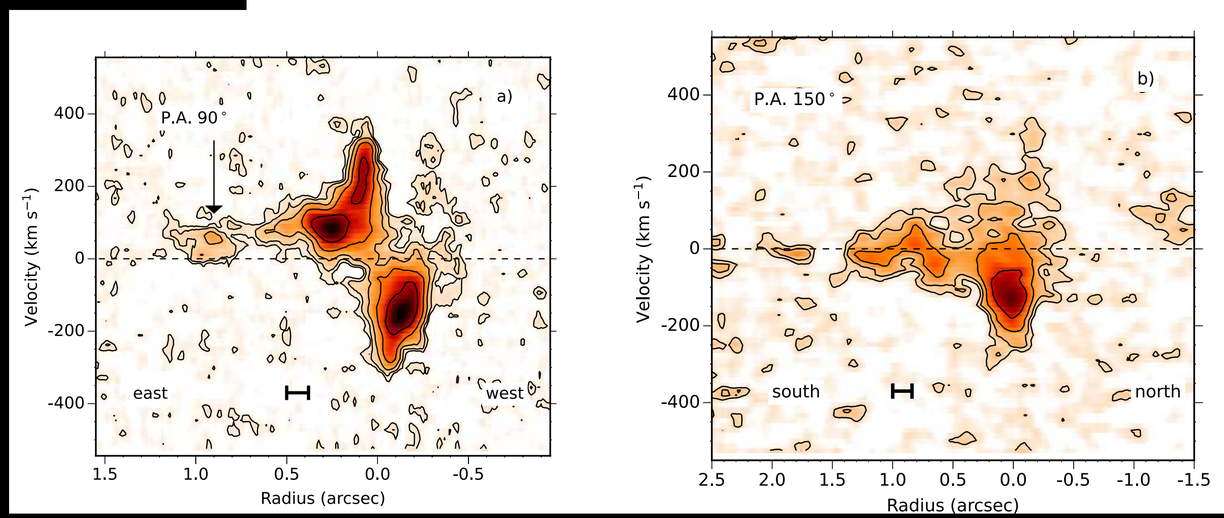


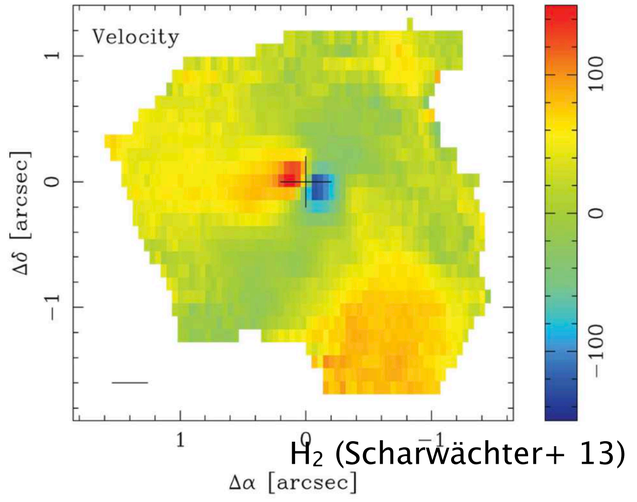
CO data shows that the less regular outer parts of the CND are connected to the large-scale filaments, suggesting accretion onto the CND.

CND is growing
and may re-orient over time, but not randomly







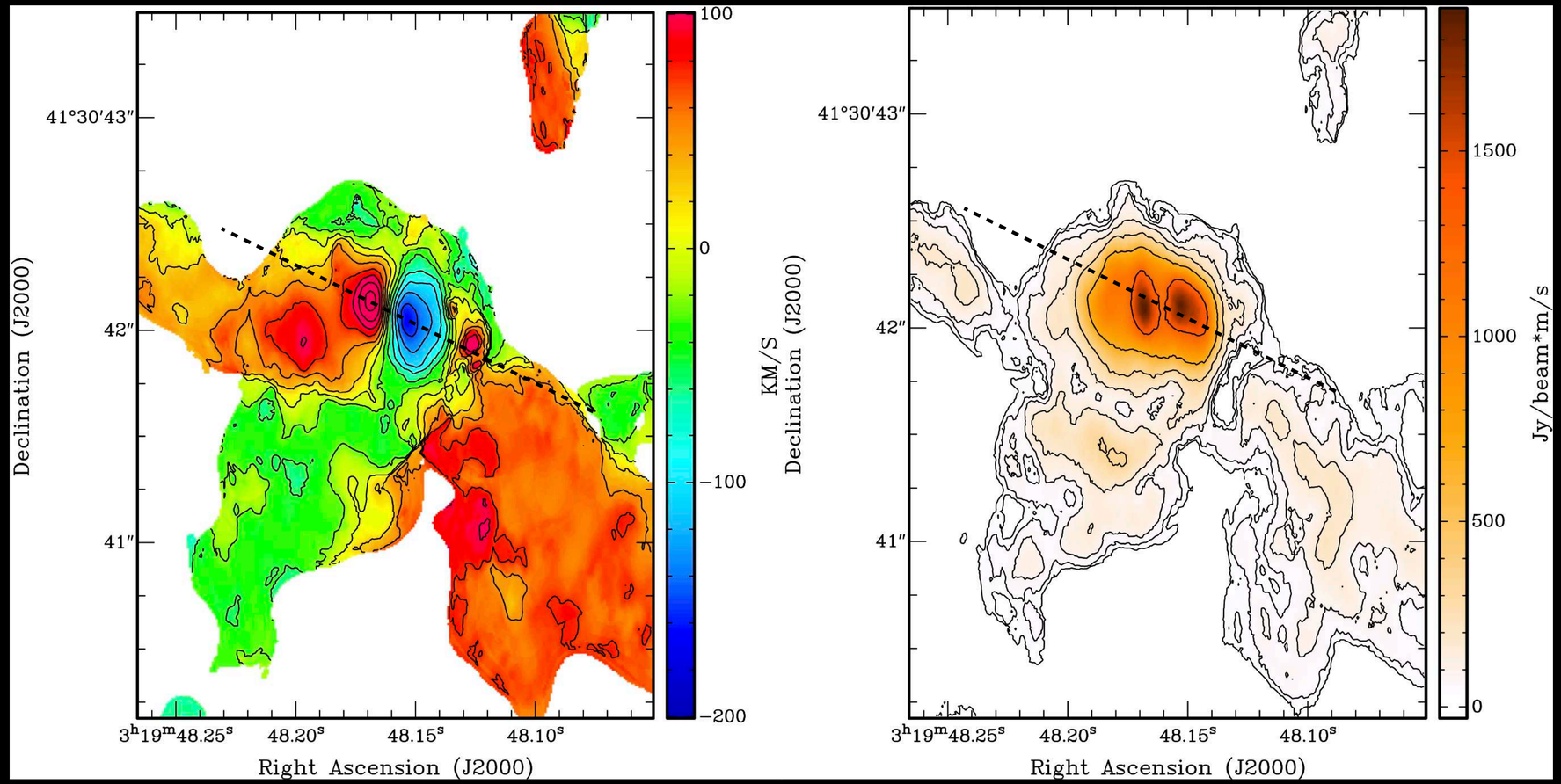


H_2 (Scharwächter+ 13)

➔ filaments providing the fuel for the AGN, mediated by the CND
➔ we see the on-going feeding of the AGN, closing the loop

Puzzling:

kinematic PA
differs from
morphological PA



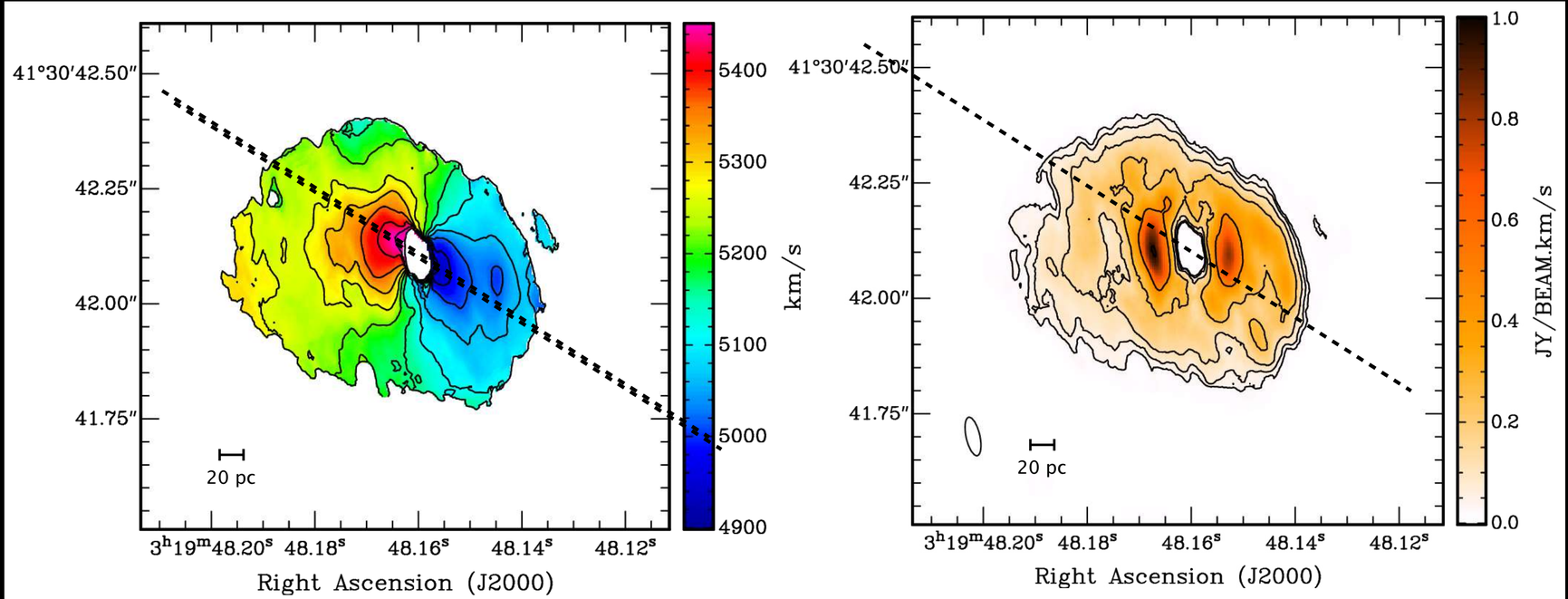
Reprocessed unpublished higher resolution observations (Nagai+)

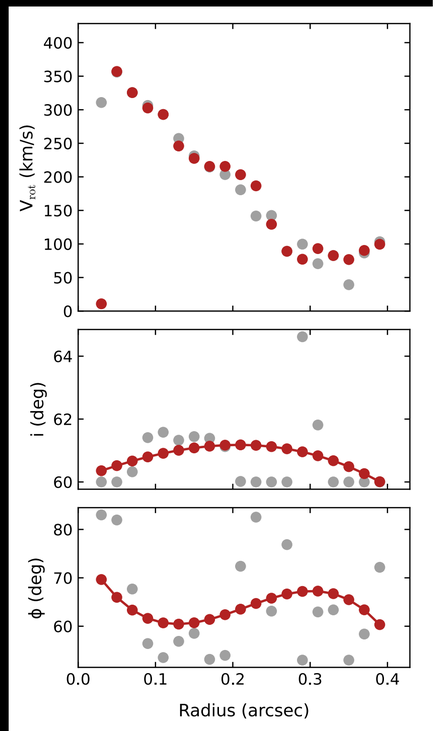
0.05 arcsec
~20 pc

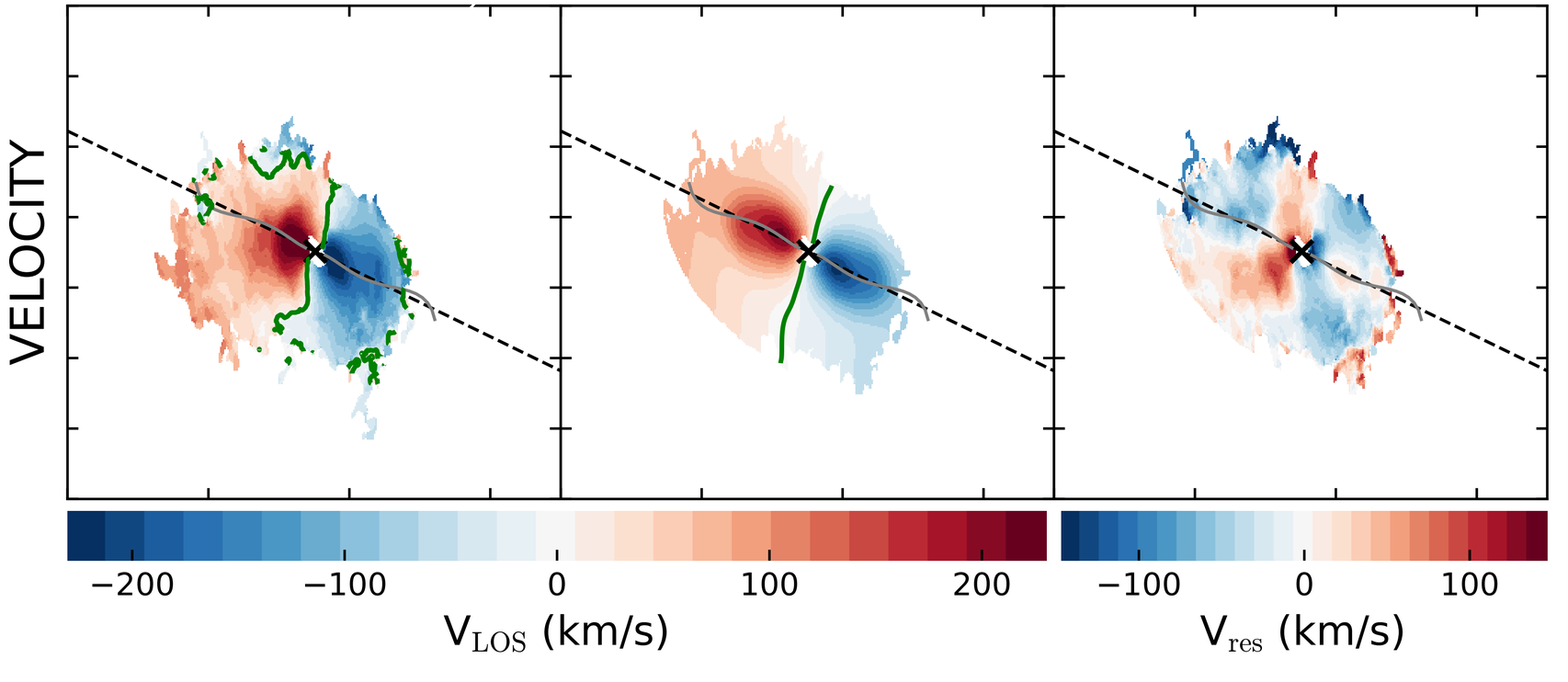
kinematic PA differs from morphological PA

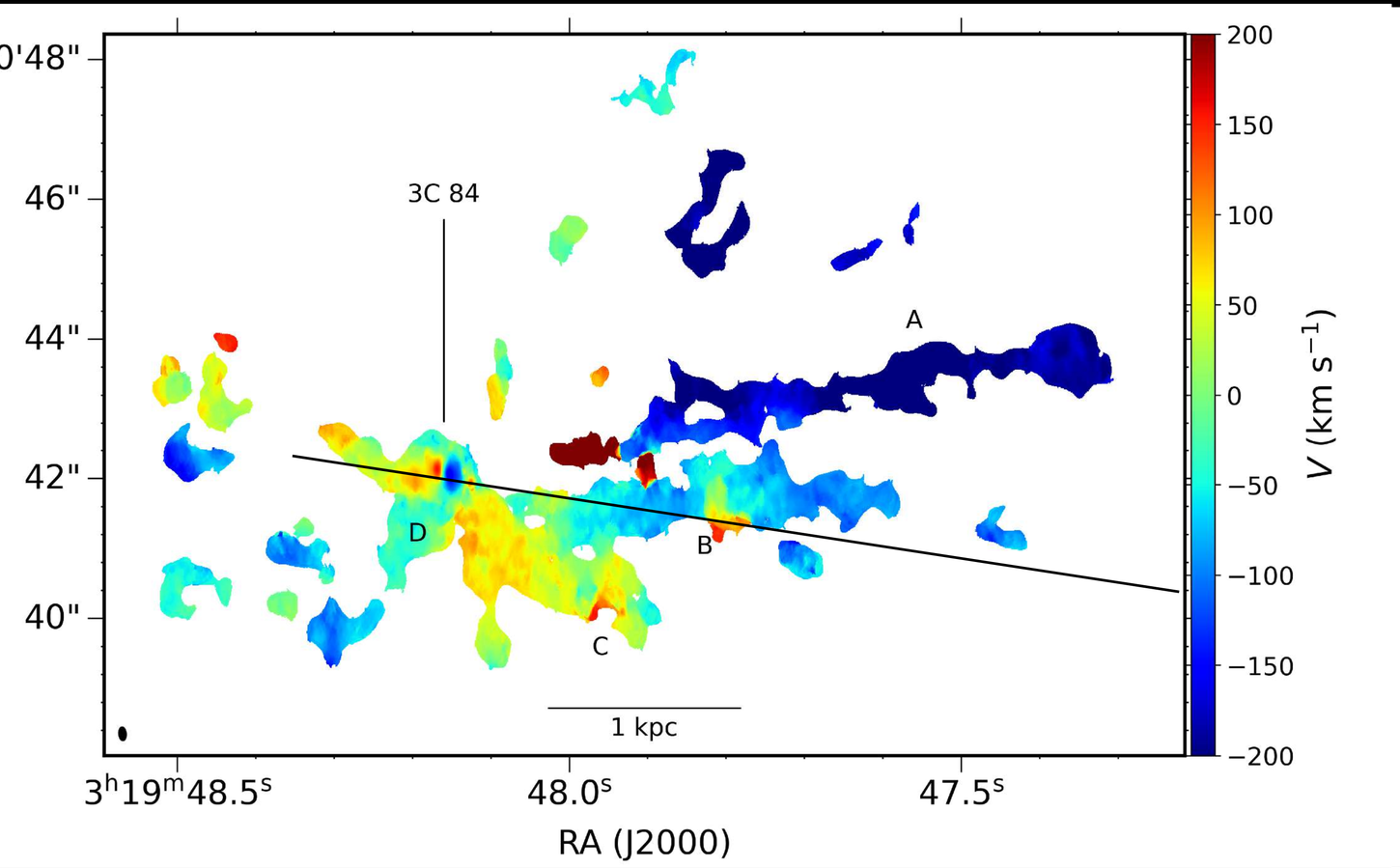
standard warp model does not fit, decline of rotation is faster than Keplerian

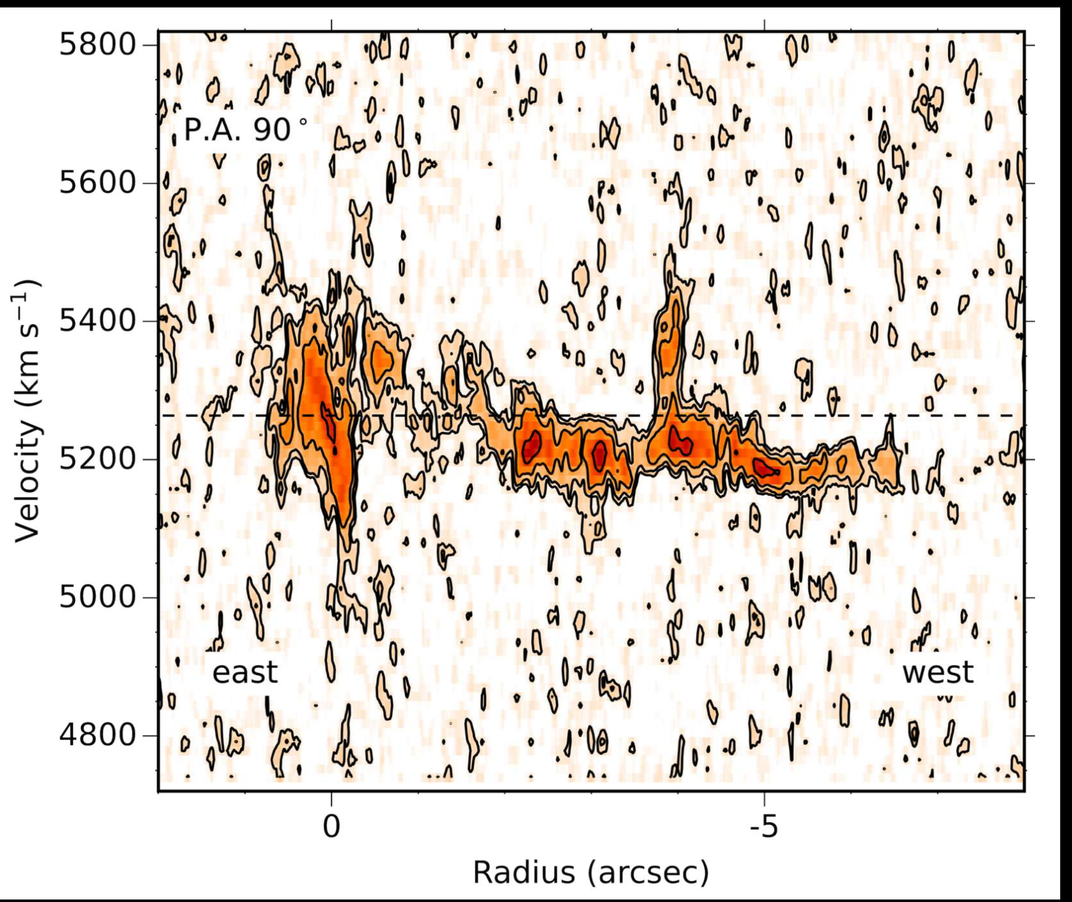
non-circular motions?







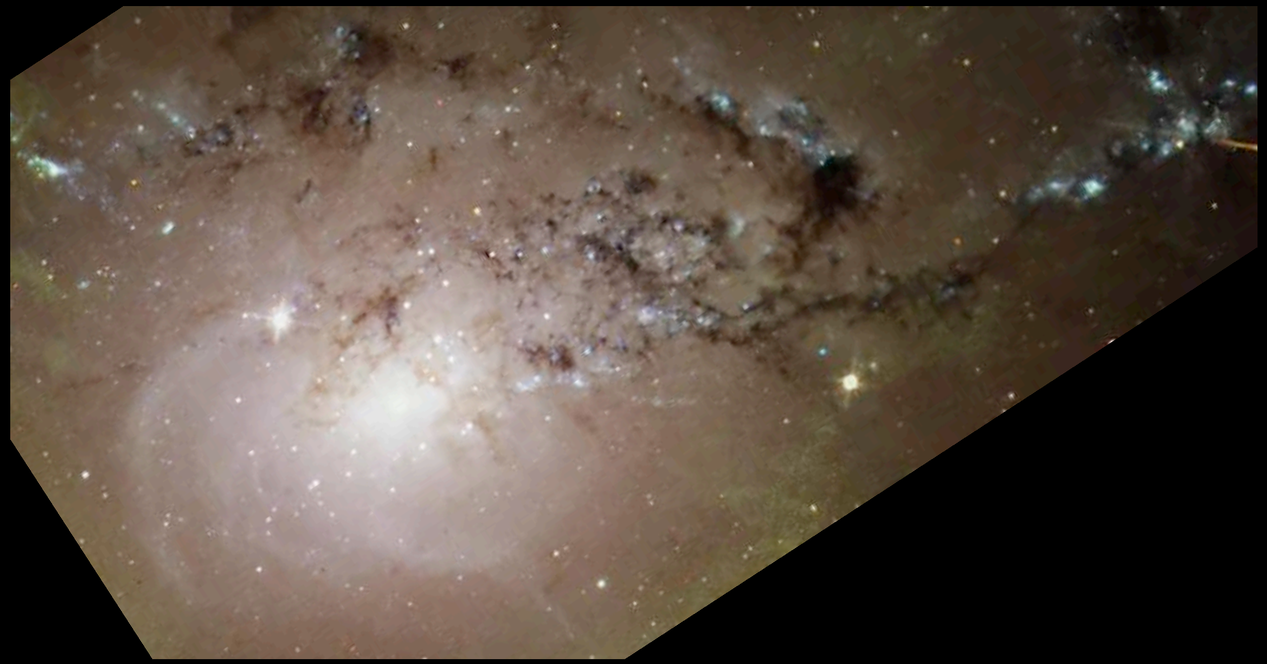


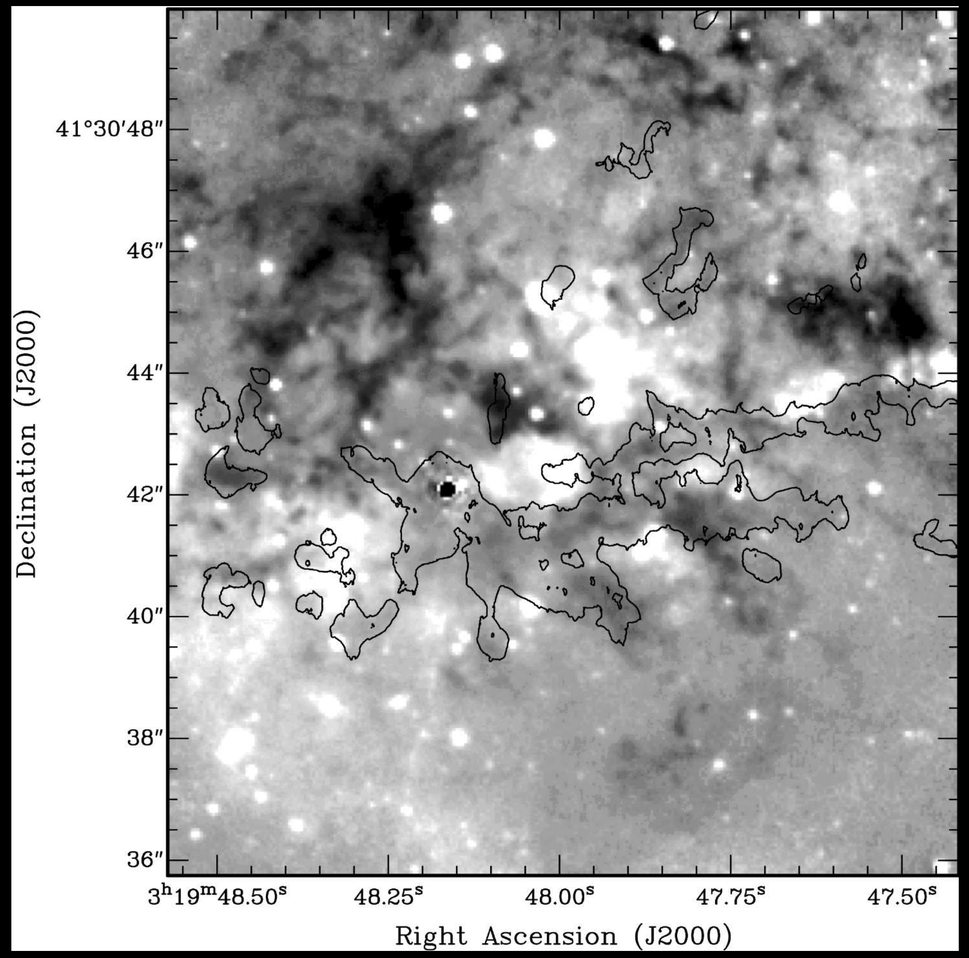


Large velocity jumps in filaments

N1275 is known to have many compact star clusters (10^7 $M_\odot$; <15 pc)
Due to interaction with compact star cluster?

What about dust? It's (too) complicated…

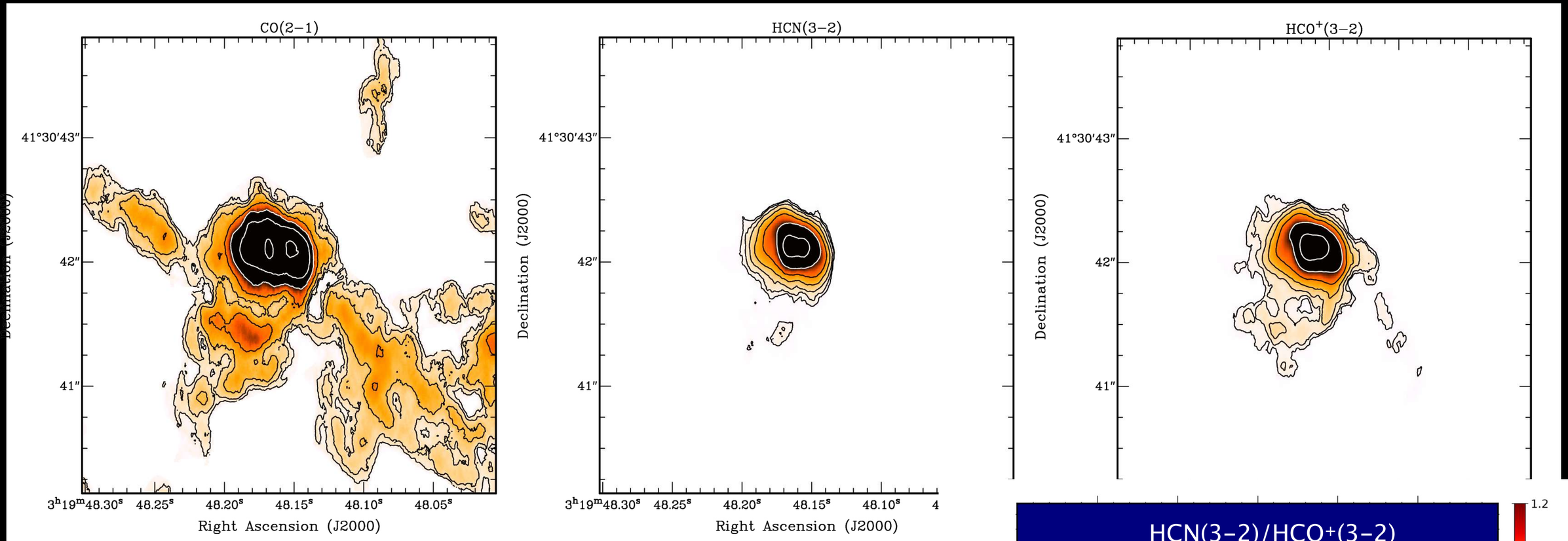




Contours are the molecular gas

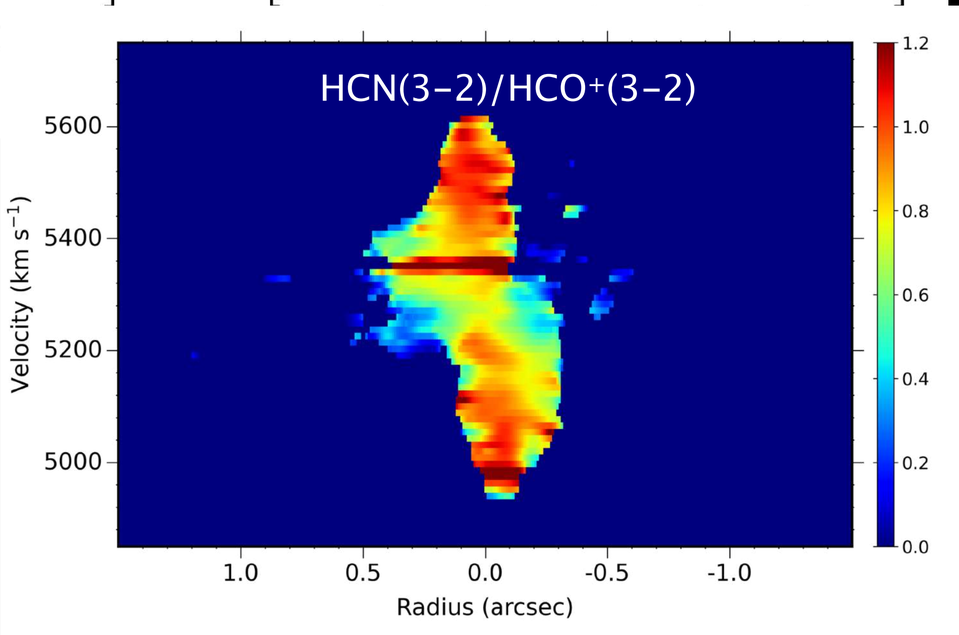
Many dust filaments due to foreground galaxy falling toward N1275 with 3000 km/s.
Are some of the dust filaments connected to the molecular gas?
Important for understanding the nature of the Hα filaments

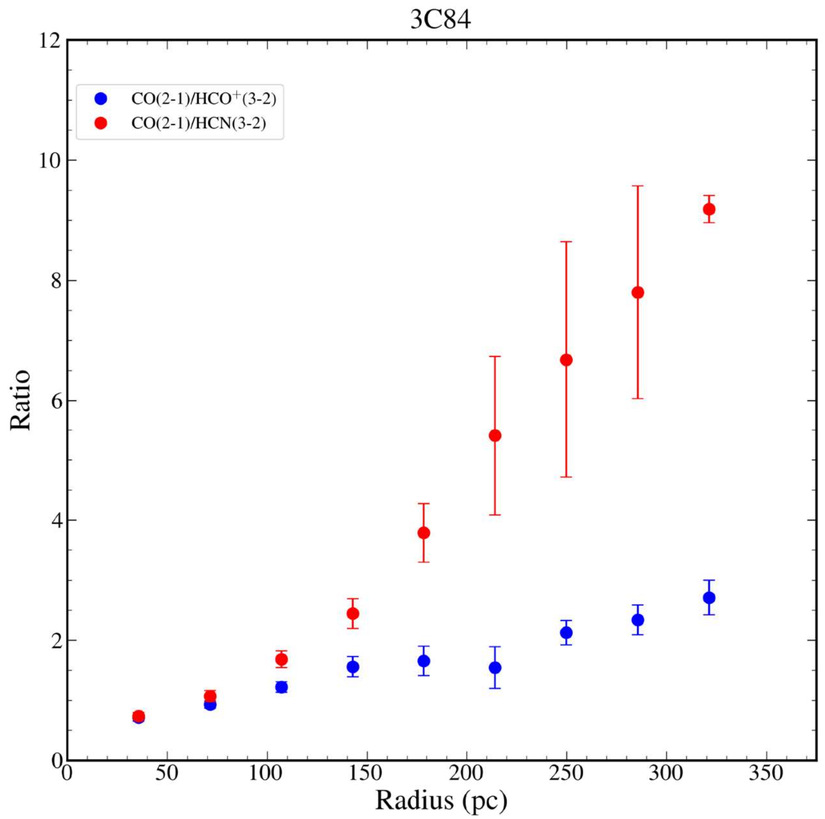
What's next?

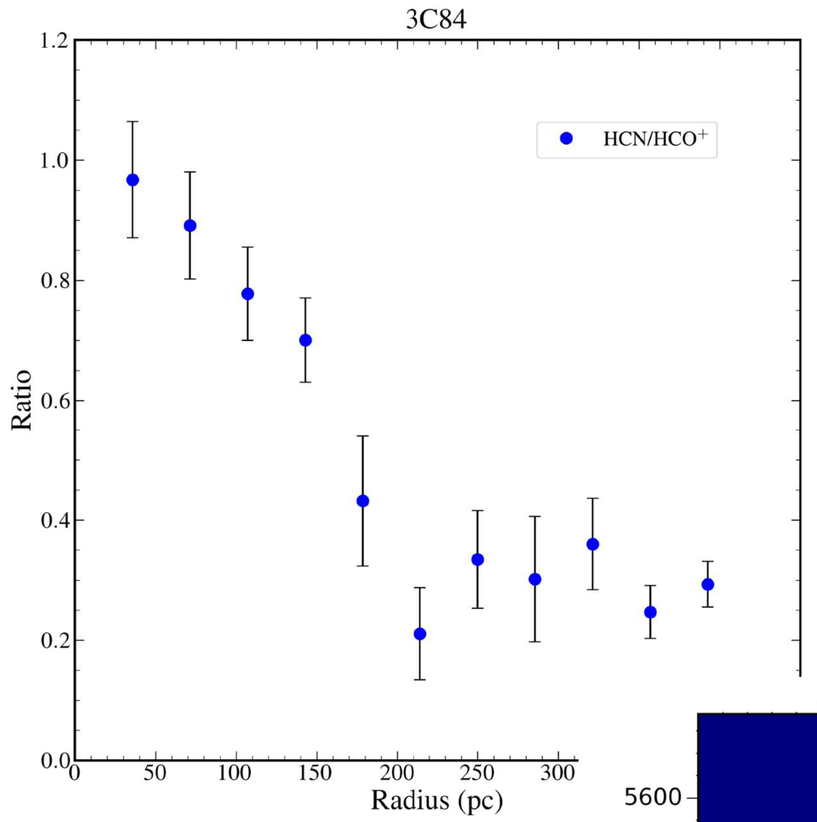


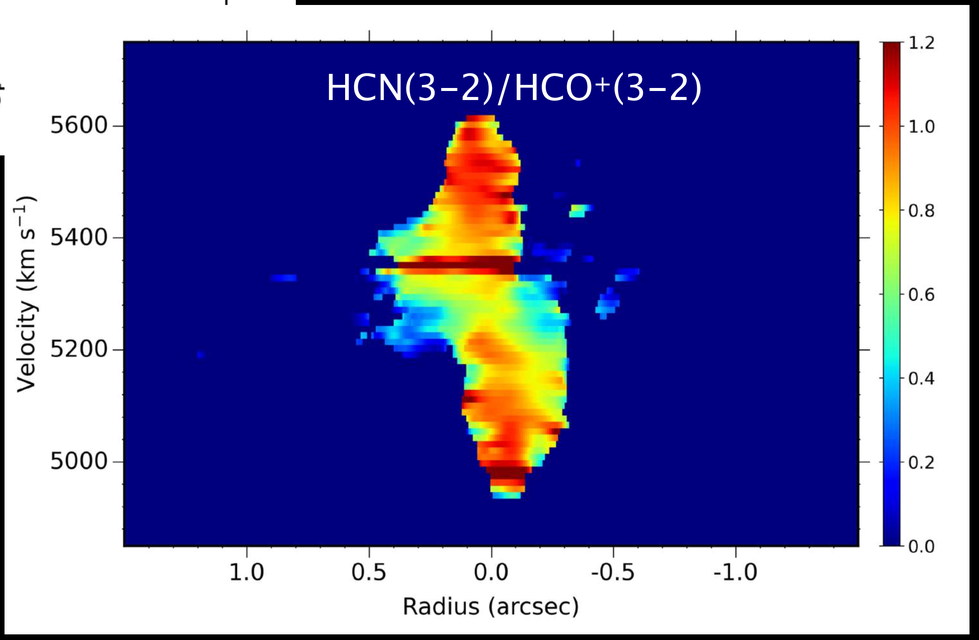
Also data available for HCN and HCO^+

Use line ratios to get information about the physical conditions in the CND





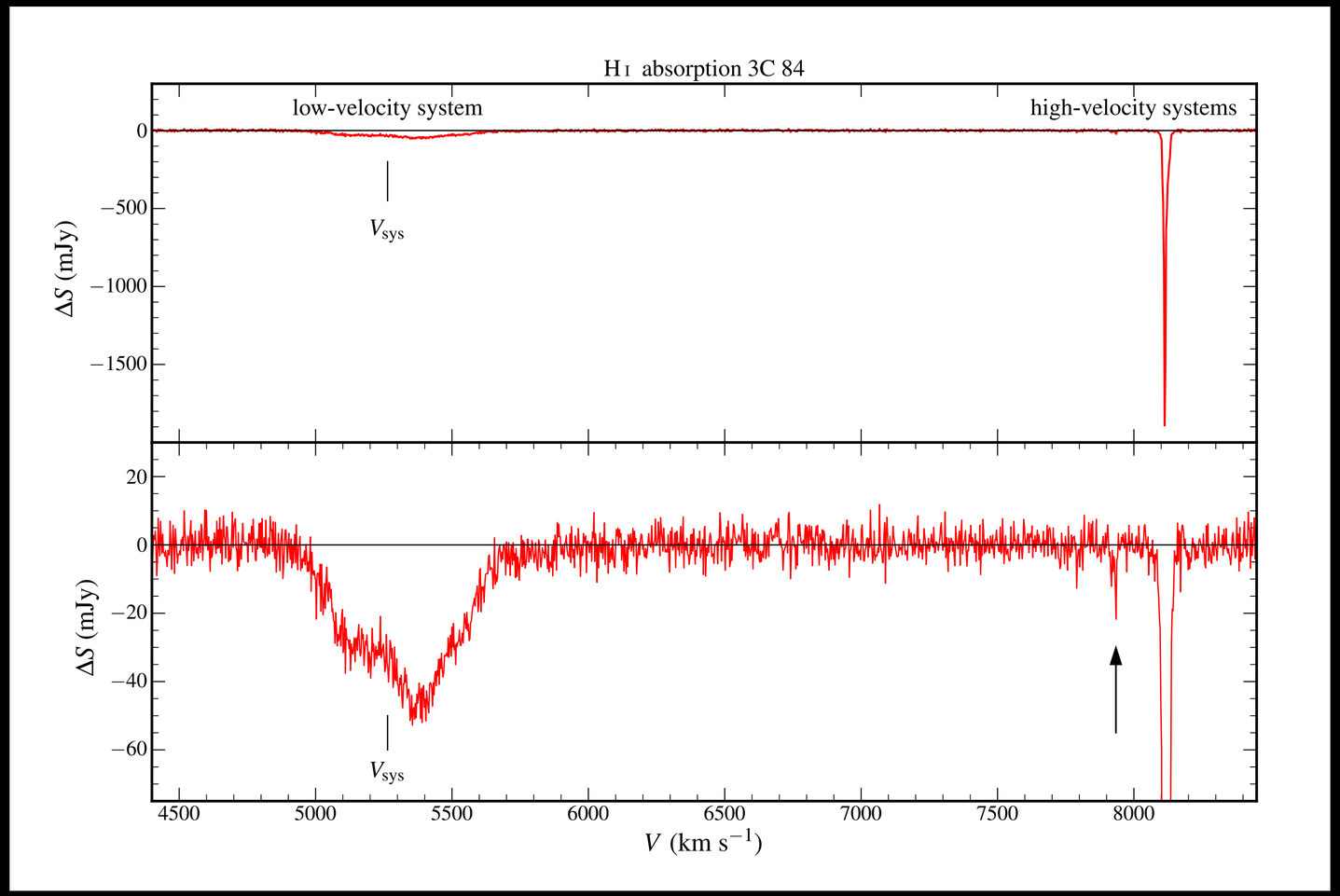


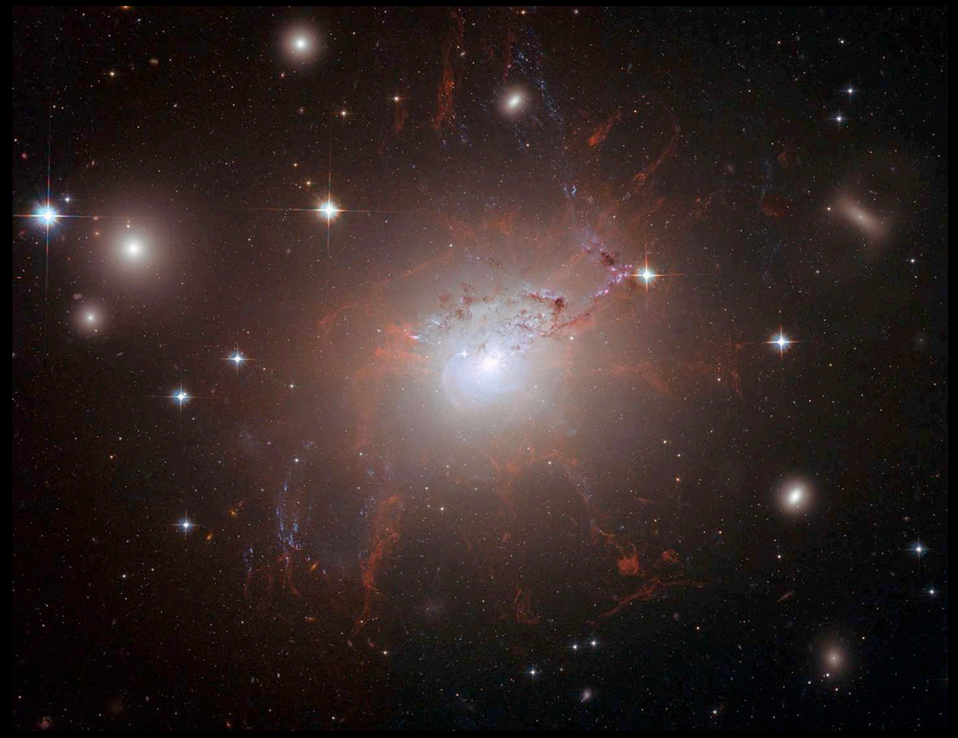


Line ratios indicate change of conditions with radius in the CND

HI absorption against 3C 84

One of the first detections of HI absorption against an AGN (De Young+ 1973, Crane+ 1982)





Two absorption systems:

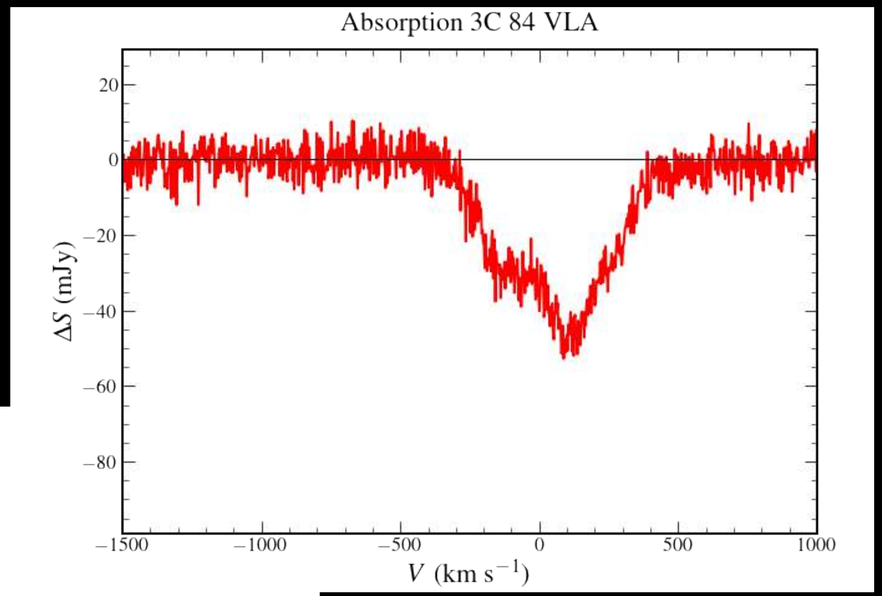
- one at the systemic velocity of NGC 1275 (LV),
- one redshifted by ~3000 km/s (HV). HV absorption is due to foreground galaxy falling into to the Perseus cluster.

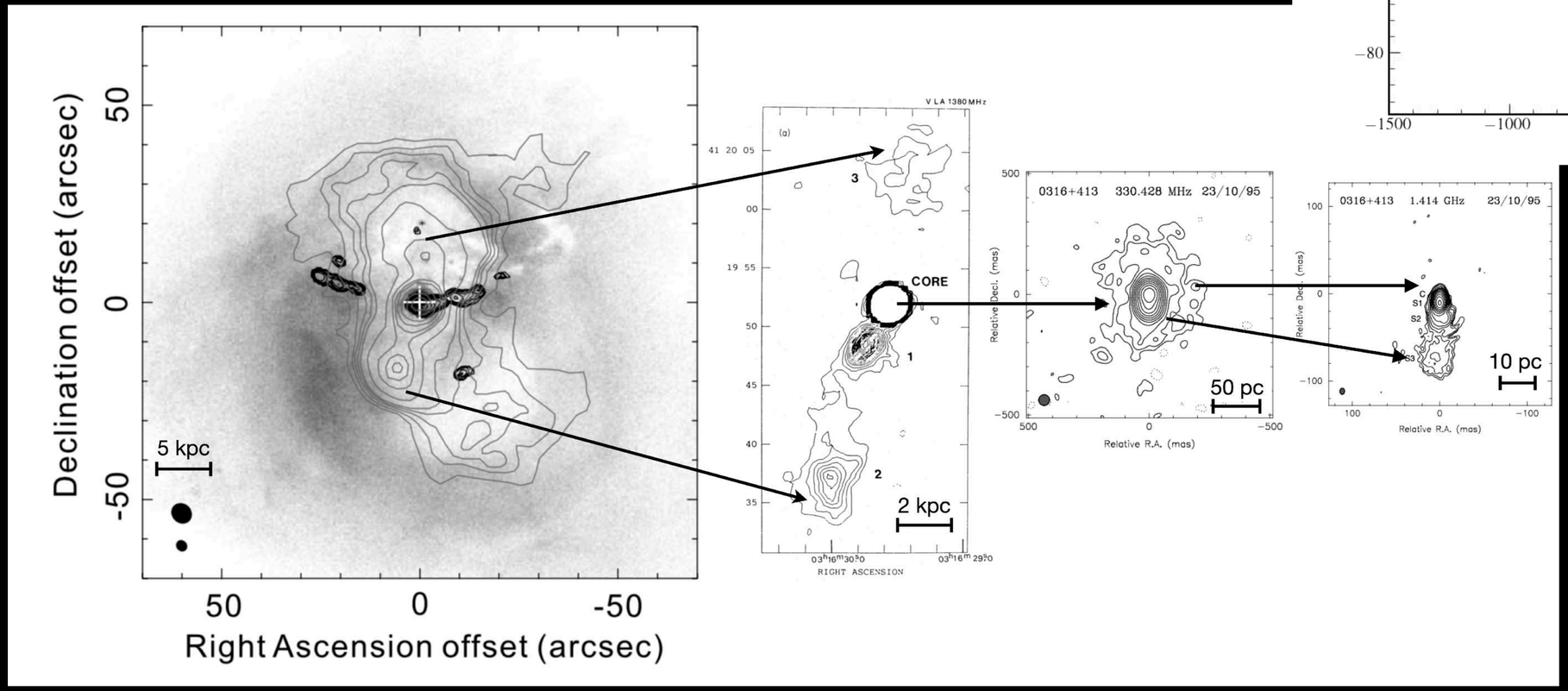
What is the nature of the LV absorption?

3C 84 has radio structures on all scales

Against which continuum is the LV absorption?

Old question (Sijbring+ 1989; Jaffe 1990)





Fabian+ 2006

Pedlar+ 1990

Radio halo 15 arcmin, outer lobes 100 arcsec, jet 18 arcsec, star forming disk 0.5 arcsec, inner jet & core < 0.1 arcsec,

To locate the absorption: observations with very different resolutions:

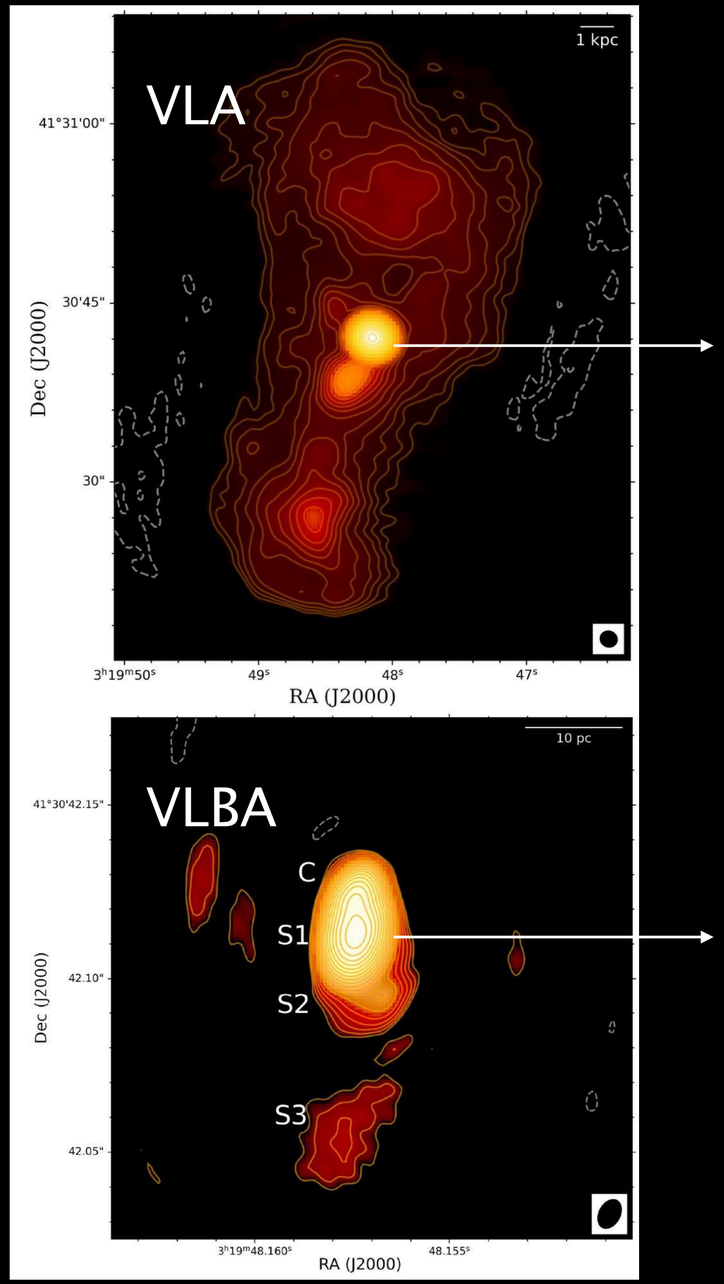
- VLA (1 arcsec)
- VLBA (0.01 arcsec)

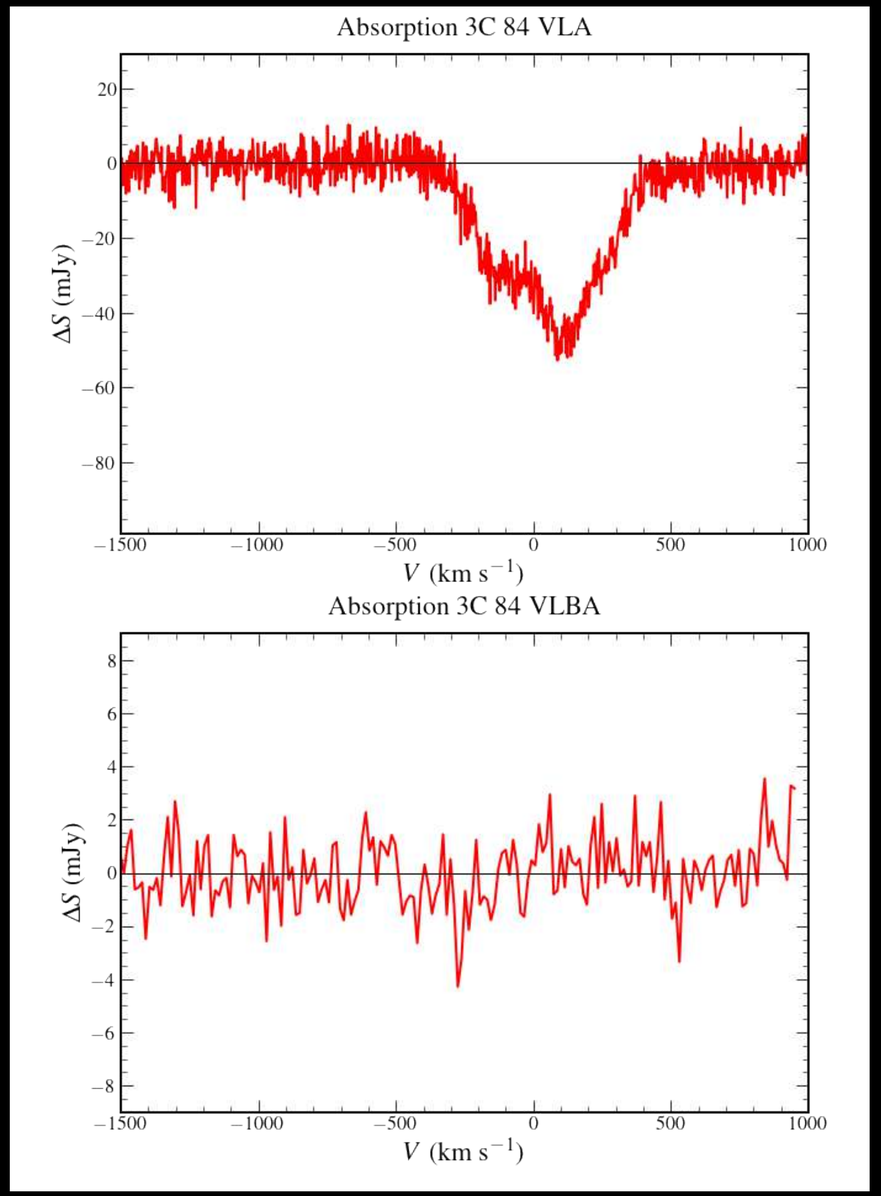
Not trivial: total flux is 22 Jy!

detect broad H I absorption with VLA

no absorption in VLBA data!!

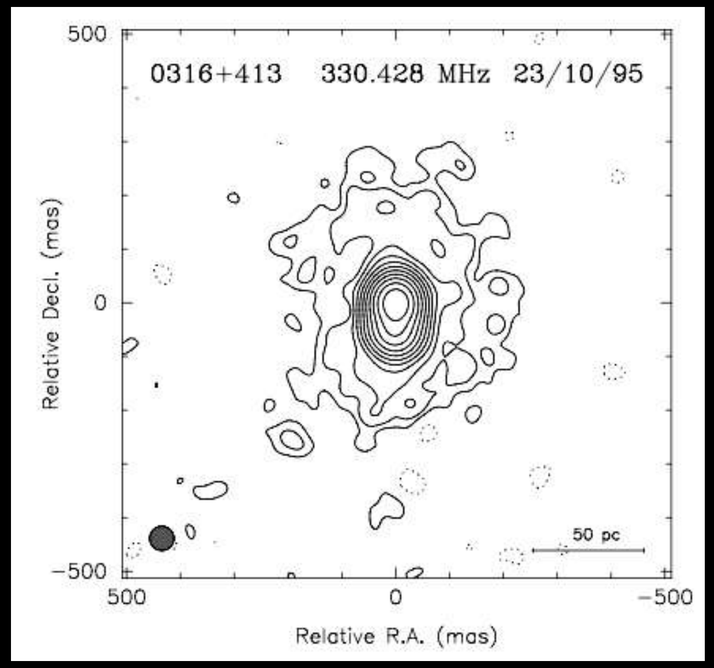
➪ absorption is not against the core/inner jet



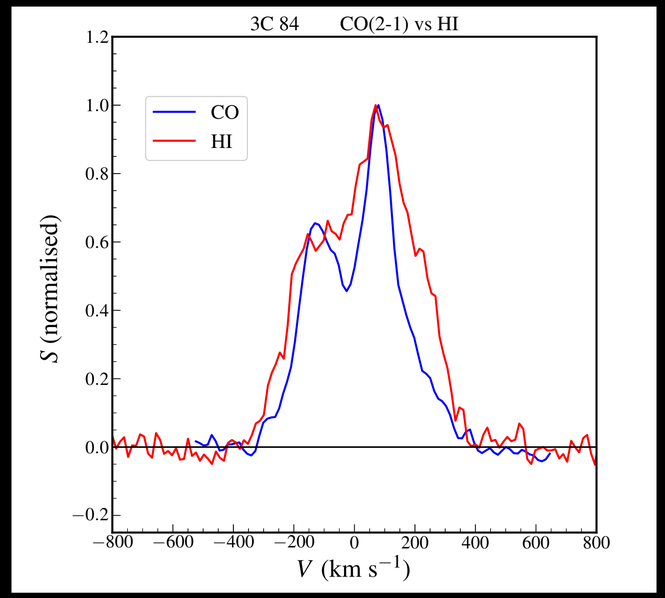


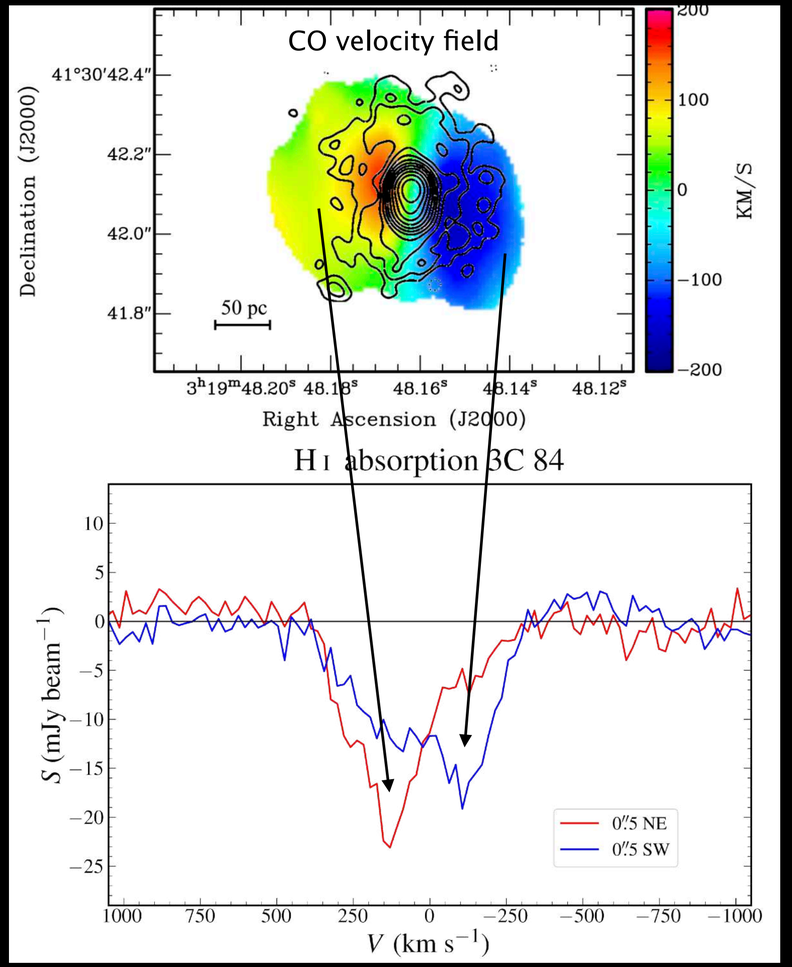
Note the different vertical scales

- H I absorption is not against the core / inner jet
- Absorption is by the CND against itself by the same gas structure as the molecular CND
- Not the result of anomalous kinematics (outflows)
- Column density 4 x 10^{22} cm^{-2} (for T_{spin} = 100 K), similar as H_2
- Very similar to what is seen in Mrk 231. Is common?



diffuse continuum structure due to star formation
330 MHz with VLBA
Silver et al. (1998)





same kinematic signature
as the molecular CND

Putting it all together …

- Circumnuclear disc warped/wobbling and not fully settled due to the accretion from various directions

- Molecular filaments in NGC 1275, flowing onto the CND:
  CND is growing from deposition of this gas
  ➔ filaments providing the fuel for the AGN (3C84), mediated by the CND
  ➔ indirectly, we see the on-going feeding of the AGN

- HI absorption shows that CND also contains HI and has star formation. Similar to Mrk 231. Such discs are more common?

- Jets inflate bubbles in the ICM, dragging gas outwards, cooled gas plays a role in feeding the AGN. These results complete the feedback loop of how an AGN can impact on its surroundings and how the effects from this impact maintain the AGN activity.

- Long-term impact of the radio jets: maintenance mode but also feeding the AGN

- No gas outflow observed