The complex nuclear regions of young radio galaxies

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Role of radio jets for feedback

- Preventing cooling (maintenance)
- Need X-ray
- Driving outflows/fountains
- Injecting turbulence
Interplay between radio jets and their “nuclear” surroundings

from Wagner & Bicknell 2011, 2012; Mukherjee, Bicknell et al. 2016, 2017, 2018
But similar results also from Cielo et al. 2018

- Jets couple strongly with host's **clumpy ISM**: whatever the initial narrowsness of the jet, the flow is broadened by the interaction with the first cloud (Wagner et al. 2012).
- Effect particularly prominent in the first phase of evolution
- **Low power jets are important!** Couple more with the ISM, will induce more turbulence and they are more numerous!

Log(n) at time: 0.92 Myr

clumpy medium (spherical distribution), high jet power

10^{45} erg s^{-1}
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Low power jets are important! Couple more with the ISM, will induce more turbulence and they are more numerous!

Jet power comparable to NGC1068!

Low jet power, clumpy medium (spherical distribution)
- Do we actually see these signs of interaction from newly born radio jets?
- Do we see the clumpy medium that should enhance the impact of the jet?
- How do the jet affect the circumnuclear regions?

Mukherjee et al. 2018
This talk

- Jet-driven HI outflows in young radio galaxies using VLBI: do we have the conditions for the jet to have an impact?

- Accretion and feedback in an obscured young radio quasar using ALMA

Using cold gas
HI (21 cm) and molecular observed at high spatial resolution
Taking snapshots of the jet–ISM interplay
HI outflows of cold gas in young objects

Outflows

Circumnuclear disks/tori

Advantage of HI: follow up VLBI
At least 15% of HI detections show HI outflows
Velocities between a few hundred to ~1300 km/s, mass outflow rates a few to 50 M⊙/yr
Mass in the HI outflows from a few x10^6 to 10^7 M⊙
Vast majority found in young (or recently restarted) radio sources (consistent with what found for ionised gas)
HI outflows traced at high spatial resolution with global VLBI

Cases of jet–driven outflows (suggested by the location of the outflow and/or low optical luminosity)

Ages: between $10^3$ and $10^4$ yrs

Ages: between $10^5$ yr and $10^6$ yr

Resolution HI observations $\sim$9 mas $\Rightarrow$ a few tens of pc
Clumpy medium and evolution of the outflows as the source expands?

- **Younger sources:**
  - VLBI recovers all flux of the HI outflows
  - absorption produced by (a few) dominant clouds
  - Outflowing HI clouds in the inner ≤100pc

- **Clumpy medium:**
  - The average densities of the clouds range between 150 cm\(^{-3}\) and 300 cm\(^{-3}\)
  - (Morganti et al. 2013)

- Schulz, RM et al. in prep

- ~300 pc
Clumpy medium and evolution of the outflows as the source expands?

More evolved (and restarted) sources

HI outflows only partly recovered by VLBI: likely mix of compact clouds and diffuse gas

HI clouds \((0.28–1.5 \times 10^4 \, \text{M}_\odot)\) observed in the inner region close to the core (<40pc)

Some results from HI and VLBI

- The radio jets can drive the (HI) outflows
- Young/smaller sources showing the most direct sign of interaction
- Evidence of clumpy medium (on tens of pc scales) in all sources → conditions favourable for the jet to have an high impact
- HI outflows observed already in the very centre of the AGN (<40 pc)
- Tentative signs of evolution of the outflow: presence of a diffuse component – not recovered by the VLBI observations – in larger sources
Accretion and feedback in an obscured, young radio quasar
PKS 1549-79 quasar in the early stage of evolution

Newly born AGN in an ongoing merger: large cocoon of material still enshrouding the radio source (highly extinguished $A_v > 4.9$). SMBH accreting at a high Eddington ratio ($0.3 < L_{bol}/L_{edd}$)

Xray UltraFastOutflow (Tombesi et al. 2013), $\sim 0.2c$

Is the powerful jet ($10^{26}$ W/Hz) clearing the central regions?

Crucial stage in the evolution

Needs the spatial resolution to trace the gas close to the nucleus => ALMA!
PKS 1549–79 quasar in the early stage of evolution

ALMA CO(1–0) and CO(3–2) detected in emission resolution from 0.05” ~ 100 pc to 0.2” (z=0.150)

Most of the “action” in the very central region and N–S direction, extended part of the jet has already emerged…
PKS 1549–79 quasar in the early stage of evolution

ALMA CO(1–0) detected in emission
Highest resolution 0.05” ~ 100 pc (z=0.150)
Large molecular outflow in the central regions (<100 pc) ➔ ~100 M_☉/yr

In agreement with simulations: a powerful source (like PKS1549–79) has a faster/more massive outflow

Evidence for accretion triggering the activity and feedback effects

Oosterloo, Morganti et al. in prep
The ALMA observations of PKS1549 show that even if the jet emerges orthogonal from a (proto) disk, it can create a cocoon of shocked and kinematically disturbed gas expanding through the disk (as suggested by simulations) ➜ effect on the kinematics and physical conditions of the circumnuclear disk.
clear effect of the AGN (jet?) on the gas: both kinematics and excitation

ALMA CO(3–2) resolution ~0.2 arcsec

High CO(3–2)/CO(1–0) ratio in the central region wrt tail: effect of AGN

Confirmed by the kinematics
PKS1549–79 is not the only case ...

Radio power of IC5063 similar to NGC1068!

Disturbed kinematics AND different conditions of the molecular gas in the jet-affected regions. Successful modelling as result of the impact of the jet

The impact of the jet can be seen in both the kinematics and the excitation of the molecular gas
Conclusions

• Young radio jet couple strongly with ISM: also for low power jets!

• Evidence of clumpy medium (on tens of pc scales) in all sources → conditions favourable for the jet to have an high impact

• Conditions of the outflows changing as radio source evolves

• Jets can produce cocoon expanding across the disk, shocking and kinematically disturbing the gas → relevant for the very inner circumnuclear regions/torus?

• Impact of the jet can be seen in both the kinematics and the excitation of the molecular gas

For the future: a large parameter space needs to be explored …