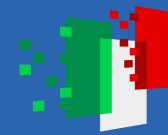




Finanziato
dall'Unione europea
NextGenerationEU



Ministero
dell'Università
e della Ricerca



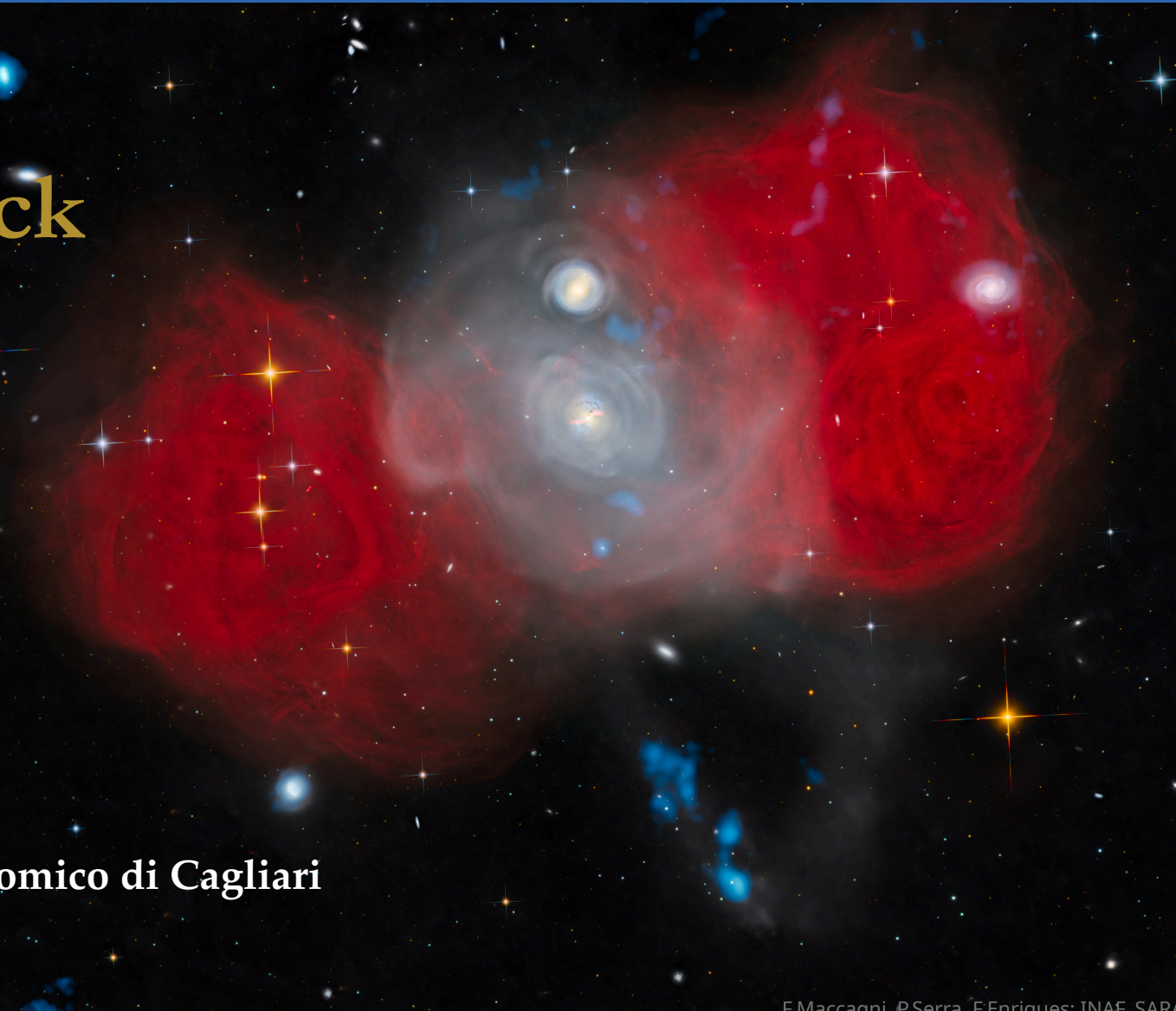
Italiadomani
PIANO NAZIONALE
DI RIPRESA E RESILIENZA



INAF
ISTITUTO NAZIONALE
DI ASTRONOMIA

AGN feeding & feedback revealed in detail by MeerKAT and the SKA

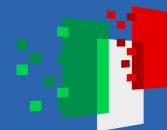
Filippo Maccagni - INAF Osservatorio Astronomico di Cagliari



F.Maccagni, P.Serra, F.Enriques; INAF, SARAO

PNRR Missione 4 • Componente 2
Investimento 3.1

STILES – IR0000034
CUP C33C22000640006



AGN are the most disruptive event in the Universe



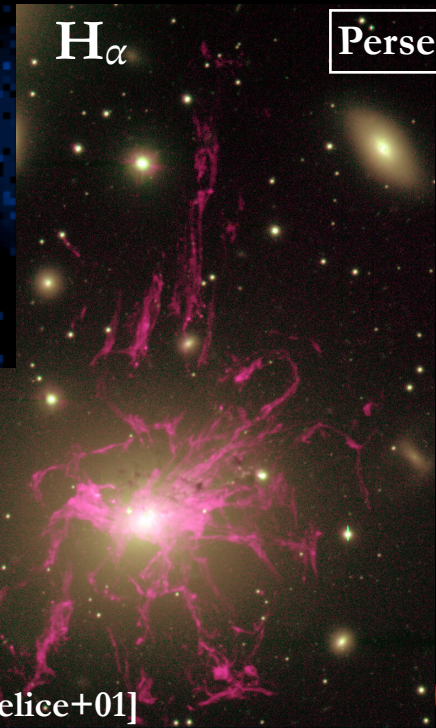
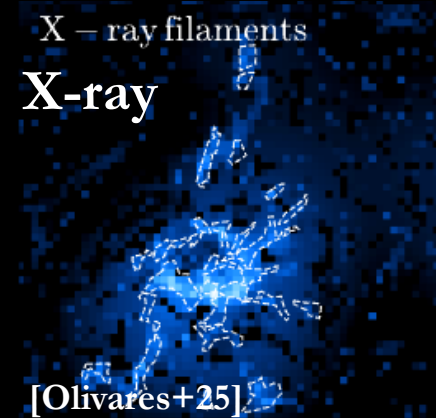
SMBH release radiative winds and radio jets displacing, shocking and heating the CGM

Perseus A, 3C 84,
NGC1275

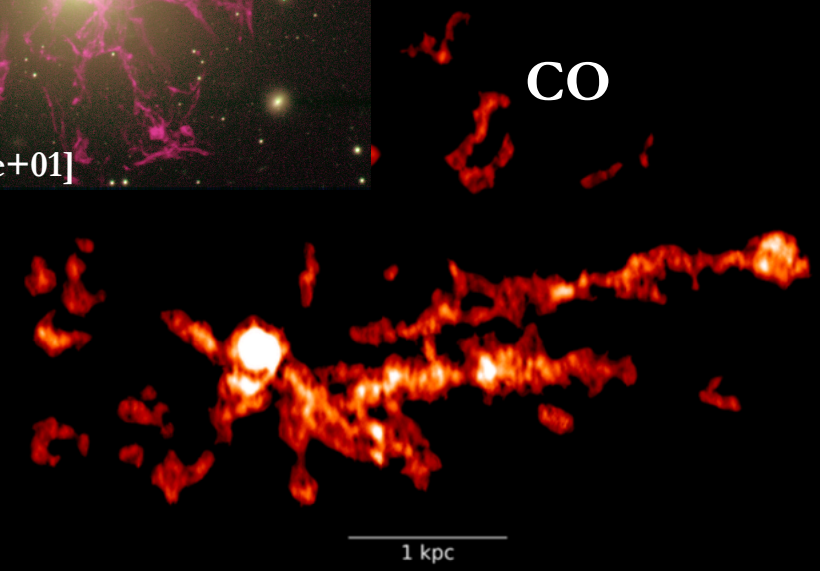
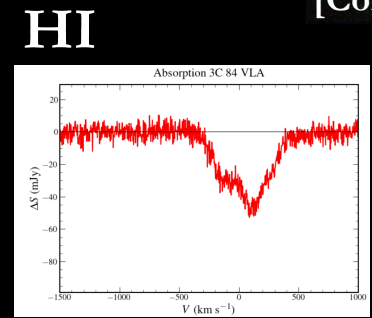


A2597

Multi-phase gas fuels Active Galactic Nuclei in clusters



Perseus A, 3C 84, NGC1275



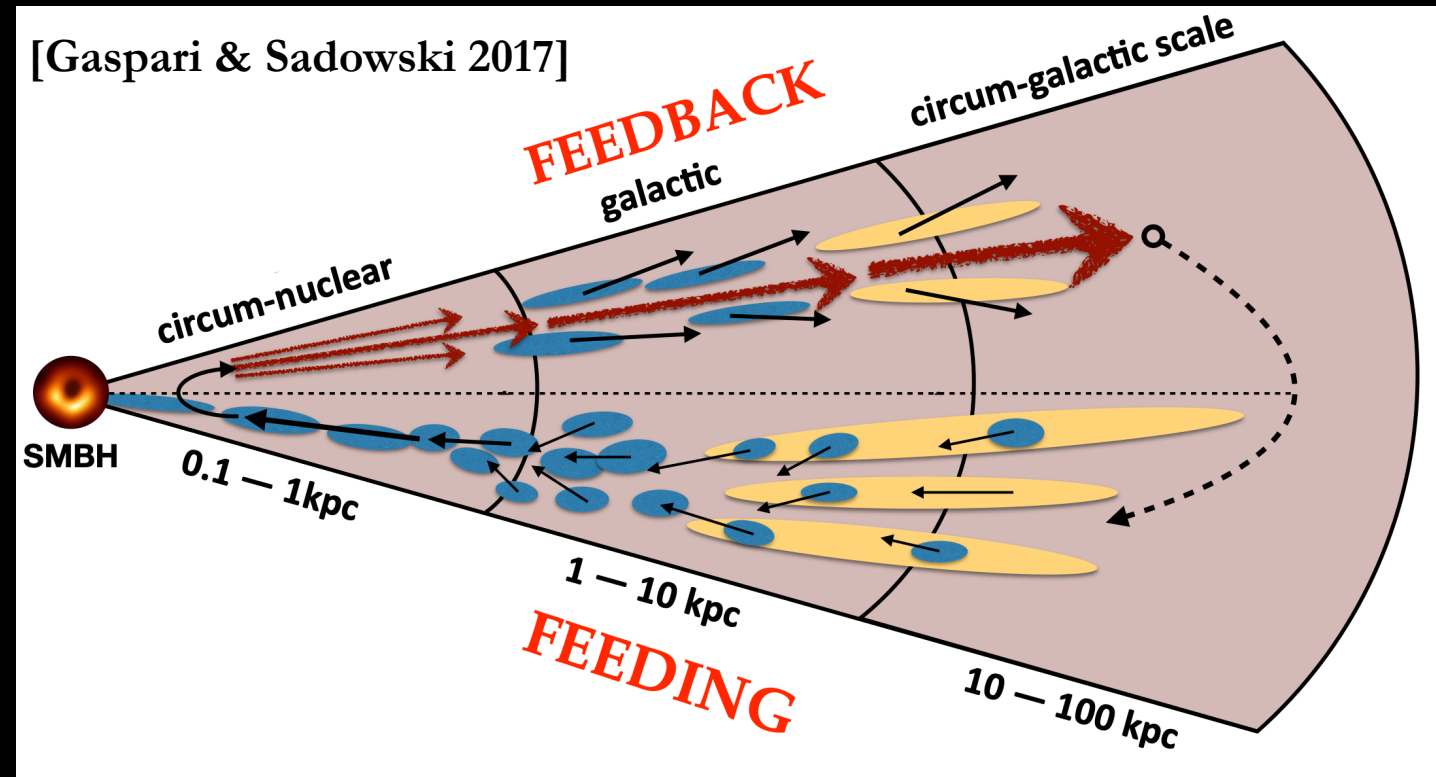
The many scales of AGN Feeding & Feedback

• SPACE

- from the circum-nuclear scale (pc) of the SMBH to the to the circum-galactic scale (hundreds of kpc)

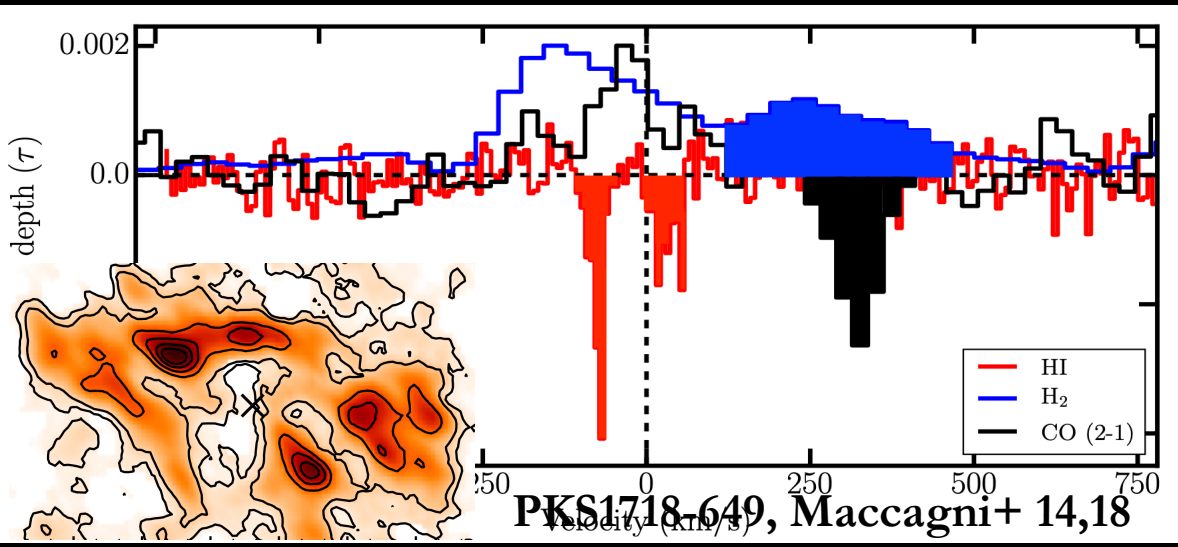
• TIME

- AGN are rapid & recursive while galaxy evolution is slow and continuous
- radio jets trace the timescales of nuclear activity

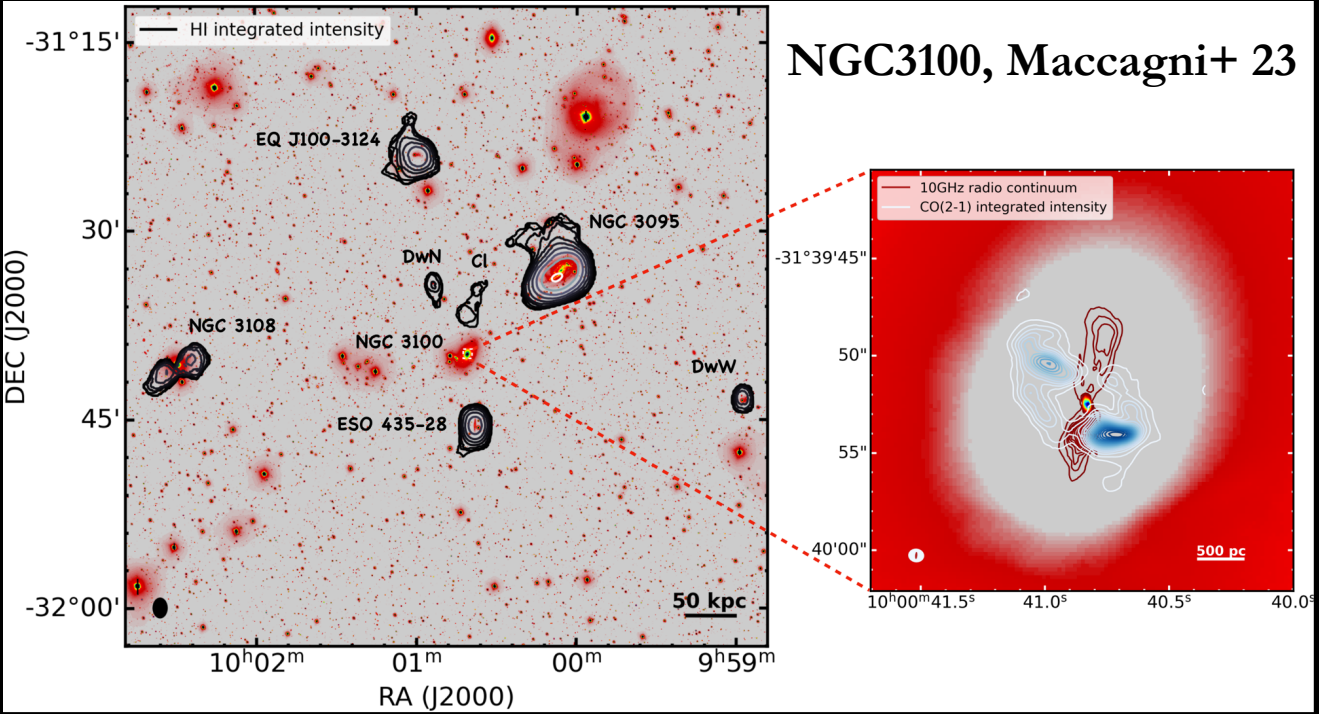


Neutral Hydrogen traces AGN feeding on all scales

HI in-falling clouds from circum-nuclear disks

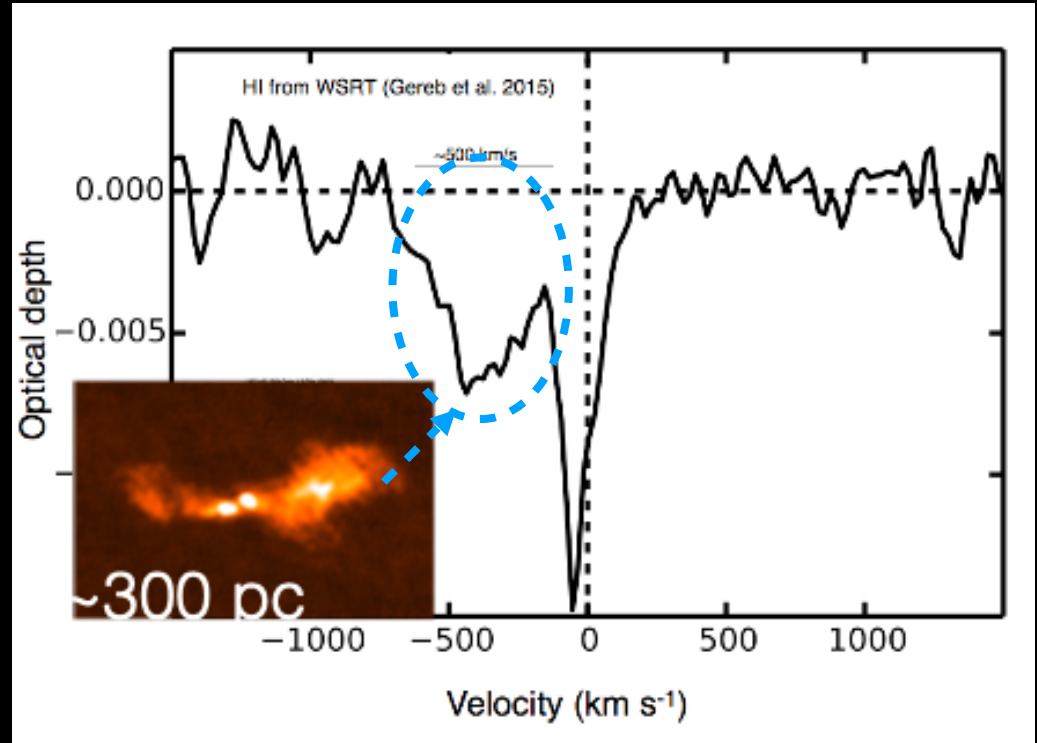


HI in-falling clouds from galaxy halo

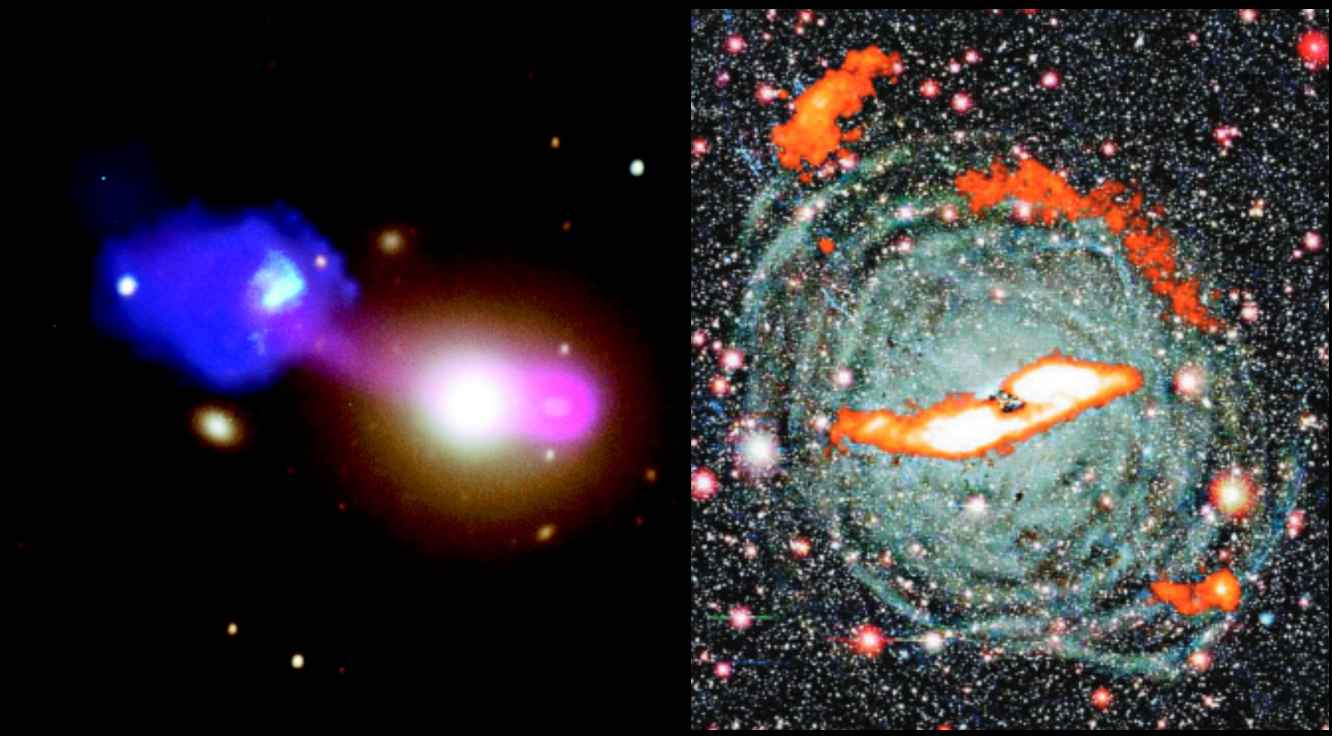


Neutral Hydrogen traces AGN feedback on all scales

Radio jets eject HI outflows on circum-nuclear scales



Radio jets shock HI on circum-galactic scales



Minkowski object Croft et al. 2006

Centaurus A - Morganti 2011

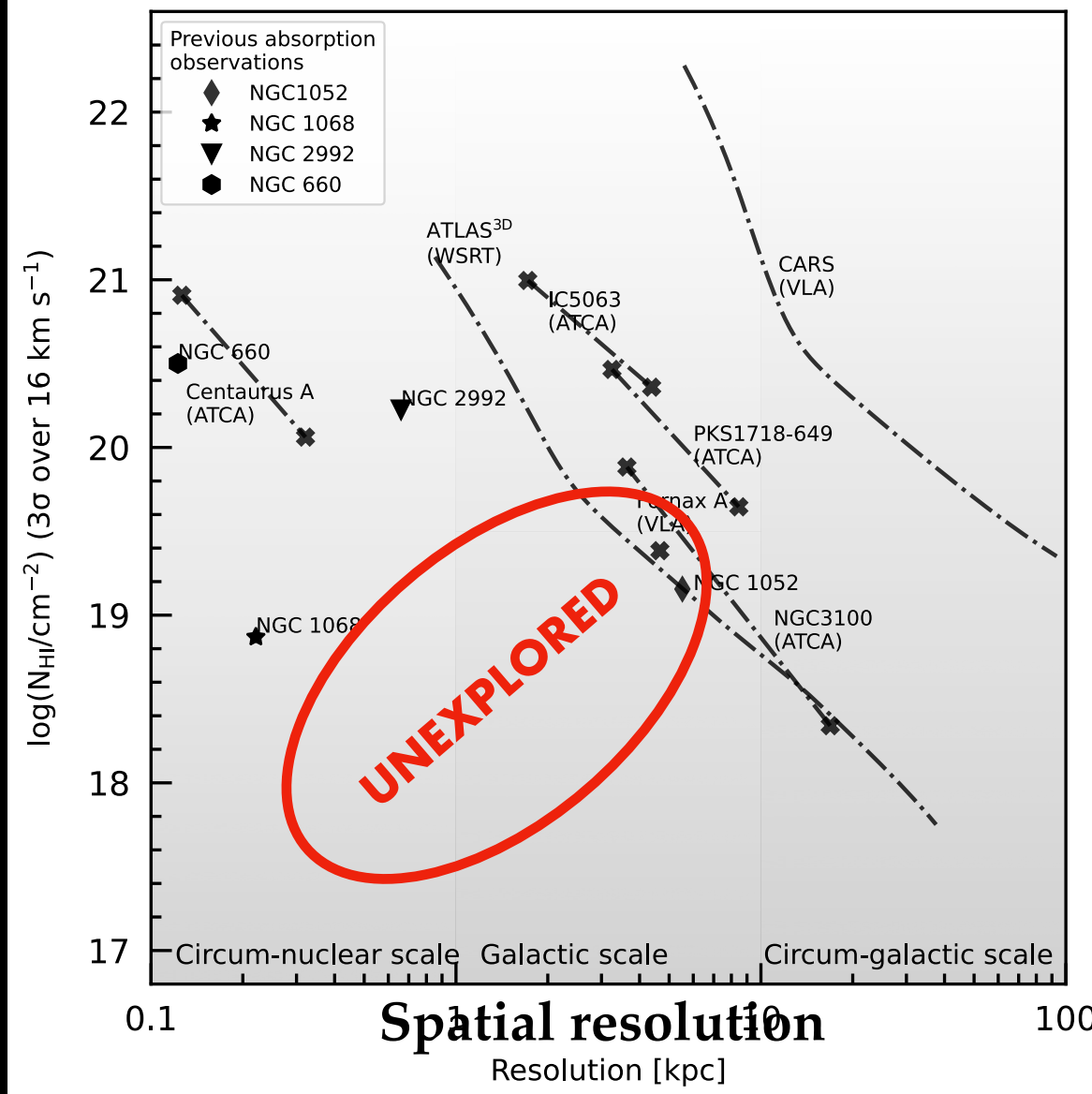
Past HI studies in AGN

in HI, AGN are ~10 times less observed than nearby SF galaxies, nevertheless

- 1/3 of ETGs has HI [Serra+12]
- stacking shows low-column density HI in all ETGs [Maccagni+17]

HI in AGN F&F has **LOW** column density

HI column density sensitivity

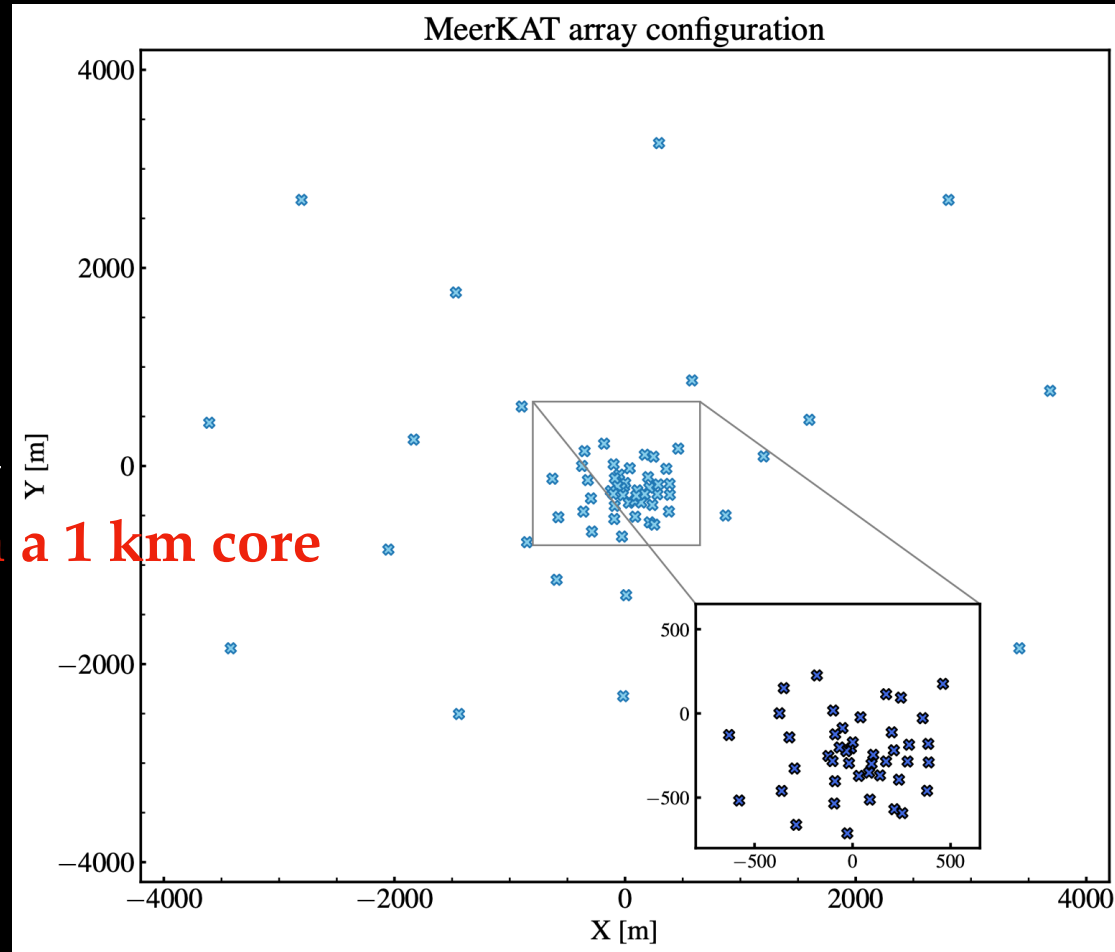


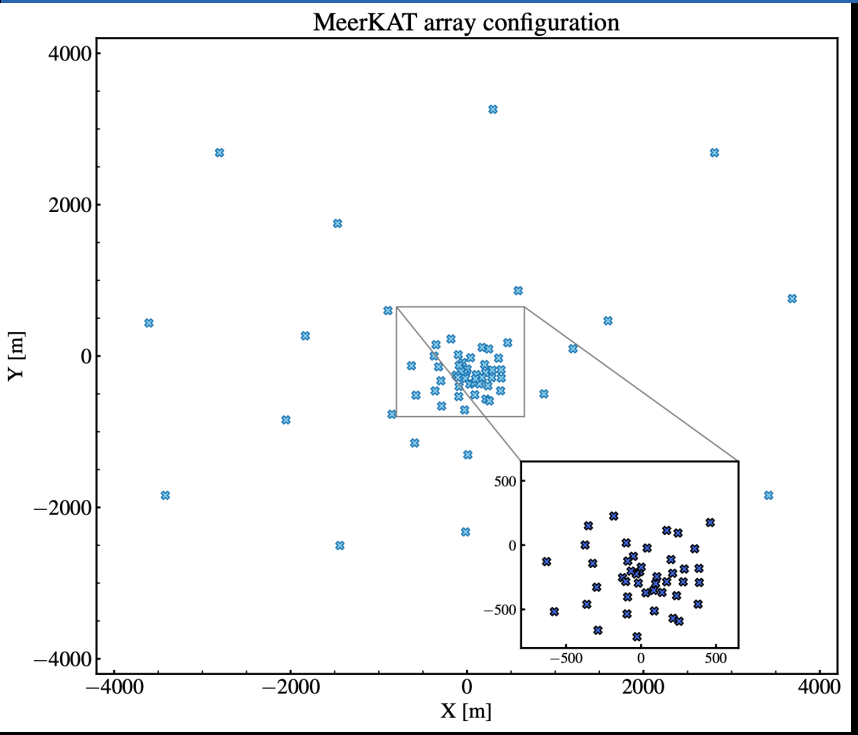
MeerKAT - telescope specs



- core of SKA-MID
- 64 dishes of 13.5m
- $T_{\text{sys}} = 22\text{K}$
- baselines 29m-8km
- 70% of baselines in a 1 km core

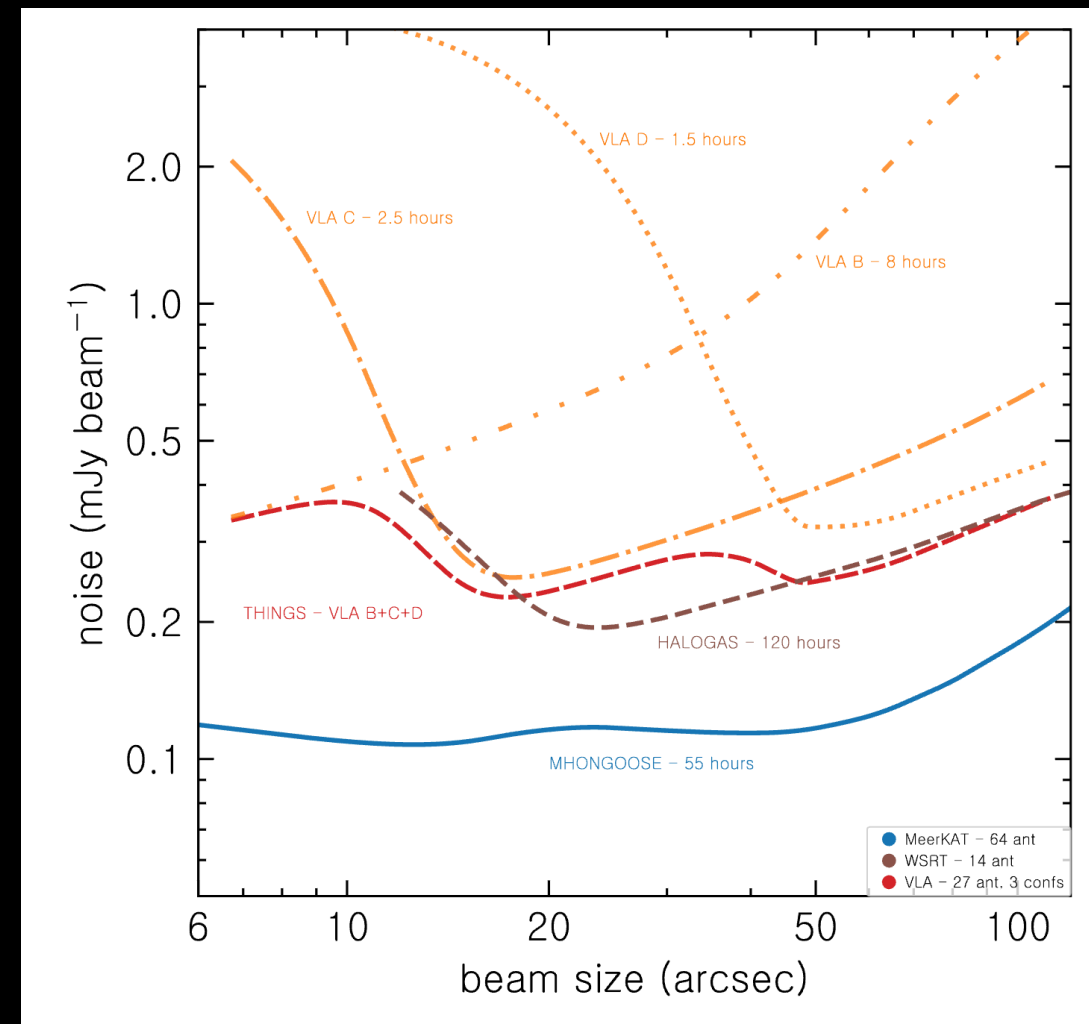
22/





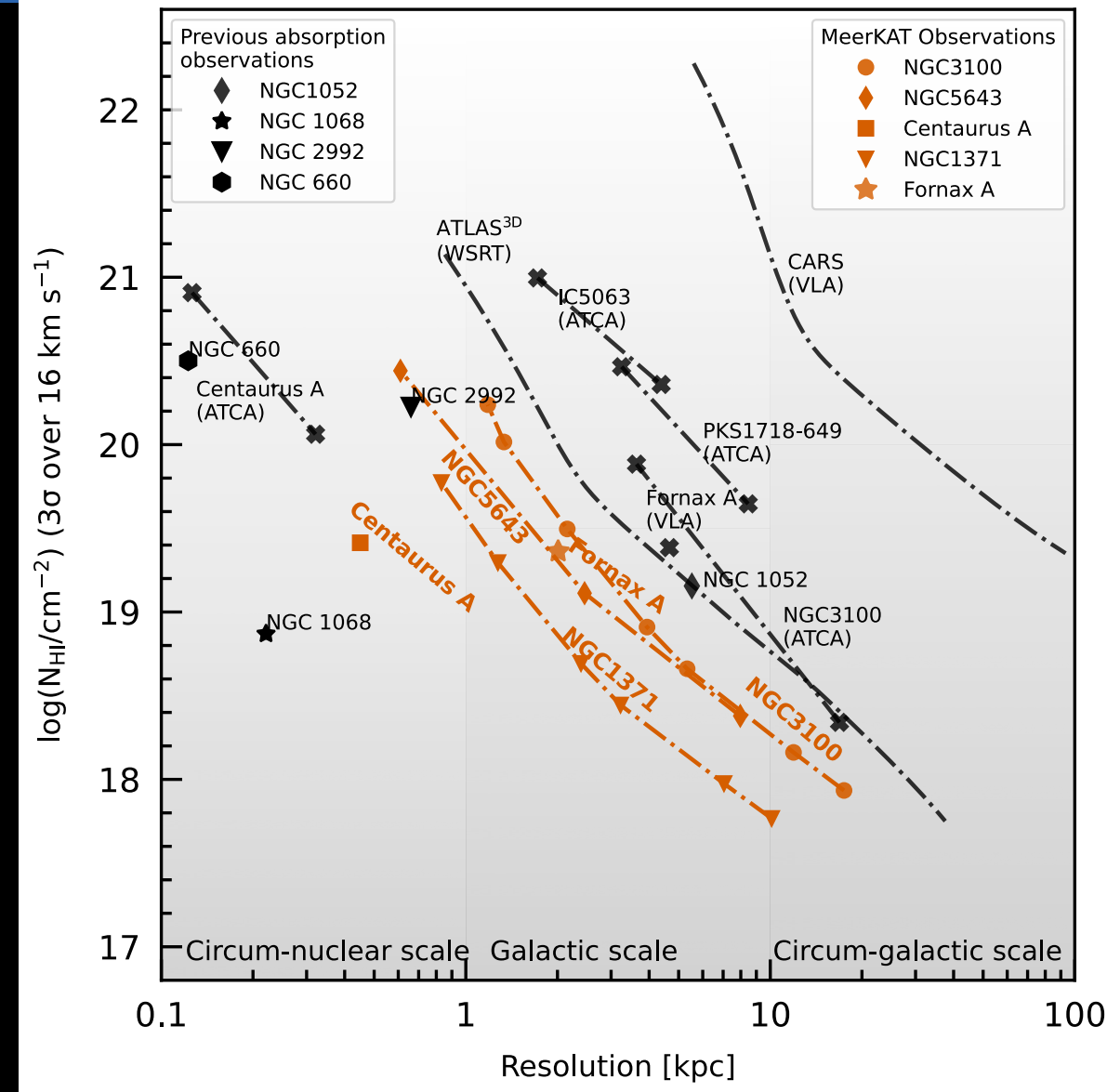
MeerKAT - main capabilities

- Flat noise answer between 6" and 90"
- 1 deg² field of view



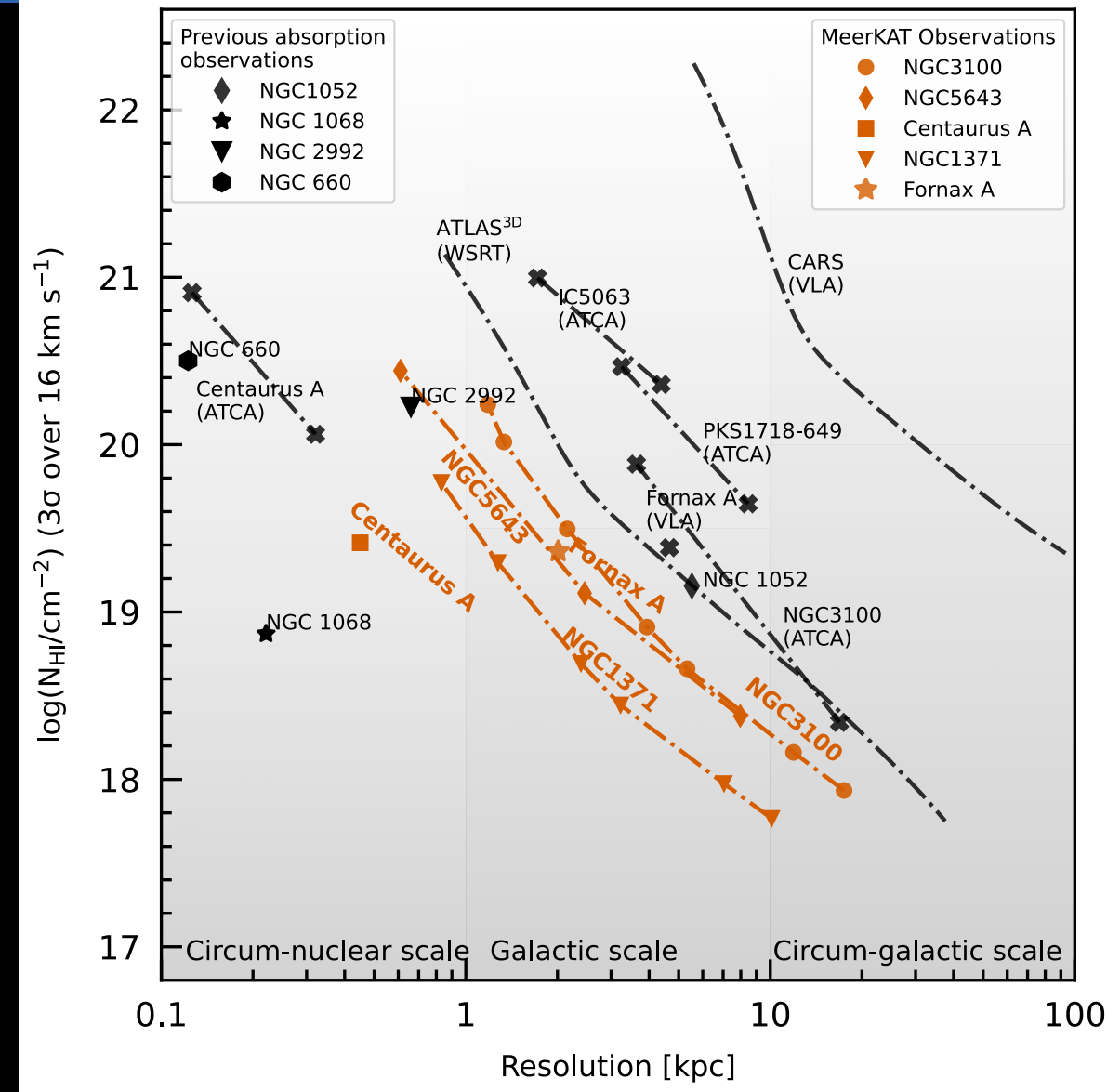
MAGNHIFFIC - MeerKAT AGN feeding & feedback investigation close-by

A new parameter space of HI observations in nearby AGN



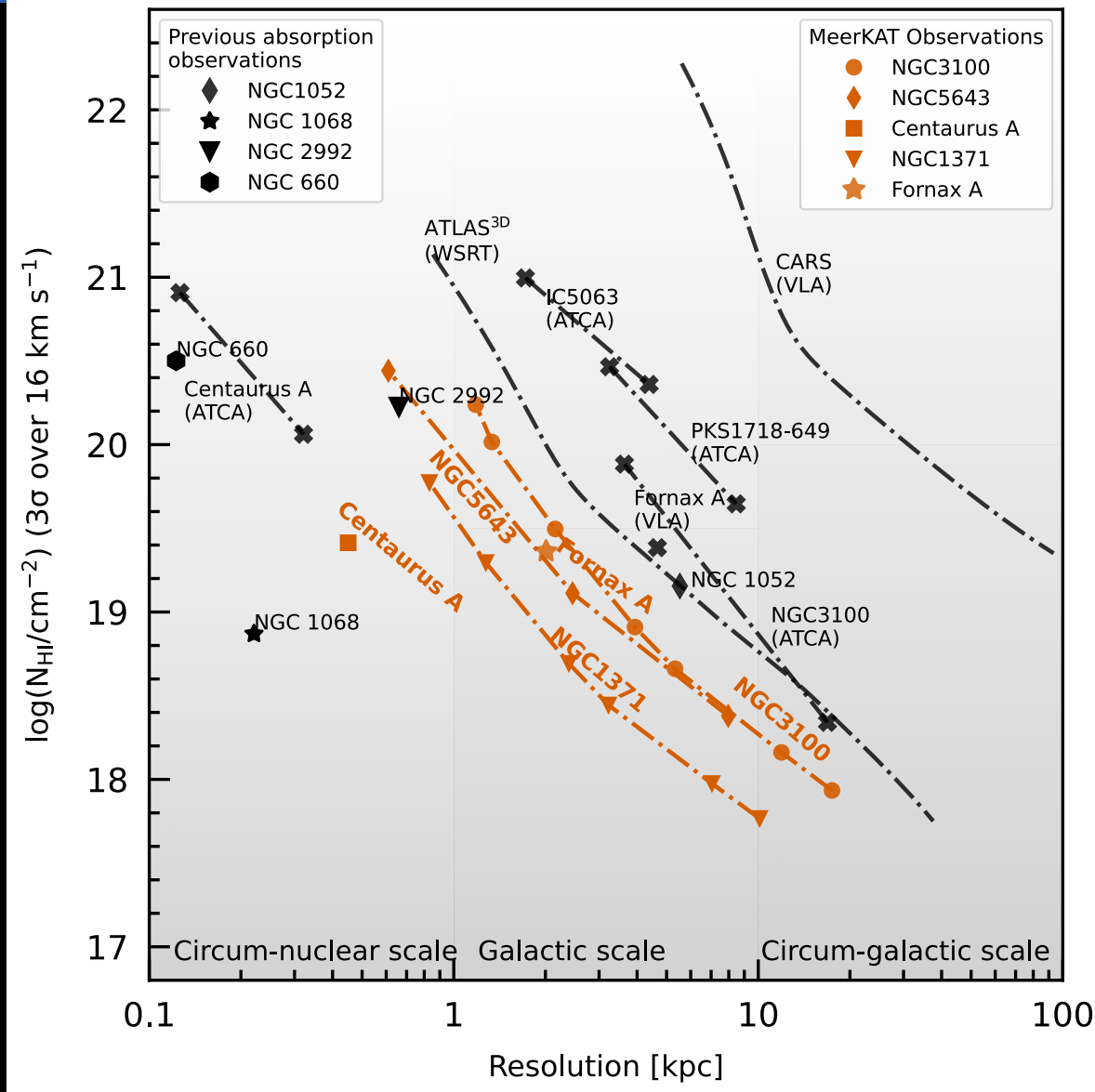
MAGNHIFVIC - sample

- 16 AGN with radio jets
 - 4 nearby AGN hosted by SF galaxies
 - 40 hours MeerKAT OT 2 (PI Maccagni)
 - 3 AGN with radio jets of different ages
 - 75 hours MeerKAT OT 3 (PI Prandoni)
 - 4 Seyfert galaxies with radio jets
 - 100 hours MeerKAT OT 6 (PI Maccagni)
- 5 nearby AGN in MHONGOOSE (PI de Blok), MeerKAT Fornax Survey (PI Serra)

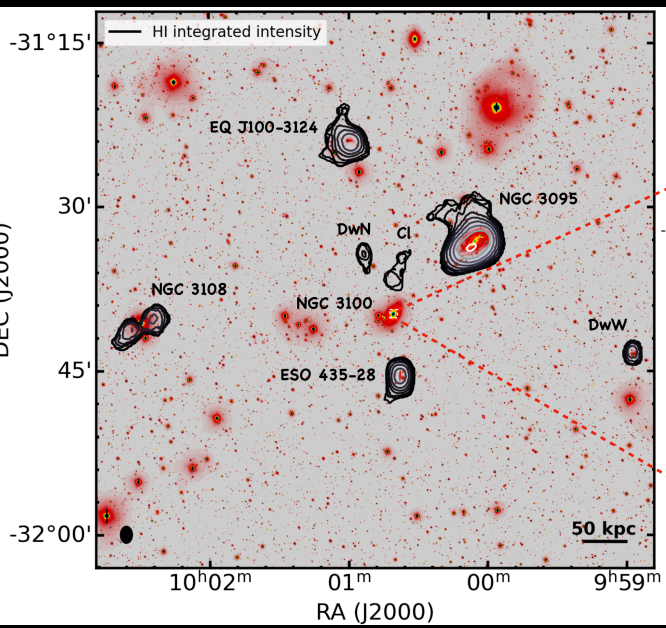


MAGNHIFVIC - goals

- Detailed high resolution wide-field studies to:
 - trace the gas flows in and out of AGN
 - link the timescale(s) of AGN to the secular evolution of galaxies
 - determine how feeding and feedback co-exist and self-sustain AGN



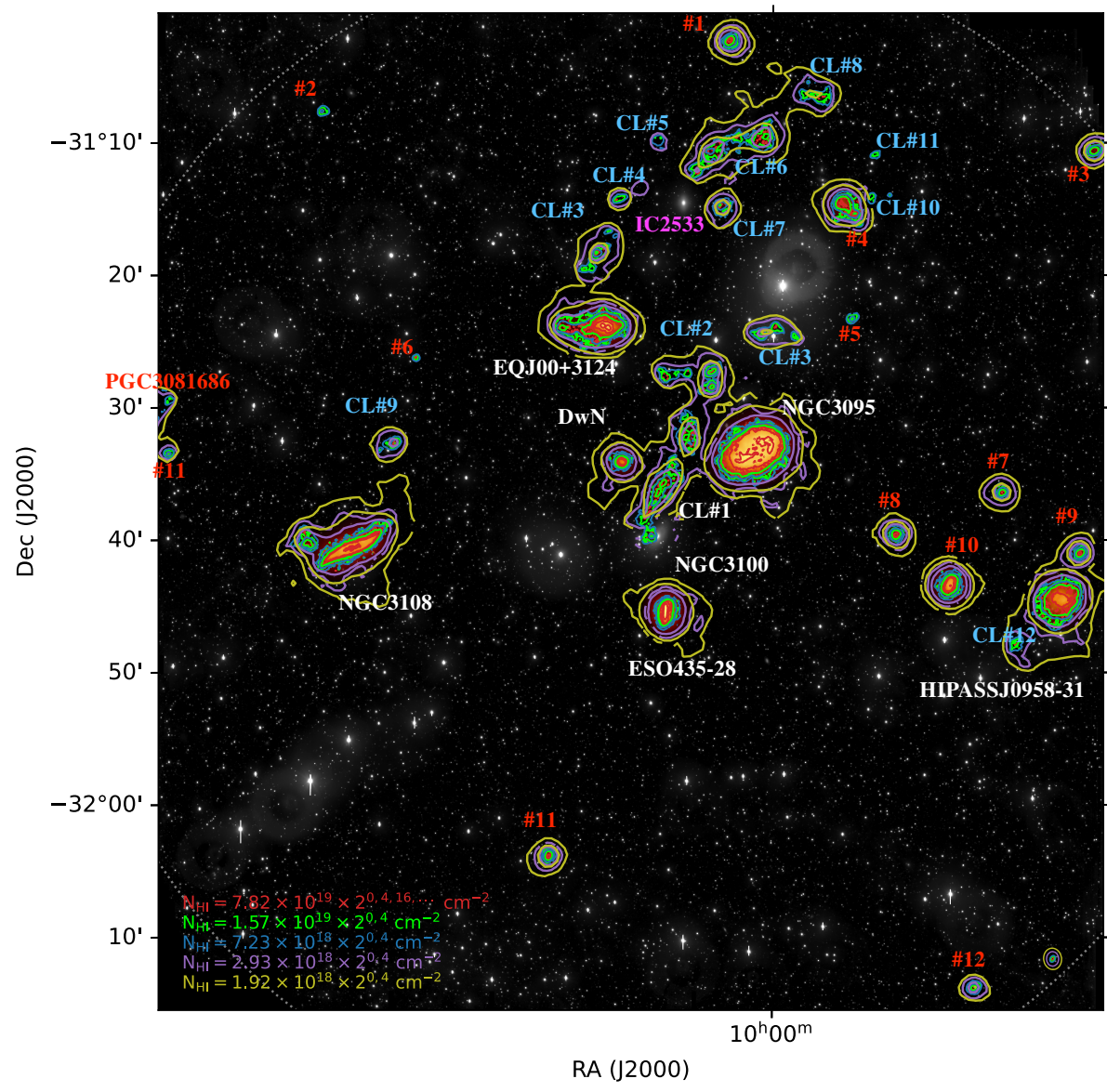
ATCA 36 hours - 90''



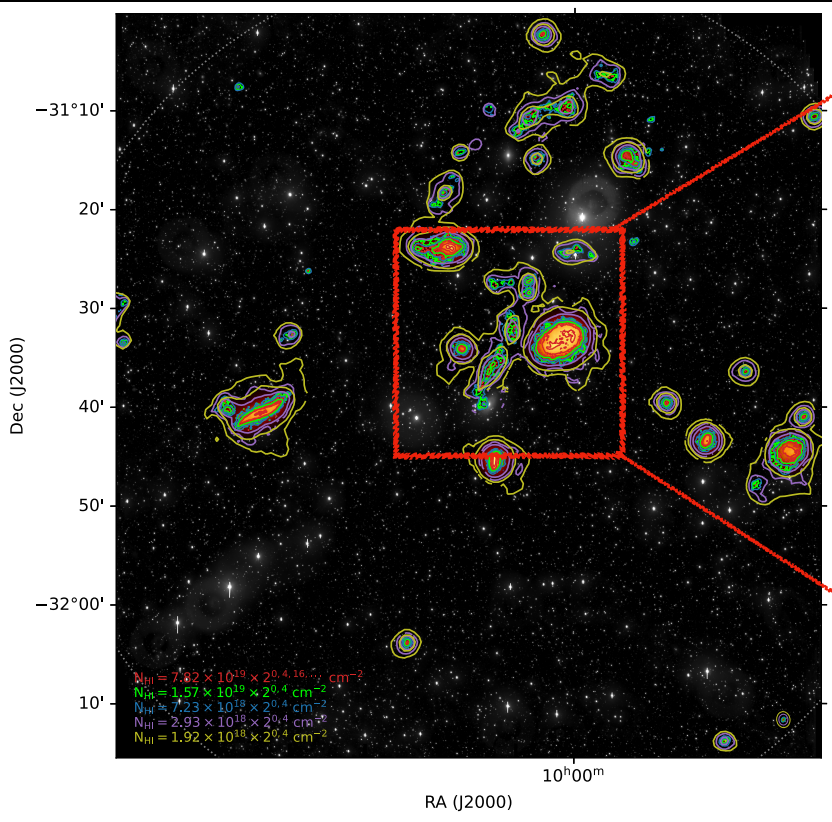
MeerKAT 25 hours:
Resolution: 10'' - 90''
 $\Delta v = 1.4 \text{ km s}^{-1}$

VST r-band
27 mag/arcsec²

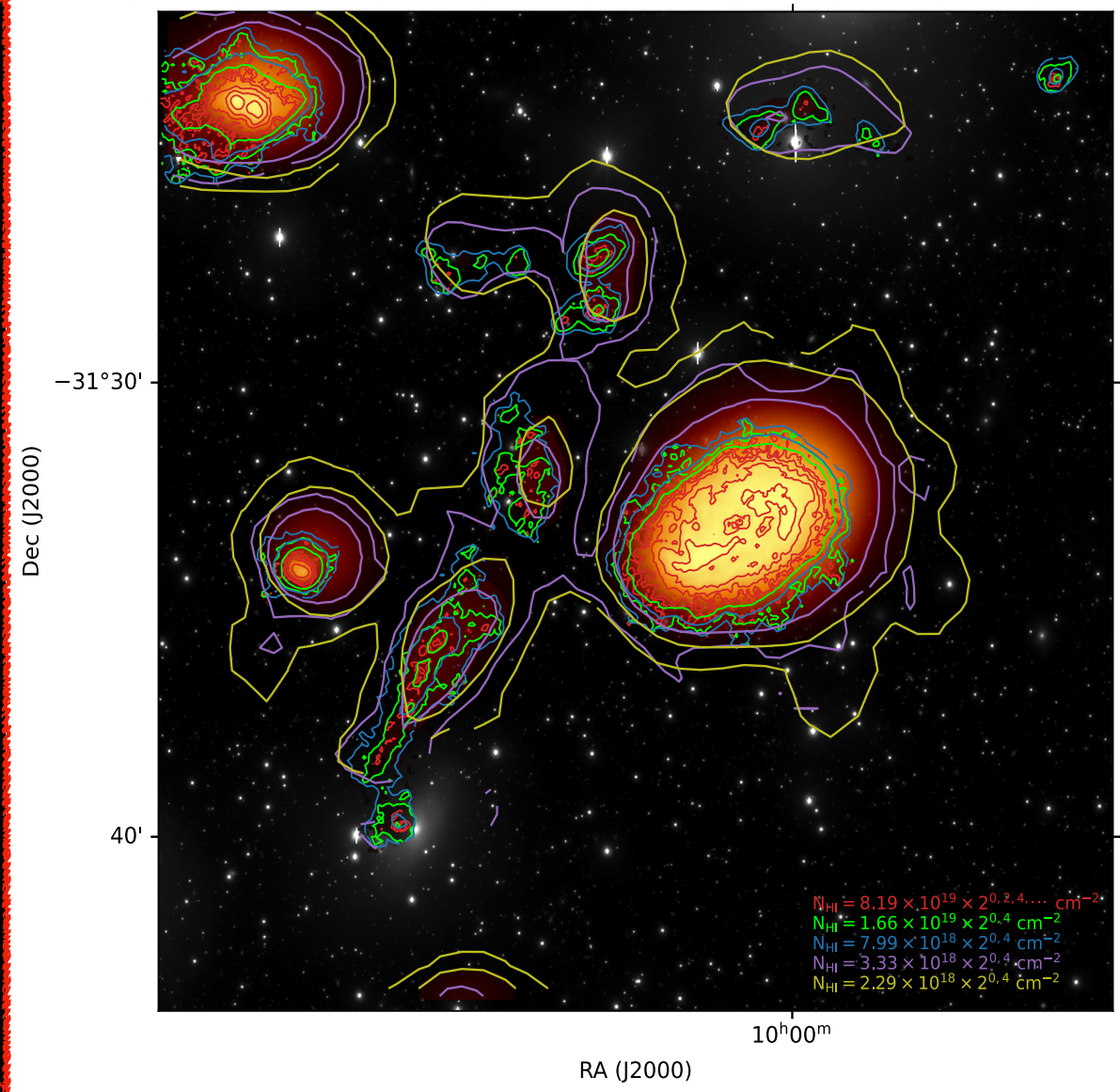
- NGC3100 is located in an HI rich group
- Previous HI detections
- HI detections associated to galaxies
- HI detections without optical counterpart



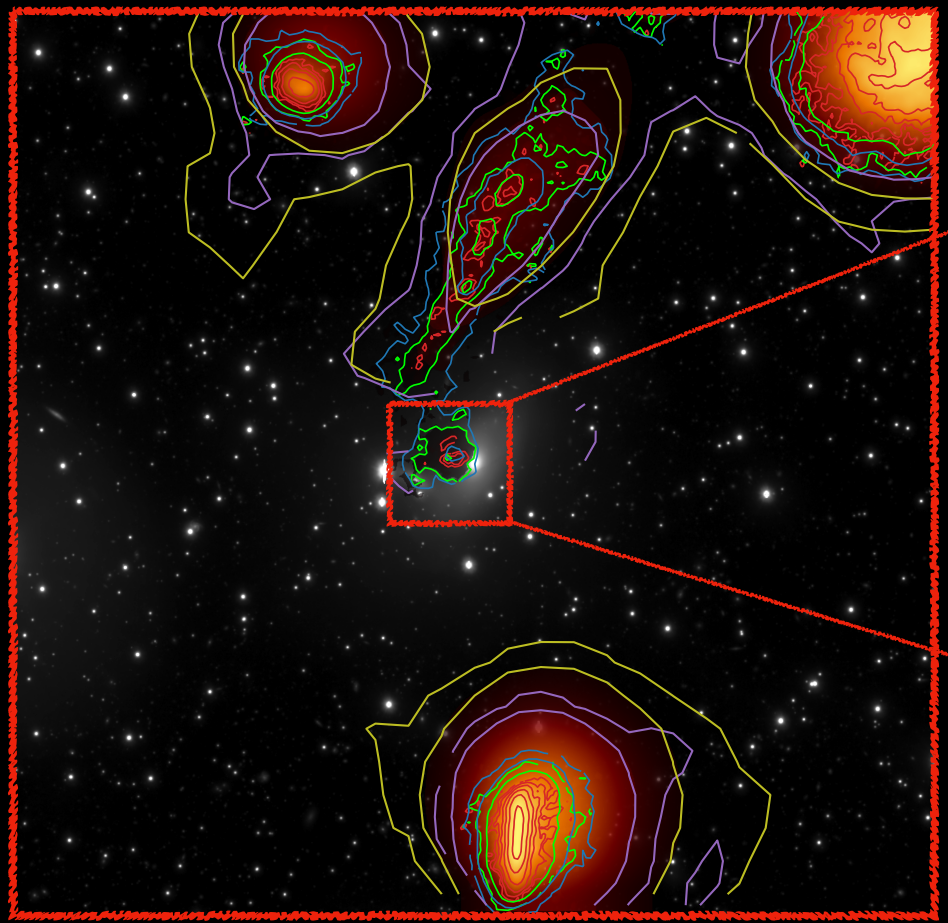
AGN feeding in NGC 3100



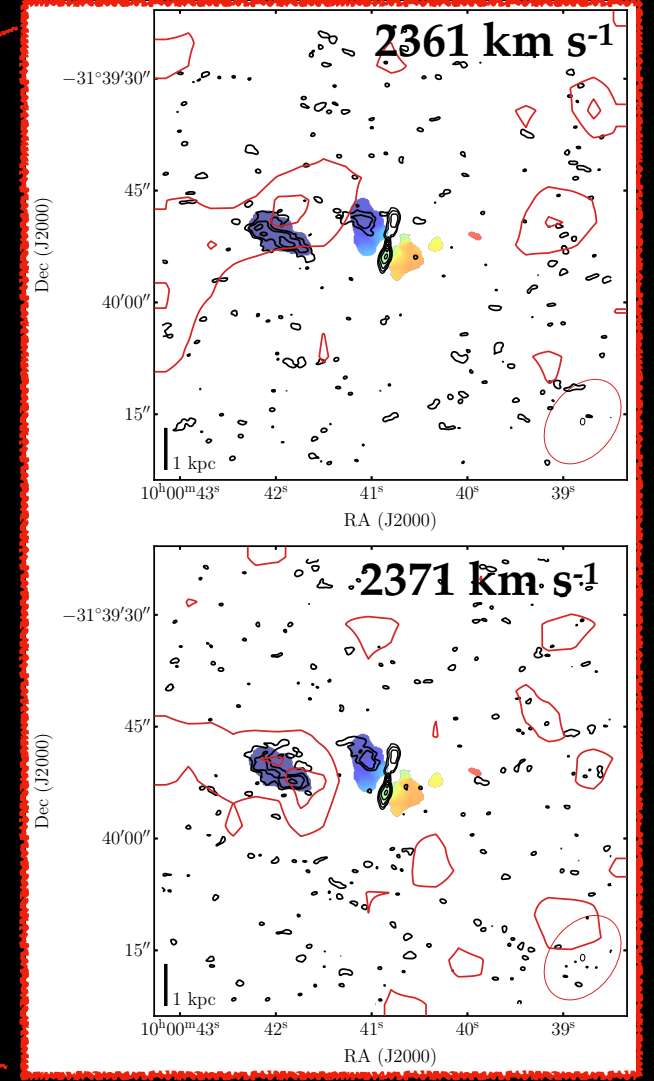
- 'Dark cloud'**
- remnant of interaction between surrounding galaxies
 - falling onto NGC3100



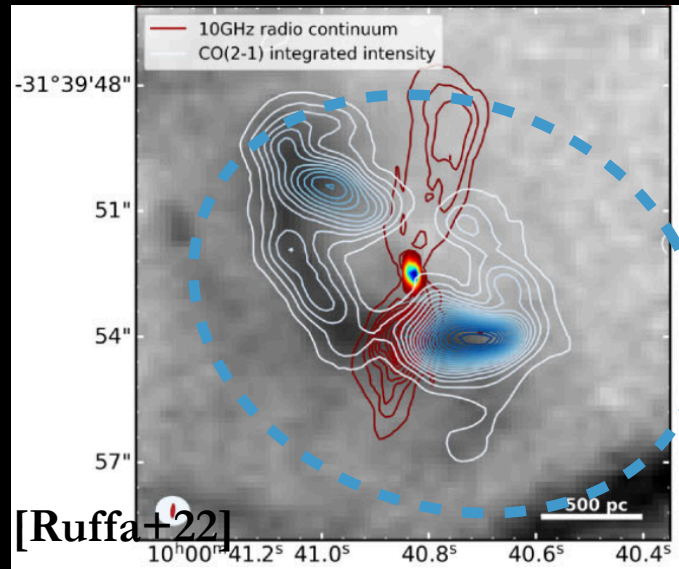
AGN feeding - HI filament falling onto the circum-nuclear disk of NGC3100



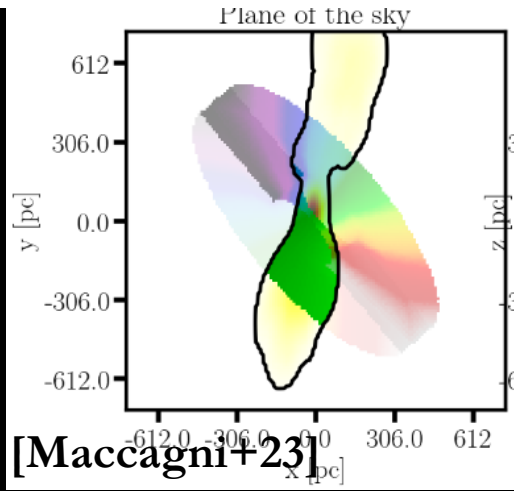
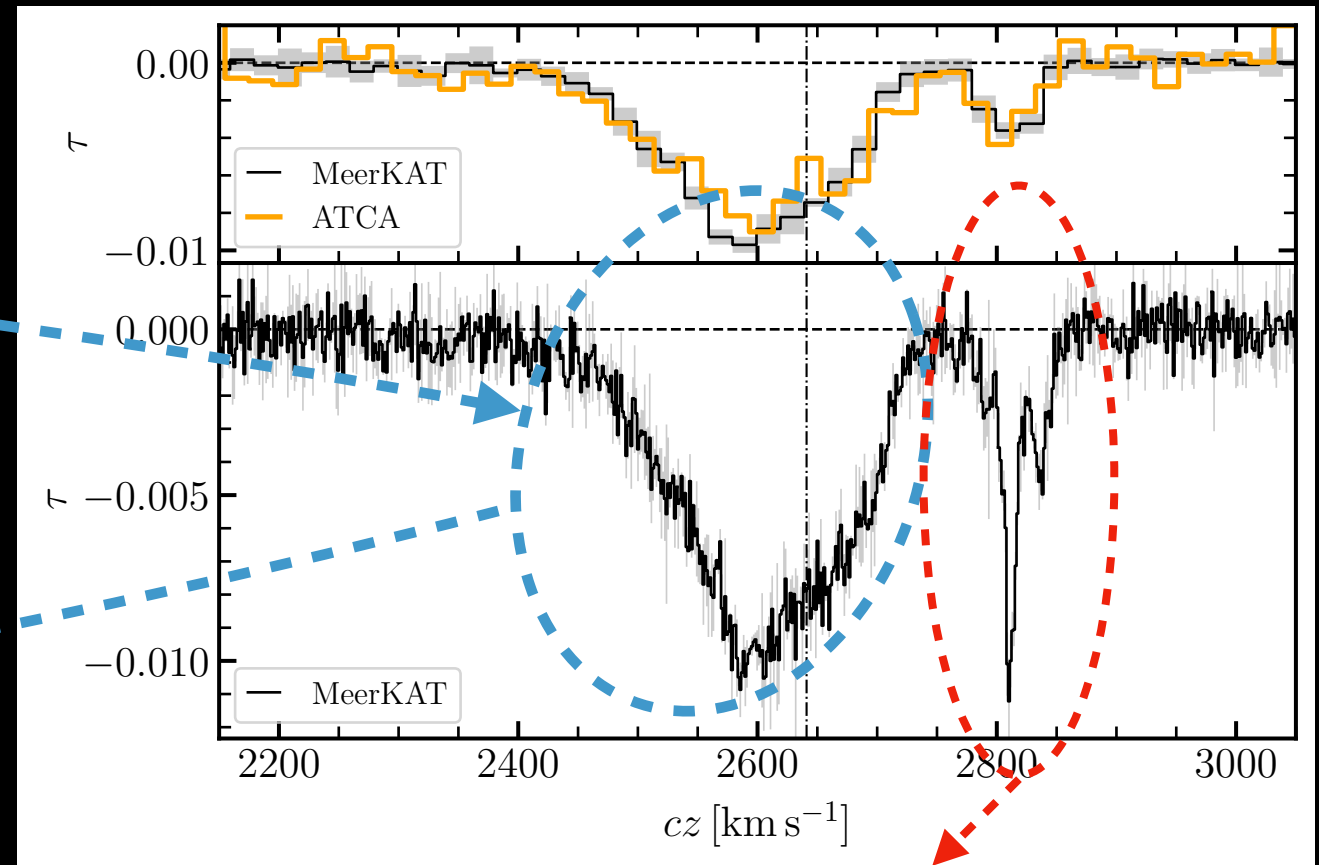
Channel maps : HI + CO (1-0)



CO circum-nuclear disk

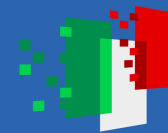


AGN feeding - HI clouds fuelling the SMBH



HI:

- atomic counterpart of circum-nuclear disk & redshifted clouds infalling within 200 pc from SMBH



Fornax A

- How did the radio lobes and inner jets form?
- In which timescales?

MeerKAT commissioning observations

Serra et al. 2019 : merger history of Fornax A

Maccagni et al. 2020 : flickering activity of the AGN

Kleiner et al. 2021 : HI and H α content of group

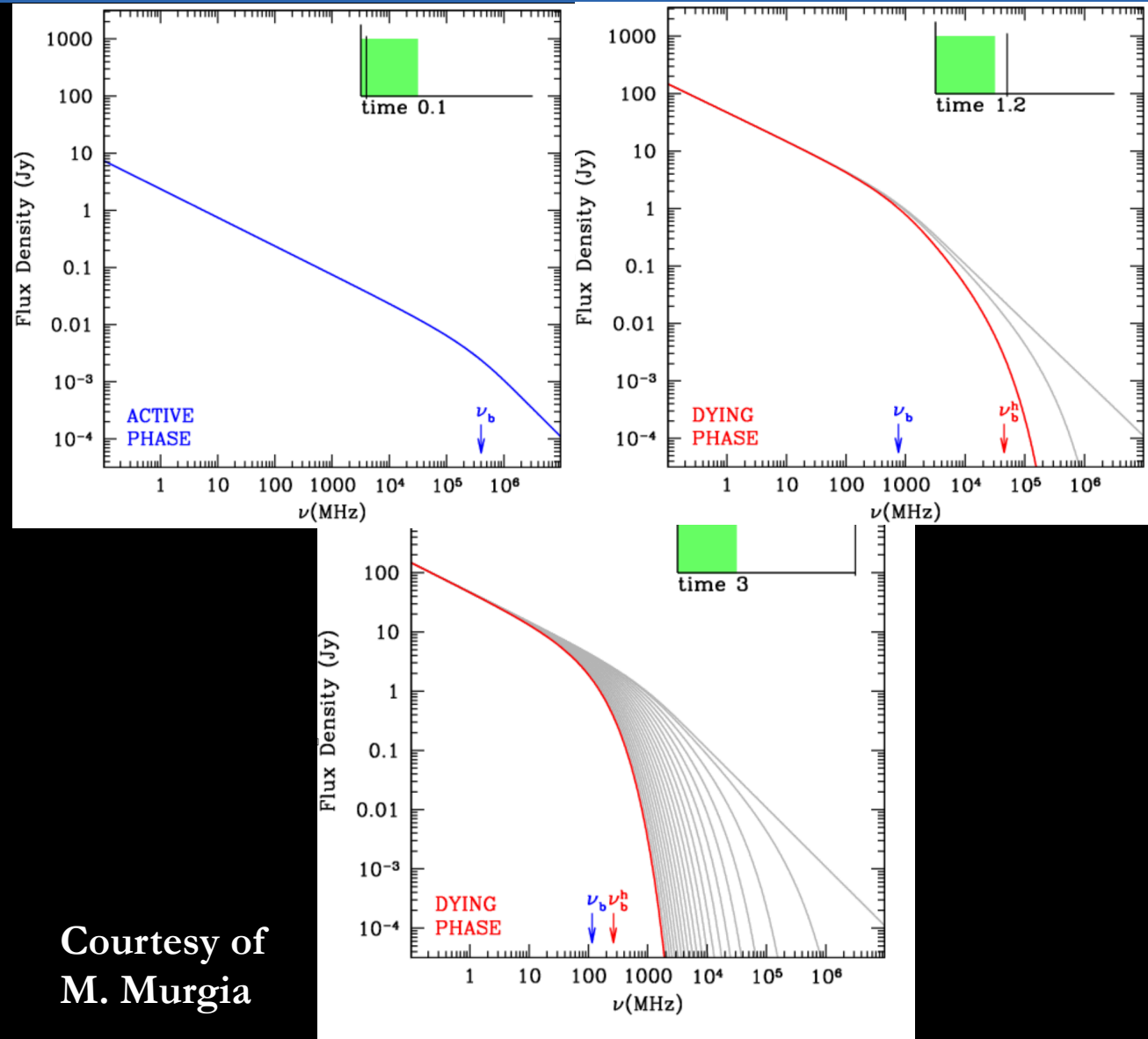
Maccagni et al. 2021 : feeding & feedback in Fornax A

Loi et al. 2022 : HI and H α depolarizing continuum from lobes

Timescale of AGN

Measured from the shape of the flux density distribution

- Synchrotron emission: high energy particles are injected in a medium with constant magnetic field, and then loose energy over time.
- Active phase + turn off
- Timescale measured from distance between frequency breaks

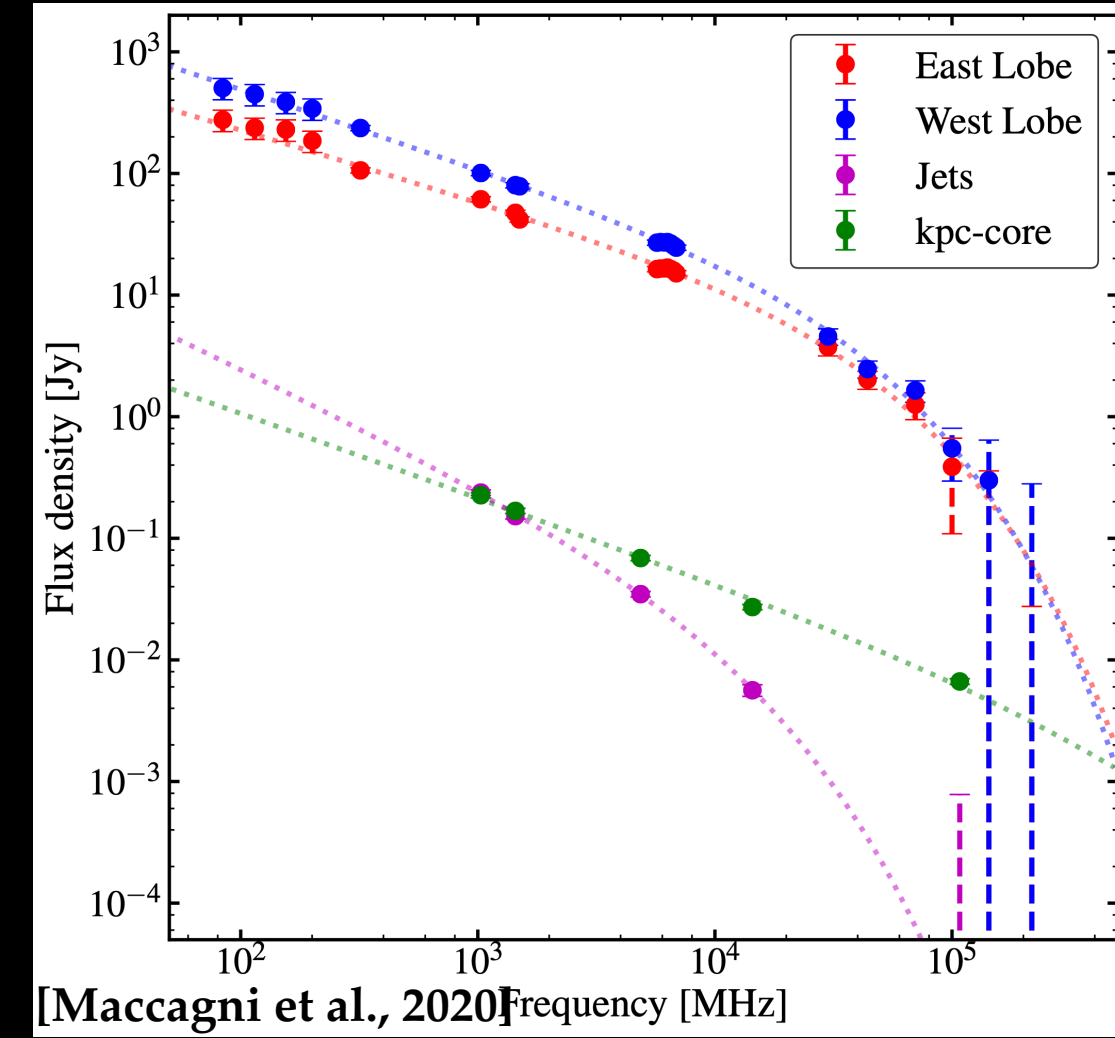


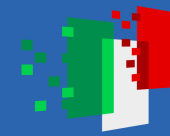
Courtesy of M. Murgia

The flickering activity of Fornax A

- **Phase 1 — Lobes**
 - 24 Myr ago began the last injection of the lobes
 - 12 Myr ago AGN switch-off
- **Phase 2 — Jets**
 - 3 Myr ago AGN formed the jets
 - 1 Myr ago AGN switch-off
- **Phase 3 — Core**
 - kpc-core is active (< 1 Myr)

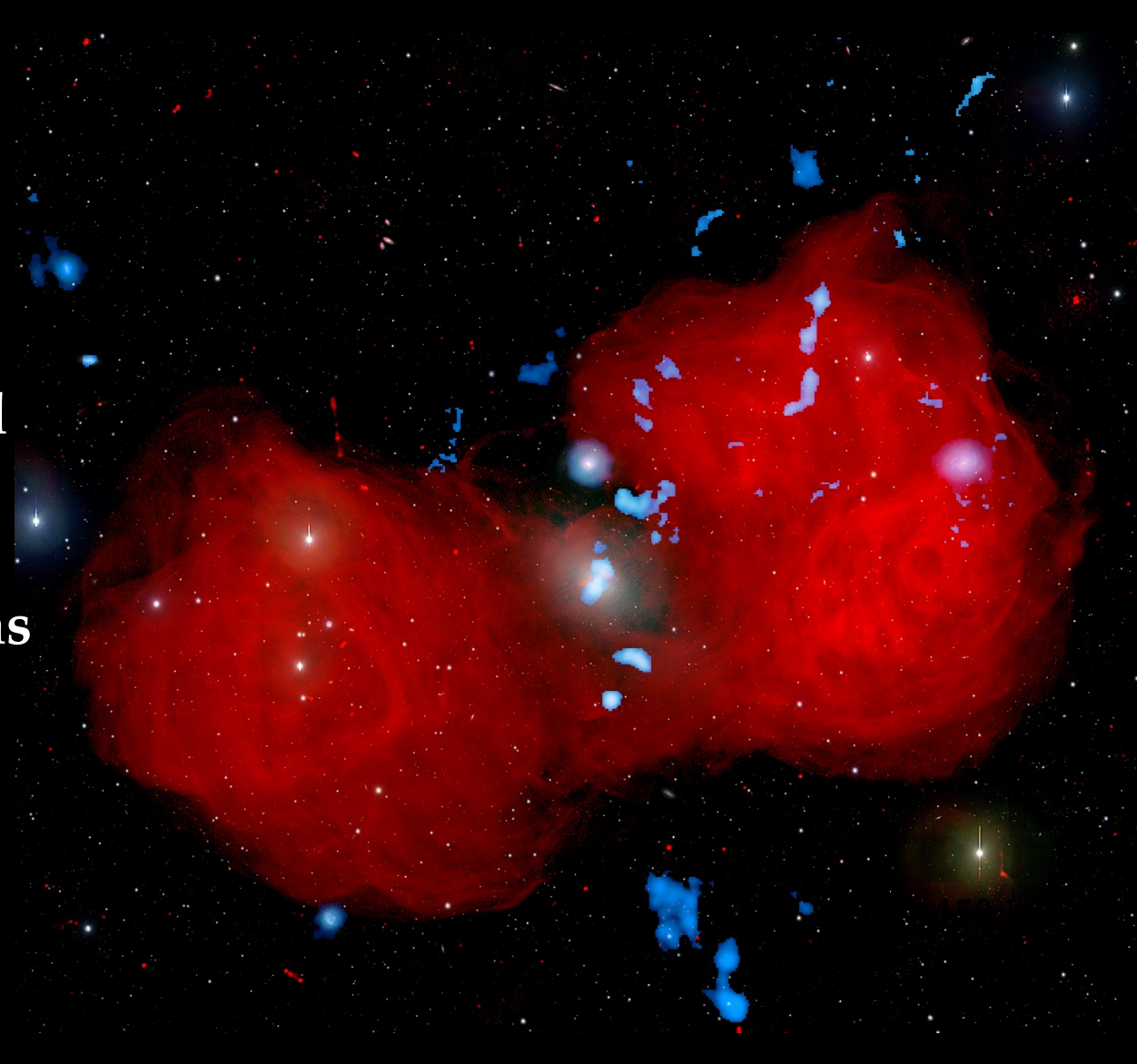
What regulates the fast duty cycle?



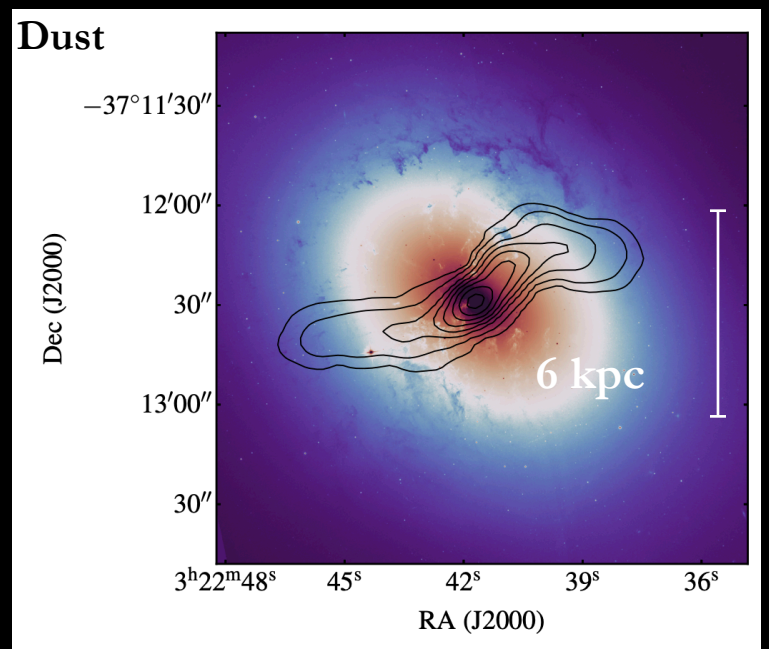


Fornax A & HI

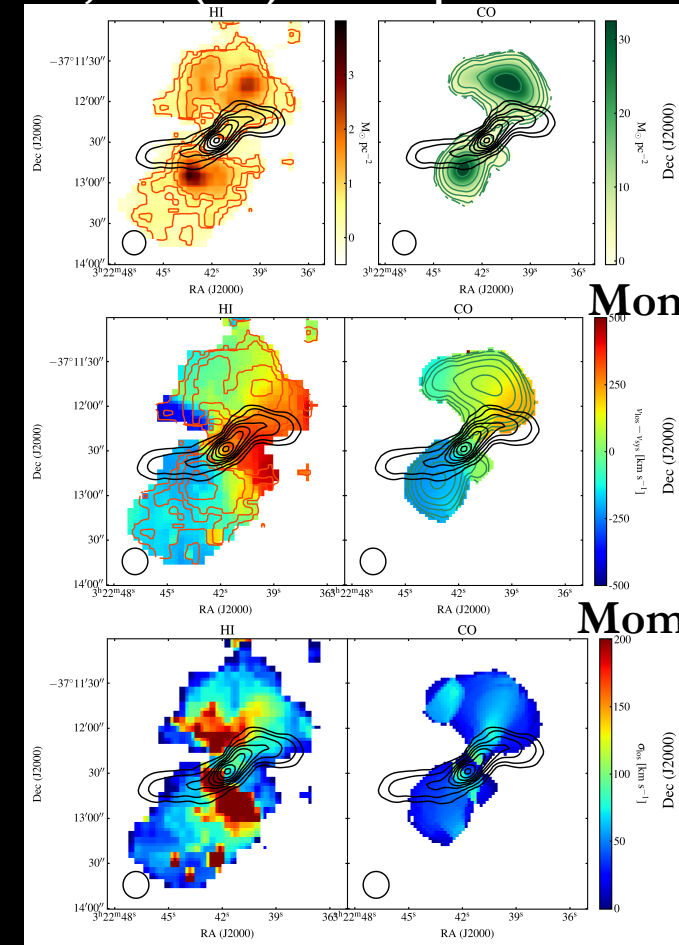
- What is fuelling and sustaining the rapid duty cycle of the AGN?
- Is AGN feedback changing the conditions of the ISM and IGM?



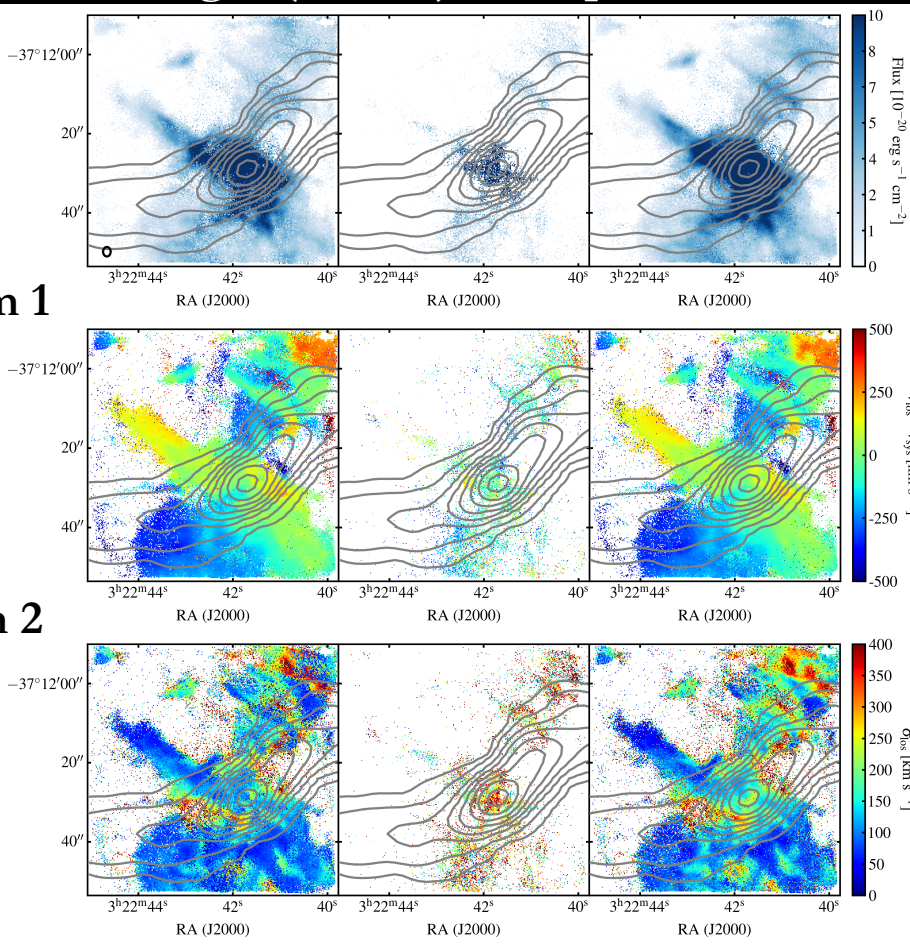
Gas distribution and kinematics in the centre



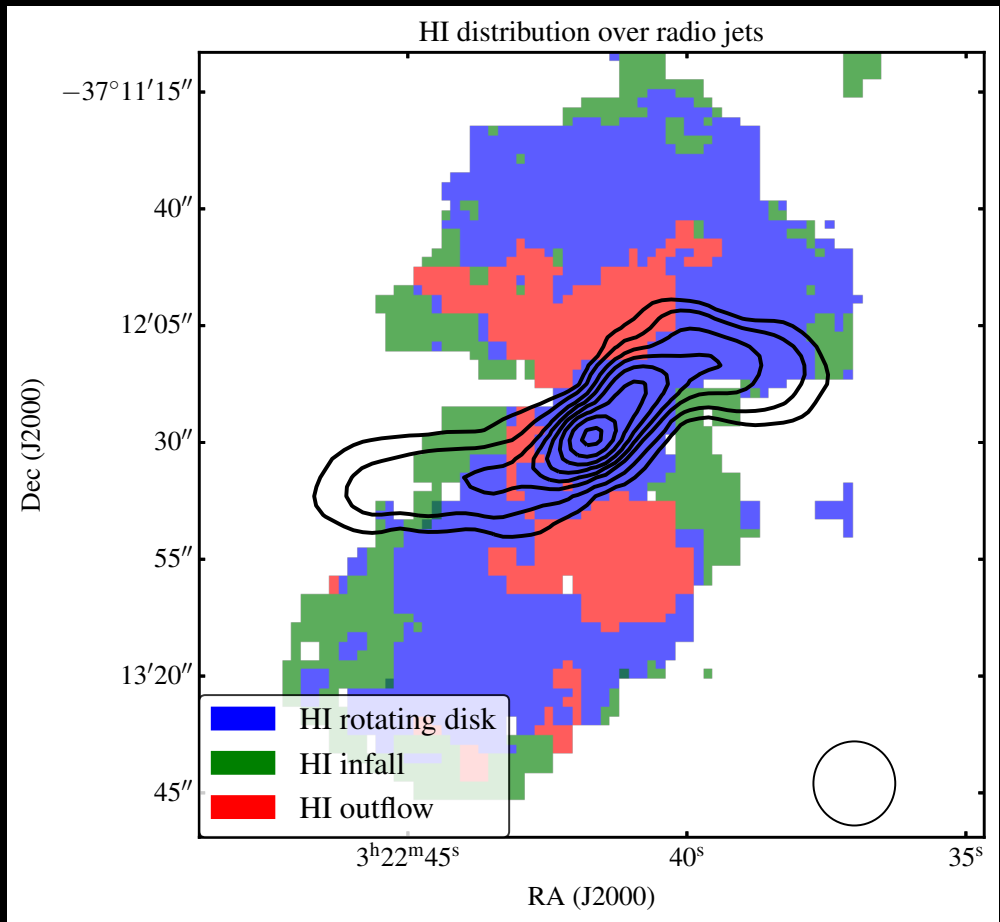
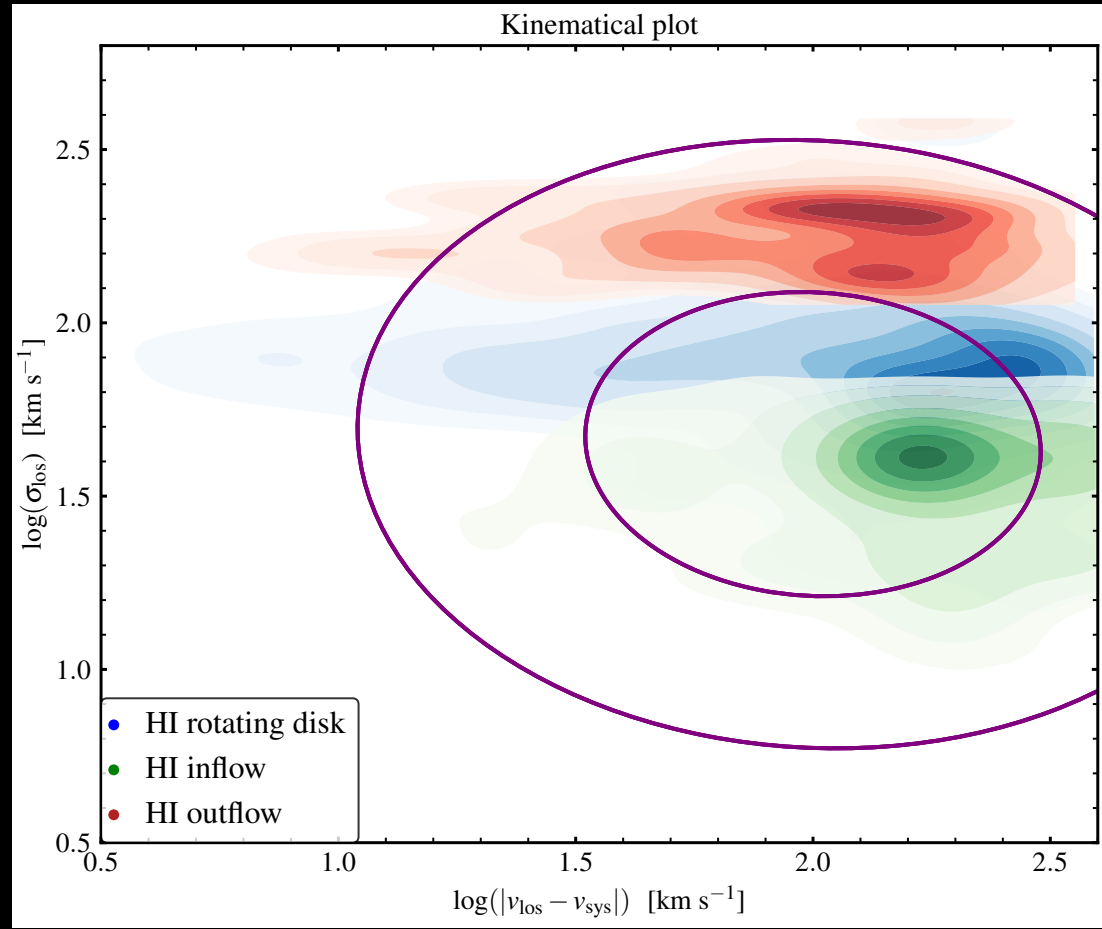
HI, CO (1-0) — 18 kpc fov



Ionised gas (MUSE) — 6 kpc fov

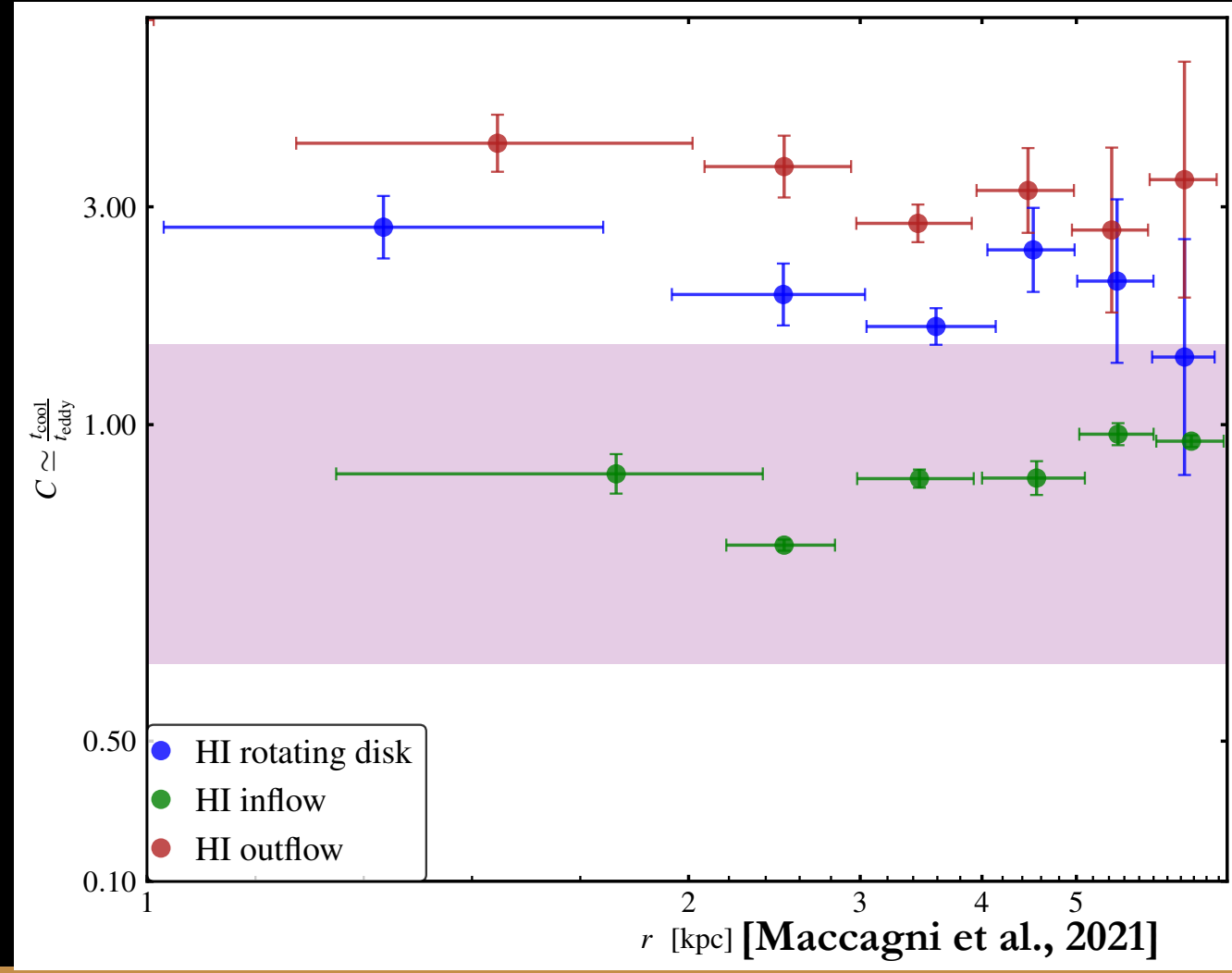
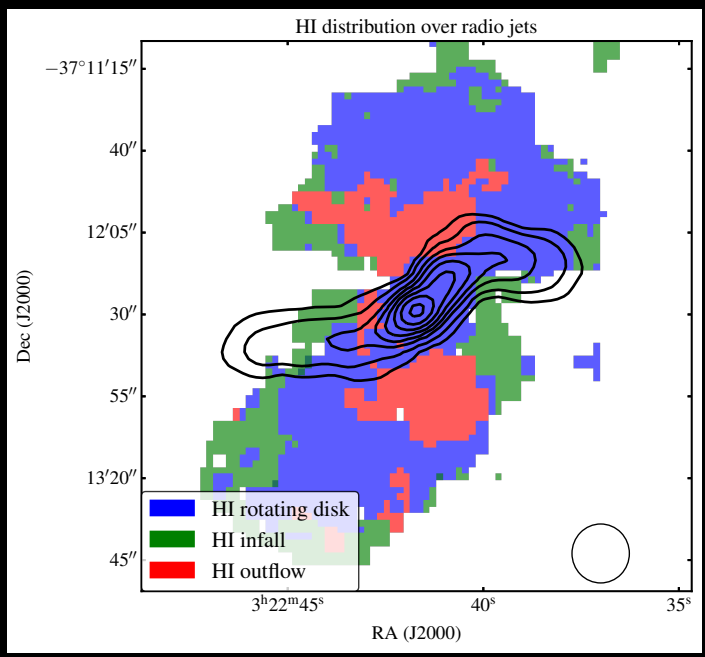


k-plot identifies regions with similar kinematics



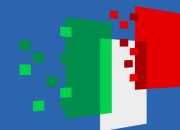
outflow
inflow
rotation

AGN feeding in Fornax A



EW filament: infall and cooling caused by turbulence

Outflow: entrained by radio jets



MeerKAT deep studies in AGN

In NGC3100 cold gas from the IGM is fuelling the circum-nuclear disk, and the SMBH

Fornax A is rapidly flickering because of multi-phase AGN feeding & feedback loop

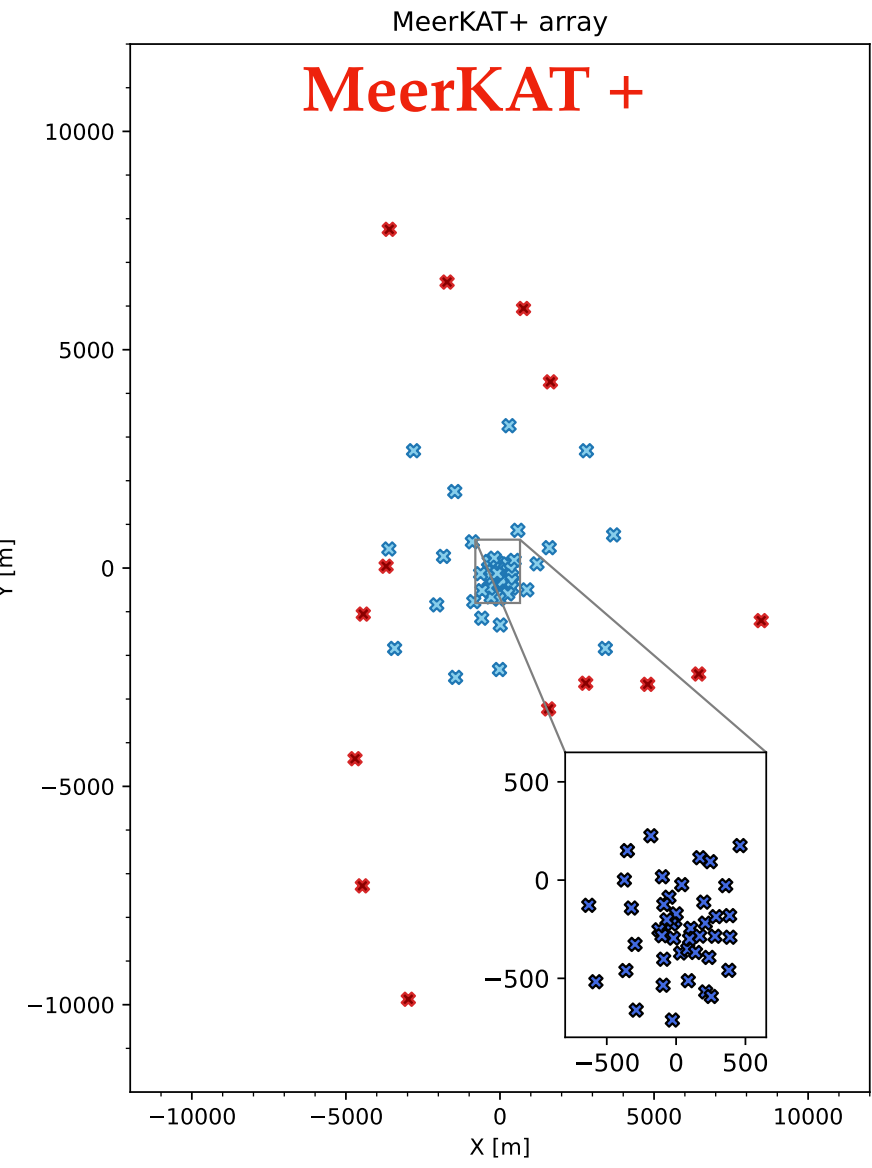
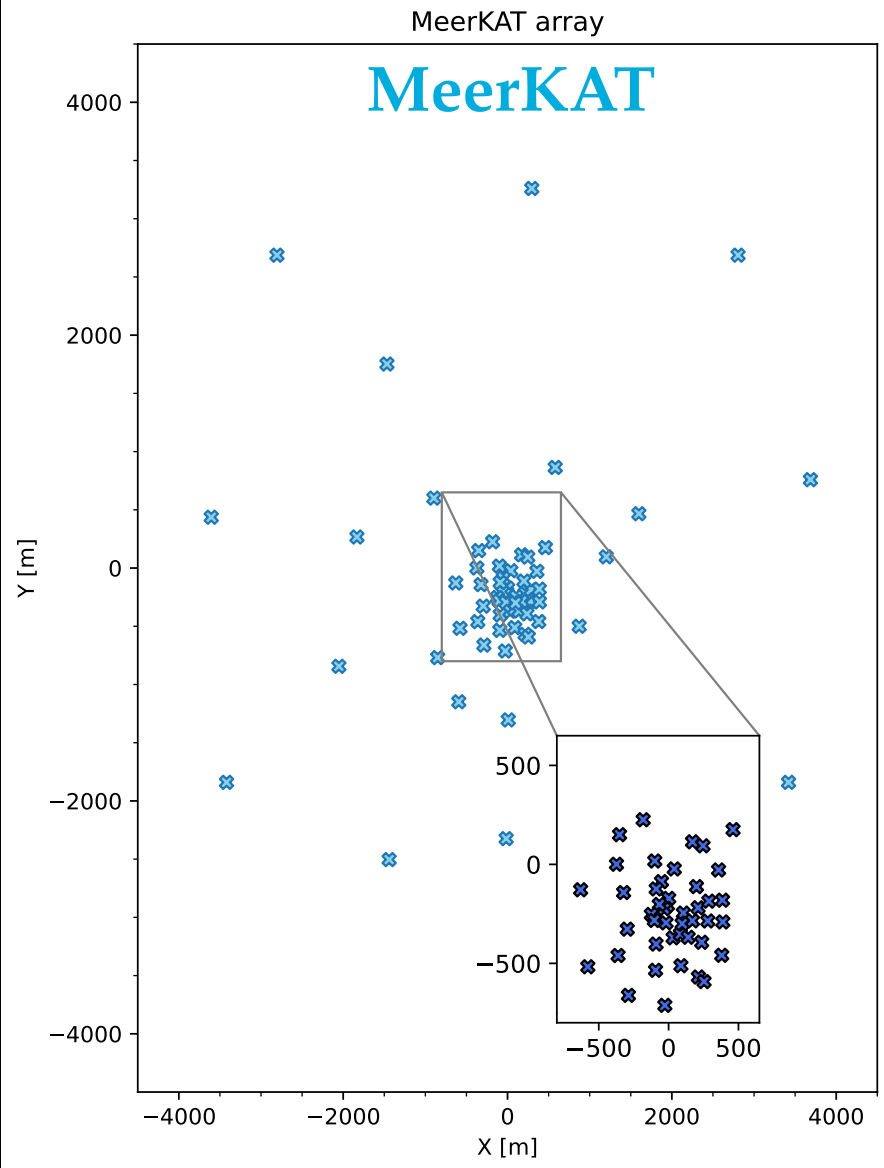
SKA-low + SKA-mid continuum & spectral will enable detailed studies of the physics of AGN feeding and feedback over statistical samples of nearby galaxies

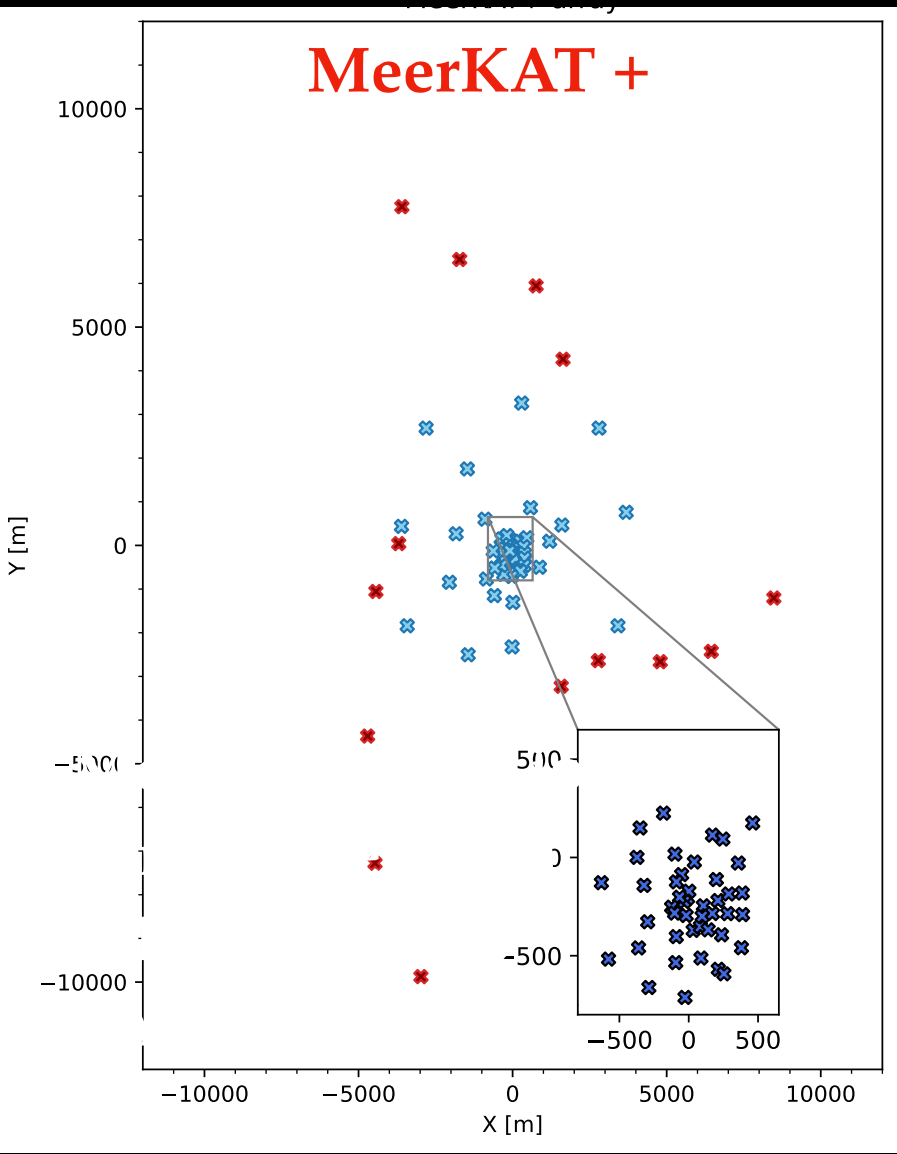
$N_{\text{HI}} = 7.82 \times 10^{19} \times 2^{0.4, 16, \dots} \text{ cm}^{-2}$
 $N_{\text{HI}} = 1.57 \times 10^{19} \times 2^{0.4} \text{ cm}^{-2}$
 $N_{\text{HI}} = 7.23 \times 10^{18} \times 2^{0.4} \text{ cm}^{-2}$
 $N_{\text{HI}} = 2.93 \times 10^{18} \times 2^{0.4} \text{ cm}^{-2}$
 $N_{\text{HI}} = 1.92 \times 10^{18} \times 2^{0.4} \text{ cm}^{-2}$

What's next?

MeerKAT+: MeerKAT extended array with SKA antennas

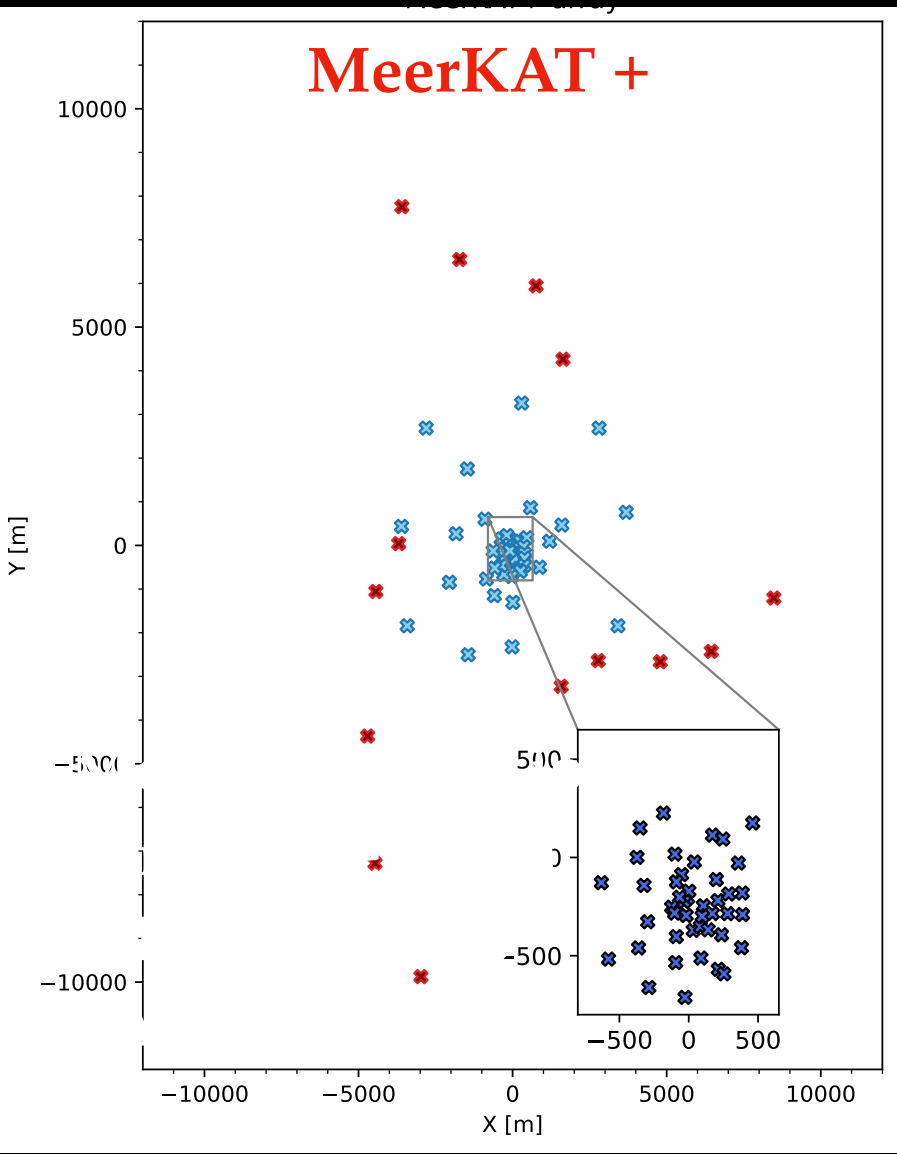
MeerKAT+ is a joint venture between MPfR, INAF & SARA0





MeerKAT+ will set the benchmark for SKA-MID studies

INAF is involved in MeerKAT+ commissioning and legacy surveys BUT most researchers actively working are post-docs with expiring contracts



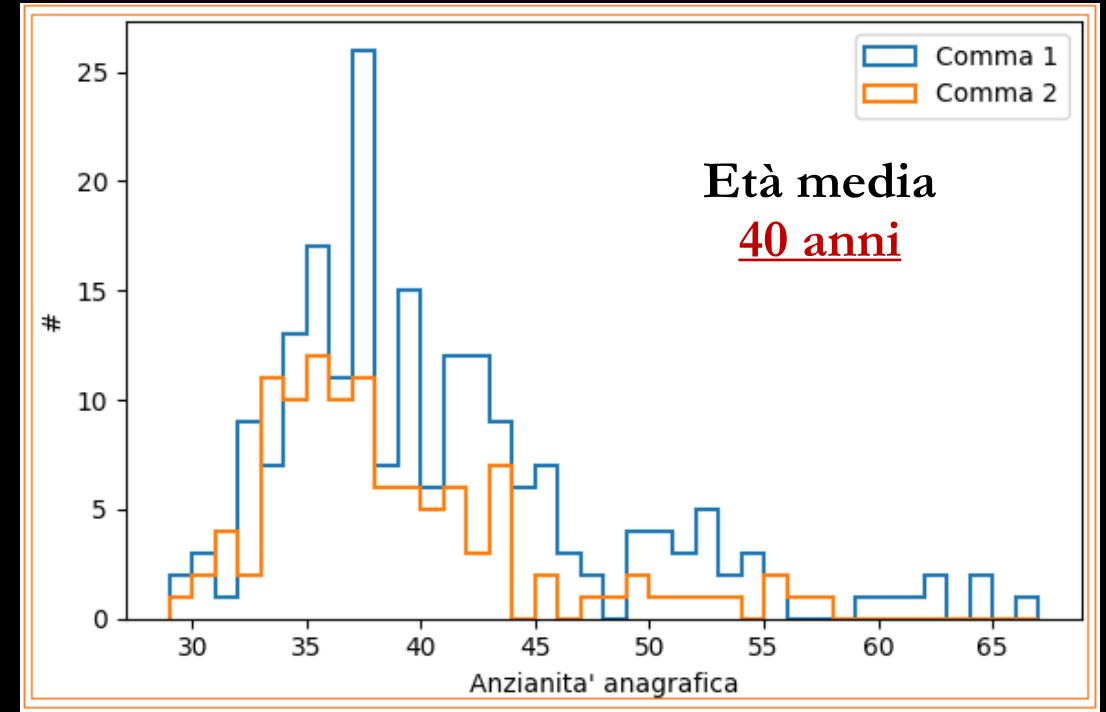
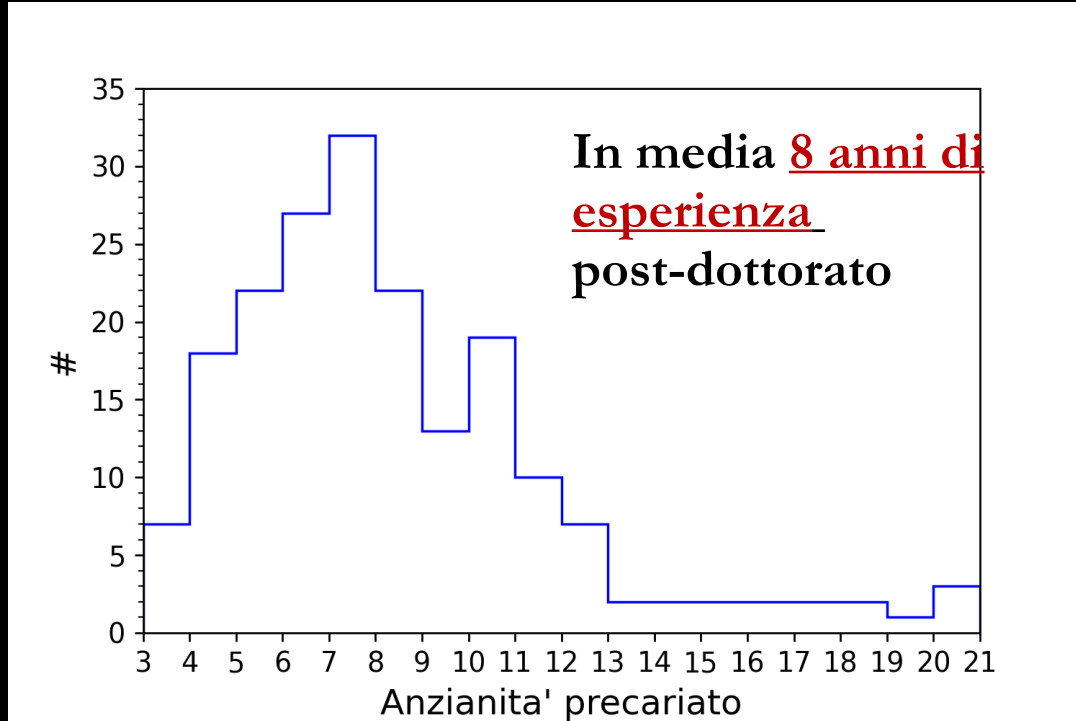
MeerKAT+ will set the benchmark for SKA-MID studies

HOW will INAF keep its expertise to maximise the outcome of SKA surveys?

MeerKAT+ is just A tip of the iceberg

INAF employees:

1.200 Tempo Indeterminato Vs 650 precari: più di 1 precario ogni 2 persone di ruolo.



Più di 100 precari con esperienza decennale rischiano l'esodo da INAF
L'impatto sui progetti nazionali e internazionali di INAF sarebbe dirompente.

Per sostenere la rete stabilizzandi firmate qui!



'Dark cloud'

- spatially and kinematically connected with **HI**

